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UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

FISH AND WILDLIFE SERVICE
Albert M. Day, Director

Special Scientific Report No. 55

A REPORT UPON THE GRAND COULEE FISH-MAINTENANCE PROJECT 1939-1947

by

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and
Mitchell G. Hanavan

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Explanatory Note

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ABSTRACT

The construction of Grand Coulee Dam, on the upper Columbia River, involved the loss of 1,140 lineal miles of spawning and rearing stream to the production of anadromous fishes. The fact that the annual value of these fish runs to the nation was estimated at $250,000 justified reasonable expenditures to assure their perpetuation. It was found economically infeasible to safely collect and pass adult fish upstream and fingerling fish downstream at the dam because of the tremendous flow of the river and the 320-foot vertical difference in elevation between forebay and tailrace.

The Grand Coulee Fish-Maintenance Project, undertaken by the United States Fish and Wildlife Service in 1939, consisted in relocating the anadroumous runs of the upper Columbia River to four major tributaries entering below the Grand Coulee damsite. These streams were believed capable of supporting several times their existing, badly depleted, run.

The plan was predicated upon the assumption that the relocated runs, in conformity with their "homing tendency", would return to the lower tributaries rather than attempt to reach their ancestral spawning grounds above Grand Coulee Dam.

This interim report covers the history and accomplishments of the Grand Coulee Fish-Maintenance Project through the initial period of relocating the runs as well as the first four years of the permanent program.

Results obtained to date indicate conclusive success in diverting the upper Columbia fish runs into the accessible lower tributaries. The results also indicate, less conclusively, that--in spite of many existing handicaps--the upper Columbia salmon and steelhead runs may be rehabilitated through the integrated program of natural and artificial propagation incorporated in the Grand Coulee Fish-Maintenance Project.

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INTRODUCTION

The Columbia Basin Reclamation Project is designed to provide irrigation for 1,200,000 acres of desert and arid farm land in the central part of Washington State. The initial development of the Reclamation Project, Grand Coulee Dam--largest man-made structure in the world--impounds a reservoir 151 miles in length, with a storage capacity of 10,000,000 acre-feet. Fully developed, the power plant at the Grand Coulee Dam will produce 8,320,000 kilowatt-hours of electric power annually. Present output is distributed for industrial and domestic use throughout the Pacific Northwest. Eventually, a portion of the fully developed electrical output will be used to pump river water into a storage reservoir for distribution through irrigation canals to the arid plateau land of Central Washington east of the Columbia River. The project is self-liquidating for all costs will be berne by water and power users.

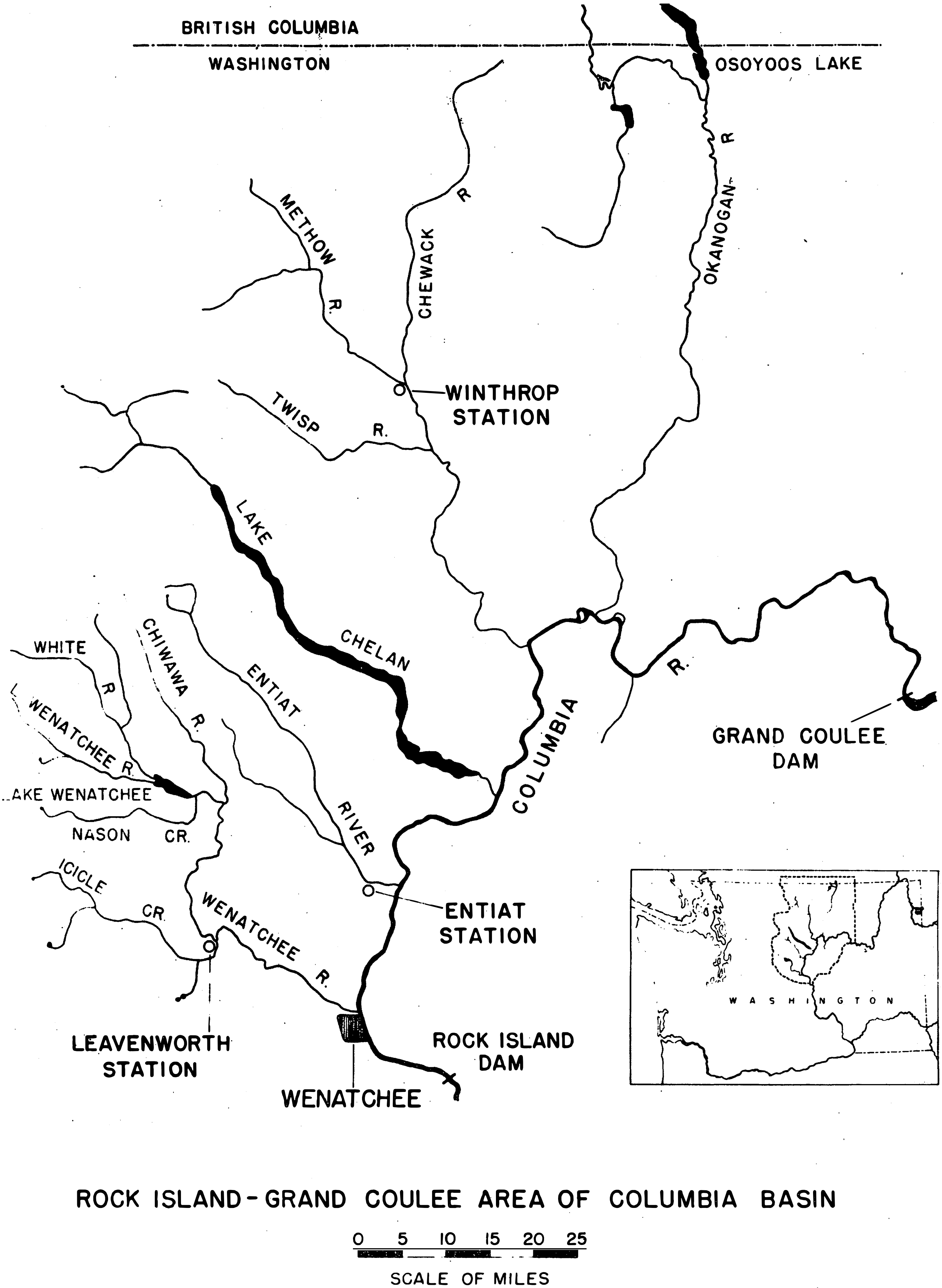
The construction of Grand Coulee Dam presented a difficult problem to the Federal and State Agencies concerned with the preservation of the fishery resources. In 1933, the first year of construction, the Fish and Wildlife Service initiated a count of all fish passing Rock Island Dam--located 145 miles below Grand Coulee--for the purpose of evaluating the anadromous-fish runs migrating into the 1,140 lineal miles of spawning and rearing grounds above the Grand Coulee dam site. (Fig. 1) It was evident that the great size of Grand Coulee Dam, with the vertical rise of 320 feet from tailrace to forebay level, would preclude the successful passage of adult fish upstream and that of fingerling migrants downstream. The perpetuation of the upper Columbia anadromous runswas economically desirable as indicated by estimates that the river above Grand Coulee Dam produced fish representing a value of approximately $250,000 annually to the commercial and sports fishermen. 1/

An investigation to determine possible means of preserving the runs was carried on by the Washington State Fisheries Department in 1937. 2/

1/ "A Report of the Board of Consultants on the Fish Problems of the upper Columbia River". Section I, 19 pages, typed, issued February 9, 1939. Section II, 83 pages, mimeographed, issued March 7, 1939. U.S. Bureau of Reclamation, Denver.

2/ "A Report of the Preliminary Investigations into the Possible Methods of preserving the Columbia River Salmon and Steelhead at the Grand Coulee Dam". Mimeographed Report by the Washington State Department of Fisheries, 121 pages, January, 1948.

Figure 1.—Map of the Rock Island-Grand Coulee area of the Columbia Basin showing the location of important centers of operations and streams mentioned in this report.



Early consideration was given to the establishment of a hatchery immediately below Grand Coulee Dam but the lack of a suitable water supply and the engineering difficulties related to the collection of adult fish rendered this plan impracticable.

As an alternative to passing fish over Grand Coulee Dam, a plan was developed that involved trapping adult fish in the three fishways at Rock Island Dam and their subsequent transfer to artificial holding areas where the fish could be retained until sexually mature. (Plate 1.) The holding areas were selected on the basis of accessibility and a suitable water supply at a point on Icicle Creek, a tributary of the Wenatchee River approximately forty miles from Rock Island Dam. At this location, the plan proposed a large hatchery capable of stocking the Wenatchee River system and of supplying eyed eggs for hatching and rearing at sub-stations located on the Entiat, Methow, and Okanogan rivers--all tributary to the Columbia River between Rock Island and Grand Coulee Dams. The "homing tendency" of salmon and steelhead trout--i.e., their proclivity to return to the streams from which they migrated to the ocean as fingerlings--was believed sufficient to effect a relocation of the runs in the span of one complete life cycle; five years for all practical purposes.

The rivers selected for the transplanted runs, historically, once were excellent salmon-producing streams. Their runs, however had been virtually decimated during the past thirty or forty years largely through the construction of impassable mill and power dams and by numerous unscreened irrigation diversions. This local depletion was, of course, augmented by the general depletion of the runs throughout the upper Columbia River drainage. Local causes of depletion had been partially corrected at the time the Grand Coulee Fish-Maintenance Program was under consideration. Several dams had been removed, others had been equipped with fishways, and progress was being made in a program to screen all major irrigation ditches. It was evident, therefore, that suitable areas were available to receive the transplanted runs.

The maintenance plan subsequently was submitted by the Secretary of the Interior to an impartial Board of Consultants for review. The Board was composed of Prof. R. D. Calkins, Professor of Economics at the University of California; Prof. W. F. Durand, Professor of Mechanical Engineering (Emeritus,) Stanford University; and Prof. W.H. Rich, Professor of Biology at Stanford University.

A final report, reviewing and approving in essence the plan as outlined by the Washington State Department of Fisheries, was prepared by the Board of Consultants and submitted to the Secretary of the Interior in two sections on February 8 and March 7, 1939. 3/

3/ "A Report of the Board of Consultants on the Fish Problems of the upper Columbia River". Section I, 19 pages, typed, issued February 8, 1939. Section II, 83 pages, mimeographed, issued March 7, 1939. U. S. Bureau of Reclamation, Denver.

The need for immediate action even before final acceptance of the plan was emphasized by the fact that the 1938 runs would be the last fish able to pass the Grand Coulee barrier. Trapping facilities at Rock Island and fish trucks of specialized design, therefore, were rushed to completion.

In accordance with the recommendations of the Board of Consultants, the responsibility for managing and operating the Grand Coulee Fish-Maintenance Project was assumed by the Bureau of Fisheries in April, 1939. It soon became evident that hatchery facilities could not be completed in time to accomodate any part of the 1939 runs. For this reason, natural holding areas, combining resting pools and spawning riffles, were therefore established in three of the four tributaries. Stream survey data and fish counts, obtained in former years, were helpful in selecting holding areas suitable for the several species and races of fish with which the program was concerned. Nason Creek, a tributary of the Wenatchee River, was reserved for spring-run steelhead and chinook. Sections of the main Wenatchee and Entiat rivers were reserved for summer-run chinook and fall-run steelhead, and Lakes Wenatchee and Osoyoos were assigned the blueback salmon.

Fish were impounded in the holding areas by means of picket racks. (Plate 2.) Close observation of the impounded populations was maintained and, as a result of the general level of successful spawning obtained during 1939, natural propagation was given equal emphasis with artificial propagation during the ensuing years of the program.

Artificial propagation centered around the main hatchery in Icicle Creek near Leavenworth, Washington, which was completed in 1940. Following artificial spawning of the fish, the eggs were incubated to the eyed stage at the Leavenworth Hatchery and certain fractions of the egg collections were then shipped to the Entiat and Winthrop substations for hatching, rearing, and subsequent liberation as fingerlings.

The Grand Coulee Fish-Maintenance Project has been in operation for nine years. The initial phase of relocating the fish runs by trucking was completed with the 1943 season. Since 1943, the adult fish have been free to pass through the Rock Island fishways and continue their migrations to the spawning grounds. The period covered by this report therefore, includes the initial phase of relocating the runs as well as the first four years of the permanent program.

Management of the Grand Coulee Fish-Maintenance Project has been shared jointly by the Branch of Fishery Biology and the Branch of Game-Fish and Hatcheries since the project was undertaken by the Fish and Wildlife Service (Bureau of Fisheries) in April, 1939. The Branch of Fishery Biology has developed and directed biological investigations at the Leavenworth Laboratory and in the field. The Branch of Game-Fish and Hatcheries has been responsible for all fish-cultural operations at the hatcheries and for the trapping and transportation of adult fish at Rock Island Dam.

Mr. Joe Kemmerich, formerly District Supervisor of the Grand Coulee hatcheries, was in direct charge of all work on the Project by the Branch of Game-Fish and Hatcheries until his retirement in 1945. Mr. E. M. Tuttle was appointed as District Supervisor following Mr. Kemmerich's retirement. The senior author has directed work at the Leavenworth Laboratory from the beginning and the junior author directed that of the field biologists from 1943 to 1947. Previous to 1943, the field investigations were under the direction of Mr. J. A. Craig, now Chief Fisheries Biologist for the American Occupation Forces in Japan, and Mr. Arnie J. Suomela, now Master Fish Warden of the Oregon State Fish Commission.

It is impossible to properly make acknowledgment to the many individuals who have contributed to the Maintenance Project at various times and in different capacities. A list would include many of the past and present personnel of the Washington State Department of Fisheries, the Oregon Fish Commission, and the Fish and Wildlife Service.

SALMON AND TROUT RUNS INVOLVED IN THE GRAND COULEE FISH-MAINTENANCE PROJECT

The commercially important fishes involved in the Grand Coulee Fish-Maintenance Project are the steelhead trout (Salmo gairdnerii), the chinook salmon (Oncorhynchus tschawytscha), the blueback salmon (Oncorhynchus nerka), and the silver salmon(Oncorhynchus kisutch).

Many details of the life history and the age at maturity of the upper Columbia River salmon and steelhead trout remain to be determined. 4/ It is known, however, that the chinook salmon mature and return from the ocean to spawn at ages ranging between two and seven years--the majority being in their fourth year. The blueback salmon return from the ocean in their third, fourth, or fifth years with fours predominating. Steelhead trout usually spawn in the spring of their fifth or sixth years with younger and older fish contributing to the spawning to a lesser extent. The time that the various runs of fish arrive at Rock Island Dam follows a consistent pattern from year to year. (Fig. 2.) The first fish to pass through the fishways are the spring steelhead. Their upstream movement past the Rock Island Dam starts during the latter part of March and usually reaches a peak early in May.

4/ These fish have been the subject of an extensive series of marking experiments carried on during the past seven years. Returns from the first of these experiments are now complete and will be reported upon in the near future.

