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Ministry of Environment
ASSESSMENT AND PLANNING DIVISION

Dutch Lake
(Clearwater, British Columbia)
Water Quality and Options for Improvements

Working Report
by
Richard N. Nordin
Aquatic Studies Branch

Victoria, British Columbia
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SUMMARY

A short study of Dutch Lake near Clearwater, was carried out to find a way of improving what appears to be deteriorating water quality.

Sampling carried out in 1979 and 1980 indicated low hypolimnetic dissolved oxygen concentrations, occasional high algal growth and very poor vertical mixing at overturn. Calculated water inflows to the lake are relatively small and the theoretical filling time is very long (about 20 years). A significant amount of residential housing is present in the watershed and may be contributing to the deteriorating water quality. The soils around the lake are very coarse and may allow more than an acceptable amount of nutrients to enter the lake.

A number of lake restorative techniques were considered and diversion of water from the Clearwater River into Dutch Lake appeared to be the best approach. A brief review of past experiences with flushing/dilution of lake systems is included.

If water quality is to be maintained or improved, the two problems of poor lake water exchange and nutrient input from septic tank effluent will have to be considered together.

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The staff of the Environmental Lab provided their usual high standard for the analysis of the water samples.

1. INTRODUCTION

In July 1979, the Deputy Minister received from the Thompson - Nicola Regional District a request to evaluate the water quality of Dutch Lake. Concern was expressed as to the apparent deteriorating water quality suspected partially to be a consequence of sewage disposal by septic tank - tile field systems in the watershed. Some guidance and advice were requested as to means of maintaining or improving the water quality of the lake.

The Clearwater Improvement District also requested information on the state of the lake and organized a public meeting in August 1980 at which representatives of Waste Management Branch, Fish and Wildlife Branch, Ministry of Health and Aquatic Studies Branch were present.

Only limited sampling was carried out because of the distance from Victoria. This report discusses the results of that sampling, and existing information on the lake. Possible options for improving the lake water quality are suggested as the result of this analysis.

2. METHODS

Field sampling was carried out using standard limnological methods. Temperature and dissolved oxygen were measured using a YSI Model 57 meter. The oxygen readings were calibrated by using Winkler titrations. Water samples were collected from the water column by use of a 8 litre Van Dorn PVC water sampler. All water samples were shipped on ice in coolers and arrived at the Ministry of Environment, Environmental Laboratory within 48 hours of collection. Methods of analysis are those described in McQuaker (1975). All of the biological and chemical data are stored on the Ministry of Environment EQUIS data base under sites 0603101, 0603102 and 0603103 and the data are available on request.

3. LAKE WATERSHED

Dutch Lake is located near Clearwater near the confluence of the Clearwater and North Thompson Rivers. The watershed is small and situated at an elevation of 765 m. It has an area of 3.9 km^2. The lake is in the Interior Douglas Fir biogeoclimatic zone (Krajina, 1969) and has 427 mm of rainfall per year (30 year mean - 1941-1970 - Ministry of Agriculture, Undated), from records for Vavenby.

The soils in the immediate watershed are described as Orthic Eutric Brunisols which are moderately coarse to very coarse textured glaciofluvial deposits. Three other groups of soils occur in the watershed but in zones further from the lake (Figure 1).

There are a few minor surface inflows to the lake and no stream outflow. A natural outflow existed at one time but was filled as a consequence of road construction along the south side of the lake. It would appear that the water which enters the lake is largely groundwater, direct surface precipitation and overland runoff. The lake level varies through the year but no lake level data are available.

The lake is shielded somewhat by hills around it and this has consequences for the physical stability of the lake (noted below).

4. LAKE MORPHOMETRY

Dutch Lake is a relatively small lake of 65.5 hectares (162 acres) water surface area excluding an island of 2.3 ha (Figure 2). The maximum depth is 39 metres, the mean depth is 14.4 metres and the volume is 9 400 000 m^3. The volumes at various depth intervals are shown in Table 1. The lake has a relatively small watershed:lake surface ratio of 6:1.

