Indian River Feasibility Studies Groundwater Exploration 1972-1982 and Chinook Pilot Hatchery Operation 1979-1980

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INDIAN RIVER FEASIBILITY STUDIES
GROUNDWATER EXPLORATION 1972-1982
AND CHINOOK PILOT HATCHERY OPERATION 1979-1980

by

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Declining salmonid stocks in the Indian River prompted enhancement activities in the area during the 1970's. Nine separate sites in the Indian River watershed were drilled and tested for water quality between 1972 and 1982. All groundwater samples showed excessively low buffering capacity and hardness, slightly acidic water and low mineral content. The Indian River surface water showed similar characteristics. In addition, unacceptably high levels of iron and zinc occurred in some of the wells. To test the suitability of well No. 2 groundwater for culture of chinook, approximately 250,000 chinook eggs were transported from the Capilano hatchery to the Indian River pilot hatchery during November 1979. In June 1980, approximately 194,300 chinook smolts each weighing approximately 3 - 6 g were released into the Indian River; of these fry, 102,512 were tagged with code 02-18-39. Although egg-to-ponding survival was 91% and egg-to-release survival was 78%, rearing mortality could be related to inferior water quality and would be likely to be more severe under production fish culture conditions. Wells No. 7b and No. 9 may be most suited for fish culture purposes, but would require treatment in the form of aeration and mineral enrichment. These studies indicate that water quality is marginal for fish culture purposes in the Indian River watershed.

Key words: Indian River, surface water, groundwater, water quality, chinook (Oncorhynchus tshawytscha), hatchery, salmon, enhancement

RÉSUMÉ

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Le déclin des stocks de saumon de la rivière Indian a donné lieu à diverses activités de mise en valeur dans la région pendant les années 1970. Ainsi, entre 1972 et 1982, on a creusé neuf puits en divers points du bassin de la rivière Indian, afin d'évaluer la qualité de l'eau. Tous les échantillons d'eau souterraine ont révélé un pouvoir tampon et une dureté très faibles, une légère acidité et une faible teneur en minéraux. Il semble que l'eau de surface présente à peu près les mêmes caractéristiques. Par ailleurs, on signale des teneurs en fer et en zinc non acceptables dans certains puits. Pour vérifier si l'eau souterraine du puits n° 2 se prêtait à l'élevage du saumon quinnat, on a transporté, en novembre 1979, environ 250 000 oeufs de cette espèce, de la piscifacture de Capilano à la piscifacture pilote de la rivière Indian. En juin 1980, environ 194 300 jeunes saumons quinnat pesant de 3 à 6 g ont été relâchés dans la rivière Indian; de ce nombre, 102 512 ont été étiquetés avec le code 02-18-39. Bien que le taux de survie des oeufs jusqu'à la mise en bassin ait été de 91% et qu'il soit passé à 78% après la mise en liberté, la mortalité pendant l'élevage pourrait s'expliquer par la mauvaise qualité de l'eau, et serait probablement encore plus élevée dans des conditions normales d'élevage. Les puits n° 7 et 9 semblent être ceux qui conviendraient le mieux aux activités de pisciculture, mais il faudrait aérer l'eau et augmenter sa teneur en minéraux. Les études montrent que la qualité de l'eau est un facteur marginal pour les activités d'élevage du poisson dans le bassin de la rivière Indian.

Mots-clés: rivière Indian, eau de surface, eau souterraine, qualité de l'eau, saumon quinnat (Oncorhynchus tshawytscha), piscifacture, saumon, mise en valeur

GENERAL INTRODUCTION

Declining salmonid stocks in the Indian River (Fig. 1) prompted enhancement activities in the area during the 1970's (Fedorenko and Shepherd 1984). A major proposal was the construction of a multi-species hatchery on Indian River that would yield over 400,000 salmon adults (Fedorenko and Shepherd 1984).

The purpose of this report is to review the available data on Indian River surface water and groundwater, and the Indian River pilot hatchery, as well as to evaluate the suitability of this water for fish culture purposes. This report is divided into two main sections; the first deals with the water quality in the watershed and the second deals with the pilot hatchery.

GROUNDWATER EXPLORATION AT INDIAN RIVER, 1972-1982

INTRODUCTION

Water quality and quantity are critical in determining the acceptability of a site for fish culture. Between 1972 and 1982, nine separate drillings were conducted in the Indian River watershed in order to locate a suitable water source for a hatchery. The first two wells were drilled in 1972 in the Hixon Creek delta (Fig. 2). These two wells were used for a chinook pilot hatchery which operated between 1979 and 1980 in order to test the suitability of Indian River groundwater for incubation and rearing of salmon. The remaining seven wells were drilled between 1981 and 1982 at a new proposed hatchery site located approximately 2 km upstream of the Hixon Creek delta (Fig. 2).

METHODS

DRILLING AND WATER TESTING

Between March and April 1972, Underwood McLellan Ltd. drilled and tested two 200 mm diameter wells located about 300 m apart in the Hixon Creek delta (Fig. 2). The two wells, referred to as well No. 1 and well No. 2, were each pumped for approximately 24 hours at a rate of 1,932 l/min and 2,304 l/min respectively and sampled for water quality at the end of each test.

During July and August 1979, wells No. 1 and No. 2 were resampled for water quality in preparation for design and construction of the pilot hatchery. Well No. 1 was sampled at 45 hr, 69 hr, 91 hr and 93 hr after the start of pumping at a rate of 3,120 l/min. Well No. 2 was sampled at 24 hr, 45 hr, 72 hr and 99 hr after the start of pumping at a rate of 3,408 l/min. Well No. 1 was resampled for water quality in February 1980, during the operation of the Indian River chinook pilot hatchery.

During March and April 1981, a second groundwater exploration program was undertaken several kilometers north of the pilot hatchery site (Fig. 2) in order to further determine the potential for groundwater supply, since the original site showed marginal groundwater quality for fish culture purposes (see the second section of this report). The new site was selected on the basis of its proximity to potential gravity supply of surface water from Indian River and tributary creeks and land topography. This second program began by drilling and

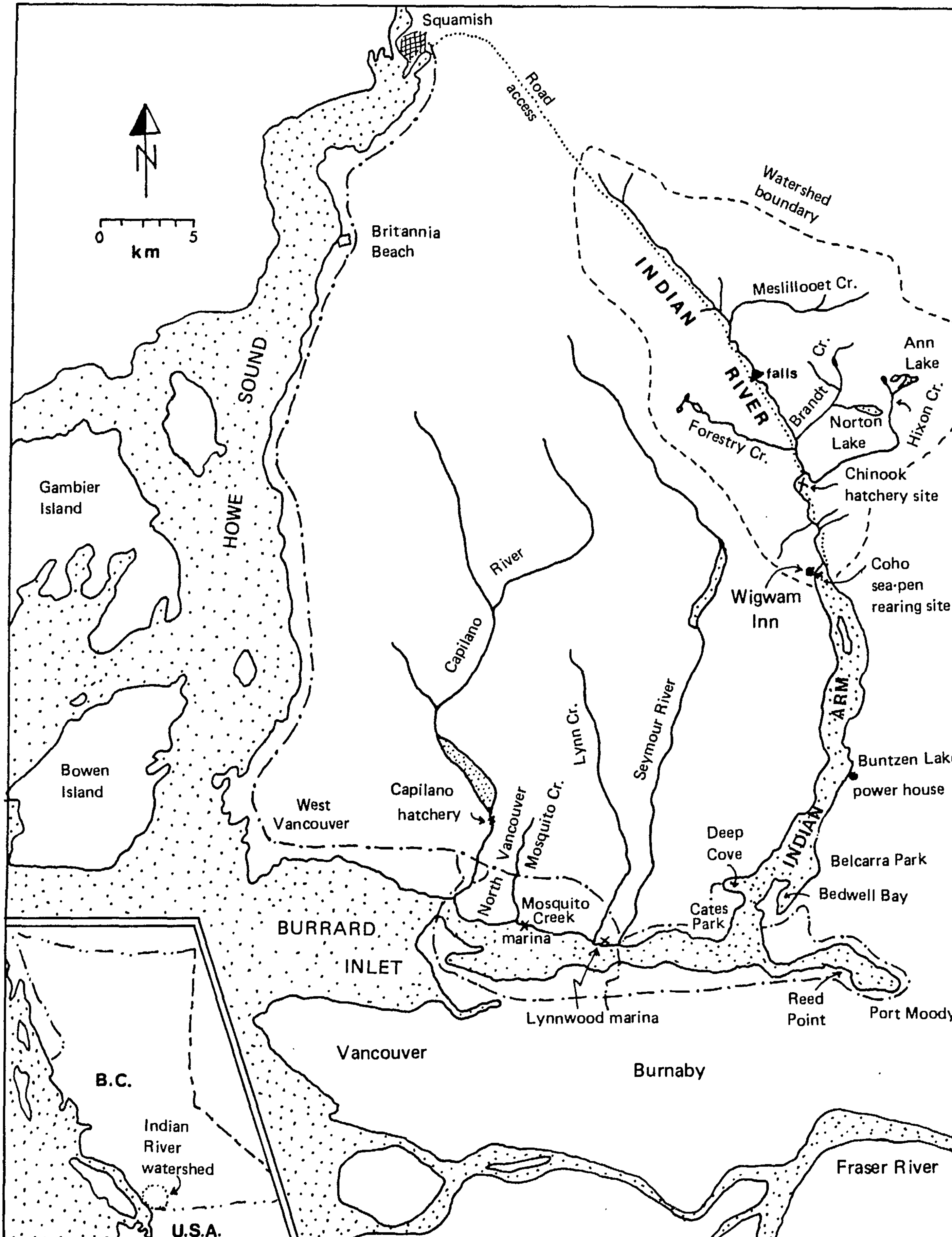


Fig. 1. Indian River watershed and the surrounding area.

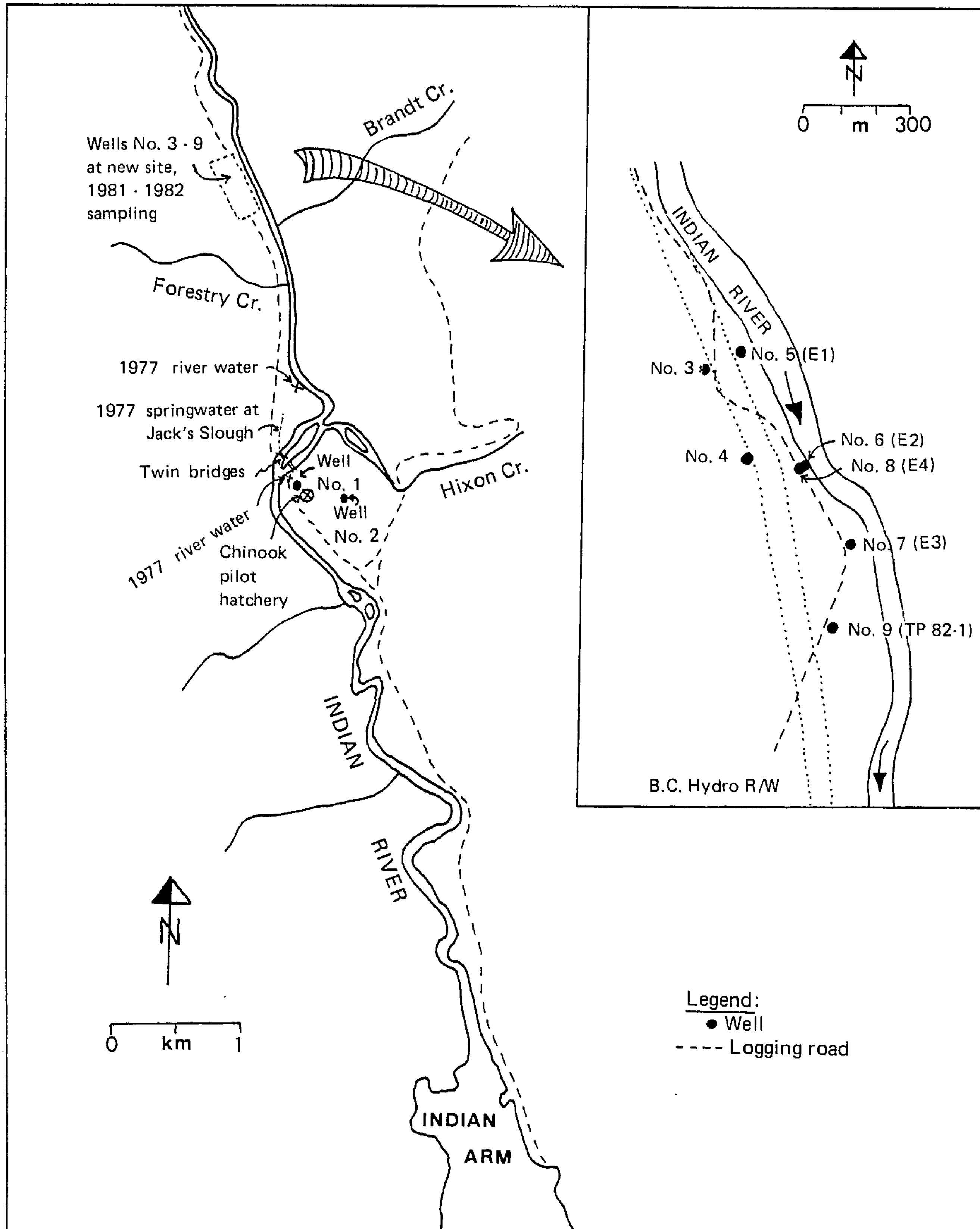


Fig. 2. Location of Indian River wells No. 1 - 9, and location of surface water and groundwater sampling sites, 1972 - 1982.

testing two 200 mm diameter wells located approximately 180 m apart and referred to as wells No. 3 and No. 4.

Well No. 3 was sampled three times at 2.0 hr, 23.5 hr and 29.0 hr after the start of pumping at a rate of 198 l/min. Pumping on this well was terminated after approximately 36 hours due to shortage of water in the aquifer. Well No. 4 was sampled four times at 2.3 hr, 22.0 hr, 30.5 hr and 45.5 hr after the start of pumping at a rate of 2,082 l/min.

During September 1981 to January 1982, additional wells were drilled in the vicinity of wells No. 3 and No. 4 in order to find better quality groundwater. Four 150 mm diameter exploration holes (E 1, E 2, E 3 and E 4 referred to in this text as wells No. 5, 6, 7 and 8 respectively) were drilled parallel and very close to the Indian River (Fig. 2). Well No. 6 was located only about 12 m away from well No. 8 in order to test the shallower aquifer only. It was thought that the groundwater in the alluvial aquifers at these near-river locations would be more suitable for hatchery purposes because of the increased influence of river water.

Six separate pump-tests with corresponding water sampling were carried out at the four wells; two of the wells, No. 5 and No. 7, were pumped with screens set at two different depths (the postscripts a and b in No. 5a, 5b and 7a, 7b indicate the deep and shallow settings respectively). The aim was to test any possible vertical zonation of hydrochemistry or hydraulic characteristics. The duration of the six pump-tests ranged from 15 hr to 22 hr depending upon when the water samples were collected. As these wells were exploration wells only, the pumping rates were low, ranging from 270 to 1,152 l/min.

In December 1982, a final test production well TP 82-1 (referred to in this text as well No. 9) located slightly downstream from the four exploration holes (Fig. 2) was drilled and tested. The 300 mm diameter well was pumped for 93 hours at a rate of 4,968 l/min. Four water samples were collected after 48.5 hr, 69 hr, 71.5 hr and 93 hr of pumping.

SAMPLE COLLECTION AND ANALYSIS OF GROUNDWATER

Water sampling and field measurements for each well were carried out during the constant rate pump-tests. The sampling was conducted either at the end of each aquifer test, generally after 24 hours of constant pumping, or at selected intervals during long-term pump-tests of up to four days (see above). Samples were delivered to the laboratory for analysis within 48 hr of sampling. Well locations, sampling dates and the groups involved in sample collection and water analyses are given in Appendix 1.

Field analysis

Field measurements were made of water temperature, dissolved oxygen (DO), total gas pressure (TGP), pH and conductivity. Water samples were collected from a piezometer tube attached to the pump head. The piezometer tube was placed into an overflow bucket in which field measurements of unstable parameters were made. Temperature was measured using hand thermometers, and after 1979, Fisher total immersion primary reference mercury thermometers (range

- 1.0°C to 51°C; expected accuracy ±0.1°C) checked with thermocouples on the DO and conductivity meters.

Conductivity, DO and TGP were measured in the overflow bucket. The DO, pH, TGP and ORP (oxygen/reduction potential) meters were calibrated before each measurement. The pH values obtained in the field and the laboratory were generally similar. However, either of the two values was often somewhat higher than the other depending on the sample. Consequently, only the laboratory pH data were used in evaluating the water quality since the laboratory technique was considered to give more standardized readings.

Ryznar and Langlier stability indices were calculated using the field temperature and pH, total filterable residue, calcium and alkalinity data.

Laboratory analysis

The water samples were analyzed by the DFO-EPS Laboratory in West Vancouver, except in 1972 when the Can Test Ltd. performed the analyses. Can Test analyzed the samples in accordance with the procedures set down by the American Public Health Association (1971). EPS analysis followed the methods outlined in the Environmental Protection Services Manual (1979).

The 1972 water samples from wells No. 1 and No. 2 and from Indian River and Hixon Creek were analyzed for dissolved metals. Thereafter, all water samples were analyzed for extractable metals. The latter value gives an indication of what the expected dissolved metal concentration may be under the worst potential set of conditions for fish culture such as low dissolved oxygen, high CO_2 and low pH. It is the dissolved metal fraction which generally causes toxic response in fish (Sigma MS 1983).

Extractable metals were determined by running the sample through ICAP (Inductively Coupled Argon Plasma). Lower detection limits for extractable forms of copper (Cu), lead (Pb), zinc (Zn), potassium (K), mercury (Hg) and iron (Fe) were obtained using the graphite furnace method. However, the extractable form of cadmium (Cd) was generally analyzed only to 0.001 mg/l detection level although the maximum Cd level recommended by Sigma(MS 1983) is less than 0.0003 mg/l.

During the testing of wells No. 5, 6, 7 and 8 in 1981 and 1982, rapid iron analysis was desired since high iron levels were previously observed in the area during the testing of well No. 4. Therefore, on-site measurements were made using pH Hach Kits (ranges 0.1-1.0 mg/l Fe and 1.0-10.0 mg/l Fe); and laboratory measurements were made on the day of sampling using a manual titration method specific to iron (ICAP analyses were also performed later). The rapid analysis was intended to provide the hydrogeologist with sufficient information on iron content enabling him to decide which hole to drill next.

SAMPLE COLLECTION AND ANALYSIS OF SURFACE WATER

The Indian River surface water was usually sampled in conjunction with test pumping and water quality sampling at each well. In most cases, a single river sample was collected in a fast flowing stretch immediately upstream of the well being tested. In addition, staff from DFO sampled the Indian River on 15 occasions between January and August 1977 at three different sites: the Indian River mainstem above and below the Hixon Creek confluence, and springwater entering a side-channel near that confluence (Fig. 2). Hixon Creek and Forestry Creek (Fig. 2) were each sampled for water quality once in 1972 and 1981 respectively.

Water sampling and analytical methods for surface water were generally similar to those described for groundwater. Field measurements included water temperature and pH. In addition to river temperatures measured during the pump-tests, continuous river temperature records were made during parts of 1951 (Marshall et al. 1976); during parts of 1959 and 1966 (Underwood McLellan and Associates Ltd. MS 1972); during January to August 1977 using Taylor seven-day thermographs at two sites (site A located on the mainstem about 180 m upstream of Hixon Creek confluence and site B located near the origin of a groundwater stream which enters Jack's Slough; Fig. 2); during parts of July and August 1978 using a Taylor seven-day thermograph; and during August to October 1981 using a Ryan thermograph. The latter was lost on October 14 due to extreme flooding conditions.

Measurements of pH were made in the field using a Hach Kit or pH meter. On August 26, 1979, spatial variation in pH was investigated using a Hach Kit at 11 sites near the Hixon Creek delta in the vicinity of the proposed hatchery intake (Fig. 3).

Flow metering stations have been maintained by the Water Survey of Canada at the following locations and times:

1) Indian River, upper station No. 8GA5 located 12 km upstream from the mouth, during 1912 to 1921;

2) Indian River at the mouth, station No. 8GA4 located 1.5 km from the mouth, during 1912 only;

3) Hixon Creek at the mouth, station No. 8GA3, during parts of 1912 to 1914.

Water levels in the Indian River above the Hixon Creek confluence were also monitored during July to December 1978 using a water level recorder.

Locations of surface water sampling sites in the Indian River, sampling dates, and the groups involved in sample collection and analysis are given in Appendix 2.

RESULTS AND DISCUSSION

INDIAN RIVER GROUNDWATER

Groundwater geology of the Indian River Valley is described by Robinson, Roberts and Brown Ltd. (MS 1972); Underwood McLellan and Associates Ltd. (MS 1972); and Brown, Erdman and Associates Ltd. (MS 1982). Appendix 3 summarizes the properties of the Indian River aquifers.

All water quality measurements were compared to the values recommended for fish culture purposes by Sigma (MS 1983). These values are summarized in Table 1. The values for the major water quality parameters of concern observed at wells No. 1 to No. 9 in the Indian River watershed are given in Table 2. Detailed data are presented in Appendices 4 to 8. Major groundwater characteristics for each well are described below.

Well No. 1

The six samples collected for water quality at well No. 1 during 1972, 1979 and 1980 showed little variation with time except for seasonal changes in water temperature (Table 2, Appendix 4). The well water measured 5.5° C to 9° C, and was low in alkalinity (4 to 7 mg/l as $CaCO_3$), hardness (2 to 5 mg/l as $CaCO_3$) and pH (5.7 to 6.0). It was undersaturated in dissolved oxygen (50%) and near saturation in dissolved nitrogen (96% to 97%).

Well No. 2

The five samples collected for water quality at well No. 2 during 1972 and 1979 showed little variation with time (Table 2, Append. 5). The well water measured 7°C to 8.3°C, and was low in alkalinity (4 to 8 mg/l as $CaCO_3$), hardness (4 to 5 mg/l as $CaCO_3$) and pH (5.3 to 6.1). It was undersaturated in dissolved oxygen (60% to 70%) but supersaturated in dissolved nitrogen (108% to 110%).