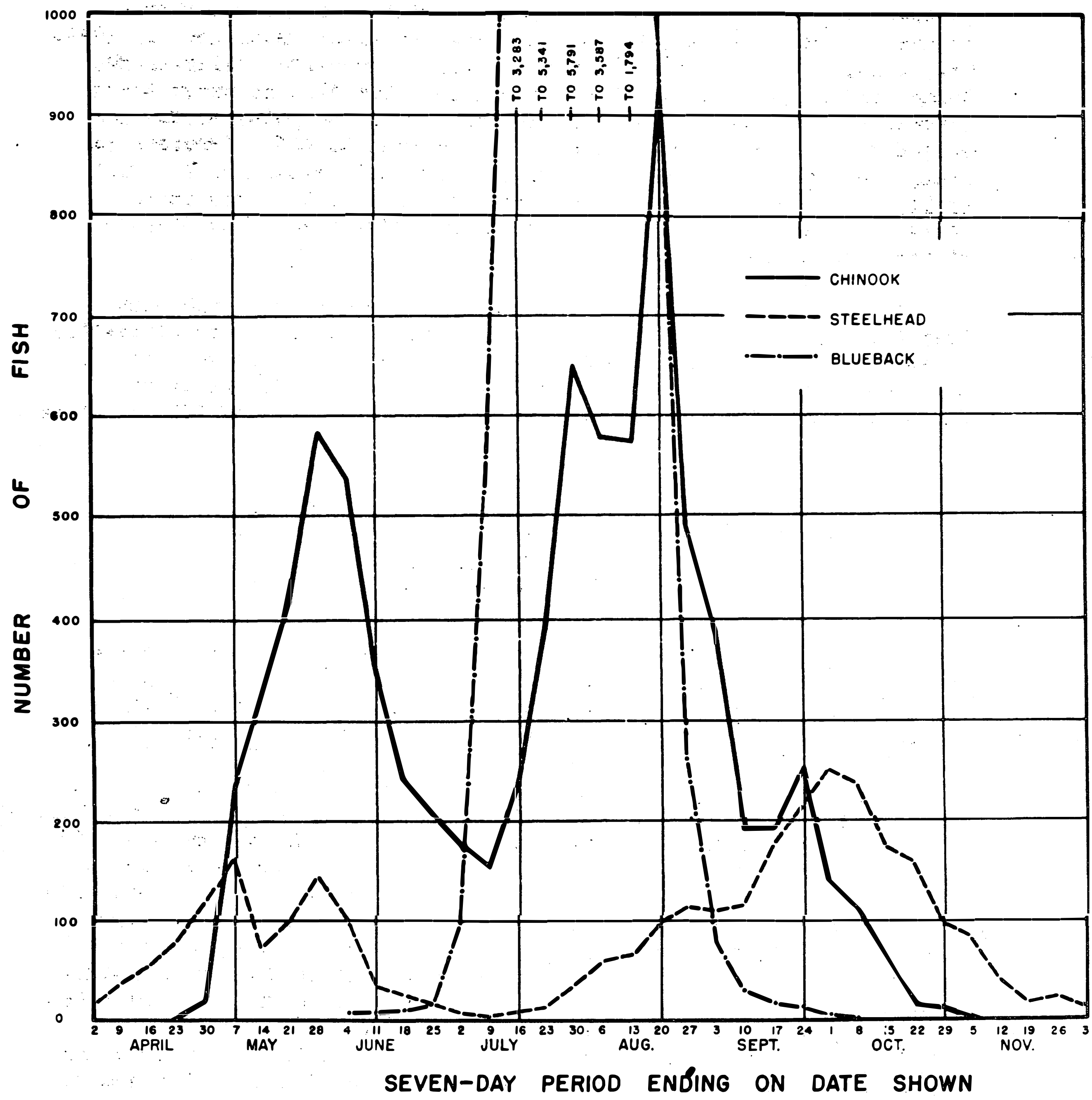


Figure 2.—The seasonal distribution of the adult fish runs entering the Grand Coulee Fish-Maintenance Project. Data based upon the means of counts at the Rock Island Dam during respective seven-day periods, 1933 to 1947 inclusive.

The spring steelhead migration over Rock Island Dam apparently is composed of fish that migrated into the Columbia during the preceding summer and fall and remained in winter residence below Rock Island Dam. Spring-run steelheads are sexually mature when they arrive in the Grand Coulee area in contrast to the unripe condition of the steelhead passing through the fishways during the late summer and fall. The steelhead are designated as "spring" or "fall" depending on the time of their arrival at Rock Island, the dividing date being arbitrarily selected as July 9. A few fall-run steelhead reach Rock Island in July, the peak of that run occurs during late September, and migrations cease with the onset of cold weather. Fall steelhead remain in the Columbia River throughout the winter and move into the tributaries early in the following spring upon the approach of sexual maturity. The spawning activity of the fall-run and that of the following spring-run so closely coincide in time as to indicate a homogeneous population.

The chinook salmon are divided into "spring" and "summer" runs according to the bimodal distribution of their arrival at Rock Island Dam. The spring chinook run appears at Rock Island during the latter part of April, reaches a peak about the end of May, and apparently terminates during early July. The run of summer chinooks overlaps the spring run and reaches a peak early in August. The two chinook runs are quite distinct, both as to average size of fish (the springs being smaller) and as to time of spawning (the springs spawning from late July to mid-September with the peak of spawning activity in August and the summers spawning from September to mid-November.) Unlike the two steelhead runs, however, both runs of chinook salmon arrive at Rock Island and spawn during the same calendar year.

Blueback salmon appear during June, reach a maximum daily count about July 25, and most of the run has passed Rock Island Dam by the first of September. Blueback spawning occurs in September and October.

Silver salmon were depleted virtually to the point of extinction in the streams above Rock Island Dam, though at one time they composed a run of considerable size. The time of appearance of this remnant has been variable during the past fourteen years, maximum counts having been recorded in August, September, or October. Spawning occurs in October but may continue into December.

The annual counts of salmon and steelhead at Rock Island Dam are shown in Tables 1-6.

TRAPPING AND TRANSPORTATION

Trapping and transportation of the fish runs started at Rock Island Dam in May, 1939, and were terminated at the close of the operations late in the fall of 1943. The left fishway at Rock Island Dam together with trapping pool, elevator, and fish truck are shown in Plate 3.

Table 1. --- Numbers of spring chinook salmon counted over Rock Island Dam.

7-day period ending	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	Mean
Mar. 5	--	--	0	--	--	--	--	--	--	--	--	--	0	0	0	
12	--	--	0	--	--	--	--	0	--	--	--	--	0	0	0	
19	--	--	0	--	--	--	--	0	--	--	--	--	0	0	0	
26	--	--	0	--	--	--	--	0	--	--	--	--	0	0	0	
Apr. 2	--	--	0	--	--	--	--	0	--	--	--	--	0	0	0	
9	--	--	0	--	--	--	--	0	0	--	--	--	0	0	0	
16	--	--	0	--	--	0	--1/	0	0	0	0	0	0	0	0	
23	--	--	1	--	--	0	--1/	15	0	0	0	0	0	0	0	2
30	--	--	3	--	--	14	--1/	129	7	14	0	2	5	7	13	19
May 7	--	--	65	6	--	28	308	901	34	33	27	16	22	35	1400	234
14	--	--	117	13	2	70	971	743	38	74	347	30	6	150	1508	319
21	--	--	511	84	7	78	571	575	420	46	1535	71	30	385	1115	418
28	--	--	532	399	30	650	437	443	326	102	2013	39	385	698	1516	582
June 4	--	--	462	727	64	235	306	215	237	182	1331	121	386	1308	1416	537
11	--	--	282	256	25	195	602	144	142	211	922	359	580	310	592	355
18	--	--	321	312	33	69	642	138	98	143	500	230	326	147	175	241
25	--	--	86	203	19	94	210	545	90	171	319	226	198	413	142	209
July 2	--	--	59	95	159	120	123	258	115	130	264	171	230	460	145	179
9	--	--	116	91	180	39	86	222	103	253	116	233	208	231	159	157
TOTAL	--	--	2555	2186	519	1592	4256	4328	1610	1359	7374	1498	2376	4144	8181	3252
Period of Counts	7/21 to 9/23	7/31 to 12/31	1/1 to 11/15	5/5 to 9/29	5/11 to 10/16	4/12 to 10/29	5/1 to 12/9	3/5 to 12/10	4/1 to 12/8	4/10 to 11/30	4/5 to 11/30	4/12 to 11/17	Continuous			

1/ Ladders closed during installation of traps.

Table 2. --- Numbers of summer chinook salmon counted over Rock Island Dam.

7-day period ending	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	Mean
July 16	--	--	38	193	148	77	305	295	194	300	253	278	303	442	272	238
23	8	--	90	1246	608	450	360	393	108	448	202	212	372	746	242	392
30	51	--	288	1530	1791	725	1057	576	227	577	296	261	587	851	278	650
Aug. 6	257	836	686	843	645	383	1099	814	103	765	520	282	572	487	367	577
13	253	741	689	275	42	419	828	826	95	1053	523	96	700	1492	575	574
20	2600	3047	2188	139	241	196	1274	495	40	1150	714	51	209	848	776	931
27	409	386	3342	65	172	82	614	387	18	457	524	83	83	530	271	494
Sept. 3	1154	133	2710	53	102	162	339	115	11	79	337	71	59	195	339	391
10	656	57	1104	85	61	171	139	149	14	64	78	52	71	41	136	192
17	210	113	437	176	65	209	314	635	15	165	165	172	111	67	52	194
24	70	67	1077	294	371	515	279	362	85	231	75	121	67	81	102	253
Oct. 1	--	58	307	306	239	344	117	98	34	121	51	70	94	42	77	140
8	--	111	627	--	65	344	76	7	9	32	26	52	52	17	48	113
15	--	350	125	--	55	111	58	3	2	8	6	28	12	7	13	60
22	--	30	42	--	9	8	28	0	5	3	1	21	11	0	35	15
29	--	27	5	--	--	15	52	6	1	1	0	23	12	2	2	12
Nov. 5	--	3	0	--	--	--	7	2	0	1	0	3	0	0	0	1
12	--	0	0	--	--	--	4	1	0	0	0	1	5	0	0	1
19	--	0	--	--	--	--	0	0	0	0	0	0	0	0	0	0
26	--	0	--	--	--	--	0	0	0	0	0	--	0	0	0	0
Dec. 3	--	0	--	--	--	--	0	0	0	0	0	--	0	0	0	0
10	--	0	--	--	--	--	0	0	0	--	--	--	0	0	0	0
17	--	0	--	--	--	--	--	--	--	--	--	--	0	0	0	0
24	--	0	--	--	--	--	--	--	--	--	--	--	0	0	0	0
31	--	0	--	--	--	--	--	--	--	--	--	--	0	0	0	0
TOTAL	5668	6482 2/	13755	5210 2/	4614	4211	6950	5164	961	5455	3771	1877	3320	5848	3585	5228
Period of Counts	7/21 to 9/23	7/31 to 12/31	1/1 to 11/15	5/5 to 9/29	5/11 to 10/16	4/12 to 10/29	5/1 to 12/9	3/5 to 12/10	4/1 to 12/8	4/10 to 11/30	4/5 to 11/30	4/12 to 11/17	Continuous			

2/ Incomplete Count

Table 3. --- Numbers of spring steelhead trout counted over Rock Island Dam.

7-day period ending	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	Mean
Mar. 5	--	--	4	--	--	--	--	9	--	--	--	--	0	--33-- Jan-Apr.	--26-- Jan-Apr.	6
12	--	--	4	--	--	--	--	7	--	--	--	--	0			5
19	--	--	2	--	--	--	--	0	--	--	--	--	0			1
26	--	--	4	--	--	--	--	0	--	--	--	--	0			2
Apr. 2	--	--	5	--	--	--	--	50	21	--	--	--	0	1		13
9	--	--	8	--	--	--	--	164	69	--	8	--	3	7		37
16	--	--	8	--	--	49	0 3/	124	296	21	15	3	1	15		53
23	--	--	28	--	--	222	0 3/	210	223	19	25	7	11	17	6	77
30	--	--	192	--	--	143	0 3/	197	455	30	58	9	11	27	46	117
May 7	--	--	338	15	--	243	350	75	307	45	42	62	30	59	372	162
14	--	--	146	35	0	67	150	131	69	79	111	28	6	78	40	72
21	--	--	89	134	55	55	259	63	127	175	84	176	12	29	26	99
28	--	--	132	304	211	395	171	87	160	113	172	34	26	26	44	144
June 4	--	--	37	618	67	100	134	36	97	28	56	65	39	0	5	99
11	--	--	9	70	15	53	114	10	54	11	55	46	2	1	3	34
18	--	--	12	32	18	28	146	3	25	7	29	22	1	0	1	25
25	--	--	3	15	9	29	42	14	61	0	3	8	0	1	1	14
July 2	--	--	0	15	26	8	16	1	6	2	0	0	0	0	5	6
9	--	--	9	18	14	1	1	18	0	2	0	4	1	0	0	5
TOTAL	--	--	1030	1256	4/ 424	4/ 1393	1383	4/ 1199	1970	532	658	464	143	294	575	971
Period of Counts	7/21 to 9/23	7/31 to 12/31	1/1 to 11/15	5/5 to 9/29	5/11 to 10/16	4/12 to 10/29	5/1 to 12/9	3/5 to 12/10	4/1 to 12/8	4/10 to 11/30	4/5 to 11/30	4/12 to 11/17	Continuous			

3/ Ladders closed during installation of traps

4/ Incomplete count

Table 4. --- Numbers of fall steelhead trout counted over Rock Island Dam.

7-day period ending	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	Mean
July 16	--	--	1	10	10	4	9	80	0	7	0	0	0	0	0	9
23	--	--	7	27	0	12	13	101	0	15	0	2	0	0	0	14
30	38	--	15	70	0	60	23	191	6	33	3	12	26	6	2	35
Aug. 6	131	3	49	77	12	62	19	361	2	44	22	7	41	35	24	59
13	90	4	85	70	36	57	117	179	13	71	42	9	44	97	69	66
20	87	0	260	59	97	45	197	130	14	81	91	16	43	183	159	97
27	149	2	306	52	68	25	135	251	40	196	80	28	33	188	133	112
Sept. 3	189	2	336	52	60	33	130	267	29	88	132	27	40	137	116	109
10	168	4	397	72	89	56	110	371	19	58	82	56	71	58	109	115
17	173	21	591	157	109	97	283	431	59	158	131	65	107	140	134	177
24	30	58	411	342	312	200	606	399	83	240	122	82	71	123	168	216
Oct. 1		70	699	125	384	90	543	405	178	406	120	121	88	120	177	252
8		36	677	--	265	126	417	259	239	482	154	90	101	114	132	238
15		51	215	--	306	39	306	252	195	337	194	83	93	102	89	174
22		31	303	--	42	34	416	342	202	247	176	84	62	55	61	158
29		23	25	--	--	67	263	130	193	177	88	62	44	60	78	98
Nov. 5		16	5	--	--	--	230	150	94	193	110	58	38	27	22	86
12		20	0	--	--	--	123	33	62	102	34	46	20	13	20	43
19		8	--	--	--	--	0	0	77	34	35	17	10	3	6	19
26		4	--	--	--	--	72	0	50	55	54	0	10	1	7	25
Dec. 3		3	--	--	--	--	0	19	27	30	23	--	10	4	1	13
10		11	--	--	--	--	32	0	9	0	--	--	15	1	9	10
17		5	--	--	--	--	--	--	--	--	--	--	6	--	6	6
24		2	--	--	--	--	--	--	--	--	--	--	2		9	3
31		0	--	--	--	--	--	--	--	--	--	--	3		3	2
TOTAL	1055 5/	583	4382	1113 5/	1790	1007	4044	4351	1591	3054	1591	865	978	1467	1540	2136
Period of Counts	7/21 to 9/23	7/31 to 12/31	1/1 to 11/15	5/5 to 9/29	5/11 to 10/16	4/12 to 10/29	5/1 to 12/9	3/5 to 12/10	4/1 to 12/8	4/10 to 11/30	4/5 to 11/30	4/12 to 11/17	Continuous			

5/ Incomplete count

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Table 5. --- Numbers of blueback salmon counted over Rock Island Dam.

