BNWL-1472
UC-48

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FROM THE CENTRAL COLUMBIA RIVER

C. D. Becker

July 1970

AEC RESEARCH &
DEVELOPMENT REPORT

BNWL-1472

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UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00061 7268

BN-7L-1472
UC-48, Biology
and Medicine

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THE CENTRAL COLUMBIA RIVER

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FIRST UNRESTRICTED
DISTRIBUTION MADE OCT 19 1970

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RICHLAND, WASHINGTON 99352

Note: This paper is based on work performed under United States Atomic Energy Commission Contract AT(45-1)-1830, in coordination with the Columbia River Thermal Effects Study program, U.S. Department of the Interior.

Printed in the United States of America
Available from
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Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

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OF JUVENILE CHINOOK SALMON FROM
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C. D. Becker

ABSTRACT

A sizeable population of adult chinook salmon now spawns each fall in the free-flowing Hanford environs of the central Columbia River. This population has acquired significance because other vital spawning areas in the mainstem Columbia have been inundated by hydroelectric development. Studies conducted in 1969 show that the progeny of the Hanford population migrates seaward from April to July in the ancient pattern that correlates with favorable water temperatures and high discharge volumes. In contrast, the passage of juvenile chinooks that now issue from upriver reaches is known to be delayed until July and August when temperatures and discharge volumes are less favorable.

Temperatures in the central Columbia are modified by discharges of heated effluent from plutonium production reactors at Hanford, in addition to largely seasonal changes in river flow, cooling or warming by the upriver reservoir complex, and summer heat input from the atmosphere. In 1968 and 1969, mean weekly water temperatures peaked in late July, August and early September with maximum daily temperatures briefly reaching 19.1 and 19.7 °C, respectively, at Priest Rapids and 19.7 and 20.6 °C at Richland.

The relationship of ambient temperatures and river discharges to the natural and delayed migration of juvenile chinooks through the Hanford area is evaluated. Maximum temperatures in the central Columbia seldom exceed 22 °C and have not been recorded as approaching 25.1 °C, the apparent upper incipient lethal limit for juvenile chinooks. Although peak summer temperatures (above 20 °C) may be suboptimum for the survival of young salmon, such conditions probably existed long before the advent of modern man. Present peak temperatures do not appear to be directly lethal even with increments of heat from reactor effluent. Potentially adverse thermal effects from reactor operation would most likely appear at subacute levels and resist casual detection. This assumes that a slight increase in excess of the annual temperature cycle does not greatly intensify other existing environmental hazards.

INTRODUCTION

Routine operation of plutonium production reactors on the U.S. Atomic Energy Commission's Hanford Reservation above Richland, Washington involves the release of heated water into the central Columbia River. Although these reactors have been operating for over two decades, public and professional concern has only recently joined to focus on potential effects of thermal loading on salmonid resources throughout the vast Columbia system. This concern has been prompted largely by the proposed siting of additional power reactors on the Columbia and at various locations on other streams inhabited by anadromous fish in the Pacific Northwest; its basis lies in awareness that any biological system is vulnerable to environmental changes that fall outside the experience of the species involved.

The AEC is cognizant of the complex problems imposed by heated reactor discharges in its environmental research program at Hanford (Nakatani, 1969). One aspect of this program deals with the bionomics of young chinook salmon (Oncorhynchus tshawytscha) originating in the central Columbia River. The relationship between ambient water temperatures and river discharges to the timing of the annual seaward migration is explored herein.

THE HANFORD SPAWNING POPULATION

Construction of hydroelectric dams on the Columbia River has now inundated hundreds of miles of primordial spawning areas formerly used by adult chinook salmon (Fulton, 1968). After completion of the John Day Dam below Arlington, Oregon and the Wells Dam above Chelan, Washington

in 1968, only the Hanford section of the main channel remains a free-flowing environment. This unaltered section extends from Richland some 93 km upriver to Priest Rapids Dam, and falls primarily within the boundaries of the Hanford Reservation (Figure 1).

A substantial population of adult chinooks now spawns each fall in the Hanford area. The number of redds produced by this population (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 3560 redds in 1968 (Watson, 1968, 1969). The increase in spawners was initiated primarily by displacement of populations following construction of Priest Rapids Dam in 1960 and aided, in part, by its "barrier effect" after completion.

