Sediment Transport by Streams in the Chehalis River Basin, Washington, October 1961 to September 1965

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1798-H

Prepared in cooperation with the Washington State Department of Water Resources

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By P. A. GLANCY

SEDIMENTATION IN SMALL DRAINAGE BASINS

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1971

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 79-610890

For sale by the Superintendent of Documents, U.S. Government Printing Office
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By P. A. GLANCY

ABSTRACT

The Chehalis River drains an area of about 2,100 square miles in southwestern Washington of which 1,813 square miles is in the study area. The average annual suspended-sediment discharge from the area during the study period (water years 1962–65) was about 540,000 tons; annual loads ranged from 270,000 to 690,000 tons. About 74 percent of the suspended-sediment discharge was derived from the Satsop and Wynoochee River drainage basins which together cover about 450 square miles. Only about 24 percent was carried by the Chehalis River past Porter above which the drainage area is 1,294 square miles. Estimated average annual suspended-sediment yield from tributary basins ranged from 20 to 1,500 tons per square mile.

Variability in sediment yield throughout the Chehalis River basin is attributed both to areal differences in the quantity and intensity of runoff during storm periods and to the variable quantities and characteristics of the sediment available for transport. These factors, in turn, are controlled by geologic and climatic factors and by land-use practices.

Most sediment transported in the basin originates from channel erosion which occurs mostly during storm runoff. During the study period, 90 percent of the suspended-sediment discharge occurred only 5–10 percent of the time at headwater sampling sites and 15–20 percent of the time at the lower main-stem stations. Observed sediment concentrations ranged from less than 1 milligram per liter to 1,220 milligrams per liter, and greatest concentrations were associated with tributary basins of highest yield.

INTRODUCTION

PURPOSE AND SCOPE

Sediment concentrations influence the suitability of water for domestic, industrial, agricultural, and conservation uses. Therefore, knowledge of fluvial-sediment concentrations and transport in a river basin is valuable in planning optimal utilization of the basin.

A reconnaissance investigation of sediment transport in the Chehalis River was made by the U.S. Geological Survey during the 4-year period October 1, 1961, to September 30, 1965 (water years 1962 to 1965, inclusive). The study was made in cooperation with the Washington State Department of Water Resources; its purpose was to develop an understanding of existing conditions of fluvial-sediment transport in the basin and to provide information that is needed for future planning of water-resources utilization. The study involved determination of sediment yield of the basin and its tributary subbasins, seasonal variations in rates of fluvial-sediment discharge, and evaluation of the factors influencing sediment movement.

Most streamflow data used in this report have been published in an annual series by the U.S. Geological Survey (1962, 1963, 1964a, 1965a, and 1966a). Suspended-sediment data collected during the study were published in the annual series (1964b, 1964c, 1965b, and 1966b).

SEDIMENT SAMPLING

The study involved collection of suspended-sediment data at about 20 stations shown on plate 1. Where possible, sampling stations were selected to coincide with streamflow gaging stations, or were located where stream-discharge data could be extrapolated from records of nearby stations. At a few places where streamflow gages were neither present nor nearby, miscellaneous water-discharge measurements were made to develop skeletal stage-discharge relations necessary to compute sediment-transport rates.

Determinations of bedload were not made because accurate techniques are not available. All quantitative determinations of sediment movement were necessarily restricted to the measurable part of the suspended-sediment load.

Sediment samples were collected daily from Chehalis River at Porter (pl. 1). Periodic (monthly) samples were collected at stations on several of the major tributaries and from Chehalis River near Grand Mound. Samples were collected on a reconnaissance basis at the remaining stations. During high-runoff periods, more frequent sampling was selectively done at all stations (pl. 1) to better define characteristics of sediment movement during the critical high-flow periods.

All samples were analyzed for sediment concentration of the water-sediment mixture. Several samples representing the varying flow conditions at most stations were analyzed for particle-size distribution of suspended sediment. The analyses were made by methods standard in the Geological Survey.

ACKNOWLEDGMENTS

This investigation was aided by land-use data furnished by W. R. Spencer of the U.S. Soil Conservation Service. Several aerial photographs were made available by the Washington State Department of Natural Resources. W. V. Frederick, C. A. Onions, M. D. ReMillard, and J. M. Stalp of the Geological Survey provided assistance in the collection and processing of sediment data. Technical review of the manuscript was made by J. C. Mundorff and George Porterfield.

DESCRIPTION OF THE BASIN

The Chehalis River basin has a drainage area of approximately 2,100 square miles in southwestern Washington (pl. 1); of this, an area of 1,813 square miles was studied. Some data also were gathered from the basin of the Wishkah River which drains an area of 102 square miles and joins the Chehalis in the upper estuary of Grays Harbor.

TABLE 1.—*Selected physiographic data for the Chehalis River basin*

Data-collection station (with station No. as on pl. 1)	Drainage area above station[1] (sq mi)	Approximate topographic relief above station (ft)
Chehalis River near Doty (200)	113	2,810
South Fork Chehalis River at Curtis (211)	125	2,900
Lake Creek at Curtis (212)	21.3	1,262
South Fork Newaukum River near Onalaska (240)	42.4	2,660
North Fork Newaukum River near Forest (245)	31.5	2,423
Newaukum River near Chehalis (250	155	3,010
Skookumchuck River at Centralia (266)	181	3,637
Chehalis River near Grand Mound (275)	895	3,692
Black River near Oakville (292)	136	2,605
Chehalis River at Porter (310)	1,294	3,782
Cloquallum Creek (published as Cloquallum River) at Elma (325)	64.9	1,402
East Fork Satsop River near Elma (342)	[2] 81	2,885
Decker Creek near Elma (343)	46.6	3,035
Middle Fork Satsop River near Elma (345)	58.9	3,287
West Fork Satsop River near Satsop (348)	94.9	3,303
Satsop River near Satsop (350)	299	3,340
Wynoochee River above Black Creek, near Montesano (374)	155	5,019
Wishkah River near Aberdeen (380)	102	1,553
Chehalis River study area	[3] 1,813	5,040

[1] Richardson (1962).
[2] Above confluence with Decker Creek.
[3] Stations 310, 325, 350, and 374.

The Chehalis River rises in the hills west of Doty and flows generally eastward to Chehalis where its course turns abruptly toward the north. From near Grand Mound the river flows northwestward to Elma, then westward to Grays Harbor at Aberdeen. The principal tributaries are the South Fork Chehalis River, which heads in the hills southwest of Curtis; the Newaukum and Skookumchuck Rivers, which rise in the foothill extensions of the Cascade Range to the east; and the Satsop and Wynoochee Rivers, which head on the south flanks of the Olympic Mountains.

Most of the basin is low lying; the land surface ranges in altitudes from sea level to about 5,000 feet. Pertinent physiographic data for the basin are given in table 1.

PRECIPITATION AND RUNOFF

The climate in the basin is characterized by warm, wet winters and cool, dry summers. A variable weather pattern within the basin, partly due to orographic controls, results in precipitation that ranges from averages of less than 45 inches per year near Chehalis to more than 220 inches per year in the upper reaches of the Wynoochee River basin (fig. 1). During the winter, the prevailing storm track from southwest to northeast is typified by generally occluded fronts that are influenced by the hills south and west of Doty, Black Hills, foothills of the Cascade Range, and the Olympic Mountains (pl. 1). The influence of these topographic features on the storm fronts results in relatively low precipitation near Chehalis in the rain shadow of the hills to the southwest, in moderately high precipitation in the headwater reaches of the Chehalis, Newaukum, and Skookumchuck Rivers, and in high precipitation in the upper Satsop and Wynoochee drainages.

The general distribution of precipitation and the great areal variability in the intensity of local precipitation during individual storms contribute to the variability of runoff in different parts of the basin (tables 3 and 4). Delayed runoff, caused by storage of precipitation as snow, normally occurs only in the upper parts of the Satsop and Wynoochee River basins.

GEOLOGY

Most of the principal physiographic features of the Chehalis River basin, such as the hills south and west of Doty, the Cascade foothills, Black Hills, and Olympic Mountains (pl. 1), were in existence before Quaternary time. The major drainage patterns of the Chehalis River system probably were also well developed, though possibly not unified and integrated as they are now.

The basin is underlain by a wide variety of lithologic units that

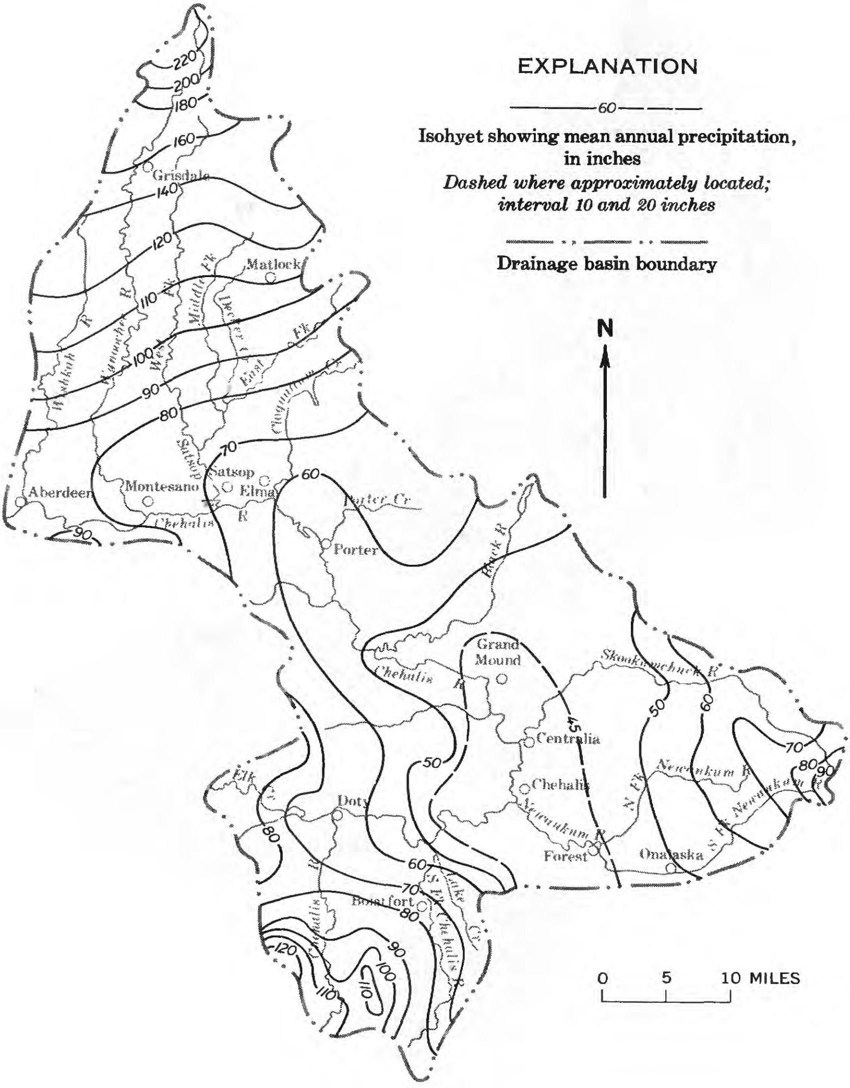


FIGURE 1.—Areal distribution of mean annual precipitation, Chehalis River basin. Prepared by U.S. Weather Bureau, using adjusted climatological data (1930–57) and values derived by correlation with physiographic factors. Published by U.S. Soil Conservation Service (1965).

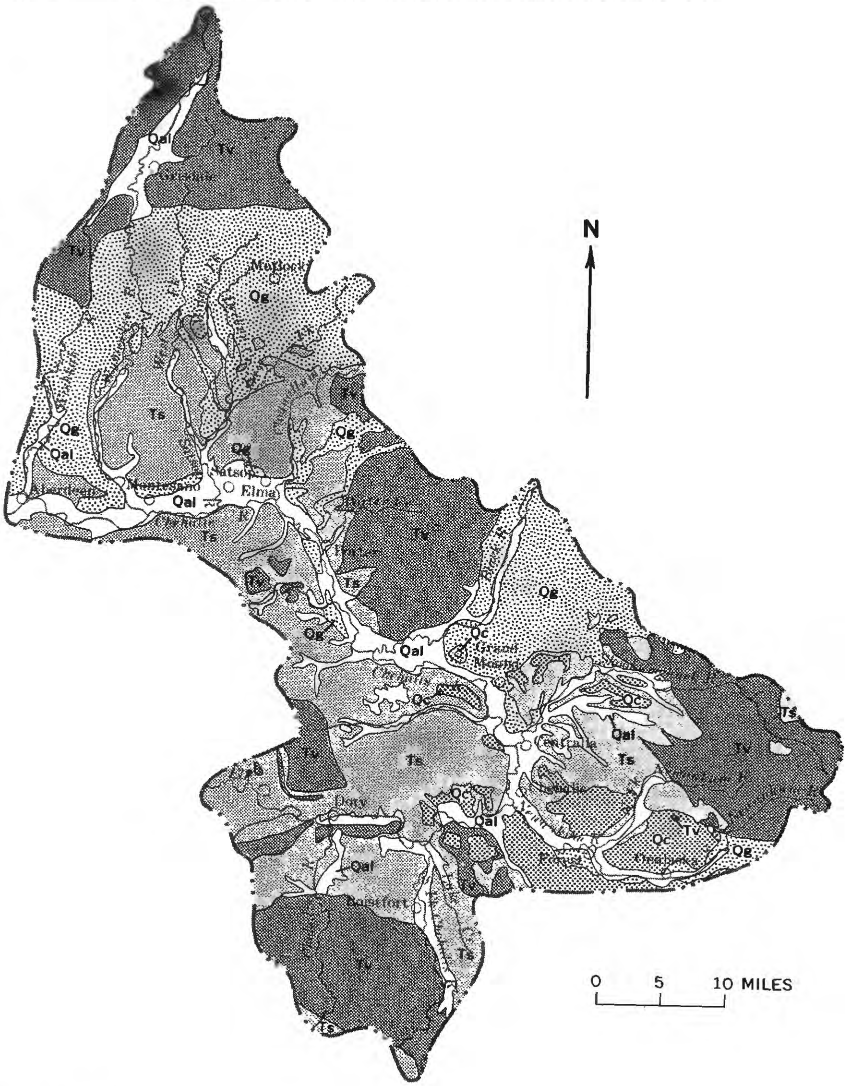


FIGURE 2.—Generalized geology, Chehalis River basin. Geology after Huntting, Bennett, Livingston, and Moen (1961).

