WATER QUALITY BRANCH
ENVIRONMENTAL PROTECTION
DEPARTMENT
MINISTRY OF ENVIRONMENT, LANDS AND
PARKS

Water Quality Assessment and Objectives for Holland Creek and Stocking Lake Watersheds Vancouver Island

OVERVIEW

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SUMMARY

THIS DOCUMENT assesses the Holland Creek and Stocking Creek watersheds located on southern Vancouver Island near Ladysmith. It is one in a series that presents water quality objectives for British Columbia. It has two parts: an overview and the report. The overview provides general information about water quality in the Holland Creek and Stocking Lake watersheds, and water quality objectives and monitoring tables for those readers requiring this information. It is intended for both technical readers and for readers who may not be familiar with the process of setting water quality objectives. The report presents the details of the water quality assessment in the Holland Creek and Stocking Lake watersheds, and forms the basis of the recommendations and objectives presented in the overview.

In the autumn of 1991, an Integrated Watershed Management Plan was initiated for the Holland Creek and Stocking Lake watersheds in response to local concerns about logging and road building in the watersheds. The planning team is co-chaired by BC Environment and the Ministry of Forests, and includes representatives of the various stakeholders in the watershed. In early 1992, the Water Quality Branch was requested to conduct a water quality assessment and recommend water quality objectives for the watersheds. The existing information was assessed, and additional water quality monitoring began in mid-1992.

This overview summarizes the results of the water quality assessment of the Holland Creek and Stocking Lake watersheds. Objectives for key drinking water characteristics (fecal coliforms, turbidity, pH, colour, and total organic carbon, plus iron, phosphorus, and chlorophyll a in Stocking Lake) in the watersheds are proposed to protect water quality, and to guide the rehabilitation and any future development of the watersheds. All available data and current water quality criteria were used to derive the water quality objectives.

PREFACE

Purpose of Water Quality Objectives

WATER QUALITY OBJECTIVES are prepared for specific bodies of fresh, estuarine and coastal marine surface waters of British Columbia as part of the Ministry of Environment, Lands and Parks' mandate to manage water quality. Objectives are prepared only for those waterbodies and water quality characteristics that may be affected by human activity now or in the future.

How Objectives Are Determined

WATER QUALITY OBJECTIVES are based on scientific guidelines called water quality criteria*. Water quality criteria relate the physical, chemical or biological characteristics of water, biota (plant and animal life) or sediment to their effects on water use. Objectives are established in British Columbia for waterbodies on a site-specific basis. They are derived from the criteria by considering local water quality, water uses, water movement, waste discharges and socio-economic factors. Socio-economic factors have rarely influenced the objectives established, except to influence the timing of the attainment of the objectives, depending on the feasibility and pace of improving impacted waters.

Water quality objectives are set to protect the most sensitive designated water use at a specific site or location. A designated water use is one that is protected in a given location and is one of the following:

- raw drinking water, public water supply and food processing
- aquatic life and wildlife
- agriculture (livestock watering and irrigation)

* The process for establishing water quality objectives is outlined more fully in *Principles for Preparing Water Quality Objectives in British Columbia.* Copies of this document are available from the Water Quality Branch, Environmental Protection Department.

- recreation and aesthetics

Each objective for a location may be based on the protection of a different water use, depending on the uses that are most sensitive to the physical, chemical or biological characteristics affecting that waterbody.

How Objectives Are Used

WATER QUALITY OBJECTIVES have no legal standing at this time and are not directly enforced. However, they do provide policy direction for resource managers for the protection of water uses in specific waterbodies. Objectives guide the evaluation of water quality, the issuing of permits, licenses and orders, and the management of fisheries and the province's land base. They also provide a reference against which the state of water quality in a particular waterbody can be checked, and help to determine whether basin-wide water quality studies should be initiated. Water quality objectives are also a standard for assessing the Ministry's performance in protecting water uses.

Objectives and Monitoring

WATER QUALITY OBJECTIVES are established to protect all uses that may take place in a given waterbody. Monitoring, which is sometimes called sampling, is undertaken to determine if the designated water uses are being protected. Monitoring usually takes place at critical times, as determined by a water quality specialist, when water quality objectives are least expected to be met. It is assumed that if all designated water uses are protected at the critical times, then they also will be protected at other times when the threat to water quality is less.

INTRODUCTION

THIS REPORT assesses water quality in the Holland Creek and Stocking Lake watersheds. Water quality objectives for key drinking water characteristics such as fecal coliforms, turbidity, colour, total organic carbon, pH, iron, and phosphorus are set to protect raw drinking water supplies, which is the most sensitive water use in the watersheds for these characteristics. An analysis of the available data suggested that objectives for other substances are not needed at this time.

A map of the watersheds is given in Figure 1. Holland Creek originates on northern and eastern slopes of the Vancouver Island Mountains (Coronation Mountain) and flows north and east about 12 km before entering Ladysmith Harbour. Water from upper Banon Creek, which originates on Coronation Mountain and Mount Hall, is diverted into the Holland Creek watershed at Holland Lake during November to May. Stocking Creek originates in Stocking Lake on the lower slopes of the Vancouver Island Mountains, flowing east and north for about 6 km before entering Davis Lagoon and Ladysmith Harbour.

Holland Creek and Stocking Lake are licensed for domestic waterworks for the Town of Ladysmith and the Saltair area of the Cowichan Valley Regional District, supplying over 9000 people. Stocking Creek is also licensed for irrigation water supply. Holland Creek supports major runs of chum salmon and minor runs of coho salmon and cutthroat and steelhead trout in the lower 2.3 km, above which impassable falls stop upstream migration. Holland Lake supports a good recreational fishery for stocked rainbow trout. Similarly, Stocking Creek supports major chum salmon and minor coho salmon and cutthroat trout runs in the lower 0.5 km, before impassable falls stop upstream migration. Stocking Lake had a good recreational fishery for rainbow trout until fish stocking was stopped in 1986 when access to the lake was closed to protect the drinking water supply.

HOLLAND - STOCKING BASIN PROFILE

Hydrology

A hydrological analysis of the Holland and Stocking watersheds was conducted to assist in the integrated watershed management planning.

Holland Creek is approximately 12 km long from its origin on Coronation Mountain to the point where it enters Ladysmith Harbour (Figure 1). The drainage area of Holland Creek near its mouth at Ladysmith is 28 km^2, ranging in elevation from sea level to 1300 m.

The Holland Creek watershed receives an average of 2200 mm of precipitation per year, with more than 80% falling during October through March. December and January are the wettest months, while July and August are the driest. Peak streamflows occur during winter rains, while low flows occur during June through September. Flows in Holland Creek are affected by: the diversion of water from the upper 7.5 km^2 of Banon Creek into Holland Lake during November through May, the storage of water in Holland and Prevost Lakes in the winter and its release in the summer, and the withdrawal of water by the Town of Ladysmith at the Chicken Ladder intake. The net effect of this water regulation is to increase low flows by up to 3 to 4 times during July, August, and September.

The Stocking Lake watershed is very small, with a drainage area of only 1.65 km^2, ranging in elevation from 360 to 600 m. The average precipitation is 1700 mm per year, with peak runoff occurring in winter and low flows in summer. Stocking Lake is a small lake with a surface area of 0.23 km^2 (23 ha), a maximum depth of 19 m, and a volume of 2091 dam^3 (dam^3 = cubic decameter = 1000 m^3). The lake is heavily used for water supply, with Ladysmith and the Cowichan Valley Regional District withdrawing about 35% of the inflow to the lake in an average year, and about 78% in a very dry year. There is no outflow from the lake during June to November when the lake is drawn down below the spillway.

Water Uses

Licenses

The only water licenses on Holland Creek are held by the Town of Ladysmith. They are authorized to withdraw up to 2728 m^3/d at the Chicken Ladder intake for waterworks. This withdrawal is supported by 370 dam^3 of storage in Holland and Prevost Lakes, and the Town is also licensed to divert up to 1820 dam^3 from upper Banon Creek to Holland Lake during November through May. Historically, Ladysmith has withdrawn water from Holland Creek during April through October, when the water is free of turbidity. Increasing water demand will make it necessary to use Holland Creek during more of the year.

The Town of Ladysmith and the Cowichan Valley Regional District hold waterworks licenses on Stocking Lake and there are two irrigation licenses on lower Stocking Creek. The CVRD and the southern part of Ladysmith use the water year-round, while the rest of Ladysmith uses it when Holland Creek is turbid, mainly during the winter.

Recreation

Water-based recreation in the watersheds includes fishing on Holland Lake and in the lower reaches of Holland and Stocking Creeks, and hiking/camping throughout the Holland Creek watershed.

Fisheries

Holland Creek anadromous (sea-run) fisheries are limited to the lower 2.3 km by impassable falls. The major runs are chum salmon with 10-year mean and maximum escapements (returning spawners) of 3800 and 10,500, respectively. There are minor runs of coho salmon (60), steelhead (25), and cutthroat trout. Holland Lake supports a good recreational fishery of stocked rainbow trout. Little is known about fish and fish habitat between Holland Lake and lower Holland Creek.

Stocking Creek anadromous fisheries are limited to the lower 0.5 km by impassable falls. The major runs are chum salmon with 10-year mean and maximum escapements of 3700 and 8700, respectively. There are minor runs of coho salmon (75) and cutthroat trout. Stocking Lake supported a good recreational fishery for rainbow trout until fish stocking was stopped in 1986, when access to the lake was closed to protect the drinking water supply.

Influences on Water Quality

Several human activities influence water quality in the Holland Creek, Banon Creek, and Stocking Lake watersheds above the water intakes for Ladysmith and the CVRD. They are all non-point, diffuse land-use activities, including forestry, forest roads, and recreation. There are no residences or waste discharges as defined under the Waste Management Act above the water intakes. Wildlife can also influence water quality.

Forestry and Forest Roads

About 95% of the combined Holland Creek, Stocking Lake, and upper Banon Creek watershed area (37 km^2) is managed for forestry by TimberWest Forest Limited, the B.C. Forest Service, and Pacific Forest Products Limited. The Town of Ladysmith owns the remaining 5% immediately surrounding Holland, Stocking, Prevost, and Heart Lakes to protect its water supply.

About 92% of the combined watershed was logged between 1900 and the 1970's, although much of this area has been reforested and has recovered hydrologically. In the future, the forest managers would like to harvest the second growth forests as they mature. Previous logging has left some cases of erosion of forest roads, stream channels, and cutblocks in Holland and upper Banon Creeks that cause periodic episodes of turbid water during rainstorms. The Integrated Watershed Management Plan (IWMP) Committee asked the landowners to develop and implement rehabilitation plans for the watersheds. TimberWest has subsequently done remedial work on failed roads and drainage structures.

Recreation

Recreational activities in the Holland Creek watershed include fishing (Holland Lake), hiking, camping (including unsanctioned cabin use), hunting, horseback riding, cycling, motor biking, and other vehicular access. The most serious concern for recreation in a community watershed is the disposal of human and domestic animal wastes. Such wastes should be disposed of so that harmful microorganisms do not enter the water supply. The level of fecal contamination tends to increase with the level of recreation in a watershed. There were no toilets in the watershed for the safe disposal of human wastes, and a cabin adjacent to the North Fork of Holland Creek had a high potential for fecal contamination of the creek. Approved toilets should be provided in high use areas, and people should be educated to dispose of human and animal feces by burying them well away from watercourses.

Wildlife

Warm-blooded animals can carry microorganisms, such as *Giardia lamblia* and *Cryptosporidium*, which are harmful to humans, causing gastrointestinal disease. The watersheds support a wide variety of warm-blooded wildlife species, but no data are available on the occurrence of these harmful microorganisms. The prevalence of *Giardia* tends to increase with the intensity of human use in a watershed.

WATER QUALITY ASSESSMENT AND OBJECTIVES

Water Quality Assessment

During the assessment of the data, several observations were made regarding water quality in the Holland Creek and Stocking Lake watersheds:

Holland Creek

- Indicators of fecal contamination occasionally exceeded the guideline for raw drinking supplies, but the standard for the treated tap water was met.
- Turbidity has exceeded the drinking water guideline occasionally in the past due to rainstorms, but recent data are inadequate to indicate if this is still the case.
- Colour occasionally exceeds the aesthetic guideline for drinking water.
- Trihalomethanes (disinfection by-products) in the chlorinated tap water were well below the drinking water guideline.
- pH met the aesthetic guideline for drinking water, except during a heavy rainstorm when the pH was lowered by the naturally low pH of rainwater.
- Metals and a wide variety of other substances met drinking water guidelines.

Stocking Lake

- Indicators of fecal contamination, turbidity, and colour met the raw drinking water guidelines.
- Trihalomethanes in chlorinated tap water met the drinking water guideline, but more monitoring is needed for confirmation.
- pH met the aesthetic guideline for drinking water except during heavy rainstorms when the pH was lowered by the naturally low pH of rainwater.

- Acid-buffering capacity is low, but there is no indication of acidification or other adverse trends over the last decade.
- Metals and a wide variety of other substances met drinking water guidelines, with the exception of iron, which exceeded the aesthetic guideline on rare occasions.
- Phosphorus and algae met drinking water guidelines, but phosphorus enrichment should be avoided to maintain water quality.

Water Quality Objectives

Water quality objectives have been set for key drinking water characteristics in the Holland Creek and Stocking Lake watersheds (Table 1). These objectives will also protect aquatic life, wildlife, water-based recreation, livestock watering, and irrigation for these characteristics. The objectives apply to the watersheds above the community water supply intakes. The proposed water quality objectives have been met with the exception of fecal coliforms and turbidity in Holland Creek.