The Hanford spawners probably originate, to a large extent, from various stocks or races formerly spawning elsewhere in the Columbia River. Due to recent inundation of mainstem spawning areas, this population may be a heterogenous mixture of genetic strains in a state of flux; distinct genotype or phenotype characteristics that provide rigid ties with the Hanford environs are presumably still lacking.

A portion of the Hanford population successfully spawns each fall below the mixing zones of the heated reactor discharges (Watson, 1968, 1969). However, success in spawning is not an indication of success in fertilization and subsequent development of eggs. Yet, proportionately, the increase in Hanford spawners has far exceeded a modest increase in runs of fall chinook passing McNary Dam (U.S. Corps of Engineers, 1968). Moreover, salmon populations above Hanford, as well as elsewhere in the Columbia system, are now supported in large part by an extensive

program of artificial propagation in hatcheries and spawning channels.

The numbers of young chinooks currently produced by natural and artificial means above Priest Rapids Dam, in comparison with total production in the Snake River, appear to be relatively low. From 1965-1967 studies, conducted at Ice Harbor Dam on the lower Snake and at Priest Rapids, Raymond (1968) estimated that 90% of the juvenile fish passing seaward issued from the Snake. Raymond's data, however, do not include progeny of fall chinooks spawning at Hanford. On the basis of over 3000 redds, these juveniles have obviously acquired considerable biological importance. But their contribution to the total seaward migration has never been measured.

SEAWARD MIGRATION TIMING

Early data on timing of the seaward migration from the central Columbia are provided by Mains and Smith (1964), whose studies were conducted in 1955 when only two major upriver dams were completed, Rock Island (1933) and Grand Coulee (1941). Seaward movement extended from early March to the end of July in 1955 and consisted of two distinct periods, one in March and April and the other in June and July. The first provided 76% of the total migration and consisted entirely of fry, while the second provided 24% and consisted largely of "fingerlings". No juvenile chinooks were available in August.

Data provided by Park (1969) from Priest Rapids Dam in 1965 and 1966 demonstrate that the main movement of young chinooks from the upper Columbia (excluding Hanford) now occurs from middle to late summer, with a dominant peak in August (60% of all fish in 1965, 40% in 1966). Changes in the upriver environment from the construction of dams and

filling of reservoirs were considered by Park to be responsible for the delay. During the intervening years since 1955, five dams were constructed above Hanford: Priest Rapids (1959), Rocky Reach (1961), Wanapum (1963), Chief Joseph (1955), and recently Wells (1967). In effect, the upper Columbia has been modified into a consecutive series of impoundments that, including massive Lake Roosevelt behind Grand Coulee Dam, extends beyond the Canadian border.

In 1969, Battelle Northwest biologists collected young chinook for analysis of food organisms and feeding activity at Hanford. Seining operations were conducted weekly at established stations from March through August. The resulting data on the migration timing of progeny produced by Hanford spawners, although not quantitative, agree essentially with the 1955 data of Mains and Smith (1964). A few fry appeared in the shore line habitats as early as mid-March, but fish were not abundant until the second week of April. Emergent fry, retaining a visible portion of the yolk sac, ranged from 34-40 mm (fork length). Population levels remained relatively high until mid-June and declined rapidly during July. No fish were obtained in August.

Basic statistics on the sizes of juvenile chinooks are given in Figure 2. The slow increase of minimum size values show that the fry emerged from the gravel over an extended period, from March to June. The increase in maximum size values in June and July suggested rapid growth under favorable environmental conditions. Analysis of length-frequency distributions (author's unpublished data) indicated that the shore line feeding population at a given station fluctuated weekly, in dynamic equilibrium to recruitment and outmigration. Maximum lengths of 70-85 mm were attained in July, although relatively few fish were

still available at this time. Presumably many of the late-run "fingerlings" (model size of 85-90 mm) observed by Mains and Smith (1964), who did not examine scales for winter annuli, were advanced juveniles of the 0-age group (originating from distant upriver areas) rather than overwintering, 1-age-group fish.

Clearly, an ecological distinction now exists between young chinooks produced in the free-flowing Hanford section and those passing seaward from impounded sections of the Columbia River above. The main differentiating feature is migration timing. Juveniles produced at Hanford retain the historical pattern detected 15 years ago by Mains and Smith (1964), whereas upriver juveniles pass through the central Columbia after considerable delay.

