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

FISH AND WILDLIFE SERVICE
Albert M. Day, Director

Special Scientific Report No. 33

AN INVESTIGATION OF FISH-MAINTENANCE PROBLEMS IN RELATION TO THE WILLAMETTE VALLEY PROJECT

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Chicago
1946

P R E F A C E

This report is based upon studies conducted during 1940, 1941, and 1942. A preliminary draft of the report was prepared at that time but, due to conditions related to the war effort and changes in the status of both authors, preparation of the final draft of the report was delayed.

The studies were made to determine the probable effects of the Willamette Valley Project as described in the War Department's report of 1938 (House Document No. 544, 75th Congress) upon the fishery resources and to determine what facilities and procedures would be required to maintain the fish populations. Changes made in the plan of the project since the preparation of the 1938 report and other changes that are contemplated have important influences upon the fish problems. As a result, much of the application of the biological findings to the individual parts of the project no longer holds true. The basic biological aspects of the investigation, however, still are pertinent and can be applied to the project as modified. The report, therefore, is published without change to preserve and make available for use the basic results of the study.

Changes in the plan of the project, insofar as known at this time, are presented in an accompanying addendum, which has been prepared jointly by the staffs of the Portland District, U. S. Engineer Department, and the Fish and Wildlife Service.

Albert M. Day, Director,
Fish and Wildlife Service

July 1946

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I N T R O D U C T I O N

The Willamette River, one of the principal tributaries of the Columbia River, drains about 11,000 square miles of northwestern Oregon between the Cascade and Coast ranges. The greater part of the main stream flows through the fertile farming lands of the Willamette Valley, finally discharging into the Columbia River at a point about ten miles west of Portland, Oregon. Most of the tributaries rising in the Coast Range are small. The principal tributaries, the Clackamas, Molalla, Santiam, Calapooya, McKenzie, and Middle Fork of the Willamette Rivers have their origins in the Cascades.

Much damage has been done in the Willamette Valley when heavy precipitation has caused the Willamette River to overflow its banks. This has been one of the factors that has led the U. S. Engineers to undertake the Willamette Valley Project. The project is described in detail in the report "Willamette River and Tributaries" by the U. S. War Department (1938). In addition to flood control it is planned to provide other benefits such as improvement of navigation, storage and diversion of water for irrigating farming lands in the valley, improvement of the polluted condition of the lower portion of the Willamette River, and finally, the development of hydro-electric power.

Initial Development

It is planned to carry out this program in two steps, or degrees of completeness. The first step is called the "initial plan" and is the one contemplated for the immediate future. The investigation that forms the basis for this report has been concerned only with making recommendations for this first or "initial" phase of the project. The ultimate development, known as the "coordinated plan", and its probable effects are mentioned only briefly in this report.

The initial plan is to be accomplished by seven storage dams on various tributaries of the river. (see Table 1 and Figure 1*). Three of these dams are on tributaries rising in the Coast Range and Calapooya Mountains. They are Fern Ridge Dam on the Long Tom River, Cottage Grove Dam on the Coast Fork of the Willamette River and Dorena Dam on the Row River. After investigation, the U. S. Fish and Wildlife Service, the Oregon Fish Commission, and the Oregon Game Commission agreed that no runs of migratory fish went past the sites of these dams and that, therefore, no migratory fish problem existed in connection with their construction. For that reason these dams will not be considered in this report.

The remaining four dams are all to be built on streams supporting populations of migratory fish. These dams and their heights for the initial development are as follows:** (1) Detroit Dam on the North Santiam River about six miles downstream from the town of Detroit.

TABLE 1. Locations and Heights of Dams

Reservoir	Stream	Height of Dam in Feet* (Initial Development)
Detroit	North Santiam River	259
Sweet Home	South Santiam River	147
Quartz Creek	McKenzie River	212
Lookout Point	Middle Fork of Willamette River	233
Fern Ridge	Long Tom River	35
Cottage Grove	Coast Fork of Willamette River	69
Dorena	Row River	102

*Height to which water level normally will be raised above normal stream level.

*Figures 1 and 8, reproduced with the permission of the Corps of Engineers, Portland District, are only preliminary and are subject to modification by final designs.

**Editorial note: See addendum for modifications of initial plan since preparation of this report.

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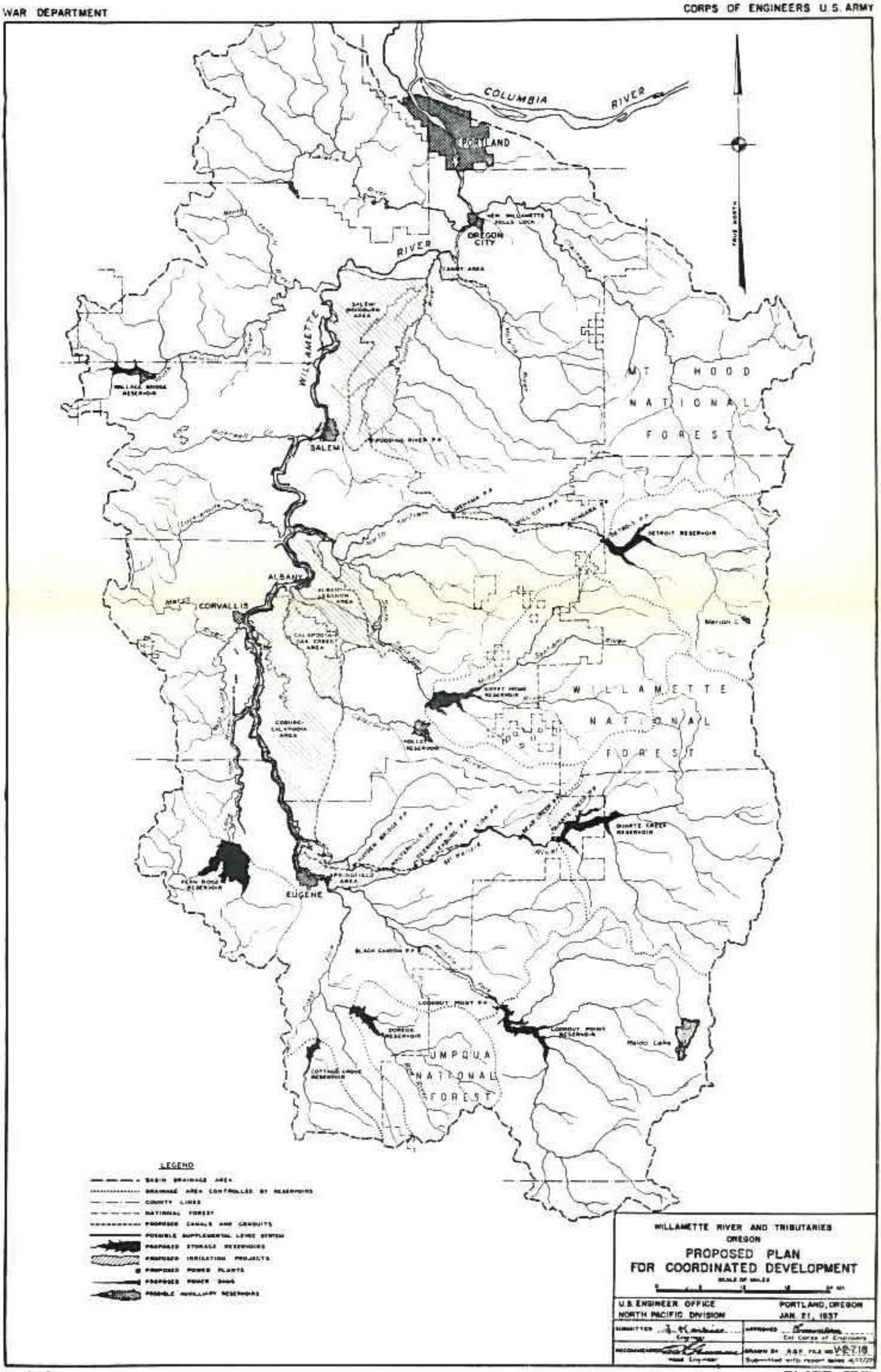

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PLATE XV

Figure 1. Willamette Valley. Showing plan for coordinated development of water resources.

This dam will raise the water level 259 feet and flood 7.6 miles of the North Santiam River, 1.6 miles of the Breitenbush River and part of Blowout Creek. (2) Sweet Home Dam, located on the South Santiam River just below the town of Sweet Home. This will raise the water level 147 feet and flood 6.8 miles of the South Santiam River and 2.8 miles of the Middle Santiam River. (3) Quartz Creek Dam on the McKenzie River will be 212 feet high. It will be built at Cook Rapids below the mouth of Quartz Creek and will flood 9.0 miles of the McKenzie River, 2.2 miles of the South Fork of the McKenzie River, 3.0 miles of Blue River and 3.5 miles of Quartz Creek. (4) Lookout Point Dam, on the Middle Fork of the Willamette River, will be located about 9 miles below the town of Oakridge and will raise the water level 233 feet and flood 6.1 miles of the North Fork of the Willamette River, 0.6 miles of Salmon Creek and 8.7 miles of the Middle Fork of the Willamette River.

The program of operation for each of the seven reservoirs is essentially the same. During the months of December and January the reservoirs will be maintained at minimum pool levels except in times of flood. The storage of flood waters will be only of such duration as to smooth out peak discharges, thereby insuring storage space for possible future floods. About the first of February, as the probability of severe floods becomes less, the reservoirs will be filled gradually from the late winter rains and spring freshets, so that by the end of April the reservoirs normally will be full. After the reservoirs are filled the normal stream flow will pass without regulation for a period of one to three months. Starting normally in June or July, the stored water will be withdrawn as required for navigation, irrigation, and power. Any stored water that remains toward the end of the season will be withdrawn by the first of December to provide full storage capacity for flood control.

Each of the four streams under consideration, the North Santiam, South Santiam, McKenzie and Middle Fork of the Willamette Rivers, supports runs of chinook salmon, and the North Santiam and South Santiam Rivers have runs of steelhead trout as well. Both of these species are anadromous. Their eggs are deposited in the gravel of freshwater streams from which the young emerge after hatching. The young fish then remain in the streams for varying lengths of time, sometimes as long as a year or more. They then go downstream to the sea. Most of their growth is accomplished in the salt water and when sexually mature, usually after 1 to 4 years in the ocean, the adult fish ascend the freshwater streams for the purpose of spawning. They spend from 2 or 3 weeks to as many months in the streams until they are completely ripe or mature, after which they deposit and fertilize their eggs in the gravel, thus completing the life cycle of the species.

It is definitely known that chinook salmon return to the same tributary from which they migrated as young fish on their way to the ocean. The information relating to the homing of steelheads is not as definite as that concerning the salmon, but from what evidence is available, it appears that they too return to their parent stream to spawn.

All four of these dams are to be built at such points that they would intercept large parts of the runs of adult spawners ascending the streams to their natural spawning areas. Therefore, if the fish are to spawn naturally after the construction of the dams, fishways must be provided so that the adult upstream migrants can pass the dams and go on to the spawning areas beyond. Arrangements must also be made for the young downstream migrants to pass the dams without hindrance or injury.

From the foregoing description of the dams and their method of operation, it is evident that they are high and that the level of the water impounded behind each of them will be subject to large fluctuations. These conditions make it very difficult to construct an ordinary type of fish ladder up which the adults could swim. Such structures would also be very expensive. Some means of trapping the fish and taking them into the pools by a form of mechanical life could be devised, but such arrangements are costly and there might be danger of injury to the fish.

To provide safe passage of the young fish downstream is still more difficult. The discharges from the reservoirs will be through deeply submerged orifices near the level of the stream beds except during the periods when the reservoirs are full and water is allowed to spill over the crests. It is doubtful that the young fish on their way to the ocean would readily find these deep openings, and it is probable that they would be injured in passing through them if they did. Any system of screening the upstream approaches to the dams and diverting the downstream migrants into passes going over or around the dams appears to be impractical and to involve prohibitive costs.

Also to be considered is the fact that for many years the Oregon Fish Commission has trapped a large proportion of the upstream migrants in each of these streams at locations not far from the proposed dam sites. These fish are held between racks until ripe; the eggs are then taken and placed in hatcheries located nearby where they are hatched and finally liberated into the tributaries from which the eggs were obtained. The Oregon Fish Commission operates these hatcheries as part of its program for the conservation and management of the fisheries of the State. Therefore, any plan for fish protection at these dams must take into consideration the facts that the hatchery facilities of the Oregon Fish Commission must be preserved or adequately replaced and that the spawning areas above the proposed dams have been largely unused for many years because of the operation of these hatcheries.

Consideration of these facts leads to the conclusion that it would be extremely expensive to pass the runs of fish over the dams, that such a procedure would be likely to fail, and that the hatcheries of the Oregon Fish Commission should be preserved if possible. Also, the Federal Government should not spend large sums of money on fish protective devices the success of which would be doubtful, in order to make available spawning areas which are now largely unused. However, it should be recognized that these spawning grounds are of large potential value and that their loss would be keenly felt if, because of some future emergency, additional spawning grounds tributary to the lower Columbia River were badly needed.

Finally, if the Federal Government makes these spawning areas permanently unavailable to the migratory fish, it should be the responsibility of that Government to carry on the artificial propagation of the runs if the State of Oregon is for any reason unable to do so on an adequate scale.

The "Coordinated Plan"

The foregoing discussion has dealt solely with the "initial plan" and this report as a whole relates to conditions as they will exist under this plan. However, for the sake of presenting a more complete picture it seems desirable to state briefly the additional features that will be imposed if and when the "coordinated plan" is effected. This plan provides for the expansion of certain features of the initial development, and particularly for the construction of additional works for the development of power.

The plan of power development is described in detail in the 1938 report of the War Department.* On the Middle Fork of the Willamette River the Lookout Point Dam will be increased in height from 233 to 293 feet, to provide head for a power plant to be installed there, and a secondary storage dam and a 14-mile conduit will deliver water to a second power development. On the McKenzie River the height of the Quartz Creek Dam will be increased from 222 to 298 feet for its power plant, and four additional power installations will be made along the stream. On the North Santiam River, in addition to adding power at the Detroit Dam, with the height of the dam increased from 259 to 366 feet, there will be three secondary storage dams and diversions to power plants farther downstream.

For a great part of the time, when the controlled flow does not exceed that required for power, the flow allowed to remain in the river bed opposite the power diversions will be the natural inflow below the main reservoirs plus the following amounts released from the reservoirs: Middle Fork of the Willamette River, 150 second-feet; McKenzie River, 400 second feet; and North Santiam River, 145 second-feet,

The expansion of the initial development to include facilities for the production of power as proposed in the "coordinated plan" would impose, when undertaken, serious hazards to the runs of migratory fishes in addition to the hazards of the initial development. Although the channels of the streams between the diversion intakes and the power plants will never become entirely dry, the planned low water flows in these sections represent but a small fraction of the present flows. These sections of stream are the ones where practically all natural spawning of chinook salmon takes place that now occurs in these tributaries. The best natural holding areas for fish to be used in fish cultural operations are also to be found in these sections. The flows proposed for the stream sections paralleling the diversions are entirely inadequate to maintain safely the populations of

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*Editorial note: See addendum for modifications of "Coordinated Plan" since preparation of this report.

fish that are found in these stream sections at the present time. The suggestion of paragraph 171 of the War Department (1938), that the "pools formed by the relatively low irrigation dams are considered to be used as holding ponds for the upstream migratory fish" appears to be a questionable proposal. Such pools would provide a poor substitute for natural stream sections as holding areas. These power developments would take out of use for fish holding and rearing about 22 miles of the North Santiam River, about 30 miles of the McKenzie River, and 15 miles of the Middle Fork of the Willamette River.

On the basis of present knowledge as to the requirements of chinook salmon for maturing, spawning, hatching and rearing it must be concluded that the completion of the coordinated development of the Willamette Valley Project would establish such hazardous conditions that the runs would probably be exterminated, except for those fish entering tributaries below the dams. Future developments in the practices of fish culture may make available methods of holding adults and hatching and rearing young chinook salmon that will reduce the importance of these hazards; but such methods are not known at this time.

It is to be noted that the approved initial project includes features estimated to cost $3,143,000 that are provided to facilitate future development of power and from which no benefits will be derived in the initial project. It should be assumed, therefore, that the coordinated plan of development eventually will be effected. The present fisheries investigations should be carried on to determine what additional provisions should be made for preserving the fishery resources of the Willamette River, if and when it becomes desirable to complete the "coordinated plan". Evidence to be presented in later sections shows that the Willamette River salmon runs are valuable enough to warrant large financial outlays for their preservation.

Scope and Objectives of Investigations

Preliminary, unpublished, reports by Mr. H. B. Holmes of the U. S. Fish and Wildlife Service while employed by the U. S. Engineers and the senior author were made with the above facts in mind and both expressed the opinion that the most feasible and satisfactory method of protecting the migratory fish at these four dams would be to make arrangements so that all of the fish could be trapped below the dams, held until ripe, the eggs taken and the young fish raised and liberated. This present investigation was made with these general recommendations in mind, but with the understanding that, if the data indicated that such a course would be unsatisfactory, the best possible and practical means for protecting the fish runs would be recommended.

In addition to the migratory fish, these streams also contain populations of resident rainbow and cutthroat trout. These species support important sport fisheries. This is particularly true of the McKenzie and Middle Fork of the Willamette Rivers. This investigation, therefore, also has been concerned with the welfare of these resident fishes. The problem of their protection was studied and recommendations relative to this portion of the problem are made.

The principal objectives of the present study can be stated in general as follows: (1) To determine whether or not the runs of fish in these tributaries are of sufficient importance and magnitude to warrant extensive works and expenditures for their protection; (2) To determine the suitability of the water released from the reservoirs for holding adult fish until they mature and for the rearing and fresh-water residence of the young fish before they go down to the ocean; (3) To determine the effect of the regulated flows on the passage of the fish, particularly upstream migrants, over dams, rapids, falls and other obstructions; (4) To determine the extent to which fish can still spawn naturally below the dams and the probable success of such spawning particularly with the thought in mind of estimating the required capacity for the hatcheries if all natural spawning were eliminated above the dams; (5) To determine proper sites and water supplies for hatcheries as well as favorable locations for racks with which to hold the mature spawners; (6) To determine the life history of the chinook salmon in the Willamette River, particularly in regard to fresh-water residence, so that the hatchery and planting schedules and the existence of the young fish in the streams below the dams in relation to the operating schedules of the reservoirs could be worked out.

It is a function of the U. S. Fish and Wildlife Service to study the effect on fish and wild life of any dam authorized by the Federal Government and to assist in planning and to approve fish-protective measures undertaken at all such projects. Also, it is the function of the U. S. Engineers to provide such facilities for fish protection as are approved and recommended for projects carried out by them. In order to properly fulfill their duties in regard to the Willamette Valley Project, these two governmental agencies undertook the cooperative investigation that is the subject of this report. It was authorized in 1940 and effectively ended, except for the preparation of this report, in December 1942. The U. S. Engineers provided the funds, laboratory space and personnel for the field work, and the Fish and Wildlife Service supervised the investigative work and provided funds for expenses incident to that supervision. The senior author supervised the investigation and the preparation of the report; the junior author was in immediate charge of the field work and the analysis of the data.

During the course of the investigation, the University of Oregon supplied laboratory and other facilities. The Oregon Fish Commission, the Oregon Game Commission, and the Washington Fisheries Department supplied data and assisted informally. Also, the investigation is indebted for data and help to Oregon State College, Idaho Fish and Game Department, McKenzie River Guides Association, Civilian Conservation Corps, U. S. Forest Service, U. S. Bureau of Reclamation, City of Tacoma, Portland Water Bureau, Mountain States Power Company, Puget Sound Power and Light Company, and Eugene Water Board.

BIOLOGY OF SALMON AND STEELHEAD TROUT

It is important to a clear understanding of the problems involved in attempting to preserve the fishery resources of the Willamette River that the general features of the biology of the several species be in mind. This is especially true of the chinook salmon and the steelhead trout because of the fact that these species are anadromous - the young must migrate to the ocean and the adults must return to the spawning streams when mature.

At the present time only "spring run" chinook salmon reach tributaries of the Willamette River above Oregon City, although other "runs" of chinook salmon have formerly occurred in lower tributaries of the Willamette River. "Spring run" chinooks make up the most valuable component of the salmon runs to the Columbia River. The adult chinook salmon belonging to the Willamette River races of spring chinooks enter the Columbia River in the late winter and early spring. The fact that anglers fishing in the vicinity of Portland make their first catches in the last week of February or the first week of March indicates that a significant part of the run has entered the lower part of the Columbia during February.

The fish escaping the sport fishery below the Oregon City falls make their way over the falls by means of a fishway which consists of man-made pools arranged in series up a natural channel near the middle of the original falls. The falls has been altered from the primitive condition by the erection, along a large part of the original crest, of a wall which provides for a relatively constant head at the intakes of power plants located on each side of the river at the falls. Under existing conditions, the fishway is absolutely necessary to provide for passage of fish over the falls.

Observations have been made of the runs of fish through this fishway by agents of the Oregon Fish Commission who have been employed for the purpose of guarding and maintaining the fishway. These observations indicate that the entire run of chinooks has passed the fishway by May 31 of each year. Although the counts are incomplete, the chief part of the run appears to pass Oregon City during the month of May, and it is largely completed by the 20th of the month. After passing the falls the fish continue up the river and enter the tributaries, migrating nearly to the locations where they will later spawn. On the four principal branches of the Willamette River which are to be dammed, full migration of fish in the tributaries is prevented during most years by racks, established in the rivers by the Oregon Fish Commission, for fish cultural operations. Judging by the time of appearance of the fish at these rack sites, it appears that the chief movement of salmon in the tributaries is completed by about the 10th of July, and that from this time until actual spawning takes place the fish remain in the deeper parts of the stream, relatively inactive, while the sex products become mature enough for spawning. Just preceding the time for spawning minor migrations take place within the tributaries. The migrations are in the nature of movements of sexually mature fish away from the

resting populations in the pools. These movements are characteristically small in that the fish have been resting in pools close to the riffles where spawning eventually takes place.

Spawning of chinook salmon in the tributaries of the Willamette River occurs from about August 20th to October 10th with the peak of spawning occurring during September. The adult chinooks thus spend the period from late February to early July in an upstream fresh water migration. From July until October there is a period of residence in the stream before spawning is completed. These fish, therefore, are subjected to some six to eight months' contact with the conditions of fresh water as they exist in the Willamette River. This period of stream residence coincides with the time during which a large part of the water stored behind the proposed dams would be released. The important bearing which the quality of this water will have upon the success of this stream residence is considered in detail in a later section of this report.

Records of the growth and distribution in fresh water and seaward migration of chinook-salmon fingerlings were obtained by fishing for fingerlings by seine, fyke net, and hook and line in the several tributaries and in the main Willamette River. The numbers and sizes of fingerlings and the dates and places of capture are presented in Table 2. The relation between the length of the fingerlings and the date of capture is shown in Figure 2. In this figure the smooth line drawn by eye to approximately fit the points of average length gives a fair representation of the growth of the fingerlings from a mean length of approximately 35 mm. in March of their first year to 100 mm. in May of their second year. The lines of maximum and minimum length are drawn to roughly fit the range of twice the standard deviation on each side of the average. These limits theoretically should include 95 percent of the fish.

The fingerlings caught in the tributaries furnish no direct evidence of time of seaward migration. They do show, however, that at least a part of the fingerlings remain in these rearing areas up to September or October of their first year and that they have left those areas, presumably by migrating, before March of their second year.

