WATER QUALITY STUDIES IN THE COLUMBIA RIVER BASIN

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FISH AND WILDLIFE SERVICE

EXPLANATORY NOTE

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for official use of Federal, State or cooperating agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Fred A. Seaton, Secretary
Fish and Wildlife Service, Arnie J. Suomela, Commissioner

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by

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Washington, D. C.

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CONTENTS

COLUMBIA RIVER BASIN

DRAINAGE AREA, 259,000 SQ. MI.

FIG. 1

Research and Investigation on the Quality of Water of the Columbia River and Effects on the Fisheries Resources

Abstract

A brief study has been made of the water quality in the Columbia River Basin. Water quality constituents evaluated were those that might relate to the productivity of the River Basin fishery. The natural water quality of the Basin has experienced a significant change in the past 45 years through the construction of multipurpose and single-purpose dams. After these dams were built, water was available for agriculture, industrial, and domestic consumption. It is the spent waters from these comsumptive uses, more than the dams themselves, that have produced this water-quality change. From the standpoint of the fishery, the seemingly most important component of water quality at this time is that of temperature. Water temperatures in the central Columbia and in the lower Snake and Yakima Rivers are quite high during the summer. Dissolved constituents have shown a marked rise during the past 45 years but have not risen to the extent that the fishery is endangered according to data presently available. Dissolved oxygen values are high throughout the Basin with the exception of the lower Willamette River.

This report should be considered as a beginning on a study of the Columbia Basin water quality and not as a report complete in itself. Its principal deficiency is a lack of data on water-temperature changes caused by water impoundment under varying conditions of impoundment. No attempt has been made to evaluate the various water constituents found in their relation to aquatic life. A study of these constituents, present and predicted future, and their relation to aquatic life seems necessary since available data on the subject are meager and conflicting.

INTRODUCTION

Streams of the Pacific Northwest are of particular value to the economy of the region because of their extensive use by anadromous fishes, because of their power potential, because some of them are favorably located for irrigation, because they afford recreation for hundreds of thousands of people, and because some can be made suitable for water-borne commerce. Many think that these varied water uses are incompatible; others think that their favored use should have priority because of its economic value or because it was there first; others feel that multipurpose use of the streams is both inevitable and desirable and that with intelligent study this can be accomplished with a minimum of damage to other uses. To develop this multipurpose water use, dams and their companion reservoirs must be built and filled.

In the early days of the region's development, dams were constructed for a particular purpose without any regard to their effect on other water uses. If the Pacific Northwest's water resources are to be developed for the good of all, these multipurpose water uses and their relations to one another must be properly evaluated on a basis of fact and not of conjecture. These relations must be understood and agreed upon by all those concerned in multipurpose water use.

This study has concerned itself with only one of the relations involved in multipurpose water use; that is the changes in water quality that have taken place, and the changes that may be expected to take place in the future as a result of multipurpose-dam construction. The correlation study to follow these water-quality data will be an evaluation and study of their effects on fish life.

The study reported on herein was sponsored by the United States Fish and Wildlife Service and the Chelan County Public Utility District with the University of Washington, through its School of Fisheries, as contractor. Data on water quality were collected and analyzed through the sanitary-engineering laboratory at the University of Washington. Additional supplemental data were obtained from the U. S. Geological Survey and other government and

private agencies whose contribution are acknowledged at the end of this report.

Causes of Water-Quality Change

The natural water quality in a river is subject to change from four man-made causes. They are:

1. Impoundment of water in reservoirs behind dams.

2. Return flows from irrigation.

3. Introduction of domestic sewage and industrial wastes.

4. Soil erosion from farming, logging, or construction activities.

5. Spray chemicals used in forestry and agriculture.

Impoundment of water

The effect of water impoundment on water quality depends upon the time of impoundment, water depth, air temperatures, character of reservoir bottom, whether highly organic or inorganic, the physical and chemical quality of water entering the reservoir, wind action to provide circulatory currents, and the point and depth of water withdrawal from the reservoir. Adverse water-quality factors in regard to fish life that may arise from water impoundment are: high water temperature, low dissolved oxygen, high or low hydrogen-ion (pH) concentration, excessive carbon dioxide, ammonia and hydrogen sulfide from organic decomposition, siltation, and accumulation of trace elements that may be toxic to fish or their food supply, such as copper, lead, selenium, and zinc. Favorable water-quality effects that may arise from impoundment are: a lowering of the downstream water temperature in the warm season and a raising in the winter; increase in downstream flow, during the normal low period, that will more effectively dilute pollutants. Release of impounded water will affect the stream quality for some distance below the dam, depending upon the water turbulence, air temperatures, and the depth of water withdrawal from behind the dam.

Return flows from irrigation

In the irrigation of land, it is necessary that the soil be well-drained so that the plant roots do not become water sick and so that salts do not accumulate at the soil surface. A favorable salt balance is attained when the drainage water has a higher salt content than the input water (1). Most irrigation projects are provided with drains or waste-ways which control the direction of ground water movement in the root zone by returning excess ground and irrigation waters to a receiving stream.

The amount of water required for irrigation varies from less than two to more than ten acre-feet of water applied per acre per year (2). Of this applied water, from 20 to 60 percent may find its way back to the stream as return flow.

These return flow waters are more mineralized and have different physical properties from the input waters. Their return to a stream will produce marked water quality changes if the quantity of return flow in relation to stream flow is significant.

Domestic sewage and industrial wastes

The quantity of wastes discharged to inland waters is continually increasing. Their content of polluting material is under surveillance by, and is in the process of being controlled by, water pollution control agencies. Uncontrolled discharge of these waste waters has, in many instances, caused serious impairment in water quality to the extent that fish life could not exist. It is to be expected that these waste waters will continue to cause less and less deleterious effects as waste treatment and other control processes become more common.

Soil erosion

Poor land management, in the form of overgrazing or improper cultivation, together with logging, mining, or construction activities that do not control soil erosion, frequently imparts so much silt to a stream that all other forms of water-quality impairment become minor in comparison.

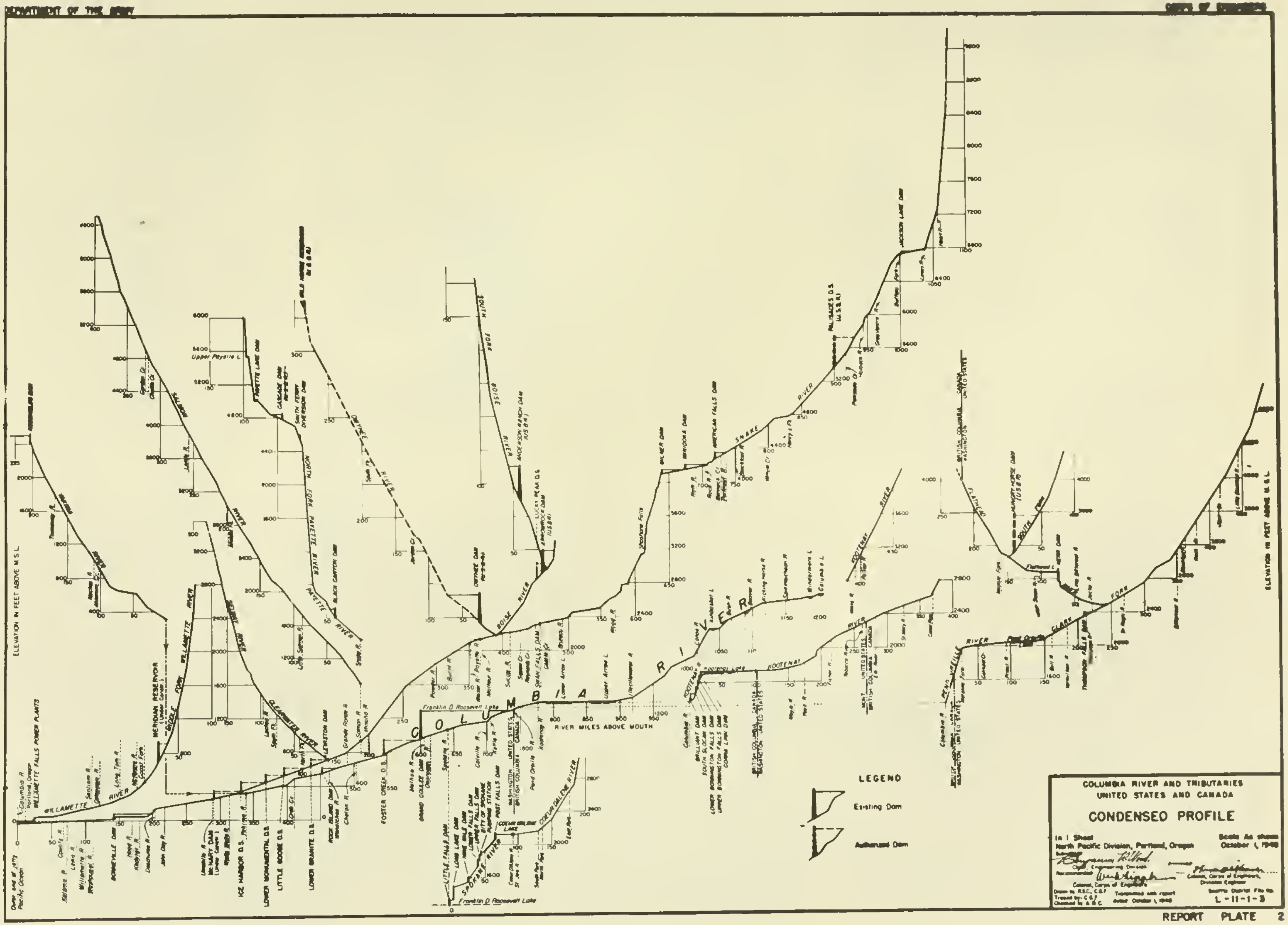

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
COLUMBIA RIVER AND TRIBUTARIES
UNITED STATES AND CANADA
CONDENSED PROFILE
In 1 Sheet
North Pacific Division, Portland, Oregon
LEGEND
Existing Dam
Authorized Dam
RIVER MILES ABOVE MOUTH
ELEVATION IN FEET ABOVE M.S.L.
COLUMBIA RIVER
SNAKE RIVER
WILLAMETTE RIVER
KOOTENAI
CLARK FORK
BOISE RIVER
NORTH FORK PAYETTE RIVER
CLEARWATER RIVER
SELWAY RIVER
SALMON RIVER
SPOKANE RIVER
BONNEVILLE DAM
McNARY DAM
ICE HARBOR D.S.
LOWER MONUMENTAL D.S.
LITTLE GOOSE D.S.
LOWER GRANITE D.S.
ROCK ISLAND DAM
FOSTER CREEK D.S.
GRAND COULEE DAM
Franklin D. Roosevelt Lake
JACKSON LAKE DAM
PALISADES D.S.
AMERICAN FALLS DAM
MINIDOKA DAM
MERIDIAN RESERVOIR
L-11-1-3
REPORT PLATE 2

FIG. 2

Columbia River Basin

The principal river basin in the Pacific Northwest is the Columbia River Basin. This river system likewise has the greatest multipurpose water uses existing and proposed. It has supported very large runs of anadromous fishes for whose continuation, huge sums of money have been spent. This water quality study has confined itself within the Columbia River Basin. Figure 1 shows the drainage boundaries of the Basin. There are some 259,000 square miles in the drainage basin, of which 39,700 are in Canada. It includes the majority of land area in the States of Washington, Idaho and Oregon, the western part of Montana, and smaller areas in Nevada, Wyoming and Utah, comprising about seven percent of the nation's area.

The Columbia River has its headwaters in Columbia Lake, British Columbia, about 70 miles north of the international border at an elevation of 2,650 feet. After flowing 465 miles through Canada in a circuitious manner, the river enters the United States near the northeast corner of Washington. It flows through Washington in a series of big bends and becomes the border between Washington and Oregon as it flows westward to the Pacific Ocean. Between headwaters and the ocean, the river is some 1,200 miles long. Its annual average discharge is around 160,000,000 acre-feet of water (or 220,000 cubic feet per second) that flows into the Pacific Ocean. The headwaters of the Columbia and its principal tributaries are in the mountains where precipitation is fairly high. Mountain snow packs produce ground storage plus seasonal peak flows in late spring.

The central part of the Columbia, like its principal tributary, the Snake, lies in an arid region where irrigation is necessary for diversified farming. About 4,500,000 acres are now (1956) under irrigation, two-thirds of which are in Southern Idaho. Ultimate development calls for a total of about 7,500,000 acres to be irrigated (3). (See table 1 and figs. 3 and 4.)

Because of its rapid fall from headwaters to the ocean, the Columbia and its tributaries offer many sites for hydroelectric-power development. Despite the fact that there are now nearly 200 hydroelectric-power developments in the Basin, only about

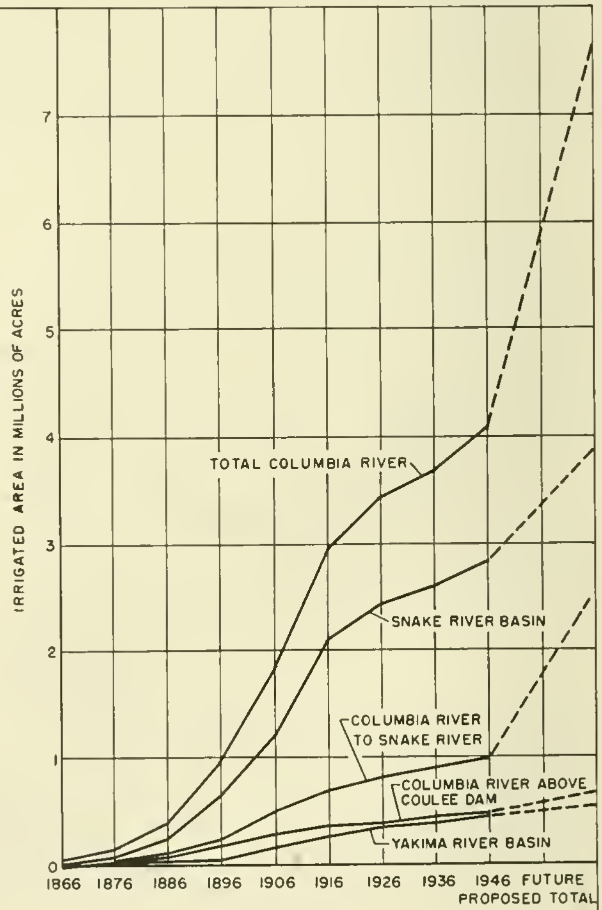
Table 1.--Irrigation, existing and proposed,2/ tributary above stated location

Location	Period	Existing irrigation acres	Proposed future irrigation acres	Total future irrigation tributary to Columbia
Columbia River above Grand Coulee Dam	1860-1946	459,670 1/	182,900 1/	642,570
Columbia River above Snake River	1860-1946	998,340	1,508,800	2,507,140
Yakima River Basin	1860-1946	439,300	94,750	----
Snake River Basin	1870-1946	2,825,256	1,031,280	----
Columbia River to The Dalles	1860-1946	4,084,508	3,199,350	7,283,858
Columbia River to Mouth	1860-1946	4,122,508 3/	3,550,320	7,672,828

1/ Includes 80,000 acres in Canada -- no estimate on proposed future irrigation in Canada.

2/ From references (3), (5), and (6).

3/ Estimate from reference (3).



IRRIGATION, EXISTING AND PROPOSED

FIG. 3

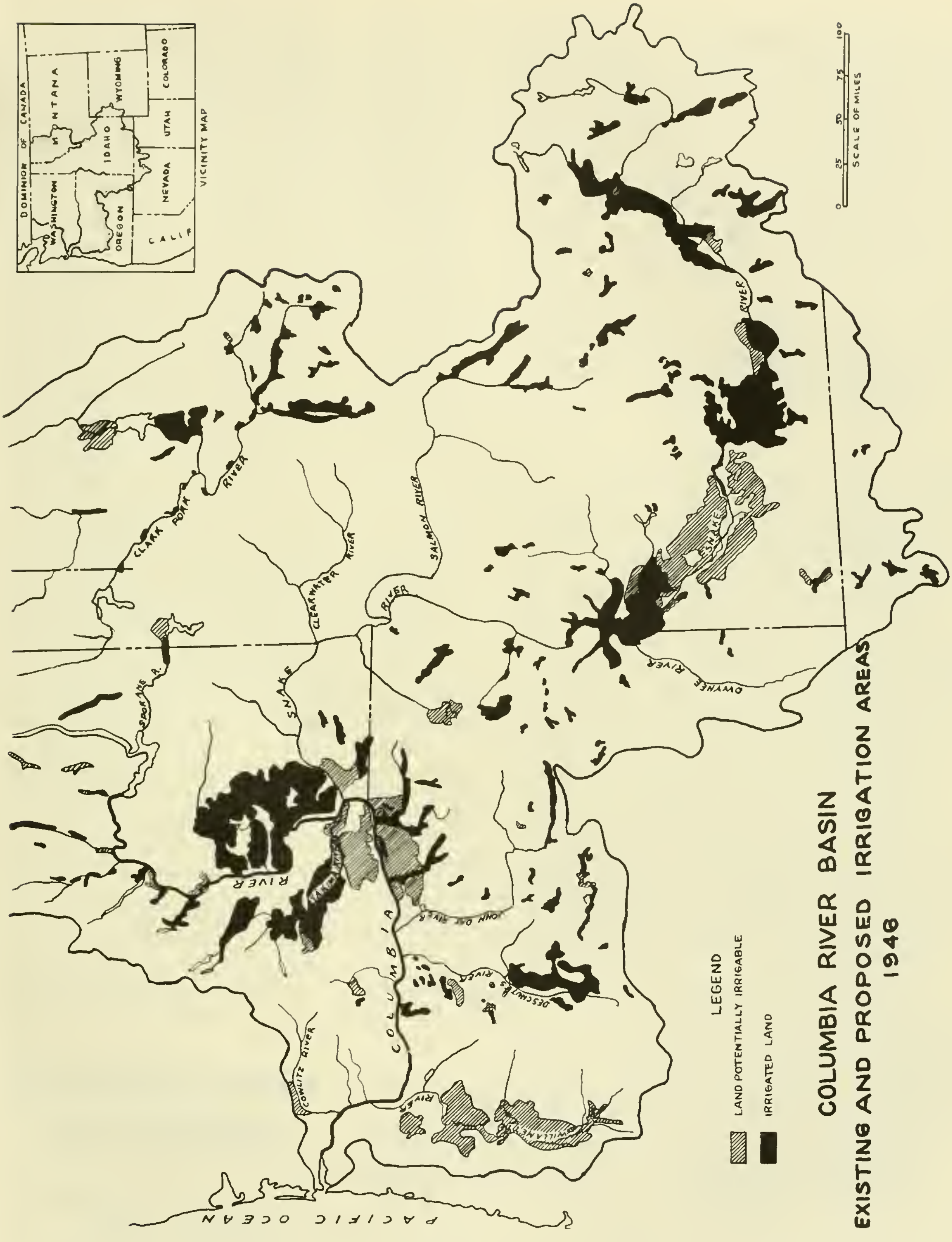
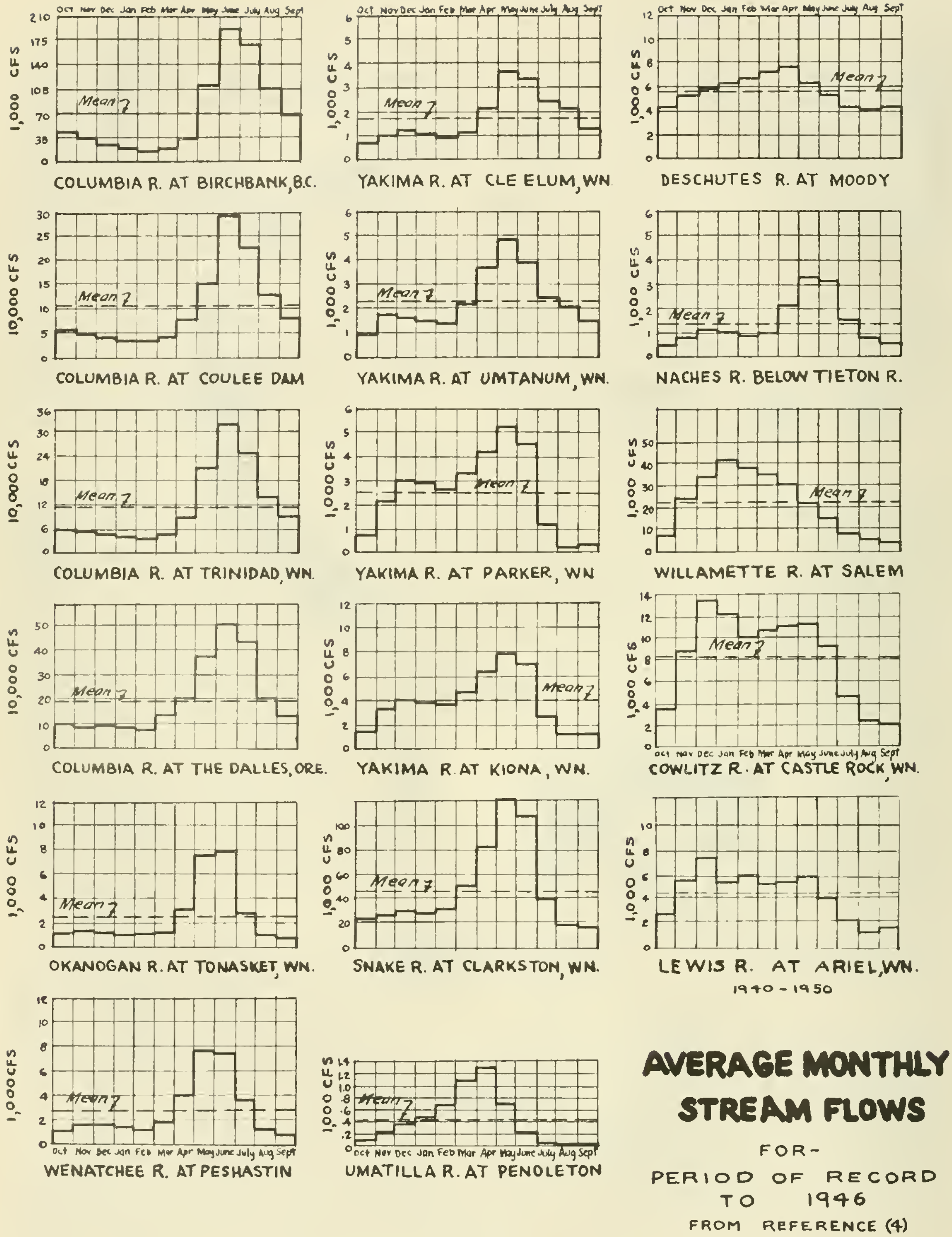

COLUMBIA RIVER BASIN
EXISTING AND PROPOSED IRRIGATION AREAS
1946
LEGEND
LAND POTENTIALLY IRRIGABLE
IRRIGATED LAND
SCALE OF MILES
0 25 50 75 100
VICINITY MAP
DOMINION OF CANADA
WASHINGTON
MONTANA
IDAHO
WYOMING
OREGON
NEVADA
UTAH
COLORADO
CALIF.
PACIFIC OCEAN
COLUMBIA
RIVER
SNAKE
SNAKE RIVER
CLARK FORK RIVER
SPOKANE R.
CLEARWATER RIVER
SALMON RIVER
OWYHEE RIVER
JOHN DAY RIVER
DESCHUTES RIVER
COWLITZ RIVER
WILLAMETTE RIVER
YAKIMA

FIG. 4



Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept
1,000 CFS
Mean
COLUMBIA R. AT BIRCHBANK, B.C.
YAKIMA R. AT CLE ELUM, WN.
DESCHUTES R. AT MOODY
10,000 CFS
COLUMBIA R. AT COULEE DAM
YAKIMA R. AT UMTANUM, WN.
NACHES R. BELOW TIETON R.
COLUMBIA R. AT TRINIDAD, WN.
YAKIMA R. AT PARKER, WN
WILLAMETTE R. AT SALEM
COLUMBIA R. AT THE DALLES, ORE.
YAKIMA R. AT KIONA, WN.
COWLITZ R. AT CASTLE ROCK, WN.
OKANOGAN R. AT TONASKET, WN.
SNAKE R. AT CLARKSTON, WN.
LEWIS R. AT ARIEL, WN.
1940 - 1950
WENATCHEE R. AT PESHASTIN
UMATILLA R. AT PENDLETON
AVERAGE MONTHLY
STREAM FLOWS
FOR-
PERIOD OF RECORD
TO 1946
FROM REFERENCE (4)

FIG. 5

40 percent of the potential of over 10,000,000 kw. has been developed (3).

The U. S. Bureau of Reclamation in its report to the 81st Congress, "The Columbia River", 1947 (3), proposed construction of 238 projects, large and small, for irrigation, power, and flood control. The U. S. Corps of Engineers, North Pacific Division, in its "Review Report on Columbia River and Tributaries" ("308 Report"), 1948, shows an ultimate development of the Columbia River Basin that will provide a total of 125,000,000 acre-feet of storage on the river and its tributaries. This storage would make possible almost a complete regulation of the river system. To accomplish this, they propose the early construction of 27 dams with an additional 131 dams, large and small, in the ultimate development.

Stream flow

Average monthly stream flows and the yearly mean for the period of record to 1946 are plotted on figure 5. Tabulated data of water quality have the stream flow recorded as of the time of sampling.

The principal tributaries of the Columbia River, their location, and their mean annual flow are: (through 1946)

River	Location	Discharge in c.f.s.
Kootenai	British Columbia, Montana, Idaho, British Columbia	28,500
Pend Oreille - Clark Fork	Montana, Idaho, British Columbia	25,800
Spokane	Idaho, Washington	7,970
Okanogan	British Columbia, Washington	3,110
Wenatchee	Washington	3,310
Yakima	Washington	5,650
Snake	Wyoming, Utah, Nevada, Idaho, Washington	50,850
Deschutes	Oregon	5,860
Willamette	Oregon	32,900
Lewis	Washington	5,900
Cowlitz	Washington	9,600

Irrigation

Columbia River Basin land has been experiencing a constant growth ir irrigation for the past 100 years. Aft r 1880, the increase in irrigated land increased rapidly until in 1946, there were over four million acres of land under irrigation (5), about three-fourths of which were in the Snake River Basin. Table 1, compiled from references (3), (5), and (6), lists the acres of irrigated land tributary to various segments of the Columbia River. Irrigation of potentially irrigable land will almost double the present irrigated area, i.e., increase the total in the Basin to over 7.5 million acres.

Figure 4 shows the location of existing and proposed irrigation areas in the Columbia River Basin. Figure 3 is a plot of the growth of irrigated land tributary to various segments of the Columbia River.

Reservoirs and dams

The construction of dams for irrigation water impoundment and for power commenced around the turn of the century. Growth of these reservoirs was rather slow until after the completion of Bonneville and Grand Coulee Dams in the late thirties. Table A in the appendix lists the major existing and proposed reservoirs in the Columbia River Basin, i.e., those storing in general over 50,000 acre-feet of water. Data for this table were obtained from references (3) and (4), and by writing the various private and public agencies concerned with water power and irrigation. Table 2 summarizes Table A by listing the total impoundments tributary to various segments of the Columbia River by time intervals of ten years. It shows that the usable storage at present is about 20 million acre-feet of water, and that if all the proposed dams are built, the usable storage will increase to about 60 million acre-feet.

Figure 6 shows the location of the reservoirs listed in Table A in the appendix. Figure 7 shows the growth of reservoirs in the Basin tributary to various segments of the Columbia River. Figure 2 shows the reservoirs in relation to stream elevations.

Procedure

The quality of water investigation has proceeded in the following sequence:

Table 2.--Reservior summary - Columbia River and Tributaries

Ten Year Development Periods

Segment No.		1906 - 1916			1916 - 1926			1926 - 1936			1936 - 1946			1946 - 1956			1956 - Proposed		
		Full pool capacity	Usable storage acre-feet	Area in acres	Full pool capacity	Usable storage acre-feet	Area in acres	Full pool capacity	Usable storage acre-feet	Area in acres	Full pool capacity	Usable storage acre-feet	Area in acres	Full pool activity	Usable storage acre-feet	Area in acres	Full pool activity	Usable storage acre-feet	Area in acres
1	Region above International Boundary, including the Kootenai and Pend Oreille	0	0	0	0	0	0	0	0	0	0	0	0	5,010,000	4,135,000	114,800	10,995,000	15,289,000	257,500
	Totals	0	0	0	0	0	0	0	0	0	0	0	0	5,010,000	4,135,000	114,800	10,995,000	15,289,000	257,500
2	Region of International Boundary to above the Snake	429,300	323,000	6,300	627,300	473,000	8,200	1,064,200	803,000	11,800	10,466,200	5,875,000	82,100	13,010,300	7,163,600	134,600	14,610,300	13,528,600	232,500
	Totals	429,300	323,000	6,300	627,300	473,000	8,200	1,064,200	803,000	11,800	10,466,200	5,875,000	82,100	18,020,300	11,298,600	249,400	25,605,000	28,817,600	490,000
3	Region of Snake River to The Dalles	1,183,600	887,000	27,200	3,265,930	2,490,000	75,900	4,681,660	3,465,000	99,200	5,489,760	4,153,000	118,200	9,029,860	6,502,000	186,400	17,992,360	23,140,000	360,600
	Totals	1,612,900	1,210,000	33,500	3,893,230	2,963,000	84,100	5,745,860	4,268,000	111,000	15,955,960	10,030,000	200,300	27,050,160	17,800,600	435,800	43,597,660	51,957,600	850,600
4	Region from The Dalles to the Mouth of the Columbia River	0	0	0	0	0	0	404,500	245,000	3,900	1,043,500	447,000	25,400	2,433,800	1,408,000	36,000	3,704,800	6,867,000	58,900
	Totals	1,612,900	1,210,000	33,500	3,893,230	2,963,000	84,100	6,150,360	4,513,000	114,900	16,999,460	10,477,000	225,700	29,483,960	19,208,600	471,800	47,302,460	58,824,600	909,500

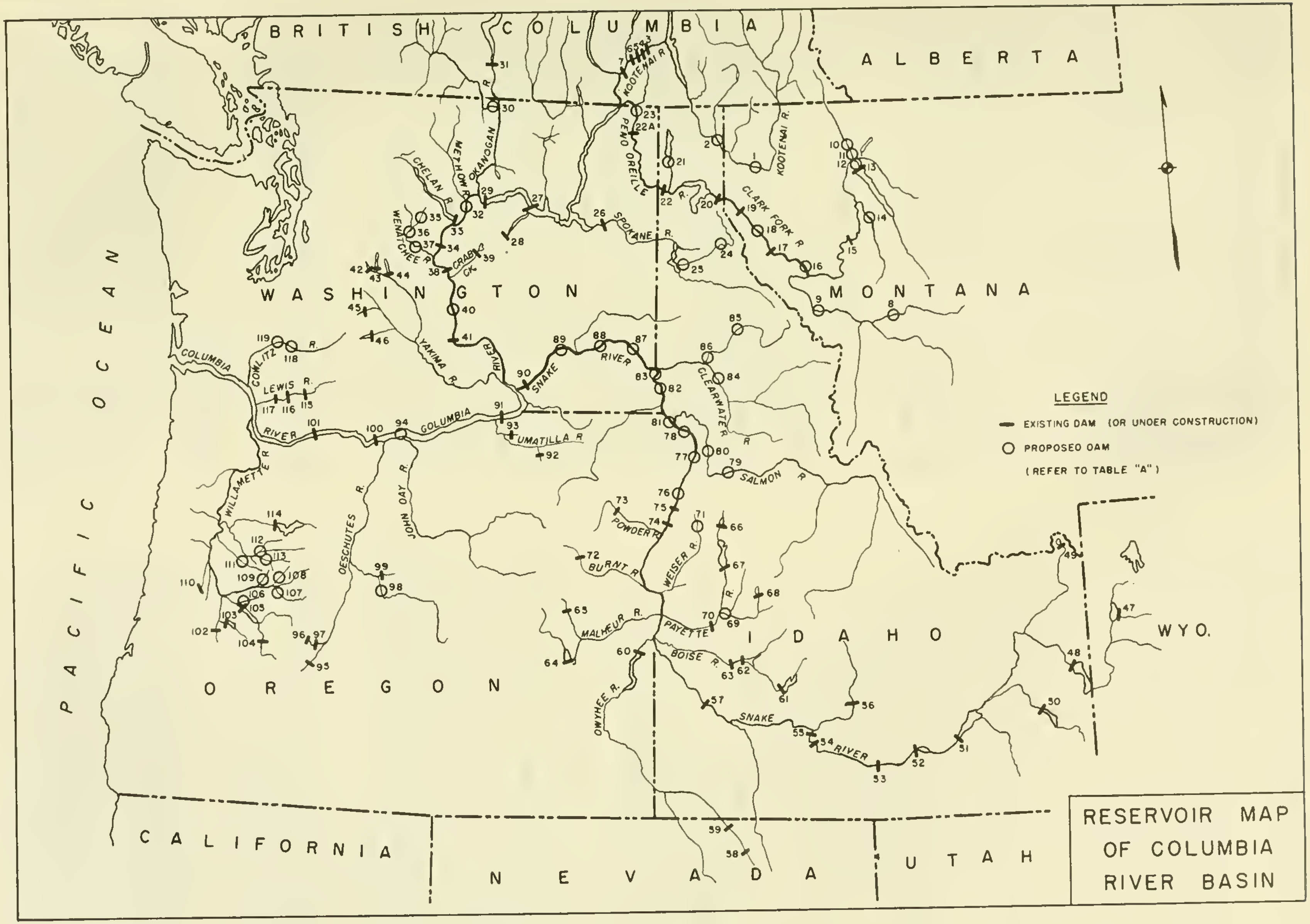
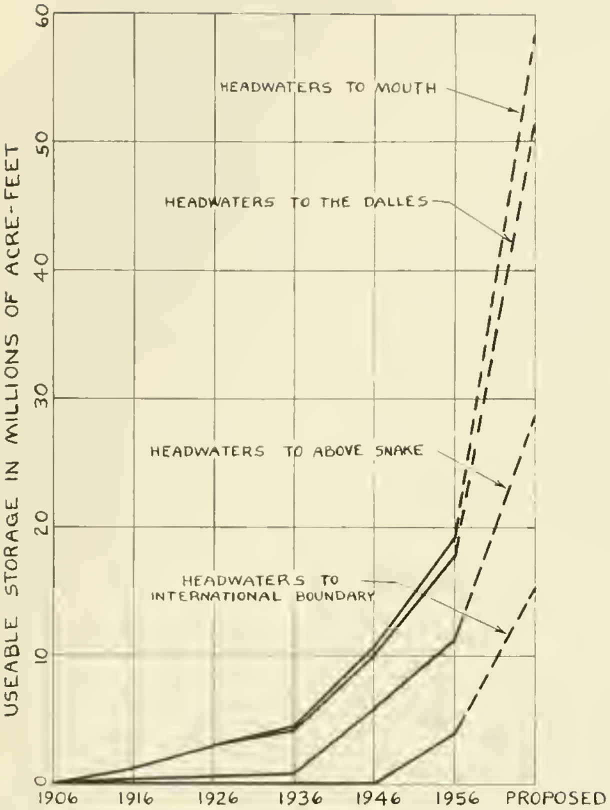

RESERVOIR MAP OF COLUMBIA RIVER BASIN
LEGEND
EXISTING DAM (OR UNDER CONSTRUCTION)
PROPOSED DAM
(REFER TO TABLE "A")
BRITISH COLUMBIA
ALBERTA
WASHINGTON
MONTANA
OREGON
IDAHO
WYO.
CALIFORNIA
NEVADA
UTAH
PACIFIC OCEAN
COLUMBIA RIVER
SNAKE RIVER
CLEARWATER R
SALMON R
CLARK FORK R
KOOTENAI R.
PEND OREILLE R.
SPOKANE R.
OKANOGAN
METHOW R
CHELAN R.
WENATCHEE R
CRAB CK.
YAKIMA R.
COWLITZ R.
LEWIS R.
WILLAMETTE R
DESCHUTES R.
JOHN DAY R.
UMATILLA R
POWDER R
BURNT R
WEISER R
PAYETTE R
MALHEUR R.
BOISE R.
OWYHEE R.

FIG. 6



USEABLE STORAGE IN RESERVOIRS OF COLUMBIA RIVER & TRIBUTARIES

FIG. 7

1. A bibliography of water quality and its relation to aquatic life was developed.

2. The literature was then searched to obtain specific information on water quality characteristics that would be detrimental to fish life.

3. Existing data on water quality in the Columbia River Basin were assembled.

4. Air temperature, reservoir, and irrigation data in the Basin were assembled.

5. Since the existing water quality data for the Basin's streams were inadequate for a study thereof, there was established a series of forty sampling stations, located (a) on the main stem of the Columbia, (b) on its principal tributaries, (c) above and below reservoirs, and (d) in the irrigated areas of the Yakima River and Columbia Basin Project.

6. Water samples were collected for those water quality constitutnts significant to fish life. Frequent samples were collected during the summer season when stream flows are low, water temperatures high, irrigation return flows at a maximum, and when biological activity is at a maximum. Less frequent samples were collected during the remainder of the years owing to limitations of the budget and available time.

7. Collected data were displayed and evaluated as shown in the subsequent pages.

8. Fishery biologists are expected to study the final evaluation of past, present, and future predicted water quality in its relation to fish life.

Collected Data

Water quality

Water quality data was obtained as far back as 1910 (U.S.G.S., W.S.P 339 and 363), when Van Winkle made the initial study of Pacific Northwest streams and lakes. Very little quality data are available (other than temperature) between this early survey and the end of World War II. The Canadian Department of Mines and Technical Surveys, Ottawa, has commenced (1949) collection of water quality data on the Columbia River and its tributaries in Canada. Water samples in Canada and those of the U.S.G.C. in the United States are frequently held for several weeks prior to analysis. This delayed sample analysis may give lower pH and alkalinity values because of the formation of carbon dioxide from organic decomposition or because of precipitation of carbonates.

The water quality data described above were copied and assembled on data sheets that tabulate the data by the year and the location.

Air temperature

Since water temperature is responsive to air temperatures, it is necessary that air temperature data, along with flow, be studied when analyzing changes in water temperatures. Accordingly, air temperatures in the Columbia River Basin were collected from 1910 to the present (copied from U. S. Weather Bureau Climatological Summaries).

These air temperatures were tabulated by monthly and yearly means for 18 selected stations in Washington, one in Idaho and nine in Oregon.

WATER QUALITY EFFECTS ON FISHES

Water quality affects anadromous fishes in different ways. It may, if adverse, discourage the adults in their upstream migration; kill them by toxicity or disease before they reach the spawning grounds; cause them to not spawn when at the spawning beds; destroy their eggs by providing an environment unfavorable for hatching; or it may cause the newly hatched fish to die through destruction of the young fish itself or its food supply. A search of the literature for specific water quality constituents and their effect on anadromous fishes was not very fruitful. Different species of fish and the same fish at different ages have varying tolerances to water constituents. The effect of a particular constituent also frequently depends upon the variation in concentration of other constituents.

A concise statement on the vagrant nature of the research and of the available data on toxicity to fishes is given in the California "Water Quality Criteria" (12). It reads as follows: "Not only are the references dealing with fish innumerable; they are also individualistic in their approaches to the problem. The conditions under which the numerous investigators conducted their experiment varied widely and were seldom standardized. Hence, the results of several investigators of the same pollutant may not compare closely. This wise discrepancy arises from variations in the species of fish or other organism used, its prior handling, the temperature, the dissolved-oxygen content, synergistic and antagonistic substances, the hardness and other mineral content of the water, and the time of exposure."

There is a dearth of specific information on water quality and fish life and a need for more study on this subject. In determining what water tests should be made in this survey, it was decided to make those where there were reports of the constituent being of possible harm to fish life and to make other tests whose values would be helpful in general water quality evaluation. (See succeeding section for tests actually made and the analytical procedure used.)

Ellis (7) describes the following waters, in the absence of toxic pollutants, as being favorable to a good mixed fish fauna:

a. Dissolved oxygen, not less than 5 p.p.m.

b. pH, approximately 6.7 to 8.6, with an extreme range of 6.3 to 9.0.

c. Specific conductance at 25° C., 150 to 500 mho x 10^{-6}, with a maximum of 1,000 to 20,000 mho x 10^{-6} permissible for streams in western alkaline areas.

d. Free carbon dioxide, not over 3 cc. per liter.

e. Ammonia, not over 1.5 p.p.m.

f. Suspended solids, such that the millionth intensity level for light penetration will not be less than 5 meters.

The International Pacific Salmon Fisheries Commission in their upper Fraser River studies (8), state the following in regard to water temperatures: "Sockeye salmon in the Fraser system have a decreasing temperature tolerance as they approach their spawning grounds. On the spawning beds, large numbers of sockeye will die without spawning if mean water temperature exceeds 63° F. Farther down the migration route, at Hells Gate, temperatures of 70° F. have caused no apparent ill effeots. . . . Columnaris disease is known to become extremely virulent at temperatures in excess of 70° F." Their studies indicate that sockeye can be expected to die when mean water temperatures exceed 68° F. for periods of several days.

The Water Pollution Research Board, London, in their 1954 report (9), had the following observations to make on effects of pollution on fish:

a. Ammonia undissociated is more toxic than is the ammonium ion; toxicity of ammonia is effected pH, carbon dioxide and dissolved oxygen concentrations. Toxicity of ammonia (undissociated) increases as oxygen concentration decreases. Carbon dioxide in low concentrations (up to 30 p.p.m.) reduces the toxicity of ammonia by lowering the pH value and thus increasing the ionization of ammonia.

b. Trout may be killed in the presence of 15 to 60 p.p.m. of CO_2 if the concentration of dissolved oxygen is less than about 30 percent of the saturation value.

c. An anionic detergent equivalent to 1.26 p.p.m. of sodium lauryl sulphate, produced a 50-percent mortality to rainbow trout after about 12 weeks exposure. When the concentration was 4 p.p.m., the median period of survival of the trout was about 7 days.

Doudoroff and Katz made a critical review of the literature on the toxicity of industrial wastes and their components to fish (10, 11). A summary of this review follows:

a. pH - under otherwise favorable conditions, pH values between 5.0 and 9.0 are not lethal for most fully developed fresh-water fishes.

b. Strong alkalies, such NaOH, $Ca(OH)_2$, and KOH, are not lethal to fully developed fish in fresh water when their concentration does not raise the pH value above 9.0.

c. Ammonia, ammonium hydroxide, and ammonium salts can be very toxic to fish. Nonionic ammonia is most toxic and its concentration increases as the pH increases. 1.2 to 3 p.p.m. of nonionic ammonia (as NH_3) has been reported as being toxic to hardy species of fish.

d. Strong mineral acids, such as H_2SO_4, HCl, and HNO_3, and some moderately weak organic acids can be lethal to fully developed fish in natural fresh water only when they reduce the pH to below 5.0.

e. Weak inorganic and organic acids, such as hydrosulfuric, hypochlorous, hydrocyanic, carbonic, chromic, tannic, and boric acids, and probably also sulfurous, benzoic, acetic, and propionic acids, can impart pronounced toxicity to some waters for fresh-water fish without lowering the pH to a value as low as 5.0.

f. Carbon dioxide - fish differ greatly in their susceptibility. Sensitive fresh-water species may succumb rapidly under concentrations of between 100 and 200 p.p.m. of free CO_2 with high dissolved oxygen concentrations. Low CO_2 concentrations are lethal when the dissolved oxygen concentration is low.

g. Solutions of hydrogen sulfide, free chlorine, chloramine, cyanogen chloride, carbon monoxide, ozone, phosphine, and sulfur dioxide, are all extremely toxic to fish. These inorganic gases may be lethal to sensitive fish in concentrations of 1.0 p.p.m. (and in some cases less than 0.1 p.p.m.) and less.

h. Silver, mercury, copper, lead, cadmium, aluminum, zinc, nickel, tin, iron, gold, cerium, platinum, thorium, and palladium, can be classified as metals of high toxicity to fish. The salts of some of these metals are comparatively harmless in highly mineralized waters, because of precipitation or because of insoluble compounds and antagonism. Some of the highly toxic metals are strongly synergistic, such as zinc and copper. Calcium tends to counteract the toxicity of some of the heavy metals. Cupric, mercuric, and silver salts have, in soft water, been toxic at metal concentrations as low as 0.02 to 0.004 p.p.m. In soft water, zinc, cadmium, lead and aluminum have proved injurious to fish at concentrations between 0.1 and 0.5 p.p.m. Nickel and chromium (and perhaps iron) have not been observed to cause toxicity much below concentrations of 1.0 p.p.m.

i. Sodium, calcium, strontium, magnesium, potassium, lithium, barium, manganous and cobaltous ions have a relatively low toxicity for fish. With but few exceptions, they have not been observed to cause toxicity at concentrations less than 50 p.p.m.

The California State Water Pollution Control Board (12) lists some additional factors concerning water quality and their effect on fish life. These factors are summarized below:

a. Algae have affected fish life by production of toxic metabolic products; by clogging fish gills when they die in huge numbers; and by depleting the oxygen supply when they die and decompose in large numbers.

b. Arsenic (a component of insecticides, weed killers, and many industrial wastes) - from the meager information available, it appears that arsenic compound concentrations of less than 1.0 p.p.m. are not harmful.

c. Bacteria - some favor fish life by creating decomposition products necessary in the food chain; others may be harmful by depleting the oxygen or by causing an infection in the fish (such as columnaris disease).

d. Benzene hexachloride (an insecticide) - gamma isomer reported to be toxic to fish at 0.05 p.p.m., the delta at 0.2 p.p.m., and the beta at 2.0 p.p.m.

e. Bromine - fish survived for 48 hours in concentrations of 10 p.p.m. of molecular bromine.

f. Cadmium - minimum lethal concentration for stickleback has been reported as 0.2 p.p.m. Cadmium salts may be more toxic.

g. Chlordane (an insecticide) - dust toxic to fingerlings of bass and bluegills at concentrations of 0.2 p.p.m.

h. Chlorides - 400 p.p.m. in fresh water reported harmful to trout.

i. Color - no reported direct effect on fresh-water fishes.

j. Cresols - 10 p.p.m. fatal to any fish under prolonged exposure.

k. Cyanides - toxic to sensitive fish at concentrations of less than 0.1 p.p.m.

l. D.D.T. (an insecticide) - concentrations of less than 0.1 p.p.m. may be lethal to fish life.

m. Dissolved solids - no appreciable effect observed if solids below 400 p.p.m.

n. Fluorides - Goldfish survived 100 p.p.m. for over 4 days.

o. Formaldehyde - 10 p.p.m. had no apparent effect on rainbow trout in 3 days.

p. Hardness - An increase in water hardness tends to reduce the toxicity of many compounds.

q. Nitrates - no observed effect on fish life; favor growth of fish by promoting growth of food chain.

r. Oil - 0.4 ml. oil per liter of water reported to be toxic to fresh-water fish. Kerosene applied at the rate of 25 gallons per acre, as a larvicide, had no effect on fresh-water fish.

s. Pentachlorophenol (wood preservative and also used for slime and algae control) - lethal to fish life at concentrations of 0.2 to 0.6 p.p.m.

t. Phenol concentrations of 1.0 p.p.m. or less will probably be safe for most fish.

u. Phosphates - not toxic to fish life and may be beneficial by increasing food chain.

v. Selenium - constant exposure to traces of selenium has produced toxic effects.

w. Silica - no reported effects.

x. Silt - fish can stand fairly heavy silt loads; the limits of which have not been established.

y. Sulfates - good game fish are found in waters containing less than 90 p.p.m. of sulfates.

z. Sulfur - no significant data. Mercaptans are reported to be toxic to fish (13) in concentrations of 0.5 to 1.0 p.p.m.

FIELD SAMPLING AND ANALYTICAL PROCEDURES - SAMPLING STATIONS

Field sampling

Sampling procedures were developed to obtain as nearly a representative sample as possible from the station to be sampled. The procedure had to be within the limitations of time, personnel, and equipment available. There was good vertical mixing at all of the stream and canal stations. In the smaller streams and canals, no significant difference in water quality could be found within the cross-section. In the larger streams, there was occasionally a slight change in water quality across the cross-section because of insufficient horizontal mixing below a large tributary. Two or three samples were collected across the cross-section of the stream (as necessary) when there was an indication of inadequate horizontal mixing. Samples were usually collected from about mid-depth.

During the 1954-1955 sampling period, a single set of samples was collected from each sampling location per visit. The single samples were composites made from several sample drops at the station. Samples for dissolved oxygen, pH, and carbon dioxide were not composited. The stations were visited three or four times a month during the summer and once in November, December, March and May. In the 1955-1956 sampling period, the stations were sampled (in the summer) every two weeks with a minimum of two sets of samples being obtained from each station on each visitation.

The water sampler most frequently used was a 1,200 ml. improved type of Kemmerer sampler. This sampler is lowered in open position to the desired depth (in a lake or where the stream flow is not rapid) and then a messenger is sent down the attached line. This messenger trips a set of holding forks and rubber stoppers move in to seal the cylinder of water within the sampler. Sample bottles are carefully filled from the sampler by use of a rubber tube at the sampler base. Sample bottles used were the regular A.P.H.A.B.O.D. bottles, having a ground glass tapered stopper and holding about 300 ml. A weighted, displacement type, sampler was used where the current was swift or where the water was shallow. This sampler holds three B.O.D. bottles. During filling, to insure a representative sample, the contents of the bottles are displaced three times into the outer container. This type of sampler begins to fill immediately on lowering and is therefore not suited for deep reservoir or lake samples. Biological samples were collected on the Wenatchee River system. This river system will be covered in a separate study report.

Analytical procedures

Water quality determinations were made: (a) in the field at, or shortly after the time of sampling, for those qualities whose value would change on standing; (b) in the laboratory within a day or two following sampling for those determinations not greatly affected by standing or where field testing would be most difficult; and (c) by a private testing laboratory for element analysis. All analyses were in accordance with "Standard Methods" (19) unless otherwise noted below.

Determinations made in the field and the analytical procedure used were as follows:

a. Temperature - a centigrade thermometer, reading to 0.1° C., was dipped in the water when possible. If not, a portable resistance thermometer was used, reading to about 0.1° F., which could be lowered to any desired depth for a temperature reading.

b. pH - these values were generally measured electrometrically, using glass and saturated calomel electrodes standardized against a buffer solution. Colorimetric pH determinations were made, using a glass disc color comparator when an electrometric unit was judged unreliable (following a trip over rough roads) and as a check on the electrometric measurement.

c. Dissolved oxygen - samples were dosed at the time of collection with reagents for the sodium azide (Alsterberg) modification of the Winkler method. Percent of saturation was computed using sea level saturation values at the temperature of sample collection. Percent of saturation values were not corrected for the altitude of sample collection, i.e., barometric pressure.

d. Carbon dioxide - total carbon dioxide was approximated by adding 0.02 N NaOH to the phenolphthalein endpoint in a carefully collected sample.

e. Ammonia - sample was preserved with 0.8 ml. of concentrated H_2SO_4 per liter of sample at time of collection.

f. Alkalinity - total bicarbonate a and carbonate (if present) alkalinity were determined by titration with 0.02 N H_2SO_4 against the phenolphthalein and methyl orange endpoints.

g. Hardness - total hardness was measured by titration using the Schwarzenbach method. Carbonate and noncarbonate hardness were calculated, using the total hardness--total alkalinity relationship.

Determinations made on samples brought back to the laboratory and the analytical procedures used were as follows:

a. Color - "Aqua Tester" was used to measure color by comparison with a glass disc calibrated against platinum-cobalt standards. Excessive turbidity was removed by centrifuging when necessary.

b. Turbidity - A Hellige turbidimeter was used to measure low turbidities. If turbidity values exceeded 30, the sample was diluted with distilled water. The turbidimeter was calibrated against a Jackson candle turbidimeter.

c. Conductivity - specific conductance was measured using a Wheatstone bridge and a specific conductance cell, calibrated against a standard KCl solution. Values were recorded in micromhos/cm., corrected to 25° C.

d. Ammonia - determinations were made by direct nesslerization in nessler tubes, and color readings were made by comparison with permanent standards, or from an electrophotometer calibrated against permanent standards. Precipitated interferring substances were removed by filtration or by centrifugation.

e. Sulfates - the turbidimetric method was used by precipitating the sulfate ion with the barium ion in acid solution. Turbidity values, converted to p.p.m. of sulfate ion, were read from a Hellige turbidimeter calibrated against standard sulfate solutions.

f. Total solids - 100 ml. of sample was evaported to dryness over a water bath, dried for at least one hour at 103° C., and weighed. Total solids and dissolved solids will have about the same value for nearly all stations where turbidities were low.

Samples for element analysis were periodically sent to a commercial laboratory set up for this type of analytical work. The elements they tested for and the methods used were as follows:

a. Iron - Thiocyanate method, reference (19).

b. Copper - Carbonate procedure, reference (19).

c. Zinc - "Colorimetric Determinations of Traces of Metals" by

E. B. Sandell, p. 458.

d. Aluminum - reference (19), p. 50.

e. Calcium - flame photometer against standards.

f. Magnesium - reference (19), titan yellow.

g. Sodium - flame photometer.

h. Potassium - flame photometer.

i. Lead - Sandell dithizone method (modified).

j. Manganese - reference (19), periodic method.

k. Silver - Sandell, dithizonate method, p. 400.

Sampling Stations - Their Selection and Location

Sampling stations were chosen to meet the following requirements:

a. Boat not required to get representative samples.

b. Station far enough below a tributary so that samples would not be overly influenced therefrom.

c. To sample the Columbia River main stem above and below those sources of water quality change that might affect the fishery, and to sample from significant intermediate points.

d. To sample important tributaries so that main stem quality changes could more accurately be evaluated.

e. To obtain water quality data from a river basin where irrigation has been stablized for a considerable period of time.

f. To evaluate water quality changes taking place in irrigation water as it passes through the canals and over the land.

g. To obtain quality data above and below water impoundments.

h. To obtain quality data on a river basin prior to dam construction.

Table 3 lists the sampling stations together with their river mile designation. River miles are the distance the station is upstream from the mouth of the Columbia River. This information was obtained from reference (18). For example, station 20 near the mouth of the Naches River has a river mile designation of CYN-445. This means that the total distance from the mouth of the Columbia River (C) to the mouth of the Yakima River (Y) and up the Yakima River to the mouth of the Naches River (N) and the sampling station is 445 miles. Figures 8 and 9 show the sampling station locations.

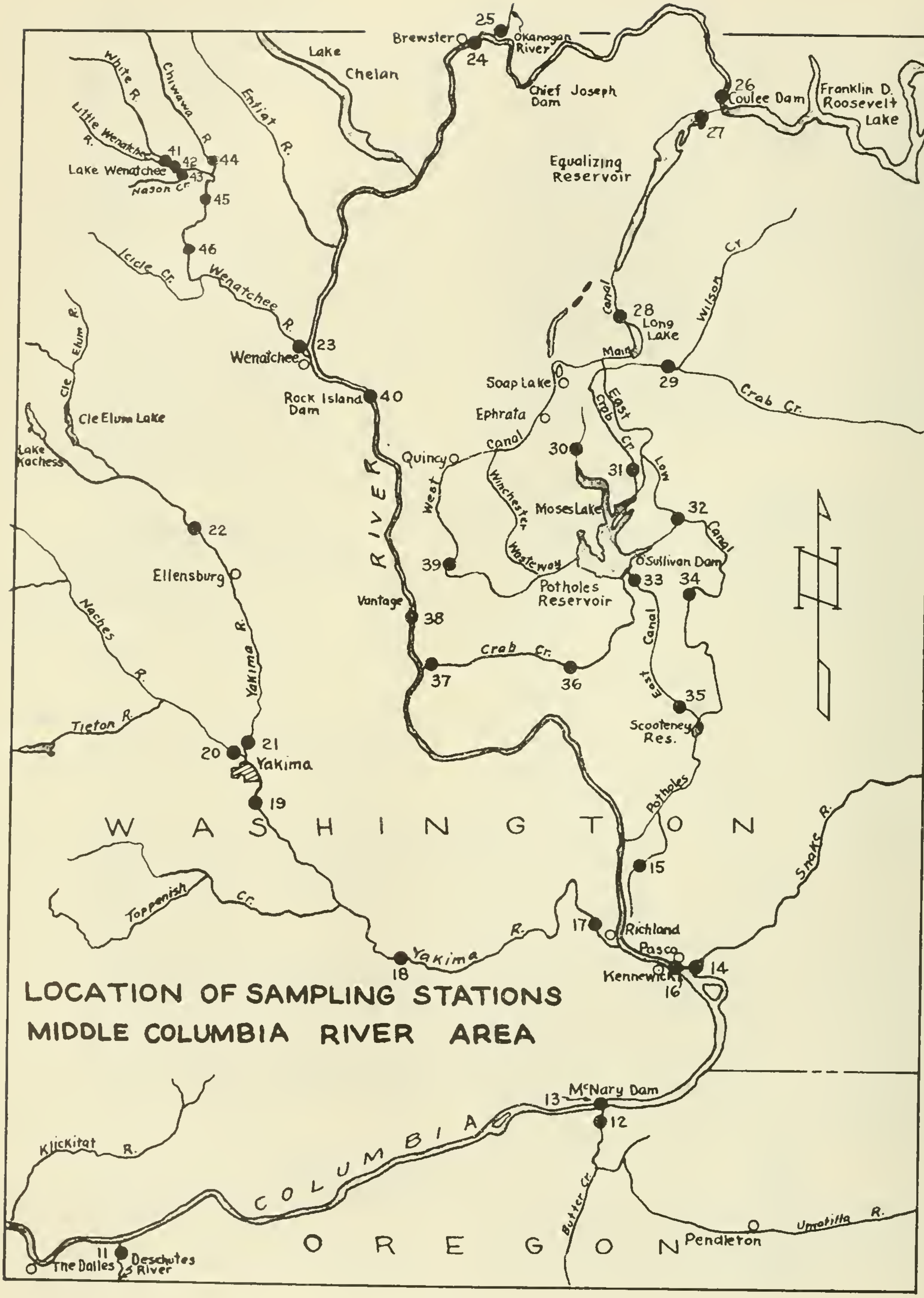
Stations 1, 3, 8, 11, 12, 14, 17, 20, 23, and 25 near the mouths of the Cowlitz, Lewis, Willamette, Deschutes, Umatilla, Snake, Yakima, Naches, Wenatchee and Okanogan Rivers respectively were selected to evaluate what effect tributaries would have on Columbia River water quality. Station 2 at Cathlamet and station 26 at Grand Coulee Dam were selected as overall reference stations for an assessment of total water quality changes in the Columbia River between the mouth and the upper limit of fish migration. Stations 7, 9, 13, 16, 38, 40, and 24, at Vancouver, Bonneville Dam, McNary Dam, Pasco, Vantage, Rock Island Dam, and Brewster respectively, serve as intermediate check stations on the progression of water quality changes in the Columbia River.

Stations 3, 4, and 5 on the Lewis River give an independent study on the effect two impoundments (Yale and Merwin) have on a stream otherwise unaffected by man-made impoundments or diversions. Stations 11, 12, 14, 17 near the mouths of the Deschutes, Umatilla, Snake and Yakima Rivers will provide data indicative of irrigation influences on a stream. Station 8 on the Willamette River will provide data on a stream heavily polluted by industry and domestic sewage.

Stations 17, 18, 19, 21, and 22 on the Yakima River provide data on the progressive effect irrigation return flow has on a river basin highly developed for

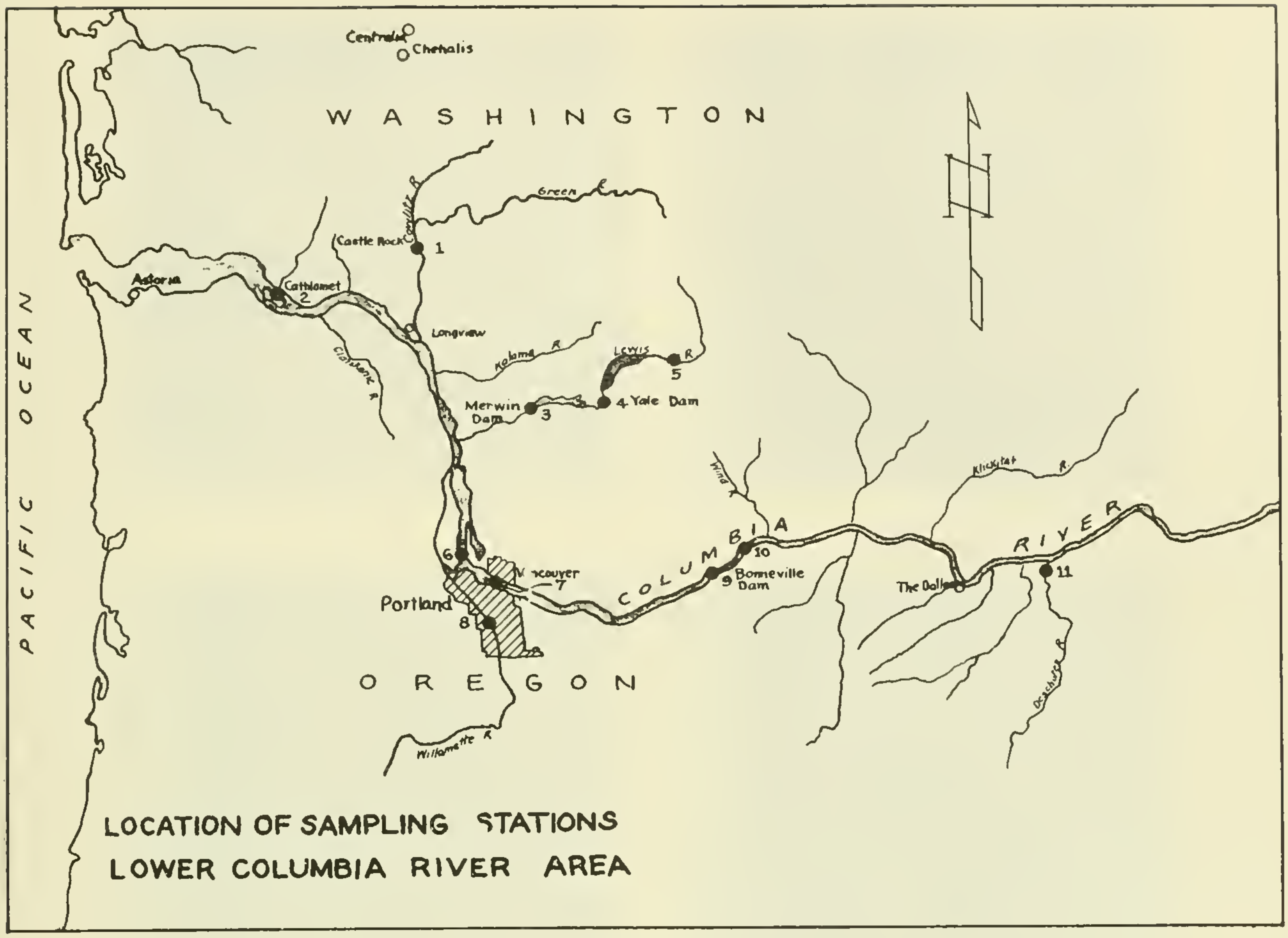
Table 3.--Stream sampling stations.