Well No. 3

The three samples collected for water quality at well No. 3 between 2 hr and 29 hr after the start of pumping generally showed little variation with time except for the concentrations of several metals (chromium, copper, manganese, sodium and zinc) which declined after the first two hours of pumping (Table 2, Appendix 6). Discounting the first sample taken at 2 hr due to its greater variability, the well water measured 8.6° C, and was low in alkalinity (10 to 11 mg/l as $CaCO_3$), hardness (9 mg/l as $CaCO_3$) and pH (6.2 to 6.8). It was also undersaturated in dissolved oxygen (45% to 50%) but supersaturated in dissolved nitrogen (119%). Nitrates averaged 0.245 mg/l and were higher compared to the other Indian River wells.

Of concern among metals was the elevated copper level which ranged from 0.006 mg/l at the 2 hr pump test to 0.003 mg/l at later tests (Appendix 6) compared to the recommended level of < 0.002 mg/l (dissolved).

This source yielded orange-stained water (indicating high iron) for the first 10 minutes of pump testing. The water then cleared and the iron remained at only around 0.04 mg/l for all pump tests carried out 2 hr after the start of pumping. Based on the above, well No. 3 appeared to be a stagnant aquifer equalibrated with iron bearing gravels and with a relatively short recharge time, probably from the river, when the water is drawn from it.

Well No. 4

The four samples collected for water quality at Well No. 4 between 2 hr and

Table 1. Water quality parameter screening table.[a]

FISH CULTURE PARAMETERS		METALS	
Parameter	Recommended screening levels	Metal	Maximum acceptable levels (mg/L)
Alkalinity	>15 mg/L as $CaCO_3$	Aluminum (total)[b]	< 0.100
Ammonia (total)	<0.05 mg/L as N	Cadmium (dissolved)[c]	< 0.0003
Dissolved oxygen	> 11.2 mg/L O_2 and > 95% saturation	Chromium (total)	< 0.040
		Copper (dissolved)	< 0.002
Dissolved gas (total)	< 103%	Iron (total)	< 0.300
Hardness	> 20 mg/L as $CaCO_3$	Mercury (total)	< 0.0002
Nitrite	< 0.015 mg/L as N	Manganese (total)	< 0.100
pH	7.2 - 8.5	Nickel (total)	< 0.045
Suspended solids	< 3 mg/L	Lead (total)	< 0.004
		Selenium (total)	< 0.050
		Zinc (dissolved)	< 0.015

a From Sigma (MS 1983).
b Total metals are determined on unfiltered samples preserved with HNO_3 acid in the field and thoroughly digested with hot acid in the laboratory.
c Dissolved metals are determined on a filtrate passed through a 0.45 μm membrane filt r in field (EPS lab does not use acid digestion).

Table 2. Values for selected water quality parameters of concern for Indian River wells No. 1 - No. 9, 1972 - 1982.[a]

		GENERAL PARAMETERS								METALS[b]			
		Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	pH	Dissolved oxygen (mg/l O_2)	Dissolved oxygen (% Sat'n)	Dissolved gases (% total)	Dissolved gases (% N_2)	Temperature[c] (°C)	Copper (mg/l Cu)	Iron (mg/l Fe)	Mercury (mg/l Hg)	Zinc (mg/l Zn)
Recommended value[d]		>15	>20	7.2 - 8.5	>11.2	>95%	<103	-	--	< 0.002 (dis.)[e]	< 0.300 (tot.)[f]	< 0.0002 (tot.)	< 0.015 (dis.)
Well No.	Sampling year												
1	1972, 1979, 1980	4 - 7	2 - 5	5.7 - 6.0	6.0	50	85 - 86	96-97	5.5 - 9	< 0.001 - 0.015 (dis.)	< 0.01 - 0.07	< 0.0002	< 0.001 (tot.)
2	1972, 1979	4 - 8	4 - 5	5.3 - 6.1	7.0 - 8.0	60 - 70	98 - 99	108 - 110	7.0 - 8.3	< 0.001	< 0.02 - 0.05 (tot.)	< 0.0002	< 0.001
3	1981	10 - 11	9	6.2 - 6.8	5.4 - 6.0	45 - 50	104 - 106	119	8.6	0.003 - 0.0035	0.04	< 0.0002	0.001 - 0.002
4	1981	14 - 15	9 - 10	6.4 - 6.6	5.0 - 5.2	40 - 42	104	120 - 121	6.9	< 0.001	1.02 - 1.06	< 0.0002	0.002 - 0.004
5a (deep)	1981	15	15	6.6	2.5	21	100	122	7.8	< 0.001	0.02	0.00049[g]	0.018
5b (shallow)	1981	13	14	6.4	5.6	47	111	115	8.6	< 0.001	0.01	0.00035[g]	0.032
6 (E 2)	1981	13	12	6.3	3.4	28	100	119	8.2	< 0.001	0.04	0.00032[g]	0.017
7a (deep)	1981	12	10	6.9	3.2	26	105	126	6.2	< 0.001	0.51	< 0.0002	0.009
7b (shallow)	1981	9	7	6.5	7.8	63	103	113	6.2	< 0.001	0.01	< 0.00044[g]	0.009
8 (E 4)	1982	13	11	6.3	3.8	31	102	121	6.7	< 0.001	0.02	< 0.0002	0.016
9 (TP 82-1)	1982	6	6 - 11	6.0 - 6.1	6.5 - 7.5	53 - 61	101 - 104	114 - 117	6.8	< 0.005 - 0.018	< 0.005 - 0.007	< 0.0002	< 0.002

[a] Excludes the 2 hr pump tests at wells No. 3 and No. 4.
[b] Extractable metal concentrations are given except where indicated; underlined metal concentrations indicate higher than recommended levels.
[c] Indicates point values only, not the seasonal range.
[d] From Sigma (MS 1983).
[e] Dissolved metals.
[f] Total metals.
[g] Suspect mercury values (see text).

45.5 hr after the start of pumping generally showed little variation with time (Table 2, Appendix 6). Discounting the first sample taken at 2 hr due to its slightly greater variability, the well water measured 6.9° C, and was low in alkalinity (14 to 15 mg/l as $CaCO_3$), hardness (9 to 10 mg/l as $CaCO_3$) and pH (6.4 to 6.6). It was also undersaturated in dissolved oxygen (40% to 42%) and supersaturated in dissolved nitrogen (120% to 121%)).

Of concern among metals was the elevated iron level which ranged from 0.824 mg/l at the 2 hr pump test to 1.06 mg/l at the 45.5 hr pump test, and was higher than the recommended level of < 0.300 mg/l (total). However, this iron appears to be tightly bound to organics since samples examined 24 hours after collection (and thus presumably well aerated) showed no signs of flocculent sedimentation (D. Graham, Sigma, pers. comm.). By comparison, the Indian River surface water sampled concurrently had an iron level of only 0.012 mg/l (Appendix 9).

<u>Wells No. 5a and No. 5b</u>

Wells No. 5a (screen depth 16.9 m to 21.0 m) and No. 5b (screen depth 10.6 m to 13.4 m) had similar water quality at the two screen depths except for dissolved gases, temperature and zinc content (Table 2, Appendix 7):

	Well No. 5a (deep)	Well No. 5b (shallow)
Dissolved oxygen	21%	47%
Dissolved nitrogen	122%	115%
Temperature	7.8° C	8.6° C
Zinc	0.018 mg/l	0.032 mg/l

The well water at both depths was low in alkalinity (13 to 15 mg/l as $CaCO_3$), hardness (14 to 15 mg/l as $CaCO_3$) and pH (6.4 to 6.6). It was undersaturated in dissolved oxygen (21% to 47%) and supersaturated in dissolved nitrogen (115% to 122%). The oxygen and nitrogen components in the shallow well come closer to saturation values than in the deeper well, perhaps reflecting a more direct contact with surface water sources. Water from both depths showed elevated zinc levels (see above) compared to the recommended value of < 0.015 mg/l (dissolved).

<u>Wells No. 6 and No. 8</u>

Wells No. 6 (screen depth 10.4 m to 11.5 m) and No. 8 (screen depth 29.5 m to 34.9 m) were drilled approximately 12 m apart. These two wells were assumed to be in the same basic groundwater zone. Water quality was generally comparable in the two wells except for water temperature (Table 2, Appendix 7). The temperature differences may be attributed to seasonal changes due to different sampling times (September for well No. 6 vs. January for well No. 8.).

The well water at both sites was low in alkalinity (13 mg/l as $CaCo_3$), hardness (11 to 12 mg/l as $CaCO_3$) and pH (6.3). It was also undersaturated in dissolved oxygen (28% to 31%) and supersaturated in dissolved nitrogen (119% to 121%). Both wells showed zinc levels (0.016 mg/l to 0.017 mg/l) just above the maximum recommended value of < 0.015 mg/l.

Wells No. 7a and 7b

Wells No. 7a (screen depth 42.6 m to 49.4 m) and No. 7b (screen depth 25.9 m to 31.4 m) had similar water quality at the two screen depths except for dissolved gases and iron content (Table 2, Appendix 7):

	Well No. 7a (deep)	Well No. 7b (shallow)
Dissolved oxygen	26%	63%
Dissolved nitrogen	126%	113%
Iron	0.51 mg/l	0.01 mg/l

The well water at both depths measured 6.2°C, and was low in alkalinity (9 to 12 mg/l as $CaCO_3$), hardness (7 to 10 mg/l as $CaCO_3$) and pH (6.5 to 6.9). As in wells No. 5a and 5b, the shallower well here showed dissolved oxygen and nitrogen values closer to saturation levels, probably reflecting a more direct contact with surface water sources. The more anoxic conditions observed in the deeper well would promote the dissolution of iron from subsurface deposits, and in fact water from the deeper well exceeded the recommended iron value of < 0.3 mg/l. High iron content was also observed at well No. 4 drilled in the same general area (see above).

Well No. 9

The four samples collected for water quality at well No. 9 between 49 hr and 93 hr after start of pumping showed little data variation with time except for the elevated copper level at the 93 hr pump test (Table 2, Appendix 8). The well water measured 6.8° C, and was low in alkalinity (6 mg/l as $CaCO_3$), hardness (6 to 11 mg/l as $CaCO_3$) and pH (6.0 to 6.1). It was also undersaturated in dissolved oxygen (53% to 61%) and supersaturated in dissolved nitrogen (114% to 117%). Of concern among metals was the elevated copper level of 0.018 mg/l) compared to the recommended value of < 0.002 mg/l (dissolved). This showed up in the last 93 hr sample along with slightly higher values for calcium, iron and sodium, and indicates the intrusion of another groundwater body into the well area; Sigma suggested that this other body was the river. Long-term pumping and sampling would be required to resolve this question.

Non-metal parameters of concern

Alkalinity ranged from 4 to 15 mg/l as $CaCO_3$ in all the wells tested (Table 2), which was below the recommended minimum value of 15 mg/l as $CaCO_3$ (Table 1). The buffering capacity of this water is therefore projected to be poor. All of the groundwater samples also showed exceptionally low hardness (overall range 2 to 15 mg/l as $CaCO_3$) compared to the minimum acceptable level of 20 mg/l as $CaCO_3$. This is of importance, since hard water may reduce the toxicity of several heavy metals such as cadmium, copper and zinc, and the severity of diseases such as gas bubble and kidney disease (Sigma MS 1983). All samples showed low ionic content as indicated by total alkalinity, specific conductance, calcium, hardness and filterable residue data.

All the groundwater sampled was also moderately to slightly acidic with a mean pH of 6.3 (range 5.3 to 6.9; Table 2). Since the minimum suggested pH value for salmonid hatcheries is 6.5 (Sigma MS 1983), the pH of the groundwater is marginally unacceptable for fish culture. The recommended pH range for hatcheries is 7.2 to 8.5 (Sigma 1983); this range allows for some pH reduction due to CO_2 production by fish respiration in intensive rearing. Operational techniques such as the use of CO_2 as an anaesthetic should be avoided at such low pH.

The combined low alkalinity, hardness, organic chelators and low pH generally result in a higher dissolved fraction of trace metals and, therefore, a higher probability of toxic effects. The presence of other pH-sensitive toxic substances such as ammonia and nitrite may cause further restrictions to fish culture (Sigma MS 1983). Finally, there may be synergistic reactions, for example, between NH_3 or CO_2 and metals. Thus, whereas individual toxicant concentrations may not be harmful, in combination they may be lethal.

Wells No. 1 and No. 2 had the lowest alkalinity, hardness, pH and ionic content of all the wells tested in the Indian River watershed (Table 2). These water characteristics were probably partly responsible for the fish health problems (coagulated-yolk and fin-rot in rearing juveniles) observed in the chinook pilot hatchery which was supplied by well No. 1 (see later section on chinook rearing).

Some of the wells such as No. 3, No. 4 and No. 6 showed elevated nitrate or phosphate levels (Appendices 6 & 7). Although culture problems are not anticipated at these concentrations, pollution problems may be encountered from hatchery discharges using these sources.

Metals of concern

Of the Indian River wells sampled for water quality between 1972 and 1982, higher than recommended metal levels were observed as follows:

	Metal (mg/l)			
	Copper (Cu)	Iron (Fe)	Zinc (Zn)	Mercury (Hg)
Recommended level	< 0.002 (dis.)	< 0.300 (tot.)	< 0.015 (dis.)	< 0.0002 (tot.)
Well No.				
1	< 0.001 - 0.015 (dis.)	-	-	-
3	0.003 - 0.0035	-	-	-
4	-	1.02 - 1.06	-	-
5a	-	-	0.018	0.00049
5b	-	-	0.032	0.00035
6	-	-	0.017	0.00032
7a	-	0.51	-	-
7b	-	-	-	0.00044
8	-	-	0.016	-
9	< 0.005 - 0.018	-	-	-

The above results must be interpreted with caution. For example, in wells No. 1 (Appendix 4) and No. 9 (Appendix 8) only one water sample out of a series of samples taken at each site showed an elevated copper level, while the remaining samples showed non-detectable levels. The higher values may indicate a real increase or, more likely, a possible contamination of the sample in the field or the laboratory (R. Holwaty, EPS, pers. comm.). The elevated copper levels observed at well No. 3 are probably real and may pose a problem in fish culture particularly due to possible synergistic reactions among individual toxicants. The high iron content in well No. 4 was confirmed by replicate samples but the value for well No. 7a was based on one sample only and should be confirmed by resampling. The elevated zinc levels observed in wells No. 5a, 5b, 6, and 8 are probably real but since only one sample was taken at each well, these values should be confirmed by resampling.

The apparent presence of mercury in wells No. 5a, 5b, 6 and 7b is probably an anomaly. Detectable mercury levels (> 0.0002 mg/l) in both the groundwater and surface water samples at Indian River (see below) were observed only during the 1981 sampling program and were probably due to an irregularity during the sampling procedure or laboratory analysis.

In summary, of the nine wells drilled in the Indian River watershed, strong evidence of iron toxicity was observed at well No. 4 and possibly No. 7a; and potential zinc toxicity was observed at wells No. 5a, 5b, 6 and 8. In addition, well No. 3 may have problems with copper contamination. The remaining wells (No. 1, 2, 7b and 9) appear to have metal concentrations acceptable for fish culture, given that other parameters such as pH remain stable.

<u>Other water quality concerns</u>

Some of the parameter variations observed between wells No. 1 and No. 2 in the Hixon Creek delta (especially temperature, Table 2) could be caused by seasonal changes in groundwater; a month's delay occurred between the 1979 pump tests for the two wells. Similarly, some of the parameter variations observed for wells No. 3 to No. 9, were probably also caused by seasonal changes in groundwater since water sampling in that area occurred over a two-year period.

In addition, the water quality results for wells No. 5 to No. 8 should be interpreted with caution since these four exploration wells were tested at very low pumping rates which would not be typical of a normal hatchery operation. The water quality might change significantly if these same sites were pumped at production well rates.

Possible contamination of the Indian River groundwater could occur from chemical control of vegetation within the B.C. Hydro's right-of-way. However, no analyses were performed to specifically determine whether any pesticides or herbicides exist in any of the well sources.

<u>Water quantity and recharge source</u>

Based on the pump-tests, the wells which were considered to be adequate in meeting the projected water demands of a flow-through hatchery and rearing facility were No. 1, 2, 4, 7, 8 and 9. The remaining wells No. 3, 5 and 6 had insufficient yield.

Pump-tests indicated that wells No. 1 and No. 2 in the Hixon Creek delta tap an unconfined aquifer which probably connects hydraulically with the Indian River. Wells No. 3 and No. 4 located further upstream, appear to tap hydrologically distinct aquifers from each other. This was suggested by water quality data, especially iron, which indicated that the aquifer supplying well No. 3 was small and probably recharged from the river.

Pump-tests for wells No. 5, 6, 7 and 8 suggested the presence of a thick, unconfined aquifer recharged from the Indian River. Of these four wells, well No. 7b with the shallower screen depth was the highest-yield exploration well. Well No. 8 also showed a good yield potential.

Well No. 9 probably taps an aquifer with an indirect artesian connection to the Indian River. Transmissivity values for this well were the highest obtained in this part of the valley; the only wells showing a higher transmissivity were No. 1 and No. 2 in the Hixon Creek delta (Appendix 2).

In summary, all the Indian River wells tested appear to tap aquifers that are linked directly or indirectly with the Indian River. Consequently, heavy and prolonged pumping should result in infiltration of surface water from the river into the underlying aquifers. Brown, Erdman and Associates Ltd. (MS 1982) estimated that the surface water may constitute up to 50% to 75% of the groundwater being pumped. Such a recharge of aquifers by the Indian River water may be advantageous since the latter is generally of better quality than the groundwater. For example, iron content in the Indian River is low (see later section on Indian River surface water) compared to some of the wells tested. In addition, pH may be more neutral, thereby keeping heavy metals out of solution; mean pH for all the groundwater sources was only 6.3 (Table 2) compared to 6.8 for the Indian River surface water (Table 3).

INDIAN RIVER SURFACE WATER

Water quality

All water quality measurements were compared to the values recommended for fish culture purposes by Sigma (MS 1983) shown in Table 1. The values for the major water quality parameters of concern in the Indian River surface water are given in Table 3. Detailed data are provided in Appendix 9. Major water quality characteristics are described below.

All surface water samples collected in the Indian River watershed between 1972 and 1982 generally showed similar water quality characteristics except for considerable seasonal changes in water temperature (Table 3). The combined samples showed extremely low alkalinity (2 to 14 mg/l as $CaCO_3$), low hardness (3 to 17 mg/l as $CaCO_3$) and often slightly acidic water. The mean pH of the surface water was 6.8, higher than the mean pH of 6.3 for the groundwater (Table 2). Hixon Creek water, sampled in 1972, showed the lowest hardness (3 mg/l as $CaCO_3$) and pH (5.4). This creek may have affected the mainstem water below the confluence as indicated by a tendency towards slightly lower overall alkalinity,

Table 3. Values for selected water quality parameters of concern for surface water in the Indian River watershed, 1972 - 1982.