Monitoring Recommendations

The recommended minimum monitoring for Holland Creek and Stocking Lake is summarized in Table 2. The monitoring is for raw water at or near the community water supply intakes, with the exception of trihalomethanes which are measured in the chlorinated tap water. The monitoring is the responsibility of the water purveyors and the Ministry of Health. It is a basic monitoring program to check the attainment of the objectives, to document water quality conditions, and to detect any trends at the intakes. Additional monitoring may be needed to evaluate conditions in the upper watersheds or specific development projects. Continuous, automatic monitoring of turbidity and flow are recommended for Holland Creek to obtain accurate records for these highly variable characteristics. A quality assurance program including field blanks and field replicates is recommended to ensure that high quality data are collected.

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FIGURE 1: HOLLAND CREEK & STOCKING LAKE

WATERSHEDS & WATER QUALITY MONITORING SITES

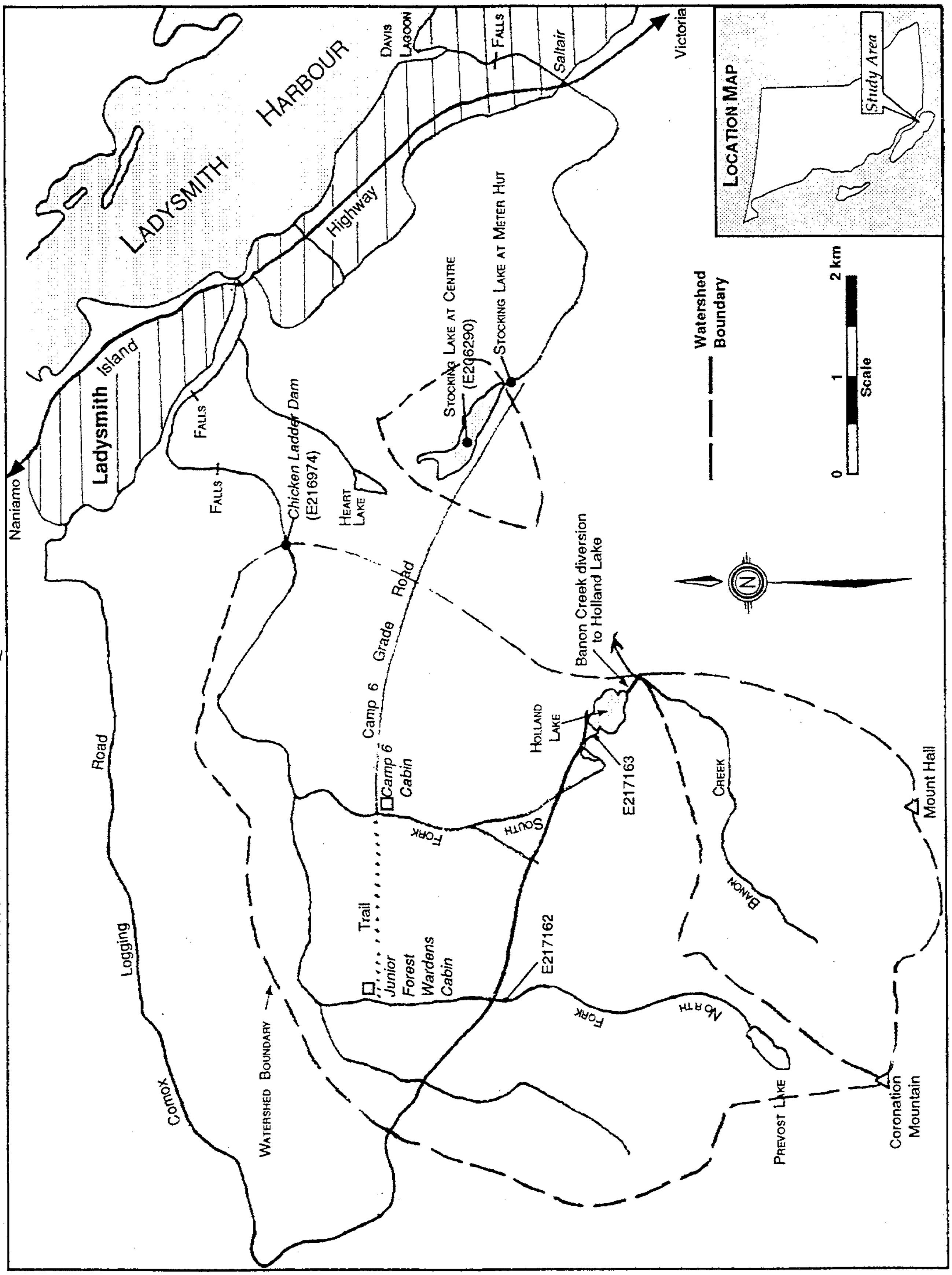

TABLE 1
HOLLAND CREEK-STOCKING LAKE BASINS
WATER QUALITY OBJECTIVES

Designated Water Uses: Aquatic life and wildlife, drinking water, primary-contact recreation, irrigation, livestock watering

Characteristic	Objectives[1,2] Holland Creek	Stocking Lake
Coliforms, fecal	10/100 mL (90th percentile[4])	10/100 mL (90th percentile[4])
Turbidity	1 NTU (maximum)	1 NTU (maximum)
Colour, true	15 TCU (maximum) or no increase if background exceeds 15 TCU	15 TCU (maximum)
Total organic carbon	2 mg/L (annual average of monthly samples)	2 mg/L (annual average of monthly samples)
pH	6.5-8.5 6.5 (5th percentile of at least 20 measurements over 2 years)	6.5-8.5 6.5 (5th percentile of at least 20 measurements over 2 years)
Iron, total	-	0.3 mg/L (maximum)
Chlorophyll a	-	2.5 μg/L (summer average [5])
Phosphorus, total	-	10 μg/L (average[3] at spring overturn)

1 These objectives apply to the Holland Creek and Stocking Lake watersheds at the community water supply intakes or at the centre of Stocking Lake for chlorophyll a and phosphorus.
2 For values below the detection limit, use the detection limit to calculate the statistic.
3 The average of samples at 1 m, mid-depth, and 1 m from the bottom.
4 The 90th percentile applies to a minimum of 10 measurements at about equal intervals over 30 days.
5 The grand average of monthly samples during May-August at depths of 0, 2, 4, and 6 m.

TABLE 2
RECOMMENDED WATER QUALITY MONITORING
HOLLAND CREEK- STOCKING LAKE BASINS

Characteristics	Frequency & Timing	Proposed Sites
	Holland Creek	
Flow	Continuous	Chicken Ladder Intake
Turbidity	Continuous	"
Coliforms, fecal	Weekly, Daily (rainstorms)	"
pH	Monthly	"
Colour, true	Monthly (Quarterly [1])	"
Carbon, total organic	Quarterly [1]	"
Trihalomethanes	Quarterly [1]	Chlorinated tap water
Giardia lamblia	Initial surveillance	Chicken Ladder intake
Cryptosporidium	Initial surveillance	Chicken Ladder intake
	Stocking Lake	
Turbidity	Monthly	Meter Hut
Coliforms, fecal	Monthly [2]	"
pH	Monthly	"
Colour, true	Monthly (Quarterly [3])	"
Iron, total	Monthly	"
Carbon, total organic	Quarterly [3]	"
Phosphorus, total	Annually at spring overturn	Centre of lake, deepest point
Chlorophyll a	Monthly, May-August	Centre of lake, deepest point
Temperature, water	Annually at spring overturn	Centre of lake, deepest point
Trihalomethanes	Quarterly [3]	Chlorinated tap water

1 Simultaneous quarterly measurements for one year if total organic carbon > 2 mg/L.
2 A minimum of 10 measurements at about equal intervals over 30 days required to check attainment of objective.
3 Simultaneous quarterly measurements for one year.

Ministry of Environment, Lands and Parks
Province of British Columbia

Holland Creek and Stocking Lake Watersheds

Vancouver Island

Water Quality Assessment and Objectives

Technical Appendix

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1. Introduction

Holland Creek supplies water to the Town of Ladysmith during April through October when the water is usually clear, and is being used increasingly at other times of the year when the water is clear. Stocking Lake supplies Ladysmith during November through March and other times of the year when Holland Creek is turbid. It also supplies south Ladysmith and the Saltair area of the Cowichan Valley Regional District year-round. The population supplied with water is about 6700 by the Town of Ladysmith (Marchand, R. Pers. comm.), and about 2500 by the Regional District (Tremble, T. pers. comm.). The locations of the watersheds are shown on Figure 1.

These watersheds are the subject of an Integrated Watershed Management Plan (IWMP), chaired by the Ministries of Environment and Forests, with representation from several stakeholders such as the Town of Ladysmith, the Cowichan Valley Regional District, forest companies, recreation groups, interested citizens, Fisheries and Oceans Canada, and the Ministry of Health. In support of the planning process, the Water Quality Branch undertook this water quality assessment to evaluate the water quality conditions in the watersheds and to establish water quality objectives. The historical water quality data were assessed and a monitoring program was designed for 1992/93 (Pommen, 1992). An interim assessment evaluated the results to March 1993, recommended interim water quality objectives for Holland Creek and Stocking Lake, and recommended monitoring for 1993/94 (Pommen, 1993). Key data from these previous reports are included in this report.

2. Hydrology

A hydrological analysis of the Holland Creek and Stocking Lake watersheds was done to support the Integrated Watershed Management Plan (Chapman and Reksten, 1992).This section presents a brief summary of the key information from this analysis needed for the water quality assessment. The locations of the watersheds are shown in Figure 1.

2.1 Holland Creek

The Holland Creek watershed has an area of 28 km^2, ranging in elevation from sea level to 1300 m, with a median elevation of 570 m. The mean annual precipitation on the Holland Creek watershed varies from 1200 mm at sea level to 2500 mm at upper elevations, with a basin average of 2200 mm. The majority of the precipitation on the Holland and Stocking watersheds occurs during the winter. The six months between October to March receive greater than 80% of the average annual precipitation. December and January are the months of highest precipitation, while July and August are the driest. The portion of the annual precipitation occurring as snow varies greatly with elevation. At sea level, about 5% occurs as snow, while at the upper elevations of the Holland Creek basin, up to 60% can occur as snow. The average for the Holland Creek watershed is about 15-20% as snow.

The mean annual runoff for the Holland Creek watershed is about 1800 mm or 1.6 m^3/s or 50,400 dam^3 (dam^3 = cubic decameter = 1000 m^3). Peak flows occur in winter due to rain or rain-on-snow, while low flows occur during June-September. The natural runoff has been altered considerably by the diversion of water from neighbouring Banon Creek into the Holland Lake reservoir, by the storage and release of water from Holland and Prevost lakes, and by the withdrawal of water by the Town of Ladysmith at the Chicken Ladder Dam. Holland Lake has a storage of 1370 dam^3, while Prevost Lake has a storage capacity of 124 dam^3.

The Town of Ladysmith has a water license to divert up to 1820 dam^3 from Banon Creek to Holland Lake during November 1 to May 31. Of this water, 770 dam^3 may be diverted through Holland Lake for immediate use during winter, and the remaining 1050 dam^3 may be stored in Holland Lake and released to augment flows in summer. In addition, there are 370 dam^3 of storage of Holland Creek water in Holland and Prevost Lakes during winter for release in summer. In 1990, the Town of Ladysmith withdrew about 966 dam^3 from Holland Creek at the Chicken Ladder Dam during April through October for water supply. This represents about 2% of the mean annual flow of Holland Creek, and up to 25-30% of the summer low flows.

The net effect of the regulation of Holland Creek is significantly increased flows during the low-flow months of July, August, and September. Mean flows during these months have increased by 2-4 times upstream from the Ladysmith intake at the Chicken Ladder Dam, and by 1.5-3 times downstream from the Chicken Ladder Dam.

2.2 Stocking Lake

The Stocking Lake watershed is very small, with an area of only 1.65 km^2. It varies in elevation from 360 to 600 m, with a median of 380 m. Mean annual precipitation is estimated to be 1700 mm. The mean annual runoff is 1300 mm or 0.068 m^3/s or 2140 dam^3. Peak flows occur in winter (Nov-Mar), with low flows in summer (Jul-Sep). Stocking Lake is a reservoir with 925 dam^3 of licensed storage. The Town of Ladysmith withdraws water from Stocking Lake (484 dam^3 withdrawn in 1990) year-round for the southern part of town, and during November-March when Holland Creek is turbid for the rest of the town. The Saltair area of the Cowichan Valley Regional District withdraws water year-round (262 dam^3 withdrawn in 1990). These withdrawals are about 35% of the inflow to Stocking Lake in an average year, and 78% in a 25-year return period low flow. There is no outflow from Stocking Lake from June to November when the lake is drawn down below the spillway (Chapman and Reksten, 1992; Woodgate, 1994).

At the crest of the spillway, the lake has an area of 23 ha, a volume of 2091 dam^3, and a maximum depth of 19 m. The mean residence time of water in the lake is about 1 year. The live storage volume in the lake between the spillway crest and the water intake invert is 1073 dam^3, and thus the mean epilimnetic residence time is about 6 months (Water Management Branch, 1986).

2.3 Precipitation

There are no stream-gauging stations in the study area, and thus the daily precipitation data from the Nanaimo City Yard (Environment Canada, Atmospheric Environment Service, station 10253GO) are used in this report to provide some indication of the pattern of rainfall and resulting runoff in the study area for the interpretation of the water quality data. Rainstorms can have a profound effect on water quality in a matter of hours or days in small watersheds such as these. This is the closest station that corresponds to the Stocking Lake and the low to mid-elevation areas of the Holland Creek watershed (Chapman & Reksten, 1992). The daily precipitation data are plotted in Figures 2, 3, and 4 along with the sampling dates for Holland Creek and Stocking Lake.

3. Water Use

3.1 Holland Creek Watershed

3.1.1 Water Licenses

The only water licenses on Holland Creek are held by the Town of Ladysmith. They are authorized to withdraw up to 600,000 gpd (2728 m^3/d) at the Chicken Ladder intake for waterworks purpose. This withdrawal is supported by 370 dam^3 of storage in Holland and Prevost Lakes. The Town is also licensed to divert up to 1820 dam^3 from Banon Creek to Holland Lake during November 1st to May 31st. The diverted water is subsequently released from Holland Lake for water withdrawal downstream on Holland Creek. Historically, Ladysmith has withdrawn water from Holland Creek during April through October, when the water is normally free of turbidity. However, increasing water demand from Ladysmith will make it necessary to use Holland Creek during more of the year (Woodgate, 1994).