In an effort to obtain direct evidence of the time of seaward migration, a fyke net was fished regularly in the main Willamette River at Corvallis. This location is such that it would intercept fingerlings migrating from the McKenzie River and middle Fork of the Willamette River but not the Santiam River. The net used was made of ½-inch stretched-mesh netting hung on pipe frames. The opening of the net was four feet square. The net was fished without wings, at the water surface, and approximately 20 feet from shore. As it is a well-known fact that salmon fingerlings migrate mainly at night, fishing was limited to that time, usually from 6:00 p.m. to 8:00 a.m. The fyke net was fished at Corvallis as follows: in 1941 on July 8, 9, 10, 15, 16, and 17; in 1942, on seven nights between May 9 and June 1, and three nights per week from October 15 to November 27; and in 1943, on January 12, 14, and 15, and February 3rd. Salmon fingerlings were caught only during May 1942 - 2 were taken on the 9th,

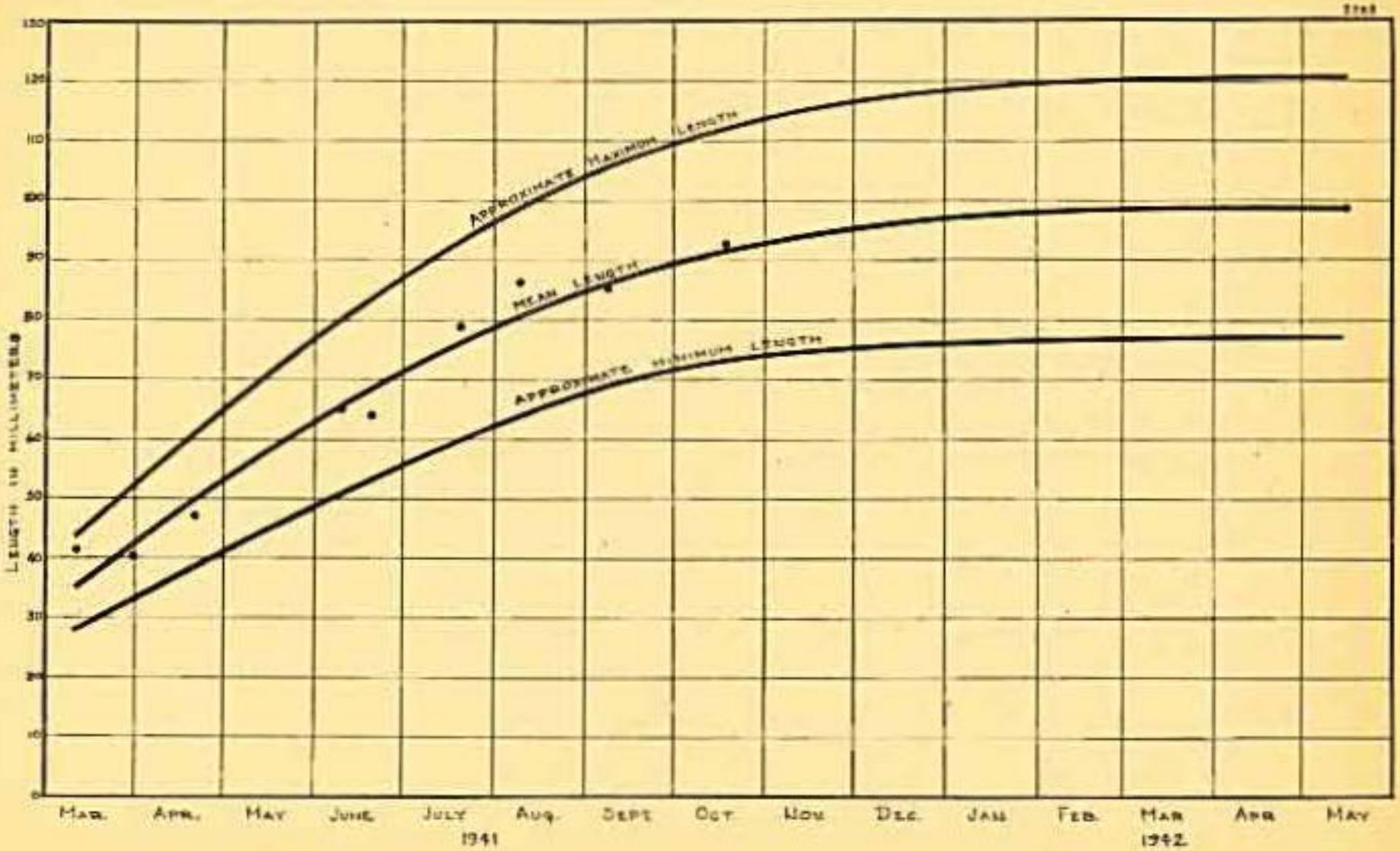

Figure 2. Lengths of chinook salmon fingerlings caught in Willamette River and tributaries in 1941 and 1942.

TABLE 2. Length frequencies of chinook salmon fingerlings of the 1940 year class caught by all methods in the Willamette River and tributaries, by dates and tributaries. Dates are 1941 except the last column which is 1942.

Length, mm.	MOLALLA RIVER				NORTH SANTIAM RIVER				SOUTH SANTIAM RIVER						
	3-27	4-23	6-10	9-3	3-13	4-24	6-12	8-4	4-22	6-11	7-21	8-4	9-24	10-20	11-7
31- 35	1	..	..	..	1	1	..	..	..	..	..	..	..	..	..
36- 40	63	..	..	..	3	11	..	..	2	..	..	..	..	..	..
41- 45	19	..	..	..	8	8	..	..	8	..	..	..	..	..	..
46- 50	8	8	..	..	13	1	1	..	9	15	..	..	..	..	..
51- 55	6	4	1	..	2	2	..	..	..	9	..	..	..	..	..
56- 60	..	5	4	..	..	..	4	..	1	2	..	..	..	..	..
61- 65	..	2	6	1	..	..	15	..	..	5	..	..	..	..	..
66- 70	..	1	8	1	..	..	10	..	..	13	2	..	..	..	..
71- 75	..	2	3	2	..	..	9	1	..	7	8	1	..	..	..
76- 80	..	..	1	14	..	..	6	2	..	3	9	3	..	..	..
81- 85	..	..	..	2	..	..	4	3	..	2	21	14	..	2	..
86- 90	..	..	..	5	..	..	..	1	..	1	13	8	3	4	..
91- 95	..	..	..	6	..	..	..	..	..	..	5	7	1	9	..
96-100	..	..	..	2	..	..	1	..	..	..	1	2	1	8	3
101-105	..	..	..	1	..	..	..	..	..	..	..	..	1	1	..
106-110	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..
111-115	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..

TABLE 2. (Continued)

Length, mm.	McKENZIE RIVER			MIDDLE FORK OF WILLAMETTE RIVER							MAIN WILLAMETTE RIVER	
	3-7	4-24	7-25*	3-10	3-14	4-21	6-16	7-22	9-5	9-6	6-18	5-12**
31- 35	1	..	..	2	6	..	..	..	..	..	..	..
36- 40	18	6	..	9	45	..	1	..	..	..	..	..
41- 45	9	3	..	7	30	4	2	..	..	..	..	..
46- 50	..	..	..	5	15	9	..	..	..	..	..	..
51- 55	..	..	..	3	4	11	6	..	..	..	..	..
56- 60	..	..	..	1	..	..	5	2	..	..	..	..
61- 65	..	..	..	..	..	..	11	4	..	..	..	..
66- 70	..	..	..	..	..	..	10	11	..	..	..	..
71- 75	..	..	..	..	..	..	7	7	..	3	..	..
76- 80	..	..	..	..	..	..	2	7	1	5	1	..
81- 85	..	..	1	..	..	..	..	3	1	3	..	..
86- 90	..	..	1	..	..	..	..	2	2	4	..	3
91- 95	..	..	1	..	..	..	..	1	6	2	.1	6
96-100	..	..	1	..	..	..	..	..	..	2	..	5
101-105	..	..	3	..	..	..	..	..	1	1	..	7
106-110	..	..	1	..	..	..	..	..	..	..	..	1
111-115	..	..	1	..	..	..	..	..	..	..	..	2

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* Selected samples. Caught by hook and line.

**Fish trapped by receding floods.

2 on the 12th, 4 on the 19th, and 1 on the 22nd. These fingerlings ranged in length from 49 to 64 mm. Upon the basis of their size and scale characteristics they all were judged to be in their first year.

The examination of some collections of fish made in pools left by flood waters, together with information on time and height of floods, has yielded data of a type that, so far as known, have not been previously used for determining the time of downstream migration. A number of ponds left by flood waters were seined for salmon fingerlings, and additional collections of salmon fingerlings trapped in such pools have been made available from those taken by personnel of the Oregon State College Department of Fish and Game Management. The principal pools that have yielded salmon fingerlings are located west of Peoria in Sec. 7, T13S, R4W, W.M. and near an old ox-bow slough of the Willamette River known as Horseshoe Lake in Sec. 22, T11S, R4W, W.M. At each location two or more pools containing flood-trapped fish were investigated. There are many hundreds of such pools in the Willamette Valley which doubtless take a large toll when floods occur during the time of downstream migration.

At the ponds near Horseshoe Lake, fish from both the 1940 and 1941 spawning were caught on May 12, 1942. The fish from the 1940 spawning, consisting of 24 yearlings, are shown in the last column of Table 2. Only one fish from a school of several dozen smaller fingerlings was caught, but it was definitely from the 1941 spawning as it had a length of 42 mm. Salmon fingerlings were caught in the pools near Peoria on April 20 and 22, 1942. The ponds were drying rapidly during the warm spring weather and a considerable number of small salmon fingerlings were already dying in one of these ponds. Thirty-five live fingerlings were also collected from this pond. The length frequency of 45 salmon fingerlings taken from one of these pools is shown in Table 3. Still another pond yielded 48 small fingerlings. It will be obvious by reference to the length distribution in Figure 2 that the smaller fish are in their first year, and accordingly are from the spawning of 1941.

TABLE 3. Lengths of 45 chinook salmon fingerlings caught in flood ponds near Peoria, April 20, 1942.

Length, mm.	Number of fish
41-45	3
46-50	22
51-55	16
56-60	4

The question arises as to the time that the fish might have entered these pools. An answer is provided by the data on heights of the Willamette River as recorded during the winter of 1941-1942, the controlling elevations in the channels leading to these ponds, and the depths at these control points at times when the river gauge heights were known. From such data it is known that the ponds near Horseshoe Lake and those near Peoria are

both connected with the river when the Albany River gauge reads 7 feet or over. The Albany River gauge records for 1941-1942 reveal that the earliest that each series of ponds was flooded in the winter of 1941-1942 was November 16, 1941. The last date that the ponds were connected with the river was February 14, 1942.

The data from fyke netting at Corvallis and observations in flood pools indicate that significant numbers of fingerlings had moved many miles downstream from the spawning areas soon after emerging from the gravel, that such fingerlings in their first year were in the main Willamette River in May, and that yearlings were in the main Willamette River at some time during the period of November to the middle of February. The presence of these two classes of fingerlings in the main Willamette River suggests, but does not necessarily prove, that there may be a seaward migration of small fingerlings within a few months after emerging from the gravel, and of larger fingerlings during the winter between their first and second years of life.

The foregoing data give evidence for a fall and winter downstream migration, but do not prove that all fish do migrate during this period. Additional evidence of the time of seaward migration of chinook salmon fingerlings can often be obtained by microscopic examination of the scales taken from returning adult fish. It is a generally established fact that the nature and spacing of circuli, or ridges upon the surface, of salmon scales provides a means of determining the age of the fish and the changes in rate of growth during the life of the salmon. There is an abrupt increase in the rate of growth at the time of migration to the ocean, which is reflected in characteristic markings on the scale such that the experienced investigator can determine from the scale the age at which the fish left fresh water. During the spawning season of 1941 scales were collected from 52 adult chinook salmon in the South Santiam River, 40 in the McKenzie River and 48 in the Middle Fork of the Willamette River. These scales were submitted for examination to Dr. Willis H. Rich, consultant in Salmon Fishery Investigations for the U. S. Fish and Wildlife Service. Dr. Rich examined them in collaboration with Mr. H. B. Holmes of the Fish and Wildlife Service, and the scales showed that the fingerlings from which these fish developed had remained in fresh water throughout their entire first growing season. They had migrated to the ocean not earlier than the fall of their first year. In this respect the scales from these Willamette River fish were similar to those of many other series of chinook salmon scales which Rich and Holmes had examined, both from the Willamette River and other tributaries of the Columbia River.

While this analysis of adult scales indicates that the fish examined had spent their first growing season in fresh water, it does not preclude the possibility that fingerlings also migrate at earlier ages. It does indicate, however, that fish migrating at an earlier age do not reappear as elements in the returning mature runs recognizable on the basis of their scales. From the later discussion of the conditions of pollution in the lower part of the Willamette River it seriously may be questioned that any summer downstream migrants are able to survive the trip to the ocean.

From a practical point of view, the essentially successful oceanward migration of chinook salmon of the Willamette River occurs during the fall and winter. This conclusion makes it mandatory that fish facilities provide adequately for carrying fingerlings through their first growing season in fresh water.

MAGNITUDE AND IMPORTANCE OF MIGRATORY FISH RUNS IN THE WILLAMETTE RIVER

In considering plans for the protection of the migratory fish in connection with the Willamette Valley project, the importance of these populations of fish must be studied so that the justification for the expenditure of funds for investigation and fish protection may be examined. These runs of fish contribute to the public welfare in several different ways. There is now no commercial fishery conducted in the Willamette River but there is an important sport fishery for chinook salmon in the Willamette Slough and in the river below Oregon City. However, as will be shown below, the chinook salmon belonging to the Willamette River runs undoubtedly form an important element in the commercial fishery conducted by trolling in the ocean and, in some years at least, in the commercial fishery of the Columbia River proper below the Willamette confluence. The steelheads are taken in the commercial fishery in the lower Columbia River and by anglers in those tributaries of the Willamette which they frequent.

Importance of the Willamette River Run in the Commercial Fisheries

The chinook salmon are by far the most important species in the Willamette River in regard to both the commercial and sport fisheries. Because of their pronounced habit of returning to spawn to the tributary from which they migrated to the sea as fingerlings, each tributary of a large river system into which chinook salmon enter has a distinct self-perpetuating population. These populations may develop physical characteristics and habits peculiar to themselves. One such habit, which is usually constant from one generation to the next, is the time at which the maturing adults enter the streams on their spawning migrations. The chinooks entering the Willamette River arrive in the lower portion of the Columbia River in the late winter and early spring. Evidence of this will be shown in the section of this report discussing the sport fishery of the Willamette.

It is not possible to arrive at an accurate estimate of the extent to which the Willamette River runs contribute to either the ocean troll fishery or the fishery of the lower Columbia River. However, it does not seem unreasonable to assume that they provide their proportional part of the ocean troll catch along with the other populations of chinook salmon. The troll fishery is carried on along the entire Pacific Coast from northern California into Alaska and evidently takes a significant part of the total amount of chinooks in the ocean. It therefore appears that a significant part of the Willamette chinook salmon are taken in the ocean before maturity.

For many years, with very few exceptions, there has been a closed season for commercial fishing on the Columbia River during March and April. It is shown in Table 4, that a large part of the sport catch of Chinook salmon in the Willamette River is made during these months so that it is a reasonable assumption that the fish pass through the lower Columbia River at approximately the same time or, on the average, somewhat earlier. However, there is some fishing in the Columbia River during February and in some years considerable catches are made. It appears probable that the Willamette River runs contribute to this February fishery. A few Willamette River chinooks are also undoubtedly caught in the Columbia River during the first few days after May 1 when the spring season opens. It is thought, however, that no great number is taken at that time, since, by May 1, the great part of the run is in the Willamette River where no commercial fishing is permitted.

The time at which the steelheads of the Willamette migrate through the lower Columbia River where the commercial fishery is carried on is not known. While the runs of this species into the Willamette River are not large, it is probable that some of them are taken by the commercial fishermen, probably during the winter fishery. There is no available evidence on which to base an estimate of the proportion of the run or the number of fish taken by this fishery.

The Sport Fishery for Chinook Salmon

The most important contribution of the Willamette River chinooks, as measured by both amount of catch and public recreation, is made through the sport fishery carried on by anglers fishing in the Multnomah Channel (Willamette Slough) from St. Helens to St. Johns, and in the Willamette River from Sellwood to Oregon City. This fishery is augmented by anglers who fish in the Columbia River in close proximity to St. Helens, by others who fish in the main Willamette River below St. Johns and by fishermen who sometimes fish between the Sellwood Bridge and Portland Harbor. This sport fishery was studied because it provides the best available basis for an estimate of the value of Willamette River chinook runs and their time of migration up the lower Willamette as well as an estimate of the abundance of salmon in the river. A chart of the fishing area is shown in Figure 3.

This fishery is conducted by sportsmen fishing with trolling gear from small craft which vary from row boats to small power yachts. In the Multnomah Channel, most of the fishing is done from boats powered with outboard motors or small boats with inboard motors. A few fishermen row, and in certain locations where the current is favorable, boats may anchor at stages of the tide permitting the gear to "work" in the current. During the height of the angling season there are large numbers of boats congregated just below the falls at Oregon City. On several occasions over 100 boats were observed fishing between the highway bridge between Oregon City and West Linn and the Oregon City Falls, a distance of one-half mile. The upper limit of fishing is set by a deadline established below the fishway at Oregon City.

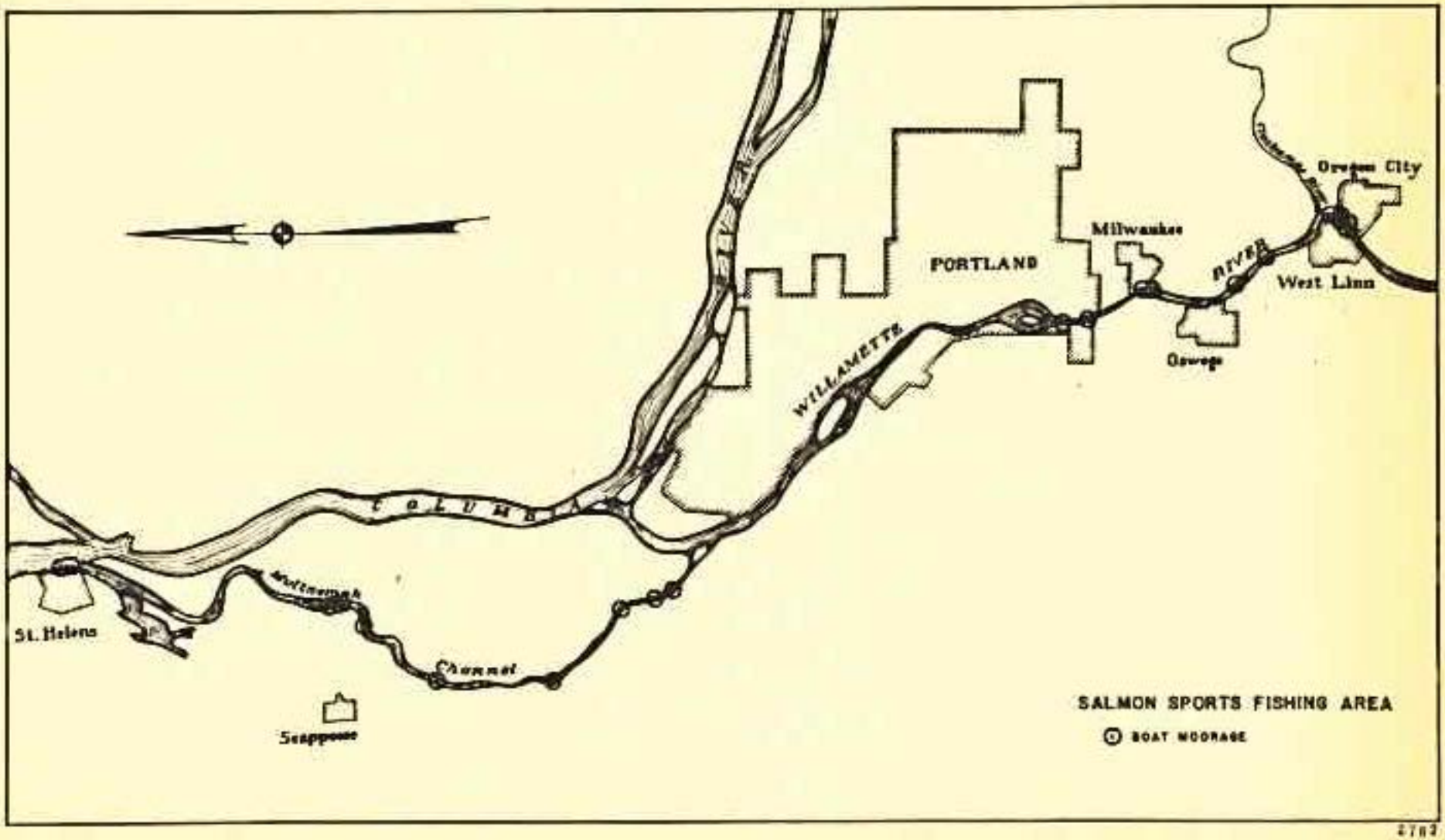

Figure 3. Sport fishing areas for chinook salmon in the lower Willamette River and Multnomah Channel.

Most of the anglers participating in the Willamette River fishery store their boats between trips at boat houses or moorages which have been established along the river for this business. There are twenty-four of these moorages making a regular and full-time business of storing boats and selling supplies during the months of March and April. The locations of these moorages are indicated by circles in Figure 3. In addition to storing privately owned boats, most of these moorages also rent boats, motors and other equipment for fishermen who require such services. At several points along the river, noticeably at the mouth of the Clackamas River and near Scappoose on Multnomah Channel, many privately owned boats are brought in by trailers, launched and taken out again on the same day, without being stored or serviced at established moorages.

The fact that a large portion of the fishermen taking part in the Willamette River angling fishery use the facilities of the established moorages made possible the accumulation of catch data on the river. In the latter part of February, each of the moorages was visited to obtain its cooperation in keeping records of fish landed, and forms were supplied for reporting the daily landings. These forms were filled out by the moorage operators and collected during the fishing seasons of 1941 and 1942. The data obtained are presented in Table 4.

These reports of landings of fish caught by anglers were made by busy moorage managers who cooperated by recording those fish landed which they personally observed. Failure to observe fish landed would tend on every occasion to decrease the reported landings below the actual catch. To avoid this bias, a study was undertaken to discover what proportion of the actual catch was being reported from the moorages. In this study use was made of average catches per boat, together with the counts of the number of boats fishing on the day that the average catches were obtained.

The procedure was as follows: Paid observers were employed to make counts of fishermen, boats and fish coming in at representative moorages. These figures were subsequently used for calculation of average catch. On the same days, surveys were conducted on the Willamette River to count the number of fishermen and boats fishing. In 1941 the trips through the fishery were made by outboard motor boat and by airplane. During 1942 when wartime restrictions barred planes from the area, an outboard motor boat was used entirely. Counts from an airplane, being more nearly simultaneous throughout the fishery, were more satisfactory than those made from a boat. To arrive at an estimated catch of fish on the Willamette River on any particular day, it was only necessary to multiply the number of boats observed fishing by the average catch per boat, which was obtained from counts made by the paid observers stationed at the moorages. As there was a considerable proportion of the fishermen who left the river before the survey was made, and another significant proportion of fisherman which started fishing after the survey was completed, it was necessary to increase the boat count on the river to compensate for these losses. This was done by increasing the boat count by the ratio between the total number of boats leaving the sample moorages during the day, and the number of boats that were on the river at the time of the survey.

TABLE 4. Number of Chinook Salmon Landed and Number of Chinook Salmon Landed per Moorage in the Willamette River by Weeks in 1941 and 1942.

Date	Number of fish reported landed			Number of fish reported landed per moorage reporting		
	Total	Multnomah Channel	Sellwood to Oregon City	Multnomah Channel	Sellwood to Oregon City	All Moorages
1941						
March 2-8	112	76	36	8	4	6
9-15	446	314	132	31	15	24
16-22	896	651	245	54	24	41
23-29	2,081	1,582	499	144	50	99
30-April 5	3,060	2,112	948	176	95	139
6-12	3,545	2,413	1,132	218	113	169
13-19	3,230	1,445	1,785	131	198	162
20-26	2,430	1,463	967	209	121	162
27-May 3	656	249	407	83	52	60
4-10	148	2	146	2	25	21
11-17	34	.....	34	....	....	....
Totals	16,638	10,307	6,331	....	....	....
1942						
Feb.23-Mar.1	9	9	0	....	....	....
2-8	80	49	31	10	15	11
9-15	181	142	39	16	7	12
16-22	339	145	194	18	24	21
23-29	1,080	626	454	63	50	57
30-Apr. 5	1,297	829	468	104	58	81
6-12	1,581	1,062	519	152	74	113
13-19	797	289	508	29	85	52
20-26	1,004	234	770	39	110	77
27-May 5	884	209	675	42	96	74
4-10	190	7	183	....	30	24
11-17	41	0	41	....	20	20
Totals	7,483	3,601	3,882	....	....	....

The data resulting from the surveys of the paid observers in 1941 are shown in Table 5 where, for each date and section of the Willamette River, is shown the number of fish, fishermen and boats counted at moorages, with a calculation of the number of fish per fisherman and fish per boat. In Table 6 are shown the various counts made on the river and at the moorages by the observers, from which may be calculated the number of fishermen per boat.

Table 7 shows the calculated total catch of fish on the river for each day in 1941 that the counts were made. In comparing the calculated catch with the catch reported landed by the moorages, it is seen that the reported catch amounted to only from 50 to 60 per cent of the calculated catch. In Multnomah Channel from 41 to 95 per cent of the calculated catch was reported and in the Willamette River from Sellwood to Oregon City 33 to 67 per cent of the calculated catch was reported in 1941. If we increase the 1941 total reported landings (see Table 4) by the ratio between the calculated catch and the reported catch for the whole angler fishery, the catch for the season will be seen to fall between 28,000 and 33,000 fish. Taking an average ratio of one hundred fish caught for every 56 fish reported landed at moorages, the calculated catch becomes 30,000 fish.