			GENERAL PARAMETERS					METALS[a]				
			Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	pH	Ammonia (tot.)[f] (mg/L or N)	Temperature[b] (°C)	Aluminum (mg/L Al)	Copper (mg/L Cu)	Iron (mg/L Fe)	Mercury (mg/L Hg)	Zinc (mg/L Zn)
Recommended value[c]			>15	>20	7.2 - 8.5	< 0.05	—	< 0.100 (tot.)[d]	< 0.002 (dis.)[e]	< 0.300 (tot.)	< 0.0002 (tot.)	< 0.015 (dis.)
Data set	Sampling site	Sampling year										
1	Hixon Cr. (near mouth)	1972	6	3	5.4	—	—	0.05 (dis.)	<u>0.025 (dis.)</u>	0.15 (tot.)	—	< 0.01 (dis.)
2	Indian R. (below Hixon Cr.)	1972	7	4	6.4	—	—	< 0.05 (dis.)	<u>0.03 (dis.)</u>	0.15 (tot.)	—	< 0.01 (dis.)
3	Indian R. (above Hixon Cr.)	1977	9.0 (4.6 - 12)[h]	12 (8 - 17)[h]	7.1 (6.8 - 7.4)[h]	(< 0.005 - 0.024)[h]	—	—	< 0.01[h]	(< 0.03 - 0.10)[h]	—	(< 0.01 - <u>0.05</u>)[f]
4	Indian R. (below Hixon Cr.)	1977	5.0 (2.6 - 9)[h]	7 (4 -12)[h]	6.5 (6.1 - 6.8)[h]	(< 0.005 - 0.008)[h]	—	—	< 0.01[h]	< 0.03[h]	—	(< 0.01 - <u>0.04</u>)[f]
5	Indian R. (spring water)	1977	4.4 (3 - 6)[h]	6 (4 - 9)[h]	6.1 (6.0 - 6.9)[h]	(< 0.005 - 0.010)[h]	—	—	< 0.01[h]	(< 0.03 - 0.04)[h]	—	(< 0.01 - <u>0.06</u>)[f]
6	Indian R. (at bridge below Hixon Cr.)	1979	8	9	6.9	< 0.005	10.5	< 0.09	< 0.001	0.03	< 0.0002	< 0.001
7	Indian R. (near well No. 1)	1979	9	13	6.8	< 0.005	15.0	< 0.09	< 0.001	< 0.01	< 0.0002	< 0.001
8	Indian R. (near wells No. 3 & 4)	1981	10	11	6.8	< 0.005	-	0.098	< 0.001	0.012	< 0.002	0.001
9	Indian R. (at bridge below Hixon Cr.)	1981	11	14	7.4	0.098	5.7	0.051	< 0.001	0.011	0.0002	< 0.001
10	Forestry Cr. (near mouth)	1981	7	6	7.0	0.092	-	0.069	< 0.001	0.012	0.0002	< 0.001
11	Indian R. (near well No. E 2)	1981	10	13	7.0	0.008	9.4	0.09	< 0.001	0.07	< 0.0002	0.002
12	Indian R. (near well No. E 1)	1981	14	16	7.4	< 0.005	7.1	< 0.05	< 0.001	0.015	<u>0.0006</u>[g]	< 0.001
13	Indian R. (near well No. E 1)	1981	10	12	7.1	< 0.005	7.1	< 0.05	< 0.001	0.06	< 0.0002	< 0.001
14	Indian R. (near well No. E 3)	1981	11	13	6.9	< 0.005	5.2	0.06	< 0.001	< 0.01	< 0.0002	< 0.005
15	Indian R. (near well No. E 3)	1981	6	8	6.7	< 0.005	4.9	<u>0.53</u>	< 0.001	<u>0.405</u>	<u>0.00031</u>[g]	0.002
16	Indian R. (near well No. E 4)	1982	8	9	6.0	< 0.005	4.4	0.05	< 0.001	0.02	< 0.0002	0.001
17	Indian R. (near well No. TP 82-1)	1982	5	7	6.5	< 0.005	4.5	0.08	< 0.005	0.015	< 0.0002	< 0.002

[a] Extractable metal concentrations are given except where indicated; underlined metal concentrations indicate higher than recommended levels.
[b] Indicates point values only, not the seasonal range.
[c] From Sigma (MS 1983).
[d] Total.
[e] Dissolved.
[f] Mean and range (in parenthesis) are given; data represent 15 separate sampling occasions between January and August 1977.
[g] Suspect mercury levels (see text).

hardness and possibly pH in the Indian River below compared to above the confluence:

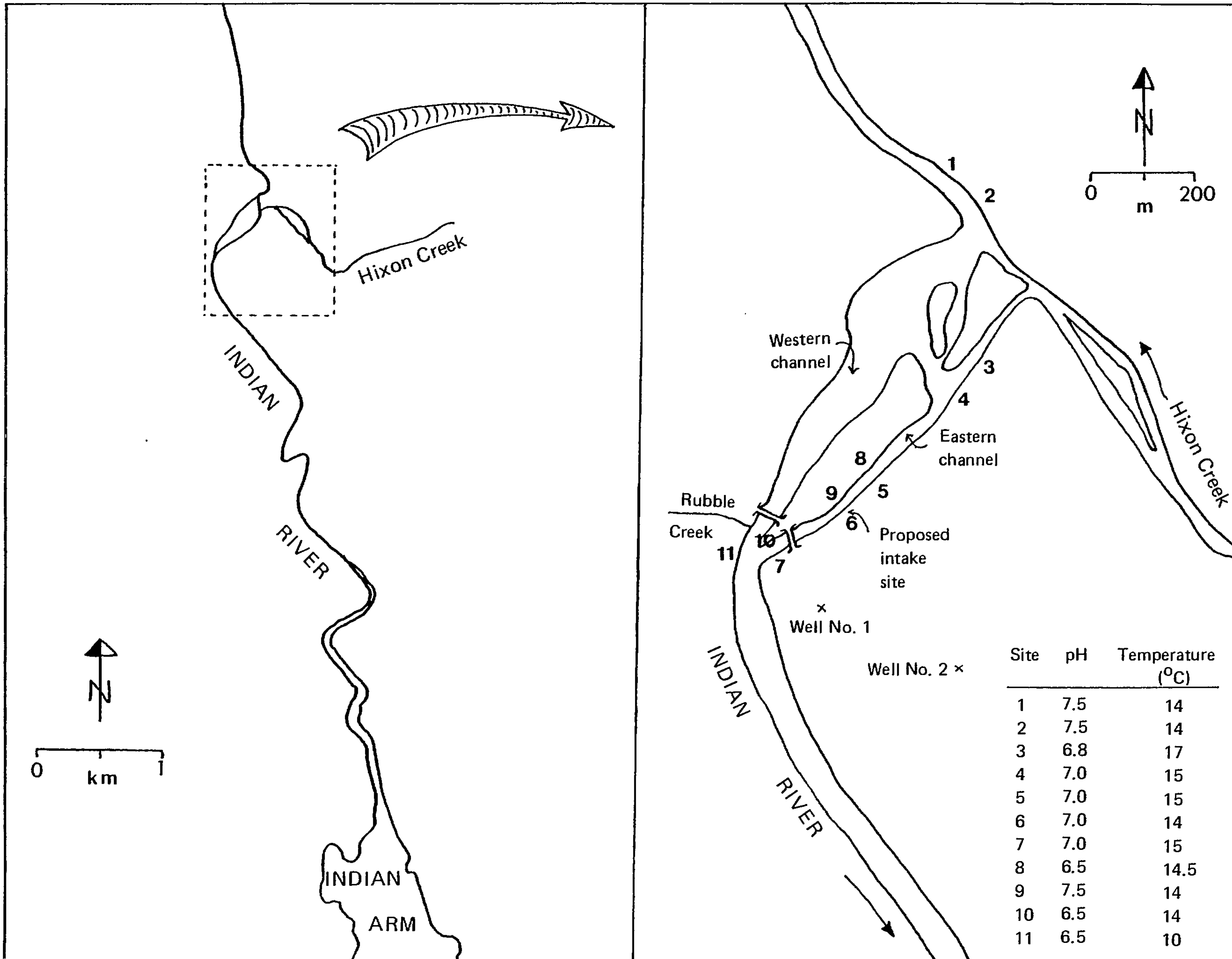
	Alkalinity (mg/l as $CaCO_3$)		Hardness (mg/l as $CaCO_3$)		pH	
	Mean	(Range)	Mean	(Range)	Mean	(Range)
Indian River (above Hixon Creek confluence)	9.2	(5.0 - 13.6)	11.3	(6.8 - 16.9)	6.8	(6.0 - 7.4)
Indian River (below Hixon Creek confluence)	7.5	(2.0 - 11.1)	9.5	(3.8 - 13.5)	6.8	(6.1 - 7.4)
Hixon Creek (1 sample)	6	---	3.3	---	5.4	---

A series of pH measurements made along the Indian River in the vicinity of the Hixon Creek delta on August 26, 1979, indicated that the pH in that river section varied spatially by up to one unit (6.5 - 7.5; Fig. 3). Above the Hixon Creek confluence (sites 1 and 2) the river water was slightly alkaline (pH 7.5) compared to the slightly acidic water at the mouth of Hixon Creek (pH 6.8, site 3). Samples from the eastern channel of Indian River below the Hixon Creek confluence showed a neutral pH of 7 and a slightly warmer (approximately 15° C) water on the east bank (sites 4 to 7) but slightly acidic (ph 6.5) and cooler water (approximately 14° C) on the west bank (sites 8 and 10). By comparison, site 11 located in the western channel of the Indian River measured only 10° C and had a pH of 6.5 indicating a different water source, possibly that of Rubble Creek (Fig. 3).

The above considerable regional and cross-sectional variation in pH observed along the Indian River in the vicinity of Hixon Creek delta may be attributed at least partly to the influence of the acidic Hixon Creek water. The creek water probably flows as a fairly discreet mass along the eastern bank of the eastern river channel. Therefore, depending on the seasonal pH changes in Hixon Creek (the creek pH measured only 5.4 in March 1972 but 6.5 to 7.0 during January 1980; Table 7) and on the relative contributions of Hixon Creek and Indian River to the mainstem flow, the pH of the river water in the vicinity of well No. 1 may vary by up to one unit.

Additional seasonal pH measurements were made during January to August 1977 at three Indian River sites (mainstem above and below the Hixon Creek confluence and springwater entering a side-channel near that confluence; Fig. 2). These data also showed distinctly different pH trends among the three sites (Fig. 4, Appendix 10). The mainstem above the Hixon Creek confluence had a near-neutral mean pH of 7.1 (range 6.8 - 7.4); the mainstem below the Hixon Creek confluence had a lower mean pH of 6.5 (range 6.1 - 6.8); and the springwater had the lowest mean pH of 6.1 (range 6.0 - 6.9). This acidic springwater combined with the relatively acidic Hixon Creek flow are probably largely responsible for the reduced pH in the mainstem below the Hixon Creek confluence.

Ammonia showed somewhat elevated levels only in two samples, both taken in July 1981, one in Indian River below Hixon Creek and one at the mouth of Forestry Creek (Appendix 9). The Indian River water reportedly contains some



Site	pH	Temperature (°C)
1	7.5	14
2	7.5	14
3	6.8	17
4	7.0	15
5	7.0	15
6	7.0	14
7	7.0	15
8	6.5	14.5
9	7.5	14
10	6.5	14
11	6.5	10

Fig. 3. Location of pH sampling sites (No. 1 - 11) on Indian River, 1979.

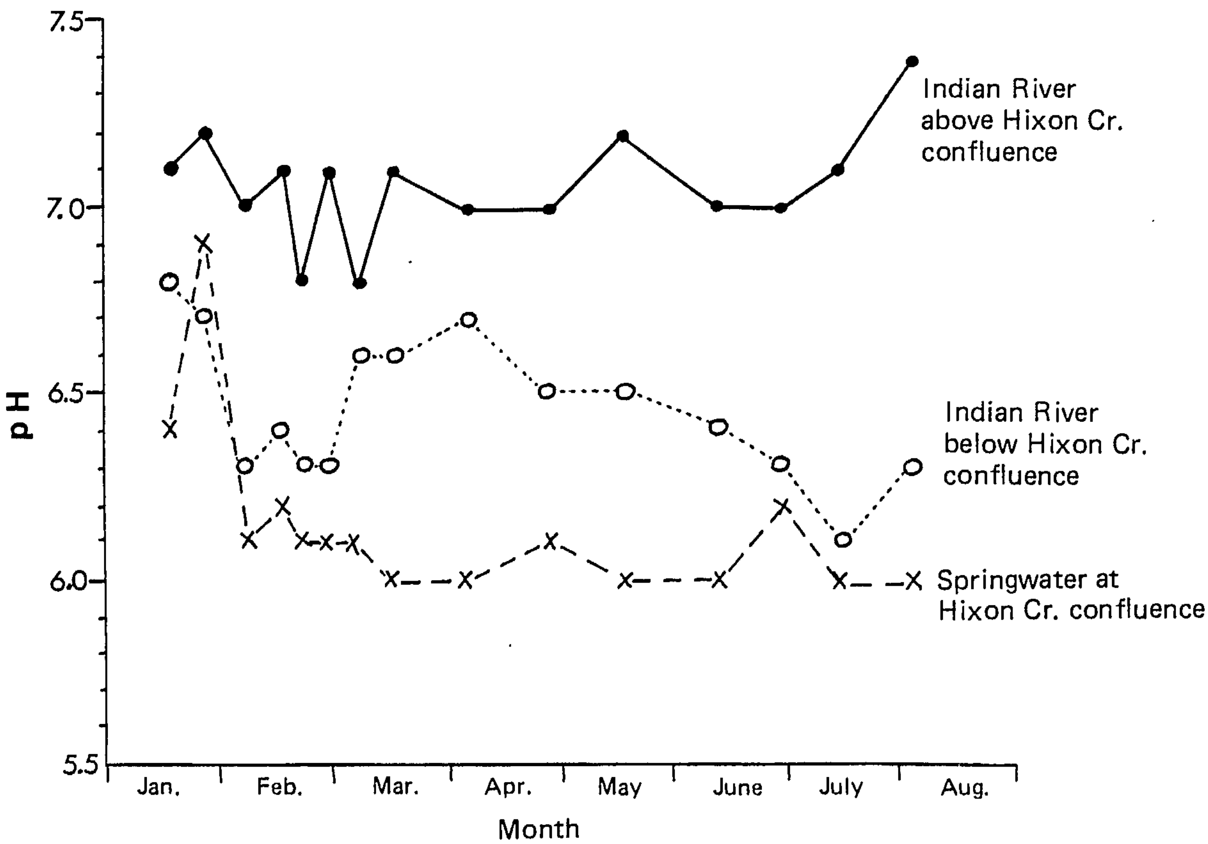


Fig. 4. The Indian River pH for surface water and springwater, January - August 1977.

glacial flour during the late summer-fall period, and definitely becomes turbid during spring or storm freshets. Concentrations of suspended solids should be quantified if the Indian River water is to be considered as a possible hatchery water source.

Of concern among metals were the occasionally observed elevated levels of aluminum, copper, iron, mercury and zinc (Table 3). As with the groundwater analysis, the metal content data for the Indian River surface water must be viewed with caution since some of the high levels were based on only one sample. Thus, only one 1972 sample from Hixon Creek and one from Indian River taken concurrently, showed higher than the recommended copper level. A high copper level was also reported for well No. 1 sampled that year (see above). These elevated copper values are suspect since none of the 45 river samples collected in 1977 nor the 12 river samples collected between 1979 and 1982 showed detectable copper concentrations. Similarly, zinc levels were undetectable in all the Indian River surface samples except for those collected during 1977 when zinc levels fluctuated from < 0.01 mg/l to 0.06 mg/l (Appendix 11). Natural contamination of the Indian River water by copper only in 1972 and by zinc only during parts of 1977 is difficult to explain since no mining activity exists in the immediate area. However, considerable zinc and copper mining activity had occurred at Brittania Beach (Fig. 1) until 1974 (Fedorenko and Shepherd 1984). A possible explanation for the few high values observed would be a chance contamination of the sample in the field or the laboratory.

Likewise, the detectable mercury levels observed in the surface samples only during the 1981 sampling period are difficult to explain and are very likely the result of contamination during sampling or laboratory analysis. Detectable mercury levels in the groundwater samples were also reported only during the 1981 sampling program, supporting the suggestion that the elevated mercury values were anomalies.

The surface sample collected on December 10, 1981 showed relatively high concentrations of both aluminum and iron (Table 3, Appendix 9). All other river samples collected that year generally had at least ten times lower levels of these metals than the maximum value observed. The high aluminum and iron levels reported for the December 10, 1981 sample are most likely the result of suspended material in the river, as the river was high and turbid on that date.

In overview, Indian River surface water probably has routinely acceptable levels of all the metals tested. The few samples showing higher concentrations of aluminum, copper, iron, mercury or zinc probably represent short-term natural or sampling anomalies.

Water flow

Flow data for the Indian River are limited. Marshall et al. (1976) reported extreme fluctuations in Indian River water levels. Underwood McLellan and Associates Ltd. (MS 1972) gave an inferred flow summary for the Indian River just below the Hixon Creek confluence for the years 1912 to 1921, based on the available flow records for that period. Limited water level measurements for July to December 1978 are available in the Indian River file No. 5830-13-16 dated October 10, 1979.

Water temperature

The available temperature data for the Indian River surface water are presented in Figure 5 and Appendices 12 and 13. The seasonal temperature pattern, based on intermittent data collected between 1951 and 1982, shows river temperatures increasing from a low of about 2° C to 4° C in January to March to approximately 15° C by August, then declining to about 4° C by December. In comparison, the groundwater temperatures remained relatively stable between 5.5°C and 9°C throughout the year (Fig. 5, Appendix 14). Similarly, temperatures of Indian River surface water and of springwater that enters a side-channel at Jack's Slough (Fig. 2) measured concurrently in 1977, showed distinct seasonal differences; the surface water temperatures increased from 3°C in January to 15°C in August, while the springwater temperatures remained relatively stable between 5°C and 8°C during that period (Fig. 5). Therefore, in order to reach target sizes by spring release dates, a hatchery facility on Indian River would have to utilize groundwater for incubation and rearing between November and April. During that period, the groundwater is considerably warmer (6 to 9°C) than the surface water (4°C or less; Fig. 5).

CONCLUSIONS

GROUNDWATER

The major parameters of concern for the Indian River groundwater are shown for each well in Table 4. All nine sites tested in the Indian River watershed had marginal water quality for fish culture due to extremely low alkalinity, extreme softness, low pH and dissolved gas problems. In addition, wells No. 4 and 7a had unacceptably high iron content, and wells No. 5, 6 and 8 had elevated zinc levels. However, copper which increases zinc toxicity through synergistic effects (Sigma MS 1983) was not detected in any of the samples involved. Finally, wells No. 3, 5 and 6 must be discounted due to low yield.

Among the wells showing good yield potential, physical treatment such as artificial buffering to increase pH, and aeration to bring dissolved gases to saturation levels, will alleviate some of the water quality problems encountered. Given such treatment, of the two wells located in the Hixon Creek delta, well No 1 appears to be the better suited for fish culture. This is due to the higher yield, undersaturation with dissolved nitrogen which therefore does not require a stripping device, and generally undetectable iron levels at well No. 1. However, both these wells had the lowest alkalinity, hardness and pH of all the nine wells tested. These water characteristics were related to the fish health problems encountered during the 1979 to 1980 chinook pilot hatchery (see later section on chinook rearing).

Of the seven wells drilled at the new upper site, well No. 7b with its shallower screen depth appears to be best suited for use in fish culture because of its high yield and relatively good water quality (the deeper screen setting at that site showed a high iron content). Wells No. 8 and 9 also indicated a good yield potential and relatively good water quality except for somewhat elevated zinc or copper levels; however, these parameters should be retested.

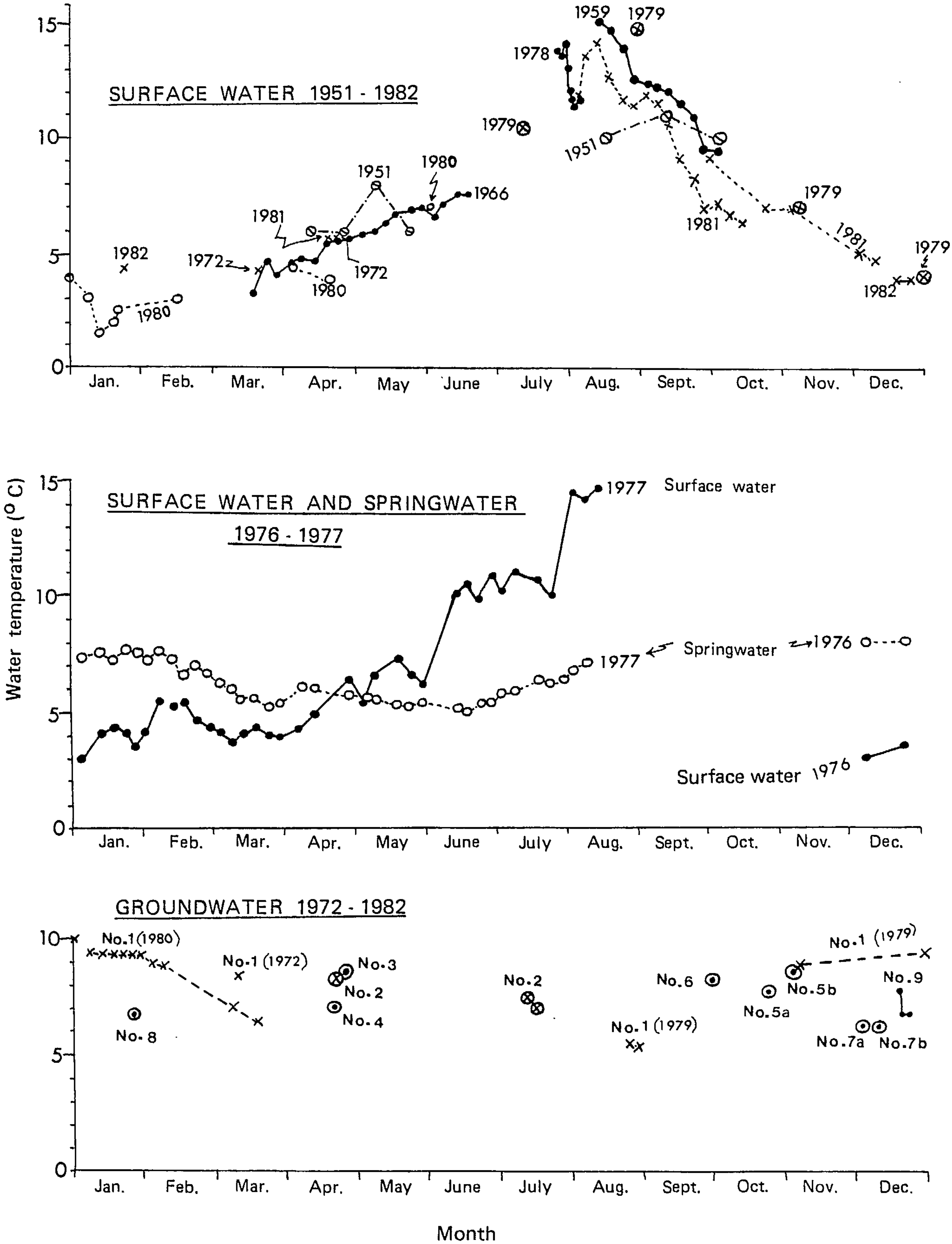


Fig. 5. Surface water, springwater and groundwater temperatures for Indian River, 1951 - 1982 (numbers indicate sampling years and wells tested).

Table 4. Summary of major problems with the groundwater quality in Indian River wells (X indicates problem; ? indicates questionable data).

Well No.	Low water quantity	Low alkalinity, hardness and pH	Dissolved gas problems	Elevated metal levels [a]
1		X	X	
2		X	X	
3	X	X	X	? (Cu)
4		X	X	X (Fe)
5a	X	X	X	X (Zn)
5b	X	X	X	X (Zn)
6	X	X	X	X (Zn)
7a		X	X	X (Fe)
7b		X	X	
8		X	X	X (Zn)
9		X	X	? (Cu)

[a] Symbols in parenthesis indicate the metal of concern.

SURFACE WATER

All surface water sampled in the Indian River watershed had extremely low alkalinity and low hardness, and was often slightly acidic. This renders the Indian River surface water only marginally suitable for fish culture purposes for the same reasons as were advanced for the Indian River groundwater (see above). In addition, the surface water temperatures are too low during the winter months to confer the desired size advantage by spring release dates; consequently, heating or the use of the warmer groundwater sources would be required. The general similarity in water quality of the Indian River surface water and groundwater strongly supports an earlier observation that the aquifers tapped draw a significant percentage of their water directly or indirectly from Indian River surface flows. Thus there is a risk that, under production pumping levels, the temperature advantage with groundwater could be lost.

CHINOOK PILOT HATCHERY, 1979 - 1980

INTRODUCTION

The Indian River chinook pilot hatchery was operated between 1979 and 1980 under contract to Indian Arm Salmon Ltd. (now Nevin Sadlier - Brown Goodbrand Ltd.). The project involved the incubation and rearing of 1979 brood chinook eggs transported from the Capilano hatchery.

