OKANAGAN AREA

HYDRAULIC CREEK AND ITS TRIBUTARIES

WATER QUALITY ASSESSMENT AND OBJECTIVES

First Printed November 1990
Reprinted without change February 1996

TECHNICAL APPENDIX

MINISTRY OF ENVIRONMENT
PROVINCE OF BRITISH COLUMBIA

OKANAGAN AREA
HYDRAULIC CREEK AND ITS TRIBUTARIES
WATER QUALITY ASSESSMENT AND OBJECTIVES

TECHNICAL APPENDIX

H.J. Singleton, R.P. Bio
Resource Quality Section
Water Management Branch

NOVEMBER, 1990

Canadian Cataloguing in Publication Data
Singleton, H. J. (Howard J.), 1947-
Okanagan area, Hydraulic Creek and its tributaries, water quality assessment and objectives

[Vol. 2] constitutes technical appendix.
ISBN 0-7726-1755-4

1. Water quality - British Columbia - Hydraulic Creek Watershed. I. BC Environment. Water Management Division. II. Title.

TD227.B7S563 1993   363.73'942'097115   C93-092123-2

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

Page

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to those individuals who provided valuable assistance in the preparation and review of this document. They include:

Mr. D.A. Dobson - former Engineering Section Head of the Water Management Program in Penticton.

Mr. S.B. Mould - Manager of the South East Kelowna Irrigation District.

Ms. H.M. Larratt - H.M. Larratt Aquatic consulting Ltd. in Kelowna.

Mr. J.H. Wenger - District Manager of the Ministry of Forests in Penticton.

Mr. J. Cheng - Regional Hydrologist of Ministry of Forests in Kamloops.

Dr. W.P. Moorehead - Medical Health Officer and Director of the South Okanagan Health Unit in Kelowna.

Dr. M.J.R. Clark - Environmental Chemist of the Ministry of Environment in Victoria.

Mr. R.J. Rocchini and Mr. L.W. Pommen - Water Quality Branch, Ministry of Environment.

Ms. L. Thomas and Ms. S. Kent - typists, Water Quality Branch, Ministry of Environment.

1. INTRODUCTION

1.1 BACKGROUND

Due to an epidemic infestation of mountain pine beetle in the extensive lodgepole pine stands of the Hydraulic Creek watershed near Kelowna, B.C., tree harvesting is occurring at an unprecedented rate to salvage the timber while it is still marketable. Since Hydraulic Creek serves as the source of drinking water for a population of 3500, and irrigation water for nearly 2000 hectares of agricultural land, representatives of the South East Kelowna Irrigation District (SEKID) have become increasingly concerned about the degradation of water quality associated with the accelerated rate of harvesting.

In 1986, on the request of the manager of SEKID, the Ministry of Forests and Lands (in consultation with representatives from the Ministry of Environment, Weyerhaeuser Canada Ltd., and SEKID) hired a consultant to provide annual assessment reports regarding the impact of logging on Hydraulic Creek water quality [3,4]. The same consultant also had conducted earlier studies[1,2] investigating the effectiveness of water improvement projects on Hydraulic Creek. Most of the background information and water quality data presented here have been extracted from the consultant's reports.[1,2,3,4]

The consultant concluded that water quality, especially turbidity and suspended solids concentrations, was being affected by logging. Given the importance of Hydraulic Creek for drinking water, irrigation water, and recreational fisheries, the Ministry of Environment decided to establish water quality objectives for the protection of existing water uses in Hydraulic Creek.

1.2 PROVISIONAL WATER QUALITY OBJECTIVES - BASIC PHILOSOPHY

Water quality objectives are established in British Columbia for water-bodies on a site-specific basis. The objective can be a physical, chemical or biological characteristic of water, biota or sediment, which will protect the most sensitive designated water use at a specific location with an adequate degree of safety. The objectives are aimed at protecting the most sensitive designated water use with due regard to ambient water quality, aquatic life, waste discharges and socio-economic factors[5].

Water quality objectives are based upon approved or working water quality criteria which are characteristics of water, biota, or sediment that should not be exceeded to prevent specified detrimental effects from occurring to a water use[5]. The working criteria come from the literature, and are referenced in the following chapters. The B.C. Ministry of Environment is developing approved criteria for water quality characteristics throughout British Columbia, to form part of the basis for permanent objectives.

As a general rule, objectives will only be set in reaches where man-made influences threaten a designated water use, either now or in the future. Provisional objectives proposed in this report are to be reviewed as more monitoring information becomes available and as the Ministry of Environment establishes approved water quality criteria.

2. WASTE DISCHARGES (Anthropogenic Activities)

The Hydraulic Creek basin is primarily an upland watershed with very little anthropogenic activity other than that associated with timber harvesting. Thus, the primary concern in the area is the broad-scale erosion of soil into the watercourse, associated with clearcut logging and road-construction activities. Water quality characteristics that may be affected by such activites include turbidity, suspended particulate matter, colour, temperature, pH, conductivity, nutrients (nitrogen and phosphorus), and pathogen levels.

Annual timber harvests in the Hydraulic Creek watershed have occurred as follows:

YEAR	LOGGED AREA (Hectares)
1962	177
1968	20
1972	182
1973	347
1974	24
1976	65
1977	48
1979	83
1981	83
1982	150
1983	106
1984	511
1985	444
1986	108
1987	644
1988	509
	Total = 3 501

During the earlier years, clearcut harvesting occurred mainly at the higher elevations, in the upper reaches of Pooley Creek, and in the Canyon Lakes area (Figure 1). The harvesting rate tapered off between 1974 and 1981 and then increased dramatically in 1984 in response to the mountain pine beetle infestation. In 1986, due to labour problems in the forest industry, no logging occurred from March to November. This is reflected in the reduced area harvested during that year as shown in the preceding Table.

At the end of 1988, 3500 hectares or 27% of the total forested area had been harvested from the watershed. However, in January, 1988, logging in the watershed was suspended pending a review of the situation by government agencies. Later in that same year logging was resumed in certain blocks.

Low intensity selective logging has occurred, primarily in the lower reaches of the watershed, over a long time period.

3. HYDROLOGY

Hydraulic Creek drains into Mission Creek about 10 km upstream from Okanagan Lake. Mission Creek empties into Okanagan Lake at Kelowna. The total drainage area of Hydraulic Creek is approximately 147 km^2. Of this area, about 92 km^2 comprises the natural drainage area of Hydraulic Creek and the additional 55 km^2 has been diverted from Canyon, Pooley, Stirling, and Afflect Creeks. The drainage basin ranges in elevation from 650 to 2170 m. The principal water storage reservoirs in the system include Hydraulic, Minnow, Haynes, Fish, Browne, and Long Meadow Lakes. These lakes are all located on a plateau at about the 1280 metre elevation (Figure 1). Hydraulic Creek flows into and out of Hydraulic Lake, which is by far the largest reservoir in the system.

Water flows in Hydraulic Creek are regulated in part by dams at the outlets of the major lakes in the system thereby increasing the storage capacity for SEKID. The discharge rate for Hydraulic Creek, measured at the outlet of Hydraulic Lake, has ranged from an historical maximum flow of 1.82 m^3/s in October, 1976, to a minimum flow of 0 m^3/s on a number of occasions, occurring usually between the months of February and June. Generally, the period of high drawdown from Hydraulic Lake occurs between about the second week of June and the third week of September for irrigation. During this period discharge rates at the outlet of Hydraulic Lake range from about 1.0 to 1.5 m^3/s. During the remainder of the year, flows are commonly below 0.1 m^3/s.

Over the 14 km stretch of Hydraulic Creek, between the outlet of Hydraulic Lake and the SEKID intake, the elevation drops from 1250 m to 650 m - a difference of 600 m. In 1974, 1975, 1982 and 1983, the upper and lower sections of the stretch were channelized by SEKID, for approximately 4 km and 1 km, respectively. Before the channelizing project, the upper portion of the creek flowed through a swampy meadow. To improve the water quality, overhanging banks were cut back, the channel was straightened and faced with a liner anchored in place with gravel[3].

