ROCK ISLAND
BACKGROUND BIOLOGY

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1. Purpose and Need. Rock Island was the first hydroelectric facility to harness the power of the mainstem Columbia River. Construction of the project involved raising a reinforced concrete structure that spanned the Columbia River at river mile (RM) 453.4, creating a 3,470-acre impoundment in central Washington (Figure 1-1). The original project included a spillway and abutment, and a powerhouse on the left (east) side of the river. Subsequent developments included expansion of the powerhouse to hold an additional six turbines, and construction of a second powerhouse (powerhouse 2) on the opposite side of the river.

The original construction of the Rock Island project was completed by the Puget Sound Power & Light Company in 1933 to provide hydropower to the greater Seattle area. Ownership was later transferred to the Chelan PUD. The Chelan PUD distributes a substantial portion of the power from Rock Island dam to customers in Chelan County. Under terms of the 19 June 1974 power purchase contract, Puget Sound Power & Light Company, now Puget Sound Energy, purchases the remaining output.

The combined effects of hydropower projects, flood control, irrigation, timber harvesting, grazing activities, commercial and sport fishery harvest, as well as changes in ocean conditions, have resulted in the decline of some stocks of mid-Columbia River salmonid fish. The Chelan PUD, in combination with Public Utility District No. 1 of Douglas County (DCPUD) is developing a conservation plan to assist the recovery of Plan Species utilizing mid-Columbia River as habitat.

Upper Columbia steelhead (*Oncorhynchus mykiss*) were listed as endangered by the National Marine Fisheries Service (NMFS) on August 18, 1997. 62 FR 43937 (August 18, 1997) Upper Columbia spring chinook have been proposed for listing, as have bull trout. 63 FR 11482 (March 9, 1998) and 62 FR 32268 (June 13, 1997). No other aquatic plant or animal species in the mid-Columbia River reach is currently listed as threatened or endangered under either the ESA or Washington State laws or regulations. Summer/fall (ocean-type) chinook salmon in the mid-Columbia River were petitioned for listing in 1993. A listing was found to be not warranted by the NMFS in 1994 and reaffirmed in 1998. 63 FR 11482 (March 9, 1998). NMFS has determined that listing of the two sockeye ESUs in the mid-Columbia is also not warranted. Summer/fall chinook and sockeye are addressed in the Agreement since they represent an important component of anadromous fish production in the mid-Columbia basin. The listing of any of these species could substantially affect operation of the Rock Island and other hydropower facilities throughout the basin. This Agreement is intended to enhance protection of these fish while providing a greater degree of certainty in long-term operation of the Rock Island project.

2. Existing Conditions

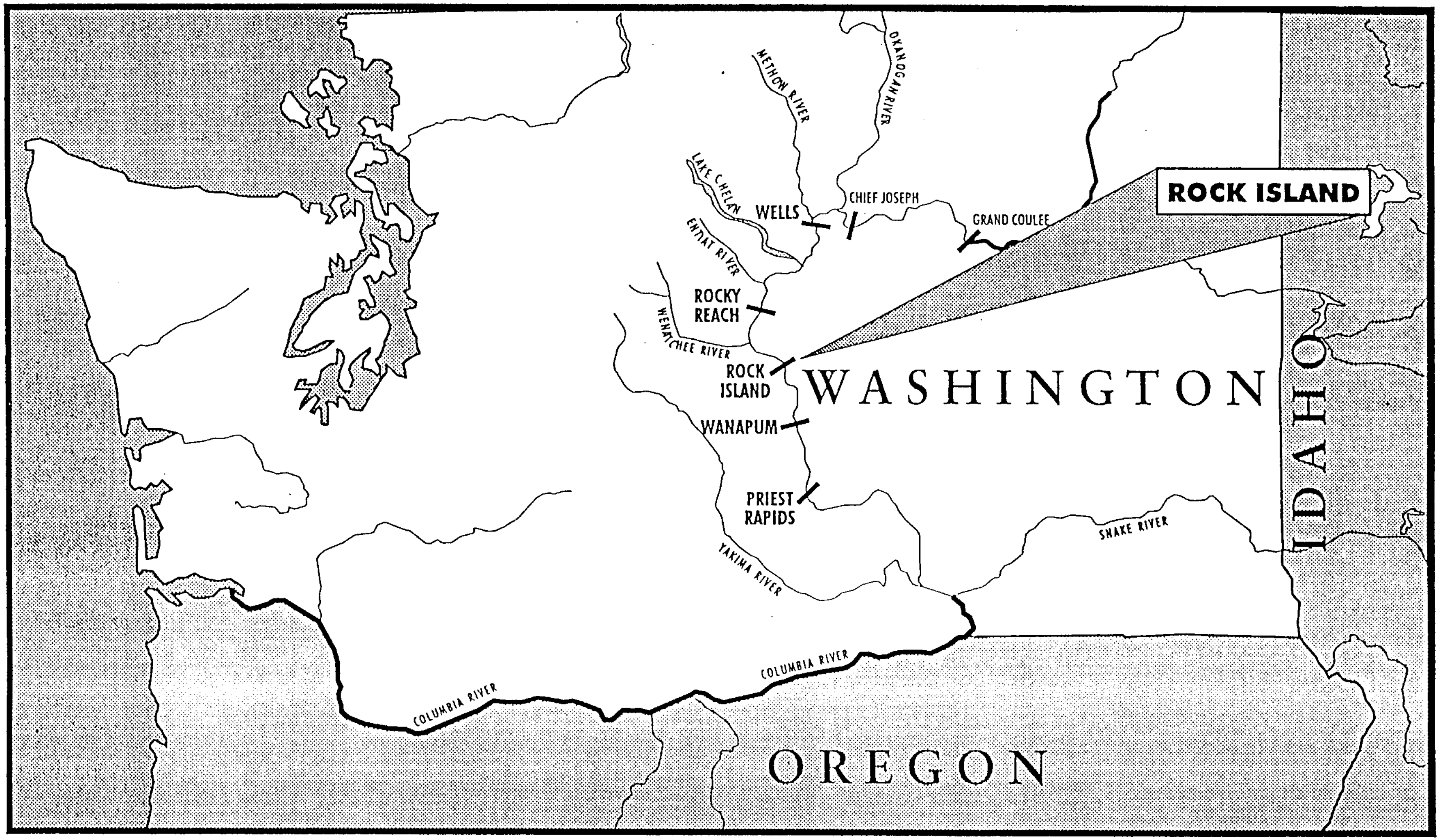

Figure 1-1. Location of the Rock Island dam and other mid-Columbia Public Utility District and federal dams in the mid-Columbia Reach (PUD projects in bold). loc-dam.rit

2.1. Environmental Setting

2.1.1. General Site Description. The Columbia River and its tributaries drain an area of 219,000 square miles in seven western states and 39,500 square miles in British Columbia. In the United States, most of the basin is located in Washington, Oregon, Idaho and Montana. The Columbia River originates at Columbia Lake on the west slope of Rocky Mountain Range in British Columbia and flows west and south, eventually draining into the Pacific Ocean between Washington and Oregon. Total river length is 1,214 miles (Bonneville Power Administration [BPA] et al. 1994a).

The Rock Island project is the third of five mainstem PUD dams below Chief Joseph dam. Rock Island dam is located at RM 453.4. Rock Island reservoir extends 20.5 miles upstream to the tailrace of Rocky Reach dam. Rock Island reservoir has a surface area of 3,470 acres, a volume of 126,000 acre-feet, an average depth of 33 feet, and a shoreline length of 42 miles. The Wenatchee River is the one major tributary flowing into Rock Island reservoir between Rock Island and Rocky Reach dams.

2.1.2. Geology. The mid-Columbia River reach forms the boundary between the North Cascade Mountains to the west and the Columbia Plateau to the east. The Cascade Mountains rise to the west of the project area, while mildly rolling hills predominate in Douglas County northeast of the project area. In some locations around the Rock Island project, basalt cliffs rise 1,000 feet above the river. Large talus slopes have formed at the base of some of these cliffs. In other locations, large terraces of sand, gravel and silt rise 400 to 500 feet above the river (BPA et al. 1994a). The Columbia River flows over mostly Paleozoic metamorphic and intrusive rocks until it reaches Rock Island dam. The foundation of Rock Island dam rests on basalt (BPA et al. 1994a). Below Rock Island dam the river passes into the Columbia basalt group (BPA et al. 1994a). Rangeland, irrigated cropland, orchards and urban development predominate the river corridor around the Rock Island project. Land throughout the project reach is predominately held in private ownership.

2.1.3. Land Use. Land use in the mid-Columbia reach varies considerably from north to south. Rangeland predominates around Rufus Woods Lake impounded by Chief Joseph dam, while irrigated cropland and orchards predominate the river corridor around the Rocky Reach project and reservoir. Below Rock Island dam, land cover is mostly rangeland, with irrigated cropland on the east side of the river. Land throughout the project reach is predominantly in private ownership, although there are a number of public land units. Federal land in the mid-Columbia River includes the Colville Indian Reservation to the north, the Okanogan and Wenatchee National Forests in sections between Wells and Rocky Reach dams, scattered tracts of U.S. Bureau of Land Management (BLM) land. There are also 13 state wildlife refuges and seven state parks in the mid-Columbia region (BPA et al. 1994b).

2.1.4. Soils. A wide variety of soils occur in the mid-Columbia reach including Cambothrids, Haploxerolls and Argixerolls. Soils range from light-colored soils, with thin "A" horizons poor in organic matter, and calcium accumulations high in the profile; to thick, very dark-brown to black soils with "A" horizons rich in organic matter, but with calcium carbonate accumulations that may be deep in the profile or absent. Soils with high accumulations of salt (Solonchak) and large amounts of exchangeable sodium (Natrargids or Solonetz) are also present (Franklin and Dyrness 1984).

2.1.5. __Vegetation__. Vegetation in the mid-Columbia region consists mainly of steppe and shrub-steppe vegetation, and forest vegetation is generally confined to mountain slopes with sufficient precipitation (Franklin and Dyrness 1973). Much of the area has been cultivated with a variety of crops or is grazed by domestic and wild livestock. Natural vegetation communities in the plan area consist of a shrub layer dominated by artemisia (*Artemisia tridentata*) along with a variety of perennial grasses. Moister sites, such as areas along streams or rivers, may be inhabited by hawthorn/snowberry (*Crataegus douglasii/Symphoricarpos albus*) and hawthorn/cow parsnip (*Crategus douglasii/Heracleum lanatum*). Other habitats with distinct vegetation communities include those with gravelly or sandy soils, shallow, stony sites; and sand dunes near the Columbia River (Franklin and Dyrness 1984).

2.1.6. __Climate__. Located in the rain shadow of the Cascade Range, the plan area is classified as arid to semi-arid and experiences low precipitation, dry summers with warm to hot temperatures and relatively cold winters. Some marine influences are still felt, but continental-type climate conditions prevail. Most of the Columbia basin receives less than 20 inches of precipitation annually, with much of this precipitation occurring in winter. Deep snow may accumulate over the mountainous areas, where water is held as natural storage until the runoff in the spring.

2.1.7. __Water Quality__. The mid-Columbia River and the Rock Island project reach of the mid-Columbia River has been classified by the Washington Department of Ecology (WDOE) as "Class A" water. On a scale ranging from Class AA (extraordinary) to Class C (fair), Class A waters are rated as "excellent". The regulations require that Class A water meets or exceeds requirements for substantially all uses. However, water quality within the mid-Columbia region occasionally does not meet state and federal water quality standards for certain parameters (e.g., total dissolved gas, water temperature). Compared to other rivers in the United States, the Columbia River carries a large volume of relatively unpolluted surface water and has few sources of pollution and wastewater.

Sources of water quality impacts in the mid-Columbia River include non-point source pollution from agriculture runoff and irrigation return, depletion of instream flows from diversions, and impoundment and flow regulation at hydropower projects. There is one large and several smaller irrigation projects that drain directly to the river or its tributaries. The major project is the Columbia Basin Project, which extends from Banks Lake to the confluence of the Snake River.

Hydropower production can affect water quality parameters that are significant to mid-Columbia fish; these parameters include TDG, water temperature, dissolved oxygen, turbidity, suspended sediments and nutrients. The status of each of these parameters in the mid-Columbia River is summarized below. Additional information regarding water quality is contained in Section 3.3.

2.1.7.1. Total Dissolved Gas. River water that contains high levels of total dissolved gas (TDG) can be harmful to fish. Total dissolved gas supersaturation often occurs during periods of high runoff and spill at hydropower projects, primarily because spill can cause significant air entrainment in spillway tailwaters. Fish and other aquatic organisms that are exposed to excessive TDG supersaturation can develop gas bubble trauma (GBT), a condition that is harmful. Total dissolved gas supersaturation in the mid-Columbia River system is well documented (see Section 3.3, Gas Supersaturation) and has been linked to mortalities and migration delays of salmon (Beiningen and Ebel 1970; Ebel et al. 1975; Gray and Haynes 1977; BPA et al. 1994a). Total dissolved gas supersaturation in the Columbia and Snake Rivers was identified in the 1960s and 1970s as a detriment to salmon, and those concerns have reappeared as management agencies have reinstituted spill as a means of aiding fish passage around Snake and lower Columbia River hydropower facilities (NMFS 1995a).

2.1.7.2. Water Temperature. Water temperatures in the mid-Columbia River reach are similar to those elsewhere in the Columbia and Snake River systems (U.S. Army Corps of Engineers [USACE] 1993). The major effect of hydropower projects on the Columbia River has been to delay the time when thermal maximums are reached and when cooling begins in late summer (BPA et al. 1994a). The thermal regime of the mid-Columbia River is largely influenced by releases from Grand Coulee dam, which is the main upstream deepwater storage project. Lake Roosevelt, the impoundment created by Grand Coulee dam, becomes thermally stratified during the summer. The mid-Columbia hydroelectric projects are run-of-river facilities with very limited capability for storage and flow regulation (see Section 2.4). In general, the very rapid flushing rates of the pools at these facilities limit the potential warming that can occur.

2.1.7.3. Dissolved Oxygen. Dissolved oxygen (DO) levels in the mid-Columbia River do not typically decline below the minimum Environmental Protection Agency (EPA) standard for DO of 8.0 mg/l, although DO levels have occasionally been slightly below the standard at Grand Coulee, Rock Island and Vernita Bar (BPA et al. 1994a).

2.1.7.4. Turbidity and Suspended Sediments. Turbidity and suspended sediments in the mid-Columbia River are relatively low (BPA et al. 1994a). The Grand Coulee project and downstream reservoirs slow the river flow and allow sediment to settle out. Turbidity and suspended sediments are commonly higher in the tributaries than in the mainstem mid-Columbia River (BPA et al. 1994a).

2.1.7.5. Nutrients. Water quality stations throughout the Columbia River typically show ammonia concentrations that are below the EPA chronic freshwater standard. However, stations at Grand Coulee and Priest Rapids have recorded ammonia maximums that exceed the standard. Mean annual phosphate concentrations often exceed levels that could stimulate algal blooms. Highest phosphate levels occur at the start of spring runoff, and in the late fall at the end of the low-flow season. High levels are also encountered in winter when biological uptake is lowest (BPA et al. 1994a).

2.1.8. Hydrology.

2.1.8.1. Mid-Columbia Reach Hydrology. The Columbia River basin is primarily a snow-fed system. Snow accumulates in the mountains from late fall through winter, then melts and produces runoff during late spring and summer. The major runoff occurs when the snow is melting during May through June, with streamflows normally peaking in early June. In late summer and fall, the river flow drops and remains relatively low through April. Rainfall occasionally increases the runoff; rain-on-snow episodes have caused some of the most significant flooding events along the mid-Columbia River.

2.1.8.1.1. Effects of Storage and Run-of-river Hydropower Projects. Hydropower projects in the Columbia River basin fall into two major categories: storage and run-of-river. The difference between the two categories helps to explain the amount and timing of streamflows. Storage projects such as Grand Coulee dam have a large usable storage space and are operated to alternately store and release water for flood control, power generation, irrigation, fish migration and other needs. They have a large operating range (the difference in elevation between minimum and maximum pool), draft large volumes of water, and shape downstream flows. Run-of-river projects, such as the mid-Columbia dams, generally have little pondage and no usable storage volume. They have a small operating range and must pass inflow most of the time.

However, project discharges are shaped to meet power demands, which are significantly higher during daylight (heavy-load) hours than during nighttime (light-load) hours. As a result, flow patterns in the mid-Columbia River are primarily shaped by the operations at the Canadian and Federal storage projects upstream, particularly Grand Coulee dam. The releases from Grand Coulee dam and regulation by Chief Joseph dam fundamentally affect the magnitude and timing of flows at the five PUD run-of-river dams.

2.1.8.1.2. Grand Coulee Flow Operations and Operating Plans. Flow releases from Grand Coulee dam and upstream projects set the flow regime for the mid-Columbia River (see Section 2.4). Daily flows are based on an operating plan that considers several related but sometimes conflicting objectives. These include:

- providing adequate flood control storage to control spring runoff;
- providing sufficient water for navigation, recreation, fish and wildlife;
- ensuring a high probability of refill to provide water for next year's operations;
- providing flows to aid downstream migration of juvenile salmon;
- providing adequate water supply for irrigation; and

- providing power generation.

According to the Columbia River Treaty, the operating plans are developed by agreement between the United States entity, represented by the BPA, and the Canadian entity, represented by B.C. Hydro. The plans are implemented by the BPA, USACE and the U.S. Bureau of Reclamation (BOR).

Annual operations at Grand Coulee (Lake Roosevelt) to meet energy demand are described below. The project releases water, or drafts, from August through December according to "rule curves" determined on an annual basis. From January through mid-April, project draft for flood control and energy production is variable based on runoff volume forecasts. From mid-April through June, Lake Roosevelt is refilled with spring runoff. Also during this time water is released to aid downstream migration of juvenile anadromous salmonids.

2.1.8.1.3. Flow Operations History in the Mid-Columbia River. Since about 1966, annual streamflow regimes in the mid-Columbia River have been affected by three different time periods of operation. These include the period from 1966 to 1972, as additional deepwater storage projects (i.e., Arrow, Libby, Mica) were being completed per the Columbia River Treaty; 1973 to 1982, as operations changed the use of the available storage gained from these projects; and 1983 to the present, when spring flow augmentation releases from these storage projects were recommended to aid migration of wild and hatchery-origin juvenile salmonids in the lower Columbia River. The effect on the annual flow regime during these periods is indicated in Figure 2-1 and is based on average monthly total discharge at Priest Rapids dam.

The flow regimes of these three periods indicate the influence of changes in storage and the shifts in operational objectives priorities. Prioritizing power generation and flood control objectives tended to result in "flattening out the hydrograph" by moving flow from spring, the period of peak natural runoff, into the fall and winter (i.e., 1973 to 1982). Placing a higher priority on downstream fish migration tends toward releases that provide a slightly higher, more natural spring peak hydrograph (i.e., 1983 to 1995). See Section 2.4 for more information on hydrology and hydropower operations.

2.1.8.2. Project Hydrology. Generally, snow accumulates in the mountains from November to March, then melts and produces peak runoff in early June. Since about 1966, annual streamflow regimes in the Rocky Reach project area have been affected by three different time periods of operation as described in 2.1.8.1.3.

The changes in storage reservoir operations, to include fish passage flow augmentation in addition to flood control and power production, have resulted in reduced flows from January through April and increased flow from May through August. The effects of fish passage operations are most apparent during years of average snowpack and drought, when power production in winter is constrained to hold water in storage for spring fish flow releases and in summer when reservoir refill probability is reduced in order to augment flows during June through August. The effects of fish passage flow augmentation during years of average and below average snowpack are shown in Figure

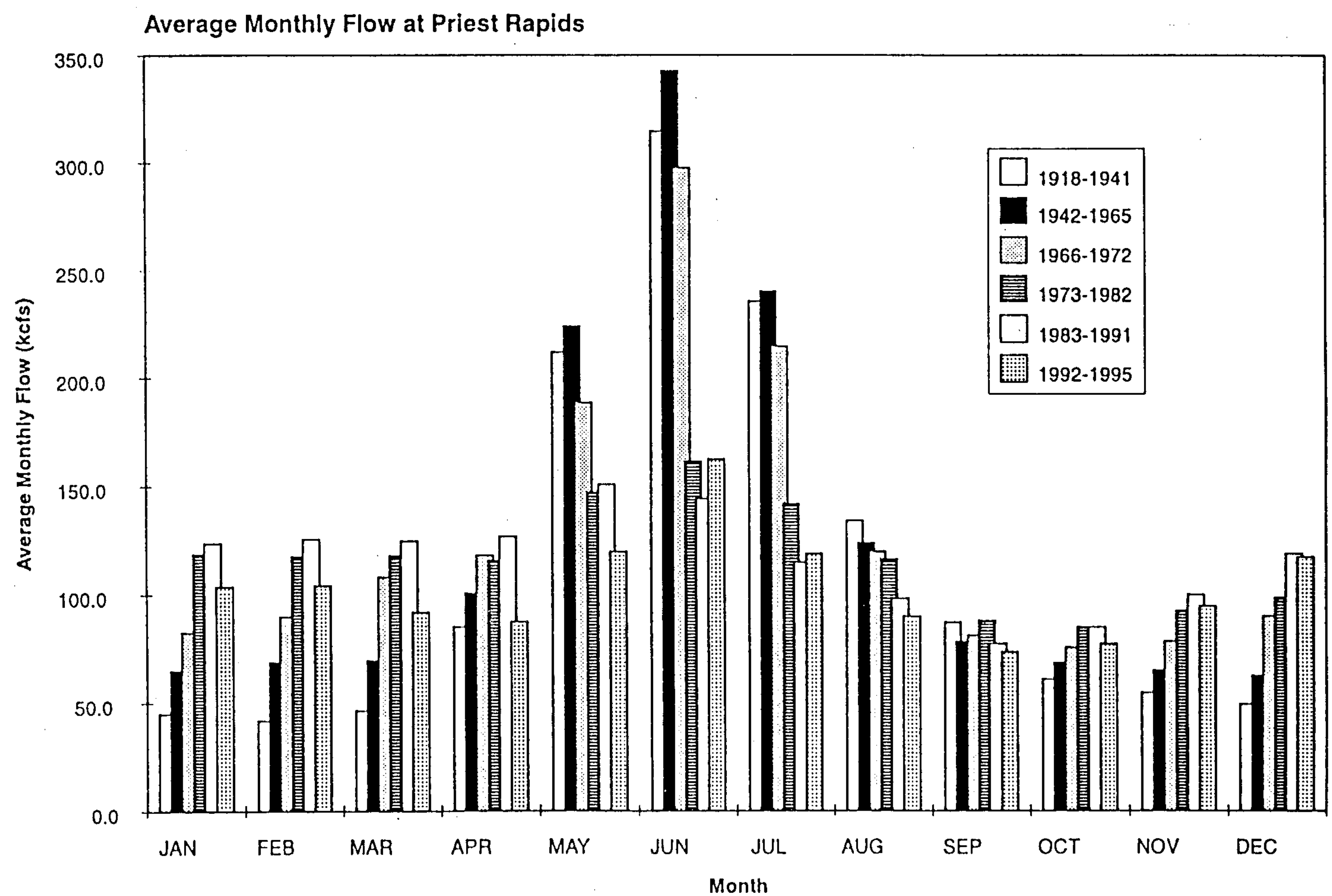

Figure 2-1 Average monthly flow at Priest Rapids dam for six different time periods: 1918-1941, 1942-1965, 1966-1972, 1973-1982, 1983-1991, and 1992-1995.

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2-2 for three time periods since storage reservoirs were completed. These periods are from 1973 to 1982, when reservoirs were managed primarily for flood control and power generation, with limited fish passage flows provided in May; the periods of 1983 to 1991, when augmentation was confined to the period 15 April through 15 June under the Northwest Power Planning Council's Water Budget; and 1992 to the present, when the NMFS Biological Opinion (BO) restructured storage releases to augment flows in the lower Columbia River from June through August. A side effect of the NMFS BO has been severe reduction in mid-Columbia River flows in April while water is stored for release during the summer.

As a run-of-river project, the Project has little pondage and no usable storage volume. Flows at Rocky Reach are primarily shaped by operations at Canadian and federal storage projects upstream, particularly Grand Coulee dam. Effects of upstream storage, reregulation, flow operations and operating plans are described in Section 5.2.

2.2. Biological Setting

2.2.1. Mid-Columbia Reach Salmon Populations. The Anadromous Fish Agreement and Habitat Conservation Plan applies to following species: spring (stream-type), summer and fall (ocean-type) chinook salmon *(Oncorhynchus tshawtscha*), steelhead (*O. mykiss*), sockeye salmon (*O. nerka*), and coho salmon (*O. kisutch*). However, the incidental take permit portion of the agreement does not apply to coho as coho are extirpated from the mid-Columbia region. General life history descriptions and current and historic run size information for these species in the Columbia River system and the mid-Columbia reach are provided below.

2.2.1.1. Chinook Salmon. Historically, chinook salmon entered the Columbia River continually from early spring through late fall. Due to overharvest and the construction of dams without fish passage, segments of the run were greatly reduced in number (Chapman et al. 1994a, 1995a). Timing of peak counts of adults passing upstream of dams is one method now used to divide the continuum into separate stocks. Another method for dividing the run into segments or stocks is through spawning areas. A window of time for egg deposition exists in each spawning area based on water temperature, and the timing of upstream migrating adults matches this window (Miller and Brannon 1982). Therefore, those adults that spawn in the upper reaches of tributaries, in the middle and lower reaches of tributaries, and in the mainstem rivers and lower reaches of tributaries can be divided into three races/demes. Because the adults of the race/deme that spawn in the upper reaches generally return past mainstem dams in the spring, they are known as spring (stream-type) chinook. Similarly, the race/deme that spawn in the middle and lower reaches of tributaries generally return past mainstem dams in the summer, and are known as summer (ocean-type) chinook salmon. Those that spawn in lower tributaries and the mainstem river arrive in the fall and are known as fall (ocean-type) chinook salmon (Meekin 1963; French and Wahle 1965; Chapman et al. 1982; Mullan 1987).

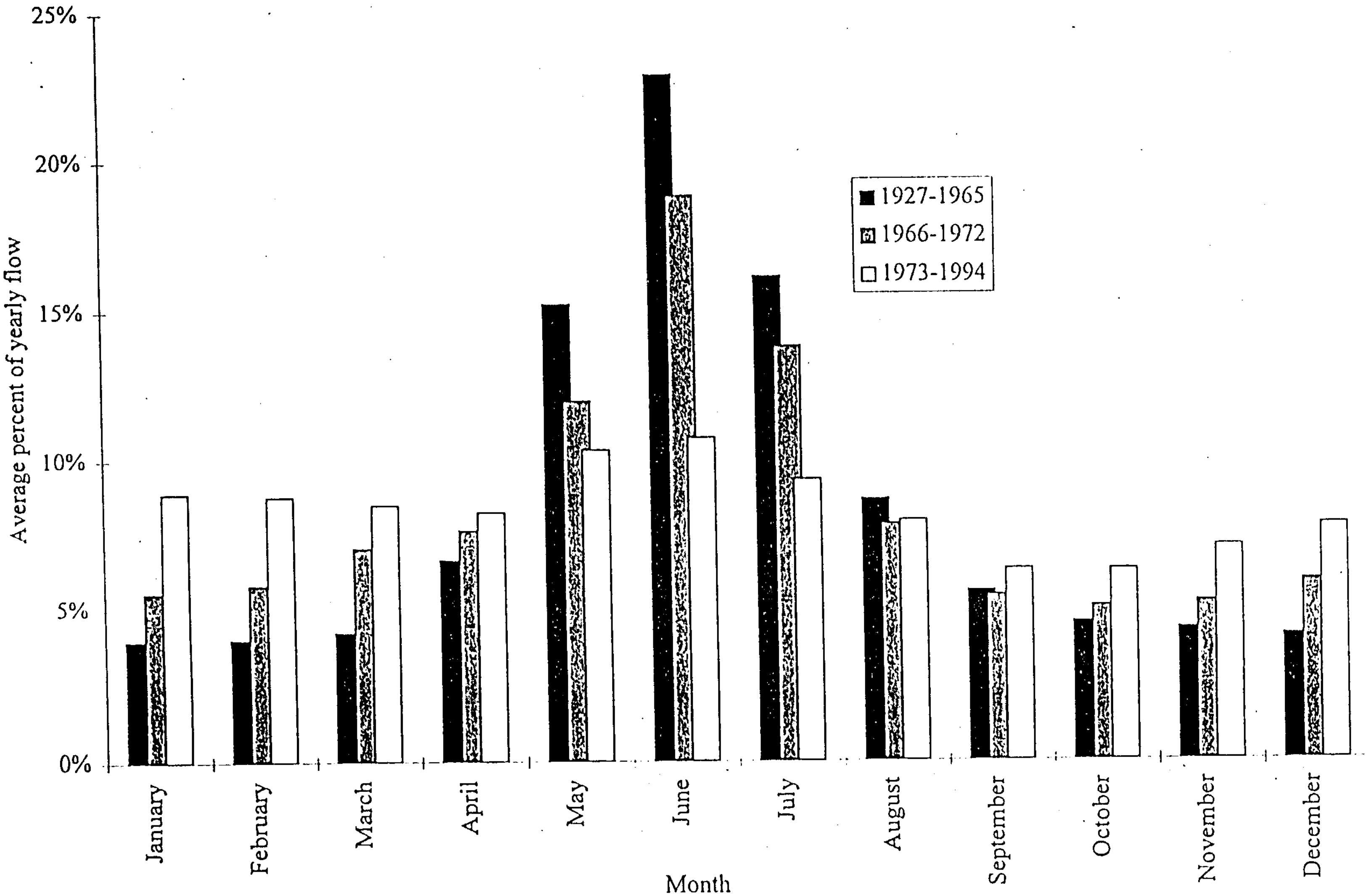

Figure 2-2 Average monthly flow at Rock Island dam during three time periods since reservoirs completed

These arbitrary classifications are based on the date of arrival at mainstem dams. The cutoff date for spring chinook, for example, is June 13 at Priest Rapids dam, and later at upstream projects. These cutoffs are not necessarily reflective of the origin of the adults (Chapman et al. 1995a). Summer and fall (ocean-type) chinook salmon are treated as one evolutionarily significant unit (ESU) since they cannot be electrophoretically separated (Chapman et al. 1994a), and also because the juveniles migrate as age 0+ (subyearlings) while spring (stream-type) chinook salmon juveniles migrate as age 1+ (yearlings).

2.2.1.2. Spring (Stream-type) Chinook Salmon. Most adult spring (stream-type) chinook salmon migrate upstream through the Columbia River to spawn after spending two to three years in the ocean (Chapman et al. 1995a; Columbia Basin Fish and Wildlife Authority [CBFWA] 1990). Upstream migrants enter the Columbia River during the spring, passing dams along the mid-Columbia from late April through mid-June (Table 2-1). Spawning begins during late July and continues through September, although the timing of peak spawning varies among tributaries (Chapman et al. 1995a; Peven 1992). In the mid-Columbia reach, wild populations of spring chinook salmon are found in the Wenatchee, Entiat and Methow River systems (Chapman et al. 1995a; Mullan 1987).

Eggs hatch in late winter and early spring after exposure to about 750 daily temperature units (DTU) (Piper et al. 1982) with emergence of fry from the gravel in April and May (Peven 1992) after a total accumulation of about 1,600 DTU (Piper et al. 1982). Juveniles may migrate to rearing areas further upstream or downstream shortly following emergence. Most parr rear in freshwater for one year before migrating to the ocean (age 1+), but a small percentage migrate as subyearlings (age 0+) into lower reaches of the watershed for overwintering before immigrating to the ocean. (Chapman et al. 1995a; CBFWA 1990; Palmisano et al. 1993). Outmigrating juveniles pass the mid-Columbia projects from mid-April to mid-June (Figure 2-3).

Naturally produced stream-type chinook juveniles pass mid-Columbia dams over a longer time period and are generally smaller than the hatchery produced juveniles. Naturally produced stream-type chinook juveniles originating from upriver areas of the mid-Columbia were found to migrate downstream at lengths of 65 to 123 mm (Table 3-2); hatchery-reared stream-type chinook juveniles are generally released at larger sizes (117 to 178 mm) (Mullan 1987).

Table 2-1. Upstream migration timing of anadromous salmonids at three mid-Columbia projects.

Species	Priest Rapids			Rock Island			Wells		
	10th	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
[1]Spring chinook	Apr 30	May 12	May 31	May 4	May 17	Jun 3	May 9	May 22	Jun 11
[2]Summer chinook	Jun 24	Jul 12	Aug 3	Jun 28	Jul 15	Aug 6	Jul 4	Jul 22	Aug 13
[2]Fall chinook	Aug 21	Sep 12	Oct 10	Aug 23	Sep 14	Oct 24	Aug 26	Sep 17	Oct 29
Steelhead	Jul 26	Sep 4	Oct 2	Jul 27	Sep 9	Oct 10	Aug 4	Sep 17	Oct 19
Sockeye	Jun 29	Jul 10	Jul 24	Jul 3	Jul 14	Jul 27	Jul 7	Jul 19	Aug 4

[1]Stream-type

[2]Ocean-type

Source: FPC 1995.

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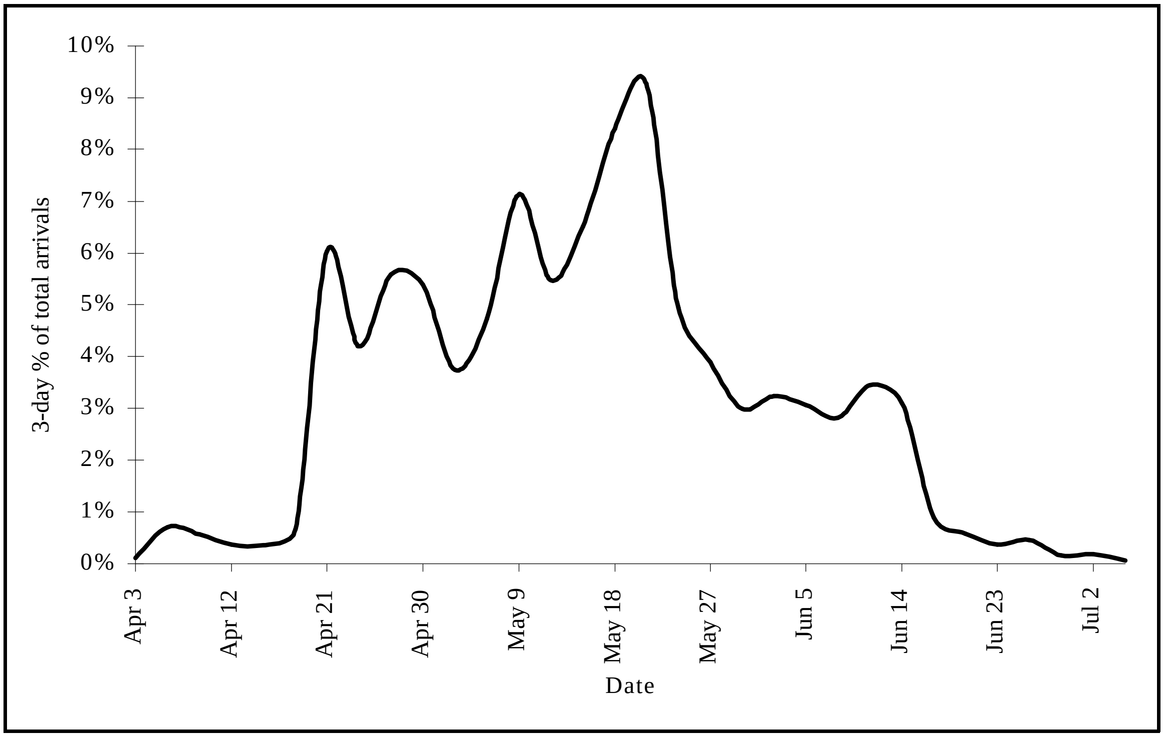

Figure 2-3. Average arrival timing of stream-type (spring) chinook salmon juveniles at Rock Island dam from 1990 to 1994
(Source: FPC 1995).

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Studies in the lower Columbia River have shown juvenile chinook outmigrants actively feed and grow during their outmigration through reservoirs. Craddock et al. (1976) found that chinook juveniles in the lower Columbia River at Kalama, Washington (of both stream- and ocean-type size) fed on aquatic insects in spring, switched to zooplankton (*Daphnia* spp.), which were most abundant during July through September and switched back to aquatic insects in the fall. The juveniles actively selected *Daphnia* and *Sida* spp. and avoided *Bosmina* spp. and cyclopoid copepods. Dawley et al. (1986) found that stream-type chinook at Jones Beach on the lower Columbia River (river mile [RM] 47) consumed primarily dipterans, followed in importance by amphipods and plant material. Stream-type chinook smolts in Lower Granite reservoir on the Snake River feed primarily on *chironomidae*, and also take minor amounts of *Cladocera*, *Ephemeroptera, Trichoptera, Plecoptera* and terrestrial insects (Chandler, J., Idaho Power Co., unpublished data). Due to limited reach-specific data, a general assumption is that juvenile chinook outmigrant feeding behavior in the mid-Columbia reach is consistent with outmigrant behavior observed in the lower Columbia River. The rapid reservoir flushing rate and lack of shallow, backwater habitat suggests the mid-Columbia system is more characteristic of a flowing system than a lake system (see Section 5.1).

The largest run of Columbia River adult spring chinook salmon on record was estimated as 281,000 fish at Bonneville dam in 1955 with the smallest estimated run at 20,185 fish in 1994 (CBFWA 1990; Fish Passage Center [FPC] 1995a). During 1980 to 1990, the average run size was 84,200 fish (Peven 1992). Meyers, et al (l998) estimated the 1990-94 geometric run to be 4,880 spawners upstream of RID. They estimate that all current trends of abundance for these stocks are downward (fig. 2-4) and have subsequently recommended these fish are warranted for endangered status under the ESA. On March 9, 1998, the upper Columbia spring chinook ESU was proposed for listing under the ESA. 63 FR 11482 (March 9, 1998).

Since 1970, hatchery production of stream-type chinook juveniles has increased, and the upriver run is now comprised of at least 60 to 70 percent hatchery adults (Palmisano et al. 1993; BPA et al. 1994a). Annual adult spring chinook returns to hatcheries above Bonneville dam peaked at over 37,000 in 1986 and 34,900 in 1990 (BPA et al. 1994a). In 1993, stream-type chinook salmon hatchery juvenile releases to the mid-Columbia reach totaled 4,171,000 (BPA et al. 1994a). Hatchery produced stream-type chinook smolts migrating through the mid-Columbia originate from Winthrop, Methow, Entiat, Eastbank, Leavenworth and WDF-COOP hatcheries.

2.2.1.3. Summer and Fall (Ocean-type) Chinook Salmon. For the purposes of the HCP, summer and fall (ocean-type) chinook salmon are treated as indistinguishable races/demes. However, when spawning is discussed, summer and fall chinook are separately identified and discussed. The fall chinook component are defined as those races/demes that spawn in the mainstem Columbia and Snake Rivers, and in the extreme lower reaches of direct tributaries to the mainstem Columbia. The summer chinook component is defined as those stocks that do not spawn in

Table 2-2. Size (mm) of downstream migrating juvenile anadromous salmonids at mid-Columbia River projects.

Species	**Priest Rapids**			**Rock Island**			**Wells**		
	Min.	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**
Spring (stream-type) chinook									
Wild				65	95	123	76		102
Hatchery				117		178	76		152
Summer and fall (ocean-type) chinook		130		40	120	165			
Summer steelhead							60		155
Wild				110	180	290	127		203
Hatchery				125	205	300	153		254
Sockeye Salmon							76		127
Wild				80	130	200			
Hatchery				100	132	215			

Source: Mullan 1987; Pevan 1992; Stuehrenberg et al. 1995; Swan et al. 1994; USACE 1994.

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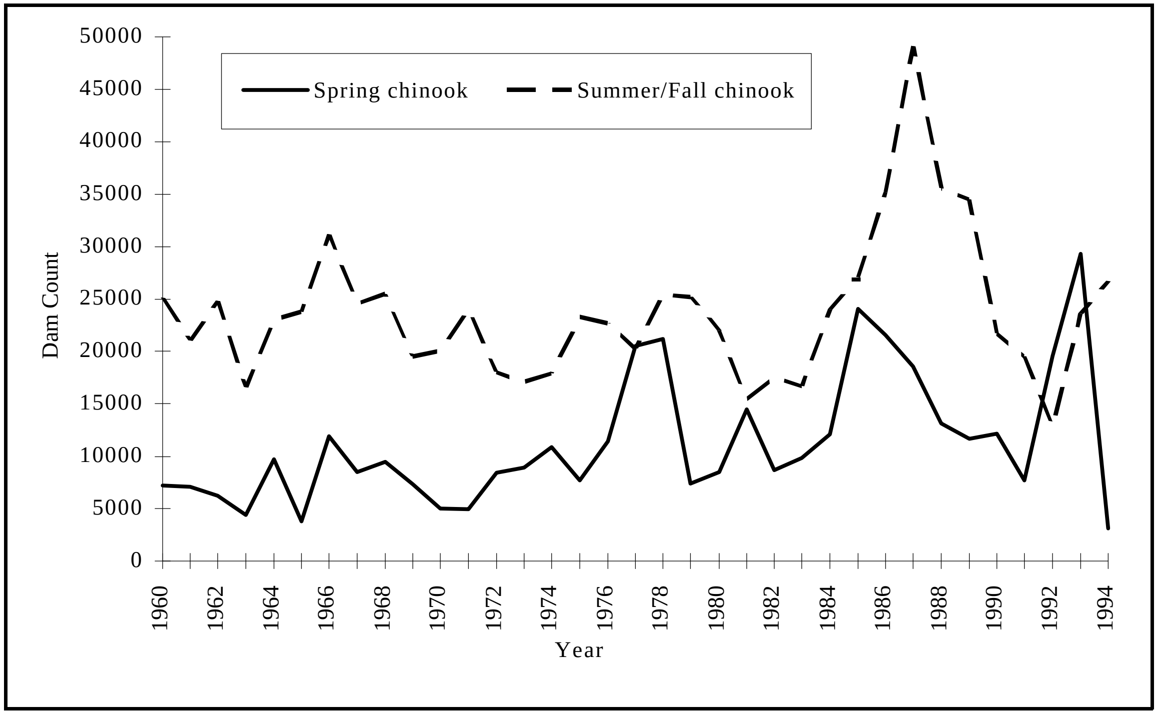

Figure 2-4. Counts of adult spring (stream-type) and summer and fall (ocean-type) chinook salmon passing Priest Rapids dam from 1960 to 1994 (Source: FPC 1995).

damcount.ov3

the aforementioned areas but do outmigrants as subyearling juveniles (age 0+), the same as fall chinook. Most summer and fall chinook salmon adults return to spawn after spending three or four years in the ocean (Peven 1992). Adults enter the Columbia River during late May to early July and pass dams on the mid-Columbia from late June through October (Table 2-1) (Peven 1992). Natural spawning of the summer chinook component occurs in the lower portions of the Similkameen River below Enloe dam (Chapman et al. 1994a), in the Okanogan River downstream of Lake Osoyoos, in the lowermost 50 miles of the Methow River, in the Wenatchee River downstream of Lake Wenatchee, and in the lower Chelan River (Chapman et al. 1994a). Spawning occurs during late September through November, with the peak spawning activity in October (Peven 1992).

Historically, the fall chinook component spawned in suitable areas from the vicinity of McNary dam on the lower Columbia, up the Snake River to Shoshone Falls, and up the Columbia River into the Canadian headwaters in the vicinity of Golden, B.C. (Chapman et al. 1994a). Currently, fall chinook are known to spawn in the tailraces of Priest Rapids, Wanapum, Wells and Chief Joseph dams (Chapman et al. 1994a). Fall chinook probably spawn below each of the mid-Columbia River dams (Dauble et al. 1994), and perhaps in other mainstem reservoir segments where suitable water velocities and substrate conditions exist. The main production area of the fall chinook component in the Columbia River basin is located 4 miles below Priest Rapids dam at Vernita Bar and continues through the Hanford Reach to the upper reaches of McNary reservoir. Peak spawning of Vernita Bar fall chinook occurs in November (Carlson and Dell 1989, 1990, 1991, 1992).

The Washington Department of Fisheries (WDF) first observed fall chinook salmon redds in the Rocky Reach reservoir (in the Wells tailrace) in 1967 (Chelan PUD 1991c). Numbers of redds have been highly variable at this location over the years, with peak counts exceeding 100 redds per year. Giorgi (1992a) described the fall chinook spawning in the Rocky Reach reservoir. He counted 85 redds on the west side of the Columbia River at RM 514 to 515 and regarded their use of the available habitat as sparse. They spawned between 5 and 32 feet deep at nose velocities measured at 2.8 to 2.9 feet per second shortly after spawning. The magnitude of these attributes are within the range of measurements noted for mainstem fall chinook spawning adults at other locales in the mid-Columbia region. Chapman et al. (1994a) suggested mainstem spawning was continuing in the Brewster Bar area following inundation by the Wells reservoir. Other surveyors have indicated potential deep water spawning near Bridgeport Bar, Washburn Island, and in areas near the Chief Joseph tailrace where substantial groundwater upwelling occurs (Hillman and Miller 1994; Chapman et al. 1994a; Swan et al. 1994; Bickford 1994). The Chelan PUD (1991c) reported redd count data from other reservoirs including the Priest Rapids and Rock Island reservoirs. Redd counts at Priest Rapids reservoir have ranged from 200 to 492 redds in the recent past (Carlson and Dell 1989, 1990, 1991, 1992). Based on this information, it is apparent that some unknown but significant amount of chinook production occurs in the mainstem river areas from the Priest Rapids dam tailrace to the Chief Joseph dam tailrace, as streambed hydraulics and substrate conditions allow.

Juveniles usually emerge in April and May and are displaced downstream within a few days to several weeks after emerging from the redd (Chapman et al. 1994a). Ocean-type (summer and fall) chinook salmon migrate as subyearlings (age 0+). Juveniles produced in the mid-Columbia tributaries, the lower Chelan River and in tailraces of dams tend to spend several weeks in the reservoirs before migrating to the ocean (Chapman et al. 1994a). The timing of juvenile outmigration varies among tributary of origin and hatchery release dates, but juvenile ocean-type chinook salmon generally migrate during the late summer and fall months, passing dams on the mid-Columbia between June and August (Figure 2-5; Table 2-3) (Mullan 1987; Peven 1992; Chapman et al. 1994a). The size of juvenile ocean-type chinook passing the mid-Columbia projects varies among the dams and according to the timing of arrival of juveniles at each dam, but lengths range from 40 to 165 mm (Table 2-2).

It is generally believed that juvenile ocean-type chinook salmon tend to use nearshore littoral habitat while stream-type juveniles tend to migrate in mid-channel (Ledgerwood et al. 1991b; Chapman et al. 1994a; Burley and Poe 1994). Ocean-type juveniles use shallow littoral areas shortly after emergence in April and May (Chapman et al. 1994a). Campbell and Eddy (1988) believe this partitioning of habitat is related to fish size and predator avoidance, with small fish using the slow velocity nearshore margin areas. They noted that chinook in the Lewis River began to move progressively offshore into faster water and established territorial feeding stations along the river bottom as they increased in size beyond 50 mm. For information on the vertical and diel distribution of ocean-type chinook migrants, see the discussion following the species life-history sections.

Ocean-type chinook migrants actively feed and grow during their outmigration through the mid-Columbia River reservoirs. Studies have shown that their diet consists primarily of aquatic insects, with minor amounts of zooplankton. Becker (1970) found that 81 percent of food items in ocean-type chinook in the Hanford Reach of the mid-Columbia River in April through June consisted of *Chironomidae* spp., followed in importance by *Trichoptera* spp. and *Hemiptera* spp., with minor amounts of *Copepoda* and *Amphipoda*. Dauble et al. (1980) also found that ocean-type chinook migrants in the Hanford Reach consumed primarily *Chironomidae* in April and May and *Trichoptera* spp. (80% by volume) in June and July. *Daphnia* spp. and terrestrial *Homoptera* spp. were also important food items. Newly emerged juveniles (34 to 45 mm) fed exclusively on Chironomids, while the largest juveniles (66 to 81 mm) fed more heavily on *Trichoptera* and zooplankton. In March the diet consisted of Chironomids, and shifted to *Trichoptera* and zooplankton by July. Although *Cyclops* spp. dominated zooplankton drift, fish fed almost exclusively on the less abundant *Daphnia* (Dauble et al. 1980).

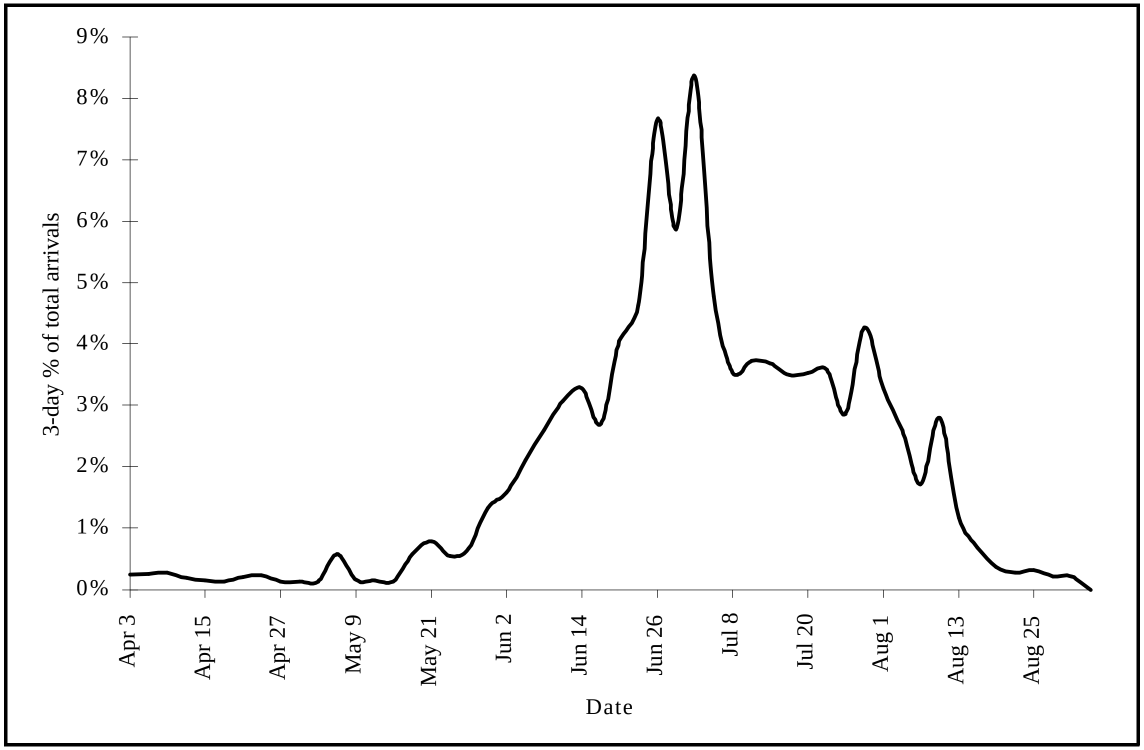

Figure 2-5. Average arrival timing of ocean-type (summer and fall) chinook salmon juveniles at Rock Island dam from 1990 to 1994 (Source: FPC 1995).

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Table 2-3. Downstream migrational timing of anadromous salmonids at mid-Columbia dams and McNary dam.

Species	Priest Rapids	Wanapum	Rock Island[9]	Wells
Stream-type (spring) chinook	Hatchery: May-mid-Jun[3]; peak: late May[3]		10% - April 23 50% - May 17 90% - June 6	Hatchery: late Apr-May[3]
Ocean-type (summer and fall) chinook	Late Jul - mid-Aug, possibly Sep[3,6]	Late Jul-Aug[6]	10% - June 4 50% - June 30 90% - July 31	Late Jun - early Aug[6]
Summer steelhead			10% - April 29 50% - May 11 90% - May 26	May[8]
Sockeye salmon			10% - April 25 50% - May 3 90% - May 24	May[7,8]

[1] Chapman et al. 1994b.
[2] Pevan 1991.
[3] Mullan 1987.
[4] Pevan 1992.
[5] FPC 1994.
[6] Chapman et al. 1994a.
[7] USACE 1994.
[8] Kudera et al. 1992.
[9] Median passage dates of 10%, 50% and 90% of juveniles calculated from Rock Island dam passage indices for each species from 1990 to 1994 (FPC 1995).

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Rondorf et al. (1990) found that ocean-type chinook migrants in McNary pool fed primarily on *Diptera*, *Trichoptera*, *Daphnia*, *Corophium*, *Hymenoptera* and *Homoptera*. *Trichoptera* disappeared from the diet in limnetic sections of the reservoir. Zooplankton were the dominant food item in embayments, while insects were dominant in littoral and limnetic areas. Preference was shown for terrestrial insects in littoral areas and embayments. These data also support the conclusion that aquatic insects comprise the primary prey items for juvenile salmonids in the mid-Columbia reach due to limited reservoir productivity (see Section 3.2.2).

The late spring and summer components of the Columbia River adult chinook populations were the most abundant, and also the most heavily fished (Chapman et al. 1994a; 1995a). Chapman (1986) estimated historic peak runs of about 2,000,000 adult summer chinook entering the Columbia River annually in 1881 to 1885. In comparison, during 1983 to 1992 the estimated run size averaged 82,580 adults (Chapman et al. 1994a). Escapement estimates at Rock Island dam from 1933 through 1942 averaged 5,658 adults and jacks. Since 1960, the number of summer and fall chinook salmon passing Priest Rapids dam has fluctuated from 13,000 to 50,000 adults (Figure 2-4). Waknitz, et al (1995) determined that the mid-Columbia summer/fall chinook ESU was not in danger of extinction or likely to become so in the future. On March 9, 1998, NMFS confirmed this and that the upper Columbia summer/fall chinook ESU was not in danger of extinction, nor likely to become endangered in the foreseeable future, and concluded that their listing under the ESA was not warranted. 63 FR 11482 (March 9, 1998).

Hatchery production of summer chinook occurs at the Wells, Eastbank and Rocky Reach/Turtle Rock hatcheries in the mid-Columbia. Fall chinook above McNary dam are reared at Priest Rapids and Rocky Reach hatcheries (BPA et al. 1994a). Hatcheries have only supplemented the total summer and fall chinook runs. Chapman et al. (1994a) estimate that about 6 percent of the summer and fall run fish are of hatchery origin. Naturally-produced fish comprise the majority of adults returning to the mid-Columbia reach (Chapman et al. 1994a). Hatchery releases of ocean-type chinook juveniles into the mid-Columbia in 1993 were 1,800,000 and 8,858,000, respectively (BPA et al. 1994a; FPC 1994).

2.2.1.4. Summer Steelhead. Adult summer steelhead enter the Columbia River during March through October, and peak migration occurs from late June through early September (CBFWA 1990). Adult steelhead migration is much more protracted than that of other anadromous salmonids in the Columbia River. Most adults pass through the mid-Columbia reach from June through late September, although some adults arrive much later at the upstream dams (Peven 1992). Spawning occurs the following year during March through July (Peven 1992; CBFWA 1990). The Wenatchee, Entiat, Methow and Okanogan Rivers support naturally spawning steelhead populations (Peven 1992). Unlike other anadromous salmonids, all steelhead do not die after spawning, but may return to the ocean. An individual steelhead may spawn more than once during its lifetime or may spawn only once and die depending on the condition of the fish after spawning (Chapman et al. 1994b), but repeat spawning is rare for mid-Columbia River steelhead (21% or less, Brown, 1995).

In the Columbia River basin, steelhead juveniles generally emerge from the gravel from July through September. After emergence, juveniles move downstream into overwintering habitats (Chapman et al. 1994b). Most parr rear in freshwater for two to three years, but the duration of freshwater residence can range from one to seven years (CBFWA 1990; Peven 1992). Peven et al. (1994) found that about 90 percent of wild steelhead juveniles in samples taken at Rock Island and Rocky Reach dams were two- and three-winter residents (equally the most common age groups). Juveniles that had spent one, or from four to seven winters in freshwater accounted for about 10 percent of juveniles sampled. Wild steelhead juveniles emigrate during the spring, passing mid-Columbia dams from April through June (Figure 2-6) (Chapman et al. 1994b). In the mid-Columbia basin, naturally produced steelhead juveniles sampled at Rock Island dam average between 163 to 188 mm long from 1986 through 1994 (Chapman et al. 1994b). Hatchery produced steelhead juveniles passing Rock Island average about 200 mm in length although the average size varies among the months sampled (Table 2-2) (Peven 1992; Fielder and Peven 1986).

No information is available about the feeding habits of steelhead juveniles in the mid-Columbia River reach. Steelhead juveniles in Lower Granite reservoir on the Snake River fed primarily on *Chironomidae*, and also took minor amounts of *Homoptera*, *Ephemeroptera*, *Trichoptera* and *Plecoptera* (Chandler, J., Idaho Power Co., unpublished data). Of over 100 stomachs examined, only two contained an unidentified fish. It may be reasonable to assume the dietary behavior of steelhead juveniles is the Snake River reservoirs is typical of steelhead juveniles in the mid-Columbia reach.

Chapman (1986) estimated that pre-dam runs of steelhead entering the Columbia River ranged from 449,000 to 554,000. Since 1938, escapement of steelhead to the Columbia River mouth reached a high of 474,000 in 1986 and a low of 105,000 in 1975. Escapement has averaged 292,000 adults since 1990 (WDFW and Oregon Department of Fish and Wildlife [ODFW] 1994). Between 1933 and 1959, adult steelhead counted at Rock Island dam averaged 2,600 to 3,700. In the 1960s, adult counts increased at Priest Rapids dam with the beginning of hatchery releases and peaked at 34,000 in 1985 (Figure 2-7). From 1989 to 1995 an average of 9,734 steelhead passed Priest Rapids dam (Brown 1995).

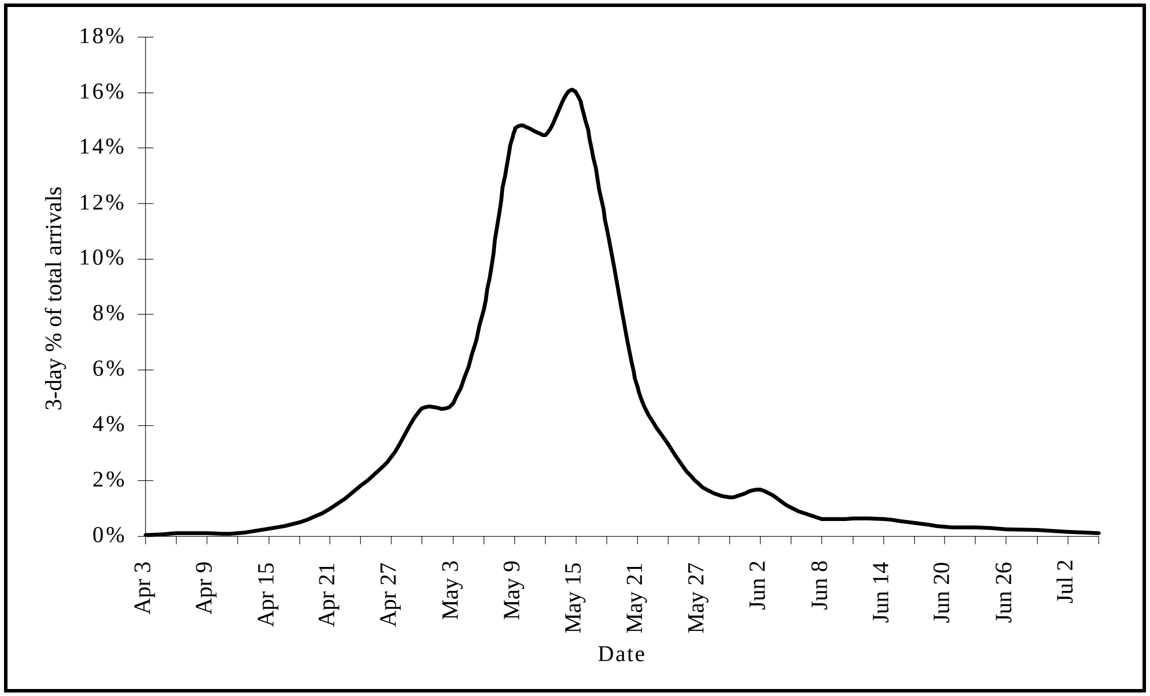

Figure 2-6. Average arrival timing of steelhead juveniles at Rock Island dam from 1990 to 1994 (Source: FPC 1995).