EXPLANATION

SURFICIAL DEPOSITS

QUATERNARY

Holocene

Qal

Alluvium

Unconsolidated deposits of silt, sand, and gravel with some clay; include low-level terrace, marsh, and peat deposits, artificial fill, and some localized glacial and landslide deposits. Easily eroded and in close contact with drainage channels

Pleistocene

Qg | Qc

Unconsolidated glacial and marine terrace deposits and consolidated surficial deposits

Qg, *chiefly unconsolidated to partly consolidated glacial deposits, including fluvial and glaciofluvial sand and gravel, silt and clay, till, and outwash. Includes some alluvium. May include marine terrace deposits in the lower Wynoochee and Satsop River drainages possibly as old as late Pliocene. Generally easily eroded except till deposits. In contact with stream channels in many places*

Qc, *cemented heterogenous mixture of volcanic gravel, sand, silt, and clay; contains some till. Deeply weathered locally. Erodibility varies depending on degree of cementation and weathering*

BEDROCK

TERTIARY

Eocene to Pliocene

Ts | Tv

Marine and nonmarine sedimentary rocks, and volcanic rocks with associated sedimentary interbeds

Ts, *marine and nonmarine sedimentary bedrock consisting of conglomeratic sand, and also silt and clay-size particles. Unit ranges widely in composition and degree of induration*

Tv, *chiefly extrusive rocks and associated sedimentary interbeds of wide composition and textural range. Contains a few small intrusive bodies. Unit ranges widely in degree of weathering and erodibility*

Contact

Drainage basin boundary

FIGURE 2.—Continued

reflect the area's complex geologic history. The principal units are igneous and sedimentary rocks of Tertiary age and unconsolidated deposits of Quaternary age, as shown in figure 2.

In most places the bedrock is deeply weathered and a soil mantle of varying thickness has developed. The dense natural vegetation of the region generally protects the soil from sheet and rill erosion; however, mass-wasting processes supply large quantities of material to the stream channels for subsequent removal.

During Quaternary time, alpine and continental glaciation and eustatic changes in sea level exerted major influences on the Chehalis River system—particularly on its sedimentation characteristics. In their upper reaches, the Wynoochee and Satsop Rivers, their tributaries, and Cloquallum Creek flow across extensive areas underlain by unconsolidated debris of glacial origin. Glaciation affected channel and flood-plain morphology and provided large quantities of detritus that became readily available for reworking and transport by fluvial action. The known extent of glaciation in the basin is shown on plate 1.

LAND USE

Land-use practices influence the runoff and erosion characteristics of a drainage basin (Lull and Storey, 1957; Rosa and Craft, 1956; Harris and Rantz, 1964; Fredricksen, 1963). Data on land use in the Chehalis River basin, summarized in table 2, show that the major part of the basin is mantled by forests. Forest-products industries unavoidably alter the natural forest environment and change the natural runoff-erosion regimen as well (Fredricksen, 1963). The percentages of woodland in the various tributary basins of the Chehalis River system are comparable, but the rates of timber harvesting vary between the basins.

Even though most of the farms in the study area are in the bottoms of the main valleys and on the valley sides that have a gentle slope, the effects of farm tillage on sediment yield are presumably small.

Less than 10 percent of the river basin is presently (1966) urbanized. Urbanization and similar human modifications of the natural landscape included under the "miscellaneous" category in table 2 have definite effects on runoff patterns and sediment yields in a drainage basin (Savini and Kammerer, 1961; Harris and Rantz, 1964). Future increases in urbanization and other human activities that modify the natural environment in the Chehalis River basin probably will increase sediment yields and initiate or further aggravate sediment problems.

TABLE 2.—*Land use in the Chehalis River basin in 1966* [1]

Subbasin	Land use (percent of basin area)					
	Cropland	Woodland	Pasture	Urban	Miscellaneous [2]	Idle [3]
Chehalis River above confluence with South Fork Chehalis River	4	94	0	<1	2	0
Newaukum River	16	77	0	1	6	0
Skookumchuck River	6	90	1	1	2	0
Black River	13	71	9	1	6	<1
Cloquallum Creek	8	83	3	<1	4	2
Satsop River	3	87	<1	<1	2	8
Wynoochee River	3	74	<1	2	3	18
Wishkah River	4	74	<1	2	3	17
Remainder of Chehalis River basin	13	73	3	1	4	6

[1] Based on written communication from W. R. Spencer, U.S. Soil Conservation Service, Olympia, Wash., 1966.
[2] Includes roads, gravel pits, parks, and similar areas.
[3] Includes rock outcrops, landslide areas, bluffs, and associated agriculturally unproductive areas.

SEDIMENT-TRANSPORT CHARACTERISTICS

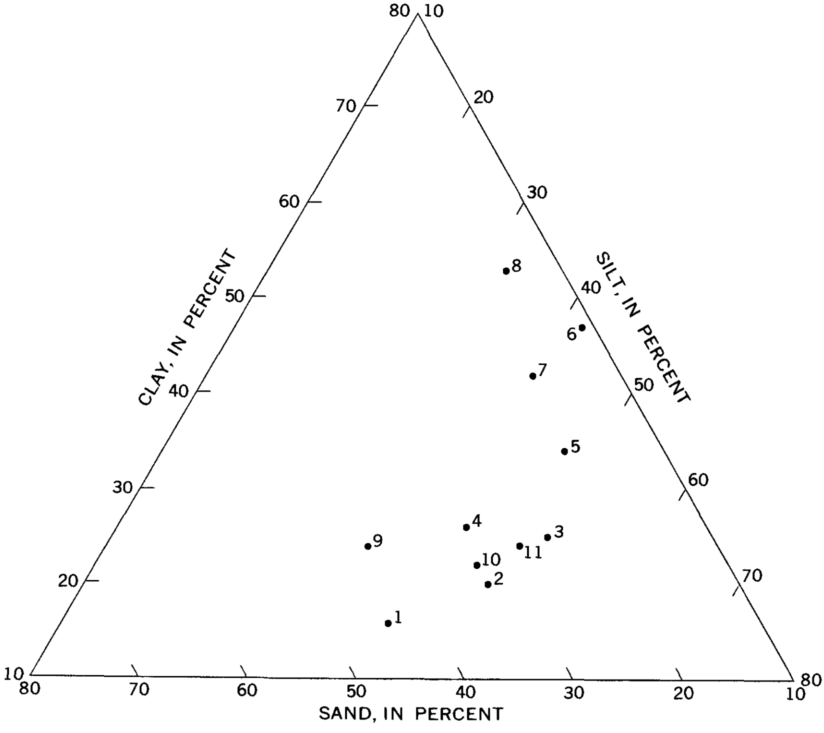
Suspended-sediment discharge varies among the streams in the Chehalis River basin (pl. 1 and table 5), but several general characteristics of transport prevail. A very minor part of the annual sediment discharge occurs during the period from May to October, when runoff is small. The rainy season generally begins early in October, when runoff, surficial flushing, and associated sediment movement

TABLE 3.—*Sediment-transport time*

Station (with station No.)	Time, in percent, during which 90 percent of the annual sediment load was transported
Chehalis River near Doty (200)	5
Newaukum River near Chehalis (250)	10
Chehalis River near Grand Mound (275)	17
Chehalis River at Porter (310)	20
Cloquallum Creek at Elma (325)	15
Satsop River near Satsop (350)	6
Wynoochee River above Black Creek, near Montesano (374)	9
Wishkah River near Aberdeen (380)	5–10

intensify with increasing frequency and intensity of rainstorms. Periods of high runoff occur most frequently during the months of November, December, and January (table 8).

Suspended-sediment concentration for a given storm generally increases as water discharge increases, and the peaks of sediment concentrations in many streams coincide with the peaks of runoff. Exceptions to this pattern occur in the Chehalis River near Grand Mound and at Porter, where sediment-concentration peaks often occur ahead of runoff peaks. At Porter the sediment-concentration peak commonly precedes the runoff peak by about 24 hours and sometimes by as much as 48 hours. Near Grand Mound, the sediment-



1. Chehalis River near Doty (2 samples).
2. South Fork Chehalis River (3 samples).
3. South Fork Newaukum River near Onalaska (4 samples).
4. North Fork Newaukum River near Forest (5 samples).
5. Newaukum River near Chehalis (17 samples).
6. Skookumchuck River at Centralia (2 samples).
7. Chehalis River near Grand Mound (7 samples).
8. Chehalis River at Porter (7 samples).
9. Cloquallum River at Elma (4 samples).
10. Satsop River near Satsop (11 samples).
11. Wynoochee River above Black Creek, near Montesano (14 samples).

FIGURE 3.—Average particle-size distribution of suspended sediment at several sampling sites.

concentration peak usually coincides with peaks of runoff but sometimes precedes it by several hours.

Runoff recessions were normally accompanied by decreases in suspended-sediment concentration at stations where sediment concentration and runoff peaks coincide. The superposition of a new rise in flow upon the recession of the preceding high flow occasionally distorts this pattern.

The basin-wide data obtained during the study period are summarized in tables 3–8. Plate 1 summarizes the sediment yields of the basin, and figure 3 illustrates the distribution of particle sizes in the sediment passing several sampling sites.

CHEHALIS RIVER ABOVE DOTY AND SOUTH FORK CHEHALIS RIVER

The Chehalis River basin above Doty and the South Fork Chehalis River basin above Curtis are the major drainages in the southern part of the study area (pl. 1). The basins have drainage areas of 113 and 125 square miles and total topographic reliefs of 2,810 and 2,900 feet, respectively (table 1). The Chehalis River basin above its confluence with the South Fork Chehalis River is woodland (94 percent) with a minor area of cropland (table 2). The South Fork Chehalis River basin is similarly covered by forests and farmland.

The mean annual precipitation in the Chehalis River basin above Doty ranges from about 65 to more than 120 inches, while in the South Fork Chehalis River basin rainfall ranges from about 50 to more than 100 inches (fig. 1).

Miscellaneous observations suggest that major floods, such as the one of November 25, 1962 (table 6), cause greater peak flows in the Chehalis River than in the South Fork Chehalis River. Data in table 4 show that the peak runoff in the Chehalis River above Doty consistently exceeds that in South Fork Chehalis River at Boistfort. Insofar as the data are comparable, they suggest that the potential for erosion and sediment transport is probably greater in the Chehalis than in the South Fork.

The suspended sediment transported annually from the Chehalis basin above Doty during the period 1962–65 was about 10 percent of the calculated average annual suspended-sediment load transported from the entire Chehalis River basin (table 5). On the basis of the above considerations, an arbitrary value of 8 percent of the total basin yield is assigned to South Fork Chehalis River. Those percentages indicate that the average annual suspended-sediment yield in the Chehalis River basin above Doty is about 470 tons per square mile, whereas the yield in the basin of the South Fork Chehalis River is about 380 tons per square mile. Those yields are greater

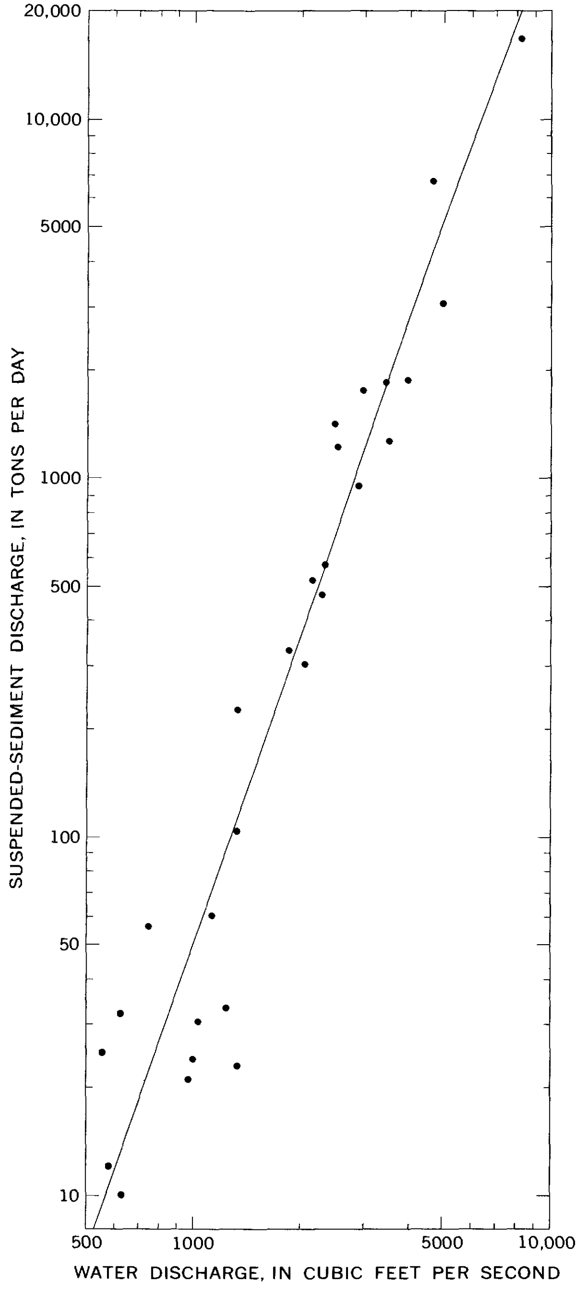


FIGURE 4.—Relation between water discharge and suspended-sediment discharge for Chehalis River near Doty.

than the average for the entire basin (300 tons per sq. mi.) and greater than those of the other upper-basin tributaries.

The relation between water discharge and suspended-sediment discharge for Chehalis River near Doty is shown in figure 4. The greatest annual suspended-sediment discharge of the study period from the subbasin occurred during the 1963 water year (table 5). Much of the year's sediment load was transported by runoff from two floods during the period November 19–28, 1962.

The channel of the Chehalis River near Doty consists of cobbles with interstitial gravel and sand. The cobbles armor the bed and thus retard scour. The bed material probably moves only during very high flows.

The streambed of the South Fork Chehalis River also consists of cobbles with interstitial gravel and sand; however, examination of the streambed during low-flow periods disclosed an abundance of gravel bars which appear to change in size and form during bank-full runoff.

Sediment transported by the Chehalis River above Doty, the South Fork Chehalis River, and their tributaries apparently is derived mainly from the reworking of alluvial materials that were in temporary deposition along major channel reaches and from erosion of residual soils (fig. 2). Interpretation of a detailed geologic map of the area (Pease and Hoover, 1957) suggests that sediment is also derived by erosion of landslide debris that is sporadically or gradually encroaching on stream courses.

Lake Creek, a tributary to South Fork Chehalis River (pl. 1), probably furnishes less than 1 percent of the total sediment load leaving the Chehalis basin (table 5). Few measurements were obtained from Lake Creek during this study.

NEWAUKUM RIVER

The Newaukum River heads in the foothills of the Cascades east of Chehalis and drains about 158 square miles in the southeastern part of the Chehalis River basin (pl. 1). The two principal tributaries of the Newaukum River are the South and North Forks. These tributaries drain 66.2 and 70.8 square miles, respectively. Topographic relief within the Newaukum basin is more than 3,000 feet (table 1), the highest altitude of more than 3,200 feet being in the South Fork drainage. The North Fork drainage has a maximum altitude of about 2,800 feet.

The Newaukum River basin is about 77 percent woodland and 16 percent cropland. The cropland percentage is the greatest of any in the Chehalis River tributary drainages.

Average annual precipitation in the Newaukum River basin ranges from 35 inches at the mouth to about 90 inches in the headwater reach of the South Fork Newaukum River (fig. 1).