4. WATER USES AND PRETREATMENT FACILITIES

Hydraulic Creek serves as the source of drinking water for a population of 3500 and for irrigation of nearly 2000 hectares of agricultural land planted primarily in fruit trees and grapes. SEKID is the licensed purveyor for this water[3].

The SEKID intake is located on Hydraulic Creek approximately 1.5 km upstream from the confluence with Mission Creek. Pretreatment facilities at the SEKID intake consist of 2 settling ponds and a balancing reservoir, rotating screens to remove large debris, and chlorination at the point of entry into the pipeline.

According to the regional Fisheries Branch[6], the entire Hydraulic Creek watercourse, from Mission Creek through to the headwaters, is important from a fisheries perspective. The lower portion of Hydraulic Creek (1 km upstream from Mission Creek) is used for spawning by rainbow trout (Oncorhynchus mykiss) entering from Mission Creek. The 14 km section between the SEKID intake and Hydraulic Lake has a resident rainbow trout population. All the lakes and feeder streams in the upper reaches of the system have fisheries value. Hydraulic Lake has a resident rainbow trout population and is enhanced by stocking with an additional 12 to 15 thousand hatchery trout per year. A fishing resort is located on Hydraulic Lake. Hydraulic Creek upstream from Hydraulic Lake is used for spawning by the resident population of rainbow trout.

Thus, the water quality should be suitable for drinking and irrigation needs at the SEKID intake (HC1), and suitable for aquatic life throughout the entire Hydraulic Creek watershed, including the lakes and their feeder streams in the upper reaches of the system. These are the proposed designated water uses. Other water use categories such as livestock watering, wildlife, and recreation/aesthetics are more tolerant to the effects of logging on water quality than the proposed designated water uses. Therefore, water quality objectives set for the proposed designated uses will provide ample protection for any other, less sensitive uses.

5. AMBIENT WATER QUALITY

Water quality data for Hydraulic Creek were available for the years 1983, and 1985 through to 1988. Monitoring occurred during the peak flow periods (May to October) of these years at a number of sites in the watershed.

5.1 MONITORING SITES

There are six monitoring sites currently being used to check water quality in the watershed. The locations of sites are shown in Figure 1 and are described as follows:

HC1 - established in 1983 and located on Hydraulic Creek near the SEKID intake slightly upstream from the settling ponds. Occasionally, samples were taken below the balancing reservoir on weekends. Some small-scale logging has occurred along Hydraulic Creek below Hydraulic Lake in 1985 and 1986.

HC2 - established in 1983 and located on Hydraulic Creek at the weir immediately below the dam at the outlet of Hydraulic Lake. This lake serves as a settling basin so that the impact on water quality at HC2 and below, of any upstream logging, is minimized.

HC3 - established in 1983 and located on Hydraulic Creek approximately 1 km upstream from Hydraulic Lake. Hydraulic Creek frequently overflows its banks during freshet at this site which is located downstream from a large (8.1 ha) swamp. Logging has occurred in this drainage.

HC4 - established in 1986 and located near the headwaters of Hydraulic Creek in a drainage area which had been clearcut in the winter of 1984/1985. Trees left in a buffer strip along the sides of the creek were uprooted in a blowdown. Creek cleanup of this area occurred in 1988.

HC5 - established in 1986 on a small stream in an undisturbed subbasin of Hydraulic Creek to serve as a control site. Because of negligible flow during the late summer, this site was replaced by one on an adjacent stream on September 23, 1986. This site served as a control for the 1986 and 1987 data, but in the late fall of 1987 the drainage area for this stream was clearcut.

HC6 - established in 1987 and located on a small tributary stream of Hydraulic Creek. A 4.4 ha swamp is located at the headwaters of this stream and a 1 ha swamp is located just upstream from the sampling site. The total drainage area for this stream is 143 ha of which nearly 50% had been logged by the end of 1987.

During 1983 and 1985, a few additional sites were sampled in the system. These sites included the SEKID settling pond, Hydraulic Creek one mile above the SEKID intake, the channelized mid section, and Hydraulic Lake. These sites were monitored for water quality at about the same low annual frequency (3 to 5 samples) as sites HC1, HC2, and HC3 during those years.

5.2 WATER QUALITY DATA AND OBJECTIVES

To set water quality objectives it is necessary to have some knowledge of the natural background levels in the system. It would be meaningless to set an objective for a particular water quality characteristic at a level which is less than that which occurs naturally. By definition, water quality objectives are designed to protect designated uses from anthropogenically generated wastes, not natural ones.

For Hydraulic Creek, no pre-operational background levels were available prior to the onset of logging in 1963. However, most of the logging that occurred before 1987 was in the buffered zone (i.e., upstream from Hydraulic Lake). Due to the ameliorating effect of Hydraulic Lake, it is doubtful that water quality downstream from Hydraulic Lake would be affected significantly during this period. Some small-scale selective logging occurred in the unbuffered zone (i.e., along Hydraulic Creek downstream from Hydraulic Lake) in 1985 and 1986. However, a review of the pre-1987 data for the SEKID intake (HC1) showed no notable changes in water quality. Hence, pre-1987 water quality data for site HC1 were considered reasonable estimates of pre-operational background levels at that location.

Site HC5, located in an unlogged subbasin of Hydraulic Creek, served as a control site from 1986 until the watershed for this tributary was clearcut in the fall of 1987. No logging or pre-logging activity occurred which may have affected the 1987 water quality data for this stream. However, in view of its lower flows (commonly drying up in summer), it is questionable whether this stream serves as a valid control for Hydraulic Creek. Water quality data for site HC5 in 1986 and 1987 appeared more variable than pre-1987 data for site HC1.

The following sections focus upon those water quality characteristics which are most affected by logging activities and that may affect the designated water-uses which include drinking water and aquatic life.

5.2.1 TURBIDITY

Turbidity is a measure of water clarity and is caused by the presence of suspended particulate matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. In analytical terms, turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample[13].

5.2.1.1 Hydraulic Creek at the SEKID Intake

To establish a water quality objective for turbidity in raw (prior to treatment) drinking water at the SEKID intake (HC1) it was necessary to determine ambient background levels for that site. As outlined in Section 5.2, pre-1987 background levels at HCl were considered a more valid basis than background levels at HC5 (1986-87) upon which to set objectives for Hydraulic Creek.

Although turbidity was not measured until 1986, it was possible to estimate turbidity values for 1983 and 1985 using the suspended solids data. The relationship between suspended solids and turbidity was determined by calculating the suspended solids:turbidity ratios for the appropriate sites using 1986 to 1988 mean data. The mean ratio for each site (HC1, HC2, and HC3) was determined and applied to the 1983 and 1985 suspended solids data, thus providing a reasonable estimate of the turbidity for those sites during 1983 and 1985.

However, because disturbances such as those associated with logging activity release a preponderance of smaller particles (i.e., larger particles settle out more quickly), the suspended solids:turbidity ratio would likely change in favour of higher turbidity as development proceeds. This trend is apparent in the changing suspended solids:turbidity ratios with time as follows:

SUSPENDED SOLIDS:TURBIDITY RATIOS

YEAR / SITE	Mean Ratio 1986	Mean Ratio 1987	Mean Ratio 1988	Overall Mean Ratio
HC1	3.0	1.3	1.2	1.8
HC2	1.9	0.65	0.86	1.1
HC3	2.4	1.2	0.9	1.5

Thus, because of the changing suspended solids:turbidity ratio over the years with increased logging activity, and because the overall mean ratios were used to calculate the turbidity values for 1983 and 1985, the turbidity values shown in Table 1 for these two years may be overestimated.

The correction factor used by Larratt and Dobson[4] to adjust for the inconsistency between 1986 and 1987 turbidity data for sites HC1 and HC2 was not used here. Larratt and Dobson[4] adjusted the 1986 turbidity data for sites HC1 and HC2 upward by a factor of 2.7 because it was suspected that the different laboratory used for analysis coupled with the longer sample storage time in 1986 resulted in lower turbidity values for that year. Larratt and Dobson[4] reasoned that the turbidity measured in 1986 at HC2 should not differ significantly from that measured in 1987 at the same site because of the stabilizing effect of Hydraulic Lake. Thus, because the actual mean turbidity measured in 1986 at HC2 was 1.37 NTU and in 1987 it was 3.7 NTU, a correction factor of $3.7 \div 1.37 = 2.7$ was used to adjust the 1986 data upwards.

