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EXPERIMENTAL DRIFTS OF JUVENILE SALMONIDS
THROUGH EFFLUENT DISCHARGES AT HANFORD
PART II. 1969 DRIFTS AND CONCLUSIONS(1)

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ABSTRACT

Field investigations to determine the effects of heated reactor discharges on juvenile salmonids passing through the central Columbia River were conducted from March to September, 1968 and 1969. The fundamental approach involved drifting test fish in liveboxes through areas of maximum thermal increments, while continuously monitoring exposure temperatures and subsequently checking immediate and delayed mortalities among test and control groups. The drifts were conducted during two periods with contrasting environmental characteristics: the early spring, when river temperatures and discharges were minimum, and the late summer, when river temperatures peaked but discharges were again low. An interim period of maximum river discharge (above 200,000 cf/sec) occurred during May, June and early July when temperatures were increasing.

Studies conducted in 1969 are detailed. Data collected in 1968 are considered in the Conclusion section. Although mortalities from thermal dose (temperature increment plus duration of exposure) were usually low, occasional drifts subjected test fish to lethal levels and resulted in significant losses. The most important environmental features influencing thermal dose were the prevailing river temperature and river discharge. Four combinations of temperature and discharge were identified that occurred in natural sequence with increasing potential for thermal damage: low temperature--low discharge (early spring), low temperature--high discharge (late spring), high temperature--high discharge (early summer), and high temperature--low discharge (late summer). The last combination occurred annually from mid-July through August, following the main migration of juvenile chinook salmon

discharges dropped below 100,000 cf/sec.

Some mortalities resulted during occasional drifts through areas along the south shoreline that received heated water via intragravel seepage from onshore retention basins. Mortalities during drifts through midriver discharge plumes (primarily the K reactor) were insignificant except under late summer river conditions. The intensity of thermal dose depended upon onsite mixing patterns. Seepage areas were characterized by reduced river flow, relatively low mixing rates and persistence of heated water close inshore with pockets of temporary thermal stratification. In contrast, plume discharges were characterized by fast river flow, relatively high mixing rates and rapid dispersal of heated water. Efficiency of the mixing process increased with increasing river discharge, thereby reducing chance exposure of migrating fish to lethal temperatures.

No evidence was obtained that, in nature, juvenile salmon voluntarily enter heated areas and were killed. Since current velocities in the central Columbia were high in relation to swimming ability of the young fish, it must be assumed that at least a portion of the total migrating population is involuntarily carried into the areas of thermal discharge. In such cases, whether or not mortality occurs depends on the intensity and duration of exposure under prevailing environmental conditions.

Shoreline seepages were potentially more hazardous than midriver discharges. In order to mitigate against excessive losses of juvenile salmonids, it is advisable that shoreline seepages or discharges be avoided at future nuclear power installations.

EXPERIMENTAL DRIFTS OF JUVENILE SALMONIDS
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PART II. 1969 DRIFTS AND CONCLUSIONS

INTRODUCTION

Routine operation of plutonium production reactors on the AEC Hanford Reservation above Richland, Washington involves the use of Columbia River water as a coolant. The diverted water, when returned into the river, has been heated to an extent that prolonged exposure to the undiluted effluent would be lethal to most species of freshwater fish. However, the central Columbia with its large flow volumes and cold currents has the physical capacity to absorb relatively vast amounts of heat. As a result, temperatures of the river above Hanford and 93 km below at Richland differ less than a few degrees. The areas of greatest hazard to migrating juvenile salmonids lie in the immediate vicinity of the effluent discharges.

Heated effluents at Hanford issue primarily from submerged outfalls located at or near midstream. Some areas along the south bank of the river also receive heated water via intragravel seepage from shoreline retention basins and from test disposal of reactor effluent into the ground. Temperatures rise sharply in the immediate vicinity of the discharges before the effluents mix and disperse in the river. These areas are potentially lethal to young migrating salmonids by exposing an unknown portion of the fish to some degree of "thermal shock" as they pass through the Hanford area on their way to the sea. Any resulting mortalities could occur in three ways, depending on the extent of thermal exposure and the thermal resistance of the species involved, namely:

- 1) immediate, direct losses, 2) delayed, latent losses, and 3) indirect

stress. Under experimental conditions, only immediate and delayed mortalities could be determined.

The initial experiments were conducted in 1968 with the dual objectives of 1) determining if, under conditions simulating natural conditions, passage through areas of thermal discharge killed young salmonids and 2) examining the physical parameters, i.e., temperature levels and exposure durations that were encountered in situ by the fish (Becker and Coutant, 1969). Objectives for 1969 remained essentially the same. These studies, of necessity restricted to the field, have been supported by other investigational phases involving thermal shock under controlled laboratory conditions (Coutant, 1969; Dean, 1969), thermal exposure and fish predation (Coutant, 1970), predatory activity of gulls (Prentice, 1969) and the relationship of temperature to seaward migration (Becker, 1970).

This report presents data assembled during livebox drifts of juvenile salmonids through effluent discharges at Hanford in 1969. It represents a continuation of work conducted in 1968, and incorporates results of the 1968 study in the Conclusions.

As in the previous year, the drifts were grouped into two general periods, the first in the early spring and the second during the summer. Whereas in 1968 the annual spring runoff of the Columbia followed a normal pattern and occurred between drift periods, in 1969 it began about six weeks earlier and was sustained for over three months. This abnormal discharge pattern was a result of operations at Grand Coulee Dam that required the lowering of Lake Roosevelt for installation of additional turbines. The excess water was passed directly downriver over various dams, resulting in supersaturation of atmospheric gases in the river. Consequently, "gas bubble" disease in experimental fish

from dissolved nitrogen adversely effected the 1969 spring data. Techniques in 1969 were modified from those in the preceding year in order to improve the collection and the validity of data. Greater effort was made to correlate the drifts with low river discharges, since the importance of low flow volume in intensifying thermal experience was clearly recognized after the first year of study.

Mr. E. F. Prentice was responsible for conducting field operations and maintaining equipment in 1969. Drs. C. C. Coutant and C. D. Becker jointly planned the operations and participated in the drifts. Messrs. W. E. Lusty, E. G. Tangen, R. G. Genoway and A. J. Scott assisted in various capacities as required. Stocks of experimental fish were supplimented by the Washington State Department of Game and the U. S. Fish and Wildlife Service.

MATERIALS AND METHODS

General procedures for in situ field operations involved the placement of juvenile salmonids in liveboxes, designed to retain the fish while permitting rapid diffusion of river water, and then drifting test groups through areas of effluent discharge to expose test fish to maximum thermal increments. Control groups were treated similarly, but the fish were drifted along the north shoreline away from the effluent discharges. Experimental fish used in 1969 were egg sac fry and 0-age chinook salmon (Oncorhynchus tshawytscha), yearling coho salmon (O. kisutch) and yearling rainbow trout or steelhead (Salmo gairdneri). The river sites where the drifts were conducted are shown in Figure 1.

Operations in 1969 are summarized as follows: 1) young salmonids

discharges for several days to permit predrift adaptation to river temperatures above Hanford. 2) Samples of test fish, usually consisting of 20-25 individuals, were placed in liveboxes attached to each side of a drift boat. 3) Samples of control fish were proportioned similarly in a second drift boat. 4) The drifts were conducted by guiding test fish through areas of effluent discharge and control fish through a path avoiding the discharges, while exposure temperatures were monitored. 5) Immediate mortalities at the end of the drifts were noted. 6) Test and control fish were retained for a six day postdrift period in floating pens well below the effluent mixing zones to detect secondary mortalities. 7) Survivors were released.

Drifts in 1969 differed from those in 1968 primarily in providing a predrift acclimation period rather than transferring the fish directly from the 100-F area hatchery, in using a 6-day postdrift retention period rather than 24 hours, in drifting control fish rather than holding them in containers aboard the drift boat, and in utilizing juvenile coho and rainbow in addition to young chinook.

