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The Limnology-Fisheries of the Okanagan Headwater Lakes

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OKANAGAN STUDY COMMITTEE

CANADA - BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT

TASK 66B

The Limnology - Fisheries of the Okanagan Headwater Lakes

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NOTICE

This report was prepared for the Okanagan Study Committee under the terms of the Canada-British Columbia Okanagan Basin Agreement. The information contained in this report is preliminary and subject to revision. The Study Committee does not necessarily concur with opinions expressed in the report.

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1. ABSTRACT

Limnological parameters and fishery characteristics of 11 of the Okanagan headwater lakes were examined in an attempt to deduce and document a) basic factors and relationships in biological productivity, b) impacts of man-made habitat alterations, and c) ultimate potentials for fish production. Intrinsic factors relating particularly to altitude and morphometry were found to set the basis for productivity. The greater precipitation associated with the higher altitudes makes for more dilute waters, while the concurrent lower temperatures and shorter growing season further hinder opportunities for biological activity. Shallower lakes with greater littoral development tend to be more productive. Within this basic framework of controlling factors, extremes of water inflow (either high or low) and of water level manipulation operate to reduce productive potentials.

Impoundment and manipulation activities are most directly detrimental to the bottom fauna, and particularly to those organisms which are most favored dietary items for rainbow -trout. Certain organisms are enhanced by manipulation, and these may support good trout production in the period of accelerated productivity immediately following impoundment. Attractive and useful rainbow trout populations can clearly be maintained in reservoirs subjected to annual drawdown affecting as much as 33% of the area and 50% of the volume, provided that drawdown depths remain sufficient to prevent winter-kill.

Stocking of fish has played, and must continue to play, a major and expanding role in the perpetuation of these fisheries. Many of the lakes are without natural reproductive opportunities and in any event could not sustain even present exploitation pressures without artificial enhancement of stocks. Indications are that intensive management on the basis of fry and yearling introductions can produce sport-fish yields of about 15 lb/acre at the higher elevations, and up to twice that amount below ± 4000 feet, provided that manipulation of water levels is not extreme and coarse fish are not present. On the basis of fishing habits prevailing in 1971, the yields cited correspond to 1:3 and 45 angling-days respectively of angling participation per surface acre.

2. SUMMARY

1) Some 130 Okanagan headwater lakes contribute to current sport fishing opportunities in the Valley. Factors influencing the biological productivity and fisheries of these waters were examined on the basis of 11 "key" lakes selected for their broad range of physiographic, physical, chemical, and hydrologic characteristics.

2) Elevation is a predominant factor in the limnology-fisheries of the headwater lakes. Eighty-three of them (64%) lie between 4000 and 5500 feet.

3) Seventy-nine of these headwater lakes, including eight of the "key" members, have been developed as active reservoirs primarily for irrigation storage. The operating schedule dictates that lowest water levels occur during autumn-winter. The extent of annual drawdown differs with reservoir characteristics and water demand. It may approach or equal 100% in some cases.

4) All but nine of the 129 lakes are less than 200 acres. The combined surface area is 10,400 acres, of which a large component is shallow, littoral habitat.

5) The eleven lakes specifically investigated undergo characteristic summer temperature stratification. This lasts longest in the deepest lakes, particularly at the lower altitudes. All but one of the lakes had severe bottom oxygen depletion.

6) Turbidity and discoloration are increased by manipulation of water levels, more so if impoundment activities have been recent.

7) Total dissolved solids content in 10 of the lakes ranged from 48 to 122 ppm. The over-riding determining factor for solute content is precipitation, which in turn is primarily controlled by altitude. Agur Lake, which has no surface outflow, has TDS of 232 ppm. The chemistry of Agur Lake is unique in many respects, and it is the most transparent, least discolored of the 11 lakes.

8) Elevated phosphorus levels occur in conjunction with recent impoundment (Lambly Lake). They also coincide with the most severe instances of bottom oxygen depletion.

9) Phytoplankton abundance and composition reflect the trophic status of the lake. Chrysophyceans are absent or scarce in only the richest lakes. The negative influence of altitude is apparent in phytoplankton production as indicated by chlorophyll concentrations. Manipulation of lake levels (drawdown) seems to enhance phytoplankton production but this is not carried through to higher trophic levels except among the newest reservoirs (Lambly Lake).

10) The lowest population of bottom fauna was found in Hydraulic Lake, which is the most severely manipulated. Bottom fauna

biomass production does not appear to be seriously jeopardized until annual water fluctuations exceed 50% in terms of volume, or 33% in terms of area. However, serious changes in bottom fauna composition are wrought by lesser degrees of manipulation. Oligochaetes and chironomids are enhanced by reservoir development and operation, whereas amphipods, molluscs, and insects other than Diptera are curtailed.