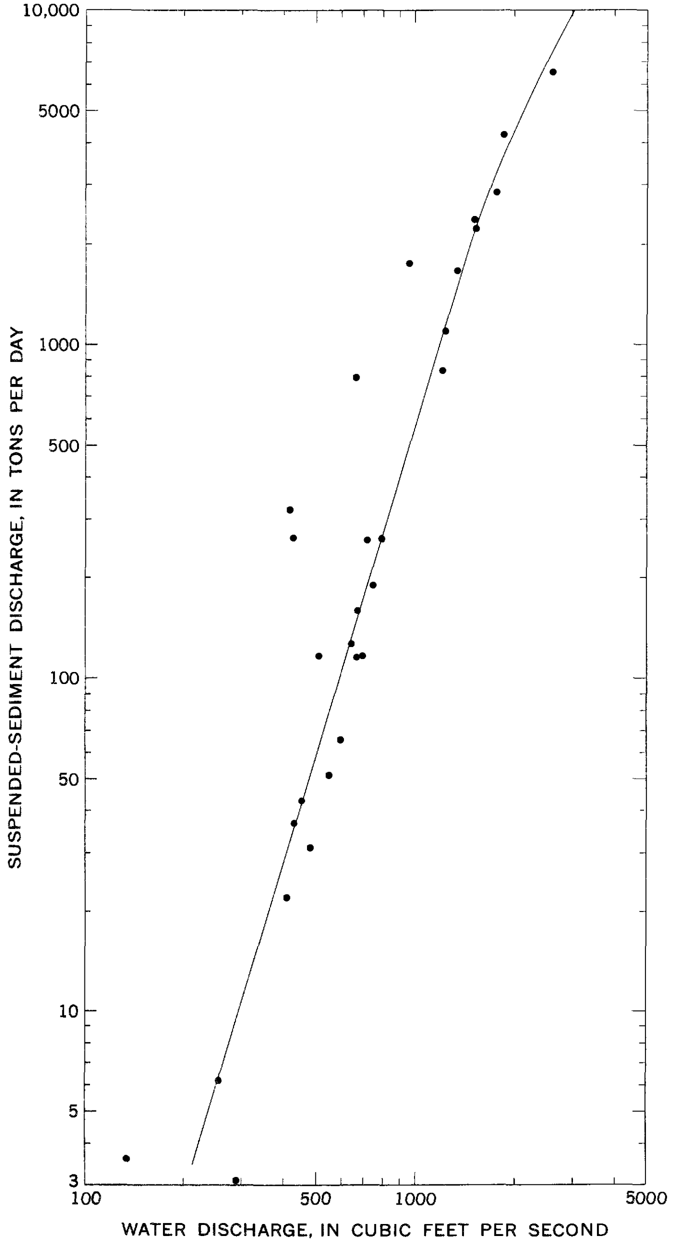


FIGURE 5.—Relation between water discharge and suspended-sediment discharge for South Fork Newaukum River near Onalaska.

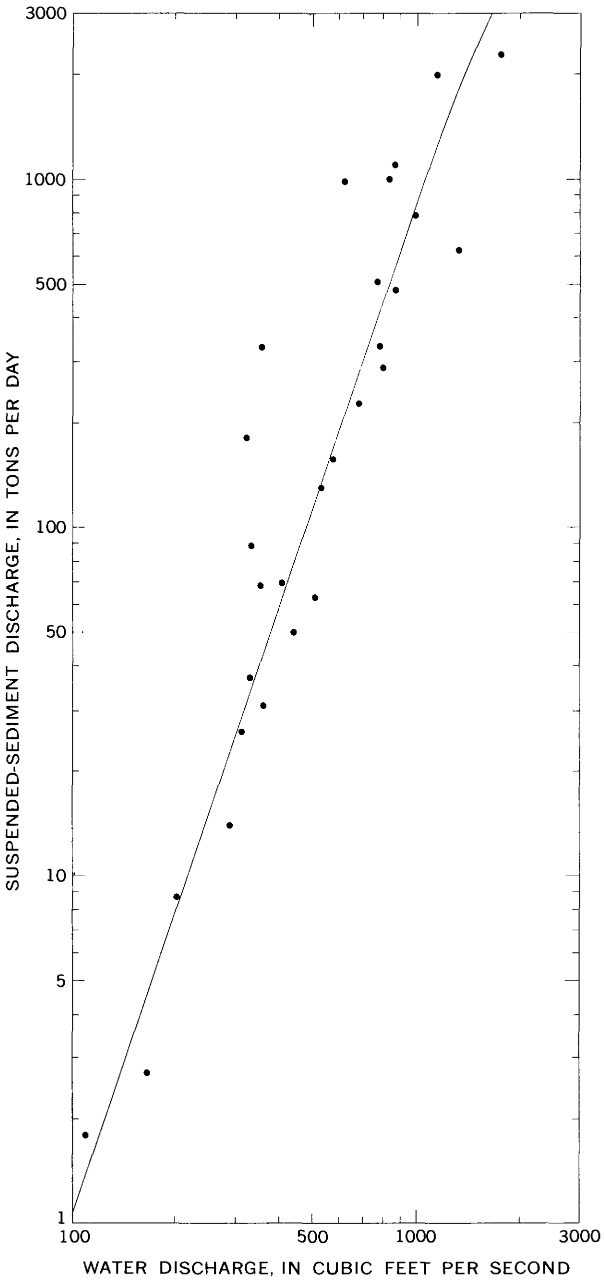


FIGURE 6.—Relation between water discharge and suspended-sediment discharge for North Fork Newaukum River near Forest.

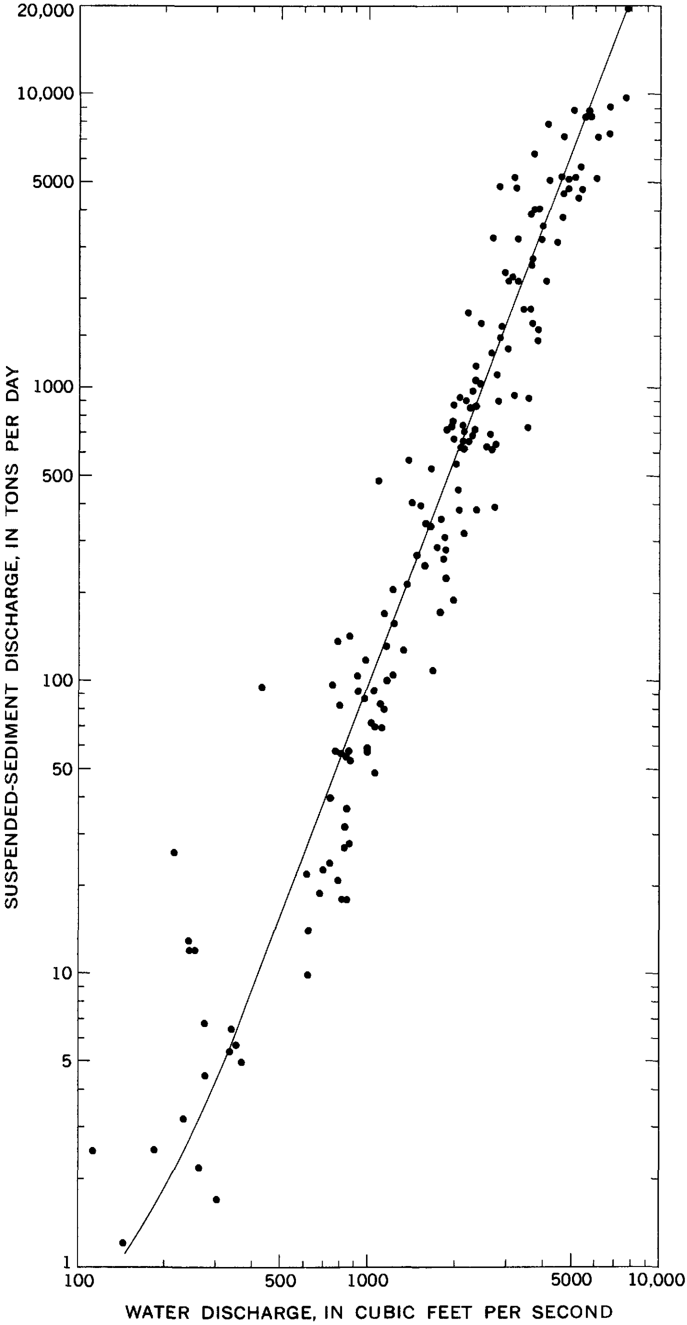


FIGURE 7.—Relation between water discharge and suspended-sediment discharge for Newaukum River near Chehalis.

Annual runoff from the Newaukum River basin during the study period ranged from 272,400 to 385,600 acre-feet. The 24-year average is 364,900 acre-feet. Annual runoff from the South Fork and North Fork Newaukum River during the study period ranged from 113,000 to 156,800 acre-feet and from 64,800 to 77,400 acre-feet, respectively.

Details of runoff and suspended-sediment discharge for the Newaukum River basin are given in tables 3–8 and are shown in figures 5–7.

Suspended-sediment concentrations in the South Fork are quite similar in magnitude to those at the main stem Newaukum station, but consistently exceed those in the North Fork.

Reconnaissance of the flood plain above each of the three sampling sites suggests that the South Fork and main stem Newaukum Rivers may be eroding sediments that have been reworked several times and that have been subjected to lengthy periods of chemical weathering between successive events of downstream movement and redeposition. Most of the sediment transported by those streams during storm runoff is silt size (fig. 3).

In the Newaukum River basin, streambeds consist mainly of cobbles, with interstitial gravel and sand. Examination of tributary and main-stem channels during low-flow periods disclosed evidence of vigorous movement of bed material, including cobble-size fragments, during the intervening periods of high streamflow; the strongest evidence for each movement was the change in shape and size of gravel bars after successive periods of high runoff.

Significant sheet or rill erosion is not evident between the upstream and downstream sampling sites. This omission indicates that the increase in load downstream is mainly the result of channel erosion between the sampling sites.

Evidence of channel erosion is shown in figure 8, which is a sequence of photographs showing intense lateral cutting of the channel along a reach of South Fork Newaukum River in sec. 35, T. 13 N., R. 1 W., approximately 4 river miles below the gaging and sampling station (pl. 1, No. 240). A general view of the concave bank in this reach is shown in figure 8A. Figures 8B and 8C, views of a specific segment of the reach, show effects of erosion as photographed on January 12 and March 31, 1965, respectively. During the intervening period, two peak flows occurred. After recession of the first peak, about 2,000 cfs (cubic feet per second), there was no evidence of channel cutting. The discharge rose for a second time about a day later, peaked at about 2,400 cfs, and then receded until March 31. Figure 8C shows channel changes that occurred during

A. Overall view of eroding channel reach, January 12, 1965.

B. At selected part of channel reach, January 12, 1965.

FIGURE 8.—Progression of lateral erosion at a site on South

C. At same part of reach, March 31, 1965.

D. At same part of reach, February 22, 1966.

Fork Newaukum River, in sec. 35, T. 13 N., R. 1 W.

the second rise. Figure 8D shows a similar view about 11 months later. The maximum water discharge during that interval was only about 1,100 cfs, and channel erosion was insignificant. The evidence therefore suggests that channel erosion takes place in that reach mainly when streamflow exceeds 2,000 cfs. Water discharge exceeded 2,000 cfs at least once each year during water years 1963–65. The general characteristics of the channel erosion described may be fairly typical of conditions throughout much of the Chehalis basin.

Some of the sediment transported by the Newaukum River and its tributaries is derived by erosion of residual soils (fig. 2). However, most of the valley-floor sediment is derived from fluviolacustrine deposits that probably were originally deposited as a result of glacial activity in the northern parts of the Chehalis River basin (Snavely and others, 1958, p. 68). Mass wasting of various materials also supplies undetermined amounts of detritus to streams in the Newaukum River basin.

SKOOKUMCHUCK RIVER

The Skookumchuck River drains about 180 square miles in the Bald Hills in the eastern part of the Chehalis basin (pl. 1). The relief, about 3,600 feet, and drainage area are only slightly greater than those of the adjacent Newaukum River basin (table 1). The Skookumchuck River basin is 90 percent woodland; the remaining 10 percent consists largely of cropland. Annual mean precipitation on the drainage ranges from about 40 to about 80 inches (fig. 1), a range of precipitation which is similar to that on the Newaukum drainage. Sediment concentrations, loads, and yields of the Skookumchuck River, however, are generally less than those of the Newaukum (tables 5, 6, and pl. 1).

The sediment transport and other hydrologic characteristics of the Skookumchuck River are probably better understood when they are compared with those of the neighboring Newaukum River. Therefore, comparisons between the two are frequently made in the following discussion.

A comparison of runoff from the two basins is difficult because only the runoff from the upper one-third of the Skookumchuck drainage is gaged; however, comparison of drainage areas of the two basins and comparison of runoff at the Skookumchuck River near Centralia with that of the North Fork and South Fork Newaukum River (table 4) suggests that the annual runoff of the Skookumchuck River is about 1.2 times that of the Newaukum River.

Other data on streamflow and suspended-sediment discharge in the Skookumchuck River basin appear in tables 3–8 and in figure 3.

Both the Newaukum and Skookumchuck Rivers flow across igneous and sedimentary rocks and their residual soil mantle in the headwater reaches and across glaciofluvial and fluvial deposits in their lower reaches. Both rivers probably remove comparable amounts of sediment that encroach on their channels as the product of mass wasting—landslides, soil creep, and mudflows.

The Skookumchuck River has a smooth increase in stream gradient from mouth to headwaters in contrast to an irregular increase of gradient of the Newaukum. The general gradient trends of the Newaukum River between the river mouth and its emergence from the hills east of Centralia are interrupted at least twice by channel-slope changes. Those breaks may be caused partly by continuing gradient adjustments resulting from a fluctuating base level at the confluence with the Chehalis River during glacial times. Adjustment of the Skookumchuck River profile to a more graded condition may have already been completed and could account for the lower general stream gradient and smaller amount of sediment transported by the Skookumchuck compared to that moved by the Newaukum.

The contrast in particle-size distribution of suspended sediment between the Skookumchuck and Newaukum Rivers (fig. 3 and table 7) suggests differences in velocity and turbulence between the two streams. The average percentage of the coarse-grained suspended load (particles greater than 0.062 mm) of the Newaukum seems to be about twice that of the Skookumchuck.

The bed of the Skookumchuck River is armored with cobbles and interstitial sand and gravel and generally resembles the beds of other streams in the upper Chehalis River basin.

CHEHALIS RIVER ABOVE GRAND MOUND

The Chehalis River drains about 895 square miles above the Chehalis River near Grand Mound measuring sites; this area includes the four major tributary basins previously discussed (pl. 1). Individual storm patterns that involve variability in precipitation with regard to intensity, duration, and areal distribution control runoff conditions at Grand Mound.

Annual peak discharges at the Grand Mound data-collection station ranged from 15,900 cfs in 1962 to 35,700 cfs in 1964 (table 4). The peak discharge recorded during 37 years of record was 48,400 cfs, in 1937. Details of water and suspended-sediment discharge are given in tables 3–8 and in figures 3 and 9.