3.1.2 Fisheries

Holland Creek is divided into anadromous (sea-run) and resident reaches by an impassable 14-m falls 2.3 km upstream from the estuary. A 2.5-m falls 1.2 km upstream from the estuary is also impassable at times. Coho salmon and steelhead use the lower 2.3 km, while chum salmon and cutthroat trout use the lower 1.2 km. Historically, chum salmon has been the dominant species with counts in excess of 15,000. The 10-year mean and maximum escapement (the number of returning spawners) is 3807 and 10,500 for chum, and 27 and 60 for coho. The maximum steelhead escapement has been 25.

Detailed fish habitat and distribution mapping are not available for Holland Creek above the falls. Resident cutthroat trout are found in areas of suitable habitat. Rainbow trout of up to 300 mm were found in Holland Creek immediately downstream from Holland Lake, and it is suspected that they were swept out of the lake during high water. Holland Lake does not have any natural inlet streams, and thus there is no spawning habitat or opportunity for natural wild fish recruitment. Rainbow trout production depends upon the routine stocking of Holland Lake, which began in 1983, and has produced a good recreational lake fishery (Woodgate, 1994). Surveys in 1986 and 1989 indicated that there were more than 700 angler-days per year of sportfishing on Holland Lake. The Ladysmith Sportsman's Club has monitored fish and water quality in Holland Lake annually since 1992 for the Fish and Wildlife Branch (Law, 1995).

3.1.3 Recreation

The B.C. Forest Service's Forest Recreation Inventory gives a high rating to Holland Lake, Prevost Lake, and the forested area between Holland Creek and South Holland Creek, which contains several original logging railway grades, the Junior Forest Wardens' cabin, and high quality hiking opportunities. The amount of recreational use in these areas is not known at this time, but includes angling, hiking, camping, hunting, cycling, and motor biking (Draft IWMP, 1994).

3.2 Stocking Lake/Creek Watershed

3.2.1 Water Licenses

The Town of Ladysmith has a waterworks license for 500,000 gpd (2273 m^3/d) on Stocking Lake, and The Cowichan Valley Regional District (CVRD) has two waterworks licenses, totaling 925 dam^3. There are two irrigation water licenses on Stocking Creek downstream from Stocking Lake between the Island Highway and the E & N Railway, totaling 61 dam^3. The CVRD and the southern part of Ladysmith use the water year-round, while the rest of Ladysmith uses the water mainly during November through March when Holland Creek can be turbid (Draft IWMP, 1994).

3.2.2 Fisheries

Stocking Creek is divided into anadromous and resident reaches by an impassable 3-m falls/dam 0.5 km upstream from the Davis Lagoon estuary (Figure 1). This lower 0.5 km is used by chum salmon, coho salmon, and cutthroat trout. The 10-year mean and maximum escapements are 3723 and 8700 for chum, and 14 and 75 for coho. There is no fish habitat and distribution mapping for Stocking Creek above the falls/dam, although resident cutthroat trout are expected in areas of suitable habitat. Stocking Lake was stocked with rainbow trout fry during 1982-86, creating a good recreational fishery. The fish stocking was stopped when access to the lake was closed by the Town of Ladysmith to protect their water supply. Surveys in 1986 and 1989 indicated that there were 50 angler-days per year of sportfishing on Stocking Lake (Law, 1995).

3.2.3 Recreation

The B.C. Forest Service's Forest Recreation Inventory rates Stocking Lake as having high potential recreational value. The lake had a good stocked fishery in the 1980's, and anglers are unhappy with the restricted access to the lake imposed by the Town of Ladysmith. Hiking occurs around the lake.

3.3 Designated Water Uses

Designated water uses are sensitive water uses that are designated for protection in a watershed or waterbody. Water quality objectives are then designed for the substances or conditions of concern in a watershed so that attainment of the objectives will protect the designated uses.

The designated water uses recommended for Holland Creek and Stocking Lake are: drinking water, aquatic life, recreation, irrigation, livestock watering, and wildlife.

4. Influences on Water Quality

The influences on water quality in the Holland Creek, upper Banon Creek, and Stocking Lake watersheds above the water intakes for Ladysmith and the CVRD are all non-point, diffuse land-use activities, including forest harvesting, forest roads, recreation, and wildlife. There are no residences (cabins are included under recreation) or waste discharges as defined under the Waste Management Act.

4.1 Land Ownership

There are four major landowners in the study area, which has an area of 37 km^2. TimberWest Forest Limited owns 20.6 km^2 or 56% of the study area, almost all of which is managed under Tree Farm Licence Number 47. The Crown owns 10.8 km^2 or 29.4% of the study area, and it is managed by the B.C. Forest Service as provincial forest. The Crown Land is also managed by BC Environment under a Registered Trapline. Pacific Forest Products Limited owns 3.4 km^2 or 9.3% of the study area, and it is designated as managed forest land. Finally, the Town of Ladysmith owns 1.87 km^2 or 5.1% of the study area immediately surrounding Holland, Stocking, Prevost, and Heart lakes to ensure that waterfront activities are compatible with the maintenance of water quality for community water supply.

4.2 Forest Harvesting and Forest Roads

The lower reaches of the study area were first harvested at the turn of the century. Over the decades, harvesting progressed to higher elevations, with the most recent logging of old growth occurring in the 1970's. The first stand of second growth was harvested in 1989 (Woodgate, 1994). Ninety-two percent of the study area has been harvested, although much of the area has been reforested and has recovered hydrologically (Hudson, 1994).

TimberWest and Pacific Forest products have no plans to harvest in the next five years since most of their forests are 21 to 60 years old. The lands in the provincial forest contain the majority of the older second growth in the study area (7.54 km^2 older than 61 years), and the B.C. Forest

Service, under the Small Business Forest Enterprise Program, has plans to harvest suitable stands in the next five years (Woodgate, 1994).

4.2.1 Holland Creek and Upper Banon Creek

Holland Creek has periodic episodes of turbid water during high flows accompanying rainstorms. A 1990 survey by Chatwin found that much of the turbidity results from historic logging and road building. He found three main sediment sources: a logged area in headwaters of Holland Creek with road and cutblock erosion, the road between Coronation and Holland lakes with blocked or missing culverts and streams running down the road, and streambank erosion, mainly in the uppermost section of the mainstem of Holland Creek (Chatwin, 1990).

Hudson (1994) conducted a watershed assessment on Holland and upper Banon creeks. He found no evidence of natural or man-induced landslides in the watersheds. There were high to extreme risks of surface erosion due to logging roads in upper Holland and Banon creeks, and channel erosion problems on Holland Creek downstream from Prevost Lake. He recommended road deactivation and restoration of natural drainage patterns.

The IWMP Committee has asked the landowners to develop and implement rehabilitation plans for the study area. TimberWest did considerable remedial work on failed roads and drainage structures in 1994.

4.2.2 Stocking Creek

Chatwin's 1990 survey of the Stocking Lake watershed found that the new Stocking Lake road was well constructed and posed little sedimentation hazard to Stocking Lake. (The author walked this road in February, 1994 and saw no evidence of significant erosion.) Chatwin also found that the 1989 cutblock (18 ha) between Heart Lake and Stocking Lake drains to Heart Lake and Holland Creek (downstream from Chicken Ladder intake), and thus did not affect Stocking Lake.

4.3 Recreation

4.3.1 Holland Creek Watershed

Recreational activities in the Holland Creek watershed include fishing (Holland Lake), hiking, camping (e.g., cabins), hunting, horseback riding, cycling, motor biking, and all terrain and other vehicular access. There are estimated to be more than 700 angler-days per year of sportfishing on Holland Lake (Law, 1995), but no estimates are available on the number of user-days for the other activities. The most serious concern for recreation in a community watershed is the disposal of human and domestic animal (e.g., dogs, horses) feces so that pathogenic microorganisms do not enter the water supply. The coliform bacteria indicator of fecal contamination in water tends to increase with the level of recreation in a watershed (AWWA, 1994). There is considerable recreation in the watershed, but there were no toilets available for the safe disposal of human wastes. Approved toilets are needed in high use areas, and people should be educated to dispose of human and animal feces by burying them at least 30 m from watercourses.

The author visited two of the cabins in the watershed in February, 1994. The "Camp 6" cabin is located on the South Fork of Holland Creek about 250 m upstream from the intersection of the creek and the Camp 6 railway grade road. The cabin is on the east side of the creek about 75 m away from and 15 m above the creek, with a ridge between the creek and the cabin. There was no toilet at the cabin, but the intervening ridge prevents any drainage to the creek from the cabin. Fecal coliforms sampled 100 m upstream and 250 m downstream from the cabin on February 18, 1994 were at low levels (0-1/100 mL) at both sites.

The "Junior Forest Wardens" cabin is located on the North Fork of Holland Creek about 100 m downstream from the Camp 6 railway grade trail. The cabin is on the east side of the creek about 20 m from the creek across relatively level ground. There was no toilet at the cabin, and there were feces on the ground all around the cabin. These feces could have been washed into the creek during snowmelt or heavy rains. Fecal coliforms sampled 100 m upstream and downstream from the cabin on February 18, 1994 were at low levels (0-4/100 mL) and showed no difference from upstream to downstream. However, it was dry at the time, with no runoff from the cabin area to the creek. A pit privy has since been constructed at the cabin (Woodgate, pers. comm.).

Another potential concern for recreation is erosion due to motor vehicle traffic. In Washington State, Reid (1981) found that the rates of erosion of gravel-surfaced roads vary directly with the frequency of use. For example, sediment production from logging roads traveled by more than four trucks per day was three orders of magnitude greater than from deactivated roads.

4.3.2 Stocking Lake Watershed

Vehicle access to the watershed is restricted by locked gates, but hiking occurs along the new road on the logging railway grade to the south of the lake, on a trail to Heart Lake to the north of the lake, and to the dam at the outlet of the lake. There are no toilets in the watershed. As for Holland Creek, the main concern is the improper disposal of human and domestic animal wastes adjacent to the water supply.

4.4 Wildlife

Wildlife can influence water quality because warm-blooded animals can carry pathogens such as *Giardia lamblia*, which cause giardiasis or "beaver fever", and *Cryptosporidium* oocysts which cause the gastrointestinal disease, cryptosporidiosis. Virtually every mammal ever checked can carry *Giardia*, while aquatic mammals and domestic livestock carry *Cryptosporidium*. In addition, warm-blooded animals excrete fecal coliforms in their feces, and can cause elevated levels of this indicator of fecal contamination in water. Fecal contamination of water by animals is generally considered to be less of a concern to human health than contamination by humans because their is less risk of inter-species transfer of pathogens. However, there is no reliable method of differentiating human and animal fecal coliforms (Warrington, 1988).

Little specific information regarding the wildlife resources of the Holland Creek/Stocking Lake study area is available. The following information is based on observations in the study area plus an understanding of wildlife resources in the region. Warm-blooded wildlife species in the study area include: black-tailed deer, black bear, cougar, wolf, Roosevelt elk, beaver, mink, raccoon, river otter, red squirrel, ermine (weasel), pine marten, Vancouver Island marmot (potentially), grouse, eagles, hawks, owls, and numerous other smaller bird species (Woodgate, 1994). A study in the Olympic Mountains of Washington State showed that the prevalence of *Giardia* in wild animals and water increased with the intensity of human use in watersheds (Ongerth *et al.*, 1995). There are no data on the occurrence of *Giardia* and *Cryptosporidium* in the study area waters, and we recommend that some initial investigations be conducted in Holland Creek.

5. Water Quality Assessment and Objectives

This report assesses water quality in the Holland Creek and Stocking Lake watersheds. Water quality objectives for key drinking water characteristics such as fecal coliforms, turbidity, colour, total organic carbon, pH, iron, and phosphorus are set to protect raw drinking water supplies, which is the most sensitive water use in the watersheds for these characteristics. An analysis of the available data suggested that objectives for other substances are not needed at this time.

The Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1993) are used to assess the suitability of Holland Creek and Stocking Lake for drinking water. The Guidelines apply to drinking water at the point of consumption (i.e., after water treatment), but they can be used to assess raw water quality where the water treatment provided does not significantly alter the water quality variables being considered. The Ministry of Health requires water purveyors to disinfect all surface water as a minimum prior to drinking (Safe Drinking Water Regulation, 1992).

5.1 Holland Creek

The Holland Creek watershed was monitored relatively frequently (daily during some periods) for turbidity and colour by the Town of Ladysmith during 1978-83, and these data are shown in Figures 5 and 6. The results for the samples collected for this study by the Town of Ladysmith and analysed by BC Environment and the Ministry of Health during October 1991 to October 1994 are presented in Table 1. The locations of the monitoring sites are shown on Figure 1.

The Town of Ladysmith also had 5 to 10 samples analysed for a wide range of characteristics from each of 4 locations in the Holland Creek system during 1975-80. The 4 locations were North Banon Creek (now diverted into Holland Lake during Nov-May), Holland L. outlet, North Fork of Holland Cr., and the Chicken Ladder Dam. Characteristics that exceeded drinking water guidelines were turbidity, pH, iron, manganese, and colour as discussed below. The guidelines for the last four are aesthetic objectives, and were exceeded most often in the headwaters of Holland Creek.

The Ministry of Health has monitored Holland Creek water at the Chicken Ladder Dam or in the water distribution system between 5 and 9 times between 1974 and 1991 for a wide range of characteristics. Colour (30 TCU), pH (6.4), turbidity (5.3 NTU), iron (0.9 mg/L), and total coliforms (111/100 mL) each exceeded drinking water guidelines on one occasion. Only the turbidity and total coliform guidelines are health-related. Health also collected a sample from Holland Creek at the Chicken Ladder intake on May 4, 1992 and analysed it for 45 characteristics relevant to drinking water. All the characteristics met the Guidelines for Canadian Drinking Water (Health and Welfare Canada, 1993).

