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COLUMBIA RIVER IRRIGATION WITHDRAWAL ENVIRONMENTAL REVIEW:

COLUMBIA RIVER FISHERY STUDY

by

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CONVERSION FACTORS

Factors for Converting English Units to International System Units (SI)[1]

The following factors may be used to convert the English units published herein to the International System of Units (SI).

Multiply English units	By	To obtain SI units
	Length	
inches (in)	2.54×10^{1}	millimeters (mm)
	2.54×10^{-2}	meters (m)
feet (ft)	3.048×10^{-1}	meters (m)
miles (mi)	1.609×10^{0}	kilometers (km)
	Area	
acres	4.047×10^{3}	square meters (m^2)
	4.047×10^{-1}	*hectares (ha)
	4.047×10^{-1}	square hectometers (hm^2)
	4.047×10^{-3}	square kilometers (km^2)
square miles (mi^2)	2.590×10^{0}	square kilometers (km^2)
	Volume	
gallons (gal)	3.785×10^{0}	**liters (l)
	3.785×10^{0}	cubic decimeters (dm^3)
	3.785×10^{-3}	cubic meters (m^3)
million gallons (10^6 gal)	3.785×10^{3}	cubic meters (m^3)
	3.785×10^{-3}	cubic hectometers (hm^3)
cubic feet (ft^3)	2.832×10^{1}	cubic decimeters (dm^3)
	2.832×10^{-2}	cubic meters (m^3)
cfs-days [(ft^3/s)·d]	2.447×10^{3}	cubic meters (m^3)
	2.447×10^{-3}	cubic hectometers (hm^3)
acre-feet (acre-ft)	1.233×10^{3}	cubic meters (m^3)
	1.233×10^{-3}	cubic hectometers (hm^3)
	1.233×10^{-6}	cubic kilometers (km^3)
	Flow	
cubic feet per second (ft^3/s)	2.832×10^{1}	liters per second (l/s)
	2.832×10^{1}	cubic decimeters per second (dm^3/s)
	2.832×10^{-2}	cubic meters per second (m^3/s)
gallons per minute (gal/min)	6.309×10^{-2}	liters per second (l/s)
	6.309×10^{-2}	cubic decimeters per second (dm^3/s)
	6.309×10^{-5}	cubic meters per second (m^3/s)

Multiply English units	By	To obtain SI units
million gallons per day (mgal/d)	4.381×10^{1}	cubic decimeters per second (dm^3/s)
	4.381×10^{-2}	cubic meters per second (m^3/s)
	Mass	
tons (short)	9.072×10^{-1}	tonnes (t)

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[1]Adapted from U.S.G.S 1976.

*The unit hectare is approved for use with the International System (SI) for a limited time. See NBS Special Bulleton 330, p. 15, 1972 edition.
**The unit liter is accepted for use with the International System (SI). See NBS Special Bulletin 330, p. 13, 1972 edition.

INTRODUCTION

The U.S. Army Corps of Engineers, Portland District, is conducting a comprehensive environmental review of the effects of water withdrawal for out-of-stream use in the Columbia River Drainage Basin within the United States. The Corps has authority under Section 10 of the Rivers and Harbors Act of 1899 to regulate and issue permits for water withdrawals from navigable waters of the United States. In recent years, there has been an increasing demand for the withdrawal of water for irrigation and other uses in the upper and midregions of the basin. As the demand increased, concerns were expressed over the cumulative impacts of these withdrawals and over the need to assess impacts to the basin as a whole.

This literature survey focuses specifically on the impacts to biological communities in the Columbia River with respect to water withdrawal. The scope of this review involves examination of the aquatic productivity and fishery resources of the main stem Columbia River and three selected tributaries; the Yakima, Umatilla, and Okanogan Rivers.

Most of the fisheries research on the Columbia River since the construction of the dams has addressed the impacts of hydroelectric structures primarily with regard to anadromous salmonids. A substantial amount of literature has been concerned with upstream and downstream fish passage problems of juvenile and adult salmonids through the hydroelectric projects, impingement and entrainment of fish through turbines and intake/diversion structures, the effects of nitrogen supersaturation, temperature, disease and other related impacts.

Wild salmon and steelhead runs have essentially been destroyed, initially by over-exploitation followed by the loss of suitable spawning habitat due to the various impoundments on the main stem and the tributaries. Hatchery production has attempted to supplant the loss of the native stocks with diminishing success from the lower reaches to the upper reaches of the basin. However, fish are now being considered in present and future water-use projects as a higher priority resource than in the past. Research is beginning to address the determination of appropriate instream flow levels required by resident and anadromous species in the mainstream Columbia River and tributaries; however, much of the information needed for optimal water and fisheries management decisions does not exist.

Unfortunately, the studies to date have been limited geographically, so only small portions of the Columbia have been studied at any one time. There has been a lack of continuity so trends (except for anadromous salmonids) are undefinable and the number of comprehensive ecological studies conducted is inadequate. The approach in this review is to examine the river as a system. We have attempted to review the quantity and quality of water, the aquatic ecology, and the fisheries of the River. Today the Columbia is little more than a series of reservoirs (except for the free-flowing Hanford Reach), an attempt has been made to describe those formed by the eleven dams along the main stem. Some of the impacts on the aquatic communities are included.

The biological communities are addressed with respect to the operational and morphometric characteristics of the reservoirs. Few projects have the data required for detailed analysis, such as that describing the Franklin D. Roosevelt Reservoir as a storage project and Rufus Woods Reservoir as a run-of-the-river project. The Hanford Reach of the Columbia is discussed as a free-flowing river environment which is now a unique part of the Columbia above Bonneville.

Specific impacts on organisms are addressed quantitatively when possible from data in the literature. The impacts in many cases are not a direct result of irrigation practices per se but are attributable to the effects of water withdrawal in general. Water management on the main stem is dominated by the production of hydroelectric energy. The impacts on the river ecology from both irrigation withdrawal and power supply are similar and no attempt has been made to separate these effects.

The purpose of this review has been to describe the current state of the biological communities of the main stem Columbia River and the selected tributaries. Water withdrawal impacts are documented to enable the Corps of Engineers to identify specific areas of concern with respect to reaching decisions on future out-of-stream use of the waters of the Columbia River. In addition, further research needs with regard to fisheries are identified.

DESCRIPTION OF STUDY AREA

Historical Data

In 1934 the U.S. Bureau of Fisheries (now the U.S. Fish and Wildlife Service) undertook a study to gather baseline data for a comprehensive project designed to maintain and rehabilitate the fisheries of the Columbia River (Rich 1948). Entitled "A Survey of the Columbia River and Its Tributaries", eight reports were published under the U.S. Fish and Wildlife Service's Special Scientific Report series (Nos. 51, 62) and the Fisheries series (Nos. 36, 37, 38, 39, 40, 57). This study divided the Columbia Basin into seven main areas and a number of sub-areas (Fig. 1, Table 1), each of which was treated as a unit in the series.

The surveys are perhaps the most comprehensive work done to date on the Columbia River and its tributaries. Typically, the reports include a listing of the streams, detailed maps of the streams surveyed, and an extensive description for each, including such parameters as average depth, gradient, water temperatures, habitat types, flow rates, and fish species present. In addition, for each stream surveyed, the types of obstructions and diversions encountered were described with regard to location, height in feet, existing protective devices for fish and recommendations for enhancing the stream habitat.

Rich (1948) indicated that the more detailed data which were not reported in the publications remained available as general field notes, on field forms, and in card files. These data were kept during the study at the Fisheries Laboratory (now the Northwest and Alaska Fisheries Center)[1]. Efforts to determine if this original data still exists have been unsuccessful (NWAFC, personal communication).

A detailed description of the Columbia River Basin including stream flow data is provided in the "308 Report" of the U.S. Army Corps of Engineers (H. Doc. 103, 1933) and also in the Columbia River and tributaries report by the Corps (H. Doc. 531, 1950; H. Doc. 403, 1963).

General Basin Description

The main stem Columbia River has a length of 1210 miles, 745 of which are in the United States. The basin has an area of 259,000 square miles (mi^2) within the United States. In Washington State the Columbia drains an area of 47,900 mi^2 (WA DOE 1979). Table 2 is a comparision of the Columbia River system with other large rivers of the United States. The Columbia ranks fifth in size of drainage and third in discharge.

The major tributaries of the Columbia which enter Washington State are the Spokane, Okanogan, Wenatchee, Yakima, Snake, Cowlitz, and Lewis

[1]2725 Montlake Boulevard, Seattle, Washington 98105.

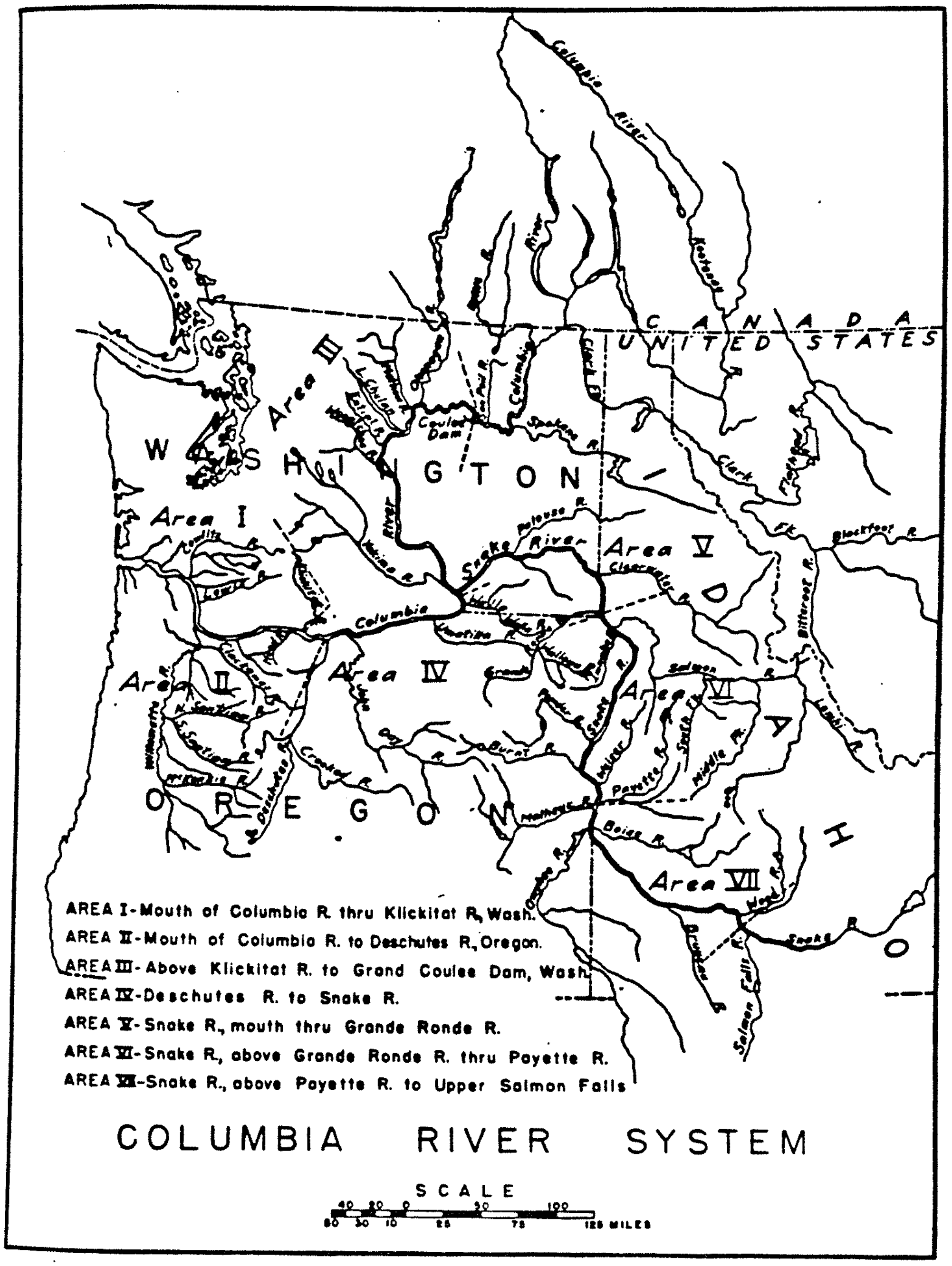

Figure 1
The Columbia River System

From Rich, 1948

Table 1. Study areas of the Columbia River Basin.[1]

AREA I - Washington side of the Columbia River from the mouth through the Klickitat River
- Sub-area 1. - Cowlitz River

AREA II - Oregon side of the Columbia River from the mouth up to but not including the Deschutes River
- Sub-area 1. - Willamette River
- Sub-area 2. - Sandy River

AREA III - Above the Klickitat River to Coulee Dam (Washington side only below the mouth of the Snake River).
- Sub-area 1. - Yakima River
- Sub-area 2. - Wenatchee and Entiat Rivers
- Sub-area 3. - Methow and Okanogan Rivers

AREA IV - Oregon side of the Columbia River from the Deschutes River to the Snake River
- Sub-area 1. - Deschutes River
- Sub-area 2. - John Day River

AREA V - Snake River from its mouth through the Grande Ronde River.
- Sub-area 1. - Tucannon and Asotin Rivers
- Sub-area 2. - Clearwater River
- Sub-area 3. - Grande Ronde River

AREA VI - Snake River from above the Grande Ronde River through the Payette River.
- Sub-area 1. - Salmon River
- Sub-area 2. - Weiser and Payette Rivers
- Sub-area 3. - Oregon streams in Area VI

AREA VIII - Snake River from above Payette River to Upper Salmon Falls
- Sub-area 1. - Malheur and Owyhee Rivers
- Sub-area 2. - Boise River

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[1] From Rich, 1948.

TABLE 2

COMPARISON OF COLUMBIA RIVER SYSTEM WITH OTHER LARGE SYSTEMS IN THE UNITED STATES[1]

River	Estimated Drainage Area, sq. mi.	Estimated Average Annual Discharge (1921-1945), cfs
Mississippi	1,243,700	620,000
Missouri (T)	529,400	70,100
Yukon	330,000	150,000
St. Lawrence*	302,000	226,000
COLUMBIA	259,000	235,000
Colorado	242,900#	#
Ohio (T)	203,900	255,000
Rio Grande	171,585	10,000

T tributary

* at International border, Lat. 45°

\# at Arizona-Mexico Border, no dependable estimate has been made because of large proportion of unmeasured consumptive uses and diversions

[1]Adapted from Gladwell and Mueller, 1967.

rivers. Oregon's tributaries to the main stem Columbia are the Umatilla, John Day, Deschutes, and Willamette rivers (Neal 1972).

The flow regime of the Columbia River system is influenced by precipitation, runoff, and dams. Precipitation is greatest in winter but the runoff increases from May through July due to snowmelt in the upper elevations. Prior to impoundment of the main stem the estimated average flows were 660,000 cubic feet per second (cfs) from May through July and 70,000 cfs from September through March (Hickson and Rodolf 1950). With the completion of 14 dams on the main stem Columbia River and over 100 on its tributaries, flows range between 150,000 to 600,000 cfs (Lockett 1962). Detailed operational characteristics of Columbia River dams are provided in the annual Columbia River Water Management reports.

Water temperatures in the main stem of the Columbia vary with season and locality (Fig. 2). The lowest temperatures occur in January and February followed by a rapid increase in the spring and summer months. The maximum water temperatures on the main stem are in August and early September. Temperatures generally increase downstream from Grand Coulee to Lake Bonneville (Moore 1969) (Fig. 2).

The annual minimum mean temperature of 2.5°C on the main stem of the Columbia is recorded at Grand Coulee during February. Water temperatures increase rapidly during the spring and early summer reaching an annual mean maximum of 20°C at Bonneville in August. During the fall, water temperatures decrease rapidly to about 12°C along the main stem in October and November. Water temperatures continue to decline through the winter months. Jaske and Goebel (1967) and Jaske and Synoground (1970) suggest that the system of impoundments on the Columbia has decreased the magnitude of daily, weekly, and seasonal fluctuations in river temperatures.

Upper Columbia. The Corps of Engineers report (H. Doc. 531, Vol. II, 1950) describes the Upper Columbia River Basin in British Columbia as a triangular area encompassing about 39,500 mi^2 on the Pacific slope of the North American cordillera (Fig. 3). Its base extends 276 miles along the international boundary from the vicinity of Akamina Pass in the Rocky Mountains on the east to the area of Frosty Mountain of the Cascade Range on the west. The eastern boundary of the basin is formed by the Continental Divide of the Rocky Mountains. The western edge of the triangle is formed by an erratic line separating the drainage of the Columbia River system from that of the Fraser River system.

Columbia Lake (elevation = 2650 feet above mean sea level, MSL) in British Columbia is the headwater of the Columbia River. The lake is connected by several miles of fast water channels to Windermere Lake which is approximately 12 miles in length. The Columbia meanders its way northward in a series of lagoon-like stretches until a large riffle called Eight Mile Rapids is encountered just above Golden, B.C. (Bryant and Parkhurst 1950).

From Lake McNaughton to its mouth on the Pacific coast at Astoria, Oregon the Columbia has become essentially a series of reservoirs formed

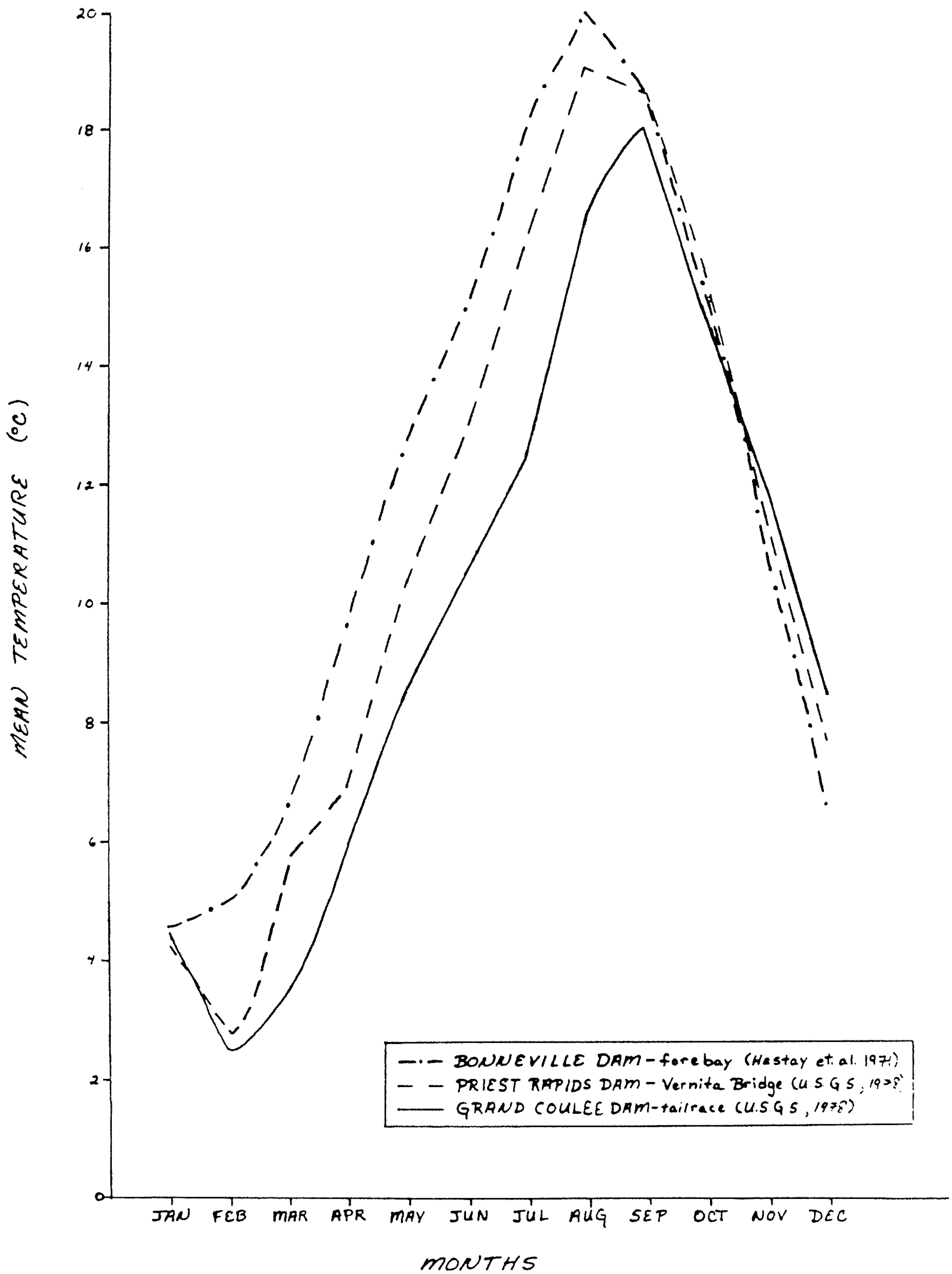


FIG. 2. PLOT OF ANNUAL MEAN MONTHLY WATER TEMPERATURES AT THREE DAMS ON THE MAIN STEM COLUMBIA RIVER.

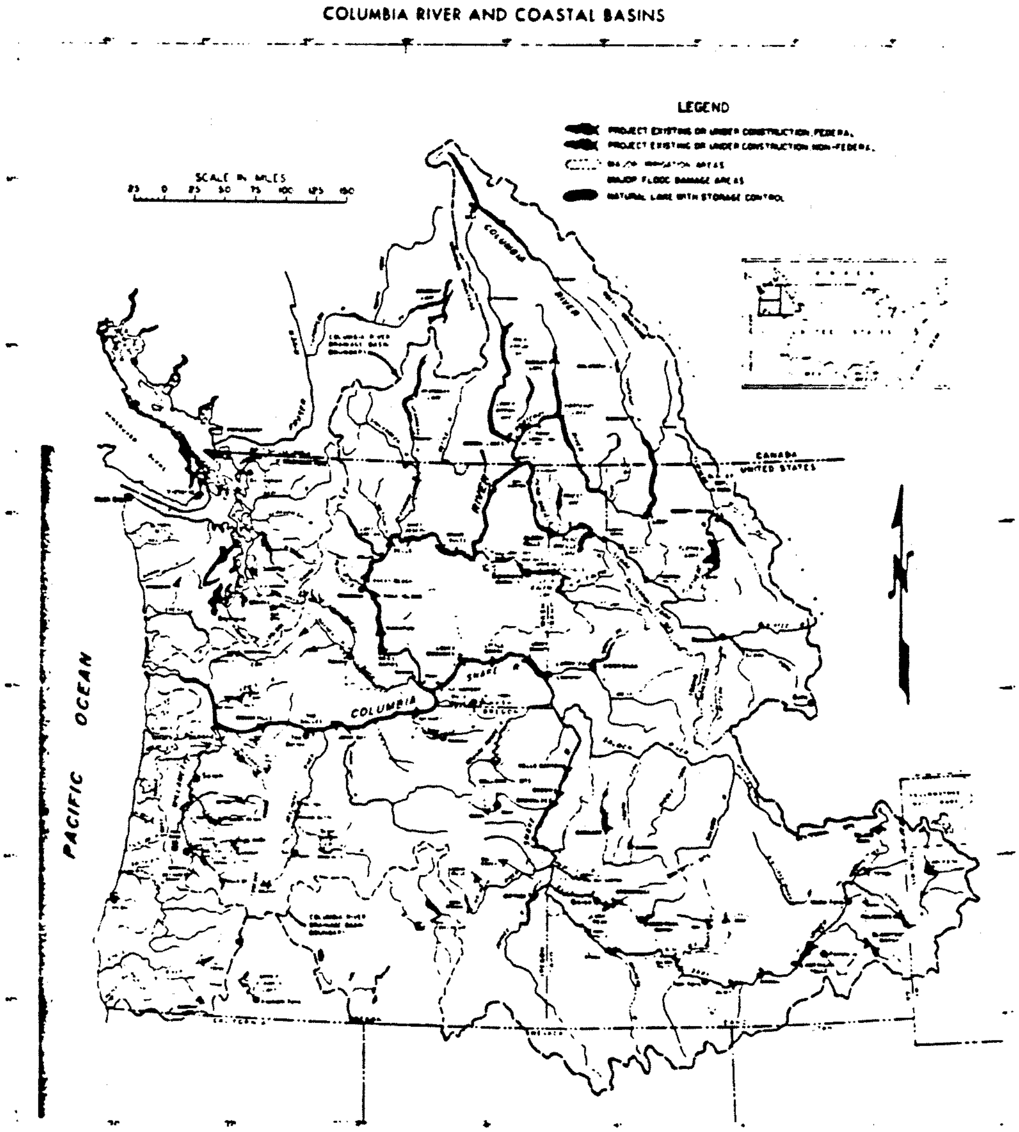


Figure 3
Columbia River and Coastal Basins

From CRWMG 1979

by the 14 dams now on the main stem. The river is best described in relation to these projects.

Lake McNaughton of the Mica project is the largest storage reservoir on the Columbia. Its volume of 20.308 million acre feet (ac ft) is more than double that of Roosevelt Lake, the second largest (Table 3). McNaughton Lake is also the deepest of the reservoirs with a maximum depth of 590 ft. Classified as a cyclic storage reservoir (i.e., one which does not refill each year if all live storage is withdrawn [CRWMG 1979]), the lake has the lowest mean annual discharge (14,848,561 ac ft) of all the projects and thus the largest storage ratio or flushing rate of approximately 1.4 years or 16 months.

The large shoreline development of 8.36 is typical of reservoirs which inundate a river valley behind a dam. This value may also suggest shallow water; however, the steep bottom slope of 0.77 and development of volume ratio of 0.32 implies rather limited littoral zones.

Water discharged from Mica Dam flows in a southerly direction towards Revelstoke, B.C. This is the site of construction of the latest impoundment on the main stem. The Revelstoke project is scheduled to begin operation in 1983 with Mica Dam regulating the seasonal stream flow for the project (CRWMG 1979).

Approximately 30 miles south of Revelstoke, the Columbia enters Upper Arrow Lake at Arrowhead, B.C. Both the Lower and Upper Arrow Lakes serve as storage reservoirs for the Hugh Keenleyside Dam. These reservoirs give the Columbia its widest breadth (mean width = 1.50 mi; Table 3) of any point on the main stem. Little distinction is made between the lakes except in terms of depth; Upper Arrow having a maximum of 426 ft while Lower Arrow is considerably shallower with a maximum depth of 131 ft.

The total volume of the lakes is approximately 7.502 million ac ft, slightly less than for Roosevelt Lake (Table 3). The mean annual discharge of 29,031,074 ac ft is double that of the Mica Project but is still barely a third of the discharge rate of other main stem reservoirs. The annual storage ratio of three months is second only to Lake McNaughton.

B.C. Research (1977) reported the results of limnological studies of four lakes in British Columbia which included the Arrow and McNaughton reservoirs. The reservoirs were considered to be oligotrophic with dissolved oxygen generally near saturation at all depths. Temperature profiles did not indicate thermal stratification during the months of the study, September and November. The nutrient levels were low as is typical of oligotrophic lakes. Phytoplankton in the Arrow and McNaughton Lakes were dominated by diatoms with a wide variety of species. Zooplankton communities showed considerable diversity with copepods predominating except in Lake McNaughton where cladocerans were in the majority. Benthic communities were dominated by Chironomidae and were depleted in littoral zones where water fluctuation occurred.

TABLE 3

MORPHOMETRIC CHARACTERISTICS OF MAIN STEM COLUMBIA RIVER PROJECTS

DAM	R. M.[1]	RESERVOIR	LENGTH (miles)	MEAN WIDTH[2] (miles)	SHORELINE LENGTH (miles)	DEPTH MAX. (feet)	DEPTH MEAN[3] (feet)	ELEVATION MAX. (feet)	ELEVATION MIN. (feet)	MAX. AREA (surf. acres x 10^3)	TOTAL VOL. (ac. ft. x 10^6)	DEVELP. VOL RATIO[4]	SHORELINE DEVELOPMENT[5]	BOTTOM SLOPE[6]	MEAN ANN. DISCHARGE[7] (acre-ft/yr)	ANN. STORAGE RATIO[8]
Mica	1018.0	McNaughton	130	1.27	381	590	191.6	2475	2320	106	20.308	0.32	8.36	0.77	14,848,561	1.368
Revelstoke	932.8	Under Constr.	---	---	---	---	---	1800	---	---	---	---	---	---	---	---
Hugh Keenleyside	780.0	Upper & Lower Arrow	136	1.50	316	U=426 L=131	58.2	1444	1377	128.9	7.302	---	6.29	---	29,031,074	0.250
Grand Coulee	596.6	F D Roosevelt	151	0.84	650	390	118	1290	1208	81	9.562	0.30	16.30	0.58	77,971,240	0.123
Chief Joseph	545.1	Rufus Woods	44	0.28	106	190	66.2	956	930	7.8	0.516	0.35	8.56	0.91	78,188,430	0.007
Wells	515.6	Pateros	28	0.60	---	109	29.0	779	771	10.7	0.310	0.27	---	0.45	81,446,281	0.004
Rocky Reach	473.0	Entiat	42	0.34	---	---	42.6	707	703	9.2	0.390	---	---	---	83,037,008	0.005
Rock Island	453.4	Rock Island	21	0.26	---	42	---	606.9	602.9	3.47	---	---	---	0.30	85,572,893	---
Wanapum	415.8	Wanapum	38	0.57	---	121	43.5	571.5	560.0	14.68	0.600	0.36	---	0.42	85,645,289	0.007
Priest Rapids	397.1	Priest Rapids	18	0.67	---	88	26.0	488.0	481.5	7.7	0.200	0.30	---	0.43	85,737,686	0.002
McNary	292.0	Wallula	61	0.98	---	130	35.4	340	335	38.1	1.350	0.27	---	0.28	122,350,413	0.011
John Day	215.6	Umatilla	76	1.11	240	145	46.3	268	257	54	2.500	0.32	7.37	0.26	124,811,901	0.020
The Dalles	191.5	Celilo	24	0.88	55	90	24.6	160.0	155.5	13.55	0.333	0.27	3.37	0.33	128,793,719	0.003
Bonneville	146.1	Bonneville	45	0.85	130	30	22.0	77	70	24.4	0.537	0.73	5.94	0.08	132,703,140	0.004

1. R. M. = River Mile, the distance from the mouth of the Columbia River to the axis of the dam as measured along the main river channel.

2. Mean Width = $\frac{\text{Maximum Area}}{\text{Length}}$

3. Mean Depth = $\frac{\text{Total Volume}}{\text{Maximum Area}}$

4. Development of Bottom Ratio = $\frac{\text{Mean Depth}}{\text{Maximum Depth}}$, lakes with a low ratio are usually conical-shaped depressions while high ratios indicate steep-sided lakes with flat bottoms. Shallow lakes, which have large values, tend to provide a greater opportunity for exposure of bottom sediments to overlying water and for circulation of bottom nutrients.

5. Shoreline Development = $\frac{\text{Shoreline Length}}{2\sqrt{(\text{Maximum Area})(\pi)}}$, serves as an index of the geological and littoral processes affecting the shape of the lake. Nearly circular lakes have values of approximately 1.0, subcircular bodies have slightly larger values while the largest are for elongated lakes. High values are indicative of lakes formed along old drainages or by impounding rivers to form a lake in the valley behind the dam. High values suggest the presence of shallow water and protected bays, appropriate areas for vegetative growth. Thus the value serves as an index of plant growth capacity and enrichment potential from nearshore development and runoff.

6. Bottom Slope = $\frac{(\text{Maximum Depth})(50\sqrt{\pi})}{\sqrt{\text{Maximum Area}}}$, a measure of the extent of shallow water and is important to the growth of rooted aquatic plants and the opportunity for wind mixing of water with bottom sediments. Low values are typical of shallow reservoirs.

7. Data are the average, annual, modified streamflow for the 40-year period of 1928-1968, for the 1970 level of irrigation development. Compiled by the Depletion Task Force of the CRWMG.

8. Annual Storage Ratio = $\frac{\text{Total Volume}}{\text{Mean Annual Discharge}}$, also termed the exchange rate or flushing rate. Although defined as a ratio this value has units in years therefore this as a measure of the amount of time required to completely flush and refill the reservoir.

Mid-Columbia. Crossing the border at Northport, Washington, the Columbia River flows into Franklin D. Roosevelt Lake. The lake is the storage reservoir for the Grand Coulee Project and essentially controls the flow of the Columbia River through the remainder of the basin. F.D.R. is the largest lake in Washington (Wolcott 1964), with a length of 151 miles (Table 3). Bennett and White (1977) published a comprehensive annotated bibliography on Roosevelt Lake.

While Roosevelt Lake's volume of 9.562 million ac ft is less than half of Lake McNaughton (20.308 million ac ft), F.D.R.'s shoreline development is double that of any other reservoir on the main stem. The extreme elongated nature of Roosevelt Lake and the entry of the Spokane River and other tributaries contribute to the large shoreline development. Roosevelt Lake is currently operated with an average annual drawdown of about 80 feet.

In comparison to the storage projects upstream of Grand Coulee (i.e., Keenleyside and Mica) the annual mean discharge is approximately three times as great (77,971,240 ac ft), but in terms of downstream projects this is a minimum value. The annual storage ratio of F.D.R. reservoir is about 45 days, the only project on the main stem in the U.S. where water retention is longer than one week.

Lake Roosevelt is operated under three seasonal patterns typical of reservoirs east of the Cascade Range. These include: 1) the summer holding or storage conservation season; 2) the fall and winter storage control or drawdown season; and 3) the spring snowmelt runoff or refill season (CRWMG 1979).

The change in mean water level for Roosevelt Lake during the year is shown in Fig. 4. Drawdown begins in December and continues through the month of March when the water elevation is reduced to approximately 1208 ft (82 ft drawdown). The refill season commences in April and the reservoir reaches an elevation of about 1290 ft in July. This water elevation is maintained through the summer and early fall.

Water discharged from Grand Coulee enters Rufus Woods Reservoir of the Chief Joseph project. This is the first of the so-called run-of-the-river projects on the main stem of the Columbia. In general, such projects have a relatively small reservoir storage capacity which usually fluctuates only a few feet with daily or weekly frequency throughout the year.

Rufus Woods has the greatest depth (190 ft) of any of the run-of-the-river project reservoirs and also has the largest fluctuation in water elevation (26 ft) (Table 3). This reservoir serves to partially re-regulate the peaking discharges from Grand Coulee Dam. In several other characteristics, however, Rufus Woods and the remaining run-of-the-river reservoirs on the mid-Columbia are similar (i.e., Pateros, Entiat, Rock Island, Wanapum, Priest Rapids).

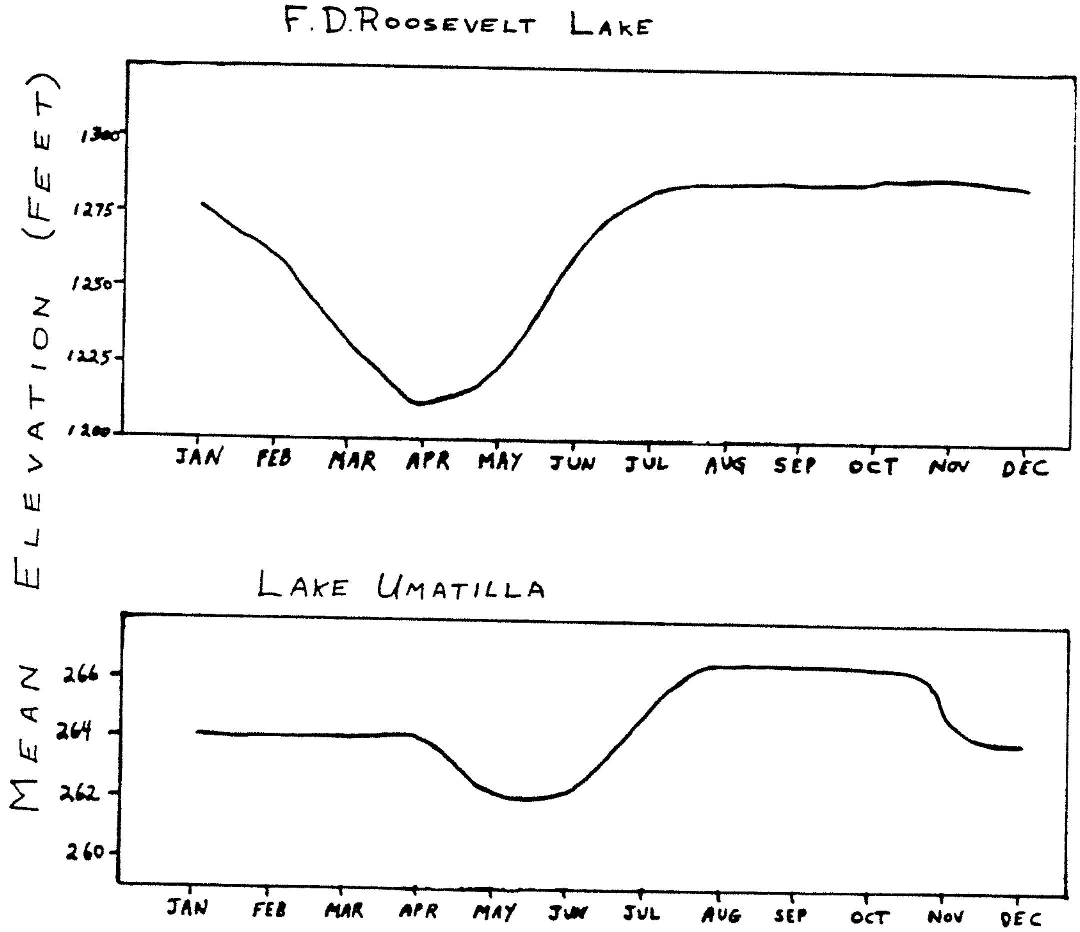


FIG. 4. WATER LEVEL CURVES FOR F.D.R. LAKE AND LAKE UMATILLA.

The volume ratios (range: 0.27 [Pateros] to 0.36 [Wanapum]) and bottom slopes, excluding Rufus Woods (range: 0.30 [Rock Island] to 0.45 [Pateros]) suggest considerable shallow areas in the reservoirs. The mean depths (Table 3) range from 26.0 ft at Priest Rapids to 66.2 ft at Chief Joseph.

The discharges from the dams increase as the river progresses down through the mid-Columbia projects. The greatest increase is found between Chief Joseph (78,188,430 ac ft) and Rocky Reach (83,037,008 ac ft), while the lower three projects (i.e., Rock Island, Wanapum, and Priest Rapids) discharge approximately 85.5 million ac ft annually.

The annual storage ratios for the mid-Columbia run-of-the-river projects vary from less than one day (Priest Rapids) to approximately two and a half days (Chief Joseph, Wanapum). These retention times are among the shortest for the main stem projects (Table 3).

The last free-flowing portion of the Columbia is between the Priest Rapids Project and the confluence of the Snake River. Known as the Hanford Reach, this 50-mile stretch of river is the only area where salmonids continue to spawn on the main stem (PNWRBC 1971). A description of the Hanford Reach is found later in this report.

Lower Columbia. Four hydroelectric dams are located on the lower Columbia River. McNary, The Dalles, and Bonneville are considered run-of-the-river while John Day is termed a storage project (CRWMG 1979).

John Day and its storage reservoir, Lake Umatilla, is the largest of the four projects, being the deepest (145 ft) and having the greatest fluctuation in elevation (11 ft) (Table 3). Lake Umatilla has an annual storage ratio of slightly over seven days, second only to Roosevelt Lake on the main stem in Washington.

Lake Umatilla is operated under four seasonal regimes in contrast to Lake Roosevelt. The annual regulation cycle includes: 1) the summer holding season; 2) the fall drawdown season; 3) the winter flood control season; and 4) the spring refill season (CRWMG 1979).

The operational cycle of Lake Umatilla is shown in Fig. 4. The water level is maintained at elevation 266 ft from July through mid-October when the fall drawdown occurs. By mid-November the water level is reduced to about 264 ft and held through March. Drawdown for flood control occurs during the months of April and May when the water level is reduced by another two feet to 262 ft. Lake Umatilla begins refilling for the summer holding season during June and July.

Lake Wallula of the McNary Project is sometimes considered a storage project (Millham 1978) because of its storage ratio of four days which is long for typical run-of-the-river projects. In terms of size and volume Lake Wallula is ranked third among the projects on the Columbia in Washington (Table 3) yet with a mean depth of 35 ft and fluctuations in elevation of only five feet it resembles a run-of-the-river reservoir.

Generally, the reservoirs on the lower Columbia are the widest (range: 0.68 mi [The Dalles] to 1.11 mi [John Day]), as the dams have inundated the lowlands of the Columbia Basin, and the dams are the lowest of any of the projects (range: 77 ft in height [Bonneville] to 340 ft [McNary]). The reservoirs are also the shallowest in the system as shown in their volume ratios, bottom slopes, and mean depths (Table 3). Lake Bonneville is the shallowest with a mean depth of 30 ft and a bottom slope of 0.08.

The four dams have the greatest mean annual discharge of any on the Columbia ranging from 122.4 million ac ft for McNary to 132.7 million ac ft for Bonneville.

WATER QUANTITY

A detailed evaluation of the water quantities in the Columbia River was beyond the scope of this review. An overview of the known inflows and diversions is presented to provide a general background of the hydraulic conditions in the river. The total annual discharge (ac ft) of dams and tributaries, and the total annual diversion (ac ft) from the main stem of the Columbia River are presented in Table 4. Only the tributaries which discharge directly into the main stem are listed. Many tributaries are ungauged. In most cases, the data are for water year (WY) 1978 (USGS 1979). When WY 1978 data were not available, the values used are the average, annual, modified streamflow for the 40-year period 1928-1968, and for the 1970 level of irrigation development (CRWMG 1979). The discharges based on the modified flows are somewhat higher than those reported for WY 1978, and are not directly comparable.

The gauged flow of the Columbia River at Northport, Washington in WY 1978 was 63,350,000 ac ft. Above Grand Coulee Dam several tributaries discharge into the river. The Spokane River discharging 5,795,230 ac ft is second only to the Snake River as a major tributary to the main stem of the Columbia. The Kettle River also adds a significant volume of water (2,226,000 ac ft) to this reach of the Columbia. The feeder canal at Grand Coulee withdraws 2,005,000 ac ft and may be the only gauged diversion on the main stem.

Grand Coulee and Chief Joseph Dam (which includes Foster Creek) discharged similar quantities (i.e., ≈ 71 million ac ft) of water during WY 1978. Above the Wells Project the Okanogan River discharges 2,161,000 ac ft and the Methow River 1,308,000 ac ft into the Columbia.

The discharge at Wells is 73,090,000 ac ft and is augmented by the Chelan River (1,543,000 ac ft) and Entiat River (342,300 ac ft) as the Columbia flows to Rocky Reach. Rocky Reach Dam discharged 74,330,000 ac ft during WY 1978. The Wenatchee River, a major tributary in the mid-Columbia Basin, adds 2,779,000 ac ft to the main stem.

The discharge at Rock Island is 77,100,000 ac ft and, based on the average modified streamflow for 1928-1968, Wanapum Dam annually discharges 85,645,289 ac ft. Priest Rapids Dam discharged 77,221,000 ac ft into the Hanford Reach during WY 1978. Two major tributaries discharge significant volumes into the main stem between Priest Rapids and McNary Dam. The Yakima added 3,108,000 ac ft to the Columbia and the Snake River, the largest tributary to the main stem, discharged 39,770,000 ac ft into the river in WY 1978.

Dams on the lower Columbia discharge the largest flows of the projects on the main stem of the Columbia. McNary discharges 122,800,000 ac ft and this flow is increased by several tributaries of which the John Day River is the most significant (1,637,000 ac ft).

Table 4. Water quantity - Columbia River.

Record Discharges (cfs)			COLUMBIA RIVER[1] Input (ac-ft)	Total Discharge	Output (ac-ft) Total Withdrawal
			Northport	63,350,000	
			Deep River		
			Big Sheep Creek		
			Onion Creek		
			Kettle River =	2,226,000	
			Sherman Creek		
			Colville River =	200,900	
			Hall Creek		
			Stranger Creek		
			Harvey Creek		
			Nez Perce Creek		
			Hunters Creek		
			Wilmont Creek		
			Ninemile Creek		
			Spokane River =	5,795,230	
			Hawk Creek		
			Sanpoil River		
					2,005,000 = Feeder Canal
Max. =	637,000	6/12/48	Grand Coulee		
Min. daily=	15,300	2/1/37	Dam =	70,850,000	
			Nespelem River		
Max. =	495,800	6/11/61	Chief Joseph		
Min. daily=	22,300	11/11/73	Dam =	70,770,000	
			+ Foster Creek[2]		
			Okanogan River =	2,161,000	
			Methow River =	1,308,000	
Max. daily=	402,000	6/15/72	Wells Dam =	73,090,000	
Min. =	17,900	10/5/70			
			Chelan River =	1,543,000	
			+ Chelan Power House[2]		
			Enitat River =	343,300	
			+ Mad River[2]		
Max. =	535,000	6/10/61	Rocky Reach		
Min. =	25,100	11/11/73	Dam =	74,330,000	
			Wenatchee River=	2,779,000	
			Squilchuck Creek		
			Stemilt Creek		
			Rock Island Creek		
Max. =	692,600	6/12/48	Rock Island Dam=	77,100,000	
Min. =	4,120	6/10/32			
			Colockum Creek		
			Moses Coulee		
			Quilamene Creek		
			Wanapum Dam =	85,645,289[3]	

Table 4. (Continued)

COLUMBIA RIVER (Continued)

			Crab Creek = 164,100
Max. =	692,600	6/12/48	Priest Rapids
Min. =	4,120	6/10/32	Dam = 77,221,000
			Yakima River = 3,108,000
			- Richland Canal[2]
			- Columbia Canal[2]
			Snake River = 39,770,000
			Walla Walla River = 405,500
Max. =	798,000	6/2/56	McNary Dam = 122,800,000
Min. =	39,500	6/10/77	
			Umatilla River = 313,900
			Alder Creek
			Willow Creek = 22,420
			Pine Creek
			Chapman Creek
			Rock Creek
			John Day River = 1,637,000
			John Day Dam = 124,811,901[3]
			Deschutes River = 4,388,000
			Fifteen Mile Creek
Max. =	1,240,000	6/6/1894	The Dalles Dam = 123,500,000
Min. =	12,100	4/16/68	
			Chenoweth Creek
			Klickitat River = 1,261,000
			Mosier Creek = 28,970
			Rock Creek
			Hood River = 822,800
			White Salmon River
			Little White Salmon River
			Wind River
			Herman Creek
			Rock Creek
			Bonneville Dam = 132,703,140[3]

[1]Total discharge and total withdrawal data are from water year 1978 (U.S.G.S. 1979).

[2]Water that is discharged or withdrawn downstream of the last gaging station on a tributary is indicated by a "+" (discharge) or "-" (withdrawal). In these cases, the net volume discharged into the Columbia River is unknown.

[3]Data are the average annual modified streamflow for the 40-year period of 1928-1968 for the 1970 level of irrigation development. Compiled by the Depletion Task Force of the CRWMG.

The average annual modified streamflow at the John Day Project is 124,811,901 ac ft. In the reach between John Day Dam and The Dalles, the Deschutes River adds 4,388,000 ac ft to the main stem. The Dalles Dam discharges 123,500,000 ac ft and several tributaries add to the Columbia River flow as the river progresses to Bonneville Dam. The major tributary in this reach is the Klickitat River which discharges 1,261,000 ac ft. Bonneville Dam, the final impoundment on the main stem, annually discharges 132,703,140 ac ft, the largest volume of any project.

WATER QUALITY

Irrigation water returning to the parent stream contains salts whose concentration has been increased by evapo-transpiration, leaching, and ion exchange (Sylvester and Seabloom 1962). Nitrates, calcium, magnesium, sodium, potassium, chlorides, and sulfates, are commonly leached from the soil by irrigation water. Specific conductance also rises as the concentration of dissolved salts increases. These return flows will produce marked water quality changes in the receiving stream if the volume of return flow is significant in relation to streamflow (Sylvester and Ruggles 1957).

Water quality in the main stem Columbia River during 1954-1957 (Sylvester and Ruggles 1957) was compared with water quality during four recent water years (Table 5). Water quality stations used by Sylvester and Ruggles below Rock Island Dam, Priest Rapids Dam, and McNary Dam near Umatilla, Oregon, coincided with current U.S. Geological Survey water quality monitoring stations. Irrigation return flows from the Columbia Basin Project enter the Columbia between Rock Island Dam and Priest Rapids Dam, and between Priest Rapids and Umatilla, Oregon (Bureau of Reclamation 1976). The Yakima and Snake Rivers, which also carry an increased load of dissolved salts from irrigation return flows, enter the Columbia between Priest Rapids and Lake Umatilla.

There were no major differences between water quality parameters in 1954-1957 and 1975-1978. Specific conductance and sulfate have generally increased below Rock Island Dam, while magnesium and sulfate have increased slightly below Priest Rapids Dam. Specific conductance, calcium, and magnesium have all increased at Umatilla, Oregon. The concentration of other ions has remained roughly the same or decreased. Turbidity was lower at all stations during water years 1975-1978, probably as a result of construction of more dams on the middle Columbia since 1957.

Specific conductance, temperature, and the concentration of chemical constituents were greater at some of the stations during low water years. Streamflow at water quality monitoring stations on the Columbia during 1977 was 15 to 38% below average, while streamflow was 13 to 18% above average during 1976 (Table 6). Both 1975 and 1978 were also below average years for streamflow.

Changes in water quality proceeding downstream were evident in 1954-1957 and were still evident in recent water years. Specific conductance, nitrite plus nitrate, sodium, sulfate, chloride, and temperature generally increased from Northport, Washington, near the Canadian border, to The Dalles, Oregon, while dissolved oxygen decreased.

Table 5 Mean annual values of water quality parameters at stations on the main stem Columbia River during 1954-1957 and water years 1975-1978 [after Sylvester and Ruggles (1957) and U.S. Geological Survey (1976-1979)].

PARAMETER	NORTHPORT WA			GRAND COULEE DAM			BEEBE WA	ROCK ISLAND DAM			
	76	77	78	75	76	78	54-57	54-57	75	76	78
Specific conductance (micromhos/cm)	138	137	139	143	143	158	126	111	145	155	165
pH	7.4	7.7	7.7	7.6	7.7	7.8	7.7	7.7	7.9	8.0	8.1
Turbidity (JTU)	2	1	1	5	4	2	16	12	5	5	4
Alkalinity (mg/l as $CaCO_3$)	61	56	60	58	58	--	58	59	55	58	--
Nitrite plus Nitrate (mg/l as N)	.08	.08	.11	.05	.17	.10	--	--	.11	.19	.12
Ammonia (mg/l as N)	.05	.05	.04	.06	.07	.05	.03	.04	.07	.05	.04
Total Phosphorus (mg/l as P)	.03	.04	.05	.04	.03	.03	--	--	.03	.07	.04
Dissolved Oxygen (mg/l)	--	--	12.0	12.5	11.6	10.9	12.2	12.1	12.3	12.5	12.4
Calcium (mg/l)	21	20	21	20	20	--	16	--	22	19	--
Magnesium (mg/l)	4.5	4.2	4.7	4.5	4.2	--	5.7	--	4.0	4.5	--
Sodium (mg/l)	1.8	1.4	2.0	2.1	2.1	--	2.1	--	2.6	3.0	--
Potassium (mg/l)	.8	.7	.9	1.1	1.1	--	1.0	--	1.1	1.1	--
Sulfate (mg/l)	12.4	13.0	12.9	11.0	11.7	--	11	11	10.6	13.5	--
Chloride (mg/l)	1.1	0.8	1.2	1.6	1.2	--	--	--	1.8	1.8	--
Temperature (°C)	9.0	9.5	9.5	--	10.0	10.0	10	10.1	--	--	--

PARAMETER	PRIEST RAPIDS DAM					PASCO WA	UMATILLA OR				DALLES OR			
	54-57	75	76	77	78	54-57	54-57	76	77	78	75	76	77	78
Specific conductance (micromhos/cm)	147	153	142	--	143	142	159	166	176	169	167	158	174	155
pH	7.9	7.9	7.9	--	7.8	7.8	7.9	7.8	8.2	7.9	7.9	7.9	8.3	7.9
Turbidity (JTU)	11	5	5	--	2	12	20	--	--	--	--	--	--	--
Alkalinity (mg/l as $CaCO_3$)	62	60	58	--	58	62	66	--	--	62	68	--	--	63
Nitrite plus Nitrate (mg/l as N)	--	.09	.16	--	.10	--	--	.20	.15	.22	.03	.20	.15	.29
Ammonia (mg/l as N)	.08	.07	.07	--	.02	.02	.05	.02	.02	.02	.03	.02	.02	.02
Total Phosphorus (mg/l as P)	--	.04	.04	--	.03	--	--	.05	.02	.05	.04	.05	.03	.06
Dissolved Oxygen (mg/l)	12.4	12.0	12.3	--	12.3	11.9	11.2	11.9	11.6	11.3	--	11.8	11.3	10.9
Calcium (mg/l)	19	21	19	--	20	17	15	20	26	17	20	17	20	19
Magnesium (mg/l)	3.0	4.7	4.3	--	4.6	4.1	3.2	4.4	4.4	5.2	5.5	4.5	5.6	5.5
Sodium (mg/l)	4.0	3.4	2.6	--	2.4	2.0	7.1	8.4	5.0	6.8	6.8	5.9	6.7	7.3
Potassium (mg/l)	1.3	1.7	1.1	--	0.9	1.1	1.9	1.4	1.3	1.4	1.4	1.3	1.3	1.6
Sulfate (mg/l)	9	13.3	11.2	--	12.6	11	15	14.5	15.5	14	14.5	13.9	15.0	12.8
Chloride (mg/l)	--	1.9	1.3	--	2.1	--	--	3.2	3.2	3.8	3.7	3.1	3.7	3.9
Temperature (°C)	10.3	--	10.5	11.0	10.0	10.7	10.5	--	11.5	11.5	12.0	10.0	--	11.2

Table 6. Discharge, in acre-feet per year, at stations on the main stem Columbia and Yakima rivers during water years 1975 to 1978. Percent deviation from the mean annual discharge for the period of record is given in parentheses. Data from USGS, 1976-1979.

STATION	WATER YEAR			
	1975	1976	1977	1978
COLUMBIA RIVER				
International Boundary	69,800,000 (-4)	85,920,000 (+17)	61,790,000 (-15)	63,350,000 (-13)
Grand Coulee Dam	78,080,000 (-3)	94,580,000 (+18)	62,990,000 (-21)	70,850,000 (-11)
Rock Island Dam	82,180,000 (-7)	103,500,000 (+16)	65,570,000 (-26)	77,100,000 (-13)
Priest Rapids Dam	83,440,000 (-4)	102,500,000 (+17)	65,400,000 (-25)	77,210,000 (-11)
Umatilla, OR	131,500,000 (-3)	156,700,000 (+15)	86,600,000 (-35)	122,800,000 (-8)
Dalles, OR	135,400,000 (-4)	159,900,000 (+13)	87,200,000 (-38)	123,500,000 (-12)
YAKIMA RIVER				
Parker, WA	2,113,000	2,720,000	359,700	2,217,000
Kiona, WA	3,034,000	3,707,000	935,700	3,180,000

Water quality data collected by Sylvester and Ruggles (1957) at two stations on the Yakima River were compared with recent water quality data (Table 7). Only minor changes in water quality have occurred at the upstream station near Thorp, Washington, since 1957. However, pronounced changes have occurred in the lower Yakima. Specific conductance, alkalinity, calcium, magnesium, sodium, sulfate, were all higher at Kiona and Richland during water years 1975-1978 than at Enterprise, near the mouth of the Yakima, during 1954-1957. Turbidity has been reduced since 1954-1957. The concentration of chemical constituents and temperature increased considerably in a downstream direction, while dissolved oxygen decreased. These changes are not surprising since the entire flow of the Yakima is used more than once for irrigation during the height of the growing season (Sylvester and Seabloom 1962).

Sylvester and Rambow (1967) stated that return flows from potentially irrigable land will flow into larger rivers such as the Columbia without serious effect. The pollutants in irrigation return flows consist of dissolved salts that are relatively unimportant when present in concentrations below known toxic levels. The surface waters of Washington normally contain extremely low levels of dissolved minerals, and the relatively high concentrations of salts in return flows are diluted by the much greater volume of flow in the Columbia River. Increased irrigation withdrawal and return flow will, however, result in greater concentrations in the main stem Columbia, particularly below the confluence of the Yakima and Snake Rivers.

Table 7. Mean annual water quality parameters at stations on the Yakima River during 1954-1957 and water years 1975-1978 [after Sylvester and Ruggles (1957) and U.S. Geological Survey (1976-1979)].

	THORP WA		PARKER WA				KIONA WA				RICHLAND WA	ENTER-PRISE WA
	54-57	75	75	76	77	78	75	76	77	78	75	54-57
Specific conductance (micromhos/cm)	71	73	130	113	171	132	223	206	345	223	246	194
pH	7.4	7.5	7.7	7.6	8.3	7.8	7.6	7.7	8.3	7.9	7.9	7.8
Turbidity (JTU)	20	8	10	11	9	9	13	9	8	18	14	33
Alkalinity (mg/1 as $CaCO_3$)	32	31	53	--	--	--	94	82	137	93	--	83
Nitrite plus Nitrate (mg/1 as N)	--	.11	.24	.12	.26	.19	.64	.64	1.00	.69	.77	--
Ammonia (mg/1 as N)	.03	.06	.12	.12	.15	.11	--	.07	.16	.04	.09	.07
Total Phosphorus (mg/1 as P)	--	.02	.10	.09	.16	.09	.15	.11	.18	.15	.14	--
Dissolved Oxygen (mg/1)	10.4	12.0	12.0	12.1	12.2	12.2	--	--	--	--	11.8	11.1
Calcium (mg/1)	18	7.8	12.7	--	--	--	22	19	32	23	--	15
Magnesium (mg/1)	1.2	2.7	4.1	--	--	--	7.6	6.6	11.8	8.2	--	2.8
Sodium (mg/1)	2.6	2.3	6.7	--	--	--	13.2	11.1	20.9	14	--	12.5
Potassium (mg/1)	1.6	0.4	1.4	--	--	--	2.5	2.1	3.7	2.6	--	2.5
Sulfate (mg/1)	2	1.5	4.3	--	--	--	12.1	9.9	23.6	13.9	--	12
Chloride (mg/1)	--	1.6	3.0	--	--	--	5.1	4.2	8.4	7.5	--	--
Temperature (°C)	6.0	7.9	10.8	9.8	9.7	10.5	13.5	10.5	12.0	12.5	11.9	11.8

FISHERIES

Salmon and Steelhead

History

The history of commercial fishing on the Columbia River can be divided into three periods in terms of harvest levels and condition of stocks. The first period, prior to the mid-1800's, was before commercial harvesting by white settlers, as recorded by early explorers Lewis, Clark, Thompson, Suckley, Cooper and Wilkes (Craig and Hacker 1940). Carey (1922) estimated a total Indian population of 50,000 along the Columbia River in that period, and the total annual harvest of chinook (*O. tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*) and chum salmon (*O. keta*), and steelhead trout (*Salmo gairdneri*) probably exceeded 18,000,000 lbs, which is greater than today's commercial catch. The catch was used for food and trade. Early Indian fishing was conducted at falls and rapids where fish passage upstream was impeded. Methods employed included basket traps, spears, and small seines aided in specific areas by the construction of weirs (Craig and Hacker 1940).