The Indian River has no native chinook salmon population, and establishing a chinook run may be difficult due to the relatively cold river temperatures. In a laboratory experiment, two groups of Big Qualicum River chinook fry were reared under temperature regimes simulating those of the donor (Big Qualicum River) and transplant (Indian River) streams (Lister MS 1968). The colder regime, typical of Indian River, reduced growth rate by more than 50%. Lister also showed that prolonged periods of relatively cold temperatures (< 7° C) just after emergence of chinook fry, depressed growth and subsequent survival to the fingerling migrant stage. This suggested that fall-run chinook, which normally occur in relatively warm streams, would experience considerable difficulty in adapting to the cold temperatures of Indian River which generally do not exceed 7° C during the entire March to June period (Fig. 5). Therefore, chinook transplants to the Indian River may not be successful unless the fry are reared at warmer water temperatures such as may be provided by a groundwater source. A chinook run has been successfully developed in the Capilano River using this approach.

The primary goal of the 1979-1980 pilot hatchery was to assess the suitability of Indian River groundwater for culture of chinook. Of special concern were the seasonal temperature changes of groundwater, and the effects of low pH, and extremely low hardness and buffering capacity on the cultured fish (see previous section on water quality).

DESCRIPTION OF THE INDIAN RIVER PILOT HATCHERY

The Indian River chinook pilot hatchery was constructed in 1979 on the Indian River, about 5 km upstream from its mouth and just below the Hixon Creek confluence (Fig. 1). The site is accessible either by gravel road from Squamish or by boat and logging road from Deep Cove (Fig. 1). The facility (Fig. 6) consisted of a hatchery and residence buildings (Fig. 7) both acquired from a local logging camp. The hatchery building contained six eight-tray vertical incubator stacks and four 6 m x 1 m x 0.8 m deep troughs used to rear the fry from ponding to 2.4 g (Figs. 8 and 9).

A rearing pond measuring approximately 24 m by 6 m by 1 m deep was excavated near the hatchery (Fig. 10) to rear the fish from approximately 2 g to release. Due to the high porosity of the gravel substrate, the pond was lined with 6 mil polyethylene plastic. Netting was strung over the pond to reduce bird predation (Fig. 11).

Water to the hatchery was supplied by the two 20 cm diameter wells drilled in 1971 to 1972 by Underwood McLellan and Associates Ltd. The primary water supply came from well No. 1 via two diesel pumps through a 15 cm diameter

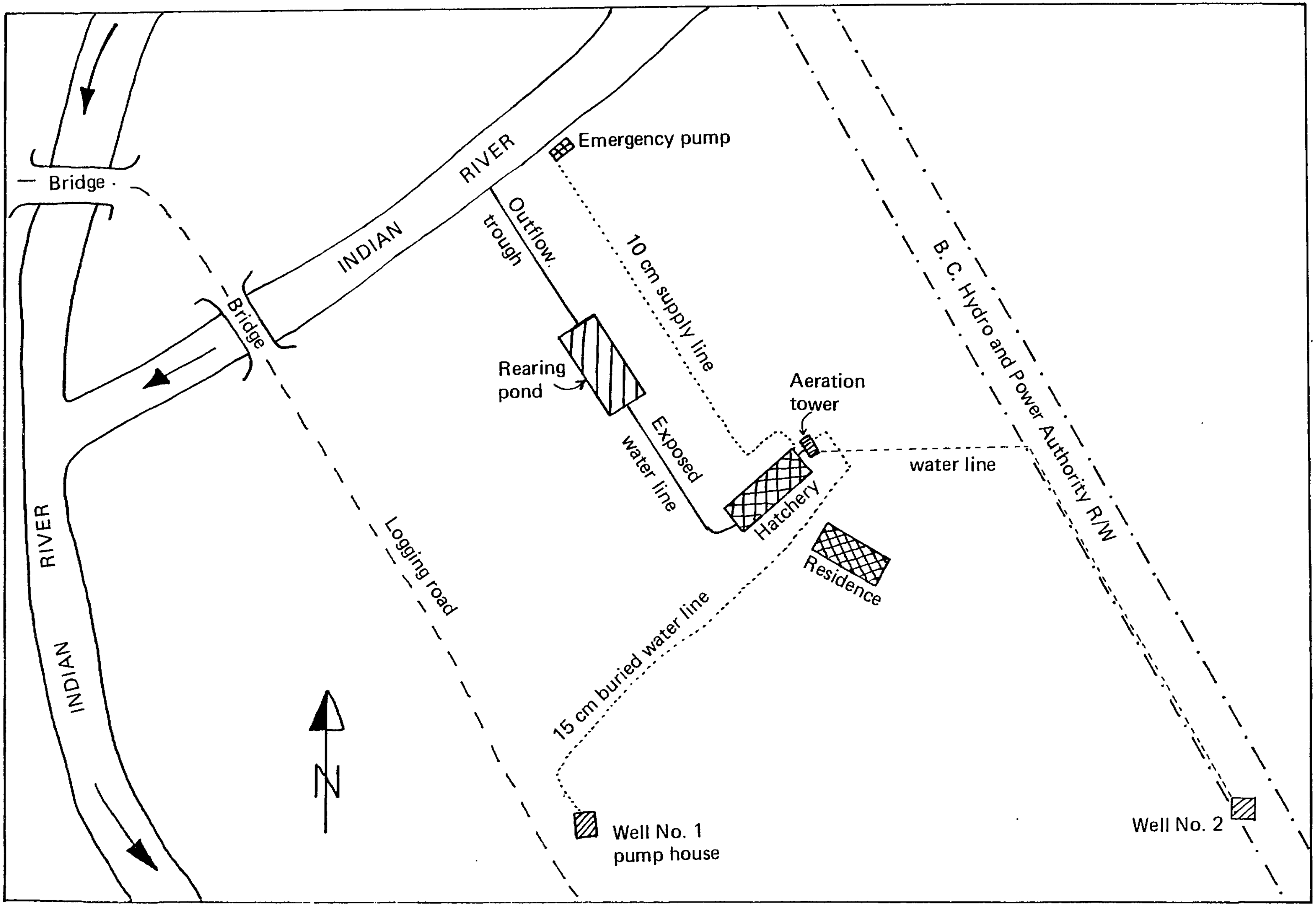


Fig. 6. Indian River chinook pilot hatchery site plan, 1979 (diagrammatic).

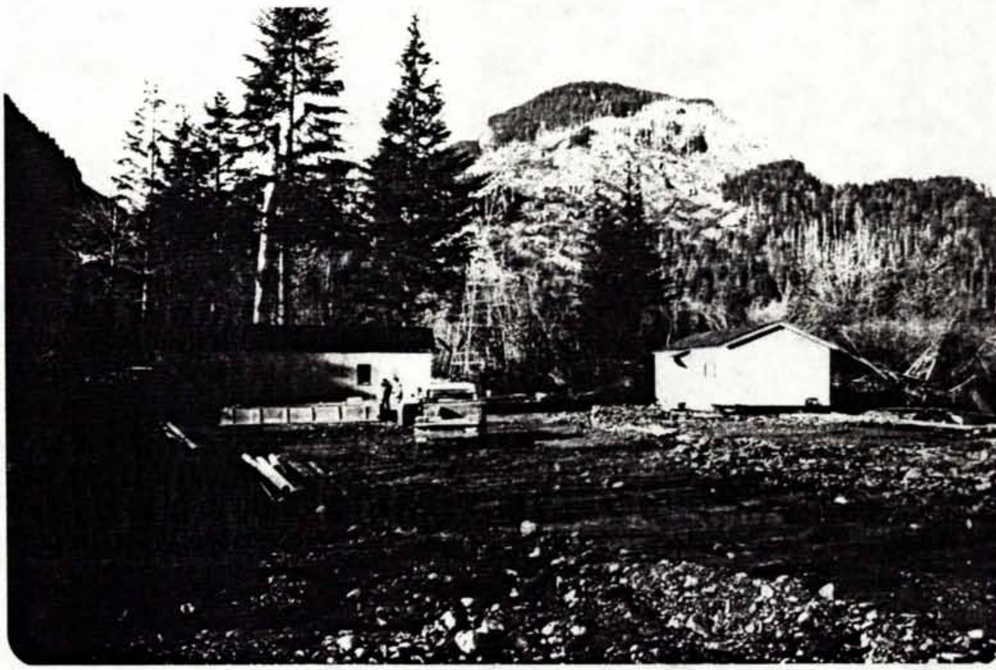


Fig. 7. Indian River pilot facility showing hatchery building (on the left) and residence building (on the right), 1979 - 1980.

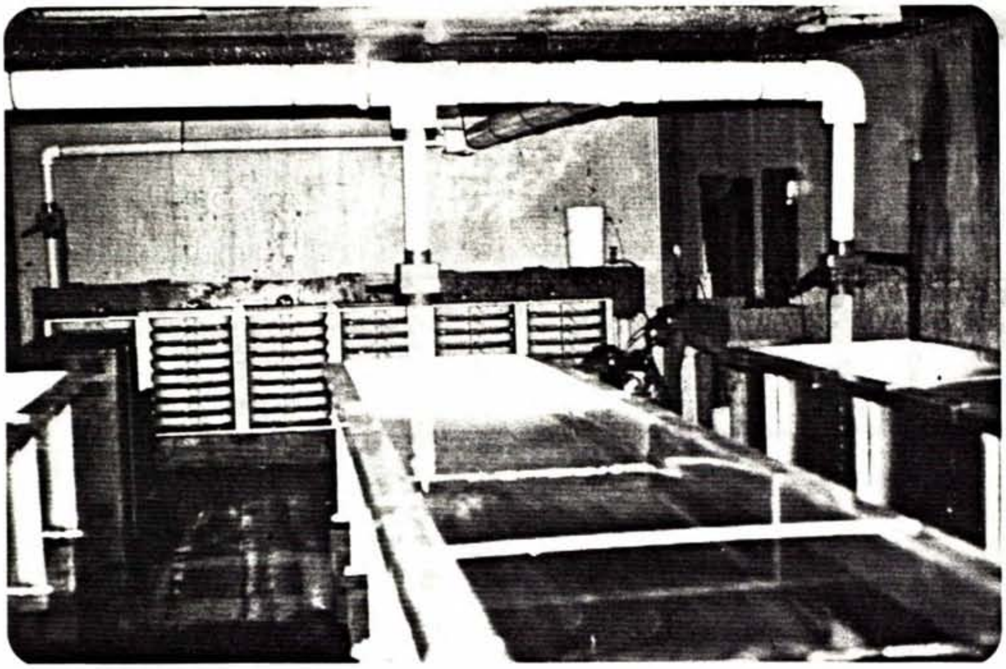


Fig. 8. Heath tray stacks (in background) and rearing troughs (in foreground), Indian River pilot hatchery, 1979 - 1980.

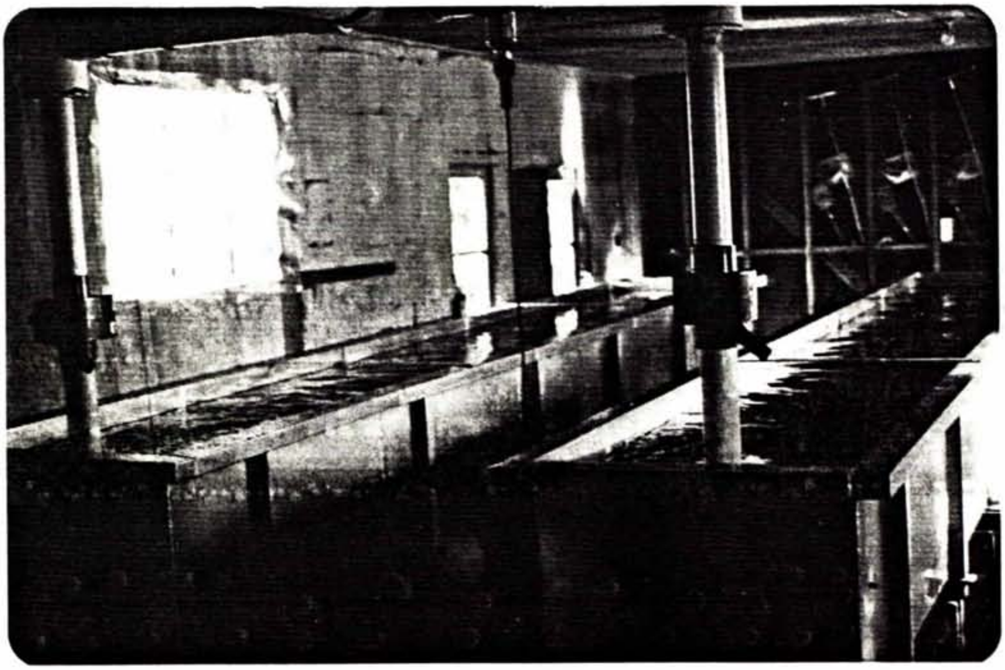


Fig. 9. Rearing troughs inside Indian River pilot hatchery, 1979 - 1980.

Fig. 10. Excavation of chinook rearing pond, Indian River pilot project, 1979 - 1980 (hatchery building is seen in background).

Fig. 11. Chinook rearing pond with overhead netting; plastic-lined outflow trough for carrying fish into Indian River is seen in foreground, 1980.

waterline leading to the top of a screen-type 4 m high aeration tower (Figs. 6 & 12). From the aeration tower, the water was gravity-fed into the hatchery building and the rearing pond. During chinook incubation and rearing, both pumps on well No. 1 malfunctioned several times for up to six hours, resulting in water shortage. Because of the continuing problems with these pumps, a standby generator and a submersible pump were installed at well No. 2. This source, however, was never used during rearing except to flush out the fry from hatchery to rearing pond. During the winter of 1980, a river back-up system was added, consisting of a diesel pump and a 10 cm diameter flexible pipe with a screened intake that led into the hatchery building (Fig. 13). The river supply was also used in the later stages of pond rearing to augment flows. All hatchery effluent was released into the Indian River mainstem.

METHODS

CHINOOK INCUBATION

On November 5, 1979, 26,400 green chinook eggs and a supply of chinook milt were transported from the Capilano hatchery to the Indian River facility. The eggs were fertilized, water-hardened for one hour, and disinfected on site by exposing them for 10 minutes to 100 ppm Bridine solution. The eggs were then placed in Heath trays for incubation. Time from fertilization to placement of eggs in Heath trays was about three hours. On November 29, 1979, an additional 223,700 eyed chinook eggs were transported from the Capilano hatchery to the Indian River facility and placed in Heath trays. Loading density for all eggs was generally 5,600 eggs per tray.

The green egg lot was treated with malachite green 11 days after fertilization. The eggs were treated with 80 ml of 3 g/l stock solution per stack every two days from November 16 to December 5, then were shocked and picked on December 6 and 7.

Throughout the remainder of the incubation period, dead eggs were removed and counted approximately once a week. During hatching, egg cases did not dissolve quickly and had to be picked off the alevins in trays.

CHINOOK REARING

Hatched chinook were held in the Heath trays until yolk was absorbed, then ponded indoors in four rearing troughs. Rearing took place under artificial light conditions that paralleled the natural light-dark cycle. When the fry reached a mean size of approximately 2.4 g they were funnelled through a 15 cm pipe (Fig. 14) into the outdoor rearing pond (Fig. 15). Water from well No. 2 was used for flushing the fish into the pond; this was the only occasion when this well was utilized. At the end of the rearing period, fry were released into the Indian River through a plastic-lined trough (Fig. 11) fitted with a pipe at the downstream end.

During rearing, fish were initially hand-fed, using the Oregon Moist Pellet (OMP) schedule (Appendix 15), every 15-20 minutes from dawn to dusk; this frequency declined to hourly feedings as the fish grew. Newly ponded fry were

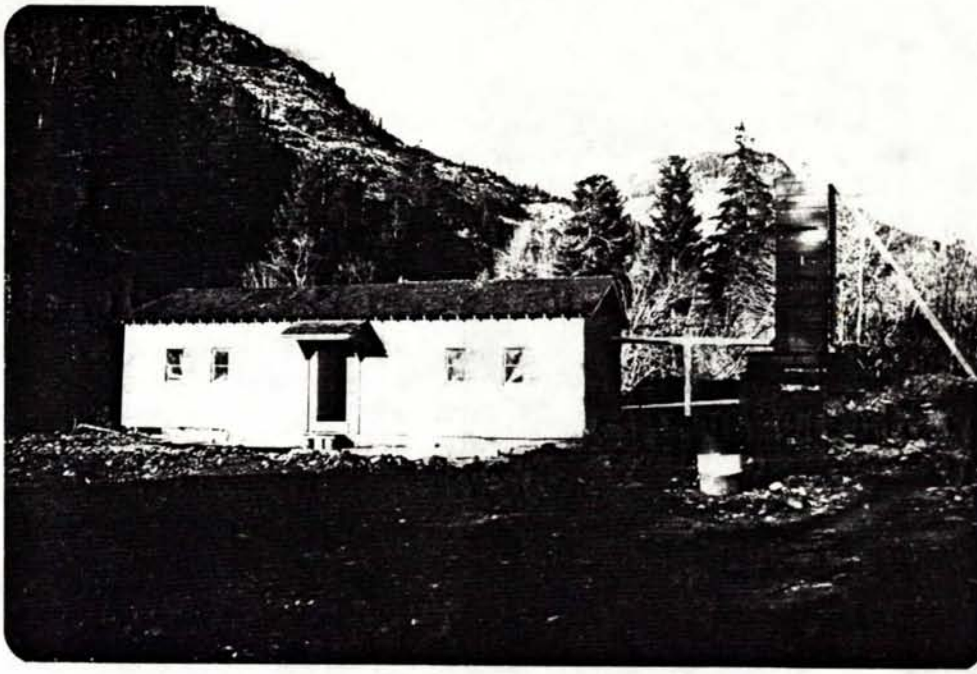


Fig. 12. Aeration tower supplying water from well No. 1 to Indian River chinook pilot hatchery, 1979 - 1980.

Fig. 13. Pumping water from Indian River into the rearing pond, 1980.

Fig. 14. Chinook fry being removed from rearing troughs and funnelled into the outside rearing pond at the Indian River chinook pilot hatchery, 1980.

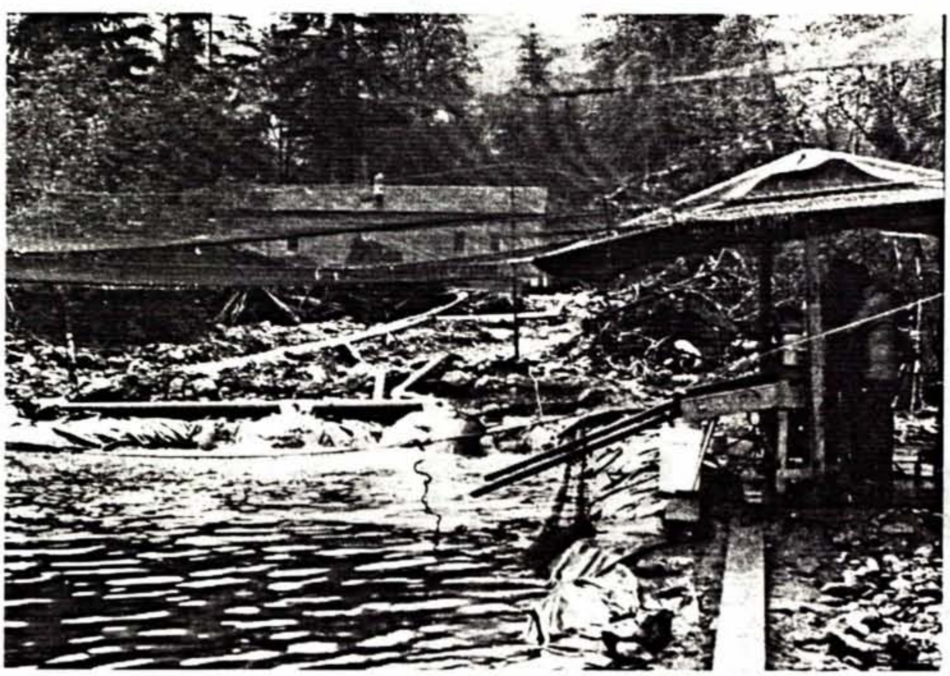


Fig. 15. Chinook rearing pond; the hatchery building is seen in background and the tagging operation in foreground, Indian River pilot project, 1980.

fed starter mash for the first few days, then 1/32 pellets for several weeks, followed by a 50:50 mix of 1/32 and 3/64 pellets.

Chinook fry were generally sampled from the troughs and the pond at weekly intervals to determine growth rate and feeding schedule. Several samples were dip-netted randomly from each trough, transferred into a preweighed bucket filled with water, and weighed in aggregate (n = 200 - 300 fish; scale accuracy of ± 1 g).

Rearing mortalities in the troughs and the pond were recorded daily and removed. Fry were also observed each day for symptoms of disease. The occurrence of white-spot disease associated with fin-rot soon after ponding in troughs, prompted treatment with 30 g of Terramycin (TM-50) daily from January 30 to February 10 in each trough's feed allotment. Rearing troughs were cleaned daily. Sludge from the rearing pond was pumped out as required using a swimming pool vacuum.

CHINOOK TAGGING

Approximately 102,000 chinook fry rearing in the pond were adipose fin-clipped and nose-tagged using code 02-18-39 between April 25 and May 7, 1980 (Fig. 15). All tagged fry were returned to the pond. No tag retention tests were carried out.

PHYSICAL SAMPLING

Water temperatures during incubation and rearing were monitored daily with a hand thermometer. Dissolved oxygen and pH were also measured on several occasions using a YSI Model 57 oxygen meter and a Fisher Digital model 609 pH meter pH respectively.

Water flow in each Heath tray was set up at 12.5 l/min at the start of incubation and was increased to 18 l/min at the buttoned-up stage. Water flow in each rearing trough was increased gradually as the fish grew, from 136 l/min in January when the fry measured approximately 0.5 g to 227 l/min in February when they measured approximately 1 g; fry in trough No. 4 were proportionately smaller and flow there was reduced accordingly. Flow in the rearing pond was also increased gradually from approximately 910 l/min when the fish were ponded in March at 2.2 g to 2.5 g, to approximately 2,270 l/min just prior to fish release in early June when the fish measured approximately 3 g to 6 g each.

CHINOOK ADULTS

Marked chinook adults from the Indian River pilot hatchery were monitored in B.C. and Alaska, Washington and Oregon commercial and sport fisheries. Tags recovered in the B.C. commercial fisheries were adjusted by the catch to sample ratio; tags recovered in the B.C. sport fisheries were expanded by a factor of three. No project tags were recovered in the U.S. waters, and chinook escapement to Indian River was not monitored. As part of the Mark Recovery Program, all marked chinook recovered in the canneries had nose-fork lengths measured.

