Anadromous Salmonids of the Hanford Reach, Columbia River: 1984 Status

C. D. Becker

September 1985

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SUMMARY

The Hanford Reach, a regulated but flowing section of the Columbia River, supports spawning populations of fall chinook salmon (Oncorhynchus tshawytscha) and steelhead (Salmo gairdneri). It also serves as a migration route for upriver runs of chinook, coho (O. kisutch) and sockeye (O. nerka) salmon, and of steelhead. Environmental studies conducted in association with activities on the Hanford Site provide a basis for assessing present ecological conditions in the Hanford Reach. Spawning populations of fall chinook salmon at Hanford increased dramatically after 1960, when Priest Rapids Dam was completed, and have remained relatively stable since 1969. Numbers of adult salmonids that traverse the Hanford Reach to upriver spawning areas have varied in recent years. Generally, upriver runs of spring, summer, and fall chinook salmon have been depressed, but the fall run has been increasing since 1980. Runs of coho salmon have fallen concomitant with cutbacks in hatchery production, particularly since 1976. Runs of sockeye salmon declined after 1968 to about 40,000 fish annually, but surged upward in 1983 and 1984. An extensive hatchery program has helped maintain upriver runs of steelhead, which also surged upward in 1983 and 1984.

Habitat modification represents the greatest threat to sustained production of fall chinook salmon in the Hanford Reach. Operations on and near the Hanford Site, such as various research and development work for the U.S. Department of Energy, releases of small amounts of radioactivity from onsite operations to river and groundwater, and operation of a steam electric plant, can have negligible effects on salmonids and other aquatic resources. Possible activities with potential for future impacts include development of a multi-unit power plant complex at Hanford, construction of a low-head hydroelectric dam above Richland, flow fluctuations from peaking power generation at Priest Rapids Dam, irrigation and reductions of instream flows, and dredging and commercial navigation above Hanford. If reproducing populations of fall chinook salmon and steelhead are to survive in the mid-Columbia River, the Hanford Reach must remain flowing, undeveloped for navigation, and with unimpaired water quality.

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1.0 INTRODUCTION

The Hanford Reach is the last unimpounded section of the mainstem Columbia River above Bonneville Dam. For this reason, the Hanford Reach represents "remnant habitat," a survivor of the river's past. Although regulated by operation of Priest Rapids Dam, the Hanford Reach remains flowing and retains many seasonal flow characteristics. The Hanford Reach contributes substantially to upriver runs of fall chinook salmon (Oncorhynchus tshawytscha, Figure 1.1) in the Columbia River. It is also used for spawning by steelhead (Salmo gairdneri) and by other species of anadromous fish as an upstream and downstream migration route.

The Hanford Reach lies primarily within or adjacent to the Hanford Site, 1,476 square kilometers in southeastern Washington that have been maintained since 1943 by the Federal government. A number of energy, defense, and other programs that support national needs are conducted at Hanford. Environmental requirements of salmonids and other aquatic resources of the Hanford Reach are considered in the planning and operational phases of these programs.

FIGURE 1.1. Chinook Salmon, Oncorhynchus tshawytscha

1.1 REPORT PERSPECTIVE

The objectives of this report are to describe the anadromous salmonid resources of the Hanford Reach, and to evaluate the effect of human activities on long-term maintenance of these resources.

The report is organized into three sections. The first section describes existing ecological features of the Hanford Reach, with emphasis on those features that influence the abundance of anadromous fish. The second section describes populations of fall chinook salmon, coho salmon (O. kisutch), sockeye salmon (O. nerka), and steelhead that use or pass through the Hanford Reach. The third section reviews current activities and possible future actions with potential for adverse effects on anadromous salmonid populations of the Hanford Reach.

1.2 HISTORICAL PERSPECTIVE

Due to heavy exploitation, the sizes of anadromous salmon runs to the Columbia River were greatly reduced prior to the construction of Bonneville Dam near the river outlet in 1938 (Smith 1979; Seufert 1980; Chapman et al. 1982). Since then, development of hydroelectric power and water storage projects throughout the Columbia River system has reduced the spawning and rearing habitat for anadromous salmonids from 422,688 to 187,205 square kilometers (Salo and Stober 1977). The creation of large pools behind the series of dams represents loss of spawning areas, which has contributed directly to the reduction of anadromous salmonid stocks (Brockson et al. 1982). The resource has never recovered its natural reproductive potential.

Other impacts on salmon and steelhead are associated with Columbia River dams and their operation. These impacts are listed below.

- mortality of juvenile outmigrants (smolts) in power-generating turbines (Cramer and Olliger 1964; Ebel 1977; Turbak et al. 1981)
- mortality from nitrogen supersaturation (Ebel 1969; Meekin and Allen 1974; Ebel et al. 1975; Weitkamp and Katz 1980)
- blockage of upstream migrations, particularly at Grand Coulee Dam (Fulton 1968, 1970)

- predation (Thompson 1959; Brown and Moyle 1981; Gray et al. 1984)
- delay in timing adult and smolt migrations (French and Wahle 1966; Raymond 1968, 1969, 1979; Collins et al. 1975; Bentley and Raymond 1976; Monan and Liscom 1976)
- transmission of infectious disease agents in fish passage facilities (Fujihara and Hungate 1971; Becker and Fujihara 1978).

In addition, dams and their reservoirs alter many different physical characteristics of a river (Baxter 1977; Baxter and Claude 1980; Brockson et al. 1982; Ward and Stanford 1979).

Assessment of the salmonid stocks today indicates that the effects have increased with the addition of each new dam, while the resiliency of the various species has steadily declined (Salo and Stober 1977). Reduction in stock sizes has been accompanied by strong, even increased, fishing pressure (Chapman et al. 1982).

Beginning with the development of fish passage facilities at dams, over 35 years of effort have been extended to prevent declines in anadromous salmon runs in the Columbia River system (Netboy 1974). Subsequent mitigation efforts have included an extensive hatchery program supported by the Federal government and the states of Washington, Oregon, and Idaho (Armacost 1979; Kaczynski and Moos 1979). As a result, unique up-river stocks of naturally spawning salmonids have been replaced through mass production of fish with common life histories, morphology and genetic characteristics. The production of hatchery and wild salmonids in the Columbia River system is now about 50:50, and it is important that the remaining wild stocks be conserved (Salo and Stober 1977).

Populations of anadromous salmonids in the Columbia River above the Bonneville pool today are largely dependent on hatchery production, and their status remains tenuous. Since the Hanford Reach provides the only natural spawning area for anadromous salmonids in the mainstem Columbia River, adverse impacts must be avoided. Existing environmental regulations make attainment of this goal possible.

2.0 THE HANFORD REACH OF THE COLUMBIA RIVER

The abiotic and biotic environment that sustains anadromous salmonids in the mid-Columbia River is now well characterized, largely because of Federal regulatory requirements (Greenwood et al. 1979). The National Environmental Policy Act (NEPA) of 1969, for example, stipulates that all environmental consequences of Federal actions must be considered and evaluated. As a result, information on the aquatic ecology of the Hanford Reach is now extensive (e.g., U.S. ERDA 1975; U.S. NRC 1975; Page et al. 1976; Gray et al. 1976; WPPSS 1977; Gray and Page 1977, 1978, 1979a, 1979b; Beak Consultants, Inc. 1980; Fickeisen et al. 1980; Neitzel et al. 1982a, 1982b; Page et al. 1982; Puget Power 1982; Rickard et al. 1982; U.S. DOE 1982).

2.1 GENERAL DESCRIPTION

The Hanford Reach of the Columbia River extends 94 kilometers from Priest Rapids Dam at River Kilometer (RKM) 639 downstream to the city of Richland (RKM 545) in southcentral Washington. The Hanford Reach runs through the northern part of the Hanford Site and along its eastern border (Figure 2.1). The Snake River and Yakima River join the Columbia River below Richland, and the combined flows enter Lake Wallula behind McNary Dam.

The Columbia River drains about 249,000 square kilometers (96,000 square miles) above Hanford. Seven dams extend from the Canadian border downstream to the Hanford Reach (Figure 2.2), and other dams are located in Canada. The dams were built primarily to provide hydroelectric power, water for irrigation, and flood control.

The Hanford Reach passes through a semi-arid plateau at about 130 meters (426 feet) above mean sea level. Summer maximum temperatures have varied from 37.8° to 46.1°C (100° to 115°F), while winter minima vary from -47° to -5.6°C (-27° to +22°F) (Stone et al. 1983). Hanford lies in the rain shadow of the Cascade Mountains, and annual precipitation averages 15.9 centimeters (6.25 inches). The wettest period, through November, December and January, provides 44% of the total annual precipitation; the driest period, July, August and September, provides only 12%.

FIGURE 2.1. Hanford Reach of the Mid-Columbia River in Washington State (Only dams directly above and below Hanford are shown)

FIGURE 2.2. Schematic View of Distance and Elevation of the Hanford Reach in Relation to Mainstem Columbia River Dams (after U.S. ACOE 1976)

2.2 PHYSICAL CHARACTERISTICS

The physical characteristics of the Hanford Reach are those of a regulated but flowing river that carries relatively large amounts of water from an extensive drainage basin.

2.2.1 River Flows

River flows in the Hanford Reach vary with seasonal runoff and power-peaking operations at Priest Rapids Dam (Whelan and Newbill 1983). The average daily discharge may range from 1,020 cubic meters per second (36,000 cubic feet per second), the minimum legal flow set by the Federal Energy Regulatory Commission, to as much as 4,530 cubic meters per second (160,000 cubic feet per second). Peak seasonal flows are due to melting of winter snowpack during June and July, augmented by local rainfall. Average daily discharges of 4350 cubic meters per second to as much as 18,418 cubic meters per second (650,000 cubic feet per second) have been recorded during spring runoff (U.S. ERDA 1975). The 55-year average daily flow rate for the Hanford Reach is 3,422 cubic meters per second (120,800 cubic feet per second). However, flows average around 2,266 cubic meters per second (80,000 cubic feet per second) or less during late summer and early fall (U.S. ERDA 1975).

Today, flow extremes are greatly moderated by the reservoir complex above Hanford, particularly during the annual spring runoff. The mean monthly volume of water passing Priest Rapids Dam from March through July, 1960 through 1970, was 61% of the mean annual volume, but this decreased to 53% from 1971 through 1979. Also, the high June flows that formerly accounted for 21% of the annual volume have decreased to 13%. The reservoir complex, therefore, has reduced the historical annual discharge pattern so that a constant flow regime is being approached (Dewaard 1981).

The width and depth of the Columbia River at Hanford vary with location and discharge volume. Width extends from 365 to 548 meters (1,200 to 1,800 feet). Midchannel depth varies from 9 to 14 meters (30 to 46 feet). River flows fluctuate daily but the range is variable (Figure 2.3). River elevation may vary as much as 3 meters (10 feet) daily in the upper part of the Hanford Reach and 1.5 meters (5 feet) further downstream when power generation at

FIGURE 2.3. Columbia River Daily Flow Patterns (spill plus turbine discharge) at Priest Rapids Dam, May Through August 1976-1977 (daily and weekly variations in discharge are due to hydroelectric generation in response to power demand; after Becker et al. 1981)

Priest Rapids Dam responds to changed consumer demand (U.S. ERDA 1975). These fluctuations cause frequent, short-term flooding and dewatering of the shoreline.

Current velocities vary from less than 0.9 to over 3.35 meters per second (3 to 11 feet per second), depending on flow stage and location. Maximum surface velocities occur near midstream during the spring spate (U.S. ERDA 1975).

2.2.2 Topography

The upper section of the Hanford Reach, from Priest Rapids to Coyote Rapids (RKM 616), is a deep, U-shaped channel with uniform features. From this point downstream to the city of Richland, the channel of the Hanford Reach is

braided around islands, submerged rock ledges and gravel bars, causing repeated pooling and channeling (U.S. ERDA 1975). The river bed typically consists of sand, gravel, cobble and large rock up to 20 centimeters (8 inches) in diameter. Sections of the stream bed include Ringold formation substrate, a conglomerate of clay, sand, gravel, and rock. Much of the shoreline is steep and includes a narrow cobble strip. Twenty-one islands are present, with cobble and/or sandy shorelines (Fickeisen et al. 1980).

