Go To Next Part

Commercial fishing regulations on the Columbia River continue to be regulated under the compact. Idaho and the basin Indian tribes do not have a vote on the compact (Coon 1985).

Seasonal and weekly periods closed to fishing have continually increased, resulting in a decline in the number of days open to fishing each year. The Columbia River commercial fishing seasons below Bonneville Dam have been reduced from over eight months per year in the early 1940s to about 82 days per year in the early 1970s to a low of 14 days in 1980 (Figure 17). The number of gill net licenses issued each year also declined from 1928 to 1969, but has increased to over 1,000 licenses since 1971 (Figure 18).

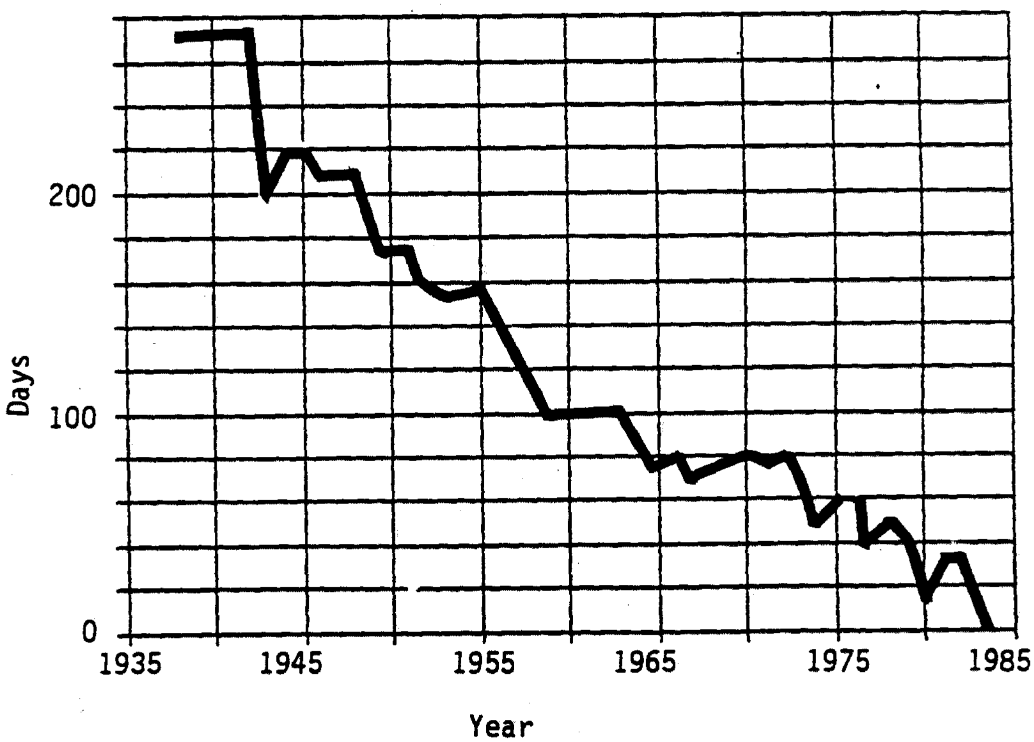

Figure 17. Days open to commercial fishing in the lower Columbia River area (Johnson, Chapman and Schoning 1948).

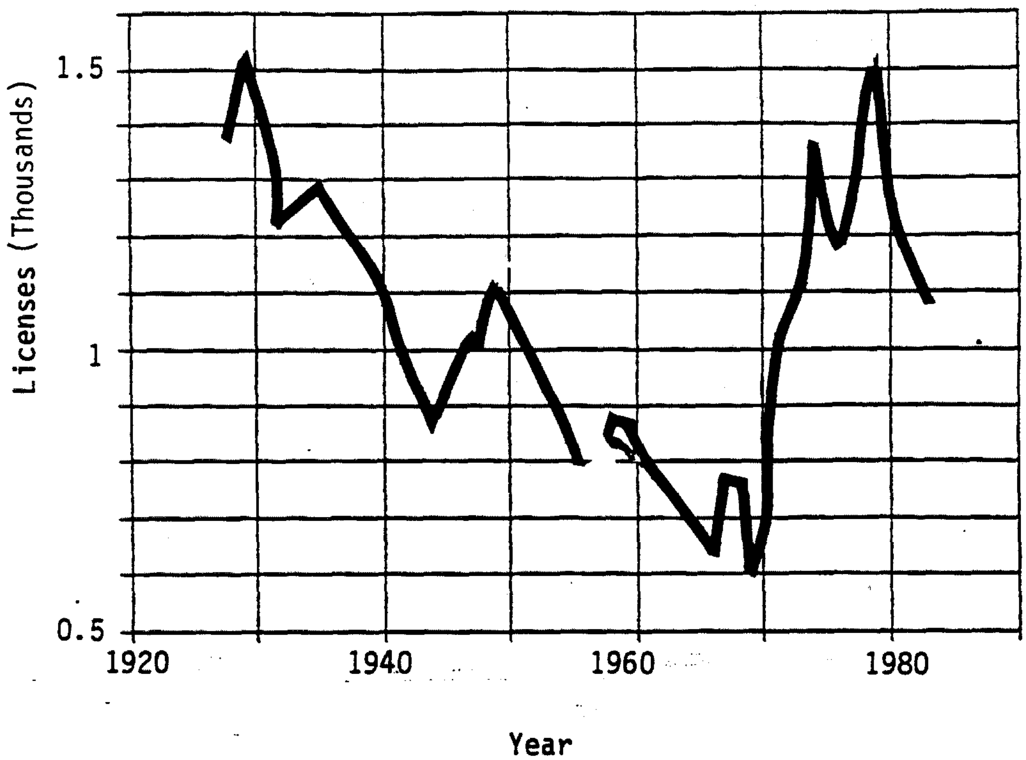

Figure 18. Gill net licenses issued annually in lower Columbia River area (ODFW 1985a; Fish Commission of Oregon and Washington Department of Fisheries 1972).

Fishing regulations in Idaho began in 1939 (Richards 1985). The most significant regulation, which was implemented in 1982, requires (in some waters) or encourages the release of wild steelhead as determined by dorsal fin height (Richards 1985; Pollard 1985a). This regulation is intended to increase reduced runs of wild steelhead in Idaho. Catch-and-release fishing for steelhead also is regulated in some Idaho streams. The chinook salmon season in Idaho was closed from 1979 to 1984 because of low escapement. In 1985, chinook sport fishing was allowed in the Little Salmon River and in the mainstem Snake River (Richards 1985).

5.2.4.2 Ocean Fisheries

Prior to 1948, there were few restrictions on the ocean fisheries (Phinney 1976). The state commercial fisheries agencies of Washington, Oregon, and California met in 1945 to discuss formation of the Pacific Marine Fisheries Commission (PMFC). A tri-state compact was authorized in 1947 by Congress and respective state legislative sessions (*see* Pacific Marine

Fisheries Compact, Pub. L. No. 80-232, 61 Stat. 419 (1947), as amended by Act of October 9, 1962, Pub. L. No. 87-766, 76 Stat. 763 (1962)). The purposes of the PMFC were to promote better use of marine fisheries and to develop a joint program of protection and prevention of physical waste in these fisheries in all areas of the Pacific Ocean and adjacent waters over which the compacting states jointly or separately acquired jurisdiction (Phinney 1976). Idaho was not a part of this compact.

The PMFC subsequently recommended salmon troll regulations that were adopted by Oregon, Washington, and Alaska. These included a minimum 26-inch length of chinook salmon, a March 15 to November 1 open season for chinook salmon, and a June 15 to November 1 open season for coho salmon. In 1975, the salmon troll regulations included a minimum length of 26-1/2 inches on chinook salmon, an April 15 through October 31 season for chinook salmon, and a June 15 through October 31 season for coho salmon (Poon and Garcia 1982).

In the mid-1970s, the inriver fisheries declined concurrently with an fluctuating ocean fisheries (Table 20). Partially as a result, the Fisheries Conservation and Management Act (FCMA), or Magnuson Act, was enacted in 1976 to provide federal jurisdiction for management of all fisheries within 200 miles of the U.S. coastline, except for the area within zero to three miles where management authority resides within each state (see Pub. L. No. 94-265, 90 Stat. 331 (codified at 16 U.S.C. 1801-1882)). This exception is subject to federal preemption by the Secretary of Commerce.

The Pacific Fishery Management Council (PFMC) and the North Pacific Fishery Management Council (NPFMC) were formed in 1977 as a result of the Magnuson Act. The councils were intended to provide a management framework for producing the optimum yield of commercial and sport fisheries on the Pacific Coast. The PFMC manages the fisheries off the coast of Washington, Oregon, and California, and the NPFMC manages the area off Alaska. Funding for the councils is provided annually as part of the U.S. Department of Commerce budget (Coon 1985).

