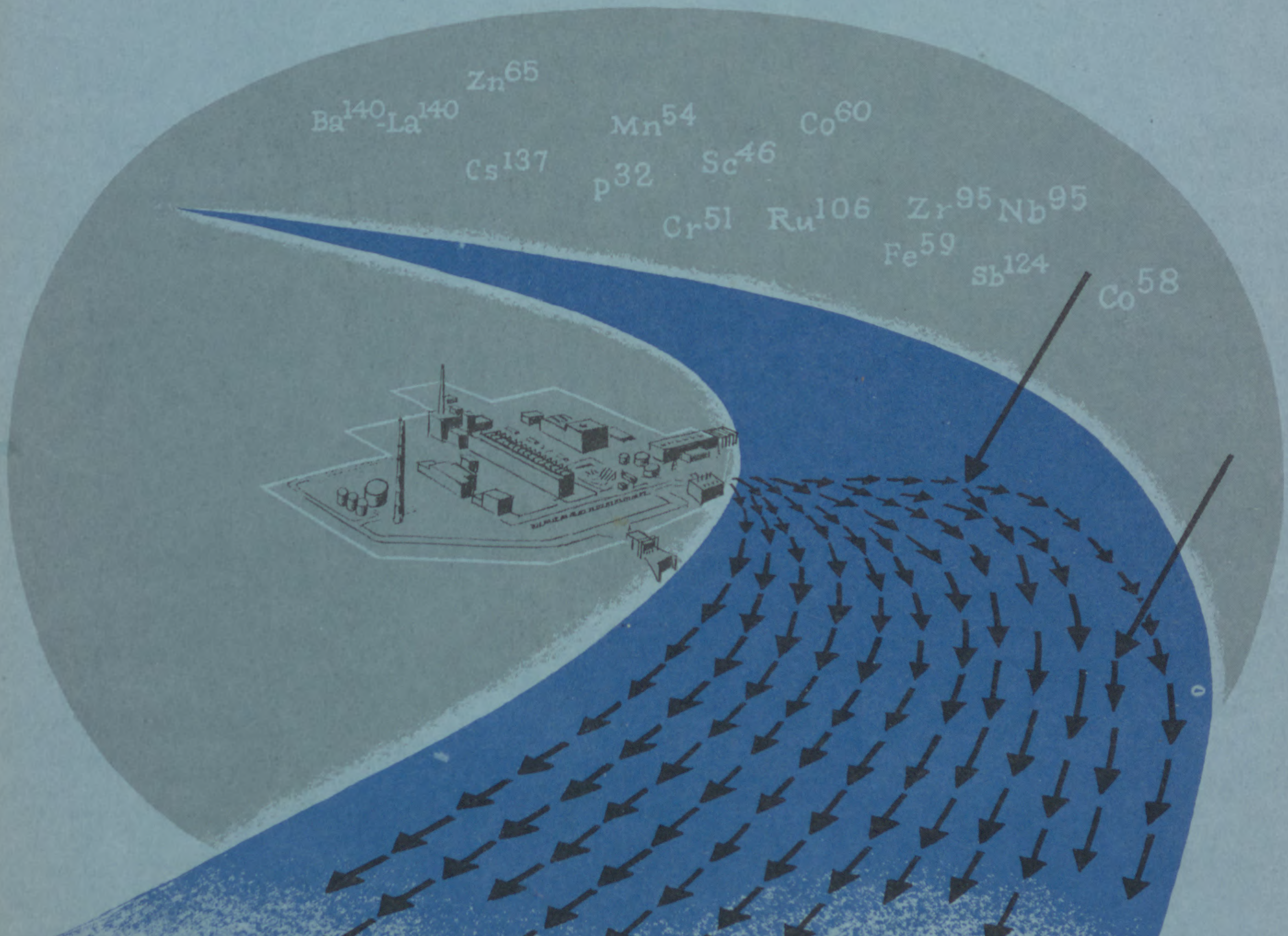
PROGRESS REPORT

# RADIONUCLIDE TRANSPORT OF THE COLUMBIA RIVER

## PASCO TO VANCOUVER, WASHINGTON REACH

**July 1962 to September 1963**




**United States Department of the Interior**

**Geological Survey**

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Progress Report

# RADIONUCLIDE TRANSPORT IN THE PASCO TO VANCOUVER, WASHINGTON REACH OF THE COLUMBIA RIVER JULY 1962 TO SEPTEMBER 1963

FOR THE PROJECT

THE OCCURRENCE, TRANSPORT, AND DISPOSITION OF RADIONUCLIDES AS SOLUTES AND ASSOCIATED WITH FLUVIAL SEDIMENTS IN THE LOWER COLUMBIA RIVER



By

W. L. Haushild, U.S. Geological Survey
R. W. Perkins, Battelle Memorial Institute
H. H. Stevens, Jr., U.S. Geological Survey
G. R. Dempster, Jr., U.S. Geological Survey
J. L. Glenn, U.S. Geological Survey

Prepared in cooperation with the
United States Atomic Energy Commission

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RADIONUCLIDE TRANSPORT IN THE PASCO TO VANCOUVER, WASHINGTON REACH OF THE COLUMBIA RIVER JULY 1962 TO SEPTEMBER 1963

PROGRESS REPORT

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By W. L. Haushild[1/], R. W. Perkins[2/], H. H. Stevens, Jr.[3/], G. R. Dempster, Jr.[4/], and J. L. Glenn[5/]

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ABSTRACT

The disposition of radionuclides in and along the 380-mile reach of the Columbia River between the Hanford, Wash., Atomic Energy Commission reactors (the major radionuclide source) and the head of the estuary is a first step in understanding the environmental cycling and ultimate fate of the discharged radioactive materials. Preliminary results for the study period, July 1962 to September 1963, are presented for radionuclide, sediment, and water data from stations on the Columbia River and from stations near the mouths of the Snake River, the Willamette River, and other Columbia River tributaries.

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1/ William L. Haushild, Research Hydrologist, U.S. Geological Survey.

2/ Richard W. Perkins, Senior Research Scientist, Battelle Memorial Institute.

3/ Herbert H. Stevens, Jr., Hydraulic Engineer, U.S. Geological Survey.

4/ George R. Dempster, Jr., Hydraulic Engineer, U.S. Geological Survey.

5/ Jerry L. Glenn, Geologist, U.S. Geological Survey.

About 275,000 curies of radioactivity were discharged by the Columbia River at Vancouver, Wash., during the period January to September 1963. Approximately 95 percent of the radionuclide discharge was chromium-51, 3 percent was zinc-65, and the remaining 2 percent was about equal amounts of scandium-46, zirconium-95-niobium-95, ruthenium-103-rhodium-103, and cerium-141. At Vancouver, about 7 percent of the chromium-51, 80 percent of the zinc-65 and zirconium-95-niobium-95, 90 percent of the scandium-46, 40 percent of the ruthenium-103-rhodium-103, and 50 percent of the cerium-141 were transported in association with the stream sediment. Comparing data for Pasco, Wash., with data for Vancouver, which is 224 river miles downstream, the proportion of the total radionuclide discharge that is transported in association with stream sediments changed from 30 to 80 percent for zinc-65, from 60 to 80 percent for zirconium-95-niobium-95, and from 1 to 10 percent for other radionuclides.

A radionuclide-discharge budget using the data for January to September 1963 at Pasco and Vancouver shows that 77 percent of the radionuclides discharged by the Columbia River at Pasco was transported past Vancouver, 19 percent decayed during transport, and 4 percent (not corrected for decay) was retained in the reach between the stations. The disposition of the Pasco radionuclide discharge varies for each radionuclide and ranges, for specific disposition items, from 56 to 87 percent for transport, 2 to 20 percent for decay, and 0 to 40 percent for retention.

Quartz, feldspar, volcanic rock fragments, and ferromagnesian minerals are the dominant constituents in sand separates from Columbia River sediments. From Pasco downstream to Vancouver, the percentage of quartz in the sand separate decreases and the percentage of volcanic rock fragments increases.

Quartz, feldspar, and "mica" (includes all 10-A clay minerals) comprise from 70 to 100 percent of the mineral suite in silt separates from the Columbia River. Montmorillonite, chlorite, and kaolinite are the principal clay minerals in the silt separates. No significant changes are discernible between Pasco and Vancouver in the silt-separate mineralogy of either Columbia River or tributary sediments.

Clay separates from Columbia River sediments contain 20 to 60 percent quartz and felspar. The most abundant clay minerals are "mica" (includes all 10-A clay minerals), montmorillonite, and various mixed-layer minerals; of the latter, montmorillonite-"mica" and montmorillonite-chlorite are most abundant and chlorite-"mica" minerals are subordinate. Kaolinite and halloysite are present in small amounts in many samples and dioctahedral vermiculite and mixed-layer vermiculite are present in small amounts in a few samples. Not enough analyses are available to establish real differences in clay-separate mineralogy between Pasco and Vancouver.

Exchange capacities for size separates from Columbia River and tributaries range from 2.6 to 11 (average 5.5) meq per 100 g (milliequivalents per 100 grams) for sand, from 5.9 to 41 (average 22) meq per 100 g for silt, and from 44 to 79 (average 60) meq per 100 g for clay. The exchange capacities of the silt and clay separates are related directly to the percentage of clay minerals in the samples and to the high content of high exchange capacity clay minerals. In the sand separate, exchange capacity is related directly to the percentage of fine-grained volcanic rock fragments.

Total-carbon content in Columbia River sediments ranges from 1.30 to 2.73 percent by weight in fine (<0.062 mm (millimeter)) sediments and from 0.12 to 0.30 percent by weight in coarse (0.062 to 1 mm) sediments. Organic carbon averages about 1.7 percent by weight (corresponding to approximately 3 percent organic matter) in fine sediments and about 0.20 percent by weight in coarse sediments. Organic-matter content may cause the high exchange capacities noted in some samples that have low clay-mineral content and may be important in the generally higher exchange capacity of suspended sediment than of streambed sediment.

Mineralogy and exchange-capacity data indicate that Columbia River sediments are potentially relatively high sorbers of ions including some radioactive ions. Changes in sand mineralogy, which are reflected in exchange capacity, could result in more potential for sorption of ions by streambed sands at Vancouver than at Pasco. Sediment-discharge data used with mineralogy and exchange-capacity data, indicate that silt and clay potentially transport approximately 90 to 95 percent of the particulate ion discharge. These data also indicate that silt could be nearly as important as clay in the transport of ions because of the dominance of silt in the transported sediment.

The runoff during the study period was generally below the long-term mean; the maximum daily discharge of the Columbia River at The Dalles, Oreg., was only 437,000 cfs (cubic feet per second). The total-sediment discharge, in millions of tons, of the Columbia River for the period, October 1962 to September 1963, was 1.1 at Pasco, 6.0 at Hood River, and 8.4 at Vancouver. The Snake and Willamette Rivers contributed 2.0 and 1.1 million tons of sediment, respectively, to the Columbia River during this year. The transported sediment was principally clay and silt; the amount of coarse sediment (>0.062 mm) was about 25 percent of the total-sediment discharge of the Columbia River at Pasco and Vancouver. Sand dunes in the Columbia River near Vancouver are about 5 feet high and about 100 to 300 feet long and they progress downstream at rates ranging from 0 to 2 feet per day during low-water discharge to 100 to 200 feet per day during high-water discharge.

## INTRODUCTION

Since the early 1940's, the U.S. Atomic Energy Commission has operated several nuclear reactors at the Hanford installation near Richland, Wash. Cooling water for the reactors is drawn from the Columbia River and, after use, is returned to the river through controlled release. During the cooling process, dissolved and suspended material in the water (some material may be introduced along with the addition of corrosion inhibitors) is activated when it is exposed to the neutron flux. Thus, the cooling effluent introduces small amounts of radionuclides into the river environment. Although much activity remains in solution and is transported directly to the ocean, some radionuclides in the river are either sorbed by organic and inorganic sediments or taken up by aquatic biota. Consequently, it is important to determine the disposition of the activity that is detained in the river system and to make an inventory of the radioactive materials being transported.

Since the beginning of operations at Hanford, radiation levels in the river have been monitored routinely to insure that permissible limits are not exceeded--levels have always been very low (Foster, 1963, 1964). Hanford personnel also conducted several research programs on various phases of both the reaction of radionuclides in the reactor effluent with Columbia River water and the dispersion of the effluent in the Columbia River (Honstead, 1957; Backman, 1962, Soldat, 1962; and Nielsen and Perkins, 1962). Nielsen (1963) reported on amounts of radionuclides, physical form of radionuclides, depletion of radionuclides in the Columbia River below Hanford, and use of radionuclide decay to date sediment deposits.

## SCOPE AND PURPOSE

As an outgrowth of earlier studies, the U.S. Geological Survey and General Electric Company, in cooperation with the U.S. Atomic Energy Commission, initiated a quantitative study of the transport and disposition of radioactivity in and along the Columbia River, and of the uptake and release of the radionuclides by sediment for the 380-mile reach of the Columbia River between Hanford and the head of the estuary. During the spring of 1965, Battelle-Northwest (Pacific Northwest Laboratories), a division of Battelle Memorial Institute, assumedthe General Electric Company's responsibilities for the Columbia River study.

In the cooperative project, the U.S. Geological Survey performed a majority of the work in determining radionuclide, water, and sediment discharges; determining textural and mineral properties of sediments; and characterization of water flow and sediment movement. Battelle-Northwest provides expertise, equipment, and work in the areas of detailed laboratory analysis of radionuclide content in water and sediment samples by advanced multidimensional and multichannel gamma-ray spectrometry as well as laboratory work on the mechanisms of radionuclide-sediment interactions. Close technical coordination exists between the Survey and Battelle-Northwest staffs.

The program to date (1965) has consisted mainly of the determination of radionuclide-transport rates for water and sediment at Pasco, Wash., Hood River, Oreg., and Vancouver, Wash. The quantity and particle size of sediment transported by the Columbia River at these stations and contributed by the Snake and Willamette Rivers--the major tributaries of the Columbia River below Hanford--were determined. This progress report is based on data collected from July 1962 to September 1963 and is the first of a series of reports on the disposition, rates of movement, and transport of radionuclides. Some data that were collected after September 1963 were used in the analysis of total-sediment discharges and the statistical analysis of the variation of radionuclide concentrations at water quality stations. This report discusses techniques used for measuring and sampling of streamflow, sediment, and radionuclides, and for analyzing data. The quantity and characteristics of the sediment and radionuclide discharges and their variations with time and space were evaluated and the data were used in the development of a radionuclide budget. The effects of radionuclide transport of mineralogy, exchange capacity, and carbon content of sediment transported by streams in the study area were analyzed and interpreted from a small amount of data. Implications resulting from the preliminary data and the future needs of the program are considered.

Symbols and terms are defined where first used and (or) in the appendix; sediment symbols and terminology are defined only in the appendix. Tables of basic data are also included in the appendix.

ACKNOWLEDGMENTS

These studies were supported by the U.S. Atomic Energy Commission. The interest and direction of Walter Belter, Chief, and Hal Bernard, Sanitary Engineer, of the Environmental and Sanitary Engineering Branch, Division of Reactor Development and Technology, U.S. Atomic Energy Commission, are appreciated.

Radiochemical analyses of the water and sediment samples were done by Battelle-Northwest at the Pacific Northwest Laboratories, a division of Battelle Memorial Institute (formerly by the General Electric Co.),

Hanford, Wash. The cooperation and guidance of Dr. Julian M. Nielsen, Director, and Dr. Jack L. Nelson, Senior Research Scientist, Pacific Northwest Laboratories, were of considerable benefit to the direction and progress of the study.

This report was prepared under the supervision of G. L. Bodhaine, district engineer, Water Resources Division, Portland, Oreg., and under the general direction of P. C. Benedict, regional research hydrologist, Water Resources Division, Menlo Park, Calif. The basic data on which the report is based were collected under the supervision of L. B. Laird, then district chemist, Water Resources Division, Portland, Oreg.

Technical guidance and assistance provided by Vance C. Kennedy, U.S. Geological Survey, Denver, Colo., were of much value in establishing and accomplishing the program for investigating the mineralogy, exchange capacity, and carbon content of stream sediments. Paul D. Blackmon, Edward J. Young, Harry C. Starkey, and I. C. Frost, U.S. Geological Survey, Denver, Colo., performed the mineralogy, exchange-capacity, and carbon-content analyses.

## GEOLOGIC AND CLIMATOLOGIC SETTING

The Columbia River above Pasco, Wash., drains rugged mountainous to hilly terrains (the Northern Cascade Range and Northern Rocky Mountains, Fenneman, 1931, plate 1) and a lower lying plateau (the Columbia River Plateau, plate 1). The mountainous to hilly terrains are underlain by granitic, metamorphic, and sedimentary rocks (Huntting, 1961; and Ross and Forrester, 1947); the plateau is underlain by volcanic rocks. The Snake River, which enters the Columbia River below

Pasco (pl. 1), also drains plateau and hilly to mountainous terrains underlain by rock types similar to those in the Columbia River basin above Pasco. Below the mouth of the Snake River to near the mouth of the Sandy River, the Columbia River and its tributaries drain chiefly continental volcanic rocks (Huntting, 1961; and Wells, 1961). From the Sandy River to the mouth of the Columbia River near Astoria, Oreg., the drainage basin passes through marine volcanic sedimentary rocks and intercalated submarine flows (Wells, 1961).

The Cascade Range divides the lower Columbia River basin into two climatologically dissimilar regions (Highsmith, 1947). East of the mountains, the climate is semiarid and either modified continental or comparatively continental; west of the mountains, the climate is mild and is semimarine in the protected western lowlands to marine at the mouth of the Columbia River and along the Pacific Coast. The annual precipitation in the Columbia River basin ranges from more than 80 inches at higher altitudes in the Coast Range (pl. 1) and in the Cascade Range to less than 10 inches in the plateau areas east of the Cascade Range. West of the Cascade Range, in protected western lowlands such as the Willamette Valley, precipitation is distributed seasonally with cool, wet winters and warm, dry summers; east of the Range, the sparse precipitation falls about equally during the cold winters and hot summers (Highsmith, 1957).

The downstream order of major tributaries of the Columbia River along the study reach are the Snake, Umatilla, John Day, Deschutes, Klickitat, Sandy, and Willamette Rivers. The Snake and Willamette

Rivers are by far the major contributors of water and sediment to the Columbia River. They are followed in approximate order of importance by the Deschutes, John Day, Umatilla, Klickitat, and Sandy Rivers. With the exception of the Snake, Willamette, and Sandy Rivers, the tributary streams drain continental volcanic rocks along the eastern slope of the Cascade Range or continental volcanic rocks of the Columbia River Plateau and fringing mountainous areas. The Willamette River flows near the boundary between continental and marine volcanic rocks, whereas the Sandy River drains almost exclusively continental volcanic rocks. The Snake, Umatilla, John Day, and Deschutes River basins and the slightly higher Klickitat River basin are in an area characterized by a modified continental interior climate. The Willamette and Sandy River basins are chiefly in the semimarine climate of a protected western lowland area (the Willamette Valley).

## RIVER SYSTEM AND WATER-QUALITY STATIONS

The flow in the Columbia River and its major tributaries is controlled and regulated by dams. The dams affect the flow and sediment movement in these rivers by storing water for power production, flood control, irrigation, water-temperature control, channel maintenance, and dilution of waste disposal. The dams within the study reach are shown in plate 1. The John Day Dam, under construction on the Columbia River, is scheduled for completion in 1967. Below Bonneville Dam, tides affect the flow of the Columbia River and the lower parts of its tributaries.

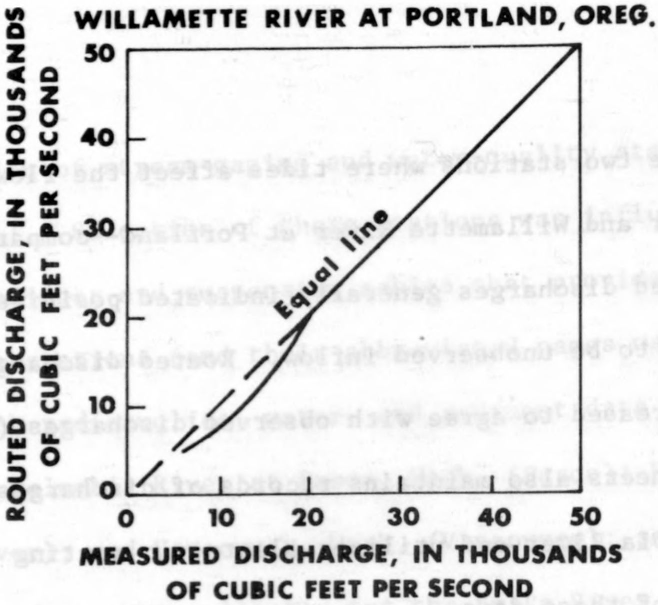
The location of stream-gaging and water-quality stations are shown in plate 1. Selection of these stations was influenced by the available bridges and suspension cables that provide access to the river. The stations (and their abbreviated names used in this report) at which radionuclide, water, and sediment data were collected are the Columbia River at Pasco, Wash. (Pasco); Hood River, Oreg. (Hood River); and Vancouver, Wash. (Vancouver); sediment and water-discharge data were collected for the Snake River at Pasco, Wash. (Snake River), and the Willamette River at Portland, Oreg. (Willamette River).

## WATER DISCHARGE

Water-discharge data are essential to determine the quantity of sediment and radionuclides transported by a river. A routing procedure was used to determine daily mean discharges in cubic feet per second at the five water-quality stations. Routing of discharges was necessary because water discharges at these stations were unknown. Total discharge, mean discharge, and the maximum and minimum daily discharges for each month are given in tables 4-8 and hydrographs of daily discharges are presented in figures 16-20, "Sediment-discharge section."

The routing procedure consisted of summing daily discharges for the nearest main stem and tributary gaging stations upstream from the station of interest. The discharges from the upstream gaging stations were routed to the station by using estimated flow times that were rounded off to the nearest day. Discharges published by the U.S. Geological Survey (1962, 1963) were the basic data used for the routing procedure. At the two stations where tides affect the flow--Columbia River at Vancouver and Willamette River at Portland--comparison of observed and routed discharges generally indicated positive differences that were assumed to be unobserved inflow. Routed discharges at these stations were increased to agree with observed discharges (fig. 1). The Corps of Engineers also maintains records of discharges from the dams on the Columbia River and utilizes electronic routing of discharges in the operation of these dams.

Water discharges at project water-quality stations were determined at the time of radionuclide or sediment sampling, and consecutive measurements of discharges were also made intermittently to determine the variation of discharge with time during a day or a tidal cycle. Water discharges were determined from measurements generally made once a month or from an index measurement of discharge (depth-velocity index) made weekly at each station. If suspended-sediment concentrations and (or) water discharges were varying rapidly, water discharges were determined more frequently. Discharge measurements were made by determining the velocity at 0.2 and 0.8 depths at many verticals in a cross section (Corbett and others, 1962). The depth-velocity index is the average product of the depths and velocities at the 0.2 depth for five verticals in the cross section. The same five verticals were used for each measurement and were located at the approximate centroids of equal discharge. An example of the relations between depth-velocity indices and observed discharges is shown in figure 2.



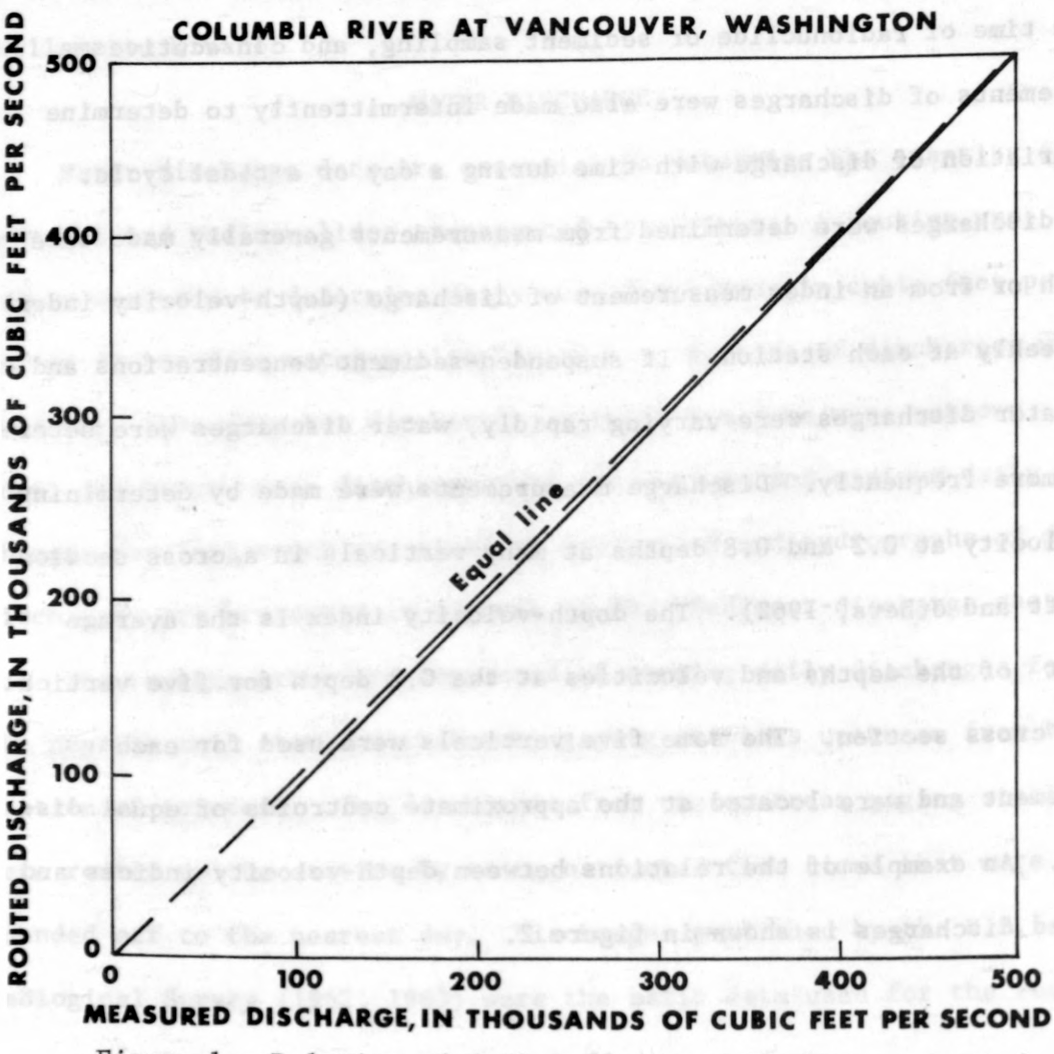




Figure 1.--Relation of daily mean water discharges; routed versus observed discharges for Columbia River at Vancouver, Wash. and Willamette River at Portland, Oreg.

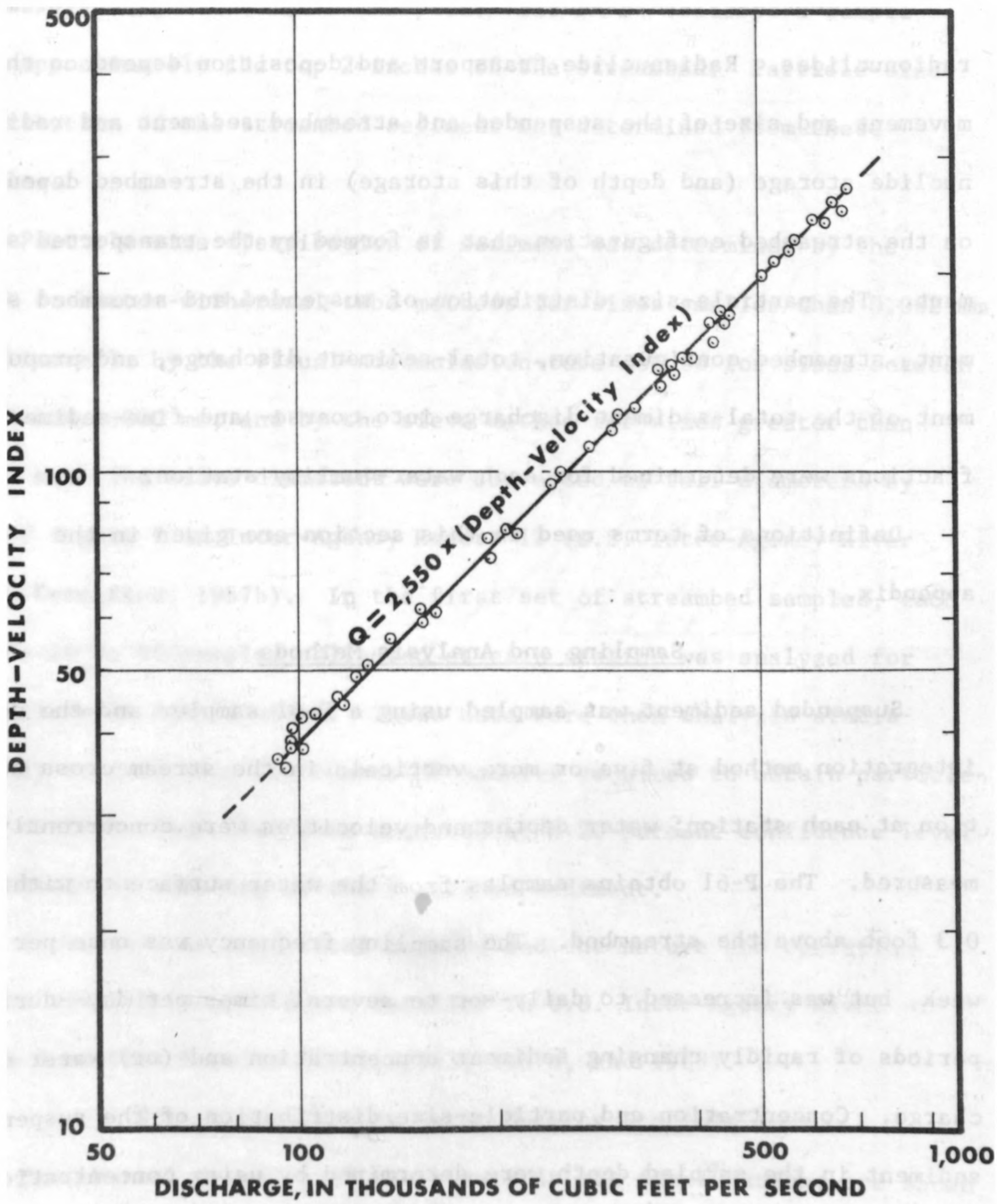



Figure 2.--Relation of depth-velocity index to observed water discharge (Q) for Columbia River at Hood River, Oreg.

## SEDIMENT DISCHARGE

Sediment data are essential in determining the transport of many radionuclides. Radionuclide transport and deposition depend on the movement and size of the suspended and streambed sediment and radionuclide storage (and depth of this storage) in the streambed depends on the streambed configuration that is formed by the transported sediment. The particle-size distribution of suspended and streambed sediment, streambed configuration, total-sediment discharge, and proportionment of the total-sediment discharge into coarse- and fine-sediment fractions were determined for each water-quality station.

Definitions of terms used in this section are given in the appendix.

### Sampling and Analysis Methods

Suspended sediment was sampled using a P-61 sampler and the depth-integration method at five or more verticals in the stream cross section at each station; water depths and velocities were concurrently measured. The P-61 obtains samples from the water surface to within 0.3 foot above the streambed. The sampling frequency was once per week, but was increased to daily--or to several times per day--during periods of rapidly changing sediment concentration and (or) water discharge. Concentration and particle-size distribution of the suspended sediment in the sampled depth were determined by using concentrations of the depth-integrated samples. Suspended sediment frequently was sampled at enough points in each of three or more verticals in a cross section to define the spatial distribution of sediment concentration and particle size. Streambed sediment at each station was sampled regularly using a U.S. BM-54 sampler. The BM-54 collects a sample from approximately the top 2 inches of the streambed. Particle-size distribution of the streambed sediment was determined from these samples.

Particle-size distribution of sediment was determined by the pipet or bottom-withdrawal-tube methods for sizes smaller than 0.062 mm (millimeter); by the visual-accumulation-tube method for sizes between 0.062 and 1.000 mm; and by the sieve method for sizes greater than 1.000 mm. The sieve diameters were converted to fall diameters by use of figure 7 in Inter-Agency Report 12 (U.S. Inter-Agency River Basin Committee, 1957b). In the first set of streambed samples, each of the 20 to 40 samples collected at each station was analyzed for particle-size distribution. These data were then analyzed statistically to determine the number of samples required to obtain particle-size distributions that were accurate at a 20-percent confidence level in subsequent sampling of the streambed sediment.

Particle-size analytical methods and the nature and operation of the sediment samplers are detailed in U.S. Inter-Agency River Basin Committee Reports (1941, 1943, 1957a, and 1963).

## Stream Geometry at Water-Quality Stations

The channel geometry of the rivers at the five stations are shown in figures 3-7. Inundated widths are nearly constant at all sites throughout the range of water discharges, except for extreme floods, which spread out over more of the respective river valleys. Divisions

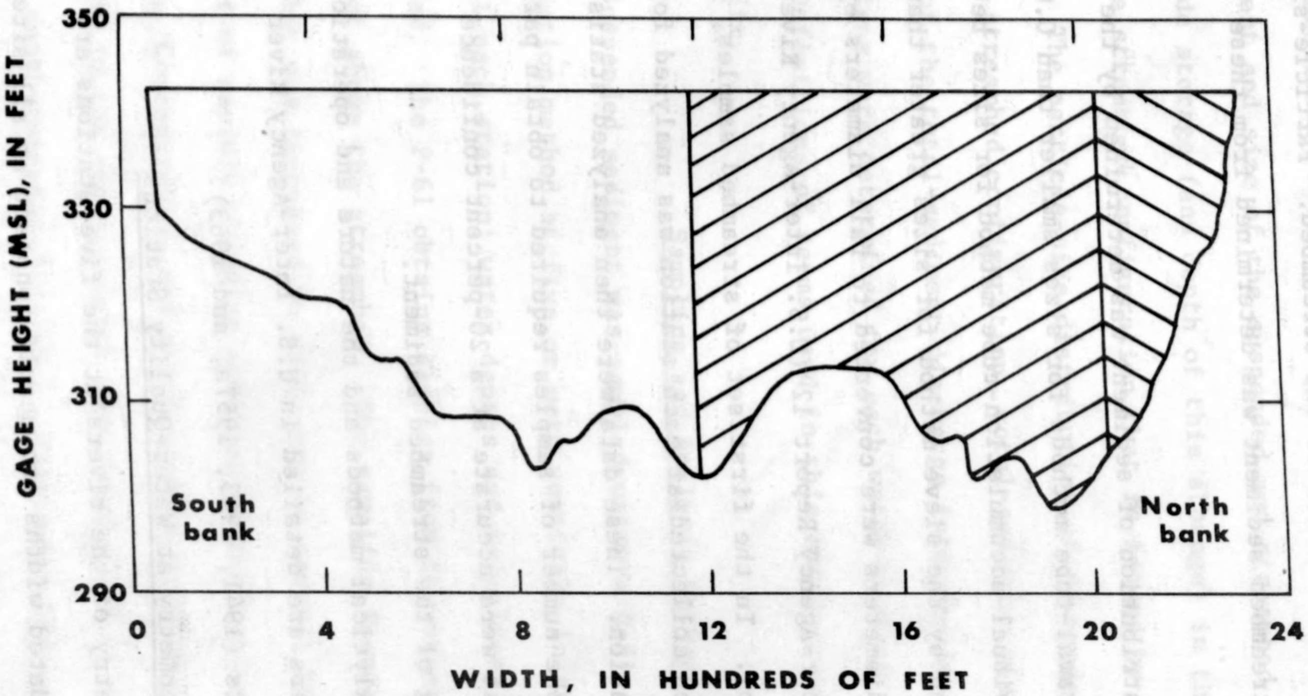



Figure 3.--Width and depths of the Columbia River at Pasco, Wash. from measurement of June 14, 1963. Divisions of width are based on major differences in particle-size distribution of the streambed sediment.

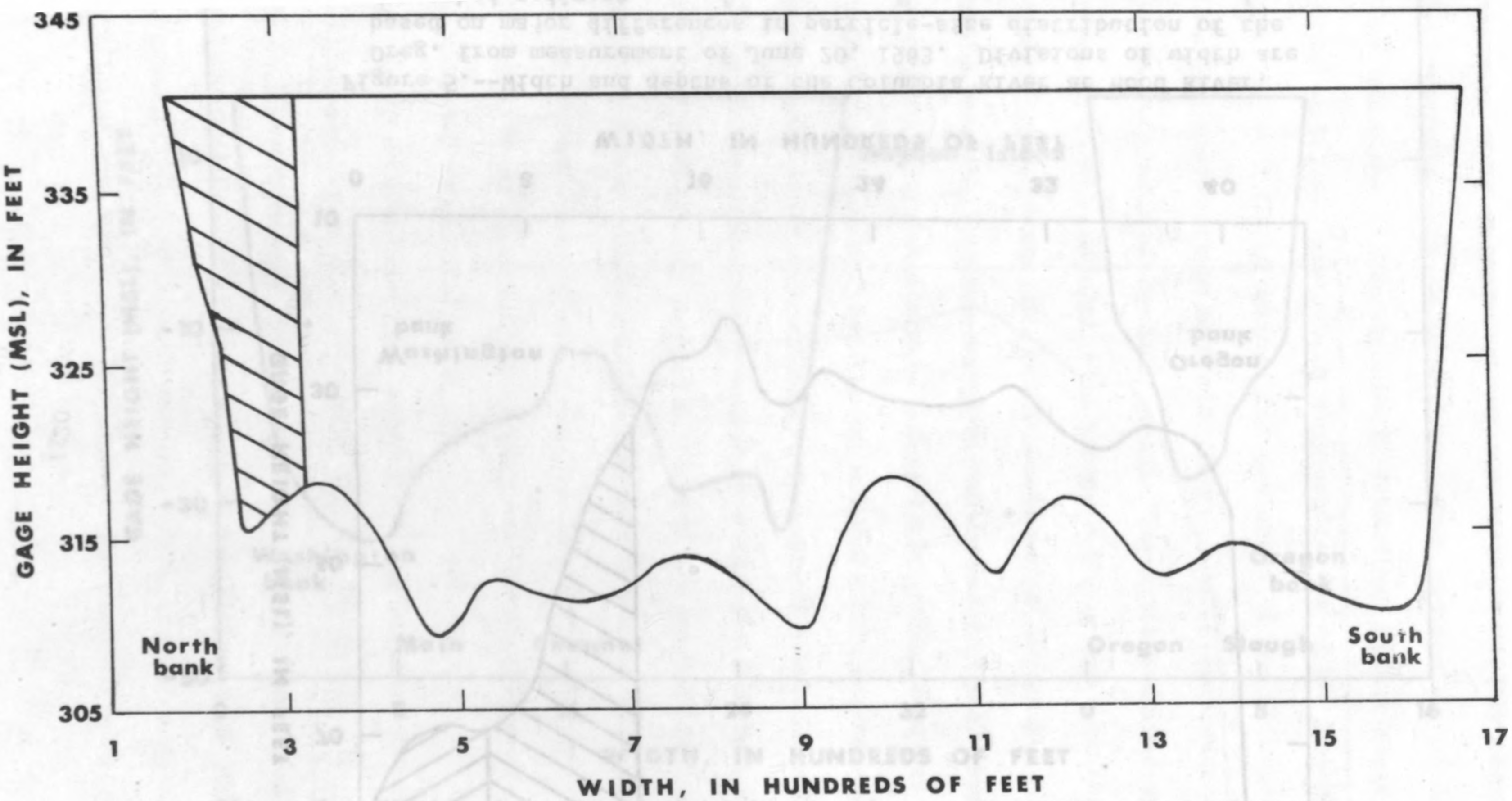



Figure 4.--Width and depths of the Snake River at Pasco, Wash. from measurement of May 27, 1963. Divisions of width are based on major differences in particle-size distribution of the streambed sediment.

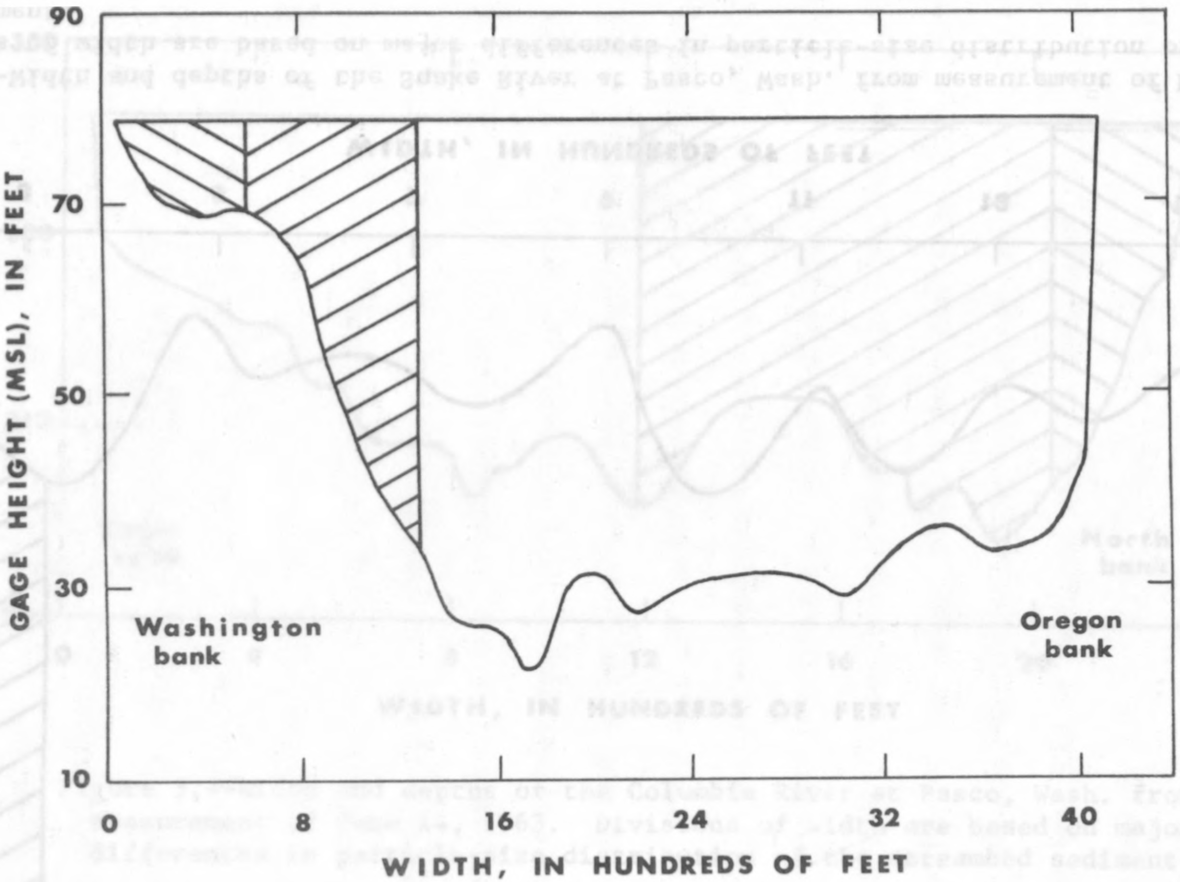



Figure 5.--Width and depths of the Columbia River at Hood River, Oreg. from measurement of June 20, 1963. Divisions of width are based on major differences in particle-size distribution of the streambed sediment.

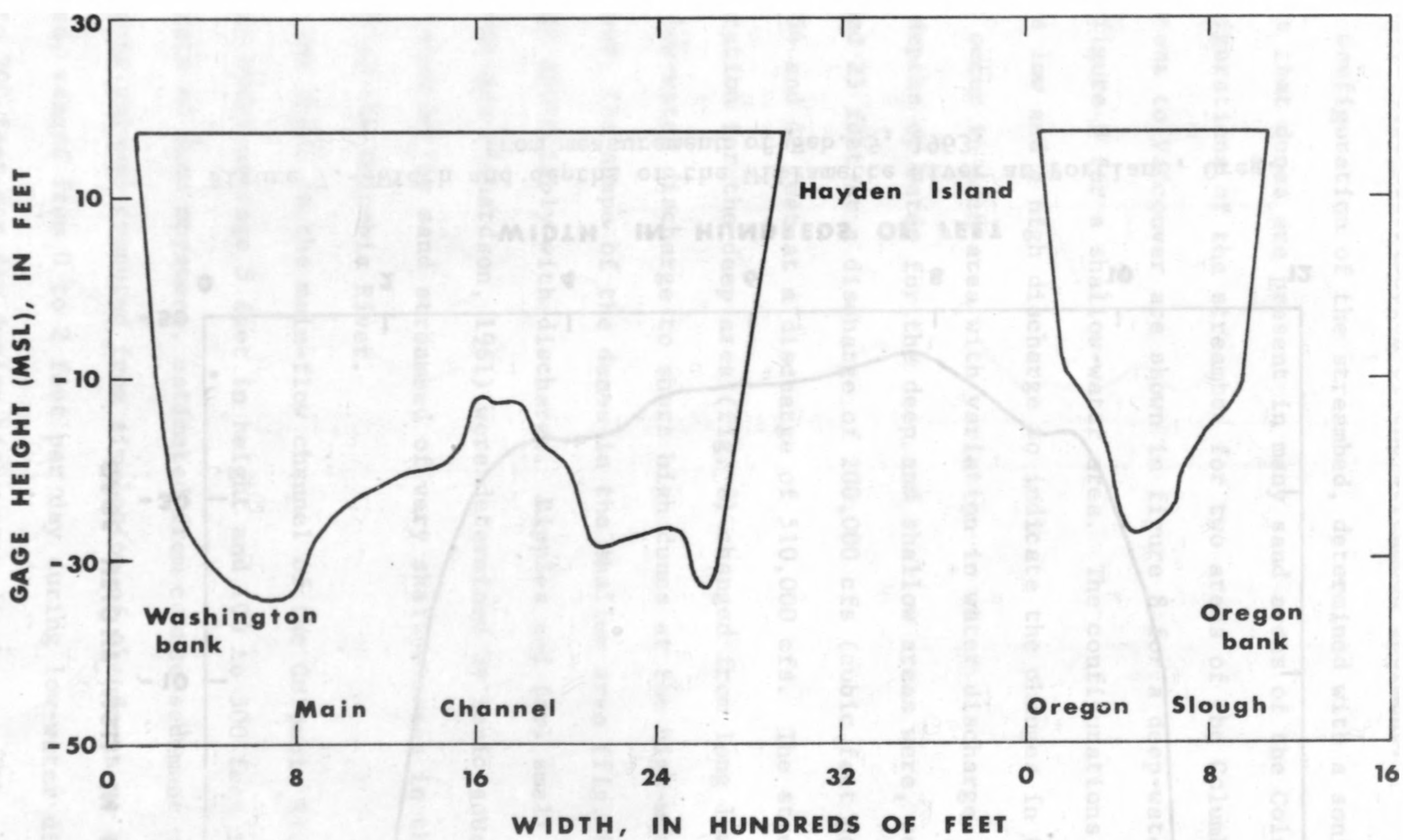



Figure 6.--Width and depths of the Columbia River at Vancouver, Wash. from measurement of June 20, 1963. Streambed of Oregon Slough has different particle-size distribution than streambed of the main channel.

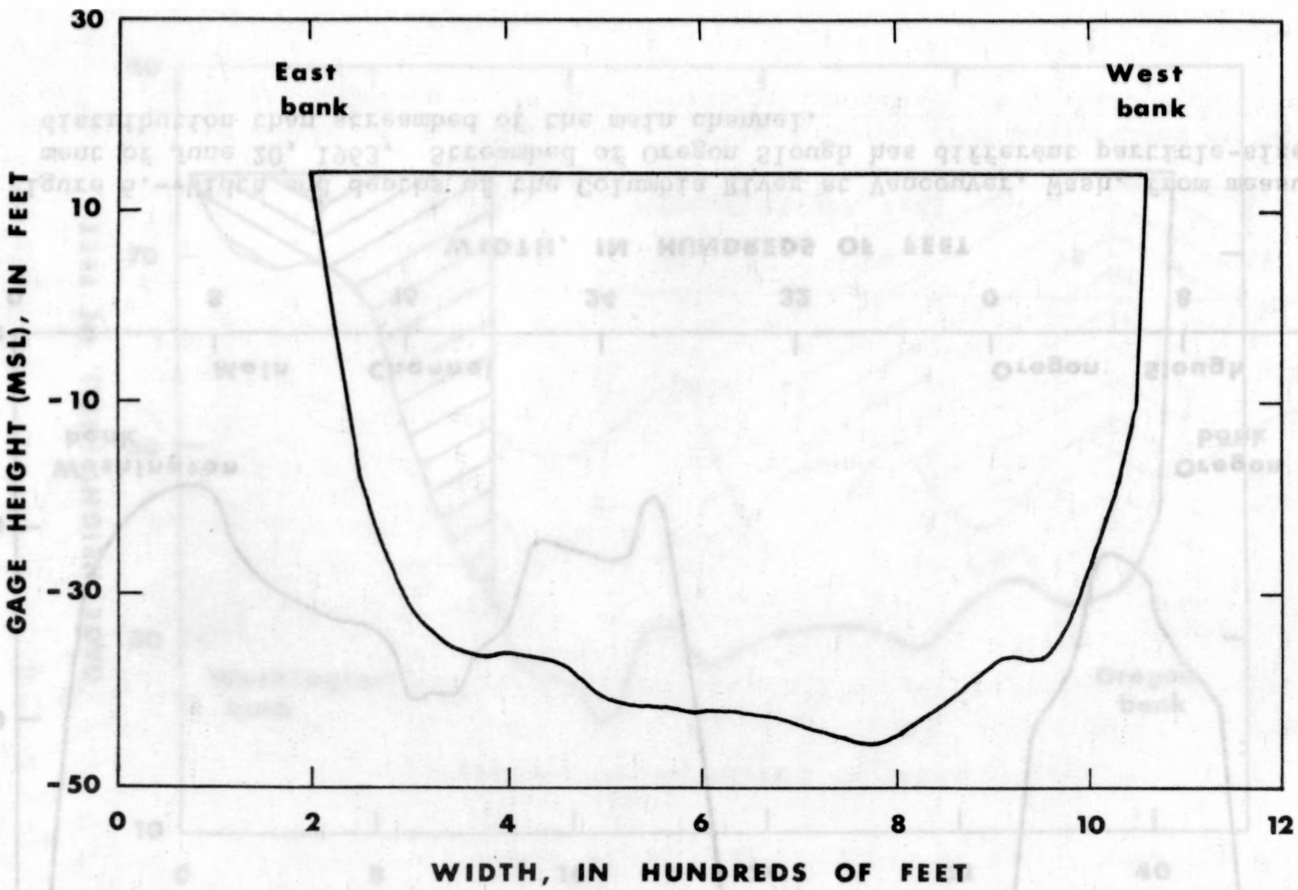



Figure 7.--Width and depths of the Willamette River at Portland, Oreg. from measurement of Feb. 5, 1963.

of the river width at each station are based on differences in particle-size distribution of the streambed sediment.

Configuration of the streambed, determined with a sonic sounder, shows that dunes are present in many sand areas of the Columbia River. Configurations of the streambed for two areas of the Columbia River adjacent to Vancouver are shown in figure 8 for a deep-water area and figure 9 for a shallow-water area. The configurations are shown for a low and a high discharge to indicate the changes in the dunes that occur in each area with variation in water discharge. The average depths of water for the deep and shallow areas were, respectively, 37 and 25 feet at a discharge of 200,000 cfs (cubic feet per second) and 54 and 42 feet at a discharge of 510,000 cfs. The streambed configuration for the deep area (fig. 8) changed from long low dunes at the low-water discharge to short high dunes at the high-water discharge. However, the shape of the dunes in the shallow area (fig. 9) did not change appreciably with discharge. Ripples and (or) small dunes (Simons and Richardson, 1961) were determined by sonic sounding or were seen on the sand streambed of very shallow areas in the study reach of the Columbia River.

