CANADA BRITISH COLUMBIA – OKANAGAN BASIN AGREEMENT

PRELIMINARY REPORT NO.16

(SUBJECT TO REVISION)

Pacific Salmon
Population and Habitat Requirements

PREPARED FOR THE
OKANAGAN STUDY COMMITTEE

CANADA - BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT

TASK 162

Pacific Salmon:

Population

and

Habitat Requirements

A report
Prepared by the Fisheries Service of the
Department of the Environment, Canada with assistance
from the Washington State Department of Fisheries

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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SUMMARY

An average of 95,000 sockeye salmon enter the Columbia River every year, of which total some 19,000 spawn in the Okanagan River between Osoyoos and Vaseaux Lakes. The range of Okanagan spawning escapement has varied between 2,000 and 45,000 since 1961.

Records show that dam construction on the Columbia River has considerably reduced the number of sockeye entering that river in the early years of the century to the present level of abundance. However, a massive transplantation program carried out between 1939 and 1946 ensured continuance of breeding stocks in the Okanagan River, and consequently the present population size is not expected to decrease.

The fry spend a full twelve months rearing in Osoyoos Lake before migrating to the ocean.

Commercial fisheries located in the Lower Columbia River return some 21,600 sockeye annually, and a further 3,100 are caught by Canadian and U.S. Indians for subsistence and ceremonial purposes. About 70 percent of these catch figures represent sockeye of Okanagan origin, and it is assessed for the purposes of this study that Canada is the direct beneficiary from all sockeye salmon that spawn and rear inside the Canadian boundary.

It is one of the constraints on the Okanagan Study that this sockeye salmon run shall be maintained.

Habitat requirements are determined on a seasonal basis in terms of water quantity and quality; in the Okanagan

River existing quality levels may also be considered in terms of quantity. Considerations of temperature and discharge in respect of upstream migration, spawning gravel areas, possible gravel scour, incubation flows, fry emergence and migration, and rearing, indicate the preferred discharge ranges given below; other discharge ranges may be found in Table 6.

Upstream Migration	Aug 1 - Sept 15	300 – 450 cfs with removal of stoplogs as necessary
Spawning	Sept 16 – Oct 31	350 – 550 cfs
Gravel Scour	Nov 1 – Feb 15	1,000 cfs max
Incubation	Nov 1 – Feb 15	175 – 1,000 cfs
Fry Emergence and Migration	Feb 16 – Apr 30	175 – 1,000 cfs
Rearing (Osoyoos Lake)	12 months	Not sensitive under expected regimes

A comparison between the preferred discharge ranges above and the recorded discharge regimes of the Okanagan and Thompson Rivers indicates that generally no significant difference exists between the two sets of ranges.

The preferred fishery discharges as derived therefore appear to be of a reasonable magnitude.

1. INTRODUCTION

The Okanagan River between Vaseaux Lake and Osoyoos Lake in Canada provides about two-thirds of the sockeye salmon population utilizing the Columbia River System annually, and the spawning habitat required for their perpetuation (Figure 1). Apart from a few chinook salmon which are observed in certain years, the sockeye may be regarded as the only salmon species utilizing the Canadian portion of this river.

An extensive report on the salmon problems associated with the proposed Okanagan Flood Control Project was made in 1954 (1). In 1963, after completion of the project the Canada Department of Fisheries submitted the following flow proposals for the spawning reaches of the Okanagan River downstream of the S.O.L.I.D. (South Okanagan Lands Irrigation District) dam through to Osoyoos Lake (2).

Period	From	To	Discharge cfs
Spawning period	Sept. 10	Oct. 25	500 cfs min.
Incubation period	Oct. 25	Feb. 10	50% reduction 250) cfs min.)
Fry migration period	Feb. 10	May 10	Increase rather than decrease in discharge preferred.

As a result of further site surveys, it was found that continued dyking and river channelling in the Okanagan River had eliminated certain spawning areas, and in 1969 it was determined that the above discharge requirements could be reduced to the following values (3).

Period	From	To	Discharge cfs
Spawning	Sept. 10	Oct. 31	250 cfs. min. 470 cfs. min.

Incubation and Fry Migration	Oct. 31	Apr. 30	170 cfs. min.

Since the Department of the Environment (formerly Department of Fisheries and Forestry) is responsible for all anadromous fish utilizing the river systems of Canada, Task 162 of the Okanagan Basin Study - Pacific Salmon, Population and Habitat - has been undertaken by the Fisheries Service of that Department.

The purpose of the present report is to review the records of sockeye escapements to the Okanagan River in the past and thereby estimate the population which may be supported under present conditions of use and management, to outline the preferred habitat requirements of the estimated population in terms of water quantity and quality, and to estimate the effects on salmon population of water quantity and quality which lie outside the range of preferred values. These estimates and determinations are based on a review and analysis of existing data, supplemented by limited field survey data and theoretical modelling. Continuing discussions between representatives of the United States and Canada concern the Interception by each nation of salmon bound for the river systems of the other nation. On the basis of a possible later agreement between the two nations, the aim of which would be to provide an equitable balance of such interceptions, it is assessed for the purpose of this study that Canada is the direct beneficiary from the Columbia River sockeye salmon that spawn and rear inside the Canadian boundary.

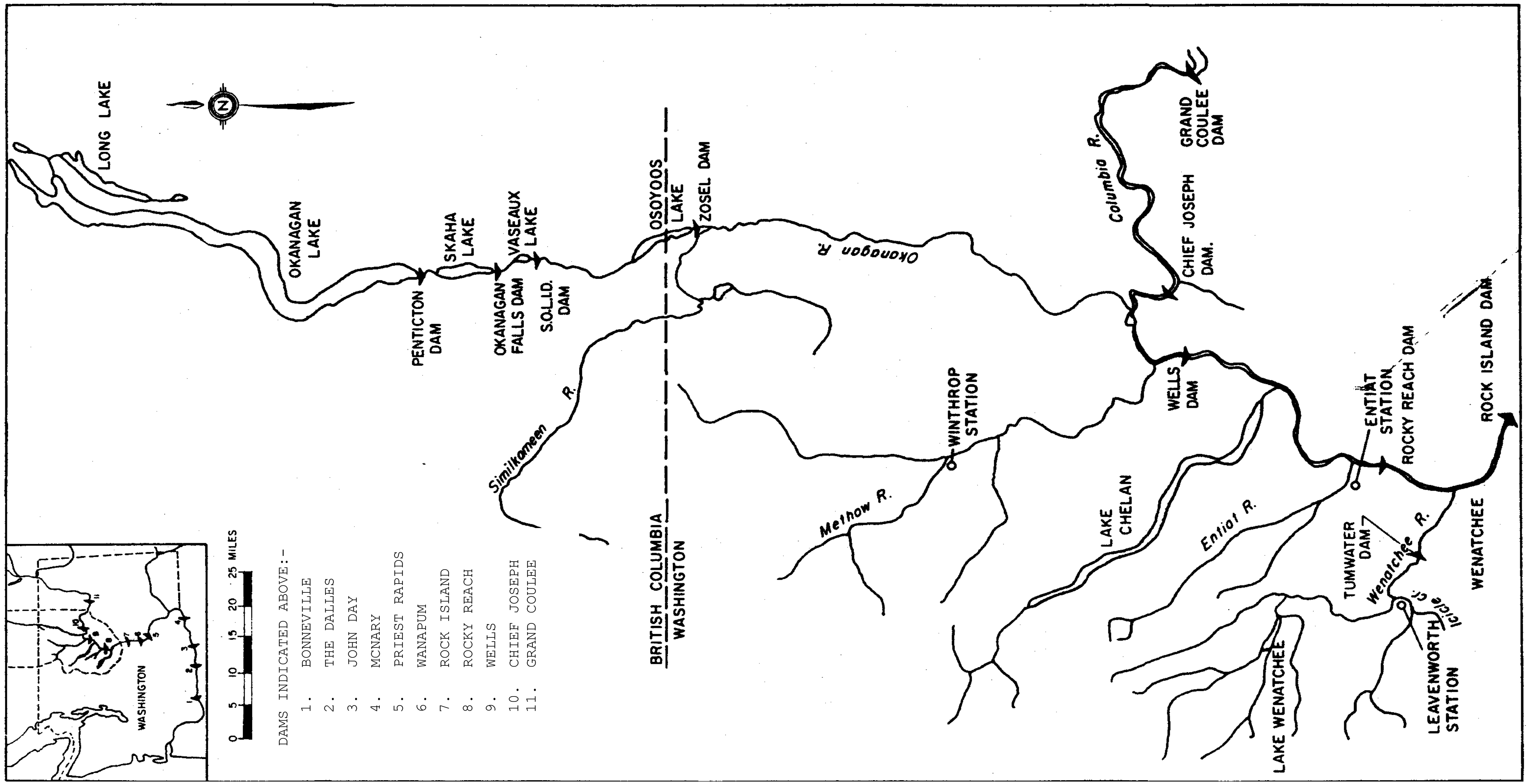


Figure 1. Location map of sockeye salmon spawning area of the Upper Columbia River.

2 METHODS AND MATERIALS

For the purpose of this report, much reliance has been placed on information revealed in reports and site analyses made by the Department of Fisheries of Canada, and the State Department of Fisheries of Washington, U. S. A. For certain background material reference has been made to residents of the Okanagan Valley, and to earlier reports concerning the Okanagan Flood Control Scheme. Site investigations during 1971 have provided data supporting theoretical temperature modelling procedures used.

The references used are enumerated at the end of this report, and are referred to by number throughout the test. Tables and figures will be found at the end of each chapter, as applicable.

3. POPULATION AND CATCH CHARACTERISTICS

3.1 History

Sockeye salmon enter the Columbia River in June and July in order to commence their annual migration to preferred spawning areas.

Past records indicate that the total run, as measured at the mouth of the river, exceeded one million fish prior to 1900, and that the subsequent migration penetrated to upstream river areas, which are now inaccessible to anadromous fishes on account of impassible dams (4). Of these salmon a significant number ascended the Okanagan River at least as far upstream as Okanagan Lake, where they are remembered by local residents to have spawned in large numbers at the mouths of tributary streams. Further evidence of this migration is given by the large number of kokanee which possess racial characteristics identical to sockeye salmon, and which now inhabit Okanagan and Skaha Lakes.