The acclimation pens for the spring drifts were positioned near the south shore above the BC reactor area (Figure 1). Spring drifts were conducted through the south shoreline seepage below BC, the south shoreline through KE-KW, and the K-N plumes. Since the C reactor was shutdown after the spring drifts (the B reactor was closed in 1968), the acclimation pens were positioned above the KE-KW reactor area for the summer drifts (Figure 1). The summer drifts were conducted through the K-N plumes as well as an inshore leak, exposed at low water, near the end of a jetty inshore from the main K reactor outfall. The postdrift retention pens were positioned in the D reactor (inactive) pumphouse

Other modifications of technique were adopted in 1969. First, the fish were drifted both at the surface and at a 3 meter depth, rather than only at the surface. The depth of a subsurface drift was controlled by installing a 20 foot pipe, which could be shifted from a horizontal to a vertical position, to the side of each drift boat; a livebox could be lowered or raised along the pipe by a rope and pulley apparatus. Second, fluorescent red floats were anchored above the midstream effluent plumes to facilitate control of drifts through the approximate discharge focus. Third, the redesigned liveboxes consisted of an open metal frame about 46 cm² covered by rubberized mesh with 1/2-inch diamond perforations. Egg sac fry and advanced fry were placed in small containers constructed of plastic window screen within each livebox since they would readily pass through the rubberized mesh, whereas yearlings were left free to move at random. Fourth, more sensitive temperature probes were used to monitor temperatures within the liveboxes.

The new probes (No. 409, Yellow Springs Instrument Co.) had a time constant of 1.7 seconds, i.e., the time required to register 63% of a sudden temperature change. (According to specifications, about 4 time constants were required for the probe to respond to 99% of the total temperature change.) The probes were delicate and required protection from mechanical damage during field operations. Temperatures were read directly on multirange Tele-thermometers (Model 46 TU, YSI), and permanent records of temperature fluctuations were made on chart recorders. Power for instrument operation was provided by batteries. (In actual field operation, excessive malfunctioning of recording equipment occurred from rapid loss of battery power and for unknown mechanical reasons.)

Drifts commenced above the effluent discharges and terminated

resulting from exposure of test fish to mixing discharges, were no longer recorded. Drifts were conducted at rates roughly equivalent to surface flow. Outboard motors were occasionally used at low speed to keep shoreline drifts from grounding and to guide drifts through areas representing maximum discharge temperatures. Discharge plumes in midchannel broke the surface as intermittent boils while seepages along the shore were visible as trickling water and rising vapors. In order to test the most stringent conditions, most of the drifts were conducted during the early morning at times corresponding to minimum river discharge as regulated upriver at Priest Rapids Dam.

For evaluation of "thermal experience" in the livebox drifts, we define the following terms:

Thermal Shock - The maximum rise in temperature experienced by test fish when they pass through an effluent discharge. Thermal shock reflects the highest thermal increment above base river temperature encountered during a drift.

Thermal Dose - The temperature increment plus the duration of exposure. Thermal dose is a precise measure of thermal effect because it includes not only the peak temperature (thermal shock), which may be very brief, but also the length of exposure to various increment levels.

Thermal Experience - A general term referring to temperature conditions encountered by test and control fish during the entire drift from start to completion.

Base Temperature - The temperature of the Columbia River above the Hanford area prior to a drift. Base temperatures approximate those recorded at Priest Rapids Dam, and are equivalent to acclimation

Mixed Temperature - The temperature of the Columbia River below an effluent discharge where thermal pulses are no longer recorded and mixing is largely complete. Drifts are normally terminated at this point.

River Discharge - The discharge in cf/sec at the approximate time a drift was conducted. Discharge volumes are determined from gauge readings at the K reactor pumphouse, which had been previously correlated with known discharge volumes.

A hypothetical example of the thermal experience of fish passing through a midstream plume is given in Figure 2, which represents a permanent record obtained on the monitoring tape of the chart recorder. Entrance into a discharge plume initiates an abrupt rise in temperature. "Thermal pulses" of decreasing magnitude portray the mixing of the heated effluent in the cooler river at progressive points within the plume. In the complete mixing zone, the temperature becomes stabilized somewhat above base river temperature. Select examples of the thermal experience of test fish are given in Figures 7-11. For these illustrations, the tape was separated into 30-second intervals and the mean temperature for each interval was plotted. Because temperature levels fluctuated with successive pulses, exposure to a given temperature was not necessarily continuous.

RESULTS

Timing of Drifts in Relation to Seaward Migration

The drifts were grouped into two periods, the first in the early spring and the second in the summer. These periods were separated

when larger volumes of river water function to dilute and dissipate the heated effluents (Figure 3).

As in 1968, the drifts were conducted during two crucial periods for evaluation of possible thermal effects. In early spring, juvenile chinook (and other young salmonids) were most abundant and small in size, river discharges were low but increasing, and water temperatures were well below preferred levels (12-14 °C) for the fish. In the summer, the remaining fish were large in size and physiologically aged to migration, river discharges were low, and water temperatures were near the annual maximum (18-20 °C).

Determining the timing of the natural migration of juvenile salmonids from the central Columbia in relation to possible effects of heated discharges was important to clarifying the problem. This relationship has been explored and prepared for publication (Becker, 1970). In 1955, juvenile salmon passed through the Hanford environs during the spring and early summer (Mains and Smith, 1964) and the migration showed two peaks, the first in March and April (mostly fry) and the second in June and July (mostly fingerlings). At the present time, however, fish originating above Priest Rapids Dam pass through Hanford at a later date, in July and August (Park, 1969). Development of the upriver reservoir complex during the past decade was assumed to be responsible for this delay by reducing migration rates in the relatively slack water habitat of impoundments (Raymond, 1968, 1969). Juvenile chinook produced in the 93 km, free-flowing section of the Columbia at Hanford apparently retain the normal migration pattern detected 15 years ago by Mains and Smith, and most have passed downriver into the forebay of McNary Dam by the end of July.

Juvenile chinook now leaving the central Columbia River, therefore, can be separated into two distinct components as the basis of migration timing (Figure 3). Those produced in the free-flowing Hanford environs retain their natural timing, whereas those originating above Hanford in tributaries; hatcheries and spawning channels are delayed up to 2 months. The delayed migrants are exposed to late season environmental conditions (i.e. warmer temperatures and lower river flows), which the fish did not encounter in earlier years when passing through the Hanford area.

Temperature and Discharge Volumes, 1969

Environmental conditions prevailing in 1969 (Figure 3) were essentially similar to those in 1968. However, increasing river discharges began about 6 weeks earlier, because of storage releases at Grand Coulee Dam to permit installation of additional turbines, and high flows were sustained for a longer period. Discharges decreased sharply in July and low flows were maintained throughout August and early September.

The spring rise in river temperatures entering the Hanford area followed a normal pattern. Temperatures were well below preferred levels for juvenile salmon in March and April, entered the preferred range (12-14° C) in late May and early June, and were sustained above preferred levels in July and August. Maximum daily temperatures briefly reached 19.7° C at Priest Rapids and 20.6° C at Richland during the summer. The 12 monthly water-temperature profiles (for 1968) show a rise of 0.5 - 3.5° C between Priest Rapids and Richland; 1-2° C of this increase in June and July is due to summer warming from the atmosphere (Moore, 1968, 1969).

Temperatures above 20°C at Priest Rapids were not reached during the summer or fall of 1969. Temperatures above this level, although well below the apparent upper incipient lethal limit of 25.1°C determined for young chinook and coho by Brett (1952), may be considered suboptimum for survival of juvenile salmonids in the river ecosystem. Brett (1960) later proposed that the upper limit of required temperature for any species of fish should not exceed that which would curtail activity below 3/4 of optimum, and recommended a "freedom" of 3°C (5.5°F) below the ultimate lethal level. This freedom would establish an arbitrary upper thermal limit of 22°C for young chinook in the central Columbia.

Weekly and Daily Fluctuations in Discharge Volumes

The data illustrated in Figure 3 are based on weekly means and do not reveal the extent of either daily or hourly fluctuations that occur from flow regulation at Priest Rapids Dam. Flows were usually reduced on weekends and increased during the week to satisfy consumptive demands for hydroelectric power. For similar reasons, flows were lowered at night and raised during the day. Weekend variations occasionally resulted in changes of the water level in the river, measured at drift locations, of up to 8 feet in 12 hours.

The mean daily discharges at Priest Rapids Dam from March through August 1969 are illustrated in Figure 4. Daily fluctuations were less pronounced in April, May, June and early July because increased runoff from snow melt (and Grand Coulee releases) provided a surplus of river water. In March and August, however, a seasonal need to conserve available water behind upriver dams existed and weekend decreases in daily discharges were extreme.

