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SALMONIDS THROUGH EFFLUENT
DISCHARGES AT HANFORD
PART I. 1968 DRIFTS

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EXPERIMENTAL DRIFTS OF JUVENILE SALMONIDS
THROUGH EFFLUENT DISCHARGES AT HANFORD

PART I. 1968 DRIFTS

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ABSTRACT

Young chinook salmon held in liveboxes were drifted through Hanford reactor discharges in the central Columbia River in order to evaluate 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. 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. No 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. 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(= thermal dose). However, the field situation is strongly influenced by environmental conditions, particularly river flow volumes and prevailing water temperatures. The 1968 drifts will be supplimented by similar studies in 1969.

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INTRODUCTION

Routine operation of nuclear reactors on the AEC Hanford Reservation above Richland, Washington involves the release of heated water into the Columbia River. The effluents discharge primarily from submerged outfalls located at or near midstream. 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 migrate seaward during the spring and summer of each year. Theoretically, an unknown portion of the migrants may pass through the mixing zones below heated discharges and experience "thermal shock." The effects of such exposure conceivably could result in mortalities of still 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.

Widespread construction of dams on the Columbia River and its tributaries during the last two decades has inundated hundreds of miles of natural spawning areas (Fulton, 1968). However, an extensive mitigation program of hatcheries and spawning channels has resulted and 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 that numerically are now of sizeable magnitude. The number of redds produced by adult chinook at Hanford (estimated by aerial survey) was relatively low prior to 1960, but has increased progressively over the past eight years to reach 3270 redds in 1967 and 3,560 redds in 1968 (Watson, 1968, 1969).

It is evident that considerable numbers of juvenile salmonids originate above or at Hanford. These fish must all 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 well 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 migration, passage through the areas of thermal discharge killed young salmonids, and 2) examining the physical parameters, i.e. temperature

levels and exposure durations, that are encountered by the fish. These field studies were supported by other investigational phases involving thermal shock under controlled laboratory conditions and trapping of naturally migrating 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 liveboxes 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 increments of heated water discharged upstream. Rearing temperatures, considered herein as equivalent to acclimation temperatures, were thus slightly warmer than the river entering the Hanford area above the reactor sites.

Operational procedures 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 livebox, attached to a boat by a cable and winch, preparatory to drifting. 3) A sample of fish was 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 livebox 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), fish were held in aluminum liveboxes measuring 75 x 62 x 62 cm and with sides perforated extensively by circular holes 4 mm in diameter. Angle aluminum stock in the corners provided structural strength. For the summer drifts (August-September), when the fish were larger and more active, the liveboxes consisted of tubular steel frames measuring 53 x 43 x 43 cm and covered with 1/2 inch rubberized mesh.

Water temperatures within the liveboxes were taken by a thermistor probe connected by an extension line (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.) were required for the probe to respond to 99% of the total temperature change.

The experimental drifts were conducted through discharge areas of various 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 liveboxes and enclosed fish were positioned immediately below the river surface, although occasional deeper drifts were made.

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 water 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 water temperatures became stabilized at approximately the hatchery acclimation temperature.

Test and control fish were maintained in pens similar in construction to the liveboxes used in the spring drifts for 24 hours and then checked

for mortalities. All survivors were then 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 at comparatively high flows.

For evaluation of the effects of "thermal shock," we should know the thermal experience of juvenile fish as they enter areas of effluent discharge. The temperature of the river above 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 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 flow volumes and current rates that carry juvenile fish through areas of effluent 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 during the period of maximum spring 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 flows were low and increasing and water temperatures were near the annual minimum. In the summer the remaining fish were large (70-95 mm fork length) and physiologically aged to migration, river flows were low and decreasing, and water temperatures were near the annual maximum. (In retrospect, it is realized that the drifts avoided the main period of air supersaturation, i.e. high nitrogen levels, associated with spillage of excess river water over upriver dams.)

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 that requires recognition. In 1955, prior to the construction of most upriver dams, 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 migrated past Byers Landing (above Richland) from early March through July. The migration 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 migration pattern observed 15 years ago by Mains and Smith (1964), fish from upriver populations now have a late or delayed migration. 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 the most critical period for survival of 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 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 annual thermal cycle of the river, there are weekly cycles and daily variations in river flow volumes. Generally high water volumes entering the Hanford area dilute the heated effluences and decrease the range in temperature between water entering and leaving the Hanford area. Peak seasonal flows generally occur during June and July (Fig. 1). Weekly cycles and daily variations in flows are regulated primarily at Priest Rapids Dam, directly above Hanford, and may result in doubling the volume of river flow within a few hours. Mixing and dispersal rates of heated effluent vary with fluctuations in low river flows, as described by Jaske et al. (in press), from 41,000 to 110,000 cf/sec.