RESULTS AND DISCUSSION

CHINOOK INCUBATION

Numbers of chinook eggs incubating, accumulated thermal units (ATU) calculated as one unit for every degree over 0°C each day, and water temperatures during incubation are presented in Table 5.

A total of 250,099 chinook eggs was transported from the Capilano hatchery to the Indian River facility in November 1979. Eggs in Lot No. 1 were received unfertilized on November 5, 1979; they showed eye development by November 28 at 226 ATU and started hatching on December 27 at 503 ATU. By 852 ATU on February 2, this lot was close to the buttoned-up stage, and the fry were ponded in a rearing trough on February 12 at 932 ATU.

Eggs in Lots No. 2 and No. 3 were fertilized at the Capilano hatchery on October 23 and 24 respectively and incubated initially in Capilano River water at 11°C to 9°C. From November 1 to 29, the eggs were incubated in the Capilano hatchery using heated spring water that measured 10°C to 12°C. The eyed eggs were transported to the Indian River hatchery on November 29 at approximately 420 ATU. The eggs hatched during early to mid-December at 475 to 590 ATU. Fry from these lots were ponded in rearing troughs on January 20, 1980 at 930 ATU.

Overall egg-to-ponding survival was 90.6%, but varied from 97.2% for Lots No. 2 and No. 3 to 34.7% for Lot No. 1. Much of the egg loss in Lot No. 1 was attributed to the 16,200 undeveloped eggs removed from that lot after shocking. Investigation indicated that these eggs were unfertilized. Adult spawners used for this egg lot were among the last chinook to be spawned at the Capilano hatchery, and quite often the last salmon spawners in a run have inferior egg quality and lower egg survival (E. Stone, pers. comm.).

CHINOOK REARING

Numbers of chinook fry rearing, their size and mean water temperatures during rearing are presented in Table 6.

On January 20, 1980, an estimated 217,600 chinook fry were transferred from Heath trays into rearing troughs No. 1, 2 and 3; and on February 12, the remaining estimated 9,159 fry were transferred into rearing trough No. 4. An estimated 212,585 fry were transferred from troughs No. 1, 2 and 3 into the rearing pond on March 19; and on June 2, an estimated 8,998 fry were transferred from trough No. 4 into the pond. The fish were free to leave the rearing pond voluntarily beginning June 2, when the screen on the pond outlet structure was removed. On June 15, some 30,000 fry still remained in the pond and were dipped out and released into the river.

The amount of feed supplied to the rearing troughs was increased gradually from less than 2 kg per day for each trough at the start of rearing in January, to around 5 kg in March when the fry were transferred to the rearing pond. The smaller numbers of fry in trough No. 4 were given proportionately less feed. The amount of feed supplied daily to the rearing pond was increased from 9 kg in March to a maximum of 24 kg in late May, then was reduced gradually to zero by

Table 5. Chinook incubation summary, 1979 brood, Indian River hatchery.

Date	No.	Details	A.T.U.	Water Temperature (°C)
		LOT NO. 1		
Nov. 5, 1979	26,400	- green eggs received	0	9.0
Dec. 7	10,200	- 16,200 eggs not fertilized due to insufficiently long egg-sperm contact.	311.5	9.5
Dec. 22	9,635		454.5	10.0
Jan. 4, 1980	9,389	- egg hatching from Dec. 27	580.0	10.0
Jan. 20	9,369		733.5	9.5
Feb. 2	9,159		852.0	8.5
Feb. 11	9,159		931.5	8.5
Feb.12	9,159	- fry ponded in rearing trough No. 4	-	-
		LOT NO. 2[a]		
Nov. 29, 1979	139,676	- eyed eggs received	428.0	9.5
Dec. 7	137,766	- eggs hatching Dec. 4-15	504.0	9.5
Dec. 22	136,983	- eggs hatched	648.5	10.0
Jan. 4, 1980	136,696		774.5	10.0
Jan. 20	135,777	- fry ponded in rearing troughs No. 1 and No. 2	927.5	9.5
		LOT NO. 3[a]		
Nov. 29, 1979	84,023	- eyed eggs received	417.5	9.5
Dec. 7	83,123	- eggs hatching Dec. 5-17	493.5	9.5
Dec. 22	82,782	- eggs hatched	638.0	10.0
Jan. 4, 1980	82,526		764.0	10.0
Jan. 20	81,651	- fry ponded in rearing troughs No. 2 and No. 3	917.0	9.5

LOT NO. 1, 2 and 3

Total eggs at start - 250,099
No. live fry at ponding - 226,587
Total mortalities - 23,512
% Egg-to-ponding survival - 90.6% (Lot 1 - 34.7%; Lot 2 - 97.2%; Lot 3 - 97.2%)

[a] 223,699 eyed eggs received from Capilano hatchery on Nov. 29 were treated as two separate lots due to slightly different A.T.U.'s per lot at time of transport from Capilano hatchery to Indian River (ie. 428 A.T.U. and 418 A.T.U.).

Table 6. Chinook rearing summary, 1979 brood, Indian River hatchery.

Date	No.	Details	Size (g)	Water Temperature (°C)
		TROUGH NO. 1		
Jan. 21, 1980 ~	76,160	- fry ponded in rearing trough	0.5	9.5
Jan. 26	75,500		0.5	9.5
Feb. 3	75,028		0.8	8.5
Feb. 12	74,880		1.0	8.5
Feb. 19	74,797		1.2	8.0
Feb. 26	74,759		1.4	7.5
Mar. 4	74,749		1.6	7.4
Mar. 12	74,712		2.0	7.0
Mar. 18	74,693	- no pin-heads observed	2.2	6.5
Mar. 19	-	- fry moved to rearing pond	-	-
				Mean 8.1
		TROUGH NO. 2		
Jan. 21, 1980 ~	70,720		0.5	9.5
Jan. 26	70,181		0.5	9.5
Feb. 3	69,879		0.8	8.5
Feb. 12	69,774		1.0	8.5
Feb. 19	69,704		1.3	8.0
Feb. 26	69,671		1.5	7.5
Mar. 4	69,654		1.8	7.4
Mar. 12	69,607		2.2	7.0
Mar. 18	69,567	- 3.4% of all mortalities were pin-heads	2.5	6.5
Mar. 19	-	- fry moved to rearing pond	-	-
				Mean 8.1
		TROUGH NO. 3		
Jan. 21, 1980 ~	70,720		0.5	9.5
Jan. 26	69,945		0.5	9.5
Feb. 3	69,311		0.8	8.5
Feb. 12	69,049		1.0	8.5
Feb. 19	68,967		1.3	8.0
Feb. 26	68,908		1.5	7.5
Mar. 4	68,869		1.8	7.4
Mar. 12	68,353		2.0	7.0
Mar. 18	68,325	- 20.6% of all mortalities were pin-heads	2.4	6.5
Mar. 19	-	- fry moved to rearing pond	-	-
				Mean 8.1

Table 6. (cont'd).

Date	No.	Details	Size (g)	Water Temperature (°C)
		TROUGH NO. 4		
Feb. 12, 1980	9,159	- fry ponded in rearing trough	0.5	8.5
Feb. 17	9,097		0.5	8.2
Feb. 25	9,078		0.6	7.7
Mar. 2	9,060		0.7	7.8
Mar. 8	9,050		0.8	7.0
Mar. 14	9,038		1.0	7.0
Mar. 24	9,031		1.3	6.0
Apr. 1	9,019		1.4	6.0
Apr. 9	9,009		1.7	5.5
Apr. 15	9,006		2.0	5.5
Apr. 24	9,004		2.2	5.5
May 11	9,002		2.6	4.5
June 2	8,998	- 5.6% of all mortalities were pin-heads - fry moved to rearing pond	-	- Mean 6.1
		REARING POND		
Mar. 19, 1980	212,585	- fry ponded from troughs No. 1, 2 and 3	2.4	6.5
Apr. 8	212,152		3.4	6.0
Apr. 19	212,142		3.6	5.5
Apr. 29	212,102		4.3	5.5
May 16	212,046		5.0	5.0
June 2	221,022	- 8,998 fry ponded from trough No. 4	-	6.0
June 5-15	220,967	- fry released voluntarily from June 2 to June 15	6.2	6.0 Mean 5.9

Total fry at start of rearing	- ~ 226,759
Total mortalities	- 5,792 (9.1% were pin-heads)
Total fry at release	- 220,967
% Start of rearing-to release survival	- 97.4% (96.6% - 98.4% in troughs; 99.7% in pond)
No. marked fry (Apr. 25 - May 7) Ad + CWT (02-18-39)	- 102,512
Estimated No. untagged fry using tagged:untagged ratio	- 91,788
Total fry released	- ~ 194,300

June 14 in order to encourage fry emigration. A total of 1,890 kg of OMP feed was used during rearing.

Fry generally fed well within a week of their transfer into the rearing troughs. Mean fry size increased steadily from around 0.5 g at the start of rearing in January to 6.2 g at final release in early June (Fig. 16, Table 6). However, fry varied in size from under 3 g to over 6 g during the potential release period (Table 6).

The total number of reared chinook fry released into the Indian Piver in June, based on the incubation and rearing inventory, was estimated to be 220,967 fish giving an overall rearing survival of 97.4%. Survival in the rearing troughs averaged 97.7% and in the pond 99.7%. Overall egg-to-release survival was 88.4%. However, the estimated total released fry based on the tagged: untagged ratio (see below) was only 194,300, giving an egg-to-release survival of 77.7%. The above discrepancy in total fry numbers at release may be partly due to initial overestimation of the number of transplanted eggs, and to underestimation of predation losses. In this report, the more conservative total fry estimate of 194,300 and overall survival of 77.7% will be used.

Fry losses during rearing were due mostly to disease and predation. In January 1980, shortly after Lots 2 and 3 were ponded in troughs, coagulated-yolk or white-spot disease, associated with fin-rot, was observed in some of the fry. Losses from this disease outbreak were estimated at approximately 2% of the total fish in troughs. On May 15, fungal nose and eye infections were observed, mostly in tagged fish. Finally, predation losses from mink occurred in the rearing pond but were probably minor. The coagulated-yolk disease is a symptom of unsatisfactory incubation conditions (Wood 1974). Causes of the disease are largely unknown, but it has been related to the presence of heavy metals (zinc, copper lead, etc.), supersaturation and excessive malachite green treatment (Wood 1974). In the present case, nitrogen gas supersaturation, low hardness and other marginally unacceptable water quality parameters may have been partly responsible.

CHINOOK TAGGING

A total of 102,512 chinook fry were adipose-clipped and nose-tagged between April 25 and May 7, 1980 using tag code 02-18-39. Delayed tagging mortalities were recorded in the subsequent rearing inventory but were negligible. After tagging was completed, tagged and untagged fish were mixed. A random sample of 470 fry was removed from the pond on June 2 and a tagged to untagged ratio of 248:222 (1:0.9) was obtained. Applying this ratio to total tagged fish gave an estimate of 194,300 chinook in the pond just prior to release.

PHYSICAL SAMPLING

Water temperatures during incubation from November to early February remained relatively constant at 9°C to 10°C (Fig. 17, Table 7). Water temperatures in the rearing troughs declined steadily from around 9.5°C in January to 4.5°C in May; temperatures in the rearing pond fluctuated between 5°C and 6.5°C from March to June (Fig. 17).

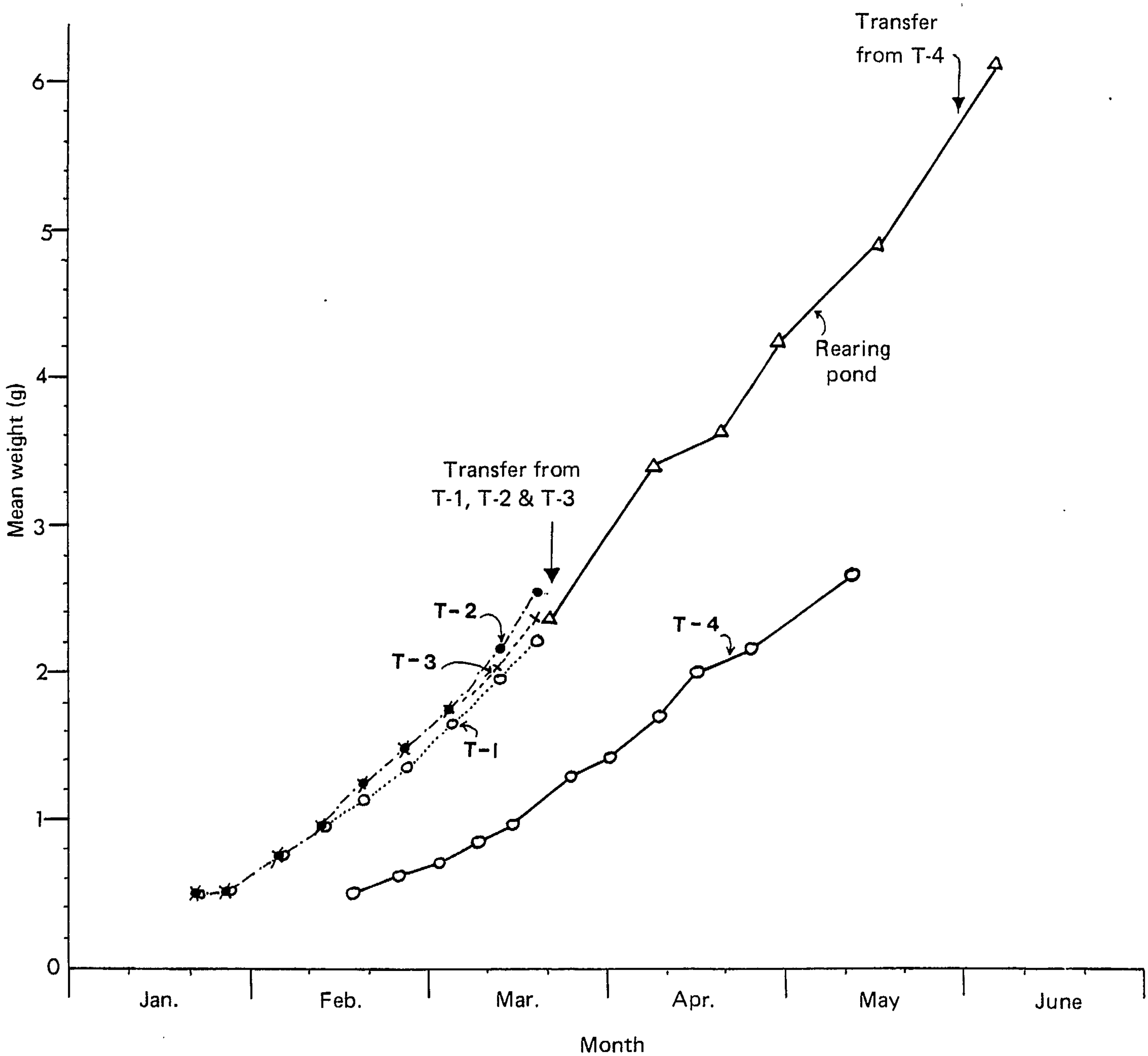


Fig. 16. Mean weights of chinook fry during rearing in troughs (T) and in pond, Indian River pilot hatchery, January to June 1980.

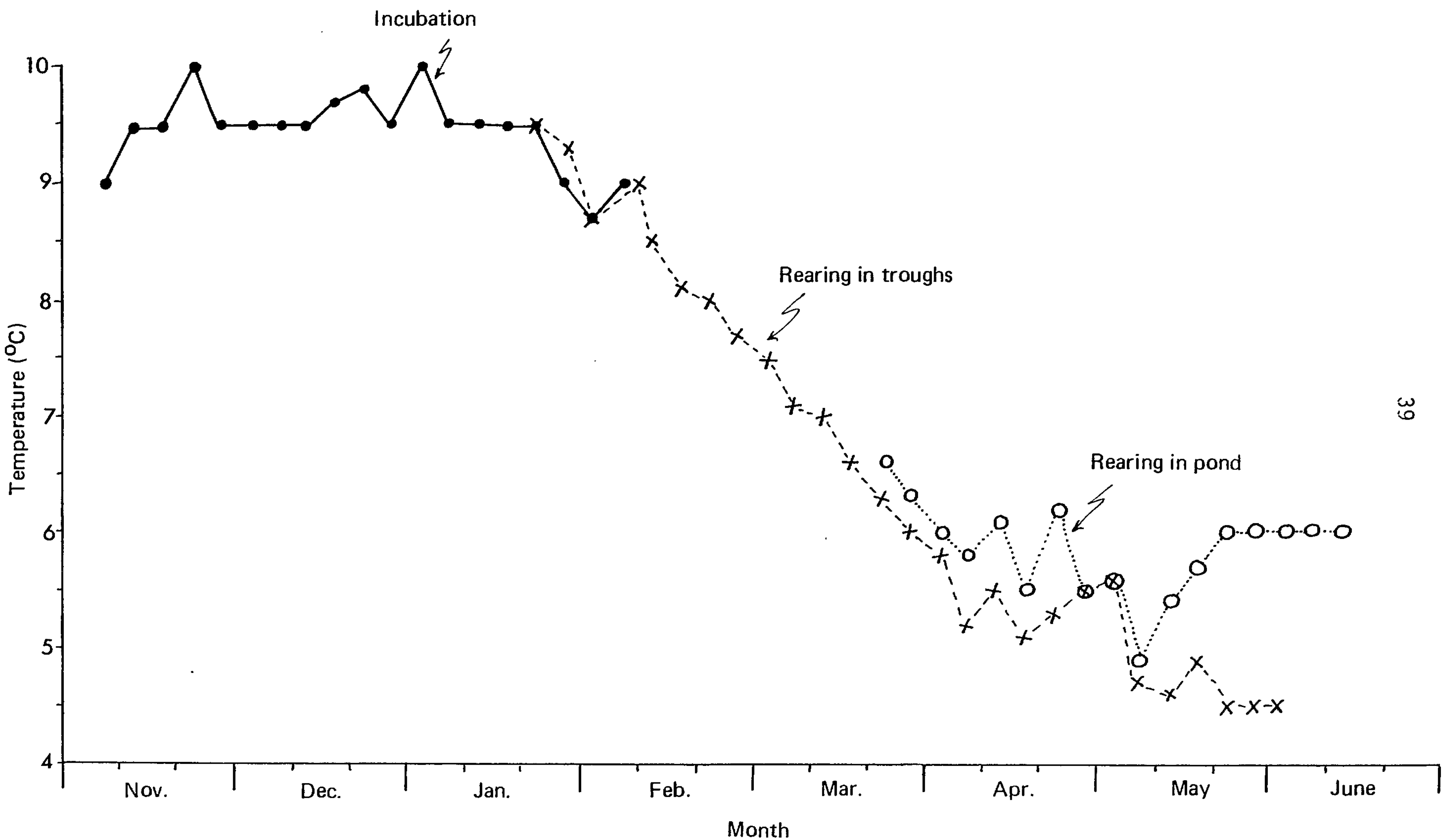


Fig. 17. Water temperatures (5 - day means) during chinook incubation and rearing, Indian River pilot hatchery, November 1979 to June 1980.

Table 7. Water temperature, dissolved oxygen and pH data available for the hatchery,[a] Indian River and Hixon Creek, during chinook incubation and rearing, 1979-1980.

Date	Temperature (°C)			Oxygen (ppm)	pH		
	Hatchery	Indian River	Hixon Creek	Hatchery	Hatchery	Indian River	Hixon Creek
				INCUBATION			
1979							
Nov. 5	9.0	7.0	-	-	-	-	-
Dec. 31	9.5	4.1	-	- 7.8 (second tray) - 6.5 (bottom tray)	6.6	6.8	-
1980							
Jan. 1	10.0	4.0	-	-	-	-	-
7	9.5	3.0	-	-	-	-	-
12	9.5	1.5	-	6.8 (bottom tray)	6.8	-	-
17	9.5	2.0	-	-	6.7	-	-
19	9.5	2.5	2.0	-	6.4	-	7.0
				REARING			
Jan. 24	9.5	1.5	-	8.0	-	-	-
28	9.5	-	-	-	6.5	-	6.5
Feb. 5	9.0	3.0	-	8.0	6.4	-	-
8	9.0	-	-	8.0	-	-	-
Mar. 7	7.1	-	-	8.0	-	-	-
18	6.5	-	-	6.8	-	-	-
23	6.5	-	3.5	-	-	-	-
Apr. 4	6.0	5.5	5.0	-	-	-	-
14-27	4.5	5.0	-	-	-	-	-
May 28-June 10	5.0	6.0	-	-	-	-	-

[a] Hatchery water was supplied by well No. 1.

From May 19 until fish release in June, additional water was pumped into the pond from Indian River. This supply probably carried a significant amount of Hixon Creek water. This creek is located just upstream from the hatchery site (Fig. 2) and has a somewhat different water quality compared to the Indian River mainstem (see previous section on Indian River surface water). Indian River water temperatures between mid-May and early June remained around 6°C (Table 7).

During incubation, oxygen measured around 7 to 8 ppm, or approximately 68% saturation (Table 7). Oxygen in the rearing troughs was around 8 ppm or approximately 72% saturation (Table 7); in the rearing pond it was a constant 11 ppm or approximately 90% saturation. Nitrogen gas supersaturation of up to 106% was observed in the rearing troughs.

During incubation in Heath trays, pH measured around 6.4 to 6.8, and in the rearing troughs it measured around 6.5 (Table 7). These pH values are only marginally acceptable for fish culture and are below the recommended pH range in hatcheries of 7.2 to 8.5 (Sigma MS 1983).

CHINOOK ADULTS

At the time of reporting, only 2-year old and incomplete 3-year old adult tag returns of Indian Arm hatchery chinook were available. The returns of 4- and 5-year old Indian River chinook should be available from the 1983 and 1984 mark recovery programs respectively.

An expanded total of 114 marked 2-year old and 110 marked 3-year old chinook originating from the Indian River pilot hatchery were recovered in 1981 and 1982 respectively in the Northern B.C., Central B.C., Georgia Strait and Johnstone Strait fisheries (Table 8). The combined Georgia Strait commercial and sport fisheries accounted for 79% and 82% of the 2- and 3-year old chinook catches respectively. Total returns by age class could not be determined since chinook escapements to Indian River were not monitored. Also, the 1982 tag recovery data for the U.S. waters were not available.