Similar data are exhibited in Table 8 for the 1942 surveys. The figures for this year are not quite as reliable as those for 1941, because of the difficulties experienced in securing observers and the method of obtaining boat counts. The table shows, however, about the same relationship between the reported catch and the independently calculated catch--the former being 62 per cent of the latter. If the 1942 total reported landings (See Table 4) are increased by the ratio between the calculated catch and the reported catch for the whole fishery, the estimated catch is 12,000 fish. These figures indicate a condition that will be referred to in connection with other facts: namely, that the run of chinook salmon to the Willamette River was smaller in 1942 than in 1941.

From the estimate of the number of fish caught in the Willamette River it can be seen that this run makes up a significant proportion of the total run of spring chinook salmon to the Columbia River. The escapement through the sport fishery is not known but it must be of considerable magnitude. The Willamette River catch alone far exceeds the total escapement of chinook salmon over Rock Island dam, and is equivalent to from one-fourth to one-third of all the spring chinook salmon which go over Bonneville Dam.

TABLE 5. Average Catch per Fisherman and per Boat, Computed from Paid Observers' Counts at the Moorages, in Willamette River Angler Fishery below Oregon City During 1941.

Date	Location	Number of fish counted	Number of fishermen counted	Number of boats counted	Fish per fisherman	Fish per boat
4- 6	Sellwood	19	192	93	0.10	0.20
4- 6	Multnomah Channel	79	290	101	0.27	0.78
4-17	Oregon City	79	193	92	0.41	0.86
4-17	Sellwood	10	62	35	0.20	0.30
4-17	Multnomah Channel	64	127	55	0.50	1.16
4-27	Oregon City	48	283	134	0.17	0.36
4-27	Sellwood	6	74	179	0.10	0.30
4-27	Multnomah Channel	43	301	117	0.14	0.37
5- 3	Oregon City	41	192	97	0.21	0.42
5- 3	Multnomah Channel	0	7	3	0.00	0.00
5-11	Oregon City	15	80	40	0.20	0.40
	Total	404	1,801	946	0.22	0.43

TABLE 6. Fishermen per Boat, Computed from Paid Observers' Counts made on the Willamette River and at the Moorages Below Oregon City, 1941.

Date	Location	Number of boats	Number of fishermen	Fishermen per boat
	River Counts			
4- 3	Multnomah Channel	54	113	2.1
4- 5	Sellwood-Oregon City	288	534	1.8
4- 6	Oregon City-Sellwood	297	537	1.8
4- 6	Multnomah Channel	508	1,280	2.5
4-16	Sellwood-Oregon City	200	341	1.7
4-17	Oregon City-Sellwood	206	364	1.8
4-17	Multnomah Channel	224	458	2.0
	Observer Counts			
4- 6	Sellwood	93	192	2.1
4- 6	Multnomah Channel	101	290	2.9
4-17	Oregon City	92	193	2.1
4-17	Sellwood	35	62	1.8
4-17	Multnomah Channel	55	127	2.3
4-27	Oregon City	134	283	2.1
4-27	Sellwood	74	179	2.4
4-27	Multnomah Channel	117	301	2.6
5- 3	Oregon City	97	192	2.0
5- 3	Multnomah Channel	3	7	2.0
5-11	Oregon City	40	80	2.0
Total River Counts		1,870	3,619	2.04
Total Observer Counts		841	1,906	2.26

TABLE 7. Comparison of Calculated Catch From River Surveys and Observers' Records With Catches Reported by Moorages, 1941.

Date and station	Catch reported by moorages	Calculated catch	Per cent that reported catches are of calculated catches
April 6 *			
Multnomah Channel	459	484	95
Sellwood-Oregon City	386	919	42
Total	845	1,403	60
April 17			
Multnomah Channel	211	512	41
Sellwood-Oregon City	280	419	67
Total	491	931	53
April 27			
Multnomah Channel	149	207	72
Sellwood-Oregon City	89	267	33
Total	238	474	50
May 3 **			
Sellwood-Oregon City	53	115	46

* Exclusive of landings at St. Helens, and with possible incompleteness described in the text.

** Four fish were reported landed at moorages in Multnomah Channel where no paid observers were stationed.

TABLE 8. Comparison of Calculated Catches From River Surveys and Observers' Records With Catches Reported by Moorages, 1942.

Date and station	Catches reported by moorages	Calculated catch	Per cent that reported catches are of calculated catches	Average catch per boat
March 21				
Sellwood-Oregon City	32	39	82	0.24
April 4				
Multnomah Channel	160	199	80	0.46
April 5				
Sellwood-Oregon City	95	140	68	0.20
April 10				
Sellwood-Oregon City	69	297	23	0.42
April 11				
Multnomah Channel	134	157	85	0.27
May 1				
Sellwood-Oregon City	93	271	34	0.53

Value of Willamette River Fish in Fish Culture

A considerable part of the chinook salmon runs escaping over the falls at Oregon City is subsequently handled in the fish cultural operations of the Oregon Fish Commission. The Commission maintains four hatcheries in the Willamette River which have had an average combined salmon egg-take of 26 million per year during the past ten years and an egg-take as high as 47 million in one year. The salmon egg-takes and fingerling liberations made at these stations as recorded in the biennial reports of the Oregon Fish and Game Commission (1919) and the Oregon Fish Commission (1919 to 1945) are shown in Table 9. This table shows the percentage of the total Oregon take of spring chinook salmon eggs which was made at Willamette River hatcheries for those years where a segregation of spring chinook salmon eggs was published. The 1942 egg-take also indicates that the run in this year was much lighter than in 1941.

The figures of Table 9 indicate that the hatcheries operating on the tributaries of the Willamette River are important units of the fish cultural establishment maintained by the Oregon Fish Commission. Besides returning large numbers of fingerlings to the Willamette River system, these hatcheries, in some years, have shipped approximately one-third of their egg-take to hatcheries on other tributaries of the Columbia River where attempts are being made to build up depleted runs. Some doubt exists as to the ultimate effectiveness of hatcheries. Assuming, however, that hatcheries largely compensate for spawning grounds made otherwise accessible to fish, it appears that the chinook salmon runs of the Willamette River are important to the success of fish cultural operation in Oregon, by providing a reliable source of spring chinook salmon eggs which can be used in restocking barren or depleted streams in other areas. As long as stream conditions in Oregon are such as to require the continuation of artificial propagation of spring chinook salmon, the Willamette River runs will be important as a source of brook stock of these valuable fish.

The tributaries of the Willamette River support runs of steelhead trout, the eggs of which are also handled in the hatcheries of the Oregon Fish Commission located on the North and South Santiam Rivers. These stations have taken as many as 5½ million steelhead eggs in a season. The records of egg-takes and fingerling liberations are shown in Table 10. Within the Willamette River the sport fishery for steelheads appears to be insignificant. These fish are probably most important for the part they contribute to the commercial fishery in the Columbia River, although the extent of this contribution is unknown.

Table 9. Hatchery operations of the State of Oregon in the Willamette River. Take of chinook eggs and liberation of fingerlings, in thousands, and per cent of the total State spring chinook salmon egg-take made in the tributaries of the Willamette River. Through 1932 the fish liberated refer to fish liberated from eggs taken in the previous year. This accounts, in part, for the excess of liberations over egg-takes; in other cases these discrepancies are the result of transfer of eggs from one hatchery to another.

Year	NORTH SANTIAM		SOUTH SANTIAM		MCKENZIE		MIDDLE FORK, WILLAMETTE		Per cent that WILLAMETTE RIVER is of State spring chinook total
	Egg-Take	Fingerling Liberation	Egg-Take	Fingerling Liberation	Egg-Take	Fingerling Liberation	Egg-Take	Fingerling Liberation	
1918	3,251	0	0	0	13,712	1,116	11,389	0	100.0
1919	8,131	0	0	0	5,896	4,057	3,845	88	100.0
1920	3,698	0	0	0	9,014	1,663	1,390	225	100.0
1921	4,001	0	0	0	7,064	0	5,281	920	100.0
1922	4,053	0	0	0	5,682	532	5,545	2,713	100.0
1923	6,838	1,490	1,202	0	12,085	0	7,260	3,808	99.9
1924	8,695	3,119	1,937	0	13,824	4,134	9,142	8,180	96.8
1925	10,505	4,890	3,818	0	3,642	5,681	4,420	7,953	98.3
1926	8,150	4,972	1,924	0	21,127	3,478	8,530	4,312	99.8
1927	4,901	5,025	393	0	27,539	4,362	4,410	8,172	99.3
1928	7,573	4,675	1,172	0	27,748	8,104	10,740	8,244	99.1
1929	9,731	5,953	257	0	19,350	11,054	8,774	10,263	99.4
1930	8,511	4,587	585	1,248	21,129	6,040	7,342	8,545	97.2
1931	2,504	6,198	329	1,563	5,095	9,845	5,033	7,155	42.0
1932	8,499	7,389	2,005	2,306	18,841	12,613	10,055	12,046	67.2
1933	3,288	3,122	...	988	11,441	4,962	5,220	5,092	54.7
1934	13,206	6,632	1,075	1,024	18,531	7,237	8,162	6,416	75.1
1935	2,127	4,952	2,006	1,975	25,117	8,208	7,453	6,881	60.5
1936	1,917	3,489	1,994	1,936	22,432	9,591	5,916	5,499	*
1937	1,036	968	1,013	995	5,022	4,658	4,635	3,760	*
1938	2,006	1,853	1,450	1,373	15,436	11,411	9,130	7,544	*
1939	3,551	3,371	931	905	12,546	7,885	6,010	5,535	*
1940	2,692	2,530	1,160	1,123	11,826	8,740	2,862	2,582	*
1941	0	1,564	3,150	2,025	18,000	9,778	10,007	5,949	*
1942	0	982	200	180	5,612	5,147	6,190	4,826	*

* No segregation as to spring chinook in official publication.

Editorial note: See addendum for 1943-1945 data.

While the egg-taking stations and hatcheries are important elements in maintaining the runs of chinook salmon and steelhead trout in the Willamette River, other contributions to these runs are not excluded. Natural spawning occurs in each tributary every year. Some fish spawn in stream sections below the racks or in secondary tributaries into which their migration is not blocked. Others spawn in stream sections above the racks where they have been able to migrate before the racks were installed or when accidents happen to the racks during the season. Some idea of the potential importance of the natural spawning areas of the Willamette River can be obtained from Table 11 which shows the percentage of presently available spawning areas in five major tributaries that will be affected by the proposed constructions.

TABLE 10. Hatchery Operations of the State of Oregon in the Willamette River. Take of Steelhead Eggs and Liberation of Fingerlings, in Thousands.

Year	NORTH SANTIAM		SOUTH SANTIAM	
	Egg-Take	Fingerling Liberation	Egg-Take	Fingerling Liberation
1926	0	0	1,059	0
1928	0	0	118	119
1929	0	0	13	411
1930	2,860	1,683	2,491	1,110
1931	1,009	1,220	1,010	767
1932	0	0	1,481	1,081
1933	145	137	475	467
1934	1,963	1,068	1,283	1,156
1935	1,051	1,020	442	429
1936	162	158	1,187	1,176
1938	774	749	745	706
1939	1,403	1,344	0	0
1940	2,230	2,091	3,335	2,670
1941	1,000	952	3,150	2,244
1942	0	0	1,581	1,215

TABLE 11. Relation of Proposed Dams to Available Spawning Areas in the main tributary basins.
(Data from Stream Surveys of the U. S. Fish and Wildlife Service)

Stream	Lineal Miles Surveyed				Square Yards of Spawning Area Available			
	Below damsite	Above damsite	Total	Percent above damsite	Below damsite	Above damsite	Total	Percent above damsite
Main Santiam	11.1	---	11.1	0	1,054,030	---	1,054,030	0
N. Santiam	66.2	61.1	127.3	48.0	1,875,001	800,778	2,684,779	30.1
S. Santiam	87.7	63.5	151.2	42.0	2,352,539	874,278	3,226,817	27.1
McKenzie	76.7	103.3	180.0	57.4	3,224,923	1,841,112	5,066,035	36.3
Middle Fork Willamette	83.6	74.5	158.1	47.1	2,501,145	1,226,140	3,727,285	32.9
Total	325.3	302.4	627.7	48.2	11,007,638	4,751,308	15,758,946	30.1

Economic Value

From the foregoing data and discussion it is possible to derive some idea of the importance and magnitude of the runs of chinook salmon and steelhead trout entering the Willamette River.

On the basis of the two years' data available, it appears that the annual sport catch of chinook salmon averages about 20,000 fish. These fish average approximately 15 pounds in weight and it is generally agreed that sport caught fish can be evaluated conservatively at one dollar a pound. On this basis the annual value of the sport catch of Willamette River salmon approximates $300,000.

In addition to this the Willamette River chinook salmon contribute significantly to the ocean troll fishery and to an unknown extent to the commercial fishery in the Columbia River, besides constituting an important brood stock for restocking in connection with fish cultural operations. The steelhead runs of this river also add to the take of the commercial fishery of the Columbia River and provide some sport and recreation.

The $300,000 annual value of the chinook sport catch alone is a 4 per cent income on $7,500,000. It is therefore evident that the Federal Government would be justified in appropriating considerable sums to assure the perpetuation and maintenance of the runs of salmon and steelhead in the Willamette River.

EFFECTS OF THE PROPOSED DEVELOPMENT ON THE FISHERY RESOURCES

The four dams proposed for construction on those tributaries of the Willamette River that support runs of chinook salmon and steelhead trout may affect the populations of fish in several different ways. The dams may intercept the adults in their upstream migration and prevent them from reaching their spawning grounds. The reduction in flow below the reservoirs while they are being filled in the spring may result in low-water obstructions becoming impassable at the time when the adults are ascending the stream. The reduced flow may prolong the period of excessive pollution in the lower Willamette River -- pollution that now forms a complete physiological barrier to the passage of fish for two or three months each year. The impounded water released from the reservoirs may be deleterious to fish below the dams because of unfavorable temperatures or chemical composition. Each of these possible unfavorable conditions has been investigated and is discussed in following sections.

Not all of the effects of the storage of water will be disadvantageous to salmon or to fish cultural operations. If racks for holding fish are maintained in the main tributaries below the dams, the regularity of the discharge during the freshet period will serve to guard against the loss of racks in the river such as frequently occurs under present conditions.

During the summer when larger volumes of water are being released from the reservoirs than would be found in the streams under natural conditions of flow, there will be increasingly favorable pool conditions for resting fish in the tributaries below the dams, provided that the water issuing from reservoirs is suitable for fish.

Reduction in Spawning and Rearing Area

Because the salmon have a tendency to migrate into the upper sections of the tributaries, the proposed dams, being located relatively far down on the streams, will provide direct barriers for such migrations. As an actual fact the sections of the tributaries which would be barred to the migration of salmon by the proposed dams constitute only a small part of the total natural spawning area in the tributaries that is available to the fish at present. As stated above, this is because the runs of fish to the tributaries of the Willamette River for which dams are proposed are intercepted by the racks established by the Oregon Fish Commission. On the McKenzie River these racks are located several miles below the proposed dam site and, therefore, the dam on this stream would not prevent movements of salmon within the limits of the present restrictions. On each of the other tributaries the fish racks are located a few miles above the proposed dam sites. On the North Santiam River the present fish racks are at the mouth of the Breitenbush River, approximately five miles above the Detroit dam site. On the South Santiam River fish racks are maintained on the Middle Fork about five miles above the Sweet Home dam site. On this stream, however, the entire run is not intercepted by these racks because a considerable number of fish spawn in the main South Santiam River. On the Middle Fork of the Willamette River the racks are established at the mouth of Salmon Creek about six miles above the Lookout Point dam site.

In order to make adequate plans for the fish protection program, the proportions of the runs of chinook salmon and steelhead trout using the obstructed and unhampered spawning areas should be known. Unfortunately, no precise numerical answer can be given to this question because exact counts of the fish passing the falls at Oregon City or passing the various dam sites are not available. However, the information that is now available provides some basis for estimating the capacity of presently available spawning areas.

Surveys were made on the North Santiam River during the spawning seasons of 1941 and 1942 to obtain an idea as to the relative distribution of chinook salmon in this stream in reference to the proposed dam below Detroit. If an equal search for fish were conducted in various sections of the stream surveyed, then the number of fish seen in each section should bear nearly a constant relation to the distribution of the entire group of fish in the stream. In practice, however, an equally intense search in the lower sections of the streams was not possible and so the proportion of fish seen there was less than that seen in the upper sections. During the 1941 survey on the North Santiam River a total of

1,441 salmon was counted. Of these 933 were observed above the dam site near Detroit and 508 were counted in the stream section between the dam site and Stayton. In the 1942 survey of the same area 442 salmon were seen. Of these 243 were counted in the stream section above the dam site, and 199 between the dam site and Stayton. These surveys indicate that about two-thirds of the salmon in the North Santiam proper spawn above the location of the proposed dam. Of these however, only a small proportion (in 1941 approximately one tenth) spawn between the rack site at the mouth of the Breitenbush River and the dam site.

In the South Santiam River, all of the chinook salmon appear to migrate for a considerable distance above the Sweet Home dam site. In the McKenzie River the racks established by the Oregon Fish Commission prevent any salmon from reaching the Leaburg Dam some miles below the Quartz Creek dam site. However, in 1942 salmon passed the racks and were observed as far upstream as Tamolitch Falls.

Tributaries of the Willamette River above Oregon City that are not to be dammed and have runs of chinook salmon are: Tualatin, Yamhill, Molalla, Pudding and Calapooya Rivers. Stream survey parties of the U. S. Fish and Wildlife Service working on the Molalla River during the spawning season recorded 882 chinook salmon in 1940 and 933 in 1941. No surveys at spawning time are known for the other main branches of the Willamette River.

Secondary tributaries of the Willamette River whose confluences with the tributaries to be dammed are below the proposed dams' sites and which are known to support populations of chinooks are: Little North Santiam River, Thomas Creek, Crabtree Creek, Mohawk River and Fall Creek.

Some measure of the importance of the stream sections to be cut off from fish by the proposed dams may be obtained from the amount of spawning area in the sections. The spawning area estimates made by the U. S. Fish and Wildlife Service are quite complete for the tributaries of the Willamette River upon which dams are proposed. A summary of these surveys made through 1941 on the North Santiam, South Santiam, McKenzie and Middle Fork of the Willamette Rivers is shown in Table 11, in which the spawning areas above the proposed dams are tabulated separately. The spawning areas classified as "available" are those areas below impassable obstructions, not including the fish racks of the Oregon Fish Commission. In each main tributary all of the stream sections and sub-tributaries considered suitable for spawning salmon were surveyed. Therefore, the total amount of "available" spawning area in each main tributary basin closely approximates the entire amount of spawning area that salmon could reach or use. Table 11 shows that about thirty per cent of the spawning area in the surveyed sections of these tributaries of the Willamette River is above the proposed dams.

This information indicates that under natural conditions, about one third of the salmon spawning in these tributaries would be barred from completing their migration to natural spawning areas located upstream from the sites for the proposed dams. However, as stated above, at the

present time fish are not permitted to reach large sections of their natural spawning areas because they are held below the racks of the Oregon Fish Commission and the eggs are taken for artificial propagation.

It should be borne in mind that the present escapement past Oregon City is responsible for the maintenance of future runs which reasonably may be expected to yield sport catches as great as 30,000 fish per year in addition to all other yields to the outside troll and Columbia River commercial fisheries. It seems highly improbable that the run could be maintained at anywhere near its present level by natural propagation alone if it were to be deprived of as much as half of its spawning area. Natural spawning of the entire run would become necessary if, for any reason, hatchery operations were to be discontinued. These spawning areas are therefore potentially valuable and the future of the salmon populations using them can only be assured by either making them accessible to the runs or providing permanent means of carrying on the artificial propagation program now in operation.

Little is known of the size of the total run of steelheads in the North and South Santiam Rivers. All evidence points to these fish spawning far up in each stream. Water conditions during the period of their spawning migration are such as to make it uncertain as to the parts of the runs that have been stopped by the present racks. On the South Santiam a part of the run goes up the Soda Fork, which is not racked. Local residents along the Breitenbush River and the upper part of the North Santiam River report that every year some steelheads have been seen in those stream sections, indicating that some of the fish pass the mouth of the Breitenbush River before the racks are installed, or else escape through the racks. The steelheads are of such importance that they as well as the chinook salmon must be considered in any fish maintenance program. Plans satisfactory for chinook salmon will also be suitable for the steelheads.

Account must be taken, also, of the fact that the areas upstream from the dam sites are actual or potential rearing areas of great value for the young salmon that remain in fresh water during their first summer. Each of the tributaries of the Willamette River now possesses populations of such fish in the upper sections. This is just as true of those tributaries where hatcheries intercept the runs as it is in streams such as the Molalla River where there is only natural propagation. This raises the interesting question of the origin of these young fish that are found in streams above the hatchery racks.

In the summers of 1941 and 1942 it was common to see chinook salmon fingerlings in the McKenzie River miles above the mouth of Gate Creek (where some hatchery fish are released). Small salmon were seined in 1941 from the river near the mouth of Martin Creek, three miles above Gate Creek, and others were caught in 1941 and 1942 by angling with small dry flies at several points farther upstream, notably just below the mouth of the Blue River, which is 14 miles above Gate Creek. In 1942, salmon fingerlings were caught in side channels near the mouth of Hills Creek, on the Middle Fork of the Willamette River, a number of miles above

Salmon Creek, where hatchery fish are released. These fingerlings may have been the progeny of fish that escaped from the racks, although hatchery men stated that it was their belief that such escapement was slight. They were especially sure that on the McKenzie River in 1940 few if any fish got by the racks. (Such fish could have given rise to the fingerlings taken in 1941). The abundance of fingerlings observed in these upstream sections indicates either (1) that considerable numbers of adults spawned above the racks; (2) that conditions were exceptionally favorable for the survival of the eggs that were spawned in these sections; or (3) that fingerlings migrated for some distance upstream from the point of hatchery release. The possibility definitely exists that even though hatchery fish are released relatively far down in the tributaries, they may migrate and make use of stream sections well above the point of release. Whatever the true explanation is for finding salmon fingerlings in the upper sections of the Willamette River tributaries, the important fact remains that these areas are being occupied at the present time (and with apparent success) by those chinook salmon fingerlings that spend their first summer in the stream. To this extent the proposed dams will bar from use areas of the Willamette River system that are presently being utilized by salmon.

Pollution

Fish ascending and descending the Willamette River are confronted by the danger of a pollution barrier. The past and probable future conditions of the river with respect to pollution have been analyzed to determine if, in the regulation of flow by the reservoirs, the reduction in flow while the reservoirs are being filled might prolong the period of serious oxygen depletion, or the increased summer flow might improve the present condition.

Water conditions in the Willamette River have been examined several times by investigators from Oregon State College (G. W. Gleeson (1936), G. W. Gleeson and F. Merryfield (1936), and H. S. Rogers, C. A. Mackmore and C. D. Adams (1930). General statements to follow have been derived from the work of Gleeson (1936) or Rogers, Mackmore and Adams (1930) unless otherwise stated. Summer surveys along the Willamette River show a condition of increasing pollution load, which becomes definitely measurable at Corvallis and continues to the entrance to Multnomah Slough, below Portland. In the middle of the winter, and early spring, the appearance of pollution is obscured. During the summer, dissolved oxygen concentrations decrease steadily downstream from Corvallis, with step-like declines below the principal sources of pollution, finally to reach complete depletion in a section several miles in extent opposite Portland.* At this time the biochemical oxygen demand increases by steps below each source of pollution, reaching an average value of 3.85 p.p.m. for 10 days' incubation at the Sellwood Bridge, at the upstream limits of Portland.

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* Editorial note: See addendum for more recent data.

Sources of pollution are untreated domestic sewage and industrial wastes. Although the Willamette Valley had in 1940 a human population (541,000) of nearly half that of the entire State of Oregon, no community of consequence had a system of sewage disposal other than discharge into the Willamette River or its tributaries. Since this enumeration was made, the population of the Valley as a whole has increased substantially, but the only existing treatment of domestic sewage for an important number of persons is at a military establishment up-river from Salem. Industrial wastes come largely from pulp and paper manufacture, food processing and textile preparation. There are five pulp and paper mills located on the Willamette River or its tributaries--two at Oregon City, and one each at Newberg, Salem and Lebanon. All use the sulphite process for at least some of their production, and discharge untreated waste sulphite liquor and "white water" into the streams (Gleason and Merryfield (1936)).According to surveys made in the present investigations, there are fruit and vegetable canneries and other food processing plants at Eugene, Salem, Woodburn, Stayton and other communities. Most of the wastes from such plants (with some exceptions) are discharged into streams without treatment, or after removal of part of the solids. Flax retting plants at the State Penitentiary, Salem, and at several other points in the valley dispose of highly polluting wastes directly into the streams. Wool washing and treating plants in Stayton, Brownsville and Salem also contribute to the pollution load.