The U.S.-Canada Pacific Salmon Treaty was signed into law in 1985. Under this treaty, both countries will be committed to preventing overfishing and to providing optimum coastwide management. The treaty reduces Columbia River Basin chinook salmon harvests off southeastern Alaska and British Columbia to

Table 20 - Comparison of Columbia River commercial landings with commercial ocean troll landings 1971-1983.[1]

Year	Chinook Salmon		
		Ocean	
	Columbia River	Oregon	Washington
1971-1975 average	324	209	262
1976	288	184	335
1977	256	340	217
1978	189	191	130
1979	171	242	123
1980	150	205	113
1981	95	158	91
1982	155	222	122
1983	55	76	49

Year	Coho Salmon		
		Ocean	
	Columbia River	Oregon	Washington
1971-1975 average	209	981	850
1976	172	1,827	1,347
1977	40	446	657
1978	136	612	547
1979	132	703	630
1980	150	374	342
1981	62	610	351
1982	206	507	239
1983	7	318	23

[1] In thousands of fish.

meet rebuilding goals for the chinook runs. Season structure (e.g., starting dates, planned inseason closures, and possible single species fisheries) is critical to developing realistic expectations of benefits from this treaty (PFMC 1985b).

5.2.5 Summary -- The Current Status of Fishing Impacts on Fish

The current ocean commercial and sport fishery is a mixed-stock fishery that harvests both hatchery-reared and natural stocks from a variety of different areas. The mixed-stock ocean harvest of Columbia River Basin salmon occurs off the coasts of Alaska, British Columbia, Washington, Oregon, and California. Ocean harvest in U.S. waters is regulated by Pacific Coast states, the Pacific Fishery Management Council, the North Pacific Fishery Management Council, and the Secretary of Commerce. In recent years there have been significant reductions in ocean harvest in an effort to reduce impacts on weak stocks. In addition, the U.S.-Canada Pacific Salmon Treaty contains provisions for limiting catches in areas off Canada and Alaska where Columbia River chinook have historically been harvested.

Inriver fishing impacts on salmon and steelhead stocks in the Columbia River Basin also have been curtailed in recent years through more restrictive gear and season regulations. Inriver commercial gill net fishing has been strictly regulated since 1982 to increase spawning escapement (Edwards 1985).

5.3 HYDROPOWER DEVELOPMENT AND OPERATIONS

5.3.1 The Development of Columbia Basin Hydropower

Hydropower development in the Columbia River Basin began in the late 1800s when dams were constructed on larger mainstem tributary systems such as the Willamette and Spokane rivers (Collins 1976). Development proceeded at a rather slow pace during the early 1900s. A common characteristic of most of these early hydropower dams was their relatively small storage capacity. The first dams constructed exclusively for hydropower were in the lower and upper Columbia River areas.

The T. W. Sullivan Dam built in 1888 at Willamette Falls on the Willamette River was the first hydroelectric facility in the Columbia River Basin. This was followed by the Monroe Street (1896) and Lower Bonnington (1898) hydroelectric dams, constructed in the Upper Columbia area on the

Spokane and Kootenay rivers by Washington Water Power Company and West Kootenay Power and Light, respectively. The Washington Water Power Company constructed four additional hydroelectric facilities on the Spokane River from 1906 to 1915.

The first hydropower dam in the Snake River Basin was built by the City of Idaho Falls at Idaho Falls-Lower in 1904. The first multipurpose projects including hydropower were constructed in the Snake River Basin by the federal government at Minidoka Dam on the Snake River in 1906, and at the Boise Diversion Dam on the Boise River in 1908. The C. P. National Company built the first private hydropower project in the Snake River Basin in 1905 on Rock Creek in the Powder River Basin, followed closely by Idaho Power Company's Shoshone Falls Dam on the Snake River in 1907.

In 1905, the Okanogan Public Utility District constructed Enloe Dam on the Similkameen River between the Snake River and Chief Joseph Dam. This was followed closely by the construction of the Naches Dam on the Naches River in 1906, and Dryden and Tumwater dams built by Valley Power Company and the Great Northern Railway on the Wenatchee River in 1907 and 1909, respectively. Dryden and Tumwater dams were acquired in the late 1940s and have been operated by Chelan County Public Utility District since that time.

After the Sullivan plant, hydropower development below Bonneville Dam did not resume until Portland General Electric Company built River Mill and Marmot dams on the Clackamas and Sandy rivers in 1911 and 1912, respectively. The next significant period of hydroelectric development in this area followed in 1929 with the construction of Bull Run Dam No. 1 on the Bull Run River by the City of Portland and then Leaburg Dam on the McKenzie River in 1930 by Eugene Water and Electric Board. Most hydroelectric development in this area occurred during the 1950s and 1960s, when 162 megawatts and 124 megawatts, respectively, were added to the area's total generating capacity. There has been very little hydroelectric development below Bonneville Dam since 1970.

The first hydroelectric development between Bonneville Dam and the confluence of the Snake River resulted from construction of the Bend and Cline Falls dams on the Deschutes River and Condit Dam on the White Salmon River all in 1913, by Pacific Power and Light Company. Pacific Power and Light Company also constructed the Powerdale Dam on the Hood River in 1923.

The first major period of hydropower development on the mainstem Columbia River commenced in the 1930s with the construction of the Rock Island Dam in 1933 by Puget Sound Power and Light Company (later acquired by Chelan PUD), followed by the completion of the Bonneville Dam by the Corps of Engineers in 1938. Within a 45-year period following these initial developments, 14 mainstem Columbia and 13 mainstem Snake River dams were completed within the natural limits of historical anadromous fish runs (Table 21). Hydropower development in the tributaries of the Columbia River Basin also continually increased since the 1930s with much of the construction occurring in the period from 1950 to 1970.

Overall, 58 dams have been constructed exclusively for hydropower in the Columbia River Basin (Table 22). Of these, 17 are located in the lower Columbia River area below Bonneville Dam. Another 15 dams are in the upper Columbia River area above Chief Joseph Dam, while 16 are located in the upper Snake River area above Hells Canyon Dam. Six dams constructed exclusively for hydropower are in the Clackamas drainage in the lower Columbia River area and in the Kootenay drainage in the upper Columbia River area above Chief Joseph Dam. The mainstem Snake not only has the most dams, but also the most large dams of any river in the entire basin.

In addition to 58 exclusively hydropower dams, there are 78 multiple purpose projects which include hydropower production in the Columbia River Basin. Of these multipurpose dams with hydropower, 19 are found in the lower Columbia River area below Bonneville Dam, 18 in the upper Columbia River area above Chief Joseph Dam and 14 in the Snake River area above Hells Canyon Dam. Multipurpose hydropower dams in the remaining three areas are fairly evenly distributed (Table 22).

The Corps (1984) states that prior to the 1930s most water resource developments in the Pacific Northwest were constructed for single purpose objectives -- mainly power generation, irrigation, flood control, or municipal and industrial water supply. These developments were mainly on coastal basin streams and on tributaries of the Columbia River, usually near large population concentrations or near areas where irrigation was feasible.

Table 21 - Completion dates of Columbia and Snake river dams which affect anadromous fish.

Dam	Year of Initial Service	Normal Maximum Head (feet)	Length of Reservoir (miles)
Columbia River			
Rock Island	1933	54	21
Bonneville	1938	62	46
Grand Coulee	1941	343	151
McNary	1953	75	61
Chief Joseph	1955	177	52
The Dalles	1957	85	24
Priest Rapids	1959	82.5	18
Rocky Reach	1961	93	42
Wanapum	1963	83.5	38
Wells	1967	72	29
John Day	1968	105	76
Keenleyside (Arrow)	1968	69	145
Mica	1973	615	135
Revelstoke	1983	425	80
Snake River			
Shoshone Falls	1907	212	
Swan Falls	1910	24	8
Lower Salmon (Salmon Falls)	1910	60	6
Upper Salmon A	1937	43	
Upper Salmon B	1947	37	
Bliss	1949	70	5
C. J. Strike	1952	88	
Brownlee	1958	272	57
Oxbow	1961	120	12
Ice Harbor	1961	100	32
Hells Canyon	1967	210	22
Lower Monumental	1969	100	29
Little Goose	1970	98	37
Lower Granite	1975	100	5

Source: Oregon Department of Fish and Wildlife (1985a), Corps of Engineers (1984).

Table 22 - Number of hydroelectric dams by major drainages in the Columbia River Basin.

