PNL-7289
UC-600

Spawning and Abundance of Fall Chinook Salmon *(Oncorhynchus tshawytscha)* in the Hanford Reach of the Columbia River, 1948-1988

D. D. Dauble
D. G. Watson

March 1990

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-7289

PACIFIC NORTHWEST LABORATORY
***operated** by*
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 7830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

NTIS Price Codes, Microfiche A01

Printed Copy

Price Code	Page Range	Price Code	Page Range
A02	1- 10	A15	326-350
A03	11- 50	A16	351-375
A04	51- 75	A17	376-400
A05	76-100	A18	401-425
A06	101-125	A19	426-450
A07	126-150	A20	451-475
A08	151-175	A21	476-500
A09	176-200	A22	501-525
A10	201-225	A23	526-550
A11	226-250	A24	551-575
A12	251-275	A25	576-600
A13	276-300	A99	601-Up
A14	301-325		

PNL-7289
UC-600

SPAWNING AND ABUNDANCE OF FALL CHINOOK SALMON (ONCORHYNCHUS TSHAWYTSCHA) IN THE HANFORD REACH OF THE COLUMBIA RIVER, 1948-1988

D. D. Dauble
D. G. Watson

March 1990

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

Historically, fall chinook salmon spawned in the mainstem Columbia River from near The Dalles, Oregon, to the Pend Oreille River in Idaho, a distance of nearly 900 km. Today, however, the 90-km-long Hanford Reach of the Columbia is the only significant mainstem spawning habitat remaining for upriver bright (URB) stocks of fall chinook salmon. This report attempts to summarize factors influencing the abundance of fall chinook salmon in the Hanford Reach from 1948 to present. The review also identifies research needed for effective management of this valuable resource.

Aerial counts of chinook salmon redds have been conducted since 1948 at Hanford to provide an index of relative abundance among spawning areas and years. The counts also have been useful to document the onset of spawning and determine intervals of peak spawning activity. Spawning for fall chinook salmon in the Hanford Reach usually has extended from mid-October to the third week in November. Time of first-observed spawning ranged from September 28 to October 26 with a median date of October 16. The median date for peak spawning, or the date of the highest total redd count, was November 11. Estimated numbers of visible redds ranged from a low of 65 in 1955 to a high of 8630 in 1987. Redd counts from the Vernita Bar and Upper Locke Island areas averaged 33% and 25% of the total, respectively, for the 41 years of record. Fall chinook salmon spawned at temperatures (daily average ranging from 12.0 to 18.5 °C). Weekly mean temperatures during peak spawning averaged 12.5 °C. Weekly average flows during peak spawning ranged from 1244 to 3276 m^3/s (44,000 to 116,000 ft^3/s) and averaged 2203 m^3/s (78,000 ft^3/s) from 1948 to 1988.

In aerial counts, the primary physical factors influencing the ability to observe redds included depth of water over the redds **and** clarity of the water. Wind action, available light, orientation of the river, and direction of the current also influenced redd counts. Field measurements suggest that the upper depth limit for detecting redds during aerial surveys conducted in 1988 was 3-4 m. Other studies indicate that fall chinook salmon spawn at depths ranging to about 8 m. Thus, a large, but unknown proportion, of redds in deeper water are not detected during aerial surveys.

Returns of adult fall chinook salmon to the Hanford Reach have increased dramatically in recent years. The increase in number of spawners reflects, in part, continued supplementation efforts at the Priest Rapids Hatchery. The relative contribution of URB stocks to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s to

50-60% of the total. The relative contribution of URB to the commercial, tribal, and sport fisheries has also increased since 1980.

A number of factors affect the abundance of fall chinook salmon in the Hanford Reach. For example, increased variability in river flow during spawning, incubation, and hatching has created major changes in environmental conditions over the last 40 years. Juvenile and adult passage at hydroelectric dams and harvest management practices also affect the number of fish returning to the Hanford Reach to spawn. Also, hatchery production has supplemented wild run production since the early 1960s, resulting in increases in the number of fall chinook salmon in recent years. Juvenile and adult passage at hydroelectric dams and harvest management practices also affect the number of fish returning to the Hanford Reach to spawn.

The status of fall chinook populations needs to be monitored because present and planned activities could have a major impact on their survival in the Columbia River. Research needs for effective management of fall chinook salmon production in the Hanford Reach include efforts to:

- improve methods for documenting the location and extent of spawning areas
- characterize habitat requirements, and determine production potential
- evaluate current supplementation programs
- maintain flow policies, and design them to protect all life stages of fall chinook salmon
- ensure adequate protection of the Hanford Reach against future development.

ACKNOWLEDGMENTS

We appreciate the thorough reviews conducted by C. Dale Becker of Pacific Northwest Laboratory (PNL) and Mike B. Dell of Grant County Public Utility District in Ephrata, Washington. George Swan (National Marine Fisheries Service, Pasco, Washington) and Mike Dell also provided reports and data from personal files. William Rickard, Robert Gray, and Richard Jaquish provided additional support. Georganne O'Connor of PNL provided editorial assistance.

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The Hanford Reach of the Columbia River provides the only major spawning habitat for the upriver bright (URB) race of fall chinook salmon (Oncorhvnchus tshawvtscha) in the mainstem Columbia River. These salmon are important to sport, tribal, and commercial fisheries because of their abundance and because they retain color and high oil content throughout their upstream spawning migration. Fall chinook salmon migrate upstream to spawning areas in the Hanford Reach from mid-August through October; they dig redds and deposit eggs from late October to late November. Embryonic development occurs in the gravel over the winter, and fry emerge in March through May. Fish rear in the main river and backwater areas for a short period before migrating seaward in late June and July (Becker 1973; Page et al. 1982).

Hanford Site biologists have conducted aerial surveys of spawning salmon in the Hanford Reach since 1948. The objective of early surveys was to determine if effluents from plutonium production reactors on the U.S. Department of Energy's (DOE) Hanford Site affected the abundance or distribution of fall chinook salmon. The DOE has continued to fund redd surveys even though the last production reactor was shut down in 1971. The annual surveys provide a continuous data base or index of abundance for 41 years of redd counts for fall chinook salmon. In addition, recent studies by public utilities, state and federal fisheries management agencies, and Indian tribes have extended the knowledge of fall chinook salmon populations in the Hanford Reach.

This report summarizes data on fall chinook salmon spawning in the Hanford Reach and presents a discussion of factors that may affect population trends. Most data are limited to fisheries agency reports and other working documents. Earlier reports by Watson (1970, 1976) provided information on fall chinook salmon spawning from 1947 to 1975. Information on anadromous salmonids associated with the Hanford Reach was summarized by Becker (1985). However, fisheries management practices in the Columbia River system have changed rapidly over the last decade, particularly under requirements of the Pacific Northwest Power Planning and Conservation Act of 1980 (CRFC 1981). New information has been generated and included in this report.

2.0 BACKGROUND

This section describes the study area and reviews migration and genetic characteristics of fall chinook salmon that affect their management and abundance. Also described is how historical development activities have influenced present dismbution of fall chinook salmon in the Columbia River.

2.1 STUDY AREA

The Hanford Reach, a 90-km segment of the Columbia River extending from the upper end of McNary Dam Reservoir (near the downstream border of the Hanford Site) to Priest Rapids Dam, remains essentially free-flowing (Figure 2.1). Flows through the Hanford Reach are regulated by releases at Priest Rapids Dam (river km 639) and other upstream dams. Daily average discharges vary seasonally and range from about 1140 to 7070 m^3/s (40,000 to 250,000 ft^3/s). The Federal Energy Regulation Commission (FERC) has established minimum licensed flows of 1086 m^3/s (36,000 ft^3/s) at Priest Rapids Dam. Beginning with construction of Bonneville Dam in 1938 and ending with John Day Dam in 1967, 11 hydroelectric dams were constructed on the Columbia River (below the Canadian border) (Figure 2.1). These dams now block access or inundate most spawning sites used historically by fall chinook salmon in the mainstem Columbia River.

2.2 MIGRATION PATTERNS AND GENETIC CHARACTERISTICS

Fall-run chinook salmon are separated from other runs of chinook salmon primarily by their period of adult migration. Typically the fall race enters the lower Columbia River in late July and August. The Army Corps of Engineers includes all adult migrants counted after July 31 at Bonneville Dam, the first mainstem dam above the mouth of the Columbia River (river km 235), as fall run fish. Because run timing is later for fish passing dams further upstream, the date separating the summer and fall runs of chinook salmon becomes later as fish migrate upstream to Hanford For example, all chinook salmon passing McNary Dam (river km 470) after August 8 and Priest Rapids Dam after August 13 are counted as fall-run fish. The major migration period for adult fall chinook salmon over McNary Dam has occurred during September (Figure 2.2). This interval coincides with a seasonal decline in maximum yearly water temperatures in the Hanfaord Reach (US DOE 1988). Peak of the rnigration over Ice Harbor and Priest Rapids dams was about one week later than McNary Dam because of the greater migration distance.

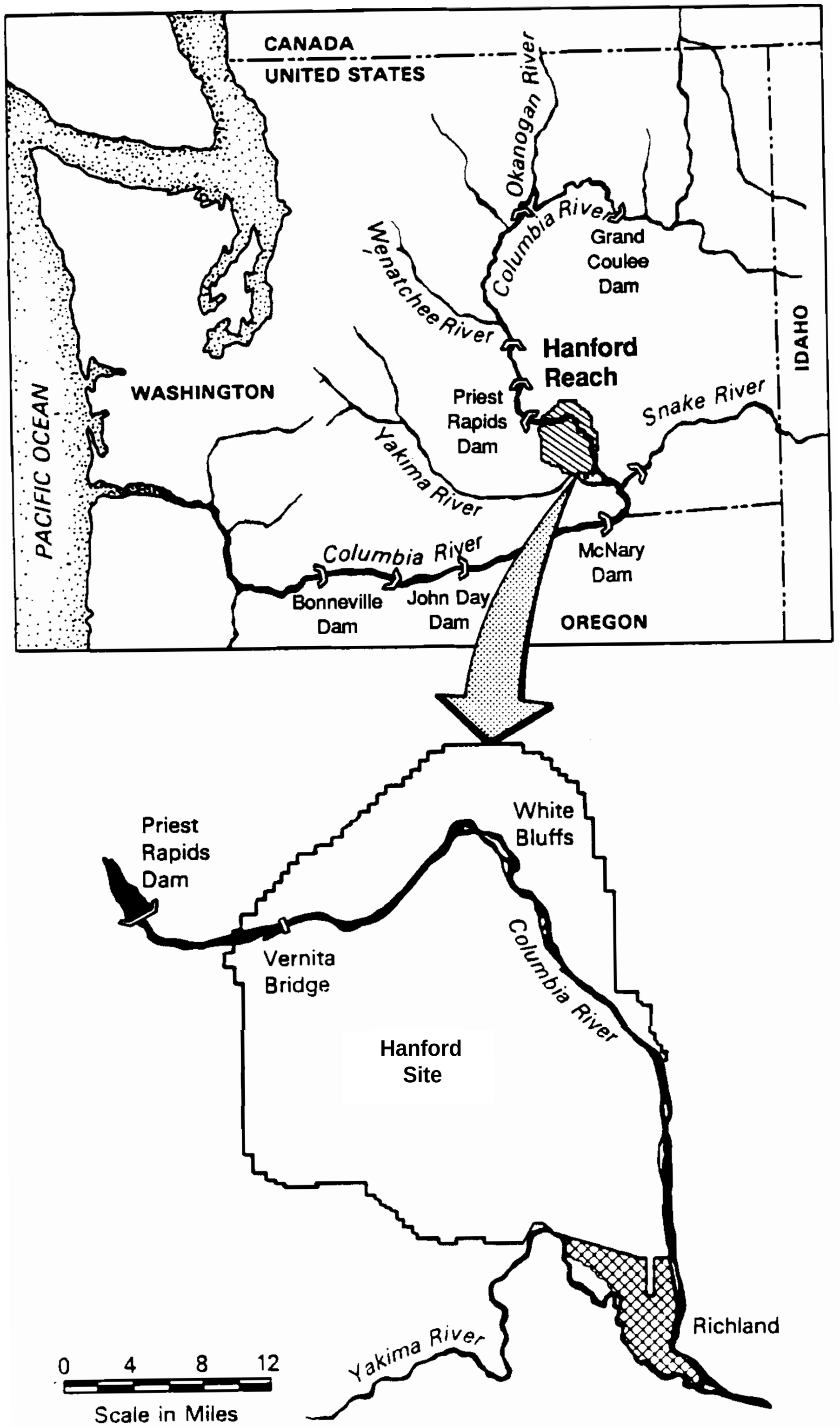

FIGURE 2.1. Location of the Study Area in southeastern Washington State

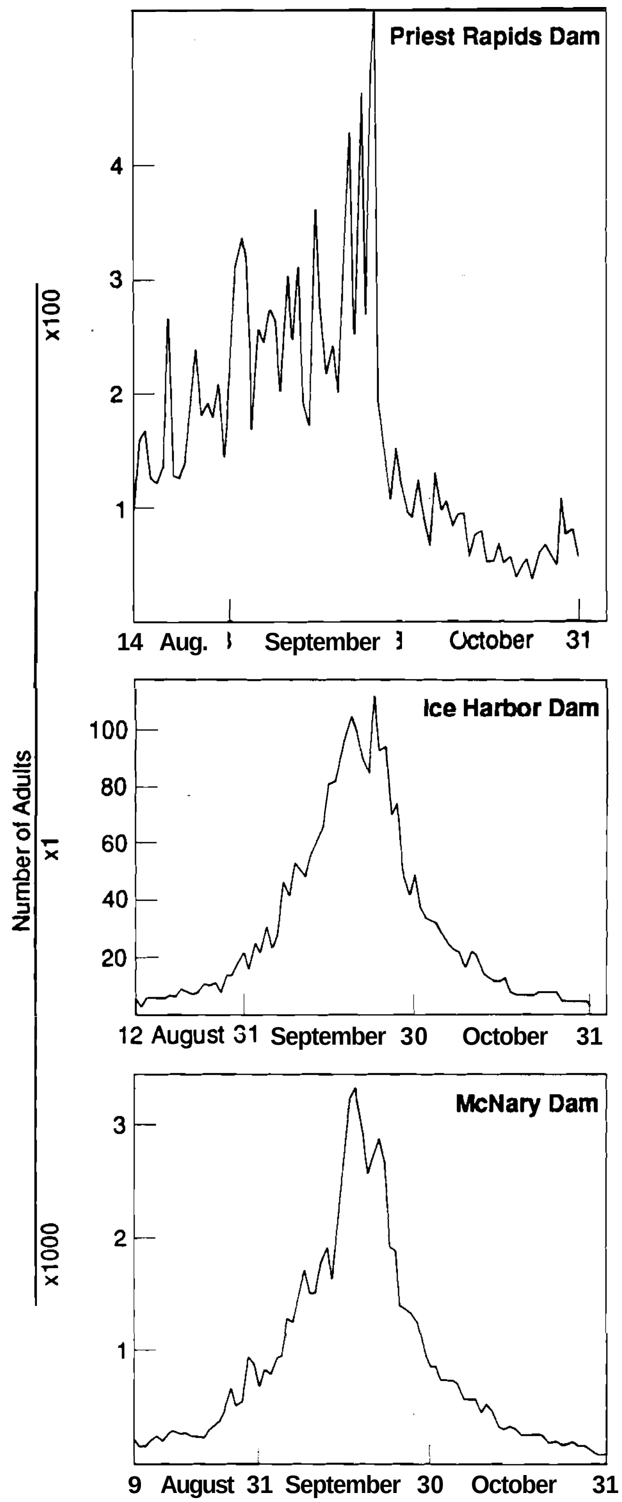

FIGURE 2.2. Run Timing for Fall Chinook Salmon Migrating Upstream past McNary, Ice Harbor, and Priest Rapids Dams, 1980 to 1988

The fall chinook salmon run entering the Columbia River is currently separated and managed by fisheries agencies as four stocks: upriver brights (URB), Bonneville Pool Hatchery stock (BPH), lower Columbia River Hatchery stock (CRH), and lower Columbia River Wild stock (CRW). The lower Columbia River stocks (wild and hatchery fish spawning below Bonneville Dam or in tributaries of the Bonneville pool) are usually designated as tules. The URB stock is primarily wild or naturally spawning and comprises populations originating from such tributaries are the Deschutes and Snake Rivers, and from the mid-Columbia River (primarily the Hanford Reach). The Hanford Reach is the only significant mainstem spawning habitat remaining for fall chinook salmon above Bonneville Dam.

The present population of URB fall chinook in the Columbia River is thought to be essentially genetically pure (Homer and Bjornn 1979). However, tule-type fall chinook salmon were periodically released from the Washington State Department of Fisheries rearing ponds at Ringold from 1963 to 1985 (M. B. Dell, Grant County P.U.D, personal communication). Fish production at the Priest Rapids Dam rearing facility has also been supplemented with eggs from the Bonneville Dam Hatchery. Adults from both the Ringold and Priest Rapids facilities return to spawn in the Hanford Reach along with their wild cohorts. Young (1980) and Young and Arthur (1982) estimated that 8% of the naturally spawning adult fall chinook salmon in the Vernita Bar area (river km 633) originated from the Priest Rapids Hatchery stock in 1979 and 27% in 1980. Thus, wild and hatchery stocks mix genetically when spawning in the Hanford Reach.