While there may be slight interlaboratory discrepancies between turbidity results, it is unlikely that the difference between identical samples would vary as much as the nearly 300% maintained by Larratt and Dobson[4]. The measurement of turbidity is fairly straightforward and provided that proper laboratory techniques are used (i.e., standardizing the nephelometer and shaking the sample before analysis), any differences in results between duplicate samples should be negligible. In addition, in view of the greater area logged in 1987 (620 ha) than in 1986 (106 ha), it is not unreasonable to believe that the increased logging activity may have caused the increase in turbidity. Internal conditions in Hydraulic Lake may also be responsible for the increased turbidity. In any case, interlaboratory comparisons using duplicate samples and standard reference samples should be performed before any correction factor is applied to the data.

In 1989, the Ministry of Forests hired a consultant to investigate the source of large amounts of organic matter accumulating in the settling pond above the SEKID intake[15]. This organic matter was believed to be largely responsible for the turbidity and suspended solids in Hydraulic Creek. Chemical analyses indicated that lignin derivative ratios in the organic matter collected from the settling pond more closely resembled the ratios typical of lake and fen margin litter (angiosperms) than that typical of softwood (gymnosperm) litter. Thus, the consultant suggested that the forest floor materials in logged areas have not yet made a significant contribution to suspended organic matter in Hydraulic Creek, and that the most likely source is eroding fens along existing channels in the unbuffered portion (downstream from Hydraulic Lake) of the watershed. However, a microscopic examination of the fen, forest, and settling pond material showed that the pond material resembled neither the fen nor the forest samples. It was suggested that a source of organic matter input, other than peat or forest humus, should be sought as a possible contributor to the pond material. Wind-blown sources were suspected as a possible contributor.

While this study indicates that the organic material in the settling pond may not originate in the clearcuts, it does not exonerate logging as a possible cause of the increased particulate matter transported down the creek. For example, nutrient releases from logged areas may stimulate the growth of phytoplankton and fen material. Increased runoff from clearcuts may accelerate erosion of the fens and result in more of this fen material being flushed into the creek. While these scenarios are based on speculation rather than solid evidence, there does appear to be a relationship between extensive clearcut logging in the watershed downstream from Hydraulic Lake since 1986, and increased particulates in the lower reach of the creek. However, it is doubtful that, with the data available coupled with the natural variability in the system, it will be possible to obtain absolute proof of water quality degradation in Hydraulic Creek by clearcut logging.

Health and Welfare, Canada[8] has set a maximum acceptable concentration of 1 NTU for turbidity in water entering a distribution system, or 5 NTU if it can be demonstrated that disinfection is not compromised by the use of this less stringent value. These guidelines, which are based on health and aesthetic considerations, have been adopted by the B.C. Ministry of Health for the Province.

As noted in Section 5.2.7, fecal coliform counts at HCl near the SEKID intake have always been well below the recommended criterion for raw drinking water. Thus, since disinfection of the raw water does not appear to be a problem, the less stringent turbidity guideline of 5 NTU is considered acceptable for water entering the SEKID distribution system.

In raw drinking water (i.e., ambient water prior to uptake and treatment by the purveyor), the primary consideration is the cost of water treatment to maintain turbidity within acceptable finished drinking water standards. It should be noted that any water, even sewage, can be treated to a level that is acceptable for drinking if one is willing to pay the cost. With this factor in mind the Ministry of Environment[9] has set two separate criteria for turbidity in raw drinking water, each of which should be applied under different circumstances. The two criteria are:

(i) For raw waters of exceptional clarity (≤5 NTU) which normally do not require treatment to reduce natural turbidity, induced turbidity should not exceed 1 NTU and the total turbidity should not exceed 5 NTU at any time.

(ii) For raw waters which normally require some form of treatment to reduce natural turbidity to a level which complies with the standard for finished water (≤5 NTU where disinfection is not compromised), induced turbidity should not exceed 5 NTU when background is ≤50 NTU. When background in >50 NTU the induced turbidity should not be more than 10% of background.

As noted, these criteria are designed to protect water users from substantial increases in water treatment costs over that normally required to treat the ambient water before development. In other words, any costs or responsibilities associated with increased turbidity levels as a result of anthropogenic activities such as logging should be borne by the polluter, not by the water-user. By the same token, the water-user should be responsible for costs incurred for treating naturally generated turbidity. Thus, the choice of which criterion to apply to a specific situation depends upon two main factors.

These are:

(i) Ambient background levels (i.e., if background levels are normally greater than or less than the 5 NTU maximum acceptable concentration for turbidity in finished water).

(ii) Whether water treatment facilities were in place prior to the advent of the discharge in question and, if so, are they sufficient to remove anthropogenically-generated turbidity and maintain turbidity in the finished water below the 5 NTU maximum acceptable concentration.

Elements of both these factors are evident at the SEKID intake on Hydraulic Creek. Historical (1983 to 1986) background turbidity levels at site HC1 near the SEKID intake (Table 1) never exceeded 5 NTU, even with the possibly overestimated values for 1983 and 1985 as discussed earlier in this section. While some treatment facilities are in place at the SEKID intake, such as settling ponds and rotating screens, these are only effective for removing larger settleable particles and floating debris. It is the smaller particles suspended in the water which contribute most towards turbidity. To remove turbidity effectively from water, some form of filtration and/or coagulation is required. Since no such treatment systems are in place at the SEKID intake, it is unlikely that the facilities can cope with the input of fines generated by logging activities and maintain the turbidity within acceptable limits in the finished water.

It should be recognized that, in terms of drinking water, the ambient water quality of Hydraulic Creek always has been borderline, even during periods of low logging impacts. Hence, any further deterioration in raw water quality, specifically turbidity and colour (Section 5.2.3), will result in unacceptable finished drinking water. Thus, to maintain the quality of the raw water at near natural levels, and to protect water users from substantial increases in water treatment costs to remove anthropogenically generated turbidity, <u>the maximum turbidity of the raw drinking water at site HC1 should not exceed 5 NTU</u>.

Hydraulic Creek water, withdrawn by SEKID, is also used for the irrigation of crops. Since restrictions for turbidity in drinking water are more stringent than those required for irrigation purposes, and because in the case of multi-use waters objectives for the most sensitive use should apply, the turbidity objective recommended for drinking water should provide ample protection for irrigation. Likewise, this recommended objective also should provide adequate protection for fish between Mission Creek and Hydraulic Lake.

5.2.1.2 Hydraulic Creek Upstream from Hydraulic Lake

As outlined in section 4, recreational fisheries has been identified as a valued resource in the upper reaches of the Hydraulic Creek watershed. Thus, McCulloch Reservoir (Hydraulic, Minnow, and Haynes Lake), and other lakes in the upper reaches of the watershed, along with their feeder streams, should be protected for recreational fisheries.

To protect aquatic life from the harmful effects of turbidity, the Ministry of Environment[9] has established the following criterion: "induced turbidity should not exceed 5 NTU when background turbidity is ≤50 NTU, nor should induced turbidity be more than 10% of background when background is >50 NTU". The reasoning behind this criterion was to maintain turbidity levels close to the natural seasonal patterns of a waterbody to which the aquatic organisms are normally subjected, while still allowing for the continued discharge of some wastes to B.C. waters. The small magnitude of the increase over background levels was considered unlikely to be harmful to aquatic organisms.

As was the case for the lower reach of Hydraulic Creek, the problem with setting turbidity objectives for the upper reaches is that there are few reliable background data upon which to base objectives. Since extensive logging has occurred at the headwaters of the feeder streams, it is not possible to obtain operational background samples. Also, because logging occurred at the higher elevations before most of the water quality monitoring was done, few pre-operational background turbidity data were available. Those few that were available were estimated from suspended solids data.