The shoreline and islands in the Hanford Reach vary in expanse according to their slopes and river stages. Large cobblestone beaches occur on very gentle slopes or flat islands. The cobblestone areas are subject to frequent water-level changes, and are kept free of overburden by currents. The vegetation of the cobblestone areas consists mainly of hardy, water-tolerant perennial forbs and grasses that grow profusely during the summer low-flow period. Additionally, four large slough areas with shallow basins and deposits of silt support a rich assembly of riparian forbs and grasses, including cattails (Typha latifolia), reed canary grass (Phalaris arundinacea), and spikerush (Eleocharis palustris). Sandbar willow (Salix exigua) grows in scattered patches along the fringes of the high-water mark.

The cobblestone substrate and associated riparian plant communities of the Hanford Reach are unique in the Columbia River ecosystem (Fickeisen et al. 1980). The physical characteristics and shoreline communities of impoundments above and below Hanford are considerably different.

2.2.3 Water Quality

The Washington State Department of Ecology (WSDOE) has designated the Hanford Reach as Class A, or excellent, for water quality requirements. This designation requires that industrial uses of the river be compatible with all other uses of the water, including drinking water, recreation and wildlife (WSDOE 1977). State standards are identified in Table 2.1.

The Columbia River Basin of eastern Washington has been developed primarily for agriculture. Water quality might be impaired by return flows of irrigation water containing fertilizers, insecticides and herbicides, by

TABLE 2.1. Water Quality Standards for the Hanford Reach of the Columbia River

Parameter	Permissible Levels
Fecal coliform bacteria	1. <100 organisms/100 mL (median) 2. <10% of samples may exceed 20 organisms/100 mL
Dissolved oxygen	>8 mg/L
Temperature	1. <20C (68F) due to human activity 2. Increases not to exceed $34/(T+9)$ where T = highest existing temperature in C outside of mixing zone.
pH	1. 6.5 to 8.5 range 2. <0.5 unit induced variation
Turbidity	<5 NTU (Nephelometric Turbidity Units - standard candle) over background turbidity
Toxic, radioactive, or deleterious material	Concentration shall be below those of public health significance, or which cause acute or chronic conditions to aquatic biota, or which may adversely affect water use.
Aesthetic value	Shall not be impaired by the presence of materials and their effects, excluding those of natural origin, which offend the senses of sight, touch or taste.

Source: After Washington State Department of Ecology 1977.

industrial wastes and domestic sewage discharges, and by silt from soil erosion. Water quality in Basin streams was examined from 1951 to 1953 (Robeck et al. 1954) and from 1954 to 1957 (Sylvester 1959). The data revealed no significant change in water quality, and indicated that future impoundments formed in the main Columbia River would not alter chemical and physical parameters sufficiently to harm aquatic life (Sylvester 1959). This conclusion proved to be essentially correct. Quality of water in the mid-Columbia River remains high today (WSDOE 1977).

The cities of Richland and Pasco obtain most of their municipal water, and the city of Kennewick obtains about 40% of its total, from the Columbia River downstream from Hanford. The combined population for the Tri-Cities is near 90,000 (Price et al. 1984).

Water quality has been routinely monitored at Hanford for many years by the U.S. Geological Survey, and by a site surveillance group on the Hanford

Site. Present conditions are represented by data taken from October 1977 to October 1980 (Table 2.2). Generally, dissolved solids range from 73 to 120 mg/L, and hardness varies from 65 to 85 mg/L. Dissolved oxygen (DO) levels range from about 8 to 13 mg/L, average 11.0 mg/L, and are usually near saturation (U.S. DOE 1982). Coliform bacteria range from 4 to 75 per 100 milliliters

TABLE 2.2. Quality Characteristics of Columbia River Water at Vernita Bridge, Above the Hanford Reach, October 1977 to October 1980

Analysis	Units of Measure	Columbia River Ambient Conditions	
		Average	Maximum
Calcium, as Ca	mg/L	19.7	24.0
Magnesium, as Mg	mg/L	4.3	5.7
Sodium, as Na	mg/L	2.3	3.1
Potassium, as K	mg/L	0.8	1.1
Bicarbonate, as HCO ₃	mg/L	67.5	82.0
Sulfate, as SO ₄	mg/L	12.8	19.0
Chloride, as Cl	mg/L	1.5	5.4
Silica, as SiO ₂	mg/L	4.8	6.6
Total alkalinity, as CaCO ₃	mg/L	55.3	67.0
Hardness, as CaCO ₃	mg/L	66.9	82.0
Non-carbonate hardness, as CaCO ₃	mg/L	11.4	22.0
Specific conductance	umho/cm	135.0	170.0
pH	units	--	8.8
Dissolved solids	mg/L	81.5	109.0
Color	(Pt-Co Units)	10.0	15.0
Suspended solids	mg/L	3.7	24.0
Turbidity	NTU	1.7	4.9
Fecal coliform bacteria	No./100 mL	2.0	13.0
Dissolved oxygen	mg/L	11.9	15.8
Total cadmium, as Cd	mg/L	1.3	3.0
Total chromium, as Cr	mg/L	3.0	20.0
Total copper, as Cu	mg/L	10.3	28.0
Total iron, as Fe	mg/L	117.3	290.0
Total lead, as Pb	mg/L	16.9	73.0
Total mercury, as Hg	mg/L	0.17	1.0
Total zinc, as Zn	mg/L	38.2	90.0
Ammonia nitrogen, as N	mg/L	0.01	0.1
Nitrate nitrogen, as N	mg/L	0.01	0.14
Ortho-phosphate, as P	mg/L	0.01	0.04
Total phosphorus, as P	mg/L	0.03	0.11
Total residual chlorine	mg/L	0.0	0.0
Oil and grease	mg/L	0.0	0.0

Source: After Puget Power 1982.

of water below Priest Rapids Dam and average about 30 per 100 milliliters. Turbidity in the Hanford Reach is generally less than 5 Jackson Turbidity Units. The river water is alkaline at pH 8 to 8.5.

Activities on the Hanford Site conform to federal and state standards designed to protect environmental quality. Each waste water discharge from various operations at Hanford has an applicable EPA permit. Water quality measurements are taken above and below Hanford to detect any affects attributable to onsite work, and to determine compliance with Class A designation requirements. Sampling in 1982 and 1983 indicated no substantial deterioration in water quality from activities at Hanford (Sula et al. 1983; Price et al. 1984). However, state water quality standards for fecal coliform bacteria, pH, and low dissolved oxygen were sometimes exceeded in river water above and in the Hanford Reach (Figure 2.4). Thus, exogenous factors can impair onsite water quality.

2.2.4 Suspended Materials

Concentrations of suspended sediment vary widely in the Hanford Reach because inputs from upriver tributaries vary seasonally (U.S. ERDA 1975). Columbia River reservoirs intercept much of the suspended material during low river flows, but some of the deposits are resuspended and washed downstream during high flows (Whetten et al. 1969; Robertson and Fix 1977).

Suspended material in river water ranges from 300 g/L in November to 35,000 g/L in April, or nearly a hundredfold variation annually (Wildung et al. 1972). The portion of suspended particles <0.5 microns diameter exceeds 50% during the spring spate, reflecting redistribution and downstream passage of fine materials. At other seasons, suspended particles from 2.0 to 5.3 microns in diameter predominate (>70%). The total carbon content of suspended material is least in the spring and greatest in the fall, which probably reflects the increased seasonal production of phytoplankton (Wildung et al. 1972; Neitzel et al. 1982a).

Deposition of water-borne materials in the Hanford Reach is limited because of strong currents. Therefore, the gravel composition of the stream bed probably remains similar to that existing centuries ago.

FIGURE 2.4. Results of Monitoring the Quality of Columbia River Water at Hanford, 1982 (after Sula et al. 1982)

Windblown sediments and erosion contribute fine materials to exposed islands, gravel bars and shorelines in the Hanford Reach. The annual spring spate, now moderated by reservoir storage and controlled release at dams, normally removes fine particulates from areas exposed during the rest of the year. However, the reduction in magnitude of the annual spring runoff during 1971-1979 has enhanced the development of shoreline and island vegetation. The high runoff of earlier years scoured many gravel and cobblestone areas free of soil and vegetation. The regulated runoff of today has lost much of its scouring action, and successional stages of vegetation are invading formerly littoral areas (Dewaard 1981).

2.2.5 Water Temperatures

Columbia River temperatures range from a maximum near 20°C in August to a minimum near 2°C in late January or February (Figure 2.5). Temperatures have been monitored at Vernita Bridge and Richland, representing the upper and lower boundaries of the Hanford Reach, from 1961 to 1980 (Whelan and Newbill 1983). Monthly average temperatures at these locations are nearly identical with slight differences related to season (Puget Power 1982).

The unimpounded river at Hanford is warmed about 0.5° to 0.75°C during August and September, primarily by insolation (Sula et al. 1983). Additionally, fluctuations in discharges at Priest Rapids Dam can impart a daily temperature variation of about 1.2°C in the spring and summer and 0.6°C in fall and winter to water entering the Hanford Reach (Puget Power 1982). Cooling water discharges from the N Reactor and Hanford Generating Plant (HGP) at RKM 611 also raise the water temperature slightly (WPPSS 1978).

Historically, the most significant change in temperature regime of the Columbia River is due to Lake Roosevelt, behind Grand Coulee Dam (RKM 961), and its massive storage capacity of 5.2 million acre feet. Other river-run reservoirs above Hanford, being much smaller, have produced no significant change in annual average water temperature (Jaske and Goebel 1967). Storage and release of water from Lake Roosevelt since 1941 have delayed the timing of peak summer temperatures in downstream sections of the Columbia River. This delay is about

FIGURE 2.5. Mean, Maximum and Minimum Daily Columbia River Water Temperatures at Priest Rapids Dam, 1960-1977 (after U.S. DOE 1982)

30 days at Rock Island Dam (RKM 729) and is reflected, to a lesser extent, as far downstream as Bonneville Dam near the river's outlet (Jaske and Synoground 1970).

Other mainstem reservoirs have little effect on temperature timing because daily discharges are a significant fraction of reservoir capacity (Jaske and Goebel 1967). The reservoir complex tends to moderate high and low temperature extremes. Also, the unimpounded Columbia River responds more rapidly than impounded areas to temperature changes from weather and industrial sources. Therefore, summer warming and winter cooling occur more rapidly in the Hanford Reach (Jaske and Synoground 1970).

3.0 SALMONID POPULATIONS

The anadromous salmonids using the Hanford Reach either for spawning, rearing of young, and downstream and upstream migration are chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), sockeye salmon (O. nerka), and steelhead (Salmo gairdneri). The largest spawning group at Hanford is the fall chinook salmon run. Anadromous salmonids share the Hanford ecosystem with nearly forty other native and introduced fish species (Gray and Dauble 1977).

Seaward migration of juvenile fish, feeding and growth in the ocean, and return to the river of origin as mature adults are typical of all anadromous salmonids (Figure 3.1). However, the timing of downstream and upstream migration, and the duration of stay in fresh water and the ocean, vary among species.

Because of differences in life cycles, some salmonids are present in the Hanford Reach each month, either as adult upstream migrants or spawners, or as juvenile residents or downstream migrants (smolts) (Figure 3.2). Upstream migration of adult salmonids at Hanford varies seasonally:

Chinook Salmon ^(a)	
spring-run	March to mid-June
summer-run	Mid-June to mid-August
fall-run	Mid-August to November
Coho Salmon	Late August to November
Sockeye Salmon	July to August
Steelhead	August to November maximum, but present all year.

-
- (a) Separation of the chinook salmon migration to the Columbia River into spring, summer, and fall runs is a man-induced artifact (Chapman et al. 1982). The original run was represented by a bell-shaped curve from April through September, with a peak generally between June 10 and 20. The early river fishery severely reduced the main summer run, leaving the spring and fall runs dominant, those runs that received some protection (Thompson 1951; Van Hying 1973). The early fishery literally took the heart out of the run (Chapman et al. 1982).