11) At least 126 of the 129 Okanagan headwater lakes have rainbow trout populations deriving from earlier, often continuing introductions. Brook trout, yellow perch, and bass occur in a few headwater lakes, but rainbow are the main angling species.

12) The highest gillnet catches of trout were made in Lambly Lake, the lowest in Hydraulic and Headwaters. Lightly exploited lakes with natural reproduction (Fish Hawk, Alex) also yielded relatively large catches.

13) Growth of trout is generally much slower than in, for example, Okanagan Lake. Growth is inversely related to altitude, presence of competitor species, reservoir manipulation, and opportunities for natural reproduction.

14) Trout appear in relatively emaciated condition in heavily manipulated lakes, and in lakes where competition for food, either among themselves or with other species, is particularly heavy.

15) Trout produce relatively more eggs in lakes such as Lambly, Jackpine, Oyama. These lakes have especially favorable feeding opportunities.

16) Amphipods are typically eaten in proportions exceeding their abundance in the fauna, indicating that trout actively select them. Amphipods are among the organisms most sensitive to reservoir manipulation. Invertebrate organisms which react positively to impoundment and manipulation are not efficiently utilized for food except in new reservoirs. Reservoir operation tends to interfere with utilization of Zooplankton because of induced turbidity. Trout in heavily manipulated lakes feed extensively on surface foods in summer.

17) Observed levels of mercury, copper, lead, and zinc; and of DDT and its derivatives, are well below tolerance standards among rainbow trout in the seven lakes sampled. DDT derivatives are more concentrated in lakes in the northeast area of the basin.

18) The eleven lakes were ranked according to various physical, chemical and biological characteristics. "Scores" of physical-chemical, bio-productivity, and trout population indices were derived from these rankings. The primary basis of productivity is clearly set by factors relating to altitude (temperature, ion concentrations, growing season), and morphometry (extent of littoral area, shoreline, etc.). Comparison of the various scores

indicates that extreme water inflow (both high and low), and extreme reservoir manipulation, are the main factors contributing to "non-conformity" in the altitude-morphometry: productivity relationship. In addition, trout populations are seen to be highly susceptible to competition from coarse fish species.

19) Although absolute tolerance limits are not readily identifiable or meaningful, it is clear that attractive and useful rainbow trout populations can be maintained in reservoirs subjected to annual drawdown affecting as much as 33% of the area and 50% of the volume. An important qualifier is that sufficient depth be maintained over winter to ensure an adequate oxygen reserve. Lakes and reservoirs with maximum depths less than 25 feet tend to winter-kill if located below ± 4000 feet elevation.

20) Most of the headwater lakes lack adequate spawning opportunities for the natural maintenance of attractive rainbow trout populations. An active stocking program is accordingly conducted and plays a key role in perpetuating the Okanagan headwater fisheries.

21) Heavy stocking in conjunction with heavy exploitation currently produces annual sport-fish (rainbow trout) yields up to 14 lb per acre from the more nutrient-deprived lakes characteristic of the higher altitudes, and up to 37 lb per acre from the richer lakes below ± 4000 feet. These 1971 peak rates of

harvest resulted from, and accordingly provided, 13 and 45 angling-days respectively of fishing participation per acre in the two lakes where they occurred (Swalwell and Pinaus).

3. INTRODUCTION

3.1 Purpose and rationale.

This investigation of the limnology of selected headwater lakes in the Okanagan Basin was undertaken as part of the Canada-British Columbia Okanagan Basin Agreement. Impetus for the investigation was a growing awareness of the role of tributary systems in water management in the Okanagan, and also the realization that these systems support considerable water-based recreation. Some 129 Okanagan headwater lakes have been identified as currently contributing to sport fishing opportunities; of these at least 79 are subject to artificial hydrologic manipulation.

"Limnology", for the purposes of this investigation, was considered in the broadest terms to include the direct fishery implications. Fisheries, in fact, delimited the scope of the study in that only headwater lakes (and/or reservoirs) with known fish populations and proven long-term fishery capability were dealt with. Small ponds with intermittent fishery potential were not considered. Also specifically excluded were the six main lakes of the valley floor, these having been investigated through a series of other tasks. Aspects of stream ecology have, likewise, been described elsewhere.

Fragmentary limnological observations have been compiled for some of the Okanagan headwater lakes as a result of a continuing program of sport fish management by the British Columbia Fish and Wildlife Branch. Certain relevant hydrologic and morphometric data have also been generated by the B.C. Water Resources Service. However, no general assessment of the limnology of these particular lakes was available, nor had there been any integrated consideration of their potential to produce fish. The present study undertook, in part, to establish such a framework. The express purpose was to define the range of limnological parameters operating in these lakes and to formulate an understanding of how these factors function and interact to delimit fish production opportunities. This information is required as a baseline for Task 18, purpose of which is to evaluate fishery potentials and opportunities under selected water management alternatives.