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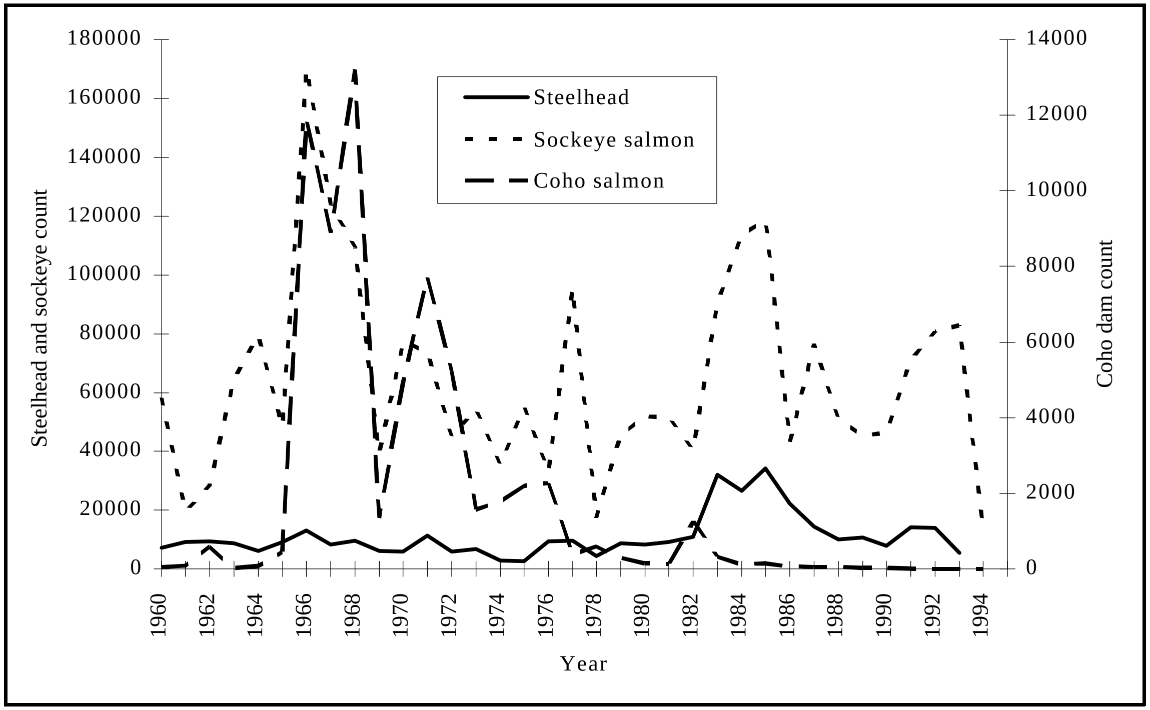

Figure 2-7. Counts of adult steelhead, sockeye and coho salmon passing Priest Rapids dam from 1960 to 1993 (Source: Coordinated Information System, FPC 1995).

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Most steelhead adults returning to the mid-Columbia reach are of hatchery origin (Peven 1992). Naturally produced adult steelhead passing Wells dam during 1982-1993 comprised about 10 percent of the steelhead counted (range 3 to 13%) (Chapman et al. 1994b). Naturally produced steelhead accounted for an average of 19 percent of the adults counted from 1986 to 1995 at Priest Rapids dam (range 10 to 29%) (Brown 1995). Naturally produced juveniles averaged 24 percent of steelhead sampled at Rock Island during 1986 to 1994, (range 15 to 38%) (Chapman et al. 1994b). Total releases of hatchery produced steelhead juveniles to the mid-Columbia reach from 1982 to 1193 ranged from approximately 700,000 to 1.2 million per year (Brown 1995). Current production continues at a proposed level of about 1 million fish.

2.2.1.5. Coho Salmon. Historically, coho salmon were present in both the Columbia and Snake River basins. Between 1938 and 1942, counts of coho passing Bonneville dam ranged between 12,000 and 18,000 fish. After this period, the coho salmon run declined substantially due primarily to overharvest (Johnson et al. 1991), with counts ranging from 2,700 to 6,100 between 1954 and 1966. Counts of adult coho salmon passing Bonneville dam have increased substantially since the late 1960s due to hatchery production. During the 1980s, counts of coho salmon passing Bonneville dam ranged from 15,000 to 131,000. Wild coho salmon are considered extinct in the upper Columbia River regions (above Priest Rapids dam) since the 1940s (Mullan 1984) but are still present in a few tributaries in the lower portions of the Columbia basin (CBFWA 1990). Coho have not been observed to spawn in any area upstream of the Project (Chelan PUD 1991c). The State of Washington does not currently recognize any natural coho stock in the mid-Columbia reach (WDF et al. 1993).

On August 18, 1997, NMFS listed the upper Columbia steelhead ESU as an endangered species under the ESA. 62 FR 43937 (August 18, 1997).

2.2.1.6. Sockeye Salmon. Sockeye salmon typically utilize lake rearing areas for one to two years, or more, before migrating to the ocean (Chapman et al. 1995b). Mid-Columbia River sockeye salmon spend two to three years in the ocean, most frequently returning to spawn in their third or fourth year of life (Mullan 1986; Chapman et al. 1995b). Adult sockeye salmon start entering the Columbia River in May and reach dams on the mid-Columbia during late May through mid-August (Table 2-1) (BPA et al. 1994a). Adults reach natural lakes in the Okanogan and Wenatchee watersheds during July through September and spawn during September to October (Mullan 1986; Chapman et al. 1995b).

Sockeye fry emerge in March and April in the Okanogan system and in April in the little Wenatchee and White Rivers (Allen and Meekin 1973). Immediately after emergence, fry move into freshwater lakes (Chapman et al. 1995b; CBFWA 1990). Newly emerged fry feed primarily in the littoral zone of lakes on Chironomidae larvae, and gradually shift to pelagic feeding on zooplankton, especially *Bosmina, Cyclops* and *Daphnia spp.*, as they mature (Groot and Margolis 1991). Sockeye salmon migrate as smolts after spending one to three years in their nursery lakes, passing mid-Columbia dams during mid-April through late May (Figure 2-8) (Chapman et al. 1995b). The mean size of wild sockeye salmon outmigrating past Rock Island have been reported to range from about 95 to 154 mm (Table 2-2) (Peven 1992); hatchery produced sockeye salmon are similarly sized.

Sockeye juveniles outmigrants from lakes during hours of low light (sunset to early morning) (Kerns 1961; Burgner 1962; Groot 1965; Hartman et al. 1967; Chapman et al. 1995b). Approximately 90 percent of movement occurs in a 4- to 5-hour period around midnight. Daily peaks have been observed to shift as seasonal changes affect the onset of darkness (Kerns 1961; Hartman et al. 1967), and according to degree of cloud cover (Foerster 1968) and turbidity (Hartman et al. 1967).

Sockeye juveniles actively migrate during their downstream migration, similar to yearling chinook and steelhead (Chapman et al. 1995b). Rates of travel up to 25 miles per day have been measured from the mid-Columbia River to Bonneville dam before most dams were in place (Chapman et al. 1995b). No information is available regarding the feeding habits of sockeye juveniles in the mainstem reservoirs of the Columbia River basin. It is expected that they feed on *Chironomidae* larvae and zooplankton such as Cladocera during their outmigration.

The abundance of natural stocks of sockeye salmon fluctuates radically in a cyclical dominance pattern of four years duration (Larkin 1988). The largest escapement of sockeye to the Columbia River mouth since 1938 was 335,000 in 1947. Estimates of run size were generally high during the 1950s, often exceeding 200,000 fish, but were generally lower during 1973 to 1983, with ranges from 18,000 to 100,000 adults. The average escapement of sockeye past Priest Rapids dam from 1989 to 1993 was 65,340 (Figure 2-7) (PSMFC 1993).

Gustafson, et al (1997) determined that sockeye originating upstream of Rock Island Dam were not presently at risk of extinction. In recent years, the majority of sockeye production in the mid-Columbia reach have returned to the Okanogan River system. However, in many years, the Wenatchee River component is greater than 50 percent of the total number of sockeye adults passing Rock Island dam (Chapman et al. 1995b). Escapement to the Wenatchee River has ranged from a low of 6,591 in 1978 to a high of 64,614 in 1977 (mean of 24,042). Escapement to the Okanogan River has ranged from a low of 1,662 in 1994 to a high of 127,857 in 1966 (mean of 36,619) (Peven 1992). Hatchery production of sockeye salmon is currently conducted at the Eastbank and Cassimer Bar hatcheries. Releases of juvenile sockeye salmon from mid-Columbia hatcheries totalled 355,000 in 1993 (FPC 1994). On March 10, 1998, NMFS found that the Okanogan River sockeye ESU and the Wenatchee River sockeye ESU were not in danger of extinction, nor likely to become endangered in the foreseeable future, and concluded listing either ESU under the ESA was not warranted. 63 FR 11750 (March 10, 1998).

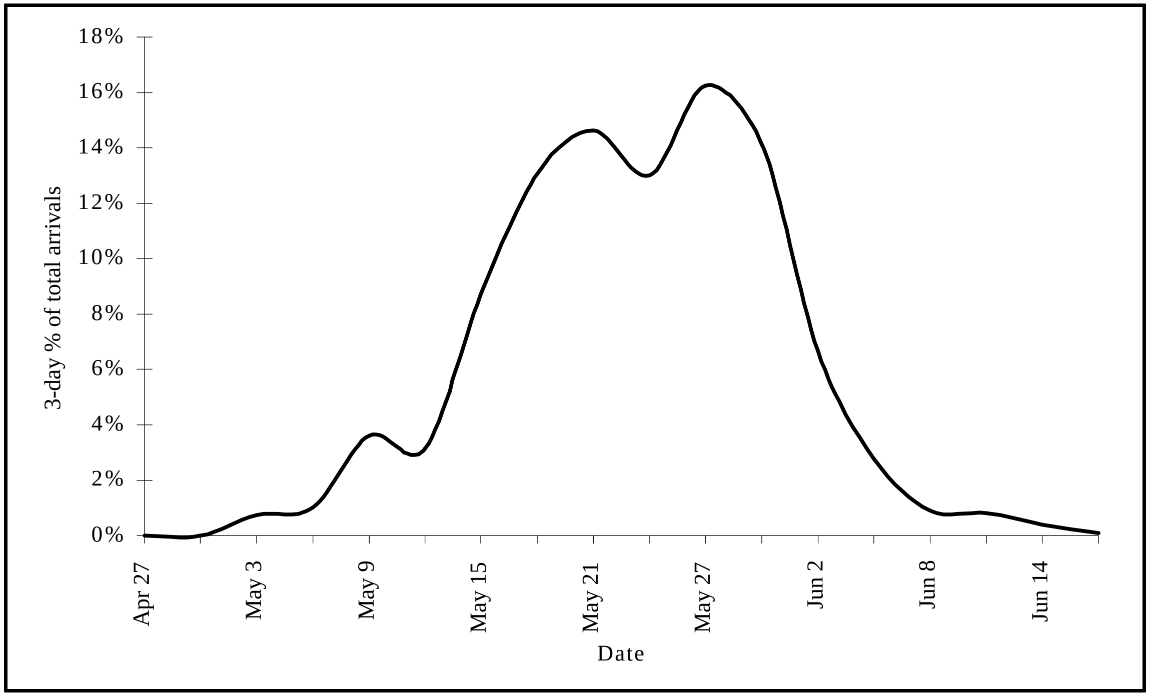


Figure 2-8. Average arrival timing of sockeye salmon juveniles at Rock Island dam from 1990 to 1994 (Source: FPC 1994a).

sockeye.ov3

2.2.1.7. Distribution of Juvenile Anadromous Salmonids in Reservoirs. Much of the available literature describing juvenile outmigration does not identify stock or species-specific behavior. This section describes the general outmigration behavior of anadromous salmonids, and identifies stock-specific behavior where data is available (Table 3-3). The vertical and horizontal distribution of outmigrating anadromous salmonid juveniles in reservoirs is highly dependent on the size of the juvenile, the time of day and other factors. Rondorf and Gray (1987) found that as ocean-type chinook juveniles reach 80 mm in June, they begin to move from shallow littoral areas to deep water in the Columbia River where current velocities are less than 4 feet per second. In the reservoirs, larger spring chinook stream-type tend to migrate in mid-channel (Chapman et al. 1995a; Burley and Poe 1994). Healy and Jordan (1982) also noted that most juvenile stream-type chinook migrated in higher velocity water near the center of the river.

There is also a diel pattern to the movement and distribution of anadromous salmonid juveniles. Campbell and Eddy (1988) observed a distribution shift at night, with juvenile anadromous salmonids moving inshore into shallow, quiescent water. Some anadromous salmonid juveniles migrate downstream throughout the day, but the majority migrate at night (Mains and Smith 1964; Lister et al. 1971). Weitkamp (1974) also recorded increased anadromous salmonid movement during the evening and early nighttime hours.

Depth distribution studies of the water column generally show juvenile anadromous salmonids outmigrants close to the surface, often within the top 20 feet. Mains and Smith (1964) indicated that where the river is greater than 10 feet deep, outmigrating juveniles preferred the surface. Since surface waters travel faster than deep waters, the outmigrants may be using the surface velocity to aid their migration. Weitkamp (1974) and SML (1973) collected salmonid outmigration data from mid-Columbia reservoirs, including Rock Island and Wanapum pools. The 1973 data show a preponderance of anadromous salmonids within the top 6.5 feet of the water column. The outmigration was slightly deeper in 1974 with the bulk of anadromous salmonids between 6.5 and 13 feet deep (Table 2-4).

A recently completed study (Rondorf, D., pers. comm. 1 July 1995) used sonar to locate juvenile anadromous salmonids, predominately stream-type chinook and steelhead, that were distributed to over 30 feet deep in Lower Granite reservoir on the Snake River. Concurrent purseseining by Muir et al. (1995) confirmed that the vast majority of the targets were stream-type chinook and steelhead outmigrants. The average depth of the juveniles was consistently deeper at night than during the day, and varied between different transects taken along the length of the reservoir. Juveniles in some areas were consistently found at shallower depths than other areas.

2.2.2. Rock Island

2.2.2.1. Life Histories of Anadromous Salmonid Fish Species. The following section presents life history information on the mid-Columbia River anadromous salmonid fish specific to the Rock Island project area. General life history descriptions for these species were presented in Section 2.2.1. Throughout this discussion, stream-type chinook are referred to as "spring chinook" when discussing adult fish. Likewise, ocean-type chinook are called "fall chinook" or "summer chinook" as adults. This distinction is done to be consistent with common biological parlance and terms used in various studies referenced to in the following sections.

Table 2-4. Depth distribution of migrant anadromous salmonids in mid-Columbia reservoirs during 1973 and 1974.

Depth Interval (ft.)	**Species**	**Year**	
		% in 1973	**% in 1974**
Surface to 6.5	Steelhead	94	11
	Chinook	79	4
	Sockeye	57	20
	Total	79	14
6.5 to 13	Steelhead	7	37
	Chinook	14	92
	Sockeye	36	80
	Total	25	57
13 to 18	Steelhead	0	52
	Chinook	8	4
	Sockeye	7	0
	Total	6	28

Source: SML 1973; Weitkamp 1974.

migsalmo.ov3

2.2.2.1.1. <u>Spring (Stream-type) Chinook</u>. Spring (stream-type) chinook salmon primarily use the Rock Island project area as a migration corridor during their upstream and downstream movements. Adult spring chinook salmon pass Rock Island dam (on their way to spawning grounds in upstream tributaries from late April to late June (Stuehrenberg et al. 1995)), with 90 percent passing from May through the beginning of June (FPC 1995a) (Figure 2-9). Spring chinook spawn in the Entiat River (Peven 1992).

Juvenile stream-type chinook passing Rock Island dam originate from natural spawning in upstream tributaries and from hatchery releases. Hatchery-produced stream-type chinook juveniles migrate past Rock Island dam as yearlings during April through mid-June, with peak passage generally occurring in late April (Chapman, et al 1995a). Naturally and hatchery-produced stream-type chinook juveniles pass Rock Island dam from April through mid-June, peaking sometime in May. Ninety percent of juvenile passage occurs during April and May (Table 2-4). The size of naturally produced stream-type chinook juveniles passing Rock Island dam has been reported as 65 to 125 mm (Chapman et al. 1995a); hatchery fish range from 117 to 178 mm (Chapman et al. 1995a). Limited observation suggests that the residence time of juvenile stream-type chinook in Rock Island reservoir is short (The Chelan PUD 1991c); therefore, these juveniles are not using Rock Island reservoir for extended rearing, but are assumed to be migrating actively while in the reservoir.

2.2.2.1.2. Summer and Fall (Ocean-type) Chinook. Summer and fall (ocean-type) chinook salmon use the Rock Island project area as a corridor during their upstream and downstream migrations. Ninety percent of adult summer and fall chinook pass Rock Island dam on their way to upstream spawning grounds from the end of June through the end of October (Figure 2-9). Summer and fall chinook spawn in the Wenatchee River from the mouth to Lake Wenatchee (Chapman et al. 1994a), and may also spawn in the Rock Island reservoir and tailrace (Stuehrenberg et al. 1995).

Ocean-type chinook juveniles migrate downstream in late summer as subyearlings, generally passing Rock Island dam during June through August (Chapman et al. 1994a). Ninety percent of juvenile passage occurs during June and July (Table 2-1). Juvenile ocean-type chinook salmon passing Rock Island dam result from both hatchery and natural production. Peven (1991b) reported modal ranges of 110 to 130 mm for juvenile hatchery-produced ocean-type chinook salmon passing Rock Island dam. Size of naturally produced ocean-type chinook ranges from 30 to 50 mm in late May/early June, increasing to 80 to 120 mm by late July (Peven and Fielder 1988, 1989, 1990). Unlike stream-type chinook, juvenile ocean-type chinook are likely to spend time rearing in Rock Island reservoir (The Chelan PUD 1991c).

2.2.2.1.3. Summer Steelhead. Summer steelhead use the Rock Island project area as a corridor for juvenile and adult migration. The majority of adult summer steelhead returning to the mid-Columbia River are hatchery-produced, but some natural production occurs in tributaries to the mid-Columbia River including the Wenatchee River and many of its tributaries (Chapman et al. 1994b). Adult summer steelhead begin arriving at Rock Island dam in May, and 90 percent pass the project from the end of July through the middle of September (Figure 2-10). Some summer steelhead overwinter in the Columbia River, passing Rock Island dam from March through June.

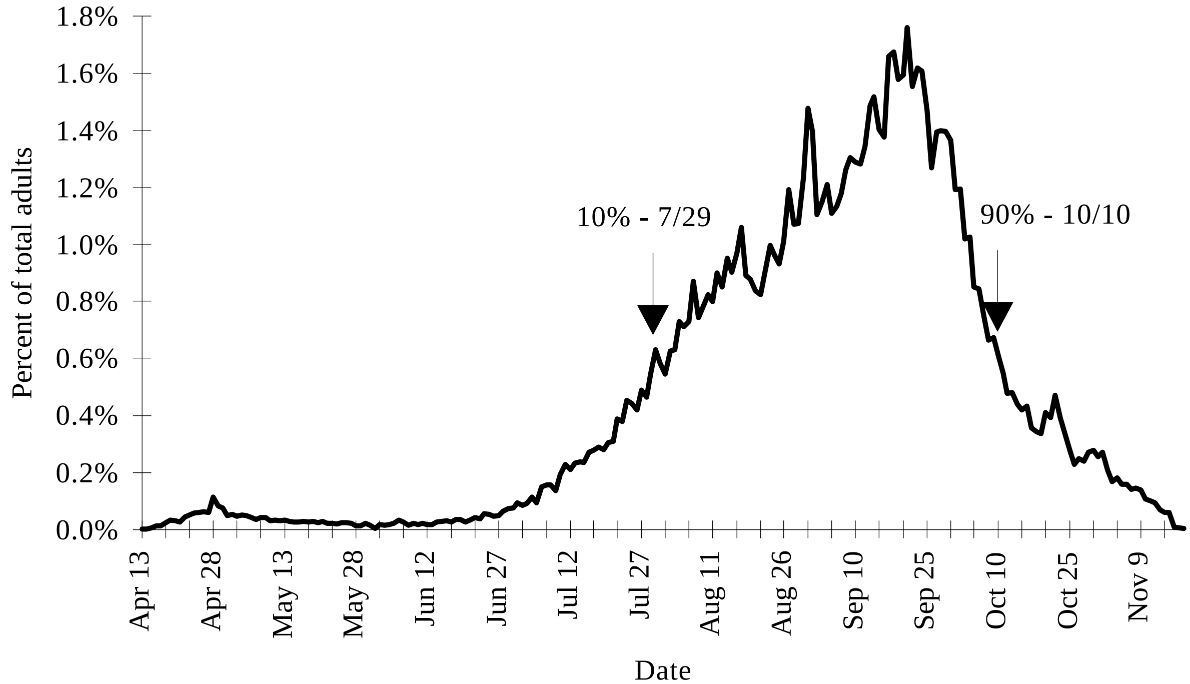


Figure 2-10. Average arrival timing of summer steelhead at Rock Island dam from 1977 to 1994 (Source: FPC 1995a).

stelhead.ri2

Naturally produced juvenile steelhead rear in fresh water for a year or more before outmigrating as smolts, and hatchery smolts are released as yearlings. Ninety percent of juvenile summer steelhead passage occurs during May (Table 2-4). The modal size of steelhead smolts passing Rock Island dam has been reported as ranging from 172 to 181 mm for naturally produced smolts and 200 to 210 mm for hatchery smolts (Peven 1991b, Peven 1992; Fielder and Peven 1986). Juvenile steelhead in Rock Island reservoir migrate actively, and residence time in the reservoir is short.

Table 2-4 Average arrival timing of naturally and hatchery-produced salmon and steelhead juveniles at Rock Island dam from 1990 to 1994.

	Proportion of smolts past the project		
Species	**10%**	**50%**	**90%**
All species	May 1	May 23	July 7
Stream-type chinook	April 23	May 17	June 7
Ocean-type chinook	June 4	June 30	July 31
Steelhead	April 29	May 11	May 26
Sockeye	April 25	May 3	May 24

Source: FPC 1995a.

2.2.2.1.4. Coho Salmon. Historically, coho salmon migrated through the Project to spawning areas in tributaries above the Project. Today, the endemic race/deme is considered extinct (CBFWA 1990). To the extent that coho are reintroduced, are residual from prior hatchery programs or are included in future hatchery programs, the mitigation and off-site compensatory measures of this plan are intended to include that species. Historical and biological data on coho in the mid-Columbia reach is included when available.

2.2.2.1.5. Sockeye Salmon. Sockeye salmon use the Rock Island project area as a corridor for juvenile and adult migration. Adult sockeye pass Rock Island dam on their way to upstream spawning grounds in Wenatchee River tributaries above Lake Wenatchee and in the Okanogan River above Lake Osoyoos (Chapman et al. 1995b). Adults arrive at the dam from June through September, with 90 percent arriving during the month of July (Figure 2-11).

Juvenile sockeye salmon passing Rock Island dam originate from upstream natural spawning areas and limited hatchery production. Ninety percent of sockeye salmon juveniles pass Rock Island dam from the last week of April through the end of May (Table 2-3). The modal size of juvenile Lake Osoyoos sockeye passing the project ranges from 115 to 154 mm, but juveniles larger than 200 mm have been reported (Peven 1991a, 1991b, 1992). Passage timing of sockeye salmon juveniles generally has a bimodal distribution because two stocks from the Okanogan and Wenatchee Rivers pass the project. Wenatchee River sockeye general pass Rock Island dam in April and Okanogan River sockeye pass in May (Peven 1989b). Okanogan River sockeye juveniles are generally larger than Wenatchee River sockeye juveniles (Peven 1989b).

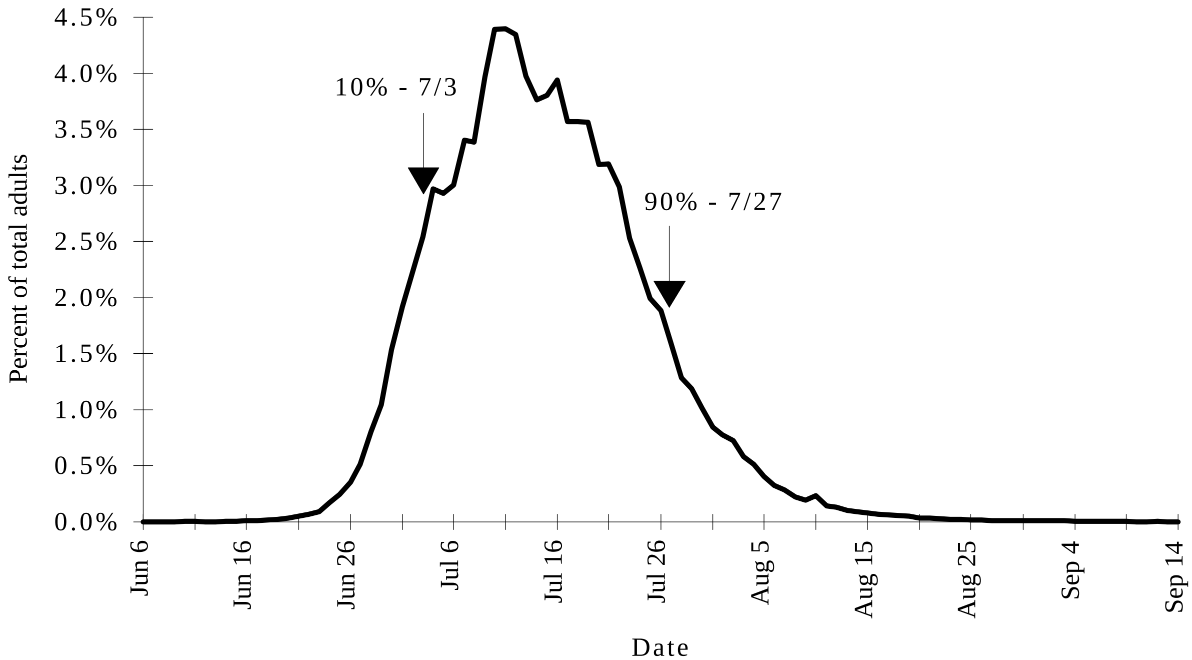


Figure 2-11. Average arrival timing of adult sockeye salmon at Rock Island dam from 1977 to 1994 (Source: FPC 1995a).

2.2.3. <u>Distribution of Fish Species</u>. The distribution pattern of fish, particularly juvenile salmonids in Project reservoir is a potentially important factor in determining effective mitigation measures for improving downstream migrant passage survival at the Project. A discussion of the horizontal, vertical and diel distribution of juveniles in the area immediately upstream of the project forebay is presented in Section 4.2. Information on the pattern of diel movements past the Project is also presented in Section 4.2.

2.3. Structural Setting

2.3.1. Mid-Columbia Region

2.3.1.1. <u>Historical Development of Columbia River Basin Hydropower Facilities</u>. Dams first began appearing in the Columbia River Basin in the late 1800s, primarily as smaller projects for lumber mills and irrigation. In both 1925 and 1927, the Federal Rivers and Harbors Act initiated plans to control flooding, generate electricity and improve navigation on the

Columbia River. As a result of this Act, plans were developed for 10 major dams on the Columbia River (NPPC 1992a).

As of 1995, there are approximately 250 projects within the basin, making it one of the most highly developed basins in the world. Twenty-seven major projects are on the U.S. portion of the mainstem Columbia and its principal tributaries, the Snake, Pend Oreille and Kootenai Rivers. Four additional large-scale projects are located in the Canadian portion of the basin. Features of these projects are noted in Table 2.5.

Mainstem Columbia River basin hydropower projects fall into two categories: storage and run-of-river. The main purpose of storage projects is to allow adjustment of the river's natural flow pattern to meet the demands of multiple uses such as power generation, irrigation and flood control. Typically, reservoir levels at storage projects fluctuate widely over the year. They are at their lowest levels in early spring prior to snowmelt and at their highest in summer for irrigation and recreation purposes. Run-of-river projects, in comparison, have limited pondage and no storage capacity. They are designed to operate within a relatively narrow range of surface elevations. Further discussion on storage versus run-of-river project operations, and the related implications of storage capacity can be found in Section 5.1 of this document.

Another feature that differentiates dams in the Columbia River basin is whether or not they allow passage of adult anadromous fish. Historically, salmon migrated nearly 1,200 miles up the Columbia River to Lake Windemere, Canada, and 600 miles up the Snake River to Shoshone Falls in Idaho. In 1939, closure of the Grand Coulee dam blocked adult anadromous fish access to the upper 500 miles of the mainstem Columbia. In 1955, access was shortened another 52 miles with the completion of Chief Joseph dam. On the Snake River, the Hells Canyon dam has made more than 50 percent of the original mainstem habitat inaccessible to anadromous fish. Dworshak dam has become the upstream limit of salmon and steelhead migration on the North Fork of the Clearwater River (BPA et al. 1994a). All dams downstream of these projects are equipped with facilities to allow passage of adult anadromous fish.

2.3.1.2. Major Features of Mid-Columbia Dams. The development of hydropower projects in the mid-Columbia began in 1933 with Rock Island dam (the first dam constructed on the mainstem Columbia). Since that time, six other projects have been added, for a total of seven projects in the mid-Columbia reach. These include the five projects operated by the PUDs; Chief Joseph dam, operated by USACE; and Grand Coulee dam, operated by BOR.

Six of the seven mid-Columbia River projects are run-of-river projects, with a primary objective of power generation. The mid-Columbia reach is not managed as a navigable waterway, and there are no locks on any of the mid-Columbia dams. Grand Coulee dam, a storage project, was built for three authorized purposes: flood control, power generation and irrigation.

Table 2.5. Major hydropower projects of the Columbia River basin (Source: USACE 1989)

Region/Project	Owner	Type of Project	Usable Storage (kaf)	Anadromous Fish Passage
Lower Columbia				
Bonneville	USACE	Run-of-river	N/A	Yes
The Dalles	USACE	Run-of-river	N/A	Yes
John Day	USACE	Storage	534	Yes
McNary	USACE	Run-of-river	N/A	Yes
Mid-Columbia				
Priest Rapids	Grant PUD	Run-of-river	<44.6	Yes
Wanapum	Grant PUD	Run-of-river	<160.2	Yes
Rock Island	Chelan PUD	Run-of-river	<135	Yes
Rocky Reach	Chelan PUD	Run-of-river	<430	Yes
Wells	Douglas PUD	Run-of-river	<300	Yes
Chief Joseph	USACE	Run-of-river	<116	No
Grand Coulee	USBR	Storage	5,185	No
Upper Columbia				
Arrow	BC Hydro	Storage	7,000	No
Revelstoke	BC Hydro	Run-of-river	N/A	No
Mica	BC Hydro	Storage	11,974	No
Snake				
Ice Harbor	USACE	Run-of-river	N/A	Yes
Lower Monumental	USACE	Run-of-river	N/A	Yes
Little Goose	USACE	Run-of-river	N/A	Yes
Lower Granite	USACE	Run-of-river	N/A	Yes
Hells Canyon	Idaho Power	Run-of-river	N/A	No
Oxbow	Idaho Power	Run-of-river	N/A	No
Brownlee	Idaho Power	Storage	975	No
Dworshak	USACE	Storage	2,016	No
Pend Oreille				
Boundary	Seattle City Light	Run-of-river	N/A	No
Box Canyon	Pend Oreille PUD	Run-of-river	N/A	No
Albeni Falls	USACE	Storage	1,155	No
Cabinet Gorge	WWP	Run-of-river	N/A	No
Noxon Rapids	WWP	Storage	N/A	No
Thompson Falls	Montana Power	Run-of-river	N/A	No
Hungry Horse	USBR	Storage	3,161	No
Kootenai				
Duncan	BC Hydro	Storage	1,399	No
Libby	USACE	Storage	4,979	No

Except for Wells dam, the run-of-river projects on the mid-Columbia are of a conventional design containing powerhouse structures, spillway structures and embankments. The area immediately upstream of a project powerhouse and spillway is referred to as the forebay, while the tailrace is on the downstream side of the project. The characteristics of the reservoir formed by a dam are dependent on the structural design of the dam and the original topography of the upstream reach. In the mid-Columbia, the upper limit of each reservoir encroaches upon the tailrace of the next project upstream, except in the case of Grand Coulee.

2.3.1.3. Fish-Related Features of the Mid-Columbia PUD Projects. Fish passage through the five mid-Columbia PUD projects is influenced by generating facilities as well as fish passage and protection facilities. The number of fish present in the system is influenced by fish production facilities owned by the PUDs. Further details of these fish-related features are provided in the following paragraphs to provide an overview of the similarities and differences found in the PUD projects.

2.3.2. Rock Island. The Rock Island project was the first dam to span the Columbia River, with construction beginning in 1930. Since then, the project has gone through two major expansions. In the early 1950s, the powerhouse containing the four original turbine units was expanded to accommodate six additional units. From 1974 to 1979, a second powerhouse was constructed on the opposite bank of the river to hold another eight units. This later construction phase also included project modifications that raised the Rock Island pool elevation by approximately 6 feet. The pool raise was necessary to compensate for higher tailwater elevations and project encroachment that occurred with completion of the downstream Wanapum project in the late 1960s.

In addition to the standard components of a hydroelectric facility, Rock Island dam contains several fish passage and protection features for both upstream and downstream migrants. Further, the Chelan PUD owns and funds the operation of the Eastbank hatchery and its associated satellite facilities as compensation for fish losses related to the Rock Island project. Descriptions of the physical features of the Rock Island dam fish-related facilities are presented in the following subsections and summarized in Table 2-6. Details on the facility operations are provided in Section 2.4.

2.3.2.1. Power Generating Facilities. The basic configuration of Rock Island dam is that of a traditional hydroelectric project with separate powerhouse and spillway structures. However, Rock Island dam is somewhat atypical in that there are two powerhouses, one each at the left and right banks (Figure 2-12). The dam spans a total of 3,115 feet, with powerhouse 1 comprising 870 feet, powerhouse 2 comprising 470 feet, the spillway comprising 1,185 feet, and the left abutment wall comprising 590 feet.

There are currently 18 turbine units and one station service unit at Rock Island dam, providing a total hydraulic capacity of 220,000 cfs. Though all are propeller-type turbines typical of low-head dams, they represent three different classes of propeller turbines, each installed during a different phase of project expansion. The original construction in the 1930s installed Nagler turbines in Units 1 to 4 in powerhouse 1 (Figure 2-13). Categorically, Nagler turbines have semi-adjustable runner blades that can be rotated through the use of a mechanical assist to adjust for changes in head. Due to stable reservoir levels, these units consequently now function as fixed-blade propeller turbines, and they are hereafter referred to and analyzed as such. The current unit turbine rating for these fixed-blade propeller units is 32,000 hp at 45-foot-net head and 100 rpm.

The second class of turbines found at Rock Island dam consists of Kaplan turbines. These units were installed as Units 5 through 10 in powerhouse 1, coming on line during the period from 1952 to 1953 (Figure 2-14). As with all Kaplan turbines, the runner blades of these units are fully adjustable. The turbine rating for the Kaplan units is 34,000 hp at 45-foot-net head and 100 rpm.

Except for the blade adjustment feature, the fixed-blade propeller turbines and the Kaplan turbines at Rock Island dam are very similar in design. All of the turbine runners in powerhouse 1 are vertically oriented, with an outer case diameter of 18.8 feet. The centerline of the runner is approximately 29 feet below the typical tailwater elevation, which, like most low-head dams, suggests favorable conditions regarding cavitation concerns.

The third class of turbines found at Rock Island dam consists of bulb turbine. Eight bulb turbines were installed as part of the powerhouse 2 construction project, coming on line in 1979 (Figure 2-15). Bulb turbines are a type of Kaplan turbine in that they have fully adjustable blades, but the distinguishing feature of a bulb turbine is its horizontal rather than vertical orientation. The Rock Island bulb turbines each have a unit turbine rating of 72,000 hp at 85.7 rpm. When installed, they were the largest bulb turbines ever constructed, with a runner casing 24 feet in diameter. The shaft centerline, which lies in a horizontal plane, is 41 feet below the normal tailwater elevation.

Because of individual characteristics, each class of turbine at Rock Island dam has a different generating capacity. For the fixed-blade units, one unit still has its original nameplate rating of 15,000 kW, while the other three have been upgraded to a nameplate rating of 20,700 kW each. The Kaplan units have a nameplate rating of 22,500 kW each, and each of the eight bulb units in powerhouse 2 has a nameplate rating of 51,300 kW. The total nameplate capacity of both powerhouses is 622.5 MW, with a total peak capability of 660 MW. This is roughly enough power to serve a city the size of Vancouver, Washington.

At the time of original construction in the 1930s, a smaller turbine unit referred to as the "Station Service Unit" was installed to supply 1,000 kW of power to the plant. The turbine is similar to the fixed-blade units installed during the same period, but is rated for only 2,100 hp. The intake to the station service unit is screened with a trashrack.

Table 2-6. Rock Island dam structural setting summary.

Generating Facilities			
Dam length (ft)			
Powerhouse 1	870		
Powerhouse 2	470		
Spillway	1,185		
Left abutment wall	590		
Total	3,115		
Start of operations	1933		
Powerhouses (combined)			
Nameplate capacity	622.5 MW		
Hydraulic capacity	220,000 cfs		
Turbine type, quantity and unit rating			
Fixed blade propeller	4 with 32,000 HP @ 45 ft net head and 100 rpm		
Kaplan	6 with 34,000 HP @ 45 ft net head and 100 rpm		
Bulb	8 with 72,000 HP @ 85.7 rpm		
Spill gate quantity, type and dimensions			
Deep	13 gates 30 ft wide by 56 ft high		
Shallow	18 gates 30 ft wide by 33.5 ft high		
Spillway design	Ogee; no energy dissipation features		
Ice and debris sluice gates	None		
Important elevations for normal operations	Normal	Maximum	Minimum
Reservoir elevation	612.6	614.1	610.1
Tailwater elevation	573.2	593.7	561.5
Gross head (ft)	39.4	20.4	48.6
Spillway crest elevation			
Deep	559.0	NA	NA
Shallow	581.5	NA	NA
Spill height (spillway crest to TW surface) (ft)			
Deep	-14.2	-34.7	-2.5
Shallow	8.3	-12.2	20.0
Tailrace depth (TW surface to apron) (ft)			
Minimum	7.2	27.7	-4.5
Maximum	70.2	90.7	58.5
Upstream Fish Passage and Protection Facilities			
Number of fishways	3		
Right bank ladder entrances	4		
Middle ladder entrances	2		
Left bank ladder entrances	2		
Fish collection channel	Extends width of Powerhouse 2 tailrace		
Pumped attraction flow	1,680 cfs for right bank fish ladder		
Downstream Fish Passage and Protection Facilities			
Operable prototype juvenile bypass facilities	gatewell orifice collection channel at Powerhouse 2		
Interim juvenile bypass system	Bypass spill		
Aerial predator control wiring	25 ft on center full width of powerhouse tailraces		

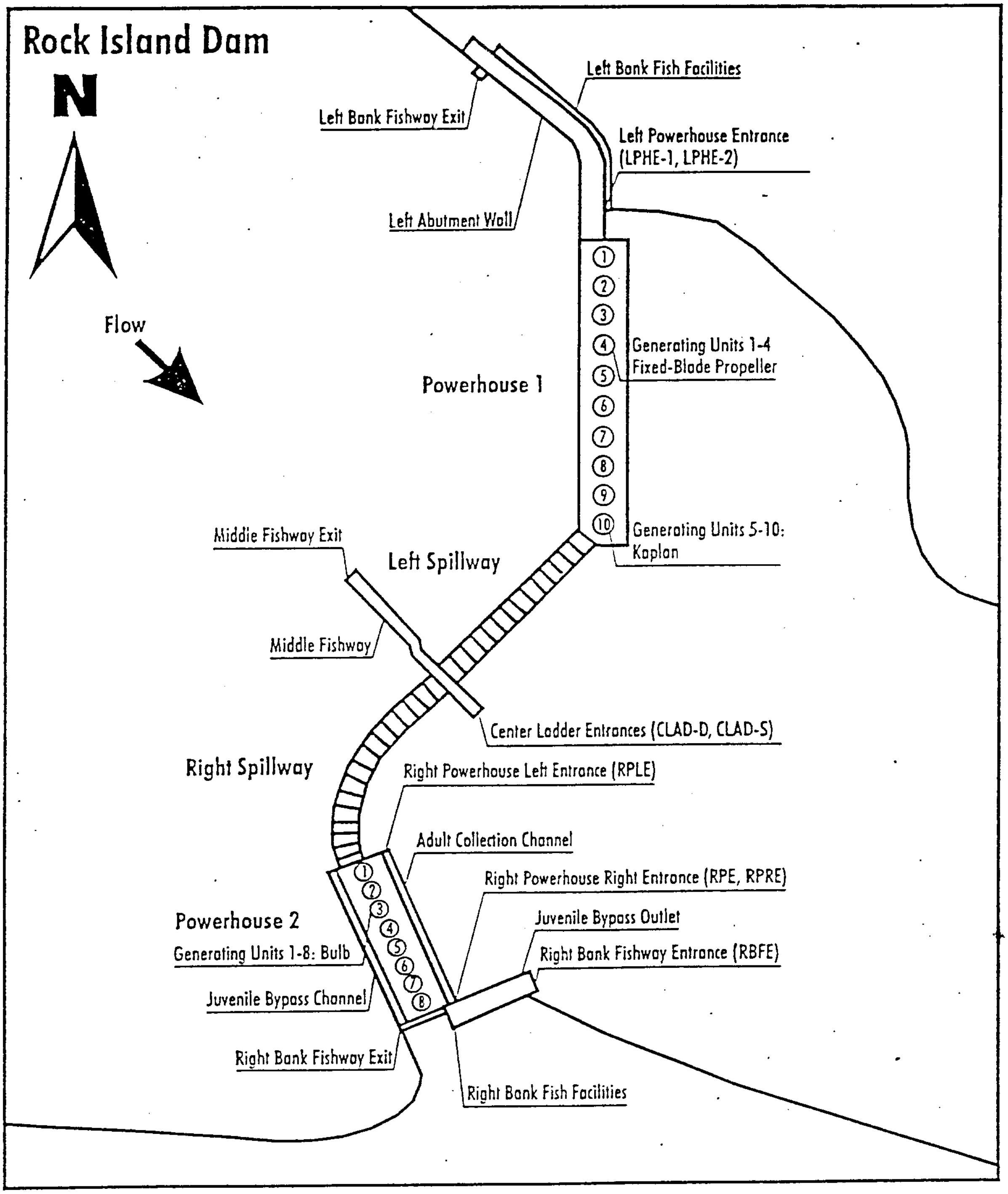
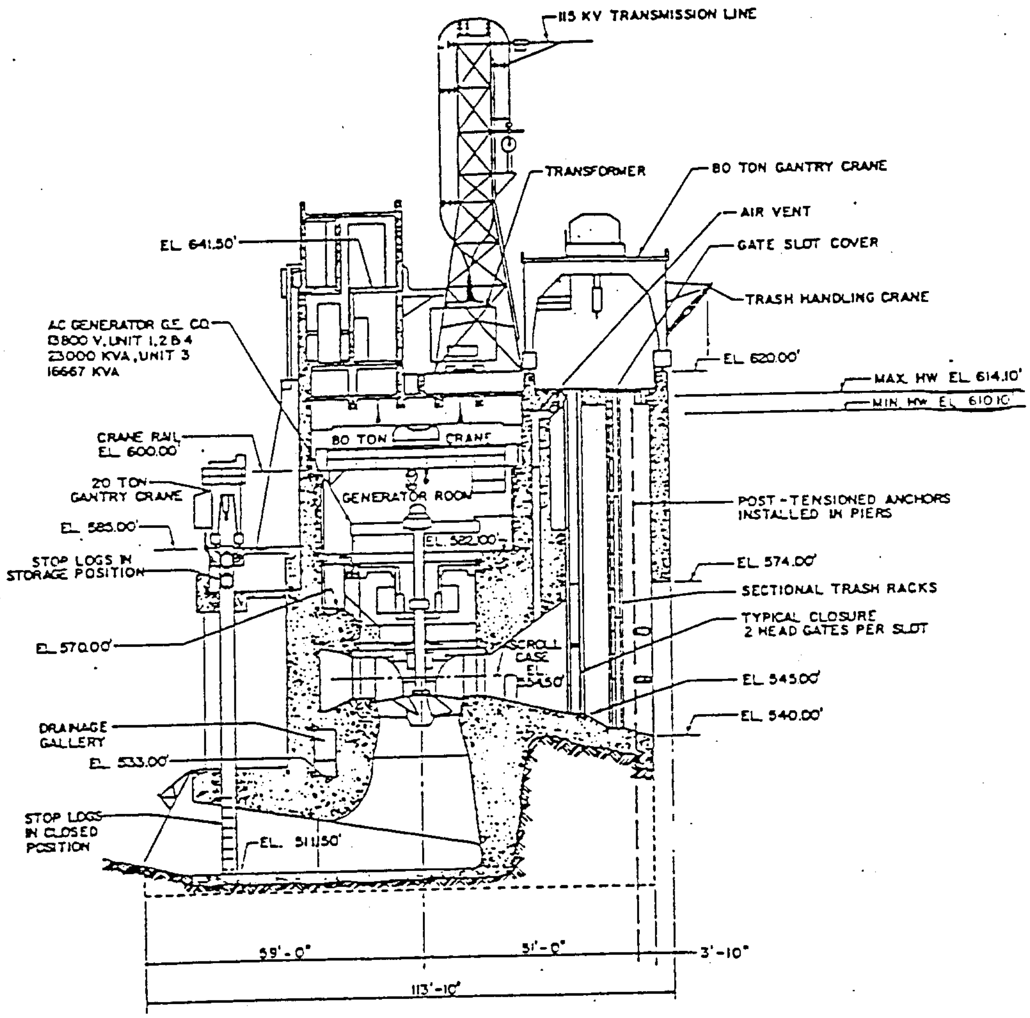


Figure 2-12 Rock Island dam general arrangement.

pass-pro.ri2



CROSS SECTION
UNITS 1-4

Figure 2-13 Rock Island dam Powerhouse 1 cross-section at fixed-blade propeller unit (Source: CCPUD 1973).

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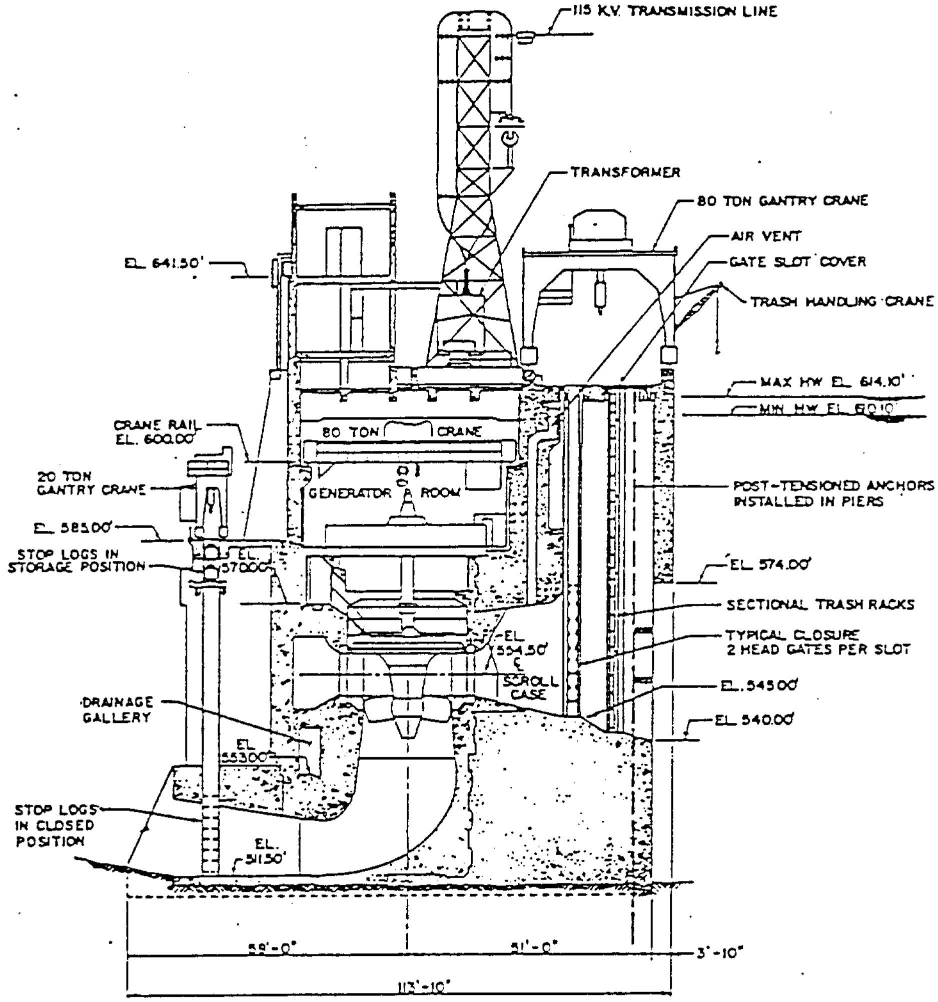


Figure 2-14 Rock Island dam Powerhouse 1 cross-section at Kaplan unit (Source: CCPUD 1973).

pwr-kap.ri2

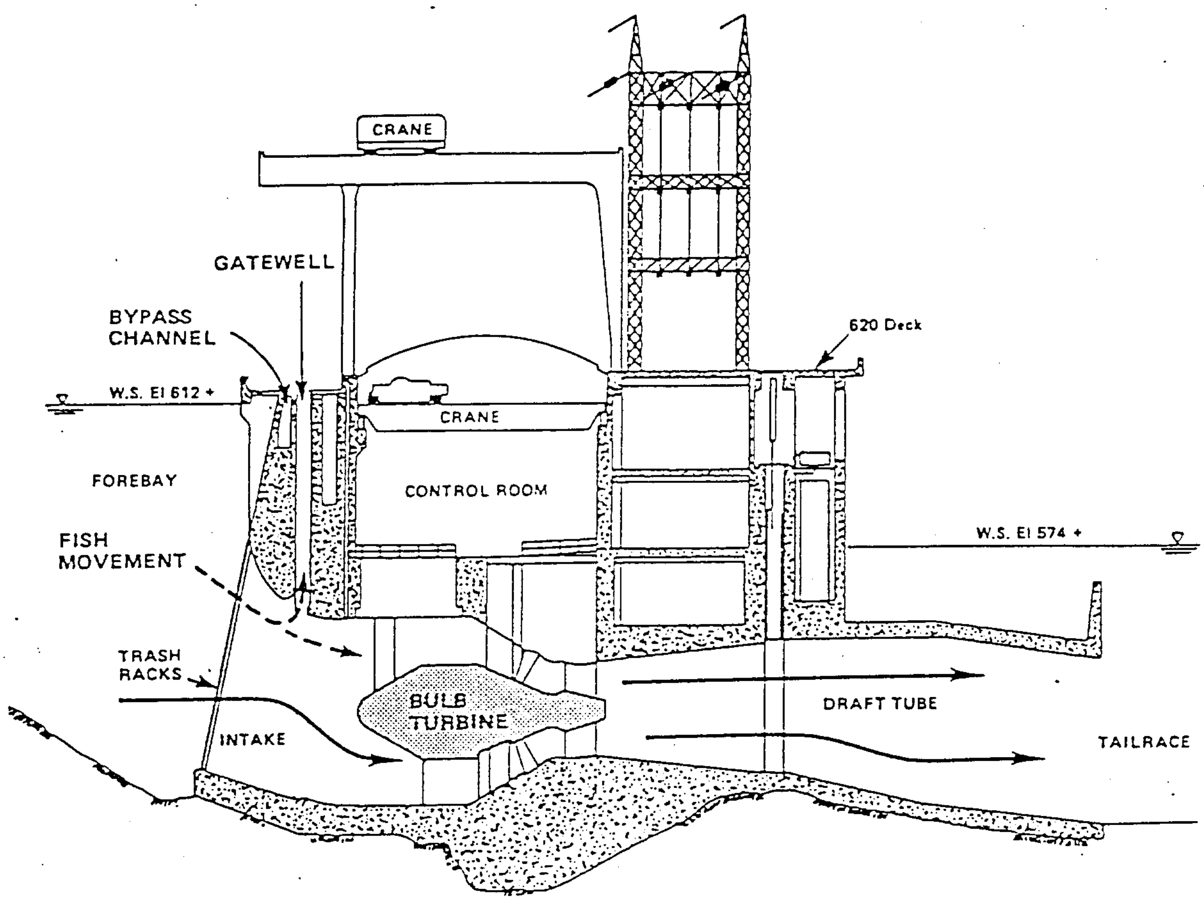


Figure 2-15 Section through bulb turbine at Rock Island dam Powerhouse 2 (Source: Olson 1983).

bulb.ri2

Powerhouse 1 has three intake galleries per turbine, each measuring 15.3 feet wide by 25 feet high at the headgate slot. If a turbine must be dewatered, two sections of headgate are lowered into the headgate slot by a gantry crane. The bottoms of the intake galleries are located 73 feet below the normal headwater surface elevation. Water exits each turbine in powerhouse 1 through a draft tube containing a broad 90-degree bend. The lowest point of the draft tube is located 62 feet below the normal tailwater elevation.

Powerhouse 2 has only two intake galleries per turbine, each measuring 20 feet wide by 48 feet high at the gatewell slot. A turbine can be dewatered by lowering a gate into the gatewell slot using the powerhouse gantry crane. The bottoms of the intake galleries are located 95 feet below the normal headwater surface elevation. Water exits each turbine in powerhouse 2 through a draft tube measuring 51 feet wide by 43.5 feet high at the exit. The lowest point of the draft tube is located at the exit, 73 feet below the normal tailwater elevation.

The spillway as originally constructed had 37 gated spill bays, each 30 feet wide. Five spill bays were eliminated when powerhouse 2 was constructed. There are now 31 spill gates: Gates 1 to 14 on the left spillway, east of the middle fishway, and Gates 16 to 32 on the right spillway. Because of the channel topography and the presence of bedrock, some gates were constructed with shallow spill bays and some with deep spill bays (Figure 2-16). The shallow spill bays are located in the center of the spillway at Gates 7 to 25, in the vicinity of what used to be Rock Island. The deep spill bays are found at Gates 1 to 6 and 26 to 32. The original gate 15 was eliminated when the middle adult fishway was installed through that opening.

The spill gates at Rock Island dam are of leaf gate design, which are opened by using a hoist or gantry crane to lift the leaf gate upwards. The gates as originally constructed were 22.5 feet deep at the shallow spill bay, and 45.0 feet at the deep spill bay. However, when the pool was raised during the 1970s construction, an additional 11 feet were added to the bottom of each leaf gate. The gate extensions are pinned to the main gate on all deep gates to comply with FERC requirements for dam safety and flood preparedness. On the shallow gates, the extensions are left unpinned for the duration of the juvenile migration period so that bypass spill can be conducted from as shallow a depth as possible. Spill consequently occurs from a depth of about 56 feet for the deep gates and about 22 feet for the shallow gates.

The spillway at Rock Island dam is an ogee design on the shallow sections and a modified ogee on the deep sections (Figure 2-16). The crest of the spillway for shallow gates is 8 feet above the normal tailwater elevation, while the crest for deep gates is 14 feet below the normal tailwater elevation.

Because the tailrace apron elevation varies across the spillway, the normal tailwater depth varies between 7 feet and 70 feet. There are no features for energy dissipation in the spillway design.

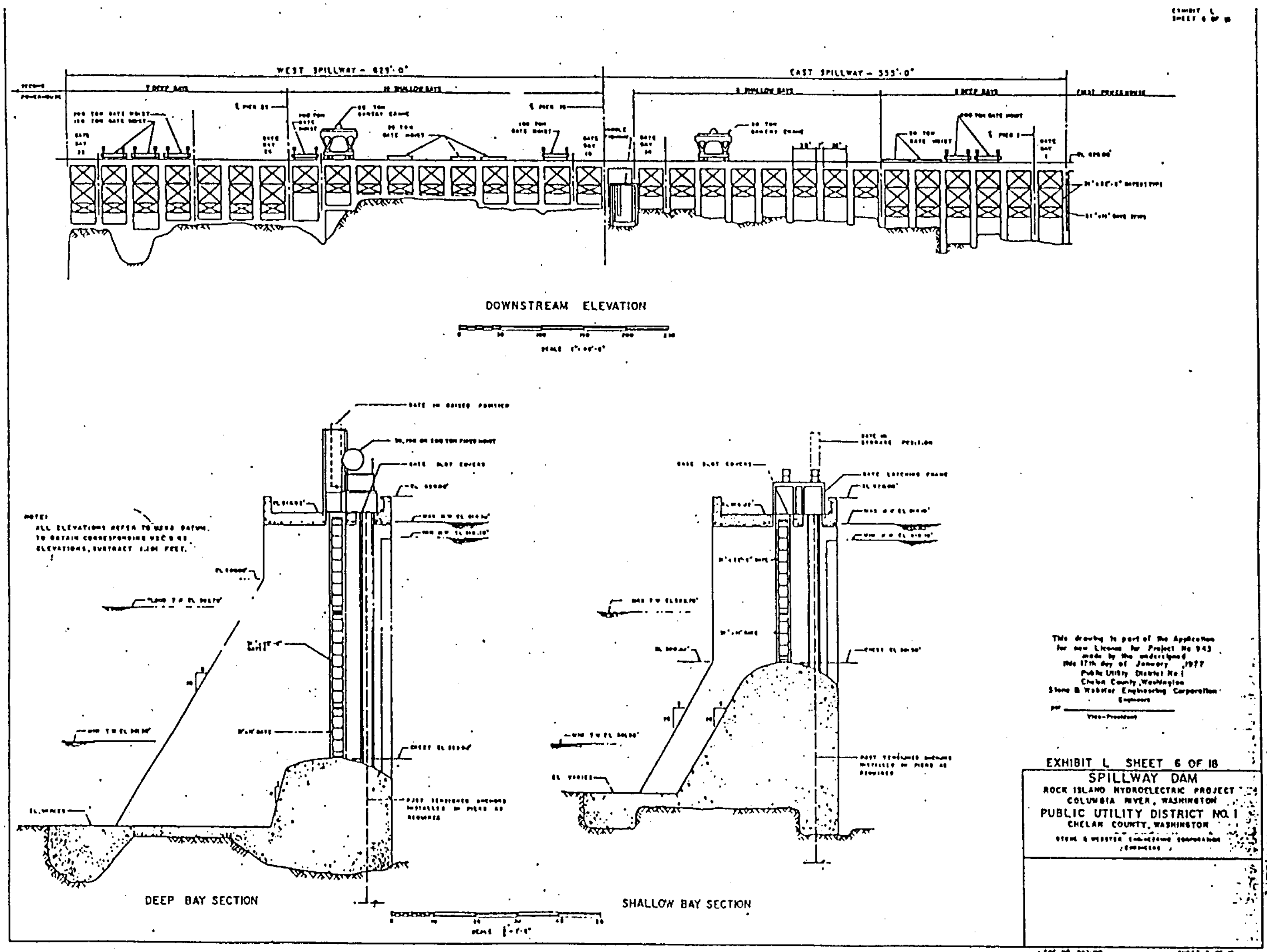


Figure 2-16 Downstream view and sections of Rock Island dam spillway (Source: CCPUD 1973).

downview.ri2

The completion of Wanapum dam in the late 1960s resulted in encroachment on Rock Island dam which raised the tailwater several feet. To compensate for this loss of operating head, the 1970s project expansion at Rock Island dam included features that allowed the headwater pool elevation to be raised approximately 6 feet. Several modifications of existing structures were made to accommodate this change, including the installation of post-tensioned anchors in powerhouse and spillway piers, powerhouse intake trashrack extensions, parapet walls to extend the height of portions of the dam, 11-foot-high gate segments added to all spill gates and extension of the upper ends of the middle and left bank fish ladders. Also during this construction phase, the existing right bank fish ladder was removed and replaced with a new fishway and powerhouse collection system.