Estimated mean annual suspended-sediment yield of the Chehalis basin above Grand Mound was 150 tons per square mile. That yield, though less than the yield of all the major tributaries upstream

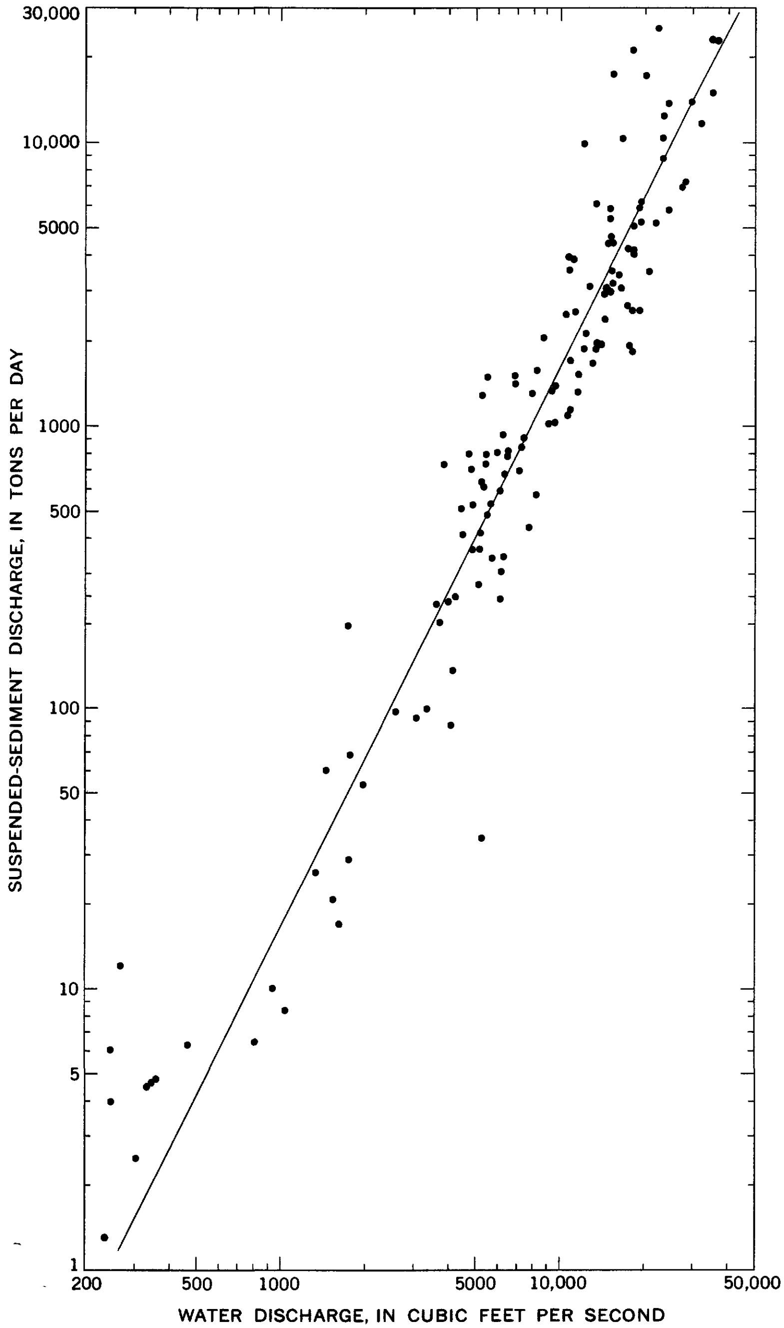


FIGURE 9.—Relation between water discharge and suspended-sediment discharge for Chehalis River near Grand Mound.

with the exception of the Skookumchuck, is about half the estimated gross yield of the study area.

The estimated mean annual suspended-sediment discharge passing Grand Mound is about 3 percent less than the sum of the discharges estimated for the upstream tributary basins (table 5). The discrepancy, if real, possibly resulted because overbank flooding along the main stem Chehalis River upstream from Grand Mound caused deposition of part of the sediment on the flood plain. During floods greater than those that occurred in 1962–65, the sediment deposited on the flood plain presumably would be remobilized and moved downstream. The difference is so small, however, that it falls within the margin of error of estimate, and no implication of actual difference is made.

Average particle size of the suspended-sediment load is smaller in Chehalis River near Grand Mound than at the upstream station near Doty (fig. 3, table 7). This smaller size is considered normal for a downstream station because decreasing gradient and turbulence in a downstream direction would probably cause the coarser sediment fraction to move as part of the bedload rather than in suspension; also, abrasion of individual particles throughout the longer transport distance tends to decrease the average particle size.

BLACK RIVER

The Black River drains 136 square miles that include the east flank of the Black Hills, Mima Prairie, and Black Lake (pl. 1). The total relief is about 2,600 feet (table 1). Annual precipitation on the basin ranges from about 45 to about 60 inches (fig. 1). Woodland covers 71 percent of the Black River basin (table 2), the smallest percentage of woodland in any of the tributary basins. The rolling semiflat nature of much of the basin favors a greater use of the land for farming (13 percent) and pasture (9 percent). The Black River basin has the greatest percentage of pastureland of any of the major Chehalis River tributaries.

Rapid runoff necessary to promote channel erosion, which is common to most of the Chehalis River basin, was not apparent in the main stem Black River during the study period. Any rapid runoff from the Black Hills or high-intensity precipitation on the remainder of the drainage is rapidly absorbed by the highly permeable glacial outwash that underlies much of the basin. The gradient of the main channel of the Black River is gentle, averaging only about 1.5 feet per mile for the lower 14 miles, and the streamflow is sluggish. Because the drainage is poorly integrated, swampy conditions are common.

The few samples collected indicated that little suspended sediment was being transported. Even during periods of general regional flooding, the Black River appeared to be virtually clear. For these reasons, the average annual suspended-sediment discharge of the Black River was estimated at less than 1 percent of the total Chehalis River discharge (table 5). The average annual suspended-sediment yield of 20 tons per square mile is the lowest of any of the major tributaries of the Chehalis River basin (table 5).

The low stream velocity eliminates channel cutting as the major source of sediment in the main river channel. The small suspended-sediment load probably results mainly from erosion in some of the tributaries and small gullies that drain the steeper slopes of the Black Hills.

CHEHALIS RIVER ABOVE PORTER

Water discharge of the Chehalis River at Porter, representing a drainage area of 1,294 square miles, reflects the combined influence of the intensity, duration, and areal distribution of storms prevailing on all the upstream tributaries previously discussed.

The Chehalis River flood plain between Porter and Grand Mound consists of stream-deposited alluvium and large quantities of glaciofluvial sediments deposited during glacial time. Numerous meander scars, oxbows, and partly reaggraded overflow channels testify that the river is constantly changing its course and reworking the sediments as they are moved intermittently toward the sea. The low gradient and meandering character of the stream in that reach also influence runoff patterns at Porter.

The Black River is the main tributary between Grand Mound and Porter, but contributes little runoff and sediment to the main stem of the Chehalis River. The amount of sediment contributed by numerous smaller tributaries is unknown.

Details of water discharge and suspended-sediment discharge for Chehalis River at Porter are given in tables 3–8 and figure 3.

Annual peak water discharges during the 4-year study period (1962–65) at the Porter gaging station ranged from 21,000 to 38,500 cfs, which was the highest discharge during 13 years of record at the station. The mean annual suspended-sediment discharge at the Porter sampling station for the study period averaged 24.2 percent of the Chehalis basin total, which is slightly less than that (24.6 percent) calculated for Chehalis River near Grand Mound, 20 miles upstream. However, annual suspended-sediment transport past Porter was determined from daily samples, whereas the annual discharge near Grand Mound was estimated using gaging-station data for streamflow and only occasional determinations of sediment discharge.

Data for specific measured floods (table 8) indicate that the suspended-sediment load passing Grand Mound generally exceeded that at Porter during periods of high runoff.

Double-mass analysis failed to indicate any trend in sediment-yield characteristics for the basin above the Porter sampling site during the study period (1962–65).

The maximum instantaneous suspended-sediment discharge of the Chehalis River at Porter during the study period is believed to have been about 12,000 tons per day; it occurred during the peak water discharge of 38,500 cfs.

The maximum measured suspended-sediment concentration at Porter was 272 mg/l (milligrams per liter), less than the maximum measured at Grand Mound site (table 6). This difference suggested the effect of dilution by low sediment concentrations in the Black River and other local runoff downstream from Grand Mound. Minimum suspended-sediment concentration of less than 1 mg/l occurred several times during low-flow periods.

The general downstream decrease in average particle size from Doty to Porter is significant. The decrease may indicate that either (1) the proportionate pickup of fine sediment increases in a downstream direction, (2) more of the coarser material is moving as bedload past the stations near Grand Mound and at Porter, or (3) individual particle abrasion in a downstream direction effectively decreases average particle size. The magnitude of channel velocities and associated turbulence at the two stations influence the ratio of suspended load to bedload. Mean-channel velocities that were measured during variable flow conditions ranged from 3.1 to 6.1 fps (feet per second) at Grand Mound and from 1.9 to 6.6 fps at Porter.

CLOQUALLUM CREEK

Cloquallum Creek drains about 65 square miles in the northern part of the Chehalis River basin. Topographic relief in the basin, a little more than 1,400 feet, is relatively small compared with the relief of most of the other tributary basins (table 1). Woodland occupies 83 percent of the area (table 2). Cropland makes up about 8 percent of the basin—almost average for the major tributary basins.

Annual mean precipitation ranges from about 60 to about 85 inches, which is less than that in most other basins (fig. 1). Annual runoff from the Cloquallum Creek basin during the study period ranged from 149,400 to 220,700 acre-feet (table 4). Annual peak water discharge ranged from 2,230 to 3,940 cfs.

Runoff in Cloquallum Creek can be categorized as nonflashy. The sluggish rise and recession of Cloquallum Creek is caused partly by the low intensity and uniform distribution of rainfall over the drainage basin, but of more importance, mostly by the permeable nature of the glacial outwash mantling much of the basin. The porous material temporarily stores great quantities of precipitation as ground water and in bank storage and releases this water gradually to the stream channels. The absence of steep slopes over most of the drainage area and the low overall topographic relief also favor gradual runoff.

The records of water discharge and sediment-discharge characteristics are given in tables 3–8 and in figure 3.

The relation of water discharge to suspended-sediment discharge, upon which calculations of annual suspended-sediment yields were based, is shown in figure 10. Ninety percent of the suspended-sediment load moved in about 15 percent of the time during the study period, whereas most of the other tributaries moved the major part of their suspended load in less time (table 3). This characteristic of Cloquallum Creek is related to its nonflashy runoff pattern.

The suspended sediment is coarser than the suspended sediment that was found in most other streams that were studied (table 7 and fig. 3). That fact may reflect the generally coarse-grained nature of the glaciofluvial material available for transport.

The channel bed at the sampling site is armored with cobbles and gravel that are probably moved only by flows approaching or exceeding bankfull stage. Fine gravel (4–8 mm), which is commonly present in alluvium that forms the banks, undoubtedly moves along the streambed during high flows.

Most erosion in the Cloquallum basin is probably the result of the same lateral channel cutting which erodes the other Chehalis tributaries.

The upper part of the Cloquallum Creek basin was occupied by margins of the Puget ice lobe during glacial times (pl. 1 and fig. 2). Along much of its course, the creek flows through glaciofluvial sediments deposited by outwash from the melting ice mass; however, erosion is retarded by the gentle runoff characteristics of the creek, as previously discussed.

SATSOP RIVER

The Satsop River, which originates in the southern part of the Olympic Mountains, flows southward to join the Chehalis River near the town of Satsop, about 17 miles upstream from Grays Harbor (pl. 1). The river system consists of four major tributaries—the East

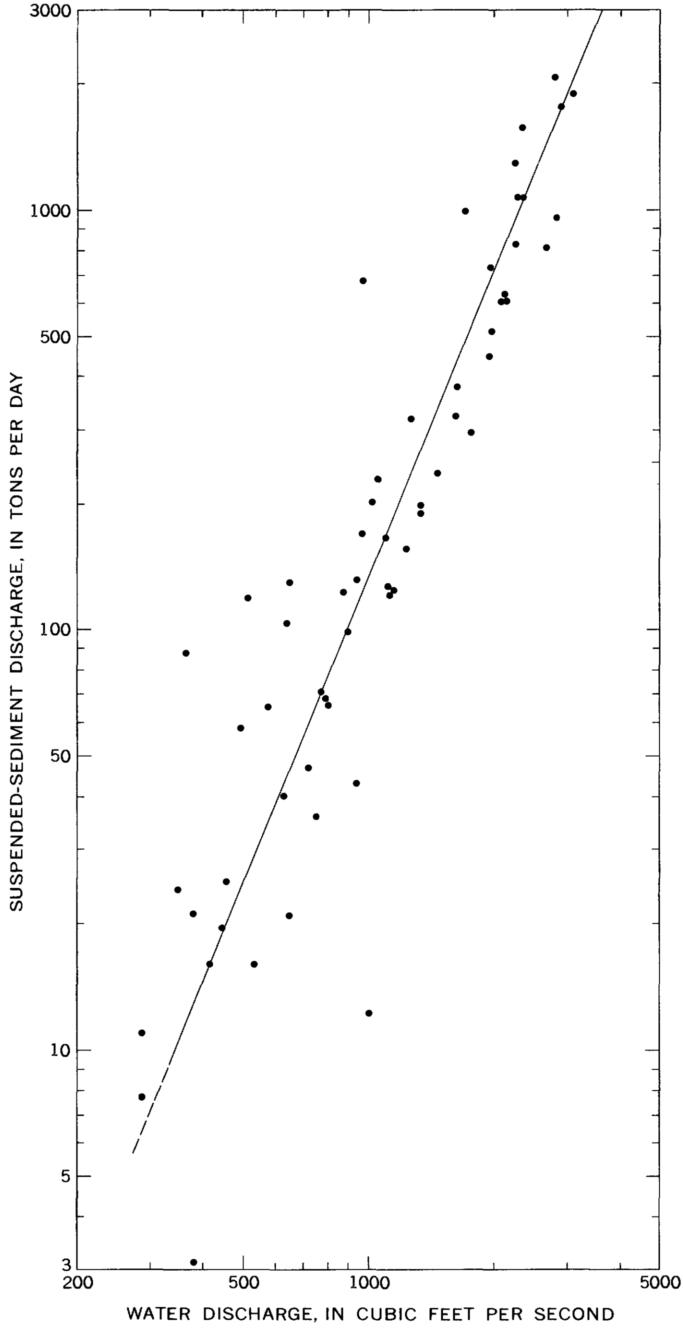


FIGURE 10.—Relation between water discharge and suspended-sediment discharge for Cloquallum Creek at Elma.

Fork, Middle Fork, and West Fork Satsop Rivers, and Decker Creek. The basin covers about 300 square miles, and topographic relief is more than 3,300 feet.

Almost 90 percent of the Satsop River basin is forested (table 2), and cropland covers 3 percent of the area. The 8 percent that is classified "idle" consists of rock outcrops, landslide areas, bluffs, and other agriculturally unproductive land.