FIGURE 3.1. Life Cycle of Anadromous Fall Chinook Salmon Associated with the Hanford Reach

FIGURE 3.2. Seasonal Distribution of Anadromous Salmonids Using the Hanford Reach

The characteristic timing of adult return migrations (ODFW and WDF 1983) and a strong homing instinct (Groves et al. 1968; Banks 1969) allow salmon to be separated into management units called runs. A single species in a large river system may have several distinct runs. In the Columbia River, spring, summer and fall runs of chinook salmon all penetrate 545 kilometers upstream to the Hanford Reach and beyond. Fall chinook salmon associated with Hanford spawn either throughout the Hanford Reach, at Vernita Bar below Priest Rapids Dam, or above Priest Rapids Dam.

The stocks of fall chinook salmon using the mid-Columbia and Snake rivers today appear to be genetically distinct (Utter et al. 1982). However, there is no clear genetic identity to the fall chinook salmon spawning in the Hanford Reach. According to F. M. Utter (National Marine Fisheries Service, Seattle, Washington), this finding is consistent with recent genetic isolation and/or sufficient gene exchange to prevent establishment of distinct protein coding genes. The lack of clear genetic identity may be attributed to the recent origin of the Hanford stock from fish misplaced by construction of mid-Columbia River dams, the rearing and release of juvenile fish at Priest Rapids Dam, and the release of juvenile fish from other stocks in the Hanford Reach.

The altered habitat represented by reservoirs between the Hanford Reach and the Pacific Ocean may have an effect on upriver populations of salmonids. Each year, substantial numbers of returning adults cannot be accounted for between Bonneville Dam and other dams on the lower Columbia River (Fredd 1966). Reservoirs are instrumental in delayed ocean entry for juvenile outmigrants, but they also provide an alternate type of freshwater rearing habitat. Recent studies (1980 to 1982) indicate that juvenile fall chinook salmon are very abundant in McNary Reservoir below the Hanford Reach after their spring emergence, and that they grow rapidly through June, while using terrestrial insects for the main portion of their diet. While competition for food and space with juvenile resident fish is minimal, predation by smallmouth bass (Micropterus dolomieu) may be substantial in some years (information provided by W. R. Nelson, USFWS, National Fishery Research Center, Cook, Washington). Whether mainstem reservoirs represent a net plus or minus for outmigrants remains unresolved.

3.1 CHINOOK SALMON

This section describes ecological characteristics of chinook salmon runs associated with the Hanford Reach. The following features are discussed: fall-run adults, spring-run and summer-run adults, juvenile production, outmigration and Hanford releases.

3.1.1 Fall-Run Adults

Historically, the main spawning areas for fall chinook salmon were tributaries of the lower Columbia River, the mainstem Columbia River, and the Snake River (Fulton 1968). Fall chinook spawning below Bonneville Dam or in tributaries of the Bonneville pool are called "tules." Those passing above the Bonneville pool and its hatchery system are called "upriver wilds" or "brights" (Horner and Bjornn 1979; ODFW and WDF 1983).

Runs of fall chinook salmon entering the Columbia River today reflect reduced population levels. From 1969 to 1978, runs ascending fishways at Bonneville Dam near the river outlet numbered about 200,000 fish annually. Nearly half of these were harvested by the Indian fishery between Bonneville and McNary Dams (Fickeisen et al. 1980). Numbers passing McNary Dam (RKM 470) averaged 71,000 fish from 1968 to 1978, but only 45,000 fish from 1978 to 1983 (Table 3.1). Above McNary Dam, the upriver run of fall chinook salmon diverts to different areas. Some enter the Snake or Yakima rivers, some spawn in the Hanford Reach, and some pass up the Columbia River over Priest Rapids Dam. Numbers of fall chinook entering the Snake River and over Ice Harbor Dam declined from 24,000 to 1,700 fish from 1968 to 1978, and averaged only 2,200 fish (range 1,600 to 3,500) from 1978 to 1983 (Table 3.1). The number passing over Priest Rapids Dam ranged between 5,400 and 16,000 from 1968 to 1982 (Tables 3.1 and 3.2). The number spawning in the mid-Columbia area (e.g., between McNary, Ice Harbor and Priest Rapids dams) is usually 25,000 to 70,000 fish.

Fall chinook salmon pass through the Hanford Reach to limited spawning areas above Priest Rapids Dam from the middle of August to November. Some spawning occurs in the tailraces of Rocky Reach and Wanapum dams (Horner and Bjornn 1979). However, the largest segment of the upriver run spawns in the Hanford area from October through November, peaking in late October and early November (Watson 1976; Chapman et al. 1983).

Adult salmonids characteristically travel parallel to the banks during upstream migrations in large rivers. In the Hanford Reach, adult chinook salmon usually migrate close to the north or east bank (Franklin County side) (Becker 1973a; Coutant 1973). The migration path is not consistent. Fish may

TABLE 3.1. Annual Estimates of Adult^(a) Fall Chinook Salmon
in the Mid-Columbia River Since 1960

Year	Dam Count			Yakima River Escapement	Interdam Population (estimate)
	McNary	Ice Harbor	Priest Rapids		
1960	47,337		10,687		
1961	41,200		11,108	87	
1962	44,116	30,049	10,082	15	3,970
1963	57,363	13,537	17,563	324	25,936
1964	58,593	11,09	14,760	120	32,616
1965	76,326	12,354	21,149	198	42,625
1966	75,119	15,018	18,821	405	40,875
1967	73,087	19,022	12,375	531	41,159
1968	72,757	24,377	11,031	186	37,163
1969	79,375	17,507	12,367	2,487	47,014
1970	61,554	10,385	16,372	1,830	32,967
1971	69,718	11,004	10,591	2,090	46,033
1972	49,307	9,436	5,782	1,480	32,611
1973	73,253	8,353	10,083	2,200	52,617
1974	62,009	2,814	7,618	1,860	49,717
1975	68,719	2,558	13,365	2,060	50,736
1976	87,991	1,474	10,774	2,640	73,103
1977	84,370	1,756	6,856	2,531	73,227
1978	44,145	1,609	6,523	1,324	34,689
1979	49,961	2,074	7,727	1,499	38,661
1980	38,910	1,744	8,441	1,167	27,557
1981	33,148	2,111	5,438		
1982	57,299	3,519	13,110		
1983	73,801	2,735	10,668		
1984	110,275	2,445	12,695		

(a) Data are total counts, and include precocious male "jacks."

Sources: Dam counts from U.S. ACOE 1983 (McNary and Ice Harbor), and Grant County Public Utility District No. 2 (Priest Rapids); see Table 3.2. Yakima River escapement from Watson, 1970; other data supplied by D. G. Watson, Pacific Northwest Laboratory.

TABLE 3.2. Counts of Adult Salmonids at the Fishway of Priest Rapids Dam

Year	Fall Chinook (a)	Spring Chinook (a)	Summer Chinook (a)	Coho (a)	Sockeye	Steelhead	Total Salmonids
1960	10,687	8,534	20,852	58	58,201	7,827	106,159
1961	11,108	8,385	18,245	88	19,793	8,559	66,178
1962	10,082	7,993	20,824	601	28,575	9,324	77,399
1963	17,563	7,597	18,511	29	64,883	9,344	177,927
1964	14,760	9,814	26,489	60	79,072	6,009	136,204
1965	21,149	5,718	24,936	448	48,340	9,041	109,632
1966	18,821	13,358	29,736	11,903	170,071	13,006	256,896
1967	12,375	10,307	26,256	8,879	123,786	7,354	188,957
1968	11,031	10,739	26,544	13,212	108,308	10,524	180,358
1969	12,367	7,142	21,277	1,351	39,240	6,650	88,027
1970	16,372	5,789	21,641	4,971	77,419	5,558	131,750
1971	10,591	5,086	20,481	7,738	73,837	11,102	128,835
1972	5,782	8,775	18,083	5,225	44,927	6,429	89,221
1973	10,083	9,967	14,351	1,576	54,480	6,999	97,456
1974	7,618	11,127	13,703	1,781	35,434	3,089	72,752
1975	13,365	8,170	22,205	2,193	55,210	2,462	103,605
1976	10,774	13,306	19,344	2,275	32,810	9,248	87,757
1977	6,856	21,217	19,605	370	95,413	9,803	153,264
1978	6,523	21,427	22,580	597	17,529	4,545	73,201
1979	7,727	7,750	22,689	311	45,662	8,409	92,548
1980	8,441	11,136	18,708	318	52,039	8,524	99,166
1981	5,438	14,787	12,381	428	51,461	9,117	93,612
1982	13,110	9,088	9,883	1,810	40,461	11,119	85,471
1983	10,668	10,780	9,573	502	90,008	31,882	153,413
1984	12,695	12,662	17,372	172	114,766	26,209	183,876

(a) Chinook and coho salmon data include precocious male "jacks."

Sources: After Olson 1981; recent data supplied by M. B. Dell, Grant County Public Utility District No. 2, Ephrata, Washington.

cross from one bank to another near obstructions or in high turbulence areas along the shoreline, which become prominent during low flow periods.

The numbers of fall chinook that spawn in the Hanford Reach increased markedly after 1960, following the construction of Priest Rapids Dam. The initial increase was probably due to the barrier created by the dam and to the upstream translocation of fish whose spawning grounds were inundated by dams

below Hanford (Watson 1970). Subsequent levels of spawners were influenced, to an undetermined extent, by smolts reared artificially and released below Priest Rapids Dam.

Annual surveys of fall chinook salmon redds have been made at Hanford since 1947 (Figure 3.3). The number of redds increased dramatically from about 300 in 1960 to 4,500 in 1969. A general decline occurred from 1970 to 1980, but the number of redds then increased to peak at 7,310 in 1984. Redd counts are limited for estimating the total number of spawners in any given year. Their main value is in establishing long-term trends that show stability, increases or decreases in the annual number of spawners. Post-dam counts of

FIGURE 3.3. Relative Abundance of Fall Chinook Salmon Redds in the Hanford Reach, 1947 through 1981 (after Watson 1970, 1976; recent data supplied by D. G. Watson, Pacific Northwest Laboratory)

spawning fall chinook at Vernita Bar show a twelvefold increase over pre-dam counts, and about a fivefold increase for the Hanford Reach (Chapman et al. 1983).

Redd counts from aircraft over large rivers are affected by stream discharge and any other condition that alters visibility. Counts made at low discharges, where more redds are visible, are usually higher than counts made at high discharges. Vernita Bar counts since 1975 at flows above 36,000 cubic feet per second reveal an average of only 34% (range 12.8% to 51.4%) of the redds counted at flows near 36,000 cubic feet per second (Chapman et al. 1983).

FIGURE 3.4. Major Spawning Areas Used by Fall Chinook Salmon in the Hanford Reach (after Watson 1976)

Even at low flows, a number of redds are always deposited each year at depths below the limit of detection from the surface or above.

Several areas at Hanford are used by fall chinook salmon to spawn (Figure 3.4). Redds are counted annually in defined spawning areas. Since 1967, most spawning has occurred at Vernita Bar (36% average contribution), which lies below Priest Rapids Dam, and at RKM 600-605 above White Bluffs (35% average contribution) (Table 3.3).

Conceivably, some areas suitable for spawning in the Hanford Reach are not used because sexually mature adults tend to concentrate upstream in the vicinity of Vernita Bar. If use of other areas could be enhanced, a larger spawning population of fall chinook might be accommodated. Present concentrations of spawners near Vernita Bar may lead to some superimposition of redds. Such superimposition may result, not from too many spawners at any one time, but rather from the long spawning season. Redds constructed early become vulnerable to overlap later when the females that arrive first die and can no longer defend their redds (Chapman et al. 1983). Females spawning in late October are unlikely to survive to mid-November, the late part of the spawning season, making early redds vulnerable.

Spawning of fall chinook salmon at Vernita Bar usually begins during the second half of October, although fish appear at the site earlier. Under ambient river temperature conditions, about 50% of the eggs deposited in redds at Vernita Bar hatch during the first half of December (Chapman et al. 1983). While fry emerge from the gravel primarily in April and May (Chapman et al. 1983), emergence may begin as early as March. The general timing of spawning, hatching, and emergence is probably similar throughout the Hanford Reach. Peak numbers of 0-age fry usually occur in shoreline areas at Hanford from April through May (Mains and Smith 1964; Gray and Page 1979a, 1979b).