The dunes in the main-flow channel of the Columbia River adjacent to Vancouver average 5 feet in height and 100 to 300 feet in length. The rate of dune movement, estimated from coarse-sediment discharges and dune volumes computed from simulation of the dunes as triangular shaped, ranged from 0 to 2 feet per day during low-water discharge to 100 to 200 feet per day during high-water discharge. The sorption,

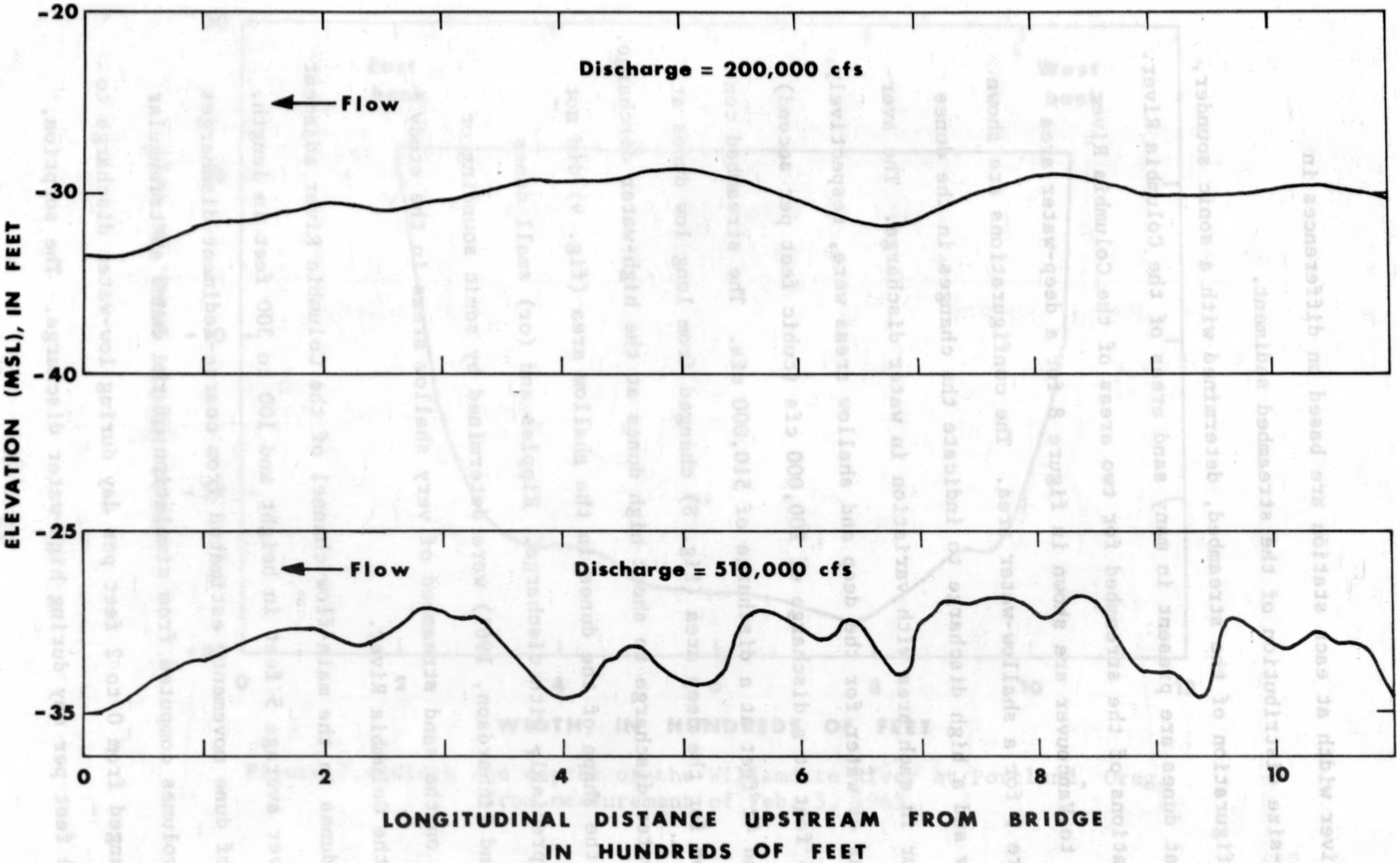



Figure 8.--Configuration of the streambed in a deep section of the Columbia River adjacent to Vancouver, Wash. at two river discharges. Vertical scale is exaggerated.

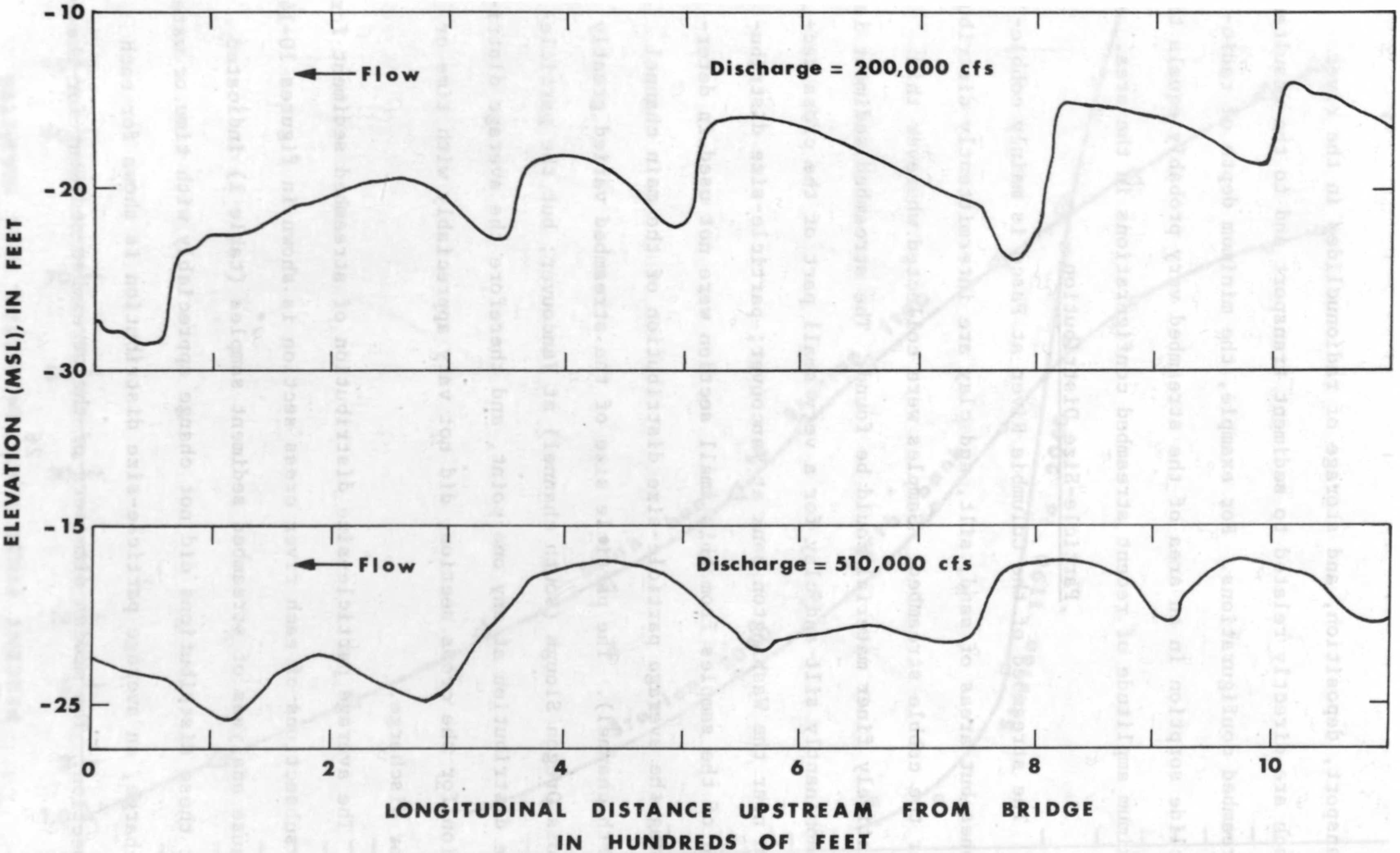



Figure 9.--Configuration of the streambed in a shallow section of the Columbia River adjacent to Vancouver, Wash. at two river discharges. Vertical scale is exaggerated.

transport, deposition, and storage of radionuclides in the river reach are directly related to sediment transport and to the resultant streambed configurations. For example, the minimum depth of radionuclide sorption in an area of the streambed very probably equals the maximum amplitude of recent streambed configurations in the area.

## Particle-Size Distribution

The streambed of the Columbia River at Pasco is mainly cobblestones but areas of sand, silt, and clay are intermittently distributed over the cobble streambed. Samples were collected wherever this relatively finer material could be found. The streambed sediment is predominantly silt and clay for a very small part of the cross section near the Washington bank at Vancouver; particle-size distribution of the samples from this small section were not used in determining the average particle-size distribution of the main channel (north channel). The particle size of the streambed varied greatly across Oregon Slough (south channel) at Vancouver; but the particle-size distribution at any one point, and therefore the average distribution for the cross section, did not vary appreciably with time or water discharge.

The average particle-size distribution of streambed sediment for the subsections of each river cross section is shown in figures 10-14. Because analyses of streambed sediment samples (table 1) indicated that these distributions did not change appreciably with time or water discharge, an average particle-size distribution is shown for each subsection. The median diameters of the streambed sediment for the

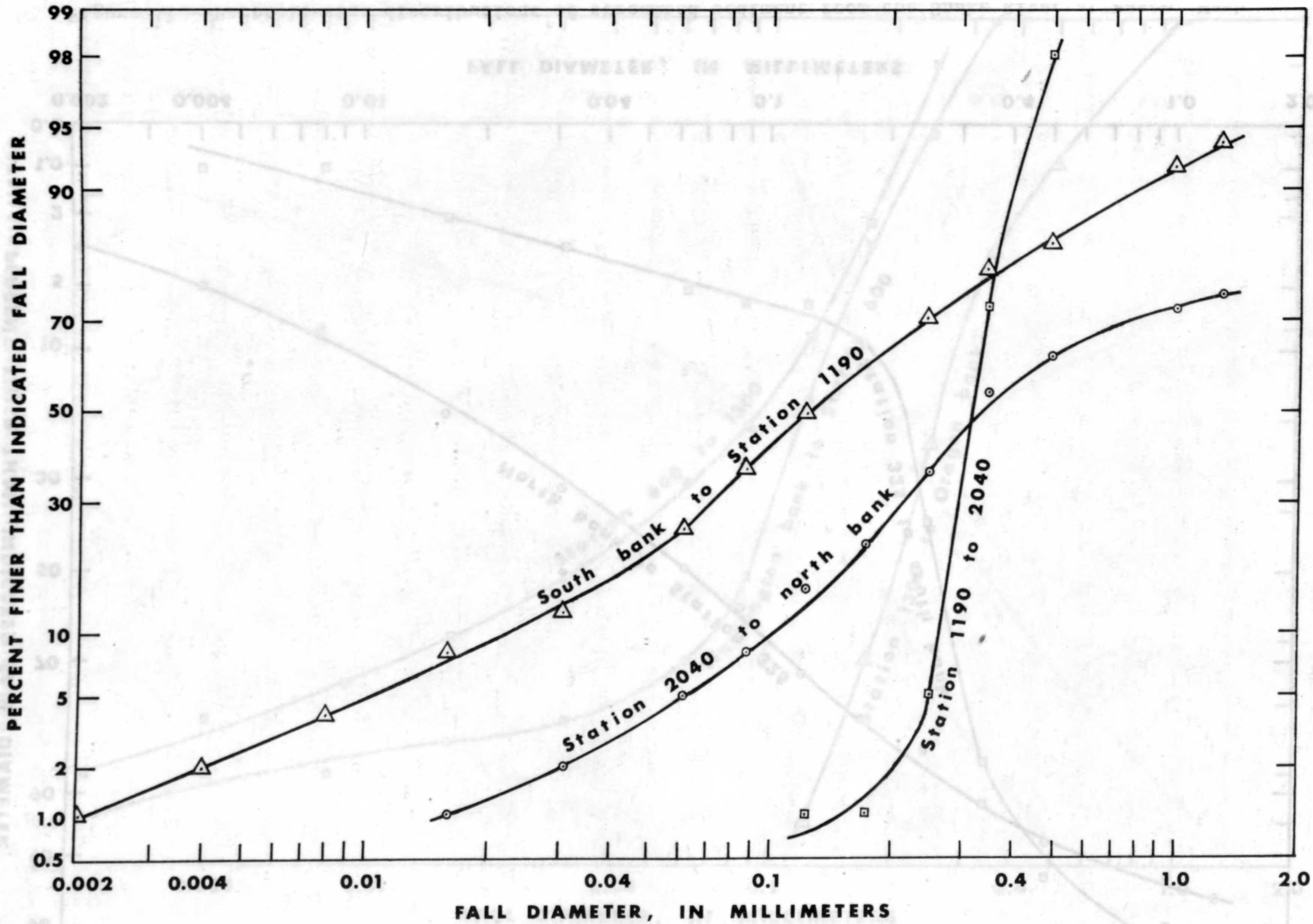



Figure 10.--Particle-size distributions of streambed sediment from the Columbia River at Pasco, Wash.

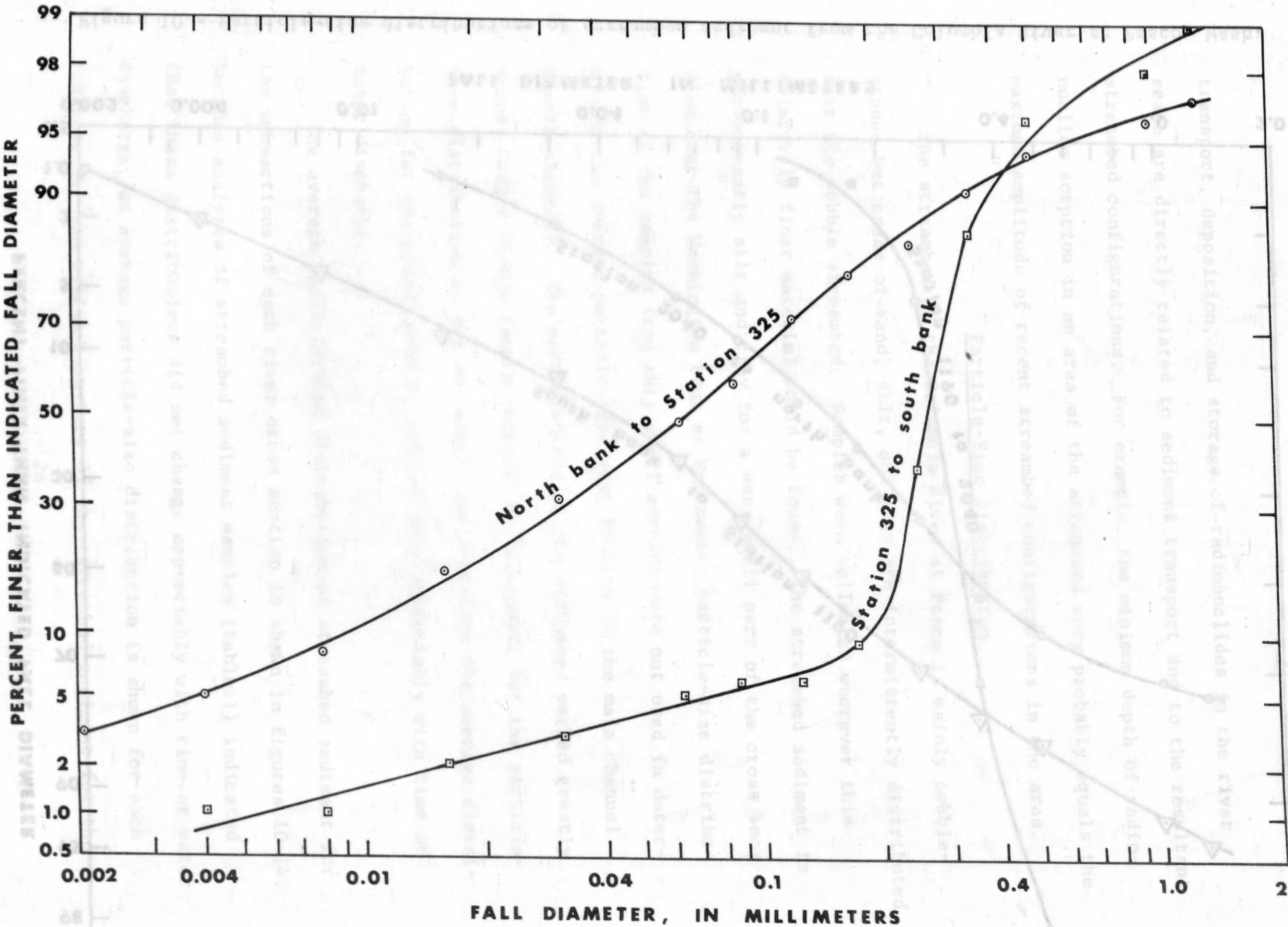



Figure 11.--Particle-size distributions of streambed sediment from the Snake River at Pasco, Wash.

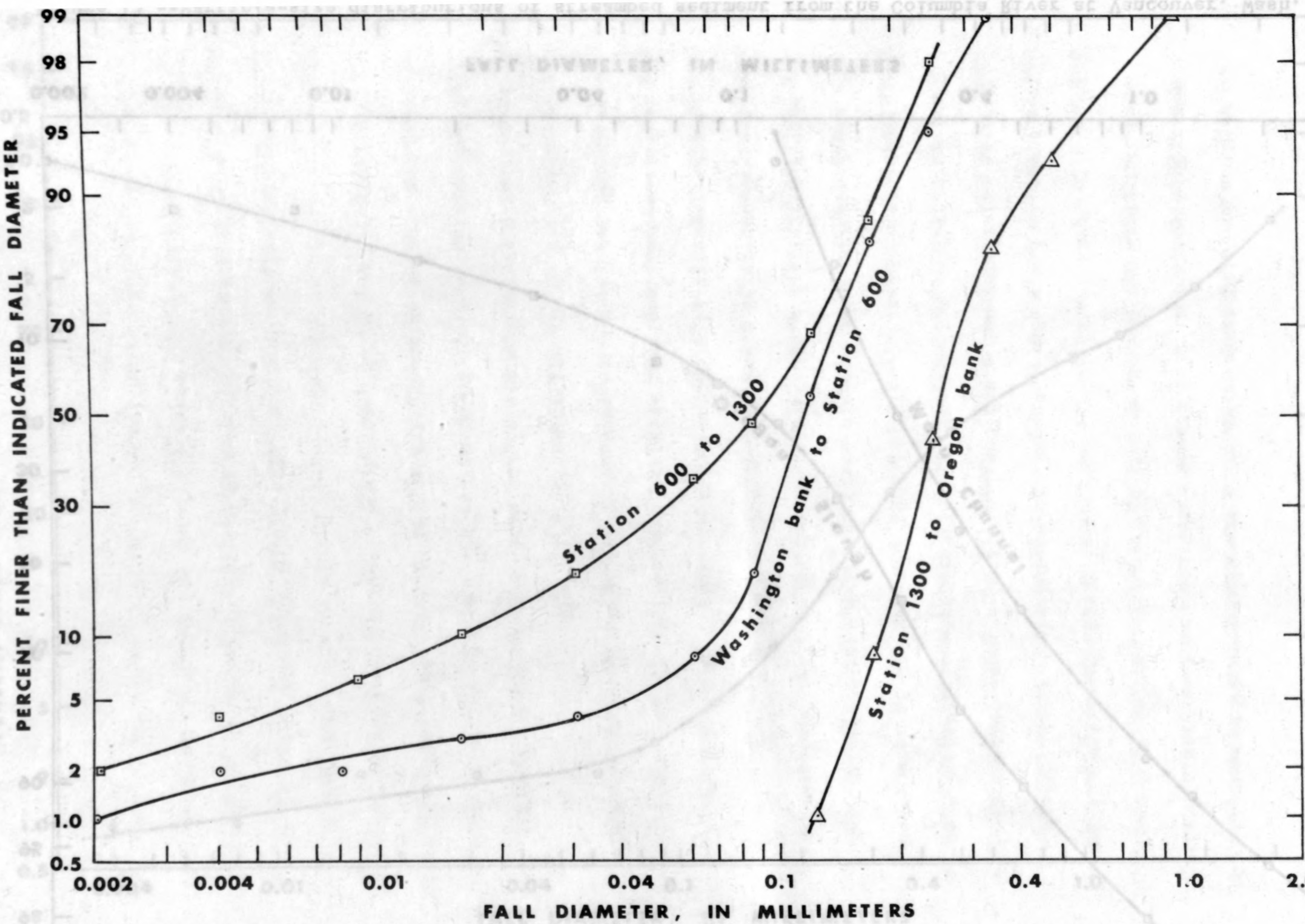



Figure 12.--Particle-size distributions of streambed sediment from the Columbia River at Hood River, Oreg.

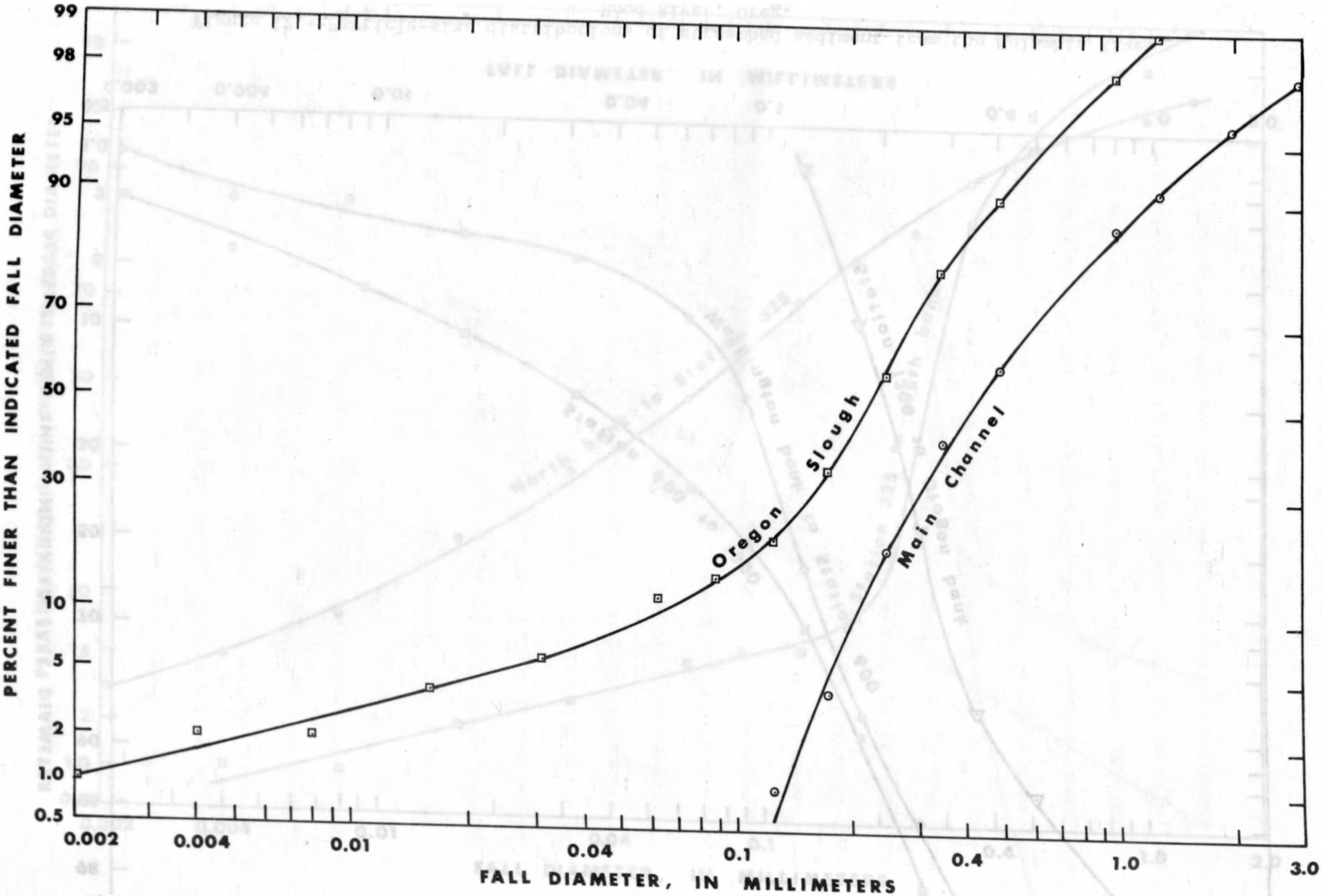



*Figure 13.--Particle-size distributions of streambed sediment from the Columbia River at Vancouver, Wash.*

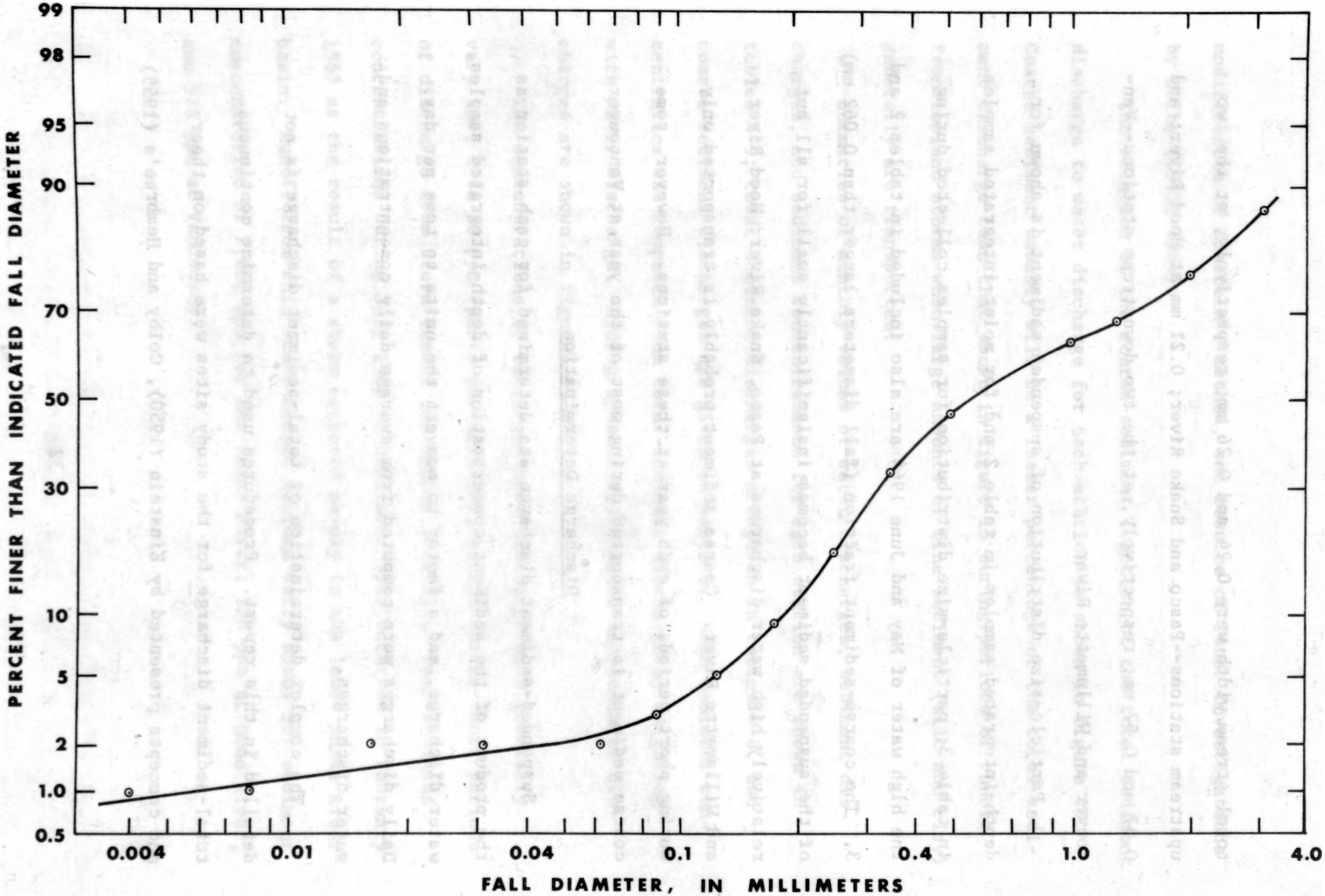



Figure 14.--Particle-size distribution of streambed sediment from the Willamette River at Portland, Oreg.

total stream width were 0.24 and 0.26 mm, respectively, at the two upstream stations--Pasco and Snake River; 0.21 mm at Hood River; and 0.37 and 0.57 mm, respectively, at the two downstream stations--Vancouver and Willamette River.

Particle-size distribution of suspended sediment is shown for depth-integrated samples in table 2 and for point-integrated samples in table 3; particle-size distribution for samples collected during the high water of May and June 1964 are also included in tables 2 and 3. The coarse-sediment fraction (fall diameters larger than 0.062 mm) of the suspended sediment becomes insignificantly small for all but relatively high water discharges at Pasco, Snake River, Hood River, and Willamette River. Coarse sediment probably is transported only during short periods of each year at these stations. However, some coarse sediment is transported during most of the year at Vancouver.

## Discharge Determination

Suspended-sediment discharge was determined for each station as the product of the sediment concentration of depth-integrated samples, water discharge, and a factor to convert the units to tons per day. Daily discharges were computed from average daily concentrations and water discharges.

The complex determination of total-sediment discharge is not detailed in this report. Procedures used to determine continuous total-sediment discharge for the study sites were based on theory and concepts presented by Einstein (1950), Colby and Hembree's (1955) modification of Einstein's method, and results of later investigations by Colby (1963, 1964).

The relation of the coarse-sediment fraction of the total sediment discharge to water discharge for each station is shown in figure 15. Coarse sediment usually will be a lesser percentage of the total sediment discharge than that shown in figure 15 during periods of runoff from lowland storms when large amounts of fine sediment (silt and clay) generally are transported.

Summaries of monthly values of water discharges, sediment discharges, and sediment concentrations for each station are shown in tables 4-9; total-sediment discharges are given in tables 4-8, and coarse-sediment discharges are given in table 9. Mean sediment concentration was computed from total-sediment discharge by weighting with water discharge. Hydrographs of daily water and sediment discharges are shown in figures 16-20.

The concentrations of total-sediment discharge were generally very low, 1 to 50 ppm (parts per million), except during short periods of discharge from storm runoff and spring snowmelt. Peak sediment concentrations during July 1962 to September 1963 occurred in February 1963 as the result of a storm centered mainly in the lower Snake River basin. Runoff from this storm caused maximum daily means for sediment concentration of 2,860 ppm for the Snake River, 720 ppm at Hood River, and 570 ppm at Vancouver.

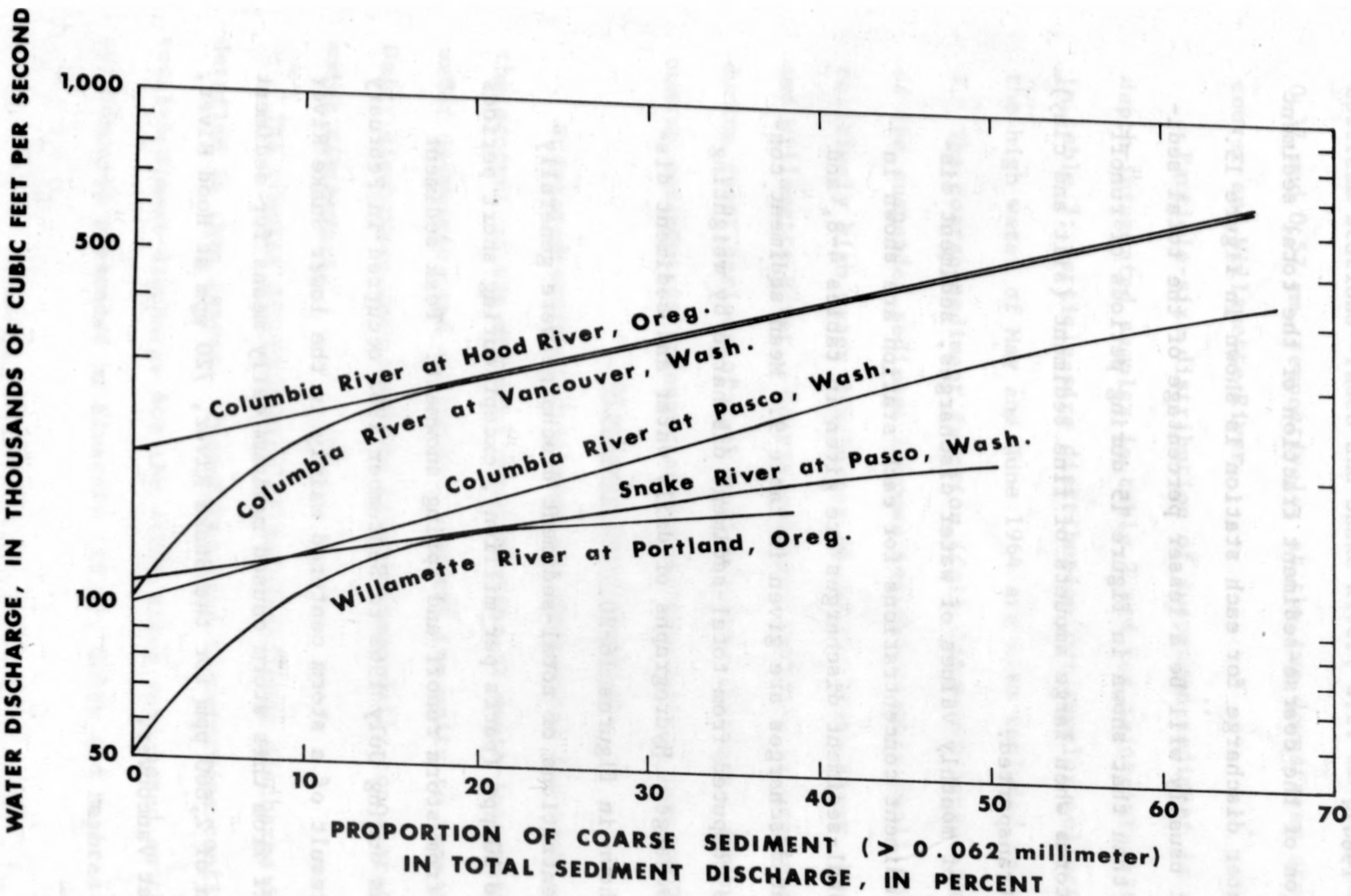



Figure 15.--The relation of the coarse-sediment fraction of the total-sediment discharge to water discharge for the Columbia River at Pasco, Wash., Hood River, Oreg., and Vancouver, Wash., the Snake River at Pasco, Wash., and the Willamette River at Portland, Oreg.

Table 9.--Amount of coarse sediment, in thousands of tons, in the total sediment discharges of the Columbia, Snake, and Willamette Rivers.

| Time period | Columbia River at Pasco, Wash. | Snake River at Pasco, Wash. | Columbia River at Hood River, Oreg. | Columbia River at Vancouver, Wash. | Willamette River at Portland, Oreg. |
|---|---|---|---|---|---|
| 1962 | | | | | |
| July | - | - | 58 | 274 | - |
| August | 9 | - | 1 | 35 | - |
| September | - | - | - | 1 | - |
| Total | 9 | - | 59 | 310 | - |
| October | - | - | - | 2 | - |
| November | - | - | - | 7 | 19 |
| December | - | - | - | 16 | 14 |
| 1963 | | | | | |
| January | - | - | - | 7 | - |
| February | - | - | 1 | 45 | 32 |
| March | - | - | - | 10 | 1 |
| April | 1 | - | - | 46 | 20 |
| May | 18 | 28 | 129 | 376 | 23 |
| June | 176 | 17 | 649 | 1,420 | - |
| July | 68 | - | 87 | 341 | - |
| August | 2 | - | - | 12 | - |
| September | - | - | - | 1 | - |
| Total | 265 | 45 | 866 | 2,290 | 109 |

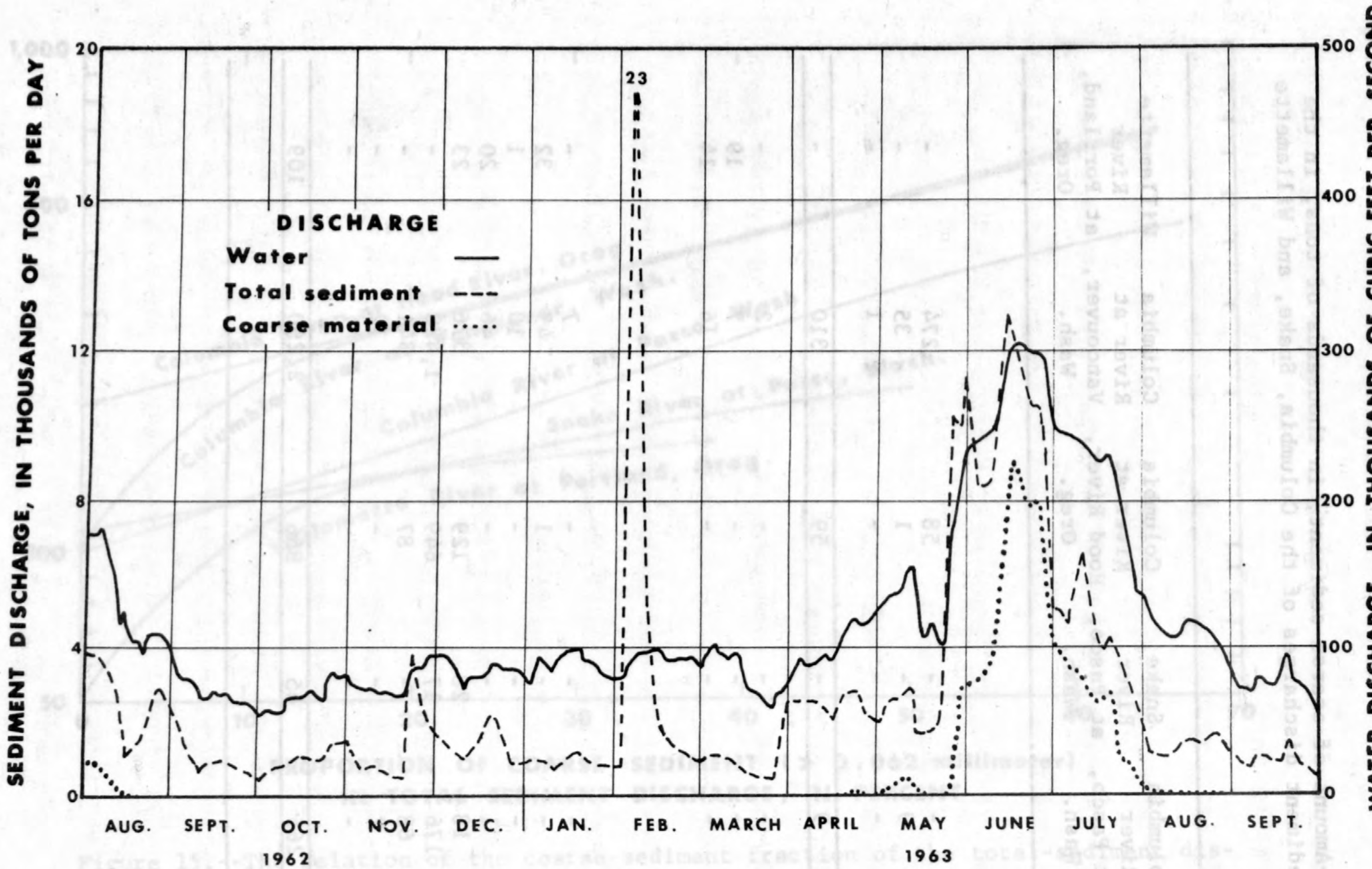



Figure 16.--Hydrographs of daily mean water and sediment discharge of the Columbia River at Pasco, Wash. from August 1962 to September 1963.

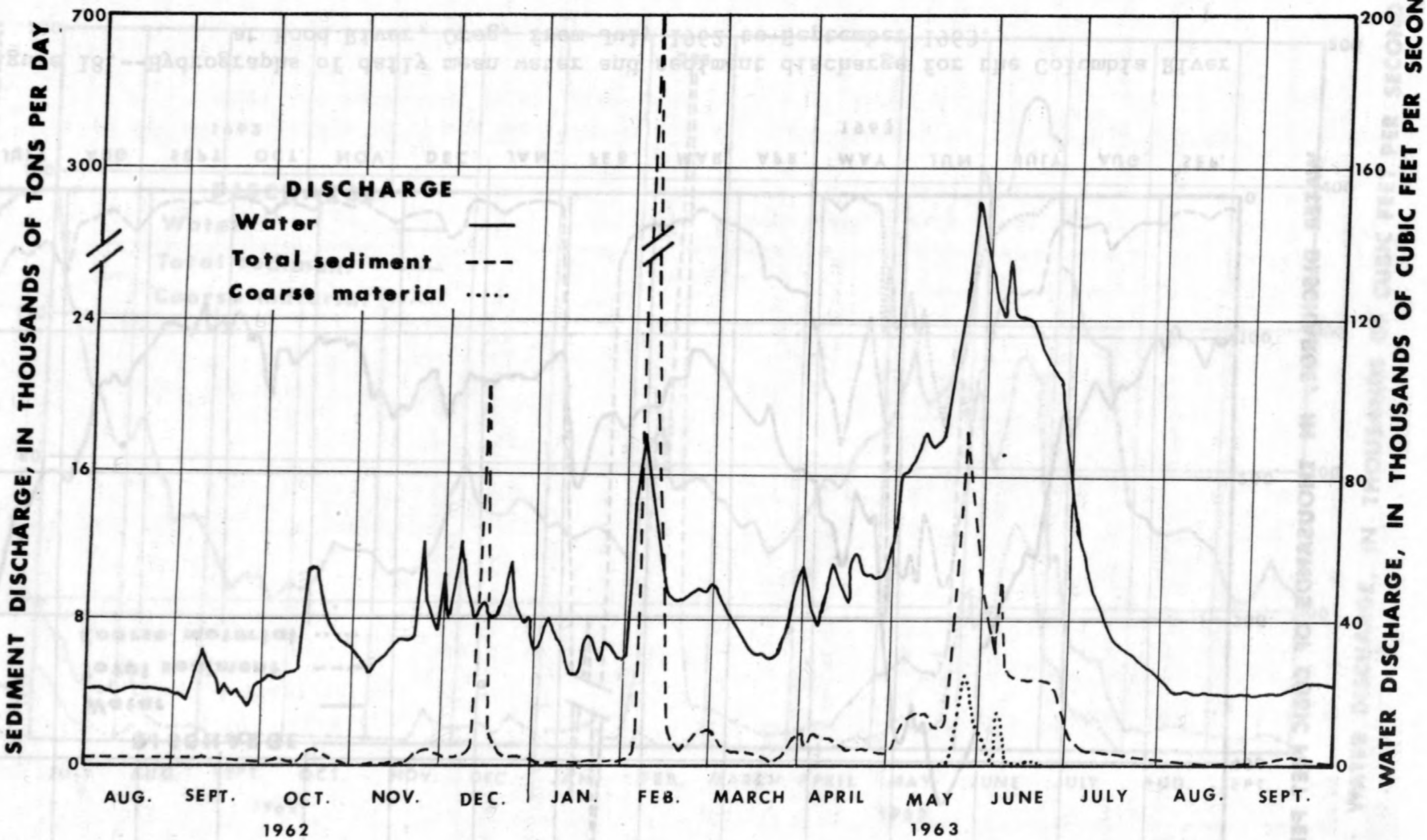



Figure 17.--Hydrographs of daily mean water and sediment discharge for the Snake River at Pasco, Wash. from August 1962 to September 1963.

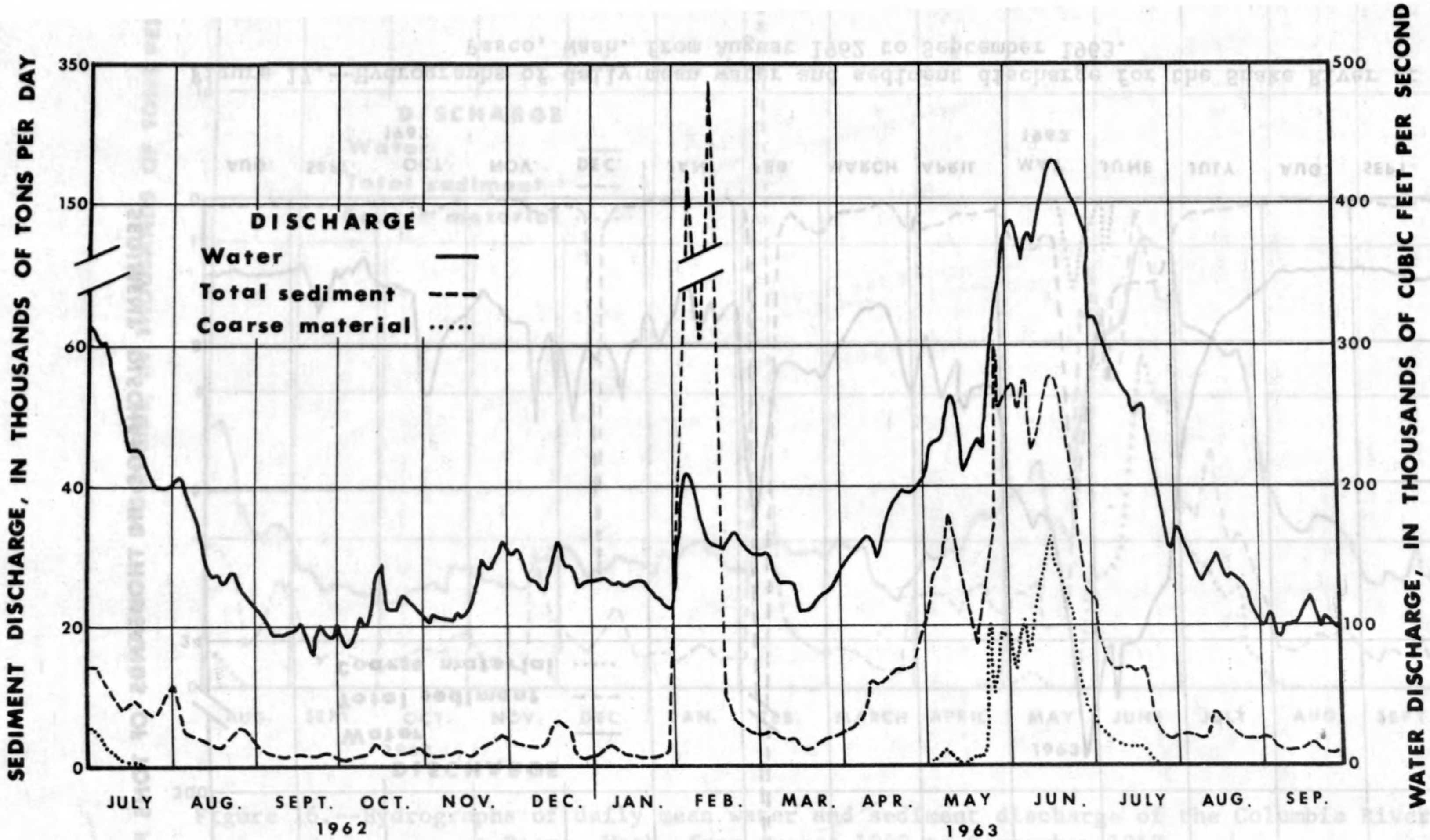



Figure 18.--Hydrographs of daily mean water and sediment discharge for the Columbia River at Hood River, Oreg. from July 1962 to September 1963.

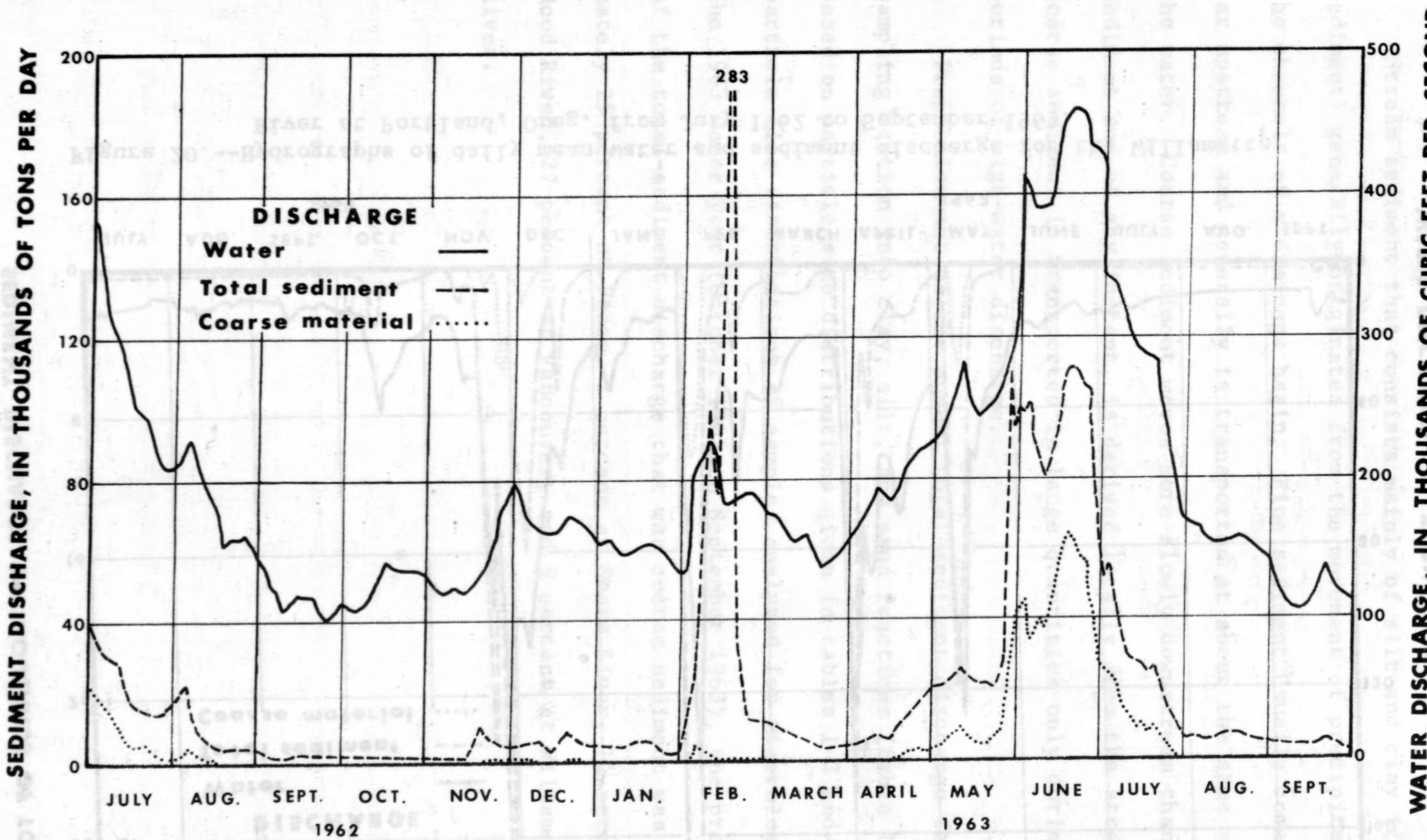



Figure 19.--Hydrographs of daily mean water and sediment discharge for the Columbia River at Vancouver, Wash. from July 1962 to September 1963.

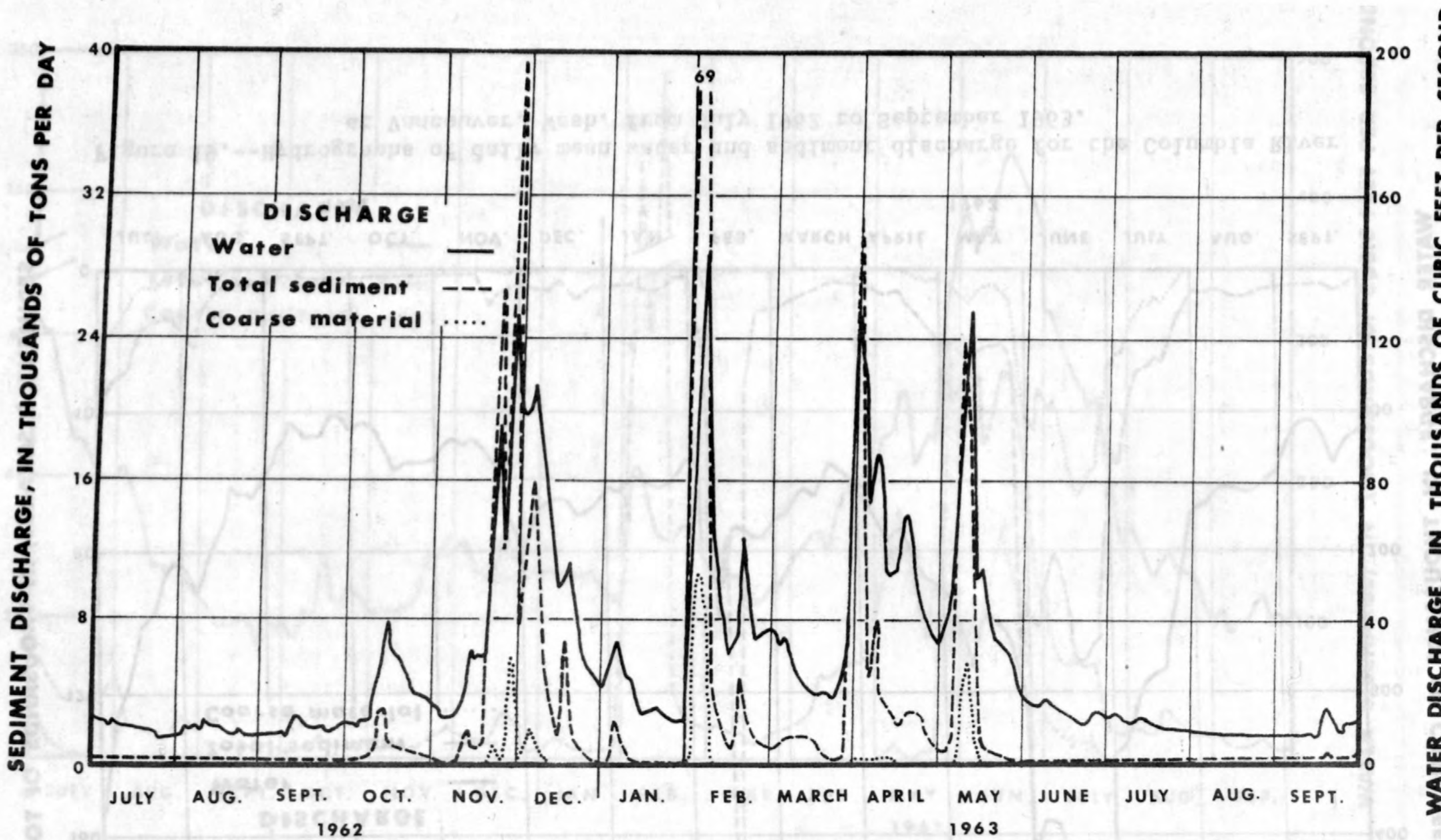



Figure 20.--Hydrographs of daily mean water and sediment discharge for the Willamette River at Portland, Oreg. from July 1962 to September 1963.