2.3.2.2. Upstream Fish Passage and Protection Facilities. Upstream passage facilities at Rock Island dam are composed of three conventional pool and weir fish ladders. The left bank ladder is 18 feet wide and located at the left side of powerhouse 1. The middle ladder is 20 feet wide and located at the approximate center of the spillway, passing between Gates 14 and 16. The right bank ladder is 15 feet wide and located at the right end of powerhouse 2. In each ladder, water is directed from one pool to the next via overflow weirs and submerged orifices. The center and left ladders have full width overflow weirs while the right ladder has Ice Harbor-style weirs, with overflow on each side and a concrete baffle in the middle.

The left bank fishway has two entrance gates, LPHE-1 and LPHE-2 (Figure 2-12). The middle fishway has two entrance gates, CLAD-D and CLAD-S, which are 4 feet and 2 feet wide, respectively. An additional side entrance on the south side of the fishway is closed under current operating criteria. The right bank fishway has four entrances equipped with wing gates that allow a maximum open width of 3.5 feet; RPLE is located at the left end of the powerhouse; RPE and RPRE are located at the right end of the powerhouse; and RPDS is located near the downstream end of the right bank fishway structure.

All three fishways are equipped with a fish counting station at the top (exit) end of the ladder. The main features of the counting stations include an observation window into the ladder and a picket barrier to guide fish close to the window. Observation windows are monitored 24 hours a day, seven days a week using video cameras. Video tapes are viewed and fish counted by Chelan PUD personnel.

Each of the ladder exits is equipped with guide slots so that the exits may be closed with stoplogs. The exits of the right and middle ladders face upstream, while the left ladder exit faces out from the bank toward the center of the stream.

All three fishways have gravity-flow of water into the tops of the ladders and auxiliary piped water supply systems that discharge additional water partway down the ladders. The auxiliary piped water supply adds flow into the lower section of the fishway to provide attraction velocities at the entrances. The left and middle fishways have gravity systems. The right bank fish facility is equipped with three electric-motor-driven pumps that are able to draw water from the tailrace and discharge it to the lower portion of the ladder. Additional water is added through a gravity system. An attraction jet is located on the face of powerhouse 2 adjacent to the RPE entrance gate. This jet is supplied by gravity-flow water. All water intakes for the ladder facilities are equipped with trashracks. The gravity water intake to the right ladder has a Ristroff-type rotating fish screen and fish bypass system.

2.3.2.3. Downstream Fish Passage and Protection Facilities. When powerhouse 2 was constructed in the 1970s, it was equipped with a juvenile bypass channel system designed to convey juveniles passing the project from the turbine intake gatewells to the tailrace. The system was included in the powerhouse design in the event that turbine intake screens would be installed as an effective juvenile bypass system. Turbine intake screens were tested in 1988 and were not successful (Fields 1989). Accordingly, any fish that enter the gates will currently do so volitionally. Olson (1982) estimated 5% of downstream migrants use this facility. The system includes two 8-inch-diameter orifices in each of the 16 gatewells at powerhouse 2 (Figure 2-17). Fish that pass through the orifices enter a bypass channel that parallels the face of the powerhouse. At the right end of the powerhouse is an overflow weir gate which is used to regulate flow through the channel at about 80 cfs. After passing over the weir gate, water drops into a 36-inch-diameter bypass pipe that discharges to the tailrace. The bypass pipe is diverted to a monitoring station that allows dewatering, fish handling and fish return during juvenile migration–mid March to September.

The 1987 Rock Island Settlement Agreement calls for additional measures to bypass juvenile migrants past the dam (FERC 1987). Until structural measures are in place, the agreement requires spill as an interim juvenile bypass measure, or as a permanent measure with limitations on the quantity determined by a conservation account. Spill is currently provided in lieu of structural measures, using the conservation account at the agencies request. In 1998 dollars, the conservation account totals $3,001,200, and is used to allocate fish spill according to current value of forgone power generation revenue. Spill for juvenile bypass is conducted at the right spillway, with prioritized use of the shallow spill gates and slotted gates for surface spill. The intent is for the Anadromous Fish Agreement and habitat Conservation Plan to prospectively supercede the Rock island Settlement Agreement but the conservation account is being carried forward.

Some downstream migrants that pass through turbines may be temporarily disoriented when they exit the draft tubes. To protect these fish from extensive predation by birds, aerial predator control stainless steel wiring has been installed along the full width of the tailraces at both powerhouses 1 and 2. The wiring consists of stainless steel wire strung 25 feet apart. Annual hazing, using pyrotechnics, is conducted to frighten gulls away from the tailrace area. A northern squawfish removal program was implemented in 1995 below both powerhouses to reduce predation on juvenile salmonids passing the project. Since 1985, a total of 16,236 have been removed, averaging 5,412 per year (West 1997).

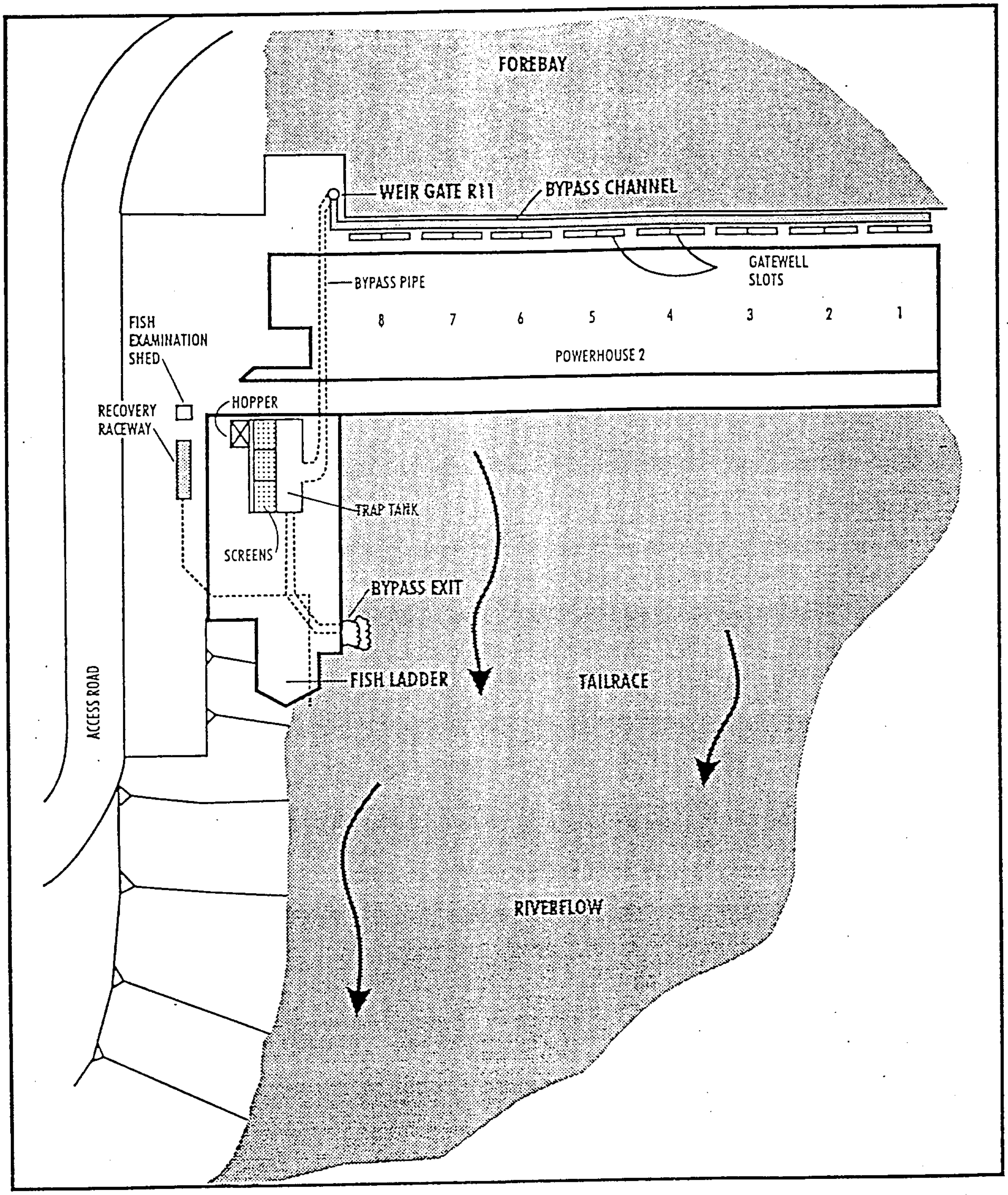


Figure 2-17 Plan view of juvenile bypass system at Rock Island dam Powerhouse 2 (Source: Olson 1983).

planview.ri2

2.3.2.4. <u>Fish Production Facilities</u>. Provisions of the 1987 Rock Island Settlement Agreement require the Chelan PUD to provide hatchery-based compensation for losses of salmon and steelhead resulting from the Rock Island project (FERC 1987). The intent is for the Anadromous Fish Agreement and Habitat Conservation plan to prospectively supercede the Rock Island Settlement Agreement, but the hatchery program is being carried forward with some modifications. Under the Rock Island Settlement Agreement Chelan PUD has funded the design, construction and operation of the Rock Island hatchery complex. The complex includes a central hatchery facility, five satellite facilities for grow-out and acclimation and three broodstock trapping sites. (Table 2-7)

The main facility is the Eastbank hatchery, located near the Columbia River just upstream from Rocky Reach dam. Satellite facilities include Carlton Pond on the Methow River, Chiwawa Pond on the Chiwawa River, Dryden Pond on the Wenatchee River, Similkameen Pond on the Similkameen River, and the Lake Wenatchee net-pens on Lake Wenatchee. Most of these facilities were constructed in 1989 (The Chelan PUD 1991c).

Eastbank hatchery serves as a central incubation and rearing hub for the five satellite facilities. Current rearing facilities at Eastbank consist of three adult holding ponds used for steelhead and chinook salmon, 70 stacks of vertical incubators, rearing troughs, 13 raceways and two half-acre rearing ponds. Additional vertical incubators have been added to replace some of the rearing troughs. The water supply system consists of four wells capable of delivering 53 cfs. The water supply for the incubators includes a chiller system for temperature control (Peck 1993a).

The Carlton Pond satellite facility contains one large rearing pond. The pond is supplied by 15 cfs of surface water pumped from the Methow River. There is also a small office at this site (Peck 1993a).

Facilities at the Chiwawa Ponds satellite include two large rearing ponds. The ponds can be supplied by 21 cfs of surface water from the Chiwawa River, and/or 12 cfs from the Wenatchee River. The site also has facilities for collecting adults from the Chiwawa River, consisting of a hydraulically operated picket weir and trap (Peck 1993a). The site has an office, shop and storage facilities.

The Dryden Pond facility consists of a large rearing pond. The surface water supply of around 16 to 30 cfs is drawn from an irrigation canal supplied from the Wenatchee River (Peck 1993a).

Facilities at Similkameen Rearing Pond consist of an office, a small shop and a large, covered rearing pond. The pond is supplied by 21 cfs pumped from the Similkameen River. An aeration system is installed to provide supplemental oxygen (Peck 1993a). The Chelan PUD has

Table 2-7. Fish production facilities owned by the mid-Columbia PUDs.

Facility / Satellite	Owner	Operator	Compensation Objective	Year Con-structed	Production Facilities: Adult Holding	Production Facilities: Incu-bation	Production Facilities: Race-ways	Production Facilities: Ponds	Production Facilities: Net-pens	Total Volume (cf)	Water Supply (cfs): Surface Water	Water Supply (cfs): Ground Water
Cassimer Bar Hatchery	DCPUD	Colville Tr.	Wells project mortality	1994	yes	yes	yes	no	no	7,600	0	1.3
Lake Osoyoos Netpens				1994	yes	no	no	no	yes	16,000	0	0
Chelan PUD Hatchery	CCPUD	WDFW	Rocky Reach pool inundation	1965	yes	yes	yes	no	no	71,500	0	8
Eastbank Hatchery	CCPUD	WDFW	Rock Island pool inundation	1989	no	yes	yes	yes	no		0	53
Carlton Pond			and project mortality	1989	no	no	no	yes	no	53,400	15	0
Chiwawa Pond				1989	no	no	no	yes	no	150,000	21	0
Dryden Pond				1989	no	no	no	no	no		30	0
L. Wenatchee Netpens				1989	yes	no	no	no	yes	59,200	0	0
Simikameen Pond				1989	no	no	yes	yes	no	92,400	21	0
Methow Hatchery	DCPUD	WDFW	Wells project mortality	1992	yes	yes	yes	yes	no	65,800	9	9
Chewuch Pond				1992	yes	no	no	yes	no	22,000	3	0
Twisp Pond				1992	yes	no	no	yes	no	27,000	3	0
Priest Rapids Hatchery	GCPUD	WDFW	Pr. Rap./Wan. pool inundation	1963	yes	yes	yes	yes	no	150,900	100	14
Rocky Reach Hatchery	CCPUD	WDFW	Rocky Reach pool inundation	1961	no	yes	yes	yes	no	176,200	44	6
Turtle Rock Pond				1961	no	no	no	yes	no	29,000	?	?
Wells Hatchery	DCPUD	WDFW	Wells pool inundation	1967	yes	yes	yes	yes	no	1,133,300	175	25

pro-fac.ov3

developed well water sources of warmer water to prevent winter temperatures from causing fish losses in the pond.

The Lake Wenatchee site consists of eight floating net-pens. Six pens (measuring 6.5 feet by 6.5 feet) are equipped for rearing sockeye salmon juveniles, while two pens (measuring 5.42 feet by 5.42 feet) are equipped for holding adult sockeye salmon for spawning (Peck 1993a).

2.4. Operational Setting. The primary objective for each of the five mainstem mid-Columbia PUD dams is to produce power. Collectively, these five dams generate over 25 billion kilowatt-hours annually, producing nearly 10 percent of the entire hydropower output in the United States. This energy is equivalent to the typical annual power production of four nuclear power plants, eight million tons of coal, or 33 million barrels of oil (Mid-Columbia Hydro Power 1993). Operation of these projects, however, must also take into account the diverse interests of a broad spectrum of agencies and river users. Aspects of project operations which strongly influence or are affected by fisheries resources are noted in the following subsections.

2.4.1. Dam and Reservoir Operations

2.4.1.1. System-wide Integration of Operations. To make optimum use of the system resources, a central control station, located in Ephrata, Washington, coordinates operations of the seven mid-Columbia projects from Grand Coulee dam to Priest Rapids dam. Thus, these projects are generating power as though they were owned and operated by a single entity. The general objective of the centralized coordination is to maximize energy production while enhancing irrigation, recreation, and other nonpower uses of the river by minimizing reservoir level fluctuations (GCPUD 1980).

The timing of flows from Grand Coulee dam through the mid-Columbia reach is controlled by the Canadian Treaty, the related Non-Treaty Storage Agreement (NTSA), the Pacific Northwest Coordination Agreement (PNCA) and the Hourly Coordination Agreement. Since 1982, when the NPPC established its first Fish and Wildlife Program, the Water Budget and other Council programs have played an increasing role in controlling flows to the mid-Columbia reach. In addition, the ESA listings of Snake River chinook and sockeye salmon, and the Kootenai River white sturgeon, have had a profound effect of mid-Columbia flows. For a more detailed discussion on system-wide issues that affect the operation of mid-Columbia PUD projects, please refer to Section 5.2.

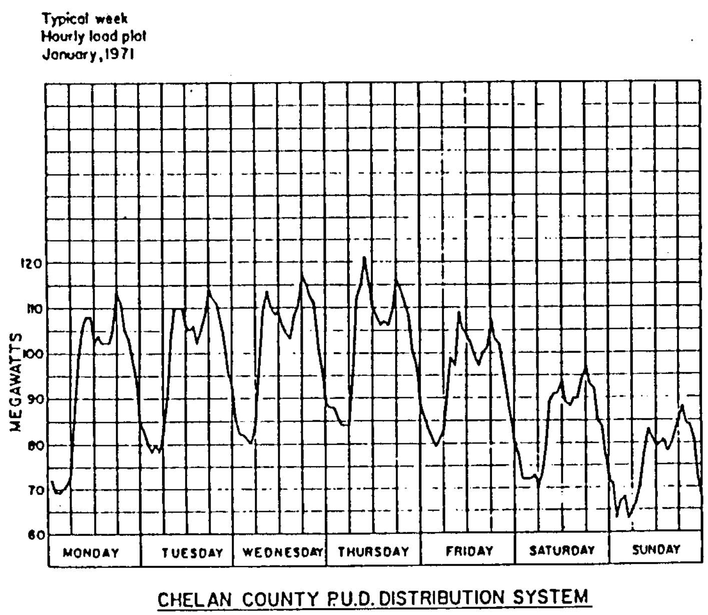
Flows through the Rocky Reach project are primarily the result of releases from Grand Coulee dam in accordance with operations of the Federal Columbia River Power System (FCRPS) and the Mid-Columbia Hourly Coordination Agreement. Like all mid-Columbia projects, Rocky Reach dam is controlled from a dispatch center located in Ephrata, Washington. The general objective of Hourly Coordination is to optimize power production while at the same time enhancing non-power uses of the mid-Columbia hydropower resources.

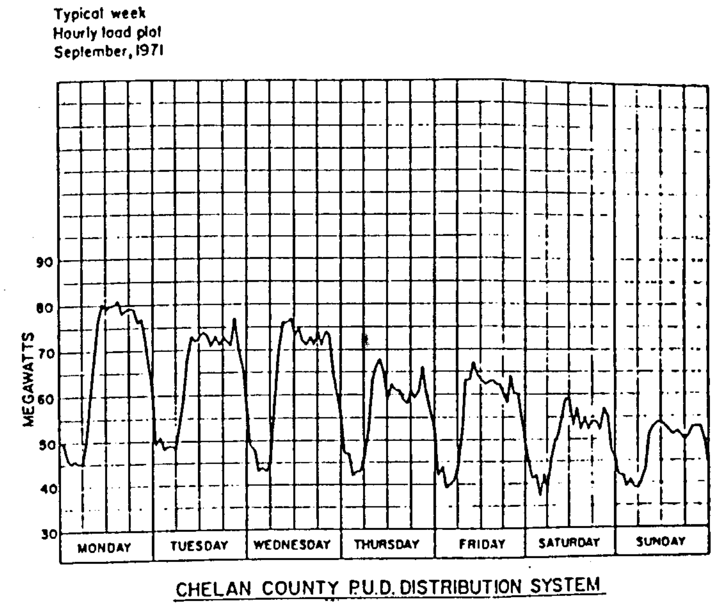
2.4.1.2. Dam and Reservoir Operation Generally. In general, operation of the mid-Columbia PUD dams is strongly tied to the instantaneous demand for power as put forth by the Hourly Coordinating Agreement. Output levels vary significantly on a daily basis, with typical daytime peaks being about 135 percent as much as the nighttime lows (Figure 2-18). This fluctuation in power demand results in dynamic conditions for turbine usage and the resulting water discharge from the project. The number of turbines in use can change frequently, especially during the early morning and late evening hours. In most cases, there are more turbines in operation during the day than at night. To meet daytime load demands, flow releases from Chief Joseph dam are timed to increase generating capability at the downstream projects throughout the day. Hourly coordination manages the operation of the various mid-Columbia powerhouses with upstream projects picking up more of the load in the morning, and downstream projects using the pulse of flow to generate in the afternoon and evening. Hourly coordination operates to maximize generation efficiency at the plants by minimizing drafting of reservoirs and maintaining efficient operating heads for the turbines.

As a general rule, the mid-Columbia PUDs operate their turbines to be at the highest efficiency possible for the instantaneous conditions of head and power demand, so as to maximize generation and revenue for the facility. When it is not necessary to operate all turbines, it is generally preferred to distribute run time so that turbine units receive approximately the same amount of usage and wear and tear. This process is relatively straightforward at Priest Rapids, Wanapum and Wells dams, which each have ten turbines of similar type and performance characteristics. Rock Island and Rocky Reach dams have more than one type of turbine, and decisions regarding turbine unit priority typically consider the discharge capacity and efficiency of each turbine type relative to the instantaneous power demand. In some cases, turbine unit priorities may be established for reasons not related to power generation, as is noted in other subsections.

From the standpoint of maximizing power production, it is a general objective of each project to minimize the amount of water discharged over the spillway. Forced spill is necessary whenever the reservoir is at its normal maximum operating level, and when the inflow into the reservoir exceeds the hydraulic capacity of those turbines being used to meet the instantaneous power demand. The amount of forced spill has dropped significantly since the implementation of the Canadian Storage Agreement in the mid-1970s. When forced spill does occur, it typically is at night when energy demand is lowest.

Forced spill is typically conducted by opening one or more spill gates. At each of the mainstem PUD projects, some or all spill gates have dedicated automatic hoists in order to accommodate sudden storm or flood events in accordance with FERC requirements. The remaining spill gates are opened and closed using gantry cranes that serve more than one spill gate and perform other maintenance duties. It is generally preferred to conduct spill through hoist-equipped gates, so that the gantry cranes remain available for other uses.





This drawing is part of the Application
for an Amendment to License for Project No. 943
made by the undersigned
this 24 day of January, 1973
Public Utility District No. 1
Chelan County, Washington
Stone & Webster Engineering Corporation
Engineers
per
Vice-President

POWER LOAD CURVES
CHELAN COUNTY P.U.D.
DISTRIBUTION SYSTEM
ROCK ISLAND HYDROELECTRIC PROJECT
COLUMBIA RIVER, WASHINGTON
PUBLIC UTILITY DISTRICT NO. 1
CHELAN COUNTY, WASHINGTON
STONE & WEBSTER ENGINEERING CORPORATION
ENGINEERS

Figure 2-18 Typical power demand of the mainstem mid-Columbia PUD projects (Source: CCPUD 1973).
power.ov3

Ice and floating debris that accumulates in the forebay is usually removed by picking with a crane, but in extreme circumstances may be removed by passing it through sluice gates located at the reservoir surface level. Since the sluice gates at these projects are much smaller than the spill gates, they may also be used during forced spill events when the discharge volumes are small. In summary, the power generating aspects of the mainstem mid-Columbia dams are very dynamic in nature. Instantaneous conditions for any particular parameter may be very different than the average daily conditions.

2.4.1.3. Project Operations. The main factor governing total plant discharges at Rock Island dam is upstream releases. The active storage capability of the Rock Island reservoir is too limited to reregulate inflow through reservoir operations. The water surface at the forebay of the Rock Island dam is designed for a normal operating range of 4.0 feet, between elevations 13.0 feet and 09.0 feet. Discharges at upstream projects are normally adjusted to match the shape of the power demand, taking into account discharge and spill requirements for other purposes such as fish passage, flood control and recreation. At Rock Island, inflow can be more than twice as high during the day than at night. Consequently, there is a high likelihood that several of the 18 turbines will go through one or more on-off cycles during a typical 24-hour period. Powerhouse 2 is prioritized for operation over powerhouse 1 during normal project operation. However, powerhouse 1 may be used when inflow exceeds the hydraulic capacity of powerhouse 2.

Rock Island dam has a total turbine discharge capacity of 220,000 cfs. On occasions when river flows at Rock Island exceed the turbine discharge capacity plus any additional nonpower needs for discharge, it becomes necessary to conduct forebay regulation spill. Also, in accordance with the 1987 Rock Island Settlement Agreement, spill is used to enhance juvenile fish passage. Spill noted in the 1991 flow conditions shown in Table 2-8 is evidence of these juvenile fish passage operations.

2.4.2. Adult Fish Passage Operations. The three Rock Island dam fishways are operated all year, except during the annual maintenance period, following criteria similar to those used at federal dams on the lower Columbia and Snake Rivers. The period from April through November is the primary passage period for adults. Specific criteria are followed to maintain the fishways in their most effective condition. Between December and February, when adult migration activities are minimal, the fishways are alternately taken out of service for annual inspection and routine maintenance. At least one fishway is maintained in operation during the winter maintenance period.

All three fishways are equipped with counting stations for monitoring adult passage at Rock Island dam. The station is operated from 15 April to 15 November each year, with video tape recordings used to count adult chinook, steelhead and sockeye passage. All other species of fish passing through the fishways are also counted.

Table 2-8. Rock Island dam powerhouse operations expressed in kcfs and percent streamflow, 1 April through 31 August 1991 (monthly ranges appear in parenthesis).

	Average kcfs				
	April	**May**	**June**	**July**	**August**
Total river flow	168.8 (145.7-184.8)	178.0 (114.5-220.2)	181.2 (121.4-206.8)	156.0 (112.7-201.3)	140.4 (106.1-173.5)
Powerhouse 1	50.0 (15.2-70.7)	29.9 (1.7-45.8)	54.6 (17.3-70.1)	44.1 (18.5-68.6)	36.4 (11.8-55.2)
Powerhouse 2	104.6 (90.5-114.3)	103.6 (75.9-114.9)	108.6 (88.9-120.3)	101.2 (83.6-115.1)	99.9 (89.3-115.9)
Spill	13.0 (0.0-41.9)	43.2 (26.5-61.1)	16.6 (4.0-55.8)	9.2 (3.9-47.6)	3.0 (0.0-10.6)
	Average percent of total flow				
Powerhouse 1	29.7 (9.6-39.8)	16.0 (1.5-22.5)	29.3 (14.3-37.9)	27.2 (15.7-38.4)	25.1 (10.8-34.9)
Powerhouse 2	62.2 (54.2-73.2)	59.0 (51.3-75.5)	60.8 (50.8-81.5)	66.1 (51.5-79.8)	72.1 (60.7-88.2)
Spill	7.5 (0.0-24.0)	24.3 (15.4-34.0)	9.2 (2.2-27.41)	5.7 (2.2-23.9)	2.04 (0.0-6.4)

Source: Peven 1991c.
op-kcfs.ri2

The left bank and middle fishways each have two entrance gates that are open at all times, with minimum weir depths specified in the operating criteria (Table 2-9). The right bank fishway has four wing gate entrances which are kept at a minimum opening of 3.0 feet at all times. The right bank fishway also has an attraction jet which discharges adjacent to the RPE entrance. This jet is operated any time the tailwater elevation is at 570 feet and above.

2.4.3. Modified Turbine Operations. The mid-Columbia system survival studies estimated survival through Rock Island reservoir and dam as 87 percent in 1982 and 84 percent in 1983 by assuming equal mortality for each of the three projects encountered between Pateros and the Rock Island tailrace (McKenzie et al. 1984a, 1984b). There were no estimates of the portions that were associated with direct and indirect turbine mortality, reservoir effects, or other factors involved with project passage. A study on the Rock Island bulb turbines indicated a turbine mortality rate of 3.9 percent for steelhead and 5.7 percent for coho (Anderson 1984), which included indirect mortality. Studies in 1997 with yearling chinook salmon found direct turbine passage mortality rates of 3.9% for

Table 2-9. Operating criteria for Rock Island dam fishways.

Water depth over ladder weirs	1.0 - 1.2 ft
Head on fishway entrances[1]	1.0 - 1.5 ft
Transportation channel flow velocity[2]	1.0 - 4.0 fps (2.0 fps preferred)
Maximum trashrack water surface differential	0.3 ft
Staff gage locations	Upstream and downstream of entrances
Left Powerhouse Entrance	
Entrance gates	LPE-1 and LPE-2 open at all times
Weir depth below tailwater	6 ft or greater
Center Ladder Entrances	
Entrance gates	CLAD-D and CLAD-S open at all times
Weir depth below tailwater	8.5 ft or greater (CLAD-D only)
Right Powerhouse / Right Bank Entrances	
Entrance gates	All four wing gates open at all times
Minimum wing gate opening	3.0 ft
Attraction jet near RPE2	On whenever tailwater elevation at 570 ft and above
Traveling screens at auxiliary water intake	At least one on whenever attraction jet is on
Jet using pumps	One screen on
Jet using gravity flow	Both screens on

1 Head is indicated by the staff gage reading immediately above the entrance minus the staff gage reading from the tailwater.

2 Specified flow velocity shall be maintained in all fish transportation channels and the lower ends of the fish ladders.

Source: CCPUD 1994b.

summ-op.ri2

the vertical kaplan units, 4.3% for bulb units and 68% for the higher turbines. (Normandeau and Skulski, 1997).

2.4.4. Existing Juvenile Bypass Channel. The results of bypass channel evaluations indicated that juvenile fish pass through the system with very little descaling or injury. However, the system is not very effective in passing large numbers of juveniles. The average bypass efficiency is estimated at 5.5 to 15.2 percent for all species passing powerhouse 2 (Olson 1982, 1983).

2.4.5. Prototype Juvenile Bypass Systems. Prototype diversion systems tested at powerhouse 2 during 1988 showed FGEs much lower than 50 percent. Velocities in front of powerhouse 2 are too strong to allow effective implementation of a screened system (Elder and Weitkamp 1990).

The prototype diversion system at powerhouse 1 achieved an overall FGE of 76 percent (McDonald, 1995). However, rather than call for a full-scale installation of this design, the fisheries agencies and tribes have decided to invoke the Conservation Account specified in the 1987 Rock Island Settlement Agreement, and have purchased spill for the 1998 juvenile fish migrations.

When daytime spill operations are required at the dam during the adult migration period, the Chelan PUD attempts to direct spill to those areas that have the least impact on fishway attraction and utilization, while still maintaining essential water control functions of dam operations. Generally, the adult passage spill schedule prioritizes spill to the shallow gates on the right spillway, narrowing this group to those gates which have adjustable gate openings. During those periods when both adult and juvenile passage criteria are in effect, the juvenile criteria have precedence.

2.4.6. Juvenile Fish Passage Operations. Current operations for juvenile anadromous salmonid passage at Rock Island dam are specified in the 1987 Rock Island Settlement Agreement and involve a spill program encompassing major portions of the spring and summer migration periods. Until 1996, required spill during the spring migration period was 50 percent of the daily average flow that would otherwise pass through powerhouse 1 and 10 percent of the daily average flow that would otherwise pass through powerhouse 2. The summer spill program entailed the release of 500,000 acre-feet of water. Beginning in 1996, the fisheries agencies and tribes invoked the conservation account, which allows them to use spill at their discretion until power losses reach $2,850,000. Details for juvenile passage spill are developed in an Annual Spill Plan prepared each year by 1 March in a joint effort by the Chelan PUD and the fishery agencies and tribes.

Duration criteria for the spring spill period are provided for at least 80 percent of the spring migrants passing Rock Island dam. Spill typically starts after an estimated 10 percent of spring migrants have passed the dam and ends when 90 percent have passed. In recent years, starting dates for the spring spill program at Rock Island dam have ranged between April 17 and April 24. The 80 percent passage criterion has resulted in a spill duration of about 30 days (FERC 1987).

The summer spill program extends for 60 days. The program typically begins in mid-June when small summer migrants are first observed passing the dam and terminates in mid-August. At least 80 percent of the 500,000 acre-feet of water allocated for summer spill must be released during June and July (FERC 1987).

Spill during both spring and summer periods is conducted using shallow spill gates on the right spillway. These shall spill gates are preferred over deep spill gates, based on results of a hydroacoustic study that indicated greater fish passage effectiveness when using only shallow gates (Raemhild et al. 1985). Experimental modified gates providing surface spill were used in 1996 in addition to the shallow gates.

During 1991, the spill programs resulted in average monthly spill ranging from 43.2 kcfs in May to 3.0 kcfs in August. When expressed as a percentage of the total river flow, the average monthly spill ranged from 2.0 percent to 24.3 percent (Peven 1991b). These values, along with the range of daily average flows, are presented in Table 2-8.

Information relating to downstream migrants at Rock Island dam is collected every year using the juvenile monitoring facility integrated into the juvenile bypass channel at powerhouse 2. This facility has been operated by the Chelan PUD since 1985. Juvenile passage data are reported to the FPC by the Chelan PUD personnel.

2.4.7. Spill Management For Dissolved Gas Control. The Chelan PUD participates in a basin-wide dissolved gas control program, which at times requires spill transfers to manage dissolved gas levels in the Columbia and Snake Rivers. Spill management requests are placed by the Fish Passage Center (FPC) and are based in part on dissolved gas monitoring data and the observed condition of migrant juveniles and adults, along with juvenile migration monitoring data. Total dissolved gas (TDG) monitoring by the Chelan PUD at the Rocky Reach forebay and tailrace has been reported hourly from April through the end of August. Related data reported at the same time include spill volume, total project flow , temperature and barometric pressures. Data are sent hourly to the U. S. Army Corp of Engineers Reservoir Control Center via the Columbia River Operational Hydromet Management System (CROHMS) network.

2.4.8. Fish Production Facility Operations. The Eastbank hatchery and its five satellite facilities were designed and constructed by the Chelan PUD to meet the production requirements specified in the 1987 Rock Island Settlement Agreement (FERC 1987). The Chelan PUD has entered into a formal arrangement with the WDFW to have that agency operate the facilities. The WDFW is responsible for the day-to-day hatchery activities and for assuring that the production programs are operated in a manner consistent with the policies and guidelines of the state. It is the responsibility of the Chelan PUD to provide facilities with sufficient production capacity, as well as adequate operation and maintenance funding, to meet the objectives of the mitigation agreements.

The 1994 production goals for the Rock Island hatchery complex are noted in Table 2-10. From these goals, it can be seen that the Eastbank hatchery serves as a central incubation and rearing hub for the five satellite facilities. Eastbank hatchery operates year-round with activities that include adult holding, spawning, incubation and rearing of summer steelhead and stream-type and ocean-type chinook salmon. Sockeye salmon are also incubated at the facility. All salmon reared at Eastbank hatchery are transferred to satellite facilities for final rearing and release. Summer steelhead raised at Eastbank hatchery are transported and released at various sites on the Wenatchee and Entiat Rivers.

The Chiwawa River satellite serves as a juvenile release site and an adult trapping site for spring (stream-type) chinook. Carlton, Dryden and Similkameen ponds serve as acclimation and release sites for juvenile ocean-type chinook. The Lake Wenatchee net-pens consist of eight pens where juvenile sockeye are reared and released, and where adult sockeye are held and spawned (Peck 1993a).

Fish released from the Rock Island hatchery complex share portions of the migration corridor used by Snake River species listed under the ESA. As facility operator, WDFW has obtained a five-year Section 10 permit under the ESA for all of its non-federally funded hatcheries in the Columbia Basin, including the Rock Island hatchery complex. The permit describes efforts made by the agency to avoid and minimize impacts to listed species. These efforts include protocols for adult collection and spawning, rearing and release strategies, fish health management programs and environmental monitoring.

3. **Salmon Protection Issues General to Mid-Columbia River Hydroelectric Projects**. The discussion in this section focuses almost exclusively on mid-Columbia River anadromous salmonids. Where relevant and when information is available, references will be made to bull trout, Pacific lamprey or other aquatic species not covered by this plan.

3.1. Upstream Migration. Prior to dam construction, upstream migrating fish encountered rapids, chutes and falls which were common in the mid-Columbia reach. The mainstem mid-Columbia PUD projects replaced the numerous natural gradient breaks with larger gradient breaks (i.e., the dams), interspersed with large pools (i.e., reservoirs). In order to pass fish over the dams, fishways were built at all five dams. Although salmon, steelhead and lamprey successfully pass upstream over projects, the PUDs continue to modify adult passage facilities to improve upstream passage conditions.

3.1.1. Dam Passage. Sources of delay in upstream migration may include extended passage time at fishway entrances, collection systems and ladders. Fallback, or the downstream movement of upstream migrants, is another potential source of delay or injury. Assessment of the magnitude and effects of migratory delay at fishway facilities is complicated by the lack of information on the time required for adult anadromous fish to migrate through the

Table 2-10. Fish production goals for 1994 for Rock Island dam mitigation hatcheries.

	Stock	Number	Number per pound	Age group	Length (mm)	Release location	Release month
Eastbank Hatchery							
Summer steelhead	Wells	200,000	6	1+	195	Entiat R., Wenatchee R.	Apr
Sockeye	Wenatchee	275,000	85-100	0+	20	Transfer: L. Wen. NP	Apr
• Chiwawa Acclimation Pond							
Spring (stream-type) chinook	Chiwawa	672,000	10-15	1+	160	On station	Apr-May
• Carlton Acclimation Pond							
Summer (ocean-type) chinook	Wells	400,000	10-15	1+	160	On station	Apr-May
• Dryden Acclimation Pond							
Summer (ocean-type) chinook	Wenatchee	864,000	10-15	1+	160	On station	Apr-May
• Similkameen Acclimation Pond							
Summer (ocean-type) chinook	Wells	576,000	10-15	1+	160	On station	Apr-May
• Lake Wenatchee Net-Pens							
Sockeye	Wenatchee	200,000	20	1+	110	On station	Oct

Source: FishPro, Inc. 1995.
progoals.ri2

unimpounded, natural reaches of the mid-Columbia. In addition, there are other environmental factors that influence migration in the mid-Columbia including hydrology, water temperature (in mainstem and tributaries), dissolved gas supersaturation (Dauble and Mueller 1993) and turbidity. Project operations such as turbine and spill schedules may also directly affect passage at these mainstem dams.

Fallback may be defined as the involuntary or voluntary downstream movement of upstream migrants. Involuntary fallback occurs when upstream migrants are forced back downstream of the dam structure. Voluntary fallback refers to the phenomenon of hatchery or tributary "overshoot," when migrants actively move back downstream in search of natal tributaries or hatchery volunteer traps. Involuntary fallbacks may eventually spawn at some location downstream of the dam, or enter the hatcheries along with "overshoots" or otherwise voluntary fallbacks. Therefore, it is extremely difficult to distinguish between voluntary and involuntary fallbacks.

There is ample evidence that, depending on the incidence of fallback, passage by adult anadromous salmonids is rapid once migrants enter the ladder portion of the fishways. Delay is more closely associated with attempts to locate entrances and negotiate transportation channels, trifurcation/bifurcation chambers, trapping facilities and counting stations (Stuehrenberg et al. 1995). Therefore, migratory delay of adults at mid-Columbia fishways is generally attributable to the amount of time required to locate entrances and to locate and enter the ladder portions of the fishways.

The impacts of delay vary by species, by race/deme, and according to hydrologic and water quality conditions. Species such as spring (stream-type) chinook, summer (ocean-type) chinook and steelhead that hold in the river for considerable periods prior to spawning are less likely to be negatively affected by slight to moderate delays at fishways. Late migrating species such as fall (ocean-type) chinook and sockeye have a much shorter migratory "window" and may be more susceptible to the effects of delayed migration on pre-spawning mortality or spawning success.

Pre-spawning mortality has been defined as all adult deaths after the point of measured escapement but prior to the completion of egg deposition in a finished redd (Chapman et al. 1991). Much of the variability in mid-Columbia mortality estimates is due to inconsistent factors and approaches being incorporated into adult mortality estimates. Fish, particularly fall chinook, that are counted as inter-dam losses or pre-spawning mortality may actually be spawning in tributary reaches outside the study areas or in mainstem areas of reservoirs where substrate and flow conditions are adequate. Some fish may also be counted as inter-dam losses due to tag losses. Variability in pre-spawning mortality estimates may also be attributed to discrepancies in dam counts when fish fall back over the dams and then are counted more than once as they attempt passage for a second or third time.

Two recently completed radio-telemetry studies were designed to supplement available information on the behavioral and life history variability of passage of adult migrants in the mid-Columbia system. These studies were conducted on chinook salmon (Stuehrenberg et al. 1995) and sockeye salmon (Swan et al. 1994). The chinook study addressed passage times and fallback for spring, summer and fall chinook throughout the mid-Columbia (Table 3-1 & 3-2). The sockeye study addressed migration upstream of Rocky Reach dam and past Wells dam. The sockeye study (Swan et al. 1994) focused on the passage times required to negotiate the Wells project fishway facilities, rates of fallback and the fates of tagged fish. Swan et al. (1994) also examined the distribution of passage times for the population of tagged sockeye allowing for determination of relative delay for various portions of the population. They also attempted to link fallback data with the incidence of spill at Wells dam.

Based on the median time required to locate entrances and negotiate collection systems at the five mid-Columbia dams, Stuehrenberg et al. (1995) stated that fishway entrance efficiency would be enhanced by reducing the number of entrances at each dam to only those openings in close proximity to the bases of the ladders. They also recommended that diffuser flows in collection systems be moved upstream in the fishways to provide less turbulant flow between the entrances and the ladders. Moving diffuser flows closer to the base of the ladders may reduce confusion in the collection systems, thus providing better attraction to the ladders.

The incidence and rates of fallback for chinook salmon during the 1993 radio-telemetry study is a useful example of the complicated migrational behavior of mid-Columbia anadromous stocks, and the difficulties associated with an analysis of the impact of dams and fishways on pre-spawning mortality and reproductive success. Spring chinook passing Rocky Reach dam provided the only instance where no fallback occurred during the entire study (Table 3-3). At the other dams, spring chinook experienced fallback at rates from 2.5 percent at the Wells dam, to 17.7 percent at Priest Rapids dam. For summer chinook, the rates of fallback ranged from 1.0 percent at Wanapum dam, to 14.3 percent at Wells dam; the rates for fall chinook ranged from 5.2 percent at the Wanapum dam, to 21.2 percent at Wells dam.

The average rate of fallback of chinook salmon over the five mid-Columbia dams varied considerably by race/deme. The summer chinook showed the lowest rate of fallback with a mid-Columbia-wide average of only 3.3 percent (Table 3-2). The fall chinook experienced the highest rate of fallback at 12.3 percent, and the spring chinook were intermediate with an average fallback rate of 7.9 percent. The highest rates of fallback were generally associated with dams that were immediately or a relatively short distance upstream from a hatchery release point or a natal tributary, indicating a high potential for overshoot and voluntary fallback. This observation is valid for the high fallback rate for fall chinook at Wells dam, which is upstream of various juvenile release sites and tributaries/mainstem habitats that support fall chinook spawning. The same observation holds true for summer chinook at Wells dam and for spring chinook at Priest Rapids dam. In addition, it is entirely possible that many of the fallbacks observed at Priest Rapids are attributable to overshoots from the Yakima or Snake Rivers (i.e., fish that are voluntarily returning downstream in search of natal streams).

Table 3-1. Comparison of median passage time (hours) for radio-tagged adult chinook salmon passing five mid-Columbia dams, 1993.

			PROJECT		
Spring (stream-type) chinook	**Wells**	**Rocky Reach**	**Rock Island**	**Wanapum**	**Priest Rapids**
Tailrace to arrival	1.4	0.7	0.9	1.5	1.4
Arrival to first fishway entry	0.9	1.4	0.9	8.9	14.4
First fishway entry to ladder entry	26.8	25.6	10.7	2.0	8.9
Passage through ladders:					
Right					
Left	2.2	3.3	0.5	4.2	2.0
Center	2.1		2.6	2.8	3.1
Total dam Passage			3.1		
Range of Total dam Passage	28.5	36.6	20.3	36.6	44.9
	2.9-1396	2.0-1108	1.2-779	2.0-1108	2.6-2084
Summer (ocean-type) chinook					
Tailrace to arrival	1.8	0.9	0.8	0.9	0.7
Arrival to first fishway entry	0.4	1.4	0.5	1.9	1.0
First fishway entry to ladder entry	33.3	10.4	8.0	20.2	25.5
Passage through ladders:					
Right					
Left	2.6	2.8	1.8	2.3	2.3
Center	2.7		2.5	2.7	2.9
Total dam Passage			1.4		
Range of Total dam Passage	46.9	22.9	14.6	22.9	29.4
	2.0-1108	2.4-682	1.2-1768	2.4-682	2.4-682
Fall (ocean-type) chinook					
Tailrace to arrival	2.4	2.4	<2.4	2.4	n/a
Arrival to first fishway entry	<2.4	4.8	<2.4	<2.4	n/a
First fishway entry to ladder entry	31.2	38.4	14.4	24.0	n/a
Passage through ladders:					
Right					
Left	2.4	4.8	4.8	4.8	n/a
Center	2.4		2.4	2.4	n/a
Total dam Passage			2.4		
Range of Total dam Passage	45.6	60.0	19.2	40.7	n/a
	4.8-828	2.4-609	2.4-1366	2.4-689	n/a

Source: Stuehrenberg et al. 1995

chinook2.ov4

Stuehrenberg et al. (1995) recognize that the high rates of fallback at some mid-Columbia dams are a major deficiency for the determination of "realistic and accurate passage survival and escapement estimates," and that, "until such adjustments are made, estimates at individual dams will remain significantly biased upward." Existing estimates of adult mortality that occur during upstream passage past dams and through reservoirs include Basham (1990) at 1 to 5 percent per dam, and Chapman et al. (1994a, 1994b, 1995a) who estimate mortality at 5 percent for summer/fall chinook, 2 to 6 percent for spring chinook and 4 percent for steelhead per dam, respectively. Dauble and Mueller (1993) conclude that there is little evidence that upstream passage contributes to measurable direct mortality of chinook and sockeye salmon in the Snake and lower Columbia Rivers.

3.1.2. Reservoir Passage. Once adult fish migrate upstream past a dam successfully, they must swim through a reach of river that has changed substantially from free-flowing conditions. Reservoir induced changes, such as reduced water velocity and increased holding area, may benefit migrating adults by decreasing travel times and adult energy consumption. Reservoir impoundments can also potentially result in increased wandering or straying (lost orientation) which could lead to higher pre-spawning mortality or reduced spawning success.

Decreased water velocity in reservoirs does not appear to slow upstream migration of adult salmon and steelhead. Prior to dam construction, chinook salmon migrated upstream in the Snake River at rates of 12 to 14 miles per day (Bjornn and Peery 1992). Steelhead migrated upstream in the unimpounded lower Columbia River at rates of 7 to 11 miles per day (Chapman et al. 1994b), and sockeye migrated at rates of 17 miles per day (Bjornn and Peery 1992) (Table 3-3).

Similar results to those of Stuehrenberg et al. (1995), discussed previously, were obtained by Bjornn et al. (1995) in a companion study conducted on the four lower Snake River projects. Of the 1,171 adult spring chinook salmon and 844 adult summer steelhead tagged at John Day dam for both studies, 339 spring chinook and 322 steelhead ascended Ice Harbor dam, the lowermost dam on the Snake River. The estimated mortality of adults from below Ice Harbor dam to the head of Lower Granite pool was 10 percent for chinook and 75 percent for steelhead in July and August, and 59 percent for steelhead in the fall (this includes unknown angler harvest and overwintering of adults in the four pools). Migration rates through the four pools ranged from 19 to 40 miles per day for spring chinook, and about 19 miles per day for steelhead (Table 3-3). These compared to migration rates in the free-flowing river reaches above Lower Granite pool of 6 to 19 miles per day for spring chinook, and less than 7 miles per day for steelhead (Table 3-3) (Bjornn et al. 1995b).

Estimates of pre-spawning mortality have been used to assess past and present salmon and steelhead numbers, and to monitor the effectiveness of mitigation procedures. Estimates of pre-spawning mortalities have been made based on comparing adult dam counts with estimates of spawning numbers in tributaries. Such inferences are inherently poor due to compounding errors

Table 3-2. Incidence and rates of fallback for chinook salmon at five mid-Columbia dams, 1993.

Location	Number of Fish Passing	Number of Fallbacks (%)	Hatchery or Major Tributary Downstream
Spring (stream-type) chinook			
Priest Rapids	197	35 (17.7)	X
Wanapum	211	17 (8.1)	
Rock Island	197	5 (2.5)	X
Rocky Reach	89	0 (0.0)	X
Wells	56	2 (3.6)	X
Total	750	59 (7.9)	
Summer (ocean-type) chinook			
Priest Rapids	261	4 (1.5)	X
Wanapum	209	2 (1.0)	
Rock Island	247	7 (2.8)	
Rocky Reach	128	5 (3.9)	X
Wells	98	14 (14.3)	X
Total	943	32 (3.3)	
Fall (ocean-type) chinook			
Priest Rapids	123	18 (14.6)	X
Wanapum	58	3 (5.2)	
Rock Island	53	7 (13.2)	X
Rocky Reach	194	22 (11.3)	X
Wells	52	11 (21.2)	X
Total	674	83 (12.3)	

Source: Stuehrenberg et al. 1995.

chinook.ov4

associated with adult dam counts, redd counts, fish per redd assumptions, redd life and spawning that may take place in waters too deep to observe or in areas not surveyed. Natural mortality rates in rivers without dams and associated impoundments fluctuate annually in response to natural disturbances and population fluctuations, and therefore are difficult to assess using adult fish counts.

There is little evidence to suggest significant impacts on adult migration and pre-spawning mortality occur in the mid-Columbia River reach reservoir environment. Bjornn and Peery (1992) included information from mid-Columbia and other run-of-river reservoirs in their comprehensive review of the effects of reservoirs on adult salmon. Based on the available information, they concluded that run-of-river reservoirs had minimal effect on migrating adults. Adult salmonids generally pass through these reservoirs at similar or faster rates than they do in the naturally flowing river. There is no evidence of serious disorientation, wandering, straying or mortality associated with reservoir conditions.

Table 3-3. Migration rates through impounded and unimpounded waters of the Columbia and Snake Rivers (miles/day).

Species	**Unimpounded**		**Impounded**	
	Snake River	**Columbia River**	**Snake River**	**Columbia River**
Chinook	6 - 19		19 - 40	15
Steelhead	7	7-11	19	4
Sockeye	11	17		15

Source: Bjornn et al. 1995; Bjornn and Peery 1992; Chapman et al. 1994a, 1994b; Stuehrenberg et al. 1995; Swan et al. 1994.

migrate.ov4

3.2. **Downstream Passage**.

3.2.1. Dam Passage. Dam structures form a physical barrier in the path of fish migrating downstream. Mechanisms that allow fish to pass from the upstream to the downstream side of any dam are:

- passage through a turbine;
- passage over a spillway or through a sluiceway;

- passage through a fish bypass system;
- passage in a downstream direction through ancillary dam facilities, such as the adult fishway facilities; or
- collection of fish on the upstream side of the structure followed by transport and release on the downstream side.

A description of each of these methods of downstream dam passage, as they relate to mainstem PUD dams, is presented in the paragraphs that follow.

3.2.1.1. Turbine Passage.

3.2.1.1.1. General Classifications of Hydroelectric Turbines. Hydroelectric turbines fall into two general classifications. The first type is the impulse turbine, which captures the force of a high-velocity jet of water at atmospheric pressure by directing it into cups at the circumference of a wheel. As a general rule, impulse turbines are not used where fish are a concern, as few fish can survive the violent conditions of the jet impulse; the turbines are also rarely used in dams with low head, such as the mid-Columbia River dams.

The second type of hydroelectric turbine is the reaction turbine, which uses the force of water under pressure to turn the submerged blades of a wheel. Reaction turbines are further divided into two groups: Francis turbines and propeller turbines. The general characteristics of Francis turbines make them best suited to conditions where there is relatively high head and a narrow range of flows. Propeller turbines, on the other hand, are better suited to low head conditions with a broader range of flows. All hydropower projects that accommodate fish passage in the mainstem Columbia and lower Snake Rivers contain propeller turbines.

Within the five PUD dams on the mainstem mid-Columbia, there are three types of propeller turbines. Kaplan turbines are the most common type, most likely because of their adjustable blade feature, which provides high operating efficiencies over a wide range of flows. Bulb turbines are the second type. Like Kaplans, bulb turbines have adjustable blades, but their horizontal configuration results in distinct design differences. The third type of mainstem PUD turbine is the fixed-blade propeller turbine. From a design sense, fixed-blade propeller turbines are nearly identical to Kaplans except that their blades are not adjustable.

3.2.1.1.2. Propeller Turbine Characteristics. Kaplan and fixed blade propeller turbines contain a runner typically consisting of four to six blades attached to a vertical shaft (Figure 3-1). Water entering the turbine intake is directed through a semi-spiral case past stay vanes and wicket gates to the blades of the turbine runner. Stay vanes are immovable structures that support the upper portion of the distributor while also guiding the angle of flow. Wicket gates are adjustable devices, which control the rate of flow past the turbine and alter the angle of flow angle approaching the blades. In bulb turbines, the shafts are mounted horizontally in tubular housings without spiral cases.

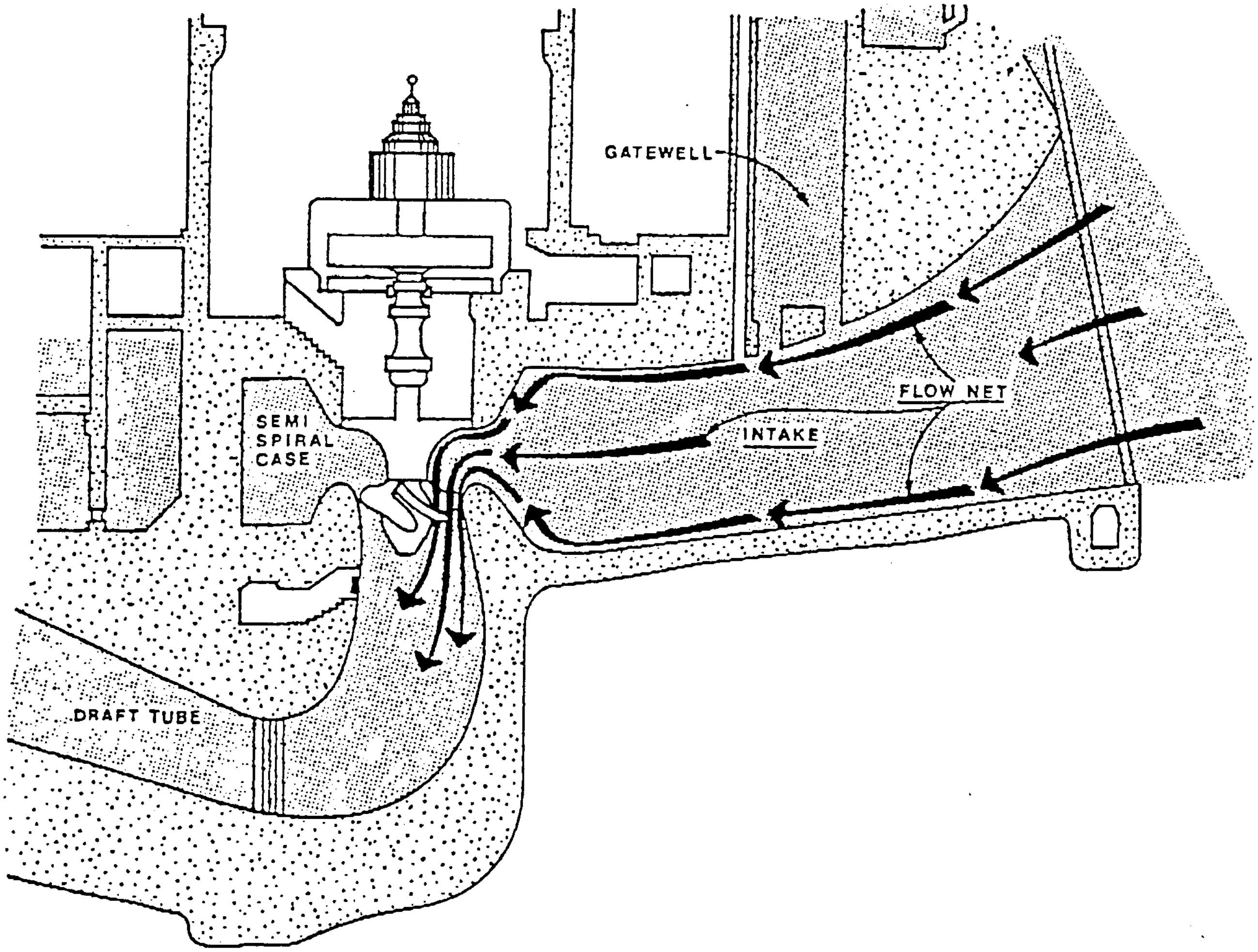


Figure 3-1 Section and flow net through typical large Kaplan turbine unit (Source: Eicher 1987).

kaplan.ov4

A critical element of powerhouse design involves placement of the turbine runner with respect to the headwater and tailwater elevations. Calculations used in this process may refer to plant *sigma* or runner *sigma*, dimensionless parameters used to define the required depth of the turbine centerline in relation to tailwater level. Plant *sigma* reflects barometric pressure at a site as well as the safety margin, while runner sigma is usually numerically smaller. The deeper the relative turbine setting (high *sigma*), the lower the potential for cavitation. Propeller turbines tend to have the runner centerline below tailwater surface elevation, and hence they are less prone to cavitation problems than Francis turbines, which typically have runner centerlines above the tailwater surface elevation (Eicher 1987). Although turbines are designed to operate without cavitation within specified criteria, cavitation does occur in actual operation. Cavitation can result in localized areas within the turbine runner where pressures reach up to 50,000 pounds per square inch. These pressures can cause blade erosion and loss of efficiency, and can be a source of fish injury and mortality (Ferguson 1994).

Turbine draft tubes are located on the discharge side of the turbine runner. In Kaplan and fixed-blade propeller turbines, the draft tubes have an elbow shape that changes the flow direction from vertical to horizontal, and a flared ending to reduce velocity at the exit. Bulb turbines typically have straight but flared draft tubes (Eicher 1987).

3.2.1.1.3. Injury Aspects of Turbine Passage. The causal factors of injury and mortality in turbines have so far been difficult to assess because it has not been possible to directly observe fish passage through turbine units. However, based on visible observation of juvenile test fish, mortality associated with turbine passage has been generally classified as direct or indirect.

Direct mortality occurs within the confines of the turbine. Based on inferential data and knowledge of turbine conditions, it is assumed that direct mortality can originate from mechanical, pressure or hydraulic-related factors. Mortality due to mechanical factors may result from blade strike or when fish are caught between turbine components. Pressure or hydraulic-related direct mortality is assumed to be caused by fish passing through areas of cavitation, hydraulic shear or other areas where pressure or velocity change may cause injury or death.

Indirect mortality occurs after fish, particularly juvenile fish, have left the turbine. It has been generally believed that the principal cause of indirect mortality of juvenile fish is predation by fish or birds. This most likely occurs in the tailrace as the juveniles recover from the disorientation and stress of turbine passage (Ledgerwood et al. 1990). Stress may also create harmful levels of physical or behavioral tension, leading to weakened resistance to disease and subsequent delayed mortality (Ferguson 1994).

A review of turbine mortality (Eicher 1987) notes that some researchers in the late 1950s hypothesized that stress to juvenile fish passing through turbines is probably indiscriminate, with the effects being uniform on all individuals. The review also cites studies that presented evidence suggesting that stress is instead discriminate, impacting only certain individuals.

3.2.1.1.4. Mechanical Injury. Mechanical injury may occur when fish come in contact with solid objects within a turbine system, including the wicket gates, guide vanes, or turbine blades. In fish that have had mechanical contact with turbine parts, damage characteristics include bruises, lacerations, skeletal fractures, or scraped, severed or crushed bodies. Evidence of mechanical injury is generally external.

Mechanical injury caused by blade strike is considered a significant factor in overall turbine passage mortality. Variables that influence the probability and effect of strike include length of fish, turbine speed and discharge, the number of turbine runner blades, and the angle at which fish approach the runner blades (Ferguson 1994). Recent investigations suggest that most mechanical injuries occur in the gaps between the blade and the hub, and between the blade tip and the discharge ring (RMC and Skalski 1994a, 1994b, Normandeau and Skalski, 1996).

3.2.1.1.5. Pressure Effects. Exposure to very low pressure or subatmospheric pressure (also referred to as negative pressure) may cause internal injury or mortality of fish. Cavitation is an extreme case of negative pressure conditions resulting from the implosion of water vapor pockets. It appears that juvenile fish are particularly vulnerable to pressure effects when they have been acclimatized to the high positive pressures found in deep reservoirs, and then are exposed to negative pressures within turbines. Since juvenile fish can generally tolerate high positive pressures, the rate of change in pressure is apparently more significant than the absolute magnitude of the change (Eicher 1987).

The susceptibility to pressure effects is related to differences in species. Fish with open swim bladders, such as salmon, can gulp air at the surface to adjust their buoyancy, while fish with closed swim bladders adjust to different depths by extracting gases and returning them to the water. When brought suddenly to low pressure, fish with open swim bladders are susceptible to swim bladder rupture and embolism, even though they are able to react to reductions in pressure rapidly (Bell 1991).

