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EXPERIMENTAL DRIFTS OF JUVENILE CHINOOK
SALMON THROUGH EFFLUENT DISCHARGES
AT HANFORD IN 1968

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ABSTRACT

Young chinook salmon held in live boxes were drifted through Hanford reactor discharges in the central Columbia River, with the objective of evaluating the affect of heated effluents on fish survival. No significant mortalities of fish were recorded from 12 drifts during the spring (March-April) when base river temperatures were low, ranging from 4 to 7.6 °C. Some mortalities occurred, however, in 3 of 24 drifts conducted in late summer (August-September) when base river temperatures extended from 17 to 19.6 °C. None of the mortalities resulted from passage through midstream discharge plumes, which were characterized by relatively moderate temperature increase and short duration of exposure to maximum temperatures. Mortalities occurred only when fish were drifted along the south bank of the river through areas receiving heated water via intragravel seepage from shoreline retention basins and experimental subsurface disposal of reactor effluents. The shoreline areas were characterized by impeded river flow, which restricted horizontal and vertical mixing and prolonged the exposure of drifted fish to excessively warm temperatures. The extent of thermal shock sufficient to cause death in the field is primarily an integrated function of temperature increase and exposure duration, as has been demonstrated in laboratory experiments. The numerous possible combinations of these two factors that occur in situ have only been partially explored.

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EXPERIMENTAL DRIFTS OF JUVENILE CHINOOK
SALMON THROUGH EFFLUENT DISCHARGES
AT HANFORD IN 1968

INTRODUCTION

Routine operation of nuclear reactors on the AEC Hanford Reservation above Richland, Washington involve the release of heated water into the Columbia River. The effluents discharge primarily from submerged outfalls located at or near midstream. But some areas along the south bank of the river also receive heated water by means of intragravel seepage from shoreline retention basins and from test disposal of reactor effluent into the ground. Although the midstream discharges generally mix rapidly in the greater water mass and colder currents of the flowing Columbia, areas exist in the immediate vicinity of effluent release where the temperatures rise suddenly before the effluents disperse in the current (Jaske et al., in press).

Adult anadromous salmonids spawn each year in the Columbia River in the Hanford environs and above. The progeny of these fish emigrate seaward during the spring and summer of each year. Theoretically, an unknown portion of the emigrants pass through the mixing zones below heated discharges and experience "thermal shock." The effects of such exposure conceivably could result in mortalities, possibly of a sizeable but now of unknown magnitude. These mortalities could occur in three ways: 1) immediate, direct losses, 2) delayed, latent losses, and 3) indirect losses through predation, latent disease, and lowered resistance to environmental stress.

Although widespread construction of dams on the Columbia River and its tributaries has inundated hundreds of miles of natural spawning areas

(Fulton, 1968), a considerable portion of the surviving salmonid run still originates above Hanford. Raymond (1967) estimated the 1965 and 1966 outmigration of juvenile fish past Priest Rapids Dam (directly above Hanford) as follows:

	<u>1965</u>	<u>1966</u>
Chinook (<u>Oncorhynchus tshawytscha</u>)	2,000,000	1,400,000
Coho (<u>O. kisutch</u>)	200,000	1,100,000
Sockeye (<u>O. nerka</u>)	3,000,000	4,000,000
Steelhead (<u>Salmo gairdneri</u>)	= 250,000	= 250,000

These populations originate from several sources--upriver tributaries, artificial spawning channels, and salmon hatcheries. Raymond's data, however, do not include juvenile fish produced from chinook and steelhead redds in that section of the Columbia below Priest Rapids Dam, which numerically are of sizeable magnitude (Watson, 1968).

It is evident that considerable numbers of juvenile salmonids originate above or at Hanford. These fish must pass through the Hanford environs on their way to the sea. The outmigration through free-flowing sections of the river occurs at rates roughly in proportion to current flow. Since the fish are distributed throughout the river cross section (Mains and Smith, 1964), a portion may be swept directly through the mixing zones below the reactor effluent discharges and be exposed to sudden temperature increases.

In view of the above considerations, experiments were commenced in 1968 with the dual objectives of 1) determining if, under conditions simulating natural emigration, passage through the areas of thermal discharge killed young salmonids, and 2) examining the physical parameters, i.e. temperature levels and exposure durations, which are encountered by the

fish. These field studies have been supported by other investigational phases involving thermal shock under controlled laboratory conditions and trapping of naturally emigrating juvenile fish in the reactor discharge plumes.