Probably construction of the first dam at the outlet of Okanagan Lake in 1915 rendered the river impassible to salmon migration upstream of this point. According to a local Indian source, during the early years of this century sufficient salmon were caught in most years to supply local needs throughout the winter (5, 6).

A review of records of the sockeye spawning escapement to the Okanagan River from 1926 to 1970 indicates that between 1926 and 1936 the average run was light to nil, and that the 1950's are evidenced by a considerable increase which since 1959 has fallen markedly (Table 1 and Figure 2).

It is not impossible that the discrepancy between Indian sources and the records commencing in 1926 may be explained by Penticton dam acting as an upstream barrier to fish passage, and consequently assisting in the trapping out of salmon stocks spawning in the vicinity of Penticton.

The increase in run size between 1936 and the 1950's is considered to result from an extensive transplantation program which was followed subsequent to construction of the Grand Coulee Dam on the Columbia River (7). Construction of this dam involved the loss of 1,140 lineal miles of spawning and rearing stream to the production of anadromous fishes in the river system, and the consequent transplantation programme included the entrapment of sockeye salmon at Rock Island Dam and their release into Lake Osoyoos and Lake Wenatchee (Washington State) in 1939 and 1940. Fingerlings reared at the Leavenworth hatchery (Washington State) were also released into Lake Osoyoos in the years 1940 to 1946, as shown in Table 2.

Since construction of the McIntyre (S.O.L.I.D.) dam on Vaseaux Lake in 1954, into which fishway facilities were not incorporated, sockeye spawning grounds on the Okanagan River have been restricted to the river area south of this dam.

3.2 Composition of Escapement

Spawning escapements of sockeye salmon are generally marked by a cyclical pattern of four year dominance. However, in the Okanagan River biological data recorded between 1966 and 1970 indicate that the numbers of three and four year old fish are in an approximately equal ratio (8). Males compose approximately 60 percent of the total population and the ratio of three-year to four-year males is 1.9 : 1. In females the ratio of four-year to three-year fish is about 1.2 : 1 (Table 3). Variations from these mean values are particularly emphasized by individual escapement years such as 1968, and it appears that a dominant year cyclical pattern has been considerably upset by the massive transplantation program referred to above.

3.3 Present Trends

Currently, annual counts of the sockeye spawning in the Okanagan River are undertaken each year by field staff of the Fisheries Service, Canada and by representatives of the Washington State Department of Fisheries. The Fisheries Service also undertakes general protection of these salmon and maintains records of the annual Indian catch.

For the purpose of this report the higher of the two annual escapement records has been adopted for further calculations, on the assumption that it provides a more accurate estimate of the true spawning escapement; for no year are the two sets of records widely divergent. For any year where a range of values is tabulated, a mean value has been applied.

Records from 1961 to 1970 indicate that the average run size entering the Columbia River is 95,000 (4).

The present escapement goal of the Washington State Department of Fisheries is 25,000 spawning sockeye in all Columbia River tributaries, and observations indicate that this magnitude of spawning population is ensured by an escapement of about 80,000 fish passing Priest Rapids Dam. Fishing seasons in the lower Columbia are regulated in order to provide for this escapement.

Okanagan River spawning escapements between 1961 and 1970 average about 19,000 sockeye annually.

It is estimated that the Okanagan River supports 66 - 74 percent of the Columbia River sockeye spawners, and it would therefore appear that the total spawning escapement of the Columbia River is currently of the order of 27,000 annually.

In consideration of the present careful regulation of fishing seasons, and the evident tenacity of this sockeye run in maintaining its present size, no future significant decrease in the Okanagan River spawning escapement is envisaged.

3.4 Catch Records

A commercial gillnet fishery takes place in the Lower Columbia River and this has returned an average of 21,635 sock-eye salmon annually for the years 1961-70 (Table 4). As mentioned previously, this fishery is limited by regulation, and since 1964 the open season has been restricted to an average of only about one week per year in the months of June and July (4).

Included in this figure is an Indian fishery upstream of Bonneville Dam (Zone 6), about ten percent of the catch from which is used for subsistence and ceremonial purposes.

Traditional upriver Indian fisheries are located in the vicinity of Wells Dam and the mouth of the Okanagan River (Colville Indians) and between Vaseaux Lake and Osoyoos Lake in Canada (Okanagan Indians). The Canadian Indian catch has averaged 957 fish per year (1961-70), principally for food purposes, while further catches by the Colville Indians average 1,228 fish annually. Some of these fish are used for food purposes, but the salmon are also highly prized for their traditional ceremonial values, and the Washington State Department of Fisheries accordingly maintains a separate catch category in order to keep a record of the level of fisheries activity associated with this important aspect of Indian life.

About 5,000 Indians, most of them of the Yakima tribe in the United States, are affected by the availability of these salmon.

Table 1. Sockeye Spawning Estimates and Indian Catch (1926-1971)
South Okanagan River - Canada

Year	Indian Catch	Total Spawning Estimate: Canadian Records	Total Spawning Estimate: U. S. Records
1926		Nil	
1927		Nil	
1929		Nil	
1930		Light	
1931		Nil	
1932		Nil	
1933		Light	
1934		300 - 500	
1935		Nil	
1936		1-50	
1952	1,796	24,000	
1953	1,278	34,000	
1954	1,560	10,000	
1955	2,480	50,000	
1956	1,345	39,000	
1957	1,120	25,000+	
1958	1,300	31,000	
1959	1,565	40,000	
1960	1,175	8,000	
1961	425	2,000+	2 - 3,000
1962	750	6,000	2 - 4,000
1963	1,270	16,000	20 -25,000
1964	775	12,000	10 -15,000
1965	1,200	5,000	10 -15,000
1966	1,200	45,000	50 -60,000
1967	900	23,000	25 -30,000
1968	1,900	15,000	10 -15,000
1969	360	2 - 5,000	10 -15,000
1970	790	5 -10,000	25 -30,000
1971	710	20 -50,000	36,000

Table 2. Adult and Fingerling Sockeye Released into Osoyoos Lake

Year	No. Adults	No. Fingerlings
1939	10,104	-
1940	9,691	569,296
1941	-	-
1942	-	654,660
1943	-	1,088,138
1946	-	337,590

Table 3. Sex Composition of Sockeye Salmon on the Okanagan River Spawning Grounds (1966 - 1970)

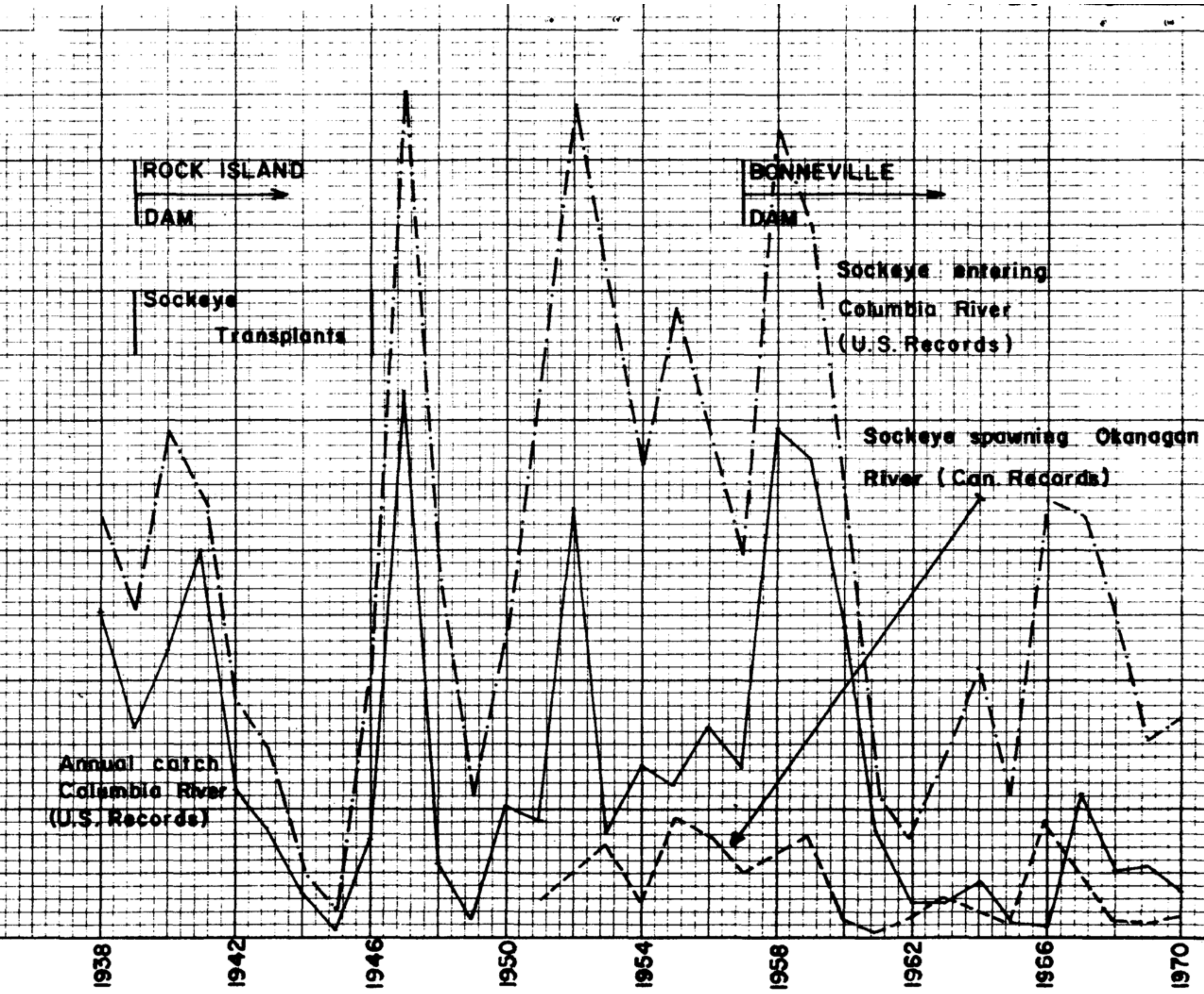
Year	3-year fish			4-year fish			Combined		
	Sample	Males	Females	Sample	Males	Females	Sample	Males	Females
1966	124	98	26	135	53	82	259	151	108
1967	205	150	55	216	86	130	421	236	185
1968	66	50	16	4l4	225	189	480	275	205
1969	25	22	3	112	52	60	137	74	63
1970	808	501	307	59	21	38	867	522	345
Totals	1,228	821	407	936	437	499	2,164	1,258	906
Percentage	100%	66.8	33.2	100%	46.8	53.2	100%	58.1	41.9

Ratio of three-year males to four-year males is: 821 : 437 = 1.88 : 1

Ratio of four-year females to three year females is: 499 : 407 = 1.23 : 1

Table 4. Annual Columbia River Sockeye Catches 1961-70

	Numbers of Fish Taken		
Zone	Commercial Catch	Ceremonial and Subsistence Catch	Total Catch
1 – 5	13,220	-	13,220
6	8,415	935	9,350
Colville	-	1,228	1,228
Okanagan	-	957	957
Total	21,635	3,120	24,755
Of Okanagan Origin (70%)	15,145	2,184	17,329



mparison of the Columbia R. & Okanagan R. sockeye runs

CONSIDERATION OF CONSTRAINTS

4.1 Social Objectives

As determined by the Okanagan Basin Study Board, one of the constraints acting on the evaluation of study results and the consequent recommendations is that the Okanagan River sockeye salmon run shall be maintained.