Station No.	River Mile Designation	Location
1	CC - 85	Cowlitz River at Castle Rock County Road Bridge
2	CC - 40	Columbia River at Puget Island Bridge (Cethlamet)
3	CL - 108	Lewis River below Merwin Dam
4	CL - 122	Lewis River below Yale Dam
5	CL - 137	Lewis River above Yale Reservoir
6	C - 100	Columbia River below Willamette River mouth
7	C - 104	Columbia River above Willamette River mouth near Interstate Bridge
8	CW - 114	Willamette River near mouth, vicinity Steel Bridge
9	C - 145	Columbia River just below Bonneville Dam
10	C-149 to C-169	Columbia River above Bonneville impoundment (Cascade Locks or Hood River Bridge)
11	CD - 204	Deschutes River near mouth
12	CU - 290	Umatilla River near mouth
13	C - 292	Columbia River just below McNary Dam
14	CS - 326	Snake River near mouth (State Highway Bridge)
15	C(P.E.C.) - 743 to 748	Potholes East Canal; Mile 65.8 for 1954-55 and Mile 71 for 1955-56
16	C - 329	Columbia River at Pasco
17	CY - 340	Yakima River at Enterprise
18	CY - 414	Yakima River, Mabton-Sunnyside Bridge
19	CY - 435	Yakima River below Union Gap
20	CYN - 445	Naches River near mouth
21	CY - 445	Yakima River above Naches River mouth
22	CY - 493	Yakima River above Thorp
23	CW - 471	Wenatchee River near mouth (Sleepy Hollow Bridge)
24	C - 530	Columbia River at Brewster
25	CO - 549	Okanagan River near mouth
26	C - 596	Columbia River below Grand Coulee Dam
27	C(M.C.)-597	Main Canal, Headworks at Grand Coulee Dam
28	C(M.C.)-627	Main Canal below Coulee City
29	CCb - 490	Crab Creek near Wilson Creek
30	CCbRF - 471	Rocky Ford Creek on Ephrata-Moses Lake Road
31	CCb - 466	Crab Creek, 4 miles northeast of Moses Lake
32	C(E.L.C.) - 667	East Low Canal at Weber Westeway (9 miles southeast of Moses Lake)
33	C(P.E.C.) - 667	Potholes East Canal below O'Sullivan Dam
34	C(E.L.C.) - 687 & 699	East Low Canal; at Warden, 1954-55; at Scootenay Waste-way, 1955-56
35	C(P.E.C.) - 695	Potholes East Canal above Scootenay Dike
36	CCb - 431	Crab Creek at Corfu
37	CCb - 411	Crab Creek near mouth
38	C - 413	Columbia River below Vantage
39	C(W.C.)-682	West Canal below Burke
40	C - 453	Columbia River at Rock Island
41	CWW - 527	Lake Wenatchee; upper end of lake, northwest corner in 50 feet of water
42	CWW - 526	Lake Wenatchee; middle of Lake, about 2 miles from upper end
43	CWNa- 523	Nason Creek; near mouth (State Park Bridge)
44	CWC - 524	Chiwawa River --near mouth (highway bridge)
45	CW - 514	Wenatchee River -- 2 miles below Plain
46	CW - 503	Wenatchee River -- Tumwater Canyon near Drury Canyon



LOCATION OF SAMPLING STATIONS
MIDDLE COLUMBIA RIVER AREA
WASHINGTON
OREGON
COLUMBIA
RIVER
Brewster
Okanogan River
Lake Chelan
Chief Joseph Dam
Coulee Dam
Franklin D. Roosevelt Lake
Equalizing Reservoir
White R.
Chiwawa R.
Entiat R.
Little Wenatchee R.
Lake Wenatchee
Nason Cr.
Icicle Cr.
Wenatchee R.
Wenatchee
Rock Island Dam
Cle Elum R.
Cle Elum Lake
Lake Kachess
Long Lake
Main Canal
Wilson Cr.
Crab Cr.
Soap Lake
Ephrata
East Crab Cr.
Low Canal
Quincy
Canal
West Canal
Winchester Wasteway
Moses Lake
O'Sullivan Dam
Potholes Reservoir
Vantage
East Canal
Ellensburg
Naches R.
Yakima R.
Tieton R.
Yakima
Scooteney Res.
Potholes
Snake R.
Toppenish Cr.
Yakima R.
Richland
Pasco
Kennewick
McNary Dam
Klickitat R.
Butter Cr.
Umatilla R.
Pendleton
The Dalles
Deschutes River

FIG. 8



LOCATION OF SAMPLING STATIONS
LOWER COLUMBIA RIVER AREA

FIG. 9

irrigation. Samples collected from station 29 on Crab Creek show the nature of the ground water seepage entering the Columbia Basin area itself. Water quality data obtained from the Columbia Basin irrigation project, stations 27, 28, 32, 33, 34, 35, 39, and 15, will show the progressive change in water quality as it progresses down the Basin canals, over the land, and back into the canals. Wenatchee River Basin stations 23, 41, 43, 44, 45, and 46 are to provide background data on a river system's quality prior to the construction of a system of dams. (These stations will be discussed in a subsequent report. Plates 1 through 10 show these sampling stations.)

WATER QUALITY CHANGES WITH STORAGE OF SAMPLES

Samples for water quality must be handled in a manner that will insure when analyzed, a representative value of the constituent actually present at the time the sample was collected. This necessitates the performance of certain techniques at the time the sample is collected. Unfortunately, many samples cannot be transported back to a laboratory for examination at the convenience of the analyst. All samples must of course be collected in clean containers and be sufficient in number to represent the average conditions in the area sampled. Samples should be stored in the dark to inhibit photosynthetic action in the sample. Examples of special care that must be afforded samples for different analyses follows:

Temperature: In shallow streams this can be determined by wading and immersing a hand thermometer for a direct reading. Reversing thermometers are best for accurate temperature measurements of larger bodies of water but are not

Sta. 1 - Cowlitz R. at Castle Rock

Sta. 2 - Columbia R. at Cathlamet

Sta. 3 - Lewis R. below Merwin Dam

Sta. 5 - Lewis R. above Yale Dam

Sta. 8 - Willamette R. near mouth

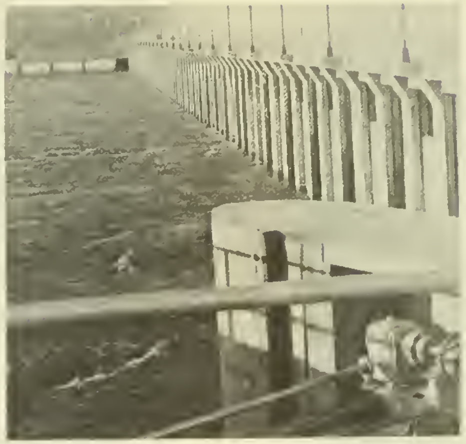
Sta. 9 - Columbia R. at Bonneville Dam

Sta. 10A - Columbia R., Hood R. Bridge

Sta. 10 - Columbia R., Cascade Locks

Sta. 11 - Deschutes R. near mouth

Sta. 12 - Umatilla R. near mouth



Sta. 13 - Columbia R. at McNary Dam

Sta. 14 - Snake R. near mouth

PLATE II

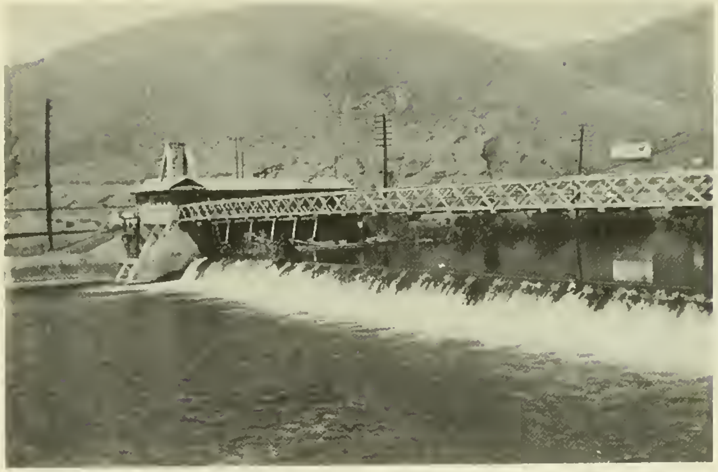
Sta. 15 - Potholes E. Canal, near Pasco

Sta. 16 - Columbia R. at Pasco

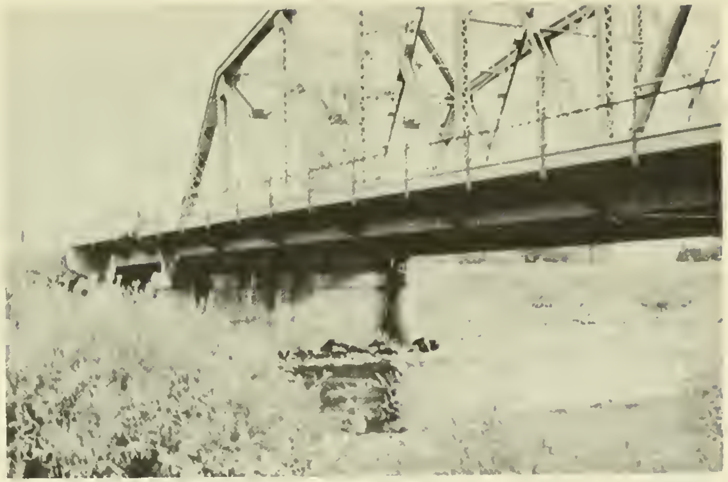
Sta. 17 - Yakima R. at Enterprise

Sta. 18 - Yakima R. at Mabton

PLATE III

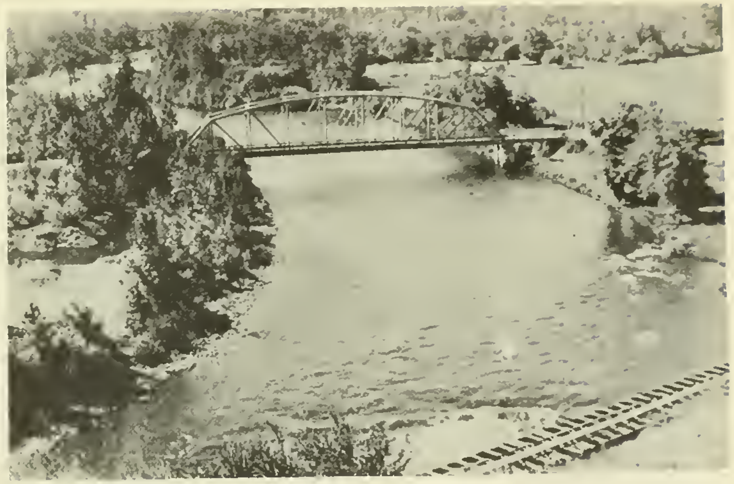


Sta. 19 - Yakima R. below Union Gap



Sta. 20 - Naches R. near mouth

Sta. 21 - Yakima R. above Naches R. mouth



Sta. 22 - Yakima R. above Thorp

PLATE IV

Sta. 23 - Wenatchee R. near mouth

Sta. 24 - Columbia R. at Brewster

Sta. 25 - Okanogan R. near mouth

Sta. 26 - Columbia R. below Grand Coulee Dam

PLATE V

Sta. 27 - Main Canal Headworks at Grand Coulee Dam

Sta. 28 - Main Canal below Coulee City

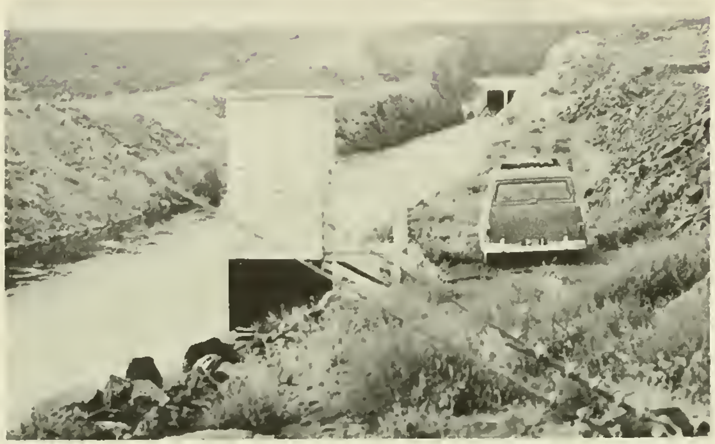
Sta. 29 - Crab Cr. near Wilson Cr.

Sta. 30 - Rocky Ford Cr.

PLATE VI

Sta. 31 - Crab Cr. 4 Miles NE of Moses Lake

Sta. 32 - E. Low Canal, Weber Wasteway



Sta. 33 - Potholes E. Canal below
O'Sullivan Dam

Sta. 34 - E. Low Canal at Warden
(Present canal end)

PLATE VII

Sta. 35 - Potholes E. Canal above
Scootenay Dike

Sta. 36 - Crab Cr. at Corfu

Sta. 37 - Crab Cr. at Beverly (near mouth)

Sta. 38 - Columbia R. at Vantage

PLATE VIII

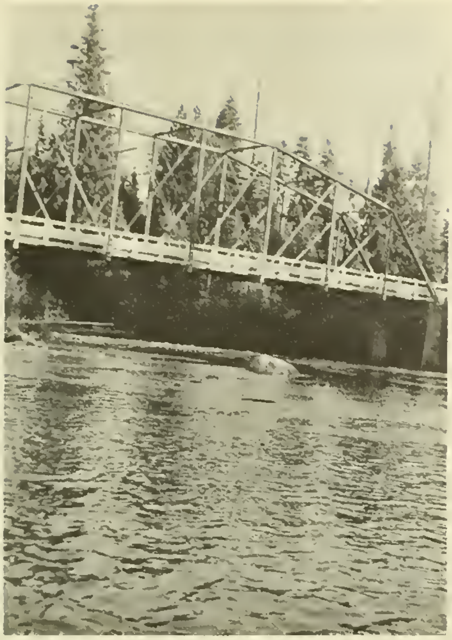
Sta. 39 - West Canal below Quincy

Sta. 40 - Columbia R. at Rock Island

Sta. 42 - Lake Wenatchee

Sta. 43 - Nason Creek

PLATE IX



Sta. 44 - Chiwawa R.

Sta. 45 - Wenatchee R. at Plain

Sta. 46 - Wenatchee R. at Tumwater Canyon

PLATE X

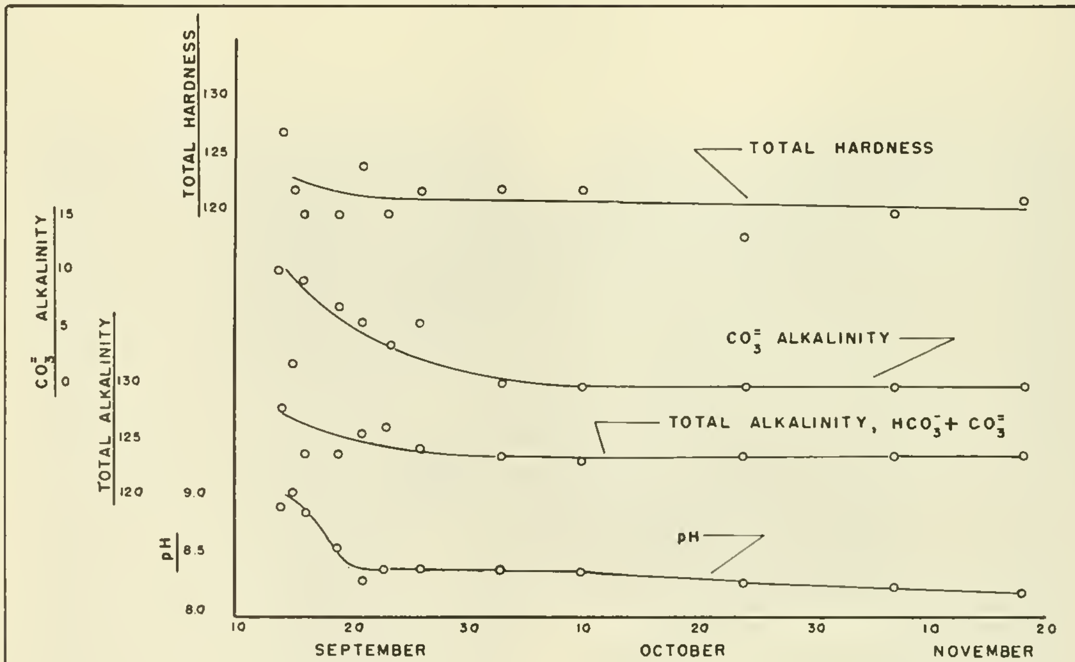
adaptable to field work involving sampling swift streams, from bridges, or lakes from small boats. A portable resistance thermometer is suitable for lakes and deep, slow moving streams as it readily gives temperature with depth. When the stream is swift, it is possible to get a reliable water temperature by leaving the samples in the stream for a sufficient period to cool or warm to the river temperature. The samples can then be quickly brought to the surface and a hand thermometer immersed in the center of the water in the samples.

Dissolved oxygen: These samples must be collected with a sampler that permits collection without agitation or exposure to air. They must be dosed, immediately following collection, with reagents for iodine liberation. Samples so dosed can be stored out of the sunlight for later titration in the laboratory. If not dosed immediately, organic decomposition will alter the dissolved oxygen content or, if the sample warms, the oxygen solubility is lessened and when the sample stopper is removed, oxygen will escape.

Carbon dioxide: This must be determined at the time of collection as organic decomposition in the sample increases the carbon dioxide content.

pH, alkalinity and hardness: These should be determined when the sample is collected, or at least within 12 hours unless the sample can be refrigerated. Production of carbon dioxide by biological decomposition will lower the pH and alkalinity of the sample on standing.

To investigate the effect of delayed analyses, samples of Snake River water were tested on collection and the remainder then returned to the laboratory for periodic determinations on pH, total alkalinity, carbonate alkalinity and total hardness. Figure 10 is an average plot of these determinations over a period of 62 days. During these 62 days, the samples remained on the laboratory shelf in a quiescent state. In the first



SNAKE RIVER

EFFECT OF SAMPLE STORAGE ON pH, ALKALINITY, AND HARDNESS.

SAMPLE COLLECTED SEPT. 14, 1955

FIG. 10

six days, the pH dropped from 9.05 to 8.4, declining steadily thereafter to 8.2. This decline can be attributed to the carbon dioxide (carbonic acid) released on decomposition of the organic matter in the sample. The carbonate ($CO_3^=$) alkalinity dropped 10 p.p.m. to zero in the course of 26 days. These carbonates were changed to the bicarbonate (HCO_3^-) by carbon dioxide in the presence of water ($CO_3^= + CO_2 + H_2O = 2HCO_3^-$). Total hardness and total alkalinity decreased 2 to 3 p.p.m. during the 62 days. This slight decrease was probably due to assimilation of these constituents in the cell structure of microorganisms and to precipitation. (Samples were not shaken prior to each determination).

Ammonia: This is largely produced by biological activity. Since ammonia determinations are not practicable to run in the field, the samples must be preserved with sulfuric acid during their transportation to the laboratory. In the laboratory, they should be refrigerated until the analysis can be made.

Color: These determinations can be made in the laboratory unless iron or manganese in any appreciable amounts are in the sample in a soluble form that will be rendered insoluble on seration. Color samples should be stored out of the bleaching action of sunlight.

Turbidity: Suspended matter in a sample tends to settle and coalesce after a period of several days. If then shaken prior to a turbidity test, the particles will not separate and give the same turbidity readings as they would if measured within a day of sample collection.

Total solids: Biological decomposition will reduce the organic solids in a sample if permitted to continue over a period of several days. Total or organic solids should be determined within a day or two of sample collection.

Others: Determinations for sulfate, conductivity and the various elements are not appreciable altered through storage of the sample prior to analyses.

RELIABILITY OF WATER QUALITY DATA

The water quality of a stream is continuously changing. In a given stream, the value of the constituent tested for will vary with the rate of stream flow, with the water use and with the air temperature or season of the year. To obtain a reliable documentation of the water quality, one has the problem of determining how many and how frequently water samples should be collected. In their 12 established sampling stations in the Columbia River Basin, the U. S. Geological Survey normally collects a water sample each day. These samples for a ten-day period are composited in ratio with each sample's conductivity. Thus, three constituent values are determined during each month of sampling. Even with these numerous samples, there are abrupt changes at some stations in the constituent values. The most accurate procedure would be the daily analysis of each sample. This becomes a virtual impossibility when the number of samples and constituents tested for are large. Collection of daily samples by a local resident of the area is a good and an inexpensive way to get numerous samples. It has the disadvantage of not permitting a test for dissolved gases, ammonia, phosphates, etc., and the samples have been stored for a considerable period prior to analysis (see section on storage of samples).

On this contract, because of the large number of sampling stations involved, because of the necessity of measuring dissolved oxygen, etc. at each station and because of a limited budget, it was not possible to get frequent samples at each station. Stations were sampled (composites at each station of two or more individual samples) with a frequency of at least once a month in the winter and up to ten times in the summer months. To evaluate the reliability of these samples with those collected by the Geological Survey in 1910-11 and 1953-54, a statistical analysis was made of the alkalinity values obtained from the lower Yakima River. (Available time would not permit a more complete analysis.)

Alkalinity values were averaged for each month of the year. For all three sets of data, it was found that these alkalinity values did not follow a normal arithmetic or geometric frequency distribution. In a frequency distribution. In a frequency plot, the data divided themselves into two distinct groups; those for low flows, and those for high flows; with an abrupt transition between the groups. Each set of data was then adjusted with each individual alkalinity value being corrected for the ratio of dilution between the flow at the time of sampling and the mean annual flow. This is an inverse relationship. Logarithmic plotting of frequency of occurrence on semi-log paper and on log probability paper showed the adjusted data to be geometrically normal. Comparative adjusted alkalinity values derived were as follows:

	U.S.G.S. 1910-11	U.S.G.S. 1953-54	Col. Riv. Sur. 1954-56
Geometric mean:	37	85	69
Standard deviation:	3.14	1.22	1.41
Alkalinity range containing 50% of the observations:	17-80	74-97	55-87

On logarithmic probability paper, all three plots overlapped in the highest value range but were well gapped throughout the remainder of the plot. The gaps between the 1910-11 values and the contemporary values were large, indicating a significant change in river alkalinity during the intervening period that is not caused by chance alone. The gap between the U.S.G.S. 1953-54 plot and the 1954-56 Columbia River Survey plot was small, the U.S.G.S. data showing the highest values. These higher values are caused principally by lower river flows during the 1953-54 sampling period. These differences in alkalinity are likewise shown in the differences between the geometric means and the standard deviations from the mean. The alkalinity range containing 50 percent of the observations has narrowed greatly since 1910, indicating an increase in year-around alkalinity values with the largest increase occurring during the non-summer months (see chapter on "Yakima, River, Irrigation and Pollutional Effects").

The standard error of the mean (S.E. $= \frac{\text{St'd. Dev.}}{N^{1/2}}$) for the 1953-54 U. S. Geological Survey's 36 samples = 1.03. This indicates, with other conditions being comparable, that the variation of 68 percent of their yearly means, by chance alone, will fall within the range of 82-88. Since this is a reasonably narrow range, it appears that tri-monthly analyses of composite samples is a practicable compromise. To narrow this range down to 84-86, 287 yearly, or 24 monthly samples would be required. This would almost require a daily sample analysis which is impracticable if a large number of sampling stations is involved.

Conductivity and solids

Solids or residue analyses are reported as either total solids or separately as suspended and dissolved solids (whose sum equals total solids). In the vast majority of samples tested, excepting for Crab Creek, the turbidity was low and the difference between total solids and dissolved solids was small. Total solids only, were measured in this study because of time limitations.

Conductivity is closely related to the dissolved ionized constituents in a water (16, 19) and can be used as a check on the dissolved solids or total solids (if turbidity is low) analysis. The test for conductivity is rapid and precise, whereas the test for solids is very slow and subject to severe errors in sampling or weighing. Over a period of time, ratios of conductivity to solids can be established for a given stream. This ratio can be used to check the reliability of any single solids determination. Figure 11 is a plot of random conductivity and total solids values obtained throughout the Columbia River Basin. A straight line relationship exists between the two. This plot is slightly curved because the higher values were for the Crab Creek area where turbidity was high. If the Crab Creek samples had been analyzed for dissolved, and not total solids, the solids values would have been lower, giving a straight line plot. From Figure 11, it is determined that any single conductivity value minus 50 can be multiplied by 0.74 to give the approximate value of the total (if turbidity is low) or dissolved solids. Using this relationship and comparing the conductivity versus solids values in the tabulations herein, it is obvious which solids values are probable in error. It should be noted that the relationship is of little value where the conductivity is less than 150 micromhos.

Hydrogen ion concentration (pH)

These values were measured in the field at the time of sampling with colori-

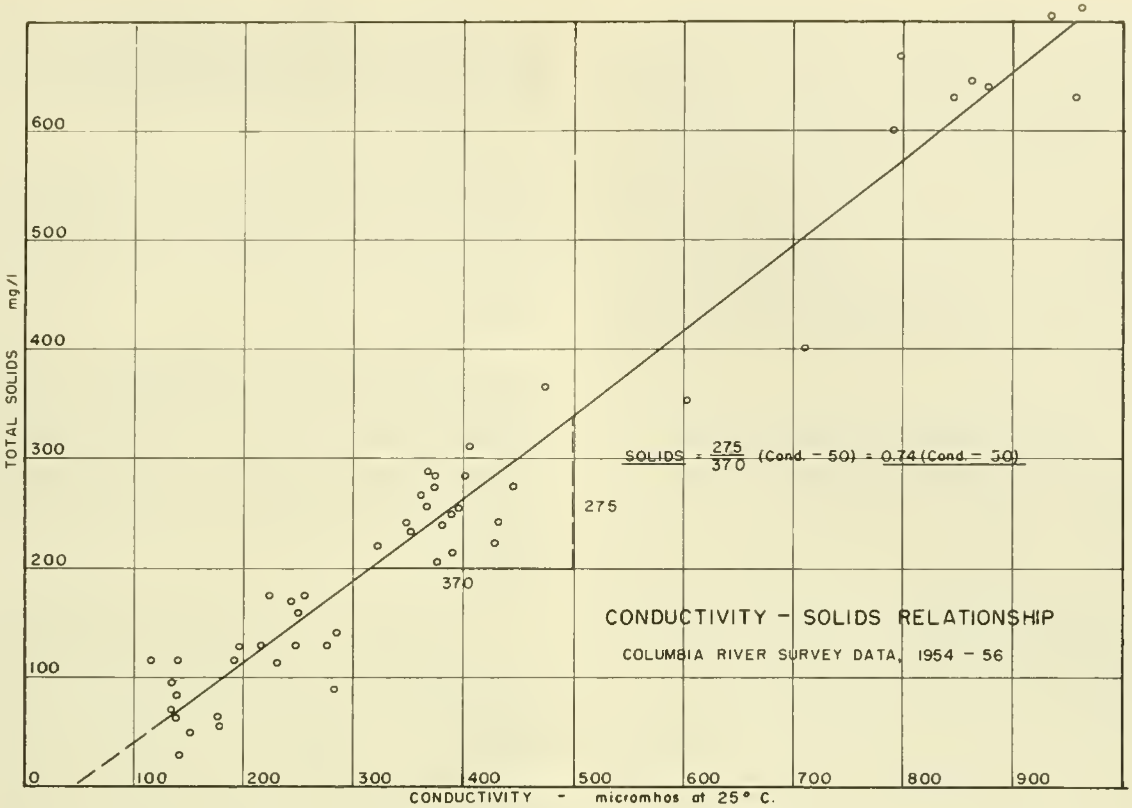


FIG. 11

metric indicators and also with a portable, battery operated, glass electrode pH meter. The glass electrode method usually gave pH values from 0-0.4 units higher than those given by the colorimetric method. Colorimetric values would differ by 0-0.2 units, depending upon the indicator used.

All of these pH values are at best, approximations, for the following reasons:

1. Colorimetric methods are subject to error from color perception of the observer, deterioration of the standards or the indicator and from pH alterations by the indicator in poorly buffered samples of water (19).

2. Electrometric methods are affected by temperature of the samples. As the sample warms, the pH will rise because of an increase in ionization in the sample and because of the nature of the electrodes themselves. This change in temperature was compensated for with the meters used when the water temperature was well above 10° C. When the water temperatures were around 10° C. or lower the pH readings would be low. Thus, if a sample warmed from 10° C. to 20° C. from the time of sampling to the time of pH measurement, the pH read would be above that actually existing in the river. Electrometric pH values should be recorded with the sample temperature at the time of pH measurement.

PRESENT STATUS OF WATER QUALITY - COLUMBIA RIVER BASIN

Reservoirs

Insufficient data were obtained from reservoirs within the Columbia River Basin to enable the presentation of normal water quality data thereon. From a study of the data obtained by the University and reservoir water quality data from other sources, there appears to be no significant effect of existing reservoirs on downstream water quality other than by a change in temperature and a levelling out of the constituent values. This has not always been true. Following the construction of Merwin Dam on the Lewis River in 1931, fish in the downstream salmon hatchery died. The death of these fish was blamed on several different factors, viz.; water quality changes brought about by the release of impounded waters with their decomposition products from a reservoir site that was not cleared of organic debris; by the leeching of alkali from the dam itself; by the leeching of toxic materials from the inundated reservoir area; by a rise in water temperatures; or from improper arrangements for hatchery operation.

A letter from the California Department of Fish and Game, December 31, 1956, is quoted in part to illustrate their experiences with new reservoirs on water quality.

"When Folsom Dam was completed last year, we experienced a very severe problem of oxygen depletion in the American River below the dam. You may know that the reservoir site was not cleared too carefully. The dam was completed in the spring of 1955 but very little water was stored that year. By September of that year the storage was down to less than 50,000 acre feet. At that time there were about ten days of extremely hot weather and the reservoir became septic. Water releases through the power house into the afterbay dam contained no dissolved oxygen and up to ten parts per million of dissolved sulfides.

"As a result the water in the afterbay reservoir became septic and a considerable mortality resulted in the trout that had been planted there a short time before.

"The Department of Fish and Game operates a salmon hatchery to replace the spawning area cut off by the construction of Folsom Dam, using water from the afterbay as a source of supply. The detention time in the afterbay reservoir is quite short, and although the reservoir is about six miles long there was insufficient seration to reoxygenate the water before it reached the hatchery intake at the afterbay dam.

"As a result, we experienced a considerable mortality of salmon in the hatchery and it took the river about seven miles to recover to a point above 5.0 parts per million with a flow of over 500 c.f.s.

"This condition persisted for about two weeks until the weather became cooler and there was some rain which produced some fresh water inflow into the reservoir.

"This is the first time this has happened in California and it caused us considerable difficulty. The problem did not occur this year because there was a great deal more water stored in Folsom Reservoir.

"This pretty well convinced us of the necessity of very good clearing of organic material from large reservoir sites. Shasta and Millerton reservoirs, which are similar in appearance and size of Folsom, had no oxygen depletion problem develop in either instance. The reservoirs were completely cleared.

"The situation at Copco Dam is somewhat different. The Klamath carried a rather considerable algae load and there is a rather well-defined thermocline in Copco Reservoir. I believe that the power house intakes are below the thermocline and as a result the discharge is deficient in dissolved oxygen at times but the river recovers very rapidly and I don't think it is having any effect on the fisheries resources of the stream."

R. M. Paul
Water Projects Coordinator

Data were collected from the Yale and Merwin Reservoirs on the Lewis River, the Bonneville, McNary and Roosevelt Reservoirs on the Columbia River and from Lake Wenatchee. These data are not included in this report as they are brief and were obtained for the purpose of interpreting downstream water quality. Lake Wenatchee water quality values will be included in a separate report on the Wenatchee River Basin.

Streams

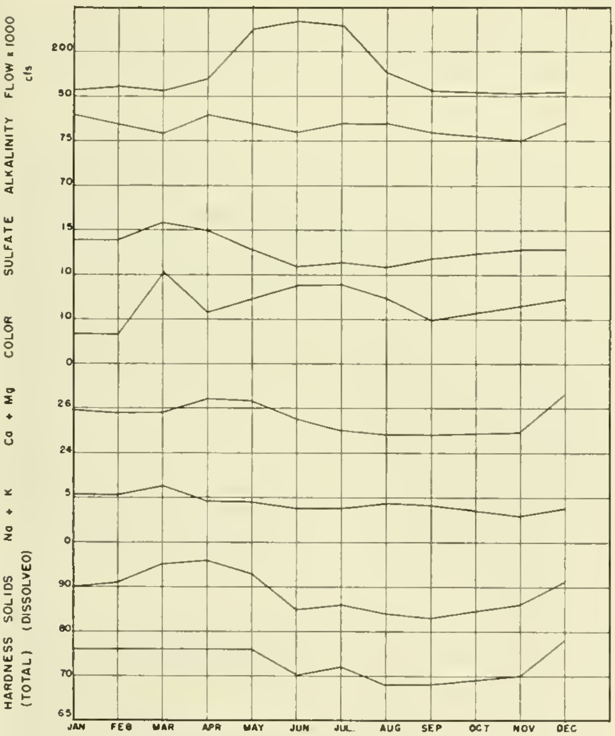
Table B in the appendix lists sampling stations one through forty together with the minimum, average and maximum constituent values observed during the sampling period of June 1954 through September of 1955. Stations 13, 14, 16, 17, 22, 23, 37, 38 and 40 are for the period of June 1954 through December 1956. Average values do not represent a true average for the period since the sampling frequency was not uniform.

The month of sample collection is indicated in the table. Table C in the appendix lists the average monthly values of the constituents at each station together with the year or years of sampling. Figures 12 through 25 illustrate the principal constituent variations at representative locations in the Columbia River Basin.

General: With the exception of the Willamette River, all streams sampled had an abundance of dissolved oxygen. Supersaturated conditions were frequent during the summer when phytoplankton activity was high. Dissolved oxygen values as low as 2.8 p.p.m. were observed in the lower Willamette River during August. The Snake, Umatilla and lower Yakima Rivers together with Crab and Rocky FordCreeks differ markedly from the other streams sampled because of their relatively high content of dissolved material, high summer alkalinities and because of their high summer water temperatures. The Snake River has a marked influence on the Columbia River water quality below Pasco.

Trace elements tested for were low. Lead and silver were not found at any sampling station. Manganese was observed in trace quantities only on the Lewis River below Merwin Dam. Traces of copper were found occasionally at several sampling stations as was zinc and aluminum.

Columbia River: Figure 12 is a monthly average plot of selected and constituents below Coulee Dam. Minimum values lag the period of high runoff by about two months because of the large storage in Lake Roosevelt and in the Canadian lakes and impoundments. The yearly fluctuation in constituents is relatively low because of the leveling-off or evening-out effect of the impoundments which mix the inflowing waters. Figure 13 is a similar plot for the Columbia River at Maryhill, 85 miles below McNary Dam. The yearly range in constituent values fluctuate far more than at Grand Coulee and they more closely follow the rate of river discharge in an inverse relationship. Maximum constituents are in the autumn when the river flow is low.

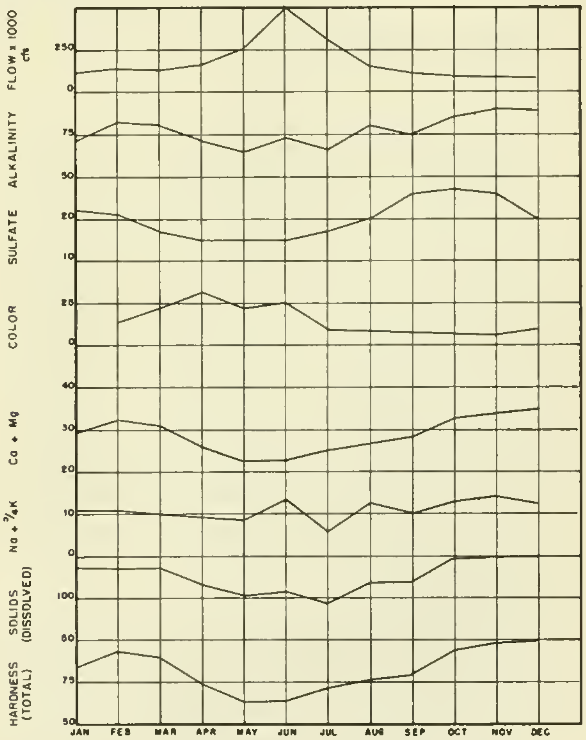


COLUMBIA RIVER AT GRAND COULEE

AVERAGE MONTHLY VALUES — YEARS 1950 – 1951

U.S.G.S DATA

FIG. 12



COLUMBIA RIVER AT MARYHILL

AVERAGE MONTHLY VALUES — YEARS 1952 - 1953

USGS. DATA

FIG. 13

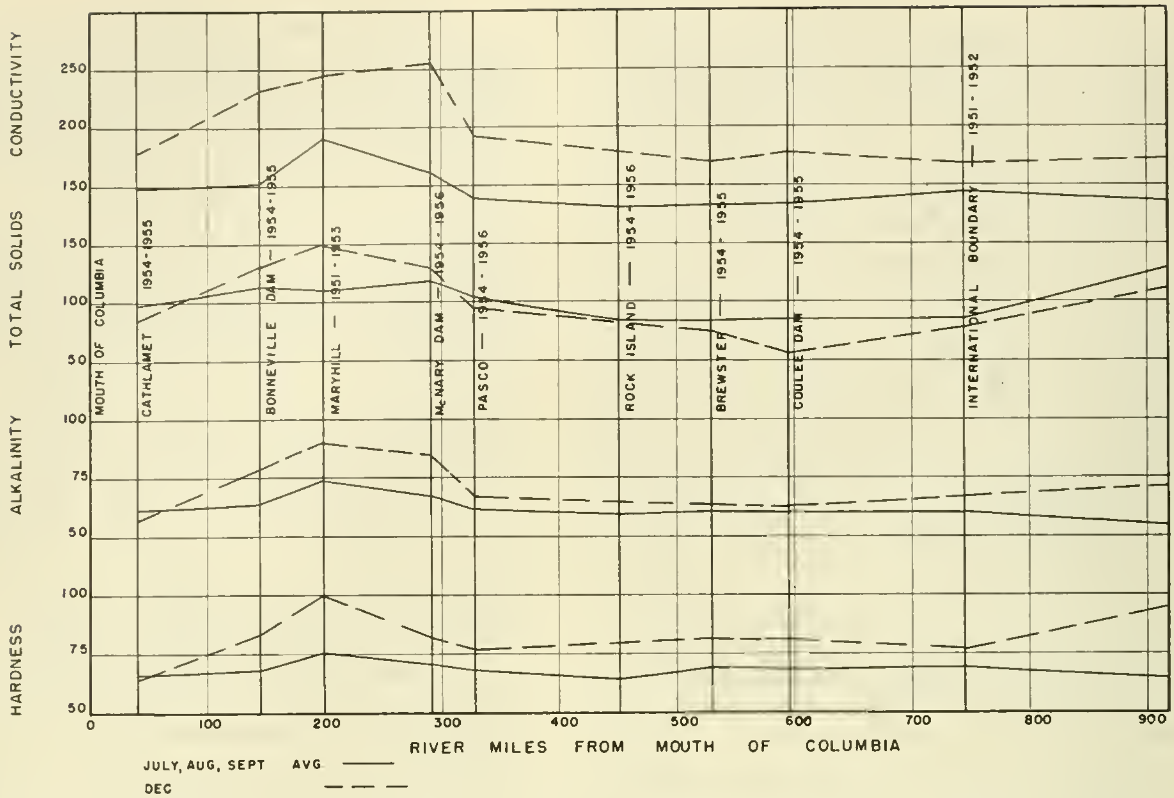


FIG 14.-- COMPARISON OF COLUMBIA RIVER WATER QUALITY — CANADA TO MOUTH

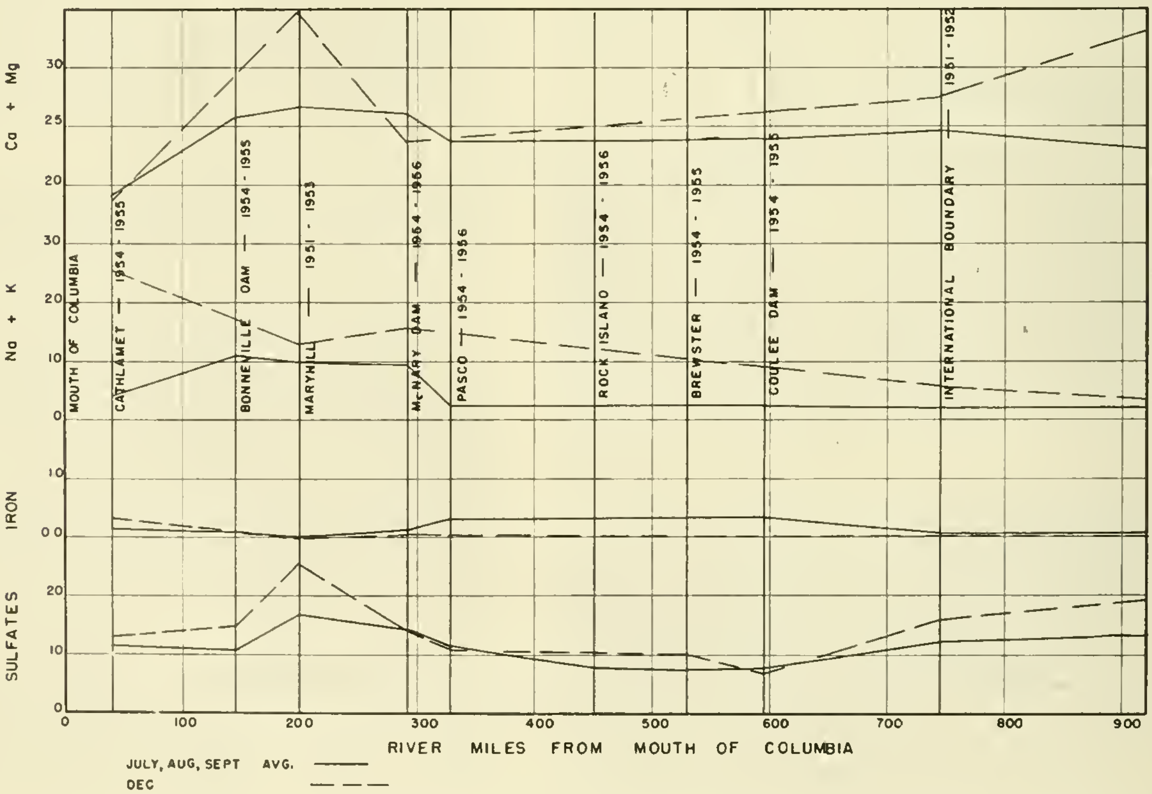


FIG. 15.-- COMPARISON OF COLUMBIA RIVER WATER QUALITY — CANADA TO MOUTH

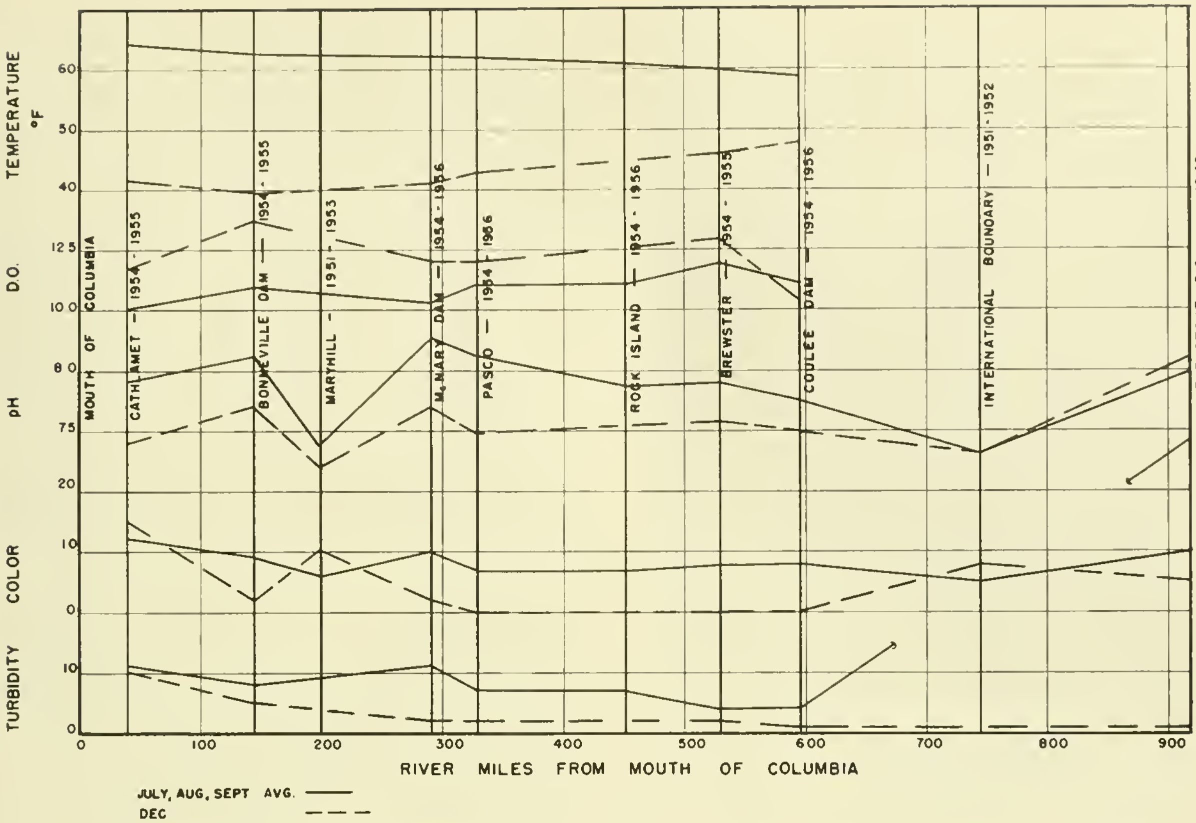
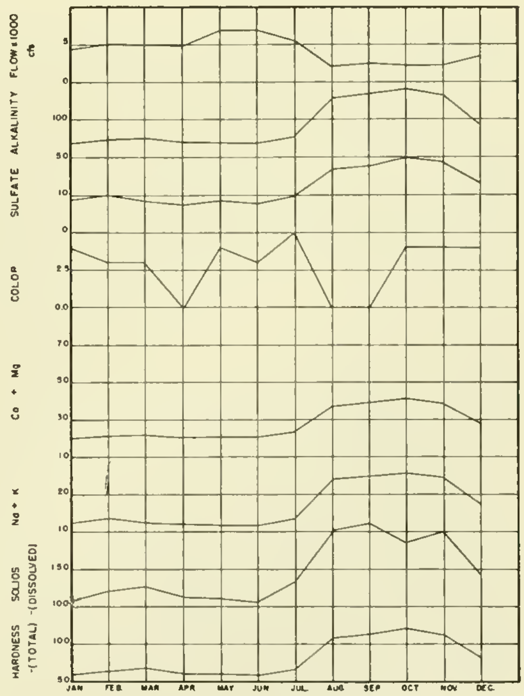


FIG. 16 COMPARISON OF COLUMBIA RIVER WATER QUALITY - CANADA TO MOUTH

Figures 14, 15 and 16 are plots of Columbia River water quality from Revelstoke, B. C. to Cathlamet, Washington, using Canadian, U.S.G.S. and University of Washington data. These figures show a general reduction in, or uniform value in, the constituents from Revelstoke, B. C. to the confluence of the Snake and Yakima Rivers near Pasco. Most of the tributaries in this stretch of the river are high quality waters. Maximum constituent values occur in the vicinity of Maryhill. From Maryhill to the mouth, most constituent values decline because of the influx of the western slop rivers that are lower in dissolved substances. Constituent values are usually higher in December than during the summer because of lower flows and lower water temperatures.

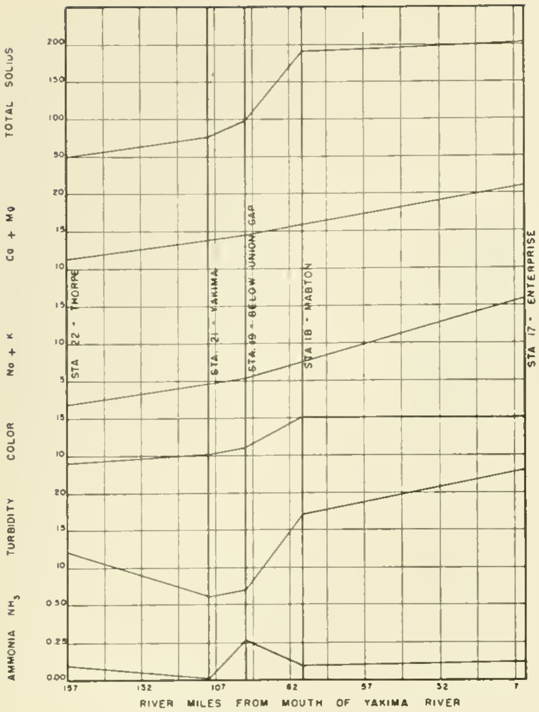


YAKIMA RIVER AT KIONA
AVERAGE MONTHLY VALUES — YEARS 1953 - 1954

U.S.G.S. DATA.

FIG. 17

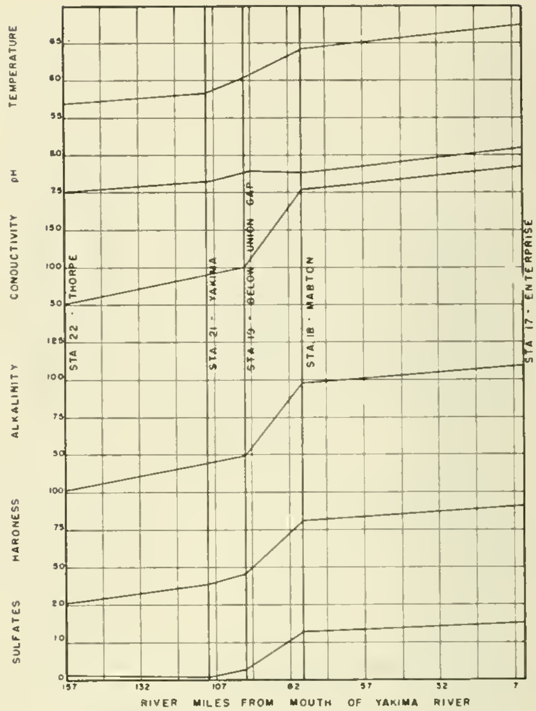
Yakima River: Figure 17 illustrates the constituents found in the lower Yakima River during a typical year. The constituents are fairly uniform in value from December to July. After July through November, the river flow sharply decreases and the constituents about double in value. As discussed in a subsequent chapter on the



AVERAGE WATER QUALITY IN YAKIMA RIVER
SUMMER 1954-55

COLUMBIA RIVER SURVEY DATA

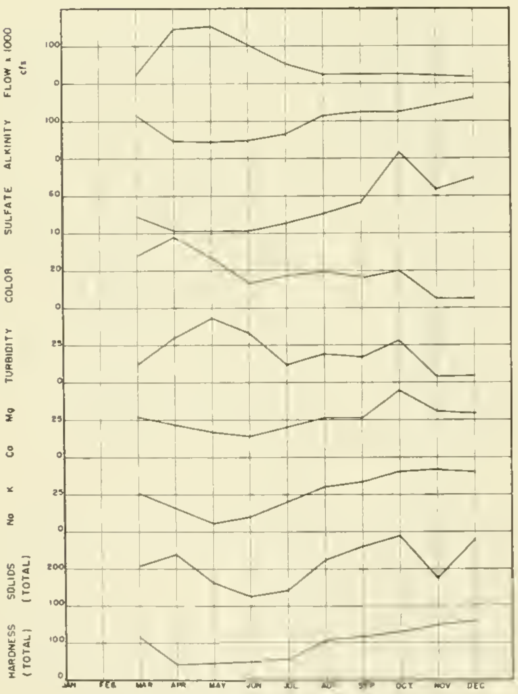
FIG. 18



AVERAGE WATER QUALITY IN YAKIMA RIVER
SUMMER 1954 - 55

COLUMBIA RIVER SURVEY DATA

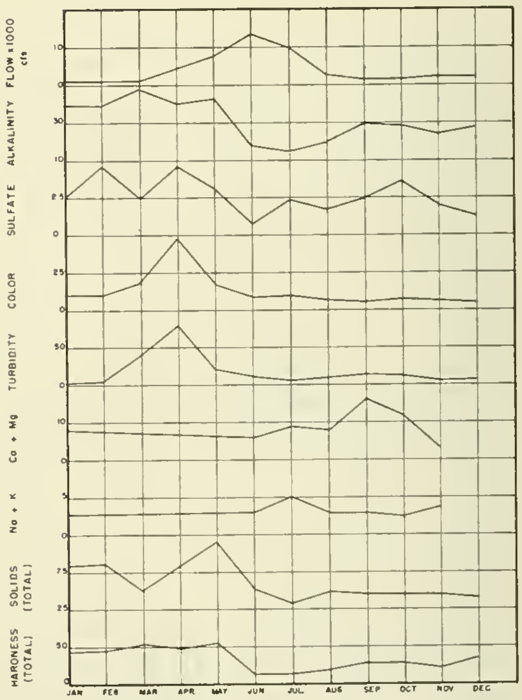
FIG. 19



SNAKE RIVER AT BURBANK
AVERAGE MONTHLY VALUES — YEARS 1954 - 1956

COLUMBIA RIVER SURVEY DATA

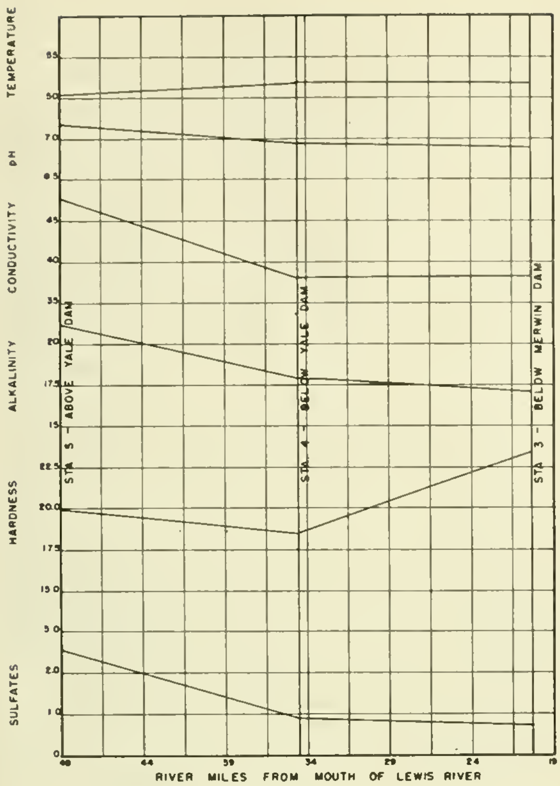
FIG. 20



WENATCHEE RIVER AT SLEEPY HOLLOW
AVERAGE MONTHLY VALUES — 1954 - 1956

COLUMBIA RIVER SURVEY DATA

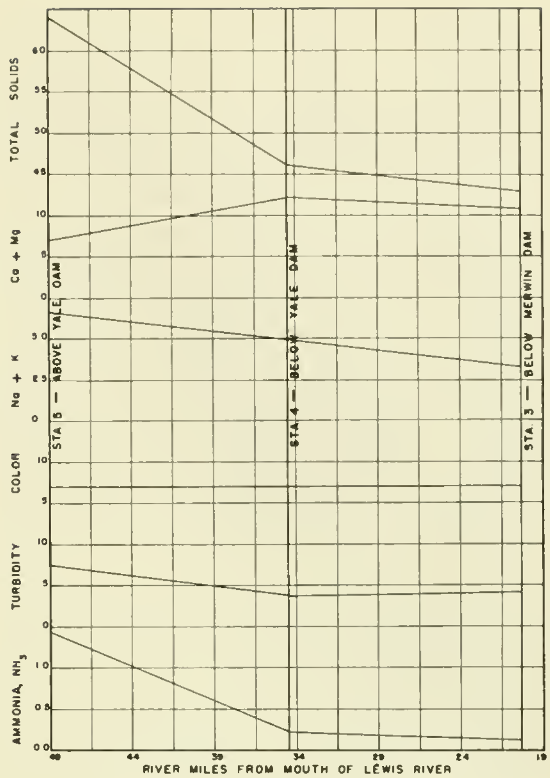
FIG. 21



AVERAGE WATER QUALITY IN LEWIS RIVER
SUMMER 1954 - 55

COLUMBIA RIVER SURVEY DATA

FIG. 22



AVERAGE WATER QUALITY IN LEWIS RIVER
SUMMER 1954 - 55

COLUMBIA RIVER SURVEY DATA

FIG. 23

Yakima River, the rise in constituents during the summer is more a function of the decrease in flow than it is a function of increased irrigation.

Figures 18 and 19 illustrate the progressive water quality change in the Yakima River during the summer as it flows from Thorp (above the irrigated area and center of population) to Enterprise, near the river mouth. A very large rise in all constituents, except for ammonia, is shown. The most pronounced increase occurs after the river enters the lower valley and passes the bulk of the irrigated acreage.

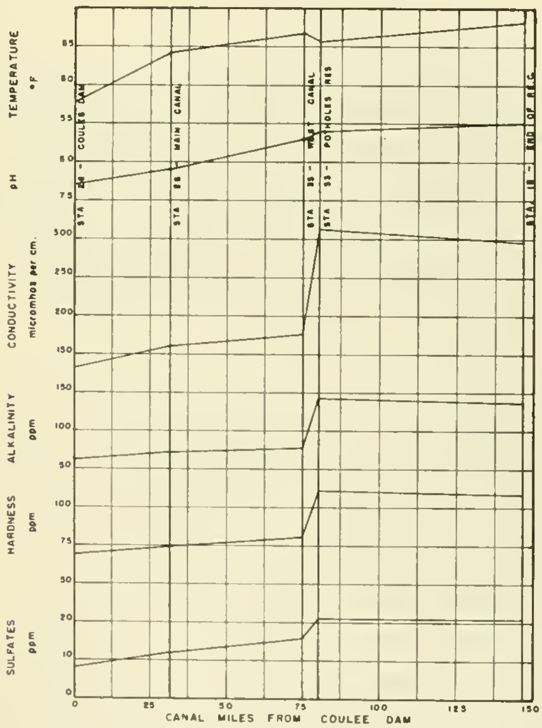
Snake River: Maximum and minimum constituent values in the Snake River are closely related to the rate of river discharge, as shown in figure 20. Color and turbidity are greatest with ~~high discharge~~ in May and the other constituents are greatest during low discharge in the autumn. At its confluence with the Columbia River below Pasco, the Snake River constituent values are much higher than those in the Columbia River. In the case of sulfate, they are several hundred percent greater.

Wenatchee River: This river is relatively low in dissolved substances as shown in figure 21. Total solids are markedly affected by the higher turbidities during the period of the spring runoff. Maximum constituent values and conductivity were observed in the winter and early spring when stream flows were low. This river system will be discussed in detail in a subsequent report.

Lewis River: The Yale and Merwin Dams are high dams used for power production. These are the only significant man-made changes in the Lewis River Basin (other than logging) that might affect water quality. Station 5 represents water quality as it enters the upper reservoir; station 4, water quality between the two reservoirs; and station 3, water quality below the reservoirs. Values plotted in figures 22-23 are for the summer period only. All values but hardness (and its constituents, calcium and magnesium) are lower below the dams than above. This can be explained by the fact that the reservoirs are large and that portion of the water they are spilling in the summer is high quality water discharged into the reservoirs during the spring runoff. Some calcium and magnesium is apparently taken into solution in the reservoirs. A slight rise in temperature is shown through the reservoirs. Dissolved oxygen below Merwin Dam ranged from 78 to over 100 percent saturation. There was a slight increase in carbon dioxide content through the reservoirs with a corresponding decrease in pH. The decrease in ammonia is probably caused by an oxidation of the ammonia to nitrites or nitrates as the water passes through the reservoirs. Water quality observations below Merwin Dam in November, December and March give generally higher constituent values (see Table C, appendix) for the reservoir discharge than for the inflow. This increase is small.