Mean annual precipitation over the Satsop River drainage ranges from about 70 to about 175 inches. Precipitation differs markedly among the tributaries within the Satsop basin (fig. 1).

The annual peak water discharge at the station Satsop River near Satsop ranged from 12,700 to 32,800 cfs during the study period. Peak discharge for 35 years of record on the Satsop River near Satsop was 46,600 cfs, in 1935.

Suspended-sediment concentration, discharge, and yield vary widely in the Satsop River drainage (tables 5 and 6). The Satsop and the Wynoochee Rivers are the highest sediment-yielding streams in the Chehalis River basin. Other data on water discharge and suspended-sediment discharge are shown in tables 3, 4, 7, and 8 and in figure 3.

The mean annual suspended-sediment discharge of the Satsop River is about 44 percent of that of the entire study area. Estimated annual suspended-sediment discharge passing the sampling reach near Satsop ranged from 120,000 tons to 310,000 tons (table 5). The resulting mean annual suspended-sediment yield of 787 tons per square mile is considerably greater than that of any of the other Chehalis River tributaries except the Wynoochee River. Annual yields of East Fork Satsop River and Decker Creek are estimated to be only 60 tons per square mile, but estimates of those of Middle Fork Satsop River (1,100 tons per sq mi) and West Fork Satsop River (1,500 tons per sq mi) are the largest for any major tributary in the Chehalis River system.

The relation between water discharge and suspended-sediment discharge for Satsop River near Satsop is shown in figure 11. About 90 percent of the estimated suspended-sediment load leaving the Satsop River basin moved through the sampling reach in about 6 percent of the time. Therefore, the major part of the load moved in a much shorter period of time than the loads of most Chehalis basin tributaries. Only the Chehalis River near Doty moved 90 percent of its load in a shorter time (table 3).

Measured suspended-sediment concentrations at Satsop River near Satsop ranged from less than 1 to 1,030 mg/l. This is the second greatest range that occurred at any sampling site in the Chehalis

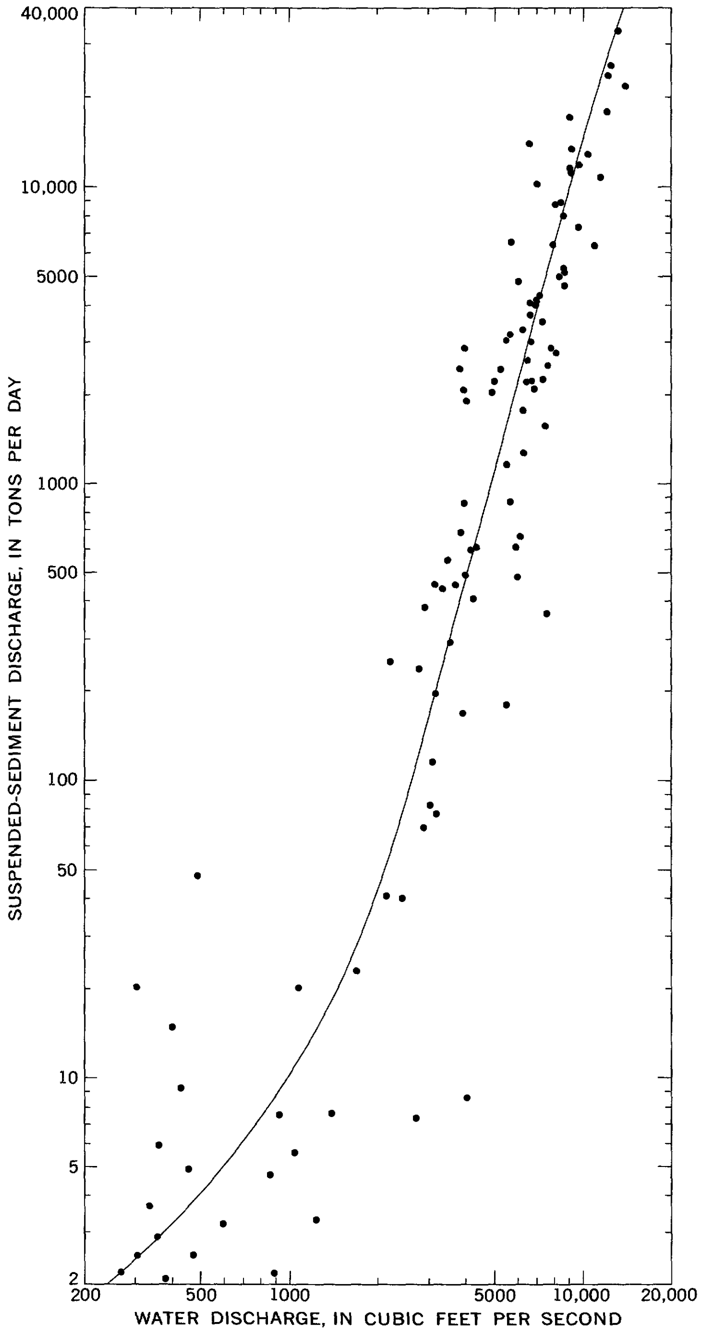


FIGURE 11.—Relation between water discharge and suspended-sediment discharge for Satsop River near Satsop.

basin during the study period and is exceeded only by the range in the Wynoochee River. Concentrations change rapidly in the Satsop River during floods, and peak concentrations tend to occur coincidentally with peak water discharges.

The suspended sediment in the Satsop River near Satsop is generally coarser grained than that in many other tributaries (fig. 3 and table 7). Movement of gravel- and cobble-size material in the bedload was clearly audible at the Satsop River sampling station during a water discharge of 13,000 cfs on December 24, 1963. Flows of that magnitude occur frequently (table 4). Mean channel velocity at this discharge is about 6 fps. The peak discharge of the study period, 32,800 cfs, was probably accompanied by a mean channel velocity of about 9 fps: at this velocity significant bedload movement would be expected.

Most erosion resulting in sediment transport by the river occurs because of direct runoff during the winter. The geologic environment (fig. 2) favors intensive erosion. Ample supplies of unconsolidated fluvial and glaciofluvial deposits and extensively weathered sedimentary rocks are available for transport.

Progressive channel changes and erosion at a site just upstream from the main-stem gaging station near Satsop are shown on plate 2. The maps, traced from aerial photographs, show extensive channel changes that have taken place in the reach during the 25-year period 1941–66. The large meander has changed its shape considerably and has moved progressively downstream. About 35 acres of farmland (equivalent to about a million tons of sediment) was removed along the convex side of the channel, and although less agriculturally productive, some land was added by deposition along the concave side of the meander. The rate of erosion increased during the 25-year period; about 10 percent of the area was removed during the first 15 years, about 46 percent during the next 6 years, 20 percent during the following 2 years, and 24 percent during the final 2 years. This rate suggests that as the meander movement progressed, the accompanying modifications of channel hydraulics accelerated the erosion. Should erosion at such rates continue, farmlands to the south will be modified rapidly, and intensified erosion, accompanied by increasing flow resistance, might initiate major channel changes. The tight channel bend shown in grids E4 and E5 of plate 2, acts as a hinge point about which the meander apparently is rotating in a counterclockwise direction. The hinge point exists because the east side of the channel downstream consists of a resistant bedrock bluff.

Point-bar deposits existed in grids B1 and B2 in 1941, and a sizable island had formed there by 1956. Development of that island

and the formation of other islands immediately downstream continued in later years. Channel braiding in grid F3 had occurred by 1956, but had disappeared by 1964. The island at the hinge point in grids E4 and E5 appeared and disappeared erratically, despite a fairly heavy vegetative cover that developed between 1941 and 1956. A minor island in grid G5 in 1941 grew steadily and formed a sizable point bar by 1964. Vegetation grew readily on gravel- and sand-bar deposits at the concave bank of the larger meander; at the same time, erosion on the convex side continued, apparently undeflected or uninhibited by the dense stands of vegetation that were progressively removed as the meander rotated and moved downstream. The farmyard in D1 appeared doomed to erosion in 1941, yet it survived and in 1966 appeared to be secure. Another farmyard in H4 appears to be threatened with destruction if the 1966 erosive trends continue.

Channel erosion may continue to compress the meander and thereby cause a cutoff to develop across the concave side during flood stages. A major channel change also is possible; the flow might take a natural southward diversion through the overflow channels (not pictured in the diagram) in the general area of G2.

The diagrams demonstrate the dynamic nature of channel erosion on the lower Satsop River, and the evolution of gravel islands and bars testifies to significant bedload movement.

Owing to differences in erosive characteristics, contributions of sediment by individual tributaries within the Satsop basin are apparently quite different (table 5, pl. 1). The tributaries comprise two general groups: East Fork Satsop River and Decker Creek, which have low sediment yields, and Middle Fork and West Fork Satsop River, which move very large quantities of sediment in comparison to other Chehalis River tributaries.

Runoff characteristics and sediment yield of the East Fork Satsop River are quite similar to those of Cloquallum and Decker Creeks and Black River. These drainages are characterized by gentle rises and very gradual recessions during most runoff events. This sluggish characteristic greatly limits channel cutting, because the turbulence and velocity necessary for severe channel erosion generally are absent. Sheet and rill erosion in the Decker Creek and East Fork Satsop River drainages presumably are minimal because of dense vegetative cover. The geologic and physiographic influences on sediment yield in this part of the Chehalis basin are similar to those discussed for the Cloquallum Creek drainage.

The range in combined annual runoff of the Middle Fork and West Fork Satsop River is estimated to be 850,000 to 1,200,000 acre-feet during the study period. The combined mean annual runoff of these streams averaged about 70 percent of the total annual Satsop basin runoff.

The lack of continuous water-discharge records for Middle Fork and West Fork Satsop River prevented development of accurate estimates of sediment discharge. The West Fork probably has a greater runoff and sediment yield than the Middle Fork. Both streams are flashy, and the streamflow from these tributaries during floods dominates the main-stem runoff.

Both the Middle and West Forks head high on the flanks of the Olympic Mountains, where mean annual rainfall ranges from 120 to 175 inches. The steep slopes in the mountains and the high precipitation favor rapid runoff. Unconsolidated or poorly consolidated deposits provide an ample supply of sediment to be transported by rapidly moving water. Runoff may also be accelerated by the clear-cut logging operations that were practiced in those areas during the study period.

WYNOOCHEE RIVER

The Wynoochee River basin is about 195 square miles in extent. The Wynoochee River heads on the south flank of the Olympic Mountains (pl. 1), flows generally southward, and empties into the Chehalis River about 10 miles upstream from Grays Harbor. Topographic relief in the basin is more than 5,000 feet (table 1).

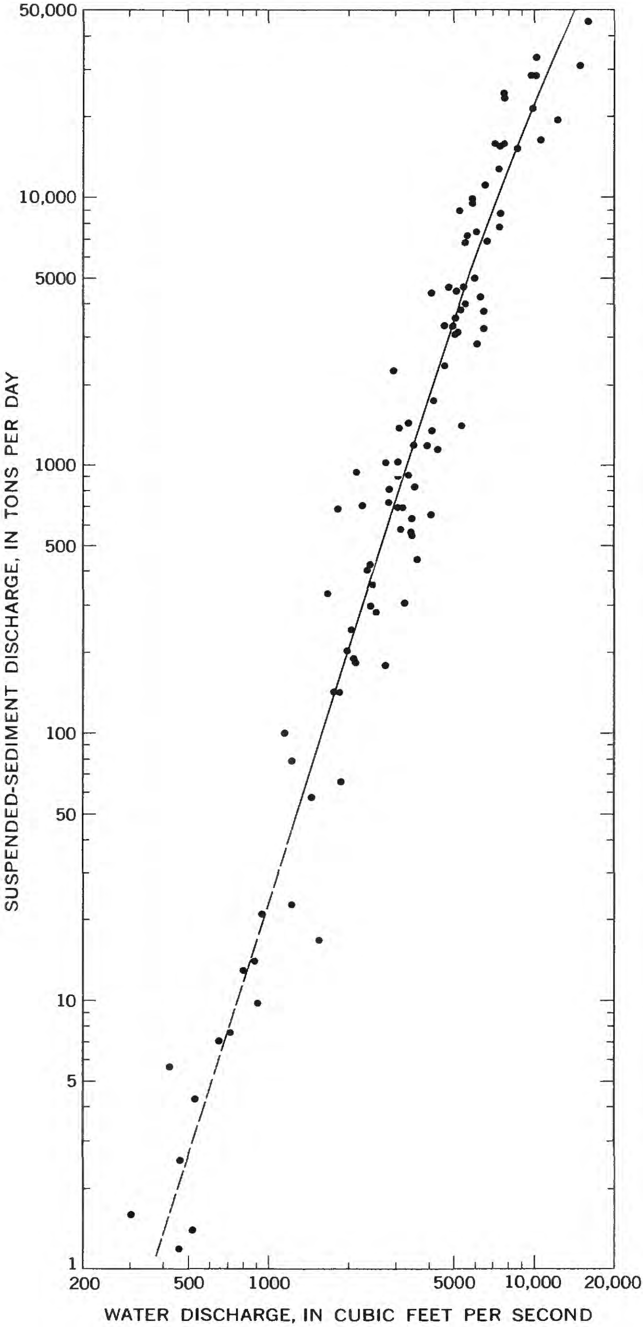
The Wynoochee River drainage is 74 percent woodland and 3 percent cropland (table 2). About 18 percent of the basin is occupied by rock outcrops, landslide areas, bluffs, and associated agriculturally unproductive areas, in contrast to most tributary basins of the Chehalis River system, which have little or no area so classified. The large areas of agriculturally unproductive land in the Wynoochee and Satsop basins reflect the ruggedness and unstable nature of the terrain, and this, in turn, suggests that flashy runoff and greater-than-average sediment yields are to be expected.

Mean annual precipitation in the Wynoochee basin ranges from about 75 to more than 220 inches (fig. 1).

The characteristics of water discharge and suspended-sediment discharge of the Wynoochee River basin are given in tables 3–8 and in figure 3.

The relation between water discharge and suspended-sediment discharge at the Wynoochee River sampling site is shown in figure 12.

Measured suspended-sediment concentration of the Wynoochee River near Montesano ranged from less than 1 to 1,220 mg/l, the maximum concentration measured in the Chehalis River basin during



-URE 12.—Relation between water discharge and suspended-sediment discharge for Wynoochee River above Black Creek near Montesano.


A
B
C
D

the study period (table 6). The concentration range is probably the greatest that occurred at any sampling site in the Chehalis basin during the study period. Concentrations change rapidly in the Wynoochee River during floods and peak concentrations tend to occur coincidentally with peak water discharges.

Sediment loads generally contain moderate quantities of sand and large percentages of silt (fig. 3). Bedload movement was clearly audible at the upper sampling site (pl. 1) on December 23, 1963, at a water discharge of about 9,300 cfs—a flow rate often exceeded during the study period (table 4).