Reduced flows can force spawning fish from redds started at higher flows. However, redds dug by fall chinook salmon at Vernita Bar can be completed in less than 24 hours and, with a diel cycle of water level fluctuations, fish displaced at low flow can complete a redd during the next high-flow period

TABLE 3.3. Distribution of Fall Chinook Salmon Redds in the Hanford Reach by Major Spawning Area

Year	Number of Redds by Spawning Area						Other Redds	Total Redds
	RKM 570 (Ringold)	RKM 587 to 592	RKM 597 (White Bluffs)	RKM 600 to 605	RKM 616 (Coyote Rapids)	RKM 632 (Midway)		
1947	0	15	25	10	0	75	115	240
1948	120	330	38	219	0	25	53	785
1949	45	50	6	195	0	1	33	330
1950	24	43	38	151	3	46	11	316
1951	5	10	45	151	5	95	3	314
1952	73	101	40	221	3	78	23	539
1953	7	5	16	38	0	83	0	149
1954	4	5	8	127	0	6	7	157
1955	0	12	0	47	0	4	1	64
1956	0	3	7	59	0	17	6	92
1957(a)	17	88	39	290	42	100	1	577
1958(a)	32	105	99	332	130	176	48	922
1959	1	0	36	101	32	111	0	281
1960	0	31	22	99	38	105	0	295
1961	0	27	43	201	23	640	4	939
1962	6	195	66	456	1	535	2	1,261
1963	0	283	127	506	14	370	3	1,303
1964	5	163	111	510	37	624	27	1,477
1965	4	262	211	588	54	659	11	1,789
1966	10	279	267	1,206	37	1,300	2	3,101
1967	28	388	273	1,192	17	1,340	29	3,269
1968	117	595	188	1,069	52	1,520	39	3,595
1969	265	820	427	1,446	50	1,500	0	4,508
1970	107	615	302	1,180	72	1,528	9	3,813
1971	182	560	416	1,071	10	1,361	0	3,600
1972	88	247	147	259	4	131	0	876
1973	137	458	179	1,273	62	856	0	2,965
1974	104	156	49	238	5	173	3	728
1975	95	458	291	752	91	995	1	2,683
1976	25	313	185	647	182	599	0	1,951
1977	15	473	355	1,577	48	772	0	3,240
1978	18	216	326	1,389	80	999	0	3,028
1979	67	396	297	1,151	92	980	0	2,983
1980	30	157	64	346	35	855	0	1,487
1981	82	421	275	1,875	80	2,132	0	4,866
1982	9	368	290	1,978	168	2,159	16	4,988
1983	24	444	511	1,994	43	2,216	0	5,290
1984	62	712	1,100	3,034	58	2,337	7	7,310

(a) 1957 and 1958 counts are corrected values. The original published values were the sum of all redds observed, i.e., the sum of all survey counts from fixed-wing aircraft.

Sources: After Watson 1970, 1976; recent data supplied by D.G. Watson, Pacific Northwest Laboratory.

(Chapman et al. 1983). In the Skagit River, Washington, marked female chinook commonly return to the same redd after displacement by temporary low flows (Stober et al. 1982).

Egg retention in carcasses of female salmon may reveal adverse conditions that limit spawning success. Egg retention by spawned-out females near and below Vernita Bar is apparently low, with less than 2% retaining over 400 eggs (Chapman et al. 1983). This indicates that water level changes from power peaking at Priest Rapids Dam do not cause significant spawning failure in the Hanford Reach. However, water level fluctuations do reduce the available spawning area, and the possibility exists that intergravel survival of embryos and emergence of alevins might be impaired.

3.1.2 Spring-Run and Summer-Run Adults

Historically, spring chinook salmon consist of an early run destined for the lower Columbia River and a later run destined for the middle and upper Columbia and Snake rivers. However, nearly all summer chinook head for the upper Columbia River (Fulton 1968; Horner and Bjornn 1981b; ODFW and WDF 1983).

Adult spring chinook pass through the Hanford Reach from April through mid-June, and usually spawn in smaller tributaries and upper reaches of principal tributaries between August and early September (Fulton 1968; Horner and Bjornn 1981b). Summer-run fish pass through Hanford from mid-June to mid-August, and usually spawn in large- to medium-sized tributaries and some mainstem areas of the Columbia River from late September to early November (Fulton 1968; Horner and Bjornn 1981c).

Today, runs of spring chinook salmon above McNary Dam are depressed. Prior to construction of most mainstem Columbia River dams (1945 to 1960), the average upriver run was about 23,000 fish. However, the annual average has dropped to about 10,200 fish (range 5,100 to 21,400 fish) at Priest Rapids Dam since 1960 (Horner and Bjornn 1981b). From 1962 to 1980, those spring chinook passing Priest Rapids Dam averaged 26% (range 11% to 46%) of the combined upper-Columbia and Snake river runs.

Runs of summer chinook salmon are the most severely depressed of all salmon runs to the Columbia River (ODFW and WDF 1983). Minimum escapement goals

at Bonneville Dam have not been reached since 1969. Prior to construction of most mainstem Columbia River dams (1945 to 1960), the average upriver run was about 33,600 fish. Since 1960, however, the run has dropped to about 21,300 fish annually (range 13,700 to 29,700) at Priest Rapids Dam (Horner and Bjornn 1981c). From 1970 to 1980, those summer chinook passing Priest Rapids Dam averaged 58% of the combined upper-Columbia and Snake river runs.

The annual sizes of spring and summer chinook runs counted at Priest Rapids Dam from 1960 to 1982 are included in Table 3.2. All juvenile fish originating above Priest Rapids Dam, including hatchery releases, subsequently pass through Hanford on their way to the sea.

3.1.3 Juvenile Production

Generally, juvenile fall chinook salmon originating from natural spawning above and in the Hanford Reach migrate seaward in their first year of life (0-age group) (Major and Mighell 1969; Bell 1973). Juvenile summer chinook originating above Hanford also migrate in their first year (Horner and Bjornn 1981c), while most juvenile spring chinook migrate as smolts in their second year (1-age group) (Horner and Bjornn 1981b).

The Hanford contribution of juvenile salmonids consists of two main segments: those fish produced from natural spawning in the Hanford Reach and those fish produced from natural spawning and hatchery releases above Hanford. In addition, some hatchery-reared fish are released in the Hanford Reach. There are no accepted estimates of the number of juvenile fall chinook produced by the naturally spawning population in the Hanford Reach.

Chinook salmon smolts passing seaward through the Hanford Reach from above McNary Dam are mixtures of hatchery and wild fish. Thus, outmigration size varies with relative success of natural production and number of hatchery releases. These factors change from year to year.

Few fall chinook have been released over the years at the Leavenworth Hatchery complex (Leavenworth, Entiat and Winthrop National Fish Hatcheries). Current production by the federal hatcheries is almost entirely of spring chinook salmon, according to a plan developed by the interagency Grand Coulee Fish Rehabilitation Committee in the 1970's (Mullan 1982).

About three million (average) spring chinook salmon smolts were released annually from the Federal hatcheries from 1976 to 1979 (Horner and Bjornn 1981b). Total artificial production was scheduled to reach about six million smolts annually in 1981. However, the gene pool of upriver spring chinook stocks has been altered by rearing of eggs taken from the lower and middle Columbia River. Today, the Wenatchee, Entiat and Methow river drainages are the only tributaries above Priest Rapids Dam that still support natural runs of spring chinook salmon (Horner and Bjornn 1981b).

An average of 2.2 million (range 844,800 to 3,824,300) summer chinook smolts were released annually at the Wells Hatchery (RKM 830) between 1968 and 1979 (Horner and Bjornn 1981c). Total artificial production (hatchery plus spawning channels) in the upper Columbia River was scheduled to be about 4.3 million smolts annually by 1980. Today, the Wenatchee, Methow, Similkamean and Okanogan river drainages produce most of the natural runs of summer chinook above Priest Rapids Dam (Horner and Bjornn 1981c).

3.1.4 Outmigration

The smolt outmigration in the Columbia River system now occurs up to 2 weeks later than it did before extensive dam construction. Impoundments represent areas of reduced currents; therefore, they tend to delay the seaward migration (Raymond 1968, 1969; Park 1969). Juvenile chinook salmon move about one third as fast through impounded sections of the river as through flowing sections. The delay has ecological implications. A normal, unrestrained outmigration is timed by nature to correspond with physiological changes (smoltification) that lead to development of seawater tolerance (Wedemeyer et al. 1980). Delay may impair the ability of smolts to adapt from fresh to salt water (Mahnken et al. 1982).

In recent years, the smolt outmigration from above Hanford has been sampled by gatewell collections at Priest Rapids Dam. However, gatewell collections provide only general estimates of annual outmigration numbers. Since the portion of smolts using the spillways varies with discharge, and spillway discharges vary seasonally and from year to year, there is room for considerable error. Gatewell sampling does identify peak outmigration periods and provides useful comparison of relative smolt abundance among species (Table 3.4).

TABLE 3.4. Peak Outmigration Dates^(a) for Juvenile Salmonids at Priest Rapids Dam, and Their Percent Relative Abundance for Years Where Data Are Comparable

Year	Fall and Summer Chinook ^(b) (0-Age Group)	Spring Chinook ^(b) (1-Age Group)	Coho	Sockeye	Steelhead
1965	Aug 11	May 19	May 12	May 3	May 20
1966	Aug 12	May 17	April 29	May 1	May 25
1967	Aug 8	May 23	May 20	May 1	May 18
1976	Aug 11	May 14 (41%)	May 19 (16%)	May 19 (34%)	May 14 (9%)
1977	ND ^(c)	May 17 (53%)	May 25 (9%)	May 14 (31%)	May 17 (7%)
1979	ND	May 19 (28%)	May 23 (17%)	May 21 (48%)	May 18 (7%)
1980	ND	May 12 (56%)	May 25 (11%)	May 14 (20%)	May 10 (13%)
1981	Aug 12	May 15 (50%)	May 21 (4%)	May 14 (40%)	May 15 (6%)
1982	Jul 29	May 7 (64%)	May 19 (1%)	May 18 (28%)	May 11 (7%)
1983	Jul 26	May 9 (39%)	May 14 (10%)	May 5 (41%)	May 9 (9%)
1984	Aug 13	May 12 (41%)	May 23 (15%)	May 12 (22%)	May 15 (22%)
Range of peak	Jul 26-Aug 13	May 7-23	Apr 29-May 25	May 1-21	May 9-25

(a) Peak migration date is the day when 50% of the total number of juveniles that season were captured.

(b) Relative abundance of chinook salmon (in parentheses) is the combined runs (fall, summer and spring).

(c) ND = No Data; total number of outmigrants could not be estimated accurately with the methods used.

Sources: Hovland et al. 1982; Weitkamp and McEntee 1982; Parametrix 1984; recent data supplied by M. B. Dell, Grant County Public Utility District No. 2, Ephrata, Washington.

Outmigrants from upriver areas were initially (1977) estimated to travel the 169 kilometers downstream to McNary Dam (through the Hanford Reach and Lake Wallula) in 7 to 15 days, depending on timing and river flow (Faurot 1979). Migration rates were estimated from fish captured, marked, and released at Priest Rapids Dam. Subsequent study revealed that captured and marked fish lingered several days in the release area. Further analysis (1982) indicated

that the true travel time was 3 days or less for juvenile salmonids actively migrating when they reached Priest Rapids Dam (Weitkamp and McEntee 1982). The rapid migration rate is attributed to swift currents in the Hanford Reach, compared to reduced currents in Columbia River impoundments.

Today, movement of 0-age group fall and summer chinook salmon from upriver areas occurs through the Hanford Reach over an extended period but typically "peaks" (reaches 50% of total seasonal passage) in August (Table 3.4, Figure 3.5). 0-age outmigrants passing seaward from above Priest Rapids Dam are usually larger than those produced in the Hanford Reach, indicating that more growth has occurred. The outmigration of the numerically dominant, 1-age spring chinook from upriver peaks near mid-May at Priest Rapids Dam, but extends from April to September (Sims and Miller 1976; Olson 1981; Hovland et al. 1982; Weitkamp and McEntee 1982). Most smolts emigrating from upriver apparently pass through the Hanford Reach without lingering in nearshore areas.