The only feeder stream to the upland lakes for which any data were available was Hydraulic Creek upstream from Hydraulic Lake. There are two sampling sites (HC3 and HC4) located in this reach of the creek. Site HC3 was established in 1983 and Site HC4 was established in 1986. The drainage area at the headwaters of Hydraulic Creek was clearcut in the winter of 1984/1985.

A review of the turbidity data for Sites HC3 and HC4 (Table 1) showed considerable variability within years; nevertheless, comparisons of annual means clearly showed a trend of increasing turbidity over the years. In 1988, the highest turbidity levels were recorded at both sites which were likely a result of the blowdown of trees left in a buffer strip along the sides of the creek and the subsequent clean-up efforts in the creek in 1988. This blowdown was likely the indirect result of clearcut harvesting where tall trees along the creek bank were left exposed and subsequently were uprooted by high winds.

At site HC3, the lowest annual mean turbidity levels were recorded in 1983 and 1986, which corresponded to periods of low logging activity in the watershed. Thus, the turbidity data for these two years may serve as an adequate basis upon which to determine background levels.

Turbidity data collected at Site HC5 in 1986 and 1987, before the watershed for this stream was logged, are reasonably close to the 1983 and 1986 turbidity values for Site HC3, and thus seem to support the use of these data as representative background levels.

Therefore, it is recommended that the background turbidity level for the reach of Hydraulic Creek upstream from Hydraulic Lake be set at 5 NTU and the turbidity objective be set at a maximum of 10 NTU in accordance with the recommended Provincial turbidity criterion[9] for the protection of aquatic life which allows for an increase of 5 NTU over background.

5.2.1.3 McCulloch Reservoir

There are no turbidity measurements, background or otherwise, for any of the upland lakes in the Hydraulic Creek system. Nevertheless, samples collected at HC2, located immediately downstream from the dam at the outlet of Hydraulic Lake, would provide a reasonable estimate of turbidity in the lake. Prior to 1987, the maximum turbidity reported for this site was 4.7 NTU. Thus, to maintain turbidity at levels acceptable for drinking water downstream as well as for aquatic life in the lake, it is recommended that the turbidity objective at HC2 be set at a maximum of 5 NTU. In addition the turbidity objective recommended for Hydraulic Creek upstream from Hydraulic Lake also should provide some protection because this creek is the main feeder stream to the Lake.

5.2.2 SUSPENDED SOLIDS

Suspended solids (sometimes referred to as "non-filterable residue") is a measure of the concentration of the suspended particulate matter in water which may include sediments, organic debris, and plankton.

5.2.2.1 Hydraulic Creek at the SEKID Intake

Drinking water has been identified as the main water use to be protected at the SEKID intake[3]. Recreational fisheries has also been identified as an important resource in the lower reach of Hydraulic Creek[6].

Neither National nor Provincial guidelines have been recommended for suspended solids in finished or raw drinking water. Suspended solids are directly related to turbidity and because turbidity, for which an objective has been set, is of primary concern in drinking water, an objective for suspended solids would be redundant. Also, as discussed in Section 5.2.1, disturbances such as those associated with logging activities release a preponderance of smaller particles which have a greater effect on turbidity levels than on suspended solids levels. Therefore, the objective recommended for turbidity at the SEKID intake (HC1) should provide ample protection from particulates in the raw drinking water.

Turbidity, as a measure of water clarity, and suspended solids, as a measure of particulate concentration, can each be used as an indicator of different harmful effects on aquatic life even though they are not independent variables. For example, increased turbidity reduces light penetration which ultimately can result in the loss of food to fish through the reduction of primary and secondary productivity. Increased turbidity also may reduce the sight radius of fish which rely upon vision for feeding. Suspended solids, on the other hand, can cause physical harm to aquatic organisms by abrasion and by clogging their gills. If the solids settle out or are filtered out in the streambed then fish spawning, rearing, and feeding habitats may be lost. Therefore, to ensure that aquatic organisms are protected from all these harmful aspects of particulate matter, a Provincial criterion[9] has been set for each of turbidity, suspended solids, and for the benthic accumulation of particulate matter in salmonid spawning areas. Turbidity has been addressed in Section 5.2.1.

The provincial criteria[9] for each of suspended solids and the benthic accumulation of particulates are as follows:

(i) Induced suspended solids should not exceed 10 mg/L when background suspended solids are ≤100 mg/L, nor should induced suspended solids be more than 10% of background when background is >100 mg/L.

(ii) The benthic accumulation of particulate matter less than 3 mm in diameter should not be significantly increased (by weight) over natural background levels. The level of significance is defined as the 95 percent confidence level applied to a comparison of average sediment compositions at the background (or control) and downstream (or affected) sites.

As per the turbidity criterion, these criteria are also based on natural background concentrations so that induced concentrations adhere to natural patterns to which the aquatic populations are normally subjected.

A review of the suspended solids data for Site HC1 (Table 2) showed that the annual means varied little for the first 3 years (1983, 1985, and 1986) that data were available, and then increased dramatically in 1987 and 1988. The maximum concentrations of suspended solids for the years 1983, 1985, and 1986 were 6, 9, and 13 mg/L, respectively. Thus, a concentration of 10 mg/L was chosen as an appropriate background concentration upon which to base the objective. In accordance with the Provincial criterion[9] to protect aquatic life, which allows for an increase of 10 mg/L over background, the recommended suspended solids objective, measured at HC1, is set at a maximum of 20 mg/L. However, as outlined earlier, because logging activities are more likely to have a greater impact on turbidity than on suspended solids, and provided that the turbidity objective for raw drinking water at HC1 is met (Section 5.2.1), it is unlikely that suspended solids concentrations as high as 20 mg/L will occur.

The Provincial criterion[9] for the benthic accumulation of particulate matter should also be met in any location that has the potential for salmonid spawning, such as the lower reach of Hydraulic Creek near its confluence with Mission Creek. However, it may be difficult to determine background levels for the application of this criterion because no sedimentation data have been collected in the watershed. Nevertheless, the turbidity objectives recommended for HC1 and HC2 (maximum of 5 NTU) should provide ample protection against the benthic accumulation of particulates in spawning areas in the lower reaches of Hydraulic Creek so that a benthic accumulation objective was considered unnecessary.

5.2.2.2 Hydraulic Creek Upstream from Hydraulic Lake

For the reach of Hydraulic Creek upstream from Hydraulic Lake, the maximum suspended solids concentrations at site HC3 were 5 and 12 mg/L for 1983 and 1986, which correspond to periods of low logging activity. These were used as a basis to set a turbidity objective to protect aquatic life and were also chosen as a basis upon which to set a suspended sediments objective. Thus, it is recommended that the background suspended solids concentration at HC3 be set at 10 mg/L and, in accordance with the Provincial criterion[9] which allows an increase of 10 mg/L, the maximum concentration of suspended solids at HC3 should not exceed 20 mg/L.

5.2.2.3 McCulloch Reservoir

A few suspended solids data, taken in 1983, were available for different locations and different depths of Hydraulic Lake and Haynes Lake. However, the few data were too variable, depending upon the location or depth sampled, to use as a basis upon which to set an objective. Furthermore, for a lake situation, a turbidity objective would be more meaningful than a suspended solids objective for aquatic life because the larger particles, which have a greater impact on suspended solids concentrations, would settle out quickly leaving the smaller particles which have a greater impact on turbidity. Therefore, a suspended solids objective has not been recommended for any lakes in the system.

5.2.3 COLOUR

In this document, colour refers to "true colour" reported in True Colour Units (TCU) which is the colour of the water with the turbidity removed. True colour in water is caused by dissolved components and may result from the presence of natural metallic ions (iron and manganese), humus and peat materials, decaying plant material and industrial wastes.

Although no pre-logging data were available for colour in Hydraulic Creek, a review of the data for periods of low logging activity (1983 and 1986), and for the control site HC5 before it was logged, indicate that the Hydraulic Creek system is naturally high in colour, often exceeding 50 TCU (Table 3). Larratt[2] attributed the high colour to dissolved organic material originating from peat bogs and swamp drainage in the upper reaches of the system. Dissolved iron also has been measured at concentrations which may contribute to the discoloured water.