5.1.1 Coliform Bacteria

Coliform bacteria are present in large numbers in the feces of warm-blooded animals, and although rarely pathogenic themselves, they are used as indicators of fecal contamination in water. Fecal coliforms are quite specific to the feces of warm-blooded animals and *E. coli* are even more specific, whereas total coliforms have many non-fecal sources (e.g., soils, plants), and thus are less indicative of fecal contamination.

Holland Creek water is chlorinated before consumption, and thus the relevant drinking water criteria are 90th percentiles of 10/100 mL for fecal coliforms and 100/100 mL for total coliforms (Ministry of Health, 1982, Nagpal *et al.*, 1995).

(a) Fecal Coliforms (including *E. coli*)

Quality assurance for fecal coliforms and *E. coli* included field replicates analysed at the same laboratory or at different laboratories on 21 occasions. The precision of the replicates, including paired fecal coliform and *E. Coli* samples, was very good, considering the inherent variability of coliform measurements (Table 1).

Table 1 shows that fecal coliforms were low (≤ 5/100 mL) at the outflow from Holland Lake. They were also low (≤ 6/100 mL) in the North Fork of Holland Creek with the exception of a value of 84/100 mL measured at the end of a rainy period from June 28 to July 5, 1992 (Figure 2). Rains can wash fecal matter into streams and increase flows, resuspending fecal matter in the stream sediments.

Fecal coliforms were periodically elevated in Holland Creek at the Chicken Ladder intake. The elevated levels (>10/100 mL) were usually associated with rainy days (Figures 2-4). The peak value of 1400/100 mL occurred during a 40-mm rainstorm on June 28-29, 1992 (Figure 2), which probably washed accumulated fecal matter from animals and humans in the watershed into the creek. Fecal coliforms were measured on 53 days between October 1991 and October 1994, with values for 16 days or 30% exceeding 10/100 mL. The 90th percentile is estimated to be about 100/100 mL, well above the drinking water guideline of 10/100 mL. May-August 1992 was the worst period, with a 90th percentile of 240, while June-Oct 1993 and April-October 1994 had 90th percentiles of 11 and 20, respectively.

We must stress that 10/100 mL is only a guideline, and that the only standard which must be met is zero fecal coliforms in the water distribution system after disinfection (Safe Drinking Water Regulation, 1992). This standard was met in the Ladysmith distribution system (Michaud, J. pers. comm., Walsh, E. pers. comm.).

The turbidity in Holland Creek was low (≤0.5 NTU) when fecal coliforms were high, enabling the chlorination to be more effective in inactivating coliforms in the treated water than if the water was turbid. Also, the Town of Ladysmith stops using Holland Creek water when it becomes turbid, manually switching to Stocking Lake water (Cale, C. pers. comm.). We are concerned that if elevated turbidity (>1-5 NTU) coincides with elevated fecal coliforms (>10/100 mL), chlorination may not be effective in inactivating pathogens in the treated water, posing a potential health hazard. The U.S. EPA Surface Water Treatment Rule stresses the importance of both low fecal coliforms (6-month 90th percentile of ≤20/100 mL) and low turbidity (≤5 NTU) in raw surface drinking water to achieve microbiologically safe water after disinfection (Von Huben, 1991).

The recommended objective for fecal coliforms in Holland Creek at the water intake is a 90th percentile of ≤10/100 mL in a 30-day period. (Fecal coliform and E. Coli levels were similar in Holland Creek, and thus the more commonly used fecal coliform indicator is deemed to be an adequate indicator of fecal contamination in Holland Creek). At least 10 samples at roughly equal intervals over 30 days are needed to calculate the 90th percentile. This objective is not met at the present time, and it is uncertain whether it can be met in the future. This will depend on the relative contributions of humans, domestic animals, and wildlife to the fecal coliforms in Holland Creek, and the effectiveness of measures to control these contributions.

(b) Total Coliforms

The total coliform situation in Holland Creek at the Chicken Ladder intake was similar to that for fecal coliforms, with elevated levels much of the time. Total coliforms were measured on 39 days during October 1991-October 1994, with values for 32 days or 82% above 100/100 mL. The 90th percentile is estimated to be 892/100 mL, well above the drinking water guideline of 100/100 mL.

We do not recommend an objective for total coliforms because it is not as specific an indicator of fecal contamination as fecal coliforms.

5.1.2 Turbidity

Turbidity is a measure of the clarity or cloudiness of water, and is measured by the amount of light scattered by the particles in the water. The criterion for drinking water that does not receive treatment to remove turbidity, such as Holland Creek, is a maximum of 1 NTU (nephelometric turbidity units), although a maximum of 5 NTU may be permitted if it can be demonstrated that disinfection is not compromised by the use of the less stringent value (Health and Welfare, 1993). The Ministry of Health has advised that 1 NTU is the appropriate objective for Holland Creek water being used as a drinking water supply treated solely by disinfection (Hazlewood, 1995).

Figure 5 shows the turbidity in Holland Creek at the Chicken Ladder intake for June 1978 to June 1983. Turbidity was measured on 298 days during this 5-year period, with 84 values (28%) exceeding 1 NTU and 11 values (4%) exceeding 5 NTU. The 11 turbidity values above 5 NTU ranged from 6 to 86 NTU, were highly episodic, lasting for a few days each during 6 rainstorms, and occurred in both summer and winter storms. We suspect that the turbidity regime in Holland Creek continues to be about the same, although frequent monitoring during rainstorms has not been done since 1978-83 (see below).

Table 1 contains the October 1991-October 1994 turbidity data for the Holland Creek watershed. The precision of seven sets of field replicates was excellent. Over these two years, turbidity was measured on 19 days at the Holland Lake outflow and the North Fork of Holland Creek, and on 38 days at the Chicken Ladder intake. These represent 2.5% and 5% of the days during the two years, and are not adequate to describe accurately the short-term (e.g., daily) turbidity fluctuations induced by rainstorms. Holland Lake and the North Fork had low turbidity, with only two days each with levels greater than 1 NTU, and maximums of ≤2 NTU.

The Chicken Ladder intake had very low turbidity, with all values <1 NTU. Turbidity was measured at Chicken Ladder shortly after (0-2 days) four rainstorms: 66 mm during Nov 18-21, 1992; 21-33 mm during May 31-June 1, 1993; 37 mm during Oct 21-23, 1993; and 81-92 mm during Feb 27-Mar 4, 1994 (Figures 2 and 3). Turbidity did not exceed 0.6 NTU on these occasions, but the storms were not very intense. The daily precipitation did not exceed 34 mm during these storms, whereas the maximum daily precipitation in an average year (2-year return period) at the Nanaimo City Yard station is 57 mm (Chapman and Reksten, 1992). Frequent monitoring during and after rainstorms is needed to generate an accurate picture of the present turbidity regime in Holland Creek. A minimum of daily monitoring should be done during and after rainstorms or rapid snowmelt, but preferably automatic turbidimeters should be used to obtain measurements at intervals of one hour or less.

The recommended turbidity objective for Holland Creek at the water intake is a maximum of 1 NTU. This objective is probably not met at present during intense rainstorms due to erosion from past land use activities in the watershed. It should be viewed as a long-term objective to strive for in watershed rehabilitation and in any future watershed development. It is particularly important to try to achieve this objective during the April through October period when Ladysmith traditionally draws water from Holland Creek. However, increasing water demand will make it increasingly necessary for Ladysmith to draw water from Holland Creek during November through March.

5.1.3 Colour

Colour in water is caused by dissolved and particulate organic and inorganic matter. True colour is a measure of the dissolved colour in water after the particulate matter has been removed, while apparent colour is a measure of the dissolved and particulate matter in water. Colour can affect the aesthetic acceptability of drinking water, and the aesthetic objective is ≤15 true colour units. Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it produces disinfection by-products such as trihalomethanes (see section 5.1.4).

True colour was measured during October 1992 and October 1994, and these data are summarized in Table 1. Seven sets of field replicates indicated good precision in the measurements.

Colour was measured at the Holland Lake outflow on 19 days, with values for two days (10%) exceeding the 15-unit objective. The maximums of 30 and 40 units occurred on December 9 and 14, 1992. The cause of this increased colour is not obvious since the rains were light then (10-15 mm/day), but may be related to the diversion of Banon Creek water into Holland Lake at this time. Apparent colour measurements by Ladysmith in 1978-83 (not shown in this report) showed similar levels with 5 of 27 > 15 units (19%) and a maximum of 30 units.

True colour was measured in the North Fork of Holland Creek on 19 days with values on six days (32%) exceeding the 15-unit objective and a maximum of 40 units. The six days occurred in both summer and winter during periods of light to moderate rain (15-35 mm/day). The rainstorms probably caused the flushing of natural, coloured organic matter from swamps and bogs in the watershed.

True colour was measured in Holland Creek at the Chicken Ladder intake on 39 days in 1992-94, with values for two days or 5% exceeding the 15-unit objective. The maxima of 20-30 units occurred in December, 1992 when the levels upstream in Holland Lake and the North Fork were 20-40 units. The Town of Ladysmith measured apparent colour frequently in Holland Creek at the Chicken Ladder intake during 1978-83, and these data are shown in Figure 6. Apparent colour was measured on 240 days, and values for only six days or 2.5% exceeded 15 units. Apparent colour is greater than true colour when particulate matter or turbidity is present, and thus it is probable that fewer than six days actually had values exceeding the 15 true colour unit drinking water objective.

The recommended objective for true colour in Holland Creek is a maximum of 15 true colour units or no increase over upstream control stations (e.g., Holland Lake outflow, Prevost Lake outflow) when they exceed 15 units during rainstorms.

5.1.4 Trihalomethanes and Total Organic Carbon

Trihalomethanes (THMs) are formed when the organic matter (e.g., organic carbon) in water is chlorinated. Some THMs are animal carcinogens, and are probably carcinogenic in humans. The interim maximum acceptable concentration (IMAC) of total trihalomethanes in drinking water is an annual average of quarterly samples of 0.1 mg/L (Health and Welfare Canada, 1993a). Martine (1994) indicated that a raw water total organic carbon (TOC) of < 2 mg/L was needed to control THM formation at < 0.08 mg/L, and the U.S. EPA proposed Information Collection Rule requires a study for the removal of disinfection by-products, such as THMs, when TOC exceeds 4 mg/L in raw water (AWWA, 1994).

THM monitoring of chlorinated Holland Creek water was done on 3 dates in 1992 (May 4, Aug 25, Sep 21) when colour was low (5 to 7 true colour units), indicating that dissolved organic carbon was low (organic carbon has not been measured). The THM results (0.014 to 0.017 mg/L) were well below the IMAC. If Ladysmith should use Holland Creek water when the colour (>15 TCU) or TOC (> 2 mg/L) are elevated, then further monitoring of the chlorinated water for THMs should be done. True colour and total organic carbon should be measured in the raw water when THMs are measured in the chlorinated water.

The recommended objective for total organic carbon in Holland Creek is an annual average of 2 mg/L, based on monthly samples of raw water.

5.1.5 pH

pH is the measurement of the hydrogen ion (H^+) in water. A pH between 0 and 7 is acidic (the lower the number, the more acidic the water) and a pH between 7 and 14 is basic (the higher the number, the more basic the water). The aesthetic objective for drinking water is a pH between 6.5 and 8.5. Corrosion of metal plumbing may occur at low and high pH, while scaling or encrustation of metal pipes may occur at high pH. The effectiveness of chlorine as a disinfectant is also reduced outside of this range.

The pH data collected during 1992-94 are summarized in Table 1. Precision was good in 6 of 7 sets of field replicates. One pair of duplicates (7.6 & 6.4 on April 5, 1994 at Holland Creek at the Chicken Ladder) had poor precision for no apparent reason. The pH in the Holland Lake outflow and the North Fork were each measured on 19 days, and all pH values were between 6.5 and 8.5. Holland Creek at the Chicken Ladder intake was measured on 38 days, and one pH value (6.3) was slightly below the objective range of 6.5-8.5. This low value occurred at the end of a 92-mm rainstorm during Feb 27-Mar 4, 1994, when the creek was dominated by low-pH surface runoff due to the rainstorm. The pH of rain is naturally low (i.e., <5.6), and a heavy rainstorm can depress the pH of surface runoff due to the limited contact between the rain and neutralizing soil and rock in the watershed. The frequency of occurrence of pH <6.5 in Holland Creek (2.6%) is similar to that in the larger Stocking Lake data base (3.7%)(See section 5.2.5).

The recommended pH objective for Holland Creek at the water intake is the same as for Stocking Lake: a range of 6.5-8.5, with the 5th percentile of the long-term pH not to be less than 6.5 to account for occasional pH depression due to rainstorms. At least 20 values in a 2-year period are needed to calculate the 5th percentile.

5.1.6 Total Metals

As outlined in section 5.1, the Town of Ladysmith and the B.C. Ministry of Health have analysed Holland Creek water at several sites from the headwaters to the Chicken Ladder intake for a wide variety of total metals on 10 to 19 occasions for each site. Several iron values and one manganese value are the only ones that exceeded drinking water guidelines based on aesthetics (e.g., staining of plumbing and clothing). Most of the values appear to have exceeded the guidelines due to elevated turbidity. Only one iron value (0.9 mg/L) exceeded the iron guideline (0.3 mg/L) at the intake, and this was probably due to the elevated turbidity of 5.3 NTU at the time.

No objectives for metals are warranted at this time because the levels in Holland Creek are low and not expected to increase.

5.2 Stocking Lake

Stocking Lake is one of six small lakes in southwestern B.C. monitored by BC Environment for possible trends in water quality due to acid rain and snow. It has been sampled monthly since 1985 for a wide variety of substances related to acidification, but key drinking water indicators such as turbidity and fecal coliforms were rarely measured until 1992 since they have little relevance to acidification.