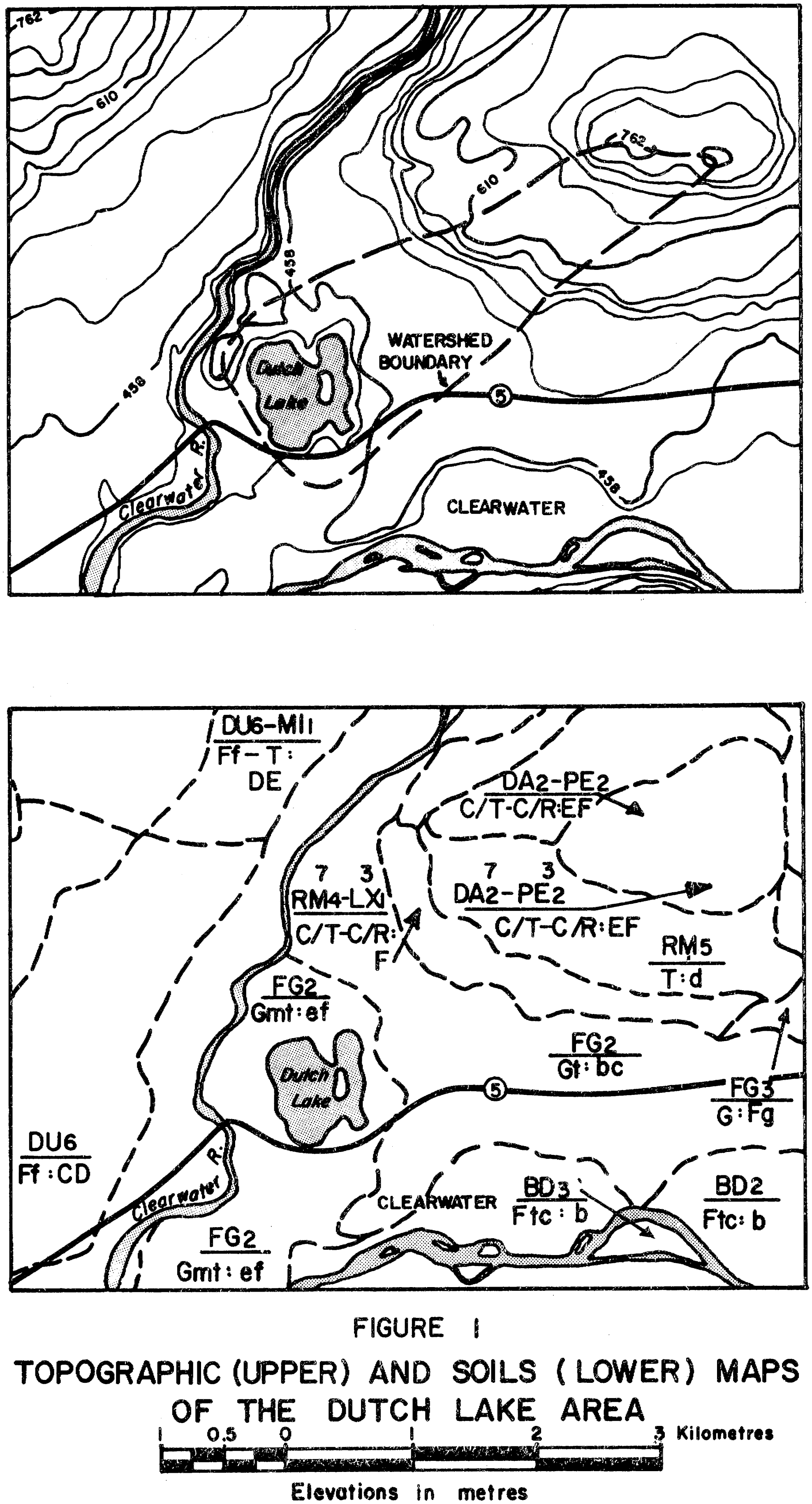


FIGURE 1

TOPOGRAPHIC (UPPER) AND SOILS (LOWER) MAPS OF THE DUTCH LAKE AREA

FIGURE 1 scale 1 cm = 500 metres

elevations in metres

soils symbols for Dutch Lake watershed (soil type / surficial geology)

FG2 - soil type - Orthic Eutric Brunisol

GMT: ef surficial geology G: glacio-fluvial

M: subdued surface expression

T: terraced

ef: slope range (9-30%)

FGz - Orthic Eutric Brunisol

Gt:bc- G: glacio-fluvial deposits

t: terraced

bc: slope (1/2-5%)

RM4-LX1 - mixture of two soil types. Dominant Lithic

C/TR - C/R:F Degraded Eutric Brunisol

- C/T - A unit of colluvium and till (C/T) with colluvium dominant (i.e., 55-70%/30-45%) and colluvium and rock (C/R) with colluvium dominant. (i.e., 55-70%/30-45%).

- F - slope in F range (15-30%) (upper case denotes complex slope)

DA2 - PE2

C/T - C/R:EF - mixture of two soil types. Dominant is Degraded Eutric Brunisol.