5.2.3.1 Hydraulic Creek at the SEKID Intake

Water colour is an important factor to consider with regard to drinking water. The B.C. Ministry of Health[7] and Health and Welfare Canada[8] have set a maximum acceptable limit of 15 TCU for colour in finished drinking water based on aesthetic considerations. This is obviously an unattainable objective in the raw drinking water given the high natural levels in the Hydraulic Creek system. Because natural colour levels are so high and variable, it is difficult to determine if logging has had any impact on water colour.

In 1982 and 1983, projects were undertaken to improve water quality at the SEKID intake by channelizing swampy sections of the creek below Hydraulic Lake. These projects may have helped remove the source of some of the colour in Hydraulic Creek. The mean annual colour at Site HC1 (Table 3) was reduced from 60 to 43 TCU from 1983 to 1986; however, sites HC2 and HC3, which are upstream from the channelizing projects, were similarly reduced in colour over the same period. From 1987 to 1988 increased colour was noted at all sites in the system (Table 3). Whether these fluctuations are due to natural causes or attributable to disturbances from logging activities is unknown.

In any case, colour per se is not a health concern in drinking water. However, because much of the colour is organic in origin, and because the drinking water is chlorinated by SEKID, which may remove some of the colour, there is a concern that potentially harmful organohalides such as trihalomethanes may be formed during this treatment. The Ministry of Health, with which the responsibility for drinking water quality lies, has tested the treated water for trihalomethanes (bromodichloromethane, bromoform, chlorodibromomethane, and chloroform) on one occasion during spring runoff in late April, 1989. Chloroform was the only trihalomethane detected at a concentration of 0.13 mg/L. This value is less than the maximum acceptable concentration (MAC) of 0.35 mg/L trihalomethanes in drinking water specified by the B.C. Ministry of Health.[7] However, it should be noted that this guideline is currently being reassessed and may change in the near future.

While an objective for colour is not recommended because it is naturally high in the system, it should be noted that the U.S. EPA[10] states that when the source water does not exceed 75 TCU, water consistently can be treated using standard coagulation, sedimentation, and filtration processes to reduce colour to substantially less than 15 TCU. Therefore, if the decision is made by SEKID to install colour removal facilities at some time in the future, then the finished drinking water standard for colour (<15 TCU) can be met most of the time.

5.2.4 NITROGEN

5.2.4.1 Nitrite (NO_2-N)

Nitrite is of concern with respect to drinking water and aquatic life. A Provincial criterion[11] of 1 mg N/L has been recommended as a maximum concentration of nitrite in raw drinking water for the protection of infants from methemoglobinemia. For aquatic life, a Provincial criterion[11] ranging from 0.02 to 0.2 mg N/L, depending upon the chloride concentration, has been recommended as a 30-day average concentration for toxicological reasons. Since aquatic life is more sensitive than are humans to nitrite, and because recreational fisheries is an important resource throughout the Hydraulic Creek system, a nitrite objective to protect fisheries interests would provide ample protection for drinking water.

As noted, the nitrite criterion for the protection of aquatic life depends upon the chloride concentration. While no chloride measurements were available for Hydraulic Creek, Okanagan Lake and other streams in the area typically have chloride concentrations of <2 mg/L. Thus, it is assumed that Hydraulic Creek has a chloride content of <2 mg/L. The Provincial criterion[11] recommends a 30-day average nitrite concentration of not more than 0.02 mg N/L, and a maximum of 0.06 mg N/L when the chloride concentration is <2 mg/L.

No data were available for nitrite alone in Hydraulic Creek, but combined nitrate plus nitrite data were available for the years 1986 to 1988 at most sites (Table 4). The highest annual mean nitrate plus nitrite concentration was 0.1 mg N/L at HC5 in 1987. The highest concentration overall recorded was 0.41 mg N/L at HC5 in 1987. Both these values are greater than the Provincial criterion maximum for nitrite alone. However, since nitrate is likely the predominant form in these waters, actual nitrite concentrations are probably less than the Provincial criteria for nitrite to protect aquatic life. While an objective for nitrite was not considered necessary, it is recommended that nitrite and chloride be measured twice to confirm that nitrite is, as predicted, below the appropriate Provincial criteria. Table 15 shows the nitrite criteria and the corresponding chloride levels at which they apply.

5.2.4.2 Nitrate (NO_3-N)

Nitrate plus nitrite concentrations in Hydraulic Creek (maximum of 0.41 mg N/L) are far below the Provincial criterion[11] (maximum of 10 mg/L) for nitrate plus nitrite in drinking water which is the most sensitive water use for nitrate. Thus, an objective for nitrate was considered unnecessary for the Hydraulic Creek system.

5.2.4.3 Ammonia

The highest concentration of ammonia measured in Hydraulic Creek (0.1 mg N/L) was far below the appropriate Provincial criterion[11] (1.4 mg/L as a 30-day average) for the protection of aquatic life (Table 5). This criterion is based on a worst-case scenario by using the maximum water temperature (18°C) and the minimum pH (6.2) in Hydraulic Creek. Thus, an objective for ammonia was considered unnecessary for the Hydraulic Creek system.

5.2.5 PHOSPHORUS

Phosphorus is usually the limiting nutrient in Okanagan headwater lakes, and is important for drinking water and fisheries because it stimulates algal growth and accelerates eutrophic conditions. Logging can increase the phosphorus concentration of runoff from logged areas.

The Ministry of Environment[12] has recommended criteria to protect these water uses from the eutrophying effect of elevated phosphorus concentrations. For raw drinking water, a maximum of 10 µg/L total phosphorus has been recommended, and from 5 to 15 µg/L for the protection of salmonids. These criteria apply only to lakes because in streams too many other factors, such as the hydrologic conditions, are involved in limiting algal growth[12]. Furthermore, in streams a large portion of the total phosphorus may be in the particulate or other non-nutritive forms. Nevertheless, data for ortho phosphorus and dissolved phosphorus indicate that there is a considerable amount of available phosphorus (Tables 6 and 7) in Hydraulic Creek and its tributaries.

In streams, elevated nutritive phosphorus concentrations may increase periphytic algal growth which can have the following detrimental effects on fish:

(i) "gluing" the gravel together thereby inhibiting redd construction by fish in spawning beds;

(ii) increasing the decaying organic fraction and restricting the flow of water through spawning bed gravel thereby reducing the amount of dissolved oxygen available for fish embryo development;

(iii) causing a change in the types of fish food organisms present.

Since measured phosphorus concentrations in streams may be meaningless as discussed above, to protect aquatic life the B.C. Ministry of Environment has recommended a criterion maximum of 100 mg/m^2 for chlorophyll a in periphytic algae[12]. The quantity of this pigment is directly proportional to the amount of periphyton present and therefore can serve as an indicator of elevated phosphorus levels. However, it should be noted that plant growth also may be stimulated by a variety of other factors such as the loss of shade. Larrat and Dobson[3] noted that some portions of Hydraulic Creek which received direct sunlight supported luxurious growth of filamentous green algae, whereas the shaded adjacent section did not. The authors stressed the importance of preserving shade trees along the stream banks.

A value of 100 mg/m^2 reflects fairly prolific periphyton growth which is clearly visible from the surface. Therefore, unless the natural substrate is covered with a noticeable carpet of periphyton, neither a water quality objective nor monitoring for chlorophyll a is necessary. Since there are no indications that periphytic algal growth is a serious widespread problem in Hydraulic Creek, except perhaps in some locations that are not shaded, neither monitoring nor a water quality objective for chlorophyll a has been recommended at the present time.

No phosphorus data were available for lakes in the Hydraulic Creek system. Some data, which often exceeded the criteria, were available for creeks in the system (Table 8) but, as noted, the criteria are not applicable to these situations. Total phosphorus data for Site HC2 (Table 8), which is located near the outlet of Hydraulic Lake, and thus reasonably indicative of the internal lake conditions, suggests that the criteria for raw drinking water and for salmonids in the lake were exceeded on a number of occasions. However, this should be confirmed by samples collected in the lake. Even if lake samples prove that the criteria have been exceeded, it would be unclear as to how much of the phosphorus, if any, could be attributed to logging activity since no pre-logging data for the lakes are available. In any case, any further increase in lake phosphorus concentrations likely would accelerate the degradation of water quality.