The water quality data for Stocking Lake for 1985 to March, 1993 are summarized in Table 2, and the sampling sites are shown in Figure 1. Table 3 shows all of the turbidity, colour, and coliform bacteria results available to October, 1994. Figure 7 shows the Secchi disk readings or extinction depths (a measure of water clarity) for 1987-94.

5.2.1 Coliform Bacteria

Stocking Lake water is chlorinated before consumption, and thus the relevant drinking water criteria are 90th percentiles of 10/100 mL for fecal coliforms and 100/100 mL for total coliforms (Nagpal *et al*, 1995).

(a) Fecal Coliforms

Table 3 shows that fecal coliforms were measured on 46 days during 1992-94. Replicate measurements were made on five days, and the precision was excellent with the exception of January 10, 1994 when values of 0, 0, and 150/100 mL were recorded. Given the two 0 values and the normally low levels in the lake, we conclude that the 150 is an error and should be ignored. Values on only two of the 46 days (4%) exceeded the criterion level of 10/100 mL, and the 90th percentile was 2/100 mL, meeting the criterion.

In addition, 72 fecal coliform samples (not shown) were collected by the Ministry of Health from consumer's taps in 1991-92 in the portion of Ladysmith receiving unchlorinated Stocking Lake water (Michaud, J. pers. comm.) (Chlorination was installed on March 16, 1993; Fleckenstein, K. pers. comm.). Only five of the 72 samples (7%) had detectable fecal coliforms, ranging from 4 to 22/100 mL, and also meeting the raw drinking water criterion, since the 90th percentile was <1/100 mL.

These results indicate that Stocking Lake is suitable as a drinking water supply with disinfection only.

The recommended fecal coliform objective for Stocking Lake is a 90th percentile of ≤10/100 mL in a 30-day period. At least 10 samples over 30 days are needed to calculate the 90th percentile.

(b) Total Coliforms

Table 3 shows that total coliforms were measured on 23 days during 1992-94. Six of 23 values (26%) exceeded 100/100 mL, and the 90th percentile was in the 200-350/100 mL range, exceeding the criterion for drinking water with disinfection only. This is not considered to be significant because total coliforms have many non-fecal sources, and the fecal coliform criterion was met.

We do not recommend an objective for total coliforms because it is not as specific an indicator of fecal contamination as fecal coliforms.

5.2.2 Turbidity

Turbidity is a measure of the clarity of water, and is measured by the amount of light scattered by the particles in the water. The criterion for drinking water that does not receive treatment to remove turbidity, such as Stocking Lake, is a maximum of 1 NTU (nephelometric turbidity units), although a maximum of 5 NTU may be permitted if it can be demonstrated that disinfection is not compromised by the use of the less stringent value (Health and Welfare Canada, 1993).

Table 3 shows that turbidity was measured 31 times on 27 days during 1985-94, with most of the data collected in 1993-94. Triplicate samples were measured on two occasions; one set had excellent precision (all 0.3 NTU), while the second set had relatively poor precision (0.5-1.2 NTU). In any event, the turbidity was low, with 30 of 31 values meeting the criterion of 1 NTU, and one value (1.2 NTU) slightly exceeding it. These data indicate that Stocking Lake is suitable for drinking water with disinfection only.

The recommended objective for turbidity for Stocking Lake is a maximum of 1 NTU.

5.2.3 Colour

Colour in water is caused by dissolved and particulate organic and inorganic matter. True colour and total absorbance colour (TAC) are measures of the dissolved colour in water after the particulate matter has been removed. Colour can affect the aesthetic acceptability of drinking water, and the aesthetic objective is ≤15 true colour units (TCU). Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it produces disinfection by-products such as trihalomethanes (see section 5.2.4).

True colour was measured on 24 days during 1992-94 (Table 3). Triplicate samples were measured on two days and the precision was good to excellent. Values on only one of 24 days slightly exceeded the aesthetic objective of 15 TCU, with a maximum of 20 TCU. Total absorbance colour was measured much more often than true colour: 98 times during 1985-94 (Table 2). Only one value, the maximum of 18 TAC units, slightly exceeded the true colour objective of 15 units. True and total absorbance colour are not directly comparable, but the TAC results confirm that colour has been low in Stocking Lake over a 10-year period.

The recommended objective for true colour in Stocking Lake is a maximum of 15 TCU.

5.2.4 Trihalomethanes and Total Organic Carbon

Trihalomethanes (THMs) are formed when the organic matter (e.g., organic carbon) in water is chlorinated. Some THMs are animal carcinogens, and are probably carcinogenic in humans. The interim maximum acceptable concentration (IMAC) of total trihalomethanes in drinking water is an annual average of quarterly samples of 0.1 mg/L. Martine (1994) indicated that a raw water total organic carbon (TOC) of < 2 mg/L was needed to control THM formation at < 0.08 mg/L, and the U.S. EPA proposed Information Collection Rule requires a study for the removal of disinfection by-products, such as THMs, when TOC exceeds 4 mg/L in raw water (AWWA, 1994).

THMs were measured in chlorinated Stocking Lake water from the Ladysmith distribution system on February 19, 1992. True colour was 10 TCU and the total THMs was 0.008 mg/L, well below the 0.1 mg/L IMAC. This single very low value, measured when the true colour, an indicator of organic carbon, was above average, suggests that THMs are unlikely to be of concern in chlorinated Stocking Lake water. However, we recommend that quarterly samples of chlorinated Stocking Lake water be taken for one year to confirm this opinion. True colour and total organic carbon in the raw water should be measured at the same time as indicators of the organic matter available to form THMs.

The recommended objective for total organic carbon in Stocking Lake is an annual average of 2 mg/L, based on monthly samples of raw water.

5.2.5 pH

Only 5 of 190 pH measurements from 1985-94 (4 of 109 sampling days or 3.7% of the days) were outside the drinking water criterion range of 6.5 to 8.5 (Table 2). These low values (5.6 to 6.37) occurred on four dates in February (1991, 1993) and March (1986, 1989) during winter rains. Rain has a naturally low pH (≤5.6), and the heavy rains (50 to 180 mm) that occurred one to two weeks prior to these dates may have temporarily lowered the pH of the surface layer of the lake where the samples were collected. The pH of the water at the depth of the water intake may not have been affected. The lower pH criterion of 6.5 is for aesthetics (not health) related to corrosion of metal plumbing at low pH, although the effectiveness of chlorine as a disinfectant is also reduced outside of this range.

The alkalinity and calcium results indicate that Stocking Lake has relatively little acid buffering capacity, and thus has a high sensitivity to acid inputs such as rain and snow. A trend analysis of the 1985-90 water quality did not find any trends that pose a threat to the environment or water use (Holms, 1994). We performed a preliminary scan of the 1985-94 data for trends, and it appears that this continues to be the case.

The recommended pH objective for Stocking Lake is a range of 6.5 to 8.5, recognizing that there may be a low frequency of exceeding the lower objective during heavy rains. For this reason, an additional objective is that the 5th percentile of the long-term pH measurements should not be below 6.5. At least 20 values over 2 years are needed to calculate the 5th percentile.

5.2.6 Metals

Metals in Stocking Lake met drinking water guidelines (Table 2) with the following exceptions:

Iron - three of 79 total iron measurements slightly (0.31-0.41 mg/L) exceeded the aesthetic guideline of 0.3 mg/L in May, June and July 1988. Dissolved iron levels were very low (0.01-0.05 mg/L) in these samples. Iron can cause staining of plumbing fixtures and clothing. Ten analyses of Stocking Lake water from the Ladysmith and Saltair distribution systems by the

Ministry of Health indicate that only one of 10 iron values (0.5 mg/L in the Saltair system) exceeded the drinking water guideline for iron (Pommen, 1992).

The recommended objective for total iron in Stocking Lake is a maximum of 0.3 mg/L.

Cadmium and Lead - each of these metals had one of 78 measurements that greatly exceeded their drinking water guidelines on June 4, 1986, while the other 77 values met the guidelines. The June 4, 1986 sample also contained the maximum recorded values for aluminum, chromium, copper, molybdenum, vanadium, and zinc (although they were all below drinking water guidelines), but a low level of suspended solids (1 mg/L). We conclude that this was an anomalous sample that was not representative of the metal levels in the lake. Accidental contamination of the sample is suspected.

No objectives are proposed for any other metals for Stocking Lake because the levels are low and we have no reason to expect them to increase due to existing or proposed watershed activities. Metals in drinking water are more often a problem due to corrosion of the distribution system plumbing by soft, acidic water than due to metals in the raw water. Analyses of Stocking Lake water from the Ladysmith and Saltair distribution systems by the Ministry of Health indicate that the only metal that exceeded drinking water guidelines was iron (Pommen, 1992).

5.2.7 Phosphorus and Algae

Total phosphorus had a maximum of 0.01 mg/L (mean = 0.005 mg/L) (Table 2), which is equal to the drinking water criterion for lakes to prevent aesthetic and taste/odour problems due to algal growth (Nordin, 1985). Chlorophyll a, a measure of algae in water, had a maximum of 2.2 μg/L (mean = 1 μg/L), meeting the guideline of 2-2.5 μg/L for lakes used for drinking water. The mean Secchi disk readings or extinction depths during the growing season (May-Oct) in Stocking Lake during 1987-94 (Figure 7) ranged between 5.6 to 6.8 m. Greater than 6 m is considered to be oligotrophic and 3-6 m is mesotrophic (Nordin, 1985). These data suggest that Stocking Lake is at the boundary between being oligotrophic and mesotrophic, and any further phosphorus enrichment could lead to increased production of algae and trihalomethane precursors and aesthetic problems such as taste and odour.

The recommended objective for total phosphorus in Stocking Lake is a maximum of 10 μg/L (0.01 mg/L) at spring overturn.

The recommended objective for chlorophyll a in Stocking Lake is a mean summer concentration of 2.5 µg/L, based on monthly samples during May through August at depths of 0, 2, 4, and 6 m.

6. Monitoring Recommendations

The water quality monitoring recommended in this section is for raw water prior to water treatment and distribution. Monitoring of treated water in the water distribution system is the responsibility of the Ministry of Health and the water purveyors. The recommended monitoring is the minimum that the water purveyors should do to determine if the water quality objectives are being achieved, to document water quality conditions, and to detect long-term trends. The monitoring is focused at the water intakes, the most important points in the watersheds for water supply, but the Town of Ladysmith may wish to extend monitoring to the upper Holland and Banon Creek watersheds to gain a better understanding of the causes of water quality conditions in the watershed or to monitor remediation work in specific parts of the watershed.

These recommendations do not address the additional monitoring that may be needed for specific developments (e.g., roads, forest harvesting, recreational activities) in the watershed. This monitoring should be planned on a case-specific basis, with monitoring immediately upstream and downstream from developments to show cause-effect relationships clearly.

6.1 Holland Creek

The recommended minimum monitoring for Holland Creek is summarized in the table below. Holland Creek is a relatively small watershed that responds rapidly within hours or days to rainstorms and snowmelt that can profoundly change flows and water quality characteristics. For this reason, we recommend that flow and turbidity be measured continuously using electronic sensors and data loggers to obtain an accurate record of these highly variable characteristics. Manual measurements would have to be done at least daily during rainstorms and high flows, and would still miss peaks that occur during a 24-hour period. Experience has shown that frequent manual sampling cannot usually be achieved because of the significant commitment of staff time, and the occurrence of emergencies during storms. Flow measurements are essential for the interpretation of the water quality characteristics. Weekly fecal coliform sampling is recommended, increasing to daily, if possible, during rainstorms that follow lengthy dry periods in the spring, summer, and fall to monitor the flushing of accumulated fecal matter from the watershed. Initial monitoring of *Giardia* and *Cryptosporidium* should be conducted to determine if these microorganisms are present in the water supply.

Recommended Holland Creek Monitoring

Characteristics	Frequency & Timing	Proposed Sites
Flow	Continuous	Chicken Ladder intake
Turbidity	Continuous	"
Fecal Coliforms	Weekly**	"
	Daily - rainstorms	"
pH	Monthly	"
True Colour	Monthly (Quarterly*)	"
Total Organic Carbon	Monthly (Quarterly*)	"
Trihalomethanes	Quarterly*	Chlorinated tap water
Giardia & Cryptosporidium	Initial monitoring	Chicken Ladder intake

* Simultaneous monitoring if total organic carbon exceeds 2 mg/L.

** Ten samples in 30 days are needed to check the objective.

6.2 Stocking Lake

The recommended minimum monitoring for Stocking Lake is outlined in the table below. Stocking Lake has a small watershed in proportion to the volume of the lake, with an average water residence time of about one year. The lake settles and buffers incoming surface runoff, greatly reducing the variability seen in neighbouring streams such as Holland Creek. Given the low variability, the good water quality, and the lack of threats to water quality in Stocking Lake, monthly monitoring is judged to be sufficient. Quarterly trihalomethane, total organic carbon, and true colour monitoring is recommended for one year to establish the annual average, since only one THM sample has been collected to date. Total phosphorus should be measured annually at spring lake overturn when the lake is at the same temperature from top to bottom (isothermal). Samples should be collected at the station over the deepest part of the lake at depths of 1 m below the lake surface, mid-depth, and 1 m above the bottom, and the results averaged to calculate the spring overturn phosphorus. Water temperature should be measured at the same depths to confirm that the lake is isothermal and completely mixed. Mean summer chlorophyll a should be measured by taking the grand mean of samples taken monthly during May through August at depths of 0, 2, 4, and 6 m over the deepest point in the lake.

Recommended Stocking Lake Monitoring

Characteristics	Frequency & Timing	Proposed Sites
Turbidity	Monthly	Stocking Lake intake at meter hut
Fecal Coliforms	Monthly**	"
pH	Monthly	"
True Colour	Monthly (Quarterly*)	"
Total Iron	Monthly	"
Total Organic Carbon	Monthly (Quarterly*)	"
Total Phosphorus & water temperature	Annually at spring overturn	Stocking L. at Centre (deepest point)
Chlorophyll a	Monthly (May-August)	Stocking Lake at Centre
Trihalomethanes	Quarterly*	Chlorinated water

* Simultaneous quarterly measurements for one year.