Study Area	Exclusive Hydropower	Multipurpose with Hydropower
Columbia River Below Bonneville Dam		
Clackamas	6	1
Columbia (mainstem)	0	0
Cowlitz	0	3
Lewis	1	3
McKenzie	5	1
Sandy	1	4
Santiam	1	4
Willamette	3	3
Total	17	19
Columbia River Between Bonneville Dam and Snake River Confluence		
Columbia (mainstem)	0	4
Crooked	1	0
Deschutes	4	2
Hood	1	1
White Salmon	0	1
Total	6	8
Columbia River Between Snake River and Chief Joseph Dam		
Columbia (mainstem)	0	5
Chelan	0	1
Naches	2	1
Okanogan	1	0
Wenatchee	1	1
Yakima	0	2
Total	4	10
Columbia River Above Chief Joseph Dam[1]		

Table 22 (cont)

Columbia (mainstem)	0	4
Colville	1	0
Cranberry	1	0
Kootenai (U.S.)	0	1
Kootenay (Canada)	6	1
Pend Oreille	4	7
Spokane	3	5
Total	15	18
Snake River Below Hells Canyon Dam		
Clearwater	0	1
Imnaha	0	3
Snake (mainstem)	0	4
Wallowa	0	1
Total	0	9
Snake River Above Hells Canyon Dam[2]		
Boise	0	3
Henry's Fork	1	0
Malad	2	0
Owyhee	0	1
Payette	0	3
Powder	1	0
Snake (mainstem)	12	7
Total	16	14
TOTAL BASIN	58	78

Source: Corps of Engineers (1975); Bonneville Power Administration (1980); Heitz et al. (1980); and Washington State Department of Ecology (1981); Corps of Engineers (1984); and Bonneville Power Administration (1983).

[1]Includes only major (equal to or greater than 5 megawatts) projects in the upper Columbia River Basin in British Columbia.

[2]Includes only major (equal to or greater than 5 megawatts) projects in the upper Snake River Basin above Shoshone Falls.

In the 1930s, Congress authorized two major multiple-purpose projects -- the Grand Coulee Project in Washington and the Bonneville Project in Oregon and Washington. This signaled the start of intensive development of the Columbia River and its tributaries. Construction of the Bonneville Project was initiated in 1933 with navigation, flood control, and power generation designed as major project purposes. This project was started by the Works Progress Administration and completed by the Corps of Engineers. The Grand Coulee Project in Washington, constructed by the Bureau of Reclamation, was authorized in 1935. The Bonneville Power Administration was created in 1937 to market the energy produced by these and other federal hydroelectric projects in the Columbia River Basin.

Following World War II, the Corps built major projects at McNary, Albeni Falls, Chief Joseph, The Dalles and in the Willamette Basin. The U.S. Bureau of Reclamation constructed projects at Hungry Horse, Anderson Ranch, and Palisades. However, during the middle and late 1950s, federal water resource development was largely curtailed. Construction continued on projects already underway, but design and construction were delayed for new projects.

The "no new starts" policy of the 1950s eventually was rescinded, and the construction of federal projects was resumed. Projects constructed by the Corps include John Day on the mainstem Columbia; Libby Dam on the Kootenai River in Montana; Dworshak on the North Fork of the Clearwater River in Idaho; Ice Harbor, Lower Monumental, Little Goose, and Lower Granite on the Lower Snake River; and additions to the Willamette Basin system of reservoirs. During this same period, the Bureau of Reclamation constructed additional projects in the Snake River Basin, and Bonneville Power Administration expanded its power transmission facilities. During the 1950s, Grant PUD, Chelan PUD, and Douglas PUD requested licenses for more large mid-Columbia River projects. During this period financing arrangements were developed whereby the power output of these projects was marketed to other utilities, as the capability of these large plants far exceeded the loads of the licensees. Under such arrangements construction was started on Priest Rapids in 1956, Rocky Reach in 1957, Wanapum in 1959, and Wells in 1963. All are in the middle Columbia River reach between the Snake River and Grand Coulee Dam (Corps 1984).

Other major hydroelectric projects were constructed by public and private utilities on tributary rivers during the 1950s and 1960s under terms of Federal Power Commission (now the Federal Energy Regulatory Commission) licenses. These included the three middle Snake projects--Brownlee, Oxbow and Hells Canyon dams--constructed by Idaho Power Company; Noxon and Cabinet Gorge Projects on the Clark Fork River constructed by the Washington Water Power Company; Box Canyon Projects on the Pend Oreille River, constructed by Pend Oreille Public Utility District; Boundary Project on the Pend Oreille River, constructed by Seattle City Light; Round Butte and Pelton projects on the Deschutes River, constructed by Portland General Electric Company; Swift and Yale projects on the Lewis River, constructed by Pacific Power and Light Company, Mossyrock and Mayfield projects on the Cowlitz River, constructed by Tacoma City Light; Carmen-Smith Project on the McKenzie River, constructed by Eugene Water and Electric Board; and Timothy Lake and North Fork projects on the Clackamas River, constructed by Portland General Electric Company (Corps 1984).

The Corps (1984) states that three events occurred in 1964 that significantly affected reservoir regulation and the flow regime of the Columbia River. These were ratification of the Columbia River Treaty with Canada, authorization of the Pacific Northwest-Southwest high voltage transmission interconnections, and the Pacific Northwest Coordination Agreement. These actions were closely interdependent, and the sequence for completion of each was tied to the accomplishments expected of each preceding dam.

The mainstem sections of the Columbia and Snake rivers represent the predominant rivers developed for hydropower in the Columbia River Basin. The mainstem Snake River has the most hydropower projects with 21, followed by the mainstem Columbia River, which has 13 projects. The most highly developed tributary drainage is the Pend Oreille River Basin in the Columbia River area above Chief Joseph Dam, which has 11 hydroelectric projects (Table 22 and C-1). The locations of major hydropower (exclusive and multipurpose) and other dams in the basin are shown in Figure 19. Appendix C (Table C-1) contains a listing of all hydropower and non-hydropower dams in the basin.

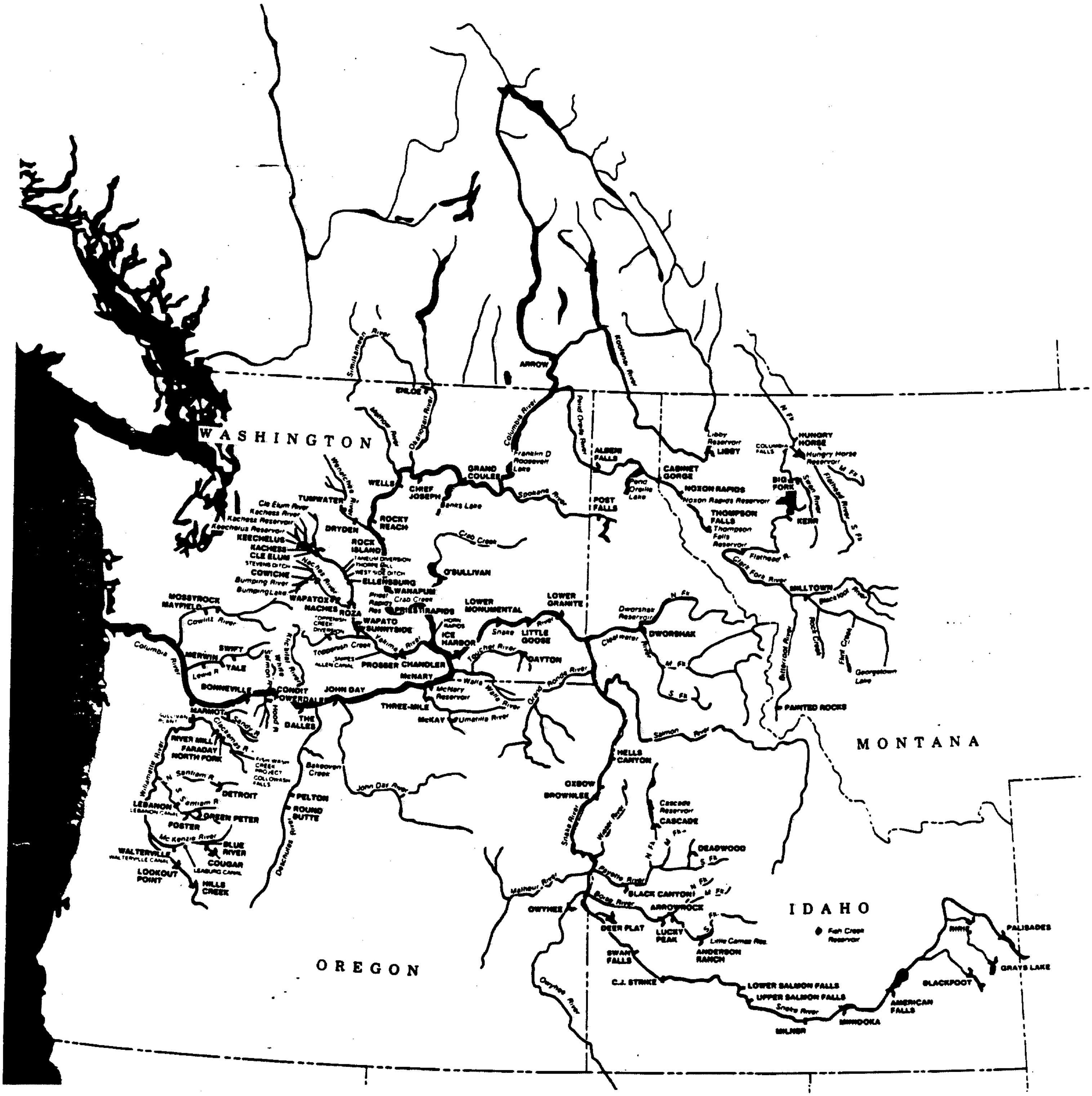

Figure 19. Location of hydropower and other dams in the Columbia River Basin.