- same as C/T-C/R above but with simple slopes in "E to F" range (9-30%)

FIGURE 2

DUTCH LAKE BATHYMETRIC MAP
DEPTHS IN METRES

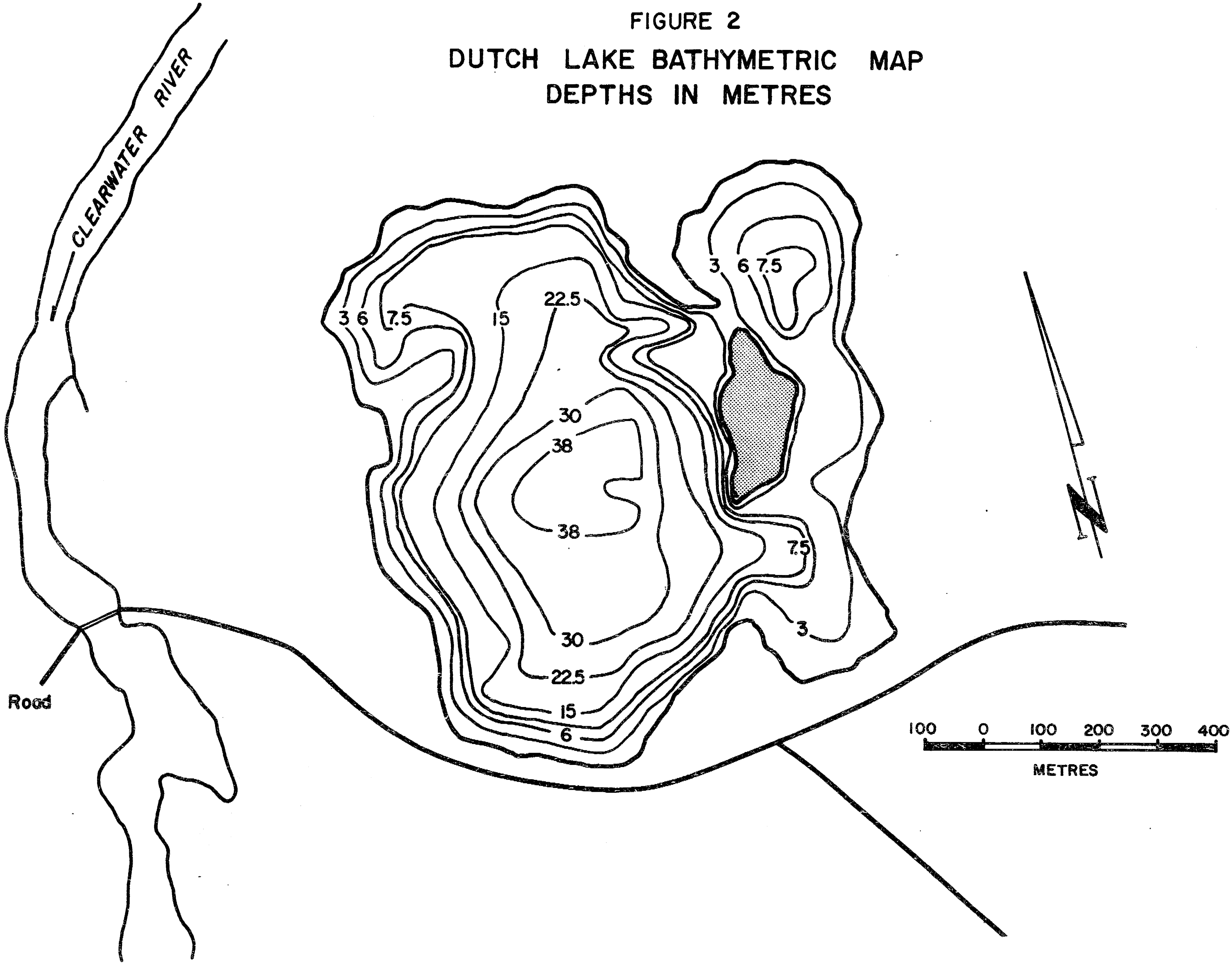


Table 1: Lake Volume Calculations

0-3 metres	1 820 000 m^3
3-6 metres	1 439 000 m^3
6-7.5 metres	574 000 m^3
7.5-15 metres	2 260 000 m^3
15-22 metres	1 854 000 m^3
22-30 metres	1 001 000 m^3
30-38 metres	475 000 m^3
	9 423 000 total

5. FISHERIES

An important and valuable sport fishery exists in the lake although summer "off-taste" problems occur with a "muddy" or "earthy" taste of fish flesh. This taste is likely a consequence of the growth of blue-green algae or actinomycete fungi(Lovell and Sackey, 1973). The predominant fish species (rainbow trout) were stocked after indigenous lake fish populations were poisoned to provide for monoculture stocking.

6. WATER BALANCE

A very important factor in determining water quality is the supply of water to the lake and, in the case of Dutch Lake, the quantification of water entering the lake (bulk water residence time) is critical. Since no data on inflow or outflow volumes exist, the water residence time (more properly, theoretical filling time) must be estimated. The estimate below is based on watershed size, estimated annual runoff and lake evaporation. The watershed area, based on topographic maps is about 3.9 km^2. The rainfall for the area averages 427 mm/yr (Vavenby station). Water yield for the Quesnel area where the rainfall is higher (514 mm), is 1.58 dam^3/ha (McKean, in prep.). Based on proportion of rainfall, the water yield for the Dutch Lake watershed should be about 1.2 dam^3/ha assuming an adjustment for the elevation (400-700 m). The amount of water reaching the lake would be 468 dam^3/yr.