MATERIALS AND METHODS

Since future drifts will be based on the 1968 operations, the methods and materials that were developed are given in detail below.

Young chinook salmon were drifted in floating live boxes through the effluent discharges. The experimental fish were progeny of adult stock spawned during the fall of 1967 at Priest Rapids Dam facilities and subsequently reared from eggs at the Battelle-Northwest hatchery, 100-F area. The fish were maintained in water drawn from the Columbia below the reactors and therefore containing diluted increments of heated water discharged upstream. Rearing temperatures, considered herein as equivalent to acclimation temperatures, were thus slightly in excess of the river entering the Hanford area above the reactor sites.

Operational procedures for 1968 can be briefly summarized as follows: 1) Young chinooks were transferred directly from the hatchery to the river where the drifts were conducted. 2) A sample of test fish was placed in a floating live box, attached to a boat by a cable and winch, preparatory to drifting. 3) A sample of fish were held aboard the boat in a container as controls and given changes of cool river water. 4) Drifts were made through areas of thermal discharge (maximum temperature points), while temperatures within the floating live box were monitored. 5) Test (drift) and control fish were held for 24 hours at river (acclimation) temperature, checked for mortalities and released.

Large plastic containers of about 7 gal capacity were used to transport juvenile fish in groups of 30-50 individuals from the hatchery to the river above the KW reactor pumphouse. On arrival at the river and periodically thereafter, a portion of the water in each container was withdrawn and replaced to maintain the "normal" temperature and to renew the supply of dissolved oxygen. Injured and moribund fish, when evident, were removed so that only individuals in apparent good condition were drifted.

During the spring drifts (March-April), the live boxes retaining the fish consisted of aluminum sheets measuring 75 x 62 x 62 cm and perforated extensively by circular holes 4 mm in diameter. Angle aluminum rods in the corners provided structural strength. For the summer drifts (August-September), when the fish were larger and more active, the live box consisted of rectangular steel frames measuring 53 x 43 x 43 cm and covered with a loose rubber mesh.

Water temperatures within the drifting live boxes were taken by a thermistor probe connected by an extension lead to recording equipment aboard the boat. Temperatures were read directly on a multirange, Tele-thermometer (Model 46 TU, Yellow Springs Instrument Co.). Simultaneously, a permanent record of temperature fluctuations was made on a strip chart recorder (Model 81, YSI), which was calibrated with the Tele-thermometer. The time constant of the probe, defined as the time required to record 63% of a sudden temperature change, was 7 sec. According to the manufacturer's probe specifications, about 4 time constants (*i. e.*, 28 sec.) are required for the probe to respond to 99% of the total temperature change.

The experimental drifts were conducted through discharge areas of several reactor sites, identified as follows:

K-Plume - combined discharges of KE and KW reactors

N-Plume - discharge of N Reactor

South Shore, below BC - auxiliary shoreline discharge of B reactor

South Shore, below K - limited shoreline seepage

South Shore, through N - auxiliary shoreline discharge

Plumes operating at peak discharge capacity or the warmed shoreline areas were selected for the drifts. In most drifts the live boxes and enclosed fish were positioned immediately below the river surface, although occasional subsurface drifts were conducted.

All drifts were conducted at rates roughly equivalent to surface current flow. An outboard motor was occasionally used to direct the path of the drift through areas that apparently represented maximum thermal increments. For example, the rise of discharge plumes in midriver were evident as large boils of water, while seepages of effluents from shoreline retention basins were characterized by vapors. The duration of the drifts was a function of the rates of current flow through the discharge points. Drifts were continued for several minutes beyond the main areas of discharge, to points where thermal pulses (indicating exposure to unmixed discharge effluents) were no longer recorded and the water temperatures became stabilized at approximately the hatchery acclimation temperature.

Experimental and control fish were maintained in pens similar in construction to the livebox used in the spring drifts for 24 hours and then checked for mortalities. All survivors were released.