Addition of the organic matter from all the domestic and industrial sources produces an increasing burden on the waters of the Willamette River. As a large part of the load is added at Salem and below, the amount of these wastes discharged, the rapidity of flow of the stream, the temperature of the water and the original dissolved oxygen content all will influence the degree of pollution observed at points below Salem (when the discharge of the stream is constant). At the time of the study by Rogers, Hockmore and Adams (1930) the Willamette River 2.5 miles below Salem carried wastes with a population equivalent of 224,000 and received an additional population equivalent of 343,700 before reaching the Sellwood bridge. As the rate of flow of the river was such that water required less than 8 days to flow from Salem to Sellwood Bridge, a significant part of the up-river pollution load had not been stabilized by the time it reached Sellwood Bridge. Thirteen per cent of Salem's waste was thus unstabilized at Sellwood Bridge, and the percentages for Newberg and Oregon City were 22 and 62 per cent respectively (Rogers, Hockmore and Adams (1930), Table X).

The final addition of wastes from the City of Portland to a stream that is already carrying a heavy pollution load at the city boundary, results in "a negative oxygen balance at some point below Sellwood", and "in zero dissolved oxygen for a length of river of about 2.7 miles" while "the length of river in which the dissolved oxygen is less than 30 percent of saturation extends for approximately 7.6 miles". (Gleason (1936), p. 29). Although Gleason stated, (p. 31) that "It appears that the condition of oxygen depletion exists for only the period of time

coincident with the low-water stage" and "this period of time in all probability never exceeds three months" (which may be true in recent years as well as in 1934), it is certain that changes in the pollution load have increased the area of oxygen depletion from that reported in 1934. The results of samples taken in the present surveys are shown in Table 12. There were times when the Willamette River from Sellwood Bridge to St. Johns, a distance of more than 13 miles, had 0.6 p.p.m. or less dissolved oxygen concentration--an amount entirely inadequate to support life in salmonid fish.

Acute pollution conditions have been observed in Portland Harbor at minimum river discharges (estimated at 4,000 second feet in the 1934 surveys). It is of interest to estimate to what degree the pollution of the Willamette River would be affected by the storage of water in the proposed Willamette Valley Project reservoirs. By reducing the flow during the period of reservoir storage in the spring the effects of pollution will be aggravated; by increasing the flow in the summer the effects of pollution will be reduced.

Table 13 shows that the lowest estimated discharge of the Willamette River at Portland when the dams are in operation would be 15,400 second feet in April and 13,300 second feet in May. Discharges as low as 14,300 second feet have occurred in May during past years so that it appears that the effect of storage would be insignificant insofar as it might increase the conditions of pollution in Portland Harbor during these months - conditions would still be much better than during the summer months. Calculations based on the data of Rogers, Hockmore and Adams (1930) show that during April and May (1) the available oxygen in the river at the upstream limits of the City of Portland will be reduced less than 8 percent by the change in flow; (2) that 3.5 to 14 times the present summer dilution will occur; and (3) that the rate of water movement through Portland Harbor will result in a period of contact of only 7 to 30 per cent of that at present obtaining during the summer. Data from the present investigation show that the temperatures prevailing in the river water in the spring significantly retard the rate of oxygen consumption by organic wastes. From 1936 to 1940 the monthly mean temperature of the Willamette River at Portland was: April, 10° C.; May, 15° C.; and June, 18° C. Parallel incubation experiments were conducted to determine the effect of temperature on the biochemical oxygen demand of an important industrial waste, waste sulphite liquor. In the period from 2 to 20 days of incubation at 15° C. the biochemical oxygen demand of this waste was 86 per cent of that at 20° C. It is concluded, therefore, that storage of water in the reservoirs during the spring, while reducing the average discharge at Portland by small amounts in April and May, will not appreciably change conditions of pollution in Portland Harbor during these two months from that existing at the present time.

TABLE 12. Dissolved Oxygen Concentration and Temperature of the Water in Willamette River at Sellwood Bridge and St. Johns Bridge, Portland.

Date	Depth, feet	Temp. °C.	D. O. p.p.m.	D. O. % sat.	Date	Depth, feet	Temp. °C.	D. O. p.p.m.	D. O. % sat.
Sellwood					St. Johns				
2-4-41	5	8.3	10.6	90	2-4-41	5	8.0	10.5	88
2-27-41	5	8.2	7.7	66	2-27-41	5	8.3	6.5	55
3-18-41	5	10.5	8.6	77	3-18-41	5	10.7	7.1	64
5-1-41	5	16.5	5.6	56	5-1-41	5	17.1	3.8	39
5-29-41	5	16.9	5.7	59	5-29-41	5	17.8	4.5	47
7-17-41	5	26.5	2.0	25	7-28-41	5	23.8	0.3	4
7-28-41	5	24.6	0.6	7	5-2-42	5	11.3	7.8	103
5-2-42	5	11.0	9.1	82	8-5-42	5	25.6	0.6	7
8-3-42	5	24.3	1.6	19	8-5-42	45	20.6	4.9	54
8-5-42	5	22.8	2.3	26	8-21-42	5	23.6	0	0
8-21-42	5	23.7	1.8	21	8-21-42	45	23.5	0	0

TABLE 13. Estimated Average Discharge of the Willamette River at Portland, and Estimate of the Discharge if the Initial Development of the Willamette Valley Project had been Completed Prior to 1928 and Operated in Accordance with Plans.

Year	Estimated actual discharge, c.f.s.		Discharge in c.f.s. under initial development	
	April	May	April	May
1929	48,000	33,000	38,000	32,000
1930	19,500	22,000	15,400	18,000
1931	over 55,000	14,300	55,000	13,300
1932	52,000	36,000	44,500	35,000
1933	41,500	45,500	34,000	44,000
1934	30,500	15,500	23,000	14,200
	Aug.	Sept.	Aug.	Sept.
1928	4,700	4,500	7,000	6,000
1929	5,200	4,500	8,000	6,000
1930	4,300	4,400	7,800	7,900
1931	4,500	4,500	8,000	8,100
1932	5,500	4,300	8,000	8,000
1933	6,500	8,200	8,200	11,400
1934	4,500	4,200	8,200	8,200

Summer conditions will be considerably improved. Table 13 shows that about 3300 second-feet more flow will be maintained at Portland during August and September than occurs at present. While the average increase in flow will about double the dilution of wastes, the effects on pollution will be greater than this because (1) a greater amount of oxygen will be available at Salem, (2) the increased rate of flow from Salem to Sellwood Bridge will reduce the length of time available for oxygen depletion, and (3) the length of time for water to pass through Portland Harbor will be shortened, also reducing the oxygen depletion from newly added and incompletely stabilized wastes. Calculations of the resulting availability of oxygen at Sellwood Bridge and the rate of flow through Portland Harbor are shown in Table 14. Calculations are conservative in that the time of flow from Salem to Sellwood Bridge has been used as reported by Rogers, Hoskmore and Adams (1930), while it would be shortened substantially by a higher discharge rate. The conclusion is made that summer water conditions in Portland Harbor resulting from the release of stored water from the Willamette River reservoirs will be improved to the same extent as if 5 times the present amount of dissolved oxygen were available at Sellwood Bridge. Whether or not this would provide

conditions suitable for the passage of fish during the low water period under existing pollution loads is unknown, but it appears likely that the dissolved oxygen concentration would never be entirely depleted as at present, and it might produce the same results as the 30 per cent reduction in pollution load that was recommended by Gleeson and Merryfield (1936) for the low water period.

The South Santiam River is the only one of the tributaries affected by the Willamette Valley Project that has serious pollution. The principal pollutant is sulphite liquor and white water from a paper plant at Lebanon. The condition of the South Santiam River before it joins the North Santiam has not been analyzed, but Rogers, Mockmore and Adams (1930) observed that the biochemical oxygen demand of these combined tributaries as they joined the Willamette was 2.4 p.p.m. They estimated that the pollution from the Lebanon paper plant had a population equivalent of 35,900. The regulation of flow in the South Santiam River by the Sweet Home Reservoir should materially improve the pollution situation in that tributary during the low-water season.

TABLE 14. Effects of Willamette Valley Project Reservoirs on Water Conditions in Portland Harbor. Calculated as if the Units of the Initial Development Had Been Completed Prior to 1928 and Operated in Accordance with Plans, and as if the Pollution Load on the River Were Similar to That of 1934.

	Oxygen available at Sellwood Bridge		Time in days for flow from Sellwood Bridge to Multnomah Channel
	Thousands of pounds	Per cent actual amount in Sept. 1934	
(September, 1934) *	96.5	100	7.6
August, 1929-1934 minimum	243	252	3.9
August, 1929-1934 maximum	259	268	3.7
August, 1929-1934 average	251	260	3.8
September, 1929-1934 minimum	257	266	3.8
September, 1929-1934 maximum	387	400	2.6
September, 1929-1934 average	271	281	3.5

* Gleeson, G. W. 1936.

Obstructions

Numerous obstructions and diversions are situated in the sections of the Willamette River to be regulated by the proposed reservoirs. The principal obstructions are: (1) the Willamette Falls at Oregon City as presently developed; (2) diversion dam on the North Santiam River above Stayton; (3) diversion dam on the North Santiam River at Mill City; (4) diversion dam on the South Santiam River at Lebanon; (5) diversion dam on the McKenzie River above Leaburg; and (6) diversion dam on the Willamette River at Eugene. Of these, the falls at Oregon City is the greatest obstacle to fish migration. Diversion of large volumes of water through power plants in the spring so reduces the flow over the dam and through the fishway as to hinder fish in locating the passage. In the past, this has frequently been overcome by one-day shutdowns of the power plants. Reduction in river flow in the spring while the Willamette Valley reservoirs are being filled will increase at times the difficulty of passage at this obstruction. The condition may become critical in years in which the spring freshets are not sufficient to fill the reservoirs. Steps should be undertaken to improve the passages over this obstruction.

Water diverted from the streams is in no case adequately screened to prevent the passage of fish down the diversions. Only one diversion takes water for irrigation. The remainder return the water to the Willamette after it is used in the production of power. The extent of fish losses by such diversions is unknown, but in the canal from the North Santiam River, which eventually receives an extraordinarily heavy load of pollution at Salem, and in the irrigation ditch, also from the North Santiam River, it must be considerable.

Effects of Water Storage Upon the Quality of Water in the Streams Below the Reservoirs

If the salmon that are to be barred from completing their spawning migration by dams in the tributaries of the Willamette River can be accommodated in the sections of these tributaries downstream from the dam and in secondary tributaries having their confluences below the dams, a reasonably easy solution will be available to one of the most vexing problems of fishery-maintenance in connection with dam projects. Further, if it becomes evident that the water issuing from the reservoirs will always be wholesome for fish, the vast potential rearing areas available for young fish in the main streams below the dams may be used to advantage. On the contrary, if the condition of the water is unwholesome as it issues from the dams during the months of the year when mature fish would be in the streams below the dams, then it will become necessary in formulating fish-facilities plans to provide that fish be not admitted to those dangerous sections of the streams. This in itself would introduce grave complications in planning and execution, complications which if surmounted mechanically might leave biological factors so out of

adjustment that the preservation of the runs still would be questionable. Furthermore, if schemes for getting the mature fish above the dams are considered, more problems are involved in view of the facts that: (1) ordinarily only a part of the fish migrate as far upstream as the dams, leaving a significant and important component of the run to encounter the conditions below the dams in spite of the arrangements for passage over the obstructions, and (2) the necessity for a downstream migration of the progeny of fish spawning above the dams would call for elaborate devices for passing them safely down stream past the dams.

In view of the importance of water conditions below the dams we must examine the circumstances as they will occur in the reservoirs and attempt to predict the kind of water conditions to be expected in the streams below the dams under the proposed schedule of operations. Furthermore, if these operations will lead to deleterious water conditions we must examine the matter further to determine whether possible alterations of the structures or their operating schedule could be made which would provide for the maintenance of satisfactory water in the stream sections below the dams. From the broader biological standpoint it is desirable to maintain the ecological conditions of streams in as nearly a natural state as is possible, and this would be true even without the necessity for maintaining a valuable run of salmon.

Present Stream Conditions in the Willamette River System

A record of stream temperatures was kept at a number of places in the Willamette River during both 1941 and 1942, and in 1941 a record was also obtained in the North Fork of the Lewis River. Table 15 presents the data. Mercury actuated disc-recording thermometers supplied a seven-day record on a single sheet. The instruments were found by frequent tests to record within their guaranteed accuracy of one per cent of the range (±0.3° C.). Maximum-minimum thermometers were read and set daily at the stations where they were used.

At various times during the field work, temperatures were obtained from streams in the Willamette River system. In addition there were records of stream temperatures made by stream survey parties of the U. S. Fish and Wildlife Service, and a daily series of noon water temperatures at the Detroit dam site taken during June, July, August and September, 1940, by representatives of the U. S. Engineer Department. The temperatures taken during stream surveys have the drawback that they were obtained at various times of the day. A study made on the recorder sheets secured in the Willamette River system indicates that the maximum temperatures usually occur late in the day, and, furthermore, that there is a seasonal variation in the monthly average time of maximum and minimum temperatures. Data for such comparisons are shown in Table 16. The value of irregular temperature observations as a basis for determining the stream temperature variations is obviously limited. Reliance has been placed, therefore, exclusively upon the data from temperature recorders, and from maximum-minimum thermometer readings.

TABLE 15. Location, Type of Instrument, and Period of Record of Stream Temperatures.

Stream	Type of Thermometer	Location	Period of Record	
			1941	1942
North Santiam River	Recording	C.C.C. Camp Mary's Creek, above Detroit	April 18-Oct. 4	Mar. 9-Oct. 28
North Santiam River	Reversing	C.C.C. Camp Mary's Creek, above Detroit	Jan. 1-April 18	- - - - - - - -
North Santiam River	Reversing	Stayton	June 8-Oct. 12	- - - - - - - -
South Santiam River	Recording	Sweet Home	April 21-Sept. 25	April 17-Oct. 29
South Santiam River	Reversing	Four miles above Foster	Feb 1-Aug. 30	- - - - - - - -
McKenzie River	Recording	Rainbow	April 10-Sept. 22	April 6-Oct. 16
McKenzie River	Reversing	Rainbow	Jan. 1-April 10	- - - - - - - -
McKenzie River	Reversing	Leaburg	June 28-Sept. 16	- - - - - - - -
Middle Fork of Willamette River	Recording	Oakridge	April 9-Sept. 22	Feb. 26-Sept. 29
Middle Fork of Willamette River	Reversing	Oakridge	Jan. 1-April 9	- - - - - - - -
Middle Fork of Willamette River	Reversing	Two miles above Lowell	June 7-Sept. 26	- - - - - - - -
North Fork of Lewis River	Recording	Three miles above Lake Merwin	April 16-Oct. 12	- - - - - - - -

TABLE 16. Time of Day That Minimum and Maximum Stream Temperatures Occurred in Tributaries of the Willamette River, 1941 and 1942.

	April	May	June	July	Aug.	Sept.
NORTH SANTIAM			1941			
Average time of minimum temperatures -- a.m.	8	8	8	7	8	10
Average time of maximum temperatures -- p.m.	4	5	5	5	4	4
SOUTH SANTIAM						
Average time of minimum temperatures -- a.m.	10	9	9	9	10	10
Average time of maximum temperatures -- p.m.	6	6	7	6	8	6
MOHAWK						
Average time of minimum temperatures -- a.m.	8	7	6	5	6	4
Average time of maximum temperatures -- p.m.	5	4	4	4	5	2
MIDDLE FORK						
Average time of minimum temperatures -- a.m.	9	9	8	8	8	9
Average time of maximum temperatures -- p.m.	5	5	5	5	5	5
NORTH SANTIAM			1942			
Average time of minimum temperatures -- a.m.	6	6	6	6	7	7
Average time of maximum temperatures -- p.m.	4	3	3	4	4	3
SOUTH SANTIAM						
Average time of minimum temperatures -- a.m.	8	9	8	8	9	11
Average time of maximum temperatures -- p.m.	4	6	5	6	6	6
MOHAWK						
Average time of minimum temperatures -- a.m.	7	8	7	6	6	7
Average time of maximum temperatures -- p.m.	4	5	4	4	4	5
MIDDLE FORK						
Average time of minimum temperatures -- a.m.	8	8	9	9	9	9
Average time of maximum temperatures -- p.m.	5	5	5	6	5	5

The stream temperature data are shown in Figure 4 together with the mean daily air temperature at the U. S. Weather Bureau station nearest the river temperature station. There is a marked correlation between air and water temperatures in each stream, although it is less on the McKenzie River at Rainbow. There is also a close correlation between the river temperatures at two different stations on the same day, with the station lower on the stream nearly always having warmer water.

The figures illustrating stream temperatures indicate that there is considerable variation in the water temperatures which may be expected under the stream conditions existing today in the tributaries of the Willamette River. Each of the tributaries of the Willamette River has winter temperatures above 4° C. (39.2° F.). Minor increases in temperature occur in each stream during the months through April so that the mean daily temperature in none of the tributaries was observed to exceed 10° C. (50° F.) before May 1, and the temperatures of all the tributaries increased at about the same rate during this period. It is during the summer that the changes in temperature take place which distinguish the different tributaries. For each month the number of days in which the stream temperature exceeded certain selected values (A) at any time during the day and (B) for 12 hours or more is shown in tables 17 and 18. The tables show the uniformity of temperature which is to be found in the McKenzie River, where the temperature of 13° C. (55.4° F.) is never exceeded. The tables also show the high temperatures that may be expected in the South Santiam River, where, for 63 days in 1941 and for 62 days in 1942, the temperature of 16° C. (60.8° F.) was exceeded for 12 hours or more per day.

The tributaries of the Willamette River in those sections where the proposed dams are to be located exhibit temperature characteristics which are generally considered to be within the range which is satisfactory for salmonoid fishes with the exception of the South Santiam River. The information supplied as to the temperature of these streams as found under conditions existing in 1941 and 1942 must be borne in mind when the analysis is made of the data on temperatures in artificial lakes, and on the predictions which will be made in a later section as to the temperature of the water issuing from the proposed reservoirs on the Willamette River.

Forecast of Changes in Stream Conditions Following Construction of the Dams

Temperature

In order to obtain data on the changes taking place in impounded waters, surveys were conducted in 1941 on the artificial lakes behind 15 hydroelectric installations, Oregon and Idaho. Additional work was done on four of these reservoirs during the summer of 1942. A preliminary examination of dam designs, reservoir volumes, areas, altitudes and schedules of operations was made to discover reservoirs in the northwest which might be considered to have water conditions similar to those that

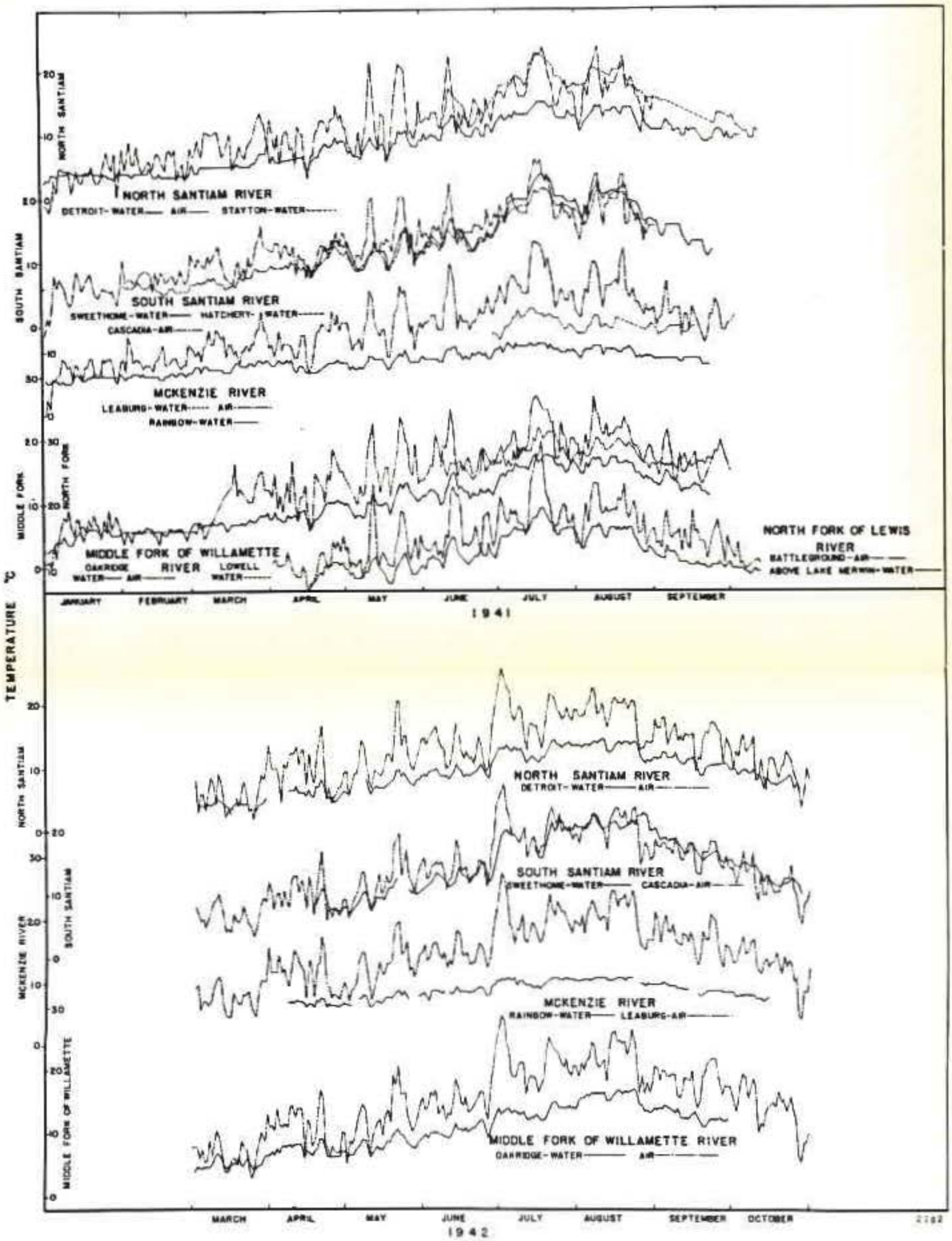

Figure 4. Daily mean stream and air temperatures in the Willamette Valley and North Fork of Lewis River.

TABLE 17. The Number of Days on Which the Water Temperature of Streams Exceeded the Stated Amounts for Any time During the Day, and for 12 Hours or More per Day, 1941.

	April	May	June	July	Aug.	Sept.	Oct.	April	May	June	July	Aug.	Sept.	Oct.
	A. Any time of day							B. 12 hours or more per day						
	North Santiam at Detroit							North Santiam at Detroit						
In record	12	29	30	31	25	30	7	12	28	30	31	25	30	7
Above 10°C.	9	29	30	31	25	1	0	0	4	22	31	25	20	0
Above 13°C.	0	0	9	31	22	1	0	0	0	0	24	17	0	0
Above 16°C.	0	0	0	10	1	0	0	--	--	--	--	--	--	--
	South Santiam at Sweet Home							South Santiam at Sweet Home						
In record	16	30	30	31	31	23	0	16	30	30	31	31	23	0
Above 10°C.	13	27	30	31	31	23	0	10	24	30	31	31	23	0
Above 13°C.	8	12	28	31	31	17	0	3	5	21	31	31	15	0
Above 16°C.	0	1	7	31	31	7	0	0	0	2	31	30	0	0
Above 23°C.	0	0	0	10	10	0	0	0	0	0	7	0	0	0
	McKenzie River at Rainbow							McKenzie River at Rainbow						
In record	16	30	30	31	21	16	0	16	30	30	31	21	16	0
Above 10°C.	2	9	15	31	17	3	0	0	0	4	19	9	0	0
	Middle Fork at Oakridge							Middle Fork at Oakridge						
In record	12	30	30	31	31	22	0	12	30	30	31	31	22	0
Above 10°C.	9	22	30	31	31	22	0	5	16	30	31	31	22	0
Above 13°C.	0	6	16	31	31	16	0	0	2	5	31	31	9	0
Above 16°C.	0	0	2	29	23	0	0	0	0	0	15	16	0	0
	Lewis River							Lewis River						
In record	14	30	30	23	31	30	12	14	30	30	23	31	30	12
Above 10°C.	12	17	30	23	31	30	5	9	11	29	23	31	26	1
Above 13°C.	0	3	13	23	29	24	0	0	0	7	23	24	1	0
Above 16°C.	0	0	1	21	17	0	0	0	0	0	10	7	0	0

TABLE 18. The Number of Days on Which the Water Temperature of Streams Exceeded the Stated Amounts for any Time During the Day, and for 12 Hours or More per Day, 1942.