7-day period ending	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	Mean
May 7	--	--	0	0	--	0	0	0	0	0	0	0	3	0	1	0
14	--	--	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	--	--	18	0	0	0	0	0	0	0	0	0	2	1	0	2
28	--	--	3	0	0	0	0	0	0	0	0	1	1	4	0	1
June 4	--	--	2	1	0	0	0	0	0	0	0	0	43	15	0	5
11	--	0	3	4	0	0	0	0	0	0	0	0	85	6	0	7
18	--	2	5	6	0	0	0	0	0	0	0	3	77	13	0	8
25	--	0	5	0	0	2	0	64	0	0	0	8	119	11	4	15
July 2	--	22	5	9	4	80	1	754	54	13	10	24	243	26	130	98
9	--	93	9	313	7	139	76	2855	347	173	47	570	425	165	2982	586
16	--	144	62	1865	2881	871	1440	7659	419	1092	266	1644	723	1540	25362	3283
23	1218	667	1058	8011	6320	8958	3519	8003	79	2124	477	1916	1672	10829	25267	5341
30	8966	561	3856	4474	4077	4530	8897	4362	38	4185	2931	576	1386	22256	15777	5791
Aug. 6	16868	410	2263	1217	919	1234	3191	1802	12	4610	5738	97	1400	7860	6182	3587
13	7668	126	3778	380	354	677	1425	499	0	2420	4520	48	623	1829	2570	1794
20	4941	104	2172	168	241	266	494	376	0	1113	2445	27	222	829	1209	974
27	827	35	561	20	74	93	374	339	0	322	804	8	79	126	246	261
Sept. 3	125	30	180	21	128	43	123	43	0	163	256	4	18	22	54	81
10	56	15	23	3	45	35	17	69	0	46	110	5	15	10	19	31
17	42	13	4	4	7	37	28	27	0	12	28	1	2	16	20	18
24	26	4	3	5	12	96	3	13	0	8	18	0	0	3	6	13
Oct. 1	--	1	1	0	5	61	0	15	0	1	5	0	1	1	1	7
8	--	0	2	--	5	0	3	9	0	0	9	0	0	0	1	3
15	--	0	0	--	8	0	0	2	0	0	0	0	0	0	0	1
22	--	0	0	--	0	0	0	3	0	0	1	0	0	0	0	0
29	--	0	0	--	--	1	0	0	0	0	0	0	0	0	0	0
Nov. 5	--	0	0	--	--	--	0	0	0	0	0	0	1	0	0	0
12	--	0	0	--	--	--	0	0	0	0	0	0	1	0	0	0
19	--	0	0	--	--	--	0	0	0	0	0	0	1	0	0	0
TOTAL	40737	2227	14013	16501	15087	17123	19591	26894	949	16282	17665	4932	7142	46563	79834	21907

Table 6. --- Numbers of silver salmon counted over Rock Island Dam.

Year	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	Mean
Total Number of Fish	182	69	10	0	58	78	13	2	29	1	22	186	166 6/	32 6/		

6/ Primarily stock relocated from Lewis River.

Fish ascending the lower half of any of the three fish ladders entered trapping pools through V-shaped tunnels. The trapping pools were floored with movable, rubber-protected, gratings which were raised at the time of loading to herd the fish through a second tunnel leading into an elevator. Counts were made as the fish passed from the trapping pool into the elevator. The elevator, consisting of a 500-gallon tank, was raised by power and the fish were released through a trap door into a chute connected with the tank of the distribution truck. At no time in this operation were the fish handled or removed from the water.

During the first season, minor difficulties of mechanical origin were encountered with the equipment but all were remedied before serious losses of fish resulted. The prompt removal of fish was found necessary to minimize the tendency of the fish to jump when the traps became crowded. This source of injury was particularly serious during the July-August period when large summer chinooks -- some weighing 40 to 50 pounds -- were present in the traps together with 3-pound bluebacks. Prompt removal of the fish through frequent hauling proved the only satisfactory means of decreasing injuries and subsequent mortality.

Wounds and bruises commonly were observed among the fish entering the traps at Rock Island. It was concluded that most of these injuries were inflicted through contact with the rocks and structural abutments below the dam, for injured fish were common at Rock Island Dam before the Grand Coulee Fish-Maintenance Project was undertaken.

Adequate, though not complete, species segregation in the loads were obtained as the fish entered the elevators from the trapping pools. A small gate at the apex of the tunnel was manually opened when fish of the desired species approached and closed at the approach of other species.

Upon arrival at their destination, the distribution trucks were backed onto unloading ramps and the fish were released through a trap door into deep water as illustrated in Plate 4.

The eight trucks used for hauling the adult fish from Rock Island Dam were equipped with 1,000-gallon tanks through which aerated water, ice-cooled if desired, constantly recirculated at the rate of 125 gallons per minute. (Plate 5.)

Chemical analyses of the truck water were performed as a routine procedure during the 1939 season and occasionally thereafter to determine the changes in water chemistry occurring under varying conditions of time and poundage of fish being transported. The water analyses were correlated with the condition of the fish upon arrival at their destination.

These data were used to establish the carrying capacity of the trucks. Size of fish and temperature of water were conditioning factors and the maxima per load established at the peak of summer hauling were: 25 large chinook (700 lbs.), or 300 blueback (900 lbs.). Scrap fish (suckers, squawfish, and chubs) often entering the loads reduced the capacity for food-fish accordingly.

The water analyses necessarily were limited to those conducted with reasonable accuracy under field conditions. They included dissolved oxygen, carbon dioxide, bicarbonate alkalinity, pH, and temperature determinations with occasional checks of free ammonia and conductivity. The changes in water chemistry occurring in the tank trucks during a typical trip are shown in Figure 3.

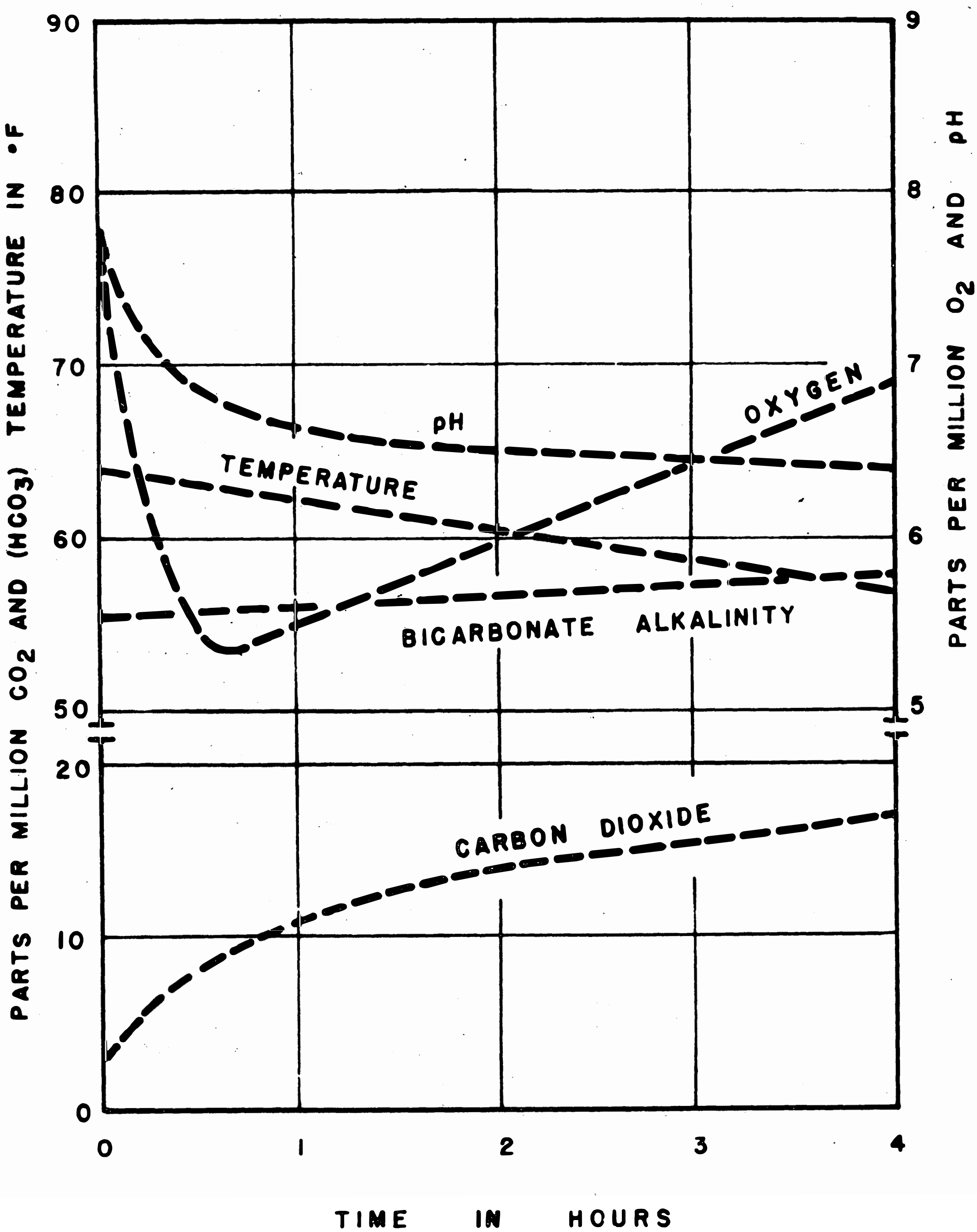
The data acquired from the routine water analyses demonstrated that the dissolved oxygen concentration dropped rapidly to a minimum point and then slowly returned to the point of saturation. The bicarbonate alkalinity showed a slight rise. The free carbon dioxide increased to 10 or 15 times the initial concentration of approximately 2 p.p.m. with an accompanying decrease in the pH.

The initial drop in oxygen reflected the restless behavior of the fish during the first 30 minutes of confinement in the truck tank. As the fish adjusted themselves to their enviroment, they became less active and, as a result, the dissolved oxygen content of the water increased.

The accumulation of carbon dioxide in the truck water caused some concern. During the fall of 1940, several loads of adult fish were exposed to abnormally high carbon dioxide concentrations produced by coupling a tank of the gas directly to the air intake of the water circulating system. Control loads carried over the same period of time consisted of hauls during which the carbon dioxide concentration accumulated under conditions of normal truck operation. Two four-hour hauls also were made in which the carbon dioxide concentrations were reduced by the continuous addition of dilute sodium carbonate solution. The separate loads of adult fish were confined in individual rearing ponds at the Leavenworth Station for observation. A comparison of the subsequent mortality and egg fertility among the various groups indicated that no increase in adult fish mortality nor reduction in egg fertility accompanied the usual accumulation of carbon dioxide in the trucks; that a rapid increase in the carbon dioxide concentrations to 35 p.p.m. or greater would produce partial or complete anesthesia of the fish without apparent harmful effect; and that adult salmon can tolerate much higher concentrations of carbon dioxide if the rate of accumulation is gradual.

With very few exceptions, the mortality among adult fish resulting from injuries sustained below Rock Island Dam or in the trapping and loading operations occurred after the fish had been released from the trucks. The actual loss of adult food-fish in the trucks during the entire five-year program of hauling totalled only 136 chinook salmon, 102 blueback salmon, and 2 steelhead trout.

Figure 3.-- The changes in water characteristics occurring in the Grand Coulee Fish-Maintenance Project distribution truck during a typical operation. Data obtained from a 435-pound mixed load containing chinook and blueback salmon, steelhead trout, and a few squawfish and suckers.



THE NATURAL PROPAGATION OF RELOCATED FISH

Stream and lake areas in which the fish were held for natural propagation were patrolled at regular intervals during the ripening and spawning periods. The frequency of inspection was dependent largely upon the size of the area and the personnel available and varied from twice daily, in the case of a small experimental area established in the Entiat River in 1940, to one inspection weekly over some parts of Lakes Wenatchee and Osoyoos. As the impounding areas included more than 100 lineal miles of stream and approximately 11 square miles of lake surface, inspection was not as complete as would have been desired.

Each dead fish recovered was examined and its sexual condition recorded. The relative numbers of spawned and unspawned fish recovered yielded evidence of the spawning success of the impounded population as a whole. Sampling errors were introduced by seasonal changes in weather and stream conditions, physical differences between the areas selected by the fish during their ripening and spawning periods, personnel limitations, and the removal of dead fish by bears and other scavengers. It is believed, however, that the samples gave a reasonably accurate indication of the spawning success of fish held for natural propagation.

Nason Creek

Nason Creek, an upper tributary of the Wenatchee River, was selected as a holding and spawning area for spring steelhead and chinook inasmuch as these fish are known to select smaller mountain streams and Nason Creek once had supported similar populations.

The watershed contains snowfields of the Cascade Mountain divide and the stream is steep and turbulent for the greater part of its length. The lower 16 miles are accessible to migratory fish and contain an abundance of sheltered pools and excellent spawning riffles. An impassable falls marked the upper limit of this natural holding area, and, at the lower end (approximately one-quarter of a mile from the mouth), a picket rack was installed.

Spring Steelhead

Spawning of the steelhead was observed soon after the first fish were released into the Nason Creek holding area in May, and continued until early July. Although observations during this period of the year were handicapped by high water conditions, there was little evidence of pre-spawning mortality and such losses are believed to have been negligible. All steelhead appearing at the rack after spawning were passed over to continue their downstream migration. The downstream migration of spent steelhead continued throughout the summer and was a matter of record until the rack was removed in the fall.

The spawning success of the spring steelhead, as indicated by the fish recovered, is presented in Table 7.

Spring Chinook

Spring chinook were observed to congregate in great numbers at the upper and lower limits of the holding area following their release into Nason Creek. At one time during 1939, approximately 1,000 chinooks were observed immediately above the rack. At night, groups of these fish could be observed swimming back and forth across the face of the rack seeking an avenue of escape. A total of 51 dead fish, or 1.3 per cent of the impounded population, was removed from the rack before the start of the spawning season. During 1940, the loss at the rack increased to 113 chinooks, or 3.5 per cent of the population. During the ensuing years, 151 fish, or 12.2 per cent of the population, were recovered in 1941, and 82 fish, or 8.1 per cent, in 1942. For the most part, these losses occurred during the June-July freshet period and followed the peak of the hauling activity by approximately three weeks. Comparatively few dead fish were recovered in the stream during the period when losses were heavy at the rack.

The spawning success of the spring chinooks is indicated by the number of fish recovered from the stream and from the rack; the data are presented in Table 8.

Unseasonable freshets during August and September of 1941 disrupted spawning ground observations. It appears probable, however, that holding was less successful in 1941 and in 1942 than it had been during the previous two years. In May 1943, the rack was destroyed by flood waters and could not be rebuilt until late in July, hence it is doubtful if any losses occurred at the rack site during this period. Spawning ground observations and redd counts in the fall of 1943 indicated that a large majority of the impounded population (progeny of the transplanted 1939 run) elected to remain and to spawn in Nason Creek although they had ample opportunity to escape downstream during the ten-week period when the rack was not in place.

Wenatchee River

The upper Wenatchee River contains extensive pool and riffle areas and, as the minimum summer flows are never less than 300 second-feet, it was believed particularly well-suited to the large summer chinooks and fall steelheads. Two racks were installed in the Wenatchee River enclosing a section spproximatley 18 miles in length immediately below Lake Wenatchee.

A maximum temperature of 70° F. was recorded during August, 1940, and the maximum diurnal fluctuation approximated 8° F. The period of high water temperatures extended from the latter part of July until early September but temperatures in excess of 65° F. normally were limited to the month of August.

Table 7. --- Data on the spring steelhead held in Nason Creek.

Year	Number Released	Number Recovered	Percentage Recovered	Fish Recovered Spawned	Unspawned	Percent Spawned
1939	1,343	595	44	590	5	99
1940	1,147	209	18	201	8	96
1941	899	222	25	215	7	97
1942	325	169	52	169	0	100
1943	60	Record incomplete - rack destroyed by flood				

Table 8. --- Data on the spring chinook held in Nason Creek.

Year	Number Released	Number Recovered	Percentage Recovered	Fish Recovered Spawned	Unspawned	Percent Spawned
1939	3,957	423	11	327	96	77
1940	3,165	574	18	387	187	67
1941	1,251	417	33	156	261	37
1942	1,014	255	25	129	126	51
1943 7/	1,191	243	20	209	34	86

7/ Rack destroyed by flood in May; all recoveries were made in the stream.

Summer Chinook

The first summer chinook were released into the Wenatchee River holding area during July or August and spawning occurred from mid-September through early November. Whereas observations along Nason Creek were conducted mainly on foot, a small rubber boat was found most effective in patrolling the Wenatchee River. A two-man inflated life raft was used for this purpose and the observers, working downstream with the current, were able to inspect both banks of the river as well as the extensive riffle areas.