Hourly fluctuations in discharge volumes at Priest Rapids during days that the drifts were conducted are shown in Figures 5 and 6. Drift Series I was conducted during sustained low flows in the morning by prearranged agreement. The other series of spring drifts were conducted without prior agreement and discharge volumes reflected the typical hourly flows prevailing (Figure 5). The fall drifts were conducted in the early morning hours to correspond with regulated low flows during August (Figure 6).

Correlation of Priest Rapids data with water levels recorded at the K reactor pumphouse indicated that approximately two hours were required for changes in regulated discharge volumes to appear downriver at the drift sites. (Priest Rapids Dam is about 25 km above the K reactor area.)

River discharges prevailing during the time young migrating salmon pass through the Hanford area influence the extent of thermal exposure. For relatively constant effluent volumes, high river flows disperse and dilute the heated effluent more effectively than low river flows. Moreover, with high discharge volumes, the migrating population presumably spreads over a wider horizontal area and the actual proportion of fish that enter effluent mixing zones is reduced.

Drift Series I (23 March)

Discharges from Priest Rapids Dam were sustained at minimum flows (about 40,000 cf/sec) during the morning when the drifts were conducted (Figure 5). In the initial series, 180 chinook egg-sac fry and 200 yearling cohos were drifted in groups of 20 fish each (Table 1). Base

were drifted along the south shoreline near the BC reactor. The thermal increment of 26.5°C was due entirely to inshore intragravel seepage. A 12.4°C increase was the maximum briefly experienced by test groups (13 to 19) drifted in midchannel through the vicinity of the K discharge plume.

Postdrift mortalities were insignificant in each drift group. Chinook losses were due to trauma from mechanical injury of the weak-swimming fry, whereas coho losses (accompanied by growth of fungus in the mouth and palatine area) probably resulted from poor physical condition. Based upon these data, no losses could be attributed directly to thermal dose. Presumably the relatively cold base river temperatures and brief exposures to thermal increments mitigated against excessive mortality.

Drift Series II (22 April)

High river flows (about 200,000 cf/sec) commenced in April (Figure 3) and were accompanied by air supersaturation, with nitrogen levels exceeding 120 percent. Experimental fish consisted of 130 chinook fry, drifted in two composite groups of 60 control and 70 test animals, and 50 yearling coho drifted in two groups of 25 (Table 2). River discharges during the drifts were about 195,000 cf/sec (Figure 5) and base river temperatures averaged 8.0°C for the day. Test groups were drifted at the surface along the south shoreline in the seepage near the BC reactor area. Due to the prevailing high river discharge, the maximum thermal shock briefly experienced by the test groups was 5.4°C . Control fish experienced a 3.2°C increment.

Significant mortality occurred among both the control and test groups during the posttest holding period (Table 2). In the controls,

5 chinook (of 70) and 25 coho (of 25) died. Mortalities were chronic and highest during the initial days following the drifts. No correlation was apparent between losses and thermal dose. About two thirds of the dead fish (control and test) showed external blisters symptomatic of "gas bubble" disease.

The influence of nitrogen was also evident during the pretest acclimation period in the river above Hanford. Substantial losses (about 50 percent) of the coho occurred prior to the drifts. Although chinook were less severely affected, they also appeared to be under stress. Symptoms among coho were more pronounced than among chinook.

Drift Series III (30 April)

Priest Rapids discharges remained high (210,000-220,000 cf/sec) during the day. Chinook fry, 80 control and 100 test, were drifted in groups of 20 fish each (Table 3). Test groups were drifted at the surface along the south shoreline near the BC reactor area. Maximum thermal shocks briefly encountered (adjusted data) were 20.7 and 21.3°C. All test fish were drifted simultaneously, but in drift boxes secured to opposite sides of the boat. Mortalities resulting from thermal dose relative to position (port or starboard) were significantly different.

Mortality among 40 fish held on the starboard side were high and occurred prior to termination of the drift, whereas immediate mortality among 60 fish held on the port side were nil. Mortalities during the postdrift holding period were minor and were attributed to nitrogen supersaturation because the fish displayed typical external symptoms of "gas bubble" disease. Only four fish died in six days among the control groups.

Since the maximum thermal shock received by test fish on the starboard (20.7°C) and port sides (21.3°C) were essentially similar, the mortalities were difficult to explain; they probably resulted from differences in exposure time (thermal dose) to temperature below maximum levels. The starboard fish received a longer exposure to increments in the 18-19°C range (Figure 7), although temperatures in both liveboxes fluctuated widely in response to inshore effluent mixing patterns.

Drift Series IV (15 May)

River discharges were reaching the annual peak during May (Figure 4). The drifts were conducted under high flows (210,000-225,000 cf/sec) and a daily mean temperature of 10.1°C (Figure 5). Nitrogen saturations reached 130 percent. The experimental fish consisted of 160 0-age chinook and 130 yearling rainbow (steelhead), and were drifted in lots of 20 fish except for one group of rainbow (Table 4). Test drifts were conducted in midchannel at the surface and the 3 meter depth near the KW and N reactor plumes, and near the south shoreline below K. Maximum thermal shocks briefly encountered were 3.9°C and 0.3°C during two separate drifts.

No immediate mortality was evident at the termination of the drifts (Table 4). Test and control groups of chinook suffered chronic mortality during the postdrift retention period, which were less than the rainbow losses. All rainbows (control and test) were dead after 5 days and most fish revealed distinctive symptoms of gas bubble disease. Since temperature increments were low, it was apparent that nitrogen and not thermal shock or thermal dose was the primary lethal cause.

Results of the drifts during the spring, conducted under environmental conditions of high river flow and air supersaturation, indicated the

existence of a species and/or size relationship to nitrogen sensitivity. Generally, 0-age chinook appear to be less severely affected by high nitrogen levels than yearling coho and rainbow. This phenomenon requires experimental confirmation under controlled conditions.

Drift Series V (1 August)

River discharges in August were near the seasonal minimum (Figure 4), temperatures reached the seasonal maximum, and levels of dissolved gases were normal. The C reactor was closed after the spring drifts were completed, eliminating the intragravel seepage area near the BC reactor. Weekly beach seining at established stations indicated that nearly all young chinooks produced in the Hanford environs had departed seaward by the end of July (Becker, 1970).

River discharges ranged from 80,000-90,000 cf/sec during the morning when the drifts were conducted and base river temperatures averaged 17.7°C for the day (Figure 6). The experimental fish consisted of 200 0-age chinook drifted in groups of 25 (Table 5). All test fish were passed in midchannel through the K reactor outfall at the surface or at 3 meters depth. Maximum thermal shocks briefly encountered by test fish ranged from 1.2 to 4.9°C.

Immediate mortalities from exposure to effluent plumes were insignificant. Test group 8, drifted at 3 meters and receiving a brief thermal shock of 4.9°C, suffered a high delayed mortality (23 of 25) after 6 days. None of the other six lots were affected similarly. The thermal experience of test groups 7 and 8 (drifted simultaneously) is illustrated in Figure 8. There was little difference in thermal experience resulting from vertical configuration of the mixing plume. Mortalities occurring

shock or thermal dose. Unknown factors probably caused the postdrift losses of these fish, which appeared to be severely emaciated at time of death.

Drift Series VI (8 August)

River discharges ranged from 75,000-80,000 cf/sec during the morning when the drifts were conducted and base river temperatures averaged 17.4°C for the day (Figure 6). The experimental fish consisted of 200 0-age chinook, drifted in lots of 25 fish (Table 6). All test fish were passed through the K reactor outfall at either the surface or at 3 meters depth. Maximum thermal shocks briefly experienced by test fish ranged from 1.6 to 9.6°C.

Immediate and delayed mortalities were low except for one lot where 5 fish (of 25) died during the postdrift holding period (Table 6). Thermal shock and thermal dose sufficient to kill significant numbers of test fish were not experienced despite efforts to direct all drifts through the focus of the main discharge plume.