The ownership of the two types of hydropower dams (exclusive and multipurpose) in the Columbia River Basin is significantly different (Table 23). Of the 58 dams developed exclusively for hydropower, 41 are privately-owned and operated. City municipalities own nine dams, while public utility groups account for three dams. These private hydropower dams are comprised of both small and large projects, with a combined total generating capacity of only about 1,800 megawatts out of the 3,183-megawatt total capacity for all dams which are operated exclusively for hydropower generation.

In contrast, the federal government plays a major role in developing multipurpose dams with hydropower as one of the purposes. The Bureau of Reclamation and Corps of Engineers operate 33 of the 78 multipurpose dams with a combined total generating capacity of 19,423 megawatts out of the 30,813 megawatt total capacity for all multipurpose dams. Private companies also operate a large number (27) of multipurpose projects (Table 23), but they are considerably smaller projects with a combined total generating capacity of only 2,352 megawatts. Public utility groups own and operate 10 multipurpose dams which also produce hydropower. These generate a total of 4,364 megawatts.

In summary, there are 136 hydroelectric projects of all categories presently operating within the Columbia River Basin, considering all projects greater than or equal to one megawatt within historical limits of anadromous fish runs, plus those projects outside the present limits of anadromous fish runs where the installed generating capacity exceeds five megawatts. Of those projects, 10 are located in British Columbia, Canada. The total reservoir storage capacity in all hydroelectric projects (including pondage in run-of-river projects) is 74.9 million acre-feet. The total installed hydroelectric generation of all of these projects is presently about 34,000 megawatts.

The Corps of Engineers (1984) defines major hydroelectric projects as those having a total storage capacity in excess of 100,000 acre-feet, or an installed power generating capacity greater than 40 megawatts. There are 66 such projects within the Columbia River Basin. Their combined total storage capacity is over 74.2 million acre-feet. Their combined hydropower generating capability is about 33,430 megawatts.

Table 23 - Ownership of hydropower dams in the Columbia River Basin.

Area	Federal/ Provincial	State	Municipal	PUDs	Private	Total
	Exclusively Hydropower					
A Lower Columbia below Bonneville	1	0	5	1	10	17
B Lower Columbia above Bonneville	0	0	0	0	6	6
C Middle Columbia	0	0	0	2	2	4
D Upper Columbia	4	0	1	0	10	16
E Lower Snake	0	0	0	0	0	0
F Upper Snake	0	0	3	0	13	16
Total Columbia Basin	5	0	9	3	41	58

Area	Federal/ Provincial	State	Municipal	PUDs	Private	Total
	Multipurpose with Hydropower					
A Lower Columbia below Bonneville	7	0	5	1	6	19
B Lower Columbia above Bonneville	4	0	0	0	4	8
C Middle Columbia	2	0	0	7	1	10
D Upper Columbia	7	0	1	2	8	17
E Lower Snake	5	0	0	0	4	9
Upper Snake	10	0	0	0	4	14
Total Columbia Basin	35	0	6	10	27	78

Sources: Corps of Engineers (1975): Bonneville Power Administration (1980); Heitz et al. (1980); and Washington State Department of Ecology (1981); Bonneville Power Administration (1983); Corps of Engineers (1984).

[1]Includes only major (equal to or greater than 5 megawatts) projects in the upper Columbia River Basin in British Columbia.

[2]Includes only major (equal to or greater than 5 megawatts) projects in the Upper Snake River Basin above Shoshone Falls.

The percentage of appropriated funds for federal multipurpose projects provides an indication of the purpose of operation. The majority of funding allocated for federal projects has been targeted for power production (Table 24). On 15 of 21 major federal projects, over 50 percent of the funds were allocated for power production. Although multipurpose in nature, most Corps of Engineers project investments were targeted primarily for hydroelectric development of the Columbia River and its major tributaries. On a percentage basis, flood control and irrigation represent the other major purposes in descending order of investment.

Table 24 - Percentage of allocation of project investment (by use) for major federal Columbia River Basin dams 1983.[1]

		Project Use(s), by Percent							
Project (Operator)	Region[2]	Power	Irrigaton	Flood Control	Navigation	Wildlife	Recreation	Other	Total $ Cost (millions)
Boise (BOR)	S	12	66	22	--	--	--	--	77.2
Columbia Basin (BOR)	UC	57	38	2	1	0.2	.01	0.03	1,648.2
Minidoka (BOR)	S	7	60	30	--	1.4	0.3	--	84.8
Yakima (BOR)	MC	6	92	1	--	1.4	0.3	--	84.8
Albeni Falls (COE)	UC	95	--	0.5	0.4	--	4.0	--	33.8
Bonneville (COE)	LC	94	--	--	6	--	0.16	0.26	779.3
Chief Joseph (COE)	UC	98	0.15	--	--	--	0.43	0.97	486.1
Cougar (COE)	LC	30	5	63	1	--	--	0.3	60.6
Detroit-Big Cliff (COE)	LC	61	8	31	.03	--	--	--	67.2
Dworshak (COE)	S	84	--	10	3	--	3	--	352.4
Green Peter (COE)	LC	55	6	34	0.4	--	--	2	90.0
Hills Creek (COE)	LC	36	9	54	1.3	--	--	0.55	49.1
Ice Harbor (COE)	S	76	--	--	23	--	--	--	200.1
John Day (COE)	LC	74	--	4	16	--	2	5	538.9
Little Goose (COE)	S	78	--	--	20	--	1.6	1	257.7
Lookout Point/Dexter (COE)	LC	48	.15	50	0.7	--	0.5	0.1	96.1
Lower Granite (COE)	S	82	--	--	13	--	3	2	413.1
Lower Monumental (COE)	MC	81	--	--	17	--	1	0.15	275.9
McNary (COE)	LC	80	--	--	19	--	0.8	--	349.0
The Dalles (COE)	LC	86	--	--	13	--	0.6	--	325.9

[1]Source: Bonneville Power Administration (1983).

[2]LC = Lower Columbia, MC = Middle Columbia, UC = Upper Columbia, S = Snake.

The effects of hydropower development on salmon and steelhead resources in the Columbia River Basin can be related to two major activities: 1) construction and development, and 2) operation. Potential environmental effects are associated with all aspects of hydroelectric project development including the construction of the dam or diversion structure, a reservoir if one exists, penstock, powerhouse and building of access roads. All impacts, which are site-specific, can occur both at the project site and downstream.

The following paragraphs provide general information describing these two activities. The resulting impacts on anadromous fish, particularly salmon and steelhead, in the Columbia River Basin are provided in the following sections.

5.3.2 The Effects of Hydropower Development on Columbia Basin Salmon and Steelhead

The direct effects of the construction of hydroelectric and multipurpose dams that include hydropower on salmon and steelhead in the Columbia River Basin can be divided into four categories:

1. Blockage of habitat.
2. Alteration of habitat.
3. Barrier to or modification of juvenile migration.
4. Barrier to or modification of adult migration.

Where no fish passage facilities have been provided, hydroelectric dams totally block anadromous fish runs on the river. In addition, dams inundate spawning and rearing habitat. Figure 5 shows areas that have been blocked by dams, thus preventing access of salmon and steelhead to natural spawning areas. Fulton (1968, 1970) compared the historical range of salmon and steelhead with the present range in the Columbia River Basin (see Appendix B). More than 55 percent of the Columbia River Basin accessible to salmon and steelhead before about 1939 has been blocked by large dams, many of which are operated exclusively or largely for generating electrical power (Thompson 1976b).