In Table 9, "fish recovered" in the Wenatchee River includes both stream and rack recoveries. There was little evidence that the rack contributed materially to prespawning losses; probably because the fish were released later in the season. at lower water levels those that existed at the time the spring fish were released in Nason Creek.

During 1941, early fall freshets and unfavorable weather conditions interfered with the recovery of spent carcasses and, in 1942, a similar bias in the recovery effort resulted from personnel separations during the spawning season. Notwithstanding these circumstances, it appears probable that the spawning was less successful during the last two years of record than during the initial two years.

Fall Steelhead

A total of 1,027 fall steelheads were impounded in the Wenatchee River area during 1939. Little could be determined with regard to their survival to the spawning season during the following spring, for the Tumwater rack washed out with the spring freshets. During the winter, a large school of steelheads occasionally was observed in the pool immediately above the lower rack. As the rack was destroyed by spring floods in 1940, no record could be obtained of the downstream migration of spent steelheads. Their survival, and spawning success, was believed to have been fairly high.

Entiat River

The Entiat watershed is mountainous and wooded and the stream is well protected by a dense marginal border of alder, willow, maple, and conifers. A portion of the 1939 summer chinook and fall-run steelhead was held in a 15-mile section of the main stem. During 1939, the minimum flow was approximately 60 second-feet and the maximum water temperature recorded was 66° F. This section, which extended between a rack installed 15 miles above the mouth of the river and an impassable falls, is marked by a moderate gradient and contains excellent pool and riffle areas.

Table 9. --- Data on summer chinook held in Wenatchee River.

Year	Number Released	Number Recovered	Percentage Recovered	Fish Recovered		
				Spawned	Unspawned	Percent Spawned
1939	3,498	1,052	30	869	183	83
1940	752	169	22	157	12	93
1941	446	94	21	56	38	60
1942	3,050	776	25	302	474	39
1943	386	(no data, rack destroyed by flood)				

Table 10. --- Data on the summer chinook held in Entiat River.

Year	Number Released	Number Recovered	Percentage Recovered	Fish Recovered		
				Spawned	Unspawned	Percent Spawned
1939	2,913	959	33	406	553	42
1940	102	71	70	59	12	83

The summer chinook held in the Wenatchee and Entiat rivers during 1939 were apportioned as equally as possible by impounding alternate loads in the two streams to assure a uniform distribution of male and female fish. As the season progressed, it became apparent that the population held in the Entiat was suffering a much heavier mortality than that held in the Wenatchee River. A majority of the dead and dying fish in the Entiat exhibited heavy fungus growths, particularly about the head and opercles. The infection also appeared among the fish held in the Wenatchee River and elsewhere, but it was much less severe. Fall-run steelhead in the Entiat River also were severely affected. Of 2,320 steelhead released during the fall of 1939, two hundred were recovered dead during the following fall and winter months. Winter ice and spring freshets prevented adequate observations and the mortality is believed to have been greater than the data indicated.

During the summer of 1940, a 3/4-mile section of the Entiat River was enclosed between racks and 102 summer chinook were released into this limited area to determine whether the severe mortality experienced during 1939 would be repeated. It was not, as the results shown in Table 10 indicate. There was no evidence of excessive fungus infections and the fish appeared to remain in good condition throughout the holding period. Although the holding area was carefully examined twice each day, 30 per cent of the impounded fish were never recovered, largely because of the formation of ice and resulting poor visibility near the close of the spawning period.

The Entiat River was abandoned as a holding area following the 1940 season because of protests from local residents that valuable pasture land was inundated by the slight backwater created above the rack.

Lake Wenatchee

The Columbia River blueback runs naturally frequent only river systems containing accessible lakes in which the fingerlings may spend the first year of their life cycle. Lake Wenatchee, a deep alpine lake surrounded by densely wooded mountains, originally supported blueback salmon although the runs had virtually disappeared before the Maintenance Program was undertaken. The lake is fed by two rivers providing suitable spawning areas--the Little Wenatchee River (containing four lineal miles of accessible spawning ground) and the White River (containing approximately seven lineal miles of spawning ground).

A rack was constructed across the outlet of Lake Wenatchee to impound the blueback in the lake as well as to prevent the entrance of summer chinook salmon from the river holding section immediately below. An unloading ramp was built on the lake shore approximately midway between the inlets and the outlets. A patrol of the lake by boat was maintained during the August-September holding period and the observations were then extended to the tributaries as the fish moved into the streams to spawn. No spawning was observed on the limited shoal areas of Lake Wenatchee nor were any spent fish recovered from the lake.

Virtually all recoveries of dead fish from the lake were made during the hauling period or shortly thereafter. Most of the dead fish recovered were found floating in the vicinity of the unloading ramp or were washed ashore on the nearby beaches. Table 11 shows total recoveries from lake and streams. Known truck losses are included with recoveries from the lake because of the evidence that the latter were attributable to injuries received before the fish were released.

Lake Osoyoos

The original distribution of blueback salmon in the upper Columbia River drainage is not known. It appears probable, however, that Lake Osoyoos--and other large glacial lakes in the Okanogan River system--at one time produced a substantial part of the entire Columbia River blueback run. Of the potential blueback salmon spawning areas in the extensive Okanogan River system, only Lake Osoyoos and approximately 20 miles of adjacent spawning stream now are accessible to salmon. What remains, however, is particularly well suited to the production of blueback salmon.

The Okanogan River system lies east of the Cascade Mountains in a semi-arid section of north-central Washington and southern British Columbia. Lake Osoyoos is bordered by high hills, barren on the lower slopes but covered with pine forests at higher elevations. Bottom lands surrounding the lake support extensive irrigated farms and orchards.

A rack was constructed across the outlet of Lake Osoyoos and an unloading ramp was located on the west shore of the lake approximately three miles from the outlet. Lake and stream patrols were maintained throughout the holding and spawning seasons. Data on releases, losses and recoveries are given in Table 12.

Seaward Migration of Naturally Spawned Fingerling Salmon

The seaward migration of chinook fingerlings from the Grand Coulee area apparently reaches a peak in the late spring or early summer, continuing throughout July until the low-water period of August. A second and smaller migration accompanies the early fall freshets of September and October. Young chinook fingerlings--progeny of naturally spawning fish--were found in greatest numbers in Nason Creek and the upper Wenatchee River during late April and early May. They spread upstream and downstream from the spawning areas and soon could be found in all of the accessible areas of the minor tributaries including snowfed rivulets that became dry later in the season. The principal early-spring movement of the chinook fingerling, however, was definitely in a downstream direction.

Table 11. --- Data on blueback held in Lake Wenatchee.

Year	Number Released	Lake Recoveries and Hauling Losses		Stream and Rack Recoveries		
		Spawned	unspawned	spawned	unspawned	Percent spawned
1939	8,148	0	120	868	75	92
1942	10,884 1/	0	103	2,266	159	92
1943	13,664 2/	0	441	---	263	--

1/ 120 females spawned for artificial propagation at Leavenworth Hatchery.

2/ Personnel were not available to examine spent blueback during the fall of 1943. It was estimated that, at one time, 3,000 blueback were on the White River spawning riffles. At the Little Wenatchee spawning traps, 550 females were spawned for artificial propagation at Leavenworth--leaving an estimated 350 females for natural spawning also in the Little Wenatchee River.

Table 12. --- Data on blueback held in Lake Osoyoos.

Year	Released	Lake Recoveries and Hauling Losses		Stream and Rack Recoveries		
		spawned	unspawned	spawned	unspawned	Percent spawned
1939	10,104	7 1/	273	346	19	95
1940	9,691	31 1/	411	627	16	98

1/ These spent fish were recovered from the lower end of the lake, indicating that some spawning may have occurred in the lake.

The length distribution of fish taken over a period of months in the upper and lower Wenatchee River is shown in Table 13. In the period covered by the table, only naturally reared fish were present in the river. The fingerlings taken in the lower Wenatchee River in May and early June, 1941, were yearlings, while those taken later were fish then in their first year. Apparently, few chinook fingerlings remain over winter in the upper tributaries as is evidenced by the absence of yearlings in the samples seined from the upper Wenatchee River samples. No yearlings were found in the lower river samples later than mid-June.

The migration of blueback fingerlings from Lakes Wenatchee and Osoyoos was observed from March through May and all migrants were yearlings ranging between 3.5 and 5 inches in length.

Steelhead spawn from April to July and the young emerge from the gravel between June and August. No well-defined seaward migration of steelhead was observed until after the fall freshets of September and October. The major migration of steelhead apparently occurs during the following spring freshet period and an undetermined percentage remains in the upper tributaries until the spring of their third year before migrating to the sea. The behavior of the steelhead, both as fingerlings and adults, has been somewhat obscured by the presence of resident rainbow trout in the tributary streams and in the main Columbia River as well.

THE ARTIFICIAL PROPAGATION OF RELOCATED FISH

The original plan for the Grand Coulee Fish-Maintenance Project was to compress the salmon runs then utilizing some 1,140 miles of the upper Columbia River and tributaries into a stream length of approximately 677 miles. Because the areas into which the relocation was planned were already supporting small runs and were also of reduced potential value for spawning and rearing due to competing water uses, the supplemental measure of artificial propagation was adopted in the Grand Coulee Fish-Maintenance Project.

Leavenworth Station

The program of artificial propagation is centered around a hatchery unit and holding pond system located on Icicle Creek three miles from the town of Leavenworth, Washington. The main hatchery unit (see Plate 6.), includes three buildings, all of reinforced concrete construction. The hatchery building contains a hatching room with 288 "deep type" concrete troughs and two two-story wings providing space for office, laboratory, conference, and storage rooms for the employees and a reception and rest room for visitors. A combined shop, garage, and warehouse building, plus a third building housing a central heating plant, cold storage unit with a sharp freezing room and two storage rooms, and food preparation equipment complete the Leavenworth building group.

Adjacent to the hatchery buildings are two groups of the Foster-Lucas type of fingerling rearing ponds: one group containing 30 ponds measuring 30 feet in width by 130 feet in length, and the other containing 40 ponds, 18 feet wide by 76 feet long.

Holding ponds for retaining adult fish, during the resting period between the time of their arrival in the Grand Coulee area and the onset of sexual maturity, were formed in a three-quarter mile section of the Icicle Creek bed across which four dams were built creating three separate holding areas. The uppermost dam was designed to regulate the flow of Icicle Creek water through the holding ponds and to divert excess water through a by-pass, 4,000 feet in length, re-entering Icicle Creek below the lowest holding area. Each holding area contained a deep and a shallow section separated by a picket rack equipped with a power-operated lift gate. The deep section was planned for retaining the salmon during the holding period and the fish were to be seined for spawning as they sought the shallow area upstream with the onset of sexual maturity.

The water supply for the Leavenworth Hatchery is derived from Icicle Creek, the Snow Lakes impoundment (tributary to Icicle Creek), and the Wenatchee River. Water from these sources may be supplemented by pumping from two 90-foot wells, each with a capacity of approximately three second-feet.

Construction of the main unit at Leavenworth was started during the summer of 1939 and completed in the following spring. The first adult fish were released into the holding ponds on June 10, 1940. Spawning operations commenced on August 22, 1940.

Substations

In addition to the central fish-cultural unit at Leavenworth, three substations were recommended by the Board of Consultants to be located on the Entiat, Methow, and Okanogan rivers. The plan of operation contemplated the transport of eyed eggs from the Leavenworth Station to the substations for hatching and rearing prior to liberation into the several tributaries. After the first one or two cycles, each substation was to become a separate unit for hatching, rearing, and stocking the four major tributaries to a population density greater than could be produced and supported through natural propagation alone.

Entiat Substation

The Entiat substation, located by the Fish and Wildlife Service at Packwood Springs, six miles above the mouth of the Entiat River, consists of a hatching room containing 52 deep concrete troughs, a heating plant, garage, cold storage unit, food preparation room, general storage space, and an office--all housed in a single reinforced concrete building. One battery of eight smaller Foster-Lucas type fingerling rearing ponds, and one battery of eight of the larger size, complete the original fish-cultural equipment of the station. The Entiat substation is supplied with water from the Packwood Springs which seasonally fluctuates between two and four second-feet. The spring water may be supplemented, as desired, by Entiat River water. The Entiat substation was opened during August, 1941.

Winthrop Substation

The Winthrop substation, located by the Washington State Department of Fisheries 45 miles above the mouth of the Methow River, is approximately twice the size of the Entiat substation. One large concrete building houses 88 deep concrete troughs, a heating plant, cold storage unit, food preparation room, garage, office, and storage space. The outside rearing equipment consists of a double battery of eight each of the two sizes of Foster-Lucas ponds. The Winthrop substation receives a maximum of five second-feet of spring water and, in addition, can draw upon the Methow River as desired.

Okanogan Substation

A third substation planned on the Okanogan River drainage was never constructed. The only suitable hatchery sites found in the Okanogan Valley were in Canada. The international complications involved, coupled with the onset of wartime building restrictions, rendered a delay in the construction of the Okanogan substation advisable--at least until such time as the need for it became more apparent.

Fish--Cultural Operations

Fish-Cultural operations during the past six years have revealed limiting deficiencies in the original plans for the three hatcheries. Certain of these limitations have been overcome by temporary expediencies, others remain as permanent barriers to the conduct of fish-cultural operations in accordance with the original plans.

At the Leavenworth Station, spawning operations cannot be performed in accordance with the design of the holding ponds. It was soon found that the maturing fish did not enter the shallow seining areas in the head of each holding section sufficiently in advance of spawning to permit egg collections. For the most part, the adult fish would slip into the seining area at night, spawn, and return to the deeper holding area the following morning. This habit was quickly checked by forcing all water through a by-pass channel in which a trap was installed. Although crude in many respects, this arrangement for collecting eggs has worked exceptionally well.

None of the Leavenworth rearing ponds can be operated during the winter months owing to ice formation in the drain pipes. It is impossible to obtain sufficient water of suitable temperature for efficient inside fish-cultural operations during the winter months as one of the wells, designed to temper the extreme temperatures of Icicle Creek, delivers water sufficiently supersaturated with nitrogen to resist all efforts, to date, at de-aeration to a gas concentration that will not produce "gas bubble" disease among the fingerlings. The eggs hatch prior to the time when the outside ponds can be used, hence the winter rearing capacity of the Leavenworth Station is restricted to the feeding-fry capacity of the 288 inside troughs, or approximately 3,500,000 fish.

Table 13. --- Size distribution of naturally-spawned chinook salmon. Lengths are in inches.

		April	May	June	July	August	Sept.	Oct.	Nov.
Upper Wenatchee River 1940	No.				148	105	102	144	113
	Mean				1.87	1.88	2.08	2.52	2.46
	Std. Dev.				.25	.28	.29	.58	.33
1941	No.	49	129	312	460	433	260		
	Mean	1.47	1.59	1.88	2.08	2.49	2.46		
	Std. Dev.	.11	.06	.28	.27	.44	.33		
Lower Wenatchee River 1940	No.				545	79	13	542	7
	Mean				3.04	3.19	4.58	5.08	5.41
	Std. Dev.				.33	.29	.37	.54	.26
1941	No.		56 1/	281	483				
	Mean		5.01	2.86	3.33				
	Std. Dev.		.38	.61	.32				

1/ Twenty-one yearlings taken during the first four days in June are included in the May sample.

A further bottleneck in the fish-cultural operations develops during the summer months as all suitable water available will operate only 40 of the smaller rearing ponds. Each rearing pond has a minimum water demand of 180 gallons per minute and the capacity of the Icicle Creek pipeline is 9,700 gallons per minute. The Wenatchee River supply was originally designed to supplement the deficiency of Icicle Creek during the summer months. After flowing through the three-mile open ditch between the intake and the hatcher, however, the Wenatchee River water reaches a maximum temperature in the mid-80's thus far exceeding the temperature suitable for coldwater fish culture. With each of the 40 smaller ponds (for which water is available) stocked with 1,100 pounds of fish, the maximum rearing capacity of the Leavenworth Station is only 2,400,000 fingerlings as of October 1 of a normal year.