In 1969, the upriver juveniles again passed Priest Rapids Dam at an abnormally late date (D. L. Park, pers. comm.). Since our seining in August proved negative, these fish apparently did not linger in the Hanford area, but passed downriver directly into the forebay of McNary Dam.

TEMPERATURE PATTERNS IN THE CENTRAL COLUMBIA

Annual changes in water temperatures of the central Columbia historically occur in response to seasonal variations in atmospheric conditions and river discharge volumes. Thermal levels are generally lowest in January and February, then rise and peak during August and September (Sylvester, 1959; Jaske and Goble, 1967; Moore, 1969). The temperature gradient of the river rises throughout the year from the Canadian border to the lowest reaches, with the greatest increase occurring during the summer when maximum quantities of atmospheric heat are added (Moore, 1968, 1969).

At the present time, temperature patterns in the central Columbia are modified by two technological innovations: 1) the establishment of a reservoir complex above Hanford, and 2) the discharge of heated water from plutonium production reactors at Hanford. Objective evaluation of the relationship of temperature to seaward migration of juvenile chinook requires that the results of these modifications first be recognized.

The Columbia system of dams, with the exception of Grand Coulee, is a system where daily discharges are a significant fraction of reservoir capacity, which permits little effective stratification (Jaske, 1963). Lake Roosevelt above Grand Coulee, however, is sufficiently large to play an important role in regulating temperatures by cooling the river during the spring and summer and warming it during the fall and winter (Jaske and Goble, 1967; Moore, 1968, 1969). As a whole, the reservoir complex appears to have caused little change in the average mean temperature of the river, but serves to decrease its annual variance and to delay the seasonal occurrence of maximum and minimum temperatures. This means that summer temperatures in the central Columbia, at the present time, are somewhat lower and winter temperatures are somewhat higher than historically recorded, and that warmer temperatures during the early fall months are caused by a time dislocation of the entire thermal cycle (Jaske and Goble, 1967; Jaske, 1969).

It has been predicted that completion of Columbia Treaty dams in Canada will cause temperature reductions of ecological significance at Priest Rapids during the warmest month of a normal year (Jaske and Goble, 1967; Jaske, 1969). The precise extent of these reductions have yet to be realized.

Thermal additions from reactor operations are routinely evaluated by the difference in river temperatures taken above Hanford at Priest Rapids and below at Richland. However, temperatures in the central Columbia are affected not only by BTU's of effluent discharged but also by prevailing, largely seasonal temperatures (modified by the reservoir complex) and flow volumes in the river proper (which dilute the heated effluent). Temperature data for 1968 and 1969, when four reactors were in operation, are illustrated in Figure 3. In 1968, the spring rise in temperature was retarded by increased flows during June due to the sudden onset of spring runoff. In 1969, peak discharges occurred about 6 weeks earlier due to operational releases from Grand Coulee, high flows were sustained for 3 months, and retardation of the spring rise in temperature was scarcely evident. In both years, mean weekly temperatures peaked in late July, August and early September with maximum daily temperatures briefly reaching 19.1 and 19.7 °C in 1968 and 1969, respectively, at Priest Rapids and 19.7 and 20.6 °C at Richland.

The concept that summer increases in river temperature between Priest Rapids and Richland (Figure 3) are due entirely to heated reactor discharges is erroneous. Data taken during reactor shutdown, July and August 1966, show a measureable temperature increase in this section of river on the basis of heat increments from natural sources alone. This thermal addition, during two of the warmest months of 1966, was estimated to raise the river temperature 1-2 °C (Moore, 1968).

TEMPERATURE AND MIGRATION

The thermal requirements of juvenile Pacific salmon (five species of Oncorhynchus) were evaluated by Brett (1952) in classic laboratory

experiments. Preferred temperatures fell between 12-14 °C during numerous trials with fish acclimated to temperatures ranging from 5 to 24 °C. The juveniles of all species avoided temperatures above 15 °C but would penetrate this strata under feeding stimuli. Brett established the ultimate upper lethal temperatures (where 50% of the test fish died after one week of exposure) at 23.8 to 25.1 °C, depending on species. Juvenile chinooks and cohos (O. kisutch) had the greatest thermal resistance. On the basis of intensive artificial propagation, Burrows (1963) established broader limits, 10.0-15.6 °C (50-60 °F), as the range for maximum productivity of fingerling salmon.