Stream sediment that consists mainly of silt and clay (fine sediment) generally originates from the movement of precipitation to the channels of a drainage basin. Fine sediment usually comes from far upstream and generally is transported at about the same speed as the water. Coarse sediment moves more slowly downstream than fine sediment and at any instant, is derived locally from the streambed. Coarse sediment is transported in large quantities only during periods of high-water discharge.

Proportionment of the annual total-sediment discharge for each sampling station into clay, silt, and sand fractions (table 10) is based on particle-size distributions given in tables 1-3 and also particle-size distributions of samples analyzed for mineralogy. For the 1963 water year (October 1962 to September 1963), the proportion of the total-sediment discharge that was coarse sediment was approximately 25 percent at Pasco, 2 percent at Snake River, 14 percent at Hood River, 27 percent at Vancouver, and 9 percent at Willamette River.

Table 10.--Estimated particle-size composition of total sediment discharge at Columbia River, Snake River, and Willamette River water-quality stations for the water year October 1962 to September 1963.

| Station | Sediment discharge (thousands of tons) | | |
|---|---|---|---|
| | Sand (>0.062mm) | Silt (0.002 to 0.062 mm) | Clay (<0.002 mm) |
| Columbia River at Pasco, Wash. | 265 | a495 | a200 |
| Snake River at Pasco, Wash. | 45 | a315 | a295 |
| Columbia River at Hood River, Oreg. | 865 | a2,650 | a800 |
| Columbia River at Vancouver, Wash. | 2,290 | a3,470 | a980 |
| Willamette River at Portland, Oreg. | 110 | 435 | 600 |

[a] Discharge from storm in early February 1963 excluded.

## WATER TEMPERATURE

Water temperatures observed concurrently with the collection of suspended-sediment samples at the five water-quality stations and daily temperatures for the Columbia River near The Dalles, Oreg., are shown in tables 11-16. Although the observation frequency at the five stations was irregular, sufficient data are available to show the probable ranges of water temperature. Water temperatures attained maximums in the low seventies (degrees Fahrenheit) during August and September and reached minimums in the thirties during January.

## MINERALOGY, EXCHANGE CAPACITY, AND CARBON CONTENT OF SEDIMENTS

As a preliminary step in understanding mechanisms of radionuclide uptake, release, and transport by Columbia River sediments, the mineralogy, exchange capacity, and carbon content of those sediments have been determined. In order to ascertain the effect of diverse geologic, topographic, and climatologic factors, samples for the determinations were collected at each of the 3 Columbia River stations and at stations near the mouths of the major tributaries within the study reach. In addition, sampling at these stations was planned so that possible variations of mineralogy, exchange capacity, or carbon content with time and (or) type of sample could be evaluated. Many complications, however, have prevented completely satisfactory accomplishment of these objectives.

The significance of climate and geologic parent material on soil formation and clay mineralogy has long been recognized (Grim, 1953; Buckman and Brady, 1960) and some relations between mineralogy, particularly clay mineralogy, and exchange capacity are well known (Grim, 1953). However, literature pertaining directly to mineralogy, exchange capacity, or carbon content of sediments of the Columbia River and its tributaries is almost nonexistent, and either general or specific studies of these characteristics in fluvial sediments are rare. Notable exceptions to the latter are the studies by Kennedy (1963, 1965), Clanton and Gloyna (1964), and Reynolds and Gloyna (1963). Kennedy's data relate mineralogy to exchange capacity and to type of load sampled in 21 streams in diverse geologic and climatologic regions of the United States. His data show definite trends in mineralogy and exchange capacity among the streams studied. The Crooked River, a tributary of the Deschutes River (pl. 1), is included in these streams. The studies by Clanton, Reynolds, and Gloyna relate mineralogy to exchange capacity and to uptake and release of fission-produced radionuclides in the Guadalupe River and its estuary, which are in Texas. These authors noted no differences in clay mineralogy and exchange capacity in the Guadalupe River sediments, despite differences in geology and climate within the Guadalupe River basin. However, the geologic, climatologic, and topographic extremes in the Guadalupe Basin perhaps are not so pronounced as those in the Columbia River basin.

## Analytical Techniques

### Sampling

Samples for mineralogy, exchange-capacity, and carbon-content analyses were collected during the first 6 months of 1963. Suspended-sediment samples from the Columbia, Snake, and Willamette Rivers are composites of samples taken vertically through the water column at five centroids of discharge; that is, from five points in a cross section representing equal parts of the stream discharge. The sampling technique consisted of slowly traversing a 3-gallon bottle in a weighted carriage through the water column until the bottle filled. Streambed-sediment samples are composites of samples collected at the locations of the five centroids using a U.S. BM-54 sampler.

Sediments from the Umatilla, John Day, Deschutes, Klickitat, and Sandy Rivers were sampled, where possible, in a manner similar to that used in the Columbia River and its larger tributaries. However, where very coarse sediment formed the streambed, such as at the John Day, Deschutes, and Klickitat River stations, samples were collected by wading in the stream and by using a shovel, a bucket, or an open pipe. All the tributary streams except the Sandy River were sampled at the first gaging station upstream from the mouth; the Sandy River was sampled at the access point nearest the river's mouth.

Consistent with the general objectives of the study, samples were collected from both suspended and streambed sediments and, at some stations, under different water discharges. The discharges during the time each sample was collected are designated only as "high" or "low" depending on how the discharge of the stream compared with the mean annual discharge. Because the discharge in some streams did not vary during the sampling period, data are not available for some streams under both "high" and "low" discharges or for both suspended and streambed sediments. Absolute values of stream discharge during the sampling period are available from the U.S. Geological Survey, Water Resources Division, Portland, Oreg.

## Laboratory Procedures

Mineralogy of the 62- to 1,000-micron separate from the sand fraction was determined by point count of constituents at 250 points in each of 30 thin sections; the data are reported as the percentage by volume that each constituent represents. Point counts on two thin sections from about half the samples suggest that a satisfactory degree of precision is obtained despite the rather limited number of points counted. Average count or the result of a single count is reported. Supplemental sand-separate mineralogy data were obtained by X-ray analysis of 16 samples, including at least 1 sample from every station.

Mineralogy of the silt (greater than 2 microns and less than 62 microns) and clay (less than 2 microns) separates was determined by X-ray diffraction, and the weight percentage of each mineral or mineral group was estimated from diffraction intensities. These estimates give only a general indication of the absolute amounts of each mineral or mineral group, but the probable accuracy of the estimates is within

10 percent. However, in comparing one sample with another, the relative amounts of each mineral or mineral group probably are correct.

The exchange capacities of the size separates were determined by equilibrating the separates over night in 1.0N neutral $NH_4Cl$ (ammonium chloride). The supernatent solutions were removed by centrifugation and decantation, and the samples were washed with alcohol to remove excess $NH_4Cl$. The ammonia then was distilled from the samples and was titrated with 0.1N HCl (hydrochloric acid). Exchange-capacity values, in milliequivalents per 100 grams, are averages of at least two determinations unless otherwise indicated.

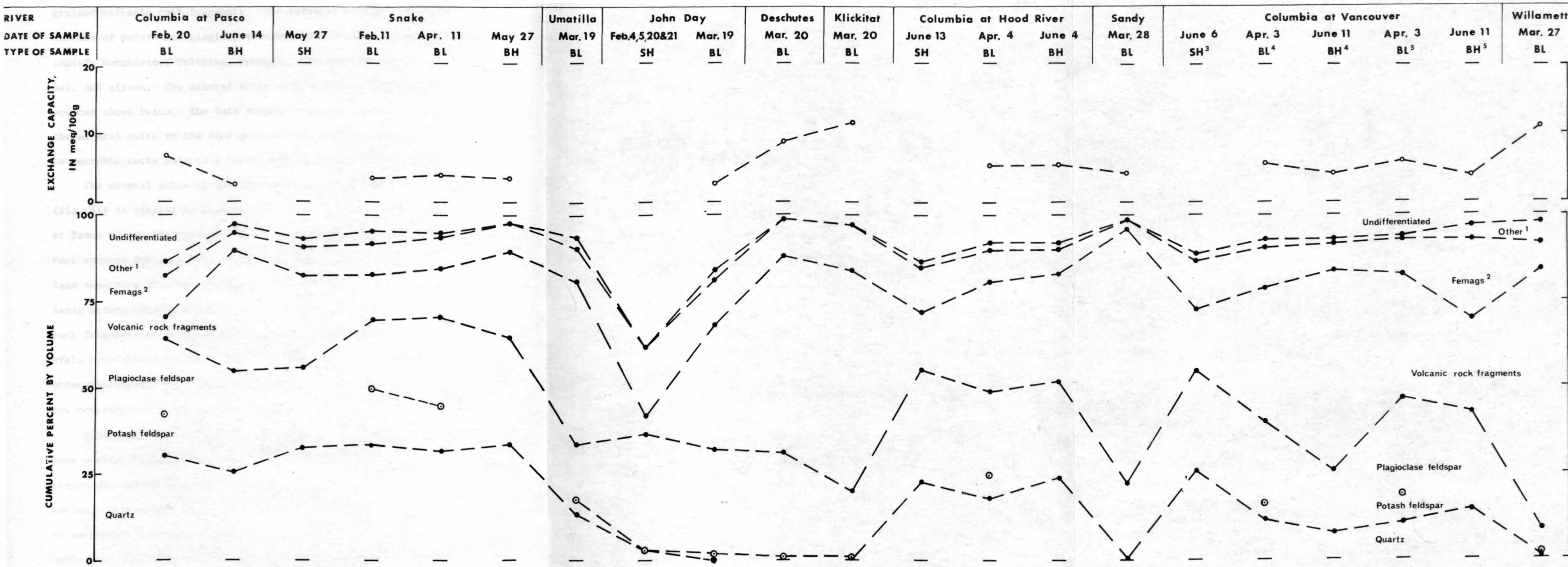
Total-carbon content of selected samples was determined by induction furnace combustion; mineral carbon was obtained by the gasometric method, and organic carbon was determined as the difference between total and mineral carbon.

## Mineralogy

### Sand Separate

The mineralogy of the sand separate is shown by the fence diagram in figure 21. The amount of a mineral or mineral group in each sample is related directly to the space between the dashed lines. In order to indicate relative mineralogic trends along the Columbia River, the data in figure 21, and in figures 22 and 23, are arranged so that, from left to right, the stations are progressively farther downstream from Pasco.

The mineral suite in sand separates from the Columbia River at Pasco consists dominantly of feldspar, quartz, and fine- to medium-




BL Bed sediment, low discharge.
BH Bed sediment, high discharge.
SH Suspended-sediment, high discharge.
1. Chert, garnet, zircon, and muscovite.
2. Hornblende, pyroxene, hypersthene, olivine, chlorite, biotite, hematite, and black opaque minerals.
3. Composite sample from north and south channels.
4. Composite sample from north channel.
5. Composite sample from south channel.

Figure 21.--Sand-separate mineralogy and exchange capacity of sediments from the Columbia River and tributaries between Pasco, Wash. and Portland, Oreg. All samples were collected during 1963. Mineralogy analyses were performed by Edward J. Young; exchange-capacity analyses were made by Harry C. Starkey.

grained volcanic rock fragments. The feldspar consists of about equal amounts of potash and plagioclase varieties. Common accessory minerals include hornblende, chlorite, pyroxene, and small amounts of chert, garnet, and zircon. The mineral suite reflects the polygenetic sediment sources above Pasco. The data suggest that the dominant sources for the mineral suite in the sand separate are plutonic igneous rocks and metamorphic rocks and, to a lesser extent, supracrustal volcanic rocks.

The mineral suite in sand separates from the Snake River at Pasco (fig. 21) is similar to that in sand separates from the Columbia River at Pasco except that perhaps relatively more detritus from volcanic rock sources and less from metamorphic rock sources is represented. Sand separates from the Umatilla, John Day, Deschutes, Klickitat, and Sandy Rivers chiefly contain (fig. 21) fine- to medium-grained volcanic rock fragments and plagioclase feldspars. The abundant accessory minerals contributed by these streams are hornblende, hypersthene, and other pyroxenes. Very little chert and quartz and no garnet or zircon are contributed by any of these streams.

Mineralogy data from X-ray analysis of sand separates (fig. 24B) show montmorillonite and kaolinite in sands from the Columbia and Snake Rivers and montmorillonite in sands from other Columbia River tributaries. Examination (by J. L. Glenn) of grain mounts and thin sections of sediments from the Columbia River and some of its tributaries indicates that the clay minerals occur chiefly as allogenic and authigenic coatings; very few sand-size grains of claystone or siltstone are present.

The relative change between Pasco and Vancouver in the mineralogy of the sand separate from the Columbia River can be evaluated if the assumption is made that, at each Columbia River station, the sand-separate mineralogy does not vary with time (equilibrium state); thus, a comparison of samples separated temporally as well as geographically is valid. Although differences in the mineralogy of the sand separates in samples from the same station may be noted from the data in figure 21, none of these differences can be attributed solely to time. In addition, both theoretical and experimental work (Sayre and Hubbell, 1965) on the transportation and dispersion of sand suggest that the assumption of no temporal variation should hold for mineralogy of sands in a natural stream that is in an equilibrium state if: (a) A station is a considerable distance downstream from an influx of different sediment, or (b) a considerable time elapses between an inflow of different sediment and sampling of the sediment in the natural stream. Because of the effect of dams on sand transport, an equilibrium state probably does not exist for the Columbia River and its tributaries; however, the effect of a dam on sand mineralogy probably would be noticed only after many years of mineralogy analyses so that an assumption of a quasi-equilibrium state over the 6 months during which the samples were collected is reasonable.

For the Columbia River stations, all located at least 5 miles from any appreciable local inflow of sediments, sand mineralogy probably is independent of time for the greater part of the year; however, sand mineralogy may vary with time during the part of the year when floods occur on the Columbia River and its tributaries. The probability of some change in mineralogy with time also may increase with distance from the headwaters of a stream.

In the following discussion, it is assumed that the possible variations of mineralogy discussed above are unimportant. In general, the available data indicate that this assumption is valid except possibly for the Columbia River sample of streambed sediment that was collected at Pasco on February 20, 1963 (fig. 21). The difference between the abundance of volcanic rock fragments in this sample and the abundance of volcanic rock fragments in the sample of streambed sediment that was collected on June 14, 1963, from the same station probably is more than can be accounted for by normal sample variance or by a difference in particle size. Because the sample of February 20, 1963, was collected shortly after a flood event in the Columbia River basin around Pasco (see fig. 16), the difference in mineralogy may be related to this event.

Two sand-separate samples collected during different discharges at the same station can be compared, as was done above, if sand-separate mineralogy is independent of time. However, when it can be shown that the particle size of the streambed sediment varies with discharge (Jordan, 1965) or with time, such a comparison is undesirable. The available data (see table 1) indicate that streambed particle size did not vary significantly with time or discharge at any Columbia River station during the report period.

Suspended sands are finer and have different particle-size distributions than streambed sands; thus, the mineralogy of suspended-sand separates at one station should be compared only with the mineralogy of suspended-sand separates at a different station and not with the mineralogy of a streambed-sand separate. This point is illustrated by the data from sand separates of suspended sediments that were collected at high discharges from both the Hood River and Vancouver stations (fig. 21). These separates contain relatively fewer volcanic rock fragments than do separates from streambed sediments that were collected during both high and low discharges at the respective stations. Although the data are not conclusive because the particle-size distributions of the samples are not known, sand separates of suspended sediments would be expected to contain fewer volcanic rock fragments than sand separates of streambed sediments, if the particle size of suspended sand is finer than the particle size of streambed sand.

Utilizing the assumption that sand mineralogy at a station does not vary with time, the change between Pasco and Vancouver in the relative mineralogy of the sand can be obtained by close study of the sand-separate data (fig. 21) for comparable samples from the respective stations. For streambed sand separates, quartz and potash feldspar decrease whereas volcanic rock fragments increase progressively from Pasco to Vancouver. For suspended-sediment sand separates, no sample of suspended sand is available from the Pasco station, and apparently no significant change in mineralogy occurs between the Hood River and Vancouver stations.

By making an additional assumption, the data in figure 21 can be used with sediment transport data to compute yearly discharges, and the absolute difference between the transport of the minerals in the sand separate at Pasco and at Vancouver can be estimated. The assumption is that the proportion of each mineral in the sand-separate load in transport is the same as the proportion of each mineral in the sand separates of the available samples that were collected from the streambed or from suspended sediments. The validity of this assumption cannot be evaluated until data are available to establish the variation of mineralogy with time. The method of sampling suspended sediment also may have resulted in samples that are not mineralogically representative of suspended sand in the stream.

The accuracy of the sand-mineralogy discharges depends on the accuracy of estimates of the amount and particle size of the total-sediment discharge as well as on the representativeness and accuracy of the sand-mineralogy data. Estimates (shown in table 10) of the amounts of total-sediment and of coarse-sediment (sediment larger than 0.062 mm in diameter) discharges generally are considered accurate. However, the estimates of the amounts of silt and clay in fine-sediment discharges are subject to considerable uncertainty because of limitations in data, sampling, and in analyzing for particle-size distributions of small amounts of fine sediment. The amount of sand discharge (shown in table 10) includes only a very small amount of sediment larger than 1 millimeter, which is the upper size limit of the sand-separate samples analyzed for mineralogy. (See tables 1 to 3.)

Estimates of yearly discharges for various minerals transported in the sand-separate part of the total sediment discharge past Pasco and Vancouver are shown in table 17. The values in this table were computed by converting the total weights of sand transported during the 1963 water year (table 10) at each station to volumes in cubic feet, using an average particle density of 2.65 and a porosity of 0.4, and multiplying the volumes by the percentages of the volumes that each constituent represents in each sample (fig. 21). These data indicate that the increase in sand-separate discharge between Pasco and Vancouver is more than enough to offset the decrease in the relative abundance of some constituents between the two stations (fig. 21). The greater volume of quartz transported at Hood River than at Vancouver (bed sediment-high discharge sample, table 17) probably is not significant because the quartz discharge at Vancouver would be greater than the discharge at Hood River if the percentage of quartz at Vancouver were increased by only 1 percent. However, the volcanic rock fragment discharge at Vancouver would still be nearly 100,000 tons greater than the discharge at Hood River, even though arbitrarily assigned errors of 20 percent for both the discharge and the mineralogy of sand were combined to produce least differences (a highly improbable combination) between discharges at the two stations.

Table 17.--Annual discharges of sand-separate minerals at three Columbia River stations, 1963 water year.

/The percentage of each constituent in sand separates of samples is shown in figure 20; estimates of the amount of sand discharge at each station are shown in table 10./

| Constituent | Annual mineral discharges, in millions of cubic feet, computed from percentages of mineral constituents in sand separates from different types of samples. | | |
|---|---|---|---|
| | Streambed sediment collected during low discharge | Streambed sediment collected during high discharge | Suspended sediment collected during high discharge |
| COLUMBIA RIVER AT PASCO, WASH. | | | |
| Quartz | 1.6 | 1.4 | - |
| Potash feldspar | .6 | - | - |
| Plagioclase feldspar | 1.2 | - | - |
| Total feldspar | 1.8 | 1.5 | - |
| Volcanic rock fragments | .3 | 1.8 | - |
| All others | 1.6 | .5 | - |
| COLUMBIA RIVER AT HOOD RIVER, OREG. | | | |
| Quartz | 3.1 | 4.2 | 4.0 |
| Potash feldspar | 1.2 | - | - |
| Plagioclase feldspar | 4.2 | - | - |
| Total feldspar | - | 4.8 | 5.5 |
| Volcanic rock fragments | 5.5 | 5.3 | 2.9 |
| All others | 3.3 | 2.9 | 4.8 |

Table 17.--Annual discharges of sand-separate minerals at three Columbia River stations, 1963 water year--Continued.

| | Annual mineral discharges, in millions of cubic feet, computed from percentages of mineral constituents in sand separates from different types of samples. | | |
|---|---|---|---|
| | Streambed sediment collected during low discharge | Streambed sediment collected during high discharge | Suspended sediment collected during high discharge |
| COLUMBIA RIVER AT VANCOUVER, WASH.[1] | | | |
| Quartz | 5.5 | 3.6 | 12 |
| Potash feldspar | 2.3 | - | - |
| Plagioclase feldspar | 10 | - | - |
| Total feldspar | 12.3 | 13 | 13 |
| Volcanic rock fragments | 17 | 22 | 8.2 |
| All others | 10 | 7.3 | 12 |

[1] Based on mineralogy analyses of samples from the North and South channels.

Specific causes of changes from Pasco to Vancouver in sand-separate mineralogy cannot be determined completely from available data. In general, the changes may be due to (a) effects of the dams in the study reach, (b) differences in particle size, or (c) contributions from tributaries. Sampling and analysis errors also may cause some apparent changes, although these errors for sands probably are quite small.

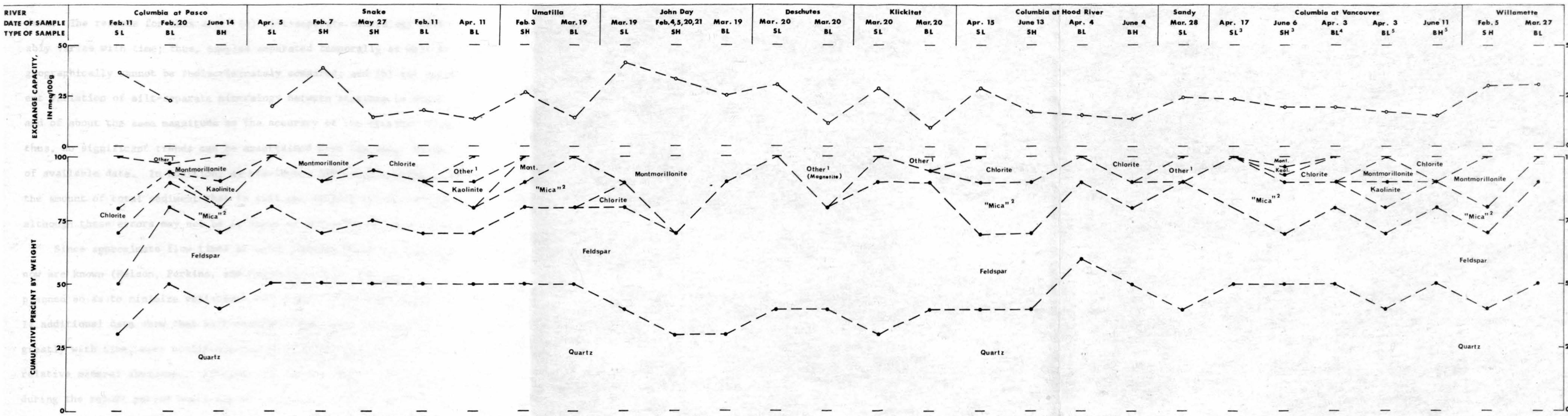
Dams may affect the mineralogy by causing selective transport of minerals through reservoirs or by causing degradation of sediment from reaches immediately below the dams. Although the Columbia River between Pasco and Vancouver is almost entirely ponded behind dams (with completion of the John Day Dam (pl. 1), the only "natural" reach will be between Bonneville Dam and Vancouver), the dams are all run-of-the-river type with very low trap efficiencies (Brune, 1953), so that the effect of those dams on mineralogy presumably is negligible.

The particle-size effect has been mentioned previously in the discussion of suspended-sand versus streambed-sand mineralogy. However, the possible effect on mineralogy of a difference in particle size between stations has not been discussed. Such a difference in particle size of streambed sediments has been established (table 1), but the significance of the difference in terms of mineralogy cannot be evaluated until relations between mineralogy and particle size of Columbia River sediments are known.

Because the sediment contributions from only two Columbia River tributaries--the Snake and Willamette Rivers--are known (table 10), the change in sand mineralogy from Pasco to Vancouver cannot be related directly to tributary inflow. The change in quartz discharge between Pasco and Vancouver is an exception. Because none of the tributaries (fig. 21) except the Snake River contributes any significant amount of quartz, intervening sediment inflow cannot increase the quartz discharge at Vancouver. In addition, the increase in particle size of streambed sands at Vancouver probably causes a decrease in the relative quartz abundance at Vancouver, so that the particle-size change does not explain the increase in quartz discharge. Very probably, a net degradation of quartz (and perhaps of other minerals) from the streambed between Pasco and Vancouver occurred during the study period.

## Silt Separate

The mineralogy of the silt separate in sediments from the Columbia River and its tributaries is shown in figure 22. The dominant constituents of the mineral suite in all samples are quartz, feldspar, and "mica" in roughly that order of relative abundance. An indeterminate amount of illite clay probably is included in the "mica" group. The three nonclay minerals (quartz, feldspar, and "mica") comprise from 70 to 100 percent of the silt-separate mineral suite that is identifiable by X-ray. Chlorite is a widespread clay mineral that occurs in significant quantities in 11 of the 29 samples and in trace amounts in 2 samples. The only other clay minerals in the silt separate are montmorillonite, which occurs in 14 of the 29 samples, and kaolinite, which occurs in only 5 of the 29 samples.




SL Suspended sediment, low discharge.
BL Bed sediment, low discharge.
BH Bed sediment, high discharge.
SH Suspended sediment, high discharge.

1. Includes undifferentiated 7-or 14-A clay minerals, amorphous material, amphibile, and magnetite.
2. Includes 10-A clay minerals as well as mica group minerals.
3. Composite sample from north and south channels.
4. Composite sample from north channel.
5. Composite sample from south channel.

Figure 22.--Silt-separate mineralogy and exchange capacity of sediments from the Columbia River and tributaries between Pasco, Wash. and Portland, Oreg. All samples were collected during 1963. Mineralogy analyses were performed by Paul D. Blackmon; exchange-capacity analyses were made by Harry C. Starkey.

In general, trends in relative or absolute silt-separate mineralogy from Pasco to Vancouver cannot be determined from the available data. The reasons for this are: (a) Silt-separate mineralogy probably varies with time; thus, samples separated temporally as well as geographically cannot be indiscriminately compared; and (b) the apparent variation of silt-separate mineralogy between stations is small and of about the same magnitude as the accuracy of the original data; thus, no significant trends can be ascertained from the small amount of available data. In addition, as previously indicated, estimates of the amount of total sediment that is silt are subject to some errors, although these errors may not be as large as those due to other factors.

Since approximate flow times of water between Pasco and Vancouver now are known (Nelson, Perkins, and Haushild, 1966), sampling can be planned so as to minimize variations with time of silt mineralogy. If additional data show that silt-separate mineralogy does not vary greatly with time, more confidence can be assigned to estimates of the relative mineral abundance. Although estimates of silt discharges during the report period would not be improved, data from subsequent years may indicate whether the data for the report period are reasonably reliable.

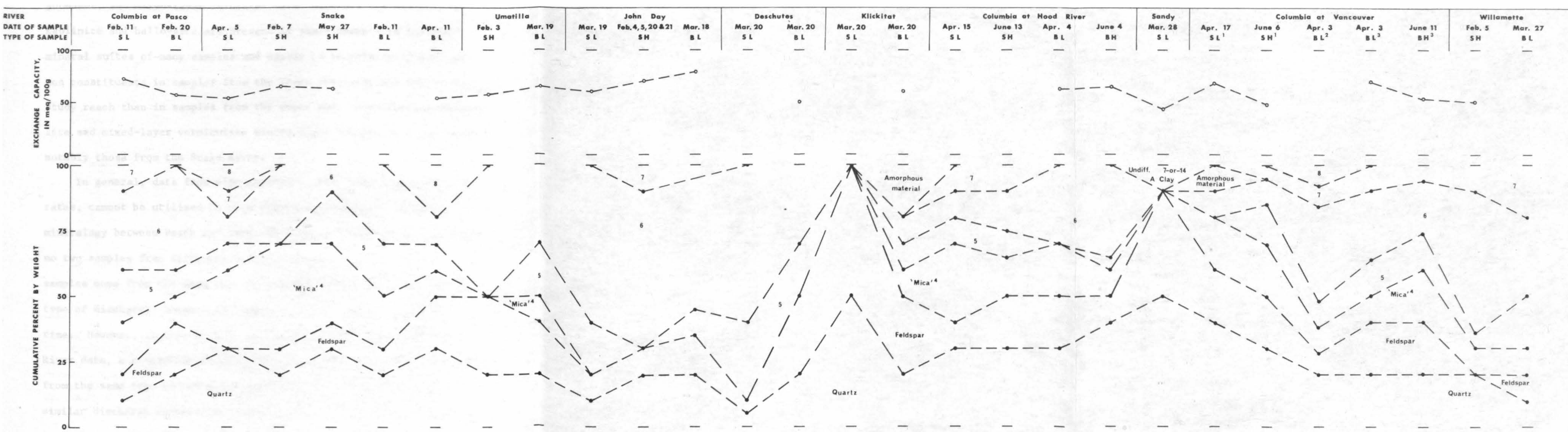
The mineralogic homogeneity among the silt-separate samples (fig. 22) from the Columbia River and its tributaries is somewhat difficult to reconcile with the known geologic complexity of the drainage basins and with the data from sand-separate mineralogy (fig. 21). Some apparent mineralogy differences between sand and silt separates are introduced

by different techniques of analysis (optical versus X-ray), and some real mineralogy differences are related to differing hydrodynamic behaviors of sand and silt particles. However, the differences between mineralogy of sand and silt from tributaries and the homogeneity in silt mineralogy of all tributaries suggest that the silt discharge from these tributaries is derived from a different source than the sand discharge.

Large areas in the drainage basins of some eastern Oregon and Washington tributaries of the Columbia River are covered by a mantle of loess, a dominantly silt deposit that presumably was derived from the Columbia River valley during one or more Pleistocene glacial stages. Also, much of the Willamette Valley floor is underlain by fluviolacustrine silt and sand (Glenn, 1965) that was derived from the upper Columbia River basin. These materials from the same original source may contribute most of the silt in the tributary valleys, whereas different rocks underlying the tributary valleys may contribute most of the sand.

## Clay Separate

The results of X-ray analysis of the clay separate of sediments from the Columbia River and its tributaries are shown in figure 23. The data indicate that an important percentage, ranging from 10 to 100 percent and averaging approximately 40 percent of the clay-size material, is quartz and feldspar. The most abundant and widespread clay minerals (fig. 23) are "mica" (includes all 10-A clay minerals, montmorillonite, and combinations of various mixed-layer minerals. Of the




SL Suspended sediment, low discharge.
BL Bed sediment, low discharge.
SH Suspended sediment, high discharge.
BH Bed sediment, high discharge.

1. Composite sample from north and south channels.
2. Composite sample from north (main) channel.
3. Composite sample from south channel.
4. Includes other 10-A clay minerals.
5. Mixed-layer chlorite-"mica" and chlorite in approximately 1:1 average proportions.
6. Montmorillonite, mixed-layer montmorillonite-"mica," and mixed-layer chlorite-montmorillonite in approximately 2.2:1.3:1.0 average proportions.
7. Kaolinite and halloysite in approximately 2:1 average proportions.
8. Mixed-layer vermiculite-"mica," dioctahedral vermiculite, and vermiculite in approximately 2:2:1 average proportions.

Figure 23.--Clay-separate mineralogy and exchange capacity of sediments from the Columbia River and tributaries between Pasco, Wash., and Portland, Oreg. All samples were collected during 1963. Mineralogy analyses were performed by Paul D. Blackmon; exchange capacity-determinations were made by Harry C. Starkey.

latter, montmorillonite-"mica" and montmorillonite-chlorite are most abundant, and mixed-layer chlorite-"mica" minerals are subordinate. Kaolinite and halloysite are present in small amounts in the clay-mineral suites of many samples and appear to be relatively more common constituents in samples from the lower (westernmost) end of the study reach than in samples from the upper end. Dioctahedral vermiculite and mixed-layer vermiculite minerals are present in a few samples, notably those from the Snake River.

In general, data from clay separates, like that from silt separates, cannot be utilized to show relative or absolute changes in clay mineralogy between Pasco and Vancouver. From a theoretical standpoint, no two samples from different stations should be compared, even if the samples come from the same type of sediment during the same relative type of discharge, because the samples are not spaced correctly in time. However, if this warning is ignored for the present Columbia River data, a comparison between mineralogy data for samples collected from the same type of sediment (suspended or streambed) and during similar discharge conditions, indicates that mineralogy may change between Pasco and Vancouver, although not enough analyses are available to establish whether mineralogy really does change.

## Exchange Capacity

The results of exchange-capacity determinations on size separates from sediments in the Columbia River and its tributaries are shown in figures 21-23 and in tables 18 and 19. The exchange-capacity values are not weighted by the percentages of sand, silt, or clay in the

Table 18.--Exchange capacities of size separates of sediments from the Columbia River. Exchange-capacity analyses were made by Harry C. Starkey.

| Size separate | Date sampled | Type of sediment and discharge[1] | Exchange capacity (meq/100g) |
|---|---|---|---|
| | | PASCO, WASH. | |
| Clay | Feb. 11, 1963 | SL | a72 |
| Do. | Feb. 20 | BL | 58 |
| Silt | Feb. 11 | SL | 36 |
| Do. | Feb. 20 | BL | 22 |
| Sand | Feb. 20 | BL | 6.4 |
| Do. | June 14 | BH | 2.6 |
| | | HOOD RIVER, OREG. | |
| Clay | Apr. 4 | BL | 62 |
| Do. | June 4 | BH | 64 |
| Silt | Apr. 4 | BL | 15 |
| Do. | Apr. 15 | SL | 29 |
| Do. | June 4 | BH | 13 |
| Do. | June 13 | SH | 17 |
| Sand | Apr. 4 | BL | 5.7 |
| Do. | June 4 | BH | 5.7 |
| | | VANCOUVER, WASH.[2] | |
| Clay | Apr. 17 | SL | a67 |
| Do. | June 6 | SH | 48 |
| Silt | Apr. 17 | SL | 24 |
| Do. | June 6 | SH | 19 |
| | | VANCOUVER, WASH.[3] | |
| Silt | Apr. 3 | BL | 19 |

Table 18.--Exchange capacities of size separates of sediments from the Columbia River--Continued.

| Size separate | Date sampled | Type of sediment and discharge[1] | Exchange capacity (meq/100g) |
|---|---|---|---|
| | | VANCOUVER, WASH.[3]--Continued | |
| Sand | Apr. 3 | BL | 5.6 |
| Do. | June 11 | BH | 4.1 |
| | | VANCOUVER, WASH.[4] | |
| Clay | Apr. 3 | BL | 69 |
| Do. | June 11 | BH | 53 |
| Silt | Apr. 3 | BL | 17 |
| Do. | June 11 | BH | 15 |
| Sand | Apr. 3 | BL | 5.9 |
| Do. | June 11 | BH | 3.7 |

[1]S, Suspended sediment; B, Bed sediment; L, Low discharge; H, High discharge.
[2]Composite sample from north and south channels.
[3]Composite sample from north channel.
[4]Composite sample from south channel.
[a]Value from single analysis of a small sample; all other values are averages of at least two analyses.

Table 19.--Exchange capacities of size separates of sediments from Columbia River tributaries. Exchange-capacity analyses were made by Harry C. Starkey.

| Size separate | Date sampled | Type of sediment and discharge[1] | Exchange capacity (meq/100g) |
|---|---|---|---|
| | SNAKE RIVER AT PASCO, WASH. | | |
| Clay | Feb. 7, 1963 | SH | 65 |
| Do. | Apr. 5 | SL | a54 |
| Do. | Apr. 11 | BL | 54 |
| Do. | May 27 | SH | 63 |
| Silt | Feb. 7 | SH | 38 |
| Do. | Feb. 11 | BL | 17 |
| Do. | Apr. 5 | SL | 19 |
| Do. | Apr. 11 | BL | a13 |
| Do. | May 27 | SH | 17 |
| Sand | Feb. 11 | BL | 3.4 |
| Do. | Apr. 11 | BL | 4.0 |
| Do. | May 27 | BH | 3.5 |
| | UMATILLA RIVER NEAR UMATILLA, OREG. | | |
| Clay | Feb. 3 | SH | 58 |
| Do. | Mar. 19 | BL | 65 |
| Silt | Feb. 3 | SH | 26 |
| Do. | Mar. 19 | BL | 14 |
| | JOHN DAY RIVER AT McDONALD FERRY, OREG. | | |
| Clay | Feb. 4,5,20,21 | SH | 70 |
| Do. | Mar. 19 | SL | a61 |
| Do. | Mar. 19 | BL | a79 |
| Silt | Feb. 4,5,20,21 | SH | 33 |
| Do. | Mar. 19 | SL | a41 |
| Do. | Mar. 19 | BL | 25 |
| Sand | Mar. 19 | BL | 2.8 |

Table 19.--Exchange capacities of size separates of sediments from Columbia River tributaries--Continued.

| Size separate | Date sampled | Type of sediment and discharge[1] | Exchange capacity (meq/100g) |
|---|---|---|---|
| | | DESCHUTES RIVER AT MOODY, NEAR BIGGS, OREG. | |
| Clay | Mar. 20, 1963 | BL | a52 |
| Silt | Mar. 20 | SL | a30 |
| Do. | Mar. 20 | BL | 5.9 |
| Sand | Mar. 20 | BL | 8.7 |
| | | KLICKITAT RIVER NEAR PITT, WASH. | |
| Clay | Mar. 20 | BL | 61 |
| Silt | Mar. 20 | SL | a28 |
| Do. | Mar. 20 | BL | 9 |
| Sand | Mar. 20 | BL | 11 |
| | | SANDY RIVER AT TROUTDALE, OREG. | |
| Clay | Mar. 28 | SL | 44 |
| Silt | Mar. 28 | SL | a24 |
| Sand | Mar. 28 | BL | 4.2 |
| | | WILLAMETTE RIVER AT PORTLAND, OREG. | |
| Clay | Feb. 5 | SH | 50 |
| Silt | Feb. 5 | SH | 30 |
| Do. | Mar. 27 | BL | 31 |
| Sand | Mar. 27 | BL | 11 |

[1]S, Suspended sediment; B, Streambed sediment; L, Low discharge; H, High discharge.

[a]Value from single analysis of a small sample; all other values are averages of at least two analyses.

individual samples; they are unweighted values for each size separate. These data indicate that exchange capacities for size separates from sediments in the Columbia River and its tributaries range, in milliequivalents per 100 grams, from 2.6 to 11 for sand, from 5.9 to 41 for silt, and from 44 to 79 for clay. The average exchange capacities, in milliequivalents per 100 grams, are 5.5 for sand separates, 22 for silt separates, and 60 for clay separates.

If exchange capacity does not vary with time and if the samples analyzed are representative, the exchange capacities of the size separates shown in tables 18 and 19 may be used to determine the exchange capacity of any sample whose particle-size distribution is known. Both assumptions probably are valid for sand; however, until more data are available, the validity of the assumptions for silt and clay cannot be determined.

Samples from the Snake River (table 19) provide data to evaluate the variation of exchange capacity with time for size separates from that river. Suspended-sediment samples (particle-size analyses for these samples are shown in table 1) collected during high discharges (table 20) indicate that, between February 7 and May 27, 1963, the exchange capacity of the suspended sediments decreased almost 33 percent and that most of the reduction resulted from a substantial decrease in the exchange capacity of the silt separate. The mineralogy of the silt separates from these Snake River samples (fig. 22) suggests that the differences in exchange capacity may be related to the presence or absence of montmorillonite. Unpublished data (U.S. Geol. Survey, Water Resources Division, Portland, Oreg.) indicate that both the unusually high exchange capacity and the somewhat different mineralogy of silt and clay separates from the Snake River (figs. 22 and 23) on February 7, 1963, are related to an unusually high but variable sediment contribution to the Snake River from the Palouse River during early February 1963.

If the appropriate exchange capacities in tables 18 and 19 are combined with the particle-size distributions of the samples in tables 1-3, the exchange capacities of these samples may be computed and compared with those of texturally similar representative soils (Bear, 1955; and Buckman and Brady, 1960) and with those for sediments and size separates from other rivers (Clanton and Gloyna, 1964; Kennedy, 1963, 1965; and Reynolds and Gloyna, 1963). In general, exchange capacities for sediments from the Columbia River and its tributaries are near or slightly higher than the high values for soils and for other river sediments. The relatively high exchange capacities of Columbia River sediments undoubtedly reflect the high content of montmorillonite and mixed-layer 2:1 clay minerals and the low content of low exchange capacity 1:1 clay minerals. Amorphous material, which can have considerable exchange capacity (Kennedy, 1965) and which was noted in some separates, and organic matter also may contribute to the high exchange capacities.

Exchange capacities for size separates from Columbia River tributaries are shown in figures 21-23 and in table 19. In general, exchange-capacity data for the tributary sediments are more incomplete than exchange-capacity data for the Columbia River sediments. Furthermore, many samples from the tributaries contained sufficient silt and clay for only one determination of exchange capacity. Consequently, the exchange-capacity values for tributary sediments probably are slightly more inaccurate than are most exchange-capacity values for Columbia River sediments. The data indicate, however, that sediments from both the tributaries and the Columbia River have relatively high exchange capacities.

Exchange-capacity values reported by Kennedy (1965) for size separates from Crooked River, a tributary of Deschutes River, are several percent higher than exchange-capacity values determined in this study for the Deschutes River. The difference, which is larger than was anticipated, may be due to the radioactive cesium method that was used by Kennedy.

The available data show no highly significant changes in exchange capacities of size separates from the Columbia River or its tributaries between Pasco and Vancouver. In general, the data suggest that exchange capacities of silt and clay separates decrease in a downstream direction from Pasco but remain unchanged or increase slightly in the sand separates. The only significant trend in separates from tributary sediments appears to be in the sand separates, for which exchange capacities seem to be greatest in streams farthest downstream from Pasco.

Weighted values of exchange capacity and discharges of exchangeable ions for the 1963 water year are shown in table 20 for the three

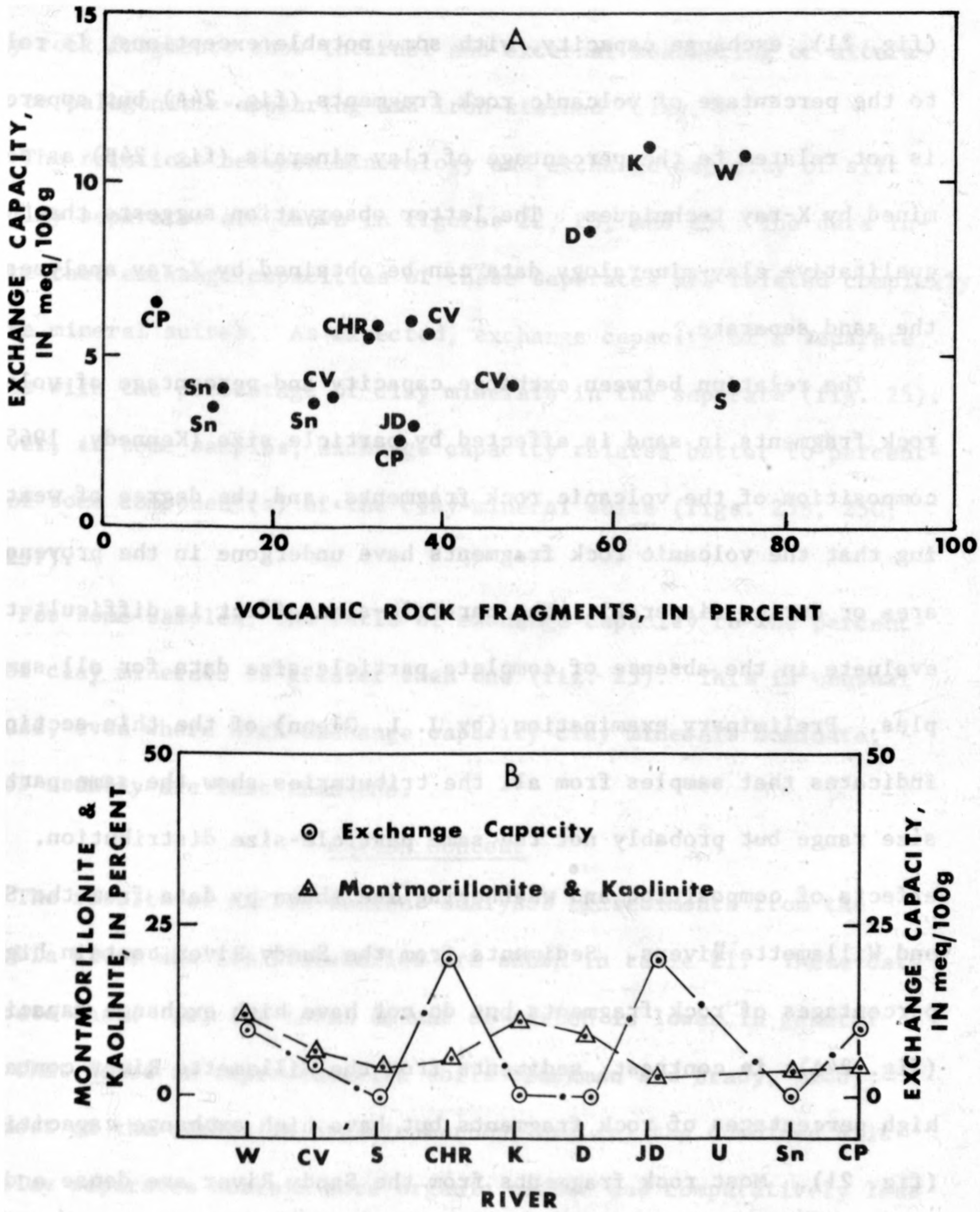
Table 20.--Estimates of weighted exchange capacities and 1963 water year discharges of exchangeable ions at three Columbia River stations.

| Size separate | Proportion of separate in 1963 water year discharge (percent) | Separate exchange capacity (meq/100g) | Weighted exchange capacity (meq/100g) | Exchangeable ions in discharge for each separate (billions of milliequivalents) | Proportion of total milliequivalents in discharge for each separate (percent) |
|---|---|---|---|---|---|
| PASCO, WASH.--Sample date, February 20, 1963 | | | | | |
| Sand | 28 | 6.4 | 1.8 | 150 | 7 |
| Silt | 52 | 22 | 11 | 1,000 | 46 |
| Clay | 20 | 58 | 12 | 1,000 | 47 |
| Total | 100 | - | 24.8 | 2,150 | 100 |
| HOOD RIVER, OREG.--Sample date, April 4, 1963 | | | | | |
| Sand | 20 | 5.7 | 1.1 | 450 | 5 |
| Silt | 62 | 15 | 9 | 3,600 | 43 |
| Clay | 18 | 62 | 11 | 4,500 | 52 |
| Total | 100 | - | 21.1 | 8,550 | 100 |
| VANCOUVER, WASH.--Sample date, April 3, 1963 | | | | | |
| Sand | 34 | 5.7 | 1.9 | 1,100 | 9 |
| Silt | 52 | 18 | 9 | 5,700 | 43 |
| Clay | 14 | 69 | 10 | 6,200 | 48 |
| Total | 100 | - | 20.9 | 13,000 | 100 |

Columbia River stations. The exchange capacities of size separates that were used to calculate the weighted values are those for streambed-sediment samples collected at low discharges (table 18) at the three stations. These exchange capacities were used because analyses are available for this type of sample and range of discharge at each station. If exchange capacities for other types of samples or average exchange capacities of all samples at each station were used, the weighted values of exchange capacity and discharge of exchangeable ions generally would not change significantly. The estimated discharge of sand, silt, and clay given in table 10 were utilized in the calculations.

The data in table 20 indicate the following: (a) Exchange capacity of the sediment discharge of the Columbia River decreased from Pasco to Vancouver, primarily because the percentage of clay in transport at Vancouver decreased whereas the percentage of sand in transport at Vancouver increased; (b) notwithstanding the decrease in exchange capacity of the sediment discharge, the milliequivalents of ions that could be transported increased at Vancouver because the sediment discharge increased substantially; and (c) the silt separate, in spite of its moderately low exchange capacity, was almost as important a potential ionic transport medium as the clay separate because silt was the dominant size of the transported sediment.

The relationship between sand-separate mineralogy and exchange capacity in sediments of the Columbia River and its tributaries can be evaluated by a study of figures 21 and 24. In the sand separate




| | | | |
|---|---|---|---|
| W | - Willamette | D | - Deschutes |
| CV | - Columbia at Vancouver, Wash. | JD | - John Day |
| S | - Sandy | U | - Umatilla |
| CHR | - Columbia at Hood River, Oreg. | Sn | - Snake |
| K | - Klickitat | CP | - Columbia at Pasco, Wash. |

Figure 24.--A, Relation between exchange capacity and percentage of volcanic rock fragments in sediments from the Columbia River and its tributaries; B, variation in percentage of montmorillonite plus kaolinite (total clay) and in exchange capacity in the sand separate of sediments from the Columbia River and its tributaries.

(fig. 21), exchange capacity, with some notable exceptions, is related to the percentage of volcanic rock fragments (fig. 24A) but apparently is not related to the percentage of clay minerals (fig. 24B) as determined by X-ray techniques. The latter observation suggests that only qualitative clay-mineralogy data can be obtained by X-ray analyses of the sand separate.

The relation between exchange capacity and percentage of volcanic rock fragments in sand is affected by particle size (Kennedy, 1965), composition of the volcanic rock fragments, and the degree of weathering that the volcanic rock fragments have undergone in the provenance area or during dispersal. The particle-size effect is difficult to evaluate in the absence of complete particle-size data for all samples. Preliminary examination (by J. L. Glenn) of the thin sections indicates that samples from all the tributaries show the same particle-size range but probably not the same particle-size distribution. The effects of composition and weathering are shown by data from the Sandy and Willamette Rivers. Sediments from the Sandy River contain high percentages of rock fragments but do not have high exchange capacities (fig. 24A); in contrast, sediments from the Willamette River contain high percentages of rock fragments but have high exchange capacities (fig. 21). Most rock fragments from the Sandy River are dense andesites that show little evidence of extensive weathering; rock fragments from the Willamette River contain larger amounts of tuffaceous, pumiceous, volcanic detritus than rock fragments from the Sandy River.

Many rock fragments show internal and external weathering or alteration to palagonitic-appearing and iron-stained "clay."

The relations between mineralogy and exchange capacity of silt and clay separates are shown in figures 22, 23, and 25. The data indicate that exchange capacities of these separates are related complexly to the mineral suites. As expected, exchange capacity of a separate varies with the percentage of clay minerals in the separate (fig. 25). However, in some samples, exchange capacity relates better to percentage of some component(s) of the clay-mineral suite (figs. 25B, 25C, and 25F).

For some samples, the ratio of exchange capacity to the percentage of clay minerals is greater than one (fig. 25). This is unusual because, even where high exchange capacity clay minerals dominate, ratios usually are less than one.

## Carbon Content

The results of carbon-content analyses of sediments from the Columbia River and its tributaries are shown in table 21. These data indicate that: (a) The total amount of carbon is lower in general than that noted in representative soils (Buckman and Brady, 1960); (b) most of the carbon is organic carbon; and (c) the combined silt and clay separates contain more organic carbon and comparatively less inorganic carbon than the sand separates. Using a value of 1.7 (Buckman and Brady, 1960) for the ratio between organic carbon and organic material, computed amounts of organic material average about

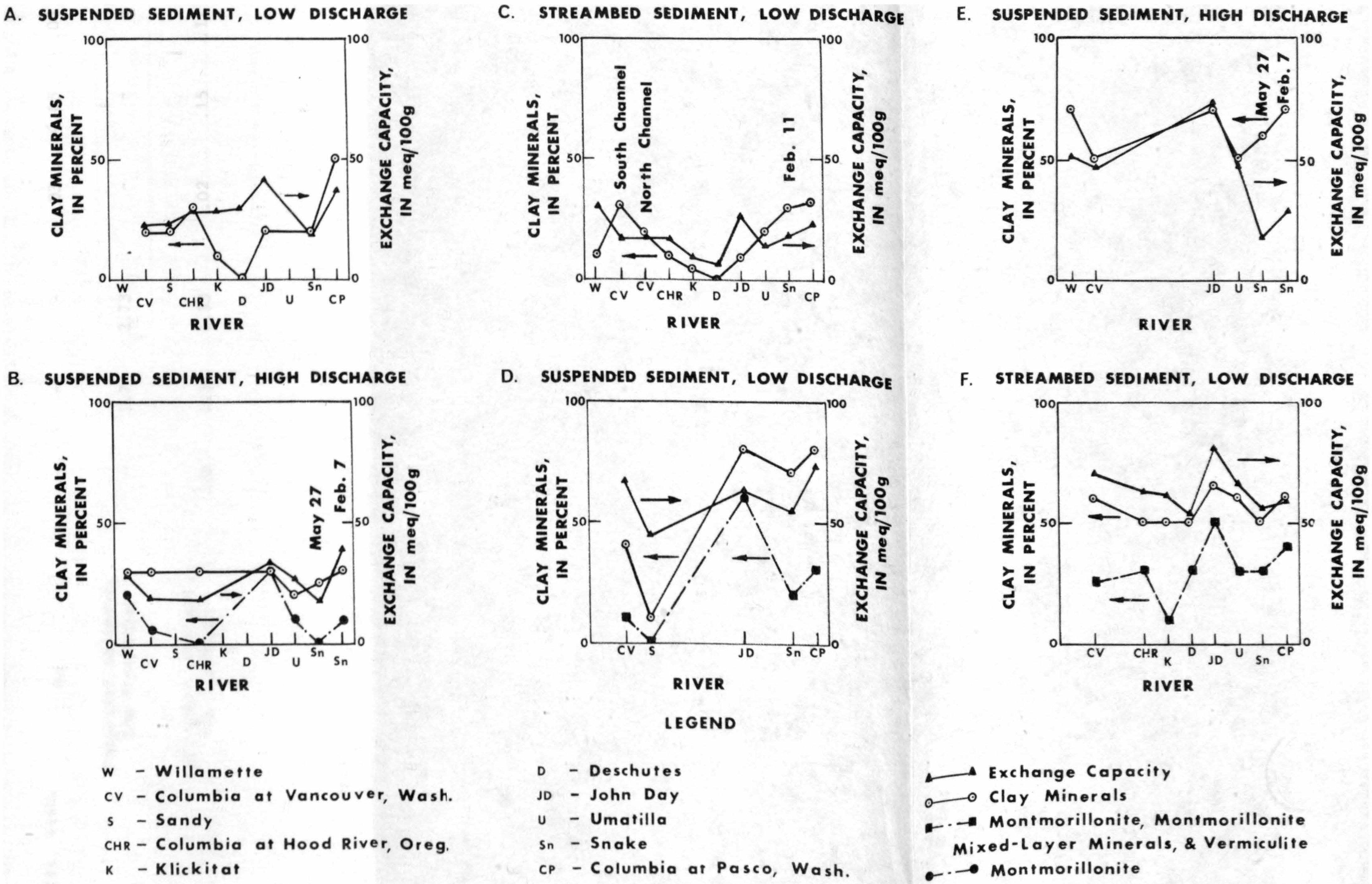



Figure 25.--Clay-mineral content and exchange capacity of silt separates (A, B, C) and clay separates (D, E, F) in sediments from the Columbia River and tributaries between Pasco, Wash., and Portland, Oreg.