Drift Series VII (20 August)

River discharges remained low (70,000-75,000 cf/sec) during the morning when the drifts were conducted and base river temperatures averaged 18.4°C for the day (Figure 6). Temperatures were near the annual peak for 1969. The experimental fish consisted of 116 0-age chinook and 72 0-age coho, and were drifted in small lots of variable numbers (Table 7). All test fish were passed through the K reactor outfall at either the surface or at 3 meters depth. Maximum thermal shocks briefly experienced by test fish ranged from 1.7 to 4.8°C.

Immediate and delayed mortalities were low and insignificant (Table 7). As in the preceding series (Series VI), lethal exposures to thermal shock and thermal dose in the K plume were insufficient to cause mortalities even though river discharges were low and water temperatures were high. Thermal experiences of test group 5 and 6 are illustrated in Figure 10.

Drift Series VIII (1 September)

Monday, September 1, was Labor Day and low flows that prevailed during the preceding weekend were sustained an additional 24 hours at Preist Rapids. River discharges were near the summer minimum (39,000-50,000 cf/sec) when the drifts were conducted and base river temperatures averaged 17.8°C for the day (Figure 6). The experimental fish consisted of 400 0-age chinook drifted in groups of 25 fish (Table 8). Test drifts were made through the K-reactor outfall and an inshore leak exposed at the prevailing low water levels near the end of the K jetty. Maximum thermal shocks received by the test fish were relatively severe, ranging from 6.8 to 30.0°C.

High immediate mortalities were experienced in three test lots (Table 8), group 4 through the main K plume at 3 meters depth (22.7°C shock), and groups 9 and 10 through the inshore leak (30.0 and 23.2°C shock). Delayed mortalities during the postdrift holding period were low but a few fish died of bacterial disease, presumably "columnaris" (Chondrococcus columnaris).

The thermal experiences of test groups 3-4, 7-8, and 15-16 are shown in Figure 11. Although high maximum temperatures were recorded during drifts through the focus of the K plume in the midchannel, the duration of exposure usually proved to be so short that few fish died as a result

of thermal dose. One exception (group 4) occurred when the test fish were drifted at 3 meters and received a maximum thermal shock of 22.7°C.

Short exposure times presumably were the basis for the lack of mortalities in some drifts through the inshore leak. In contrast, exposure times and high temperatures were sufficient to cause mortalities in two drifts (groups 9-10) through the leak. In all leak drifts, the direction was manipulated by outboard motor to guide and temporarily hold the fish in the discharge. This series of drifts demonstrate the potential hazard resulting from a combination of peak temperatures and low discharge volumes during the late summer. Under such conditions, lethal exposure to temperatures may even occur in a midstream plume. The inshore leak, with its reduced mixing patterns and inshore eddy behind the jetty, revealed lethal temperatures and effluent mixing patterns typical of shoreline seepages at seasonal minimum flows.

DISCUSSION

1969 Drifts in Relation to 1968 Drifts

The thermal experience of juvenile salmonids (chinook, coho and rainbow) under field conditions in 1969, when tests under low river discharges were emphasized, are summarized in Figure 12. Data for the 1968 drifts are summarized in Figure 13. In these figures, the base river temperature is given on the ordinate and the maximum temperature encountered by test fish is on the abscissa. The diagonal line represents the ultimate incipient lethal temperature of 25.1°C (from Brett, 1952) and is the sum of any combination of ordinate and abscissa readings. Maximum temperatures (thermal shock) during the drifts fall either in the zone of thermal tolerance or the zone of thermal resistance.

Young salmon can theoretically live in the zone of thermal resistance for a definite period of time, which is essentially a function of the distance of the exposure temperature beyond the incipient lethal level (Fry, 1964). However, field conditions and fluctuating temperatures of the mixing zones probably impose stress in excess of those observed in the laboratory.

Spring drifts were scantily represented in 1969 because of excessive mortalities during the postdrift retention period, a consequence of high nitrogen levels in the river water. Peak temperatures during the drifts usually fell well within the zone of thermal tolerance (Figure 12). Exposures to lethal temperatures (thermal shock) resulted in three test drifts through the shoreline seepage below the BC reactor, but the exposure duration (thermal dose) was sufficient to cause mortality in only one group. Temperatures and exposure durations in drifts through the K plume and along the south shore through K were insufficient to cause death. These results agree essentially with data obtained in 1968, when no significant mortalities occurred during the spring drifts (Figure 13). Low mortality levels during the spring (March, April, and May) were probably due to mitigating environmental conditions, i.e., relatively low base river temperatures and high river discharges (Figure 4). A potentially hazardous area existed below the BC reactor where intragravel seepage of effluent raised inshore temperatures to lethal levels.

Summer drifts in 1969 exposed fish to thermal shock in both the tolerance and resistance zones (Figure 12). Four drifts resulted in near total mortalities, two through the inshore K leak and two through the main K plume in midriver. However, lethal thermal doses were not encountered in the majority of the drifts through the K plume albeit

environmental conditions were extreme, i.e., high base river temperatures and low river discharges (Figure 4). Exposure durations were normally too short to cause excessive mortality in most test drifts even when maximum temperatures exceeded the arbitrary 25 °C lethal limit. No summer drifts through midstream plumes in 1968 exposed test fish to a lethal thermal dose (Figure 13). In 1968 and 1969 combined, three drifts with maximum temperatures falling in the tolerance zone caused significant mortalities for reasons inadequately known.

Effect of Depth

Drifts were conducted both at the surface and at a depth of 3 meters in 1969, whereas only surface drifts were made in 1968. Subsurface drifts were conducted primarily through midstream plumes because mechanical damage to liveboxes resulted from intermittent bottom contact in shoreline drifts over shallow water. Base river temperatures at the surface and at 3 meters were similar during the spring, but were usually somewhat lower (<0.5 °C) in subsurface drifts during the summer. The thermal experience of test fish held in both positions while simultaneously drifted through the K plume proved to be somewhat different (Figures 8-11). This difference was expected on the basis of known effluent mixing patterns (Jaske, Templeton and Coutant, in press).

A difference in mortality associated with depth occurred in two tests. In the first (Drift Series V, groups 7-8), immediate losses were nil but retention losses were severe among fish drifted at 3 meters; this case was atypical since death was preceded by emaciation. In the second (Drift Series VIII, groups 3-4), immediate and 24 hr mortalities were excessive among the 3 meter fish and apparently resulted from thermal dose during the drift (Figure 11). No data were obtained to demonstrate a persistent effect related to a combination of pressure

and temperature.

Immediate vs Delayed Mortalities

Test and control fish were held 6 days postdrift in 1969 for identification of immediate and delayed mortalities, whereas a 24 hour retention period was used in 1968. Mortality data (Tables 1-8) demonstrate that lethal effects from thermal dose among test fish usually appeared at the termination of a drift or within 24 hrs. Thus, data from the short postdrift observation period in 1968 were reasonably valid. Chronic mortalities from high nitrogen levels during the 1969 spring drifts involved both control and test fish and usually appeared after the first day of retention. Sporadic mortalities from mechanical damage (injury followed by infection with fungi) appeared during the longer postdrift observation period.

Effects of Dissolved Nitrogen

Supersaturation with nitrogen in the Columbia River during the spring and summer, when large volumes of water are passed over spillways at dams, has become an environmental hazard to young salmonids (Ebel, 1970). Due to the separation in time of the livebox drifts into early spring and summer periods, excessive nitrogen levels were apparently avoided in 1968. The 1969 spring drifts were severely effected by nitrogen supersaturation resulting from early releases of stored water at Grand Coulee, which passed over the spillways at Priest Rapids Dam above Hanford. Losses of test fish from "gas-bubble" disease occurred in the predrift accumulation pen (severity unrecorded) and during the postdrift retention period (Tables 2-4). The mortalities were largely chronic and involved both test and control fish. Although the data are admittedly limited, there was little evidence that excessive nitrogen combined with moderate thermal shock to increase mortalities of fish drifted through effluent discharges substantially over losses of fish drifted along the north shoreline.

Physical Characteristics of Shoreline and Midriver Discharges

The physical parameters of drifts conducted through areas of shoreline seepage (and the K leak) contrasted with those of the midriver plumes. The differences were related to thermal effects among test fish. Generally, peak temperatures were higher and exposure durations were longer in shoreline seepage drifts thereby resulting in greater mortality.