Gatewell sampling data indicate that the timing of 0-age fall chinook salmon outmigration from above Hanford now differs from its timing before dam construction. In 1955, the outmigration of juvenile fall chinook through the Hanford Reach extended from March through July, and there were two distinct downstream movements. The early movement occurred in March and April, and consisted entirely of 0-age fry. The second movement occurred in June and July, and consisted largely of 1-age fingerlings (Mains and Smith 1964). The small fry evidently emerged from the gravel and started downstream almost immediately. The larger fingerlings from upstream spawning areas appeared in early July with the first major increase in river discharge.

The 1955 outmigration took place before construction of Priest Rapids Dam in 1959, and before subsequent construction of Wanapum, Rocky Reach and Wells dams above Hanford. The 0-age fish appeared early in 1955, and outmigration was soon completed. In recent years, these fish have appeared later, and outmigration is prolonged. This suggests that conditions in upriver reservoirs may be adverse for small, weakly swimming fry that have recently emerged from streambed gravel.

The horizontal and vertical distribution of juvenile outmigrants in the water column of the Hanford Reach was also examined in 1955. At that time,

FIGURE 3.5. Outmigration Pattern of Juvenile Spring Chinook and Sockeye Salmon and Steelhead Trout at Priest Rapids Dam in 1982 (after Weitkamp and McEntee 1982)

stations near the banks accounted for the heaviest catches per unit of effort (50% to 60%), but numerous fish were taken at all stations across the river width (40% to 50%). The outmigrants also preferred the surface zone; 44% of the catch taken near the surface, 28% at mid-depth and 29% near the bottom (Mains and Smith 1964).

In late summer 1983, data were collected on the horizontal and vertical distribution of large, later summer chinook salmon outmigrants in the Hanford Reach. These fish passed primarily through the bottom midchannel area of the river, a finding consistent with studies of large salmonid smolts moving seaward in other rivers (Dauble and Page 1984). Most of these smolts migrated during hours of darkness.

Backwater sloughs and shoreline indentations are temporary foraging sites for 0-age fall chinook in the Hanford Reach (Becker 1973b). Because currents are reduced in such shoreline areas and many are warmed by insolation, they are favored by fry with limited swimming ability and stamina. Also, food organisms may be more available to fry in shoreline areas than in offshore, mainstream currents.

The major food items of 0-age chinook salmon in the Hanford Reach are aquatic insects, primarily larvae and adult forms of caddisfly (Trichoptera) and midge fly (Chironomidae) (Becker 1973a; Dauble et al. 1980). Feeding trends relate to seasonal availability of different food organisms. Adult caddisfly and midge fly pupae represent the main food items, by number and volume, of the larger, transitory spring chinook smolts (Gray and Page 1977, 1979a). Caddisfly larvae, fish, spiders and larvae and adult midge flies are also taken. Chinook smolts may prey on smaller chinook fry. Zooplankton, primarily *Daphnia*, may become important food items for larger outmigrants in June and July.

The normal residence time of emergent fry in shoreline areas of the Hanford Reach is probably brief because progeny of the fall run typically move seaward after spring emergence. Rising water temperatures and high flows in May and June may stimulate outmigration from Hanford. Small numbers of 0-age fry can still be collected in nearshore areas in early July, before water temperatures peak, but virtually all are absent later.

3.1.5 Fish Releases

Two rearing facilities on the Hanford Reach contribute juvenile chinook salmon to the outmigration. One is the spawning channel and hatchery at Priest Rapids Dam, and the other is the Ringold fish-rearing facility at RKM 570.

A spawning channel was completed in 1963 at Priest Rapids Dam as a mitigation facility for loss of spawning grounds from construction of Priest Rapids and Wanapum dams. However, the channel failed to operate effectively, and both juvenile production and adult returns were poor (Allen and Meekin 1973). It is now used primarily as a rearing facility for juvenile fall chinook salmon produced at the Priest Rapids Hatchery.

The Priest Rapids Hatchery started operation in 1972. It produced an average of 2.6 million (range 1.2 to 5.5 million) 0-age-group fall chinook salmon annually from 1974 to 1982 (Figure 3.6). Production effort was increased dramatically in 1982, and 10.3 million fish were released from the facility in 1983 and 1984. Release usually occurs from mid-May to late June.

Today, juvenile chinook reared at downstream locations are also released at Hanford, e.g., 3.8 million fall chinook salmon from the Ronneville Hatchery in 1984. The goal of fishery management agencies is to increase substantially the number of future spawners, particularly "upriver brights," in the Hanford Reach. These fish will contribute to the commercial, Indian, and sport fisheries.

Artificial production at the Priest Rapids Hatchery depends largely on eggs stripped from adult chinook returning to its fish ladders. Currently, wild fish are also collected from the ladder on the left (east) bank because volunteer returns to the channel and trap on the east bank do not meet hatchery egg quotas. Therefore, annual releases from Priest Rapids represent mixtures of wild and hatchery stocks. Of the fall chinook salmon spawning at Vernita Bar from 1980-1982, an estimated 18% to 33% originated at the hatchery (Chapman et al. 1983). The hatchery fish may tend to concentrate at the upper end of the Hanford Reach near their release site.

The Ringold facility is operated by the Washington Department of Fisheries and Department of Game. Artificial production began in 1962, primarily of fall

FIGURE 3.6. Releases of Juvenile Fall Chinook Salmon from Priest Rapids Rearing Facilities 1962-1983 (data supplied by M. B. Dell, Grant County Public Utility District No. 2, Ephrata, Washington)

and spring chinook salmon but including some coho salmon and steelhead. Production has varied from year to year (Figure 3.7). Fall chinook salmon are usually released as fry in April, May or June, and spring chinook salmon as yearlings in late winter. Releases of fall chinook yearlings are planned for March 1985 at Ringold.

3.2 COHO SALMON

This section describes ecological characteristics of coho salmon runs associated with the Hanford Reach. Population levels of naturally spawning coho salmon in upriver areas are now decimated, and upriver rearing and stocking programs have been de-emphasized.

FIGURE 3.7. Releases of Juvenile Chinook Salmon from Ringold Rearing Facilities (data supplied by R. Woodin, Washington Department of Fisheries, Olympia, Washington)

3.2.1 Adults

Historically, adult coho salmon do not spawn in the Hanford Reach. Some migrate through Hanford annually to upstream spawning areas. Coho formerly occurred in several streams of the mid-Columbia River, including the Yakima, Wenatchee and Methow rivers and as far upstream as the Methow River, but were not abundant (Fulton 1970). Early water development projects impacted coho runs because juveniles spend a full year growing in streams before migrating to the ocean (Chapman et al. 1982). Today, most coho salmon entering the Columbia River spawn in small and moderately sized tributary streams below The Dalles Dam (Fulton 1970; Horner and Bjornn 1981a). Population levels are supported by hatchery production because natural runs are depressed (ODFW and WDF 1983).

From 1954 through 1981, those adult coho salmon penetrating upriver passed McNary Dam from August through October, with the peak movement in September (U.S. ACOE 1983). Passage at Priest Rapids Dam occurred a week or two later. Counts of coho adults at Priest Rapids Dam have declined greatly in recent

years. The counts ranged from 1,000 to 13,000 fish annually from 1966 to 1976, a result of extensive upriver hatchery production. Counts dropped to less than a thousand for most subsequent years as production was curtailed (Table 3.2).

3.2.2 Juvenile Production

Natural production of coho salmon in upriver tributaries is limited. Therefore, the number of smolts passing seaward through the Hanford Reach varies primarily in relation to hatchery releases.

Hatchery production of coho above Hanford began in 1942, but releases did not contribute noticeably to the outmigration until 1966. From 1964 to 1979, an average of 2.9 million coho smolts (range 400,000 to 9.6 million), including Ringold production, were released annually in the upper Columbia River (Horner and Bjornn 1981a). In response to these releases, over a million coho smolts were estimated to pass seaward over Priest Rapids Dam in 1966 and 1967 (Table 3.5).

TABLE 3.5. Estimated Numbers of Salmonid Smolts Passing Downstream at Priest Rapids Dam 1965-1983, Where Data are Available (estimated by species and run)

Year	Fall and Summer Chinook (0-Age Group)	Spring Chinook (1-Age Group)	Coho	Sockeye	Steelhead
1965	1,700,000	170,000	220,000	2,900,000	270,000
1966	1,400,000	350,000	1,170,000	4,000,000	240,000
1967	1,500,000	270,000	1,170,000	1,000,000	266,000
1976	2,300,000	1,600,000	600,000	1,600,000	400,000
1977	ND ^(a)	2,500,000	500,000	2,000,000	400,000
1979	ND	2,400,000	600,000	4,000,000	350,000
1980	ND	3,400,000	300,000	1,200,000	400,000
1981	ND	3,900,000	150,000	2,300,000	250,000
1983	1,500,000				

(a) ND = No Data; incomplete sampling during outmigration period.

Source: After Park and Bentley 1968; CFWMG 1982; Raemhild et al. 1984.

The Leavenworth Hatchery complex ceased massive production of juvenile coho salmon in 1974 because of failure to establish a sustaining population in any mid-Columbia tributary streams (Mullan 1982; 1984a). These cutbacks caused the number of outmigrants at Priest Rapids Dam to drop sharply by 1976 and to remain low thereafter (Table 3.5). However, some juvenile coho are still released at the Wells Dam Facility, operated by the Washington Department of Game.

The Rocky Reach spawning channels and the rearing ponds at Ringold were the only facilities releasing coho smolts into the upper Columbia River in 1979 (Horner and Bjornn 1981a). The Washington Department of Fisheries recently phased out production of coho salmon in favor of chinook salmon for enhancement of upriver runs. Consequently, the relative abundance of juvenile coho at Priest Rapids Dam dropped to 4% of all salmonid outmigrants in 1981 and 1% in 1982 (Table 3.4).

3.2.3 Outmigration

Outmigrant coho salmon, primarily 1-age fish, appear at Priest Rapids Dam from April to September with peaks occurring in May (Table 3.4). Juvenile coho move into gatewell collectors at Priest Rapids Dam primarily at night (Olson 1981). Migration times of juvenile coho from Priest Rapids Dam to McNary Dam, about 3 days or less, are similar to those of juvenile chinook salmon (Weitkamp and McEntee 1982).

Some coho salmon smolts may overwinter in the Hanford Reach. In spring 1978, several fish were collected at Hanford that appeared to be 2-year-old residents (Gray and Page 1979b). D. D. Dauble (Pacific Northwest Laboratory) suggests that if occasional overwintering occurs, it may represent "residualism" from delayed hatchery release or retarded migration through impounded areas upstream.

The few juvenile coho salmon collected at Hanford consumed primarily fish larvae, midge fly larvae and pupae, and caddisfly larvae and adults (Gray and Page 1979b). Food habits are similar to those of other juvenile salmonids passing through the Hanford Reach.

3.2.4 Fish Releases

Releases of coho salmon at Hanford are limited. At the Ringold rearing facility, production records show four releases of yearling coho from 1969 to 1972, which consisted only of 130,000 to 320,000 fish. The last release was made in 1978, a large group of 1,102,000 fish.

Releases at Ringold and elsewhere in the upper Columbia River have consisted almost entirely of mixed early- and late-run coho salmon stocks from the lower Columbia River. Thus, the gene pool of the upriver run was greatly altered (Horner and Bjornn 1981a). Use of inappropriate stocks may have adversely affected the survival of upriver coho runs.

3.3 SOCKEYE SALMON

This section describes ecological characteristics of sockeye salmon runs associated with the Hanford Reach. Population levels of sockeye salmon above Hanford now depend entirely on the success of natural spawning in a few stream-lake ecosystems.

3.3.1 Adults

Adult sockeye salmon, like coho salmon, do not spawn in the Hanford Reach, but migrate through it annually to upstream spawning areas. Virtually all adult sockeye entering the lower Columbia River today are destined for the upper reaches, where the major production areas are Lake Wenatchee on the Wenatchee River and Lake Osoyoos on the Okanogan River (Allen 1977; ODFW and WDF 1983).