A related and secondary objective, and one which has emerged as being of considerable importance, was simply to gain overall familiarity with the headwater lakes here represented, and with how they are linked to Okanagan water management practices. These practices have direct and important fishery management implications which involve the majority of the lakes.

3.2 Scope and schedule of investigation.

It was obviously not possible to investigate 129 lakes with the time and resources available. The approach adopted was to select a few key lakes exhibiting a variety of gross characteristics, and to examine as many aspects as possible of their limnology-fisheries. Eleven lakes were incorporated in this itinerary, and discontinuous observations were also made on several others as time permitted. The ultimate objective was to characterize lakes and their associated fishery resources rather than to deduce complex limnological mechanisms. To this effect, seasonal trends in biological and physical-chemical parameters were employed strictly as aids to this characterization.

With the exception of two lakes which were not included in the first series, the eleven key lakes were each visited on three occasions in 1971. The first visit was made between June 9 and 16, the second between July 19 and August 26, and the third between September 25 and October 26. The scheduling was intended to coincide with onset of thermal stratification (first visit), with height of stratification (second visit), and with complete autumn turnover (third visit). These criteria were generally met except that the deepest lakes had not fully circulated by the time of the final visit.

In the following account the eleven lakes are consistently treated in their order of clockwise occurrence, commencing from the southwest, in the Okanagan Basin.

3.3 Conversion of metric units.

Certain data contained in this report are given in metric units. Equivalent English unit values are given simultaneously when convenient. Conversions can be achieved by reference to the following list:

1 meter = 100 centimeters = 3.281 feet
1 square kilometer = 0.386 square miles
1 liter = 1000 cubic centimeters = 0.88 Imp. quart
1 kilogram = 1000 grams = 2.205 pounds
1 kilogram per hectare = 0.892 pounds per acre

4. ACKNOWLEDGMENTS

Numerous agencies and individuals co-operated with, and participated in, this study. Laboratory and office facilities were provided at the main Study Office through the courtesy of Study Director A.M. Thomson. Personnel of the British Columbia Fish and Wildlife Branch provided background data, some items of equipment, and information and advice on local conditions. The Socio-Economics study group provided rental of a vehicle. Various instruments were loaned from the Fisheries Research Board Freshwater Institute, Canada Centre for Inland Waters, and Inland Waters Branch, all of Environment Canada. The latter agency performed all laboratory analyses of chemical constituents, costs of which were assigned to Task 124. Local officials of the B.C. Water Rights Branch provided information on the construction and operation of reservoirs; their maps were the basis of most of the morphometry determinations. Resort operators at the various lakes co-operated fully with the field program.

Messrs. R. Bernhardt and W. Baxter assisted ably with the field work and some of the analyses. Mr. M. Pomeroy identified and enumerated phytoplankton; Mr. D. Findlay conducted the chlorophyll determinations. Analysis of fish tissues for heavy metal and pesticide residues were done by B.C. Dep. of Agriculture; costs were assigned to Task 115. Some supplementary mercury determinations were undertaken by the Heavy Metals Section of the Freshwater Institute in Winnipeg. Personnel of the B.C. Fisheries Research and Technical

Services section assisted with preparation and interpretation of fish scales for ageing.

Dr. J.G. Stockner advised during the conceptual stages of the study and also in the interpretations. Mr. G. McKenzie drafted the figures, while Mrs. R. Morion and Mrs. L. Lowe typed the manuscript.

5. THE GEOGRAPHIC BACKGROUND

The inherent biota and productive capacities of lakes are largely the product of their geological history, the development of soils and vegetation in the watershed, and climate (Rawson 1960). As an aid to understanding the limnology of the headwater lakes, the physiography of the area is briefly summarized below.

Latitude and longitude co-ordinates and drainage connections for the 129 Okanagan headwater lakes are given in Appendix Table A and are shown in general format in Fig. 1, Locations are summarized in Table 1 for the eleven lakes selected for detailed observation under Task 66. Many of the lakes, including eight of the present series, have been developed as storage for irrigation and/or municipal purposes. Most of the lakes lie in sub-basins tributary to Lake Okanagan. Of the present series, Swalwell Lake drains first into Wood Lake via Ellison Lake, while Oyama Lake drains first into Kalamalka. Agur Lake has no surface outflow.

The Okanagan Basin lies in that limnological region designated the Southern Interior Plateau (Northcote and Larkin 1956). This is an area of mostly sedimentary and volcanic rock, extensively glaciated, and with a mantle of lacustrine silts in many places (Schofield 1943; Mathews 1944). Lakes in this zone characteristically have total dissolved solids in excess of 100 parts per million, high standing crops of plankton and bottom fauna, and variable fish quantities (Northcote and Larkin 1956).