The second period began in 1866 when a saltery was established, succeeded several years later by a cannery which was highly successful. This was a period of drastic declines in the Indian populations, principally by disease, accompanied by a dramatic increase in the non-Indian population through immigration. Fishing methods evolved, through a process of competition and regulation, from beach seines, fish wheels and traps, to present-day use of drift and set gillnets and coastal trolling. This period was also one of moderate disturbances of the watershed through mining, logging and irrigation diversion, but the total area of watershed available for spawning and rearing of salmonids was not greatly reduced. The stocks of summer-run chinook salmon declined primarily through over-fishing and watershed disturbance, but the overall catch of chinook remained fairly constant because the effort shifted to spring- and fall-run stocks (Beiningen 1976).

The third period, from 1940 to present, coincides with major fish habitat destruction and stream flow alteration through the proliferation of hydroelectric and irrigation dams, accelerated logging, and riparian development. During this period the Indian catch declined drastically as the falls and rapids were inundated by reservoirs. The Indian and non-Indian commercial catch averaged 8,000,000 lb annually for all salmonid species from 1940 to 1974 (Netboy 1974). During this period the construction of dams reduced the available habitat from 163,000 mi^2 to 72,800 mi^2 and caused substantial mortality of seaward migrants and returning adults (Salo and Stober 1978). In spite of all efforts to improve conditions for fish passage, mortality of mid-Columbia runs continues at a level which probably precludes the survival of natural (wild) stocks. Stocks from below Bonneville Dam and the lower Columbia River appear to have good potential and are being maintained at moderate levels through regulation and intensive hatchery production. Hatcheries now produce half of all Columbia River salmonids (Salo and Stober 1978).

A treaty-Indian fishery based on the use of set gillnets has developed on the Bonneville and Dalles Reservoirs following inundation of Celilo Falls by Bonneville Dam in 1938. The 1974 Boldt ruling requiring that treaty Indians have the opportunity to harvest half of all harvestable salmon and steelhead will result in changes in methods and locations of harvest and the Columbia River stocks will continue to change.

The advent of dams on the main stem Columbia River with fish counting facilities has enabled accurate enumeration of salmon and steelhead runs to the lower- and mid-Columbia River and the identification of distinct stocks of chinook and steelhead based on differences in run timing. The escapements of spring, summer, and fall chinook salmon and summer and winter steelhead are not managed separately by regulating the catch seasonally. The condition of the lower- and mid-Columbia River salmonid stocks is monitored by the annual fish counts at Bonneville and Rock Island Dams.

Mid-Columbia Salmon Runs

The annual counts of salmonids to the mid-Columbia River past Rock Island Dam are summarized during the period 1933 to 1974 in Table 8 (Beiningen 1976). Chinook runs collectively (spring, summer and fall stocks) remained fairly constant through 1952, averaging 8,435 fish annually. After 1953 the counts increased four-fold, averaging 34,319 annually through 1970. From 1971 to 1974 the counts declined slightly, averaging 25,587. The relative contribution of spring, summer and fall stocks to the upriver escapement can be determined from counts at Bonneville Dam after 1938. During the period 1938 to 1975 the spring-run chinook counts averaged 123,500 (April and May upstream migration), the summer-run chinook counts averaged 58,600 (separate peaks during July and early September) and the fall chinook counts averaged 149,900 (August and September upstream migration). Expressed as percentages of the total chinook escapement these stocks represented 37.2 percent, 17.6 percent, and 45.2 percent, respectively.

The runs of coho salmon past Rock Island Dam are of minor importance, averaging only 86 fish annually from 1933 to 1965 and 5859 from 1966 to 1974 (Table 8). These coho are almost entirely of hatchery origin and pass upriver during September to November.

Sockeye, or blueback salmon, comprise an important segment of the upriver run. Their numbers have fluctuated widely, ranging from over 100,000, to less than 10,000, but generally varying from 30,000 to 70,000 (Table 8). The runs pass upriver in late June and July to lake-fed tributaries of the Yakima, Wenatchee, and Okanogan Rivers.

Table 8 --Annual Fish Counts, by Species, Rock Island Dam, 1933-74

	Year	Chinook	Coho	Blueback	Steelhead	Total Fish
	1933	5,668	182	40,737	1,055	47,642
	1934	6,482	69	2,227	583	9,361
	1935	16,310	10	14,013	5,412	35,745
	1936	7,396	---	16,501	2,369	26,266
	1937	5,133	58	15,087	2,214	22,492
	1938	5,803	78	17,123	2,400	25,404
	1939	11,206	13	19,591	5,427	36,237
	1940	9,492	2	26,894	5,550	41,938
	1941	2,571	29	949	3,561	7,110
	1942	6,814	1	16,282	3,586	26,683
	1943	11,145	22	17,665	2,249	31,081
	1944	3,375	186	4,932	1,329	9,822
	1945	5,696	166	7,142	1,121	14,125
	1946	9,992	32	46,563	1,761	58,348
	1947	11,786	229	79,834	2,115	93,964
	1948	7,095	29	84,627	2,319	94,070
	1949	12,358	40	18,682	2,460	33,540
	1950	8,292	72	50,059	1,846	60,269
	1951	18,794	8	102,724	2,932	124,458
	1952	20,114	22	113,703	3,015	136,854
	1953	30,908	40	152,013	4,071	187,032
	1954	33,261	43	91,184	5,400	129,888
	1955	25,733	51	155,782	3,902	185,468
	1956	24,910	29	92,209	1,780	118,928
	1957	50,745	33	71,267	4,013	126,058
	1958	32,981	76	97,947	6,121	137,125
	1959	23,344	118	72,251	4,145	99,858
	1960	26,535	94	60,341	6,216	93,186
	1961	33,077	50	19,233	7,042	59,402
	1962	34,155	737	29,253	7,605	71,750
	1963	34,688	13	64,750	7,078	106,529
	1964	39,951	61	69,411	5,016	114,439
	1965	36,407	258	42,380	6,062	85,107
	1966	48,533	8,342	164,547	9,734	231,176
**	1967	38,345	6,222	119,765	5,506	169,838
**	1968	37,871	9,259	104,790	7,880	159,800
**	1969	31,970	947	37,965	4,979	75,861
**	1970	34,342	3,483	74,904	3,144	115,873
**	1971	28,342	5,423	71,438	8,312	113,515
**	1972	25,585	3,661	43,467	4,813	77,526
	1973	26,825	4,605	68,732	5,157	105,319
	1974	21,597	*10,788	33,859	1,885	65,607

* Rocky Reach count through December 3. Run still exceeding 100 fish per day when counting terminated.

** Computed estimates from Priest Rapids counts.

From Beiningen, 1976

Steelhead runs past Rock Island Dam have been relatively minor, but constant in number, in comparison with the salmon runs. In most years from 1933 to 1974 the counts ranged from 2000 to 7000 (Table 8). The upriver runs consist primarily of summer-run steelhead which peak during July and early September. While the escapement of summer-run steelhead has been held fairly constant since 1933, the run size, as reflected in the commercial harvest, has declined due to mortality of juveniles and adults at dams, overfishing, and habitat loss (Beiningen 1976). Winter-run steelhead essentially all return to tributary streams below Bonneville Dam and the lower Columbia River. Their numbers have increased since 1953 due to artificial propagation.

Chum salmon return in moderate numbers from mid-October through November to tributaries below Bonneville Dam, very few pass Bonneville Dam (Chaney and Perry 1976).

Information on the size of various runs is obtained through catch statistics, counting facilities at dams, hatchery returns, and spawning ground counts. Fish of hatchery origin are accurately accounted but wild stocks are not because of the difficulty in obtaining accurate counts in tributaries which are not weired or dammed. The wild stocks still constitute at least half of the Columbia River runs and greater effort should be made to compile information on the abundance, timing and spawning locations of returning adults and on the abundance, timing and oceanic distribution of seaward migrants.

An ocean troll fishery began off the mouth of the Columbia River shortly after 1900 and gradually expanded northward up the Washington and Canadian coastlines into Southeast Alaska and southward to California. This fishery has harvested an increasingly large share of the Columbia River production. It has been estimated that in recent years the ocean troll and ocean sport fishery harvests from 66 to 85 percent of all salmon produced by the Columbia River (Beiningen 1976). This intense fishery of mixed wild and hatchery stocks originating from the Columbia complicates the management of the wild stocks because of their lower production rates.

Commercial Harvest

The present status of fish stocks and fisheries is well described and documented in Investigative Report E of Columbia River Fisheries Project (CRFP) (Beiningen 1976). The commercial landings by species and by management area for commercial and sport year are presented in a comprehensive series of tables and figures which summarize historical and recent information through 1974. This series should be updated through annual status reports of the Oregon Department of Fish and Wildlife (ODFW) and Washington Department of Fisheries (WDF) Annual Status Reports. The catches of chinook, sockeye, chum and steelhead have all declined drastically from peak levels which were reached in the early 1900's. The present coho catch is less than during peak years but is being maintained at a relatively high level through hatchery production (Table 9).

Table 9.--Columbia River Commercial Landings of Chinook, Coho, Sockeye, Chum and Steelhead, in Pounds and Numbers, since 1866.

Date	Chinook pounds (thousands)	Chinook numbers (thousands)	Coho pounds (thousands)	Coho numbers (thousands)	Sockeye pounds (thousands)	Sockeye numbers (thousands)	Chum pounds (thousands)	Chum numbers (thousands)	Steelhead pounds (thousands)	Steelhead numbers (thousands)	Total pounds (thousands)	Total numbers (thousands)	Date
1866	272	15									272	15	1866
1867	1,224	66									1,224	66	1867
1868	1,904	102									1,904	102	1868
1869	6,800	367									6,800	367	1869
1870	10,200	550									10,200	550	1870
1871	13,600	733									13,600	733	1871
1872	17,000	916									17,000	916	1872
1873	17,000	916									17,000	916	1873
1874	23,800	1,283									23,800	1,283	1874
1875	25,500	1,375									25,500	1,375	1875
1876	30,600	1,650									30,600	1,650	1876
1877	25,840	1,393									25,840	1,393	1877
1878	31,280	1,686									31,280	1,686	1878
1879	32,640	1,760									32,640	1,760	1879
1880	34,040	1,843									36,040	1,843	1880
1881	37,400	2,016									37,400	2,016	1881
1882	36,808	1,984									36,808	1,984	1882
1883	42,799	2,307									42,799	2,307	1883
1884	42,160	2,273									42,160	2,273	1884
1885	37,658	2,030									37,658	2,030	1885
1886	30,498	1,644									30,488	1,644	1886
1887	24,208	1,305									24,208	1,305	1887
1888	25,320	1,365									25,320	1,365	1888
1889	18,135	978			1,211	340			1,726	230	21,072	1,562	1889
1890	22,821	1,230			3,800	1,120			2,812	398	29,632	2,749	1890
1891	24,065	1,297			1,053	303			2,010	275	28,030	1,875	1891
1892	23,410	1,262	284	32	4,525	130			4,920	674	33,139	2,098	1892
1893	19,637	1,059	1,979	221	2,071	595	157	13	4,435	608	28,279	2,496	1893
1894	23,875	1,287	2,900	325	2,979	856			3,565	488	33,327	2,956	1894
1895	30,253	1,631	6,723	758	1,225	352	1,530	126	3,378	463	43,159	3,330	1895
1896	[illegible]	1,360	2,999	335	1,155	332			3,377	463	32,755	2,490	1896
1897	29,867	1,610	4,138	463	882	253			3,138	430	38,025	2,756	1897
1898	23,180	1,250	4,449	498	4,534	1,303			1,787	245	33,950	3,296	1898
1899	18,771	1,012	2,013	225	1,630	468	774	63	816	112	24,004	1,880	1899
1900	19,235	1,037	3,055	341	895	257	1,203	98	1,401	192	25,799	1,926	1900
1901													1901
1902	23,034	1,242	716	80	1,159	333	707	58	584	80	26,200	1,793	1902
1903	27,917	1,505	820	93	570	164	680	56	493	66	30,488	1,884	1903
1904	31,783	1,713	2,125	238	878	252	1,407	115	671	92	36,864	2,410	1904
1905	33,023	1,781	1,824	204	528	152	1,751	144	608	92	37,808	2,373	1905
1906	[illegible]	1,616	1,014	113	531	153	1,891	155	442	61	35,653	2,130	1906
1907	24,257	1,307	2,159	242	374	107	1,534	126	403	55	28,721	1,837	1907
1908	19,743	1,064	2,137	239	584	168	1,140	94	729	100	24,380	1,665	1908
1909	17,119	923	2,869	321	1,704	490	1,679	137	1,175	161	24,535	2,032	1909
1910	[illegible]	1,363	4,687	524	424	122	4,525	371	378	51	35,330	2,433	1910
1911	[illegible]	[illegible]	5,400	604	407	117	3,656	298	584	80	[illegible]	[illegible]	1911
1912	21,386	1,153	2,165	242	558	160	1,272	104	2,147	294	27,530	1,953	1912
1913	19,394	1,045	2,786	312	758	218	905	74	2,168	297	26,556	1,946	1913
1914	22,499	1,970	4,744	531	2,401	690	3,351	275	1,908	261	38,501	3,127	1914
1915	32,127	1,732	2,267	254	371	107	5,884	483	2,690	368	43,039	2,944	1915
1916	[illegible]	[illegible]	[illegible]	396	258	74	5,288	433	1,581	217	[illegible]	[illegible]	1916
1917	[illegible]	1,591	4,372	489	542	156	3,649	299	2,233	306	40,448	2,841	1917
1918	[illegible]	1,577	6,674	747	2,573	739	2,030	166	3,023	414	44,125	3,643	1918
1919	[illegible]	1,675	6,170	690	494	142	5,134	421	1,900	260	44,934	3,188	1919
1920	[illegible]	1,070	1,838	206	178	51	1,278	105	1,168	160	30,312	2,188	1920
1921	[illegible]	1,162	2,338	261	411	118	328	27	1,021	140	[illegible]	[illegible]	1921
1922	[illegible]	988	6,150	688	2,093	601	601	49	2,163	296	30,153	2,000	1922
1923	[illegible]	1,163	6,965	779	2,605	749	1,735	142	2,684	368	35,007	3,201	1923
1924	[illegible]	1,206	7,796	872	501	144	3,927	322	3,193	437	38,167	2,981	1924
1925	[illegible]	1,247	7,937	888	384	110	3,795	311	2,907	398	42,333	3,144	1925
1926	[illegible]	1,135	6,606	739	1,478	425	2,234	183	3,843	526	35,507	3,018	1926
1927	[illegible]	1,294	5,209	583	468	134	4,655	382	3,147	431	37,688	2,824	1927
1928	[illegible]	979	3,723	416	327	94	8,497	697	2,160	296	33,127	2,481	1928
1929	[illegible]	979	6,701	750	685	197	3,718	305	2,870	393	32,521	2,623	1929
1930	[illegible]	1,082	7,737	865	668	192	773	63	2,404	329	31,823	2,531	1930
1931	[illegible]	[illegible]	2,714	304	281	81	239	20	2,126	291	[illegible]	1,848	1931
1932	[illegible]	863	4,096	458	191	55	1,174	96	1,432	196	23,550	1,668	1932
1933	[illegible]	1,013	2,702	302	471	135	1,659	136	1,958	268	26,846	1,891	1933
1934	[illegible]	1,013	4,775	534	467	134	1,663	136	1,919	263	27,901	2,080	1934
1935	[illegible]	[illegible]	2,684	300	48	33	810	66	1,764	242	25,756	1,441	1935

continued

Table 9 (continued)

1936	15,966	860	1,739	185	302	87	1,142	94	2,304	316	23,529	1,542	1936
1937	18,654	1,006	1,842	206	335	96	1,910	157	1,933	265	24,674	1,730	1937
1938	12,418	660	2,311	259	425	122	1,915	157	1,764	242	18,833	1,449	1938
1939	13,499	728	1,539	171	270	78	1,174	96	1,438	197	17,911	1,270	1939
1940	13,516	729	1,373	154	362	104	1,253	103	2,825	387	19,329	1,477	1940
1941	[illegible]	1,253	1,045	117	506	145	4,150	340	2,664	293	31,605	2,188	1941
1942	18,689	1,007	845	72	192	55	5,191	426	1,839	200	26,546	1,760	1942
1943	11,426	616	706	79	146	42	960	79	1,515	167	14,753	983	1943
1944	14,060	758	1,333	171	55	15	275	23	1,720	180	17,643	1,147	1944
1945	12,973	699	1,836	205	9	3	589	48	1,964	203	17,369	1,158	1945
1946	14,278	770	1,060	119	129	37	887	73	1,726	183	18,078	1,182	1946
1947	17,309	933	1,498	168	718	206	496	41	1,649	179	21,664	1,527	1947
1948	17,352	935	1,173	131	96	28	1,045	86	1,579	157	21,247	1,337	1948
1949	16,769	581	899	101	24	7	545	45	814	88	13,051	822	1949
1950	10,422	562	1,048	117	169	49	700	58	965	102	13,304	887	1950
1951	10,036	541	968	108	169	49	532	44	1,207	154	12,913	896	1951
1952	7,271	392	1,074	120	609	175	309	25	1,462	188	10,724	900	1952
1953	6,967	376	458	51	146	42	249	20	1,901	225	9,721	714	1953
1954	5,313	286	303	34	243	70	320	26	1,468	154	7,647	570	1954
1955	8,582	463	599	67	200	57	126	10	1,288	142	10,804	758	1955
1956	8,179	441	460	51	287	82	46	4	812	108	9,783	686	1956
1957	5,919	319	391	44	240	69	32	3	741	98	7,323	533	1957
1958	6,434	347	168	19	724	208	89	7	700	92	8,114	673	1958
1959	4,594	248	120	13	636	183	43	4	673	108	6,065	556	1959
1960	3,928	212	159	18	394	113	15	1	723	94	5,219	438	1960
1961	4,166	224	383	43	158	45	17	1	716	101	5,434	414	1961
1962	5,467	295	606	67	52	15	48	4	723	89	6,891	480	1962
1963	4,346	234	501	56	49	14	15	1	972	117	5,884	422	1963
1964	4,484	242	1,964	220	68	20	24	2	425	55	6,965	539	1964
1965	6,143	331	1,902	213	23	7	8	1	510	65	8,584	612	1965
1966	3,612	195	4,389	491	17	5	11	1	393	47	8,423	739	1966
1967	4,974	268	3,818	427	195	56	10	1	445	50	9,442	802	1967
1968	4,097	221	962	108	90	26	3	1	428	45	5,580	401	1968
1969	5,776	311	1,663	186	105	30	4	1	490	48	8,038	576	1969
1970	6,462	348	5,746	643	56	16	8	1	308	33	12,579	1,041	1970
1971	5,967	322	2,278	255	286	82	8	1	468	51	9,004	711	1971
1972	5,685	306	1,239	139	276	79	18	1	667	63	7,883	588	1972
1973	8,552	461	1,905	213	18	5	18	1	634	52	11,125	732	1973
1974	3,629	196	2,482	278	2	1	11	1	385	19	6,309	494	1974
1975	6,591	323	3,581	362	0	0	6	1	70	7	8,248	492	1975

From Beiningen, 1976

The catch of all Columbia River salmonids by commercial and sport fisheries and the total minimum run size since 1938 is shown graphically in Fig. 5 (Beiningen 1976). A downward trend since 1925 is readily apparent as is the relatively recent but rapid emergence of the sport fishery as a competitor for the harvestable production. While sport fishing for Columbia River salmon has occurred continuously during the past 100 years, only since 1950 has the sport catch constituted a significant part of the total harvest of coho and chinook. Sport and commercial catch data, compared by Beiningen (1976) during 1970 to 1974, shows the sport fishery accounted for 24 percent of the coho harvest and 19 percent of the chinook harvest. The history of management regulation and legislation of the commercial and sport fishery is well summarized in CRFP Report I (Ortmann et al. 1976). Chronological lists of season and gear regulations from 1877 to 1975 are presented. Of particular interest is a graphical representation of the Columbia River commercial fishing seasons from 1907 to 1975 in which the actual fishing days are compiled for non-Indian and Indian fisheries (Fig. 6). The figure portrays the high degree of restriction under which the fishery operates in the lower Columbia River in order to meet escapement goals, particularly of the spring and summer chinook runs. Also indicated is the gradual expansion of the Indian set net fishery in Bonneville Reservoir, particularly on the winter chinook run.

The commercial catch of Columbia River salmon stocks originating from main stem and tributaries above Bonneville but which were caught below Bonneville Dam is listed in Table 10 for the years 1967-1977 (1977 Annual Report, ODFW). An obvious trend is apparent from these data in that the catch of spring, summer, and fall chinook, coho, and sockeye since 1963 all were substantially below the average for the past decade.

The harvest of chinook, steelhead and sockeye from the main stem Columbia River above Bonneville Dam is listed in Table 11 and Figure 7 (Beiningen 1976). Also indicated is the percent of the total commercial harvest of these species by Indians. This percentage has been steadily increasing and by 1975 had reached 40.6 percent of the total catch.

The available information on commercial and personal use harvest of salmon and steelhead by Indians from tributaries is summarized by Beiningen (1976). Beiningen states that records of commercial sales to licensed buyers are available "but are incomplete on other Indian fish marketing practices, and are virtually non-existent on the personal use fisheries". The situation is similar for Indian commercial and personal use fisheries in Oregon. The available data on observed landings by the Colville Indians on the Okanogan River and by the Yakima Indians on the Yakima River are summarized in Table 12 (Beiningen 1976). The catch in the Okanogan River was largely of sockeye with small numbers of chinook salmon. In the Yakima River the catch is comprised mostly of chinook with small numbers of coho salmon.

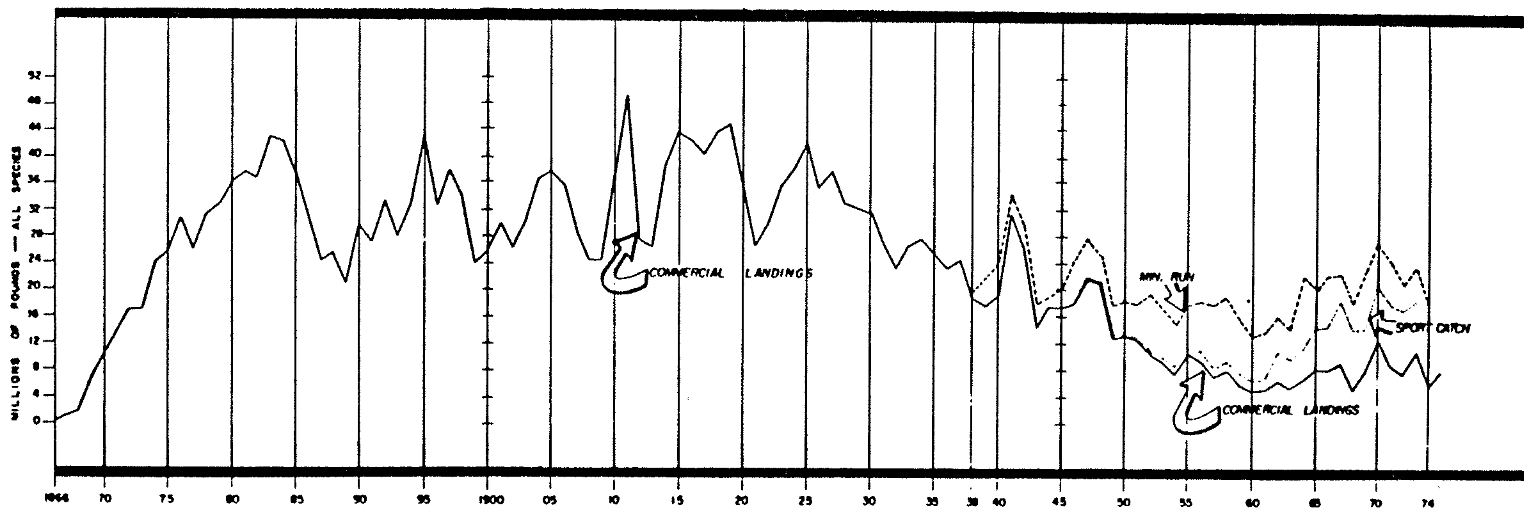


FIG 5 COLUMBIA RIVER COMMERCIAL LANDINGS, ALL SALMONID SPECIES, SINCE 1866; TOTAL MIN RUN, ALL SALMONID SPECIES, SINCE 1938; SPORT CATCHES, ALL SALMONID SPECIES, SINCE 1946, IN MILLIONS OF POUNDS.

From Beiningen, 1976

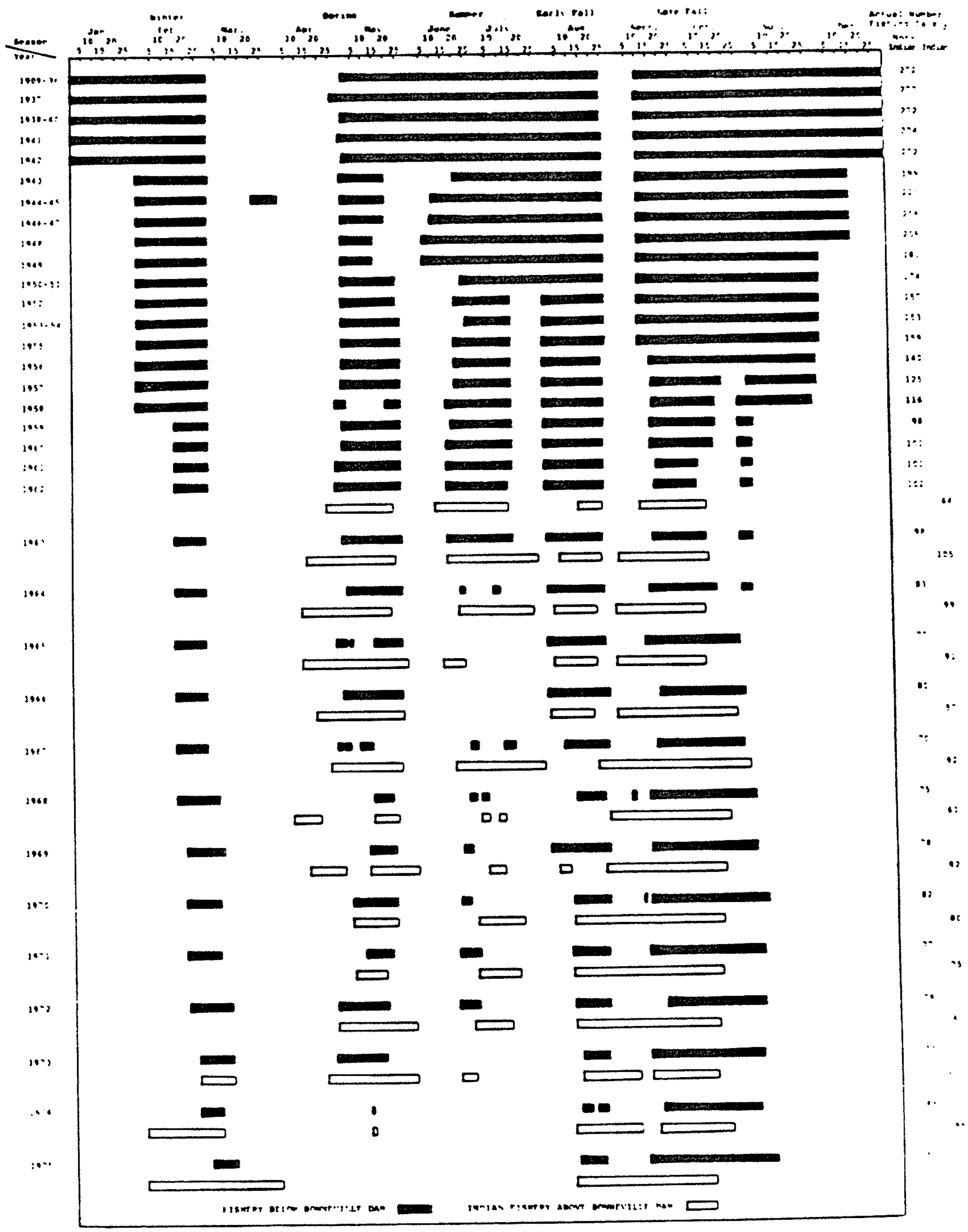


FIGURE 6 COLUMBIA RIVER COMMERCIAL FISHING SEASONS, 1909-75 (FROM [illegible] 1966 AND [illegible] ANNUAL STATUS REPORTS)

1/ Numbers are actual fishing days and not total days in periods due to weekly [illegible] [illegible] commercial fishery not established prior to 1962

From Ortmann, 1976

Table 10 Commercial catch (in thousands of fish) of upriver Columbia River stocks of salmon below Bonneville Dam, 1967-77.

Year	Chinook			Coho 1/	Sockeye
	Spring	Summer 2/	Fall		
1967	33.0	0.7	121.9	1.7	21.2
1968	13.1	1.4	50.6	10.3	20.3
1969	30.7	1.6	108.0	1.4	16.2
1970	31.4	3.1	149.6	33.5	13.0
1971	22.6	4.5	93.8	15.9	54.9
1972	69.9	3.2	96.3	9.8	51.8
1973	60.5	1.2	105.4	5.1	2.3
1974	8.4	0.0	52.2	10.1	0.0
1975	0.0	0.0	95.9	3.3	0.0
1976	0.0	0.0	33.3	1.2	0.1
1977	9.6	0.0	68.2	2.3	0.0
Average 1967-76	27.0	1.6	90.7	9.2	18.0

1/ Based on one-half the early fall season catch.
2/ Incidental catch made during the open shad and sockeye seasons.

From ODFW, 1977

Table 11. Harvest of chinook, steelhead and sockeye from the main stem Columbia, in pounds, including Indian landings and per cent Indian catch of total landings.

Year	Indian Landings				Total Landings				Per Cent Indian Catch
	Chinook	Steelhead	Sockeye	Total	Chinook	Steelhead	Sockeye	Total	
Celilo Falls									
1938	1,311,505	262,903	86,497	1,660,905	12,418,480	1,764,429	424,583	14,607,492	11.4
1939	1,087,536	186,771	71,648	1,345,955	13,498,816	1,438,499	269,813	15,207,133	8.8
1940	1,616,510	340,936	155,372	2,112,818	13,516,133	2,825,372	361,867	16,703,372	12.6
1941	3,038,244	320,506	106,179	3,464,929	23,238,468	2,663,736	505,692	26,407,896	13.1
1942	2,464,574	274,033	47,832	2,786,439	18,679,071	1,839,114	192,423	20,710,608	13.5
1943	1,548,345	214,729	27,461	1,790,535	11,426,482	1,514,466	146,084	13,087,032	13.7
1944	1,273,418	303,506	16,331	1,593,255	14,077,112	1,720,062	54,754	15,851,928	10.0
1945	941,949	302,118	3,794	1,247,861	12,972,680	1,963,507	8,693	14,944,880	8.3
1946	1,927,071	345,294	22,898	2,295,263	14,277,809	1,725,629	128,515	16,131,953	14.2
1947	2,120,552	245,575	119,624	2,485,751	17,302,661	1,649,085	718,334	19,670,080	12.6
1948	2,599,957	188,295	51,605	2,839,857	17,352,323	1,579,023	95,854	19,027,200	14.9
1949	1,011,478	211,590	12,579	1,235,647	10,767,540	814,045	23,975	11,605,560	10.6
1950	1,516,762	156,099	45,394	1,718,255	10,287,493	964,981	169,160	11,421,634	15.0
1951	1,474,763	255,867	32,254	1,762,884	10,029,388	1,205,726	169,466	11,404,580	15.4
1952	1,790,658	406,961	88,212	2,285,831	7,262,438	1,464,440	608,654	9,335,532	24.5
1953	1,120,844	500,734	48,469	1,670,047	6,929,823	1,908,643	116,193	8,984,659	18.6
1954	570,477	180,675	44,942	796,124	5,312,698	1,467,496	243,374	7,023,568	11.3
1955	1,475,582	338,892	168,548	1,983,022	8,581,852	1,297,468	200,442	10,079,762	19.7
1956	634,630	170,652	105,625	910,907	8,178,509	811,809	287,058	9,277,376	9.8
19-Year Average									13.6

continued

TABLE 11 (continued)

Year	Indian Landings				Total Landings				Per Cent Indian Catch 3/
	Chinook	Steelhead	Sockeye	Total	Chinook	Steelhead	Sockeye	Total	
Above Bonneville Dam									
1957	55,949	1,227	484	57,660	5,918,902	739,610	240,142	6,898,654	0.8
1958	150,354	28,332	19,139	197,825	6,434,033	675,866	723,578	7,833,477	2.5
1959	32,090	4,769	2,595	39,454	4,594,309	672,649	635,746	5,902,704	0.7
1960	34,550	7,808	1,869	44,227	3,927,982	722,509	394,091	5,044,582	0.9
1961	116,432	14,444	397	131,273	4,160,206	715,728	158,014	5,033,948	2.6
1962	144,977	3,369	12,421	160,767	5,467,268	723,358	51,693	6,242,319	2.6
1963	544,108	64,031	28,822	636,961	4,346,055	972,160	48,362	5,366,577	11.9
1964	645,726	52,872	51,575	750,173	4,484,032	425,000	68,206	4,977,238	15.1
1965	873,455	104,472	22,629	1,000,556	6,142,931	510,055	22,903	6,675,889	15.0
1966	203,147	14,760	16,648	234,555	3,612,185	393,329	17,269	4,022,783	5.8
1967	1,020,507	135,505	118,209	1,274,221	4,974,125	445,250	195,157	5,614,532	22.7
1968	766,312	86,976	17,162	870,450	4,077,105	427,499	89,553	4,594,157	18.9
1969	1,364,068	141,781	42,489	1,586,752	5,775,874	490,339	104,478	6,370,691	24.9
1970	956,899	115,522	13,039	1,085,460	6,461,690	310,368	55,697	6,827,755	15.9
1971	1,201,290	228,584	77,512	1,507,386	5,967,229	467,507	285,628	6,720,364	22.4
1972	1,341,802	323,584	88,706	1,754,092	5,684,644	667,085	275,582	6,627,311	26.5
1973	1,717,184	296,744	6,058	2,019,986	8,552,374	634,110	15,880	9,202,364	22.0
1974	1,235,157	116,472	185	1,351,814	3,628,500	185,403	185	3,814,088	35.4
1975 2/	2,482,859	51,810	---	2,534,669	6,191,117	---	---	6,242,927	40.6

1/ This table does not include commercial landings of coho and chum salmon which in some years are caught in considerable numbers by the non-Indian fishery below Bonneville Dam but are not caught in significant numbers by the Indian fishery above Bonneville Dam.

2/ Landing data for 1975 are preliminary.

3/ Substantial numbers of chinook salmon in "Total Landings" are produced below Bonneville Dam and are not returning to the Indians' usual and accustomed fishing areas. Therefore, the percentage of "common stocks" caught is much higher than figures in this column.

From Beiningen, 1976

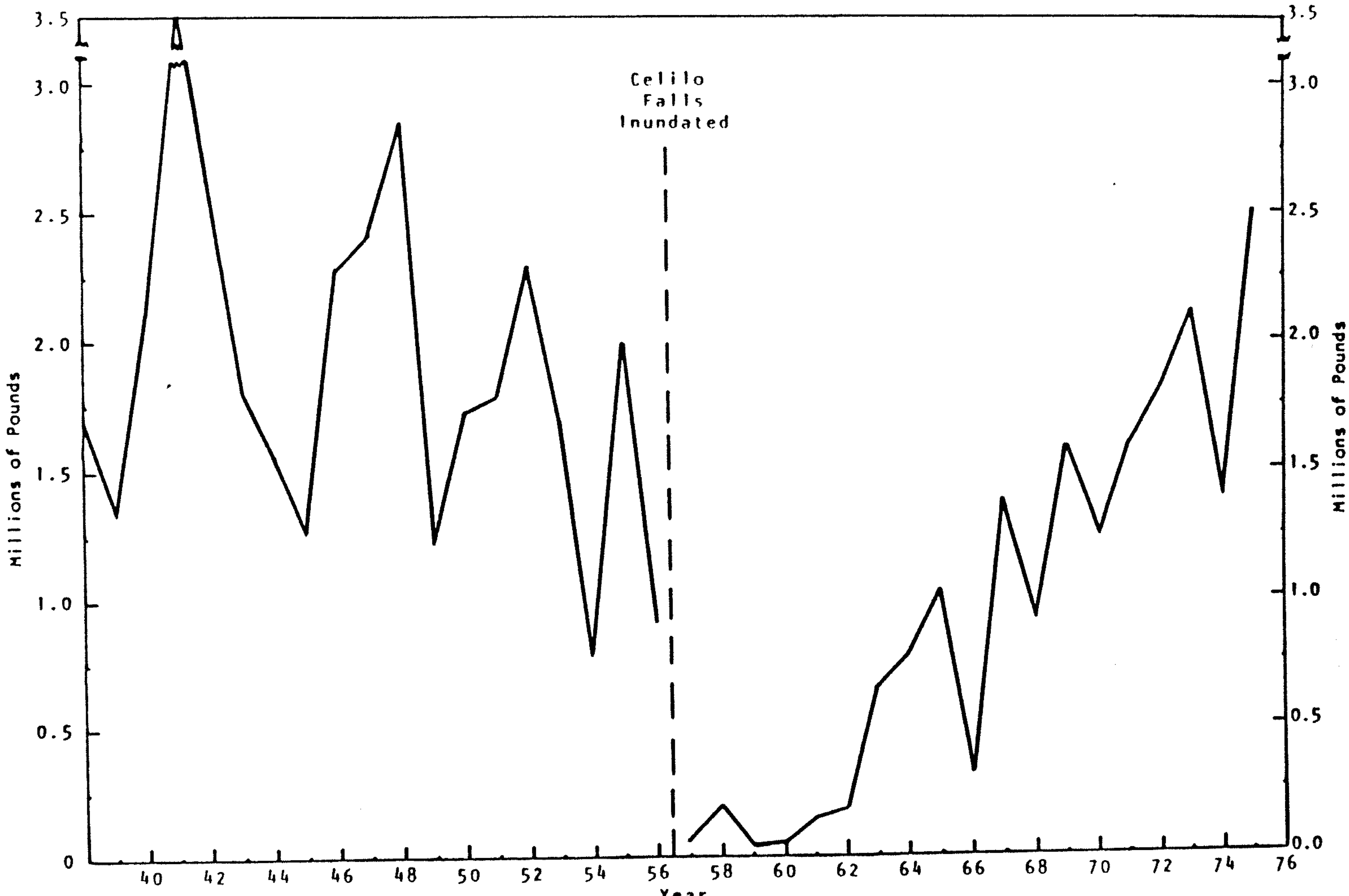


Figure 7. Total Commercial Landings of Salmon and Steelhead Made by Indians Fishing with Dip Nets at Celilo Falls 1938-56 and With Set Nets Above Bonneville Dam, 1957-75

From Beiningen, 1976

Table 12. Numbers of fish taken by Indians in the Okanogan and Yakima Rivers.

	Okanogan		Yakima	
Year	Sockeye	Chinook	Chinook	Coho
1947	5,000		---	---
1948	5,000		---	---
1949	500		---	---
1950	2,500		---	---
1951	5,000		---	---
1952	3,000		---	---
1953	4,500		1,600	300
1954	3,900		3,400	300
1955	4,600		1,900	400
1956	3,600		1,400	500
1957	3,600		7,900	200
1958	500		4,400	300
1959	600		3,700	100
1961	200		5,000	200
1962	200		4,200	300
1963	200		3,000	---
1964	200		3,200	---
1965	300		1,800	---
1966	500		4,800	---
1967	7,500	---	3,200	---
1968	2,500	100	2,400	---
1969	300	150	600	---
1970	400	100	1,500	---
1971	1,200	100	1,200	---
1972	1,300	70	500	---
1973	900	40	3,200	---
1974	800	---	1,800	---

Data from Investigative Reports of The Columbia River Fisheries Program. Report R by Beiningen, 1976.

Shad, Sturgeon, Smelt

Shad

American shad were introduced into the Columbia River in the 1870's and have since flourished. Annual migrations upriver were limited to below Celilo Falls until 1957 when the Celilo Reservoir inundated the falls and permitted shad to extend upriver over 400 miles. Shad now spawn and rear successfully in reservoirs of the lower and middle Columbia River. The runs through the Bonneville Dam fish passage facility exceeded 617,000 in 1965 (1977 Annual Report, ODFW); however, the total upstream migration is considerably greater than this number as many pass Bonneville Dam uncounted through the navigation lock. Shad counts in 1978 exceeded 860,000 at Bonneville and 1,200,000 at the Dalles (USACOE, Annual Fish Passage Rept., 1978).

Before 1965, shad were harvested during the salmon fishing seasons in June and July, but since summer fishing was terminated in 1964 to protect the summer chinook stocks, shad have been harvested during short shad and sockeye seasons. Approximately 63,000 shad were harvested by all commercial fisheries in 1977 (1977 Annual Report, ODFW).

Sturgeon

White sturgeon (*Acipenser transmontanus*) and green sturgeon (*Acipenser medirostris*) occur in the main stem Columbia River. White sturgeon are sought primarily, both by commercial and sport fishermen, because of their better flavor. Sturgeon were plentiful in the Columbia River until the early 1900's when overfishing depleted the number of spawners. Size limits were subsequently imposed which protected the mature fish and the stocks have since increased to relatively healthy levels.

Before 1975 most commercially caught sturgeon in the Columbia River were taken incidentally by the salmon net fisheries below the Bonneville Dam site. Landings of white and green sturgeon combined during the past 10 years have averaged about 8,400. Since 1975, a severe curtailment of salmon net fisheries to protect summer-run chinook salmon has caused the commercial salmon net fishery to turn to setlining. The present annual catch of about 9,000 is considered an indication of good health of the sturgeon population (1977 Annual Report, ODFW). Approximately 500 sturgeon were landed by the Indian fisheries above Bonneville Dam in 1977. Green sturgeon do not ascend above Bonneville Dam; however, residual populations may be landlocked in some reservoirs of the lower-, mid-, and upper-Columbia River.

Smelt

The commercial catch of smelt (*Thaleicthys pacificus*) (eulachon) from the Columbia River and tributaries from 1967 to 1977 is listed in Table 13 (1977 Annual Report, ODFW). The catch has averaged 1,757 pounds annually during the past decade with a narrow range of variability.

Table 13. Commercial landings (in thousands of fish) of sturgeon, shad, and smelt from the Columbia River by non-Indian and Indian fisheries, 1967-77.

Year	Sturgeon 1/ White Non-Indian	Sturgeon 1/ White Indian	Sturgeon 1/ Green	Shad Non-Indian	Shad Indian	Smelt 2/ (Pounds)
1967	3.8	0.2	1.3	221.8	5.7	1,000.8
1963	3.5	0.3	0.7	81.5	1.4	948.5
1969	7.3	0.4	2.0	45.5	2.1	1,090.1
1970	6.3	0.4	1.5	59.1	6.4	1,198.9
1971	7.0	0.8	1.5	40.3	6.7	1,761.7
1972	7.4	0.8	1.3	55.3	4.9	1,643.5
1973	9.7	1.0	1.0	49.1	4.8	2,434.4
1974	8.6	0.7	3.5	45.9	3.6	2,351.2
1975	11.4	0.7	1.2	64.5	8.5	2,071.7
1976	18.3	0.6	2.6	60.9	19.5	3,060.1
1977	9.0	0.5	0.7	62.4	0.6	1,812.5
Average (1967-76)	8.4	0.6	1.7	72.3	6.4	1,757.1

1/ Numbers of white sturgeon based on 40 lb./fish average weight; green sturgeon 35 lb./fish average weight.
2/ Total landings from Columbia River and tributaries.

From ODFW, 1977

Sport Fishery

Management

The sport fisheries of the Columbia River are managed by four States Agencies and five Indian tribes in waters contiguous to state and reservation lands. In Washington, the Washington Department of Fisheries (WDF) manages salmon, shad, smelt and sturgeon, while the Washington Department of Game (WDG) manages steelhead, searun cutthroat, and resident trout. The management of all fish species is accomplished in Idaho by the Idaho Department of Game (IDG) and in Oregon by the Oregon Department of Fish and Wildlife (ODFW). In addition, the Confederated Tribes of Warm Springs Reservation manage the sport fishery on reservation lands in Oregon as do the Yakima and Colville Tribes on reservation lands in Washington.

Season and area closures are promulgated to protect the seaward migrations of salmon and steelhead smolts, and the spawning escapements of returning adults. Virtually all catch information available in the literature pertains to salmon and steelhead. Sport angling for non-salmonid species on the main stem Columbia River and on the lower reaches of tributaries is either relatively minor or is not censused systematically. Catch and effort statistics should be developed for each reservoir and tributary stream.

Coastal fishery

The harvest of chinook and coho salmon by the coastal sport fishery has increased tremendously in the past 15 years. The proportion of commercial versus sport catch in the ocean fishery has shifted since the early 1960's from a ratio of 90/10 to 67/33 (Beiningen 1976). Recreational fishing at the mouth of the Columbia River was reported as early as 1906 but was insignificant until recently. Oregon and Washington began compiling comprehensive catch statistics in the early 1960's.

Main stem Columbia River

A developing sport fishery for walleye (*Stizostedion vitreum*) exists on Roosevelt Lake. A description of this fishery in 1973 was reported by Nielsen (1975). The walleye catch was estimated at 12,800 and catch per angler-hour was 0.4. The walleye fishery appears to have good potential for continued development in Roosevelt Lake and other reservoirs of the main stem Columbia River because spawning and food requirements are compatible with prevailing conditions, namely rising water levels during April and May when spawning occurs, and an abundance of juvenile cyprinids and catastomids for forage.

A minor bank fishery exists on Roosevelt Lake for rainbow and kokanee during late winter and early spring but no catch statistics are available.

The sport catch of salmon and steelhead on the main stem Columbia River above Bonneville is summarized in Table 14 (adapted from 1977 Annual Report, ODFW). The total sport catch of salmonids has not exceeded 5,000 during any year from 1968 to 1978. The average catches of spring and fall chinook have been approximately equal and less than 500. The annual coho catch is negligible. The summer steelhead was the most important sport species during this period; catches averaged 1402 fish annually.

Angling for shad occurs primarily below Bonneville Dam; however, accurate catch estimates are unavailable because sampling effort is lacking. Sport catch estimates below Bonneville Dam ranged between 10,000 and 15,000 in 1974, 1975, and 1976, and 2,800 in 1977. No catch was reported above Bonneville Dam (1977 Annual Report, ODFW).

Angling for sturgeon concentrates mainly below Bonneville Dam. No catch data are reported in the literature for the lower and mid-Columbia. Increasingly good fishing in the past few years has attracted considerable angler interest. The sport catch of white sturgeon in 1977 was estimated at 22,800 (1977 Annual Report, ODFW).

Angling for smelt occurs below Bonneville Dam. Records of sport catch are unavailable.

Yakima River

No catch and effort statistics for the sport fishery were reported in the literature surveyed. References mentioned a summer fishery for rainbow trout and a winter fishery for mountain whitefish (*Prosopium williamsoni*) but no statistics were given. Legal-size rainbow trout are stocked annually into feeder streams of the Yakima River during the summer trout season. No sport catch of salmon or steelhead is reported in the available literature.

Okanogan River

Angling for rainbow trout occurs in tributary streams during the summer but no catch or effort statistics were located. The Okanogan River is closed to angling for salmon and steelhead.

Umatilla River

The Umatilla River supports a modest sport fishery for summer-run steelhead. The sport catch during the period 1968 to 1978 is reported in 1977 Annual Report, ODFW, as follows:

Year	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Catch	775	803	1,307	735	1,913	326	338	379	116	354

In addition, legal-size rainbow trout are stocked annually in the Umatilla River. In 1977, approximately 9,000 rainbow trout were planted in a 20-mile reach. An additional 46,000 fingerling rainbow trout were stocked into an area which was rehabilitated in 1974. Several ponds of the Umatilla River Basin are managed for put-and-take trout fishing (1977 Annual Report, ODFW).

Table 14. Sport catch of salmon and steelhead on main stem Columbia River above Bonneville Dam, 1968-78.[1]

Year	Spring Chinook	Summer Chinook	Fall Chinook	Coho	Summer Steelhead	Winter Steelhead
1968-9	600	0	300	17	3470	0
1969-0	500		300	15	1655	
1970-1	700		600	29	1943	
1971-2	174		589	18	1829	
1972-3	653		417	18	1716	
1973-4	1010		358	17	1568	
1974-5	199		274	10	825	
1975-6	18		578	22	0	0
1976-7	16		333	13	0	41
1977-8	727	0	311	0	1018	4
$\bar{x}$ =	459.7		406.0	14.1	1402.4	

[1]Adapted from ODFW, 1977.

HATCHERIES

History

The first hatchery on the Columbia River was built in 1876 by the Oregon and Washington Fish Propagating Co. (Cobb 1921). As a measure of the early-day concern for declining Columbia River salmon runs, at least 24 hatcheries were operating in Oregon and Washington by State and Federal Governments and by private industry by 1907. Through 1910 over 550,000,000 chinook, coho, and steelhead had been stocked in Columbia Basin streams. These early hatcheries were never evaluated, but it is generally believed that the production of adults was low because of the practices of planting fry into areas that were not favorable for survival.

Present Status

The number of hatcheries declined during a period of severe criticism of their value. This was followed by the general acceptance of hatcheries as mitigation for the construction of dams. There was no other available recourse and as the technology of fish culture improved, they were gradually accepted. By 1974, 44 hatcheries in Washington, Oregon, and Idaho were producing 170,000,000 salmon and steelhead annually (Ortmann *et al*. 1976).

Although hatcheries have existed on the Columbia River for 100 years, effective production has been achieved only since about 1960 (Ortmann *et al*. 1976). Improved aquaculture practices include developments in diet, disease control, engineering and the matching of artificial rearing with the natural life histories of the species and races.

Hatcheries are operated by the Washington Department of Fisheries (WDF), the Washington Department of Game (WDG), the Oregon Department of Fish and Wildlife (ODFW), the Idaho Department of Fish and Game (IDFG), and the United States Fish and Wildlife Service (USFWS). Financial support is provided by the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, National Marine Fisheries Service (NMFS), and hydroelectric companies or Public Utility Districts (PUD).

The NMFS supports operation of 21 hatcheries and 6 rearing ponds in the Columbia and Snake Rivers. In Fiscal Year (FY) 1975, $4,754,800 was spent on operation of these hatcheries which produced about half of all salmon and steelhead in the Columbia Basin.

The USFWS operates 11 anadromous fish hatcheries which produce 60,000,000 salmon and steelhead fingerlings annually. A salmon Cultural Development Center, Longview, Washington, is maintained to research improvements in fish culture technology.

State agencies operated 58 rearing sites in FY 1974, including 35 hatcheries and 13 ponds. Additional salmon and steelhead were reared at trout hatcheries.

Washington Hatcheries

Salmon and steelhead are produced for the Columbia River in 16 hatcheries and 8 rearing ponds including those below Bonneville. Additional steelhead are produced in trout hatcheries. The primary and secondary purposes of the hatcheries are to enhance existing runs and to mitigate lost or depressed runs (Table 15).

Oregon Hatcheries

Oregon operates 14 hatcheries and 4 rearing ponds which produce salmon and steelhead for the Columbia River. Primary and secondary purposes of the hatcheries are to enhance existing runs and to mitigate lost or depressed runs (Table 15).

Production

Hatcheries producing salmon and steelhead smolts in the lower and mid-Columbia River in 1974 are listed in Table 15. The principal species and races produced by these hatcheries are spring and fall chinook and coho salmon and steelhead trout. Summer chinook are produced by two hatcheries on the Deschutes River and by three hatcheries on tributaries to the Columbia River. Chum salmon are produced at only the Little White Salmon Hatchery above Bonneville.

Most hatchery production occurs at Bonneville Pool and below (Table 16). From a total fingerling production of nearly 5,783,000 pounds in 1974, about 988,000 pounds (17 percent) was produced on the Snake River system, about 566,000 pounds (10 percent) was produced in the middle Columbia River system above the confluence of the Snake River, and about 4,228,000 pounds (73 percent) was produced by hatcheries below the confluence of the Snake River. Most production from below the Snake River was from hatcheries below Bonneville. The hatcheries below Bonneville experience the highest yields because they do not contend with mortalities associated with fingerling and adult passage at the dams.

In terms of numbers of smolts, the 1974 plantings totaled 18,000,000 spring and summer chinook, 93,800,000 fall chinook, 29,100,000 coho, and 19,000,000 steelhead.

A more detailed listing of present hatchery plantings in numbers of fish to specific tributaries was compiled from 1977 annual reports of the WDF and the ODFW (Table 17). The bulk of hatchery-produced chinook and coho salmon are released into tributaries of the lower Columbia River. No plantings of salmon or steelhead were reported for the Umatilla and Okano-

Table 15. Hatcheries of the lower and middle Columbia River and of tributary streams, excluding the Snake River, and species produced, 1974.

Name	Location	Operating Agency	Spring Chinook	Summer Chinook	Fall Chinook	Coho	Steelhead	Chum
Lower Columbia River								
Carson N.F.H.	Wind R.	USFWS	x		x	x	x	
Eagle Cr. N.F.H.	Eagle Cr.	USFWS	x		x	x	x	
Little White Salmon N.F.H.	Little White Salmon R.	USFWS	x		x	x		x
Spring Cr. N.F.H.	Spring Cr.	USFWS			x	x		
Willard N.F.H.		USFWS	x		x	x		
Klickitat Salmon H.	Klickitat R.	WDF	x		x	x		
Skamania Trout H.	Wind R.	WDG			x		x	
Cascade F.H.	Columbia R.	ODFW				x		
Oxbow F.H.	Herman Cr.	ODFW			x	x		
Oak Springs H.	Deschutes R.	ODFW		x				
Round Butte H.	Deschutes R.	ODFW	x	x			x	
Middle Columbia River								
Ringold Salmon Pond	Columbia R.	WDF	x		x	x		
Ringold Trout Pond	Columbia R.	WDG					x	
Wells H.	Columbia R.	PUD	x				x	
Rocky Reach H.	Columbia R.	PUD				x		
Priest Rapids H.	Columbia R.	PUD			x			
Columbia Basin H.	Crab Cr.	WDG					x	
Chelan H.	Columbia R.	PUD					x	
Naches H.	Yakima R.	WDG					x	
Yakima H.	Yakima R.	WDG					x	
Entiat N.F.H.	Entiat R.	USFWS	x	x				
Leavenworth N.F.H.	Wenatchee R.	USFWS	x	x				
Winthrop N.F.H.	Methow R.	USFWS		x				

Modified from Investigative Reports of The Columbia River Fisheries Project. Report M by Ortmann et al. 1976.

Table 16. Location and pounds planted of salmon and steelhead in the lower and mid-Columbia River and tributaries, excluding the Snake River, 1974.

	Species and Race				
Location planted	Coho	Spring Chinook	Summer Chinook	Fall Chinook	Steelhead
Lower Columbia River					
Deschutes R.		20,899			
Klickitat R.	41,104	71,520		17,346	
Bonneville Pool	173,470	145,098		293,327	
Middle Columbia River					
Wells Dam	18,375		49,632		8,895
Rocky Reach	40,823				
Wenatchee R.	40,228	24,754			
Priest Rapids				36,234	
Ringold		136,288		123,750	44,095
Other					43,364

Modified from Investigative Reports of The Columbia River Fisheries Project. Report M by Ortmann et al. 1976.

Table 17. Hatchery plantings of salmon and steelhead to main stem and tributaries of lower and middle Columbia River, Umatilla River, Yakima River and Okanogan River by agency and species, 1977.