Usually, two experimental drifts were completed during each day in the field, and one control group was established daily. Because of peaking power demands at Priest Rapids Dam, above the Hanford complex, the drifts were conducted under a variety of river flow conditions. To test the most stringent conditions, i.e., low river flow, some drifts were attempted in early morning hours. This schedule proved difficult, and most drifts were of necessity conducted during daytime working hours when flow volumes were near the upper end of the daily range.

For evaluation of the effects of "thermal shock," we are concerned with the thermal experience of juvenile fish as they enter the areas of effluent discharge. The temperature of the river as the fish enter the Hanford section is defined herein as the base temperature. Temperatures under which the experimental chinooks were reared at the BNW hatchery (i.e., acclimation temperatures), derived from the Columbia below the discharge points and thus slightly above water temperatures entering the Hanford area, are considered roughly equivalent to the base temperature. (For the purpose of the experimental drifts, the difference is not considered significant because Brett (1952) found that the thermal resistance times of young salmonids varied only slightly over a wide range of acclimation temperatures.) Accordingly, thermal shock is defined herein as the sharp rise in temperature experienced by a fish as it passes through an effluent discharge. Thermal shock is dependent upon the degrees in temperature increment. Thermal dose, a more comprehensive term, is defined as the temperature increment plus the duration of exposure. Under natural river conditions, thermal shock and thermal dose vary in relation to discharge volumes and current flow that carry juvenile fish through the points of discharge.

RESULTS

Environmental Conditions

The experimental drifts, conducted for the first time by BNW at Hanford in 1968, were grouped into two periods, Period No. 1 - Spring (March 11 to April 8) and Period No. 2 - Summer (August 19 to September 18). No drifts were made in the early summer period of maximum runoff. However, from the point of thermal effects, the drifts were conducted during two crucial periods. In the spring the fish were very abundant and small, about 35-50 mm fork length (having recently hatched), river discharges were low and increasing, and water temperatures were near the annual minimum. In the summer the fish were large (70-95 mm fork length) and physiologically aged to emigration, the river discharges were low and decreasing, and water temperatures were near the annual maximum.

The timing of the natural outmigration of juvenile salmonids from the central Columbia, in relation to the timing of the experimental drifts, is an important factor which requires recognition. In early years, the young of anadromous salmonids left the Hanford environs of the Columbia River primarily during the spring and early summer. Mains and Smith (1964), reporting on studies conducted in 1955, found that young chinooks emigrated past Byers Landing (above Richland) from early March through July. The emigration showed two main peaks, one in March and April (mostly fry) and the other in June and July (mostly "yearlings"). If this was the normal pattern, the majority of the fish departed before temperatures in the river peaked in late summer and fall. However, the outmigration now occurs over a longer period due to the retarding effect of impoundments

in the upper Columbia River. Raymond (1967) stated that over 60% of the juvenile chinooks in 1965 and over 40% in 1966 passed Priest Rapids Dam (above Hanford) in August. This phenomena was reported and discussed in detail by Park (1969). While young chinooks of the Hanford population apparently retain the early emigration pattern observed 15 years ago by Mains and Smith (1964), fish from upriver populations now have a late or delayed emigration. Consequently, at the present time young salmonids occur in the Hanford area over an extended period, from March through August (Fig. 1). The late summer, with seasonally warmest temperatures and lowest discharges entering the Hanford area, may be considered to be the most critical time for juvenile fish.

Temperatures of the Columbia River during March and April (Period No. 1) were well below the preferred level for young salmon, established experimentally at 12-14 °C by Brett (1952). River temperatures both above and below the effluent discharges increase during subsequent months and historically rise above the zone of thermal preferendum during July, August and September (Fig. 1). Natural river temperatures, however, have never been recorded as reaching the upper incipient lethal level for young chinook salmon, determined by Brett (1952) to be 25.1 °C (where 50% of the fish die after one week of exposure).

In association with the thermal cycle of the river, there are annual, weekly and daily cycles in river discharge volumes. High water volumes entering the Hanford area serve to dilute the heated effluents and decrease the range in temperature between water entering and leaving the Hanford area. Peak seasonal discharges, regulated in part by upriver dams, generally occur during June and July (Fig. 1). Weekly and daily cycles in discharge

are also created by Priest Rapids Dam, directly above Hanford, which may result in doubling the volume of river flow within a few hours.

The mixing and dispersal rates of heated effluent vary with the fluctuations in river discharge as described by Jaske, et al. (in press).