Table 21.--Carbon content in sediments from the Columbia River and its tributaries. Analyses were performed by I. C. Frost

| River and date sampled | Type of sediment and discharge | Carbon content, in percent by weight: Clay-silt (less than 62µ) Mineral | Clay-silt (less than 62µ) Organic | Clay-silt (less than 62µ) Total | Sand (62-1,000µ) Mineral | Sand (62-1,000µ) Organic | Sand (62-1,000µ) Total |
|---|---|---|---|---|---|---|---|
| Columbia at Pasco, Wash. Feb. 20, 1963 | Streambed sediment, low discharge | <0.02 | 1.6 | 1.63 | <0.02 | 0.30 | 0.30 |
| Snake at Pasco, Wash. Feb. 11 | do. | - | - | - | .06 | <.05 | .08 |
| Snake at Pasco, Wash. Apr. 11 | do. | - | - | - | .04 | .05 | .09 |
| Umatilla at Umatilla, Oreg. Mar. 19 | do. | <.02 | 1.0 | 1.01 | .03 | .14 | .17 |
| Deschutes at Moody, nr Biggs, Oreg. Mar. 20 | do. | - | - | - | <.02 | <.05 | .05 |
| Klickitat near Pitt, Wash. Mar. 20 | do. | - | - | - | .03 | <.05 | .06 |
| Columbia at Hood River, Oreg. Apr. 15 | Suspended sediment, low discharge | - | 2.7 | 2.73 | - | - | - |
| Columbia at Hood River, Oreg. Apr. 4 | Streambed sediment, low discharge | .03 | 1.3 | 1.33 | .02 | .15 | .17 |

Table 21.--Carbon content in sediments from the Columbia River and its tributaries--Continued.

| River and date sampled | Type of sediment and discharge | Carbon content, in percent by weight: Clay-silt (less than 62μ) Mineral | Clay-silt (less than 62μ) Organic | Clay-silt (less than 62μ) Total | Sand (62-1,000μ) Mineral | Sand (62-1,000μ) Organic | Sand (62-1,000μ) Total |
|---|---|---|---|---|---|---|---|
| Sandy at Troutdale, Oreg. Mar. 28, 1963 | Streambed sediment, low discharge | - | - | - | <0.02 | <0.05 | 0.02 |
| Columbia at Vancouver, Wash. (North Channel) Apr. 3 | do. | 0.04 | 2.1 | 2.09 | .03 | .09 | .12 |
| Columbia at Vancouver, Wash. (South Channel) Apr. 3 | do. | .02 | 1.3 | 1.30 | .03 | .17 | .20 |
| Willamette at Prtld, Oreg. Feb. 5 | Suspended sediment, high discharge | - | - | - | .02 | .31 | .33 |
| Total for all streams | | <.13 | 10.0 | 10.09 | <.32 | <1.41 | 1.59 |
| Average for all streams | | <.03 | 1.7 | 1.68 | <.03 | <.13 | .14 |

3 percent by weight in fine sediments and less than 0.3 percent by weight in coarse sediments.

Size separates from suspended-sediment samples apparently contain a greater amount of organic carbon than corresponding size separates from streambed-sediment samples (table 21). If the difference is shown by additional data to be a real difference, then organic-matter content may be an important cause of the generally higher exchange capacities of suspended sediment than of streambed sediment (tables 19 and 20). Organic-matter content may cause the high exchange capacities noted in some samples that have low percentages of clay minerals.

## RADIONUCLIDE TRANSPORT

### Sampling and Analyses

The radionuclide concentrations of the river water (solutes), the sediment transported in suspension in the river (filtered sediment), and the streambed sediment were determined for the Columbia River at Pasco, Hood River, and Vancouver. Sampling frequency for these determinations was about monthly from July to December 1962 and approximately biweekly thereafter.

Samples of river water and suspended sediment were obtained by traversing a weighted bottle between the water surface and the streambed. The weighted bottle was traversed at a constant rate until it was full; one or two traverses were usually enough. Three-gallon bottles were used in an upright position, and samples were obtained from the water surface to about 1-1/2 feet above the streambed. Sampling by this method does not obtain samples at stream velocity. Because the bottle may become full at any point in the sampling traverse, all increments of the stream depth may not be represented equally in the sample. Therefore, the sediment concentration is only approximately representative of the concentration in the sampled depth, especially during high- and medium-water discharges when large concentration gradients with depth exist because coarse sediment is suspended.

Three-gallon samples of river water and suspended sediment were used for analyses of radionuclide content. These samples were obtained at each of five or six verticals located at the centroids of equal discharge. The sediment was separated from the river water at the time of sampling by filtering the sample through a filter with 0.3 micron openings. Five to 10 ml (milliliters) of formaldehyde were added to the water and, within 1 to 2 days after sampling, both the water and sediment samples were transmitted to the Hanford laboratories for analysis of radionuclide content.

The characteristics of streambed sediment at a river cross section generally vary laterally. The number of sampling locations needed to define any characteristic at a chosen confidence level can be evaluated statistically, as was done in the program for determining the particle-size distribution of the streambed sediment at the sediment-discharge stations. Unfortunately, the statistically determined number of sampling locations (and, therefore, the confidence level) is generally compromised by practical considerations. The number of sampling locations for determining radionuclide content of streambed sediment at each station depended on the number of samples that could be analyzed for this study with the available equipment and staff at the Hanford laboratories. The availability of sediment on the streambed was an additional factor at Pasco. Locations of samples in a river cross section were determined from flow characteristics and from particle-size distribution of streambed sediment in the cross section.

The streambed sediment was sampled as described in the section on sediment transport. About 300 to 400 g (grams) of streambed sediment were obtained from each sampling location. The samples were ovendried prior to transmittal to the laboratories at Hanford for radionuclide analysis.

Concentrations of six radionuclides were determined for most of the water and filtered sediment samples, and concentrations of four or five radionuclides were determined for the streambed sediment samples. Methods and techniques of radionuclide analysis that have been developed at the Hanford laboratories (Perkins, Nielsen, and Diebel, 1960; and Perkins, 1965) were used. Units of radionuclide concentration are disintegrations per minute per milliliter of water or per gram of sediment. The unit used for radionuclide discharges is the curie, which equals $2.22 \times 10^{12}$ dpm (disintegrations per minute). The radionuclides and their symbols and half-life periods (Goldman, 1962) are: scandium-46 ($Sc^{46}$) 84 days; chromium-51 ($Cr^{51}$) 27.8 days; zinc-65 ($Zn^{65}$) 245 days; zirconium-95-niobium-95 ($Zr^{95}Nb^{95}$) 65 and 35 days, respectively; ruthenium-103-rhodium-103 ($Ru^{103}Rh^{103}$) 40 and "unknown" days, respectively; cerium-141 ($Ce^{141}$) 32.5 days; cobalt-60 ($Co^{60}$) 5.26 years; manganese-54 ($Mn^{54}$) 314 days; sodium-24 ($Na^{24}$) 15 hours; copper-64 ($Cu^{64}$) 12.9 hours; lanthanum-140 ($La^{140}$) 40.2 hours; and neptunium-239 ($Np^{239}$) 2.35 days.

Spatial and Temporal Variation of Radionuclide

Concentrations at the Water-Quality Stations

A study was conducted from May to December 1963 to determine the magnitude and significance of variations in radionuclide concentrations of water and filtered sediment with time and spatial location. At each station, the variation in radionuclide concentration with depth was studied by comparing concentrations from samples collected 2 to 3 feet below the water surface with concentrations from samples collected 2 to 3 feet above the streambed; lateral variation in radionuclide concentration was analyzed by comparing data from samples collected at five verticals. In addition, the variation in radionuclide concentrations of duplicate samples simultaneously obtained at one vertical was investigated for each station.

The radionuclide concentrations for the several spatially separated locations were determined from samples collected at different times during the sampling day. The time required for sampling at the comparative locations ranged from a few minutes for duplicate sampling at a vertical, or sampling near the water surface and streambed at a vertical, to 1 to 2 hours for obtaining samples from each of the five verticals in the cross section. The assumption was made that radionuclide concentrations were not changing significantly during the sampling period.

Radionuclide concentrations for the water and filtered sediments from these samples were analyzed statistically by using the analyses of variance (Waugh, 1943) to determine the existence of real differences in concentrations laterally, vertically, and between duplicate samples. If the mean concentrations determined from all samples collected during May to December 1963 at each like, but spatially separated, location were not significantly different then the differences in concentations for like locations in space at a particular time probably were chance rather than real differences.

Results of the statistical analyses are shown in tables 22 and 23. The analyses indicate that, at each station, radionuclide concentrations of the solutes and filtered sediments at the five verticals were not significantly different from one another and that variance in concentrations of duplicate samples was insignificant. At Hood River, solute radionuclide concentrations from near the water surface are statistically similar to solute concentrations from near the streambed, but radionuclide concentrations of the filtered sediment near the water surface are significantly different from concentrations near the streambed. A trend toward differences in radionuclide concentration of filtered sediment obtained from different sampling depths also is indicated at Pasco.

Ratios of radionuclide concentration in filtered sediment from near the water surface to this concentration in filtered sediment from

Table 22.--Statistical significance of differences between chromium[51] concentrations for various locations in a river cross section and for duplicate samples.

[The critical values of Student's t, from table 1 by Youden, 1951, for comparisons of concentrations from two sets of 5, 7, 8, 13, and 15 samples are, respectively, 2.31, 2.16, 2.14, 2.06, and 2.05 for a 5 percent probability level and are, respectively, 1.86, 1.77, 1.76, 1.71, and 1.70 for a 10 percent probability level.]

| May to December 1963 | | Chromium[51] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Filtered river water | | | Sediment filtered from river water | | |
| Sampling location or type of sample | No. of samples | Mean conc. (dpm/ml) | σ (dpm/ml) | Student's t | Mean conc. (dpm/ml) | σ (dpm/ml) | Student's t |
| **COLUMBIA RIVER AT PASCO, WASH.** | | | | | | | |
| Vertical 1 | 8 | 11 | 2.7 | | 0.6 | 0.3 | |
| | | | | 0 | | | 0.5 |
| Vertical 2 | 8 | 11 | 4.2 | | .7 | .4 | |
| | | | | 0 | | | 0 |
| Vertical 3 | 8 | 11 | 3.8 | | .7 | .3 | |
| Duplicate 1 | 7 | 18 | 14 | | 1.2 | .7 | |
| | | | | .1 | | | 0 |
| Duplicate 2 | 7 | 17 | 15 | | 1.2 | .8 | |
| Near water surface | 15 | 20 | 14 | | 1.1 | .7 | |
| | | | | 0 | | | 1.2 |
| Near streambed | 15 | 20 | 14 | | 1.6 | 1.5 | |
| **COLUMBIA RIVER AT HOOD RIVER, OREG.** | | | | | | | |
| Vertical 1 | 7 | 5.1 | 1.3 | | .2 | .07 | |
| | | | | .8 | | | .5 |
| Vertical 2 | 7 | 4.5 | 1.4 | | .3 | .1 | |
| | | | | 1.1 | | | .3 |
| Vertical 3 | 7 | 5.3 | 1.3 | | .2 | .09 | |
| Duplicate 1 | 7 | 7.5 | 1.9 | | .3 | .1 | |
| | | | | .1 | | | 0 |
| Duplicate 2 | 7 | 7.6 | 2.1 | | .3 | .07 | |

Table 22.--Statistical significance of differences between chromium[51] concentrations for various locations in a river cross section and for duplicate samples--Continued.

| May to December 1963 | | Chromium[51] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Filtered river water | | | Sediment filtered from river water | | |
| Sampling location or type of sample | No. of samples | Mean conc. (dpm/ml) | σ (dpm/ml) | Student's t | Mean conc. (dpm/ml) | σ (dpm/ml) | Student's t |
| COLUMBIA RIVER AT HOOD RIVER, OREG.--Continued | | | | | | | |
| Near water surface | 13 | 7.6 | 3.4 | 0.1 | 0.3 | 0.1 | 2.7 |
| Near streambed | 13 | 7.7 | 3.1 | | .5 | .3 | |
| COLUMBIA RIVER AT VANCOUVER, WASH. | | | | | | | |
| Vertical 1 | 7 | 4.4 | 1.2 | .4 | .2 | .1 | 0 |
| Vertical 2 | 7 | 4.7 | 1.4 | .9 | .2 | .09 | 0 |
| Vertical 3 | 7 | 4.1 | 1.0 | | .2 | .08 | |
| Duplicate 1 | 5 | 5.8 | 2.6 | .04 | .3 | .1 | 0 |
| Duplicate 2 | 5 | 5.7 | 2.4 | | .3 | .1 | |
| Near water surface | 13 | 6.6 | 3.4 | 0 | .3 | .1 | 0 |
| Near streambed | 13 | 6.6 | 3.2 | | .3 | .1 | |

Table 23.--Statistical significance of differences between zinc$^{65}$ concentrations for various locations in a river cross section and for duplicate samples.

[The critical values of Student's t, from table 1 by Youden, 1951, for comparisons of concentrations from two sets of 5, 7, 8, 13, and 15 samples are, respectively, 2.31, 2.16, 2.14, 2.06, and 2.05 for a 5 percent probability level and are, respectively, 1.86, 1.77, 1.76, 1.71, and 1.70 for a 10 percent probability level.]

| May to December 1963 | | Zinc$^{65}$ | | | | | |
|---|---|---|---|---|---|---|---|
| Sampling location or type of sample | No. of samples | Filtered river water: Mean conc. (dpm/ml) | Filtered river water: σ (dpm/ml) | Filtered river water: Student's t | Sediment filtered from river water: Mean conc. (dpm/ml) | Sediment filtered from river water: σ (dpm/ml) | Sediment filtered from river water: Student's t |
| **COLUMBIA RIVER AT PASCO, WASH.** | | | | | | | |
| Vertical 1 | 8 | 0.4 | 0.3 | 0 | 0.1 | 0.04 | 0 |
| Vertical 2 | 8 | .4 | .4 | 0 | .1 | .04 | 0 |
| Vertical 3 | 8 | .4 | .3 | | .1 | .06 | |
| Duplicate 1 | 7 | .2 | .08 | 0 | .1 | .03 | 0 |
| Duplicate 2 | 7 | .2 | .08 | | .1 | .05 | |
| Near water surface | 15 | .3 | .2 | 0 | .1 | .04 | 1.6 |
| Near streambed | 15 | .3 | .2 | | .2 | .09 | |
| **COLUMBIA RIVER AT HOOD RIVER, OREG.** | | | | | | | |
| Vertical 1 | 7 | .05 | .04 | .5 | .1 | .05 | 0 |
| Vertical 2 | 7 | .04 | .03 | 0 | .1 | .06 | 0 |
| Vertical 3 | 7 | .04 | .03 | | .1 | .06 | |
| Duplicate 1 | 7 | .005 | .004 | .5 | .08 | .05 | 0 |
| Duplicate 2 | 7 | .006 | .005 | | .08 | .05 | |

Table 23.--Statistical significance of differences between zinc$^{65}$ concentrations for various locations in a river cross section and for duplicate samples--Continued.

| May to December 1963 | | Zinc$^{65}$ | | | | | |
|---|---|---|---|---|---|---|---|
| | | Filtered river water | | | Sediment filtered from river water | | |
| Sampling location or type of sample | No. of samples | Mean conc. (dpm/ml) | $\sigma$ (dpm/ml) | Student's t | Mean conc. (dpm/ml) | $\sigma$ (dpm/ml) | Student's t |
| COLUMBIA RIVER AT HOOD RIVER, OREG.--Continued | | | | | | | |
| Near water surface | 15 | 0.01 | 0.01 | | 0.06 | 0.05 | |
| | | | | 0 | | | 2.4 |
| Near streambed | 15 | .01 | .01 | | .1 | .03 | |
| COLUMBIA RIVER AT VANCOUVER, WASH. | | | | | | | |
| Vertical 1 | 7 | .03 | .02 | | .08 | .04 | |
| | | | | .9 | | | 0 |
| Vertical 2 | 7 | .04 | .03 | | .08 | .04 | |
| | | | | 0 | | | 0 |
| Vertical 3 | 7 | .04 | .03 | | .08 | .04 | |
| Duplicate 1 | 5 | .008 | .005 | | .07 | .06 | |
| | | | | 0 | | | 0 |
| Duplicate 2 | 5 | .008 | .003 | | .07 | .05 | |
| Near water surface | 13 | .008 | .004 | | .05 | .04 | |
| | | | | .6 | | | .2 |
| Near streambed | 13 | .009 | .005 | | .06 | .04 | |

near the streambed were determined for the three Columbia River stations. The temporal distributions of these ratios are shown for zinc-65 in figure 26 and for chromium-51 in figure 27. These data indicate a decrease in the ratios of radionuclide concentration during the late fall at Pasco and at Hood River. The large variations in radionuclide concentrations with depth are more than can be realistically accounted for by differences between the concentrations of suspended sediment at the depths that were sampled. Investigation of the variation in radionuclide concentration of filtered sediment with sampling depth is part of the continuing program.

The lateral variations in the concentration of radionuclides and in the particle-size distribution of the streambed sediment for Hood River are shown in table 24. The data indicate that radionuclide concentrations differ for sediments that have either varying or fairly uniform particle-size distribution; thus, indicating that a considerable number of samples are necessary to obtain statistically accurate radionuclide concentrations for either uniform- or nonuniform-size sediment.

The water discharge from Priest Rapids Dam, located a few miles upstream from the Hanford reactors, is varied to meet power demands when the river discharge at Pasco is less than about 120,000 cfs. Discharges are less than 120,000 cfs about 8 months each year. The temporal distribution of water discharge at Priest Rapids Dam and the subsequent distribution at Pasco are shown in figures 28 and 29 for parts of March 4 to 5, 1962, and March 2 to 3, 1965, respectively.

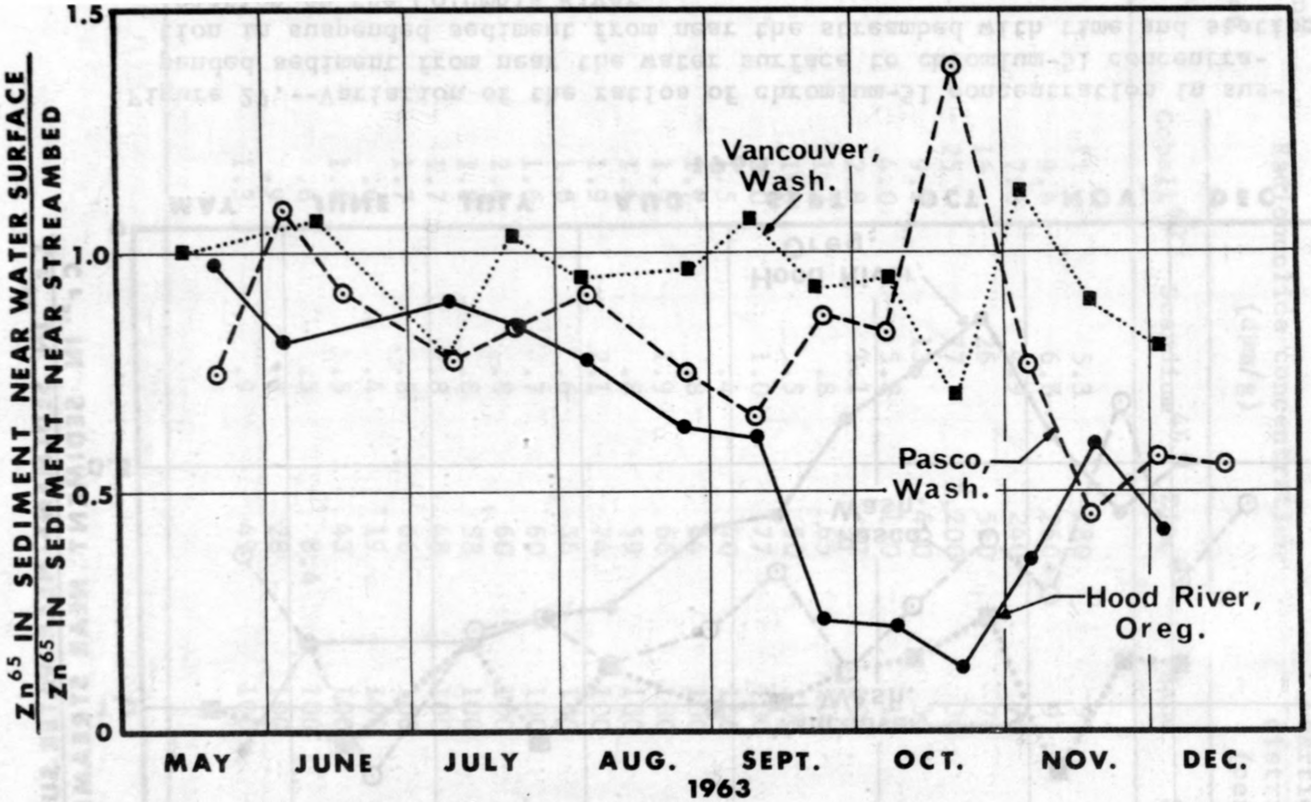



Figure 26.--Variation of the ratios of zinc-65 concentration in suspended sediment from near the water surface to zinc-65 concentration in suspended sediment from near the streambed with time and station location on the Columbia River.

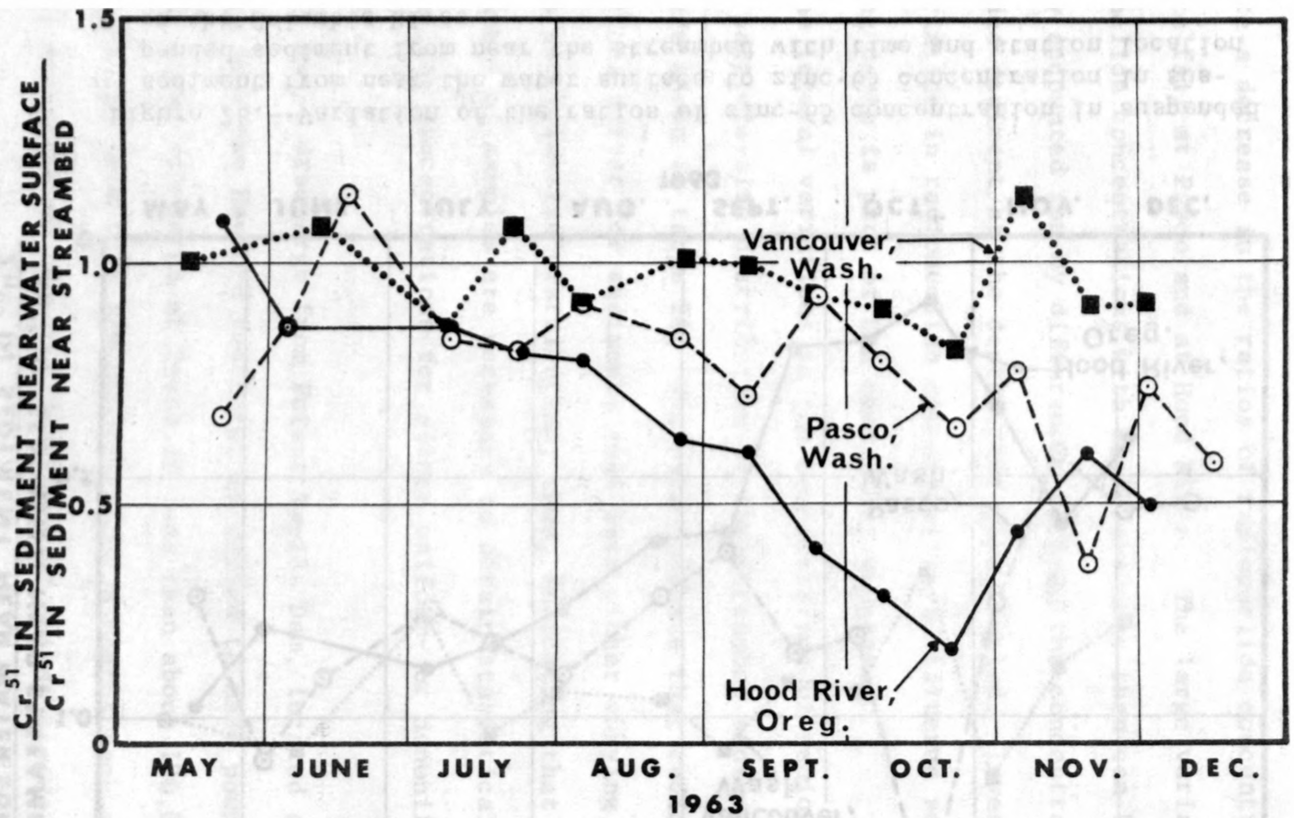



Figure 27.--Variation of the ratios of chromium-51 concentration in suspended sediment from near the water surface to chromium-51 concentration in suspended sediment from near the streambed with time and station location on the Columbia River.

Table 24.--Concentration of radionuclides and particle-size distribution of streambed sediment of the Columbia River at Hood River, Oreg. on June 4, 1963.

| Stationing from Washington shore (ft) | Radionuclide concentration (dpm/g) | | | Particle-size distribution (percent) | | |
|---|---|---|---|---|---|---|
| | $Cobalt^{60}$ | $Scandium^{46}$ | $Zinc^{65}$ | Sand | Silt | Clay |
| 280 | 11 | 5.3 | 280 | 93 | 6 | 1 |
| 440 | 9.6 | 6.6 | 260 | 97 | 2 | 1 |
| 610 | 7.6 | 4.9 | 240 | 76 | 21 | 3 |
| 800 | 16 | 26 | 510 | 76 | 22 | 2 |
| 900 | 25 | 77 | 1,200 | 30 | 67 | 3 |
| 990 | 9.2 | 13 | 400 | 54 | 43 | 3 |
| 1,130 | 4.0 | 5.8 | 150 | 18 | 75 | 7 |
| 1,330 | 2.8 | 1.1 | 97 | 100 | 0 | 0 |
| 1,440 | 1.7 | .8 | 65 | 100 | 0 | 0 |
| 1,550 | 1.6 | .5 | 50 | 100 | 0 | 0 |
| 1,670 | 2.0 | 1.0 | 77 | 100 | 0 | 0 |
| 1,800 | 1.5 | .4 | 40 | 100 | 0 | 0 |
| 1,920 | 1.7 | .8 | 64 | 100 | 0 | 0 |
| 2,040 | 1.9 | 1.9 | 66 | 100 | 0 | 0 |
| 2,160 | 1.6 | .8 | 59 | 100 | 0 | 0 |
| 2,280 | 1.9 | 2.1 | 74 | 100 | 0 | 0 |
| 2,420 | 1.6 | .6 | 56 | 100 | 0 | 0 |
| 2,520 | 1.6 | .7 | 60 | 100 | 0 | 0 |
| 2,640 | 2.6 | .8 | 60 | 100 | 0 | 0 |
| 2,760 | 1.8 | .8 | 58 | 100 | 0 | 0 |
| 2,880 | 1.7 | .8 | 48 | 100 | 0 | 0 |
| 2,980 | 1.7 | .8 | 66 | 100 | 0 | 0 |
| 3,120 | .6 | .4 | 19 | 100 | 0 | 0 |
| 3,260 | 1.0 | .5 | 43 | 100 | 0 | 0 |
| 3,360 | .6 | .3 | 8.4 | 100 | 0 | 0 |
| 3,480 | .9 | .7 | 28 | 100 | 0 | 0 |
| 3,600 | 1.3 | .9 | 49 | 100 | 0 | 0 |

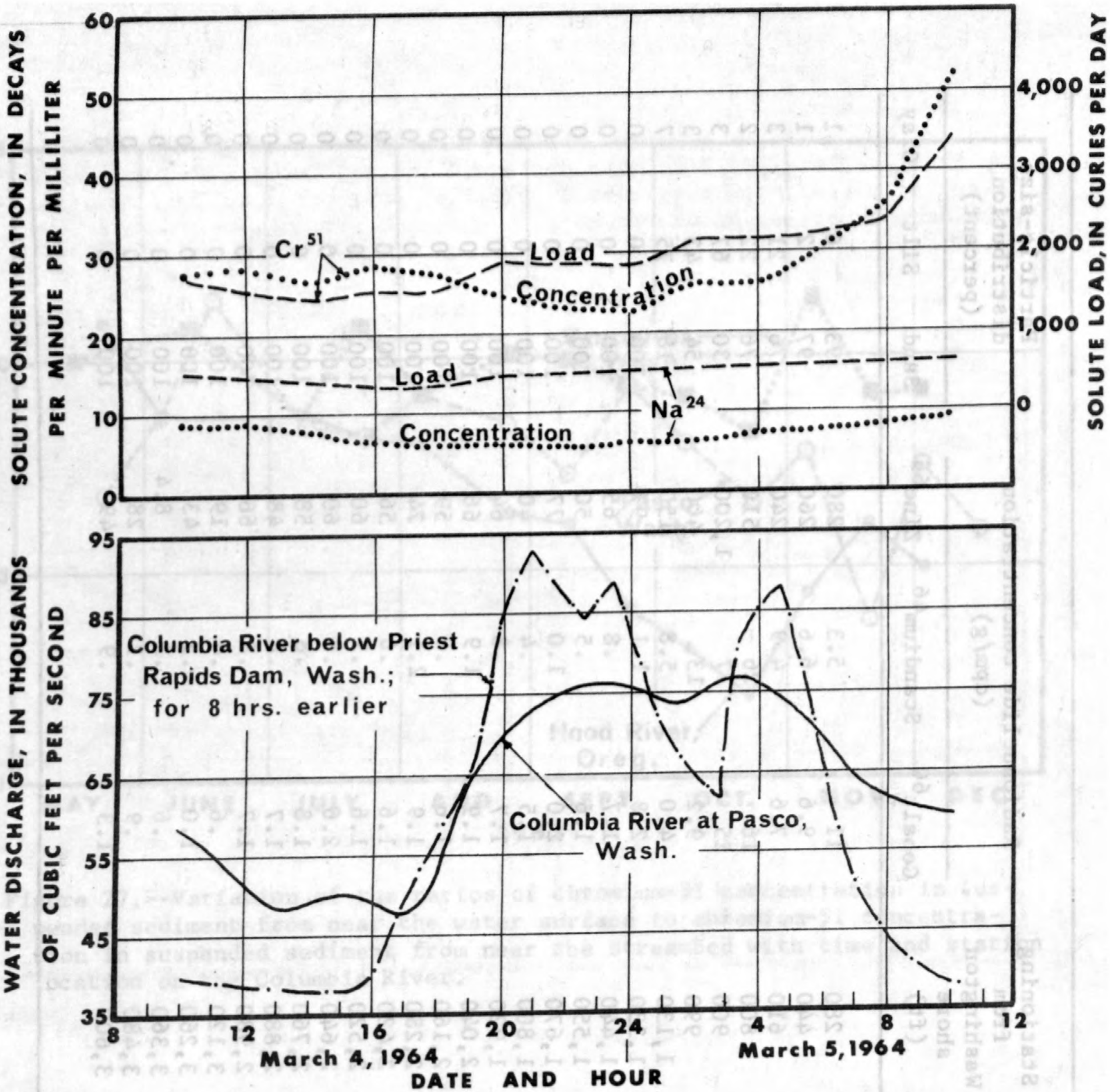



Figure 28.--Diurnal variation of water discharges and radionuclide concentrations and discharges of the Columbia River.

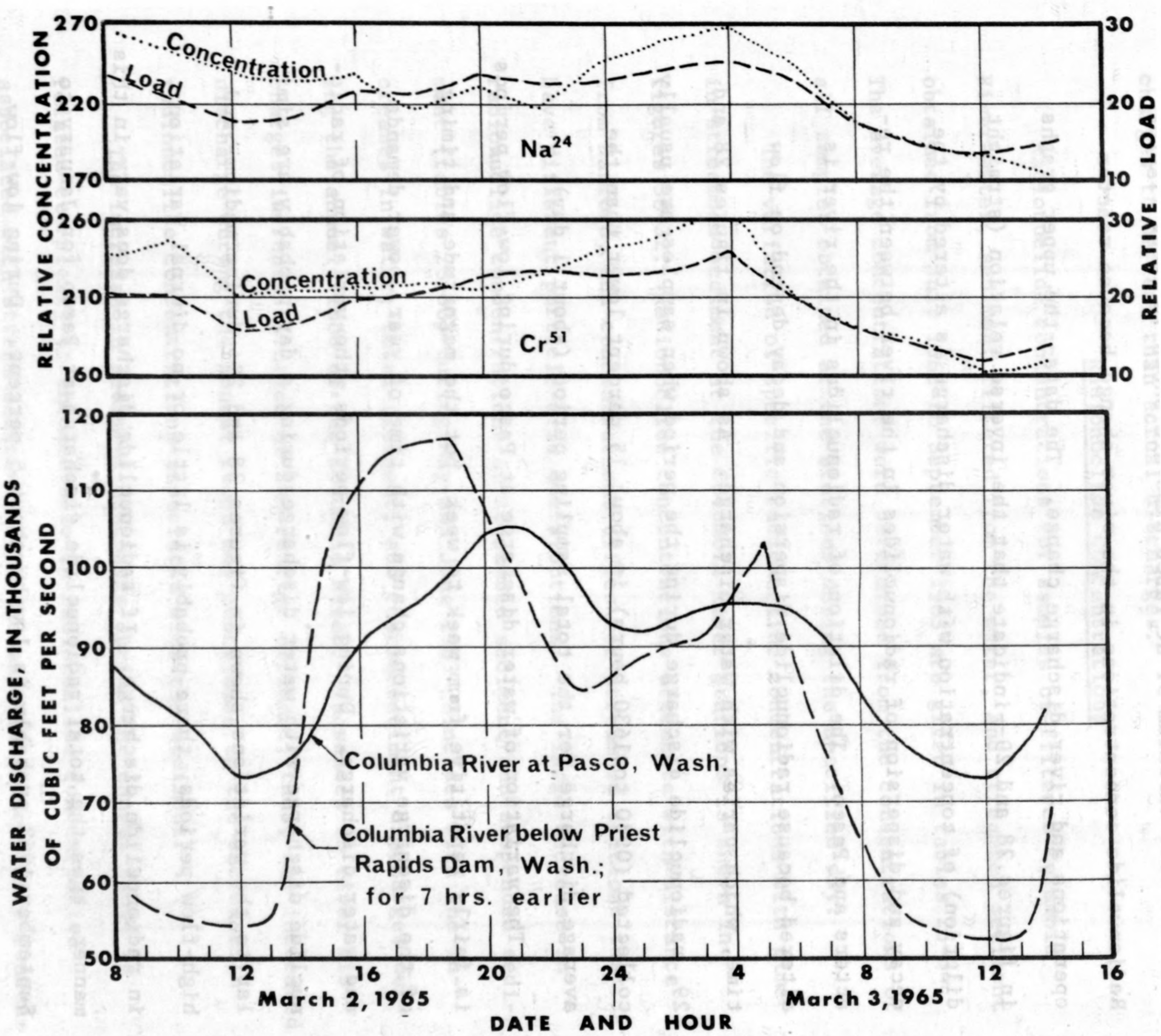



Figure 29.--Diurnal variation of water discharges and radionuclide concentrations and discharges of the Columbia River.

The temporal distribution of the concentration and discharge of sodium-24 and chromium-51 at Pasco also are shown in these figures. Radionuclide concentrations in the river change because reactor operations and river discharge change. The data--the upper graphs in figures 28 and 29--indicate that the inverse relation (straight dilution) of concentration with water discharge is altered by the decay and dispersion of radionuclides in the river between the reactors and Pasco. The dilution of radionuclides in the river is altered because radionuclide dispersion and decay depend on flow time, which varies with water discharge. As shown in figures 28 and 29, radionuclide discharge during the period when samples are usually collected (0930 to 1630 hours) is about 15 percent lower than the average discharge for the total sampling period (about 1 day).

The variation of water discharge at Pasco during low-flow periods is fairly repetitive from week to week, but the magnitude and timing of the discharge variations change with time of year, power demands, and water discharge. During low-flow periods, the variation of radionuclide discharge with water discharge during a day probably are similar to the variations shown in figures 28 and 29; during medium- and high-flow periods, there probably is little or no diurnal variation in radionuclide discharge. If radionuclide discharge does vary in this manner, then the total radionuclide discharge at Pasco for January to September 1963 probably is low by about 5 percent. During low-flow periods, the low radionuclide concentrations at the time of sampling are used to compute discharges; this procedure causes computed discharges to be less than actual discharges.

Radionuclide Concentrations

Radionuclide concentrations for samples of filtered Columbia River water, sediment filtered from the water, and streambed sediment obtained from July 1962 to September 1963 are given in tables 25-34. The average concentrations were determined from the concentrations of all samples obtained at the stations during the specified day.

The variation of specific radionuclide concentrations with time in streambed sediment at the Columbia River stations is shown in figures 30-32. Radionuclide concentrations attenuate with distance from Hanford, and concentrations differ for streambed sections that have different particle-size distributions. The large decrease in radionuclide concentrations of streambed sediment and suspended sediment (tables 28-30) during May and June 1963 coincides with the increases in water, total-sediment, and coarse-sediment discharges during the annual flood of the Columbia River. Increases in river discharges increase dilution of the reactor effluent; thus, the increased discharge during the annual flood may contribute to the decrease in radionuclide concentrations associated with the sediment.

The increase in sediment discharge during the annual flood is related complexly to the decrease in radionuclide concentration associated with stream sediment. The decrease in radionuclide concentration of the sediment filtered from the river water during May and June 1963 is caused partly by changes in both the amount of sediment

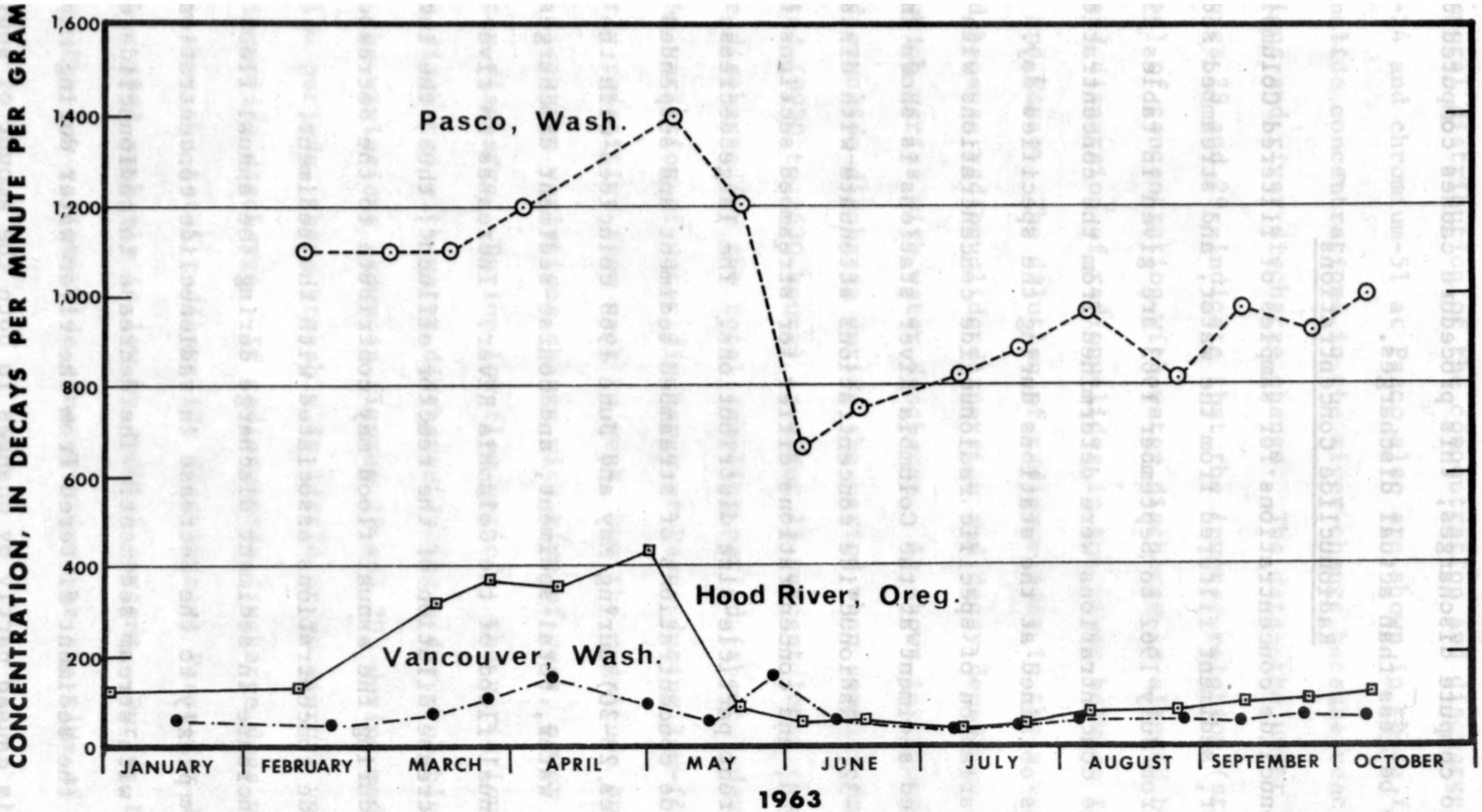



Figure 30.--Variation of zinc-65 concentration in coarse streambed sediment from the Columbia River with time and station location.

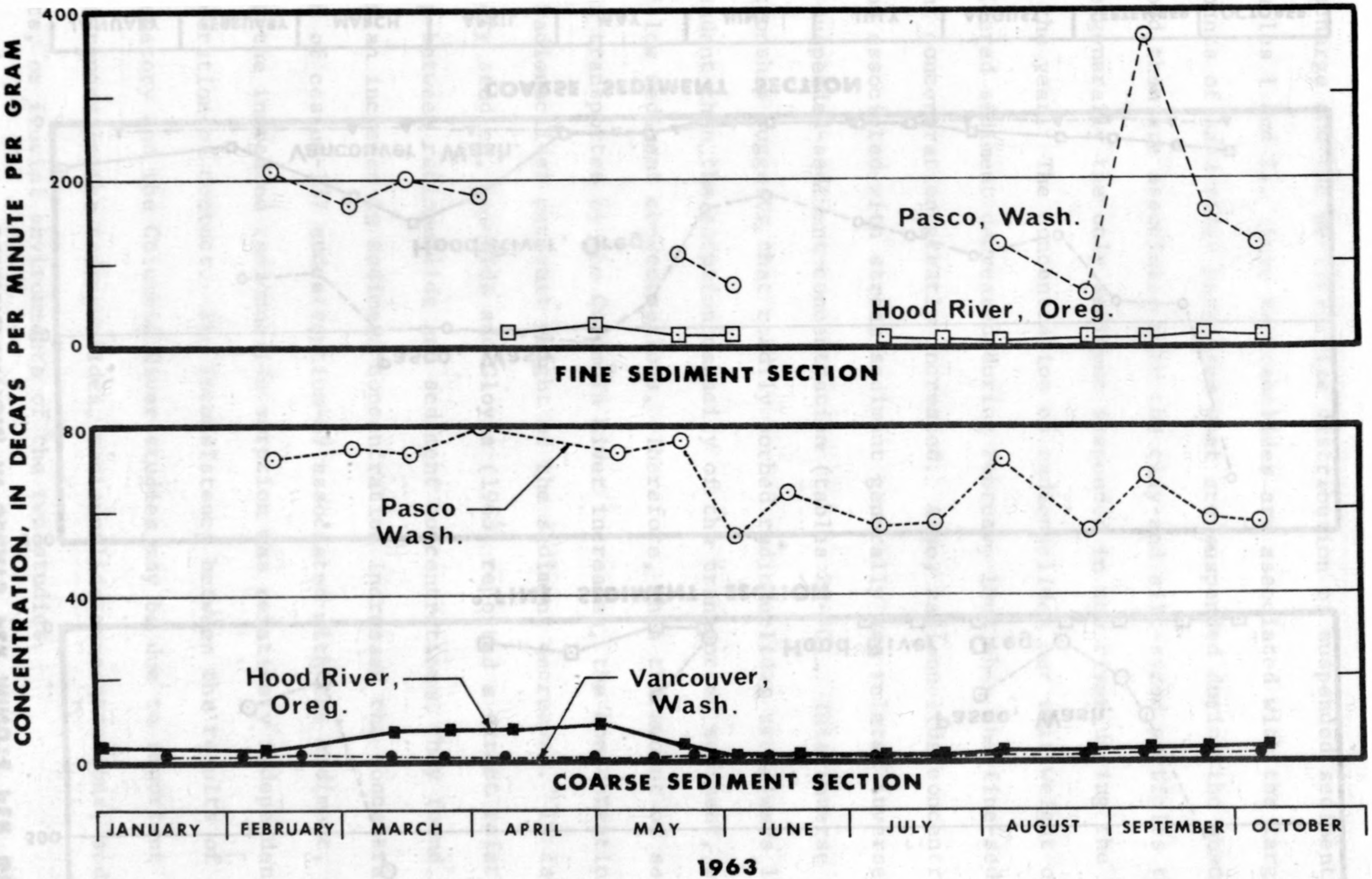



Figure 31.--Variation of cobalt-60 concentration in streambed sediment from the Columbia river with sediment size, time, and station location.

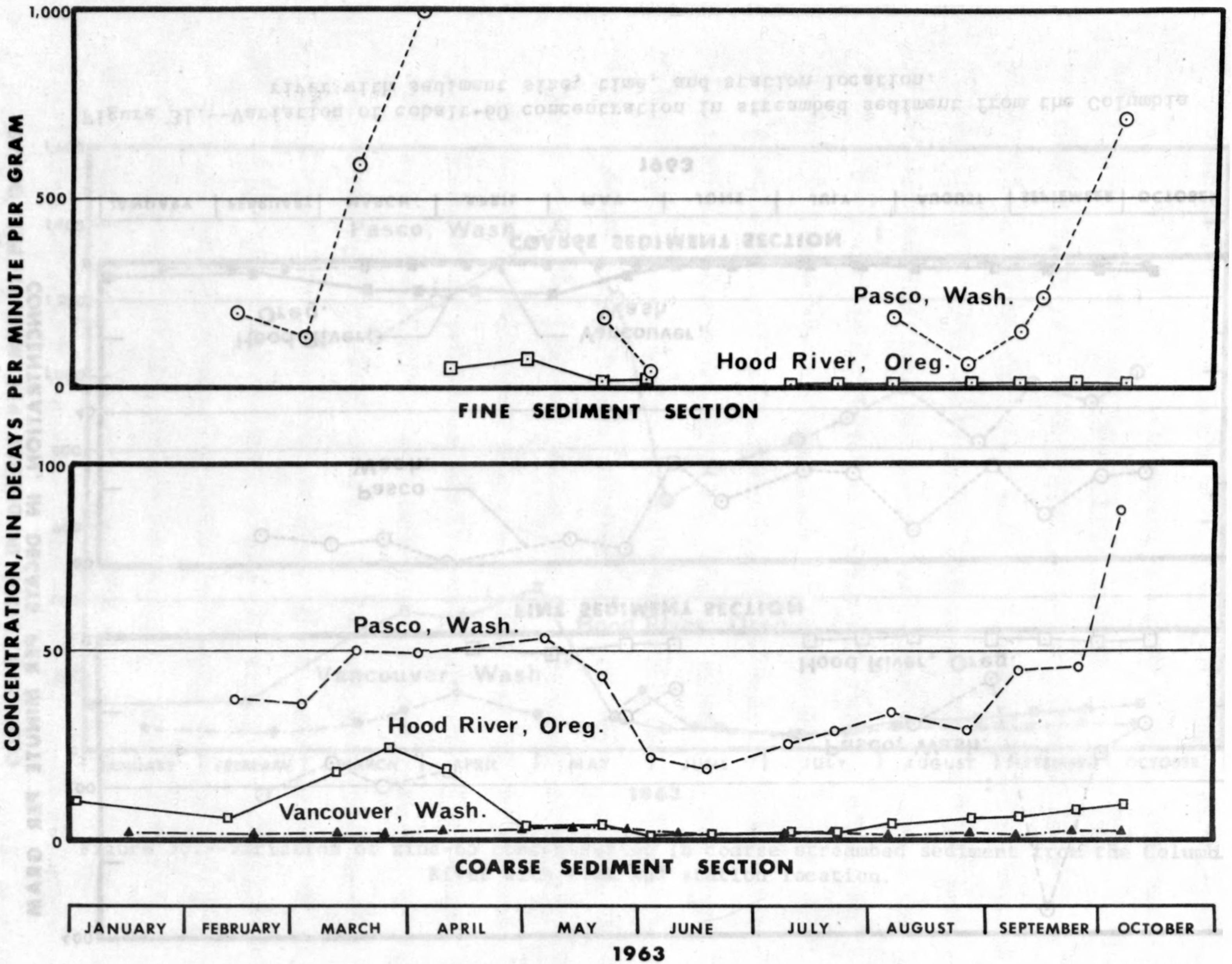



Figure 32.--Variation of scandium-46 concentration in streambed sediment from the Columbia River with sediment size, time, and station location.

discharge and the particle-size distribution of suspended sediment (tables 1 and 2). Less radionuclides are associated with the larger amounts of sand-sized particles that are suspended during the annual flood than are associated with the clay-and silt-sized particles that are generally the only sediment suspended in the river during the rest of the year. The concentration of radionuclides per unit weight of filtered sediment decreased during February 1963 when the fine-sediment concentration greatly increased. Also, radionuclide concentration associated with stream sediment generally was related inversely to suspended-sediment concentration (tables 28-30). This inverse relationship suggests that readily sorbed radionuclides are always less abundant than the sorption capacity of the transported sediment, even for low sediment concentrations. Therefore, when the amount of sediment transported by the Columbia River increases, the concentration of radionuclides per unit weight of the sediment decreases. In laboratory studies, Reynolds and Gloyna (1963) reported a direct relationship between radionuclide and sediment concentrations. They found that an increase in sediment concentration increased the concentration of cesium-137 and strontium-89 associated with the sediment, and that the increased radionuclide sorption was relatively independent of duration of contact. The inconsistency between the results of the laboratory and the Columbia River studies may be due to important differences in the radionuclides, radionuclide concentrations, sediments, or fluvial environments of the two studies.

The decrease in radionuclide concentration associated with the streambed sediment as water discharge increases may be explained qualitatively by changes in sediment transport. The sediment discharge of the Columbia River may be divided into a period of high discharge during the annual flood and a period of low discharge during the remainder of the year (figs. 16-20). The transport of coarse sediment is large during the annual flood and small (insufficient amount to significantly change daily discharges computed from suspended-sediment concentrations) during the remainder of the year. However, the discharge of fine sediment during periods of low-water discharge sometimes is increased substantially by increases in tributary flows that are of short-term duration but highly concentrated with fine sediment.

During low-discharge periods, the sorption potential of the streambed sediment may increase because (a) the amount of fine sediment in and on the streambed (depositing) increases and (or) (b) the coating of coarse-sediment particles by fine sediment increases. The transported sediment is mostly suspended clay and silt but even these fine particles must have some contact and interchange with the sediment of the streambed (Einstein, 1950, and Colby, 1964). Fine sediment may be deposited in areas where the water is quiet or slowly moving. The clay coating of coarse particles is maximum when the transport of coarse particles is minimum. The quantity of coarse sediment transported during the low-discharge periods is small (the coarse particles are not suspended but move in contact--or near contact--with the bed) and the dunes and ripples formed in the streambed change shape and progress downstream very slowly. When coarse-sediment particles are not actively transported, abrasion and scouring forces are minimal and are unable to remove much clay coating from the coarse particles. The increased sorption potential of the streambed, combined with high radionuclide concentrations in the water during periods of low-water discharge, cause high radionuclide concentrations in the surficial streambed sediment.

More coarse sediment is discharged during the annual flood than during periods of low-water discharge. Sediment particles are sheared off the streambed and transported downstream, thus exposing underlying streambed particles. The newly exposed particles, because of more decay after deposition, have less sorbed radioactivity than the departed particles. Clay coatings on the coarse sediment likely are removed (or partly removed) by abrasive forces caused by the greater transport of coarse sediment. The resuspension of deposited sediment and the abrasion of clay coatings tend to decrease the concentration of radionuclides in the surficial streambed sediment as well as in the sediment in transport. Also, dunes on the streambed progress downstream rapidly during high-water discharge (Simons, Richardson, and Nordin, 1965) owing to increased erosion of particles from their upstream face and deposition of particles on their downstream face. This erosion and deposition of particles quickly mixes the sediment in the dunes so that the surficial sediments are composed of particles from throughout streambed depths approximately equal to the amplitude of the local dunes. The distribution of the radionuclide concentration with streambed depth therefore would change, even though the total concentration in the streambed may not change greatly. Additional data from cores are needed to determine exactly what happens.