** Ten samples in 30 days are needed to check the objective.

6.3 Quality Assurance

To demonstrate that the data collected are of acceptable quality, periodic quality assurance samples or measurements should be collected. These should include replicate samples or measurements (e.g., duplicates, triplicates) collected in the field, to show the repeatability or precision of the data. Replicates can also indicate if sporadic contamination is occurring. Field blanks (samples of sterile, deionized water that are subjected to the same operations as real samples except for immersion in the water) should also be submitted to detect any contamination introduced during shipping, sampling, handling, or analysis. Substances present in small amounts and/or which are susceptible to contamination, such as fecal coliforms, total phosphorus, and total iron should have periodic blanks, especially if unusual levels or variability are noticed. The Ministry of Environment, Lands and Parks has prepared a manual on water sampling (Cavanagh *et al*, 1994), and other manuals for sampling, field quality assurance, and data interpretation are planned or in preparation.

Continuous monitoring of flow and turbidity also requires quality assurance measures. Flow monitoring should conform to Environment Canada's Water Survey of Canada national standards. The Water Quality Branch of BC Environment is preparing a field manual for continuous water quality monitoring (e.g., turbidity), which will contain guidance on quality assurance.

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FIGURE 1: HOLLAND CREEK & STOCKING LAKE

WATERSHEDS & WATER QUALITY MONITORING SITES

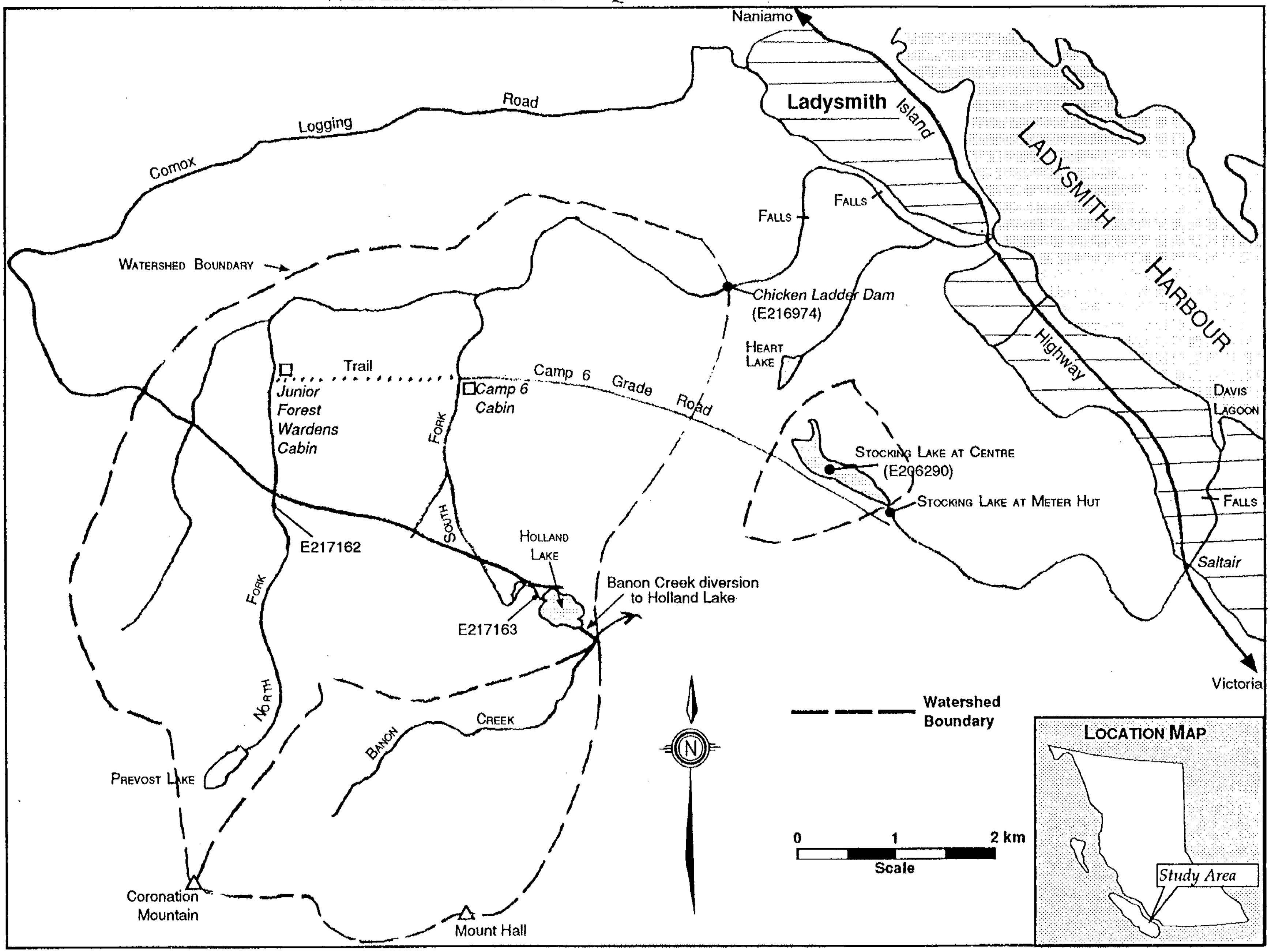

Figure 2. Nanaimo City Yard (AES 10253GO) Daily Precipitation, April 1992 to March 1993

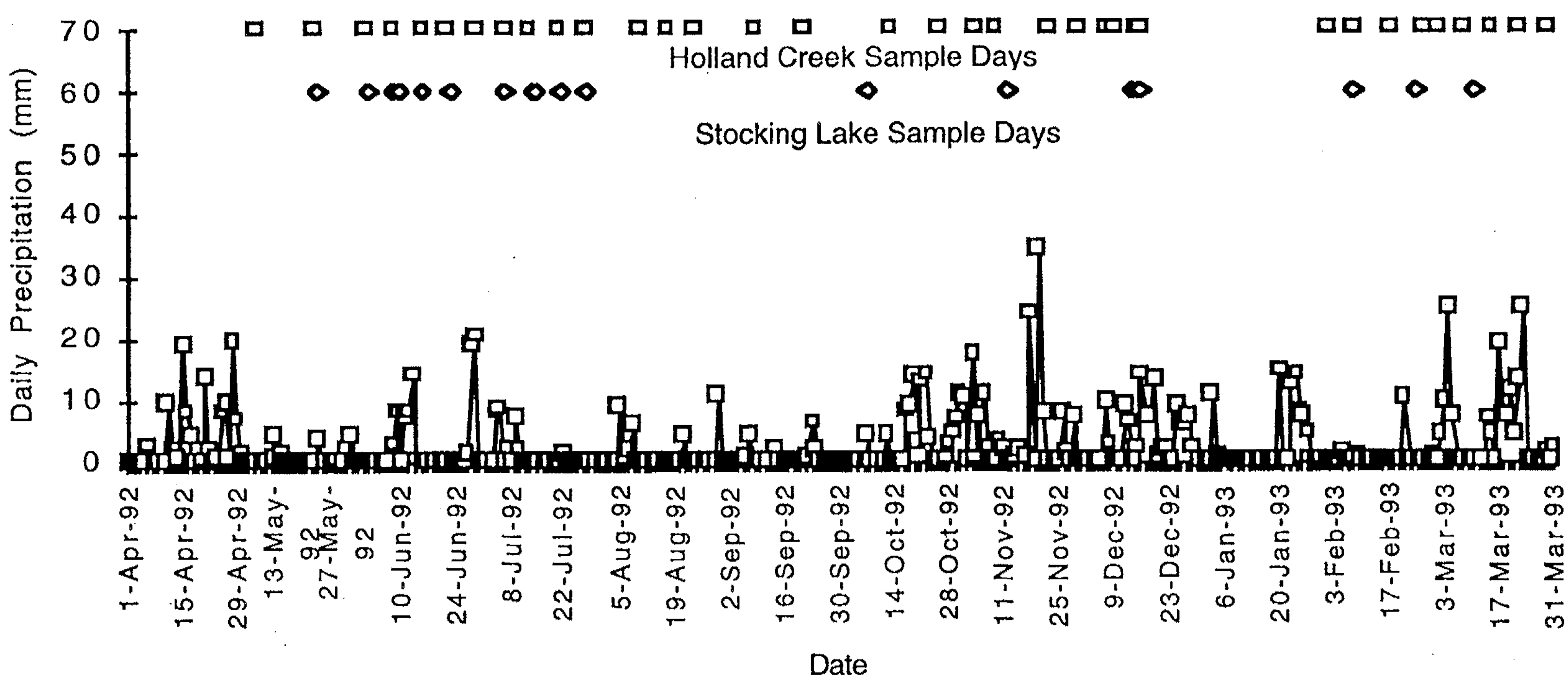

Figure 3. Nanaimo City Yard (AES 10253GO) Daily Precipitation, April 1993 to March 1994

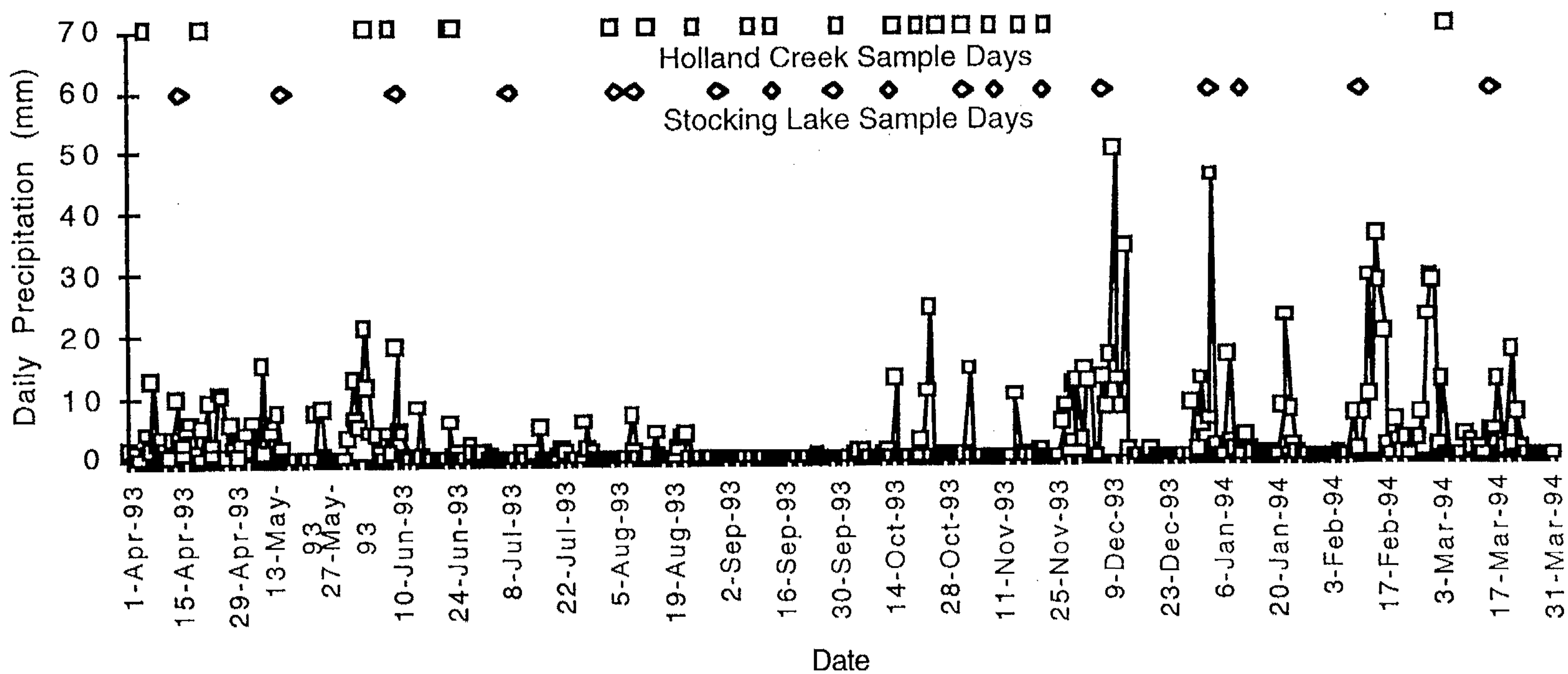

Figure 4. Nanaimo City Yard (AES 10253GO) Daily Precipitation, April 1994 to October 1994