	April	May	June	July	Aug.	Sept.	Oct.	April	May	June	July	Aug.	Sept.	Oct.
	A. Any time of day							B. 12 hours or more per day						
North Santiam at Detroit								North Santiam at Detroit						
In record	24	26	30	31	31	30	27	24	26	30	31	31	30	27
Above 10°C.	0	6	18	31	31	30	8	0	0	8	31	31	23	0
Above 13°C.	0	0	3	25	26	6	0	0	0	0	15	18	0	0
Above 16°C.	0	0	0	2	2	0	0	..	..	..	..	..	..	..
South Santiam at Sweet Home								South Santiam at Sweet Home						
In record	14	26	30	24	31	30	28	14	28	30	24	24	30	28
Above 10°C.	5	20	30	24	31	30	28	2	6	28	24	24	30	27
Above 13°C.	0	2	23	24	31	30	15	0	0	6	24	24	30	10
Above 16°C.	0	0	4	24	31	28	1	0	0	0	20	24	18	0
Above 23°C.	0	0	0	4	17	0	0	..	..	..	..	..	..	..
McKenzie River at Rainbow								McKenzie River at Rainbow						
In record	25	28	30	31	30	27	15	25	28	30	31	30	27	15
Above 10°C.	0	3	15	29	30	12	0	0	0	1	1	15	0	0
Middle Fork at Oakridge								Middle Fork at Oakridge						
In record	30	31	30	31	30	29	0	30	31	30	31	30	29	0
Above 10°C.	2	11	28	31	30	29	0	0	1	15	31	30	28	0
Above 13°C.	0	0	10	31	30	26	0	0	0	1	25	27	7	0
Above 16°C.	0	0	1	21	26	1	0	0	0	0	2	0	0	.0

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will arise in the proposed reservoirs. No one reservoir was found which appeared on physical considerations to approximate conditions of the proposed impoundments. The chief difference lies in each case in the time and degree of drawdown. Tieton reservoir, on the Tieton River, Washington, comes nearest to having operating and size conditions comparable with the proposed Willamette reservoirs, but it lacks the volume of inflowing water which will be characteristic of the latter. As it appeared that an intensive examination of one or two reservoirs would not give an adequate basis for making predictions of water conditions behind the Willamette dams, preliminary studies were undertaken on as many high dam reservoirs as could be conveniently visited in the northwest in 1941. It was believed that such a survey would yield information on water conditions in impoundments of sufficiently diverse physical conditions of basin and storage to indicate the range of variation within reservoirs and admit of correlation of conditions with structure or operation of the dams. The studies provided the basis for conclusions regarding the probable effects of the Willamette Valley Project reservoirs on the temperature of water in the stream sections below the dams. The 1942 artificial lake examinations were to verify previous results on the most promising lakes, and to collect special data.

The 15 reservoirs studied in this survey are listed in Table 19. Long Lake, an impoundment on the Spokane River, presents highly specialized conditions which will not be duplicated in the proposed Willamette reservoirs. It will not be considered further.

The remaining artificial lakes possess the characteristics in common that the impounding dams raise the water level at some time to over 100 feet, all but Salmon River have some outflow from outlets located a considerable distance below spillway level, and none receives appreciable amounts of domestic or organic industrial pollution. Arrowrock receives additions to its natural load of silt from placer mining and dredging operations. Shannon and Merwin receive water laden with glacial silt.

Six impoundments with subsurface outlets, Bull Run, Cushman, Deadwood, Merwin, Owyhee, and Shannon were not drawn down more than a few feet in 1941. Of the remainder, Arrowrock and Tieton were drawn down the most during 1941. Deadwood, Merwin and Owyhee were drawn down but a few feet whenever visited in 1942. Cushman, Merwin and Shannon had rivers entering them which discharged over 100 c.f.s. during the summer. The present lakes Cushman, Ole Klum, Kachess and Keechelus are built up from natural deep lakes of glacial origin. The last three are least similar to the proposed Willamette reservoirs of any studied.

TABLE 19. Reservoirs Investigated in 1941 and 1942.

Name	Location	Times Visited	
		1941	1942
Arrowrock Reservoir	Boise River, Idaho	1	0
Bull Run Reservoir	Bull Run River, Oregon	4	0
Lake Cle Elum	Cle Elum River, Washington	3	0
Lake Cushman	North Fork Skokomish River, Washington	2	0
Deadwood Reservoir	Deadwood River, Idaho	1	1
Lake Keechelus	Keechelus River, Washington	2	0
Lake Kachelus	Yakima River, Washington	1	0
Long Lake	Spokane River, Washington	1	0
Magic Reservoir	Wood River, Idaho	1	0
McKay Reservoir	McKay Creek, Oregon	1	0
Lake Merwin	North Fork of Lewis River, Washington	9	4
Owyhee Reservoir	Owyhee River, Oregon	1	2
Salmon River Reservoir	Salmon Falls River, Idaho	1	0
Lake Shannon	Baker River, Washington	2	0
Tieton Reservoir	Tieton River, Washington	4	4

On the basis of size and the volume of water flowing into the reservoir during the summer months, Arrowrock, Cushman and Merwin are most comparable to the proposed Willamette reservoirs, but only the first was greatly drawn down. Of the other impoundments, Tieton and Owyhee appear to have yielded information bearing most directly on the Willamette problem.

Temperature records at all depths in the reservoirs were obtained by means of a reversing thermometer which was lowered to the desired depth and tripped by a messenger which slipped along the line suspending it. A heavy cotton cash cord was used for suspending both the thermometer and the water sample bottle. Marks were placed on the line, after it was shrunk, to indicate the distance from the end to which the instrument was attached. There was some variation in the length of this line due to additional shrinkage and elongation under tension, but the deviations from the measured distances were known to be not greater than 5 or 6 per cent. The thermometer was graduated to five-tenths of a degree Centigrade. Usually when taking reservoir temperatures, the attempt was made to space observations at such depths that temperature differences of about 1° C. were obtained between successive levels. At levels where great temperature changes with depth occurred, this meant determination at 1 or 2 foot intervals. In lower, more uniform layers, 25 to 100 occurred between observations.

It is well known that deep lakes in temperate regions warm up much more rapidly at the surface than at greater depths. As the surface water is raised in temperature the density decreases and stratification develops because of the resistance to mixing resulting from the difference in density. Over ranges of slight density differences, wind forces are

adequate to set up currents which tend to mix the surface layers of the lake, but the effects of the wind diminish rapidly with depth. Wind effects are reduced also as greater density differences are encountered at subsurface levels. As the surface water temperature continues to increase with the progress of the season, the wind finally can cause circulation of only the surface water and a condition of thermal stratification ensues. In natural lakes in temperate regions when thermal stratification is complete, three layers in the lake can be recognized: a surface, warm, circulating layer ("epilimnion"); a bottom, cold, relatively stable layer ("hypolimnion"); and a transitional zone where change in temperature with depth is very rapid ("thermocline").

The development of a thermocline establishes a barrier between the surface water and the bottom water of a stratified lake, through which little mixing occurs. This barrier provides density differences with depth in natural lakes such that wind action can establish essentially free circulation in the epilimnion, and effectively bars the extension of the circulation into the hypolimnion. In natural lakes the outflow of water from the lake almost always occurs through a low place in the shore, allowing the withdrawal of surface, i.e., epilimnion, water. These conditions in natural lakes provide for the virtual complete isolation of the water of the hypolimnion for several months of the year. This water is relatively cold and stable as regards its temperature. If the water contained organic matter at the time the lake became stratified in the spring, the organic material held in the water of the hypolimnion would be retained there to be decomposed by bacteria throughout the period of stratification. Any additional organic material resulting from the falling into the hypolimnion of the bodies of organisms dying in the epilimnion, would contribute to the organic load to be oxidized in the bottom layer of water. The oxidation of such unstable matter in the bottom, non-circulating layer of a natural deep lake accounts for the commonly observed fact that in such lakes the water below the thermocline contains reduced amounts of oxygen, and has increased carbon dioxide content and acidity.

The development of a thermocline is such an important characteristic of deep natural lakes of the temperate zone, that the presence or absence of a thermocline in any body of water, and the characteristics of the water above, in, and below the thermocline should be carefully examined wherever comparisons are to be made. On the basis of water temperature distribution in a lake, the thermocline has been defined by Birge (1904) and by Welch (1935) as those depths where the decline in temperature reaches or exceeds 1° C. per meter (0.55° F. per foot) of depth. Such a definition is probably adequate for recognition of the physical conditions in a natural lake with a surface outlet when mixing of the lake no longer occurs. Insofar as reservoirs are concerned, the establishment of the temperature conditions meeting the definition of a thermocline does not lead, necessarily, to the establishment of conditions of epilimnion and hypolimnion comparable with that in natural lakes. As will be shown in later paragraphs, subsurface currents are of frequent occurrence in reservoirs, and these are of sufficient velocity to create different relationships between the bottom layers and overlying water masses than occurs in natural lakes. The fact that water is withdrawn from the

hypolimnion through subsurface outlets leads to sufficient mixing forces within that layer to create different physical and chemical conditions there than would be found in an equally deep natural lake with a surface outlet.

As temperature stratification, either with or without the formation of a characteristic thermocline, occurs in all deep lakes and reservoirs, it is of paramount interest to observe the degree of stratification and the depths to which the different layers extend. Where thermocline conditions become established, the epilimnion in natural lakes varies in thickness from place to place (Welch 1935). As indicated later, no significant variation in level of water of a given temperature has been observed in the reservoirs studied. Table 20 gives records of determinations of depth to the thermocline in representative lakes, and in Table 21 there are shown the data for thickness and temperature of the epilimnion, the depth to the hypolimnion and the temperature in the hypolimnion obtained during the careful surveys of New York lakes by Birge and Juday (1911). The data presented in these tables show that the depth to which the epilimnion extends varies with the lake, the season, and the year, but that lakes in widely separated parts of North America have thicknesses of the epilimnion falling in the range of 23 to 53 feet. Furthermore, the conditions of the hypolimnion are found established in the New York lakes at depths from 39 to 72 feet below the surface. As regards temperature, the water of the hypolimnion in these lakes was always well within limits satisfactory for salmonid fish.

In all lakes which become well stratified, the water of the epilimnion in July and August is raised to a temperature too high to be favorable for salmonid fish. If water from the surface of such bodies were to flow into a stream in sufficient quantity during these months to create stream temperatures as high as the temperature of the lake surface, it would probably produce unsatisfactory stream conditions for salmon. It is important, therefore, to observe in what way the depth of the epilimnion varies in a reservoir during the summer as the water is drawn down, to calculate for the proposed Willamette reservoirs the time at which epilimnion water may be expected to be discharged, and to predict what the temperature of the epilimnion will be when it finally starts out the discharge outlets. The data obtained during the surveys of reservoir lakes will be used for these calculations and predictions.

TABLE 20. Depth to the Thermocline in Deep Lakes.

Lake	Depth to Thermocline (feet)	Date	Authority
Crescent Lake, Washington	49	Aug. 17, 1913	Kemmerer, et al., 1923
Elephant Butte Reservoir, New Mexico	30	July 13-17, 1937	Ellis, 1940
Green Lake, Wisconsin	30	Aug. 14, 1906	Birge and Juday, 1911
Green Lake, Wisconsin	36	1910	Birge and Juday, 1914
Green Lake, Wisconsin	46	1911	Birge and Juday, 1914
Green Lake, Wisconsin	33	1912	Birge and Juday, 1914
Hayden Lake, Idaho	33	Aug. 25, 1912	Kemmerer, et al, 1923
Karluk Lake, Alaska	26	Aug. 15, 1926	Juday, et al, 1932
Priest Lake, Idaho	26	Aug. 17, 1911	Kemmerer, et al, 1923
Sullivan Lake, Washington	23	Aug. 5, 1911	Kemmerer, et al, 1923
Lake Washington, Washington	26	Aug. 9, 1913	Kemmerer, et al, 1923
Lake Washington, Washington	39-49	.....	Scheffer and Robinson, 1939

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TABLE 21. Thickness and Temperature of Epilimnion, and Depth to and Temperature in the Hypolimnion of New York Lakes. Data Modified From Table III, Birge and Juday, 1914.

Lake	Year	Depth of Lake (feet)	EPILIMNION		HYPOLIMNION	
			Thickness (feet)	Temperature (°C.)*	Depth to (feet)	Temperature (°C.)*
Canadice	1910	83	23	22.2-21.8	39	11.2-8.0
Canandaigua	1910	280	39	21.7-19.7	66	8.2-5.4
Canandaigua	1911	...	39	20.7-18.3	66	7.7-4.3
Cayuga	1910	435	49	19.8-19.2	72	9.8-4.4
Cayuga	1911	...	53	20.0-18.6	69	9.3-4.1
Hemlock	1910	90	26	22.0-21.7	46	12.4-9.3
Keuka	1910	183	30	21.2-19.3	49	9.7-6.4
Keuka	1911	...	36	20.6-19.5	59	7.1-4.8
Owasco	1910	177	39	21.5-19.5	66	10.8-7.0
Owasco	1911	...	39	19.8-19.5	66	9.3-6.3
Owasco	1912	...	49	19.6-18.2	66	10.1-7.3
Seneca	1910	618	39	20.0-18.0	66	10.2-4.2
Seneca	1911	...	49	20.0-18.4	72	7.5-4.0
Skaneateles	1910	297	30	22.7-19.0	59	9.3-5.4
Skaneateles	1911	...	52	19.6-18.8	72	9.5-4.4

* The first figure gives the temperature at the top of the layer and the second figure the temperature at the bottom of the layer.

Because variations in temperature for a given depth have been reported in natural lakes, Welch (1935), temperatures were recorded at two or more distances from the dams in the impoundments surveyed in 1941 and 1942. It was found that for equal levels the water temperature is nearly the same throughout the main part of the reservoir. Typical examples of the temperatures observed are shown in Figure 5. The difference at the station 9 miles from the dam on Lake Mervin is explained on the basis of the large inflow of cool river water over the relatively shallow depth at this station. The principal study of reservoir water temperatures accordingly is based upon series of observations made at points from 1/4 mile to 1 mile above the dams. The distribution of temperatures with respect to depth and time of the year, for 14 of the lakes surveyed are shown in Figure 9. The data for Owyhee for 1938 and 1939 were supplied by the U. S. Bureau of Reclamation.

The temperature data have been studied to determine whether a thermocline could be distinguished by the criterion of a temperature decline of 0.3° C. per foot, and to determine the thickness of the epilimnion in those reservoirs where such a thermocline developed.

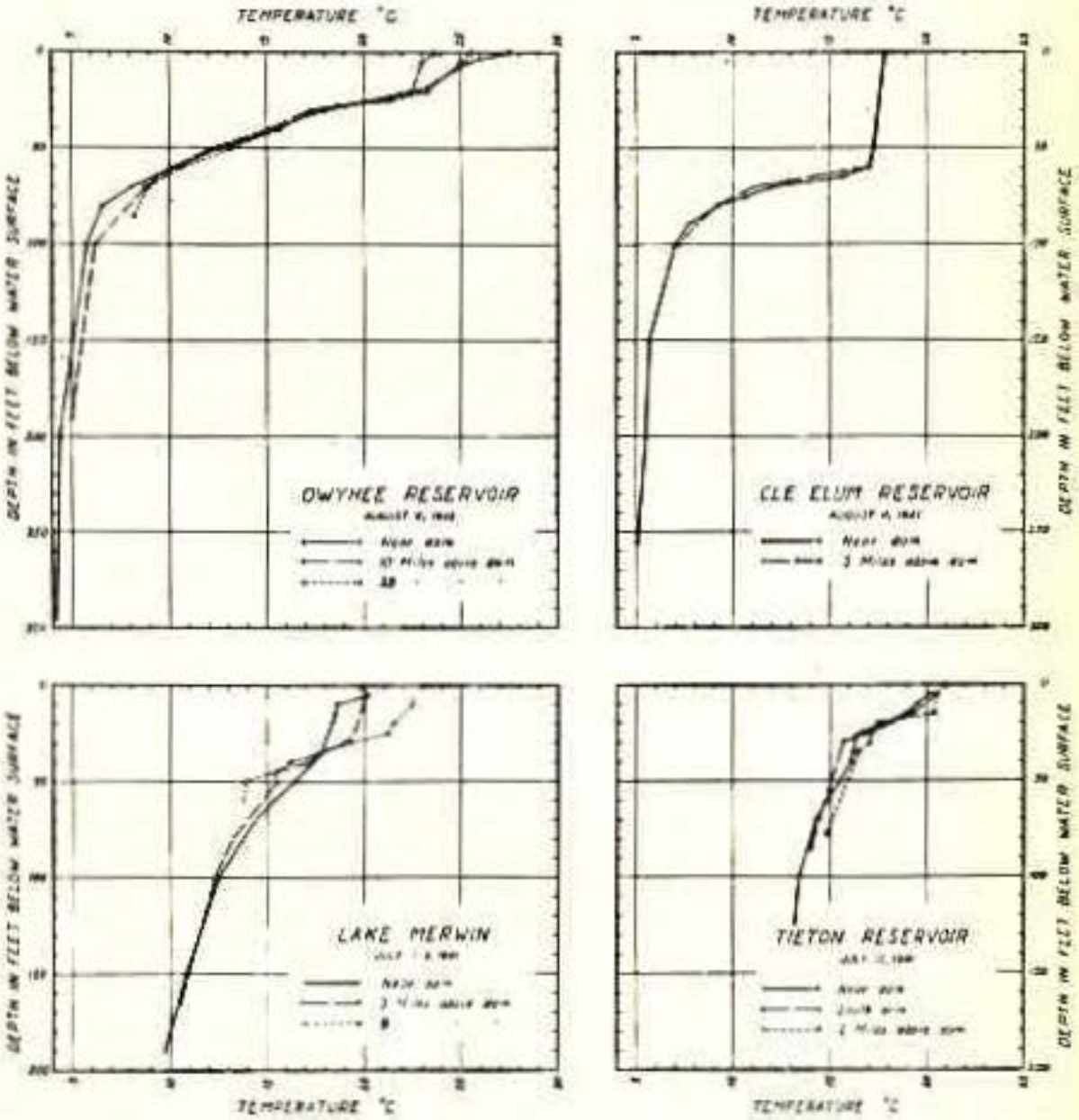

Figure 5. Variation between depth-temperature relation at different distances from the dam in reservoirs surveyed

As indicated previously, the classical concepts of "thermocline", "epilimnion" and "hypolimnion" are not fully applicable to conditions in artificial lakes. These terms are used in the discussion of reservoirs only as they refer to the temperature characteristics of the water. From the data shown in Table 22, it is seen that in the eight reservoirs where a thermocline was formed, the upper boundary of the thermocline varied from 10 to 70 feet depth, and the thickness of the transitional layer varied from 2 to 30 feet.

TABLE 22. Dates and depths over which temperature decline of greater than 1° C. per meter depth was observed in reservoirs studied in 1941, and temperature ranges in water above and below this layer. Data for station nearest to dam.

Reservoir	Date	Thermocline depth (feet)	Temperature range above thermocline (°C.)	Temperature range below thermocline (°C.)
	1941			
Bull Run	3/26	15-17	8.8	7.5 - 5.5
Bull Run	7/17	10-30	24.2 - 23.1	13.2 - 6.1
Ole Blum	8/4	60-70	17.8 - 17.0	12.0 - 5.1
Ole Blum	9/4	45-47	15.9 - 15.6	9.0 - 6.2
Cushman	7/29	30-45	20.7 - 20.2	15.2 - 6.0
Hardwood	8/20	23-40	19.9	9.6 - 6.1
Bachess	5/25	50-55	13.2 - 10.5	8.0 - 4.2
Bachess	8/2	40-45	18.2 - 17.8	9.8 - 4.4
Keechelus	8/2	25-35	17.5 - 17.2	7.0 - 4.5
Owyhee	8/22	30-60	22.7 - 21.3	8.7 - 4.6
Salmon	8/21	40-45	19.2 - 16.7	12.7 - 7.6
	1942			
Hardwood	8/18	25-40	20.5 - 18.6	8.3 - 5.9
Herwin	7/1	17-25	22.2 - 19.6	13.7 - 8.8
Owyhee	8/8	30-50	27.5 - 18.1	12.5 - 4.2

Figure 6 shows better than any description, the variations in temperature with depth in the water of the reservoirs investigated. Except in Lake Herwin in February (when the temperature was quite uniform from top to bottom at 5.7 to 5.9° C.) all the lake observations showed that some thermal stratification occurred which gave rise to the characteristically shaped curves of temperature with depth when the data were plotted. With the advance of the season the temperature of the water in the reservoir at all levels was observed to increase (in those reservoirs visited more than once), but the water of shallower depths increased in temperature most rapidly. In Herwin, which was visited most often during the summer, the maximum temperature of the surface

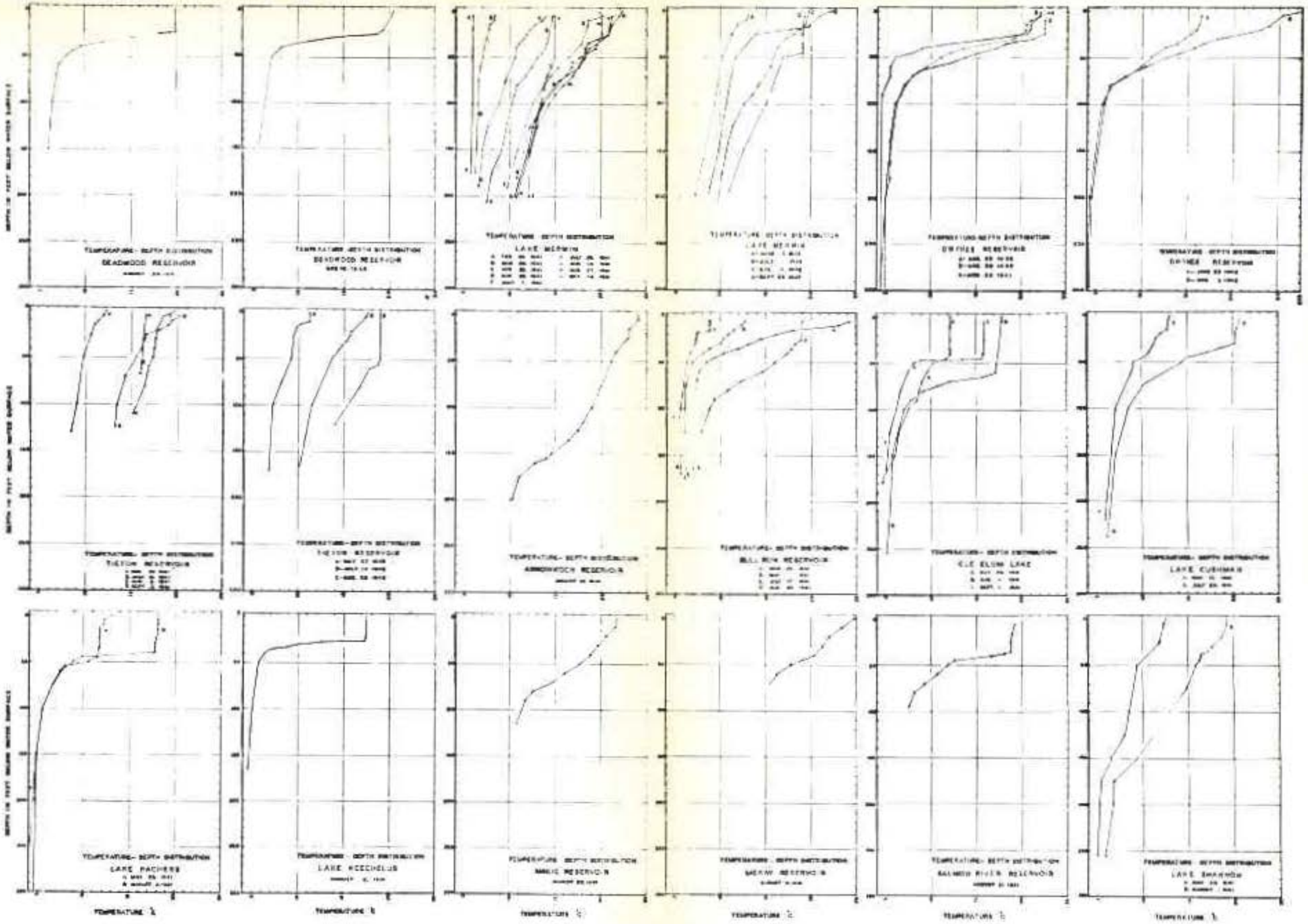

Figure 6. Variation in water temperature with depth and date in reservoirs surveyed.