3.2.1.1.6. Shear Effects. It has been hypothesized that turbine environments may contain boundary planes of water caused by two adjacent high-velocity water flows, that could cause mortality in fish. The severing of juvenile fish that have passed through turbines is often thought to be due to shear effect, but can also be logically attributed to other sources (Eicher 1987). Data indicate that shear damage to fish is most likely to occur at velocities greater than 40 fps (Bell 1991).

Shear may be the most difficult mechanism of mortality to quantify and is also the least understood. Shear may actually be increased by some mitigation efforts such as juvenile fish guidance screens, which affect flow patterns into turbine intakes. The resulting redistribution of flow may increase the amount, incidence and effect shear has on the juveniles that pass through the unit (Ferguson 1994).

3.2.1.1.7. Analysis of Factors Causing Injury. There are varied opinions among investigators as to the paramount cause of injury to juvenile fish passing through turbines. Theoretical analysis alone will not provide the type of information needed to justify future turbine design modification that might enhance juvenile fish passage. What is needed are well-designed and well-executed experiments at existing dams (Bell 1981).

The following quote from Eicher (1987) present an excellent summary of the primary factors causing injury to juvenile migrants passing through large Kaplan turbines. These factors apply as well to the fixed blade propeller and bulb turbines found on the mid-Columbia projects.

> The only plausible manner in which to deal with assignment of injury is through analysis of factors for each turbine type in prototype studies. . . . In examination of 19 Kaplan turbine studies involving working units, no relationship of mortality to head could be found. In the 15 prototype units studied, only two explore the relationship between tailwater and mortality. . . . [Because only two sizes were used in studies,] no relationship can be shown for size of fish. No relationship between mortality and peripheral runner speed can be developed in the 12 Kaplan studies appropriate for this. Although individual studies show changes in mortality levels when efficiencies are manipulated, the total of six studies providing these data is too small for meaningful correlations. . . . Although mortality can be linked to efficiency of Kaplan turbines, the efficiency and mortality curves are both so gradual and flat that discrete peaks are not apparent, making the relationship vague. No effect of pressure is indicated by juvenile mortality comparisons with head and runner/tailwater levels except for individual unit manipulations.
>
> The above virtually exhausts the list of recognized injury sources for Kaplan units, yet mortality does occur, leaving only mechanical injury and that resulting from such things as subatmospheric pressure including cavitation, and water shear. In spite of the confidence assumed by many researchers that certain injury can be assigned to water shear, it has yet to be demonstrated where and how this phenomenon occurs or that injuries assigned to it are not actually caused by other sources. As mentioned previously, few injury types can be exclusively or positively attributed to but one cause. The most plausible type of mechanical injury in Kaplan units is that occurring at the blade ends where a gap usually exists of a size and shape to draw fish into it to be ground between the blade and containment ring. It could quite logically account for the amount of mortality found in most Kaplans. No other logical source of mechanical injury is

> apparent in Kaplan turbines. It does not appear possible that many mortalities could occur to fish approaching or intersecting the blades of this runner type. . . . The majority of fish probably contact the blades near the hub where the least damage potential exists. In a 24-foot diameter runner turning 75 rpm, the blade, at a point close to the hub, is moving only about 15 feet per second, hardly enough velocity to damage fish with the smooth rounded surface typical of the leading edge of this type of blade. If the exact routes taken by fish in passing over turbine blades could be discovered, a positive step would be made in correcting mortality in this type of turbine. Cavitation unquestionably occurs under some conditions in Kaplan units but does not appear to be severe under design operating conditions.

3.2.1.1.8. Effects of Turbine Operating Efficiency. In the mid-1960s, while measuring turbine mortality for the Kaplan turbines at Big Cliff dam on the North Santiam River, Oregon, Oligher and Donaldson found that survival generally increased with unit efficiency (Ferguson 1994). Noting similar trends in other studies for Kaplan and Francis turbines, Bell (1981) speculated that fish survival is probably best at peak turbine efficiency, when conditions within the turbine are generally the smoothest possible and the least likely to have cavitation events that might impact fish passage. However, an analysis by Eicher (1987) noted that the data set is too small to draw any direct or statistically significant relationship between turbine operating efficiency and mortality (see quote above).

The Fish Passage Plan (FPP) for the federal projects on the lower Columbia and Snake Rivers recommends the operation of turbines within one percent of peak efficiency to enhance juvenile fish passage survival (USACE 1995b). The one percent guidelines were recommended by turbine manufacturers, who theorized that turbine flow conditions within this range would be equal to peak turbine flow conditions due to the broad efficiency curves for Kaplan turbines (Bell, pers. com., 7 April 1995). The precise benefits to fish survival of operating within this range of turbine efficiencies are unknown (NMFS 1995a).

During a turbine passage survival workshop sponsored by the USACE from 31 May to 1 June 1995, experts debated whether or not juvenile fish passage is necessarily best at peak turbine efficiency. At turbine settings beyond the peak, in which the gates are full open and there is a higher blade angle, the flow passages are less constricted; there is also a lower probability of fish coming into contact with the structural boundaries (Sheldon, letter to John W. Ferguson, 19 June 1995). Research plans are currently under development to determine whether or not the causes of juvenile turbine mortality can be isolated, measured, and mitigated through advanced turbine design. These research efforts will include investigations involving the relationship between turbine efficiency and juvenile fish passage survival (USACE 1994).

Table 3-4. Summary data from juvenile fish turbine mortality studies (page 1 of 4).

			Turbine Characteristics						Test Results						
Site	**Original Reference**	**Citation (see Notes)**	**Head (ft)**	**Turbine Diameter (in)**	**RPM**	**Peripheral Velocity (fps)**	**Turbine Operator**	**Species**	**Fish Size (mm)**			**Mortality (%)**			**Visible Injury (%)**
									Min	**Max**	**Median**	**Low**	**High**	**Ave.**	
Kaplan turbines															
Salmonid species															
Big Cliff	Oligher, Donaldson 1965	2	98	148	164	52.8		Spr. chinook			100	4.5	22.0		
Big Cliff	Oligher, Donaldson 1965	2	98	148	163	52.8		Spr. chinook			100	5.5	10.3		
Bonneville	Holmes 1952	2	40-60	300	75			Fall chinook	80	120		11.0	15.0		
Bonneville	Weber 1954	2	64		75			Chinook						3.9	
Bonneville	Ledgerwood et al.1990	3	60	330	69.2	99.6	Peak Eff.	Chinook	83.4	99.4	91	2.0	3.0	2.5	
Foster	Bell and Bruya 1981	2	101	100	257	112		Chinook						11.2	
Foster	Wagner and Ingram 1973	2	101	100	257	112		Chinook						6.1	
Hadley Falls	Steir and Kynard 1986	3	51	172	128	95.8	76-80%	Atl. salmon	190	280	235	11.8	13.7	12.8	
Hadley Falls	Kynard et al. 1982	2	51	170	129			Atl. salmon						4.9	
Hadley Falls	Stier 1983	2	51	170	129			Atl. salmon				12.8	13.1		
Little Goose	Iwamoto et al. 1994	1	98				135MW	Chinook						8.0	
Lower Granite	Iwamoto et al. 1994	1	99				135 MW	Chinook						17.7	
McNary	Schoeneman et al. 1961	2	85	280	87.5			Chinook						11.0	
Rocky Reach	RMC and Skalsi (1994)	1			-- information being compiled --										
Sullivan	Massey 1967	2	41		240			Steelhead				7.7	9.9	8.8	

Table 3-4. Summary data from juvenile fish turbine mortality studies (page 2 of 4).

			Turbine Characteristics					Test Results							
Site	Original Reference	Citation (see Notes)	Head (ft)	Turbine Diameter (in)	RPM	Peripheral Velocity (fps)	Turbine Operation	Species	Fish Size (mm)			Mortality (%)			Visible Injury (%)
									Min	Max	Median	Low	High	Ave.	
Salmonid species - Continued															
Sullivan	Massey 1967	2	41	240				Chinook				10.5	11.8	11.2	
Tusket	Smith 1969	2	27		225			Atl. salmon						16.5	
Wells	Weitkamp et al. 1985	2	65					Steelhead						16.0	
Non-salmonid species															
Allis Chalmers	Cramer, Oligher 1960	2	5-45	12	1400			Largem. bass	38	61		4.0	94.0		
Conowingo	RMC 1990b	3	90	ng	ng		Variable	Amer. shad			515	16.7	50.0	10.7	
Craggy	RMC 1990c	3	22	69	229	68.8	13 Degrees	Bluegill	76	119	98			6.0	
Craggy	RMC 1990c	3	22	69	229	68.8	13 Degrees	Bluegill	122	221	172			14.0	
Craggy	RMC 1990c	3	22	69	229	68.8	28 Degrees	Channel cat.	119	221	170			7.0	
Craggy	RMC 1990c	3	22	69	229	68.8	28 Degrees	Channel cat.	224	330	277			7.0	
Craggy	RMC 1990c	3	22	69	229	68.8	13 Degrees	Channel cat.	119	221	170			10.0	
Craggy	RMC 1990c	3	22	69	229	68.8	13 Degrees	Channel cat.	224	330	277			21.0	
Crescent	RMC 1992b	3	27	108	144	67.9	Peak Eff.	Blueback h.	60	90	75		4.0	4.0	
Hadley Falls	RMC 1992b	3	51	172	128	95.8	35%, #1	Amer. shad	55	110	83			0.0	
Hadley Falls	RMC 1992b	3	51	172	128	95.8	100%, #1	Amer. shad	55	110	83			2.7	
Hadley Falls	RMC 1992b	3	51	172	150	112.3	100%, #2	Amer. shad	55	110	83			10.9	

Table 3-4. Summary data from juvenile fish turbine mortality studies (page 3 of 4).

Site	Original Reference	Summary Table Citation	Turbine Characteristics: Head (ft)	Turbine Diameter (in)	RPM	Peripheral Velocity (fps)	Turbine Operation	Test Results: Species	Fish Size (mm) Min	Fish Size (mm) Max	Fish Size (mm) Median	Mortality (%) Low	Mortality (%) High	Mortality (%) Ave.	Visible Injury (%)
Hadley Falls	Bell and Kynard 1985	3	51	172	128	95.8	Peak Eff.	Amer. shad	430	600	515			21.5	
Hadley Falls	Bell 1982	2	51	170	129			Amer. shad				0.0	17.0		
Hadley Falls	Kynard et al. 1982	2	51	170	129			Amer. shad							
Hadley Falls	Kynard et al. 1982	2	51	170	129			Blueback h.				63.0	83.0		
Hadley Falls	Taylor 1983	2	51	170	129		5.5	Clupeids	60	90				82.0	
Hadley Falls	Taylor 1983	2	51	170	129		12	Clupeids	60	90				82.0	
Hadley Falls	Taylor 1983	2	51	170	129		16.5	Clupeids	60	90				62.0	
Kleber	Johnston, Ransom 1991	3	44	ng	450		50-100%	Resident	100	199	150				20
Kleber	Johnston, Ransom 1991	3	44	ng	450		50-100%	Resident	200	299	250				55
Kleber	Johnston, Ransom 1991	3	44	ng	450		50-100%	Resident	300	600	450				57
Kleber	Johnston, Ransom 1991	3	44	ng	450		50-100%	Resident	116	467	292			43.0	
Marshall	CP&L 1988	3	31.4	149.4	212	138.2	Variable	Resident	80	440	260			17.3	8
Marshall	CP&L 1988	3	31.4	149.4	212	138.2	Variable	Bluegill			ng			5.4	
Safe Harbor	RMC 1991a	3	55	220	109	104.7	Peak Eff.	Amer. shad	95	140	118			2.0	
Tusket	Smith 1961	2	27		225			Gaspereau (ale.)						50.3	
Tusket	Snith 1969	2	27		225			Gaspereau (ale.)						52.9	

Table 3-4. Summary data from juvenile fish turbine mortality studies (page 4 of 4).

Site	Original Reference	Summary Table Citation	Turbine Characteristics: Head (ft)	Turbine Diameter (in)	RPM	Peripheral Velocity (fps)	Turbine Operation	Species	Test Results: Fish Size (mm) Min	Max	Median	Mortality (%) Low	High	Ave.	Visible Injury (%)
Bulb turbines															
Salmon species															
Essex	Knight, Kuzmeskis 1982	2,3	29	144	129	80.8	Peak Eff.	Alt. salmon	225	330	278			2.0	
Rock Island	Olson, Kaczynski 1980	2,3	40	276	85.7	103.2	Peak Eff.	Coho	113	119				7.0	
Rock Island	Olson, Kaczynski 1980	2,3	40	276	85.7	103.2	Peak Eff.	Steelhead			165			3.1	
Rocky Reach	RMC and Skalsi (1994)	1		--information being compiled--											
Non-salmonid species															
Vanceburg	Olson et al. 1988	3	30	240	ng		Variable	Sauger	210	252	231		14.6	14.6	
Propeller (fixed-blade) turbines															
Salmonid species												12.8	22.0	17.7	
Rocky Reach	RMC and Skalsi (1994)	1		--information being compiled--											
Non-salmonid species												12.8	22.0	17.7	
Morrow	Bohr and Liston 1987	3	12	54	175	41.2	Variable	Resident			Variable	0.4	7.9	7.9	1.4
Rothschild	Dames and Moore 1991	3	20	ng	ng		Variable	Resident			Variable				2.1
Safe Harbor	RMC 1991a	3	55	240	76.6	80.2	Peak Eff.	Amer. shad	95	140	118			2.0	
Thornapple	Everhart 1991	3	15	110	120	57.6	Variable	Resident			Variable			4.7	

Notes:

1. Citation:
   1) ibid
   2) Eicher Associates 1987
   3) Stone & Webster 1992

turbmort.ov4

3.2.1.1.9. General Estimates of Turbine Mortality. Juvenile turbine passage survival studies for the Columbia and Snake Rivers began in the 1950s and have continued on a sporadic basis to the present. The results of several studies reviewed by Iwamoto and Williams (1993) showed juvenile turbine passage mortality estimates ranging from 2 to 20 percent. A recent study of direct juvenile passage mortality in Kaplan turbines at Rocky Reach dam determined a range of 4 to 6 percent (RMC and Skalski 1994b, Normandeau and Skalski, 1996). Table 3-4 provides a summary of several studies that have examined juvenile turbine passage mortality in propeller-type turbines, using information provided primarily by review articles by Eicher (1987) and Stone and Webster (1992).

3.2.2. Passage During Spill.

3.2.2.1. Dam Spillway Passage. A second option for juveniles passing a project is passage over the spillway. Flow over the mid-Columbia project spillways occurs either as: 1) spill for passage of juvenile migrants; 2) spill due to flows exceeding the powerhouse capacity of the project (forced spill); or 3) spill due to lack of demand for energy from the project (overgeneration spill). Fish passage spill occurs only during the juvenile migration season, generally from April through August. This can be further subdivided into spring spill (April through early June), which targets spring migrants (stream-type chinook, sockeye and steelhead), and summer spill (mid June through August), which targets ocean-type chinook juveniles (CBFWA 1995).

The objective of passing juveniles over the spillway is to avoid exposure to the turbines, which can cause significant mortality (see previous section on turbine passage). The advantages of spill passage are a potentially high effectiveness in diverting fish away from turbine intake, (at many but not all projects) and the ease and flexibility of its implementation. However, juveniles passing over the spillway face several risks. First, the juveniles can sustain physical injuries, such as descaling, that may incapacitate or even kill them. Second, increasing spill may result in higher total dissolved gas (TDG) supersaturation levels, which in turn may cause gas bubble trauma (GBT) in juveniles and adults. (see Section 3.3 for a thorough discussion of TDG and GBT.) Juveniles are also subjected to predation upon entry into the tailrace. Individuals that become injured or disoriented while passing over the spillway may be more susceptible to predation.

Potential adverse effects resulting from spill as passage, or from any project passage route, can be categorized as either direct or indirect effects. Direct effects are a consequence of physical injury incurred during passage, for example through spillways or sluiceways and resulting in immediate or delayed mortality (Chapman et al. 1994a). Indirect effects result from debilitated, disoriented, or stunned juvenile fish being exposed to additional sources of mortality such as predation once past the project (Chapman et al. 1994a). In general, relative to other means of passage currently available, spillways are the most benign route for juveniles to pass the mid-Columbia projects (Chapman et al. 1994a; Chapman et al. 1994b). It is a relatively straightforward calculation to quantify the direct effects associated with spill as passage. Injuries sustained by juveniles passing through a spillway or sluiceway either kill the fish instantaneously or result in death after a short period of time. Survival of fish passing through spillways of dams on the Columbia River has been estimated to be 98 to 100 percent (Anderson et al. 1993).

The indirect effects of spill are much less well known. Juveniles surviving the spillway and the immediate downstream area are subject to additional sources of mortality. Some factors that may affect indirect mortality from spill passage include position of the fish in the river, velocity of the water downstream of the project, degree of debilitation, time of day, presence of predators, and water temperature. Ideally, the overall effect of spill as passage, in terms of the survival of juvenile fish, should be analyzed from the dam to a point well downstream from the spill discharge (Chapman et al. 1994a). The only study on the Snake/Columbia River system that has attempted to quantify the indirect mortality associated with the many routes of dam passage was conducted at Bonneville dam from 1987 to 1990 (Ledgerwood et al. 1991a). Researchers determined in 1990 that, on average, there was no significant difference in the total mortality that resulted when juveniles passed through the second powerhouse turbines, or the juvenile bypass system, or the juvenile bypass system outfall plume (egress). Other studies have indicated that cumulative direct and indirect mortality resulting from spill passage may be as high as 64 percent (Parametrix 1986).

One advantage of spill passage over juvenile bypass systems is the potential reduction in predation resulting from the release of a concentrated stream of juveniles at a fixed point, such as occurs at the outfall of a juvenile bypass system. However, predation can occur in either type of bypass if juveniles become debilitated in some manner (Chapman et al. 1994a).

Spill effectiveness is defined as the proportion of juvenile fish passed through spill relative to the total number passing the project. Instantaneous spill effectiveness applies to those hours during which spill actually occurred. This differs from 24-hour daily average effectiveness, which may include time periods when no spill occurred. All effectiveness values presented herein are instantaneous values. Spillways are typically assumed to have a 1:1 ratio of percent total fish to percent total river flow passed (i.e., spilling 50% of total flow results in 50% of juveniles passing over the spillway) until site specific studies show otherwise. However, effectiveness can vary from year to year and project to project (Ransom and Steig 1995). Even with the variability in spill effectiveness at some projects, there is still a fairly good relationship between spill and the proportion of juveniles passed at most mid-Columbia projects (Chapman et al. 1994a).

Several reasons may account for the variability in spill effectiveness observed at mid-Columbia dams. The particular turbines and spill bays operated during a study may influence the way juvenile fish distribute themselves across the face of the dam (Ransom and Malone 1989). In addition, operation of a sluiceway, if present, may produce added attraction flow to increase passage over the spillway (Ransom and Malone 1989), and thus increase spill effectiveness. Differences in fish behavior from year to year and by species (race/deme) may also influence the results (Ransom and Malone 1989). The particular methods used to collect and analyze the data also may affect the results (Ransom and Malone 1989).

3.2.3. Ice and Trash Sluiceway Passage. In the late 1970s, the surface skimming ice-trash sluiceways on some Columbia and Snake River dams were considered as a possible means of safely bypassing juvenile migrants past turbine units. Although the sluiceways were not designed to pass large volumes of water (<3 to 5 kcfs), biologists believed that the surface-oriented nature of the juvenile migrants could result in a disproportionately high percentage of migrants passing through the sluiceway.

Examination of sluiceway effectiveness at Columbia River facilities has since shown that sluiceways are indeed more effective at passing juvenile fish than spillways (Ransom and Steig 1995). Existing data indicate average sluiceway effectiveness ranges from 8:1 to 13:1, depending on the season, versus the 1:1 to 2:1 ratios typically measured or assumed for spillways. The effectiveness of a sluiceway at passing fish has been shown to be dependent on the position of the sluiceway in relation to the turbines. Sluiceways located over turbines are more effective than sluiceways adjacent to turbines or spillways. Sluiceways located over turbines range from 13.2:1 to 20.1:1 in effectiveness, depending on the season, versus 1.7:1 to 7.2:1 effectiveness for sluiceways adjacent to powerhouses or spillways (Ransom and Steig 1995). Sluiceways may be more effective at bypassing juveniles during the day than at night (Ransom and Malone 1989).

3.2.4. Juvenile Bypass Systems. Although most of the mainstem dams in the Columbia River basin were constructed with fish passage devices to assist the upstream migration of adult fish returning to spawn, very few provisions were originally made to allow downstream migration of juvenile fish other than by passage over the spillways or, during power production, through turbines. As the number of mainstem dams on the Columbia and Snake Rivers increased, their cumulative impact on mortality of downstream migrating fish began to be recognized as a significant fisheries management problem. In the early 1950s, the US Army Corps of Engineers started the Fish Passage Development and Evaluation Program (FPDEP) to develop methods of safe juvenile fish passage at the mainstem dams (BPA et al. 1994a). Other entities have cooperated with this program and contributed additional research efforts, including the US Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), the fisheries agencies of many states and Canada, and many public and private industrial concerns.

A thorough review of juvenile bypass system models, prototype studies and full-scale applications developed through 1986 is presented by Stone and Webster (1986). The review subdivides bypass systems into four groups:

- behavioral barriers
- physical barriers

- fish-diversion devices
- fish-collection devices

Behavioral barriers attempt to move fish away from an area of concern by invoking behavioral responses in the fish. Measures that have been investigated include electrical screens, air bubbles, lights of various types, and sound barriers. These types of barriers hold special appeal in that they allow the water to pass freely, avoiding the associated problems of debris accumulation and lowered turbine efficiency. However, there has been limited success with these measures under conditions experienced at large mainstem dams (Stone and Webster 1986). A possible exception is the use of sound barriers, which are receiving continued investigative support through the Portland District and the Waterways Experiment Station (WES) of the USACE (Ferguson, pers. comm., 25 April 1995).

Physical barriers and diversion devices are the most common bypass measures on the Columbia and Snake River dams. These two measures must be combined in the case of downstream migrating fish, since for every barrier there must also be an escape route to allow bypass of the dam. More and more, it is being found that the effectiveness of the Columbia River bypass systems lies not so much in the physical barrier but rather in the ability of the fish to locate and utilize the bypass entrance. This is due to the fact that design parameters for physical barriers are well understood, being based primarily on the swimming abilities and physical size of the fish of concern. The success of the bypass devices, on the other hand, is dependent largely on fish behavior, which can vary considerably under the array of conditions found at mainstem dams.

3.2.5. Physical Barriers. Nearly all physical barriers at mainstem Columbia basin dams involve a fish screen mechanism. As a result of years of investigative studies and evaluations of full-scale applications, the NMFS has developed fish screen criteria to enhance the performance of these facilities (NMFS 1994). Fish swimming ability is a primary consideration in these criteria. Swimming ability can be estimated according to the species and size of fish, but swimming ability varies, according to factors such as the duration of swimming time required, the level of dissolved oxygen, water temperature, light conditions, the physical condition of the fish, and the migrational stage. The fish screen criteria established by the NMFS provide a fair margin of safety to account for these factors. Some of the fish screen criteria, as currently specified by NMFS, are as follows.

- Screen approach velocities must not exceed 0.40 fps to accommodate the swimming capabilities of salmonid juveniles.
- The sweeping velocity (which is the water velocity component parallel to the screen face) must be greater than the approach velocity to minimize sediment accumulation and to facilitate debris removal.
- The minimum size of screen openings is dependent on whether or not the screen is composed of perforated plate, profile bar screen, and woven wire screen. The screen material must provide a minimum of 27 percent open area.

- The face of the screen surface must be placed flush with any adjacent screen bay, piers, or walls.
- Structural features must be provided to protect the integrity of the fish screens from large debris. These features might include trashracks, log booms, sediment sluices, or other measures as needed.
- The fish screens must be designed in a manner that eliminates undesirable hydraulic effects that may delay or injure fish. Often times, a structure such as an upstream training wall must be installed to direct the angle of flow towards the screen face. Large projects most often require hydraulic modeling to identify and modify problems associated with these features.

Juvenile screening facilities have been added as a retrofit to turbine intakes at several mainstem projects. Early investigations showed that it was not possible to achieve full screening of turbine intake flows due to constrained areas within the existing powerhouse structures, excessive water velocities, and conflicts with intended project operations. Consequently, partial screening systems have been installed that are able to reduce, though not eliminate, turbine passage mortality. The fish screens installed at mainstem projects intercept approximately the upper third of the turbine intake flow (DeHart 1993). The screens are typically mounted at an oblique angle in the turbine intake as a means of maximizing the available surface area and reducing the approach velocities through the screen.

Fish screens impact flow conditions in the turbine intake, typically causing water to be deflected and accelerated toward the bottom of the intake. These changes may result in reduced turbine efficiency, greater pressure drops across the turbine runners, and redistribution of fish to lower portions of the water column. While fish screens should significantly reduce the number of fish passing through turbines, the mortality rate for fish passing the turbines may be higher than the base case prior to screen installation due to the altered flow conditions (BPA et al. 1994b).

3.2.6. Bypass Facilities. The fish screen barriers at most Columbia basin projects divert fish into gatewells located above the turbine intakes. The gatewells were originally designed for purposes of turbine operation and maintenance. Modification of the gatewells for use as juvenile bypass facilities typically involves the installation of orifices that lead to a collection channel inside the dam. The collection channels run the length of the powerhouses, then change to either pipelines or open flumes that carry fish to release sites below the project or, in the case of four projects on the Lower Columbia and Snake Rivers, to transportation facilities.

The NMFS has developed bypass facility criteria with the objective of moving downstream migrating fish with a minimum of injury or delay (NMFS 1994). Criteria cover aspects of the bypass layout, entrance conditions, conduit design, and outfall conditions. While some of these criteria are based upon the swimming ability of the juvenile fish, others are concerned with juvenile behavioral responses to hydraulic conditions at the barrier and through the bypass facilities. Hydraulic conditions vary considerably from site to site and also change in response to seasonal flows. As a result, the design of bypass facilities is not a generic process and is very much dependent on the collection of site-specific hydraulic and biological data.

At a workshop in April 1995 in Portland, Oregon concerning the status of juvenile bypass systems in the Columbia basin, there was general agreement that the current critical data gap in bypass system development is the lack of understanding of juvenile fish behavioral responses. Fish behavior may explain why there has been such variation in the effectiveness of juvenile bypass systems in the Columbia basin, with some systems being abandoned while others attract more than 90 percent of the downstream migrants (DeHart 1993; Johnson et al. 1992). Research efforts during the next few years are expected to focus on the following areas:

- distribution and diel behavior of various juvenile fish species as they approach and traverse dam barriers, spillways and bypass entrances;
- velocity vector characteristics in the forebay and at bypass entrances;
- juvenile fish responses to velocity gradients;
- juvenile fish condition and stress responses at bypass entrances, conduits and outfalls.

Additional research efforts are focusing on surface collector bypass systems owing largely to the success of the Wells dam bypass system completed in 1989. Since juvenile anadromous fish tend to migrate in the top 20 to 30 feet of a reservoir, surface collector systems attempt to provide an opportunity for discovering passage before juveniles dive to depths of 60 to 80 feet in the course of following flow towards turbine intakes and fish screen barriers. The Wells dam system is comprised of vertical baffle slots to create attraction flow into the bypass, while other prototype systems are examining shallow skimmer weirs and orifices similar to the sluiceways at Ice Harbor and the Dalles dams (BPA et al. 1994b). In its first three years of full operation, the Wells dam juvenile bypass system achieved an average fish passage efficiency (FPE) of over 89 percent (Skalski 1993).

Direct juvenile bypass mortality has been measured in the range of 1 percent to 3 percent, which excludes outfall mortality. Mortality rates vary with species and age of fish due to factors such as propensity for scale loss and impingement on the screens (NMFS 1995a). The level of mortality due to predation at the outfall requires further investigation (Ferguson 1994).

3.2.7. <u>History of Bypass System Development at the Mid-Columbia Projects</u>. The three mid-Columbia PUDs have been actively seeking the best measures to protect downstream migrants since the mid-1970s. At that time, an ad-hoc committee, with representatives from the fisheries agencies and the PUDs, was formed to reach agreement on mitigation measures at the five mid-Columbia projects. Although some issues were resolved, differences remained. In 1978, the fisheries agencies and tribes filed pleadings with the FERC for each of the licensed projects. This filing led to negotiations in 1979 that resulted in the Interim Mid-Columbia Settlement Agreement. This settlement established minimum flow and spill levels for fish protection during the spring migration period, and directed a series of investigations be conducted on methods of improving protection of anadromous salmonids (The Chelan PUD 1991c).

There were 66 studies conducted between 1980 and 1984 under the auspices of the Interim Mid-Columbia Settlement Agreement. Additional studies and mitigation measures were conducted under a series of stipulations and revised stipulations that succeeded the interim agreement (The Chelan PUD 1991c). The Priest Rapids, Wanapum and Rocky Reach dams are still operating under revised stipulations, while the Rock Island and Wells projects obtained settlement agreements regarding juvenile downstream migrant issues in 1987 and 1990, respectively.

3.2.8. Ancillary Passage Routes. Support functions at hydroelectric projects sometimes involve the withdrawal of reservoir water and discharge to the downstream side of the dam, resulting in a potential passage route for fish to pass the dam. These functions might include auxiliary water supplies for the fishways, attraction jet supplies, or supplies for small turbines to operate fish pumps or site utilities. These functions typically consume a very small percentage of the total project discharge. Several early projects on the mainstem Columbia River included juvenile bypass conduits at the intakes for these support function water supplies (DeHart 1993).

3.2.9. Collection and Transport Systems.

3.2.9.1. Fish Transportation on the Lower Snake and Columbia Rivers. In order to improve the survival of juvenile fish migrating past the dams and through reservoirs in the lower Snake and lower Columbia Rivers, the Juvenile Fish Transportation Program (JFTP) was developed by the NMFS and the USACE in cooperation with the fish agencies and tribes. The program was started in the early 1970s and expanded to large-scale operations in 1977. Essentially, the program uses barges and trucks as a mass-transit system to move juveniles downstream in an attempt to increase juvenile downstream migration survival and, ultimately, adult returns. In 1981, the NMFS transferred the operation of the transport program to the USACE (BPA et al. 1994a).

The JFTP currently collects juvenile anadromous salmonids for transport at four federal dams having fish screen and bypass facilities: Lower Granite, Little Goose and Lower Monumental dams on the Snake River; and McNary dam on the lower Columbia River. After being separated from adult anadromous salmonids, larger resident fish and debris, juvenile anadromous salmonids are either routed directly onto a barge for transport, or into raceways and held for later transport by truck or barge. Barges constantly circulate river water that juveniles can imprint on the chemical composition of the water, helping them locate their home stream when they return as adults. Trucks are used to transport the smaller numbers of juveniles collected during the early and final states of the season. The transport program operates from April through October on the lower Snake River and from April through December on the lower Columbia River (BPA et al. 1994a).

As many as 15 to 20 million young salmon and steelhead are transported each year through the JFTP. The past 20 years of research on various aspects of truck and barge transport have failed to identify direct negative impacts on homing or survival that can be attributed to transportation. The majority of tests have also shown that transportation returns more adult fish than in-river passage. Nonetheless, within the region there is considerable debate over the benefits of transporting fish and the acceptability of the program (BPA et al. 1994a).

3.2.9.2. Fish Transportation on the Mid-Columbia River. None of the mid-Columbia mainstem projects have navigation locks, and the downstream Priest Rapids dam is the only one of the five dams capable of having a barge reach the lower Columbia River. Consequently, the transportation of fish collected from the upper four mid-Columbia projects would have to rely on trucking, or new systems would need to be developed to transfer fish around each dam. As a result, the Chelan PUD and the DCPUD have never evaluated collection and transportation alternatives.

3.2.10. Juvenile Reservoir Passage. Reservoir impoundment can create increased rearing area and provide overwintering habitat for juvenile anadromous salmonids. It can also affect the outmigration of anadromous salmonid juveniles by causing residualization, extended travel times and decreased survival rates. The use of the term "extended travel times" refers to slower rates of travel by outmigrating juvenile anadromous salmonids. Juveniles, when exposed to extended travel times and increased water temperatures, can residualize (become residents) and fail to migrate to the ocean. The following section describes background information on reservoir-related effects of residualization, delay and mortality. Information on predation, a major cause of mortality, is covered in Section 4.5.

Raymond (1968, 1969, 1979) and Bently and Raymond (1976) estimated that juvenile anadromous salmonids move through the Snake River and lower Columbia River impoundments one-half to one-third slower than they would through free-flowing river sections of the same length. According to Raymond (1979) juvenile steelhead and chinook migrate through free-flowing stretches of river at 14 miles per day, while they move through impounded waters at 5 miles per day. Giorgi, et al (1997 reported migration rates from Rock Island to McNary dams averaged 13.4, 9.7, 16.3 and 18.9 miles per day respectively for yearlings and subyearlings, chinook, sockeye and steelhead juveniles.

Due to reservoir construction, water velocities through the Snake and lower Columbia River are today much slower than historically (CBFWA 1990). The predicted average water particle travel time (WPTT), at a flow of 100 kcfs in the 200 miles of the lower Columbia River from the head of McNary reservoir to Bonneville dam, is 23.3 days or 8.7 miles per day. The WPTT for the entire 142 miles of the mid-Columbia reach is 8.6 days, or about 16.5 miles per day (see Section 5, System-wide Issues). Although several studies indicate that water velocity is a primary determinant of juvenile migration speed (Smith 1982; Buettner and Brimmer 1995; Berggren and Filardo 1993) other studies suggest factors other than flow may be affecting the dynamics of out-migration (Achord et al. 1995; Beeman and Rondorf 1992; Mains and Smith 1964; Chapman et al. 1994a).

Extended travel times due to passage through reservoirs also increases potential exposure of juvenile outmigrants to predatory fish and reduces migration survival. Sims and Ossiander (1981) reported stream-type chinook and steelhead juvenile survival improved with increasing flow. While increasing flow may increase migration speed and associated reservoir survival through the lower Columbia and Snake River impoundments, there is less evidence to suggest that increased flows will increase survival in the mid-Columbia. This is particularly true for ocean-type chinook salmon in the mid-Columbia (Chapman et al. 1994a).

In view of the uncertain benefit of further increases in WPTT, improving juvenile outmigrant survival in the mid-Columbia reach may best be achieved by predator control and improved dam passage conditions.

3.3. Water Quality.

3.3.1. Dissolved Gas Supersaturation. Total dissolved gas (TDG) supersaturation is a condition that occurs in water when atmospheric gases are forced into solution at pressures that exceed the pressure of the over-lying atmosphere. Water containing more than 100 percent TDG is in a supersaturated condition. Water may become supersaturated with atmospheric gases through natural or dam-related processes. These processes either cause an increase in the amount of air dissolved in water or reduce the amount of air the water will hold. Fish and other aquatic organisms that are exposed to excessive TDG supersaturation can develop gas bubble trauma (GBT), a class of harmful and often fatal symptoms.

The occurrence of TDG supersaturation in the Columbia River system is well documented and has been linked to mortalities and migration delays of salmon (Beiningen and Ebel 1970; USACE 1994; Gray and Haynes 1977). Total dissolved gas supersaturation in the Columbia and Snake Rivers was identified in the 1960s and 1970s as a detriment to salmon, and those concerns have reappeared as management agencies have reinstituted spill as a means of aiding fish passage around hydropower facilities (NMFS 1995a).

Total dissolved gas supersaturation occurs in the Columbia River during periods of high runoff and spill at hydropower facilities, primarily because spill in deep tailrace pools can cause significant entrainment of gases during deep plunge and turbulence of the water. Water passed through turbines does not increase in gas saturation to any appreciable degree (BPA et al. 1994a). The majority of variation in TDG measured just downstream of spillways is explained by the variation in spill rate; the second-most influential variable is spillway plunge depth as indicated by tailrace elevation and stilling basin depth (BPA et al. 1994a). Total dissolved gas supersaturation varies substantially by season and by dam (BPA et al. 1994a).

In addition to depth and pressure, TDG supersaturation can be affected by water temperature. As water temperature increases, the amount of dissolved gas that can be held in solution decreases, resulting in greater TDG saturation levels even though the concentration of dissolved gas remains constant.

3.3.2. History of TDG Supersaturation in the Mid-Columbia River. Meekin and Allen (1974a) provided the first comprehensive survey of TDG levels in the mid-Columbia River (based on data obtained from 1965 to 1971). Their results indicated that Grand Coulee dam produced high levels of TDG supersaturation and that the downstream mid-Columbia dams increased TDG supersaturation only slightly over those arriving at each dam. Meekin and Allen (1974a) also monitored the river upstream of Grand Coulee dam in 1965, 1970 and 1971 and found TDG supersaturation to some degree at all sites. Waters in Lake Roosevelt and entering the lake from Canada contained TDG levels of over 120 percent.

The extent of in-river mortality currently caused by TDG supersaturation in the mid-Columbia River is unknown (BPA et al. 1994a). Weitkamp and Katz (1980) estimated a 6 to 60 percent mortality of adult salmon and steelhead migrating upstream in the mid-Columbia River during TDG supersaturation studies from 1965 to 1970. High mortality was associated with TDG levels exceeding 120 percent and low mortality with TDG levels less than 112 percent. Direct mortality effects on juvenile fish have rarely been observed in the Columbia River, but such observations can be difficult and actual effects remain uncertain (BPA et al. 1994a).

Since 1984, TDG has been monitored throughout the mid-Columbia River by the PUDs and reported to the USACE (1993) as part of the Columbia and Snake Rivers Dissolved Gas Monitoring Program. Monitoring occurs during the fish migration season, April through September, at each dam, including Chief Joseph (STN 2512), Wells (STN 2407), Rocky Reach (STN 2307), Rock Island (STN 2204), Wanapum and Priest Rapids (STN 2007). Monitoring results indicate that TDG in the mid-Columbia River has been consistently supersaturated during the April to September monitoring period each year. However, the magnitude of TDG supersaturation levels has been highly variable between stations and over each sampling season. Because of this variability, no strong and consistent trends are evident regarding spill effects on TDG supersaturation and dissipation of TDG supersaturation through the mid-Columbia region.

The USACE (1993) has made statistical comparisons of TDG data at and between mid-Columbia River sampling stations. These comparisons suggest TDG levels have generally increased as spill has increased, and also suggest that TDG levels have generally increased in a downstream direction. Specific comparisons of data from adjacent stations suggests that TDG levels have generally increased between the Chief Joseph and Wells forebays, and between the Rock Island and Priest Rapids forebays. Total dissolved gas levels have generally not changed between the Wells and Rocky Reach forebays, and between the Rocky Reach and Rock Island forebays. Total dissolved gas levels have also generally not changed between the Priest Rapids forebay and the next downstream station at the McNary dam forebay, although this comparison is made difficult by the effects of Snake River inflow.

The trends suggested by these comparisons are not reliable, since most of correlations are poor due to substantial data variability (USACE 1993).

The 1993 TDG monitoring data, which is the most recent data currently available from the USACE (1993), is informative in that high flows in the Snake and Columbia Rivers resulted in substantial spill and high TDG supersaturation levels. Total dissolved gas supersaturation levels entering the mid-Columbia River reach from Grand Coulee varied widely (i.e., 100 to 127%). Total dissolved gas supersaturation levels between Grand Coulee and Priest Rapids did not vary much from inflowing levels, and high levels were either maintained when spill was occurring in the mid-Columbia reach, or sometimes decreased from high levels if no spill occurred.

3.3.3. GBT Effects on Anadromous Salmonids. Gas bubble trauma (GBT) effects on anadromous salmonids are well documented, although most information has been obtained in laboratory or field-based bioassay studies (Weitkamp and Katz 1980). Much remains to be learned about the physiological and behavioral aspects of GBT in the natural environment. Dissolved gas supersaturation thresholds for signs of GBT in anadromous salmonids were developed by the NMFS GBD Panel in June 1994 (Table 3-5) (NMFS 1995b).

External signs of GBT include exophthalmia or "pop eye," bubble or blister formation under the skin, hemorrhages, over-inflation of swim bladder and body cavities, and bubbles or emboli in gill blood vessels. Behavioral effects include loss of equilibrium, loss of swimming performance (including speed, direction and avoidance response), violent writhing, lethargy and reduced feeding (Weitkamp and Katz 1980). Exposure to TDG supersaturation can also delay migrations and weaken fish condition (Bjornn et al. 1994). Adult salmon exposed to TDG supersaturation at or above 106 percent gain less distance and swim less time than do unexposed fish (SRSRT 1993). In general, behavioral effects of GBT appear to follow that expected from any fish suffering severe physical stress that impedes or damages its respiratory and equilibrium functions. The physiological and behavioral effects of TDG supersaturation can make anadromous salmonids more susceptible to disease or predation (BPA et al. 1994a). However, the results of research on increased susceptibility to predation are mixed. Colt and Neitzel (1994) found that predation of 10 to 11 cm rainbow trout by 50 to 60 cm rainbow trout was significantly higher at TDG supersaturation levels of 125 to 130 percent than at lower TDG test levels. However, Mesa and Warren (1994) found no significant increase in predation of juvenile chinook salmon by northern squawfish in tests that exposed fish to a TDG supersaturation level of 120 percent.

Table 3-5. Signs of gas bubble trauma in salmonids.

Sign	TDG Threshold (sea level)	Age/Class
Cardiovascular bubbles	acutely lethal at ~ 115-118%	Juveniles & adults
Subdermal emphysema including lining of mouth	~ 110%	Juveniles & adults
Bubbles in lateral line	~ 110%	Juveniles & adults
Over-inflation of swimbladder in small fish	~ 103%	Swim-up fry & juveniles
Rupture of swimbladder in small fish	~ 110%	Swim-up fry & juveniles
Exopthalmia and ocular lesions	Unknown, 102% for ocular lesions	Juveniles & adults
Bubbles in intestinal tract	102 - 110%	Juveniles & adults
Loss of swimming ability	~ 106% (see Schiewe 1974)	Juveniles & adults
Reduced growth	102 - 105% (Chinook, lake trout)	Juveniles
Immuno-suppression (if present)	>108% (see Krise 1994 and unpublished)	Juveniles & adults
Reduced ability to adapt to saltwater	refer to Shrimpton 1993	Juveniles

Source: NMFS 1994.

sign-gbt.ov4

3.3.3.1. Mortality Thresholds for Anadromous Salmonids Exposed to TDG Supersaturation. Although GBT causes a variety of physiological and behavioral effects, the primary cause of death has generally been attributed to anoxia resulting from stagnation of blood flow (Weitkamp and Katz 1980). Much is known about mortality of fish exposed in captivity to certain gas levels, but little is known about threshold levels for mortality in the natural environment (NMFS 1995b). The USACE (1993) suggested a lower mortality threshold occurs at a TDG supersaturation level of 110 percent and a high threshold at 115 to 118 percent; the transition from lower to higher thresholds involved a shift in bubble related mechanisms that lead to death (BPA et al. 1994a). Jensen et al. (1986) concluded that the boundary between chronic and acute trauma risk of TDG supersaturation occurs at 108-116 percent DGS. The USACE (1993) assumed that mortality of juveniles due to gas saturation begins at TDG supersaturation levels greater than 108 percent, and occurs at rates defined by an empirical mortality rate curve.

Ebel et al. (1975) developed a relationship of chinook juvenile travel time, gas saturation and survival for the Snake River from Salmon River to Ice Harbor dam. This relationship indicated decreasing travel time from 25 to 12 days increased survival from 25 to 50 percent. The relationship suggested that reducing TDG supersaturation levels to 109 percent for part of migration increased survival from 25 to 37 percent. It also suggested that when river flows were high and corresponding gas saturation levels were high, mortality from gas can override other mortality factors and result in substantial losses of juveniles (i.e., 40% to 90% loss).

The CRiSP.1 fish passage model, used in the Columbia System Operation Review (SOR) (BPA et al. 1994a), has also attempted to develop a quantitative relationship of TDG supersaturation effects on juvenile mortality. The relationship was derived using several data and information sources. It assumes that mortality starts at TDG levels of 108 percent, does not accumulate greatly until 120 percent, and approaches 50 percent mortality when TDG of 130 percent is sustained for over two days duration (BPA et al. 1994a). The CRiSP.1 model does not account for any TDG-related indirect mortality citing inadequate quantitative information on indirect mortality (BPA et al. 1994a). The CRiSP.1 analyses suggested that gas mortality is the third highest contributing factor affecting in-river juvenile mortality during high flow conditions and the seventh highest contributing factor during low flow conditions (BPA et al. 1994a).

3.3.3.2. Tolerance of Anadromous Salmonids to TDG Supersaturation. Factors that can affect anadromous salmonid tolerance to TDG supersaturation include life stage, size, species and depth distribution (Weitkamp and Katz 1980). The effects of GBT in anadromous salmonids vary by life stage. Tolerance of immature life stages generally decreases with increasing age and sizes (Weitkamp and Katz 1980). For example, tolerance to TDG supersaturation decreases from high tolerance of eggs to low tolerance in older juveniles. In salmonid sac fry, GBT effects are mainly confined to formation of bubbles along the yolk sac membrane, causing erratic swimming behavior. The signs and symptoms of GBT in juveniles and adults are similar and include those as listed above. However, it is generally felt that susceptibility to GBT differs between juveniles and adults, although study results show considerable variation. Weitkamp and Katz (1980) state that adults are generally the most tolerant free-swimming life stage, whereas BPA et al. (1994a) concludes that adults are more susceptible to the physiological effects of TDG supersaturation than juveniles due to more developed organs.

Depth distribution of anadromous salmonids is a major factor affecting their tolerance to TDG supersaturation. Changes in the incidence of GBT occurs with depth. This results from hydrostatic pressure exerted on a fish at depth that limits the effects of supersaturation. Approximately each three feet of depth exerts additional pressure sufficient to compensate for approximately 10 percent of saturation (Weitkamp and Katz 1980). Given the opportunity to sound, anadromous salmonids can survive for extended periods of time in deep water with TDG supersaturation exceeding 110 percent without significant incidence of GBT (Weitkamp and Katz 1980; Meekin and Turner 1974; Weitkamp 1976). An apparent threshold exists near TDG supersaturation levels of 120 to 125 percent for juvenile anadromous salmonids that are held in shallow water (approximately three feet or less). Increases over this range can produce a rapid increase in the incidence of GBT and death. Below this range, incidence of GBT and mortality is low. For anadromous salmonids maintaining a deeper distribution, the critical TDG supersaturation level would be higher (Weitkamp and Katz 1980).

Weitkamp and Katz (1980) stated that fish will not eliminate gas (i.e., de-gas) in their tissues when they sound, and the tissue will again be supersaturated upon return to the surface. However, this may not be a problem for fish that sound frequently in the natural environment. Weitkamp and Katz (1980) have shown that lethal or sublethal emboli formation takes substantially longer than time required for de-gassing of tissues. Weitkamp and Katz (1980) conclude that this may enable periodically sounding fish to spend some time each day near the surface without suffering GBT effects.

The depth-related GBT effects have been verified in the mid-Columbia River in live-cage studies conducted on juvenile coho salmon (Ebel 1969), juvenile chinook salmon at Priest Rapids (Weitkamp 1976), juvenile chinook, coho and steelhead at Wells (Meekin and Turner 1974) and juvenile coho at Rocky Reach (Meekin and Turner 1974). Volition cage tests found that the fish spent sufficient time at depth to avoid any effects of 120 to 125 percent saturation, although the tests were not specifically designed to determine the fish's ability to detect and avoid TDG supersaturation (Meekin and Turner 1974; Weitkamp 1976). These depth-related GBT effects indicate that depth distribution of fish in supersaturated waters is a key factor in estimating TDG supersaturation effects and tolerance.

Intermittent (i.e., pulsed) exposure to TDG supersaturation may increase the level of supersaturation anadromous salmonids can tolerate (Weitkamp and Katz 1980). Studies by Weitkamp and Katz (1980), Meekin and Turner (1974) and Weitkamp (1976) indicate that intermittent exposure, either by changes in TDG supersaturation levels of the water or by sounding, will allow fish to tolerate an exposure time that is greater than the sum of the intermittent exposures. This indicates that some recovery occurs during periods of reduced supersaturation between exposures. However, manipulating spill to achieve significant reductions in TDG supersaturation on an intermittent basis is not feasible for most Columbia River projects because of reservoir capacity constraints. For example, a recent Lower Granite dam test that decreased spill from 150,000 to 60,000 cfs for four hours only resulted in a 4 percent decrease in TDG supersaturation (SRSRT 1993).

The ability of anadromous salmonids to tolerate TDG supersaturation may be increased if supersaturation can be detected and avoided. It is generally accepted that anadromous salmonids are not able to detect and avoid TDG supersaturation, but this may not hold for all species or conditions (Weitkamp and Katz 1980). For example, volition cage studies by Ebel (1971) found that juvenile chinook salmon were unable to detect, or were unwilling to avoid supersaturation conditions. In the Meekin and Turner (1974) study, juvenile chinook salmon showed an avoidance of supersaturated water, while juvenile coho salmon demonstrated no such avoidance. Blahm et al. (1975) found that juvenile steelhead avoided supersaturated waters, while juvenile chinook apparently did not. Weitkamp and Katz (1980) reported apparent detections and avoidance of supersaturation by juvenile chinook salmon and steelhead.

The SOR notes that TDG supersaturation may be an issue that relates to fish guidance. Where fish guidance is designed on assumed travel of smolts in the upper 15 to 30 feet of the water column, for example, smolt travel at depth in the forebay to avoid supersaturated water could affect guidance success and fish could go through the turbines rather than the fishway.

3.3.3.3. Results of Recent GBT Monitoring in the Mid-Columbia River. Recent site-specific monitoring in the mid-Columbia River indicates that the incidence of GBT has been minor except in 1997 and 1998, years with extreme high flows, involuntary spill and TDG levels. The PUDs are now monitoring juvenile fish for symptoms of GBT following renewed concerns about the potential effects of increased spill.

In 1993, a systematic program for monitoring migrating anadromous salmonids for signs of GBT was implemented by the FPC at various sites along the Columbia and Snake Rivers. Rock Island is the only site in the mid-Columbia River reach that is included in the program, but the Chelan PUD adding sampling at Rocky Reach in 1996. The monitoring program in 1993 showed that in spite of high spill, the observed impacts of TDG supersaturation were minor (FPC 1994). Gas bubble trauma was observed at Rock Island on only two of 16 sample dates, and in only 2 percent or less of sampled fish. The fish are only monitored externally for appearance of gas bubbles in the fin; no internal monitoring for GBT has been conducted. Recent research has shown that the GBT starts off as internal lesions and only later are detectable externally (Weitkamp and Katz 1980). Therefore, GBT monitoring that is based only on external monitoring could underestimate the potential incidence of GBT. Recent monitoring has included microscopic examination of the lateral line. In 1996 and 1997 with TDG levels higher than in 1993, GBT levels in the Mid-Columbia were high enough to cause concern.

The PUDs previously sponsored research on GBT symptoms in fish from the five mid-Columbia dam reservoirs (Dell et al. 1975). For the study, most fish were captured in the reservoir using trap nets and beach seines and examined at time of capture for external signs of gas bubbles under the skin, in the fins, on the body (including lateral line) and in the mouth and eyes. Fish were also examined for exopthalmia. The incidence of GBT in fish was 2.8 percent at Wells, 3.6 percent at Rocky Reach, 0.9 percent at Rock Island, 16.1 percent at Wanapum and 0.8 percent at Priest Rapids.

3.3.3.4. Regulations Regarding Supersaturation. The EPA has recommended a criterion for TDG concentrations of no more than 110 percent for freshwaters. The WDOE standard governing the mid-Columbia River also specifies that activities shall not increase TDG above 110 percent without authorization from WDOE. The Oregon Department of Environment Quality (DEQ) standard specifies that TDG will not exceed 105 percent for waters of less than 2 ft depth, and 110 percent elsewhere, except in a 10-year, 7-day flood flow.

Current operations are in frequent violation of these standards, even under normal operations (BPA et al. 1994a). Dissolved gas supersaturation is listed as a top water quality concern in the Columbia River reach from Grand Coulee to the Snake River confluence by SOR Water Quality Work Group survey of regional agencies involved in water quality (BPA et al. 1994a).

There has been debate over the appropriateness of using the current 110 percent standard, since the standard is exceeded frequently under normal operating conditions, and it impedes implementation of voluntary spill as a means of passing juvenile fish (DFOP 1994). The CBFWA has recommended that TDG supersaturation and GBT monitoring be used to guide in-season spill decisions at each project, citing scientific criticism of the 110 percent criterion and frequent exceedances of the criterion under normal operations. The USACE has favored limitation of spill based on concern over TDG supersaturation levels. In 1993, the NMFS stated that spill be managed at federal projects to minimize periods when TDG supersaturation exceed 110 percent, unless otherwise requested by NMFS (1993). In May 1994, NMFS prepared a Gas Bubble Disease and Management Program Plan for guiding management actions during the May-June 1994 special spill operations at Columbia and Snake River projects. The plan specified TDG supersaturation and GBT monitoring, and a plan-of-action for curtailment of spill if TDG supersaturation exceeded 120 percent or GBT exceeded 5 percent in juvenile anadromous salmonids or 2 percent in adults.

An informal effort has been initiated to modify the TDG standard to 120 percent (BPA et al. 1994b). The WDOE and DEQ are in the process of working together to change procedures for issuing such modifications. The new procedures have been coordinated and similar for both WDOE and DEQ. Previously, WDOE issued short-term modifications (WAC 173-201A-110) allowing exceedance of the 110 percent standard when necessary to accommodate increased spill to aid outmigration of smolts in the Columbia River. The new standards allow TDG levels of 120% in the tailrace and 115% in the forebay of the next project downstream to allow voluntary spill for juvenile fish passage with the limitations removed when flow exceeds the 10-year 7 day flood level. A Gas Bubble Disease Working Group was established by NMFS in 1994 to develop a scientifically sound monitoring program and identify information/research needs relative to TDG supersaturation effects on migrating anadromous salmonids and other biota in the Columbia River (NMFS 1995b). The group believes the existing standard of 110 percent will adequately protect fish on purely biological grounds, with more stringent levels advisable for "full protection" (NMFS 1995b). The group recommends development of further information in order to adequately balance TDG supersaturation conditions and availability of water for outmigration (NMFS 1995b).

3.3.3.5. Previous System-wide Measures and Initiatives to Control TDG Supersaturation. Initial concerns with TDG supersaturation in the 1960s and 1970s prompted some measures and initiatives to control supersaturation in the Columbia River system. Reduction and control of TDG supersaturation was approached in three primary ways. Upriver storage reservoirs were constructed to store and spread spring flows over a longer time, and reduce spillage at dams. Also, full complements of turbines were installed at various dams to maximize turbine flow and reduce involuntary spill. Fliplips were retrofitted to spillways at four of the federal dams to reduce plunging and supersaturation (BPA et al. 1994a). These measures were largely effective in minimizing spillage and TDG increases. However, supersaturation concerns have now reappeared as management agencies have recommended increased spill as a means of aiding fish passage around hydropower facilities (NMFS 1995a).

3.3.3.6. Current System-wide Mitigation and Monitoring Measures. Total dissolved gas is monitored throughout the mid-Columbia River by the USACE as part of the Columbia and Snake Rivers Dissolved Gas Monitoring Program described above in which the PUDs assist with monitoring in the mid-Columbia. Monitoring occurs during the fish migration season (April through September). Other pertinent information is also monitored, including water temperature, total river flow and spill quantities. The PUDs are also continuing to monitor for symptoms of GBT, as required by FERC. Elsewhere, juvenile anadromous salmonids are routinely monitored for GBT symptoms as part of the FPC's Smolt Monitoring Program at selected Snake and Columbia River dams, but only at Rock Island and Rocky Reach (Chelan PUD funded) in the mid-Columbia region.

3.3.4. Water Temperature. The thermal regime of the mid-Columbia River is largely controlled by releases at Grand Coulee dam. While the mid-Columbia PUD projects may have limited capacity to affect water temperature, high water temperatures are a water quality issue, particularly during low flow conditions.

3.3.4.1. Effects on Anadromous Salmonids. High water temperature can pose a significant problem for salmon and steelhead by potentially increasing the incidence of disease; altering the timing of adult and juvenile migrations; changing incubation, hatching and maturation times; and affecting gas supersaturation (BPA et al. 1994a; Chapman et al. 1994a, 1995a; Dauble and Mueller 1993). In addition, given sufficient magnitude and duration of exposure, high water temperatures can be lethal to fish.

Water temperatures exceeding 19°C to 21°C have been shown to cause delay in migrating adult anadromous salmonids (Dauble and Mueller 1993). Within the mid-Columbia River, no delay of migration has been observed on the mainstem, but warm water flowing out of the Okanogan River has caused fish to remain in the mainstem until temperatures decreased (Chapman, et al, 1995). Spawning fish have limited energy reserves, and any delay in migration may reduce those energy reserves to the point where the fish may not be able to spawn successfully (BPA et al. 1994a). High temperatures not only reduce energy reserves by extending the period of migration but also by increasing the metabolic rate of the fish.

Above a certain threshold, high water temperatures can be lethal to salmon and steelhead given sufficient duration of exposure. The ultimate upper lethal temperature for juvenile spring chinook and sockeye salmon is 25.1°C and 24.4°C, respectively (Brett 1952). Adult anadromous salmonids are generally less tolerant of high water temperatures. When exposed to temperatures of 21°C or above for greater than seven days, 50 percent of adult salmon and steelhead populations experience mortality (Dauble and Mueller 1993). Nevertheless, mortality of fish may not be observed even when recorded temperatures exceed known lethal thresholds because fish may avoid high temperatures by ceasing migration or seeking out areas of cooler water (e.g., areas of in-channel groundwater upwelling).

Water temperatures at levels that may not directly kill anadromous salmonids may cause indirect stress-related mortality (Dauble and Mueller 1993). In addition, the rate of pre-spawning mortality can be increased by warm temperatures in combination with other stresses such as disease through pathogenic agents and TDG (Dauble and Mueller 1993).

3.3.4.2. Water Temperature Conditions in the Mid-Columbia River. Cumulatively, the storage dams on the Columbia River delay the time when thermal maximums are reached and when cooling begins in late summer (BPA et al. 1994a). The dams may also slightly increase the overall average annual temperature depending on reservoir volume, surface area and thermal stratification potential (BPA et al. 1994a). The two WDOE segments of the Columbia River affecting the PUD projects (WA-CR-1030 and WA-CR-1040) are not on the Clean Water Act Section 303(d) list as being water quality limited for temperature. However, EPA has cited water temperature as a concern from Bonneville dam to Chief Joseph dam (USACE 1994a). Monitoring data from the mid-Columbia reach indicate water temperatures commonly exceed the 18°C water temperature standard. Moreover, water temperatures measured in the mid-Columbia River have exceeded levels shown to cause delays in upstream migration and have exceeded criteria set by the NPPC for some species (Table 3-6). Annual maximum water temperatures from 1989 to 1994 have been approximately 20°C (USACE 1993). Water temperatures measured at Chief Joseph dam are occasionally higher than at Wells or any of the other PUD dams. In 1984, the maximum temperature at Chief Joseph dam was 23.0°C, while the maximum water temperature at mainstem PUD dams was 22.3°C (USACE 1993).

Table 3-6. Water temperature criteria for salmon and steelhead (ºC).

Species	Upstream Migration	Spawning	Incubation	Preferred	Optimum	Upper Lethal
Chinook						
Fall (ocean-type)	11-19	6-14	5-14	7-14	12.00	25.00
Spring (stream-type)	3-13	6-14	5-14	7-14	12.00	25.00
Summer (ocean-type)	13-20	6-14	5-14	7-14	12.00	25.00
Steelhead	-	4-9	-	7-14	10.00	24.00
Sockeye	7-16	11-12	-	11-14	-	-

Source: NPPC 1992a.

The mid-Columbia hydroelectric projects are run-of-river facilities with limited capability for storage and flow regulation. The thermal regime of the mid-Columbia River is largely influenced by releases from Lake Roosevelt at Grand Coulee dam, which has the largest storage capacity of any reservoir on the Columbia River system. Lake Roosevelt has a hydraulic residence or retention time (i.e., flushing rate) of approximately 11 to 32 days and becomes thermally stratified during the summer. Flushing rate is influenced by level of inflow, outflow and forebay elevation. The shortest flushing rate occurred, for example, in February 1995 when project outflow exceeded inflow to the greatest extent. The longest flushing rate most likely occurs in early fall, September and October, when forebay elevation is high and project outflow and inflow are low. Grand Coulee dam is equipped with a single fixed elevation outlet, and water temperatures below the facility are heavily dependent on the depth of the thermocline. The inability to draw water from various elevations is likely one reason why water temperatures measured below Grand Coulee can be quite warm (USACE 1993).