One indication of historical trends in salmonid habitat alteration by hydroelectric dams and multipurpose dams is the total amount of water stored by hydroelectric dams (total storage capacities). Total storage capacity ranges from zero storage for exclusive hydropower dams in the Snake River area below Hells Canyon Dam to over 47.5 million acre-feet in the upper Columbia River above Chief Joseph Dam area (Table 25). Overall, the six areas in the Columbia River Basin have a total hydroelectric storage capacity of over 74.9 million acre-feet. This total storage capacity is equivalent to about 56 percent of the 1929-1978 average annual modified runoff volume of the Columbia River at The Dalles.

Table 25 - Storage capacity of hydroelectric dams and multipurpose dams in the Columbia River Basin.[1]

Area	Total Storage Capacity[2] (acre-feet) Hydroelectric Dams	% Total	Multipurpose Dams	% Total
A. Columbia River below Bonneville Dam	69,200	14.2	5,216,600	7.0
B. Columbia River between Bonneville Dam and Snake River confluence	37,400	7.6	5,349,400	7.2
C. Columbia River between Snake River and Chief Joseph Dam	2,400	0.5	3,116,500	4.2
D. Columbia River above Chief Joseph Dam[3]	134,800	27.5	47,526,700	63.8
E. Snake River below Hells Canyon Dam	0	0	5,350,100	7.2
F. Snake River above[4] Hells Canyon Dam	246,100	50.2	7,869,960	10.6
Total Columbia Basin	489,900	100.0	74,429,300	100.0

Sources: COE (1975); WSDE (1981); BPA (1980); Heitz et al. (1980); BPA (1983); COE (1984).

[1]Calculated from information presented in Appendix C.

[2]Includes active and inactive storage capacity.

[3]Includes only major projects (equal to or greater than 5 megawatts) in the upper Columbia River Basin in British Columbia.

[4]Includes only major projects (equal to or greater than 5 megawatts) in the upper Snake River Basin above Shoshone Falls.

However, the total storage capacity figures listed above for hydroelectric projects is not entirely usable for hydropower purposes. For example, the storage capacity numbers listed include both active and inactive storage. Inactive storage is water that is stored below the level of the reservoir that can be run through the turbines or spilled. If all the active storage has flowed out of a reservoir, then only inactive storage will remain and this water cannot be released from the reservoir. Also, some of the storage space in Canadian projects was developed solely for use in Canada. Finally, reservoirs constructed for multipurpose use are operated to supply water for irrigation, flood control, navigation, domestic, municipal or industrial use, etc.

Another indicator of historical trends in salmonid habitat alteration by hydroelectric dam development is the cumulative storage capacity during five-year increments. This information is plotted, for both hydroelectric dams and multipurpose dams which include hydropower, for each of the six regions in Figures 20 and 21. Most of the cumulative storage capacity for hydroelectric dams in the basin occurred in the upper Snake River area when the Hells Canyon project added nearly 168,000 acre-feet of storage in 1967. The second largest increase in cumulative storage capacity for hydroelectric dams occurred in the upper Columbia River area above Chief Joseph Dam when 68,000 acre-feet were added by the Sevenmile project in 1979 and nearly 48,000 acre-feet were added during the 1950-1955 period (Figure 20). For the lower Columbia River area below Bonneville Dam, the greatest increase in storage capacity for hydroelectric dams occurred from 1955 to 1965 when nearly 42,000 acre-feet were added to the system (Figure 20). Pelton Dam, built on the Deschutes River in 1957, accounts for nearly all of the storage in the area of the Columbia River between Bonneville Dam and the Snake River. Pelton has a storage capacity of 37,300 acre-feet.

For multipurpose dams that include hydropower, the greatest increase in cumulative storage capacity occurred in the upper Columbia River area above Chief Joseph Dam, particularly after Mica and Libby dams became operational as a result of the Columbia River Treaty in the 1970s (Figure 21). These two multipurpose projects alone provide over 25.8 million acre-feet of storage. The second and third greatest increases in cumulative storage capacity also

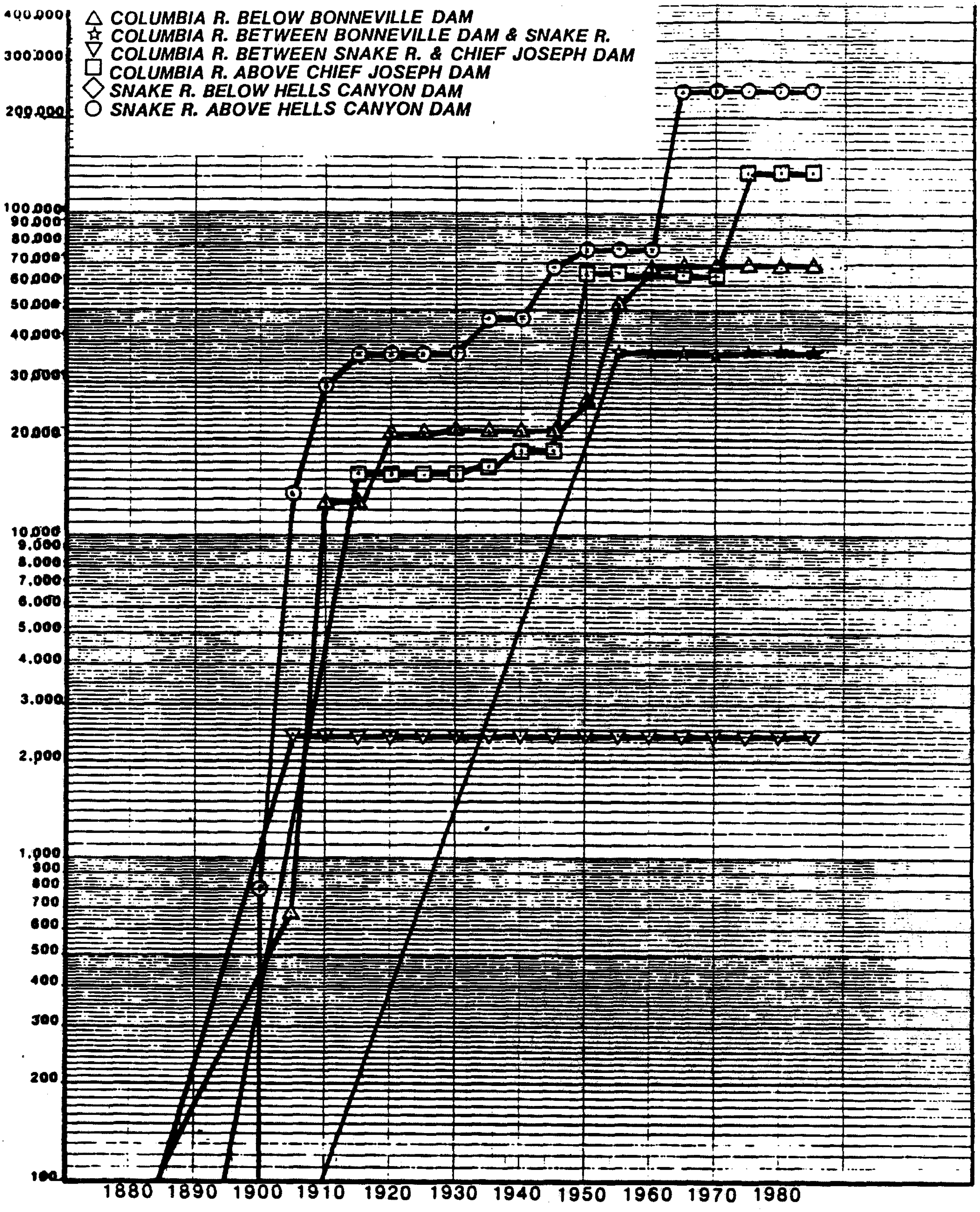

Figure 20. Cumulative storage capacity of strictly hydropower dams in the Columbia River Basin (COE 1975; WDOE 1981; COE 1984).