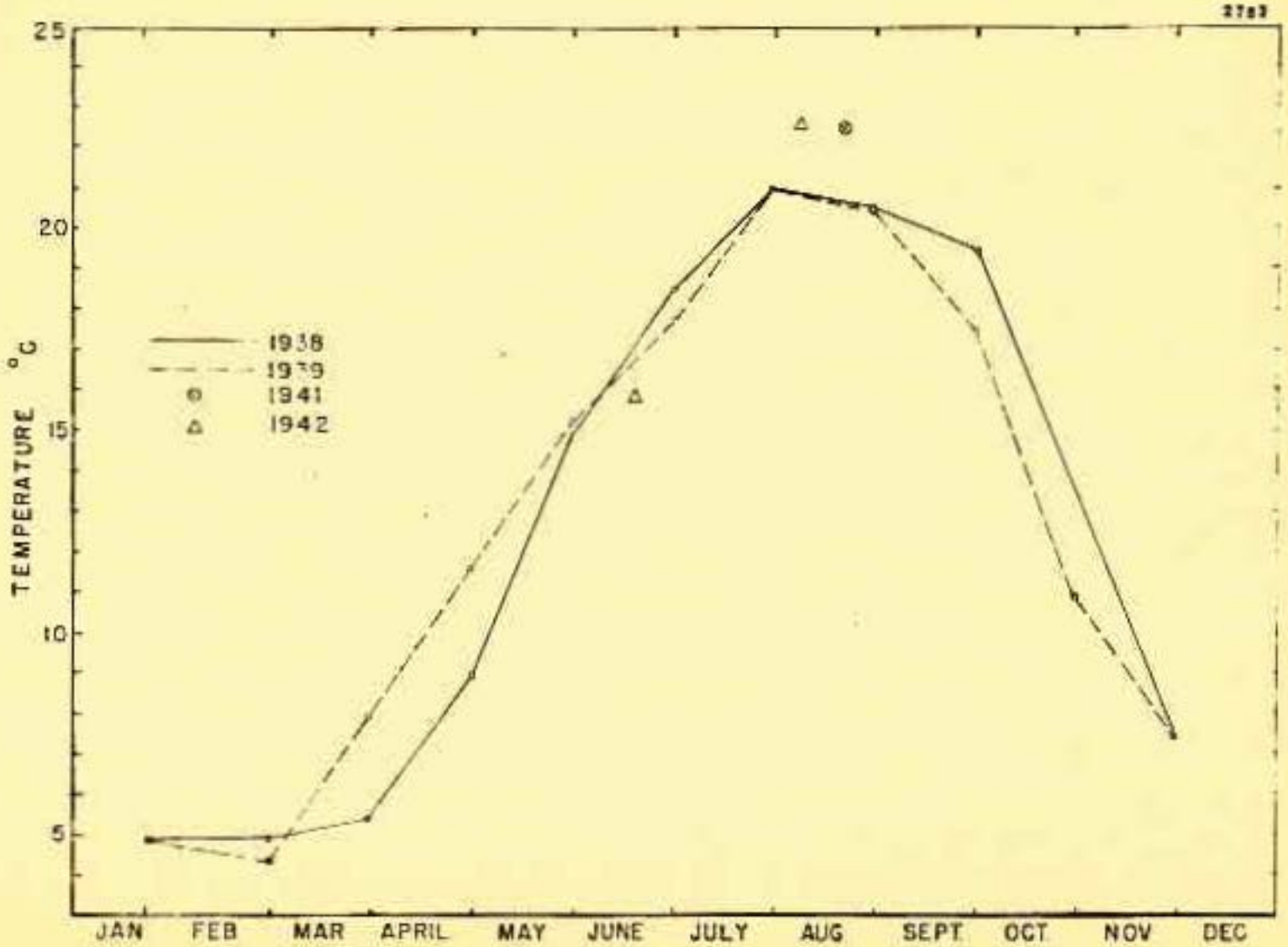

Figure 7. Average temperature of the surface 30 feet in Owyhee reservoir at the end of each month in 1938 and 1939, and on August 22, 1941, June 20, 1942, and August 8, 1942 (Data for 1938 and 1939 supplied by U. S. Bureau of Reclamation).

water was reached in the latter part of July. It appears from what data are available from other reservoirs that the maximum surface temperatures in them also occurred in the latter part of July or the first week of August. For 1938 and 1939 when monthly temperatures were obtained in Owyhee the maximum average temperature for the surface 30 feet occurred in the July observations (taken during the last four days of the month). The variation in mean temperatures of the surface 30 feet in Owyhee for 1938 and 1939 is shown in Figure 7.

It would seem reasonable to assume that the temperature of the water discharged from a submerged outlet of a reservoir is the same as that of the water in the reservoir at the depth of the outlet. This has been verified by outlet temperatures taken on the same day as reservoir temperatures at three reservoirs. The correspondence of temperatures at the outlet level and of the discharged water are shown in Table 23. These data indicate that the temperature of the water immediately below the dam is close to that of the water at the level of the outlets in the reservoir, but one cannot conclude from this that the temperature of the stream sections below the dam is fixed thereby at the temperature of the outlet water. The water flowing down the stream bed will be subjected to the same thermal influences as a stream that has not been impounded. It may have its temperature increased or decreased in a few miles below the dam, depending upon the air temperature and the amount of stream turbulence. For example, stream temperatures taken at two points along the Tieton River 3 and 15 miles below the Tieton reservoir were observed to be as much as 4° C. above and as much as 2° C. below the outlet temperature. When the stream temperature was lower than the outlet, the station farthest below the dam had a lower temperature than the one nearer the dam, and when the temperature of the stream was higher than the outlet, the reverse was true, indicating that the effects of the thermal forces acting upon the water were progressive and took place in the stream.

TABLE 23. Comparison of Temperature of Outlet Water and of Water at Outlet Depth in Reservoir Lakes.

Reservoir	Date, 1941	Temperature of Outlet Water (°C.)	Temperature of Water at Outlet Depth in Reservoir (°C.)
Cle Elum	May 24	9.4	8.5
Cle Elum	August 4	16.9	17.0
Cle Elum	September 4	16.0	15.9
Keechelus	May 24	10.1	11.5
Keechelus	August 2	17.3	17.2

For the purpose of this study it is assumed that salmon should not be subjected to water temperatures in excess of 16° C. It is, of course well known that salmon do survive temperatures greater than this but 16°C. was arbitrarily selected as a basis for studying the temperature problem because of general agreement among biologists that higher temperatures are likely to be dangerous and should be avoided if possible. A similar analysis could, of course, be made for any other temperature selected as critical.

The data on temperatures were analyzed to determine, for the Willamette River reservoirs, the probability of withdrawing water having a temperature in excess of this selected value. Because all of the reservoirs surveyed had summer surface temperatures in excess of 16° C., it was concluded that the surface layer of water must not be withdrawn before its temperature drops below 16° C. some time in the fall. Most of the reservoir surveys did not extend late enough in the season to show the time of cooling. Lake Cle Elum had dropped to 14.9° C. on September 4, 1941; Tieton was at 16.6° C. on September 3, 1941. Differing from these, the surface of Lake Merwin had a temperature of 19.1° C. on September 22, 1942; and Owyhee (See Figure 7) evidently does not drop to 16° C. until about the middle of October. It is concluded that the surface temperatures in the proposed Willamette Valley reservoirs can not be relied upon to drop below 16° C. before the end of salmon spawning about October first.

Having concluded that the surface layer of warm water should not be withdrawn from the reservoirs, the probable depth of the warm water must be considered.

Table 24 shows, for each of the reservoirs surveyed in 1941 and 1942, the depth to which water as warm as 16° C. extended and the dates of the observations. These depths range from 17 to 140 feet and average 52 feet. This range is so great that it is of little value in forecasting future conditions in the Willamette reservoirs unless the data can be further analyzed.

Several factors could affect the depth of the warm surface layer of water in a reservoir with a deep outlet. Among them are (1) wind action, which tends to mix the water and thereby to increase the volume of water in the epilimnion, (2) accumulation in the epilimnion of warm water flowing into the reservoir (3) withdrawal of warm water through the submerged outlets in extreme cases of drawdown, and (4) movement of a constant quantity of warm water into a narrowing section as the reservoir is drawn down. Factors (3) and (4) did not apply to most of the reservoirs surveyed which were not significantly drawn down during the seasons of observation. Tieton and Cle Elum reservoirs were drawn down and factors (3) and (4) were observed to apply.

TABLE 24. Depth of Surface Layer of Water Warmer Than 16° C. in Reservoirs Surveyed in 1941 and 1942.

Reservoir	Date Surveyed	Depth of Water Warmer Than 16° C. (feet)
	1941	
Arrowrock	8/18	140
Bull Run	7/17	20
	8/29	50
Clu Klum	8/4	62
Cushman	7/29	43
Deadwood	8/20	30
Keechelus	8/2	41
Keechelus	8/2	28
Magic	8/20	60
McKay	8/16	64
Merwin	7/7	54
	7/28	71
	8/14	71
	8/28	78
Owyhee	8/22	43
Salmon	8/21	41
Shannon	8/1	48
Tieton	7/15	42
	8/5	90
	9/3	59
	1942	
Deadwood	8/18	25
Merwin	7/1	20
	8/4	40
	9/22	68
Owyhee	6/20	17
	8/8	37
Tieton	7/14	19
	8/26	90

When Tieton reservoir was examined on July 15, 1941, water warmer than 16° C. extended to a depth of 42 feet, and consisted of 62,000 acre-feet of water. Between July 15 and August 5, when the next examination was made, the reservoir had been drawn down about 30 feet. On the latter date the water warmer than 16° C. extended to the bottom of the reservoir at a depth of 90 feet. The quantity of warm water, however, was almost exactly the same as on July 15.

In 1942 the Tieton reservoir was not drawn down far enough to draw upon the 16° C. water. On July 14 water warmer than 16° C. extended to a depth of 19 feet and consisted of 38,000 acre-feet. During the next 43 days to August 26, the reservoir was drawn down 30 feet and the water warmer than 16° C. extended to a depth of 90 feet. Of the 71 feet of increase in depth of warm water, 6 feet can be accounted for as due to drawdown of the surface water into a narrower section of the reservoir, and the remaining 65 feet was due to an increase in amount of warm water to more than double its volume on the earlier date.

Lake Cle Elum in 1941 illustrates the effects of withdrawing from the surface layer. On August 4 the water warmer than 16° C. extended down to the submerged outlet, 64 feet below the surface, and consisted of 175,000 acre-feet. During the following month the reservoir was drawn down 38 feet. At the end of that time the surface layer having a temperature slightly less than 16° C., had become reduced to a depth of 45 feet and consisted of approximately 95,000 acre-feet of water. Approximately 80,000 acre-feet of the warm water had been drawn off during the month.

The great depth of warm water in Arrowrock reservoir can be explained in part by drawdown, which caused the previously warmed surface layer to occupy a narrower and therefore a deeper space. The 140-foot layer of warm water observed on August 18 represented 128,000 acre-feet of water. On July 1 when the water surface was 65 feet higher than on August 18, this volume of surface water occupied a depth of only 40 feet.

After eliminating the data on Arrowrock, Tieton and Cle Elum reservoirs because they were influenced by drawdown, the remaining data were inspected for evidences of a seasonal increase in the depth of the surface layer of warm water that could be ascribed to other factors. Most of the reservoirs that were surveyed more than once during the summer show the expected increase. The prevailing rate of increase in depth of warm water through July and August was judged to be approximately 0.6 foot per day. Owyhee reservoir in 1938 and 1939 is an outstanding exception, in that the water warmer than 16° C. extended to a nearly constant depth from in June until the end of September. Lake Merwin also presented irregularities. In 1942 the depth of the surface layer with temperature above 16° C. followed very closely the estimated increase of 0.6 foot per day. It increased from 20 feet on July 1 to 40 feet on August 4, and to 68 feet on September 28. In contrast with this, in 1941 the warm layer in Lake Merwin first increased in depth from 54 feet on July 7 to 71 feet on July 28; showed no further increase by August 14; then increased to 78 feet by August 28.

By interpolation in the case of reservoirs that were surveyed more than once, and approximation in the case of some others that were visited once near August first, the approximate depth of water warmer than 16° C. on August first was estimated. The data are given in Table 25. These values range from 27 to 71 feet and average 40 feet.

TABLE 25. Approximate Depth in Reservoirs on August First of Water Warmer Than 16° C.

Reservoir		Depth (Feet)
Bull Run	1941	34
Cushman	1941	45
Keechelus	1941	40
Keechelus	1942	27
Norwin	1942	71
Norwin	1942	38
Shannon	1941	48
Owyhee	1938	32
Owyhee	1939	33
Owyhee	1942	34
Average		40

Upon the basis of this average depth on August first and the observed rate of deepening of approximately 0.6 feet per day it is estimated that the surface layer of water warmer than 16° C. would extend to a depth of 67 feet by the middle of September and to 76 feet by the end of September. This at best, is only a rough approximation, as it is based upon the average of variable data and involves the unreliable procedure of extrapolation. However, it is the best available estimate of the depth to which water warmer than 16° C. would extend in the proposed Willamette Valley reservoirs if there was no drawdown.

*The schedules of operation for the proposed Willamette Valley reservoirs (see Figure 8) call for a great amount of drawdown during the summer months, which would increase the depth of the surface layer of warm water. Taking the Detroit reservoir as of 1934 as an example, it is found that the reservoir would be completely filled during the spring and drawdown would start about June first. On August first it would be drawn down approximately 41 feet; on September first 87 feet; and on October first 162 feet. If, upon the basis of the preceding analysis of existing reservoirs, it be assumed that the surface layer of water warmer than 16° C. would have a depth of 40 feet on August first, this

*Editorial note: See Addendum. Due to changes in location, height, storage capacity, and schedules of operation of the major reservoirs, the application of observed temperature stratification in reservoirs to the proposed reservoirs in the Willamette Project must be restudied and modified to conform with the revised plans.

warm water would consist of 45,000 acre-feet. If it be assumed further that the quantity of warm water would not increase during the remainder of the summer, it still would increase in depth (thickness) as it was drawn down into the narrower part of the reservoir, and would reach the elevation of the bottom of the outlet about September 5. Following that date the discharge drawn from storage would be exclusively water above 16° C. Similar calculations for other years and all reservoirs are given in Table 26.

TABLE 26. Calculated dates on which water warmer than 16° C. would reach bottom of reservoir outlets, upon basis of proposed schedules of reservoir operation and the assumptions that the warm water would occupy a depth of 40 feet on August 1 and that following that date the quantity of warm water would remain constant.

Year	Reservoir			
	Lookout Point	Quartz Creek	Detroit	Sweet Home
1928	Oct. 15	Oct. 25	Oct. 25	Aug. 20
1929	Oct. 25	Oct. 20	Oct. 15	Sept. 1
1930	Oct. 1	Oct. 10	Sept. 20	Aug. 25
1931	Sept. 25	Oct. 20	Sept. 15	Aug. 25
1932	Nov. 1	Oct. 25	Nov. 1	Sept. 15
1933	Nov. 1	Oct. 25	Oct. 25	Oct. 10
1934	Sept. 5	Oct. 5	Sept. 5	Aug. 15

The above computations do not take into consideration the observation that the volume of warm water increases as the season progresses. The Detroit reservoir, as of 1934, is used again to illustrate the addition of this factor of increasing volume of warm water. In this case computations start with July first. Assuming a 40-foot depth of warm water on August first and an increase in depth of 0.6 foot per day as a result of increasing volume alone it is estimated that the depth of warm water on July first would be 21.4 feet. For convenience, the even value of 20 feet is used. This 20-foot layer of water warmer than 16° C. on July first would consist of 32,000 acre-feet of water. By August 26, the volume of warm water would have increased to 63,000 acre-feet and the layer would have reached the bottom of the outlet. Similar calculations for other years and all reservoirs are given in Table 27.

TABLE 27. Calculated dates on which water warmer than 16° C. would reach bottom of reservoir outlets, upon basis of proposed schedules of reservoir operation and upon the assumptions that the warm water would occupy a depth of 20 feet on July 1, that the quantity of warm water would be increased by the addition of 0.6 feet per day at the bottom of the warm layer, and that the depth of warm water would be increased by this warm water being lowered into narrower sections of the reservoir as the reservoir was drawn down.

Year	Reservoir			
	Lookout Point	Quartz Creek	Detroit	Sweet Home
1928	Sept. 17	Oct. 3	Sept. 18	Aug. 13
1929	Sept. 28	Oct. 2	Sept. 18	Aug. 18
1930	Sept. 12	Sept. 18	Sept. 3	Aug. 18
1931	Sept. 5	Sept. 24	Sept. 3	Aug. 15
1932	Oct. 5	Oct. 5	Oct. 2	Aug. 22
1933	Oct. 6	Sept. 21	Oct. 9	Sept. 1
1934	Aug. 29	Sept. 12	Aug. 26	Aug. 4

Another factor must be taken into consideration in forecasting the temperature of water to be withdrawn from the proposed reservoirs. In general the water entering the reservoir would flow along the bottom of the reservoir until it reached water of the same density. As temperature probably would be the only factor influencing density, it safely may be concluded that the inflow would contribute to the water in the reservoir of the same temperature. It accordingly might add to the surface layer of warm water or flow under it, either to mingle with water at a greater depth or to be drawn off through the bottom outlet.

Upon the basis of data for 1941 and 1942, presented in Figure 4, it appears that the water of the North Santiam River entering the Detroit reservoir never would reach a temperature as warm as 16° C. Therefore, when the reservoir was drawn down to the extent of drawing upon the warm surface layer, the cooler inflowing water would run along the bottom of the reservoir and be drawn off without extensive mixing with the stored water. The temperature of the stream just below the reservoir would depend therefore upon the temperatures and relative quantities of stored and inflow water that were drawn off. Again taking the year 1934 as an example it is found by reference to Figure 8 that during the month of September approximately 70 per cent of the outflow would be from storage and 30 per cent from the natural inflow. By reference to Figure 4 it is found that the trend of daily mean temperatures of inflow is from approximately 12° C. at the beginning of September down to 9° C. at the end of that month. The inflow on September first at a mean temperature of 12° C. (representing 30 per cent of the outflow)

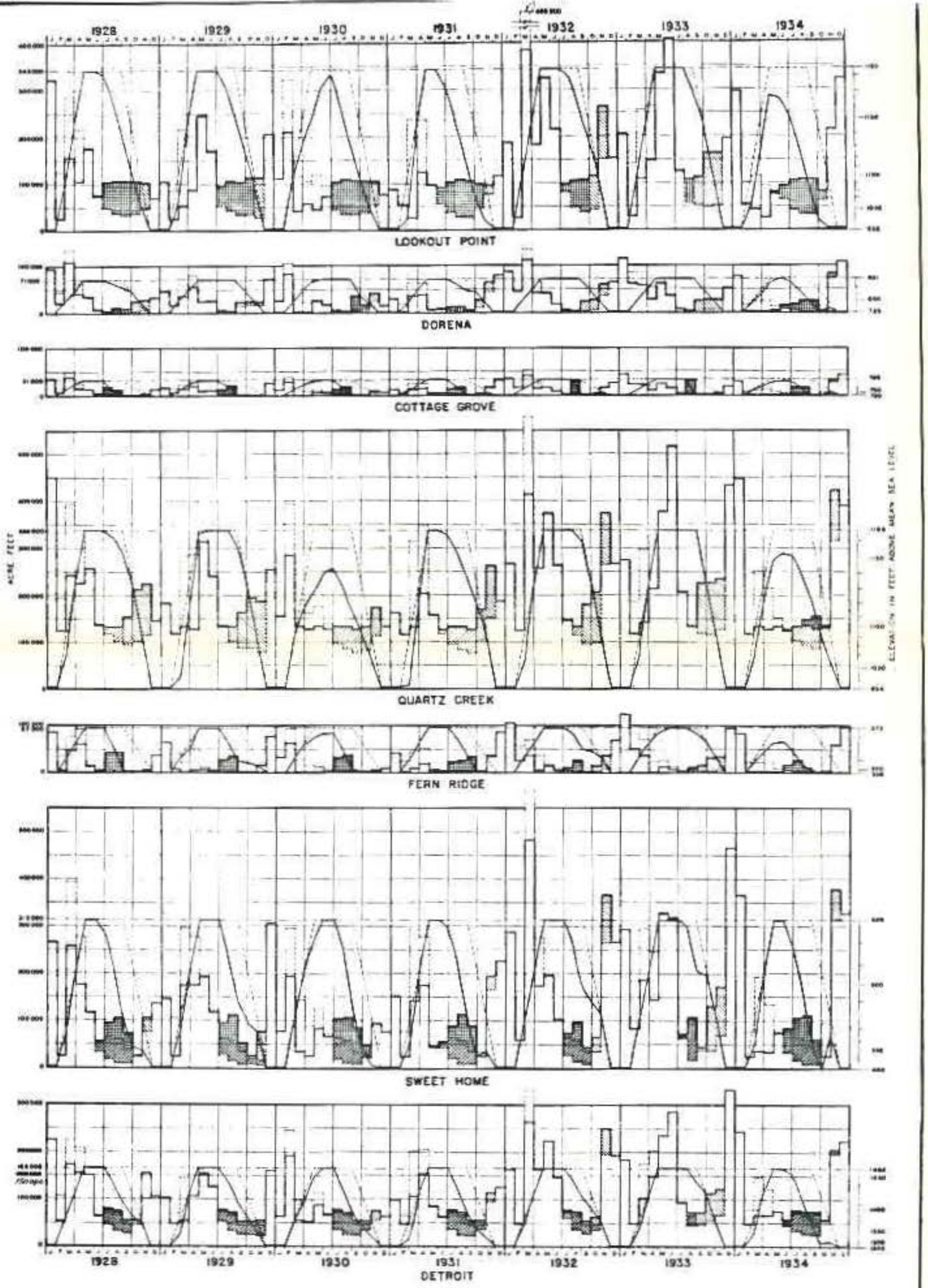

PLATE XX

Figure 8. Proposed schedules of operation of reservoirs of initial development in Willamette Valley. (Note error in left marginal scale of bottom panel; the lower 200,000 should read 150,000)

would compensate for stored water at 17.7° C. in maintaining an outflow temperature of 16° C. Upon the same basis, the 10.5° C. inflow at the middle of September would compensate for stored water at 18.3° C; and 9° C. inflow at the end of September would compensate for stored water at 19° C.

The year of 1934 is the most extreme of seven years for which proposed schedules of operation are presented. In such a year the reservoir would be drawn down most rapidly and during the critical month of September the proportion of discharge that would come from storage would be the greatest. Both conditions would contribute toward high temperature of outflow. The next most serious year, 1931, presents the following conditions: Assuming the conditions presented in Table 27, the 16° C. water would reach the outlet about September 3. During September, inflow would contribute 40 per cent of the outflow. In this case the water drawn from storage during the middle of September could have a temperature of 19.7° C. without causing the mixed outflow to exceed 16° C.

The Quartz Creek reservoir on the McKenzie River presents no problem from the standpoint of the temperature of the outflow. According to the proposed schedule of operation, it would not be drawn down as early as the Detroit reservoir and the inflow is cooler. In a year like 1934, the worst of the seven example years, the warm water theoretically would not reach the outlet until September 12 (See Table 27). At that time inflow having a mean temperature of approximately 10° C. would contribute approximately 55 per cent of the outflow. This inflow accordingly would compensate for stored water at 23.3° C. while maintaining a combined outflow at 16° C. Even the warmest of the stored water probably would not reach 23° C.

The Lookout Point Reservoir on the Middle Fork presents no possibility of warm outflow, except in a year like 1934, when the 16° C. water theoretically would reach the outlet on about the first of September. At that time the inflow, contributing 30 per cent of the outflow, would have a mean temperature of about 14° C. By the middle of September, when the mean inflow temperature would be about 12.5° C., the water drawn from storage could be as high as 17.5° C. without producing a mixed outflow temperature in excess of 16° C.

The Sweet Home reservoir on the South Santiam River presents a serious problem from the standpoint of temperature of outflow. Even the more conservative estimates which are presented in Table 26 indicate that in six of the seven example years the 16° C. water would reach the outlet before the end of the salmon spawning period. Upon the basis of a continually increasing volume of warm water, as presented in Table 27, the warm water usually would reach the outlet in August.

The situation at the Sweet Home reservoir is made more serious by the fact that the inflow becomes very warm. In 1942 a daily mean temperature of 23° C. was reached on one occasion, and throughout the months of July and August, and most of September, the daily mean temperature exceeded 16° C. The inflow throughout this period would contribute to the surface warm layer in the reservoir, thereby increasing its volume and causing it to reach the outlet earlier.

Before summarizing the preceding analysis of reservoir temperatures, the authors wish to emphasize the fact that the forecasts of discharge temperatures are based upon rather limited observations of existing reservoirs that differ significantly from the proposed Willamette Valley reservoirs. Certain average temperature conditions observed to prevail in the surveyed reservoirs have been assumed to apply under the specific physical and operational conditions presented by the proposed reservoirs. As the observed temperature conditions were extremely variable, the averages applied to the proposed reservoirs must be looked upon as only approximations of the most probable values. The conclusions reached accordingly must be considered only as tentative and approximate.

Two principal factors have been assumed to influence the depth of the surface layer of warm water in the proposed reservoir. One is the gradual increase in volume of warm water and the other is the deepening of a warm layer of constant volume by confining it in a narrower section of the reservoir as a result of lowering the water level. These two factors, observed to prevail independently in existing reservoirs, have been assumed to prevail simultaneously in the proposed reservoirs. This assumption probably is not entirely justified. The more probable situation is that the actual result will fall at some point between that determined by one of the two factors alone and the combination of the two. Accordingly, the dates on which water warmer than 16° C. would reach the reservoir outlets probably would be between those presented in Table 26 and those in Table 27.