2.3 PAST AND PRESENT DISTRIBUTION OF FALL CHINOOK SALMON

Historically, fall chinook salmon spawned in the mainstem Columbia River from near The Dalles, Oregon (river km 308), upstream to the Pend Oreille and Kootenay rivers in Idaho (river km 1200, see Figure 2.3). Additional spawning areas were located in the lower Snake River (Fulton 1968). There may be some overlap with the earlier-spawning summer race of fall chinook salmon in the upper Columbia River drainage because of similar life history patterns. Current separation is based on run timing over dams (reviewed in Mullan 1987) Access of fall chinook salmon to the upper portion of the Columbia River drainage was blocked by Grand Coulee Dam at river km 959 in 1941 (Chapman 1943). Construction of McNary Dam in 1953 and John Day Dam in 1968 inundated about 200 km of additional mainstem spawning habitat (Van Hyning 1973). There is some evidence that construction of the Dalles Dam may have displaced spawners to upstream areas. Celilo Falls, which was almost impassable to adult salmonids during low flows,

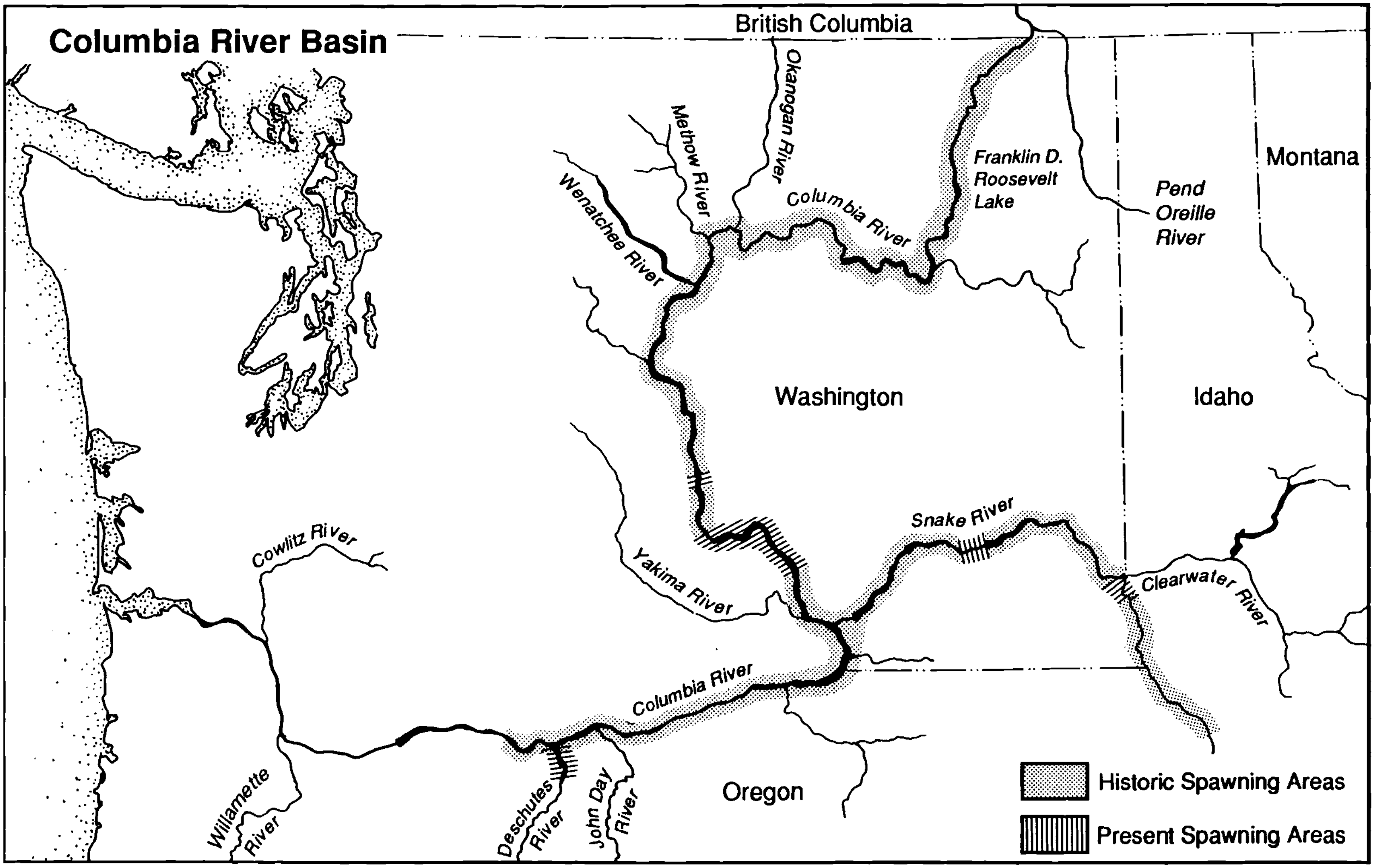

FIGURE 2.3. Comparison of Historical and Present-Day Spawning Sites for Fall Chinook Salmon in the Columbia River Drainage

was flooded out by The Dalles Dam in 1957. Removal of this potential barrier to upstream migration may have increased access of fall chinook salmon to additional upstream production areas (including the Hanford Reach) for spawning and rearing. For example, run size over McNary Dam averaged about 8600 adult fall chinook salmon for 1954 to 1957. This increased to about 62,000 adults per year for the three years following construction of The Dalles Dam. A listing of hydroelectric dams in the Columbia River and their construction dates, locations, and relative size is provided in Table 2.1.

Currently, most URB chinook salmon of natural origin come from the Hanford Reach. Minor spawning areas are located in the lower Deschutes and Yakima rivers. Some URB also spawn in the mainstem Columbia below Wanapum and Rock Island dams (Homer and Bjornn 1979). The URBs are also artificially produced at the Priest Rapids Hatchery and released below Priest Rapids Dam (river km 639) and sometimes farther downstream at the Ringold rearing facility (river km 577).

There is no evidence that spawning habitat limits fall chinook salmon production at current escapement levels to the Hanford Reach. However, less than half of all known spawning sites have been characterized. Optimal escapement values for the wild URB fall chinook salmon are currently being studied with Pacific Salmon Treaty funds (Norman 1987; De Vore 1989). Spawning habitat was not perceived as a limiting factor to fall chinook salmon production by

TABLE 2.1. Construction Timeline and Other Characteristics for Dams on the Mainstem Columbia River (Source: USACE 1975)

Project Name	Year Completed	River km	Reservoir Length (km)	Active Storage (Acre ft)
Bonneville	1938	239	77	87,000
The Dalles	1957	309	39	53,000
John Day	1968	348	121	535,000
McNary	1953	470	95	185,000
Priest Rapids	1959	639	90	45,000
Wanapum	1963	668	29	161,000
Rock Island	1933	729	32	9,000
Rocky Reach	1961	763	68	36,000
Wells	1967	330	45	125,000
Chief Joseph	1955	877	82	115,000
Grand Coulee	1941	961	243	5,232,000

fisheries management agencies in 1982, given a spawning escapement goal of 40,000 adults above McNary Dam (TAC 1982). However, this assessment may need revision because current escapement to the Hanford Reach now approaches 100,000 adult spawners annually.

3.0 HANFORD REACH SPAWNING SURVEYS

This section describes fall chinook salmon redds were surveyed in the Hanford Reach, provides estimates of redd abundance by river location, and summarizes river temperatures and flows during spawning. Also discussed are how physical habitat variables influence distribution of redds in the Hanford Reach and factors that limit estimates of redd abundance.

3.1 SPAWNING SURVEY METHODS

Aerial counts of chinook salmon redds (spawning surveys) have been conducted annually at Hanford since 1948 from fixed-wing aircraft. One to seven surveys were flown each year at approximately weekly intervals over the spawning period from late September to November. Estimates of the number of redds were made at altitudes of 800 to 1200 ft (244 to 366 m) and at air speeds of 75 to 100 miles (120 to 161 km) per hour. When salmon redds were widely spaced, they were enumerated individually. When redds were close together or overlapped, they were estimated in units of 10 or 50. Two or more counts were made of areas of heavy spawning for each survey. Estimates of the number of redds were also compared between observers whenever possible. The angle of approach of the airplane was varied to obtain optimum visibility. Counts were usually obtained near mid-day with the sun at the observer's back, and polarized glasses were sometimes worn to reduce glare.

Aerial surveys are more effective in the Hanford Reach than in some other river systems because of the large size of the redds and the general clearness of the water. Average area of completed chinook salmon redds in the upper Hanford Reach was about 17 m^2 (Chapman et al. 1986), or about four times larger than redd sizes found in smaller rivers (Burner 1951). Secchi disc measurements (an indication of water clarity) at Priest Rapids Dam were consistently high and ranged from 3.0 to 4.5 m during October and November, 1976-1982 (Chapman et al. 1983).

Newly excavated redds appear from the air as light-colored, regularly shaped circular or oval areas that contrast with the normally darker periphyton-covered substrate. The redds remain visible for about 6 weeks before their surface becomes recolonized by algae growth. Thus, some redds counted at the beginning of the spawning period may not be visible by the end of spawning.

Redd counts in the Hanford Reach were made by D.G. Watson in all but 4 of 41 consecutive years of observation. Counts were made by R.F. Foster in 1947 and 1948, and by W.G. Hanson in 1957 and 1958. D.D. Dauble assisted with counts in 1987 and 1988. Because one observer made most of the estimates, year-to-year variation in counts was assumed to be consistent with that observer's ability to estimate. However, estimates can be expected to vary. between observers. For example, in one study of salmon spawning (where fish numbers were estimated in groups of 100 and 1000), a lack of precision between observers resulted in variances of ± 50% (Bevan 1961).

Aerial surveys provide a year-to-year index of relative abundance and variation in redd numbers. The estimates reported here are not absolute measures of the spawning population, because of highly variable conditions under which surveys must be conducted. Major variables that affect the accuracy of aerial surveys include river discharge, depth of spawning, cloud cover, and turbulence caused by winds (see Section 3.5).

Aerial surveys are useful to document the onset of spawning and to determine intervals of peak spawning activity. They also provide information on other qualitative aspects such as habitat selection and species interactions (Heggberget et al. 1986). Follow-up surveys with SCUBA (Swan et al. 1988) help delineate the boundaries of use in deeper water where redds are not visible from aircraft.

3.2 TIMING AND ABUNDANCE OF SALMON SPAWNING

Spawning for fall chinook salmon in the Hanford Reach usually extended from mid-October to the third week in November. Time of the first-observed spawning ranged from September 28 to October 26 with a median date of October 16 (N = 40). If initiation of spawning is taken as the interval where >5% of the peak count was first recorded, the median date would be about 1 week later, at October 24. We defined peak spawning as the date of the highest total redd count, and this ranged from October 26 to November 26 (N = 40). The median date for peak spawning was November 11. Peak spawning, as used here, does not represent the specific time of maximum redd construction because the redd count for each survey is a cumulative estimate of redds constructed prior to the survey date.

Counts of visible redds from 1948 to 1988 are summarized by designated spawning area in Table 3.1. Corresponding locations for the 10 designated areas are shown in Figure 3.1. Redds observed outside these 10 areas are included in the "other" column. Most of the "other" redds reported since 1980 were located at China Bar, a man-made shoal constructed near river km 628. The yearly redd total was calculated using peak counts from within each of the designated areas. The maximum count for an individual survey was not used because the date for peak spawning sometimes differed among spawning areas. This was mainly because of variations in conditions within and among the spawning surveys.

TABLE 3.1. Summary of Peak Redd Counts for 10 Designated Areas, 1948-1988

Year	Number of Redds											
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9	Area 10	Other	Total
1948	120	330	0	38	69	83	90	2	0	53	2	787
1949	45	51	0	9	156	26	13	6	1	1	6	334
1950	24	35	0	36	74	58	14	9	3	44	0	315
1951	5	7	3	45	90	38	21	2	5	95	3	316
1952	73	1	0	0	0	1	0	0	23	40	3	539
1953	7	5	0	10	38	0	10	0	0	83	0	145
1954	4	12	0	8	83	44	1	0	7	6	0	167
1955	0	11	0	0	34	12	1	1	0	3	0	65
1956	0	3	0	7	40	17	0	6	0	17	0	94
1957	17	87	15	39	170	34	90	1	42	100	1	648
1958	32	87	100	99	223	45	64	48	130	176	2	1215
1959	1	0	0	36	60	40	1	0	32	111	0	281
1960	0	0	31	19	67	23	9	0	34	90	0	295
1961	0	15	12	49	86	46	7	4	23	640	0	940
1962	5	75	120	66	262	98	88	1	1	405	0	1260
1963	0	122	159	116	345	56	100	3	13	396	1	1318
1964	5	55	94	110	245	99	119	26	36	624	0	1511
1965	4	136	123	202	345	50	112	11	54	652	3	1778
1966	10	132	140	267	697	230	270	2	37	1300	0	3116
1967	34	205	160	248	499	155	455	28	17	1340	1	3343
1968	130	250	320	186	437	135	182	19	52	1500	5	3649
1969	252	401	410	427	903	126	362	30	50	1075	4	4322
1970	90	367	230	302	746	159	259	2	72	1486	9	3815
1971	183	374	180	386	740	72	230	24	10	1361	3	3601
1972	77	131	103	131	110	52	74	0	4	127	0	876
1973	121	330	123	170	722	176	283	29	59	882	5	3033
1974	76	113	28	49	86	47	67	0	4	153	3	728
1975	68	263	140	261	373	79	215	52	86	995	1	2683
1976	17	162	140	185	384	105	140	7	182	599	0	1951
1977	7	291	140	355	1136	161	263	8	47	760	0	3347
1978	18	156	60	326	789	74	386	73	145	975	0	3064
1979	66	229	145	297	672	172	257	42	92	980	0	2975
1980	29	112	32	64	194	33	119	0	35	856	0	1487
1981	82	222	190	270	1103	151	553	58	80	2120	0	4866
1982	7	149	210	278	1102	160	560	79	149	2060	12	4988
1983	24	284	200	511	1310	198	453	33	43	2216	0	5290
1984	88	514	190	1052	1920	85	853	87	55	2314	7	7342
1985	12	624	250	770	1949	370	863	152	107	2411	15	7645
1986	14	490	250	672	1810	370	1074	213	73	3082	22	8294
1987	251	780	320	900	1870	95	951	142	74	3150	27	8630
1988	264	715	330	828	1680	310	870	202	123	2742	48	8485

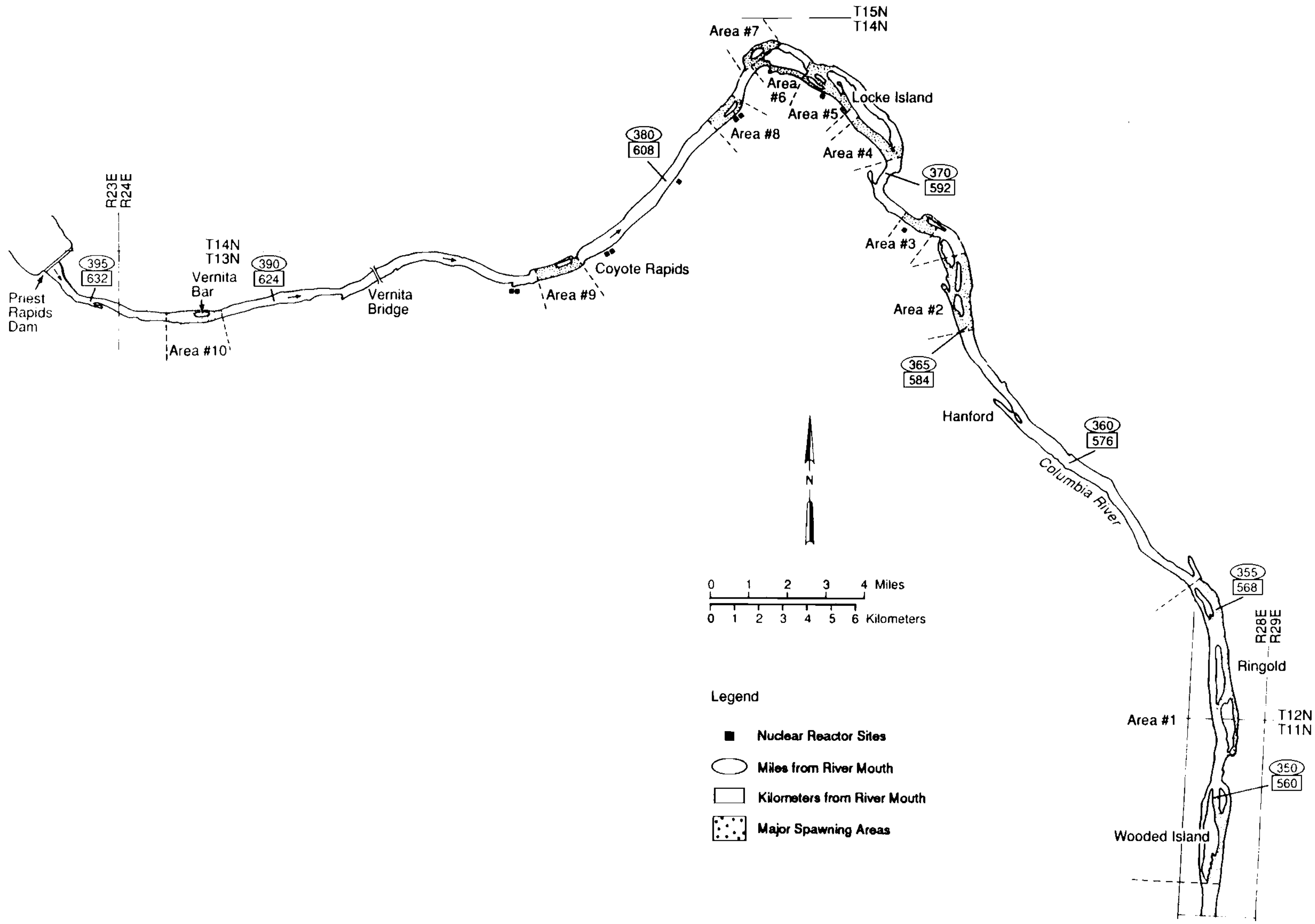

FIGURE 3.1. Major Fall Chinook Salmon Spawning Areas in the Hanford Reach of the Columbia River

Estimated numbers of visible redds ranged from a low of 65 in 1955 to a high of 8630 in 1987. Area 10 (Vernita Bar) and Area 5 (Upper Locke Island) were the most important spawning areas. Redd counts in these locations averaged 33 and 25% of the total, respectively, for the 41 years of record. Areas 2, 4, 6, and 7 collectively contained about 33% of the total redds from 1948 to 1988. Although the number of redds increased dramatically for Area 10 (Vernita Bar) after construction of Priest Rapids Dam (an average of 16% of the redds were counted there before 1960), changes in counts from other spawning areas generally reflected changes observed for the entire Hanford Reach. Minor spawning areas (average contribution <5% of the total number of redds observed) contributed up to 20% of the total redds observed for certain years. However, changes in their relative importance appeared related to a decrease in the number of fish spawning in the major spawning areas, rather than an increase in use of minor spawning areas. A summary of the Hanford spawning surveys by date and location is provided in Table A.1.

Trends in the number of redds observed at Hanford from 1948 to 1988 are shown in Figure 3.2. Redd counts ranged from <100 to about 1200 per year from 1948 to 1962. Counts increased to a peak of 4322 redds in 1969, then averaged about 2300 redds/year from 1971 to 1980. The number of redds increased steadily in the 1980s, and averaged over 8000 redds annually from 1985 to 1988.

Data from 1964 to 1988 was used to determine if there was a relationship between Hanford Reach redd counts and the escapement of adult fall chinook (Figure 3.3). This analysis indicates a strong correlation between the two variables. A plot of the residuals indicates that use of this regression equation to predict escapement may be limited at counts of <1000 redds. The redd-to-fish ratio also provides a population index. The redd-to-fish ratio based on adults plus jacks averaged 16.3:1 for 1964 to 1988 (range 5-39:1). A less variable ratio is achieved using dam passage counts of adults only (average 9.4:1, range 3.1-16:1). The wide range in redd-to-fish ration shows the limited value of redd counts to obtain precise estimates of spawning populations.

3.3 TEMPERATURE AND FLOWS IN THE HANFORD REACH DURING SPAWNING

The range of temperatures over which fall chinook salmon spawn in the Hanford Reach each fall reflects the seasonal temperature cycle occurring in the Columbia River (Figure 3.4). Temperatures average about 16°C on October 1 and decline to about 9°C by the end of November. Fall chinook salmon spawned at temperatures (daily average) ranging from 12.0 to 18.5°C.

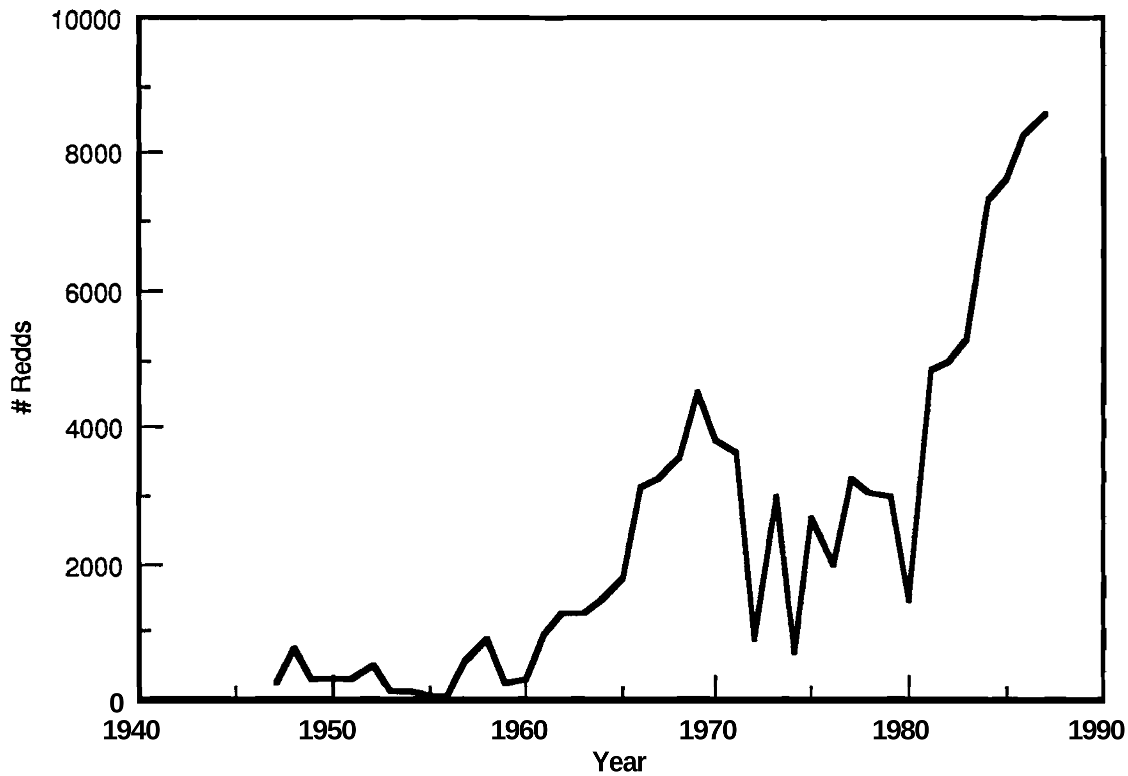

FIGURE 3.2. Long-Term Trend for Salmon Redds Observed During Aerial Surveys of the Hanford Reach

Weekly mean temperature at first observed spawning was 15.3°C for the 41 years from 1948 to 1988. About 75% of the spawning was initiated at weekly mean temperatures of 14 to 16°C (Figure 3.5). Daily average temperatures at peak spawning ranged from 6.8 to 15.5°C (median temperature 11.9°C). Weekly mean temperatures during peak spawning averaged 12.5°C for 1948 to 1988 (Figure 3.6). There was no significant difference ($t = 0.931$; $p = 0.36$) between weekly mean temperatures before and after construction of Priest Rapids Dam for the peak spawning period.