## Radionuclide Discharge

Daily mean radionuclide discharges were estimated for the three Columbia River stations. Radionuclide concentrations for successive samples of river water and filtered sediment were averaged and considered to be the concentration for the day that was midway between the sampling days. Daily mean concentrations for other days were estimated by temporally prorating the differences between average concentrations, with consideration given to major changes in water and sediment discharges. Daily mean discharges were computed using the estimated concentrations and routed water discharges. Monthly radionuclide-discharge data are given in tables 35-37 for the solute discharges and in tables 38-40 for the discharges associated with the transported sediments. Total radionuclide discharges for each month and for the period from January to September 1963, shown in table 41, are the summation of the solute discharges and the discharges associated with stream sediment. Radionuclide discharges associated with stream sediments include both the discharges associated with suspended sediment (determined by using the radionuclide concentration of the filtered sediment) and the discharges associated with coarse sediment transported on or near the streambed (determined by using the radionuclide concentration of the streambed sediment). The variations in

Table 41.--Estimates of total radionuclide discharges of the Columbia River, in curies.

| Time period | Chromium51 | | | Zinc65 | | | Scandium46 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pasco, Wash. | Hood River, Oreg. | Vancouver, Wash. | Pasco, Wash. | Hood River, Oreg. | Vancouver, Wash. | Pasco, Wash. | Hood River, Oreg. | Vancouver, Wash. |
| 1963 | | | | | | | | | |
| January | 22,000 | 18,000 | 20,000 | 800 | 500 | 500 | 190 | 110 | 70 |
| February | 22,000 | 16,000 | 20,000 | 1,200 | 600 | 600 | 200 | 90 | 100 |
| March | 34,000 | 24,000 | 28,000 | 1,900 | 700 | 700 | 250 | 110 | 110 |
| April | 39,000 | 33,000 | 35,000 | 2,300 | 1,100 | 1,000 | 270 | 180 | 180 |
| May | 32,000 | 33,000 | 39,000 | 2,000 | 1,500 | 1,600 | 270 | 260 | 310 |
| June | 42,000 | 36,000 | 35,000 | 1,800 | 1,600 | 1,700 | 340 | 260 | 300 |
| July | 50,000 | 36,000 | 31,000 | 1,500 | 900 | 1,000 | 240 | 130 | 140 |
| August | 47,000 | 36,000 | 31,000 | 700 | 400 | 300 | 210 | 50 | 40 |
| September | 49,000 | 34,000 | 27,000 | 800 | 100 | 100 | 260 | 20 | 20 |
| Total | 337,000 | 266,000 | 266,000 | 13,000 | 7,400 | 7,500 | 2,200 | 1,100 | 1,200 |

Table 41.--Estimates of total radionuclide discharges of the Columbia River, in curies--Continued.

| Time period | Zirconium$^{95}$-Niobium$^{95}$ | | | Ruthenium$^{103}$-Rhodium$^{103}$ | | | Cerium$^{141}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pasco, Wash. | Hood River, Oreg. | Vancouver, Wash. | Pasco, Wash. | Hood River, Oreg. | Vancouver, Wash. | Pasco, Wash. | Hood River, Oreg. | Vancouver, Wash. |
| 1963 | | | | | | | | | |
| January | 150 | 110 | 110 | 110 | 110 | 130 | - | - | - |
| February | 120 | 150 | 140 | 140 | 170 | 200 | - | - | - |
| March | 140 | 130 | 150 | 80 | 110 | 140 | - | - | - |
| April | 160 | 220 | 220 | 100 | 170 | 160 | - | - | - |
| May | 180 | 280 | 300 | 80 | 220 | 210 | 420 | 630 | 830 |
| June | 200 | 260 | 330 | 100 | 180 | 200 | 480 | 990 | 870 |
| July | 150 | 130 | 150 | 70 | 70 | 110 | 540 | 750 | 470 |
| August | 80 | 40 | 40 | 60 | 40 | 60 | 440 | 310 | 220 |
| September | 90 | 20 | 20 | 60 | 30 | 50 | 160 | 50 | 80 |
| Total | 1,300 | 1,300 | 1,500 | 800 | 1,100 | 1,300 | - | - | - |

the discharges of specific radionuclides with time, type of transport, and station location are shown in figures 33-38.

The compositions of the total annual radionuclide discharges at Pasco and Vancouver are given in table 42. These data show that chromium-51 discharge is essentially the same proportion of the total discharge at the two stations but that zinc-65 discharge and scandium-46 discharge is a smaller percentage of the total discharge at Vancouver than at Pasco. The percentage of the total zinc-65 discharge associated with the transported sediment at Vancouver is three times that at Pasco. The percentage of scandium-46 transported in association with stream sediment remains nearly the same at both stations. "Fallout" radionuclide discharge is a greater part of the total discharge at Vancouver than at Pasco and more of the "fallout" radionuclide load is associated with the transported sediment at Vancouver. The percentage of the total zirconium-95-niobium-95 discharge that is associated with the transported sediment changes considerably between Pasco and Vancouver.

## Budget of Radionuclide Transport

The radionuclide discharge at Pasco is the input to the river reach being studied, and the radionuclide discharge at Vancouver is the output. The total-radionuclide discharge is composed of radionuclides transported as solutes and in association with the sediment. A gross budget uses only input and output data and does not provide information about the location of, or the mechanism of, changes in the radionuclide transport that occur in the river between Pasco and

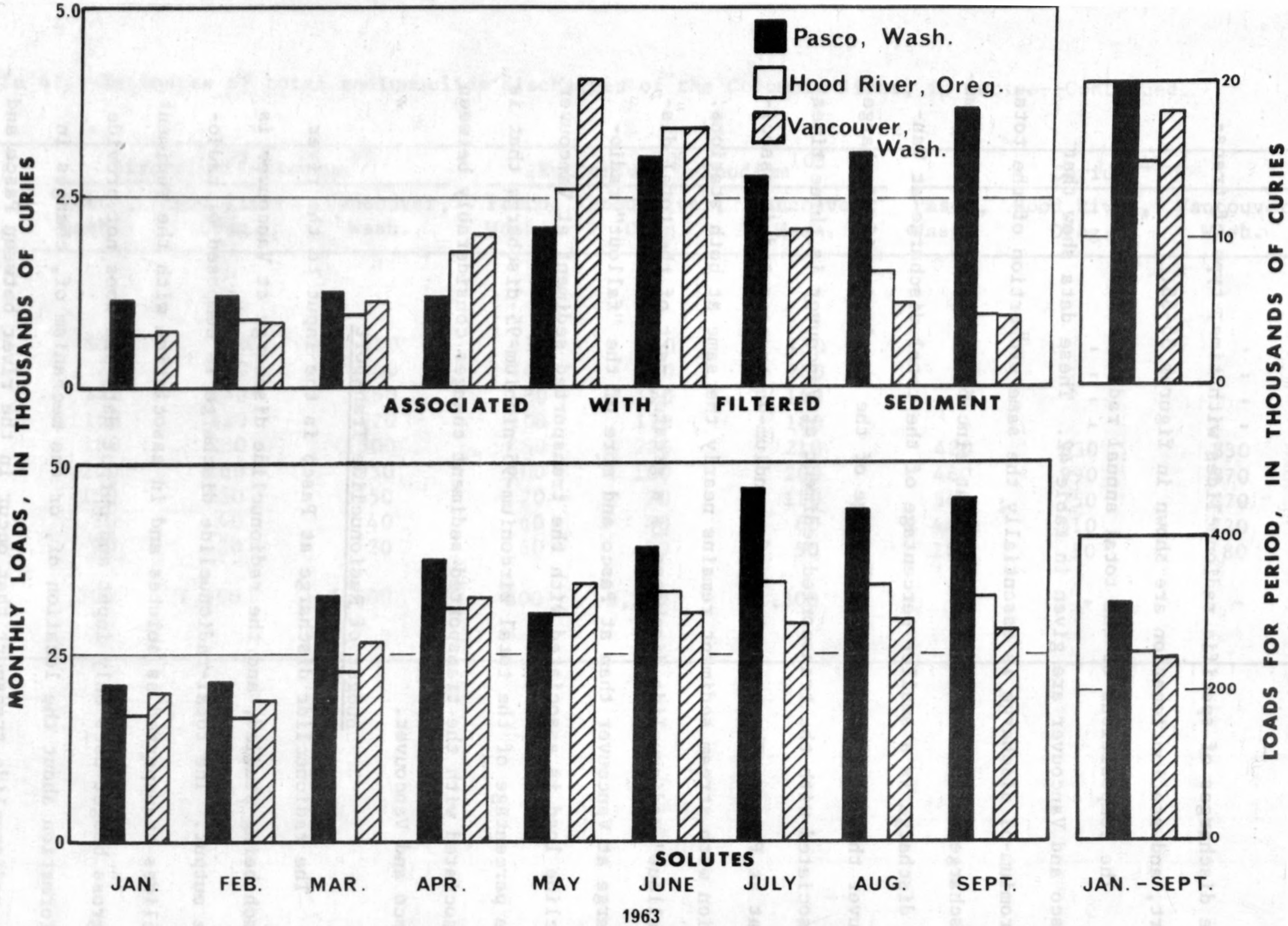



Figure 33.--Variation of chromium-51 discharge of the Columbia River during the period, January to September 1963, with type of transport, time, and station location.

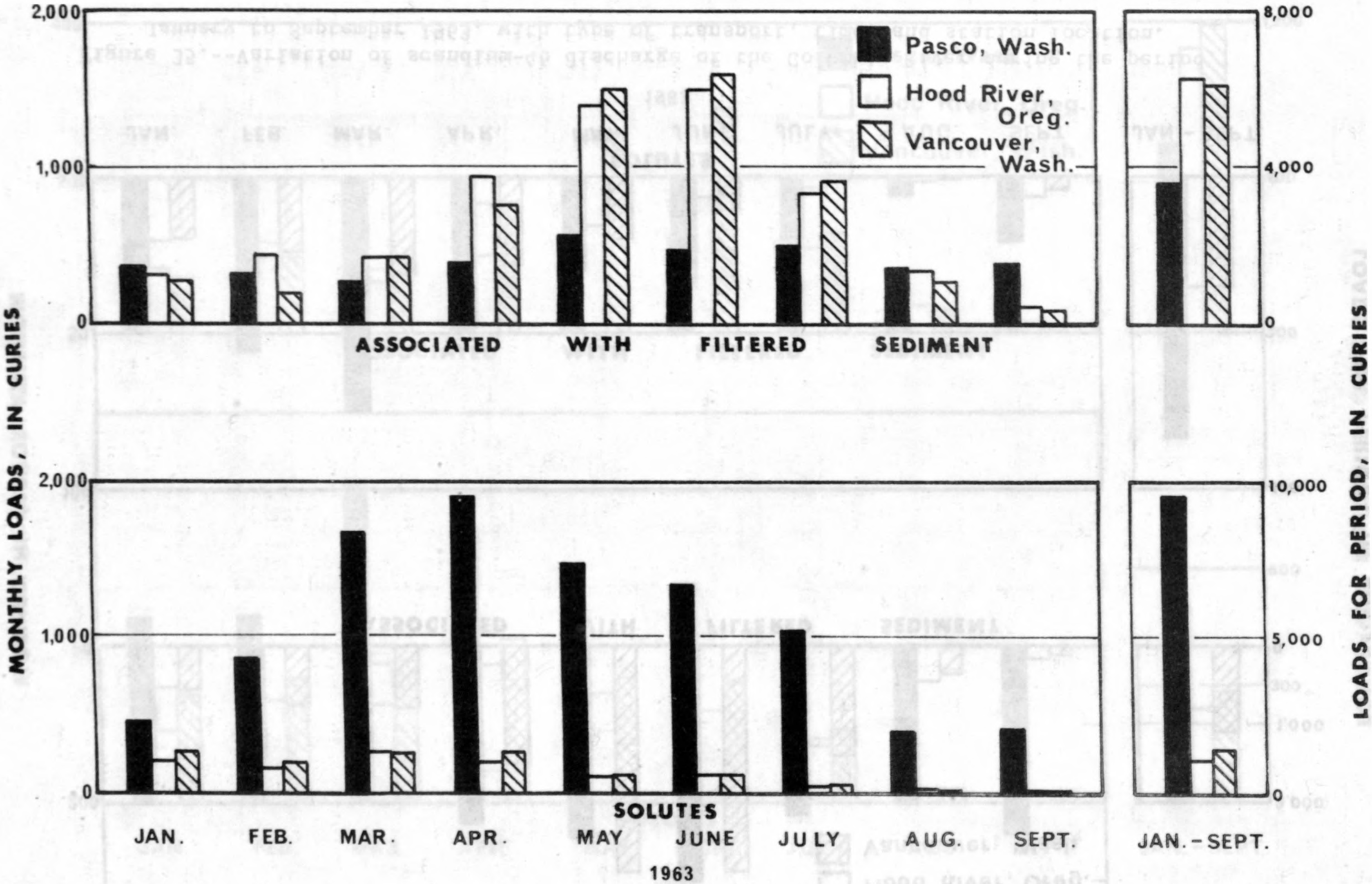



Figure 34.--Variation of zinc-65 discharge of the Columbia River during the period, January to September 1963, with type of transport, time, and station location.

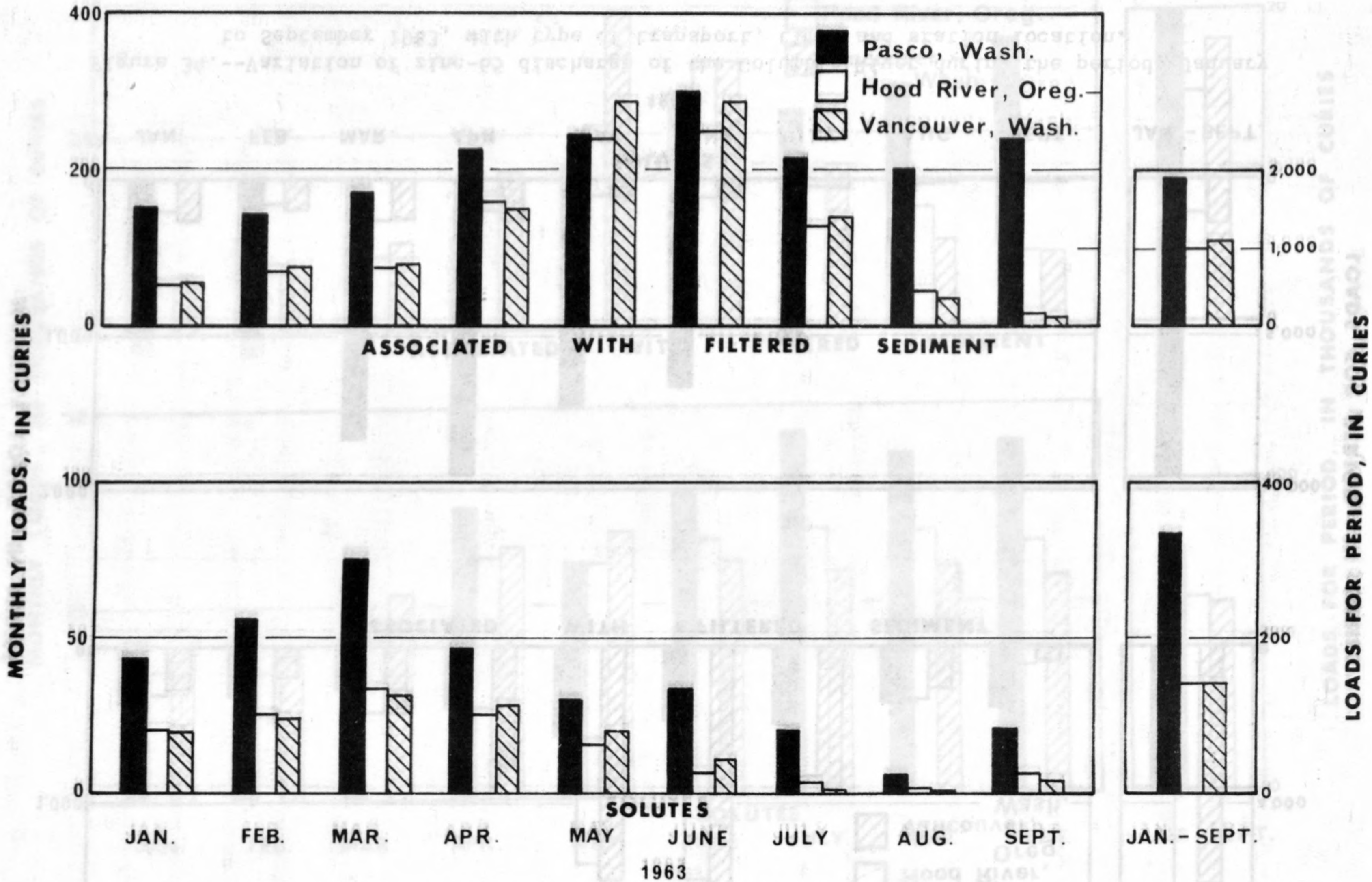



Figure 35.--Variation of scandium-46 discharge of the Columbia River during the period, January to September 1963, with type of transport, time, and station location.

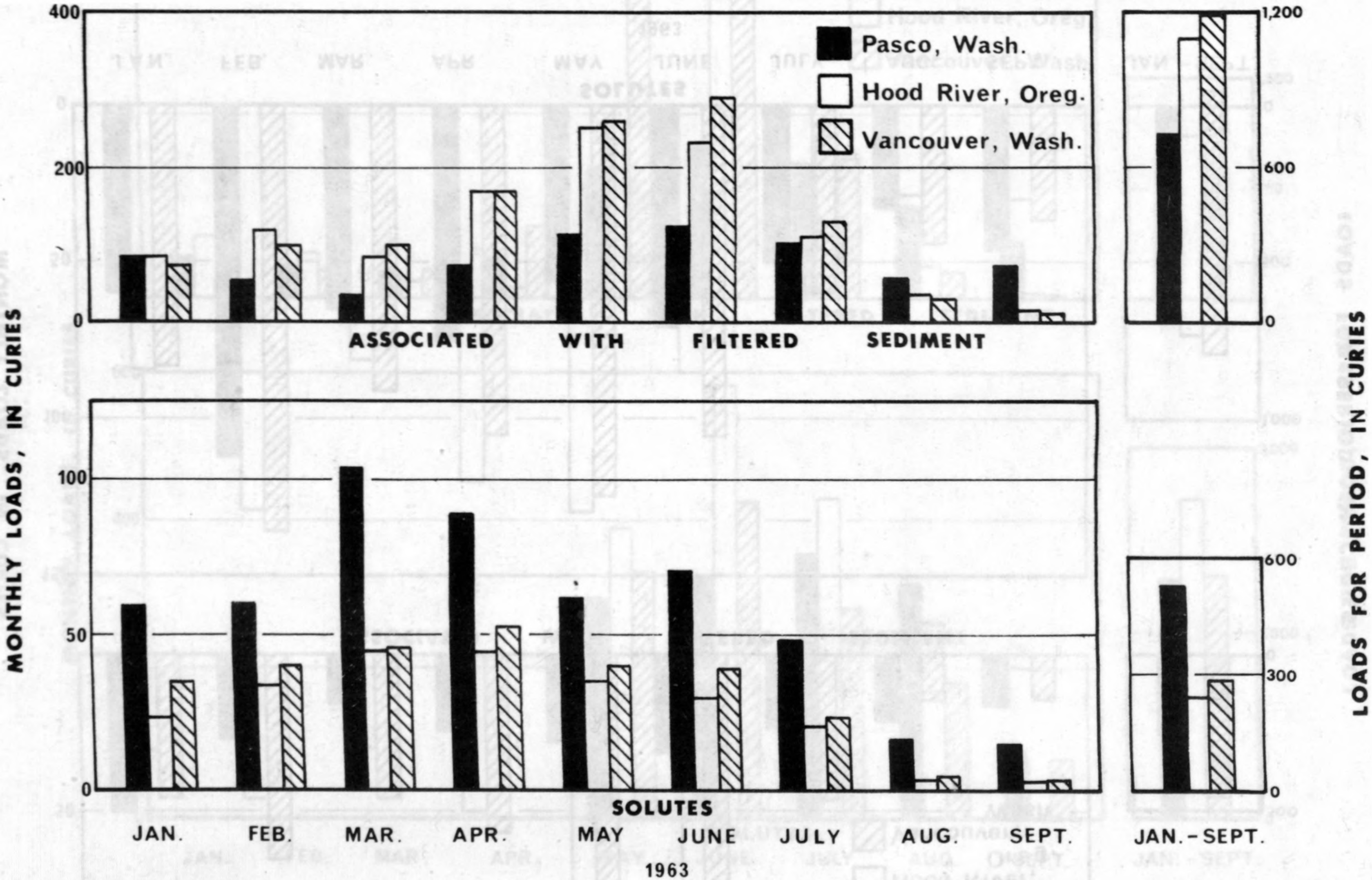



Figure 36.--Variation of zirconium-95-niobium-95 discharge of the Columbia River during the period, January to September 1963, with type of transport, time, and station location.

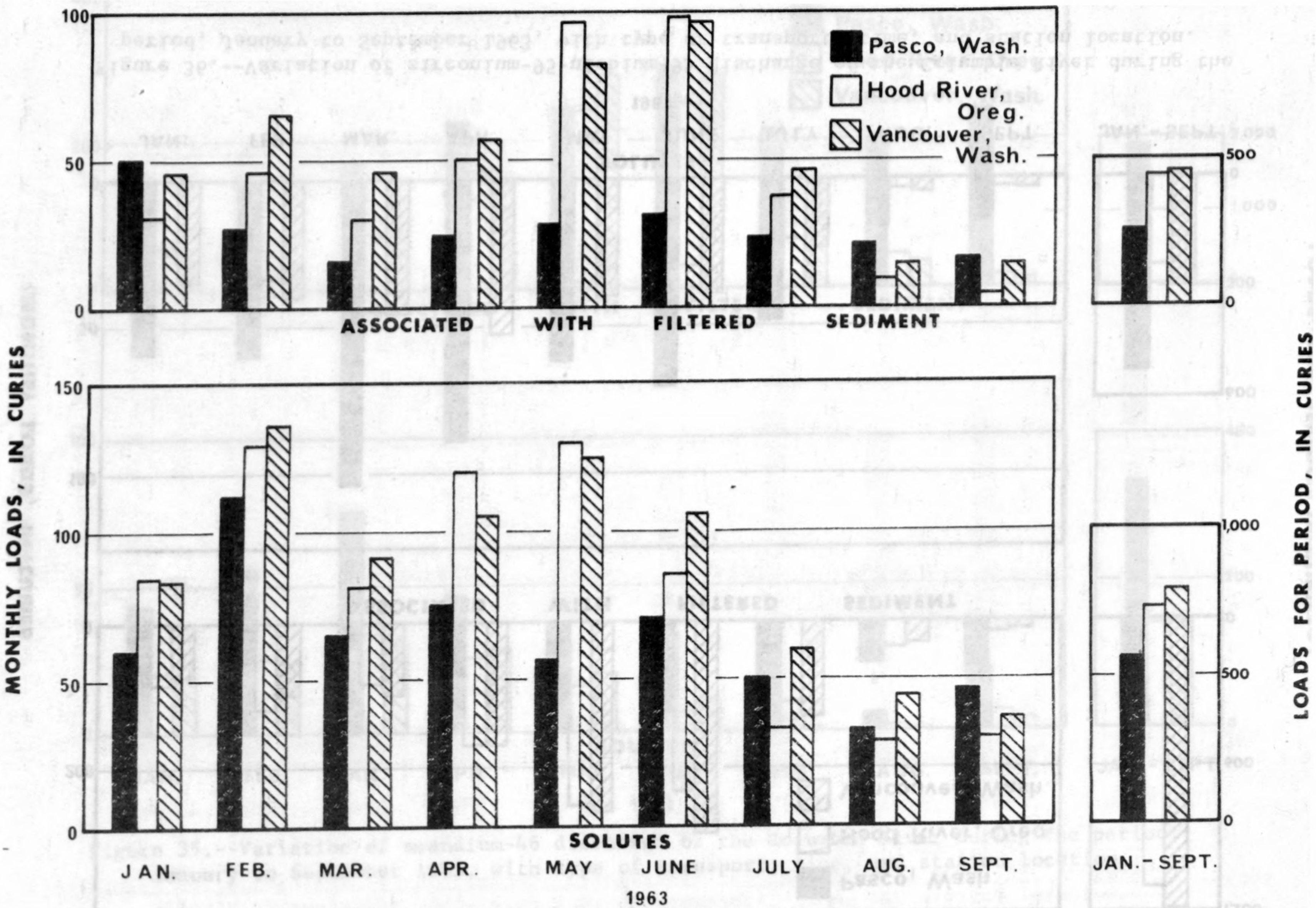



Figure 37.--Variation of ruthenium-103-rhodium-103 discharge of the Columbia River during the period, January to September 1963, with type of transport, time, and station location.

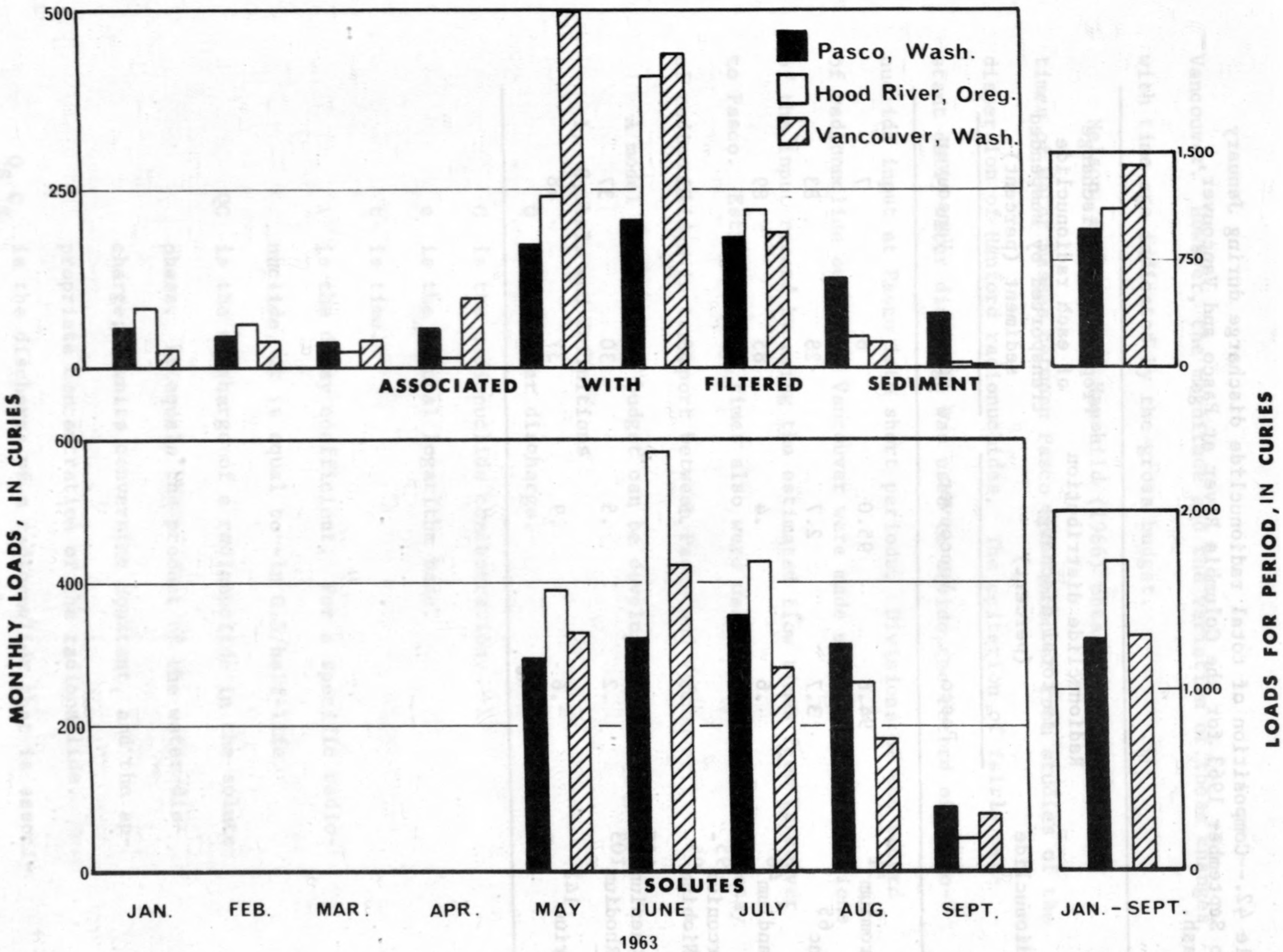



Figure 38.--Variation of cerium-141 discharge of the Columbia River during the period, January to September 1963, with type of transport, time, and station location.

Table 42.--Composition of total radionuclide discharge during January to September 1963 for the Columbia River at Pasco and Vancouver, Wash.

| Radionuclide | Radionuclide distribution in total discharge (percent) | | Proportion of discharge of each radionuclide transported by suspended sediment (percent) | |
|---|---|---|---|---|
| | Pasco | Vancouver | Pasco | Vancouver |
| Chromium$^{51}$ | 94.6 | 95.0 | 6 | 7 |
| Zinc$^{65}$ | 3.7 | 2.7 | 28 | 83 |
| Scandium$^{46}$ | .6 | .4 | 85 | 89 |
| Zirconium$^{95}$-Niobium$^{95}$ | .3 | .5 | 58 | 81 |
| Ruthenium$^{103}$-Rhodium$^{103}$ | .2 | .5 | 30 | 37 |
| Cerium$^{141}$ | .6 | .9 | 37 | 48 |

Vancouver. However, the magnitude and the variation of these changes with time are indicated by the gross budget.

Nelson, Perkins, and Haushild (1966) obtained estimated flow times of water masses between Pasco and Vancouver from studies of the dispersion of Hanford radionuclides. The criterion of fairly constant daily water discharge was used to divide the record of radionuclide input at Pasco into short periods. Divisions of the record of radionuclide output at Vancouver were made comparable to divisions of the input record by using the estimated flow times from Vancouver to Pasco. Estimated flow times also were used in computing the decay of radionuclides in transport between Pasco and Vancouver.

A model of the gross budget can be developed as follows:

1. Symbols and definitions

$Q$ is the water discharge.

$C$ is the radionuclide concentration.

$e$ is the natural logarithm base.

$t$ is time.

$\lambda$ is the decay coefficient. For a specific radionuclide, it is equal to -ln 0.5/half-life.

$QC$ is the discharge of a radionuclide in the solute phase. It equals the product of the water discharge, a units conversion constant, and the appropriate concentration of the radionuclide.

$Q_S C_S$ is the discharge of a radionuclide that is associated with the transported sediment. It equals the product of the water discharge, a units conversion constant, and the appropriate concentration of the radionuclide.

$Q_T\ C_T$ is the total discharge of a radionuclide. It equals the sum of $Q_S\ C_S$ and QC.

P & V are subscripts used to indicate that the discharges are, respectively, for the Columbia River at Pasco and the Columbia River at Vancouver.

Fines is a subscript used to designate the fine sediment fraction of the total sediment load.

Storage is the depletion from (a loss), or addition to (a gain), radionuclide transport in a river reach.

2. For the total discharge of radionuclides

$$Q_{TV}\ C_{TV} = Q_{TP}\ C_{TP} - \text{Storage} \quad (1)$$

where Storage accounts for all of the changes in the total radionuclide discharge that occur between Pasco and Vancouver.

3. For the radionuclides transported as solutes

$$Q_V\ C_V = Q_P\ C_P - \text{Storage}_2 \quad (2)$$

This storage may be divided into:

a. depletion caused by decay, estimated from:

$$Q_P\ C_P\ (1-e^{-\lambda T}) \quad (3)$$

where T is the flow time from Pasco to

Vancouver of the water containing the

solutes and;

b. the remaining depletion, expressed by the term, $Storage_3$.

Equation 2 then becomes,

$$Q_V C_V = Q_P C_P - (1-e^{-\lambda T}) Q_P C_P - Storage_3 \quad (4)$$

4. For the radionuclides transported in association with the sediment

$$Q_{SV} C_{SV} = Q_{SP} C_{SP} - Storage_4 \quad (5)$$

The time that sediment spends in traveling from Pasco to Vancouver is unknown and varies from the same as the flow time of the water for fine particles to many years for coarse particles. The decay losses for the radionuclides associated with the sediment during transport may be approximated as follows:

For the fine sediment, the approximate decay losses are:

$$\left[ Q_{SP} C_{SP} (1-e^{-\lambda T}) \right] \text{Fines} \quad (6)$$

where T is the flow time of water from Pasco to Vancouver.

Coarse sediment probably spends enough time in transport through the river reach so that all radionuclides associated with them can be considered to be completely decayed during transport.

Equation 5 then becomes:

$$Q_{SV}\, C_{SV} = Q_{SP}\, C_{SP} - \left[ (1-e^{-\lambda T})\, Q_{SP}\, C_{SP} \right] \text{Fines} - \text{Storage}_5 \quad (7)$$

where $\text{Storage}_5$ is all changes, other than decay, in radionuclide transport associated with sediment.

5. Equation (1) may then be expanded as follows:

$$Q_{TV}\, C_{TV} = Q_V\, C_V + Q_{SV}\, C_{SV} \quad (8)$$

$$Q_{TP}\, C_{TP} = Q_P\, C_P + Q_{SP}\, C_{SP} \quad (9)$$

and

$$Q_V\, C_V + Q_{SV}\, C_{SV} = Q_P C_P - (1-e^{-\lambda T}) Q_P\, C_P - \text{Storage}_3 + Q_{SP}\, C_{SP} - \left[ (1-e^{-\lambda T})\, Q_{SP}\, C_{SP} \right] \text{Fines} - \text{Storage}_5 \quad (10)$$

$$\text{If Storage}_6 = \text{Storage}_3 + \text{Storage}_5 \quad (11)$$

Then:

$$\text{Storage}_6 = (Q_P\, C_P - Q_V\, C_V) - Q_P\, C_P\, (1-e^{-\lambda T}) + (Q_{SP}\, C_{SP} - Q_{SV}\, C_{SV}) - \left[ Q_{SP}\, C_{SP}\, (1-e^{-\lambda T}) \right] \text{Fines} \quad (12)$$

The storage determined by using equation (12) is affected by several factors occurring in the river between Pasco and Vancouver:

1. Fallout.--"Fallout" radionuclides enter the Columbia River with the inflow between Pasco and Vancouver. This additional input was approximated in the budget by assuming that:

   a. The concentrations of "fallout" radionuclides at Pasco and in the inflow to the reach were equal.

b. The inflow to the reach equaled the difference between the water discharges at Vancouver and Pasco (fig. 39).

The assumptions affect the accuracy of the budget for "fallout" radionuclides.

2. Sorption.--Sorption by stationary or semistationary sediment and uptake by biota depletes the radionuclides in the river. These losses may be either permanent or temporary.

3. Infiltration.--Radionuclides leave the reach with influent flow from the river.

4. Decay.--Radionuclides decay in the reach according to a well-known relation between the specific radionuclides and time.

5. Interchange.--Interchange between the radionuclides as solutes and the radionuclides associated with the sediment may affect decay, sorption, and infiltration in the reach.

6. Errors.--Errors in radionuclide concentrations, water discharge, and the method used in determining the input and output discharges may be important.

The radionuclide discharges at Pasco and Vancouver were used to compute the four components of the right side of equation (12). The components are radionuclide decay during transport between Pasco and Vancouver and differences between decay-corrected radionuclide discharges at these stations. Both the decay and the differences in discharges were computed for radionuclide discharges separated into transport as solutes and transport associated with stream sediment. The values for these components were then summed to obtain the total

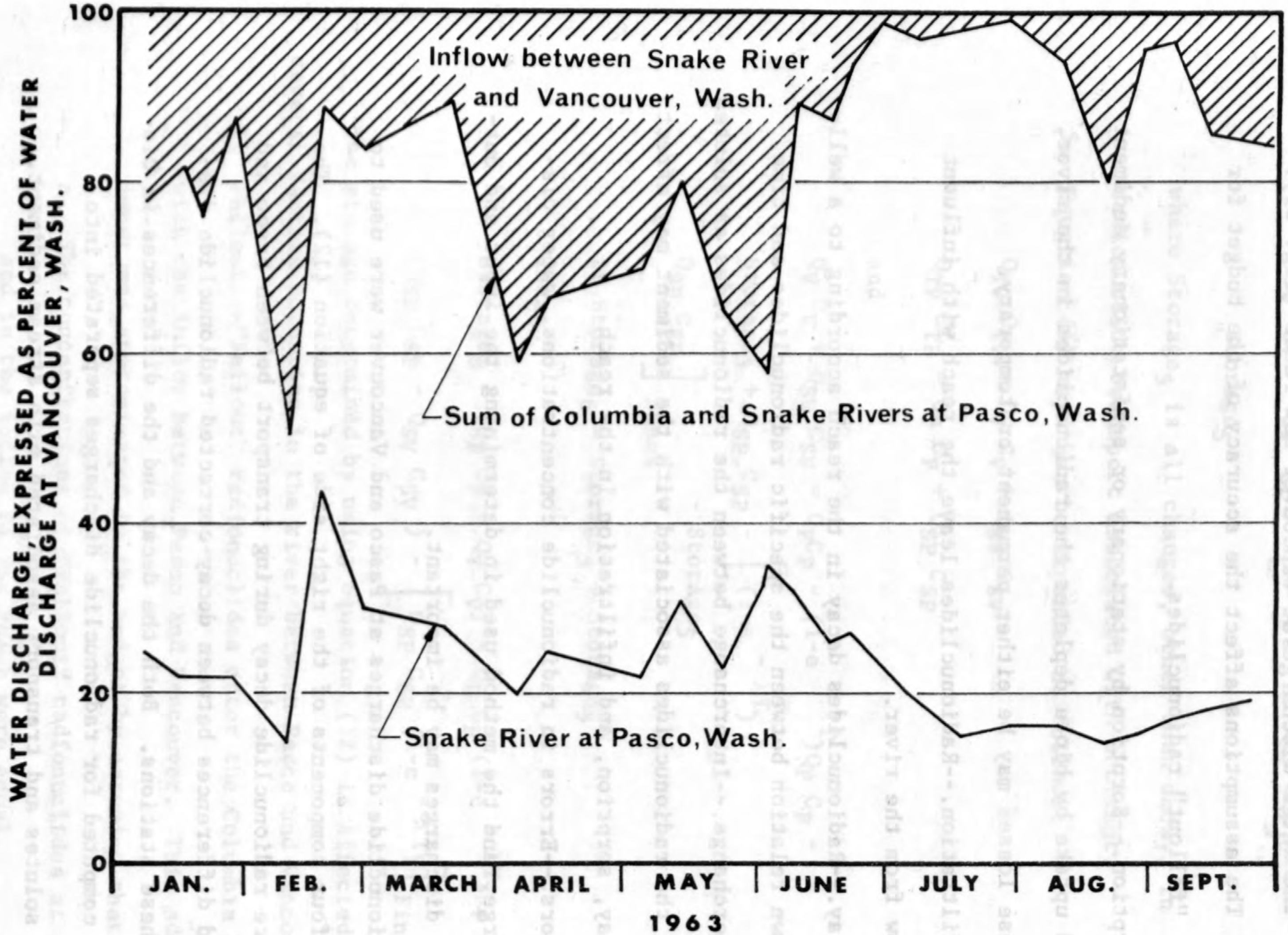



Figure 39.--The temporal variation of the proportionment of the water discharge of the Columbia River at Vancouver, Wash. among the: (1) Discharge of the Snake River at Pasco, Wash., (2) discharge of the Columbia River at Pasco, Wash., and (3) inflow between the Snake River and Vancouver, Wash.

gross storage ($Storage_6$). Cumulative values of the four components of equation (12) are shown for each of six radionuclides in figures 40-45. The magnitude of each of the components in relation to one another is easily ascertained from the data on the figures. The direction of the graphs of the cumulative data shows when gains (Pasco discharge less than Vancouver discharge) or losses (Pasco discharge greater than Vancouver discharge) were occurring in the reach between the two sites. The slopes of the graphs are the rates of gains or losses in the river reach between Pasco and Vancouver.

Losses and gains for chromium-51 (fig. 40) may well be of the same magnitude as the errors in the input and output discharges. The gains in the chromium-51 solute discharge may indicate some release from streambed sediment within the reach. The change from a gain to a loss in the reach coincides with these inflections for the other radionuclides. Probably, the approximation of the decay for chromium-51 during transport through the reach is of the correct magnitude.

Large quantities of zinc-65 that are solutes at Pasco are transferred to the sediment in the Pasco to Vancouver reach. The results of this interchange are shown in figure 41 by: (a) The gain in the discharge of zinc-65 associated with the sediments, (b) the loss in the solute transport, and (c) the substantial loss in the total zinc-65 discharge. The approximation of solute decay losses during transport is probably too large because of the interchange.

Practically, there is a continuous loss of scandium-46 during transport both as a solute and in association with the sediments

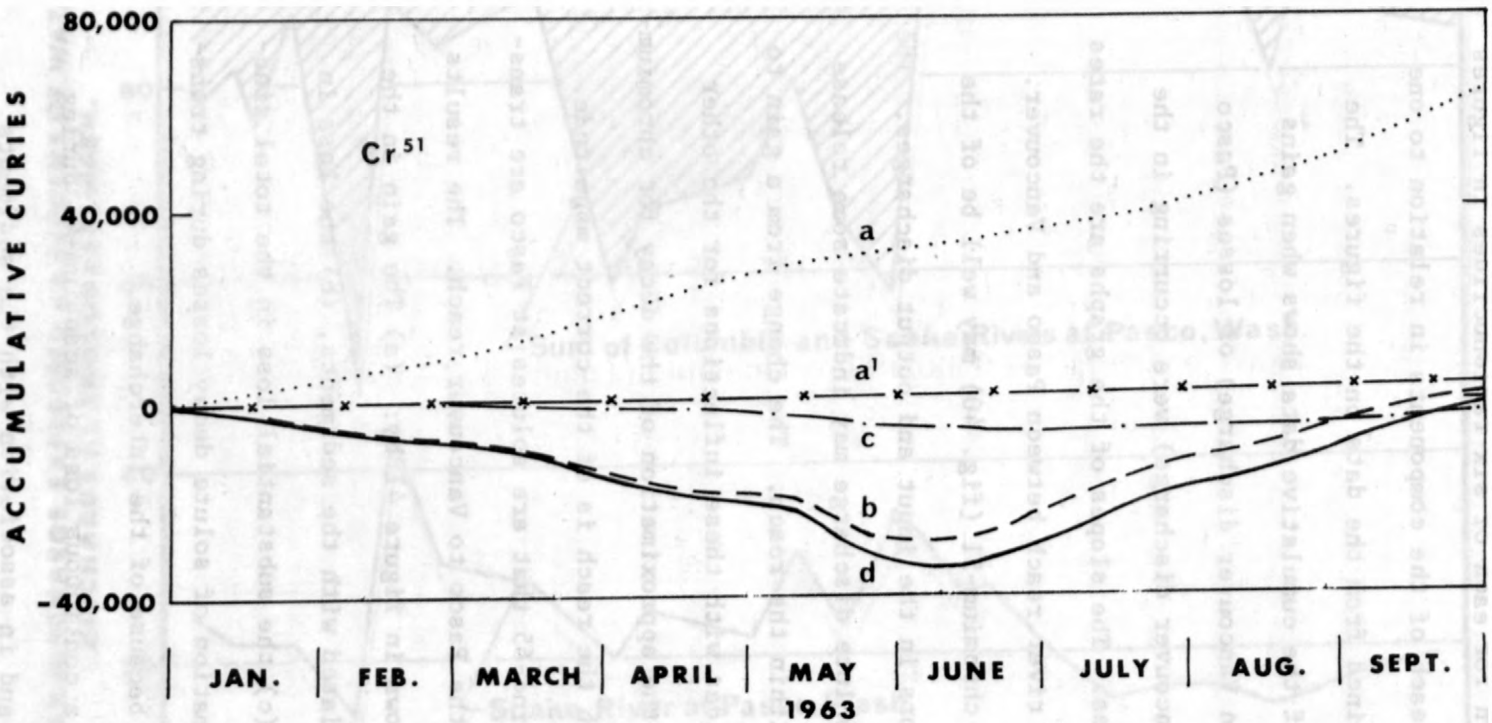



Figure 40.--The accumulative chromium-51 decay during transport as solute (a) and associated with transported sediment (a') in the Columbia River between Pasco and Vancouver, Wash., and the accumulative differences between the decay-corrected chromium-51 discharges at these stations; differences in solute discharges (b), the differences in discharges associated with transported sediment (c) and differences in the total discharge (d), d = b+c.

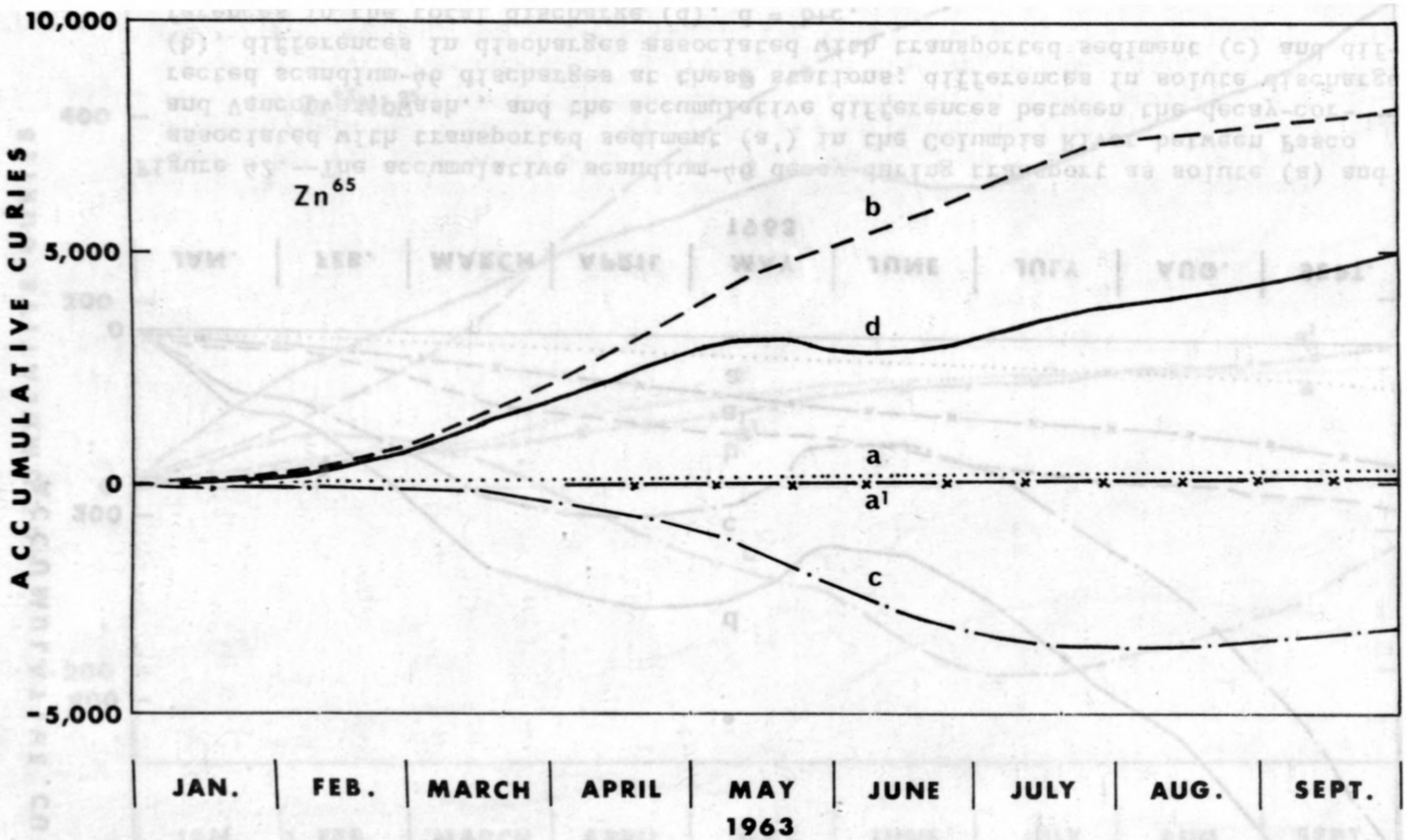



Figure 41.--The accumulative zinc-65 decay during transport as solute (a) and associated with transported sediment (a') in the Columbia River between Pasco and Vancouver, Wash., and the accumulative differences between the decay-corrected zince-65 discharges at these stations; differences in solute discharges (b), differences in discharges associated with transported sediment (c) and differences in the total discharge (d), d = b+c.

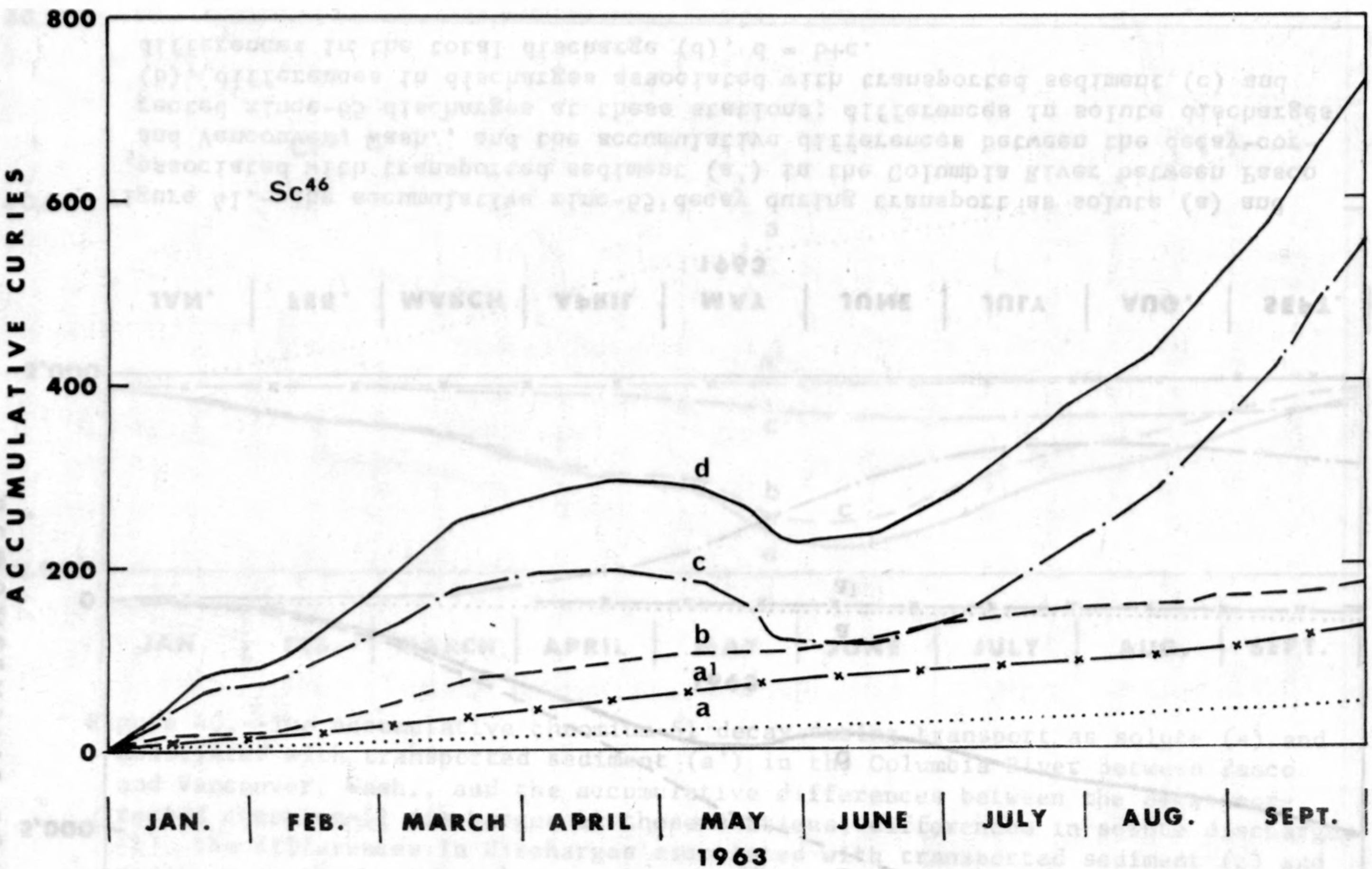



Figure 42.--The accumulative scandium-46 decay during transport as solute (a) and associated with transported sediment (a') in the Columbia River between Pasco and Vancouver, Wash., and the accumulative differences between the decay-corrected scandium-46 discharges at these stations; differences in solute discharges (b), differences in discharges associated with transported sediment (c) and differences in the total discharge (d), d = b+c.