5.2.6 WATER TEMPERATURE

Clearcut logging can result in increased water temperature through the loss of shade and increased ground temperature.

Increased water temperature of raw drinking water is a concern for aesthetic reasons because it can adversely affect the taste and odour of the water. In addition, for health concerns, the loss of shade may accelerate algal growth and any increase in organic matter will increase the chlorine demand, and increase the potential for trihalomethane formation in the finished drinking water. Health and Welfare Canada[8] and the B.C. Ministry of Health[7] recommend that the temperature of finished drinking water should not exceed 15°C.

Elevated water temperatures also are important from a fisheries perspective if critical survival temperatures are exceeded. Critical survival temperatures depend upon the species as well as the life stage. For rainbow trout, spawning and embryo development are the most sensitive periods. The U.S. EPA[10] recommends that the maximum weekly average temperature should not exceed 8 to 10°C during spawning and a maximum of 13 to 15°C for embryo survival. For juveniles and adults, a maximum weekly average of 18 to 19°C, and a maximum of 22 to 24°C is recommended. Since spawning and embryo development of rainbow trout usually occur in the spring, well before peak water temperatures are reached in the Hydraulic Creek system, the criteria for juveniles and adults are more appropriate. The maximum water temperature recorded for Hydraulic Creek is 18°C (Table 9), and thus does not exceed the critical survival temperature for juvenile or adult rainbow trout.

In B.C., it is not unusual for ambient water temperatures to exceed 15°C. Peak water temperatures in the Hydraulic Creek system generally appear to range from 16 to 18°C through July and August (Table 9). Comparison of peak temperatures over 1986, 1987, and 1988 indicate a slight increase at most monitoring sites. However, because water temperature is dependent upon so many environmental factors, such as local weather conditions, the depth and volume of water, residence time, and groundwater input, it is difficult to determine the impact of logging alone.

Since 18°C is the highest temperature measured over the 3-year period of record, it is recommended that the maximum temperature should not exceed 18°C at the established stream sites (HC1 to HC4) for both the protection of raw drinking water and aquatic life.

5.2.7 MICROBIOLOGICAL INDICATORS

Microbiological indicators are used to measure the risk of disease from pathogenic bacteria. In areas subjected to anthropogenic activities including logging, the potential for the increased transmission of water-borne disease exists. In addition, clear-cut harvesting can increase surface run-off which may result in animal wastes being washed directly into the water-course without the benefit of soil-filtration. These factors are important from a health perspective when the water is used as a source for drinking, recreation, livestock watering, or irrigation of crops eaten raw.

Fecal coliform bacteria, associated primarily with mammalian feces, have historically been the indicator of choice, but their presence does not always correlate well with the incidence of disease. Total coliform bacteria are even worse indicators of disease risk because they include strains that naturally inhabit soils and vegetation. Coliforms are therefore now being supplanted by more specific indicators. These include Escherichia coli and enterococci which are good indicators of gastrointestinal disease[14].

Fecal and total coliforms were sampled in the Hydraulic Creek watershed only during 1986 when logging activity was low due to labour problems in the forest industry. Fecal coliforms never exceeded a Most Probable Number (MPN) of 2 per 100 mL at the sites tested including HC1 at the SEKID intake (Table 11). No fecal coliforms were detected at the control site, HC5. Total coliforms were much higher (maximum MPN's of 44 per 100 mL at HC3 and 43 per 100 mL at HC1) as shown in Table 12, but as noted earlier, this group of organisms is a poor indicator of disease risk.

While any water, even sewage, can be treated to a quality acceptable for drinking, the important factor with respect to raw water is the treatment cost to attain microbiologically safe conditions in the finished water. Since the raw water is chlorinated on uptake, the purveyor (SEKID) should be protected from additional treatment costs. Thus, in accordance with the

Provincial water quality criteria[14] for microbiological indicators for raw water receiving disinfection only, it is recommended that at HC1:

(i) fecal coliform counts should not exceed 10 per 100 mL in at least 90% of the raw water samples taken in a 30-day period;

(ii) *Escherichia coli* counts should not exceed 10 per 100 mL in at least 90% of the raw water samples taken in a 30-day period;

(iii) Enterococci counts should not exceed 3 per 100 mL in at least 90% of the raw water samples taken in a 30-day period.

Since drinking water is the most sensitive water use to disease risk, these objectives will provide sufficient protection for all other uses of the water.

5.2.8 OTHER WATER QUALITY CHARACTERISTICS

Data for other water quality characteristics that may be affected by logging activities, such as pH (Table 10), and specific conductivity (Table 13), showed no obvious changes or trends over the period of record. Furthermore, the data for these characteristics were within guidelines recommended for raw drinking water at HC1, or for aquatic life throughout the system, and thus objectives were not considered necessary.

6. CONCLUSIONS

The logging activities in the Hydraulic Creek watershed appear to be having a detrimental effect on water quality in the system. While no pre-logging water quality data were available, data collected during periods of low logging activity and from a control stream indicated that some water quality characteristics have increased considerably during periods of accelerated harvesting. The characteristics most affected include turbidity and suspended solids. For other water quality characteristics such as colour, water temperature, and phosphorus, although variations in the data were noted it was not clear whether the changes were due to logging or to natural causes.

Provisional water quality objectives were set for those water quality characteristics that exceeded or were near criteria levels for designated water uses, and that may be affected by logging activities. They include turbidity, suspended solids, microbiological indicators, and water temperature. These objectives are summarized in Table 14. Although water colour was very high in the Hydraulic Creek system, it appeared to originate from natural sources and not from logging activities. Therefore, a water quality objective for colour was not recommended.

7. MONITORING

Water quality monitoring in Hydraulic Creek has been performed on an approximately weekly frequency, from mid-March or April through to about mid-October, for the past three years (1986, 1987, and 1988). Weekly monitoring should continue each year over these same months to ensure that water quality objectives are being met.

Water quality characteristics that should be measured on a weekly basis at four established sites (HC1 to HC4) include turbidity, suspended solids, and water temperature. In addition, microbiological indicators should be measured at HC1 on a weekly basis throughout the monitoring period. Nitrite alone and chloride should be checked twice during one monitoring season at each of the four sites (HC1 to HC4) to confirm that the appropriate criterion for aquatic life (Table 15) is not being exceeded.

An additional monitoring site in Hydraulic Lake should be included. Since residence time of the epilimnetic water in Hydraulic Lake is estimated to be less than six months, we recommend that, as per the phosphorus criterion, total and dissolved phosphorus in Hydraulic Lake should be measured at least monthly during the growing season (from May to September). In addition, total and dissolved phosphorus also should be measured simultaneously at site HC2 for one growing season to determine if this site would serve as an adequate substitute for the lake site in future years. If the mean epilimnetic phosphorus concentrations at the two sites do not differ significantly at the 95% confidence level, then the lake site could be abandoned in favour of site HC2. The recommended monitoring schedule is summarized in Table 16.

8. REFERENCES CITED

1. Larratt, H.M. 1984. Water Quality Report for South East Kelowna Irrigation District. Prepared for SEKID, Kelowna, B.C.

2. Larratt, H.M. 1985. Water Quality Report II. South East Kelowna Irrigation District. Prepared for SEKID, Kelowna, B.C.

3. Larratt, H.M. and D. Dobson. 1986. Hydraulic Creek Water Quality Study; 1986 Results. Kelowna, B.C.

4. Larratt, H.M. and D. Dobson. 1987. Hydraulic Creek Water Quality Study; 1987 Results. Kelowna, B.C.

5. Water Management Branch, B.C. Ministry of Environment. 1986. Principles for Preparing Water Quality Objectives in British Columbia. Victoria, B.C.

6. Jones, D. 1988. (Personal Communication) Fish and Wildlife, Habitat Protection. Penticton, B.C.

7. B.C. Ministry of Health. 1982. British Columbia Drinking Water Quality Standards. Victoria, B.C.

8. Health and Welfare Canada. 1989. Guidelines for Canadian Drinking Water Quality. Prepared by the Federal-Provincial Subcommittee on Drinking Water. Ottawa.