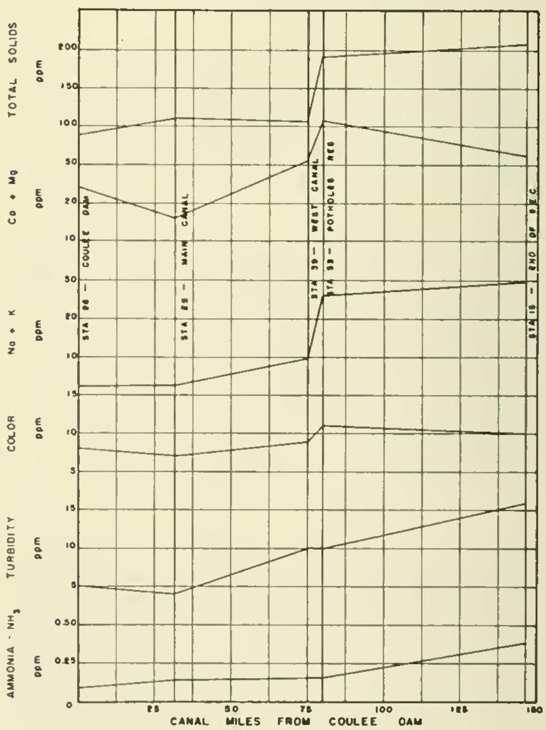
Columbia Basin Irrigation Canal: Irrigation canals were sampled in the Columbia River Basin Project to give information on the water quality as it traversed the land and to give some indication of the quality of future return flow waters from the project, once a stablized water table is reached. The project was but partially developed in the summers of 1954 and 1955 when sampling was conducted. A total of 110,000 acres of a future total of some 1,000,000 acres was under irrigation in 1954. The U. S. Bureau of Reclamation forecasts that 600,000 acres will be under irrigation by 1961. They expect to apply about four acre-feet of water per acre of land during the irrigation season of which perhaps fifty percent will ultimately find its way back to the Columbia River as return flow. Figure 8 shows the location of the sampling stations in the Basin development.

Figures 24 and 25 are a plot of average summer water qualities at selected stations along the main canals. The water for irrigation is pumped from behind Coulee Dam to the main canal which traverses two artificial lakes to its diversion into the west and east canals. Some 80 miles from Coulee Dam, the spent and excess irrigation waters are collected in the Potholes Reservoir which in turn supplies the Potholes East Canal. The last sampling station plotted (station 15) is on this canal. At station 15, the irrigation water had traversed some 150 miles of canals and



AVERAGE WATER QUALITY IN IRRIGATION CANALS
SUMMER 1954 - 1955
COLUMBIA BASIN PROJECT

FIG. 24



AVERAGE WATER QUALITY IN IRRIGATION CANALS
SUMER 1954 - 1955
COLUMBIA BASIN PROJECT

FIG. 25

reservoirs and some of it had passed over the fields. A large rise in all constituents is shown in figures 24 and 25. The rise is particularly abrupt after the water passes through the Potholes Reservoir. At station 15, the water quality is very similar to that of the lower Snake and Yakima Rivers. This is to be expected since the soil characteristics are similar. Thus, we can expect that the future return flows from the Columbia Basin Project will have an effect on the Columbia River water quality similar to that produced by the Yakima and Snake Rivers. It will be a less pronounced effect than that of the Snake River because the irrigated acreage will be smaller.

Crab and Rocky Ford Creeks: These creeks were sampled because they indicate the quality of natural drainage waters from the Columbia Basin area. They are both high in dissolved constituents and quite alkaline. Crab Creek, near its mouth (station 37) is quite turbid, very warm in the summer, highly alkaline, and has a relatively high sodium and sulfate content. It can be expected that Crab Creek water will improve in quality as increasing amounts of spent and surplus irrigation waters are discharged therein.

MONTHLY CHANGES IN RIVER TEMPERATURES

Thermograph installations are maintained on the Columbia River main stem and on its principal tributaries by the U. S. Fish and Wildlife Service and on the Wenatchee River system by the Chelan County P.U.D. Limited thermograph records have been obtained by the Washington Pollution Control Commission on the Yakima River at Donald, Chandler and Richland for the summer of 1955. Thermometer readings are taken regularly by the U. S. Corps of Engineers, the Bureau of Reclamation and power companies at their major dams. At Vancouver, Washington, the U. S. Weather Bureau has been taken hand thermometer readings of the Columbia River since 1941. Hand thermometer temperatures have been obtained to an extensive or limited degree in the Basin by the Hanford Engineering Works, the Washington Pollution Control Commission, Health Department and Department of Fisheries, the U. S. Public Health Service, the City of Portland and Wenatchee, Oregon State College and the University of Washington.

Table 4 lists the thermograph data obtained by the U. S. Fish and Wildlife Service and the Chelan County P.U.D.

A compilation of average monthly water temperatures for different streams on similar years is of value for purposes of comparison and to document river basin temperatures at that time. Table 5 lists the average monthly water temperatures for the years, or portions of the years, of 1954-1956 at 34 stations in 14 rivers and creeks of the Columbia River Basin where temperature data were available. Temperatures in the table followed by an asterisk are approximate only as they were calculated from limited hand thermometer readings corrected for diurnal temperature fluctuations. The following observations can be made from a study of table 5:

1. The Columbia River discharges to the ocean from October to February, water that is from 1-5° F. colder than the water at Coulee Dam for the same time. From March to September, it discharges at a temperature from 2-6° F. warmer than at Coulee Dam. Highest water temperatures are in August and lowest in March. During a typical year, the temperature will vary throughout the river from 36° F. at Coulee Dam to 65° F. near the mouth.

2. The Okanogan River discharges to the Columbia River during the summer at a lower temperature than it has at Oroville, 73 miles upstream. This is due, evidently, to the discharge of colder stream and ground water into the Okanogan below Oroville.

3. In the Wenatchee River system, temperatures extend from the freezing level in February to about 61° F. in August. During the summer, water discharged into the headwaters of the Wenatchee River from Lake Wenatchee has about the same temperature as the water discharged to the Columbia River, 55 miles downstream. The normal summer warming of the river throughout its course is offset by the inflowing cooler Chiwawa River and Nason and Icicle Creeks.

4. Water temperatures in Crab Creek are markedly influenced by discharges of

Table 4.--Thermograph record inventory.

Station	River	Period of Record	Yearly Record	Summer Only	Incom-plete Record	Some Hand Thermometer
Bonneville	Columbia	1939-	x			x
Boundary	"	1944-1949		x		
Bridgeport	"	1945-1951		x		
Coulee Dam	"	1944-		x	x	
The Dalles	"	1944-		x	x	
Elmer City	"	1945-		x	x	x
Pasco	"	1945-		x	x	
Priest Rapids	"	1945-1951		x		x
Rock Island	"	1933-	x			x
Umatilla	"	1945-	x	x		
Clarkston	Snake	1945-1951		x		x
Riparia	"	1945-1951		x	x	x
Sacajawea	"	1944-		x		x
Miller	Deschutes	1945-		x	x	x
Lewiston	Clearwater	1944-1951		x		x
Little Falls	Spokane	1946-1949		x		x
Monitor	Wenatchee	1946-		x	x	x
Monse	Okanogan	1945-1952		x	x	x
Oroville	"	1949-		x		
Chelan Falls	Chelan	1945-1951		x	x	x
Richland	Yakima	1945-		x		x
Various	Willamette	1948-		x		
Headwater	Wenatchee	1955-	x			
Plain	"	1955-	x			
Tumwater Canyon	"	1955-	x			
Leavenworth	"	1955-	x		x	
Peshastin	"	1955-	x			
Dryden	"	1955-	x			
Cashmere	"	1955-	x			
Outlet	Nason Creek	1955-	x			
Outlet	Chiwawa	1955-	x		x	
Outlet	Icicle Creek	1955-	x		x	

Table 5.--Average monthly water temperatures °F. during the period 1954-56.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Yakima River[5]												
Thorp	--	--	40*	--	45*	53*	59	54	54	--	43*	35*
Above Naches	--	--	--	--	--	55*	63	59	56	--	--	--
Parker	--	--	41*	--	48*	58*	62	62	59	--	--	35*
Mabton	--	--	--	--	--	61*	65	67	61	--	--	--
Chandler	--	--	--	--	--	--	68.5	69.5	60.9	53.9	--	--
Richland	--	--	44*	--	58*	65.1	70.4	71.3	64.2	56*	49*	35*
Umatilla River												
Mouth[1]	--	--	--	--	--	55*	61*	70*	62*	--	--	41*
Deschutes River												
Mouth[5]	--	--	48*	--	54*	61	63.0	63.5	58.7	53.9	49*	41*
Willamette River[5]												
Portland	--	--	45*	--	56*	58	64	69	63	--	--	44*
Lewis River[5]												
Above Yale Res.	--	--	39*	--	42*	45*	49	50	50	--	--	41*
Below " "	--	--	--	--	--	47*	49*	51*	53*	--	--	--
" Merwin Dam	--	--	41*	--	45*	51*	51	51	53	--	52*	45*
Cowlitz River[5]												
Castle Rock	--	--	42*	--	50*	53*	56	58	57*	--	--	43*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Columbia River												
Elmer City[2]	--	--	36*	--	--	52.3	55.3	60.9	61.3	61	55*	48*
Brewster[5]	--	--	37*	--	48*	54*	57.6	60.7	61.7	--	53*	46*
Rock Island[1]	42	39.5	39	42.8	49.1	53.0	58.6	61.7	61.0	55.1	51.3	45.2
Priest Rapids[5]	--	--	39*	--	50*	55*	58	63	--	--	53*	45*
Pasco[4]	--	--	41*	46*	53*	55*	58.5	63.9	62.0	57	53*	43*
Umatilla[1]	39.1	39.9	42.9	47.9	52.3	55.4	60.2	63.7	63.2	55.5	50.6	43.9
Bonneville[1]	38.9	39.7	43.3	48.6	53.7	56.5	61.0	64.2	63.2	56.2	50.5	42.1
Vancouver[1]	39	39	43.5	--	53.8	56*	61*	65*	64	--	52*	--
Cathlamet[5]	--	--	42*	--	55*	--	61.2	64.7	63.6	--	51*	41*
Okanogan River												
Oroville[1]	--	--	--	--	--	64.0	69.7	69.1	64.5	--	--	--
Mouth[1]	--	--	40*	--	61*	54*	65	69	64	--	44*	32.2*
Wenatchee River[3]												
Headwaters	34.6	34.1	34.5	38.2	42.9			60.0	58.8	51.6	42.6	38.1
Below Plain	32.8	32.5	35.5	39.2	42.1			57.9	55.3	47.5	36.1	33.7
Above Leavenworth	33.8	32.7	35.9	41.8	44.8			58.6	56.6	--	34.2	34.9
Near Cashmere	33.8	32.8	37.2	42.0	43.9			60.4	57.0	47.7	37.4	33.1
Monitor	--	--	--	--	--	48.3	53.0	60.9	59.0	48*	--	--
Nason Creek[3]	33.5	32.3	35.8	39.7	42.1			57.3	53.5	43.6	35.1	32.9
Chiwawa River[3]	--	32.8	35.6	39.5	40.4			52.6	50.9	41.0	35.1	--
Icicle Creek[3]	34.3	33.8	37.3	40.2	41.5			56.9	54.0	43.1	--	35.0
Crab Creek[4]	--	--	51*	72*	75*	67.7*	71.2	71.0	66.6	--	45*	32.2
Snake River												
Sacajawea[2]	--	--	43*	--	53*	57	66.2	72.4	67.4	57	46*	35*

* Limited data
1 1954
2 1955
3 1955-56
4 1954-55-56
5 1954-55

waste irrigation water. This is the warmest stream observed in the Basin. Afternoon temperatures have reached 84.7° F. near the creek mouth during unusually warm weather.

5. The Snake River reaches a temperature in excess of 72° F. in August and less than 35° F. in the winter. In August, it is 8.5° F. warmer than the Columbia River at its confluence and in December it is 8° F. colder. In late July of 1956 (a warm summer), afternoon water temperatures exceeded 77° F.

6. The Yakima River has the largest temperature rise during the summer, from its headwaters to confluence with the Columbia, of any stream in the Columbia River Basin. In August, between Thorp and the outlet at Richland (160 miles), the temperature increases from 54° F. to 71.3 ° F. This high temperature rise of 17° F. is due largely to irrigation return flows. In late July of 1956, temperatures of 67° F. at Thorp and 83° F. at Richland (corrected for diurnal fluctuation) were observed.

7. In the late summer, the Umatilla River flow becomes very small due to a seasonal reduction in flow and diversions for irrigation. Water temperatures in August reached 78° F. in the late afternoon.

8. Deschutes River temperatures are close to those of the Columbia at its confluence. This large river (M.A.F. of about 6200 c.f.s.) has little influence on Columbia River water temperatures.

9. The lower Willamette River is warm during the late summer. Water temperatures in excess of 71° F. were observed in late August of 1955 when air temperatures were below normal.

10. The Lewis River is one of the coldest tributaries of the Columbia River during the summer. At Merwin Dam, during the periods of observation, the water temperature extended from a low of 39° F. in March to a daily high of 56° F. in September.

11. The Cowlitz, like the Lewis River, has a cooling effect on the Columbia River during the summer. The maximum daily temperature observed in the Cowlitz River during the summer of 1954 was 61° F.

Columbia River temperatures

Yearly temperatures are recorded on the Columbia River at four locations, viz.: Vancouver, Bonneville, Umatilla and Rock Island. Tables 6-9 list the average monthly temperatures and figures 26-29 depict these temperatures for the period of record.

Figures 26-27 for Vancouver and Bonneville are very similar, as one would expect, with water temperatures at Vancouver being slightly higher during the summer and slightly lower than at Bonneville during the remainder of the year. The maximum temperature always occurred in August, excepting for the year 1941, when it occurred in July. In July of 1941, the river flow was the lowest on record because of the need to fill the Grand Coulee Reservoir. Maximum August temperatures range from 63° F. to about 69° F. with an average of 67° F. while minimum temperatures in January range from 34° F. to 42° F. with an average of 38° F. This gives an average yearly temperature variation at Vancouver and Bonneville of 29° F.

At Umatilla (fig. 28) the Columbia River is 1-2 degrees colder than at Bonneville during the spring, summer and autumn and is about one degree warmer in the winter Maximum water temperatures in August range from 63.5° F. - 67.5° F. with an average of 66.5° F. Minimum water temperatures in January range from 35-40° F. with an average of 39° F. This gives an average yearly temperature variation of 27.5° F. Umatilla temperatures could be average only for the limited period of 1950-1955. It is quite probable that the temperature ranges would be wider if data for earlier years were available.

In October, November, December and January, the Columbia River at Rock Island is about one degree warmer than at Umatilla. For the remainder of the year, it is 1-3 degrees cooler. Figure 29 shows a maximum temperature variation in August of 61.5° F. - 68.5° F. with an average of 65° F. The minimum temperature in February ranges from 32° F. - 42.5° F. with an average of 37. It is significant to note that the maximum and minimum water temperatures occurred prior to water impoundment at Grand Coulee.

On figure 29, the average monthly air temperature at Wenatchee (for period of

Table 6.--Columbia River at Vancouver, Washington
Monthly temperatures °F., 1941-1954, at 10 ft. depth.
Data from Elmer Fisher, U. S. Weather Bureau, Portland, Oregon

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1941	--	--	--	53.8	58.1	60.2	70.4	69.4	63.2	57.0	49.5	43.7
1942	34.4	40.0	43.5	51.3	54.9	58.3	66.0	69.2	64.8	59.4	47.0	42.4
1943	33.3	38.4	42.3	50.0	53.0	57	63.9	67.4	65.6	58.4	47.3	41.3
1944	37.8	40.7	43.8	48.5	56.5	60.4	66.6	67.6	65.4	60.2	49.8	41.0
1945	40.9	41.1	43.4	49.1	55.0	59.7	68.4	68.7	65.0	57.5	48.1	40.1
1946	40.0	38.4	43.8	49.9	54.7	58.7	64.6	67.3	65.5	55.3	43.5	38.3
1947	34.1	38.0	43.1	49.7	54.0	58.8	64.5	68.0	64.2	58.2	49.7	43.4
1948	38.8	38.6	43.5	44.6	51.3	57.3	64.4	67.3	64.4	55.4	47.2	38.9
1949	32.4	34.4	42.5	49.8	52.8	58.4	65.3	67.3	64.3	54.1	49.6	42.6
1950	34.0	35.0	42.6	47.0	51.9	55.7	62.1	67.3	65.3	57	47.9	43.7
1951	39.3	37.8	41.0	49.3	50.3	58.5	63.5	66.8	63.6	56.5	46.9	41.2
1952	35.0	39.6	42.0	50	54	58	65	68	64	60	47	41
1953	43.0	43.0	44.6	50	53.9	56.3	63.8	67.2	64.8	57.9	50.6	44.3
1954	39	39	43.5	55	53.8							
Avg.	37.1	38.8	42.7	49.5	53.9	58.1	65.2	67.9	64.7	57.2	48.0	41.7

Table 7.--Columbia River at Bonneville
Average monthly water temperatures °F., 1944-1955.
Data from U. S. Corps of Engineers and U. S. Fish and Wildlife Service

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1938	--	--	--	--	54.5	58.8	66.8	68.1	67.5	59.3	46.8	38.8
1939	39.8	38.5	44.5	51.0	55.4	58.4	65.7	68.7	64.0	57.2	46.8	42.5
1940	37.0	39.3	46.4	51.9	57.3	62.7	67.7	68.7	66.8	59.7	45.7	38.8
1941	37.1	40.2	46.6	53.2	57.5	62.1	70.0	69.7	63.7	57.1	49.3	43.2
1942	34.8	38.7	42.5	50.6	54.5	58.3	66.0	68.6	65.1	59.3	47.5	41.9
1943	37.1	38.8	43.4	49.1	--	--	--	--	--	--	--	--
1944	--	--	--	--	--	60.4	67.3	67.9	65.4	60.4	50.6	41.8
1945	41.2	41.1	43.0	--	--	59.0	65.8	68.4	63.0	57.7	47.1	40.6
1946	40.3	39.5	--	--	--	58.8	62.9	67.7	64.3	56.6	46.0	43.9
1947	38.9	40.9	47.4	51.2	56.4	59.2	64.6	66.6	64.7	59.3	51.0	46.8
1948	41.6	39.6	42.9	49.4	51.6	55.2	59.0	63.1	63.2	57.5	50.3	43.9
1949	37.4	--	44.2	49.5	52.1	55.7	61.7	67.5	64.8	--	--	--
1950	34.2	35.0	42.6	47.5	52.4	55.2	62.8	67.5	66.0	56.7	47.9	43.8
1951	40.5	38.0	40.9	49.3	52.8	57.1	64.5	66.9	64.5	57.5	47.1	41.1
1952	35.1	38.3	42.1	49.9	54.3	58.8	64.5	67.8	64.8	60.6	48.2	41.8
1953	42.4	43.2	45.5	48.6	54.8	57.6	64.4	68.3	62.8	58.2	50.9	44.6
1954	38.9	39.7	43.3	48.6	53.7	56.5	61.0	64.2	63.2	56.2	50.5	42.1
1955	39.2	39.7	40.3	46.1	53.4	57.8	61.1	66.2	64.6	57.0	45.4	39.5
Avg.	38.4	39.4	43.7	49.7	54.2	58.4	64.5	67.3	64.0	58.0	48.2	42.2

Table 8.--Columbia River at Umatilla, Oregon
Average monthly water temperatures °F., 1944-1955.
Data from U. S. Fish and Wildlife Service and U. S. Corps of Engineers

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1944	--	--	--	--	--	--	67.0	68.8	--	--	--	--
1945	--	--	--	--	--	57.8	64.8	68.3	--	--	--	--
1946	--	--	--	--	--	58.6	63.8	68.1	64.4	--	--	--
1947	--	--	--	--	--	58.9	65.0	67.0	64.7	--	--	--
1948	--	--	--	--	--	--	--	67.1	--	--	--	--
1949	--	--	--	--	53.4	56.7	63.9	66.9	63.7	--	--	--
1950	35.5	36.5	42.4	47.1	51.9	55.6	63.0	67.5	65.3	57.4	49.5	44.3
1951	40.1	39.4	41.6	49.5	53.5	58.5	63.4	67.1	64.4	57.5	48.3	39.9
1952	36.2	37.7	41.4	49.7	53.3	58.4	64.8	67.2	64.9	60.0	49.6	44.0
1953	42.9	42.2	44.2	46.6	--	56.7	62.8	67.6	64.9	58.9	--	44.7
1954	39.1	39.9	42.9	47.9	52.3	55.4	60.2	63.7	63.2	55.5	50.6	--
1955	39.2	39.0	39.3	45.2	51.7	56.1	59.6	66.0	64.7	57.8	50.9	--
Avg. 1950-55	38.8	39.1	41.9	47.7	52.5	56.8	62.3	66.5	64.6	57.8	49.8	43.2

Table 9.--Columbia River at Rock Island
Average monthly water temperatures °F., 1933-1955.
Data from Puget Sound Power and Light Company, and
U. S. Fish and Wildlife Service

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1933	--	33	39.5	46	48.5	54.5	60	64.5	60	53	46.5	41
1934	39	40	43	49	53	58	64	66	61	54.5	47.5	41
1935	34.5	37	41	46.5	51	55.5	60.5	63	63	55	42.5	39.5
1936	37	32.5	38	46	50.5	56	64.5	67	63	57	43.5	38.5
1937	32.5	32	36	47	51.5	55.5	65	66	64	56.5	47	39.5
1938	36.5	36.5	41.5	47.5	51.5	56.5	65	66.5	65	57	44.5	37
1939	36	34.5	40	48	52.5	56	63	66.5	63	56	47	43
1940	37	37	43.5	49	55	60	65.5	66.5	66.5	60	48.5	40.5
1941	38	38.5	42.5	50	54	59	65.5	68.5	66	59	52.5	46
1942	38.5	36.5	38.5	44	50.5	55.5	61	66.5	66	61	54	47.5
1943	41	40	39.5	42	48	54	60	64.5	64.5	60.5	54.5	47
1944	43.5	40.6	39.5	44	49	55	62	66	64.5	61	55.3	47
1945	43	41.4	41.5	43	49	55	61.5	65	63	60.5	52.8	46
1946	43	40.5	41	43	50.5	55.5	59.5	65.5	63.5	58.5	51.3	46.5
1947	41	37.7	39	42.5	50.5	55	60.5	64.5	62	60	54.0	47
1948	42	38.0	39	42	46.5	55	60	63.5	62.5	59	52.0	45
1949	38	35.9	38.5	42	49	54.5	61	64.5	63.5	59.5	53.4	47.5
1950	41.8	36.5	36.1	40.4	47.4	51.7	59	63.3	62.9	59.4	52.3	44.8
1951	39.3	36.2	35.7	40.5	46.3	52.9	59.8	63.3	65	61	53.2	45.5
1952	39	35.8	38	44	50.2	54.9	59.8	63.5	63	61	55.3	48.5
1953	44	42.4	41.5	44.5	50.5	54.5	59.4	63.8	63.3	60.6	54.2	48
1954	42.5	39.6	38.5	42.8	49.1	53.0	58.5	61.7	61.0	55.1	51.3	45.2
1955	41.0	38.4	37.2	41.3	47.6	53.3	56.8	62.1	61.3	58.2	49.5	43.3
Avg.	39.3	37.2	39.3	44.5	50.0	55.2	61.5	64.8	63.5	58.5	50.6	44.1

* Averaged to nearest half degree for most of 1933-1949 as temperatures were recorded to nearest degree.

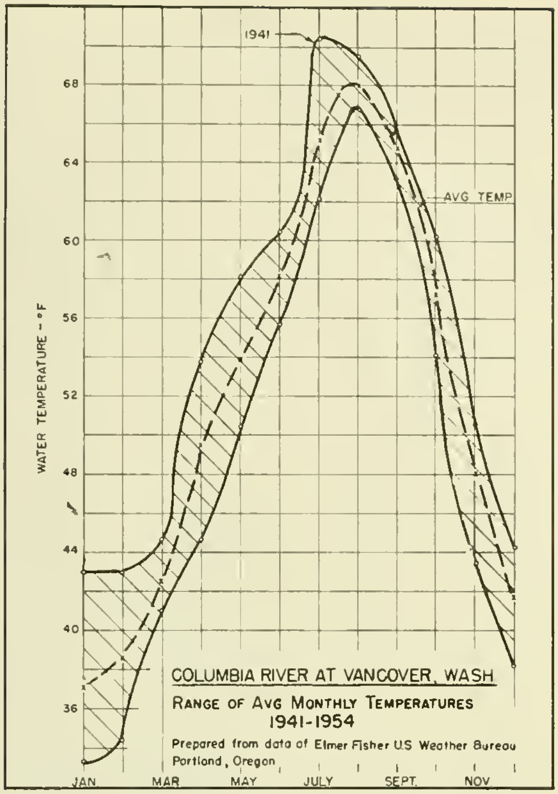


FIG. 26

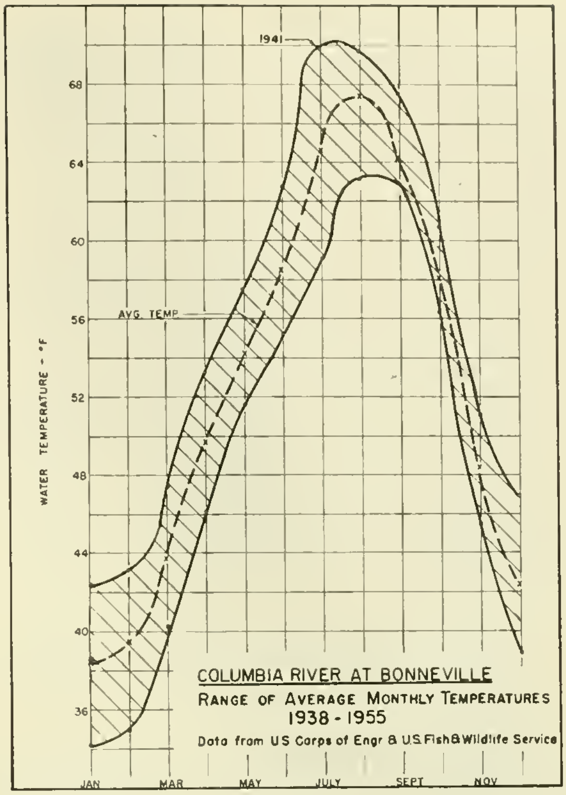


FIG. 27

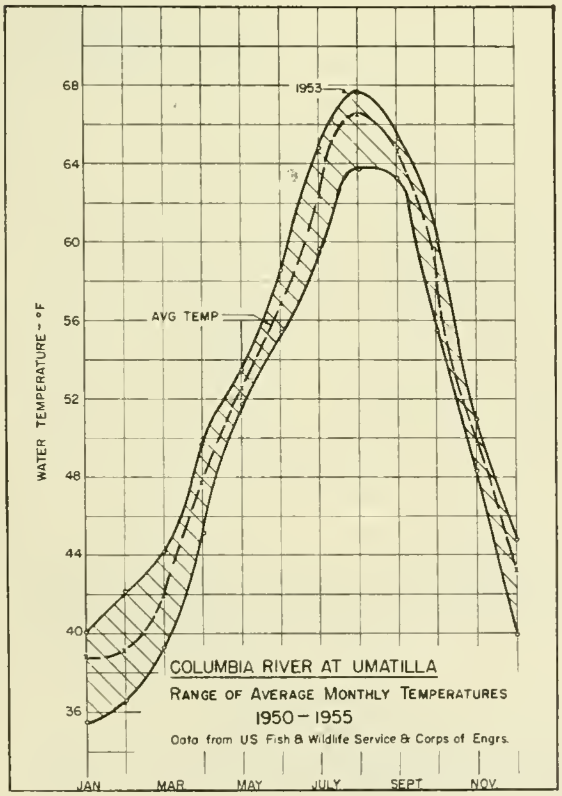


FIG. 28

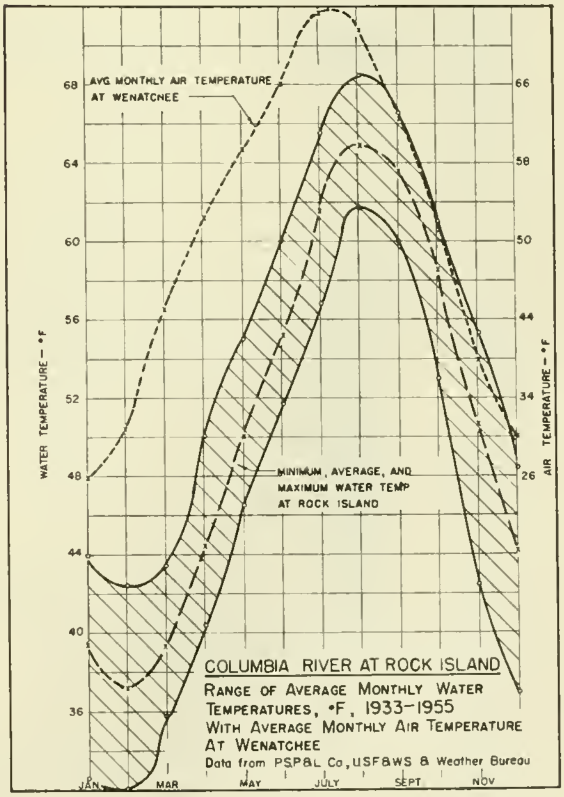
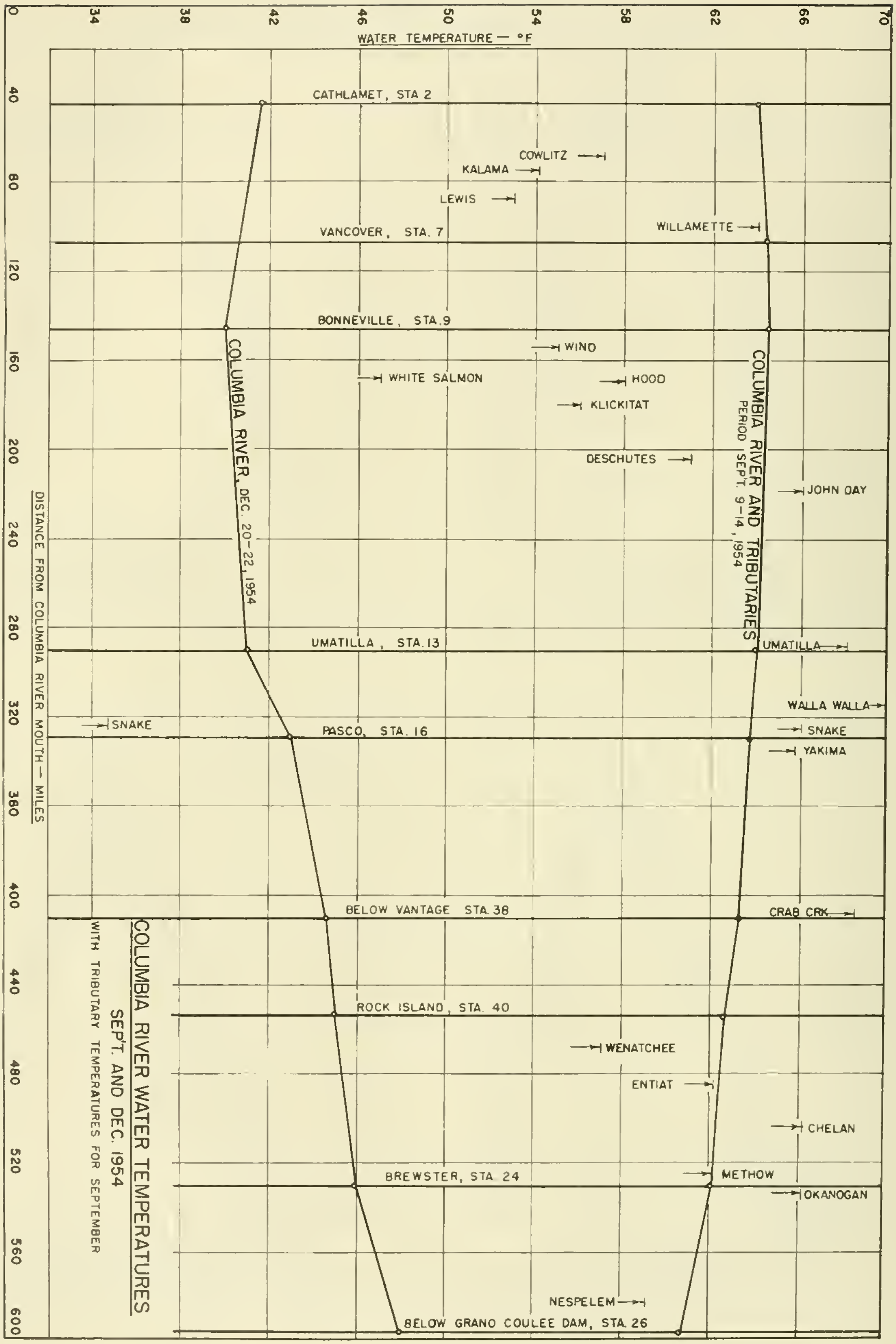


FIG. 29



COLUMBIA RIVER WATER TEMPERATURES
SEP'T. AND DEC. 1954
WITH TRIBUTARY TEMPERATURES FOR SEPTEMBER
WATER TEMPERATURE — °F
DISTANCE FROM COLUMBIA RIVER MOUTH — MILES
COLUMBIA RIVER, DEC. 20–22, 1954
COLUMBIA RIVER AND TRIBUTARIES
PERIOD SEP'T. 9–14, 1954
CATHLAMET, STA 2
COWLITZ
KALAMA
LEWIS
VANCOVER, STA. 7
WILLAMETTE
BONNEVILLE, STA. 9
WIND
WHITE SALMON
HOOD
KLICKITAT
DESCHUTES
JOHN DAY
UMATILLA, STA. 13
UMATILLA
WALLA WALLA
SNAKE
PASCO, STA. 16
SNAKE
YAKIMA
BELOW VANTAGE STA. 38
CRAB CRK.
ROCK ISLAND, STA. 40
WENATCHEE
ENTIAT
CHELAN
BREWSTER, STA. 24
METHOW
OKANOGAN
NESPELEM
BELOW GRAND COULEE DAM, STA. 26

FIG. 30

record) has been plotted. (Wenatchee was selected as the air temperature in Wenatchee is representative of the Columbia Basin.) Note the similarity between the air and water temperature patterns. Air temperatures range from a low of 26° F. in January to a high of 74° F. in July for a range of 48° F., water temperature range is 28° F. The rate of rise and fall of monthly air temperatures is about twice that of the water temperatures. Water temperature changes lag air temperature changes by about one month. This is due to the high heat capacity of the water and the 750 miles of river lying above Rock Island.

Figure 30 illustrates the relative water temperatures in the Columbia River from Grand Coulee Dam to Cathlamet during a period in September 1954 when tributary water temperatures had been taken. It also shows temperatures in December of 1954 for purposes of comparison (no tributary temperatures). In September, the water left Coulee Dam with a temperature of 60.6° F. Flowing downstream, the temperature gradually rose to a high of 64.4° F. at Bonneville and then gradually declined to 63.9° F. at Cathlamet. Tributary streams on the east side of the mountains that flow through areas of irrigated farming, or areas where solar radiation is at a maximum, were warmer than the Columbia. (Okanogan, Chelan, Crab Creek, Yakima, Snake, Walla Walla, Umatilla and John Day Rivers.) Tributary streams west of the mountains and those on the eastern slope receiving a minimum of solar radiation were cooler. (Nespelem, Entiat, Wenatchee, Deschutes, Klickitat, Hood, White Salmon, Wind, Lewis, Kalama and Cowlitz Rivers.) The Methow and Willamette Rivers temperatures were about the same as the Columbia. In December, the water left Grand Coulee Reservoir at a temperature of 48° F., declining gradually to 43° at Pasco. Between Pasco and Umatilla, the temperature fell 2° F. because of the colder Snake River inflow. A low temperature of 40° F. was observed at Bonneville, with a gradual rise down river to 41.5°F., at Cathlamet, illustrating the warmer winter air temperature effect west of the Cascades.

Yakima and Wenatchee Rivers and Columbia Basin irrigation temperatures

Water temperature data at selected points along the stream are available from only the Yakima and Wenatchee Rivers (other than the Columbia). Figure 31 is a plot of

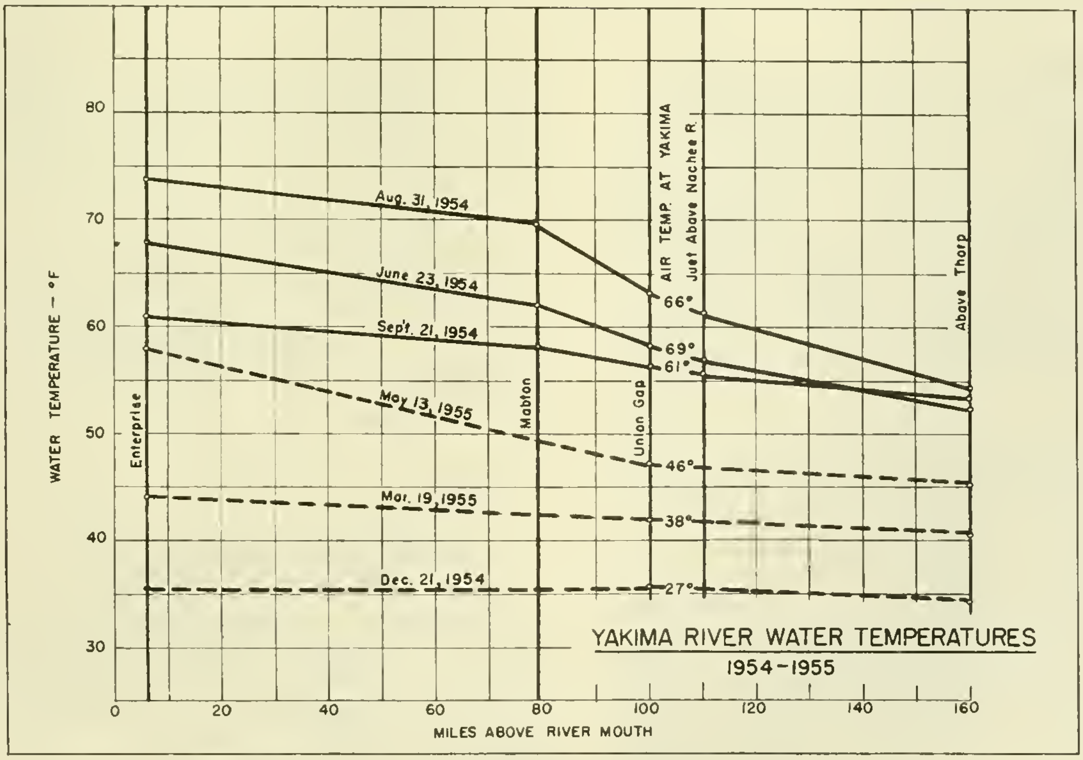


FIG. 31

water temperatures (corrected for diurnal variation) in the Yakima River between Enterprise (near Richland) and Thorp (above Ellensburg) for selected days of the year. The irrigation season extends from March to October with the heaviest water applications being from May through September. Irrigation return flows enter the river below Ellensburg and from below Yakima to the river mouth. Most of the return flows bring water into the river at a temperature higher than the river temperature. The water temperature increase, between Thorp and Enterprise of 3.5° F. at the beginning of the irrigation season in March, rises to a 20° F. increase in August at the end of the heavy irrigation season. Average air temperatures at Yakima are shown on the figure for the date of sampling. These are the average for the day preceeding temperature measurement, the day of measurement and the day following. In December, March and May, the water temperature around Yakima is higher than the air temperature. In June, August and September, the water temperature is lower than the air temperature in the vicinity of Yakima. This illustrates the effect of solar heating in the winter and spring together with the entrance of ground waters higher in temperature than the air. These ground waters and the reservoirs have a cooling effect in the summer.

Figure 32 shows the warmer water discharge by Lake Wenatchee being cooled below the outlet by the colder water of the Chiwawa River and Nason Creek. The only significant change in temperature between the headwaters and the outlet occurs in the spring and autumn. In the spring the water temperature increases about 4° F. and in the autumn decreases about 4° F. between the headwaters and the outlet. Air and water temperatures have about the same relationship as on the Yakima River.

The water temperature rise in the Columbia Basin main irrigation canals between Grand Coulee Dam and the 145 miles of canals and reservoirs is shown in figure 33. A temperature rise of 14° F. is noted for August 17, 1955. This is a common rise on sunny days. The canal water temperatures are very sensitive to air temperatures when immediately below a large reservoir. On June 29 and July 22, a temperature decline beyond the Potholes Reservoir is shown when normally the temperature would rise. This decline is caused by less than average air temperatures on the preceeding day and day of the observations. The temperature decline beyond the Potholes Reservoir in September shows how the reservoir water, warmed during the summer, is cooled when it is released in a stream for intimate contact with autumn air temperatures. Rapid water temperature rises are shown through the broad and shallow Equalizing and Potholes Reservoirs. Average monthly air temperatures for the month of observation are shown for Moses Lake weather station, this being about the center of the Basin. Water temperatures are higher than air temperatures for each month excepting June, indicating a high degree of solar radiation absorption.

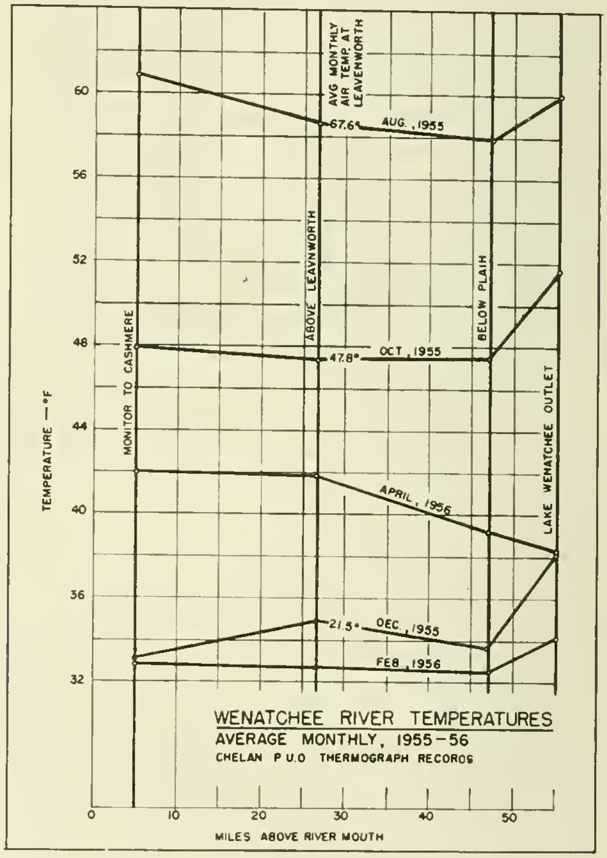


FIG. 32

NORMAL RIVER WATER TEMPERATURE CHANGES WITH DISTANCE

A stream, during its normal unhindered flow, will usually experience a rise or fall in water temperature as it progresses downstream. The magnitude of this temperature change is related to the depth of flow, quantity of flow, turbulence, season of the

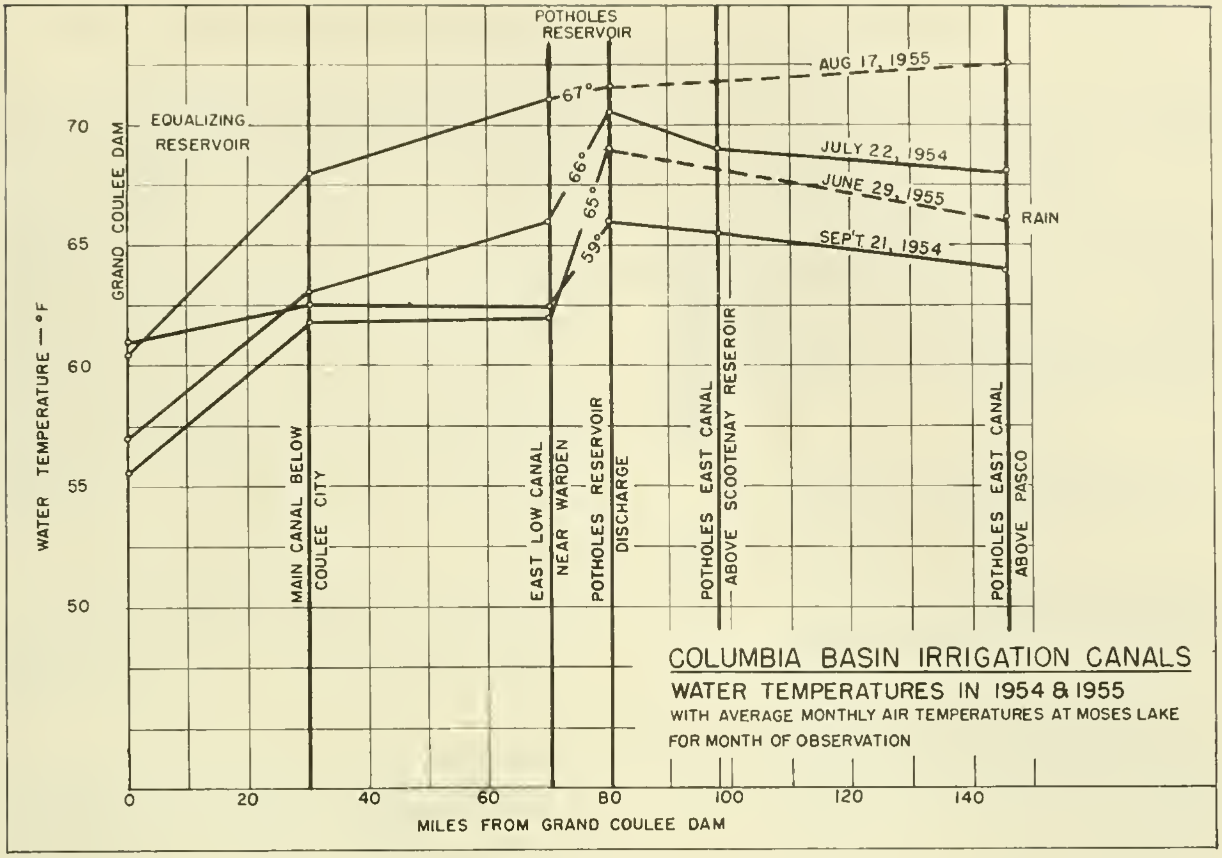


FIG. 33

year, relationship between upstream and downstream air temperatures, shading afforded by vegetation or land masses (or other factors that will affect absorption of solar radiation), tributary streams, and the entrance of ground water. It is necessary to know these normal temperature changes if estimations are to be made on the effect reservoirs have had on the temperature of a particular stream. Few temperature data are available on Pacific Northwest streams for stream sections where man has not already produced some structure to change the original stream environment.

Table 10 shows the normal temperature rise or fall in streams where the stream section did not contain an impoundment or a tributary of any significant magnitude. In the streams listed, large impoundments exist on the upstream waters. These produce a moderating effect on the water temperature which is particularly significant at the upstream station shown herein on table 10.

Only general stream characteristics are given as it is impracticable to attempt the computation of water temperature changes in relationship with each of the influencing variables. Data shown are for the period of observation only and should not necessarily be construed as being representative of usual conditions. Temperature change values are all reasonable and comparable excepting for the lower Snake River in the early summer where a temperature fall of from 1.55 to 2.13° F. per 100 river miles was observed. A temperature increase would have been expected because of the difference between air and water temperatures and because of absorption of solar radiation. In early June of 1945 and 1950 the Snake River was experiencing its maximum yearly runoff, which, with a late snow melt, might account for the temperature decline. This is not true in July of 1945 where the temperature decrease was still greater and the flow much lower. It is possible that cold ground water in appreciable quantities enters the river in this section or that the points of hand thermometer temperature readings were not representative of the average river temperature.

Table 10.--Normal river water temperature changes--°F per 100 miles

Data from U. S. Fish and Wildlife Service
and Columbia River survey

River stretch	Miles	Time period	Flow x1000 c.f.s.	River * charat-teristics	Upstream water temp.	Down. water temp.	Upstream air temp.	Down. air temp.	Water temp. change of per 100 mi.
Wenatchee River		1955-56							
Plain-Cashmere	27	Dec.	2.07	1,5,7,9	33.7	33.1	20.5	24.8	2.22-
"	"	Feb.	0.88	"	32.5	32.8	21.3	21.6	1.11+
"	"	Apr.	5.95	1,4,7,9	39.2	42.0	47.2	54.2	10.3+
"	"	June	13.55	"	45.3	46.7	55.2	63.0	5.2+
"	"	Aug.	2.68	"	57.9	60.4	63.1	71.5	9.28+
"	"	Oct.	1.82	"	47.4	47.7	43.9	49.8	1.11+
Yakima River		1954							
Thorp-Selah	53	July	4.28	1,4,8,9	58.3	61.7	64.7	66.6	6.4+
"	"	Aug.	3.29	"	52.7	58.8	62.8	65.4	11.5+
"	"	Sep.	2.85	"	51.7	55.8	57.3	59.5	7.7+
		1954-55							
Union Gap-Enterprise	96	July	4.50	2,4,8	59.8	69.3	66.6	72.5	9.9+
"	"	Aug.	1.48	"	61.2	70.0	65.4	69.2	9.2+
"	"	Sep.	1.67	"	57.7	64.6	59.5	63.1	7.2+
"	"	Dec.	2.22	2,5,8	35.0	35.5	31.5	36.1	0.5+
"	"	Mar.	1.44	"	41.5	44.0	37.1	42.0	2.6+
"	"	May	2.41	2,4,8	47.0	57.0	54.0	57.9	10.4+
Columbia River		1955							
Elmer City-Rock Island	140	June	448	3,4,10	52.4	53.3	65.8	67.3	0.64+
"	"	July	404	"	55.3	56.8	68.7	69.3	1.07+
"	"	Aug.	182	"	60.9	62.1	70.6	71.5	0.86+
"	"	Sep.	113	"	61.3	61.3	62.7	63.5	0.0
"	"	Oct.	63	"	62.2	58.2	49.3	49.8	2.86-
		1954							
Umatilla-Bonneville	144	Feb.	127	3,5,10	39.9	39.7	40.7	40.5	0.14
"	"	Apr.	159	3,4,10	47.9	48.6	51.3	50.0	0.49+
"	"	June	504	"	55.4	56.5	64.6	58.6	0.77+
"	"	Aug.	221	"	63.7	64.2	69.5	63.8	0.35+
"	"	Oct.	110	"	55.5	56.2	50.1	52.2	0.48+
"	"	Dec.	103	3,5,10	43.9	42.1	33.1	38.1	1.25-
		1954							
Bonneville-Cathlamet	106	July	430	3,5	61.0	61.4	62.7	60.0	0.38+
"	"	Aug.	230	"	64.2	63.8	63.8	60.9	0.38-
"	"	Sep.	150	"	63.2	62.8	62.0	59.2	0.38-
Snake River		1950							
Clarkston-Riparia	71	Early June	164	3,4,8	54.5	53.4	64.0	63.3	1.55
"	"	Late Aug.	27	"	65.9	66.4	73.4	70.8	0.70+
		1945							
Riparia-Burbank	66	June	111	3,4,8	61.7	60.4	60.9	66.6	1.97-
"	"	July	36	"	74.2	72.8	71.3	75.4	2.13-
"	"	Aug.	19	"	72.3	73.6	70.0	73.2	1.97+
"	"	Sep.	20	"	61.5	64.9	57.5	62.1	5.17+

* 1. Turbulent with many rapids
2. Few rapids
3. Deep flowing
4. Mostly sunny weather
5. Partly cloudy weather
6. Mostly overcast
7. Upstream section of stretch mountainous
8. Farming throughout stretch
9. Some shading of stream
10. Reservoir immediately upstream

DIURNAL WATER TEMPERATURE VARIATIONS

Large diurnal water temperature fluctuations are found in the rivers east of the Cascade Mountains because of the extremes between daytime and night time air temperature. This daily fluctuation in air temperature for eastern Washington (and other eastern areas in the Columbia River Basin) will vary from 20° to 50° F. in the summer while in western Washington, the fluctuation is from 10° to 30° F. These diurnal air temperature fluctuations make individual water temperature readings invalid insofar as the average daily water temperature is concerned unless this individual reading be adjusted for the relationship between the temperature reading at that time of day to the average daily temperature.

The streams studied herein are all in eastern Washington with the exception of the Columbia River at Bonneville which is influenced by east-of-the-mountain water temperatures.

Tabulated water temperature data that are available for normal usage give the maximum and minimum daily temperatures or the temperatures taken at specific times during the day, as for example, 8:00 a.m. and 4:00 p.m., or at midnight, 8:00 a.m. and 4:00 p.m. What is the relationship between these temperatures and the average daily water temperature, or the relationship of a temperature value taken at a particular hour to the average daily water temperature?

The diurnal water temperature ranges on a given stream at a given location are dependent upon the following factors:

1. Quantity of flow.
2. Time of year.
3. Daily temperature fluctuations at location.
4. Daily temperature fluctuations upstream from location.
5. Upstream impoundments.
6. Upstream environment, such as presence of irrigation return waters, snow melt, shading from trees and land masses, temperature of tributary stream and depth of water flow.
7. Flow time from critical upstream conditions to station or location in question.

Table 11 lists the diurnal water temperature variations by the month for selected streams where maximum and minimum temperature data were available. Maximum and minimum daily fluctuations for a given month are shown. A study of this table indicates the following general relationships:

1. The smaller the stream, the greater is the temperature fluctuation.
2. That significant temperature fluctuations are present in the winter unless the streams are covered with ice.
3. That diurnal water temperature fluctuations are greatest when there is the greatest difference between the mean deaily air temperature and water temperature.
4. That the largest daily temperature variations are in August and the least in December.

Figures 34 and 35 are plots of typical diurnal water temperature fluctuations for different environmental conditions on streams of widely varying flow characteristics. It is evident from a study of these figures that water temperatures taken at any random hour of the day may vary widely from the average daily temperature. It is also evident that no particular hour can be established for a given stream at which time the water temperature will be representative of the daily average temperature. A discussion of figures 34 and 35 follows.

Chiwawa River: The Chiwawa is a cold river, flowing 35 miles from the eastern Cascade Mountain slopes through forested land to its confluence with the Wenatchee River. It has a mean annual flow of about 460 c.f.s. The upper curve (fig. 34) is typical for the summer months while the lower curve is typical for the spring and autumn. There is very little diurnal variation in the winter months. During the summer,

Table 11.--Diurnal temperature variations °F.

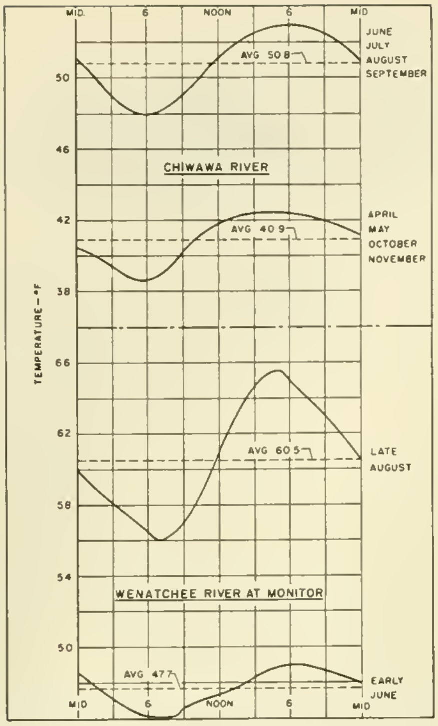
Typical values prepared from U. S. Fish and Wildlife Service, Chelan County Public Utility District, Puget Sound Power and Light Company, and Washington Pollution Control Commission records.

Maximum and minimum monthly diurnal temperature differences. Where maximum value only is given, this is the monthly variation.

Location	January		February		March		April		May		June	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Columbia River												
Inter'l Bdry.	-	-	-	-	-	-	-	-	-	-	1	0
Elmer City	-	-	-	-	-	-	1	0	2	0	1	0
Bridgeport	-	-	-	-	1	-	-	-	2	-	1	-
Rock Island	2	0	2	0	3	0	4	1	4	0	1	0
Priest Rapids	-	-	-	-	-	-	-	-	3	-	2	-
Pasco	-	-	-	-	-	-	-	-	-	-	3	-
Umatilla	1	0	2	0	2	0	2	1	1	1	1	0
Dalles	-	-	-	-	-	-	-	-	1	-	1	-
Bonneville	1	0	1	0	1	0	1	0	1	0	1	0
Spokane River												
Little Falls	-	-	-	-	-	-	-	-	-	-	2	-
Okanogan River												
Oroville	-	-	-	-	-	-	-	-	10	1	9	3
Wenatchee River												
Headwaters	1	0	1	0	1	0	1	0	9	0	-	-
Tumwater Can.	-	-	5	0	9	0	6	3	5	1	-	-
Peshastin	2	0	3	0	5	1	5	3	4	1	-	-
Cashmere	3	0	3	0	7	1	8	2	5	1	-	-
Nason Creek	3	0	1	0	6	0	7	4	8	2	-	-
Chiwawa River	-	-	0	0	7	0	9	3	6	2	-	-
Icicle Creek	4	0	2	0	4	0	6	3	6	1	-	-
Yakima River												
Donald	-	-	-	-	-	-	-	-	-	-	-	-
Chandler	-	-	-	-	-	-	-	-	-	-	-	-
Richland	-	-	-	-	-	-	-	-	-	-	5	1
Snake R. Mouth	-	-	-	-	-	-	-	-	-	-	3	0
Deschutes R. Mouth	-	-	-	-	-	-	-	-	-	-	4	-

Table 11. - Continued

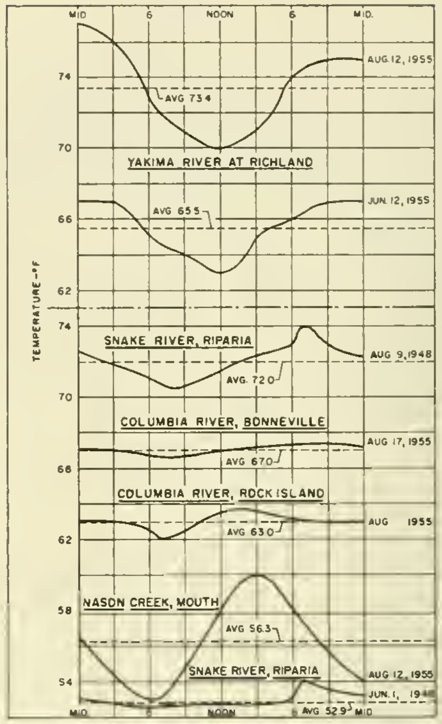
Location	July Max.	July Min.	August Max.	August Min.	September Max.	September Min.	October Max.	October Min.	November Max.	November Min.	December Max.	December Min.
Columbia River												
Inter'l Bdry.	2	0	1	0	2	0	-	-	-	-	-	-
Elmer City	1	0	2	0	2	0	-	-	-	-	-	-
Bridgeport	2	-	2	-	2	-	-	-	-	-	-	-
Rock Island	1	0	2	0	2	0	1	0	1	0	1	0
Priest Rapids	3	-	3	-	3	-	2	-	-	-	-	-
Pasco	4	-	3	-	3	-	-	-	-	-	-	-
Umatilla	1	0	2	0	2	1	2	0	1	0	1	0
Dalles	1	-	0	-	1	-	-	-	-	-	-	-
Bonneville	1	0	1	0	1	0	1	0	1	0	1	0
Spokane River												
Little Falls	1	-	1	-	1	-	-	-	-	-	-	-
Okanogan River												
Oroville	13	4	9	2	7	0	5	0	-	-	-	-
Wenatchee River												
Headwaters	-	-	9	2	5	0	4	0	2	0	2	0
Tumwater Canyon	-	-	10	4	8	3	8	0	4	0	2	0
Peshastin	-	-	8	2	6	0	5	0	6	0	2	0
Cashmere	-	-	8	3	8	3	6	0	4	0	2	0
Nason Creek	-	-	11	7	9	3	5	1	4	0	2	0
Chiwawa River	-	-	9	6	9	1	6	1	5	0	-	-
Icicle Creek	-	-	8	3	4	1	2	0	-	-	2	0
Yakima River												
Donald	8	2	10	6	8	2	5	1	-	-	-	-
Chandler	9	-	11	5	9	4	5	2	-	-	-	-
Richland	7	1	8	3	8	1	-	-	-	-	-	-
Snake R. Mouth	5	1	5	2	5	1	3	1	-	-	-	-
Deschutes R. Mouth	5	-	4	-	3	-	-	-	-	-	-	-



DIURNAL TEMPERATURE VARIATIONS IN A COLD AND MEDIUM TEMPERATURE RIVER

PREPARED FROM CHELAN P.U.D. AND F. & W.S. THERMOGRAPH RECORDS

FIG. 34



DIURNAL TEMPERATURE VARIATIONS

PREPARED FROM F. & W.S. THERMOGRAPH RECORDS

FIG. 35

the minimum temperature is observed about the time of sunrise, 6:00 a.m., while the maximum temperature is about the time of sunset in this shaded valley, 6:00 p.m. In the spring and autumn, the minimum temperature remains at about 6:00 a.m. while the maximum temperature occurs about one hour earlier than in the summer. A temperature fluctuation of 5° F. is shown for the summer and 3.8° F. for the spring and autumn.

Wenatchee River at Monitor: The Wenatchee is a medium temperature river, originating at Lake Wenatchee on the eastern slope of the Cascade Mountains and flowing some 55 miles to the Columbia River. It has a steep gradient for flow and passes through areas of small forest cover. The mean annual flow is about 2700 c.f.s. A diurnal temperature variation of 9.5° F. is shown for late August and 3° F. for early June. The August curve is characterized by its abrupt temperature changes, indicating in this unregulated stream, a direct sensitiveness to air temperature changes. Sensitiveness to air temperature is also indicated by the minimum temperature being at 7:00 a.m. and the maximum at 5:00 p.m., about the time when the sun's rays reach and leave the river areas.