Shoreline drifts were characterized by 1) prolonged exposure to mixing effluent, because of relatively slow passage rates resulting from restricted downriver flow; 2) high thermal dose, because of reduced effluent mixing with the receiving river water along the shore; and 3) gradual temperature decline, because of the extended mixing zone passing downriver before dispersal.

Midriver drifts through the main discharge plumes, in contrast, were characterized by 1) brief exposure to mixing effluent, because of relatively rapid passage rates resulting from unrestricted downriver flows; 2) low thermal dose, because of efficient effluent mixing with the receiving river water in midstream; and 3) rapid temperature decline, because of the shortened mixing zone passing downriver before primary dispersal. Exposures to peak temperatures in a plume usually occurred within a few minutes of initial contact. Exposures to fluctuating temperatures, which indicated the primary mixing zone below a midstream plume, usually occurred within 10 minutes at minimum river flows. After initial contact, the intensity and fluctuation of plume temperatures dropped rapidly to harmless levels.

The dissimilar thermal parameters of shoreline and midriver effluent discharges was clearly affected by differences in current patterns and river discharge volumes (which regulate mixing) between the two

sites. Drifts in 1969 were closely correlated with daily and weekly periods of minimum river discharge (Figure 4). Drifts during the spring (23 March-14 May) occurred during rising discharges (39-225 thousand cf/sec) but low base temperatures (4-10 °C). Drifts during the summer (1 Aug.-1 Sept.) occurred during seasonal minimum discharge volumes (39-60 thousand cf/sec) but high base river temperatures (17-19 °C). A wide range of temperature and flow conditions occurs annually in the central Columbia River, and the effect of effluent discharges on young salmonids clearly relate to these features.

CONCLUSIONS

The 1969 experimental drifts terminate two successive years of field studies dealing with the effects of heated effluent discharges on juvenile salmonids passing seaward through the Hanford area of the central Columbia River. The following conclusions, therefore, are derived from data collected in both 1968 and 1969 although only the latter are detailed herein.

As noted previously (Becker and Coutant, 1969), mortality of fish under simulated migration conditions is primarily a function of thermal experience, i.e., temperature increase and exposure duration (= thermal dose). These intergraded functions determine the lethal effect, if any, of "thermal shock" as migrating fish pass through mixing effluent discharges. Obviously, if the temperature is sufficiently high and the exposure duration sufficiently long, any species of fish experiencing thermal dose will be killed. The precise relationship can be determined in laboratory experiments (Coutant, 1969; Dean, 1969), but the data have not been extended to field conditions with a high degree of confidence

because wide temperature fluctuations occur randomly in the primary mixing zones before thermal stabilization occurs. Moreover, unknown intrinsic factors are operative under field situations that are largely reduced or eliminated in controlled laboratory studies.

An ideal evaluation program (for thermal studies) must combine laboratory and field data in order to obtain ecological meaning with respect to the survival value for a species (Mihursky and Kennedy, 1967).

Environmental conditions in the central Columbia during the time when juvenile salmonids are present play a dominant role in influencing thermal experience, potential or realized. The two most important factors appear to be prevailing base river temperatures and river discharge volumes. Throughout the annual migration season (Figure 3), there exists a well defined sequence based on four combinations of temperature and discharge. These are, in succession, low temperature--low discharge (early spring), low temperature--high discharge (late spring), high temperature-high discharge (early summer), and high temperature-low discharge (late summer). The potential hazard to juvenile salmonids resulting from discharges of heated effluents tends to increase from March through August. Environmental conditions appear to be most severe during the late summer, after fish produced in the free-flowing river at Hanford have departed seaward.

Low Temperature--Low Discharge

During early spring (March-April), river temperatures and flow volumes are low (Figures 3-4). (High flows began early in 1969, due to releases at Grand Coulee Dam). Chinook fry first emerge from the gravel of the river bed in the Hanford environs during this time. Many weakly swimming fry are apparently carried directly downriver and contribute to the "early seaward migration" detected by Mains and Smith (1964). Other

fry appear in inshore areas for an indeterminate period of feeding and growth before departing seaward (Becker, 1970). Data from livebox drifts in 1968 and 1969 reveal only one instance of significant mortality, through a shoreline seepage area during early spring; no losses were recorded in plume drifts. The general lack of thermal deaths apparently is due largely to low base river temperatures.

Surface mixing patterns at the K plume under river flows of 41,000 and 80,000 cf/sec are shown in Figures 14-15. Maximum thermal increments above base river temperature cover a broader surface area behind the plumes at the lower flow, and the width of the 1-6°C ΔT mixing zone extending downriver is considerably wider. If base river temperatures are low, as in early spring, thermal increments sufficient to cause mortalities exist only in the focal base of the plume. If currents are rapid, as in the central Columbia, exposure to maximum temperatures would necessarily be brief and usually impart merely a sublethal thermal dose. Exposure (of confined fish) to high temperatures is apparently longer in the shoreline seepage areas and some deaths may result.

Low Temperatures--High Discharges

The period of high discharge normally occurs in late spring and early summer (May-July), accompanied by a rise in river temperatures to about 16 °C (Figures 3-4). Many juvenile salmon are moving seaward and an abundance of fish occur in inshore feeding areas at Hanford. Although river temperatures are near optimum, air supersaturation (nitrogen) becomes an added environmental hazard when surplus water is passed over spillways of upriver dams.

Surface mixing patterns at the K plumes under river flows of 110,000 cf/sec are illustrated in Figure 16. Maximum thermal increments (6-9 °C) occur at the precise points of discharge and the width of

the mixing zone extending downriver has narrowed under increased flows. River flows during spring runoff, however, usually exceed the illustrated 110,000 cf/sec and peaked above 270,000 cf/sec in both 1968 and 1969. Prevailing high discharges provide protection for the migrants from thermal increments by rapidly mixing and dispersing heated effluents in the vast water mass throughout the main seaward migration period.

High Temperatures--High Discharges

River temperatures reach and exceed thermal preferendum (12-14 °C) for young salmon in early summer (June and July). Discharge volumes remain relatively high until mid-July (Figures 3-4). High nitrogen levels in the river water remain a hazard. Most juvenile chinook salmon produced in the Hanford area apparently have passed downriver by the end of July (Becker, 1970). Prevailing high discharges apparently mitigate against excessive losses of the migrants during this period. Our drift data, however, indicate that shoreline seepages are potentially lethal even during high discharges.

High Temperatures--Low Discharges

A condition of high temperatures (near 20 °C) and low river discharges (below 100,000 cf/sec) prevails (Figures 3-4) in late summer (Aug.-Sept.). Whereas most Hanford juveniles have departed, a delayed migration of young salmonids produced above Hanford continues through August (Park, 1969). During periods of minimum flows on weekends, mortality of test fish from thermal dose do occur during some livebox drifts. Surface mixing patterns prevailing in the discharge plumes approximate those of 41,000 cf/sec (Figure 14), but river temperatures are high rather than low as in early spring. With base river temperatures of 18 °C, increments over 8 °C will expose migrating fish to temperatures above the arbitrary upper incipient lethal limit of 25 °C. The mixing zone

with VT 3-8°C extends for a considerable distance downriver under low flow conditions. The potential for lethal exposure among migrating fish clearly exists at this time. However, significant mortality rarely occurs during plume drifts and lethal temperatures are infrequently recorded. (These results, which would be unexpected in laboratory tests, may have been partly influenced by inability to direct all test fish into the precise center of a discharge plume under field conditions.) Temperatures in shoreline seepages proved to be more excessive than in plumes, and mortalities of drifted fish were common.

Physical parameters between mixing patterns in shoreline seepages and midstream plumes are clearly different. The following contrasting features of the two effluent disposal sites are evident.

Shoreline Seepages

Mortality does occur during some drifts through areas heated by intragravel seepage from effluent retention basins along the south shoreline. A particularly hazardous area existed below the BC reactor area in 1968 and early 1969, which was eliminated with closure of the C reactor after the 1969 spring drifts. Other shoreline seepages still exist in the Hanford area but these are limited in volume and area, and must be considered of minor consequence. Shoreline seepages are less affected by changing river flows than midstream plumes, apparently because thermal stratification persists along the inshore zone and inefficient mixing occurs as a result of reduced flow in shallow water. Discharges from the leak near the end of the K jetty move inshore at river flows below 120,000 cf/sec, since an eddy exists behind the riprap (Figures 14-16) that reduces mixing efficiency and simulates a shoreline seepage.