Tagged 2- and 3-year old Indian River hatchery chinook were captured between July and September 1981 and April and September 1982 respectively in the commercial fishery; and between May and December 1981, and January and September 1982 respectively in the Georgia Strait sport fishery. The fork length (± 1 S.E.) of Indian River hatchery chinook captured in the B.C. commercial fishery averaged 45.0 cm ± 0.8 cm (range 39.6 cm to 47.3 cm) for 15 2-year olds captured between July and September, and 61.5 cm ± 1.9 cm (range 51.8 cm to 72.2 cm) for 14 3-year olds captured between April and September.

CONCLUSIONS

The egg-to-release survival of 78% obtained for the Indian River hatchery chinook was slightly higher than the 72% given in the DFO - Enhancement Opportunities Bio-standards (updated September 1982). However, the bio-standard survival levels are conservative and often exceeded in pilot operations due to the greater care given to pilot projects.

Table 8. Mark recoveries of 2- and 3-year old chinook (1979 brood) released from Indian River pilot hatchery.[a]

Tag code	02-18-39
Date of release	June 15, 1980
Mean weight at release	3-6 g
No. tagged fish released	102,512

TAG DISTRIBUTION

Area[b]	1981 2-year olds	1982[c] 3-year olds	1983 4-year olds
Northern B.C. Troll	0	9	N/A[d]
Central B.C. Troll	0	8	N/A
Central B.C. Net	6	0	N/A
North & Central B.C. Net	1	0	N/A
Central B.C. Sport	0	3	N/A
Georgia Strait Troll	18	51	N/A
Georgia Strait Net	3	0	N/A
Georgia Strait Sport	69	39	N/A
Johnstone Strait Net	17	0	N/A
Capilano hatchery strays	0[e]	0[e]	0[e]
Escapement to Indian River	N/A	N/A	N/A
U.S. Water	0	N/A	N/A
Total	114	110	-

[a] Tag recovery data for B.C. waters from: Bailey et al. (1983) (for 1981 recoveries) and B.C. Regional Mark Recovery Program, Listing of 1982 Canadian Recoveries of Chinook (preliminary data) (for 1982 recoveries); tag recovery data for U.S. waters from: Washington Dept. Fisheries, Coded Wire Tag Data Base.

[b] See Appendix Fig. 1 and Appendix 16 for location of Statistical Areas.

[c] B.C. data are preliminary;U.S. data are not yet available.

[d] Not available.

[e] Eldon Stone, Capilano hatchery (pers. comm).

The Indian River pilot hatchery project was considered to be successful based on good egg-to-release survival despite the marginally acceptable water quality, and confirmed the favourable winter temperature regime of groundwater. However, rearing mortality could be related to inferior water quality and would be likely to be more severe under production fish culture conditions.

Based on the above observations concerning the Indian River surface and groundwater quality and chinook pilot hatchery, it is unlikely that a major multi-species hatchery would be successful on Indian River. Given the marginal water quality for fish culture in this watershed, a more viable approach to salmonid enhancement would be a facility that concentrated on species requiring little or no freshwater rearing, such as pink and chum.

SUMMARY

GROUNDWATER

The following general observations regarding water quality were made for the nine wells tested in the Indian River watershed:

1. Values for principal water quality parameters ranged as follows: temperature 5.5°C to 9°C; alkalinity 4 to 15 mg/l as $CaCO_3$; hardness 2 to 15 mg/l as $CaCO_3$; pH averaged 6.3 and ranged from 5.3 to 6.9; dissolved oxygen was undersaturated and ranged from 21% to 70%; total dissolved gases were undersaturated in wells No. 1 and No. 2 (range 85% to 99%) and oversaturated in most other wells (range 100% to 105%); dissolved nitrogen was undersaturated in well No. 1 and oversaturated in all other wells (range 108% to 126%). In addition, copper, iron and zinc levels were higher than the recommended levels in several of the wells tested.

2. The groundwater from all the nine wells tested is considered to be unsuitable or only marginally suitable for fish culture purposes if left untreated. Of particular concern are the extremely low buffering capacity, extreme softness and low pH (the above values were lowest for wells No. 1 and No. 2), dissolved gas problems, and in some cases toxic heavy metal concentrations.

3. Given appropriate physical treatment such as mineral enrichment and aeration, the wells best suited for fish culture are No. 7b and No. 9. However, the available mineral enrichment methods may not be economic and logistically feasible given the remoteness of the site.

SURFACE WATER

The following general observations regarding water quality were made for the Indian River surface water:

1. Values for principal water quality parameters ranged as follows: temperature from about 4°C between December and March to about 15°C in July and August; alkalinity 2 to 14 mg/l as $CaCO_3$; hardness 3 to 17 mg/l as $CaCO_3$; pH averaged 6.8 and ranged from 6.0 to 7.4 but 5.4 at

Hixon Creek. Hixon Creek water had the lowest hardness (3 mg/l as $CaCO_3$) and pH (5.4), and affected water characteristics of the Indian River below the creek confluence. Aluminum, copper, iron, mercury and zinc showed occasional elevated levels but some of these values are suspected to be anomalies.

2. The Indian River surface water is only marginally acceptable for fish culture purposes if left untreated, mainly due to extremely low buffering capacity, extreme softness and slightly acidic water.

3. The Indian River surface water temperatures during winter months are too low to provide size advantage by spring release dates; consequently, heating or the use of a warmer groundwater source would be required.

CHINOOK PILOT HATCHERY

1. Approximately 250,000 chinook eggs were transported from the Capilano hatchery to the Indian River pilot hatchery in November 1979.

2. The eggs were incubated to the buttoned-up stage in Heath trays; the fry were ponded and reared up to 2.4 g in indoor troughs, then were transferred to an outdoor pond and reared to 3 g to 6 g prior to release to the river.

3. The overall egg-to-ponding survival was 91%; the overall egg-to-release survival was 78%.

4. In early June 1980, approximately 194,300 3 g to 6 g chinook smolts were released into the Indian River. Of these fish, 102,512 were tagged with tag code 02-18-39.

5. Adult tag returns of Indian River hatchery chinook were available at the time of reporting only for 2- and 3-year old fish. Of the 224 tags recovered in 1981 and 1982, over 80% came from the Georgia Strait commercial and sport fisheries. Mean fork lengths of the 2- and 3-year old chinook sampled from the commercial catch were 45.0 cm and 61.5 cm respectively.

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Appendix 1. Indian River groundwater testing program, 1972 - 1982.

Well No.	Well Symbol	Well location (Fig. 2)	Sampling date	Group responsible for: Sample collection	Group responsible for: Sample analysis
1	No. 1	Hixon Cr. delta	March 20, 1972	Underwood McLellan and Associates	Can Test Ltd.
2	No. 2	Hixon Cr. delta	April 23, 1972	Underwood McLellan and Associates	Can Test Ltd.
1	No. 1	Hixon Cr. delta	Aug. 25 - 27, 1979	Dept. Fisheries and Oceans	EPS - DFO[a]
2	No. 2	Hixon Cr. delta	July 12 - 15, 1979	Dept. Fisheries and Oceans	EPS - DFO
1	No. 1	Hixon Cr. delta	Feb. 5 , 1980	Dept. Fisheries and Oceans	EPS - DFO
3	No. 3	~ 2 km upstream of Hixon Cr. delta	Apr. 23 - 24, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [c]
4	No. 4	~ 2 km upstream of Hixon Cr. delta	Apr. 20 - 22, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [c]
5	E[b]1-1	"	Oct. 23, 1981	Sigma Env. Consultants Ltd.	EPS - DFO
5	E 1-2	"	Nov. 4, 1981	Sigma Env. Consultants Ltd.	EPS - DFO
6	E 2	"	Sept. 30, 1981	Sigma Env. Consultants Ltd.	EPS - DFO
7	E 3-1	"	Dec. 4, 1981	Sigma Env. Consultants Ltd.	EPS - DFO
7	E 3-2	"	Dec. 10, 1981	Sigma Env. Consultants Ltd.	EPS - DFO
8	E 4	"	Jan. 25, 1982	Sigma Env. Consultants Ltd.	EPS - DFO
9	TP 82-1	"	Dec. 21 - 22, 1982	Sigma Env. Consultants Ltd.	EPS - DFO

[a] EPS - DFO water quality laboratory in West Vancouver.

[b] 'E' indicates exploration well.

[c] Can Test Ltd. also did preliminary testing.

Appendix 2. Indian River watershed surface water testing program, 1972 - 1982.

Data set	Sampling location (Fig. 2)	Sampling date	Group responsible for: Sample collection	Group responsible for: Sample analysis
1	Hixon Cr. near mouth	March 29, 1972	Underwood McLellan & Associates	Can Test Ltd.
2	Indian R. below Hixon Cr.	March 29, 1972	Underwood McLellan & Associates	Can Test Ltd.
3	Indian R. above Hixon Cr.	Jan. - Aug.[a] 1977	Dept. Fisheries and Oceans	EPS - DFO [b]
4	Indian R. below Hixon Cr.	Jan. - Aug.[a] 1977	Dept. Fisheries and Oceans	EPS - DFO [b]
5	Near Indian R. & Hixon Cr. confluence (springwater)	Jan. - Aug.[a] 1977	Dept. Fisheries and Oceans	EPS - DFO [b]
6	Indian River at bridge below Hixon Cr.	July 12, 1979	Dept. Fisheries and Oceans	EPS - DFO [b]
7	Indian River near well No. 1	Aug. 27, 1979	Dept. Fisheries and Oceans	EPS - DFO [b]
8	Indian River nearwWells No. 3 & 4	April 21, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [b]
9	Indian River at bridge below Hixon Cr.	July 31, 1981	Dept. Fisheries and Oceans	EPS - DFO [b]
10	Forestry Creek near mouth	July 31, 1981	Dept. Fisheries and Oceans	EPS - DFO [b]
11	Indian River near well No. 6	Sept. 30, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [b]
12	Indian River near well No. 5a	Oct. 23, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [b]
13	Indian River near well No. 5b	Nov. 4, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [b]
14	Indian River near well 7a	Dec. 4, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [b]
15	Indian River near well 7b	Dec. 10, 1981	Sigma Env. Consultants Ltd.	EPS - DFO [b]
16	Indian River near well No. 8	Jan. 25, 1982	Sigma Env. Consultants Ltd.	EPS - DFO [b]
17	Indian River near well 9	Dec. 21, 1982	Sigma Env. Consultants Ltd.	EPS - DFO [b]

[a] The site was sampled on 15 occasions between January and August 1977.

[b] EPS - DFO water quality laboratory in West Vancouver.

Appendix 3. Well and aquifer parameters, Indian River groundwater exploration program, 1972 - 1982.[a]

Well No.	Well Symbol	Date of aquifer tests	Duration of pumping (hr)	Well diameter (mm)	Depth of drilling (m)	Screen depth (m)	Available drawdown (m)	Average pumping rate (m^3/day)	Specific capacity (m^3/day/m)	Transmissivity (m^3/day/m)	Potential pumping rate (m^3/day)
1	No. 1	1972 March 19 - 20	~24	203	19.8	15.2 - 18.3	0.7	2,776	4,197	24,803 (min)	32,659
2	No. 2	1972 April 22 - 23	~24	203	79.2	53.3 - 56.4	1.4	3,310	2,357	24,803	30,482
3	No. 1	1981 April 23 - 24	36	203	32.8	22.7 - 27.7	12	285	24 (220)[b]	300	13,000[c]
4	No. 2	1981 April 20 - 22	48	203	37.5	27.5 - 34.1	-	3,000	222 (2,100)[b]	3,370	20,000[c]
5a	E 1-1	1981 Oct. 22 - 23	~24	150	33.2	16.9 - 21.0	14	779	71	446[d]	745[e]
5b	E 1-2	1981 Nov. 3 - 4	~24	150	33.2	10.6 - 13.4	9	365	56	353[d]	380[e]
6	E 2	1981 Sept. 29 - 30	~24	150	12.8	8.8 - 11.6	7.5	327	232	300[d]	1,305[e]
7a	E 3-1	1981 Dec. 3 - 4	~24	150	64.4	42.6 - 49.4	40	1,308	127	680[d]	3,810[e]
7b	E 3-2	1981 Dec. 9 - 10	~24	150	64.4	26.0 - 31.4	24	1,384	256	682[d]	4,610[e]
8	E 4	1982 Jan. 24 - 25	~24	150	35.1	29.5 - 34.9	26	1,226	104	-	2,030[e]
9	TP 82-1	1982 Dec. 18 - 22	94	305	33.5	28.6 - 33.4	6.9	7,154	1,438	3,451	9,850

[a] Sources:
Wells No. 1 and No. 2 (Robinson, Roberts and Brown Ltd. 1972);
Wells No. 3 and No. 4 (Brown, Erdman and Associates Ltd. 1981);
Wells No. 5, No. 6, No. 7 and No. 8 (Brown, Erdman and Associates Ltd. 1982);
Well No. 9 (Brown, Erdman and Associates Ltd. 1983).

[b] Value in parenthesis is the theoretical specific capacity corrected for incomplete well development which caused high aquifer and well losses.

[c] For properly constructed wells.

[d] Approximate calculated value.

[e] Representative only for 150 mm diameter wells because larger diameter wells would have greater specific capacity.

Appendix 4. Water quality for Indian River well No. 1, 1972, 1979, 1980.

	WELL NO. 1						
Sampling date	1972 March 20	1979 Aug. 25	1979 Aug. 26	1979 Aug. 27	1979 Aug. 27	1980 Feb. 5[a]	1980 Feb. 5[b]
No. hrs after start of pumping	~ 24 hr	45 hr	69 hr	91 hr	93 hr	—	—
Parameter[c]							
Alkalinity (total)	7.0	3.7	3.6	3.6	3.6	4.1	4.6
Ammonia (total)	-	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.082
Chloride	0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.66	0.51
Colour	< 0.5	-	-	-	-	-	-
Conductivity (lab; μ mhos/cm)	-	15.5	15.4	16.3	15.6	13.9	14.7
Dissolved oxygen	-	6.0	6.0	6.0	6.0	-	8
Dissolved oxygen (% Sat'n)	-	50	50	50	50	-	72
Dissolved gas (% Total)	-	85	86	86	86	-	98
Dissolved gas (% N_2 Sat'n)	-	96	97	96	96	-	106
Hardness (as $CaCO_3$)	2.4	5	5	5	5	4.11	4.31
Nitrite	-	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Nitrate	0.14	0.14	0.14	0.13	0.13	0.13	0.13
pH (field)	-	6.0	6.0	6.0	-	6.4	6.4
pH (lab)	6.0	5.9	5.9	5.7	5.8	-	-
Phosphate	< 0.1 (dis)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.021
Residue (total)	13.1	18+	18+	18+	18+	13+	13+
Residue (filterable)	13	18	18	18	18	13	13
Residue (non-filterable)	0.1	< 5	< 5	< 5	< 5	< 5	< 5
Silica	3.2 (dis & tot)	1.5	1.6	1.5	1.5	1.6	1.6
Sulfate	< 1 (dis)	1.8	1.9	1.9	1.7	2.0	2.2
Taste and odour	✓	✓	✓	✓	✓	✓	✓
Temperature (°C)	8 - 9	5.5	5.5	5.5	5.5	9	9
Turbidity (FTU + JTU)							
Metals[d]							
AL	< 0.05 (dis)	< 0.09	< 0.09	< 0.09	< 0.09	< 0.09	< 0.09
AS	-	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
BA	-	0.005	0.005	0.005	0.005	0.005	0.005
CA	0.5 (dis)	1.53	1.55	1.6	1.6	1.4	1.5
CD	-	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CO	-	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
CR	< 0.01 (dis)	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
CU	0.015 (dis); 0.03 (tot)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
FE	0.05 (dis); 0.07 (tot)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
HG	-	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
K	< 0.1 (dis)	0.20	0.21	0.21	0.21	0.23	0.23
MG	< 0.3 (dis)	0.18	0.19	0.18	0.18	0.137	0.149
MN	< 0.05 (dis)	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
MO	-	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
NA	0.9 (dis)	0.6	0.6	0.6	0.6	0.5	0.55
NI	-	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08
P	-	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
PB	< 0.01 (dis)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SB	-	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08
SE	-	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
SI	3	1.57	1.59	1.6	1.6	1.5	1.5
SN	-	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
SR	-	0.007	0.007	0.007	0.008	0.006	0.007
TI	-	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009
V	-	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
ZN	< 0.01 (dis)	0.0015	< 0.001	0.0012	0.0010	< 0.001	< 0.001

[a] Sampled at intake of rearing trough No. 3.

[b] Sampled at outlet of rearing trough No. 3; water quality of well water reflects effects of rearing.

[c] Values are given in mg/l unless indicated otherwise.

[d] Extractable metals are given unless indicated otherwise (eg. total or dissolved).

Appendix 5. Water quality for Indian River well No. 2, 1972 & 1979.

	WELL NO. 2				
Sampling date	1972 April 23	1979 July 12	1979 July 13	1979 July 14	1979 July 15
No. hrs after start of pumping	15 hr	24 hr	45 hr	72 hr	99 hr
Parameter[a]					
Alkalinity (total)	8	4.7	4.7	4.7	4.4
Ammonia (total)	-	0.0065	0.0075	0.0139	0.0153
Chloride	0.5 (dis)	< 0.05	< 0.05	< 0.5	< 0.5
Colour	0.5	< 5	-	-	-
Conductivity (lab; µ mhos/cm)	-	18	18.2	17.4	17.5
Dissolved oxygen	-	8.0	7.0	7.0	7.0
Dissolved oxygen (% Sat'n)	-	70	60	60	60
Dissolved gas (% Total)	-	99	98	98	98
Dissolved gas (% N_2 Sat'n)	-	108	110	109	109
Hardness (as $CaCO_3$)	4.1	5.1	5.3	5.2	5.2
Nitrite	-	< 0.005	< 0.005	< 0.005	< 0.005
Nitrate	< 0.1 (dis)	0.15	0.18	0.15	0.18
pH (field)	-	6.0	6.0	6.3	6.3
pH (lab)	5.3	6.1	6.0	6.0	6.0
Phosphate	< 0.1 (dis)	< 0.005	< 0.005	< 0.005	< 0.005
Residue (total)	19.1	22+	22+	16+	17+
Residue (filterable)	19	22	22	16	17
Residue (non-filterable)	0.1	< 5	< 5	< 5	< 5
Silica	4.9 (dis & tot)	2.2	2.3	2.12	2.12
Sulfate	< 0.5 (dis)	2.1	2.1	2.3	1.8
Taste and odour	✓	✓	✓	✓	✓
Temperature (°C)	8.3	7.5	7.0	7.0	7.0
Turbidity (FTU + JTU)	0.1	< 1.0	< 1.0	< 1.0	< 1.0
Metals[b]					
AL	< 0.05 (dis)	< 0.09	< 0.09	< 0.09	< 0.09
AS	-	< 0.15	< 0.15	< 0.15	< 0.15
BA	-	0.004	0.004	0.003	0.004
CA	< 0.5 (dis)	1.7	1.8	1.8	1.8
CD	-	< 0.001	< 0.001	< 0.001	< 0.001
CO	-	< 0.015	< 0.015	< 0.015	< 0.015
CR	< 0.005 (dis)	< 0.015	< 0.015	< 0.015	< 0.015
CU	< 0.005 (dis)	< 0.001	< 0.001	< 0.001	< 0.001
FE	0.05 (dis & tot)	0.032	0.037	0.019	0.019
HG	-	< 0.0002	< 0.0002	< 0.0002	< 0.0002
K	< 0.1 (dis)	0.2	0.23	0.23	0.23
MG	1.0 (dis)	0.19	0.20	0.20	0.20
MN	< 0.05 (dis)	< 0.003	0.003	< 0.003	0.004
MO	-	< 0.15	< 0.15	< 0.15	< 0.15
NA	2.5 (dis)	0.68	0.7	0.8	0.7
NI	-	< 0.08	< 0.08	< 0.08	< 0.08
P	-	< 0.3	< 0.3	< 0.3	< 0.3
PB	< 0.01 (dis)	< 0.001	< 0.001	< 0.001	< 0.001
SB	-	< 0.08	< 0.08	< 0.08	< 0.08
SE	-	< 0.15	< 0.15	< 0.15	< 0.15
SI	-	2.3	2.4	2.3	2.3
SN	-	< 0.2	< 0.2	< 0.2	< 0.2
SR	-	0.009	0.009	0.009	0.009
TI	-	< 0.009	< 0.009	< 0.009	< 0.009
V	-	< 0.05	< 0.05	-	-
ZN	< 0.005 (dis)	< 0.001	< 0.001	< 0.001	< 0.001

[a] Values are given in mg/l unless indicated otherwise.

[b] Extractable metals are given unless indicated otherwise (eg. total or dissolved).

Appendix 6. Water quality for Indian River wells No. 3 and No. 4, 1981.