Projection of these data to Figure 3 demonstrate that temperatures in the central Columbia are sustained well below preferred levels in March and April during the initial emergence of fry. Temperatures enter the preferred range, where conditions are presumably near optimum for all life processes, in May and June. In July and August, temperatures rise into the upper zone of thermal tolerance where normal life functions are presumably modified in reaction to higher heat regimes. Simultaneously begins the summer period of low flow. Young chinook that hatch and reside continuously in the central Columbia from April through June, potentially the maximum residence span, must normally adapt to a thermal increase exceeding 10 °C.

Limited data are available on environmental conditions during out-migration in earlier years. Mains and Smith (1964) recorded temperatures of 4.4 to 15.6 °C (40-60 °F) during the movement of juvenile chinooks from the Snake River in 1954 and 1955, and from the central Columbia in 1955. The first spring freshet in March and early April triggered the initial departures of fingerlings from the Snake, and the migration

peaked in mid-April about one month ahead of maximum daily discharges. Neither temperature nor discharges were correlated with initial fry movement on the central Columbia in 1955 (Mains and Smith, 1964), but the first major increase in flow during June initiated the movement of "fingerlings". (Spring flows were delayed in 1955 from storage of water in Grand Coulee pool.)

At Hanford, in 1969, emergent fry first appeared in shore line zones in March when midriver temperatures were low, at 3-5 °C. Population abundance peaked from mid-April to mid-June when temperatures extended from 7-15 °C and discharge volumes reached a seasonal maximum. In July, with inshore populations greatly reduced, temperatures climbed to 17-19 °C and discharge volumes dropped (Figure 3). Temperatures in the inshore feeding areas, however, were consistently elevated a few degrees above those in midstream due to reduced currents and solar radiation. In effect, by the end of July, the summer warming of the river and reduced flows tended to "flush" remaining juvenile salmon from the Hanford section. The main period of seaward migration was closely correlated with preferred temperatures of 12-14 °C and peak spring discharges.

Park's (1969) data show that the bulk of the seaward migrants originating above Hanford now pass Priest Rapids in July and August. Present environmental conditions are such that ambient temperatures during these months are near the annual maximum and discharge volumes are approaching the annual minimum (Figure 3). The ecology of these juveniles as they move towards the sea may differ substantially from that of fish originating at Hanford, which have departed earlier.

DISCUSSION

The natural outmigration of young chinooks is a phenomenon that involves successive correlation in time between emergence, favorable river temperatures and discharges, and physiological adjustment to seaward movement. In the view of Thompson (1959), salmon (i.e., O. nerka) historically pass through a chain of favorable environments connected with a definite season in time and place in such a way to provide for maximum survival rates. Young chinooks in the Columbia system must adhere to links in a similar chain in which, however, the migration timing in relation to temperature is but one phase vital to completion of their life cycle.

Juvenile chinooks leaving the central Columbia River can now be separated into two components on the basis of migration pattern. Those produced in the free-flowing Hanford environs retain their natural timing, whereas those originating above Hanford (tributaries, hatcheries and spawning channels) are delayed up to 2 months. This delay, presumably due to augmentation of the reservoir complex within the last decade, exposes the upriver juveniles to temperatures above and river flows below what they would normally encounter when passing through the Hanford area.

Park (1969) postulated that juvenile chinooks find environmental conditions in the Columbia River most favorable for survival in the spring, whereas fish passing through impounded areas during July and August encounter conditions that are far from optimum. The relationship of migration timing to seasonal changes in ambient water temperatures, and also to river discharges, thus requires closer scrutiny.

At the present time, the magnitude of temperature rise in the central Columbia is influenced not only by effluent discharges from the Hanford reactors but also by volumes of river flow, the cooling or warming provided upriver by Lake Roosevelt, and the natural heat input (during the summer) in the free-flowing section. Winter temperatures are somewhat higher and summer temperatures are somewhat lower than in earlier years (Jaske and Goble, 1967; Jaske, 1969). Moderate reduction of the annual temperature range alone would appear to favor the survival of young salmonids.