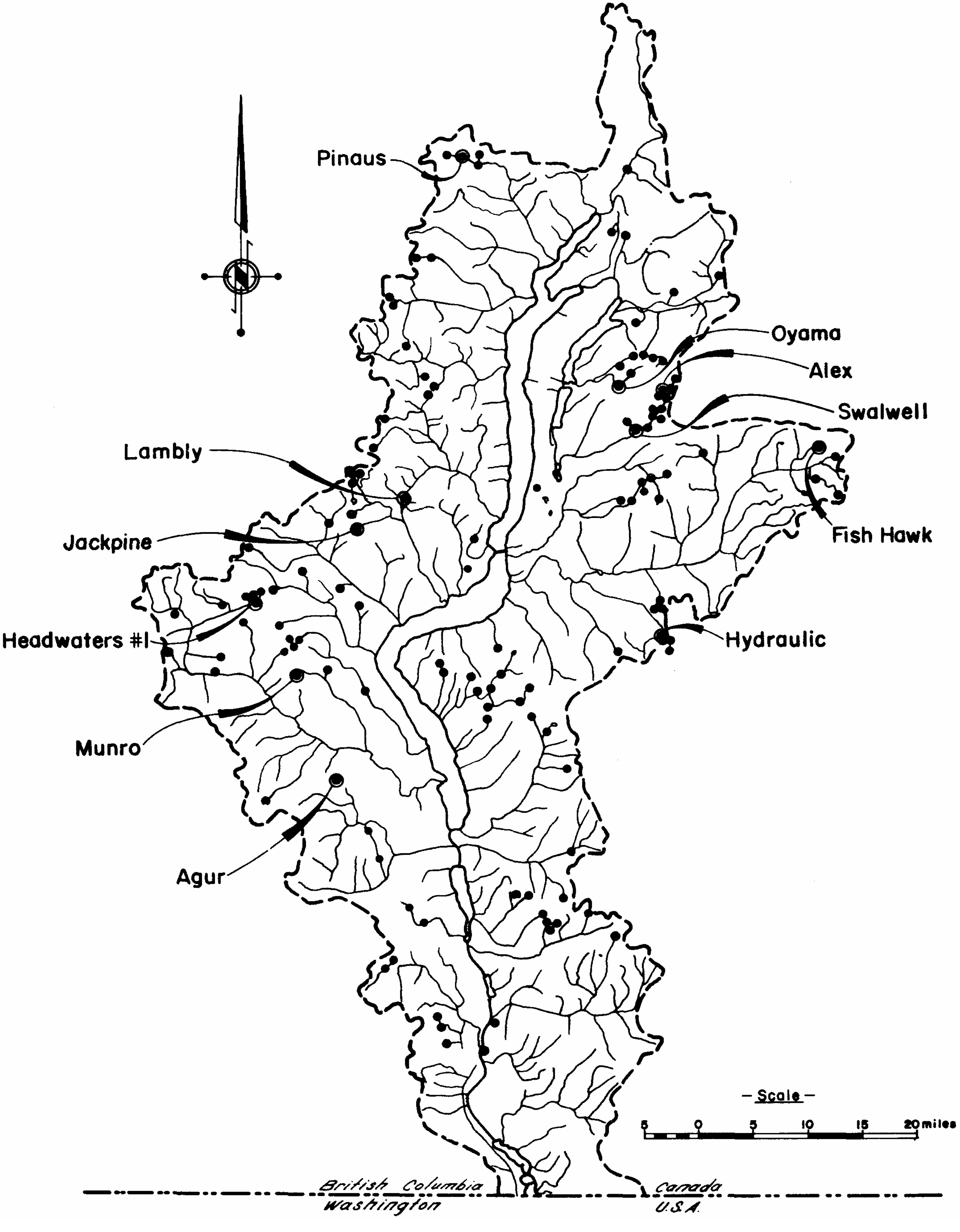

Fig.1 Locations and drainages of 129 headwater lakes containing sport fish populations in the Okanagan Basin. The eleven lakes selected for detailed study in 1971 are indicated separately.

TABLE 1 . Some geographic features of eleven selected headwaters lakes in the Okanagan Basin, 1971.