9. Singleton, H.J. 1985. Water Quality Criteria for Particulate Matter. Resource Quality Section, Water Management Branch, Ministry of Environment, Victoria, B.C.

10. U.S. EPA. 1976. Quality Criteria for Water. U.S. Environmental Protection Agency. Washington, D.C.

11. Nordin, R.N. and L.W. Pommen. 1986. Water Quality Criteria for Nitrogen (Nitrate, Nitrite, and Ammonia). Resource Quality Section, Water Management Branch, Ministry of Environment and Parks, Victoria, B.C.

12. Nordin, R.N. 1985. Water Quality for Nutrients and Algae. Resource Quality Section, Water Management Branch, Ministry of Environment, Victoria, B.C.

13. APHA, AWWA, and WPCF. 1985. Standard Methods for the Examination of Water and Wastewater. 16th Edition. Washington, D.C.

14. Warrington, P.D. 1988. Water Quality Criteria for Microbiological Indicators; Technical Appendix. Resource Quality Section, Water Management Branch, Ministry of Environment, Victoria, B. C.

15. Butt, G. 1989. Assessment of Organic Matter Sources in Hydraulic Creek. Submitted to: Penticton Forest District, Penticton, B.C.

FIG. I HYDRAULIC CREEK WATERSHED

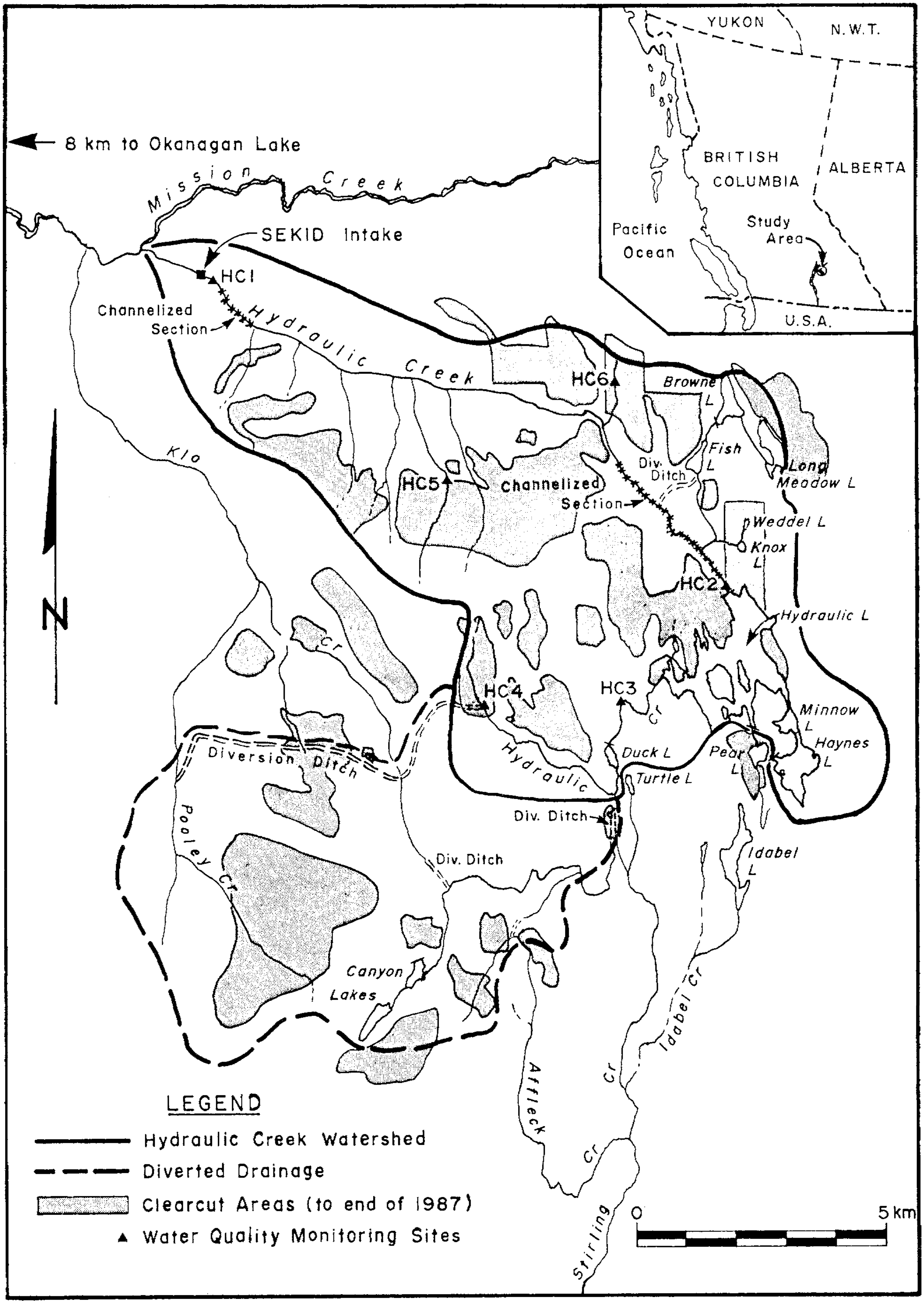

TABLE 1

TURBIDITY (NTU)

YEAR	1983*				1985*				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1	5	3.3	2.2	2.5	5	4.9	0.5	2.4	29	2.7	0.6	1.6	28	7.4	2.4	5.4	21	12.0	2.6	5.5
HC2	5	4.4	<0.9	<1.9	5	3.5	0.9	2.3	29	4.7	0.4	1.4	19	7.4	2.1	3.7	17	7.3	2.0	3.5
HC3	4	3.3	<0.7	<2.0	5	12.6	0.7	5.3	29	4.6	0.7	1.8	27	13.1	0.9	5.3	20	51.0	4.0	11.7
HC4									29	2.8	0.1	0.8	28	8.0	0.5	1.5	20	15.0	0.6	2.6
HC5**									26	3.0	0.3	1.0	20	8.1	0.4	1.2	12	4.5	0.5	1.0
HC6													18	45.0	9.8	21.0	20	25.0	7.0	11.1

* Estimated values based on suspended solids:turbidity ratio of means for 1986 and 1987 at the appropriate sites

** Control site in 1986 and 1987, logged in 1988.

TABLE 2

SUSPENDED SOLIDS (mg/L)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1	5	6	4	4.6	5	9	1	4.4	28	13	1.0	4.7	28	19	1.0	7.2	21	17.0	1.0	6.7
HC2	5	5	<1	<2.2	5	4	1	2.6	20	7	0.5	2.6	19	6	1.0	2.4	17	6.0	1.0	3.0
HC3	4	5	<1	<3.0	5	19	<1	<8	26	12	0.5	4.3	27	28	1.0	6.4	20	60.0	2.0	10.2
HC4									17	12	0.1	2.9	28	6	1.0	1.7	13	17.0	1.0	4.4
HC5**									15	15	1.0	3.5	20	22	1.0	2.2	4	3.0	1.0	1.5
HC6													18	8	1.0	2.1	18	9.0	1.0	3.1

** Control site in 1986 and 1987, logged in 1988.

TABLE 3

COLOUR (TCU)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1	5	83	38	60	5	79	40	54	29	60	30	43	28	65	23	46	21	130	37	66
HC2	5	57	39	49	5	66	35	46	29	60	15	35	19	65	31	42	17	70	33	52
HC3	4	80	73	76	5	80	34	57	29	70	30	49	27	70	33	51	20	80	28	51
HC4									29	70	20	47	28	85	20	46	20	130	32	60
HC5**									26	70	30	54	20	80	29	50	12	110	55	70
HC6													18	160	68	116	20	200	55	140

**Control site in 1986 and 1987, logged in 1988

TABLE 4

NITRATE & NITRITE (mg/L-N)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1									29	0.09	0.01	0.03	28	0.07	0.00	0.02	16	0.370	0.006	0.044
HC2									29	0.17	0.01	0.04	19	0.02	0.00	0.01	5	0.044	0.006	0.014
HC3									29	0.02	0.01	0.01	27	0.14	0.00	0.02	8	0.075	0.005	0.017
HC4									29	0.13	0.01	0.05	28	0.32	0.00	0.06	10	0.192	0.006	0.039
HC5**									26	0.36	0.01	0.08	20	0.41	0.00	0.10	9	0.351	0.006	0.065
HC6													18	0.02	0.00	0.01	11	0.025	0.006	0.011