Agency	Planting location (Reach)	Species	Brood year	Fingerlings	Yearlings
Lower Columbia River (excluding Snake R.)					
USFWS	Col. R. (Wind-White Sal.)	fall chin.	76	14,435,436	3,915,686
		coho	75		1,446,240
	Wind R.	spr. chin.	75		2,812,853
	Big White Salmon	fall chin.	76	2,899,442	
	Little White Salmon	fall chin.	76	11,570,511	
		coho	75		238,350
		coho	76	3,300,000	
	Drano Lake	coho	76	145,800	
WDG	Walla Walla R.	steelhead	76		36,734
	Wind R.	steelhead	76		76,933
	Klickitat R.	steelhead	76		101,968
		steelhead	77	6,579	
WDF	Klickitat R.	spr. chin.	75		600,284
		spr. chin.	76	315,470	
		fall chin.	76	1,517,992	
		coho	75		1,014,014
		coho	76	112,757	415,455
	Cunningham Cr.	coho	76	73,381	
	W. Fk. Klickitat	spr. chin.	76	58,032	
	Diamond Fk. Cr.	spr. chin.	76	21,744	
ODFW	Deschutes R.	steelhead	76	504,401	
		spr. chin.	75		135,340
		coho	76	252,475	
	Hood R.	steelhead	76	159,215	
Middle Columbia River					
WDG	Col. R. (Esquatzel Coulee)	steelhead	76		158,163
	Lower Crab Creek	steelhead	76		4,334
	Methow R.	steelhead	76		147,982
	Col. R. (Alkali-Squilchuck)	steelhead	76		48,445
	Wenatchee R.	steelhead	76		74,525
	Icicle Cr.	steelhead	76		32,414
	Entiat R.	steelhead	76		45,011
	Col. R. (Chelan)	steelhead	76		68,703
WDF	Col. R. (Esquatzel Coulee)	spr. chin.	75		124,000
		fall chin.	76	1,226,061	
	Col. R. (Alkali-Squilchuck)	coho	75		584,257

Table 17 (Continued)

WDF	Col. R. (Chelan)	spr. chin.	75	750,453	94,353
	Lake Chelan	fall chin.	76	40,207	83,600
	Sanpoil	fall chin.	76		74,889
	Col. R. (Lake Roosevelt)	fall chin.	76	56,337	
Umatilla River					
ODFW	--No salmon or steelhead plantings reported--				
Yakima River					
WDG	Yakima R. (lower)	steelhead	76		51,970
	Naches R.	steelhead	76		5,600
	Yakima R. (lower)	spr. chin.	75		13,300
WDF	Naches R.	coho	76	173,600	
	American R.	coho	76	179,800	
	Little Naches R.	coho	76	173,600	
	Yakima	coho	76	502,200	
Okanogan River					
	--No salmon or steelhead plantings reported--				

Data from: 1. Oregon Dept. Fish and Wildlife, 1977 Annual Report, Fisheries.

2. Washington State Dept. Fish Prog. Rep. No. 77.

gan Rivers in 1977. Moderate numbers of yearling steelhead, small numbers of spring chinook and moderate numbers of fingerling coho are released in the Yakima River system. Releases into tributary streams of the middle Columbia River include moderate numbers of steelhead and small numbers of chinook and coho. Small numbers of chinook also were planted near Grand Coulee Dam.

Survival and Harvest

The first large-scale evaluation program to determine the contribution of hatchery-reared salmonids to the fisheries was undertaken in 1962. An analysis of preliminary data for fall chinook was made by Cleaver (1967). An analysis of more complete data was reported by Worland, Wahle, and Zimmer (1969) and summarized by Ortmann *et al*. (1976). In all, 30,900,000 chinook were released at 12 hatcheries during a four-year period. The returns were monitored for six years in the ocean and Columbia River sport and commercial fisheries, at the hatcheries, and at spawning grounds. The catch distribution of 289,325 hatchery chinook from the 1961 brood year was as follows:[1]

Fishery	Number Returned	Percent of Returns
Ocean sport	43,680	15.2
Ocean commercial	158,036	55.0
Columbia R. sport	305	0.1
Columbia R. commercial	85,305	29.7

The ratio of catch to escapement was estimated at 8.5:1. The returns indicated that 3.97 hatchery-produced chinook were caught for every 1000 fingerling chinook released.

A more detailed distribution was determined for the hatchery brood years 1962 through 1965, as shown in Table 18.

Of special interest in these statistics is the high catch rate of Columbia River fall chinook by the Canadian troll fishery (33.7 percent), and the nearly equal division of catch off the Washington Coast by the sport and commercial fishery (18.6 and 19.3 percent, respectively).

The hatchery evaluation study was extended in 1965 and 1966 to include the release of 4,100,000 marked coho salmon fingerlings at 20 hatcheries. The returns were monitored for three years and evaluated by Wahle, Vreeland, and Lander (1974). The returns indicated that 55 coho were caught for every 1000 fingerlings released. The catch distribution of

[1]Source: IRCRFP - Report in Ortmann *et al*.

Table 18. Distribution of returns to commercial and sport fisheries from marked fall chinook salmon released from hatcheries on the Columbia River during 1962 through 1965.

Ocean Fisheries	Type of Fishing	No. of Fish Caught	Percent
Southeast Alaska	Commercial	2,416	0.2
British Columbia	Commercial	460,952	33.7
Washington	Sport	255,230	18.6
	Commercial	264,688	19.3
Oregon	Sport	22,437	1.6
	Commercial	39,390	2.9
California	Sport	371	.0
	Commercial	5,145	0.4
River Fisheries	**Type of Fishing**	**No. of Fish Caught**	**Percent**
Columbia River	Sport	803	0.1
	Gillnet	255,331	18.7
	Indian	61,442	4.5
TOTAL		1,368,205	100.0

Data from: Investigative Reports of The Columbia River Fisheries Project. Report M by Ortmann et al. 1976.

2,116,067 marked hatchery coho from the 1965-1966 brood years is listed in Table 19.

The relatively low catch rate of Columbia River coho by the Canadian troll fishery (5.9 percent) was compared with the catch rate of fall chinook (33.7 percent), and the high catch rate of coho by the Oregon troll fishery (29.4). As with fall chinook, the catch of coho off the Washington Coast was divided equally between sport and commercial trollers (16.4 and 16.8, respectively).

The catch distribution of hatchery-produced salmon and steelhead expressed as percent of releases is summarized in Table 20 (Ortmann et al. 1976). In this table Ortmann distinguishes between fall and spring chinook and includes information on steelhead. Because the catch data are expressed as percent of release, the information represents an important evaluation of hatchery production in the Columbia River. However, the statistics were preliminary when published and should be verified or corrected as necessary. The combined commercial and sport catch by all coastal fisheries was 1.0 percent for fall and spring chinook, 5.6 percent for coho, and 2.5 percent for steelhead.

A recent preliminary evaluation of hatchery production in Oregon, including the Columbia River, was made by Gunsolus (1978). Gunsolus noted that the return of coho to Oregon and Columbia River fisheries has leveled off in spite of increased hatchery production. The average yield of adults from the annual release of 20-30 million smolts from 1960 to 1967 was as large as that obtained from the annual release of 30 to 40 million smolts after 1967 (Figs. 14 and 15). The survival pattern of upriver spring chinook has leveled off. The reason for this is unclear and is proposed for study.

Table 19. Distribution of returns to commercial and sport fisheries from coho salmon released from hatcheries on the Columbia River during 1965, 1966.

Ocean Fisheries	Type of Fishing	No. of Fish Caught	Percent
British Columbia	Commercial	123,839	5.9
Washington	Sport	347,093	16.4
	Commercial	355,941	16.8
Oregon	Sport	197,608	9.3
	Commercial	621,019	29.4
California	Sport	16,815	0.8
	Commercial	196,757	9.3
Freshwater Fisheries	**Type of Fishing**	**No. of Fish Caught**	**Percent**
Columbia River	Sport	20,205	1.0
	Commercial	223,741	10.6
	Indian	11,049	0.5
TOTAL		2,116,067	100.0

Data from: Investigative Reports of The Columbia River Fisheries Project. Report M by Ortmann et al. 1976.

Table 20. The percentage of Columbia River hatchery salmon and steelhead releases which were harvested by Pacific Coast fisheries by state or province by fishery type.

	Catch/Release Ratio in Percent (Preliminary)											
	Alaska	B.C.	Washington		Oregon		California		Columbia River			Pacific Coast
Species	Comm.	Comm.	Sport	Comm.	Sport	Comm.	Sport	Comm.	Sport	Comm.	Ind.	Total
Fall chinook	.002%	.337%	.186%	.193%	.016%	.029%	0	.004%	.001%	.187%	.045%	1.0%
Spring chinook	.21%	.28%	.01%	.12%	0	.03%	0	.02%	.13%	.13%	.18%	1.0%
Coho	0	.33%	.92%	.94%	.52%	1.64%	.05%	.52%	.06%	.59%	.03%	5.6%
Steelhead (1)	0	0	0	0	0	0	0	0	2.5%	0	0	2.5%

(1) Steelhead returning to hatcheries or streams below The Dalles Dam.

Data from Investigative Reports of Columbia River Fisheries Project. Report M by Ortmann et al. 1976.

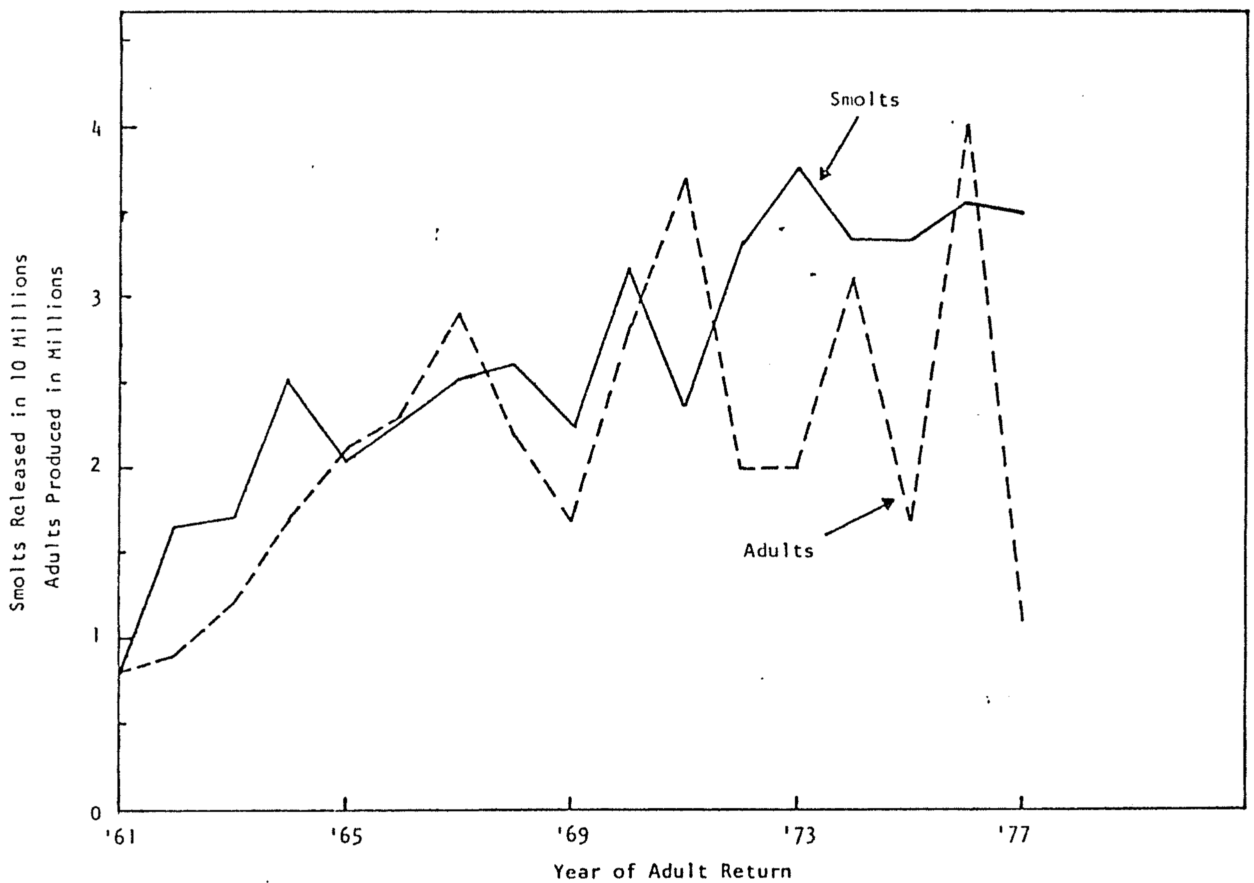


Fig 8. Comparison of Hatchery Smolts Released and Adults Produced 1 Year Later

From Gunsolus, 1979

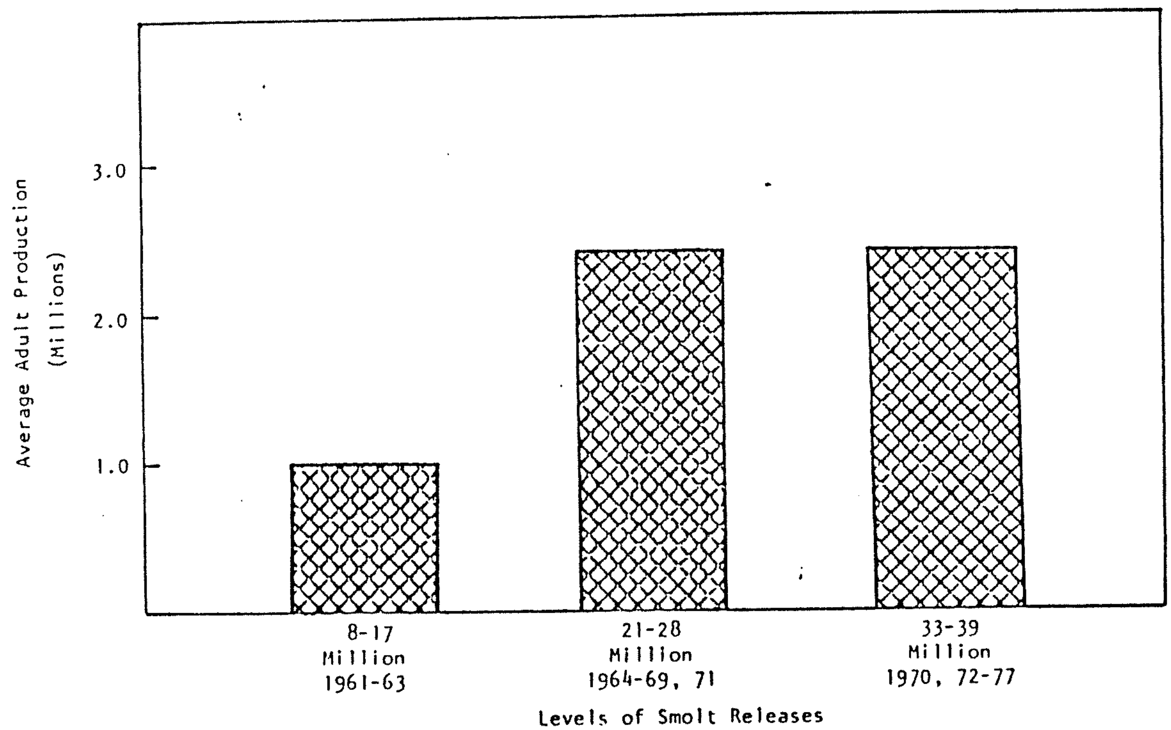


Fig **9.** Comparison of Average Adult Coho Production and Level of Hatchery Smolt Releases 1961-77

From Gunsolus, 1979

BIOLOGICAL COMMUNITIES OF MAIN STEM RESERVOIRS

Introduction

This chapter considers the biological communities of the eleven U.S. reservoir systems on the Columbia River and is divided into two parts. Part I describes the aquatic productivity of the reservoirs, and Part II, the fish populations. The ecosystem is described for storage projects (Roosevelt Lake, Umatilla Lake), and run-of-the-river projects (mid- and lower Columbia projects). Where data are available on specific projects an attempt is made to relate the biological communities to reservoir morphometry and existing water management characteristics.

Some generalizations are appropriate regarding the classification of dams on the Columbia which may either be storage or run-of-the-river. Storage projects provide more short-term habitat stability as water is retained for longer periods of time; however, they have large annual water level fluctuations. In contrast, the run-of-the-river dams control the flow of the river with little capability for extended water retention. The ecologies of the two types are different.

The literature on reservoir ecology is extensive and appears in a wide range of varied journals, reports from agencies, and books. Baxter (1977) has reviewed the literature on the environmental effects of dams and impoundments, providing an extensive bibliography on the topic.

Reservoirs vs. Natural Lakes. As previously noted, the Columbia River is now essentially a series of reservoirs extending from Lake McNaughton in British Columbia to the Bonneville pool in Washington. Several characteristics are common to each of the reservoirs. When artificial impoundments are constructed on rivers, their shape is generally different from natural lakes (Hutchinson 1966). Shoreline development is almost always higher than for natural lakes and the shapes of their longitudinal profiles differ (Baxter 1977). Natural lakes are usually deepest near the center, while artificial reservoirs are deepest just upstream from the dam. Therefore, surface currents passing down the reservoir will not dissipate themselves in shallow water as they do in natural lakes, but may be deflected downward or be reflected backward at the dam.

The initial shoreline formed by an impoundment is one of submergence (Johnson 1977) which will not persist. By the physical processes of waves, currents and ice, it will be modified and eventually the shoreline development will be reduced (Baxter 1977).

Although natural lakes are influenced by the same processes, reservoir shoreline modification occurs at an accelerated rate due to drawdown strategies which expose larger areas to the effects of these processes (Baxter 1977). Sloughing of reservoir banks have generated seiches up to 65 ft in Roosevelt Lake (Jones and Peterson, no date) which tend to occur during periods of unusually low water levels.

Sedimentation. Materials eroded from the banks of a reservoir tend to deposit and accumulate. The location of deposition is determined by the morphometry of the lake and the water currents (Baxter 1977). If the bottom has only a slight gradient and strong currents along the shore, the material may be deposited near shore, forming spits or sand bars. If the bottom incline is steep and nearshore currents weak, the debris will be carried to the deeper portions of the reservoir and deposited.

Physical Limnology. In run-of-the-river projects the annual storage ratio or flushing rate is minimal in comparison to the storage impoundments. Therefore, circulation in run-of-the-river reservoirs is generally dominated by near-field effects (e.g., those associated with the inflow and outflow) rather than by far-field effects (e.g., thermal circulation and wind-generated currents) that prevail in storage and natural lakes (Baxter 1977). Thermal stratification has been documented only in Roosevelt Lake (Jaske 1965; Stober et al. 1977).

The discharge usually occurs from a point well below the surface and may occur simultaneously at more than one level, thus causing currents atypical of natural lakes. If the water is stratified, the discharge will be drawn from a layer at the level of the outlet inducing internal currents (withdrawal currents) with the net result of little vertical movement (Baxter 1977).

Density currents may be established in storage reservoirs as a result of inflowing water having a different temperature and/or sediment load from the standing water (Baxter 1977) and mixing occurs at some point downstream in the reservoir. A line of convergence is established when the inflowing water plunges below the surface (Baxter 1977) and a resultant upstream current is generated carrying the sediment load back upstream. Where the two currents meet, the debris is immobilized and may precipitate out. Jaske (1965, 1966) and Jaske and Snyder (1967) discuss the apparent density-flow regime of Roosevelt Lake. It is unlikely that density currents of any significant magnitude are developed in run-of-the-river projects.

Chemical Limnology. Chemical composition of reservoir waters is dependent upon the chemical constituents of the inflowing water and precipitation-runoff. In mature reservoirs leaching of soluble material from the flooded basin is minimal (Baxter 1977). Generally, water in run-of-the-river projects is similar in chemical composition to the water discharged from the storage reservoirs upstream. An added dimension to the Columbia River system is the return flow from irrigation projects which discharge into Columbia River tributaries and ultimately enter the main stem itself. Perhaps the most significant tributary in this regard is the Yakima, which discharges into the upper reach of Lake Wallula of the McNary project.

In general, impoundment tends to improve water quality (Purcell 1939) by acting as a sink for suspended sediments, reducing the bacterial population, thus increasing the dissolved oxygen concentration (Baxter 1977).

In summary, the biological communities of the impoundment projects on the Columbia are related to the specific morphometry and limnology of the reservoir system which they inhabit. The following discussion will address the major factors influencing the reservoir ecology for the projects where data are available.

Aquatic Productivity

Phytoplankton. The phytoplankton of the main stem of the Columbia River have been sampled at Northport, Washington (USGS 1978), Roosevelt Lake (Stober et al. 1977), Rufus Woods Reservoir (Erickson et al. 1977), the Hanford Reach (Wolf et al. 1976), Warrendale, Oregon (USGS 1977), and at several points below Portland (Clark and Snyder 1970). Yakima River phytoplankton have been sampled near Kiona, Washington (USGS 1978). Diatoms dominated the phytoplankton communities at all locations. The dominant genera were *Asterionella, Fragillaria, Melosira, Synedra, Tabellaria,* and *Cyclotella*. The genera *Melosira, Cyclotella, Navicula*, and *Scenedesmus* were usually dominant in the Yakima River, but the blue-green alga, *Oscillatoria*, comprised over 50 percent of the phytoplankton community in September, November, and January. A complete list of phytoplankton species is contained in Table 21.

The period of peak phytoplankton abundance was in spring or early summer (April-June) and was usually followed by a secondary bloom in fall (September-October). Chlorophyll a levels during the peak were 11.1 mg/m^3 in the forebay of Roosevelt Lake (Stober et al. 1977), 10.35 mg/m^3 in Rufus Woods Reservoir (Erickson et al. 1977), 8.25 mg/m^3 at the Hanford Reach (Wolf et al. 1976), and 27.5 mg/m^3 in the lower Columbia (Clark and Snyder 1970). Chlorophyll a levels were lowest during the winter, when minimum values ranged from 0.4 mg/m^3 in Roosevelt Lake to 1.8 mg/m^3 in the lower Columbia.

Primary production has been determined in Roosevelt Lake and the Hanford Reach. Average production during the growing season (May to October) was 620 mg C/m^2/day in the forebay of Roosevelt Lake (Stober et al. 1977). The rate of carbon uptake in surface waters of the Hanford Reach was near zero from January through March. Values of up to 0.033 mg C/ℓ/hr were recorded during June and September. This maximum rate of primary production is low, and is comparable to the rate in unproductive, oligotrophic lakes (Wolf et al. 1976). Although comparison of the primary production in these two areas is probably not valid, since it represents comparison of a lentic with a lotic environment, these values represent the only data which were found.

Development of phytoplankton populations in lakes and reservoirs is strongly dependent on water retention time, or flushing rate. Density and stability of phytoplankton tend to be greatest in lakes with high retention

Table 21. Occurrence of phytoplankton genera at several locations on the main stem Columbia River and in the Yakima River.

Organism	Columbia River				
	Northport WA[1]	Rufus Woods Reservoir[2]	Hanford Reach[3]	Warrendale OR[1]	Yakima River[1]
CHLOROPHYTA (Green algae)					
Cladophora			x		
Schroederia	x				x
Ankistrodesmus	x				x
Chodatella	x				x
Dictyosphaerium	x				
Kirchneriella					x
Oocystis	x				x
Quadrangula					x
Tetraedron					x
Actinastrum		x	x		x
Pediastrum		x	x		x
Scenedesmus	x		x		x
Elakatothrix	x				
Gloeocystis	x				
Sphaerocystis	x				
Carteria	x				x
Chlamydomonas	x				x
Chlorogonium					x
Pandorina		x			x
Pteromonas					x
Cosmarium	x	x			
Closterium		x	x		
Spirogyra		x	x		
Staurastrum		x	x		
Dimorphococcus				x	
Microspora		x			
Stigeoclonium		x	x		
Coelastrum					x
Micractinium					x
Eudorina			x		
Mougeotia			x		
Characium			x		
Penium			x		
Zygnema			x		
Asterococcus			x		
Golenkinia			x		
Ulothrix			x		

continued

Table 21 - Continued

Organism	Columbia River				
	Northport WA[1]	Rufus Woods Reservoir[2]	Hanford Reach[3]	Warrendale OR[1]	Yakima River[1]
CHRYSOPHYTA (Diatoms)					
Ceratoneis			x		
Cymatopleura			x		
Rhopalodia			x		
Cyclotella	x	x	x	x	x
Melosira	x	x	x	x	x
Stephanodiscus	x	x	x		
Rhizosolenia	x		x		
Achnanthes	x				x
Cocconeis	x	x	x		x
Rhoicosphenia			x		x
Amphora	x	x			x
Cymbella	x	x	x		x
Epithemia	x	x	x		
Diatoma	x		x		x
Asterionella	x	x	x	x	
Fragilaria	x	x	x	x	x
Hannaea	x				
Synedra	x	x	x		x
Gomphonema	x	x	x		x
Meridion		x			x
Navicula	x	x	x		x
Gyrosigma		x	x		x
Nitzschia	x		x		x
Tabellaria	x	x	x		
Chrysococcus	x				
Dinobryon	x		x		x
Ochromonas	x				
Frustulia		x	x		
Amphipleura		x	x		
Pinnularia		x	x		
Surirella		x	x		
Diatomella		x			
CYANOPHYTA (Blue-green algae)					
Anabaena	x				
Anabaenopsis					x
Aphanizomenon					x
Agmenellum					x
Anacystis					x
Lyngbya			x		x
Oscillatoria	x		x	x	x

continued

Table 21 - Continued

Organism	Columbia River				
	Northport WA[1]	Rufus Woods Reservoir[2]	Hanford Reach[3]	Warrendale OR[1]	Yakima River[1]
Spirulina					x
Phormidium	x				
Rhaphidiopsis					x
Oedogonium			x		
Tolypothrix			x		
EUGLENOPHYTA					
Chroomonas	x				x
Cryptomonas					x
Euglena					x
RHODOPHYTA					
Audouinella			x		
PYRRHOPHYTA					
Glenodinum	x				
Ceratium		x	x		

[1]USGS, 1978

[2]Erickson et al., 1977

[3]Wolf et al., 1976

Table 22. Occurrence of zooplankton species at several locations on the main stem Columbia River.

Organism	Roosevelt Lake[1]	Hanford Reach[2]	McNary Reservoir[3]
CLADOCERA			
Leptodora kindtii	x	x	x
Eurycercus lamellata		x	
Sida crystallina	x		x
Diaphanosoma brachyurum	x		x
Daphnia pulex		x	
Daphnia middendorffiana		x	
Daphnia galeata mendotae	x		x
Daphnia thorata	x		
Daphnia schodleri	x		
Daphnia parvula	x		
Scapholeberis kingi	x		x
Holopedium gibberum	x		
Simocephalus serrulatus	x		
Bosmina longirostris	x	x	x
Ilyocryptus sordidus			x
Macrothrix laticornis			x
Monospilus dispar			x
Leydigia quadrangularis			x
Alona quadrangularis		x	x
Alona costata	x	x	x
Alona guttata	x	x	
Alona rectangula	x	x	
Alona rustica	x		
Pleuroxus denticulatus	x	x	x
Pleuroxus trigonellus			x
Pleuroxus aduncus			x
Chydorus sphaericus	x		x
Ceriodaphnia pulchella			x
Ceriodaphnia quadrangula	x		
COPEPODA			
Epischura nevadensis	x		x
Diaptomus ashlandi	x	x	x
Diaptomus novamexicanus	x		
Cyclops vernalis			x
Cyclops bicuspidatus thomasi	x	x	x
Mesochra alaskana			x
Canthocampus staphylinoides			x
Bryocampus zschokkei			x

[1] Earnest et al., 1966

[2] Page and Neitzel, 1976

[3] Scarola, 1968

times and lowest in lakes with short retention times (Brook and Woodward 1956; Wetzel 1975). Short retention times were detrimental to the build-up of large phytoplankton populations in Rufus Woods Reservoir, which had a maximum retention time of four days (Erickson et al. 1977). Increased water discharge also had an adverse impact on phytoplankton loss (Schulte and Lackey 1974). Reduction of the flushing rate resulted in increased chlorophyll levels in the north pool of Banks Lake, Washington, an irrigation equalizing reservoir (Stober et al. 1977). Increased irrigation withdrawal is likely to affect the retention time and influence the development of phytoplankton in the main stem Columbia River reservoirs.

The settling of organic and inorganic turbidity loads is also related to retention time (Wetzel 1975). Longer retention times allow for more settling of suspended material which suppresses phytoplankton growth by limiting light levels. Low retention times contributed to high turbidity in a Missouri River reservoir where turbidity was a limiting factor to phytoplankton abundance (Benson and Cowell 1967). At present, turbidity is not a problem in the Columbia River.

Zooplankton. The zooplankton community has been sampled at several locations along the main stem Columbia River, including Roosevelt Lake (Earnest et al. 1966; Stober et al. 1977), Rufus Woods Reservoir (Erickson et al. 1977), the Hanford Reach (Page and Neitzel 1976), McNary Reservoir (Scarola 1968), and the lower Columbia below Portland (Clark and Snyder 1970). The cladocerans *Bosmina longirostris* and *Daphnia* sp., and the copepods *Cyclops bicuspidatus* and *Diaptomus ashlandi*, were the dominant species at all locations. A complete species list is contained in Table 22.

Zooplankton densities were generally low, except during the period of peak abundance, which varied from June to September at the different sampling locations. Maximum densities were 50,000 organisms/m^3 (Earnest et al. 1966) and 60,000/m^3 (Stober et al. 1977) in Roosevelt Lake, 25,195/m^3 in Rufus Woods Reservoir (Erickson et al. 1977), 12,000/m^3 at the Hanford Reach (Page and Neitzel 1976), and 12,500/m^3 in the lower Columbia (Clark and Snyder 1970). The maximum densities in Roosevelt Lake are comparable to the maximum density of 54,900/m^3 in eutrophic Canyon Ferry Reservoir (Wright 1958), but much lower than in some productive lakes. Mean annual density was 109,200/m^3 in Granite Lake and 182,500/m^3 in Moses Lake, both located in the Columbia Basin (Whittaker and Fairbanks 1958).

Low water retention times prevent the build-up of large populations of zooplankton in Columbia River impoundments (Earnest et al. 1966, Erickson et al. 1977). *Diaptomus* and *Cyclops* (Copepoda) have lifespans in excess of 150 days, and *Bosmina* and *Daphnia* (Cladocera) live for 19 and 11-16 days, respectively, at 20°C (Pederson 1974). If the retention time of a reservoir is low, populations of cladocerans and copepods arising in the reservoir will be carried downstream by the relatively rapid flow of water before completing their life cycles and depositing eggs for the next generation.

The abundance of zooplankton in the Columbia appears to be correlated with retention time. Higher densities were found in Roosevelt Lake, with an average retention time of 45 days (Bureau of Reclamation 1976), than in Rufus Woods Reservoir, which has a maximum retention time of only four days (Erickson et al. 1977). The free-flowing Hanford Reach and the lower Columbia had the lowest densities. Reduction in retention time of the reservoirs would further reduce zooplankton densities, while any increase in retention time would aid the build-up of zooplankton and benefit planktivorous fish species.

Reservoir Benthos. The bottom fauna of Roosevelt Lake consisted almost exclusively of Oligochaeta (aquatic worms) and Chironomidae (midge larvae) (Ernest et al. 1966). Snails, phantom midge larvae (*Chaoborus*), biting midge larvae (Ceratopogonidae), and *Hydra* were collected only occasionally. Chironomids and oligochaetes also dominated the benthos of nearby Banks Lake (Stober et al. 1976) and are probably the most abundant organisms in other main stem Columbia River reservoirs. Chironomid abundance reached a peak in August and September, while oligochaetes maintained low but relatively constant numbers throughout the year. The density of all bottom organisms in Roosevelt Lake was low due to the effects of fluctuating water levels (Earnest et al. 1966).

Fishes of the Main Stem

Fish species found in the Columbia River and their distribution in the main stem are listed in Table 23. From the literature, 61 species of fish have been identified from the Bonneville pool to Franklin D. Roosevelt Lake (Grand Coulee Project). The fish may be conveniently grouped into four categories: anadromous salmonids, cold-water game fish, warm-water game fish, and non-game fish. The four species of salmon (*Oncorhynchus tshawytscha, O. nerka, O. kisutch, O. keta*) and steelhead are the primary species supporting Indian and non-Indian commercial and sport fisheries on the Columbia. Two species have resident populations: kokanee (*O. nerka*) and rainbow trout (*S. gairdneri*). The anadromous salmonids in general may be found to migrate up the main stem to Chief Joseph Dam, which is the upstream extent of anadromous fish migration (Allen 1976). Chum salmon (*O. keta*) are limited to the lower portion of the Columbia not migrating past Lake Celilo.

Sixteen species of cold-water game fish have been identified in the main stem of the Columbia. Kokanee, cutthroat (*Salmo clarki*) and brown trout (*S. trutta*) (an exotic species, i.e. not native to the Columbia system) are generally found only in Rufus Woods and Roosevelt reservoirs. Dolly Varden (*Salvelinus malma*) are somewhat more widespread in their distribution extending from Roosevelt Lake down river to Priest Rapids. The American shad (*Alosa sapidissima*), an anadromous species introduced to the Columbia, has a range from the mid-Columbia through the lower reaches of the river. Rainbow trout, mountain whitefish (*Prosopium williamsoni*), and white sturgeon (*Acipenser transmontanus*) are the only cold-water game fish species which are found throughout the main stem.

Table 23

FISH SPECIES OF THE MAIN STEM COLUMBIA RIVER

SPECIES	SCIENTIFIC NAME	Bonneville	The Dalles	John Day	McNary (incl. Hanford)	Priest Rapids/ Wanapum	Rock Island/ Rocky Reach	Wells	Chief Joseph	Grand Coulee
<u>Anadromous Salmonids</u>										
Chinook salmon	*Oncorhynchus tshawytscha*	x	x	x	x	x	x	x		
Sockeye salmon	*Oncorhynchus nerka*	x	x	x	x	x	x	x		
Coho salmon	*Oncorhynchus kisutch*	x	x	x	x	x	x	x		
Chum salmon	*Oncorhynchus keta*	x	x							
Steelhead	*Salmo gairdneri*	x	x	x	x	x	x	x		
<u>Cold Water Game Fish</u>										
Kokanee	*Oncorhynchus nerka*								x	x
Rainbow trout	*Salmo gairdneri*	x	x	x	x	x	x	x	x	x
Cutthroat trout	*Salmo clarki**				x				x	x
Brook trout[1]	*Salvelinus fontinalis*								x	x
Brown trout[1]	*Salmo trutta*					x	x	x	x	
Dolly Varden	*Salvelinus malma*					x	x	x	x	x
American shad[1]	*Alosa sapidissima*	x	x	x	x	x	x			
Burbot	*Lota lota**				x	x			x	x
Mountain whitefish	*Prosopium williamsoni*	x	x	x	x	x	x	x	x	x
Lake whitefish[1]	*Coregonus clupeaformis**				x				x	x
Pygmy whitefish	*Prosopium coulteri*									x
Broad whitefish[1]	*Coregonus nasu* (?)									
White sturgeon	*Acipenser transmontanus*	x	x	x	x	x	x	x	x	x
Green sturgeon	*Acipenser medirostris* (?)									
Eulachon[1]	*Thaleichthys pacificus* (?)									
Grass pickerel [1]	*Esox americanus vermiculatus* (?)									

continued

Fish Species of the Main Stem Columbia River - page 2

SPECIES	SCIENTIFIC NAME	Bonneville	The Dalles	John Day	McNary (incl. Hanford)	Priest Rapids/ Wanapum	Rock Island/ Rocky Reach	Wells	Chief Joseph	Grand Coulee
<u>Warm Water Game Fish</u>										
Walleye[1]	*Stizostedion vitreum vitreum*	x	x	x	x	x	x	x	x	x
Yellow perch[1]	*Perca flavescens*	x	x	x	x	x	x	x	x	x
Largemouth bass[1]	*Micropterus salmoides*	x	x	x	x	x	x	x		x
Smallmouth bass[1]	*Micropterus dolomieui*	x	x	x	x	x	x	x		x
Black crappie[1]	*Pomoxis nigromaculatus*	x	x	x	x	x	x	x	x	
White crappie[1]	*Pomoxis annularis*	x	x	x	x	x	x	x		
Bluegill[1]	*Lepomis macrochirus*	x	x	x	x	x	x	x		
Pumpkinseed[1]	*Lepomis gibbosus*	x	x	x	x	x	x	x		
Channel catfish[1]	*Ictalurus punctatus*	x	x	x	x	x	x			
Black bullhead[1]	*Ictalurus melas**				x					
Brown bullhead[1]	*Ictalurus nebulosus*	x	x	x	x	x	x	x		
Yellow bullhead[1]	*Ictalurus natalis**				x					
<u>Non-Game Fish</u>										
Northern squawfish	*Ptychocheilus oregonensis*	x	x	x	x	x	x	x	x	x
Peamouth	*Mylocheilus caurinus*	x	x	x	x	x	x	x	x	x
Chiselmouth	*Acrocheilus alutaceus*	x	x	x	x	x	x	x	x	x
Largescale sucker	*Catostomus macrocheilus*	x	x	x	x	x	x	x	x	x
Bridgelip sucker	*Catostomus columbianus*	x	x	x	x	x	x	x	x	x
Mountain sucker	*Catostomus platyrhynchus*				x					
Longnose sucker	*Catostomus catostomus*								x	x
Redside shiner	*Richardsonius balteatus*	x	x	x	x	x	x	x	x	x
Speckled dace	*Rhinichthys osculus**				x				x	
Leopard dace	*Rhinichthys falcatus**				x					
Longnose dace	*Rhinichthys cataractae**				x					
Carp[1]	*Cyprinus carpio*	x	x	x	x	x	x	x	x	x
Threespine stickleback	*Gasterosteus aculeatus*	x	x	x	x	x	x	x		
Tadpole madtom[1]	*Noturus gyrinus*	x	x	x	x					

continued

Fish Species of the Main Stem Columbia River - page 3

SPECIES	SCIENTIFIC NAMES	Bonneville	The Dalles	John Day	McNary (incl. Hanford)	Priest Rapids/ Wanapum	Rock Island/ Rocky Reach	Wells	Chief Joseph	Grand Coulee
Tench[1]	*Tinca tinca*	x	x	x	x	x	x	x		
Pacific lamprey	*Entosphenus tridentatus*	x	x	x	x	x	x	x		
Western brook lamprey	*Lampetra richardsoni**				x					
River lamprey	*Lampetra ayresi**				x					
Sandroller[1]	*Percopsis transmontana*	x	x	x	x	x	x	x		
Tui chub	*Gila bicolor* (?)									
Prickly sculpin	*Cottus asper**				x				x	
Torrent sculpin	*Cottus rhotheus**				x				x	
Mottled sculpin	*Cottus bairdi**				x					
Piute sculpin	*Cottus beldingi**				x					
Reticulate sculpin	*Cottus perplexus**				x					
Slimy sculpin	*Cottus cognatus**									
Shorthead sculpin	*Cottus confusus**									
Margined sculpin	*Cottus marginatus**									
Coastrange sculpin	*Cottus aleuticus* (?)									
Riffle sculpin	*Cottus gulosus* (?)									

(?) = Referenced on species lists from various sources; distribution not provided.

* = Distribution of these species in the Columbia is wider than indicated, but no definite records of recent distribution are available.

1 = Exotic species, not native to the Columbia River Basin.

The twelve species of warm-water fish found in the Columbia are considered exotics. These introduced species are generally found throughout the river (e.g., walleye [*Stizostedion vitreum vitreum*], yellow perch [*Perca flavescens*] and basses [*Micropterus* spp.]). The crappies (*Pomoxis* spp.), bluegill (*Lepomis macrochirus*) pumpkinseed (*L. gibbosus*) and *Ictalurids* (i.e., bullheads) are distributed in the mid- and lower reaches of the Columbia.

Non-game fish constitute approximately half (30) of the species found in the Columbia. The squawfish (*Ptyocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), chiselmouth (*Acrocheilus alutaceus*), largescale sucker (*Catostomus macrocheilus*) and bridgelip sucker (*C. columbianus*), redside shiner (*Richardsonius balteatus*), and carp (*Cyprinus carpio*), an exotic, are found throughout the main stem. The tench (*Tinca tinca*) (an exotic), Pacific lamprey (*Entosphenus tridentatus*, and sandroller (*Percopsis transmontana*) are distributed in the mid- and lower portions of the river.

STORAGE RESERVOIRS

General Description and Ecology

Franklin D. Roosevelt Lake is the storage pool for the Grand Coulee Dam Project. Although utilized primarily for hydroelectric power generation, the project is also used for flood control, irrigation water supply, and recreation. The operational strategy and aquatic environments of Roosevelt Lake may be characterized as a typical storage project on the main stem of the Columbia River.

Roosevelt Lake is perhaps the most productive of the Washington reservoirs on the main stem due to its extended storage ratio of approximately 45 days. In contrast, plankton communities in run-of-the-river reservoirs are depleted continuously because of the short retention times which inhibit plankton from completing their life cycles (Kiser 1964).

Long retention times, however, are not a guarantee of productivity. Stability of the reservoir elevation has a profound effect on the aquatic productivity which is generally highest in the shoreline littoral zones of standing water bodies, except when these areas are periodically dewatered. Unstable water levels also accelerate sloughing of reservoir banks which can add sediment decreasing the euphotic zone or suffocating the benthic organisms. Terrace slopes along several of the main stem reservoirs have become unstable due to saturation of the reservoir waters and rapidly lowering water levels. Major landslides have occurred at times of extreme low-water levels in Roosevelt Lake (Jones and Peterson, no date).

Fishes of Lake Roosevelt

Most storage reservoirs experience little or no daily fluctuations in water levels but have major seasonal drawdowns. The elevation of Lake Roosevelt is dropped from a maximum of 1290 ft to 1208 ft beginning in February of each year prior to the spring flood season. The timing of the drawdown in relation to the various life history stages of the fish species inhabiting Roosevelt Lake is illustrated in Figs. 10, 11 and 12. Analysis of the drawdown regime by Stober et al. (1977), for 36 years of record, showed a trend of increasing drawdown with time. Three periods were identified: 1941-1951, when drawdown did not exceed 30 feet; 1952-1965, when drawdown was relatively consistent at 40 feet; and 1966-1976, when drawdown reached extremes of 130 and 133 feet in 1969 and 1974, but ranged from 64 to 88 feet during the remaining years. Minimum water level elevations occurred from late winter to early spring but most often occurred in April.

Stober et al. (1977) reviewed the origins of twelve species of fish captured in the forebay of Lake Roosevelt during 1976-1977. Substantial introductions of kokanee were made from 1952 to 1945 and then were discontinued. Kokanee dominated the samples taken by the NMFS (Snyder,

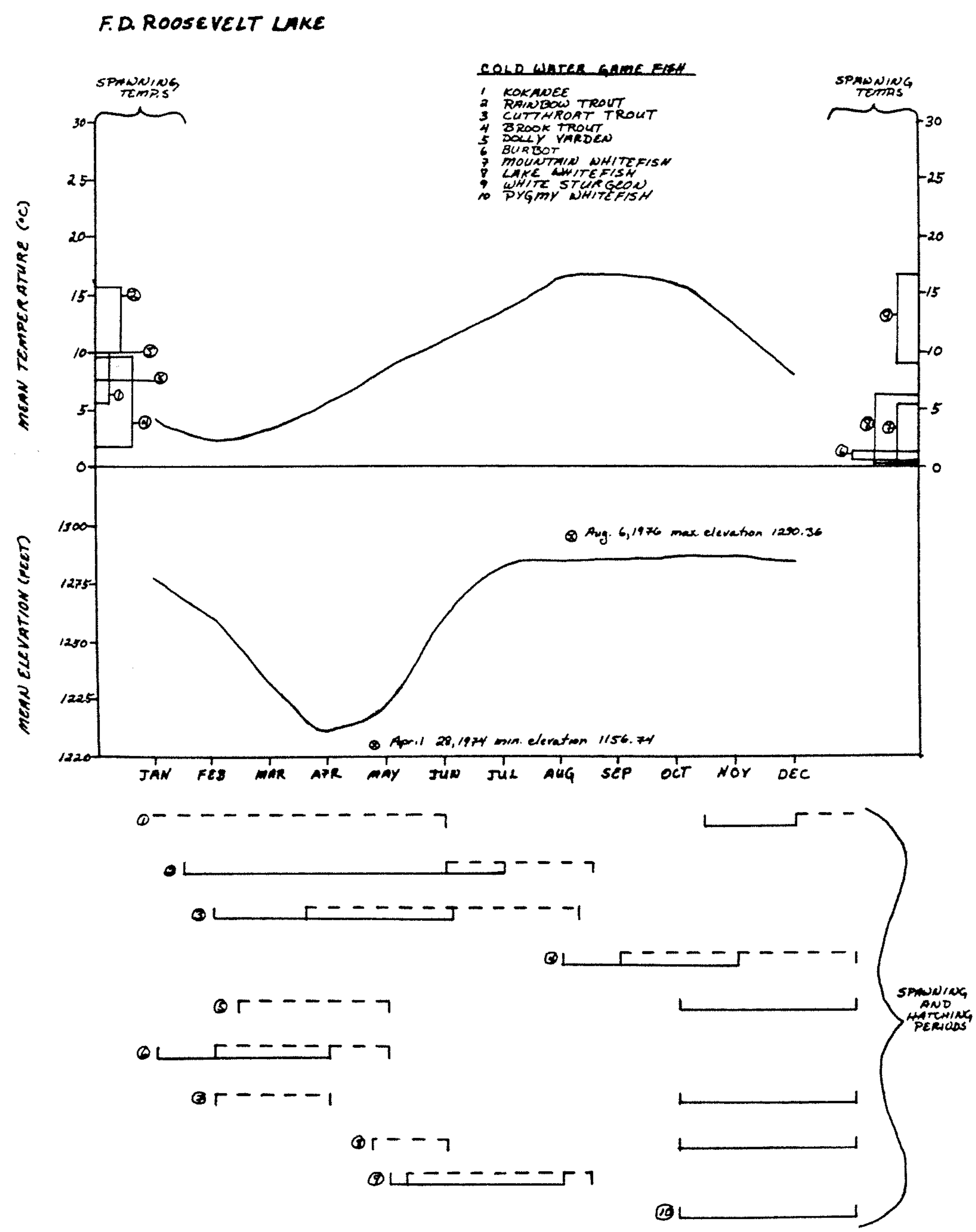


Fig. 10. Franklin D. Roosevelt Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

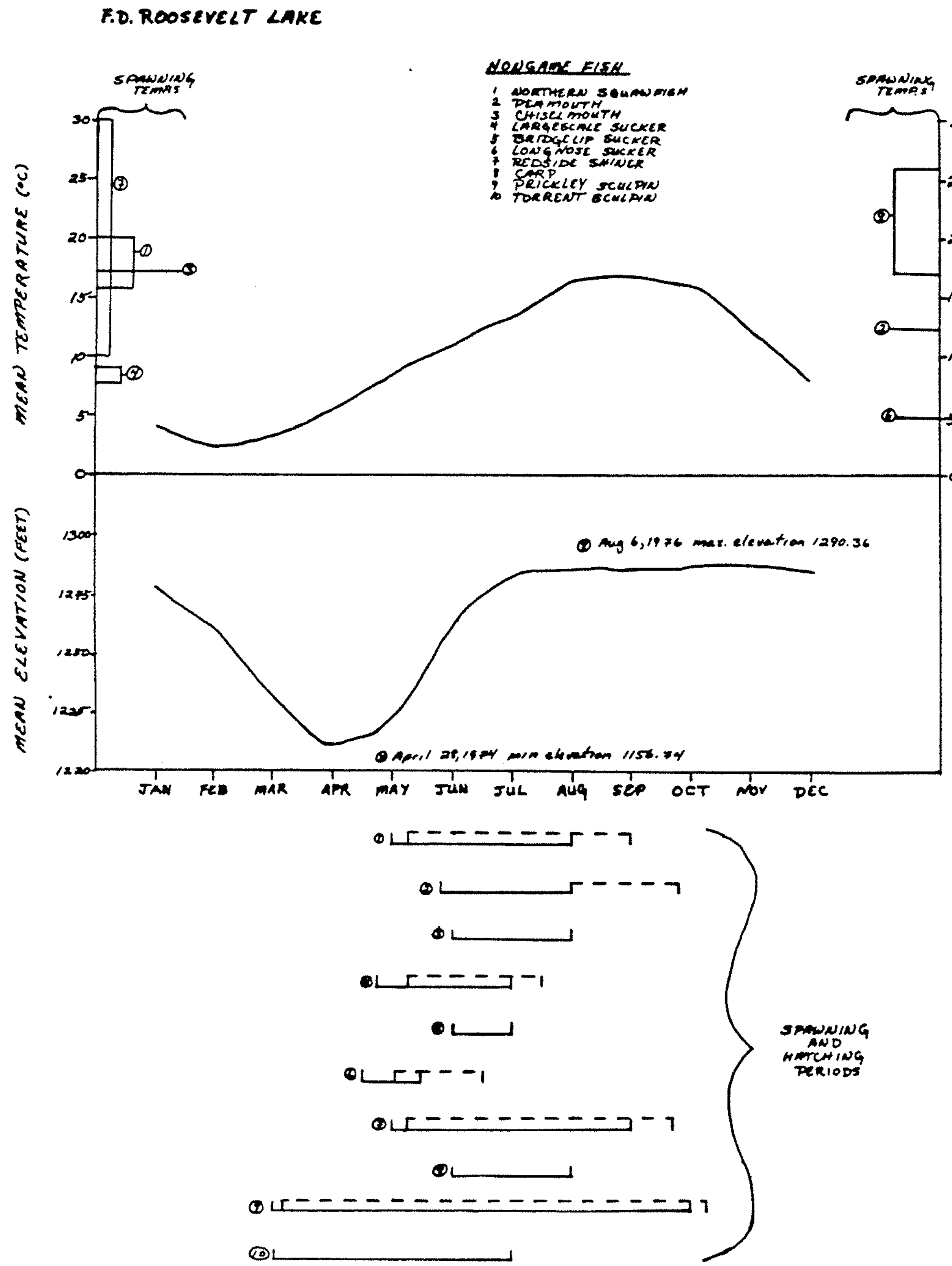


Fig. 11. Franklin D. Roosevelt Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

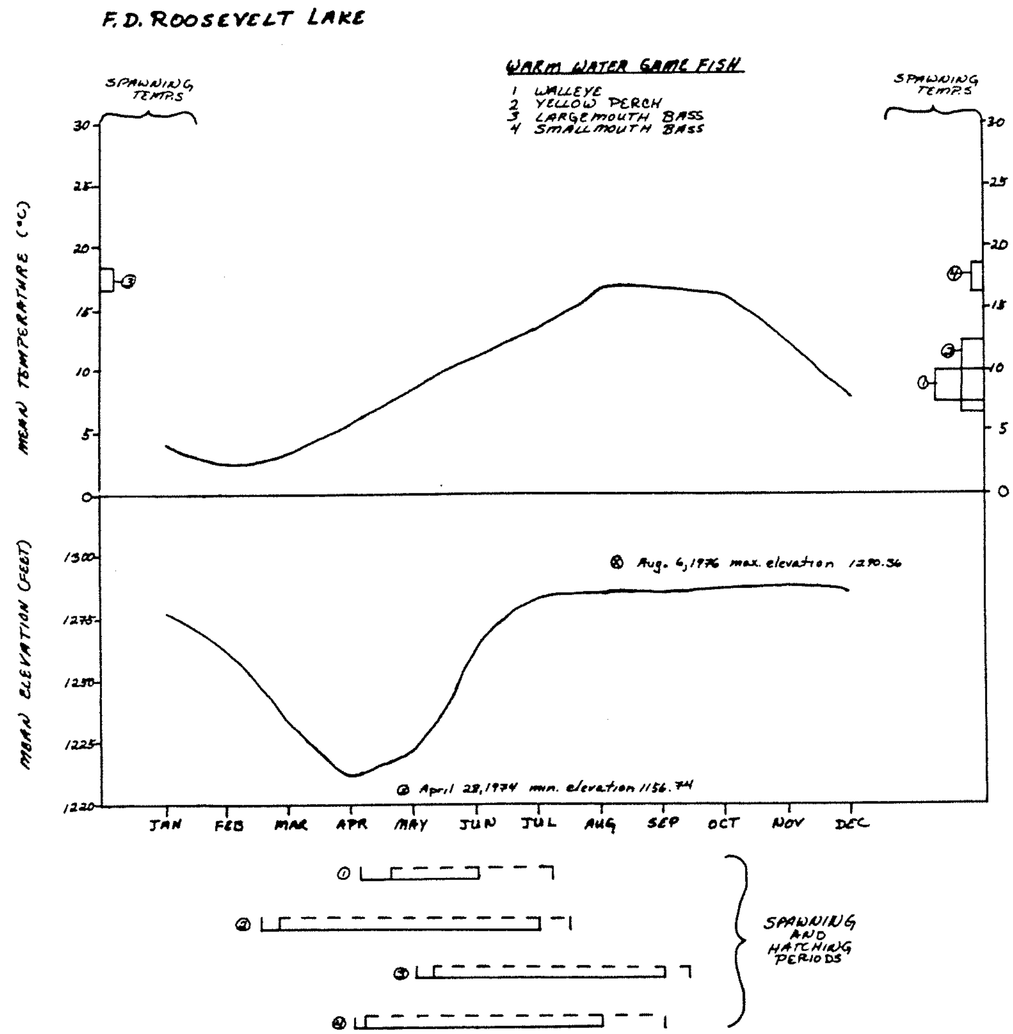


Fig. 12. Franklin D. Roosevelt Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

personal comm.) from the forebay in 1966 and 1967 (reported by Stober et al. 1977); however, they only contributed 12 percent by number and 9.7 percent of the biomass in the 1976-1977 gillnet samples. The gillnet catch was predominantly composed of squawfish (51%) and walleye (13.5%). The proportion of game (seven species) to non-game fish (five species) was 35.8 : 64.2 percent. The greatest abundance in the near-surface gillnet catches occurred in August. This was confirmed by acoustic surveys.

The abundance of kokanee has declined while the number of walleye and non-game fish has increased. Stober et al. (1977, 1979a and 1979b) have demonstrated the successful reproduction of kokanee salmon in talus lake shorelines in nearby Banks Lake. They also measured the effects of annual spring drawdown on fry survival. Similar talus shorelines occur in FDR reservoir and there is also an unknown amount of habitat in the tributaries. The large drawdown in Roosevelt Lake severely reduces the success of shoreline spawning kokanee, a condition which apparently has progressively worsened throughout the history of the reservoir (Fig. 10). Stream spawners such as rainbow, cutthroat and brook trout as well as Dolly Varden and mountain whitefish have a low abundance in the forebay. The ability of stream spawning species to populate this large reservoir appears limited. Lake whitefish, which are winter spawners, may also be severely impacted by early spring drawdown (Stober 1977). The eggs and alevins of the species spawning in the littoral zone with long incubation periods (up to eight months from beginning to end for kokanee) are dessicated during drawdown thus limiting the reproductive success of these species.

Examination of Fig. 11 for non-game fish in Lake Roosevelt shows that the abundant northern squawfish spawns in the spring and incubates for a short period during a rising reservoir level. Most other non-game fishes have a similar reproductive cycle which is less susceptible to drawdown since spawning and incubation periods occur generally in late spring (May) through early fall (October). Therefore, these species would be expected to be more abundant than the game fish species if other habitat requirements are satisfactory. Stober et al. (1977) found that squawfish, peamouth and suckers were among the most abundant non-game species in the forebay of Roosevelt Lake.

Walleye is the second-most abundant species in Lake Roosevelt forebay. It spawns on a rising water level (Fig. 12) which enhances the reproductive success of this exotic species. Scott and Crossman (1973) stated that walleye typically spawn in lake shoals or streams. The piscivorous nature of the walleye, although it may prey on non-game species, enhances its survival while the yellow perch may be limited because of greater requirements for plankton or benthic food sources. The abundance of the basses is unknown as they have not been sampled intensively; however, spawning on a rising water level should enhance their survival.

An additional effect of the annual drawdown is to concentrate fish. This increases predation on juveniles and Ricker (1941), Scott and Crossman (1973), and Bell (1973) documented the loss of juvenile salmonids to predation by squawfish. It is reasonable to assume that other opportunistic feeders will take advantage of similar situations.

The residence time of fish in the forebay of Lake Roosevelt appears to be limited due to continual entrainment through the penstock and spillway openings (Stober et al. 1977). The most abundant non-game and game species in the upper reaches of Rufus Woods Reservoir were squawfish and walleye, respectively (Erickson et al. 1977). Because their seasonal behavior in the water column is similar, their entrainment and subsequent recruitment from Grand Coulee is probably in proportion to their abundance in the forebay.

Water temperature is another important factor in reservoir environments. Roosevelt Lake is unique among the main stem reservoirs in displaying thermal stratification (Jaske 1966; Jaske and Goebel 1967). In May the reservoir becomes stratified (Stober et al. 1977) and remains so through September. This further concentrates the abundant fish species (walleye and squawfish) in the epilimnetic layer of the forebay. During the remainder of the year the density of fishes declines. In the forebay of Lake Roosevelt thermal stratification tends to concentrate a prey and predator species in the same section of the water column, kokanee were found to occur at greater depths than walleye.

Nielson (1974) found that walleye supported the only sport fishery on F.D.R. reservoir. The fishery is concentrated around the mouth of the Spokane River arm of the reservoir. This non-native species was introduced sometime during the 1940's or early 1950's. It has adapted to the conditions in this large storage reservoir and is presently under-exploited by the sport fishery.

Fishes of Banks Lake

Adjacent to Roosevelt Lake is the irrigation equalizing reservoir for the Columbia Basin Irrigation Project known as Banks Lake. Banks Lake is a storage reservoir with a much longer retention time than F.D.R. It is a shallow basin and is also affected by an annual drawdown. It is interesting to compare these reservoirs because they contain water from the same source and are affected by similar operational impacts with somewhat different results. The diversion of Columbia River water into Banks Lake has created a productive sport fishery. A brief review of Banks Lake is included to serve as an example of the aquatic resources which may be created and sustained under proper management when irrigation water is diverted from the main stem Columbia River.

Banks Lake is characterized by a two-pool system with a mean depth of 41 feet and a maximum surface area of 27,000 acres. The north pool extends from the north dam to the Steamboat Rock area, contains about 15 percent of the lake volume and is directly influenced by the pumped input of water from Lake Roosevelt forebay. Stober et al. (1976 and 1977) described the limnology and fisheries research conducted on Banks Lake from 1973-1977.

During the summer irrigation season the north pool was characterized by reduction of the temperature, transparency, retention times (≈ 8 days), and zooplankton abundance compared to the south pool (retention time ≈ 80 days). During winter, water temperatures were warmer in the north pool if pumping from F.D.R. reservoir occurred. In addition, the north pool showed thorough mixing of the water column, greater concentrations of plant nutrients (nitrates and phosphates) and a correspondingly greater phytoplankton production than found in the south pool. Nitrate limitation occurred throughout the lake after pumping and irrigation drafting had ceased for a period of time. Zooplankton developed in the south pool, the more stable portion of the lake. In general, the lake was classified as a nitrate-limited oligotrophic system.