The gross lake evaporation would be approximately 700 mm or a loss of 458 dam^3/year. Net evaporation (700-427 mm) would amount to 273 mm/year. The bulk water residence (filling time), based on these data would be 9424 (lake volume in dam^3) divided by 468 (mean annual water yield in dam^3) or 20.14 years.

A filling time of 20 years is, in relative terms, very long and makes the lake very susceptible to nutrient inputs since virtually no nutrient material is removed from the lake basin. Long filling time (poor "flushing") and more or less constant nutrient supply appear to be the major factors governing the water quality of the lake. Filling time appears to be an accurate term since little water leaves the basin other than by evaporation.

There are two water licences on the lake but these are for 1 acre foot (1.2 dam^3) and 2 acre feet (2.4 dam^3) respectively and are a very minor component of the water balance.

7. LIMNOLOGY AND WATER QUALITY

The record for information collected is not sufficiently frequent to describe the lake on a fine scale. The four sampling trips which were made in this study are described separately and overall interpretation follows.

The only historical data available were collected by Northcote and Larkin (1956). They gave some morphometric data (mean depth of 15 metres, maximum depth of 41 metres, surface area of 63.5 ha), and indicated that littoral areas comprise 50% of the lake surface area. They reported a total dissolved solids value of 155 mg/L, a moderate plankton standing crop, low quantity of benthic animals and no fish caught at the time of netting.

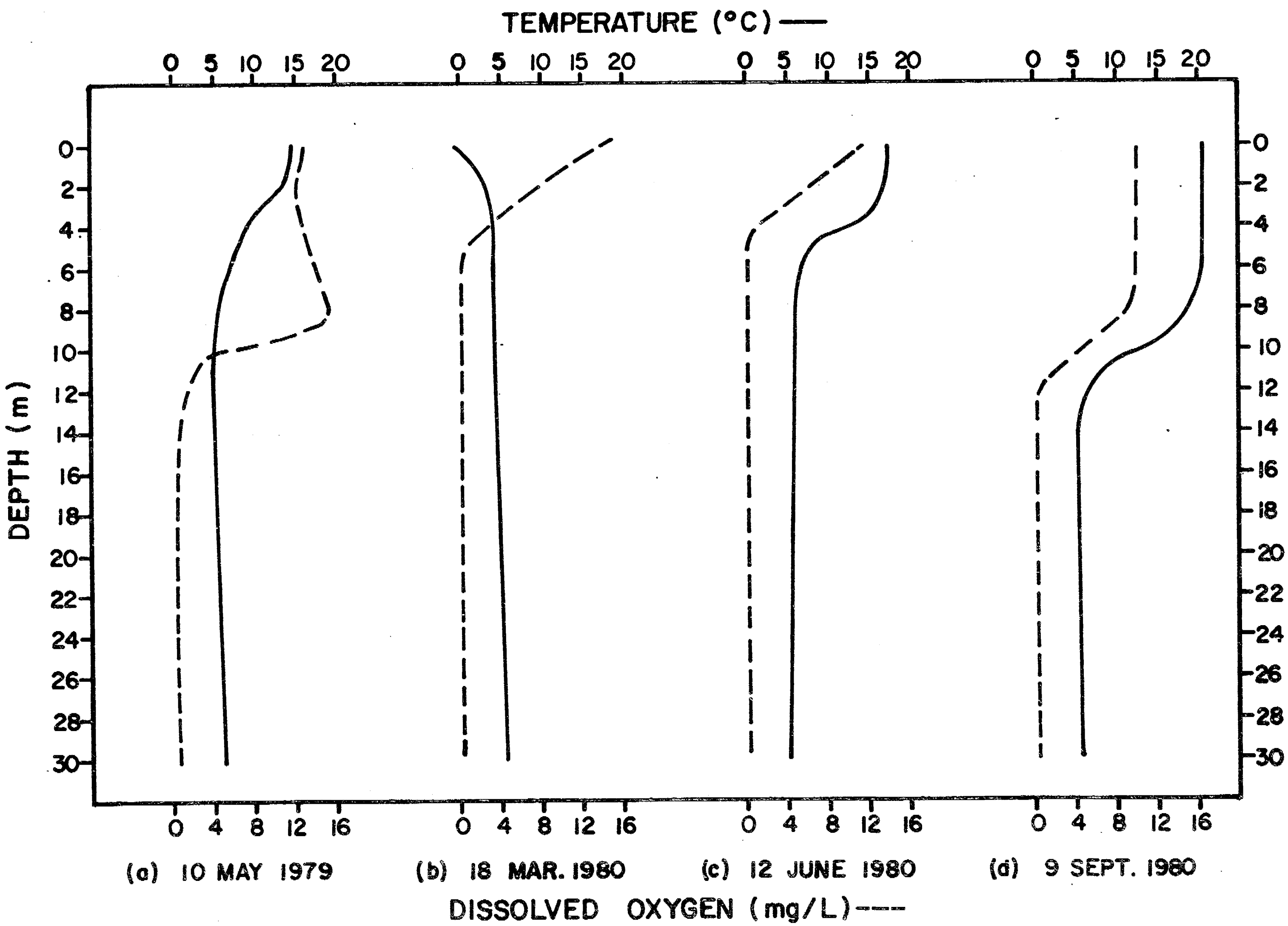
The first recent water quality sampling was carried out by the Waste Management Branch on May 10,1979. The results, from samples collected, a few weeks after ice went off the lake, showed that the lake was strongly stratified with a surface temperature of 15°C and an epilimnion about 5 m thick. The hypolimnion, from 9 metres to the bottom was virtually devoid of oxygen (Figure 3(a)). The lack of oxygen in the hypolimnion was very unusual and unexpected. The lake apparently did not undergo any vertical mixing after the ice left the lake. Mixing requires that the water column be nearly the same temperature and that the wind blow across the lake surface to mix the lake. It would appear that the lake surface warmed and stratified before the wind mixed the lake or that no winds of sufficient velocity occurred. The lake is sheltered by surrounding hills so wind mixing may be impeded.