Daily average flows during redd surveys ranged from 1410 to 3790 m^3/s (50,000 to 134,000 ft^3/s) from 1948 to 1988 ($N = 182$). Weekly average flows during peak spawning ranged from 1244 to 3276 m^3/s (44,000 to 116,000 ft^3/s) and averaged 2203 m^3/s (78,000 ft^3/s) over this interval (Figure 3.7). The range of daily average discharge noted during peak spawning (Figure 3.8) ranged from about 1200 to 3800 m^3/s from 1959 to 1985.

Weekly average flows during peak spawning were significantly higher (Mann-Whitney U Test: $Z = -1.758$; $p = 0.08$) after construction of Priest Rapids Dam. Weekly average flows during peak spawning averaged 2005 m^3/s (71,000 ft^3/s) from 1949 to 1959 (before the dam was

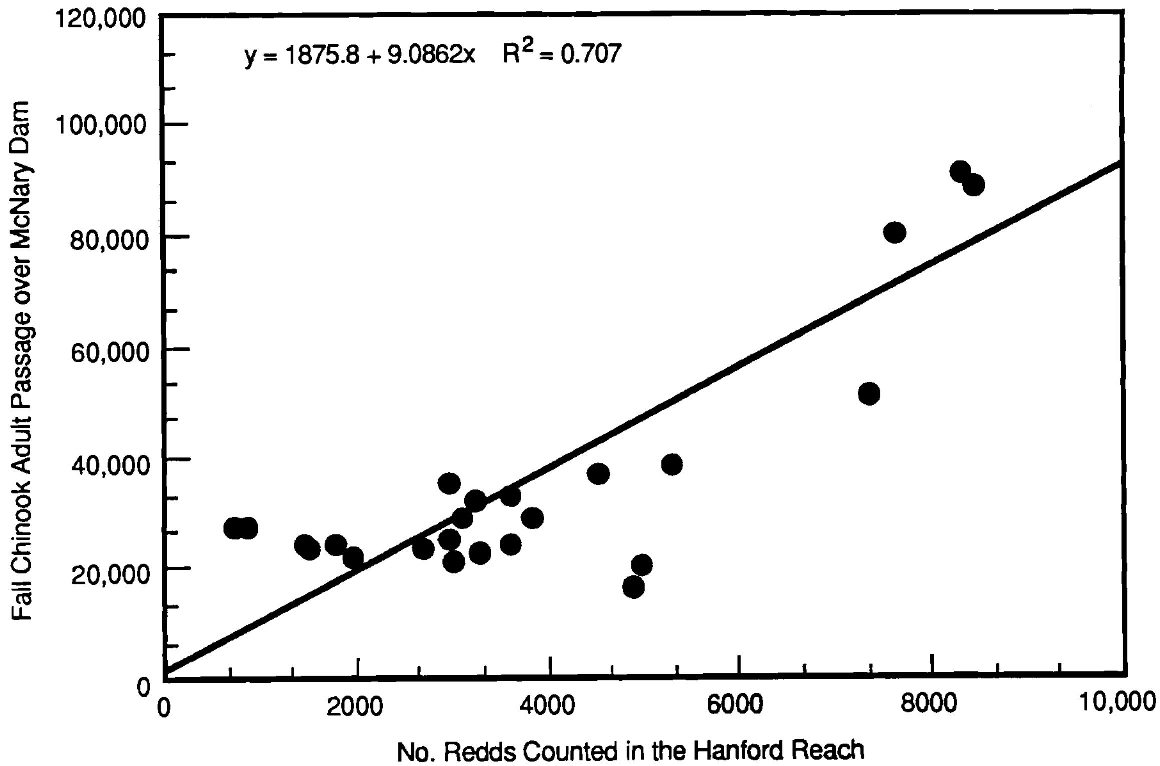

FIGURE 3.3. Relationship Between Adult Escapement over McNary Dam and Hanford Redd Counts

built) and 2287 m^3/s (81,000 ft^3/s) from 1960 to 1988. Increased flows are more likely due to changes in upstream storage practices rather than operation of Priest Rapids Dam because of its limited storage capacity relative to Grand Coulee Dam. The effects of increased flow during spawning are unknown. Bauersfeld (1978) and Chapman et al. (1983) speculated that higher flows may provide more spawning habitat by increasing the relative amount of shoreline area (i.e., bottom area). However, this would only be true within limits of available substrate size and velocity.

3.4 PHYSICAL HABITAT VARIABLES AFFECTING DISTRIBUTION OF REDDS

In addition to temperature and flow, substrate and river velocity affect the spatial distribution of redds. The depth at which fall chinook salmon spawn depends on daily and seasonal flows (discharge plus spill) at Priest Rapids Dam. Maximum spawning depth cannot be determined by aerial surveys because visibility is limited to depths < 2 to 4 m. Chapman et al. (1986) characterized the distribution of redds at Vernita Bar with SCUBA and reported that the range in spawning depth (i.e., depths between redds) varied as much as 8.5 m. Maximum depths where spawning was observed were 7 m at mimimum regulated flows (1020 m^3/s). Daily flow

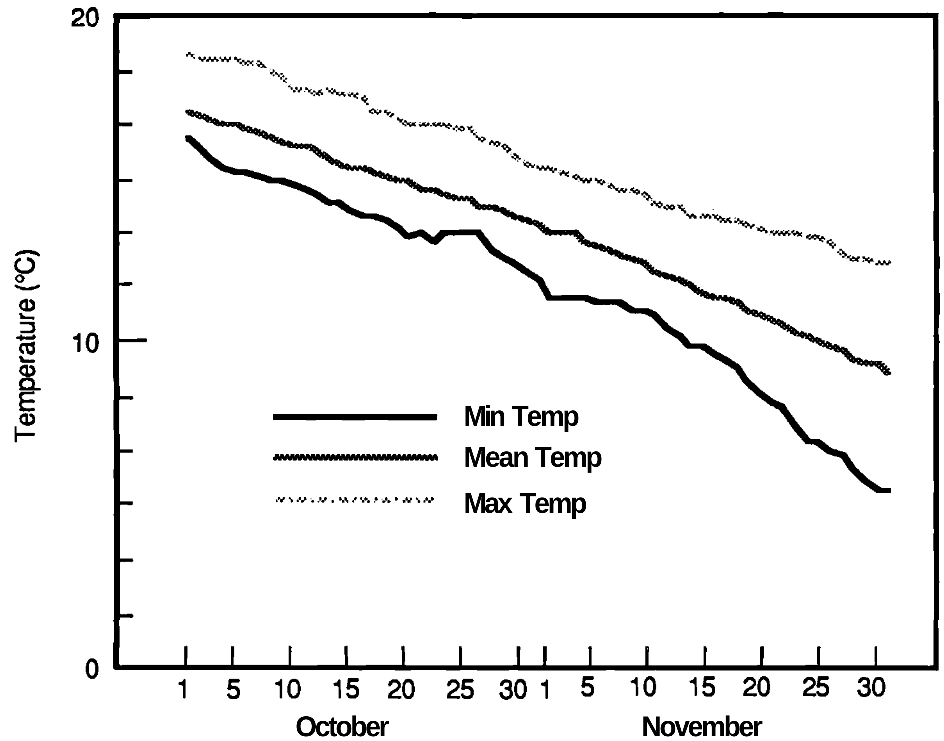

FIGURE 3.4. Daily Average Temperature Range **During** Fall Chinook Salmon Spawning, 1965 to 1985

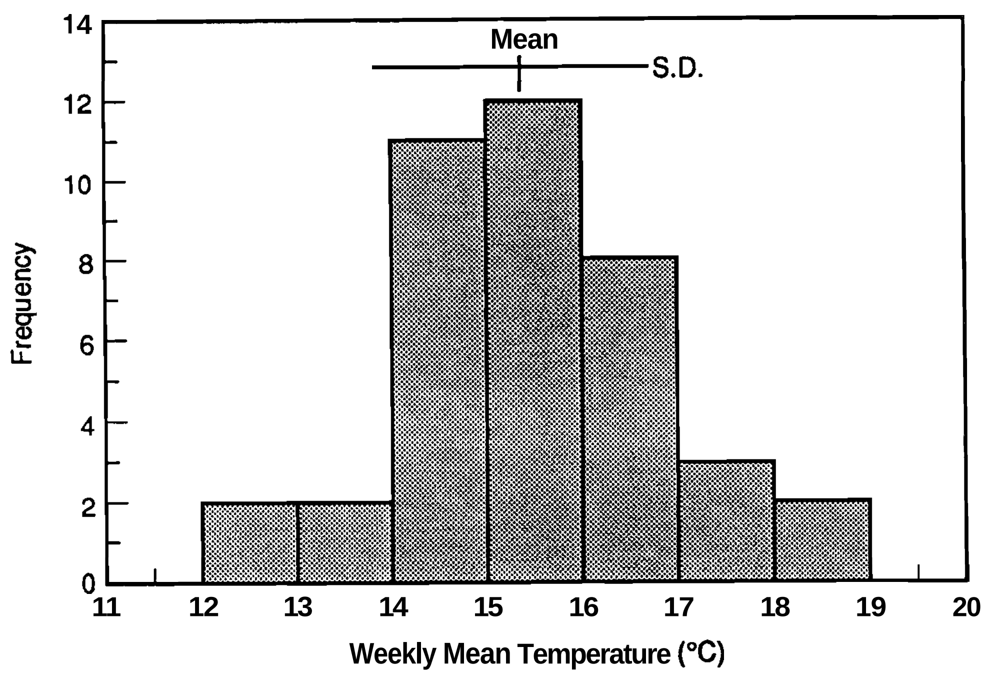

FIGURE 3.5. Frequency Plot of Weekly Mean Temperature at Fit Observed Spawning, 1949-1988

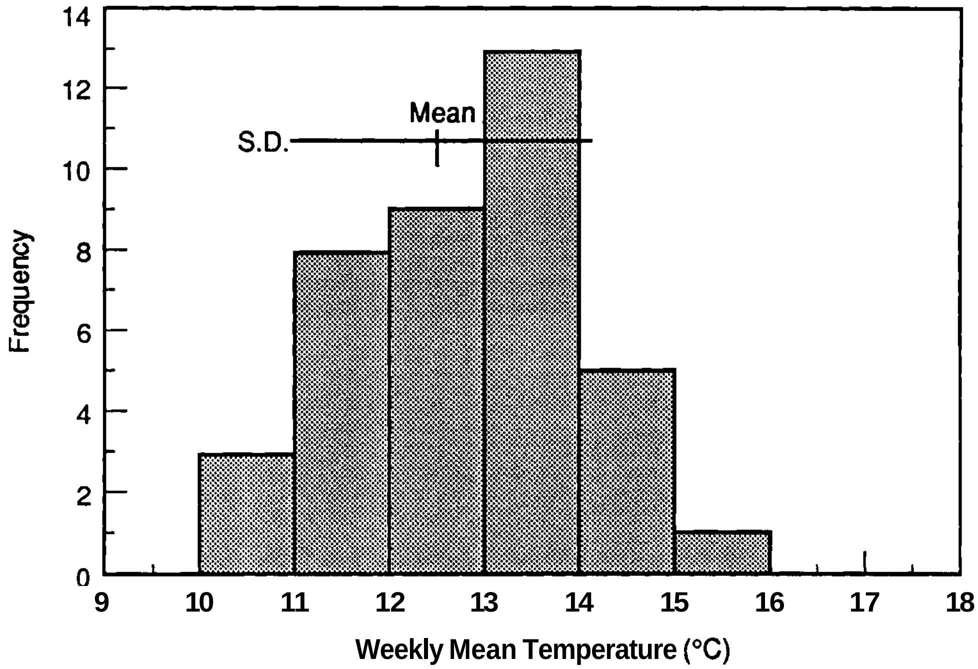

FIGURE 3.6. Frequency Plot of Weekly Mean Temperature at Peak Spawning, 1949-1988

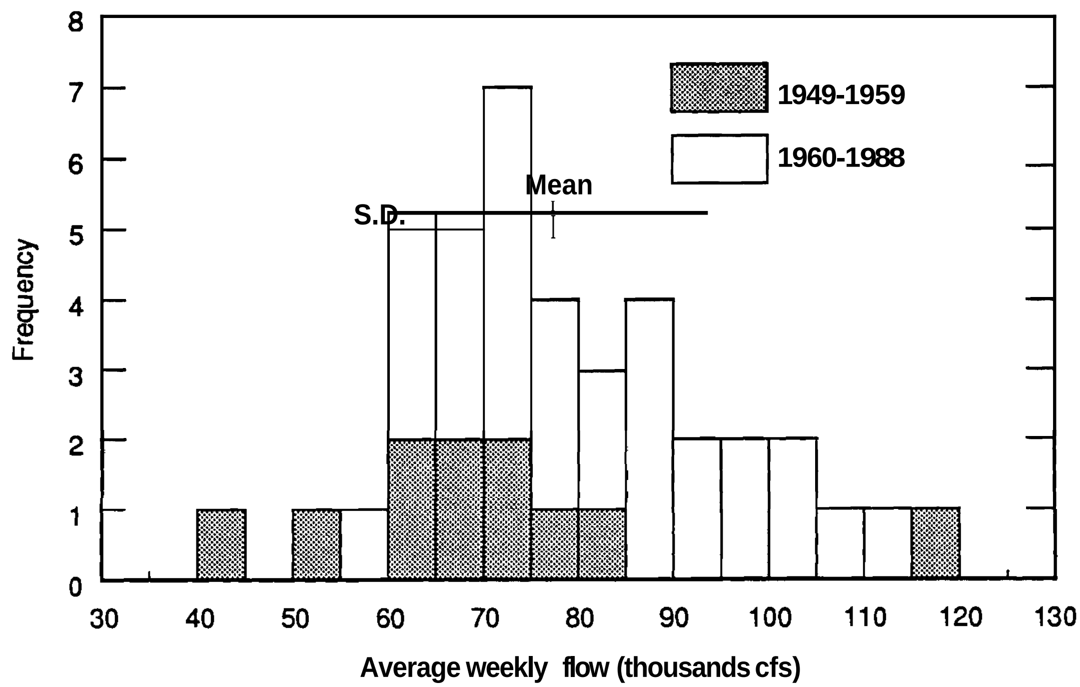

FIGURE 3.7. Frequency Plot of Average Weekly Flows During Peak Spawning. **A** comparison is made between flows before (1949-1959) and after (1960-1988) construction of Priest Rapids Dam.

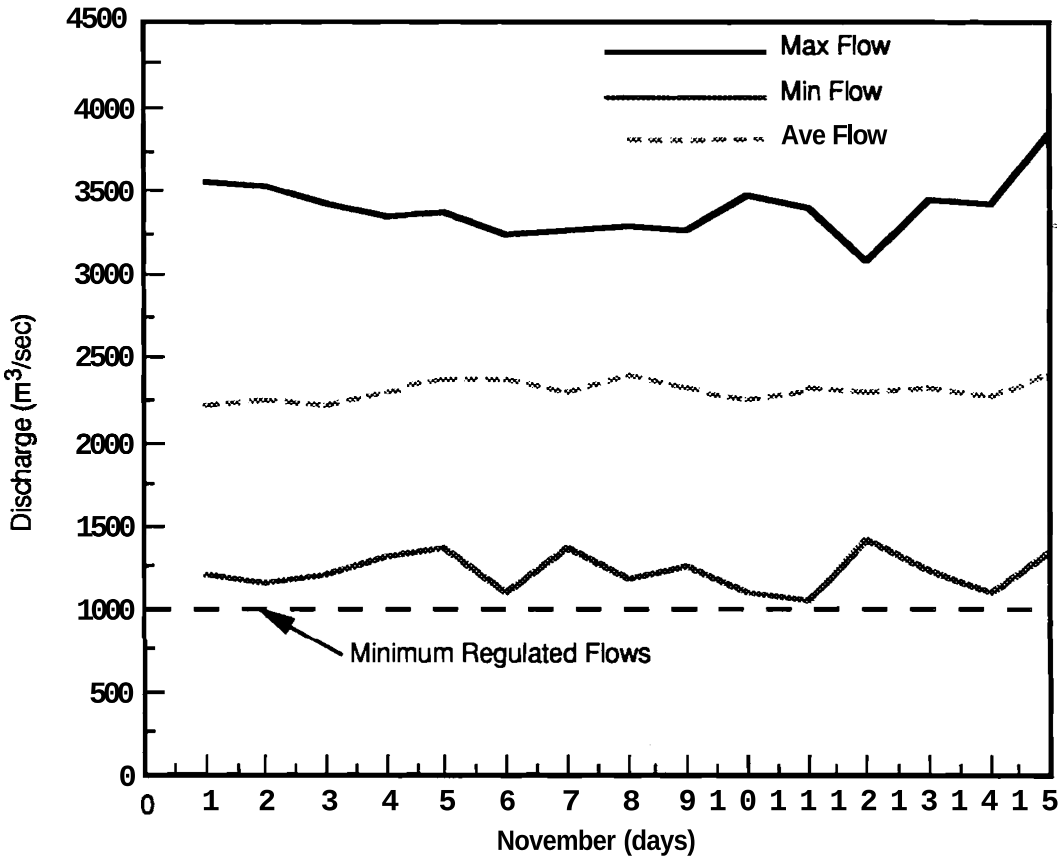

FIGURE 3.8. Range of Daily Average Discharge at Priest Rapids Dam During Peak Spawning, 1959-1985

patterns also influenced depths that salmon spawn. For example, fluctuations in discharge at Priest Rapids Dam caused water depths to fluctuate up to 4.5 m in areas where salmon spawned (Chapman et al. 1986).

To test the hypothesis that distribution of redds in the Hanford Reach was influenced by depth, the mean redd depth versus maximum channel depth (depths determined with the vegetation line representing the water surface) was plotted for five study areas in the upper Hanford Reach using data reported by Swan et al. (1988). Results indicated a nonsignificant regression between mean redd depth and channel depth ($F = 3.82$; $p = 0.15$). This suggests that, within these five locations, selection of spawning sites was not strongly influenced by available depth. Mean depth of redds in the study areas ranged from 1.0 to 7.5 m, where depth of channel ranged from 3 to 12 m. These depths are assumed high because the vegetation line is more indicative of annual average flows (3500 m^3/s) than average flows that occur during spawning (2200 m^3/s).

Presence of suitable substrate also affects the distribution of salmon redds. Substrate composition is usually characterized by visually estimating the composition of surface gravel (Platts et al. 1983). Other physical habitat variables that may influence selection of a spawning site (and survival of embryos and alevins) by adult salmon include percent fine sediments, dissolved oxygen, and intergravel permeability (reviewed in Chapman 1988).