Yakima River at Richland: This is a warm, regulated, medium sized river, having an average discharge at Kiona of about 3900 c.f.s. From the headwaters in Lake Keechelus, it flows some 205 miles through mountainous and farming areas to its confluence with the Columbia River at Richland. During the late summer, nearly the entire river flow at Richland consists of warm, irrigation return flows. In figure 35, a daily temperature variation of 7° F. is shown for August and 4° F. for June. An interesting feature of these curves is the displacement (from other rivers) of the times of minimum and maximum daily temperatures. Minimum temperature is at noon while maximum temperature is at midnight. The river temperature at Richland then is responsive to the air temperatures over the large irrigated area in the lower river valley where most of the return flow originates. A flow time of about six hours from the center of this irrigated area to Richland is indicated.

Snake River at Riparia: The Snake River is a cold river in the winter and a warm river in the summer. It is the principal tributary of the Columbia, having a

Table 12.--Comparison of average daily temperature in streams.

From thermograph records with average daily temperatures from averaging; daily maximum and minimum temperatures; 8 a.m. and 4 p.m.; and midnight, 8 a.m. and 4 p.m. temperatures - °F.
(Prepared from figs. 34 and 35)

Stream	Daily temp. avg.	Max. temp.	Min. temp.	Avg. max. & min.	8 a.m. temp.	4 p.m. temp.	Avg. 8 a.m. 4 p.m.	Mid. temp.	8 a.m. temp.	4 p.m. temp.	Avg. temp.
Chiwawa River, Summer	50.8	53.0	47.9	50.5	48.5	52.7	50.6	51.0	48.5	52.7	50.7
" " , Spring-Fall	40.9	42.4	38.6	40.5	39.7	42.4	41.0	40.5	39.7	42.4	40.9
Wenatchee River, August	60.5	65.5	56.0	60.7	56.4	65.3	60.8	60.0	56.4	65.3	60.6
" " , June	47.7	49.0	46.0	47.5	46.0	48.8	47.4	48.5	46.0	48.8	47.8
Yakima River, August	73.4	77.0	70.0	73.5	71.3	71.8	71.5	77.0	71.3	71.8	73.4
" " , June	65.5	67.0	63.0	65.0	64.2	65.5	64.8	67.0	64.2	65.5	65.6
Snake River, August	72.0	74.0	70.5	72.2	70.5	72.6	71.5	72.5	70.5	72.6	71.9
" " , June	52.9	54.0	52.5	53.2	52.7	52.9	52.8	53.0	52.7	52.9	52.9
Columbia River, Bonneville	67.0	67.4	66.6	67.0	66.6	67.3	66.9	67.0	66.6	67.3	67.0
" " , Rock Island	63.0	63.7	62.0	62.9	62.2	63.5	62.8	63.0	62.2	63.5	62.9
Nason Creek, August	56.3	60.0	53.0	56.5	54.1	59.8	56.9	56.5	54.1	59.8	56.8

mean annual flow of about 47,000 c.f.s. at Clarkston. The river and its tributaries are regulated for power and the irrigation of 2,800,000 acres throughout its 1060 miles of flow. Temperature fluctuations of 3.5° F. are shown in August and 1.5° F. in June. These lower temperature variations are due to the river's large size, great length, many impoundments and the fact that it receives a maximum of solar radiation which brings its average summer water temperature to near the average air temperature. An interesting feature of these Snake River diurnal water temperature plots is the "saw tooth" effect at the time of maximum temperature. This abrupt maximum temperature rise to about 7:00 p.m. illustrates the effect of unhindered solar radiation on the river immediately above Riparia, Washington.

Columbia River at Bonneville: The diurnal temperature variation at Bonneville is very slight, even in the middle of August where 0.7° F. is shown on figure 35. This variation is slight because of the river's huge bulk, the dampening effect of the Bonneville Reservoir and because the average water and air temperatures are near one another.

Columbia River at Rock Island: A diurnal temperature variation of 1.7° F. is shown for August. The temperature variation is greater here than at downstream Bonneville because the river flow is less, because the Rock Island Reservoir provides less dampening effect than the Bonneville and because the average air temperature is considerably higher than the average water temperature.

Nason Creek: This is a large creek (flow not measured) which flows for about 20 miles through reaches shaded by both timber and the mountains. It is tributary to the headwaters of the Wenatchee River. A diurnal water temperature variation of 7° F. is shown for August. Due to the effects of shading the maximum temperature occurs at 3:00 p.m. rather than in the normal late afternoon or early evening. Minimum daily temperature is at the usual 6:00 a.m.

Determination of Average Daily Water Temperatures

Table 12 lists the average daily temperatures computed from thermograph records for the streams shown on figures 34 and 35. It then compares these true daily average temperatures with daily average temperatures obtained by averaging; maximum and minimum daily temperatures; 8:00 a.m. and 4:00 p.m. temperature; and midnight, 8:00 a.m. and 4:00 p.m. temperatures. These data show that the average of the daily maximum and minimum temperatures are within 0.5° F. of the correct average; that the average of the 8:00 a.m. and 4:00 p.m. temperatures can differ by as much as 2° F. from the correct average and; that the average of the midnight, 8:00 a.m. and 4:00 p.m. temperatures will vary by 0.5° F. from the true average.

It is suggested that when thermograph records are tabulated, that the maximum and minimum daily temperatures be recorded (as is usually the case). It is further suggested that when daily temperatures are recorded from reading a thermometer, that they be recorded for 8:00 a.m. and 4:00 p.m. when the stream has a normal daily temperature fluctuation (low about 6:00 a.m. and high about 6:00 p.m.) and that when the daily fluctuation is not normal (like on the Yakima at Richland) that they be recorded for 8:00 a.m. and 8:00 p.m.

The typical diurnal temperature curves of figures 34 and 35 can be used to convert any instantaneous temperature readings for a similar stream to the average daily water temperature.

EFFECT OF EXISTING RESERVOIRS ON DOWNSTREAM WATER TEMPERATURES

Impoundments will affect downstream water temperatures depending upon:

1. Volume of water impounded.
2. Average impounded water depth.
3. Surface area of impoundment.
4. Depth at which water is withdrawn.
5. Climatic conditions - wind and amount of sunlight.
6. Characteristics of upstream water shed.
7. Season of the year.

8. Ratio of length to width.

9. Ratio of width to depth as water surface falls during depletion period.

Impoundments studied were the Yale and Merwin Reservoirs on the Lewis River, Grand Coulee Equalizing on the Columbia River Basin Main Canal, and the Roosevelt, McNary and Bonneville Reservoirs on the Columbia River. Relatively small and shallow impoundments, like the Bonneville and Rock Island Reservoirs, were observed to have no appreciable effect on downstream water temperature.

Table 13 shows the average monthly temperature changes through the reservoirs for the months when data had been obtained. The data from which these temperature differences were obtained were limited, excepting for Lake Roosevelt where daily temperatures were available from Fish and Wildlife Service thermograph records. Other temperature differences were observed from one to four times monthly. A discussion of this table follows:

Yale: Impoundment commenced in this reservoir on August 1, 1952. It is a medium depth, average sized reservoir, having a length to width ratio of 13.6. The Lewis River, flowing into the reservoir, heads up in the glaciers on Mt. Adams and Mt. St. Helens and flows through timbered country to the reservoir. For this reason, the river is relatively cold the year around and the reservoir discharges a water warmer than the inflow for most of the year. The large

Table 13.--Average monthly temperature change in water from upstream to downstream of reservoirs*

Reservoir	Average volume ac. ft. x1000	Average surface area acres	Average depth feet	Average monthly temperature change through reservoir								Theor. Detention at average flow-days
				Mar.	May	June	July	Aug.	Sept.	Nov.	Dec.	
Yale	354	3,477	155	0.9+	7.0+	2.4+	0.5+	0.8+	4.5+	-	1.1+	40
Merwin	393	3,863	125	0.7+	4.0-	2.7+	2.3+	0.4-	0.8-	-	2.9+	43
Yale-Merwin [1]	747	7,340	140	1.6+	3.0+	5.1+	1.4+	0.8+	3.1+	-	4.0+	83
Grand Coulee [1] Equalizing	951	24,500	52	-	-	7.0+	7.5+	5.9+	2.0+	-	-	140
Roosevelt [2]	8,252	70,300	328	-	-	1.9-	1.9-	0.1-	3.6+	-	-	35
Bonneville [1]	480	20,300	50	0.2+	-	0.1-	0.1-	0	0	0	0.5-	1
McNary [1,3]	790	37,900	70	1.5-	0.1-	0.7-	0.0	0.1+	0.5+	0.2+	0.2-	2
Temp. Columbia River at Pasco				40.6	52.5	56.3	58.9	63.8	62.4	53.0	43.0	
Temp. Snake River near Mouth				43.1	55.0	61.1	65.9	70.9	66.3	46.4	34.7	

* Plus sign indicates temp. rise in degrees F through reservoir; minus, temp. fall; - indicates no data.

[1] Data for 1954-55 from University of Washington data.

[2] Data for 1944-45 and 47 from Fish and Wildlife Service thermograph records.

[3] Temp. above McNary Dam measured at Pasco. This shows temp. change accounting for warmer or colder Snake River inflow below Pasco.

temperature rise in May shows the effect of the heavy runoff of melting snow water encountering the warmer reservoir. The temperature rise in August and September illustrates the effect of drawdown on the reservoir which brings the upper layers of warmer water into the more restricted area at lower depths and thus produces a greater depth of warmer water.

Merwin: Impoundment commenced on May 13, 1931. This reservoir is immediately below the Yale Dam and is somewhat larger, but shallower, than the Yale Reservoir. It has a length to width ratio of 23.3 which will provide less short-circuiting through the reservoir and more mixing than in the shorter Yale Reservoir. The single set of temperature data obtained in May appears to be in error. In August and September, water is discharged slightly colder than the reservoir influent. During the other months, the discharged water is warmer than the influent.

Yale - Merwin: Since these reservoirs are close together, they are considered herein as a single reservoir. Their combined effect is to continually increase the Lewis River water temperature from about one to five degrees fahrenheit. During the period of low-stream flow in September, the water temperature increase is about three degrees fahrenheit.

Grand Coulee Equalizing: This is a long and shallow reservoir used to equalize the flow of pumped water into the Columbia Basin irrigation system. It has a length to width ratio of 13.5. Data were available only for the summer months. The effect of solar heating on a shallow impoundment is quite evident. During June and July, temperature increases of over seven degrees fahrenheit were observed. In August and September, the inflowing water from Lake Roosevelt had warmed sufficiently to reduce this temperature increase to six and two degrees respectively.

Roosevelt: This is an exceptionally long, deep, and large reservoir, having a length to width ratio of 167 which will provide for some mixing of water in the reservoir and reduce the amount of stratification. Data were available for only the summer months. In June and July, the reservoir reduces the Columbia River water temperature by about two degrees. In August, the water level is falling in the reservoir and the warmer upper layers are reaching the turbine intakes, producing no appreciable temperature change between upstream and downstream. In September, the warmer water has reached the turbine intakes and the average effect is to increase the Columbia River temperature by 3.6° F.

McNary: This is a relatively shallow, run of the river impoundment, having a length to width ratio of 61. The Snake River flows into the impoundment 32 miles above the dam. This is the major tributary of the Columbia River and its temperature will materially affect the reservoir temperature. In the winter, the Snake River is colder than, and in the summer it is warmer than, the Columbia River at Pasco. Since the reservoir does not always provide complete mixing, a slight temperature gradient is usually noticeable across the reservoir at McNary Dam.

To evaluate the temperature change through this reservoir, it was necessary to compute the theoretical temperature of the mixed flow of the Columbia and Snake Rivers below Pasco. This composite temperature was then taken as the upstream temperature. Referring to table 13 it is apparent that the impoundment produces a net cooling effect (0.1° - 1.5° F.) in the winter and spring and a warming effect (0.1° - 0.5° F.) on the lower Columbia in the late summer and fall.

Table 14 shows the temperature changes in the reservoirs based on their volume, depth and area. These data will be used in predicting future temperature changes in the Columbia River.

Table 13 shows that temperature changes in reservoirs cannot be generalized, such as, they warm the downstream water in the winter and cool it in the summer. Each reservoir behaves in accordance with its own peculiar environment.

Temperature stratification in reservoirs:

The temperature of the water downstream from an impoundment will vary according to the depth from which the water is withdrawn. A study of references (17), (22), (42) and (43) plus University of Washington observations shows that of the 19 reservoirs observed, all but Lake Roosevelt show marked temperature stratification in the spring, summer and fall and a lesser

Table 14.--Average monthly temperature changes through reservoirs - area, volume, depth relationships; from table 13*

	Mar.	May	June	July	Aug.	Sept.	Nov.	Dec.
Yale - Merwin Reservoir								
Temperature Change in °F per 10^6 Ac. Ft.	2.1+	4.0+	6.8+	1.9+	1.1+	4.1+	-	5.4+
" " " " " 10^4 Acres Area	2.2+	4.1+	6.9+	1.9+	1.1+	4.2+	-	5.5+
" " " " " 100 Ft. Depth	1.1+	2.1+	3.6+	1.0+	0.6+	2.2+	-	2.9+
Grand Coulee - Equalizing								
" " " " " 10^6 Ac. Ft.	-	-	7.3+	7.9+	6.2+	2.1+	-	-
" " " " " 10^4 Acres Area	-	-	2.9+	3.1+	2.4+	0.8+	-	-
" " " " " 100 Ft. Depth	-	-	13.5+	14.5	11.4+	3.8+	-	-
Roosevelt								
" " " " " 10^6 Ac. Ft.	-	-	0.23-	0.23-	0.01-	0.44+	-	-
" " " " " 10^4 Acres Area	-	-	0.27-	0.27-	0.01-	0.51+	-	-
" " " " " 100 Ft. Depth	-	-	0.58-	0.58-	0.03-	1.09+	-	-
McNary (Corrected for Snake River Inflow)								
" " " " " 10^6 Ac. Ft.	1.9-	0.13-	0.89-	0.0	0.13+	0.63+	0.25+	0.25-
" " " " " 10^4 Acres Area	0.4-	0.03-	0.18-	0.0	0.03+	0.13+	0.05+	0.05-
" " " " " 100 Ft. Depth	2.1	0.14	1.0	0.0	0.14+	0.72+	0.29+	0.29-

* Plus sign indicates temperature rise through reservoir; minus, temperature fall; - indicates no data available.

stratification in the winter. The extent of this stratification depends upon the length of the reservoir, wind action on the surface layers, amount of inflow and outflow and relative temperature of inflow to reservoir temperatures. Wind is the principal factor in mixing the summertime warm surface layers into the reservoir body since the rate of molecular diffusion is low and because water has a high heat capacity.

Figure 36 of Lake Merwin was prepared from the unpublished data of Richard Smith (22) and is corroborated by reference (17) and University of Washington data. Yale Reservoir shows a similar temperature stratification. A pronounced warming from solar radiation is quite evident in the summer months with no marked thermocline. Comparing the temperature at the turbine intake with the upstream water temperature indicates that the Merwin Reservoir, prior to construction of the upstream Yale Reservoir, had a general warming effect on downstream waters in the winter and cooling effect in the summer. After constructing Yale Reservoir, this was no longer true and the combined effect of the two reservoirs in series is to produce a year around warming of downstream water (table 13).

Figure 37 was prepared from General Electric Company data (42) and from Fish and Wildlife Service thermograph records at Umatilla. The lack of stratification is due to the shallow depth of the reservoir and the short detention period for inflowing water. Slight differences between downstream water temperatures and the temperature at the depth of the turbine intakes (55 feet) is probably due to a difference in the thermometer calibrations.

A sharp thermocline is shown for May 19, 1955. During this period, the Columbia River and Snake River flows were about equal and the warmer Snake River water was contained in the upper layers of the reservoir. By June 16, 1955, the Columbia flow had more than doubled that of the Snake and mixing occurred to destroy the temperature gradient.

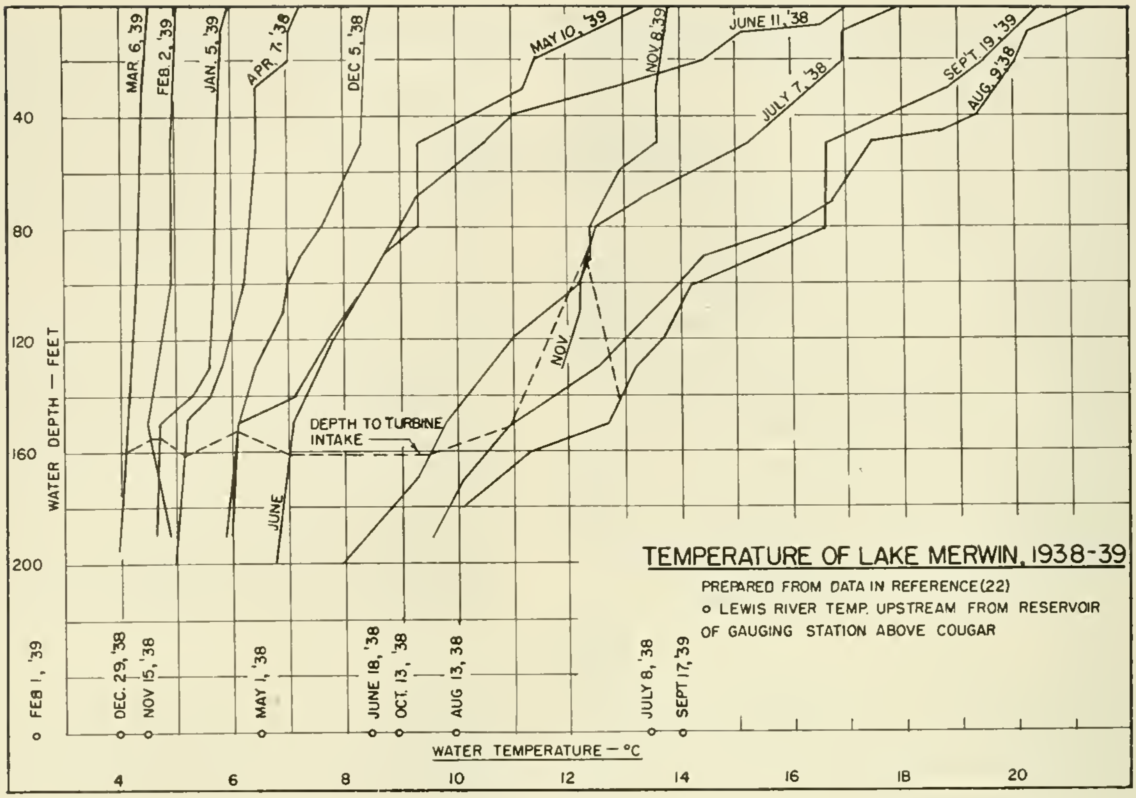

TEMPERATURE OF LAKE MERWIN, 1938-39
PREPARED FROM DATA IN REFERENCE (22)
o LEWIS RIVER TEMP. UPSTREAM FROM RESERVOIR OF GAUGING STATION ABOVE COUGAR
DEPTH TO TURBINE INTAKE
WATER DEPTH — FEET
WATER TEMPERATURE — °C
MAR. 6, '39
FEB. 2, '39
JAN. 5, '39
APR. 7, '38
DEC. 5, '38
MAY 10, '39
NOV 8, '39
JUNE 11, '38
JULY 7, '38
SEPT. 19, '39
AUG. 9, '38
NOV
JUNE
FEB 1, '39
DEC. 29, '38
NOV 15, '38
MAY 1, '38
JUNE 18, '38
OCT. 13, '38
AUG 13, '38
JULY 8, '38
SEPT 17, '39

FIG. 36

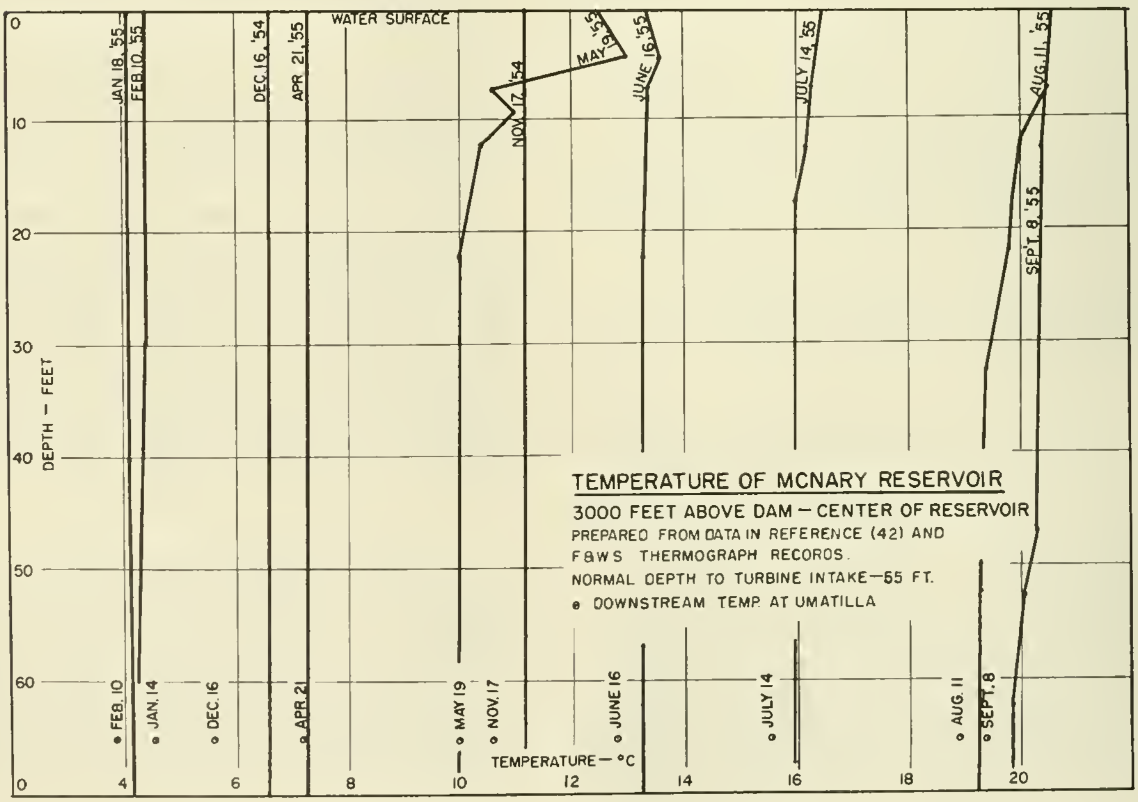

TEMPERATURE OF MCNARY RESERVOIR
3000 FEET ABOVE DAM — CENTER OF RESERVOIR
PREPARED FROM DATA IN REFERENCE (42) AND F&WS THERMOGRAPH RECORDS.
NORMAL DEPTH TO TURBINE INTAKE—65 FT.
• DOWNSTREAM TEMP. AT UMATILLA
WATER SURFACE
DEPTH — FEET
TEMPERATURE — °C
JAN 18, '55
FEB.10, '55
DEC.16, '54
APR. 21, '55
NOV. 17, '54
MAY 19, '55
JUNE 16, '55
JULY 14, '55
AUG. 11, '55
SEPT. 8, '55
FEB.10
JAN.14
DEC.16
APR.21
MAY 19
NOV.17
JUNE 16
JULY 14
AUG. 11
SEPT. 8

FIG. 37

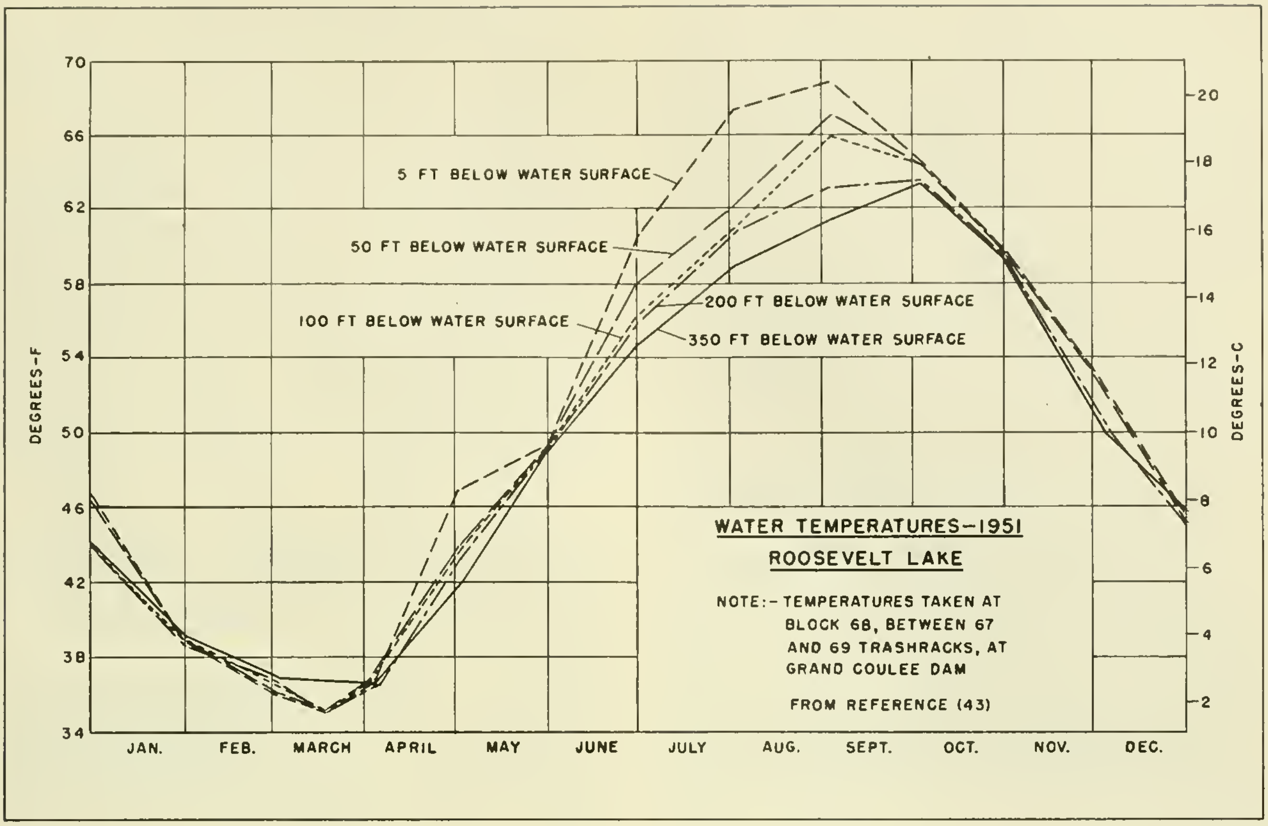


FIG. 38

Water temperatures for Lake Roosevelt in the year 1951 are shown in figure 38. The Columbia River flow during 1951 was the second highest flow on record for the International Boundary gaging station. Even though this high flow would provide extraordinary flushing action, the temperature gradients shown in figure 38 are similar to those in reference (44) and to data obtained by the University. A maximum temperature gradient of 4.5° C. is shown for August with half of this temperature change occurring in the upper 50 feet. Other than in the summer, the temperature change from surface to bottom is very slight.

Minimum temperatures were in March when the deepest water was the warmest, this deep water being nearest to the temperature of maximum density (4° C.). Maximum surface temperatures were near the first of September while the maximum temperature for water withdrawal through the turbines (at 260 ft. depth) was in the first part of October when the reservoir was drawn down. Isothermal conditions are shown at the end of January, May and October, when overturns are possible. These isothermal conditions are a function of both atmospheric temperature changes and river inflow.

<u>Effect of Grand Coulee Dam on Columbia River Temperatures at Rock Island</u>:

Water temperatures at Rock Island Dam have been kept by the Puget Sound Power and Light Company since 1933. These temperatures were used for pre and post Grand Coulee Dam construction comparisons. As the water temperature is a function of air temperature and flow rate in a given stream, a five-year period (1934-38) prior to construction of Grand Coulee Dam and a five-year period after construction (1946-50) were chosen when the air temperatures and flow were similar. Figure 39 shows a comparison of these air temperatures and flow for the two five year periods. Air temperature were taken for Nespelem, Washington as this was the weather station that would most closely approximate upstream weather conditions. A close agreement is shown for the

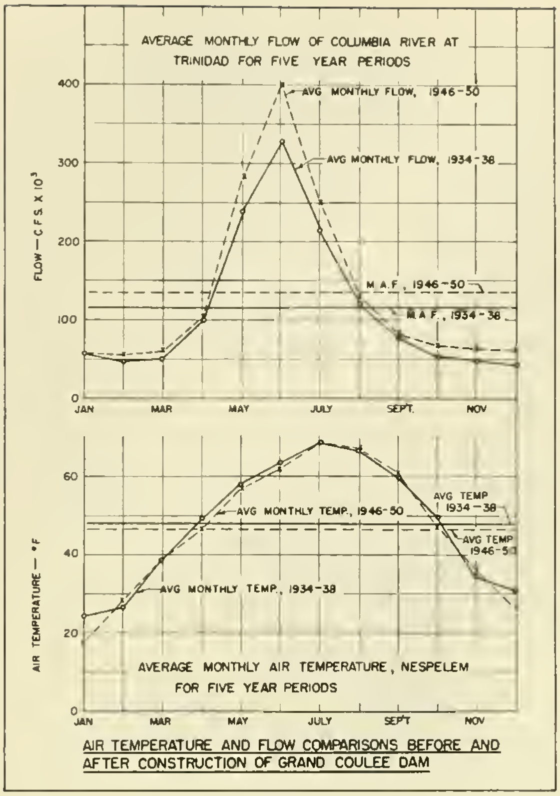


FIG. 39

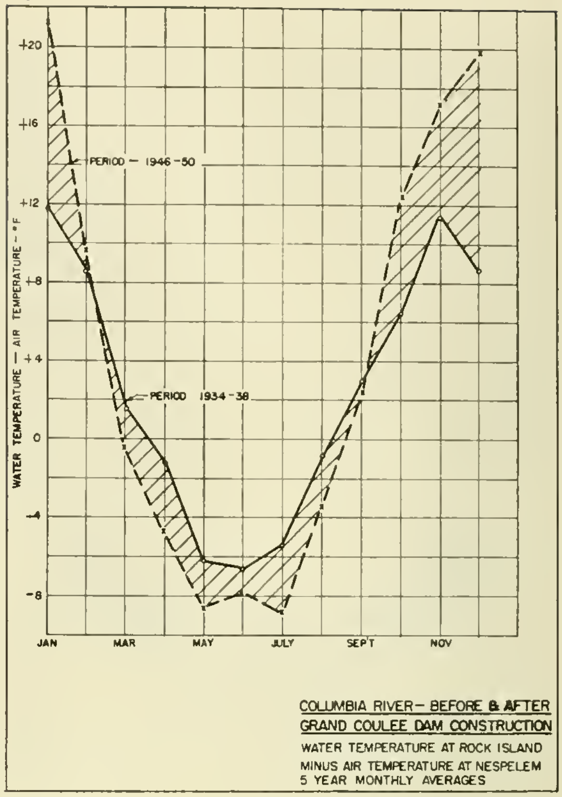


FIG. 40

two periods of air temperatures. Flow comparisons were made using the U.S.G.S. gaging station records for Trinidad, Washington, just below Rock Island Dam. These flow rates agree fairly closely excepting for the spring months. The spring flood of 1948 caused the 1946-50 flow rate to be greater than the 1934-38 rate.

Assuming then that the flow rates for these periods are comparable, a comparison of water temperature at Rock Island and air temperatures at Nespelem was made for each month in the two five-year periods. Each year, the water temperatures and air temperatures were summed monthly in a cumulative total, beginning with October of the previous year. From these cumulative monthly totals, the monthly difference between water and air temperatures was obtained for each year. The succeeding monthly difference then, between these monthly water and air temperature differences was tabulated and averaged (plus or minus) by the month for each five-year period. Figure 40 is a plot of these average monthly temperature differences. It shows a cooling effect on the Columbia River from the Grand Coulee Dam construction

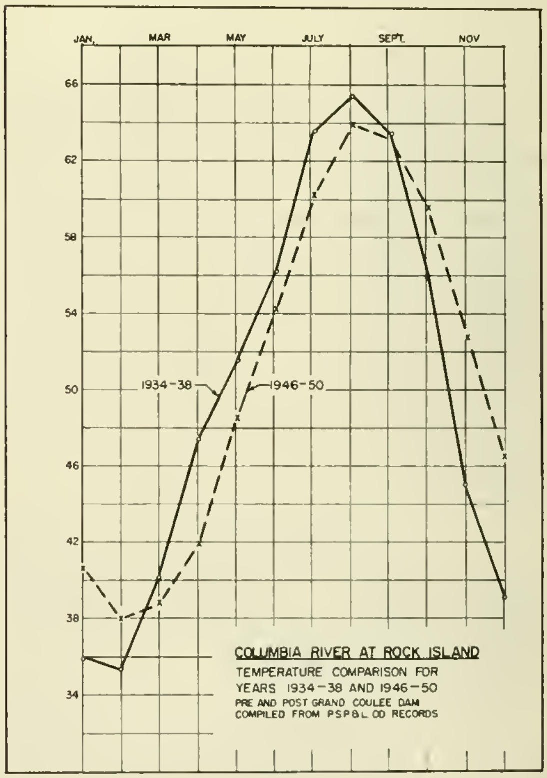


FIG. 41

of one to three degrees fahrenheit in the summer and a warming effect of up to eight degrees in the winter.

A simpler approach to the temperature comparison is to assume that the flow and air temperatures during the period 1934-38 and 1946-50 are similar. With this assumption, the average monthly water temperatures at Rock Island can be compared by obtaining the five year monthly averages and plotting. This has been done in figure 41 which indicates a warming effect from Grand Coulee Dam construction of about seven degree fahrenheit maximum in the winter and a cooling effect of about three degrees maximum in the summer.

An evaluation of future temperature changes that may take place in the Columbia River as a result of dam construction is contained in a later chapter of this report.

In comparing upstream and downstream water temperatures at a particular reservoir, it must be kept in mind that the river water temperatures, in the absence of a reservoir, would tend to increase in the same stretch during the summer and perhaps decrease during the winter.

WATER QUALITY COMPARISONS 1910-11 TO 1952-56

Selected Stations - Columbia and Tributary Rivers

In 1910, 1911 and 1912, Walton Van Winkle of the U. S. Geological Survey conducted the first systematic study of seasonal surface water quality characteristics in the States of Oregon and Washington. His work is published in U.S.G.S., W.S.P. 339 and 363 (49). At each selected sampling station, daily samples of water were collected and mailed to a laboratory where 10 consecutive samples were united. The analysis was made from this composite. Analytical and sample collection methods used by the U. S. Geological Survey today are comparable to those used by Van Winkle excepting that samples are now composited by volume according to their specific conductance.

Between the time of Van Winkle's work and 1949, practically no water quality data were obtained in the Columbia River Basin excepting for a few studies in limited areas like the Willamette Valley, Yakima Valley, and a section of the lower Columbia River. Since the purpose of this section is to note any significant changes in river water quality that have occurred since man commenced his multipurpose water uses, comparisons can be made only between Van Winkle's data and that obtained by the U. S. Geological Survey and the University of Washington in very recent years. A close, direct comparison cannot be made between these sets of data since there is some difference in sampling and analytical technique; some differences in sampling points and time of day and frequency of sampling; differences in the time of sample storage before analysis; and because the stream flows were not the same in the two time periods under comparison. Figure 42 illustrates the change in water quality at a particular point during the course of a year's sampling with changing rates of river discharge. It will be noted that in general, the constituents are highest during low discharge and lowest during periods of high stream discharge. Curves for other locations (figs. 10-19, reference 50) will show less or more marked changes with a change in flow. These quality changes

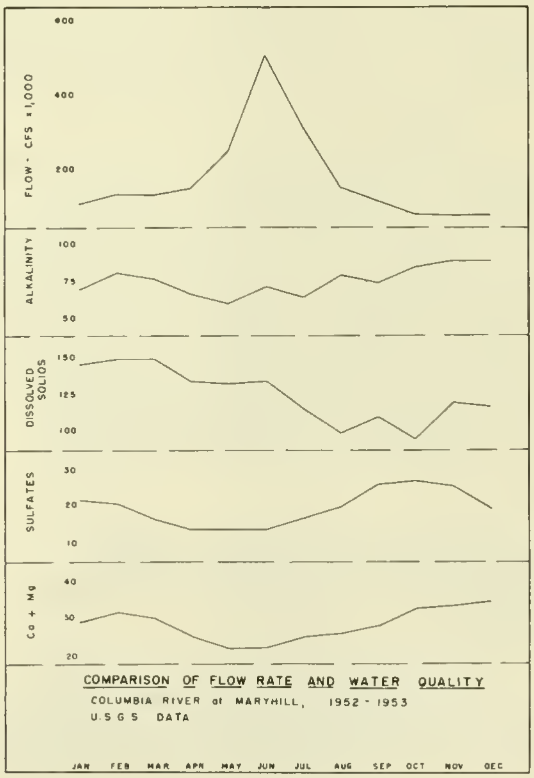


FIG. 42

are evened out or are delayed when there is a large upstream impoundment. Color and turbidity may be greatest during periods of high discharge. Their comparison by weighted averages is questionable.

In the Columbia River Basin, Van Winkle's data are compared with contemporary data in tables 15 to 23 and figures 43 to 59 for the following locations:

- Columbia River at Northport (International Boundary)
- Columbia River at Pasco
- Columbia River at Cascade Lock and Maryhill
- Wenatchee River at Cashmere
- Snake River at Burbank, Central Ferry, and Clarkston
- Yakima River at Cle Elum
- Yakima River at Prosser and Kiona
- Deschutes River at Moody
- Okanogan River at Okanogan and near the mouth

These tables and figures show the actual observed constituents. To properly evaluate the change in constituents, the reader must also compare the difference in stream discharge for that month (a higher discharge results in more dilution of constituents).

Table 24 is a compilation of the yearly weighted averages for seven of these stations. Average monthly values are weighted according to flow by multiplying the average monthly flow by the average monthly constituent, summing them for the year, and dividing the sum by the total of the monthly flows. Table 25 shows the approximate changes in population, industry, and irrigated acreage from 1910 to 1950 and table 26 gives the changes in river constituents on a tonnage basis. These tables and figures are described below:

Columbia River at Northport (International Boundary), Figures 43 and 44, Table 15:

The Columbia River and tributaries above the International Boundary pass through a series of large lakes or impoundments. These impoundments tend to even out the river flow and the change in water quality that comes with changes in river flow, 5,039,000 acre-feet of impounded water have been added to this stream section since 1910. Decreases in dissolved constituents will be reflected in downstream stations three months past the period of high runoff (figs. 10 and 11, reference 50) whereas in a stream without impoundments, these changes will be observed coincidental with the change in flow. Between 1910 and 1950, there was a 46 percent increase in watershed population, a 32 percent increase in irrigated acreage and an industrial waste addition to the river equivalent to an estimated population of 513,000 persons on an oxygen demand basis. The average river discharge during these two periods of comparison differed by only 4 percent.

Figures 43 and 44 show an increase in all constituents excepting for sodium plus potassium and silica. An increase in all mineral constituents could be expected because of an increase in waste discharge to the river, denudation of forest cover from logging and because of an increase in irrigation. Between 1910 and 1952, the river constituents increased by the following percentages: Alkalinity - 5; hardness - 14; dissolved solids - 6; sulfate - 19; calcium plus magnesium - 14; chloride - 125; and nitrates - 220. Iron showed no change while sodium plus potassium decreased 41 percent and silica 20 percent. The 300 percent increase in nitrates and 200 percent in chlorides can be expected from the increased discharge of organic matter and municipal wastes to the river. No plausible explanation can be advanced as to why silica and sodium plus potassium did not also increase during this period of time.

Columbia River at Pasco, Figures 45 and 46, Table 16:

The data shown herein for 1954-56 were collected by the University and do not represent as accurate a representation of the water constituents as do those collected by the U. S. Geological Survey since sample collection was less frequent. There are no flow data for the 1910 sampling period. Since these two sets of data are not directly comparable, they can be examined only in a very general sense. Sodium plus potassium values have shown an apparent decrease (as at Northport) and calcium plus magnesium and sulfates have shown little change. The

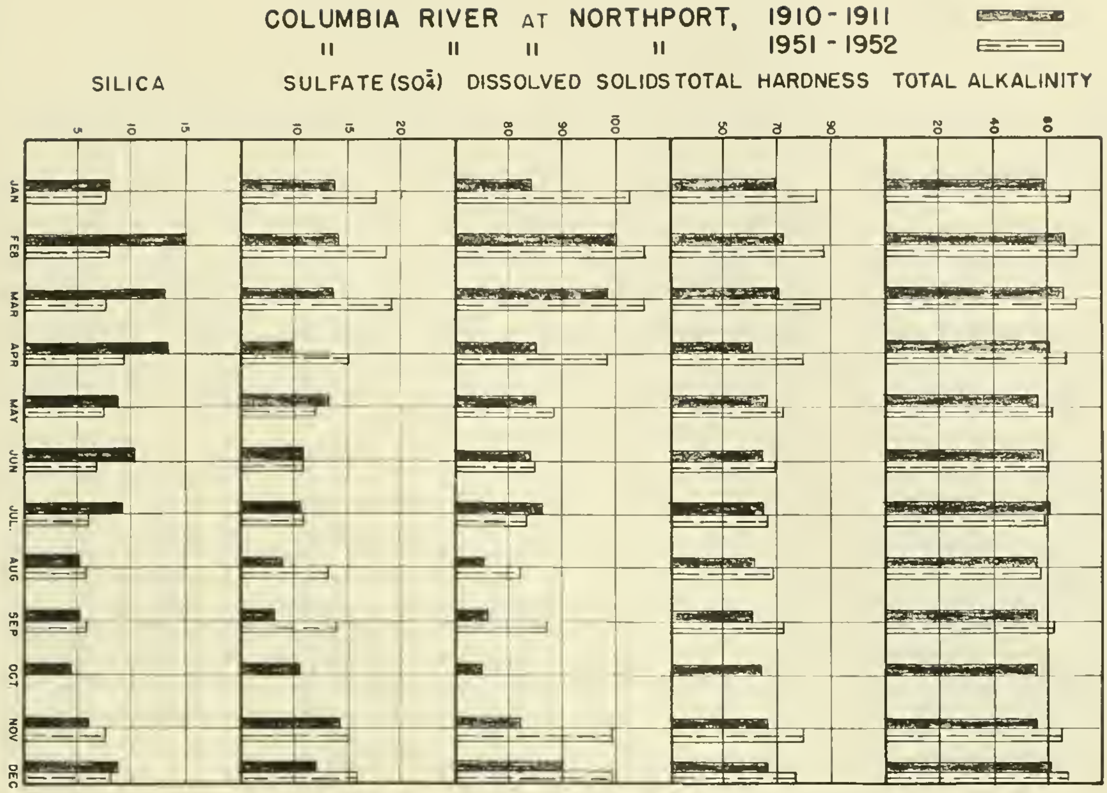

COLUMBIA RIVER AT NORTHPORT, 1910-1911
" " " " 1951 - 1952
SILICA
SULFATE (SO4)
DISSOLVED SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
JAN
FEB
MAR
APR
MAY
JUN
JUL.
AUG
SEP
OCT.
NOV
DEC

FIG. 43

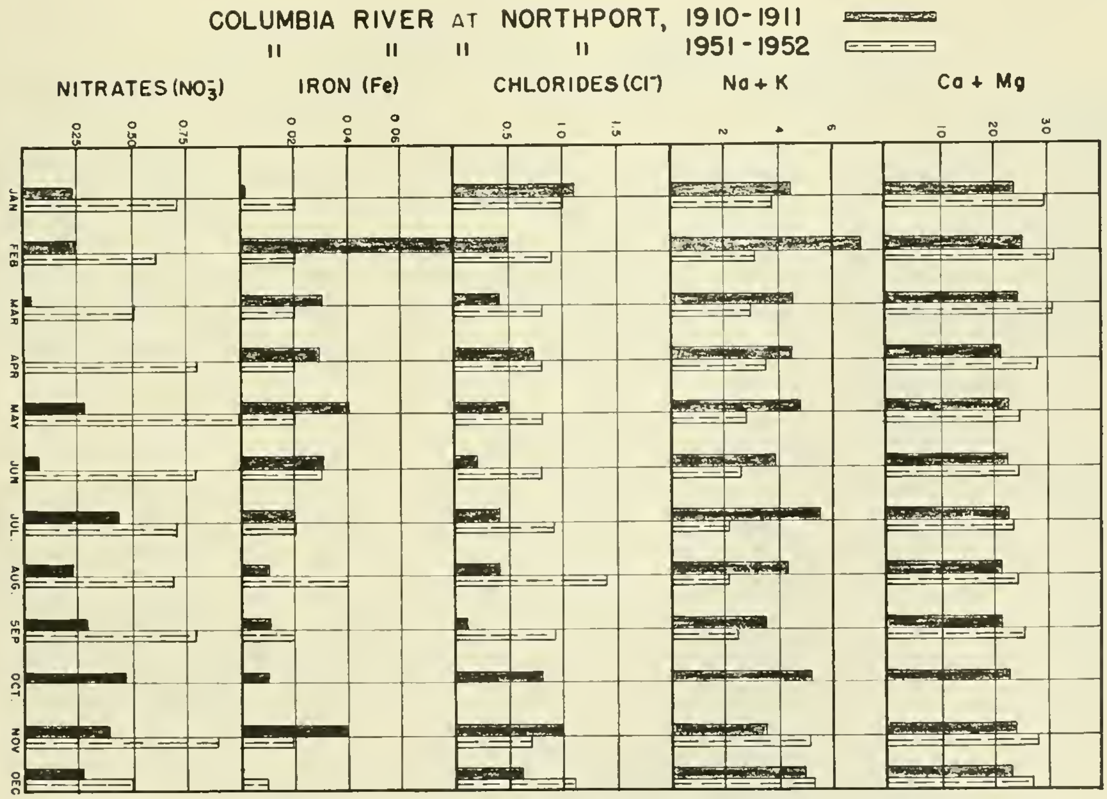

COLUMBIA RIVER AT NORTHPORT, 1910-1911
" " " " 1951 - 1952
NITRATES (NO3)
IRON (Fe)
CHLORIDES (Cl)
Na + K
Ca + Mg
JAN
FEB
MAR
APR
MAY
JUN
JUL.
AUG.
SEP
OCT.
NOV
DEC

FIG. 44

Table 15.--Water quality comparison.

Columbia River at Northport, 1910-11 (U.S.G.S.)

In P.P.M.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[1]	4	3	3	3	3	3	3	3	3	3	3	3
Flow x 1,000	-	-	-	-	-	-	-	-	-	-	-	-
Total Alk.[2]	59	67	66	61	57	59	61	56	56	56	57	62
Sulfate	13.8	14	13.3	10	13	10.5	10.5	8.9	8.0	10.5	14.3	12
Silica	7.9	15	13	13.1	8.6	10.2	8.9	5	4.8	4.1	6	8.4
Total Hardness[3]	69	72	70	61	65	64	64	61	60	64	66	67
Dis'l. Solids	84	100	98	85	80	84	86	75	76	75	80	90
Na + K	4.5	7.0	4.6	4.5	4.8	3.9	5.5	4.2	3.5	5.1	3.6	5.0
Ca + Mg	23.8	25.3	24.4	21.5	22.8	22.7	22.9	21.4	21.7	22.9	23.8	23.4
Chlorides	1.1	0.5	0.4	0.7	0.5	0.2	0.4	0.4	0.1	0.8	1.0	0.6
Iron (Fe)	T	0.08	0.03	0.03	0.04	0.03	0.02	0.01	0.01	0.01	0.04	T
Nitrate (NO_3)	0.23	0.23	0.04	0.0	0.27	0.07	0.43	0.29	0.46	0.46	0.38	0.27

Columbia River at Northport, 1951-52 (U.S.G.S.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[1]	3	3	3	3	3	3	3	3	3	0	2	2
Flow x 1,000	39	40	39	71	224	245	182	96	55	69	50	44
Total Alk.[2]	69	71	71	67	62	60	58	58	63	-	66	68
Sulfate	17	18	19	15	12	11	11	13	14	-	15	16
Silica	7.3	7.9	7.3	9.2	7.4	6.7	6.0	5.7	5.6	-	7.4	8.0
Total Hardness[3]	83	87	86	79	71	69	67	68	72	-	79	77
Dis'l. Solids	102	105	105	98	88	85	83	82	87	-	99	99
Na + K	3.7	3.1	3.0	3.5	2.8	2.5	2.1	2.1	2.4	-	5.1	5.4
Ca + Mg	29.0	31.0	30.9	28.1	25.1	24.5	23.9	24.3	25.7	-	28.1	27.2
Iron (Fe)	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.04	0.02	-	0.02	0.01
Chlorides (Cl^-)	1.0	0.9	0.8	0.8	0.8	0.8	0.9	1.4	0.9	-	0.7	1.1
Nitrates (NO_3^-)	0.7	0.6	0.5	0.8	1.0	0.8	0.7	0.7	0.8	-	0.9	0.5

1 Each sample represents composite of 10 or more daily samples
2 As p.p.m. $CaCO_3$
3 Computed from Ca and Mg as $CaCO_3$

Table 16.--Water quality comparisons.

Columbia River at Pasco, 1910-11 (U.S.G.C.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[1]	4	3	3	2	3	3	3	3	3	3	3	3
Flow x 1,000	-	-	-	-	-	-	-	-	-	-	-	-
Total Alk.	65	65	49	57	54	57	59	61	57	58	57	60
Sulfate	11	14	15.5	12.5	9.0	9.0	7.6	8.4	11	12	12	12
Color	-	-	36	-	7	8	-	-	-	-	-	-
Turbidity	4	17	46	15	10	4	2	2	3	2	2	3
Total Hardness[2]	70	66	60	61	56	64	63	62	62	62	62	68
Na + K	5.1	8.5	7.6	8.8	7.2	7.0	6.1	6.4	4.0	5.4	4.2	3.6
Ca + Mg	24.7	23.3	21.1	20.3	19.8	22.8	22.1	22.7	22.8	22.7	22.1	23.1
Total Solids	88	98	127	98	96	83	80	83	78	79	81	84
Iron (Fe)	0.01	0.12	0.15	0.27	T	T	T	0.01	0.02	0.03	0.01	T

Columbia River at Pasco, 1954-56 (University of Washington)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[3]	-	-	1	1	2	3	8	10	8	2	2	1
Flow x 1,000	-	-	88	154	204	420	341	164	106	71	70	71
Total Alk.	-	-	69	66	68	58	58	63	65	56	63	67
Sulfate	-	-	16	16	15	8	8	10	10	12	8	11
Color	-	-	8	20	13	11	10	8	5	10	4	0
Turbidity	-	-	8	19	19	14	8	9	5	13	6	2
Total Solids	-	-	84	160	120	115	96	124	92	90	76	95
Na + K	-	-	-	-	-	2.8	2.0	3.1	2.2	4.2	3.3	-
Ca + Mg	-	-	-	-	-	13.4	25	21.7	24.1	22.7	21.6	-
Iron (Fe)	-	-	-	-	-	0.02	0.3	0.04	0.60	0.02	0.05	-
Total Hardness	-	-	83	70	77	65	65	68	69	65	70	77

1 Each sample represents composite of 10 daily samples
2 Computed as p.p.m. $CaCO_3$ from Ca and Mg content
3 Each sample represents composite of 2 or more individual samples

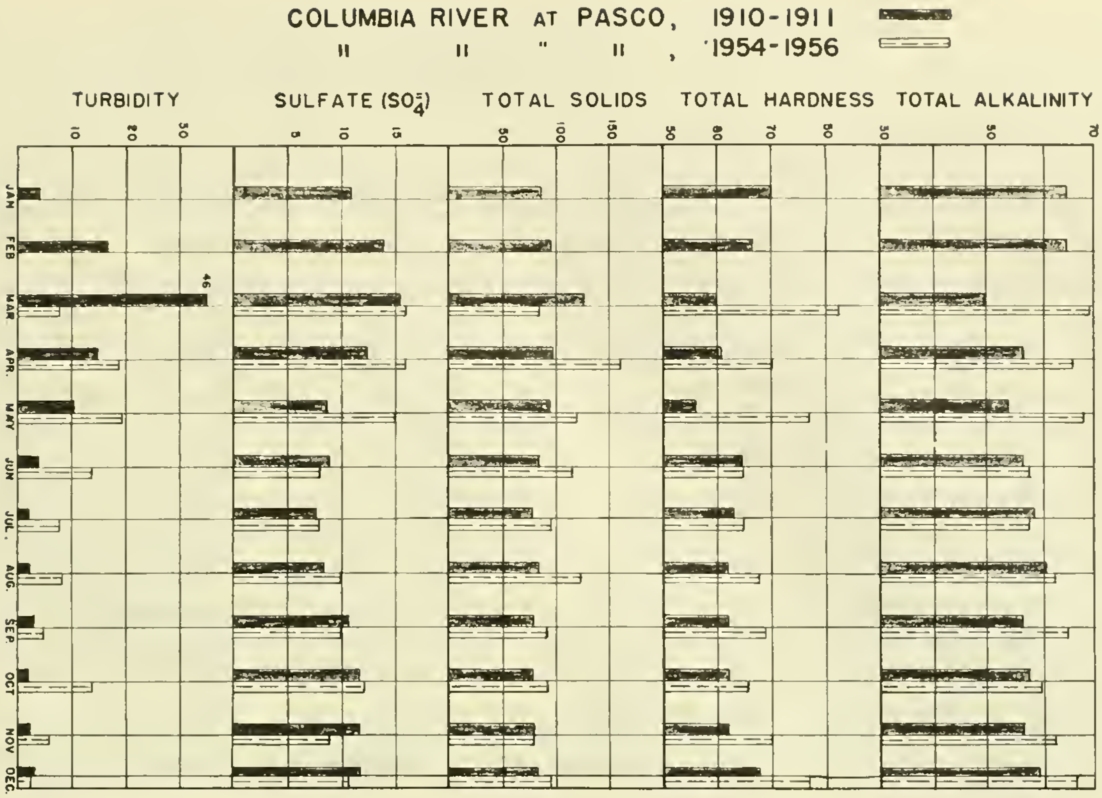

COLUMBIA RIVER AT PASCO, 1910-1911
" " " ", 1954-1956
TURBIDITY
SULFATE ($SO_4^=$)
TOTAL SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
JAN
FEB
MAR.
APR.
MAY
JUN
JUL.
AUG.
SEP
OCT
NOV
DEC.
46

FIG. 45

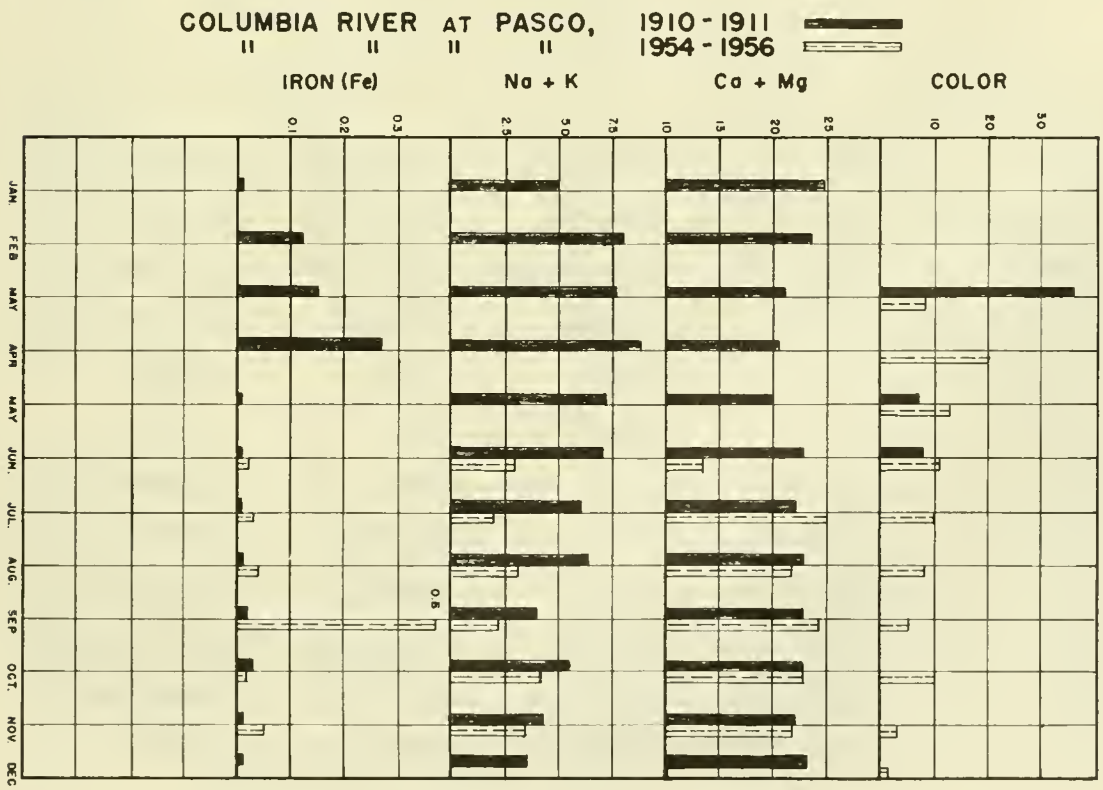

COLUMBIA RIVER AT PASCO, 1910-1911
" " " ", 1954-1956
IRON (Fe)
Na + K
Ca + Mg
COLOR
JAN.
FEB
MAY
APR
MAY
JUN.
JUL.
AUG.
SEP
OCT.
NOV
DEC
0.6

FIG. 46

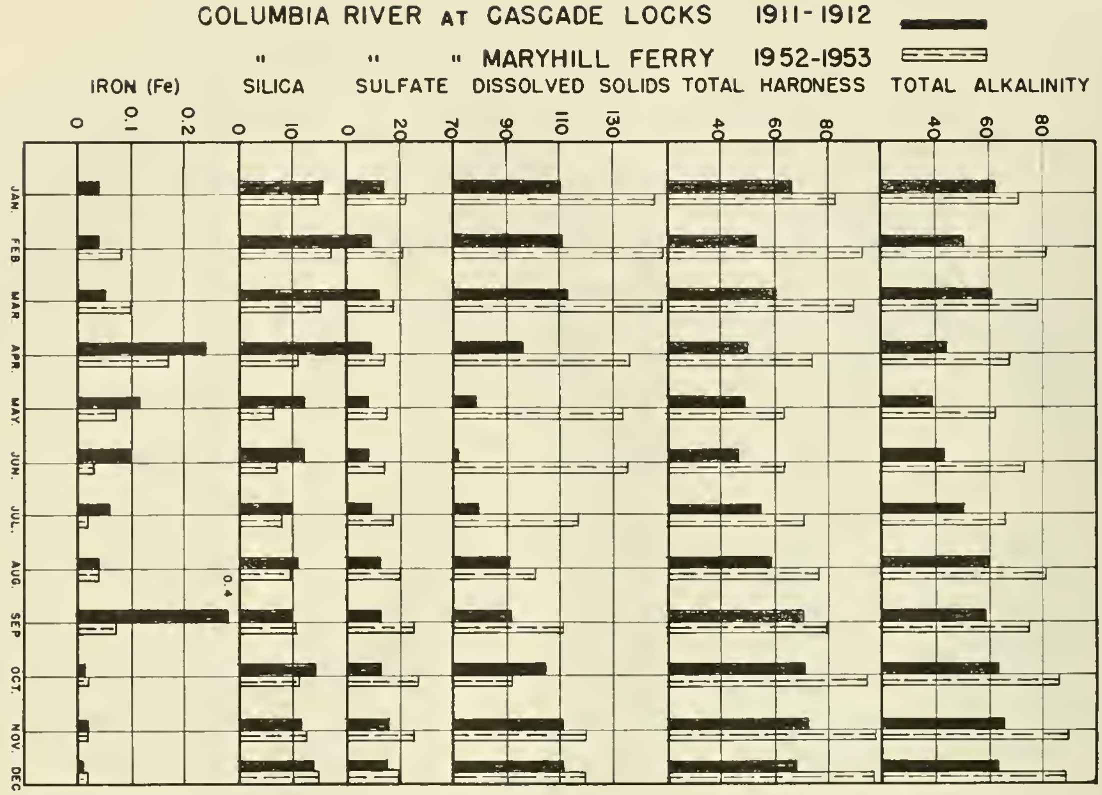

COLUMBIA RIVER AT CASCADE LOCKS 1911-1912
" " " MARYHILL FERRY 1952-1953
IRON (Fe)
SILICA
SULFATE
DISSOLVED SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
0 0.1 0.2
0 10
0 20
70 90 110 130
40 60 80
40 60 80
0.4
JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC.