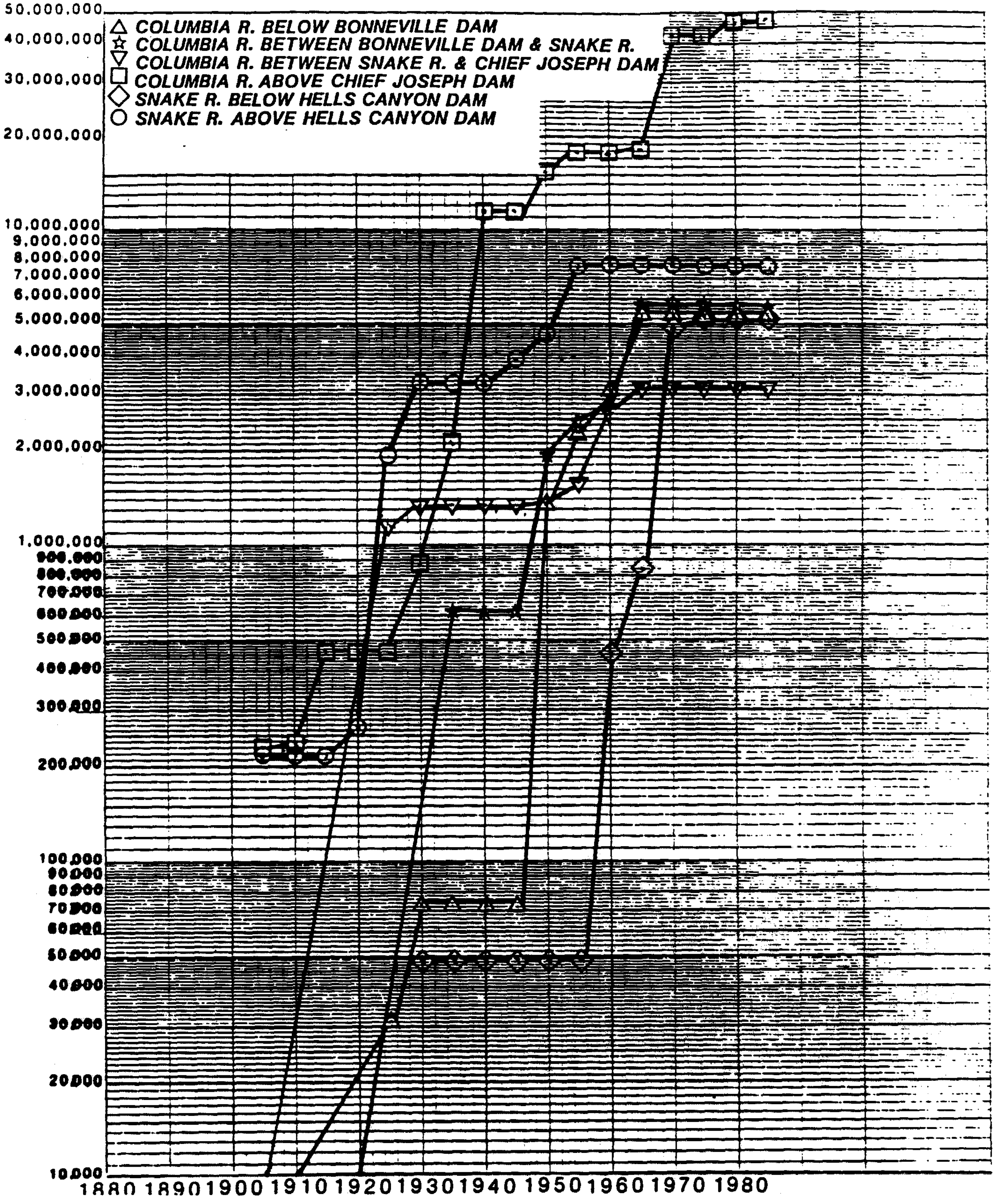

Figure 21. Cumulative storage capacity of multipurpose hydropower dams in the Columbia River Basin (COE 1975, WDOE 1981, COE 1984).

occurred in this area when Grand Coulee Dam was closed in 1941 (9.56 million acre-feet) and when Revelstoke became operational in 1983 (4.3 million acre-feet). The greatest increases in storage capacity for multipurpose projects in the two lower Columbia River areas and two Snake River areas occurred from 1950 to 1975, although a significant amount of storage capacity was added in the upper Snake River area above Hells Canyon Dam during the 1924-1932 period. The majority of multipurpose storage in the middle Columbia River area between the Snake River and Chief Joseph Dam occurred during two discrete periods, one from 1928 to 1933, and the other from 1959 to 1967 (Figure 21).

5.3.2.1 Run-of-River Projects

Much of the earliest and most recent hydroelectric development has been small run-of-river projects which use small, high gradient streams to produce electricity. Many of these small projects involve a low diversion structure within the streambed, and use a pipeline, canal, and/or pressure penstock to convey water to the powerhouse. Once the falling water is used to generate electricity, it is returned to the stream, usually somewhat downstream from the diversion point. A few projects involve construction of a new storage dam or a larger impoundment structure to divert the necessary flows and create the hydraulic head needed to produce energy. Finally, a number of projects use an existing dam and/or conduit to divert the water (Washington Department of Ecology 1985).

The actual construction of a dam or diversion structure has considerable potential for adverse environmental impact. Erosion and bed load (sediment) increases can occur when clearing the stream bank, blasting underlying bedrock, or during construction within the stream channel. Water quality standards may not be met, and other adverse impacts to anadromous fish and habitat may occur as a result of construction work within the stream channel, particularly during periods of low flow (Washington Department of Ecology, 1985).

5.3.2.2 Storage Projects

A number of large, multipurpose reservoir projects have been developed in the Columbia River Basin, most notably in the area of the Columbia River above Chief Joseph Dam. Large storage projects can cause significant environmental impacts of a different nature. A reservoir has low water velocity, which may result in changes in water temperature, dissolved oxygen levels, turbidity, water chemistry, and aquatic habitat. In deep reservoirs, thermal and chemical stratification is likely to occur with potentially significant effects on the aquatic life in and downstream of the reservoir. Downstream effects can be beneficial or adverse, depending on the site, water quality, size of reservoir and facility design (Washington Department of Ecology 1985).

In general, creation of a reservoir transforms an ecosystem dependent on moving water into one dependent on still water. This results in substantial changes in the distribution, abundance, and diversity of organisms and in the carrying capacity of the habitat. Also, it has the potential for increased predation of juvenile salmon and steelhead.

Impacts on salmon and steelhead related to creation of reservoirs behind dams also include inundation of important spawning areas. For example, Wells Dam flooded important spawning areas for summer chinook in the mainstem of the middle Columbia River area. This resulted in a drastic decline in chinook redds after 1967 (Appendix A, Figure A-91). John Day and McNary dams inundated a total of 137 miles of important fall chinook spawning areas in the mainstem of the Columbia River.

Finally, water temperatures increase during the summer because of the greater surface area of large storage impoundments. Collins (1976) reported that conditions in the Brownlee Dam reservoir are too severe for young salmonids. A high degree of thermal stratification develops in the reservoir with surface temperatures reaching lethal levels while the cooler subsurface water becomes deficient in oxygen. Most mainstem Columbia and Snake river impoundments, other than Grand Coulee, are run-of-river impoundments in which daily flow-through represents a significant fraction of each reservoir's storage capacity. This feature limits significant thermal stratification effects in mainstem run-of-river reservoirs.

Flows and river temperatures in the mainstem Columbia River, however, are influenced by releases from Grand Coulee Dam. For example, releases at Grand Coulee Dam trigger releases at all downriver dams since their active storage capacities are limited. This accounts for the "river run" designation of the mainstem reservoirs below Grand Coulee Dam. The existing reservoir system has caused no significant change in the average annual temperature of the mainstem Columbia River. However, storage and release of water from Lake Roosevelt since 1941 have delayed the timing of peak summer temperatures below Grand Coulee Dam. This delay is about 30 days at Rock Island Dam and is reflected, to a lesser extent, as far downstream as Bonneville Dam. The mainstem reservoir complex has moderately high and low extremes so that river temperatures are now slightly lower in summer and slightly higher in winter (Jaske and Goebel 1967, Jaske 1969, Jaske and Synoground 1970). Seasonal temperatures in the mid-Columbia River (below Priest Rapids Dam) from 1965 to 1983 peaked near 20°C (Whelan and Newbill 1983).

5.3.2.3 Mainstem Hydroelectric Projects

Except for sockeye salmon, which require a lake nursery area for their freshwater rearing habitat, salmon and steelhead have evolved in a free-flowing river environment. The predevelopment riverine ecology provided generally favorable conditions permitting juvenile anadromous fish to survive and enter the ocean to feed and grow, as well as favorable conditions for adults to return to natal streams and spawn. The riverine ecology of the Columbia and Snake rivers and many of their major tributaries has been altered significantly by dam development in less than half a century (Ebel et al. 1979). For example, upriver salmon and steelhead in the mainstem Snake and Columbia rivers are now confronted with up to eight or nine large impoundments and dams to pass, during their downstream and upstream migrations.

Development of multipurpose dams and hydroelectric projects on the mainstem Columbia and Snake rivers has greatly altered the natural flows in the Columbia River drainage. Runoff during the spring is stored in large headwater reservoirs for use during periods of naturally low flows. While regulating the river in this fashion increases the energy production capability, it changes the natural runoff pattern. In particular, hydroelectric regulation reduces river flows during the spring when juvenile salmon and steelhead are migrating downstream to the ocean. A major consequence of dam development and reservoir storage on the mainstem Columbia and Snake rivers is a reduction in flows and an increase in the cross-sectional area of river, resulting in delays in downstream migration.