This decision may be reviewed as being based on

(a) Moral and possibly legal obligations to the United States involving State law, National Act and International treaty.

(b) The preservation of an integral part of an ecosystem, and the consequent preservation of significant parts of an associated social system.

4.2 Regulations

The pertinent regulations (4.1(a)) with respect to fisheries are summarized below.

State of Washington - Fisheries Code (1968-69)

It is the State policy to maintain sufficient flow to support fish populations at all times.

Fishways are to be provided in dams or obstructions; if considered impractical, hatcheries may be provided in lieu.

"In the event of any construction that will use or change the natural flows of the river" complete plans for the protection of fish life are to be furnished to the Director,

Canada - Fisheries Act (1952-70)

Owner shall provide a fish pass at every slide, dam, and other obstruction at the request of the Minister. If provision of fish passage is not feasible, then hatchery facilities shall be provided to maintain the annual fish run.

Water release shall at all times be sufficient for the safety of fish and flooding of spawning grounds downstream of obstructions.

The Boundary Water Treaty (1909)

Osoyoos Lake (but not the Okanagan River) is by definition in the Treaty a "Boundary Water". The Treaty states that any interference or diversion "causing injury across the boundary may give rise to the same rights and entitle the injured parties to the same legal remedies as if such injury were to take place in the country where such diversion or interference occurs."

4.3 Interpretation

It appears from a review of the foregoing regulations that, notwithstanding the necessity or desirability of supporting the native fishery, failure to maintain discharges downstream of Vaseaux Lake adequate for the support of the spawning sockeye population, will have international implications.

Problems of an international nature can be referred to the International Joint Commission for study and recommendation. However, the Commission has no authority to impose a solution without the joint consent of the two Governments.

5. HABITAT REQUIREMENTS

The annual cycle and corresponding habitat requirements of the Okanagan River Sockeye salmon are summarized below In 5.1, and are considered in greater detail in 5.2. The findings, in terms of preferred seasonal discharges, are given in 5.3.

The estimated effects of discharge levels both higher and lower than the preferred values are referred to in 5.3, and given in greater detail in Table 6. These values have been derived from a review of the results of Task 23 (Appendix C-l), and some minor revisions may be noted.

5.1 General

In early summer, sockeye salmon commence their migration from the ocean up the Columbia River to the Okanagan River spawning areas. They generally enter the river above Osoyoos Lake in early August, but may hold for a period in the cooler lake water for up to one month. Spawning takes place only when water temperatures fall considerably, that is between mid-September and the end of October, with a peak generally in mid October.

The eggs hatch during late winter and the fry migration takes place during the late March to early April period (1).

The fry spend a full year rearing in Osoyoos Lake before proceeding to the ocean in the following April or May, where they remain for a further two or three years before returning to spawn.

Water requirements for these phases of the cycle are indicated below.

<u>Upstream Migration,</u> August 1 - September 15

Discharges sufficient to allow unimpeded passage upstream past any obstructions to spawning grounds located between Oliver and Vaseaux Lake.

Water quality adequate to prevent pre-spawning mortalities as a result of disease (9).

<u>Spawning ,</u> September l6 - October 31

Discharge sufficient to allow access to adequate preferred spawning gravel areas by a maximum of 40,000 spawners.

Water quality adequate to prevent pre-spawning mortalities or reduced spawning success as a result of disease.

<u>Gravel Scour,</u> November 1 - February 15

Discharges lower than those which will produce velocities capable of scouring river gravel and deposited eggs.

<u>Incubation,</u> November 1 - February 15

Discharges sufficient to ensure that dehydration or freezing of salmon eggs deposited between September 51 and October 30 cannot occur.

Water quality adequate to prevent mortalities due to disease, physiological stresses, or physical causes.

<u>Hatching and Fry Migration -</u> February l6 - April 30.

Discharges maintained at levels not lower than those existing between October 30 and February 15, in order to prevent stranding and dehydration of fry and to assist their downstream migration to Lake Osoyoos.

Water quality adequate to prevent mortalities due to disease, physiological stresses, or physical causes.

Rearing, 12 months

Discharges and water quality adequate to provide lake rearing conditions satisfactory to the salmon fry for a twelve month residence period.

5.2 Considerations

The habitat requirements cited in 5.1 are given in greater detail in this section.

Discharge requirements have been determined from biological and engineering site surveys made between 1968 and 1971. Water quality information has been taken from 1971 site data, from theoretical predictions, and from other comparative sources.

5.2.1 Upstream Migration

5.2.1.1 Osoyoos Lake

As indicated, sockeye salmon generally enter the Okanagan River from Lake Osoyoos in early August.

It may be noted (16) that at lake levels of 10 - 20 meters, the water temperature in August 1971 was recorded to be 9 - 18°C at a dissolved oxygen level in excess of 8 ppm, and it is considered that the fish may therefore hold in these relatively cool lake waters for up to one month.

5.2.1.2 Physical Obstructions

Between Osoyoos Lake and Oliver thirteen "vertical drop structures" (VDS) are located in the channelised river bed, in order to compensate for the hydraulic head loss originally made up by the meandering river channel (Figure 3). A series of six notches in each of these, with associated downstream works, designed by the Department of Fisheries in 1954 for the Okanagan Flood Control Project, ensure that salmon are allowed to proceed upstream to preferred spawning grounds without difficulty. The design discharge for upstream migration was taken as 421 cfs, with all notches operating.

However, since the actual water levels in the channel sections are lower than those anticipated by design, at discharges below about 400 cfs certain Irrigation and domestic water intakes cannot be operated (10). Accordingly, stoplogs are placed at certain drop structures in order to "pond up" the water at low discharges, and thus allow all intakes to remain operable.

Sockeye salmon are unable to surmount the stoplogs, and it is therefore essential to the safety of the salmon run that at least one of the above notches retain no stoplogs during the migration period. Such a condition is currently arranged on site annually between representatives of the Federal Fisheries Service and the Provincial Water Resources Service.

Although records do not indicate any difficulty in ascent of the drop structures by sockeye due to high river discharges, it is probable that discharges significantly higher than the design discharge may prevent upstream migration, especially if the fish are in a weakened condition. Records are not available of the effects of river discharges less than 100 cfs, but in terms of physical obstruction alone, it seems probable that although relatively few mortalities may be expected at 100 cfs, a significantly greater number would occur at 50 cfs.

5.2.1.3. Water Quality

Sockeye Temperature Tolerance. A synthesis of various data indicates that the tolerance range of sockeye salmon is as shown below:

Optimum Range	0°C.	11 – 14.5°C.	24.5°C
	(Lower Lethal)	(Preferred)	(Upper lethal)
Migration Range		7.2 – 15.6°C	21.2°C
General Spawning Range		10.5 – 12.2°C	21.2°C
Hatching Range	0.4°C	4.5 – 13.3°C (preferred)	14.5°C

At temperatures outside the above preferred ranges, swimming ability, energy conversion, and disease resistance of a fish are impaired. Summer and fall rises in water temperature can thus cause delay, loss or reduction of spawning ability, and mortality, during the periods of upstream migration and spawning.

There is some evidence from U.S. records which indicates high temperatures reduce the survival of upstream migrants, and Canadian records indicate that in 1970 approximately 2,000 pre-spawning mortalities were caused by disease, accompanied by high water temperatures. However, the validity of the above tolerances as applied to Okanagan River sockeye has not been confirmed, and the data should therefore be considered with some reservation.

Temperature Records

No river temperature data is available for the migration period prior to 1971. In that year thermographs in the Okanagan River were maintained by the Fisheries Service (a) between Vaseaux Lake (S.O.L.I.D. dam) and Highway 97 road bridge, (b) near Oliver, and (c) upstream of Osoyoos Lake Monthly maximum temperatures were found to be as follows:

	August	September	October
(a)	27°C	21.2°C	15°C
(b)	26.2°C	17.8°C	
(c)	26.7°C	21.4°C	13°C

The maximum daily temperature increase between stations (a) and (c) was 4°C in August and 1°C in September.

Comparison of these data with the quoted sockeye temperature tolerances indicates that when the salmon arrive on the spawning grounds they are already in a highly stressed condition as a result of excessive water temperature. Any aggravation of this condition may result in mortality.

Temperature Prediction

The dearth of river temperature data, and the need to determine the approximate range of discharge at which the least temperature rise between Vaseaux Lake and Osoyoos Lake may be anticipated, led to the construction of temperature prediction model. This was based on a method used for prediction of the Shuswap River temperature under varying conditions (3).

It was considered that the discharge range obtained would represent a generally valid estimate for the Okanagan River between Penticton and Osoyoos Lake.

The principal variables governing river temperature at Osoyoos Lake are considered to be quantity and temperature of river outflow from Vaseaux Lake at S.O.L.I.D. dam, quantity and temperature of influent ground water during the incremental downstream distance, incoming solar radiation, and other atmospheric variables (See. also Appendix 1).

The river temperature rise was calculated on the basis of synthesized extremely hot spells of weather for the months of August, September and October, in order to estimate the maximum rise likely to occur in one day; calculations were performed for each of four river discharges: 80 cfs, 170 cfs, 380 cfs and 500 cfs.

These basic river temperature increases were then modified by the inflow of ground water assumed to occur on a linear basis within the reach considered; groundwater temperature was assumed to be 10°C, with the rate of inflow (a) assumed to be dependent upon the channel discharge, and (b) assumed to be independent of channel discharge.