FIG. 47

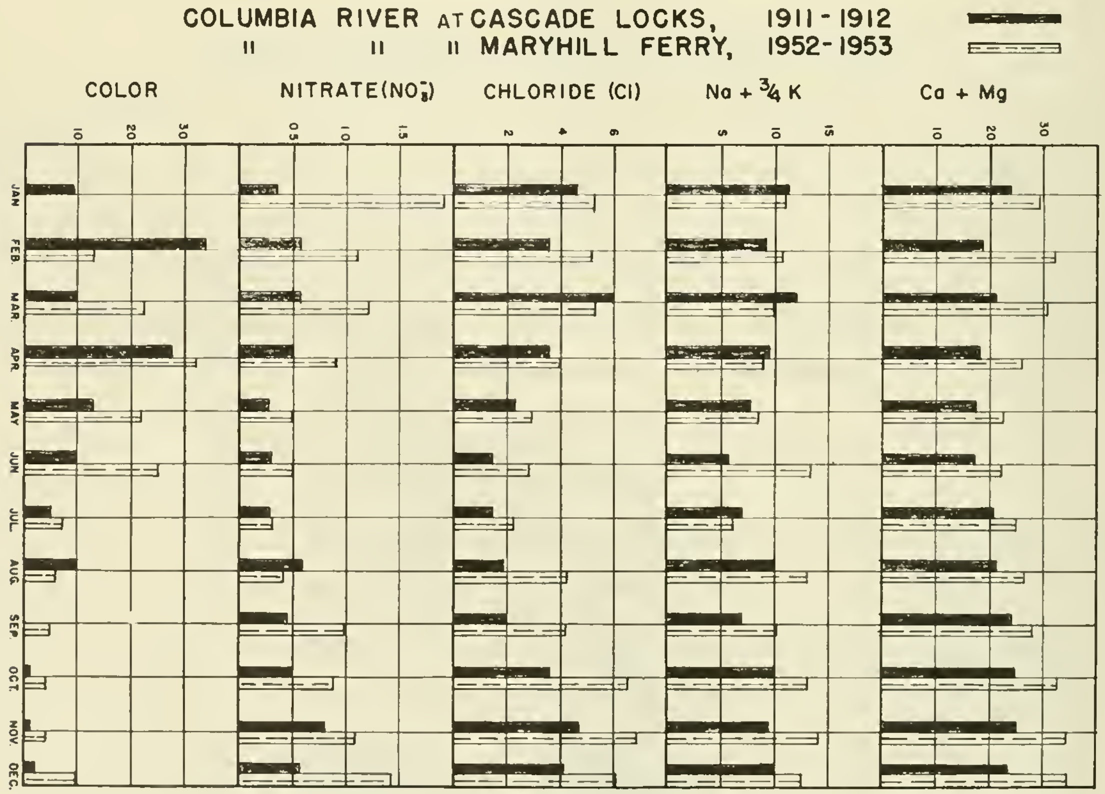

COLUMBIA RIVER AT CASCADE LOCKS, 1911-1912
" " " MARYHILL FERRY, 1952-1953
COLOR
NITRATE(NO3)
CHLORIDE (Cl)
Na + 3/4 K
Ca + Mg
10 20 30
0.5 1.0 1.5
2 4 6
5 10 15
10 20 30
JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC.

FIG. 48

other constituents have shown an increase. Twelve million acre-feet of impounded water have been added to the Columbia River and its tributaries above Pasco since 1910.

Columbia River at Maryhill and Cascade Locks, Figures 47 and 48, Table 17:

The 1910-11 data were obtained at Cascade Locks, 60 miles downstream from Maryhill, location of the 1952-53 sampling station. Between these two sampling stations, the Deschutes, Hood, Klickitat, White Salmon, and Wind Rivers are tributary to the Columbia River. The combined flow from these tributaries is about 6 percent of the Columbia River flow. Since this is a small percentage, the water quality of the Columbia River at Maryhill will not differ significantly from that at Cascade Locks. These tributaries carry less dissolved material than does the Columbia River at this location.

The mean river discharge in the two periods under comparison differed by less than 4,000 c.f.s. All constituents increased excepting for silica and iron. These may have shown a decrease in the 42-year period because of the precipitation of collodial silica and iron in the upstream reservoirs constructed subsequently to 1910. Some of the silica may have been taken up in the cells of diatoms whose abundance has been increased with the construction of reservoirs. Seventeen million five hundred thousand acre-feet of impounded water have been added to the Columbia River above The Dalles since 1910.

Between the periods under comparison, the upstream irrigated acreage increased by 76 percent, the upstream watershed population by 84 percent and an industrial waste population equivalent of 1,813,000 persons was added. This increase in waste addition and irrigation return flows resulted in the following percentage increase in constituents (based on yearly weighted averages, table 24): Alkalinity - 52; hardness - 40; dissolved solids - 32; sulfate - 70; calcium plus magnesium - 35; sodium plus potassium 38; color - 45; chlorides - 52; and nitrate - 80. Silica showed a 23 percent and iron a 50 percent decrease in the same 42-year

Table 17.--Water quality comparison.

Columbia River at Cascade Locks (60 miles below Maryhill), 1911-12.

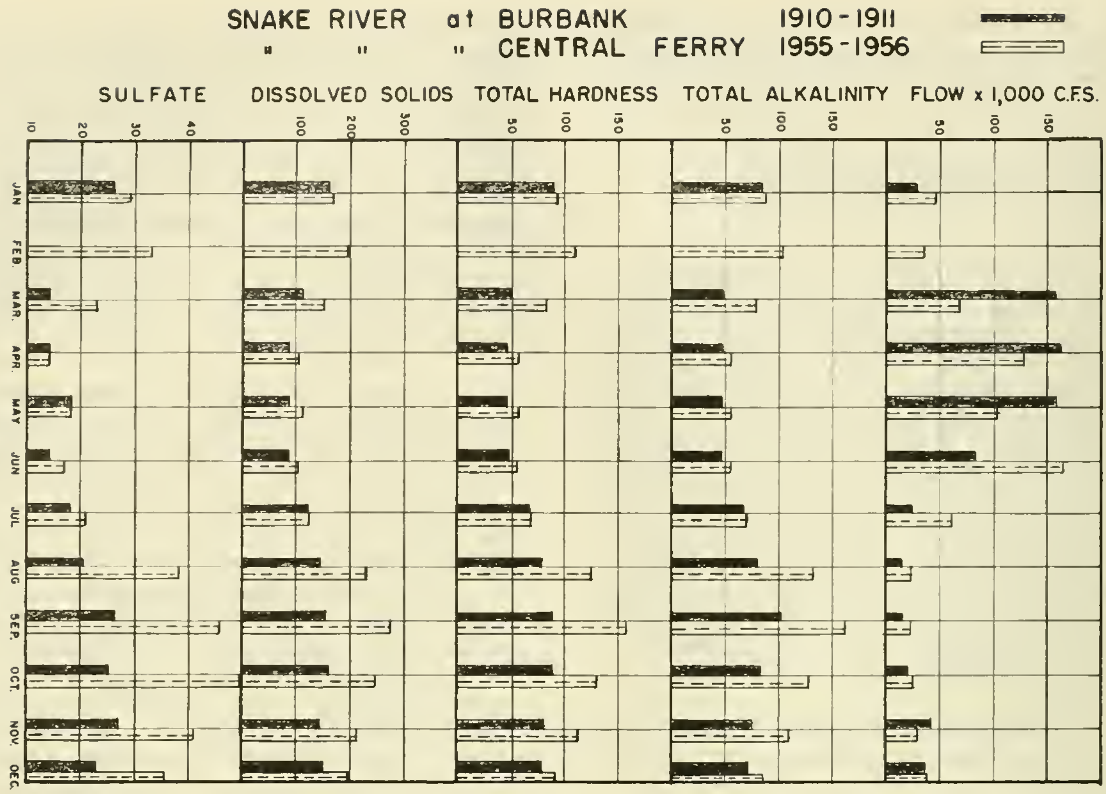
In P.P.M.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[1]	3	3	3	3	3	3	3	4	3	3	3	3
Flow x 1,000 c.f.s.[2]	81	110	82	181	372	522	305	180	129	85	78	70
Total Alk.	63	51	61	45	39	44	51	61	59	64	66	64
Total Hardness	67	53	60	50	49	47	55	59	71	71	73	68
Dissolved Solids	110	110	113	98	78	72	79	91	92	105	111	111
Sulfate (SO_4)	14	10	13	10	8	9	10	12	13	13	14	15
Silica	16	20	20	19	12	12	10	11	10	14	12	14
Iron	0.04	0.04	0.05	0.24	0.11	0.10	0.06	0.04	0.4	0.01	0.02	0.01
Ca + Mg	23.9	18.4	21.3	17.9	17.6	17.4	20.4	21.6	24.3	24.7	25.6	23.8
Na - 3/4 K	11.0	9.0	12.0	9.4	7.5	5.8	6.6	9.7	6.8	10.0	9.5	9.8
Chloride (Cl^-)	4.6	3.6	6.0	3.5	2.2	1.5	1.5	1.9	2.0	3.6	4.7	4.1
Nitrate (NO_3^-)	0.35	0.56	0.55	0.48	0.26	0.29	0.26	0.59	0.45	0.50	0.81	0.57
Color	9	34	10	27	13	10	5	10	-	1	1	2

Columbia River at Maryhill Ferry (60 miles above Cascade Lock)
1952-53 (U.S.G.S.)

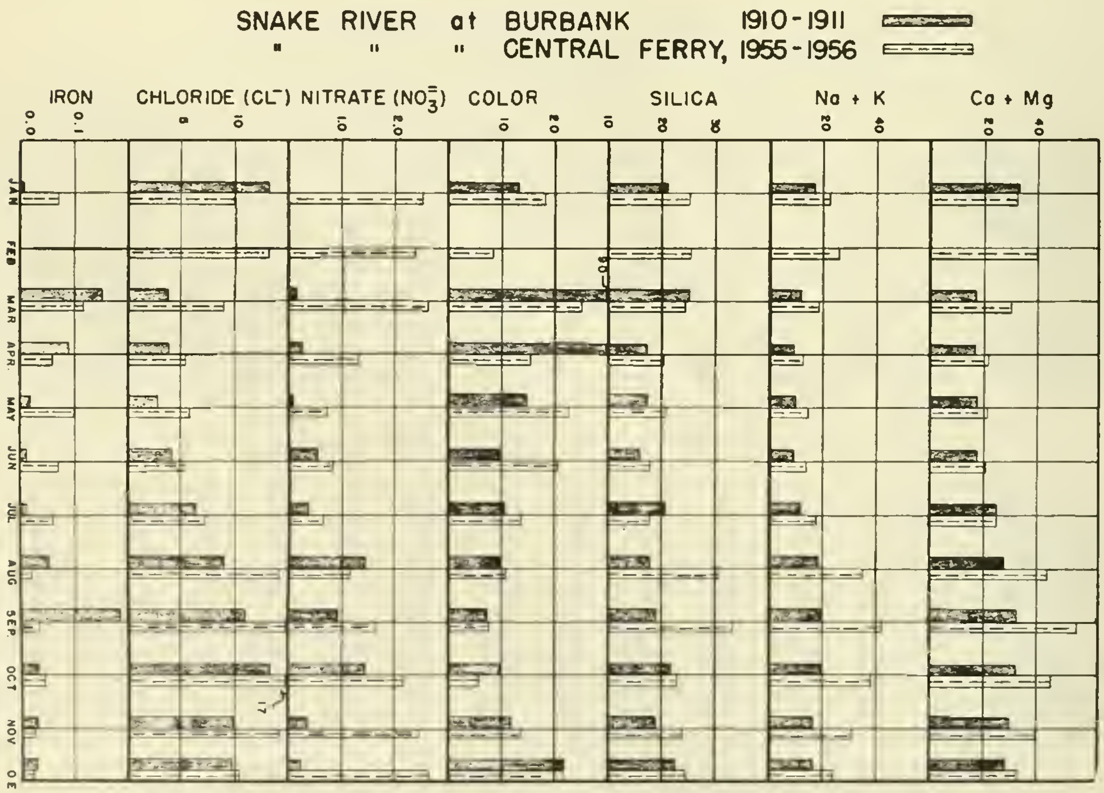
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[1]	2	3	3	3	3	3	3	3	3	2	1	3
Flow x 1,000 c.f.s.	112	140	138	156	252	510	320	156	119	86	85	81
Total Alk.	71	82	78	68	62	73	66	80	75	86	90	89
Total Hardness	83	93	89	74	63	64	71	76	80	95	98	99
Dissolved Solids	146	149	149	135	133	135	116	100	111	92	120	118
Sulfate ($SO_4^=$)	22	21	17	14	14	14	17	20	26	27	26	20
Silica	15	17	15	11	6.5	7.5	8.0	8.6	11	11	13	16
Iron[3]	-	0.08	0.10	0.17	0.07	0.03	0.02	0.04	0.07	0.02	0.02	0.02
Ca + Mg	29	32	30.5	25.8	22.5	22.6	25.1	26.7	28.2	33	34	35
Na + 3/4 K	10.7	10.6	9.9	9.0	8.4	13.4	5.8	12.9	10.1	13.1	14.2	12.6
Chloride (Cl^-)	5.3	5.2	5.3	4.0	2.9	2.8	2.2	4.3	4.2	6.5	6.9	6.1
Nitrate (NO_3^-)	1.9	1.1	1.2	0.9	0.5	0.5	0.3	0.4	1.0	0.9	1.1	1.4
Color[3]	-	13	22	32	22	25	7	6	5	4	4	10

1 U.S.G.S. samples; each sample represents composite of 10 or more daily samples
2 Flow at the Dalles, Oregon
3 Taken from 1951-52 U.S.G.S. Water Quality Data



SNAKE RIVER at BURBANK 1910-1911
" " " CENTRAL FERRY 1955-1956
SULFATE
DISSOLVED SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
FLOW x 1,000 C.F.S.
JAN
FEB.
MAR.
APR.
MAY
JUN
JUL
AUG
SEP.
OCT.
NOV.
DEC.

FIG. 49



SNAKE RIVER at BURBANK 1910-1911
" " " CENTRAL FERRY, 1955-1956
IRON
CHLORIDE (CL⁻)
NITRATE (NO_3^-)
COLOR
SILICA
Na + K
Ca + Mg
JAN
FEB
MAR
APR.
MAY
JUN
JUL
AUG
SEP.
OCT
NOV

FIG. 50

period. As shown in figures 47 and 48, these constituent increases or decreases show no monthly correlation with changes in stream discharge or with the period of irrigation and return flows. This lack of correlation can be attributed to the complexity of water quality variables upstream from Maryhill.

Snake River, Figures 49 and 50, Table 18:

The U.S.G.S. water quality data were collected at Burbank near the Snake River mouth for the 1910-11 period. From 1951 to 1955, the U.S.G.S. collected water quality data from the Snake River near Clarkston. In October of 1955, this station was moved downstream to Central Ferry because the Clearwater River, tributary at Clarkston, was not thoroughly mixed in the Snake at the sampling station below Clarkston. The data in table 18 is for both the Clarkston and Central Ferry stations as indicated in the footnote. Central Ferry is 84 miles and Clarkston 140 miles upstream from Burbank. Water quality values at these stations are comparable since there are no intervening cities or industries and the intervening tributaries (Palouse and Tucannon Rivers) have a combined flow of only 1 percent of that in the Snake River.

Between 1910 and 1950, the Snake River watershed impoundment behind dams increased by 4,075,000 acre-feet, the population increased by 77 percent, irrigated acreage 79 percent and industrial wastes comparable to a population of 768,000 persons on an oxygen basis was added to the watershed. The Snake River flow in the 1910-11 period was 31 percent higher than in the recent period under comparison. This diluting effect of higher flows will be compensated for by making the comparison on the basis of weighted averages (table 24).

All constituents, excepting for color, were higher in the 1952-56 analyses than in the 1910-11. The most noticeable increases were in the summer and autumn when the irrigation return flows were greatest. Based on the yearly weighted averages, the percentage increase in constituents were as follows: Alkalinity - 60; hardness - 70; dissolved

Table 18.--Water quality comparisons.

Snake River at Burbank, 1910-11 (U.S.G.C.)

In P.P.M.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[1]	4	-	2	3	3	3	3	3	3	3	3	3
Flow x 1,000	2721	-	157	162	160	84	25	14.1	15.1	21.0	42	35.9
Total Alk.[2]	84	-	48	48	45	48	67	81	103	84	75	73
Sulfate	26	-	14	14	18	14	18	20	26	25	27	23
Color	13	-	90	30	14	9	10	9	7	9	11	21
Turbidity	5	-	212	53	12	19	17	26	57	45	16	61
Ca + Mg	32.5	-	17.2	16.3	16.2	17.3	24.1	27.4	31.3	30.7	28.1	27.2
Na + K	16.0	-	11	8.6	9.1	8.5	10.3	17.0	18.0	18.6	15.0	14.7
Diss. Solids	161	-	113	89	89	86	121	144	159	165	146	151
Total Solids	167	-	318	181	130	129	133	195	224	196	187	196
Iron (Fe)	T	-	0.15	0.09	0.02	0.01	0.01	0.05	0.18	0.03	0.03	0.03
Total Hardness[3]	91	-	49	47	46	48	69	79	90	89	82	78
Silica	21	-	25	17	17	16	20	17	18	21	18	22
Nitrate (NO_3^-)	0.05	-	0.14	0.24	0.0	0.5	0.35	1.4	0.9	1.4	0.3	0.2
Chloride (Cl^-)	13.5	-	3.6	3.7	2.6	4.0	6.3	8.8	10.6	13	9.9	9.6

Snake River at Central Ferry (near Pomeroy)
1955-56 (U.S.G.C.)

	Jan.	Feb.	Mar.	April	May*	June*	July*	Aug.*	Sept.*	Oct.	Nov.	Dec.
Times Sampled[1]	5	7	6	6	3	3	3	3	3	8	9	8
Flow x 1,000	47	36	68	128	102	165	61	24	22	25	30	38
Total Alk.[2]	88	103	79	55	57	57	71	133	162	128	110	86
Sulfate	28	33	23	14	18	17	21	38	46	50	41	36
Color	18	8	25	15	22	20	13	10	7	5	13	17
Ca + Mg	32	38.6	29.3	20.2	20.1	19.7	23.8	43	54	44	38.4	31.8
Na + K	22.5	25.6	17.8	11.7	13.6	12.6	16.4	34	41	36.5	29.6	22.4
Diss. Solids	173	200	153	105	115	105	125	234	278	249	214	201
Iron	0.07	0.01	0.12	0.06	0.10	0.07	0.06	0.02	0.03	0.04	0.03	0.02
Total Hardness[3]	93	111	85	57	58	56	69	126	158	131	113	92
Silica	25	25	24	20	20	17	17	30	33	22	23	24
Nitrate (NO_3^-)	2.5	2.4	2.6	1.3	0.7	0.8	0.6	1.1	1.6	2.1	2.4	2.6
Chloride (Cl^-)	10	13	9	5.5	5.7	5	7	14	15	17	14	10.5

* Data for Snake River near Clarkston, 1952-53.
1 Each sample represents composite of one to 10 daily samples.
2 As p.p.m. $CaCO_3$
3 Computed from Ca and Mg as $CaCO_3$.

solids - 54; sulfate - 65; calcium plus magnesium - 69; sodium plus potassium - 89; silica - 21; color - (-) 55; nitrate - 360; chloride - 82; and iron - 29.

Okanogan River at Okanogan and near mouth, Figure 51, Table 19:

The 1910-11 U.S.G.S. data were collected at Okanogan, 25 miles above the mouth where the 1954-55 data were obtained by the University. U.S.G.S. data have not been collected from the Okanogan River in sufficient quantity to be used in these comparisons. The University data used was not collected as frequently as the 1910-11 data and, therefore, the comparison must be very general. There are no significant tributaries between Okanogan and the river mouth. The Okanogan River was not gauged in 1910-11. Three hundred and twenty-five thousand acre-feet of storage were added to Lake Okanogan in 1915.

Irrigated acreage has increased 175 percent, population 230 percent, and an industrial waste population equivalent of 15,000 persons has been added to the watershed during the 40-year comparison period. While these percentages are high, the total population and irrigated area are not relatively large for a river basin with a mean discharge of 2,800 c.f.s. From figure 51 and table 19, a general increase in values during the 40-year period can be noted with the exception of turbidity and sodium plus potassium.

Wenatchee River, Figures 52 and 53, Table 20:

In 1910-11, the Wenatchee River was sampled at Cashmere by the U.S.G.S. and in 1954-56 at Sleepy Hollow by the University. Sleepy Hollow is 5 miles downstream from Cashmere and there are no intervening tributaries of any consequence. University data, although limited in frequency of sampling, is used for the later period as insufficient U.S.G.S. data are available.

The Wenatchee River watershed with a mean annual flow of 2,900 c.f.s. has the smallest irrigated acreage and population (with no significant industrial waste contribution) of any of the streams under

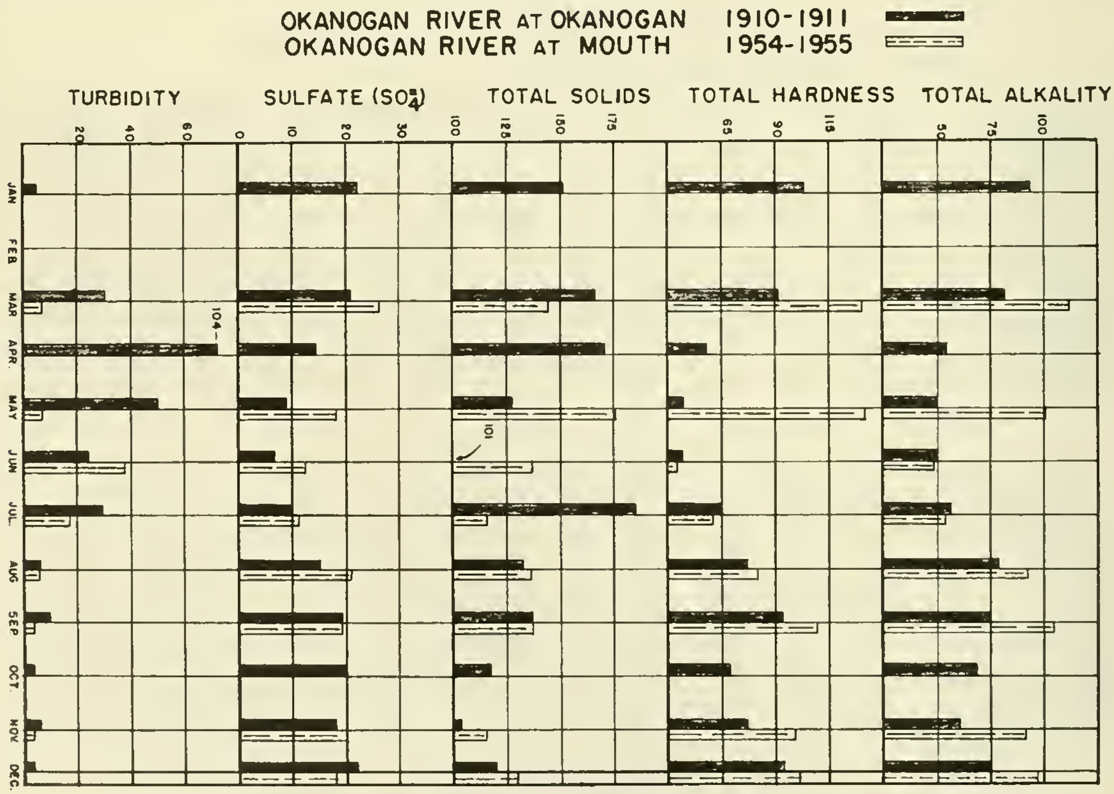


FIG. 51

Table 19.--Water quality comparison

Okanogan River at Okanogan (25 miles above mouth)
1910-11 (U.S.G.S.)

In P.P.M.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Time Sampled[1]	1	0	3	-	3	3	3	3	3	3	3	3
Flow x 1,000	-	-	-	-	-	-	-	-	-	-	-	-
Total Alk.	93	-	82	55	49	49	57	78	75	69	62	74
$CO_3^=$	0	-	0	0	0	0	0	0	0	0	0	0
Sulfate	22	-	21	14.1	8.5	6.1	9.7	15	19	20	18	22
Color	-	-	18	10	8	-	-	-	-	-	-	-
Turb.	5	-	30	104	50	24	29	6	9	4	6	4
Ca + Mg	36.8	-	31.7	20	16.6	20.5	18.5	29.7	29.9	28.1	24.0	31.2
Na + K	10	-	9.7	8.5	7.2	6.5	10.4	10.2	8.9	9.9	7.0	6.9
Total Solids	150	-	166	170	127	101	185	132	136	117	103	120
Iron (Fe)	T	-	0.03	0.03	0.03	0.01	0.02	0.02	0.02	0.02	0.01	0.01
Total Hardness[2]	103	-	90	57	47	47	64	77	93	69	72	93

Okanogan River near mouth, 1954-55 (University of Washington)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[3]	0	0	1	0	1	2	6	5	5	0	1	1
Flow x 1,000	-	-	1.3	-	1.7	12.9	7.8	2.6	2.1	-	1.7	1.9
Total Alk.	-	-	112	-	101	48	54	92	104	-	91	97
$CO_3^=$	-	-	0	-	0	0	0	1	2	-	0	0
$SO_4^=$	-	-	26	-	18	12	11	21	19	-	20	18
Color	-	-	10	-	10	35	23	10	6	-	4	2
Turb.	-	-	7	-	7	37	17	6	4	-	4	1
Ca + Mg	-	-	-	-	-	-	24.3	-	23.04	-	-	-
Na + K	-	-	-	-	-	-	7.1	-	5.2	-	-	-
Total Solids	-	-	143	-	175	135	115	135	135	-	115	130
Iron	-	-	-	-	-	-	0.07	-	0.3	-	-	-
Total Hardness	-	-	130	-	132	43	61	81	109	-	99	102

1 Each sample represents composite of 10 daily samples
2 Computed as p.p.m. $CaCO_3$ from Ca and Mg content
3 Each sample represents composite of 2 or more individual samples

Table 20.--Water quality comparison.

Wenatchee River at Cashmere, 1910-11 (U.S.G.S.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[1]	4	3	2	3	3	3	3	3	3	3	3	3
Flow x 1,000	1.22	1.43	4.6	7.4	13	7.3	4.6	1.7	.9	2.8	4.0	1.5
Total Alk.	24	42	27	35	16	13	16	21	26	18	15	21
Sulfate	5.4	9.8	5.2	9.0	8.1	7.3	8.6	6.2	5.8	6.9	7.5	8.1
Color	-	-	8	9	7	7	-	-	-	-	-	-
Turbidity	1	2	22	23	18	11	10	9	4	5	4	3
Ca + Mg	7.5	12.8	11.1	10.6	5.9	6.0	5.3	6.6	8.8	6.5	5.8	7.2
Na + K	3.6	7.7	4.8	6.6	4.2	3.1	4.1	3.3	4.3	3.4	3.1	3.2
Total Solids	45	77	93	87	60	46	36	43	46	36	37	41
Iron	0.01	0.17	0.04	0.07	0.01	T	0.02	0.01	0.01	0.03	0.01	T
Total Hardness[2]	22	40	34	32	18	18	16	23	26	19	18	22

Wenatchee River at Sleepy Hollow (5 miles below Cashmere)
1954-56 (University of Washington)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled[3]	1	1	2	1	2	3	8	8	6	4	4	2
Flow x 1,000	0.9	1.0	1.0	4.6	7.5	13.3	9.8	2.9	1.3	1.5	1.92	1.7
Total Alk.	39	39	48	40	43	17	14	19	29	28	24	27
Sulfate	2.5	4.6	2.4	4.6	3.1	0.7	2.3	1.7	2.4	3.6	1.9	1.2
Color	10	10	18	48	17	8	9	6	5	7	6	4
Turbidity	2	5	40	80	18	11	5	8	13	11	4	5
Ca + Mg	8	-	-	-	-	5.8	8.8	7.4	16	11.6	2.9	-
Na + K	2.6	-	-	-	-	3.0	5.0	2.9	2.8	2.4	3.6	-
Total Solids	84	86	50	-	115	53	34	49	46	45	44	40
Iron	0.01	-	-	-	-	0.20	0.01	0.02	0.05	0.03	0.00	-
Total Hardness	43	45	53	48	55	14	14	19	28	28	22	35

1 Each sample represents composite of 10 or more daily samples
2 Computed from Ca and Mg in p.p.m. $CaCO_3$
3 Each sample is average of 2 or more daily samples

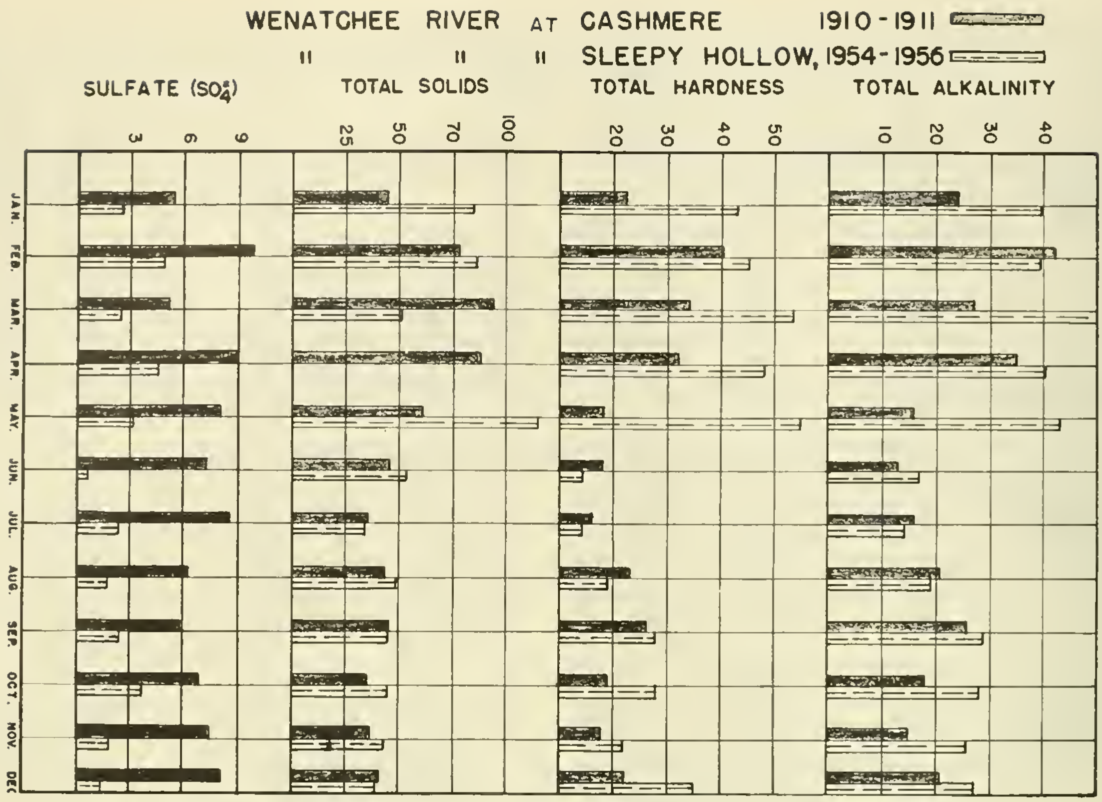

WENATCHEE RIVER AT CASHMERE 1910-1911
" " " SLEEPY HOLLOW, 1954-1956
SULFATE ($SO_4^=$)
TOTAL SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
3 6 9
25 50 70 100
20 30 40 50
10 20 30 40
JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV. DEC.

FIG. 52

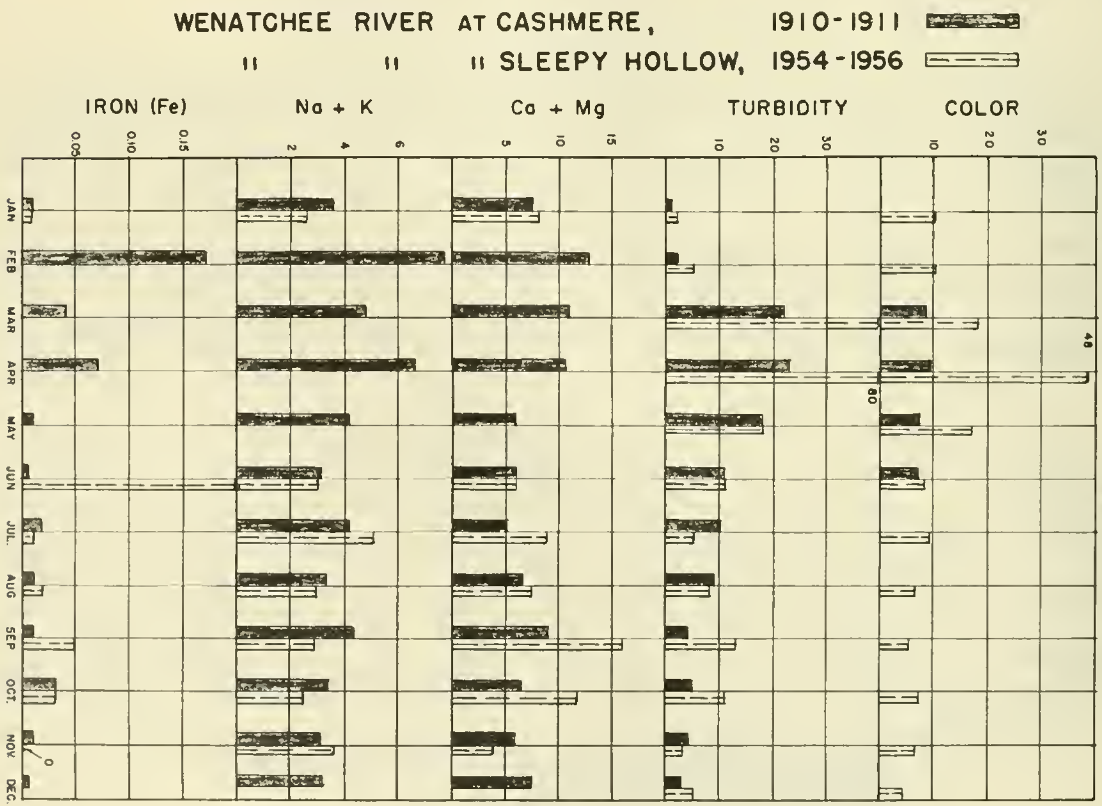

WENATCHEE RIVER AT CASHMERE, 1910-1911
" " " SLEEPY HOLLOW, 1954-1956
IRON (Fe)
Na + K
Ca + Mg
TURBIDITY
COLOR
0.05 0.10 0.15
2 4 6
5 10 15
10 20 30
10 20 30
48
60
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT. NOV. DEC.

FIG. 53

comparison. From 1910-1950, the population increased from 6,200 to 12,000 and the irrigated acreage from 19,000 to 26,000 acres. These small increases together with logging constitute the only changes in the watershed during this 40-year period. It is then to be anticipated that the water quality in 1910 would be about the same as in 1955. From table 24 of weighted averages and figures 52 and 53, a small increase in all constituents other than sulfates is noted. On a percentage basis, the increases were: Alkalinity - 24; hardness - 22; total solids - 16; calcium plus magnesium - 11; sodium plus potassium - 3; color - 60; turbidity - 21; and iron - 400. Sulfates decreased 71 percent. The increase in color may be due largely to fruit tree leaves and the replacement of coniferous trees with deciduous following logging. The increase in iron is to be questioned as the iron data for 1954-56 is meager. Irrigation developments were reaching their maximum around 1910 on the Wenatchee River. A rapid leeching of sulfate-bearing salts into the river at this time may account for the subsequent decrease in sulfates.

Yakima River at Cle Elum, Figures 54 and 55, Table 21:

The Yakima River at Cle Elum offers an interesting comparison in water quality with the passage of time. Watershed population has decreased slightly because of the decline in coal mining around Roslyn. Increased storage for irrigation in Lake Keechelus, Cle Elum and Kachess has largely taken place since 1910. Logging on the watershed has increased since 1910.

All water quality constituents have decreased slightly excepting for alkalinity, iron and nitrates. This decrease may be attributed to a reduction in coal-washing wastes and the 829,000 acre-feet of impoundment created since 1910. The percentage decrease was as follows: Hardness - 16; dissolved solids - 17; sulfate - 76; calcium plus magnesium - 13; sodium plus potassium - 19; chlorides - 27; and silica - 26. Alkalinity increased 4, iron 50 and nitrate 88 percent. The increase in nitrate is probably due to organic decomposition in the impoundments. An increase

Table 21.--Water quality comparison.
Yakima River at Cle Elum, 1910-11 (U.S.G.S.)
In P.P.M.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Time Sampled(1)	4	3	3	3	3	3	3	3	3	3	3	3
Flow x 1,000	0.9	1.1	3.0	5.7	5.3	2.5	1.1	1.0	0.5	1.4	4.2	1.6
Total Alk.(2)	25	30	18	22	25	26	26	31	33	24	20	22
Sulfate	6.7	8.5	8.3	6.6	5.6	5.4	4.5	4.3	6.9	6.1	4.0	8.5
Color	-	-	3	3	2	-	-	-	-	-	-	-
Dis'l. Solids	44	56	52	49	45	62	49	46	49	41	39	40
Na + K	3.1	-	3.3	3.9	4.4	4.3	5.0	4.6	3.3	3.9	2.6	2.7
Ca + Mg	10.1	8.8	9.1	8.0	8.0	8.0	8.0	10.2	11.0	8.2	7.7	8.8
Iron (Fe)	T	0.15	0.03	0.01	0.01	0.01	0.01	T	0.01	0.01	0.02	T
Total Hardness(3)	29	26	28	26	23	23	23	30	33	24	22	25
Silica	8.3	14	12	11	11	14	10	7.9	10	7.7	7.7	7.4
Chlorides (Cl^-)	1.5	0.5	1.0	1.5	1.6	2.4	2.6	1.4	1.5	2.5	1.4	1.0
Nitrate (NO_3^-)	0.4	0.03	0.28	0.1	T	T	T	T	0.1	0.63	1.5	T

Yakima River at Cle Elum, 1952-53 (U.S.G.S.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled(1)	3	1	3	3	3	3	3	3	3	-	-	-
Flow x 1,000	0.61	1.07	0.58	1.31	0.71	2.87	2.60	2.76	1.96	0.82	0.11	0.13
Total Alk.(2)	30	30	31	26	30	25	25	23	23	-	-	-
Total Hardness(3)	30	24	29	24	28	23	25	27	25	-	-	-
Dis'l. Solids	46	40	47	38	45	35	33	33	33	-	-	-
Ca + Mg	10.1	8.4	10.0	8.5	9.5	8.1	8.3	9.0	8.3	-	-	-
Na + K	3.4	3.0	3.1	3.3	3.2	3.2	1.9	1.5	1.7	-	-	-
Sulfate	2.0	2.0	2.5	1.8	1.9	3.2	2.2	1.9	2.0	-	-	-
Iron (Fe)	0.04	0.04	0.02	0.02	0.03	0.04	0.03	0.03	0.02	-	-	-
Silica	9.8	9.9	9.2	8.5	10.7	7.6	7.0	7.0	6.9	-	-	-
Chlorides (Cl^-)	1.3	1.2	1.2	1.0	1.1	1.0	1.1	1.7	1.0	-	-	-
Nitrate (NO_3^-)	0.6	0.7	0.5	0.4	0.4	0.4	0.4	0.6	0.6	-	-	-
Color	5	4	5	7	8	5	6	9	7	-	-	-

(1) Each sample represents composite of 10 or more daily samples.
(2) As p.p.m. $CaCO_3$.
(3) Computed from Ca + Mg as $CaCO_3$.

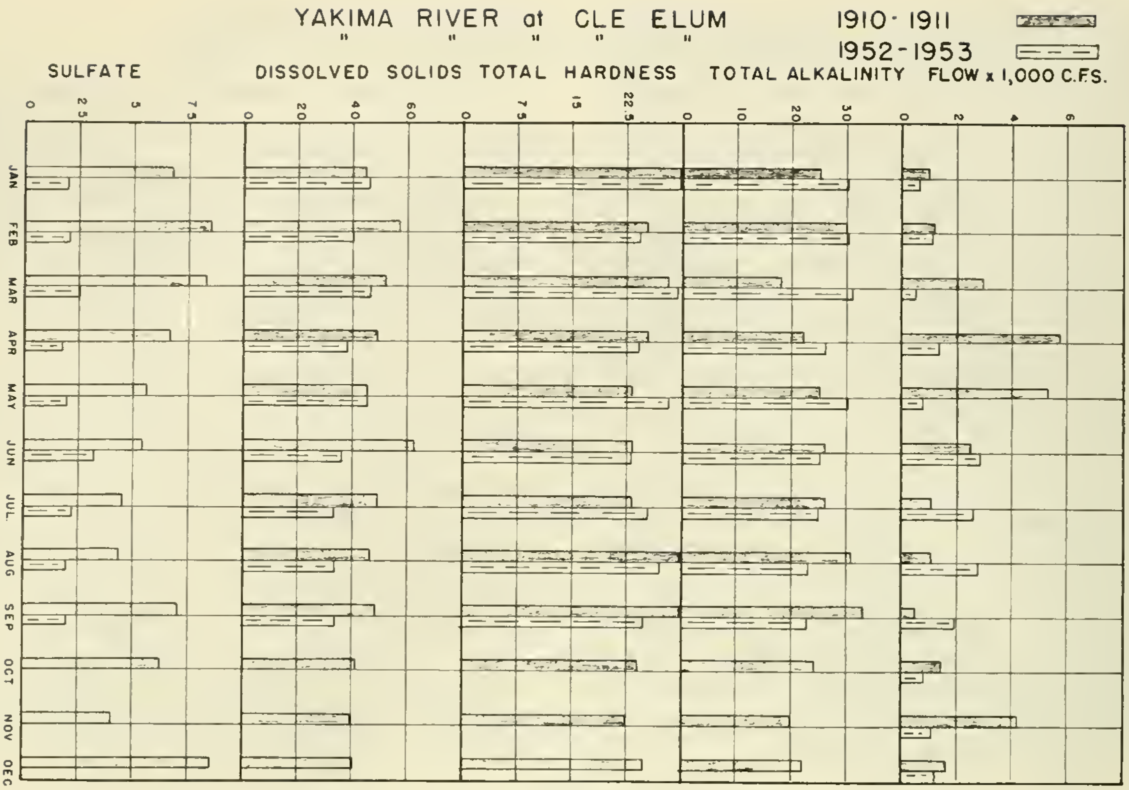

YAKIMA RIVER at CLE ELUM 1910-1911
1952-1953
SULFATE
DISSOLVED SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
FLOW x 1,000 C.F.S.
JAN
FEB
MAR
APR
MAY
JUN
JUL.
AUG
SEP
OCT
NOV
DEC

FIG. 54

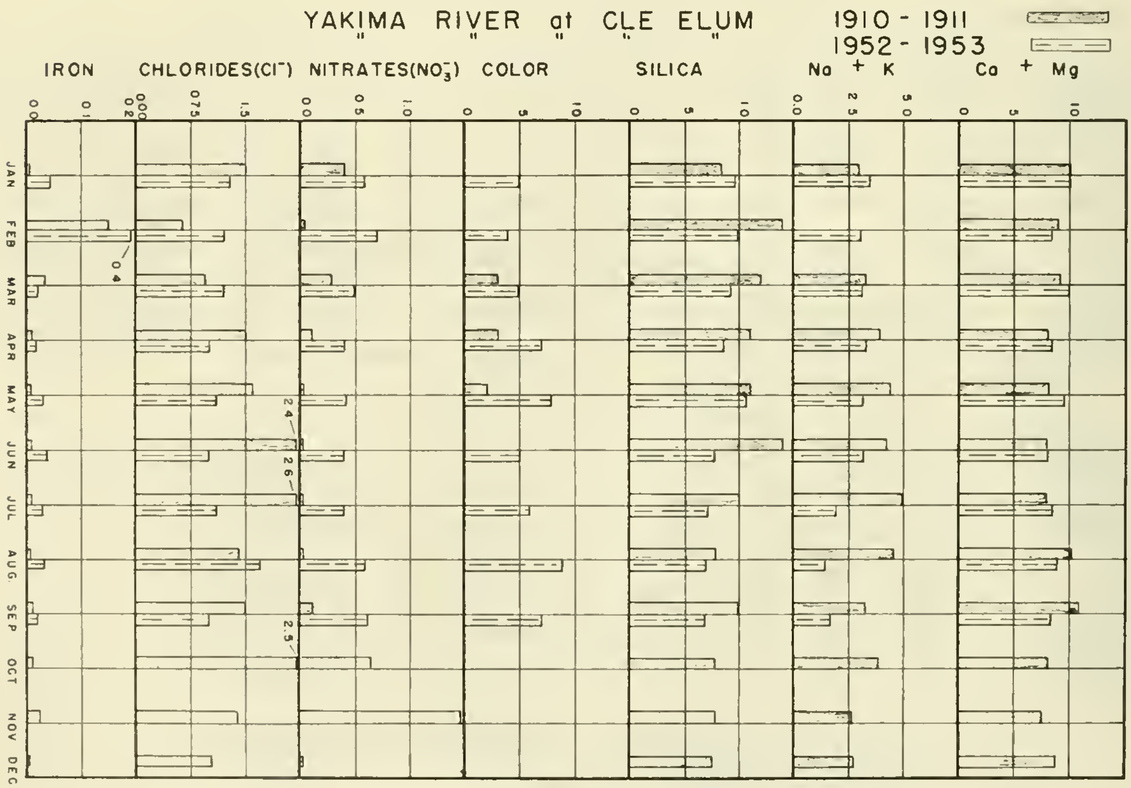

YAKIMA RIVER at CLE ELUM 1910 - 1911
1952 - 1953
IRON
CHLORIDES(Cl⁻)
NITRATES(NO₃⁻)
COLOR
SILICA
Na + K
Ca + Mg
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG.
SEP
OCT
NOV
DEC

FIG. 55

in iron may be the result of anaerobic decomposition at the resrrvoir bottom with the resulting increase in iron solutibility

Yakima River at Prosser and Kiona, Figures 56 and 57, Table 22:

The U. S. Geological Survey water quality samples collected in 1910-11 were taken from the Yakima River at Prosser while those collected in 1953-54 were at Kiona, 16 miles downstream from Prosser. There are no tributaries of any significance between these stations. During the irrigation season, return flows from the Roza project enter the river between these stations.

Between 1910 and 1950, the watershed population increased by 124 percent, the irrigated acreage by 131 percent and an industrial waste population equivalent of 138,000 persons was added to the river. River flow was regulated for irrigation purposes by the construction of the Keechelus, Kachess, Cle Elum, Bumping, and Tieton Reservoirs, impounding a total of 1,064,000 acre-feet.

On comparing the 1910 and 1954 quality data, it will be observed that all constituents have increased during the 43 year period excepting for sulfate, color and iron which have decreased. The largest increases occurred in the late summer and autumn when irrigation return flows were greatest. Nitrates and alkalinity showed an increase for all months.

Comparing quality values in the two time periods and using weighted averages to compensate for the heavier flow in 1910-11, the percentage increase in the constituent was as follows: Alkalinity - 55; hardness - 34; silica - 28; dissolved solids - 27; calcium plus magnesium - 38; sodium plus potassium - 48; chlorides - 52; and nitrate - 640. Sulfate decreased 23 percent and iron 700 percent. The effect of irrigation on water quality is discussed in a subsequent chapter of this report.

Deschutes River at Moody, Figures 58 and 59, Table 23:

The Deschutes River has been controlled for power and irrigation development by

Table 22.--Water quality comparison.

Yakima River at Prosser, 1910-11 (U.S.G.S.)

In P.P.M.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled(1)	4	3	3	3	3	3	3	3	3	3	3	3
Flow x 1,000	2.45	3.7	14.5	12.0	11.5	5.4	1.1	.38	.43	1.6	7.1	3.9
Total Alk.(2)	62	68	56	50	44	45	-	110	110	87	45	51
Sulfate	18	20	12	8.5	10	12	-	43	53	31	16	18
Color	8	-	-	35	18	62	-	-	8	11	40	7
Dis'l. Solids	113	140	100	83	75	90	149	208	245	168	128	101
Na + K	11	17	10.5	8.2	7.3	7.3	-	30	30	19	8.3	11
Ca + Mg	22	22	17	16.5	15.3	14.5	-	40	41	31	18	18
Iron (Fe)	T	0.30	0.26	0.09	0.15	0.17	-	T	0.02	0.02	0.04	0.02
Silica	15	34	26	16	12	13	-	20	23	19	12	17
Chlorides (Cl^-)	4.9	5.1	1.7	1.8	1.3	1.9	-	12	14	8.3	4.5	4.4
Nitrate (NO_3^-)	T	0.52	0.07	0.13	0.33	0.05	-	0.6	0.17	1.7	0.3	0.17
Total Hardness(3)	63	66	51	50	44	41	-	118	122	89	54	54

Yakima River at Kiona[4], 1953-54 (U.S.G.S.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled(1)	3	2	3	3	3	3	3	3	1	3	3	2
Flow x 1,000	4.42	5.00	4.84	4.87	6.87	6.92	5.49	2.27	2.51	2.28	2.16	3.54
Total Alk.(2)	68	73	75	71	70	69	78	129	135	142	133	93
Sulfate	8.7	9.9	8.5	7.5	8.6	7.9	9.7	17	18	20	19	13
Color	4	3	3	0	4	3	5	0	0	4	4	4
Dis'l. Solids	108	121	127	114	111	107	133	200	211	185	201	142
Ca + Mg	19.9	21.1	22.2	20.6	20.8	20.6	22.7	36.7	38.6	41.5	38.7	27.8
Na + K	12.3	13.7	12.6	12.0	11.7	11.6	13.6	23.9	25.1	25.8	24.7	17.4
Total Hardness(3)	59	64	67	60	60	58	66	107	113	121	114	81
Iron (Fe)	0.00	0.02	0.02	0.01	0.03	0.00	0.00	0.00	0.00	0.05	0.16	0.00
Silica	19	21	24	18	23	23	23	31	35	30	32	24
Chlorides (Cl^-)	3.7	4.0	3.8	3.5	3.8	3.3	3.5	6.2	6.4	6.3	7.9	4.7
Nitrate (NO_3^-)	1.7	2.3	1.7	1.3	1.5	1.4	1.6	1.6	1.9	2.0	2.9	2.7

(1) Each sample represents composite of 10 or more daily samples.
(2) As p.p.m. $CaCO_3$.
(3) Computed from Ca + Mg as $CaCO_3$.
(4) 16 miles downstream from Prosser.

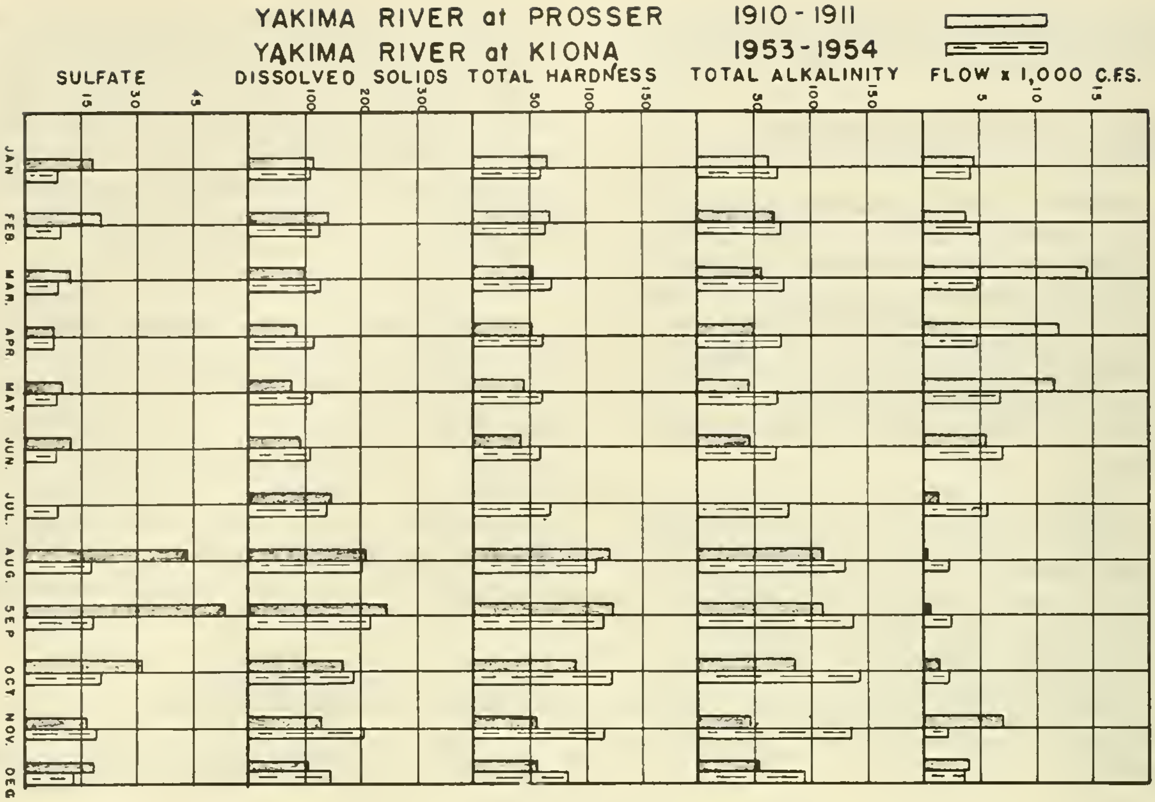

YAKIMA RIVER at PROSSER 1910-1911
YAKIMA RIVER at KIONA 1953-1954
SULFATE
DISSOLVED SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
FLOW x 1,000 C.F.S.
JAN
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP
OCT
NOV.
DEC

FIG. 56

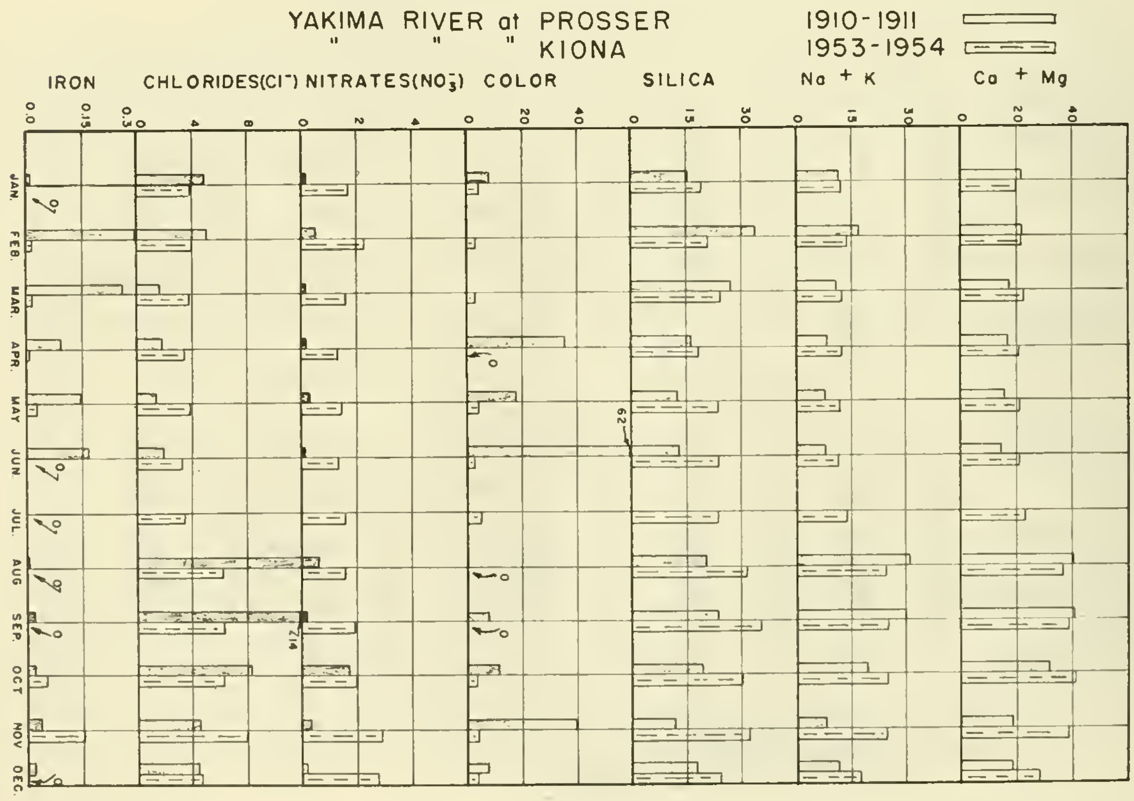

YAKIMA RIVER at PROSSER 1910-1911
" " " KIONA 1953-1954
IRON
CHLORIDES(Cl⁻)
NITRATES(NO₃⁻)
COLOR
SILICA
Na + K
Ca + Mg
JAN.
FEB.
MAR.
APR.
MAY
JUN
JUL.
AUG
SEP.
OCT
NOV
DEC.

FIG. 57

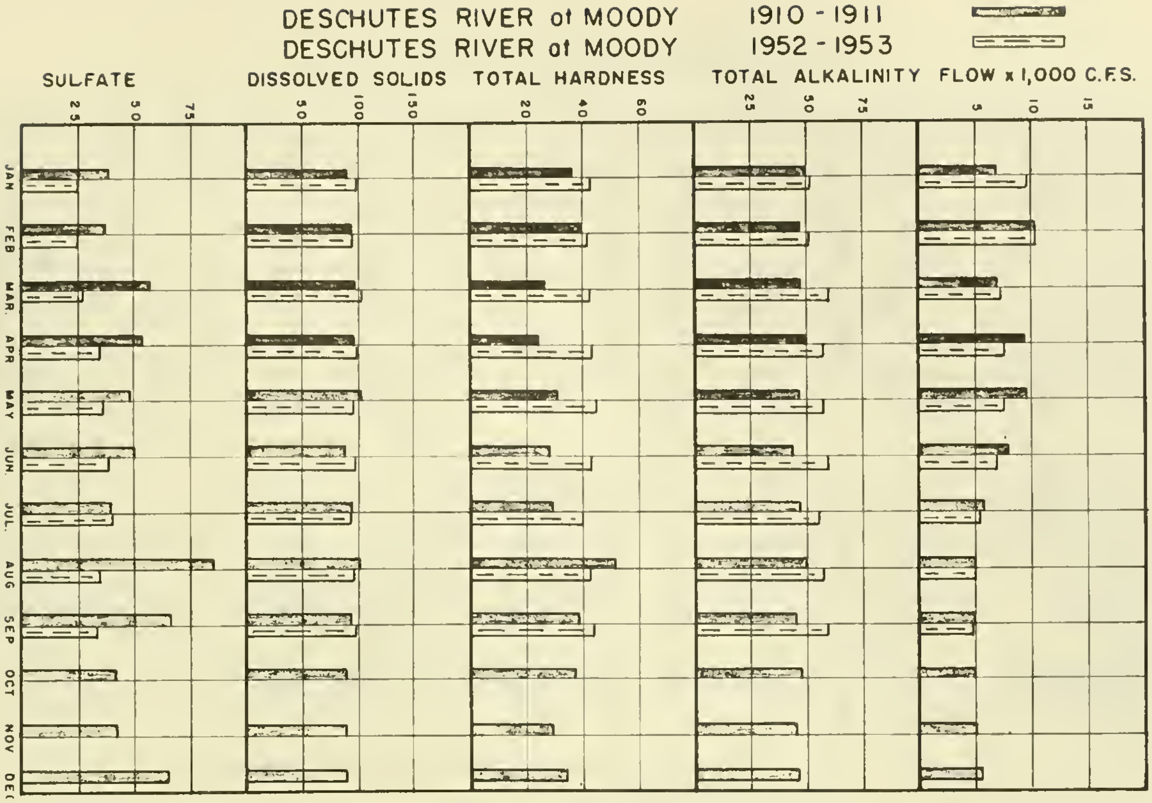

DESCHUTES RIVER at MOODY 1910 - 1911
DESCHUTES RIVER at MOODY 1952 - 1953
SULFATE
DISSOLVED SOLIDS
TOTAL HARDNESS
TOTAL ALKALINITY
FLOW x 1,000 C.F.S.
25 50 75
50 100 150
20 40 60
25 50 75
5 10 15
JAN
FEB
MAR.
APR
MAY
JUN.
JUL.
AUG
SEP
OCT
NOV
DEC

FIG. 58

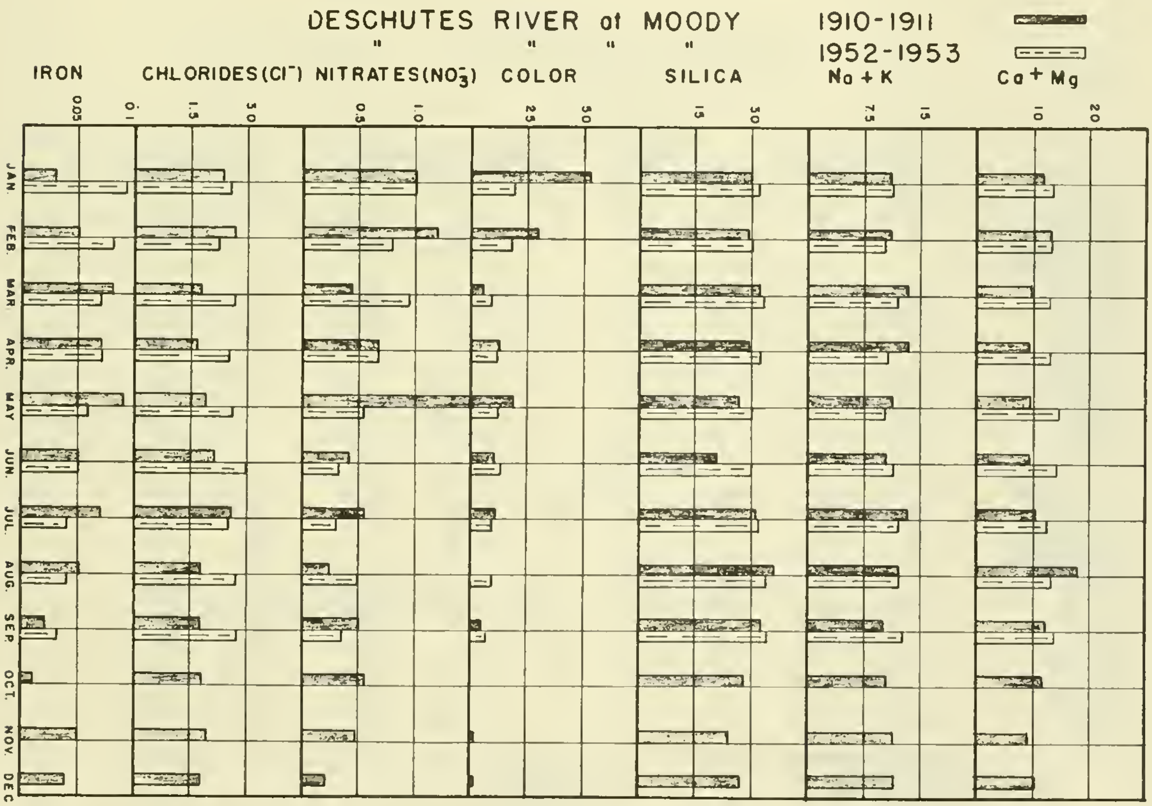

DESCHUTES RIVER at MOODY 1910-1911
" " " " 1952-1953
IRON
CHLORIDES(Cl⁻)
NITRATES(NO₃⁻)
COLOR
SILICA
Na + K
Ca + Mg
0.05 0.1
1.5 3.0
0.5 1.0
25 50
15 30
7.5 15
10 20
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC

FIG. 59

Table 23.--Water quality comparison.