Examination of the streambed during low-flow periods showed that movement of bed material occurred during preceding periods of storm runoff. After recession of the medium-to-high flows, irregular-shaped concretions derived from erosion of marine sedimentary bedrock are exposed in the streambed where they have been uncovered by movement of the bed material. After brief exposure to sun and air—generally only days to weeks—the concretions were found to be decomposed by desiccation cracking. Figure 13 shows several typical concretions removed from the submerged streambed and exposed to the atmosphere. During the exposure period, several rainstorms and showers occurred, interspersed with intervals of sunshine. Alternate wetting and drying seemed to accelerate decomposition. The cracking destroys the concretions and renders the remnants susceptible to ready transport by flowing water. The concretions are good indicators of turnover or shifting of the gravel-size bed material; their presence in a fresh, undecomposed condition after most flood recessions testifies to frequent movement of bed and bar materials.

The general physical environment of the Wynoochee River basin resembles the environments of the Middle Fork and West Fork Satsop Rivers; similar characteristics include steep slopes, precipitation patterns, annual runoff patterns, and lithology. Together the three streams discharged about 70 percent of the mean annual suspended-sediment discharge in the study area (pl. 1).

An aerial reconnaissance of the region in April 1966 suggested that freshly logged areas in the headwater reaches were more widespread in the Satsop River basin than in the Wynoochee River basin. If the difference is as great as appearances suggested, the land-use factor may partly account for the smaller average sediment discharge of the Wynoochee.

Much of the sediment yield of the Wynoochee River basin probably

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FIGURE 13.—Concretions removed from the submerged bed of the Wynoochee River, showing progressive decomposition while exposed to the atmosphere. Exposure times: *A*, 0 (wet); *B*, 1 day; *C*, 3 days; *D*, 1 week.

is derived from lateral channel migration and the accompanying reworking of flood-plain deposits.

Several barren scarps, hundreds of feet high, rise above the Wynoochee River. The scarps probably result from mass wasting caused at least in part by the river undercutting the bases of unstable hill slopes. Rapid movement of debris down the slopes apparently occurs rather frequently and thus contributes to the sediment load of the river. Evidence of gentler downslope movement of rock and soil debris is common along the main valley. A sizable but undetermined quantity of debris is removed from the toes of the slow-moving masses by channel erosion.

A reconnaissance of the main valley above Grisdale after the flood of November 20, 1962, disclosed many fresh erosion scars along tributary valleys. Extensive bed movement of detritus, including abundant large-size gravel and cobbles, was apparently commonplace along the main river channel and also along many of the tributaries. Movement of the bedload and coarse-grained sediment is facilitated in this area by steep channel gradients; the main river channel has a uniform gradient of about 30 feet per mile for about 7 miles above Grisdale.

Undetermined quantities of suspended sediment also are set in motion as a result of gravel-mining operations in the river channel just upstream from the bridge on U.S. Highway 410. The sediment here was not measured during the study period because the gravel-mining operation is downstream from the lowermost sediment-sampling site.

WISHKAH RIVER

The Wishkah River drains about 100 square miles in the extreme northwestern part of the Chehalis River basin (pl. 1). The river heads in the foothills on the south flank of the Olympic Mountains, flows southward, and joins the Chehalis River at the head of Grays Harbor.

Although adjacent to the Wynoochee River basin, the Wishkah River drainage has a much lower topographic relief, nearly 1,600 feet (table 1). Land use in the Wishkah River basin is almost identical with that of the Wynoochee River basin, 74 percent being woodland, 4 percent cropland, and 17 percent agriculturally unproductive areas (table 2).

Annual precipitation on the Wishkah River basin ranges from about 85 to about 140 inches (fig. 1).

Flood runoff in the Wishkah River generally occurs coincidentally with that of the Wynoochee and Satsop Rivers although the runoff pattern of the Wishkah may be less flashy than those of the Wynoochee and Satsop Rivers. Good correlations cannot be made, however, because the Wishkah River basin has no continuously recording streamflow measurement stations.

The estimated annual suspended-sediment load of the Wishkah River is equivalent to about 5 percent of the Chehalis basin total (table 5) or about 30,000 tons. The sediment transported by the Wishkah was not included as part of the total Chehalis load because the Wishkah River generally is not considered a tributary to the main stem of the Chehalis. Available data on suspended-sediment discharge of the Wishkah are given in tables 3, 5, 6, 7, and 8.

The streambed is composed of some cobbles and a large quantity of pea gravel, with interstitial sand and silt. Stream velocities during average storm runoff should be adequate to move the bed material.

The Wishkah River drainage traverses mainly marine sedimentary rocks and unconsolidated sedimentary deposits of fluvial and glaciofluvial origin (fig. 2). Most erosion in this subbasin probably is caused by the lateral channel cutting of the unconsolidated flood-plain deposits and by the removal of the sediment furnished to the channel through mass wasting.

SUMMARY

Fluvial-sediment transport and yield vary considerably throughout the Chehalis River basin. The largest quantities of sediment discharged annually come from the Middle Fork and West Fork Satsop River and from the Wynoochee River. The basins of the Skookumchuck River and Cloquallum Creek have low sediment yields, and those of Black River, East Fork Satsop River, and Decker Creek have still smaller yields.

The estimated annual suspended-sediment discharge from the 1,813-square-mile study area ranged from 270,000 to 690,000 tons during the study period (1962–65). The average annual yield of the basin was estimated to be about 300 tons per square mile of drainage area. Average annual yields of sampled tributaries were estimated to range from 20 tons per square mile in the Black River basin to 1,500 tons per square mile in the West Fork Satsop River basin.

The maximum measured concentrations were 1,030 mg/l in the Satsop River near Satsop and 1,220 mg/l in the Wynoochee River above Black Creek near Montesano. The greatest measured instantaneous suspended-sediment loads were 50,100 tons per day for the Satsop River near Satsop and 45,000 tons per day for the Wynoochee River above Black Creek near Montesano.

Sediment yield is closely related to streamflow, particularly to the rate of direct runoff resulting from major rainstorms during the winter. Peak water discharge, peak suspended-sediment concentration, and peak load generally occurred coincidentally at the sampling sites. The exceptions were on the main stem Chehalis River near Grand Mound and at Porter. Peak sediment discharges and concentrations occasionally preceded peak water discharge near Grand Mound and generally preceded peak water discharge at Porter. Suspended-sediment concentration in the Chehalis River at Porter was generally less than that at the Grand Mound site for given discharges, but magnitudes of suspended-sediment loads passing the two sites during a given high-water event were less consistent.

A trilinear plot (fig. 3) of mean percentages of clay, silt, and sand for individual stations shows that the coarse-grained fraction of the suspended load was generally greater at upstream sampling sites, whereas the fine-grained fraction increased downstream. Tributaries having the flashiest runoff characteristics generally moved a coarser suspended load. However, the nature of particle-size distribution in a given tributary system also is related to the nature of the sediment available for transport; the particle-size distribution reflects the influence of both channel hydraulics and characteristics of the sediment source.

The tributary basins having the greatest sediment yields have the following characteristics in common: An abundance of material susceptible to erosion; areas with highest precipitation and steep slopes favoring rapid runoff; and areas undergoing land-use practices that favor sediment movement.

Analysis of sediment and streamflow data at all sampling stations showed a characteristic that is common to many river systems (Swenson, 1964, p. 223–226) : most of the sediment load moves during short periods of high runoff. The length of time required for transport of the major portion of the total suspended-sediment load, however, varied from place to place. For example, passage of 90 percent of the total load during the study period required 20 percent of the time for the main stem at Porter in contrast to only 5 percent of the time at the upstream site near Doty.

During the short periods of high runoff, sediment concentrations attain greater magnitudes in the upstream reaches than in the downstream reaches. The highest sediment concentrations sampled were in the Satsop and Wynoochee Rivers. The Chehalis River near Doty, the South Fork Chehalis River, and the Newaukum River had fairly high concentrations but the concentrations were considerably lower than those of the Satsop and Wynoochee Rivers. Skookumchuck River, Chehalis River near Grand Mound and at Porter, Cloquallum

Creek, and possibly Wishkah River can be grouped into the next lower order with respect to peak sediment concentration. Black River, East Fork Satsop River, and Decker Creek seem consistently to have very low concentrations.

The factors most affecting changes in the sedimentation characteristics of the basin are (1) natural changes caused by environmental evolution of the basin, (2) manmade changes in the runoff characteristics of major channels (including impoundment, diversions, and channel changes), and (3) changes in land use in the basin that affect runoff patterns and the quantity and nature of sediment available for movement.

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TABLES 4-8

TABLE 4.—*Summary of runoff in the Chehalis River basin, water years 1962–65*

Station (with station No.)	Area above data-collection station (sq mi)	Peak discharge		Annual-runoff		
		Cfs	Date	Acre-ft	Inches	Percent of 1958–65 average
1962						
Chehalis River near Doty (200)	113	5,940	11–22	336,400	56	80
South Fork Chehalis River at Boistfort (210)	48.0	1,910	12–21	110,800	43	[1] 77
South Fork Newaukum River near Onalaska (240)	42.4	1,290	12–24	113,000	50	80
North Fork Newaukum River near Forest (245)	31.5	872	12–24	64,800	39	89
Newaukum River near Chehalis (250)	155	3,580	12–24	272,400	34	74
Skookumchuck River near Centralia (260)	61.7	2,020	12–21	138,900	42	78
Chehalis River near Grand Mound (275)	895	15,900	12–21	1,550,000	32	74
Chehalis River at Porter (310)	1,294	21,000	12–23	2,219,000	32	74
Cloquallum Creek at Elma (325)	64.9	2,230	12–23	149,400	43	73
East Fork Satsop River near Elma (342)	65.9	1,680	12–24	211,800	60	79
Satsop River near Satsop (350)	299	12,700	12–23	1,193,000	75	80
Wynoochee River above Save Creek, near Aberdeen (360)	74.1	6,280	1–3	497,800	126	82
Wynoochee River above Black Creek, near Montesano (374)	155	8,600	1–3	727,400	97	80
Total study area [2]	1,813	--	--	4,289,000	44	77
1963						
Chehalis River near Doty (200)	113	12,400	11–25	392,700	65	93
South Fork Chehalis River at Boistfort (210)	48.0	3,460	2–3	145,500	57	[1] 102
South Fork Newaukum River near Onalaska (240)	42.4	2,790	11–19	126,100	56	89
North Fork Newaukum River near Forest (245)	31.5	2,520	11–19	68,300	41	88
Newaukum River near Chehalis (250)	155	6,960	11–20	326,500	40	87
Skookumchuck River near Centralia (260)	61.7	4,000	11–20	167,200	51	93
Chehalis River near Grand Mound (275)	895	29,800	11–21	2,027,000	42	96
Chehalis River at Porter (310)	1,294	29,300	11–28	2,899,000	42	97
Cloquallum Creek at Elma (325)	64.9	3,940	11–20	200,000	58	97
East Fork Satsop River near Elma (342)	65.9	3,740	11–20	259,500	74	96
Satsop River near Satsop (350)	299	32,800	11–20	1,405,000	88	98
Wynoochee River above Save Creek, near Aberdeen (360)	74.1	15,900	11–19	576,000	146	94
Wynoochee River above Black Creek, near Montesano (374)	155	23,200	11–20	863,200	113	94
Total study area [2]	1,813	--	--	5,367,000	58	96

[1] Period of record 1944–50 plus 1961–65, rather than 1958–65.
[2] Based on summations and averages for stations 310, 325, 350, and 374, excludes all drainages below confluence with Wynoochee River.

TABLE 4.—*Summary of runoff in the Chehalis River basin, water years 1962–65* —Continued

Station (with station No.)	Area above data-collection station (sq mi)	Peak discharge		Annual runoff		
		Cfs	Date	Acre-ft	Inches	Percent of 1958–65 average
1964						
Chehalis River near Doty (200)	113	9,450	1–25	443,000	74	105
South Fork Chehalis River at Boistfort (210)	48.0	4,330	1–25	158,200	62	[1] 110
South Fork Newaukum River near Onalaska (240)	42.4	3,160	1–25	156,800	69	111
North Fork Newaukum River near Forest (245)	31.5	2,770	1–25	77,400	46	100
Newaukum River near Chehalis (250)	155	7,970	1–25	385,600	48	104
Skookumchuck River near Centralia (260)	61.7	5,990	1–25	199,500	61	111
Chehalis River near Grand Mound (275)	895	35,700	1–26	2,265,000	47	108
Chehalis River at Porter (310)	1,294	38,500	1–27	3,217,000	47	108
Cloquallum Creek at Elma (325)	64.9	2,950	1–25	220,700	64	108
East Fork Satsop River near Elma (342)	65.9	2,460	1–25	288,200	82	107
Satsop River near Satsop (350)	299	14,300	1–25	1,658,000	104	112
Wynoochee River above Save Creek, near Aberdeen (360)	74.1	7,530	10–21	658,500	167	108
Wynoochee River above Black Creek, near Montesano (374)	155	10,300	12–23	995,300	129	109
Total study area [2]	1,813	--	--	6,091,000	63	109
1965						
Chehalis River near Doty (200)	113	8,360	12–22	391,000	65	93
South Fork Chehalis River at Boistfort (210)	48.0	3,780	12–23	124,700	49	[1] 87
South Fork Newaukum River near Onalaska (240)	42.4	2,340	1–30	133,800	59	95
North Fork Newaukum River near Forest (245)	31.5	1,330	12–22	77,100	46	100
Newaukum River near Chehalis (250)	155	6,500	12–23	358,000	45	97
Skookumchuck River near Centralia (260)	61.7	4,420	12–22	172,500	52	96
Chehalis River near Grand Mound (275)	895	26,200	12–24, 1–30	2,029,000	43	97
Chehalis River at Porter (310)	1,294	34,000	1–31	2,923,000	42	98
Cloquallum Creek at Elma (325)	64.9	3,070	11–30	194,200	56	95
East Fork Satsop River near Elma (342)	65.9	2,780	11–30	247,100	70	92
Satsop River near Satsop (350)	299	19,500	11–30	1,336,000	84	90
Wynoochee River above Save Creek, near Aberdeen (360)	74.1	11,800	11–30	510,400	129	84
Wynoochee River above Black Creek, near Montesano (374)	155	15,900	11–30	820,900	108	90
Total study area [2]	1,813	--	--	5,274,000	55	94

[1] Period of record 1944–50 plus 1961–65, rather than 1958–65.
[2] Based on summations and averages for stations 310, 325, 350, and 374, excludes all drainages below confluence with Wynoochee River.