Historically, sockeye salmon returning to the Columbia River were already reduced to a remnant run by the time Grand Coulee Dam was built. The depletion resulted from overharvesting and the damming of rearing lakes (Chapman et al. 1982). Grand Coulee Dam blocked access to more rearing lakes, particularly those in Canada (Fulton 1970; Mullan 1984b), and lakes in Idaho were subsequently blocked by dams built on the Snake River system.

The Leavenworth National Fish Hatchery (Wenatchee River system) was developed as a mitigation facility for loss of sockeye spawning areas. However, artificial production at this facility was discontinued in 1965 (Wahle et al.

1979; Allen and Meekin 1980). Consequently, the last major runs of adult sockeye salmon passed McNary Dam in 1966, 1967 and 1968, when they averaged 127,000 fish (U.S. ACOE 1983). There was no commercial sockeye harvest in the lower Columbia River from 1972 to 1983, but a limited season was permitted in 1984. Runs of sockeye over Priest Rapids Dam surged upward in 1983 and 1984 (Table 3.2).

Adult sockeye salmon pass upstream through the Hanford Reach primarily from June to early September, peaking in July (U.S. ACOE 1983). Since 1979, counts at Priest Rapids Dam have declined, to range from 40 to 50 thousand fish (Table 3.2). Counts of adult sockeye at Priest Rapids Dam are usually higher than counts at McNary Dam (U.S. ACOE 1983). Since very few sockeye divert to the Yakima River or Snake River, the counts should be nearly equal. Operation of the locks at McNary Dam for barge and boat traffic may permit uncounted sockeye salmon to pass upriver.

3.3.2 Juvenile Production

The number of sockeye salmon smolts passing seaward each year through the Hanford Reach now depends entirely on natural reproduction of upstream runs. Sockeye alevins emerge from gravel in April and May, and enter nursery areas in lakes for 1 to 3 years before outmigration (Foerster 1968).

For over 25 years, starting in 1940, large numbers of sockeye smolts were produced at the Leavenworth Hatchery Complex and released in Lake Wenatchee. However, production was abandoned in the late 1960's because of a low 0.04 benefit/cost ratio (Wahle et al. 1979) and severe problems with sockeye salmon virus disease. Some year classes experienced catastrophic losses from the virus, for which there is still no known control (Mullan 1984b).

Estimates of smolts passing Priest Rapids Dam from 1965 to 1982, when data are available, range from 1.0 to 4.0 million (Table 3.5). Proportionately, sockeye salmon smolts now represent 20% to 48% of all smolts taken in gatewell collections at Priest Rapids Dam (Table 3.4). The contribution of naturally spawning sockeye to the total smolt outmigration remains substantial.

3.3.3 Outmigration

Peak outmigration (50% total passage) of sockeye salmon smolts at Priest Rapids Dam usually occurs in May (Table 3.4), but seasonal movement varies (Figure 3.5). Smolts enter the gatewells at Priest Rapids Dam at all hours of the day, but greatest numbers appear in the afternoon (Olson 1981). In terms of relative abundance, numbers of sockeye smolts are usually second to those of chinook salmon in gatewell collections.

Young sockeye salmon feed primarily on zooplankton and phytoplankton in lake nursery areas (Foerster 1968). This preference for plankton is in contrast to the more insectivorous habits of other juvenile salmonids. However, gut analysis from a few sockeye smolts taken at Hanford showed primarily midge fly and caddisfly pupae (Gray and Page 1979a).

The few juvenile sockeye salmon collected at Hanford in June and July (Gray and Page 1979a; Page et al. 1982) represent outmigrants. The Hanford Reach is not a nursery area for juveniles.

3.3.4 Fish Releases

No sockeye salmon are artificially reared and released in the Hanford Reach.

3.4 STEELHEAD

This section describes ecological characteristics of steelhead runs associated with the Hanford Reach. Population levels of steelhead at Hanford and above Priest Rapids Dam now appear to be related to the success of artificial rearing and release programs, combined with habitat improvement in tributaries used for spawning.

3.4.1 Adults

Both resident and anadromous forms of steelhead occur in the Hanford Reach. Based on the time that adult anadromous forms appear in the lower Columbia River, they are classified either as winter or summer run. The winter run enters the Columbia River from November through April and spawns primarily

in tributaries below Bonneville Dam. The summer run enters the river from April through October and spawns primarily in areas above Bonneville Dam (Fulton 1970).

The summer steelhead run is further represented by two groups. The first appears from June to early August, and travels to tributaries throughout the system. The second appears from August to October, and travels to tributaries in the Snake River (ODFW and WDF 1983). Although the upriver runs migrate at different seasons, they both spawn during the winter and spring (Fulton 1970).

Adult steelhead show peak periods of migration through the Hanford Reach, but some migrants are passing through, holding, or spawning at Hanford throughout the year. An upriver run occurs over McNary Dam below Hanford from April through October, but peak movement occurs in August and September (U.S. ACOE 1983). The migration of steelhead over McNary Dam from 1971 to 1982 averaged about 11,000 in August and 24,000 in September. Many of these fish were destined for the Snake River.

The steelhead migration at Priest Rapids Dam above Hanford also peaks in August and September. However, more adult steelhead pass over Priest Rapids Dam and Ice Harbor Dam in October, April and May than over McNary Dam. This suggests that some adult steelhead pause in the Hanford Reach during late fall or winter before continuing their upstream migration (Watson 1973).

From 1962 to 1971, the number of adult steelhead passing Priest Rapids Dam averaged 9,700 fish (Watson 1973). From 1972 to 1982, the numbers passing the same site ranged from 2,000 to 11,000 and averaged about 7,000 fish (Table 3.2). Thus, recent returns have been sustained with some year-to-year variations. In 1983 and 1984, the number of steelhead passing Priest Rapids Dam more than doubled (Table 3.2). This sudden increase is likely due to recent stocking, enhancement and management practices, and to improved spring spill programs that aid survival of downstream migrants.

In addition to runs passing upriver over McNary and Ice Harbor dams, about 10,000 to 15,000 steelhead enter the Yakima River each year, about 4,000 to 5,000 enter the Walla Walla River, and about 2,700 are taken regionally by sport fishermen (Watson 1973). Assuming 20% mortality for missing fish, an

average of about 10,000 steelhead may have spawned annually in the Hanford Reach from 1962 to 1971. However, there are no firm data to support this estimate. Steelhead have been reared and released at the Ringold Hatchery since 1962, and a significant sport fishery now occurs on returns to this facility (Allen 1977).

Steelhead collected in the Hanford Reach are usually 3 to 4 years old (U.S. DOE 1982). Since most steelhead in the Mid-Columbia River are produced in hatcheries, they will have only one freshwater annulus when released as smolts.

Steelhead spawn in the Hanford Reach from February through May, from the mouth of the Yakima River to Priest Rapids Dam (Fulton 1970; Watson 1973). Gravid females have been collected at Hanford in late April and early May, spent males in August, and a spent female in February (Page et al. 1976; Gray and Page 1977). Some steelhead and rainbow trout have been collected at Hanford throughout the year.

The portion of steelhead that survive to spawn again is usually small. Repeat spawners range from 5% to 31% in some British Columbia streams (Withler 1966), and from 4.4% to 14% in Washington State (Wydowski and Whitney 1979). Because of fish passage problems at dams (Collins et al. 1975), the number of adult steelhead that reach the sea and return to spawn a second time at Hanford is probably low.

Estimates of steelhead spawners in the Hanford Reach by aerial enumeration of redds are complicated by high flows and turbidity during the late winter spawning period (Watson 1973). Several sites appear to provide suitable conditions for spawning and egg incubation (Figure 3.8). However, only a few steelhead redds have been detected in the Hanford Reach, primarily in the section extending from Ringold to Priest Rapids Dam.

3.4.2 Juvenile Production

Juvenile steelhead usually spend 1 to 3 years in freshwater before passing seaward during the spring and summer. Steelhead outmigrants at Priest Rapids Dam ranged from 240,000 to 400,000 annually during certain years from 1965 to

FIGURE 3.8. Likely Spawning Areas for Steelhead in the Hanford Reach (after Fickeisen et al. 1980)

1982 (Table 3.5). Proportionately, steelhead represent from 6% to 22% of the annual smolt outmigration at Priest Rapids Dam (Table 3.4).

The total estimated number of steelhead smolts passing seaward from the Hanford Reach each year has been between 2.0 and 2.2 million (Fickeisen et al. 1980). This represents the sum of the outmigration from above Priest Rapids Dam, the contribution from natural spawning in the Hanford Reach, and hatchery releases at Ringold.

3.4.3 Outmigration

The outmigration from above Priest Rapids Dam generally occurs from mid-April to early July (Figure 3.5), with a peak (50% total passage) in May (Table 3.4). Smolts have been collected at Hanford from April through June with peak catches in May (Gray et al. 1976; Gray and Page 1978, 1979a). Marks indicate that most of these fish were produced at upriver hatcheries.

Diel migration patterns of salmonid outmigrants at Priest Rapids Dam tend to vary. Initial studies indicated that most steelhead smolts (61%) entered the intake gatewells after dark (Sims and Miller 1976). Recent studies indicate variable movement rates at night and a strong movement after sunrise (Olson 1981). In the Snake River, most steelhead smolts (76%) move from impounded waters at night, and the portion collected in the lighted surface zone (0 to 7.3 meters) declines from day (74%) to night (36%), reflecting this movement (Smith 1974). Steelhead smolts passing downstream at Priest Rapids Dam probably move directly through the Hanford Reach to Lake Wallula and beyond.

Although several thousand adult steelhead potentially spawn at Hanford, few fry have been collected there despite extensive effort (Fickeisen et al. 1980; U.S. DOE 1982). In contrast to chinook fry, steelhead fry apparently do not occupy shoreline areas to any extent at Hanford. This difference may reflect the relative abundance of adult chinook salmon and steelhead spawners.

3.4.4 Fish Releases

Juvenile summer-run steelhead are produced at the Ringold Facility. From 146,000 to 201,000 smolts were released annually in the Hanford Reach from 1980 to 1984, usually in April and May (Figure 3.9). The releases represent about 25% of the steelhead smolts reared artificially from Hanford upstream to Wenatchee (Fickeisen et al. 1980). Most Ringold releases remain locally for about a month, and a few overwinter in the Hanford Reach (Gray and Page 1978).

FIGURE 3.9. Releases of Juvenile Steelhead from Ringold Rearing Facilities (data supplied by J. Gearheard, Washington Department of Game, Olympia, Washington)

4.0 POTENTIAL HABITAT MODIFICATIONS

A number of present and potential activities could alter the Columbia River habitat in such a way as to adversely affect populations of fall chinook salmon, steelhead and other salmonids associated with the Hanford Reach. These activities can be placed into two general categories: present and possible future activities on the Hanford Site (onsite), and regional growth and development activities in the mid-Columbia River Basin (offsite). Some illustrative examples are briefly discussed in this section. Historical and other background information is provided for perspective on cause-and-effect relationships.

4.1 HANFORD SITE (ONSITE) ACTIVITIES

Several contractors now operate various facilities in the 1,476-square-kilometer (570-square-mile) expanse of the Hanford Site, where public access is restricted. Considerable research and development work is sponsored by the U.S. Government through the Department of Energy, with emphasis on nuclear energy technology. A dual-purpose reactor at RKM 611 produces both plutonium (the N Reactor) and electrical power (the Hanford Generating Project or HGP). Other operations sponsored by the government at Hanford in 1984 include a fast-flux (sodium) test facility, a basalt waste storage project, a chemical extraction facility for spent nuclear fuel (PUREX), and defense waste management. Emissions of radioactive, hazardous or other materials from plant operations are prevented or kept within Federal guidelines, and monitoring is conducted to detect any fugitive releases to air and offsite water.