The resulting river temperature increases for August between Vaseaux and Osoyoos Lakes were estimated to be as listed below and depicted in Figure 4.

River Channel Discharge	Groundwater Inflow	Temperature Increase
cfs	cfs	0°C
80	35	5.1
80	70	0.8
170	50	3.1
170	70	2.1
380	70	2.2
500	70	2.4

It is evident that these estimated temperature increments are of the same order of magnitude as the maximum dally increment recorded in August 8, 1971, of 4°C at a river discharge of 710 cfs.

From a review of these results it is considered that the predicted water temperature rise for each of the four discharges may be expected to be only approximately correct, but that the trends shown for the range of discharges are valid indications of temperature variation.

Conclusion

It is apparent from the values given above and also from Figure 4 that the maximum dally temperature rise anticipated between Vaseaux and Osoyoos Lakes is highly dependent upon the magnitude and distribution of influent groundwater within the reach.

Assuming the groundwater inflow to consist of 70 cfs linearly distributed, and to be subject to no temperature rise after inflow to the river, then the least temperature increase in the channel may be expected at discharges of 80 cfs or less.

However, these assumptions are not necessarily justified, and it appears that temperatures at discharges of less than about 200 cfs are considerably more sensitive to input variations than those in excess of 200 cfs. Temperatures at discharges below 100 cfs appear to be particularly sensitive to the governing assumptions.

Consequently it is considered that discharges of less than 100 cfs pose a considerable risk to the safety of the sock-eye run, while those between 100 cfs and 200 cfs may also be contributory factors in causing mortalities, and should also be avoided. Similarly, discharges above 500 cfs should be avoided on account of the greater potential for water temperature increase and also excessive velocity considerations at the vertical drop structures.

Optimum discharges are expected to remain within the range of 300 - 450 cfs.

5.2.2 Spawning

5.2.2.1 Timing and Location. Spawning activities take place generally from mid-September to the end of October, with a peak in mid-October.

Field surveys made In 1947, 1951 and 1952, and between 1956 and 1971 indicate that within the Okanagan River similar reaches are preferred from year to year by spawning salmon and that the most heavily populated reach is the "unimproved" section between the junction of Vaseaux Creek and the Okanagan River and commencement of channelisation some one half mile downstream of Highway 97 bridge (Figure 3).

An unrecorded number of sockeye spawn in Osoyoos Lake. It may be that they represent about 5% - 10% of the escapement upstream of the lake.

5.2.2.2. <u>Estimation of Spawning Gravel Requirements</u> (See also <u>Appendix 2)</u>

<u>Gravel Available.</u> Engineering and hydraulic site surveys were made in 1968-69 by the Department of Fisheries in order to determine the spawnable gravel areas available to salmon at that time. The surveys, which included 26 cross sections together with water surface profiles, was carried out at discharges of 540 cfs, 380 cfs and 210 cfs. At the discharges of 540 cfs and 380 cfs the areas of spawning gravel falling within the water depth and velocity parameters of 8-l8 inches and 0.8 to 2.5 feet per second, and consisting of 1.5 - 4 inches diameter gravel, were calculated (11).

"Good" spawning gravel was designated as that satisfying all three of the above parameters, while "medium" spawning gravel satisfied only two. It is considered that of these two designations, "good" spawning gravel alone is adequate to meet sockeye requirements. Area estimates of "medium" spawning gravel are therefore disregarded in further calculations.

On the basis of interpolation of the above data, spawning gravel areas were also predicted for discharges of 250 cfs, 125 cfs and 90 cfs. Accordingly, graphs of available spawning gravel area versus discharge were obtained (Figure 6).

Gravel Requirements per Redd

The gravel area to be allocated to each pair of spawners was estimated from comparative and site data to be 5 square yards, to accommodate the actual average redd size plus inter-redd space (9, 12, Appendix 2).

Sockeye Support Values of Discharge

The spawning gravel areas as determined above at a range of discharges were surveyed in the river area between Vaseaux Lake (at S.O.L.I.D. dam) and the V.D.S.13 in 1968-69. At that time it was determined that 77% of the total number of spawners were utilizing 52% of the "good gravel" area.

By comparing this figure with the other observed data concerning the measured areas of "good gravel" within certain river reaches, and also the average distribution of spawners in the river between 1947 and 1970, it was possible to derive a pro-rated figure for the effective spawning population in the river. This figure, which may be used in conjunction with the graph on Figure 6, takes into account not only the area of good gravel available, but also the sections preferred by spawning salmon (Appendix 2).

The "good gravel" areas required for specified spawning populations, together with the equivalent discharges, may be found in Table 5. In summary, the preferred discharge range for spawning lies between 350 and 550 cfs, while ranges of 300 - 350 cfs and 550 - 700 cfs are considered to represent a relatively small loss in spawning area potential.

5.2.2.3 Water Quality

Temperature Effects

Records of river temperatures during the spawning period are available as indicated previously. Due to the dearth of these records the temperature prediction model was extended into September and October in order to determine the river discharges at which risk of excessive temperatures might be minimized.

Using the same rationale as before it was estimated that the least risk of allowing the river temperature to rise significantly is obtained at a discharge greater than 200 cfs, while the risk is considerably increased at discharges below 100 cfs (Figure 5). On account of the generally reduced water temperatures after August, the cooling effects of irrigation return flow do not appear to significantly affect variations of the daily river temperature rise at higher river discharges. Therefore, no upper limit of discharge range for temperature optimization is given for September.

5.2.3 Gravel Scour and Incubation

5.2.3.1. Discharges

It is of consequence that river discharges during the period when salmon eggs are in the gravel should remain within a certain range.

Maximum discharge values may be determined by an estimation of the maximum permissible eroding velocity of water with respect to spawning size gravel. Low values are determined by consideration of the maximum discharges existing at the time of egg deposition. The incubation discharge is that which ensures that all eggs deposited during the previous spawning period remain submerged throughout the winter.

Scouring Velocity. Mean water velocities were computed at a range of discharges for four cross sections of the Okanagan River, taken to be representative of typical spawning gravel areas. Comparison was then made with the particle sizes found to be eroded at the velocities so determined (13). The findings indicate that scour of half inch gravel with associated eggs may commence locally at a discharge of 500 cfs but will probably not occur generally at discharges lower than 1300 cfs (Figure 7). Accordingly, it is assumed that little erosion of eggs will commence at discharges below 1000 cfs.

Incubation. From the data obtained from the 1968-69 survey, the incubation flows respective to spawning flows of 80 cfs, 130 cfs, 250 cfs, and 380 cfs were determined such that all eggs would remain submerged throughout the winter. These respective values were shown to be 70 cfs, 90 cfs, 150 cfs, and 170 cfs; in no case is the incubation flow likely to exceed l80 cfs. Other values may be interpolated from the graphical representation in Figure 8.

5.2.3.2. Water Quality

Siltation. Silt is carried in river as bed load and as suspended load. The bed load in particular may penetrate the gravel together with river flow, and can thereby affect salmon eggs either by direct abrasion, by altering the chemical characteristics of surrounding waterbody, or by clogging the intergravel pores sufficiently to reduce the availability of dissolved oxygen to the eggs.

However, the Okanagan River carries a relatively low sediment load due to the presence of upstream lakes, which settle out much of the sediment. Accordingly, siltation has not been recorded to be a problem to egg survival.

5.2.4. Hatching and Fry Migration

In order to prevent the stranding and dehydration of salmon fry and to assist in their downstream migration to Osoyoos Lake, discharges not lower than those obtaining in the period November 1 to February 15, should be continued.

5.2.5. Rearing

The time limitations have not allowed a full determination of the rearing environment of Osoyoos Lake to be undertaken. However, qualitative observations indicate that the sockeye yearlings migrating from Osoyoos Lake to the Columbia river are generally of stronger appearance than those rearing elsewhere in the system (8).

Current evidence indicates that the available nutrients in this lake are important in ensuring an ample food supply, and furthermore, that the present nutrient supply is not likely to be significantly affected by any alteration of the river discharges presently envisaged under the Okanagan Basin Study (14,15).

Investigations into the rearing potential of Osoyoos Lake may be undertaken in the future by the Washington State Department of Fisheries.

5.3 Findings

A summary of the discharges preferred by sockeye salmon utilizing the Okanagan River, as derived from the findings cited in 5.2, is given below.

Upstream Migration	Aug 1 - Sept 15	300 - 450 cfs with removal of stocklogs as necessary.
Spawning	Sept l6 - Oct 31	350 - 550 cfs
Gravel scour	Nov 1 - Feb 15	1,000 cfs max.
Incubation	Nov 1 - Feb 15	175 - 1000 cfs
Pry Emergence and Migration	Feb l6 - Apr 30	175 cfs min.
Rearing	12 months	Not sensitive under expected regimes.

Other, less preferred, discharges for the foregoing periods are also indicated in the findings of 5.2, and are given in greater detail in Table 6. A score between 10 and 0 has been allocated to each discharge range, depending on the desirability of that range. These scores are equivalent to the "Absolute Scores" determined in Task 23 (g), which have been revised where necessary as determined by the new findings (17).

The above discharge ranges estimated to be preferred by sockeye salmon have been determined by technical survey and analysis. In order to arrive at a first order estimate of the validity of these synthetically determined discharge ranges, comparisons were made with the monthly recorded runoffs of the Okanagan River at Penticton in 1923 and 1953, and of the South Thompson River at Monte Creek in 1963.

It was found that differences between "preferred Sockeye discharges" and recorded runoff were not significant, except in the months of August and September. The divergence is explained by the necessity for optimisation of temperature regimes (see also Appendix 3).