Twenty-two fish species were identified in Banks Lake. Yellow perch, lake whitefish and kokanee comprised about 90 percent of the catch. Responses of the three major species indicated general avoidance of the reduced temperature, food supply and increased water velocities in the north pool. Yellow perch remaining in the north pool exhibited lower growth rates and condition. All three species were dependent on the cladoceran zooplankton *Daphnia* as the major food source. The numbers of walleye and northern squawfish were extremely small. Northern squawfish were only caught in the northern part of Banks Lake. Entrainment of fish through the feeder canal from F.D.R. reservoir was sampled during the 1976 irrigation pumping season (March to October). Kokanee were the predominate game fish followed by walleye and yellow perch. Non-game species in order of decreasing abundance were prickly sculpin, carp, largescale sucker, northern squawfish, longnose sucker, peamouth, and bridgelip sucker. It is interesting to note that fish were not entrained through the unscreened intake in the forebay of Lake Roosevelt in proportion to their abundance in the forebay.

Extreme drawdown of Banks Lake during the spring of 1973 and 1974 of 24.9 and 23.6 ft, respectively, reduced the reproductive success of yellow perch and kokanee salmon which are lakeshore spawning species. Lake whitefish, which utilize the same reproductive habitat were not seriously affected due to fry emergence prior to drawdown. The numbers of large perch (>200 mm) and juvenile kokanee declined in the lake following these large drawdowns. The low abundance of the 1973 and 1974 year classes of kokanee was documented by gillnet and irrigation canal entrainment samples, shoreline spawning counts and the decline in the 1976 and 1977 sport fishery. A study of the kokanee reproduction in the lake, which lacks tributaries suitable for spawning, indicated an October-November spawning season with egg incubation and fry emergence extending until early June.

Stober et al. (1979b) made a comparative study of kokanee fry emergence in Banks Lake for 1977, 1978 and 1979 by monitoring the catch of fry in emergence traps placed in the spawning areas. Most spawning and subsequent emergence was found to occur on steep talus shorelines ranging in depth from 5 to 15 ft below full pool elevation; however, additional spawning, when large numbers of fish were present, occurred to depths of 45 ft.

The relationships between the depth range of the kokanee spawning area, time of spawning, egg incubation period and fry emergence and the spring reservoir drawdown for each year were analyzed graphically. Drawdown limits (rule curves) which allow fry emergence to occur were developed for small spawner populations restricted between 5 and 15 ft depths and a large population spawning to 22 ft depths. The rule curves can be used to determine a water level management strategy for kokanee fry survival as well as to estimate the loss when the curves are exceeded.

Fish loss due to entrainment occurred principally through the irrigation canal. The total estimated loss (19 species) was 432,608 and 218,178 in 1975 and 1976, respectively. Point estimates of the total entrainment of kokanee were 128,397 and 50,007 in 1975 and 1976, respectively. The majority of the kokanee entrained from the lake were mature age III. Loss of this age group through the irrigation canal in 1976 severely reduced the brood stock needed for the lake. Spawners declined to about 1,851 in 1976 (Stober et al. 1979a) compared to about 10,000 in 1975. The evidence clearly indicated that a year class of kokanee reduced by lake drawdown prior to emergence cannot sustain unlimited irrigation canal entrainment losses without serious reductions occurring in the population.

Beginning in 1977 (Stober et al. 1979a), a net barrier 4400 ft in length was placed to screen mature kokanee from the main irrigation canal intake. The net was constructed of 83 mm stretched-measure dacron. Maintenance equipment was designed and constructed to haul the net and cleaning was done with high pressure water jets. Comprehensive evaluation of the screening efficiency of the barrier was conducted by numerous methods. Annual canal entrainment of kokanee declined from 60-67 percent before to 18-3 percent after installation. An estimated 35,381 adult kokanee were retained in the lake during the fall of 1978 based on mark and recapture from purse seine catches. Sonic-tracked kokanee were retained by the barrier and fish late in the season "homed" to beach spawning sites. A creel census estimated anglers caught 46,427 kokanee in 1978. The catch per angler hour was 0.250 while all other species declined to 0.042. The sport catches in 1971-1972 and 1975-1976 were 72,885 and 75,035, respectively. The estimated value of the sport fishery in 1971-1972 was $1.6 million (Duff 1973) while 1975-1976 estimates ranged to $3.2 million (Stober et al. 1977). Irregardless of the economic criteria applied, the Banks Lake sport fishery is increasingly important to the residents of the State of Washington. If the management techniques developed are applied, a sustained sport fishery can be maintained in this operating irrigation reservoir.

Fishes of Lake Umatilla

The other main stem Columbia River reservoir designed for storage in Washington State is Lake Umatilla of the John Day Project. As was previously discussed, the projects west of the Cascade Range operate under a three-part seasonal regime (Grand Coulee) (CRWMG 1979). In general, however, these projects are ultimately regulated in much the same manner.

The pool elevation is reduced to the minimum level for flood control prior to the spring runoff season. This annual drawdown is the most significant factor influencing the biological communities in the reservoirs. Water is also discharged even during drought periods to maintain a minimum flow level in the river (Bennett and White 1977). Maintaining flows usually poses few problems for such projects since their storage capacity is substantially greater than the quantity of water discharged.

The quality of the water discharged from storage projects is dependent upon the level from which it is drawn. Surface water releases will typically have warmer temperatures and enhance the habitat in the tailrace for warm-water fish species. Where hypolimnetic discharge occurs, cold-water species will tend to accumulate in the tailrace (Bennett 1970). Jaske (1966) evaluated the use of discharges from Lake Roosevelt to cool the waters of the Columbia River downstream.

The level of the discharge also influences the biological productivity of the downstream waters by the amount of nutrients and plankton in the discharge (Bennett 1970). Depending on which layer of water is released from the storage reservoir, the productivity may vary substantially.

Table 3 lists the differences between the Roosevelt and Umatilla storage reservoirs. The Umatilla reservoir is approximately one-third as long (56 mi) as Roosevelt Lake, yet it is the widest of the main stem reservoirs in Washington (1.11 mi). The area of Lake Umatilla is also approximately one-half (38,100 surf. ac.) of Lake Roosevelt's maximum area of 81,000 surf. ac. Development of volume for the two storage reservoirs are similar with Lake Umatilla's value of 0.32, just slightly above Roosevelt's figure of 0.30. The bottom slope for Lake Umatilla (0.26) is less than half that for Lake Roosevelt (0.58) indicating the decreased streambed gradient found in the lower portion of the Columbia River. This is further illustrated by the relatively shallow mean depth of 46.3 ft for the Umatilla reservoir in comparison with 118 ft for Roosevelt Lake.

The drawdown strategy is different for the two projects. Lake Roosevelt commences drawdown during February (Fig. 4) and is fluctuated in elevation by about 82 ft, from 1290 ft down to 1208 ft. Drawdown in Lake Umatilla occurs in April (Fig. 4) and may fluctuate from 268 ft to 257 ft, a total of only 11 ft.

The results of these operating strategies distinguish the two. Lake Roosevelt has an annual storage ratio on the order of 45 days and discharges approximately 78 million ac ft per year. In contrast, the storage ratio of Lake Umatilla is only 7 days, but its mean annual discharge of 125 million ac ft is 60 percent greater than for Lake Roosevelt.

Similar species of fishes are found in Lake Roosevelt and Lake Umatilla with the exception of anadromous salmonids in the latter (Table 28), although little documentation is available on the species and their abundance in Lake Umatilla. Temperatures, drawdown, and water quality conditions are different for the two projects and certainly influence the fish species inhabiting the two.

The cold-water game fish species prefer a stream environment for spawning (Fig. 13). Successful reproduction of American shad is apparently occurring in the Columbia River (USACOE, 1978). The status of white sturgeon is less certain. The warm-water game fish (Fig. 14) and the non-game fish (Fig. 15) are generally all spring and summer spawners with short incubation periods. Since the water level increases during the summer when most spawning and incubation occurs, the reproductive success would not be limited by this factor.

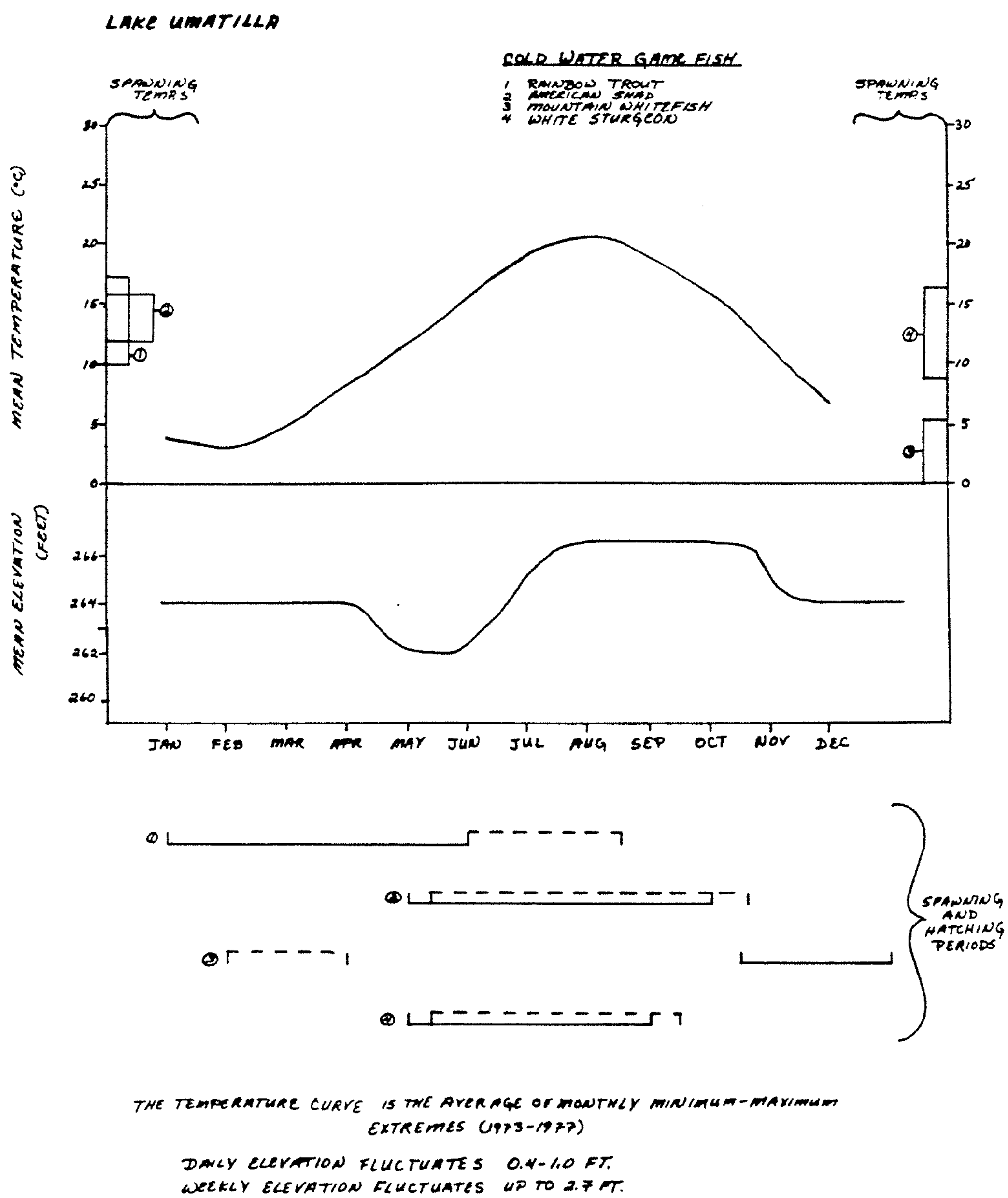


Fig. 13. Lake Umatilla temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

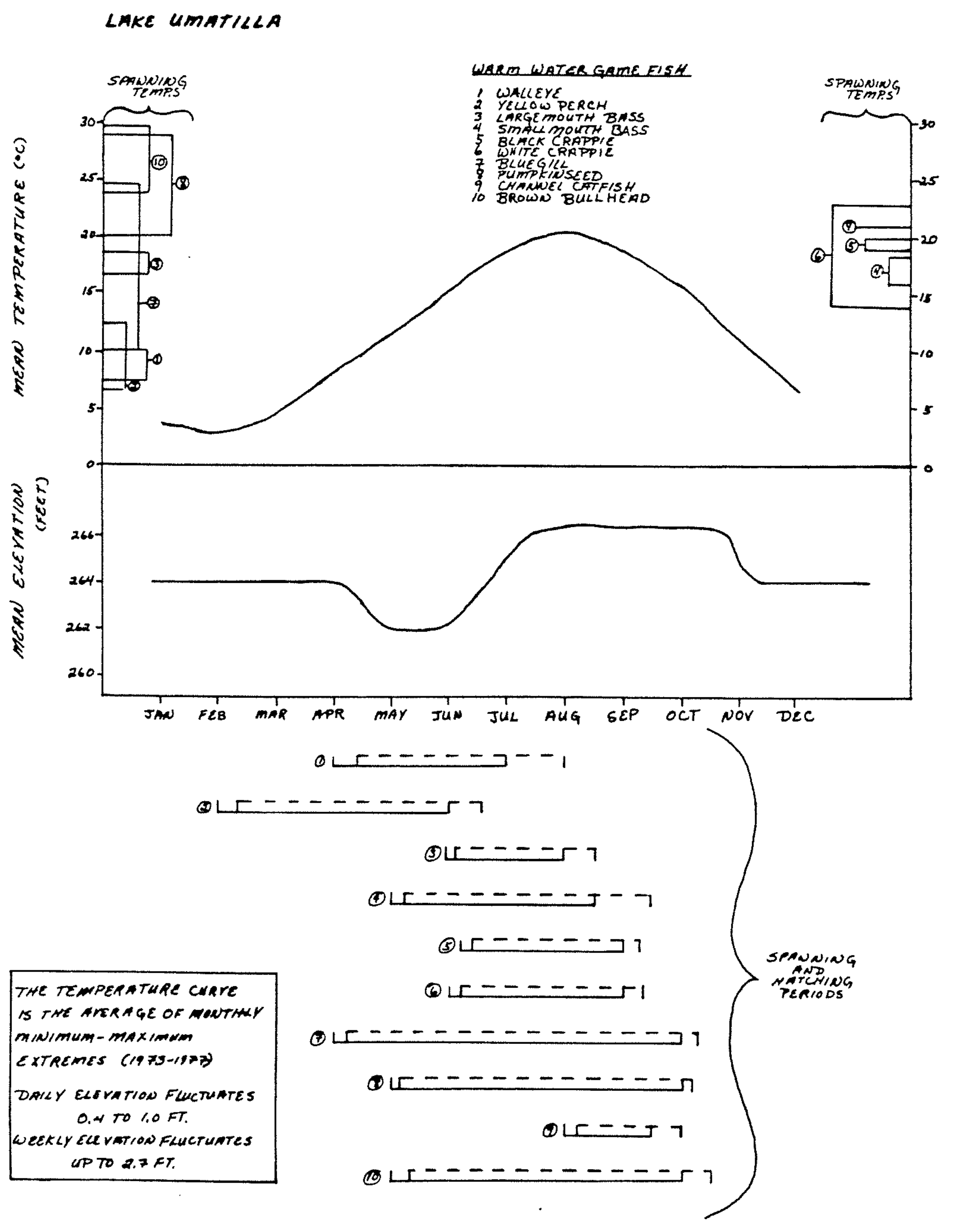


Fig. 14. Lake Umatilla temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

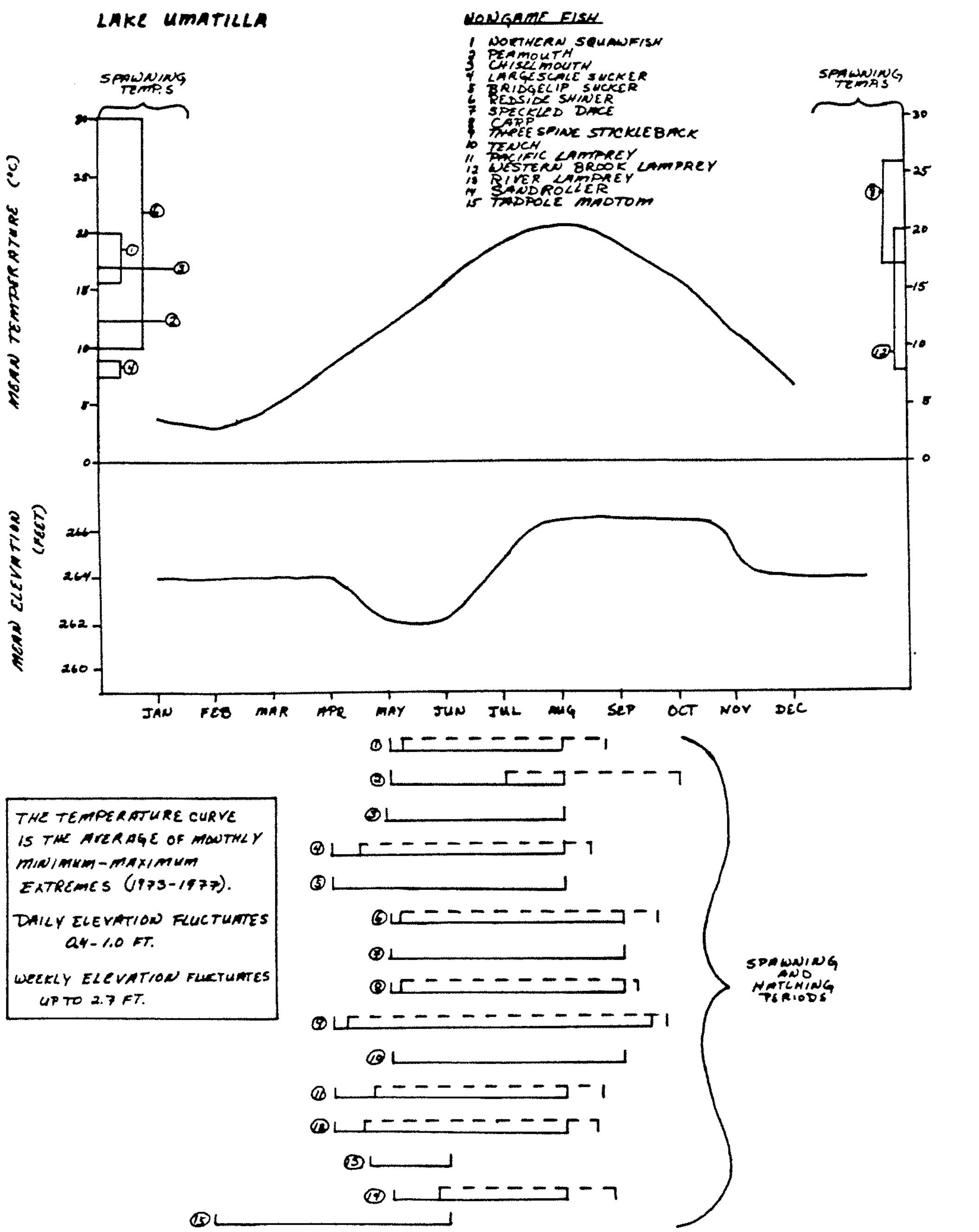


Fig. 15. Lake Umatilla temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

RUN-OF-THE-RIVER RESERVOIRS

General Description and Ecology

The impoundment (Rufus Woods) behind Chief Joseph Dam is an example of a run-of-the-river reservoir. Rufus Woods is characterized by an extremely short water retention time (2.5 days) with rapid, frequent fluctuations in discharge and water level, Erickson et al. (1977). These characteristics, combined with a narrow, steep-sided basin with a continuously sloughing shoreline, have resulted in a very unproductive aquatic ecosystem.

Rufus Woods has a low development of volume ratio (0.35), typical of the V-shaped trough of an inundated river valley (Table 3) with only limited areas of shallow water. It has the highest bottom slope (0.91) of any project on the main stem. These factors limit habitat available for spawning and rearing for the warm-water littoral species as the redside shiner and many of the centrarchids. Rufus Woods has only one significant tributary, the Nespelem River, and spawning area is limited to a 1-mile segment between the mouth and impassable falls. Phytoplankton populations are supported by recruitment from F.D.R. reservoir. Zooplankton production is low in F.D.R. reservoir, and these organisms tend to disintegrate on passage through the Grand Coulee turbines. Benthic production may be less affected by flushing; however, no data are available for verification. Fish production is generally very low. The species in greatest abundance in the Grand Coulee tailrace are those predominant in the upstream reservoir forebay.

As the river moves downstream between Grand Coulee and Chief Joseph the velocity decreases and the depth gradually increases. This creates three general environmental zones: 1) a free-flowing region in the upper reach; 2) a central area characteristic of both river and lake; and 3) a lagoon of quiet water in the forebay of the dam where the depth is greatest (Baxter 1977). Recruitment from upstream production enters at the inflow-tailrace region (Zone 1) and feeding fish congregate in this area. The central stretch, although the velocity is reduced, is too swift to sustain much production of its own. The forebay provides habitat for open-, deep-, and still-water species, but productivity is the lowest in the reservoir and the fish are susceptible to entrainment through turbines or to spillway loss. Thermal stratification does not occur at any time of the year.

Operation of the reservoir limits fish production in Rufus Woods. While there are some minimal seasonal adjustments (see Figs. 16, 17), reservoir elevations usually fluctuate up and down on a daily basis. Forebay fluctuations at Chief Joseph can be seven feet per day, and the tailrace of Grand Coulee can change at least 16 ft (Erickson et al. 1977). Fluctuations may increase when the dam is raised to 956 ft and the third powerhouse at Grand Coulee becomes fully operational. This prevents establishment of productive vegetation in much of the littoral zone and exposes spawning areas. Species that spawn in lake shallows, such as carp and most warm-water game fish, will be reduced in number while species able

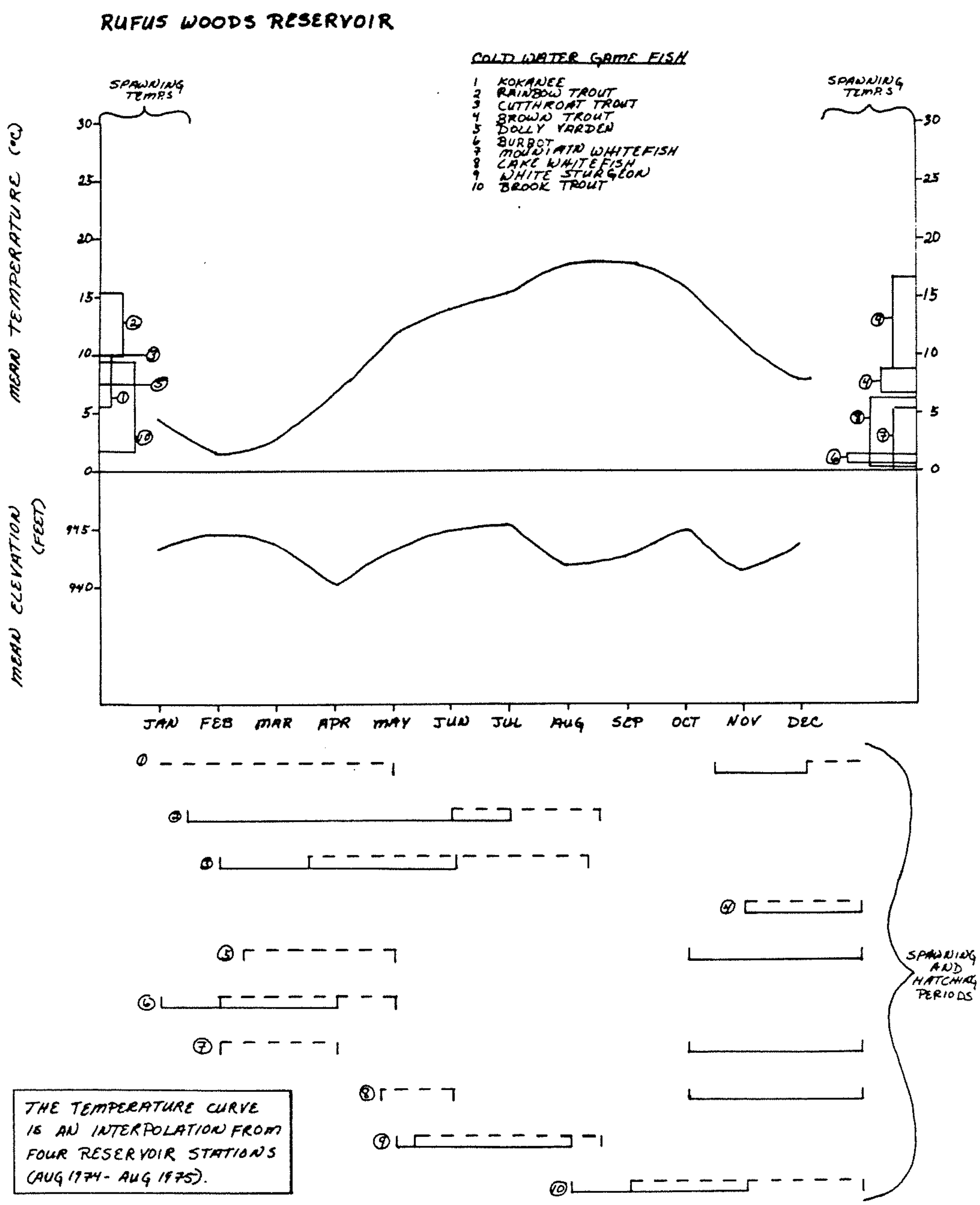


Fig. 16. Rufus Woods Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

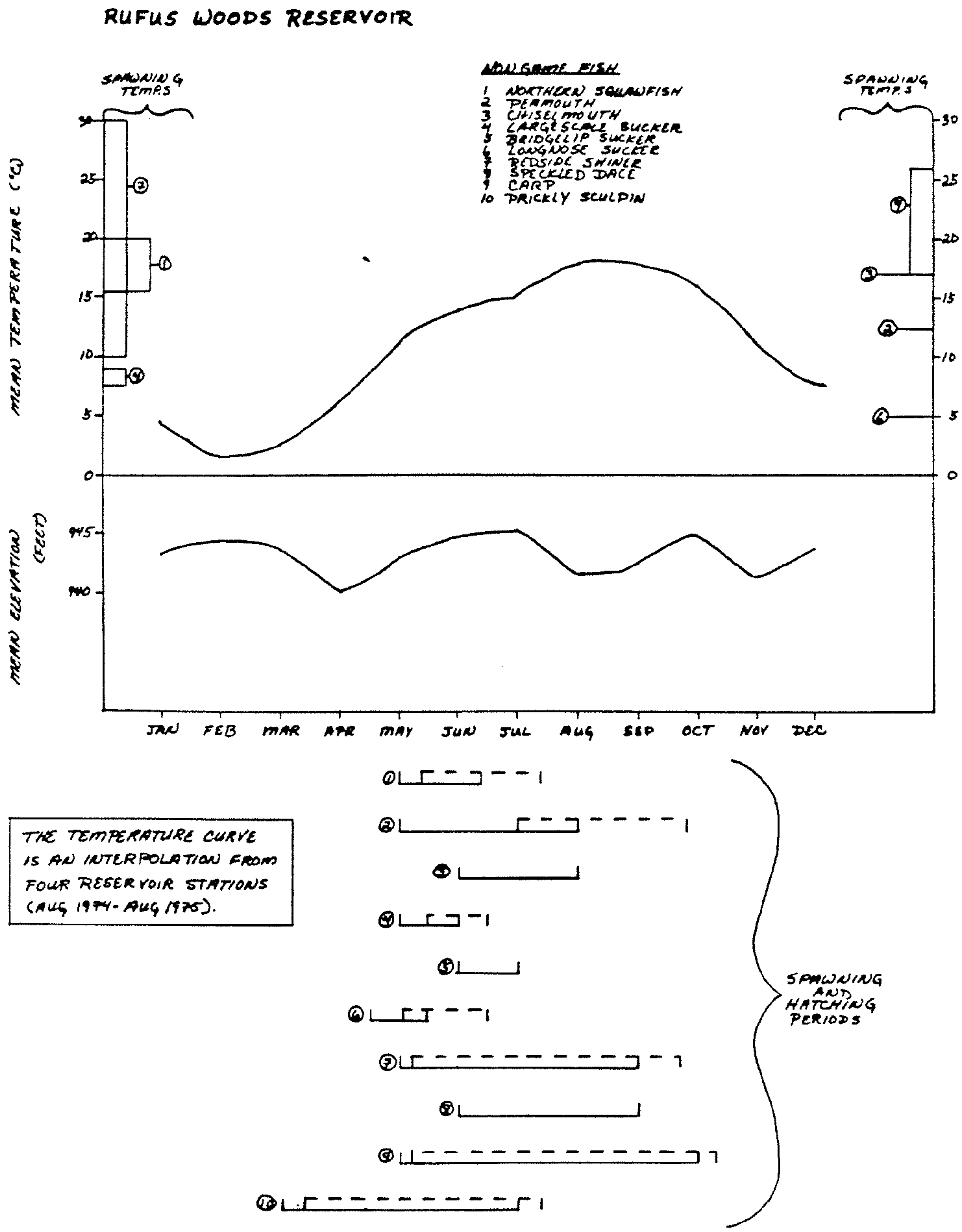


Fig. 17. Rufus Woods Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

to spawn in streams or deeper water will have the advantage. In years of high flow when daily fluctuations are less marked, littoral species will be more successful. In dry years, however, fluctuations are maximized, severely inhibiting littoral spawners, thus year classes will be very irregular. Unstable water levels have probably held down reproduction in Rufus Woods of some fish species, such as walleye and yellow perch (Wash. Dept. Fish. 1972; Erickson et al. 1977).

Seasonal spawning periods are May to August for most warm-water and non-game species (Figs. 17 and 18). Cold-water species spawn during the spring or fall and the latter incubate throughout most of the year. Water temperatures of the reservoir must be within limits required for spawning or reproductive success will be marginal. Carp and black crappie are not abundant in Rufus Woods as the temperature requirements are not met (Figs. 17 and 18). In general, temperature is not as limiting for spawning as fluctuating daily and seasonal water levels. Stable daily water levels during any spawning period will encourage reproductive success. Daily fluctuations have also been shown to create a type of freshwater "intertidal" zone, where the benthic community is lower in diversity and density in comparison to areas which remain submerged (Fisher and LaVoy 1972).

Fish Species

The factors discussed above explain why the fish populations in Rufus Woods are extremely low and are concentrated in the upper end of the reservoir. Plankton and fish are transported to this area via the discharge from Grand Coulee Dam.

Squawfish are the dominant species in Rufus Woods (Erickson et al. 1977). While they feed primarily on fish, they are omnivorous, taking zooplankton, insects, crustaceans, molluscs, and detritus. Since age-zero squawfish are abundant, spawning is apparently successful, probably in the tailrace or in lower reaches of streams entering the reservoir (Erickson et al. 1977). Detritus feeders, such as the largescale and bridgelip suckers, and bottom feeders, including the peamouth and prickly sculpin, are proportionately well-represented. These species are not dependent on planktonic production, and all are capable of stream spawning. Carp, another detritus feeder, is not as common as might be expected, probably due to high temperature requirements for reproduction (see Fig. 17) and a littoral spawning habit. Walleye, a predatory species, is common, but apparently does not spawn successfully in Rufus Woods. Recruitment is thought to occur from F.D.R. (Neilsen 1974; Erickson et al. 1977), though some spawning may take place in the tailrace. A normally prolific species, the yellow perch is limited by extreme fluctuations in water levels which expose its egg masses. This same problem probably restricts other warm-water game fish, such as panfish, bass, and catfish, all of which spawn in shallow water near shore. Trout have not done well in Rufus Woods, primarily due to limited spawning area in tributaries. Other reasons may include a scarcity of insect and zooplankton food resources and competition and predation from squawfish and walleye.

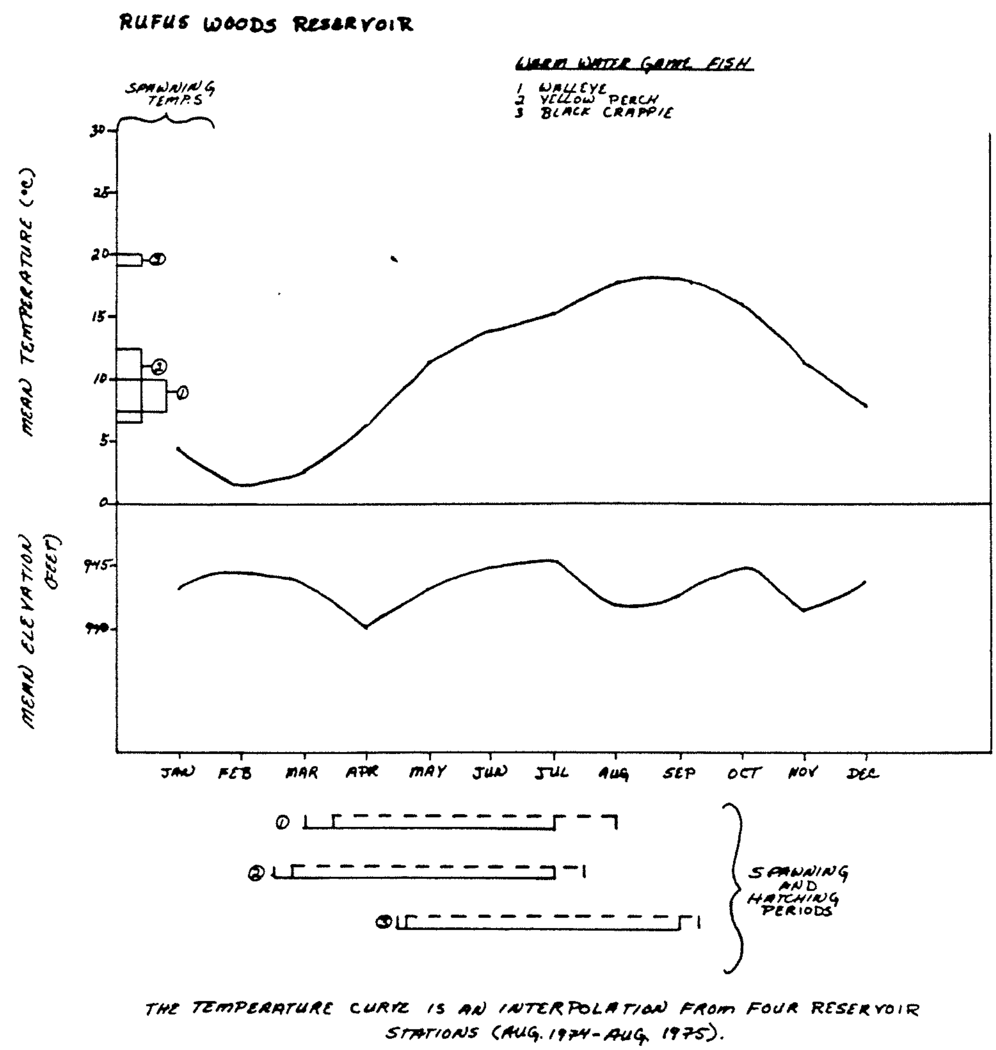


Fig. 18. Rufus Woods Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

The description and interpretation of Rufus Woods may be regarded as typical of the remaining eight run-of-the-river reservoirs. Examining Table 3 allows a comparison of the various parameters of the impoundments on the Columbia main stem. All the projects share the morphometry of inundated stretches of a river valley including low development of volume ratios and moderately steep bottom slopes, both indicating limited shallow water. In general there is a progression within the reservoirs beginning with a riverine tailrace progressing to an elongated, flowing mid-region culminating in a static forebay adjacent to the dam. As run-of-the-river reservoirs, all have short retention times, with little or no thermal stratification, and flushing of any local aquatic production. Rapid, frequent daily fluctuations in water level are the dominant pattern, with seasonal variations less marked. These daily fluctuations vary between the projects. Rock Island and Rocky Reach have the lowest range between maximum and minimum forebay elevations (4 ft; see Figs. 19 to 21), while Wanapum and Priest Rapids have the greatest range (10 ft; see Figs. 22 to 24). The fluctuations at Wells Dam are also high (8 ft; see Figs. 25 to 27). The more moderate fluctuations at Rock Island and Rocky Reach will be less deleterious to spawning by carp, sandroller, and many warm-water game species such as yellow perch, bass and sunfish. The fish species in Rufus Woods are expected to be essentially the same as those of the lower reservoirs, but there exists no data on relative abundance for most other projects.

In discussing the similarities of the run-of-the-river projects, it must be emphasized that generalizations cannot adequately describe the nature of a particular impoundment. For example, Rufus Woods remains unique in many of its characteristics. The bottom slope of 0.91 is the maximum recorded for main stem projects, indicating very little shallow water. The lake is one of the longest (44 mi) of the run-of-the-river reservoirs, and has no significant tributaries, a feature shared with Priest Rapids and Wanapum Reservoirs. Tributaries provide spawning areas and may carry plankton and nutrients into the river, therefore Rufus Woods is likely to be one of the least productive of the run-of-the-river projects. An infamous distinction is that anadromous fish runs are blocked from Rufus Woods by Chief Joseph Dam (Allen 1977).

In addition, there are two downstream "gradients" that may affect fish production. The first is a warming trend in water temperatures. Lake Bonneville may be 3 to 4°C warmer than Rufus Woods from February through August (Hastay et al. 1971; Erickson et al. 1977; see also Figs. 28 to 30). The higher annual temperatures in Lakes Bonneville and Celilo will be more favorable for spawning by carp, black crappie, brown bullhead and channel catfish (see Figs. 28 to 33). The second is a cumulative productivity effect. Downstream reservoirs have input of plankton and nutrients from adjacent tributaries, nutrients from irrigation runoff, and the downstream recruitment of production from reservoirs above. Thus reservoirs on the lower Columbia have a greater potential for productivity than does Rufus Woods.

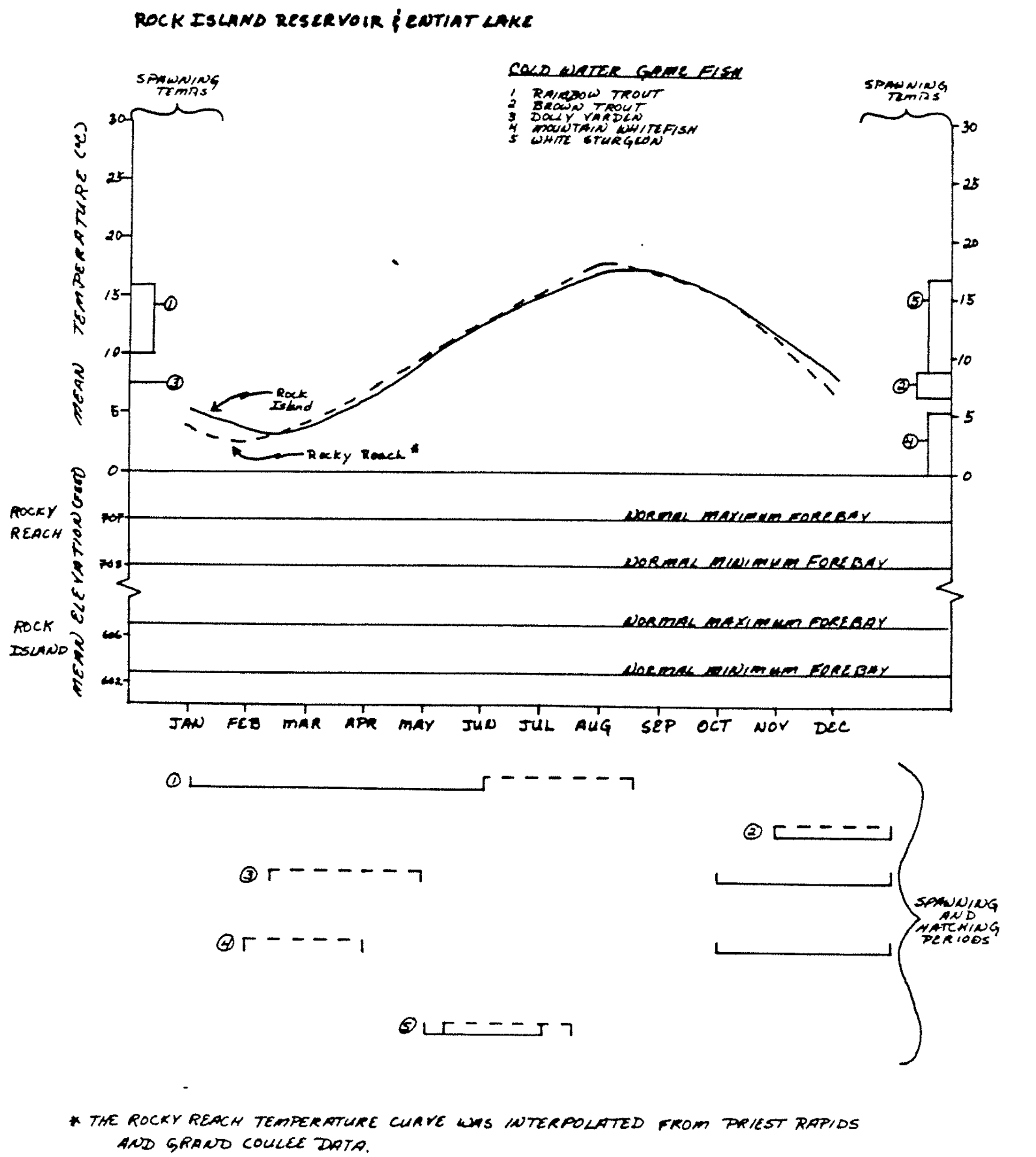


Fig. 19. Rock Island Reservoir and Entiat Lake temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

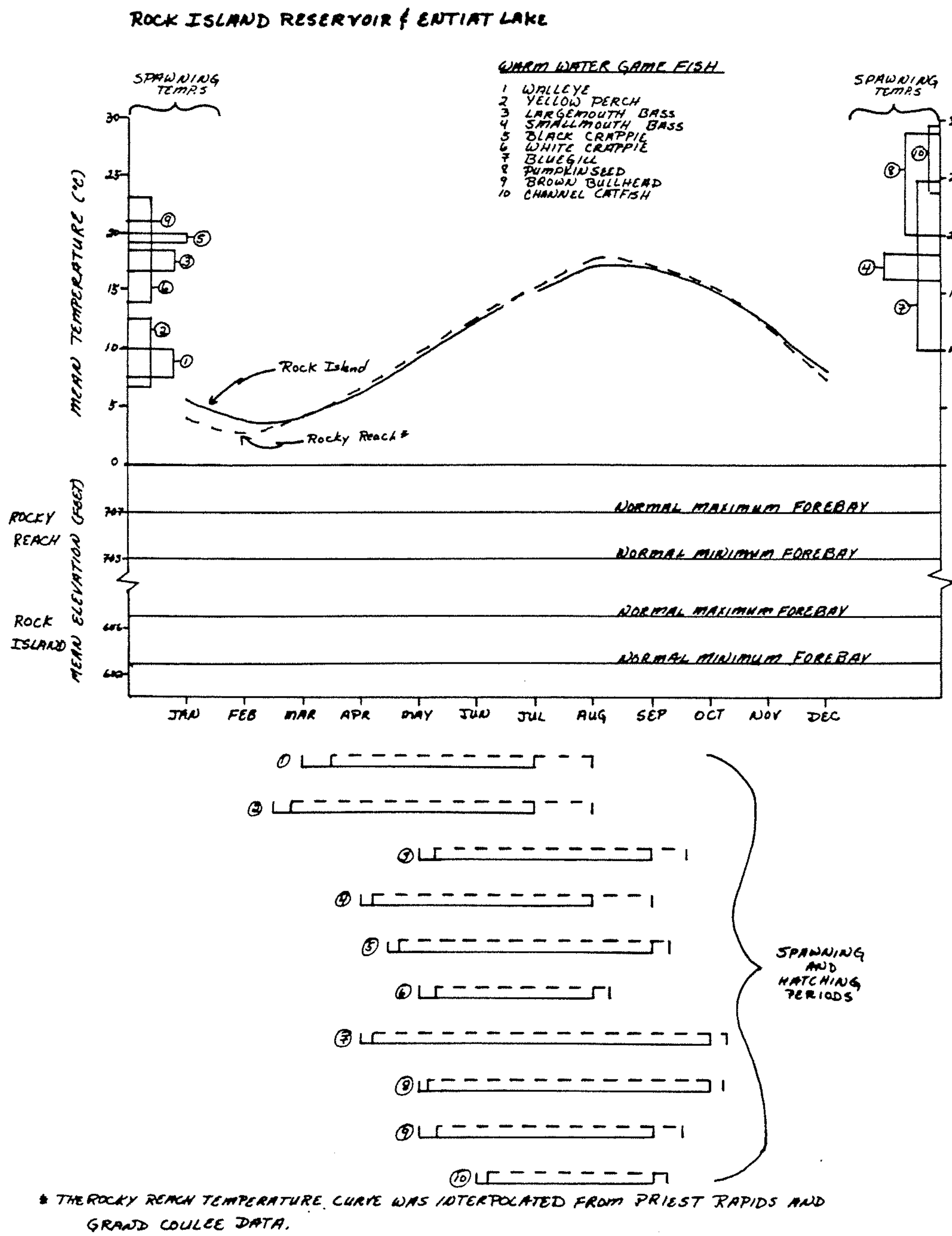


Fig. 20. Rock Island Reservoir and Entiat Lake temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

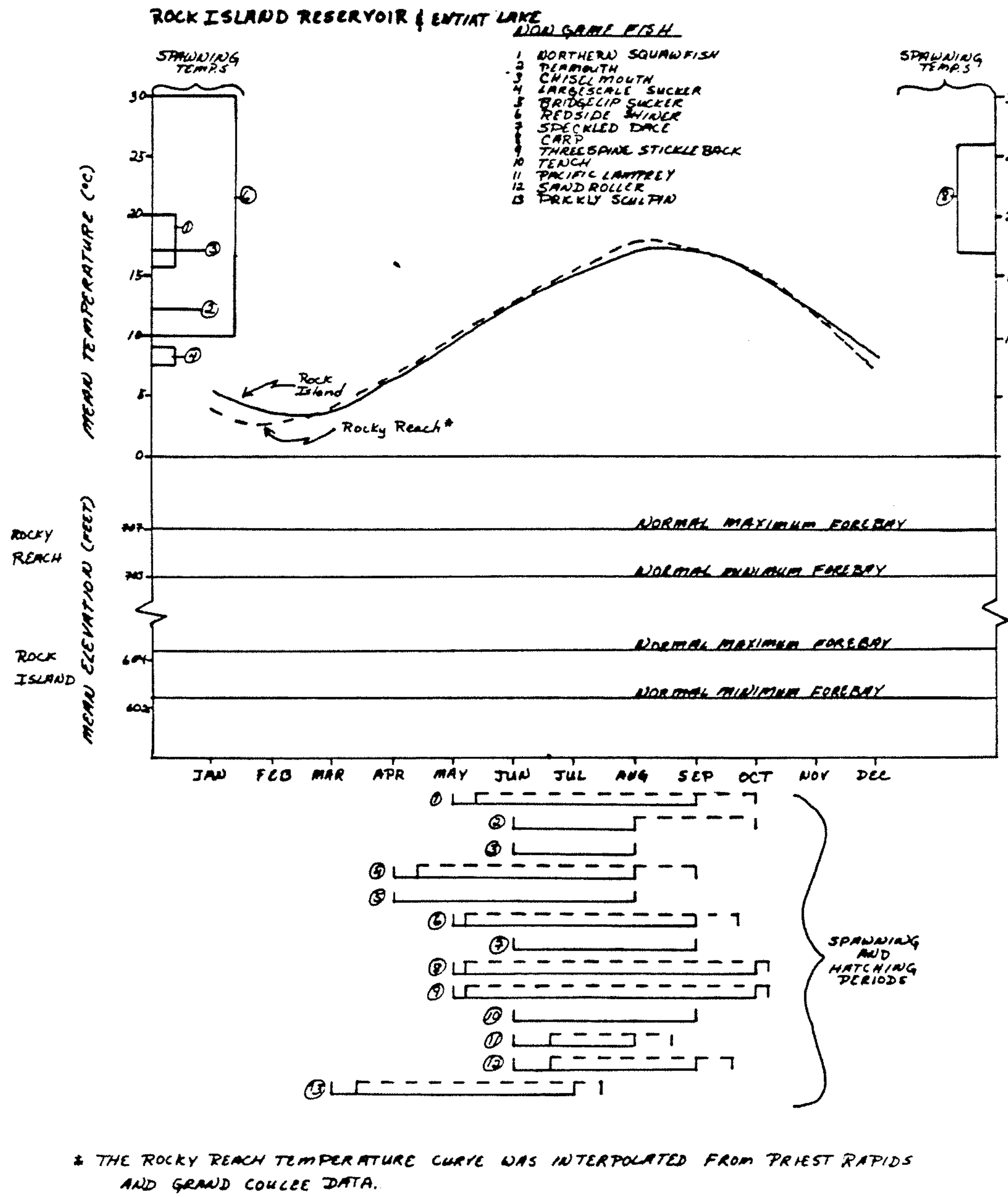


Fig. 21. Rock Island Reservoir and Entiat Lake temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

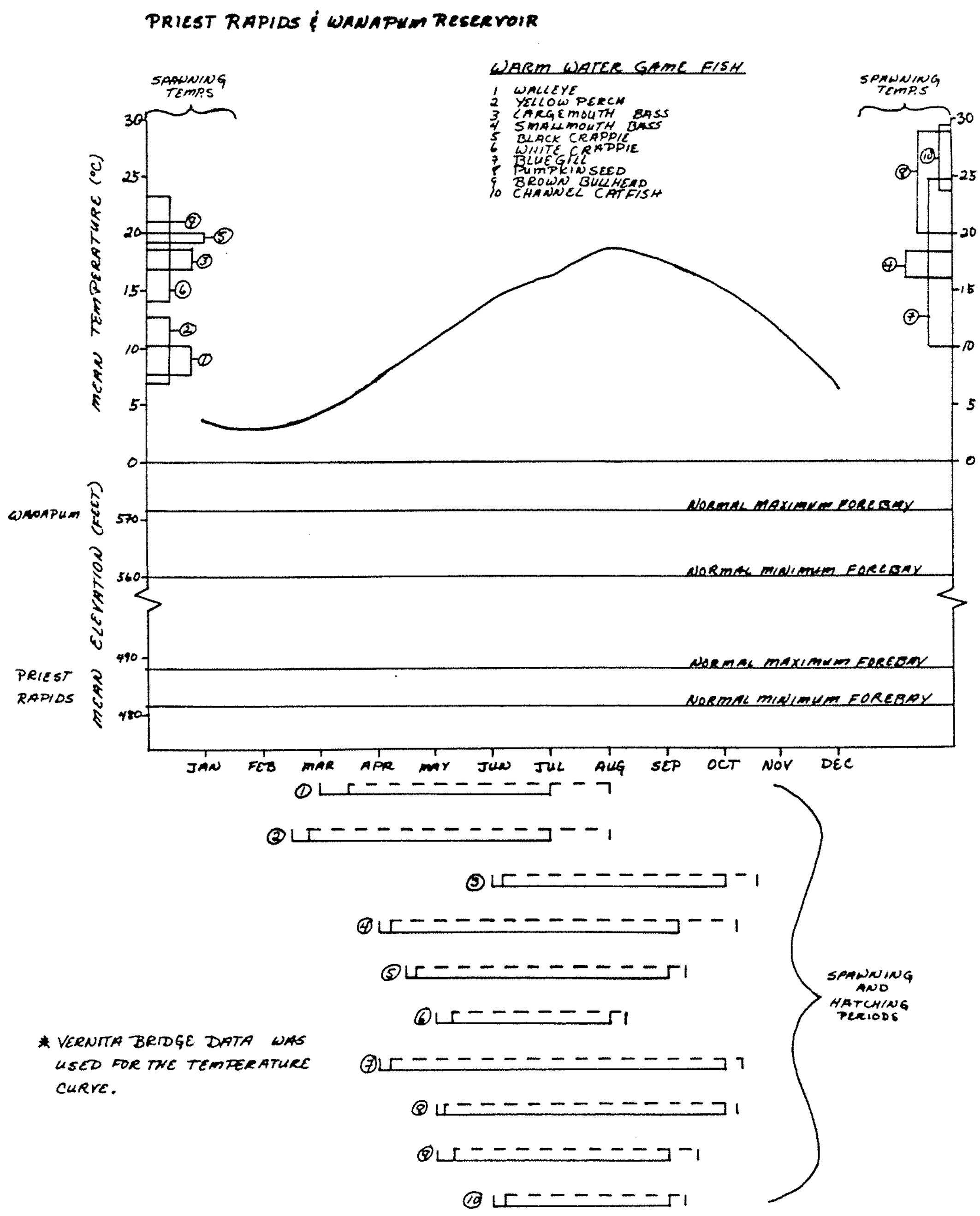


Fig. 22. Priest Rapids and Wanapum Reservoirs temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

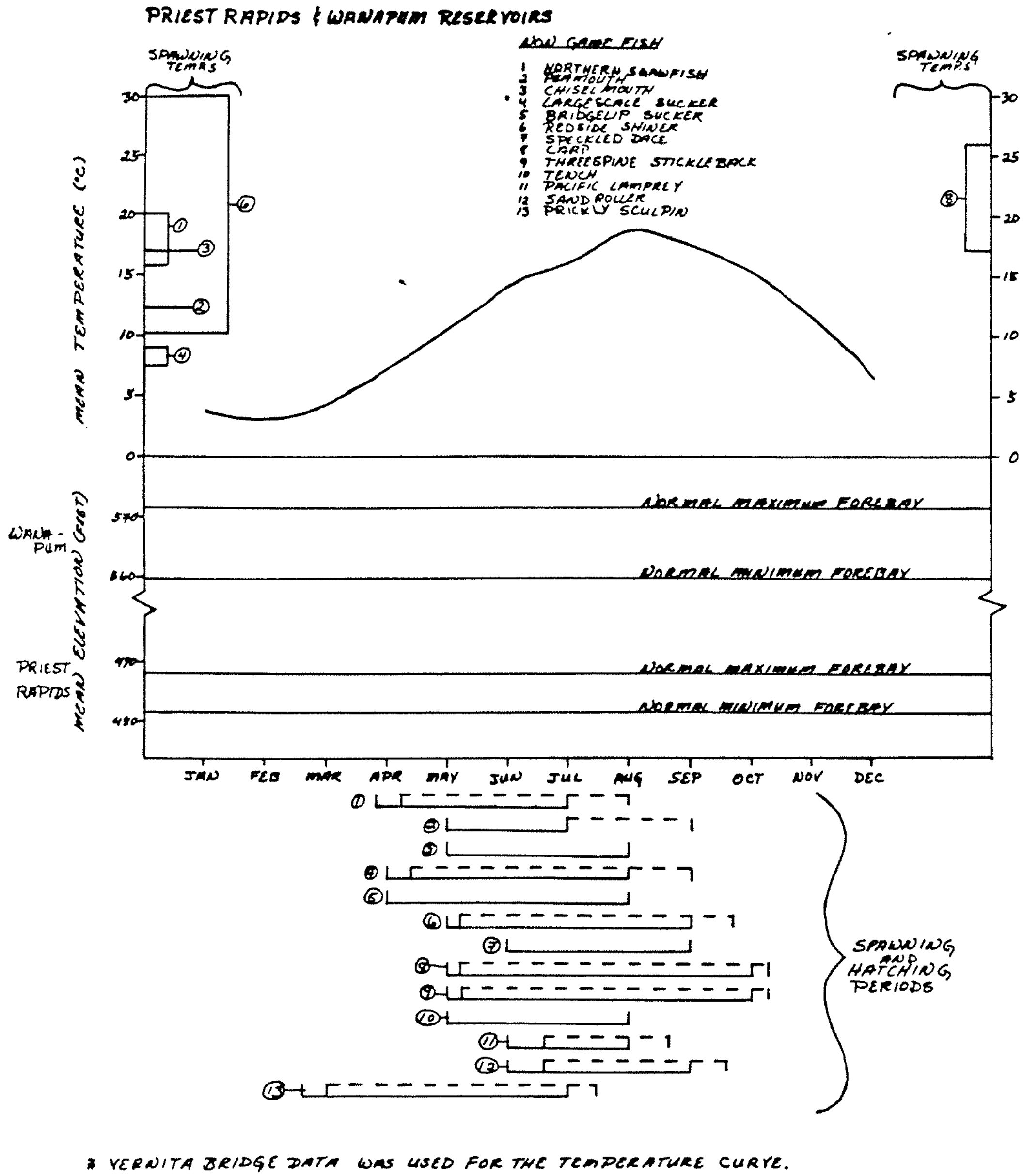


Fig. 23. Priest Rapids and Wanapum Reservoirs temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

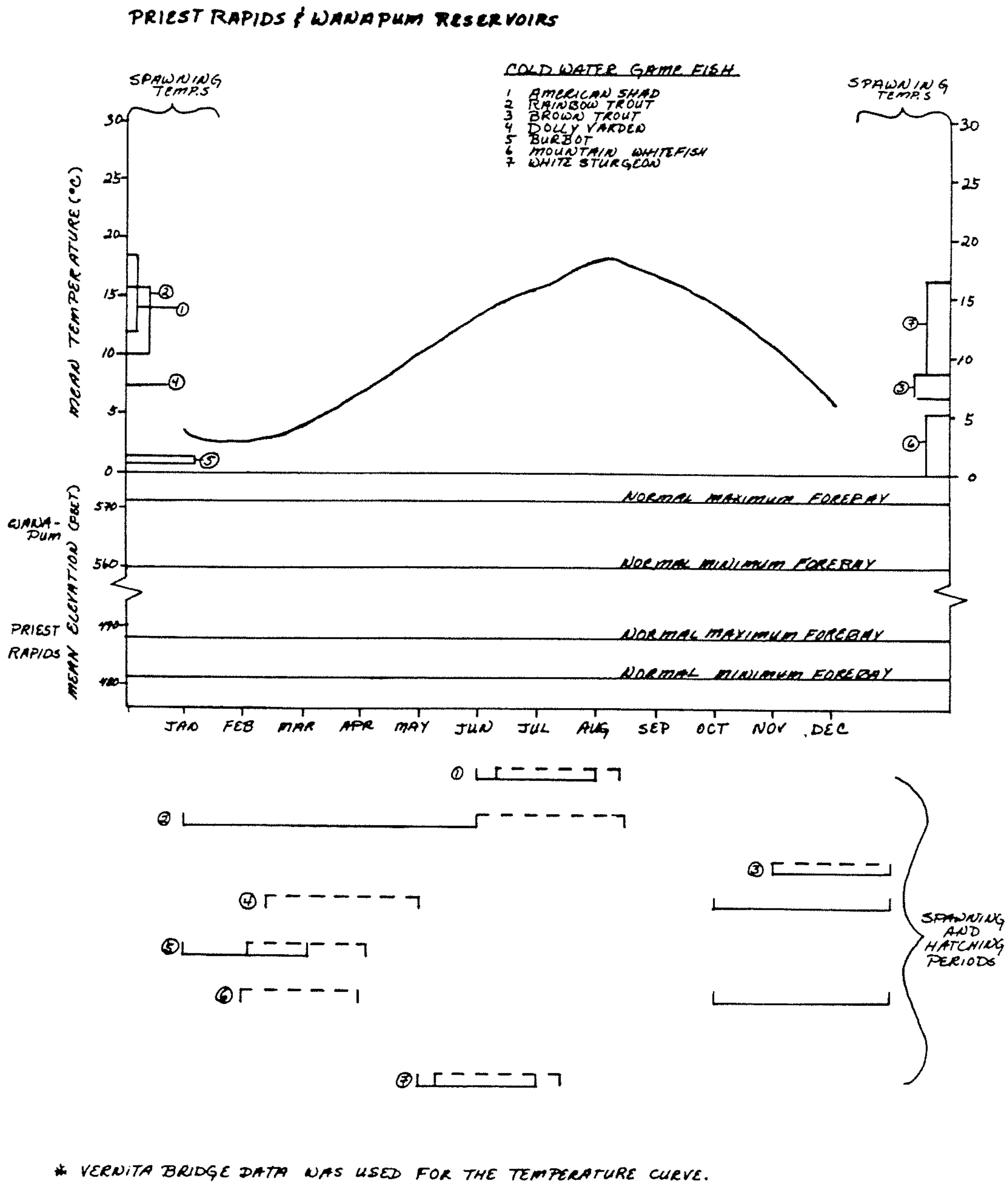
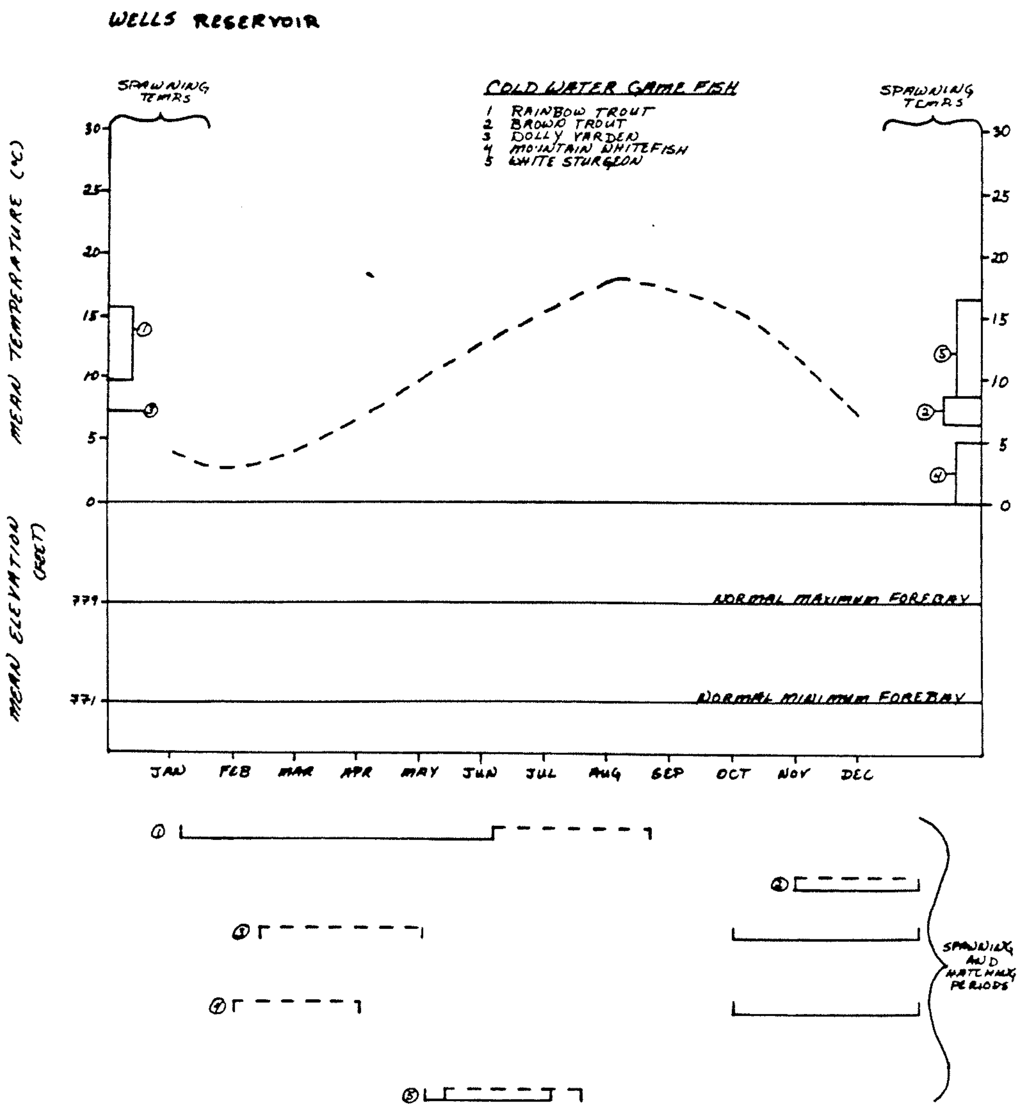


Fig. 24. Priest Rapids and Wanapum Reservoirs temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.