The nutrient concentrations were also very high at this time, with total phosphorus being 37 ug/L at the surface and 24 ug/L at 20 metres depth. Dissolved total phosphorus was 9 ug/L at both depths. Total nitrogen was 2 mg/L at the surface and 1 mg/L at 20 m. Nitrate was 40 ug/L at the surface and 20 ug/L at 20 m. Both phosphorus and nitrogen concentrations would be considered very high.

As a consequence of the high nutrient concentrations, the concentration of chlorophyll a (a measure of algal growth in the water) was very high at 36 ug/L.

On 18 March 1980, the next sample date, approximately 40 cm of ice covered the lake. A heavy growth of algae (the blue-green *Aphanizomenon*) was present in the top one to two metres of the water. Samples taken indicated 135 ug/L chlorophyll a, which can only be described as extremely high. The temperature (Figure 3(b)) was zero at the ice-water interface and increased to 3°C at 5 metres and to 5°C at 40 metres. Although temperatures above 4°C would not be expected to occur, an increasing salinity gradient existed which may have allowed such a temperature structure to exist. The specific conductance at the surface was 189 umhos/cm increasing to 206 at 10 metres and increasing greatly beyond 25 m to 289 umhos/cm. This salinity gradient may affect the physical stability of the lake in that vertical mixing at spring overturn would be more difficult if a density difference in

FIGURE 3
DUTCH LAKE DISSOLVED OXYGEN AND TEMPERATURE PROFILES



the water column existed. In combination with the sheltered nature of the lake, this may explain the lack of mixing noted above.

In the water column, oxygen was supersaturated at the surface (14.9 mg/L) but decreased to 7.8 mg/L at 2 metres and to 3.7 mg/L at 5 metres. Oxygen concentrations below 15 metres were less than 1 mg/L.

Water chemistry during this sample period was also notable. The pH was very high (8.7) at the surface (likely a consequence of the algal growth). Nutrients were very high, particularly ammonia which increased from 44 ug/L (0 metres) to 367 ug/L (10 m) to an extraordinary 9050 ug/L at 40 metres. The latter implies that the bottom waters had not mixed for a considerable time or that active biochemical processes were present in the hypolimnion. High concentrations of ammonia such as these, if mixed into surface waters at overturn could be toxic to fish populations. High concentrations were noted on the summer sampling trip as well (see below). Organic nitrogen ranged from 0.5 to 2.0 mg/L during this time. Phosphorus was extremely high with total ranging from 41 ug/L at 10 m to 219 ug/L at the surface (largely algal cells) and 1.3 mg/L (1300 ug/L) at 40 metres. Total dissolved phosphorus was 7-16 ug/L indicating phosphorus was largely particulate. The sample from 40 metres depth contained very high concentrations of silica (15.5 ug/L), total iron (25.7 ug/L) and alkalinity (151 ug/L).

On <u>June 11, 1980</u>, the lake was sampled and water quality in relative terms was good. It appeared that at least partial overturn had occurred in the previous six to eight weeks. The surface temperature was 19°C and the epilimnion was fairly shallow extending down to only 3 metres. A wide thermocline between 3 and 8 metres existed and the hypolimnion (less than 5°C) was from 9 metres to the bottom (Figure 3c). The lake was anaerobic below 10 metres indicating either incomplete mixing or a very high oxygen demand. It is unclear if the salinity gradient was intact since samples were only taken down to 15 metres.