** Control site in 1986 and 1987, logged in 1988

TABLE 5

AMMONIA (mg/L-N)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1									29	0.03	0.01	0.02								
HC2									29	0.10	0.01	0.03								
HC3									29	0.03	0.01	0.02								
HC4									29	0.02	0.01	0.01								
HC5**									26	0.05	0.01	0.02								
HC6																				

**Control site

TABLE 6

ORTHO PHOSPHORUS (mg/L)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1													20	0.009	0.003	0.006				
HC2													18	0.009	0.003	0.005				
HC3													10	0.009	0.003	0.004				
HC4													5	0.004	0.003	0.003				
HC5**													2	0.004	0.003	0.004				
HC6													16	0.029	0.003	0.014				

** Control site

TABLE 7

DISSOLVED PHOSPHORUS (mg/L)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1													28	0.018	0.003	0.009				
HC2													19	0.017	0.004	0.010				
HC3													27	0.018	0.003	0.006				
HC4													23	0.008	0.003	0.004				
HC5**													14	0.006	0.003	0.004				
HC6													17	0.043	0.010	0.024				

** Control site

TABLE 8

TOTAL PHOSPHORUS (mg/L)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1									7	0.05	0.03	0.03	19	0.044	0.015	0.031				
HC2									4	0.05	0.02	0.03	19	0.026	0.012	0.019				
HC3									4	0.03	0.02	0.02	18	0.048	0.009	0.020				
HC4									5	0.04	0.03	0.03	19	0.017	0.003	0.009				
HC5**									2	0.14	0.02	0.08	10	0.010	0.003	0.006				
HC6													12	0.148	0.045	0.074				

**Control site

TABLE 9

WATER TEMPERATURE (°C)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1									25	16.0	3.0	9.2	27	16.0	1.0	8.0	19	18.0	2.0	10.3
HC2									24	17.0	4.5	10.0	19	18.0	5.0	12.5	15	18.0	10.0	14.1
HC3									23	15.0	0.5	7.8	19	16.0	1.0	8.8	18	17.0	1.0	9.4
HC4									23	15.0	2.0	8.8	24	18.0	1.0	8.6	17	17.0	2.0	10.1
HC5**									21	8.0	0.5	4.9	12	9.0	1.0	5.6	13	16.0	1.0	7.2
HC6													18	15.0	1.0	8.6	18	17.5	2.0	11.3

** Control site in 1986 and 1987, logged in 1988

TABLE 10

LAB pH

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1	4	7.3	7.0	7.1	5	7.6	7.0	7.2	29	7.7	7.3	7.5	28	8.3	7.1	7.6	21	7.8	6.5	7.1
HC2	4	6.7	6.5	6.6	5	7.2	6.6	6.8	29	7.4	6.5	6.8	19	7.6	6.6	7.0	17	7.5	6.2	6.9
HC3	3	6.7	6.6	6.7	5	7.2	6.7	7.0	29	7.3	6.7	7.0	27	7.6	6.7	7.1	20	7.3	6.4	6.9
HC4									29	7.6	7.0	7.4	28	8.1	7.1	7.7	20	7.7	6.8	7.2
HC5**									26	7.6	6.4	7.3	20	7.8	7.4	7.6	12	7.7	6.8	7.2
HC6													17	7.6	7.0	7.2	20	7.4	6.5	7.1

** Control site in 1986 and 1987, logged in 1988

TABLE 11

FECAL COLIFORMS ((Most Probable Number/100 mL)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)																				
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1									7	2	0	0.3								
HC2									12	2	0	0.3								
HC3									8	2	0	0.2								
HC4									7	2	0	0.3								
HC5**									6	0	0	0								
HC6																				

** Control site

TABLE 12

TOTAL COLIFORMS (Most Probable Number/100 ml)

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)																				
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1									7	43	4	12								
HC2									12	21	2	12								
HC3									8	44	2	19								
HC4									7	28	2	13								
HC5**									6	11	2	4								
HC6																				

** Control site

TABLE 13

SPECIFIC CONDUCTIVITY (μhmos cm^{-1})

YEAR	1983				1985				1986				1987				1988			
Area Logged (ha)	106				444				108				620				509			
Site Number	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean	n	Max	Min	Mean
HC1									29	137	41	68	28	184	38	80	21	117	40	67
HC2									29	129	30	37	19	38	28	32	17	35	28	31
HC3									29	55	15	28	27	83	18	38	20	57	20	33
HC4									29	108	9	77	28	133	69	100	20	142	56	106
HC5**									26	98	43	62	20	83	52	63	12	81	53	63
HC6													17	100	46	71	20	112	15	51

** Control site in 1986 and 1987, logged in 1988

TABLE 14

PROVISIONAL WATER QUALITY OBJECTIVES FOR HYDRAULIC CREEK

SAMPLING SITES	HC1 SEKID[2] INTAKE	HC2 OUTLET OF HYDRAULIC LAKE	HC3 UPSTREAM FROM HYDRAULIC LAKE	HC4 HEADWATERS OF HYDRAULIC CREEK
DESIGNATED WATER USES	DRINKING WATER, IRRIGATION, AQUATIC LIFE	DRINKING WATER, IRRIGATION, AQUATIC LIFE	AQUATIC LIFE	AQUATIC LIFE
TURBIDITY	5 NTU Maximum	5 NTU Maximum	10 NTU Maximum	10 NTU Maximum
SUSPENDED SOLIDS	20 mg/L Maximum	not applicable	20 mg/L Maximum	not applicable
TEMPERATURE	18°C Maximum	18°C Maximum	18°C Maximum	18°C Maximum
Microbiological Indicators:[1]		not applicable		
Fecal Coliforms	10/100 mL			
<u>Escherichia Coli</u>	10/100 mL			
Enterococci	3/100 mL			

[1] Should not be exceeded in at least 90% of the raw water samples taken in a 30-day period.
[2] South East Kelowna Irrigation District

TABLE 15

CRITERIA FOR NITRITE FOR PROTECTION OF FRESHWATER AQUATIC LIFE

Chloride Concentration (mg/L)	Maximum Nitrite Concentration (mg/L as N)	Average Nitrite Concentration* (mg/L as N)
less than 2	0.06	0.02
2-4	0.12	0.04
4-6	0.18	0.06
6-8	0.24	0.08
8-10	0.30	0.10
greater than 10	0.60	0.20

* the 30-d average chloride concentration should be used to determine the appropriate 30-d average nitrite criterion.

TABLE 16

RECOMMENDED MONITORING FOR HYDRAULIC CREEK AND HYDRAULIC LAKE

SITES	FREQUENCY AND TIMING	CHARACTERISTICS TO BE MEASURED
HC1 SEKID INTAKE	Weekly from April 1 to October 15	Turbidity, Suspended solids, Temperature, and Microbiological Indicators.
	Twice during one monitoring season only (April 1 to October 15).	Nitrite and Chloride
HC2 Outlet of Hydraulic Lake	Weekly from April 1 to October 15	Turbidity, Suspended solids, and Temperature
	Twice during one monitoring season only (April 1 to October 15)	Nitrite and Chloride
	At least monthly during the growing season (May through September)	Total and Dissolved Phosphorus
HC3 Upstream from Hydraulic Lake	Weekly from April 1 to October 15	Turbidity, Suspended solids, and Temperature
	Twice during one monitoring season only (April 1 to October 15)	Nitrite and Chloride
HC4 Headwaters of Hydraulic Creek	Same as Site HC3	Same as Site HC3
Hydraulic Lake[1] Mid-lake site	At least monthly during the growing season (May through September	Total and Dissolved Phosphorus

[1] Should be sampled in the epilimnion and both HC2 and the lake site should be sampled simultaneously or as closely as reasonably possible.

NOTE: Sampling may need to be increased to check objectives, depending on circumstances.