It also is to be noted that the temperature of 16° C. was arbitrarily selected as the maximum to which salmon should be subjected. The tolerance of salmon to high temperatures has not been adequately investigated. It is known, however, that temperature tolerance is influenced by other conditions such as condition of the fish, concentration of fish, volume of water, and gas and chemical content of the water. A safely low value accordingly has been selected for the preceding analysis. The selected temperature of 16° C. includes not only the surface, circulating layer of nearly uniform temperature (the epilimnion), but also a part of the thermocline in which the temperature changes rapidly with depth. Therefore, if a slightly higher temperature had been selected, lesser values for the depths of the surface warm layer would have been obtained, and the computed dates on which this warm layer would reach the outlets would have been somewhat later.

From the preceding analysis of reservoir temperatures it appears that, at least in some years, stored water warmer than 16° C. would be withdrawn from all reservoirs during the last month or more before the salmon complete spawning. In the case of the Detroit, Quartz Creek and Lookout Point dams the mixture of this warm, stored water with the cooler inflow usually would produce a mixed outflow cooler than 16° C. However, in extremely low-water years such as 1934 it is probable that the outflow at Detroit and Lookout Point would slightly exceed 16° C. The Sweet Home dam on the South Santiam River would present a more serious problem in water temperatures. In this reservoir it appears quite certain that water from the epilimnion, at temperatures probably exceeding 20° C.,

would be withdrawn during a considerable period of time during which the inflow is too warm to improve the situation. It has been mentioned above that salmon do survive water temperatures above the selected critical temperature of 16° C. but that these higher temperatures are not considered desirable if they can be avoided.

Consideration has been given to the possibility of preventing too high a temperature of the outflow from the proposed reservoirs by modification of operating schedules or design of the dams. It appears that the slight danger, in exceptional years, of warm outflow at the Detroit and Lookout Point reservoirs might be eliminated by holding in those reservoirs a part of the water that is scheduled for release for navigation during August and September and drawing more heavily upon the Quartz Creek reservoir. Another possible remedy for these two reservoirs would be to increase the initial height of the dams so as to provide more dead storage. Neither of these corrective measures could be applied to the Sweet Home reservoir. A radical change in operation schedules would be required to permit the withdrawal of only cool water from that reservoir. It is assumed that the height of the dam could not be increased because the initial development calls for building it to its full height.

Chemical Constituents

The lake surveys of 1941 and 1942 included considerable work to determine the chemical changes undergone by water on storage. While it was possible in the case of water temperatures to classify the lakes studied and to predict within limits the probable temperatures at the level of discharge from the proposed Willamette reservoirs, much less exact conclusions are possible from chemical analyses of the water. The chemical constitution of stored water was found to vary in such unpredictable ways as to invalidate specific conclusions regarding conditions in an unexamined reservoir.

Samples were taken by a one-liter Kemmerer closing bottle. In the earlier surveys water samples were taken at depths 10 to 25 feet apart, but after peculiar variations were found it was usual to take samples every 5 feet to a depth of 80 feet and thereafter 10 to 25 feet apart to the bottom. All chemical determinations were made in accordance with the "standard methods" of the American Public Health Association (1936), most analyses being conducted in the field with the aid of portable equipment.

At the beginning of the investigation, in 1941, a number of chemical constituents were tested for in several lakes, but as practically no significant results were recorded within the sensitivity of the analytical methods used, these tests were not carried out on later samples, or in 1942. Tests for soluble phosphates, ammonia, nitrites, and nitrates gave results indicating less than the minimum amounts detectable by the methods employed, except that samples taken next to the bottom on two occasions showed traces of phosphates. There remain to be considered

the results of determinations involving dissolved oxygen, hydrogen ion concentration (pH), and methyl orange alkalinity. The first two are factors that change with biological conditions in all bodies of water. Dissolved oxygen is produced in the lighted layers of a lake or reservoir by the photosynthetic activity of aquatic plants as a by-product of the manufacture of carbohydrates. The pH is influenced by the metabolism of both animals and plants and by the decay of organic material on the bottom or in the water. The methyl orange alkalinity is relatively unaffected by processes of metabolism, as it is largely determined by the inorganic material in solution, and is thus dependent upon the source of water and the geological nature of the country through which the water flows before it is stored.

In all of the reservoirs studied the dissolved oxygen concentration, expressed as per cent of saturation (calculated with corrections for altitude) was high at the surface—frequently being in excess of 100 per cent. The variation with depth was quite unpredictable during the summer. In thermally stratified artificial lakes the lower layer always had considerably less than 100 per cent of saturation.

In parts per million of oxygen, however, there was little uniformity. Some examples of oxygen distribution with depth are shown in Figure 9. In one reservoir it remains at a high value from the surface to about 30 feet depth, then suddenly declines to a low amount (sometimes to zero), and after a few feet depth of such oxygen-poor water, the concentration of dissolved oxygen increases again and even exceeds (in parts per million) that of the surface layer in successively deeper samples. In another, it falls off regularly in each sample from succeeding depths. In still another it is at a fairly high value down to about 30 feet depth and then increases in concentration enormously (up to more than 200 per cent of saturation), followed by a rapid decline with depth to rather low values near the bottom. In reservoirs where remarkably sharp increases or decreases in dissolved oxygen concentration were observed, the sudden change occurred in the thermocline region, but in other artificial lakes where temperature stratification of the water was similar, no such variations of dissolved oxygen concentrations in thin strata were noted. In general the impoundments with thermal stratification were more variable in dissolved oxygen content than those that did not stratify.

The changes in dissolved oxygen concentration in the reservoirs during the season show that there is a continual process of decomposition of organic matter in the subsurface water. Samples taken in the early spring show uniformly high oxygen content, as per cent of saturation. In Lake Merwin in February the values were about 95 per cent of saturation at all depths. Similar high concentrations were found in Bull Run in March, and in some other artificial lakes samples taken in May showed a rather uniform saturation with oxygen at all depths. Later in the season the water from lower levels in the reservoirs always showed a low oxygen content -- 15 to 30 per cent of saturation. Artificial lakes with thermal stratification had the greater reduction. For those impoundments which were not visited early in the season, the lower oxygen concentrations found at depths during the summer can safely be assumed to be the result

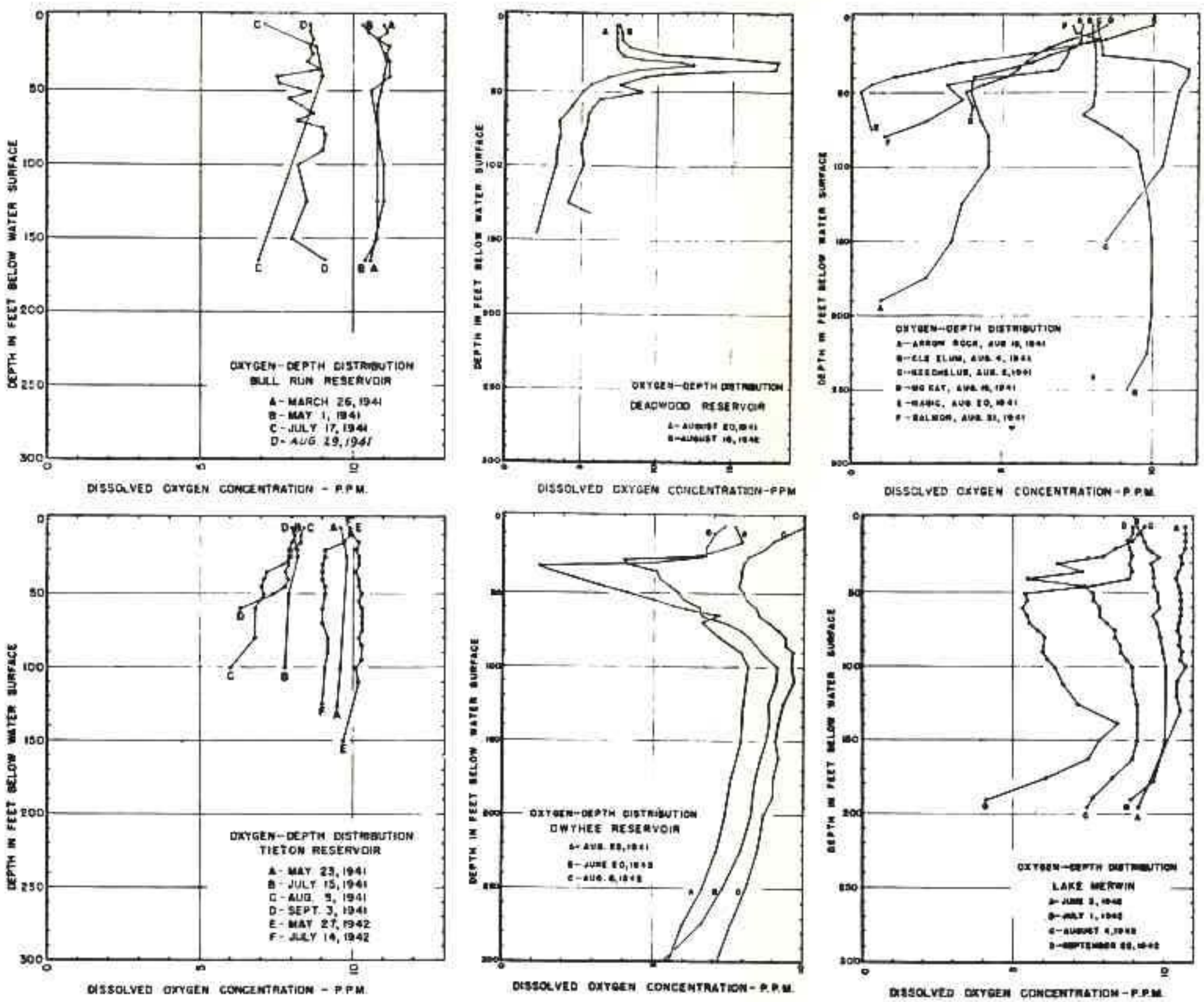

Figure 9. Distribution of dissolved oxygen with depth in reservoirs surveyed in 1941 and 1942.

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of similar processes acting on stored, isolated water which started out, at the spring turn-over, with a high per cent saturation of oxygen. One conclusion from these surveys is, therefore, that discharges from the lower layers of a reservoir lake during the summer and fall will consist (in whatever proportion stored water is to the total discharged) of water in which organic decomposition has taken place, and this water contains the products of such decomposition. Such processes also occur in natural lakes, but these almost always have their outlet (if any) draining only surface water. The dilution of stored water with river water, which was hypothesized in the discussion of temperature, would only tend to reduce the concentration of the decomposition products, it would not eliminate them. This conclusion is of considerable importance, as data to be supplied later show that serious fish-cultural difficulties have been associated with the use of such water.

The hydrogen ion concentration often varied inversely with the dissolved oxygen concentration. The water was found to be alkaline at the surface with an increase in acidity with depth, until in most of the deep reservoirs slightly acid water was found toward the bottom. In strata with high oxygen content, the pH value was high (sometimes exceeding the phenol red range, 8.4); and where a stratum of low dissolved oxygen occurred the water became less alkaline.

With two exceptions the methyl orange alkalinity was uniform from top to bottom in the reservoirs studied. The exceptions occurred in Magic and Owyhee reservoirs. The cause of the variation in Magic reservoir is not known. In Owyhee reservoir it is associated with a phenomenon, other than methanolism, which will be discussed later. The alkalinity of the water varied from reservoir to reservoir. Impoundments west of the Cascade Mountains had relatively low alkalinity, as did Hardwood reservoir, which mainly holds snow water at a high elevation in Central Idaho. Artificial lakes east of the Cascades had higher alkalinity, with those in eastern Oregon and southern Idaho having much higher values than those in the Cascade Mountains of eastern Washington. Methyl orange alkalinity is a useful characteristic for classifying water, as it has been found unvarying as to depth, season, and even between years for most lakes.

Owyhee reservoir exhibits peculiarities in water conditions which were searched for in other artificial lakes, especially Merwin, but were not found well developed except at Owyhee. These conditions are similar to those found by Ellis (1940) in Elephant Butte reservoir and ascribed by him to currents established by sudden inflows of silt-carrying water of high density. Somewhat similar conditions have been observed associated with water of high silt content in Lake Mead. In the reservoirs of the Tennessee Valley Authority, where such conditions have been studied by Wiebe (1939, 1940) it was concluded that the water movements were brought about by the continuous drawdown and the influx of silt-laden water from tributaries. The data for Owyhee reservoir are shown in Figure 10 as two charts showing the distribution of dissolved oxygen (in parts per million) with depth and along the length of the reservoir in late June and early August, 1942. Smoothed lines connect points of equal dissolved oxygen concentration.

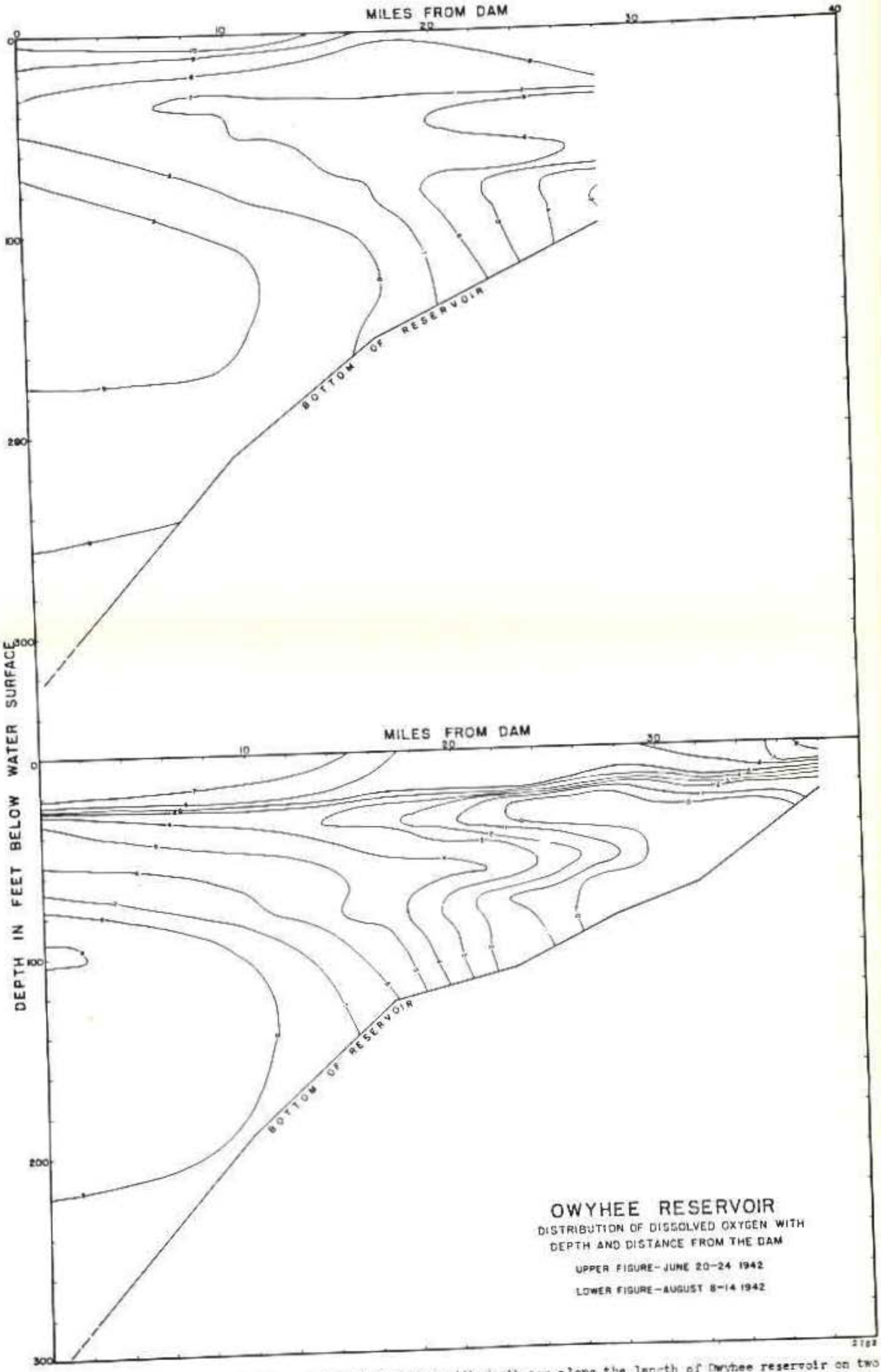

Figure 10. Distribution of dissolved oxygen with depth and along the length of Owyhee reservoir on two dates in 1942. The numbers on the lines indicate the concentration of dissolved oxygen in parts per million. Lines connect points of equal oxygen concentration.

These figures may be interpreted in the following way: During the winter the water in Owyhee reservoir becomes homogeneous. Free circulation can take place, if induced by wind forces, and the entire body of water develops a high dissolved oxygen content, similar to the condition found in Lake Merwin in February. As the lake warms in the spring the subsurface waters become isolated from the surface because of thermal stratification, as described previously. In the spring, also, a large inflow of water occurs, much of it from land drainage in southern Oregon, southern Idaho and northern Nevada, but mixed with sufficient snow water to give the river a low temperature (and therefore a high density). This high density water of rather high organic content (some of it is back drainage from irrigation) settles to the lower levels of the upper end of the reservoir. As water is withdrawn from the reservoir at a depth of about 75 feet, water must move from the upper end of the reservoir to replace that discharged. The result is that a mass of water having high organic-matter content moves out into the impoundment. As the stream temperatures increase in the spring the inflowing water of high organic content reaches a density found in the thermocline depth. As the discharge is only slightly below this level in the reservoir, the water moves along this level rather rapidly. All the time the water has been in the reservoir, the organic matter has been decomposing and taking up oxygen from the water. In the lower levels the process is slowed down because of the low temperatures; nearer the surface the process is accelerated by higher temperatures. The result is that, although the water in the low oxygen zone between 30 and 40 feet entered the reservoir later than that of most of the water of low oxygen concentration at greater depths, the former has lost more oxygen than the latter.

This explanation of water movements in the reservoir accounts for the non-uniform distribution of alkalinity which was observed. The river water, especially late in the spring and summer, had a high alkalinity (this may have been due in part to the contained silt). On June 25, 1942, the Owyhee River at U. S. Highway No. 95 had an alkalinity of 116 p.p.m. It almost certainly was substantially higher in August. During the early spring, however, when the snow-water content of the river was large, both the alkalinity and its silt content must have been lower than in June. Thus we find that in the lower end of the lake, where the silt had partly cleared from the upper levels, the alkalinity increased with depth. Increasing away from the dam we find the alkalinity increasing, and the alkalinity of the surface waters becoming greater than that of the lower levels. Between June and August the alkalinity of the upper end of the reservoir increased due to the movement of high silt-content water down the lake.

The conditions observed in Owyhee reservoir in 1942 serve to explain the dissolved oxygen distribution found near the dam (Figure 10). Similar processes may be acting in Lake Merwin, as evidenced by a slight unevenness in the dissolved oxygen distribution along the length of the reservoir. If so, the organic content of the water in this impoundment must be low, because the oxygen consumption is small, in spite of subsurface temperatures considerably higher than those found at Owyhee.

All the artificial lakes studied had had water in them for 10 seasons or longer. It is unfortunate that no newly filled large reservoir was available for study as it is felt that water conditions, in particular the amount of organic matter to be stabilized, will be quite different in a newly filled reservoir in comparison with one that has had a number of years to "age". A number of observations were made, however, on the water in Fern Ridge reservoir, the first unit of the Willamette Valley Project to be placed in operation. Daily water samples and temperatures were secured at the dam, and several surveys of the impoundment were made during the spring and summer of 1942. As the maximum depth of water reached in these samples was 27 feet, the data have little interest or application in relation to the larger units of the project and will not be presented in detail at this time. The observations are of interest in showing the conditions in a newly filled impoundment, as Fern Ridge reservoir was first filled during the winter of 1941-1942.

Water samples were taken daily in Fern Ridge reservoir from February 14 to August 31, 1942. They were taken at a depth of 5 feet and showed dissolved oxygen concentrations from 10.8 p.p.m. (March) to 3.3 p.p.m. (August). There was considerable daily variation, frequently associated with wind direction and intensity. Samples taken at stations in the lake always showed a decline in dissolved oxygen concentration from the surface to the bottom. The lowest dissolved oxygen concentration was 1.0 p.p.m. at 22 feet on July 9. The total solids content regularly was approximately 70 p.p.m. and the methyl orange alkalinity was an average of the alkalinity values of the two streams flowing into the reservoir. The impounded water became dark brown in color early in July; later a slightly iridescent scum formed on the surface. In spite of the fact that the reservoir covered no previous water area except the beds of the creeks, the water swarmed with algae in July. At all times in July and August the odor of hydrogen sulfide could be detected, and it was pronounced when the water samples were withdrawn from near the bottom. Fern Ridge reservoir gave every indication during the summer of 1942 that the amount of organic matter being stabilized was near the limit of its capacity in the absence of septic conditions. This organic material was derived from the vegetation remaining after the floor of the reservoir was cleared, and from the soil on the bottom. Conditions in Fern Ridge are favorable for the oxidation of these substances and the reaeration of the water. The maximum depth is less than 36 feet. There was evidence that free circulation of the water occurred throughout the warm period, especially at times when strong winds struck the water surface. As the ratio of surface area in acres to volume in acre feet (1:11) was relatively large (this value for typical impoundments is: Hardwood, 1:52; Marmin, 1:109; Cayuga, 1:89; and Tieton, (1:50), aeration was probably effective in maintaining the dissolved oxygen concentration above zero. It is doubtful that similar conditions will obtain in the larger units of the Willamette Valley Project, where the ratio of surface area to volume will vary from 1:61 to 1:97, and where great depths of water will make thermal stratification likely. Septic conditions will probably occur in the lower strata of these reservoirs during the first years after construction. Better water might be achieved by more thorough clearing

of the bottom, particularly by burning all combustible material (or even by stripping top soil, especially from low areas where the organic content is particularly high). It would probably be prevented also by modifying the storage and release schedules during the first years of dam operations so as to decrease the length of time that water stands in the reservoir.

Previous Experience With Stored Water for Salmon Propagation

In preceding sections, the temperature and chemistry of stored water have been described as they were found in a number of impoundments and a rough forecast were made of temperature and chemical conditions that might prevail below the dams of the Willamette Valley Project. It was concluded that temperatures will be suitable in most cases, but that the chemical changes in storage lead to the accumulation of decomposition products in the water that may be harmful to fish.

Some doubt has been cast upon the suitability of stored water for fish life by past observations made on the North Fork of the Lewis River, in western Washington. An impassable dam (Merrill), erected to store water for power production, was constructed in 1927 and 1928 at a point about 20 miles upstream from the Columbia River. To protect the fish runs, a hatchery and holding pond were constructed on a small tributary, Colvin Creek, approximately three miles below the dam. The hatchery water supply was derived principally from the Lewis River supplemented by the small flow of Colvin Creek.

Prespawning losses of adult salmon held in the Colvin Creek pond following capture at Merrill Dam were severe. Likewise, an abnormally high mortality of eggs, fry, and fingerlings was reported at the hatchery during periods when Merrill Dam was discharging stored water. These observations led to studies of the Lewis River salmon problems during 1937 and 1938 by K. T. Smith of the Washington State Department of Fisheries. Smith* found that adult fish trapped at Merrill Dam and transferred to a small tributary, Cougar Creek, a few miles above the dam could be held with much lower mortality than was experienced at Colvin Creek. Although several variables may be found in a comparison between the waters of Cougar Creek and those of the Lewis River at Colvin Creek, Smith concluded that some unidentified factor associated with water storage was responsible for the abnormal mortality at Colvin Creek. From this conclusion, a general distrust of stored water for fish-cultural purposes has developed.

Assuming the existence of an unknown toxic factor associated with the impounded water of Lewis River as postulated by Smith, it appears that the operation at the Merrill Dam has little in common with that at the proposed dams of the Willamette Valley Project.

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*Unpublished data furnished by Washington Department of Fisheries.

Ariel Dam is at such a low altitude that the Lewis River is a quiet stream devoid of rapids in the section between the dam and the Columbia River. Field analyses are reported by Smith showing virtually no increase in the oxygen concentration as the water moves between Ariel Dam and the mouth of Colvin Creek even when the discharged water is less than 60 per cent saturated. Likewise, when the discharged water has a high carbon dioxide content, it is reported to lose only a minute amount through equilibration with the atmosphere. In contrast with this picture, the tributaries of the Willamette below the proposed dam sites are highly turbulent streams. For example, the drops in the first ten miles below the proposed dams are: Detroit, 310 feet; Sweet Home, 115 feet; Quartz Creek, 160 feet; and Lookout Point, 120 feet. Each of these streams abounds in white water reaches, where intimate contact is maintained between the water and the atmosphere, which promotes rapid reaeration of the stream. If the factor which makes Lewis River water unsuitable for fish culture is a volatile substance, it would be lost from water discharged from a Willamette dam (if, indeed, it was present), within a short distance downstream.