Algal growth was very low (chlorophyll *a* was below the detection limit of 0.5 ug/L), the water clarity was high (8.9 metre Secchi disc depth) and nutrients relatively low (9-21 ug/L total phosphorus, ortho-phosphorus less than 3 ug/L).

Sampling on September 10, 1980, gave results similar to June in several ways. The lake stratification was similar to June except a much larger epilimnion existed. The hypolimnion was still anaerobic from 10 metres to the bottom. Nutrients were low (8-10 ug/L total P) in the epilimnion but increased through the hypolimnion (to 920 ug/L total P at 30 metres). The water clarity was high and algal growth very low in surface water (6-10 ug/L chlorophyll *a* between 0-10 metres). Algal growth reached a peak at 15 metres with a concentration of 10.2 ug/L chlorophyll *a*. The Secchi disc reading was greater than 7 metres.

In summary, the data collected indicate that water quality conditions vary a great deal depending on the season. Based on the limited sampling done, some periods of the year show very high nutrients and algal growth, while others exhibit low nutrients and algal growth and good water clarity. The lake may be partially meromictic and circulate infrequently. A large amount of nutrients is present at all times of the year in the hypolimnion and may become available under certain mixing conditions. Algal growth may occur largely in the epilimnion and upper thermocline in late summer and fall. Large amounts of algal growth might be expected in surface waters in spring when ice cover melts and late autumn when some hypolimnetic water is circulated into surface waters. A summary of water quality data is shown in Table 2.

8. OPTIONS FOR WATER QUALITY IMPROVEMENT

The concerns with water quality apparently centre around algal growth and oxygen depletion. The algal growth is episodic but causes the hypolimnetic oxygen depletion when dead algal cells sink and decompose. The growth also is the basis for complaints regarding recreation and aesthetics. The factors which govern algal growth are nutrient supply and hydraulic residence time; a number of options are available to modify these two factors.

Table 2

Summary of Water Quality - Dutch Lake

Parameter	Mean	Epilimnetic Range	Hypolimnetic Range
Color (true color units)	11.4 (n=7)	<5 - 5	<5 - 50
pH	8.1 (n=12)	7.8 - 8.5	7.2 - 7.8
Res 105 C (total solids)	128 (n=10)	108 - 128	124 - 208
Res 550 C (volatile solids)	81 (n=10)	56 - 80	76 - 156
Res NF 105 (suspended solids)	9.8 (n=10)	1 - 17	3 - 58
Res NF 550 (vol.susp. solids)	6.2 (n=10)	<1 - 2	<1 - 44
Specific conductance (umhos/cm)	204.3 (n=12)	179 - 206	205 - 289
Turbidity (NTU)	2.74 (n=9)	0.6 - 11	1.1 - 7.3
Total alkalinity	109.2 (n=10)	95.9 - 110	110 - 151
Organic carbon	8.4 (n=11)	5 - 14	5 - 15
Ammonia	1.6 (n=13)	0.037 - 0.367	0.17 - 9.05
Nitrate/nitrite	0.023 (n=15)	<0.02 - 0.05	<0.02 - 0.02
Kjeldahl nitrogen	2.13 (n=10)	0.45 - 2.0	0.66 - 10
Chemical oxygen demand	18.4 (n=10)	15.7 - 35.9	<10 - 19.9
Ortho-phosphorus	0.003 (n=13)	<0.003 - 0.006	<0.003 - <0.003
Total - phosphorus	0.195 (n=15)	0.008 - 0.219	0.021 - 1.3
Silica	3.0 (n=10)	0.5 - 2.3	2.3 - 15.5
Chlorophyll <u>a</u>	0.016 (n=9)	<0.0005 - 0.135	0.0102
Calcium (dissolved)	22.6 (n=12)	19.0 - 23.5	23.6 - 25.7
Magnesium (dissolved)	8.0 (n=12)	7.4 - 8.8	8.0 - 8.5

All values in mg/L, unless noted

< indicates "less than"

A variety of methods have been used to improve lake water quality. These include: dredging; nutrient inactivation (by aluminum or iron compounds); aeration; lake bottom sealing; drawdown - sediment aeration and drying; biotic harvesting; dilution/flushing; sewage diversion; sewage treatment; and improved land use practices. Some of these are clearly impractical for this situation. The most suitable would be aeration - to control internal (in-lake) generation of nutrients, dilution and sewage diversion.