Descriptions of five spawning areas reported by Swan et al. (1988) were used to evauate the importance of substrate type (as percent composition based on particle size) to redd location. The most abundant substrate at all but one spawning area was rubble (10 to 20 cm diameter), and 61% of all redds occurred on this substrate. The hypothesis that overall distribution of redds was proportional to the distribution of substrate was also tested and rejected at $P < 0.001$. Although a significant difference was found between available substrate and spawning locations for three of the five study sites (chi square analysis, $p > 0.5$), the Ho was rejected for spawning sites located at river km 594 and at river km 635. This suggests that redds were not equally distributed among available substrate types. Chapman et al. (1986) reported that 36% of the spawning substrate at Vernita Bar was cobble (rocks >76 rnrn diameter).

Salmon spawning at Hanford may also be influenced by flow velocities. A wide range in velocities over redd sites can be expected in the Hanford Reach because of fluctuating discharges at Priest Rapids Dam. Chapman et al. (1983) reported the near-bed velocities in spawning areas at Vemita Bar ranged from 0.20 to >1.95 m/s. A significant positive correlation ($r^2 > 0.82$) existed between depth and water velocity at each of three transects on Vemita Bar where data were collected (Chapman et al. 1983). Thus, these two variables cannot be treated independently. Although water velocity criteria for fall chinook salmon range from 0.186 to 0.805 m/s in Oregon (Smith 1973), chinook salmon spawn where velocities are as high as 1.14 m/s in the Columbia River (reviewed in Smith 1973).

3.5 MAJOR FACTORS INFLUENCING HANFORD REACH REDD COUNTS

Spawning surveys provided a relative measure of abundance for chinook salmon redds that can be observed from the air. The primary physical factors that influenced the ability to observe redds included depth of water over the redds and clarity of water. These factors are interrelated because water clarity also affects the maximum depth at which redds can be observed.

Wind action on the water surface reduced visibility, and strong winds influenced ability to control the position of the survey aircraft. Increased turbidity from eroded river banks and upstream construction activities also reduced visibility within localized areas. Available light also limits the effectiveness of observing redds because redds in the deeper areas are not visible under heavy cloud cover. Meteorologic and hydrologic conditions often changed during a single survey flight. Thus, parts of the approximately 70 km spawning area could not be surveyed with the same degree of accuracy.

Spawning areas near Vernita Bar were more subject to flow changes from daytime release of water from Priest Rapids Dam than were downstream locations. The high rocky bluff on the south side of the river also casts shadows over part of the spawning area during the latter part of the season. The orientation of the river and direction of the river current also change in the Hanford Reach. These factors affect the influence of light and wind on visibility.

Changes in water depth and weather often occurred during a single flight. For example, salmon redds may be viewed at Vernita Bar under one scenario (say, 40,000 ft^3/s) while redds viewed at Ringold (64 km downstream) may not experience similar flows until several hours later. Under the current operating regime at Priest Rapids Dam (i.e., decreased flows in the morning and increased flows at night since 1980), mid-day flows are always higher and depths greater at downstream locations than at Vernita Bar. Potential bias in redd counts because of inter-survey changes in water depth would be reduced only if minimum flow regimes were maintained at Priest Rapids Dam for >12 hr before aerial spawning surveys.

Beginning in 1979, redd surveys were conducted mainly on weekends because discharge at Priest Rapids Dam was usually regulated at lower levels. This schedule theoretically increased the likelihood of counting redds located in deeper water, which were not visible at higher flows. However, no significant difference (Mann-Whitney U Test: $Z = -0.563$; $P = 0.57$) was found between flows at surveys taken on weekdays from 1949 to 1978 and flows at surveys taken on weekends from 1979 to 1988. Thus, changes in redd counts since 1979 are not related to changes in daily average flow during surveys.

In 1988, unpainted sheets of plywood (–1.2 m x 2.4 m) were sunk at four different depths near river km 595. The depth of these bottom markers was then correlated with shoreline markers placed on a concrete boat ramp that were visible from the air. The maximum depth for observing the plywood markers during three separate aerial surveys was 4 m. Similar measurements of salmon redds located in the main river channel were made during aerial surveys by observers in a boat. Measured depths for redds visible from the air ranged to 3 m. Collectively, these observations suggest that the upper depth limit for detecting redds during aerial surveys in 1988 was between 3 and 4 m. This compares with studies on Vemita Bar by Chapman et al. (1983) that reported redds in water depths >2.4 m (8 ft) could not be observed from aircraft.

For some parts of the Hanford Reach, accurate estimates of salmon redds were difficult to determine during peak spawning because redds were concentrated in high-use areas. For example, Swan et al. (1988) estimated a range of redd densities from 12 to 48 redds/acre for five study sites in the Hanford Reach. Up to 186 redds/acre reported in areas of concentrated spawning. Extensive spawning on Vernita Bar (Area 10) and in Areas 2 through 7 results in superimposition and overlapping of redds. Chapman et al. (1983) reported that redd overlap occurred at the end of the spawning season because the early-spawning females could no longer defend their redds. Increased use of the Hanford Reach by returning adults may result in higher densities of redds if available spawning habitat is limited.

4.0 POPULATION CHARACTERISTICS

Management of anadromous fish populations is usually based on the annual escapement or numbers of fish returning to the spawning grounds. Estimates of adult spawners, eggs deposited, and subsequent survival of embryos and juveniles to catchable size (for both commercial and sport fisheries) can then be factored to evaluate population status. This section summarizes population characteristics that influence adult spawning and outmigration of juveniles in the Hanford Reach.

4.1 ESCAPEMENT ESTIMATES

There are no estimates of fall chinook escapement to the Hanford Reach before completion of McNary (1953), Ice Harbor (1962), and Priest Rapids dams (1959). However, an estimate of URB escapement to the Hanford Reach can be obtained if the ratio of URB to lower Columbia River stocks is assumed to be similar for the period immediately after dam construction (3 to 7 years). For example, from relative proportions of fish passing McNary Dam from 1954 to 1956 (before construction of the Dalles Dam), those passing Priest Rapids Dam from 1960 to 1967, and those passing Ice Harbor Dam from 1962 to 1967 (before construction of John Day Dam), escapement estimates for the Hanford Reach range from 13,300 to 76,200 chinook salmon for 1948 to 1953. This compares with estimates of total escapement (jacks + adults) above Bonneville Dam ranging from 33,307 to 190,505 fish from 1948 to 1953 (Watson 1970).

The current status of the URB population in the Hanford Reach was estimated from the number of fall chinook salmon passing McNary, Priest Rapids, and Ice Harbor dams (based on USACE annual fish passage reports). Because counts after 1964 separate adults and jacks, the maximum number of adults reaching the spawning grounds for the last 25 years can be estimated. Data on sex ratios, fecundity, spawning success, and fry survival can then be used to estimate the numbers of juvenile outmigrants.

Returns of adult fall chinook salmon to the Hanford Reach ranged from about 16,000 to 38,000 fish from 1964 to 1983. Returns increased dramatically, as has escapement over McNary Dam in recent years, and a peak estimate of 107,903 spawning adults was obtained in 1987 (Table 4.1). Estimated escapement to the spawning grounds from 1985 to 1988 was 16 to 22% lower than total returns because more fish were harvested by the sports fishery, and returns to the Priest Rapids Hatchery channel trap were increased. The increase in number of spawners reflects, in part, continued supplementation efforts at the Priest Rapids Hatchery. Current hydroelectric operations that allow increased flows during smolt outmigration may also increase survival of juvenile fall chinook from the Hanford Reach when they pass downriver dams.

TABLE 4.1. Estimated Run Size and Escapement of Fall Chinook Salmon to Spawning Grounds in the Hanford Reach, 1962-1988. Escapement equals passage of salmon over McNary Dam minus Ice Harbor and Priest Rapids dam passage totals, and are corrected to account for removal of fish by anglers and the Priest Rapids Hatchery. Estimates of escapement to the Yakima River, number of adults returning to the Priest Rapids Hatchery, and sport catch in the Hanford Reach are from Carlson and Dell (1989).

Year	Total Run Size	Total Adult Run	Spawning Escapement
1962	3,985	NA	NA
1963	26,263	NA	NA
1964	32,736	24,322	24,032
1965	42,823	24,500	24,360
1966	41,360	28,551	28,079
1967	41,710	23,393	23,188
1968	37,349	24,318	24,067
1969	49,501	35,366	34,939
1970	34,797	27,616	26,748
1971	48,123	32,404	31,398
1972	34,089	27,501	26,749
1973	54,817	34,697	33,044
1974	51,577	26,910	25,847
1975	52,796	22,702	22,242
1976	75,743	21,733	21,140
1977	75,748	32,176	31,527
1978	36,013	21,349	20,578
1979	40,160	25,142	23,558
1980	28,725	21,047	20,266
1981	25,600	16,293	15,069
1982	40,670	20,640	20,540
1983	60,398	38,209	36,983
1984	95,439	49,103	44,874
1985	173,894	74,464	43,607
1986	205,263	87,042	75,928
1987	152,611	107,903	90,553
1988	136,154	83,315	73,717

Jack:adult ratios differ between Bonneville Dam (includes both tule and URB counts) and McNary Dam (URB only). Although the relative proportion varies among years, the trends are usually consistent for all Columbia River dams, particularly during the last 10 to 15 years (Table 4.2). In general, a greater proportion of jacks occur in the total escapement to the Hanford Reach than at Bonneville Dam. Since 1960, jack:adult ratios for passage over Priest Rapids and Ice Harbor dams were more variable than jack:adult ratios for the Hanford Reach and McNary Dam.

The relative use of the Hanford Reach has increased from about 60% of the total URB run above McNary Dam in the 1960s to nearly 80% of the run in recent years (Figure 4.1). The proportion of adult fall chinook passing Priest Rapids Dam to upstream spawning areas has remained stable during this interval. For example, an average of about 18% of the NcNary Dam count was destined for spawning areas upstream of Priest Rapids Dam from 1970 to 1988. However, the total run size past Priest Rapids Dam has increased dramatically because of the increase in overall run size. Numbers of fall chinook salmon over Priest Rapids Dam increased from about 5,000 fish per year in 1978-1981 to about 21,000 fish per year from 1985 to 1988. In contrast, the proportion of the run entering the Snake River (based on passage counts over Ice Harbor Dam) has declined in the last 20 years from 40% to less than 5% of the total number of fish passing McNary Dam. The decline in chinook salmon runs to the Snake River has been attributed to losses of juvenile salmon during turbine passage and to migration delay caused by reservoirs (Raymond 1979). Also, Ice Harbor, Oxbow, and Brownlee dams flooded or blocked access to former spawning areas used by fall chinook salmon in the Snake River drainage (Fulton 1968).

4.2 POPULATION STRUCTURE

Salmon returning to spawn in the Hanford Reach currently originate from wild, or naturally spawning (Hanford Reach), and hatchery populations (Ringold and Priest Rapids hatcheries). The age structure and sex ratios of these populations were determined by the Washington Department of Fisheries in 1987 (Roler 1988; Figure 4.2). All 2-year-old salmon and most 3-year-old fish were males. However, the male:female ratio was about 35:65 for fish returning to the Hanford Reach and Priest Rapids Hatchery at ages 4 and 5. Sex ratios for Priest Rapids Hatchery and Hanford Reach populations were similar (Figure 4.2). However, a greater proportion of males returned to the Ringold Hatchery, mainly because of the high number of jacks at ages 1 and 2.

Age data were examined from two different groups where information was available (adult returns from 1966 to 1979 and 1983 to 1987) to determine if the age structure of fall chinook in the Hanford Reach had changed after hatchery releases were increased. A chi-square analysis

TABLE 4.2. Contribution of Jacks to Total Run of Columbia River Fall Chinook Salmon, 1960-1988. Values are given as a percent of the total **run** passing each river dam.

	Location in Columbia River						
Year	Bonneville[a]	The Dalles[a]	John Day[a]	McNary[a]	Priest Rapids[b]	Ice Harbor[b]	Hanford Reach
1960	11			23	24		
1961	13			28	41		
1962	8	14		18	22		
1963	23	49		53	80		
1964	10	28		31	53	18	26
1965	28	50		46	61	34	42
1966	18	21		32	50	15	30
1967	28	55		41	58	26	43
1968	23	34	42	32	52	20	34
1969	30	50	55	30	61	22	22
1970	24	49	50	30	68	13	15
1971	24	49	48	30	33	15	32
1972	31	56	64	24	60	20	17
1973	30	45	52	36	52	19	36
1974	33	55	56	44	34	15	48
1975	21	48	58	57	68	25	57
1976	30	55	65	67	49	25	71
1977	36	46	59	55	41	31	57
1978	28	35	46	36	27	31	40
1979	24	39	49	37	37	41	38
1980	17	20	31	23	29	33	21
1981	31	40	50	37	30	63	34
1982	28	49	55	46	33	54	49
1983	31	36	43	34	22	35	37
1984	40[c]	43[c]	47[c]	45[c]	38	33[c]	48
1985	45[c]	50[c]	57[c]	54[c]	45	78[c]	54
1986	46[c]	51[c]	51[c]	53[c]	36	46[c]	57
1987	17[c]	19[c]	20[c]	23[c]	12	19[c]	29
1988	20[d]			32[d]	17[d]	35[d]	37

(a) From H. Jensen, Oregon Department of Fish & Wildlife (ODFW), personal communication.
(b) From M. B. Dell, Grant Co. Public Utility District (PUD), personal communication.
(c) From U.S. Army Corps of Engineers Annual Fish Passage Reports.
(d) From U.S. Army Corps of Engineers 1988 Daily Summary Fish Report.

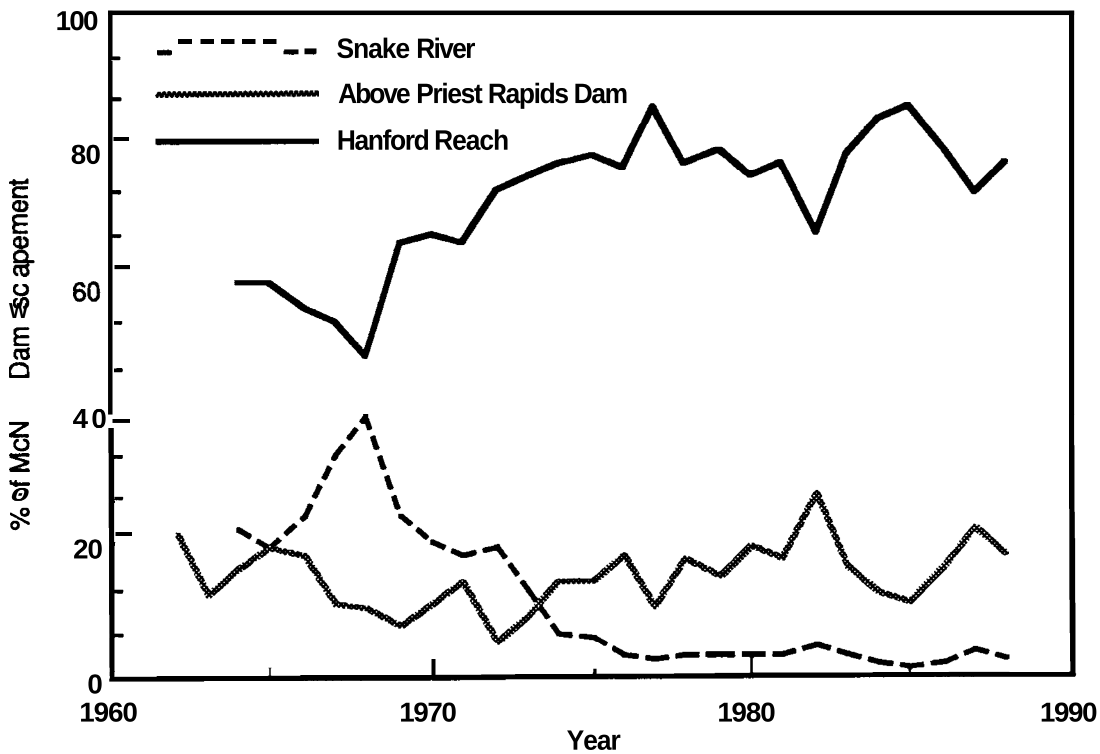

FIGURE 4.1. Destination of Adult Fall Chinook Salmon Passing McNary Dam, 1962-1988

indicated that the age distribution of these two groups was significantly different at $p < 0.001$. It appeared that a greater proportion of age 2 salmon were present in 1983-1987 populations than in the 1966-1979 grouping (Figure 4.3).

4.3 CONTRIBUTION OF HANFORD REACH SALMON TO THE FISHERY

The relative contribution of Hanford stocks (URB) to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s to 50 to 60% of the total in recent years (Table 4.3). This change is mainly a result of the increased numbers of URB adults returning to the Hanford Reach, rather than a decline in other fall chinook salmon stocks. Although LRH stocks have also shown a marked increase in population size, numbers of Bonneville Pool Hatchery (BPH) fish have declined significantly during the same interval. The lower Columbia River wild (LRW) stocks historically have been the least abundant of the fall chinook stocks, and run size has flucuated from about 4 to 13% of the total run to the Columbia River.

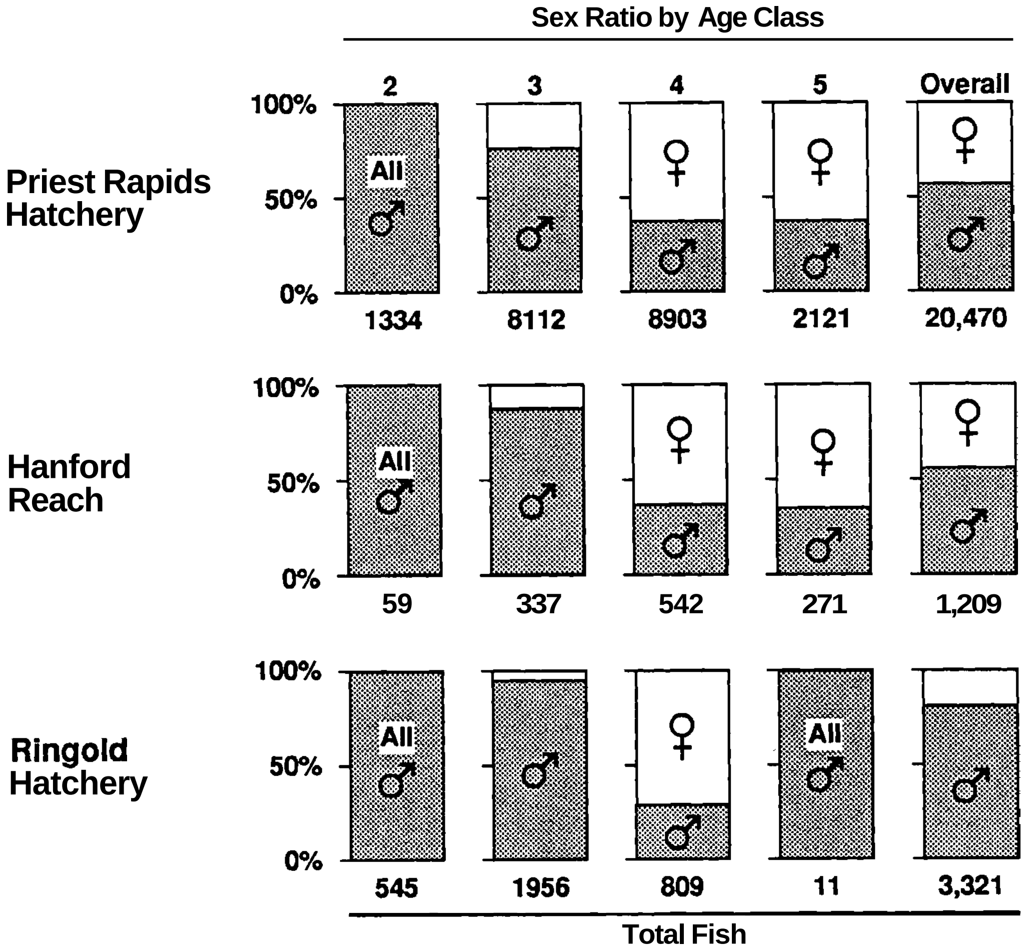

FIGURE 4.2. Sex Ratios for Different Age Classes of Hatchery and Naturally Spawning Upriver Bright Fall Chinook Salmon (data from Roler 1988)

The relative importance of URB salmon to the commercial and sport fisheries in the Columbia River is summarized in Table 4.4. No distinct trends were obvious for total catch of fall chinook salmon from 1980 to 1985. However, fall chinook populations increased nearly three-fold from 1985 to 1988. The relative contribution of URB to the commercial, tribal, and sport fisheries has increased since 1980. In 1988, URB comprised 28, 96, and 39% of the commercial, tribal, and sport fish catch of fall chinook salmon in the Columbia River, respectively (Table 4.4). Increased contribution of URB fall chinook salmon to the total harvest of fall chinook may be explained, in part, by court decisions that have shifted much of the harvest from in-river commercial (zone 1-5) to tribal (zone 6) (Horner and Bjornn 1979).