Deschutes River near Moody, 1910-11 (U.S.G.S.)

In P.P.M.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled(1)	3	3	3	3	3	4	2	1	3	3	3	3
Flow x 1,000	7.0	10.2	6.9	9.4	9.6	8.0	5.8	4.8	5.0	5.0	5.1	5.4
Total Alk.(2)	48	47	46	48	46	43	47	49	45	47	45	46
Sulfate	3.9	3.6	5.8	5.3	4.8	5.0	3.9	8.4	6.6	4.2	4.2	6.4
Color	52	30	5	12	18	10	10	-	4	0	2	2
Dis'l. Solids	90	92	96	95	101	87	94	100	91	88	88.3	88.3
Na + K	10.9	10.1	13.3	13.6	11.2	10.6	13.5	12.0	10.3	10.6	11.3	11.6
Ca + Mg	11.8	13.1	9.9	9.3	9.2	9.7	10.5	18.0	12.5	12.0	9.4	10.9
Iron (Fe)	0.03	0.05	0.08	0.07	0.09	0.05	0.07	0.05	0.02	0.01	0.05	0.04
Total Hardness(3)	36	39	26	24	31	28	29	51	38	37	29	33
Silica	29	28	32	29	26	21	31	36	32	28	24	27
Chlorides (Cl^-)	2.3	2.7	1.8	1.6	2.0	2.2	2.6	1.8	1.8	1.9	2.0	1.8
Nitrate (NO_3^-)	1.0	1.2	0.44	0.67	1.5	0.41	0.54	0.24	0.5	0.57	0.47	0.22

Deschutes River near Moody, 1952-53 (U.S.G.S.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Times Sampled(1)	3	2	3	3	3	3	3	3	3	-	-	-
Flow x 1,000	9.7	10.1	7.1	7.5	7.5	6.9	5.3	5.0	4.8	-	-	-
Total Alk.(2)	52	51	59	57	57	59	55	57	59	-	-	-
Total Hardness	42	41	42	43	44	43	40	42	44	-	-	-
Ca + Mg	13.4	13.0	13.6	13.	14.4	14.4	12.6	13.4	14.0	-	-	-
Na + K	11.2	10.2	12.0	10.8	10.6	11.4	12.0	12.2	12.8	-	-	-
Sulfate	2.5	2.4	2.7	3.6	3.6	3.8	4.0	3.5	3.3	-	-	-
Iron (Fe)	0.11	0.08	0.07	0.07	0.06	0.05	0.04	0.04	0.03	-	-	-
Silica	32	30	33	32	30	30	32	34	34	-	-	-
Chlorides (Cl^-)	2.6	2.2	2.7	2.5	2.6	3.0	2.5	2.7	2.8	-	-	-
Nitrate (NO_3^-)	1.00	0.80	0.97	0.67	0.53	0.33	0.30	0.50	0.37	-	-	-
Dis'l. Solids	98	94	101	97	96	98	93	95	97	-	-	-
Color	19	18	9	11	12	13	10	9	7	-	-	-

(1) Each sample represents composite of 10 or more daily samples
(2) As p.p.m. $CaCO_3$.
(3) Computed from Ca and Mg as $CaCO_3$.

Table 24.--Water quality comparisons.

Yearly weighted averages[1] of tables.

In P.P.M.

1910-1911-1912 Data

Station	Columbia River Northport[2]	Columbia River Maryhill	Pasco[9]	Okanogan River[9]	Wenatchee River	Yakima River Cle Elum	Yakima River Prosser	Snake River[6]	Deschutes River[3]
Flow x 1,000	106[4]	183	123[4]	2.9[4]	4.22	2.37	5.70	68	7.4
Total Alk.	59	48	57	56	21	23	53	55	47
Total Hard.	64	55	62	58	23	25	53	56	33
Diss. Solids	83	88	-	-	-	47	102	108	94
Total Solids	-	-	87	125	50	-	-	-	-
Sulfate	10.9	10	9.8	10.3	7.7	5.9	13	17	5.0
Ca + Mg	22.7	19.9	22.6	21.0	6.2	8.4	17.7	19.5	11.2
Na + K	4.6	7.9	6.1	7.6	3.5	3.7	9.9	10.8	11.8
Color	-	11	-	-	8	-	-	33	18
Turbidity	-	-	-	-	14	-	-	-	-
Iron	0.02	0.10	0.01	0.02	0.02	0.02	0.14	0.07	0.06
Chlorides	0.4	2.5	-	-	-	1.5	2.7	5.1	2.1
Nitrate	0.25	0.39	-	-	-	0.32	0.23	0.26	0.79
Silica	8.6	13	-	-	-	10.4	18	19	29

1952-1956 Data

Station	Columbia River Northport	Columbia River Maryhill	Pasco	Okanogan River	Wenatchee River	Yakima River Cle Elum	Yakima River Prosser	Snake River	Deschutes River
	(2)					(8)	(7)	(5)	(3)
Flow x 1,000	101.9	179.3	140	3.8	3.96	1.94	4.27	52.1	7.0
Total Alk.	62	73	62	67	26	24	82	88	56
Total Hard.	73	77	69	69	28	21	71	95	42
Diss. Solids	88	116	-	-	-	39	129	166	96
Total Solids	-	-	110	131	58	-	-	-	-
Sulfate	13	17	10.6	14.6	2.2	1.4	10	28	3.2
Ca + Mg	25.9	26.9	20.0	24.0	6.9	7.3	24.4	33	13.6
Na + K	2.7	10.9	2.7	6.7	3.6	3.0	14.6	20.4	11.3
Color	-	16	-	-	13	-	-	15	12
Turbidity	-	-	-	-	17	-	-	-	-
Iron	0.02	0.05	0.16	0.12	0.1	0.03	0.02	0.09	0.06
Chlorides	0.9	3.8	-	-	-	1.1	4.1	9.3	2.6
Nitrate	0.8	0.7	-	-	-	0.6	1.7	1.2	0.7
Silica	6.9	10	-	-	-	7.7	23	23	31

1 Weighted according to flow.
2 Less October
3 Less Oct.,Nov.,Dec.
4 Estimated
5 At Clarkston
6 At Burbank less Feb.
7 At Kiona
8 1953-54
9 Data approximate and used only for future predictions.

Table 25.--Approximate Changes in Upstream Watershed Population, Industry and Irrigated Area, 1910 to 1950; x 10^3

	Columbia River Northport	Pasco	Maryhill	Yakima River Cle Elum	Kiona	Wenatchee River	Okanogan River	Deschutes River	Snake River
Upstream				1910					
Population	240	486	936	5.3	63	6.2	27	20	336
Industry P. E.	-	-	-	-	-	-	-	-	-
Irrigated Acres	280	547	2273	-	184	19	20	61	1573
				1950					
Population	351	931	1716	3.4	141	12	89	44	596
Industry P. E.	513	823	1813	0*	138	0	15	0	768
Irrigated Acres	370	923	4010	-	424	26	57	118	2826
				Increase in Period					
Population	111	445	780-	1.9	78	6	62	24	260
Industry P. E.	513	823	1813	0	138	0	15	0	768
Irrigated Acres	90	376	1737	-	240	7	37	57	1253

Industry Population Equivalents are estimated.

Table 26.-- Change in River Constituents, ±, 1000 Tons per year, 1910-1955.

	Columbia River Northport	Maryhill	Yakima River Cle Elum	Kiona	Wenatchee River	Snake River	Deschutes River
Alkalinity	306	4450	2.1	143	20	1940	64
Hardness	921	3930	-8.4	89	20	2300	64
Diss. Solids	512	5000	-16.9	133	32	3420	14
Sulfate	215	1250	- 9.5	- 15	- 22	650	- 13
Ca + Mg	328	1250	- 2.3	33	2.8	800	17
Na + K	-194	536	- 1.4	23	0.4	570	- 3.5
Iron	0	- 9	0.02	- 0.6	0.8	1.2	0
Chlorides	51	232	- 0.8	6.9	-	248	3.5
Nitrate	57	55	0.6	7.3	-	55	- 0.6
Silica	-174	-535	- 5.7	25	-	24	14

Computed from yearly weighted average values using average flow for the two time periods.

the impoundment of 377,000 acre-feet in 4 reservoirs built after 1910. Between 1910 and 1950, the population in the Deschutes River watershed increased by 120 percent, the irrigated acreage by 94 percent and there was no significant industrial waste contribution. All water quality constituents increased during this time with the exception of sulfates, sodium plus potassium and nitrates. There was no change in the iron content. October, November and December data were not collected in 1952-53. If these data had been collected, it is possible that all constituents with the exception of sulfate would have shown an increase. Percentage increases were as follows: Alkalinity - 19; hardness - 27; dissolved solids - 2; calcium plus magnesium - 21; silica - 7; and chlorides - 24. Sodium plus potassium had a 4 percent decrease, nitrate 11 percent and sulfate 36 percent.

Nitrates and sodium plus potassium should have increased during the 43 year period in a river basin like the Deschutes. The only explanation that can be advanced for their decrease is that the comparison period did not extend over a full water year.

<u>Summary</u>:

A comparison of the water quality data in 1910-11 with that in 1952-56 gives a general rise in all constituents. The increase in all watersheds is not the same because of a difference in waste discharge, water impoundment, irrigated acreage or because the soil composition differs. The decrease in some values is not consistent and not easily explained in most instances. Irrigation return flows have caused the greatest increase in water quality values. These return flows can normally be expected to show an increase in all constituents over that in the water first applied to the land. Domestic sewage and industrial waste discharges will increase all constituents (unless the water supply is of much higher quality than that in the adjacent stream), particularly so in the case of nitrates and chlorides. Water impoundments will tend to even out water quality changes, increasing the values during periods of high flow and reducing them during periods of low flow.

The decrease in constituents may be caused by one of the following reasons in cases where there has been no reduction in watershed pollutants:

1. Precipitation of iron, silica, sulfates, etc. in reservoirs or irrigated lands constructed since 1910.

2. Rapid leeching of constituents in the new irrigation developments occurring around 1910. Proportionately speaking, very little acreage was placed under irrigation just prior to the 1952-56 period of data collection. The large scale Columbia Basin development is contributing little return flow as the ground water table has not risen sufficiently.

3. Uptake of silica by diatoms living in the new reservoir impoundments. These diatoms are either carried downstream or settle to the reservoir bottom where they are covered by silt.

4. Analytical technique differences.

5. Incomplete yearly data for comparison.

6. Increased river flow between 1910 and 1950.

Alkalinity increased at all locations under comparison with the largest percentage increase being on the Columbia River at Maryhill, the Yakima River at Kiona and in the Snake River. Hardness increased at all locations excepting for the Yakima River at Cle Elum. The greatest percentage increase in hardness was in the Snake River, the Columbia River at Maryhill, and the Yakima River at Kiona. Dissolved solids, calcium plus magnesium, chlorides and nitrates increased at all but one station with the greatest increases occurring at the same station as above.

In no case did the water quality constituent increase to the point that the water was nearing the upper limit for acceptability as a source of public or industrial water supply, source of irrigation water or for the propagation of fish life. A subsequent chapter in this report discusses the probable changes in water quality that may occur with future river basin development.

YAKIMA RIVER IRRIGATION AND POLLUTIONAL EFFECTS

The Yakima River is the most highly developed and most highly utilized water source in the Columbia River Basin. Its waters irrigate 425,000 acres and receive the treated waste discharges from some 76,000 persons and from industries (mostly late summer food processing) having an oxygen demand population equivalent of 138,000 persons. Table 27 lists the principal irrigation projects (see map of area) and diverted irrigation water for the irrigation year of 1954. The average diverted water per acre was 4.48 acre-feet for the season. If this quantity of water were applied uniformly to the 425,000 acres irrigated in the valley, an average total river flow of 5,820 c.f.s. would be required to supply this diversion.

In the peak irrigation months of July and August, an average of 0.921 acre-feet per acre per month of water was applied to the land which would require a total river flow of 6,580 c.f.s. Considering July and August of 1954 to be average irrigation months and with a total average Yakima River available flow of 5,100 c.f.s. in July and August, it is apparent that the water diverted for irrigation exceeds the river flow by about 1,400 c.f.s. This extra water used comes from irrigation return flows upstream from the point of diversion. Thus, the entire river flow is utilized for irrigation with some of the water being passed over the land more than once.

During the late summer, there are times when nearly the entire river flow is diverted near Parker (between Wapato

FIG. 60

Table 27.--Yakima River Basin irrigation[1]

Month in 1954	Kittitas 54,500 acres		Tieton 24,500 acres		Roza 65,000 acres		Sunnyside 81,000 acres		Reservation 132,000 acres	
	Avg. Diver. c.f.s.	Acre Ft/ac. applied	Avg. Diver. c.f.s.	Acre Ft./ac. applied	Avg. Diver. c.f.s.	Acre Ft/ac. applied	Avg. Diver. c.f.s.	Acre Ft/ac. applied	Avg. Diver. c.f.s.	Acre Ft/ac. applied
April[2]	471	0.171	60	0.122	612	0.469	1080	0.665	1490	0.558
May	813	0.89	272	0.663	917	0.839	1252	0.919	2071	0.934
June	790	0.865	329	0.800	910	0.832	1258	0.920	1984	0.893
July	989	1.08	339	0.823	1003	0.920	1243	0.912	1940	0.874
August	1091	1.19	346	0.841	931	0.852	1265	0.925	1769	0.797
September[2]	758	0.608	318	0.562	686	0.462	1076	0.578	1393	0.458
Total		4.804		3.811		4.374		4.919		4.514

Avg. diverted water per acre, 1954 = 4.484 acre-feet.

[1]U. S. B. R. Yakima, data. Data for small canals not listed.

[2]Partial months.

In 1954, total irrigated area, Yakima Project, was 425,000 acres. If 4.484 acre-feet was applied to this acreage, it would require a total diversion = 5,820 c.f.s. for a period of 5-1/2 months (irrigation season).

Table 28.--Irrigation Return Flows, Yakima River, Between Parker and Kiona, with Monthly Precipitation Averages for the Years of 1949 through 1953.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
				Yakima River Near Parker - C.F.S.								
	1532	2558	3407	2708	3840	3701	3659	3609	4674	1109	453	476
				Yakima River at Kiona - C.F.S.								
	3020	3485	4385	4159	5186	5222	5481	6568	6945	2610	1867	2018
1	2878	3244	3986	3671	4610	4444	"	"	"	"	"	"
				Kiona Flow Minus Parker Flow[2]								
	1346	686	579	963	770	743	1822	2959	2271	1501	1414	1542
				Precipitation at Prosser - Inches								
	0.83	1.11	0.96	1.23	0.78	0.64	0.41	0.53	1.15	0.04	0.27	0.26

Yakima River at Parker; Drainage Area = 3650 sq. mi.
" " " Kiona ; " " = 5600 " "

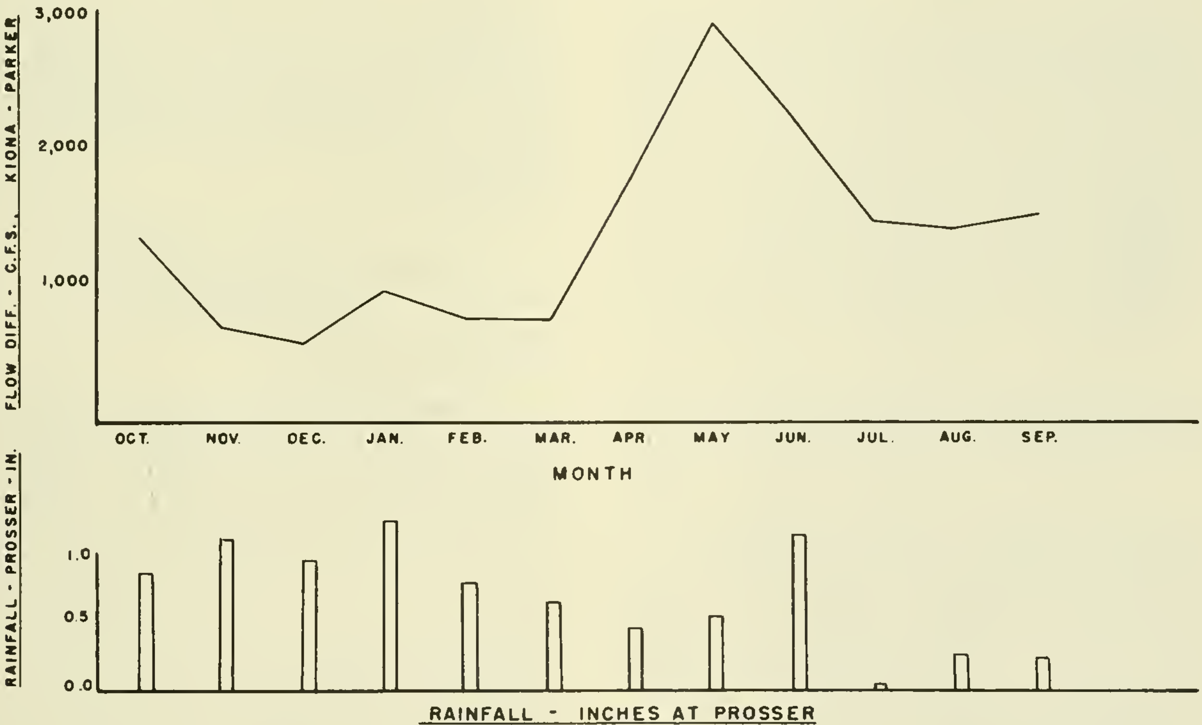
1 Tributary flow from Toppenish and Satus Creeks subtracted.
2 Largely irrigation return flows.

and Union Gap) yet at Kiona, about 70 miles downstream, the river flow (with no natural tributaries at this time of year) will be around 2,000 c.f.s. This 2,000 c.f.s. is made up almost entirely of irrigation return flows. These return flows continue into the river bed from ground water depletion after the irrigation season has ended in September. Table 28 lists the 1949-53 average river flows at Parker and Kiona together with their difference and the average monthly precipitation at Prosser. Since this is an arid area (average yearly precipitation at Prosser is 7.54 inches), the difference in flow between Parker and Kiona is made up largely of irrigation return flows.

Figure 61 is a plot of these flow differences and the average monthly precipitation. Irrigation return flows continue through March and increase abruptly with the commencement of the irrigation season in April. Maximum return flows are in May when irrigation diversions are high, air temperatures relatively low and consumptive use is low. Return flows drop to around 1,500 c.f.s. in July and August when air temperatures are high and consumptive use is greatest.

From the table of water quality comparisons in 1953-54 for the Yakima River at Kiona (table 22), it will be noted that the time of highest water quality (lowest mineral constituents) is in April, about the time when irrigation commences. The average monthly flow at Kiona in April is about the same as for the preceding months of January, February and March and is less than that in the succeeding months of May, June and July. (Water quality constituents are usually inversely proportional to the flow.) If it would be assumed that the water quality constituents in April are representative of those that would be present in the absence of large return flows and summertime food processing, a comparison can be made between these April values and the high constituent values in September.

Table 29 shows the comparison of the April and September 1953-54 constituent



YAKIMA RIVER PARKER TO KIONA

IRRIGATION RETURN FLOWS AND PRECIPITATION

FIG. 61

Table 29.--Comparision of water quality, Yakima River, Prosser to Kiona[1]

Constituent	April 1953-54	September 1953-54 unadjusted	September 1953-54 adjusted to April flow	September 1910-11 unadjusted	September 1910-11 adjusted to Sept. 54 flow	Constituent increase 1910-1954
Flow x 10^3	4.87	2.51	-	0.43	-	-
Total alkalinity	71	135	70	110	19	116
Total hardness	60	113	58	122	21	92
Sulfate	7.5	18	9.3	53	9	9
Dissolved solids	114	211	109	245	42	169
Ca + Mg	20.6	38.6	19.9	41	7.0	31.6
Na + K	12.0	25.1	12.9	30	5.1	20
Silica	18	35	18	23	4	31
Chlorides	3.5	6.4	3.3	14	2.4	4.0
Nitrate	1.3	1.9	1.0	0.17	0.03	1.87

[1] Adjusted values consider dilution effect from difference in flows.

values unadjusted and adjusted for the differences in flow in April and September. When the September values are adjusted by a dilution factor of 1.94 for the difference in flows, it will be noted that the water quality (or total content of impurities) is about the same in April and in September. From observing the flows and quality values in the other months, it is evidence that the quantity of impurities discharged by the Yakima River to the Columbia River is about the same each month of the year, regardless of other factors.

If the 1910-11 water quality data for the Yakima River at Prosser in September are adjusted for the differences in flow between 1910-11 and 1953-54, a comparison can be made of the change in water quality due to an increased irrigated acreage of 240,000 acres and an added total population equivalent of 216,000 persons. Table 29 shows this comparison in the last column. From an actual weight basis then, the irrigation of an additional 240,000 acres and the addition of a population equivalent of 216,000 persons between 1910 and 1950 has resulted in the following percentage increases in constituents: Alkalinity - 610; hardness - 435; sulfate - 100; dissolved solids - 400; calcium plus magnesium - 450; sodium plus potassium - 390; silica - 775; chlorides - 166; and nitrates - 6,250 percent. These are very large increases and are representative only of a change in the maximum yearly constituent values in September for the years compared.

DOMESTIC SEWAGE AND INDUSTRIAL WASTE DISCHARGE

Present conditions:

The Columbia River Basin has been growing in population at a rate comparable to the entire Pacific Northwest. Table 30 shows that, in 1950, the Columbia River Basin population (which includes portions of seven states and a portion of British Columbia) was about three and one-quarter million persons of which close to one and one-half million lived in cities having a population in excess of 1,000 persons and where their domestic sewage was discharged, treated or untreated, to the Columbia River system. Table 32 lists by number the significant industries as of about 1950 that discharge waste waters to the Columbia River system. These are industries whose waste waters have a potential damaging effect to the water quality. Listed are 406 food industries (canneries with processing plants, breweries and meat products), 19 pulp or pulp and paper mills, 25 lumber products (waste wood, glue, etc.), 7 primary metal (chemical wastes from processing), 84 chemical and mining (ore processing and recovery), 17 textile (wood and flax), 5 fabricated metal (metal treating wastes), 6 petroleum and coal processing (chemical and organic wastes), and 25 miscellaneous industries such as rendering works and ammonia plants. Table 34 shows these industries with organic wastes to have an estimated population equivalent (based on the biochemical oxygen demand) of over 9 million persons or over 6 times that of the sewered population. Altogether, there is at present an oxygen demand on the river system comparable to domestic sewage discharged from about 11 million persons. From the industrial waste standpoint, the pulp and paper mills are by far the most significant contributors.

An analysis of water quality data shows that these pollutants have had no serious overall effect on the water quality of the Columbia River itself. Pulp mill discharges have produced heavy Sphaerotilus sp., (a filamentous bacteria, producing masses of slimy floc-like material) growths below Camas that clog the nets of fishermen. This study did not include localized effects on water quality in the immediate vicinity of waste discharges. A few of the Columbia River tributaries have dissolved oxygen deficiencies. This is in the late summer when stream flows are low, water temperatures are high, biological life is flourishing and when organic pollutants are near maximum. The most significant of these observed was the Willamette River in the vicinity of Portland where dissolved oxygen concentrations of less than 3 p.p.m. were observed in late August. No other serious dissolved oxygen deficiencies were observed in any of the streams.

Future conditions:

The prediction of future changes in the Columbia River Basin is, of course, subject to many variables and to a very wide interpretation of the effects of these variables. General assumptionsmade in predicting these future conditions are as follows:

1. That the major multipurpose water developments on the river system will have been well consumated by the year 2000.

2. That the basin population will continue to grow in proportion to the remainder of the Pacific Northwest.

3. That the industrial development of the basin will continue with more rigid controls on waste discharges than in the past and that many industries presently discharging strong wastes will have these waste strengths and volumes greatly reduced.

4. That no dams will be built on the Columbia River below Bonneville Dam.

5. That the principal areas of industrial concentration will be in the Portland-Vancouver-Longview and Pasco-Richland-Kennewick vicinities with a somewhat lower concentration in the Wenatchee and Canadian portions of the Columbia River. The principal tributaries with industrial developments join the Columbia River in these areas. They are the Willamette, Snake and Yakima Rivers. The Spokane River will have its industrial and domestic waste loads minimized by its 75 miles flow to the Grand Coulee Reservoir itself.

6. That water pollution control authorities will prevent the discharge of any toxic, highly alkaline or highly acidic wastes to the streams.

7. That sewage treatment plants discharging to the basin streams will be providing an average biochemical oxygen demand reduction of 65%.

8. That all domestic sewage dicharged in the basin will receive either primary or secondary treatment with the majority being secondary (a more complete treatment than primary).

Table 30.--Population data[1]

Columbia River Basin

State or Province	1900	1910	1920	1930	1940	1950
British Col.	55,000[3]	75,000[3]	85,734	103,544	121,216	165,374
Montana	100,517	140,080	156,476	156,993	172,519	185,730
Idaho	145,828	302,695	403,186	417,667	497,139	569,089
Washington	217,316	454,547	501,529	553,809	635,673	856,684
Oregon	348,104	568,641	663,299	778,674	882,944	1,508,600
Wy. Utah,&Nev.	1,972	9,369	8,190	8,300	9,760	11,654
Total	868,737	1,550,332	1,818,414	2,018,987	2,319,251	3,297,131

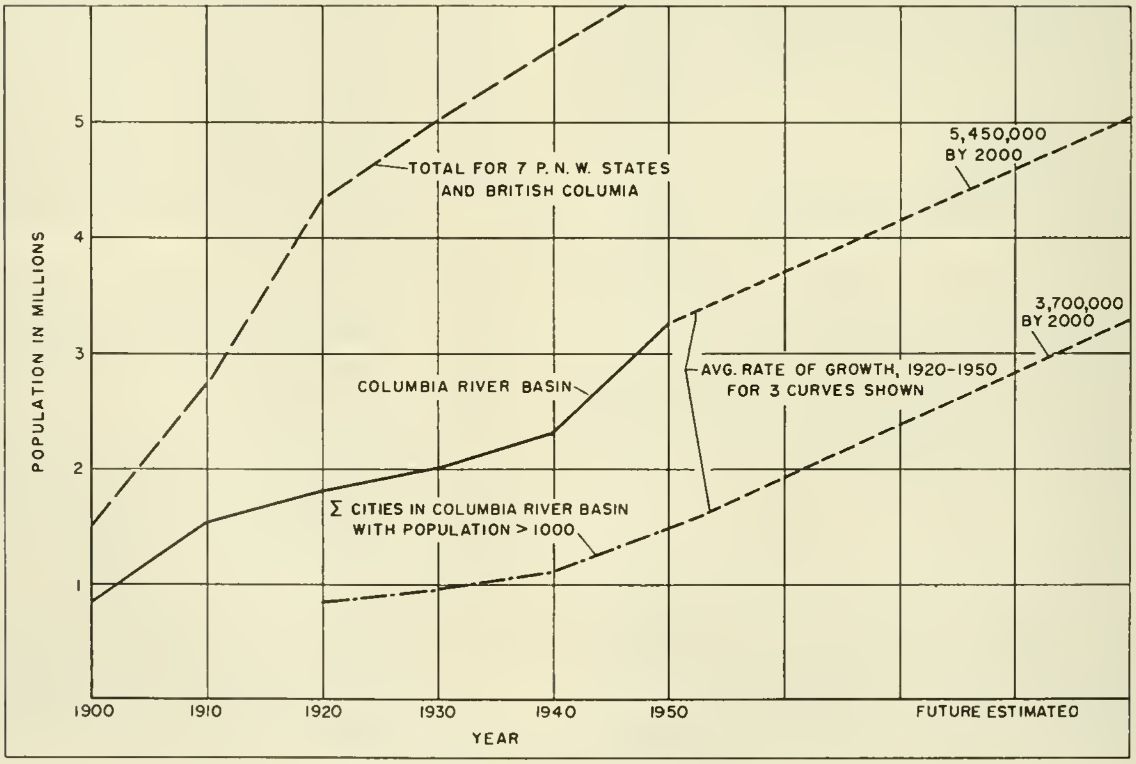
Total State and Province Population

State or Province	1900	1910	1920	1930	1940	1950
British Col.	178,657	392,480	524,582	694,263	817,861	1,165,210
Montana	243,329	376,053	548,889	537,606	559,456	591,024
Idaho	161,772	325,594	431,866	445,032	524,873	588,637
Washington	518,103	1,141,990	1,356,621	1,563,396	1,736,191	2,378,963
Wyoming	92,531	145,965	194,402	225,565	250,742	290,529
Utah	376,749	373,351	449,396	507,847	550,310	688,862
Nevada	42,335	81,875	77,407	91,058	110,247	160,083
Oregon	413,536	672,765	783,389	953,786	1,089,684	1,521,341
Total	2,027,102	3,510,073	4,366,552	5,018,553	5,639,364	7,384,649

Cities over 100 Total Population by Drainage Basin

	1920	1930	1940	1950
Col. R. above Gd. Coulee Dam-26 cities	222,601	246,260	269,195	328,742
Col. R. above Snake R.toG.C. 26 cities	61,865	77,299	89,478	165,940
(Yakima R. Basin - 12 cities)	37,349	41,977	50,695	73,843
(Snake R. Basin - 46 cities)	153,805	159,846	201,173	264,256
Col. R., Snake R. to the Dallas-56 cities	190,719	200,067	250,248	327,479
" ",Dalles to the Mouth 42 cities	379,472	444,138	495,091	672,413
Total 150 Cities	1,045,811	1,169,586	1,355,880	1,832,673

1. From references 3, 6, 29, 30, 31 and 41
2. British Columbia data for 1901, 1911, 1921, 1931, 1941 and 1951
3. Estimated for British Columbia - data not available.



POPULATION GROWTH AND PREDICTION

FIG. 62

Population: Table 30 and figure 62 show the past population growth in the Columbia River Basin and in the Pacific Northwest since 1900. The basin population can be expected to grow because of an increase in the rate of births over deaths, because of an increase in irrigated land and because of increased industrial development attracted by the abundance of water and low cost electrical power.

Figure 62 shows a predicted Columbia River Basin population of about 5-1/2 million persons by the year 2000 with 3.7 million of these residing in cities of over 1000 population that will contribute domestic sewage to the basins streams. These predicted populations (and they are nothing more than an estimate) were determined by averaging the rate of population growth for the period 1920-1950 in the 3 categories shown on figure 62, i.e., the total Pacific Northwest, the Columbia River Basin and the basin cities over 1000 population contributing sewage to the streams. This average growth rate was then projected to the year 2000 as shown on figure 62.

Waste Characteristics: Table 31 lists the assumed characteristics of domestic and industrial wastes that are or will be discharged in the Basin. Domestic sewage values shown are average ones commonly used in the field of sewage treatment. Industrial waste oxygen consuming values were averaged from studies of typical industries in the Columbia and Ohio River Basins (37). Table 32 lists those industries, by location on the Columbia River system, whose waste discharges might have a deleterious effect on water quality.

Table 31.--Assumed characteristics of treated domestic sewage and industrial wastes[1]

A. Domestic Sewage	
Flow rate	100 gal./capita/day
Total Solids	325 P.P.M.
Suspended Solids	60 P.P.M.
Dissolved Solids	265 P.P.M.
PH	7.8 P.P.M.
Alkalinity	75 P.P.M.
Chlorides	30 P.P.M.
Ammonia	7 P.P.M.
5 day 20°C B.O.D.	70 P.P.M. or 0.058 lbs. O_2
1 day " "	22 " " 0.018 "
2 day " "	38 " " 0.032 "
3 day " "	51 " " 0.043 "
4 day " "	62 " " 0.052 "
6 day " "	77 " " 0.064 "
7 day " "	82 " " 0.068 "
8 day " "	87 " " 0.073 "
1st Stage 20°C B.O.D.	103 " " 0.086 "
B. Industrial Wastes	
Food processing plants	4050 population equivalent (avg. of 82 plants)
Pulp and paper	373,000 population equivalent (avg. of 15 plants)
Textile	5,270 " " (avg. of 28 plants)
Petroleum & Coal Prod.	10,400 " " (avg. of 11 plants)
1 Population equivalent	0.167 lbs. O_2., 5 days @ 20°C
" " "	0.245 " " , 1st Stage

[1]Averaged from references (36, 37 and 38)

Domestic and Industrial Pollution Estimates: This study has concerned itself only with the relationship of the waste discharges to the dissolved oxygen content of the Columbia River. Predictions on other water quality changes are made in subsequent chapters on this study.

Table 34 shows the data used to arrive at the estimated dissolved oxygen deficit in the Columbia River in the year 2000 as a result of domestic and industrial waste discharges. Population increases between 1950 and 2000 were obtained by using the growth rate shown in figure 62. Industrial wastes are shown as population equivalents, i.e., how many persons would produce a domestic sewage (untreated) having the same oxygen consuming properties. These population equivalents were doubled in the 3 upper segments of the Columbia River between 1950 and 2000. They were kept stationary for the lower segment from The Dalles to the mouth as it seems most likely that the installation of recovery and treatment processes in the pulp and paper and in the food industries will so reduce the strength of their wastes that this will allow for increased industrial development without causing an increase in water pollutants.

The critical period for dissolved oxygen values should be in August and September. Low river flows for this period are shown in tables 33 and 34. It can be expected that these low flow values will be increased as more regulatory structures are built on the river system.

The total estimated biochemical

Table 32.--Number of industries with waste discharge, treated and untreated[1]

Basin Segment	Food*	Pulp and* Paper	Lumber and Products	Primary Metal	Chemical and Mining	Textile*	Fabricated Metal	Petroleum* and Coal	Miscellaneous
Columbia R. Above Grand Coulee Dam	33	1	14	4	41	0	1	1	8
Columbia R. Below Grand Coulee and Above Snake R.	74	0	3	0	11	0	0	1	6
Yakima R. Basin	29	0	0	0	2	0	0	0	2
Snake R. Basin	62	1	0	0	13	0	0	1	0
Columbia R. Below Snake R. to the Dalles	70	1	1	0	13	0	0	1	0
Columbia R. Dalles to the Mouth	138	16	7	3	4	17	4	2	9
Total	406	19	25	7	84	17	5	6	25

[1]From references (34) (36) (6)

*Organic wastes consuming oxygen.

Table 33.--Columbia River regulated flow characteristics.

River Segment	Discharge - C. F. S. - Regulated[1]				Approx. Avg. Water Temp. in Aug. & Sept. °C	Dissolved Oxygen Saturation P. P. M.	Approx. Area Segment Aug. & Sept. Acres
	Maximum	Mean	Minimum[2]	Minimum Aug. & Sept. Flow			
Above Grand Coulee Dam	550,000	95,000	21,000	43,000	16	9.95	64,000
Below Grand Coulee Dam and Above Snake R.	693,000	120,000	35,000	52,000	17	9.74	34,800
Below Snake R. to The Dalles	1,000,000	186,000	63,000	82,000	18	9.54	68,500
Dalles to Mouth	1,000,000+	221,000	68,000	88,000	18	9.54	61,000

[1]From period of 1941-1953

[2]Minimum discharge in Dec. or Jan.

Table 34.--Estimated industrial and domestic pollution load.

Columbia River Segment	Year 1950		Year 2000[2]		Critical period minimum flow from table 33[3] c.f.s.	Total dissolved oxygen demand year 2000 municipal industrial lbs./day[4]	Total estimated oxygen demand in year 2000 Aug. - Sept. P.P.M.	Estimated in segment segment in daily P.M.M.[5]	Estimated dissolved oxygen deficit in river P.P.M.[6]
	Municipal sewage discharge persons	Industrial waste population equivalent	Municipal sewage discharge persons	Industrial waste population equivalent					
Above Grand Coulee Dam	329,000	513,000	810,000	1,000,000	43,000	315,000	1.26	0.1	0
Below Grand Coulee and Above Snake River	166,000	310,000	410,000	600,000	52,000	339,700	1.22	0.1	0
Below Snake River to the Dalles	327,000	1,900,000	810,000	3,800,000	82,000	1,091,000	2.47	0.1	1.2
Dalles to the Mouth	672,000	6,670,000	1,660,000	6,700,000	88,000	581,000	1.22	0.15	0.9
TOTAL	1,495,000	9,393,000	3,700,000	12,100,000					

1 From reference (34) and table 232.
2 Using growth rate of municipalities from figure 62. Industrial wastes doubled except for Lower Columbia.
3 Not corrected for future impoundment regulation.
4 Assuming waste remains in river segment long enough to exert entire first stage B.O.D. from table 31 and one-half of oxygen demand of next upstream segment carried to downstream segment.
5 From reference (39), table 25 using water depth of 20 feet.
6 Assuming no oxygen added from photosynthesis.

oxygen demand values shown in table 34 were obtained by multiplying the populations by the B.O.D. values given in table 31 and by using the August-September flow rates. In the upper 3 segments of the River it was assumed, because of the many impoundments that will be in existence, that the waste would remain in the segment long enough to exert its entire first stage oxygen demand. To this was added one-half of the upstream segment oxygen demand to allow for oxygen demands beyond the first stage. Because there will be no impoundments in the lower river segment, a flow time of 2 days to the river mouth was taken for the industrial wastes and 3 days for the domestic wastes. (The industries contributing the strong wastes stretch further down the Columbia River than does the bulk of the population.) A maximum predicted oxygen depletion of 2.5 p.p.m. is shown for the segment of the river between the Snake River confluence and The Dalles. Depletion of around 1.25 p.p.m. are shown for the other 3 segments.

Reaeration of the river water takes place concomitantly with this deoxygenation. It is very difficult to obtain any precise reaeration coefficients for a stream such as the Columbia. Accordingly, low values of reaeration were assumed. A value of 6 pounds of oxygen per day, per acre of water surfaces, was assumed for the upper 3 segments where the river will be a series of impoundments and 9 pounds was taken for the more rapidly flowing (and mixing) lower segment. These reaeration values do not take into account any oxygen supplied from photosynthesis.

The estimated dissolved oxygen deficit in the 4 river segments (table 34) was obtained by multiplying the daily reaeration by the segment flow time and subtracting the product from the oxygen demand. Deficits of around 1 p.p.m. are shown for the Columbia River between the Snake River confluence and the mouth. It is believed, however, that there will be no actual deficit in the year 2000 because minimum river flows should be greater during that period (unless the Canadian divert upper Columbia River waters) and photosynthetic activities should be great in August and September for oxygen production.

Table 35.--Watershed usage factors for water quality prediction[1].

River and location	Watershed area sq. mi.	1910				1950 plus				Future - year 2000[3]			
		c.f.s.[2]	Total pop.	Irrig. acres	Usage factor	c.f.s.[2]	Total pop.	Irrig. acres	Usage factor	c.f.s.[2]	Total pop.	Irrig. acres	Usage factor
Yakima - Kiona	5.6	5.70	63	184	362	4.27	279	424	4930	5.65	508	534	8560
Yakima - Cle Elum	0.5	2.37	5.3	<1	4	1.94	3.4	<1	4	1.96	6	<1	6
Snake - Clarkston	103	68	336	1573	76	52	1364	2826	718	50	2521	3857	1886
Columbia - Northport	60	106	240	280	11	102	864	370	52	94	1606	565	161
Columbia - Pasco[4]	101	123	486	547	21	123	1754	923	130	123	3181	2507	643
Columbia - Dalles	237	183	936	2273	49	179	3529	4010	334	195	6456	7284	1017
Wenatchee - Cashmere[5]	1.3	4.22	6.2	19	21	3.96	12	26	61	3.3	40	26	242
Deschutes - Moody[5]	10.5	7.4	20	61	16	7.0	44	118	71	5.9	146	164	386
Okanogan - Okanogan[4]	7.9	2.9=	27	20	24	2.9	104	57	259	2.9	117	87	674

1 Values x 10^3 except for usage factor.
2 Mean annual flow for period of record.
3 Assuming same rate of growth throughout Columbia River Basin plus 1950 industrial waste pop. equiv. doubled.
4 Using mean annual flow of record.
5 Assuming an industrial waste contribution equal to future population.

Table 36.--Estimated future water quality characteristics[1]

Yearly weighted average values

	Yakima River Kiona	Yakima River Cle Elum	Snake River Clarkston	Columbia River Northport	Columbia River Pasco	Columbia River Dalles	Wenatchee R. Cashmere	Deschutes R. Moody	Okanogan R. Okanogan
Total Alkalinity	105	25	148	70	85	133	49	107	86
Total Hardness	85	25	166	97	103	130	51	93	88
Dissolved Solids	150	47	272	101	218[2]	183	94[2]	107	142[2]
Sulfate	13	5.9	48	19	14	34	8	5	22
Ca + Mg	30	8.4	58	34	23	44	10	27	29
Na + K	18	3.7	38	4.6	6	18	4	12	8
Iron	0.14	0.03	0.13	0.03	0.7	0.1	0.45	0.06	0.2
Chlorides	5.2	1.5	17	2.2	-	7	-	5	-
Nitrate	2.9	0.9	2.9	2.3	-	1.5	-	0.8	-
Silica	27	10.4	30	8.6	-	13	-	42	-

[1] Computed from Tables 35 and 24. Where a 1950 constituent was less than the 1910, the 1910 value is recorded.

[2] Total Solids

Sample Calculation - Yakima River at Kiona:

Change in usage factor, 1910-1950 = 4568; 1950 - Future = 3630; Alk. change = 29

$\frac{4568}{29} = \frac{3630}{x}$; $x = 23$ Future estimated alkalinity = 82 + 23 = 105

In summation, the Columbia River system should experience no appreciable dissolved oxygen reductions, other than localized affects, to the year 2000 provided that these broad assumptions prove to be valid.

PREDICTION OF FUTURE WATER QUALITY

The quality of water in a river unaffected by man's activities is related to the size of the watershed, the amount of river discharge, climatological conditions and the nature of the soil and rock formations. The larger the watershed for a given rate of flow, the greater will be the amount of mineral matter taken into solution. Conversely, the greater the rate of flow for a given watershed area, the less will be the amount of matter taken into solution. The solvent effect of the water is dependent upon the water temperature, water pH or carbon dioxide content and on the solubility of the soil and rock formation in the watershed. Dissolved material is usually greatest in a water draining an area of fine textured, alkaline soil. Normally, the dissolved constituents in a given stream are present in an inverse ratio to stream discharge. Color and turbidity are usually present in somewhat of a direct ratio to stream discharge, increasing particularly after a heavy rainstorm.

Man has altered this natural water quality by the construction of reservoirs, return of spent irrigation waters, discharge of domestic sewage and by the discharge of industrial wastes. In a given watershed, a very detailed analysis and study would be necessary to separate the effect each of these man-made changes has had on the river water quality constituents. In general, reservoirs have their principal effect on water quality by reducing turbidity and by changing the downstream water temperatures. They may slightly increase or decrease the dissolved constituents but do not produce any marked effect therein except, if the reservoir is large, to even out the normal changes in constituents with changes in stream discharge.

Since the marked changes in water quality are then caused by irrigation and pollutants, a prediction of future water quality will necessitate the relating of these factors to stream flow and watershed area for a given drainage basin. Industrial waste discharges have been previously computed (tables 32 and 34) on a population equivalent basis determined by their biochemical oxygen demands related to that of domestic sewage. This equivalent does not necessarily hold for the other constituents in a waste discharge, such as dissolved solids, but they are comparable and will be so used for lack of a better unit or units of evaluation.

Watershed Usage Factors:

To combine these stream water quality variables, a factor has been devised which will be called the "Watershed Usage Factors". This factor, with components therein in units X 10^3, is equal to: (Population is for watershed plus industrial waste equivalent)

$$\frac{\text{Population X Irrigated Acreage}}{\text{Discharge in C.F.S. X Watershead Area in Sq. Mi.}}$$

Table 35 represents a computation of these "Watershed Usage Factors" for streams in the Columbia River Basin where water quality data are available for purposes of future quality prediction. In the table, these factors are computed for the period of 1910-12, 1950-56 and for the future year 2000. The factors for 2000 were computed using the mean stream discharge of record, a uniform watershed population increase throughout the Columbia River Basin, as shown in figure 62, and an industrial waste contribution double that of 1950. Industrial wastes should more than triple in the next 40 years. However, more and improved methods of industrial waste treatment should be in use, thus lessening the quantity of pollutants. In watersheds like the Wenatchee and Deschutes where there now are no significant industrial pollutants, it was assumed that these would be built in the future to the extent of their discharging pollutants equivalent to the predicted population.

The "Watershed Usage Factors" in table 35 show very definitely the relationship between the stream flow and the use made of the water. The highly developed Yakima River in 1950 has a usage factor 7 times as great as the next highest, the Snake. At The Dalles the Columbia River, although receiving the pollutants from the

Table 37.-- Estimated Future Water Quality Characteristics - Maximum Monthly Values[1]

	Yakima R. Kiona	Snake R. Clarkston	Columbia R. Dalles	Wenatchee R. Cashmere	Deschutes R. Moody	Okanogan R. Okanogan
Total Alkalinity	167	270	148	75	140	155
Total Hardness	122	280	158	110	103	175
Dissolved Solids	245	375	245	190[2]	130	185[2]
Sulfate	53	95	55	10	9	35
Ca + Mg	42	95	56	47	38	37
Na + K	30	82	26	9	27	11
Iron	0.3	0.2	0.25	0.2	0.1	0.3
Chlorides	14	24	12	-	6	-
Nitrate	5	3.5	3	-	1.5	-
Silica	45	60	20	-	45	-

1 1910 values recorded when they exceeded 1950 values.
2 Total Solids.

Maximum values for each constituent will occur in different months of the year.
Computed on a quality observed and not weight basis.

Table 38.--Estimated Future Water Temperatures After Proposed Reservoir Construction

River and Location	Σ Acre-Feet Storage x 10^6 [1]	Σ Res. Area Acres x 10^4 [1]	Temp. Rise from Storage °F [3]	Temp. Rise from Area °F [4]	Avg. Temp. Rise °F	Present Aug. Temp. °F	Estimated Future Temp. °F
Columbia R., Bridgeport	38	57	70	50	60	60.9	70 +
Okanogan R.	1.9	2.3	3.5	2	3	69	70 +
Wenatchee R.	Data not available					60.9	62 +
Columbia R., Rock Island	40	61	74	54	64	61.7	70 +
Yakima R.	No significant change					71.3	71
Columbia R., Pasco	41	64	76	56	66	63.9	70 +
Snake R., Burbank[2]	15	35	28	31	29	72.4	75 +
Columbia R., Umatilla	56	99	103	87	95	63.7	70 +
Columbia R., Bonneville	58	103	107	91	99	64.2	70 +

1 Proposed Construction
2 Using low dams in place of high dam at Hells Canyon.
3 Using 1.85°F of temp. rise per 10^6 acre-feet storage.
4. Using 0.88°F " " " " 10^4 acres reservoir surface area.

Snake, Yakima and other tributaries, has a usage factor only half that of the Snake River because of the high flow rate in the Columbia. The Yakima River at Cle Elum has a very low usage factor because of the low watershed occupancy. Large increases in usage factors between 1910 and 1950 are accompanied by marked increases in the constituents of the water.

Prediction of Constituents in Year 2000:

Table 36 lists the predicted water quality constituents in the year 2000, obtained by relating the change in the watershed usage factor between 1910 and 1950 with the change in the constituents during that period. By direct proportion, this constituent was then projected to the year 2000 by the change in the usage factor between 1950 and 2000. It should be stressed that these predictions are gross approximations and that past changes in water quality may not necessarily be reflected in like future changes. With the increased use of complex chemical substances in industry, the household and in agriculture, substances will be added to the streams not now present, or present now in minute quantities.

Table 36 lists predictions only on those substances where sufficient background data are available for a prediction. Not shown are such constituents of quality as pH, temperature, boron, fluoride, specific conductance, carbon dioxide, ammonia, dissolved oxygen and the trace elements like copper and aluminum. Dissolved oxygen changes are discussed elsewhere in this report. PH values rise with increasing quantities of irrigation return flow. In the future it can be expected that the pH values in the water will be 0.1 to 0.3 higher than in 1955. Carbon dioxide (where the pH is less than 8) and ammonia should more than double in the future as organic matter in the rivers undergoes decomposition. Trace elements should show a marked increase with the advent of more metal and chemical industries and the use of more pesticides and weed killers.

The estimated future water quality characteristics in table 36 all appear quite reasonable excepting for total solids and iron in the Columbia River at Pasco and iron in the Wenatchee River. Estimated values for the Columbia River at Pasco, the Wenatchee and Okanogan Rivers are subject to more question than the others since the data for these river estimates are more limited than it is on the other locations. Since these are yearly weighted average values, it can be expected that during the late summer and autumn (when stream flows are low, irrigation returns are large and food industry waste discharges are great) most of the values shown in table 36 will be exceeded by 10 to 100 percent. Applying the "Watershed Usage Factors" to the differences in the maximum monthly water quality values shown in the tables on "Water Quality Comparisons", estimated maximum future constituent values are obtained and given in table 37. These maximum values for each constituent at a particular location will not all be of maximum value during the same time period. Time periods of maximum concentrations should not exceed one month in duration. In computing these future constituent concentrations, it was assumed that there would be no future change in river flows. If river discharges are increased during the summer and autumn through construction of increased impoundments, these constituent values will be decreased through dilution. The most accurate method of predicting future water quality would be on a weight basis, taking stream discharge into account. This is not possible throughout the Basin because of limited past and future discharge data.

Hydrogen ion (pH) and carbonate alkalinity values will be high in several locations during the summer or autumn. From a study of present values, it is predicted that future pH and carbonate alkalinity values can be expected to reach or exceed the following magnitudes during a month or so at the following locations:

	pH	$CO_3^=$
Columbia River, Pasco to Bonneville	8.6	20
Yakima River, Prosser to Mouth	9.0	35
Snake River, lower section	9.1	60
Deschutes River, lower section	8.6	20
Okanogan River, lower section	8.5	15

Estimated Water Temperatures From Future Impoundments:

Insufficient data and studies are available to make a reasonably reliable prediction of water temperature changes that will be caused by the construction of new reservoirs in the Columbia River Basin. A previous chapter in this report discusses the effect of existing reservoirs on downstream water temperatures. Table 14 in the chapter gives the average monthly temperature changes through four reservoirs. These reservoirs show a maximum monthly water temperature increase averaging 1.85° F. for each million acre-feet of impoundment or 0.88° F. increase for each 10,000 acres of average water surface area during the month of August when water temperatures are at a maximum.

Proposed reservoirs for construction in the Basin are of all shapes, sizes and depths. Little data are available on some of the proposed reservoirs. Since the above average temperature increases are for reservoirs of widely differing characteristics, these figures will be used in predicting future temperatures in the different river basins if all proposed reservoirs are constructed. Table 38 lists the summation of the average or usable (whichever data were available) reservoir storage and the average reservoir surface area above different locations in the Basin. Reservoir data to 1955 were obtained from governmental agencies, private power companies and the Canada Department of Northern Affairs and Natural Resources. (These reservoir data are subject to some change as dam planning is in a constant state of revision.) The table gives the theoretical rise in river water temperature if the increased impoundments were to increase the water temperatures as they did in the four existing reservoirs used for comparison purposes. Obviously, the river temperatures will not rise as shown in the table. The last column in the table is a guess at what the actual river temperatures may be if the proposed reservoirs are constructed. This shows all river temperatures, excepting the Wenatchee, to be in excess of 70° F. during the month of August with the Snake River temperatures exceeding 75° F. (Snake River water temperatures in August of 1956 occasionally reached 75° F.)

Another factor that will increase river temperatures materially is increased irrigation return flows. If the majority of the water to be stored in future reservoirs is contained in large, deep impoundments, it is possible that some river temperatures in August may actually be decreased or at least held to present levels. There is a definite need for more study and data on river water temperatures, the influence thereon by dam construction and irrigation return flows and the effect these predicted temperatures will have on the fish life in a particular stream.

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Table A.--Columbia River Basin

Significant reservoir data - existing and proposed projects[1]

No.	Stream and reservoir, dam or project name	River miles to mouth of Columbia	River miles to Columbia River	Date impoundment commenced	Reservoir surface area in acres: Minimum	Average	Full pool
	KOOTENAI RIVER:						
1	Libby Dam Site	985	213	Proposed	17,000	35,000	48,000
2	Katka Dam Site	933	161	Proposed		11,700	
3	Corra Linn Dam	787	15	1932	109,000	117,000	133,000
4	Upper Bonnington Dam	786	14	Constructed			
5	Lower Bonnington Dam	785	13	Constructed			
6	South Slocum Dam	784	12	Constructed			
7	Brilliant Dam	772	772	Constructed			
	PEND OREILLE RIVER:						
8	Nine-mile Prairie Dam Site	1,134	388	Proposed		13,500	
9	Quartz Creek Dam Site	1,048	302	Proposed		800	
10	Glacier View Dam Site	1,168	422	Proposed			
11	Canyon Creek Dam Site	1,156	410	Proposed		1,200	
12	Coram Dam Site	1,142	396	Proposed		2,000	
13	Hungry Horse Dam	1,145	399	September 1951	5,500	21,300	23,800
14	Swan Lake Dam Site	1,108	363	Proposed			
15	Kerr Dam	1,064	319	Constructed			
16	Paradise Dam Site	990	244	Proposed		66,200	
17	Thompson Falls Dam	954	208	Constructed			
18	Trout Creek Dam Site	930	184	Proposed		1,900	
19	Noxon Rapids Dam	806	160	1956	5,600	8,500	8,650
20	Cabinet Gorge Dam	896	150	1952	3,200	3,200	3,200
21	Priest River #4 Dam Site	883	137	Proposed		28,000	
22	Albernie Falls Dam	836	90	June 1952	86,000	91,000	94,600
22a	Box Canyon Dam			1955			
23	Boundary Dam Site	764	18	Proposed		21,200	
	SPOKANE RIVER:						
24	Leland Glen Dam Site	818	175	Proposed		4,900	
25	Springston Dam Site	766	123	Proposed		31,400	
26	Long Lake Dam	679	36	1915	3,600	5,000	5,000
27	Grand Coulee Dam	597	597	April 1938	46,500	70,300	79,400
28	Grand Coulee Equalizing Res.*			May 1951	5,970	24,500	27,970
29	Chief Joseph Dam	545	545	1955		6,200	7,800
	OKANOGAN RIVER:						
30	Similkameen Dam Site	607	73	Proposed		19,500	
31	Okanogan Lake Dam	552	119	1915		81,500	
32	Wells Dam Site	516	516	Proposed		6,800	
	CHELAN RIVER:						
33	Lake Chelan Dam	503	5	1927	31,600	32,300	32,950
34	Rocky Research Dam	474	474	Under construction	8,800	9,300	9,600
	WENATCHEE RIVER:						
35	Chiwawa Dam Site			Proposed			
36	Plain Dam Site			Proposed			
37	Tumwater Canyon Dam Site			Proposed			
38	Rock Island Dam	453	453	1933	Run of River Dam		
39	O'Sullivan Dam*	451	40	May 1951	5,400	21,000	28,000
40	Wanapum Dam Site	Actual Site not yet selected		Proposed			
41	Priest Rapids Dam	396	396	Under construction	7,000	8,500	11,000
	YAKIMA RIVER:						
42	Keechelus Dam*	538	203	January 1906	1,245	1,900	2,526
43	Kachess Dam*	528	193	June 1911	2,744	3,400	4,543
44	Cle Elum Dam*	519	184	February 1932	1,982	3,600	4,812
45	Bumping Lake Dam*	506	171	November 1910	630	1,000	1,305
46	Tieton Dam*	485	150	April 1925	111	1,900	2,528
	SNAKE RIVER:						
47	Jackson Lake Dam*	1,326	1,002	1916		23,100	25,540
48	Palisades Dam	1,226	902	1956	5,000	10,500	16,000
49	Island Park Dam*	1,254	930	November 1938	135	7,200	7,794
50	Blackfoot Dam*	1,153	829	1924			
51	American Falls Dam	1,039	715	May 1926		38,000	56,055
52	Minidoka Dam (Lake Walcott)	999	675	Constructed			
53	Milner Dam	964	640	Constructed			
54	Upper Salmon Falls Dam	906	582	Constructed			
55	Lower Salmon Falls Dam	897	573	Constructed			
56	Magic Dam	955	631	Constructed			
57	C. J. Strike Dam	816	492	September 1951	6,600	7,100	7,500
58	Wildhorse Dam*	1,002	678				
59	Skull Creek Dam*	978	654				
60	Owyhee Dam*	744	420	October 1932	5,730	10,000	13,000
61	Anderson Ranch Dam	839	515	December 1945	635	3,800	4,741
62	Arrow Rock Dam*	793	469	February 1915		2,600	3,150
63	Lucky Peak Dam*	783	459	1955	830	2,100	2,850
64	Warm Springs Dam*	801	477	November 1919	100	3,300	4,440
65	Agency Valley Dam*	789	465	December 1935		1,400	1,905

No.	Stream and reservoir, dam or project name	Reservoir size: Length miles	Reservoir size: Avg. width miles	Storage capacity--acre feet: Dead	Storage capacity--acre feet: Usable storage	Storage capacity--acre feet: Full pool	Water depth: Average	Water depth: Full pool	Normal head on turbine intakes or outlets
	KOOTENAI RIVER:								
1	Libby Dam Site	95	0.8	975,000	5,010,000	5,985,000	290	360	225
2	Katka Dam Site						271	273	
3	Corra Linn Dam	66	2.5		826,455	1,500,000		500	
4	Upper Bonnington Dam								
5	Lower Bonnington Dam								
6	South Slocum Dam								
7	Brilliant Dam								
	PEND OREILLE RIVER:								
8	Nine-mile Prairie Dam Site				960,000		306	311	
9	Quartz Creek Dam Site				pondage		130	131	
10	Glacier View Dam Site								
11	Canyon Creek Dam Site				pondage		153	153	
12	Coram Dam Site				pondage		108	113	
13	Hungry Horse Dam	34	1	486,000	2,982,000	3,468,000	464	487	240
14	Swan Lake Dam Site				234,000				54
15	Kerr Dam								
16	Paradise Dam Site				4,080,000		243	248	
17	Thompson Falls Dam								
18	Trout Creek Dam Site				poodage		99	105	
19	Noxon Rapids Dam	37	0.4	80,000	300,000	380,000			69
20	Cabinet Gorge Dam	24	0.2	30,600	77,000	108,000			36
21	Priest River #4 Dam Site				870,000		47	47	
22	Albernie Falls Dam	67	2.2	389,000	1,153,000	1,542,000		35	35
22a	Box Canyon Dam								
23	Boundary Dam Site				pondage		320	325	
	SPOKANE RIVER:								
24	Leland Glen Dam Site				370,000		270	275	
25	Springston Dam Site				2,595,000		127	132	
26	Long Lake Dam	22	0.4	149,000	104,000	253,000			37
27	Grand Coulee Dam	150	0.9	4,330,000	5,072,000	9,402,000	328	378	262
28	Grand Coulee Equalizing Res.*	27	2	569,500	705,600	1,275,100	52	65	53
29	Chief Joseph Dam	51	0.2	481,000	37,000	518,000		200	178
	OKANOGAN RIVER:								
30	Similkameen Dam Site				1,620,000		244	247	
31	Okanogan Lake Dam	69	2		325,000				
32	Wells Dam Site						65	79	
	CHELAN RIVER:								
33	Lake Chelan Dam	48	1.1	70,000	678,000	748,000			20
34	Rocky Reach Dam	45			47,000				77
	WENATCHEE RIVER:								
35	Chiwawa Dam Site				330,000				567
36	Plain Dam Site				1,050,000				164
37	Tumwater Canyon Dam Site								
38	Rock Island Dam	18		Run of River Dam			65	67	52
39	O'Sullivan Dam*	20	2	162,000	513,000	675,000		118	112
40	Wanapum Dam Site								
41	Priest Rapids Dam	18	0.7	200,000	70,000	270,000			85
	YAKIMA RIVER:								
42	Keechelus Dam*	6	0.75		115,000	153,000		61	90
43	Kachees Dam*	12	0.75		180,000	239,000		70	69 1/4
44	Cle Elum Dam*	9	1		330,000	436,900		130	130
45	Bumping Lake Dam*	4	0.5		28,000	37,200		37	37
46	Tieton Dam*	9	0.5		150,000	198,000		182	160
	SNAKE RIVER:								
47	Jackson Lake Dam*	25	3		635,000	847,000	27	41	38
48	Palisades Dam	21	2.75	200,000	1,200,000	1,400,000	195	245	123
49	Island Park Dam*	11	1	400	127,000	127,000	70	72	70
50	Blackfoot Dam*	11			410,000				
51	American Falls Dam	25	3		1,270,000	1,700,000	43	60	54.5
52	Minidoka Dam (Lake Wallott)								
53	Milner Dam								
54	Upper Salmon Falls Dam								
55	Lower Salmon Falls Dam								
56	Magic Dam								
57	C. J. Strike Dam	24	0.5	210,000	40,000	250,000	80	105	24
58	Wildhorse Dam*								
59	Skull Creek Dam*								
60	Owygee Dam*	52	0.5	405,000	715,000	1,120,000		315	200
61	Anderson Ranch Dam	20	0.5	70,000	423,000	493,200	303	334	196
62	Arrow Rock Dam*	17	0.25		215,000	286,600	237	253	111
63	Lucky Peak Dam*	12	0.4	26,000	280,000	306,000	175	235	225
64	Warm Springs Dam*	7.5	3	1,400	191,000	192,400		92	79
65	Agency Valley Dam*	3	1		45,000	60,000		80	76.8

No.	Stream and reservoir, dam or project name	River miles to mouth of Columbia	River miles to Columbia River	Date impoundment commenced	Reservoir surface area in acres Minimum	Average	Full pool
	SNAKE RIVER Cont'd:						
66	Smith Ferry Dam*	827	503	Constructed			
67	Cascade Dam*	797	473	November 1947	5,600	20,000	26,500
68	Deadwood Dam*	804	480	November 1930	250	2,400	3,100
69	Garden Vallye Dam Site	763	439	Proposed			
70	Black Canyon Dam	731	407	Constructed			
71	Lost Valley Dam Site*	764	440	Proposed	370	1,100	1,230
72	Unity Dam*	694	370	1937			
73	Thief Valley Dam*	680	356	1932			
74	Brownlee Dam	604	280	Under construction	6,800	10,000	13,250
75	Oxbow Dam	590	276	Under construction	1,250	1,250	1,250
76	Hells Canyon Dam Site	574	250	Proposed	5,000	16,000	24,800
77	Pleasant Valley Dam Site	540	216	Proposed	4,200	5,600	6,300
78	Mountain Sheep	519	195	Proposed		1,300	1,700
79	Crevice Dam Site	612	288	Proposed		8,000	
80	Freedom Dam Site	581	257	Proposed		2,900	
81	Nez Perce Dam Site	510	186	Proposed		31,600	
82	Asotin Dam Site	475	151	Proposed		3,700	
83	Clarkston Dam Site	465	141	Proposed		1,400	
84	Koosksia Dam Site	521	197	Proposed		23,500	
85	Elkberry Dam Site	540	216	Proposed		10,400	
86	Bruce's Eddy Dam Site	506	182	Proposed		5,300	
87	Lower Granite	437	113	1967		3,800	5,100
88	Little Goose Dam Site	396	72	1965		7,300	9,700
89	Lower Monumental Dam Site	369	45	1963		4,100	5,450
90	Ice Harbor Dam	334	10	Under construction		7,000	9,250
91	McNary Dam	292	292	October 1953		28,500	37,900
	UMATILLA RIVER:						
92	McKay Dam*	336	47	December 1927	10	950	1,275
93	Cold Springs Dam*	316	27	1907	140	1,500	1,550
	DESCHUTES RIVER:						
94	John Day Dam Site	217	217	Proposed	33,	33,000	44,000
95	Wickiup Dam*	429	225	December 1942		8,000	10,640
96	Crescent Lake Dam*	459	255	August 1922		3,000	4,000
97	Crane Prairie Dam*	439	235	November 1922	10	3,700	4,940
98	Prineville Dam Site*	374	170	Proposed			
99	Ochoco Dam*	371	167	June 1918	100	700	1,000
100	The Dalles Dam	192	192	Under construction		8,200	11,000
101	Bonneville Dam	145	145	January 1938		15,500	20,300
	WILLAMETTE RIVER:						
102	Cottage Grove Dam*	317	215	Constructed			
103	Dorena Dam*	316	214	November 1949	500	1,200	1,840
104	Hills Creek Dam Site	337	235	Proposed	1,200	2,100	3,000
105	Lookout Point Dam	310	208	1954	1,850	3,400	4,360
106	Fall Creek Dam Site*	308	206	Proposed	440	1,200	1,880
107	Cougar Dam Site	339	237	Proposed	390	1,100	1,550
108	Blue River Dam Site*	332	230	Proposed	100	800	1,010
109	Gate Creek Dam Site	317	215	Proposed			
110	Fern Ridge Dam*	269	167	November 1941	1,480	6,000	9,370
111	Holley Dam Site*	272	170	Proposed	400	1,500	2,120
112	Green Peter Dam Site	267	165	Proposed	910	2,400	3,580
113	Cascadia Dam Site	270	168	Proposed			
114	Detroit Dam Site	270	168	1953	1,450	2,500	3,580
	LEWIS RIVER:						
115	Swift Dam	135	48	Under construction			
116	Yale Dam	123	36	August 1952	2,715	3,500	3,783
117	Merwin Dam	108	21	May 1931	3,035	3,900	3,921
	COWLITZ RIVER:						
118	Mossy Rock Dam Site	133	65	Proposed		11,000	
119	Mayfield Dam Site	120	52	Proposed		2,800	

[1] Note included is 17,000,000 acre-feet of usable storage proposed for impoundment in Canada.