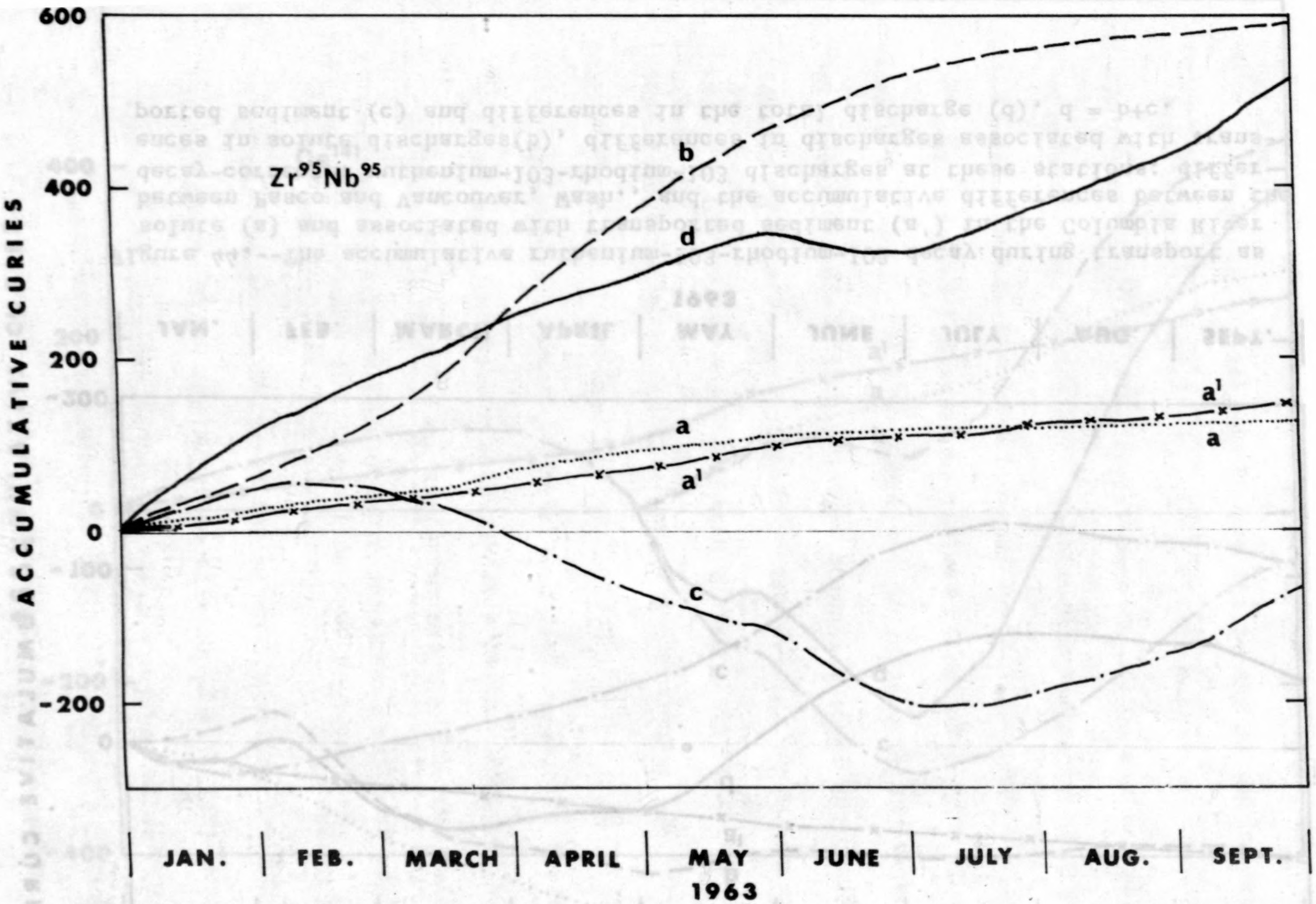



Figure 43.--The accumulative zirconium-95-niobium-95 decay during transport as solute (a) and associated with transported sediment (a') in the Columbia River between Pasco and Vancouver, Wash., and the accumulative differences between the decay-corrected zirconium-95-niobium-95 discharges at these stations; differences in solute discharges(b), differences in discharges associated with transported sediment (c) and differences in the total discharge (d), d = b+c.

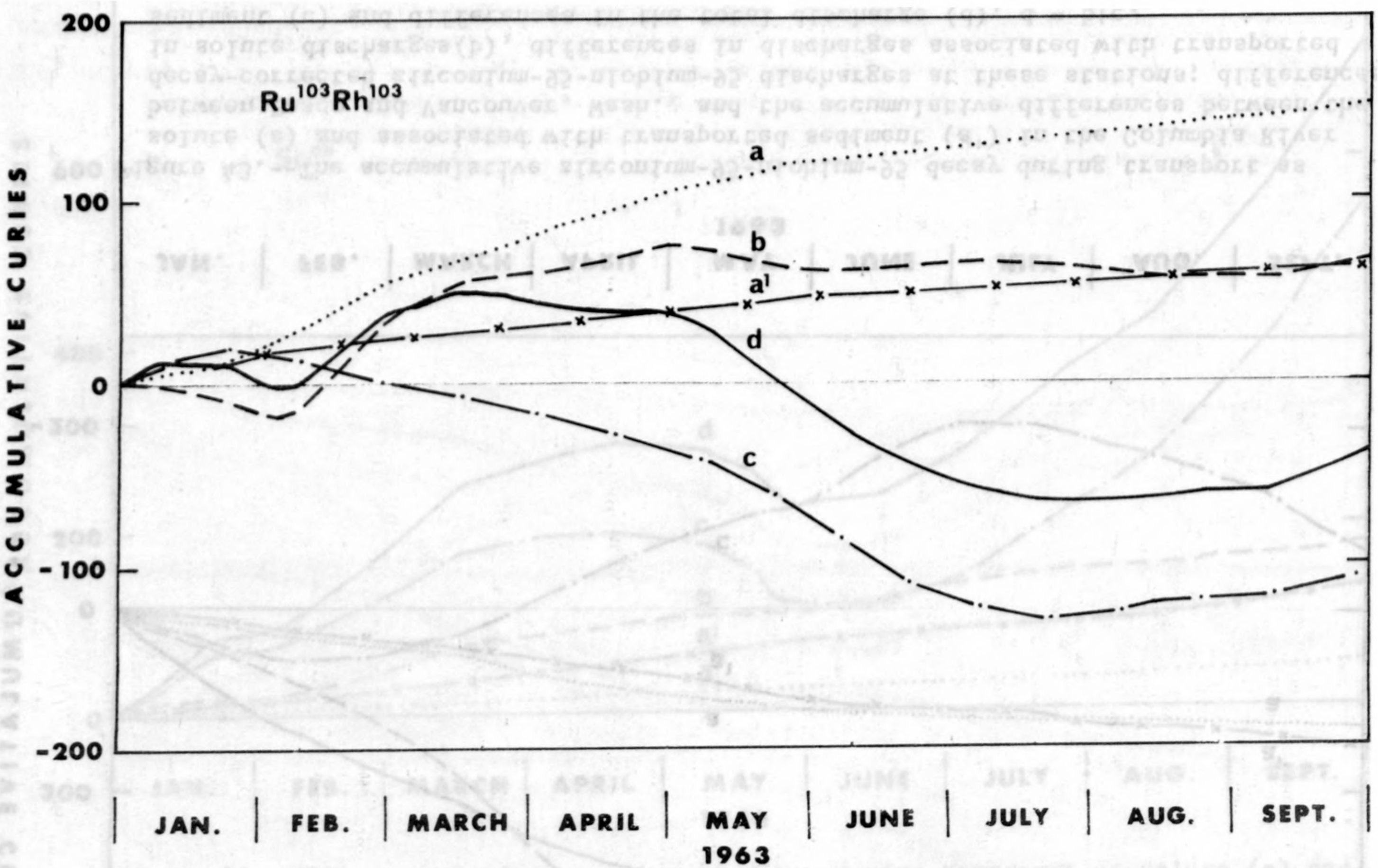



Figure 44.--The accumulative ruthenium-103-rhodium-103 decay during transport as solute (a) and associated with transported sediment (a') in the Columbia River between Pasco and Vancouver, Wash., and the accumulative differences between the decay-corrected ruthenium-103-rhodium-103 discharges at these stations; differences in solute discharges(b), differences in discharges associated with transported sediment (c) and differences in the total discharge (d), d = b+c.

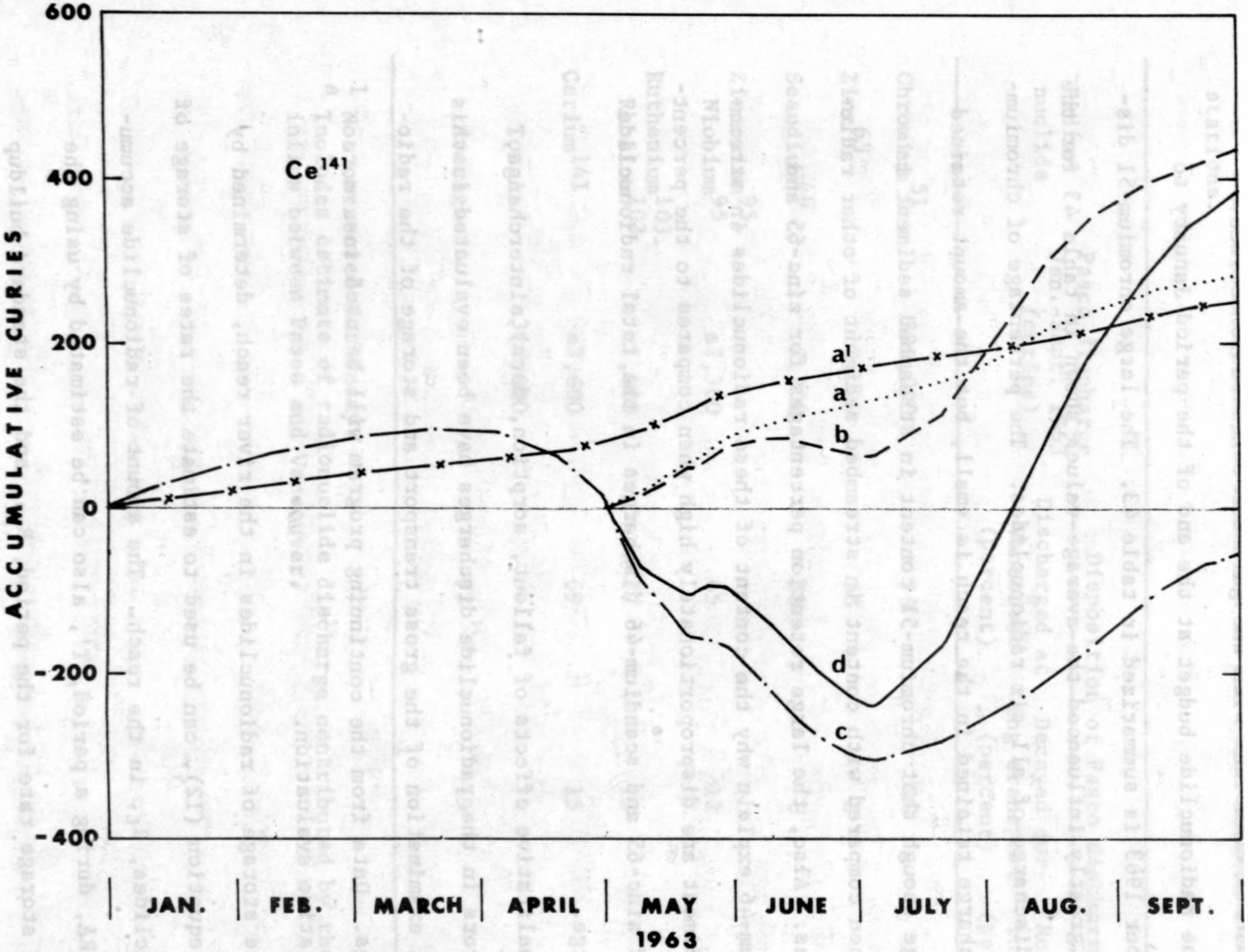



Figure 45.--The accumulative cerium-141 decay during transport as solute (a) and associated with transported sediment (a') in the Columbia River between Pasco and Vancouver, Wash., and the accumulative differences between the decay-corrected cerium-141 discharges at these stations; differences in solute discharges (b), differences in discharges associated with transported sediment (c) and differences in the total discharge (d), d = b+c.

(fig. 42), although the small gain in the transport associated with the sediment coincides with the gain for other radionuclides.

The radionuclide budget at the end of the period January to September 1963 is summarized in table 43. The large chromium-51 discharge greatly influenced the average values shown in table 43 for the total discharge of all six radionuclides. The percentage of chromium-51 discharge retained in the reach is small, but the amount retained is large enough that chromium-51 content in streambed sediment is high when compared with content in streambed sediment of other radionuclides. Also, the large retention percentages for zinc-65 and scandium-46 explain why the content of these radionuclides in streambed sediment are disproportionately high when compared to the percentages of zinc-65 and scandium-46 discharges in the total radionuclide discharge.

Qualitative effects of fallout, sorption, decay, interchange, and errors in the radionuclide discharges have been evaluated in this initial examination of the gross transport and storage of the radionuclides. Data from the continuing program will be used in a more quantitative evaluation.

The storage of radionuclides in the river reach, determined by use of equation (12), can be used to estimate the rates of storage of radionuclides, $R_t$, in the reach. The amount of radionuclide accumulated, RA, during a period, T', also can be estimated by using the average storage rate for the period, $R_{T'}$, and the standard buildup

Table 43.--The disposition of the radionuclide discharge of the Columbia River at Pasco, Wash. for January to September 1963 among the discharge at Vancouver, Wash., the decay during transport between Pasco and Vancouver, and the retention in the reach between the two stations.

| Radio-nuclide | Pasco discharge Jan.-Sept. 1963 (curies) | Disposition of Pasco discharge | | |
|---|---|---|---|---|
| | | Discharged at Vancouver (percent) | Decayed during transport (percent) | [1]Retained in reach (percent) |
| Chromium$^{51}$ | 337,000 | 79 | 19 | 2 |
| Zinc$^{65}$ | 13,000 | 58 | 2 | 40 |
| Scandium$^{46}$ | 2,200 | 55 | 8 | 37 |
| Zirconium$^{95}$-Niobium$^{95}$ | a2,300 | 65 | 12 | 23 |
| Ruthenium$^{103}$-Rhodium$^{103}$ | a1,400 | 87 | 13 | 0 |
| Cerium$^{141}$ | a3,600 | 69 | 15 | 16 |
| Total | a360,000 | - | - | - |
| Average | - | 77 | 19 | 4 |

[1] Not corrected for decay.
[a] Includes estimate of radionuclide discharge contributed by the inflow between Pasco and Vancouver.

equation (Friedlander and Kennedy, 1955):

$$RA = \frac{R_{T'}}{\lambda} (1-e^{-\lambda T'})$$

where $R_{T'}$, $\lambda$, and T' are consistent in units of time.

Data from the continuing program will be used to determine the variation of radionuclide storage rates with time and with changes in hydrologic and hydraulic conditions. This data may show that storage rates are either constant within seasons from year to year or variations in the rates are predictable within seasons from known changes in hydraulic and (or) hydrologic conditions. Then, average storage rates for given time increments can be used and the inventory, IR, of a radionuclide in the river reach can be estimated from:

$$IR = RA_1 (e^{-\lambda T_1}) + RA_2 (e^{-\lambda T_2}) + \text{----} RA_n (e^{-\lambda T_n})$$

where

$T_1$ is the time for an integer division of the year; that is, 1 week, biweekly, etc.

$RA_{1,2----n}$, is the amount of radionuclide accumulated during $T_{1,2----n}$.

The total time required in the above summation is determined by the half life of the radionuclide. Ten half lives may be more than enough time because radioactivity is reduced by a factor of 1/1024, $(1/2)^{10}$, during this time.

## SUMMARY OF RESULTS

Variations in textural characteristics and discharges of stream sediments were determined for the hydraulic and hydrologic conditions that existed during the report period, July 1962 to September 1963. Determinations of radionuclide transport and of mineralogy, exchange capacity, and carbon content of stream sediments were somewhat restricted because data were temporally and spatially limited. The radionuclide discharge was proportioned between transport as solute and transport associated with stream sediments. The gross total storage of radionuclides in the Columbia River between Pasco and Vancouver was estimated, and the dependency of radionuclide storage on various environmental factors was evaluated qualitatively. The radionuclide transport was related to sediment discharge, mineral and textural properties of the sediment, and the transport and movement of different sizes of sediment.

At the water-quality stations on the Columbia River, solute radionuclide concentrations and radionuclide concentrations of suspended sediments did not vary significantly with lateral location, and concentrations of solute radionuclides did not vary significantly with vertical location. However, at Hood River, the radionuclide concentrations in suspended sediment from 2 to 3 feet below the water surface were significantly lower than radionuclide concentrations in suspended sediment from 2 to 3 feet above the streambed; important differences in these concentrations were observed at Pasco. The differences in radionuclide concentrations in suspended sediment from different stream depths were maximum during October and November 1963. Radionuclide concentrations from duplicate samples of river water were statistically similar for radionuclides both as solutes and associated with filtered sediment.

Radionuclide concentration in surficial streambed sediment changes considerably with lateral location if particle-size distribution of sediment changes, but radionuclide concentration also changes with lateral location within sediment that is fairly uniform in particle size (all are sand size).

When average daily water discharges are less than about 120,000 cfs, large diurnal variations in water discharge from Priest Rapids Dam cause large diurnal variations in the radionuclide concentrations at the Pasco station. Consequently, the radionuclide discharges during low-water discharges at Pasco probably are consistently low because the time of sampling generally coincides with the time of low-radionuclide concentrations. Daily water discharges are less than 120,000 cfs for about 8 months each year.

Radionuclide concentrations in stream sediments decrease with downstream distance from Pasco and also during the annual flood of the Columbia River. The decrease in concentrations of radionuclides associated with suspended and streambed sediments during the annual flood was related to: changes in the particle size of the suspended sediment; dilution of radionuclide concentrations by the increased water discharge; and, qualitatively, changes in sediment transport and deposition. The unit-weight concentration of radionuclides associated with the suspended sediment decreased in the Columbia River during the large influx of fine sediment in February from the Snake

River, but the total amount of radionuclides associated with the sediment did not change. Radionuclide concentration of suspended sediment generally is related inversely to sediment concentration. Apparently, enough suspended sediment is always present in the river (even at low concentrations) to sorb all the readily available radionuclides; therefore, an increase in the amount of sediment transported by the river only dilutes the radionuclide content per unit weight of sediment.

Chromium-51 is the most abundant radionuclide in the Columbia River. About 95 percent of the 275,000 curies discharged at Vancouver during January to September 1963 was chromium-51. The composition (93 percent solute) of the chromium-51 discharge does not change during transport. Zinc-65, the next most abundant radionuclide, is approximately 70 percent solute at Pasco but is only about 20 percent solute at Vancouver. During transport, much zinc-65 is sorbed by stream sediment. "Fallout" radionuclides added to the Columbia River with the inflow between Pasco and Vancouver obscure changes in "fallout" discharge composition.

Radionuclide transport associated with stream sediments correlates with water discharge of the Columbia River; monthly discharges for all radionuclides were maximum during the months of the annual flood, May to July 1963. This type of radionuclide transport also correlates well with sediment discharge; however, it does not increase when fine-sediment discharge increases greatly during late fall, winter, and early spring.

The temporal distribution of solute radionuclide discharge varies for each radionuclide, but the data indicate that solute discharges for all radionuclides, except chromium-51, are highest during the late winter and early spring. Chromium-51 solute discharge attained maximum levels during July to September. The time difference between chromium-51 and other radionuclide maximums may be caused by a change in corrosion inhibition practice (chromium-51 is added with the inhibitor) or may be an occurrence that happened only during this report period.

Incorporation of radionuclide discharges into a gross budget of radionuclide transport at Pasco and at Vancouver indicates that decay during transport, "fallout" radionuclide input, accuracy of discharge determinations, and interchange between transport media affect the radionuclide transport between the two stations. Input from fallout greatly increases the transport of cerium-141, zirconium-95-niobium-95, and ruthenium-103-rhodium-103 between Pasco and Vancouver and, as expected, changes in "fallout" radionuclide transport roughly correlate with changes in tributary discharge. Differences in the chromium-51 discharges at Pasco and Vancouver are probably of the same magnitude as the errors in the chromium-51 discharges at these stations. Sorption of solute radionuclides by stream sediments greatly affects the transport and decay of zinc-65 and scandium-46. The decay of radionuclides transported as solutes was computed by using approximate flow times determined from radioactive-tracer studies. The time spent by sediment in transport through the reach depends on particle size and varies from the flow time of water to many years. Therefore, the decay of radionuclides associated with the transported sediment cannot be determined easily, but the decay was approximated by using estimated travel times that varied with particle size of the sediment. No determination was made of the quantity of radionuclides carried out of the river by water infiltrating the bed and banks, but the loss of radionuclides with the influent flow from the river probably is small.

The relative importance of each factor that affects radionuclide transport and the variation of radionuclide transport with time and with changes in hydraulic and hydrologic conditions need to be evaluated before radionuclide storage in the river reach can be estimated from the gross budget. However, the budget of radionuclide transport indicates that, during the period January to September 1963, 77 percent of the radionuclides discharged at Pasco was transported past Vancouver, 19 percent decayed during transport, and 4 percent (not corrected for decay) was retained in the river reach.

The relative and absolute variation of mineralogy, exchange capacity, and carbon content of sediments in the Columbia River between Pasco and Vancouver may be determined from the limited data, if the following assumptions are made: (a) Variations of mineralogy and exchange capacity with time are not significant, and (b) the sediments analyzed are representative of those comprising the sediment discharge. For sands, the available data indicate that these assumptions are valid. For silts and clays, only inconclusive results can be obtained from the available data, but the data generally suggest that time may not be a significant factor.

Sand-separate mineralogy indicates that sands from the Columbia River are chiefly quartz, feldspar, and volcanic rock fragments. Accessory minerals in the sands include hornblende, chlorite, pyroxene, and small amounts of chert, garnet, and zircon. The mineralogy of sand separates from the Snake River is similar to that of sand separates from the Columbia River, whereas sand separates from the Umatilla, John Day, Deschutes, Klickitat, Sandy, and Willamette Rivers are comprised of greater amounts of volcanic rock fragments and lesser amounts of quartz and feldspar than sand separates from the Columbia River. Clay minerals in sand separates occur principally as allogenic and authigenic coatings of montmorillonite and kaolinite.

From Pasco to Vancouver, the percentages of quartz and potash feldspar in the sand separates of sediments from the Columbia River decrease, whereas the percentages of volcanic rock fragments increase. Similar changes in relative abundance of these minerals occur in sand separates from sediments of tributaries between Pasco and Vancouver. Therefore, the changes in mineralogy of Columbia River sands probably are caused by sediment inflow from the tributaries. However, either selective transport of minerals through the three reservoirs between Pasco and Vancouver or an increase in particle size of the streambed sand, in part, may be reflected in the changes in sand-separate mineralogy.

A comparison of the transport of sand-separate minerals at Pasco with the transport of these minerals at Vancouver during the 1963 water year indicates that the increased sand discharge at Vancouver more than offsets the decrease in relative abundance of some constituents between the two stations. Because the tributaries between Pasco and Vancouver contribute very little quartz, the greater quartz discharge at Vancouver suggests that quartz (and probably other minerals) was degraded from the Columbia River streambed during the report period.

Silt separates from sediments in the Columbia River and its tributaries contain 70 to 100 percent quartz, feldspar, and "mica" (includes all 10-A clay minerals) in roughly that order of relative abundance. The abundant clay minerals found in silt separates are chlorite, montmorillonite, and kaolinite in that general order. Homogeneity in silt-separate mineralogy along the study reach of the Columbia River and in all the tributaries suggests that the silt load is derived from a nearly homogeneous source that occurs throughout the Columbia River basin.

Clay separates from sediments in the Columbia River and its tributaries average 40 percent quartz and feldspar and range from 10 to 100 percent of these minerals. The most abundant clay minerals are "mica" (includes all 10-A clay minerals), montmorillonite, and combinations of various montmorillonite or "mica" mixed-layer minerals. Kaolinite and halloysite are fairly widespread clay minerals that may be found more commonly in samples from the Vancouver end of the study reach than in those from the Pasco end. However, there are apparently no highly significant changes in clay mineralogy between Pasco and Vancouver.

Exchange capacities for size separates from sediments of the Columbia River and its tributaries average, in milliequivalents per 100 grams, 5.5 for sand, 22 for silt, and 60 for clay. In general, these exchange capacities are near or slightly higher than exchange capacities for texturally similar representative soils or for size separates from many other streams. Exchange capacities of sand separates are related to the percentages of fine- to medium-grained volcanic rock fragments, many of which show allogenic or authigenic clay coatings. Exchange capacities of silt and clay separates are related inversely to the percentages of quartz and feldspar and directly to the percentages of high exchange capacity 2:1-type clay minerals.

Although no highly significant changes are apparent in exchange capacities of size separates of sediments from the Columbia River and its tributaries, the data suggest that silt- and clay-separate exchange capacities decrease, whereas sand-separate exchange capacities remain unchanged or increase slightly between Pasco and Vancouver.

If exchange capacities of the size separates are weighted by the percentages of sand, silt, and clay in the total sediment discharge for the 1963 water year at each station, the exchange capacity of the sediment discharge decreased from Pasco to Vancouver because the percentage of clay in the sediment discharge decreased and the percentage of sand increased. Notwithstanding the decrease in exchange capacity of the sediment discharge, the milliequivalents of ions that could be transported by the sediment increased because the sediment discharge increased substantially. In addition, the silt part of the discharge actually could transport nearly as much of the ion load as the clay part because much more silt is transported.

Carbon that is mainly organic is less than 2 percent by weight of the sediments from the Columbia River and its tributaries. Computed percentages of organic material (organic carbon times 1.7) average about 3 percent by weight in fine sediments and 0.3 percent by weight in coarse sediments. Suspended sediments generally contain more organic carbon than do streambed sediments.

Sand-separate mineralogy establishes that volcanic rock fragments are important constituents that become relatively more abundant with distance downstream from Pasco. Exchange-capacity data indicate that the percentage of volcanic rock fragments directly relates to the exchange capacity of the sand separate. Therefore, the sand separate at Vancouver has greater potential for sorption of radioactive ions than the sand separate at Pasco. Because more sand is transported past Vancouver than past Pasco, the sand separate should be relatively more important as a potential radionuclide-transport medium at Vancouver.

Mineralogic analyses of silt and clay separates indicate that quartz, feldspar, montmorillonite and mixed-layer montmorillonite minerals, "mica" (including illite), chlorite, and small amounts of 1:1-type clays are the dominant constituents. Silt and clay have relatively high exchange capacities and potentially could sorb large amounts of certain radioactive ions. Although clay has greater sorption capacity, silt is almost as important as clay in the transport of ions because silt is the dominant transported sediment. Together, clay and silt transport 90 to 95 percent of the ion load carried by sediments.

Small amounts of organic matter in sediments from the Columbia River and its tributaries may be important because organic matter has a very high exchange capacity and may selectively sorb certain ions.

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APPENDIX

Definitions

Coarse sediment, or coarse-grain sediment.--Sediment that is larger than 0.062 mm (millimeter) in diameter.

Dunes.--Irregularly spaced low mounds of loose sand on the streambed. Dunes travel slowly downstream as the result of sand being moved along their comparatively gentle upstream slopes and being deposited on their steeper downstream slopes.

Fall diameter.--The diameter of a sphere that has a specific gravity of 2.65 and has the same standard fall velocity as a sediment particle.

Fine sediment, or fine-grain sediment. Sediment that is smaller than 0.062 mm in diameter.

Median diameter.--The fall diameter for which 50 percent, by weight, of the sediment particles is finer.

Particle-size classification of sediment:

Clay.--Particles less than 0.004 mm in diameter for particle-size analysis and less than 0.002 mm for mineralogy and exchange-capacity analyses.

Silt.--Particles ranging from 0.004 to 0.062 mm in diameter for particle-size analysis and from 0.002 to 0.062 mm for mineralogy and exchange-capacity analyses.

Sand.--Particles ranging from 0.062 to 2.0 mm in diameter for particle-size analysis and from 0.062 to 1.0 mm for mineralogy and exchange-capacity analyses.

Gravel.--Particles ranging from 2.0 to 64.0 mm in diameter.

Sediment.--Inorganic or organic particles that originate from weathering, chemical precipitation, or biological activity; the particles are transported, suspended, or deposited by water, air, ice, gravity, organisms, or combinations thereof.

Sediment concentration.--The ratio of the dry weight of sediment to the total weight of the fluid-sediment mixture, expressed in parts per million.

Standard fall velocity.--The average rate of fall that a sediment particle would finally attain if falling alone in quiescent distilled water of infinite extent and at a temperature of 24°C.

Streambed sediment, or bed material.--Sediment of which the streambed is composed.

Suspended-sediment discharge.--Rate of sediment movement determined directly from streamflow and the sediment concentration of depth-integrated samples which are obtained by sampling the flow from the water surface to within 0.3 foot of the streambed.

Total-sediment discharge.--Weight of sediment that moves through a cross section perpendicular to the direction of flow in a unit time.

## Tables of Basic Data and Computed Parameters

Table 1.--Particle-size analyses of streambed sediment.

[Methods of analysis: P, pipette; S, sieve; W, in distilled water; C, chemically dispersed; V, visual accumulation tube]

| Date of collection | Number of sampling stations | Water discharge (1,000 cfs) | Percent finer than indicated particle size (millimeters) | | | | | | | | | | | | | | | | | | Methods of analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.088 | 0.125 | 0.175 | 0.250 | 0.350 | 0.500 | 1.000 | 1.300 | 2.000 | 3.100 | 16.0[a] | 32.0[a] | |
| COLUMBIA RIVER AT PASCO, WASH.--SOUTH BANK TO STATION 1190 | | | | | | | | | | | | | | | | | | | | | |
| Oct. 11, 1962 | 5 | 62.1 | 1 | 1 | 4 | 9 | 14 | 25 | 38 | 51 | 62 | 73 | 86 | 90 | 95 | 97 | 100 | - | - | - | SVPWC |
| Jan. 30, 1963 | 23 | 77.7 | 1 | 2 | 4 | 6 | 10 | 19 | 30 | 42 | 55 | 64 | 71 | 76 | 89 | 92 | 100 | - | - | - | SVPWC |
| Mar. 21 | 22 | 64.4 | 2 | 2 | 5 | 8 | 13 | 30 | 42 | 54 | 63 | 73 | 79 | 82 | 91 | 92 | 100 | - | - | - | SVPWC |
| June 14 | 22 | 286 | - | - | - | - | - | 1 | 2 | 5 | 12 | 28 | 43 | 51 | 64 | 66 | 100 | - | - | - | SV |
| Sept. 3 | 21 | 66.6 | 2 | 2 | 3 | 5 | 7 | 8 | 13 | 22 | 36 | 53 | 70 | 78 | 86 | 92 | 100 | - | - | - | SVPWC |
| COLUMBIA RIVER AT PASCO, WASH.--STATION 1190 TO 2040 | | | | | | | | | | | | | | | | | | | | | |
| Aug. 7, 1962 | 8 | 164 | - | - | - | - | - | - | - | - | - | 3 | 79 | 98 | 100 | - | - | - | - | - | V |
| Oct. 11 | 4 | 62.1 | - | - | - | - | - | 1 | 1 | 1 | 2 | 6 | 68 | 96 | 100 | - | - | - | - | - | V |
| Jan. 30, 1963 | 14 | 77.7 | - | - | - | - | - | - | - | - | - | 3 | 79 | 98 | 100 | - | - | - | - | - | V |
| Mar. 21 | 15 | 64.4 | - | - | - | - | - | 1 | 2 | 3 | 4 | 8 | 72 | 98 | 100 | - | - | - | - | - | VPWC |
| June 14 | 13 | 286 | - | - | - | - | - | - | - | - | - | 6 | 63 | 98 | 100 | - | - | - | - | - | V |
| Sept. 3 | 17 | 66.6 | - | - | - | - | - | - | - | - | - | 2 | 76 | 99 | 100 | - | - | - | - | - | V |
| COLUMBIA RIVER AT PASCO, WASH.--STATION 2040 TO NORTH BANK | | | | | | | | | | | | | | | | | | | | | |
| Jan. 30, 1963 | 8 | 77.7 | - | - | - | - | - | 1 | 3 | 6 | 11 | 24 | 40 | 49 | 60 | 63 | 100 | - | - | - | SV |
| Mar. 21 | 9 | 64.4 | - | 1 | 1 | 2 | 3 | 7 | 12 | 19 | 24 | 37 | 63 | 71 | 82 | 86 | 100 | - | - | - | SVPWC |
| June 14 | 10 | 286 | 1 | 1 | 1 | 2 | 3 | 6 | 9 | 21 | 32 | 47 | 60 | 65 | 75 | 77 | 100 | - | - | - | SVPWC |
| Sept. 3 | 7 | 66.6 | 1 | 1 | 2 | 3 | 5 | 9 | 12 | 24 | 38 | 59 | 72 | 77 | 86 | 88 | 100 | - | - | - | SVPWC |
| SNAKE RIVER AT PASCO, WASH.--NORTH BANK TO STATION 325 | | | | | | | | | | | | | | | | | | | | | |
| Aug. 10, 1962 | 4 | 19.0 | 3 | 4 | 10 | 22 | 42 | 60 | 69 | 78 | 86 | 94 | 97 | 97 | 98 | 99 | 100 | - | - | - | SVPWC |
| Oct. 26 | 2 | 33.0 | 6 | 10 | 14 | 38 | 58 | 82 | 87 | 94 | 96 | 97 | 98 | 98 | 98 | 98 | 100 | - | - | - | SVPWC |
| Jan. 24, 1963 | 2 | 35.7 | 3 | 4 | 6 | 16 | 34 | 71 | 83 | 90 | 92 | 94 | 96 | 98 | 98 | 98 | 100 | - | - | - | SVPWC |
| Apr. 4 | 2 | 41.0 | 4 | 5 | 10 | 17 | 30 | 47 | 62 | 85 | 92 | 95 | 96 | 96 | 98 | 98 | 100 | - | - | - | SVPWC |
| May 27 | 3 | 142 | 1 | 1 | 1 | 2 | 2 | 5 | 6 | 41 | 60 | 74 | 90 | 93 | 95 | 96 | 100 | - | - | - | SVPWC |
| Aug. 15 | 3 | 21.9 | 2 | 4 | 6 | 10 | 19 | 30 | 39 | 47 | 52 | 56 | 69 | 81 | 91 | 93 | 100 | - | - | - | SVPWC |
| SNAKE RIVER AT PASCO, WASH.--STATION 325 TO SOUTH BANK | | | | | | | | | | | | | | | | | | | | | |
| Aug. 10, 1962 | 20 | 19.0 | - | - | - | 1 | 2 | 4 | 5 | 7 | 11 | 46 | 91 | 91 | 99 | 100 | - | - | - | - | SVPWC |
| Oct. 26 | 15 | 33.0 | - | - | - | 1 | 2 | 5 | 6 | 8 | 13 | 50 | 91 | 98 | 98 | 99 | 100 | - | - | - | SVPWC |
| Jan. 24, 1963 | 28 | 35.7 | - | - | - | 1 | 1 | 2 | 3 | 3 | 4 | 36 | 83 | 100 | - | - | - | - | - | - | VPWC |
| Apr. 4 | 28 | 41.0 | - | - | - | - | 1 | 2 | 2 | 2 | 4 | 36 | 88 | 99 | 100 | - | - | - | - | - | VPWC |
| May 27 | 26 | 142 | - | - | - | - | - | 1 | 1 | 1 | 2 | 27 | 75 | 93 | 96 | 98 | 100 | - | - | - | SVPWC |
| Aug. 15 | 26 | 21.9 | 2 | 4 | 5 | 9 | 11 | 16 | 16 | 17 | 20 | 40 | 89 | 97 | 98 | 98 | 100 | - | - | - | SVPWC |
| COLUMBIA RIVER AT HOOD RIVER, OREG.--WASHINGTON BANK TO STATION 600 | | | | | | | | | | | | | | | | | | | | | |
| July 10, 1962 | 2 | 269 | - | 1 | 1 | 2 | 2 | 6 | 24 | 58 | 82 | 94 | 99 | 100 | - | - | - | - | - | - | VPWC |
| Sept. 11 | 2 | 104 | 2 | 3 | 4 | 6 | 8 | 13 | 19 | 58 | 87 | 97 | 99 | 100 | - | - | - | - | - | - | VPWC |
| Jan. 8, 1963 | 3 | 127 | 1 | 1 | 2 | 3 | 5 | 10 | 17 | 56 | 84 | 96 | 100 | - | - | - | - | - | - | - | VPWC |
| June 4 | 3 | 365 | 1 | 2 | 2 | 2 | 3 | 5 | 10 | 44 | 82 | 94 | 98 | 98 | 99 | 100 | - | - | - | - | SVPWC |

## Table 1.--Particle-size analyses of streambed sediment--Continued.

| Date of collection | Number of sampling stations | Water discharge (1,000 cfs) | Percent finer than indicated particle size (millimeters) 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.088 | 0.125 | 0.175 | 0.250 | 0.350 | 0.500 | 1.000 | 1.300 | 2.000 | 3.100 | 16.0[a] | 32.0[a] | Methods of analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COLUMBIA RIVER AT HOOD RIVER, OREG.--STATION 600 TO STATION 1300 | | | | | | | | | | | | | | | | | | | | | |
| July 10, 1962 | 6 | 269 | 1 | 4 | 6 | 12 | 22 | 43 | 58 | 80 | 98 | 99 | 99 | 100 | - | - | - | - | - | - | VPWC |
| Sept. 11 | 4 | 104 | 1 | 2 | 3 | 5 | 10 | 21 | 32 | 51 | 72 | 97 | 100 | - | - | - | - | - | - | - | VPWC |
| Apr. 4, 1963 | 7 | 144 | 2 | 4 | 5 | 8 | 13 | 26 | 36 | 56 | 82 | 96 | 97 | 98 | 100 | - | - | - | - | - | VPWC |
| June 4 | 6 | 365 | 4 | 6 | 9 | 15 | 28 | 54 | 64 | 83 | 95 | 98 | 99 | 99 | 100 | - | - | - | - | - | VPWC |
| COLUMBIA RIVER AT HOOD RIVER, OREG.--STATION 1300 TO OREGON BANK | | | | | | | | | | | | | | | | | | | | | |
| July 10, 1962 | 22 | 269 | - | - | - | - | - | - | - | - | 7 | 42 | 81 | 92 | 99 | 100 | - | - | - | - | SV |
| July 31 | 8 | 192 | - | - | - | - | - | - | - | - | 8 | 49 | 86 | 96 | 100 | - | - | - | - | - | V |
| Sept. 11 | 15 | 104 | - | - | - | - | - | 1 | 1 | 1 | 4 | 32 | 77 | 89 | 98 | 100 | - | - | - | - | SVPWC |
| Oct. 15 | 8 | 134 | - | - | - | - | - | 1 | 1 | 1 | 7 | 51 | 88 | 95 | 99 | 100 | - | - | - | - | SVPWC |
| Jan. 8, 1963 | 19 | 127 | - | - | - | - | 1 | 2 | 2 | 2 | 8 | 44 | 81 | 92 | 100 | - | - | - | - | - | VPWC |
| Apr. 4 | 20 | 144 | - | 1 | 1 | 2 | 4 | 6 | 6 | 6 | 14 | 46 | 82 | 93 | 100 | - | - | - | - | - | VPWC |
| June 4 | 20 | 365 | - | - | - | - | - | - | - | - | 6 | 47 | 84 | 93 | 99 | 100 | - | - | - | - | SV |
| COLUMBIA RIVER AT VANCOUVER, WASH.--MAIN CHANNEL | | | | | | | | | | | | | | | | | | | | | |
| July 5, 1962 | 23 | 323 | - | - | - | - | - | - | - | - | 1 | 13 | 36 | 55 | 87 | 92 | 97 | 99 | 100 | - | SV |
| Sept. 7 | 27 | 124 | - | - | - | - | - | - | - | 2 | 5 | 19 | 41 | 60 | 88 | 91 | 95 | 97 | 100 | - | SV |
| Dec. 26 | 21 | 163 | - | - | - | - | - | - | 1 | 1 | 3 | 23 | 46 | 61 | 86 | 90 | 96 | 98 | 100 | - | SV |
| Apr. 3, 1963 | 19 | 160 | - | - | - | - | - | - | - | 2 | 6 | 24 | 46 | 63 | 84 | 89 | 94 | 98 | 100 | - | SV |
| June 11 | 20 | 397 | - | - | - | - | - | - | - | - | 3 | 17 | 42 | 59 | 91 | 94 | 98 | 99 | 100 | - | SV |
| COLUMBIA RIVER AT VANCOUVER, WASH.--OREGON SLOUGH | | | | | | | | | | | | | | | | | | | | | |
| July 5, 1962 | 6 | 323 | - | 1 | 2 | 3 | 6 | 11 | 16 | 21 | 32 | 57 | 76 | 88 | 98 | 99 | 100 | - | - | - | SVPWC |
| Dec. 26 | 19 | 163 | 1 | 1 | 2 | 3 | 5 | 12 | 14 | 20 | 34 | 58 | 81 | 91 | 97 | 99 | 100 | - | - | - | SVPWC |
| Apr. 3, 1963 | 21 | 160 | 1 | 2 | 3 | 4 | 6 | 11 | 15 | 24 | 41 | 62 | 82 | 92 | 98 | 99 | 100 | - | - | - | SVPWC |
| June 11 | 22 | 397 | 1 | 2 | 2 | 4 | 6 | 12 | 14 | 20 | 33 | 55 | 79 | 90 | 98 | 100 | - | - | - | - | SVPWC |
| WILLAMETTE RIVER AT PORTLAND, OREG. | | | | | | | | | | | | | | | | | | | | | |
| July 6, 1962 | 22 | 10.6 | - | - | - | 1 | 1 | 1 | 2 | 4 | 8 | 16 | 31 | 46 | 63 | 69 | 77 | 87 | 95 | 100 | SVPWC |
| Dec. 20 | 20 | 44.7 | 1 | 1 | 1 | 2 | 2 | 3 | 4 | 6 | 11 | 19 | 31 | 46 | 60 | 64 | 74 | 83 | 94 | 100 | SVPWC |
| Mar. 27, 1963 | 20 | 25.4 | - | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 8 | 20 | 36 | 48 | 66 | 70 | 80 | 90 | 97 | 100 | SVPWC |

[a]Sieve diameter; relationship of sieve diameter to fall diameter is unavailable.

## Table 2.--Particle-size analyses of suspended sediment, depth-integrated samples.

[Methods of analysis: B, bottom-withdrawal tube; P, pipet; W, in distilled water; C, chemically dispersed; V, visual accumulation tube]

| Date of collection | Time | Water discharge (1,000 cfs) | Water temperature (°F) | Sediment concentration (ppm) | Percent finer than indicated particle size, in millimeters | | | | | | | | | | | Methods of analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.125 | 0.250 | 0.350 | 0.500 | 1.000 | |
| **COLUMBIA RIVER AT PASCO, WASH.** | | | | | | | | | | | | | | | | |
| May 31, 1963 | 1220 | 236 | 57 | 18 | - | - | - | - | - | 71 | 85 | 98 | 99 | 100 | | V |
| June 17 | 1200 | 306 | 61 | 15 | 20 | 22 | 29 | 38 | 45 | 52 | 60 | 96 | 100 | - | | VBWC |
| June 3, 1964 | 1045 | 304 | 56 | 32 | - | - | - | - | - | 42 | 48 | 62 | 94 | 100 | | V |
| June 12 | 1130 | 379 | 56 | 37 | 14 | 21 | 30 | 44 | 51 | 56 | 68 | 88 | 99 | 100 | | VBWC |
| June 22 | 1100 | 422 | 58 | 26 | - | - | - | - | - | 63 | 70 | 94 | 100 | - | | V |
| June 23 | 1015 | 425 | 58 | 25 | 17 | 21 | 30 | 38 | 48 | 52 | 64 | 88 | 99 | 100 | | VBWC |
| **SNAKE RIVER AT PASCO, WASH.** | | | | | | | | | | | | | | | | |
| Dec. 13, 1962 | 1455 | 103 | 43 | 154 | 15 | 20 | 23 | 30 | 39 | 69 | 89 | 100 | - | - | | VBWC |
| Feb. 7, 1963 | 1530 | 98.4 | 41 | 2,670 | 47 | 70 | 93 | 100 | - | - | - | - | - | - | | PWC |
| May 24 | 1240 | 144 | 57 | 47 | 28 | 28 | 42 | 63 | 63 | 63 | 74 | 98 | 100 | - | | VPWC |
| May 27 | 1540 | 145 | 56 | 40 | 35 | 48 | 62 | 75 | 80 | 83 | 88 | 97 | 100 | - | | VBWC |
| May 18, 1964 | 1320 | 151 | 55 | 52 | - | - | - | - | - | 69 | 77 | 95 | 99 | 100 | | V |
| May 22 | 1140 | 200 | 52 | 105 | 17 | 25 | 38 | 53 | 62 | 66 | 74 | 91 | 100 | - | | VPWC |
| June 5 | 1120 | 173 | 54 | 48 | 22 | 29 | 44 | 58 | 68 | 71 | 75 | 96 | 100 | - | | VBWC |
| June 9 | 1510 | 256 | 52 | 177 | 11 | 16 | 23 | 36 | 45 | 57 | 66 | 83 | 98 | 100 | | VPWC |
| June 30 | 0810 | 121 | 61 | 136 | 44 | 61 | 81 | 93 | 93 | 96 | 96 | 98 | 100 | - | | VPWC |
| **COLUMBIA RIVER AT HOOD RIVER, OREG.** | | | | | | | | | | | | | | | | |
| Feb. 6, 1963 | 1300 | 207 | 38 | 286 | 38 | 60 | 82 | 97 | 100 | - | - | - | - | - | | PWC |
| Feb. 12 | 1140 | 147 | 40 | 461 | 76 | 87 | 98 | 100 | - | - | - | - | - | - | | BWC |
| Feb. 13 | 1230 | 166 | 40 | 729 | 65 | 87 | 100 | - | - | - | - | - | - | - | | PWC |
| Feb. 15 | 1035 | 162 | 30 | 275 | 78 | 90 | 98 | 100 | - | - | - | - | - | - | | BWC |

Table 2.--Particle-size analyses of suspended sediment, depth-integrated samples--Continued.

| Date of collection | Time | Water discharge (1,000 cfs) | Water temperature (°F) | Sediment concentration (ppm) | Percent finer than indicated particle size, in millimeters 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.125 | 0.250 | 0.350 | 0.500 | 1.000 | Methods of analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COLUMBIA RIVER AT VANCOUVER, WASH.--MAIN CHANNEL | | | | | | | | | | | | | | | | |
| Nov. 21, 1962 | 1145 | 192 | 52 | 72 | - | 46 | 54 | 67 | 79 | 98 | 100 | - | - | - | | VBWC |
| Feb. 8, 1963 | 0920 | 218 | 40 | 240 | 47 | 60 | 75 | 91 | 96 | 98 | - | - | - | - | | BWC |
| Feb. 14 | 1015 | 138 | 39 | 355 | 66 | 88 | 97 | 100 | - | - | - | - | - | - | | PWC |
| Feb. 15 | 0940 | 152 | 40 | 561 | 77 | 95 | 97 | 100 | - | - | - | - | - | - | | BWC |
| May 12-18, 1964 | (a) | b261 | - | 44 | - | - | - | - | - | 84 | 88 | 98 | 100 | - | | V |
| May 19-25 | (a) | b368 | - | 108 | - | - | - | - | - | 68 | 72 | 95 | 98 | 100 | | V |
| May 26-June 1 | (a) | b365 | - | 90 | - | - | - | - | - | 70 | 72 | 90 | 98 | 100 | | V |
| June 2-8 | (a) | b439 | - | 110 | - | - | - | - | - | 58 | 66 | 89 | 98 | 100 | | V |
| June 9-15 | (a) | b513 | - | 174 | - | - | - | - | - | 71 | 74 | 86 | 96 | 98 | 100 | V |
| June 16-19 | (a) | b553 | - | 132 | - | - | - | - | - | 61 | 72 | 96 | 98 | 100 | | V |
| June 23-29 | (a) | b537 | - | 119 | - | - | - | - | - | 44 | 58 | 90 | 99 | 100 | | V |
| June 30-July 7 | (a) | b447 | - | 82 | - | - | - | - | - | 60 | 63 | 90 | 98 | 100 | | V |
| July 8-20 | (a) | b371 | - | 46 | - | - | - | - | - | 81 | 82 | 95 | 100 | - | | V |
| COLUMBIA RIVER AT VANCOUVER, WASH.--OREGON SLOUGH | | | | | | | | | | | | | | | | |
| Feb. 14, 1963 | 1140 | 20.2 | 39 | 300 | 67 | 81 | 84 | 86 | 88 | 88 | 89 | 94 | 100 | - | | VBWC |
| WILLAMETTE RIVER AT PORTLAND, OREG. | | | | | | | | | | | | | | | | |
| Nov. 23, 1962 | 1315 | 82.0 | 47 | 85 | - | 55 | 60 | 82 | 88 | 98 | 100 | - | - | - | | VBWC |
| Feb. 5, 1963 | 0950 | 141 | 47 | 126 | 45 | 53 | 61 | 73 | 81 | 90 | 97 | 100 | - | - | | VBWC |
| Apr. 1 | 1345 | 127 | 47 | 91 | 63 | 63 | 75 | 86 | 98 | 98 | 99 | 100 | - | - | | VPWC |
| Jan. 9, 1964 | 1055 | 80.0 | 43 | 76 | 81 | 81 | 81 | 91 | 91 | 95 | 100 | - | - | - | | VPWC |
| Jan. 21 | 0945 | 158 | 44 | 156 | 52 | 57 | 57 | 72 | 82 | 84 | 93 | 100 | - | - | | VPWC |
| Jan. 27 | 1000 | 182 | 42 | 125 | 41 | 48 | 60 | 68 | 76 | 81 | 88 | 99 | 100 | - | | VBWC |
| Jan. 29 | 1030 | 148 | 46 | 60 | 49 | 67 | 80 | 80 | 80 | 87 | 93 | 99 | 100 | - | | VPWC |
| Jan. 31 | 1140 | 117 | 46 | 45 | 50 | 58 | 68 | 80 | 88 | 93 | - | - | - | - | | BWC |

a Composite of daily samples taken at one vertical.
b Average water discharge during composite period.