Comparable limitations of the rearing capacity also exist at the Entiat Hatchery. Sufficient spring water is avialable during the winter months to permit operating only one of the smaller Foster-Lucas rearing ponds as well as the 56 inside troughs. In terms of propagating chinook salmon, for which this station is used, the maximum capacity is only 270,000 feeding fry.

No provision for holding adult fish to secure a continuing egg supply was made in the original plans for the Entiat Station. To remedy this deficiency, a small adult fish holding pond--connected to the Entiat River by a short fish ladder--was constructed. The pond was built under wartime restrictions on materials but, in spite of its crude nature, has proved very efficient in attracting and holding adult fish.

The Winthrop Station has sufficient spring water available, in combination with Methow River water, to operate only 16 of the smaller Foster-Lucas rearing ponds as well as the 88 troughs during the winter months. In terms of chinook salmon, the capacity of the station is approximately 2,500,000 if the fish are liberated during the first spring after hatching, or 350,000 fish if liberated during the first fall. When both spring and summer chinook are propagated, the extended distribution of the egg collections permits some overlapping in the use of available troughs. In terms of blueback salmon, the capacity of the Winthrop Station is only 700,000 fingerlings assuming liberation of the fish 12 months after egg collection.

As at the Entiat Station, no provision was made at Winthrop for securing a continuing supply of eggs. This limitation was corrected in the same way as at Entiat by constructing a holding pond for adult fish with material and equipment at hand. Like that at Entiat, this installtion, although crude, has functioned exceedingly well.

The overall success obtained from artificial propagation during the initial seven-year period of the Grand Coulee Fish-Maintenance Project has been only fair at best. It is, however, constantly improving as the many unanticipated problems are being identified and effectively solved by carefully designed and executed research. The hatchery production and distribution records during the past eight years are summarized in Tables 14-21.

Table 14. --- Hatchery production and distribution records, 1940 brood.

Species	No. of Adult Fish Received	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. of Fingerlings Released	Location of Fingerling Releases
Spring Chinook	922	306	Records combined with summer chinooks			
Summer Chinook	4,299	1,062	3,979,700	2,682,192	1,619,013	Entiat River 583,900 Icicle Creek 512,557 Methow River 522,556
Blueback	17,124	3,791	6,065,800	4,506,877	1,008,312	Osoyoos Lake 569,296 Wenatchee Lake 414,016 Icicle Creek 25,000
Silver	(?) 10	6	7,400	6,250	5,470	Icicle Creek 5,470

Table 15. --- Hatchery production and distribution records, 1941 brood.

Species	No. of Adult Fish Received	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. of Fingerlings Released	Location of Fingerling Releases
Fall Steelhead	4,084	539	1,839,100	1,576,696	371,768	Methow River 114,460 Entiat River 43,680 Wenatchee River 84,860 Icicle Creek 128,768
Spring Steelhead	1,071	292	1,130,200	989,000	Records combined with fall Steelhead	
Quinault Blueback	Received as eyed eggs		210,816	208,152	91,740	Bumping Lake 1/ 25,777 Entiat River 59,998 Icicle Creek 1,945 Experiments 4,020

1/ Experimental transplantation in Yakima River drainage.

Table 15. (Continued)--- Hatchery production and distribution records, 1941 brood.

Species	No. of Adult Fish Received	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. of Fingerlings Released	Location of Fingerling Releases
McKenzie Chinook	Received as eyed eggs		1,000,000	888,200	683,202	Icicle Creek 683,202
Summer Chinook	778	36	111,900	98,754	85,489	Entiat River 85,489
Blueback	851	20	19,500	17,540	12,459	Lake Wenatchee 12,459
Silver	29	10	15,600	13,149	11,050	Icicle Creek 11,050

Table 16. --- Hatchery production and distribution records, 1942 brood.

Species	No. of Adult Fish Received	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. of Fingerlings Released	Location of Fingerling Releases
Fall Steelhead	1,521	648	1,954,388	1,531,498	185,007	Icicle Creek 185,007
Spring Steelhead	202	149	489,322	379,157	38,950	Entiat River 7,974 Icicle Creek 30,976
Steelhead	Cross of spring and fall run parents		81,320	52,694	9,648	Icicle Creek 9,648
Big White Salmon Chinook	Received as eyed eggs		100,000	92,000	70,878	Icicle Creek 70,878
Spring Chinook	45	20	51,800	46,235	30,124	Methow River 30,124

Table 16. (Continued) --- Hatchery production and distribution records, 1942 brood.

Species	No. of Adult Fish Received	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. of Fingerlings Released	Location of Fingerling Releases
Summer Chinook	2,387	184	560,168	382,705	250,736	Icicle Creek 117,600 Entiat River 55,940 Methow River 77,196
Blueback	4,547	1,003	2,132,786 1/	1,534,805	930,111	Lake Wenatchee 275,451 Lake Osoyoos 654,660
Lewis River Silver	Received as eyed eggs		91,440	88,000	69,627	Icicle Creek 69,627
Lake Chelan "Kokanee"	Received as eyed eggs		100,000	64,265	22,341	Entiat River 22,341

1/ Includes 382,350 green eggs collected in Little Wenatchee River.

Table 17. --- Hatchery production and distribution records, 1943 brood.

Species	No. of Adult Fish Received	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. of Fingerlings Released	Location of Fingerling Releases
Fall Steelhead	3,051	1,043	3,159,523	27,739,582	1,521,609	Wenatchee R. 180,481 Entiat River 599,778 Methow River 741,350
Spring Steelhead	599	517	1,440,264	1,207,266	899,114	Wenatchee R. 279,869 Entiat River 619,245
Lewis R. Silver	Received as eyed eggs		157,000	152,318	141,221	Icicle Creek 112,267 Entiat River 28,954

Table 17. (Continued) --- Hatchery production and distribution records, 1943 brood.

Species	No. of Adult Fish Received	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. of Fingerlings Released	Location of Fingerling Releases
Spring Chinook	5,560	1,284	2,919,614	2,537,494	2,298,318	Icicle Creek 356,126 Wenatchee R. 697,478 Entiat River 590,954 Methow River 653,760
Summer Chinook	1,478	79	204,508 1/	138,470	116,597	Icicle Creek 85,347 Entiat River 31,250
Blueback	2,766	767	3,476,192 2/	2,910,421	2,630,899	L. Wenatchee 1,453,973 Lake Osoyoos 1,088,138 Methow River 88,788

1/ Includes 62,082 received from Carson hatchery as eyed eggs.

2/ Includes 681,922 received from Carson hatchery as eyed eggs and 1,644,700 green eggs collected in Little Wenatchee River.

Table 18. --- Hatchery production and distribution records, 1944 brood.

Species	Station	No. of Fish Entering Holding Pond	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. Finger- lings Released	Location of Fingerling Releases
Fall Steelhead	Leavenworth	1,068 1/	341	824,463	273,059	266,155	Icicle Creek
	Winthrop	213 1/	81	351,642	310,137	191,211	Methow River
Spring Steelhead	Leavenworth	12	12	Records combined with fall steelheads			
Spring Chinook	Leavenworth	2 (males)		0			
	Winthrop	15 (11 males)	4	4,164	3,844	3,605	Methow River
Summer Chinook	Entiat	23 (12 males)	11	17,457			
		Eyed eggs from Carson		32,618	46,593	43,464	Entiat River
	Winthrop	1 (male)					
	Leavenworth	8 (males)					
Blueback	Entiat	3	0	0	199,394	180,938	L. Wenatchee
	Leavenworth	22	12	219,549			
	Leavenworth 2/		146				
	Leavenworth	Eyed eggs from Carson		292,273	285,550	237,428	L. Wenatchee
	Winthrop	Eyed eggs from Carson		79,000	74,338	64,939	Methow River
"Kokanee"	Leavenworth 2/			200,418	124,252	85,648	L. Wenatchee
						29,189	Icicle Creek
Silver	Leavenworth	128	123	188,175	154,783	133,703	Icicle Creek
	Winthrop	Eyed Eggs from Carson		52,265	47,795	40,082	Methow River
	Entiat	Eyed Eggs from Lewis R.		108,000	105,595	99,485	Entiat River

1/ Transported by truck from Rock Island Dam during fall of 1943.
2/ Collected at Lake Wenatchee.

Table 19. --- Hatchery production and distribution records, 1945 brood.

Species	Station	No. of Fish Entering Holding Pond	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. Fingerlings Released	Location of Fingerling Releases
Fall Steelhead	Winthrop	Eyed eggs from Carson		70,143	68,469	46,428	Methow River
Hybrid Steelhead	Leavenworth	Eyed eggs from Carson		27,011	26,613	16,519	Icicle Creek
Spring Steelhead	Entiat	17	10	28,923	22,619	16,473	Entiat River
	Leavenworth	56	56	83,018	67,448	56,463	Icicle Creek
	Winthrop	Eyed eggs from Carson			53,218	32,952	Methow River
Fall Chinook	Leavenworth	Eyed eggs from Spring Cr.		767,360	752,721	606,328	Icicle Creek
Spring Chinook	Winthrop	96	18(77 males)	60,000	54,148	46,345	Methow River
Summer Chinook	Leavenworth	51	14(26 males)	25,931	Transferred to Entiat		
	Entiat	500	131(287 males)	240,731	238,185	206,446	Entiat River
Blueback	Entiat	59	59	36,900	Combined with Lake Wenatchee stock		
	Leavenworth	64 1/	24	32,192	Combined with Lake Wenatchee stock		
	Leavenworth 2/		414	709,186	701,273	601,113	L. Wenatchee
	Leavenworth	Eyed eggs from Carson		167,521	145,603 3/	40,533 3/	L. Wenatchee
	Winthrop	Eggs from Carson		109,032 4/			
	Winthrop	Fingerlings from Leavenworth			80,360	79,879	On hand, 11/30/46

1/ Including 12 hauled from Wenatchee River near Dryden.
2/ Collected at Lake Wenatchee.
3/ 80,360 transferred to Winthrop as fingerlings.
4/ All but 411 of the shipment lost.

Table 20. --- Hatchery production and distribut on records, 1946 brood.

Species	Station	No. of Fish Entering Holding Pond	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. Finger-lings Released	Location of Fingerling Releases
Steelhead	Leavenworth	80	36	136,279	125,450	111,155	Icicle Creek
	Entiat	32	4	7,318	Transferred to Leavenworth		
	Winthrop	24	6	12,188	9,950	9,378	Methow River
Spring	Entiat	300	128	188,159	Transf. to Winthrop		
	Winthrop	487	199	604,457	603,730	480,627	Methow River
Summer Chinook	Leavenworth	267	54	121,878	113,534	73,633	Icicle Creek
						206,812	Methow River
	Winthrop	166	69	143,183	558,379	120,390	Entiat River
				881,743	301,115	251,438	Entiat River
	Entiat	774	429	-535,738 transf. to Winthrop			
				4,424,948	3,407,238		
Blueback	Leavenworth	3,904	3,648	-750,000 transf. to Winthrop			
						1,688,670	L. Wenatchee
						337,590	L. Osoyoos
	Winthrop	99	38	40,939	769,941	97,000	Methow River

Table 21. --- Hatchery production and distribution records, 1947 brood. 1/

Species	Station	No. of Fish Entering Holding Pond	No. of Fish Artificially Spawned	No. Eggs Collected	No. Feeding Fingerlings Produced	No. Fingerlings Released	Location of Fingerling Releases
Steelhead	Leavenworth Winthrop Entiat	71 20 77	43 20 16	118,107 42,278 24,253	110,619 36,013 22,513	88,010 22,513 22,276	Icicle Creek Methow River Entiat River
Spring Chinook	Leavenworth Winthrop	459 363	414 348	926,286 1,084,709	820,108 952,787	804,330 912,889	Icicle Creek Methow River
Summer Chinook	Entiat	408	206	608,791	576,254	94,671	Trans. to Leavenworth
Blueback	Leavenworth Winthrop	3,114 2/ 701	2,758 689	3,607,836 793,484	3,236,046 724,338		
Silvers	Leavenworth Winthrop	166 41	152 ? 3/	210,855 20,925	151,812 14,706		

1/ Data complete as of April 1, 1948.
2/ Little Wenatchee River.
3/ Records incomplete on Winthrop silver salmon.

Laboratory Research and Development

Research in the fields of fish pathology, fish nutrition, and hatchery technique was undertaken at the Leavenworth laboratory following the appointment of a permanent biologist in July, 1941. Additional appointments to the laboratory personnel were made during the following year and a cooridinated research program initiated.

Pathological Investigations

Pathological investigations have revealed that mechanical injuries, complicated by one or two diseases, precluded successful retention of adult fish during the relocation phase of the Grand Coulee Fish-Maintenance Project. These diseases are caused by the establishment and growth of the common fish-fungus Saprolegnia parasitica (Coker) and the little known micro-organism Chrondrococcus (Bacillus) columnaris (Davis). Apparently, infections by either organism ordinarily follow mechanical injury of the epithelial tissues although the pathogenicity of C. columnaris may be enhanced sufficiently by high water temperatures to cause primary infection. In addition, infections by the parasitic copepod Salmincola falculata Wilson, Trichodina(Cyclochaeta)sp., and Ichthyophthirius sp., commonly were found on the adult fish. None of the exoparasites are believed to have contributed materially to the mortality.

No practical method for treating the adult fish was found. The usual water flow through the holding ponds at Leavenworth, approximating 100 cubic feet per second, precluded mass treatment. Seining the fish from the holding ponds for individual treatment obviously would be impractical. Treatment of the fish in the tank trucks as they arrived at the holding ponds would be feasible but it would not prevent subsequent infection. The ubiquitous distribution of Saprolegnia spores, and of C. columnaris as well, assures the certainty of subsequent infection from an indigenous origin.

The cessation of the trucking of adult fish from Rock Island Dam in 1944 was accompanied by a marked decrease in the mortality of adult fish in the hatchery holding areas. Although many of the adult fish now exhibit traumatic injuries as they enter the holding areas, the incidence is not so high as when the fish were being trucked.

Diseases have played an exceedingly important role in limiting the efficiency of fingerling production. None of the methods for controlling fish diseases known at the time that the rearing program was undertaken in 1940 was applicable to the large type of fish-cultural equipment on the project. The use of Icicle Creek water, which supports a fair population of resident fishes, assured a source of disease-producing organisms.

During July, 1941, nine different infectious diseases were found concurrently among fingerling stock in the Leavenworth rearing ponds with no satisfactory control measure available for any. Under such conditions, satisfactory fingerling production could not be expected, nor was it obtained.

Prolonged treatments with formalin, that previously had been developed for application in shallow troughs only, were quickly adapted to the deep throughs at the three Grand Coulee hatcheries and eventually to the rearing ponds. The perfection of formalin treatments eliminated parasitic disease as a factor limiting fingerling production.

Bacterial gill disease, however, proved the greatest single source of losses, particularly in the Foster-Lucas type rearing ponds where conditions appear exceptionally favorable for its development. This disease seldom appeared of consequence among fingerling fish reared in the deep troughs.

The relatively small number of eggs collected during the fall of 1941 permitted rearing most of the fingerling stock in troughs during the summer of 1942 and satisfactory results were obtained except for one group of bluebacks carried in an outside pond. Increased egg collections in the fall of 1942, however, again required the use of the rearing ponds during the 1943 season and bacterial gill disease exacted a serious toll of fingerling stock as it had during the summer of 1941. Late in the summer of 1943, the use of Roccal (a trade name for a ten per cent aqueous solution of alkyl-dimethyl-benzyl-ammonium chloride) in prolonged treatments was found to be an effective control for bacterial gill disease. The discovery that Roccal would effectively eliminate bacterial gill disease as well as certain other diseases in prophylactic treatments has proven of great consequence in the program of artificial propagation.

The effect of the research program in raising production efficiency may be observed by reference to Table 22 in which is shown the percentage of mortality of native salmon during the successive years.