Table 5. Sockeye Support Values of Spawning Gravel and Discharges

Spawning Count	Gravel Required sq. yd.	Equivalent Spawning Discharge cfs	Incubation Discharge cfs
10,000	37,200	50 approx.	40 est.
20,000	74,400	90	70
30,000	111,600	195	125
35,000	130,200	325	163
38,900	141,000	470	170
40,000	148,800	(470)	(170)
50,000	186,000	(470)	(170)

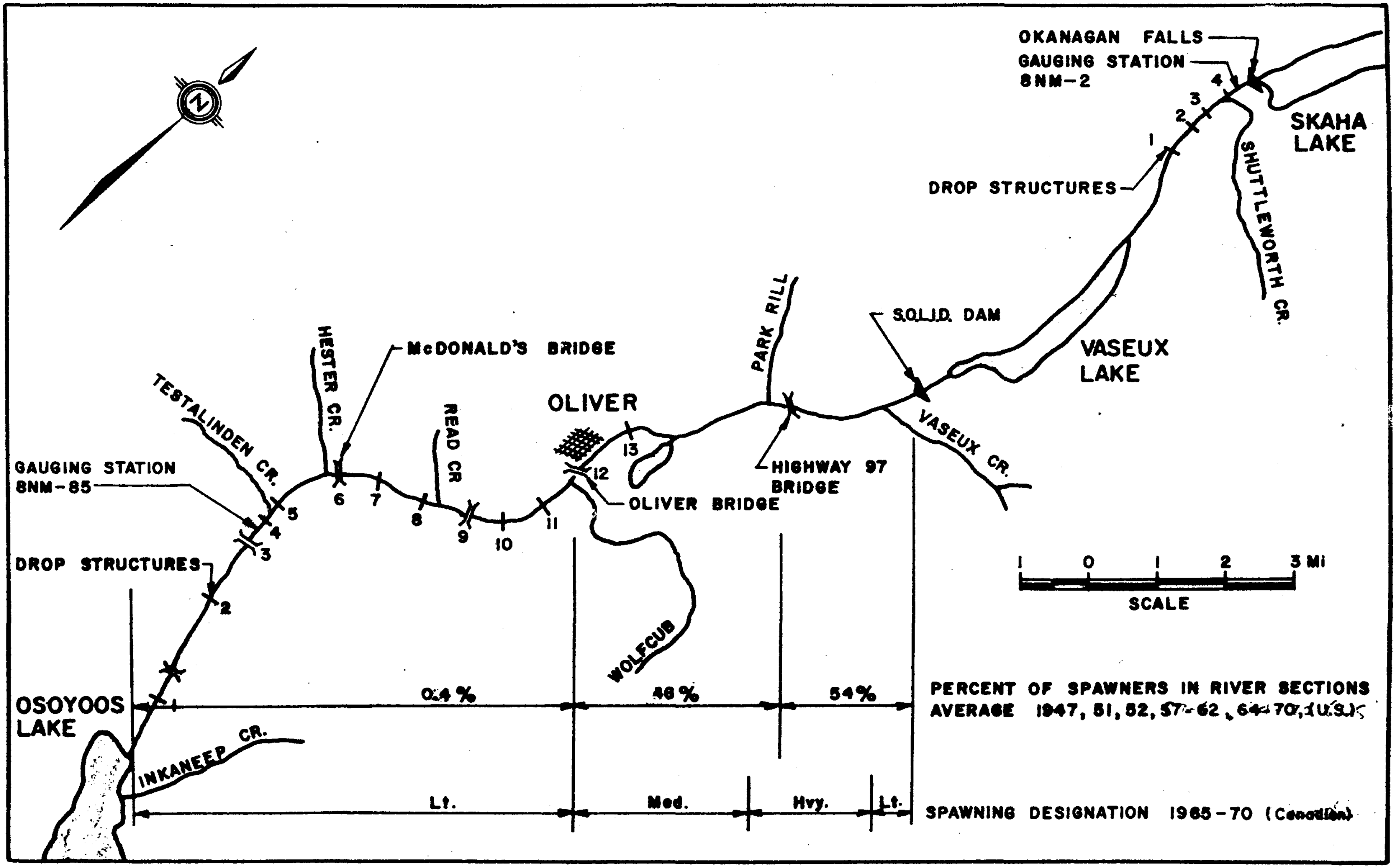
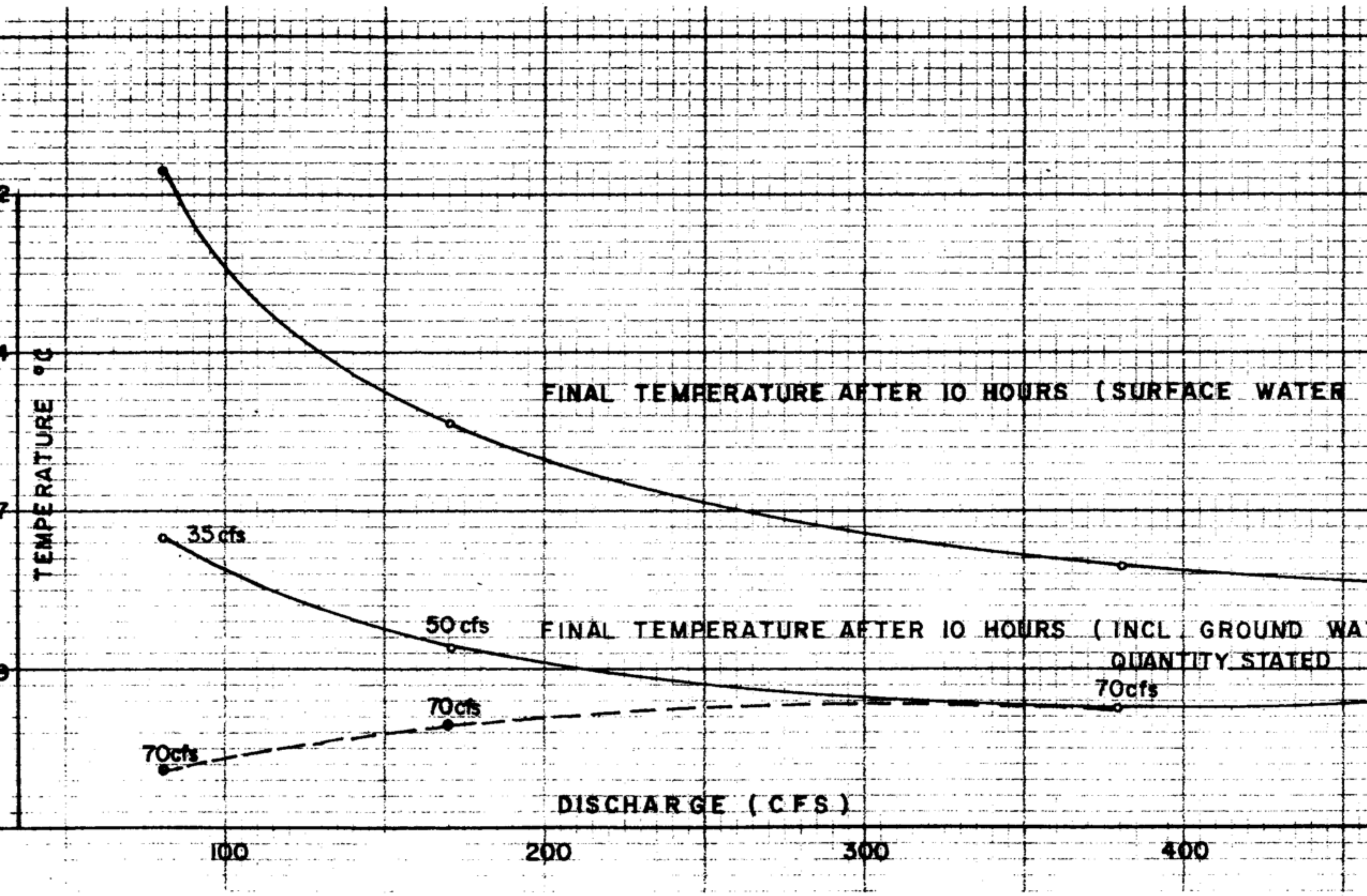
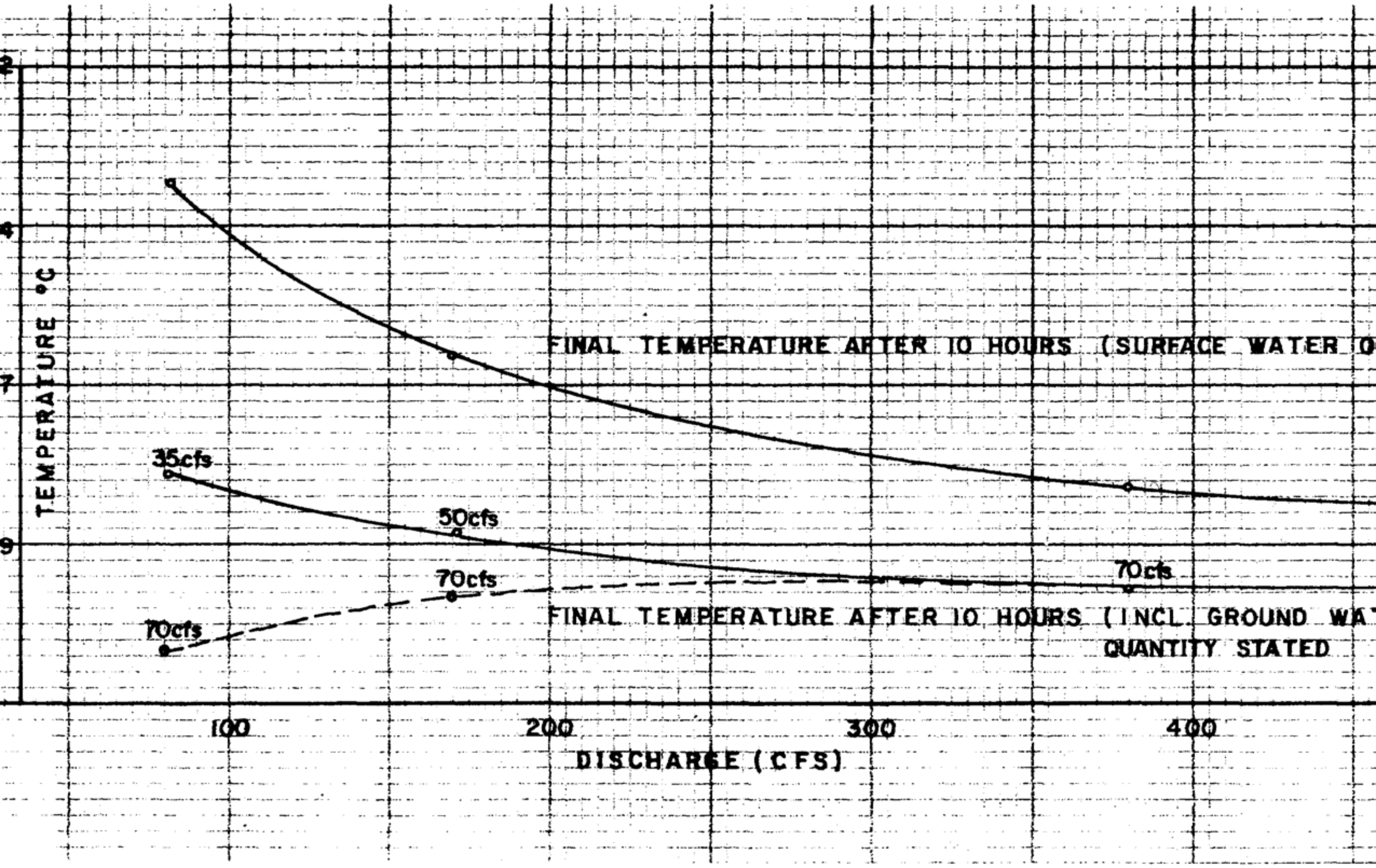


Figure 3. Okanagan River from Skaha Lake to Osoyoos Lake.