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 in fast currents 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 in restricted currents 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 thermal stratification.

Drift Data: Spring

Basic data of the spring drifts are presented in Table 1. Twelve drifts were completed involving 432 experimental and 256 control fish. 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 that occurred among both test and control fish were likely due to injuries received during manipulation. Base temperatures during March and April ranged from 4.0 to 7.6 °C, a relatively cold condition for juvenile salmonids (Brett, 1956). 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.

(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 are carried downriver, the pulses decrease until complete mixing of effluent in the river occurs. For purposes of illustration (Figures 2-10), the tape was separated into 30 sec. intervals and the mean temperatures for each interval was plotted. It is readily evident that thermal experience of test fish consisted of exposure to fluctuating temperatures of varying degrees of intensity and duration, a condition difficult to analyze or duplicate in laboratory experiments.

Drift Data: Summer

Basic data of the summer drifts are presented in Table 2. Twenty-four drifts were completed involving 882 experimental and 488 control fish. The test fish at this time were large, measuring about 70-95 mm fork length, and showed advanced smolt characteristics. 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. Base temperatures during August and September ranged from 16.8 to 19.4 °C, or within the upper range of thermal tolerance for juvenile salmonids (Brett, 1952). None of the drifts through the midstream plumes, where passage was 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 Figures 7-10. 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 (Figures 9 and 10.)

DISCUSSION

Direct mortalities of young salmonids under simulated migration conditions, as evidenced from livebox 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 flows and current velocities, prevailing water temperatures, the amount of effluent discharged at a specific site, and the extent of effluent mixing.

Evaluation of conditions that may cause mortality of young salmonids 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 other factors 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 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 midriver plumes does not appear to be sufficient alone to cause excessive mortalities. Although river temperatures are higher in the summer, passage through the midriver plumes is generally rapid and mixing is sufficiently complete that potential harmful effects appear to be minimized. However, under certain conditions of exposure such as entrance directly into the focal base of an 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 tolerance. 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 migrating salmon are killed (immediate or delayed mortality) when passing through areas of effluent discharge is incompletely answered by the 1968 experimental drifts. Modification of 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 migrants 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 migrate 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 hydroelectric dams on salmon environment and salmon migration,

the question of significance of mortalities identified from thermal increments is 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 (1969). 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⁾	Approx. Flow ⁽²⁾ (cf/sec)		Base	Temp., °C Max.	Shock ⁽³⁾	Drift	No. Exp'l Fish Control	Drift	Mortality (24 hr) Control
<u>Plume Discharges</u>											
1	3/11	K-plume, midstream	130,000	4.4	6.4	2.0	20	20	1	0	
2a	3/12	K-plume, midstream	134,000	4.0	7.6	3.6	22	20	0	0	
2b	3/12	N-plume, midstream	134,000	5.2	5.6	0.4	----- (see 2a) -----				
5	3/25	K-plume, midstream	134,000	5.0	6.6	1.6	40	40	0	0	
6	3/25	N-plume, midstream	130,000	6.0	6.6	0.6	40	-	0	-	
8	4/2	K-plume, midstream	116,000	5.6	7.2	1.6	40	-	0	-	
11a	4/8	K-plume, midstream (10' below surface)	101,000	6.4	9.4	3.4	40	40	0	0	
11b	4/8	N-plume, midstream (10' below surface)	101,000	7.6	8.0	0.4	----- (see 11a) -----				
12	4/8	K-plume, midstream (20' below surface)	101,000	6.4	9.0	2.6	40	-	0	-	
<u>Shoreline Seepages</u>											
3	3/12	South Shore, through N	134,000	5.0	8.4	3.4	40	20	1	0	
4	3/13	South Shore, below BC	134,000	4.0	7.8	3.8	30	36	1	0	
7	4/2	South Shore, below BC	116,000	5.8	19.0	13.2	40	40	0	1	
9	4/2	South Shore, below K	116,000	6.2	9.0	2.8	40	40	1	1	
10	4/2	South Shore, below BC	116,000	6.2	17.8	11.6	40	-	0	-	

(1) Lateral position of the plume drifts.

(2) Mean daily Priest Rapids discharge. (Flow at precise time of drifts unknown.)