Drifts through the plumes differed in physical parameters from drifts along the shoreline. Plume drifts were characterized by 1) short exposures, because of unrestricted downstream passage relative to fast current flow; 2) sudden temperature increases, because of rapid entrance into an isolated plume; and 3) sudden temperature declines, because of rapid mixing of the plume with the receiving river water. In contrast, shoreline drifts were characterized by 1) long exposures, because of low downstream passage rates relative to restricted current flow; 2) moderate temperature increases, because of slower entrance into the heated seepage areas; and 3) gradual temperature declines, because of limited mixing of discharges with the receiving river water and pockets of temporary surface stratification.

Drift Data: Spring

Basic data of the spring drifts are presented in Table 1. Twelve drifts involving 432 experimental and 256 control fish were completed. The test fish at this time were small, measuring about 35-50 mm fork length. Immediate mortalities and those observed after the 24 hr retention period were insignificant. The few deaths occurred among both test and control fish, and were likely due to injuries received during manipulation. Note that base temperatures during March and April ranged from 4.0 to 7.6 °C, a relatively cold condition for juvenile salmonids (Brett, 1952). Thermal shock exceeded 10 degrees in only two instances. Drifts No. 7 and 10 along the south shoreline below the BC reactor exposed fish to "hot" water for over 40 minutes.

More detailed illustrations of thermal experience, or the extent of temperatures encountered and the duration of exposures during the spring drifts, are shown in Figures 2-6.¹ The high exposure temperatures in drifts No. 7 and 10 were not consistently maintained for more than a few 30 sec. intervals.

Drift Data: Summer

Basic data of the summer drifts are presented in Table 2. Twenty-four drifts involving 882 experimental and 488 control fish were completed. The test fish at this time were large, measuring about 70-95 mm fork length, and apparently physiologically developed past their normal migration time. A few immediate mortalities and distress of test fish were detected in drifts No. 3, 12, and 13. Delayed mortalities observed after the 24-hour retention period appeared to be significant in only these three experiments. These drifts (marked with arrows on Table 2) involved prolonged exposure (about 40 minutes) to heated water along the south shoreline below the BC reactor area. Drift No. 3 subjected the fish to maximum temperature shock of 10.6 °C, whereas drifts No. 12 and 13 had maximum temperature shocks of 3.8 and 5.4 °C, respectively. Note that base temperatures

¹ To illustrate the method used to prepare Figures 2-10, a hypothetical illustration of the thermal experience of juvenile salmon passing through a midstream plume is given in Figure 12. This figure represents a permanent record, which was obtained on the monitoring tape of a strip chart recorder aboard the drift boat. The thermal "pulses" reflect the mixing of the discharged effluent. As the fish were carried downriver, the pulses decreased until complete mixing of effluent in the river occurred. For purposes of illustration (Figures 2-10), the tape was separated into 30 sec. intervals and the mean temperature for each interval was plotted. It is readily evident that thermal experience of test fish consisted of exposure to fluctuating temperatures of varying degrees intensity and duration, a condition difficult to analyze or duplicate in laboratory experiments.

during August and September ranged from 16.8 to 19.4 °C, or within the range of thermal resistance for juvenile salmonids (Brett, 1952). None of the drifts through the midstream plumes, where passage is relatively rapid, resulted in excessive mortality. (Some losses resulted from drifts No. 9a and 10a; in these cases, three deaths among the control group in 9a suggest the interaction of unknown factors, possibly due to "rough" handling of the fish.)

More detailed illustrations of thermal experience or thermal dose (temperature increment and duration of exposure) during the summer drifts are shown in Figs. 7-10.¹ Generally, exposure to effluents heated more than a few degrees above base temperatures was of a short duration except for the slow, shoreline drifts below BC and N reactors (Figs. 9 and 10).

DISCUSSION

Direct mortalities of young salmonids under simulated emigration conditions, as evidenced from live box drifts of juvenile chinooks, is primarily a function of thermal experience, i.e., temperature increase and exposure duration. These integrated functions determine the lethal effect, if any, of "thermal shock" as the fish enter and pass through areas where heated effluents are discharged from operating reactors. However, environmental conditions in the Columbia River also influence thermal experience, potential or realized. The most important factors appear to be river discharge volumes and current velocities, prevailing water temperatures, the amount of effluent discharged at a specific site, and the extent of effluent mixing.