	Altitude		Location		Drainage Area		Drainage
	Feet	Meters	Latitude	Longitude	Miles^2	Km^2	Course
AGUR	3800	1158	49°35'00"	119°49'50"	0.7	1.81	No drainage
MUNRO	5200	1585	49°42'50"	119°55'10"	1.0	2.59	Trout Creek
HEADWATERS #1	4200	1280	49°48'40"	120°00'20"	10.5	27.20	Trout Creek
JACKPINE	4300	1311	49°54'50"	119°48'10"	2.2	5.70	Powers Creek
LAMBLY	3800	1158	49°57'30"	119°42'30"	11.1	28.75	Lambly Creek[a]
PINAUS	3300	1006	50°25'40"	119°35'50"	16.0	41.44	Equesis Creek
OYAMA	4400	1341	50°06'10"	119°16'10"	9.2	23.83	Oyama Creek
ALEX	4800	1463	50°06'10"	119°12'40"	4.5	11.66	Vernon Creek
SWALWELL	4500	1372	50°03'10"	119°13'50"	24.3	62.94	Vernon Creek
FISH HAWK	6000	1829	50°01'40"	118°51'30"	2.1	5.44	Mission Creek
HYDRAULIC	4000	1219	49°46'10"	119°11'10"	19.3	49.99	Mission Creek

[a] Diverted from natural Lambly Creek drainage to Powers Creek

The Okanagan Valley itself is rimmed by two mountain ranges which reach altitudes in excess of those generally encountered in the Interior Plateau. These constitute the East and West Okanagan Highlands of Brink and Farstad (1949), and are designated limnologically as the Southern Interior Highland by Northcote and Larkin (1956). Precipitation here is higher, summers are cooler, and winters are longer and more severe than on the adjacent plateau and in the valleys. Lakes in this limnological region tend to have lower TDS, brown-stained water, and low values of plankton, bottom fauna, and fish (Northcote and Larkin 1956).

The vast majority of the Okanagan headwater lakes, including all 11 selected for detailed study, lie in the Southern Interior Highlands region by virtue of being above 3000 feet elevation. However, three of these lakes, lying between 3000 and 4000 feet, show characteristics intermediate between those suggested by Northcote and Larkin as distinguishing lakes on the plateau per se from those of the highland region. It is thus apparent that a limnological gradient in fact separates these two regions; and it would appear that altitude, or some function of altitude, is the primary determining factor.

Altitude among the Okanagan headwater lakes has profound effects on temperature, length of growing season, and precipitation. Isohyets of annual precipitation have been drawn for the entire Basin under Task 53, incorporating a grid-square technique on the basis of altitude and latitude (W. Obedkoff, pers. comm.). Annual precipitation at each of the 11 key lakes was interpolated from this plot and shows more than a 2-fold variation. The values are as follows:

Agur	19 inches
Munro	25 "
Headwaters No. 1	24 "
Jackpine	22 "
Lambly	22 "
Pinaus	24 "
Oyama	27 "
Alex	30 "
Swalwell	28 "
Fish Hawk	40 "
Hydraulic	26 "

The positive relation between precipitation and altitude is readily seen by comparing these data with Table 1. An important qualification is that precipitation also increases from south to north, and from west to east in the basin.

The size and nature of a drainage basin act in conjunction with precipitation to determine the available run-off to a lake. This in turn influences the nature and amounts of nutrient materials transported to the lake, and the rate at which materials are flushed out (Patalas 1960; Vollenweider 1968). Drainage basin areas for each of the 11 selected lakes are given in Table 1. As an example of the impact it might be noted again that Agur Lake, with the smallest drainage area and the least precipitation, has no surface outflow.

Of the 11 key lakes specifically studied, all but Alex are accessible by motor vehicle (see Table 2 for access times and distances). Alex Lake requires a 45-minute hike from Dee Lake. None of these lakes lies more than 30 miles from Highway 97, which runs north to south through the valley.

TABLE 2 . Description of access, 11 selected headwater lakes in the Okanagan Basin, 1971.

Lake	Distance (miles) from Hwy. 97 (or other paved road) to lake	Condition of Access	Access time, minutes
AGUR	13	Fair	30
MUNRO	17	Poor	60
HEADWATERS #1	16	Good	45
JACKPINE	26	Fair	75
LAMBLY	18	Good	45
PINAUS	6	Good	30
OYAMA	10	Poor	70
ALEX	±17	Hike	90
SWALWELL	9	Good	40
FISH HAWK	35	Fair	90
HYDRAULIC	30	Good	45

6. SELECTION OF KEY LAKES

A considerable dilemma was posed by the number of variables known to be involved in the fishery potentials of these lakes, and the time and resource constraints avail-able to conduct the investigation. It was necessary to rely completely on the accumulated knowledge and opinions of local personnel of the B.C. Fish and Wildlife Branch, particularly Fishery Biologist S. MacDonald, for the selection of representative lakes exhibiting a range of variables for study of their comparative impacts. Since so many of the lakes are impounded, artificial manipulation played a key role in this selection. Eight of the 11 lakes finally chosen for study are impounded (a similar ratio as in the overall basin). Besides its obvious impact on fish food organisms, impoundment also has other important management implications for fisheries. Among these implications are optimization of stocking rates relative to manipulated habitat dimensions; and depth-survival relations, particularly under ice cover in winter. The annual operating schedule for the Okanagan reservoirs dictates that lowest water levels occur during the critical autumn-winter period.