Okanagan River - August, Water temperature downstream from S.O.L.I.D. dam



Okanagan River - September Water, temperature Downstream from S.O.L.I.D dam

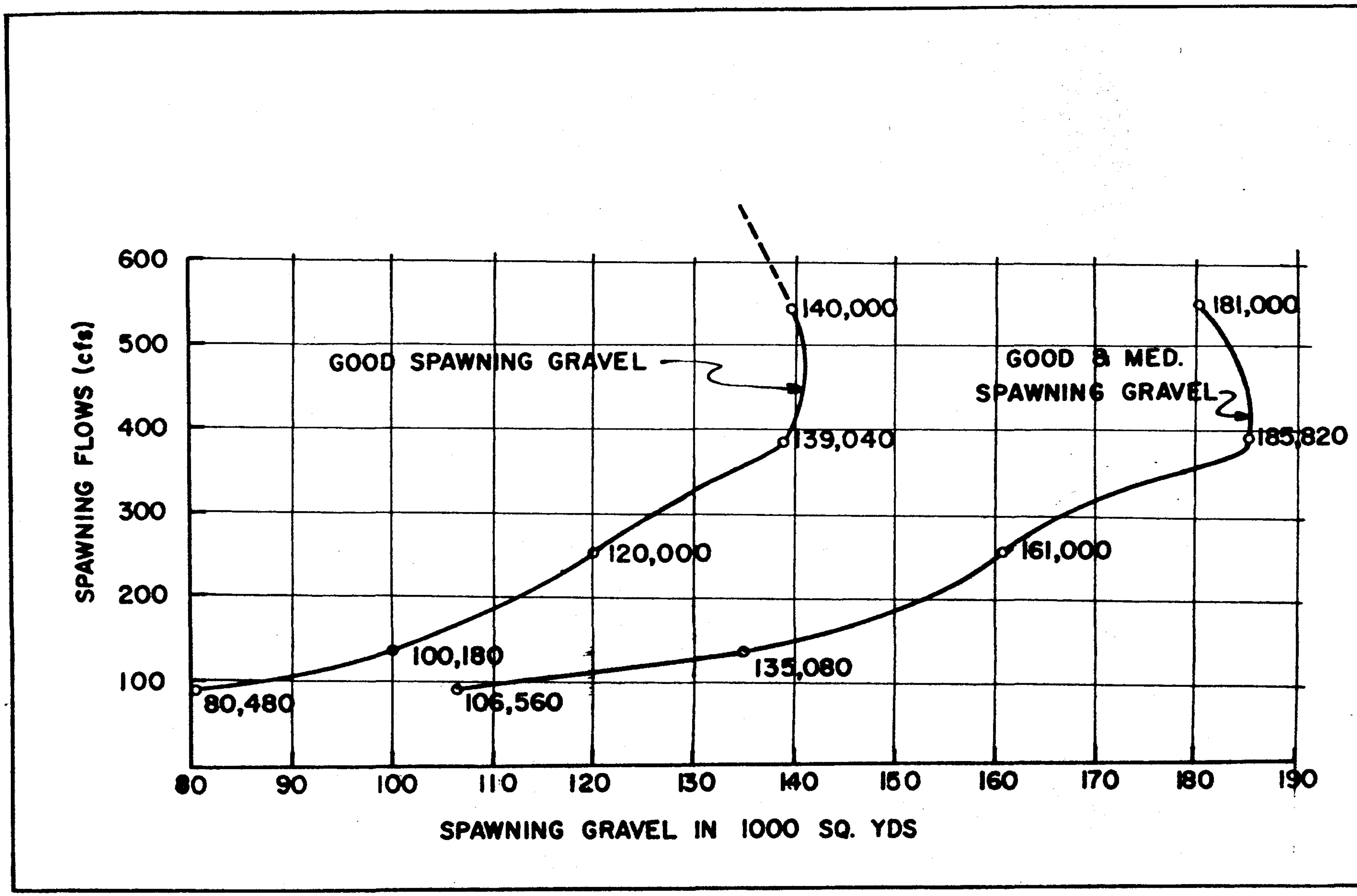
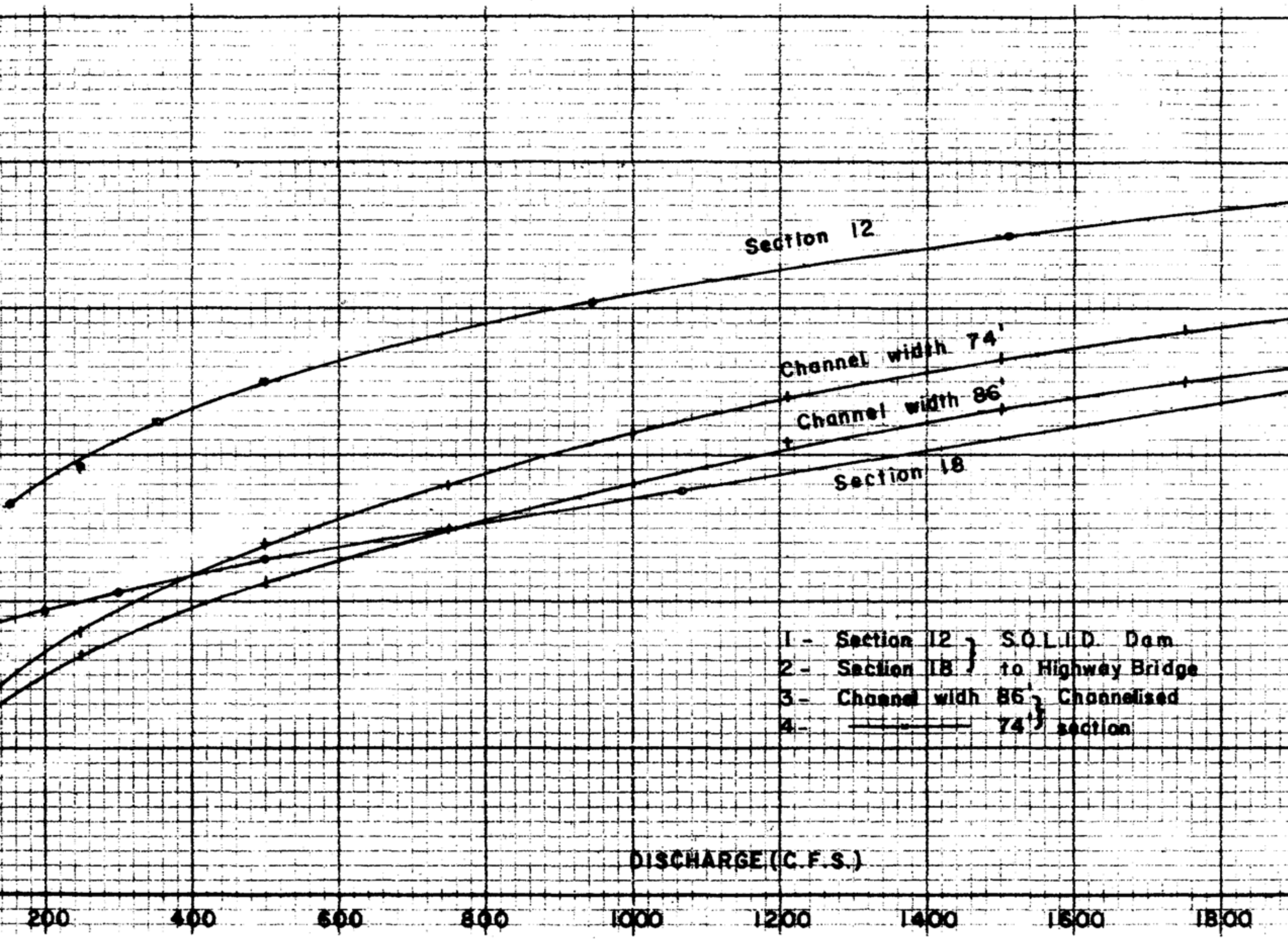


Figure 6. Discharge versus spawning gravel area (S.O.L.I.D. Dam to V.D.S. 13)