# Table 3.--Particle-size analyses of suspended sediment, point-integrated samples.

[Methods of analysis: B, bottom-withdrawal tube; S, sieve; W, in distilled water; C, chemically dispersed; V, visual accumulation tube]

| Date of collection | Time (24 hr) | Water Discharge (1,000 cfs) | Water temperature (°F) | Sampling Station | Total Depth (ft.) | Sampling point: Velocity (fps) | Sampling point: Depth (ft) | Sampling point: Concentration (ppm) | Percent finer than indicated particle size, in millimeters: 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.125 | 0.250 | 0.350 | 0.500 | 1.000 | Methods of Analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COLUMBIA RIVER AT PASCO, WASH. | | | | | | | | | | | | | | | | | | | | |
| June 3, 1964 | 0945 | 304 | 56 | 1340 | 33.5 | - | 31.6 | 91 | - | - | - | - | - | 16 | 20 | 61 | 98 | 100 | - | V |
| | 1020 | 304 | 56 | 1340 | 33.5 | 2.38 | 32.2 | 97 | - | - | - | - | - | 17 | 21 | 66 | 97 | 100 | - | V |
| | 1210 | 304 | 56 | 1770 | 36.5 | 3.86 | 35.2 | 83 | - | - | - | - | - | 20 | 23 | 58 | 93 | 100 | - | V |
| | 1130 | 304 | 56 | 1770 | 36.5 | - | 36.2 | 192 | - | - | - | - | - | 8 | 10 | 35 | 95 | 100 | - | V |
| June 12 | 1440 | 379 | 56 | 960 | 35.5 | 3.78 | 34.5 | 68 | - | - | - | - | - | 31 | 37 | 78 | 98 | 100 | - | V |
| | 1355 | 379 | 56 | 960 | 35.5 | - | 35.0 | 76 | - | - | - | - | - | 27 | 33 | 73 | 98 | 100 | - | V |
| | 0950 | 379 | 56 | 1340 | 34.8 | 4.71 | 27.9 | 56 | - | - | - | - | - | 35 | 40 | 70 | 98 | 100 | - | V |
| | 1000 | 379 | 56 | 1340 | 34.8 | - | 31.5 | 79 | - | - | - | - | - | 24 | 28 | 58 | 98 | 100 | - | V |
| | 0855 | 379 | 56 | 1340 | 34.8 | - | 34.3 | 307 | - | - | - | - | - | 8 | 10 | 24 | 79 | 100 | - | V |
| | 1250 | 379 | 56 | 1770 | 39.8 | 4.33 | 38.8 | 103 | - | - | - | - | - | 23 | 28 | 70 | 99 | 100 | - | V |
| | 1205 | 379 | 56 | 1770 | 39.8 | - | 39.3 | 257 | - | - | - | - | - | 6 | 8 | 58 | 98 | 100 | - | V |
| | 0940 | 379 | 56 | 1980 | 37.7 | 3.78 | 36.7 | 70 | - | - | - | - | - | 32 | 45 | 79 | 98 | 100 | - | V |
| | 0830 | 379 | 56 | 1980 | 37.7 | - | 37.4 | 143 | - | - | - | - | - | 19 | 25 | 53 | 98 | 100 | - | V |
| June 22 | 1310 | 422 | 58 | 960 | 36.5 | 3.46 | 35.1 | 29 | - | - | - | - | - | 47 | 57 | 92 | 99 | 100 | - | V |
| | 1215 | 422 | 58 | 960 | 36.5 | - | 36.0 | 37 | - | - | - | - | - | 38 | 43 | 81 | 98 | 100 | - | V |
| | 1415 | 422 | 58 | 1340 | 35.5 | 3.56 | 34.5 | 67 | - | - | - | - | - | 20 | 23 | 67 | 98 | 100 | - | V |
| | 1350 | 422 | 58 | 1340 | 35.5 | - | 35.0 | 113 | - | - | - | - | - | 14 | 16 | 46 | 97 | 100 | - | V |
| | 1000 | 422 | 58 | 1770 | 39.9 | 4.82 | 37.9 | 49 | - | - | - | - | - | 29 | 34 | 75 | 98 | 100 | - | V |
| | 0900 | 422 | 58 | 1770 | 39.9 | - | 39.4 | 175 | - | - | - | - | - | 7 | 11 | 54 | 94 | 100 | - | V |
| | 1035 | 422 | 58 | 1980 | 38.8 | 4.27 | 36.8 | 52 | - | - | - | - | - | 27 | 34 | 67 | 97 | 100 | - | V |
| | 0925 | 422 | 58 | 1980 | 38.8 | - | 38.3 | 81 | - | - | - | - | - | 19 | 24 | 54 | 94 | 100 | - | V |
| SNAKE RIVER AT PASCO, WASH. | | | | | | | | | | | | | | | | | | | | |
| May 24, 1963 | 1020 | 144 | 41 | 415 | 24.1 | 3.08 | 14.5 | 27 | 48 | 49 | 57 | 63 | 69 | 76 | 90 | 100 | - | - | - | VBWC |
| | 1035 | 144 | 41 | 415 | 24.1 | 2.60 | 19.3 | 35 | 35 | 46 | 51 | 65 | 69 | 72 | 79 | 99 | 100 | - | - | VBWC |
| | 1025 | 144 | 41 | 415 | 24.1 | - | 23.6 | 118 | 14 | 18 | 21 | 25 | 27 | 31 | 34 | 82 | 100 | - | - | VBWC |
| | 0915 | 144 | 41 | 1040 | 22.4 | 4.36 | 17.9 | 40 | 47 | 50 | 60 | 63 | 71 | 78 | - | - | - | - | - | BWC |
| | 0900 | 144 | 41 | 1040 | 22.4 | - | 21.1 | 47 | 28 | 34 | 42 | 50 | 55 | 57 | 60 | 84 | 100 | - | - | VBWC |
| | 1115 | 144 | 41 | 1560 | 30.2 | 5.26 | 6.0 | 39 | | 19 | 32 | 56 | 62 | 70 | - | - | - | - | - | BWC |
| | 1110 | 144 | 41 | 1560 | 30.2 | 5.02 | 12.1 | 38 | 17 | 27 | 32 | 47 | 55 | 72 | - | - | - | - | - | BWC |
| | 1050 | 144 | 41 | 1560 | 30.2 | 4.81 | 18.1 | 42 | 9 | 15 | 43 | 48 | 70 | 72 | 85 | 100 | - | - | - | VBWC |
| | 1040 | 144 | 41 | 1560 | 30.2 | 4.17 | 24.2 | 59 | 24 | 39 | 49 | 60 | 65 | 71 | 77 | 98 | 100 | - | - | VBWC |
| | 1025 | 144 | 41 | 1560 | 30.2 | 3.24 | 28.9 | 97 | 13 | 16 | 22 | 28 | 32 | 35 | 40 | 87 | 100 | - | - | VBWC |
| May 18, 1964 | 1020 | 151 | 54 | 415 | 23.9 | 3.34 | 19.1 | 63 | - | - | - | - | - | 59 | 68 | 95 | 100 | - | - | V |
| | 1000 | 151 | 54 | 415 | 23.9 | - | 23.4 | 109 | - | - | - | - | - | 36 | 45 | 83 | 100 | - | - | V |
| | 1140 | 151 | 54 | 750 | 26.9 | 3.03 | 21.4 | 146 | - | - | - | - | - | 35 | 57 | 97 | 100 | - | - | V |
| | 1120 | 151 | 54 | 750 | 26.9 | - | 26.4 | 390 | - | - | - | - | - | 16 | 27 | 72 | 98 | 100 | - | V |
| | 0950 | 151 | 54 | 1040 | 21.7 | - | 21.2 | 80 | - | - | - | - | - | 44 | 45 | 74 | 100 | - | - | V |
| | 1120 | 151 | 54 | 1265 | 25.5 | - | 25.0 | 88 | - | - | - | - | - | 33 | 33 | 45 | 98 | 100 | - | V |
| | 1240 | 151 | 54 | 1560 | 27.9 | 3.26 | 26.6 | 108 | - | - | - | - | - | 35 | 41 | 87 | 99 | 100 | - | V |

Table 3.--Particle-size analyses of suspended sediment, point-integrated samples--Continued.

| Date of collection | Time (24 hr) | Water Discharge (1,000 cfs) | Water temperature (°F) | Sampling Station | Total Depth (ft.) | Sampling point Velocity (fps) | Sampling point Depth (ft) | Sampling point Concentration (ppm) | 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.125 | 0.250 | 0.350 | 0.500 | 1.000 | Methods of Analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Percent finer than indicated particle size, in millimeters | | | | | | | | | | | |
| SNAKE RIVER AT PASCO, WASH.--Continued | | | | | | | | | | | | | | | | | | | | |
| May 22, 1964 | 1428 | 200 | 52 | 415 | 24.2 | 3.80 | 19.4 | 155 | - | - | - | - | - | 48 | 52 | 63 | 100 | - | - | V |
| | 1430 | 200 | 52 | 415 | 24.2 | - | 20.9 | 145 | - | - | - | - | - | 47 | 50 | 65 | 98 | 100 | - | V |
| | 1410 | 200 | 52 | 415 | 24.2 | 3.19 | 23.2 | 246 | - | - | - | - | - | 32 | 38 | 44 | 100 | - | - | V |
| | 1306 | 200 | 52 | 750 | 27.4 | 4.38 | 21.9 | 241 | - | - | - | - | - | 43 | 52 | 96 | 100 | - | - | V |
| | 1305 | 200 | 52 | 750 | 27.4 | - | 24.3 | 321 | - | - | - | - | - | 33 | 40 | 94 | 100 | - | - | V |
| | 1255 | 200 | 52 | 750 | 27.4 | - | 27.1 | 624 | - | - | - | - | - | 18 | 22 | 64 | 100 | - | - | V |
| | 1200 | 200 | 52 | 1040 | 22.8 | 5.72 | 18.2 | 128 | - | - | - | - | - | 49 | 50 | 81 | 99 | 100 | - | V |
| | 1200 | 200 | 52 | 1040 | 22.8 | 4.30 | 20.5 | 190 | - | - | - | - | - | 33 | 35 | 72 | 99 | 100 | - | V |
| | 1140 | 200 | 52 | 1040 | 22.8 | - | 22.5 | 500 | - | - | - | - | - | 13 | 13 | 36 | 82 | 100 | - | V |
| | 1025 | 200 | 52 | 1265 | 26.8 | - | 26.3 | 138 | - | - | - | - | - | 45 | 47 | 66 | 98 | 100 | - | V |
| | 0930 | 200 | 52 | 1560 | 28.7 | - | 26.6 | 131 | - | - | - | - | - | 61 | 75 | 98 | 100 | - | - | V |
| | 0900 | 200 | 52 | 1560 | 28.7 | 4.09 | 27.7 | 200 | - | - | - | - | - | 41 | 58 | 86 | 99 | 100 | - | V |
| June 5 | 1330 | 173 | 54 | 415 | 25.2 | - | 24.7 | 125 | - | - | - | - | - | 29 | 32 | 35 | 85 | 100 | - | V |
| | 1040 | 173 | 54 | 750 | 28.2 | 3.72 | 22.5 | 63 | - | - | - | - | - | 48 | 54 | 92 | 99 | 100 | - | V |
| | 1140 | 173 | 54 | 750 | 28.2 | - | 25.3 | 95 | - | - | - | - | - | 38 | 43 | 87 | 100 | - | - | V |
| | 1020 | 173 | 54 | 750 | 28.2 | - | 27.7 | 370 | - | - | - | - | - | 10 | 15 | 96 | 100 | - | - | V |
| | 1140 | 173 | 54 | 1040 | 23.9 | 3.60 | 21.7 | 81 | - | - | - | - | - | 35 | 35 | 61 | 98 | 100 | - | V |
| | 1120 | 173 | 54 | 1040 | 23.9 | 3.42 | 22.9 | 170 | - | - | - | - | - | 18 | 18 | 55 | 99 | 100 | - | V |
| | 1100 | 173 | 54 | 1040 | 23.9 | - | 23.4 | 66 | - | - | - | - | - | 49 | 50 | 65 | 96 | 100 | - | V |
| | 0910 | 173 | 54 | 1560 | 30.3 | - | 27.3 | 36 | - | - | - | - | - | 64 | 77 | 98 | 100 | - | - | V |
| | 1030 | 173 | 54 | 1560 | 30.3 | 2.96 | 29.3 | 78 | - | - | - | - | - | 52 | 64 | 96 | 99 | 100 | - | V |
| | 0950 | 173 | 54 | 1560 | 30.3 | - | 29.8 | 75 | - | - | - | - | - | 48 | 59 | 96 | 100 | - | - | V |
| June 9 | 1535 | 256 | 52 | 415 | 26.2 | 5.04 | 20.8 | 173 | - | - | - | - | - | 52 | 62 | 78 | 96 | 100 | - | V |
| | 1603 | 256 | 52 | 415 | 26.2 | - | 23.0 | 170 | - | - | - | - | - | 53 | 61 | 75 | 94 | 99 | 100 | V |
| | 1500 | 256 | 52 | 415 | 26.2 | - | 25.7 | 517 | - | - | - | - | - | 19 | 20 | 30 | 59 | 95 | 100 | V |
| | 1600 | 256 | 52 | 1040 | 24.9 | 6.65 | 19.8 | 198 | - | - | - | - | - | 44 | 49 | 77 | 99 | 100 | - | V |
| | 1620 | 256 | 52 | 1040 | 24.9 | 4.80 | 23.9 | 386 | - | - | - | - | - | 22 | 36 | 44 | 96 | 100 | - | V |
| | 1540 | 256 | 52 | 1040 | 24.9 | - | 24.5 | 791 | - | - | - | - | - | 11 | 14 | 30 | 80 | 100 | - | V |
| | 1430 | 256 | 52 | 1516 | 30.7 | 7.97 | 12.0 | 180 | - | - | - | - | - | 63 | 81 | 99 | 100 | - | - | V |
| | 1420 | 256 | 52 | 1516 | 30.7 | 7.57 | 17.8 | 213 | - | - | - | - | - | 62 | 80 | 99 | 100 | - | - | V |
| | 1410 | 256 | 52 | 1516 | 30.7 | - | 27.5 | 236 | - | - | - | - | - | 58 | 74 | 99 | 100 | - | - | V |
| | 1350 | 256 | 52 | 1516 | 30.7 | - | 30.4 | 377 | - | - | - | - | - | 39 | 54 | 88 | 97 | 100 | - | V |
| COLUMBIA RIVER AT HOOD RIVER, OREG. | | | | | | | | | | | | | | | | | | | | |
| Feb. 13, 1963 | 1305 | 166 | 40 | 2500 | 41.6 | 1.56 | 1.0 | 719 | 71 | 84 | 96 | 100 | - | - | - | - | - | - | - | BWC |
| | 1300 | 166 | 40 | 2500 | 41.6 | 1.50 | 8.3 | 727 | 72 | 87 | 96 | 100 | - | - | - | - | - | - | - | BWC |
| | 1255 | 166 | 40 | 2500 | 41.6 | 1.34 | 16.6 | 726 | 71 | 88 | 96 | 100 | - | - | - | - | - | - | - | BWC |
| | 1245 | 166 | 40 | 2500 | 41.6 | 1.18 | 24.9 | 725 | 74 | 88 | 97 | 100 | - | - | - | - | - | - | - | BWC |
| | 1230 | 166 | 40 | 2500 | 41.6 | 1.03 | 33.2 | 715 | 74 | 93 | 97 | 100 | - | - | - | - | - | - | - | BWC |
| | 1210 | 166 | 40 | 2500 | 41.6 | .62 | 40.3 | 737 | 72 | 88 | 97 | 100 | - | - | - | - | - | - | - | BWC |

## Table 3.--Particle-size analyses of suspended sediment, point-integrated samples--Continued.

| Date of collection | Time (24 hr) | Water Discharge (1,000 cfs) | Water temperature (°F) | Sampling Station | Total Depth (ft.) | Sampling point: Velocity (fps) | Sampling point: Depth (ft) | Sampling point: Concentration (ppm) | Percent finer than indicated particle size, in millimeters: 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.125 | 0.250 | 0.350 | 0.500 | 1.000 | Methods of Analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COLUMBIA RIVER AT HOOD RIVER, OREG.--Continued | | | | | | | | | | | | | | | | | | | | |
| June 3, 1964 | 1310 | 460 | 58 | 1600 | 50.9 | 1.68 | 49.9 | 123 | - | - | - | - | - | 35 | 49 | 97 | 100 | - | - | V |
| | 1250 | 460 | 58 | 1600 | 50.9 | - | 50.4 | 146 | - | - | - | - | - | 31 | 43 | 96 | 100 | - | - | V |
| | 1110 | 460 | 58 | 2050 | 48.6 | - | 43.7 | 74 | - | - | - | - | - | 49 | 62 | 100 | - | - | - | V |
| | 1020 | 460 | 58 | 2050 | 48.6 | 2.30 | 47.6 | 113 | - | - | - | - | - | 33 | 43 | 98 | 100 | - | - | V |
| | 1000 | 460 | 58 | 2050 | 48.6 | - | 48.1 | 131 | - | - | - | - | - | 29 | 39 | 97 | 98 | 99 | 100 | V |
| | 1510 | 460 | 58 | 2500 | 47.2 | 2.75 | 42.5 | 152 | - | - | - | - | - | 42 | 57 | 99 | 100 | - | - | V |
| | 1455 | 460 | 58 | 2500 | 47.2 | 2.43 | 46.2 | 192 | - | - | - | - | - | 24 | 29 | 99 | 100 | - | - | V |
| | 1445 | 460 | 58 | 2500 | 47.2 | - | 46.7 | 234 | - | - | - | - | - | 20 | 28 | 98 | 99 | 100 | - | V |
| | 1330 | 460 | 58 | 2950 | 49.9 | 3.20 | 29.9 | 60 | - | - | - | - | - | 66 | 79 | 99 | 100 | - | - | V |
| | 1300 | 460 | 58 | 2950 | 49.9 | 2.88 | 44.9 | 81 | - | - | - | - | - | 51 | 65 | 99 | 100 | - | - | V |
| | 1240 | 460 | 58 | 2950 | 49.9 | 2.00 | 48.9 | 138 | - | - | - | - | - | 34 | 44 | 99 | 100 | - | - | V |
| | 1215 | 460 | 58 | 2950 | 49.9 | - | 49.4 | 261 | - | - | - | - | - | 18 | 24 | 97 | 100 | - | - | V |
| | 1020 | 460 | 58 | 3500 | 44.0 | 2.42 | 39.6 | 63 | - | - | - | - | - | 64 | 77 | 98 | 99 | 100 | - | V |
| | 1000 | 460 | 58 | 3500 | 44.0 | 1.78 | 43.0 | 93 | - | - | - | - | - | 46 | 60 | 98 | 99 | 100 | - | V |
| | 0930 | 460 | 58 | 3500 | 44.0 | - | 43.5 | 109 | - | - | - | - | - | 37 | 50 | 95 | 99 | 100 | - | V |
| June 11 | 1230 | 555 | 56 | 1600 | 52.0 | 3.57 | 41.6 | 115 | - | - | - | - | - | 56 | 72 | 100 | - | - | - | V |
| | 1210 | 555 | 56 | 1600 | 52.0 | 3.20 | 46.8 | 144 | - | - | - | - | - | 46 | 57 | 99 | 100 | - | - | V |
| | 1200 | 555 | 56 | 1600 | 52.0 | 1.84 | 51.0 | 240 | - | - | - | - | - | 27 | 39 | 97 | 100 | - | - | V |
| | 1125 | 555 | 56 | 1600 | 52.0 | - | 51.5 | 293 | - | - | - | - | - | 26 | 37 | 89 | 100 | - | - | V |
| | 1250 | 555 | 56 | 2050 | 49.3 | 2.90 | 44.4 | 216 | - | - | - | - | - | 30 | 41 | 95 | 99 | 100 | - | V |
| | 1230 | 555 | 56 | 2050 | 49.3 | 2.30 | 48.3 | 221 | - | - | - | - | - | 26 | 38 | 96 | 100 | - | - | V |
| | 1210 | 555 | 56 | 2050 | 49.3 | - | 49.0 | 332 | - | - | - | - | - | 19 | 25 | 92 | 100 | - | - | V |
| | 1040 | 555 | 56 | 2500 | 50.7 | 3.02 | 45.6 | 220 | - | - | - | - | - | 28 | 41 | 98 | 100 | - | - | V |
| | 1000 | 555 | 56 | 2500 | 50.7 | 2.04 | 49.7 | 221 | - | - | - | - | - | 29 | 40 | 98 | 100 | - | - | V |
| | 0920 | 555 | 56 | 2500 | 50.7 | - | 50.4 | 325 | - | - | - | - | - | 21 | 24 | 96 | 100 | - | - | V |
| | 1255 | 555 | 56 | 2950 | 52.9 | 2.90 | 47.6 | 143 | - | - | - | - | - | 44 | 57 | 99 | 100 | - | - | V |
| | 1230 | 555 | 56 | 2950 | 52.9 | 1.88 | 51.9 | 254 | - | - | - | - | - | 25 | 36 | 97 | 100 | - | - | V |
| | 1155 | 555 | 56 | 2950 | 52.9 | - | 52.6 | 326 | - | - | - | - | - | 19 | 26 | 94 | 99 | 100 | - | V |
| | 0950 | 555 | 56 | 3500 | 42.9 | 3.54 | 38.6 | 122 | - | - | - | - | - | 49 | 62 | 98 | 100 | - | - | V |
| | 0930 | 555 | 56 | 3500 | 42.9 | 2.63 | 41.9 | 166 | - | - | - | - | - | 35 | 46 | 85 | 97 | 98 | 100 | V |
| | 0905 | 555 | 56 | 3500 | 42.9 | - | 42.4 | 202 | - | - | - | - | - | 32 | 43 | 86 | 98 | 99 | 100 | V |
| COLUMBIA RIVER AT VANCOUVER, WASH. | | | | | | | | | | | | | | | | | | | | |
| Feb. 14, 1963 | 1331 | 158 | 39 | 1370 | 28.7 | 2.58 | 1.0 | 387 | 73 | 90 | 97 | 99 | 99 | 99 | 100 | - | - | - | - | SBWC |
| | 1313 | 158 | 39 | 1370 | 28.7 | 2.29 | 11.4 | 378 | 76 | 87 | 95 | 99 | 99 | 99 | 100 | - | - | - | - | SBWC |
| | 1303 | 158 | 39 | 1370 | 28.7 | 2.12 | 17.1 | 391 | 72 | 88 | 96 | 99 | 99 | 99 | 100 | - | - | - | - | SBWC |
| | 1253 | 158 | 39 | 1370 | 28.7 | 1.61 | 22.8 | 378 | 74 | 87 | 95 | 99 | 99 | 99 | 100 | - | - | - | - | SBWC |
| | 1235 | 158 | 39 | 1370 | 28.7 | 1.34 | 27.4 | 373 | 71 | 83 | 94 | 98 | 99 | 99 | 100 | - | - | - | - | SBWC |
| May 20, 1964 | 0915 | 403 | 57 | 400 | 44.4 | 2.35 | 43.4 | 79 | - | - | - | - | - | 67 | 77 | 91 | 97 | 99 | 100 | V |
| | 0900 | 403 | 57 | 400 | 44.4 | - | 43.9 | 106 | - | - | - | - | - | 47 | 58 | 68 | 85 | 98 | 100 | V |
| | 1155 | 403 | 57 | 800 | 39.3 | - | 35.4 | 66 | - | - | - | - | - | 41 | 45 | 92 | 100 | - | - | V |

# Table 3.--Particle-size analyses of suspended sediment, point-integrated samples--Continued.

| Date of collection | Time (24 hr) | Water Discharge (1,000 cfs) | Water temper-ature (°F) | Sampling Station | Total Depth (ft) | Sampling point: Velocity (fps) | Sampling point: Depth (ft) | Sampling point: Concen-tration (ppm) | Percent finer than indicated particle size, in millimeters: 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.125 | 0.250 | 0.350 | 0.500 | 1.000 | Methods of Analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | COLUMBIA RIVER AT VANCOUVER, WASH.--Continued | | | | | | | | | | | | |
| May 20, 1964 | 1145 | 403 | 57 | 800 | 39.3 | 2.66 | 38.3 | 218 | - | - | - | - | - | 23 | 27 | 66 | 97 | 100 | - | V |
| | 1135 | 403 | 57 | 800 | 39.3 | - | 38.8 | 234 | - | - | - | - | - | 21 | 24 | 62 | 97 | 98 | 100 | V |
| | 0940 | 403 | 57 | 1200 | 37.5 | 3.26 | 30.0 | 112 | - | - | - | - | - | 44 | 49 | 97 | 100 | - | - | V |
| | 0930 | 403 | 57 | 1200 | 37.5 | - | 33.8 | 166 | - | - | - | - | - | 32 | 42 | 98 | 100 | - | - | V |
| | 0910 | 403 | 57 | 1200 | 37.5 | 1.70 | 36.5 | 352 | - | - | - | - | - | 22 | 35 | 94 | 100 | - | - | V |
| | 0850 | 403 | 57 | 1200 | 37.5 | - | 37.0 | 329 | - | - | - | - | - | 16 | 19 | 88 | 99 | 100 | - | V |
| | 1150 | 403 | 57 | 1800 | 29.0 | 2.85 | 23.2 | 97 | - | - | - | - | - | 52 | 61 | 99 | 100 | - | - | V |
| | 1130 | 403 | 57 | 1800 | 29.0 | - | 26.1 | 120 | - | - | - | - | - | 42 | 52 | 98 | 99 | 100 | - | V |
| | 1115 | 403 | 57 | 1800 | 29.0 | 1.71 | 28.0 | 225 | - | - | - | - | - | 24 | 30 | 94 | 99 | 100 | - | V |
| | 1100 | 403 | 57 | 1800 | 29.0 | - | 28.5 | 213 | - | - | - | - | - | 18 | 22 | 92 | 98 | 100 | - | V |
| | 0915 | 403 | 57 | 2300 | 41.4 | 2.64 | 33.1 | 83 | - | - | - | - | - | 68 | 83 | 98 | 100 | - | - | V |
| | 0930 | 403 | 57 | 2300 | 41.4 | - | 37.3 | 99 | - | - | - | - | - | 56 | 71 | 96 | 98 | 100 | - | V |
| | 0945 | 403 | 57 | 2300 | 41.4 | 1.38 | 40.4 | 124 | - | - | - | - | - | 47 | 61 | 95 | 99 | 100 | - | V |
| | 1000 | 403 | 57 | 2300 | 41.4 | - | 40.9 | 128 | - | - | - | - | - | 45 | 59 | 94 | 99 | 100 | - | V |
| | 1215 | 403 | 57 | a660 | 36.6 | 2.24 | 29.3 | 116 | - | - | - | - | - | 48 | 62 | 98 | 100 | - | - | V |
| | 1230 | 403 | 57 | a660 | 36.6 | - | 32.9 | 123 | - | - | - | - | - | 46 | 59 | 98 | 100 | - | - | V |
| | 1245 | 403 | 57 | a660 | 36.6 | 1.38 | 35.6 | 193 | - | - | - | - | - | 30 | 43 | 96 | 98 | 100 | - | V |
| | 1300 | 403 | 57 | a660 | 36.6 | - | 36.1 | 204 | - | - | - | - | - | 27 | 39 | 97 | 100 | - | - | V |
| June 8 | 0950 | 557 | 56 | 410 | 51.7 | - | 45.2 | 82 | - | - | - | - | - | 74 | 87 | 95 | 100 | - | - | V |
| | 0930 | 557 | 56 | 410 | 51.7 | 1.78 | 50.7 | 122 | - | - | - | - | - | 48 | 54 | 63 | 73 | 90 | 100 | V |
| | 0910 | 557 | 56 | 410 | 51.7 | - | 51.4 | 138 | - | - | - | - | - | 42 | 46 | 54 | 69 | 89 | 100 | V |
| | 1240 | 557 | 56 | 800 | 50.7 | - | 45.7 | 211 | - | - | - | - | - | 35 | 42 | 76 | 98 | 100 | - | V |
| | 1220 | 557 | 56 | 800 | 50.7 | 3.29 | 49.7 | 394 | - | - | - | - | - | 16 | 19 | 52 | 90 | 98 | 100 | V |
| | 1200 | 557 | 56 | 800 | 50.7 | - | 50.4 | 520 | - | - | - | - | - | 12 | 14 | 51 | 91 | 97 | 100 | V |
| | 1010 | 557 | 56 | 1200 | 44.0 | 3.82 | 35.2 | 156 | - | - | - | - | - | 42 | 52 | 98 | 99 | 100 | - | V |
| | 0955 | 557 | 56 | 1200 | 44.0 | 3.37 | 39.6 | 227 | - | - | - | - | - | 29 | 37 | 97 | 99 | 100 | - | V |
| | 0945 | 557 | 56 | 1200 | 44.0 | 2.13 | 43.0 | 601 | - | - | - | - | - | 12 | 14 | 78 | 97 | 98 | 100 | V |
| | 1230 | 557 | 56 | 1800 | 35.0 | 3.39 | 28.0 | 146 | - | - | - | - | - | 37 | 48 | 98 | 100 | - | - | V |
| | 1215 | 557 | 56 | 1800 | 35.0 | 3.60 | 31.5 | 175 | - | - | - | - | - | 38 | 47 | 96 | 98 | 100 | - | V |
| | 1205 | 557 | 56 | 1800 | 35.0 | 2.31 | 34.0 | 266 | - | - | - | - | - | 25 | 33 | 92 | 98 | 100 | - | V |
| | 1045 | 557 | 56 | 2300 | 41.4 | 4.20 | 16.6 | 85 | - | - | - | - | - | 75 | 87 | 100 | - | - | - | V |
| | 1025 | 557 | 56 | 2300 | 41.4 | 3.96 | 24.8 | 89 | - | - | - | - | - | 71 | 81 | 98 | 100 | - | - | V |
| | 1010 | 557 | 56 | 2300 | 41.4 | 3.68 | 33.1 | 100 | - | - | - | - | - | 63 | 74 | 97 | 100 | - | - | V |
| | 0955 | 557 | 56 | 2300 | 41.4 | 3.32 | 37.3 | 107 | - | - | - | - | - | 61 | 71 | 98 | 99 | 100 | - | V |
| | 0950 | 557 | 56 | 2300 | 41.4 | 2.56 | 40.4 | 179 | - | - | - | - | - | 36 | 45 | 79 | 97 | 100 | - | V |
| | 0915 | 557 | 56 | 2300 | 41.4 | - | 40.9 | 208 | - | - | - | - | - | 32 | 40 | 72 | 95 | 98 | 100 | V |
| | 1340 | 557 | 56 | a660 | 36.8 | 3.50 | 22.1 | 154 | - | - | - | - | - | 37 | 46 | 90 | 97 | 100 | - | V |
| | 1330 | 557 | 56 | a660 | 36.8 | 1.66 | 29.4 | 395 | - | - | - | - | - | 15 | 16 | 46 | 85 | 98 | 100 | V |
| | 1320 | 557 | 56 | a660 | 36.8 | 1.58 | 33.1 | 506 | - | - | - | - | - | 12 | 15 | 56 | 96 | 100 | - | V |
| | 1310 | 557 | 56 | a660 | 36.8 | 1.30 | 35.8 | 659 | - | - | - | - | - | 10 | 12 | 52 | 95 | 100 | - | V |
| | 1255 | 557 | 56 | a660 | 36.8 | - | 36.3 | 307 | - | - | - | - | - | 15 | 17 | 54 | 96 | 100 | - | V |

a Oregon Slough

## Table 3.--Particle-size analyses of suspended sediment, point-integrated samples--Continued.

| Date of collection | Time (24 hr) | Water Discharge (1,000 cfs) | Water temper- ature (°F) | Sampling Station | Total Depth (ft) | Sampling point: Velocity (fps) | Sampling point: Depth (ft) | Sampling point: Concen- tration (ppm) | Percent finer than indicated particle size, in millimeters: 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.062 | 0.125 | 0.250 | 0.350 | 0.500 | 1.000 | Methods of Analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COLUMBIA RIVER AT VANCOUVER, WASH.--Continued | | | | | | | | | | | | | | | | | | | | |
| June 22, 1964 | 1145 | 684 | 60 | 1200 | 49.8 | 4.14 | 39.8 | 198 | - | - | - | - | - | 32 | 41 | 90 | 97 | 100 | - | V |
| | 1130 | 684 | 60 | 1200 | 49.8 | 3.22 | 44.8 | 287 | - | - | - | - | - | 22 | 25 | 44 | 83 | 96 | 100 | V |
| | 1120 | 684 | 60 | 1200 | 49.8 | 2.22 | 48.8 | 875 | - | - | - | - | - | 7 | 9 | 58 | 83 | 97 | 100 | V |
| | 1105 | 684 | 60 | 1200 | 49.8 | - | 49.3 | 483 | - | - | - | - | - | 12 | 17 | 65 | 88 | 97 | 100 | V |
| | 0930 | 684 | 60 | 2300 | 49.7 | 4.16 | 29.8 | 98 | - | - | - | - | - | 59 | 69 | 91 | 99 | 100 | - | V |
| | 0915 | 684 | 60 | 2300 | 49.7 | 3.20 | 39.8 | 114 | - | - | - | - | - | 55 | 73 | 99 | 100 | - | - | V |
| | 0850 | 684 | 60 | 2300 | 49.7 | 2.90 | 44.7 | 132 | - | - | - | - | - | 47 | 63 | 98 | 100 | - | - | V |
| | 0845 | 684 | 60 | 2300 | 49.7 | 2.10 | 48.7 | 217 | - | - | - | - | - | 29 | 40 | 88 | 99 | 100 | - | V |
| | 0840 | 684 | 60 | 2300 | 49.7 | - | 49.2 | 295 | - | - | - | - | - | 22 | 28 | 68 | 92 | 97 | 100 | V |
| | 1205 | 684 | 60 | a660 | 38.0 | 3.76 | 30.4 | 209 | - | - | - | - | - | 26 | 32 | 67 | 97 | 100 | - | V |
| | 1155 | 684 | 60 | a660 | 38.0 | 2.94 | 34.2 | 366 | - | - | - | - | - | 15 | 17 | 59 | 93 | 100 | - | V |
| | 1145 | 684 | 60 | a660 | 38.0 | 2.20 | 37.0 | 738 | - | - | - | - | - | 8 | 16 | 85 | 98 | 100 | - | V |
| | 1135 | 684 | 60 | a660 | 38.0 | - | 37.5 | 529 | - | - | - | - | - | 11 | 13 | 56 | 96 | 100 | - | V |
| July 9 | 0835 | 444 | 63 | 1200 | 36.6 | - | 36.1 | 121 | - | - | - | - | - | 23 | 30 | 73 | 96 | 100 | - | V |
| | 0900 | 444 | 63 | 2300 | 39.0 | 2.38 | 38.0 | 76 | - | - | - | - | - | 32 | 47 | 95 | 99 | 100 | - | V |
| | 0840 | 444 | 63 | 2300 | 39.0 | - | 38.5 | 82 | - | - | - | - | - | 30 | 43 | 92 | 99 | 100 | - | V |
| | 1250 | 444 | 63 | a660 | 37.8 | 1.64 | 31.2 | 122 | - | - | - | - | - | 20 | 24 | 57 | 93 | 98 | 100 | V |
| | 1200 | 444 | 63 | a660 | 37.8 | 1.80 | 36.8 | 91 | - | - | - | - | - | 28 | 31 | 60 | 90 | 99 | 100 | V |
| | 1140 | 444 | 63 | a660 | 37.8 | - | 37.3 | 89 | - | - | - | - | - | 28 | 31 | 59 | 92 | 98 | 100 | V |

a Oregon Slough

Table 4.--Water discharge, total sediment discharge, and total sediment concentration of the Columbia River at Pasco, Wash.

| Time period | [1]Water discharge | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1962 | | | | | | | | | | | |
| August | 3,950 | 127 | 179 | 94.2 | 83.1 | 2.7 | - | 1.1 | 8 | - | 4 |
| September | 2,070 | 69.0 | 89.4 | 50.8 | 30.8 | 1.0 | 2.2 | .56 | 6 | 9 | 4 |
| Total | 6,020 | - | - | - | 113.9 | - | - | - | - | - | - |
| Average | - | 98.6 | - | - | - | 1.9 | - | - | 7 | - | - |
| Extremes | - | - | 179 | 50.8 | - | - | - | .56 | - | - | 4 |
| October | 2,100 | 67.7 | 84.6 | 48.7 | 31.2 | 1.0 | 1.5 | .53 | 6 | 7 | 4 |
| November | 2,190 | 73.1 | 99.1 | 55.8 | 38.5 | 1.3 | 5.0 | .33 | 6 | 24 | 2 |
| December | 2,660 | 85.9 | 98.5 | 71.6 | 40.7 | 1.3 | 2.2 | .92 | 6 | 9 | 4 |
| 1963 | | | | | | | | | | | |
| January | 2,690 | 86.8 | 101 | 70.6 | 29.6 | .95 | 1.4 | .66 | 4 | 5 | 3 |
| February | 2,530 | 90.5 | 106 | 63.0 | 133 | 4.8 | 23.4 | .79 | 19 | 103 | 4 |
| March | 2,470 | 79.6 | 104 | 58.5 | 31.1 | 1.0 | 2.5 | .47 | 5 | 11 | 3 |
| April | 3,050 | 102 | 122 | 76.9 | 72.4 | 2.4 | 3.0 | 2.0 | 9 | 11 | 6 |
| May | 4,390 | 142 | 231 | 89.1 | 131 | 4.2 | 11.7 | 1.4 | 11 | 19 | 6 |
| June | 8,140 | 271 | 307 | 229 | 342 | 11.4 | 15.3 | 6.3 | 16 | 19 | 9 |

Table 4.--Water discharge, total sediment discharge, and total sediment concentration of the Columbia River at Pasco, Wash.--Continued.

| Time period | Water discharge[1] | | | | Total sediment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | Mean[2] (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1963 (Cont.) | | | | | | | | | | | |
| July | 6,380 | 206 | 254 | 112 | 134 | 4.3 | 7.0 | 2.1 | 8 | 11 | 5 |
| August | 3,350 | 108 | 135 | 80.4 | 44.8 | 1.4 | 2.2 | 1.1 | 5 | 6 | 4 |
| September | 2,140 | 71.4 | 95.6 | 52.8 | 23.9 | .80 | 1.6 | .43 | 4 | 6 | 3 |
| Total | 42,100 | - | - | - | 1,050 | - | - | - | - | - | - |
| Average | - | 115 | - | - | - | 2.9 | - | - | 9 | - | - |
| Extremes | - | - | 307 | 48.7 | - | - | 23.4 | .33 | - | 103 | 2 |

[1] Summation of routed discharges of the Columbia River at Priest Rapids Dam, Wash. and Yakima River at Kiona, Wash.
[2] Discharge weighted.
K 1,000.

Table 5.--Water discharge, total sediment discharge, and total sediment concentration of the Snake River at Pasco, Wash.

| Time period | [1]Water discharge | | | | Total sediment: Discharge | | | | Total sediment: Concentration | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1962 | | | | | | | | | | | |
| August | 712 | 23.0 | 35.0 | 17.0 | 15.1 | 0.49 | 0.56 | 0.33 | 8 | 9 | 7 |
| September | 696 | 23.2 | 35.0 | 15.4 | 6.1 | .20 | .40 | .04 | 3 | 7 | 1 |
| Total | 1,410 | - | - | - | 21.2 | - | - | - | - | - | - |
| Average | - | 23.1 | - | - | - | .35 | - | - | 6 | - | - |
| Extremes | - | - | 35.0 | 15.4 | - | - | .56 | .04 | - | 9 | 1 |
| October | 1,060 | 34.2 | 59.0 | 19.0 | 14.2 | .46 | 1.28 | .17 | 5 | 8 | 2 |
| November | 1,060 | 35.5 | 66.8 | 25.1 | 11.7 | .39 | 1.25 | .08 | 4 | 9 | 1 |
| December | 1,260 | 40.8 | 62.0 | 26.8 | 62.7 | 2.02 | 22.5 | .35 | 18 | 175 | 4 |
| 1963 | | | | | | | | | | | |
| January | 992 | 32.0 | 40.2 | 22.5 | 9.2 | .30 | .51 | .15 | 3 | 5 | 2 |
| February | 1,580 | 56.5 | 88.9 | 30.4 | 1,400 | 49.9 | 686 | .17 | 327 | 2,860 | 2 |
| March | 1,210 | 39.1 | 55.6 | 26.5 | 31.9 | 1.03 | 2.12 | .38 | 10 | 15 | 5 |
| April | 1,550 | 51.6 | 59.2 | 38.6 | 44.0 | 1.47 | 3.33 | .74 | 11 | 31 | 6 |
| May | 3,270 | 106 | 152 | 73.9 | 202 | 6.52 | 18.6 | 1.94 | 23 | 49 | 9 |
| June | 3,390 | 113 | 143 | 71.1 | 187 | 6.21 | 11.1 | 1.92 | 20 | 29 | 10 |

Table 5.--Water discharge, total sediment discharge, and total sediment concentration of the Snake River at Pasco, Wash.--Continued.

| Time period | [1]Water discharge | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1963 (Cont.) | | | | | | | | | | | |
| July | 1,220 | 39.2 | 73.9 | 25.3 | 24.1 | 0.78 | 1.8 | 0.40 | 7 | 9 | 6 |
| August | 672 | 21.7 | 27.0 | 18.2 | 9.5 | .31 | .41 | .27 | 5 | 6 | 5 |
| September | 700 | 23.3 | 27.5 | 18.7 | 9.0 | .30 | .42 | .20 | 5 | 6 | 4 |
| Total | 18,000 | - | - | - | 2,000 | - | - | - | - | - | - |
| Average | - | 54.7 | - | - | - | 5.48 | - | - | 41 | - | - |
| Extremes | - | - | 152 | 18.2 | - | - | 686 | .08 | - | 2,860 | 1 |

[1]Discharge is for station located about 8 miles upstream at Ice Harbor Dam, Wash.
[2]Weighted with water discharge.
K 1,000.

Table 6.--Water discharge, total sediment discharge, and total sediment concentration of the Columbia River at Hood River, Oreg.

| Time period | [1]Water discharge | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1962 | | | | | | | | | | | |
| July | 7,420 | 219 | 315 | 188 | 333 | 10.7 | - | 6.6 | 17 | 20 | 13 |
| August | 4,870 | 157 | 209 | 121 | 168 | 5.4 | 12.3 | 2.1 | 13 | 22 | 6 |
| September | 2,950 | 98.2 | 117 | 80.5 | 52.1 | 1.7 | 4.7 | .98 | 7 | 15 | 4 |
| Total | 15,000 | - | - | - | 553 | - | - | - | - | - | - |
| Average | - | 166 | - | - | - | 6.0 | - | - | 13 | - | - |
| Extremes | - | - | 315 | 80.5 | - | - | - | .98 | - | 22 | 4 |
| October | 3,400 | 109 | 143 | 86.8 | 59.1 | 1.9 | 3.9 | .94 | 6 | 10 | 4 |
| November | 3,520 | 117 | 158 | 99.6 | 60.9 | 2.0 | 4.3 | 1.1 | 6 | 10 | 4 |
| December | 4,320 | 139 | 162 | 123 | 130 | 4.2 | 11.4 | 1.7 | 11 | 26 | 5 |
| 1963 | | | | | | | | | | | |
| January | 3,960 | 128 | 137 | 114 | 62.5 | 2.0 | 3.1 | 1.2 | 6 | 10 | 4 |
| February | 4,650 | 166 | 213 | 108 | 2,020 | 72.2 | 332 | 5.3 | 161 | 720 | 13 |
| March | 4,070 | 131 | 156 | 111 | 133 | 4.3 | 6.7 | 2.2 | 12 | 16 | 7 |
| April | 5,100 | 170 | 201 | 133 | 333 | 11.1 | 17.9 | 4.7 | 24 | 33 | 13 |
| May | 8,120 | 262 | 396 | 202 | 943 | 30.0 | 65.8 | 15.0 | 43 | 62 | 26 |
| June | 11,800 | 395 | 438 | 320 | 1,650 | 54.8 | 67.1 | 24.3 | 51 | 60 | 28 |

Table 6.--Water discharge, total sediment discharge, and total sediment concentration of the Columbia River at Hood River, Oreg.--Continued.

| Time period | Water discharge[1] | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1963 (Cont.) | | | | | | | | | | | |
| July | 7,790 | 251 | 332 | 151 | 415 | 13.3 | 25.6 | 4.1 | 20 | 29 | 9 |
| August | 4,340 | 140 | 177 | 107 | 162 | 5.2 | 8.9 | 3.6 | 14 | 21 | 11 |
| September | 3,030 | 101 | 123 | 89.1 | 73.2 | 2.4 | 4.1 | 1.3 | 9 | 15 | 5 |
| Total | 64,100 | - | - | - | 6,040 | - | - | - | - | - | - |
| Average | - | 176 | - | - | - | 165 | - | - | 35 | - | - |
| Extremes | - | - | 438 | 86.8 | - | - | 332 | .94 | - | 720 | 4 |

[1]Summation of routed discharges of the Columbia River at The Dalles, Oreg., and the Klickitat River near Pitt, Wash.
[2]Discharge weighted.
K 1,000.

Table 7.--Water discharge, total sediment discharge, and total sediment concentration of the Columbia River at Vancouver, Wash.

| Time period | [1]Water discharge | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1962 | | | | | | | | | | | |
| July | 8,200 | 264 | 356 | 205 | 681 | 22.1 | - | 13.4 | 31 | - | 21 |
| August | 5,490 | 177 | 230 | 142 | 265 | 14.0 | 23.1 | 3.3 | 18 | 37 | 8 |
| September | 3,470 | 116 | 138 | 96.2 | 54.8 | 1.8 | 3.8 | 1.2 | 6 | 10 | 4 |
| Total | 17,200 | - | - | - | 1,000 | - | - | - | - | - | - |
| Average | - | 187 | - | - | - | 12.7 | - | - | 22 | - | - |
| Extremes | - | - | 356 | 96.2 | - | - | - | 1.2 | - | - | 4 |
| October | 3,970 | 128 | 162 | 103 | 82.1 | 2.6 | 4.2 | 2.0 | 8 | 10 | 7 |
| November | 4,230 | 141 | 183 | 119 | 163 | 5.4 | 33.1 | 1.6 | 14 | 71 | 5 |
| December | 5,130 | 166 | 198 | 144 | 146 | 5.9 | 7.5 | 3.0 | 10 | 16 | 7 |
| 1963 | | | | | | | | | | | |
| January | 4,610 | 149 | 158 | 133 | 124 | 4.0 | 6.3 | 2.6 | 10 | 15 | 7 |
| February | 5,370 | 192 | 249 | 131 | 2,130 | 76.2 | 159 | 3.6 | 147 | 566 | 10 |
| March | 4,760 | 153 | 177 | 131 | 207 | 6.4 | 10.7 | 3.6 | 15 | 23 | 10 |
| April | 5,830 | 194 | 223 | 159 | 325 | 10.8 | 21.9 | 4.1 | 21 | 36 | 10 |
| May | 8,740 | 282 | 421 | 226 | 1,180 | 36.8 | 118 | 21.0 | 50 | 104 | 32 |
| June | 12,600 | 434 | 459 | 361 | 2,870 | 94.6 | 111 | 59.8 | 84 | 92 | 61 |

Table 7.--Water discharge, total sediment discharge, and total sediment concentration of the Columbia River at Vancouver, Wash.--Continued.

| Time period | [1]Water discharge | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1963 (Cont.) | | | | | | | | | | | |
| July | 8,590 | 277 | 355 | 168 | 842 | 27.2 | 56.5 | 7.1 | 36 | 59 | 16 |
| August | 4,920 | 159 | 194 | 137 | 210 | 6.8 | 9.8 | 4.9 | 16 | 21 | 13 |
| September | 3,540 | 118 | 140 | 105 | 131 | 4.7 | 7.3 | 2.4 | 14 | 19 | 8 |
| Total | 72,300 | - | - | - | 8,420 | - | - | - | - | - | - |
| Average | - | 199 | - | - | - | 22.9 | - | - | 43 | - | - |
| Extremes | - | - | 459 | 103 | - | - | 159 | 1.6 | - | 566 | 5 |

[1]Summation of routed discharges of the Columbia River at The Dalles, Oreg. and downstream tributaries adjusted for unmeasured inflow.
[2]Discharge weighted.
K 1,000.

Table 8.--Water discharge, total sediment discharge, and total sediment concentration of the Willamette River at Portland, Oreg.

| Time period | [1]Water discharge | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1962 | | | | | | | | | | | |
| July | 303 | 9.77 | 12.9 | 8.28 | 3.5 | 0.11 | 0.22 | 0.09 | 4 | 10 | 4 |
| August | 284 | 9.16 | 11.7 | 8.27 | 9.2 | .29 | .38 | .27 | 12 | 12 | 12 |
| September | 286 | 9.53 | 12.5 | 8.15 | 7.7 | .26 | .34 | .22 | 10 | 10 | 10 |
| Total | 873 | - | - | - | 20.4 | - | - | - | - | - | - |
| Average | - | 9.49 | - | - | - | .22 | - | - | 9 | - | - |
| Extremes | - | - | 12.9 | 8.15 | - | - | .38 | .09 | - | 12 | 4 |
| October | 693 | 22.4 | 41.0 | 10.5 | 28.0 | .90 | 3.32 | .26 | 15 | 34 | 9 |
| November | 1,400 | 46.7 | 128 | 10.8 | 263 | 8.5 | 43.2 | .18 | 70 | 135 | 6 |
| December | 1,820 | 58.7 | 108 | 20.8 | 139 | 4.35 | 17.2 | .34 | 28 | 62 | 6 |
| 1963 | | | | | | | | | | | |
| January | 580 | 18.7 | 34.3 | 11.1 | 17.7 | .57 | 2.41 | .24 | 11 | 28 | 6 |
| February | 1,600 | 57.3 | 145 | 13.9 | 284 | 9.59 | 69.7 | .30 | 66 | 206 | 8 |
| March | 881 | 28.4 | 90.9 | 18.8 | 68.3 | 2.19 | 30.7 | .46 | 29 | 126 | 9 |
| April | 2,040 | 67.8 | 131 | 34.4 | 168 | 5.31 | 34.1 | .93 | 31 | 109 | 10 |
| May | 1,660 | 53.6 | 128 | 18.0 | 138 | 4.12 | 24.0 | .29 | 31 | 75 | 6 |
| June | 451 | 15.0 | 18.8 | 11.2 | 7.3 | .24 | .30 | .18 | 6 | 6 | 6 |

Table 8.--Water discharge, total sediment discharge, and total sediment concentration of the Willamette River at Portland, Oreg.--Continued.

| Time period | [1]Water discharge | | | | Total sediment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Discharge | | | | Concentration | | |
| | Total (K-cfs days) | Daily mean (K-cfs) | Daily max. (K-cfs) | Daily min. (K-cfs) | Total (K-tons) | Daily mean (K-tons) | Daily max. (K-tons) | Daily min. (K-tons) | [2]Mean (ppm) | Daily max. (ppm) | Daily min. (ppm) |
| 1963 (Cont.) | | | | | | | | | | | |
| July | 372 | 12.0 | 14.8 | 9.89 | 9.2 | 0.30 | 0.43 | 0.20 | 9 | 12 | 6 |
| August | 274 | 8.84 | 9.6 | 8.38 | 10.1 | .32 | .40 | .27 | 14 | 16 | 12 |
| September | 294 | 9.80 | 13.7 | 7.56 | 8.0 | .27 | .40 | .21 | 10 | 14 | 10 |
| Total | 12,000 | - | - | - | 1,140 | - | - | - | - | - | - |
| Average | - | 33.1 | - | - | - | 3.00 | - | - | 35 | - | - |
| Extremes | - | - | 145 | 7.56 | - | - | 69.7 | .18 | - | 206 | 6 |

[1]Summation of routed discharges of the Willamette River at Wilsonville, Oreg., and downstream tributaries and adjusted for unmeasured inflow.
[2]Discharge weighted.
K 1,000.