The effects of a series of impoundments and barriers on the timing of migrating fish to optimal ocean and spawning ground conditions are not completely understood (Ebel et al. 1979), but data from Raymond (1968a, 1968b, 1969) indicate that juvenile chinook salmon now migrate about one-third as fast through impounded reaches of the river as through the few remaining free-flowing reaches. During low flow years, Ebel et al. (1979) estimate that juvenile chinook salmon and steelhead migrating from the Salmon River will take 78 days to reach the Columbia River estuary, arriving about 40 to 50 days later than they did before all the dams were constructed. The impoundment of water in headwater storage reservoirs and the regulation of river flows by mainstem run-of-river dams has more than doubled the time required for the hazardous migration to the sea.

Reservoir lengths of mainstem Columbia and Snake River dams range from one mile for the Upper Salmon B project on the Snake River to 151 miles for the Grand Coulee project on the Columbia River (Table 21). Reservoir lengths and capacities are directly related to fish passage time (Bell et al. 1976).

As noted above, the total biological effect of these significant changes in the time of migration of juvenile anadromous fish is not yet completely understood. It has been suggested that an immediate effect in low-flow years is a tendency for some juveniles to stop migrating to sea and spend several months in fresh water before re-smolting and migrating to saltwater. Some of these fish, however, spend the rest of their lives in fresh water, never becoming a productive member of their species. Thus, this increase in travel time affects the ability of the juvenile salmon to make a successful transition from freshwater to saltwater. Of even greater consequences are the effects of increased mortality due to prolonged exposure to predatory fish and birds. As a result of reduced flow rate and therefore longer exposure to the sun, river temperatures and higher dissolved oxygen levels in the water are lower. These and associated changes in the water chemistry, along with increased exposure to pollutants, stresses fish and causes greater susceptibility to disease (Ebel et al. 1979).

Adults migrating to natal spawning grounds also are delayed at dams during high-flow years, due to their difficulty in locating fish ladder attraction flows. This can result in increased exposure to nitrogen supersaturation which has caused direct mortality to fish (Beiningen and Ebel, 1970). Delayed indirect mortality from increased incidence of disease caused by prior exposure to high nitrogen superstaturation also has been measured (Ebel et al. 1975).

5.3.3 The Effects of Hydropower Operation on Columbia River Basin Salmon and Steelhead

Operation of multipurpose projects has a systemwide effect on anadromous fish in the Columbia River Basin because of the integrated operation of the various federal projects to maximize efficiency in attaining power and flood control objectives. The Columbia River Treaty and Pacific Northwest Coordination Contract Agreement have strengthened the concept of a single system operation for hydropower, flood control and other purposes. System operational impacts on anadromous fish are primarily related to reduction of natural spring flows because of upstream storage and the maximization of power generation which limits the amount of spill available for reducing turbine related mortalities. A smaller spring freshet results in increased travel time to the ocean and, therefore, decreased survival for juvenile anadromous fish.

Operational impacts on salmonids of Columbia River Basin hydroelectric dams and multipurpose dams that include hydropower have been summarized as follows (Natural Resources Consultants 1981):

- o turbine mortalities;
- o delayed migration;
- o gas supersaturation of water;
- o combined effects resulting from regulated stream flows and temperature regimes;
- o susceptibility of outmigrants to predators; and
- o power peaking operations.

Any structure built within a stream channel has the potential to impede movement of aquatic organisms (especially anadromous fish) and sediment. This can be especially harmful to anadromous fish which rely on a flowing stream habitat for spawning, incubation, and rearing. An improperly designed or operated facility can result in significant mortality to juvenile fish migrating downstream and to adult fish migrating upstream to spawn (Washington Department of Ecology 1985).

A diversion structure can kill fish at the intake if water velocities are such that fish become trapped on the intake screen. If no screen exists, the fish may go through the hydraulic turbines, usually with high mortality rates. A poorly designed intake structure may trap air, resulting in high dissolved gas levels in the water released from the powerhouse site. This can cause a fatal condition in fish similar to "the bends" (Washington Department of Ecology 1985).

Furthermore, pipeline, canal, or penstock leakage can destablize slopes and lead to pipeline failure, land slides, or other mass wastage of slopes. Resulting erosion can hurt stream productivity.

One indication of the historical change in operation of hydroelectric facilities is cumulative power output. Trends in total cumulative power output for each of the six study areas in the Columbia River Basin are illustrated in Figure 22. Power output overall has increased from virtually nothing in 1884 to over 34,000 megawatts today. The upper Columbia River area above Chief Joseph Dam has shown the greatest cumulative power output in the basin. This is primarily the result of large, provincial/federal multipurpose dams such as Mica and Revelstoke in Canada, and Chief Joseph and Grand Coulee in the U.S.

Originally, when hydroelectric dams were constructed in the Northwest, upstream passage facilities for adult fish at the dams were considered adequate to sustain salmon and steelhead runs. Since that time, much concern and effort have shifted to provide safe downstream passage at the dams for juvenile salmonids. Once it has passed safely through the reservoir, the smolt must negotiate the physical barrier of the dam. The fish will either pass over the spillway (if water is being spilled) or be drawn by the flow through the turbines.

With present operating conditions and spill levels, the most hazardous course for juvenile salmon and steelhead is to pass through the turbine. Studies have shown that as juvenile salmonids are drawn through the power turbines, they are subjected to a variety of conditions that can cause injury and death. Rapid changes in pressure, physical strikes, and cavitation

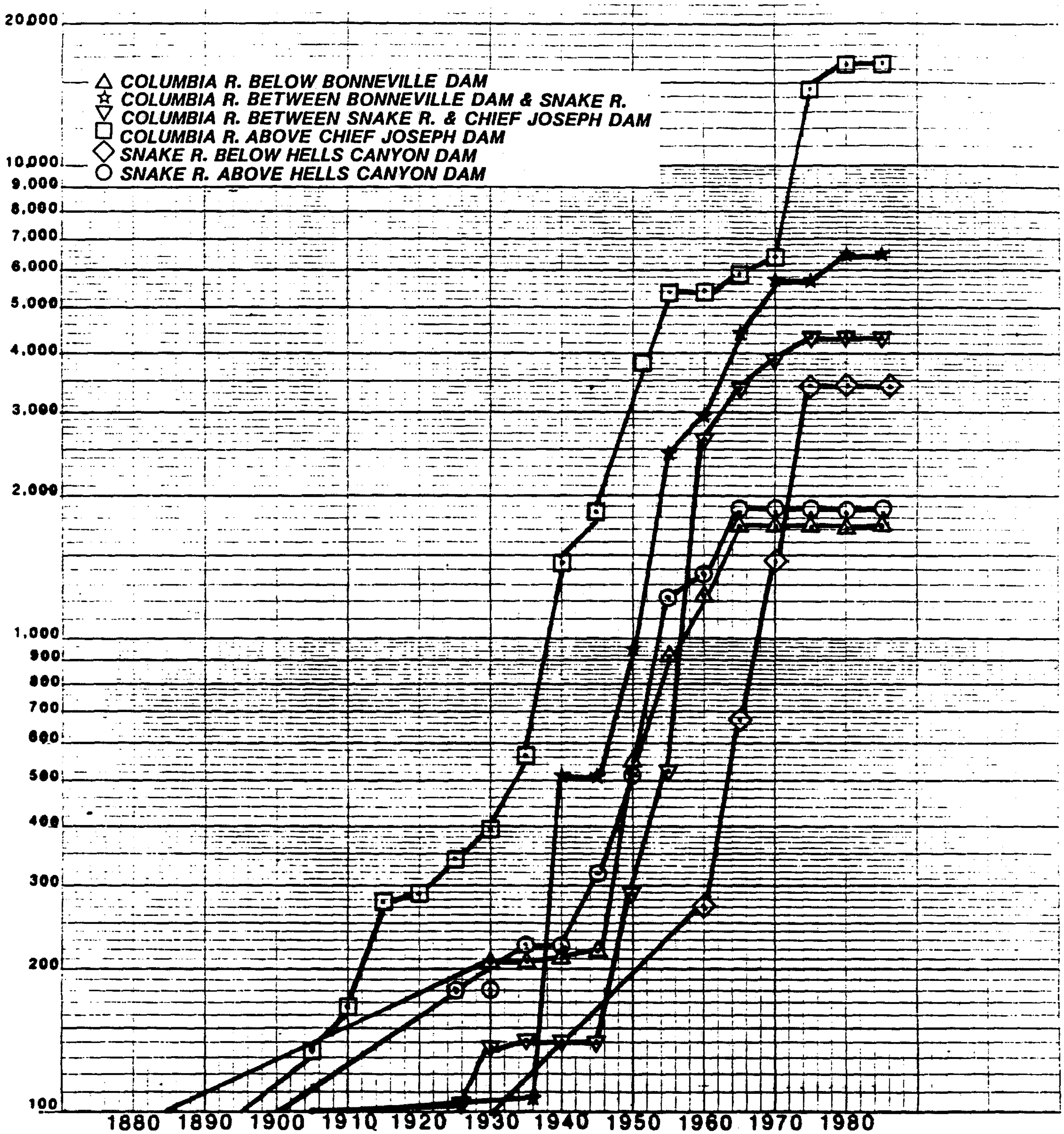

Figure 22. Total cumulative power output in the Columbia River Basin (COE 1975; Heitz et al. 1980; BPA 1980; WDOE 1981; BPA 1983; COE 1983).

within each turbine are the major contributors to juvenile mortality as the fish pass from the top of the dam through the turbine intake and out a tunnel at the base of the dam. Cavitation is defined as the formation of voids around a body in a liquid when the local pressure is lower than vapor pressure (U.S. Department of Interior 1975). The moving turbine blades and shearing action of the water in the turbine also can cause injuries or death. Also, juvenile salmonids become stunned and disoriented as they move through the turbines, thus increasing their vulnerability to predators, especially squawfish and sea gulls, which are abundant in the backroll of the turbine discharge at the base of most dams.