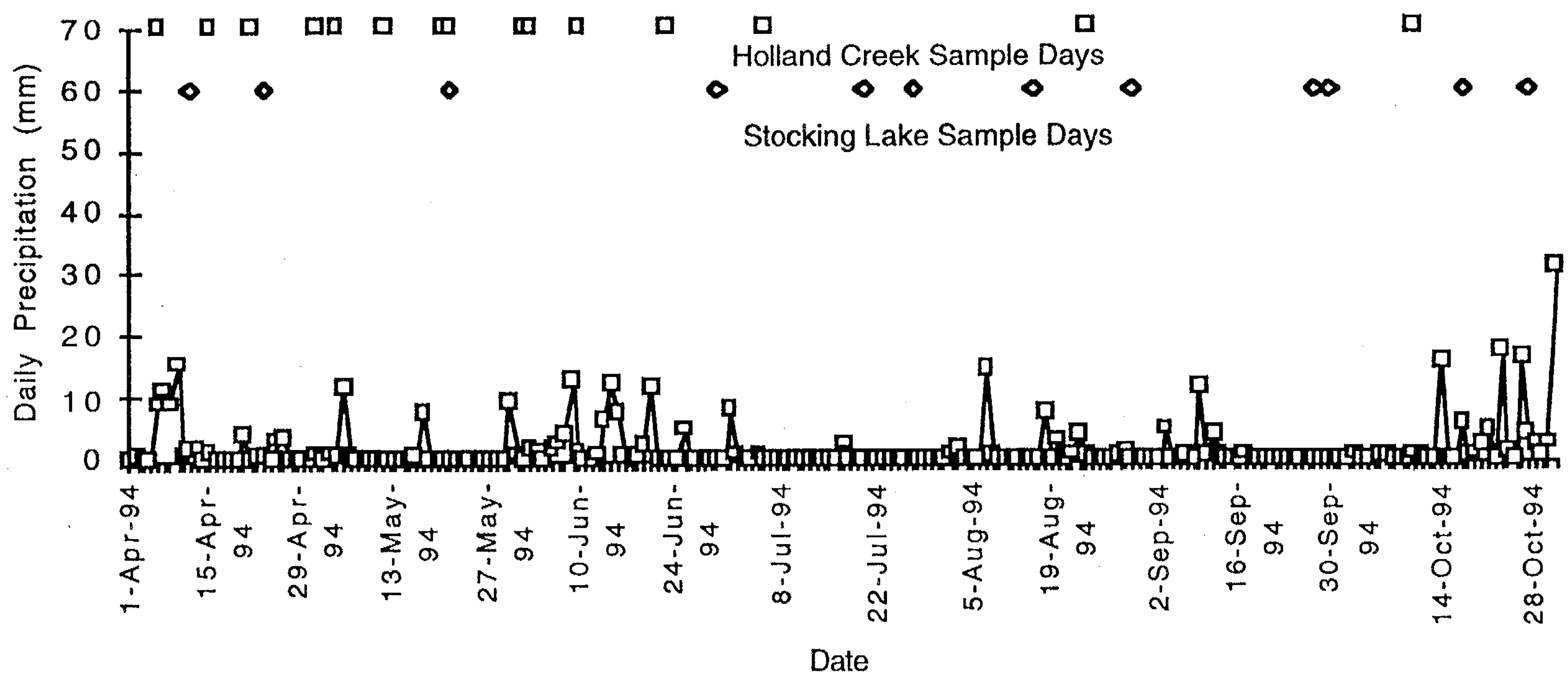

Figure 5. Turbidity in Holland Creek at Chicken Ladder Intake, 1978-83

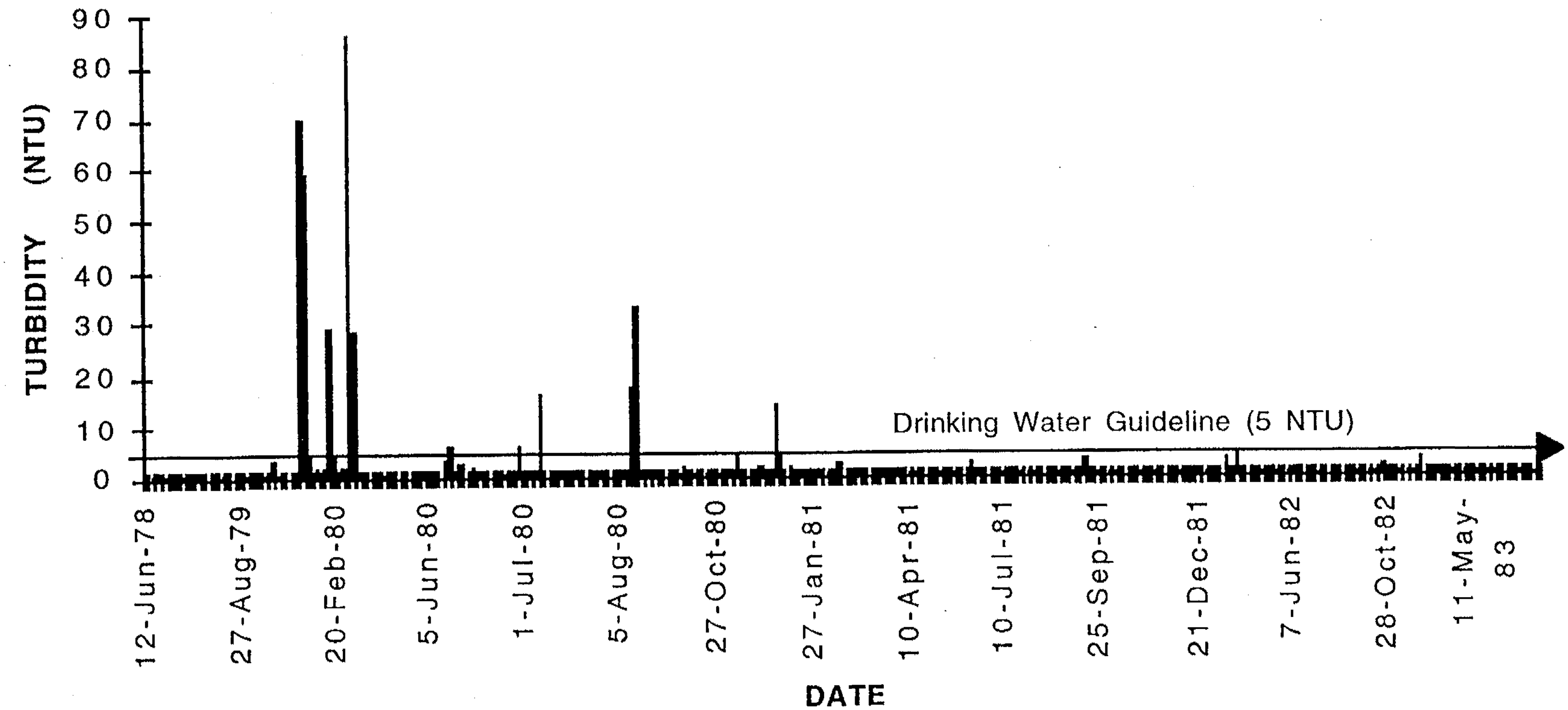

Figure 6. Water Colour in Holland Cr. at Chicken Ladder Intake, 1978-83

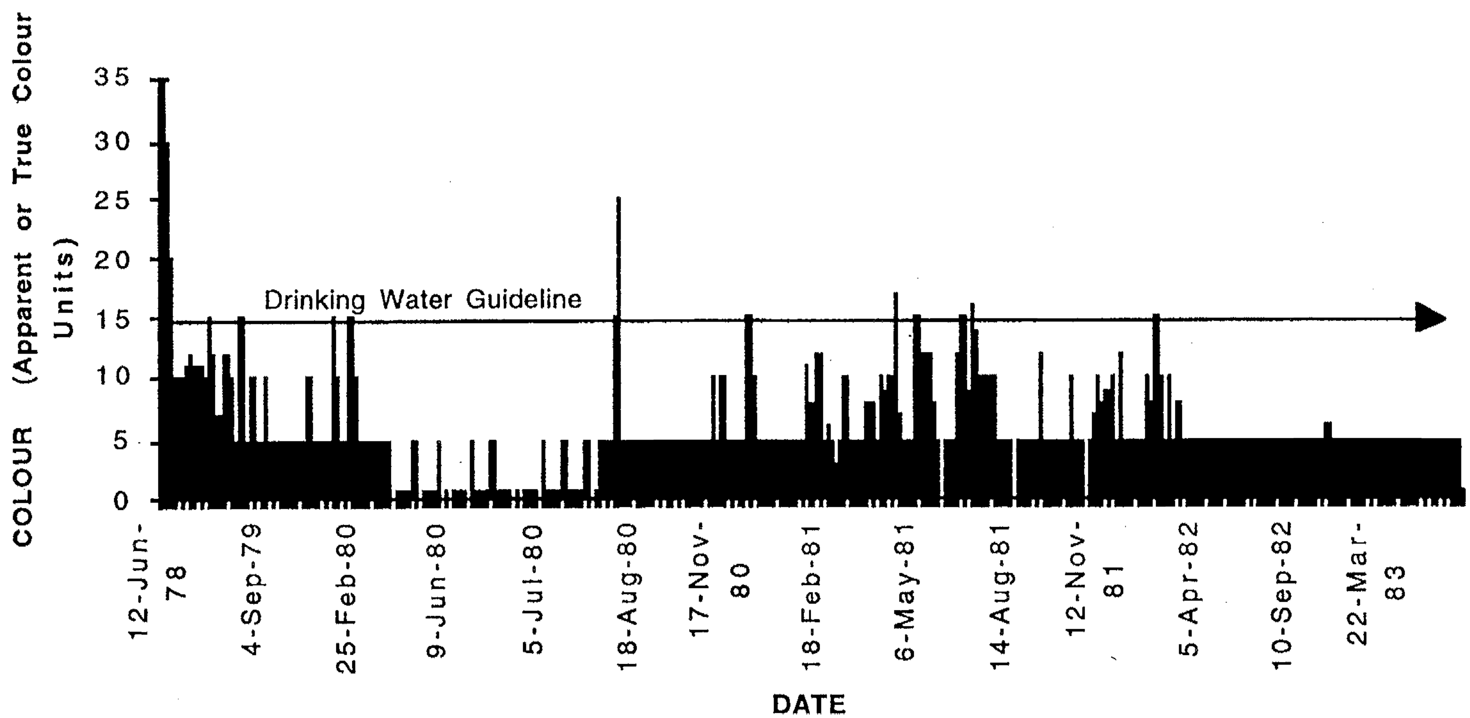

Figure 7. Stocking Lake at Centre (E206290) Secchi Depths, 1987-94

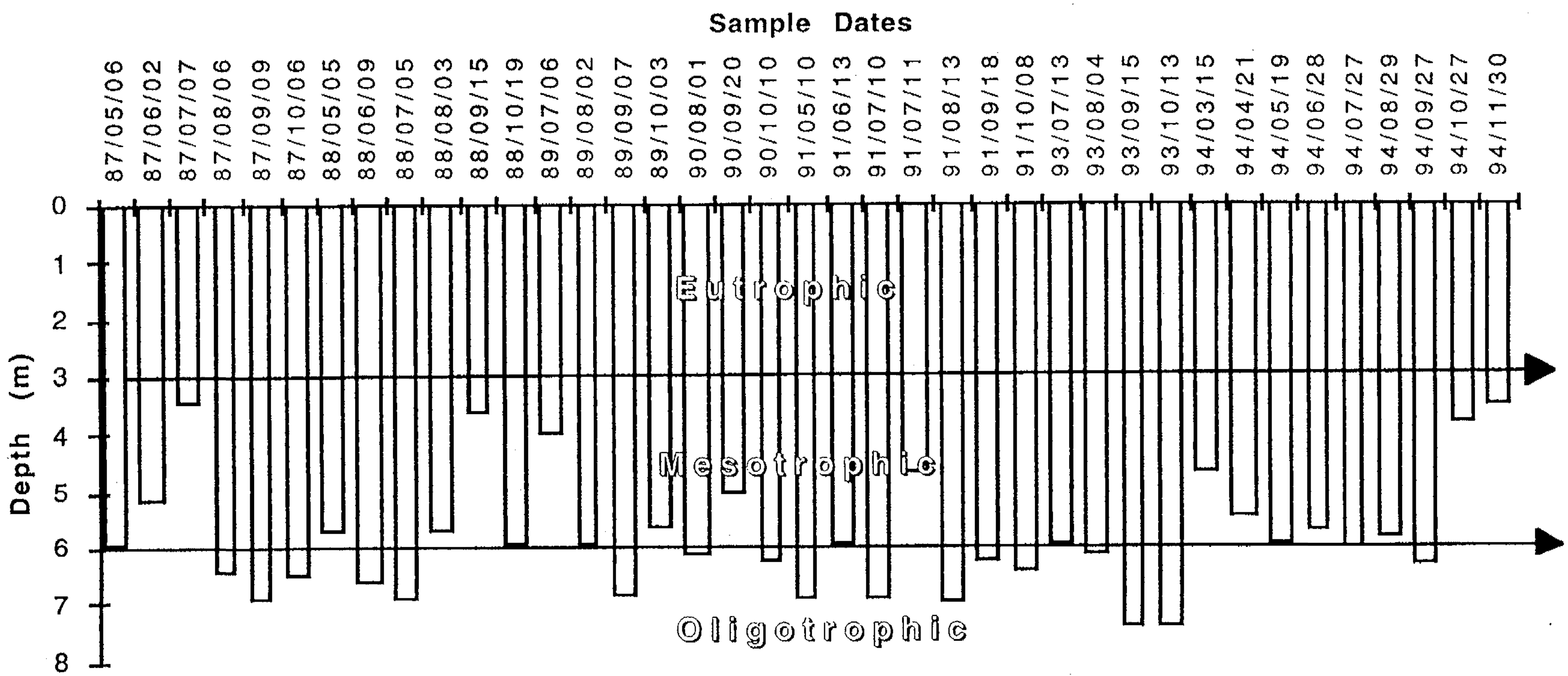

Table 1. Holland Creek Water Quality, October 1991 - October 1994

STATION	HOLLAND LAKE OUTFLOW (SEAM: E217163)				HOLLAND CREEK, NORTH FORK (SEAM: E217162)				HOLLAND CREEK AT CHICKEN LADDER DAM (SEAM: E216974; MOH: 13ELAD007 & 13DLAD007)				
DATE	pH	True Colour TCU	Turbidity NTU	Fecal Coliforms #/100 mL	pH	True Colour TCU	Turbidity NTU	Fecal Coliforms #/100 mL	pH	True Colour TCU	Turbidity NTU	Fecal Coliforms #/100 mL	Total Coliforms #/100 mL
24-Oct-91									6.6	15	0.4	<2	111
4-May-92									6.7	12	0.4	25	690
19-May-92												**260**	770
1-Jun-92												< 1	125
8-Jun-92	6.7,6.7,6.6	15,10,10	0.5,0.4,0.4	<2,<2,<2	7.0	< 5	0.1	< 2	7.3,7.2,7.4	5,5,5	0.2,0.2,0.2	4, 6	56
15-Jun-92												**145**	760
22-Jun-92	6.7	10	0.7		7.1	5	0.3		7.2	5	0.3	**56**	410
29-Jun-92												**E1400**	E1600
6-Jul-92	7.9	5	0.6	1	7.5	**30**	0.7	**84**	7.4	10	0.5	**220**	520
13-Jul-92												**21**	55
20-Jul-92												**128**	275
27-Jul-92	7.1	5	0.6	< 2	7.3	5	0.2	2	7.3	5	0.3	**23**	892
10-Aug-92	7.2	10	0.5	< 2	7.3	5	0.3	4				4	
17-Aug-92												**51**	102
24-Aug-92	7.8	10	0.8	< 2	7.4	5	0.4	1	7.3	5	0.4	**26**	41
8-Sep-92	7.6	10	0.4	1	7.4	5	0.3	6	7.0	5	0.3		
21-Sep-92	7.3	10	0.3	< 2	7.7	< 5	**1.4**	< 2	7.6	5	0.2		
13-Oct-92	7.7	10	0.9	< 2	7.3	5	0.8	< 2	7.7	5	0.8		
26-Oct-92												9	99
4-Nov-92	6.5	15	**1.4**	5	6.5	**20**	0.6	3					
9-Nov-92												2	480
23-Nov-92	7.2	10	0.8	2	6.9	**20**	0.5	< 2	6.6	15	0.6	5	260
30-Nov-92												11	118
7-Dec-92												2	150
9-Dec-92	7.5	**30**	**1.6**	2	7.4	**20**	**2.0**	1	7.4	**20**	0.6		
14-Dec-92	7.0	**40**	0.8		7.6	**20**	0.6		7.2	**30**	0.3		
15-Dec-92												4	165
16-Dec-92									7.8	10			
1-Feb-93												< 1	100
8-Feb-93												4	132
17-Feb-93									6.6,6.7	<5,<5	0.1,0.1		
26-Feb-93									7	< 5	0.2		
1-Mar-93									6.8	< 5	0.2		
8-Mar-93									7.9	8	0.4	3	139
15-Mar-93									7.7	5	0.3		
22-Mar-93									6.7	10	0.5		
29-Mar-93									6.5	5	0.2		

Values in BOLD exceed drinking water quality guidelines

E=Estimated

Table 1 continued. Holland Creek Water Quality, October 1991 - October 1994

STATION	HOLLAND LAKE OUTFLOW (SEAM: E217163)				HOLLAND CREEK, NORTH FORK (SEAM: E217162)				HOLLAND CREEK AT CHICKEN LADDER DAM/RESERVOIR (SEAM: E216974; MOH: 13ELAD007 & 13DLAD007)				
DATE	pH	True Colour TCU	Turbidity NTU	Fecal Coliforms #/100 mL	pH	True Colour TCU	Turbidity NTU	Fecal Coliforms #/100 mL	pH	True Colour TCU	Turbidity NTU	Fecal Coliforms #/100 mL	Total Coliforms #/100 mL
5-Apr-93	6.8	10	0.5	<2	6.6	15	0.4	1	6.8	10	0.2		
20-Apr-93	7.9	10	0.4	<2	7.5	10	0.3	<2	7.2	<5	0.2		
1-Jun-93	7.2	15	0.3	2	7.2	**40**	0.3	6	7.2	15	0.2	**12**	
7-Jun-93									7.7	10	0.3	**11***	
22-Jun-93									7.3,7.3,7.3	10,5,10	0.2,0.1,0.1		
23-Jun-93	7.1,7.0	10,15	0.4,0.3	<1,<1*	7.0,7.0	10,10	0.1,0.2	<1,3*				10,5*	
3-Aug-93												<2	680
13-Aug-93	8.1	5	0.3	<1*	8.1	5	0.1	2*	7.9	5	0.1	7*	
24-Aug-93												2	640
7-Sep-93									7.1	5	<0.1	<1*, 5	110
13-Sep-93									7.6	5	0.1	1*, <2	210
30-Sep-93	6.9	5	0.5	1*	7.1	<5	0.1	<1*					
14-Oct-93									7.2	5	<0.1	1*, 2	100
20-Oct-93									7.1	5	<0.1	4*	
25-Oct-93									7.1	10	0.1	4*, 6	110
1-Nov-93										5	0.2	4*, 8	100
8-Nov-93									7.1	10	0.1	2*, 2	930
15-Nov-93									7.0	15	0.3	**19*, 18**	650
22-Nov-93									7.7	5	0.1	2*, 4	760
4-Mar-94									6.3	10	0.6		
5-Apr-94									7.6,6.4	10, 10	0.2, 0.2	0*	
13-Apr-94												3, 1, 2*	
19-Apr-94												0, 0, 1*	
29-Apr-94												0, 0, 0*	
2-May-94												0, 3, 3*	
9-May-94												20,0,10*,6	E280
18-May-94				0, 0, 0*									
19-May-94												2, 1, 2*	
30-May-94												**12,15,22***	
31-May-94												4	E580
7-Jun-94												0, 0, 3*,2	
20-Jun-94												**27,27,23*,22**	E590
5-Jul-94												**28**	E670
22-Aug-94									6.9	5	0.3	2	E370
10-Oct-94												2	E1370

Values in BOLD exceed drinking water quality guidelines

**E. Coli*

Table 2. Summary of Water Chemistry Data for Stocking Lake, 1985-93 (SEAM # E206290)

CHARACTERISTIC	UNITS	NUMBER OF VALUES	VALUES			STANDARD DEVIATION
			MAX	MIN	MEAN	
GENERAL IONS						
Acidity - free	ueq/L	90	2.50	<0.1	0.170	0.260
Acidity - total	µeq/L	1	120.00	120.00	120.000	nil
Acidity - pH 8.3	µeq/L	93	222.00	0.00	58.020	37.000
pH	units	77	7.60	**5.70**	7.02	0.310
pH (Rain)	units	90	7.50	**5.60**	6.95	0.304
Alkalinity - total (4.5)	mg/L	12	11.10	6.90	9.920	1.120
Alkalinity - total	µeq/L	91	356.00	31.30	177.870	35.830