Another point of difference between Lake Merwin (Ariel Dam reservoir) and the proposed Willamette reservoirs is in the period of retention of water in the impoundment. The volume of water to be discharged from the Willamette dams would be greatly in excess of the normal river flow in August and September. From Lake Merwin, on the other hand the discharges for power generation are carefully adjusted to equal the inflowing water from the Lewis River. There is, therefore a marked difference in the percentage of Lake Merwin water that is drawn off during the month of August (say) and the percentage discharge from the proposed Willamette reservoirs. A volume of water equal to only 16 per cent of Lake Merwin was drawn off in August, 1941. If the Willamette reservoirs had been operating according to the plans for the initial development during the years 1928 to 1934 they would have discharged volumes of water equal to 29 to 68 per cent of their August first volumes. All this demonstrates that the rate at which water will pass through the proposed Willamette reservoirs is much higher than that at Lake Merwin, and hence the average period for the effects of storage to accumulate will be much shorter for the Willamette impoundments.

A factor distinctly different between Lewis River and proposed conditions on the Willamette River tributaries is the manner of holding the maturing adult fish. A large part of the Lewis River mortalities were in fish held in Colvin Creek ponds but no maturity, or in eggs from fish matured in these ponds. In the proposed holding areas on the Willamette River tributaries, the maturing fish will be confined to sections of the natural streams (as they are at present, by the Oregon Fish Commission), and not to small ponds. There was no evidence that fish in the main Lewis River below the dam reacted unfavorably to the water conditions there.

In summary, it is believed that by exercising adequate precaution in removing decomposable material from the areas to be flooded, the waters as found several miles below the proposed dams of the Willamette Valley Project will prove as suitable for the maintenance of the fishery resources as they are at the present time.

Effects of Willamette Valley Project on Resident Trout

Each of the tributaries of the Willamette River to be dammed provides trout fishing for hundreds of anglers each year. This fishing is distributed over many linear miles of streams, a large part of which is above the dams and includes the reservoir areas. Highway surveys conducted on several Saturdays and Sundays on the McKenzie River between McKenzie Bridge and Walterville Bridge in 1941 indicated that from one-fifth to one-third of the men fishing from the bank were fishing in the sections of the river that would be flooded by the reservoir.

On the Middle Fork of the Willamette and the McKenzie River there is a relatively high fishing intensity from river boats, operated either by fishermen or professional boat guides. Catches by such anglers are both relatively and absolutely greater than that of sportsmen on foot on the same sections of stream. In 1941 through the cooperation of an association of guides, the location of catch was recorded for 4,929 trout caught before August 25 on the McKenzie River. On this stream boat-fishing is legally prohibited above the mouth of Blue River. From the mouth of Blue River to Quartz Creek—the reservoir area—2,910 trout (59 per cent) were caught; from Quartz Creek to Vida 1,949 (40 per cent) were caught; and below Vida 64 (1 per cent) were caught. These figures indicate that on the McKenzie River a large part of the boat fisherman's catch is made in what will be the reservoir area. Interviews with guides who have had extensive experience landing boat fishing parties on the Middle Fork of the Willamette River reveal that probably an even higher proportion of the trout are caught in this stream from boats in the reservoir area than is the case in the McKenzie River.

As boat fishing for trout is one of the important recreational attractions in this part of Oregon, it should be kept in mind as an activity that will be seriously interfered with as the result of construction of dams on the McKenzie and Middle Fork of the Willamette Rivers.

Because of the plans for operation of these reservoirs, which necessitate wide fluctuations of water level, it is probable that the impounded waters will not be productive trout areas. Therefore, the stream sections to be flooded are likely to be of little value for trout fishing. Also, there may be losses to the trout populations because of interference with their natural upstream and downstream movements. This loss of fishing area and possible damage to the trout populations could perhaps be compensated for by additional planting of hatchery-reared trout in these areas.

FISH-MAINTENANCE PROPOSALS

Preceding sections of this report have shown that important and valuable runs of chinook salmon are endangered by the proposed dams of the Willamette Valley project. The designers of the project have recognized the value of these fish and the importance of preserving the runs by anticipating costs of one million dollars for fish facilities (U. S. War Department (1938), paragraph 170). It now remains to decide upon the fish-maintenance proposals which should be put into effect.

Many methods of fish-maintenance have been considered during the course of the Willamette investigations. They have ranged from plans to institute complete natural propagation, with provisions for utilization of spawning grounds above the dam sites, through plans for diversion of the runs to undammed tributaries, to complete reliance on artificial propagation. Each plan has advantages and disadvantages that had to be weighed in relation to other plans, the known life history of the fish, and the proposed designs and operating schedules of the dams. Consideration also had to be given to damage by construction of the dams to the fish-cultural facilities of the Oregon Fish Commission, which that Commission would desire to continue to operate.

Any plan of fish maintenance that includes natural spawning above the reservoir dams would have the advantage of utilizing extensive natural spawning and rearing areas that otherwise would be permanently lost. On the other hand, such a plan would involve the difficult, expensive, and even questionable procedure of providing for the passage at the dams of adult fish migrating upstream and fingerlings on their way to the ocean. The great range of variation in water levels in the proposed storage reservoirs would present a difficult problem in design of fishways. For the passage of upstream migrants, this problem possibly could be solved without the necessity of using untried principles; but provision for the passage of downstream migrants at a high dam with bottom outlet and fluctuating forebay level has never been attempted. The reaction of seaward migrants to such reservoir conditions is unknown. Failing to find a surface outlet, the fish might become landlocked, or they might find their way to the submerged outlets where they probably would be killed by abrupt change in pressure or by the turbulent dissipation of energy in the water below the outlets. Methods of capturing downstream migrants in a reservoir and transporting them over the dam have been proposed, but as none has been tried as yet their feasibility remains unknown. These uncertainties alone are sufficient to discourage recommendation at this time of any plan that requires that the fish pass the storage dams. The plan has the further disadvantage that it is not in keeping with the Oregon Fish Commission's present program of artificial propagation.

The least expensive plan, the one that calls for the least modification of present conditions, and the one that is best adapted to the fish-cultural practices of the Oregon Fish Commission, is to confine the migratory fish to the areas below the reservoirs and to propagate artificially all fish that normally would have migrated beyond the dam sites. Because a great part of the adult fish that normally migrate beyond the dam sites now are taken for artificial propagation, this plan would call for relatively small increases in hatchery capacities for handling eggs and fry. It would be necessary, however, to expand materially the facilities for rearing the fingerlings in order to compensate for the loss of natural rearing area. At the present time the fingerlings reared in the hatcheries are liberated at some time during their first summer. The fingerlings then remain in the stream until the following spring before migrating to the ocean. It has been shown that after liberation from the hatcheries the fingerlings become widely distributed in the stream, even to considerable distances upstream from the point of liberation. Confining the runs to the areas below the reservoir dams therefore would materially reduce the available, natural rearing area. To prevent stocking the remaining area more heavily it would be necessary to retain a part of the fingerlings in the hatchery ponds until migration time.

This plan of confining all of the migratory fish to the areas below the reservoirs is dependent to a greater extent than any other plan upon satisfactory quality of water discharged from the reservoirs. Analysis of similar existing reservoirs, presented in an earlier section, has shown that there is danger that the water discharged from the reservoirs might not be satisfactory. It is believed, however, that this condition, if it should exist, would be corrected within a few miles below the dam by exposure to the air in the turbulently flowing streams. From analysis of temperature conditions in existing reservoirs, it has been concluded that there would be no danger of the discharge from the Quartz Creek reservoir becoming too warm; that temperatures below the Detroit and Lookout Point reservoirs might exceed the tolerance of salmon during exceptionally low-water years; and that toward the end of most summers the discharge at the Sweet Home reservoir definitely would be too warm for holding adult salmon. Slight adjustment of the reservoir operation schedules probably would provide satisfactory temperatures below all but the Sweet Home reservoir.

As unfavorable temperature conditions below the Sweet Home reservoir preclude the possibility of holding adult fish there, some other plan of salmon maintenance must be considered for the South Santiam River. The adult fish might be caught below the dam at the time of their arrival and transported by tank truck to the section of stream above the reservoir where they now are held for artificial propagation. Another possibility would be to transfer the run permanently to some other tributary where it could be maintained by either natural or artificial propagation or a combination of the two. The choice between these two possibilities

should depend primarily upon the availability of a suitable location for transplanting the run. Provided such is available, the proposal of transplanting the run has the advantage that it eliminates the task of perpetual trapping and hauling of adult fish to the area above the dam and return hauling of the fingerlings to the stream below the dam.

For that part of the run handled in hatcheries, standard fish-cultural methods should be applied. Furthermore, there should be active biological research to determine improvements in hatchery techniques with special reference to the overall mortality from egg to returning adult for fish in the Willamette River system and under the changing stream conditions imposed as a result of dam construction. It is believed that a research staff should be engaged well in advance of any construction on the dams and should become thoroughly familiar with the problems of fish culture in relation to the dams, as they develop. At the first unit of the project experiments should be conducted to determine the effects of stored water on fish and to effect improvement of hatchery rearing and feeding methods.

In some respects the dams of this project are only potential barriers to most of the fish in the Willamette River, because the Oregon Fish Commission, in theory, blocks off the entire run by its racks. As has been stated before, these racks actually do not always hold all the fish and are not even installed every year in every tributary. When the dams actually are completed, however, the future runs of fish will be absolutely dependent upon the success of the maintenance plans established. When the dams are in, there will be no vast natural spawning area above the racks where escaping fish can find room to deposit their eggs. When the dams are in, the natural safety factors which formerly protected the runs when accidents happened to racks, or in the years when racks were not installed, will not be operative. In this respect the dams of the Willamette Valley project will be actual barriers of the most serious nature, even in streams like the McKenzie River, where, in theory, no salmon have been allowed to approach within miles of the proposed dam site for 25 years.

CONCLUSIONS

Proposed dams of the Willamette Valley Project will interfere with spawning runs of chinook salmon on four tributaries of the Willamette River and with steelhead trout runs to two tributaries. At least local interference with resident trout will occur on all tributaries to be dammed.

Adult chinook salmon make a rather rapid migration through the lower part of the river, which they enter in February, March and April, and spend a relatively long time in the streams close to the place where they will eventually spawn. The period from the first part of July to September is spent by the chinook salmon resting in deep pools while the sex products are becoming mature. This period is an important one in the life history of the fish for the success of the run, as during this time the fish appear to be quite sensitive to unfavorable environmental conditions.

The Willamette River salmon runs provide a sport fishery which yields approximately 20,000 chinooks in a year. In addition, other thousands of fish are taken by the commercial troll and gillnet fisheries. These runs represent an important component of the whole Columbia River "spring" run, which, in turn, is an important and valuable part of the Columbia River salmon runs. A large part of the Willamette River run will be jeopardized by the proposed structures. The Willamette River fish also contribute a large share of the spring chinook salmon eggs for restocking streams in Oregon.

On three tributaries of the Willamette River the present fish-cultural facilities of the Oregon Fish Commission are located above the proposed dam sites. If fish-cultural policies of this body are to be maintained, the relocation of these hatcheries and egg-taking establishments will be necessary. The simplest relocation would involve establishment of hatcheries below the dams, with provisions for holding adult fish in stream sections below the dams. The feasibility of such a scheme depends upon the suitability for fish of the water in the stream below the dam.

At the present time the lower section of the Willamette River is effectively blocked by pollution to the migration of fish during several months of summer and fall. This condition will be improved somewhat by the additional flow of water coming from summer storage releases.

Present water conditions in the streams, especially temperature, have been investigated. Except for certain periods on the South Santiam River, each tributary of the Willamette River has excellent temperature conditions for salmonoid fish at the location of the proposed dam. Water temperatures only rarely exceed 16° C. (61° F.)

for an entire day. The maximum water temperature was reached in all streams studied during the middle of July in both 1941 and 1942.

A series of fifteen reservoirs in Oregon, Washington and Idaho was examined to provide information as to the probable temperature distribution with depth that would arise in the proposed Willamette reservoirs. In reservoirs with relatively small amounts of water flowing into them, temperature-depth conditions corresponding to those in a thermocline were established. The greatest depth to which water of 16° C. extended was from 20 to 140 feet in different reservoirs, with the usual maximum depth of 16° C. water during the summer being about 50 to 60 feet. The volume of warm water usually increases as the summer progresses. As reservoirs are emptied the depth of the warm layer increases as it is drawn down into the narrowing section of the reservoir. Water entering a reservoir normally mingles with reservoir water of the same temperature, or if cooler than any of the stored water, it flows along the bottom and will be drawn off through bottom outlets.

By application of these reservoir temperature conditions to proposed schedules of operation of the reservoirs of the Willamette Valley project, it tentatively has been concluded that, with minor changes in schedules of operation, the discharge from none of the reservoirs except the Sweet Home on the South Santiam River will become too warm for salmon.*

Evidence from chemical studies on impounded waters indicates that an accumulation of decomposition products characteristically takes place in the subsurface layers. Difficulties experienced in artificial propagation below the storage reservoir on the North Fork of the Lewis River, Washington, are believed associated with the discharge of water containing such products. Any fish-maintenance scheme entailing the use of stream sections below the dams for fish culture should be so designed that the fish are held a number of miles below the dam so that the flow may facilitate the elimination of volatile decomposition products.

It is recommended that a combined scheme of artificial and natural propagation be undertaken to maintain the runs of chinook salmon and steelhead trout affected by the proposed dams. It is assumed, in making the recommendations, that fish-cultural practices will continue to improve and that eventually methods will develop which could, if necessary be relied upon for the entire support of runs.

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*Editorial note. See addendum for change in reservoir plans.

RECOMMENDATIONS

It is recommended that if the proposed storage reservoirs of the initial development are constructed on the Middle Fork, McKenzie, South Santiam and North Santiam Rivers, provision be made for continuance of the fish cultural operations under conditions and on a scale comparable with the present, that the fish cultural facilities and operations be extended as required to include artificial propagation of all salmon and steelhead trout that are prevented by the dams from reaching their natural spawning areas, and that the schedule of operations and other activities in connection with the project be such as to provide flows, temperatures and other conditions necessary for the migration of fish and the success of such natural propagation as will take place below the racks where fish are taken for artificial propagation. This recommendation would require the following:

1. On the Middle Fork of the Willamette River, where all of the fish-cultural facilities are above the proposed reservoir, it would be essential that the egg-taking station be moved to some favorable location a few miles below the Lookout Point Dam.

As the hatchery would not be flooded by the initial reservoir, it would remain available, but its use would necessitate transportation of the eggs to the hatchery and the return hauling of the fingerlings to the river below the dam. Some additional increase in capacity of the hatchery would be necessary to care for additional fish that would have to be handled. Serious consideration should be given to moving the hatchery to a new site below the dam.

2. On the McKenzie River no changes would be required in the location of fish-cultural facilities, as all are below the proposed Quartz Creek Dam.

3. On the North Santiam River no changes would be required in the location of the hatchery which is below the proposed Detroit Dam; but it would be necessary to move the egg-taking station to a new site below the dam. Some increase in the egg and fry carrying capacity of the hatchery may be necessary.

4. On the South Santiam River the fish-cultural facilities are above the proposed Sweet Home Dam. There are several possible solutions to the problem: (a) An egg taking station might be operated at a point below the dam and the eggs taken to the present hatchery site for hatching and rearing and the fingerlings returned and liberated at a point below the dam. The objection to this procedure is that the water temperatures below the dam may be so high as to result in heavy losses of adult fish during the holding period. (b) If a suitable location could be found on another tributary of the Willamette system the run might be relocated to that tributary

and adequate hatchery facilities provided. (c) The adult fish could be perpetually trapped and hauled from below the Sweet Home Dam to the present holding area, the eggs and young handled in the present hatchery and the fingerlings liberated below the dam. Under plans (a) and (c) increased egg and fry carrying capacity would be required. The problem needs further study.

5. To compensate for the loss of natural rearing area, provision should be made at all of the fish-cultural stations for retaining approximately half of the fingerlings in the rearing ponds until the normal time of migration. This will require additional ponds and water supply, additional storage space for perishable food, and increased personnel. The extent of additional facilities will vary at the different stations and details will require further study.

6. To assure that no adult fish would be able to pass the racks of the egg-taking stations it is recommended that more dependable racks be constructed. This probably will require a permanent apron on which a well-designed picketed barrier can be installed each season.

7. The schedules of operation of the reservoirs should be reconsidered and changes be made to assure that water too warm for the holding of adult salmon would not be withdrawn from the reservoirs on the Middle Fork, McKenzie, and North Santiam Rivers.

8. All diversions at which there is any possibility of fish being lost should be adequately protected by mechanical screens. According to Oregon Law, responsibility for adequate protection falls on the proprietors. The U. S. Engineer Department is not responsible for the protection of diversions other than its own, but having made large financial contributions toward the perpetuation of fish runs in the Willamette Valley, the Federal Government should exercise its influence to prevent the loss of these fish at any illegally or carelessly operated diversions.

9. Adequately trained fisheries-biological personnel should be employed at least one year before actual construction begins on any dam on the North Santiam, South Santiam, McKenzie or Middle Fork of the Willamette Rivers and continue their investigations throughout the period of dam construction and for as long thereafter as may be necessary to assure that adequate measures are taken to solve unforeseen difficulties with fish. This personnel should be adequate to conduct experiments at the first units to be constructed, which will provide data for improving methods of holding, hatching, rearing, feeding and releasing salmon used in artificial propagation, as well as providing information for the improvement of the plans specified for later units.

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ADDENDUM

The comprehensive plan for the development of Willamette River Basin Project was authorized in 1938. The studies upon which the accompanying report were based were initiated in 1940 before major changes were contemplated in the original plan. The discussions in the report accordingly deal with the plan of development as originally set up in H. D. No. 544. Due to later hydrological and subsurface exploration data and changes in economic developments at certain reservoir locations, a number of modifications have been required or are contemplated in the original plan. Some of these changes will modify the general findings and conclusions of the report. Various changes or modifications of the original plans are discussed in subsequent paragraphs.

North Santiam River

The Detroit Dam as now planned is the same as that proposed in the "coordinated plan" in the Willamette River Basin Project, that is, it will be a high dam designed for the ultimate development of power. It will be built to its full height of 366 feet initially with storage capacity of 455,000 acre-feet. Storage of 300,000 acre-feet would be reserved for flood control instead of 165,000 acre-feet as originally planned. The comprehensive plan of development on North Santiam River may require the additional construction of a low dam, probably at the Big Cliff Site some 3 or 4 miles below Detroit Dam, for re-regulation of flow and development of power. The original "coordinated plan" for further power development by canals below this site is subject to further study due to questionable economic feasibility.

South Santiam River

The originally authorized Sweet Home Dam undoubtedly will be eliminated due to economic development in the previously proposed reservoir area. A number of alternate plans are under study which include a main river reservoir about 9 miles below Sweet Home, similar in height and storage capacity to the Sweet Home Dam, or a series of dams on headwater tributaries on the South Santiam and on tributaries below Sweet Home.

McKenzie River

The originally proposed reservoir site at Quartz Creek probably will be eliminated due to unfavorable foundation conditions. A number of alternate plans are under consideration which include a dam of similar height about 6 miles downstream from Quartz Creek, or a dam with similar storage capacity about 17 miles above the mouth of McKenzie River, or three headwater tributary dams located respectively on the South Fork, Blue River, and Gate Creek. Power development might ultimately be possible under some of these alternate plans for storage, but no final decision has been made for development of power on the main stream or its tributaries. Due to economic infeasibility, it is unlikely that any power development by canals or diversion from the main river will be undertaken regardless of which reservoir plan may be adopted.

Middle Fork Willamette River

The dam originally proposed at the Lookout Point Site has now been eliminated due to excessive costs. A dam site has been selected at Meridian about 15 miles downstream from the original site. The height of this dam will be 290 feet, which is greater than the 233 feet originally proposed under the "initial plan", and less than the 293 feet proposed under the "coordinated plan" as presented in H. D. No. 544. Storage capacity at Meridian Dam will be 400,000 acre-feet, whereas, 340,000 acre-feet was proposed under the "initial plan" for Lookout Point Dam. An auxiliary flood control reservoir of about 100,000 acre-feet capacity is proposed for construction on Big Fall Creek, a tributary entering the Middle Fork below Meridian Dam. At some future time when power might be developed under the "coordinated plan", Meridian Dam would not be raised as was contemplated for the Lookout Point Dam in H. D. No. 544; instead it is probable that an additional storage reservoir would be constructed on the main stream below the mouth of Hills Creek. The canal diversions for power originally contemplated have now been eliminated and any power development between Hills Creek and the head of Meridian pool would be a low dam, probably at the Lookout Point Site.

Long Tom, Coast Fork, and Row Rivers

Fern Ridge Dam on Long Tom River and Cottage Grove Dam on Coast Fork Willamette River have been constructed substantially as originally planned. Construction has been resumed recently at Dorena Dam on Row River and it will be built substantially as originally planned.

Reservoir Regulation

A number of changes have been made in the plan of reservoir regulation from those shown in Figure 8. Inasmuch as these changes are somewhat similar for each reservoir, they are discussed under the features or interests for which regulation schedules are required.

a. Flood control: A modification has been made in the reservoir regulation schedules for flood control. The schedules shown in H. D. No. 544 (See Figure 8 of accompanying report) permitted holding full reservoir level until September 1 and complete evacuation of exclusive flood control storage by December 1 of each year. A change in regulation schedule allows full reservoirs to be held until September 15 before evacuation must be initiated and the reservoirs would be drawn-down to minimum flood control pool by November 15. Otherwise, regulation schedules for flood control are identical to those originally planned.

b. Navigation: Releases in the interest of navigation will be substantially the same as outlined in H. D. No. 544 except for reservoirs where more storage will be available such as Detroit Dam on North Santiam River and Meridian Dam on Middle Fork Willamette River. The added reservoir capacity will be used to provide further increases in the minimum flow of the respective tributaries and on the main Willamette River during the low water season.

c. Irrigation: Revised irrigation plans for the Willamette Valley indicate that ultimately a much larger acreage would be served and the total amount of water required would be considerably greater than that originally contemplated. The irrigation storage required in the individual reservoirs is very materially changed from the plans presented in H. D. No. 544. Originally, regulation schedules for Lookout Point, Dorena, Cottage Grove, and Fern Ridge Dams were not set up for irrigation. Present plans are to obtain some irrigation storage in all of the Willamette Basin Project reservoirs. Under ultimate irrigation development in an average year the draw-down at Dorena, Cottage Grove, and Fern Ridge Reservoirs would be earlier than that indicated in Figure 8. The modification of plans for reservoirs where irrigation storage would be obtained may materially alter the distribution of summer releases from individual reservoirs in the combined interest of navigation and irrigation in the critical water years on the respective tributaries.

d. Releases for migratory fish: Certain studies have been made and others are in progress for increasing releases for migratory fish over the plan of releases indicated in H. D. No. 544. It appears that insofar as flood control, navigation, and irrigation are concerned, reservoir releases during the storing period in spring months and throughout the summer can readily be adjusted without interference

to obtain better than minimum requirements for migratory fish. When power is installed under a "coordinated plan", the additional releases of water in the spring for the benefit of migratory fish would reduce the storage for power in critical years.

e. Power releases: In present studies of storage regulation, power releases are given the least priority and are controlled in such a manner as as not to be detrimental to irrigation, navigation, fish, or other conservation uses.

Pollution

In a report entitled "1945 Progress Report on Pollution of Oregon Streams", by Fred Merryfield and W. G. Wilmot, published as Bulletin No. 19 of the Engineering Experiment Station of Oregon State College, are presented the results of pollution surveys of the Willamette River conducted during the summer of 1944. This survey showed that during August and September the oxygen content of the main Willamette River below Springfield was distinctly lower than in 1929. Starting a few miles downstream from Salem, the oxygen content was found to decrease rapidly, reaching 5 p.p.m. just above the Newberg sewer outlets, and dropping to 1 p.p.m. just above Oregon City. At Oregon City the biochemical oxygen demand in 1944 was 12.6 p.p.m., which is nearly 3 times the 4.5 p.p.m. observed in 1929.

The 1944 survey shows much greater need for pollution abatement, in which the increase in low water flow by release from the reservoir of the Willamette Basin Project will be an important factor.

Salmon Hatchery Operations

The following table will supplement Table 9 of the report in bringing the records of egg collections up to date:

Year	North Santiam	South Santiam	McKenzie	Middle Fork
1943	853,100	188,300	4,415,000	1,617,000
1944	1,474,700	84,900	1,197,000	2,430,000
1945	907,700	1,445,700	1,780,000	1,473,000