	WELL NO. 3			WELL NO. 4			
Sampling date	1981 April 23	1981 April 24	1981 April 24	1981 April 20	1981 April 21	1981 April 21	1981 April 22
No. hrs after start of pumping	2.0 hr	23.5 hr	29.0 hr	2.3 hr	22.0 hr	30.5 hr	45.5 hr
Parameter[a]							
Alkalinity (total)	9.9	10.3	10.8	13.1	14.1	15.1	14.2
Ammonia (total)	< 0.005	< 0.005	< 0.005	0.051	0.043	< 0.045	< 0.045
Chloride	0.61	0.56	0.59	0.84	0.76	0.77	0.64
Colour	< 5.0	-	-	-	-	-	-
Conductivity (field; µ mhos/cm)	18.0	20.0	22.0	28.0	25.0	25.0	25.0
Conductivity (lab; µ mhos/cm)	29.2	30.0	35.5	35.0	35.0	32.8	32.4
Dissolved oxygen	6.5	5.4	6.0	4.4	5.0	5.1	5.2
Dissolved oxygen (% Sat'n)	55.2	45.2	50.3	35.4	40.1	41.1	42.2
Dissolved gas (% Total)	105.6	103.6	104.3	-	-	104.1	103.6
Dissolved gas (% N_2 Sat'n)	119.0	119.1	118.6	-	-	120.9	120.0
Hardness (as $CaCO_3$)	9.8	9.2	9.3	10.6	10.4	9.5	9.2
Nitrite	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Nitrate	0.280	0.230	0.226	0.135	0.167	0.175	0.178
pH (field)	5.7	5.5	5.7	6.5	6.5	6.7	6.5
pH (lab)	7.1	6.8	6.2	6.4	6.4	6.6	6.5
Phosphate	< 0.005	< 0.005	< 0.005	< 0.011	0.011	< 0.011	0.012
Residue (total)	32+	32+	34+	34+	33+	29+	31+
Residue (filterable)	32	32	34	34	33	29	31
Residue (non-filterable)	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Silica	6.4	7.5	6.7	5.8	5.5	5.3	5.1
Sulfate	2.7	2.7	2.7	4.0	3.5	2.0	2.1
Taste and odour	✓	✓	✓	← "Minerally" taste →			
Temperature (°C)	8.7	8.5	8.6	7.0	6.9	6.9	7.0
Turbidity (FTU + JTU)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	2.5	3.5
Ryznar stability index	14.6	14.8	14.6	13.6	13.5	13.5	13.7
Langlier saturation index	- 4.5	- 4.7	- 4.5	- 3.5	- 3.5	- 3.4	- 3.6
Oxygen/Reduction potential	-	30	70	150.0	120.0	110.0	130.0
Metals[b]							
AL	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.07	< 0.05
AS	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075
BA	0.004	0.002	0.002	0.007	0.005	0.006	0.006
CA	3.3	3.1	3.13	3.6	3.54	3.06	3.04
CD	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CO	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075
CR	0.0323	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075
CU	0.006	0.003	0.0035	0.002	0.001	< 0.001	< 0.001
FE	0.047	0.039	0.040	0.824	1.02	1.06	1.06
HG	< 0.0002	< 0.0002	< 0.0002	0.0006	< 0.0002	< 0.0002	< 0.0002
K	0.291	0.227	0.238	0.311	0.316	0.293	0.288
MG	0.37	0.35	0.36	0.38	0.38	0.46	0.38
MN	0.034	0.009	0.010	0.037	0.040	0.039	0.038
MO	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
NA	2.64	1.66	1.9	2.19	1.91	1.59	1.67
NI	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
P	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
PB	0.006	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SB	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
SE	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075
SI	5.7	5.6	5.6	5.14	4.86	5.0	4.9
SN	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
SR	0.027	0.026	0.026	0.024	0.024	0.023	0.023
TI	< 0.004	0.010	0.009	< 0.004	< 0.004	< 0.004	< 0.004
V	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
ZN	0.008	0.001	0.002	0.003	0.004	0.002	0.002

[a] Values are given in mg/l unless indicated otherwise.

[b] Extractable metals.

Appendix 7. Water quality for Indian River wells No. 5, 6, 7 and 8 (E 1, E 2, E 3 & E 4), 1981 - 1982.

	WELL NO.					
Sampling date	5a 1981 Oct. 23	5b 1981 Nov. 4	6 1981 Sept. 30	7a 1981 Dec. 4	7b 1981 Dec. 10	8 1982 Jan. 25
Parameter[a]						
Alkalinity (total)	14.5	12.8	13.0	11.7	8.8	13.0
Ammonia (total)	< 0.005	< 0.005	0.043	< 0.005	< 0.005	< 0.005
Chloride	3.9	2.4	0.6	1.3	0.8	< 0.5
Colour	< 5.0	< 5.0	< 5.0	< 5.0	5.0	< 5.0
Conductivity (field; μ mhos/cm)	34.0	32.0	27.0	16.0	12.0	21.0
Conductivity (lab; μ mhos/cm)	50.5	46.6	36.6	33.5	23.6	33.1
Dissolved oxygen	2.5	5.6	3.4	3.2	7.8	3.8
Dissolved oxygen (% Sat'n)	20.5	47.0	28.1	25.7	62.8	31.1
Dissolved gas (% Total)	100.3	100.5	100.3	104.7	102.8	102.1
Dissolved gas (% N_2 Sat'n)	121.5	114.7	119.4	125.7	113.4	121.0
Hardness (as $CaCO_3$)	14.8	14.0	12.0	10.0	6.9	11.1
Nitrite	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Nitrate	0.115	0.131	0.283	0.096	0.176	0.20
pH (field)	6.3	6.3	-	7.1	7.2	6.2
pH (lab)	6.6	6.4	6.3	6.9	6.5	6.3
Phosphate	< 0.005	< 0.005	0.060	0.024	0.009	< 0.005
Residue (total)	44+	38+	29+	27+	26+	32+
Residue (filterable)	44	38	29	27	26	32
Residue (non-filterable)	< 5	< 5	< 5	< 5	< 5	< 5
Silica	6.7	4.0	4.1	5.8	3.0	5.1
Sulfate	3.7	5.9	< 1.0	3.7	2.4	3.8
Taste and odour	✓	✓	✓	✓	✓	✓
TDS	-	-	-	-	-	-
Temperature (°C)	7.8	8.6	8.2	6.2	6.2	6.7
Turbidity (FTU + JTU)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ryznar stability index	13.4	13.5	13.6	13.2	13.8	13.9
Langlier saturation index	- 3.5	- 3.6	- 3.7	- 3.0	- 3.3	- 3.8
Metals[h]						
AL	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
AS	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075
BA	0.005	0.008	0.013	0.003	0.008	0.007
CA	5.01	4.81	4.18	3.48	2.43	3.82
CD	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CO	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075
CR	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075
CU	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
FE	0.02 (tot)	0.01 (tot)	0.036 (tot)	0.51 (tot)	0.007 (tot)	0.02 (tot)
HG	0.00049	0.00035	0.00032	< 0.0002	0.00014	< 0.0002
K	0.375	0.384	0.318	0.244	0.070	-
MG	0.55	0.48	0.37	0.33	0.19	0.39
MN	0.002	0.004	0.011	0.011	0.002	0.002
MO	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
NA	2.79	2.48	1.52	1.73	0.97	1.65
NI	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
P	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
PB	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SB	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
SE	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075
SI	6.4	4.0	4.3	6.0	3.1	5.3
SN	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
SR	0.037	0.030	0.025	0.023	0.013	0.025
TI	< 0.004	< 0.004	0.009	< 0.004	< 0.004	< 0.004
V	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
ZN	0.018	0.0317	0.017	0.009	0.009	0.016

[a] Values are given in mg/l unless indicated otherwise.
[b] Screen depth from 16.9 m to 21.0 m.
[c] Screen depth from 10.6 m to 13.4 m.
[d] Screen depth from 8.8 m to 11.6 m.
[e] Screen depth from 42.6 m to 49.4 m.
[f] Screen depth from 26.0 m to 31.4 m.
[g] Screen depth from 29.5 m to 34.9 m.
[h] Extractable metals are given unless indicated otherwise (eg. total).

Appendix 8. Water quality for Indian River well No. 9 (TP 82-1), 1982.

	WELL NO. 9			
Sampling date	1982 Dec. 21	1982 Dec. 21	1982 Dec. 22	1982 Dec. 22
No. hrs after start of pumping	48.5 hr	69 hr	71.5 hr	93 hr
Parameter[a]				
Alkalinity (total)[b]	6.0	6.0	6.0	6.0
Ammonia (total)	< 0.005	< 0.005	< 0.005	< 0.005
Chloride	0.5	0.5	0.7	0.7
Colour	-	-	-	-
Conductivity (field; µ mhos/cm)	12	11	11	11
Conductivity (lab; µ mbos/cm)	19.1	19.1	19.2	18.9
Dissolved oxygen	7.1	7.5	6.6	6.5
Dissolved oxygen (% Sat'n)	57.8	61.1	53.8	52.8
Dissolved gas (% Total)	102.1	103.6	101.2	103.4
Dissolved gas (% N_2 Sat'n)	113.9	114.8	113.8	116.9
Fluoride	< 0.03	< 0.03	< 0.03	< 0.03
Hardness (as $CaCO_3$)	6.0	6.2	6.2	10.9
Nitrite	< 0.005	< 0.005	< 0.005	< 0.005
Nitrate	0.13	0.13	0.13	0.14
Oxygen/Reduction potential (mV)	190	160	170	160
pH (field)	6.7	6.1	6.5	6
pH (lab)	6.3	6.1	6.1	6.0
Phosphate	< 0.005	< 0.005	< 0.005	< 0.005
Residue (total)	23	16+	17+	23+
Residue (filterable)[c]	18	16	17	23
Residue (non-filterable)	5	< 5	< 5	< 5
Silica	2.1	2.1	2.1	2.2
Sulfate	3.3	2.9	3.7	4.7
Taste and odour	✓	✓	✓	✓
Temperature (°C)	6.75	6.75	6.75	6.75
Turbidity (FTU + JTU)	< 0.1	< 0.1	< 0.1	< 0.1
Ryznar stability index	14.5	15.1	14.7	14.7
Langlier saturation index	- 3.9	- 4.5	- 4.1	- 4.3
Metals				
AL	< 0.05	< 0.05	< 0.05	< 0.05
AS	< 0.05	< 0.05	< 0.05	< 0.05
BA	0.006	0.006	0.007	0.006
CA	2.0	2.2	2.2	4.2
CD	< 0.002	< 0.002	< 0.002	< 0.002
CO	< 0.005	< 0.005	< 0.005	< 0.005
CR	< 0.005	< 0.005	< 0.005	< 0.005
CU	< 0.005	< 0.005	< 0.005	0.018
FE	< 0.005	< 0.005	< 0.005	0.007
HG	< 0.0002	< 0.0002	< 0.0002	< 0.0002
K	1.5	0.14	0.14	0.15
MG	0.20	0.2	0.2	< 0.1
MN	< 0.001	< 0.001	< 0.001	< 0.001
MO	< 0.005	< 0.005	< 0.005	< 0.005
NA	0.7	0.8	0.7	1.6
NI	< 0.02	< 0.02	< 0.02	< 0.02
P	< 0.05	< 0.05	< 0.05	0.05
PB	< 0.02	< 0.02	< 0.02	< 0.02
SB	< 0.05	< 0.05	< 0.05	< 0.05
SE	< 0.05	< 0.05	< 0.05	< 0.05
SI	1.8	1.8	1.8	2.2
SN	< 0.01	< 0.01	< 0.01	< 0.01
SR	0.01	0.01	0.01	0.02
TI	< 0.002	< 0.002	< 0.002	< 0.002
V	< 0.01	< 0.01	< 0.01	< 0.01
ZN	< 0.002	< 0.002	< 0.002	< 0.002

[a] Values are given in mg/l unless indicated otherwise.
[b] Filterable residue and alkalinity for well sample 1 (48.5 hr) and 4 (93 hr) are approximate values only.
[c] Extractable metals.

Appendix 9. Water quality for Indian River surface water, 1972 - 1982.

Sampling date / Sampling site	1972 March 29 Hixon Cr. (near mouth)	1972 March 29 Below Hixon Cr.	1977 January - August Above Hixon Cr.[a]	Below Hixon Cr.[a]	Spring-water at creek and river confluence[a]	1979 July 12 At bridge below Hixon Cr.	1979 Aug. 27 Near well No. 1
Parameter[b]							
Alkalinity (total)	6.0	7.0	9.0 (4.6 -12)	5.0 (2.6 - 9)	4.4 (3 - 6)	7.5	8.9
Ammonia (total)	-	-	(< .005 - .024)	(< 0.005 - .008)	(< 0.005 - .010)	< 0.005	< 0.005
Chloride	< 0.5	0.5	-	< 0.5 - 1.4	-	< 0.5	< 0.5
Colour	7.0	2.5	-	-	-	7	-
Conductivity (field μ mhos/cm)	-	-	-	-	-	-	-
Conductivity (lab μ mhos/cm)	-	-	32.7 (23 - 41)	23.2 (14.4 - 36.2)	24.0 (18.8 - 57)	24.2	32.6
Dissolved oxygen	-	-	-	-	-	-	-
Dissolved oxygen (% Sat'n)	-	-	-	-	-	-	-
Dissolved gas (% Total)	-	-	-	-	-	-	-
Dissolved gas (% N_2 Sat'n)	-	-	-	-	-	-	-
Hardness (as $CaCO_3$)	3.3	4.0	11.5 (8.1 - 16.9)	6.7 (3.8 - 11.9)	6.1 (4.0 - 9.0)	9	13
Nitrite	-	-	< 0.005)	< 0.005	< 0.005	< 0.005	< 0.005
Nitrate	0.1 (dis)	< 0.1 (dis)	0.13 (.08 - .19)	0.14 (.06 - .23)	0.25 (.11 - .34)	0.07	0.13
pH (field)	-	-	-	-	-	7.0	7.0
pH (lab)	5.4	6.4	7.1 (6.8 - 7.4)	6.5 (6.1 - 6.8)	6.1 (6.0 - 6.9)	6.9	6.8
Phosphate	< 0.1 (dis)	< 0.1 (dis)	(< .01 - .04)	(< 0.01 - .03)	(< .01 - .04)	< 0.005	< 0.005
Residue (total)	-	-	33 (20 - 50)	27 (15 - 46)	28 (18 - 40)	27+	28+
Residue (filterable)	-	-	24 (16 - 30)	18 (10 - 28)	17 (13 - 30)	27	28
Residue (non-filterable)	2.3	0.9	<10	< 10	< 10	< 5	< 5
Silica	3.4 (tot)	2.9 (tot)	1.7 (1.1 - 2.1)	1.6 (.7 - 2.7)	1.5 (1.2 - 1.8)	1.4	1.6
Sulfate	< 1.0	< 1.0	4.7 (3.1 - 7.2)	3.0 (1.5 - 4.1)	2.6 (2 - 3.6)	2.2	4.1
Taste and odour	✓	✓	✓	✓	✓	✓	✓
Temperature (℃)	-	-	-	-	-	10.5	15.0
Turbidity (FTU & JTU)	0.6	0.2	(< .5 - 1.8)	(< 9.5 - 2.4)	(< 0.5 - 1.3)	< 1.0	< 1.0
Metals[c]							
AL	< 0.05 (dis)	< 0.05 (dis)	-	-	-	< 0.09	< 0.09
AS	-	-	-	-	-	< 0.15	< 0.15
BA	-	-	-	-	-	0.007	0.011
CA	0.5 (dis)	< 0.5 (dis)	3.9 (2.8 - 5.9)	2.3 (1.3 - 4.1)	2.0 (1.3 - 2.4)	3.2	4.4
CD	-	-	-	-	-	< 0.001	< 0.001
CO	-	-	-	-	-	< 0.015	< 0.015
CR	< 0.01 (dis)	< 0.01 (dis)	-	-	-	< 0.015	< 0.015
CU	0.025 (dis)	0.03 (dis)	< 0.01	< 0.01	< 0.01	< 0.001	< 0.001
FE	0.05 (dis); 0.15 (tot)	0.01 (dis & tot)	(< 0.03 - 0.10)	(< 0.03 - 0.03)	(< 0.03 - 0.04)	0.03	< 0.01
HG	-	-	-	-	-	< 0.0002	< 0.0002
K	-	< 0.01 (dis)	0.26 (.18 - .42)	0.22 (.14 - .31)	0.15 (.09 - .03)	0.2	0.3
MG	0.3 (dis)	1.0 (dis)	0.40 (.28 - .52)	0.22 (.13 - .40)	0.24 (.16 - 7.2)	0.3	0.4
MN	< 0.05 (dis)	< 0.05 (dis)	-	-	-	< 0.003	< 0.003
MO	-	-	-	-	-	< 0.15	< 0.15
NA	0.5 (dis)	0.6 (dis)	0.74 (.48 - .97)	.69 (.46 - 1.2)	0.63 (.52 - .82)	0.6	0.9
NI	-	-	-	-	-	< 0.08	< 0.08
P	-	-	-	-	-	< 0.3	< 0.3
PB	< 0.01 (dis)	< 0.01 (dis)	< 0.02	< 0.02	< 0.02)	< 0.001	< 0.001
SB	-	-	-	-	-	< 0.08	< 0.08
SE	-	-	-	-	-	< 0.15	< 0.15
SI	-	-	-	-	-	1.5	1.8
SN	-	-	-	-	-	< 0.2	< 0.2
SR	-	-	-	-	-	0.013	0.018
TI	-	-	-	-	-	< 0.009	< 0.009
V	-	-	-	-	-	< 0.05	< 0.05
ZN	< 0.01 (dis)	< 0.01 (dis)	(< .01 - .05)	(< .01 - .04)	(<.01 - .06)	< 0.001	< 0.001

Appendix 9. (Cont'd).

Sampling date	1981 April 21	1981 July 31	1981 July 31	1981 Sept. 30	1981 Oct. 23	1981 Nov. 4	1981 Dec. 4	1981 Dec. 10	1982 Jan. 25	1982 Dec. 21
Sampling site	Near wells No.3 & No.4	At bridge below Hixon Cr.	Forestry Cr. (near mouth)	Immediately Upstream of the well tested:						
				6	5a	5b	7a	7b	8	9
Parameter[b]										
Alkalinity (total)	10.2	11.1	6.6	9.9	13.6	10.1	10.7	6.4	7.5	5.0
Ammonia (total)	< 0.005	0.098	0.092	0.0075	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.005
Chloride	0.62	< 0.50	< 0.50	0.95	0.67	0.75	1.42	0.86	0.50	0.7
Colour	-	-	-	< 5.0	< 5.0	< 5.0	< 5.0	10	< 5.0	-
Conductivity (field μ mhos/cm)	-	-	-	27.0	28.0	22.0	18.0	13.0	16.0	10
Conductivity (lab μ mhos/cm)	32.5	36.8	19.0	33.8	44.0	33.0	36.5	22.9	27.4	18.4
Dissolved oxygen	-	-	-	11.0	12.2	11.6	11.5	12.5	-	12.8
Dissolved oxygen (% Sat'n)	-	-	-	93.7	98.1	93.8	90.3	97.6	-	96.8
Dissolved gas (% Total)	-	-	-	101.9	101.0	100.1	101.7	100.0	102.8	103.6
Dissolved gas (% N_2 Sat'n)	-	-	-	104.1	101.8	101.8	104.8	100.7	-	105.3
Hardness (as $CaCO_3$)	10.9	13.5	6.0	12.6	16.4	12.3	13.1	8.3	8.9	6.8
Nitrite	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Nitrate	0.133	0.007	0.006	0.273	0.156	0.141	0.165	0.118	0.450	0.11
pH (field)	-	-	-	-	7.6	7.0	7.3	7.1	-	6.6
pH (lab)	6.8	7.4	7.0	7.0	7.4	7.1	6.9	6.7	6.0	6.5
Phosphate	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.008	0.013	< 0.005	0.076
Residue (total)	26+	27+	28+	29+	34+	29+	26+	23+	26+	18+
Residue (filterable)	26	27	28	29	34	29	26	23	26	18
Residue (non-filterable)	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Silica	2.14	1.93	1.68	1.8	2.4	2.0	1.8	1.21	2.3	1.5
Sulfate	4.4	5.0	2.9	3.1	6.7	5.3	6.4	4.7	4.1	2.8
Taste and odour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Temperature (℃)	5.7	-	-	9.4	7.1	7.1	5.2	4.9	4.4	4.5
Turbidity (FTU + JTU)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	1.0	< 1.0	6.0	1.2	< 0.1
Metals[b]										
AL	0.098	0.061	0.069	0.09	< 0.05	< 0.05	0.05	0.53	0.05	0.08
AS	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.05
BA	0.011	0.011	0.005	0.011	0.013	0.01	0.011	0.012	0.016	0.006
CA	3.67	4.65	2.09	4.45	5.68	4.23	4.49	2.60	3.02	2.2
CD	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.002
CO	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.005
CR	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.0075	< 0.005
CU	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.005
FE	0.012	0.011	0.012	0.07	0.015	0.06	< 0.01	0.405	0.02	0.015
HG	< 0.0002	0.0002	0.0002	< 0.0002	0.0008	< 0.0002	< 0.0002	0.00031	< 0.0002	< 0.0002
K	0.279	0.308	0.142	0.278	0.332	0.310	0.296	0.230	-	0.18
MG	0.42	0.46	0.19	0.37	0.53	0.41	0.45	0.43	0.34	0.20
MN	< 0.001	< 0.001	< 0.001	0.003	< 0.001	0.002	< 0.001	0.014	0.001	< 0.001
MO	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.005
NA	0.98	0.86	0.86	0.81	0.95	0.71	0.91	0.55	0.95	0.6
NI	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.02
P	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.05
PB	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.02
SB	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.05
SE	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.075	< 0.05
SI	2.05	1.82	1.59	1.93	2.22	1.99	2.11	2.15	2.47	1.3
SN	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.01
SR	0.017	0.020	0.009	0.019	0.023	0.017	0.019	0.011	0.016	0.01
TI	< 0.004	0.008	0.008	< 0.004	< 0.004	< 0.004	< 0.004	< 0.014	0.004	< 0.002
V	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.01
ZN	0.001	< 0.001	< 0.001	0.002	< 0.001	< 0.001	< 0.005	0.002	0.001	< 0.002

[a] Mean and range (in parenthesis) are given; data represent 15 separate sampling occasions between January and August 1977.

[b] Values are given in mg/L unless indicated otherwise.

[c] Extractable metals are given unless indicated otherwise (eg. total or dissolved).

Appendix 10. Indian River pH values at three locations, January - August 1977.

Data set	Sampling Date	pH		
		Site 1[a]	Site 2[a]	Site 3[a]
1	Jan. 17	7.1	6.4	6.8
2	Jan. 25	7.2	6.9	6.7
3	Feb. 8	7.0	6.1	6.3
4	Feb. 16	7.1	6.2	6.4
5	Feb. 21	6.8	6.1	6.3
6	Feb. 28	7.1	6.1	6.3
7	Mar. 7	6.8	6.1	6.6
8	Mar. 16	7.1	6.0	6.6
9	Apr. 6	7.0	6.0	6.7
10	Apr. 28	7.0	6.1	6.5
11	May 18	7.2	6.0	6.5
12	June 12	7.0	6.0	6.4
13	June 30	7.0	6.2	6.3
14	July 15	7.1	6.0	6.1
15	Aug. 3	7.4	6.0	6.3
Mean	-	7.1	6.1	6.5
Range	-	(6.8 - 7.4)	(6.0 - 6.9)	(6.1 - 6.8)

[a] Site 1 - Indian River above Hixon Creek confluence; ~ 1.2 km upstream of twin bridges;
Site 2 - Springwater entering a side channel near Hixon Cr. confluence;
Site 3 - Indian River below Hixon Creek confluence; at twin bridges (Fig.2).