The increased efficiency of artificial propagation, plus the reduced mortality among adult fish following cessation of trapping at Rock Island Dam has done much in enabling artificial propagation, to fulfill its intended role in the Grand Coulee Fish-Maintenance project.

Nutritional Investigations

The prolonged rearing of salmon, as attempted in the Grand Coulee Fish-Maintenance Project, acutely emphasized the inadequacy of knowledge concerning the nutritional requirements of fingerling salmon. Many diets commonly fed in the usual short-term hatchery operations proved to be inadequate when fed over a longer rearing period.

The ultimate objective of the nutritional investigations undertaken at the Leavenworth Laboratory has been the development of a feeding program that will produce a maximum number of fingerlings in a sound physical condition at a minimum cost. All nutritional experiments have been designed to reveal various phases of that objective.

Table 22. --- Percentage mortality of native salmon.

Species	Brood Year	Rearing Season	Total No. of Eggs Received	Per cent Loss of Eggs & Fry	No. Feeding Fingerlings Produced	Per cent Loss of Fingerling	No. Finger-lings Released	Per cent Total Loss
Summer Chinook	1940	1941	3,979,700	32.6	2,682,192	39.5	1,619,013	59.3
Blueback	1940	1941	6,065,800	25.7	4,506,877	77.8	1,008,312	83.4
Summer Chinook	1941	1942	111,900	11.7	98,754	13.4 1/	85,489	23.6
Blueback	1941	1942	19,500	10.0	17,540	29.0 2/	12,459	36.1
Summer Chinook	1942	1943	560,180	31.7	382,705	34.5	250,736	55.2
Blueback	1942	1943	2,132,786	28.0	1,534,805	39.4	930,111	56.4
Summer Chinook	1943	1944	204,508	32.3	138,470	15.8	116,188	43.2
Blueback	1943	1944	3,476,192	16.3	2,910,421	9.6	2,630,899	24.3
Summer Chinook	1944	1945	50,075	7.0	46,593	6.7	43,464	13.2
Blueback	1944	1945	590,820	5.3	559,282	13.6	483,305	18.2
Summer Chinook	1945	1946	266,662	10.7	238,185	13.3	206,446	22.6
Blueback	1945	1946	945,799	10.5	846,876	14.8	721,525	23.7

1/ Trough rearing only.
2/ Mostly trough reared.

Most of the usual ingredients of fish diets have been nutritionally evaluated, both individually and in combination, under conditions present at the Grand Coulee hatcheries. The methods employed in preparing and presenting diets were found to affect not only the nutritional properties of diets, but the degree of wastage from unconsumed food as well. The nutritional investigations, therefor, have included studies of diet preparation as well as diet composition.

As a result of the various nutritional investigations, a standard feeding program has been adopted for the hatcheries. As soon as any of the advanced fry evidence interest in food, a small quantity of salmon meal is maintained on the water surface of the trough so that food will be available to the fish at all times. When most of the fry in a trough will take food, the diet is changed to a mixture of 50-50 beef and hog liver for three weeks, followed by the routine diet of 20 per cent each of beef liver, hog liver, and hog spleen; 30 per cent salmon viscera; and 10 per cent commercial fish meal. This has been adopted as the standard fingerling diet and is fed until the fish are liberated. The meat and fish fractions for not more than a two-day supply are ground separately and only a single day's requirements are mixed. After thorough mixing of the ingredients, approximately two pounds of salt are added to each 100 pounds of food, and the mixture is mechanically beaten until the salt has reacted with the hog liver and spleen to produce a maximum "bind" that will resist disintegration during the feeding. All diets, except the meal, are fed by means of a modified potato ricer. Small hand ricers are used for trough feeding and a larger device, handling 10 pounds of food, has been developed for feeding fish in the rearing ponds.

Another approach towards a reduction in food costs has been the development of quantitative rationing on the basis of body weight. Feeding charts have been developed for both blueback and chinook fingerlings--based upon the factors of water temperature and size of the fish--that will assure feeding of adequate amounts of food without wastage by over-feeding. A further advantage of the feeding chart is that any refusal by the fish to consume their allotted food-which is often an early indication of trouble-is immediately detected.

Hatchery Technique Investigations

The methods employed in various fish-cultural operations often cause significant losses at hatcheries. This is particularly true during the early life of the fish when they are very easily injured by rough treatment. Mortalities, extending well into the fingerling stage, often reflect upon the methods employed during spawning and the subsequent handling of the eggs and fry.

The third phase of the Leavenworth Laboratory research program has been an attempt to evaluate all fish-cultural methods and to develop more efficient methods where the existing ones were found undesirable.

Significant differences in mortality were found to be associated with different methods employed in transporting green eggs from the spawning grounds to the hatchery. In some instances, the mortality inflicted during transportation has been exceptionally severe, involving more than one-half of the eggs collected. Apparently, the sensitivity of salmon eggs to mechanical shock increases progressively from the time the eggs are taken until well through the "green" stage, and there is no "safe" period, commonly believed to exist for approximately twenty-four hours following fertilization. The most satisfactory method found to date for transporting green eggs from field collecting stations to the hatchery, where the period of time involved is less than three hours, is the use of sealed containers. One-to-five-gallon wide-mouth glass "buckets" have been used. Because of the danger of breakage and the subsequent loss of large numbers of eggs, however, an inert metal container would be preferable but--to date--unobtainable. These containers are filled to not more than two-thirds of their capacity with soft eggs, filled to capacity with water, and sealed with a gasketed screw cap. The sealed container eliminates all surface agitation which appears to be responsible for much of the mechanical shock transmitted to eggs during transportation.

The so-called "white spot" disease of fish eggs and fry, which is a localized coagulation of the yolk material, appears to result from mechanical shock rather than, as commonly assumed, from invasion by pathogenic organisms. The transportation of green eggs in sealed containers has eliminated virtually all "white spot" disease at the Grand Coulee hatcheries. Eggs exhibiting the characteristic lesions of "white spot" do not die invariably before or at the time of shocking. An undue mortality, persisting well into the feeding-fingerling stage does however occur in groups of fish showing a high incidence of "white spot" disease as eggs.

The design and installation of movable spawning traps in the Leavenworth holding ponds has eliminated all necessity for the undesirable handling of adult fish in seines or dip nets during the spawning operations. The mortality of sexually immature fish resulting from handling also has been materially reduced by use of spawning traps and the amount of labor required in the spawning operations cut in half.

A material loss of eggs was found to result from the killing of partially ripe female fish. The earlier practice of killing all female fish that will yield eggs upon pressure has been altered to include holding apparently mature females for an additional day in a separate compartment in the spawning traps. The loss of eggs caused by the killing of sexually immature female fish has been virtually eliminated by adopting this procedure.

The careful exclusion of water, blood, and slime from the spawning pails has resulted in a significant reduction in egg mortality. Likewise, the practice of bleeding female salmon prior to spawning, and the use of a modified Oregon-type beaded-point spawning knife to prevent the cutting of eggs, has reduced the number of unfertilized eggs obtained in the spawning operations.

THE GEOGRAPHIC DISTRIBUTION OF RETURNING PROGENY OF RELOCATED STOCK

The 1942 runs over Rock Island Dam contained the first returning mature progeny of transplanted stock--namely, chinook and blueback in their third year. In 1943, transplants dominated the runs and, by 1944, when the hauling was discontinued, the runs were essentially all progeny of relocated stock.

Observations were made during these three years, and have been continued up to the present time, in an effort to appraise the distribution of the migrations into the various tributaries together with the numbers of adult fish appearing immediately below Grand Coulee Dam.

In 1942 and 1943, small lots of transplanted three-year chinook and blueback, recognizable by their small size, were released above Rock Island Dam. Traps were installed in fishways located in three of the four tributaries to check upon the homing of progeny from the relocated stocks. Results in 1942 were inconclusive because of high water in the Okanogan and the lack of a trapping site in the Methow. During 1943, however, recoveries of approximately one-third of the fish released at Rock Island indicated that 75 per cent of the 3-year chinook released from Rock Island Dam entered the Wenatchee River, 10 per cent entered the Entiat, and 15 per cent migrated to the Methow. Of the 3-year blueback released at Rock Island, 30 per cent of recoveries were made in the Wenatchee River and 70 per cent in the Okanogan. No salmon were observed below Grand Coulee Dam during either year.

In 1944, when the Rock Island fish ladders were opened to the free passage of fish, the estimated distribution--based upon adult fish and redds observed in the tributaries--was essentially the same as in 1943. Similar counts during 1945 indicated an increase in the chinook population of the Methow River to approximately 45 per cent of the total number observed with 40 per cent in the Wenatchee and 15 per cent in the Entiat. High water in the Okanogan River during 1945 and 1946 again precluded estimates of the blueback populations for those years. Observations were too limited during 1946 and 1947 to permit any estimate of the spawning distribution of chinook salmon, other than to note that they were widely distributed in all streams excepting the Okanogan River which has little spawning area suitable for this species. The blueback escapement into Lake Wenatchee in 1946 and into both Lake Osoyoos and Lake Wenatchee during 1947 was undoubtedly the largest in many years but a complete count could not be obtained.

Few salmon have been observed at any time immediately below Grand Coulee Dam where large eddies, located at either side of the spillway, provide collection pools in which any fish present may be readily observed. In 1944, six chinook were seen, in 1945 the estimate was 50 chinook and 12 blueback, and in 1946 the maximum count included 22 chinook and 4 blueback. 8/ During 1947, no salmon were observed or reported immediately below Grand Coulee Dam.

Since 1944, the spring runs of steelheads and chinooks have successfully reached the spawning grounds of the upper tributaries. Fortunately, their period of migration during the spring and early summer coincides with water conditions favorable for passing obstructions. Nason Creek has been well seeded by spring chinook for the past four years and fair numbers of spring-run fish also have been found in other branches of the Wenatchee River, the upper Entiat, and in the Methow River drainage.

The summer chinooks and the bluebacks, however, have experienced great difficulty in successfully passing the low-water barriers. As a result, the concentration of spawners in the lower reaches of the rivers increases during low-water years. This undesirable condition was particularly evident in the Wenatchee River during 1944 and 1945. In 1946 and 1947, higher water during the summer months permitted the fish to migrate without hindrance. It is evident, however, that many of the late-run chinook prefer spawning areas in the lower reaches of the rivers.

The tendency of the summer chinook to spawn in the lower reaches of the major tributaries, together with some evidence of spawning activity below Grand Coulee Dam in 1945, indicated the need for a complete survey of possible spawning activity in the main stem of the Columbia between Rock Island and Grand Coulee dams. An aerial survey of this section was made on October 15, 1946, and although the number of chinook salmon observed in relation to the number of completed redds indicated that spawning was not at its peak, 102 nesting areas (many containing more than one redd) were observed between the Chelan River and Grand Coulee Dam. On October 23, the lower part of this section was resurveyed and 32 additional nesting areas were observed below the mouth of the Entiat River--a section that did not contain redds at the time of the survey one week earlier.

8/ Visibility below Grand Coulee Dam improves in August and September when the flow of the river is less than 100,000 c.f.s. The eddies then have a fairly smooth surface and the tendency of the salmon to school in quiet water permits a reasonably accurate count.

It is reasonable to assume that many of the spawning chinooks observed in the main river above Rock Island Dam were progeny of transplanted stock. It is quite possible, however, that there may be a substantial exchange between this population and those normally spawning below Rock Island Dam. Aerial surveys extending below Rock Island Dam to the mouth of the Snake River, a distance of 135 miles, revealed spawning chinooks on a majority of the shallow rubble bars which are numerous through this entire section of the Columbia River. A total of 785 nesting areas were observed in this lower reach of the river.

In general, the spring runs of chinook and steelhead have shown a strong tendency to return to the upper stream areas where they were reared or released as fingerlings. The blueback will return to the lakes but have been handicapped by the low water barriers of late summer. Many of the relocated, late-run chinook have shown a tendency to revert to spawning grounds in the lower courses of the streams; areas which, presumably, are best suited to their racial requirements. All available evidence indicates that the relocation of the upper-Columbia salmon and steelhead runs to areas below the Grand Coulee Dam was successful to a degree exceeding expectations.

A QUANTITATIVE APPRAISAL OF THE EARLY RETURNS FROM FISH RUNS RELOCATED IN THE GRAND COULEE FISH-MAINTENANCE PROJECT

Wide annual variations in the fish runs to the Columbia River are apparent quite irrespective of any index of abundance that is used. This fact, coupled with the short period over which data are available, militates against any accurate appraisal of the effect of relocation upon the fish runs of the upper Columbia.

The relocation of fish runs occasioned by the construction of Grand Coulee Dam was an experimental operation on a vast scale. At the very outset, there was ample reason for doubting if the process of relocation, involving as it did the trapping, hauling, and impounding of adult salmon in large numbers, could be accomplished without at least a temporary decline in the production levels. As the program progressed, these doubts were increased by the substantial mortality of adult salmon, both in the hatchery holding ponds and in the more extensive natural holding areas. Recent data, however, indicate that the returns from the relocated runs generally have exceeded early expectations.

The returns from the initial phase of relocation, which extended from 1939 to 1943 inclusive, were essentially complete with the runs of 1943 through 1947. Data relating to the years 1939-1947 are included in Table 23 which shows the fish counts at Bonneville Dam, the estimated catch above Bonneville, and the estimated spawning escapements above the commercial fishing zone for each year for which the information is available. These data have been summarized so as to indicate the estimated relationship between the three principal runs of migratory fishes into the Grand Coulee area and the comparable runs of the entire Columbia River above Bonneville Dam. Data relating to the steelhead run are not included since the time when the Rock Island contingent of that species passes Bonneville Dam has not been adequately established. This contingent is of minor importance, averaging less than 3 per cent of the spawning escapement above Bonneville.

The evaluation of the early returns from the Grand Coulee Fish-Maintenance Project is based upon the contribution of the relocated runs to the comparable escapment for the Columbia River as a whole above Bonneville Dam. The unit of measurement, a percentage, was derived from the following equation:

$$R_p = \frac{Rc}{Bc - c/w} \times 100$$

Wherein:

R_p = The percentage of Rock Island fish in a given escapement

Rc = Rock Island Dam count

Bc = Comparable count over Bonneville Dam

c = Poundage of fish reported from the commercial fishing zone extending 55 miles above Bonneville Dam

w = Average weight of the fish (used to convert weight to numbers)

R_p appears as the final entry for each run shown in Table 23.

The advantage of this unit of measurement lies in the elimination of the variable factor of fishing intensity which reduces actual numbers, such as the Bonneville and Rock Island counts, to measures of escapements rather than measures of production. Three sources of error are inherent in this unit of measurement, namely; the unreported catch above Bonneville (Indian subsistence and sports catches); the natural mortality of fish between Bonneville and Rock Island Dams; and the lack of positive identification of overlapping chinook runs due to the arbitrary selection of dividing dates. None of these factors is believed to be sufficiently large or variable to affect the validity of the analysis.

Table 23. --- Data concerning the three major runs to the Grand Coulee area,--blueback, spring chinook, and summer chinook. Included are counts of fish passing Bonneville Dam, numbers taken commercially above Bonneville, escapements and Rock Island counts.