* THE TEMPERATURE CURVE WAS INTERPOLATED FROM PRIEST RAPIDS AND GRAND COULEE DATA.

Fig. 25. Wells Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

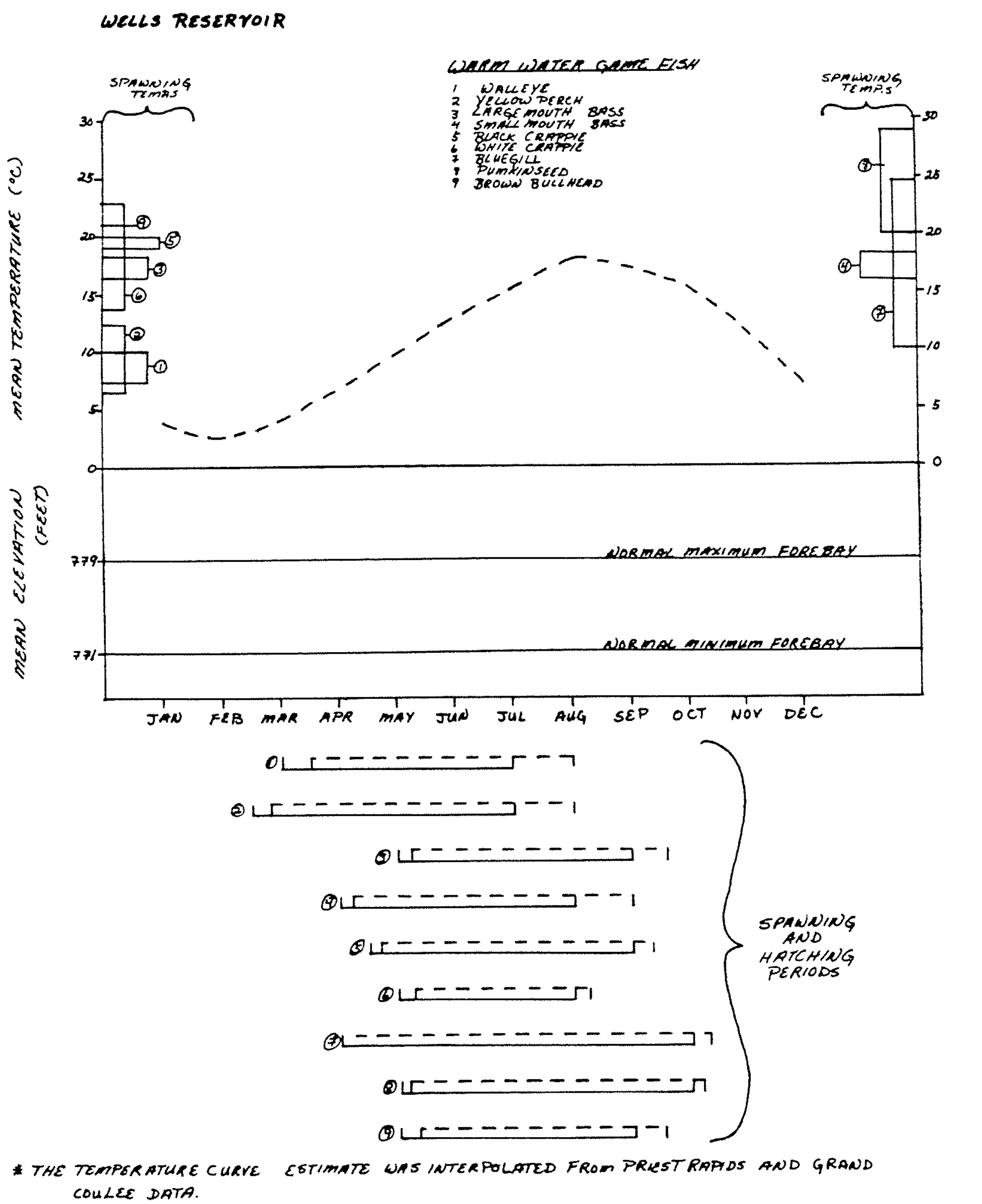
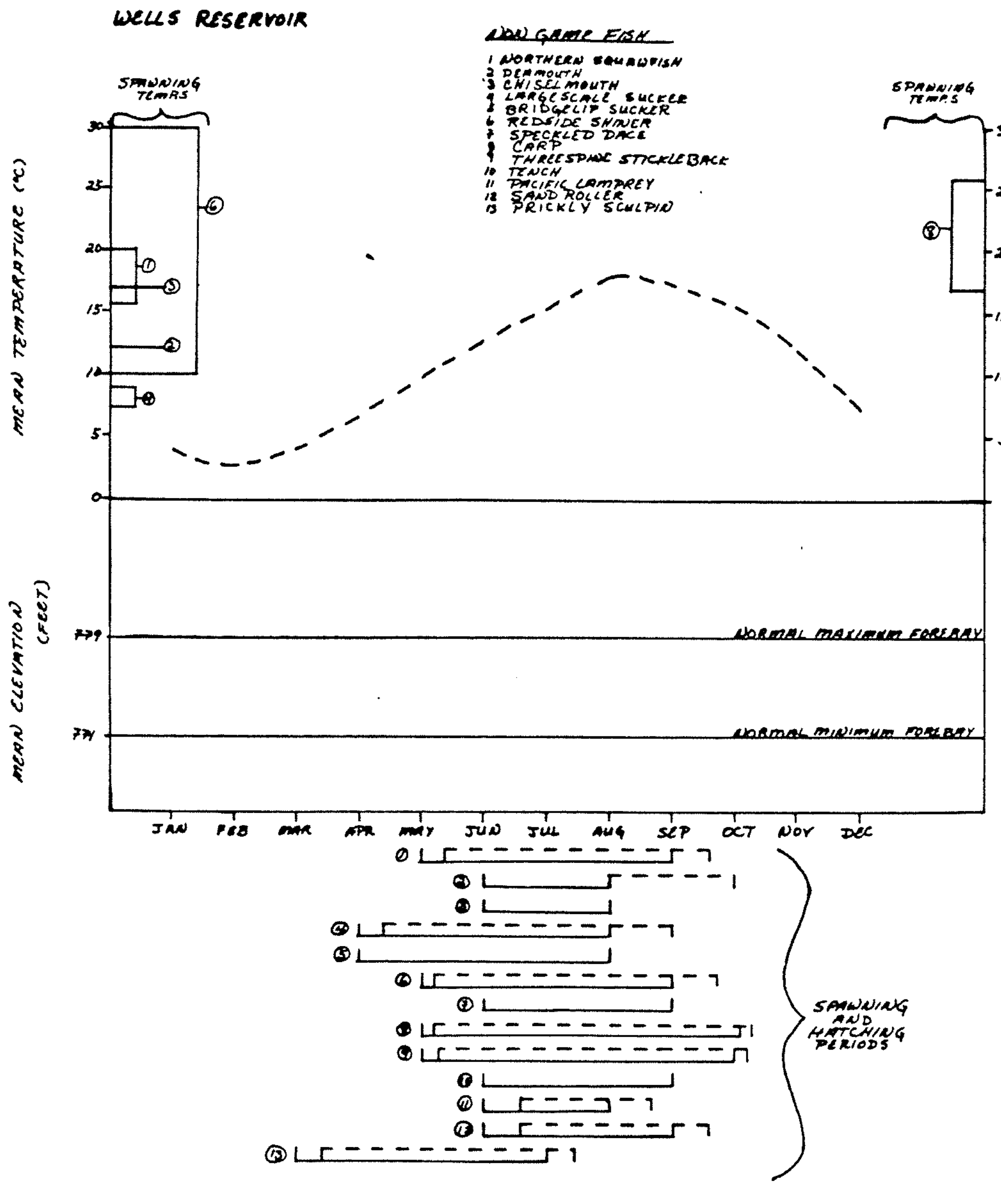


Fig. 26. Wells Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.



* THE TEMPERATURE CURVE WAS INTERPOLATED FROM PRIEST RAPIDS AND GRAND COULEE DATA.

Fig. 27. Wells Reservoir temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

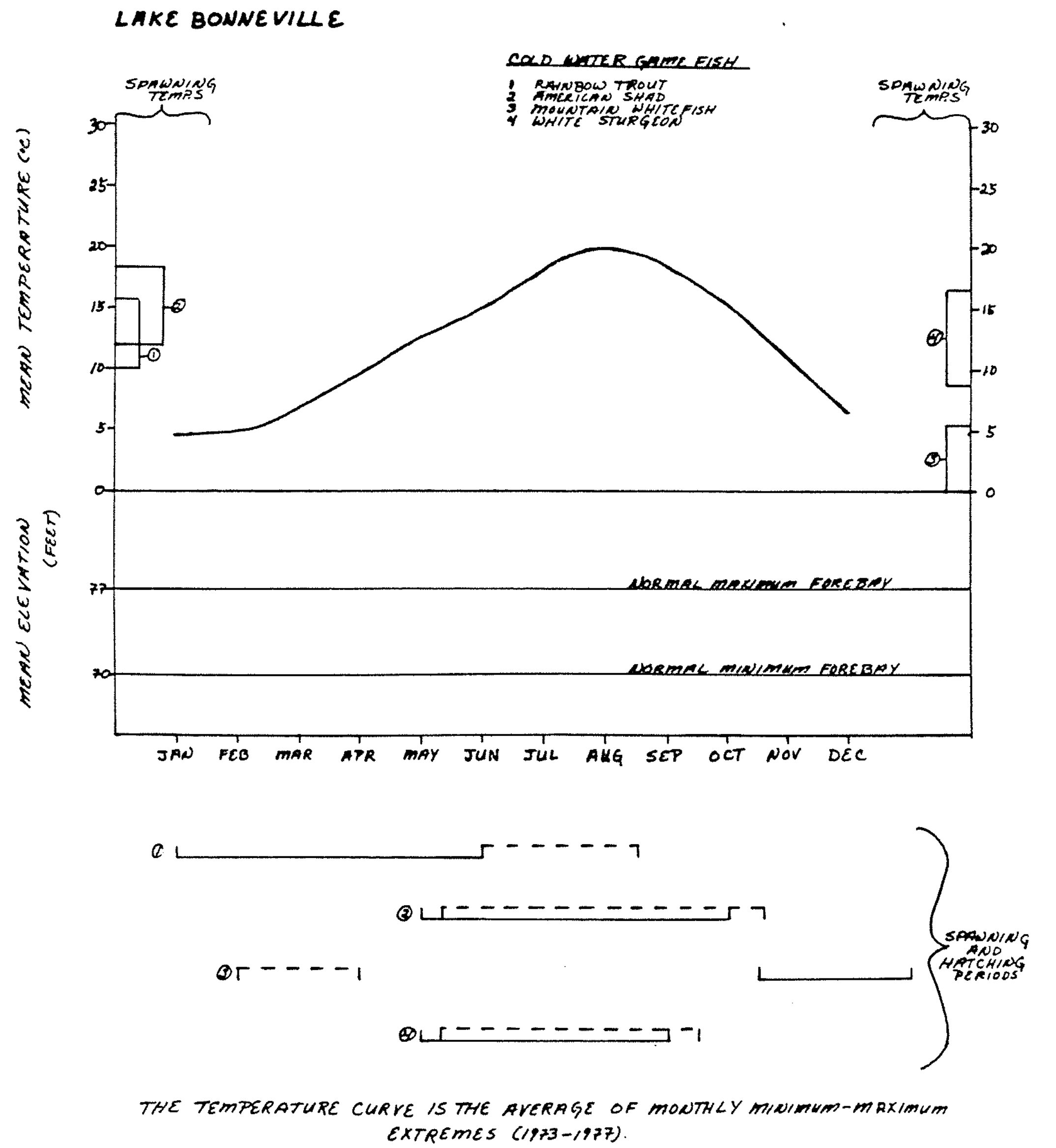


Fig. 28. Lake Bonneville temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

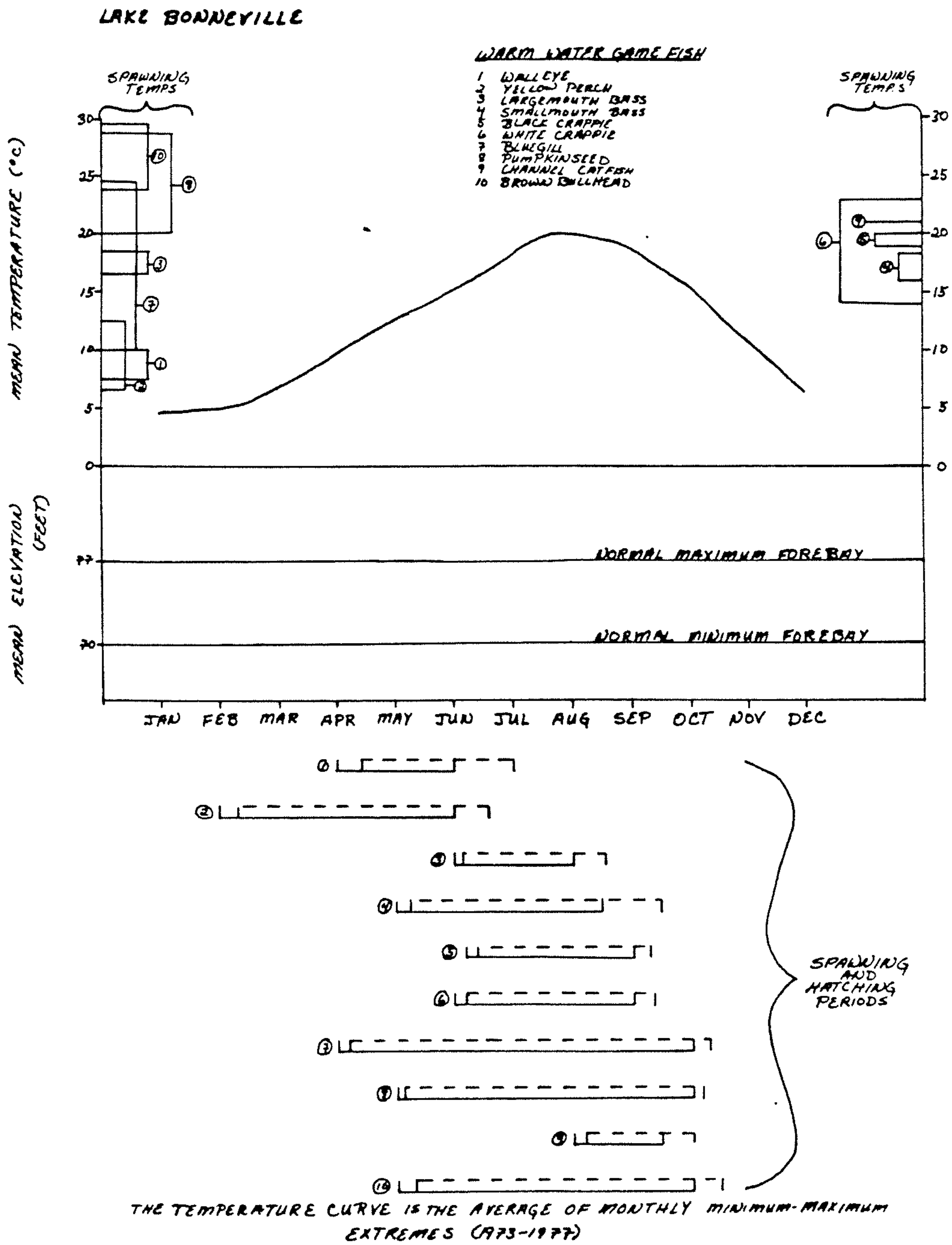


Fig. 29. Lake Bonneville temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

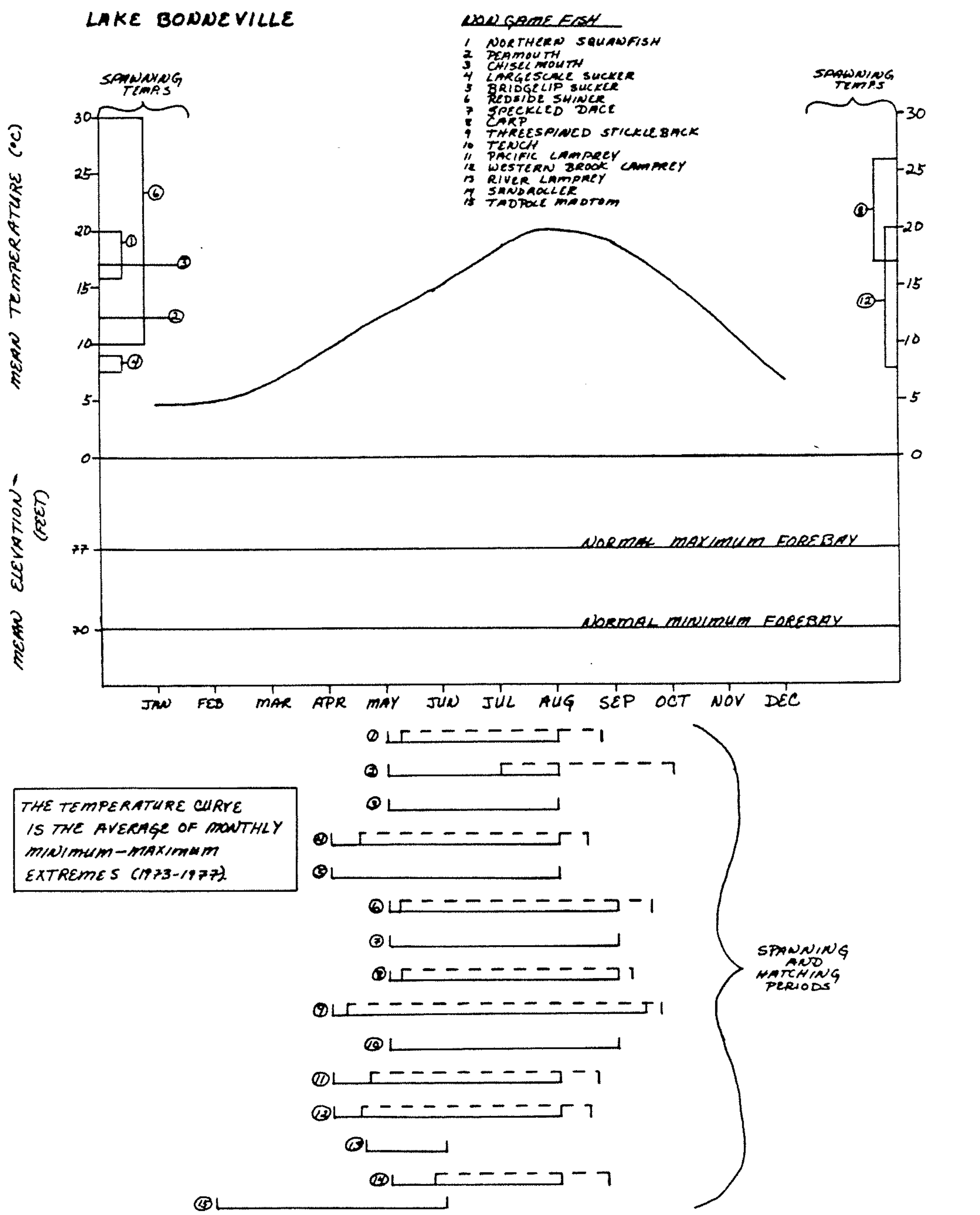


Fig. 30. Lake Bonneville temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

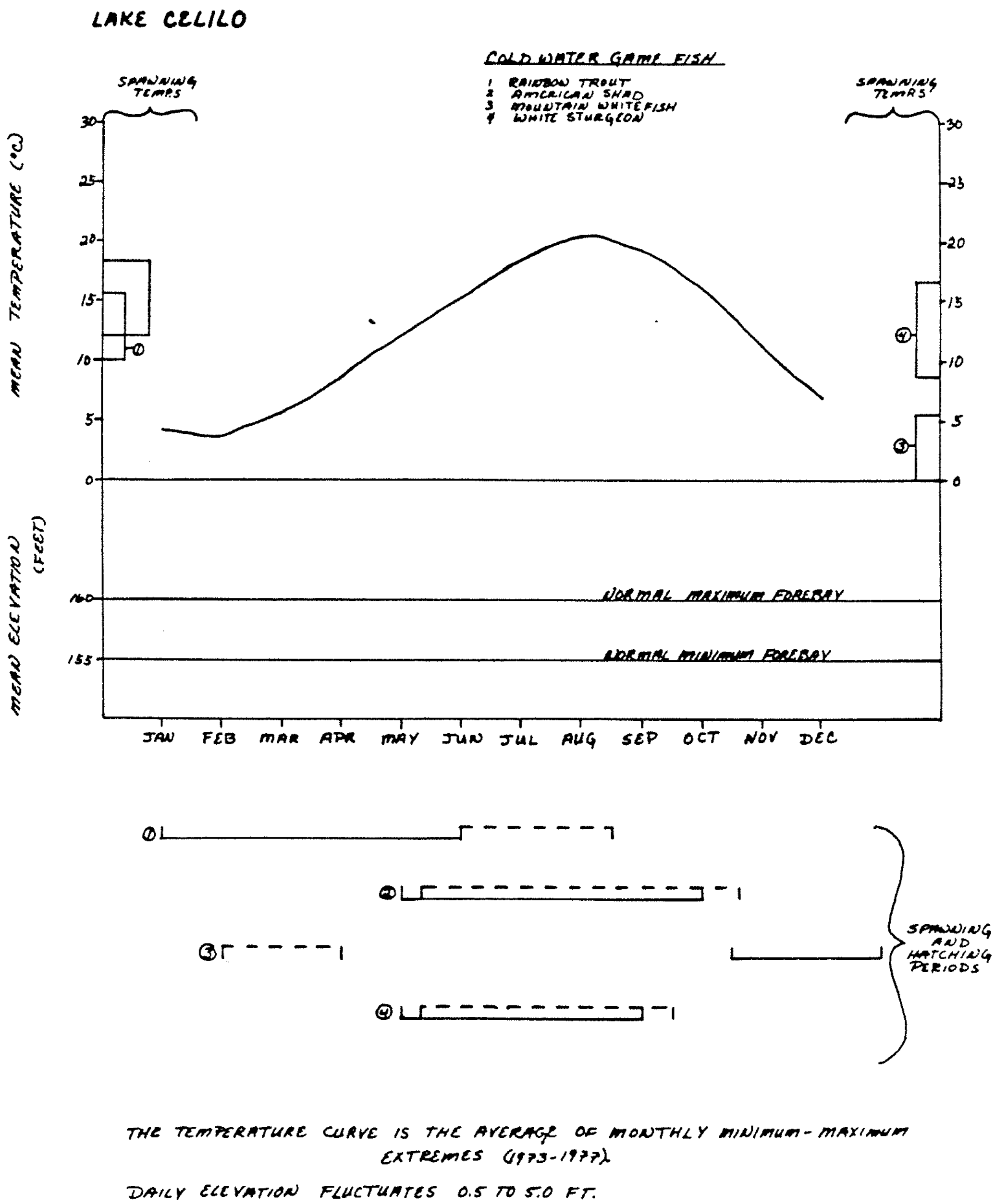


Fig. 31. Lake Celilo temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

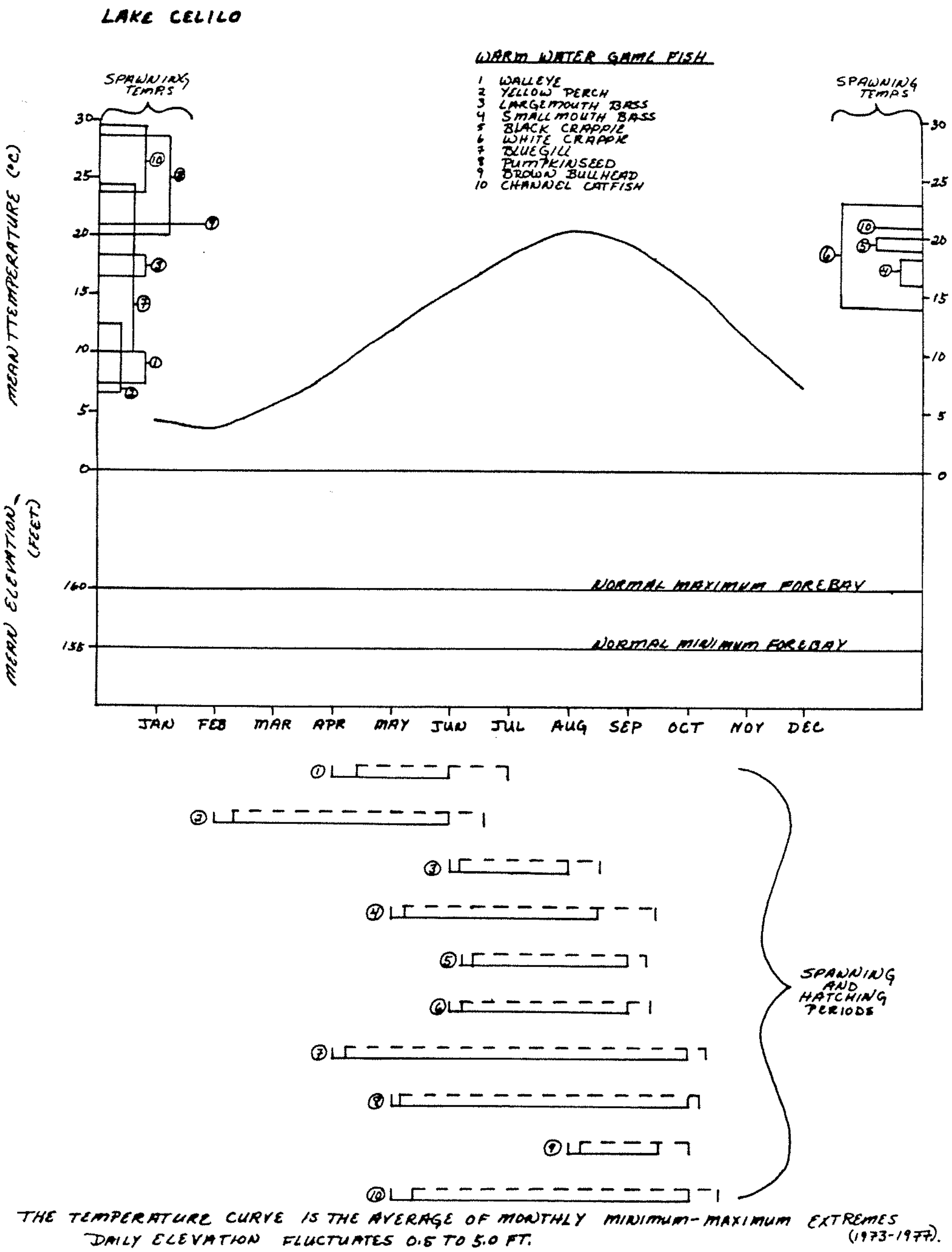


Fig. 32. Lake Celilo temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

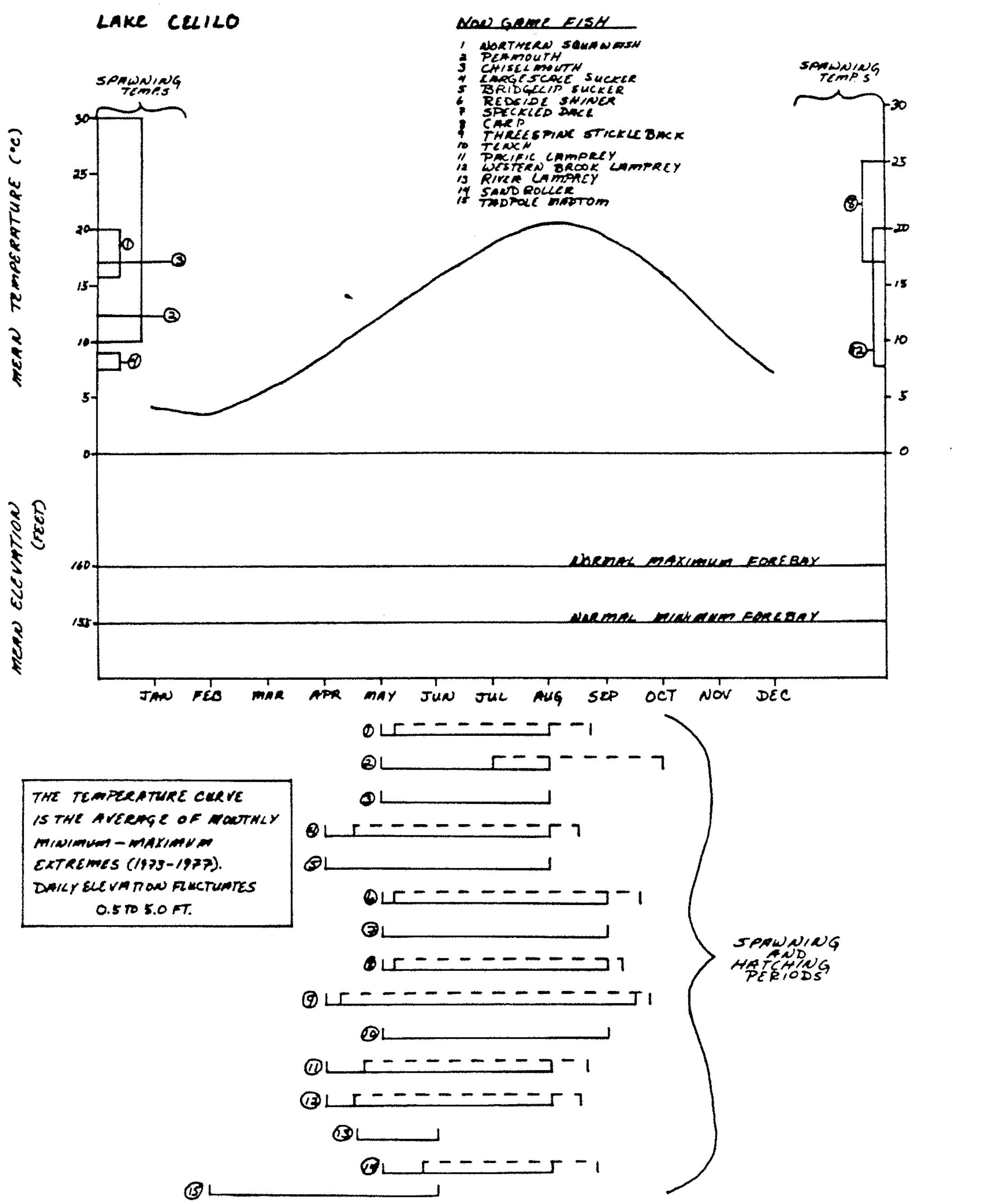


Fig. 33. Lake Celilo temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

These differences between Rufus Woods and other reservoirs may lead to several differences in fish fauna. Overall fish populations in other reservoirs may be higher due to shallower bottom slopes, nutrient input from tributaries, increased tributary spawning area, and warmer temperatures. The warmer temperatures might support larger populations of warm-water game fish, though water level fluctuations will still affect spawning success in the littoral zone. Stream spawners, such as cold-water game fish and several non-game species, may be more abundant in run-of-the-river projects if their habitat remains somewhat stable.

Two of the lower run-of-the-river reservoirs have special features that will influence their fish fauna. Lake Bonneville has a relatively small mean depth, with a high development of volume ratio and a very low bottom slope. Hence its shallow water areas should be extensive. Such a feature will encourage productivity and littoral species. However the annual storage ratio (retention time) is very short (1.5 days) and the high flow will carry away much of the production. Daily water level fluctuations remain high (7 ft), thus inhibiting shallow water spawning (see Fig 28).

Lake Wallula, behind McNary Dam, is influenced in its upper end by the free-flowing Hanford Reach. This area will accommodate more riverine species including chinook salmon which spawn at Hanford. In addition, the Snake River joins the Columbia in Lake Wallula, increasing the flow by half (USGS 1978) and perhaps increases the reservoir's productivity. A storage ratio of approximately four days, the longest of the run-of-the river reservoirs, may further enhance Wallula's productivity over other similar projects.

HANFORD REACH

General Description and Ecology

The Hanford Reach segment of the Columbia River is located between the headwaters of Lake Wallula and Priest Rapids Dam. The extent of the reach is approximately 50 miles, from R.M. 345, eight miles north of Richland, Washington, to R.M. 396 at Priest Rapids Dam. The flow through the Hanford Reach is regulated by the discharge from Priest Rapids Dam. Since the reach is not impounded by a dam, it is often referred to as the last "free flowing" section of the Columbia River in the United States above Bonneville Dam (e.g., Parametrix 1979). The flow of the river provides an optimal habitat for salmonids, sturgeon and other cold-water game fish. Salmon continue to spawn and rear in this reach of the river (Battelle 1976; Parametrix 1979).

This portion of the river has a shallower mean depth and a greater diversity of habitat types than the sections inundated by reservoirs. Depths sampled near the Hanford Generating Plant (R.M. 380) ranged from 18 to 32 ft and for calculation of productivity a mean depth of 20 ft was estimated (Battelle 1976). These depths are lower than those of any of the reservoir projects. Therefore, relative to the reservoirs there should be more shallow water in the reach, promoting productivity ind increasing habitat for shallow water species.

The wide range of habitats is reflected in the diversity of fish found in the Hanford Reach. These areas include cool, free-flowing sections, gravel bars, and islands, with sloughs and coves with warmer water. The free-flowing stretches have been crucial for preserving runs of wild chinook salmon and steelhead, and also support white sturgeon stocks (Battelle 1976; Parametrix 1979). The slower, warmer waters of sloughs maintain relatively large populations of warm-water game species (Parametrix 1979). The upper end of the reach is narrower, deeper, straighter, with little development of shoreline and no islands. The lower portion is wider, shallower, and contains sloughs and islands. The river continues into Lake Wallula, and thus has both lotic and lentic habitats (Gray and Dauble 1977).

The current velocity near the Hanford Generating Project is high, averaging 3 to 5 ft/sec (Battelle 1976). This is comparable to the velocity in the upper riverine section of Rufus Woods. High velocity environments are optimal for salmonids and less so for most slower swimming fish, such as suckers and centrachids. White sturgeon also prefer swift currents. The rapid flow carries away much local productivity, and most plankton in the Hanford Reach originates in upstream reservoirs (Battelle 1976).

Water levels through the Hanford Reach are dependent on discharges from Priest Rapids Dam, and fluctuations are presently 4 to 8 ft daily due to hydroelectric peaking operation (Parametrix 1979). These unstable water levels will limit reproduction of littoral-spawning fish species, such as most warm-water game fish and carp. Eggs of individuals that happen to spawn below daily minimum levels will not be affected. In addition, vegetation in the exposed zone will be less productive, and fresh-water 'intertidal' zones (i.e., water fluctuation zones) have been found to be lower in density and diversity of benthic invertebrates (Fisher and LaVoy 1972).

In October and November the flow is reduced daily to the spring minimum of 36,000 cfs, in order to prevent fall chinook salmon from spawning at levels that will be exposed the following spring (Bauersfeld 1978). Lake and mountain whitefish also spawn in the fall but do not spend time constructing a nest. Thus once-daily minimum flows may not deter whitefish, and eggs deposited during maximum flow periods could be exposed in the next cycle.

Stream spawning species will be less affected by water level changes, but the Hanford Reach has no tributaries. The Yakima River joins the Columbia 10 miles below Hanford and the Snake 11 miles further downstream. These rivers and Lake Wallula probably provide spawning and rearing habitat, but the extent of use of these areas is unknown. Warm-water game fish and some non-game species such as peamouth and squawfish may prefer the more lacustrine environment of Lake Wallula for spawning. Chiselmouth and trout may use the Yakima and its smaller tributaries for spawning.

The annual temperature cycle at Hanford is much the same as for the rest of the Columbia. Temperatures of water leaving the Hanford Reach at Richland are slightly above that of the water entering at Priest Rapids (USGS 1978). Most of the heat increment is from natural effects, but some is due to the Hanford Generating Project (Becker 1970). From July through September temperatures approach the upper limits of heat tolerance of young salmonids (16-20°C), though the lethal temperature is not reached (25°C) (Becker 1970). The river is well-mixed, and there is no thermal stratification.

Periphyton

The periphyton community of the Hanford Reach was sampled by Page and Neitzel (1978) and Page et al. (1979) using glass slides. The diatom genera *Navicula*, *Nitzschia*, and *Synedra* dominated the benthic flora during most sampling periods. *Gomphonema*, another diatom, was dominant in March 1977. Table 24 contains a list of genera that were collected. Chlorophyll a concentrations ranged from 68 mg/m^2 in March 1977 to 129 mg/m^2 in June 1978. Dry weight of periphyton and total organic matter were highest in September and lowest in March. Diversity values for Columiba River microflora were low.

River Benthos

The benthic macroinvertebrate fauna of the Hanford Reach has been investigated at river mile (R.M.) 380 (Wolf 1976) and 352 (Page and Neitzel 1976, 1977, 1978; Page et al. 1979). The bottom fauna at the upstream site

TABLE 24. Periphyton genera collected in the Hanford Reach of the Columbia River (after Page and Neitzel 1978 and Page et al. 1979).

CHRYSOPHYTA (Diatoms)

Amphipleura
Amphora
Asterionella
Caloneis
Cocconeis
Cyclotella
Cymatopleura
Cymbella
Diatoma
Dinobryon
Diploneis
Epithemia
Fragilaria
Frustulia
Gomphonema
Gyrosigma
Hannaea
Melosira
Navicula
Nitzschia
Rhizosolenia
Rhoicosphenia
Rhopalodia
Stephanodiscus
Synedra
Surirella
Tabellaria

CHLOROPHYTA (Green algae)

Ankistrodesmus
Closterium
Cosmarium
Pediastrum
Scenedesmus
Staurastrum
Stigeoclonium
Treubaria

CYANOPHYTA (Blue-green algae)

Anabaena
Plectonema

(R.M. 380) was dominated by sponges (*Spongilla lacustris*), caddisfly larvae (*Trichoptera*), and midge larvae (*Chironomidae*). A total of 77% of all organisms collected (excluding sponges) were trichopterans. *Hydropsyche cockerelli*, *Cheumatopsyche campyla*, and *Cheumatopsyche enonis* were the dominant trichopterans, while *Oecetis* and *Brachycentrus* were collected occasionally. Chironomids rarely formed more than 25% of the community (exclusive of sponges). Sponges occurred less frequently in the samples collected at the downstream site (R.M. 352), where chironomid larvae tended to be more numerous than caddisfly larvae. Other taxa (Table 25) were encountered irregularly and in smaller numbers than these larvae at both sites.

Populations of insect larvae were highest in the fall and winter and lowest in the summer. Diversity was low at both sites, reflecting single dominance and lack of complexity.

Fishes

The fish populations of Hanford have been well-studied by Battelle Pacific Northwest Laboratories (Battelle 1976; Gray and Dauble 1977). Sampling areas were upstream at the Hanford Generating Plant (R.M. 380) and downstream near R.M. 350. The most common fish found were squawfish, redside shiner, chinook salmon, largescale sucker, and peamouth. Relative abundance of these species varied at upstream and downstream sites, and with sampling year. In general, fish with diverse, less selective diets appear to be more successful. Squawfish are often predaceous on other fish, but in the Hanford Reach their primary food items were caddisflies, the larvae of which constitute over three-fourths of benthic invertebrates (Battelle 1976). Fish that rely heavily on plankton or other open-water food items were not common at Hanford (or elsewhere in the Columbia), since primary productivity is very low. This includes several warm-water game fish. Fish species such as suckers, peamouth, and sculpins, feed on detritus or benthic organisms, which are relatively abundant. Redside shiners are also numerous and are reported to be non-selective feeders (Battelle 1976). Chiselmouth are common and probably encounter little competition as periphyton feeders. They are not frequently found in Rufus Woods, F.D.R. or Banks Lake Reservoirs (Erickson et al. 1977; Stober et al. 1977a,b). Greater relative abundance in the Hanford Reach may be due to preference for a more riverine flow and to recruitment from a large population of chiselmouth in the Yakima River.

Cold-water game fish and salmon are more successful in the Hanford Reach than elsewhere in the main stem Columbia. Chinook salmon and steelhead trout spawn successfully due to suitable gravel bars and good flow. Young chinook are abundant in the reach. White sturgeon prefer and may require swift, cold, deep water. Hanford contains excellent sturgeon habitat and a resident landlocked stock (Batelle 1976; Parametrix 1979). Rainbow trout are found in greater numbers in the reach than in Rufus Woods (Battelle 1976; Erickson et al. 1977). However, lack of spawning tributaries and suitable open-water food items may restrict trout

TABLE 25. Benthic invertebrate taxa collected in the Hanford Reach of the Columbia River (from Wolf 1976).

Porifera - Sponges

Spongilla lacustris

Coelenterata

Hydra sp.

Platyhelminthes - Flatworms

Dugesia sp.

Nematoda - Roundworms

Annelida - Segmented Worms

Arthropoda

Crustacea

Gammarus sp.
Pacifasticus trowbridgii

Arachnida - Spiders and Mites

Hydracarina sp.

Insecta

Ephemeroptera - Mayflies
Odonata - Dragonflies
Trichoptera - Caddisflies

Hydropsyche cockerelli
Cheumatopsyche campyla
Cheumatopsyche enonis
Brachycentrus sp.
Oecetis sp.

Diptera

Simulium sp. - Blackflies
Chironomidae - Midgeflies

Mollusca

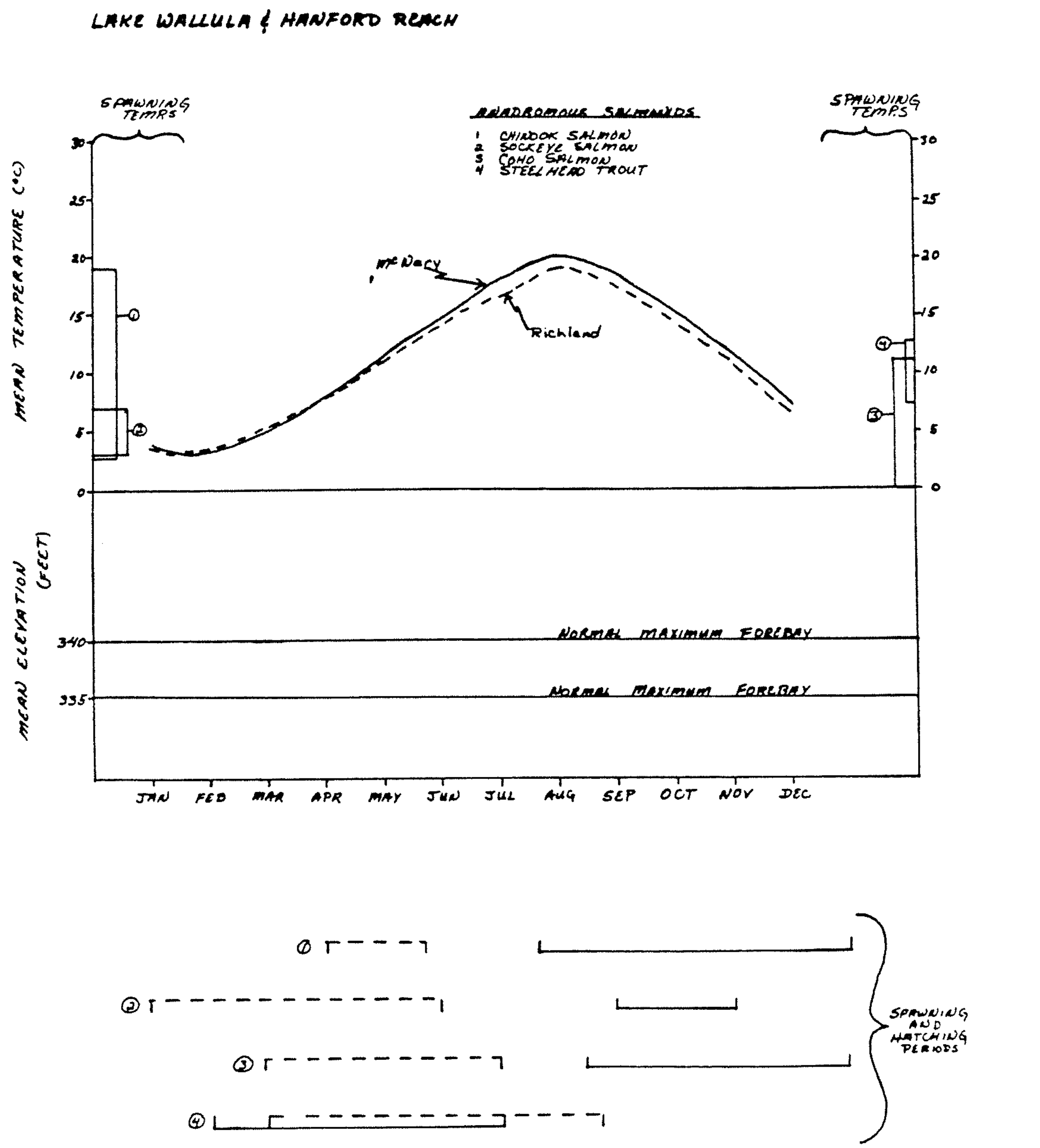
Physa sp.
Limnaea sp.
Fisherola nuttalli

populations in general. Whitefish, which bottom feed and have a diverse diet, have been more successful than trout.

Warm-water game fish find better conditions in the lower section of the Hanford Reach than in run-of-the-river reservoirs. Some species, for example yellow perch and black crappie, may be constrained by several factors. Flow may be too swift, fluctuating water levels may dewater eggs, and pelagic food items may be scarce. Habitat should be slightly better for channel catfish and small-mouth bass, but neither is common. Walleye were rarely found. One hypothesis is that this species has begun to expand its range in the Columbia by moving downstream from F.D.R. Lake. Little data are available concerning its presence in the lower Columbia, although it has been observed. This species is a particularly voracious piscivore and may eventually establish itself as a dominant species. Figures 34 to 37 show spawning requirements of fish found in Hanford Reach in relation to seasonal temperatures and water levels.

The Hanford Reach shares several characteristics with run-of-the-river reservoirs, but has little in common with the two storage projects (F.D.R. and Umatilla Lakes). The flow of the river is unimpeded, thus retention time is short, as in the run-of-the-river reservoirs. This effectively flushes much of the production out of the reach; however, productivity in the water column is not a criterion of a healthy river system. The discharge of Priest Rapids Dam determines the flow through the reach, hence the same daily fluctuations in water level found in the reservoirs also occur in this reach. The seasonal cycle of water temperatures is also similar throughout the river. The above characters maintain some similarity between the fauna of the Hanford Reach and the reservoirs, but the distinctive character of the reach remains. As the last free-flowing section, it is the only area on the main stem Columbia where wild salmon and steelhead successfully reproduce.

Even though this reach of the river is unique and provides the only remaining habitat in the main stem river necessary for the reproduction of wild salmon and steelhead, we could not find data specifically identifying the instream discharges required to insure the future reproductive success of these fishes. Until data which evaluate the effects of discharge become available, it will be very difficult to develop an optimum water management strategy. The relationship between the minimum and optimum discharges required by the critical life history stages of salmonids naturally reproducing in this reach is needed in order to evaluate the effects of the numerous alternative water management strategies proposed.



* HANFORD REACH IS INCLUDED IN McNARY.

Fig. 34. Lake Wallula and Hanford Reach temperature and elevation curves with spawning temperatures and spawning and hatching periods of anadromous salmonids.

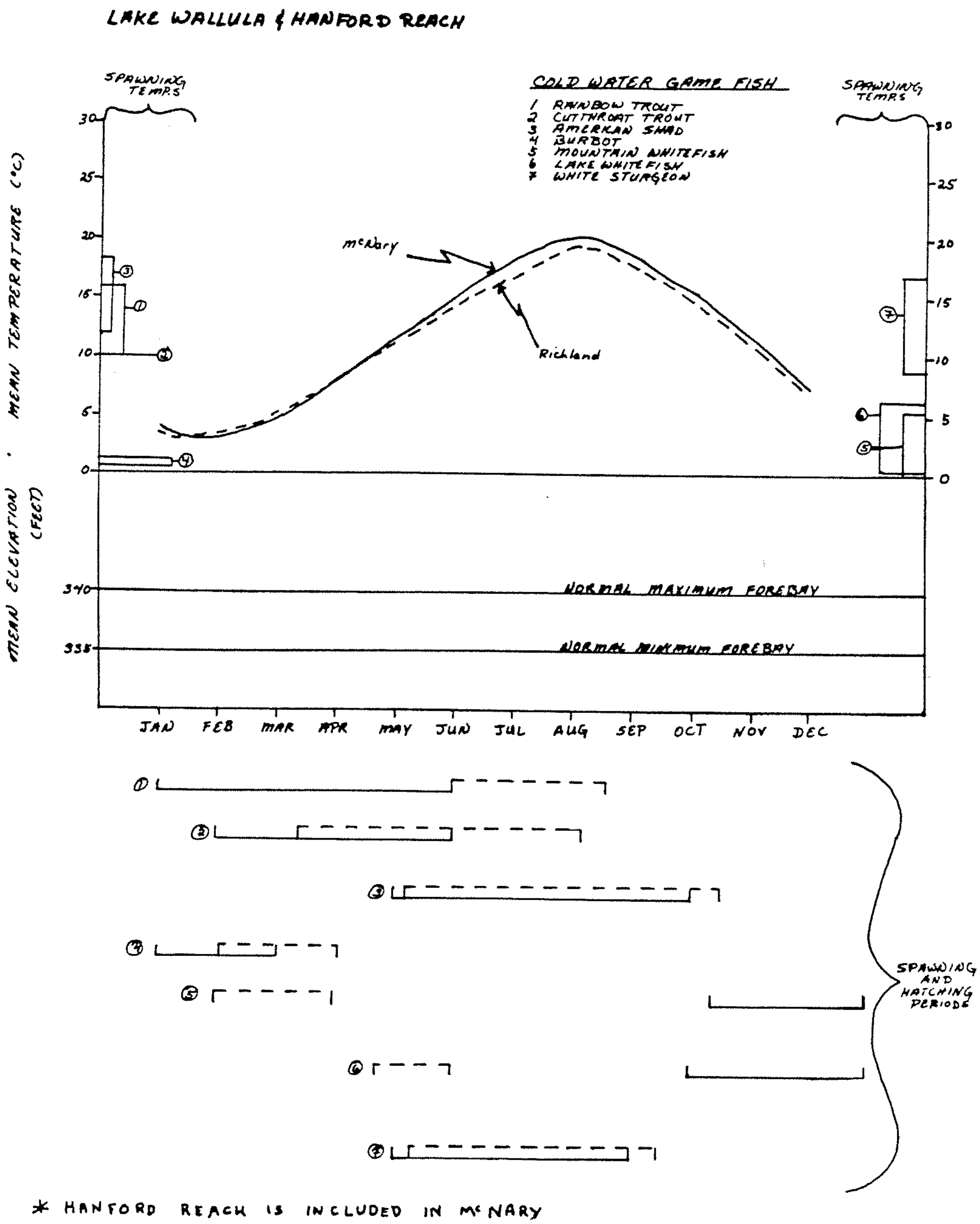


Fig. 35. Lake Wallula and Hanford Reach temperature and elevation curves with spawning temperatures and spawning and hatching periods of cold-water game fish.