Mortality rates of juvenile salmonids at individual dams depend on many factors, including relative amounts of water passing through the powerhouse (turbine efficiency) and spillway; the size, species, and condition of the fish; the type of turbine; the operating load; and pertinent plant characteristics (Collins 1976), (Bell et al. 1967). Schoeneman, Pressey and Junge (1961) estimated the mortality rate of juvenile chinook salmon passing over the spillway to be about 2 percent; and the direct mortality of salmonids passing through turbines, such as those found on the Columbia and Snake rivers, to be about 11 percent. Other authors report juvenile fish mortality estimates of 15 percent per dam as conservative (Junge 1980; Collins 1976). Chaney and Perry (1976) reported that juvenile salmonid mortalities average 15 to 20 percent at each mainstem dam, depending on flow conditions. Studies by Long et al. (1968, 1975) showed mortalities as high as 30 percent for juvenile coho salmon passing through turbines at Ice Harbor and Lower Monumental dams on the Snake River when indirect mortality for predation was included. Losses from predation vary from dam to dam and year to year depending on the fluctuating populations of predators. However, when the predation loss at dams is combined with the direct loss in turbines, it is apparent that the turbine-related mortality occurring to a population of downstream migrants passing over a long series of dams can be significant. For example, in the low-flow years of 1973 and 1977 when almost all of the juvenile migrants had to pass through turbines, losses of 95 percent and 99 percent, respectively, were estimated for Snake River spring chinook salmon and steelhead (Sims et al. 1978).

These losses are compounded by the number of dams through which fish must pass. Assuming a range of 15 to 30 percent juvenile mortality and 5 to 10 percent adult mortality per dam, cumulative percentage mortalities are indicated in Table 26. (This assumption is used only for the purpose of illustration since actual mortalities may be higher or lower depending on project design, fish species, and the use of mitigative measures such as transportation.) Therefore, if 100 juvenile salmonids began their downstream migration above Wells Dam on the Columbia River, the cumulative mortality of passing a series of nine dams would result in only four to 23 fish surviving to below Bonneville Dam. If 100 adults began their migration upstream from below Bonneville Dam, the cumulative mortality of passing nine dams would result in from 39 to 63 fish surviving to above Wells Dam. From a historical perspective, the cumulative mortality rate for downstream juvenile migrants has increased with the completion of each mainstem dam since Rock Island Dam was built in 1933.

Table 26 - Cumulative juvenile and adult salmonid mortalities at dams.

	Cumulative Mortality								
Number of Dams	1	2	3	4	5	6	7	8	9
JUVENILES									
15 percent average mortality per dam	15	28	39	48	56	62	68	73	77
30 percent average mortality per dam	30	51	66	76	83	88	92	94	96
ADULTS									
5 percent average mortality per dam	5	10	14	19	23	26	30	34	37
10 percent average mortality per dam	10	19	27	34	41	47	52	57	61

Hydroelectric dams and multipurpose dams also can create a condition where the water becomes supersaturated with gases. This is frequently referred to as "nitrogen supersaturation" because air is nearly four-fifths nitrogen. This condition is lethal to fish at high levels of gas pressure (Collins 1976). It occurs when large volumes of water plunge over a spillway into a deep pool below the dam forcing entrapped air into solution with water. The gases are continually dissolved and added to the water as long as the spilling continues. Fish trapped in supersaturated water suffer from "gas bubble disease." Dissolved gases are adsorbed in the bloodstream and air bubbles are formed when the gases leave solution. Mortalities created by supersaturation have been high for both adult and juvenile salmonids in high flow, high spill years. High total dissolved gas levels (exceeding 130 percent saturation) occurred during the late 1960s and early 1970s on the mainstem Columbia and Snake rivers due to large amounts of spilled water in high flow years because there was neither adequate upstream storage nor sufficient powerhouse capacities to control the flow. The severity of gas bubble disease and its consequences depend on the level of supersaturation, the duration of exposure, water temperature, general condition of the fish, and swimming depth maintained by the fish (Ebel and Raymond 1976).

Another operational impact of hydroelectric dams and multipurpose dams on salmonids is the combined impact of altered stream flows on the migration rate of juvenile salmonids and exposure to supersaturated water. As discussed earlier, migration rate is related to stream flow (i.e., higher water velocity results in higher rate of fish migration) (Ebel and Raymond 1976). Delays in outmigration of juvenile salmonids can result in extended exposure to supersaturated water during some high flow years. Ebel and Raymond (1976) found that survival of juvenile chinook salmon and steelhead decreased in the Snake River to Ice Harbor Dam from over 90 percent through 1968 to about 70-75 percent in 1969. This decline was related to increased exposure to higher nitrogen supersaturation. Survival of chinook smolts, however, from Ice Harbor Dam to The Dalles Dam in 1969 was slightly higher than in previous years (67 percent). Conversely, lower steelhead survival was attributed to increased exposure to supersaturated water in the Columbia River. Most yearling chinook migrated downstream in April and early May when flows were 80,000 to 100,000 cubic feet per second in the Snake River and about 300,000 cubic feet per second in the Columbia River. Steelhead migrated two weeks later when flows were higher. Thus, steelhead were exposed longer to higher levels of supersaturation and consequently suffered higher mortality than chinook salmon in this stretch of river. Spillway deflectors have been installed at most of the mainstem Columbia and Snake river dams to reduce nitrogen supersaturation, and total dissolved gas levels now are monitored closely throughout the smolt migration period. However, at very high spill levels spillway deflectors become ineffective.

Fish passage facilities have been constructed at many dams to provide access for adult anadromous salmonids migrating from the ocean to upstream spawning areas. Flows and spills also have been adapted to provide maximum attraction and unimpeded passage for adults. However, some adult fish passageways are not designed, operated or maintained adequately, and flow and spill conditions at the base of some dams (e.g., mainstem Columbia River and Snake River) can discourage fish movement in the river or mask fishway attraction flows. These factors result in delayed upstream migration as fish search for and ascend fish ladders. This has resulted in significant pre-spawning mortality of adult fish and reduced success of late spawners. Weiss (1970) observed that chinook salmon suffered mortalities of about 13 percent during both spring and summer periods of 1970 in passing Bonneville Dam, and from 12 to 25 percent mortality in passing The Dalles Dam in 1970. Gibson et al. (1979) state that adult salmonid mortalities in migrating past the four lower Columbia River dams can be related to flow. Except for John Day Dam, estimated losses are correlated highly with flow, with no significant loss for average flows of about 150,00 cubic feet per second. At John Day Dam an adult mortality of about 20 percent occurs independently of flow (Gibson et al. 1979). Passage delays at individual dams can range from two to four days for adult salmon (Van Hyning 1973).

Columbia and Snake river hydroelectric dams are used presently to provide about 80 percent of the firm, or base, energy supply in the Pacific Northwest, while thermal electric plants provide about 20 percent of the firm energy supply. Increased use of the hydropower system to provide power during peak demand periods could result from numerous factors, some of which include installation and operation of additional turbine units; overloading and partial loading of all units; increases in future power loads; use of additional storage now or in the future; changes in water levels (and frequency of changes) in the forebays of existing plants; installation of more thermal generating plants; and expansion of the Northwest-Southwest intertie system (Bell et al. 1976).

Since the beginning of operation of Rock Island Dam in 1933 and Bonneville Dam in 1938, not only have additional dams been constructed in the Columbia and Snake rivers, but additional units have been installed and operated at most of the projects. The addition of turbine units has reduced the amount of spill and provided additional peaking capability, allowing more water and fish to pass through the powerhouse, where the fish are vulnerable to turbine mortality discussed previously.

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