By comparison, the mid-Columbia run-of-river projects have very rapid flushing rates on the order of hours to a few days depending on inflow. The relatively short detention times at mid-Columbia facilities limit the potential warming that can occur within each reservoir. The PUD project reservoirs have a mostly river-like water quality character, with no thermal stratification. Water temperatures do not appear to be significantly warmed through the mid-Columbia projects (USACE 1993). Comparison of data collected at mid-Columbia TDG monitoring stations for the last 11 years indicates both cooling and warming can occur between the projects (USACE 1993). This lack of a consistent thermal effect suggests that significant warming or cooling does not occur as water travels through the mid-Columbia pools.

3.3.4.3. <u>Current Water Temperature Regulations</u>. State of Washington water quality standards (WAC 173-201-080) classify the mid-Columbia River as Class A (excellent) water. Waters with this designation are required to meet or exceed the requirements for specific uses which include anadromous salmonid migration, rearing and spawning. The water temperature standard states that water temperature shall not exceed 18.0°C due to human activities. In addition, temperature increases shall not at any time exceed t=28/(T+7), where "t" represents the maximum permissible temperature increase at a dilution zone boundary and "T" represents the background temperature measured at points unaffected by the discharge. When natural conditions exceed 18°C, no temperature increase will be allowed that will raise the receiving water temperature by greater than 0.3°C.

3.3.4.4. <u>Current Mitigation and Monitoring Measures</u>. No mitigation has been directed specifically toward dealing with any water temperature problems in the mid-Columbia River. However, monitoring is conducted annually by the PUDs in conjunction with the dissolved gas monitoring as required in FERC licenses.

The potential for improving water temperatures within the mid-Columbia reach is limited. Lake Roosevelt is large and deep enough to stratify and provide a source of cold water during summertime. In concept, summer releases from Lake Roosevelt at Grand Coulee dam could decrease water temperatures in receiving waters if drawn from below the thermoline. However, Grand Coulee does not currently have the capability to selectively withdraw waters from Lake Roosevelt to reliably accomplish such releases (BPA et al. 1994a).

3.4. <u>Reservoir Production</u>. Mainstem spawning and rearing habitat for anadromous salmonids in the mid-Columbia reach was inundated by the creation of five PUD reservoirs between Priest Rapids dam (RM 397) and Chief Joseph dam (RM 545.1). The total surface area of the Columbia River between Priest Rapids and Chief Joseph dams doubled from 23,000 acres to 46,000 acres following inundation by the dams (Mullan et al. 1986). Since upstream passage facilities were not provided when Chief Joseph dam was constructed, Chief Joseph dam is the upstream extent of mainstem anadromous salmonid production. Natural anadromous salmonid spawning in the mainstem mid-Columbia River presently is limited primarily to the free-flowing Hanford reach downstream of Priest Rapids dam, and to the major tributaries including the Wenatchee, Chelan, Entiat, Methow and Okanogan River systems. Mainstem spawning also occurs in the upstream portions of the reservoirs in project tailraces areas where streambed hydraulics and substrate conditions allow (Carlson and Dell

1989, 1990, 1991, 1992; Dauble et al. 1994; Chapman et al. 1994a). Reservoir production concerns and issues are related to a reduction in fish habitat for spawning and juvenile rearing life history stages. The factors affecting reservoir habitat for these life stages are discussed in the following sections.

3.4.1. Spawning Habitat.

3.4.1.1. Existing Issues. Issues related to reservoir effects upon the existing spawning sites include: deposition of fine sediments that may reduce incubation and spawning success; scour and relocation of gravel near the tailrace of each dam; and pool level fluctuations and the possibility of reduced production through redd dewatering. The importance of mainstem Columbia River reservoir spawning habitats varies by species and race/deme. Data are not available to support substantial mainstem spawning for spring chinook, steelhead, sockeye or bull trout in the mid-Columbia reservoirs. The following species-specific accounts focus on mainstem spawning conditions in the mid-Columbia River basin.

3.4.1.2. Spawning Conditions in the mid-Columbia River. The following paragraphs describe spawning conditions for the various salmonid species covered by the plan.

3.4.1.2.1. Chinook. Fall (ocean-type) chinook salmon are known to spawn in the upstream portions of the reservoir in project tailrace areas where stream velocities, substrate and intergravel flows remain sufficient for redd development and embryo incubation (Dauble et al. 1994; Chapman et al. 1994a). Significant fall chinook spawning also occurs downstream of Priest Rapids dam in the free-flowing Hanford Reach of the Columbia River (Carlson and Dell 1989; Chapman et al. 1994a).

3.4.1.2.2. Sockeye. Sockeye spawning in the Okanogan and Wenatchee Rivers has been documented during September to October (Mullan 1986). Limited spawning may occur in the Methow and Entiat Rivers maintaining remnant sockeye populations from previous introductions (Mullan 1986). Because of the necessity for juvenile lake rearing, sockeye are not regarded as a mainstem spawner.

3.4.1.2.3. Summer Steelhead. Steelhead spawning has not been observed in the reservoirs but some potential spawning could occur in areas of substantial groundwater upwelling. Past decisions regarding mitigation for steelhead spawning habitat (The Chelan PUD 1991c) have assumed that if steelhead used the reservoirs they would have similar spawning requirements as summer and fall chinook salmon. The effects of reservoir inundation on steelhead spawning production may be expected to be similar to effects on summer and fall chinook.

3.4.1.2.4. Tributary Bedload and Fine Sediment Deposition Effects on Reservoir Spawning Habitat. Smoothing of the hydrograph and lack of significant reservoir fluctuation from Columbia Basin hydroelectric development has increased the amount of fine sediment present in mainstem cobble substrate, especially in the lower portions of reservoirs (Falter et al. 1991). Mainstem anadromous salmonid spawning is concentrated at the upstream portions of reservoirs, where it is generally assumed river hydraulics are sufficient to maintain well-sorted substrates that are relatively free of fine sediment. However, a more likely criteria for concentrating spawning to upstream reservoir areas may be the occurrence of water velocity enabling adult anadromous salmonids to move cobble substrate for redd construction (Hays, pers. comm., 20 July 1995).

Columbia River mainstem tributaries have the potential to deposit bedload material into reservoirs, forming alluvial fans at the confluences. If amounts of fine sediment are not excessive, then bedload material could provide a good source of spawning substrate, so long as local water velocities are appropriate for spawning and they are sufficient to keep excessive levels of fine sediment from accumulating. Fine sediment loading in the Okanogan Basin in considered high, while the Methow and Wenatchee River systems transport a moderate level of fine sediment (Rensel 1993). Specific fine sediment data are lacking from tributary deltas, making quantative assessments of spawning conditions difficult.

Fine sediment deposition in mainstem Columbia River reservoirs generally occurs in locations where low river velocities and channel hydraulics are inappropriate for spawning anadromous salmonids. Since the majority of known mainstem spawning sites in reservoirs are located in tailrace areas, it is assumed that changes in sediment deposition may not affect existing potential spawning habitat.

3.4.1.2.5. Gravel Transport in the Tailrace. Construction of dams alters sediment transport relations in the tailrace. Bedload carried by high flows is deposited in the deep, low velocity impoundments upstream. The high velocity flows exiting the dam carry no bedload, and, thus, are better able to mobilize gravels in the tailrace and transport them downstream.

The mid-Columbia dams are operated as run-of-river facilities, therefore, transport of gravels out of the tailrace following construction was probably high. Subsequent construction of large storage reservoirs in the upper Columbia basin has reduced annual flow peaks. The reduction in annual peak flows has substantially reduced the rate at which bedload is transported out of the tailraces below the mid-Columbia dams.

Transport of gravel below the dams caused by localized high water velocities may relocate some suitable spawning substrate slightly downstream. High tailrace water velocities should also function to prevent fine sediment from accumulating on the river bed for a slightly greater distance downstream than the gravel relocation, thereby maintaining potential suitable spawning substrate in tailrace areas. It is also likely the tailrace hydraulics may contribute to intergravel flow conditions conducive to spawning (Chapman et al. 1994a) and movement of substrate to form a redd (Hays, pers. comm., 20 July 1995).

To date, mainstem spawning in the tailrace areas has probably been increasing since the 1980s (Mullan 1987; The Chelan PUD 1991c), although documentation of increased tailrace spawning activity may be an artifact of researchers spending more time and effort looking for mainstem spawning. Such data indirectly suggest any gravel relocation in the tailraces has not adversely reduced spawning opportunities. Tailrace hydraulic effects may be maintaining spawning opportunities in the reservoirs, particularly for summer and fall chinook (Giorgi 1992a; Chapman et al. 1994a; Dauble et al. 1994).

3.4.1.2.6. Fluctuating Pool Elevations. Maximum pool fluctuations in mid-Columbia reservoirs are generally less than 10 feet. They occur primarily in winter (Zook 1983; Chapman et al. 1994a) during the period when chinook embryos and alevins are incubating in the substrate. Reservoir spawning is suspected to occur in relatively deep mainstem waters near the upstream portions of the reservoirs. Giorgi (1992a) observed chinook spawning in the Wells tailrace area (Rocky Reach reservoir) at depths between 8 and 23 feet, with most redds constructed at depths greater than 20 feet. Fluctuations up to 10 feet should not affect spawning and incubation success for deep reservoir spawning. Production occurring in less than 10 feet of water may be subject to fluctuating water levels. Reservoir fluctuations may affect nose velocities and selection of spawning sites.

Dewatering of redds due to fluctuating water levels in the mid-Columbia region has been extensively studied (Chapman and Welsh 1979; Chapman et al. 1982; Neitzel et al. 1983). Fluctuations in water levels could have an adverse effect on embryos depending upon the degree and duration of the fluctuation and the stage of development of the embryos. The critical hatching stage of pre-emergent fry susceptible to dewatering occurs from late November through late April, annually (Chapman et al. 1982). Studies indicate prolonged periods of dewatering, up to 12 days, do not reduce embryo survival (Becker et al. 1983; Neitzel et al. 1983). Following hatching, alevins can withstand only a brief period (1 to 2 hours) of dewatering without reductions in survival. However, static intergravel water, moisture or relative humidity greater than 90 percent are sufficient to protect alevins during dewatering for periods up to 8 hours (Neitzel et al. 1983; Reiser and White 1981). Given the lack of shallow water spawning sites, the preference for deep spawning (perhaps due to tailrace hydraulics), the brief periods of reservoir fluctuation and the low magnitude of reservoir fluctuations, it is unlikely substantial losses to incubating embryos or alevins are occurring in the reservoirs.

Additional protection for incubating eggs, embryos and fry is provided by implementation of the 1986 Vernita Bar Settlement Agreement (VBA). Reverse load factoring, high nighttime discharge and lower daytime discharge, is provided by the GCPUD projects during the adult fall chinook spawning period, 15 October through late November, in the Hanford Reach area of the Columbia River downstream of Priest Rapids dam. A Protection Level Flow is established based on redd placement on Vernita Bar at completion of spawning. The Protection Level Flow is then maintained throughout the egg incubation, hatching and fry emergence period to prevent dewatering redds and subsequent high mortality of eggs, embryos or fry.

3.4.1.3. Previous and Existing Mitigation Measures. Existing mitigation for losses of mainstem spawning habitat due to inundation by the reservoir has been stipulated in the various Settlement Agreements for the projects.

3.4.2. Rearing Habitat.

3.4.2.1. Existing Issues. Issues related to reservoir effects on securing habitat include: aquatic productivity, macroplytes, waterlevel fluctuations, and water quality. These issues are discussed in relation to reservoir conditions and by species.

3.4.2.1.1. Reservoir Conditions. The mid-Columbia PUD projects are operated as run-of-the-river facilities with reservoirs that have rapid flushing rates and no thermal stratification during summer. Most shorelines are steep with relatively little littoral area in comparison to their size. Rapid water exchange and relatively featureless shorelines severely limit juvenile anadromous salmonid rearing area. The majority of reservoir margins are undeveloped, and riparian habitat adjacent to the reservoir is sparse, characteristic of the dryland climate.

Whitefish, trout and char were the dominant resident species prior to reservoir inundation. The change from lentic to lotic environment undoubtedly reduced the resident salmonid fish populations. Under present conditions, few salmonids reside in the reservoir and their numbers represent less than one percent of the total fish numbers sampled (Dell et al. 1975; Zook 1983; Mullan et al. 1986). Habitat alteration created a subsequent shift in species composition toward dominance by cool water non-game species.

Non-game fish such as sucker, chub, squawfish and shiners, make up the majority of the reservoir resident fish population. An initial "explosion" of non-game fish after inundation was followed by a reduction and, over the last decade, an eventual leveling off of non-game species. Mullan (1986) theorized that the mid-Columbia reservoirs are dominated by trophic generalists, such as cyprinids, in part because of minimal predation. The reservoirs lack a substantive population of highly piscivorous keystone predators such as walleye (Burley and Poe 1994). Mullan (1986) states that, "Systems lacking piscivores, as in mid-Columbia reservoirs, are competition dominant." Growth and production are stifled due to lack of resources, with a large component of the energy intake going into maintenance activities (Regier et al. 1979).

Factors with the potential to affect the rearing capacity of reservoirs include flushing rate, thermal regime, degree of primary and secondary productivity, level of submerged macrophyte growth, deposition of fine sediment, water quality conditions and fluctuating water levels. An assessment of these factors in mid-Columbia River reservoirs related to their effects on rearing habitat is discussed below.

3.4.2.1.2. Reservoir Flushing and Turnover Rate. Water retention, or flushing rate, of reservoirs is a function of the total reservoir volume divided by inflow over a given period of time. The flushing rate for the mid-Columbia River PUD reservoirs ranges from a low of 0.2 days (5 hours) at Rock Island in June to a high of approximately 10 days at Wanapum in September depending upon river flows and reservoir volume. The mean annual flushing rate ranges between 0.6 and 5.6 days and averages 2.6 days for the five mid-Columbia PUD reservoirs. Such rapid flushing rates are primarily related to the shallow depths of the reservoirs. Average water velocity through the mid-Columbia reach from Wells tailrace to Priest Rapids dam at river flows between 79 and 270 kcfs is estimated to be 0.9 to 3.1 fps. (Chapman et al. 1994a). Reservoir flushing rate is an important consideration for aquatic productivity as discussed below.

3.4.2.1.3. Aquatic Productivity, Zooplankton Abundance. Aquatic productivity is typically high in free-flowing sections of mainstem rivers. Dauble et al. (1980) found a diverse aquatic macroinvertebrate and zooplankton community in the Hanford Reach below Priest Rapids dam. Reservoir inundation typically decreases productivity and diversity of benthic and limnetic invertebrate fauna (Mullan 1986). Productivity of the mid-Columbia reservoirs is limited by rapid flushing rates, cold temperatures and lack of shallow water areas. The invertebrate community is dominated by chironomidae, oligochaetes and zooplankton (Falter et al. 1991; Rondorf and Gray 1987). Thus, anadromous salmonid juveniles, which prefer large, high energy content food items such as trichoptera (see Section 2.2) switch first to chironomids then to zooplankton as abundance of the former food items declines (Rondorf and Gray 1987). Therefore, productivity may limit the feeding efficiency of juvenile anadromous salmonids, which must expend more energy to capture lower energy content prey in the reservoirs as compared to free-flowing reaches (Rondorf and Gray 1987).

Most of the primary and secondary production potential in the mid-Columbia region is generated from upstream sources due to the slow turnover rate, large storage capacity and source of nutrients. Lake Roosevelt (upstream of Grand Coulee dam) is the single most important factor influencing aquatic productivity in the downstream PUD reservoirs (Rensel 1993).

The thermal regime of the mid-Columbia River is also influenced by releases from Grand Coulee dam, which has the largest storage capacity of any reservoir on the U.S. portion of the Columbia River system. Lake Roosevelt exhibits strong thermal stratification during summer months. Since Grand Coulee dam is not equipped with selective depth-withdrawal facilities, downstream water temperatures are heavily dependent on the depth of the Lake Roosevelt thermocline.

The flow-through characteristics of the mid-Columbia dam reservoirs result in primary productivity being largely dependent on detritus, sessile (attached) algae and macrophytes (Mullan 1986). The turnover time of water in the pool is too short in summer to permit development of extensive and diverse zooplankton communities.

3.4.2.1.4. Submerged Macrophytes. Submergent aquatic plants are increasing in some of the mid-Columbia reservoirs. The benthic community in these submerged macrophyte beds is similarly increasing as riverine macrophytes effectively create substrate by velocity reduction and subsequent particle trapping, encouraging settling of organic-rich soils (Falter et al.

1991). Macrophyte beds eventually increase the production of benthic food organisms, as well as providing additional surface area for algae and invertebrates. They may also provide cover for rearing juvenile anadromous salmonids and other fish species.

The dominant species within the aquatic plant communities in the mid-Columbia PUD reservoirs (Truscott 1991) is non-native Eurasion watermilfoil (*Myriophyllum spicatum*), which forms large, dense monotypic beds with a relatively low volume to edge ratio. These conditions may not provide as much cover and rearing opportunities as native plants, but they still offer substantial habitat for shallow water fishes (Engel 1990, 1995). Only under very dense conditions would milfoil act to reduce the productive capacity of aquatic habitats.

Given the steep bathymetry of the reservoirs, it is not likely that the density of submerged macrophytes will become a problem for fish rearing. Therefore it is reasonable to conclude that continued development of macrophyte beds in the reservoirs should improve aquatic productivity in the reservoir and benefit shallow water fish rearing.

3.4.2.1.5. <u>Fluctuating Pool Levels and Potential for Fish Stranding</u>. Many small fish, including chinook salmon fry, use shallow water habitat and embayments. Chinook salmon fry move into shallow, quiescent habitat at night (Hillman et al. 1989b). This characteristic is apparently typical of most salmonids of all life stages and sizes (Campbell and Eddy 1988). Trenches or depressions in the river bottom can form isolated pools at low reservoir levels. Juvenile fish trapped in such pools can perish from desiccation, if the pool drains as water moves through the substrate, or increased predation.

Two types of shoreline and bottom configurations can increase the potential for juvenile fish stranding. Backwater embayments with shallow, narrow entrances to the main river (e.g., a bar across the entrance) have the potential to isolate large numbers of juveniles from the main channel. Such sites may sustain juvenile fish trapped in the embayment for short periods of low reservoir elevation, but expose the fish to increased predation. Extensive flat areas of the reservoir bottom that are exposed at low reservoir levels may also trap juveniles in shallow pools and channels that form in depressions in the substrate. Juvenile fish stranded in such a manner would not survive if water levels stay low for more than an hour or two (The Chelan PUD 1991c). However, mid-Columbia River reservoirs generally consist of steep morphologies along the river margins and have very little backwater or shallow areas (Zook 1983) thereby reducing the potential for stranding juvenile fish.

Changes in reservoir water elevations result from two process: 1) reservoir drafting that creates a reduction in forebay elevations; and 2) flow decreases that affect tailrace elevations. Mid-Columbia River reservoir drafting, by itself, poses little risk for stranding juvenile fish because drafting is infrequent, and forebay levels change slowly (generally less than 3 inches per hour) since the surface areas of the forebays are large in comparison to the hydraulic capacities of the powerhouses. Thus, juveniles have time to leave the shallows (The Chelan PUD 1991c). Coordinated operation of the hydroelectric system from Grand Coulee dam to Priest Rapids dam strives to hold all reservoirs as close to full as possible to optimize gross head (mid-Columbia Hourly Coordination Agreement). Flow reductions following evening peaking may create rapid decreases immediately downstream of the projects. However, backwater effects from the downstream reservoir tailrace elevations moderate rapid reservoir elevation fluctuations and reduce the potential to strand juvenile fish.

3.4.2.1.6. Deposition of Tributary Bedload and Fine Sediment, Rearing Effects. Increased storage in upriver reservoirs has reduced the frequency and magnitude of floods in the Columbia River. Reduced river velocities have increased the amount of fine sediments present in the cobble substrate, especially in the lower portions of the reservoirs.

Silt built up in the delta of tributaries entering the mid-Columbia River reservoirs has formed mud flats in some areas. Tributaries deposit bedload material as the streams discharge into reservoirs, creating alluvial fans at the confluences. Fine sediment loading in some tributaries is considered high. Excessive deposition of fine sediment can result in loss of cover and altered invertebrate production. Quantitative data on delta sediment composition are lacking; however, the effects appear localized. In general, these areas increase shallow margin habitat and encourage the growth of submerged macrophytes. As a result, these areas are potentially productive sites that could indirectly benefit long-term rearing production of anadromous salmonids and lamprey (Mullan et al. 1992a; Chapman et al. 1994a).

3.4.2.1.7. Water Quality. Water quality in the mid-Columbia reach is influenced by Grand Coulee dam and mid-Columbia PUD projects have limited capability for flow regulation. Dissolved oxygen is adequate in all reaches, with exception of some extreme backwaters where aquatic weed growth restricts water flow. Turbidity is generally very low in the reservoirs (Rensel 1993). Additional information regarding water quality in the mid-Columbia reach is found in Section 2.1.7, Water Quality.

3.4.2.2. Status of In-Stream Rearing. The importance of mainstem Columbia River reservoir habitat for rearing juvenile anadromous salmonids varies by species and race/deme. Stream-type (spring) chinook, steelhead and sockeye do not appear to use the shoreline habitats of the mainstem Columbia River, but outmigrate in the mid-channel areas of reservoirs. The river is regarded as a migration corridor in which food may be encountered. Limnetic zooplankton and drift may be a primary source of food in the diets of yearling outmigrants (Healy and Jordan 1982; Ledgerwood et al. 1991b; Burley and Poe 1994).

3.4.2.2.1. Ocean-type (Summer and Fall) Chinook. Ocean-type (summer and fall) chinook salmon juveniles use the mainstem reservoirs for rearing in late spring and early summer (Chapman et al. 1994a; Burley and Poe 1994). Recently emerged ocean-type chinook juveniles rear throughout the shallow, low velocity areas of the reservoirs in April and May. After reaching approximately 50 mm in size, they move slightly offshore into faster flowing water and typically establish feeding territories along the river bottom (Campbell and Eddy 1988; Rondorf and Gray 1987; Hillman et al. 1988; Chapman et al. 1994a). Chinook may sight feed on limnetic species when available, but prefer benthic macroinvertebrates in the drift when rearing (Chapman et al. 1994a). Based on these criteria, it appears that most suitable chinook rearing habitat is found in the upstream portions of the reservoirs, where river velocities are greater and the substrates are coarser (less fine sediment) than downstream in the reservoirs. However, no surveys have been done in the mid-Columbia reservoirs to determine habitat preferences and rearing areas of ocean-type chinook salmon.

3.4.2.2.2. Summer Steelhead. Ninety percent of the steelhead production upstream of the Priest Rapids project occurs in hatcheries (Chapman et al. 1994b). The balance of the production occurs in the tributaries, although some minor amount of reservoir rearing may occur during overwintering.

3.4.2.2.3. Rainbow Trout. The small number of resident rainbow trout present in mid-Columbia reservoirs are likely the result of hatchery steelhead and resident rainbow trout production programs. Resident rainbow trout do not appear to be self-sustaining in the reservoirs. Infrequent observations of rainbows in fishway viewing facilities suggest random sightings rather than a discrete spawning run (Zook 1983).

Self-sustaining populations of rainbow, cutthroat and brook trout are maintained in the tributaries (Zook 1983). Based on this evidence, the rearing potential for steelhead and resident rainbow is believed to be limited in the reservoirs.

3.4.2.2.4. Sockeye. Although sockeye could conceivably rear in the reservoirs, the rapid flushing rate, low primary productivity and lack of abundant zooplankton limit production potential. The Wells pool may be a source of rearing habitat for the small but sustained run of Methow River sockeye (Bickford 1994; Chapman et al. 1995b), and the Rocky Reach pool for the remnant run of Entiat River sockeye (Mullan 1986; Chapman et al. 1995b).

3.4.2.3. Previous and Existing Mitigation Measures. Mitigation for anadromous salmonid losses at the projects, including lost spawning and rearing habitat due to reservoir impoundment, has been stipulated in the Settlement Agreements and in prior mitigation agreements.

3.5. Predation.

3.5.1. Causes of Increased Predation. Construction of hydropower facilities on the mid-Columbia River have created impoundments with habitat more conducive to predators compared to the pre-impounded free flowing river. Changes in physical habitat, water quality and downstream passage conditions have combined to increase the abundance of predators and the risk of juvenile outmigrant mortality due to predation (Mullan et al. 1986; Chapman et al. 1994a). Dams present an obstacle to the downstream migration of juvenile anadromous salmonids, often causing them to concentrate in forebays before finding a route past the dam. Concentrations of juvenile anadromous salmonids provide a ready food supply for predators that congregate at such sites (Beamesderfer and

Rieman 1991). Passage through turbines, spillways or bypass facilities may stun, disorient or injure some juvenile anadromous salmonids, making them less capable of escaping predators. Sediment that formerly would have been suspended during high spring flows settles out in upstream impoundments, resulting in reduced turbidity in the mid-Columbia River. Clearer water makes juvenile outmigrants potentially more visible and more susceptible to predation.

In addition to juvenile outmigrants being more susceptible to predators while migrating past the dams, the number of predators is presumed to have increased to levels greater than pre-impoundment in the mid-Columbia reach. The deep, low velocity habitat created by impoundments is preferred by northern squawfish (*Ptychocheilus oregonensis*), the major native predator fish of juvenile anadromous salmonids. Two gamefish species, walleye and smallmouth bass, were introduced into the Columbia River system in the 1940s to 1950s to provide sportfishing opportunities (Henderson and Foster 1956; Zook 1983). These piscivorous gamefish have become established in the mid-Columbia reservoirs, and they also prey on juvenile anadromous salmonid outmigrants. The following sections provide a general background description of predation in the mid-Columbia reach, and they identify potential methods for reducing predation-related mortality of juvenile anadromous salmonids. Specific measures to reduce predation-related mortality of juvenile anadromous salmonid outmigrants are described in Section 4.5.

3.5.2. Resource at Risk. Juvenile anadromous salmonids are exposed to predation as they migrate downstream through the mid-Columbia system. Table 3-7 summarizes the species, size and age of juvenile outmigrants in the mid-Columbia. Juvenile anadromous salmonids, on the other hand, are preyed upon frequently as they migrate downstream through the mid-Columbia reach (Burley and Poe 1994).

The annual juvenile anadromous salmonid outmigration has two distinct temporal peaks; one in the late spring and one in the mid-summer. The spring peak of the juvenile anadromous salmonid outmigration occurs in late April and early May, and is primarily composed of stream-type (spring) chinook and sockeye salmon and steelhead. Outmigrating stream-type chinook, and steelhead, called yearling migrants, have reared for one or more years in artificial production facilities or in

Table 3-7. Juvenile migrant species, size and age in mid-Columbia.

Species	Size TL (mm)	Age	Migration Timing
Stream-type (spring) chinook			
Hatchery	126-171[1]	1+	Spring
Natural production	76-102[2]	1+	Spring
Ocean-type (summer and fall) chinook			
Hatchery	93-126[1]	0+	Summer
Hatchery	149-171[1]	1+	Summer
Natural production	25-105	0+	Summer
Steelhead			
Hatchery	177-224[1]	1+	Spring
Natural production	127-203[3]	2-3	Spring
Sockeye			
Hatchery[4]	70-109[1]	1+	Spring
Natural production	76-127[3]	2-3	Spring
Lamprey			
Natural production	122-303[5]	5+	Spring

[1] FishPro 1995

[2] McGee et al. 1983

[3] Zook 1983

[4] Size when released into rearing lake

[5] Scott and Crossman 1979

tributary streams and exceed 70 mm total length. Hatchery-produced fish may be 50 mm larger than naturally produced juveniles of the same age. Hatchery-produced stream-type chinook and steelhead may be released en masse into the river system or into acclimation ponds from where the fish leave volitionally.

Juvenile ocean-type (summer and fall) chinook dominate the summer peak of outmigrating salmonids. These fish migrate downstream as subyearlings, juveniles that have reared for less than one year in freshwater and thus tend to be smaller than the stream-type chinook, which move through earlier in the season (Chapman et al. 1994a). Smaller ocean-type chinook use the littoral areas of impoundments during migration, typically moving downstream slowly along the reservoir margins. As the fish grow they begin to use the mid-channel areas more frequently (Chapman et al. 1994a). As with stream-type chinook, ocean-type hatchery fish tend to be larger than wild fish of the same age are either released directly into the mid-Columbia River or to acclimation ponds from which they enter the river volitionally.

3.5.3. Predators.

3.5.3.1. Fish. The principal predators in the mid-Columbia system are piscivorous fish, including one native species, the northern squawfish, and two introduced gamefish, walleye and smallmouth bass. A brief life history of each of these predators follows. Table 3-8 summarizes the life history and habitat preferences of these three predator species.

3.5.3.1.1. Northern Squawfish. The northern squawfish is a slow-growing, long-lived predator. Northern squawfish spawn during the summer on gravelly riffles or beach areas. Spawning occurs from late May to early July. Northern squawfish are mass spawners; large groups of males congregate at the spawning sites. Solitary females move in quickly to lay eggs, then leave. Eggs hatch approximately one week later. Juvenile northern squawfish utilize shallow areas with submerged vegetation. As they grow, northern squawfish move into deeper water. In summer, adult northern squawfish prefer shallow, low velocity areas in cool lakes or rivers. During the winter they use deeper water and pools (Scott and Crossman 1973).

Northern squawfish pose the greatest predation threat to migrating juvenile anadromous salmonids in the Columbia River system because of their number and distribution. Northern squawfish accounted for over 75 percent of the total catch of predator fish in the mid-Columbia during a recent survey (Loch et al. 1994). Because of the concentrations of prey and favorable hydraulic conditions, areas adjacent to and downstream of tailraces have become preferred habitat of northern squawfish. The distribution of northern squawfish in dam tailraces appears to be related to water discharge and velocity distributions (Faler et al. 1988). Laboratory experiments have suggested that large northern squawfish become fatigued quickly at water velocities above 3.3 fps (Mesa and Olsen 1993). In a study at McNary dam on the lower Columbia River, northern squawfish remained in backwaters and sheltered areas away from the dam when velocities exceeded 3.3 fps. When the velocity dropped to around 2.3 fps, the northern squawfish moved in close to the dam and juvenile bypass outfalls (Faler et al. 1988).

Northern squawfish apparently congregate near the tailrace to take advantage of the ready food supply. Northern squawfish are opportunistic feeders that concentrate specifically on the food source that is most abundant and easiest to obtain. The gut contents of northern squawfish collected from the tailrace sampling areas at all of the mid-Columbia projects contained a higher proportion of juvenile salmonids than squawfish collected in the forebays or mid-reservoirs of the same projects (Sauter et al. 1994). In a study conducted in the John Day reservoir from 1983 to 1986, juvenile salmonids accounted for 21 percent of the diet of 300 mm northern squawfish and 83 percent of the diet of larger squawfish (Poe et al. 1991). The length of juvenile salmonids consumed by northern squawfish also increases progressively with the length of the squawfish (Figure 3-2).

Table 3-8 . Summary of life history traits of major predators in the mid-Columbia system (from Wydoski and Whitney, 1979).

Species	**Life span (yrs)**	**Adult size FL (mm)**	**Adult habitat**	**Common prey items**	**Preferred life history Temperature (°C)**	**Preferred spawning habitat**	**Type of spawning**	**Timing of spawning**	**Size at onset of piscivory (mm)**
Northern squawfish	16-20[1]	600[1]	Shallow areas of lakes. Areas of slow to moderate current in rivers	fish; crustaceans; aquatic invertebrates[1]	16-22[1]	Riffles or rocky shoals with gravel substrate[1]	Broadcast	June-Aug[1]	175[2]
Smallmouth bass	6-10[3]	300[3]	Moderately shallow water over riffles or shoals in lakes or rivers[3]	fish; crustaceans; aquatic invertebrates[1]	21-27[1]	Sloughs, littoral areas with sand and gravel bottoms[4]	Nest builders	April-June	75[1]
Walleye	10-12[3]	750[4]	Deep or turbid lakes or large streams	fish	13-21[3]	fast, turbulent water over gravel/cobble or rocky shoals[3]	Broadcast	April-June	150[1]

[1] Wydoski and Whitney, 1979

[2] Poe et al. 1991

[3] Scott and Crossman, 1973

[4] Zook et al. 1983

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Species	**Life span (yrs)**	**Adult size FL (mm)**	**Adult habitat**	**Common prey items**	**Preferred life history Temperature (°C)**	**Preferred spawning habitat**	**Type of spawning**	**Timing of spawning**	**Size at onset of piscivory (mm)**
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[1] Wydoski and Whitney, 1979

[2] Poe et al. 1991

[3] Scott and Crossman, 1973

[4] Zook et al. 1983

Juvenile salmonids are not a major prey species for northern squawfish in riverine environments under natural conditions (Brown and Moyle 1981). A study in the free-flowing portion of the Willamette River found that only 2 percent of the northern squawfish stomachs sampled contained juvenile salmonids, despite the fact that sampling took place during the peak juvenile salmonid outmigration (Buchanan et al. 1981).

3.5.3.1.2. Smallmouth Bass. Smallmouth bass are a gamefish that have inhabited the mid-Columbia reach since at least the 1940s (Henderson and Foster 1956). Preferred habitat for this species includes rocky shoals, banks or gravel bars. Adult smallmouth bass in the mid-Columbia are most abundant around the deltas of warmer tributary rivers. The optimal temperature range for this species is from 21 to 27 °C, which is higher than the temperatures typically observed in the mid-Columbia reservoirs. Ideal spawning temperatures for this species range from 15.5°C to 18.5°C, with spawning occurring generally from May to July (Wydoski and Whitney 1979). However, such temperatures do not occur consistently in the mid-Columbia reservoirs until late summer. Smallmouth bass build and defend nests in sloughs and littoral areas with sand and gravel substrates. Such areas are generally lacking in the mid-Columbia system. It is believed that primary natural reproduction of smallmouth bass in the mid-Columbia occurs only in the free-flowing Hanford Reach below Priest Rapids dam (Zook 1983). However, young-of-year smallmouth bass have been captured during gatewell dipping operations at Grant County PUD projects, indicating that some natural production is occurring in Priest Rapids and Wanapum reservoirs (Carlson, pers. comm., 11 July 1995). A well established smallmouth bass population exists throughout the Okanogan River, and is believed to be the primary source of adult bass encountered in mid-Columbia reservoirs.

In a 1993 survey of the mid-Columbia system conducted by the National Biological Survey (NBS) and the WDFW, smallmouth bass were the second most abundant predator species captured, but accounted for only nine percent of the total catch (Sauter et al. 1994). The majority of the bass caught in the 1993 NBS survey were taken from the reservoir forebays, and the fewest from the tailraces (Burley and Poe 1994). The overall abundance of smallmouth bass in the mid-Columbia system appears to be low.

The preference of smallmouth bass for low velocity shoreline areas in the mid-Columbia reservoirs may reduce their predation on some juvenile salmonid outmigrants. While juvenile stream-type salmonid outmigrants move through the mid-reservoir areas and may avoid interactions with smallmouth bass, juvenile ocean-type salmonid migrants use the shoreline areas and may become an important prey item for smallmouth bass (Poe et al. 1991). In a recent study conducted at the upstream end of McNary reservoir, juvenile salmonids were the major prey items for all size groups of smallmouth bass during the summer, representing 59 percent of their diet (Tabor et al. 1993). All identifiable consumed salmonids were categorized as ocean-type chinook salmon smaller than 85 mm.

3.5.3.1.3. Walleye. Walleye are a cool water, piscivorous gamefish believed to have moved downstream into the mid-Columbia reach from a population established for recreational fishing in Lake Roosevelt in the late 1950s (Zook 1983). Walleye are large fish, with an average size of approximately 750 mm at an age of 10 years (Zook 1983). Walleye have fairly general spawning requirements, preferring coarse gravelly substrates in fast, turbulent water in rivers, or along gravelly beaches (Scott and Crossman 1973). Suitable spawning habitat appears to be plentiful in the mid-Columbia. Although spawning is suspected to be occurring, evidence of successful reproduction has not been observed (Zook 1983). Temperatures in the mid-Columbia tend to be lower than is considered optimum for fry survival (Mullan et al. 1986). The quiet, highly productive habitat required for juvenile rearing is also scarce (Zook 1983). Recruitment of walleye into the mid-Columbia reservoirs is suspected to result from the entrainment of young fish through Grand Coulee dam during spring runoff (Zook 1983).

Walleye were the least abundant predator encountered in the 1993 NBS survey of the mid-Columbia, accounting for only four percent of all predators caught (Burley and Poe 1994). Of the walleye captured during this survey, eighty-nine percent were caught from dam tailraces, while the remaining eleven percent were caught in mid-reservoir and forebays (Loch et al. 1994). Numbers of walleye captured were greatest at the Wanapum and Rocky Reach projects in the mid-Columbia reach survey.

The relatively high numbers of walleye caught in dam tailraces during the spring suggest that walleye may be attracted to the concentrations of juvenile salmonids there. No specific dietary data are available for walleye in the mid Columbia. However, investigations of walleye food habits on the lower Columbia, which is generally considered to be comparable to the mid-Columbia regarding predation impacts, suggest that walleye in the tailraces are not responding to concentrations of juvenile salmonids. Juvenile salmonids accounted consistently for only 18 to 24 percent of the walleye's diet (Sauter et al. 1994), even when large concentrations of juvenile salmonids were available. Walleye observed in dam tailraces in the Columbia River system during the spring may be spawning runs. In other locations, the fast, turbulent water below dams is the preferred spawning habitat (Scott and Crossman 1973). No surveys of potential walleye spawning sites have been completed in the mid-Columbia PUD project reaches.

Adult walleye are nocturnal feeders and forage near the bottom of the reservoirs. Walleye smaller than 300 mm, which forage in shallower areas, tend to feed more heavily on juvenile salmonids in the lower Columbia River (Poe et al. 1991). Because of the generally low level of juvenile salmonid consumption and relative scarcity of walleye in the mid-Columbia reservoirs, they are not considered to have a major impact on juvenile salmonid survival migration at this time.

3.5.3.2. Gulls. Concentrations of juvenile anadromous salmonids near tailraces of the mid-Columbia projects are also susceptible to predation by birds. Ring-billed gulls are the most prevalent avian predator in the mid-Columbia reach. This is a ubiquitous species with very general habitat preferences. Ring-billed gulls are found all along the west coast from northern Washington to Mexico. The birds breed and raise their young during the summer. Young ring-billed gulls mature in three years. Gulls forage below dams where turbulent currents from the spillways and turbines carry young juvenile salmonids near the surface. Ruggerone (1986) estimated that ring-billed gulls consumed 2 percent of the salmon and steelhead passing Wanapum dam in 1982. Since that time, wires strung across dam tailraces have hindered bird access to vulnerable juvenile salmonids and, coupled with gull hazing programs, are believed to have reduced predation losses.

3.5.4. <u>Degree of Risk to the Resource</u>. Northern squawfish appear to select preferentially stream-type chinook and sockeye salmon over steelhead because of their smaller size during the spring migration period. Data collected from 1983 to 1986 in John Day reservoir indicated that northern squawfish consumed consistently more anadromous salmonids from the smaller size groups available (Poe et al. 1991). Stream-type chinook and sockeye salmon, particularly those resulting from natural reproduction, are the smallest juvenile salmonids present during the spring outmigration and, thus, sustain heavier predation losses than larger steelhead juveniles. In the study mentioned above, conducted at the John Day reservoir, stream-type chinook and sockeye salmon could not be distinguished from each other in the gut contents of northern squawfish. These species together accounted for 78 percent of the total number of juvenile salmonid outmigrants, but comprised approximately 90 percent of the juvenile salmonids consumed by northern squawfish in the John Day reservoir (Poe et al. 1991).

Because of their larger size, outmigrating steelhead are susceptible to predation only by the largest northern squawfish. While steelhead made up approximately 21 percent of the spring juvenile anadromous salmonid outmigration past the John Day reservoir from 1983 to 1986, this species accounted for only 10 percent of the prey fish eaten by northern squawfish (Poe et al. 1991).

Ocean-type chinook salmon migrating downstream during the summer months are probably the resource most at risk of predation in the mid-Columbia reach. The lower flows at this time of year allow northern squawfish to move in close to dam spillways and bypass facilities where concentrations of injured or disoriented juvenile anadromous salmonids may be found. Ocean-type chinook are the smallest juvenile migrants and prefer to migrate downstream slowly along the reservoir margins. This prolongs the time that they are susceptible to predators. Additionally, ocean-type chinook migration habitat overlaps with that of smallmouth bass, which feed heavily on salmonid fry when available. Higher water temperatures at this time of year result in all predators being more active, thereby increasing the risk of predation-related mortality on juvenile ocean-type chinook salmon.

3.5.5. <u>Quantification of Predation Losses</u>. In 1982 ODFW and USFWS, funded by BPA, began a cooperative study to estimate the number of juvenile anadromous salmonids lost to predation by piscivorous fish in the John Day reservoir. A predator indexing approach was used to estimate the magnitude of predation on juvenile salmonids by piscivorous fish (Vigg and Burley 1990). Four indices were developed to estimate the overall level of predation. These indices include:

CI (consumption index):	The number of anadromous salmonids consumed per day by an individual predator
DI (density index):	An estimate of the density of predators in the sampling area
AI (abundance index):	The abundance of predators in the sampling area (DI * surface area in hectares)
PI (predation index):	The product of consumption and abundance (CI*AI)

The results of the modeling indicated that piscivorous fish predators consumed up to 19 percent of all juvenile salmonids migrating through the John Day reservoir, and consumed up to 61 percent of ocean-type chinook (Riemen et al. 1991). Because of their abundance and high consumption indices, northern squawfish were the most significant predator, accounting for approximately 78 percent of the juvenile salmonids lost to predation. Introduced predator species, such as smallmouth bass and walleye, accounted for the remainder of the losses.

The original estimates of the total predation loss in the John Day reservoir were based on a pooled predation rate for the entire reservoir. Subsequent studies have shown that partitioning the reservoir into three or more sample areas and developing separate indices for each area provides a better estimate of the actual predation losses. Partitioning of John Day reservoir and recalculation of the predation indices reduced the estimated number of juvenile anadromous salmonids consumed by predators by 50 percent (Petersen 1994) However, predation related mortality still represented a substantial loss of juvenile salmonids during downstream migration in the lower Columbia River.

The level of predation by northern squawfish in the Mid-Columbia River was indexed in 1993 (Sauter et al. 1994; Loch et al. 1994). Each reservoir was partitioned into three sample areas: the tailrace, forebay and mid-reservoir. As in the John Day study described previously, northern squawfish were the most abundant piscivorous predator encountered in the mid-Columbia. Density index values for northern squawfish varied by location and season but were generally highest at the tailraces and increased in the summer (Loch et al. 1994; Beamesderfer and Riemen 1991). Predator index values were highest at the Rocky Reach, Priest Rapids and Wanapum tailraces.

3.6. Fish Production Facilities. The first fish hatchery in the Columbia River basin was built in 1877 on the Clackamas River, a tributary of the Willamette River in Oregon. This was the first of several hatcheries constructed through the turn of the century to support commercial fisheries.

A second phase of major hatchery construction occurred in the basin in the 1950s as a result of the Mitchell Act passed in the U.S. Congress in 1938. Today, there are approximately 90 fish production facilities in the Columbia Basin that support important Indian treaty, sport and commercial fisheries. The annual catch from Mitchell Act facilities alone averaged 2 million adult anadromous salmonids per year between 1960 and 1985. It is estimated that hatchery fish currently account for 70 percent of spring chinook in the basin, 80 percent of summer chinook, 50 percent of fall chinook and 70 percent of steelhead (BPA et al. 1994a).

3.7. Hatchery Production in the Mid-Columbia Reach.

3.7.1. Grand Coulee Fish Maintenance Project. To compensate for the affects of Grand Coulee Dam, the Grand Coulee Fish Maintenance Project (GCFMP) initiated by the Federal Bureau of Fisheries in 1939. The program was implemented as a result of construction of Grand Coulee dam on the Columbia River. No adult fish passage facilities were built into the dam, resulting in the loss of 1,140 lineal miles of anadromous fish spawning and rearing habitat above the project. The last run of adult salmon and steelhead to pass the Grand Coulee site occurred in 1938.

The GCFMP stated that hatchery production would be used to replace lost anadromous fish resources. The earliest plans called for a facility to be sited downstream of Grand Coulee dam; however, lack of a suitable water supply and engineering difficulties related to collection of broodstock made these plans impracticable. As an alternative, a plan was developed to relocate the anadromous runs blocked by the Grand Coulee dam to the Okanogan, Methow, Wenatchee and Entiat Rivers. At the time, the salmon and steelhead runs in these rivers were severely depressed; it was believed these rivers were capable of supporting several times their existing production.

The revised plan for the GCFMP called for trapping all adult chinook, sockeye, coho and steelhead that appeared in the fishways at Rock Island dam. These fish were to be transferred to a planned hatchery facility on Icicle Creek, a tributary of the Wenatchee River, approximately 40 miles from Rock Island dam. This hatchery was to hold and spawn the adults, supply eyed eggs to substations on the Entiat, Methow and Okanogan Rivers and provide fingerlings for stocking the Wenatchee River system.

It was evident that the GCFMP hatchery facilities could not be constructed in time to accommodate the 1939 run of anadromous salmonids, and interim plans were made to propagate stocks via natural spawning. Natural holding areas, combining resting pools and spawning riffles, were established in three of the tributaries. Fish were impounded in the holding areas behind picket racks. Spring-run steelhead and spring chinook were propagated in Nason Creek, a tributary of the Wenatchee River. The mainstem Wenatchee and Entiat Rivers were used to propagate summer chinook and fall steelhead. Lake Wenatchee and Lake Osoyoos were used for sockeye. Spawning at these sites in 1939 resulted in natural propagation being given equal emphasis as hatchery propagation in subsequent years of the program.

The Leavenworth hatchery on Icicle Creek was completed and put into operation in 1940. Adult holding and spawning, as well as incubation of eggs to the eyed stage were conducted at the hatchery. Over the years, varying numbers of eyed eggs were shipped to the Entiat and Winthrop substations for hatching, rearing and release. Fingerlings were also released to the Wenatchee River directly from the hatchery. A summary showing the range of the production activities for the years between 1940 and 1947 is found in Table 3-9.

Table 3-9. Fish production activities of the GCFMP from 1940 to 1947.

	Production Range		
Species	**Spawned**	**Eggs Collected**	**Fingerlings**
Spring Chinook	20 - 1,284	51,800 - 2,900,000	30,124 - 2,300,000
Summer Chinook	11 - 1,062	17,457 - 3,900,000	? - 1,600,000
Sockeye	20 - 3,791	19,500 - 6,000,000	12,459 - 1,008,312
Coho	6 - 152	7,400 - 210,855	5,470 - 151,812
Fall Steelhead	341 - 1,043	824,463 - 3,159,523	266,155 - 1,521,609
Spring Steelhead	12 - 517	? - 1,440,264	? - 899,114

Source: Fish and Hanavan 1948.

prod-act.ov4

Between 1939 and 1943, the GCFMP program collected and used all adult anadromous salmonids that arrived at the Rock Island dam fishways. After 1943, portions of the adult returns were allowed to pass through the fishways to migrate and spawn naturally.

The facilities developed for the GCFMP have evolved into the Leavenworth, Entiat and Winthrop National Fish Hatcheries (NFH) operated by the USFWS. They have operated continuously since their creation.

The implementation of GCFMP had a profound impact on the genetic makeup of the current stocks of the mid-Columbia region. All races/demes of spawning an anadromous fish in the mid-Columbia tributaries originated from a mix of fish collected at Rock Island dam between 1939 to 1943 under the GCFMP. Because of the implementation of the GCFMP over this period, all of these races/demes became homogenized both temporally as well as geographically. Since the GCFMP era, there has been extensive mixing of progeny of hatchery broodstock with progeny of wild spawning adults in tributaries and mainstem areas. Recent electrophoretic analysis has demonstrated the high genetic similarity between adults from the various tributaries (Chapman et al. 1994a). NMFS has determined that mid-Columbia stocks of spring chinook, summerfal chinook and steelhead each constitute single ESUs, while the two sockeye populations are separate ESUs (Bushy, et al, 1995; Waknitz, et al, 1995; Gustafson, et al, 1997; and Meyers, et al, 1998).

3.7.1.1. Compensation for Habitat Inundation. A second phase of hatchery development in the mid-Columbia region occurred between 1961 and 1967 with the construction of four main facilities. These facilities were intended to compensate for lost production in the mainstem mid-Columbia caused by pool inundation by the five PUD mainstem projects. Three sites, Priest Rapids, Turtle Rock and Wells, were developed originally as spawning channels. However, they had limited success due to high pre-spawning mortality, and in the early 1970s were converted into conventional fish production facilities and their programs modified accordingly. The other site, Chelan hatchery, was a conventional hatchery. All facilities are still in operation.

3.7.1.2. Compensation for Tributary Losses. The third phase of hatchery development in the mid-Columbia region has occurred since 1989 with the development of several sites for the enhancement of tributary production. The programs are the result of long-term settlement agreements for the Wells and Rock Island projects and are compensation for anticipated fish passage losses. The facilities include the Methow hatchery and its two satellite acclimation ponds; the Eastbank hatchery and its five satellites; and experimental facilities at Cassimer Bar hatchery.

3.7.2. Current Hatchery Production. The current hatchery production and facilities are described in an exhibit to the Anadromous Fish Agreement and Habitat Conservation Plan. Recent production numbers are summarized in Table 3-10.

The PUD hatchery facilities are operated by the WDFW with the exception of the Cassimer Bar facilities which are operated by the Colville Tribe. WDFW has obtained a Section 10 permit Incidental Take Permit under the ESA to address activities which might impact listed Snake River species. The permit includes coverage of the PUD hatcheries operated by WDFW.

3.7.3. Current Issues. Concerns relating to hatchery production can be classified into two main categories. The first category involves direct interactions between hatchery and wild races/demes, including the following:

- competition
- predation
- disease

The second category encompasses concerns relating to race/deme integrity and genetic diversity of both captive and wild fish. These include:

- extinction
- inadvertent artificial selection
- loss of within-population variability
- loss of between-population variability

Table 3-10. Production goals for 1994 for anadromous salmonid hatcheries in the mid-Columbia basin (page 1 of 3).

Facility / Species	Stock	lbs.	Number	Age Group	Length (mm)	Release Location	Month
Cassimar Bar Hatchery							
Sockeye	Okanogan	150	15,000	0+	68	Transfer: L. Osoyoos NP	Apr
Sockeye	Okanogan	1,038	95,500	0+	70	Lake Osoyoos	May
*Lake Osoyoos Net Pens							
Sockeye	Okanogan	176	15,000	0+	72	Lake Osoyoos	May
Chelan Hatchery							
Summer steelhead	Wells	13,333	200,000	0+	145	Transfer: Turtle Rock	Nov
Rainbow trout	Mt. Whitney	20,000	195,000	1+	190	Local lakes	May-Aug
Resident cutthroat	Twin Lakes		65,000	0+	70	Lake Chelan	Oct
Kokanee	L. Whatcom		2,000,000	0+	45	Lake Chelan	May
Eastbank Hatchery							
Summer steelhead	Wells	33,333	200,000	1+	195	Entiat R., Wenatchee R.	Apr-May
*Chiwawa Acclimation Pond							
Spring chinook	Chiwawa	53,760	672,000	1+	160	On-station	Apr-May
*Carlton Acclimation Pond							
Summer chinook	Wells	32,000	400,000	1+	160	On station	Apr-May
*Dryden Acclimation Pond							
Summer chinook	Wenatchee	69,120	864,000	1+	160	On station	Apr-May
*Similkameen Acclimation Pond							
Summer chinook	Wells	46,080	576,000	1+	160	On station	Apr-May

Table 3-10. Production goals for 1994 for anadromous salmonid hatcheries in the mid-Columbia basin (page 2 of 3).

Facility / Species	Stock	lbs.	Number	Age Group	Length (mm)	Release Location	Month
*Lake Wenatchee Net Pens							
Sockeye	Wenatchee	1,000	200,000	1+	110	On station	Oct
Entiat NFH							
Spring chinook	Entiat	20	2,000	0+	80	Transfer: USFWS Res.	Apr
Spring chinook	Entiat	4,000	400,000	0+	80	On station	May
Spring chinook	Entiat	40,000	400,000	1+	170	On station	Apr
Leavenworth NFH							
Spring chinook	Leavenworth	80	2,000	1+	125	Transfer: USFWS Res.	Jan
Spring chinook	Leavenworth	162,500	1,625,000	1+	170	On station	Apr
Methow Hatchery							
Spring chinook	Chew., Tw.	32,353	550,000	1+	145	Transfer: Che., Twisp	Feb-Mar
Spring chinook	Methow	16,667	250,000	1+	150	On station	Apr
*Chewuch Accimation Pond							
Spring chinook	Chewuch	16,667	250,000	1+	150	On station	Apr
*Twisp Acclimation Pond							
Spring chinook	Twisp	16,667	250,000	1+	150	Onstation	Apr
Priest Rapids Hatchery							
Fall chinook	Priest Rapids	100,000	5,000,000	0+	95	On station	Jun
Fall chinook	Little White	34,000	1,700,000	0+	95	On station	Jun
Rocky Reach Hatchery							
Fall chinook	Wells, Priest			0+		Transfer: Turtle Rock	

Table 3-10. Production goals for 1994 for anadromous salmonid hatcheries in the mid-Columbia basin (page 3 of 3).

Facility / Species	Stock	lbs.	Number	Age Group	Length (mm)	Release Location	Month
Turtle Rock Ponds							
Summer chinook	Wells	29,400	1,600,000	0+	95	On station	May-Jun
Fall chinook	Priest Rapids	25,000	200,000	1+	170	On station	Apr
Summer steelhead	Wells	6,000	40,000	1+	195	Entiat R.	Apr-May
Summer steelhead	Wells	24,000	160,000	1+	195	Wenatchee R.	Apr-May
Wells Hatchery							
Summer chinook	Wells	24,200	484,000	0+	125	On station	Jun
Summer chinook	Wells	32,000	320,000	1+	160	On station	Apr
Summer steelhead	Wells	81,818	450,000	1+	195	Methow R.	Apr
Summer steelhead	Wells	27,273	150,000	1+	195	Similkameen R.	Apr
Summer Steelhead	Wells	1,818	10,000	1+	195	Chiwack/Twisp R.	Apr
Fall chinook	Wells	2,000	100,000	0+	95	Transfer: L. Chelan NP	May
Rainbow trout	Spokane	4,950	24,750	1+	185	Local lakes	Apr
Winthrop NFH							
Spring chinook	Winthrop	100,000	1,000,000	1+	170	On station	Apr

Source: WDFW 1995.

* Satelliate facility

progoals.ov4

3.7.4. **Interactions Between Hatchery Stocks and Wild Stocks**.

3.7.4.1. Competition. Competition between hatchery and wild juveniles may occur where food and space requirements overlap. Impacts may be highest at hatchery release sites where large concentrations of hatchery fish can overwhelm the capacity of the immediate environment. Impacts are assumed to diminish downstream as the hatchery fish disperse. The impact on wild fish from hatchery fish being released at high density may be exacerbated by hatchery fish deficiencies in foraging and habitat selection behavior. As these hatchery fish disperse, adapt to their environment, and learn to forage for natural food, competition at the release site may be reduced. Little data exists for evaluating adverse behavioral effects of hatchery fish on wild fish in the Columbia basin. One study presents evidence that larger hatchery juvenile chinook pulled smaller wild chinook with them as they migrated downstream (BPA et al. 1994a) and resulted in excessive predation by other fish on the smaller wild chinook. Other species released from the hatchery (e.g., steelhead) apparently did not affect wild juvenile chinook.

Increased migration time caused by the reservoirs could increase competition for available food supply between emigrating juvenile hatchery and wild chinook. Differences in release timing programmed into the hatchery programing could diminish competition. No studies have been conducted in the Columbia River to quantify interaction between hatchery and wild juvenile fish during the outmigration period.

3.7.4.2. Predation. Little data are available that quantify predation of hatchery fish on wild fish. Since salmonid predators are thought to prey on fish about one-third their size or less, the relative size of hatchery juveniles and wild juveniles suggests the potential for predation is low. The biggest threat from predation is likely to occur when large hatchery juveniles, such as steelhead, are released over emerging wild chinook salmon (BPA et al. 1994a).

3.7.4.3. Disease. There is limited information on the impact of infectious diseases on natural fish production in the mid-Columbia River. Recent investigations into the impacts of infectious diseases, primarily bacterial kidney disease (BKD), on wild and hatchery fish have been conducted in the Snake River. Elliott and Pascho (1994) reported results of investigations on the impacts of BKD caused by the pathogen *Renibacterium salmoninarum* to wild and hatchery fish health and horizontal transmission relative to barge transportation operations. While these investigations apply directly only to the Snake River, conclusions from these studies can be considered during project operation, facilities design and program implementation in the mid-Columbia River.

One objective of BKD investigations in the Snake River was to determine the prevalence and level of infection in hatchery and wild juvenile stream-type (spring/summer) chinook salmon. Prevalence of BKD ranged from 47 percent in summer chinook to 95 percent in spring chinook. However, the level of infection in the majority (65% to 97%) of *R. salmoninarum*-positive fish was low for nearly all sampling locations. Results from 1992 were similar to results from 1988 to 1991 monitoring. Juveniles from two hatchery populations were sampled in Idaho for comparison with wild fish. Both hatchery groups showed low prevalence and infection level for BKD. Even though prevalence and infection level appears to be low in most wild and hatchery races/demes in the Snake River, Elliott and Pascho (1994) cautioned that past research results indicate that BKD prevalence and infection level in stream-type chinook parr are poor indicators of impacts of BKD in later life stages.

Elliott and Pascho (1994) also investigated the incidence of potential horizontal transmission between BKD infected juveniles and healthy juveniles relative to the current Snake and lower Columbia River barge transportation program. Laboratory studies in 1991 and 1992 showed that *R. salmoninarum* can be transmitted from healthy brook trout, *Salvelinus fontinalis*, or chinook salmon during 48-hour exposure challenges from chinook salmon infected with BKD at levels similar to those observed during 1988 to 1991 monitoring. The laboratory studies showed that high prevalence of infection generally coincided with higher levels of infection. However, prevalence of BKD-positive fish did not exceed 14 percent in any test group.

Infection of juvenile stream-type chinook salmon was accomplished in greater than 50 percent of exposed fish within a 48-hour challenge period at a concentration of approximately $1x10^5$ *R. salmoninarum* cells per mL. However, field monitoring of transport barges detected only one incidence in only one transport barge. No incidences were detected in juvenile fish collection raceways or Columbia River water samples at higher concentrations than the 1989 investigations. The authors cautioned that although these results may indicate low impacts to juvenile migration survival from BKD infection, the effects of longer exposure to the BKD pathogen and success of horizontal transmission at these low *R. salmoninarum* concentrations are still unknown.

3.7.5. Race/deme Integrity and Genetic Diversity.

3.7.5.1. Extinction. The risk of extinction becomes a possibility when a wild race/deme is very small, and removing fish for broodstock purposes threatens the replacement rate. Early broodstock collections in the Columbia basin may have led to depletion of wild races/demes. Recent broodstock collection activities have been reduced to lower the risk of depleting wild donor races/demes.

Another risk towards extinction can result from fishing pressure on mixed races/demes. If large populations of hatchery fish become the target of heavy fishing pressure where wild races/demes are intermixed, then wild fish may be harvested inadvertently at a much greater proportion relative to their total population than hatchery fish.

3.7.5.2. Inadvertent Artificial Selection. Inadvertent artificial selection (domestication) can occur from a variety of hatchery practices that cause nonrandom mortality and selection, and where rearing and release strategies differ substantially from natural life history patterns. Inadvertent selection can be avoided through implementation of strict mating and fertilization protocols, and by ensuring that hatchery fish are, qualitatively, as similar to naturally produced fish as possible (BPA et al. 1994a).