At this time, these onsite activities have negligible effects on aquatic resources of the Hanford Reach, largely because operations adhere to protective environmental regulations. For example, chemical and radioactive emissions to air and water are kept well within conservative regulatory standards. Environmental monitoring programs are conducted to assure compliance. Existing federal and state regulations require that the effects of all major construction and operation activities on the Hanford Site be assessed to ensure against

environmental deterioration. These regulations also require that potential impacts on the environment and its biota be minimal. Three activities at Hanford that illustrate carefully monitored events are first reviewed. They are emissions of heat and radionuclides, and operation of the HGP. Discussion of these existing "controlled" activities is followed by review of a potential future onsite activity at Hanford, a multi-unit power plant complex.

4.1.1 Direct Releases of Heat and Radionuclides to the River

The Hanford Site was established in 1943-1945 to produce nuclear materials, primarily plutonium, during World War II. Between 1944 and 1964, the Columbia River at Hanford also received heat from the cooling water discharges of up to nine plutonium production reactors. In 1964 (the last year during which all units were operated), loading from these sources exceeded 23,000 megawatts thermal (MWt) when all reactors were operated at average levels (U.S. DOE 1982). Temperatures of each reactor effluent at the point of discharge then generally exceeded 85°C (185°F). All reactors operated with direct, once-through cooling, and discharges were through vertical outfalls to the center of the Columbia River.

These conditions no longer exist. The last single-purpose plutonium production reactor was deactivated in early 1971. Today, discharges to the Columbia River adhere to requirements of a National Pollutant Discharge Elimination System (NPDES) permit. Most heat from the N Reactor is transferred to the HGP as steam for production of electricity in its normal, dual-purpose, operational mode. The N Reactor and HGP, operating simultaneously, release 3,100 MWt to the river. If the N Reactor were operated in a single-purpose mode, about 4,000 MWt would be passed to the Columbia River (U.S. DOE 1982; Ecker et al. 1983). Thus, thermal releases to the Columbia River at Hanford today are many times less than thermal loads discharged from the original plutonium production reactors.

Until early 1971, cooling water discharges from the plutonium-production reactors released radioactive materials directly to the mid-Columbia River. Most of these materials were not fission products from the splitting of uranium and plutonium atoms, but isotopes from neutron bombardment of elements in the cooling water or in the reactor piping (Foster et al. 1961; Foster 1972).

However, trace amounts of irradiated fuel were occasionally passed to the Columbia River through the cooling water discharge (Robertson and Fix 1977).

Monitoring during those early years revealed no adverse effects from radionuclides on fishery resources of the Columbia River, and exposures to humans were well within acceptable limits (Foster 1972). After cessation of cooling water discharges, measurable concentrations of radioactive materials in the Hanford Reach decreased to extremely low or unmeasurable levels within 18-24 months (Cushing et al. 1981), although, the deeper sediment deposits in downstream reservoirs still retain low concentrations of the long-lived radionuclides (Nelson and Haushild 1970; Haushild et al. 1975; Robertson and Fix 1977). The N Reactor, which operates today (the only plutonium-producing reactor now operating), has a closed primary cooling loop, and bleed-off from this loop is passed through a liquid effluent control system. Therefore, direct release of radioactivity from the N Reactor to the Columbia River is limited.

4.1.2 Indirect Releases of Radionuclides Through Groundwater

In the early days of the Hanford operations, large volumes of process cooling water contaminated with low-level radioactivity were generated from processing of irradiated materials to extract uranium and plutonium. Most of the contaminated liquid was deliberately allowed to infiltrate the ground. The ion exchange properties of the soil selectively removed much of the radioactivity, and concentrations were further reduced by diffusion, radioactive decay, and dilution (Sula et al. 1983). Since the liquids tended to move downward and laterally through the soil, some of the more mobile radionuclides reached the unconfined aquifer representing groundwater under the Hanford Site. At present, radioactive decay in the groundwater is proceeding faster than new radioactivity is being added.

The intrasoil movement of radionuclides on the Hanford Site has been closely monitored over the years (ERDA 1975; Eddy et al. 1983; Greager 1983; Wilbur et al. 1983; Law and Allen 1984) and continues today. Movement of the contaminated groundwater plume is gradually east and southeast towards the Columbia River. Some groundwater entering the Columbia River at Hanford now contains low-level radioactivity, particularly the mobile (but short-lived)

element tritium. The monitoring program clearly shows that amounts of radioactivity entering the river, while measurable, are well below DOE concentration guides (Sula et al. 1983; Price et al. 1984). Further, the groundwater contribution of radioactivity is diluted by Columbia River water, and soon becomes indistinguishable from radioactivity contributed by natural sources and atmospheric fallout (WSDOE 1980).

All waste management operations at Hanford adhere to Federal and state regulations. Radiation releases to air and water are very low and present no significant hazard to public health and safety (WSDOE 1980; Sula et al. 1983). Today, shutdown of the original production reactors and addition of liquid effluent control systems at N Reactor have substantially reduced direct both heat and radionuclide discharges to the Columbia River (Price et al. 1984).

4.1.3 Operation of a Steam-Electric Plant

The Hanford Generating Project (HGP) at RKM 611 is a steam-electric power plant owned and operated by the Washington Public Power Supply System (WPPSS). Steam for the HGP's turbine generators is produced by the N Reactor. Water for once-through cooling of HGP condensers is drawn from the Columbia River. Depending on pumping mode, the temperature of the cooling water (not the discharge plume) may increase 19° to 24°C (Neitzel et al. 1982c). Three potential impacts on salmonids are associated with this type of power generation: entrainment through the plant cooling system, impingement on plant intake screens, and thermal shock from encountering the heated discharge plume.

However, entrainment of juvenile salmonids is not a problem at HGP because these fish are too large to pass through the revolving intake screens. Moreover, impingement on the HGP intake screens was examined and found to be relatively low, except for 0-age group fall chinook salmon (Page et al. 1977, 1978). Implementation of a live fish return and a continuous screen wash on the intake screens has now reduced impingement of these fish to almost zero.

Migrating salmonids may be thermally shocked if they encounter elevated temperatures of a midstream discharge plume. The HGP must have an NPDES permit, but is exempt from federal requirements for closed-cycle cooling systems

because of its age under Section 316 (a) of the Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977 (Greenwood et al. 1979). However, state water quality standards still apply. Studies showed that the thermal discharge from HGP exceeded state water quality standards under certain conditions of water temperature and flow.

To establish a scientific basis for evaluating the impacts of cooling water discharges, research has been conducted on indigenous aquatic populations of the Hanford Reach for over 5 years (Page et al. 1976; Gray et al. 1976; Gray and Page 1977, 1978, 1979a, 1979b). Findings were presented in a 316 (a) report (WPPSS 1978), which demonstrated a general absence of appreciable harm to aquatic resources of the Hanford Reach (Neitzel et al. 1982c). As a result, the Washington State Department of Ecology, with the concurrence of Region X EPA, granted a waiver of state thermal discharge limits for HGP, with one exception. After 1983, discharge of heated water from HGP to the Columbia River is prohibited each year from July 1 to September 7, when ambient water temperatures are high, flows are low and the smolt outmigration is underway.

4.1.4 Multi-Unit Power Plant Complex at Hanford

Some long-range plans envision the Hanford Site as a future multi-unit power plant complex (Harty and Dowis 1983). Power plants under construction or planned on the Hanford Site must prepare environmental impact statements and comply with Federal and state regulations designed to minimize environmental impacts. WPPSS Nuclear Projects 1, 2, and 4 are sited at RKM 566, about 19 kilometers north of Richland. In 1982, Projects 1 and 4 were mothballed because of reduced projections of future power demand and escalating costs. In 1983, Project 2 entered the testing stage, and it reached full operation in the fall of 1984. The plants are provided with intake structures designed to minimize impingement and entrainment of fish. Because these plants have closed-cycle cooling and mechanical draft cooling towers, they require considerably less cooling water than plants with direct, once-through cooling. Limited amounts of tower makeup water are drawn from the Columbia River, and some tower blowdown enriched in dissolved solids and containing trace amounts of chlorine residuals is returned to the river (U.S. NRC 1975).

Adherence to Federal and state regulations is a requirement of the planning, construction, licensing, and operational phases of all power plants in the United States today. Potential environmental impacts of individual plants on regional locales receive close scrutiny. Each current WPPSS project was designed to protect the ecosystem and biota of the Hanford Reach. Thus, WPPSS Project 2, as it is currently operating, is expected to have minimal impact.

A multi-unit complex would present a different environmental situation. Stresses from several plants operating simultaneously might be cumulative on aquatic resources of the Hanford Reach. The effects of combined operational stresses would intensify under chronic, low-flow conditions associated with over-allocation of river water.

Fortunately, anadromous salmonids and other aquatic biota are considered in the assessment and operational phases of all onsite major programs as required by federal and state laws. Environmental requirements make it unlikely that activities on the Hanford Site will alter physical and chemical characteristics of the adjacent Columbia River sufficiently to impact valued fishery resources.

4.2 REGIONAL (OFFSITE) ACTIVITIES

The effects of offsite factors are currently minimal, but could intensify as growth and development continue in the mid-Columbia Basin. Some regional changes now being considered have potential future impact, and a number of them are described below. Regional activities include flow fluctuations from peaking power generation at upriver dams, construction of a low-head hydroelectric dam above Richland, reductions of instream flows from irrigation and other diversions, and dredging and commercial navigation in the Hanford Reach.

4.2.1 Peaking Power Generation at Upriver Dam

Water level fluctuations are a common result of hydroelectric power generation in western rivers (Geen 1974; Bayha and Koski 1974; Haber et al. 1978; Hildebrand et al. 1980). In the Columbia River system, increased use of

the peaking mode of power generation and the addition of generating units at dams tend to increase the frequency and extent of water level fluctuations (Bell et al. 1976).

Except for Lake Roosevelt behind Grand Coulee Dam, mid-Columbia River reservoirs have only limited capacities for water storage. Lake Roosevelt can store 5.2 million acre feet. In contrast, the total capacity of all "river run" reservoirs from Hanford to Grand Coulee Dam is only 0.41 million acre feet. Therefore, the whole mid-Columbia reservoir system from Chief Joseph to Priest Rapids is driven by the hydraulic and storage capacities of Grand Coulee Dam. When Priest Rapids Dam is operated to provide maximum power generation during periods of maximum power demand (power peaking), water levels in the Hanford Reach vary hourly. Because storage capacity behind Priest Rapids Dam is limited, daily and weekly fluctuations in water level at Hanford are due to a combination of Priest Rapids operation and systematic releases originating at Grand Coulee Dam.

Water levels in the Hanford Reach can vary up to 2 or 3 meters (6.6 or 9.8 feet) daily (U.S. ERDA 1975; WPPSS 1978). Water level fluctuations cause stranding of adult and juvenile fish along shorelines subject to alternating flooding and dewatering. Young 0-age fall chinook salmon produced in the Hanford Reach are susceptible to stranding during the spring months (Becker et al. 1981). The spawning of adult fall chinook salmon at Vernita Bar during October and November may also be affected (Bauersfeld 1978). Spawning at high flows can lead to exposure and dewatering of redds at low flows.

Considerable field and laboratory research has been conducted to eliminate or minimize effects on chinook salmon spawning from operation of Priest Rapids Dam (Parametrix, Inc. et al. 1979; Chapman et al. 1981, 1983; Weitkamp et al. 1982; Neitzel et al. 1984). This research has identified operational techniques that permit successful spawning of fall chinook salmon, and has examined intergravel conditions that promote survival of eggs and alevins during periodic drawdowns. The ecological information obtained from this research, properly applied, will make power generation at Priest Rapids Dam compatible with spawning requirements of adult salmonids and minimize impacts on intra-gravel development of eggs and alevins.

4.2.2 Potential Hydroelectric Dam on the Hanford Reach

One alternate use of the Hanford Reach considered by the U.S. Army Corps of Engineers is construction of a dam (the proposed Ben Franklin Dam) above Richland at RKM 560. The dam would have a nominal full-pool elevation of 122 meters above mean sea level, impound the present flowing river to Priest Rapids Dam, and convert most of the Hanford Reach to a run-of-the-river reservoir (U.S. ACOE 1969).