The variables considered in the selection of key lakes, and the resulting choices are summarized in the matrix of characteristics, Table 3.

TABLE 3. Matrix of variables considered in the selection of key headwater lakes in the Okanagan Basin for study of limnology-fisheries interactions.

Altitude		High	Moderate	Low
		Fish Hawk Munro Alex	5 lakes	Pinaus Agur Lambly
Side of Basin		West	East	
		6 lakes	5 lakes	
Area		Small		Large
		Alex Agur		Swalwell Oyama
Depth		Shallow		Deep
		Agur Fish Hawk		Pinaus
TDS		Low	Moderate	
		Alex	Agur	
Impoundment		Very recent	Mod. recent	Long ago
		Lambly	Headwaters	Jackpine
Manipulation	None	Minor		Extensive
	Alex	Pinaus		Hydraulic Headwaters Jackpine Lambly
Coarse fish		Absent		Present
		Lambly		Headwaters Hydraulic
Stocked		None	Moderate	Heavy
		Alex	Munro	Pinaus
Access, accommodation		Poor		Excellent
		Munro		Pinaus

7. METHODS

Temperature, dissolved oxygen, pH, specific conductance, transparency, and water level data were obtained during all visits to the 11 lakes. The second and third trips provided information on nutrients and dissolved ions, plankton, bottom fauna, and fish. Each visit was of 1 to 3 days' duration.

Bathymetric maps were already available for eight of the lakes. The remaining three (Agur, Alex, and Fish Hawk) were sounded by handline. Some supplementary handline soundings were also done on Headwaters Lake No. 1. Soundings were timed along charted transects and were plotted on maps enlarged from topographic series or aerial mosaics. Depth contours were plotted at 2-meter intervals. Depth zone areas were determined by planimeter, and volumes were calculated according to formula (3) of Hutchinson (1957) Chapter 2. For reservoirs of known dimensions, areas and volumes were extracted from capacity curves formulated by the British Columbia Water Resources Service. Units were converted to the metric system throughout.

Water transparency was measured with a 20-cm Secchi disc painted with alternating black and white quadrants. Temperature and dissolved oxygen were measured in vertical profile with a YS1 Model 54 meter. pH was determined with a Hach color comparimeter, and specific conductance was measured in the field with a Beckman RA2A conductivity meter. Water samples for nutrient and ion analyses were packed with ice and shipped in coolers to the West Water Quality Subdivision, Department of the Environment, Calgary. Analyses were usually conducted within 24 hr of sampling.

Integrated vertical water samples for phytoplankton qualitative examination and chlorophyll determination were taken with a flexible plastic tube (Lund and Tailing 1957). Samples were obtained through the upper 7 m during the midsummer series, and through twice the depth of the Secchi disc visibility in autumn. Both series represented approximations of the euphotic zone, the latter probably being more definitive in this regard (Michalski 1971). Non-integrated vertical samples for chlorophyll determination were also obtained at midsummer; these samples were taken with a 2-litre Van Dorn bottle at surface, 1.5, 3, 5, and 7 m, and at deeper levels in the deepest lakes. Chlorophyll was determined by filtering 500 ml of sample through a Whatman GF/C filter, extracting in 90% acetone with the aid of a tissue grinder, and reading on a fluorometer (Schindler et al. 1971). The fluorometer was standardized with acetone extracts of phytoplankton in which pigments had been determined spectrophotometrically. The results are expressed as chlorophyll _a_, but undoubtedly include some decomposition products. A second 500-ml aliquot from the vertically-integrated samples was treated with Lugol's solution and settled for 24 hr, whereupon the plankton was pipetted off the bottom for analysis of species composition and abundance.

In addition to the above, total vertical net plankton hauls were taken through the maximum depth, i.e. at the limnology station, in each lake in autumn. The net used was the Wisconsin type with a mouth diameter of 24 cm, and fitted with No. 20 Nitex cloth.

Bottom fauna was sampled with a 6-inch Ekman dredge. Samples were taken at 1.5, 3.0, 5.0, 7.0, 10.0, 15.0, 20.0, etc., meters during the summer series, and at equivalent depths (compensating for intervening reductions of lake levels) in autumn. The samples were washed initially on a 20 mesh/cm screen, and organisms were picked from a 10% aliquot of this residue estimated on a grid pan. The remaining 90% of residue was washed through a 7 mesh/cm screen before picking. The procedure allowed for estimation of loss of organisms through the coarse screen; this was never consistently significant and was discounted. Organisms were preserved in 95% ethanol for later enumeration and weighing in the laboratory. Oligochaetes, because of their fragile nature, were counted in the field. Wet weights were determined for each dredge sample, with mollusc shells (considered as 2/3 of wet weight: Atton and Johnson MS 1970) being deducted. The results are given as wet weight per dredging; conversion to kilograms per hectare wet weight can be accomplished by multiplying by 431 (Dredge X 43.1 = gm/m^2 ; gm/m^2 X 10 = kg/ha).