3.7.5.3. Loss of Within-population Variability. A number of hatchery practices can lead to loss of within-population variability. Broodstock selected for particular traits can lead to loss of traits that may have benefit to the wild gene pool. Examples of this event include marked shifts in population run timing over several generations when broodstock is selected only from one segment of the natural run cycle. Loss of within-population variability can also occur where a disproportionate ratio of males are mated to females or the mating population is small. Current hatchery practices avoid these types of selections.

3.7.5.4. Loss of Between-population Variability. This type of genetic impact can occur when broodstock is collected from locations that are remote to the targeted watersheds. In the past, non-indigenous stocks and hatchery derived stocks were commonly mixed. For genetic and fish health reasons, that practice has been discontinued and race/deme transfers are limited. Crossing of unrelated races/demes can also occur with high straying rates of hatchery fish into non-targeted streams.

3.7.6. Implications for the HCP. The majority of current issues regarding anadromous salmonid production operations are common to hatcheries throughout the Pacific Northwest. Significant improvements in hatchery practices have been instituted in PUD funded facilities. However, the influence of past hatchery practices in the basin are still evident. On-going efforts by the state and PUDs strive to minimize the deleterious effects of hatchery practices on wild populations and yet ensure a harvestable surplus of anadromous salmonids.

4. Salmonid Protection Issues and Existing Mitigation Measures Specific to Rocky Reach Dam. Section 4 addresses fish protection issues and existing mitigation measures for anadromous salmonid species specific to the Project. Issues discussed include upstream and downstream passage of adult and juvenile salmonids, water quality, reservoir production, predation and fish production associated with the Project. Existing mitigation measures related to each of these issues are also described.

4.1. Upstream Passage of Adult Fish. General issues related to upstream passage of adult salmonids in the mid-Columbia River are addressed in Section 3.1. The following section addresses issues specific to existing mitigation and monitoring programs for adult upstream passage in the Project area. Timing of adult passage at the Project is detailed in Section 2.2.

Rock Island dam has three fishways, one on each shoreline and in the middle of the spillway, and a collection channel across powerhouse 2 to facilitate upstream passage of adults past the project. Adult counting stations are located on each ladder. After negotiating the dam, adults migrate through the reservoir as they pass upstream. Section 4.1.1 addresses issues and mitigation for adult passage at the dam, and Section 4.1.2 addresses issues and mitigation for adult passage through the reservoir. Generally, adult mid-Columbia River anadromous salmonids are present in the project area from April through November, although adult steelhead may be present year-round.

4.1.1. Upstream Passage at Rock Island Dam. The term adult fishway is defined in this document as all structural and operational components of adult fish passage facilities at the projects, including entrances, collection systems, ladders, water supply system, attraction jets, counting and brood stock collection facilities and exits. A full description of the structural and operational aspects of the Project's adult fishway is provided in Section 2.4. Potential biological issues related to upstream passage of adult fish via the fishway facilities include delay, adult fallback and pre-spawning mortality. The following is a discussion of these issues as they apply to the Project.

4.1.1.1. Adult Dam Passage Issues. Based on annual review by the Fish Passage Center (FPC) and the Rock Island Coordinating Committee (RICC), upstream passage facilities at Rock Island are maintained and/or upgraded as necessary during the (annual) winter maintenance period. Recently, a major study of adult anadromous salmonid migration in the project area has helped to further identify issues with passage of adult chinook salmon at the project (Stuehrenberg et al. 1995). Terms describing features of Rock Island adult collection and fishway facilities used in this section are defined as follows (in order of their use):

RPRE: Right powerhouse right entrance
RPLE: Right powerhouse left entrance
CLAD: Center ladder entrance
RPE: Right powerhouse entrance (spill)
LPHE: Left powerhouse entrance
RBFE: Right bank fishway entrance.

4.1.1.1.1. Delay. Stuehrenberg et al. (1995) indicate that adult spring, summer and fall chinook salmon quickly located the Rock Island fishway entrances in 1993 (Table 4-1). Median total dam passage times for all three races/demes of chinook salmon at Rock Island were much faster than times observed at other fishways in the mid-Columbia, lower Columbia and Snake Rivers.

Median total passage times at Rock Island dam for adult spring, summer and fall chinook salmon are shown in Table 2-1. Spring, summer and fall chinook adults required an average of 20.3, 14.6 and 19.2 hours to pass Rock Island dam during 1993 (Stuehrenberg et al. 1995). The efficiency of adult fishway entrances at Rock Island varied by location and stock in 1993. Spring and summer chinook entered the fishway primarily through the right powerhouse right (RPRE) and left (RPLE) entrances, and exited often through the right bank fishway entrance (RBFE). Fall chinook showed a strong preference for the right bank fish ladder and most frequently entered through the RBFE.

Based on these results, the RBFE was inefficient at passing spring and summer chinook salmon, but was the most effective entrance for fall chinook salmon adults. Only the RPE next to the spillway was relatively ineffective at passing all three races/demes over the Rock Island project.

No detailed radio-telemetry information regarding adult passage efficiency at Rock Island dam are available at this time for other salmonid species, such as steelhead, sockeye, or for bull trout or lamprey.

4.1.1.1.2. <u>Adult Fallback</u>. Adult fallback is defined as voluntary or involuntary downstream movement of upstream migrating adults across a dam. See Section 3.1.1 for a general discussion regarding adult fallback. Stuehrenberg et al. (1995) reported that 2.5 percent of radio-tagged spring chinook adults (5 of 197) fell back past Rock Island dam in 1993. All five of these adults successfully passed the project on the subsequent attempt. Only 2.8 percent of summer chinook salmon adults (7 of 147) fell back. Two of these fish later reascended the adult fishway, while five were last seen in the Rock Island tailrace. For fall chinook salmon, 13.2 percent (7 of 53) of radio-tagged adults fell back over Rock Island dam; one of these adults reascended the fishway, while six were last seen in the tailrace. Stuehrenberg et al. (1995) stated that they could not determine whether or not adults remaining in the mainstem below Rock Island dam had relocated to mainstem spawning areas or were unsuccessful migrants.

Stuehrenberg et al. (1995) could not determine whether or not the adult summer and fall chinook salmon that fell back and did not reascend the fishway may have "overshot" their intended destinations and fell back actively across the dam as they headed back downstream. They offered no evidence that these fish might have otherwise migrated past the Rock Island project and spawned at some upstream location. Overall, the incidence and frequency of fallback at Rock Island dam appears to be low compared to other Columbia Basin mainstem dams (Stuehrenberg et al. 1995).

No information regarding adult fallback at Rock Island dam is available for other aquatic species such as steelhead, sockeye, bull trout or lamprey.

4.1.1.1.3. <u>Adult Losses at the Project</u>. Interdam loss, defined as disappearance between two hydropower projects, is one possible component of pre-spawning mortality of adult salmonids, as are other factors such as disease, harvest, etc. Pre-spawning mortality, in turn, is defined as mortality between the time of measured escapement and the time of egg deposition (Chapman et al. 1991). See Section 3.1.1 for a discussion regarding sources of pre-spawning mortality and interdam loss in the Mid-Columbia Region. Interdam loss can be further differentiated into losses at the dam and in the reservoir and tailrace areas.

Losses of adult anadromous salmonids that may take place at Rock Island dam have not been enumerated. There are no known causes of direct adult mortality at Rock Island dam. Known causes of adult mortality that could potentially occur at Rock Island dam are total dissolved gas (TDG) supersaturation, and mortality associated with fallback over the spillway or through the turbines.

Stuehrenberg et al. (1995) found that one spring chinook salmon adult was last recorded stationary at the dam, and three were last recorded downstream of the dam. Seven adult summer chinook were last recorded downstream of the project, and three last recorded upstream of the project. Six tagged fall chinook were last recorded in the Rock Island dam tailrace, and one was last recorded in the reservoir in the vicinity of the dam (Stuehrenberg et al. 1995). The fate of the adult salmonids last recorded in the tailrace is not known, although they may have spawned there. It is not possible to compute percentages of adults either lost at the project or that spawned below the project from the data as presented in Stuehrenberg et al. (1995). Little data on adult losses at Rock Island dam are available for steelhead.

4.1.1.2. Previous and Existing Mitigation Measures. The Chelan PUD made several changes to fishway structures and operations at Rock Island dam as a result of the 1987 Settlement Agreement (FERC 1987). First, a comprehensive hydraulic evaluation of the right bank fish ladder was performed, including evaluation of the effect of tailwater elevation on the flows in the right fishway. Starting in 1988, right bank fishway channel walls were smoothed and pilasters filled to reduce friction losses in the channel, the attraction water system was modified to enhance reliability and meet criteria and lights were placed immediately upstream of the right-bank counting station to minimize avoidance by adult chinook salmon.

The fishway facilities at the Rock Island project are successful in passing adult anadromous salmonids upstream (FPC 1992, 1994). Fishway operating criteria are reviewed on an annual basis in the agreement with the RICC. The facilities are inspected annually by the FPC. Reports based on these inspections have been produced annually for 11 years and have contributed to the development of fishway operating criteria and fine-tuning of fishway operations (CBFWA 1994)

4.1.1.3. Effectiveness of Existing Mitigation. Relative effectiveness of the Rock Island fishways has been assessed by comparison of performance with other fishways in the mid-Columbia River. The adult chinook salmon radio-telemetry study conducted by Stuehrenberg et al. (1995) is the only work that provides a systematic evaluation of several mid-Columbia fishways. Based on these results, it appears that the Rock Island fishways are among the most efficient in attracting adults to the fishway entrances. The median time required for adult chinook to pass through the Rock Island collection system and enter ladder sections of the fishways was comparable to the other mid-Columbia fishway facilities. Data from Stuehrenberg et al. (1995) indicate that all races/demes of adult chinook salmon took an average amount of time to negotiate the adult fishway at Rock Island dam as compared to the other four mid-Columbia projects. The median total passage time at Rock Island dam for spring, summer and fall chinook salmon was lower than for fishways at all the other mid-Columbia projects.

No detailed radio-telemetry information is available regarding the effectiveness of existing mitigation at Rock Island dam to address potential adult passage concerns for steelhead and sockeye. It is reasonable to expect that mitigation addressing adult chinook salmon delays, fallback and losses at the project and reservoir will have similar effects on adult passage of other anadromous salmonid species.

4.1.1.4. Ongoing Monitoring. The FPC conducts annual inspections of the fishway facilities at Rocky Reach dam. The MCCC coordinates fishway modifications/improvements resulting from problems, if any, identified during the FPC inspections.

4.1.2. Upstream Reservoir Passage. Once adult anadromous salmonids pass the dam, they navigate the reservoir to reach tributary spawning areas. Rock Island reservoir has one major tributary, the Wenatchee River, which is used for spawning by most salmonid species covered by this plan. Spring and summer chinook salmon, steelhead and sockeye salmon are known to spawn in the Wenatchee River or its tributaries. Therefore, not all adult anadromous salmonids passing the dam are destined for areas upstream of Rocky Reach dam. Since counting takes place only at Rock Island and Rocky Reach dams, and occurs inconsistently in the Wenatchee River, it is not possible to enumerate losses of adult anadromous salmonids between Rocky Reach and Rock Island dams. Passage of adult anadromous salmonids through reservoirs has been documented in other areas of the Columbia River Basin (Bjornn and Peery 1992; Bjornn et al. 1994, 1995a). Only one study (Stuehrenberg et al. 1995) has been performed on the mid-Columbia River reservoirs. See Section 3.1.1 for a discussion regarding travel time and survival of salmonid species through the Mid-Columbia Region.

4.1.2.1. Adult Reservoir Passage Issues.

4.1.2.1.1. Travel Time. Travel time of adult anadromous salmonids through both impounded and free-flowing reaches is relatively well known in the Columbia River Basin. The decreased water velocity that resulted from impoundment of the Rock Island reservoir appears to have increased the speed of adult anadromous salmonid passage through the pool. Adult salmonid travel rates range from under 7 to 17 miles per day in unimpounded reaches of the lower Columbia and Snake Rivers (see Section 3.1.1). At an average rate of 13 miles per day, adult anadromous salmonids would need about 1.6 days to traverse the 20.5 miles of Rock Island reservoir. Stuehrenberg et al. (1995) found that spring, summer and fall chinook traveled the reservoir in a median time of 13.5 hours (36 miles per day), 14.3 hours (34 miles per day) and 14.4 hours (34 miles per day), respectively. These rates are considerably faster than those reported for the same species in free-flowing reaches of the lower Columbia and Snake Rivers (12 to 14 miles per day) (Bjornn and Peery 1992). Adults traveling faster through the reservoir should use less energy reserves and be less susceptible to disease, harvest and water quality effects than adults that traveled at slower speeds through free-flowing river reaches prior to dam construction.

Travel rates of other species covered by this plan through the Rock Island reservoir are unknown. See Section 3.1.1 for a discussion of steelhead, and sockeye travel rates in other mid-Columbia, lower Columbia and Snake River reservoirs.

4.1.2.1.2. Adult Passage Success in the Reservoir. As stated earlier, adult loss between projects has two components: loss at the project and loss in the reservoir. Due to lack of comprehensive fish counts in the Wenatchee River for all aquatic species covered by this plan, it is not possible to differentiate loss in the project area from turnout into the Wenatchee River. Passage success in other mid-Columbia River reservoirs varies by time of year, species and project. Loss of adult chinook salmon in the reservoir cannot be calculated from Stuehrenberg et al. (1995), since the fate of fish last tracked in Rock Island reservoir and below Rocky Reach dam is not clear. The authors could not account for three summer chinook salmon and two fall chinook salmon in Rock Island reservoir; all spring chinook salmon were accounted for. One fall chinook salmon was last tracked in the reservoir and one was last tracked at the mouth of the Wenatchee River, where it may have spawned. Twenty-six fall chinook salmon were last located in the Rocky Reach tailrace and could not be verified as passing upstream of Rocky Reach dam. These fish may have spawned in the tailrace, but the authors stated that they could not distinguish mainstem spawning adults from mortalities. These low numbers of unaccounted-for fish suggest that the survival of adult chinook salmon in Rock Island reservoir is very high.

4.1.2.2. Previous and Existing Mitigation Measures. There is no evidence to suggest that any adverse impacts on adult migration or subsequent pre-spawning survival occur in the Rocky Reach reservoir. Accordingly, no mitigation measures have ever been proposed.

4.1.2.3. Effectiveness of Existing Mitigation. Since adult salmonid passage rates through the reservoir are faster than through unimpounded rivers, no mitigation is needed for reservoir effects.

4.1.2.4. Ongoing Monitoring. Monitoring efforts specifically designed to evaluate reservoir-related impacts on adult salmonid migrants in the Project's reservoir are unnecessary due to rapid adult passage rates.

4.2. Downstream Passage of Juvenile Salmonids.

4.2.1. Downstream Passage at Rock Island Dam.

4.2.1.1. Juvenile Dam Passage Issues. Mechanisms that allow migrating juvenile salmonids to pass from the upstream to the downstream side of any dam include different combinations of the following:

- passage through a turbine;
- passage over a spillway or through a sluiceway;
- passage through a permanent juvenile bypass system;
- passage in a downstream direction through ancillary dam facilities, such as the adult fishway facilities; or
- collection of juvenile fish on the upstream side of the structure followed by transport and release on the downstream side.

Issues for each of these methods of downstream dam passage as they relate to the Rocky Reach project are presented in this section.

4.2.1.1.1. Turbine Passage. To date, the factors causing injury and mortality in turbines have been difficult to assess because it has not been possible to directly observe fish passage through turbine units. However, based on visible observation of test fish, mortality associated with turbine passage has generally been classified as either direct or indirect. Direct mortality occurs within the confines of the turbine and is assumed to originate from mechanical, pressure or hydraulic-related factors (Eicher 1987). Indirect mortality can result from conditions such as stress and backroll entrapment, which are not normally lethal in themselves, but that may result in increased risk of predation or injury during subsequent downstream migration. A more detailed discussion of factors causing turbine mortality is presented in Section 3.2.1.

Fundamental relationships as they relate to turbine passage and mortality have not yet been established between physical variables such as turbine criteria and hydrographic conditions, and biological variables such as species, size, condition and health (Iwamoto and Williams 1993). However, based on current understanding, it is often possible to suggest whether or not a particular feature will have positive or negative impact on turbine mortality. In the discussion that follows, project-specific features of the Rock Island dam turbines are noted that may affect turbine mortality. Certain characteristics of the four different turbine types need to be emphasized:

- The original construction in the 1930s installed Nagler turbines in Units 1 to 4 in powerhouse 1. The blade adjustment feature of these Nagler units is no longer functional, and these units consequently now function as fixed-blade propeller turbines.
- The large fixed-blade propeller turbines are very similar in design to the six Kaplan turbines located in Units 5 to 10 of powerhouse 1, except that the Kaplans have adjustable blades.
- The eight bulb turbines located in powerhouse 2 are a type of Kaplan turbine in that they have fully adjustable blades, but the distinguishing feature of a bulb turbine is that they are oriented horizontally instead of vertically.
- The Station Service Unit located in powerhouse 1 is a true fixed-blade propeller turbine as opposed to the modified Nagler fixed-propeller turbines in Units 1 to 4. Furthermore, the Service Station Unit has only about one-twentieth of the capacity of the larger units.

System survival studies conducted during 1982 and 1983 using juvenile stream-type (spring) chinook salmon in the mid-Columbia reach included a survival estimate for the river segment above Rock Island dam (McKenzie et al. 1984a, 1984b). By making the assumption that mortality would be equal for each of the three projects encountered between Pateros (near the confluence of the Methow River) and the Rock Island tailrace, the estimate of survival through Rock Island reservoir and dam was reported as about 87 percent in 1982 and 84 percent in 1983, for an average of about 86 percent survival (i.e., a

14 percent project mortality). There were no specific estimates made as to the portions that were associated with direct and indirect turbine mortality, reservoir effects or other factors involved with project passage.

A review of nine turbine passage studies conducted for lower Columbia and Snake Rivers dams found that Kaplan turbine-passage mortality estimates varied from 2 to 20 percent (Iwamoto and Williams 1993). Recent studies conducted at Rocky Reach dam measured direct mortality at about 6 percent for Kaplan turbines and 4 percent for fixed-blade turbines (RMC and Skalski 1994a, 1994b; RMC 1994). A study of the Rock Island bulb turbines indicated a turbine mortality rate of 3.9 percent for steelhead and 5.7 percent for coho (Anderson 1984). Studies in 1997 with yearlings chinook salmon found direct turbine passage mortality rates of 3.9% for the vertical Kaplan units, 4.3% for the bulb units and 6.8% for the Nagler turbines (Normandeau and Skalski, 1997).

Juvenile fish approaching Rock Island dam encounter different turbine intake configurations depending on whether they approach powerhouse 1 or powerhouse 2. Intakes for both powerhouses extend relatively deep into the water column. The bottoms of the powerhouse 1 intake galleries are located 73 feet below the normal headwater surface elevation, while those of powerhouse 2 are located 95 feet below the surface. Vertical distribution studies conducted at Rock Island have shown that most downstream migrants passing through turbine intakes during the day are located in the top third of the intake column; during the night they tend to be somewhat deeper and are situated in the top half of the column (Figure 4-1) (Hays 1984; Raemhild et al. 1984a; Steig et al. 1987). Juvenile fish trajectories in the turbine intake appear to follow flow lines, and fish velocities are consistent with model studies of flow for Rock Island dam (Steig et al. 1987). Based on the current understanding of flow lines through Kaplan turbines, these data suggest that most juvenile fish pass the powerhouse 1 turbines in the vicinity of the hub or the center of the blades, which is believed to provide safer passage than passing near the periphery of the blades (see Section 3.1.1).

Recent studies conducted at Rocky Reach appear to contradict the general assumption that juvenile fish passage is safer at the hub than at the periphery. Experimental juvenile fish were released at depths 10 feet and 30 feet below the turbine intake ceiling to simulate passage near the hub and periphery, respectively. Higher injury and mortality rates were associated with passage near the hub (RMC and Skalski 1994b). The direct passage mortality rate for yearling chinook passing through the first of the new Kaplan units was 5% On the other hand, survival through a fixed blade turbine, which has no gap at the hub, was higher than survival through an adjustable-blade Kaplan (RMC 1994; RMC and Skalski 1994a). Though these results are not statistically significant, they do suggest that significant mortality may occur at the hub. However, tests conducted in 1996 failed to show the same difference in survival rates between fish released at the two depths (Normandeau and Skalski, 1996).

Turbine designs with narrower gaps between the runner blades and the hub might result in reduced juvenile fish entrainment and injury.

The horizontal distribution of downstream migratory juvenile fish at the Rock Island project results in relatively even passage rates through the turbine units of both powerhouses (Raemhild et al. 1985; Steig et al. 1987). There is evidence at powerhouse 2 that spring anadromous salmonid migrants tend to approach the turbines from the right bank shore (Raemhild et al. 1985). The occurrence of spill does not appear to have a strong influence on the horizontal distribution of juvenile fish passage at powerhouse 2 (Raemhild et al. 1984a, 1985).

Control of all of the large turbines at Rock Island is accomplished through a computerized system that distributes loads across both powerhouses. The control system utilizes an electronic governor to adjust the blade angles and the wicket gate openings of the bulb and Kaplan turbines. The electronic governor also adjusts the wicket gates on the fixed-blade turbines. Based on the immediate power demands and flow conditions at Rock Island, the control system is used to turn on or off particular turbines and to adjust those turbines which are operating to their most efficient configuration.

Operation of the Rock Island turbines is generally prioritized so that the most efficient turbines are used most frequently. Consequently, both the fixed-blade and Kaplan turbines of powerhouse 1 are block loaded, that is, operated primarily on an on/off basis, with very little adjustment in their generating load. The generating swings required to meet instantaneous power demands are typically met through adjustments to the bulb turbines in powerhouse 2. In effect, the older, less efficient turbines are used only at peak operating efficiency, while the more efficient bulb turbines are automatically adjusted to provide the best possible turbine efficiency.

The Fish Passage Plan (FPP) for federal projects recommends the operation of turbines within one percent of peak efficiency during juvenile anadromous salmonid migration periods (USACE 1995b). This is based largely on the hypothesis that juvenile fish survival is probably best at peak turbine efficiency, when conditions within the turbine are generally the smoothest possible and the least likely to have cavitation events which might impact fish passage (Bell 1981). However, a series of turbine survival tests conducted at Lower Granite dam during 1995 yielded results that do not support this hypothesis. Juvenile fish were released at mid-elevation of intake bay 4A under three operating conditions: at peak efficiency with a discharge of 18,000 cfs; in cavitation mode with a discharge of 19,000 cfs; and within normal efficiency range but at a lower discharge of 13,500 cfs. Juvenile fish survival during the turbine cavitation mode was virtually identical to that observed at peak efficiency. The highest survival for the study was 97.2 percent, which was observed for the normal efficiency range with lower discharge (Normandeau Associates et al. 1995). The Rock Island turbines are operated at or near their peak efficiency. The precise benefits of operating near peak efficiency are unknown, especially in light of the recent test results from Lower Granite dam.

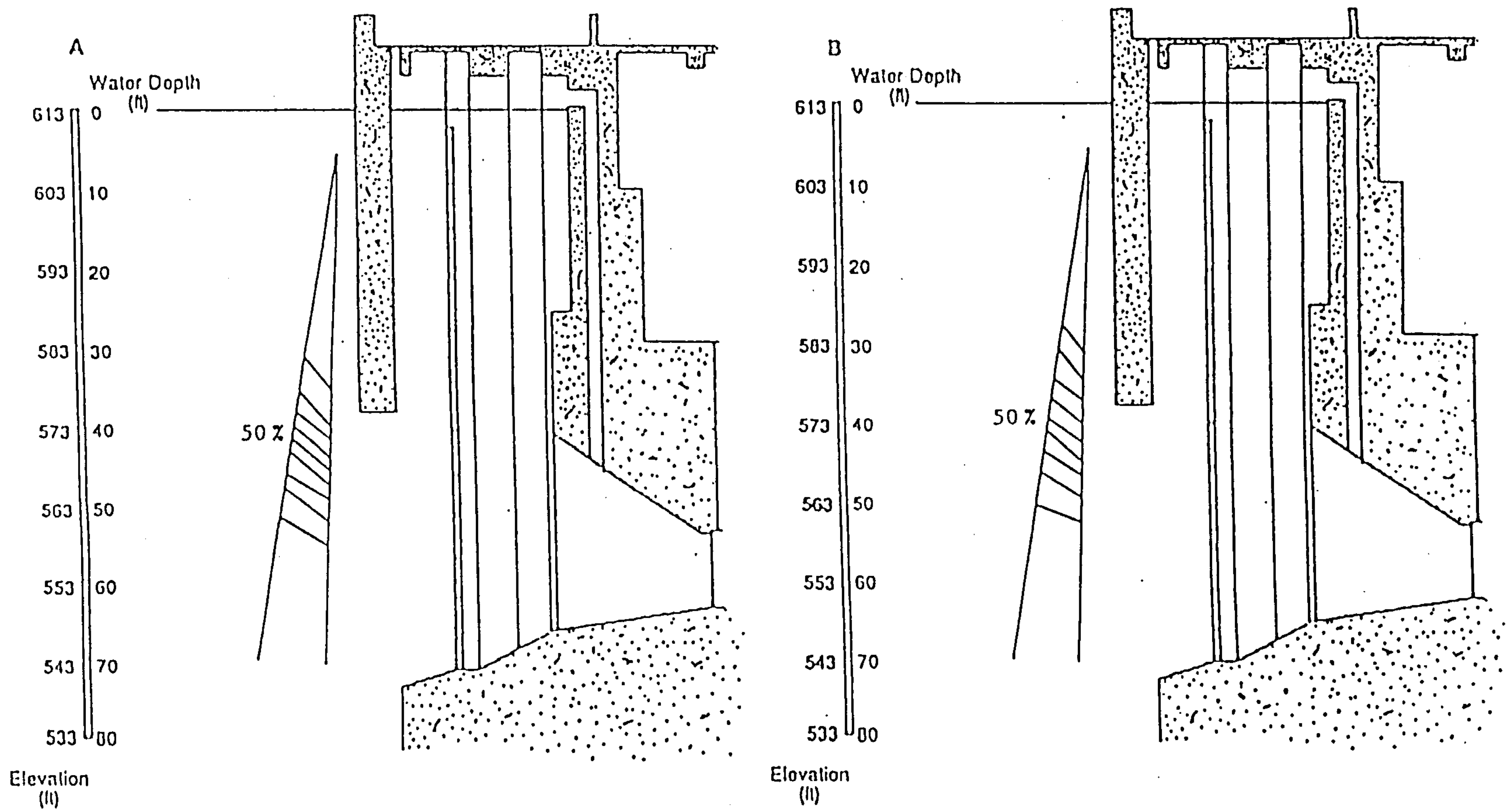

Figure 4-1 Vertical distribution of fish in front of Powerhouse 1 at a) beginning and b) end of study period (Source: Steig et al. 1987). vertical.ri3

4.2.1.1.2. Dam Spillway Passage. Flow over the Rock Island project spillway occurs either as spill for passage of juvenile anadromous salmonid migrants, or as forced spill when flows exceed the 220 kcfs powerhouse hydraulic capacity (USACE 1989). Fish passage spill occurs only during the juvenile migration season, from April through August. This can be further subdivided into spring spill, from mid-April through May, and summer spill, from mid-June through August (TheChelan PUD 1993a). Figure 4-2 presents the average percent of flow spilled at Rock Island dam from 1990-1994. The highest spill occurs in May, with minor amounts occurring in June and July.

Spill is used to improve downstream passage survival of juvenile chinook and sockeye salmon and steelhead trout past Rock Island dam, and to speed downstream migration. Section 2.2.2 provides detailed information regarding run timing, age and size of the juvenile migrants for these species at Rock Island dam. Generally, spring spill is targeted at spring migrants such as stream-type chinook, sockeye and steelhead, while summer spill is targeted at ocean-type chinook juveniles. There are advantages and disadvantages to passing juveniles over the spillway. Section 3.3 discusses total dissolved gas (TDG) supersaturation and gas bubble trauma (GBT) associated with spill.

One unique aspect of spill at Rock Island dam has been the use of shallow versus deep spillbays for fish passage spill. The shallow spillgates at Rock Island dam provide surface spill, as opposed to the deep spillgates which provide subsurface spill at depths shallower than, but comparable to, turbine intake depths. Research at Rock Island dam has shown that shallow spillbays are more effective at passing juvenile migrants (percent fish: percent water ratio of 1.6:1) than deep spillbays (percent fish: percent water ratio of less than 1:1) during the spring period when stream-type migrants are present (Ransom and Steig 1995). Deep spill was not investigated for the summer period when mostly ocean-type chinook migrants are present. At some projects, spill during the summer period is less effective at passing juveniles than spring spill (Ransom and Steig 1995). However, research at Rock Island has not demonstrated a difference in shallow spill effectiveness between the spring and summer periods (Ransom and Steig 1995). During the spring of 1996, the Chelan PUD initiated a program to test and evaluate shallow and surface spill entrance configurations on the south spillway. Further tests and addition of more modified surface spill gates took place in 1997.

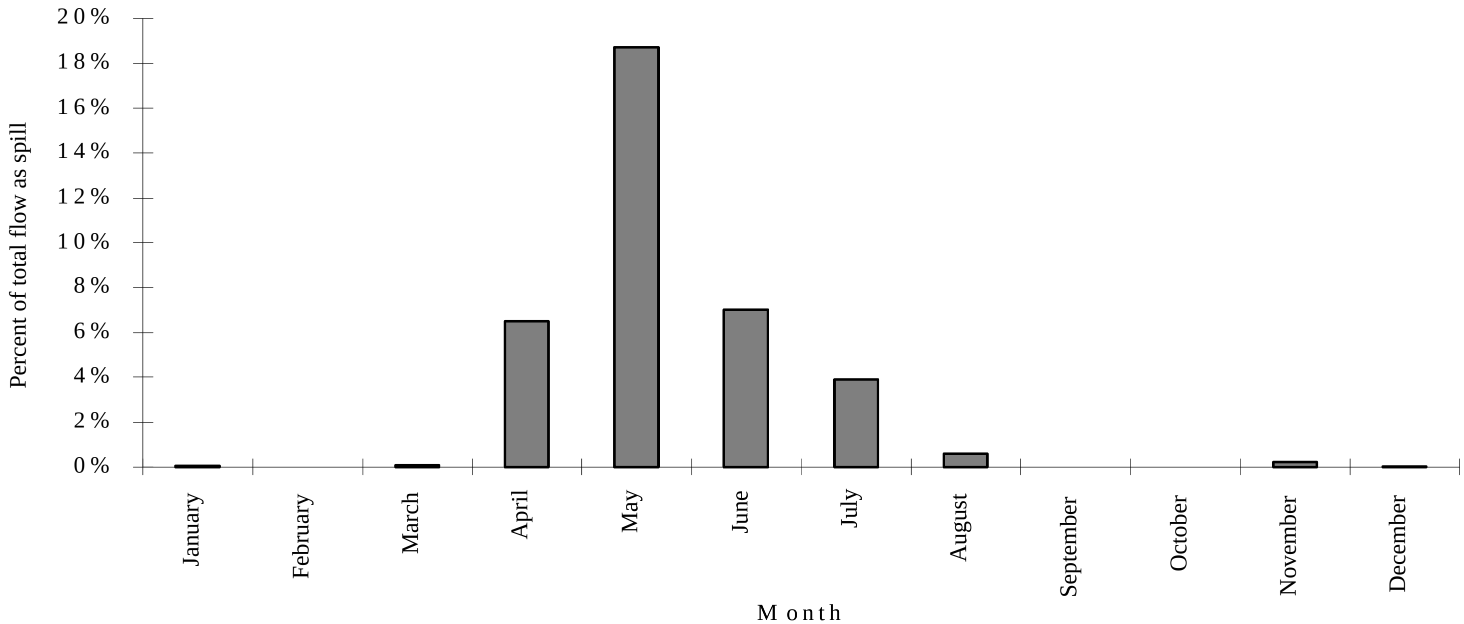

Figure 4-2. Percent of monthly flow spilled at Rock Island dam from 1990 to 1994 (USACE 1995d).

avg%.ri3

4.2.1.1.3. Juvenile Bypass Systems. Two issues are involved in the development and operation of any juvenile bypass system. First, physical conditions must exist and design criteria must be used that provide safe passage conditions for juvenile migrants. Second, juvenile migrants must discover and use the bypass system. It is this second issue that, in most cases, determines the overall effectiveness of a bypass system.

The 1987 Rock Island Settlement Agreement calls for the Chelan PUD to study, design, develop, test and install mechanical juvenile bypass systems at both powerhouse 1 and powerhouse 2. The agreement further stipulates that if a prototype bypass system at either powerhouse achieves a fish guidance efficiency (FGE) of at least 50 percent based on the average of all species, then installation of the system will be decided by the fishery agencies and tribes. For any prototype system developed having an FGE less than 50 percent, the decision to install full scale bypass systems will be made only by mutual consent of all parties involved with the Settlement Agreement. Decisions to install a bypass will also be contingent upon final cost estimates for the system relative to estimated capital costs specified in the Settlement Agreement (FERC 1987). Turbine deflection screen prototype juvenile bypass systems have been tested at both powerhouses of Rock Island dam. The powerhouse 2 prototype system was not successful, achieving far less than the 50 percent FGE criteria (Fielder, et al, 1989). The powerhouse 1 prototype, though initially showing only moderate effectiveness, exhibited average FGEs greater than 50 percent in 1994 and 1995 (Peven and Truscott 1992; Steig et al. 1994; Peven and McDonald 1994; McDonald 1995).

Vertical distribution studies conducted at Rock Island dam indicate that most salmon and steelhead juveniles pass though the upper half of the turbine intakes (Hays 1984; Raemhild et al. 1984a; Steig et al. 1987). It appears that most juvenile fish approaching the powerhouses must sound (or are passively drawn down in the flow net) as they enter the turbine intakes (Steig et al. 1987). Similarly, the evidence of “outboard” effects in horizontal distribution data suggests juveniles are approaching the powerhouses predominantly from the shore, and to a lesser extent from the center of the channel (Raemhild et al. 1985; Steig et al. 1987). Most final bypass designs span the full width of each powerhouse when installed.

Baseline distribution data are essential in siting effective guidance and bypass systems. However, there is evidence at Rock Island dam that juvenile bypass systems can impact flow lines of water entering the powerhouses, and hence can impact the distribution of the juvenile fish they are intended to intercept. Hydroacoustic studies found juvenile fish trajectories were steeper and distributions were deeper when a prototype intake diversion screen was in place (Raemhild et al. 1988; Steig et al. 1994). The USACE (1994) has expressed concern that this steeper approach may distribute juveniles closer to the periphery of the runner blade, where mortality is expected to be higher than at the hub. Screens may also disrupt smooth turbine flow lines and reduce turbine operating efficiencies, thereby resulting in higher turbine mortality (USACE 1994).

Juvenile fish diverted away from turbine intakes need to be directed into bypass conveyance facilities with minimal delay. When powerhouse 2 was constructed in the 1970s, it was equipped with a juvenile bypass channel designed to convey fish from the turbine intake gatewells to the tailrace. The results of studies that examined the effectiveness of this facility are discussed further under Previous and Existing Mitigation.

4.2.1.1.4. Ancillary Passage Routes. The three adult fishways at Rock Island dam are operated continuously, except when they are alternately dewatered during two to three months in the winter for routine maintenance. Downstream migrants passing near the fishway exits may be entrained in the gravity flow of water into each fishway and subsequently pass through the dam in the adult ladders. Downstream migrants may also be entrained in the intake flow to the gravity system providing auxiliary water. These latter intakes are equipped with trash racks and fish screens that meet current screen criteria.

4.2.1.1.5. Collection and Transport of Juvenile Fish. An alternative passage route involves collecting juvenile migrants on the upstream side of a dam and transporting them past one or more dams to be released. While this mechanism avoids the potential of direct impacts caused by turbine, spillway or ancillary routes of passage, the mortality that results from collection and transportation must be taken into account.

It is feasible that a collection component could be integrated with the existing juvenile bypass system at powerhouse 2 or with juvenile bypass systems at Powerhouse 1. The existing bypass system currently captures an estimated 5 to 15 percent of the outmigrants approaching the dam in the immediate vicinity of powerhouse 2 (Olson 1982, Olson 1983). Criteria for the proposed juvenile bypass systems call for passage of at least 50 percent of the migrants based on an average of all species (FERC 1987). Transportation mechanisms able to accommodate these numbers of fish would be required. Barge transportation from Rock Island dam is not an option since there are no navigation locks at the downstream Wanapum and Priest Rapids dams.

4.2.1.2. Previous and Existing Mitigation. The Rock Island project has implemented many programs to minimize and mitigate the impact of downstream dam passage on juvenile salmonid migrants. These actions, described in detail in the following paragraphs, involve the following:

- modified turbine operations;
- existing juvenile bypass channel;
- prototype juvenile bypass systems;
- fish passage spill; and
- fish production as mitigation.

4.2.1.3. Modified Turbine Operations. Based on knowledge of juvenile anadromous salmonid passage behavior at Rock Island dam, the Chelan PUD has modified some of its normal turbine operating procedures in an effort to enhance passage survival. This is accomplished through block loading the less efficient fixed-blade and Kaplan turbines at their most efficient setting, and using the more efficient bulb turbines to accommodate the generation swings. Also, a computerized control system is used to automatically adjust the turbines to the best efficiency for any given load and head conditions.

4.2.1.4. Existing Juvenile Bypass Channel. Rock Island powerhouse 2, constructed during the 1970s, was equipped with a juvenile bypass system designed to convey fish from the turbine intake gatewells to the tailrace. Main features of the system include two eight-inch-diameter entrance ports in each gatewell, a bypass channel which runs parallel to the face of the powerhouse, and a 36-inch-diameter bypass pipe that discharges to the tailrace. A juvenile fish trapping system, incorporated into the bypass in 1981, enables juveniles to be collected for enumeration and other sampling needs (Olson 1982).

During 1981 and 1982, the Chelan PUD evaluated the utility and efficiency of the bypass channel (Olson 1982, 1983). Objectives of these studies included:

- determination of whether or not the fish passed through the system unharmed;
- determination of the proportion and promptness of juvenile fish entering the bypass channel from the gatewells;
- evaluation of the effectiveness of using electronic juvenile fish counters in the system;
- estimation of the bypass efficiency of the system; and
- estimation of the horizontal distribution of juvenile fish passing powerhouse 2.

The results of the studies indicated that juveniles pass through the system with very little descaling or injury. However, the system is not very effective in collecting juvenile fish. Approximately 60 percent of juveniles released directly into the gatewells entered the bypass channel. The remaining 40 percent apparently swam down the gatewells and passed through the turbines. Recovery rates of juvenile test fish released upstream of the powerhouse averaged 15.2 percent for coho in 1981 and 5.5 percent combined for coho, steelhead and chinook in 1982 (Olson 1982, 1983).

The Rock Island juvenile bypass channel is well equipped to allow fish handling and observation. Since 1985, it has been operated by Chelan PUD personnel as a juvenile monitoring station on the mid-Columbia (Fielder and Peven 1986; Peven 1991b). Data from the juvenile monitoring program are reported daily to the FPC by the Chelan PUD.

4.2.1.5. Prototype Juvenile Bypass Systems. The Chelan PUD has developed and evaluated several juvenile bypass systems aimed at reducing the numbers of fish passing through the Rock Island turbine units. Between 1988 and 1990, efforts were concentrated on a bypass system for powerhouse 2. A similar system for powerhouse 1 was the focus for bypass development between 1991 and 1995. Currently, bypass efforts are focused on surface oriented spill using modified spillgates.

The powerhouse 2 prototype development was initiated in 1988 at Turbine Unit 1. The general design of the system utilized a bar screen extending downward from the top of the turbine intake to divert approaching fish into the gatewell (Figure 4-3). Once in the gatewell, juvenile fish were able to access the existing gatewell orifices and bypass channel, allowing discharge to the tailrace.

Seven different prototype configurations were examined in the 1988 study by altering screen lengths and angles, screen gaps and screen porosities. An eighth configuration representing baseline conditions with no bar screen deployed was also evaluated. Results indicated that the trajectory angle of juvenile fish approaching a screened unit was steeper than that of juveniles approaching an unscreened unit. The prototype also influenced vertical distributions and led to a more even distribution of juveniles throughout the water column, whereas the baseline condition showed a greater proportion of juveniles in the upper water column (Raemhild et al. 1988).

Complications with prototype performance resulted in loss of equipment and lack of sufficient data to allow fish guidance efficiency (FGE) determinations for all configurations. None of the prototype configurations were successful at passing large numbers of juvenile fish (Fielder 1989). Elder and Weitkamp (1990) concluded that the water velocities in front of powerhouse 2 are too strong to allow effective implementation of a bar-screen type diversion system.

A prototype bypass system for powerhouse 1 was designed during 1991, building upon information learned from hydraulic model studies of the turbine intake area and a 1987 hydroacoustic study of the powerhouse. The general design of the system consisted of a bar screen deflector (BSD) deployed at a 45-degree angle near the top of the turbine intake, and a vertical barrier screen (VBS) installed in the gatewell slot (Figure 4-4). The system, installed in the center intake bay of Turbine Unit 8 at powerhouse 1, also included the following modifications to the existing structure (Peven and Truscott 1992):

- a pier nose extension to hold the trashrack in a new upstream location;
- a false guide wall extending from the forebay down toward the intake ceiling and up toward the gatewell slot; and
- removal of one of the two intake struts.

Between 1992 and 1994, studies were conducted to evaluate the effectiveness of the prototype diversion system (Peven and Truscott 1992; Steig et al. 1994; Peven 1994 and McDonald). In its first year of evaluation, the bar screen deflector showed mixed results in diverting juvenile fish from the turbine intakes, and exhibited an overall FGE of 35 percent for all species and migration periods combined. The incidence of descaling and injury observed on juveniles guided into gatewells by the prototype system was low enough to suggest there was no major problem with the guidance equipment. However, impingement of ocean-type chinook juveniles on the bar screen deflector (BSD) occurred at rates as high as 38 percent, and was substantially greater in spring tests than in summer tests. It was speculated that the increase in size of ocean-type juveniles throughout the spring and

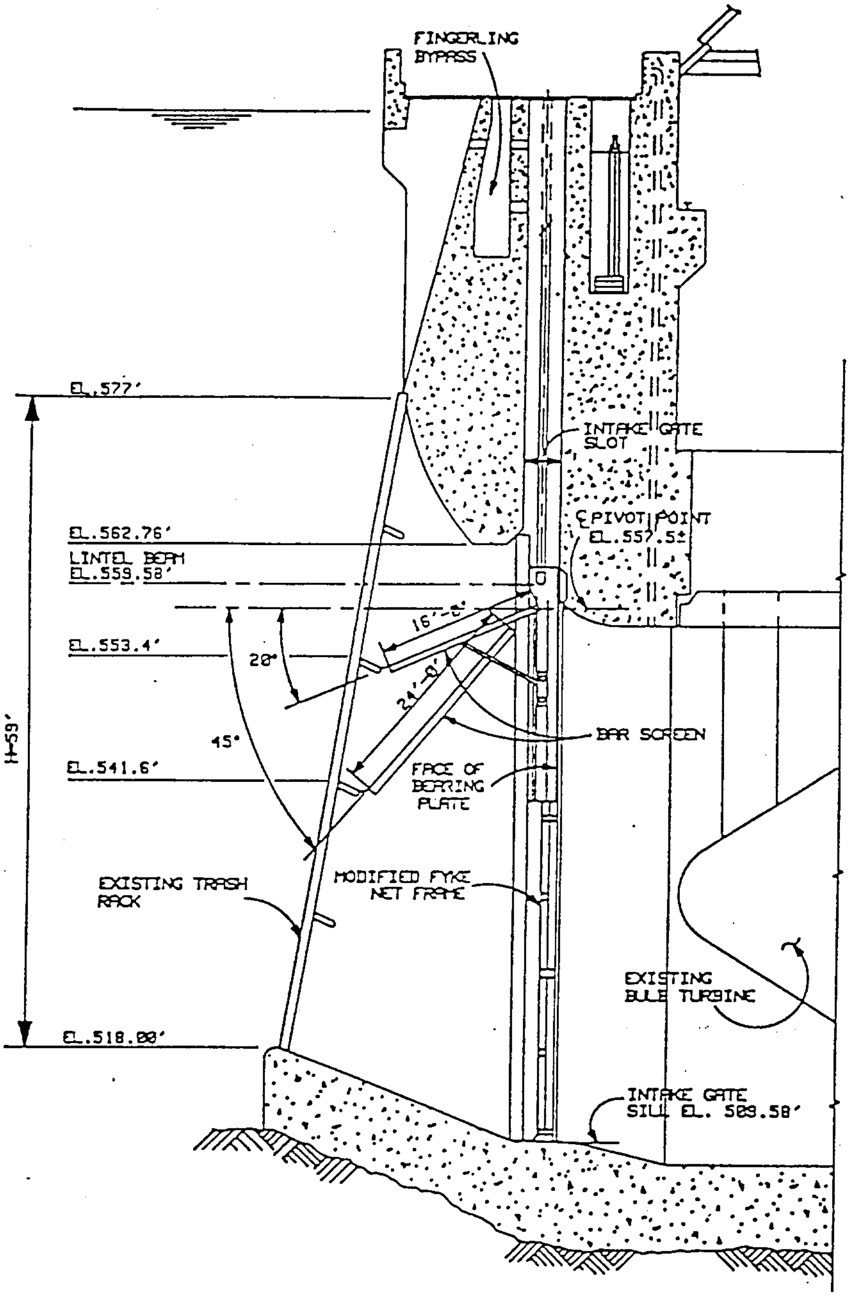

Figure 4-3 Cross-section of Powerhouse 2 showing prototype bar screen in position (Source: Raemhild et al. 1988).

cros-sec.ri3

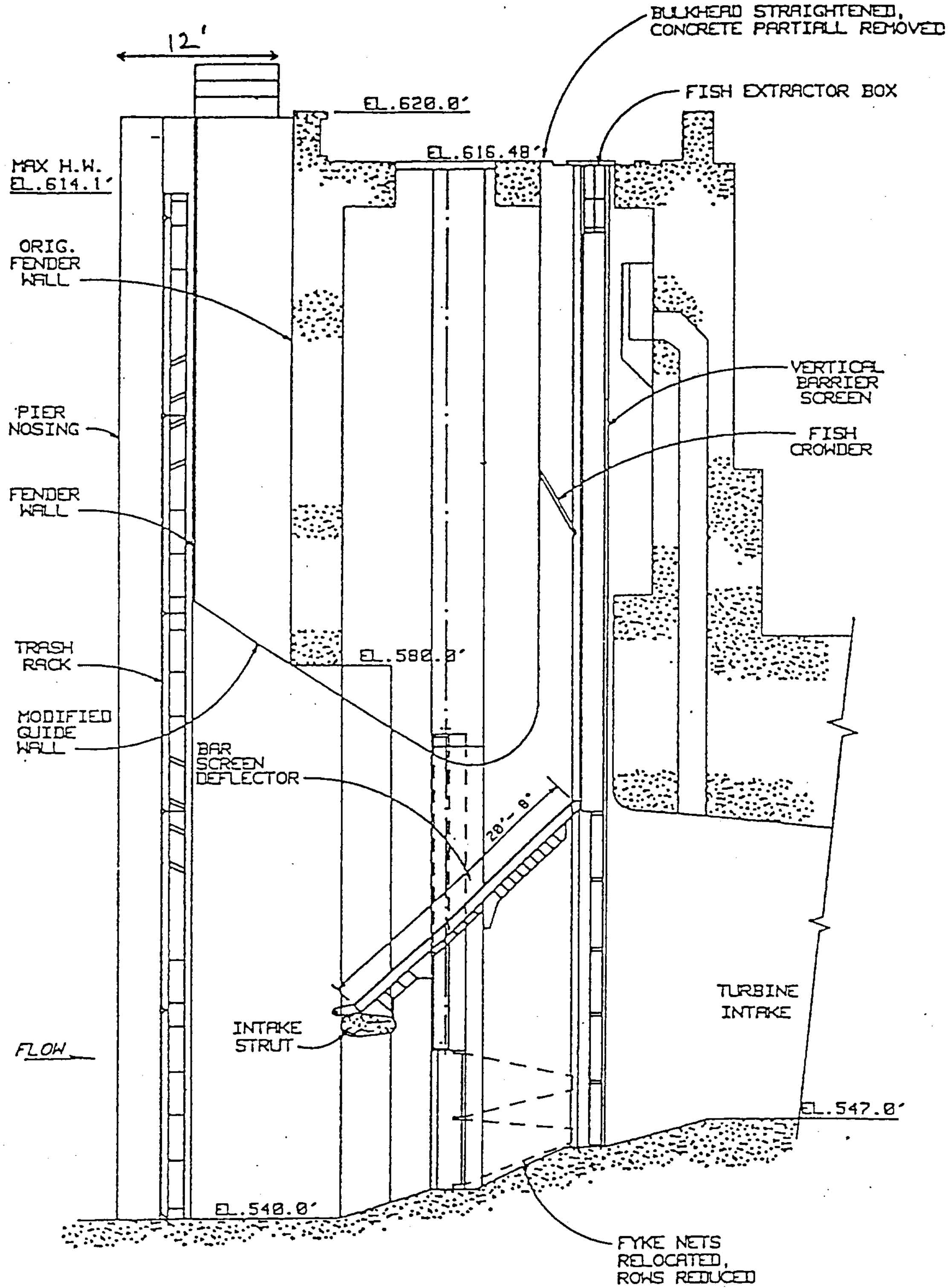

Figure 4-4 Cross-section of Powerhouse 1 prototype bar screen deflector in place (Source: Peven and McDonald 1994).

crospwr1.ri3

summer, going from approximately 45 mm fork length in late May to 70 mm overall in late June, factored into their ability to avoid impingement (Peven and Truscott 1992).

All of the powerhouse 1 evaluations between 1992 and 1994 utilized fyke nets to estimate the numbers of juvenile fish passing through the turbines. The prototype configuration during 1992 and 1993 placed the fyke nets and their frame directly below the vertical barrier screen. However, model studies conducted on this configuration indicated that flows were significantly reduced and that hydraulic conditions could be improved by opening the area behind the vertical barrier screen (VBS) and BSD. Consequently, during the 1994 evaluation, the fyke nets were moved forward to a position below the upstream edge of the bar screen deflector (Steig et al. 1994). The 1994 prototype achieved an average FGE greater than 50 percent (Peven and McDonald 1994), which was a slight improvement over the previous two years.

In 1995, a new prototype was constructed in the center intake bay of Turbine Unit 7 and was tested during the spring and summer juvenile migration periods. The new prototype was similar to the previous prototype constructed in Turbine Unit 8 except that pier nose extensions were not added. The overall FGE for the 1995 prototype was 76 percent, which substantially exceeds the criterion of 50 percent FGE established in the Rock Island Settlement Agreement. When segregated into spring and summer migration periods, the data indicate an overall FGE of 78 percent for spring migrants and 64 percent for summer migrants (McDonald 1995).

4.2.1.6. Fish Passage Spill. The spillway at Rock Island dam is currently operated to pass spring and summer juvenile migrants according to the plan presented in the 1987 Rock Island Settlement Agreement between the fishery agencies and tribes and the Chelan PUD. This program began in 1987 and has continued with modifications through the present. The agreement calls for spring spill of 10 percent of instantaneous flow through powerhouse 2, and 50 percent of the flow through powerhouse 1 during the middle 80 percent of the spring juvenile migration. Generally, 80 percent of the spring migrants pass Rock Island dam between the last week in April and the first week in June (Table 2-3), and spring spill coincides with this time period. The shallow spillbays are used because shallow spill is more effective than deep spill at Rock Island dam (Ransom and Steig 1995). The settlement agreement also calls for 500,000 acre-feet of water to be provided as spill during the summer juvenile migration period. Although the settlement agreement does not specify the hours for spill, the Chelan PUD has provided fish passage spill from 2000 hours to 0600 hours during the spring period before goslings leave island nesting sites, from 2000 hours to 0800 hours after goslings leave, and 2000 hours to 0600 hours during the summer period. Beginning in 1996, the fisheries agencies and tribes invoked the conservation account (as defined in the 1987 Settlement Agreement), which allows them to use spill at their discretion until power revenue losses for the term reach $3,000,200 in 1998.

4.2.1.7. Fish Production as Mitigation. The Chelan PUD provides hatchery-based compensation for anadromous salmonid losses resulting from Rock Island dam, in accordance with provisions of the 1987 Settlement Agreement. The compensation program set forth in the agreement calls for the design, construction, operation, maintenance and evaluation of facilities capable of rearing and releasing 250,000 pounds of salmon and 30,000 pounds of steelhead. The program is to be carried out in a manner consistent with the maintenance of genetically distinct stocks in the mid-Columbia river system above Rock Island dam. To that end, the design of the facilities will incorporate the capability of incubating, rearing, adult trapping and holding for up to five discrete races/demes of salmon and summer steelhead (FERC 1987).

In response to these requirements, the Chelan PUD coordinated with the fisheries agencies and tribes to develop a production plan and to select sites for facilities as appropriate to meet the intent of the production plan. In 1989, the Chelan PUD completed construction of the Rock Island hatchery complex, consisting of the main Eastbank hatchery facility and its five satellite facilities: the Carlton, Chiwawa, Dryden, and Similkameen rearing and acclimation ponds and the Lake Wenatchee net-pens.

The production plan currently in effect calls for the production of one race/deme of spring (stream-type) chinook, two races/demes of summer (ocean-type) chinook salmon and one stock each of sockeye and steelhead. The facilities are operated under a formal agreement by the WDFW.

The 1987 Settlement Agreement sets up a process by which the hatchery production levels may be adjusted to account for findings from juvenile and adult anadromous salmonid survival studies. Production may also be adjusted when the juvenile run size increases to at least 110 percent of the run size used in initial plan development, where run size is based on a rolling five-year average. This adjustment is intended to account for increased project-related losses associated with increased numbers of fish passing the Rock Island project, and cannot be made any earlier than six years after adjustments based on juvenile and adult survival studies are made. The Settlement Agreement also includes provisions whereby some of the Rock Island hatchery production can be credited against the mitigation production requirements of the Chelan PUD's Rocky Reach project, contingent upon implementation and proven effectiveness of a summer spill program (FERC 1987).

4.2.2. Effectiveness of Existing Mitigation. System survival studies conducted during 1982 and 1983 using juvenile stream-type (spring) chinook salmon in the mid-Columbia reach included a survival estimate for the river segment above Rock Island Dam (McKenzie et al. 1984a, 1984b). By making the assumption that mortality would be equal for each of the three projects encountered between Pateros (near the confluence of the Methow River) and the Rock Island tailrace, the estimate of survival through Rock Island reservoir and dam was reported as about 87% in 1982 and 84% in 1983, for an average of about 86% survival i.e., a 14% project mortality. There were no specific estimates made as to the portions that were associated with direct and indirect turbine mortality, reservoir effects or other factors involved with project passage. However, speculation at the time associated most of the project passage mortality with direct turbine mortality.

A review of nine turbine passage studies conducted for lower Columbia and Snake River dams found that total mortality estimates (direct and indirect effects) for Kaplan turbines varied from 2% to 20% (Iwamoto and Williams 1993). A study of the Rock Island bulb turbines indicated a total turbine mortality rate of 3.9% for steelhead and 5.7% for coho (Olson and Kaczynski 1980). Recent studies conducted at Rocky Reach dam measured direct mortality at about 6% for Kaplan turbines and 4% for fixed-blade turbines (RMC and Skalski 1994a, 1994b; RMC 1994). Similar studies in 1997 at Rock Island Dam, using balloon tags, determined direct mortality of yearling chinook salmon to be 4.3% for the bulb turbines, 3.9% for the First Powerhouse Kaplan turbines, and 6.8% for the Nagler turbines (Normandeau and Skalski 1997). These studies indicate that direct and indirect turbine mortality at Rock Island Dam may be much lower than thought previously for large turbines in general. The low head of the Rock Island project may be a reason why turbine passage mortality rates are lower than many of the mortality rates reported by Iwamoto and Williams (1993). However, Chelan PUD has embarked on a juvenile fish bypass program (Section 6.2.3), consisting primarily of spill, to reduce juvenile fish turbine passage at Rock Island Dam.

4.2.2.1. Existing Juvenile Bypass Channel. The results of bypass channel evaluations indicated that juvenile fish pass through the system with very little descaling or injury. However, the system is not very effective in passing large numbers of juveniles. The average bypass efficiency is estimated at 5.5 to 15.2 percent for all species passing powerhouse 2 (Olson 1982, 1983).]

4.2.2.2. Juvenile Bypass Systems. Prototype diversion systems tested at powerhouse 2 during 1988 showed FGEs lower than 50 percent. The conclusion was made that velocities in front of powerhouse 2 are too strong to allow effective implementation of a screened system (Elder and Weitkamp 1990).

In 1995, the prototype diversion system at powerhouse 1 achieved an overall FGE of 76 percent (McDonald 1995). However, rather than call for a full-scale installation of this design, the fisheries agencies and tribes have decided to invoke the Conservation Account specified in the Rock Island Settlement Agreement and have purchased spill for the 1998 juvenile fish migrations.

4.2.2.3. Fish Passage Spill. Fish passage spill as a mitigation measure for juvenile downstream passage impacts has had consistently high effectiveness at Rock Island dam. The estimated instantaneous spill effectiveness is greater than 1.6:1 for both the spring and summer passage period (Ransom and Steig 1995). A statistically significant, positive relationship has been defined between the percentage of juvenile fish passed and the percentage of flow spilled for Rock Island dam (Chapman et al. 1994a). The surface spill gates have been highly efficient in passing juvenile salmonids during the past two years, with the six newest notched gates giving a fish passage efficiency of 44.8 fish per unit of flow versus 16.2 fish per unit of flow for the standard gates (Iverson and Keister 1997). During the spring spill study in 1997, the proportion of all salmonids passed through spill was estimated at 26% with hydroacoustics, but three of the notched gates were in experimental locations that were not productive. The high flows also resulted in limitations on the effective use of spill because of TDG concerns. The spillway was more effective in 1997 for passing steelhead than for chinook salmon, with 38% of radio tagged steelhead detected passing through the spillway (Stevenson et al. 1997). During the summer study, when TDG restrictions were lifted and total river flows were lower, the spillway passed 54% of the fish.

4.2.2.4. Fish Production as Mitigation. The hatchery-based compensation program specified in the 1987 Settlement Agreement has been implemented and is being conducted as intended. A main hatchery facility and five satellite tributary facilities have been constructed as part of an effort to maintain genetically distinct stocks in the mid-Columbia River system above Rock Island dam. The first releases from program facilities occurred with a 1990 release of sockeye. In 1991, releases were made for all stocks specified in the program.

Evaluations of the effectiveness of the compensation program are incomplete at this time. Marked adult fish originating from the program facilities have been recovered from the adult trap at Wells dam and from spawning grounds in the Wenatchee, Methow, Okanogan and Similkameen Rivers. Preliminary information is available for 1991 and 1992 recoveries, while recoveries for 1993 and 1994 are not yet available (Chapman et al. 1994b).

4.2.3. Downstream Reservoir Passage Issues. The following section describes background information on reservoir-related effects on juvenile salmonid outmigration. Information on predation, a major source of juvenile mortality, is discussed in Section 4.5 . The effects of reservoir impoundment on juvenile salmonids are presented in Section 4.4 .

4.2.3.1. Travel Time. The rapid flushing rate of Rock Island reservoir (USACE 1995(d)) appears to positively influence juvenile migration because average juvenile salmonid travel times through the reservoir are rapid.

Water velocities and migration rates in the Rock Island reservoir are favorable for faster migration rates and higher reservoir survival than expected for the Snake and lower Columbia River. Under existing conditions, water velocities in the mid-Columbia reach are roughly twice as fast as water velocities in the Snake and lower Columbia River system. At 80,000 cfs, a commonly occurring base spring flow rate for the Snake River, the average cross-sectional velocity in Lower Granite reservoir is about 0.7 fps (USACE 1992). At 130,000 cfs, a similarly common base spring flow rate for Rocky Reach reservoir, the average reservoir velocity is about 1.5 fps. At 140,000 cfs (add 10,000 cfs flow from Wenatchee River), velocities through the downstream Rock Island, Wanapum and Priest Rapids reservoirs are 2.6, 1.0 and 1.5 fps, respectively (FERC 1995).