(3) 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)	Approx. Flow (2) (cf/sec)	Temp., °C			No. Exp'l Fish Drift Control		Mortality (24 hr) Drift Control	
				Base	Max.	Shock (3)				
<u>Plume Discharges</u>										
1a	8/19	K-plume, midstream	100,000	17.8	18.4	0.6	20	20	1	0
1b	8/19	N-plume, midstream	100,000	18.0	19.0	1.0	----- (see 1a)		-----	
2a	8/19	K-plume, midstream	100,000	17.8	18.6	0.8	20	-	2	-
2b	8/19	N-plume, midstream	100,000	17.8	18.4	0.6	----- (see 2a)		-----	
5a	8/21	K-plume, midstream (15' below surface)	105,000	17.8	18.6	0.8	33	18	2	1
5b	8/21	N-plume, midstream (15' below surface)	105,000	18.2	18.6	0.4	----- (see 5a)		-----	
9a	8/26	K-plume, midstream	95,000	17.3	22.7	5.4	36	40	7	3
9b	8/26	N-plume, midstream	95,000	17.8	19.2	1.4	----- (see 9a)		-----	
10a	8/26	K-plume, outer (north)	95,000	17.3	23.1	5.8	39	-	8	-
10b	8/26	N-plume, outer (north)	95,000	17.8	19.0	1.2	----- (see 10a)		-----	
11	8/27	K-plume, outer (north)	104,000	17.2	22.2	5.0	39	37	0	1
15a	8/30	K-plume, outer (north)	104,000	18.2	21.6	3.4	33	-	1	-
15b	8/30	N-plume, outer (north)	104,000	18.0	18.6	0.6	----- (see 15a)		-----	
16a	9/4	K-plume, inner (south)	110,000	18.0	19.6	1.6	40	39	1	1
16b	9/4	N-plume, inner (south)	110,000	18.4	23.0	4.6	----- (see 16a)		-----	
17a	9/4	K-plume, inner (south)	110,000	18.0	20.8	2.8	40	40	1	1
17b	9/4	N-plume, inner (south)	110,000	18.6	23.4	4.8	----- (see 17a)		-----	

Table 2, cont.

Drift Number	Date	Area (1)	Approx. Flow ⁽²⁾ (cf/sec)	Temp., °C Base Max.	Shock ⁽³⁾	No. Exp'l Fish Drift Control	Mortality (24 hr) Drift Control
18a	9/5	K-plume, inner (south)	85,000	18.4	25.2	40	0
		N-plume, inner (south)	85,000	18.8	25.2	----- (see 18a)	-----
19a	9/5	K-plume, outer (north)	85,000	18.4	20.6	40	3
19b	9/5	N-plume, outer (north)	85,000	18.8	19.6	----- (see 19a)	-----
20a	9/11	K-plume, inner (south)	100,000	18.8	22.2	40	0
20b	9/11	N-plume, inner (south)	100,000	19.4	25.4	----- (see 20a)	-----
21a	9/11	K-plume, outer (north)	100,000	18.8	24.4	40	1
21b	9/11	N-plume, outer (north)	100,000	19.0	20.2	----- (see 21a)	-----
22a	9/12	K-plume, inner (south)	95,000	18.6	23.4	40	0
22b	9/12	N-plume, inner (south)	95,000	19.6	25.0	----- (see 22a)	-----
23a	9/12	K-plume, outer (north)	95,000	18.8	22.8	40	0
23b	9/12	N-plume, outer (north)	95,000	19.4	20.4	----- (see 23a)	-----
24a	9/18	K-plume, outer (north)	100,000	16.8	20.2	40	1
24b	9/18	IV-plume, outer (north)	100,000	17.6	18.4	----- (see 24a)	-----

Drift Number	Date	Area ⁽¹⁾	Approx. Flow ⁽²⁾ (cf/sec)	Temp., °C			No. Exp'l Fish Drift Control		Mortality (24 hr) Drift Control	
				Base	Max.	Shock ⁽³⁾				
3 ←	8/20	South Shore, below BC	103,000	17.4	28.0	10.6	45	20	26	--
4	8/20	South Shore, through N	103,000	18.4	24.0	5.6	39	0	0	--
6	8/23	South Shore, below BC	102,000	17.2	24.0	6.8	27	40	2	1
7	8/23	South Shore, below CB	102,000	17.2	20.8	3.6	40	--	4	--
8	8/23	South Shore, through N	102,000	18.2	22.6	4.5	35	--	0	--
12 ←	8/27	South Shore, CB - N	104,000	17.0	20.8	3.8	38	--	23	--
13 ←	8/28	South Shore, CB - N	140,000	17.4	22.8	5.4	39	34	21	1
14	8/30	South Shore, below CB	104,000	17.4	21.0	3.6	40	40	1	0

(1) Lateral position of the plume drifts.

(2) Mean daily Priest Rapids discharge. (Flow at precise time of drifts unknown.)

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

(4) 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)

FIGURE 12
Hypothetical Illustration of Thermal Experience of Test Fish Passing Through a Midstream Plume, as Permanently Recorded. Strip Chart Tape. (Dots Indicate Mean Exposure Temperature, Above Base River Temperature, per 30 sec Interval.)

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