Table 11.--Observed temperatures of the Columbia River at Pasco, Wash., in degrees fahrenheit, August 1962 to September 1963.

| Day | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - | 43 | - | - | - | - | - | - |
| 2 | - | - | - | 58 | - | - | - | - | - | - | - | 61 | - | - |
| 3 | - | - | - | - | - | - | - | - | 43 | 49 | - | - | - | 68 |
| 4 | - | 66 | 60 | - | - | - | - | 43 | - | - | 58 | - | - | - |
| 5 | - | - | - | - | - | - | 42 | 42 | - | - | - | 62 | - | - |
| 6 | - | - | - | - | - | - | - | - | - | 49 | 55 | - | 68 | - |
| 7 | - | - | - | 57 | 49 | - | - | - | - | - | - | - | - | - |
| 8 | - | - | - | - | - | 45 | 40 | - | 48 | - | - | - | - | - |
| 9 | - | - | 60 | - | - | 45 | 41 | - | - | 50 | - | 63 | - | - |
| 10 | - | 63 | - | - | - | - | - | - | 47 | - | - | - | - | 69 |
| 11 | - | - | - | - | - | - | 41 | 44 | - | - | 58 | - | - | - |
| 12 | - | - | - | - | 48 | - | - | - | - | - | - | - | 70 | - |
| 13 | - | - | - | 54 | 48 | - | 41 | - | - | 52 | - | - | - | - |
| 14 | 65 | 64 | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 | - | - | - | - | - | 41 | 40 | - | 47 | - | - | - | - | - |
| 16 | - | - | - | 51 | - | - | - | - | - | 54 | - | - | - | - |
| 17 | - | - | 58 | - | 51 | - | - | - | - | - | 61 | 64 | - | 64 |
| 18 | - | - | - | - | - | - | - | 45 | 47 | - | - | - | - | - |
| 19 | - | 68 | - | - | 51 | - | - | - | - | - | - | - | 66 | - |
| 20 | 71 | 70 | - | - | 48 | - | 42 | - | - | - | - | - | - | - |
| 21 | - | - | - | - | - | - | - | 47 | - | 58 | 61 | - | - | - |
| 22 | - | - | - | - | - | - | - | - | - | - | - | 64 | - | - |
| 23 | - | - | - | 50 | - | 41 | - | - | 48 | 58 | - | - | - | - |
| 24 | 67 | - | 59 | - | - | - | - | - | - | - | - | - | - | - |
| 25 | - | - | - | - | - | - | - | - | - | - | 59 | - | - | 67 |
| 26 | - | - | - | - | 46 | - | - | 47 | - | 55 | - | - | 65 | - |
| 27 | - | 67 | - | 51 | - | - | - | - | - | - | - | - | - | - |
| 28 | - | - | - | 49 | - | - | - | - | - | 57 | - | - | - | - |
| 29 | 65 | - | - | - | - | 38 | - | 46 | 51 | - | - | - | - | - |
| 30 | 64 | - | 57 | - | - | - | - | - | - | - | - | 64 | - | - |
| 31 | - | - | - | - | 46 | - | - | - | - | 57 | - | - | - | - |

Table 12.--Observed temperatures of the Snake River at Pasco, Wash., in degrees fahrenheit, August 1962 to September 1963.

| Day | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - | - | - | - | - | - | 68 | - |
| 2 | - | - | 65 | - | - | 41 | - | - | 48 | - | - | 63 | - | - |
| 3 | - | - | - | - | - | - | - | - | - | 51 | 57 | - | - | - |
| 4 | - | - | - | - | - | - | - | 43 | 49 | - | - | - | - | - |
| 5 | - | - | 64 | 53 | 41 | - | 34 | - | 48 | - | 57 | - | - | 70 |
| 6 | - | - | - | - | - | - | - | - | 47 | - | - | - | - | - |
| 7 | - | 70 | - | - | - | - | 41 | - | 48 | 50 | 55 | - | - | - |
| 8 | - | - | - | - | - | - | 38 | 44 | 48 | - | - | - | 70 | - |
| 9 | - | - | - | 52 | - | - | 37 | - | - | - | - | - | - | - |
| 10 | - | - | - | - | 42 | - | - | - | - | 54 | 58 | 68 | - | - |
| 11 | - | - | - | - | - | 36 | 37 | - | 50 | - | - | - | - | - |
| 12 | - | - | 58 | - | - | - | 38 | - | - | - | - | - | - | - |
| 13 | - | 67 | - | - | 43 | - | - | 42 | - | - | 59 | - | - | 69 |
| 14 | - | - | - | 49 | - | - | 37 | - | - | 55 | - | - | - | - |
| 15 | 71 | - | - | - | - | - | - | - | - | - | - | - | 73 | - |
| 16 | - | - | 57 | - | - | - | - | - | - | - | - | - | - | - |
| 17 | - | - | - | - | 43 | 35 | - | - | 49 | 54 | - | - | - | - |
| 18 | - | 63 | - | - | - | - | 37 | - | - | - | 65 | 69 | - | - |
| 19 | - | - | - | 49 | - | - | - | - | 49 | - | - | - | - | - |
| 20 | - | - | - | - | - | - | - | - | - | 58 | 64 | - | - | 67 |
| 21 | 77 | 64 | - | - | 43 | - | - | 43 | - | - | - | - | - | - |
| 22 | - | - | 56 | - | - | - | - | - | - | 59 | - | - | - | - |
| 23 | - | - | - | 47 | - | - | - | - | - | - | - | - | - | - |
| 24 | - | - | - | 46 | - | 35 | - | - | - | - | - | - | - | - |
| 25 | - | 64 | - | - | - | - | - | 47 | - | 57 | - | 68 | - | - |
| 26 | - | - | 53 | - | - | - | - | - | 49 | 57 | 62 | - | - | - |
| 27 | 71 | - | - | - | 41 | - | - | - | - | 56 | - | - | 72 | 65 |
| 28 | - | - | - | 44 | - | - | 44 | 47 | - | - | - | - | - | - |
| 29 | - | - | - | - | - | - | - | - | - | 57 | - | - | - | - |
| 30 | - | - | - | 43 | - | - | - | - | 52 | - | - | - | - | - |
| 31 | 68 | - | 53 | - | - | 34 | - | - | - | 58 | - | - | - | - |

Table 13.--Observed temperatures of the Columbia River at Hood River, Oreg., in degrees fahrenheit, July 1962 to September 1963.

| Day | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - | - | - | - | 52 | - | - | - | - |
| 2 | - | - | - | 62 | - | - | - | - | - | - | - | - | 62 | - | - |
| 3 | - | - | - | - | - | - | 47 | - | - | - | - | - | - | - | 70 |
| 4 | - | - | - | - | - | 47 | - | - | - | 49 | - | 59 | - | - | - |
| 5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 | - | - | - | - | - | - | - | 38 | 44 | - | - | - | - | - | - |
| 7 | - | - | - | - | - | - | - | - | - | - | 53 | - | - | - | - |
| 8 | - | 67 | - | - | 55 | - | 44 | 41 | - | - | - | - | - | - | - |
| 9 | - | - | - | - | - | - | - | - | - | - | - | - | 63 | - | - |
| 10 | 64 | - | - | - | - | - | - | - | - | 49 | - | - | - | - | 70 |
| 11 | - | - | 65 | 58 | - | - | - | - | - | - | - | - | - | - | - |
| 12 | - | - | - | - | - | - | - | 40 | - | - | - | - | - | - | - |
| 13 | - | - | - | - | 54 | - | - | 40 | 46 | - | - | 62 | - | - | - |
| 14 | - | - | - | - | - | 46 | - | - | - | - | - | - | - | - | - |
| 15 | - | - | - | 57 | - | - | - | 39 | - | 49 | - | - | - | - | - |
| 16 | - | - | - | - | - | - | - | - | - | - | 58 | - | - | - | 66 |
| 17 | - | 69 | - | - | - | - | 40 | - | - | - | - | - | 65 | - | - |
| 18 | - | - | 66 | - | - | - | - | 41 | - | - | - | 64 | - | - | - |
| 19 | 63 | - | - | - | 52 | - | - | - | 46 | - | - | - | - | - | - |
| 20 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 21 | - | - | - | - | - | 47 | - | - | - | - | 60 | - | - | - | - |
| 22 | - | - | - | - | - | - | 38 | - | - | - | - | - | - | - | - |
| 23 | - | - | - | 58 | - | - | - | - | - | 49 | - | - | 68 | - | - |
| 24 | - | 69 | - | - | - | - | - | - | - | - | - | - | - | - | 68 |
| 25 | - | - | 67 | - | - | - | - | - | - | - | - | 62 | - | - | - |
| 26 | 68 | - | - | - | - | - | - | - | 47 | - | - | - | - | 68 | - |
| 27 | - | - | - | - | 49 | - | - | 44 | - | - | - | - | - | - | - |
| 28 | - | - | - | - | - | 44 | - | - | - | - | - | - | - | - | - |
| 29 | - | - | - | - | - | - | - | - | - | - | 59 | - | - | - | - |
| 30 | - | 68 | - | - | - | - | - | - | - | - | - | - | 65 | - | - |
| 31 | 69 | - | - | 57 | - | - | - | - | - | - | - | - | - | - | - |

Table 14.--Observed temperatures of the Columbia River at Vancouver, Wash., in degrees fahrenheit, July 1962 to September 1963.

| Day | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 | - | 68 | - | - | 57 | - | 44 | - | - | - | - | - | - | - | - |
| 3 | - | 68 | - | - | - | - | - | - | - | 46 | - | - | 62 | - | - |
| 4 | - | - | - | 62 | - | - | - | 40 | - | - | - | - | - | - | 70 |
| 5 | 62 | - | 68 | - | - | 46 | - | - | - | - | - | - | - | 67 | - |
| 6 | - | - | 66 | - | - | - | - | 39 | - | - | - | 58 | - | - | - |
| 7 | - | - | - | - | 54 | - | - | - | 44 | - | - | - | - | - | - |
| 8 | - | - | - | - | - | - | - | 40 | - | - | 54 | - | 62 | - | - |
| 9 | - | 68 | - | 59 | - | - | 42 | - | - | 49 | - | - | - | - | 70 |
| 10 | - | - | - | - | - | 44 | - | - | - | - | 52 | - | - | - | - |
| 11 | 66 | - | - | - | - | - | - | - | - | - | - | 59 | - | - | - |
| 12 | - | - | - | - | - | - | - | - | 44 | - | - | - | - | - | - |
| 13 | - | - | 64 | - | - | - | - | 39 | - | - | - | - | - | 69 | - |
| 14 | - | - | - | - | - | - | - | 39 | - | - | 54 | - | - | - | - |
| 15 | - | 69 | - | - | 52 | - | - | 40 | - | - | - | - | - | - | - |
| 16 | - | 67 | - | 57 | - | - | 39 | - | - | - | - | - | 65 | - | - |
| 17 | - | - | - | - | - | - | - | - | - | 48 | - | - | - | - | 66 |
| 18 | 63 | - | - | - | - | 46 | - | 42 | - | - | - | - | - | - | - |
| 19 | - | - | - | - | - | 45 | - | 42 | - | - | - | - | - | - | - |
| 20 | - | - | - | - | - | - | - | - | - | - | - | 64 | - | 69 | - |
| 21 | - | - | 64 | - | 52 | - | - | - | 48 | - | - | - | - | 68 | - |
| 22 | - | 68 | - | - | - | - | - | - | - | - | - | - | 65 | - | - |
| 23 | - | 66 | - | - | 48 | - | - | - | - | - | 59 | - | - | - | 67 |
| 24 | 68 | - | - | 58 | - | - | 37 | - | - | - | - | - | - | - | - |
| 25 | - | - | - | - | - | - | - | 44 | 46 | 50 | - | - | - | - | - |
| 26 | - | - | - | - | 49 | 42 | - | 44 | - | - | - | - | - | - | - |
| 27 | - | - | - | - | - | - | - | - | - | - | - | 61 | - | 68 | - |
| 28 | - | - | 61 | - | - | - | - | - | - | - | 60 | - | - | - | - |
| 29 | - | 67 | - | - | 46 | - | - | - | - | - | - | - | - | - | - |
| 30 | - | - | - | - | - | - | - | - | - | 50 | - | - | - | - | - |
| 31 | - | - | - | - | - | - | - | - | - | - | - | - | 67 | - | - |

Table 15.--Observed temperatures of the Willamette River at Portland, Oreg., in degrees fahrenheit, July 1962 to September 1963

| Day | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | 73 | - | 62 | - | - | - | - | - | 47 | - | - | 64 | - | - |
| 2 | - | - | - | - | - | - | 44 | - | - | 49 | - | - | - | - | - |
| 3 | - | - | - | - | - | 45 | - | - | - | - | 50 | - | - | - | - |
| 4 | - | - | - | - | - | - | - | 44 | - | 49 | - | - | - | - | - |
| 5 | - | - | - | - | - | - | - | 46 | - | 49 | - | - | - | - | - |
| 6 | 67 | - | - | - | 53 | - | - | - | - | - | - | - | - | - | - |
| 7 | - | - | - | - | - | 47 | - | 47 | 47 | - | - | - | - | - | - |
| 8 | - | - | - | - | - | - | - | - | - | 49 | 49 | - | - | 71 | - |
| 9 | - | - | - | 63 | - | - | - | - | - | - | 51 | - | - | - | - |
| 10 | - | - | - | - | - | 46 | 39 | - | - | - | 52 | 60 | - | - | - |
| 11 | - | - | 64 | - | - | 44 | - | 48 | - | - | - | - | - | - | 69 |
| 12 | 66 | - | - | - | - | - | - | - | - | - | - | - | 64 | - | - |
| 13 | - | - | - | 51 | - | - | - | - | - | - | 52 | - | - | - | - |
| 14 | - | 66 | - | - | 51 | - | - | - | 47 | - | - | - | - | - | - |
| 15 | - | - | - | - | - | - | 35 | 46 | - | - | - | - | - | - | - |
| 16 | - | - | - | - | - | - | - | - | - | - | - | - | - | 70 | - |
| 17 | 66 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 | - | - | 63 | 53 | - | - | - | - | - | - | - | - | - | - | - |
| 19 | - | - | - | 53 | - | - | - | - | - | 46 | - | - | 65 | - | - |
| 20 | - | 68 | - | - | 49 | 48 | - | 47 | 48 | - | - | 69 | - | - | 66 |
| 21 | - | 68 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 22 | - | - | - | - | - | - | - | - | 50 | - | 64 | - | - | - | - |
| 23 | - | - | - | - | 47 | - | - | - | - | - | - | - | - | 69 | - |
| 24 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 25 | - | - | - | 56 | - | - | - | - | - | 50 | - | - | - | - | - |
| 26 | - | - | 63 | - | 47 | - | - | - | - | - | - | - | - | - | - |
| 27 | - | - | - | - | - | - | - | - | 49 | - | - | - | - | - | - |
| 28 | - | 65 | - | - | 46 | 41 | - | 47 | - | - | - | - | - | - | - |
| 29 | - | - | - | - | - | - | - | - | - | - | 61 | - | 67 | - | - |
| 30 | - | - | - | 54 | 46 | - | - | - | - | - | - | - | - | - | 64 |
| 31 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Table 16.--Observed temperatures of the Columbia River near The Dalles, Oreg., in degrees fahrenheit, July 1962 to September 1963.

| Day | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 63 | 70 | 67 | 63 | 57 | 47 | 44 | 36 | 42 | 47 | 51 | 58 | 62 | 66 | 68 |
| 2 | 63 | 69 | 67 | 64 | 57 | 48 | 44 | 36 | 43 | 47 | 51 | 58 | 62 | 67 | 68 |
| 3 | 62 | 69 | 68 | 64 | 57 | 47 | 44 | 36 | - | 47 | 51 | 58 | 62 | 68 | 67 |
| 4 | 62 | 69 | 68 | 64 | 57 | 47 | 44 | 36 | 43 | 47 | 51 | 58 | 62 | 68 | 67 |
| 5 | 62 | 70 | - | 63 | 57 | 47 | 44 | 37 | 43 | 47 | 51 | 58 | 63 | 68 | 68 |
| 6 | 63 | 69 | 67 | 62 | 57 | 46 | 43 | 37 | 43 | 48 | 51 | 58 | 63 | 68 | 69 |
| 7 | 62 | 68 | 67 | 61 | 56 | 46 | 43 | 37 | 43 | 48 | 51 | 58 | 63 | 68 | 69 |
| 8 | 63 | 67 | 67 | 61 | 55 | 46 | 43 | 37 | 44 | 48 | 52 | 58 | 63 | 69 | 70 |
| 9 | 63 | 66 | 66 | 60 | 55 | 46 | 43 | 37 | 44 | 48 | 52 | 58 | 64 | 69 | 70 |
| 10 | 63 | 66 | 66 | 60 | 55 | 46 | 43 | 37 | 44 | 48 | 52 | 57 | 64 | 70 | 70 |
| 11 | 63 | 67 | 66 | 60 | 55 | 46 | 42 | 38 | 44 | 48 | 52 | 58 | 64 | 70 | 70 |
| 12 | 64 | 68 | 65 | 59 | 55 | 46 | 40 | 38 | 44 | 48 | 53 | 58 | 63 | 70 | 70 |
| 13 | 64 | 68 | 65 | 59 | 54 | 46 | 39 | 39 | 44 | 49 | 53 | 59 | 64 | 70 | 70 |
| 14 | 64 | 68 | 65 | 59 | 54 | 46 | 39 | 39 | 44 | 50 | 53 | 59 | 65 | 70 | 69 |
| 15 | 64 | 68 | 65 | 58 | 53 | 46 | 39 | 39 | 44 | 49 | 53 | 61 | 65 | 70 | 68 |
| 16 | 64 | 69 | 65 | 57 | 53 | - | 40 | 40 | 44 | 49 | 53 | 62 | 64 | 70 | 67 |
| 17 | 64 | 70 | 65 | 57 | 53 | 46 | 40 | 40 | 44 | 48 | 56 | 62 | 65 | 70 | 66 |
| 18 | 64 | 70 | 65 | 57 | 53 | 46 | 39 | 40 | 44 | 48 | 56 | 63 | 65 | 71 | 66 |
| 19 | 64 | 70 | 65 | 57 | 52 | 47 | 38 | 40 | 44 | 48 | 57 | 63 | 65 | 70 | 66 |
| 20 | 64 | 69 | 65 | 57 | 52 | 46 | 38 | 41 | 44 | 49 | 58 | 63 | 65 | 69 | 67 |
| 21 | 65 | 69 | 65 | 58 | 51 | 47 | 37 | 41 | 45 | 49 | 58 | 62 | 65 | 69 | 67 |
| 22 | 66 | 69 | 65 | 58 | 51 | 47 | 37 | 41 | 45 | 48 | 59 | 61 | 66 | 69 | 67 |
| 23 | 67 | 68 | 65 | 57 | 50 | 47 | 38 | 41 | 45 | 49 | 59 | 61 | 66 | 69 | 67 |
| 24 | 67 | 68 | 65 | 57 | 50 | 46 | 38 | 41 | 45 | 49 | 59 | 61 | 66 | 68 | 66 |
| 25 | 68 | 70 | - | 57 | 49 | 46 | 37 | 41 | 45 | 50 | 59 | 61 | 65 | 68 | 66 |
| 26 | 68 | 69 | 66 | 57 | 49 | 45 | 37 | 42 | 45 | 50 | 59 | 61 | 65 | 67 | 66 |
| 27 | 68 | 68 | 66 | 57 | 49 | 44 | 37 | 42 | 46 | 50 | 59 | 61 | 66 | 68 | 66 |
| 28 | 69 | 66 | 66 | 57 | 49 | 44 | 37 | 42 | 47 | 50 | 58 | 61 | 67 | 68 | 67 |
| 29 | 69 | 66 | 64 | 57 | 48 | 44 | 37 | - | 46 | 50 | 58 | 61 | 67 | 69 | 67 |
| 30 | 69 | 66 | 64 | 57 | 48 | 44 | 37 | - | 47 | 51 | 58 | 61 | 66 | 68 | 67 |
| 31 | 70 | 67 | - | 57 | - | 44 | 37 | - | 47 | - | 58 | - | 66 | 68 | - |
| Average | 65 | 68 | 66 | 59 | 53 | 46 | 40 | 39 | 44 | 49 | 55 | 60 | 64 | 69 | 68 |

Table 25.--Concentration of radionuclides in filtered Columbia River water at Pasco, Wash., in disintegrations per minute per milliliter.

| Date | Scandium$^{46}$ x$10^3$ | Chromium$^{51}$ | Zinc$^{65}$ x$10^3$ | Zirconium$^{95}$-Niobium$^{95}$ x$10^3$ | Ruthenium$^{103}$-Rhodium$^{103}$ x$10^2$ | Cerium$^{141}$ x$10^2$ |
|---|---|---|---|---|---|---|
| 1962 | | | | | | |
| [1]Aug. 14 | 8.8 | 8.0 | 6.7 | 9.2 | 1.4 | - |
| Oct. 30 | 15 | 9.8 | 9.0 | 16 | 2.0 | 3.1 |
| 1963 | | | | | | |
| Jan. 9 | 14 | 10 | 19 | 18 | 1.4 | - |
| Feb. 13 | 15 | 8.4 | 22 | 24 | 2.7 | 1.5 |
| Mar. 4 | 31 | 14 | 58 | 19 | 3.6 | 6.8 |
| Mar. 18 | 34 | 20 | 93 | 60 | 3.9 | - |
| Apr. 3 | 13 | 10 | 66 | 26 | 3.6 | - |
| May 6 | 12 | 9.5 | 57 | 20 | 1.4 | 7.1 |
| May 21 | 2.8 | 6.7 | 22 | 11 | .9 | 6.2 |
| June 4 | 4.8 | 4.2 | 18 | 8.8 | 1.0 | 2.7 |
| June 17 | 3.2 | 4.2 | 14 | 6.8 | .6 | 3.7 |
| July 9 | 2.2 | 6.3 | 16 | 8.4 | .8 | 1.5 |
| July 22 | 3.4 | 9.4 | 17 | 6.6 | .7 | 7.5 |
| Aug. 6 | 1.6 | 6.0 | 8 | 3.6 | .6 | 11 |
| Aug. 26 | 1.7 | 11 | 11 | 5.4 | 1.2 | 7.9 |
| Sept. 10 | 1.6 | 22 | 18 | 3.3 | 1.3 | 38 |
| Sept. 25 | 2.0 | 14 | 20 | 11 | 2.3 | 1.8 |
| Oct. 7 | 1.2 | 23 | 23 | 9.6 | 2.2 | 3.4 |

[1]Concentrations for other radionuclides, in disintegrations per minute per milliliter, are: sodium$^{24}$, 7.9; copper$^{64}$, 7.8; lanthanum$^{140}$, 0.2; and, neptunium$^{239}$, 1.9.

Table 26.--Concentration of radionuclides in filtered Columbia River water at Hood River, Oreg., in disintegrations per minute per milliliter.

| Date | Scandium$^{46}$ x$10^3$ | Chromium$^{51}$ | Zinc$^{65}$ x$10^2$ | Zirconium$^{95}$-Niobium$^{95}$ x$10^3$ | Ruthenium$^{103}$-Rhodium$^{103}$ x$10^2$ | Cerium$^{141}$ x$10^2$ |
|---|---|---|---|---|---|---|
| 1962 | | | | | | |
| [1]July 31 | 4.6 | 3.7 | 1.6 | 1.8 | 1.5 | - |
| Oct. 15 | - | 5.7 | .8 | 2.4 | 1.2 | - |
| 1963 | | | | | | |
| Jan. 8 | 5.2 | 4.1 | 8.7 | 4.8 | 1.2 | - |
| Feb. 12 | 3.8 | 3.1 | .7 | 7.0 | 3.7 | - |
| Mar. 13 | 6.4 | 4.6 | 6.9 | 7.4 | 1.5 | - |
| Mar. 26 | 11 | 7.2 | 8.7 | 15 | 1.3 | - |
| Apr. 10 | 2.3 | 5.2 | 4.0 | 6.9 | 2.2 | - |
| May 1 | 4.5 | 6.0 | 1.9 | 6.7 | 2.5 | - |
| May 21 | .7 | 3.1 | .5 | 2.7 | 1.2 | 7.6 |
| June 4 | .6 | 2.8 | 1.8 | 2.5 | .7 | 2.6 |
| June 18 | .4 | 2.2 | .6 | 1.3 | .6 | 5.0 |
| July 9 | .6 | 4.2 | .5 | 2.7 | .7 | 5.4 |
| July 23 | - | 3.6 | .5 | - | - | - |
| Aug. 6 | - | 7.6 | .2 | - | .5 | 8.2 |
| Aug. 26 | - | 7.1 | .4 | 1.0 | .9 | 3.8 |
| Sept. 10 | 2.1 | 10 | .2 | .6 | .8 | 1.6 |
| Sept. 24 | 2.2 | 8.9 | .4 | 1.0 | 1.0 | .5 |
| Oct. 8 | 2.6 | 8.7 | .6 | 1.6 | 1.2 | .2 |

[1]Concentrations for other radionuclides, in disintegrations per minute per milliliter, are: manganese$^{54}$, 0.9; and, neptunium$^{239}$, 180.

Table 27.--Concentration of radionuclides in filtered Columbia River water at Vancouver, Wash., in disintegrations per minute per milliliter.

| Date | Scandium$^{46}$ x$10^3$ | Chromium$^{51}$ | Zinc$^{65}$ x$10^2$ | Zirconium$^{95}$-Niobium$^{95}$ x$10^3$ | Ruthenium$^{103}$-Rhodium$^{103}$ x$10^2$ | Cerium$^{141}$ x$10^2$ |
|---|---|---|---|---|---|---|
| 1962 | | | | | | |
| [1]July 24 | 2.3 | 2.2 | 1.8 | 1.9 | 0.7 | - |
| Oct. 8 | - | 5.5 | .4 | 2.7 | 1.2 | - |
| 1963 | | | | | | |
| Jan. 16 | 5.0 | 4.4 | 8.6 | 7.2 | 1.2 | - |
| Feb. 19 | 2.6 | 2.6 | 2.0 | 6.4 | 3.2 | - |
| Mar. 12 | 5.5 | 5.3 | 3.5 | 7.0 | 1.7 | - |
| Mar. 25 | 9.5 | 5.7 | 7.7 | 12 | 1.0 | - |
| Apr. 9 | 2.9 | 5.1 | 5.0 | 9.2 | 1.8 | - |
| Apr. 30 | 4.1 | 5.2 | 2.2 | 6.0 | 1.8 | - |
| May 14 | 1.5 | 3.2 | 1.0 | 4.0 | 1.3 | 4.8 |
| May 28 | 1.9 | 3.0 | .8 | 3.4 | 1.1 | 3.9 |
| June 11 | .6 | 2.2 | 1.3 | 2.9 | .6 | 2.7 |
| July 8 | .4 | 2.6 | .6 | 3.1 | .6 | 2.8 |
| July 22 | - | 2.9 | .5 | - | - | - |
| Aug. 5 | - | 6.2 | .4 | - | - | - |
| Aug. 27 | - | 5.5 | .5 | 1.3 | .9 | 4.0 |
| Sept. 9 | - | 5.3 | .3 | .6 | .8 | 3.2 |
| Sept. 23 | 1.4 | 9.5 | .4 | 1.7 | 1.0 | .5 |
| Oct. 7 | 2.1 | 5.0 | .5 | 1.0 | 1.1 | .5 |

[1]Concentrations for other radionuclides, in disintegrations per minute per milliliter, are: manganese$^{54}$, 0.8; and, neptunium$^{239}$, 120.

Table 28.--Concentration of radionuclides in sediment filtered from Columbia River water at Pasco, Wash., in disintegrations per minute per gram.

| Date | Scandium$^{46}$ | Chromium$^{51}$ | Zinc$^{65}$ | Zirconium$^{95}$-Niobium$^{95}$ | Ruthenium$^{103}$-Rhodium$^{103}$ | Cerium$^{141}$ |
|---|---|---|---|---|---|---|
| 1962 | | | | | | |
| [1]Aug. 14 | 30,000 | 340,000 | 59,000 | 8,700 | 3,200 | - |
| Oct. 30 | 20,000 | 250,000 | 38,000 | 21,000 | 11,000 | 12,000 |
| 1963 | | | | | | |
| Jan. 9 | 20,000 | 200,000 | 54,000 | 7,700 | 6,600 | 6,600 |
| Feb. 13 | 4,100 | 29,000 | 11,000 | 2,400 | 900 | 1,400 |
| Mar. 4 | 15,000 | 140,000 | 27,000 | 3,000 | 1,700 | 4,300 |
| Mar. 18 | 34,000 | 190,000 | 39,000 | 4,400 | 1,600 | - |
| Apr. 3 | 6,900 | 50,000 | 14,000 | 2,400 | 900 | - |
| May 6 | 10,000 | 74,000 | 16,000 | 3,200 | 800 | 8,400 |
| May 21 | 7,300 | 63,000 | 20,000 | 4,900 | 1,000 | 5,200 |
| June 4 | 4,200 | 43,000 | 8,200 | 1,500 | 400 | 2,600 |
| June 17 | 2,000 | 18,000 | 4,500 | 830 | 200 | 1,200 |
| July 9 | 2,600 | 36,000 | 6,100 | 1,400 | 300 | 2,600 |
| July 22 | 6,700 | 85,000 | 14,000 | 2,800 | 400 | 4,600 |
| Aug. 6 | 4,400 | 64,000 | 15,000 | 3,000 | 1,500 | 6,300 |
| Aug. 26 | 12,000 | 230,000 | 19,000 | 2,900 | 1,300 | 6,500 |
| Sept. 10 | 19,000 | 390,000 | 46,000 | 6,600 | 900 | 13,000 |
| Sept. 25 | 39,000 | 420,000 | 46,000 | 12,000 | 3,100 | 3,600 |
| Oct. 7 | 19,000 | 350,000 | 33,000 | 3,500 | 1,100 | 2,300 |

[1]Concentrations for other radionuclides, in disintegrations per minute per gram, are: copper$^{64}$, 570,000; lanthanum$^{140}$, 180,000; and, neptunium$^{239}$, 110,000.

Table 29.--Concentration of radionuclides in sediment filtered from Columbia River water at Hood River, Oreg., in disintegrations per minute per gram.

| Date | $Scandium^{46}$ | $Chromium^{51}$ | $Zinc^{65}$ | $Zirconium^{95}$-$Niobium^{95}$ | $Ruthenium^{103}$-$Rhodium^{103}$ | $Cerium^{141}$ |
|---|---|---|---|---|---|---|
| 1962 | | | | | | |
| [1] July 31 | 800 | 8,000 | 3,100 | 300 | 100 | - |
| Oct. 15 | - | 22,000 | 3,700 | 600 | 400 | - |
| 1963 | | | | | | |
| Jan. 8 | 1,800 | 19,000 | 7,200 | 1,200 | 300 | 2,500 |
| Feb. 12 | 20 | 300 | 200 | 80 | 30 | 30 |
| Mar. 13 | 1,400 | 18,000 | 6,800 | 1,100 | 400 | 500 |
| Mar. 26 | 1,500 | 19,000 | 8,400 | 1,300 | 500 | - |
| Apr. 10 | 1,500 | 18,000 | 10,000 | 1,600 | 500 | - |
| May 1 | 1,100 | 12,000 | 5,700 | 1,000 | 300 | - |
| May 21 | 700 | 7,800 | 5,400 | 900 | 300 | 1,500 |
| June 4 | 400 | 5,500 | 2,300 | 400 | 200 | 500 |
| June 18 | 400 | 5,000 | 2,400 | 300 | 100 | 500 |
| July 9 | 900 | 13,000 | 5,800 | 1,000 | 400 | 2,300 |
| July 23 | 900 | 14,000 | 5,700 | 600 | 100 | 600 |
| Aug. 6 | 1,000 | 27,000 | 7,000 | 600 | 200 | 1,100 |
| Aug. 26 | 700 | 28,000 | 5,300 | 600 | 100 | 800 |
| Sept. 10 | 400 | 22,000 | 2,600 | 300 | 80 | 40 |
| Sept. 24 | 700 | 45,000 | 4,600 | 700 | 200 | - |
| Oct. 8 | 900 | 41,000 | 4,000 | 600 | 300 | 100 |

[1] Concentrations for other radionuclides, in disintegrations per minute per gram, are: $manganese^{54}$, 200; and, $neptunium^{239}$, 100.

Table 30.--Concentration of radionuclides in sediment filtered from Columbia River water at Vancouver, Wash., in disintegrations per minute per gram.

| Date | Scandium[46] | Chromium[51] | Zinc[65] | Zirconium[95]-Niobium[95] | Ruthenium[103]-Rhodium[103] | Cerium[141] |
|---|---|---|---|---|---|---|
| 1962 | | | | | | |
| [1]July 24 | 600 | 5,600 | 2,900 | 200 | 90 | - |
| Oct. 8 | - | 19,000 | 2,000 | 1,200 | 900 | - |
| 1963 | | | | | | |
| Jan. 16 | 1,000 | 12,000 | 3,600 | 1,300 | 300 | 500 |
| Feb. 19 | 80 | 700 | 700 | 100 | 200 | 40 |
| Mar. 12 | 1,100 | 16,000 | 5,300 | 1,400 | 500 | 500 |
| Mar. 25 | 1,400 | 21,000 | 7,200 | 1,400 | 500 | - |
| Apr. 9 | 1,500 | 21,000 | 8,800 | 2,400 | 800 | - |
| Apr. 30 | 900 | 11,000 | 4,300 | 800 | 300 | - |
| May 14 | 1,200 | 18,000 | 5,000 | 900 | 200 | 200 |
| May 28 | 300 | 5,900 | 2,200 | 300 | 200 | 500 |
| June 11 | 300 | 4,400 | 2,000 | 300 | 100 | 400 |
| July 8 | 600 | 7,700 | 3,500 | 600 | 200 | 1,000 |
| July 22 | 500 | 8,800 | 3,200 | 400 | 100 | 400 |
| Aug. 5 | 500 | 18,000 | 4,300 | 400 | 100 | 600 |
| Aug. 27 | 500 | 25,000 | 3,300 | 400 | 100 | 400 |
| Sept. 9 | 200 | 12,000 | 1,400 | 200 | 500 | 80 |
| Sept. 23 | 200 | 17,000 | 1,400 | 200 | 50 | - |
| Oct. 7 | 400 | 26,000 | 2,400 | 400 | 200 | - |

[1]Concentrations for other radionuclides, in disintegrations per minute per gram, are: manganese[54], 200; and, neptunium[239], 200.

Table 31.--Concentration of radionuclides in sediment from streambed of the Columbia River at Pasco, Wash., in disintegrations per minute per gram.

| Date | Scandium[46] Section Middle | Scandium[46] Section Ends | Chromium[51] Section Middle | Chromium[51] Section Ends | Zinc[65] Section Middle | Zinc[65] Section Ends | Cobalt[60] Section Middle | Cobalt[60] Section Ends | Manganese[54] Section Middle | Manganese[54] Section Ends |
|---|---|---|---|---|---|---|---|---|---|---|
| 1962 | | | | | | | | | | |
| Aug. 14 | 40 | 40 | 130 | 320 | 920 | 690 | 80 | 40 | - | - |
| Oct. 30 | - | 190 | - | 2,800 | - | 1,600 | - | 90 | - | - |
| 1963 | | | | | | | | | | |
| Feb. 13 | 40 | 200 | - | - | 1,100 | 3,600 | 70 | 210 | 90 | 220 |
| Mar. 4 | 40 | 130 | - | - | 1,100 | 3,100 | 80 | 170 | 90 | 160 |
| Mar. 18 | 50 | 590 | - | - | 1,100 | 6,100 | 70 | 200 | 100 | 450 |
| Apr. 3 | 50 | 1,000 | - | - | 1,200 | 6,500 | 80 | 180 | 100 | 390 |
| May 6 | 50 | - | - | - | 1,400 | - | 70 | - | 110 | - |
| May 21 | 40 | 180 | - | - | 1,200 | 2,800 | 80 | 110 | 110 | 220 |
| June 4 | 20 | 30 | - | - | 660 | 1,100 | 50 | 70 | 50 | 100 |
| June 17 | 20 | - | - | - | 750 | - | 60 | - | 60 | - |
| July 9 | 20 | - | - | - | 820 | - | 60 | - | 80 | - |
| July 22 | 30 | - | - | - | 880 | - | 60 | - | 70 | - |
| Aug. 6 | 30 | 180 | 120 | 2,500 | 970 | 1,800 | 70 | 120 | 80 | 130 |
| Aug. 26 | 30 | 60 | 200 | 1,100 | 810 | 1,100 | 60 | 60 | 60 | 50 |
| Sept. 10 | 40 | 140 | 260 | 2,300 | 970 | 4,300 | 70 | 370 | 60 | 150 |
| Sept. 25 | 40 | 230 | 460 | 4,800 | 920 | 2,600 | 60 | 160 | 60 | 170 |
| Oct. 7 | 90 | 710 | 1,400 | 15,000 | 1,000 | 3,500 | 70 | 120 | 90 | 310 |

Table 32.--Concentration of radionuclides in sediment from streambed of the Columbia River at Hood River, Oreg., in disintegrations per minute per gram.

| Date | Scandium$^{46}$ Main channel | Scandium$^{46}$ Near shore channel | Chromium$^{51}$ Main channel | Chromium$^{51}$ Near shore channel | Zinc$^{65}$ Main channel | Zinc$^{65}$ Near shore channel | Cobalt$^{60}$ Main channel | Cobalt$^{60}$ Near shore channel |
|---|---|---|---|---|---|---|---|---|
| 1962 | | | | | | | | |
| July 31 | 2 | 4 | 40 | 110 | 60 | 170 | 2 | 10 |
| Oct. 15 | 6 | 18 | 150 | 500 | 90 | 280 | 2 | 13 |
| 1963 | | | | | | | | |
| Jan. 8 | 9 | - | 130 | - | 120 | - | 4 | - |
| Feb. 12 | 5 | - | 70 | - | 130 | - | 3 | - |
| Mar. 13 | 17 | - | - | - | 310 | - | 7 | - |
| Mar. 26 | 24 | - | - | - | 370 | - | 8 | - |
| Apr. 10 | 18 | 23 | - | - | 350 | 500 | 8 | 16 |
| May 1 | 2 | 72 | - | - | 430 | 1,000 | 9 | 24 |
| May 21 | 3 | 16 | - | - | 80 | 400 | 4 | 10 |
| June 4 | .8 | 20 | - | - | 50 | 440 | 2 | 12 |
| June 18 | .9 | - | - | - | 50 | - | 2 | - |
| July 9 | .6 | 8 | - | - | 40 | 290 | 1 | 7 |
| July 23 | 1 | 8 | - | - | 40 | 160 | 1 | 6 |
| Aug. 6 | 3 | 8 | 150 | 340 | 60 | 110 | 2 | 4 |
| Aug. 26 | 4 | 9 | 220 | 420 | 80 | 180 | 2 | 8 |
| Sept. 10 | 6 | 7 | 270 | 340 | 90 | 120 | 2 | 5 |
| Sept. 24 | 7 | 12 | 360 | 880 | 100 | 260 | 2 | 11 |
| Oct. 8 | 8 | 11 | 410 | 920 | 110 | 200 | 3 | 6 |

Table 33.--Concentration of radionuclides in sediment from streambed of the Columbia River at Vancouver, Wash., in disintegrations per minute per gram.

| Date | Scandium$^{46}$ North channel | Scandium$^{46}$ South channel[a] | Chromium$^{51}$ North channel | Chromium$^{51}$ South channel[a] | Zinc$^{65}$ North channel | Zinc$^{65}$ South channel[a] | Cobalt$^{60}$ North channel | Cobalt$^{60}$ South channel[a] |
|---|---|---|---|---|---|---|---|---|
| 1962 | | | | | | | | |
| July 24 | 0.3 | 0.1 | - | - | 20 | 20 | 0.4 | 0.2 |
| Oct. 8 | .4 | 1 | 30 | 50 | 20 | 30 | .3 | .6 |
| 1963 | | | | | | | | |
| Jan. 16 | .5 | 2 | 20 | 50 | 40 | 60 | .6 | 1 |
| Feb. 19 | .4 | 2 | 10 | 40 | 20 | 50 | .5 | 1 |
| Mar. 12 | .7 | 1 | - | - | 40 | 70 | .7 | 1 |
| Mar. 25 | 1 | 3 | - | - | 60 | 100 | .8 | 2 |
| Apr. 9 | 1 | 4 | - | - | 60 | 180 | 1 | 2 |
| Apr. 30 | .9 | 2 | - | - | 50 | 90 | .9 | 1 |
| May 14 | [b]2 | | - | - | [b]60 | | [b]1 | |
| May 28 | .7 | 10 | - | - | 30 | 250 | .8 | 5 |
| June 11 | .6 | .8 | - | - | 20 | 30 | .7 | .9 |
| July 8 | .4 | .7 | - | - | 30 | 40 | .4 | .8 |
| July 22 | .5 | 2 | - | - | 30 | 50 | .5 | 1 |
| Aug. 5 | .6 | 2 | 40 | 140 | 30 | 50 | .7 | 1 |
| Aug. 27 | .5 | 3 | 50 | 150 | 20 | 70 | .5 | 1 |
| Sept. 9 | .5 | 3 | 50 | 260 | 20 | 60 | .5 | 1 |
| Sept. 23 | .7 | 5 | 80 | 420 | 20 | 90 | .5 | 2 |
| Oct. 7 | .5 | 5 | 60 | 480 | 20 | 80 | .5 | 2 |

[a]One sample through April 1963 and three samples thereafter.
[b]North and South channels combined.

Table 34.--Radionuclide content in water and sediment from the Snake and Willamette Rivers.

| Radionuclide | Concentration | | |
|---|---|---|---|
| | Filtered water (dpm/ml) | Suspended sediment (dpm/g) | Streambed sediment (dpm/g) |
| Snake River at Pasco, Wash., Sept. 25, 1962 | | | |
| Chromium$^{51}$ | $10^{-2}$ | $5x10^{3}$ | - |
| Zinc$^{65}$ | $10^{-3}$ | $7x10^{3}$ | - |
| Zirconium$^{95}$-Niobium$^{95}$ | $10^{-3}$ | $9x10^{2}$ | 1 |
| Ruthenium$^{103}$-Rhodium$^{103}$ | $5x10^{-3}$ | $5x10^{2}$ | 1 |
| Willamette River at Portland, Oreg., Oct. 1, 1962 | | | |
| Chromium$^{51}$ | $6x10^{-3}$ | $5x10^{2}$ | - |
| Zinc$^{65}$ | $10^{-3}$ | $10^{2}$ | - |
| Zirconium$^{95}$-Niobium$^{95}$ | $10^{-3}$ | $2x10^{2}$ | .9 |
| Ruthenium$^{103}$-Rhodium$^{103}$ | $2x10^{-3}$ | $2x10^{2}$ | .4 |

Table 35.--Estimated discharges and mean concentrations of radionuclides as solutes for the Columbia River at Pasco, Wash.

| Time period | Chromium[51] Total discharge (curies) | Chromium[51] [1]Mean conc. (dpm/ml) | Zinc[65] Total discharge (curies) | Zinc[65] [1]Mean conc. (dpm/ml X10[3]) | Scandium[46] Total discharge (curies) | Scandium[46] [1]Mean conc. (dpm/ml X10[4]) | Zirconium[95]-Niobium[95] Total discharge (curies) | Zirconium[95]-Niobium[95] [1]Mean conc. (dpm/ml X10[4]) | Ruthenium[103]-Rhodium[103] Total discharge (curies) | Ruthenium[103]-Rhodium[103] [1]Mean conc. (dpm/ml X10[2]) | Cerium[141] Total discharge (curies) | Cerium[141] [1]Mean conc. (dpm/ml X10[2]) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1963 | | | | | | | | | | | | |
| January | 21,000 | 7 | 450 | 2 | 43 | 2 | 60 | 2 | 60 | 2 | - | - |
| February | 21,000 | 8 | 860 | 3 | 57 | 2 | 61 | 2 | 110 | 4 | - | - |
| March | 33,000 | 12 | 1,700 | 6 | 75 | 3 | 100 | 4 | 65 | 2 | - | - |
| April | 37,000 | 11 | 1,900 | 6 | 47 | 1 | 89 | 3 | 75 | 2 | - | - |
| May | 30,000 | 6 | 1,500 | 3 | 29 | .6 | 67 | 1 | 57 | 1 | 250 | 5 |
| June | 39,000 | 4 | 1,300 | 2 | 34 | .4 | 71 | .8 | 71 | .8 | 270 | 3 |
| July | 47,000 | 7 | 1,000 | 2 | 21 | .3 | 49 | .7 | 50 | .7 | 350 | 5 |
| August | 44,000 | 12 | 390 | 1 | 7 | .2 | 17 | .5 | 33 | .9 | 310 | 8 |
| September | 46,000 | 19 | 410 | 2 | 21 | .9 | 15 | .6 | 42 | 2 | 89 | 4 |
| Total | 318,000 | - | 9,500 | - | 330 | - | 530 | - | 560 | - | - | - |
| Average | - | 8 | - | 2 | - | 0.9 | - | 1 | - | 2 | - | - |

[1]Weighted with water discharge.

Table 36.--Estimated discharges and mean concentrations of radionuclides as solutes for the Columbia River at Hood River, Oreg.

| Time period | Chromium[51] | | Zinc[65] | | Scandium[46] | | Zirconium[95]-Niobium[95] | | Ruthenium[103]-Rhodium[103] | | Cerium[141] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total discharge (curies) | [1]Mean conc. (dpm/ml) | Total discharge (curies) | [1]Mean conc. (dpm/ml X10[2]) | Total discharge (curies) | [1]Mean conc. (dpm/ml X10[3]) | Total discharge (curies) | [1]Mean conc. (dpm/ml X10[3]) | Total discharge (curies) | [1]Mean conc. (dpm/ml X10[2]) | Total discharge (curies) | [1]Mean conc. (dpm/ml X10[2]) |
| 1963 | | | | | | | | | | | | |
| January | 17,000 | 4 | 200 | 5 | 20 | 5 | 23 | 5 | 84 | 2 | - | - |
| February | 16,000 | 3 | 160 | 3 | 25 | 5 | 34 | 7 | 130 | 2 | - | - |
| March | 22,000 | 5 | 260 | 6 | 33 | 7 | 45 | 10 | 81 | 2 | - | - |
| April | 31,000 | 6 | 200 | 4 | 25 | 4 | 45 | 8 | 120 | 2 | - | - |
| May | 30,000 | 3 | 110 | 1 | 16 | 2 | 35 | 4 | 130 | 2 | 390 | 4 |
| June | 33,000 | 2 | 120 | .9 | 7 | .5 | 26 | 2 | 86 | .7 | 580 | 4 |
| July | 34,000 | 4 | 41 | .5 | 3 | .4 | 21 | 2 | 33 | .4 | 430 | 6 |
| August | 34,000 | 7 | 16 | .3 | 1 | .2 | 3 | .6 | 28 | .6 | 260 | 6 |
| September | 33,000 | 10 | 12 | .3 | 6 | 2 | 3 | .9 | 30 | .9 | 47 | 1 |
| Total | 250,000 | - | 1,100 | - | 140 | - | 240 | - | 720 | - | - | - |
| Average | - | 4 | - | 2 | - | 2 | - | 4 | - | 1 | - | - |

[1]Weighted with water discharge.

Table 37.--Estimated discharges and mean concentrations of radionuclides as solutes for the Columbia River at Vancouver, Wash.

| Time period | Chromium[51] Total discharge (curies) | Chromium[51] [1]Mean conc. (dpm/ml) | Zinc[65] Total discharge (curies) | Zinc[65] [1]Mean conc. (dpm/ml X10[2]) | Scandium[46] Total discharge (curies) | Scandium[46] [1]Mean conc. (dpm/ml X10[3]) | Zirconium[95]-Niobium[95] Total discharge (curies) | Zirconium[95]-Niobium[95] [1]Mean conc. (dpm/ml X10[3]) | Ruthenium[103]-Rhodium[103] Total discharge (curies) | Ruthenium[103]-Rhodium[103] [1]Mean conc. (dpm/ml X10[2]) | Cerium[141] Total discharge (curies) | Cerium[141] [1]Mean conc. (dpm/ml X10[2]) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1963 | | | | | | | | | | | | |
| January | 20,000 | 4 | 260 | 5 | 19 | 4 | 35 | 7 | 83 | 2 | - | - |
| February | 19,000 | 3 | 200 | 3 | 23 | 4 | 40 | 7 | 140 | 2 | - | - |
| March | 26,000 | 5 | 250 | 5 | 32 | 6 | 46 | 9 | 91 | 2 | - | - |
| April | 33,000 | 5 | 260 | 4 | 28 | 4 | 53 | 8 | 100 | 2 | - | - |
| May | 34,000 | 4 | 120 | 1 | 20 | 2 | 40 | 4 | 120 | 1 | 330 | 3 |
| June | 31,000 | 2 | 120 | .8 | 11 | .8 | 42 | 3 | 100 | .7 | 430 | 3 |
| July | 29,000 | 3 | 58 | .6 | .2 | .02 | 24 | 2 | 64 | .7 | 280 | 3 |
| August | 29,000 | 5 | 25 | .5 | .1 | .2 | 5 | .9 | 44 | .8 | 180 | 3 |
| September | 26,000 | 7 | 16 | .4 | 4 | .1 | 4 | .1 | 37 | 1 | 78 | 2 |
| Total | 250,000 | - | 1,300 | - | 140 | - | 290 | - | 790 | - | - | - |
| Average | - | 4 | - | 2 | - | 2 | - | 4 | - | 1 | - | - |

[1]Weighted with water discharge.

Table 38.--Estimated discharges and mean concentrations of radionuclides associated with sediments for the Columbia River at Pasco, Wash.

| Time period | Chromium$^{51}$ | | Zinc$^{65}$ | | Scandium$^{46}$ | | Zirconium$^{95}$-Niobium$^{95}$ | | Ruthenium$^{103}$-Rhodium$^{103}$ | | Cerium$^{141}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) |
| 1963 | | | | | | | | | | | | |
| January | 1,100 | 94,000 | 370 | 31,000 | 150 | 12,000 | 89 | 7,300 | 50 | 4,100 | 59 | 4,900 |
| February | 1,200 | 22,000 | 320 | 6,000 | 140 | 3,000 | 56 | 1,000 | 27 | 500 | 46 | 800 |
| March | 1,200 | 98,000 | 270 | 22,000 | 170 | 14,000 | 38 | 3,000 | 16 | 1,300 | 39 | 3,100 |
| April | 1,600 | 55,000 | 400 | 13,000 | 230 | 8,000 | 73 | 2,500 | 24 | 800 | 56 | 1,900 |
| May | 2,100 | 39,000 | 530 | 10,000 | 240 | 4,000 | 110 | 2,100 | 28 | 500 | 170 | 3,200 |
| June | 3,100 | 22,000 | 480 | 3,000 | 300 | 2,000 | 130 | 900 | 31 | 200 | 210 | 1,500 |
| July | 2,800 | 50,000 | 500 | 9,000 | 220 | 4,000 | 100 | 1,900 | 21 | 400 | 180 | 3,300 |
| August | 3,100 | 170,000 | 350 | 19,000 | 200 | 11,000 | 59 | 3,200 | 22 | 1,200 | 120 | 6,800 |
| September | 3,700 | 370,000 | 390 | 40,000 | 240 | 25,000 | 72 | 7,400 | 17 | 1,700 | 76 | 7,800 |
| Total | 20,000 | - | 3,600 | - | 1,900 | - | 730 | - | 240 | - | 960 | - |
| Average | - | 52,000 | - | 9,000 | - | 5,000 | - | 1,900 | - | 600 | - | 2,500 |

[1]Weighted with sediment discharge.

Table 39.--Estimated discharges and mean concentrations of radionuclides associated with sediments for the Columbia River at Hood River, Oreg.

| Time period | Chromium$^{51}$ | | Zinc$^{65}$ | | Scandium$^{46}$ | | Zirconium$^{95}$-Niobium$^{95}$ | | Ruthenium$^{103}$-Rhodium$^{103}$ | | Cerium$^{141}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) |
| 1963 | | | | | | | | | | | | |
| January | 700 | 27,000 | 300 | 12,000 | 53 | 2,100 | 88 | 3,400 | 30 | 1,200 | 87 | 3,400 |
| February | 900 | 1,000 | 400 | 500 | 69 | 80 | 120 | 100 | 42 | 50 | 63 | 80 |
| March | 1,000 | 18,000 | 400 | 8,000 | 77 | 1,400 | 89 | 1,600 | 30 | 600 | 23 | 400 |
| April | 1,800 | 13,000 | 900 | 7,000 | 160 | 1,200 | 170 | 1,200 | 50 | 400 | 13 | 100 |
| May | 2,600 | 7,000 | 1,400 | 4,000 | 240 | 600 | 250 | 700 | 92 | 200 | 240 | 600 |
| June | 3,400 | 6,000 | 1,500 | 2,000 | 250 | 400 | 230 | 400 | 96 | 200 | 410 | 700 |
| July | 2,000 | 12,000 | 800 | 5,000 | 130 | 800 | 110 | 700 | 37 | 200 | 220 | 1,400 |
| August | 1,500 | 23,000 | 300 | 5,000 | 48 | 700 | 35 | 500 | 9 | 100 | 47 | 700 |
| September | 900 | 31,000 | 100 | 4,000 | 18 | 600 | 15 | 500 | 4 | 100 | 7 | 200 |
| Total | 15,000 | - | 6,300 | - | 1,000 | - | 1,100 | - | 390 | - | 1,100 | - |
| Average | - | 6,000 | - | 3,000 | - | 400 | - | 500 | - | 200 | - | 500 |

[1]Weighted with sediment discharge.

Table 40.--Estimated discharges and mean concentrations of radionuclides associated with sediments for the Columbia River at Vancouver, Wash.

| Time period | Chromium[51] | | Zinc[65] | | Scandium[46] | | Zirconium[95]-Niobium[95] | | Ruthenium[103]-Rhodium[103] | | Cerium[141] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) | Total discharge (curies) | [1]Mean conc. (dpm/g) |
| 1963 | | | | | | | | | | | | |
| January | 700 | 14,000 | 300 | 5,000 | 55 | 1,100 | 76 | 1,400 | 46 | 900 | 26 | 500 |
| February | 900 | 1,000 | 400 | 500 | 74 | 90 | 100 | 100 | 66 | 80 | 38 | 40 |
| March | 1,100 | 14,000 | 400 | 5,000 | 80 | 1,000 | 100 | 1,200 | 46 | 600 | 40 | 500 |
| April | 2,000 | 15,000 | 800 | 6,000 | 150 | 1,100 | 170 | 1,200 | 57 | 400 | 98 | 700 |
| May | 4,400 | 9,000 | 1,500 | 3,000 | 290 | 600 | 260 | 600 | 82 | 200 | 500 | 1,100 |
| June | 4,300 | 4,000 | 1,600 | 1,000 | 290 | 200 | 290 | 200 | 97 | 80 | 440 | 400 |
| July | 2,200 | 6,000 | 900 | 3,000 | 140 | 400 | 130 | 400 | 42 | 100 | 190 | 600 |
| August | 1,500 | 17,000 | 300 | 3,000 | 38 | 400 | 31 | 400 | 14 | 200 | 37 | 400 |
| September | 900 | 17,000 | 90 | 2,000 | 12 | 200 | 13 | 200 | 14 | 300 | 4 | 80 |
| Total | 18,000 | - | 6,300 | - | 1,100 | - | 1,200 | - | 460 | - | 1,400 | - |
| Average | - | 6,000 | - | 2,000 | - | 300 | - | 400 | - | 100 | - | 400 |

[1]Weighted with sediment discharge.

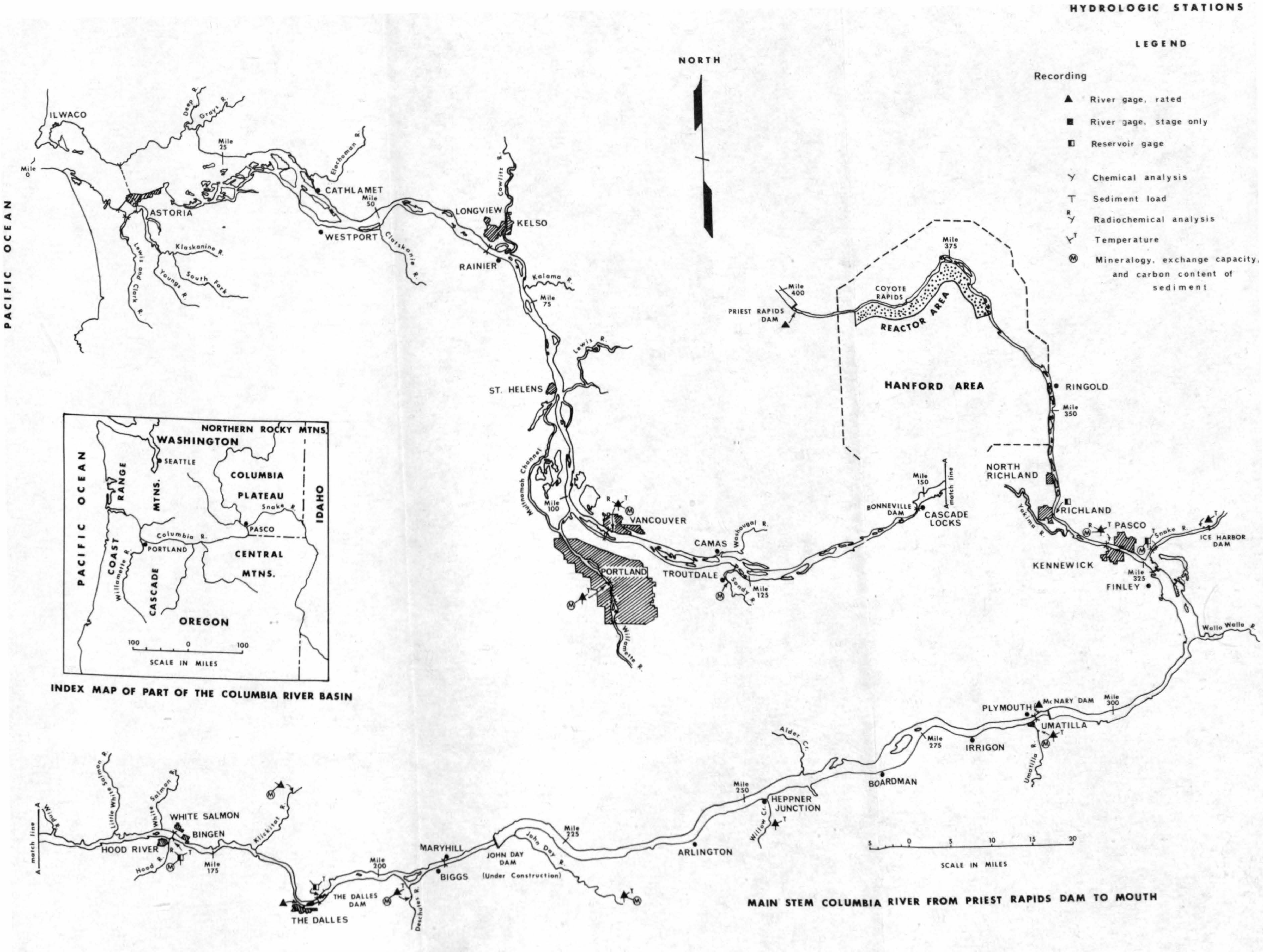

PLATE 1 - MAP OF COLUMBIA RIVER STUDY AREA