These higher velocities are reflected in faster migration rates for juvenile salmon through the mid Columbia River. Chapman and McKenzie (1981) observed hatchery spring chinook travel times from Pateros to Priest Rapids dam of 7.0 to 7.4 miles per day. Observed migration speeds of yearling chinook and steelhead have ranged from 7 to 12 miles per day and 14 to 15 miles per day, respectively (FPC 1990, 1991). Chapman et al. (1994b) observed travel time ranges for hatchery steelhead of 11.6 to 16.9 miles per day from the Methow River to McNary dam. These observed ranges of juvenile travel times are considerably faster than those observed in the lower Columbia River, which are generally less than 7 miles per day. The median migration rate of steelhead through the lower mid-Columbia (Rock Island Dam to McNary Dam) was 30 km/d for PIT tagged juveniles from 1989-1995 (Giorgi et al. 1997). In the Snake River, median migration rates reported for steelhead in 1994, when flows during the migration averaged about 80,000 cfs, ranged from 10.3 - 15.0 km/d for steelhead migrating from Silcott Island to McNary Dam (Muir et al. 1995). Thus, available evidence indicates that, under normal flow conditions, steelhead migrate through the mid-Columbia River about twice as fast as steelhead migrating through the Snake River system. In very high flow years, median migration rates for steelhead through the Snake River approach those seen in the mid-Columbia during normal flows. In 1996, a high flow year (100,000 cfs - 150,000 cfs), Snake River steelhead migration rates (Port of Wilma to McNary Dam) ranged from 19.9 km/d to 43.6 km/d (Smith et al. 1997 Draft for peer review). These higher reservoir velocities and faster steelhead migration rates through the mid-Columbia support the use of Snake River estimates of survival per kilometer of reservoir travel as conservative surrogate estimates of steelhead passage survival for the mid-Columbia reservoirs.

Data suggesting that predation is the primary source of reservoir mortality, and not other factors such as low water velocity, are supported by the rapid juvenile travel times observed in the mid-Columbia River reach. Travel times of stream-type and ocean-type chinook salmon and steelhead released above Wells dam and recaptured at Rock Island dam showed little difference between years though average flows ranged from 87 kcfs to 147 kcfs (Chelan PUD 1991c). Analyses of the correlation between stream-type chinook and steelhead travel time, flow and gill ATPase level indicated that flow did not have a large influence on migration rate in the mid-Columbia River reach over the range of observed flows, 130 kcfs to 180 kcfs (FPC 1990, 1991; Beeman et al. 1990). As stated previously, observed juvenile salmonid travel times in the mid-Columbia reach are faster than those observed in the lower Columbia and Snake Rivers, indicating that juvenile migration is not delayed significantly by reservoir impoundment. These travel time analyses all included juveniles that migrated through Rocky Reach reservoir. While no juveniles were collected at Rocky Reach dam to specifically assess travel time through the reservoir, conclusions drawn from the studies previously cited can be applied to Rocky Reach reservoir because test fish traversed the reservoir on their way to recapture sites.

4.2.3.2. Survival. Juvenile survival through Rock Island reservoir has not been directly assessed to date. However, average mid-Columbia River juvenile survival estimates have been made for hatchery stream-type chinook and steelhead. Juvenile survival estimates per project for passage through the Wells, Rocky Reach and Rock Island dams and reservoirs for juvenile stream-type chinook were 87 percent and 83 percent in 1982 and 1983, respectively (McKenzie et al. 1984a, 1984b). The prorated per-project survival rate for all five mid-Columbia River dams for juvenile stream-type chinook was estimated at 88 percent in 1984. For juvenile stream-type chinook and steelhead it was 85 percent and 92 percent, respectively, in 1985 (FPC 1986). Reservoir mortality cannot be separated from direct project mortality in these juvenile per-project survival estimates.

4.3. Water Quality.

4.3.1. Dissolved Gas Supersaturation.

4.3.1.1. Existing Issues. Total dissolved gas (TDG) supersaturation is a condition that occurs in natural waters when atmospheric gases are in solution at pressures exceeding the pressure of the over-lying atmosphere. Columbia River TDG supersaturation often occurs during periods of high runoff and spill at hydropower facilities, primarily because spill in deep tailrace pools can cause significant entrainment of gases during deep plunge of the water. Total dissolved gas supersaturation conditions can persist and accumulate through the mid-Columbia River reach, since the reach consists of relatively deep pools behind each dam, providing less effective dissipation than naturally shallower, more turbulent river systems. Fish and other aquatic organisms that are exposed to excessive TDG supersaturation can develop gas bubble trauma (GBT), a condition that is often harmful or even fatal.

An introduction to the causes and effects of TDG supersaturation and GBT, and the existing issues regarding TDG and GBT in the mid-Columbia River are described in detail in Section 3.3. The following discussion only deals with additional site-specific details regarding TDG supersaturation and GBT at the Project.

4.3.1.1.1. Total Dissolved Gas in the Vicinity of the Project. Total dissolved gas supersaturation is monitored at the Rock Island project as part of the Columbia and Snake Rivers Dissolved Gas Monitoring Program conducted in cooperation with the USACE and project owners. Monitoring occurs during the salmonid migration season, which is April through September. Data are collected hourly and transmitted to the USACE North Pacific Division Headquarters. These data are then compiled, along with pertinent flow, spill and water temperature information, and posted on the Columbia River Hydromet Management System (CROHMS) and the COE internet homepage. The CROHMS is used for real-time review by authorized users and potential system spill adjustment recommendations.

Total dissolved gas at Rock Island is monitored in the forebay at powerhouse 2 and in the tailrace since 1996. Data have been collected since 1983 at the Rock Island forebay station by the

Chelan PUD (USACE 1994). Daily average TDG measurements at the Rocky Reach, Rock Island and Wanapum dam forebay monitoring stations from 1984 to 1994 generally exceeded 100 percent and, therefore, were consistently in a supersaturated condition during the April to September monitoring period. In general, daily average TDG levels most commonly ranged between 105 and 115 percent during 1984 to 1994 (USACE 1994). The maximum observed TDG levels were 132 percent, 131 percent and 133 percent, respectively, at the Rocky Reach, Rock Island and Wanapum dam forebay stations (Koehler and McDonald). Such maximum levels could cause serious GBT effects depending on duration, species/life stage differences and other conditions, such as depth and water temperature (see Section 3.3) (Ebel et al. 1975).

Total dissolved gas levels at Rock Island dam are primarily determined by TDG levels in water passing from upstream dams. Correlation of TDG data from the Rocky Reach and Rock Island forebay stations (USACE 1993, 1994) indicates that TDG levels at the two sites do not differ consistently (Figure 4-5). This suggests that TDG is neither significantly increased nor dissipated from spill at Rocky Reach dam and subsequent flow through the Rock Island reservoir. A comparison of 1994 TDG data from the Rock Island and Wanapum forebays indicates a similar relationship, but with greater variability (Figure 4-6). A statistical comparison by USACE (1994) also indicated a poor correlation. However, this was not the case in 1996 and 1997. High flows and spills in 1996 and 1997 resulted in consistent increases in TDG from Rock Island forebay to the Wanapum forebay (Figure 4-7) between TDG in the Wanapum forebay and spill at Rock Island dam (Figure 4-8). These high levels of TDG occurred during periods of high spill in the mid-Columbia River during 1990 and 1994. TDG levels at Rock Island dam are primarily determined by TDG levels at Rocky Reach dam (Figure 4-5). TDG was almost always higher at Rock Island than at Rocky Reach dam during 1994 (Figure 4-5), indicating that significant dissipation does not occur through the Rock Island reservoir. Spill for juvenile fish passage at Rock Island dam may result in elevated TDG levels at Wanapum dam (Figure 4-6).

Evidence of GBT in the Vicinity of the Project. Site-specific monitoring in the vicinity of the Rock Island project prior to 1996 has suggested that the incidence of GBT has been minor. The Chelan PUD co-sponsored a study of GBT symptoms on fish, primarily juveniles, in the five mid-Columbia project pools during the 1974 May through August spill season (Dell et al. 1975). Total dissolved gas level during the study averaged about 119 percent (range 111 to 128 percent) in the Rock Island forebay and about 119 percent (range 108 to 128 percent) in the Wanapum forebay. Rock Island dam spilled up to 50 percent of total river flow during the study due to the limited hydraulic capacity of the original powerhouse (75 kcfs) before the second powerhouse was built, which increased Rock Island total capacity to 220 kcfs (Dell et al. 1975). All fish were examined externally for gas bubbles under the skin, in the fins, on the body and in the mouth and eyes.

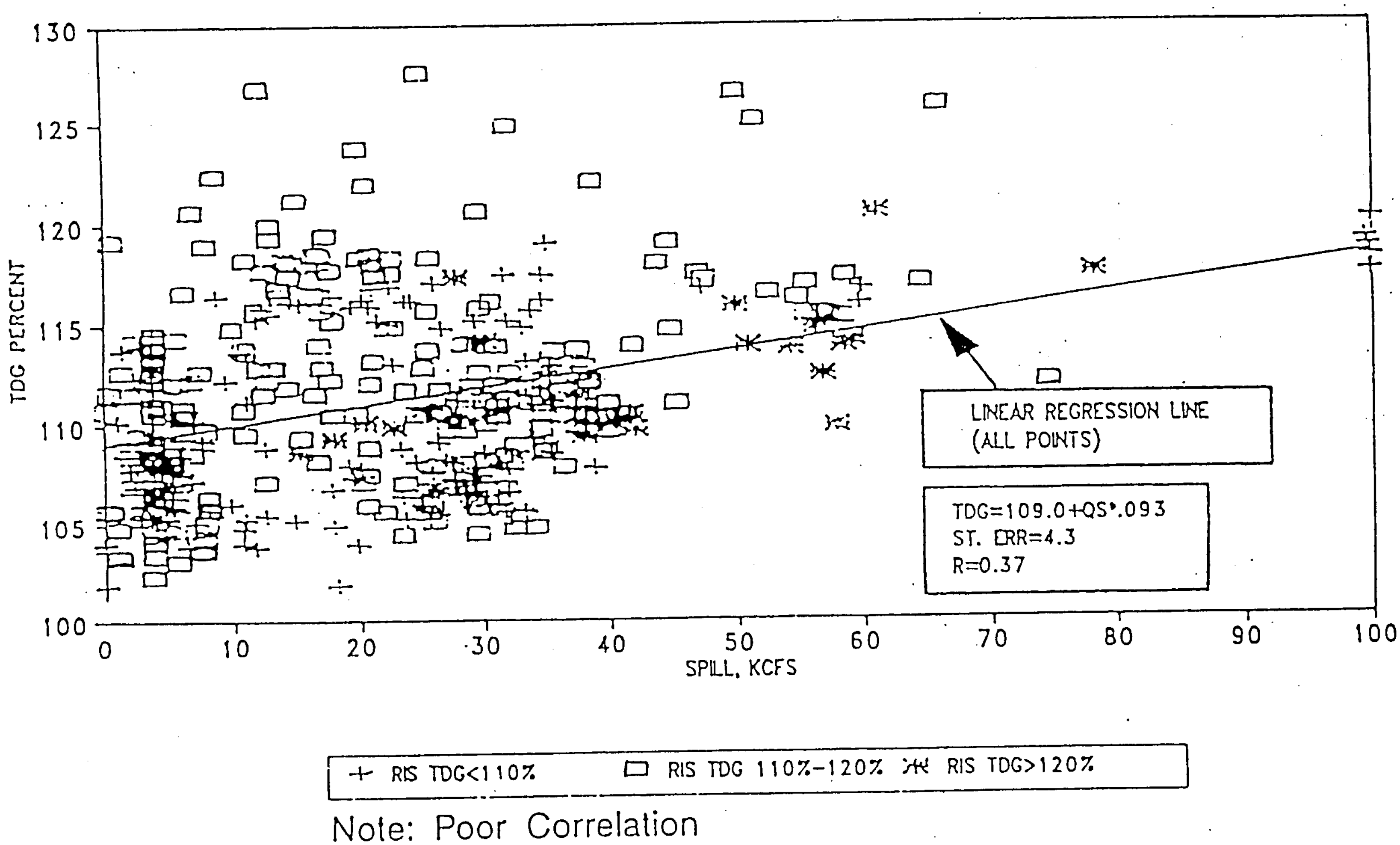

Figure 4-6 Relationship of spill at Rock Island dam and TDG at the Wanapum forebay during 1984 to 1993 (Source: USACE 1993).
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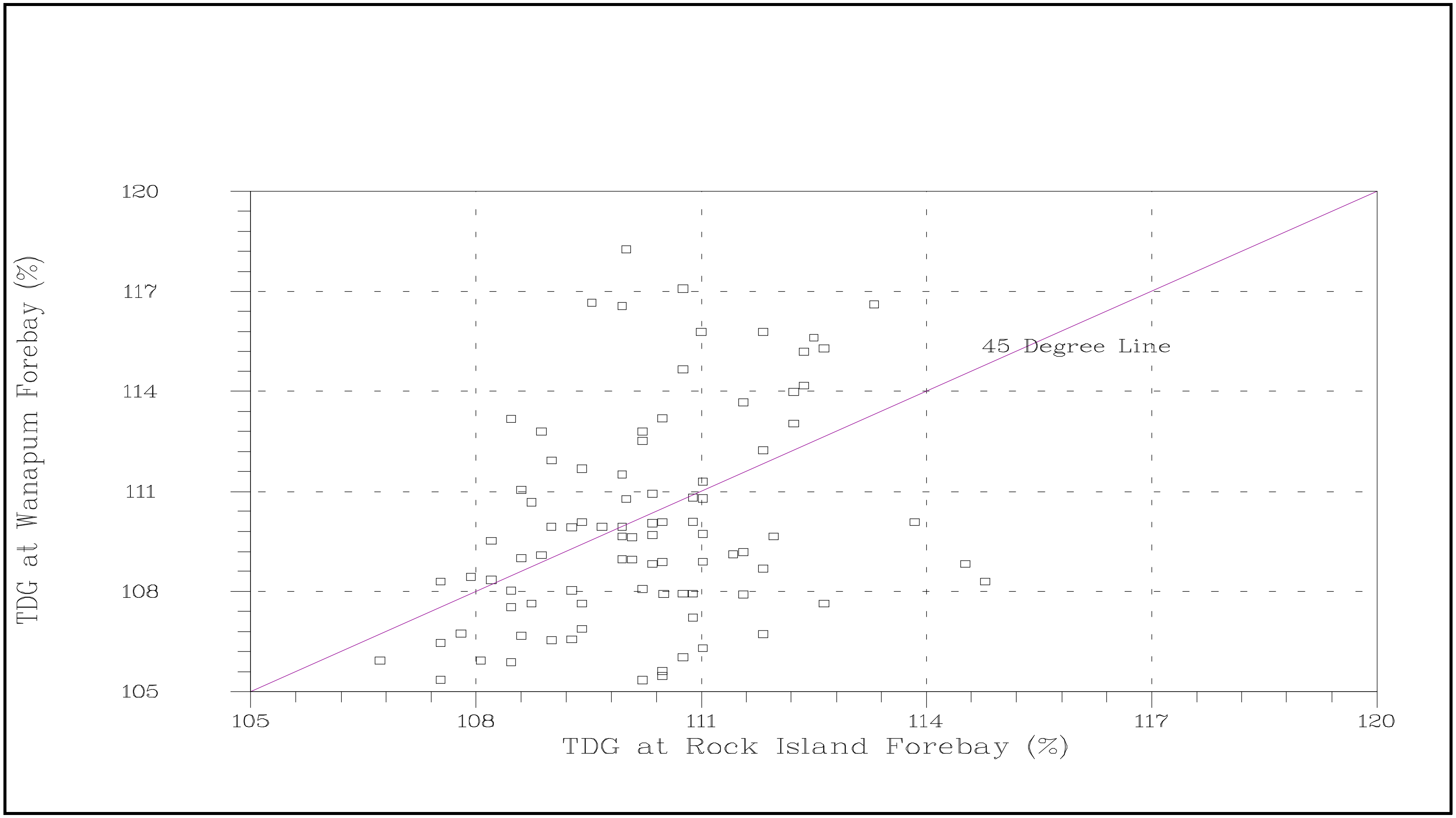

Figure 4-7. Relationship of TDG at Rock Island and Wanapum forebays in 1994 (Source: USACE 1994).

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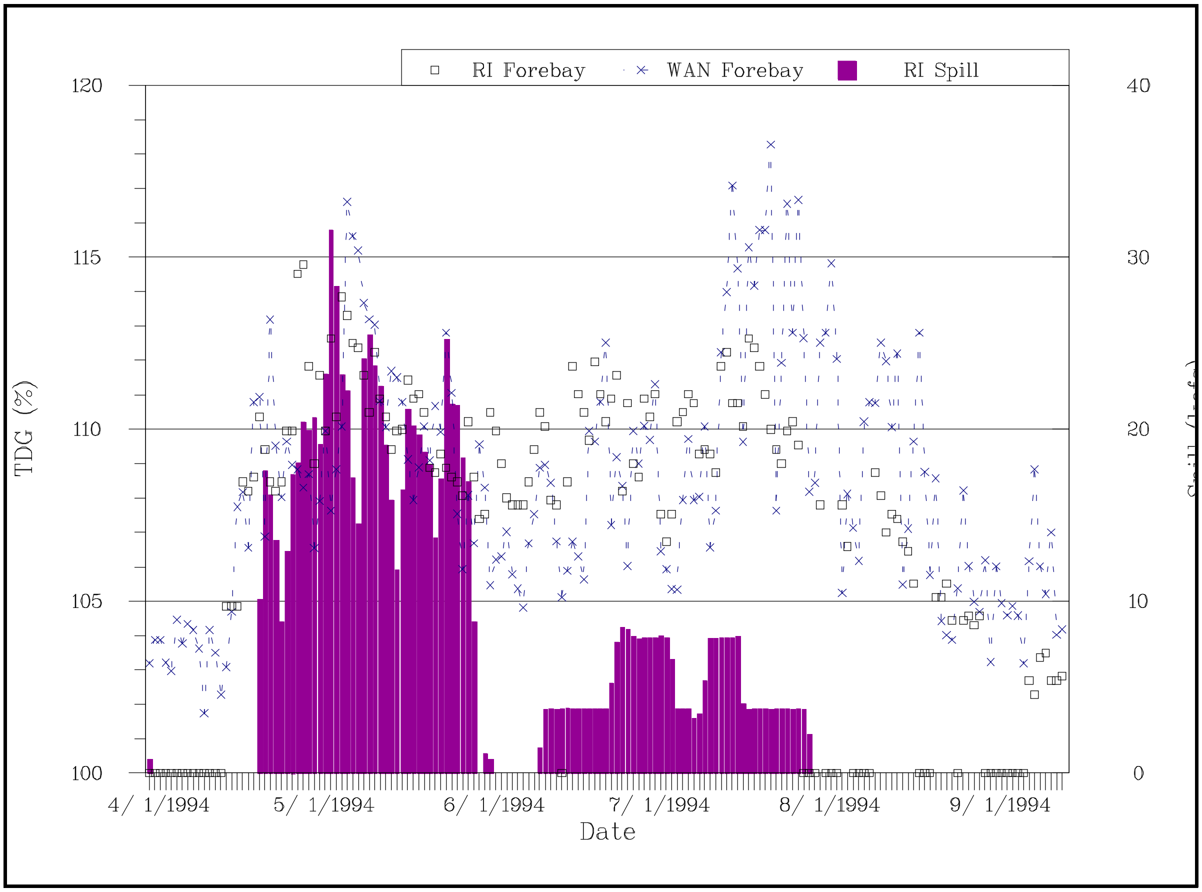

Figure 4-8. Total dissolved gas (TDG) at Rock Island and Wanapum forebays, and spill at Rock Island dam during April to September 1994 (Source: USACE 1994).

tdgriwan.ri3

Evidence of GBT was observed in 0.9 percent and 16.1 percent of the fish examined in the Rock Island and Wanapum pools, respectively. The relatively high incidence of GBT in the Wanapum pool was attributed to two factors: (1) relatively high spill at Rock Island dam; and (2) the method of fish capture (i.e., Merwin trap), whereby fish were led up an inclined net and held near the surface where TDG and incidence of GBT may have been higher than at greater depth.

In the 1990s, GCPUD was required by the Washington Department of Ecology (WDOE) to monitor juvenile fish for symptoms of GBT following renewed concerns about the potential effects of increased spill (Carlson, pers. comm., 17 May 1995). Again, incidence of GBT was minor with symptomatic evidence seen in a low percentage of juveniles sampled.

See Section 3.3.3 for a discussion of the overall incidence of GBT in fishes from the mid-Columbia River. This section also discusses the effects of juvenile fish depth distribution on the incidence of GBT, which may have been related to the high incidence of GBT observed in the Merwin Trap in Wanapum reservoir. Juvenile salmonids that migrate in deep water and then move rapidly toward the surface are more susceptible to GBT in waters with high TDG supersaturation (Ebel et al. 1975). Total dissolved gas supersaturation also has been known to cause adult delay at the fishways at other Columbia River projects (Ebel et al. 1975).

4.3.1.1.2. Project-Specific Measures for TDG Supersaturation Abatement at the Project. No project-specific measures have been installed for TDG supersaturation abatement at Rock Island. The 1994 Detailed Fishery Operating Plan (DFOP), which included comprehensive recommendations for operation of Columbia River mainstem projects for protection and enhancement of fish resources, provided a general system-wide strategy for TDG supersaturation management. The DFOP recommended managing spill by monitoring TDG supersaturation and possible related GBT symptoms in juvenile and adult salmonids during migration periods. Dissolved gas management and control at Rock Island are provided by Chelan PUD criteria and will result in spill requests derived from TDG monitoring at the Rock Island forebay, the observed condition of migrant juveniles and adults and juvenile passage monitoring data. The Chelan PUD did not provide specific project operating criteria for, and are not bound by, the terms and conditions contained in the 1994 DFOP. However, the Chelan PUD does participate in the system-wide strategy for TDG supersaturation management and abatement.

4.3.1.1.3. Effectiveness of Current Measures. No structural project-specific TDG supersaturation management measures have been required to date at Rock Island. The Rock Island project may increase TDG supersaturation levels during periods of low to moderate levels of spill at the dam. However, high spill in excess of 50 percent of flow does appear to increase TDG levels in the Wanapum dam forebay. Data collected in 1996 and 1997 indicate that spilling through either or both full and notched gates at Rock Island Dam increases TDG levels in the tailrace. Due to total river flows that exceeded the hydraulic capacity of the dam and requests for high volume spill from the fisheries agencies and tribes, the Chelan PUD has not been able to test the TDG characteristics of Chelan's preferred bypass option, spill through only notched gates. The Chelan PUD, with the approval of the Rock Island Coordinating Committee, will attempt to determine the TDG characteristics of spill through notched gates in 1998. If it is determined that Chelan's preferred bypass option (spill through only notched gates) does not meet Washington State TDG standards, the Chelan PUD will undertake a comprehensive gas abatement program for Rock Island Dam. This program will include, but will not be limited to: monitoring of TDG characteristics of spill through notched gates, modeling of possible gas abatement structures, construction of a prototype gas abatement structure, determination of TDG characteristics and fish mortality associated with prototype gas abatement structure, and construction of gas abatement structures in preferred fish spill gates at Rock Island Dam.

4.3.1.2. Ongoing Monitoring Efforts. Total dissolved gas monitoring occurs in the forebays (and tailraces since 1996) of Rock Island, Rocky Reach and Wanapum dams. Beginning in 1996, monitoring stations downstream of the tailrace monitored TDG levels in water discharged from the spillways at Rock Island dam. Other pertinent information is also monitored, including water temperature, total river flow, turbine discharge and spill discharge. It is intended that the TDG monitoring program be somewhat adaptive, i.e., additional coverage and types of data may be warranted as real-time information is obtained and analyzed. Also, the onset and effects of GBT are still incompletely understood and remain controversial. Adjustments to ongoing monitoring and spill management guidelines could occur pending further biological and physical findings into GBT causes and effects. Juvenile salmonids are routinely examined for external GBT symptoms as part of the Fish Passage Center's (FPC) Smolt Monitoring Program (SMP) at selected Snake and Columbia River dams, but only at Rock Island and Rocky Reach (since 1997) in the mid-Columbia region are monitored.

4.3.2. Water Temperature.

4.3.2.1. Existing Issues. The potential effect of dams on water temperatures on the Columbia River depends on the extent of river impoundment and regulation of streamflows at hydropower facilities. River flow regulation can alter the natural heating and cooling of the river to which salmonids have adapted, affecting the incidence of disease, timing of migrations, maturation of spawners, time of incubation and hatching, and level of TDG supersaturation (BPA et al. 1994a; Chapman et al. 1994a; Dauble and Mueller 1993). A general discussion of existing issues regarding water temperature in the mid-Columbia River are described in detail in Section 3.3.4. The following discussion addresses only additional site-specific details regarding water temperature at the Project.

4.3.2.1.1. Water Temperature Conditions in the Vicinity of the Project. Water temperature conditions at the Rock Island powerhouse have been recorded since 1933. For the period 1951 to 1968, the mean monthly water temperatures for the four months of the year during which water temperatures typically are highest were: 15.4°C in July; 17.4°C in August;

17.3°C in September; and 15.4°C in October. All of these readings were in compliance with current Class A water temperature standards (The Chelan PUD 1973). Water temperature monitoring has been conducted from 1984 through 1994 by the Chelan PUD in conjunction with TDG monitoring at the Rock Island facility. As with the TDG data, water temperature data are obtained from approximately April through September each year. Water temperature and TDG data are collected hourly and transmitted via satellite to the USACE CROHMS database.

Water temperature at Rock Island dam forebay during 1994 is presented in Figure 4-9. Water temperature does not appear to substantially increase from Rocky Reach dam to Rock Island dam (USACE 1993). Comparison of water temperatures recorded at Rocky Reach dam and Rock Island dam during the last 11 years indicates that water can either warm or cool between the two facilities (USACE 1993). Water temperature at the Rock Island forebay can reach 18°C during July (Figure 4-9), which exceeds criteria set by the NPPC for some salmonid species. For example, the temperature below the project in 1994 was over the NPPC chinook and steelhead juvenile maximum preferred temperature of 14.4°C from the last week of June through the end of the juvenile migration period.

The lack of a consistent thermal effect between Rocky Reach dam and Rock Island dam suggests that substantial heat exchange does not occur as water travels through the Rock Island reservoir. As a run-of-river project, Rock Island reservoir has a rapid flushing rate that averages less than one day. Pools with rapid flushing rates have a mostly river-like character, including weak and intermittent or non-existent thermal stratification (Johnson et al. 1978; Kimmel and Groeger 1984; Cox 1984). In addition, rapidly flushed pools often do not permit substantial heat input and concomitant water temperature increases in pool outflow.

4.3.2.1.2. Evidence of Effects on Salmonids in the Vicinity of the Project. Currently no problems associated with water temperature are being observed at the Rock Island facility (Hevlin, pers. comm., 27 January 1995; Woodin, pers. comm., 26 January 1995). The WDOE segment of the Columbia River affected by the Rock Island facility (Chief Joseph dam to Priest Rapids dam) is not on the Clean Water Act Section 303(d) list as being water quality limited for temperature. However, EPA has cited water temperature as a concern from Bonneville dam to Chief Joseph dam (BPA et al. 1994a). Monitoring-data from the mid-Columbia River reach near Rock Island dam indicate that water temperatures commonly exceed the 18°C water temperature standard during July, August and September. Moreover, water temperatures measured at Rock Island dam have exceeded levels shown to cause delays in upstream migration and have exceeded criteria set by the Northwest Power Planning Council (NPPC) for some species.

4.3.2.2. Mitigation and Monitoring Measures. No mitigation has been directed specifically toward water temperature. However, monitoring is conducted annually by the Chelan PUD in conjunction with the dissolved gas monitoring as described above.

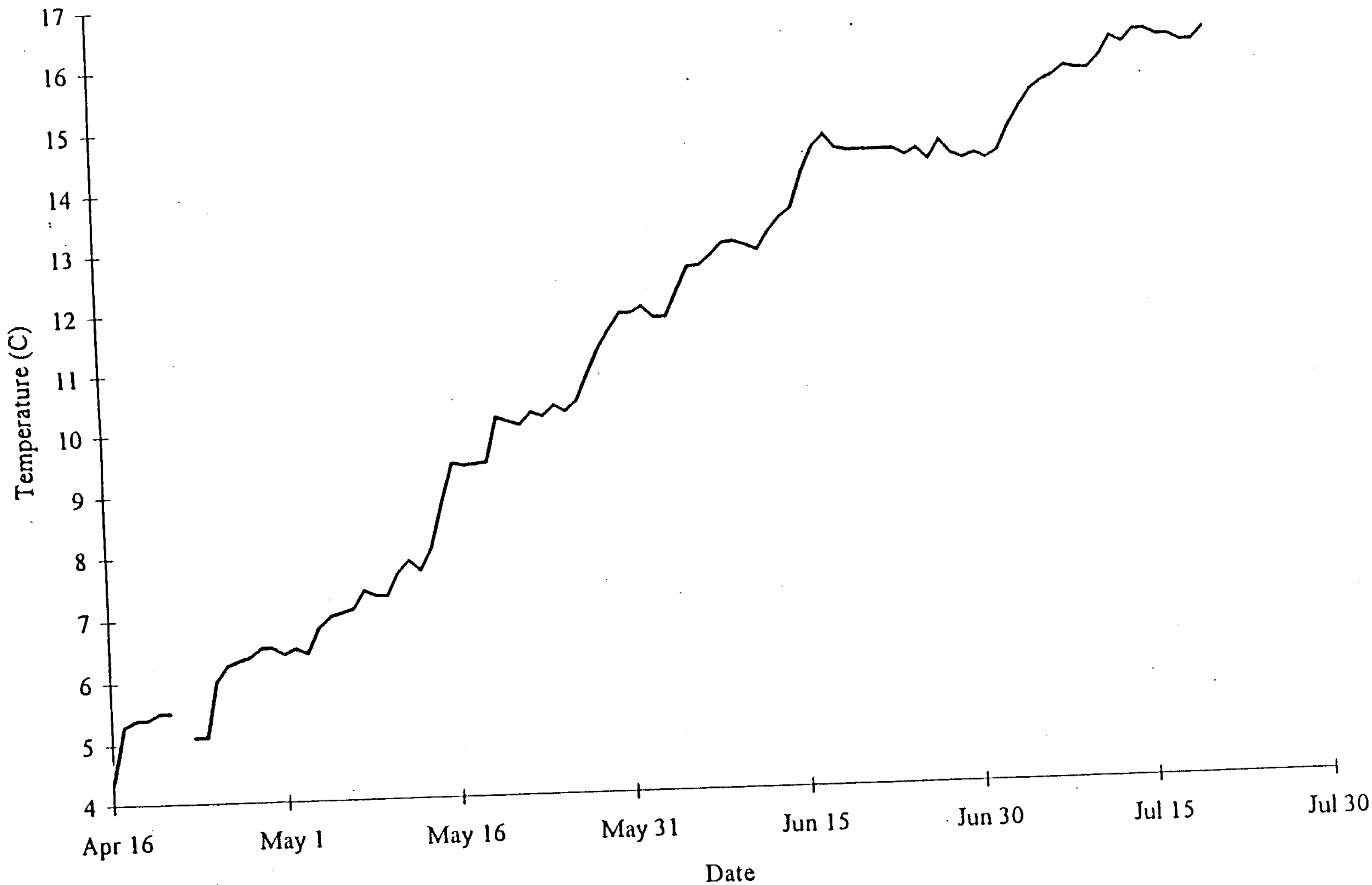

Figure 4-9 Water temperature in the Rocky Reach dam forebay during April through July 1993 (Source: USACE 1995d).

The potential for improving water temperatures within the mid-Columbia River reach, including the reservoir, is limited. Augmentation releases in the summer from Lake Roosevelt at Grand Coulee dam could perhaps decrease water temperatures in waters flowing into Rocky Reach reservoir. Lake Roosevelt is large and deep enough to stratify and provide a source of cold water during summertime. However, Grand Coulee does not currently have the selective withdrawal capability to release waters at depth from Lake Roosevelt to reliably accomplish decreases in water temperature (BPA et al. 1994a).

4.3.2.3. Effectiveness of Mitigation. No effects to salmonids due to water temperature have been observed at the dam. In addition, no effects have been observed at the Project, while temperature-related problems have been observed at other facilities on the Columbia and Snake Rivers during the same time period.

4.4. Reservoir Production. The creation of Rock Island reservoir in 1933 impacted potential spawning and rearing fish habitat in a 20.5-mile reach of the Columbia River. Inundation of the river created a pool with slower water velocities and greater depths than those present under free-flowing conditions. The effect of these physical changes on the fish community in the mid-Columbia reach varied by life stage and species. A general discussion of the impacts of inundation on potential spawning and rearing of aquatic species covered by this plan is presented in Section 3. The following section describes issues and mitigation measures specific to the Rock Island project reach.

4.4.1. Spawning Habitat.

4.4.1.1. Existing Issues. The Rock Island project reach primarily supports spawning and rearing of the fall (ocean-type) component of chinook salmon and serves as a migration corridor for other species of anadromous salmonids. Fall chinook salmon have been found to spawn in deep water reservoir habitat in the mid-Columbia River (Dauble et al. 1994). Given spawning depths up to 35 feet noted elsewhere in the mainstem Columbia River (Meekin 1967; Chapman and Welsh 1979; Chapman et al. 1982; Giorgi 1992a), reservoir spawning in Rock Island reservoir may still be occurring in deep water areas. Stuehrenberg et al. (1995) lost track of 11 percent (6 of 53) of the adult fall chinook salmon passing Rock Island dam in the area of the Rock Island dam tailrace. It is possible some of these fish used Rock Island tailrace for spawning. However, fall chinook salmon spawning in the tailrace of Rock Island dam has not been documented. One adult was last tracked in the Wenatchee River mouth, and may have spawned there. One adult was last tracked in Rock Island reservoir, near Rock Island dam (Stuehrenberg et al. 1995). It is unknown whether or not the adult last tracked in the reservoir area spawned.

The Wenatchee River is the one major tributary flowing into Rock Island reservoir containing suitable spawning habitat. Little potential spawning habitat is available in the smaller tributaries to Rock Island reservoir. Most of the smaller tributaries flow only during precipitation events or transport irrigation return flows during the irrigation season. No adult chinook salmon have been observed spawning in tributaries to Rock Island reservoir other than the Wenatchee River. Tributary spawning by steelhead in the Rock Island project area has not been well documented. The following tributaries may have sufficient flow into Rock Island reservoir at peak flows in February and March to attract steelhead adults: Rock Island Creek, Stemilt Creek and Squilchuck Creek. Electrofishing surveys by the Washington Department of Fish and Wildlife (WDFW) have documented the presence of juvenile resident rainbow or steelhead in the lower reaches of Stemilt and Squilchuck Creeks (Brown, pers. comm., 30 May 1995). These juveniles may have been locally produced or migrated upstream into the stream mouths from Rock Island reservoir.

4.4.1.2. Tributary Bedload and Fine Sediment Deposition. No data about deposition of fine sediment in Rock Island pool are available. Tributary inflow into Rock Island reservoir is limited primarily to the Wenatchee River drainage. Fine sediment loading in the Wenatchee River basin is considered moderate, and less than the fine sediment loading in comparable mid-Columbia tributaries. Silt and other fine sediment continue to settle in the reservoir in the vicinity of the confluence of Rock Island reservoir and the Wenatchee River. Sedimentation effects are localized and no known loss of existing or potential spawning sites occurs due to these deposits. Although deposition of tributary bedload could provide a source of substrate for potential spawning habitat, this has not been documented in Rock Island reservoir.

4.4.1.3. Previous and Existing Mitigation Measures. Existing mitigation for losses of mainstem spawning habitat due to inundation by Rock Island reservoir has been stipulated in the 1987 Settlement Agreement for the Rock Island project (FERC 1987). The agreement specifies hatchery fish production to compensate for spawning losses.

4.4.2. Effectiveness of Existing Mitigation Measures. Section 4.2.2 discusses the effectiveness of existing hatchery-based mitigation for spawning or spawning habitat losses due to the existence of the Project.

4.4.2.1. Ongoing. No ongoing monitoring of spawning or spawning habitat is conducted in the Rock Island project area.

4.4.3. Rearing Habitat.

4.4.3.1. Existing Issues.

4.4.3.1.1. Reservoir Conditions. The Rock Island project area includes the tailrace, extending approximately 1,000 feet below Rock Island dam, and Rock Island reservoir, a 20.5-mile-long reservoir upstream of Rock Island dam. The upper end of the project area extends to approximately 1,000 feet below Rocky Reach dam. The reservoir has a total surface area of 3,470 acres, a volume of 126,000 acre-feet, and an average depth of 33 feet. Water temperature ranges from just above 0°C to over 18°C. Reservoir with rapid flushing rates generally have weak intermittent or no stratification during the summer (Johnson et al. 1978; Kimmel and Groeger 1984; Cox 1984). Although Rock Island reservoir has 42 miles of shoreline, most of the shoreline is steep and the proportion of littoral area in the reservoir is small in comparison to its size. The 220 surface acres of submerged plant communities (Truscott 1991) comprise only 6 percent of the surface area of the reservoir. The reservoir has almost no backwater area and a shoreline to length ratio of only 2:1, the lowest of the five mid-Columbia River reservoirs. The effects of rapid water exchange, a relatively steep, rocky shoreline and lack of riparian habitat on juvenile salmonid rearing in reservoirs is unknown. However, the steep, rocky shoreline would likely have an impact on juvenile ocean-type chinook rearing based on reports of habitat preferences in Lower Granite and McNary reservoirs (Bennett et al. 1993; Key et al. 1994). Although there is an abundance of rocky and rip-rapped shoreline areas, there is little backwater habitat suitable for warmwater species.

Factors with the potential to affect the rearing capacity of the reservoir include its flushing rate, thermal regime, degree of primary and secondary productivity, level of submerged macrophyte growth, deposition of fine sediment, water quality conditions and fluctuating water levels in the reservoir. A general assessment of these factors in Rock Island reservoir and information specific to the Rock Island project area is presented in this section.

4.4.3.1.2. Reservoir Flushing and Turnover Rate. At Rock Island reservoir, water retention, or the flushing rate, ranges from 14 hours during high spring runoff conditions in June to approximately 1.2 days during low flow conditions in February, with an annual average turnover rate of less than one day. This flushing rate is considered very rapid in comparison to lower Columbia mainstem and other mid-Columbia River reservoirs.

4.4.3.1.3. Nutrients, Aquatic Productivity, Zooplankton Abundance. Due to the rapid flushing rate of Rock Island reservoir, primary productivity is limited. Reservoir productivity is primarily dependent on detritus, sessile algae and macrophytes (Chelan PUD 1991c). The reservoir flushing rate is too rapid in summer months for development of a diverse zooplankton community. Turbidity is generally low, with secchi disk readings measuring 6 to 18 feet, except during peak flow events in tributaries entering the reservoir (Chelan PUD 1991c). Lack of nutrient input into the reservoir also inhibits aquatic zooplankton community development.

4.4.3.1.4. Submerged Macrophytes. In 1984, a survey of the mid-Columbia River between Rock Island and Wells dams (RM 453.4 to RM 515.1) found Eurasian watermilfoil (*Myriophyllum spicatum*) made up less than 10 percent of the aquatic plant acreage. In 1991, the Rock Island reservoir contained about 220 surface acres of submerged plant communities, of which Eurasian watermilfoil was the dominant species (Truscott 1991). Truscott (1991) reported that Eurasian watermilfoil comprised 138 acres (64 percent) of the aquatic macrophyte community. Other aquatic macrophytes present in the reservoir include: *Elodea canadensis, Potamogeton pusillus* and *Potamogeton crispus*. Eurasian watermilfoil continues to displace native plant species, increasing its percentage in the submerged plant community (Truscott 1991).

4.4.3.1.5. Fluctuating Water Levels in the Project Reservoir and Potential for Fish Stranding. Rock Island reservoir generally consists of a steep morphology along river margins with very limited backwater and shallow areas. Areas around tributary confluences and near islands offer the greatest potential for stranding juvenile salmonids. No studies or evidence of stranding juvenile salmonids are available for Rock Island reservoir. Daily drafting at Rock Island dam is a relatively slow process and does not represent a large stranding concern to juvenile fishes. Normal project operation is to maintain the forebay elevation in the top 6 inches to 1 foot of its operating range to maximize head and, therefore, energy production.

4.4.3.1.6. Deposition of Tributary Bedload and Fine Sediment, Rearing Effects. Reduction of peak flows and lack of significant water level fluctuation in Rock Island reservoir probably have increased the amount of fines present in the cobble substrate. No known adverse effects on ocean-type chinook salmon or other aquatic species have been observed in the Rock Island reservoir.

4.4.3.2. Water Quality. There is no indication that the Project is having an adverse effect on water quality parameters that would reduce the reservoir rearing production potential.

4.4.3.3. Status of In-Stream Rearing in the Project Reservoir. The importance of mainstem reservoir habitat for rearing of mid-Columbia fishes varies by species and race/deme. Juvenile stream-type chinook salmon, steelhead and sockeye salmon do not appear to rear extensively in the shoreline habitats of the mainstem Columbia River, but outmigrate in the thalweg. The river primarily functions as a migration corridor in which food may be encountered.

Ocean-type chinook salmon juveniles use Rock Island reservoir for rearing in late spring through summer. Several researchers have identified the habitat preferences of ocean-type chinook in the mid-Columbia and Snake Rivers. Bennett et al. (1993) found that ocean-type chinook salmon outmigrants prefer beaches with greater than 75 percent sand in Lower Granite reservoir on the Snake River. Key et al. (1994) used a beach seine to capture ocean-type chinook salmon outmigrants in McNary and Lower Granite reservoirs on the Columbia and Snake Rivers. Few fish were caught where the depth was less than 0.25 meters at 15 meters from shore; most were caught where the depth was 0.54 to 1.75 meters at 15 meters from shore. Very few were caught where depth exceeded 1.756 meters at 15 meters shore. Key et al. (1994) hypothesized that avoidance of extremely shallow water was an adaptation to minimize avian predation, and avoidance of deep water was an adaptation to minimize predation by piscivorous fishes.

Based on these habitat preferences, steep, rocky shorelines do not represent good rearing habitat for ocean-type chinook salmon. In Rock Island reservoir the amount of suitable habitat for ocean-type chinook salmon, which consists of fine substrates, low velocity and shallow shoreline slope, is unknown but likely represents a small percentage of the shoreline of the reservoir.

4.4.3.4. Previous and Existing Mitigation Measures. Full and complete mitigation for all spawning and rearing habitat modifications due to reservoir impoundment at the Rock Island project has been provided in the 1987 Settlement Agreement (FERC 1987). The license articles include hatchery production mitigation for assumed reservoir losses.

4.4.3.5. Ongoing Monitoring. There is no current or proposed monitoring of rearing habitat in the Rocky Reach project reach, other than that as set forth in the Anadromous Fish Agreement and Habitat Conservation Plan.

4.5. Predation. The following section describes the risk of juvenile salmonid outmigrant mortality due to predation at the Rocky Reach project and Chelan PUD efforts designed to improve outmigrant survival. Discussion of potential predation on juvenile outmigrants at the mid-Columbia PUD projects involves use of the terms tailrace, forebay and mid-reservoir areas. For a general description of predation in the mid-Columbia River, including a brief life history of each major predator species, see Section 3.5.

4.5.1. Status of Predator Populations.

4.5.1.1. Northern Squawfish. Northern squawfish, a large native member of the minnow family, are abundant in the Rock Island project area and are a significant source of outmigrant mortality. In a 1993 survey conducted by the WDFW to assess the significance of predation, 700 northern squawfish were captured over four days of sampling at Rock Island (Burley and Poe 1994). Northern squawfish accounted for approximately 95 percent of all predators caught at Rock Island during both the spring and summer sampling periods (Table 4-2). The size of anadromous salmonids consumed by northern squawfish also increases progressively with the size of the squawfish. In a study conducted in the John Day reservoir from 1983 to 1986, salmonids accounted for 21 percent of the diet of 300 mm northern squawfish and 83 percent of the diet of larger squawfish (Poe et al. 1991). The northern squawfish caught by the WDFW at Rock Island averaged 332 mm in length. Squawfish of that size are capable of consuming salmonid juveniles up to 155 mm long (Poe et al. 1991).

Northern squawfish prefer areas of slow water velocity, especially where low velocity borders high-velocity areas (Faler et al. 1988). Such sites are common in the Rock Island tailrace. Previous studies have documented high concentrations of northern squawfish in dam tailraces on the lower Columbia, and attributed such concentration to the existence of low velocity refuges near sites

Table 4-2. Number of predatory fish caught at Rock Island project site during 1993 WDFW survey.

Species	**Number**	**Percent of Total Catch**
	Spring	
Northern Squawfish	162	95
Walleye	8	5
Smallmouth Bass	0	0
	Summer	
Northern Squawfish	538	94
Walleye	32	5.5
Smallmouth Bass	3	0.5

Source: Burley and Poe 1994.
pred.ri3

which frequently contain large numbers of injured or disoriented prey fish (Beamesderfer and Rieman 1991; Poe et al. 1991). In 1993, predation indexing studies conducted by the WDFW and National Biological Survey (NBS) found that the density of northern squawfish in the Rock Island reach was also highest in the tailrace-boat restricted zone (BRZ) (Loch et al. 1994). An angling program which began in 1995 has removed over 16,000 fish in three seasons, averaging over 5,400 fish per year.

4.5.1.2. Smallmouth Bass. Smallmouth bass were the least abundant predator captured at Rock Island in the 1993 WDFW survey (Burley and Poe 1994). Only three smallmouth bass were taken over the four days of sampling (Table 4-2). Smallmouth bass captured at Rock Island during the 1993 WDFW survey were taken from the reservoir forebay and mid-reservoir sample sites.

Smallmouth bass are not known to reproduce in Rock Island reservoir, probably due to water temperature limitations (Zook 1983). Water temperatures in Rock Island reservoir are typically lower than those preferred by smallmouth bass (Wydoski and Whitney 1979). Preferred spawning temperatures for this species range from 16-18°C (Wydoski and Whitney 1979; Scott and Crossman 1973); such temperatures consistently occur only in August and September at Rock Island. A rise in river flow and associated decrease in water temperature during spawning season will cause adult bass to abandon their nests and has been linked to a total loss of annual production in the lower mid-Columbia reach (Zook 1983).

Smallmouth bass appear to selectively feed on ocean-type chinook salmon in other portions of the Columbia River (Tabor et al. 1993) where the littoral areas used by young chinook salmon for rearing are inhabited by smallmouth bass. However, the small size of the smallmouth bass population suggests that predation by smallmouth bass on juvenile salmonids is minimal in Rock Island reservoir (Burley and Poe 1994).

4.5.1.3. Walleye. There appear to be more walleye in the Rock Island project area than at any of the other mid-Columbia reservoirs. Forty walleye were captured during the 1993 WDFW survey at Rock Island compared to 27 at Wells, 24 at Rocky Reach, 18 at Wanapum and 13 at Priest Rapids. Seventy-two percent of the walleye caught at Rock Island were taken in the tailrace (Burley and Poe 1994). Concentrations of walleye observed in the tailraces of the mid-Columbia projects may represent either spawning runs (Brown and Williams 1985) or a feeding response to the concentrations of vulnerable salmonids in the tailrace (Burley and Poe 1994).

Despite the presence of walleye in the Rock Island tailrace, which may represent a spawning run, there is no direct evidence that walleye are successfully reproducing in the Rock Island project area (Zook 1983). Bennett (1991) suggested that the two factors most limiting walleye recruitment in the mid-Columbia River were low turbidity and a lack of juvenile rearing habitat. Walleye require shallow, highly productive backwater areas for rearing. Because of the short water retention times and precipitous shorelines, the Rock Island reservoir lacks sites with warm, quiet water and abundant plankton production (Zook 1983). Walleye currently inhabiting Rock Island reservoir are believed to have originated upstream in Lake Roosevelt, and have been carried downstream to Rock Island reservoir during spring high flows.

No specific dietary data were available for walleye captured in the Rock Island project area during a 1993 National Biological Survey (NBS) study (Burley and Poe 1994). A study of walleye food habits at the John Day reservoir in the lower Columbia River suggested that juvenile anadromous salmonids consistently accounted for only about 18 to 24 percent of the walleye diet there, even when juvenile anadromous salmonids were abundant and highly concentrated in areas occupied by walleye (Poe et al. 1991). Should the population of walleye at Rock Island substantially increase, this species could impact survival of the juvenile anadromous salmonids passing the project.

In summary, because of their number and behavior of targeting outmigrating juvenile salmonids as a food source, northern squawfish are the primary predator of concern at the Rock Island project (Burley and Poe 1994). Smallmouth bass and walleye are not numerous in Rock Island reservoir, resulting in minimal predation of juvenile anadromous salmonid outmigrants.

4.5.1.4. Gulls. A 1982 study at Wanapum dam, downstream of Rock Island, indicated that gulls were consuming a substantial number of outmigrating juveniles (Ruggerone

1986). Prior to installation of protective devices, ring-billed gulls consumed an estimated 2 percent of all juvenile salmonids passing Wanapum dam. Although site-specific studies were not conducted at Rock Island, gulls have been observed feeding heavily on juvenile anadromous salmonid outmigrants in the Rock Island tailrace.

Gull hazing and installation of protective devices have been implemented at Rock Island dam. Hazing measures are the use of pyrotechnics to frighten gulls away from the tailrace area. Stainless steel wires have also been installed in the Rock Island tailrace area to discourage gull predation on juvenile salmonids. The protective measures have significantly reduced gull-related predation at Rock Island dam (McDonald, pers. comm., 20 July 1995).]

4.5.2. Vulnerability of Juvenile Salmonids to Predation. Several million juvenile salmonid outmigrants pass through the Rocky Reach project area each year (FPC 1994). Concentrations of outmigrating salmonids are common in the dam forebay and near the turbine and spillway outflow area below the powerhouse. Not only do the juvenile outmigrants become concentrated near the project site, but some fish may be disoriented or injured passing through the dam, making them more susceptible to predation.

4.5.2.1. Tailrace. Downstream migrating anadromous salmonids pass Rock Island dam either through the turbines, over the spillway or through a juvenile bypass channel at powerhouse 2. Passage via turbines or spill is known to temporarily stun, injure or kill some young fish (Eicher Associates 1987; Muir et al. 1994). Juvenile anadromous salmonids frequently become disoriented in the strong, turbulent currents immediately below the dam. These disoriented or injured fish are less adept at escaping predators. Backwater eddies downstream of the dam tailraces provide ideal holding areas for northern squawfish, which prey upon the disoriented salmonids (Faler et al. 1988). Gulls also show a feeding response to the concentrations of disabled juvenile salmonids in dam tailraces (Ruggerone 1986).

In 1993, the WDFW and NBS assessed predation at the Rock Island project and developed consumption, density, abundance and predation indices (Table 4-3) (Burley and Poe 1994). They indicated that predation near the tailrace poses a significant risk to juvenile anadromous salmonid outmigrants at Rock Island (Table 4-3). The tailrace sampling area for this study was subdivided into the tailrace boating restriction zone (BRZ) immediately below the dam, and the overall tailrace sampling area that extended approximately 4.7 miles downstream. The density index for northern squawfish in the tailrace-BRZ sampling area below Rock Island dam was the highest of all of the mid-Columbia projects (Loch et al. 1994). Samples of the gut contents of northern squawfish collected in sampling areas near the dam indicated that they fed almost exclusively on juvenile salmonids during the spring (Table 4-4) (Loch et al. 1994). The northern squawfish predation index for the Rock Island tailrace BRZ was second highest of all the mid-Columbia projects in the spring, but dropped substantially during the summer (Loch et al. 1994).

Samples of northern squawfish gut contents during the summer suggest that northern squawfish in the tailrace switch to other food items during the summer or go hungry (Loch et al. 1994). The majority of squawfish sampled near the dam had empty stomachs, and the majority of fish ingested by northern squawfish were non-salmonids (Table 4-4). Lower project flows, and associated lower water velocities, may allow squawfish to approach the dam more closely and, thus, prey more efficiently (Faler et al. 1988), but there are simply fewer juvenile salmonid outmigrants during the summer (Figure 4-10). Even though the density of ocean-type chinook salmon outmigrating during the late summer is low, the size of these juveniles make them particularly vulnerable to predation by squawfish near the dam.

Table 4-3. Northern squawfish (>250 mm fl) index values for various locations at the Rock Island reservoir, 1993.

		Spring		
Project location	**CI[1]**	**DI[2]**	**AI[3]**	**PI[4]**
Tailrace	0.9	1.317	0.70	0.63
Tailrace - BRZ[5]	1.0	3.742	0.14	0.14
Forebay	0.4	1.350	0.31	0.12
Forebay - BRZ[5]	0.4	1.206	0.13	0.05
Mid-reservoir	0.2	1.581	0.31	0.06
		Summer		
Project location	**CI[2]**	**DI[3]**	**AI[4]**	**PI[5]**
Tailrace - overall	0.1	1.317	0.70	0.07
Tailrace - BRZ[6]	0.0	3.742	0.14	0.00
Forebay - overall	0.0	1.350	0.31	0.00
Forebay - BRZ[6]	0.0	1.206	0.13	0.00
Mid-reservoir - overall	0.2	1.581	0.31	0.06

[1]Consumption Index = Number of organisms consumed per day by an individual predator
[2]Density Index = Estimated number of predators per sample area
[3]Abundance Index = DI * Surface area
[4]Predation Index = CI * AI
[5]Values for boating restricted zone only.
Source: Loch et al. 1994.

quaw.ri3

Table 4-4. Stomach contents of northern squawfish (> 250 mm fl) caught by electroshocking at Rock Island project during the spring and early summer, 1993.

Spring							
Reservoir Location	**Sampling Date**	**No. of Squawfish**	**% empty guts**	**% fish in diet**	**salmonids as % of prey fish consumed**	**total number of salmonids consumed**	**salmonids as a % of the total diet**
Tailrace	5/04-5/05	40	10	94	97	85	91
Tailrace-BRZ	5/04-5/05	28	11	95	96	54	91
Forebay	5/11-5/12	29	41	91	70	19	64
Forebay-BRZ	5/11-5/12	18	61	100	100	10	100
Mid-reservoir	4/29-4/30	31	52	35	67	4	23

Summer							
Reservoir Location	**Sampling Date**	**No. of Squawfish**	**% empty guts**	**% fish in diet**	**salmonids as % of prey fish consumed**	**total number of salmonids consumed**	**salmonids as a % of the total diet**
Tailrace	7/14-7/15	115	66	38	7	1	5
Tailrace-BRZ	7/14-7/15	94	67	36	0	0	0
Forebay	7/13-7/14	18	78	25	0	0	0
Forebay-BRZ	7/13-7/14	5	60	0	0	0	0
Mid-reservoir	7/01-7/02	133	29	14	62	13	9

Source: Sauter et al. 1994.

stomach.ri3

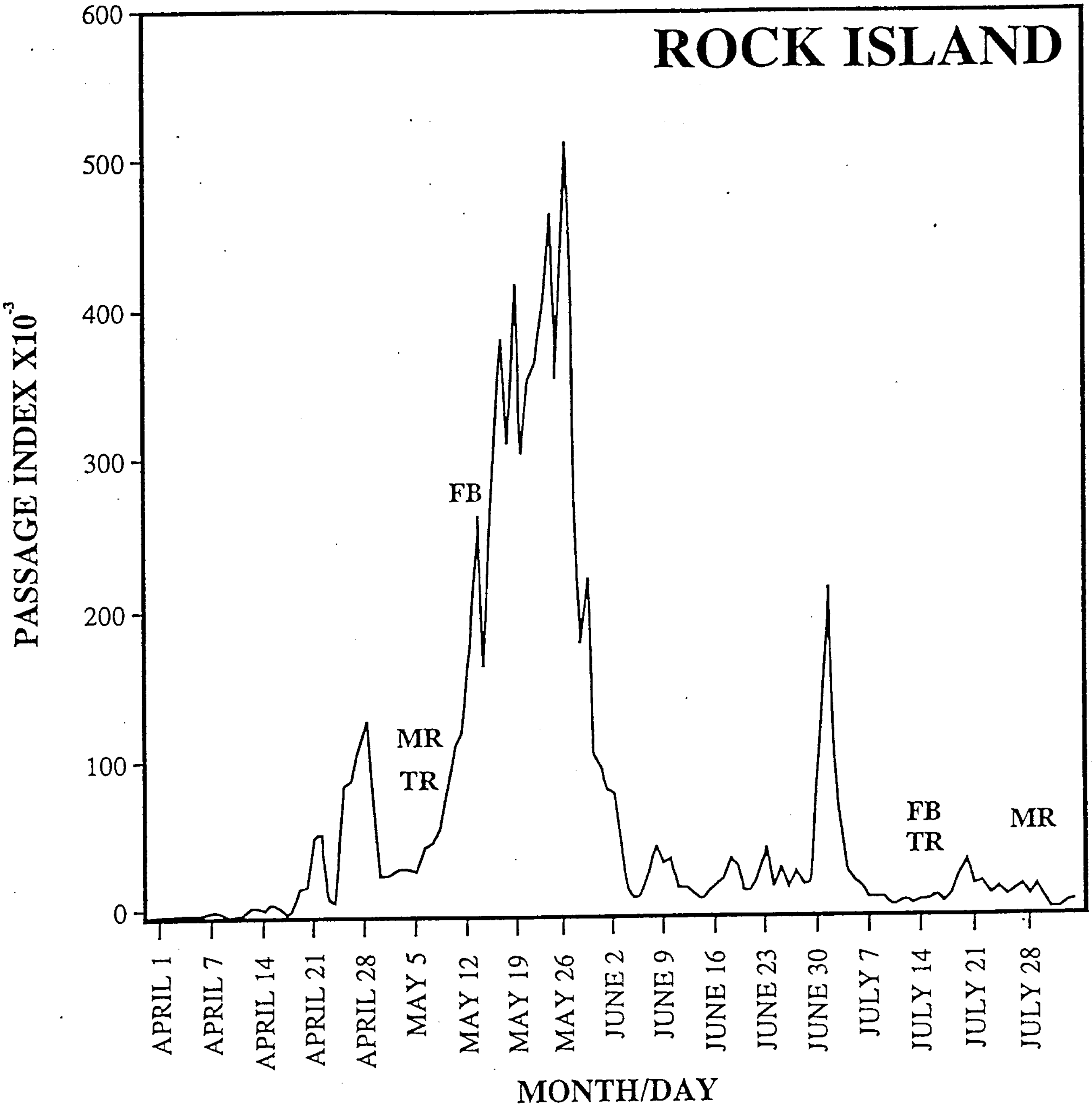

Figure 4-10 Timing of consumption index sampling during 1993 with respect to juvenile salmonid passage indices at the Rock Island project. Approximate sample times for tailrace (TR), and immediate downstream mid-reservoir (MR), and forebay (FB) locations are indicated. The MR locator represents sampling at Crescent Bar, downstream of Rock Island dam (Source: Sauter et al. 1994).

passage.ri3

4.5.2.2. Reservoir Forebays. Juvenile anadromous salmonids migrating downstream through Rock Island reservoir may concentrate in the forebay immediately upstream of the dam prior to finding a way through the dam. As in the tailrace areas, northern squawfish and other predators are attracted to such concentrations of juvenile anadromous salmonids.

Density indices of northern squawfish in the Rock Island forebay sample area during the spring were lower than those observed in the tailrace BRZ (Table 4-3) (Loch et al. 1994). Gut sample contents of northern squawfish during the spring indicated that squawfish fed almost exclusively on juvenile salmonids (Table 4-4). No juvenile anadromous salmonids were identified in gut content samples from 23 squawfish sampled in the forebay area in mid-July. The lack of juvenile salmonids in squawfish gut samples during the summer may reflect the fluctuation in migration timing of juvenile salmonids.