A number of ecological impacts would result from dam construction and operation. The dam would inundate most spawning and rearing areas of anadromous salmonids in the Hanford Reach and virtually eliminate the surviving run of fall chinook salmon. It would also reduce the survival rate of spring and summer chinook, coho, and sockeye salmon produced above Hanford; destroy steelhead spawning and rearing habitat; inundate ponds used to rear salmonids at Ringold; and contribute directly to other impacts from environmental alteration (Harty 1979; Fickeisen et al. 1980). The additional reservoir created behind the dam would further slow the seaward migration of juvenile salmonids and perhaps adversely affect the critical smoltification process (Wedemeyer et al. 1980).

At the present time, plans for constructing the dam have been shelved because of adverse environmental impacts and an unfavorable cost/benefit ratio. The possibility remains, however, that a dam might be constructed on the Hanford Reach in the future if societal needs and perceptions of value change.

4.2.3 Irrigation and Instream Flow Reduction

The primary consumptive use of Columbia River water is for agricultural irrigation, and this use will probably increase in future years. However, other factors contribute to periodic low flows in the Columbia River ecosystem. The adverse ecological effects resulting from withdrawal of water and low river flows are complex.

Instream flow reduction in the Columbia River has become a concern of the U.S. Army Corps of Engineers (U.S. ACOE 1976a, 1976b), as well as fishery management agencies (NPPC 1982). Instream flow reduction results from withdrawal of water for irrigation or pumped storage projects, and storage of water in

upriver reservoirs to enhance irrigation or power generation. Diverting large quantities of Columbia River water to the southwestern United States remains a possibility. Offstream pumping to a storage reservoir is also planned as a mitigation measure to help maintain flows in a salmon-producing tributary, the Umatilla River.

Today, the largest consumptive user of Columbia River water is the Columbia Basin Irrigation Project, which now irrigates about 530,000 acres, or about half of the project's full estimated potential. Some irrigation water is returned to the Columbia River via surface runoff and underground seepage. However, quality of water used for irrigation can be impaired through the addition of fertilizers, pesticides, other chemicals, and organic wastes. Measures to maintain water quality are not required because a 1977 amendment exempts agricultural waste water from requirements of the Clean Water Act.

A related feature of irrigation along the middle and upper Columbia River is infiltration of soil layers by moisture, which increases the likelihood of mudslides on steep slopes. Several slides have recently occurred on the high east bank of the Hanford Reach in Franklin County, presumably from soil super-saturation. Mudslides increase turbidity, lowering the quality of river water below the site, and may affect the upstream migration path of adult salmonids.

Fish passage problems at dams for adult and juvenile salmonids become acute during low-flow years. Also, water rights for irrigation are subject to maximum allocation during drouth, a societal factor that complicates a power and fishery management problem.

Mortality of outmigrating salmonids is high when most of the spring and summer river discharge is passed through power-generating turbines (Collins et al. 1975). For example, flow/survival estimates for yearling chinook salmon at Bonneville Dam were developed by fishery agencies for comparisons between 1979 (average flows 255,000 cfs), 1980 (261,000 cfs) and 1981 (215,00 cfs). Survival was nearly doubled by increasing flows from 215,000 to 260,000 cfs (CRWMG 1982).

The problem of passing adult salmonids upriver through fishways at dams is also compounded during low-flow periods (Collins et al. 1962; Weaver 1963;

Leman and Paulik 1966; Bell et al. 1976). Adults may be prevented from entering fish ladders, and upstream migration is slowed. Moreover, water temperatures above normal are associated with low flows during the summer and fall. Low flows and warmer river temperatures increase the threat of infectious disease from such pathogens as Flexibacter columnaris to returning adult fish and possibly to seaward migrants (Becker and Fujihara 1978).

Today, after extensive development, the Columbia River can no longer be viewed as a surplus resource. Future commitments of water will cause adverse effects on other river uses (U.S. ACOE 1976a). The impact of low flows on anadromous salmonid resources of the mid-Columbia River remains a valid environmental concern (U.S. ACOE 1976b). Part of the recommended solution is a water budget that provides a minimum flow based on forecasted runoff for January through July at selected dams, including Priest Rapids Dam. The water budget was created primarily to protect salmonid outmigrants (NPPC 1982).

In the past, anadromous salmonids have received low priority in conflicts among users of Columbia River water. However, the Northwest Power Planning Council, established on April 28, 1981, pursuant to the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (Public Law 96-501), changed this situation. The Council is required by law to develop and conduct a comprehensive program to protect, mitigate, and enhance fish and wildlife along the Columbia River and its tributaries (Hemmingway 1983). Maintenance of instream flows during smolt outmigration via the water budget, combined with habitat improvement projects, are mitigation methods developed for this purpose.

4.3 DREDGING AND COMMERCIAL NAVIGATION

Sporadic efforts have been made to obtain federal funding for navigation locks in Priest Rapids Dam and other upstream dams as far as Wenatchee, and to dredge the Hanford Reach to enhance commercial traffic. Excavation of a navigation channel through Hanford would alter the existing river channel, and would destroy sections of the stream bed with a gravel composition uniquely suited for salmonid spawning. A number of other impacts can be projected (Allen and Hardy 1980; Simpson et al. 1982). For example, the biomass of

benthic invertebrates available for fish food would be reduced. Dredge spoils deposited on the bank would alter or destroy existing riparian habitats, and bow waves from large navigation vessels would continually wash the shoreline, resuspend silt, and strand juvenile fish. Therefore, excavation and use of the Hanford Reach for commercial navigation is incompatible with the spawning of salmonids.

In January 1980 the U.S. Army Corps of Engineers held an open discussion on two "management plans" for the Hanford Reach (Ben Franklin Dam and navigation), along with two alternatives. The alternatives were to retain present river management policies or to classify the Hanford Reach as a "wild and scenic river." Present river management policies may be adequate for maintaining salmonid populations in the Hanford Reach. A "wild and scenic river" classification, which includes construction of limited public access and recreational facilities, might increase public use. However, additional protective regulations would then limit further encroachment.

5.0 ASSESSMENT

The anadromous species most likely to be affected by human-induced modifications of habitat in the Hanford Reach is the fall chinook salmon. This assessment reviews the status of fall chinook salmon in the flowing mid-Columbia River and evaluates the effect of potential modifications in the Hanford Reach.

5.1 FALL CHINOOK SALMON AT HANFORD

Chinook salmon from the Columbia River Basin once comprised the largest and most important spawning population of chinook salmon in the world (Ricker 1959). Population levels of anadromous salmonids above McNary Dam have been greatly reduced. Fall chinook that spawn at Hanford contribute substantially to the surviving runs of anadromous fish in the Columbia River Basin. The Hanford population is important in many ways:

- The fish are "upriver brights," a race low in abundance elsewhere in the Columbia River system.
- Future increases in abundance of chinook salmon above Priest Rapids Dam are limited by lack of mainstream spawning areas, modification of rearing areas due to stream fluctuations, and high juvenile mortality rate at dams.
- Management agencies now trap most fall chinook salmon moving upriver at the Priest Rapids fish ladder for hatchery rearing programs.
- Enhancement programs by the State of Washington for fall chinook salmon in the Columbia River and its tributaries above Priest Rapids Dam are now reduced.
- Federal hatcheries above Hanford now concentrate on production of spring chinook salmon.

Habitat destruction in the Columbia River ecosystem has made operation of an extensive hatchery program necessary. Historically, the Federal government has assumed responsibility for supporting salmonid production facilities on the Columbia River as mitigation for losses from hydroelectric projects. Future

hatcheries will likely be funded by electric-rate-payers through the Bonneville Power Administration. However, hatchery programs are costly, often plagued by low returns, and may provide only for minimal sustenance of the managed stocks.

The role of salmonid hatcheries on the Columbia River has been to substitute artificial production for natural production. The substitute fish may not be the same kind genetically as those lost (Cleaver 1977), and their quality may be less than wild fish. Experimental studies indicate that the character of wild salmonid stocks will function to increase their probability for survival. These attributes are controlled largely by genetic factors, the frequencies of which can be modified in a single generation by the artificial environment of hatcheries (McIntyre and Reisenbichler 1977). Many resource managers in the Pacific Northwest believe that maintaining genetic pools in populations that spawn naturally is a top priority (Bjornn 1977; Reisenbichler and McIntyre 1977; Salo and Sober 1977).

Fall chinook salmon spawn naturally in the Hanford Reach. But they are not true "wild fish," if defined as "members of a naturally produced and maintained population existing in a natural setting," because hatchery releases supplement natural production.

The fall chinook salmon population in the Hanford Reach today represents a mixed gene pool (Utter et al. 1982; also according to F. M. Utter, NMFS, Seattle, Washington, 1984). There are several possible reasons. For example, the run originated from misplaced stocks during construction of dams on the mid-Columbia River; the Priest Rapids hatchery has used eggs taken from down-river stocks and from intercepted upriver stocks as well as from Priest Rapids stocks; and large numbers of juveniles reared at other hatchery facilities have been released at Hanford. Massive releases from other sources, as practiced today with "Bonneville brights," will prevent the genetic makeup of fall chinook salmon in the Hanford Reach from stabilizing. While annual introductions of hatchery fish may have commercial (and political) value, development of a "wild fish" (sensu stricto) population is prevented.

The loss of spawning areas in the mid-Columbia River from dam construction, followed by elimination of many distinct breeding stocks, shows the need to preserve remaining spawning habitat and to maintain stock integrity. That

the Hanford Reach has become a major spawning area for fall chinook salmon reflects the innate adaptability of the species in the face of heavy exploitation and habitat changes.

5.2 EFFECTS ON THE HANFORD REACH

An assessment of actual (occurring now) or potential (may occur in the future) activities on salmonid resources of the Hanford Reach can be made on the basis of the discussion in Section 4. Major effects are associated with changes that might occur in the future, particularly effects that alter or degrade the riverine environment (Figure 5.1).

Construction of a dam above Richland that would inundate the Hanford Reach, and dredging and commercial navigation in the Hanford Reach, have

Event	Life Phase						Environment	
	Return Migration	Onsite Spawning	Intragravel Development	Onsite Feeding	Seaward Migration	Water Quality	Habitat Loss	Water Level Fluctuations
Hanford Site Activities	○	○	○	○	○	○	○	○
Direct Release of Heat and Radionuclides	○	○	○	○	○	◐	○	○
Indirect Release of Radionuclides	○	○	○	○	○	○	○	○
Power Plant Complex	○	○	○	○	◐	◐	○	○
Peaking Power Generation	○	◐	○	◐	○	○	◐	◐
Hydroelectric Dam	◐	◐	◐	◐	◐	◐	●	◐
Irrigation and Flow Reduction	◐	◐	◐	◐	◐	◐	◐	○
Dredging and Navigation	◐	◐	◐	◐	○	◐	◐	◐

○ No Effect
◐ Limited Effect
◐ Considerable Effect
● Severe Effect

FIGURE 5.1. Assessment of Effects from Present or Potential Activities on Salmonid Resources of the Hanford Reach, Based on Life Cycle Phase and Environment

potential to adversely impact anadromous salmonids. Implementation of the projects may be precluded by existing environmental statutes.

The maintenance of adequate instream flows in the Hanford Reach is also crucial for survival of anadromous salmonid runs. Reduced flows often intensify potential adverse effects from other instream uses, for example, the use of a stream as a diluent for waste heat, cooling tower blowdown, low-level radioactivity, and waste water from agricultural, domestic, municipal, and industrial sources.

Water quality is often a function of stream flow. Low flows often mean impaired water quality, and can shift an environmental stress, or combination of stresses, from acceptable to unacceptable. Over the long term, the chemical characteristics of Columbia River water must remain unimpaired to protect salmonids and other aquatic resources of the Hanford Reach. Future growth and development in the Columbia Basin, and strong competition for a finite water supply, will compound the problem of maintaining water quality and instream flows that provide adequate protection.

In 1983 and 1984, runs of adult fall chinook salmon, sockeye salmon, and steelhead over McNary Dam showed impressive increases. These increases may reflect the success of recent fishery management policies, particularly success in reducing mortality of smolts at dams during outmigration. Any policy that effectively increases the ratio of returns per parent spawner will also increase the need to maintain the Hanford Reach as a natural spawning area. Given the present precarious status of salmonid runs in the Columbia River Basin, enhancement of naturally spawning populations must receive high priority among resource managers.

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