7. Okanagan River Discharge vs. average velocity vs. erodible particle size

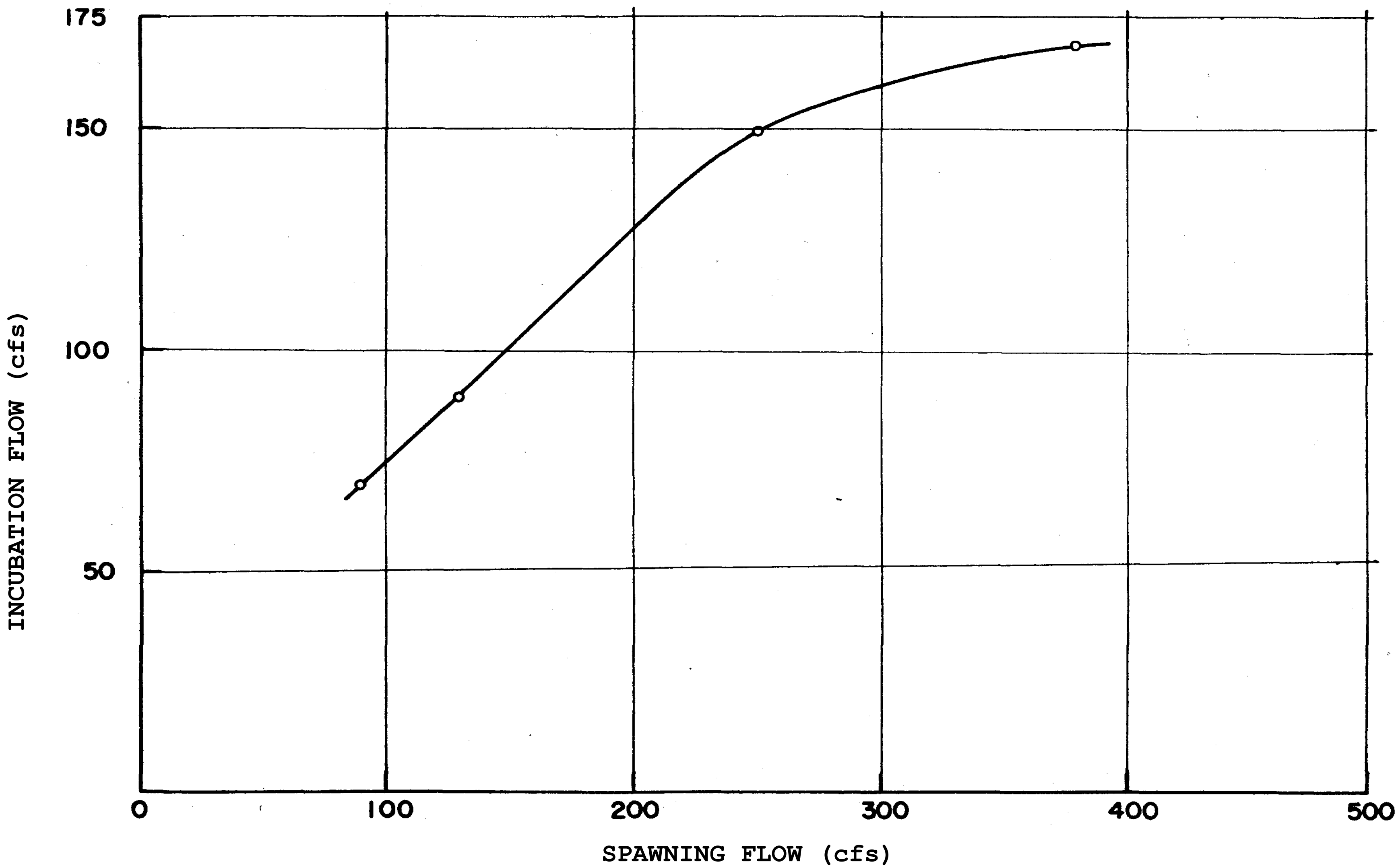


Figure 8. Incubation flow versus spawning flow

Table 6. Periodic Scoring of Discharge Ranges with Respect to Salmon Spawning and Incubation Requirements Okanagan River

(Downstream of S.O.L.I.D. dam, Sept - Apr., and at Oliver for August)

Time	Discharge Range cfs	Score	Comment
Aug 1 - Sept 15	300 - 450	10	Good
	200-300, 450-550	7	Fair
	100-200, 500-700	4	Undesirable
	<100, >700	2	Unacceptable
Sept 16 - Oct 30	350 - 550	10	Good
	250-350, 550	8	Fair
	175 - 250	6	Adequate
	100-175, >700	4	Undesirable
	<100, >1000	2	Unacceptable

Range of Incubation Flow cfs	For Range of Spawning Flow cfs	Score
175 - 500		1.0 x 10 = 10
165 - 175	350 - 550	8 = 8
150 - 165		7 = 7
125 - 150		6 = 6
100 - 125		5 = 5
180 - 500	550 - 700	0.8 x 10 = 8
170 - 180		8 = 6
170 - 500		0.8 x 10 = 8
150 - 170	250 - 350	8 = 6
120 - 150		6 = 5
150 - 500	100 - 250	0.4 x 10 = 4
100 - 150		8 = 3
500 - 1000	100 - 700	0.8 x 8 = 6
1000 - 1300	(unless given above)	6 = 5
200 - 1000	700 - 1000	0.4 x 10 = 4
175 - 200		8 = 3
<75 or >1300	At all times	0.2 x 4 = 1

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11. Parameters taken from Department of Fisheries and Forestry, observed data on Adams River - 1966, Fulton River - 1964, and Robertson Creek Spawning Channel - 1961.

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15. "Task 23/24 (h), Okanagan Basin Study: Preliminary Evaluation, Water Quality," Environment Canada, Fisheries Research Board 1971.

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APPENDIX I

<u>OKANAGAN RIVER TEMPERATURE STUDY</u>

<u>Method</u>

For this study a computer program developed under the I.P.S.F.C. for estimating temperature changes in streams was used. The temperature rise was calculated for three months -August, September, October - and at four different discharges -80 cfs, 170 cfs, 380 cfs and 500 cfs. The following information must be punched on computer data cards:

1) Mean depth of stream
2) Atmospheric pressure
3) Wind speed
4) Humidity
5) Average Cloud Cover
6) Solar radiation incidental to the surface, corrected for reflected solar radiation.
7) Starting water temperature.

(1) Calculation of the mean depth of stream:

The studied length of the river was divided into two parts, S.O.L.I.D. dam to V.D.S.13, and V.D.S.13 to Osoyoos Lake.

(a) S.O.L.I.D. dam to V.D.S.13

For this part of the river the D.O.F.F. survey from 1968-69 was used. The total time in which water flows through this part was calculated, and the river was divided into hourly reaches. For each hourly reach one area was chosen as typical.

For this area the Manning's "n" was calculated for known discharge Q = 380 cfs. The discharges were calculated for two different depths and a discharge versus depth curve was plotted. From the discharge curve the average depth was found for 80 cfs, 170 cfs, and 500 cfs.

(b) V.D.S.13 to Osoyoos Lake

For this part of the river the "Okanagan Flood Control," 1958 report was used (10). Two typical cross sections were chosen and the discharges for 3 different depths were calculated. For this calculation Manning's "n" = 0.021 was used. From the plotted discharge curve, mean depths of 80 cfs, 170 cfs, 380 cfs and 500 cfs were taken. The hourly reaches were calculated from known velocity, in terms of distance.

(2) Atmospheric Pressure

Average atmospheric pressure was calculated for each month from "Monthly Records, Meteorological Observations in Canada" - Station Penticton, for 10 year period 1961 - 1970.

(3) Wind speed was assumed to be equal to river velocity.

(4) Average hourly humidity was calculated from "Monthly Records Meteorological Observations in Canada" - Station Penticton for 10 year period 1961 - 1970.

(5) Average Cloud Cover

Average cloud cover was assumed to be 0.

(6) Solar Radiation

Maximum hourly solar radiation for the first week of each month was calculated from "Monthly Radiaton" - Station Summerland for the 10 year period 1961 - 1970. This figure was adjusted by 6% for reflected solar radiation.

(7) Air Temperature

Air temperature was calculated as the mean of the maximum and average temperature for the first week of each month. Data for these calculations were obtained from "Monthly Records Meteorological Observations in Canada" - Station Oliver.

(8) Starting Water Temperature

Starting water temperature was assumed to be:

l8.3°C in August

21.2°C

l4.5°C in September

l8.3°C

11.1°C in October

13.9°C

The river was divided into 10-hourly reaches. Temperatures were calculated from 08:30 to 17:30 hours. Input valves were punched on to computer data cards running one card for each hour. A table was constructed from the hourly temperature increase data as on the computer output. From this table graphs of final temperature against discharge were drawn for each hour reach.

The actual water temperature obtained from thermographs installed in the river showed that the calculated increase in water temperature was too high, as a result of water returning from irrigation lowering the water temperature in the river. The amount of ground water was estimated to be:

35 cfs, 70 cfs	for	80 cfs	river discharge
50 cfs, 70 cfs	for	170 cfs	river discharge
70 cfs	for	380 and 500 cfs	river discharge

The temperature of ground water was estimated to be 10°C, and influence was assumed to be linear for the reach considered. Its temperature was assumed for calculation purposes to remain constant downstream after inflow to the river, although in practise a temperature increase must occur with distance downstream due to solar radiation.

APPENDIX 2

ESTIMATION OF SPAWNING GRAVEL REQUIREMENTS

1. Sex ratio, 1966 - 1970 is:

females to males : 42% to 58%.

Hence assume effective spawning population (females only) to be 42% of count.

2. Assume that 10% of spawners (counted and effective) utilize gravel downstream of V.D.S.13, and that year to year distribution of salmon between S.O.L.I.D. dam and Osoyoos Lake remains approximately constant.

3. (a) In 1968, at 380 cfs, 77% of fish utilized 52% of gravel (= good gravel). (Ref. Field Data, Fisheries Service, 1969).

(b) In 1968, Area 1 (S.O.L.I.D. dam to McIntyre Creek - 0 sq yd good gravel

Area 2 (McIntyre to Highway Bridge - 29,486 sq yd good gravel

Area 3 (Highway Bridge to V.D.S.13)- 108,249 sq yd good gravel

Area 4 (V.D.S.13 to Osoyoos Lake) - gravel area not surveyed

$$\frac{\text{Area 2}}{\text{Area (1+2+3)}} = \frac{29{,}486}{138{,}355} = 21.3\%$$

(c) Between 1947 and 1970 approximately 54% of spawners counted utilized Areas 1 and 2 (Ref. 8) Combining 1, 2 and 3 above, it is apparent:

That 54% of spawners counted utilize Area 1 and 2

(= Area of 2), and that 77% of these prefer good gravel. Thus 54% x 77% = 42% of spawners counted prefer good gravel in Area 2.

Accordingly, we can say either:

42% of counted spawners prefer good gravel In Area 2, or

$\frac{42}{21.3}$ x counted spawners prefer good gravel in Areas (1+2+3)

(d) Note that a graph of "Discharge vs. Good Gravel" in Areas (1 + 2 + 3) is available (Figure 5).

4. Gravel area requirement per pair of spawners was found as follows:

(a) 8 sq yd reported by C. J. Burner for Columbia River sockeye (Ref. 12).

(b) Biological observations that Okanagan River sockeye tend to locally bunch and crowd together in the preferred spawning areas.

(c) The estimate of 4 sq yd per pair used in Task 23 for salmon requirements appears to be too low inasmuch as calculations indicate anticipated sockeye escapement figures based on that value to be in excess of recorded escapements.

(d) Accordingly, a figure of 5 sq yd has now been adopted.

5. Hence a pro-rated figure for the effective spawning population is obtainable, which may be used in conjunction with the graph in 3 (d); hence the corresponding gravel area required. This pro-rated figure takes into account not only the area of good

gravel available, but also the areas preferred by the salmon.