4.5.2.3. Mid-reservoir. Predation losses of juvenile salmonids to northern squawfish in the main portion of Rock Island reservoir appear to be minimal. Northern squawfish were less abundant in the mid-reservoir at Rock Island than at any of the other mid-Columbia reservoirs (Burley and Poe 1994). Juvenile salmonids accounted for 23 percent of the northern squawfish gut contents taken from the mid-reservoir at Rock Island during the spring, but only 9 percent of the gut contents of northern squawfish in the summer of 1993. No concentrations of prey or predators were observed at the mid-reservoir sites. The relative scarcity of juvenile salmonids in the gut contents of northern squawfish taken from the mid-reservoir, as compared to the tailrace and forebay, suggests that juveniles are more adept at avoiding northern squawfish away from the dam site.

In summary, predation near the tailrace of the Rock Island project area is the biggest concern, because of the apparent site-specific vulnerability and concentration of juvenile salmonids. Concentrations of outmigrating juvenile salmonids may be exposed to potential predation in the forebay, but predators do not appear to target the juvenile salmonids as successfully in this area. Predation in the mid-reservoir appears to be low in Rock Island reservoir.

4.5.3. Existing Mitigation Measures. At present, mitigation measures implemented to reduce predation at the Rock Island project include the installation of wires across the tailrace BRZ and hazing to prevent gulls from feeding on juvenile anadromous salmonids. No specific data are available on the effectiveness of the gull wires at Rock Island, but Ruggerone (1986) suggested that such measures would likely eliminate most consumption of salmonids by gulls in the areas protected by wires. Annual hazing is conducted during peak juvenile salmonid outmigration to frighten gulls away from the tailrace. A squawfish reduction program was initiated at Rock Island Dam in 1995.

4.5.4. Ongoing Monitoring Efforts. No program for monitoring anadromous salmonid loss to predation is being conducted at this time.

5. System-Wide Issues. The preceding sections describe background material on issues that affect anadromous salmonids and other plan species at each of the mid-Columbia PUD projects. Some of those issues are the result of physical features and operational measures that affect the overall mid-Columbia River. These system-wide issues influence the ability of the PUDs to limit the impact of individual projects on potentially listed species. Likewise, the many agreements and processes that control the release of water from Grand Coulee dam limit the ability of the PUDs to manipulate flow in the mid-Columbia reach. This section will describe the processes, agreements, and treaties that affect the physical and biological characteristics of the mid-Columbia reach. It then presents a qualitative analysis of the cumulative effects of these factors.

5.1. Physical Characteristics of Mid-Columbia Projects. The physical characteristics of the mid-Columbia projects affect the ability of the PUDs to influence physical conditions on the river for migrating anadromous salmonids. These characteristics include the storage capacity of the projects and the key features of the reservoirs. A description of the physical, environmental and biological characteristics of each project is presented in the project HCPs. Only project characteristics which have system-wide implications are discussed in this section.

5.1.1. Storage Capacity. Most hydroelectric dams in the Columbia River basin fall into one of two categories according to their ability and capacity to store and release water. The project categories are "storage" and "run-of-river." Storage projects have a large usable volume and are operated to store and release water for purposes such as flood control, power generation, irrigation, fish and wildlife mitigation, and other needs. They have large operating ranges (the difference in elevation between minimum and maximum operating pool) and can release, or draft, large volumes of water.

Run-of-river projects generally have little usable pondage and no storage volume. They have a small operating range and so must pass inflow most of the time. Figure 5-1 depicts the usable storage volume of each of the major reservoirs on the upper and mid-Columbia River. The mid-Columbia PUD projects and the federally owned Chief Joseph dam contain less than five percent of the major usable storage upstream of the Snake River confluence. Table 5-1 presents this information in tabular form, along with other characteristics of the projects.

Because of their limited storage capacity, the mid-Columbia PUDs have little ability to manipulate Columbia River flow for juvenile anadromous salmonid migration or other purposes. They essentially pass inflow received from upstream projects. Since the next upstream project with any appreciable storage capacity is Grand Coulee, flow that is needed to satisfy mid-Columbia PUD and downstream obligations for most purposes is provided by regulation at Grand Coulee. The mid-Columbia projects do have a limited ability to store and release water on an hourly basis, but can influence flow for only a short period of time.

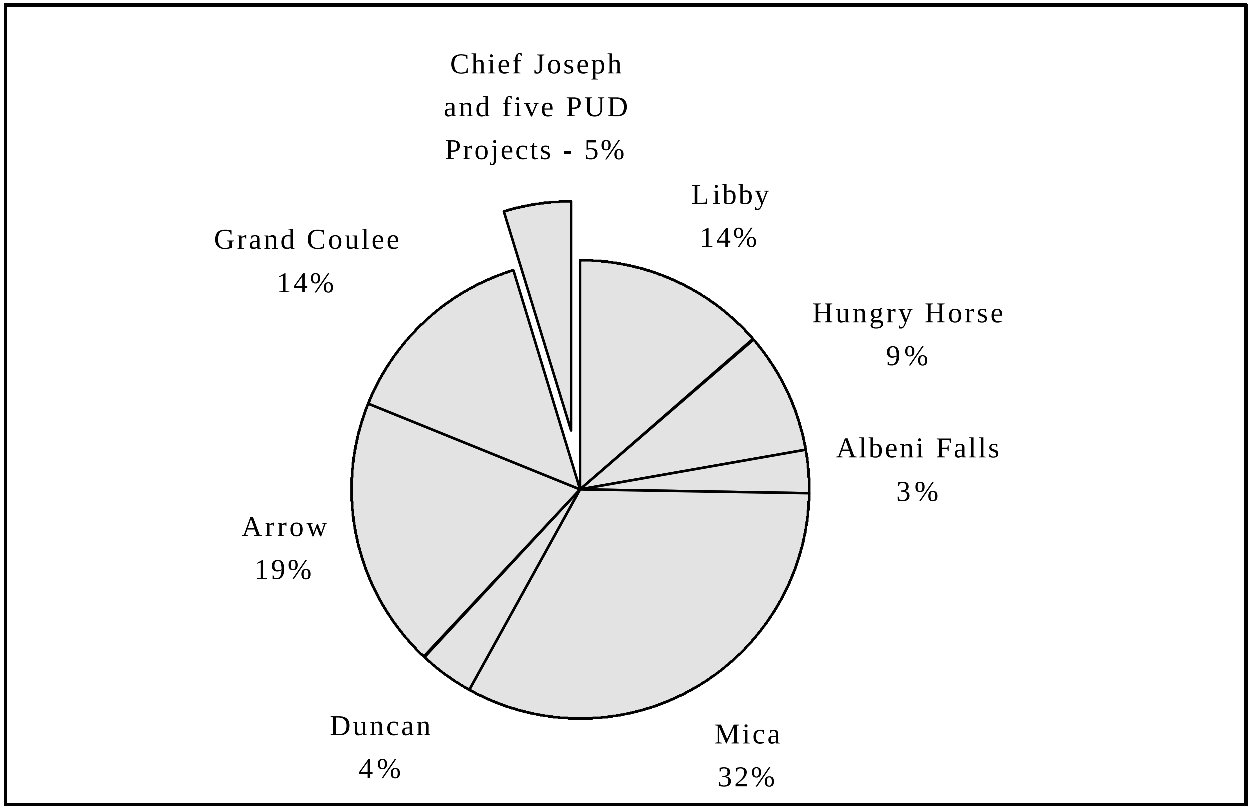

Figure 5-1. Graphical representation of storage capacity of upper and mid-Columbia River dams. The percentage of usable storage capacity, as opposed to total capacity, is much less than 5 percent for the mid-Columbia PUD projects and Chief Joseph dam (Source: USACE 1989; Zook 1983; BPA et al. 1994). piechart.ov5

Table 5-1. Useable storage capacity, operating range and construction completion date of selected major Columbia and Snake River dams.

Project	Useable Storage (kaf)	Normal Operating Range (ft)	Year Completed
Upper Columbia River			
Libby	4,980	172	1973
Hungry Horse	3,161	224	1953
Albeni Falls	1,155	11.5	1955
Mica	11,974	155	1973
Duncan	1,399	98	1987
Arrow	7,000	66	1968
Mid-Columbia River			
Grand Coulee	5,186	82	1942
Chief Joseph	116	26	1961
Wells	< 300	10	1967
Rocky Reach	< 430	4	1961
Rock Island	< 135	4	1933
Wanapum	< 160.2	10	1964
Priest Rapids	< 44.6	4.5	1961
Snake River			
Dworshak	2,016	155	1973
Brownlee	975	101	1959
Lower Granite		5	1975
Little Goose		5	1970
Lower Monumental		3	1970
Ice Harbor		3	1962

Source: USACE 1989; Zook 1983; BPA et al. 1994a.

[1] Total storage volumes instead of useable storage volumes are presented.

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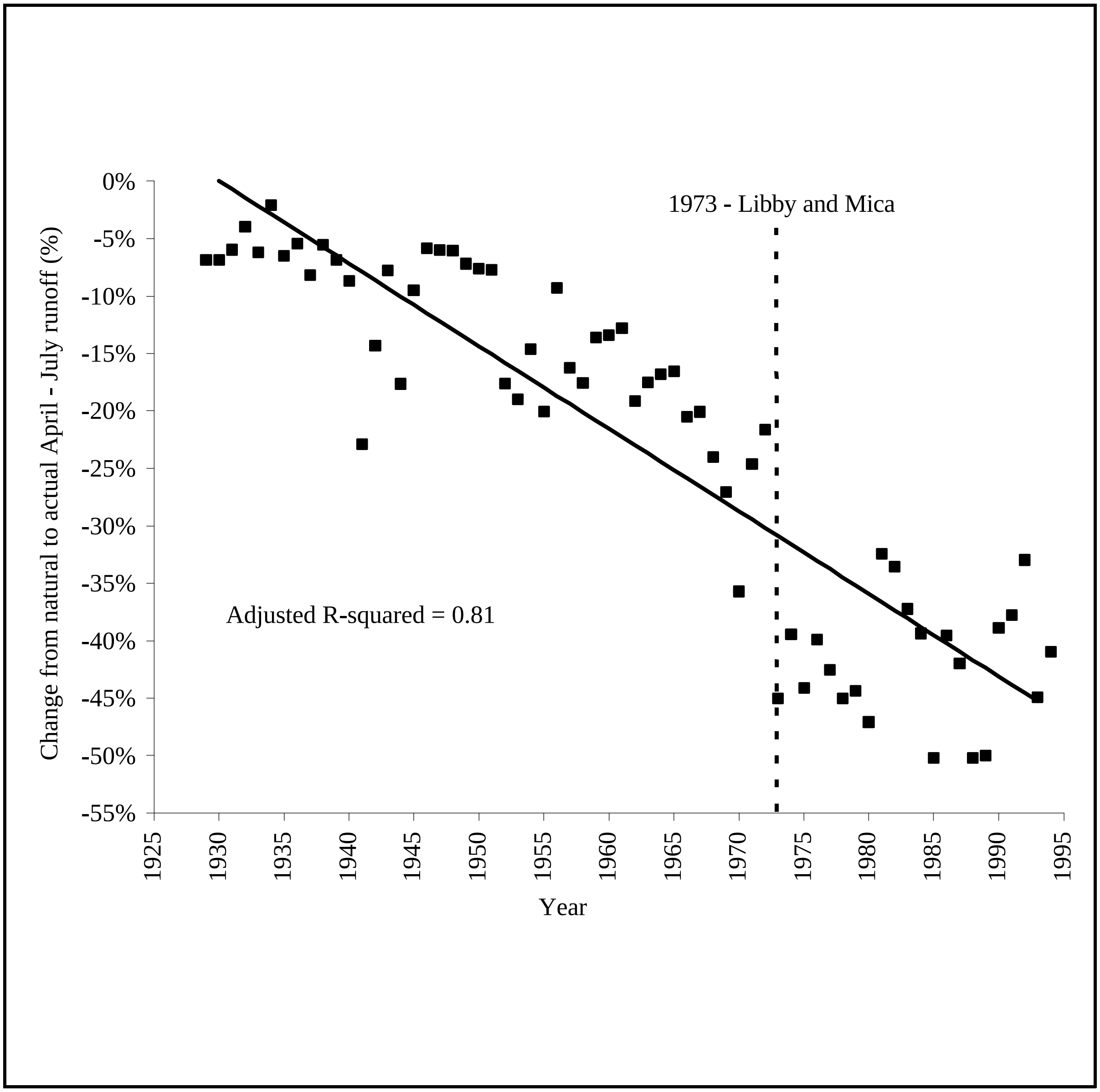

Figure 5-2. The difference between natural (unregulated) and actual (regulated) April to July flow at Priest Rapids dam from 1929 to 1994 (Source: BPA et al. 1994a). nat2act.ov5

5.1.2. Reach Characteristics. Certain features of mid-Columbia River reservoirs provide a better environment for adult and juvenile anadromous salmonid migrants than is found at many of the federal projects on the Snake and lower Columbia rivers. One of these characteristics is water particle travel time (WPTT), or the time, expressed in days, that a theoretical particle of water would take to travel the length of a reservoir. To standardize WPTT when making comparisons between reaches of different lengths, this section refers to water velocity expressed as miles per day. The water velocity characteristics of the river are of interest because of the potential relationship between WPTT and the travel time of juvenile yearling anadromous salmonids through a reservoir (Berggren and Filardo 1993). It should be noted that factors other than WPTT also affect fish travel time, including degree of smoltification, smolt condition, and water temperature. There is very little information available for the mid-Columbia reservoirs to either establish or refute the relationship between water velocity characteristics and anadromous salmonid travel time for this reach. Some studies suggest a strong correlation between flow and survival (Hilborn et al. 1994), while others suggest a weak relationship (between WPTT and juvenile salmonid travel time) (Berggren and Filardo 1993; Giorgi and Stevens 1994). Figure 5-3 shows the predicted water velocity at various flows for the mid-Columbia river reach (head of Wells reservoir to Priest Rapids dam) which has been calculated from data supplied by the NPPC (Ruff, J., pers. comm., 1 March 1995).

The predicted WPTT for the entire 142 miles of the mid-Columbia reach at flow of 100 kcfs is 8.6 days, which equals a velocity of about 16.5 miles per day. In contrast, the WPTT through the 200 miles of the lower Columbia River from the head of McNary reservoir to Bonneville dam at 100 kcfs is 23.3 days, or a velocity of 8.7 miles per day. Therefore, the predicted velocity of water through the mid-Columbia River reservoirs is nearly double its velocity in the lower Columbia River reservoirs (Figure 5-4).

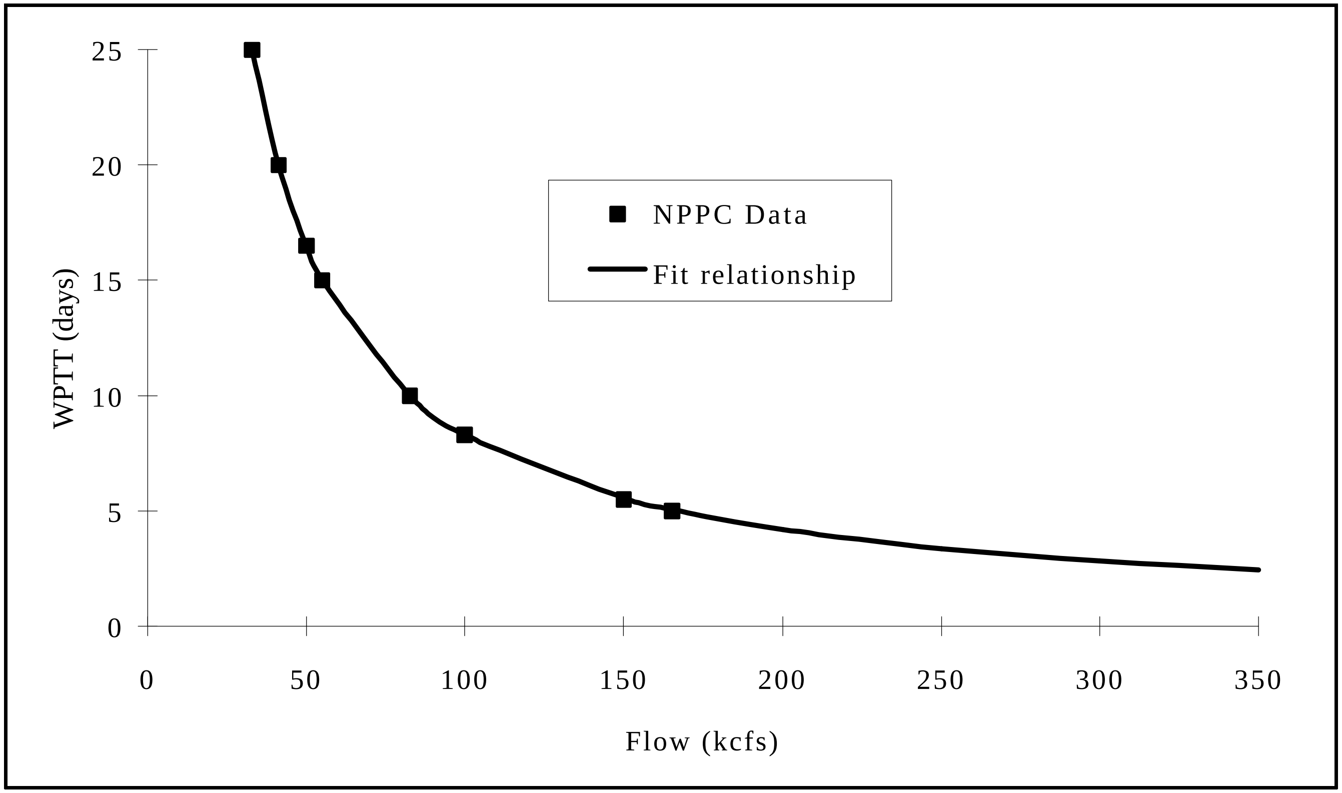

Figure 5-3. The relationship between flow and water particle travel time (WPTT) for the mid-Columbia River reach between the head of Wells reservoir and Priest Rapids dam (Source: NPPC 1995).

wptt.ov5

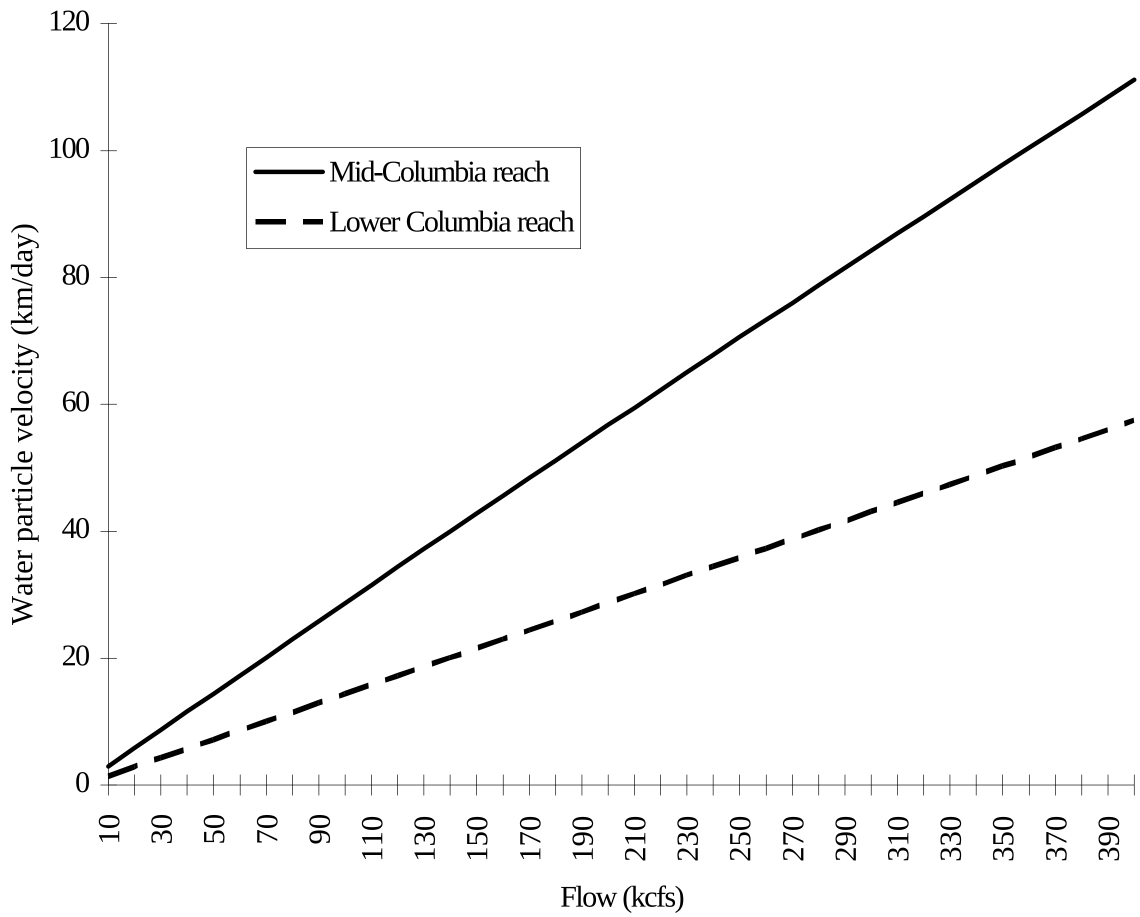

Figure 5-4. The relationship between flow and water particle velocity for the mid-Columbia River reach between the head of Wells reservoir and Priest Rapids dam and the lower Columbia River reach between the head of McNary pool and Bonneville dam (Source: NPPC 1995).

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5.2. <u>Issues that may Affect Take Under ESA Section 10</u>. Factors influencing the ability of the PUDs to mitigate impacts to listed species include the many agreements, regulations and programs that determine flow into the mid-Columbia River reach from Grand Coulee dam. The Canadian Treaty and the related Non-Treaty Storage Agreement (NTSA) control the timing of flow into this reach. Since the NPPC established its first Fish and Wildlife Program in 1982, the Water Budget and other NPPC programs have played an increasing role in controlling flows in the mid-Columbia River reach. In addition, the ESA listings of Snake River chinook and sockeye salmon, and Kootenai River white sturgeon, have had a significant effect on mid-Columbia flows.

The following section address power issues and fisheries issues. Power issues tend to result in flattening out the hydrograph by moving flow from the spring, during peak runoff conditions, into the fall and winter. This is a result of many factors, primarily power demand in the winter, flood control, and power generation in excess of demand in the spring. Fish issues tend to restore the hydrograph to the historical spring flow peak, although this may not always be the primary intent. Some fish issues attempt to manipulate flow and spill in more complex ways. The fisheries issues will be discussed first, in the order in which they have take effect, followed by the power issues, also in historical sequence. The physical impacts of each issue are estimated and presented. The unique biological impacts of some issues are also presented below. Since most of these issues involve the manipulation of large volumes of water, the biological impacts are similar, and vary according to the relative effect of each issue on flow in the mid-Columbia River reach. For this reason, the biological impacts of flow manipulation are discussed separately.

Following is a brief timetable of events that potentially affect conditions in the mid-Columbia River reach. Most of the notable events that affect flows involve construction of the major storage projects upstream from the mid-Columbia reach in the U.S. and Canada. Since the storage projects were completed, most events that have a major effect on flow involve efforts to mitigate for fisheries impacts in the Columbia River basin. Significantly, almost none of these mitigation efforts to date involve stocks of anadromous salmonids that originate in or above the mid-Columbia reach. This timetable provides the rationale for selecting the time periods used in the qualitative analysis of the effects of system-wide factors on the mid-Columbia reach.

1942 Grand Coulee completed, with over 5 million acre-feet (MAF) of storage.

1955 Hungry Horse (1953) and Albeni Falls add over 4 MAF of storage capacity, almost doubling storage above the mid-Columbia River reach. No major storage projects will be built for 13 years.

1967 With the completion of Wells dam, the mid-Columbia PUD projects are all in place. Total storage capacity added by PUD projects is approximately 1.1 MAF.

1968 Arrow dam adds 7 MAF to the upper Columbia storage capacity. This the first project completed under the Columbia River Treaty between the U.S. and Canada. Even though the treaty was signed in 1964, Columbia River flows were not affected until Arrow dam was built.

1973 Libby and Mica add another 17 MAF to upper Columbia system storage, doubling storage capacity again. The storage reservoirs are complete, with the exception of Duncan (1.4 MAF; completed 1987).

1983 First implementation of the NPPC Water Budget calling for 1.19 MAF from upper Snake and 3.45 MAF from Columbia River storage reservoirs for a total of 4.6 MAF flow augmentation during the spring.

1991 ESA listings are proposed for Snake River sockeye salmon.

1991 ESA listings are proposed for Snake River spring/summer and fall chinook salmon. The total flow augmentation volume provided during the spring period doubled to over 10 MAF by 1993. The possibility exists that all U.S. and potentially some Canadian storage in the upper Columbia River will be used for spring and summer flow augmentation.

1995 The NMFS Biological Opinion on endangered Snake River salmon calls for more spring flow augmentation from the upper Columbia River storage reservoirs than was required in previous years. In addition, the cessation of juvenile transportation from McNary dam may have a profound adverse impact on smolt-to-adult survival rates for mid-Columbia stocks.

1996 The expiration of agreements such as Canadian Treaty Storage and the PNCA may affect anadromous salmonids that originate in the mid-Columbia River reach.

5.2.1. Canadian Entitlement Purchase Agreement.

5.2.1.1. General Description. The Columbia River Treaty was signed with Canada in 1964 (BPA 1979). It called for the construction of four storage projects to provide additional flow regulation on the Columbia River. Three of the projects were built in Canada (Mica, Arrow Lakes [Keenleyside], and Duncan Lake), and the fourth, Libby dam, was built in the U.S. The surplus generation from the three Canadian projects was sold to the U.S. in 1964 through the Canadian Entitlement Purchase Agreement (BPA 1979). Each mid-Columbia project benefits from the flows from this "Treaty Storage" space and thus generates an allocation of the power. The mid-Columbia PUDs receive about 26 percent of the U.S. power benefits from the treaty (BPA 1979). The agreement begins to expire in 1998 and the Canadian share of the allocation power must be returned to Canada by 2003. In 1997, the agreement was extended until 2024.

5.2.1.2. Impacts On Mid-Columbia Projects.

5.2.1.2.1. Physical Impacts. The effect of the Columbia River Treaty on mid-Columbia River flows has been substantial. The Treaty increased upper Columbia River system storage capacity from about 9.5 MAF to about 35 MAF over a period of 19 years (1968 - 1987). This storage capacity has enabled flow shaping to the extent that fall and winter flows are much higher and spring and summer flows are lower than the period from 1927 to 1967 (Figure 5-2). A general result of flow manipulation made possible by the large storage reservoirs is shown in Table 5-2. Even with the added flow from the current flow augmentation program, theoretical water particle travel time in the mid-Columbia has increased from pre-storage reservoir conditions by 63 percent in May and June, and 78 percent in July.

Table 5-2. Changes in mid-Columbia reach flow which resulted from the change in the hydrograph made possible by the construction and operation of the upstream storage reservoirs under the treaty. Flow data for 1990 to 1994 (current operations) is compared to years from before 1973 with similar April through July unregulated runoff volume (pre-storage) (NPPC, USGS and USACE).

Period and Parameter	Pre-storage Period	Current Operations	Percent Change
Spring flow (kcfs)	262	159	-63%
Summer flow (kcfs)	230	128	-78%

The U.S. has prepared an environmental impact statement on the return of the power to Canada beginning in 2003 (U.S. Entity 1994). The Columbia River System Operation Review (SOR) DEIS included model results concerning the additional water needed to return power to Canada, and estimated that the actual effect on flows would be less than one additional kcfs per month (BPA et al. 1994a). The SOR did not identify which projects would be generating the return power. Therefore, the river reach that would be affected by the additional flow is not known.

However, the addition of approximately one kcfs per month in either the Snake or Columbia Rivers is not considered a significant impact to the mid-Columbia River reach.

5.2.2. Hourly Coordination Of Projects On The Mid-Columbia River.

5.2.2.1. General Description. The first 10-year Hourly Coordination Agreement was signed in 1977 by the three mid-Columbia PUDs and the BPA. The objective of the agreement was to coordinate the operation of Grand Coulee, Chief Joseph and the five PUD projects in an efficient manner. The last Hourly Coordination Agreement was signed in 1997.

5.2.2.2. Impacts On Mid-Columbia Projects.

5.2.2.2.1. Specific Biological Impacts. Chapman et al. (1994a) estimated the effects of the agreement as a reduced risk of stranding of juvenile migrants, since the reservoirs would fluctuate less under the agreement. No impact to overall flow volumes during the juvenile migration season occur as a result of this agreement.

5.2.3. Non-Treaty Storage Agreement (NTSA).

5.2.3.1. General Description. The NTSA was signed by BPA and Canada in 1984. It formalized and extended yearly agreements that had been made since the completion of Mica dam on the upper Columbia River by British Columbia Hydropower (BC Hydropower) in 1973. Mica dam had been built with 5.0 MAF more storage capacity than agreed to in the Columbia River Treaty. The NTSA set the U.S. portion of that capacity at about 2.25 MAF. Storage and releases from Mica, which involve the NTSA volume, are scheduled based on the agreement. The NTSA volume in Mica is generally used to add flexibility to the Federal Columbia River Power System (FCRPS). For example, the extra water volume needed to meet NMFS flow targets at McNary dam, specified in the 1995 Biological Opinion on endangered Snake River salmon, is expected to come from NTSA storage (MacKay, pers. comm., 25 February 1995).

5.2.3.2. Impacts On Mid-Columbia Projects.

5.2.3.2.1. Physical Impacts. The physical impacts of the NTSA are largely encompassed by the impacts of the NPPC flow augmentation program. Most of the NTSA volume is used each year for spring and summer flow augmentation in the lower Columbia River.

5.2.4. Pacific Northwest Coordination Agreement (PNCA). The Pacific Northwest Coordination Agreement (PNCA) was signed in 1964 by seventeen major federal and non-federal hydroelectric generating entities in the Columbia River basin, including all the mid-Columbia PUDs. The agreement addresses the need to operate the Columbia River as a single coordinated system for the purposes of power generation. The goal of the PNCA is to maximize power generating efficiency in the basin, after first allowing for the needs of all non-power water uses, such as flood control, irrigation, recreation, and fish and wildlife.

5.2.4.1. Impacts On Mid-Columbia Projects.

5.2.4.1.1. Physical Impacts. Hydroproject operations under the PNCA affects flows in the mid-Columbia reach. The coordinating entities agree on hydropower operations that use available water in the most efficient manner for power generation, after required non-power uses have been satisfied. Since efficiency entails meeting power demand with available generation resources, the operation of storage reservoirs is scheduled to match system generation with system power demand as closely as possible, given non-power constraints on storage reservoir operations. This results in flow shaping on hourly, daily, weekly and seasonal basis. Since the water volume available for shaping is determined by runoff, the PNCA uses flow forecasts to fine tune releases for power generation and non-power uses.

In recent years, an increasing number of non-power uses has taken priority over the PNCA in scheduling storage reservoir releases. Specifically, releases of water from upriver storage projects for the purpose of aiding juvenile anadromous salmonid migration in the mainstem Snake and lower Columbia rivers conflict with the seasonal scheduling of the PNCA for power purposes. For example, the flow augmentation program may call for 1 MAF from Canadian Treaty Storage to increase lower Columbia River flow in May. The water is released from Canadian storage, and the PNCA coordinates the power generation from this water. The PNCA no longer determines the release of this volume from storage; this is at odds with efficient use of water for power generation since the spring is normally a period of flows in excess of power demand.

Since the PNCA expires in 2003, there is some question as to its effect on flows in the mid-Columbia reach in the future. The SOR (BPA et al. 1994a) examined five possible scenarios for the future operation of the agreement. Of these, only option 5, which assumes a new PNCA to enhance non-power considerations, would result in substantial enhancement of spring and summer flows. All other options examined by the SOR result in higher fall and winter and lower spring and summer flows. A successor PNCA is in the process of being finalized to that it can become effective in February 1999.

5.2.5. NPPC Fish and Wildlife Program and Amendments.

5.2.5.1. Columbia River Water Budget/Flow Augmentation. The Water Budget was first implemented in 1983 as part of the NPPC Fish and Wildlife Program. The intent of the Water Budget was to set aside a specified volume of water to be used for flow augmentation in the Snake and lower Columbia Rivers if average flows were forecast to drop below specified levels and juvenile anadromous salmonids were determined to be migrating through those reaches (NPPC 1987). The Water Budget would only be used if the January through July runoff volume forecast was for less than 29 MAF at Lower Granite and 90 MAF at The Dalles. The Water Budget was amended (NPPC 1991) to include additional flow augmentation volumes and remove a 140 kcfs flow cap in the mid-Columbia River at Priest Rapids dam.

The volume of water called for by the NPPC in their Fish and Wildlife Program and various amendments does not necessarily equal the flow augmentation volumes discussed in this section. The BPA counts all water released that is not needed for power generation purposes as flow augmentation volume. Therefore, the volumes discussed herein may be larger than the volumes called for by the NPPC Program. Since 1991, the NMFS biological opinions and subsequent Section 7 consultations have altered substantially the operation of the FCRPS insofar as the flow augmentation volumes provided. Before the Snake River salmonid species were listed, the Water Budget, which has been implemented since 1983, provided up to 1.2 MAF in the spring from Snake River storage and up to 3.45 MAF in the summer from upper Columbia River storage in order to aid migrating Snake River smolts in the lower Columbia River. Since 1992, the volume of the Water Budget has increased substantially. The upper Columbia River has provided 6.4 to 8 MAF and the Snake River 1.6 to 2.9 MAF (Table 5-3). In 1994, the Water Budget used a volume of water equivalent to 70 percent of the total U.S. system storage capacity to provide flows for juvenile migration. This water was provided by several means; see the ESA discussion below for more information.

The period during which flow augmentation will be provided for juvenile migrants is defined as April 10 to June 20 in the Snake River and April 20 to June 30 in the lower Columbia River. The NMFS Biological Opinion further calls for unspecified flow augmentation to be provided for summer migrating juveniles during July in the lower Columbia River (NMFS 1995b). In practice the Water Budget managers (FPC) request flow augmentation releases when juveniles are present at Lower Granite and McNary (FPC 1994). In addition, the BO prescribes additional releases in the Snake for fall chinook juveniles in July and adults (to lower Snake River water temperature) in September. These latter releases probably do not significantly affect stocks that originate in the mid-Columbia River reach. Figure 2-3 shows the difference in flows before and after the Water Budget volume increased substantially in 1991. The effect of the flow augmentation on the mid-Columbia River flows has been minimal in May, and slightly larger in June and July. This is a direct result of shifting more water from the fall and winter period into the juvenile migration period.

Table 5-3. Water year (percent of 50-year average January-July runoff volume at The Dalles Dam) and water budget volumes provided from Snake and upper Columbia River storage projects since 1983.

		Storage Volume Released (MAF)		
Year	**Water Year**	**Snake Storage**	**Columbia Storage**	**Total**
1983	129%	1.2	3.5	4.7
1984	105%	0	0	0
1985	83%	0	0	0
1986	102%	0	3.1	3.1
1987	72%	0.4	2.5	2.9
1988	70%	0.5	3.4	3.9
1989	86%	0.4	3.2	3.6
1990	94%	0.4	2.7	3.1
1991	89%	1.2	0	1.2
1992	45%	1.6	6.4	8.0
1993	83%	2.9	7.6	10.5
1994	72%	2.65	7.95	10.6
1995	94%[1]	1.3[2]	6.7[2]	8.0[2]

1 Final forecast for January through July runoff volume (BPA Power Supply Forecast).

2 Projected need based on the April final January through July runoff volume forecast and the flow targets in the 25 January 1995 draft of the NMFS Biological Opinion (Table 5-3; BPA Power Supply Forecast).

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5.2.6. <u>Vernita Bar Settlement Agreement</u>. The Vernita Bar Settlement Agreement (VBA) was made between the mid-Columbia PUDs, the BPA, and the State and Tribal Fishery Agencies in 1988 (FERC 1988). Through the agreement, the parties established a flow regime for the Hanford reach of the Columbia River below Priest Rapids dam. The regime was designed to provide protection for mainstem spawning fall (ocean-type) chinook salmon, and the VBA establishes flows for spawning through emergence of the fry from the gravel. The flows are provided from Grand Coulee dam, re-regulated at Wanapum and Priest Rapids dams to minimize water elevation drops below Priest Rapids, and measured as elevations at Vernita Bar, the main spawning area, which is 4 miles below the project.

5.2.6.1. Impacts On Mid-Columbia Projects.

5.2.6.1.1. Physical Impacts. The VBA establishes minimum flows at the main fall (ocean-type) chinook spawning area, using a complex set of rules that consider the location of the redds within the channel, as well as the periods for egg incubation, hatching and fry emergence. The initial flows for spawning are designed to minimize spawning above the 50 kcfs elevation at Vernita Bar. Flows during the time before egg hatching are allowed to drop to 36 kcfs for short periods. Flows after hatching and before emergence of fry from the gravel are based on a set of rules designed to keep the redds from drying out, or dewatering. Figure 5-5 shows the flows for the historical period and the years immediately before and after the VBA. Flows have increased dramatically during the late fall and winter period from their historical levels during the mid-1980s. Since the implementation of the Agreement, November through January flows have been slightly higher, and February and March flows slightly lower. However, it is difficult to separate changes in the mid-Columbia River hydrograph due to implementation of the VBA from differences in water years, system operations and a variety of other factors.

5.2.6.1.2. Specific Biological Impacts. One positive impact of the VBA is the intended effect on the spawning success of Hanford reach fall chinook salmon. Stranding of redds below the specified elevations has decreased to near zero percent since the implementation of the agreement (Carlson and Dell 1989, 1990, 1991, 1992). Therefore, the spawning and incubation success of this stock has been estimated to have increased significantly since before the VBA was implemented based on redd counts, spawning and incubation success, and the relative health of the Hanford Reach up-river bright fall chinook adult returns (Carlson and Dell 1989, 1990, 1991, 1992) compared to other fall chinook adult returns in the Columbia River basin.

One effect of the VBA may be that the federal government has less ability to augment spring flows in extremely low flow years. Reduced flexibility in late winter would have occurred in 1992 through 1994 if a high (70 kcfs) Protection Level Flow had been established on Vernita Bar. Releasing water from Grand Coulee to maintain the 70 kcfs Protection Level Flow would have precluded storage of the full flow augmentation volume due to the high Grand Coulee discharge

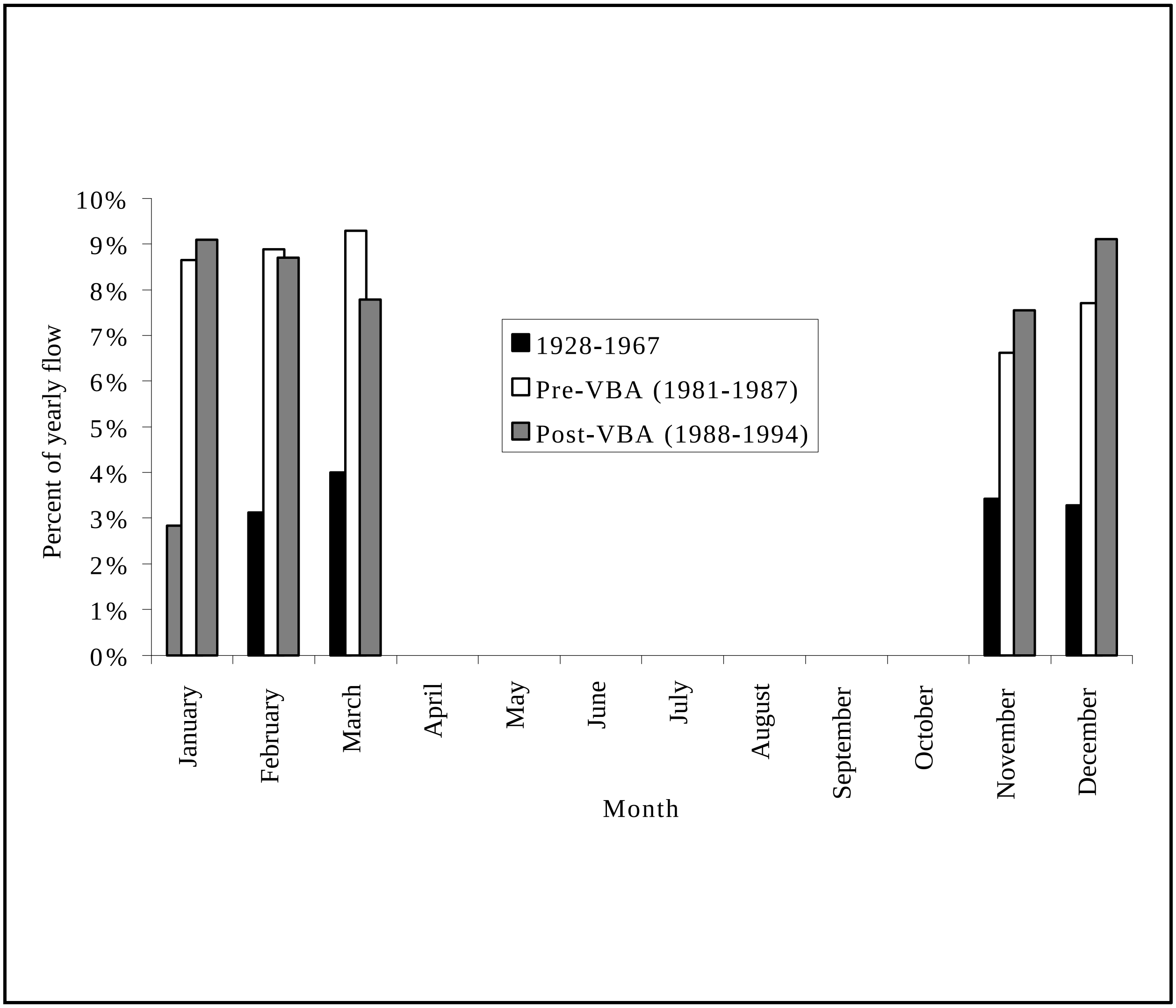

Figure 5-5. Winter monthly flow as a fraction of yearly flow below Priest Rapids dam, during the 40-year historical period and five years before and after the VBA (Source: USACE 1995d).

combined with low runoff volumes (Osborn, pers. comm., 3 August 1995). This reduced flexibility would have had an impact on Snake, mid-Columbia and lower Columbia River stocks of anadromous salmonids. A reduction in the volume of water available for flow augmentation results in a smaller portion of spring and summer migrants benefitting from increased flows, which would likely result in a decrease in a decrease in juvenile passage survival.

5.2.7. ESA Listings Of Columbia River Basin Fish Species. The recent listings of anadromous salmonids in the Snake River have had a substantial effect on the mid-Columbia reach, most notably in terms of reshaping flows to meet lower Columbia River flow targets. Under the ESA, the operating agencies, consisting of the BPA, the USACE and the USBR must consult with the NMFS to determine whether or not operation of the FCRPS may place the listed species in jeopardy of extinction (ESA section 7).

The operating agencies first prepare a Biological Assessment (BA) of the effect of the proposed operation of the FCRPS on the listed species [ESA section 7(c)]. In response, the NMFS prepares a Biological Opinion (BO) in which they determine if the proposed operations "is … likely to jeopardize the continued existence of any endangered … or threatened species" [ESA section 7(a)(2)]. If the operating agencies are found by NMFS as not placing the species in jeopardy of extinction, the proposed operation is accepted in the BO as a "no jeopardy" finding, and the consultations ended. If the operating agencies are found to be placing the species at risk of extinction through their operation of the FCRPS, the NMFS issues a finding of "jeopardy" in the BO. The NMFS then determines "reasonable and prudent alternatives" to the proposed action that the operating agencies must take in order to avoid placing the listed species in jeopardy of extinction [ESA §7(b)(3)(a)].

5.2.7.1. Columbia River Basin Listings and Proposed Listings. As of 1998, there are six species (ESUs) of Columbia River basin anadromous salmonids that are currently listed as endangered under the ESA: Upper Columbia River steelhead are listed while upper Columbia River spring chinook are proposed for listing. Snake River spring/summer (stream-type) chinook, (ocean-type) fall chinook, and sockeye salmon are also listed as endangered. Snake River steelhead are listed as threatened. All species migrate through the lower Columbia River as juveniles and adults, therefore any action taken by the operating agencies which affects the operation of the lower Columbia FCRPS or the physical conditions of the lower Columbia River may affect mid-Columbia species of interest. Of particular interest to the PUDs are actions taken by the operating agencies which influence the physical environment of the mid-Columbia reach or operation of the mid-Columbia projects.

5.2.7.1.1. NMFS 1995 Biological Opinion Flow Targets. Although flow during the juvenile migration period (generally April-June) in the lower Columbia and Snake Rivers is largely dependent on the volume and timing of the spring runoff, the NMFS 1995 Biological Opinion (BO) on the operation of the FCRPS specifies flow targets at Lower Granite and McNary dams, which the operating agencies must attempt to meet. The NMFS has proposed a “reasonable and prudent alternative” to the operating agencies' proposed action that sets flow targets higher and for a longer duration, through the summer period, in 1995 than in previous opinions. The targets from the proposed action the “reasonable and prudent alternative” from the 1994 BO, and the NMFS reasonable and prudent alternative, are shown in Table 5-4.

In hydroregulation model simulations, using the 1929 through 1978 50-year water record and current constraints, including the new integrated rule curves for Hungry Horse and Libby dams (NPPC 1994c), the 1995 spring flow targets have a relatively high probability of being met (Table 5-4). The summer targets are not likely to be met, but nonetheless these targets may entail the release of up to 8 MAF for spring and summer flow augmentation (R. Schiewe, pers. comm., 6 March 1995).

The operating agencies attempt to meet flow targets through many means. One of the most effective means of meeting these flow targets is to store water during late winter and early spring, when water releases from storage reservoirs are usually greater than natural runoff into the system, in order to meet power demand and flood control requirements. This is accomplished primarily by purchasing energy to meet firm demand, and entering into power exchanges with other generating utilities, alleviating the need to generate power from the FCRPS. This in turn prevents drafting storage reservoirs and shifting flood control responsibility to other storage reservoirs. All the water so released is counted toward the flow augmentation volume, as it would not normally have been released during the spring for purposes other than enhancement of juvenile outmigration.

5.2.7.1.2. Lower Columbia River Operations. In their 5 March 1995 final BO on Snake River endangered salmon, NMFS calls for the cessation of smolt transportation via barging from McNary dam for the spring migration period. Lack of barging during the spring period may greatly affect the smolt to adult survival of both wild and hatchery origin spring chinook, steelhead, and sockeye from the mid-Columbia Reach. In addition, the in-season Technical Management Team may request the cessation of transportation for summer migrants (summer and fall chinook). This one operation may have a greater impact on survival to adulthood of smolts that originate in or above the mid-Columbia reach than any other single issue (Chapman et al. 1994a). Research has demonstrated a positive benefit of transporting steelhead and both spring, and summer and fall chinook smolts from McNary dam (Fisher 1994). Transport benefit ratios (TBR; ratio of adult returns from transported smolts to adult returns from inriver-migrating smolts) averaged 1.73:1 for yearling chinook migrants, 2.25:1 for steelhead, and 3.74:1 for subyearling chinook during NMFS experiments from 1979 to 1988 at McNary dam (Fisher 1994). Analysis of the impacts are beyond the scope of the HCP. However, the cessation of spring and possibly summer transport from McNary dam will impact mid-Columbia PUD actions, as will any other NMFS actions taken in the lower Columbia River.

5.2.7.2. Kootenai River White Sturgeon. The Kootenai River white sturgeon were listed as an endangered species by the USFWS in 1994. The sturgeon inhabit a reach of the Kootenai River in Idaho and British Columbia between Libby dam in Montana and Kootenai Lake in British Columbia. The USFWS Federal Register notice of the listing decision states that Libby dam flow regulation is a primary cause for the decline of the species (U.S. Federal Register 1994).

5.2.8. Impacts On Mid-Columbia Projects.

5.2.8.1. Physical Impacts. The impact of the Water Budget flow augmentation on flow in the mid-Columbia reach is substantial. For example, in 1994 the Water Budget used 6.6 MAF of upper Columbia River basin storage in the spring and 1.33 MAF in the summer. Assuming the spring flow augmentation period lasted from 20 April to 30 June and the summer period lasted from 1 July through 31 July, then the flow would have increased an average of about 47 kcfs in the spring and 22 kcfs in the summer. Table 5-5 presents the results of a simple analysis of the effects of Water Budget flow augmentation on flow and water particle travel time at Priest Rapids dam. With flow augmentation, spring flow increased while summer flows decreased. Similar changes in estimated WPTT were evident.

Table 5-5. Changes in flow which resulted from the NPPC Water Budget flow augmentation from Upper Columbia River storage at Priest Rapids dam. Flow data for 1990 to 1994 (significant flow augmentation) was compared to years between 1973 and 1985 with similar April through July runoff volume (without significant flow augmentation) (NPPC, USGS, and USACE)

Period and parameter	Without Augmentation	With Augmentation	Percent Change
Spring flow (kcfs)	138	159	+13%
Summer flow (kcfs)	130	128	-2%

Likewise, the impact of Libby dam operations for sturgeon spawning is also significant. The USFWS 1995 Biological Opinion establishes flow targets of 25 to 35 kcfs at Bonners Ferry in June and early July for sturgeon spawning for 1995 to 1998. This will result in an estimated additional 1.5 MAF being released from Libby in 1995. This water will also be passed on through Grand Coulee dam and contribute to the total flow augmentation volume in order to also aid anadromous salmonid outmigration. The additional volume may increase flow about 16 kcfs in June and early July in the mid-Columbia River reach. Had this augmentation taken place in 1994, it would have represented about 11 percent of the 1 June through 15 July average flow.

5.3. Possible Physical Effects of These Issues. The issues previously discussed individually and in concert shape year-round operation of the mid-Columbia projects. They affect daily flows that enter the mid-Columbia River reach from Grand Coulee dam, and indirectly affect physical parameters such as dissolved gas and temperature. It is important to note that the physical effects of many of these issues cannot be determined wholly on an individual issue basis.

To a certain extent, flow determines other physical conditions in the mid-Columbia River reach. One of the most important parameters for migrating juvenile and adult anadromous salmonids is TDG. Flow exceeding the powerhouse capacity of a project results in spill at the project and increases the amount of atmospheric gas held in solution in the water below the project. See Section 3.3 for a detailed discussion of the effects of spill on TDG. Water temperature is also highly correlated with flow. Low flow and high ambient temperature can result in elevated water temperature in the summer months. See Section 3.3 for a discussion of the effects of flow on water temperature. Flow can also affect the water particle travel time through the five PUD projects. See Section 3.1 for a discussion on water particle travel time through the mid-Columbia River reach.

5.4. Possible Biological Effects of These Issues. The issues discussed previously also affect the plan species. The physical effects of the issues translate into biological effects on the juvenile and adult fish. While the physical effects of these issues are relatively easily observable, the biological effects are much harder to determine with precision. See Sections 3.1 and 3.2 for discussions on adult and juvenile anadromous salmonid travel time through the mid-Columbia River reach. Total dissolved gas levels can have a direct impact on juvenile and adult fish survival; see Section 3.3. Water temperature can influence juvenile and adult travel time and survival; see Section 3.3. Flow can also affect many other biological parameters, such as availability and suitability of spawning and rearing habitat in the reservoirs (see Section 3.4), and predation on juvenile migrants (see Section 3.5).

6. Remaining Salmonid Survival Issues to be Mitigated. Since construction of the dam, the Chelan PUD has invested millions of dollars searching for ways to reduce potential impacts of the project on mid-Columbia River salmonids. Conditions of the original FERC license and subsequent agreements with the Joint Fisheries Parties have outlined a number of measures implemented by the Chelan PUD to improve migration survival and production of mid-Columbia River salmonids. The previous section described the variety of potential issues associated with operation of the project and identified potential outstanding impacts. This section provides a brief summary of the issues addressed in the previous section and identifies those issues that may cause potential "take" of a species.

6.1. **UpStream Passage of Adult Fish**.

6.1.1. Upstream Passage at the Project. Since construction of the Rock Island project in 1933, upstream adult salmonid passage facilities have been frequently modified and updated to meet operating criteria. These modifications are implemented as agreed by the Rock Island Coordinating Committee (RICC). In 1993, a radio-telemetry study of adult chinook salmon was conducted to assess passage conditions throughout the mid-Columbia reach (Stuehrenberg et al. 1995). Based on on-site observations and the results of the radio-telemetry study, the existing facilities at Rock Island dam appear to be operating successfully. All entrances to adult salmonid passage facilities, other than the right powerhouse entrance (RPE), were effective in passing spring, summer and fall chinook salmon adults above Rock Island dam. Modifications to the fishways to meet operating criteria have been addressed under existing agreements.

6.1.2. Upstream Reservoir Passage. Upstream passage of adult fish through Rocky Reach reservoir does not appear to cause significant delay or mortality and is not considered an outstanding technical issue.

6.2. Downstream Passage of Juvenile Salmonids.

6.2.1. Downstream Passage at the Project. Juvenile salmonids moving downstream through the project reach potentially pass through 20.5-mile long Rock Island reservoir before encountering Rock Island dam. Once at the dam, juvenile salmonids pass downstream through the turbines, over the spillway, through the juvenile bypass system at powerhouse 2, or through adult fishways. Evaluation of the powerhouse 2 juvenile bypass system determined that 5 to 15 percent of the juveniles approaching the powerhouse were passing through the system. However, this is a small portion of the total juvenile outmigrant population passing Rock Island dam. Therefore, most juveniles passing Rock Island dam pass the project via spill or through the turbines.

The Chelan PUD has investigated several measures designed to enhance passage survival of juvenile salmonid migrants. These measures included testing mechanical juvenile bypass prototype at powerhouse 1 and 2, providing an interim spill program until final juvenile bypass system installation, investigating alternative methods, such as surface spill, to increase juvenile fish guidance efficiency (FGE) per recommendation of the Rock Island Coordinating Committee (RICC) and mitigating for project-related mortality by providing hatchery production of stream-type and ocean-type chinook, and sockeye salmon per the 1987 Rock Island Settlement Agreement. An overall downstream passage plan has been developed for the Rock Island project as part of the Anadromous Fish Agreement and Habitat Conservation Plan.

6.2.2. Downstream Reservoir Passage. Under existing conditions, water particle travel time (WPTT) in the mid-Columbia River is roughly twice as fast as the WPTT in the lower Columbia River. Additionally, Rock Island reservoir is the smallest of the mid-Columbia reservoirs, with a total surface area of 3,470 acres, and has the fastest turnover rate, averaging less than one day. These factors combine to move water rapidly through Rock Island reservoir in comparison to lower Columbia mainstem and other mid-Columbia River mainstem reservoirs. In view of the uncertainty concerning the benefit of further decreases in WPTT, improving downstream passage survival through Rock Island reservoir may best be achieved by measures directed toward predator control.

6.3. Water Quality.

6.3.1. Dissolved Gas Supersaturation. Daily average total dissolved gas (TDG) levels below Rock Island dam during the juvenile and adult anadromous salmonid migration season, which is April through September, exceed the state water quality standard of 110 percent at nearly any spill level. These levels are primarily dictated by flow releases and spill from upstream projects, and dominated by releases and spill from Grand Coulee dam and spill at Chief Joseph dam. In spite of the occasional high levels of TDG observed at Rock Island dam, monitoring of external symptoms in juvenile salmonid outmigrants had shown a low incidence of gas bubble trauma (GBT) prior to 1996. In 1996, TDG levels in the Rock Island forebay regularly exceeded 120 percent, and 100 percent of juvenile salmonid migrants exhibited GBT symptoms during the period of highest TDG levels. After spill at Grand Coulee was reduced, the incidences of TDG and GBT symptoms both decreased rapidly (Hays, pers. comm., 20 May 1996). The Chelan PUD currently monitors TDG levels and water temperatures at the project and cooperates with federal operators in a system-wide TDG supersaturation abatement program.

6.3.2. Water Temperature. The thermal regime of the mid-Columbia River is determined by the temperature of water released from Grand Coulee dam. Rock Island reservoir has a very short hydraulic retention time that does not allow thermal stratification or significant solar heating and concomitant water temperature increases. No mitigation has been directed at modifying water temperature, but monitoring is conducted by the Chelan PUD in conjunction with TDG monitoring.

6.4. Reservoir Production. Little is known regarding the effects of environmental conditions on adult spawning and juvenile rearing of plan salmonids in the Rock Island reservoir. Adult fall chinook salmon may spawn in the Rock Island tailrace and all species spawn in the Wenatchee River system, but no other species are known to spawn in the project area (Mullan et al. 1986). Because chinook salmon have been observed spawning in deep water (Chapman and Welsh 1979; Giorgi 1992a; Dauble et al. 1994), minor reservoir fluctuations are not expected to impact fall chinook spawning habitat. Existing mitigation for impacts to mainstem habitat due to Rock Island reservoir has been stipulated in the 1987 Settlement Agreement for the Rock Island project.

6.5. Predation. Operation of the Rock Island project exposes mid-Columbia anadromous salmonids to predation because it concentrates juveniles during downstream migration, and it provides rearing and feeding habitat for native and non-native predators. Gulls and northern squawfish congregate to prey on juvenile outmigrants as they pass the dam, which may result in significant outmigrant mortality (Ruggerone 1986; Loch et al. 1994; Burley and Poe 1994). The population of walleye and smallmouth bass in Rock Island reservoir is low, presumably due to low water temperatures and lack of backwater rearing areas, thereby reducing the risk of predation by these species.

Mitigation measures currently employed in the project area by the Chelan PUD are the installation of gull wires, hazing designed to prevent gulls from preying on juvenile salmonids in the tailrace and implementation of a squawfish removal program at both powerhouse 1 and 2. The Chelan PUD is considering a removal program for squawfish in the reservoir. No monitoring program exists for evaluating juvenile salmonid losses due to predation. Improving juvenile salmonid production and survival through predator-control methods is one goal of the HCP.

7. Alternatives to Proposed Conservation Measures. The Chelan PUD has considered several alternatives to the measures discussed in the preceding sections of this plan and has analyzed the relative benefits and disadvantages of each. The following paragraphs briefly describe the alternatives considered and the principal reasons for their elimination. A more detailed discussion of alternatives to the proposed plan is contained in the NEPA compliance document for the Agreement by the USFWS and the NMFS.

7.1. Actions Considered But Not Implemented.

7.1.1. Turbine Intake Screens as Primary Bypass Measure. See Section 4.2.2.3, Prototype Juvenile Bypass Systems, for a discussion of the testing conducted on turbine intake screens at both powerhouses.

7.1.2. Turbine Sluice - Speed-No-Load Operation. Operation of selected turbines in non-power generation modes was investigated as a juvenile salmonid bypass alternative. Operation at speed-no-load is not likely to yield higher survival of fish than for turbine passage under normal operating loads since most injuries observed in balloon tag studies appeared to be mechanical in nature rather than from pressure or cavitation effects.

7.2. Alternatives Eliminated from Detailed Consideration.

7.2.1. Operation of Rock Island Dam With a Non-Power License. The use of the project in non-power mode, while still providing for flood control, recreation and other project purposes, would require spilling 100 percent of river flow, which would increase TDG to environmentally detrimental saturation levels. The absence of electrical energy generation would also eliminate the only available source of revenues for other measures in the plan, such as predator control and off-site activities such as hatcheries and habitat restoration, all of which would still be needed to meet overall salmonid productivity goals of the plan.

7.2.2. Dam Removal. Removal of Rock Island Dam would eliminate the need for an HCP, thus it is not considered as a mitigative measure in this HCP.

7.2.3. Reservoir Drawdowns. Reservoir drawdowns have been proposed by some interest groups as a universal tool for improving fish survival through mainstem Columbia River hydroelectric projects. The premise that a reservoir drawdown would improve survival is based on three assumptions: 1) fish migration speed is proportional to water particle travel time (or average flow velocity); 2) faster migration through the reservoir improves the survival rate of fish and; 3) the improved survival rate from reduced travel time exceeds detrimental effects of drawdown on the target species. Drawdown has not been included in the HCP toolbox of on-site mitigation measures because no evidence from the mid-Columbia supports the premise that reduced travel time of salmonid species increases survival. The detrimental ecological effects of drawdown include reduction in habitat and food organisms that ocean-type chinook depend on when rearing in mid-Columbia reservoirs, including the reservoir. Drawdowns would also disable the project fishways, blocking return of adult salmonids.

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