Examination of Figure 3 shows that temperatures of the mixed water (reactor plus river) at Richland adhere closely to, but persist somewhat above, that of the unmixed water entering the Hanford area. In March and April, when the first Hanford fry emerge from the gravel, river temperatures (about 3-5 °C) are well below the preferred level for young salmon. Preferred thermal levels for fish are considerably higher when they are acclimated (i.e., occur in nature) at low temperatures (Ferguson, 1955). Moreover, since juvenile salmon are considered to be intolerant of extreme low temperatures, (Brett, 1952), it is logical that additions of heat by the Hanford discharges during early spring is not harmful and may actually benefit emergent fry. This assumption is substantiated by studies at the Battelle-Northwest Laboratory, which show that slightly warmer water favors the development of eggs and survival of young chinooks in our hatchery when river temperatures are near the winter minimum (Nakatani, 1969, Coutant, 1970). Slight winter warming may also benefit production of aquatic insects, primarily midges (Tendipedidae), utilized as food by young chinooks in the central Columbia (Becker, 1970).

Records at Priest Rapids and Richland reveal that river temperatures reach preferred levels (12-14 °C) for juvenile salmon during May and June, but extend above these levels in late June. The most critical period for survival occurs in July, August and September when temperatures

enter the upper zone of thermal tolerance, above preferred but still below a 25.1 °C lethal limit. Data assembled at Hanford reveal that temperatures in the central Columbia rarely reach 22 °C, and have never been recorded as approaching 25 °C.⁽¹⁾ Although maximum summer temperatures (above 20 °C) may be considered suboptimum for the survival of juvenile salmonids, such conditions probably existed long before the advent of modern man. High summer temperatures coupled with low flows, in fact, may well have played a major evolutionary role in the development of the spring migration characteristic.

In the free-flowing Hanford section, any potential effects on young salmon resulting directly or indirectly from peak summer temperatures would theoretically operate more selectively upon juveniles originating above Hanford because of delay in their time of passage. However, the reservoir complex below Hanford also retards seaward migration (Raymond, 1968, 1969). Modification of habitat from construction of dams and creation of impoundments on the lower Columbia may, in fact, obscure the distinct migration patterns of the two populations at Hanford and tend to equalize any inherent differences in survival rates to the sea.

Present thermal levels in the central Columbia, on the basis of Brett's (1952) classic studies, do not appear to be directly lethal to young chinooks even with moderate thermal loading by discharges of reactor effluent at Hanford. This concept applies the principle that the

⁽¹⁾ Brett (1960) 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 that a "freedom" of 3 °C (5.5 °F) below the ultimate level should be provided.

upper incipient lethal temperature separates the zone of thermal tolerance, where a fish can live indefinitely without dying from excessive heat, from the zone of thermal resistance, where a fish ultimately succumbs to the heated environment (Fry, Hart, and Walker, 1946). On this basis, any actual or hypothetical effects from reactor operations alone would most likely be manifest only at subacute levels and tend to resist casual detection. This assumes that insidious effects from various combinations of other environmental hazards (trauma from bypassing dams, reduced migration rates in reservoirs, high nitrogen levels from spillway supersaturation, chronic predation, enzootic disease, dissolved industrial and agricultural toxicants, etc.) are not greatly intensified by a slight thermal increase in excess of the annual temperature cycle. Salmonid fishes, as well as all aquatic organisms, respond to the total environment and not to temperature increases alone.

LITERATURE CITED

- Becker, C. C. 1970. Feeding bionomics of juvenile chinook salmon in the central Columbia River. Northwest Science 44 (2):75-81
- Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus. J. Fish. Res. Bd. Canada 9 (6): 265-323.
- _____. 1960. Thermal requirements of fish - three decades of study, 1940-1970, p. 110-117. In: Biological Problems in Water Pollution, 2nd Seminar, 1959. Tech. Rept. W60-3, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
- Burrows, R. E. 1963. Water temperature requirements for maximum productivity of salmon, p. 29-38. In: Proc. 12th Pacific Northwest Symposium on Water Pollution Research. Water Temperature...Influences, Effects and Control. Corvallis, Ore.
- Coutant, C. C. 1969. Temperature, reproduction and behavior. Chesapeake Sci. 10 (3/4): 261-274.
- Ferguson, R. C. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish Res. Bd. Canada 15 (4): 607-624.
- Fry, F. E., J. S. Hart and K. F. Walker. 1946. Lethal temperature relations for a sample of young speckled trout (Salvelinus fontinalis). Univ. Toronto Biol. Series No. 54, Publ. Ontario Fish. Res. Lab., No. 66:5-35.
- Fulton, L. A. 1968. Spawning areas and abundance of chinook salmon (Oncorhynchus tshawytscha) in the Columbia River basin--past and present. USFWS, Spec. Sci. Rept.--Fish. No. 571. 26 p.