TABLE 5.—*Summary of estimated annual suspended-sediment*

Station (with station No.)	1962			1963		
	Annual load (tons)	Percentage of total basin load	Yield (tons per sq mi)	Annual load (tons)	Percentage of total basin load	Yield (tons per sq mi)
Chehalis River near Doty (200)	21,000	7.8	186	70,000	10.1	619
South Fork Chehalis River at Curtis (211)	--	--	--	--	--	--
Lake Creek at Curtis (212)	--	--	--	--	--	--
South Fork Newaukum River above Onalaska (240)	3,100	1.1	73	13,000	1.9	307
North Fork Newaukum River near Forest (245)	1,900	.7	60	6,000	.9	190
Newaukum River near Chehalis (250)	13,000	4.8	84	36,000	5.2	232
Skookumchuck River at Centralia (266)	--	--	--	--	--	--
Chehalis River near Grand Mound (275)	58,000	21.5	65	160,000	23.2	179
Black River near Oakville (292)	--	--	--	--	--	--
Chehalis River at Porter (310)	70,300	26.0	54	138,000	20.0	107
Cloquallum Creek at Elma (325)	4,200	1.6	65	9,100	1.3	140
East Fork Satsop River near Elma (342)	--	--	--	--	--	--
Decker Creek near Elma (343)	--	--	--	--	--	--
Middle Fork Satsop River near Elma (345)	--	--	--	--	--	--
West Fork Satsop River near Satsop (348)	--	--	--	--	--	--
Satsop River near Satsop (350)	120,000	44.4	401	310,000	44.9	1,040
Wynoochee River above Black Creek, near Montesano (374)	77,000	28.5	497	230,000	33.3	1,480
Wishkah River near Aberdeen (380)	--	--	--	--	--	--
Total for study area [2]	270,000	--	137	690,000	--	349

[1] Estimate based on extension of data from other subbasins.
[2] Total of loads passing stations 310, 325, 350, and 374.

discharge in the Chehalis River basin, water years 1962–65

1964			1965			Average percentage of total basin load	Average annual yield (tons per sq mi)
Annual load (tons)	Percentage of total basin load	Yield (tons per sq mi)	Annual load (tons)	Percentage of total basin load	Yield (tons per sq mi)		
52,000	8.8	460	69,000	11.5	611	9.6	469
--	--	--	--	--	--	[1] 8.0	[1] 380
--	--	--	--	--	--	[1] <1.0	[1] 150
13,000	2.2	307	25,000	4.2	590	2.4	319
7,000	1.2	222	6,400	1.1	203	1.0	169
42,000	7.1	271	56,000	9.3	361	6.6	237
--	--	--	--	--	--	[1] 4.0	[1] 130
160,000	27.1	179	160,000	26.7	179	24.6	150
--	--	--	--	--	--	[1] <1.0	[1] 20
152,000	25.8	117	150,000	25.0	116	24.2	98
11,000	1.9	169	11,000	1.8	169	1.6	136
--	--	--	--	--	--	[1] <1.0	[1] 60
--	--	--	--	--	--	[1] <.5	[1] 60
--	--	--	--	--	--	[1] 12.0	[1] 1,100
--	--	--	--	--	--	[1] 27.0	[1] 1,500
250,000	42.4	836	260,000	43.3	870	43.8	787
180,000	30.5	1,160	180,000	30.0	1,160	30.6	1,070
--	--	--	--	--	--	[1] 5.0	[1] 290
590,000	--	299	600,000	--	304	--	300

TABLE 6.—*Water discharges and measured maximum and minimum instantane-*

Station (with station No.)	Instantaneous water discharge				
	Maximum			Minimum	
	Cfs	Date	Recurrence interval (yrs)	Cfs	Date
Chehalis River near Doty (200)	12,400	11–25–62	3.5	24	8–10–65
South Fork Chehalis River at Boistfort (210)	4,330	1–25–64	4.0	1.4	8– 9–65
South Fork Chehalis River at Curtis (211)	--	--	--	--	--
Lake Creek at Curtis (212)	--	--	--	--	--
South Fork Newaukum River near Onalaska (240)	3,160	1–25–64	--	23	10– 5–61 7–31–65
North Fork Newaukum River near Forest (245)	2,770	1–25–64	--	2.0	8– 1–65
Newaukum River near Chehalis (250)	7,970	1–25–64	5.5	27	10–11–63
Skookumchuck River at Centralia (266)	--	--	--	--	--
Chehalis River near Grand Mound (275)	35,700	1–26–64	5.5	118	8– 2–65
Black River near Oakville (292)	--	--	--	--	--
Chehalis River at Porter (310)	38,500	1–27–64	8.0	288	10– 5–61
Cloquallum Creek at Elma (325)	3,940	11–20–62	5.5	16	9– 7–65
East Fork Satsop River near Elma (342)	3,740	11–20–62	--	60	9–25–63
Decker Creek near Elma (343)	--	--	--	--	--
Middle Fork Satsop River near Elma (345)	--	--	--	--	--
West Fork Satsop River near Satsop (348)	--	--	--	--	--
Satsop River near Satsop (350)	32,800	11–20–62	4.0	220	9–24–65
Wynoochee River above Black Creek, near Montesano (374)	23,200	11–20–62	3.0	5.0	9–27–65
Wishkah River near Aberdeen (380)	--	--	--	--	--

[1] Occurred more than once during low-flow periods.
[2] Based on partly estimated water discharge.

ous concentrations and discharge of suspended sediment, for water years 1962–65

Instantaneous sediment concentration				Instantaneous sediment discharge			
Maximum		Minimum		Maximum		Minimum	
mg/l	Date	mg/l	Date	Tons per day	Date	Tons per day	Date
743	12–22–64	3	7–20–62	16,610	12–22–64	<0.5	7–20–62
731	12–22–64	118	12–21–64	5,290	12–22–64	154	12–21–64
208	1– 2–63	6	2–28–62	1,570	1– 2–63	<.5	8–22–62
88	4–27–62	6	10–13–61	78	4–27–62	<.5	8–22–62
927	11–19–62	4	3–28–62 7–16–63	6,610	11–19–62	.8	7–16–63
634	11–24–64	4	10–13–61	2,260	11–20–62	<.5	7–19–62
943	1–25–64	<1	11–15–62	19,600	1–25–64	<.5	8–27–62
451	11–24–64	6	7–16–63	4,080	11–20–62	.7	7–16–63
434	2– 3–63	<1	6–22–62 9–27–62	25,500	1–25–64	<.5	6–22–62 9–27–62
13	7–19–62	3	2–28–62	--	--	--	--
272	11–25–64	<1	(1)	--	--	<.5	(1)
276	11–30–64	2	11–13–62	2,090	11–30–64	<.5	7–19–62
52	11–27–63	<1	10–14–62	218	11–27–63	<.5	10–14–62
24	2– 5–63	<1	7–19–62 8–23–62 10–14–63	--	--	<.5	8–23–62
452	12–23–63	2	8–24–62	2,370	11–27–63	<.5	8–24–62
871	12–23–63	1	11–20–61 8–23–62	[2] 23,000	12–23–63	<.5	8–23–62
1,030	11–30–64	<1	5–25–63	50,100	11–30–64	<.5	5–25–63
1,220	12–23–63	<1	(1)	45,000	11–30–64	<.5	(1)
334	11–24–64	1	7–20–62	3,880	11–24–64	<.5	7–20–62 8–23–62

TABLE 7.—*Summary of particle-size distribution of suspended sediment in Chehalis River Basin*

Sampling date	Time (24 hr)	Water: Temperature (°C)	Water: Discharge (cfs)	Water: Approximate mean velocity (ft per sec)	Suspended sediment: Concentration (mg/l)	Suspended sediment: Discharge (tons per day)	Particle-size distribution (by percent): Clay (<0.004 mm)	Silt (0.004–0.062 mm)	Sand (0.062–2.00 mm)
Chehalis River near Doty (200)									
1- 2-63	0140	7	2,980	--	217	1,750	18	43	39
12-22-64	1120	4	4,630	--	619	7,740	13	37	50
South Fork Chehalis River at Boistfort (210)									
1- 2-63	0250	7	9,600	--	208	5,390	23	50	27
12-22-64	0915	4	1,130	--	483	1,470	17	44	39
South Fork Newaukum River near Onalaska (240)									
11-19-62	2330	11	2,640	7.4	927	6,610	28	54	18
11-20-62	1200	9	1,780	6.3	600	2,880	27	59	14
2- 3-63	1000	7	1,880	6.5	831	4,220	21	36	43
11-24-64	1235	7	1,530	6.0	576	2,380	23	43	34
North Fork Newaukum River near Forest (245)									
12-23-61	1920	8	575	4.8	101	157	25	35	40
11-20-62	0100	10	1,780	6.3	470	2,260	15	54	31
11-20-62	1100	9	1,000	5.5	292	789	30	39	31
2- 2-63	1450	4	323	4.2	208	181	34	38	28
11-24-64	1150	8	1,160	5.7	634	1,990	24	45	31
Newaukum River near Chehalis (250)									
11-20-62	0745	10	5,640	5.9	492	7,490	47	40	13
11-20-62	1555	9	5,110	5.8	427	5,890	45	43	12
11-26-62	1105	8	3,540	5.3	209	2,000	46	41	13
1- 2-63	0025	7	1,580	3.9	120	512	28	56	16
2- 3-63	1050	6	4,640	5.6	551	6,900	36	54	10
3-29-63	1955	7	2,720	4.7	283	2,080	30	46	24
1- 1-64	1345	9	2,340	4.5	254	1,600	30	43	27
1- 1-64	2145	8	3,450	5.1	404	3,760	39	45	16
1-25-64	1210	7	6,380	6.1	943	16,200	40	45	15
11-24-64	1310	4	4,120	5.4	807	8,980	30	51	19
12-14-64	2125	3	2,170	4.4	155	908	27	51	22
12-22-64	0820	2	3,640	5.2	400	3,930	22	50	28
12-23-64	0845	4	6,020	6.0	316	5,140	33	47	20
1- 2-65	1430	4	1,590	3.9	81	348	32	47	21
1-27-65	1415	8	5,040	5.7	385	5,240	28	52	20
1-28-65	1245	7	3,670	5.2	266	2,640	27	47	26
1-30-65	1030	8	5,420	5.9	326	4,770	36	48	16
Skookumchuck River at Centralia (266)									
11-20-62	0920	10	9,100	--	166	4,080	50	41	9
1-27-65	1600	8	5,800	--	214	3,350	44	44	12
Chehalis River near Grand Mound (275)									
11-21-62	0820	9	29,700	5.5	180	14,400	45	31	24
11-26-62	1330	9	24,500	5.3	210	13,900	50	34	16
1- 2-63	1100	8	10,500	3.2	140	3,970	28	57	15
1- 3-63	1110	9	9,620	3.1	53	1,380	30	58	12

TABLE 7.—*Summary of particle-size distribution of suspended sediment in Chehalis River basin*—Continued

Sampling date	Time (24 hr)	Water			Suspended sediment				
		Temperature (°C)	Discharge (cfs)	Approximate mean velocity (ft per sec)	Concentration (mg/l)	Discharge (tons per day)	Particle-size distribution (by percent)		
							Clay (<0.004 mm)	Silt (0.004–0.062 mm)	Sand (0.062–2.00 mm)
Chehalis River near Grand Mound (275)—Continued									
2– 3–63	1215	6	15,500	5.0	424	17,700	30	46	24
1– 2–64	0930	7	15,000	4.9	146	5,190	43	41	16
1–26–64	1035	--	36,200	6.1	237	23,200	67	14	19
Chehalis River at Porter (310)									
12–19–61	1800	--	12,800	4.2	28	968	--	--	22
4–28–62	1850	9	10,300	3.6	73	2,030	41	41	18
10– 9–62	0730	11	3,520	1.9	64	608	--	--	15
11–21–62	0955	8	23,500	5.8	114	7,230	59	26	15
11–27–62	1145	8	26,900	6.3	64	4,650	67	--	--
1– 3–63	1240	8	15,200	4.5	52	2,130	41	--	--
1– 3–64	1000	7	17,800	4.9	56	2,690	50	24	26
1–26–64	1810	7	28,800	6.6	126	9,800	75	19	6
11–25–64	1450	6	14,000	4.3	195	7,370	51	35	14
12– 1–64	1135	9	20,400	5.5	91	5,010	43	46	11
1–28–65	1010	7	24,000	6.0	90	5,830	52	35	13
Cloquallum Creek at Elma (325)									
1– 1–64	1915	8	2,250	5.3	214	1,300	28	25	47
11–30–64	1530	9	2,800	5.6	276	2,090	30	24	46
1–27–65	0900	7	2,340	5.4	170	1,070	22	34	44
1–30–65	1430	7	2,290	5.4	174	1,080	16	43	41
Satsop River near Satsop (350)									
10– 9–62	1040	10	3,970	3.3	193	2,070	24	57	19
11–21–62	1120	9	8,740	4.8	341	8,050	37	--	--
1– 3–63	1600	8	9,740	5.1	279	7,340	26	51	23
11–26–63	2300	8	12,100	5.7	546	17,900	28	45	27
12–23–63	0015	8	9,180	5.0	449	11,100	15	36	49
12–23–63	1015	8	10,520	5.3	491	13,900	18	41	41
1–25–64	0920	6	14,100	6.1	571	21,700	18	33	49
11– 4–64	0750	9	5,390	3.8	372	5,410	32	49	19
11–24–64	0720	8	10,400	5.3	950	26,700	22	49	29
11–30–64	1200	9	18,000	6.9	1,030	50,100	24	51	25
12– 2–64	1445	8	9,600	5.1	392	10,200	16	46	38
1–27–65	1015	6	11,800	5.6	631	20,100	21	40	39
Wynoochee River above Black Creek near Montesano (374)									
4–28–62	0740	7	2,840	--	96	736	40	41	19
11–21–62	1240	8	5,140	--	228	3,160	30	56	14
2– 5–63	0730	8	7,650	--	774	16,000	29	45	26
11–14–63	1205	9	5,620	--	478	7,250	37	42	21
11–26–63	2220	8	8,670	--	653	15,300	25	50	25
12–23–63	0115	8	6,570	--	632	11,200	20	50	30
12–23–63	1315	8	9,780	--	1,101	29,100	18	42	40
1–25–64	0725	6	7,490	--	387	7,830	18	37	45
11– 4–64	0600	9	2,980	--	283	2,280	20	53	27
11– 4–64	1050	11	4,060	--	408	4,470	26	55	19
11–24–64	0530	8	7,680	--	1,190	24,700	16	50	34
11–30–64	1405	8	16,000	--	1,040	45,000	27	49	24
1–27–65	1130	5	7,300	--	655	12,900	18	47	35
1–30–65	1330	7	7,550	--	426	8,680	19	48	33
Wishkah River near Aberdeen (380)									
12–23–63	0210	8	3,550	--	154	1,480	45	48	7
12–23–63	1540	8	3,700	--	210	2,100	--	--	9

TABLE 8.—*Water discharge and suspended-sediment transport for periods of high runoff, during water years 1962–65*