Evaluation of conditions which may cause mortality of young salmon passing through effluent mixing zones in the river is complex. No simple

answers can be derived. Extrinsic factors such as the physical condition of the test fish, handling procedures, levels of nitrogen saturation in the river, and others perhaps unrecognized influence the experimental data. Theoretically, an indication of these "external" conditions is obtained by observation of control fish. But the stress situation imposed by thermal exposure of test fish may increase operational effects of the "external" conditions, biasing experimental results.

The data presented herein pertain only to experiments conducted under the environmental conditions prevailing in 1968 and cannot accurately be generalized. We can, however, advance the following tentative conclusions.

River temperatures in the spring are low, and the extent of temperature rise at the midstream plumes does not appear to be sufficient alone to cause excessive mortalities. Although river temperatures are higher in the summer, passage through the midstream plumes is generally rapid and mixing is sufficiently complete that potential harmful effects appear to be minimized. However, under certain conditions of exposure, i.e., entrance directly into the focal base of the outlet plume, mortalities may be expected to result.

Mortalities do result from drifts through heated water issuing from intergravel seepage along the south shoreline, particularly below the BC area. Mixing with the cooler river water in these areas is restricted and exposures of experimental fish are prolonged due to low current velocities. This effect is particularly evident in the summer when base river temperatures are high. Young salmonids, however, are known to be extremely sensitive to small temperature changes and will avoid areas in excess of their

preferendum (Alabaster, 1963; Brett, 1952; Bardach and Bjorklund, 1957). We have no evidence that the fish voluntarily enter and linger in the warmed shoreline areas for a sufficient period to be killed. (C reactor was deactivated in the spring of 1969.)

The thermal experience of juvenile chinooks under field conditions in 1968 is summarized in Fig. 11. The base or river temperature is given on the ordinate, and the degrees of temperatures imparted by the thermal discharges are given on the abscissa. Temperatures during the spring were generally below the preferred level for young salmonids, but two drifts along the south shore below the BC reactor entered the upper zone of thermal resistance. Drifts during the summer occasionally passed the fish through temperatures above the ultimate incipient lethal level (50% mortality in 1 week of exposure, according to Brett, 1952). However, significant mortalities (indicated by arrows) did occur during two shoreline drifts in which exposure temperatures failed to exceed the lethal level.

The pertinent question of whether or not young emigrant salmon are killed (immediate or delayed mortality) when passing through areas of effluent discharge is incompletely answered by the 1968 experimental drifts. Modifications in techniques in 1969 are expected to provide more satisfactory evidence. The fact that reservoirs delay the timing of the outmigration so that the majority of the upriver emigrants now pass downriver over Priest Rapids Dam in July and August (Raymond, 1967; Park, 1969), when river temperatures reach an annual maximum, imposes additional stress on the fish. Progeny of fall chinook salmon spawning in the Hanford environs, however, apparently still emigrate seaward during the spring when water temperatures are relatively low and discharge volumes are high.

The occurrence of some mortalities must be distinguished from significant mortalities. If the temperatures are high enough and the exposure duration long enough, all juvenile salmon experiencing thermal shock or thermal dose will be killed. This relationship can be precisely determined in laboratory experiments, but the data cannot reliably be extended to field conditions. In the absence of thorough knowledge of long-term population dynamics of salmon in the Columbia, and with the recognized detrimental effects of dams for hydroelectric development, the question of significance of mortalities identified from thermal shock is largely a value judgment much subject to bias. In this context it should be noted that, of salmon now produced in upper Columbia River drainage, 90% issue from the Snake River and 10% from above Priest Rapids Dam, according to Raymond (1968). These data do not consider the fish produced at Hanford, many of which hatch below the reactor discharges, or in the Priest Rapids spawning channel. Of the roughly 10% which pass seaward through Hanford (the percentage may vary from year to year), the actual proportion that directly enter the effluent outfalls is unknown. Due to the low ratio of discharge volume to total water mass, this proportion must be relatively small. Studies at Hanford are presently directed towards determining if some mortalities do occur. Once this point is established, if in the affirmative, the question of significance must be resolved.

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Table 1. Summary: Spring drifts of young chinook salmon through areas of thermal discharge, Hanford environs, 1968.