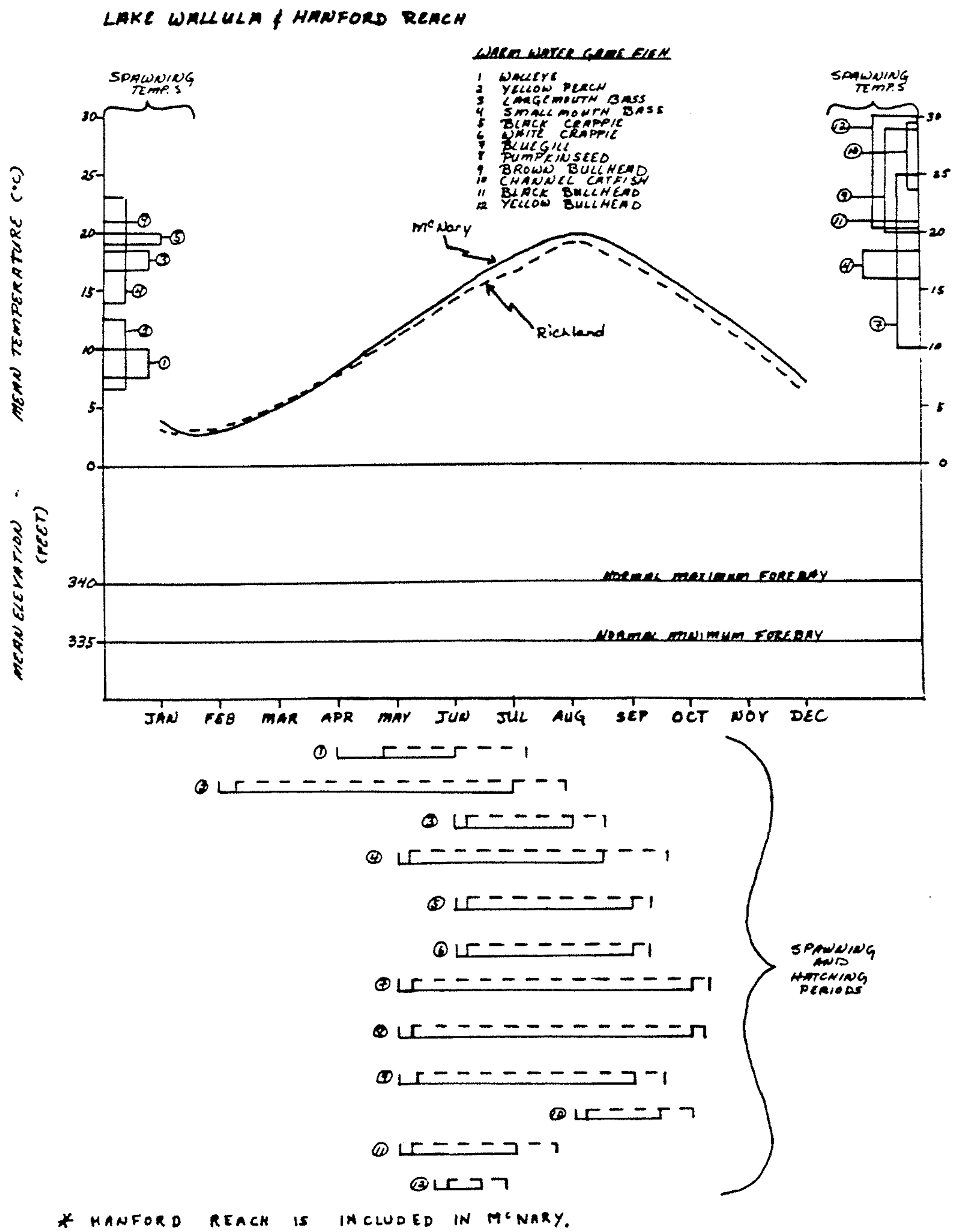


Fig. 36. Lake Wallula and Hanford Reach temperature and elevation curves with spawning temperatures and spawning and hatching periods of warm-water game fish.

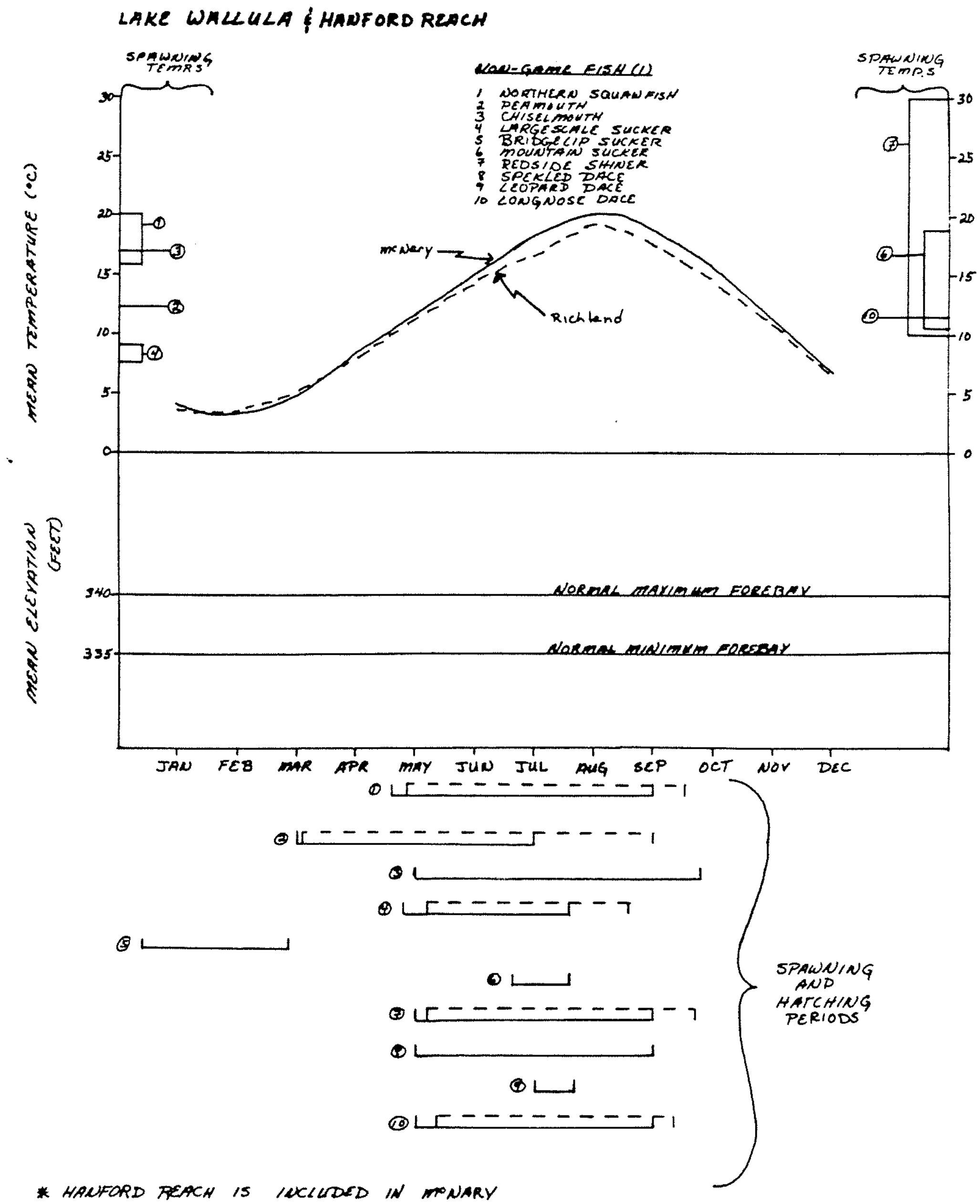


Fig. 37a. Lake Wallula and Hanford Reach temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

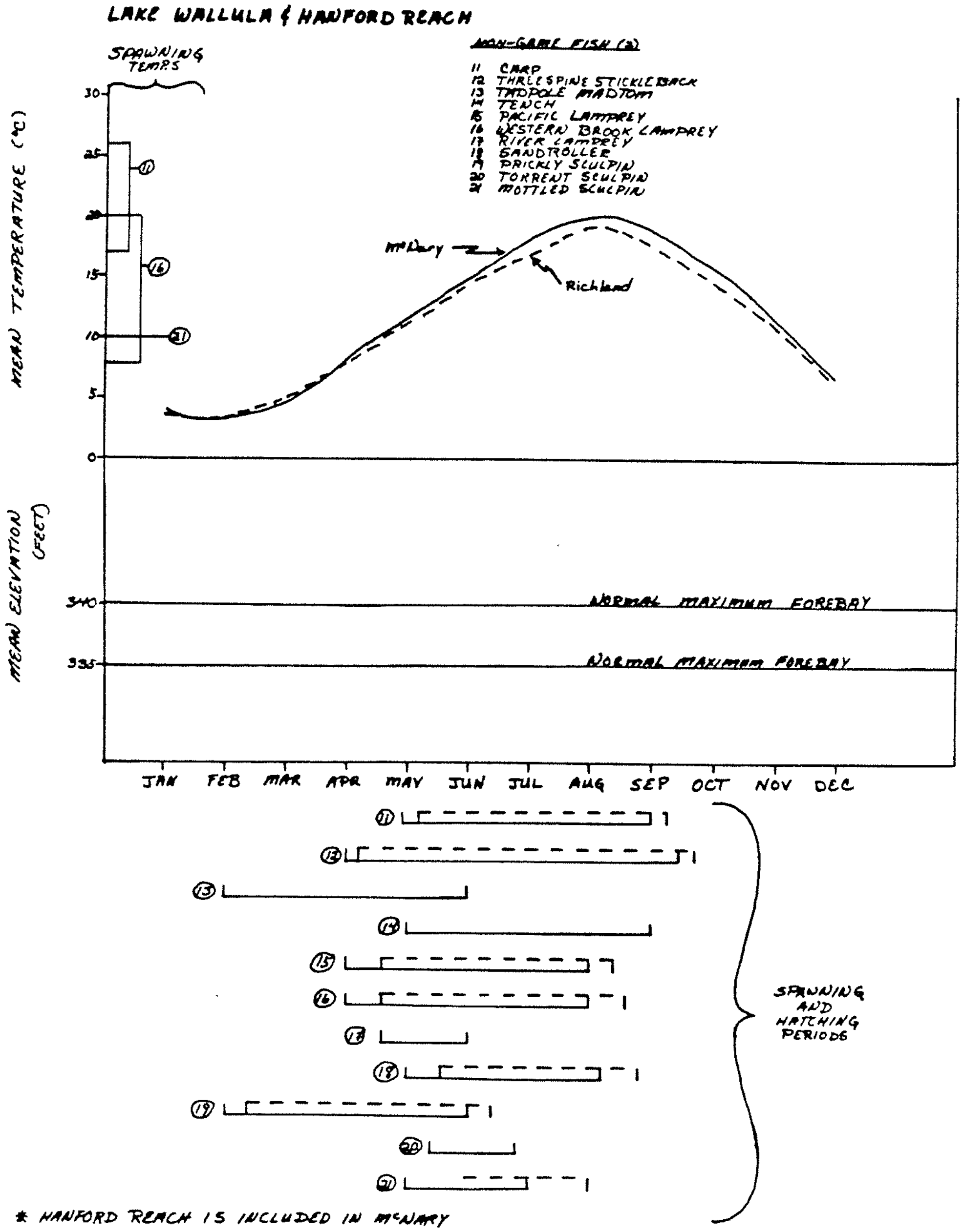


Fig. 37b. Lake Wallula and Hanford Reach temperature and elevation curves with spawning temperatures and spawning and hatching periods of non-game fish.

SELECTED TRIBUTARIES

Introduction

The tributaries of the Columbia River between Bonneville and Grand Coulee Dams are similar in several aspects. In general, these streams form in high subhumid mountains and in their lower reaches pass through flatter, semi-arid terrain. In the upper reaches the gradient is steep, hence water velocity is high, and may lead to scouring of the streambed. Downstream the topography is flatter; stream flow is reduced and there is some deposition of the sediment load. The water temperature increases as a result of lower flow and higher air temperatures. Water flow is generally dependent on snowmelt in the mountains. Thus there is a marked variation between high flows in spring and early summer, and yearly lows in August and early fall.

Nearly all of the tributaries in the study area have a substantial portion of the discharge diverted for irrigation purposes. This ranges from withdrawals which completely dewater lower portions of the Umatilla (Nielson 1950) to pumping and diversions from the Okanogan and its tributaries which divert only six percent of the main stem discharge during the irrigation season (PNRBC 1977b; USGS 1979). Effects of irrigation are manifested in the rivers at periods of reduced flow when streams are at their seasonal low, allowing temperatures to increase further. Irrigation return flows, carrying high concentrations of nutrients, are added when the river is least able to dilute the concentrations.

The characteristics of the tributaries may be distinguished from those of the main stem Columbia. The outstanding features of the main stem are dams and impoundments, while those of the tributaries are seasonal flow variation and irrigation withdrawal. Yearly flow cycles on the Columbia are regulated through the use of storage reservoirs such as Roosevelt Lake and the B.C. storage projects (i.e., Lake McNaughton and Arrow Lakes). Water management on the tributaries has fewer means to regulate seasonal flow levels. Reservoirs on the Okanogan and Umatilla are primarily for irrigation purposes (Bryant and Parkhurst 1950; USGS 1978), while the six storage units in the Yakima headwaters do not have the capacity to supply adequately both the heavy seasonal demands of irrigation and natural summer flows. Plans exist to enlarge Bumping Lake to increase summer minimum flows for fishery resources on the Yakima River (USBR 1977). Storage reservoirs not only ameliorate low summer flows on the main stem but also control flood waters. In contrast, the general lack of storage on the tributaries makes them susceptible to flooding (PNRBC 1977a,b). High spring flows may scour the riverbeds of attached organisms, reducing productivity as well as reduce the survival of stream spawning fishes.

Dams present barriers to migrating fish on the main stem, but combinations of low flows and high temperatures found in the lower reaches of tributaries can be just as effective as dams for inhibiting fish passage. Spawning salmonids are prevented from entering the Yakima and Okanogan in late summer until temperatures decline in the fall (PNRBC 1977a,b). The lower section of the Umatilla is completely dewatered, thus blocking migration altogether (Nielson 1950, Smith 1973). Salmon and steelhead do, however, spawn in the tributaries, if they arrive preceding or after periods of dewatering or adverse temperatures in the lower reaches. The shallower depth of the streams is favorable for salmon rearing, and is another contrast to the main stem, with its inundated former spawning and rearing areas.

No data were found on the bottom fauna of the Yakima, Okanogan, or Umatilla rivers. The bottom fauna of the Cedar River (Malick 1977) and the Skagit River (Graybill et al. 1979), two western Washington streams, and the Clearwater River, Idaho (MacPhee and Brusven 1973, Brusven and Trihey 1978) was dominated by aquatic insects. Dipterans, primarily chironomids, were the most abundant organisms in all of these streams, while mayfly nymphs (Ephemeroptera), stonefly nymphs (Plecoptera), and caddisfly larvae were also important in the benthic macroinvertebrate community. The fauna of the Yakima, Okanogan, and Umatilla rivers would probably be similar to the fauna of these streams.

Yakima River

General Description. The Yakima River is the largest river system entirely within Washington State, draining an area of 6150 square miles (Bryant and Parkhurst 1950; Lee et al. 1976). The river drops 2100 feet in a slight gradient from its origin in Lake Kacheelus in the eastern Cascades to its confluence with the Columbia at Richland, Washington (R.M. 335.2) (Bryant and Parkhurst 1950). The main stem is 216 miles long, but the total length of the system including tributaries is 799 miles (Lavier 1976b). The Naches River is the largest of over 17 main stem tributaries; irrigation drainage canals now add to this number. Bryant and Parkhurst (1950) have described in great detail the dams, diversions, and stream character of the Yakima system. Figure 38 shows the main stem Yakima, its tributaries, and points of diversion for irrigation.

Water Quantity. The Yakima discharges approximately 2.5 million ac ft of water into the Columbia annually, but this is less than the 4 million ac ft possible (USGS 1978; Sylvester and Seabloom 1962). The difference is evapo-transpirative loss due to irrigation. Table 26 summarizes the sources of input and withdrawal along the main stem Yakima. Below the origin at Kecheelus Lake, the two major sources of inflow are the Cle Elum River, which includes releases from the largest storage reservoir in the basin, and the Naches River, the largest tributary and location of Rimrock, Bumping, and Clear Lake reservoirs. Data were not found for the irrigation diversion canals from which to accurately determine the withdrawal of water.

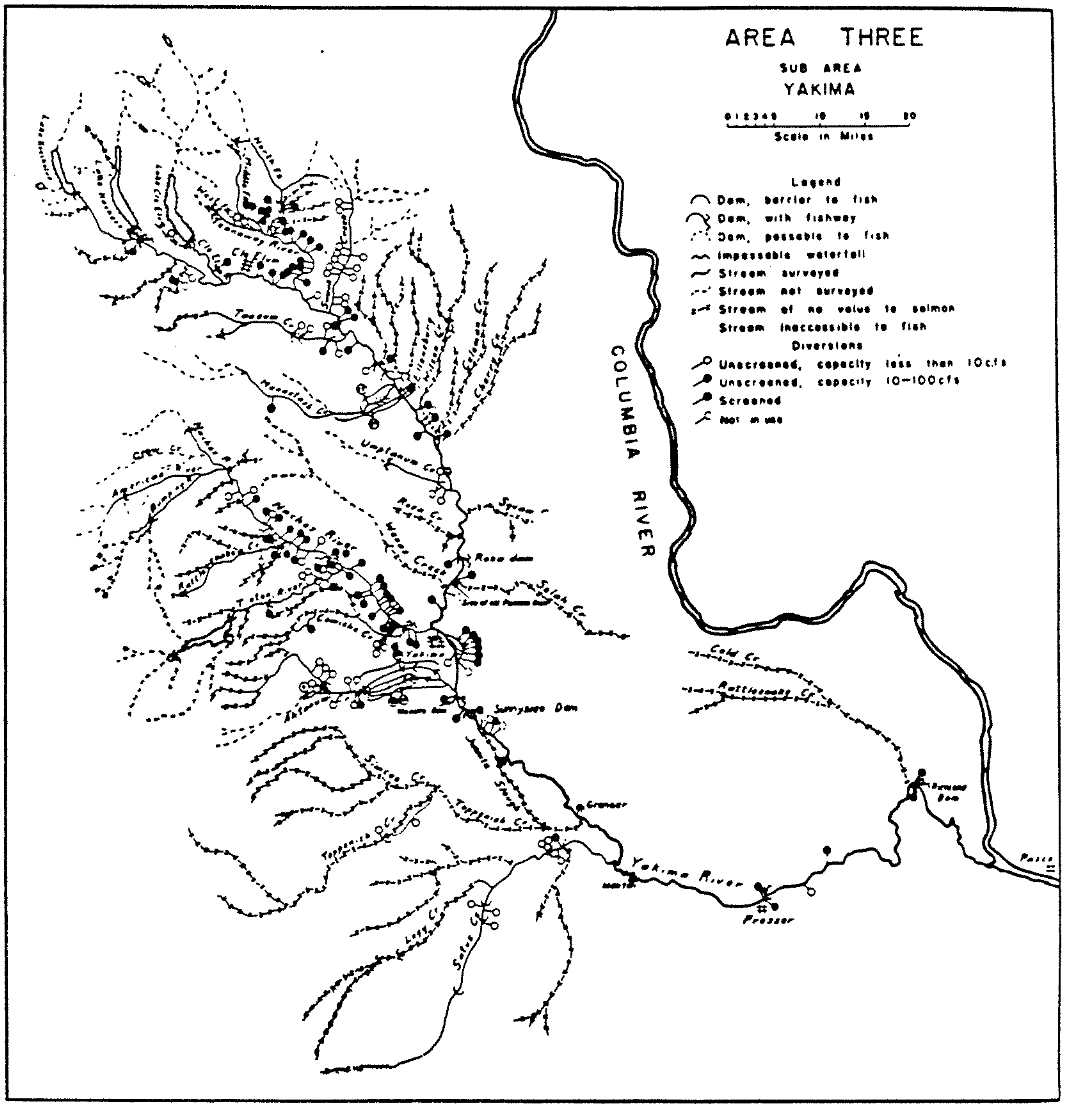


Fig. 38. Yakima River and tributaries from Bryant and Parkhurst, 1950.

Table 26. Water Quantity - Yakima River.

YAKIMA RIVER[1]

Input (ac-ft)		Output (ac-ft)
	Total Discharge	Total Withdrawal
Keechelus Lake	= 232,300 (270,020)	
Price Creek		
Swamp Lake Creek		
Mosquito Creek		
Telephone Creek		
Stampede Creek		
Cedar Creek		
Hudson Creek		
Cabin Creek		
Kachess River	= 143,500 (233,759)	
		Kittitas Diversion Canal
Silver Creek		
Tucker Creek		
Big Creek		
Little Creek		
Peterson Creek		
Spex Arth Creek		
Cle Elum River	= 718,600 (729,505)	
		Cle Elum Town Ditch
		Frazer Ditch
		O'Conner Ditch
Tillman Creek		
Crystal Creek		
Thornton Creek		
Teanaway River		
Kittitas Main Canal Wasteway		
Horseshoe Canyon Creek		
Morrison Canyon Creek		
		Swauk Creek Irrigation Ditch
Swauk Creek		
		Cascade Flume Canal
		Garrison Ditch
		Ellison Ditch
		Westside Irrigation Co. Canal
Taneum Creek		
		Ole Town Irrigation Canal
		Ellensburg Power Canal
Dry Creek		
Ellensburg Power Canal Outfall		
		Mills Power Creek
Manastash Creek		
Reecer Creek		
		Fogerty Ditch
		Tjossem Ditch
		Reed Ditch
		Grinrod-Doughty Ditch
		Damon Mill Ditch
		Stone-McGaff Ditch System
		Stein-McLeod Ditch
Fogarty Ditch Outfall		
Benway Canyon Creek		
Wilson Creek		
Umtanum Creek		
McPherson Canyon Creek		
Squaw Creek		
Roza Creek		
Burbank Creek		
Selah Creek		

YAKIMA RIVER (Continued)

	Selah-Moxee Canal
Wenus Creek	
	Taylor Ditch
Moxee Creek	
Naches River = 957,400 (1,427,301)	
Roza Canal Wasteway	
Wide Hollow Creek	
	Cascade Lumber Co. Ditch
	Moxee
	Union Gap Ditch
	Richartz Ditch
	Lesh Ditch
	Bachelor Creek Ditch
Ahtanum River = 77,600	
	Old Reservation Canal
	Sunnyside Canal
	Flint Ditch
E. Toppenish Drain Canal	
	Kirkwood Ditch
Toppenish Creek	
	Snipes Mountain Lateral Canal
Satus Creek	
Sulphur Creek Wasteway = 152,850[2]	
	Chandler Canal
	Prosser Power Canal
	Gibbon Station Diversion Ditch
Spring Creek	
Snipes Creek	
	Kiona Canal
Yakima River at Kiona (last gaging station before confluence with Columbia River) = 3,108,000	
Corral Canyon Creek	
Cold Creek	
	Richland Canal
	Columbia Canal

[1]Total discharge and total withdrawal data are unadjusted from water year 1978. Discharges in parentheses are adjusted for changes in reservoir contents. (U.S.G.S. 1979)

[2]Data for March 1976-February 1977.

Half a million acres (13.5 percent of the total basin area) are irrigated (PNRBC 1977a). Irrigated agriculture is the largest water user in the basin, and the river system is managed to maximize water availability during the summer and fall. Six reservoirs in the headwaters store water to augment the naturally low summer-fall flows; a network of dams, diversions, canals, and drains distribute the water for use and reuse. Thus, the character of the basin is artificial and water is intensively managed (Lee et al. 1976). As a result of irrigation return flows, the lower river is laden with nutrients and is perhaps 4°C higher in temperature than the natural stream would be (Sylvester and Seabloom 1962).

The Yakima Irrigation Project storage system operates on a filling schedule in fall and winter, after the irrigation season, and on a forecasted runoff basis after January 1. Most precipitation falls in winter and mountain snowmelt adds to the flow through July. Storage released during the period July through October maintains the river flow and provides most of the water for irrigation (Bryant and Parkhurst 1950; USGS 1978). Only Cle Elum and Kachess Lakes have dead storage; the other four reservoirs (i.e., Bumping, Clear Creek, Kecheelus, and Rimrock) can be completely drafted if the entire storage is needed for irrigation.

Fishes. Prior to development of irrigation, the Yakima was a major producer of salmon. The former runs of about 600,000 fish dropped drastically from 1890 to 1905, and have since declined to about 11,000 fish (Lavier 1976a). Table 27 lists the size of chinook, coho, and steelhead runs and general areas of spawning. Dams, unscreened diversions, low flow rates, and high temperatures have all contributed to the loss.

Patten et al. (1970) studied the distribution of fish in the Yakima and concluded that temperature was the main determinant of the distribution patterns. Table 28 gives the overall distribution of each species in the Yakima. The lower reach of the river (below Chandler Dam) contains each of the warm-water game species, but only three of the cold-water game fish. Above Roza Dam (the upper reach of the Yakima) more trout species and sculpins are found, but only bluegill and pumpkinseed among the warm-water game species. Salmon and most non-game fish can be found in nearly all segments of the river. Although a species may be found throughout the river, its abundance may be much greater upstream or downstream of the mid-river diversion dams (Sunnyside and Wapato Dams). The catches along the river give a better indication of habitat preferences. Table 29 shows catch per unit effort of each species above and below Wapato and Sunnyside Dams. During summer months an increase from 15°C above the dams to 20°C below them was recorded (Patten et al. 1970). Over two-thirds of the catch of each of the eight species of salmon and cold-water game fish was made above Wapato Dam, while the reverse pattern was true of all seven species of warm-water game fish. A similar division was true of the non-game fish. Warm-water species such as squawfish, peamouth, chiselmouth, dace and carp predominated downstream, while lampreys, sculpins, mountain sucker and other cold-water species were found upstream of Wapato Dam. Walleye were not found in the Yakima during this 1957-1958 study (Patten et al. 1970).

Table 27. Present use of the Yakima River for spawning by anadromous salmonids[1]

SPECIES	NUMBER OF INDIVIDUALS	LOCATION
Spring chinook	3,000	Above Teanaway River
Fall chinook	1,000	Below Wapato Dam
Coho	1,000	Above Teanaway River
Steelhead	3,000	Above Umtanum Creek

[1]Adapted from Lavier, 1976, and Patten et al. 1970.

Table 28

SPECIES LIST FOR THE MAIN STEM YAKIMA RIVER

SPECIES	SCIENTIFIC NAME	Below Chandler Dam	Between Chandler and Wapato Dam	Between Wapato and Roza Dam	Above Roza Dam	Location not specified
<u>Anadromous Salmonids</u>						
Chinook salmon	*Oncorhynchus tshawytscha*	x	x	x	x	
Coho salmon	*Oncorhynchus kisutch*	x	x	x	x	
Steelhead	*Salmo gairdneri*	x	x	x	x	
<u>Cold Water Game Fish</u>						
Kokanee	*Oncorhynchus nerka*					x
Rainbow trout	*Salmo gairdneri*	x	x	x	x	
Cutthroat trout	*Salmo clarki*			x		
Brook trout[1]	*Salvelinus fontinalis*				x	
Brown trout[1]	*Salmo trutta*	x		x	x	
Dolly Varden	*Salvelinus malma*				x	
Burbot	*Lota lota*					x
Mountain whitefish	*Prosopium williamsoni*	x	x	x	x	
White sturgeon	*Acipenser transmontanus*					x
<u>Warm Water Game Fish</u>						
Yellow perch[1]	*Perca flavescens*	x	x			
Largemouth bass[1]	*Micropterus salmoides*	x	x	x		
Smallmouth bass[1]	*Micropterus dolomieui*	x	x			
Black crappie[1]	*Pomoxis nigromaculatus*	x	x			
Bluegill[1]	*Lepomis macrochirus*	x	x	x	x	
Pumpkinseed[1]	*Lepomis gibbosus*	x	x	x	x	
Black bullhead[1]	*Ictalurus melas*	x	x			

Table 28 (continued)

Species list for the main stem Yakima River - page 2

SPECIES	SCIENTIFIC NAME	Below Chandler Dam	Between Chandler and Wapato Dam	Between Wapato and Roza Dam	Above Roza Dam	Location not specified
<u>Non-Game Fish</u>						
Northern squawfish	*Ptychocheilus oregonensis*	x	x	x	x	
Peamouth	*Mylocheilus caurinus*	x				
Chiselmouth	*Acrocheilus alutaceus*	x	x	x	x	
Bridgelip sucker	*Catostomus macrocheilus*	x	x	x	x	
Largescale sucker	*Catostomus columbianus*	x	x	x	x	
Mountain sucker	*Catostomus platyrhynchus*		x	x	x	
Redside shiner	*Richardsonius balteatus*	x	x	x	x	
Speckled dace	*Rhinichthys osculus*	x	x	x	x	
Leopard dace	*Rhinichthys falcatus*	x	x	x	x	
Longnose dace	*Rhinichthys cataractae*	x	x	x	x	
Carp[1]	*Cyprinus carpio*	x	x	x		
Pacific lamprey	*Entosphenus tridentatus*	x	x	x	x	
Western brook lamprey	*Lampetra richardsoni*	x	x	x	x	
Sandroller[1]	*Percopsis transmontanus*		x	x		
Tui chub	*Gila bicolor*					x
Prickly sculpin	*Cottus asper*		x	x	x	
Torrent sculpin	*Cottus rhotheus*		x	x	x	
Mottled sculpin	*Cottus bairdi*		x	x	x	
Piute sculpin	*Cottus beldingi*			x	x	
Shorthead sculpin	*Cottus confusus*					x

[1]Exotic species, not native to the Columbia River Basin.

Table 29. Catch per unit of effort of fish species in the Yakima River, downstream and upstream of the Sunnyside and Wapato irrigation diversions, 1957-58.[1]

Species	Downstream the diversions	Upstream the diversions
	CPUE	CPUE
Lamprey	18	146
Salmon	108	2,076
Mountain whitefish	958	2,124
Cutthroat trout	0	6
Rainbow trout	22	268
Brown trout	10	20
Brook trout	0	20
Dolly Varden	0	2
Chiselmouth	9,624	2,058
Carp	2,550	16
Peamouth	2	0
Northern squawfish	4,320	1,560
Longnose dace	346	384
Leopard dace	238	68
Speckled dace	2,084	712
Redside shiner	2,098	4,090
Bridgelip sucker	1,060	954
Largescale sucker	3,136	1,890
Mountain sucker	34	194
Black bullhead	104	0
Sandroller	10	44
Pumpkinseed-bluegill	562	12
Smallmouth bass	830	0
Largemouth bass	692	6
Black crappie	1,642	0
Yellow perch	28	0
Prickly sculpin	6	16
Mottled sculpin	8	1,802
Piute sculpin	0	804
Torrent sculpin	30	2,566

[1]Adapted from Patten, B.G., R.B. Thompson, and W.D. Gronlund. 1970. Distribution and abundance of fish in the Yakima River, Wash., April 1957 to May 1958. U.S. Fish and Wildl. Serv. Spec. Sci. Rept. Fish 603. 18 pp.

Fish species in the reservoirs have not been adequately sampled. Kokanee and rainbow trout are present in all the reservoirs, and most of the reservoirs also support populations of cutthroat, Dolly Varden, brook trout, mountain whitefish, and burbot. Non-game species are also present. Fish present in the reservoirs with no dead storage are subject to elimination in dry years when the reservoir is completely emptied for irrigation purposes. This occurred in Rimrock Lake in the late summer of 1979 eliminating a substantial sport fishery for the next several years.

Okanogan River

General Description. The Okanogan River Basin drains 8600 mi^2 in the United States and Canada (Walters 1974). Figure 39 shows the main stem and major tributaries of the Okanogan River. The headwaters of the Okanogan River are in Lake Okanogan, British Columbia. The river flows in a southerly direction through northern Washington. The river length is 194.5 miles, 80 of which lie within the United States (Bryant and Parkhurst 1950; PNRBC 1977). The Okanogan drops from 920 ft at the international boundary to about 780 ft at the confluence (R.M. 533.5) with the Columbia River near Brewster, Washington (Walters 1974). Flow velocity is minimal due to the slight river gradient, with the only fast water encountered at the Janis-Riverside Rapids, below Tonasket, Washington. The upper river valley is mountainous with subhumid weather, but moving south a semi-arid climate prevails.

Temperatures are lowest in January (0.3-1°C) and highest in August (17.5-21.8°C). Along the course of the river, maximum temperatures are encountered just above the confluence of the Similkameen River, and increase again as the river approaches the Columbia. Summer water temperatures in the Okanogan are often high, attracting non-game fish (e.g. suckers, squawfish, carp) and delaying anadromous fish migration. The greatest streamflow occurs in April through July owing to snowmelt in the mountains. In the United States there are four dams on the river, and there has been no river channeling for flood control (PNRBC 1977). The two dams which store irrigation water are both located at Conconully. Enloe Dam on the Similkameen and Zosel Dam on the main stem were constructed for hydroelectric generation and lumber production, respectively.

Water Quantity. The major tributary to the Okanogan River is the Similkameen which contributes approximately 75 percent of the average 2.1 million ac ft of water annually inflowing from Canada (PNRBC 1977). The United States utilizes the Similkameen to provide irrigation water for nearly all of the river valley north of Tonasket. The water from other tributary streams and lakes is also used extensively for irrigation. Additional water is pumped directly from the Okanogan River and diverted for irrigation usage. An estimated total of 100,000 ac ft of surface water is diverted annually for irrigation (Walters 1974). The discharge at the Okanogan-Similkameen confluence is the same as at the Okanogan mouth. The Okanogan River discharges an average of 2.2 million ac ft annually into the Columbia River (Walters 1974). Table 30 indicates the

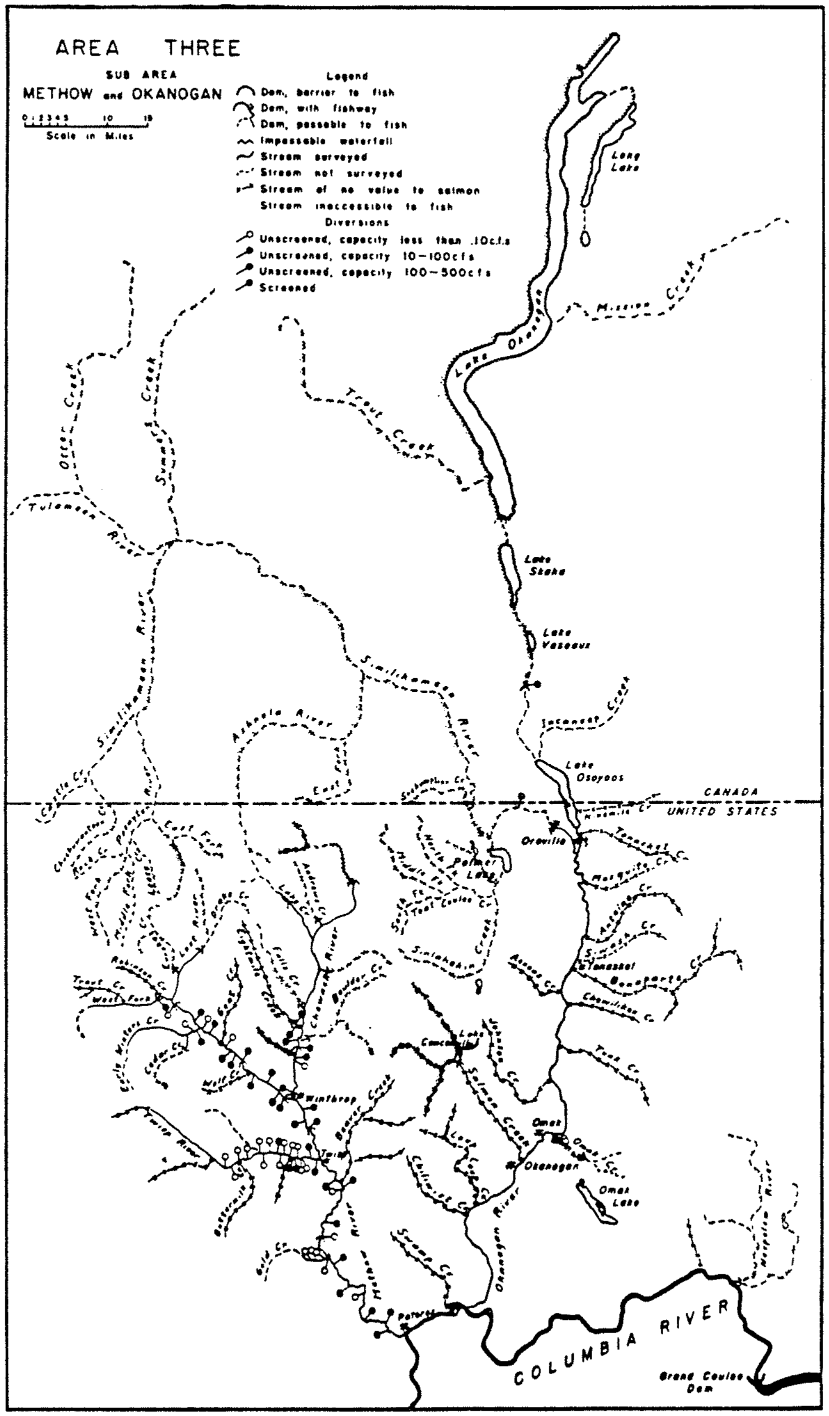


Fig. 39. Okanogan and Methow Rivers and tributaries. From Bryant and Parkhurst, 1950.

Table 30. Water Quantity - Okanogan River.

OKANOGAN RIVER[1]

Input (ac-ft)		Output (ac-ft)
	Total Discharge	Total Withdrawal
Oliver, B.C. =	443,300	
Osoyoos Lake		
Inkaneep Creek		
Mica Creek		
Strawberry Creek		
Long Joe Creek		
Haynes Creek		
Ninemile Creek		
Tonasket Creek =	1,830	
Zosel Millpond =	471,300	
Similkameen River =	1,702,000	
- Oroville-Tonasket Irrigation Canal[2]		
Mosquito Creek		
Whitestone Lake Creek		
Antoine Creek		
Siwash Creek		
Bonaparte Creek		
Aeneas Creek		
McLoughlin Canyon Creek		
Chewiliken Creek		
Tunk Creek		
Johnson Creek		
Pothole Canyon Creek		
Wannacott Creek		
Omak Creek =	3,290[3]	
Salmon Creek		
Felix Creek		
Tallant Creek		
Loup Loup Creek		
Chiliwist Creek		
Davis Canyon Creek		
Confluence with the Columbia =	2,161,000	

[1]Total discharge and total withdrawal data are from water year 1978 (U.S.G.S. 1979).
[2]The last gauge station on the Similkameen River is before the Oroville-Tonasket Irrigation Canal, which withdraws an unknown amount of water. Therefore, the actual discharge of the Similkameen River is less than the total discharge given.
[3]Water year 1977.

tributaries which discharge directly into the Okanogan River. For the most part, the tributaries are ungauged and no data are available on the quantity of water which they contribute to the main stem of the Okanogan. The surveyed literature did not indicate the diversion locations nor the volume of water withdrawn by such facilities.

Fishes. The fish of the Okanogan River have not been adequately censused. Table 31 is an incomplete listing, summarizing passing references to distributions (Bryant and Parkhurst 1950; PNRBC 1977). Anadromous fish utilize the Okanogan below falls and dams on the lower Similkameen and at Lake Vaseux. Table 32 lists the size of runs of summer chinook, sockeye, and steelhead. The river is a major producer of sockeye salmon.

Resident fish are dominated by non-game species, which are favored by low flow and warm temperatures. Squawfish, suckers, and carp are common in both the main stem and the lakes. Warm-water game fish also prefer the higher temperatures of the Okanogan. Species such as largemouth bass, yellow perch, catfish, and sunfish are found in the lower part of the river and in the lakes of the mid-reach. Cold-water game fish (e.g., kokanee, trout and whitefish) favor Lake Okanogan at the headwaters of the river (Bryant and Parkhurst 1950) but kokanee are also found in the mid-reach lakes, and rainbow trout occur throughout the system. Other trout species are generally in smaller, higher tributary streams (PNRBC 1977). Burbot are taken in the lakes of the Okanogan, as these provide the deep, cold water this species requires.

Umatilla River

General Description. The confluence of the Umatilla River with the main stem Columbia is located at R.M. 288.8. The Umatilla is 91.3 miles in length and averages 40 to 75 ft in width. Decreasing in elevation from 2340 ft to 334 ft msl, the Umatilla drains approximately 2700 mi^2 of northern Oregon (Hogenson 1964). The basin supports angling, hunting and irrigation (Smith 1973). Figure 40 shows the main stem and major tributaries of the Umatilla River.

Water Quantity. Excessive irrigation demands on the Umatilla have caused the diversion of the entire flow of several tributaries (Nielson 1950; Smith 1973). The average monthly flow at the mouth of the Umatilla River has ranged from 1.5 to 13,200 cfs, with a mean of 575.6 cfs between the 1970 to 1976 water years (USGS 1971-1977). Table 33 indicates the total annual discharge of the tributaries which empty into the main stem of the Umatilla and the diversion projects and the volume of water withdrawn. Approximately 78 percent (246,130 ac ft ÷ 313,900 ac ft) of the Umatilla main stem flow was diverted in WY 1978 (USGS 1979). The North Fork tributaries discharge the largest volume of water (173,800 ac ft) into the main stem. At the confluence with the Columbia River, the Umatilla discharges 313,900 ac ft. Several feeder canals (e.g., Western Land Canal, Furnish Canal, Umatilla Canal, West Division Canal) annually divert in excess of 30,000 ac ft (USGS 1979).

Table 31

SPECIES LIST FOR THE OKANOGAN RIVER

SPECIES	SCIENTIFIC NAME	Below Osoyoos	Lake Osoyoos	Lake Skaha/ Lake Vaseux	Lake Okanogan	Similkameen River	Location not specified
Anadromous Salmonids							
Chinook salmon	*Oncorhynchus tshawytscha*	x	x			x	
Sockeye salmon	*Oncorhynchus nerka*	x	x				
Steelhead	*Salmo gairdneri*	x					
Cold Water Game Fish							
Kokanee	*Oncorhynchus nerka*		x	x	x		
Rainbow trout	*Salmo gairdneri*		x	x	x		
Brook trout[1]	*Salvelinus fontinalis*						x
Cutthroat trout	*Salmo clarki*						x
Brown trout [1]	*Salmo trutta*						x
Burbot	*Lota lota*		x	x	x		
Mountain whitefish	*Prosopium williamsoni*	x	x		x		
Lake whitefish[1]	*Coregonus clupeaformis*	x			x		
Dolly Varden	*Salvelinus malma*						x
Warm Water Game Fish							
Yellow perch[1]	*Perca flavescens*		x	x			
Largemouth bass[1]	*Micropterus salmoides*	x	x				
Crappie[1]	*Pomoxis* spp.	x					
Sunfish[1]	*Lepomis* spp.	x					
Pumpkinseed[1]	*Lepomis gibbosus*			x			
Catfish[1]	*Ictalurus* spp.	x					
Black bullhead[1]	*Ictalurus melas*		x				
Non-Game Fish							
Northern squawfish	*Ptychocheilus oregonensis*	x	x	x	x	x	
Suckers	*Catostomus* spp.	x	x	x	x	x	
Largescale sucker	*Catostomus macrocheilus*					x	

Table 31 (continued)

Species List for the Okanogan River - page 2

SPECIES	SCIENTIFIC NAME	Below Osoyoos	Lake Osoyoos	Lake Skaha/ Lake Vaseux	Lake Okanogan	Similkameen River	Location not specified
Bridgelip sucker	*Catostomus columbianus*		x			x	
Mountain sucker	*Catostomus platyrhynchus*					x	
Longnose sucker	*Catostomus catostomus*			x			
Redside shiner	*Richardsonius balteatus*	x	x	x	x		
Speckled dace	*Rhinichthys osculus*					x	
Leopard dace	*Rhinichthys falcatus*				x		
Longnose dace	*Rhinichthys cataractae*			x			
Carp[1]	*Cyprinus carpio*	x	x	x	x	x	
Peamouth	*Mylocheilus caurinus*	x	x		x		
Chiselmouth	*Acrocheilus alutaceus*			x			
Lake chub	*Couesius plumbeus*			x			
Tench[1]	*Tinca tinca*		x				
Prickly sculpin	*Cottus asper*				x		
Torrent sculpin	*Cottus rhotheus*					x	
Mottled sculpin	*Cottus bairdi*					x	
Slimy sculpin	*Cottus cognatus*		x				

Adapted from Bryant, F.G. and Z.E. Parkhurst. 1950. A survey of the Columbia River and its tributaries. Part 4. Area III. U.S. Fish and Wildlife Ser. Spec. Sci. Rept. Fisheries 37. 108 pp.
Pacific Northwest River Basins Commission. 1977. The Okanogan River Basin. Level B Study. PNRBC. 100 pp. + appendices.
Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. of Canada. Bull. 184. 966 pp.
Black, E.C. 1953. Upper lethal temperatures of some British Columbia freshwater fishes. J. Fish. Res. Bd. Canada 10:196-210.

[1]Exotic species, not native to the Columbia River Basin.

Table 32

PRESENT USE OF THE OKANOGAN RIVER FOR SPAWNING BY ANADROMOUS SALMONIDS[1]

SPECIES	NUMBER OF INDIVIDUALS	LOCATION
Summer chinook	1000-3000	Below Lake Vaseux
Summer chinook	1,100	Similkameen River below Enloe Falls and Dam
Sockeye	54,000	Below Lake Vaseux
Steelhead	750	Below Lake Vaseux

[1]Adapted from Pacific Northwest River Basins Committee, 1977. The Okanogan River Basin, level B study of the water and related land resources. 100 pp. + appendices.

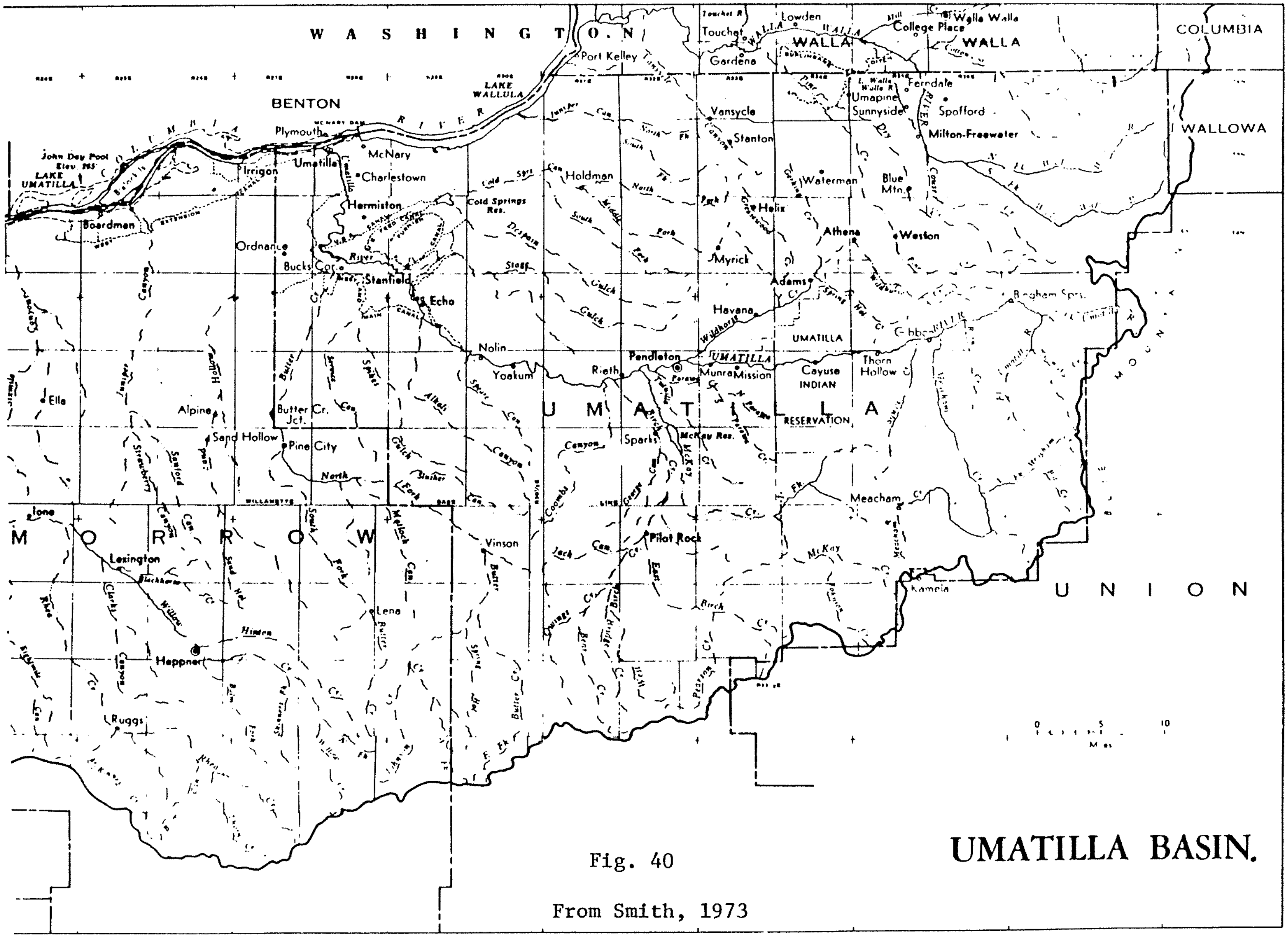


Fig. 40

From Smith, 1973

Table 33. Water Quantity - Umatilla River.

UMATILLA RIVER[1]

Input (ac-ft)	Total Discharge	Total Withdrawal	Output (ac-ft)
Shimmiehorn Creek Thomas Creek South Fork North Fork Total =	173,800		
Ryan Creek Meacham Creek Squaw Creek Wildhorse Creek McKay Creek = Tutuilla Creek Birch Creek Coombs Canyon Speare Canyon	56,580		
		74,830	= Western Land Canal (Westland Main Canal)
Alkali Canyon			
		4,900	= Allen Canal
		31,040	= Furnish Canal
		67,350	= Umatilla Project Feed Canal (U.S. Feed Canal)
		17,540	= Maxwell Canal (U.S.A. Canal)
		50,470	= West Division Mainland (West Extension Canal)
Stage Gulch North Fork Butter Creek =	20,790	246,130	= Total Withdrawal
Confluence with the Columbia =	313,900		

[1]Total discharge and total withdrawal data are from water year 1978 (U.S.G.S. 1979).

Fishes. Smith (1973) listed the distribution of known fish species in the Umatilla Basin (Table 34). The pattern that emerges is essentially the same as that noted in the Yakima and Okanogan, i.e., warm-water species in the lower reaches and reservoirs and cold-water species in the headwaters and upstream tributaries. Warm-water game fish (bass, crappie, bluegill, and catfish) were found only in the lower half of the river and in the two reservoirs. Trout and whitefish occurred in the upper Umatilla, in headwaters of creeks, and in Meachem Creek, the tributary farthest upstream. Remnant salmon and steelhead runs spawned in the upper section of the river. Non-game fish such as squawfish, carp, chiselmouth, suckers and redside shiner are found only in the main stem and in the reservoirs. Sculpins, Pacific lamprey, and dace are also found in these locations and in the cooler tributaries as well (Smith 1973).

Anadromous fish have been almost extirpated throughout the Umatilla, due to irrigation withdrawals and concomitant reduction of flows in summer months. Low water volume, at the mouth, prevents spawning by anadromous fish throughout the basin, except for a few steelhead that enter the river before irrigation resumes in mid-May (Nielson 1950). Fulton (1968) and Smith (1973) both indicate that a remnant spring chinook run remains, though Nielson (1950) implies salmon were eliminated from the Umatilla. Smith (1973) also lists a remnant run of coho, but Nielson (1950) makes no mention of the species, and the Umatilla is missing from Fulton's (1970) list of past and present coho spawning areas.

Table 34

SPECIES LIST FOR THE UMATILLA RIVER

SPECIES	SCIENTIFIC NAME	Umatilla River below Pendleton	Cold Springs Reservoir	Butter Creek	Birch Creek	McKay Creek & Res.	Umatilla River above Pendleton	Meachem Creek	Other
Anadromous Salmonids									
Chinook salmon	*Oncorhynchus tshawytscha*						x		
Coho salmon	*Oncorhynchus kisutch*						x		
Steelhead	*Salmo gairdneri*				x		x	x	
Cold Water Game Fish									
Rainbow trout	*Salmo gairdneri*	x	x	x	x	x	x	x	
Brook trout[1]	*Salvelinus fontinalis*							x	
Dolly Varden	*Salvelinus malma*						x		
Whitefish[1]	*Coregonus* spp.						x		
Warm Water Game Fish									
Largemouth bass[1]	*Micropterus salmoides*	x	x			x			
Smallmouth bass[1]	*Micropterus dolomieui*								Hat Rock Pond
Black crappie[1]	*Pomoxis nigromaculatus*					x			
White crappie[1]	*Pomoxis annularis*	x	x						
Bluegill[1]	*Lepomis macrochirus*	x	x			x			
Channel catfish[1]	*Ictalurus punctatus*								McNary Pond
Brown bullhead[1]	*Ictalurus nebulosus*	x	x			x			
Non-Game Fish									
Northern squawfish	*Ptychocheilus oregonensis*	x				x	x	x	
Chiselmouth	*Acrocheilus alutaceus*	x					x		
Suckers (2 spp.)	*Catostomus* spp.	x	x			x	x		
Redside shiner	*Richardsonius balteatus*	x					x	x	
Dace	*Rhinichthys* spp.	x	x	x	x	x	x	x	
Carp[1]	*Cyprinus carpio*	x	x						
Pacific lamprey	*Entosphenus tridentatus*	x	x	x	x	x	x	x	
Sculpins	*Cottus* spp.	x	x	x	x	x	x	x	

[1]Exotic species, not native to the Columbia River Basin.

IMPACTS OF IRRIGATION WATER WITHDRAWAL ON FISHERIES

Introduction

Literature specifically addressing the impacts of water withdrawal for irrigation on fish is virtually non-existent. Therefore, the approach used in documenting the various impacts relies on research conducted on fisheries which have been affected by hydroelectric dam operations, logging operations, thermal discharges from nuclear power plants, etc. In most instances, it is impossible to definitively conclude that a specific problem will occur in the Columbia due to irrigation water withdrawal since detailed data are unavailable.

The flow diagram portrayed in Figure 41 identifies the major potential impacts that may result from withdrawing Columbia River water for irrigation. Water withdrawal occurs by streamflow diversion into irrigtaion facilities, thus reducing the water level of the source. Return flows from irrigation projects will increase the water level in the area where discharge occurs. Therefore, the net effect of using Columbia River Basin water will be fluctuating water levels in the tributaries and ultimately in the main stem.

A number of effects on fish species regarding high- and low-water levels have been documented in the literature. The flow diagram, while at first glance appearing complex, is in reality a simplified generalization of potential impacts. The value of the diagram is to emphasize the complexity of analyzing and attempting to predict the effects of water withdrawal on biological communities.

In endeavoring to assess the impacts on fish species (or any other organism, for that matter) the level of complexity is magnified. It cannot be overly stressed that it is often not possible to accurately predict the effects on particular species given the general lack of understanding of ecosystem dynamics. It is important to realize that in most cases organisms will not be exposed to environmental factors which induce immediate, measurable impacts. The effects of subtle environmental changes often do not manifest themselves instantaneously. This is perhaps where knowledge is most limited. Long-term research studies are required to adequately assess the effects of environmental perturbations on aquatic populations. Such research is by necessity site-specific and the results cannot be simply applied to other locations.

A further consideration compounding the problem of predicting impacts is the capability of organisms to acclimate to alterations in their environment. Ecologists generally recognize two general zones for a given environmental gradient (Vernberg and Vernberg 1972). The *zone of lethality* (zone of resistance adaptation) is the extreme point where mortality occurs. The *zone of compatibility* (biokinetic zone; zone of capacity adaptation)

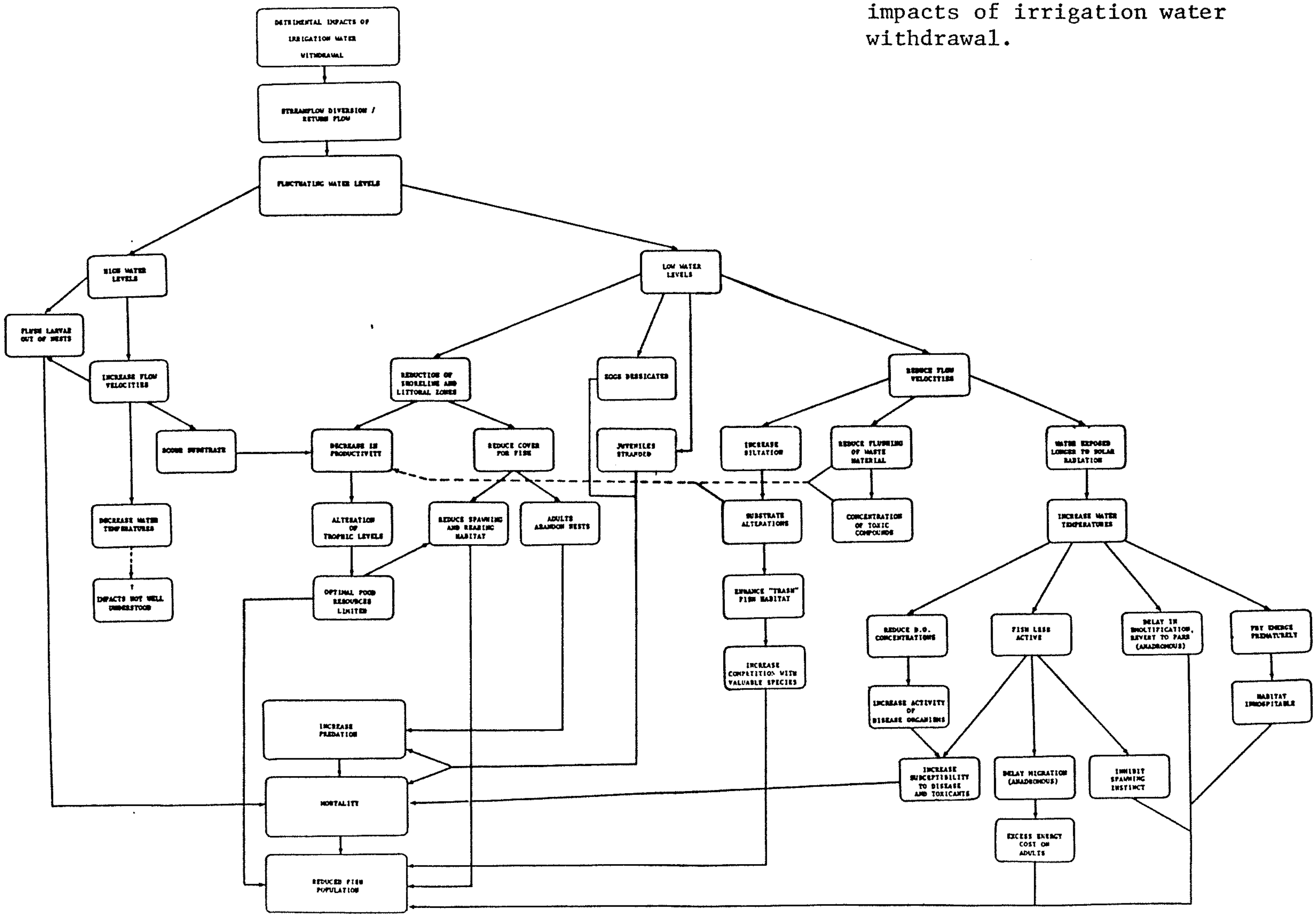


Fig. 41. Flow diagram of detrimental impacts of irrigation water withdrawal.

is defined as the intermediate level of the environmental gradient where organisms may survive. These zones not only differ among species but change as an organism progresses through various life stages.