Fish were sampled with gangs of green twined nylon gillnets of the type used by the British Columbia Fish and Wildlife Branch for experimental netting. These gangs comprised

40 feet each of 1, 11/2 2, 21/2, 3 and 31/2-inch mesh connected in random series. The nets were set suspended from the surface; they hung to an average depth of about 10 feet. Two gangs were set simultaneously; one on the 4 m contour and the other at 7 m. The nets caught all but the youngest trout, and possibly missed certain "minnow" species.

8. HISTORY AND OPERATION OF RESERVOIRS

As indicated above, eight of the current series of 11 headwater lakes have been developed as active reservoirs. Agur Lake is not impounded; it has no surface outflow. Alex Lake, with a small beaver dam on its outlet, is not artificially controlled. Fish Hawk Lake, although not controlled at the time of the study, was in the process of being impounded in the summer and fall of 1971.

It was pointed out in the introduction that impoundment and water level manipulation are important factors in the ecology and fishery potential of these reservoirs. Some attention is accordingly given here to characterizing these operations for the eight active reservoirs in the present series. Histories of the reservoirs are outlined below, and recent operations (1965-1971) are summarized in Table 4.

8.1 Munro Lake

The last significant impoundment works on this lake took place in 1931. The earliest work was done in 1920 when a 2-foot dam was built at the south end to divert the natural drainage from O'Hagan Creek. At the same time a short ditch and control dam were constructed to permit diversion to Darke Creek. In 1930-31 the ditch was deepened slightly, creating 6 feet of active storage. The lake normally requires 2 years to fill, and as the headgate has

TABLE 4. Summary of operations of 11 selected headwater lakes in the Okanagan Basin, 1965 - 71.

	Area, acres	Depth fluctuation (ft)		% total area exposed by drawdown		% total volume reduced by drawdown		Last year of major works
		Range	Mean	Range	Mean	Range	Mean	
AGUR	8.6	--	2.0	--	13	--	<18	N/A
MUNRO	34.5	0.0 - 6.0	4.7	0 - 25	20	0 - 17	13	1931
HEADWATERS #1	161	3.0 -14.2	6.6	10 - 27	16	18 - 76	37	1961
JACKPINE	106	3.6 -10.6	7.5	13 - 42	29	28 - 71	53	1953
LAMBLY	182	4.2 -20.2	12.5	23 - 41	31	41 - 63	47	1970
PINAUS	407	--	4.4	--	4	--	6	1951
OYAMA	630	3.2 - 4.9	4.1	7 - 20	15	14 - 25	19	<1950
ALEX	21	--	4.3	--	5	--	3	N/A
SWALWELL	750	4.2 -10.7	7.2	20 - 35	27	14 - 31	27	1944
FISH HAWK	43	--	0	--	0	--	0	N/A
HYDRAULIC	644	6.3 -24.7	12.8	24 - 92	51	48 - 97	74	1950

been leaking for about 20 years it has hampered efficient utilization of the lake for storage. The dam at the south end was improved, but not raised, in 1948 (P. Munro, pers. comm.). The lake was emptied of live storage in 1969 and again in 1971.

8.2 Headwaters Lake No. 1

This lake was first impounded in the early 1920's. Additional work to increase storage was done at least once prior to 1961 when the dam was rebuilt. Storage at that time was increased from about 1300 acre-feet to 2163 acre-feet, involving a 7-foot rise in water level (K. Blagborne, pers. comm.).

8.3 Jackpine Lake

A dam was constructed on the outlet about 1917. This, in conjunction with some ditching at the outlet, created 450 acre-feet of live storage. Storage was considerably increased by various modifications and improvements in the intervening years to 1953-54. At that time, an inclined gate was installed and the culvert partially replaced, but storage capacity was unchanged at about 960 acre-feet. In 1970-71 the dam was rebuilt but the same capacity was retained (C. Small, pers. comm.).

8.4 Lambly Lake

An earthen dam was constructed at the north end of Lambly Lake in 1937 in order to divert water from Lambly Creek into Powers Creek. The dam was raised about 2 feet in 1962, and an additional 2 feet in 1971. A dam was built on the south end of the lake in 1952. In 1969 the storage was drained to permit construction of a new dam and trenching between the two main portions of the lake (map notes; J. Botham, pers. comm.). The resultant 8-foot increase in water level inundated an additional 49 acres and more than tripled the live storage, from 612 to 2,178 acre-feet.