- Jaske, R. T. 1963. Some observations of Columbia River and reservoir behavior from Hanford experience, p. 98-100. In: Proc. 12th Pacific Northwest Symposium on Water Pollution Research. Water Temperatures... Influences, Effects and Control. Corvallis, Ore.
- _____ 1969. Columbia River temperature trends - fact and fallacy. U. S. Atomic Energy Comm. Doc. BNWL-SA-2536. Richland, Wash. 22p.
- _____ and J. B. Goeble. 1967. Effects of dam construction on temperatures of Columbia River. J. Amer. Water Works Assoc. 59:935-942.
- Mains, E. M. and J. M. Smith. 1964. The distribution, size, time and current preferences of seaward migrant chinook salmon in the Columbia and Snake Rivers. Fish. Res. Papers, Wash. State Dept. Fisheries 2: 5-43.
- Moore, A.M. 1968. Water temperatures in the Columbia River Basin July 1966 to September 1967. Open File Report, U. S. Geological Survey, Northwest Water Resources Data Center, Portland, Ore. 39 p.
- _____ 1969. Water temperatures in the Columbia River Basin October 1967 to September 1968. Ibid. 29 p.
- Nakatani, R. E. 1969. Effects of heated discharges on anadromous fishes, p. 294-317. In: Biological Aspects of Thermal Pollution (P. A. Krenkel and F. L. Parker, eds.) Vanderbilt Univ. Press. Nashville, Tenn.
- Park, D. L. 1969. Seasonal changes in downstream migration of age-group 0 chinook salmon in the upper Columbia River. Trans. Amer. Fish. Soc. 98 (2): 315-317.
- Raymond, H. L. 1968. Migration rates of yearling chinook salmon in relation to flows and impoundments in the Columbia and Snake Rivers. Trans. Amer. Fish. Soc. 97(4): 356-359.

- _____ 1969. Effect of John Day Reservoir on the migration rate of juvenile chinook salmon in the Columbia River. Ibid. 98(3): 513-514.
- Sylvester, R. O. 1959. Water quality study of Wenatchee and middle Columbia Rivers before dam construction. USFWS, Spec. Sci. Rept.-- Fish. No. 290 116 p.
- Thompson, W. F. 1959. An approach to population dynamics of the Pacific red salmon. Trans. Amer. Fish. Soc. 88:206-209.
- U. S. Army Corps of Engineers. 1968. Annual fish passage report, Oregon and Washington, 1968. U. S. Army Engineer Districts, Portland and Walla Walla. (NPD PL-79) 15 p. (+ 79 tables, 27 plates).
- Watson, D. G. 1968. Chinook salmon spawning near Hanford - 1967, p. 9.15-9.16. In: Pacific Northwest Lab., Ann. Rept. for 1967. Vol. I. Biological Sciences. Battelle-Northwest, Richland, Wash.
- _____ 1969. Chinook salmon spawning near Hanford - 1968, p. 2.31-2.32. In: Pacific Northwest Lab., Ann. Rept. for 1968. Vol. I Life Sciences, Part 2 Ecological Sciences. Battelle-Northwest, Richland, Wash.

FIGURE 1. The Hanford Environs of the Central Columbia River

FIGURE 2. Length Parameters (mean, standard deviation, and range) of Juvenile Chinook Salmon Taken in the Hanford Environs, March-July, 1969

FIGURE 3. Mean Weekly Water Temperatures in the Columbia River at Priest Rapids, February-November, 1968-1969. (Preferred temperature of 12-14 °C for juvenile salmon taken from Brett, p952.)

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