Drift Number	Date	Area (1)	Drift Time (min)	Temp., °C		Shock (2)	No. Exp'l Fish		Mortality (24 hr)	
				Base	Max.		Drift	Control	Drift	Control
<u>Plume Discharges</u>										
1	3/11	K-plume, midstream	20	4.4	6.4	2.0	20	20	1	0
2a	3/12	K-plume, midstream	20	4.0	7.6	3.6	22	20	0	0
2b	3/12	N-plume, midstream	12.5	5.2	5.6	0.4	----- (see 2a) -----			
5	3/25	K-plume, midstream	20	5.0	6.6	1.6	40	40	0	0
6	3/25	N-plume, midstream	13	6.0	6.6	0.6	40	-	0	-
8	4/2	K-plume, midstream	17	5.6	7.2	1.6	40	-	0	-
11a	4/8	K-plume, midstream (10' below surface)	19	6.4	9.4	3.4	40	40	0	0
11b	4/8	N-plume, midstream (10' below surface)	13	7.6	8.0	0.4	----- (see 11a) -----			
12	4/8	K-plume, midstream (20' below surface)	20	6.4	9.0	2.6	40	-	0	-
<u>Shoreline Seenages</u>										
3	3/12	South Shore, through N	30	5.0	8.4	3.4	40	20	1	0
4	3/13	South Shore, below BC	43.5	4.0	7.8	3.8	30	36	1	0
7	4/2	South Shore, below BC	43.5	5.8	19.0	13.2	40	40	0	1
9	4/2	South Shore, below K	45	6.2	9.0	2.8	40	40	1	1
10	4/3	South Shore, below BC	41	6.2	17.8	11.6	40	-	0	-

(1) Lateral position of the plume drifts.

(2) Calculated as the difference between base and maximum temperature.

Table 2. Summary: Summer drifts of young chinook salmon through areas of thermal discharge, Hanford environs, 1968.

Drift Number	Date	Area (1)	Drift Time (min)	Temp., °C			No. Exp'l Fish		Mortality (24 hr)	
				Base	Max.	Shock (2)	Drift	Control	Drift	Control
<u>Plume Discharges</u>										
1a	8/19	K-plume, midstream	18	17.8	18.4	0.6	20	20	1	0
1b	8/19	N-plume, midstream	12	18.0	19.0	1.0	----- (see 1a)		-----	
2a	8/19	K-plume, midstream	20	17.8	18.6	0.8	20	-	2	-
2b	8/19	N-plume, midstream	12	17.8	18.4	0.6	----- (see 2a)		-----	
5a	8/21	K-plume, midstream (15' below surface)	20.0	17.8	18.6	0.8	33	18	2	1
5b	8/21	N-plume, midstream (15' below surface)	14.0	18.2	18.6	0.4	----- (see 5a)		-----	
9a	8/26	K-plume, midstream	20	17.3	22.7	5.4	36	40	7	3
9b	8/26	N-plume, midstream	18.0	17.8	19.2	1.4	----- (see 9a)		-----	
10a	8/26	K-plume, outer (north)	20	17.3	23.1	5.8	39	-	8	-
10b	8/26	N-plume, outer (north)	18	17.8	19.0	1.2	----- (see 10a)		-----	
11	8/27	K-plume, outer (north)	20	17.2	22.2	5.0	39	37	0	1
15a	8/30	K-plume, outer (north)	20	18.2	21.6	3.4	33	-	1	-
15b	8/30	N-plume, outer (north)	13	18.0	18.6	0.6	----- (see 15a)		-----	
16a	9/4	K-plume, inner (south)	20	18.0	19.6	1.6	40	39	1	1
16b	9/4	N-plume, inner (south)	14	18.4	23.0	4.6	----- (see 16a)		-----	
17a	9/4	K-plume, inner (south)	20	18.0	20.8	2.8	40	40	1	1
17b	9/4	N-plume, inner (south)	18	18.6	23.4	4.8	----- (see 17a)		-----	

Table 2, cont.