We have no evidence that unconfined fish are involuntarily carried into or voluntarily penetrate heated water areas near the shore. Voluntary entrance may occur in seepage areas during early spring when river temperatures are well below the thermal preferendum of 12-14 °C (Brett, 1952) for young salmonids. However, fish are known to be extremely sensitive to small temperature changes (Bull, 1936) and will avoid, if physically possible, areas warmed in excess of their preferendum (Alabaster, 1963; Brett, 1952; Bardach and Bjorklund, 1957). Heavy concentrations of nonmigrating young chinook occur near the banks in the Hanford area from April through July, as indicated by seining activity (Becker, 1970). Concentrations of migrants also pass near the banks, although the fish are generally well distributed throughout the entire horizontal area of the river (Mains and Smith, 1964). The conclusion is explicit and inescapable--shoreline seepages represent a potentially lethal area to migrating juvenile salmonids regardless of the extent of fish avoidance or existing river temperature and flow. Consequently, any shoreline discharges should be curtailed at existing nuclear power installations and such discharges should be avoided at facilities being planned or under construction.

Plume Discharges

Although mortality may also result among fish drifted through midstream plumes, these losses are limited and occur primarily under late season conditions of maximum temperatures and minimum flows. Most Hanford juvenile chinook migrate seaward under protection of favorable river temperatures and flows exceeding 100,000 cf/sec. This migration timing has evolved as a natural phenomena over thousands of years. But young salmonids produced above Hanford apparently now pass Priest Rapids

plumes with mixing patterns shown in Figure 14 at a season when river temperatures are in the upper zone of thermal tolerance. (We obtained no catches of late migrating fish in an inclined plane trap fished behind the K plume in August and September of 1969).

The thermal hazard represented by a midstream plume appears to be less than a shoreline discharge. Potential harm depends upon ambient river conditions and whether or not the fish actually pass through the focal base of a plume before mixing reduces temperatures of the effluent to sublethal levels. During active migration, juvenile chinook in the central Columbia exhibit a preference for the surface zone (44 percent occur within 30 inches of the surface) and the fish are horizontally distributed across the entire river with greatest concentrations near the shore (Mains and Smith, 1964). The proportion of juvenile salmonids entering the mixing zone of a midstream plume is unknown, but is probably small due to the disproportionate ratio of effluent volume to total water mass. The proportion of fish that actually encounter lethal temperatures at the focal base of a plume is presumably even less. Temperatures of a plume generally lose 80 percent of ΔT within 5 seconds of discharge as measured at the river surface. Water leaving the submerged effluent pipes (that open upward) are discharged at high velocities and a shear plane initially exists between the heated discharge and the cool river water. Theoretically, this shear could reduce possible collisions of small fish with maximum discharge temperatures as they pass downriver.

Lethal temperatures exist only for a relatively short distance in the mixing turbulence before dispersal to sublethal levels even

apparently so brief that there is little response by sensitive fish tissue in most field situations. Nevertheless, under environmental conditions in July and August (high temperatures and low discharges), mortality was evident in some of the plume drifts. Yet, as Alabaster (1963) pointed out, fish introduced into effluent outfalls in cages are deprived of the opportunity to escape unfavorable conditions thereby making survival minimum.

The reactor effluents at Hanford issue primarily from a single point discharge with a high exit velocity, which is carried upward and downriver during the mixing process. Horizontal spreading in the mixing zone, as well as the area of peak temperature near the outlet, decreases with increased river flow up to 110,000 cf/sec (Jaske, et al., in press), as shown in Figures 14-16. The most successful diffuser for direct disposal of reactor effluent in the center of a large, cool and fast-flowing river like the central Columbia, for the purpose of reducing thermal effects on migrating juvenile fish, is not necessarily a single point discharge. There is ample reason to believe that a comprehensive hydraulic investigation on other types of midriver diffuser outlets would prove rewarding. Such outlets as a multiple port diffuser might facilitate the mixing process by providing a broader horizontal mixing zone while simultaneously lowering maximum temperatures near the foci. An alternative would be to provide for minimizing effluent temperatures before release by onshore dilution with river water, by cooling towers or by cooling ponds at added economic cost.

If the undiluted effluent falls in the range of lethal temperature and mortalities of young salmonids can occur, there is reason for concern. We have demonstrated with our livebox drift experiments that this does not necessarily mean the risk of kill from thermal dose is excessive,

only that losses may occur under certain conditions. We have attempted to clarify these conditions by defining environmental features prevailing in the central Columbia River in relation to the Hanford effluent discharges and the migration timing of the fish.

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Table 1. Series I. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 23 March 1969.

Group	Number and Species (1)	Area and Depth of Drift	River Flow cf/sec	Temperature, °C		Mortality, day:								
				Base	Maximum Shock (2)	0	1	2	3	4	5	6 Total (3)		
1. Control	20 chinook	North Shore, K to N, Surface	40,000	4.0	4.0	0.0	0	0	0	0	0	0	0	0
2. Control	20 chinook	"	"	"	"	"	0	0	0	0	0	0	0	0
3. Control	20 coho	"	"	"	"	"	0	0	0	0	0	0	0	0
4. Control	20 coho	"	"	"	"	"	0	0	0	0	0	1	0	1
5. Test	20 chinook	South Shore, below B. C 40,000 Surface	40,000	4.0	30.5	26.5	0							
6. Test	20 coho	"	"	"	"	"	0	0	1	0	0	0	2	3
7. Test	20 chinook	Midchannel, K to N, Surface	40,000	4.0	12.0	8.0	0	0	0	0	0	0	0	0
8. Test	20 chinook	"	"	"	"	"	0	0	0	0	0	0	0	0
9. Test	20 coho	"	"	"	"	"	0	0	0	0	0	0	0	0
10. Test	20 coho	"	"	"	"	"	0	0	0	0	1	0	0	1
11. Test	20 chinook	South Shore, below K, Surface	39,000	6.0	6.0	0.0	0	0	0	0	1	0	0	1
12. Test	20 coho	"	"	"	"	"	0	0	0	0	0	0	0	0

Table 1. (Continued)

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:								Total ⁽³⁾
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6		
13. Test	20 chinook	Midchannel, K to N, Surface	39,000	4.2	16.6	12.4	0	0	0	0					
14. Test	20 chinook	Midchannel, K to N, 3 meters	39,000	"	"	"	0	0	0	0	0	1	0	1	
15. Test	20 coho	Midchannel, K to N, Surface	39,000	"	"	"	0	0	1	0	1	0	0	2	
16. Test	20 coho	"	"	"	"	"	0	0	0	0	0	0	1	1	
30-17. Test	20 chinook	Midchannel, K to N, 3 meters	40,000	4.2	16.6	12.4	0	0	0	0	0	0	0	0	
18. Test	20 coho	"	"	"	"	"	0	0	0	0	0	0	0	0	
19. Test	20 coho	"	"	"	"	"	0	0	0	0	1	0	0	1	

(1) Chinook were egg sac fry reared at BNW's 100-F Area hatchery; coho were yearlings from Ice Harbor Dam, U.S. Fish and Wildlife facilities.

(2) Calculated as the degrees increment above base river temperature.

(3) Mortalities due primarily to trauma from mechanical injury.

Table 2. Series II. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 22 April 1969.

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:							
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6	Total ⁽³⁾
1. Control	60 chinook	North Shore, CB to N, Surface	195,000	8.0	11.2	3.2	4	4	1	1	-	1	2	13
2. Control	25 coho	"	"	"	"	"	4	10	2	1	-	5	2	24
3. Test	70 chinook	South Shore (seepage), Surface	195,000	8.7	14.1	5.4	0	2	2	0	-	1	0	5
4. Test	25 coho	"	"	"	"	"	11	13	1					

(1) Chinook were fry (34-40 mm fork length) and coho were yearlings (95-130 mm fork length) seined from the Columbia River above Hanford.

(2) Calculated on the degrees increment above base river temperature.

(3) Chronic mortalities due largely to air supersaturation, i.e. nitrogen or "gas bubble" disease.

Table 3. Series III. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 30 April 1969.