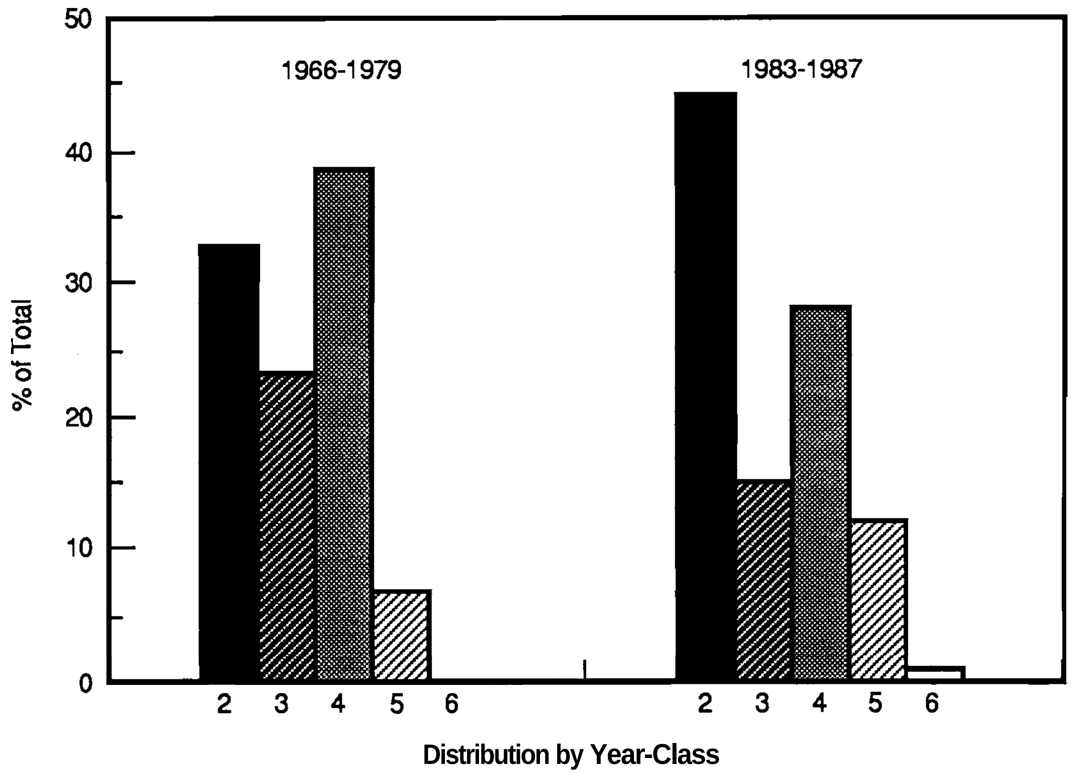

FIGURE 4.3. Age Composition of Upriver Bright Fall Chinook Salmon Populations (modified from Roler 1988)

TABLE 4.3. Relative Contribution (in thousands of fish) of Upriver Bright and Other Fall Chinook Salmon Stocks to Total Runs of Columbia River Fall Chinook Salmon, 1980-1988 (ODFW/WDF 1989)

Year	URB	BPH	LRH	LRW	Total
1980	76.8	97.8	105.6	38.8	319.0
1981	66.6	86.3	94.9	25.0	272.8
1982	79.0	120.7	139.5	13.0	342.2
1983	86.1	28.9	88.1	16.8	219.9
1984	131.4	47.5	102.4	13.3	294.6
1985	195.6	33.0	111.0	13.3	352.9
1986	281.5	16.5	154.9	24.8	477.7
1987	419.4	9.1	344.2	37.9	810.6
1988	339.9	12.3	309.9	41.7	703.8

URB = Upriver bright.
BPH = Bonneville Pool Hatchery.
LRH = Lower River Hatchery.
LRW = Lower River wild.

TABLE 4.4. Catch Statistics for Upriver Bright Fall Chinook Salmon and Relative Importance of the URB Catch (based on total fall chinook salmon harvest) to Commercial and Sport Fisheries in the Columbia River, 1981-1988. Total catch values are based on recoveries of coded wire tags (ODFW/WDF 1989).

	Total Catch (thousands)				URB as % of Fall Chinook Catch			
Year	Commercial Zone 1-5(a)	Tribal Zone 6(b)	Sport Catch	Total Catch	Commercial Zone 1-5(a)	Tribal Zone 6(b)	Sport Catch	Total Catch
1980	112.3	32.6	5.2	150.1	4.5	27.6	5.2	10.0
1981	28.7	47.5	4.7	80.9	18.4	28.2	14.9	20.4
1982	88.7	52.7	5.4	146.8	5.1	5.3	3.7	5.1
1983	23.4	20.9	3.8	48.1	18.4	58.4	18.4	35.7
1984	59.2	49.6	17.2	126.0	40.0	58.5	25.6	45.6
1985	55.8	67.1	15.9	138.8	61.8	80.9	57.2	70.5
1986	147.1	96.2	24.1	267.4	39.1	93.3	44.8	58.7
1987	302.1	122.5	55.9	480.5	34.5	98.0	32.6	50.5
1988	280.8	124.0	42.2	447.0	28.4	96.1	39.1	48.2

(a) Zone 1-5 includes Columbia River mouth to river km 235.
(b) Zone 6 includes river km 235-470.

5.0 FACTORS AFFECTING ABUNDANCE OF FALL CHINOOK SALMON IN THE HANFORD REACH

The size of the fall chinook salmon population in the Hanford Reach is influenced by several variables, including adult spawning habitat, egg-to-fry survival of the naturally spawning population, numbers of juvenile hatchery fish released into the Hanford Reach, survival of smolts during downstream migration, ocean survival, and harvest by ocean and in-river fisheries (Figure 5.1) Each variable is discussed in some detail below.

5.1 AVAILABLE SPAWNING HABITAT

Our aerial surveys indicate little recruitment of spawners to new areas that appear to be suitable for spawning. Rather, spawning densities appear to be increasing in high-use areas. Other areas of the Hanford Reach remain relatively unused. The extent of spawning in deep water areas where visibility from aircraft is restricted is largely unknown. However, Swan (1989) speculated that up to 80% of fall chinook salmon in the Hanford Reach may spawn in water too deep to detect by aircraft. This estimate was based on the difference between dam passage counts of adult salmon and aerial estimates of redds. But, it likely overestimates the relative importance of deep water areas to salmon spawning because it assumes 100% of the redds in shallow-water areas are counted during aerial surveys.

Our aerial surveys indicate that extensive overlapping of redds occurs in the heavily used spawning areas. Swan (1989) also found that deep-water (>3 m depth) redds commonly overlapped during the latter part of the spawning season. The impact of this on fry production is unknown. But, superimposition of redds in high use areas could disrupt egg pockets and reduce production in areas where suitable spawning habitat is limited. Chapman et al. (1983) did not note extensive superimposition of redds at Vemita Bar from 1978 to 1980. However, escapement of fall chinook salmon to the Hanford Reach has increased almost four-fold since then.

It is clear that fall chinook salmon spawn over a wide range of conditions in the Hanford Reach. Thus, further studies on habitat requirements and physical factors influencing spawning site selection are needed to acquire a better understanding of the current use of spawning sites and resultant carrying capacity of the Hanford Reach for fall chinook salmon.

5.2 EGG-TO-SMOLT SURVIVAL,

Increased variability in flow during incubation and hatching has created a major change in environmental conditions for fall chinook salmon populations over the last 40 years. These

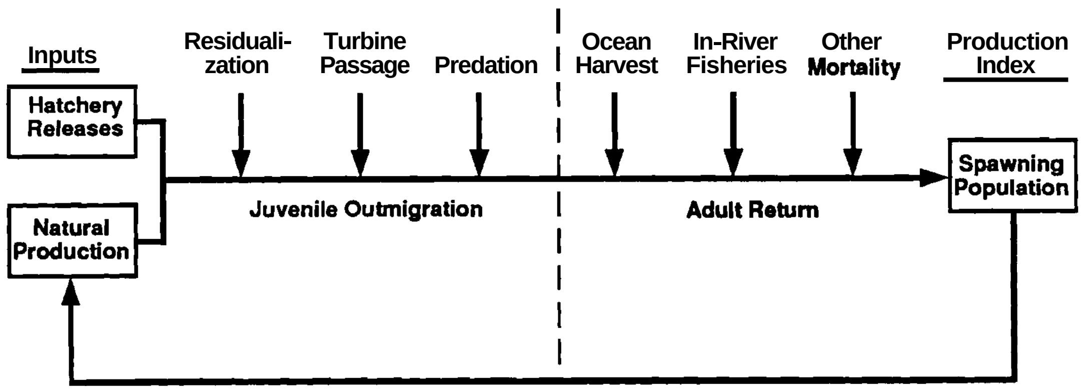

FIGURE 5.1. Conceptual Diagram Illustrating Major Variables Affecting Production of Fall Chinook Salmon During Their Life Cycle

changes in flow may affect the survival of developing eggs and embryos (desiccation), and emergent *fry* (stranding). Variable flows are due to construction of upstream dams that store and release water in response to irrigation and power demands. Water storage practices have altered both seasonal and daily flow patterns. Seasonal flows in the Hanford Reach have been more variable since the construction of Grand Coulee Dam in 1941. Increased variation in weekly and daily flows was evident beginning in the mid-1950s (Figure 5.2). Average discharge during the spawning period also appears to have increased in the last 40 years. Diel flow variation during spawning is extensive (Figure 5.3). Mean ratios of maximum to minimum daily discharge at Priest Rapids Dam ranged from 2.2 to **4.3** from 1972 to 1986 (Table 5.1).

Short-term fluctuations in flow that expose redds above the water surface may not impact the survival of salmonid life-stages developing in the gravel if adequate ground water (bank storage) is available to maintain intergravel flows (Meekin 1967; Neitzel et al. 1984). However, the range of flows necessary for survival can change during the over-winter incubation period. For example, pre-hatch stages of salmonids are more tolerant of dewatering than post-hatch stages (Becker and Neitzel 1985). Cleavage eggs and embryos can obtain oxygen from air by diffusion if moisture and temperature conditions are favorable. In contrast, eleutheroembryos and alevins require oxygenated water for respiration (Becker and Neitzel 1985). Extended periods of low flow occurring after fry emergence have caused mortality of juvenile fall chinook salmon in the Hanford Reach because of desiccation and stranding (Page 1976; Bauersfeld 1978).

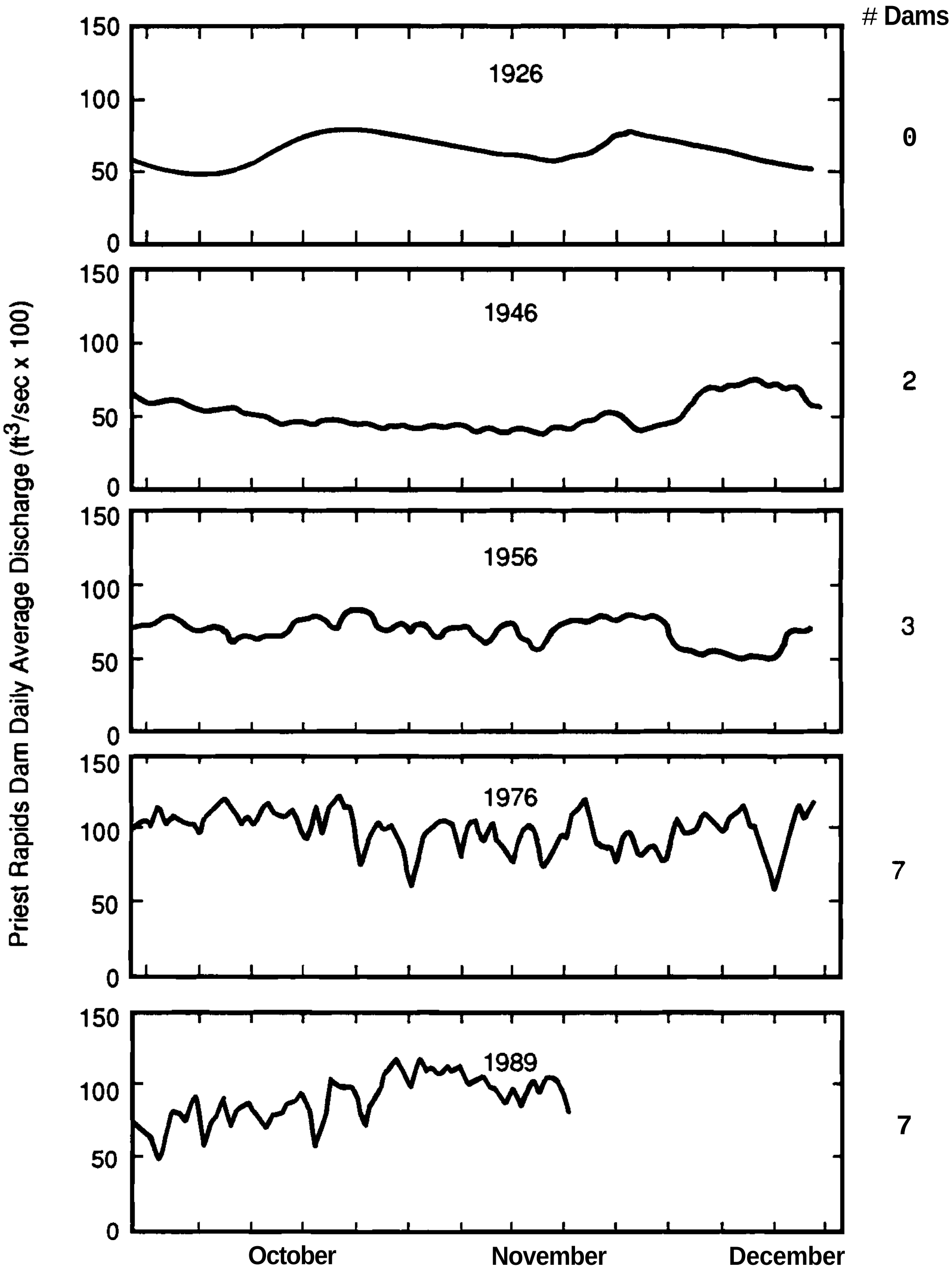

FIGURE 5.2. Historical Changes in Seasonal Flow Patterns in the Hanford Reach During Fall Chinook Salmon Spawning

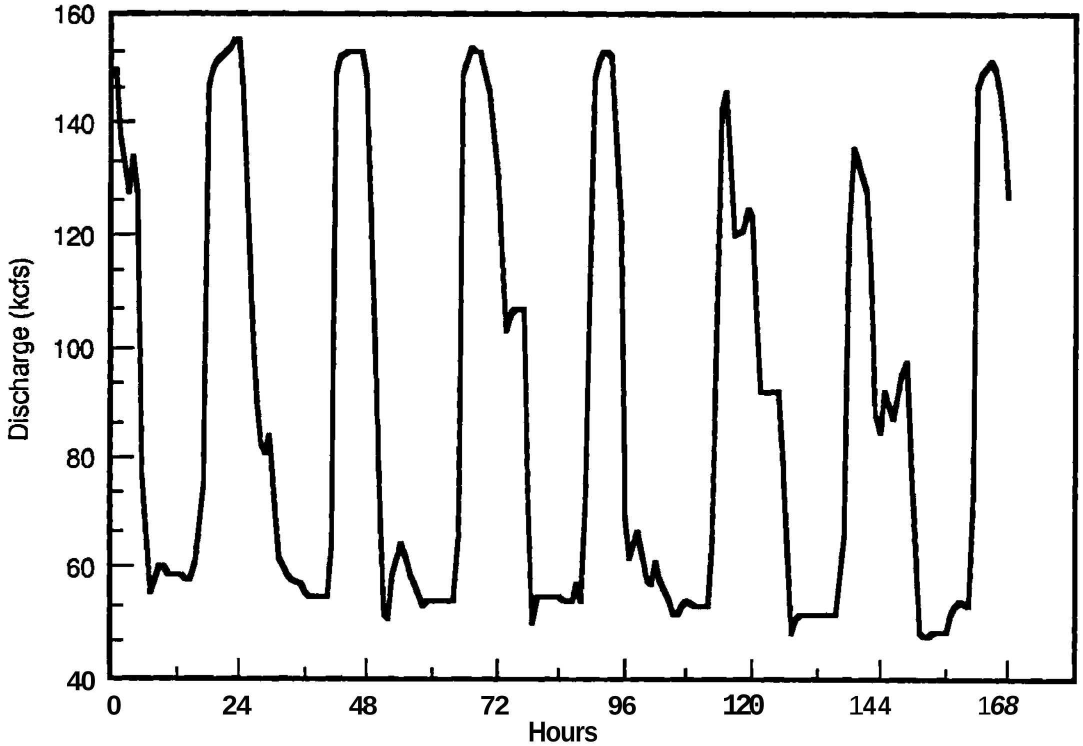

FIGURE 5.3. Range of Flows During the Peak Spawning Period in November 1988

5.3 HATCHERY CONTRIBUTION

Juvenile hatchery fall chinook salmon released to the Hanford Reach have supplemented wild run production since the early 1960s and numbers have increased dramatically in recent years (Table 5.2). Initial releases of fish were from the Ringold rearing ponds and/or from the Priest Rapids Dam (PRD) spawning channel. Adult returns from these facilities first occurred in 1965 and 1967, respectively (Allen 1977). Maximum production from the PRD spawning channel occurred in 1968 when approximately 7 million fish were released. This facility was built in 1963 to mitigate the loss of chinook salmon spawning grounds resulting from construction of Priest Rapids and Wanapum dams (Allen and Meekin 1973). The spawning channel had several problems, including adult pre-spawning mortalities, siltation of developing embryos, and poor adult returns. The last release of juvenile fish from the spawning channel occurred in 1978.

Upriver bright fall chinook salmon were trapped in the fish ladders at Priest Rapids Dam for use in artificial propagation efforts at the PRD spawning channel and the hatchery (Homer and Bjornn 1979; Becker 1985). An average of 35% (range 10 to 66%) of the adult upriver run was

TABLE 5.1. Diel Flow Variation in the Hanford Reach During Fall Chinook Salmon Spawning, 1972-1986. Values represent the mean ratio of maximum to minimum daily discharge at Priest Rapids Dam.

Year	October	November
1972	2.6	2.5
1973	2.9	2.2
1974	2.6	2.9
1975	2.3	2.2
1976	2.4	2.4
1977	2.7	3.5
1978	2.7	3.7
1979	3.2	4.3
1980	3.3	4.3
1981	2.7	4.0
1982	3.1	4.1
1983	2.3	2.2
1984	2.6	2.5
1985	2.5	2.8
1986	3.0	2.8

removed for this purpose from 1963 to 1982 (M.B. Dell, Grant County PUD, personal communication). This practice reduced the number of fish available to seed upstream spawning areas below Wanapum and Rocky Reach dams (Mathews and Paulik 1967) and may have eliminated spawning off the mouth of the Wenatchee River (Mullan 1987). In recent years, adult returns to the Priest Rapids Hatchery outlet stream have satisfied most of the hatchery egg requirements, and ladder trapping has been reduced or eliminated. Thus, spawning by fall chinook salmon above the Hanford Reach may be expected to increase.