When an organism is exposed to a perturbation in the environment, acclimatization occurs through a sequence of events (Vernberg and Vernberg 1972). If the change is of such magnitude and duration that the organism cannot adequately compensate, mortality will result. An array of changes in the environment acting simultaneously will further complicate the organism's response to the given situation. Prosser (1958) suggests that the duration of exposure to a stressful environment must be considered as well. Acclimatization will occur only after the physiological components of an organism have acted in a highly integrative manner (Vernberg and Vernberg 1972). Species possessing the ability to adapt quickly to environmental changes will proliferate over those that are less adaptable.

In summary, the impacts discussed in this section should be considered as only approximate guidelines with respect to the potential effects of water withdrawals on fish species inhabiting the Columbia River Basin. Much of the information concerns specific species at various life stages. It is inappropriate to conclude, based on these data, what the specific impact will be on a particular species until further research is completed.

Water Quantity Impacts

Projected Changes in Flow. Increased withdrawals of water for irrigation will deplete streamflows in the Columbia, resulting in reduced flow velocities and lower water levels. Columbia River water is already fully utilized, and expansion of any one use will require reductions in allocations to other uses. Current forecasts predict an increase of 3.0 to 4.2 million irrigated acres by the year 2020, over the present level of 7 million acres (USACOE 1976). This increase will result in an estimated depletion of 8.5 million ac ft/yr in Columbia River water supplies. If such increases occur, less water will be available for fish, hydropower, and other uses.

In order to study future impacts, the Corps of Engineers has used three levels of irrigation development: 1) the present level of development; 2) development for the year 2020 as projected by the U.S. Office of Business Economics - Economic Research Service (OBERS); and 3) development for the year 2020 projected by the Pacific Northwest states. The OBERS projection estimates 10 million acres will be irrigated by 2020, while the Pacific Northwest states foresee 11.2 million acres under irrigation.

The Corps of Engineers has evaluated each of these levels of development from the perspective of four proposed minimum stream flow regimes. Alternative 1 allows minimum flows to drop to zero at any time, and favors hydropower planning. Alternative 2 is the present established minimum flows. Alternative 3 arbitrarily sets minimum flows at levels midway between the hydropower and fisheries levels at approximately 40 percent of the fishery flow. Alternative 4 is recommended by the Columbia Basin Fishery Technical Committee (CBFTC) and provides minimum flows essential to preservation of present levels of anadromous fish resources. The recommended flow levels are given in Table 35. The minimum instream flow recommendations are not specifically related to irrigation depletion, except insofar as irrigation withdrawal decreases the total amount of water available for other uses.

The four alternatives provide for widely diverging minimum flows. The CBFTC has emphasized that its recommendations are not optimal and are only the absolute minimum flows required to maintain anadromous fish runs at their present status (USACOE 1976). However, the fishery flows are presented as "high" minimum flows of the four alternatives and are characterized as "extreme" in the power impact analysis (USACOE 1976). None of the alternatives specifically considers resident fish; the CBFTC flow recommendations are primarily concerned with anadromous fish needs. It is not possible for any one flow regime to satisfy the requirements of all the fish species of the Columbia, much less the many different uses.

The alternative minimum flows will have very different effects on fish populations. The CBFTC has rated the adverse effects of each flow regime on twelve factors affecting anadromous fish: adult passage, spawning and holding; juvenile migration, predation, rearing and stranding; sport, Indian and commercial fisheries; water quality; and estuary effects (Table 36). The minimum flow allowances most advantageous to hydropower (i.e. Alternative 1) were assessed to have maximum adverse effect in all categories. The fisheries alternative (i.e. Alternative 4) was most advantageous to fish.

The Corps assesses the impact of each alternative on resident fisheries of storage and run-of-the-river projects in the lower Snake River and the middle and lower Columbia (USACOE 1976). No summary was presented and any overall evaluation is difficult to make. Effects of each flow alternative on spawning, rearing and food production areas varied widely between each project and reach of the river. Generally all flow recommendations caused water level fluctuations in reservoirs which exposed spawning and rearing areas. The recommended minimum flow for anadromous fish was only slightly less adverse to resident fishes than the hydropower flows.

Irrigation depletion and minimum instream flow levels are two separate problems in the management of Columbia River water, and each will have different effects on storage and run-of-the-river reservoirs. If irrigation withdrawal is increased, storage projects would release less water in the spring for flood control and would be unable to fill as high during the summer storage season. Thus seasonal fluctuation in level would be slightly reduced. Run-of-the-river projects would receive reduced flows but overall there would be minimal impact on the operation of these reservoirs.

Table 35

MINIMUM INSTREAM FLOW ALTERNATIVES
(1,000 CFS)

	Alt 1		Alt 2		Alt 3		Alt 4	
	Inst	Aver Daily	Inst	Aver Daily	Inst	Aver Daily	Inst	Aver Daily
Grand Coulee - Priest Rapids Dams								
December - March	0		36	36	14	16	36	40
1-15 April					14	16	36	40
16 April - 15 June		No Limit			24	44	60	110
16 June - July					14	32	36	80
August					24	44	60	110
September - November	0		36	36	14	18	36	45
Lower Granite - Ice Harbor Dams								
December - March	0		5	5	10	20	20	20
1-15 April					10	27	20	40
16 April - 15 June		No Limit			12	36	30	90
16 June - July					10	27	20	40
August					10	13	20	20
September - November	0		5	5	10	13	20	20
McNary - Bonneville Dams								
December - March	0		50	50	10	24	20	60
1-15 April					16	32	40	80
16 April - 15 June		No Limit			28	80	70	200
16 June - July					20	48	50	120
August					20	52	50	130
September - November	0		50	50	16	26	40	65

From USACOE, 1976

Table 36

IMPACTS OF ALTERNATIVE MINIMUM INSTREAM FLOW LEVELS ON ANADROMOUS FISHERY

Minimum Flow Alternative	Lower Columbia River				Middle Columbia River				Lower Snake River			
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 1	Alt 2	Alt 3	Alt 4	Alt 1	Alt 2	Alt 3	Alt 4
Adults												
Passage	1	4	3	7	1	4	3	7	1	2	3	6
Spawning	1	9	9	9	1	4	3	7	-	-	-	-
Holding	1	7	7	9	1	9	7	9	1	2	2	7
(Average)	(1)	(6.7)	(6.3)	(8.3)	(1)	(5.7)	(4.3)	(7.7)	(1)	(2)	(2.5)	(6.5)
Juveniles												
Migration	1	4	2	7	1	4	3	7	1	4	2	7
Predation	1	4	6	8	1	4	2	6	1	5	4	7
Rearing	1	5	3	7	1	6	3	6	-	-	-	-
Stranding	1	4	3	6	1	9	5	9	-	-	-	-
(Average)	(1)	(4.3)	(3.5)	(7)	(1)	(5.8)	(3.3)	(7)	(1)	(4.5)	(3)	(7)
Fishing												
Sport	1	3	2	6	1	4	3	5	1	4	3	5
Indian	1	5	4	7	1	5	4	6	-	-	-	-
Commercial	1	6	5	9	-	-	-	-	-	-	-	-
(Average)	(1)	(4.7)	(3.7)	(7.3)	(1)	(4.5)	(3.5)	(5.5)	(1)	(4)	(3)	(5)
Water Quality	1	3	2	4	1	3	2	4	1	2	2	6
Estuary Effects	1	5	2	6	-	-	-	-	-	-	-	-
AVERAGE	1	4.7	3.5	6.5	1	4.8	3.3	6.1	1	3.1	2.6	6.1

1 - Maximum adverse effect
10 - Minimum adverse effect
\- Little or no discernible effect or rating not applicable

From USACOE, 1976

In comparison to effects of irrigation depletion on reservoir operation, changes in minimum instream flows will have a major impact on both types of impoundments. Levels recommended for anadromous fish will require substantial drafting of storage reservoirs. Minimum flow guidelines favoring power production will generally cause greater fluctuations in forebay and tailwater areas, while flows recommended for preservation of fish runs will tend to reduce these fluctuations.

It cannot be predicted which minimum flow alternative (or some compromise) will be adopted. In light of this uncertainty and the disparity in impacts of each alternative, this section will discuss general effects of changes in water level and flow velocity on aquatic organisms. Data relating to the Columbia River and its fishes is lacking, but specific reference will be made to the limited material that is available. Increasing the quantitative data base for key species in the Columbia River is an urgent need.

Fluctuating Water Levels (Reservoirs).

Effects on Aquatic Productivity. Fluctuating water levels, and lowered flows particularly, will be the major negative effect of increasing irrigation withdrawals. Water level fluctuation has frequently caused reductions in bottom fauna in reservoirs (Fillion 1967; Stober et al. 1976; Kaster and Jacobi 1978). In unregulated lakes, bottom organisms are usually most abundant in the region from 1.6 to 10 ft in depth, or in the littoral zone (Welch 1952). Reservoir drawdown eliminates the benthos in the littoral zone by exposure to desiccation and freezing temperatures, resulting in maximum abundance below the drawdown limit. Lake Roosevelt is drawn down approximately 82 ft each year, exposing the entire littoral zone (Stober et al. 1977a). As the reservoir is filled, the exposed area may be recolonized to some extent (Stober et al. 1976; Kaster and Jacobi 1978). Recolonization required three months to reach the pre-drawdown level of abundance in a Wisconsin reservoir (Kaster and Jacobi 1978).

Reducing the level of drawdown resulted in increased benthic invertebrate abundance in a Missouri River reservoir (Benson and Hudson 1975). Chironomids and mayfly nymphs migrated with water level fluctuations in another Missouri River reservoir (Cowell and Hudson 1967).

Any increase in the level of drawdown resulting from irrigation withdrawal will expose more area of a reservoir bottom to desiccation, further reducing benthic standing crop. Reduced drawdown, however, would probably result in increased abundance of benthic organisms.

Reduced productivity leads to alteration in trophic levels and decreases in food resources for fish. Ellis (1941) noted that fluctuating water levels limited fish food production through prevention of establishment of aquatic vegetation. Aronin and Mikheev (1963) also found that fluctuation in water level of shallows reduced the area of summer feeding grounds in a Soviet reservoir. Water level fluctuations damaged food resources to the extent of altering fish fauna from salmonids to coarse fish in Swedish impoundments (Nilsson 1966).

Effects on Fish Habitat. In addition to lowering productivity, reduction of the littoral zone reduces habitat for fish. Aass (1960) stated that fish species which inhabit shallow waters will be significantly reduced in number or killed off entirely by repeated drops in water level. Munro and Larkin (1950) noted the importance of a well-developed littoral zone in the production of fish and fish food organisms and warned of lowering reservoir levels in winter months in preparation for spring runoff. Aggus (1979) observed that a decline in water level reduces the volume of bodies of water, thus concentrating fish and subjecting them to increased predation and competition for food and space. Frequent changes in water level prevent establishment of aquatic vegetation in the shallows and this in turn limits cover for fish (Ellis 1941).

Effects on Fish. Fluctuating water levels adversely affect reproductive activities of fish in a variety of ways: delay of spawning migrations, impact on breeding condition, reduction of spawning area, dewatering and exposure of eggs and alevins, stranding of fry, and delay of downstream migration of smolts.

Reduction of spawning area is a major problem caused by water level fluctuations. Aronin and Mikheev (1963) found that fluctuations in reservoir shallows destroyed conditions for reproduction of fish. Impoundments throughout the Columbia River Basin have inundated former salmon spawning grounds (Beiningen 1976).

Low water levels dewater eggs and trap pre-emergent fry in the gravel (CFRC 1979). Species having short incubation periods (most warm-water game and non-game species) will be affected by daily fluctuations of sufficient magnitude to expose spawning beds. Salmonids have longer incubation periods, usually lasting through winter months into spring. They will be affected by seasonal winter drawdown of reservoirs, as well as by daily large fluctuations. Stober et al. (1977*b*, 1979) linked spring irrigation drafting of Banks Lake with decline in reproductive success of beachspawning kokanee and yellow perch. These studies showed that year classes of kokanee are severely reduced by large drawdowns prior to fry emergence. Winter water level fluctuations will also impact the reproductive success of lake whitefish. Hassler (1970) similarly noted that large year classes of northern pike were associated with stable or rising water levels, while small year classes were found when levels dropped.

In addition to Banks Lake (Stober et al. 1977*b*) Stober has found water level fluctuations to be an important determinant of fish populations in Rufus Woods Reservoir and in the forebay of F.D.R. Lake (Erickson et al. 1977; Stober et al. 1977*a*). As a storage reservoir, F.D.R. has an early spring drawdown to accommodate snow melt water runoff. Fish that spawn prior to drawdown and incubate for several months, such as kokanee and lake whitefish, were found in small numbers and judged to be limited by drawdown. Drawdown may also make access to reservoir tributaries more difficult, thus affecting the ability of rainbow trout to reach spawning grounds. Walleye was the most abundant game fish, with the major reason for its success being spawning and incubation periods during rising water levels. This factor also aided many non-game species, among them squawfish, peamouth, longnose sucker, and bridgelip sucker. All spawn at times of stable or rising water (Stober et al. 1977*a*). Seasonal drawdown in Rufus Woods was not as great a factor, but large daily fluctuations probably limited reproduction of yellow perch, prolific shallow water spawner (Erickson et al. 1977).

After hatching and emergence, fry of many species of fish feed and school in shallows, where they are subject to stranding by falling water levels. Winter hydroelectric drawdowns in Soviet storage reservoirs resulted in mass mortality of young fish, particularly carp (Aronin and Mikheev 1963). Extensive drawdowns of Lake Nasser stranded *Tilipia* fry (Ryder and Henderson 1975). Therefore, water level fluctuations in reservoirs directly influence the reproductive success of fish species in the impoundments.

Fluctuating Water Levels (Rivers). Although fluctuating water levels create many of the same problems in rivers as they do in reservoirs, there are differences between the two environments. As rivers have virtually no storage capacity, they will experience more acutely the effects of short-term fluctuations. The major effects of fluctuating water levels in rivers will be on stream benthos and on stream spawning species such as anadromous salmonids. The riverine sections of the current study area are the tributaries to the Columbia and the Hanford Reach.

Effects on Periphyton. Flow fluctuation and reduced flow may have detrimental effects on the periphyton, or attached algae. Loss of periphyton in the stream margins due to desiccation during flow reductions has been observed below hydroelectric dams (Neel 1963; Radford and Hartland-Rowe 1971; Kroger 1973). Reductions in periphyton production may affect other levels in the food web, particularly in large, unshaded rivers, where periphyton may be an important energy source.

Reduced current velocity can affect composition and growth of periphyton. Diatoms dominated the periphyton community in a laboratory stream with fast current velocity (1.2 fps), while filamentous green algae dominated a community subject to lower velocity (0.3 fps) (McIntire 1966). The highest productivity was maintained at the faster velocity. If phosphorus concentration was above 30-45 μg/l, periphyton growth in western Washington streams was enhanced by increased velocity up to 1.7 fps (Horner 1978). At higher velocities, erosion of periphyton was greater than growth.

Effects on Benthos. Streamflow fluctuation below dams may have a significant impact on stream benthos. Flow fluctuations due to hydroelectric peaking submerge the stream margins during part of the day and expose them to desiccation and freezing during the remainder of the day. Substantial insect mortality has been observed in the margins of streams due to stranding and subsequent desiccation following flow reductions (Powell 1958; Kroger 1973; Brusven et al. 1974). Continued daily exposure prevents recolonization of the stream margins, resulting in reduced abundance, biomass, and diversity in the affected areas (Powell 1958; Fisher and LaVoy 1972; MacPhee and Brusven 1973; Brusven and Trihey 1978; Graybill et al. 1979). The margins of large streams are generally more productive than the midstream areas (Needham 1934; Needham and Usinger 1956; Kennedy 1967). The productive margins are eliminated by periodic flow fluctuations.

High or low current velocity during maximum and minimum daily flows have also reduced bottom fauna in some streams. Flushing action during high flows reduced the standing crop of benthic organisms in a stream in Alberta (Radford and Hartland-Rowe 1971), while low current velocity during daily minimum flows appeared to limit the abundance and diversity of swift-water insects in the Kennebec River, Maine (Trotzky and Gregory 1974).

In addition to affecting benthic standing crop directly, flow fluctuations may also increase the drift rate of benthic organisms. Rapid flow reductions have frequently been observed to increase the drift rate of aquatic insects (Minshall and Winger 1968; Pearson and Franklin 1968; Radford and Hartland-Rowe 1971; MacPhee and Brusven 1973). Sudden increases in flow, both artificial and natural, have also been shown to increase invertebrate drift (Anderson and Lehmkuhl 1968; Pearson and Franklin 1968).

Water level fluctuations of 4 to 8 ft presently occur in the Hanford Reach (Campbell et al. 1979). Fluctuations of this magnitude must alternately expose and submerge a considerable area of the shoreline and result in wide fluctuation in current velocity over the streambed. This perturbation may explain the limited diversity of the benthos reported by Wolf (1976).

Reduced flow due to irrigation will result in physical changes in the affected rivers including decreases in depth, wetted area, and current velocity. Current velocity is affected most by flow reduction (Ward 1976*a*) and is a major factor controlling the distribution of benthic invertebrates in streams (Hynes 1970). Many benthic invertebrates have specific current requirements for feeding or respiration. Particular species may be confined to definite ranges of current speed. The majority of benthic organisms in Convict Creek, California, preferred bottom current velocities between 1 to 1.2 feet per second (fps) and depths of 0.25 to 0.5 ft (Kennedy 1967). Optimal conditions for benthic insects existed at a depth of 0.9 ft with an average current velocity above the site (not bottom current velocity) of 2.6 fps in a Montana stream (Gore 1978). Reduced velocity may eliminate species with requirements for high current velocity. Brusven and Trihey (1978) examined the Clearwater River in Idaho during the filling of Lower Granite Pool. They found that the mayflies and caddisflies were lost as current velocity decreased during the transition from a lotic (riverine) to a lentic (still-water) environment.

Effects on Fish. Fluctuating water levels affect food resources of fish through the effect on benthic organisms and aquatic productivity. Fish habitat will also be reduced. A change in bottom food due to drawdown was one factor in reduction of trout populations in the Saskatchewan River (Millar and Palty 1959). Similarly, Powell (1958) found that insects preferred by trout were the most heavily impacted by diurnal fluctuations caused by power dam operation. Neel (1966) commented on the fact that daily fluctuations in reservoir releases discourages littoral stream life. Reduction of flows on the Clearwater River caused fish to move laterally in search of habitat with similar flow (Haber et al. 1978). Normal behavioral activities were disrupted for several hours.

Townsend (1975) thought that decreased water levels might delay walleye spawning runs in a Canadian river. However, in a study of sockeye salmon in the Cedar River, Stober and Graybill (1974) found that the summer minimum flow level (75 cfs) was adequate for initiation of the spawning run. Flows should then gradually increase to the middle of the spawning season to a "peak" spawning flow of 250 cfs when the maximum number of sockeye was spawning. The peak spawning flow provides the greatest spawnable area at the lowest discharge. An additional increase of 20 percent in the spawning area could be achieved during the last half of the season by increasing the discharge to 500 cfs. Modeling these data, Miller (1976) suggested that unless spawning flows are reduced to uncommonly low levels (preventing fish passage), they will have little impact on sockeye production. Flood flows have a much greater negative effect, and dams controlling flood waters were judged to be beneficial to the sockeye salmon. McKinley (1956) made similar observations on the negative effects of depths and velocities caused by flows above 5000 cfs on chinook spawning in the Cowlitz River. Flows exceeding 400 cfs in the Wynoochee River were detrimental to spawning of chum, coho, and chinook salmon (Deschamps et al. 1966). Sudden lowering of water levels immediately prior to spawning was associated with large numbers of atretic eggs in northern pike ovaries (June 1970).

Water levels must be sufficient to accomodate the spawning population. Drawdown eliminated suitable spawning grounds for trout in the Saskatchewan River and is thought to be the major cause of declines in trout numbers (Miller and Palty 1959). Bauersfeld (1978) documented numbers of fall chinook in the Hanford Reach which are prevented from spawning by present minimum flow allowances. In 1977 only 7,000 fish (3,527 redds) spawned in the Hanford Reach out of a total reach escapement of over 30,000 fish (the remaining fish were unaccounted for). All successful redds were below water levels created by the present licensed minimum flow of 36,000 cfs. Bauersfeld (1978) estimates there is spawning area sufficient to support an additional 10,000 fish between water levels resulting from flows of 36,000 and 70,000 cfs. He also cites research on the Lewis River, where fall chinook spawning success had a strong negative correlation with flows less than 1500 cfs.

Low water levels occurring after spawning will dewater eggs, trap pre-emergent fry, and strand young fish (CRFC 1979). Bauersfeld (1978) estimated that over 800,000 chinook swim-up fry were dewatered and killed by low-flow tests in April 1976 in the Hanford Reach. Sudden flow reductions also stranded fish below a power dam in Colorado (Powell 1958).

Instream Depth and Velocity Needs for Fish. The passage of adult migrants may be curtailed by high water levels and velocities which make finding a fish ladder more difficult (Chaney 1978). Untimely discharge of large quantities of water can create currents which may confuse returning adults and lead them into incorrect paths for migration (Fraser 1972). This problem may alter the timing of a migrant and facilitate depletion of energy reserves before reaching the spawning grounds (Brett 1957). In choosing a site for spawning, salmon and trout may use velocity and the depth of water as criteria (Fraser 1972). The range of tolerances of depth and velocity for spawning adults may be a determining factor in the reproductive success of a species. Optimum ranges of Columbia river species for which data were available are given in Table 37. Note that many of the reported criteria are taken from data collected on small rivers. The range of extrapolation for Table 37 is limited primarily by the difference in cross sectional area between a small and large river. Unfortunately, the preferred velocity ranges given for the various species sheds no light on the reason for observed abundance of certain species in the areas of the river which have been studied. Further evaluation of specific ranges for fish in the Columbia river system is needed to better understand where habitat alteration has broadened or narrowed the reported ranges for velocity and depth.

The habitat preference for spawning adult fish can be quantitatively evaluated using the standard U.S. Geological Survey procedure. This method assumes that the distribution and abundance of a species in an area is not influenced by any single streamflow parameter, but includes a combination of velocity, depth, substrate and water quality (Bovee 1978). Field studies provide measurements of these parameters which are closely related to the hydrology of a river (Collings *et al*. 1972).

Multiple-user water resource management for a system which includes fishery resources requires the establishment of the area available to support spawning fish over a range of discharges (Stober and Graybill 1974). Ideally this should be based on stream survival rates and the actual numbers of fry produced from the river. In the absence of these data, an

Table 37. Depth and velocity criteria for depths and velocities preferred by spawning adult anadromous salmonids, cold water gamefish, warm water gamefish and rough fish.

	Depth (ft)	Velocity (ft/sec)
Anadromous Salmonids		
Fall chinook[1] (Columbia River)	4.00-6.50	2.75-3.75
Chinook[2]	0.50-1.40	1.20-2.25
Fall chinook[7]	.8	1.00-3.00
Chinook[3] (Skagit River)	1.70-4.20	1.80-3.70
Spring chinook[2]	0.60-1.25	0.80-2.00
Spring chinook[7]	.8	1.00-3.00
Spring chinook[1] (Cowlitz River)	1.00-3.50	1.00-1.75
Sockeye[2]	0.55-1.60	1.10-1.90
Sockeye[8]	.5-1.8	.93-2.59
Sockeye[1, 6]	1.0 -1.50	1.75-1.80
Coho[2]	0.40-1.15	0.82-2.00
Coho[7]	.6	1.00-3.00
Coho[4]	0.66-0.83	0.83-2.31
Winter steelhead[2]	0.80-1.79	1.40-2.86
Steelhead[7]	.6	1.00-3.00
Steelhead[5]	0.40-2.30	1.20-3.57
Steelhead[3] (Skagit River)	0.90-2.90	1.50-3.00
Cold Water Gamefish		
Kokanee[2]	0.21-0.75	0.35-1.35
Cutthroat trout[2]	0.57-0.98	0.48-1.50
Rainbow trout[2]	0.50-1.40	0.89-2.60
Rainbow trout[4]	0.70-1.00	1.0
Brown trout[2]	0.50-1.15	1.09-2.50
White sturgeon[4]	Not observed	Fast
Mountain whitefish[2]	0.75 & greater	1.00-2.18
Mountain whitefish[4]	20.0-40.0	0.48 & greater
Warm Water Gamefish		
Yellow perch[4]	1.70-10.0	Low
Smallmouth bass[4]	1.98-2.97	Less than .56
Walleye[4]	1.0 -2.5	Low
Rough Fish		
Northern squawfish[4]	1.0 -11.9	Less than .60
Longnose dace[4]	Shallow	1.5 -2.0

[1]Chambers et al. (1955).

[2]Bovee (1978) utilizes the 50% probability ranges.

[3]Graybill et al. (1979) utilizes 80% probability ranges.

[4]Li et al. (1979).

[5]Hunter (1973).

[6]Clay (1961).

[7]Thompson (1972).

[8]Stober and Graybill (1974) utilize 80% probability ranges.

estimate of the capacity of the Hanford Reach or selected tributaries of the Columbia River should be developed based on the area available to accommodate spawning adults. For example, a series of measurements of depth, velocity and width should be taken from 10 to 25 points along each cross section (i.e. transect) for different quantities of discharge in known spawning reaches of a river (Stober and Graybill 1974; Bovee and Milhous 1978). These points could then be plotted on a plane-table map of the river reach (Collings 1974). Table 37 could then be consulted for the preferred depth and velocity of a species, and by noting areas of overlap the amount of preferred area available for spawning in the reach could be ascertained (Collings 1974). The relationship between preferred area and quantity of discharge can then be plotted and a curve fitted through regression techniques (Collings *et al*. 1972; Stober and Graybill 1974). The inflection point of the curve would determine the peak spawning discharge for the particular species being evaluated (Collings 1974). Utilizing a minimum of the water resource, the peak spawning discharge will submerge the greatest perimeter of the river reach (Collings 1974). In general, the instream cross-sectional wetted area is combined with the depth and velocity in order to obtain a discharge which permits maximum spawnable area (Stober and Graybill 1974; Collings 1974). Since such studies are lacking on rivers the size of the Columbia it will also be necessary to verify the depth and velocity criteria in Table 37 by making additional measurements of redd depths and velocities in the Hanford Reach.

Effects of Water Velocity on Fish.

Effects on Development. The abundance of fish species may be largely determined by the water velocity in their environment (Fraser 1972; Priimachenko 1961; Powell 1958). Flow velocities have important effects on early embryo development, juvenile and adult migration, habitat preferences, and choices of spawning grounds.

Changes in water velocity influence incubation and development of eggs and larval fish. Increases in water velocity, due to higher flows of water, have been shown by McNeil (1968) to dislodge salmon eggs and alevins from redd sites. Water velocity must be high enough to transport sufficient oxygen (O_2) within gravel to developing steelhead and chinook embryos (Silver *et al*. 1963). Steelhead and coho fry from embryos reared in reduced water velocities were smaller than those from higher flow conditions (Shumway *et al*. 1964). The effect of velocity may be independent of O_2 concentrations.

Characteristic flow requirements have been determined for some juvenile salmonids and are presented in Table 38. The data is sketchy and variable, since the information was taken from both artificial channels and natural streams (Giger 1973). Flow velocities should be such that fish can successfully complete their life cycle. Since fish are also limited by temperature tolerance, a major change in water velocity may adversely affect species survival by warming or cooling the

Table 38. Depth and velocity characteristics of juvenile salmonid microhabitats.[1]

Species	Age	Length (inches)	Depth (ft)	Velocity (ft/sec)	Reference
Steelhead trout	0	1.25	<.49	<.49	Everest and Chapman (1972)
	1	3.7	1.97-2.46	.49-.98	Everest and Chapman (1972)
	0, 1 (?)	Varied	.59-2.20	.20-1.61	Thompson (1972)
Chinook salmon	0	2.4	.49-.98	<.49	Everest and Chapman (1972)
	0	-	.98-4.0	.20-.79	Thompson (1972)
Coho salmon	0 (?)	2.6-3.5	-	.3 -.69	Pearson et al. (1970)
	0 (?)	-	.98-4.0	.20-.79	Thompson (1972)
Cutthroat trout	0, 1, 2 (?)	Varied	1.3 -4.0	.20-1.61	Thompson (1972)
Brown trout	-	8.4	-	.39-.69	Baldes and Vincent (1969)
Brook trout	-	7.9	-	.33 (mean)	Wickham (1967)

[1] Data from Giger (1973)

water (Wash. Wat. Res. Cent., 1967).

Residualization and Fish Passage. One of the most important effects of reduced water velocities in the Columbia River is the delay of downstream migration of salmon smolts which results in residualization. If smolts are excessively delayed, they will be exposed to temperatures over 12.2°C which may cause them to revert to parr (Adams et al. 1975) Regardless of temperature, if steelhead smolts remain in fresh water by late June, they will revert to parr (Zaugg et al. 1972). These fish have a much higher mortality when moving to seawater. Delayed fish that residualize do not contribute to adult fisheries, and very few holdovers (fish delaying seaward migration for a year or more) survive to return as adults (CRFC 1979). The travel time for migrating juveniles through eight dams on the Snake and Columbia rivers may be reduced from 69 days in low water years to 23 days in high flow years (CRFC 1979; see also Bentley and Raymond 1976). In general, the rate of fish migration is directly related to the discharge (Raymond 1968). Movement of juvenile salmon through Columbia and Snake River reservoirs requires higher flow conditions than movement through free-flowing sections in order to maintain the same rate of migration (Collings et al. 1975).

Migration delay is caused not only by reduced flow rates through reservoirs, but also by reluctance of juvenile fish to pass through turbines during periods of low flow (Hays et al. 1978). Regulating the spill pattern across the face of a dam has been tested to promote smolt migration, discourage residualization, and lower mortality rates during low water years (Faurot 1979, Hays et al. 1978; Sims and Miller 1977). Spill manipulation has been marginally successful in attracting smolts away from turbine areas at projects where the spillways are adjacent to the turbine entrances (e.g. Priest Rapids) (Hays et al. 1978). The timing, location and volume of spill may be adjusted to direct the movement of large concentrations of smolts downstream with a minimum of impounded water. A flow net (i.e., velocity field) is established in the forebay waters when spilling occurs (Hays et al. 1978). Thus, spill becomes more effective in transporting smolts by having the flow net intercept the fish as they travel close to or past a spillway. However, spill is not totally effective in eliminating smolt migratory problems.

Bypass systems are an alternative means of moving smolts past dams. Fish are captured with traveling screens before entering the turbines and later transported downstream by truck, plane or barge (Hays et al. 1978). This procedure requires handling, which may injure fish and cause subsequent mortality.

During years of high flow, smolt mortality due to migration is 35 to 45 percent, which compares to 70 to 85 percent for low flow years (CRFC 1979). Mortality rates of 15 to 20 percent per dam result from migrants passing through turbines (Long et al. 1968; Schoeneman et al. 1961). Direct mortality from spilling is relatively minor compared to turbine mortalities (Schoeneman et al. 1961). Further research is needed in order to find the best alternative for safely and quickly passing juvenile salmonids through a series of impoundments with a minimal depletion of valuable water supplies (CRFC 1979).

Thermal Impacts

The flow diagram (Fig. 41) shows the potential impacts of irrigation water withdrawal on aquatic organisms due to increased water temperatures. The discharge and the velocity of flow through the reservoirs and river channels is reduced, exposing reduced quantities of water to solar radiation. Return flows of surface water from irrigation projects have been found to be substantially warmer after passage through the canals and laterals common to irrigated agriculture (Sylvester and Seabloom 1962). If large amounts of ground water are returned downstream of major agricultural projects the instream flow may be increased with high quality cool water; however, little is known regarding the quality or quantity of ground water returning from irrigated agricultural projects (Sylvester and Seabloom 1962).

Lower Trophic Levels.

Algae and Diatoms. Increases in water temperature may affect the algal community by causing changes in species composition. The optimum, rather than the uppor lethal temperature, is of major importance (Bush et al. 1974), and the temperature need not reach lethal limits in order for an algal species to be replaced by a more tolerant species. Diatoms grow best at 15°C to 25°C, green algae at 25°C to 35°C, and blue-green algae at 30°C and 40°C, but there are wide specific differences within these groups (Hawkes 1969). Diatom-dominated communities often change to blue-green dominated communities (Bush et al. 1974; Patrick 1974).

The consequences of increased temperature are difficult to predict, since other environmental conditions such as light and nutrient supply determine whether succession to the more tolerant species will occur (Bush et al. 1974). Small temperature increases from the lower end of the tolerance range toward optimum temperatures may increase diversity and biomass (Patrick 1974).

Currently, maximum temperatures along the length of the Columbia are within the optimal range for diatoms. Maximum recorded temperatures during the water year 1977, a below-average year for streamflow, ranged from 20°C at Northport to 22.5°C at Umatilla. Nutrient levels were also relatively low in the Columbia.

Diatoms are usually dominant in the Yakima River, but *Oscillatoria*, a blue-green alga, has become important during some months. The maximum temperature of 26°C during 1977, was 1° higher than the upper optimum temperature for diatoms. However, the concentrations of nitrite plus nitrate and total phosphorus at Kiona, Washington, were considerably higher than in the lower Columbia.

Zooplankton. Temperature controls the life cycle and development of zooplankton. Increases in water temperature within the range of tolerance result in an accelerated rate of development but decreased life-span (Hutchinson 1967), reproduction at shorter intervals (Hall 1964), and increased metabolic rate (Heinle 1969). In a laboratory experiment, zooplankton responded to elevated temperatures through changes in turnover rate, changes in species composition, and mortality (Carlson 1974). Warmer water temperatures in the south pool of Banks Lake favored zooplankton development (Stober et al. 1977), while cold water temperatures retarded growth in Roosevelt Lake (Earnest et al. 1966).

Optimal and upper lethal temperatures for freshwater zooplankton are not well known. Carlson (1974) maintained cladoceran communities at temperatures ranging from 21°C to 42°C. The community at 25°C had the greatest diversity and density after 35 days. The upper limit of thermal tolerance for *Scapholeberis kingi*, a cladoceran species present in Roosevelt Lake and McNary Reservoir, was 33°C ± 2°, well above the upper lethal limit for salmon.

Benthic Invertebrates. Higher temperatures resulting from reduced flow may also result in decreased abundance of benthic invertebrates, especially stream species that are stenotherms (Hynes 1970). If stream temperatures are raised by just a few degrees, the growth of immature insects will be stimulated (Nebecker 1971) and disrupt life history patterns (Ward 1976*a*).

Many species of aquatic insects are dependent on thermal signals to initiate embryological development and hatching, control the rate of growth, and stimulate the emergence of adults. These species may be eliminated under the altered thermal regime below deep reservoirs with hypolimnial drains (Lehmkuhl 1974, Ward 1976*b*). Numbers and species of mayflies and other insects with strict thermal requirements were greatly reduced below a hypolimnial-release reservoir on the Saskatchewan River (Lehmkuhl 1972). Stream temperatures below the reservoir were warmer than normal during the winter and cooler than normal during summer. The reduced number of species was attributed to the absence of normal near-freezing temperatures in the winter to stimulate egg development and to insufficient degree days for growth and adult emergence, especially during the spring.

Fish. Thermal effects on fish have been summarized by Prosser (1967), Hochachka (1969) and Fry and Hochachka (1970). Chavin (1973) has edited a collection of papers on the responses of fish to environmental changes.

Temperature is perhaps the most critical parameter that fish species must accommodate in their environment (Dean 1973). Cherry et al. (1975) and Coutant (1977) have summarized the existing data on temperature preferenda of fish species based on field and laboratory studies. Table 39

Table 39. Summary of available data on final preferendum and upper and lower avoidance temperatures of Columbia Basin fish from field and laboratory studies. Numbers here may vary somewhat from the original author's interpretation. Sp = spring; W = winter; F = fall; Su = summer; YOY = young of the year.[1]

Species	Size or age	Temp (°C) Upper avoidance	Final preferendum	Lower avoidance	Location	Reference
Alosa sapidissima (American shad)	Small	30			Connecticut R., Conn.	Marcy et al. 1972
Catostomus catostomus (longnose sucker)			11.6		Moosehead L., Me.	Cooper & Fuller 1945
Coregonus clupeaformis (lake whitefish)			11.9		Moosehead L., Me.	Cooper & Fuller 1945
	Small		12.7		Lab	Ferguson 1958
	Larvae		17		South Bay, Lake Huron, Ontario	Reckahn 1970
	Larvae					
	12.9 mm		12-16		Lab	Hoagman 1974
	17.8 mm	17	13.5	12	Lab	Hoagman 1974
	23.1 mm	19	15.5	14.5	Lab	Hoagman 1974
Cottus bairdii (mottled sculpin)			16.5		S. Ontario streams	Ferguson 1958
C. cognatus (slimy sculpin)	Large	6		4	L. Michigan	Wells 1968
Cyprinus carpio (carp)	Large	34.5		27	Wabash R., Ind.	Gammon 1973
	Large		29.3-31.9[a]		L. Monona, Wis.	Neill 1971
	Large		28.2-30.7[b]		L. Monona, Wis.	Neill 1971
	Young	35	32	28	Lab	Pitt et al. 1956
	Young	33.5	31.9	30	Lab[a]	Neill 1971
	Young	32.3	32	29.5	Lab[b]	Neill 1971
	Adult (Sp)		27.4		Lab	Reutter & Herdendorf 1974
	Adult (Su)		29.7		Lab	Reutter & Herdendorf 1974
	Adult	>31	29	24	Lab	Reynolds unpublished data

Table 39. (Continued)

Esox americanus vermiculatus (grass pickerel)	Small		26		Lab	Ferguson 1958
Ictalurus natalis (yellow bullhead)	Adult (Su)		28.3		Lab	Reutter & Herdendorf 1974
I. nebulosus (brown bullhead)	Adult (W)		11.9		Lab	Reutter & Herdendorf 1974
	Adult (Sp)		23.5		Lab	Reutter & Herdendorf 1974
	Adult (Su)		24.9		Lab	Reutter & Herdendorf 1974
	Adult (F)		23.6		Lab	Reutter & Herdendorf 1974
	93-193 mm		27.3		Lab	Richards 1974
	Adult		29-31		Lab	Crawshaw 1975[b]
I. punctatus (channel catfish)	Large	32		26	Wabash R., Ind.	Gammon 1973
	Large	34			White R., Ind.	Proffitt 1969
	Adult (Su)		25.2		Lab	Reutter & Herdendorf 1974
	Adult (F)		25.3		Lab	Reutter & Herdendorf 1974
		35	30.5	23	Lab	Cherry et al. 1975
Lepomis gibbosus (pumpkinseed)	Large		28.5-32[a]		L. Monona, Wis.	Neill 1971
	Large		27-29[b]		L. Monona, Wis.	Neill 1971
	Small		31.5		Lab	Ferguson 1958
	Adult (Sp)		24.2		Lab	Reutter & Herdendorf 1974
	Adult (Su)		27.7		Lab	Reutter & Herdendorf 1974
	Large	>31	26	<22	Lab	Reynolds unpublished data
L. macrochirus (bluegill)			29.4-31.3		L. Monona, Wis.	Neill 1971
	53-99 mm		28.8-31.2[a]		L. Monona, Wis.	Neill 1971
	53-99 mm		27-29[b]		L. Monona, Wis.	Neill 1971
	100-193 mm		29.6-32.6[a]		L. Monona, Wis.	Neill 1971
	100-193 mm		27.2-29[b]		L. Monona, Wis.	Neill 1971
			32.3		Lab	Ferguson 1958
	Young	32.1	30.2	28.5	Lab[a]	Neill 1971
	Young	32.5	31.5	28.5	Lab[b]	Neill 1971
	Young	33.1	31.2	29.3	Lab	Beittinger 1974
	Adult (W)		27.4		Lab	Reutter & Herdendorf 1974

Table 39. (Continued)

	Adult	35	32	26	Lab	Cherry et al. 1975
	45-110 mm	33.0	32.3	26	Lab	Reynolds & Casterlin 1976
	120-155 mm		30.5		Lab	Reynolds et al. 1976[a]
Lota lota lacustris (burbot)	Small		21.2		Lab	Crossman et al. 1953 cited by Ferguson 1958
L. lota maculosa (burbot)			11.4		Moosehead L., Me.	Cooper & Fuller 1945
Micropterus dolomieui (smallmouth bass)			21.3		Nebish L., Wis.	Hile & Juday 1941
			21.4		S. Ontario streams	Ferguson 1958
	Small		28.0		Lab	Ferguson 1958
	YOY (W)		18.0		Lab	Barans & Tubb 1976
	YOY (Sp)		19-24		Lab	Barans & Tubb 1973
	YOY (Su)		31		Lab	Barans & Tubb 1973
	YOY (F)		24-27		Lab	Barans & Tubb 1973
	YOY (F)		26.6		Lab	Reutter & Herdendorf 1974
	YOY	35	31.1	25	Lab	Reynolds & Casterlin 1976[a]
	Adult (W)		12-13		Lab	Barans & Tubb 1973
	Adult (Sp)		15-16		Lab	Barans & Tubb 1973
	Adult (Su)		30.0		Lab	Barans & Tubb 1973
	Adult (F)		21-23		Lab	Barans & Tubb 1973
		33	31.3	26	Lab	Cherry et al. 1975
Micropterus salmoides (largemouth bass)	Large		26.6-27.7		Norris Res., Tenn.	Dendy 1948
	Large	30	27-30		Par Pond, S.C.	Clugston 1973
	72-99 mm		29.3-30.9		L. Monona, Wis.	Neill 1971
	100-408 mm		29.3-32[a]		L. Monona, Wis.	Neill 1971
	100-408 mm		26.5-29.1[b]		L. Monona, Wis.	Neill 1971
	Adult	29	27	25.5	Small Tenn. Lakes	Coutant 1975
	Small		30-32		Lab	Ferguson 1958
	Small	30.7	29	27.5	Lab	Neill 1971
	Adult	30			Pond C., Savannah R. Plant, S.C.	Siler & Clubston 1975
	110-160 mm YOY		30.1		Lab	Reynolds et al. 1976[a]

Table 39. (Continued)

	110-150 mm YOY	34	30	21	Lab	Reynolds & Casterlin 1976[a]
	50-460 g		30.2		Lab	Reynolds et al. 1976[b]
Oncorhynchus keta (chum salmon)	Small		14.1		Lab	Brett 1952
O. kisutch (coho salmon)	Adult (Sp)		11.4		Lab	Reutter & Herdendorf 1974
	Adult		16.6		L. Michigan	Spigarelli 1975
O. nerka (sockeye salmon)					Cultus L., B.C.	Foerster 1937
			10.6-12.8		Horsetooth Res., Colo.	Horak & Tanner 1964
		21			Okanagan R., Wash.	Hajor & Mighel 1966
	Small		14.5		Lab	Brett 1952
O. tshawytscha (chinook salmon)	Small		11.7		Lab	Brett 1952
	Adult		17.3		L. Michigan	Spigarelli 1975
Perca flavescens (yellow perch)	Small		12.2		Muskellunge L., Wis.	Hile & Juday 1941
	Large		20.2		Muskellunge L., Wis.	Hile & Juday 1941
			20.2		Silver L., Wis.	Hile & Juday 1941
			21.0		Nebish L., Wis.	Hile & Juday 1941
			20.8		Trout L., Wis.	Hile & Juday 1941
			19.7		L. Nipising, Ont.	Ferguson 1958
			21.2		L. Opeongo, Ont.	Ferguson 1958
			21.0		Costello L., Ont.	Ferguson 1958
				11	L. Michigan	Wells 1968
	Small		21.0		Lab	Ferguson 1958
	Small		24.2		Lab	Ferguson 1958
	Small	26.5	23.3	20.2	Lab[a]	Neill 1971
	Small	25	22.5	19.5	Lab[b]	Neill 1971
	Small		23.3		Lab	McCauley & Read 1973
	Adults		20.1		Lab	McCauley & Read 1973
	YOY (W)		10-13		Lab	Barans & Tubb 1973
	YOY (Sp)		18.0		Lab	Barans & Tubb 1973
	YOY (S)		25-27		Lab	Barans & Tubb 1973

Table 39. (Continued)

	YOY (F)		28.0		Lab	Barans & Tubb 1973
	Adult (W)		7-12		Lab	Barans & Tubb 1973
	Adult (Sp)		13-16		Lab	Barans & Tubb 1973
	Adult (S)		27.0		Lab	Barans & Tubb 1973
	Adult (F)		22-25		Lab	Barans & Tubb 1973
	Adult (W)		14.1		Lab	Reutter & Herdendorf 1974
	Adult (S)		20.9		Lab	Reutter & Herdendorf 1974
	Adult (F)		19.9		Lab	Reutter & Herdendorf 1974
Pomoxis annularis (white crapple)	Large	27		22	Wabash R., Ind.	Gammon 1973
	Adult (W)		19.8		Lab	Reutter & Herdendorf 1974
	Adult (Sp)		18.3		Lab	Reutter & Herdendorf 1974
	Adult (F)		10.4		Lab	Reutter & Herdendorf 1974
Pomoxis nigromaculatus (black crappie)	Large		27.8-29.8[a]		L. Monona, Wis.	Neill 1971
	Large		27-28.2[b]		L. Monona, Wis.	Neill 1971
	Small	30		26.5	Lab[a]	Neill 1971
	Small	29.5		25.5	Lab[b]	Neill 1971
	Adult (W)		20.5		Lab	Reutter & Herdendorf 1974
	Adult (Sp)		21.0		Lab	Reutter & Herdendorf 1974
	Adult (Su)		21.7		Lab	Reutter & Herdendorf 1974
	Adult (F)		22.2		Lab	Reutter & Herdendorf 1974
	Medium	26	24	20	Lab	Reynolds unpublished data
Salmo gairdneri (rainbow trout)	Adult		18.9-21.1		Horsetooth Res., CO.	Horak & Tanner 1964
	Red fingerlings		22		Lab	Javaid & Anderson 1967[a,b]
	Starved fingerlings		18		Lab	Javaid & Anderson 1967[a,b]
	Fingerlings	22-22	18-19	14	Lab	McCauley & Pond 1971
	Adult		13		Lab	Garside & Tait 1958
	Adult		16.5		L. Michigan	Spigarelli 1975
		19	18	13	Lab	Cherry et al. 1975

Table 39. (Continued)

S. trutta			12	L. Oredon, France	James 1931
(brown trout)		20		Lab	Alabaster & Downing 1966
	Young		17.6	Lab	Ferguson 1958
	Adult		13.8	L. Michigan	Spigarelli 1975
Tinca tinca (tench)		26		Lab	Alabaster & Downing 1956

[a]Day; [b]Night; [c]May be other genera as well. See Reynolds et al. 1977a.

[1] Table adapted from Coutant, 1977.

shows the preferred temperatures of species common to the Columbia River Basin.

Acclimation. It is generally acknowledged that water temperature does control the function and activities of fish species (Lantz 1971), as they are classical examples of poikilothermic organisms, i.e. body temperatures fluctuating in response to the environment. Several researchers (e.g., Brett 1952; Ebel *et al*. 1971; Cherry *et al*. 1975, 1977; Crawshaw 1977; Gibbons 1977; Hokanson *et al*. 1977) have conducted studies which document acclimation of fishes to thermal gradients. Short-term deviations from a given temperature affect respiratory requirements, produce acid-base imbalance, and cause disturbances in fluid-electrolyte regulation (Crawshaw 1977). Acclimation occurs over a period of time when the physiology of the fish is able to counteract these alterations.

Cherry *et al*. (1975) found that as the acclimation temperature was lowered, avoidance decreased and the difference between the upper and lower avoidance range increased at each acclimation level. Eurythermal species, centrarchids, ictalurids, and most cyprinids generally had a range difference of at least 10°C or more between the upper and lower avoidance temperatures at each acclimation level.

Further studies conducted by Cherry *et al*. (1977) indicated that avoidance temperatures increased as acclimation temperatures increased. Upper avoidance tests at high acclimation temperatures (30-36°C) either equalled or exceeded the seven-day upper lethal temperature limit of the species by 1-2°C. Avoidance was below this upper lethal limit when tested at the acclimation temperature closest to the final temperature preference for each species (Cherry *et al*. 1977). Final temperature preferences were usually greater than 29°C for most centrarchids, greater than 24°C for most cyprinids, and less than 19°C for salmonids (Table 39).

Brett (1952) and Ebel *et al*. (1971) found that the range of acclimation temperatures for Pacific salmon was from 5 to 24°C and significant differences existed between the species. Spring chinook and coho were found to be most resistant while pink and chum salmon were the least resistant. Sockeye had a greater resistance to prolonged exposure to high temperatures. No species of Pacific salmon could tolerate temperatures in excess of 25.1°C for a week's duration. Brett (1952) also noted an intolerance to low temperatures which restricted the species' biokinetic range.

Hokanson *et al*. (1977) developed a yield model to demonstrate the effects of temperature on juvenile rainbow trout over time. When yield was plotted against mean temperature, the curve of response to fluctuating temperatures was shifted horizontally an average of 1.5°C towards colder temperatures than the curve of response to constant temperature treatments. This response pattern to fluctuating temperatures indicated that rainbow trout do not respond to mean temperature, but they acclimate to some value between the mean and maximum daily temperature.

Gibbons (1977) examined the effects of dam-related temperature changes on the early life history of chinook salmon in the Skagit River, Washington. No evidence could be found that the spawning pattern and timing have been altered for Skagit River chinook salmon. Gibbons (1977) suggests that perhaps through a physio-biochemical mechanism the fish have become acclimated to the increasing water temperatures in the Skagit.

It is reasonable to suggest that the fish populations of the Columbia River Basin have adapted to the environmental perturbations of the system. The effect on fish of increasing water withdrawal for irrigation will depend in large part on its overall effect on the total river environment. If changes occur gradually species will probably be capable of accommodating minor alterations in temperature.

Effects on Reproduction and Development. Fish reproduction has been shown to be affected by water temperature. Eschmeyer and Smith (1943) found that warm-water fish species were not reproducing below Norris Dam in Tennessee even though they occurred in relatively large numbers. The absence of reproduction was caused by low water temperatures. Benson (1973) has also shown that decreases in water temperature caused atresia (i.e., degeneration of eggs) in northern pike.

Seymour (1956) carried out comprehensive studies on temperature effects on chinook salmon from the egg to fingerling stage. A common trend was found for the relationship of temperature to the number of vertebrae, egg mortality, the number of abnormal fry, and the duration of the hatching period. For eggs reared at temperatures ranging from 4.4 to 14.4°C minimal effects occurred but increased at both higher and lower temperatures. In terms of mortality and growth rate, the optimum temperature for chinook salmon development is 11.1°C for eggs and 14.4°C for fingerlings.

Combs (1965) also studied the effects of temperature on the development of salmon eggs. The lower temperature threshold for normal development of sockeye eggs ranged from 4.4 to 5.8°C. An upper threshold of 12.7 to 14.2°C was also established for sockeye.

Slight increases or decreases in water temperature caused by expanded irrigation water withdrawal could be expected to further impact the important salmon fisheries in the Columbia River Basin. Minor temperature fluctuations can directly influence year-class strength.

Garside (1966) conducted experiments on the relation of oxygen concentration to temperature on the development of embryos of brook and rainbow trout. Embryonic development measured by the times required to attain a series of embryonic stages was accelerated by increasing temperatures. The rate of development was increasingly retarded by progressively lower levels of dissolved oxygen. The time of hatching and length of incubation periods were similarly influenced by temperature and the concentration of dissolved oxygen.

Dissolved oxygen concentrations have been shown to be decreasing in the main stem of the Columbia and also in the tributaries (see Water Quality and Gas Saturation Impact Sections). In particular, reduced oxygen concentrations are markedly lower in comparison with historical data on the lower Yakima and may be attributed to irrigation return flows. Increasing irrigation will most likely continue to decrease the dissolved oxygen concentrations by return flows and with potential fluctuations in temperatures, early life stages of fish may be impacted.

Effects on Food Consumption. A complex relationship exists between food consumption of fish and water temperature. Hathaway (1927) found that pumpkinseeds, bluegills, and largemouth black bass (i.e., warm-water game fish) consume approximately three times as much food per day at 20°C as at 10°C. Small fish ate more in proportion to body weight than did the larger individuals of the same species. When water temperatures remained at 10°C over several weeks the depression of food consumption due to cold was not counteracted by acclimation but rather became more pronounced.

However, Latta (1969) found that the mortality rate of brook trout fry (i.e., cold-water game fish) from starvation increased in a curvilinear pattern as water temperatures increase. Starvation lowered the resistance of juvenile fish to biological and physical stresses of the environment.

The above examples contrast the environmental requirements of warm-water species with cold-water fish. Depending on the extent to which irrigation water withdrawal modifies the thermal regime species composition may change, with certain fish predominating over other, perhaps more valuable species.

Effects of Disease. Water temperatures have been shown to be directly correlated with fish diseases. Becker and Fujihara (1978) have written a comprehensive monograph summarizing previous literature and reporting the results of recent studies on the fish pathogen *Flexibacter columnaris* in the Columbia River Basin. The pathogen was rarely isolated in Columbia River water during the winter months but appeared in early spring when temperatures rose above 10°C. A high incidence of the disease was noted in 1970 and 1973 and was correlated with above normal air temperatures, and unusually low river flows. Cool water temperatures in anadromous fish spawning tributaries were found to inhibit pathogenesis of *F. columnaris*. Mortality from the disease in chinook salmon was shown to be related to the age of the fish and water temperature. Older individuals were more resistant than younger fish and mortality occurred at a faster rate at higher temperatures (Becker and Fujihara 1978).

Fryer et al. (1976) studied *Aeromonas salmonicida* and *A. liquefaciens* infection in chinook salmon and steelhead trout. It was also found in this study that the progress of the diseases was accelerated at higher temperatures and retarded at lower temperatures. Bacterial kidney disease was found to cause between 78 to 100 percent mortality in the temperature range of 616 to 12.2°C. Higher temperatures had a suppressing effect, which was well marked at 20.5°C.

The most significant conclusion of Becker's and Fujihara's (1978) studies was that extended seasons of low river flow and warm temperatures appear to significantly enhance the epizootiology of *F. columnaris* in Columbia River fish populations. The authors stress that the disease problem may intensify in the future if increasing amounts of Columbia River water are withdrawn for irrigation.

Effects on Fish Movement. Water temperatures have been shown to influence fish movements in a body of water. Sullivan (1954) showed that fish moving in a temperature gradient select a particular temperature because of the effect of the thermal regime on their movements. Maximum cruising speed as measured at different equilibrium temperatures is greatest at the fish's preferred temperature. The maximum cruising speed that can be maintained by fish increases when they become acclimated to the water temperature and peaks at the preferred temperature. Brett et al. (1958*a*) also demonstrated the profound effect that temperature exerted on the cruising speed of juvenile sockeye and coho salmon. Optimum cruising speeds occurred at 15°C for sockeye and 20°C for coho salmon.

Brett (1958*b*) found that temperatures could be a inhibiting factor on fish metabolism. Low temperatures could depress metabolism to a point of near or total inactivity. High temperatures on the other hand overload basal metabolism and ultimately the same result occurs; activity is seriously limited.

These temperature effects have been documented with regard to the anadromous salmonids in the Columbia River Basin. Major and Highell (1966) discovered that high water temperature in the Okanogan River is a major cause of delay in sockeye salmon migrations. Above 21°C, rising or stable Okanogan River temperatures block the entry of fish from the main stem of the Columbia into the Okanogan; falling temperatures allow the migration to resume. Below 21°C, migration is not inhibited by rising or constant temperatures.

Thomas (1975) (see also Bams 1969, Coburn and McCart 1967) reported that higher water temperatures increase migration. Chinook salmon fry in simulated incubation channels were subjected to artificially-induced variables of temperature, turbidity and water flow. Increased water temperature and turbidity both produced major increases in migration while doubling the water flow did not.

Juvenile salmon and steelhead undergo smoltification which is the physiological process allowing the fish to adjust from a freshwater environment to one of saltwater. During this smoltification process the juveniles are motivated to migrate downstream. Adams et al. (1975) found that nonmigratory steelhead (parr) undergo a transformation to smolts when water temperatures are below 11.6°C. However, Zaugg et al. (1972) observed that steelhead smolts revert to parr if they are kept for extended periods in water above 12.2°C. Adams et al. (1975) also found that survival for steelhead smolts which reverted to parr was only about 20 percent.

A further effect of delayed migration is the residualization (i.e., loss of the migratory urge) of the juveniles (Ebel 1977). The juveniles remain in the reservoirs and do not complete their ocean life stage. Thus, they do not contribute to the economically valuable adult fisheries (CRFC 1978). Residualism may also increase the extent of predation on juvenile downstream migrants. Many residual fish, both salmon and steelhead, attain a size where they subsist largely on small fish (Bell 1973).

Temperatures above 12.2°C are often reached by mid-May in the Columbia River (CRFC 1978). If irrigation water withdrawal would raise water temperatures only slightly, larger numbers of anadromous salmonids could have their seaward migration delayed, causing extensive mortality and residualism.