8.5 Pinaus Lake

Pinaus Lake was originally dammed by a wooden structure of unknown vintage. In 1951 this dam was replaced by one of concrete, permitting about 5 feet of drawdown or 2,156 acre-feet of storage (J. Botham, pers. comm.).

8.6 Oyama Lake

Oyama Creek was diverted for irrigation as early as 1892, but the first dam was constructed on Oyama Lake in 1905. This dam was improved in 1951 (and also on one earlier occasion). The dam was reconstructed in 1968 to increase the active storage by some 400 acre-feet to 4,988 acre-feet (map notes; J. Botham, pers. comm.).

8.7 Swalwell Lake

The first rock-filled crib dam on Swalwell (Beaver) Lake was probably constructed in 1907. This structure was replaced in 1944,and 12 more inches of fill were added to the top of the dam in 1964. The present storage is approximately 9,585 acre-feet.

8.8 Hydraulic Lake

This lake was impounded in 1910 by means of three earth-fill dams. In 1950, fill over the North Dam culvert was excavated and replaced. Work was in progress in 1971 to raise the dams and clear trees from the lake shore.

Of the impounded lakes, Hydraulic is subject to the most drastic manipulation (Table 4). The percent of its volume removed by drawdown has averaged 74% since 1965, and bottom exposure has been as high as 92%. Jack-pine and Lambly Lakes have experienced approximately 50% loss of volume annually, on the average, over the same period. Swalwell and Headwaters Lake No. 1 are also seriously affected by drawdown. Pinaus, by virtue of its considerable dimensions and narrow operating range, suffers the least physical impact among the regulated lakes.

9. MORPHOMETRY

Habitat dimensions (i.e. size and depth relations) are of fundamental importance in aquatic situations. They influence the nature and productivity of the biota and are basic parameters in the carrying capacities and harvest potentials for fish.

Depth contours for the 11 lakes are plotted on the outline maps (Fig. 2-12, at back of report). Limnology sampling stations, located at the maximum depth of each lake, are shown on the maps. The basic morphometric data are given in Appendix Table B and are summarized in Table 5.

The eleven lakes range in area from 4 to 303 hectares (9 to 750 acres). With the exception of Ellison Lake (520 acres) and Swan Lake (973 acres), Swalwell is the largest headwater lake in the basin. Ellison, Swan and Tugulnuit are not properly considered as headwater lakes since they lie on the valley floor. However, they are noted here because they were not included in the mainstem sampling program. Except for Pinaus Lake (mean depth 22.0 meters, = 72 feet), the lakes may be described as shallow. Mean depths in the other 10 lakes range from 2.1 m in Fish Hawk to 9.8 in Swalwell.

Maximum depths are also listed (Table 5), but as a limnological indicator are less diagnostic than mean depths (Rawson 1955).

Shore development (relation of shore length to the circumference of a circle equal in area to that of the

TABLE 5 . Summary of morphometric features, at full supply level, of eleven selected headwater lakes in the Okanagan Basin, 1971.

	Water area		Depth, meters		Perimeter with Islands (km)	Shore development		No. of islands
	acres	hectares	max.	mean		with Isl.	without isl.	
AGUR	8.6	3.5	7.0	3.31	1.19	--	1.22	0
MUNRO	34.5	13.9	11.3	4.29	1.50	--	1.14	0
HEADWATERS #1	161	65.2	8.0	4.90	6.10	2.93	2.08	4
JACKPINE	106	42.9	7.5	3.67	3.91	--	1.70	0
LAMBLY	182	73.7	9.5	3.84	6.85	--	2.25	0
PINAUS	407	164.7	57.6	22.03	8.84	--	1.95	0
OYAMA	630	254.9	23.9	6.53	17.95	3.17	2.51	28
ALEX	21	8.5	9.3	4.06	1.56	--	1.52	0
SWALWELL	750	303.5	30.5	9.76	16.68	2.71	2.11	15
FISH HAWK	43	17.4	6.0	2.05	1.93	--	1.34	0
HYDRAULIC	644	260.6	8.5	3.60	22.15	3.90	2.90	15

lake) is quite uniform among the 11 lakes, ranging from 1.14 to 2.90. Values for Headwaters #1, Oyama, Swalwell and Hydraulic Lakes, all of which contain islands, increase substantially when island shorelines are incorporated.

The "flushing" period, or time required for an amount of water equal to the lake volume to pass through its outlet, is a significant limnological parameter. Agur Lake, with no surface outlet, has a high mineral content (TDS = 232), whereas lakes such as Headwaters and Hydraulic, with relatively rapid replacement, have low TDS and low standing crops of organisms.