Colour, True	TCU	11	**20.00**	5.00	6.820	4.620
Colour	TAC	80	**18.00**	<1	6.220	2.850
Colour	SWU	1	10.00	10.00	10.000	nil
Chloride - dissolved	mg/L	6	1.90	1.50	1.750	0.150
- soluble	mg/L	94	3.24	0.82	1.810	0.444
Fluoride - Dissolved	mg/L	12	<0.1	<0.1	0.100	0.000
Hardness - Dissolved	mg/L	4	10.30	8.60	9.470	0.800
Solids - dissolved(0.45µm)	mg/L	25	30.00	18.00	23.760	3.220
Solids - dissolved (1.0µm)	mg/L	55	42.00	12.00	26.180	5.630
Solids - suspended	mg/L	7	2.00	<1	1.280	0.490
Solids - total	mg/L	12	30.00	19.00	24.750	3.280
Solids - fixed suspended	mg/L	6	1.00	<1	1.000	0.000
Specific Conductivity	µS/cm	100	38.00	13.00	30.490	4.030
Turbidity	NTU	8	0.40	0.60	0.490	0.060
Sulphate - dissolved	mg/L	6	2.00	1.70	1.850	0.105
- soluble	mg/L	94	2.49	1.36	1.860	0.204
Sodium - dissolved	mg/L	6	1.70	1.40	1.480	0.117
Sodium - soluble	mg/L	91	2.03	0.90	1.320	0.167
NUTRIENTS						
Ammonium - NH4	mg/L	90	0.16	<0.01	0.016	0.019
Ammonia - Dissolved	mg/L	12	0.02	<0.005	0.007	0.004
Chlorophyll a	µg/L	38	2.2	<0.5	1.0	0.5
Phosphorus - total	mg/L	80	0.011	<0.003	0.005	0.002
Phosphorus-dissolved	mg/L	95	0.01	<0.003	0.003	0.001
Phos. O. - dissolved	mg/L	6	<0.003	<0.003	0.003	0.000
Kjeldahl Nitrogen	mg/L	77	0.35	0.06	0.130	0.040
NO2/NO3 - Dissolved	mg/L	12	0.03	<0.02	0.022	0.004
Nitrate - Soluble	mg/L	90	3.34	<0.01	0.132	0.374

VALUES IN BOLD EXCEED DRINKING WATER GUIDELINES.

Table 2 continued. Summary of Water Chemistry Data for Stocking Lake, 1985-93

CHARACTERISTIC	UNITS	NUMBER OF VALUES	VALUES			STANDARD DEVIATION
			MAX	MIN	MEAN	
METALS						
Aluminum - total	mg/L	98	0.20	<0.01	0.054	0.035
- dissolved	mg/L	67	<0.1	<0.01	0.039	0.031
Arsenic - total	mg/L	23	<0.3	<0.25		
- dissolved	mg/L	2	<0.3	<0.25		
Boron - dissolved	mg/L	46	0.03	<0.01	0.016	0.006
Barium - total	mg/L	23	0.02	<0.01	0.010	0.002
- dissolved	mg/L	46	0.01	<0.01	0.010	0.000
Calcium - total	mg/L	79	5.12	1.05	3.580	0.620
- dissolved	mg/L	46	4.79	0.03	3.450	0.842
- soluble	mg/L	90	4.67	0.85	3.490	0.529
Cadmium - total	mg/L	78	**0.02**	<0.0005	0.0005	
- dissolved	mg/L	44	<0.01	<0.0005		
Cobalt - total	mg/L	79	0.50	<0.1	0.105	0.045
- dissolved	mg/L	46	<0.1	<0.1	<0.1	0.000
Chromium - total	mg/L	79	0.03	<0.01	0.011	0.003
- dissolved	mg/L	46	0.04	<0.01	0.011	0.005
Copper - total	mg/L	78	0.04	<0.001	0.006	0.006
- dissolved	mg/L	45	<0.01	<0.001	0.004	0.004
Iron - total	mg/L	79	**0.41**	<0.01	0.083	0.071
- dissolved	mg/L	46	0.18	<0.01	0.037	0.031
Potassium - dissolved	mg/L	6	0.30	0.20	0.250	0.055
- soluble	mg/L	94	0.97	<0.1	0.271	0.088
Magnesium - total	mg/L	79	0.85	0.25	0.534	0.087
- dissolved	mg/L	46	0.62	<0.02	0.511	0.103
- soluble	mg/L	90	0.62	0.22	0.485	0.070
Manganese - total	mg/L	79	0.04	<0.01	0.011	0.005
- dissolved	mg/L	46	0.02	<0.01	0.010	0.001
Molybdenum - total	mg/L	79	0.08	<0.01	0.010	0.008
- dissolved	mg/L	46	0.01	<0.01	0.010	0.000
Nickel - total	mg/L	78	<0.05	0.002	0.030	0.023
- dissolved	mg/L	46	<0.05	0.002	0.018	0.023
Lead - total	mg/L	78	**0.30**	<0.001	0.002*	0.053
- dissolved	mg/L	45	<0.1	<0.001	<0.001	0.050
Vanadium - total	mg/L	79	0.03	<0.01	0.011	0.003
- dissolved	mg/L	46	0.02	<0.01	0.011	0.002
Zinc - total	mg/L	79	0.02	<0.005	0.009	0.004
- dissolved	mg/L	42	0.02	<0.005	0.007	0.003

* Excluding maximum value of 0.30 mg/L

VALUES IN BOLD EXCEED DRINKING WATER GUIDELINES.

Table 3. Stocking Lake Water Quality for Key Drinking Water Characteristics, 1985-94

Date	Turbidity NTU	True Colour TCU	TAC Colour TAC units	Fecal Coliforms #/100 mL	Total Coliforms #/100 mL
85/06/11	0.5				
85/07/03	0.5				
85/08/08	0.5				
85/09/10	0.4				
85/10/07	0.4				
85/11/04	0.5				
89/11/07	0.5				
92/05/19				<2*	150*
92/06/01				<1*	80*
92/06/08				3*	36*
92/06/09		5			
92/06/15				**170***	**350***
92/06/22				<1*	**190***
92/07/06				<1*	2*
92/07/13				2*	3*
92/07/14		5			
92/07/20				<1*	**200***
92/07/27				<1*	3*
92/10/07		5		<2	
92/11/12		10		<2	
92/12/14				<1*	<1*
92/12/16	0.6	**20**		<2	
93/02/08	0.3	5		<2	
93/02/24				<2*	
93/03/11	0.5	5		<2	
93/04/14	0.3	5		<2	
93/05/10	0.4	5		1	
93/06/08	0.5	10		0	
93/07/13	0.3	5	7	<1	
93/08/04	0.3,0.3,0.3	5,5,5	6,6,6	<1,<1,<1	
93/08/09				**44***	46*
93/08/30				2*	2*
93/09/13	0.2	5	6	<1*, <1	10*
93/09/28				<1*	<1*
93/10/13	0.2	5	12	<1*, <1	3*
93/11/01				<1*	8*
93/11/09	0.3	5	5	1	
93/11/21				<1*	7*
93/12/06	0.5	5	5	<1	
94/01/02				1*	14*
94/01/10	1.2,0.5,0.5	10,5,5	6,6,6	0, 0, 150	
94/02/10	0.4	<5	4	0, 0	
94/03/15	0.4	5	5	0	
94/04/10				<2*	**140***
94/04/21	0.3	5	8	0	
94/05/19	0.3	5	7	1	
94/06/28	0.4	5	<1	0	
94/07/20				2*	**E980***
94/07/27	0.4	5	4	0	
94/08/14				2*	E20*
94/08/29	0.3	5	<1	0	
94/09/25				<2*	50*
94/09/27	0.3	<5	3	0	
94/10/17				<2*	E60*
94/10/27	0.4	10	6	0	

* Values from Stocking Lake at Meter Hut (Ministry of Health sites 13ESAL007 & 13DSAL007); rest of values are from Stocking Lake at Centre (SEAM site E206290)

Values in bold exceed drinking water quality guidelines.