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:								Total ⁽³⁾
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6		
1. Control	20 chinook	North Shore, CB to K, Surface	210,000	8.1	8.1	0.0	0	1	0	0	0	0	0	1	
2. Control	20 Chinook	"	"	"	"	"	0	0	0	1	0	0	1	2	
3. Control	20 chinook	"	"	"	"	"	0	0	0	0	0	1	0	1	
4. Control	20 chinook	"	"	"	"	"	0	0	0	0	0	—	—	0	
5. Test	20 chinook	South Shore, CB to K, (seepage) Surface	220,000	8.1	28.8	20.7 ⁽⁴⁾	13	3	0	0	0	1	0	17	
6. Test	20 chinook	"	"	"	"	" ⁽⁴⁾	19	0	1	—	—	—	—	20	
7. Test	20 chinook	"	"	8.1	29.4	21.3 ⁽⁴⁾	0	0	0	1	0	0	2	3	
8. Test	20 chinook	"	"	"	"	" ⁽⁴⁾	0	0	0	3	0	1	0	4	
9. Test	20 chinook	"	"	"	"	"	0	0	—	—	3	0	3	6	

(1) Chinook were reared from eggs at BNW's 100-F Area hatchery.

(2) Calculated as the degrees increment above base temperature.

(3) Chronic losses due largely to air supersaturation, i.e. nitrogen or "gas bubble" disease; acute losses due to thermal dose.

(4) Thermal experience is graphed in Figure 7.

Table 4. Series IV. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 15, May, 1969.

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:								Total ⁽³⁾
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6		
1. Control	20 chinook	North Shore, K to N, Surface	225,000	9.5	10.0	0.5	0	3	3	-	1	2	-	9	
2. Control	20 rainbow	"	"	"	"	"	0	8	12	0				20	
3. Control	20 chinook	North Shore, 3 meters	225,000	9.5	10.0	0.5	0	1	1	-	1	0	-	3	
4. Control	20 chinook	"	"	"	"	"	0	12	0	-	1	0	-	13	
5. Control	20 rainbow	"	"	"	"	"	0	1	12	-	7			20	
6. Test	20 chinook	Midchannel, K to N, Surface	220,000	9.5	12.4	3.9	0	2	0	-	2	0	-	4	
7. Test	20 chinook	Midchannel, K to N, 3 meters	"	"	"	"	0	3	0	-	3	0	-	6	
8. Test	20 chinook	"	"	"	"	"	0	8	6	-	1	1	-	16	
9. Test	20 rainbow	Midchannel, K to N, Surface	"	9.5	12.4	3.9	0	3	17				20		
10. Test	20 rainbow	Midchannel, KW to N, 3 meters	"	"	"	"	0	1	11	-	8			20	
11. Test	20 chinook	South Shore, K to N, Surface	210,000	10.9	11.2	0.3	0	4	5	-	3			13	
12. Test	20 chinook	"	"	"	"	"	0	4	6	-	4	1	-	15	
13. Test	20 rainbow	"	"	"	"	"	0	1	12	-	7	0	-	20	
14. Test	30 rainbow	"	"	"	"	"	0	5	16	-	9			30	

(1) Chinook were reared at BNW's 100-F Area hatchery; rainbow were yearlings reared at the Ringold hatchery, Washington State Department of Game.

(2) Calculated as the degrees increment above base temperature.

(3) Chronic mortalities largely due to air supersaturation, i.e. nitrogen or "gas bubble" disease.

Table 5. Series V. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 1 August 1969.

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:							
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6	Total
1. Control	25 chinook	North Shore, K to D, surface	80,000	18.0	18.0	0.0	0	1	0	0	1	2	1	5
2. Control	25 chinook	North Shore, 3 meters	"	17.2	17.2	0.0	1	1	1	1	0	3	1	8
3. Test	25 chinook	Midchannel, K to N, surface	80,000	18.0	19.4	1.4	0	0	1	1	2	3	2	9
4. Test	25 chinook	Midchannel, K to N, 3 meters	"	17.2	18.4	1.2	0	0	0	2	0	3	3	8
5. Test	25 chinook	Midchannel, K plume, surface	90,000	(3)			0	0	0	1	1	1	0	3
6. Test	25 chinook	Midchannel, K plume, 3 meters	"	(3)			0	0	0	0	0	1	0	1
7. Test	25 chinook	Midchannel, K to N surface	90,000	18.0	21.4	3.4 ⁽⁴⁾	0	1	0	0	0	0	1	2
8. Test	25 chinook	Midchannel, K to N, 3 meters	"	17.4	22.3	4.9 ⁽⁴⁾	0	4	2	2	5	7	3	23

(1) Chinook were reared at BNW's 100-F Area hatchery.

(2) Calculated as degrees increment above base temperature. Exposure to peak temperatures was very brief.

(3) Recorders malfunctioned.

(4) Thermal experience is graphed in Figure 8. Fish in Test Group 8 were severely emaciated at time of death.

Table 6. Series VI. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 8 August 1969.

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:							
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6	Total
1. Control	25 chinook	North Shore, K to N, surface	80,000	17.6	17.6	0.0	0	0	0	0	0	0	0	0
2. Control	25 chinook	North Shore, 3 meters	"	"	"	"	0	0	0	0	0	0	0	0
3. Test	25 chinook	Midchannel, K to N, surface	80,000	18.2	22.2	4.0 ⁽³⁾	0	0	0	0	0	0	1	1
4. Test	25 chinook	Midchannel, 3 meters	"	17.4	27.0	9.6 ⁽³⁾	0	0	0	0	1	0	0	1
5. Test	25 chinook	Midchannel, K to N, surface	75,000	17.7	21.3	3.6	0	0	2	2	0	1	0	5
6. Test	25 chinook	Midchannel, 3 meters	"	17.4	21.5	4.1	0	0	0	0	0	0	0	0
7. Test	25 chinook	Midchannel, K to N, surface	75,000	17.4	19.0	1.6	0	0	0	0	0	0	0	0
8. Test	25 chinook	Midchannel, K to N, 3 meters	"	17.4	27.0	9.6	0	0	0	0	0	0	0	0

(1) Chinook were reared at BNW's 100-F Area hatchery.

(2) Calculated as degrees increment above base temperature. Exposure to peak temperatures very brief.

(3) Thermal experience graphed in Figure 9.

Table 7. Series VII. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 20 August 1969.

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:						
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6 Total ⁽⁵⁾
1. Control	25 chinooks	North Shore, K to N, surface	70,000	18.4	0.0	0.0	0	0	0	—	—	—	0
2. Control	25 chinooks	North Shore, 3 meters	"	"	"	"	0	0	0	—	—	—	0
3. Control	16 cohos	North Shore, surface	70,000	(3)			0	0	0	—	—	—	0
4. Control	16 cohos	North Shore, 3 meters	"	(3)			0	0	0	—	—	—	0
5. Test	35 chinooks	Midchannel, K to N, surface	70,000	18.3	23.1	4.8 ⁽⁴⁾	0	0	0	—	—	—	0
6. Test	31 chinooks	Midchannel, 3 meters	"	18.5	23.1	4.6 ⁽⁴⁾	0	1	0	—	—	—	1
7. Test	20 cohos	Midchannel, Surface	75,000	18.3	20.0	1.7	0	0	0	—	—	—	0
8. Test	20 cohos	Midchannel, 3 meters	"	18.5	20.2	1.7	0	0	0	—	—	—	0

(1) Chinook and coho yearlings were reared at BNW's 100-F area hatchery.

(2) Calculated as degrees increment above base temperature. Exposure to peak temperatures very brief.

(3) Recorder malfunctioned.

(4) Thermal experience graphed in Figure 10.

(5) Lost fish after 3 days retention in a wind storm.

Table 8. Series VIII. Drifts of juvenile salmonids through areas of thermal discharge, Hanford environs, 1 September 1969.