Blueback	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947
(1) Bonneville	75,040	73,382	148,805	65,741	55,463	39,844	15,071	9,501	74,354	171,238
(2) Catch above 1/	36,444	33,372	72,664	47,376	20,504	9,914	7,897	1,433	13,035	52,072
(2)/(1)x100	48.6	45.5	48.8	70.3	37.0	24.9	52.3	15.1	17.6	30.4
(3) Escapement	38,596	40,010	76,141	18,365	34,959	29,930	7,174	8,068	61,319	119,166
(4) Rock Island	17,123	19,591	26,894	949	16,282	17,665	4,932	7,142	45,029	79,833
(4)/(3)x100	44.4	49.0	35.3	5.2	46.6	59.0	68.7	88.5	73.4	67.0
Spring Chinook										
(5) Bonneville 2/	22,371	76,708	66,378	72,310	40,471	65,500	30,865	43,515	67,520	133,562
(6) Catch above 3/	5,300	20,700	10,650	30,010	17,050	10,890	13,500	12,600	9,420	15,350
(7) Escapement	17,071	56,008	55,728	42,300	23,421	54,610	17,365	39,915	58,100	118,212
(8) Rock Island 4/	1,592	4,256	4,328	1,610	1,359	7,374	1,498	2,376	4,144	8,181
(8)/(7)x100	9.3	7.6	7.8	3.8	5.8	13.5	8.6	7.7	7.1	6.9
Summer Chinook										
(9) Bonneville 5/	14,777	23,477	21,966	16,408	24,637	13,484	12,604	27,620	51,011	38,860
(10) Catch above 6/	1,490	1,420	2,930	8,010	1,980	760	2,770	880	2,780	2,980
(10)/(9)x100	10.1	5.9	13.4	49.0	8.0	5.6	22.0	3.2	5.4	7.7
(11) Escapement	13,287	22,057	19.036	8,398	22,657	12,724	9,834	26,740	48,231	35,880
(12) Rock Island 7/	4,211	6,950	5,164	961	5,455	3,771	1,877	3,320	5,848	3,585
(12)/(11)x100	31.8	31.5	27.1	11.5	24.1	29.6	19.1	12.4	12.1	10.0

1/ Converted to numbers of fish by average weight of 2.7 lbs. per fish - all years.
2/ Count through Bonneville Dam fishways, January through May.
3/ Catch above Bonneville, January through May.
4/ Count at Rock Island Dam through July 9.
5/ Count through Bonneville Dam fishways, June and July.
6/ Catch above Bonneville, June and July.
7/ Count at Rock Island after July 9.

To analyze the estimated production levels of the runs affected by the construction of Grand Coulee Dam, the data were broken into two periods: the initial period between 1938 and 1942 when the runs were the progeny of fish unaffected by the relocation program; and the period 1943 to 1947 which reflects the production levels of the relocated runs.

The data for 1941 were not included in the comparative analysis. During 1941, abnormally low natural flows--particularly during the period of the blueback and summer chinook runs--were further aggravated by the impoundment of some 5,500,000 acre-feet of water in the Grand Coulee Reservoir. There is valid evidence that the record low river flow formed a block to the migrating salmon at Celilo Falls. As a result, the fishery above Bonneville captured 70.3 percent of the blueback run counted over Bonneville Dam in comparison with a mean annual catch of 39.0 percent during the decade 1938-1947. As further evidence of an atypical situation during 1941, many adult blueback salmon entered and died in minor tributaries between Bonneville Dam and Celilo Falls: an unprecedented condition. Abnormally high water temperatures associated with the reduced water flows undoubtedly increased the normal river mortality attributable to disease. The summer chinook runs no doubt were similarly affected although the widespread distribution of this run above Bonneville obscures the quantitative picture. The spring chinook runs presumably were affected in minor degree.

An analysis of variance of the blueback data from Table 23 using the segregation of data previously described gives the following results:

Mean percentage contribution to escapement prior to relocation (1938-1942) - 43.8; following relocation (1943-1947) - 71.3:

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	8	2,264.22	
Before and After	1	1,679.94	1,679.94
Within Periods	7	584.28	83.47

F = 20.13 P = Less than .01

These data warrant the definite conclusion that the relocation process did not adversely affect the production level of bluebacks that prevailed during the three-year period immediately preceding relocation. In fact, there is valid evidence for the belief that the Columbia River blueback runs have been materially increased through the various measures employed in the relocation procedure. The blue-back salmon, with very few exceptions, spawn in the areas above Rock Island Dam. Because of this fact, practically the entire blueback run of the Columbia has been involved in the Service's Grand Coulee Fish-

Maintenance Project. The total blueback run to the Columbia each year can be estimated by adding the Bonneville Dam counts for this species and the commercial catch below Bonneville. These data in Table 24 show: the decline in the total run that occurred between 1940 and 1943 (prior to the time when the relocation could have been a factor); the continued and sharp decline during the years 1944 and 1945 as a consequence of the extremely low spawning escapement of 1941 (when only 949 adult fish entered the Grand Coulee area); and the spectacular recovery in both the commercial fishery and the spawning escapement during 1946 and 1947 (all progeny of relocated parents).

Similar treatment of the spring chinook data by analysis of variance yields the following results:

Mean percentage contribution to escapement prior to relocation (1938-1942) - 7.6; following relocation (1943-1947) - 8.7:

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	8	39.20	
Before and After	1	2.84	2.84
Within Periods	7	36.36	5.19

F = 1.82 P = Greater than .05

It may be tentatively concluded, in the light of the above data, that there has been no significant change in the productivity levels of the spring chinook runs as a consequence of the relocation process. Further quantitative evidence is available from the Yakima River, where annual counts of the spring chinook migration at Roza Dam have been secured since 1940. These are as follows:

1940 -	1,011	1944 -	242
1941 -	239	1945 -	447
1942 -	521	1946 -	989
1943 -	689	1947 -	2,645

Although these counts represent a very small part of the escapement of spring chinook (line 7, table 11) the coefficient of correlation between that part and the whole is high (r = .93, $P < .01$). The coefficient of correlation of Rock Island spring chinook counts with the escapement, for a like period, is not significantly different from Roza (r = .85, $P < .01$). By inference, therefore, the runs to a great majority of the remaining spawning areas must also show a high degree of correlation with the total escapement. It follows that any significant change in production levels following the transplantation of the runs would be reflected in their proportional representation in the escapements.

Table 24. --- Estimated Total run of Adult Blueback Salmon to the Columbia River (all data in thousands).

Year	Bonneville Count	Catch below Bonneville	Estimated Total run
1938	75	92	167
1939	73	47	120
1940	149	37	186
1941	66	106	172
1942	55	38	93
1943	40	34	74
1944	15	8	23
1945	10	1	11
1946	74	28	102
1947	171	167	338

Similar treatment of the summer chinook data by analysis of variance gives the following results:

Mean percentage contribution to escapement prior to relocation (1938-1942) - 28.6; following relocation (1943-1947) - 16.6:

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	8	617.04	
Before and After	1	319.19	319.19
Within Periods	7	297.85	42.55

F = 7.50 P = Greater than .01 but less than .05

These data may indicate some decrease in the productive level of the Grand Coulee summer chinook runs, but the fact that this race spawns below Rock Island Dam as well as above leaves room for doubt that a decline actually occurred, If, as noted in the preceding section of this report, a portion of the progeny of transplanted summer chinook spawned below Rock Island Dam, a false indication of reduced production levels would result.

It is not implied that these data accurately reflect trends in abundance of the salmon runs affected by the Grand Coulee Dam nor should these tentative conclusions be used in predicting future developments. Suffice it to say that conclusions, based upon the meager evidence available to date, strongly indicate that the upper river blueback runs have benefitted by the relocation process and there is little reason to believe that either the spring or summer chinook runs have materially suffered thereby.

BARRIERS TO THE MIGRATIONS OF SALMON

IN THE GRAND COULEE AREA

Certain obstacles remain in the pathway to full realization of the potentialities of the Grand Coulee Fish-Maintenance Project. The four major rivers utilized in the Project formerly supported large runs of salmon, most of which had been exterminated prior to 1939 when the Project was undertaken. Many of the installations responsible for the greatly reduced runs to these tributaries--primarily irrigation diversions, hydroelectric power installations, and barrier dams serving various purposes--still exist although their effect upon the salmon has been reduced by corrective measures. Most of the important diversions in the area were screened, more or less effectively, and some of the barriers were removed during the 1930's. Several diversion dams remain, however, as hazards to both upstream and downstream migrations.

There are two diversion dams in the Wenatchee River that are particularly harmful to the salmon runs, namely the Dryden Dam and the Tumwater Dam. Their effect is threefold: they cause pre-spawning losses through injuries sustained at these structures, low water in the bypassed river section forces blueback salmon to spawn in the main-stem areas that are not suited to that species, and the low-water barrier also promotes an undesirable accumulation of chinook spawners which results in over-population of the limited spawning riffles available below the barrier.

The first of these low-water barriers, the Dryden power and irrigation diversion, is located eight miles below the Leavenworth Hatchery and 15 miles above the mouth of the Wenatchee River. This installation diverts virtually the entire low-water flow of the river from a one-mile section of the river bed between the dam and the tail-race of the power plant. In 1944, 50 second-feet of stored water were released from the Snow Lakes reservoir of the Leavenworth Hatchery for the purpose of augmenting the water flow through the river channel belowthe Dryden Dam. This flow was in addition to approximately 15 second-feet that are passed through the fishways. The combined flow was meager, however, in relation to the wide stream bed below the dam and improvised channeling of the riffles was necessary to provide a suitable depth of water. The 63 cfs. flow through the river channel obviously offered little attraction for the fish in competition with 300 to 800 cfs. at the tailrace of the power plant. Many of the fish refused to continue up the stream in spite of a rack constructed across the power house tailrace. These emergency measures proved far from satisfactory as it was found, later in the season, that the riffle areas below the Dryden power house supported the greatest concentration of spawning fish observed anywhere in the Wenatchee River system.

The second barrier, the Tumwater Dam and power diversion, is located 15 miles above Dryden. This structure diverts water from a 2-mile section of river between the dam and the power plant. The minimum flow through the bypassed river section during 1944 was about 35 cfs. and was subject to fluctuations during periods of varying power demand. The intermittent diversion of water through the power plant served to prevent an accumulation of fish in the power house tailrace but the minimum flow was not sufficient to permit passage of adult fish over the shallower riffles.

Several remedial measures for obtaining increased flows, improved channels, and other conditions more favorable for the fish runs at both Dryden and Tumwater are now under consideration and it is hoped that permanent effective remedies can be developed. Otherwise the existence of the Wenatchee River salmon runs, particularly the blueback runs, will be in jeopardy during every low-water year.

None of the other river systems contain major barriers comparable in effect to Dryden and Tumwater of the Wenatchee. Each of them, however, does have small dams--certain of them seasonal structures--that require frequent inspection and minor alterations to assure free passage for the fish at all times. Several of the larger structures are equipped with fishways but additional fishways, together with extensive redesign of the existing facilities, are needed before the rivers will be satisfactory avenues for migrating fish. The responsibility for protecting the fish during their upstream and downstream migrations in the streams of the Grand Coulee area is vested in the Washington State Department of Fisheries.

CONCLUSIONS

One principal objective of the Grand Coulee Fish-Maintenance Project--namely the relocation of the upper-river salmon and steelhead runs from the main stem to the tributaries entering the Columbia below and the Grand Coulee dam site--has been successful and the general level of production during the initial phase of the program has been satisfactory.

The outlook for rehabilitating the salmon populations of the Grand Coulee Area through adequate protection, natural spawning, and effective artificial propagation appears possible but difficult. Many of the factors responsible for the original depletion of the Okanogan, Methow, Entiat, and Wenatchee salmon runs still remain in effect. In addition, the up-river salmon runs must eventually face a series of major multiple purpose water-use projects--one of which is now under construction. Whether the early-running Columbia River salmon races--which are dependent upon a suitable fresh-water environment for a significant fraction of their life-span--successfully can surmount the increasing development of the Columbia River and its tributaries is questionable.

EXPLANATION OF PLATES

1. --- The Rock Island Dam of the Puget Sound Power and Light Company. The fish ladders at this structure offered a feasible site for trapping the upper Columbia River salmon runs during their spawning migration. Traps were installed in each of the three fish ladders which are located at either end of the dam and at the downstream tip of Rock Island near the center river.

2. --- The Nason Creek Rack -- a typical installation designed to prevent the adult fish from returning to the Columbia River during the relocation phase of the Grand Coulee Fish-Maintenance Project.

3. --- The left trap at Rock Island Dam. The upper end of the fish ladder parallels the left margin of the plate. Fish ascending the lower end of the fish ladder were diverted into the adjacent trap through either of two tunnels -- the entrance to which is located immediately under the man in the center foreground. The trap was emptied by raising a sloping grilled false floor, thus forcing the fish through another tunnel into the elevator at the bottom of the tower. The elevator was raised and the fish released through a trapdoor into the curved chute leading to the tank of the truck on the loading ramp.

4. --- Unloading a tank truck. At the destination, a short chute was attached to the rear of the truck and a trapdoor in the tank opened. The resulting rush of water swept the fish from the tank.

5. --- One of the eight tank trucks used for distributing adult and fingerling fish on the Grand Coulee Fish-Maintenance Project. Water in the 1,000-gallon tank was continuously circulated at the rate of 125 gallons per minute by a gasoline-powered auxiliary pump. Cooling could be effected, when desired, by diverting the circulating water through an ice compartment placed between the cab and the tank.

6. --- The Leavenworth Hatchery and rearing ponds -- the central point for artificial propagation on the Grand Coulee Fish-Maintenance Project.