Releases of juvenile fall chinook salmon from the Ringold rearing facility were irregular, but averaged about 1 million smolts/year for 19 of the last 27 years when fish were released. Egg sources for Ringold releases have included the Klickitat, Spring Creek, Abernathy, Bonneville, and Priest Rapids hatcheries. Fish were released as fry, fingerlings, or yearlings.

The PRD hatchery has been used to supplement the naturally spawning fall chinook salmon runs since 1973. Of the approximately 8.5 million hatchery fish released annually to the Hanford Reach from 1981 to 1988, >80% originated from the PRD hatchery. Adult fall chinook salmon

TABLE 5.2. Releases of Juvenile Fall Chinook Salmon from the Priest Rapids Dam (PRD) and Ringold Rearing Facilities, 1962-1988 (From M.B. Dell, Grant County Public Utility District, personal communication)

Release Year	Number Released (millions) PRD Spawning Channel	PRD Hatchery	Ringold	Other	Total
1962	0	0	0.02	0	0.02
1963	0	0	0.04	0	0.04
1964	1.07	0	0.19	0	1.26
1965	0.35	0	0.01	0	0.36
1966	1.18	0	0.17	0	1.35
1967	1.47	0	0.51	0	1.98
1968	7.14	0	1.84	0	8.98
1969	2.99	0	2.50	0	5.49
1970	2.00	0	0	0	2.00
1971	1.80	0	2.31	0	4.11
1972	2.85	0	1.32	0	4.17
1973	0.41	0.26	0	0	0.66
1974	0.54	2.37	1.75	0	4.66
1975	0.72	0.56	0	0	1.29
1976	0.55	1.34	0.90	0	2.79
1977	0.31	0.91	0	0	1.22
1978	0.04	1.42	0.50	0	1.96
1979	0	1.20	0	0	1.20
1980	0	2.71	0.94	0	3.65
1981	0	4.83	0	0	4.83
1982	0	5.51	0.79	0	6.30
1983	0	10.30	0	1.32	11.62
1984	0	9.74	2.10	0	11.84
1985	0	6.99	1.20	0.14	9.33
1986	0	6.36	1.30	0.20	7.86
1987	0	6.05	1.10	1.04[a]	8.19
1988	0	7.71	0	0	7.71

(a) Transferred to the Yakima River for release.

that return to the hatchery outlet stream, or are trapped in the fish ladders at Priest Rapids Dam, are the primary source of eggs for the hatchery. However, hatchery production was supplemented in the early 1980s with eggs from the Bonneville Hatchery. The number of returning adults has been sufficiently high since 1985 so that significant numbers of excess eggs and fry have been available for transfer to Bonneville, Klickitat, and other hatchery facilities. Production goals are expected to be maintained near present level (M.B. Dell, Grant County PUD, personal communication).

To minimize competition with naturally produced salmon, Priest Rapids Hatchery fish are released after most of the naturally produced fish have migrated downstream. Peak abundance of the naturally produced fall chinook salmon occurs in mid-May, and most of these fish migrate out of the Hanford Reach by the end of June (Page et al. 1982). The hatchery fish, released in mid- to late-June are larger than the few naturally produced fish remaining in the Hanford Reach (Dauble et. al. 1984).

Chapman et. al. (1983) estimated the returning adult population to the Hanford Reach in 1980-1982 accounted for 14 to 26% of hatchery fish. The proportion of hatchery fish above Vernita Bridge (mainly Vernita Bar) was estimated to range from 18 to 33% over the same 3 years. However, numbers of fish released from the Priest Rapids hatchery have doubled since these studies. Thus, relative contribution of hatchery fish to the runs may now be higher.

5.4 SMOLT SURVIVAL DURING REARING AND OUTMIGRATION PERIOD

5.4.1 Past Effects of Hanford Operations

Historical energy-development activities (i.e., production of nuclear materials for weapons production) at Hanford that potentially impacted fall chinook salmon survival included the release of heat, chemicals, and radionuclides through the discharge of reactor cooling water to the river, as and impingement and/or entrainment of fish at reactor cooling water intake structures. The potential for each of these impacts has changed since salmon spawning surveys were initiated in 1948. For example, single-purpose plutonium-production reactors discharged heat and radionuclides into the Columbia River between 1944 and 1971. The marked rise in numbers of salmon redds during 1965 to 1969 was not considered related to the decrease in the number of reactors operating during that period, but to other factors, such as displacement of fish from other mainstem spawning areas (Watson 1970). Paulik (1970) conducted a detailed analysis of fall chinook salmon redd counts and concluded that dam construction was probably the critical factor controlling the number of fall chinook salmon spawning in the Hanford Reach from 1947 to 1969.

More recently, Becker (1985) reviewed potential impacts to salmonids from reactor operations and found no evidence of adverse effects to fall chinook salmon from radioactive materials.

Major spawning areas between river km 585 and 605 were subjected to incompletely mixed reactor effluents for several years. Salmon spawning was sometimes noted within 100 m of the outfall (Watson 1970). However, because the heated effluents rose toward the river surface, influence on eggs and embryos that develop in the bottom substrate was reduced. The general distribution of fall chinook salmon redds did not change following closure of reactors located immediately upstream from major spawning areas (Watson 1970). Additionally, thermal discharges from reactors had no effect on the upstream migration of chinook salmon adults or on the downstream passage of juveniles (Templeton and Coutant 1971). The N-Reactor was the only reactor discharging heated effluent to the Hanford Reach after 1971. The closest known spawning ground was located about 5 km downstream of the discharge port, and maximum temperature increases there were estimated at <0.3°C or insufficient to affect embryo survival (DOE 1988). Avoidance behavior may have also reduced the potential for juvenile salmon to be exposed to lethal temperatures from thermal plumes at the point of discharge (Gray et al. 1977). The N-Reactor has not operated since 1987 and is currently in "dry layup" status.

Juvenile (0-age) chinook salmon were found to be impinged on the traveling screens or entrained in the intake system of the Hanford Generating Project (HGP) in the 1970s (Gray et al. 1975). However, a series of improvements, including reductions of screen sizes from 6 to 3 mm (1/4- to 118-in.) mesh and a continuous screen wash with a fish return reduced these losses to negligible levels (Page et al. 1977). Fish impingement and traveling screen passage was studied at the adjacent N-Reactor water intake system in 1977. Entrainment was not considered a problem because of the small screen size (118-in. mesh). Mortalities to 0-age fall chinook salmon fry were estimated to represent <0.001% of the population.

5.4.2 Current Effects of Hanford Activities

At present, the only thermal discharge to the Hanford Reach occurs at the Washington Nuclear Power Plant (WNP-2) outfall at river km 566. Thermal discharges to the river are from the cold leg of the recirculating cooling water system, and maximum discharge temperatures are about 29°C (84°F). (NRC 1981). However, no evidence exists that downstream migrating salmonids encountering the WNP-2 plume would be exposed to lethal conditions (WPPSS 1985). The intake screen at WNP-2 is located at mid-channel and is sufficiently small that potential for entrainment and/or impingement of juvenile salrnonids is negligible.

Indirect releases of radionuclides and chemical constituents to the Columbia River occur as a result of current and past waste disposal practices, and movement of mobile elements is monitored by onsite DOE contractors. Radiological and chemical monitoring results indicate that some contaminants were elevated in groundwater near operating areas (Jaquish and Bryce 1989). For example, concentrations of ^{90}Sr in the 100-N and 200-East Areas exceeded Environmental Protection Agency's (EPA) drinking water standards in 1988. Tritium continued to move slowly with the general groundwater flow and discharge to the Columbia River. However, dilution by the Columbia River reduces the concentration of radionuclides, and amounts of low-level radioactivity measured in the Columbia River were well below drinking water standards established by the State of Washington and EPA (Jaquish and Bryce 1989).

5.4.3 Effects of Downstream Dams

Juvenile fall chinook salmon from the Hanford Reach must pass four hydroelectric dams before they reach the Columbia River estuary. Potential impacts to smolts during downstream migration that decrease survival and/or potential for adult return are well documented and include delayed migration, predation from birds and resident fish, direct and indirect mortality during turbine passage, and losses from disease and exposure to excess levels of atmospheric gas (reviewed in Collins et al. 1975; Raymond 1979). The main cause for historical decline of salmon populations in the Columbia River Basin has been mortality of juveniles migrating downstream through dams and impoundments (Raymond 1988). Potential mortality is related to flows during migration, i.e., lower flows result in increased passage through turbines and added delay in passage through reservoirs. For example, mortality of salmon smolts was estimated at 45% for each project (dam plus reservoir) during low flow years of 1973 and 1977, compared to 15% mortality per project during the higher runoff and spill in 1978 (Raymond 1988). Species-specific differences in run timing, behavior, or size at migration may influence potential for survival during downstream migration. For example, juvenile fall chinook salmon may be more susceptible to predation than other salmonids in the Columbia River because they are smaller when they migrate to the ocean (Horner and Bjornn 1979).

Current management strategies for increasing survival of fall chinook salmon smolts (and other juvenile salmonids) include maintaining higher flows during smolt outmigration, installing screens to bypass downstream migrants past turbines, and transporting smolts by barge and/or truck past downstream dams. A major fish bypass and collection facility at McNary Dam collects juvenile fall chinook salmon from June through August. Fish are then transported to below Bonneville Dam for release. Collection and loading for transport stresses juvenile salmon, but this is not perceived as a problem for fall chinook salmon (Maule et al. 1988). Screening turbine intake screens for other U.S. Army Corps of Engineers dams on the Columbia River is currently being considered.

5.5 COMMERCIAL AND SPORT HARVEST

Although the size of the fall chinook salmon run declined coincidently with loss of spawning habitat in the mid- and upper Columbia River during the 1950s, abundance of adult fish in the lower tributaries and above Bonneville Dam showed the same relative change in run size. According to Van Hyning (1973), this indicated a common factor, such as an increase in ocean fishing, affected survival. Thus, commercial harvest is a major factor influencing fall chinook abundance in the Columbia River.

The total harvest of adult URB (excluding ocean harvest) increased from a low of 9% of the fall chinook run in 1982 to about 63% of the run in 1988. However, the increased harvest has apparently not reduced escapement totals. Total escapement increased from 50,600 adults in 1981 to 176,900 adults in 1987 (Table 5.3). The commercial in-river harvest (Zone 1-5) removed an average of 14% of the total adult URB run from 1980 to 1986 and the mbal fishery (Zone 6) took about 23% of the total during the same interval. Sport fishermen caught about 3% of the total run and only 7% of the total adult harvest from 1980 to 1988 (Table 4.4). Although the proportion of catch for these three fisheries was different, the average share of the total harvest was similar for each fishery on a year-to-year basis.

Data from the recovery of tagged hatchery chinook salmon were summarized to address basin-wide declines in Columbia River stocks (Chapman et al. 1982). Analysis of data from coded-wire tag recoveries indicated that ocean harvest rates exceeded in-river harvest rates for upper Columbia River fall chinook (Lander 1970). Ocean exploitation rates in the late 1970s ranged from 58 to 73% of the total harvest (Chapman et. al. 1982). The Pacific Fisheries Management Council (PFMC 1982) estimated that 86% of the total ocean harvest of URB fall chinook occurred in British Columbia and Alaska. Canadian trollers caught an average of 41% of the upper Columbia River fall chinook from 1970 to 1974 (Beiningen 1976). Before 1987, only salmon released from the Priest Rapids Hatchery were used to monitor URB harvest in mixed fisheries. An estimated 69% of Hanford Reach URB hatchery stocks were recovered in offshore fisheries in Alaska and British Columbia (WDF 1981).

TABLE 5.3. Catch Statistics (thousands of fish) for Adult Upriver Bright Fall Chinook Salmon Entering the Columbia River, 1980-1988 (ODFW/WDF 1989)

Year	Commercial Harvest	Tribal Harvest	Sport Catch	Total Catch	Total Run Size	Escapement
1980	5.1	9.0	0.9	15.0	76.8	61.8
1981	2.4	13.4	0.7	16.0	66.6	50.6
1982	4.5	2.8	0.2	7.5	79.0	71.5
1983	4.3	12.2	0.7	17.2	86.0	68.8
1984	23.7	29.0	4.4	57.1	151.4	94.3
1985	34.5	54.3	9.1	97.9	195.1	97.2
1986	58.9	90.1	10.8	159.8	281.5	121.7
1987	104.3	120.0	18.2	242.5	419.4	176.9
1988	79.9	119.2	16.5	215.6	339.9	124.3

No comparable information exists on the relative contribution of naturally spawning URB stocks to the ocean fisheries. However, a multi-agency study was initiated in 1987 to determine the importance of this stock in ocean and Columbia River fisheries. The Washington Department of Fisheries (WDF), the Yakima Indian Nation (YIN), the Columbia River Intertribal Fish Commission (CRIFTC), and the U.S. Fish and Wildlife Service (USFWS) are implanting coded-wire tags in naturally produced juvenile fall chinook. Information from tag recoveries will be used to manage harvest of returning adults and to evaluate potential impacts to the stock from activities in the Columbia Basin (Norman 1987; DeVore 1989).

5.6 OTHER FACTORS AFFECTING ADULT SURVIVAL

Adult salmonids have problems passing hydroelectric dams when migrating upstream to their spawning grounds. Some portion of interdam differences in adult passage counts over ladders has been attributed to "dropback" mortality (Fredd 1966). Adult losses of 20% have been noted at a lower Columbia River Dam (Junge 1980). Differences in counts between dams influence the accuracy of estimates of adult escapement to upstream spawning areas, including estimates for the Hanford Reach. Passage problems and associated mortalities are thought to be usually greater for fall chinook salmon than other races because fall chinook return in later summer and fall when river flows are lower and temperatures are higher (Collins et al. 1962). Average delays in passage for upstream migrating adults ranged from 18 to 216/h for various studies conducted in the Columbia and Snake rivers from 1948 to 1977 (reviewed in Haynes and Gray 1980). The additive effects of extensive passage delays resulting from dropback, milling, and/or greater swimming depths could delay migration timing and ultimately affect spawning success for fall chinook salmon in the upper Snake River (Haynes and Gray 1980). Other conditions associated with passing fish past barriers may contribute to mortality. For example, crowding associated with fish ladders and elevated temperatures occurring during late summer migration may increase potential for disease transmission from the pathogen Flexibacter columnaris and other infectious diseases (Becker and Fujihara 1978; Homer and Bjornn 1979).

Impacts from pollution point sources or chemicals contained in runoff from irrigation returns are also a consideration. For example, there is evidence that fluoride released from an aluminum plant above John Day Dam impacted passage time and survival of adult salmonids (Damaker and Day 1984,1985).

6.0 RECOMMENDATIONS FOR FUTURE MANAGEMENT OF FALL CHINOOK SALMON IN THE HANFORD REACH

Care must be taken to protect and enhance the URB stock of fall chinook salmon because the Hanford Reach is the major spawning area for this valuable resource. Widespread habitat destruction in the Columbia River has increased the importance of the Hanford Reach to fall chinook salmon populations in the last 40 years. Runs to the Hanford Reach have increased because hydroelectric development has eliminated most other mainstem spawning areas, natural production has been sustained, and extensive hatchery outplanting has occurred. However, it should not be assumed that runs can be maintained with present management strategies. The status of fall chinook populations needs to be monitored because of potential for changes in water use practices (i.e., irrigation needs, hydroelectric power generation), ocean and in-river harvest, and future development projects that may impact water quality. These and other unforeseen activities may have a major impact on the future survival of fall chinook salmon in the Hanford Reach. The following sections discuss research needs for effective management of fall chinook salmon production in the Columbia River.

- Improve the documentation of current fall chinook salmon spawning areas

  Fall chinook salmon spawning areas at Vernita Bar have been described by Chapman et al. (1986), and other sites have been studied by Swan et al. (1988). But these sites are only a portion of the known spawning sites in the Hanford Reach. Additional characterization is needed to accurately evaluate changes in spawning area boundaries and redd abundance resulting from future activities in the Hanford Reach or from changes in present management policies. Locations of spawning areas should be mapped and physical variables described before available spawning habitat and production potential of the Hanford Reach can be further assessed.

  Aerial photography can be useful in providing a permanent record of spawning areas. However, the authors and others (Chapman et al. 1983) have found this method less useful for quantitative analysis. Visual inspection of salmon spawning is superior to aerial photography for estimating redds. SCUBA can be used in conjunction with aerial surveys to obtain additional information on redd abundance and location (Swan et al. 1988). Our analysis of photographic techniques indicated that color video was superior to color photographs for documenting location and estimating abundance of salmon redds. Salmon redds that were visible across the entire river channel (depth estimated to 4 m) with video film (and with the naked eye) were not visible in photographic prints. Visual counts of redds made from aircraft remain superior to estimates of redd numbers made from film. Further development of techniques, including photographic mapping, is needed to obtain a permanent record of salmon spawning locations. Permanent record of locations will provide a means to assess changes as a result of future development activities in the Hanford Reach.

- Characterize habitat requirements and determine production potential of fall chinook salmon in the Hanford Reach

  Although principal spawning areas in the Hanford Reach have been identified, densities of redds within and between areas are highly variable. Given the range of conditions (i.e., depth, substrate, current velocity) in which fall chinook salmon spawn, it is doubtful that all suitable areas are used. It may be that key factors difficult to measure or not identified also contribute to selection of spawning areas. Studies should be initiated to characterize the physical and hydrologic parameters that influence selection of salmon spawning sites and embryo survival. This information can be used to develop a preliminary habitat suitability model for assessing population change and for evaluating production potential in the Hanford Reach.

- Evaluate current supplementation programs

  Increased hatchery production may be the only means of maintaining and/or increasing fall chinook salmon production in the mid-Columbia River, particularly if current spawning areas are used at their maximum potential. Present salmon production facilities in the Hanford Reach are funded by a combination of state and federal agencies and public utility districts. Management policies at the Priest Rapids Hatchery are not likely to change in the immediate future, and funds for the Ringold rearing facility have been cut from the federal budget year after year, and the future of this facility depends on maintaining or supplementing the annual budget. Management of naturally produced populations may take on increased importance if hatchery supplementation strategies fail or if run size decreases because of increased commercial and sport harvest and/or other mortality factors. Recent studies with steelhead indicate that wild spawners were more likely to produce surviving subyearlings and smolts than are hatchery smolts (Chilcote et al. 1986). Thus, the genetic integrity of wild populations in the Hanford Reach could be threatened with increased hatchery supplementation or introduction of stocks from other basins. Evaluation of current hatchery programs is ongoing (Norman 1987), and this information needs to be considered in resource planning by state and federal agencies and tribes. Additionally, fisheries management policies influencing hatchery production and regulation of commercial and tribal fisheries must be factored into the assessment of the relative importance of the Hanford Reach to fall chinook salmon populations.

- Maintain flow policies designed to protect all life stages of fall chinook salmon

Results from extensive field and laboratory studies conducted to date (Parametrix et al. 1979; Chapman et al. 1983; Weitkamp et al. 1982; Neitzel et al. 1984) characterized salmon spawning on Vernita Bar in relation to flow patterns and assessed the effect of various flows on eggs and alevins. A long-term (1998 to 2005) Vernita Bar Settlement Agreement was approved by a Federal Energy Regulatory Commission (FERC) order in December 1988 that established obligations and procedures to protect fall chinook salmon at Vernita Bar. Activities include monitoring redd construction and maturation from egg to emergent fry and providing adequate flows during spawning and egg incubation (Carlson and Dell 1989). It is important that agencies and utilities continue to cooperate in establishing flow regimes that protect fall chinook salmon in the Hanford Reach. These flow regimes need to consider the entire life cycle of fall chinook salmon, from spawning to outmigration.