Aeration can be considered, although there are a number of limitations. There are two basic aeration processes: destratification which circulates the entire lake using rising air bubbles by a compressor via perforated pipes; and hypolimnetic aeration which introduces oxygen into the hypolimnion without destroying the lake stratification. Destratification aeration would be very dangerous to use as it would initially circulate high concentrations of ammonia and oxygen consuming organic material which could cause a major fish kill. Destratification aeration would also change the heat budget of the lake and could eliminate favourable water temperature for fish. Hypolimnetic aeration is possible but would be very expensive - probably in the order of $100,000 to $200,000 for initial equipment and installation plus operation, making it economically unfeasible. Aeration does not appear to be well suited for this situation.

Dredging would appear to be far too expensive for consideration and nutrient inactivation would likely provide only temporary improvement.

Control of watershed nutrients appears to be essential. A number of methods of minimizing nutrients from sewage are possible. These would include sewage collection and transport outside the watershed or stringent zoning and set back requirements. The former would be extremely expensive, the latter probably the best approach to nutrient control although existing dwellings would not be affected. The amount of development over the past 30 years is most evident from air photos (Figure 4).

Figure 4. Air photos of the Dutch Lake Watershed. Upper taken in 1948. Lower taken 29 August 1979 (BC 79192 #114) See also BC 4335 #39 (1965), BC 5467 #146 (1972) and BC 7778 #66 (1975)

However, both nutrient supply and water residence time (flushing time) are important factors in controlling algal growth and it is the second aspect which presents the best opportunity for water quality improvement. To reduce water residence time, water would have to be diverted into the lake. The Clearwater River is the best source as it provides a large amount of high quality water within a reasonable distance.

It is possible to introduce water into the lake either by pumping it or by gravity flow. Pumping would have a lower initial but high operating cost, gravity flow a higher initial cost but very low operating cost. For delivering large volumes of water, the gravity flow would be the preferred system. Some of the factors involved are considered below.

For pumped supply, a well yielding 500 gallons per minute (a well of this yield was drilled in 1980 near the Clearwater River by the Clearwater Improvement District) would, if pumped continuously, supply 1195 dam^3 per year. This would decrease the water residence time from 20 years to 5.7 years. However the pumping costs would probably be \$15,000 - \$20,000 per year which seem to make this method unfeasible, considering future energy costs.

A more reasonable alternative would be to divert water from the Clearwater River at an elevation which would allow gravity flow into Dutch Lake by way of a pipe, or flume. Year-round inflow would be preferable, both to improve water quality and to maintain lake water levels at a chosen elevation. Diversion of water at selected periods of the year, for instance at high river flows in May or June would be less advantageous for flushing and would require much higher flows over a shorter period in order to give an equivalent annual water exchange rate.

A diversion of 0.028 m^3/sec (1 cubic foot per second) results in an addition of 892 dam^3 to the lake and reduces the water residence time to 6.9 years. Increasing the diverted water to 0.056 m^3/sec (2 cubic feet per second) reduces the water residence time of the lake to 4.2 years or if five cfs is diverted the water residence time is 1.9 years.

To convey a flow of 0.028 m^3/sec. at a velocity of about 0.3 metres per second requires approximately a 20 cm (8 inch) pipe. The length of pipe needed (if a pipe is used) would require detailed documentation of elevations of the lake and of the river, but assuming a length of 1.6 km (1 mile) the system would cost approximately $24,000 for materials but $100,000 for installation. An alternative would be a flume which might be obtained more cheaply (used) and convey a larger volume of water. A flume could not be used in winter because of ice formation, but larger flow during the ice free period could compensate for this. The gravity flow system would not be without some disadvantages. Easements would be required for the area the pipeline or flume would cross, some type of intake structure would be necessary, a water rights application for diverting the water would be required as well as construction of an outflow channel from the lake. All of these items (particularly the intake structure) would require careful cost estimates before proceeding.

Funding of such a project is a difficult aspect to address. There is no established source of government funding for lake restoration or water quality improvements. Mechanisms exist for funding sewage projects (Sewage Facilities Assistance Act) to improve water quality but there are no mechanisms for funding problems such as exist at Dutch Lake, where an alternative to sewage collection and treatment is possible. A source of funds which has been used in a similar project was the Lottery Fund, administered by the Ministry of the Provincial Secretary and Government Services. Organziation of a rehabilitation project might be expedited by forming an Improvement District under the Municipal Act.

Increasing water exchange rates in lakes has proved to be a successful approach in a number of other cases. In British Columbia, diversion of Shinish Creek water into Chain Lake was attempted but the volume of water did not appear to be sufficient to be effective and the inflow was poorly located (Northcote, 1967; Ennis, 1972). In Saskatchewan, good quality water was diverted from Diefenbaker Reservoir to Buffalo Pound Lake and caused substantial improvement to the lake (Hammer, 1972).