* No power developed.

No.	Stream and reservoir, dam or project name	Reservoir size: Length miles	Reservoir size: Avg. width miles	Storage capacity--acre feet: Dead	Storage capacity--acre feet: Usable storage	Storage capacity--acre feet: Full pool	Water depth: Average	Water depth: Full pool	Normal head on turbine intakes or outlets
	SNAKE RIVER Cont'd:								
66	Smith Ferry Dam*								
67	Cascade Dam*	18	2.75	50,000	654,000	704,100		66	41
68	Deadwood Dam*	3.5	2.0	1,500	160,000	161,900		138	129
69	Garden Valley Dam Site				1,250,000	1,330,000			
70	Black Canyon Dam				425,000				277
71	Lost Valley Dam Site*	4	0.5	1,300	49,000	50,500		70	50
72	Unity Dam*				25,000				
73	Thief Valley Dam*				17,400				
74	Brownlee Dam	57.5	0.36	470,000	1,000,000	1 470,000	173	277	120
75	Oxbow Dam	11.5	0.17	75,000		75,000	82	117	Surface
76	Hells Canyon Dam Site	93	0.5	520,000	3,880,000	4,400,000	518	602	289
77	Pleasant Valley Dam Site	34	0.25	530,000	520,000	1,050,000	365	402	200
78	Mountain Sheep	21	0.25		82,000	110,000		158	93
79	Crevice Dam Site				1,030,000		517	517	
80	Freedom Dam Site				180,000		226	226	
81	Nez Perce Dam Site				4,800,000		615	615	
82	Asotin Dam Site				pondage		140	158	
83	Clarkston Dam Site				pondage		40	50	
84	Koosksia Dam Site				3,100,000		514	514	
85	Elkberry Dam Site				1,690,000		553	553	
86	Bruce's Eddy Dam Site				510,000		359	359	
87	Lower Granite	27	0.3	174,000	15,000	189,000		100	55
88	Little Goose Dam Site	41	0.4	433,000	29,000	462,000		120	70
89	Lower Monumental Dam Site	27.5	0.3	231,000	16,000	247,000		120	65
90	Ice Harbor Dam	35	0.4	388,000	29,000	417,000		100	70
91	McNary Dam	61	1.0	707,000	170,000	880,000		90	55
	UMATILLA RIVER:								
92	McKay Dam*	4	1	6	68,000	73,830		154	140
93	Cold Springs Dam*	2.5	0.75		37,000	50,000		61.5	61.5
	DESCHUTES RIVER:								
94	John Day Dam Site	75	0.9	1,590,000	130,000	1,720,000		100	70
95	Wickiup Dam*	9	2.5		140,000	187,300		89	79
96	Crescent Lake Dam*	4	2		64,000	86,000		24	24
97	Crane Prairie Dam*	3	3		41,000	55,340		24	21
98	Prineville Dam Site*				76,000	78,000			
99	Ochoco Dam*	4.5	1		37,000	48,590		88	83
100	The Dalles Dam	31	0.6	264,000	53,000	317,000		100	60
101	Bonneville Dam	48	0.7	430,000	107,000	537,000		65	40
	WILLAMETTE RIVER:								
102	Cottage Grove Dam*								
103	Dorena Dam*	5	0.6	7,000	70,000	77,500	75	100	90
104	Hills Creek Dam Site	7	0.7	77,000	291,000	368,000	280	330	150
105	Lookout Point Dam	14	0.5	105,000	351,000	456,000	200	250	150
106	Fall Creek Dam Site*	6	0.5	10,000	115,000	125,000	130	180	160
107	Cougar Dam Site	6	0.4	29,000	202,000	231,000	360	440	240
108	Blue River Dam Site*	7	0.2	5,000	85,000	90,000	240	290	240
109	Gate Creek Dam Site								
110	Fern Ridge Dam*	5	3.0	7,000	95,000	102,000	30	48	25
111	Holley Dam Site*	4	0.8	7,000	90,000	97,000	120	150	120
112	Green Peter Dam Site	11	0.5	38,000	322,000	360,000	300	340	210
113	Cascadia Dam Site								
114	Detroit Dam Site	9	0.6	115,000	340,000	455,000	315	375	165
	LEWIS RIVER:								
115	Swift Dam	12							
116	Yale Dam	9	0.75	212,231	190,000	401,800	155	280	60
117	Merwin Dam	12	0.5	159,000	245,000	404,500	125	205	162
	COWLITZ RIVER:								
118	Mossy Rock Dam Site				1,100,000		345	345	350
119	Mayfield Dam Site				pondage		185	205	180

Table B.--Minimum, Average and Maximum Observed Constituent
Values at Stations Indicated, 1954 - 1956

Station	Libby Dam Site			Katka Dam Site			Corra Linn Dam		
Month Recorded	3,5,6,7,8,9,12			3,5,6,7,8,9,11,12			3,5,6,7,8,9,11,12		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	3.10	8.4	17.7	124	222	495	1.22	2.87	8.10
Temp. °F	42.8	51.5	60.8	41.4	60.3	67.5	40.6	50.7	56.0
D.O.	9.65	10.9	12.9	8.3	10.4	12.7	8.25	10.2	12.3
D.O. % Sat.	95	99	119	90	104	130	76	91	109
CO_2	1.0	1.4	2.2	0	0.8	2.0	1.0	2.1	4.0
pH	6.8	7.1	7.3	7.35	7.8	8.4	6.4	6.9	7.85
Alkalinity	19	24	31	46.5	61.5	78	14	17.5	22
HCO_3^-	19	24	31	46.5	61.5	78	14	17.5	22
$CO_3^=$	0	0	0	0	0	6	0	0	0
Hardness	14	22	48	53	64	81	12	20	58
Carb.	14	21	29	47	60	70	12	16	20
Noncarb.	1	1	19	0	4	14	0	4	41
SO_4	0	1.3	6.0	7	12	20	0	0.7	2.[illegible]
Color	3	13	22	5	12	25	3	6	15
Turb.	1	7	15	2	9	23	0	4	12
Iron		0.40*		0.02	0.15	0.40	0.03	0.19	0.70
Copper		0.00*		0.00	0.02	0.20	0.00	0.029	0.200
Zinc		0.00*				0.0	0.00	0.05	0.3
Lead		0.0*				0.0			0.0
Aluminum		0.00*		0.00	0.12	1.00	0.00	0.02	0.10
Calcium		8.0*		10	18	24	4	9	12
Magnesium		0.2*		0.1	1.1	3.4	0	1	6
Sodium		2.00*		0.0	5.6	16.0	1.0	2.4	6.0
Potassium		1.80*		0.8	3.1	15.0	0.0	1.7	7.0
Manganese		0.000*				0.000		0.0	0.001
Silver		0.000*				0.000			0.000
Total Solids	32	52	130	25	95	120	10	41	95
Conductivity	41	57	73	110	150	201	32	40	57

1 Jan
2 Feb.
3 Mar.
4 Apr.
5 May
6 June
7 July
8 Aug.
9 Sept.
10 Oct.
11 Nov.
12 Dec.
* Single Observation

Station	Upper Bonnington Dam			Lower Bonnington Dam			South Slocum Dam		
Month Recorded	3,5,6,7,8,9,12			3,5,6,7,8,9,12			3,5,6,7,8,9,11,12		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	no	data	avail.	1.00	2.13	4.48	121.3	303.4	556.6
Temp. °F	39.9	51.5	64.4	39.0	50.2	55.8	41.1	57.8	65.3
D.O.	8.8	10.6	12.7	9.9	11.1	12.8	10.4	11.9	14.2
D.O. % Sat.	80	95	119	92	98	119	100	114	124
CO_2	0.5	1.5	2.5	1.0	1.5	2.5	-	-	-
pH	6.5	7.0	7.4	7.0	7.2	7.7	7.2	7.6	8.0
Alkalinity	14	18.0	22	13	22	29	53	65	74
HCO_3^-	14	18.0	22	13	22	29	53	65	74
$CO_3^=$	0	0	0	0	0	0	0	0	0
Hardness	14	18	31	13	21	37	61	70	79
Carb.	14	16	19	13	20	28	61	66	69
Noncarb.	0	2	12	0	1	24	0	4	10
SO_4	0	1	2.5	0	2.5	21	13	13	15
Color	2	6	15	0	7	15	4	13	20
Turb.	0	3	9	0	7	34	3	10	15
Iron		1.5*		0.03	0.10	0.20			
Copper		0.000*		0.000	0.002	0.008			
Aluminum		0.01*		0.01	0.12	0.50			
Calcium		12*		1	8	12			
Magnesium		0.0*		0.0	0.3	1.0			
Na		3.5*		2	4	5			
K		1.4*		1.4	3	7			
Total Solids	13	42	95	19	63	120	112	137	172
Conductivity	32	38	48	33	51	71	125	150	164
Zinc		0.0*				0.0			
Lead		0.0*				0.0			
Manganese		0.000*				0.00			
Silver		0.000*				0.00			

1 Jan.
2 Feb.
3 Mar.
4 Apr.
5 May
6 June
7 July
8 Aug.
9 Sept.
10 Oct.
11 Nov.
12 Dec.
* Only one sample measured

Station	Brilliant Dam			Nine-mile Prairie Dam Site			Quartz Creek Dam Site		
Month Recorded	3,5,6,7,8,9,11			3,5,6,7,8,9,12			3,5,6,7,8,9,11,12		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	111.5	306.2	535.4	6.5	12.3	27.7	98.6	268.0	535.1
Temp. °F	41.1	60.5	68.0	43.8	61.8	71.4	39.2	57.4	67.6
D.O.	9.3	11.5	13.7	2.8	6.3	10.5	9.4	11.3	13.7
D.O. % Sat.	100	115	126	30	62.5	88	101	111	131
CO_2	0.0	0.7	2.0	2.0	7.0	11.5	0	0.8	1.5
pH	7.3	7.8	8.6	6.3	6.9	7.2	7.2	8	8.5
Alkalinity	49	63	78	22	32	50	48	65	80
HCO_3^-	49	63	78	22	32	50	48	63	80
$CO_3^=$	0	0	0	0	0	0	0	2	12
Hardness	56	68	84	21	29	43	51	68	83
Carb.	56	62	72	21	27	34	48	64	80
Noncarb.	0	6	15	0	2	13	0	4	9
SO_4	6	10	15	0.0	1.5	2.6	6	12	22
Color	5	10	20	7	19	30	2	9	22
Turb.	3	11	18	1	9	20	2	8	19
Iron		0.06*		0.10	0.18	0.35		0.10*	
Copper		0.003*		0.000	0.000	0.002		0.000*	
Aluminum		0.00*		0.00	0.07	0.30		0.02*	
Calcium		16*		8	12	18		25*	
Magnesium		2*		0.0	0.7	2.0		0.8*	
Na		3.0*		2.0	3.5	5.0		9*	
K		1.5*		0.6	3.1	9.0		2.0*	
Total Solids	95	122	156	50	97	164	70	109	185
Conductivity	110	140	227	51	73	94	104	156	231
Zinc		0.2*				0.2		0.1*	
Lead		0.0*				0.0		0.0*	
Manganese		0.000*				0.000		0.000*	
Silver		0.000*				0.000		0.000*	

1 Jan
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3 Mar.
4 Apr.

5 May
6 June
7 July
8 Aug.

9 Sept.
10 Oct.
11 Nov.
12 Dec.
* Only one sample measured

Station	Glacier View Dam Site			Canyon Creek Dam Site			Coram Dam Site		
Month Recorded	3,5,6,7,8,9,11,12			3,5,6,7,8,9,11,12			6,7,8,9,12		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (100 cfs)	98.6	269.8	535.1	4.5	5.2	6.7	0.010	0.053	0.151
Temp. °F	39.7	60.3	66.9	40.8	58.9	67.6	41.2	63.7	77.9
D.O.	9.7	11.2	13.5	9.8	11.0	13.2	9.5	11.9	13.4
D.O. % Sat.	100	110	129	99	108	121	100	123	155
CO_2	0.0	0.7	2.0	0.0	0.0	1.0	0	0	0
pH	7.5	8.1	8.5	7.8	8.2	8.6	8.1	8.4	9.0
Alkalinity	48	66	80	52	60	81	61	162	234
HCO_3^-	48	64	80	47	55	69	61	131	214
$CO_3^=$	0	2	14	0	5	16	0	31	74
Hardness	55	69	83	36	45	62	64	119	178
Carb.	48	65	80	36	45	62	61	119	178
Noncarb.	0	4	11	0	0	0	0	0	3
SO_4	6	12.9	23	0	1	5	4	11	17
Color	1	10	32	0	8	15	3	13	30
Turb.	2	10	26	1	5	18	2	6	17
Iron		0.10*			0.05*			0.10*	
Copper		0.005*			0.000*			0.000*	
Aluminum		0.02*			0.00*			0.00*	
Calcium		17*			7*			21*	
Magnesium		4.0*			1.8*			3.5*	
Na		4.0*			10*			6*	
K		1.3*			2.2*			2.2*	
Total Solids	75	127	190	86	103	135	85	201	330
Conductivity	111	159	235	101	120	141	127	297	471
Zinc		0.0*			0.0*			0.0*	
Lead		0.0*			0.0*			0.0*	
Manganese		0.000*			0.000*			0.000*	
Silver		0.000*			0.000*			0.000*	

1 Jan.
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3 Mar.
4 Apr.

5 May
6 June
7 July
8 Aug.

9 Sept.
10 Oct.
11 Nov.
12 Dec.
* Only one sample measured

Station	Hungry Horse Dam			Swan Lake Dam Site			Kerr Dam		
Month Recorded	3,4,5,6,7,8,9,10,11,12			3,4,5,6,7,8,9,10,11,12			6,7,8,9		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	91	251	479	19.9	39.1	110.2	-	-	-
Temp. °F	41.0	59.5	69.4	34.7	64.0	77.2	59.9	68.0	75.2
D.O.	7.8	10.5	12.5	7.9	10.2	13.3	8.25	9.16	10.95
D.O. % Sat.	83	104	126	91	106	142	90	100	122
CO_2	0.0	0.5	2.0	0.0	0.2	2.0	0	0	0
pH	7.5	8.2	8.9	7.5	8.6	9.1	8.30	8.62	8.85
Alkalinity	54	68	89	40	101	161	100	139	234
HCO_3^-	54	66	85	40	84	157	90	125	206
$CO_3^=$	0	2	17	0	17	56	0	14	28
Hardness	54	72	107	39	100	160	94	110	132
Carb.	54	68	89	39	99	160	94	110	132
Noncarb.	0	4	22	0	1	11	0	0	0
SO_4	8	15	24	6	41	137	13	21	33
Color	2	12	30	5	19	38	3	9	20
Turb.	1	13	35	2	19	61	2	12	30
Iron	0.00	0.06	0.24	0.01	0.16	0.40	0.00	0.26	0.50
Copper	0.00	0.009	0.10	0.00	0.014	0.20	0.00	0.001	0.01
Aluminum	0.005	0.010	1.00	0.00	0.05	0.30	0.01	0.16	1.00
Calcium	7	20	47	10	27	50	24	31	43
Magnesium	0.1	3.5	8.0	0.2	2.9	8.8	0.4	2.3	7.4
Na	3.5	8.0	15.0	5.0	25.4	38.0	16	23	34
K	0.8	2.4	7.0	0.8	3.4	10.0	3.8	6.8	13.0
Total Solids	55	123	320	86	220	605	150	196	280
Conductivity	119	167	256	97	298	510	228	300	407
Zinc			0.0			0.0	0.0	0.02	0.1
Lead			0.0			0.0			0.0
Manganese			0.0			0.0			0.00
Silver			0.00			0.00			0.00

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Station	Paradise Dam Site			Thompson Falls Dam			Trout Creek Dam Site		
Month Recorded	6,7,8,9,10,11,12, 3,4,5,			3,4,5,6,7,8,9,10,11,12			6,7,8,9		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	65	202	447	1.50	3.92	14.20	-	-	-
Temp. °F	40.6	57.0	67.3	35.1	63.1	77.2	57.7	64.8	71.1
D.O.	8.55	10.65	12.97	7.9	10.2	13.6	8.15	9.08	9.5
D.O. % Sat.	88	105	116	83	107	149	86	95	122
CO_2	0.0	0.6	1.5	0	0.6	4.0	0	1.7	2.5
pH	6.65	8.06	8.60	7.30	8.17	8.90	7.2	7.8	8.5
Alkalinity	52	62	75	48	114	158	56	106	150
HCO_3^-	52	61	75	48	103	158	56	106	150
$CO_3^=$	0	0.5	16	0	11	30	0	0	0
Hardness	56	68	91	46	97	133	47	88	120
Carb.	52	61	75	46	97	133	47	88	120
Noncarb.	0	7	22	0	0	0	0	0	0
$SO_4^=$	6	9	23	0	16	28	0.0	14	24
Color	0	7	20	4	15	40	5	15	25
Turb.	1	8	22	2	23	110	5	16	30
Iron	0.00	0.17	0.60	0.00	0.09	0.30			
Copper	0.00	0.002	0.01	0.00	0.009	0.10			
Aluminum	0.00	0.18	1.50	0.00	0.08	1.00			
Calcium	12.0	18.6	24.0	1.0	23.0	51.0			
Magnesium	0.1	2.9	6.0	0.2	3.4	9.0			
Na	0.5	1.8	4.0	1.5	15.9	25.5			
K	0.4	1.2	2.0	0.2	3.3	12.0			
Total Solids	60	102	270	133	206	310	120	194	280
Conductivity	114	141	193	115	256	377	119	228	331
Zinc			0.0			0.0			
Lead			0.0	0.0	0.0	0.2			
Manganese			0.00			0.00			
Silver			0.00			0.00			

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Station	Noxon Rapids Dam			Cabinet Gorge Dam			Priest River #4 Dam Site		
Month Recorded	3,5,6,7,8,9,12			6,7,8,9			6,7,8,9		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	-	-	-	0.19	1.83	5.16	2.54	3.58	5.53
Temp. °F	34.7	58.2	67.5	51.6	58.0	63.8	54.4	59.0	67.3
D.O.	8.95	10.2	12.7	9.70	10.50	11.95	9.35	10.24	11.8
D.O. % Sat.	86	99	119	91	99	117	90	100	123
CO_2	0.0	1.3	3.0	0.0	0.9	2.0	0.5	1.1	1.7
pH	7.30	7.72	8.6	7.20	7.75	8.50	7.3	7.7	8.3
Alkalinity	33	51	73	26	35	46	35	46	53
HCO_3^-	33	51	73	26	34	46	35	46	53
$CO_3^=$	0	0.2	4.0	0.0	0.5	4.0	0	0	0
Hardness	30	47	65	20	32	40	34	39	45
Carb.	30	46	65	20	31	40	34	39	45
Noncarb.	0.0	1.3	12.0	0.0	0.5	5.0	0	0	0
SO_4	0.0	3.1	6.0	0	2	6	0.0	0.4	3.0
Color	3	11	27	2	10	20	3	11	20
Turb.	1	6	16	2	4	12	2	5	12
Iron		0.10*							
Copper		0.000*							
Aluminum		0.00*							
Calcium		14*							
Magnesium		0.5*							
Na		7.0*							
K		1.2*							
Total Solids	50	96	250	45	73	130	51	75	105
Conductivity	70	110	173	56	74	93	78	93	106
Zinc		0.0*							
Lead		0.0*							
Manganese		0.00*							
Silver		0.00*							

1 Jan. 2 Feb. 3 Mar. 4 Apr. 5 May 6 June 7 July 8 Aug. 9 Sept. 10 Oct. 11 Nov. 12 Dec.
* Only one sample measured

Station	Albernie Falls Dam			Boundary Dam Site			Leland Glen Dam Site		
Month Recorded	3,5,6,7,8,9,10,11,12			1,2,3,4,5,6,7,8,9,10,11,12			3,5,6,7,8,9,11,12		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	0.30	2.74	4.78	0.85	4.84	19.90	63.1	195.0	436.7
Temp. °F	35.1	54.0	66.7	32.0	52.2	67.3	37.2	56.7	63.6
D.O.	9.10	10.35	13.40	9.20	11.20	14.20	10.7	12.3	15.0
D.O. % Sat.	88	95	115	93	102	117	10.7	118	132
CO_2	0.5	1.2	4.0	0	1.3	2.5	0.0	1.1	2.0
pH	7.0	7.5	8.4	6.90	7.52	9.05	7.5	7.7	8.3
Alkalinity	21	29	46	11.0	25.4	69.5	57	62	70
HCO_3^-	21	29	46	11.0	25.0	69.5	57	62	70
$CO_3^=$	0	0	0	0.0	0.5	8.0	0	0	0
Hardness	19	29	49	7	24	70	63	71	96
Carb.	19	27	46	7	23	59	57	62	70
Noncarb.	0	2.0	11	0	2	15	0	9	26
SO_4	0.0	1.9	6.0	0.0	2.1	4.6	0	8	16
Color	0	9	20	0	9	48	0	8	20
Turb.	0	12	76	1	12	80	1	5	9
Iron	0.00	0.13	0.50	0.00	0.04	0.20			
Copper	0.000	0.003	0.030	0.000	0.001	0.010			
Aluminum	0.00	0.18	1.30	0.00	0.01	0.03			
Calcium	0.5	14.2	60.0	4.0	7.7	13.0			
Magnesium	0.1	1.2	3.0	0.1	2.0	4.6			
Na	0.0	2.8	11.5	1.0	1.9	4.0			
K	0.2	1.6	7.0	0.4	1.6	3.0			
Total Solids	17	50	119	19	56	270	50	86	123
Conductivity	43	63	167	29	56	118	115	143	175
Zinc		0.0	0.05			0.0*			
Lead		0.0	0.0			0.0*			
Manganese			0.00			0.00*			
Silver			0.00			0.00*			

1 Jan. 2 Feb. 3 Mar. 4 Apr. 5 May 6 June 7 July 8 Aug. 9 Sept. 10 Oct. 11 Nov. 12 Dec.
* Single observation

Station	Springston Dam Site			Long Lake Dam			Grand Coulee Dam		
Month Recorded	1954-6,7,8,9,11,12 1955-3,5,6,7,8,9			1954 - 6,7,8,9,11,12 1955 - 3,5,6,7,8,9			1954 - 7, 8, 9		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	1.26	4.70	14.00	51	189	425	1.7	2.7	3.2
Temp. °F	32.2	61.0	72.9	35.8	55.8	62	56.9	59.2	62.4
D.O.	7.80	9.70	13.80	9.05	11.45	13.55	9.65	10.45	11.35
D.O. % Sat.	84.0	96.2	104.0	87	108	128	93	103	110
CO_2	0	1.0	2.5	0.5	1.1	3.0	0	0.9	3
pH	7.3	7.9	8.6	6.9	7.4	8.4	7.5	7.8	8.2
Alkalinity	40	82	123	55	62	79	59	62	68
HCO_3^-	40	81	123	55	62	79	59	62	68
$CO_3^=$	0	0.7	12	0	0	0	0	0	0
Hardness	22	85	132	63	70	91	64	67	70
Carb.	22	78	116	55	61	68	59	62	64
Noncarb.	0	7	31	0	9	23	0	6	9
SO_4	7	17	26	4	9	16	6	9	17
Color	2	14	40	0	7	20	0	10	20
Turb.	1	11	45	0	4	10	1	3	5
Iron	0.01	0.12	0.30	0.00	0.30	1.00			
Copper	0.00	0.006	0.02	0.00	0.002	0.01			
Aluminum	0.00	0.01	0.02	0.00	0.08	0.50			
Calcium	18	23	29	13	22	40			
Magnesium	0.2	0.7	1.5	0.2	1.4	3.6			
Na	3.0	4.0	6.0	0.0	1.5	4.0			
K	1.2	2.1	3.0	0.6	1.1	2.0			
Total Solids	65	130	173	50	84	215	65	89	155
Conductivity	88	190	284	117	138	178	128	136	142
Zinc	0.0	0.1	0.3	0.0	0.0	0.2			
Lead			0.0			0.0			
Manganese			0.00			0.00			
Silver			0.00			0.00			

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8 Aug.
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10 Oct.
11 Nov.
12 Dec.
* Only one sample measured

Station	Grand Coulee Equalizing Res.			Chief Joseph Dam			Similkameen Dam Site		
Month Recorded	1954 - 6,7,8,9, 1955 - 6,7,8,9			1954 - 7,8,9 1955 - 3			1954 - 7,8,9,11,12 1955 - 3,5		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	1.70	3.21	6.60	-	-	-	0.092	0.094	0.095
Temp. °F	61.3	64.8	70.4	41.4	66.0	75.7	45.7	55.7	62.0
D.O.	8.25	9.28	9.95	6.0	10.7	15.5	9.6	11.12	13.9
D.O. % Sat.	91	97	101	70	113	182	88	106	142
CO_2	0	0.6	1.2	0	0	0	0	2	4.5
pH	7.7	8.0	8.5	7.8	8.5	9.2	7.5	7.9	8.1
Alkalinity	64	72	82	110	191	230	115	164	205
HCO_3^-	64	71	82	110	163	212	115	164	205
$CO_3^=$	0	0	0	0	28	72	0	0	0
Hardness	62	74	82	128	149	165	129	134	148
Carb.	62	71	82	110	145	165	129	134	145
Noncarb.	0	2	13	0	5	45	0	0.2	3
SO_4	6	12	21	20	27	44	7	23	28
Color	1	8	20	10	53	180	0	6	15
Turb.	1	4	10	16	56	230	2	5	10
Iron		0.00*		0.10	0.10	0.10	0.00	0.10	0.20
Copper		0.000*		0.00	0.00	0.00	0.00	0.005	0.01
Aluminum		0.5*		0.05	0.35	0.70	0.01	0.01	0.01
Calcium		15*		32	38	45	23	25	26
Magnesium		1.0*		0.50	0.75	1.00	1.00	1.25	1.50
Na		1.0*		25	28	32	19	21	24
K		1.5*		5.0	5.2	5.4	5.4	5.5	5.6
Total Solids	75	101	165	245	343	429	205	250	320
Conductivity	135	162	197	235	380	474	322	374	429
Zinc		0.0*				0.0			0.1
Lead		0.0*				0.0			0.0
Manganese		0.00*				0.00			0.00
Silver		0.00*				0.00			0.00

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8 Aug.
9 Sept.
10 Oct.
11 Nov.
12 Dec.
* Only one sample measured

Station	Okanogan Lake Dam			Wells Dam Site			Lake Cheland Dam		
Month Recorded	1954- 6,7,8,9,11,12 1955- 3,5,			1954- 6,7,8,9			1954- 6,7,8,9 1955- 6,7,8,9		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	0.049	0.077	0.096	-	-	-	0.35	0.54	0.73
Temp. °F	35.4	61.5	76.5	63.0	65.3	68.7	63.9	68.3	73.8
D.O.	7.3	10.5	12.9	9.00	10.00	10.65	7.75	8.82	9.75
D.O. % Sat.	69	106	136	97	105	113	81	97	110
CO_2	0	0.2	3	0	0.04	0.5	0	0	0
pH	7.6	8.3	8.9	8.0	8.2	8.3	8.2	8.5	8.9
Alkalinity	139	168	260	71	85	129	107	142	186
HCO_3^-	111	156	260	71	84	127	43	128	166
$CO_3^=$	0	12	44	0	0.7	2	0	14	28
Hardness	91	140	210	72	80	96	99	111	129
Carb.	71	140	210	71	78	90	99	111	129
Noncarb.	0	1.3	20	0	1.7	9	0	0	0
SO_4	27	48	85	6	17	25	13	21	29
Color	5	19	60	1	8	15	3	11	25
Turb.	4	22	130	2	9	27	5	11	20
Iron	0.01	0.07	0.10				0.10	0.24	0.40
Copper	0.000	0.003	0.008				0.000	0.002	0.010
Aluminum	0.00	0.01	0.01				0.02	0.13	0.40
Calcium	22	24	28				21	37	56
Magnesium	0.8	1.3	2.0				0.5	2.6	7.4
Na	24	38	58				16	20	24
K	4.2	5.1	7.0				4.2	7.2	14
Total Solids	255	310	411	60	128	235	110	190	242
Conductivity	330	412	710	164	179	212	248	311	386
Zinc			0.0						0.0*
Lead			0.1						0.0*
Manganese			0.00						0.00*
Silver			0.00						0.00*

1 Jan. 5 May 9 Sept.
2 Feb. 6 June 10 Oct.
3 Mar. 7 July 11 Nov.
4 Apr. 8 Aug. 12 Dec.
* Only one sample measured

Station	Rocky Reach Dam			Chiwawa Dam Site			Plain Dam Site		
Month Recorded	1954- 7,8,9 1955- 6,7,8,9			1954-7,8,9			1954-6,7,8,9		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	0.025	0.043	0.055	0.202	0.258	0.313	0.025	0.029	0.037
Temp. °F	60.3	66.3	70.3	62.8	68.3	72.5	56.6	72.9	86.9
D.O.	8.95	9.45	10.55	9.15	9.68	10.25	7.35	9.50	9.85
D.O. % Sat.	95	101	118	98	106	115	89	101	118
CO_2	0	0	0	0	0	0	0	0	0
pH	7.90	8.36	8.65	8.2	8.44	8.6	8.3	8.6	8.8
Alkalinity	63	74	80	129	160	193	306	329	350
HCO_3^-	55	71	80	113	144	169	244	280	309
$CO_3^=$	0	3	8	0	16	24	16	49	76
Hardness	74	77	84	101	113	132	150	167	180
Carb.	63	73	78	101	113	132	150	167	180
Noncarb.	0	4	12	0	0	0	0	0	0
SO_4	9	13	21	23	25	28	70	162	420
Color	2	9	20	5	13	25	15	35	65
Turb.	2	13	60	4	14	32	20	33	60
Iron	0.05	0.15	0.30						
Copper	0.000	0.011	0.050						
Aluminum	0.01	0.24	1.00						
Calcium	15	23	32						
Magnesium	0.2	1.1	2.4						
Na	1	4	6						
K	1.4	3.2	9.0						
Total Solids	71	101	195	175	210	241	595	657	804
Conductivity	136	164	183	308	337	416	797	842	895
Zinc			0.0						
Lead			0.0						
Manganese			0.00						
Silver			0.00						

1 Jan. 5 May 9 Sept.
2 Feb. 6 June 10 Oct.
3 Mar. 7 July 11 Nov.
4 Apr. 8 Aug. 12 Dec.

Station Month Recorded	Tumwater Canyon Dam Site 1954-6,7,8,9,11,12 1955-3,5,6,7,8,9 1956-4,5,6,7,9,10,11,12			Rock Island Dam 1954-6,7,8,9,11,12 1955-3,5,6,7,8,9 1956-4,5,6,7,8,9,10,11,13			O'Sullivan Dam 1954-6,7,8,9 1955-5,6,7,8,9		
Constituents	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Flow (1000 cfs)	0.016	0.034	0.060	42	191	419	0.080	0.173	0.270
Temp. °F	34.2	66	84.7	39.6	58.6	68.7	58.0	66.6	72.9
D.O.	7.60	9.68	14.10	9.6	11.8	15.8	8.35	9.37	10.75
D.O. % Sat.	85	101	117	92	115	144	93	100	112
CO_2	0	0	0	0.00	0.94	9.00	0	0.03	0.50
pH	8.20	8.65	9.00	6.30	8.00	8.90	8.00	8.37	8.70
Alkalinity	187	315	403	56	61	71	65	77	91
HCO_3^-	166	276	373	0	58	71	60	72	83
$CO_3^=$	6	36	100	0	1	13	0.	5	10
Hardness	110	196	230	56	66	94	73	80	93
Carb.	110	196	230	53	60	71	65	76	89
Noncarb.	0	0	0	0	6	23	0	4	13
SO_4	33	116	220	4	10	19	6	16	33
Color	15	39	125	0	9	22	0	10	20
Turb.	25	151	440	0	9	31	2	10	20
Iron	0.00	0.20	0.80	0.00	0.09	0.52	0.05	0.14	0.20
Copper	0.000	0.001	0.004	0.000	0.007	0.040	0.000	0.010	0.040
Aluminum	0.000	0.06	0.50	0.00	0.05	0.20	0.005	0.021	0.050
Calcium	1	39	71	17.0	20.8	26.4	21	31	48
Magnesium	0.1	5.0	18.0	0.3	1.9	6.0	0.3	2.1	6.0
Na	2	105	135	0.5	7.8	20.0	2.5	4.9	7.0
K	3.9	17.8	50	0.6	1.4	2.6	1.2	3.5	9.0
Total Solids	275	706	1655	61	95	182	67	108	159
Conductivity	445	878	1180	116	145	190	143	175	217
Zinc			0.0			0.0			0.0*
Lead			0.0			0.0			0.0*
Manganese			0.00			0.00			0.00*
Silver			0.00			0.00			0.00*

1 Jan. 2 Feb. 3 Mar. 4 Apr.
5 May 6 June 7 July 8 Aug.
9 Sept. 10 Oct. 11 Nov. 12 Dec.
* Only one sample measured

Station Month Recorded	Wanapum Dam Site 1954-6,7,8,9 1955-3,5,6,7,8,9 1956-4,5,6,7,8,9,10,11,12,1		
Constituents	Min.	Avg.	Max.
Flow (1000 cfs)	69	193	445
Temp. °F	37.8	57.0	64.6
D.O.	9.8	11.6	15.2
D.O. % Sat.	94	110	121
CO_2	0	1.3	2.5
pH	7.2	7.81	8.3
Alkalinity	50	59	70
HCO_3^-	50	59	70
$CO_3^=$	0	0	0
Hardness	54	64	92
Carb.	50	58	70
Noncarb.	0	6	22
SO_4	4	9	21
Color	0	8	20
Turb.	1	9	35
Iron			
Copper			
Aluminum			
Calcium			
Magnesium			
Na			
K			
Total Solids	49	86	155
Conductivity	110	129	171
Zinc			
Lead			
Manganese			
Silver			

1 Jan. 2 Feb. 3 Mar. 4 Apr.
5 May 6 June 7 July 8 Aug.
9 Sept. 10 Oct. 11 Nov. 12 Dec.

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Cowlitz River at Castle Rock Number: 1 Designation: CC-85.2

Period of Summary: 1954-1955

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[1]	July[1]	Aug.[1]	Sept.[1]	Oct.	Nov.	Dec.[1]
Avg. Flow x 10^3			5.7		12.8	17.7	9.8	4.3	3.1			5.7
No. Sample Composites			1		1	2	3	5	2			1
Water Temp. °F			42.8		49.5	53.4	56.8	57.8	57.2			42.8
Diss. Oxygen			12.1		10.4	10.9	10.3	10.6	10.2			12.1
% D. O. Satur.			97		96	101	99	103	98			97
Carbon Dioxide			1		1.5	2.0	1.7	1.2	1.3			1
pH[3]			7.1		7.1	7.1	7.07	7.2	7.15			7.1
Ammonia NH_3			0.05		0	-	-	T	T			0.05
Total Alk. $CaCO_3$			23		20	20	21	27	29			23
HCO_3^-			23		20	20	21	27	29			23
$CO_3^=$			0		0	0	0	0	0			0
Total Hard. $CaCO_3$			28		20	15	17	27	24			26
Carb. Hard. $CaCO_3$			23		20	15	17	27	24			23
Non-Carb. Hard.			5		0	0	0	0	0			3
Sulfates $SO_4^=$			T		1	T	2.7	1.6	1.5			0
Color			18		22	13	15	14	7			6
Turbidity			6		7	15	8	7	5			1
Total Iron			-		-	-	0.40	-	-			-
Copper			-		-	-	0	-	-			-
Zinc			-		-	-	0	-	-			-
Lead			-		-	-	0	-	-			-
Aluminum			-		-	-	0	-	-			-
Calcium			-		-	-	8.0	-	-			-
Magnesium			-		-	-	0.2	-	-			-
Sodium			-		-	-	2.0	-	-			-
Potassium			-		-	-	1.80	-	-			-
Manganese			-		-	-	0	-	-			-
Silver			-		-	-	0	-	-			-
Total Solids			32		42	43	43	47	78			45
Cond. umhos. 25°			62		44	42	48	60	73			67

1 1954
2 1955
3 See discussion

Station: Columbia River at Cathlamet Number: 2 Designation: C-39.5

Period of Summary: 1954-1955

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.[1]
Avg. Flow x 10^3			146		257	565	416	215	155		125	124
No. Sample Composites			1		1	1	5	7	6		1	1
Water Temp. °F			41.4		55.0	58.1	62.3	66.0	64.5		51.1	41.6
Diss. Oxygen			12.5		10.2	11.4	11.3	9.6	9.3		10.5	11.7
% D. O. Satur.			98		96	111	113.5	104	96.5		90	92
Carbon Dioxide			1.5		2	1	0.9	0.6	0.5		1.0	2
pH[3]			7.5		7.5	7.35	7.88	7.95	7.9		7.9	7.4
Ammonia NH_3			0.2		0.04-	0.32	T	T	T		0	0
Total Alk. $CaCO_3$			78		55	47	52	65	65		70	57
HCO_3^-			78		55	47	51	65	65		70	57
$CO_3^=$			0		0	0	1	0	0		0	0
Total Hard. $CaCO_3$			61		57	53	59	68	71		71	64
Carb. Hard. $CaCO_3$			61		55	47	52	65	65		70	57
Non-Carb. Hard.			0		2	6	7	3	6		1	7
Sulfates $SO_4^=$			18		16	8	7.9	14.4	12.1		13	13
Color			15		25	10	15	12	9		5	15
Turbidity			12		3	20	14	6	13		4	10
Total Iron			0.4		0.05	0.25	0.12	0.15	0.15		0.02	0.30
Copper			0.2		0	0.008	0.020	0	0.06		0.016	0
Zinc			0		0	-	0	0	0		0	0
Lead			0		0	-	0	0	0		0	0
Aluminum			0		0	0.10	0.015	0.5	0		0.01	0.05
Calcium			17		17	20	17.5	17	18		21	18
Magnesium			0.5		1.0	0.2	2.4	1.1	0.7		0.6	0.6
Sodium			7.0		12.0	6.0	1.0	2.7	4.0		16.0	10.0
Potassium			0.8		1.4	1.2	1.5	1.5	1.4		2.5	15.0
Manganese			0		0	-	0	0	0		0	0
Silver			0		0	-	0	0	0		0	0
Total Solids			77		89	102	100	78	114		110	85
Cond. Umhos. 25°			149		130	110	125	150	173		197	176

1 1954
2 1955
3 See discussion

Station: Lewis River Below Merwin Dam Number 3 Designation: CL-108.3

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.[1]
C.F.S. Ave. Flow x 10^3			2.8		4.0	7.0	4.4	1.8	2.2		3.9	5.5
No. Sample Composites			1		1	2	6	7	5		1	1
Water Temp. °F			40.6		45.0	51.2	51.2	51.3	53.5		52.5	45.2
Diss. Oxygen			12.2		11.6	11.5	10.7	10.0	9.0		8.9	11.0
% D. O. Satur.			95		95	103	96	89.5	82.4		81	92
Carbon Dioxide			1		1.5	1.2	1.8	1.8	3.1		2.0	1.5
pH[3]			7.0		7.0	6.85	6.92	6.88	6.9		6.8	7.0
Ammonia NH_3			0.40		0.04-	0.25	0.14	T	0.06		0	0
Total Alk. $CaCO_3$			16		18	16.5	16.6	18.3	17.2		22	17
HCO_3^-			16		18	16.5	16.6	18.3	17.2		22	17
$CO_3^=$			0		0	0	0	0	0		0	0
Total Hard. $CaCO_3$			14		15	39.5	16.9	23.1	14.2		17	15
Carb. Hard. $CaCO_3$			14		15	16.5	16.6	18.3	14.2		17	15
Non-Carb. Hard.			0		0	23	0.3	4.8	0		0	0
Sulfates $SO_4^=$			1		T	0.65	1.25	0.36	0.7		0	0
Color			7.5		5	7.0	8	8	4		4	3
Turbidity			2.9		5	2.5	4.4	4.5	5.6		2	1
Total Iron			0.40		0.10	0.05	0.70	0.15	0.04		0.05	-
Copper			0.20		0	0.008	0.010	0	0.02		0.006	-
Zinc			0		0	-	0	0	0.3		0	-
Lead			0		0	-	0	0	0		0	-
Aluminum			0.10		0.01	0.05	0.01	0.01	0.01		0	-
Calcium			4		11	12	4	11	9.5		6	-
Magnesium			0		0.2	0	6	0	0.4		1.0	-
Sodium			3.0		6.0	3.0	1.0	.25	1.0		4.0	-
Potassium			0		0.6	0.6	1.1	4.2	1.0		1.2	-
Manganese			0		0	-	0.001	0	0		0	-
Silver			0		0	-	0	0	0		0	-
Total Solids			13		21	31.5	42	50	49		30	30
Cond. umhos. 25°			45		37.8	38.0	36.8	39.3	39.6		57	51

1 1954
2 1955
3 See discussion

Station: Lewis River below Yale Dam Number: 4 Designation: CL-122.5

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.[1]
C.F.S. Avg. Flow x 10^3			-		-	-	-	-	-			-
No. Sample Composites			1		1	2	6	7	4			1
Water Temp. °F			39.9		49	47.5	50.1	55.6	54.0			42.3
Diss. Oxygen			12.2		11.8	11.2	11.0	10.3	9.2			10.8
% D. O. Satur.			93.5		102	95.5	98.0	98.0	85			87
Carbon Dioxide			1.5		1.5	1.75	1.25	1.4	1.6			2
pH[3]			6.9		7.1	6.88	6.91	7.03	6.98			6.9
Ammonia NH_3			0.14		0.04-	0.22	0.08	0.59	T			T
Total Alk. $CaCO_3$			17		21	17.3	16.3	18.6	19.2			18
HCO_3^-			17		21	17.3	16.3	18.6	19.2			18
$CO_3^=$			0		0	0	0	0	0			0
Total Hard. $CaCO_3$			16		18	20	17.4	19.2	17.3			20
Carb. Hard. $CaCO_3$			16		18	17.3	16.3	18.6	17.3			18
Non-Carb. Hard.			0		0	2.7	1.1	0.6	0			2
Sulfates $SO_4^=$			1		T	0.8	1.2	0.4	1.2			0
Color			7.5		5	7.5	7.5	9	4			2
Turbidity			2.3		T	3	2.8	3.1	5.5			0
Total Iron			-		-	-	-	1.5	-			-
Copper			-		-	-	-	0	-			-
Zinc			-		-	-	-	0	-			-
Lead			-		-	-	-	0	-			-
Aluminum			-		-	-	-	0.01	-			-
Calcium			-		-	-	-	12.0	-			-
Magnesium			-		-	-	-	0	-			-
Sodium			-		-	-	-	3.5	-			-
Potassium			-		-	-	-	1.4	-			-
Manganese			-		-	-	-	0	-			-
Silver			-		-	-	-	0	-			-
Total Solids			8		22	34.5	42.5	52	55			-
Cond. umhos. 25°			41.5		36.4	38.0	34.2	39.4	40.7			47

1 1954
2 1955
3 See discussion

Station: Lewis River Above Yale Dam Number: 5 Designation: CL-137

Period of Summary: 1954-1955

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.[1]
Avg. Flow x 10^3			1.32		4.44	4.28	2.92	1.31	1.00			2.41
No. Sample Composites			1		1	1	6	7	4			1
Water Temp. °F			39.0		43.7	47.0	52.2	52.5	50.9			41.2
Diss. Oxygen			12.8		11.4	11.5	10.9	10.8	10.5			12.6
% D. O. Satur.			97		93	98	99	97.8	93.5			99
Carbon Dioxide			1.5		1.0	1.0	1.3	1.4	1.5			1
pH[3]			7.0		7.0	7.0	7.13	7.4	7.32			7.0
Ammonia NH_3			0.12		0.04−	0.23	0.15	0.08	5.3			0
Total Alk. $CaCO_3$			22		19	16	17.2	25.4	26.8			20
HCO_3^-			22		19	16	17.2	25.4	26.8			20
$CO_3^=$			0		0	0	0	0	0			0
Total Hard. $CaCO_3$			20		16	17	19.4	22.8	21.0			20
Carb. Hard. $CaCO_3$			20		16	16	17.2	22.8	21.0			20
Non-Carb. Hard.			0		0	1	2.2	0	0			0
Sulfates $SO_4^=$			1		T	1.5	1.3	4.8	2.6			0
Color			5		5	7	8	8	5			0
Turbidity			3.1		4	4	4.5	9.5	11.5			0
Total Iron			-		-	0.15	-	0.12	0.06			-
Copper			-		-	0.008	-	0	0.001			-
Zinc			-		-	-	-	0	0			-
Lead			-		-	-	-	0	0			-
Aluminum			-		-	0.05	-	0.255	0.015			-
Calcium			-		-	10	-	5.5	4.75			-
Magnesium			-		-	0.0	-	0.7	0.15			-
Sodium			-		-	5.0	-	2.5	4.5			-
Potassium			-		-	1.6	-	4.5	1.9			-
Manganese			-		-	-	-	0	0			-
Silver			-		-	-	-	0	0			-
Total Solids			48		21	38	52	77	91			20
Cond. umhos. 25°			58		36	33	39	57	61			55

1 1954
2 1955
3 See discussion

Station: Columbia River below Willamette[4] Number: 6 Designation: C-100

Period of Summary: 1954-1955

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[1]	July[1]	Aug.[1]	Sept.[1]	Oct.	Nov.[1]	Dec.[1]
Avg. Flow x 10^3			142.9		226.6	546.1	424	216.0	186.9		121.3	134.1
No. Sample Composites			1		1	2	4	3	1		1	1
Water Temp. °F			41.1		53.6	56.3	61.8	65.0	64.4		51.8	44.7
Diss. Oxygen			14.2		12.6	12.4	12.0	10.85	10.6		11.0	12.2
% D. O. Satur.			111		116	118.3	122	114.5	111.2		100	100
Carbon Dioxide			-		-	-	-	-	-		-	-
pH(3)			7.2		7.6	7.55	7.55	7.8	7.7		7.5	7.2
Ammonia NH_3			-		-	-	-	T	-		-	-
Total Alk. $CaCO_3$			72		68	57	60	68	65		68	74
HCO_3^-			72		68	57	60	68	65		68	74
$CO_3^=$			0		0	0	0	0	0		0	0
Total Hard. $CaCO_3$			-		-	-	58	73	71		-	-
Carb. Hard. $CaCO_3$			-		-	-	58	68	65		-	-
Non-Carb. Hard.			-		-	-	0	5	6		-	-
Sulfates $SO_4^=$			-		-	-	13	13	15		-	-
Color			-		-	-	17	13	4		-	-
Turbidity			10		15	15	12	6.7	3		5	5
Total Iron			-		-	-	-	-	-		-	-
Copper			-		-	-	-	-	-		-	-
Zinc			-		-	-	-	-	-		-	-
Lead			-		-	-	-	-	-		-	-
Aluminum			-		-	-	-	-	-		-	-
Calcium			-		-	-	-	-	-		-	-
Magnesium			-		-	-	-	-	-		-	-
Sodium			-		-	-	-	-	-		-	-
Potassium			-		-	-	-	-	-		-	-
Manganese			-		-	-	-	-	-		-	-
Silver			-		-	-	-	-	-		-	-
Total Solids			125		126	136	140	137	140		124	172
Cond. umhos, 25°			-		-	-	-	160	159		-	-

1 1954
2 1955
3 See discussion
4 Data From City of Portland, Oregon

Station: Columbia River above Willamette River Number: 7 Designation: C-104

Period of Summary: 1954(4) - 1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.
C.F.S.												
Avg. Flow x 10^3			116.3		200.2	530	420	197	140		111.5	
No. Sample Composites			1		1	3	6	5	4		1	
Water Temp. °F			41.1		53.7	57.0	61.1	54.6	64.7		51.9	
Diss. Oxygen			13.7		11.6	12.6	12.1	10.6	10.4		12.6	
% D. O. Satur.			108.		107	121	122	113	107		114	
Carbon Dioxide			-		-	2	0.7	0	0.5		-	
pH(3)			7.55		7.8	7.65	7.79	7.85	8.14		7.5	
Ammonia NH_3			-		-	0.23	0.22	0.11	0.38		-	
Total Alk. $CaCO_3$			69		64	54	56	66	69		77	
HCO_3^-			69		64	54	56	66	69		72	
$CO_3^=$			0		0	0	0	0	0		0	
Total Hard. $CaCO_3$			-		-	59	60	72	74		-	
Carb. Hard. $CaCO_3$			-		-	54	56	66	69		-	
Non-Carb. Hard.			-		-	5	4	6	5		-	
Sulfates $SO_4^=$			-		-	8	7.7	10.8	12.0		-	
Color			-		-	12	10	10	7		-	
Turbidity			10		15	13	15	8.0	7.5		5.0	
Total Iron			-		-	-	0.06	-	-		-	
Copper			-		-	-	0.003	-	-		-	
Zinc			-		-	-	0.2	-	-		-	
Lead			-		-	-	0.0	-	-		-	
Aluminum			-		-	-	0.0	-	-		-	
Calcium			-		-	-	16	-	-		-	
Magnesium			-		-	-	2	-	-		-	
Sodium			-		-	-	3.0	-	-		-	
Potassium			-		-	-	1.5	-	-		-	
Manganese			-		-	-	0	-	-		-	
Silver			-		-	-	0	-	-		-	
Total Solids			147		116	117	124	128	141		149	
Cond. umhos. 25°						110	102	159	176			

1 1954
2 1955
3 See discussion
4 1954 data from City of Portland, Oregon

Station: Willamette River near mouth Number: 8 Designation: CW-113.5

Period of Summary: 1954(4) - 1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.[1]
C.F.S.												
Avg. Flow x 10^3			18.3		27.7	15.8	10.0	7.0	10.0			-
No. Sample Composites			1		1	4	6	5	4			1
Water Temp. °F			44.7		55.3	58.4	64.3	69.5	63			43.8
Diss. Oxygen			10.5		9.3	7.3	6.0	4.0	5.6			10.5
% D. O. Satur.			87		88	70.6	62.5	44.6	57.4			86
Carbon Dioxide			-		-	4.5	5.2	10.3	7.1			-
pH(3)			6.7		6.9	7.0	6.8	7.02	6.94			6.8
Ammonia NH_3			-		-	0.25	0.26	0.32	0.13			-
Total Alk. $CaCO_3$			27		29	28	31	36	31			43
HCO_3^-			27		29	28	31	36	31			43
$CO_3^=$			0		0	0	0	0	0			0
Total Hard. $CaCO_3$			-		-	21	27	35	28			-
Carb. Hard. $CaCO_3$			-		-	21	27	35	28			-
Non-Carb. Hard.			-		-	0	0	0	0			-
Sulfates $SO_4^=$			-		-	2.6	1.0	1.6	1.4			-
Color			-		-	12	19	10	15			-
Turbidity			10		5.0	4.0	8.7	9.9	12			15
Total Iron			-		-	0.10	0.10	0.35	0.17			-
Copper			-		-	0.002	0	0	0			-
Zinc			-		-	-	0.2	-	0			-
Lead			-		-	-	0	-	0			-
Aluminum			-		-	0.30	0.01	0.02	0.017			-
Calcium			-		-	10	18	12	10.5			-
Magnesium			-		-	0	1.0	0.2	1.05			-
Sodium			-		-	3.0	2.0	4	4			-
Potassium			-		-	0.6	1.0	9	2.4			-
Manganese			-		-	-	0	-	0			-
Silver			-		-	-	0	-	0			-
Total Solids			77		67	76	98	102	122			108
Cond. umhos. 25°						51	66	85	71			-

1 1954
2 1955
3 See discussion
4 1954 data from City of Portland, Oregon

Station: Columbia R. Bonneville Dam at Power House Number: 9 Designation: C-145.3
Period of Summary: 1954 - 1955

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.[1]
Avg. Flow x 10^3			117		182	516	405	201	139		108	99
No. Sample Composites			1		1	2	6	7	6		1	1
Water Temp. °F			42.3		56.7	57.8	60.9	64.5	63.1		50.0	39.2
Diss. Oxygen			13.7		11.2	11.65	11.2	10.82	10.9		11.7	13.7
% D. O. Satur.			109		107	113	112	112	112		104	105
Carbon Dioxide			1		1	1.5	1	-	-		-	1.5
pH(3)			7.8		7.7	7.35	7.85	8.25	8.3		7.4	7.7
Ammonia NH_3			0.05		0.04	0.38	0.18	0.03	T		0	0.04
Total Alk. $CaCO_3$			73		60	51	54	67	71		80	79
HCO_3^-			73		60	51	54	62	67		80	79
$CO_3^=$			0		0	0	0	5	4		0	0
Total Hard. $CaCO_3$			81		67	55	60	70	73		82	83
Carb. Hard. $CaCO_3$			73		60	51	54	67	71		80	79
Non-Carb. Hard.			8		7	4	6	3	2		2	4
Sulfates $SO_4^=$			19		13	10.8	8.5	10.8	13.5		22	15
Color			8		22	13	11	10	6		2	2
Turbidity			5		13	8	10	6	8		3	5
Total Iron			-		-	-	-	-	0.10		-	-
Copper			-		-	-	-	-	0		-	-
Zinc			-		-	-	-	-	0.1		-	-
Lead			-		-	-	-	-	0		-	-
Aluminum			-		-	-	-	-	0.02		-	-
Calcium			-		-	-	-	-	25		-	-
Magnesium			-		-	-	-	-	0.8		-	-
Sodium			-		-	-	-	-	9.0		-	-
Potassium			-		-	-	-	-	2.0		-	-
Manganese			-		-	-	-	-	0		-	-
Silver			-		-	-	-	-	0		-	-
Total Solids			112		119	105	108	118	113		120	130
Cond. umhos. 25°			186		143	118	125	154	174		230	231

1 1954
2 1955
3 See discussion

Station: Columbia R. near Cascade Locks(4) Number: 10 Designation: C-148.9 and C-168
Period of Summary: 1954 - 1955

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.[1]
Avg. Flow x 10^3			118		213	517.0	405.0	201	139		108.49	98.64
No. Sample Composites			1		1	2	6	7	6		1	1
Water Temp. °F			42.1		-	58.0	61.2	64.6	63.2		50.0	39.7
Diss. Oxygen			13.35		11.13	11.45	11.0	10.75	10.95		11.3	13.5
% D. O. Satur.			106		105	111.5	109.5	112.5	113		100	103
Carbon Dioxide			1		1	1.5	0.3	0	0.5		-	2
pH(3)			7.8		7.7	7.55	7.89	8.32	8.4		7.9	7.7
Ammonia NH_3			0.04		0.04	0.22	0.16	0.03	0.20		0	0
Total Alk. $CaCO_3$			74		60	51	57	68	72		80	78
HCO_3^-			74		60	51	57	65	68		80	78
$CO_3^=$			0		0	0	0	3	4		0	0
Total Hard. $CaCO_3$			83		60	57	61	71	73		81	82
Carb. Hard. $CaCO_3$			74		60	51	57	68	72		80	78
Non-Carb. Hard.			9		0	6	4	3	1		1	4
Sulfates $SO_4^=$			23		18	13.9	8.8	13.1	13.1		15	15
Color			13		32	13	11	10	7		4	1
Turbidity			12		26	10	12	8	7		3	7
Total Iron			-		-	-	0.1	-	-		-	-
Copper			-		-	-	0.005	-	-		-	-
Zinc			-		-	-	0	-	-		-	-
Lead			-		-	-	0	-	-		-	-
Aluminum			-		-	-	0.02	-	-		-	-
Calcium			-		-	-	17	-	-		-	-
Magnesium			-		-	-	4	-	-		-	-
Sodium			-		-	-	4.0	-	-		-	-
Potassium			-		-	-	1.3	-	-		-	-
Manganese			-		-	-	0	-	-		-	-
Silver			-		-	-	0	-	-		-	-
Total Solids			106		151	122	124	131	125		135	135
Cond. umhos. 25°			188		144	117	128	158	178		221	235

1 1954
2 1955
3 See discussion
4 1954 Samples collected at Cascade Locks and 1955 collected at Underwood, Wash.