- Ensure adeauate protection of the Hanford Reach against current activities and future development activities

Regulatory aspects and Northwest politics will continue to influence the management of fall chinook salmon in the Hanford Reach. The Hanford Reach is currently under study by the National Park Service and the U.S. Fish and Wildlife Service to determine if it should be protected under the Wild and Scenic River designation or some other status. A moratorium on development was initiated in November 1988 and will protect the Hanford Reach for up to 8 years (U.S. House of Representatives, H.R. 3614). Two past development activities have potentially jeopardized the fall chinook salmon population. For example, the Army Corps of Engineers proposed to construct Ben Franklin Dam near river km 563 in the late 1970s. Such a structure would have eliminated most of the salmon spawning areas in the Hanford Reach (Fickeisen et al. 1980). Another plan recently considered was construction of a shallow-draft navigation channel through the Hanford Reach. This project could severely impact fall chinook salmon by reducing available spawning habitat, increasing sedimentation, and increasing mortality from barge activity and changes in flows.

Operation of hydroelectric facilities for irrigation needs and power production will continue to have a major impact on the survival of fall chinook salmon. Adequate controls on upstream industries, including irrigation practices, that alter the use and quality of the Columbia River are also needed. For example, the continuing erosion of some high bank areas in the Hanford Reach produces high loads of silt. The instability of banks (e.g., the White Bluffs near river km 595) is due, in part, to discharge of irrigation waste water on land to the north and east of the river. Possible impacts of the increased siltation on salmon spawning and the potential for change in channel morphology and flows because of bank slumping need to be recognized.

- Develop methods to predict potential exposure scenarios for redds downstream of contaminants originating from waste storage

  Following the shut-down of N-Reactor in 1987, emphasis at Hanford has shifted from nuclear fuel production to cleanup of existing waste sites. A Tri-Party Agreement was established between the U.S. Department of Energy, the State of Washington, and the U.S. Environmental Protection Agency mandating cleanup of existing nuclear waste sites at Hanford (WSDE et al. 1989). The long-term effects (if any) on fall chinook salmon of nuclear waste materials that migrate from present storage sites and enter the Columbia River *are* unknown. Methods *are* not yet available to predict potential exposure scenarios for fall chinook salmon embryos developing in redds downstream of contaminants originating from hazardous waste storage. However, future groundwater transport models and site characterization efforts should evaluate the potential for contaminants to intersect major spawning areas.

It is evident that issues surrounding the status of fall chinook salmon populations in the Hanford Reach are complex. However, resources agencies should not consider activities within the Hanford Reach as the controlling variable for fall chinook salmon production in the Columbia River system. Rather these populations should be viewed as an important contribution. A holistic approach to management of fall chinook salmon would include the development and maintenance of suitable spawning and rearing habitat in other areas of the Columbia River drainage.

Chapman, D. W., D. E. Weitkamp, T. L. Welsh, M. B. Dell, and T. H. Schadt. 1986. "Effects of River Flow on the Distribution of Chinook Salmon Redds." Trans. Am. Fish. Soc. 115:537-547.

Chilcote, M. W., S. A. Leider, and J. J. Loch. 1986. "Differential Reproductive Sucess of Hatchery and Wild Summer-Run Steelhead under Natural Conditions." Trans. Am. Fish. Soc. 115:726-735.

Collins, G. B., J. R. Gauley, and C. H. Elling. 1962. "Ability of Salmonids to Ascend Fishways." Trans. Am. Fish. Soc. 91:1-7.

Collins, G. B., W. J. Ebel, G. E. Monan, H. L. Raymond, and G. K. Tanonaka. 1975. The Snake River Salmon and Steelhead Crisis. Its Relation to Dams and the National Energy Crisis National Marine Fisheries Service, Seattle, Washington.

Columbia River Fisheries Council (CRFC). 1981. Columbia River Basin Salmon & Steelhead Management Framework Plan. Columbia River Fish Council, Portland, Oregon.

Damaker, D. M. and D. B. Day. 1984. Adult Fish Delay at John Day Dam. NOAA/NMFS Report to the U.S. Army Corps of Engineers, Northwest and Alaska Fisheries Center, Seattle, Washington. 26 p.

Damaker, D. M. and D. B. Day. 1985. Effects of Water-Borne Pollutants on Salmon Passage at John Day Dam. Columbia River (1982-1984). NOAA/NMFS Report to the U.S. Army Corps of Engineers, Northwest and Alaska Fisheries Center, Seattle, Washington.

Dauble, D. D., T. L. Page, and R. W. Hanf, Jr. 1984. Distribution of Juvenile Salmonids in the Columbia River Near N Reactor, Spring 1984. WHC-EP-0175, Prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

De Vore, J. 1989. The Capture and Tagging of Wild Upriver Bright Fall Chinook Pre-Smolts on the Hanford Reach of the Columbia River. 1988. Progress Report 88-25. Washington Department of Fisheries, Battle Ground, Washington.

Fickeisen, D. H., D. D. Dauble, D. A. Neitzel, W. H. Rickard, R. L. Skaggs, and J. L. Warren. 1980. Aquatic and Riparian Resource Study of the Hanford Reach, Columbia River. Prepared for the U.S. Army Corps of Engineers, Seattle, Washington by Battelle, Pacific Northwest Laboratories, Richland, Washington.

Fredd, L. C. 1966. Analysis of Differences in Fish Counts at Columbia River Dams. 1957-1965, DA-35-026-CIVENG-65-44,Fish Commission of Oregon, Portland, Oregon.

Fulton, L. A. 1968. Spawning Areas and Abundance of Chinook Salmon Oncorhynchus tshawytscha in the Columbia River Basin- Past and Present. U.S. Fish and Wildlife Service Special Scientific Report Fisheries No. 571, Washington, D.C.

Gray, R. H., T. L. Page, E. G. Wolf, and M. J. Schneider. 1975. A Study of Screen Impingement and Fish Passage at Hanford Generating Project- A Progress Report. Prepared for Washington Power Supply System, Richland, Washington by Battelle Northwest Laboratories, Richland, Washington.

7.0 REFERENCES

Allen, R. L. 1977. "Status of the Upper Columbia River Salmon and Steelhead Runs". In Columbia River Salmon and Steelhead, Spec. Pub. No. 10, ed. E. Schweibert, pp. 23-30. American Fisheries Society, Washington, D.C.

Allen, R. L., and T. K. Meekin. 1973. An Evaluation of the Priest Rapids Chinook Salmon Spawning Channel. 1963-1971. Washington State Department of Fisheries, Tech. Rep. 11, Olympia, Washington.

Bauersfeld, K. 1978. The Effect of Daily Flow Fluctuations on Spawning Fall Chinook in the Columbia River. Washington State Department of Fisheries, Tech. Rep. 38, Olympia, Washington.

Becker, C. D. 1973. "Food and Growth Parameters of Juvenile Chinook Salmon, Oncorhynchus tshawytscha, from the Central Columbia River." Fish. Bull. 71:387-400.

Becker, C. D. 1985. Anadromous Salmonids of the Hanford Reach. Columbia River: 1984 Status. PNL-5371, Pacific Northwest Laboratory, Richland, Washington.

Becker, C. D. and M. P. Fujihara. 1978. The Bacterial Pathogen ***Flexibacter** columnaris* and its Epizootiology among Columbia River Fish, Monograph No. 2. American Fisheries Society, Washington, D.C.

Becker, C. D. and D. A. Neitzel. 1985. "Assessment of Intergravel Conditions Influencing Egg and Alevin Survival During Salmonid Redd Dewatering." Environ. Biol. of Fishes. 12(1):33-46.

Beiningen, K. T. 1976. "Fish Runs." In Investigative Reports of Columbia River Fisheries Project, Pacific Northwest Regional Commission, Portland, Oregon.

Bevan, D. E. 1961. "Variability in **Aerial** Counts of Spawning Salmon." J. Fish. Res. Board Can. 18:337-348

Burner, C. J. 1951. "Characteristics of Spawning Nests of Columbia River Salmon," Fisheries Bulletin 61, U.S. Fish and Wildlife Serv, Vol. 52, pp. 97-110.

Carlson, C., and M. Dell. 1989. Vernita Bar Monitoring for 1988-1989. Annual Report, Grant County Public Utility District, Ephrata, Washington.

Chapman, W. M. 1943. "The Spawning of Chinook Salmon in the Main Columbia River." Copeia. (3):168-170.

Chapman, D. W. 1988. "Critical Review of Variables Used to Define Effects of Fines in Redds of Large Salmonids." Trans. Am. Fish. Soc. 117:1-21.

Chapman, D. W., J. M. Van Hyning, and D. H. McKenzie. 1982. Alternative Approaches to Base Run and Compensation Goals for Columbia River Salmon and Steelhead Resources, Prepared for Chelan, Grant, and Douglas County Public Utility Districts.

Chapman, D. W., D. E. Weitkamp, T. L. Welsh, and T. H. Schadt. 1983. Effects of Minimum Flow Regimes on Fall Chinook Spawning at Vernita Bar 1978-1982. Prepared for Grant County Public Utility District No. 2, Ephrata, Washington by Don Chapman Consultants, Inc., McCall, Idaho and Parametrix, Inc., Bellevue, Washington.

Gray, R. H., R. G. Genoway, and S. A. Barraclough. 1977. "Behavior of Juvenile Chinook Salmon Oncorhynchus tshawytscha in Relation to Simulated Thermal Effluent." Trans. Am. Fish. Soc. 106(4):366-370.

Haynes, J. M. and R. H. Gray. 1980. "Influence of Little Goose Dam on Upstream Movement of Chinook Salmon (Oncorhynchus tshawytscha)." Fish. Bull. 78:185-190.

Heggberget, T. G., T. Haukeb, and B. Veie-Rosvoll. 1986. "An Aerial Method of Assessing Spawning Activity of Atlantic Salmon, Salmo salar L., and Brown Trout, *Salmo* trutta L., in Norwegian Streams." J. Fish Biol. 28:33-342.

Horner, N. and T. C. Bjornn. 1979. Status of Upper Columbia River Fall Chinook Salmon. Prepared for the U.S. Fish and Wildlife Service, Boise, Idaho. 45 p.

Jaquish, R. E., and R. W. Bryce. 1989. Environmental Monitoring at Hanford for 1988. PNL-6825, Pacific Northwest Laboratory, Richland, Washington.

Junge, C. 1980. Techniaue for Assessing Responsibility for Passage Losses at Columbia and Snake River Dams. Columbia River Fisheries Council. Portland, Oregon.

Lander, R. H. 1970. Distribution in Marine Fisheries of Marked Chinook Salmon From the Columbia River Hatchery Program. 1963-66, Vol. 2, No. 1, p. 28-55. Research Report, Fish Commission of Oregon, Portland, Oregon.

Mathews, S. B., and G. J. Paulik. 1967. An Analysis Pertaining to the Percentage of the Priest Rapids Fall-Chinook Salmon Runs Which Originally Spawned Above Rock Island Dam. Washington State Department of Fisheries. Olympia, Washington.

Maule, A. G., C. B. Schreck, C. S. Bradford, and B. A. Barton. 1988. "Physiological Effects of Collecting and Transporting Emigrating Juvenile Chinook Salmon Past Dams on the Columbia River." Trans. Am. Fish. Soc. 117:245-261.

Meekin, T. K. 1967. Observations of Exposed Fall Chinook Redds Below Chief Joseph Dam During Periods of Low Flow - October 1966 through January 1967. Washington State Department of Fisheries, Olympia, Washngton.

Mullan, J. W. 1987. Status and Propagation of Chinook Salmon in the Mid-Columbia River through 1985. U.S. Fish and Wildlife Service, Leavanworth, Washington. U.S. Fish and Wildlife Service Biol. Rep., Vol. 87, No. 3.

Neitzel, D. A., C. D. Becker, C. S. Abernathy, D. W. Carlisle, and E. W. Lusty. 1984. Dewatering of Vernita Bar Chinook Salmon Redds: An Assessment of Potential Impacts. Prepared for the Public Utility Dismct of Grant County by Battelle, Pacific Northwest Laboratories, Richland, Washington.

Norman, G. 1987. The Capture and Tagging of Wild Upriver Bright Fall Chinook in the Columbia River at the Hanford Reach. 1987. Washington Department of Fisheries Prog. Report 87-16, Battle Ground, Washington.

Oregon Department of Fish and Wildlife/Washington Department of Fisheries (ODFW/WDF). 1989. Status Report: Columbia River Fish Runs and Fisheries 1960-1988. ODFW/WDF, Portland, Oregon, and Olympia, Washington.

Pacific Fisheries Management Council (PFMC). 1982. Proposed Plan for Managing the 1982 Salmon Fisheries off the Coasts of California, Oregon, and Washington. Pacific Fisheries Management Council, Portland, Oregon.

Page, T. L. 1976. Observations on Juvenile Salmon Stranding in the Columbia River, 1976. To United Engineers and Constructors for Washington Public Supply System by Battelle Northwest Laboratories, Richland, Washington.

Page, T. L., D. D. Dauble, and D. A. Neitzel. 1982. Columbia River Aquatic Ecological Studies Near the Skagit/Hanford Nuclear Project: Final Report. Prepared for Northwest Energy Services Company, Kirkland, Washington by Battelle, Pacific Northwest Laboratories, Richland, Washington.

Page, T. L., D. A. Neitzel, and R. H. Gray. 1977. Impingement Studies at 100 N Reactor Water Intake. BNWL-2401, Pacific Northwest Laboratory, Richland, Washington.

Parametrix, Inc. 1979. Vernita Bar Spawning Survey 1978-1979. Doc. 79-1221-36F. Prepared by Parametrix, Inc., Bellevue, Washington, for Grant County Public Utility District, Ephrata, Washington.

Paulick, G. J. 1970. Statistical Analysis of Factors Influencing Fall Chinook Redd Counts in the Hanford Reach of the Columbia River. University of Washington Center for Quantitative Science, Seattle, Washington. 12 p.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for Evaluating Stream, Riparian, and Biotic Conditions. General Technical Report INT-138. U.S. Department of Agriculture, Forest Service, Ogden, Utah.

Raymond, H. L. 1979. "Effects of Darns and Impoundments on Migrations of Juvenile Chinook Salmon and Steelhead from the Snake River, 1966 to 1975." Trans. Am. Fish. Soc. 108:505-529.

Raymond, H. L. 1988. "Effects of Hydroelectric Development and Fisheries Enhancement on Spring and Summer Chinook Salmon and Steelhead in the Columbia River Basin." N. Am. Fish. Mgmt. 8:1-24.

Roler, R. 1988. Age-Composition and No. Tag Rates of Upriver Bright Fall Chinook, 1987. Progress Report 88-23, Washington Department of Fisheries, Battleground, Washington.

Smith, A. K. 1973. "Development and Application of Spawning Velocity and Depth Criteria for Oregon Salmonids." Trans. Am. Fish. Soc. 102:312-316.

Swan, G. A., E. M. Dawley, R. D. Ledgerwood, W. T. Norman, W. F. Cobb, and D. T. Hartman. 1988. Distribution and Relative Abundance of Deep-Water Redds for Spawning Fall Chinook Salmon. National Marine Fisheries Service, NOAA, Seattle, Washington, and Horton Dennis and Associates, Inc., Kirkland, Washington.

Swan, G. A. 1989. "Chinook Salmon Spawning Surveys in Deep Waters of a Large, Regulated River." Regulated Rivers: Research & Management, 4:355-370.

Templeton, W. L. and C. C. Coutant. 1971. "Studies of the Biological Effects of Thermal Discharges from Nuclear Reactors to the Columbia River at Hanford." In Environmental Aspects of Nuclear Power Stations. pp. 591-614. International Atomic Energy Agency. Vienna, Austria.

Technical Advisory Committee (TAC). 1982. Columbia River Bright Fall Chinook Salmon Escapement Goal. Washington State Department of Fisheries. Olympia, Washington.

U.S. Army Corps of Engineers (USACE). 1975. McNary Second Powerhouse, Revised Draft Environmental Impact Statement. Office of the Chief of Engineers, Department of the Army, Washington, D.C.

U.S. Department of Energy (DOE). 1988. 316(a) Demonstration for Operation of N Reactor in Dual-Purpose Mode. U.S. Department of Energy, Richland, Washington.

U.S. Nuclear Regulatory Commission (NRC). 1981. Final Environmental Statement Related to the Operation of WPPSS Nuclear Project No. 2. NUREG-0812, Washington D.C.

Van Hyning, J. M. 1973. Factors Affecting the Abundance of Fall Chinook Salmon in the Columbia River. Oregon Fish Commission Research Report, Vol. 4, No. 1, pp. 1-84.

Washington Department of Fisheries (WDF). 1981. Review of 1980 North Pacific Fisheries Management Council Preferred Options and Refinement to the Analysis of Upper Columbia River "Bright" Fall Chinook Management Needs and Opportunities for 1981. Washington Department of Fisheries, Battle Ground, Washington.

Washington Public Power Supply System (WPPSS). 1985. Operational Ecological Monitoring Program for Nuclear Plant 2, 1985 Annual Report. Washington Public Power Supply System, Richland, Washington.

Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy (WSDE). 1989. Hanford Federal Facility Agreement and Consent Order. Washington State Department of Ecology, Washington, D.C.

Watson, D. G. 1970. Fall Chinook Salmon Spawning in the Columbia River Near Hanford. BNWL-1515, Pacific Northwest Laboratory, Richland, Washington.

Watson, D. G. 1976. Temporal and Spatial Fall Chinook Salmon Redd Distribution Near Hanford 1967-1976. BNWL-2163. Pacific Northwest Laboratory, Richland, Washington.

Weitkamp, D., D. Chapman, T. Welsh, and T. Schadt. 1982. 1980 Vernita Bar Spawning Survey. Doc. 82-0910-019F. Grant County Public Utility District No. 2, Ephrata, Washington.

Young, W. 1980. Contribution of Priest Rapids Hatchery Fall Chinook to Artificial and Natural Spawning Populations in the Hanford Reach of the Columbia River in 1980. Washington Department of Fisheries, Olympia, Washington.

Young, W. and and R. Arthur. 1982. Contribution of Priest Rapids Hatchery Fall Chinook to Artificial and Natural Spawning Populations near Priest Rapids Dam during 1979. Washington Department of Fisheries, Olympia, Washington.