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:							
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6	Total
1. Control	25 chinook	North Shore, K-N, surface	39,000	18.0	18.0	0.0	0	0	0	0	0	0	0	0
2. Control	25 chinook	North Shore, K-N, 3 meters	"	17.4	17.4	0.0	0	0	0	0	0	0	0	0
3. Test	25 chinook	Midchannel, K-N, surface	39,000	17.9	37.0	19.1 ⁽³⁾	0	0	0	0	0	0	0	0
4. Test	25 chinook	Midchannel, K-N, 3 meters	"	17.7	40.4	22.7 ⁽³⁾	10	10	0	0	3	1	1	25
5. Test	25 chinook	Midchannel, K plume, surface	39,000	18.1	29.1	11.0	0	0	0	0	0	0	0	0
6. Test	25 chinook	Midchannel, K plume, 3 meters	"	17.8	(4)		0	0	0	0	0	0	0	0
7. Test	25 chinook	Midchannel, K plume, surface	40,000	18.1	37.8	19.7 ⁽³⁾	0	0	0	0	0	0	0	0
8. Test	25 chinook	Midchannel, K plume, 3 meters	"	17.8	28.4	10.6 ⁽³⁾	0	0	0	0	0	0	1	1
9. Test	25 chinook	South Shore, K leak, surface	40,000	18.3	48.3	30.0	25							25
10. Test	25 chinook	"	"	18.0	41.2	23.2	25							25

Table 8 (continued)

Group	Number and Species ⁽¹⁾	Area and Depth of Drift	River Flow cf/sec	Temperature, °C			Mortality, day:								
				Base	Maximum	Shock ⁽²⁾	0	1	2	3	4	5	6	Total	
11. Test	25 chinook	South Shore, K leak, surface	50,000	18.3	24.2	6.9	0	0							0
12. Test	25 chinook	South Shore, K leak, 3 meters	"	17.8	(4)		0	0	0	0	0	0	0	0	1
13. Test	25 chinook	South Shore, K leak, surface	"	18.0	27.9	9.9	0	0	0	0	0	0	0	0	0
14. Test	25 chinook	South Shore, K leak, surface	"	18.3	25.9	7.6	0	0							.0
15. Test	25 chinook	Midchannel, K plume, surface	60,000	18.4	25.2	6.8 ⁽³⁾	0	0	0	0	0	0	0	0	0
16. Test	25 chinook	Midchannel, K plume, 3 meters	"	18.3	26.6	8.3 ⁽³⁾	0	0	0	1	0	0	0	0	1

(1) Fingerling spring chinook (40/lb) were obtained from the Little White Salmon hatchery, US Fish and Wildlife Service.

(2) Calculated as degrees increment above base temperature.

(3) Thermal experience graphed in Figure 11.

(4) Recorder malfunction.

(5) Fish lost in wind storm.

FIGURE 1. LOCATION OF LIVEBOX DRIFTS WITH JUVENILE SALMONIDS IN RELATION TO HEATED DISCHARGES AT HANFORD, CENTRAL COLUMBIA RIVER, 1969.

30 Second Intervals →

FIGURE 2. HYPOTHETICAL ILLUSTRATION OF THERMAL EXPERIENCE OF TEST FISH DRIFTED THROUGH A MIDRIVER PLUME, AS PERMANENTLY RECORDED ON STRIP CHART TAPE. (DOTS INDICATE THE MEAN EXPOSURE TEMPERATURE, ABOVE BASE RIVER TEMPERATURE, PER 30 SEC INTERVAL.)

WATER TEMPERATURE, 1952, 1964

--- RICHLAND, TEMPERATURE

○ ○ ○ PRIEST RAPIDS, DISCHARGE

TEMPERATURE, °C

PREFERRED TEMPERATURE RANGE
FOR YOUNG SALMON (BRETT, 1952)

PRIEST RAPIDS MIGRATION (PARK, 1969)

HANFORD MIGRATION (MAINS AND SMITH, 1964)

MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER

FIGURE 3. MEAN WEEKLY WATER TEMPERATURES IN THE CENTRAL COLUMBIA RIVER AT PRIEST RAPIDS DAM AND RICHLAND, PLUS DISCHARGE VOLUMES AT PRIEST RAPIDS DAM, 1969. (KNOWN PERIODS OF SEAWARD MIGRATION OF JUVENILE CHINOOK ARE INDICATED.)

FIGURE 4. DATES LIVEBOX DRIFTS WERE CONDUCTED IN RELATION TO DAILY COLUMBIA RIVER DISCHARGES
AT PRIEST RAPIDS DAM, MARCH THROUGH APRIL, 1969.

DAILY FLUXTUATIONS IN COLUMBIA RIVER DISCHARGES AS REGULATED AT PRIEST RAPIDS DAM DURING EXPERIMENTAL DRIFTS, SPRING 1969

FIGURE 5. DAILY FLUCTUATIONS IN COLUMBIA RIVER DISCHARGES AS REGULATED
AT PRIEST RAPIDS DAM DURING LIVEBOX DRIFTS, SPRING 1969.

DISCHARGES AS REGULATED AT PRIEST RAPIDS DAM DURING EXPERIMENTAL DRIFTS, SUMMER 1969

DISCHARGE, cfs $\times 10^3$

FIGURE 6. DAILY FLUCTUATIONS IN COLUMBIA RIVER DISCHARGES AS REGULATED
AT PRIEST RAPIDS DAM DURING LIVEBOX DRIFTS, SUMMER 1969.

FIGURE 7. THERMAL EXPERIENCE OF TEST FISH IN GROUPS 5-6 (STARBOARD) AND 7-9 (PORT) IN DRIFT THROUGH SHORELINE SEEPAGE AREAS, SERIES III

Becker
Figure 8

FIGURE 8. THERMAL EXPERIENCE OF TEST FISH IN GROUP 7 (SURFACE) AND GROUP 8 (3 METERS) IN DRIFT THROUGH K PLUME, SERIES V.

Becker
Figure 9

FIGURE 9. THERMAL EXPERIENCE OF TEST FISH IN GROUP 3
(SURFACE) AND GROUP 4 (3 METERS) IN DRIFT
THROUGH K PLUME, SERIES VI

7/18/80
R2.70

FIGURE 10. THERMAL EXPERIENCE OF TEST FISH IN GROUP 5
(SURFACE) AND GROUP 6 (3 METERS) IN DRIFT
THROUGH K PLUME, SERIES VII

NUMBER OF 30 SEC INTERVALS

FIGURE 11. THERMAL EXPERIENCE OF TEST FISH IN GROUPS 3-4,
7-8, AND 15-16 IN DRIFTS THROUGH THE K PLUME,
SERIES VIII

MAXIMUM THERMAL EXPOSURE OF JUVENILE
SALMONIDS (TEST) DURING LIVEBOY DRIFTS
THROUGH EFFLUENT DISCHARGES IN 1969
(TEMPERATURE CRITERIA ADOPTED FROM BRETT, 1952)

DAU-203HCO-3

FIGURE 12. MAXIMUM THERMAL EXPOSURES OF JUVENILE SALMONIDS (TEST) DURING
LIVEBOX DRIFTS THROUGH EFFLUENT DISCHARGES AT HANFORD IN 1969.
(TEMPERATURE CRITERIA ADOPTED FROM BRETT, 1952.)

Maximum Temperature Increment (°C)

March-April

August-September

FIGURE 13. MAXIMUM THERMAL EXPOSURES OF JUVENILE CHINOOK (TEST) DURING
LIVEBOX DRIFTS THROUGH EFFLUENT DISCHARGES AT HANFORD IN
1968. (TEMPERATURE CRITERIA ADOPTED FROM BRETT, 1952.)

*DETECTION LIMIT OF AERIAL INFRARED IMAGING SYSTEM $\sim 0.5^{\circ}C$

FIGURE 14. COLUMBIA RIVER SURFACE TEMPERATURE FLOW PATTERNS BY INFRARED IMAGERY
AT 41,000 cf/sec FLOW (FROM JASKET, et.al. _____)

*DETECTION LIMIT OF AERIAL INFRARED IMAGING SYSTEM $\sim 0.5^\circ C$

FIGURE 15. COLUMBIA RIVER SURFACE TEMPERATURE FLOW PATTERNS BY INFRARED IMAGERY
AT 80,000 cf/sec FLOW (FROM JACKET, et.al.____)

*DETECTION LIMIT OF AERIAL INFRARED IMAGING SYSTEM $\sim 0.5^{\circ}C$

FIGURE 16. COLUMBIA RIVER SURFACE TEMPERATURE FLOW PATTERNS BY INFRARED IMAGERY
AT 110,000 cf/sec FLOW (FROM JASKE, et.al. _____)