Periods of high runoff (dates)	Duration (days)	Station (with station No.)	Water discharge: Acre-ft	Water discharge: Yield (acre-ft per sq mi)	Concentration (mg/l): Maximum estimated	Concentration (mg/l): Maximum measured	Concentration (mg/l): Discharge-weighted mean	Suspended-sediment transport: Load (tons)	Suspended-sediment transport: Yield (tons per sq mi)
		Water year 1962							
12-19 to 12-27	9	South Fork Newaukum River near Onalaska (240).	11,500	270	325	257	81	1,260	30
12-19 to 12-27	9	North Fork Newaukum River near Forest (245).	7,930	252	270	240	65	706	22
12-20 to 12-28	9	Chehalis River near Grand Mound (275)	201,000	225	91	90	47	12,800	14
12-20 to 1-2	14	Chehalis River at Porter (310)	376,000	291	89	76	36	18,300	14
4-6 to 4-10	5	Chehalis River near Grand Mound (275)	43,400	48	63	51	23	1,340	1.5
4-6 to 4-12	7	Chehalis River at Porter (310)	74,300	57	54	54	20	2,030	1.6
4-6 to 4-9	4	East Fork Satsop River near Elma (342)	3,720	56	23	13	7	33	.5
4-6 to 4-9	4	Satsop River near Satsop (350)	23,100	77	185	168	49	1,550	5.2
4-26 to 4-30	5	Chehalis River near Doty (200)	12,000	106	155	122	50	815	7.2
4-27 to 5-1	5	Chehalis River near Grand Mound (275)	54,200	61	83	70	36	2,650	3.0
4-27 to 5-2	6	Chehalis River at Porter (310)	81,600	63	106	106	36	4,010	3.1
4-26 to 4-30	5	Cloquallum Creek at Elma (325)	4,200	65	49	40	16	90	1.4
4-27 to 4-30	4	Satsop River near Satsop (350)	27,900	93	186	154	53	2,010	6.7
4-27 to 4-30	4	Wynoochee River above Black Creek, near Montesano (374).	16,800	109	182	96	60	1,380	8.9
		Water year 1963							
10-7 to 10-12	6	Chehalis River at Porter (310)	38,200	30	96	85	41	2,120	30
10-7 to 10-11	5	Cloquallum Creek at Elma (325)	3,350	52	90	79	33	153	52
10-7 to 10-11	5	East Fork Satsop River near Elma (342)	2,330	35	22	22	7	22	35
10-7 to 10-16	10	Chehalis River near Grand Mound (275)	57,500	64	46	34	23	1,760	2.0
10-7 to 10-16	10	Chehalis River at Porter (310)	72,400	56	96	85	29	2,870	2.2
10-7 to 10-16	10	Satsop River near Satsop (350)	59,700	200	778	778	140	11,400	38
10-7 to 10-16	10	Wynoochee River above Black Creek, near Montesano (374).	47,600	307	710	627	203	13,200	85
11-10 to 11-14	6	Newaukum River near Chehalis (250)	7,480	48	85	58	17	175	1.1
11-10 to 11-17	8	Chehalis River near Grand Mound (275)	68,700	77	47	45	19	1,810	2.0
11-10 to 11-18	9	Chehalis River at Porter (310)	69,600	54	40	37	25	2,340	1.8

11-10 to 11-13	4	Cloquallum Creek at Elma (325)	3,830	59	43	11	13	66	1.0
11-19 to 11-23	5	South Fork Newaukum River near Onalaska (240).	9,300	219	1,100	927	513	6,500	153
11-19 to 11-23	5	North Fork Newaukum River near Forest (245).	5,930	188	722	470	336	2,710	86
11-19 to 11-23	5	Newaukum River near Chehalis (250)	25,900	167	540	492	312	11,000	71
11-19 to 11-23	5	Skookumchuck River at Centralia (266)	32,000	177	183	179	67	2,930	16
11-19 to 11-23	5	Chehalis River near Grand Mound (275)	159,000	177	357	319	137	29,600	33
11-19 to 11-24	6	Chehalis River at Porter (310)	198,000	153	227	182	103	27,800	22
11-19 to 11-23	5	Cloquallum Creek at Elma (325)	15,700	242	180	75	99	2,110	32
11-19 to 11-23	5	Satsop River near Satsop (350)	110,000	367	1,790	341	845	126,000	422
11-19 to 11-23	5	Wynoochee River above Black Creek, near Montesano (374).	73,500	474	1,780	228	882	88,200	569
11-24 to 11-28	5	Newaukum River near Chehalis (250)	25,200	163	312	209	158	5,410	35
11-24 to 11-30	7	Chehalis River at Porter (310)	297,100	116	94	94	49	19,900	15
11-24 to 11-29	6	Satsop River near Satsop (350)	81,100	137	550	220	185	20,400	68
11-24 to 11-29	6	Wynoochee River above Black Creek, near Montesano (374).	49,900	162	670	229	297	20,200	130
12-14 to 12-17	4	Chehalis River near Doty (200)	7,240	64	66	64	23	223	2.0
12-14 to 12-18	5	Newaukum River near Chehalis (250)	8,910	57	52	42	19	229	1.5
12-14 to 12-20	7	Chehalis River near Grand Mound (275)	69,700	78	50	46	24	2,250	2.5
12-14 to 12-21	8	Chehalis River at Porter (310)	109,600	85	44	34	14	2,130	1.6
12-14 to 12-17	4	Cloquallum Creek at Elma (325)	5,720	88	58	41	21	160	2.5
12-14 to 12-18	5	Satsop River near Satsop (350)	47,300	158	230	225	69	4,460	15
12-29 to 1-5	8	Chehalis River near Doty (200)	25,300	224	268	217	94	3,240	29
12-30 to 1-8	10	Newaukum River near Chehalis (250)	15,800	102	125	120	31	676	4.4
12-30 to 1-5	7	Chehalis River near Grand Mound (275)	94,600	106	147	140	54	6,980	7.8
12-30 to 1-9	11	Chehalis River at Porter (310)	189,000	146	135	127	37	9,590	7.4
1-31 to 2-12	6	South Fork Newaukum River near Onalaska (240).	7,480	176	990	831	355	3,610	176
2-1 to 2-7	6	North Fork Newaukum River near Forest (245).	4,720	150	662	582	161	1,030	150
1-31 to 2-8	9	Newaukum River near Chehalis (250)	30,400	196	647	637	247	10,200	196
1-31 to 2-8	9	Chehalis River near Grand Mound (275)	195,300	218	476	424	139	36,800	218
1-31 to 2-12	13	Chehalis River at Porter (310)	291,700	225	227	216	77	30,700	225
2-2 to 2-7	6	Satsop River near Satsop (350)	67,100	224	820	702	291	26,600	224
2-2 to 2-8	7	Wynoochee River above Black Creek, near Montesano (374).	55,800	360	1,420	1,140	429	32,600	360
3-27 to 4-3	8	Newaukum River near Chehalis (250)	22,500	145	287	283	96	2,940	19
3-27 to 4-3	8	Chehalis River near Grand Mound (275)	139,400	156	174	168	73	13,800	15
3-28 to 4-4	8	Chehalis River at Porter (310)	188,800	146	148	142	61	15,700	12
3-27 to 4-2	7	Satsop River near Satsop (350)	46,600	156	53	53	24	1,550	5.2
3-27 to 4-2	7	Wynoochee River above Black Creek, near Montesano (374).	26,800	173	116	116	42	1,530	9.9
5-5 to 5-8	4	Newaukum River near Chehalis (250)	5,060	33	29	28	10	68	.4
5-5 to 5-9	5	Chehalis River near Grand Mound (275)	40,000	45	33	30	11	623	.7
5-5 to 5-11	7	Chehalis River at Porter (310)	70,400	54	24	24	12	1,170	.9
5-5 to 5-8	4	Wynoochee River above Black Creek, near Montesano (374).	12,600	81	171	165	39	667	4.3

TABLE 8.—*Water discharge and suspended-sediment transport for periods of high runoff, during water years 1962–65*—Continued

Periods of high runoff (dates)	Duration (days)	Station (with station No.)	Water discharge		Suspended-sediment transport				
					Concentration (mg/l)				
			Acre-ft	Yield (acre-ft per sq mi)	Maximum estimated	Maximum measured	Discharge-weighted mean	Load (tons)	Yield (tons per sq mi)
Water year 1964									
10-21 to 10-30	10	Newaukum River near Chehalis (250)	6,680	43	87	82	28	257	1.7
10-21 to 10-24	3	Chehalis River near Grand Mound (275)	17,500	20	94	70	53	1,260	1.4
10-21 to 10-30	10	Chehalis River at Porter (310)	71,400	55	94	82	37	3,640	2.8
10-21 to 10-30	10	Satsop River near Satsop (350)	90,000	301	915	537	221	27,100	91
10-21 to 10-30	10	Wynoochee River above Black Creek, near Montesano (374).	65,600	423	990	457	341	30,400	196
11-13 to 11-16	4	Chehalis River at Porter (310)	75,900	59	90	76	35	3,600	2.8
11-13 to 11-16	4	Satsop River near Satsop (350)	48,400	162	247	222	64	4,180	14
11-13 to 11-16	4	Wynoochee River above Black Creek, near Montesano (374).	32,100	207	785	636	198	8,640	56
11-26 to 11-28	3	Newaukum River near Chehalis (250)	5,180	33	35	12	17	120	.8
11-23 to 11-26	4	Chehalis River at Porter (310)	89,900	69	42	42	27	3,340	2.6
11-26 to 11-28	3	East Fork Satsop River near Elma (342)	6,880	104	61	52	29	272	4.1
11-25 to 11-28	3	Satsop River near Satsop (350)	48,400	162	890	747	283	18,600	62
11-25 to 11-28	4	Wynoochee River above Black Creek, near Montesano (374).	39,600	256	1,200	661	403	21,700	140
12-19 to 12-24	6	Chehalis River at Porter (310)	81,800	63	76	34	36	3,960	3.1
12-19 to 12-23	5	Cloquallum Creek at Elma (325)	6,770	104	60	18	27	253	3.9
12-24 to 12-26	3	Newaukum River near Chehalis (250)	3,970	26	20	6	9	49	.3
12-25 to 12-26	2	Chehalis River near Grand Mound (275)	16,600	19	17	12	11	248	.3
12-19 to 12-25	7	Chehalis River at Porter (310)	93,500	72	76	34	33	4,220	3.3
12-22 to 12-26	5	Satsop River near Satsop (350)	75,100	251	967	949	370	37,800	126
12-22 to 12-26	5	Wynoochee River above Black Creek, near Montesano (374).	54,100	349	1,240	1,220	587	43,200	279
12-31 to 1-3	4	Newaukum River near Chehalis (250)	11,400	74	692	528	204	3,160	20
1-1 to 1-3	3	Chehalis River near Grand Mound (275)	60,700	68	178	146	80	6,580	7.4
1-1 to 1-4	4	Chehalis River at Porter (310)	104,900	81	125	119	59	8,360	6.5
12-31 to 1-3	4	Cloquallum Creek at Elma (242)	2,900	138	400	214	136	1,650	25
1-24 to 1-31	8	Newaukum River near Chehalis (250)	42,100	272	1,030	943	320	18,400	118
1-24 to 2-5	6	Chehalis River near Grand Mound (275)	350,300	391	432	420	102	48,700	54
1-24 to 2-5	8	Chehalis River at Porter (310)	505,200	390	178	170	63	43,500	34
1-24 to 1-29	6	Cloquallum Creek at Elma (325)	16,500	254	240	224	94	2,100	33
1-24 to 1-31	8	Satsop River near Satsop (350)	119,300	399	805	571	184	29,900	100
1-24 to 1-31	8	Wynoochee River above Black Creek, near Montesano (374).	60,900	393	408	387	109	9,000	58

Water year 1965

11-3 to 11-7	5	Chehalis River at Porter (310)	7,490	6	69	58	111	1,130	0.9
11-3 to 11-5	3	Cloquallum Creek at Elma (325)	1,750	27	97	90	39	93	1.4
11-3 to 11-7	5	Satsop River near Satsop (350)	23,600	79	391	372	82	2,630	8.8
11-3 to 11-7	5	Wynoochee River above Black Creek, near Montesano (374).	15,600	101	420	408	103	2,190	14
11-23 to 11-28	6	South Fork Newaukum River near Onalaska (240).	6,960	164	590	576	175	1,660	39
11-23 to 11-28	6	North Fork Newaukum River near Forest (245).	4,260	135	846	634	201	1,170	37
11-23 to 11-28	6	Newaukum River near Chehalis (250)	22,800	147	993	807	334	10,300	67
11-23 to 11-29	7	Chehalis River at Porter (310)	150,800	117	367	272	95	19,400	15
11-22 to 11-28	7	Cloquallum Creek at Elma (325)	8,500	131	312	260	75	875	14
11-23 to 11-28	6	Satsop River near Satsop (350)	53,600	179	1,620	950	400	29,200	98
11-23 to 11-28	6	Wynoochee River above Black Creek, near Montesano (374).	35,800	231	1,520	1,190	394	19,200	124
11-30 to 12-4	5	Newaukum River near Chehalis (250)	25,200	163	505	238	147	5,050	33
11-30 to 12-7	8	Chehalis River at Porter (310)	270,000	209	136	105	64	23,600	18
11-29 to 12-5	7	Cloquallum Creek at Elma (325)	19,400	300	281	276	108	2,850	44
11-29 to 12-5	7	Satsop River near Satsop (350)	120,300	402	1,430	1,030	472	77,200	258
11-29 to 12-5	7	Wynoochee River above Black Creek, near Montesano (374).	84,300	544	1,390	1,040	508	58,300	376
12-14 to 12-18	5	South Fork Newaukum River near Onalaska (240).	2,980	70	86	86	21	85	2.0
12-14 to 12-18	5	North Fork Newaukum River near Forest (245).	2,260	72	170	138	25	78	2.5
12-14 to 12-16	3	Newaukum River near Chehalis (250)	8,310	54	181	168	57	648	4.2
12-14 to 12-17	3	Chehalis River at Porter (310)	61,700	48	84	42	35	2,960	2.3
12-21 to 12-29	9	Chehalis River near Doty (200)	45,900	406	795	743	235	14,700	130
12-21 to 12-29	9	South Fork Chehalis River at Boistfort (210).	20,700	430	760	731	301	8,470	176
12-21 to 12-29	9	Newaukum River near Chehalis (250)	46,400	300	645	570	207	13,100	84
12-21 to 12-31	11	Chehalis River at Porter (310)	400,300	309	192	165	57	31,000	24
12-21 to 12-29	9	Cloquallum Creek at Elma (325)	14,700	227	103	94	34	674	10
1-26 to 2-4	10	Newaukum River near Chehalis (250)	56,400	364	486	385	267	20,500	132
1-27 to 2-5	10	Chehalis River at Porter (310)	467,500	361	128	112	49	31,200	24
1-26 to 2-3	9	Cloquallum Creek at Elma (325)	27,200	419	198	170	99	3,650	56
1-26 to 2-3	9	Satsop River near Satsop (350)	151,200	506	863	670	280	57,700	193
1-26 to 2-3	9	Wynoochee River above Black Creek, near Montesano (374).	91,000	587	764	650	286	35,400	228
2-26 to 3-2	5	Newaukum River near Chehalis (250)	7,870	51	57	56	206	221	1.4
2-27 to 3-4	6	Chehalis River at Porter (310)	92,000	71	90	86	39	4,930	3.8
2-26 to 3-2	5	Cloquallum Creek at Elma (325)	6,060	93	81	79	33	274	4.2
2-26 to 3-2	5	Satsop River near Satsop (350)	42,900	143	249	208	65	3,810	13
2-26 to 3-2	5	Wynoochee River above Black Creek, near Montesano (374).	28,100	181	360	328	115	4,390	28

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