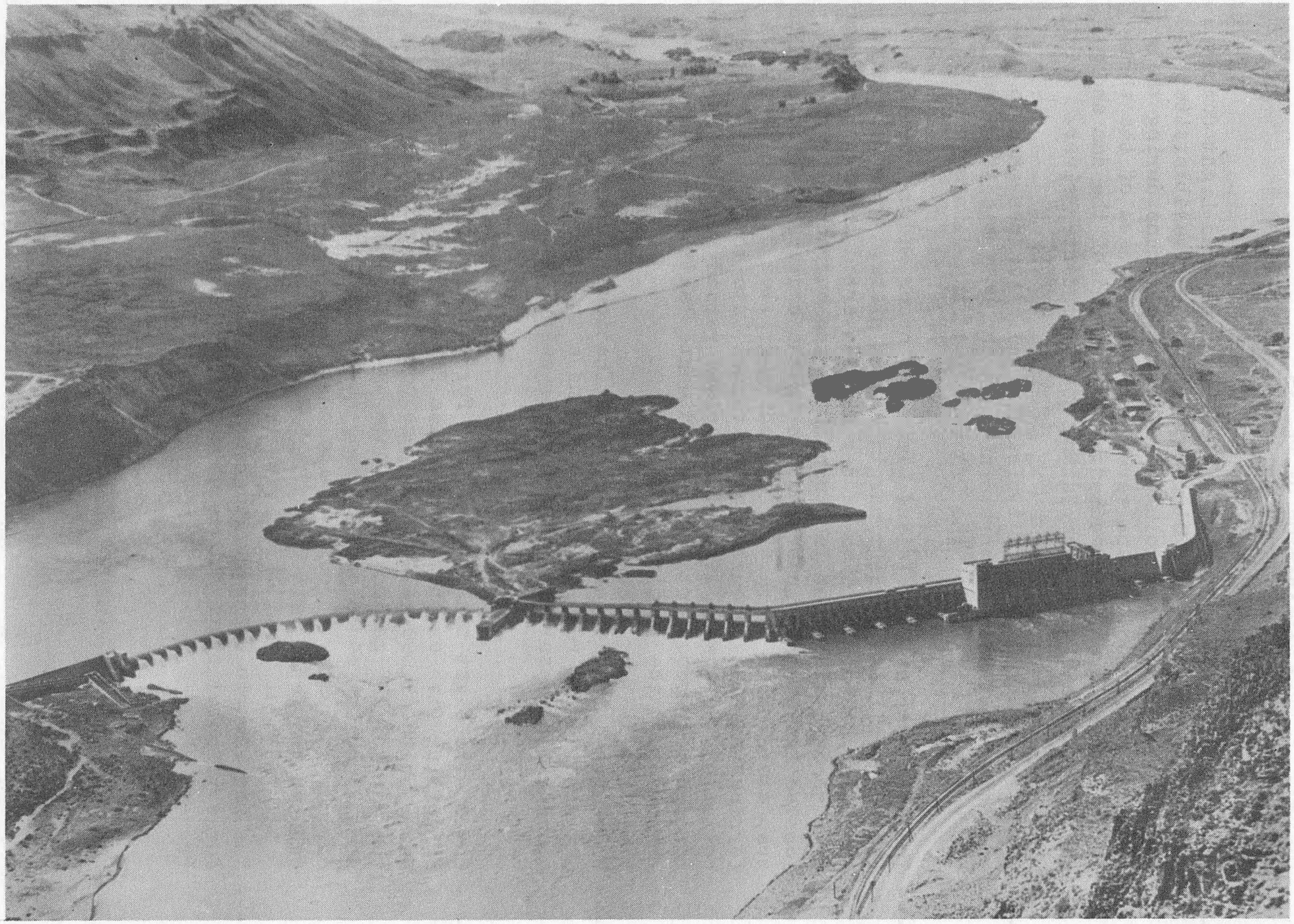


Plate 1

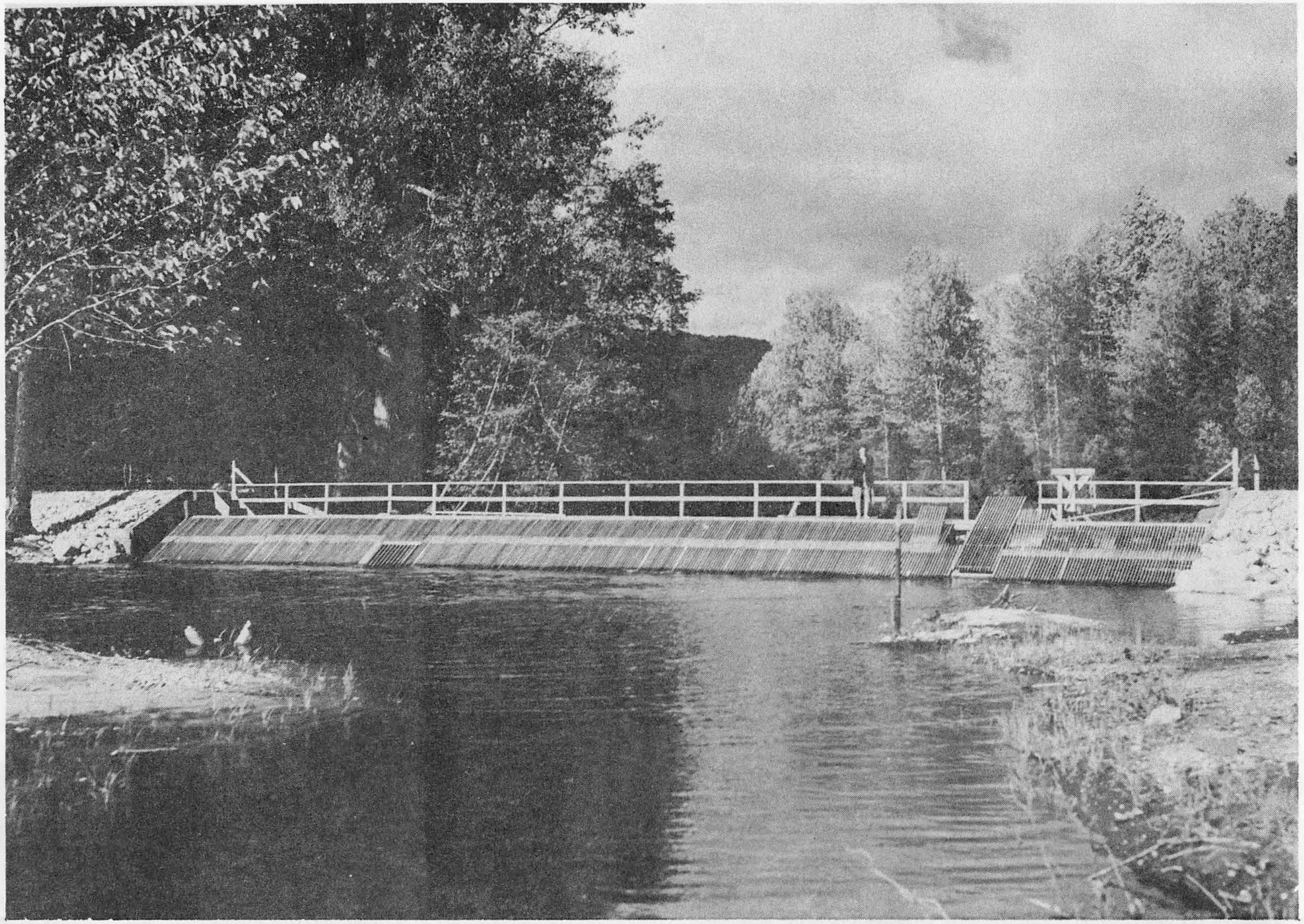


Plate 2

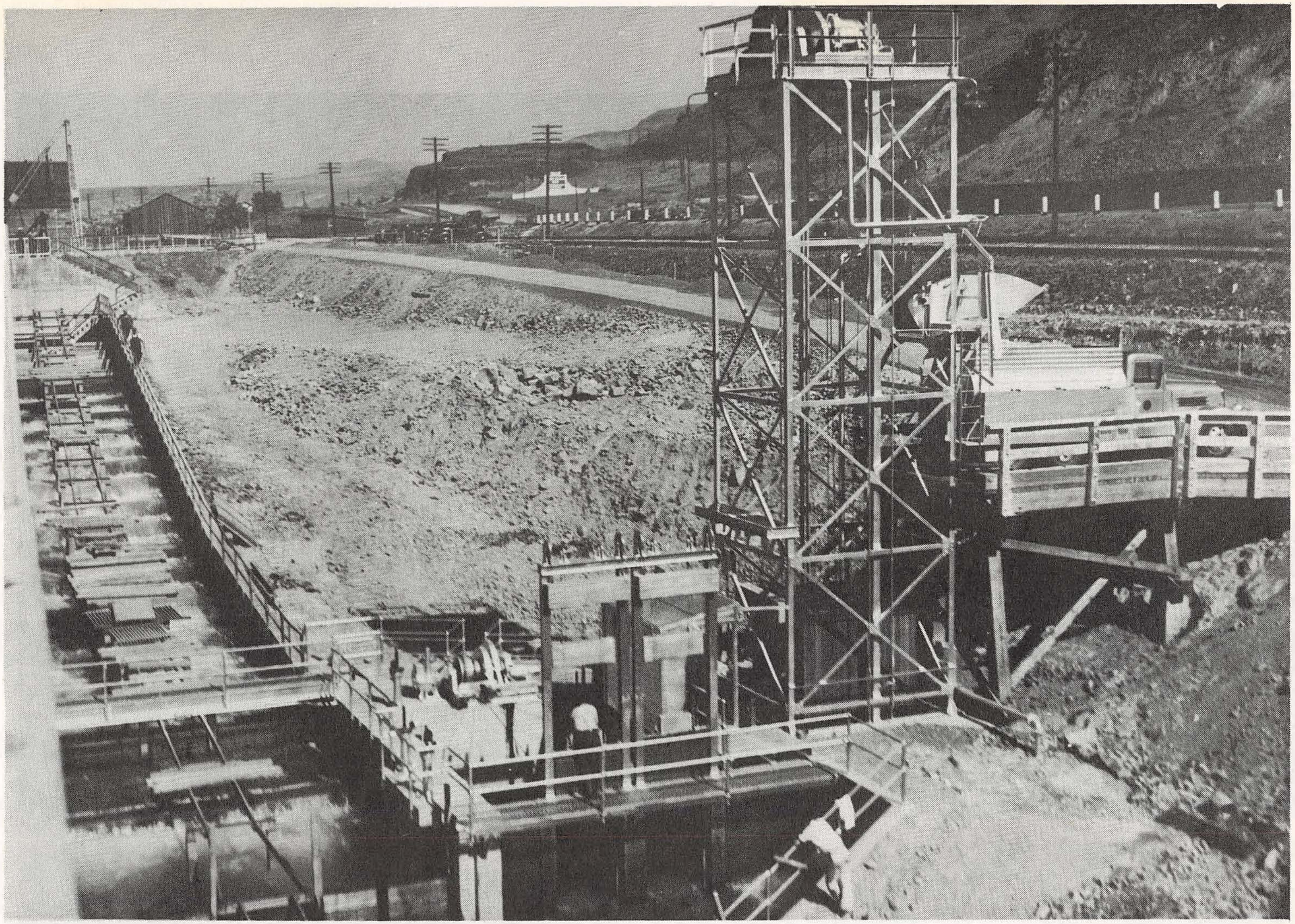


Plate 3

Plate 4

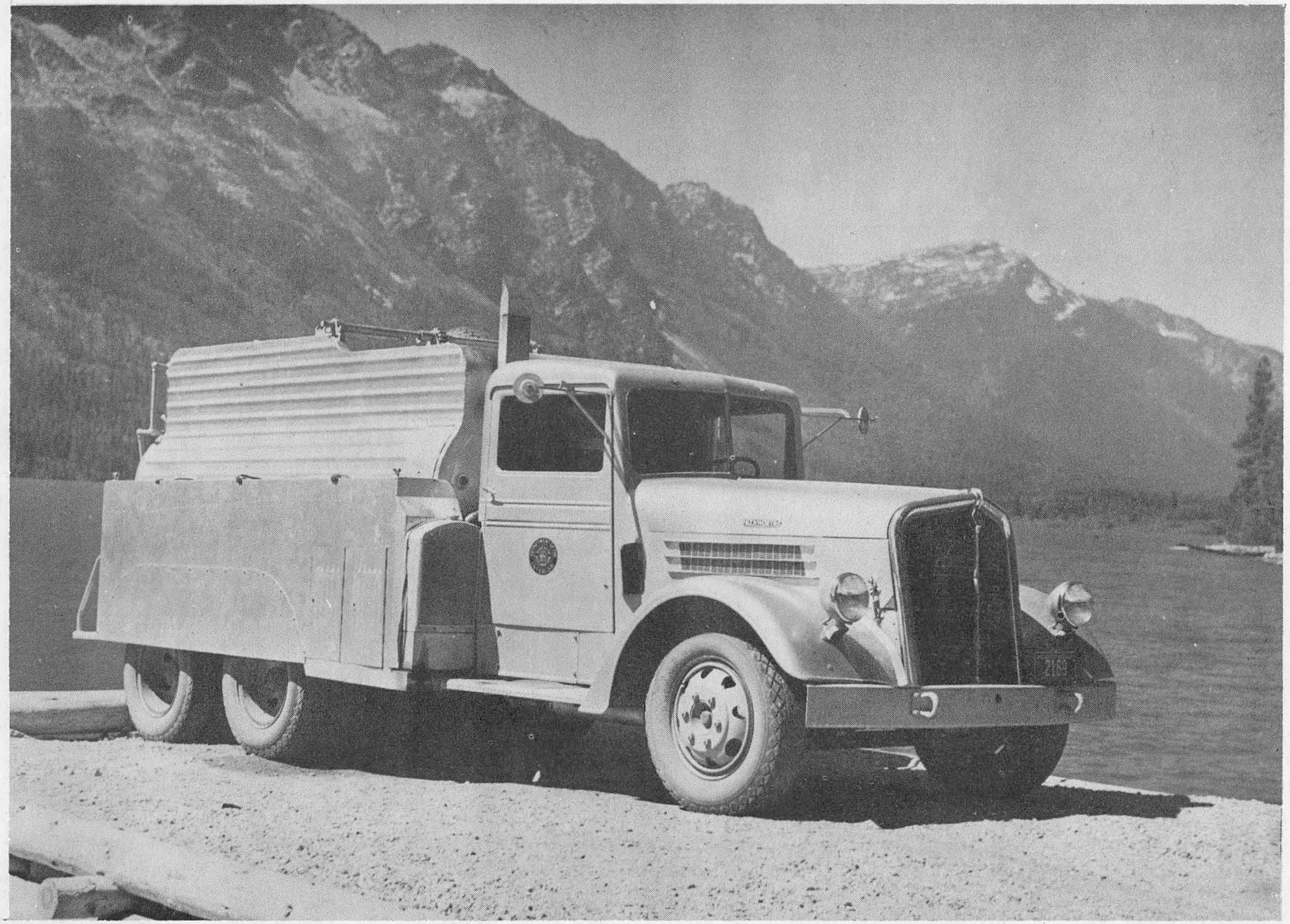


Plate 5

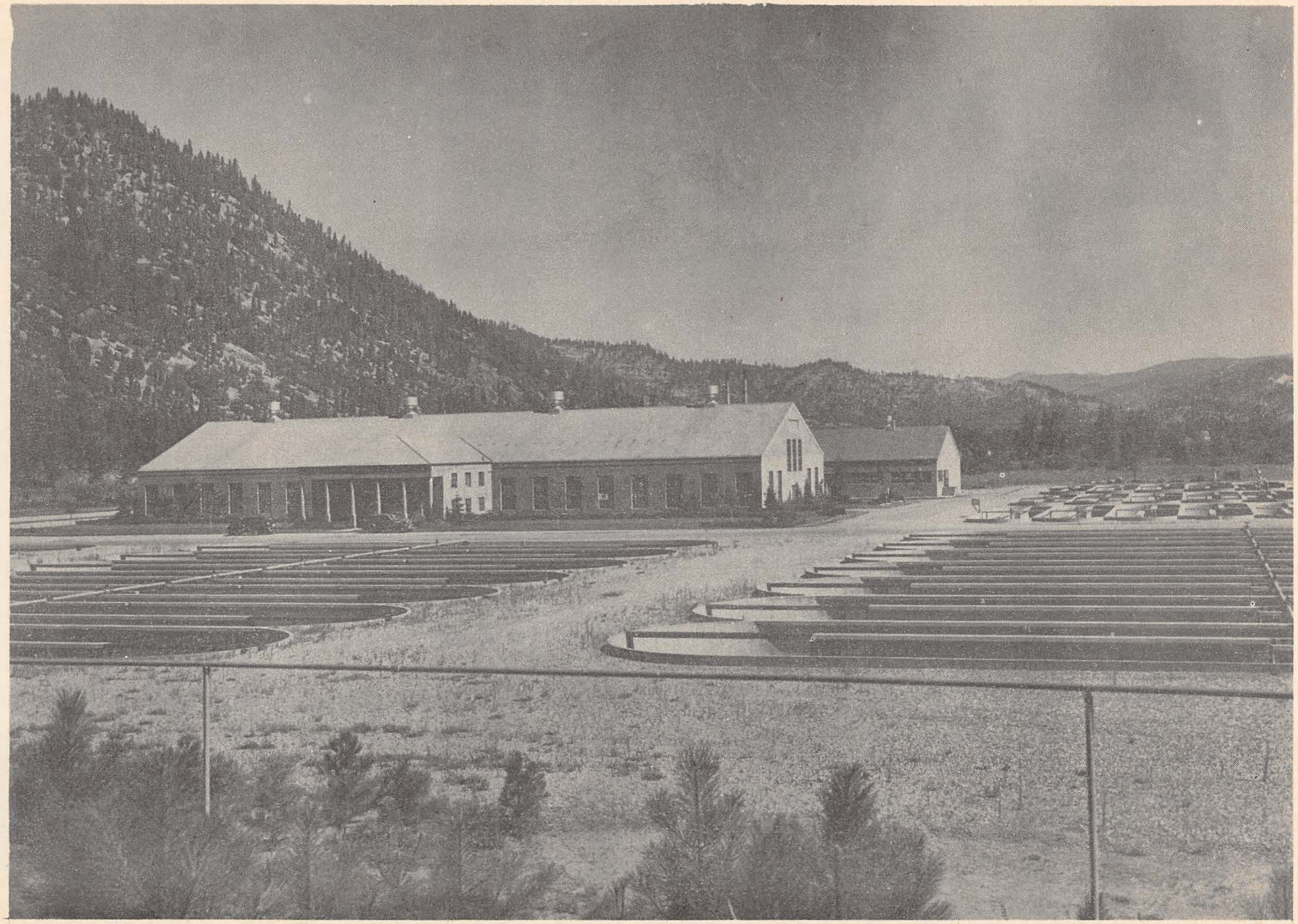


Plate 6