Appendix 11. Extractable zinc (Zn) concentrations in the Indian River surface water sampled at three locations, January - August 1977.

Data set	Sampling Date	Zinc concentration (mg/l)[a]		
		Site 1[b]	Site 2[b]	Site 3[b]
	1977			
1	Jan. 17	0.02	0.02	0.04
2	Jan. 24	0.02	0.03	0.01
3	Feb. 7	0.04	0.02	0.02
4	Feb. 16	0.04	0.02	0.02
5	Feb. 21	0.03	0.06	0.01
6	Feb. 28	0.05	0.02	0.03
7	Mar. 7	0.02	0.02	0.01
8	Mar. 17	0.05	0.01	0.01
9	Apr. 7	0.05	0.01	0.02
10	Apr. 27	0.04	0.02	0.02
11	May 19	0.03	0.01	0.01
12	June 14	0.02	0.01	0.01
13	June 30	0.01	--	0.01
14	July 15	0.01	--	--
15	Aug. 2	0.01	--	--

[a] Detection limit was 0.01 mg/l Zn.

[b] Site 1 - Indian River above Hixon Creek confluence.
Site 2 - Springwater near Hixon Cr./Indian R. confluence.
Site 3 - Indian River below Hixon Creek confluence.

Appendix 12. Indian River surface water temperatures, 1951, 1959, 1966, 1972, 1978, 1979, 1980, 1981 and 1982.

Date		Temp. (°C)
1951 [a]		
Apr.	11	6
	25	6
May	9	8
	23	6
Aug.	16	10
Sept.	12	11
Oct.	4	10
1959 [b]		
Aug.	11 - 15	15.5
	16 - 20	15.0
	21 - 25	13.9
	26 - 31	12.7
Sept.	1 - 5	12.4
	6 - 10	12.3
	11 - 15	12.1
	16 - 20	11.7
	21 - 25	11.0
	26 - 30	9.6
Oct.	1 - 5	9.6
1966 [c]		
Mar.	15 - 20	3.3
	21 - 25	4.7
	26 - 31	4.1
Apr.	1 - 5	.6
	6 - 10	4.8
	11 - 15	4.7
	16 - 20	5.5
	21 - 25	5.6
	26 - 30	5.7
May	1 - 5	5.8
	6 - 10	6.0
	11 - 15	6.4
	16 - 20	6.8
	21 - 25	7.0
	26 - 31	7.0
June	1 - 5	6.6
	6 - 10	7.2
	11 - 15	7.6
	16 - 20	7.6

Date		Temp. (°C)
1972 [d]		
Mar.	20	4.4
Apr.	23	5.6
1977		
see Append. 12.		
1978 [e]		
July	26	13.9
	27	13.6
	28	14.2
	29	14.4
	30	12.8
	31	12.8
Aug.	1	12.2
	2	11.7
	3	11.7
	4	11.4
	5	11.7
1979		
July	12[d]	10.5
Aug.	27[d]	15.0
Nov.	5[f]	7.0
Dec.	31[f]	4.1
1980 [f]		
Jan.	1	4.0
	7	3.0
	12	1.5
	17	2.0
	19	2.5
Feb.	5	3.0
Apr.	4	5.5
	14-27	5.0
May 28 - June 10		6.0
1981 [g]		
Apr.	21[h]	5.7
Aug.	1	12.0
	2	12.3
	3	11.3
	4	11.5
	5	12.1

Date		Temp. (°C)
1981 (cont'd)		
Aug.	6	12.6
	7	13.5
	8	14.1
	9	14.1
	10	14.3
	11	14.3
	12	14.3
	13	14.3
	14	14.1
	15	14.0
	16	13.0
	17	13.0
	18	13.0
	19	13.3
	20	11.4
	21	12.0
	22	11.5
	23	11.8
	24	11.5
	25	11.8
	26	11.8
	27	11.3
	28	11.5
	29	11.5
	30	11.5
Sept.	1	12.3
	2	12.8
	3	11.0
	4	11.9
	5	11.9
	6	11.5
	7	11.4
	8	11.5
	9	11.8
	10	11.8
	11	11.3
	12	11.5
	13	10.8
	14	10.0
	15	9.5
	16	9.4

Date		Temp. (°C)
1981 (cont'd)		
Sept.	17	9.4
	18	8.8
	19	9.0
	20	8.9
	21	8.8
	22	8.8
	23	8.4
	24	8.1
	25	7.4
	26	7.5
	27	7.0
	28	6.8
	29	6.8
	30	7.0
Oct.	1	7.0
	2	7.1
	3	7.3
	4	7.3
	5	7.3
	6	7.3
	7	7.0
	8	6.9
	9	6.5
	10	6.5
	11	6.5
	12	6.5
	13[i]	6.3
Sept.	30[j]	9.4
Oct.	23[j]	7.1
Nov.	4[j]	7.1
Dec.	4[j]	5.2
	10[j]	4.9
1982 [k]		
Jan.	25	4.4
Dec.	18	4.0
	19	4.0
	20	4.5
	21	4.5
	22	4.0

[a] From Marshall et al. (1976).
[b] Five-day mean water temperatures for Indian River extrapolated from temperature curves in Underwood McLellan and Associates Ltd. (1972).
[c] Five-day mean water temperatures for Indian River extrapolated from temperature curves in Lister (MS 1968) and Underwood McLellan and Associates Ltd. (MS 1972).
[d] Measured during pump tests on wells No. 1 and No. 2.
[e] Measured using a Taylor 7-day thermograph.
[f] Measured during chinook pilot hatchery study.
[g] Measured using a Ryan thermograph, except where indicated.
[h] Measured during pump tests on wells No. 3 and No. 4.
[i] Thermograph lost due to extreme flooding conditions.
[j] Measured during pump tests on wells No. 5, 6 and 7.
[k] Measured during pump tests on wells No. 8 and 9.

Appendix 13. Indian River surface water (Site A) and springwater (Site B) temperatures, December 1976 - August 1977[a].

Date	Temp. (°C) Site A	Temp. (°C) Site B	Date	Temp. (°C) Site A	Temp. (°C) Site B	Date	Temp. (°C) Site A	Temp. (°C) Site B	Date	Temp. (°C) Site A	Temp. (°C) Site B
1976			1977			1977			1977		
Dec 9[b]	3	8	Feb. 1	4.3	7.5	Mar. 1	4.1	6.4	Apr. 1	-	-
22[b]	3.5	8	2	3.9	7.5	2	3.9	6.4	2	-	-
1977			3	3.9	7.3	3	4.4	6.3	3	-	-
Jan. 1	-	-	4	4.7	7	4	4.4	6.2	4	-	-
2	-	-	5	-	7	5	4.3	6.1	5	6.2	6.0
3	-	-	6	-	-	6	3.9	6.1	6	5.0	6.1
4[b]	3	7.5	7	5.5	7.5	7	3.9	6.0	7	4.6	6.1
5	-	-	8	5.5	7.6	8	3.6	6.0	8	3.9	6.1
6	-	-	9	5.6	7.6	9	3.1	6.0	9	3.9	6.1
7	-	-	10	5.3	7.5	10	4.5	5.8	10	4.2	6.1
8	-	-	11	5.6	7.4	11	3.9	5.8	11	5.3	5.9
9	-	-	12	5.3	7.5	12	4.1	5.7	12	5.0	6.0
10	-	-	13	5.0	7.5	13	3.9	5.7	13	4.7	6.1
11	3.6	8	14	5.2	7.4	14	4.2	5.5	14	5.4	6.1
12	3.9	7.6	15	5.6	6.9	15	4.2	5.5	15	4.6	6.1
13	4.6	7.6	16	5.5	6.8	16	5.4	5.7	16	4.8	6.1
14	4.4	7.5	17	5.5	6.6	17	5.0	5.8	17	-	-
15	4.1	7.5	18	5.5	6.5	18	3.9	5.6	18	-	-
16	4.4	7.5	19	5.6	6.5	19	3.7	5.5	19	-	-
17	4.4	5.8	20	5.5	6.5	20	3.8	5.5	20	-	-
18	4.7	7.5	21	5.6	7.0	21	4.1	5.4	21	-	-
19	4.6	7.8	22	5.2	7.0	22	4.1	5.2	22	-	-
20	4.1	7.5	23	4.7	7.1	23	3.9	5.3	23	-	-
21	4.4	7.5	24	4.7	7.0	24	3.6	5.3	24	-	-
22	3.9	7.5	25	3.5	6.7	25	4.2	5.1	25	-	-
23	-	-	26	4.3	6.8	26	3.9	5.3	26	-	-
24	-	-	27	4.7	6.8	27	3.8	5.5	27	7.0	5.9
25	3.9	8	28	4.1	6.5	28	4.2	5.5	28	5.7	5.8
26	3.6	8				23	-	-	23	6.6	5.7
27	3.3	7.8				30	-	-	30	6.4	5.7
28	3.2	7.5				31	-	-			
29	3.1	7.5									
30	3.2	7.5									
31	4.3	7.5									
1977			1977			1977			1977		
May 1	6.0	5.7	June 1	-	-	July 1	11.5	5.5	Aug. 1	-	6.6
2	5.7	5.8	2	-	-	2	9.9	5.6	2	15.0	6.7
3	5.0	5.9	3	-	-	3	9.6	5.9	3	13.9	6.8
4	4.9	5.8	4	-	-	4	10.2	6.0	4	14.3	6.8
5	5.3	5.8	5	-	-	5	9.7	6.0	5	14.6	6.9
6	6.6	5.7	6	-	-	6	9.7	6.0	6	14.0	7.0
7	6.7	5.7	7	-	-	7	11.4	5.9	7	13.8	7.1
8	6.3	5.8	8	-	-	8	11.6	5.6	8	14.2	7.1
9	7.0	-	9	-	-	9	11.3	5.8	9	14.4	-
10	6.7	-	10	-	-	10	11.3	6.0	10	14.0	-
11	-	-	11	-	-	11	-	-	11	14.2	-
12	-	-	12	9.7	5	12	-	-	12	14.8	-
13	-	-	13	10.0	5	13	-	-	13	14.8	-
14	-	-	14	10.2	5.3	14	-	-	14	14.5	-
15	-	-	15	10.3	5.3	15	11.1	6.0	15	-	-
16	-	-	16	10.3	5	16	11.4	6.0	16	-	-
17	-	-	17	10.9	4.8	17	10.5	6.3	17	-	-
18	7.9	5.0	18	10.5	5	18	10.8	6.6	18	-	-
19	7.0	5.5	19	10.8	5	19	10.2	6.8	19	-	-
20	7.0	5.6	20	10.0	5	20	10.5	6.4	20	-	-
21	6.1	5.1	21	9.4	5.3	21	9.9	6.5	21	-	-
22	7.1	5.4	22	9.7	5.3	22	9.9	6.3	22	-	-
23	6.6	5.5	23	10.6	5.3	23	9.4	6.3	23	-	-
24	6.1	5.7	24	-	-	24	11.1	6.1	24	-	-
25	7.0	5.0	25	-	-	25	9.9	6.2	25	-	-
26	5.6	5.6	26	-	-	26	11.6	6.0	26	-	-
27	5.7	5.7	27	-	-	27	-	-	27	-	-
28	6.8	5.3	28	-	-	28	-	6.5	28	-	-
29	6.6	5.4	29	10.3	5.5	23	-	6.3	23	-	-
30	-	-	30	11.5	5.5	30	-	6.5	30	-	-
31	-	-				31	-	6.6	31	-	-

[a] Site A located on mainstem about 180 m upstream of Hixon Cr. confluence;
Site B located near the origin of groundwater stream which enters Jack's Slough (Fig. 2)

[b] Spot temperatures.

Appendix 14. Groundwater temperatures[a] for the Indian River wells, 1972, 1979, 1980, 1981 and 1982.

Date	Well No.	Temp (°C)
1972		
March	No. 1	8-9
Apr. 23	No. 2	8.3
1979		
July 12	No. 2	7.5
13	No. 2	7.0
14	No. 2	7.0
15	No. 2	7.0
Aug. 25	No. 1	5.5
26	No. 1	5.5
27	No. 1	5.5
Nov. 5	No. 1	9.0
Dec. 31	No. 1	9.5
1980		
Jan. 1	No. 1	10.0
7	No. 1	9.5
12	No. 1	9.5
17	No. 1	9.5
19	No. 1	9.5
24	No. 1	9.5
28	No. 1	9.5
1980 (cont'd)		
Feb. 5	No. 1	9.0
8	No. 1	9.0
Mar. 7	No. 1	7.1
18	No. 1	6.5
1981		
Apr. 20	No. 4	7.0
21	No. 4	6.9
22	No. 4	7.0
23	No. 3	8.7
24	No. 3	8.6
Sept. 30	No. 6 (E 2)	8.2
Oct. 23	No. 5a (E 1-1)	7.8
Nov. 4	No. 5b (E 1-2)	8.6
Dec. 4	No. 7a (E 3-1)	6.2
10	No. 7b (E 3-2)	6.2
1982		
Jan. 25	No. 8 (E 4)	6.7
Dec. 18	No. 9 (TP 82-1)	7.8
19-22	No. 9 (TP 82-1)	6.8

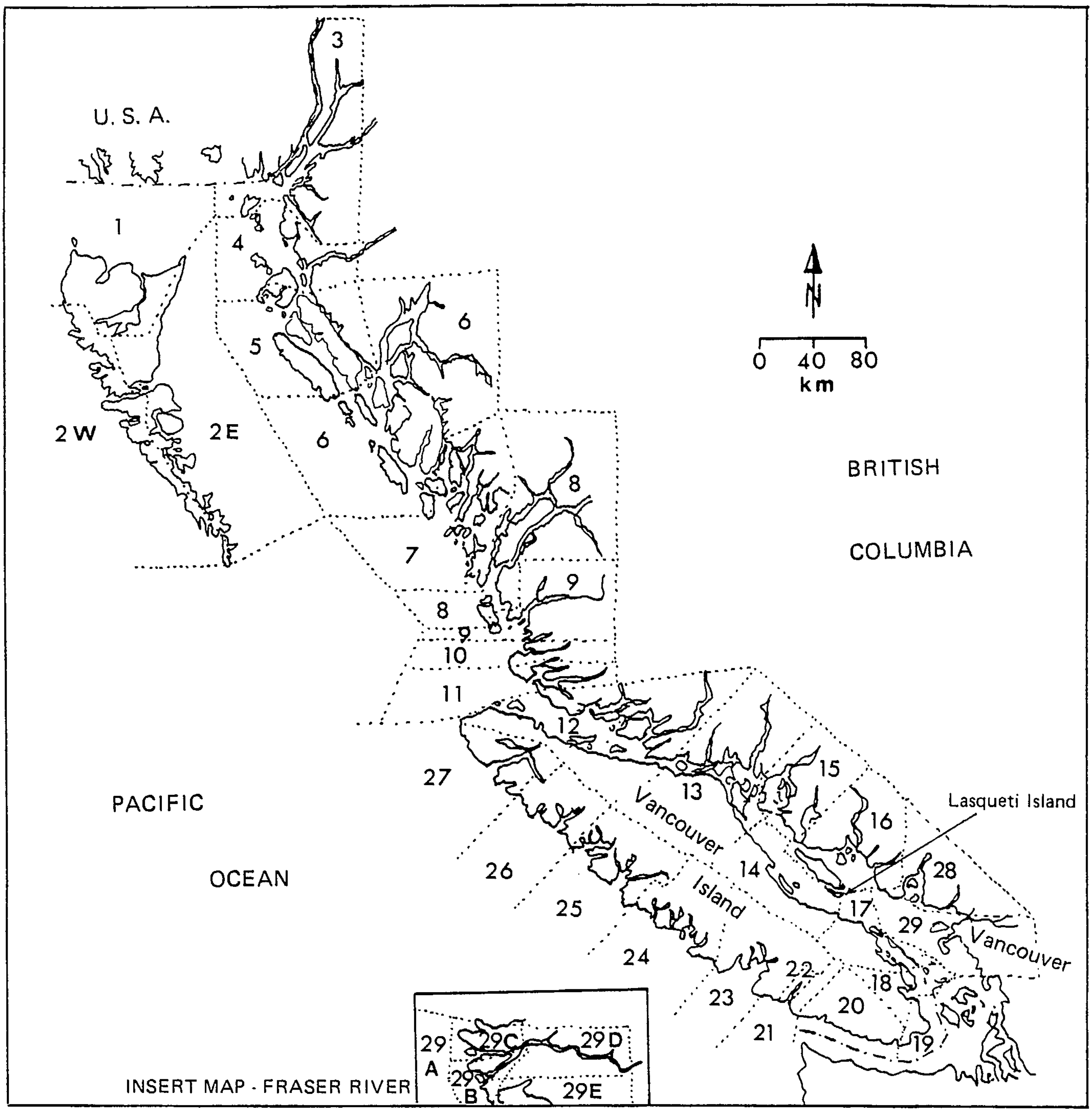
[a] Obtained during pump tests.

Appendix 15. OMP maximum ration % body weight/day feeding chart (Stauffer's formula).

Water Temperature (°C)	Fish weight (g) 0.20	0.40	0.60	0.80	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	14.0	16.0	18.0	20.0	25.0
3	2.81	2.23	1.95	1.77	1.64	1.30	1.14	1.04	.96	.90	.86	.82	.79	.76	.72	.68	.65	.63	.61	.56
4	4.04	3.21	2.80	2.55	2.36	1.88	1.64	1.49	1.38	1.30	1.24	1.18	1.14	1.10	1.03	.98	.94	.90	.87	.81
5	5.22	4.14	3.62	3.29	3.05	2.42	2.12	1.92	1.79	1.68	1.60	1.53	1.47	1.42	1.33	1.27	1.21	1.16	1.12	1.04
6	6.35	5.04	4.40	4.00	3.71	2.95	2.57	2.34	2.17	2.04	1.94	1.86	1.78	1.72	1.62	1.54	1.47	1.42	1.37	1.27
7	7.43	5.89	5.15	4.68	4.34	3.45	3.01	2.74	2.54	2.39	2.27	2.17	2.09	2.02	1.90	1.80	1.72	1.66	1.60	1.49
8	8.46	6.72	5.87	5.33	4.95	3.93	3.43	3.12	2.89	2.72	2.59	2.47	2.38	2.30	2.16	2.05	1.96	1.89	1.82	1.69
9	9.46	7.51	6.56	5.96	5.53	4.39	3.84	3.49	3.24	3.04	2.89	2.77	2.66	2.57	2.42	2.30	2.20	2.11	2.04	1.89
10	10.42	8.27	7.23	6.56	6.09	4.84	4.23	3.84	3.56	3.35	3.19	3.05	2.93	2.83	2.66	2.53	2.42	2.33	2.25	2.08
11	11.35	9.01	7.87	7.15	6.64	5.27	4.69	4.18	3.88	3.65	3.47	3.32	3.19	3.08	2.90	2.75	2.63	2.53	2.45	2.27
12	12.24	9.72	8.49	7.71	7.16	5.68	4.96	4.51	4.19	3.94	3.74	3.58	3.44	3.32	3.13	2.97	2.84	2.73	2.64	2.45
13	13.11	10.40	9.09	8.26	7.67	6.08	5.32	4.83	4.48	4.22	4.01	3.83	3.69	3.56	3.35	3.18	3.04	2.93	2.82	2.62
14	13.95	11.07	9.67	8.79	8.16	6.47	5.66	5.14	4.77	4.49	4.26	4.08	3.92	3.79	3.56	3.38	3.24	3.11	3.01	2.79
15	14.76	11.71	10.23	9.30	8.63	6.85	5.98	5.44	5.05	4.75	4.51	4.32	4.15	4.01	3.77	3.58	3.43	3.29	3.18	2.95
16	15.55	12.34	10.78	9.79	9.09	7.22	6.30	5.73	5.32	5.00	4.75	4.55	4.37	4.22	3.97	3.77	3.61	3.47	3.35	3.11
17	16.31	12.95	11.31	10.28	9.54	7.57	6.61	6.01	5.58	5.25	4.99	4.77	4.59	4.43	4.17	3.96	3.79	3.64	3.51	3.26
18	17.05	14.54	11.83	10.74	9.97	7.92	6.92	6.28	5.83	5.49	5.21	4.99	4.80	4.63	4.36	4.14	3.96	3.81	3.67	3.41
19	17.78	14.11	12.33	11.20	10.40	8.25	7.21	6.55	6.08	5.72	5.44	5.20	5.00	4.83	4.54	4.31	4.13	3.97	3.83	3.56
20	18.48	14.67	12.81	11.64	10.81	8.58	7.49	6.81	6.32	5.95	5.65	5.40	5.20	5.02	4.72	4.48	4.29	4.12	3.98	3.70

Appendix 16. Catch regions and their corresponding Statistical Areas in British Columbia.

Catch region[a]	Abbreviation	Corresponding Statistical Areas (Appendix Fig. 1)
Northern Troll	NTR	1-5
Central Troll	CTR	6-12, 30
Northwest Vancouver Island Troll	NWTR	25, 26, 27
Southwest Vancouver Island Troll	SWTR	21, 23, 24
Juan de Fuca Troll	JFTR	20
Georgia Strait Troll	GSTR	13-18, 29A
Combination Region	NTR/CTR	1-5, 6-12, 30
Combination Region	C/NWTR	25-27, 6-12, 30
Combination Region	NW/SWTR	21, 23, 24-27
Northern Net	NN	1-5
Central Net	CN	6-11
Northwest Vancouver Island Net	NWVN	25-27
Southwest Vancouver Island Net	SWVN	21-24
Juan de Fuca Net	JFN	20
Johnstone Strait Net	JSN	12, 13
Georgia Strait Net	GSN	14-18
Fraser River Gillnet	FGN	29A-29E
Combination Region	NN/CN	14-18, 29A-29E
Combination Region	GSN/FGN	1-5, 6-11
Northern Sport	NSPT	1-5
Central Sport	CSPT	6-12, 30
West Coast Vancouver Island Sport	WSPT	21-27
Georgia Strait Sport	GSPT	13-20, 28, 29



Appendix Fig. 1. Statistical fishing zones in British Columbia.