In Switzerland, two attempts were made to improve the Rotsee (Minter, 1948) and Lake of Inkwill (Dunst et al., 1974) however the problem of insufficient volume of inflow resulted in little improvement in water quality. In the U.S.A. projects have been carried out on Lake of the Four Seasons, Indiana (Dustman in Dunst et al., 1974) using algicides, alum treatment as well as flushing and excellent results were forthcoming. Another project on which a variety of techniques were used was Snake Lake, Wisconsin. In this case hypolimnetic pumping, alum treatment and flushing were used and a significant improvement obtained (Born et al., 1973). The best documented projects and among the most successful are at Green Lake and Moses Lake in Washington. Green Lake was dredged before city water was added to the lake. Improvement has been excellent (Oglesby, 1968, 1969; Oglesby and Edmondson, 1966; Shepherd, 1968; Sylvester and Anderson, 1960, 1964). Moses Lake has benefited from dilution of the lake by Columbia River water (Welch and Patmont, 1978; Welch, 1979). Moses Lake dilution was increased to 11% of lake volume per day from 1% per day and the increased dilution caused an improvement (combined chlorophyll a and Secchi depth) of 51%. In both these latter cases, the lakes are very highly flushed in comparison to Dutch Lake, however the important factors are the inflow water phosphorus concentration in comparison to lake concentration and the change in water exchange rate. The mean Clearwater River total phosphorus concentration is 7 ug/L in comparison to the epilimnetic lake concentration (40 ug/L, hypolimnetic up to 1300 ug/L), and the water exchange rate would be substantially improved if at least one cfs were diverted. Effects of this diversion on the river would be negligible. The mean annual flow of the Clearwater River is 8010 cubic feet per second (224.3 m^3/sec) and even low flow (27 m^3/sec) is such that the diversion would have a negligible effect on the river. The return flow to the Clearwater River from Dutch Lake would have higher nutrients than the river but because of the available dilution, the effect would generally be unmeasurable.

9. DISCUSSION

It appears imperative that to improve the water quality of Dutch Lake, nutrient dilution by increased flushing and minimization of nutrient input, particularly from housing in the watershed, be considered. Nutrient input from septic tank - tile field disposal systems has not been quantified, but it appears to be the most likely major source of man-generated nutrients in the watershed and the only one which can be controlled. Control can take a number of forms: zoning prerogatives (restricted further development, increased setbacks, or decreased density), modified disposal (holding tanks, enforced maintenance, i.e. pumpouts of tanks), different systems (vacuum, composting) and partial or complete collection (sewers) although the latter is unquestionably expensive. Before any plans for dealing with the problem of septic tank disposal are made, a detailed examination of the soils should be carried out to determine their suitability for receiving septic tank effluent and to calculate the amount of nutrients transferred to the lake.

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Government of Canada
Gouvernement du Canada

Fisheries and Oceans
Pêches et Océans

Fisheries - Pacific Region
1090 West Pender Street
Vancouver, B.C.
V6E 2P1

Pêches - Région du Pacific
1090 rue West Pender
Vancouver (C.-B.)
V6E 2P1

Your file Votre référence

Our file Notre référence 5903-85-C261

March 9, 1983.

P.M. Brady, Director
Water Management Branch,
Ministry of the Environment,
Province of British Columbia,
Parliament Buildings,
Victoria, B.C.,
V8V 1X5.

ATTENTION: D. Crossman, D. Fuller

Dear Sirs:

RE: DUTCH LAKE HYDROLOGY, CLEARWATER, B.C.

The information provided by your Department has proved to be of great value in our early feasibility studies for the proposed Clearwater Pilot Fish Hatchery. In particular, the report by Mr. R. Nordin entitled "Dutch Lake Water Quality and Options for Improvement" has enabled us to better evaluate the groundwater - surface water relationships in this area.

We note in Mr. Nordin's report that further information on the area is required to better define the particular flushing characteristics of Dutch Lake. Please find enclosed a copy of a report "First Stage Groundwater Evaluation for Water Supply", by our consultants, Piteau & Associates which defines the groundwater regimes in the immediate vicinity. I believe you will find that the data contained in this report will help to answer some of your information needs with respect to the lake.

Yours truly,

A.F. Lill, P. Eng.,
Chief Engineer,
Salmonid Enhancement Program.

Encl.

PITEAU & ASSOCIATES
GEOTECHNICAL CONSULTANTS

KAPILANO 100, SUITE 408
WEST VANCOUVER, B.C.
CANADA V7T 1A2
TELEPHONE (604) 926-8551
TELEX 04-352578

DOUGLAS R. PITE
FREDERIC B. CLA
DENNIS C. MARTI
R. ALLAN DAKIN
ALAN F. STEWART

DEPARTMENT OF FISHERIES AND OCEANS

PACIFIC REGION, VANCOUVER, B.C.

PROPOSED CLEARWATER RIVER SALMON HATCHERY

CLEARWATER, B.C.

1 STAGE GROUNDWATER EVALUATION FOR

WATER SUPPLY

FEBRUARY, 1983

82-498

On file in Groundwater