From the above assumptions the figure is derived as follows:

SC = total count of spawning salmon in Areas (1+2+3+4)

E = effective spawners - 42% x SC

F = effective spawners in Areas (1 + 2 + 3) = 90% x E

PF = pro-rated figure x $\frac{42}{21.3}$ x F

Then good gravel required - 5 x PF

i.e. good gravel = 5 x $\frac{42}{21.3}$ x 0.42 x SC = 3.72 x SC

6. Gravel requirements with respect to spawning estimate are then found as follows:

Spawning Count	Gravel Required (yd sq)
10,000	37,200
20,000	74,400
30,000	111,600
35,000	130,200
38,900	141,000
40,000	148,800
50,000	186,000

From the "Discharge vs Spawning Gravel" graph, it is apparent that good sockeye support gravel is available up to l4l,000 square yards only.

Thus it is evident that when the total salmon count exceeds approximately 38,900, a certain percentage of spawners may be forced to utilize "medium" spawning gravel. Site observations indicate that this "medium" gravel is only marginally satisfactory to support adequate sockeye spawning.

APPENDIX 3

COMPARISON BETWEEN DISCHARGE REGIMES

In order to make comparison between the preferred fisheries discharges in the Okanagan River and the recorded discharge regime of such a river system, the following method was adopted.

6.1 The monthly runoff of the Okanagan River at Penticton for two seasons of divergent runoff patterns, 1923 and 1953, and also that of the South Thompson River at Monte Creek for 1963, were determined as percentages of the annual runoff of the respective rivers.

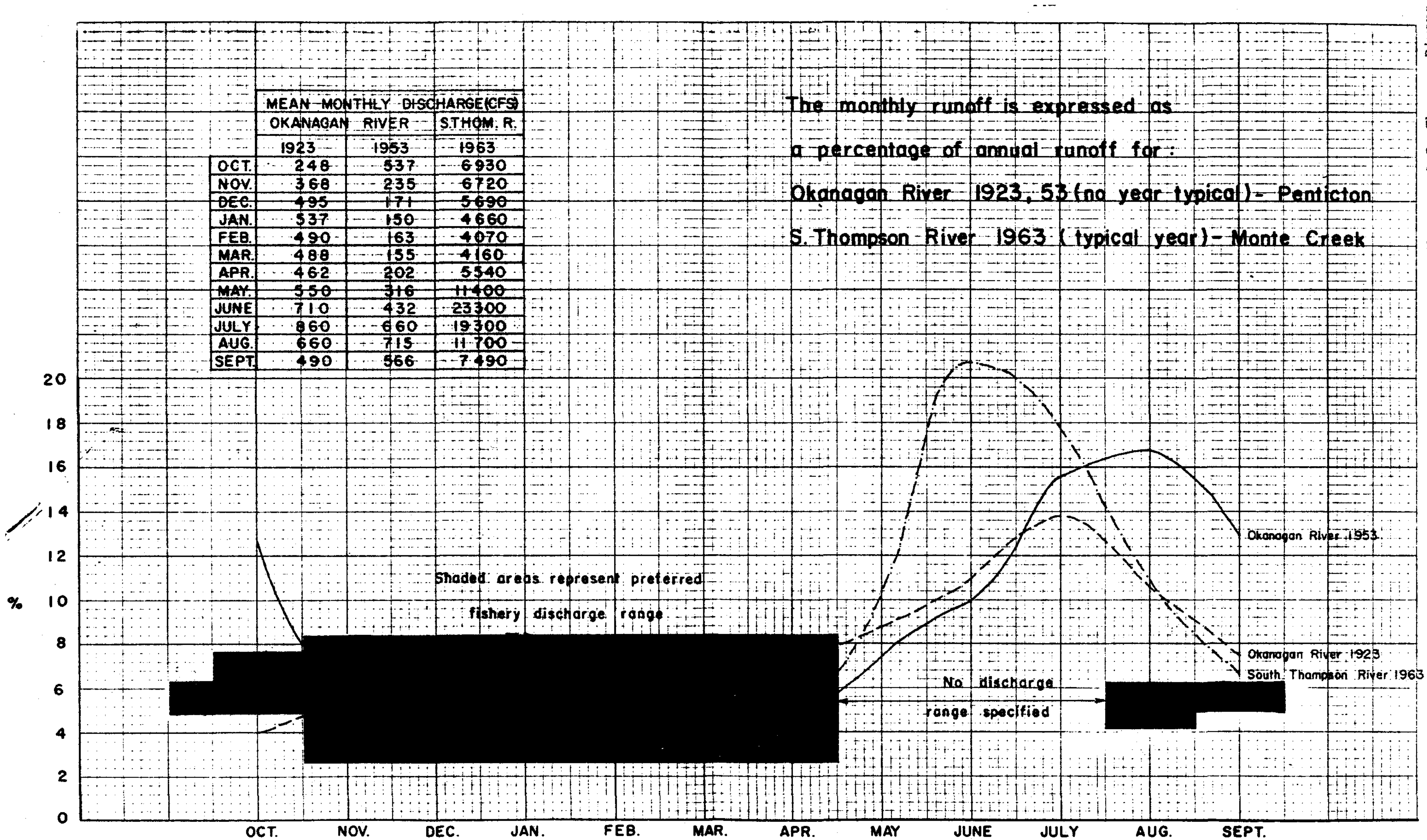
6.2 The monthly ranges of preferred fisheries discharges were expressed as percentages of the mean annual discharge multiplied by twelve.

6.3 A comparison of the two estimates indicates:

(a) 6.1 and 6.2 to be similar from November to April, and not dissimilar from May to July.

(b) 6.1 to be considerably greater than 6.2 in August, and marginally in September.

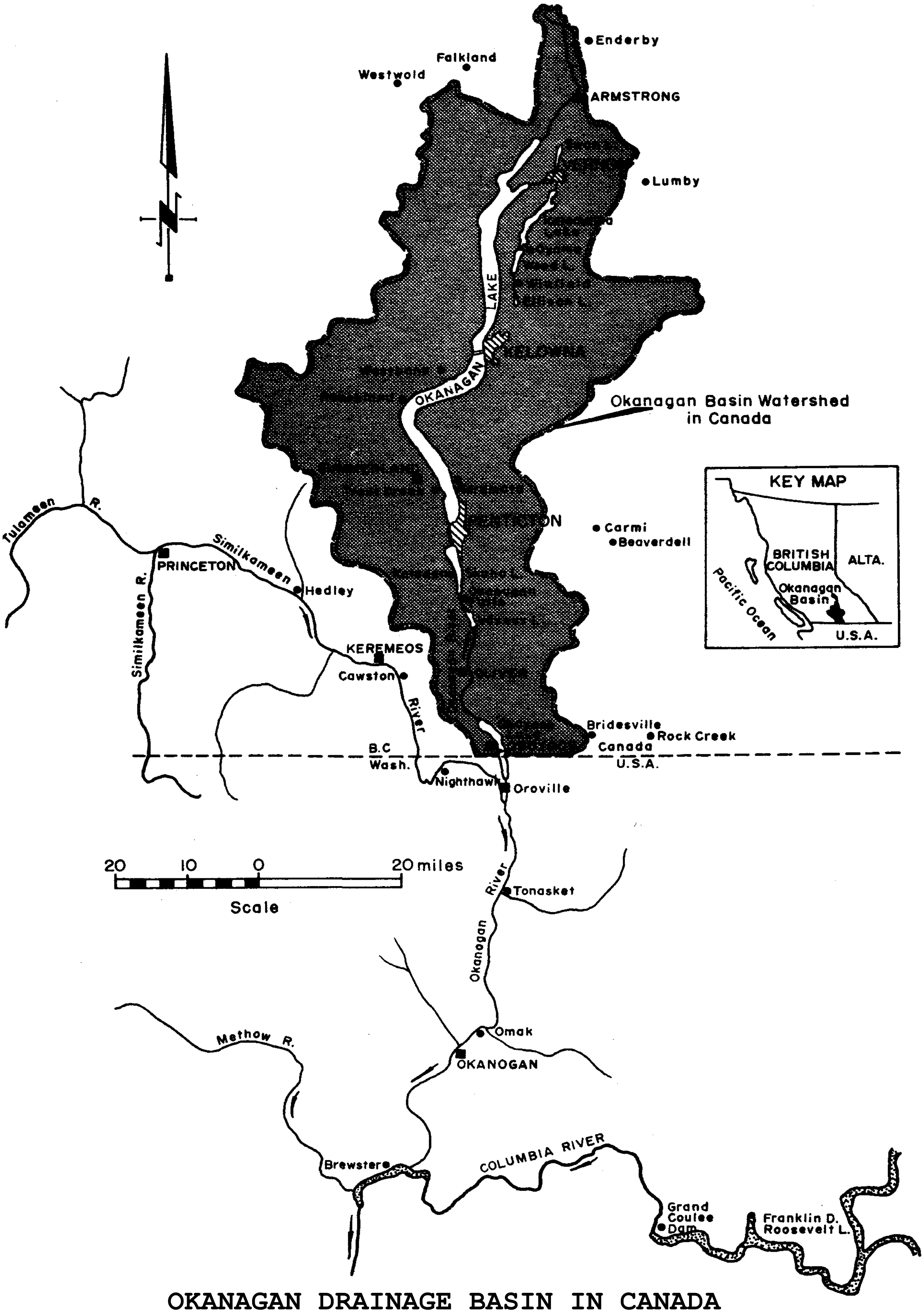
This comparison indicates that the "preferred fisheries discharges," as determined by technical surveys and analysis are of the same order of relative magnitude as naturally occurring conditions. Where a considerable discrepancy occurs this is explained by consideration of the regimes of high temperature which may occur in such a river/lake system.



	MEAN MONTHLY DISCHARGE (CFS)		
	OKANAGAN RIVER		S.THOM. R.
	1923	1953	1963
OCT.	248	537	6930
NOV.	368	235	6720
DEC.	495	171	5690
JAN.	537	150	4660
FEB.	490	163	4070
MAR.	488	155	4160
APR.	462	202	5540
MAY.	550	316	11400
JUNE	710	432	23300
JULY	860	660	19300
AUG.	660	715	11700
SEPT.	490	566	7490

Figure 9. Comparitive Time Distribution of Annual Runoff for Okanagan and S. Thompson Rivers

Figure 9. Comparitive Time Distribution of Annual Runoff for Okanagan & S. Thomson Rivers



OKANAGAN DRAINAGE BASIN IN CANADA