In summary, water temperatures have a diversity of effects on fish species at all levels of development. It is difficult to identify specific effects in a natural environment given the complexity of ecosystem dynamics. Non-thermal factors, such as photoperiod, circadian rhythms, currents, social and biotic interactions, stresses, diseases, or chemicals can affect thermal responses (Reynolds 1977). These factors may account for the discrepancies noted between field and laboratory studies.

The degree to which water temperatures will be affected by irrigation water withdrawal will ultimately depend on the quantity of water removed from and returned to the system and also the seasonal hydraulic regime. Water withdrawn in years of low flows and unseasonably high air temperatures may induce several severe thermal impacts on the fisheries in contrast to water withdrawal during high water years.

Siltation-Turbidity Impacts

Siltation (deposit of sediments) and turbidity (suspended sediments) should both increase as a result of increased irrigation withdrawals. Runoff and return flows from irrigating additional lands will carry more sedimentation into natural tributaries. Unlined return canals contribute heavier silt loads than lined or subsurface drains (Sylvester and Seabloom 1962). Turbidity in the Wenatchee River doubled over a 45-year period, due to increased agriculture and other human activities (Sylvester and

Ruggles 1957). Increased sediment due to irrigation will more seriously affect the water quality of Columbia River tributaries than that of the reservoirs. Impoundments on the main stem slow river velocity and allow some of the sediment to settle (Sylvester and Ruggles 1957). Therefore, turbidity will be lower on the main stem than in the tributaries, which provide most of the spawning areas for anadromous salmonids. Increased siltation in tributary spawning beds will have a greater impact on these fish populations than sediment loads dropped in the main stem reservoirs.

Effects of sediments on aquatic biota have been extensively studied and reviewed (Iwamoto et al. 1978). In general, observed effects have been detrimental. Algae, phytoplankton, zooplankton, benthos, aquatic insects, and fish are all adversely affected by suspended, shifting, and deposited sediments.

Effects on Algae and Phytoplankton. Algae and phytoplankton are affected primarily by reduced light transmission and physical damage from moving material. Turbidity has repeatedly been found to reduce light penetration, thus reducing the depth of photosynthetic activity (Chandler 1942; Chapman 1963; Bullard 1965; Cairns et al. 1972). Turbidity is a major limiting factor to plankton abundance in the Missouri River system (Benson and Cowell 1967). Studies of streams and impoundments have found reduced algal or phytoplankton concentrations in turbid waters when compared to clear waters (Buck 1956; Herbert et al. 1961; Cordone and Pennoyer 1960; Sherk et al. 1976). Samsel (1973) found that sediments from construction activities resulted in a reduction of transparency of about 50 percent as measured by Secchi disk, and were apparently responsible for a threefold reduction in algal productivity in a Virginia impoundment.

Chapman (1963) noted that moving sediment may grind or dislodge algae. Shifting deposited sand (0.008-0.015 in.) prohibited establishment of periphyton along an English riverbed (Nuttall 1972).

The effects of light reduction and bed instability can lead to changes in the composition of aquatic plant communities. Species associated with clear water will decrease or disappear, while those often found with mud and silt will increase (Hansmann and Phinney 1973; Samsel 1973).

Effects on Macroinvertebrates. Invertebrates and aquatic insects appear to suffer more from deposited sediments than from turbidity. Perhaps the major effect of siltation is the reduction of diversity brought about by a loss of interstices in the substrate. Numerous studies have documented a decrease in species diversity and density along a gradient from gravel to sand and silt substrates (Leonard 1962; Ruggles 1966; Cairns 1967; Chutter 1969; Pennak and Van Gerpen 1947; Sprules 1947). When fine sediment is deposited on gravel, species diversity and densities have been found to drop significantly (Cordone and Pennoyer 1960; Herbert et al. 1961; Bullard 1965; Reed and Elliott 1972; Nuttall and Bielby 1973). Bjornn et al. (1974) noted lower densities of insects in riffle areas containing large amounts of sediments less than 1/4 of an inch in diameter. Investigating the effects of landslide debris in the Clearwater River, Washington, Cederholm et al. (1978) found a significant negative correlation between mean numbers of benthic invertebrates and gravel size less than 0.033 in. Deposited sediment may reduce accessibility to micro-habitats by embedding the edges of cobbles (Brusven and Prather 1974), and it may also entomb benthic organisms such as mussels, which then die of oxygen depletion (Ellis 1931).

Suspended sediments also limit insect populations. Movement of particles may dislodge or injure insects (Tarzwell 1938), and respiratory surfaces may be abraded. Vegetation used as food and cover can be removed (Rees 1959). Several studies have described decreases of benthic organisms associated with high silt loads. Branson and Batch (1972) observed a 90 percent reduction in numbers and kinds of benthic fish food organisms at silt loads of 3,000 parts per million (ppm) from Kentucky stip mine operations. In a 10-year stream survey Roback (1962) found numbers of caddis fly larvae genera decreased from 16 to 7 at sediment concentrations in excess of 500 ppm. Wagner (1959) and Ziebel (1960) reported decreases in productivity of 85 percent at silt concentrations ranging from 91 to 103 ppm in the Wynoochee River. Addition of more than 80 ppm of inert solids to the normal suspended particle concentration of 40 ppm caused a 60 percent reduction in population of riffle macroinvertebrates (Gammon 1970). Estuarine copepods ingested fewer food organisms as silt concentration increased (Sherk et al. 1976).

Effects on Fish. The majority of research on sedimentation effects has dealt with fish (Iwamoto et al. 1978). Siltation and turbidity adversely affect fish at every stage of their life cycle. As with benthic invertebrates, deposited sediments have a greater impact on fish than do suspended sediments. The primary action of siltation is on spawning beds and deposited eggs.

Siltation will lower the average size of bed material; salmon and trout avoid areas with high percentages of sand, silt, and clay (Burner 1951; Stuart 1953). Eggs deposited in fine gravel or gravel with a high percentage of fines have a lower percentage of fry surviving to emergence (Harrison 1923; Hobbs 1937; Shapovalov and Berian 1940; Shaw and Maga 1943; Koski 1966). Shelton (1955) found higher emergence of chinook fry from one to three-inch gravel than from small gravel less than one inch. In six Alaska streams an inverse correlation was found between the percentage of gravel less than 0.021 inch in diameter and returning adult salmon (McNeil and Ahnell 1964). Gravel size between 0.033 in. or less also showed an inverse correlation with respect to pink salmon fry production (Shapley 1964). Koski (1975) found a decrease of 1.26 percent in survival to emergence of chum salmon fry for each one percent increase in sand (fines between 0.003 and 0.085 in). In various experiments Phillips et al. (1966) found decreases in coho and steelhead fry emergence with increases of gravel and fines less than 0.21 in, 0.025 in to 0.076 in, and less than 1/2 inch in diameter.

Sediment reduces emergence through two mechanisms: decreasing intragravel water flow and oxygen, and acting as a physical barrier to fry emergence (Koski 1972). Cooper (1956, 1959, 1965) has shown reduced flow of water through gravel due to deposition of fine sediment (< 0.008 in), with resultant lowering of dissolved oxygen levels. Other investigators have reported similar findings (Wickett 1958; McNeil and Ahnell 1964), though Kingsbury (1973) found no significant relationship between fine sediment and intragravel oxygen. Embryos which receive less oxygen during development have higher mortality (Coble 1961; Mason 1969) and emerge later, thus are at a disadvantage in seeking food and living space (Alderdice et al. 1958; Shumway et al. 1964; Brannon 1965; Mason 1969).

Harrison (1923) was the first researcher to note the difficulty fry have in escaping from fine gravel. These observations have been substantiated by subsequent studies (Hobbs 1937; White 1943; Koski 1966; Hausle and Coble 1976).

After emergence, deposited sediments are not as detrimental to fry. Food becomes a more critical factor for pike (Hassler 1970), though McCrimmon (1954) found available shelter was the most important determinant in survival of Atlantic salmon (*Salmo salar*) fry. Sediment covers intragravel crevices which juvenile fish use for shelter. This has been found to reduce the carrying capacity of streams for young salmon and trout (Cordone and Kelley 1961; Bjornn et al. 1974). Fish vacate pools in summer after heavy accumulation of sediments (Gammon 1970).

The effects of turbidity on fish are less conclusively known than those of deposited sediments. Numerous studies have found no lethal effects from suspended particles (Wallen 1951; Cordone and Pennoyer 1960; Everhart and Duchrow 1970; Neumann et al. 1975).

Coal washery wastes at 50, 100 and 200 ppm were not lethal to fish, according to Herbert and Richards (1963). McCrimmon (1954) found no appreciable effects of turbidities up to 1,150 ppm on parr stages of Atlantic salmon. Others, however, have observed several harmful effects.

Stuart (1953) found that trout ova which attracted silt particles from the water, soon became coated with sediment, and died. Eyed ova and alevins resisted deleterious effects from suspended sediment for a short time, but alevins constantly exposed to turbid water eventually died from inflammation of gill membranes. Turbidity of 1,000 to 2,500 ppm from a gold-dredging operation killed all rainbow trout eggs experimentally planted in an Oregon river (Campbell 1954). Bianchi (1963) also found that suspended sediment was an important determinant of trout embryo survival.

Movement of bed load can also be detrimental to fish development. High flows can smother eggs with silt, scour redds and expose eggs, and damage eggs and larvae by abrasion from moving particles (Gangmark and Broad 1956; Sheridan and McNeil 1960; Tyler and Gibbons 1973; Meehan (1974).

In addition to increasing susceptibility to disease, suspended sediments interfere with the respiratory function of the gills. Sherk et al. (1974) found that various sediments clogged gill interstices, coated epithelia, and blocked secondary lamellae.

Tolerance to turbid waters has been reported for many fish (Langlois 1941; Hamilton 1961; Gammon 1970; Sherk et al. 1974), but these same authors list other species which require clear water (e.g., perch, whitefish) and even seasonal differences in tolerance of turbidity. Buck (1956) found growth rate, production, and reproduction for warm-water game fish in clear ponds (< 25 ppm) was greater than in intermediate ponds (25 to 100 ppm) and much greater than in muddy ponds (> 100 ppm). Game fish, which sightfeed, may be at a selective disadvantage in turbid waters against bottom feeders such as carp (Stroud 1967).

Turbid waters also affect migration. Thomas (1975) found fry migration increased as turbidity increased. Several authors have noted that waters high in suspended sediments may delay or divert spawning runs, or be avoided by spawning salmon (Smith 1939; Servizi et al. 1969; Mortensen et al. 1976).

There are few positive effects derived from siltation and turbidity. High turbidity may serve as concealment and protect young salmon during downstream migration (McCrimmon 1954). There is a decline in fishing success for game species, which are primarily sight feeders, when turbidity is high (Buck 1956; Koski 1972). While this may not be a positive effect from the sportsman's point of view, it is a reduction in predation on the fish.

Gas Saturation Impacts

Nitrogen. Nitrogen supersaturation occurs when water is spilled over dams. Nitrogen is forced into solution by the change in the partial pressures of atmospheric gases (of which nitrogen is 78%) as the water plunges from the spillway of a dam into the tailrace (SML 1972). Since the volume of water spilled ultimately determines the degree of nitrogen saturation (Meekin and Allen 1974), reduction in spilling results in lower saturation levels. During the fall and winter months when water is not spilled over main stem dams, normal nitrogen saturation levels (i.e., 100%) are found (WDF 1974). In general, higher nitrogen saturation levels are noted in the reservoir tailrace than in forebay areas (Meekin and Allen 1974); however, when numerous reservoirs occur end-to-end, as on the Columbia, without intervening free-flowing reaches, supersaturation can extend through several reservoirs.

The entire mid-Columbia is supersaturated with nitrogen at values of 120-130 percent during periods of high runoff in the spring (WDF 1974; Dell et al. 1975). Nitrogen supersaturation has been found to be detrimental to fish in the Columbia River (Ebel 1969; Beiningen and Ebel 1968; Rulifson and Abel 1971). The downstream migrations of juvenile salmonids overlap the period of high spills from spring runoff (WDF 1974). Juvenile fish showed a lower tolerance to increasing water temperatures when nitrogen was present at supersaturated levels (Ebel 1969; Ebel et al. 1971). Water supersaturated with nitrogen causes mortality in juvenile and adult salmonids, the extent of which depends on the degree of exposure (Beiningen and Ebel 1968; Chaney 1978).

Several researchers have studied the specific effects of nitrogen supersaturation on various fish species and found that threshold levels generally range from 110-130 percent depending on water depth (Rucker and Tuttle 1948; Harvey and Cooper 1962; Nebeker and Brett 1976; Fickeison et al. 1973; Rucker and Kangas 1974; Meekin and Turner 1974; Meekin and Allen 1974; Jensen 1974; Blahm 1974; Weitkamp 1975; Dawley et al. 1975; Bouck et al. 1976; Blahm et al. 1975; Bentley et al. 1976).

Gas bubble disease (GBD) and mortality are the primary detrimental effects associated with dissolved nitrogen concentrations at threshold levels (Parametrix 1975). Fish tolerance to gas supersaturation is influenced by water depth, duration of exposure, and age. Table 40 summarizes the various studies which have documented the effects of nitrogen supersaturation on several fish species.

Blahm et al. (1975) found that detrimental effects of nitrogen supersaturation varied according to the length of exposure. Chinook, coho, steelhead, rainbow trout, whitefish and largemouth bass were exposed to nitrogen levels of 130 percent for 8 of every 24 hours. Mortality did not exceed 50 percent if the fish were placed in nitrogen-saturated water (i.e., 100%) for the remaining 16 hours. However, when fish were continuously exposed to supersaturated levels of nitrogen (130%), mortality rates exceeded 50 percent during the first day.

TABLE 40. Threshold levels of fish species for nitrogen supersaturation[1]

Species	N_2(%)	TGP(%)[2]	Effects	References
Eggs and Larvae				
sockeye (*Oncorhynchus nerka*)	108-110		GBD[3] and mortality (mort.)	Harvey & Cooper (1962)
trout	110-115		critical range	Rucker & Tuttle (1948)
chinook (*Oncorhynchus tshawytscha*)	122		0 mort.	Meekin & Turner (1974)
steelhead (*Salmo gairdneri*)	122		50% mort.	Meekin & Turner (1974)
coho (*Oncorhynchus kisutch*)	128		0 mort.	Rucker & Kangas (1974)
chinook	128		0 mort.	Rucker & Kangas (1974)
Juveniles				
chinook	115-130	110-126	80% mort. 55 days(d) exposure	Blahm (1974), Blahm et al. (1975)
steelhead	115-130	110-126	80% mort. 55 d	" "
cutthroat (*Salmo clarki*)	115-130	110-126	80% mort. 55 d	" "
sockeye		110	0 mort. 26-48 d	Nebeker & Brett (1976)
coho		110	0 mort. 26-48 d	" "
steelhead		110	5% mort. 26-48 d	" "
sockeye		115	50% mort. 21 d	" "
coho		115	10% mort. 26 d	" "
steelhead		115	50% mort. 21 d	" "
sockeye		120	50% mort. 2 d	" "
coho		120	50% mort. 5.5 d	" "
steelhead		120	50% mort. 2 d	" "
chinook	135	122	64-100% mort. 3-8 d	Meekin & Turner (1974)
chinook	124	124	92-100% mort. 5-7 d	" "
chinook	125	114	8-100% mort. 6 d	" "
chinook		124-127	67-97% mort. 60 d, 7.9 ft water	Dawley et al. (1975)

Table 40 (continued)

Species	N_2(%)	TGP(%)[2]	Effects	References
chinook	130		<50% mort. at 8 hour exposure/d but 50% mort. at <24 hrs if continuously exposed	Blahm et al. (1975)
coho	130			" "
steelhead	130			" "
rainbow	130			" "
whitefish (*Prosopium williamsoni*)	130			" "
largemouth bass (*Micropterus salmoides*)	130			" "
chinook	135		Can tolerate this level for 16 hrs if returned to saturated (100 TGP) for 8 hours.	Blahm et al. (1975)
steelhead	135			" "
chinook	124		3-5 ft (water depth), 10 d, 4-44% mort.	Meekin & Turner (1974)
chinook	124		5-7 ft, 14 d, 4-16% mort.	" "
coho	124		3-5 ft, 7 d, 18% mort.	" "
steelhead	124		3-5 ft, 10 d, 24% mort.	" "
steelhead	124		5-7 ft, 14 d, 20% mort.	" "
chinook		123	8-10 ft, 14 d, 0 mort., 0 GBD	" "
steelhead		123	8-10 ft, 14 d, 0 mort., 0 GBD	" "
squawfish		123	8-10 ft, 14 d, 0 mort., 0	" "
(*Ptychocheilus oregonensis*)		123	8-10 ft, 14 d, 0 mort., 0 GBD	" "
coho		125	8-10 ft, 7 d, 0 mort.	" "
chinook, coho, steelhead		126-127	0-2 ft, 3 d, 100% mort.	" "
" " "		" "	0-7 ft, 21 d, 4% coho & 60% chinook, steelhead mort.	" "
" " "		" "	0-10 ft, 21 d, 3% chinook mort., no other morts.	" "
chinook		118-126	10 d, 0 mort.	Weitkamp (1975)
chinook		" "	0-6.6 ft, 20 d, 17% mort.	"
chinook		" "	0-9.8 ft, 20 d, 21% mort.	"
chinook		" "	3.3-6.6 ft, 20 d, 1% mort.	"
chinook		" "	6.6-9.8 ft, 20 d, 1% mort.	"
chinook		125	<6.6 ft, 20 d, 30 & 60% mort.	"

Table 40 (continued)

Species	N_2(%)	TGP(%)[2]	Effects	References
chinook		125	<9.8 ft, 20 d, 1 & 7.5% mort.	Weitkamp (1975)
chinook		125	0-13.1 ft, 20 d, 0 mort.	"
Unidentified Life Stage				
sockeye (adult)	>120	120	estimated 50% mort., passing Wells dam (1967-1969)	Meekin & Allen (1974c)
mountain whitefish		≤130	listed in the order of increasing tolerance	Fickeisen et al. (1973)
rainbow trout		≤130		"
pumpkinseed (*Lepomis gibbosus*)		≤130		"
blue gill		≤130		"
(*Lepomis macrochirus*)		≤130		"
largescale sucker		≤130		"
(*Catostomus columbianus*)				"
black bullhead (*Ictalurus melas*)		≤130		"
smallmouth bass (*Micropterus dolomieui*)		≤130		"
squawfish		126	.82 ft, <1 d, 100% mort.	Bentley et al. (1976)
"		120	12 d, 60% mort.	"
"		117	12 d, 32% mort.	"
"		110	12 d, 89% showed signs of GBD	"
"		107	12 d, 0 mort.	"
"		100	12 d, 0 mort.	"
largemouth bass		125	2.1 ft, 20 d, <10% mort.	Bouck et al. (1976)
black bullhead		125	96 hrs, 50% mort.	Fickeison et al. (1973)
carp (*Cyprinus carpio*)	131	130	signs of GBD	Jensen (1974)
white crappie (*Pomoxis annularis*)	131	130	signs of GBD	Jensen (1974)

[1]Data from EBEL (1975) and Weitkamp, D.E. & M. Katz (1977). [2]TGP = Total Gas Pressure. [3]GBD = Gas Bubble Disease

Cramer and McIntyre (1974) observed that Columbia River chinook stocks with the longest history of exposure to supersaturation were the most tolerant of nitrogen levels above 100 percent.

Northern squawfish are able to avoid areas of high nitrogen saturation by migrating to deeper water levels or less saturated areas (Bentley et al. 1976).

Studies with various species of juvenile salmonids indicate that they may compensate for total nitrogen saturation levels up to 125 percent by remaining in deeper water (Parametrix 1975). Since hydrostatic pressure increases with depth, by migrating to deeper water nitrogen remains in solution in the blood of fish inhibiting GBD.

Currently, peak irrigation withdrawal coincides with the timing of the maximum spills at Columbia River main stem dams (ID/IFS 1976). If additional water is withdrawn for irrigation from the river, spill volume will probably decrease. Therefore, nitrogen supersaturation may be reduced along with detrimental impacts on fish.

Oxygen. The highest levels of dissolved oxygen (D.O.) concentrations occur in the main stem of the Columbia River during periods of high runoff in May and June (SML 1972). D.O. levels are generally higher in surface waters than in deeper layers (SML 1974).

Depressed D. O. levels often become apparent in tributaries with extensive irrigation return flows (Sylvester and Seabloom 1962). Warm air temperatures and solar radiation combine to raise the water temperature of irrigation return flow considerably. Increased water temperatures of irrigation return flows have been shown to reduce D.O. levels in Yakima River (Sylvester and Seabloom 1962).

D.O. may also be limited in the tributaries by low summer streamflow (McNeil 1968). Adverse effects on the development of incubating eggs which are exposed to low D.O. in intergravel water have been documented by several researchers. Alderdice et al. (1958) found that very low oxygen levels at early egg incubation stages produced severe morophometric abnormalities in chum salmon. Eggs in an advanced stage of development were stimulated to hatch prematurely causing mortality under low oxygen conditions.

Doudoroff and Warren (1965) reported that the rates of embryonic and larval development, the size of larvae at the times of hatching and of completion of yolk absorption were all dependent on oxygen concentration. Garside (1966) similarly noted that the rate of development of brook and rainbow trout was increasingly retarded by progressively lower levels of D.O. Silver et al. (1963) and Shumway et al. (1964) observed that steelhead, coho, and chinook reared in water with low or intermediate oxygen concentration were smaller in size and had a longer incubation period. Table 41 summarizes the threshold levels and effects

Table 41. The oxygen response thresholds for various Columbia River species collected from the literature. The response levels reported are incipient oxygen levels where effects first become apparent thus providing a "biological indication" of the onset of hypoxic stress. A) Freshwater species, B) Anadromous species, C) Eggs and larvae (freshwater and anadromous)[1]

			Level of dissolved oxygen					
Species	Size	Temp (C)	PO_2 mm Hg	ml O_2/l	mg O_2/l	% Satn.	Response to oxygen level	Reference
A. Brown bullhead, *Ictalurus nebulosus*	43-127 g	9-10	60	4.87-4.76	6.95-6.80	38.0	onset of oxygen--dependent oxygen uptake	Grigg (1969)
Rainbow trout, *Salmo gairdneri*	682-1136 g	20	78	3.20	4.59	50	below this level blood is not fully saturated with oxygen	Irving et al. (1941)
" "	120-250 g	8.5-15	80-100	3.63-5.14	5.18-7.34	50.7-63.7	circulatory changes occur, including a slowing of heart	Randall and Smith (1967)
Carp, *Cyprinus carpio*	77-350 g	10	50	2.51	3.59	31.7	standard oxygen uptake elevated (depressed at lower levels)	Beamish (1964)
	30-600 g	20	80	3.29	4.71	51.3		
" "	235-785 g	13.3-25	80	2.74-3.04	5.39-4.34	50.9-51.6	blood ceased to be fully saturated with O_2 below this level	Itazawa (1970)
Walleye, *Stizostedion vitreum*	2 yr-old	22	35.2-70.4	2.8-1.4	4-2.0	45.3-22.7	loss of negative phototaxis (light avoidance behavior)	Scherer (1971)
			70.4-96.8	3.85-2.8	5.5-4.0	45.3-62.3	increased mobility, "darting" behavior	
Largemouth bass, *Micropterus salmonides*	5-9 cm	--	--	3.15	4.5	--	some indication of avoidance behavior	Whitmore et al. (1960)
				1.1	1.1	--	marked avoidance	
Brook trout (speckled trout) *Salvelinus fontinalis*	682-1136	20	77.95	3.21	4.59	50	blood ceases to be fully satd. with O_2 below this level	Irving et al. (1941)

Table 41. (Continued)

Brook trout (speckled trout) *Salvelinus fontinalis*	17-65 g	5	100	5.66	8.09	63.2	onset of O_2-dependent metabolism	Graham (1949)
		8	80	4.19	5.99	50.7	reduced cruising speed	
		20	154	6.34	9.06	98.8	onset of O_2 dependent metabolism	
		5-20	116.9-118.7	6.72-4.82	9.6-6.88	75	reduced activity, all temps.	
" "	56-140 g	10,15	80	4.03-3.63	5.75-5.18	50.7-51.0	standard oxygen uptake reduced below this level	Beamish (1964)
Brown trout, *Salmo trutta*	682-1136 g	20	77.95	3.21	4.59	50	blood ceases to be fully satd. with O_2 below this level	Irving et al. (1941)
Rainbow trout, *Salmo gairdneri*	13.3±1.4	17±.5	156.6	6.82	9.74	100	any reduction in oxygen led to more rapid death in cyanide	Downing (1954)
" "	20 mos old	8-10	78.85-79.95	4.16-3.97	5.94-5.67	50	43% reduction in maximum swimming speed	Jones (1971b)
		21-23	77.85-77.6	3.15-3.04	4.50-4.34	50	30% reduction in maximum swimming speed	
" "	235-510 g	2.3-13	100	6.11-4.71	8.73-6.74	63.1-63.6	blood is not fully satd. with oxygen below this level	Itazawa (1970)
" "	--	15	78.45	3.55	5.08	50	altered respiratory quotient, little capacity for anaerobic metabclism below this level	Kutty (1968a)
	--	15	80-100	3.63-4.53	5.18-6.47	51.0-63.7	changes in oxygen transfer factor and effectiveness of O_2 exchange occur	Randall et al. (1967)

Table 41. (Continued)

Rainbow trout, *Salmo gairdneri*	400-600 g	13.5	80	3.74	5.35	51.0	breathing amplitude and buccal pressure elevated	Hughes and Saunders (1970)
" "	approx. 300 g	10,15, 20	80	3.30-4.03	4.71-5.75	50.7-51.3	below this level blood is not fully satd. with oxygen	Cameron (1971)
" "	1-11 g	17.5	93.8	4.05	5.78	60	toxicity of zinc, lead, copper, phenols increased markedly below this level	Lloyd (1961)
Largemouth bass, *Micropterus salmoides*	juvenile	25	92.3-110.7	3.5-4.2	5-6	59.7-71.6	final (maximum sustained) swimming speed reduced below this level	Dahlberg et al. (1968)
Bluegill, *Lepomis macrochirus*	5-9 cm	--	--	2.1	3.0	--	some avoidance behavior	Whitmore et al. (1960)
				1.1	1.5	--	strong avoidance	
B. Anadromous species								
Steelhead *Salmo gairdneri* - *see freshwater species*								
Sockeye salmon, *Oncorhynchus nerka*	50 g	20-24	155.9-154.9	6.42-5.97	9.17-8.53	100	available oxygen level appears to limit active metabolism and maximum swimming speed	Brett (1964)
" "	1579 g	13	100	4.72	6.74	63.6	blood ceases to be fully O_2 saturated below this level	Davis (1973)
" "	1.5-1.7 kg	15	78.45	3.55	5.07	50	elevated blood and buccal pressure and breathing rate increased	Randall and Smith (1967)

Table 41. (Continued)

Coho salmon, *Oncorhynchus kisutch*	6.3-11 cm	"summer tempera- tures"	--	3.15	4.5	--	erratic avoidance behavior	Whitmore et al. (1960)
	5.1-14.8 cm	12±1	130.8	6.3	9.0	83.1	below this level acute mortality in kraft pulpmill effluent increased	Hicks and DeWitt (1971)
" "	Juvenile	10-20	157.7-155.9	7.93-6.42	11.33-9.17	100	reduction of O_2 below saturation produced some lowering of maximum sustained swimming speed	Davis et al. (1963)
" "	"	20	155.9	6.42	9.17	100	as above	Dahlberg et al. (1968)
" "	"	"	136-67.9	5.6-2.8	8.0-4.0	87.2-43.6	growth rate propor- tional to oxygen level with best growth at 8.0 mg/liter, lowest at 4.0 mg/liter	Hermann (1958)
Chinook salmon, *Oncorhynchus tshawytscha*	6.3-11 cm	"summer temps"	--	3.15	4.5	--	marked avoidance of this level in summer	Whitmore et al. (1960)
		"fall temps"	--	--	4.5	--	little avoidance of this level in fall	
" "	Juveniles	10-20	157.7-155.9	7.93-6.42	11.33-9.17	100	reduction of O_2 below saturation pro- duced some lowering of maximal sustained swimming speed	Davis et al. (1963)
American shad, *Alosa sapidissima*	--	--	--	1.75-2.1	2.5-3.0	--	threshold for migra- tion through polluted areas	Chittenden (1973)
				2.8	4.0	--	necessary for spawning areas	

Table 41. (Continued)

				C. Eggs and larvae				
Rainbow trout, larvae, *Salmo gairdneri*	1+8 day old larvae	10+1	100	5.03	7.18	63.4	elevated heart and breathing rates below this level. Bradycardia (heart rate slows) sets in at lower O_2 levels	Holeton (1971)
Chum salmon eggs, *Oncorhynchus keta*	early stage eggs	10	13.9	.7	1	8.8	retarded development, deformities, mortality, respiratory O_2-dependence	Alderdice et al. (1958)
	pre-hatch eggs	10	>97.4	>4.9	>7.0	>61.8	oxygen level required for normal development and non O_2-dependent metabolism	
" "	5 day	8.0-8.2	22.2	1.17	1.67	14.07	critical oxygen level for supply of oxygen demand and non O_2-dependent metabolism	Wickett (1954)
	(eyed) 85 day eggs	3.6-4.9	>60.3	>3.5	>5.0	>38.1		

[1]Davis (1975)

of reduced oxygen on several species of fish as reported by numerous investigators.

Future irrigation development will ultimately reduce streamflow, especially in tributaries; thus, with increasing water temperatures lower D.O. levels will result (ID/IFS 1976). The extent and longevity of the reduced D. O. concentrations will depend on the quantity of water withdrawn and the quality of the return flow. Fish species will be particularly susceptible to the adverse effects described above if the periods of low D.O. levels coincide with spawning and incubation times.

Disease Impacts

Wood (1968) and Bell (1973) have reviewed in detail fish diseases and their effects. These authors considered diseases which were of primary concern in hatcheries and specified the symptoms, causative agents, and required treatments.

Fish diseases may be classified into one of six general categories: 1) nutritional or organic; 2) bacterial; 3) viral; 4) external parasites; 5) internal parasites; and 6) fungi (Bell 1973). The diseases common to wild fish populations are discussed below.

Bell (1973) suggests that fish populations inhabiting lakes and reservoirs tend to experience more disease epidemics than fish species found in free-flowing rivers. Diseases in impoundments generally occur as a result of widespread parasite infections (Bell 1973).

Parasite fauna of rivers tend to change to lentic forms after impoundment. In general, a decrease in parasitism occurs during the first few years following impoundment, with an increase occurring as the system stabilizes (Bauer and Stolyarov 1961; Hoffman and Bauer 1971). Factors which control parasite populations include temperature (and seasons) and host immunity (Hoffman and Bauer 1971).

In the Columbia River reservoirs the myxosporidan, *Ceratomyxa shasta* (an internal fish parasite) has been identified. Conrad and Decew (1966) report a 58 percent mortality rate for hatching salmon and rainbow trout reared in Columbia River water with the parasite. Water temperatures above 10°C are required for initial infection and the disease progresses rapidly with increased water temperatures (Bell 1973).

Parasites such as *Ichthyophthirius*, *Trichodiniasis*, *Lernaea*, *Ergasilus*, and *Argulus* may decimate fish populations when conditions find fish in confined areas (Hoffman and Bauer 1971). *Ichthyophthiriosis* is the most widespread external parasitic disease of fish.

In shallow water areas snail populations are high and many parasitic trematodes such as *Diplostomum* and *Posthodiplostomum* which use snails as intermediate hosts are also abundant (Hoffman and Bauer 1971).

Other fish disease agents include bacteria (e.g., *Aeromonas salmonicida* = Furunculosis; see Thermal Impacts for *F. columnaris* discussion), viruses (e.g., sockeye and chinook salmon virus, lymphocystis) and fungi (e.g., *Saprolegnia parasitica*) (Bell 1973). Bacterial diseases are known to infect most species of fish and have wide temperature tolerances. Viruses, in addition to infecting salmonids, have also been shown to attack walleye and most centrarchids (Bell 1973). Fish eggs are particularly susceptible to fungal diseases and high mortalities generally result. Warm water temperatures are optimal for fungi infections.

Water withdrawal for irrigation may enhance environmental conditions for fish diseases. Parasites, fungi, viruses, and bacteria in general, proliferate in warm water. Fish weakened by disease are less able to withstand other environmental stresses and predation generally increases (Hoffman and Bauer 1971). Reducing water levels may concentrate fish making them more susceptible to disease and decreasing water depth may provide additional habitat for intermediate hosts of parasites. Parasitic nematodes and viruses from infested fields are transported by runoff water to uninfected areas (USBR 1976), thereby increasing the potential for epidemics. Continued irrigation development may then cause fish diseases to become more widespread.

Water Quality Impacts

Irrigation return flows will influence water quality in the receiving stream only if the quantity of return flow is significant relative to streamflow (Sylvester and Ruggles 1957). An estimated 400,000 ac ft of water were returned to the Columbia in 1970 by the Columbia Basin Project (U.S. Bureau of Reclamation 1976). This return flow amounted to only 0.46 percent of the mean annual flow of the Columbia River. Under average flow conditions, the return flows from the Project were responsible for an increase in conductivity of three micromhos/cm and an increase in nitrate of 0.01 mg/ℓ in the Columbia. The U.S. Bureau of Reclamation (1976) concluded that increased return flows under consideration in 1976 would have an insignificant effect on the quality of the river beyond the dilution zones at the points of entry because of the relatively small amount of water entering the much larger flow in the river.

Increased withdrawal of irrigation water from the Columbia will reduce streamflow at the same time as it results in increased return flows. If greater amounts of water continue to be withdrawn, the volume of return flow will become larger in relation to the streamflow and eventually begin to significantly affect water quality in the river. The effect will be greatest during periods of minimum flow and during low flow years. However, the amount of return flow will have to be increased considerably before effects are evident, since even a doubling of the 1970 return flow from the Columbia Basin Project would amount to less than one percent of the mean annual flow in the Columbia River.

Some of the potential effects of increased irrigation water withdrawal and return flow on water quality include increases in the concentration of dissolved salts and pesticides, and reduction in dissolved oxygen resulting from higher temperatures under reduced flow conditions. The impact of important water quality parameters on aquatic organisms is discussed below. This information was derived mainly from Sylvester and Rambow (1967).

Ammonia Nitrogen. Fish suffer distress at concentrations of 0.3 mg/ℓ and greater, but the majority of values indicated lie above 1.0 mg/ℓ. The toxicity of a given concentration increases with increasing pH and lowered oxygen concentrations. Ammonia also serves as a nutrient for nuisance algal growth.

Chloride. Chloride concentrations as low as 400 mg/ℓ may be harmful to fish (trout), but in general the tolerance limits appear to be substantially above this amount.

Conductivity. Conductivity is a measure of all ionized materials in solution in the water. Fish are affected by the mineral content of water, as indicated by conductivity, because the osmotic pressure varies with the mineral content. Fish vary both in their requirements for osmotic pressure and in their range of adaptability to different values. Fish that spend their entire life in freshwater are more sensitive than salmon, which migrate between the ocean (which has a conductivity of about 50,000 micromhos/cm^2) and freshwater. It is not possible to formulate a standard for conductivity, since data on specific fish requirements are inadequate.

Dissolved Oxygen. Reduction in the amount of available oxygen has a marked effect on many physiological, biochemical, and behavioral processes in fish (Davis 1975). Adequate oxygen levels for swimming, migration and feeding are necessary for survival of healthy fish populations. Low oxygen levels have been shown to influence growth rate, food conversion efficiency, and feeding in some species. Avoidance behavior has been reported for salmon and other species in response to low oxygen. Developing fish eggs and larvae show a number of responses to low oxygen including retarded growth, reduced yolk sac asorption, developmental deformities, and mortality.

The accepted minimum level for dissolved oxygen is 5 mg/ℓ (Bell 1973). For the cold water biota, however, the dissolved oxygen concentration should be at or near saturation. For successful incubation of salmon and trout eggs, dissolved oxygen must not fall below 7 mg/ℓ at any time.

Fluoride. The lowest concentration at which adverse effects are reported (slower and reduced hatching of fish eggs) is 1.5 mg/ℓ.

Hardness. The principal cations responsible for hardness in water are calcium and magnesium. Animals do not appear to be affected by the presence of either calcium or magnesium in concentrations acceptable in water for domestic purposes. Calcium seems to decrease the toxicity of many pollutants toward fish.

Nitrate and Nitrite. Fish are relatively indifferent to nitrate, although the associated nitrite can be toxic to them. Nitrite is readily oxidized or reduced, and seldom persists as long as nitrate. A major problem with nitrate is eutrophication. Blooms of algae and massive growths of aquatic plants are possible when nitrate concentration in the presence of other essential nutrients, is about 0.5 mg/ℓ or less.

Phosphorus. Phosphorus is usually present in natural waters in limited amounts. Additional phosphorus from runoff from land fertilized with phosphate-containing materials and from sewage, can contribute to the growth of algae, especially when water is impounded. Nuisance blooms can occur even with very small phosphorus concentrations. Heavy blooms have been observed in lakes when the phosphorus concentrations exceeds 0.03 mg/ℓ. Low retention times in the Columbia River reservoirs would probably preclude any large algal blooms, regardless of nutrient levels.

Potassium. Adverse effects upon fish have been reported at concentrations of 50 mg/ℓ, especially in soft water and water low in total salt content. Some potassium appears to stimulate plankton growth. The range of potassium concentrations over which plankton growth is enhanced appears to be on the order of 0-5 mg/ℓ.

Sodium. Within the limits imposed on sodium by commonly accepted standards of conductivity, sodium has negligible effect on most beneficial uses of water.

Sulfate. There is no evidence from the literature to suggest that sulfate is a serious problem in fish management, at least at the level of the USPHS limit for drinking water of 250 mg/ℓ.

Turbidity. Turbidity reduces photosynthesis by limiting light penetration and interferes with fish feeding by reducing visibility. It may affect the temperature structure of lentic waters by modifying the penetration pattern of radiant energy and may be directly lethal to fish. The threshold turbidity values at which any of these effects become apparent are well above 5 JTUs.

Pesticides. The two main groups of synthetic pesticides are the chlorinated hydrocarbons and organophosphates. The chlorinated hydrocarbons are more toxic to fish and are more persistent in the environment than organophosphates. Practically all organophosphates persist for less than a year and some hydrolyze into less toxic products within a few days in the environment (Bell 1973).

Aquatic organisms accumulate chlorinated hydrocarbons directly by absorption and by eating contaminated organisms. The transfer of pesticide residues from prey to predator in the food chain ultimately results in residues in the higher trophic levels many thousand times higher than ambient water levels. Some chlorinated hydrocarbon pesticides including DDT, DDE, DDD, aldrin, dieldrin, endrin, chlordane, heptachlor, toxaphene, lindane, endosulfan, and benzene hexachloride are considered especially hazardous because of their persistence and accumulation in aquatic organisms. Fish may survive relatively high residue concentrations in their body fats, but residues concentrated in the eggs of mature fish may be lethal to developing fry. High levels may make fish unacceptable for human consumption (Environmental Studies Board 1973).

Pesticides are toxic to fish over a wide range of concentrations. For example, the 96 hr LC50 values (the concentration of a pesticide that will kill 50 percent of the test organisms in 96 hours) of 13 different organophosphate pesticides ranged from 5.2 μg/ℓ to 610,000 μg/ℓ for various freshwater fish species (Pickering et al. 1962). Toxicity may be modified by differences in formulation of the pesticide, environmental conditions, animal size and age, and physiological condition. Studies cited by the Environmental Studies Board (1973) suggest that insects and crustaceans tend to be as sensitive or more sensitive to various insecticides than fish, while many molluscs and oligochaetes tend to be less sensitive. Herbicides, in general, are less toxic to fish than insecticides.

Safe concentrations in water have been determined for many pesticides. Recommended maximum concentrations for chlorinated hydrocarbon pesticides ranged from 0.002 μg/ℓ for parathion to 0.4 μg/ℓ for oxydementon methyl. Aquatic life should be protected as long as the concentration of the pesticide in the water does not exceed the recommended maximum concentration.

A large number of pesticides are used on irrigated land in the Columbia Basin Project. A pesticide-monitoring program initiated in 1973 has detected DDT, DDE, Ronnel, and Thiodon (endosulfan) in minute concentrations in some samples from open irrigation channels and buried pipe drains. The pesticides were considered to be of relatively minor significance (U.S. Bureau of Reclamation 1976). No data on pesticide levels in the Columbia River are available from the USGS. However, pesticides are monitored in the Yakima River at Kiona. None of the following pesticides: PCB, aldrin, atralindane, chlordane, DDD, DDE, DDT, diazinon, dieldrin, endrin, ethion, heptachlor, lindane, malathion, methoxychlor, methyl parathion, methyl trithion, parathion, toxaphene, trithion, 2,4-D, 2,4,5-T, silvex, or simazine were detected during water year 1978 (USGS 1979). Pesticide levels are probably low at present in the Columbia, which received proportionately less return flow than the Yakima.

Polychlorinated Biphenyls. Polychlorinated biphenyls (PCBs) have been found in fish in many parts of the world at levels that may have adverse effects. PCBs are manufactured for use as dielectric fluids, hydraulic fluids, and plasticizers. It is apparent that widespread pollution of major waterways has occurred, and that appreciable residues exist in fish (Environmental Studies Board 1973).

There have been a limited number of studies on the toxicity of PCBs to aquatic organisms, and these show a considerable variation in toxicity of PCBs to different species. The LC50 values for 15-day intermittent-flow bioassays with bluegills and channel catfish ranged from 10 to 300 μg/ℓ. Other studies cited by the Environmental Studies Board (1973) indicate that concentration of PCBs in fish tissue occurs under chronic exposure. Concentrations of 0.01 μg/ℓ of PCB in water over periods of up to 36 weeks can lead to dangerous levels of PCBs in the tissue of aquatic organisms. PCB concentrations ranging from 0.5 to 10 μg/ℓ in water have interfered with the reproduction of several aquatic organisms, and concentrations as low as 0.5 μg/g in whole salmon eggs have caused mortality.

PCBs have recently been found in the sumps under hydroelectric generators at Grand Coulee Dam, and some of the PCBs may have entered the Columbia River (Seattle Post-Intelligencer 9/23/79). The PCBs were formerly used as coolant for the generators. Waste coolant was washed into the sumps where it was allowed to accumulate. The PCBs were discovered during an investigation of a fish kill which occurred in the summer of 1977. The Environmental Protection Agency has not yet released its report of the investigation.

Entrainment and Impingement Impacts

Withdrawal of water from a river or lake can result in entrainment of biological organisms and impingement if the intake is screened. On the Columbia River, entrainment and impingement have been studied at the cooling water intakes of the Hanford Generating Plant (HGP) and the 100-N reactor (Page et al. 1977a, 1977b, 1978; Gray et al. 1978).

Water intake structures at the HGP and the 100-N reactors are generally similar. Incoming water passes through trash racks and vertical travelling screens before entering the pump suction wells. Fish escape ports are located between the trash rack and the screens. Water velocity through the travelling screens at minimum river elevation was 2.36 fps at HGP (Gray et al. 1975) and 2.86 fps at 100-N (Page et al. 1977b). Total intake capacity ranged from 420,000 gallons per minute (GPM) at 100-N to 564,000 gpm at HGP.

At HGP, the travelling screens behind the trash racks impinged a significant number of fish with chinook salmon fry representing 58 percent of the total. The number (9-18 percent of the affected population) was considered significant (Gray et al. 1978). Other impinged species included: sockeye salmon, coho salmon, mountain whitefish, threespine stickleback, redside shiner, peamouth chub, prickly sculpin, largescale sucker, Pacific lamprey, American shad, northern squawfish, piute sculpin, carp, and yellow perch. Twice as many yellow perch fry and 30 times as many chinook salmon fry were impinged at HGP as at 100-N; however, virtually all were killed at the 100-N reactor. Environmental stimuli (e.g., water velocity, circulation patterns) at 100-N may have induced fish to avoid the screen (Page et al. 1978).

Fish passing through the screens at HGP suffered 100 percent mortality as they subsequently passed through the condensers. Reducing the screen mesh size from 1/4 inch (in) to 1/8 in and closing the gap between and along the screen frames eliminated screen passage but increased impingement (Gray et al. 1978).

The HGP intake and its operation were further modified to increase the survival of the impinged fish, since less than 5 percent of the impinged fish were collected alive (Page et al. 1977a). To prevent suffocation and continuous recycling of fish as the screens rotated, fish buckets were installed at the base of each screen frame. Fish were removed from the buckets by a low-pressure spray (15 pounds per square inch [psi]) and returned to the river downstream of the facility. After the fish were removed, a high-pressure spray was used to remove debris. These design modifications increased survival rates to 97 percent for chinook salmon fry and 92 percent for yellow perch fry (Page et al. 1977a, Gray et al. 1978).

Methods for Reducing Entrainment and Impingement. A large number of larval exclusion systems have been developed to reduce impingement and entrainment losses at water intakes. The major types are discussed below. In conjunction with the following kinds of intake systems available, site selection to avoid spawning and rearing areas where high concentrations of juvenile fish occur is of major importance. Entrainment and impingement of fish can be minimized by placement in the depths of reservoirs or in free-flowing reaches where water velocities are sufficiently high to minimize the concentration of fishes.

Artificial Filter Bed. Artificial filter beds utilize a granular filter material to prevent debris and aquatic life from entering a water withdrawal system. Currently there are major engineering problems to be resolved, including development of a suitable filter medium, design of a reliable yet effective and environmentally acceptable backwash system, and the ability to meet all site-imposed restrictions relating to natural river turbidity, flooding characteristics, channel stability, and ice loads. Artificial filter bed capacities are presently limited to small quantities of water (Richards 1978a).

A model high-capacity filter has been tested, and the results have been summarized by Stober (1978). Filter flow velocities of 0.01 to 0.02 fps had no observable effect on the horizontal or vertical mobility of juvenile fish or invertebrates; however, plankton were not excluded. Suspended sediment caused the greatest short-term reduction in filter performance. Therefore, performance and reliability would be greatly reduced in turbid river environments, but may be more promising in usually less-turbid reservoirs.

Ranney Collector. Ranney collectors cause minimal environmental impact because the intakes are buried beneath the riverbed or river bank. Typical yields of Ranney collectors range up to 2,800,000 ft^3/day; however, larger systems can yield up to 11,900,000 ft^3/day. Velocities through the riverbed caused by the collector average 0.020 in/s, so impingement of larval fish or free-floating river organisms would not be expected to occur. Ranney Collectors are only successful in areas where there are permeable sand and gravel aquifers connected hydraulically with a surface source (Mikels and Bennett 1978).

Ranney Surface Water Intake. Ranney surface water intakes are located above the bottom of the stream or lake to minimize the effect on bottom-dwelling organisms. They may also be located at mid-stream, i.e., away from the nearshore, shallow-water habitats where aquatic life is most abundant. The openings in the intake screens can be any size or shape that is considered environmentally suitable. Since the flow velocity of the river is greater than that of the intake screen, fish fry and other aquatic organisms can swim in and out of the openings without injury (Mikels and Bennett 1978).

Porous-Dike Structures. A porous dike resembles a breakwater surrounding a water intake. It has a cobble on gravel core to allow free passage of water while presenting a physical and behavioral barrier to aquatic organisms. Physical exclusion will occur because nothing larger than the pores in the dike will be able to pass through. Behavioral exclusion is also likely to occur, since some organisms which could fit through the pores may choose to avoid the dike. It is not certain at this time whether a porous dike can successfully exclude fish and larvae while continuing to reliably supply water (Schrader and Ketschke 1978).

Perforated-Pipe Intake. The perforated-pipe intake in its least complex form is simply a pipe section with small holes or slots through which the water passes. Modified perforated-pipe intakes have an internal sleeve device to produce uniform inflow velocities along the surface of the pipe. The tightly-wound wedge-wire (profile-wire) screen variation of the perforated pipe, with circumferential slot opening widths of about 0.04 in or less, has the ability to reduce the entrainment of very small organisms. The basic perforated pipe has been used successfully for many years. However, it has limits of size practicality and has not been considered adequate for handling large quantities of water required for once-through power plant cooling systems. Perforated-pipe intakes up to about 125,000 gpm capacity have been used by industry, but most are much smaller (Richards 1978b). This type of intake has been installed on the WNP 1, 2 and 4 power plants sited at Hanford to supply makeup water for cooling towers.

Fine-Mesh Travelling Screens. Conventional vertical travelling screens are used extensively at power plants. The concept of using fine-mesh screens for exclusion of larvae relies on gentle impingement on the screen surface or retention of larvae within the screening basket, washing of screen panels or baskets to transfer organisms into a sluiceway, and then sluicing the organisms back into the source water body. Biological effectiveness depends on efficient handling at various stages in the system. This type of intake was used at the Hanford Generating Plant and the 100-N reactor. Fine-mesh travelling screens offer long-term proven technology for screening large volumes of water required for once-through cooling systems (Sharma 1978).

The Passavant screen is a type of vertical travelling screen that has been in use in Europe for almost 30 years. In a conventional vertical travelling screen, water passes through the front screen belt and then the back screen belt, whereas in the Passavant screen, water enters between the two belts and passes laterally through both the belts. The screening surface of the Passavant screen is theoretically doubled as compared to the same size conventional screen (Siddle and Sharma 1978). Due to design flexibility, the single-entry, double-exit screen has a slight advantage over the conventional vertical travelling screen (Sharma 1978).

Increased withdrawal of irrigation water from the Columbia River may necessitate construction of more intake structures. Improperly designed structures can impinge and entrain substantial numbers of fish fry, including the fry of important species such as chinook salmon. However, effective larval exclusion systems developed for power plant cooling intakes are presently available. Application of this current technology to irrigation water intakes would virtually eliminate impingement and entrainment of juvenile fish.

SUMMARY AND CONCLUSIONS

This literature survey focuses specifically on the impacts to aquatic communities and fish species in the Columbia River and selected tributaries with respect to present and future withdrawal of water for out-of-stream use. Wild salmon and steelhead runs have essentially been destroyed, initially by over-exploitation followed by the loss of suitable spawning habitat and migration routes of juveniles due to impoundment of the main stem and tributaries. Hatchery production has been utilized in an attempt to mitigate the loss of native stocks with diminishing success from the lower to the upper reaches of the basin.

The morphometric parameters of the fourteen reservoirs on the main stem are compared. The known or expected aquatic productivity and operational effects on the early life history stages of associated fishes were evaluated for the two storage and nine run-of-the-river main stem reservoirs in the U.S. The limited ecological data available indicated that aquatic productivity was higher in storage reservoirs and lower in run-of-the-river reservoirs primarily due to the longer retention time of water in storage reservoirs.

Sixty-one species of fish have been reported in the main stem from Lake Roosevelt to Bonneville pool and were grouped into four categories: anadromous salmonids, cold-water game, warm-water game and non-game fish. The four species of Pacific salmon and one anadromous species of trout, the steelhead, support the Indian and non-Indian commercial and sport fisheries. Access for anadromous fish on the main stem extends to Chief Joseph Dam. The only natural salmon spawning areas remaining in the Columbia River are found in the free-flowing Hanford Reach and some of the tributaries to the main stem. The early life history stages of cold-water game fish (16 species), warm-water game fish (12 species) and non-game fish (30 species) were evaluated in terms of daily, seasonal and annual changes in water level elevation and temperature in each reservoir. In general, native cold-water species (i.e., kokanee) are declining, while the exotic (non-native) American shad and non-native warm-water (i.e., walleye) and non-game species (i.e., squawfish, peamouth, chiselmouth, suckers, etc.) are increasing. This is primarily due to the spring and summer spawning seasons of the more successful species which spawn on reservoir shoals and incubate on rising water levels. The eggs and fry of those species spawning or incubating on declining or frequently changing water levels are dessicated and thus less successful.

The ecological relationships and fisheries management strategies which insure a substantial sport fishery in off-stream irrigation storage reservoirs undergoing similar operational impacts is demonstrated in a review of the Banks Lake investigations. The increasing walleye sport fish population in Lake Roosevelt, the kokanee salmon troll fishery on Banks Lake and the warm-water sport fisheries in the numerous reservoirs of the

Columbia Basin Irrigation Project will all demand more intensive management in the future. These reservoirs provide a substantial sport fish potential which may be managed more productively than the mid and lower mainstream Columbia River.

Review of the selected tributaries, i.e., Yakima, Okanogan and Umatilla Rivers, showed that all have a substantial portion of the discharge diverted for irrigation purposes. Reduced instream flow results in reduced water velocities and higher water temperatures which have been found to inhibit fish passage. Irrigation return flows carry higher concentrations of nutrients and other pollutants into the lower reaches of streams when the dilution factors are lowest. This has been found to result in a shift from diatoms to blue-green algae in some lower stream reaches. The distribution of fish species in the tributaries due to irrigation withdrawal results in warm-water species in the lower reaches and reservoirs and cold-water species in the headwaters and upstream tributaries. Anadromous fish have almost been eliminated.

The withdrawal of irrigation water can result in multiple impacts which manifest their effects on aquatic organisms over both short and long time periods. We have attempted to deal with these effects from a review of the specific information available for the Columbia River and tributaries as well as by reviewing the broad information available on the requirements for fish, including instream flow, temperature, siltation-turbidity, gas saturation, disease, and other aspects of water quality. Entrainment and impingement impacts received special attention.

The importance of the Hanford Reach for the spawning of wild salmon and steelhead, sturgeon and other cold-water game fish cannot be over emphasized because this is the remaining free-flowing reach. Hydroelectric peaking causes daily and seasonal discharge fluctuations which may have negative effects on the fishes. Even though this reach of the river provides the only remaining habitat on the main stem necessary for the reproduction of wild salmon and steelhead, data were not found specifically identifying the instream discharge required to insure the future reproductive success of these fishes. Until such data become available for the critical life history stages of salmon and steelhead in the Columbia River it will be very difficult to either develop optimum water management strategies or to critically evaluate those instream discharges proposed by numerous agencies.

Maximum water temperatures occur on the main stem during August and early September and generally increase downstream from Lake Roosevelt to Bonneville reaching an annual mean maximum of 20°C in August. The system of impoundments has decreased the magnitude of daily, weekly and seasonal fluctuations in river temperatures. Most of the heat increment is from natural effects, but some is due to the Hanford Generating Project. From July through September temperatures approach the upper limits of heat tolerance of young salmonids (16-20°C, though the lethal temperature [25°C] is not reached). High temperatures due to low flows and warm irrigation return flows have been found to block salmon migrations into the Yakima, Okanogan, and Snake Rivers during the late summer and early fall season. Temperatures above 12.2°C in late spring have been found to delay salmon smolts on their seaward migration causing extensive mortality due to residualism in the reservoirs.

Siltation and turbidity can increase as a result of irrigation withdrawal and runoff return flow from the additional land irrigated. Increased sediment due to irrigation will more seriously affect the water quality of the basin tributaries than the main stem because of the lower dilution factors in the former and the proximity to the source. The sediment loads will be deposited in the main stem reservoirs and will have less effect on river water quality. The tributaries present the little remaining spawning habitat for anadromous and other cold-water game species which has already been lost by impounding the main stem. The effects of excessive sediments on aquatic life have been extensively studied and negative effects have been demonstrated on nearly all forms of aquatic biota. The reproductive efficiency of salmonids can be severely reduced by excess amounts of fine particles in the spawning gravel.

The entire mid-Columbia is supersaturated with nitrogen at values of 120-130 percent during periods of high runoff in the spring. This has been shown to have serious detrimental effects on the downstream migrations of juvenile salmonids and resident species, although the actual impact is not known. Peak irrigation withdrawal presently coincides with the timing of the maximum spill at main stem dams. If additional water is withdrawn for irrigation the spill volume will probably decrease, thereby reducing nitrogen supersaturation.

The saturation of dissolved oxygen in the lower reaches of tributaries receiving warm irrigation return flows will decrease. The extent of longevity of these conditions may continue until natural seasonal stream flows return. This will adversely affect the aquatic life in these areas.

Parasites, fungi, viruses and bacteria proliferate in warm water. Fish weakened by disease are less able to withstand other environmental stresses and predation generally increases. Reducing water levels will concentrate fish making them more susceptible to disease. Continued irrigation development may enhance environmental conditions which cause fish diseases to become more widespread.

Irrigation return flows already degrade the water quality of tributary streams but are not expected to have a significant influence on the main stem river due to the relatively small volumes returning to this large river.

The entrainment of aquatic organisms with the withdrawal of water or their impingement on intake screens is common. Intake siting to avoid high concentrations of organisms is effective in minimizing this problem. A technology has been developed which can be applied to exclude aquatic organisms. Effective when used properly in specific locations are: artificial filters, Ranney collectors, Ranney surface water intakes, porous-dike intakes, perforated-pipe intakes and fine-mesh travelling screens.

In summary, the apparent increases in the populations of exotic species like the American shad in the lower river and the walleye in Lake Roosevelt indicate that the native sport and commercial species are less able to adapt to this massively altered aquatic environment. The diversion and impoundment of Columbia River water (e.g., Columbia Basin Irrigation Project) has been found to create significant new aquatic environments for kokanee and other cold-water sport fishes in upstream reservoirs and for warm-water sport fishes in downstream reservoirs. We can no longer afford to neglect these fish resources created by the diversion of Columbia River water and must begin to aggressively manage them as an important component in the management of water supplies. If substantial additional irrigation withdrawal occurs the fish species which are successfully able to compete under the conditions imposed should be managed most intensively. The evidence strongly suggests that efforts to enhance the salmon and steelhead runs returning to the upper basin are not likely to be successful on a large scale.

Future Research and Monitoring

Additional research and monitoring is needed for the following:

1) A network should be developed to monitor the long-term changes in water quality in selected tributaries and the main stem river.

2) Research leading to the intensive management and harvest of the exotic sport and commercial fishes increasing along the main stem should be initiated.

3) The efforts to develop new techniques for the culture of salmon and steelhead should be intensified.

4) The instream flow requirements for the successful spawning and rearing of salmonids must be determined for the Hanford Reach.

5) Comprehensive ecological baseline monitoring of selected main stem reservoir environments from Lake Roosevelt to Bonneville is long overdue.

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DESCRIPTION OF STUDY AREA

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