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Deechutes River at mouth Number: 11 Designation: CD-203.6

Period of Summary: 1954 - 1955

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[1]	July[1]	Aug.[1]	Sept.[1]	Oct.	Nov.[1]	Dec.[1]
Avg. Flow x 10^3			5.17		6.72	4.5	5.7	4.94	4.9		4.99	4.93
No. Sample Composites			1		1	1	3	5	2		1	1
Water Temp. °F			48.7		54.2	65.3	65.9	62.1	58.9		49.1	40.8
Diss. Oxygen			11.8		10.62	10.2	10.1	11.05	11.08		11.35	13.2
% D. O. Satur.			102.5		99	108	107.5	113.5	109		99	102
Carbon Dioxide			0		T	0	0	0.1	0		1	1
pH(3)			8.4		8.0	8.3	8.3	8.3	8.35		8.0	8.0
Ammonia NH_3			0.70		0.04-	-	0	T	T		0	T
Total Alk. $CaCO_3$			55		52	53	54	66	62		61	66
HCO_3^-			55-		52	47	49	58	57		61	66
$CO_3^=$			T		0	6	5	8	5		0	0
Total Hard. $CaCO_3$			42		42	46	38	45	43		60	62
Carb. Hard. $CaCO_3$			42		42	46	38	45	43		60	62
Non-Carb. Hard.			0		0	0	0	0	0		0	0
Sulfates $SO_4^=$			5		4	T	0.7	0.8	1		0	0
Color			8		17	5	10	9	4		2	0
Turbidity			9		18	4	2.3	4.2	4		1	3
Total Iron			-		-	-	0.05	-	-		-	-
Copper			-		-	-	0	-	-		-	-
Zinc			-		-	-	0	-	-		-	-
Lead			-		-	-	0	-	-		-	-
Aluminum			-		-	-	0	-	-		-	-
Calcium			-		-	-	7.0	-	-		-	-
Magnesium			-		-	-	1.8	-	-		-	-
Sodium			-		-	-	10	-	-		-	-
Potassium			-		-	-	2.2	-	-		-	-
Manganese			-		-	-	0	-	-		-	-
Silver			-		-	-	0	-	-		-	-
Total Solids			86		107	117	109	109	98		90	100
Cond. umhos. 25°			101		102	104	108	126	127		139	141

1 1954
2 1955
3 See discussion

Station: Umatilla River at mouth Number: 12 Designation: CU-2893

Period of Summary: 1954

C.F.S.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Avg. Flow x 10^3						0.32	0.060	0.042	0.038			0.135
No. Sample Composites						1	3	5	2			1
Water Temp. °F						57.8	61.9	71.0	62.8			41.2
Diss. Oxygen						11.15	12.0	11.85	11.85			12.7
% D. O. Satur.						108	120	131.5	122.5			100
Carbon Dioxide						0	0	0	0			0
pH(3)						8.1	8.2	8.65	8.3			8.2
Ammonia NH_3						-	0.1	0.02	0			0.14
Total Alk. $CaCO_3$						73	80	173	223			217
HCO_3^-						69	78	143	185			197
$CO_3^=$						4	2	30	40			20
Total Hard. $CaCO_3$						72	76	138	170			92
Carb. Hard. $CaCO_3$						72	76	138	170			92
Non-Carb. Hard.						0	0	0	0			0
Sulfates $SO_4^=$						13	7.7	12.2	12.0			11
Color						10	13	18	6			3
Turbidity						7	5	8.2	2.5			3
Total Iron						-	0.10	-	-			-
Copper						-	0	-	-			-
Zinc						-	0	-	-			-
Lead						-	0	-	-			-
Aluminum						-	0	-	-			-
Calcium						-	21	-	-			-
Magnesium						-	3.5	-	-			-
Sodium						-	6.0	-	-			-
Potassium						-	7.2	-	-			-
Manganese						-	0	-	-			-
Silver						-	0	-	-			-
Total Solids						133	139	208	313			280
Cond. umhos. 25°						162	127	339	381			471

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Columbia River at McNary Dam   Number: 13   Designation: C-2920

Period of Summary: 1954-1955-1956

	Jan.	Feb.	Mar.[2]	April[3]	May[2&2]	June[1&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[1&3]	Dec.[1]
C.F.S. Avg. Flow x 10^3			109	322	343	517	379	195	136	104	103	91.5
No. Sample Composites			1	1	2	2	8	10	7	2	2	1
Water Temp. °F			41	47	54.3	56.5	61	62.24	64.1	61.1	51.1	41
Diss. Oxygen			12.52	11.0	10.55	11.55	11.15	10.25	9.45	9.3	10.1	12
% D. O. Satur.			98	92	98.0	110.5	112	108.2	98.4	94	90	94
Carbon Dioxide			1	1.5	1.3	1.0	0.6	0.1	0.1	0	0.5	1
pH[4]			7.9	8.0	7.8	7.83	8.0	8.34	8.46	8.5	7.9	7.7
Ammonia NH_3			0.04	0.25	0.12	T	0.19	T	T	T	T	0
Total Alk. $CaCO_3$			85	56	60	59	59	72	70	82	85	85
HCO_3^-			85	56	60	59	59	68	65	73	85	85
CO_3^-			0	0	0	0	0	4	5	9	0	0
Total Hard. $CaCO_3$			90	58	59	60	65	72	77	86	98	82
Carb. Hard. $CaCO_3$			85	56	59	59	59	72	70	82	85	82
Non-Carb. Hard.			5	2	0	1	6	0	7	4	13	0
Sulfates $SO_4^=$			18	13	12	12.9	11.6	14.8	16.2	23	20	14
Color			18	30	22	20	11	10	10	12	4	2
Turbidity			12	25	17	20	12	11	9	20	8	2
Total Iron			0.30	-	0.05	0.06	0.02	0.19	0.19	0.01	0.00	0.05
Copper			0.100	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zinc			0.0	-	0.0	-	-	-	0.0	-	-	0.0
Lead			0.0	-	0.0	-	-	-	0.0	-	-	0.0
Aluminum			0.10	-	0.00	0.005	0.01	0.002	0.008	0.025	0.03	0.00
Calcium			20	-	7	12.0	18	21	30	23.5	13.5	23
Magnesium			1.5	-	0.1	3.6	1.0	3.2	4.9	7.4	5.8	0.6
Sodium			8.0	-	6.0	3.5	7.0	5.8	7.7	13.2	13.5	14.0
Potassium			1.0	-	0.8	1.2	2.0	4.3	1.7	2.1	4.7	1.8
Manganese			0.000	-	0.000	-	-	-	0.000	-	-	0.000
Silver			0.00	-	0.00	-	-	-	0.00	-	-	0.0
Total Solids			67	180	166	116	100	135	120	150	115	130
Cond. Umhos. 25°			187	130	129	130	135	167	182	228	240	255

1 1954
2 1955
3 1956
4 See discussion

Station: Snake River at Mouth   Number: 14   Designation: CS 326.2

Period of Summary: 1954-1955-1956

	Jan.	Feb.	Mar.[2]	April[3]	May[2&3]	June[2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[1&3]	Dec.[1]
C.F.S. Avg. Flow x 10^3			23.1	147	155	105	49	24	22	25.5	26	19.9
No. Sample Composites			1	1	2	2	9	10	8	2	2	1
Water Temp. °F			43.1	51.1	55.0	60.6	68.4	70.6	66.8	60.8	45	34.7
Diss. Oxygen			12.3	10.7	10.1	9.6	9.28	10.7	9.9	9.8	11.4	13.3
% D. O. Satur.			99	95.5	94.9	96	101.0	119	106	95	95	94
Carbon Dioxide			0	1.5	1.5	0.5	0.8	0	0	0	0	T
pH[4]			8.3	8.25	7.5	7.9	8.2	8.8	8.8	8.6	8.2	8.2
Ammonia NH_3			0.05	0.24	0.09	0.55	0.25	T	0.10	T	T	0
Total Alk. $CaCO_3$			115	47	44	51	64	114	128	131	127	161
HCO_3^-			111	47	44	51	57	85	104	117	115	157
CO_3^-			4	0	0	0	7	29	24	14	12	4
Total Hard. $CaCO_3$			116	40	43	48	59	108	120	130	135	160
Carb. Hard. $CaCO_3$			115	40	43	48	59	108	120	125	127	160
Non-Carb. Hard.			1	0	0	0	0	0	0	5	8	0
Sulfates SO_4			32	12	11.5	9.4	24	33	43	121	53	85
Color			28	38	28	20	16	18	19	20	10	5
Turbidity			12	30	43	28	20	18	25	28	15	5
Total Iron			0.40	-	0.25	0.13	-	0.16	0.01	0.035	0.01	0.1
Copper			0.200	-	0.000	0.08	-	0.000	0.001	0.000	0.01	0.000
Zinc			0.0	-	0.0	-	-	0.0	0.0	-	0.0	0.0
Lead			0.0	-	0.0	-	-	0.0	0.0	-	0.0	0.0
Aluminum			0.00	-	0.00	0.02	-	0.11	0.03	0.01	0.00	0.05
Calcium			25	-	17	13.3	-	27.1	37.5	38.6	30	28
Magnesium			2.0	-	0.4	2.10	-	4.0	4.9	5.8	0.8	1.4
Sodium			23	-	5.0	9.80	-	28.0	29.4	37.0	38	36
Potassium			2.6	-	0.8	1.40	-	4.18	3.0	3.7	3.9	4.6
Manganese			0.000	-	0.000	-	-	0.00	0.00	-	0.00	0.00
Silver			0.00	-	0.00	-	-	0.00	0.00	-	0.00	0.00
Total Solids			180	240	162	133	149	221	273	289	201	280
Cond. umhos. 25°			100	125	102	123	173	332	354	433	405	510

1 1954
2 1955
3 1956
4 See discussion

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Potholes, E. Canal, Mile 65.8 Number: 15 Designation: C-(P.E.C.) 743

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.	April	May	June[2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.
C.F.S.												
Avg. Flow x 10^3						0.088	0.089	0.085	0.080			
No. Sample Composites						1	4	8	6			
Water Temp. °F						65.8	69.4	72.0	66.0			
Diss. Oxygen						9.3	9.3	9.4	9.1			
% D. O. Satur.						99 *	101	106	96.8			
Carbon Dioxide						0	0	0	0			
pH*						8.3	3.6	8.6	8.7			
Ammonia NH_3						0.47	0.87	T	0.13			
Total Alk. $CaCO_3$						112	156	141	143			
HCO_3^-						106	138	124	130			
$CO_3^=$						6	18	17	13			
Total Hard. $CaCO_3$						102	115	108	111			
Carb. Hard. $CaCO_3$						102	115	108	111			
Non-Carb. Hard.						0	0	0	0			
Sulfates $SO_4^=$						14	24	24	20			
Color						10	12	10	6			
Turbidity						30	17	11	7			
Total Iron						0.15	0	0.37	0.03			
Copper						0.002	0	0	T			
Zinc						-	0	0.1	0			
Lead						-	0	0	0			
Aluminum						0.15	0.03	0.02	T			
Calcium						32	25	28.7	34			
Magnesium						0.4	3.0	1.47	4.2			
Sodium						17	34	23.3	19.5			
Potassium						3.0	7.2	8.3	5.2			
Manganese						-	0	0	0			
Silver						-	0	0	0			
Total Solids						202	211	206	210			
Cond. umhos. 25°						234	312	316	321			

1 1954
2 1955
* See discussion

Station: Columbia River at Pasco Number: 16 Designation: C-328.5

Period of Summary: 1954-1955-1956

	Jan.	Feb.	Mar.[2]	April[3]	May[2&3]	June[1,2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[2&3]	Dec.[1]
C.F.S.												
Avg. Flow x 10^3			87.5	145	197	425	340	162	107	73	70	71.1
No. Sample Composites			1	1	2	3	8	10	8	2	2	1
Water Temp. °F			40.6	46.0	52.8	56.0	59	64.2	63.0	62.8	52.6	43.0
Diss. Oxygen			13.0	12.9	11.9	11.8	11.4	10.6	11.3	9.7	10.5	12.0
% D. O. Satur.			99	108	104	112	112	111	102	97	95	97
Carbon Dioxide			1	1.5	T	0.9	0.9	0.4	0.7	1.3	1.0	1.5
pH(4)			7.9	7.9	7.3	7.7	7.9	8.2	8.3	8.4	7.8	7.5
Ammonia NH_3			0.1	0.12	T	T	T	T	0.01	T	T	T
Total Alk. $CaCO_3$			69	66	68	58	58	63	65	58	63	67
HCO HCO_3^-			69	66	68	58	58	62	65	58	63	67
$CO_3^=$			0	0	0	0	0	1	T	0	0	0
Total Hard. $CaCO_3$			83	70	78	65	65	69	69	65	70	77
Carb. Hard. $CaCO_3$			69	66	68	58	58	63	65	58	63	67
Non-Carb. Hard.			14	4	10	7	7	6	4	7	7	10
Sulfates $SO_4^=$			16	16	15	8	8	9.5	16	11.5	8	11
Color			8	20	14	11	11	6	5	10	4	0
Turbidity			8	19	19	14	7	8	6	13	6	2
Total Iron			-	-	-	0.02	0.30	0.04	0.60	0.02	0.05	-
Copper			-	-	-	0.010	0.004	0.000	0.000	0.000	T	-
Zinc			-	-	-	-	0.0	0.0	0.0	-	0	-
Lead			-	-	-	-	0.0	0.0	0.0	-	0	-
Aluminum			-	-	-	0.00	0.00	0.08	0.01	0.04	0.06	-
Calcium			-	-	-	13.0	19	18.8	24	17.9	21	-
Magnesium			-	-	-	4.4	6	3.0	0.1	4.8	0.6	-
Sodium			-	-	-	2.0	1.0	1.5	1.0	3.5	2.0	-
Potassium			-	-	-	0.8	1.0	1.65	1.2	0.7	1.3	-
Manganese			-	-	-	-	0.00	0.00	0.00	-	0	-
Silver			-	-	-	-	0.00	0.00	0.00	-	0	-
Total Solids			84	160	124	115	95	118	92	90	77	95
Cond. umhos. 25°			179	155	145	119	128	146	140	149	158	192

1 1954
2 1955
3 1956
4 See discussion

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Yakima River Enterprise Number: 17 Designation: CY - 340

Period of Summary: 1954-1955-1956

	Jan.	Feb.	Mar.[2]	April[3]	May[2&3]	June[1,2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[1&3]	Dec.[1]
C.F.S. Avg. Flow x 10^3			1.5	13.4	8.32	8.73	4.66	2.14	2.23	2.44	2.90	2.10
No. Sample Composites			1	1	2	3	7	11	9	2	2	1
Water Temp. °F			43.7	53.7	58.5	63.1	69.1	71.1	66.3	58.6	47.5	35.1
Diss. Oxygen			12.4	10.3	10.0	9.3	9.7	10.8	10.2	10.5	11.0	13.6
% D. O. Satur.			101	101	98	95.5	107	121	106	102	93.5	97
Carbon Dioxide			0	3.0	2.8	1.3	0.5	0	0.1	0	0.62	2.0
pH			8.5	8.1	7.4	7.6	8.1	8.5	8.4	8.5	7.7	7.5
Ammonia NH_3			0.05	0.13	0.10	0.28	0.12	0.07	0.06	T	T	0.0
Total Alk. $CaCO_3$			118	62	55	65	87	141	141	131	112	124
HCO_3^-			108	62	55	65	84	125	133	117	112	124
$CO_3^=$			10	0	0	0	3	16	8	14	0	0
Total Hard. $CaCO_3$			120	53	46	56	76	116	116	118	104	102
Carb. Hard. $CaCO_3$			118	53	46	56	76	116	116	118	104	102
Non-Carb. Hard.			2	0	0	0	0	0	0	0	0	0
Sulfates $SO_4^=$			18	7	14	10	11	21.6	17	20.9	14	13
Color			12	40	26	18	18	12	10	18	7	4
Turbidity			6	34	66	32	28	16	15	20	18	2
Total Iron			0.30	-	0.01	0.13	-	0.06	0.15	0.03	0.05	0.10
Copper			0.0	-	0.0	0.05	-	0.0	0.20	0.0	0.012	0.00
Zinc			-	-	-	-	-	0.0	0.0	-	-	0.0
Lead			-	-	-	-	-	0.0	0.0	-	-	0.2
Aluminum			0.0	-	0.0	0.03	-	0.21	0.03	0.02	0.01	0.05
Calcium			20	-	1.0	13.5	-	28	33	38	20	20
Magnesium			1.5	-	0.5	2.1	-	3.4	4.3	8.2	2.2	0.2
Sodium			15	-	3.0	15.5	-	22.7	15.5	21	20	16
Potassium			2.0	-	0.2	1.8	-	5.1	3.0	3.3	3.0	2.5
Manganese			-	-	-	-	-	0.0	0.0	-	-	0.0
Silver			-	-	-	-	-	0.0	0.0	-	-	0.0
Total Solids			134	310	226	190	182	208	228	228	194	165
Cond. umhos. 25°			269	134	156	135	185	311	308	324	280	302

1 - 1954
2 - 1955
3 - 1956

Station: Yakima River - Mabton - Sunnyside Bridge 1954 Number: 18 Designation: CY-414

Period of Summary: 1954 - 1955

	Jan.	Feb.	Mar.	April	May	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.
C.F.S. Avg. Flow x 10^3						-	-	-	-			
No. Sample Composites						4	5	8	4			
Water Temp. °F						-	-	66.9	61.4			
Diss. Oxygen						8.6	8.9	9.2	9.2			
% D. O. Satur.						86	94	99	93.3			
Carbon Dioxide						2.1	2.0	1.0	1.6			
pH*						7.3	7.7	7.9	7.8			
Ammonia NH_3						-	0.1	0.1	0.1			
Total Alk. $CaCO_3$						58	82	123	129			
HCO_3^-						58	82	123	129			
$CO_3^=$						0	0	0	0			
Total Hard. $CaCO_3$						50	70	100	106			
Carb. Hard. $CaCO_3$						50	70	100	106			
Non-Carb. Hard.						0	0	0	0			
Sulfates $SO_4^=$						11	9	17	14			
Color						16	15	15	12			
Turbidity						23	17	16	12			
Total Iron						-	-	-	-			
Copper						-	-	-	-			
Zinc						-	-	-	-			
Lead						-	-	-	-			
Aluminum						-	-	-	-			
Calcium						-	-	-	-			
Magnesium						-	-	-	-			
Sodium						-	-	-	-			
Potassium						-	-	-	-			
Manganese						-	-	-	-			
Silver						-	-	-	-			
Total Solids						170	157	214	218			
Cond. umhos. 25°						121	176	252	279			

1 1954
2 1955
* See discussion

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Yakima River below Union Gap Number: 19 Designation: C-1 434.9

Period of Summary: 1954 - 1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.[1]
C.F.S. Avg. Flow x 10^3			-		-	-	-	-	-			-
No. Sample Composites			1		1	2	5	7	4			1
Water Temp. °F			41.0		48.0	57.9	62.2	62.4	59.0			34.7
Diss. Oxygen			12.2		10.4	10.0	10.0	10.0	9.7			12.4
% D. O. Satur.			97		90	97	102	102	94			97
Carbon Dioxide			1		1.5	2.0	1.2	1.1	1.0			1
pH*			7.9		7.4	7.4	7.9	7.8	7.7			7.9
Ammonia NH_3			1.0		0.04	0.48	0.14	0.17	0.28			1.0
Total Alk. $CaCO_3$			73		48	40	42	53	59			73
HCO_3^-			73		48	40	41	53	59			73
$CO_3^=$			0		0	0	1	0	0			0
Total Hard. $CaCO_3$			65		46	40	42	48	51			65
Carb. Hard. $CaCO_3$			65		46	40	42	48	51			65
Non-Carb. Hard.			0		0	0	0	0	0			0
Sulfates $SO_4^=$			5		5	4	1.5	3.0	3.8			5
Color			10		27	14	13	10	8			10
Turbidity			7.7		15	13	5	5	6			7.7
Total Iron			-		-	-	-	0.10	-			-
Copper			-		-	-	-	0.00	-			-
Zinc			-		-	-	-	0.00	-			-
Lead			-		-	-	-	0.00	-			-
Aluminum			-		-	-	-	0.00	-			-
Calcium			-		-	-	-	14.00	-			-
Magnesium			-		-	-	-	0.50	-			-
Sodium			-		-	-	-	4.00	-			-
Potassium			-		-	-	-	1.20	-			-
Manganese			-		-	-	-	0.00	-			-
Silver			-		-	-	-	0.00	-			-
Total Solids			68		104	100	68	116	106			68
Cond. umhos. 25°			161		101	75	90	112	122			161

1 1954
2 1955
* See discussion

Station: Naches River at Mouth Number: 20 Designation: C1M - 444.9

Period of Summary: 1954

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C.F.S. Avg. Flow x 10^3						5.2	3.0	1.0	1.0			
No. Sample Composites						1	3	5	2			
Water Temp. °F						51.6	57.5	61.3	54.0			
Diss. Oxygen						10.5	10.1	10.6	10.8			
% D. O. Satur.						98	93	103	-			
Carbon Dioxide						1.3	1.8	0.4	0.8			
pH*						7.2	7.4	8.1	7.6			
Ammonia NH_3						-	-	0	0			
Total Alk. $CaCO_3$						28	27	38	43			
HCO_3^-						28	27	36	43			
$CO_3^=$						0	0	2	0			
Total Hard. $CaCO_3$						20	25	35	39			
Carb. Hard. $CaCO_3$						20	25	35	39			
Non-Carb. Hard.						0	0	0	0			
Sulfates $SO_4^=$						6.0	1.3	1.6	2.5			
Color						20	13	9	3			
Turbidity						12	3	4	5			
Total Iron						-	-	-	-			
Copper						-	-	-	-			
Zinc						-	-	-	-			
Lead						-	-	-	-			
Aluminum						-	-	-	-			
Calcium						-	-	-	-			
Magnesium						-	-	-	-			
Sodium						-	-	-	-			
Potassium						-	-	-	-			
Manganese						-	-	-	-			
Silver						-	-	-	-			
Total Solids						89	59	52	100			
Cond. umhos. 25°						59	58	80	90			

* See discussion

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Yakima River above Naches Junction Number: 21 Designation: CY - 445

Period of Summary: 1954

C.F.S.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Avg. Flow x 10^3						5.4	4.2	3.3	2.9			
No. Sample Composites						1	3	5	3			
Water Temp. °F						55.6	61.5	60.2	56			
Diss. Oxygen						10.3	9.9	10.7	10.0			
% D. O. Satur.						97	99	106	99			
Carbon Dioxide						1.7	1.3	0.9	0.8			
pH*						7.3	7.6	7.9	7.6			
Ammonia NH_3						-	-	T	0			
Total Alk. $CaCO_3$						41	40	48	51			
HCO_3^-						41	40	48	51			
$CO_3^=$						0	0	0	0			
Total Hard. $CaCO_3$						34	38	42	38			
Carb. Hard. $CaCO_3$						34	38	42	38			
Non-Carb. Hard.						0	0	0	0			
Sulfates $SO_4^=$						T	T	0.04	1			
Color						10	15	12	5			
Turbidity						12	4.4	4.4	2.6			
Total Iron						-	-	-	-			
Copper						-	-	-	-			
Zinc						-	-	-	-			
Lead						-	-	-	-			
Aluminum						-	-	-	-			
Calcium						-	-	-	-			
Magnesium						-	-	-	-			
Sodium						-	-	-	-			
Potassium						-	-	-	-			
Manganese						-	-	-	-			
Silver						-	-	-	-			
Total Solids						83	66	71	85			
Cond. umhos. 25°						79.5	86	95	100			

* See discussion

Station: Yakima River above Thorp Number: 22 Designation: CY - 493

Period of Summary: 1954-1955-1956

C.F.S.	Jan.	Feb.	Mar.[2]	April	May[2]	June[1,2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[1&3]	Dec.[1]
Avg. Flow x 10^3			0.41		1.96	4.05	3.69	2.98	2.62	1.60	0.43	0.69
No. Sample Composites			1		1	3	7	9	7	2	2	1
Water Temp. °F			40.6		43.2	54.7	59.7	56.4	56.6	53.9	41.0	35.1
Diss. Oxygen			13.4		11.6	10.0	9.5	10.4	9.7	10.0	11.4	13.2
% D. O. Satur.			104		93	94	94	100	93	94	90	93
Carbon Dioxide			0.5		1.5	1.1	0.9	0.9	1.2	3.0	1.5	1.5
pH			8.4		7.3	7.3	7.6	7.5	7.7	7.6	7.5	7.5
Ammonia NH_3			0.04		0.04	0.19	T	0.05	0.05	T	T	0.00
Total Alk. $CaCO_3$			46		44	30	26	27	26	31	39	41
HCO_3^-			46		44	30	26	27	26	31	39	41
$CO_3^=$			0		0	0	0	0	0	0	0	0
Total Hard. $CaCO_3$			46		42	25	28	26	27	32	41	40
Carb. Hard. $CaCO_3$			46		42	25	26	26	26	31	39	40
Non-Carb. Hard.			0		0	0	2	0	1	1	2	0
Sulfates $SO_4^=$			3.50		6.00	0.87	0.89	1.29	1.64	5.0	2.5	0.00
Color			20		20	12	8	8	7	11	12	0
Turbidity			9		54	33	4	7	6	22	40	0
Total Iron			0.50		0.20	0.15	-	0.12	0.10	0.04	0.03	-
Copper			0.000		0.000	0.008	-	0.000	0.00	0.001	0.000	-
Zinc			-		-	-	-	0.00	0.00	-	-	-
Lead			-		-	-	-	0.000	0.00	-	-	-
Aluminum			0.000		0.000	0.05	-	0.33	0.02	0.02	0.000	-
Calcium			9		9	13.0	-	7.4	22.7	9.4	9.6	-
Magnesium			0.10		0.10	0.10	-	1.15	1.4	1.7	1.0	-
Sodium			4.0		3.0	2.0	-	1.42	0.7	7.25	2.5	-
Potassium			0.2		0.4	0.4	-	2.25	0.8	1.35	2.4	-
Manganese			-		-	-	-	0.00	0.00	-	-	-
Silver			-		-	-	-	0.00	0.00	-	-	-
Total Solids			26		74	65	57	42	31	68	63	25
Cond. umhos. 25°			94		84	53	53	51	51	77	90	101

1 - 1954
2 - 1955
3 - 1956

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Wenatchee River near Mouth Number: 23 Designation: CW - 471

Period of Summary: 1954-1955-1956

	Jan.[3]	Feb.[3]	Mar.[2&3]	April[3]	May[2&3]	June[1,2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[2&3]	Nov.[1&2]	Deo.[1&2]
C.F.S.												
Avg. Flow x 10^3	0.85	0.95	0.98	4.6	11.3	13.33	9.77	2.92	0.96	1.49	1.98	1.64
No. Sample Compositee	1	1	2	1	2	3	8	8	6	4	2	2
Water Temp. °F	32.0	35.9	40.9	46.2	47.6	50.7	54.1	61.7	60.5	50.2	42.3	32.6
Diss. Oxygen	14.2	14.0	12.8	11.5	11.8	11.1	10.6	10.1	10.6	11.1	12.2	13.6
% D. O. Satur.	100	104	102	99	102	100	100	103	108	100	100	96
Carbon Dioxide	2.0	1.5	1.25	2.5	1.75	1.33	1.3	1.2	0.4	1.4	1.2	1.5
pH	7.2	7.3	7.4	7.4	7.4	7.1	7.1	7.6	8.1	7.8	7.7	7.5
Ammonia NH_3	0.27	0.16	0.16	0.25	0.04	0.08	0.17	0.08	0.07	0.11	0.12	0.19
Total Alk. $CaCO_3$	39	39	48	40	43	25	14	20	29	28	26	27
HCO_3^-	39	39	48	40	43	25	14	19	26	28	26	27
$CO_3^=$	0	0	0	0	0	0	0	1	3	0	0	0
Total Hard. $CaCO_3$	43	45	53	48	55	14	14	19	28	28	22	34
Carb. Hard. $CaCO_3$	39	39	48	40	43	14	14	19	28	28	22	27
Non-Carb. Hard.	4	6	5	8	12	0	0	0	0	0	0	7
Sulfates $SO_4^=$	2.5	4.6	2.4	4.6	3.1	1.0	1.4	1.7	2.1	3.6	0.9	0.6
Color	10	10	19	48	17	8	9	6	5	7	6	4
Turbidity	2	5	40	80	18	11	5	8	13	10	3	5
Total Iron	0.01	-	-	-	-	0.02	0.01	0.02	0.03	0.03	-	-
Copper	0.00	-	-	-	-	0.000	0.000	0.00	0.00	0.00	-	-
Zinc	-	-	-	-	-	-	0.00	-	-	-	-	-
Lead	-	-	-	-	-	-	0.00	-	-	-	-	-
Aluminum	0.00	-	-	-	-	0.005	0.00	0.00	0.01	0.03	-	-
Calcium	4.0	-	-	-	-	5.0	8.5	23.2	9.9	10.4	-	-
Magnesium	4.0	-	-	-	-	0.8	0.3	1.8	3.8	1.2	-	-
Sodium	1.0	-	-	-	-	1.8	2.5	1.5	2.0	2.0	-	-
Potassium	1.6	-	-	-	-	1.2	2.5	1.4	1.6	0.4	-	-
Manganese	-	-	-	-	-	-	0.0	-	-	-	-	-
Silver	-	-	-	-	-	-	0.0	-	-	-	-	-
Total Solids	84	86	50	270	115	53	39	49	46	45	18	40
Cond. umhos. 25°	78	85	102	94	54	37	32	46	60	63	52	69

1 - 1954
2 - 1955
3 - 1956

Station: Columbia River at Brewster Number: 24 Designation C-5 30.1

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.[1]
C.F.S.												
Avg. Flow x 10^3			80.3		69.7	362	343.1	147	98		63.1	71.8
No. Sample Composites			1		1	3	7	5	5		1	1
Water Temp. °F			37.2		47.5	53.1	57.6	60.7	61.8		52.7	45.9
Diss. Oxygen			15		12.9	13.3	13.1	11.5	11.3		11.7	12.9
% D. O. Satur.			111		111	122	127	116	115		107	108
Carbon Dioxide			1.0		1.0	1.0	1.1	0.6	1.2		1.5	1.5
pH*			7.7		7.9	7.5	7.8	8.0	7.9		7.7	7.6
Ammonia NH_3			0.10		0.02	0.21	0.06	0.09	0.07		0.00	0.00
Total Alk. $CaCO_3$			67		70	61	61	62	60		61	63
HCO_3^-			67		70	61	61	62	60		61	63
$CO_3^=$			0		0	0	0	0	0		0	0
Total Hard. $CaCO_3$			81		96	66	68	73	67		72	82
Carb. Hard. $CaCO_3$			67		70	61	61	62	60		61	63
Non-Carb. Hard.			14		26	5	7	11	7		11	19
Sulfates $SO_4^=$			16		15	8.3	6.6	7.4	7.8		10	10
Color			5		10	14	11	9	4		3	0
Turbidity			7		7	7	6	4	3		5	2
Total Iron			-		-	-	-	-	-		-	-
Copper			-		-	-	-	-	-		-	-
Zinc			-		-	-	-	-	-		-	-
Lead			-		-	-	-	-	-		-	-
Aluminum			-		-	-	-	-	-		-	-
Calcium			-		-	-	-	-	-		-	-
Magnesium			-		-	-	-	-	-		-	-
Sodium			-		-	-	-	-	-		-	-
Potassium			-		-	-	-	-	-		-	-
Manganese			-		-	-	-	-	-		-	-
Silver			-		-	-	-	-	-		-	-
Total Solids			69		118	104	97	73	82		80	75
Cond. umhos. 25°			168		175	128	129	133	134		149	167

1 1954
2 1955
* See discussion

Station: Okanogan River at Mouth Number: 25 Designation: CO -548.6
Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.[1]
C.F.S.												
Avg. Flow x 10^3			1.26		1.67	12.85	7.93	2.59	2.09		1.70	1.85
No. Sample Composites			1		1	2	6	5	5		1	1
Water Temp. °F			40.1		60.8	55.4	64.9	68.6	64.4		43.7	32.2
Diss Oxygen			11.9		10.1	10.2	9.0	8.7	9.6		11.3	13.8
% D. O. Satur.			92		104	96	94	95	101		92	95
Carbon Dioxide			1.0		0.0	2.0	1.75	0.02	T		2.0	2.5
pH			8.1		8.3	7.3	7.6	8.2	8.2		7.9	7.3
Ammonia NH_3			0.12		0.08	0.25	0.09	0.12	T		0.00	T
Total Alk. $CaCO_3$			112		101	48	54	92	104		91	97
HCO_3^-			112		101	48	54	91	102		91	97
$CO_3^=$			0		0	0	0	1	2		0	0
Total Hard. $CaCO_3$			130		132	44	61	81	109		99	102
Carb. Hard. $CaCO_3$			112		101	44	54	81	104		91	97
Non-Carb. Hard.			18		31	0	7	0	5		8	5
Sulfates $SO_4^=$			26		18	12	11	21	19		20	18
Color			10		10	33	23	10	16		4	2
Turbidity			7		7	38	17	6	4		4	1
Total Iron			-		-	-	0.03	-	0.300		-	-
Copper			-		-	-	0.000	-	0.020		-	-
Zinc			-		-	-	0.000	-	0.30		-	-
Lead			-		-	-	0.000	-	0.000		-	-
Aluminum			-		-	-	0.01	-	0.01		-	-
Calcium			-		-	-	23	-	23		-	-
Magnesium			-		-	-	0.8	-	0.4		-	-
Sodium			-		-	-	4.5	-	4.0		-	-
Potassium			-		-	-	2.6	-	1.2		-	-
Manganese			-		-	-	0.000	-	0.000		-	-
Silver			-		-	-	0.000	-	0.000		-	-
Total Solids			143		173	134	114	134	134		115	130
Cond. umhos. 25°			284		255	94	122	207	239		230	276

1 - 1954
2 - 1955

Station: Columbia River below Coulee Dam Number: 26 Designation: C - 596.3
Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.[1]	Dec.[1]
C.F.S.												
Avg. Flow x 10^3			79		68	367	325	147	93.3		51.1	69.9
No. Sample Composites			1		1	2	6	5	5		1	1
Water Temp. °F			35.8		43.3	54.2	56.7	59.4	60.5		54.5	47.9
Diss. Oxygen			12.3		12.1	13.7	13.1	10.7	9.7		9.3	10.4
% D. O. Satur.			89		97	127	125	105	97		87	83
Carbon Dioxide			1.0		1.0	1.0	0.9	0.9	1.1		1.5	3
pH			7.3		8.4	7.4	7.6	7.8	7.9		7.8	7.5
Ammonia NH_3			0.03		0.04	0.12	0.03	0.06	0.09		0.00	0.00
Total Alk. $CaCO_3$			79		68	64	60	61	59		62.5	62
HCO_3^-			79		68	64	60	61	59		62.5	62
$CO_3^=$			0		0	0	0	0	0		0	0
Total Hard. $CaCO_3$			79		91	66	67	71	66		70	81
Carb. Hard. $CaCO_3$			79		68	64	60	61	59		63	62
Non-Carb. Hard.			0		23	2	7	10	7		7	19
Sulfates $SO_4^=$			15		16	8	7	8	8		15	7
Color			5		8	8	10	9	4		2	0
Turbidity			8		3	8	5	4	2		2	1
Total Iron			0.30		0.05	0.80	0.17	0.25	0.51		0.01	-
Copper			0.000		0.001	0.006	0.004	0.000	0.000		0.002	-
Zinc			0.000		0.000	-	0.100	0.000	0.000		0.000	-
Lead			0.000		0.000	-	0.000	0.000	0.000		0.000	-
Aluminum			0.50		0.02	0.20	0.020	0.19	0.02		0.000	-
Calcium			20		22	25	21	28	17		21	-
Magnesium			1.5		0.3	0.2	1.9	1.7	1.7		0.4	-
Sodium			3.0		3.0	2.0	2.0	0.7	0.5		1.0	-
Potassium			0.6		1.4	0.6	1.6	0.9	1.0		1.3	-
Manganese			0.00		0.00	-	0.000	0.000	0.000		0.00	-
Silver			0.000		0.000	-	0.000	0.000	0.000		0.00	-
Total Solids			59		125	102	82	76	97		50	55
Cond. umhos. 25°			169		172	130	131	131	133		153	178

1 - 1954
2 - 1955

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Main Canal Headworks at Coulee Dam Number: 27 Designation: C-(MC)-597.5

Period of Summary: 1954

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C.F.S.												
Avg. Flow x 10^3							3.13	2.83	1.90			
No. Sample Composites							3	3	2			
Water Temp. °F							57.5	59.2	62.0			
Diss. Oxygen							11.2	10.1	9.9			
% D. O. Satur.							108	99	101			
Carbon Dioxide							1.33	0.8	0.2			
pH							7.8	7.7	7.9			
Ammonia NH_3							0.00	T	0.00			
Total Alk. $CaCO_3$							62	63	62			
HCO_3^-							62	63	62			
$CO_3^=$							0	0	0			
Total Hard. $CaCO_3$							68	67	66			
Carb. Hard. $CaCO_3$							62	63	62			
Non-Carb. Hard.							6	4	4			
Sulfates $SO_4^=$							10	8	10			
Color							15	10	4			
Turbidity							3	3	2			
Total Iron							-	-	-			
Copper							-	-	-			
Zinc							-	-	-			
Lead							-	-	-			
Aluminum							-	-	-			
Calcium							-	-	-			
Magnesium							-	-	-			
Sodium							-	-	-			
Potassium							-	-	-			
Manganese							-	-	-			
Silver							-	-	-			
Total Solids							78	112	70			
Cond. umhos. 25°							132	138	138			

Station: Main Canal below Coulee City Number: 28 Designation: C-(MC)-627

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.	April	May	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.
C.F.S.												
Avg. Flow x 10^3						3.64	3.97	3.22	2.30			
No. Sample Composites						2	6	5	5			
Water Temp. °F						62.2	65.1	66.3	63.7			
Diss. Oxygen						9.3	9.3	9.0	9.4			
% D. O. Satur.						94	98	95	97			
Carbon Dioxide						0.50	0.83	0.40	0.74			
pH						7.8	7.9	8.0	8.1			
Ammonia NH_3						0.26	0.05	0.07	0.13			
Total Alk. $CaCO_3$						80	71	70	68			
HCO_3^-						80	71	70	68			
$CO_3^=$						0	0	0	0			
Total Hard. $CaCO_3$						80	74	70	73			
Carb. Hard. $CaCO_3$						80	71	70	68			
Non-Carb. Hard.						0	3	0	5			
Sulfates $SO_4^=$						15	12	11	10			
Color						6	10	9	4			
Turbidity						5	5	4	3			
Total Iron						-	-	0.000	-			
Copper						-	-	0.000	-			
Zinc						-	-	0.000	-			
Lead						-	-	0.000	-			
Aluminum						-	-	0.50	-			
Calcium						-	-	15	-			
Magnesium						-	-	1.0	-			
Sodium						-	-	1.0	-			
Potassium						-	-	1.5	-			
Manganese						-	-	0.000	-			
Silver						-	-	0.000	-			
Total Solids						123	110	97	110			
Cond. umhos. 25°						169	161	156	155			

1 - 1954
2 - 1955

Station: Crab Creek near Wilson Creek Number: 29 Designation CCb - 490

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May	June	July[1]	Aug.[1]	Sept.[1]	Oct.	Nov.	Dec.
C.F.S. Avg. Flow x 10^3			-				-	-	-			
No. Sample Composites			1				3	3	2			
Water Temp. °F			41.4				70.9	69.6	65.0			
Diss. Oxygen			11.1				7.6	12.8	11.8			
% D. O. Satur.			87				86	142	125			
Carbon Dioxide			0.00				0.00	0.00	T			
pH			7.8				8.5	8.7	8.5			
Ammonia NH_3			0.02				0.09	0.02	T			
Total Alk. $CaCO_3$			110				198	192	221			
HCO_3^-			110				165	151	206			
$CO_3^=$			0				33	41	15			
Total Hard. $CaCO_3$			155				152	143	155			
Carb. Hard. $CaCO_3$			110				152	143	155			
Non-Carb. Hard.			45				0	0	0			
Sulfates $SO_4^=$			44				28	23	23			
Color			180				55	15	30			
Turbidity			230				37	29	38			
Total Iron			-				-	0.10	-			
Copper			-				-	0.000	-			
Zinc			-				-	0.000	-			
Lead			-				-	0.000	-			
Aluminum			-				-	0.38	-			
Calcium			-				-	38	-			
Magnesium			-				-	0.75	-			
Sodium			-				-	28	-			
Potassium			-				-	5.2	-			
Manganese			-				-	0.000	-			
Silver			-				-	0.000	-			
Total Solids			429				335	313	355			
Cond. umhos. 25°			235				399	396	400			

1 - 1954
2 - 1955

Station: Rocky Ford Creek near Moses Lake Number: 30 Designation CCb RE-471

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June	July[1]	Aug.[1]	Sept.[1]	Oct.	Nov.[1]	Dec.[1]
C.F.S. Avg. Flow x 10^3			-		-		0.093	0.095	0.095		-	-
No. Sample Composites			1		1		4	3	3		1	1
Water Temp. °F			47.8		62.0		59.0	56.4	56.8		49.5	45.7
Diss. Oxygen			10.6		13.9		11.6	10.9	10.5		10.2	10.5
% D. O. Satur.			92		142		115	104	101		89	88
Carbon Dioxide			2.0		2.0		1.4	2.0	2.0		2.5	4.5
pH			8.1		8.0		7.9	8.0	7.6		7.7	7.6
Ammonia NH_3			0.15		0.06		0.00	T	0.00		0.00	0.00
Total Alk. $CaCO_3$			150		145		177	162	168		157	153
HCO_3^-			150		145		177	162	168		157	153
$CO_3^=$			0		0		0	0	0		0	0
Total Hard. $CaCO_3$			136		148		134	130	130		131	136
Carb. Hard. $CaCO_3$			136		145		134	130	130		131	136
Non-Carb. Hard.			0		3		0	0	0		0	0
Sulfates $SO_4^=$			24		22		25	27	23		23	7
Color			8		8		10	7	2		4	0
Turbidity			5		3		5	4	6		6	2
Total Iron			-		-		0.000	-	0.20		-	-
Copper			-		-		0.000	-	0.010		-	-
Zinc			-		-		0.000	-	0.10		-	-
Lead			-		-		0.000	-	0.000		-	-
Aluminum			-		-		0.010	-	0.010		-	-
Calcium			-		-		26	-	23		-	-
Magnesium			-		-		1.5	-	1.0		-	-
Sodium			-		-		24	-	19		-	-
Potassium			-		-		5.6	-	5.4		-	-
Manganese			-		-		0.000	-	0.000		-	-
Silver			-		-		0.000	-	0.000		-	-
Total Solids			239		289		255	260	252		215	225
Cond. umhos. 25°			380		364		361	381	362		390	429

1 - 1954
2 - 1955

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Crab Creek (Willow Run) No. Moses Lake Number: 31 Designation: CCb-466.5

Period of Summary: 1954-1955

	Jan.	Feb.	Mar.[2]	April	May[2]	June[1]	July[1]	Aug.[1]	Sept.[1]	Oct.	Nov.[1]	Dec.[1]
C.F.S. Avg. Flow x 10^3			-		-	0.049	0.068	0.090	0.086		-	-
No. Sample Composites			1		1	1	4	3	3		1	1
Water Temp. °F			45.3		67.1	71.1	69.9	61.1	64.8		48.6	35.4
Diss. Oxygen			11.2		9.9	9.4	11.1	9.7	9.8		11.1	12.8
% D. O. Satur.			90		107	106	120	99	104		100	92
Carbon Dioxide			T		0.0	0.0	0.0	0.5	0.5		0.0	3.0
pH			8.2		8.4	8.9	8.6	8.0	8.2		8.2	8.0
Ammonia NH_3			0.05		0.04	0.00	T	T	0.02		0.10	0.14
Total Alk. $CaCO_3$			143		152	170	159	152	167		192	260
HCO_3^-			143		138	126	134	151	162		189	260
$CO_3^=$			0		14	44	25	1	5		3	0
Total Hard. $CaCO_3$			132		91	146	139	140	132		160	210
Carb. Hard. $CaCO_3$			132		91	146	139	140	132		160	210
Non-Carb. Hard.			0		0	0	0	0	0		0	0
Sulfates $SO_4^=$			41		28	61	52	40	33		68	85
Color			60		30	15	19	17	12		15	7
Turbidity			130		90	11	9	6	8		14	9
Total Iron			-		-	-	0.100	-	0.10		0.010	-
Copper			-		-	-	0.000	-	0.000		0.008	-
Zinc			-		-	-	0.000	-	0.000		0.000	-
Lead			-		-	-	0.100	-	0.000		0.000	-
Aluminum			-		-	-	0.01	-	0.010		0.000	-
Calcium			-		-	-	22	-	23		28	-
Magnesium			-		-	-	2.0	-	1.0		0.8	-
Sodium			-		-	-	24	-	33		58	-
Potassium			-		-	-	4.2	-	4.2		7.0	-
Manganese			-		-	-	0.000	-	0.000		0.000	-
Silver			-		-	-	0.000	-	0.000		0.000	-
Total Solids			341		411	273	270	303	307		355	400
Cond. umhos. 25°			348		408	369	365	377	452		603	710

1 - 1954
2 - 1955

Station: East Low Canal (Weber Waterway) Number: 32 Designation: C-(ELC)-667

Period of Summary: 1954

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C.F.S. Avg. Flow x 10^3						-	-	-	-			
No. Sample Composites						2	4	3	3			
Water Temp. °F						63.4	67.0	65.3	64.5			
Diss. Oxygen						9.8	10.0	9.9	10.0			
% D. O. Satur.						101	107	104	105			
Carbon Dioxide						0.0	0.0	0.2	0.0			
pH						8.0	8.2	8.1	8.3			
Ammonia NH_3						0.00	0.02	0.01	0.00			
Total Alk. $CaCO_3$						88	97	74	75			
HCO_3^-						86	96	74	75			
$CO_3^=$						2	1	0	0			
Total Hard. $CaCO_3$						93	81	75	74			
Carb. Hard. $CaCO_3$						88	81	74	74			
Non-Carb. Hard.						5	0	1	0			
Sulfates $SO_4^=$						20	19	15	14			
Color						9	10	9	3			
Turbidity						8	8	11	8			
Total Iron						-	-	-	-			
Copper						-	-	-	-			
Zinc						-	-	-	-			
Lead						-	-	-	-			
Aluminum						-	-	-	-			
Calcium						-	-	-	-			
Magnesium						-	-	-	-			
Sodium						-	-	-	-			
Potassium						-	-	-	-			
Manganese						-	-	-	-			
Silver						-	-	-	-			
Total Solids						144	118	153	107			
Cond. umhos. 25°						209	179	167	172			

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: East Low Canal at Warden Number: 34 Designation: C-(ELC)-687

Period of Summary: 1954-1955

C.F.S.	Jan.	Feb.	Mar.	April	May	June[2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.
Avg. Flow x 10^3						-	0.40	0.43	0.43			
No. Sample Composites						1	4	5	4			
Water Temp. °F						64.0	68.8	67.5	62.8			
Diss. Oxygen						9.6	9.6	9.2	9.5			
% D. O. Satur.						101	106	100	98			
Carbon Dioxide						0.0	0.1	0.0	0.0			
pH						8.1	8.3	8.4	8.4			
Ammonia NH_3						0.44	0.08	0.07	0.07			
Total Alk. $CaCO_3$						78	74	74	74			
HCO_3^-						71	70	71	72			
$CO_3^=$						7	4	3	2			
Total Hard. $CaCO_3$						78	80	76	75			
Carb. Hard. $CaCO_3$						78	74	74	74			
Non-Carb. Hard.						0	6	2	1			
Sulfates $SO_4^=$						9	13	15	13			
Color						12	9	9	6			
Turbidity						60	9	7	11			
Total Iron						0.30	0.000	0.11	0.10			
Copper						0.006	-	0.000	0.050			
Zinc						-	-	0.000	0.000			
Lead						-	-	0.000	0.000			
Aluminum						0.10	-	0.36	0.01			
Calcium						32	-	20	23			
Magnesium						0.2	-	1.5	0.7			
Sodium						6	-	3	3			
Potassium						1.8	-	4.0	2.4			
Manganese						-	-	0.000	0.000			
Silver						-	-	0.000	0.000			
Total Solids						195	109	108	98			
Cond. umhos. 25°						155	168	164	163			

1 - 1954
2 - 1955

Station: Potholes Reservoir Discharge Number: 33 Designation: C-(PEC)-677

Period of Summary: 1954-1955

C.F.S.	Jan.	Feb.	Mar.	April	May	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.
Avg. Flow x 10^3						0.58	0.55	0.56	0.47			
No. Sample Composites						2	6	5	6			
Water Temp. °F						66.5	60.2	69.0	66.8			
Diss. Oxygen						8.7	9.2	8.5	8.8			
% D. O. Satur.						94	101	94	96			
Carbon Dioxide						0.0	0.0	0.0	0.0			
pH						8.2	8.6	8.5	8.5			
Ammonia NH_3						0.41	0.05	0.09	0.10			
Total Alk. $CaCO_3$						148	151	132	139			
HCO_3^-						140	133	115	131			
$CO_3^=$						8	18	17	8			
Total Hard. $CaCO_3$						120	114	106	109			
Carb. Hard. $CaCO_3$						120	114	106	109			
Non-Carb. Hard.						0	0	0	0			
Sulfates $SO_4^=$						20	23	20	20			
Color						12	11	12	10			
Turbidity						17	10	9	5			
Total Iron						0.10	-	0.32	0.20			
Copper						0.010	-	0.000	0.000			
Zinc						0.000	-	0.000	0.000			
Lead						0.000	-	0.000	0.000			
Aluminum						0.10	-	0.21	0.02			
Calcium						30	-	30	56			
Magnesium						0.5	-	1.3	7.4			
Sodium						21	-	22	16			
Potassium						5.6	-	9.5	4.2			
Manganese						0.000	-	0.000	0.000			
Silver						0.00	-	0.000	0.000			
Total Solids						201	197	177	192			
Cond. umhos. 25°						331	316	287	318			

1 - 1954
2 - 1955

Station: Potholes East Canal above Scootenary Dike Number: 35 Designation: C-(PEC)-695

Period of Summary: 1954

C.F.S.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Avg. Flow x 10^3							0.231	0.302	0.249			
No. Sample Composites							4	3	2			
Water Temp. °F							70.2	69.0	63.7			
Diss. Oxygen							9.7	9.6	9.8			
% D. O. Satur.							108	106	102			
Carbon Dioxide							0.0	0.0	0.0			
pH							8.5	8.4	8.4			
Ammonia NH_3							0.0	0.0	0.0			
Total Alk. $CaCO_3$							175	143	158			
HCO_3^-							154	125	155			
$CO_3^=$							21	18	3			
Total Hard. $CaCO_3$							120	105	109			
Carb. Hard. $CaCO_3$							120	105	109			
Non-Carb. Hard.							0	0	0			
Sulfates $SO_4^=$							25	25	24			
Color							14	15	10			
Turbidity							10	18	17			
Total Iron							-	-	-			
Copper							-	-	-			
Zinc							-	-	-			
Lead							-	-	-			
Aluminum							-	-	-			
Calcium							-	-	-			
Magnesium							-	-	-			
Sodium							-	-	-			
Potassium							-	-	-			
Manganese							-	-	-			
Silver							-	-	-			
Total Solids							218	200	208			
Cond. umhos. 25°							374	316	329			

Station: Crab Creek at Corfu Number: 36 Designation: CCb-431

Period of Summary: 1954

C.F.S.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Avg. Flow x 10^3						0.026	0.026	0.029	0.033			
No. Sample Composities						1	2	3	3			
Water Temp. °F						68.9	81.6	76.0	65.5			
Diss. Oxygen						8.6	9.0	8.3	9.4			
% D. O. Satur.						96	112	98	99			
Carbon Dioxide						0.0	0.0	0.0	0.0			
pH						8.5	8.6	8.7	8.6			
Ammonia NH_3						0.0	T	T	0.03			
Total Alk. $CaCO_3$						329	338	322	329			
HCO_3^-						293	292	266	281			
$CO_3^=$						36	46	56	48			
Total Hard. $CaCO_3$						180	175	157	167			
Carb. Hard. $CaCO_3$						180	175	157	167			
Non-Carb. Hard.						0	0	0	0			
Sulfates $SO_4^=$						180	290	127	107			
Color						50	52	32	23			
Turbidity						60	27	32	30			
Total Iron						-	-	-	-			
Copper						-	-	-	-			
Zinc						-	-	-	-			
Lead						-	-	-	-			
Aluminum						-	-	-	-			
Calcium						-	-	-	-			
Magnesium						-	-	-	-			
Sodium						-	-	-	-			
Potassium						-	-	-	-			
Manganese						-	-	-	-			
Silver						-	-	-	-			
Total Solids						804	678	641	612			
Cond. umhos. 25°						885	858	836	824			

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: Crab Creek at Beverly Number: 37 Designation: CCb-411

Period of Summary: 1954-1955-1956

C.F.S.	Jan.	Feb.	Mar.[2]	April[3]	May[2&3]	June[1,2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[1&3]	Dec.[1]
Avg. Flow x 10^3			0.032	0.050	0.032	0.028	0.029	0.031	0.036	0.051	0.045	0.025
No. Sample Composites			1	1	2	3	7	7	8	2	2	1
Water Temp. °F			51.1	73.0	72.2	67.7	73.1	73.9	67.7	57.3	42.0	32.2
Diss. Oxygen			10.7	10.1	7.8	9.1	8.9	8.9	9.4	11.1	11.8	14.5
% D. O. Satur.			96	114	89	99	102	104	102	107	94	99
Carbon Dioxide			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pH			8.5	8.8	8.2	8.6	8.6	8.6	8.6	8.8	8.3	8.5
Ammonia NH_3			0.03	0.15	0.13	0.22	0.09	0.07	0.10	T	T	0.00
Total Alk. $CaCO_3$			312	360	327	352	297	306	300	294	337	362
HCO_3^-			294	325	258	314	263	271	264	251	307	324
$CO_3^=$			18	35	69	38	34	35	36	43	30	38
Total Hard. $CaCO_3$			220	194	205	218	193	190	184	189	205	240
Carb. Hard. $CaCO_3$			220	194	205	218	193	190	184	189	205	240
Non-Carb. Hard.			0	0	0	0	0	0	0	0	0	0
Sulfates $SO_4^=$			33	144	91	148	114	126	100	172	87	110
Color			45	35	29	93	43	36	34	40	30	15
Turbidity			47	175	150	211	166	219	146	60	51	35
Total Iron			0.40	-	0.150	0.08	-	0.36	0.13	0.04	0.06	0.30
Copper			0.000	-	0.000	0.002	-	0.000	0.001	0.000	0.002	0.000
Zinc			0.000	-	0.000	-	-	0.000	0.000	-	0.000	0.000
Lead			0.000	-	0.000	-	-	0.000	0.000	-	0.000	0.000
Aluminum			0.100	-	0.010	0.025	-	0.140	0.002	0.002	0.000	0.070
Calcium			30	-	31	24	-	40	42	63	19	31
Magnesium			1.5	-	0.10	7.2	-	5.8	4.9	10.0	0.8	0.8
Sodium			100	-	120	68.5	-	105	102	126	102	135
Potassium			12.5	-	16.6	27.5	-	25.6	13.0	6.9	13.0	8.5
Manganese			0.000	-	0.000	-	-	0.000	0.000	-	0.000	0.000
Silver			0.000	-	0.000	-	-	0.000	0.000	-	0.000	0.000
Total Solids			601	904	749	769	675	831	640	636	631	620
Cond. umhos. 25°			790	1180	853	933	815	845	861	937	953	1054

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Station: Columbia River at Vantage Number: 38 Designation: C - 421

Period of Summary: 1954-1955-1956

C.F.S.	Jan.	Feb.	Mar.[2]	April[3]	May[2&3]	June[1,2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[1&3]	Dec.[1]
Avg. Flow x 10^3			86.0	141.0	192.0	394.0	374.0	162.7	99.4	70.5	63.5	67.0
No. Sample Composites			1	1	2	3	8	7	8	2	2	1
Water Temp. °F			39.6	41.7	50.0	55.9	59.1	64.2	65.6	60.7	52.2	44.6
Diss. Oxygen			14.3	14.2	14.0	13.0	12.2	11.1	10.9	9.8	10.5	12.5
% D. O. Satur.			110	112	123	123	121	115	116	98	96	103
Carbon Dioxide			1.0	1.5	1.0	0.8	1.6	0.3	0.12	2.5	1.75	2.0
pH			8.1	8.0	7.4	7.7	7.9	8.1	8.4	8.4	7.8	7.9
Ammonia NH_3			0.45	0.09	0.09	0.22	0.08	0.12	0.10	T	T	T
Total Alk. $CaCO_3$			68	68	65	61	58	60	62	56	61	62
HCO_3^-			68	68	65	61	58	59	59	56	61	62
$CO_3^=$			0	0	0	0	0	1	3	0	0	0
Total Hard. $CaCO_3$			80	75	75	60	64	65	66	62	70	82
Carb. Hard. $CaCO_3$			68	68	65	60	58	60	62	56	61	62
Non-Carb. Hard.			12	7	10	0	6	5	4	6	9	20
Sulfates $SO_4^=$			19	16	12	7	9	7.5	9.3	13.5	11.5	13
Color			5	15	12	12	13	7	6	8	5	0
Turbidity			9	9	22	16	7	8	5	10	8	0
Total Iron			0.500	-	0.10	-	0.04	0.04	0.10	0.02	0.00	0.05
Copper			0.000	-	0.000	-	0.003	0.005	0.030	0.000	0.002	0.000
Zinc			0.000	-	0.000	-	0.000	0.000	0.000	-	0.000	0.000
Lead			0.000	-	0.000	-	0.000	0.000	0.000	-	0.000	0.000
Aluminum			0.200	-	0.000	-	0.010	0.010	0.010	0.000	0.000	0.05
Calcium			20	-	22	-	17	21.3	21	23.1	19	20
Magnesium			1.0	-	0.4	-	6.0	2.15	0.50	2.65	0.60	0.60
Sodium			3.0	-	4.0	-	1.0	3.75	2.0	3.25	15.0	20.0
Potassium			0.6	-	1.4	-	1.0	1.7	1.2	1.6	1.9	1.3
Manganese			0.000	-	0.000	-	0.000	0.000	0.000	-	0.000	0.000
Silver			0.000	-	0.000	-	0.000	0.000	0.000	-	0.000	0.000
Total Solids			83	182	132	98	95	94	86	84	93	60
Cond. umhos. 25°			168	190	146	123	134	138	143	142	183	219

1 - 1954
2 - 1955
3 - 1956

WATER QUALITY SUMMARY - AVERAGE MONTHLY IN P.P.M.

Station: West Canal below Quincy Number: 39 Designation: C-(WC)-680

Period of Summary: 1954-1955

C.F.S.	Jan.	Feb.	Mar.	April	May[2]	June[1&2]	July[1&2]	Aug.[1&2]	Sept.[1&2]	Oct.	Nov.	Dec.
Avg. Flow x 10^3					-	0.175	0.211	0.154	0.146			
No. Sample Composites					1	2	6	5	5			
Water Temp. °F					58.0	65.3	68.4	68.1	65.3			
Diss. Oxygen					10.8	9.7	9.2	9.4	9.1			
% D. O. Satur.					105	103	100	103	97			
Carbon Dioxide					0.0	0.0	0.0	0.0	0.1			
pH					8.3	8.2	8.3	8.5	8.4			
Ammonia NH_3					0.02	0.36	0.07	0.08	0.11			
Total Alk. $CaCO_3$					75	87	78	75	73			
HCO_3^-					75	82	73	70	69			
$CO_3^=$					0	5	5	5	4			
Total Hard. $CaCO_3$					85	88	81	78	76			
Carb. Hard. $CaCO_3$					75	87	78	75	73			
Non-Carb. Hard.					10	1	3	3	3			
Sulfates $SO_4^=$					14	18.5	20	12	14			
Color					15	4	13	10	8			
Turbidity					13	11	12	8	7			
Total Iron					-	0.20	-	0.23	0.075			
Copper					-	-	-	0.000	0.020			
Zinc					-	-	-	0.000	0.000			
Lead					-	0.000	-	0.000	0.000			
Aluminum					-	0.05	-	0.02	0.008			
Calcium					-	30	-	21	35.7			
Magnesium					-	0.3	-	2.4	3.3			
Sodium					-	7.0	-	7.0	2.75			
Potassium					-	2.0	-	9.0	1.50			
Manganese					-	-	-	0.000	0.000			
Silver					-	-	-	0.000	0.000			
Total Solids					110	100	119	109	97			
Cond. umhos. 25°					165	186	186	170	164			

1 - 1954
2 - 1955

Station: Columbia River at Rock Island Number: 40 Designation: C - 453.4

Period of Summary: 1954-1955-1956

C.F.S.	Jan.	Feb.	Mar.[2]	April[3]	May[2&3]	June[1,2&3]	July[1,2&3]	Aug.[1,2&3]	Sept.[1,2&3]	Oct.[3]	Nov.[3]	Dec.
Avg. Flow x 10^3			85.5	126	197.5	390.3	287.2	125.8	94.9	74.0	73.0	
No. Sample Composites			1	1	2	3	8	8	7	2	2	
Water Temp. °F			37.8	43.7	48.5	54.5	58.0	62.2	62.7	60.0	54.4	
Diss. Oxygen			15.2	14.3	13.3	12.7	12.2	10.7	10.4	9.8	10.8	
% D. O. Satur.			113	119	110	116	119	109	106	98	101	
Carbon Dioxide			1.00	2.00	1.75	1.57	1.44	1.20	0.93	2.00	1.25	
pH			7.8	7.7	7.6	7.5	7.8	7.9	7.9	8.0	8.1	
Ammonia NH_3			0.03	0.24	0.04	0.05	0.04	0.05	0.08	T	T	
Total Alk. $CaCO_3$			65	63	62	55	58	59	59	55	58	
HCO_3^-			65	63	62	55	58	59	59	55	58	
$CO_3^=$			0	0	0	0	0	0	0	0	0	
Total Hard. $CaCO_3$			76	72	74	61	62	64	65	64	64	
Carb. Hard. $CaCO_3$			65	63	62	55	58	59	59	55	58	
Non-Carb. Hard.			11	9	12	6	4	5	6	9	6	
Sulfates $SO_4^=$			15	16	17	8.0	7.8	7.5	8.3	8.2	10.5	
Color			7	20	18	8	10	6	4	10	5	
Turbidity			7	20	15	13	7	8	6	12	5	
Total Iron			-	-	-	-	-	-	-	-	-	
Copper			-	-	-	-	-	-	-	-	-	
Zinc			-	-	-	-	-	-	-	-	-	
Lead			-	-	-	-	-	-	-	-	-	
Aluminum			-	-	-	-	-	-	-	-	-	
Calcium			-	-	-	-	-	-	-	-	-	
Magnesium			-	-	-	-	-	-	-	-	-	
Sodium			-	-	-	-	-	-	-	-	-	
Potassium			-	-	-	-	-	-	-	-	-	
Manganese			-	-	-	-	-	-	-	-	-	
Silver			-	-	-	-	-	-	-	-	-	
Total Solids			70	113	141	83	81	84	83	55	123	
Cond. umhos. 25°			161	154	140	115	126	129	135	125	128	

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