APPENDIX A

SUMMARY OF REDD COUNTS

TABLE A.1. Summary of Redd Counts by Area, 1948-1988. The highest count for individual areas were summed to obtain the peak redd counts (shown in Table 3.2)

Year	Date		Location 1	2	3	4	5	6	7	8	9	10	Other	Total
1948	Nov 8	Mon	120	330	0	38	69	83	90	2	0	53	2	787
1949	Oct 18	Tues	1	5	0	0	19	5	5	0	0	1	3	39
	Oct 26	Wed	45	51	0	9	156	26	13	6	1	0	6	313
	Nov 16	Wed	35	44	0	0	105	19	0	6	0	0	0	215
1950	Oct 26	Tues	24	30	0	36	72	58	14	0	2	44	0	280
	Nov 10	Fri	21	35	0	30	74	39	13	9	3	41	0	265
1951	Oct 16	Tues	0	0	3	0	0	Survey terminated between 100-H and 100D areas--poor visibility					1	4
	Oct 26	Fri	0	3	0	24	43	32	0	2	5	95	2	206
	Nov 7	Wed	5	7	0	45	90	38	21	0	0	91	0	297
1952	Oct 17	Fri	0	1	0	0	0	1	0	0	0	2	0	4
	Oct 23	Thur	73	Records for redd location/number are lost for Ringold to 100-D Area						---	21	38	1	311
	Nov 5	Wed	66				'			--	23	40	3	528
	Nov 21	Fri	29							–		5	7 1	133
1953	Oct 16	Fri	0	0	0	0	5	0	0	0	0	11	0	16
	Oct 22	Thur	0	0	0	0	14	0	0	0	0	51	0	68
	Nov 5	Thur	0	2	0	6	38	0	0	0	0	83	0	139
	Nov 24	Tues	7	5	0	10	40	0	0	0	0	53	0	115
1954	Oct 14	Thur	0	0	0	0	0	0	0	0	0	0	0	0
	Oct 25	Mon	0	5	0	0	54	34	1	0	7	6	0	107
	Nov 2	Tues	4	12	0	8	83	44	0	0	5	4	0	160
1955	Oct 13	Thur	0	1	0	0	10	0	0	0	0	1	0	12
	Oct 28	Fri	0	0	0	0	33	10	1	1	0	1	0	46
	Nov 14	Mon	0	11	0	0	34	12	0	0	0	3	0	60
1956	Oct 22	Mon	0	0	0	2	16	14	0	4	0	9	0	45
	Nov 2	Fri	0	0	0	7	40	16	0	6	0	17	0	86
	Nov 16	Fri	0	3	0	1	34	17	0	5	0	15	0	75
1957	Oct 11	Fri	17	1	15	1	0	0	0	0	42	32	1	109
	Oct 24	Thur	1	67	1	15	74	34	12	1	1	0	0	206
	Oct 29	Tues	8	87	1	39	170	30	90	0	0	100	0	525
	Nov 6	Wed	1	1	0	0	0	0	0	0	0	0	0	2
1958	Oct 13	Mon	32	5	100	1	28	2	6	1	130	81	2	388
	Oct 20	Mon	3	0	7	7	8	3	1	0	6	0	0	35
	Oct 27	Mon	0	87	0	99	223	45	64	48	56	176	0	798
	Nov 3	Mon	15	27	0	26	97	25	0	17	0	2	0	209
	Nov 10	Mon	0	8	14	0	0	0	17	15	0	0	0	54
	Nov 17	Mon	0	1	0	0	1	0	0	0	0	0	0	2
1959	Oct 13	Tues	0	0	0	0	0	0	0	0	1	6	0	7
	Oct 27	Tues	0	0	0	8	10	5	0	0	1	30	0	54
	Nov 10	Tues	1	0	0	36	60	40	1	0	32	111	0	281

TABLE A.1 (contd)

Year	Date		Location 1	2	3	4	5	6	7	8	9	10	Other	Total
1960	Sep 28	Wed	0	0	0	0	0	0	0	0	24	16	0	40
	Oct 18	Tues	0	0	16	14	0	2	2	0	34	61	0	129
	Nov 10	Thur	0	0	31	19	67	23	9	0	19	90	0	258
1961	Nov 6	Sat	0	15	12	19	82	46	7	4	23	160	0	368
	Nov 13	Fri	0	0	0	49	86	45	6	0	2	640	0	828
1962	Oct 15	Mon	0	1	0	0	0	0	0	0	0	43	0	45
	Oct 22	Mon	2	13	16	11	11	2	0	0	1	56	0	112
	Nov 1	Thur	4	66	80	48	151	98	83	0	0	310	0	840
	Nov 9	Fri	4	60	120	66	262	83	88	1	0	367	0	1051
	Nov 21	Wed	5	75	33	0	83	22	13	0	0	405	0	636
1963	Oct 8	Tues	0	0	0	0	0	0	0	0	0	3	0	3
	Oct 18	Fri	0	0	2	0	0	0	0	1	0	54	0	57
	Oct 28	Mon	0	29	56	40	75	13	38	1	9	178	0	439
	Nov 5	Tues	0	73	102	112	187	24	84	3	13	346	0	944
	Nov 12	Tues	0	122	159	116	345	56	100	2	12	342	0	1254
	Nov 21	Thur	0	90	113	54	209	53	90	2	8	284	0	903
1964	Oct 21	Wed	0	0	13	5	20	1	21	2	16	102	0	180
	Oct 30	Fri	0	29	94	110	226	90	110	26	36	300	0	1021
	Nov 16	Mon	5	55	70	91	245	99	119	12	24	624	0	1339
1965	Oct 21	Wed	0	0	10	3	13	1	12	1	3	58	0	101
	Oct 29	Fri	3	73	75	47	231	30	99	10	154	497	3	1122
	Nov 11	Thur	4	136	123	202	345	37	112	11	130	NS*	3	1003
	Nov 16	Tues	3	117	111	138	298	50	96	8	24	652	3	1477
1966	Oct 6	Thru	0	0	0	0	0	0	0	0	0	1	0	1
	Oct 21	Fri	1	8	8	0	9	0	7	1	2	44	0	80
	Oct 26	Wed	10	36	30	46	59	27	42	2	0	284	0	536
	Nov 2	Wed	8	132	120	267	459	230	270	1	37	1300	0	2824
	Nov 9	Wed	9	113	140	263	697	160	220	0	4	1085	0	2691
	Nov 23	Wed	1	64	70	78	197	35	54	0	1	420	0	920
1967	Sep 28	Thur	0	0	0	0	0	0	0	0	0	0	0	0
	Oct 16	Mon	0	0	0	0	0	0	0	0	0	0	0	0
	Oct 26	Thur	0	5	4	6	13	8	35	0	4	348	1	424
	Nov 2	Thur	24	148	77	207	342	110	162	8	15	775	0	1868
	Nov 8	Wed	21	180	160	248	499	155	244	28	6	1340	0	2881
	Nov 15	Wed	34	205	160	182	458	150	455	23	17	660	0	2344
	Nov 22	Wed	15	124	115	209	480	110	307	20	4	780	1	2165
1968	Oct2	Wed	0	0	0	0	0	0	0	0	0	1	0	1
	Oct 14	Mon	0	10	0	5	0	0	0	0	0	25	0	25
	Oct 21	Mon	24	46	61	51	44	16	31	0	1	0	0	274
	Oct 29	Tues	79	183	300	186	355	135	182	19	35	1500	0	2974
	Nov 6	Wed	130	250	300	169	437	107	138	14	50	910	0	2505
	Nov 15	Fri	111	214	320	134	742	79	162	14	52	1400	5	3233

TABLE A.1. (contd)

Year	Date		Location											
			1	2	3	4	5	6	7	8	9	10	Other	Total
1969	Oct 13	Mon	11	0	0	0	0	0	0	0	0	0	0	11
	Oct 21	Tues	7	16	12	4	15	0	10	1	0	80	0	145
	Oct 30	Thur	82	155	190	245	246	60	106	6	32	710	4	1836
	Nov 6	Thur	145	401	410	427	903	126	362	30	50	1034	0	3888
	Nov 11	Mon	252	189	220	309	365	97	180	26	14	1011	0	2663
	Nov 23	Sun	175	221	210	375	762	111	260	NS(a)	NS	1075	0	3189
1970	Oct 8	Thur	14	1	10	0	0	0	0	0	2	39	3	69
	Oct 15	Thus	22	6	16	0	1	0	0	0	0	66	6	117
	Oct 22	Thur	13	20	41	22	27	20	26	2	2	130	6	309
	Oct 28	Wed	21	244	230	237	322	63	125	0	72	980	9	2303
	Nov 5	Thur	74	360	215	302	541	152	228	0	34	1428	2	3336
	Nov 12	Thur	90	367	210	277	746	159	259	0	43	1486	6	3643
	Nov 19	Thur	65	195	150	239	566	99	209	0	17	1094	0	2634
1971	Oct 18	Mon	21	10	2	7	6	1	0	0	0	41	3	91
	Oct 28	Thur	44	108	47	32	86	22	48	0	1	310	0	698
	Nov 4	Thur	156	308	160	370	659	72	130	12	9	1120	0	2996
	Nov 16	Tues	183	374	180	386	740	32	230	24	10	1361	0	3504
1972	Oct 13	Fri	4	0	0	0	1	0	0	0	0	0	0	5
	Oct 24	Tues	6	0	0	0	0	0	0	0	0	0	0	6
	Nov 6	Mon	71	78	67	120	109	23	74	0	0	96	0	638
	Nov 14	Tues	77	66	54	59	110	52	69	0	4	127	0	618
	Nov 27	Mon	71	131	103	131	88	42	33	0	0	61	0	660
1973	Oct 15	Mon	121	40	7	0	26	6	37	0	9	110	5	361
	Oct 26	Fri	55	108	32	73	151	55	95	2	59	429	3	1062
	Nov 2	Fri	44	86	40	114	288	82	144	3	59	599	4	1463
	Nov 13	Tues	43	330	123	170	722	176	283	7	29	882	1	2766
1974	Oct 15	Tues	76	11	0	0	0	2	0	0	0	13	3	105
	Oct 24	Thur	54	13	11	4	8	9	8	0	0	30	2	139
	Nov 5	Tues	35	44	0	1	16	34	25	0	1	153	0	309
	Nov 15	Fri	61	74	12	12	86	13	67	0	0	76	0	401
	Nov 26	Tues	59	113	28	49	72	47	62	0	4	142	0	576
1975	Oct 16	Thur	68	0	2	0	0	0	0	0	0	37	0	107
	Oct 24	Wed	62	263	140	256	373	50	215	30	46	427	1	1863
	Nov 1	Fri	7	261	120	261	359	79	151	52	NS	NS	0	1290
	Nov 19	Wed	2	19	0	--------- -Survey Terminated Due to Fog-------------							0	21
	Nov 20	Thur	0	146	54	21	218	13	124	0	86	995	0	1657
1976	Oct 12	Tues	15	0	0	6	0	0	0	0	0	5	0	26
	Oct 26	Tues	17	110	106	84	367	79	110	7	105	320	0	1305
	Nov 5	Fri	2	137	140	185	384	105	135	6	182	599	0	1875
	Nov 15	Mon	2	162	102	158	356	76	140	2	123	487	0	1608

TABLE A.1. (contd)

Year	Date		Location											
			1	2	3	4	5	6	7	8	9	10	Other	Total
1977	Oct 13	Thur	7	12	0	1	2	8	0	0	6	6	0	42
	Oct 24	Mon	5	104	64	118	234	44	77	2	29	242	0	919
	Oct 31	Mon	6	268	110	265	519	58	209	4	47	215	0	1701
	Nov 7	Mon	2	198	------ --Survey discontinued--High winds and dust---------									200
	Nov 10	Thur	2	291	140	355	1136	161	263	8	37	760	0	3153
	Nov 17	Thur	0	205	110	347	1013	99	169	4	23	145	0	2115
1978	Oct 9	Mon	0	0	0	0	0	0	0	0	0	0	0	0
	Oct 16	Mon	0	0	0	0	0	0	0	0	0	0	0	0
	Oct 26	Thur	0	33	13	5	41	4	31	0	5	50	0	182
	Nov 6	Mon	18	71	38	19	53	2	90	0	20	20	0	331
	Nov 11	Sat	0	156	60	326	789	74	386	73	145	975	0	2984
1979	Oct 7	Sun	1	0	0	0	1	0	0	0	0	0	0	2
	Oct 27	Sat	9	73	27	97	170	28	87	8	13	176	0	688
	Nov 3	Sat	25	214	105	297	672	172	257	42	92	980	0	2856
	Nov 20	Tues	66	229	145	240	67	Survey interrupted--Dense fog		---	---	142	0	889
1980	Oct 16	Thur	0	0	0	0	0	0	0	0	0	0	0	0
	Oct 24	Fri	2	19	7	5	13	8	8	0	0	18	0	80
	Nov 4	Tues	29	112	32	64	194	33	119	0	35	856	0	1474
	Nov 13	Thur	18	102	0	0	53	5	87	0	0	288	0	553
1981	Oct 17	Sat	8	3	3	2	19	0	13	0	11	76	0	135
	Oct 24	Sat	45	113	47	38	390	70	222	26	55	736	0	1742
	Nov 4	Wed	82	222	163	215	809	118	323	58	62	343	0	2395
	Nov 8	Sun	31	173	190	270	1103	151	553	38	80	2120	0	4709
1982	Oct 19	Tues	0	9	0	1	2	2	12	0	3	0	0	24
	Oct 24	Sun	0	29	17	15	163	36	102	8	71	542	0	1383
	Oct 31	Sun	0	85	83	129	561	93	352	31	100	1970	6	3404
	Nov 7	Sun	5	149	170	232	1102	160	560	32	149	2060	12	4631
	Nov 20	Sat	7	146	210	278	852	119	450	79	113	1523	16	3793
1983	Oct 16	Sun	0	0	0	0	0	0	0	1	0	13	0	14
	Oct 23	Sun	0	11	10	7	32	14	23	5	13	196	0	311
	Nov 1	Tues	11	100	77	236	657	75	291	28	35	1020	0	2530
	Nov 8	Tues	5	284	160	425	1122	140	407	16	21	1090	0	3670
	Nov 12	Sat	24	233	200	511	1310	198	453	33	43	2216	0	5221
1984	Oct 17	Wed	0	3	0	0	0	0	0	0	0	3	0	6
	Oct 21	Sun	0	1	0	0	8	1	10	0	0	153	0	173
	Oct 27	Sat	0	102	47	352	599	47	299	14	55	1537	3	2995
	Nov 5	Mon	81	379	90	950	1430	57	853	87	33	1080	0	5040
	Nov 11	Sun	88	514	190	1052	1920	53	835	85	27	2314	0	7078
	Nov 18	Sun	27	384	90	635	1108	85	542	84	21	1374	7	4351
1985	Oct 20	Sun	0	18	0	12	37	1	12	2	0	399	1	482
	Oct 26	Sat	0	51	5	130	298	37	107	13	37	595	4	1277
	Nov 3	Sun	12	624	250	770	1949	370	863	152	107	2411	15	7523
	Nov 9	Sat	0	314	42	334	1030	91	589	151	60	2047	11	4669

TABLE A.1. (contd)

Year	Date		Location 1	2	3	4	5	6	7	8	9	10	Other	Total
1986	Oct 8	Wed	0	0	0	0	0	0	0	0	0	0	0	0
	Oct 19	Sun	0	0	2	1	0	2	3	0	0	28	1	37
	Oct 25	Sat	1	14	11	26	77	13	65	11	4	305	1	528
	Nov 1	Sat	14	312	120	308	872	127	598	119	32	1640	16	4158
	Nov 8	Sat	10	490	250	656	1740	370	1074	199	51	2635	17	7492
	Nov 15	Sat	14	321	180	672	1810	190	1020	213	73	3082	14	7589
	Nov 22.	Sat	11	325	200	515	1440	168	799	201	49	2768	22	6498
1987	Oct 17	Sat	4	0	0	0	0	0	0	0	0	2	0	6
	Oct 24	Sat	3	0	0	2	2	0	21	1	5	21	0	55
	Oct 31	Sat	19	95	44	161	332	60	135	49	32	678	15	1620
	Nov 7	Sat	75	463	150	709	1626	86	709	132	74	2086	27	6137
	Nov 15	Sun	183	780	320	900	1870	90	951	117	37	2613	25	7886
	Nov 22	Sun	251	402	150	499	1372	95	600	142	50	3150	22	6733
1988	Oct 17	Mon	0	6	0	1	0	0	5	0	0	9	2	23
	Oct 22	Sat	0	4	0	2	7	5	5	0	0	50	0	73
	Oct 29	Sat	6	156	80	147	411	71	243	43	63	877	21	2118
	Nov 5	Sun	160	555	190	679	1680	310	870	202	123	2742	48	7559
	Nov 14	Tues	264	715	350	828	1550	220	743	184	112	2213	42	7221
	Nov 20	Mon	6	217	0	250	Survey discontinued--High winds and river level							473

(a) NS = Not surveyed.

TABLE **A.2**. Estimated Number of Redds for the Lower Yakima River (river km to Richland)

Year	Peak Count
1960	0
1961	29
1962	5
1963	108
1964	40
1965	66
1966	135
1967	177
1968	62
1969	829
1970	634
1971	88
1972	136
1973	174
1974	131
1975	339
1976	240
1977	82
1978	32
1979	0
1980	11
1981	12
1982	33
1983	50
1984	118
1985	45
1986	134
1987	14
1988	8

DISTRIBUTION

No. of COPIES	
OFFSITE	
12	DOE/Office of Scientific and Technical Information
	J. Athearn U.S. Army Corps of Engineers North Pacific Division P.O. Box 2870 Portland, OR 97208-2870
	D. Bennett Fish & Wildlife Dept. University of Idaho Moscow, ID 83843
	R. R. Boyce Oregon Department of Fish & Wildlife 506 S.W. Mill St. P.O. Box 59 Portland, OR 97207
	T. C. Bjornn, Leader Idaho Cooperative Fish Research Unit University of Idaho Moscow, ID 83843
	M. J. Schneider Division of Fish & Wildlife Bonneville Power Administration P.O. Box 3621 Portland, OR 97208
	G. R. Bouck Division of Fish & Wildlife Bonneville Power Administration P.O. Box 3621 Portland, OR 97208
	S. Smith Division of Fish & Wildlife Bonneville Power Administration P.O. Box 3621 Portland, OR 97208

No. of Copies	
	D. Johnson Division of Fish & Wildlife Bonneville Power Administration P.O. Box 3621 Portland, OR 97208
	P. Poe Division of Fish & Wildlife Bonneville Power Administration P.O. Box 3621 Portland, OR 97208
	D. W. Chapman Chapman and Associates P.O. Box 1362 McCall, ID 83638
	H. Wagner Northwest Power Planning Council Fish & Wildlife Division 851 S.W. 6th Portland, OR 97205
	C. McConnaha Northwest Power Planning Council Fish & Wildlife Division 851 S.W. 6th Portland, OR 97205
	M. Cueco Columbia River Intertribal Fish Commission 975 Sandy Blvd., Suite 202 Portland, OR 97214
	D. R. Geist Washington Department of Fisheries 500 N. Morain, Suite 1200B Kennewick, WA 99336
	D. Fast Yakima Indian Nation - Fisheries P.O. Box 151 Toppenish, WA 98948

No. of
Copies

A. Giorgi
National Marine Fisheries Service
2725 Montlake Blvd., East
Seattle, WA 98112

R. Kindley
PNUCC
One Main Place
101 S.W. Main
Suite 810
Portland, OR 97204

W. Maslen
Division of Fish & Wildlife
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

J. A. Mullan
USFWS, Leavenworth National Fish Hatchery
Rt. 1, Box 123-A
Leavenworth, WA 98826

W. R. Nelson
USFWS, National Fishery Research Center
Willard Substation
Star Route
Cook, WA 98605

R. Lincoln
Washington Department of Fisheries
Habitat Management Division
115 General Administration Bldg.
Olympia, WA 98504

P. Mundy
Columbia River Intertribal Fish Commission
975 S.E. Sandy Blvd., Suite 202
Portland, OR 97214

J. R. Palensky
Northwest Power Planning Council
850 S.W. Broadway
Suite 1100
Portland, OR 97205

No. of
Copies

J. Skalski
Center for Quantitative Sciences
HR-20
University of Washington
3737 15th Ave., N.E.
Seattle, WA 98195

H. L. Raymond
National Marine Fisheries Service
Northwest and Alaska Fisheries Center
2725 Montlake Blvd. East
Seattle, WA 98112

C. B. Schreck, Leader
Oregon Cooperative Fish Research Unit
Oregon State University
Corvallis, OR 97331

R. L. Tuck, Director
Fish and Wildlife Resource Mgmt.
P.O. Box 151
Toppenish, WA 98948

F. Olney
U.S. Fish and Wildlife Service
9317 Highway 99, Suite 1
Vancouver, WA 98665

Roy Sampsell
RHS & Associates
P.O. Box 69427
Portland, OR 97201

R. M. Woodin
Department of Fisheries
Habitat Management
Rm 115 General Administration Building
Olympia, WA 98504

G. Swan
National Marine Fisheries Service
Pasco Industrial Park
Pasco, WA 99301

No. of
Copies

ONSITE

3 DOE Richland Operations Office

M. W. Tiernan
R. F. Brich
P. W. Kruger

80 Pacific Northwest Laboratory

W. J. Bair
C. D. Becker
C. E. Cushing
D. D. Dauble (30)
L. E. Eberhardt
R. M. Ecker
J. W. Falco
R. H. Gray
J. M. Hales
H. H. Harty
P. C. Hays
G. P. O'Connor
W. D. McCormack
D. A. Neitzel
T. L. Page
W. T. Pennell
K. R. Price
W. H. Rickard
L. E. Rogers
B.D. Shipp
R. L. Skaggs
J. A. Strand
W. L. Templeton
B. E. Vaughan
D. G. Watson (20)
H. E. Westerdahl
Technical Report Files (5)
Publishing Coordination