Drift Number	Date	Area (1)	Drift Time (min)	Temp., °C			(2)		No. Exp'l Fish		Mortality (24 hr)	
				Base	Max.	Shock			Drift	Control	Drift	Control
18a	9/5	K-plume, inner (south)	20	18.4	25.2	6.8	40	40	0	1		
		N-plume, inner (south)	18	18.8	25.2	6.4	----- (see 18a)					
19a	9/5	K-plume, outer (north)	17	18.4	20.6	2.2	40	-	3	-		
19b	9/5	N-plume, outer (north)	16	18.8	19.6	0.8	----- (see 19a)					
20a	9/11	K-plume, inner (south)	20	18.8	22.2	3.4	40	40	0	1		
20b	9/12	K plume, inner (south)	16	19.4	25.4	6.0	----- (see 20a)					
21a	9/11	K-plume, outer (north)	18	18.8	24.4	5.6	40	-	1	-		
21b	9/11	N-plume, outer (north)	16	19.0	20.2	1.2	----- (see 21a)					
22a	9/12	K plume, inner (south)	20	18.6	23.4	4.8	40	40	0	1		
22b	9/12	N-plume, inner (south)	18	19.6	25.0	5.4	----- (see 22a)					
23a	9/12	K-plume, outer (north)	14	18.8	22.8	4.0	40	-	0	-		
23b	9/12	N-plume, outer (north)	14	19.4	20.4	1.0	----- (see 23a)					
24a	9/18	K-plume, outer (north)	16	16.8	20.2	3.4	40	40	1	40 ⁽³⁾		
24b	9/18	N-plume, outer (north)	14	17.6	18.4	0.8	----- (see 24a)					

Shoreline Seepages

3	8/20	South Shore, below BC	54	17.4	28.0	10.6	45	20	26	-		
4	8/20	South Shore, through N	22.5	18.4	24.0	5.6	39	0	0	-		
6	8/23	South Shore, below BC	31	17.2	24.0	6.8	27	40	2	1		

Table 2, cont.

Drift Number	Date	Area (1)	Drift Time (min)	Temp., °C			No. Exp'l Fish Drift Control	Mortality (24 hr)	
				Base	Max.	Shock (2)		Drift	Control
7	8/23	South Shore, below CB	25	17.2	20.8	3.6	40	-	4
8	8/23	South Shore, through N	15	18.2	22.6	4.5	35	-	0
12	8/27	South Shore, CB through N	40	17.0	20.8	3.8	38	-	23
13	8/28	South Shore, CB through N	40	17.4	22.8	5.4	39	34	21
14	8/30	South Shore, below CB	25	17.4	21.0	3.6	40	40	1

(1) Lateral position of the plume drifts.

(2) Calculated as the difference between base and maximum temperature.

(3) Water level dropped during the night, exposing and killing the controls.

FIGURE 1
 Mean Weekly Water Temperatures In the Columbia River at Priest Rapids Dam and Richland, Plus Discharge Volumes at Priest Rapids Dam, 1968

FIGURE 2
Thermal Experience of Young Chinook Salmon During Drifts
Through the K-Plumes, Spring 1968

FIGURE 3
Thermal Experience of Young Chinook Salmon During Drifts Through the N-Plumes,
Spring 1968

FIGURE 4
Thermal Experience of Young Chinook Salmon During Drifts
Along the South Shore Below K, Spring 1968

FIGURE 5
Thermal Experience of Young Chinook Salmon During Drifts
Along the South Shore Through N, Spring of 1968

FIGURE 6
Thermal Experience of Young Chinook Salmon During Drifts
Along the South Shore Below CB, Spring 1968

FIGURE 7
Thermal Experience of Young Chinook Salmon During Drift
Through the K Plumes, Summer 1968

FIGURE 7, (cont'd.)

Thermal Experience of Young Chinook Salmon During Drift
Through the K Plumes, Summer 1968

FIGURE 8
Thermal Experience of Young Chinook Salmon During Drifts
Through the N-Plumes, Summer 1968

FIGURE 8, (cont'd.)
Thermal Experience of Young Chinook Salmon During Drifts
Through the N-Plumes, Summer 1968

FIGURE 9
Thermal Experience of Young Chinook Salmon During Drifts
Along the South Shoreline Below BC, Summer 1968

FIGURE 10
Thermal Experience of Young Chinook Salmon During Drifts Along the South
Shoreline Below N, Summer 1968

FIGURE 11
Maximum Thermal Exposure of Juvenile Chinooks (Test) During
Livebox Drifts Through Effluent Discharges in 1968.
(Temperature Criteria Adopted From Brett, 1952.)