Sediment Transport by Streams in the Palouse River Basin, Washington and Idaho, July 1961–June 1965

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1899–C

Prepared in cooperation with the Washington State Department of Water Resources

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By P. R. BOUCHER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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SEDIMENT TRANSPORT BY STREAMS IN THE PALOUSE RIVER BASIN, WASHINGTON AND IDAHO, JULY 1961-JUNE 1965

By P. R. BOUCHER

ABSTRACT

The Palouse River basin covers about 3,300 square miles in southeastern Washington and northwestern Idaho. The eastern part of the basin is composed of steptoes and foothills which are generally above an altitude of 2,600 feet; the central part is of moderate local relief and is mantled chiefly by thick loess deposits; and the western part is characterized by low relief and scabland topography and is underlain mostly by basalt.

Precipitation increases eastward across the study area. It ranges annually from 12 to 18 inches in the western part and from 14 to 23 inches in the central part, and it exceeds 40 inches in the eastern part.

Surface runoff from the basin for the 4-year period of study (July 1961–June 1965) averaged 408,000 acre-feet per year, compared with 445,200 acre-feet per year for the 27-year period of record. The eastern part of the basin contributed about 55 percent of the total, whereas the central and western parts contributed 37 percent and 8 percent, respectively. Most sediment transport from the Palouse River basin and the highest sediment concentrations in streams occurred in the winter. Of the several storms during the study period, those of February 3–9, 1963, December 22–27, 1964, and January 27–February 4, 1965, accounted for 81 percent of the total 4-year suspended-sediment load; the storm of February 3–9, 1963, accounted for nearly one-half the total load. The discharge-weighted mean concentration of suspended sediment carried in the Palouse River past Hooper during the study period was 2,970 milligrams per liter.

The average annual sediment discharge of the Palouse River at its mouth was about 1,580,000 tons per year, and the estimated average annual sediment yield was 480 tons per square mile. The yield ranged from 5 tons per square mile from the western part of the basin to 2,100 tons per square mile from the central part. The high yield from the central part is attributed to a scarcity of vegetal cover, to the fine-grained loess soils, and to rapid runoff during winter storms. Sediment yield from the eastern part of the basin ranged from 460 to more than 1,000 tons per square mile.

During high flow, silt particles make up the largest part of the suspended-sediment load, whereas during low flow, clay particles represent the greatest part. On the average, the suspended sediment transported by the Palouse River past Hooper contained 3 percent sand, 68 percent silt, and 29 percent clay. Unmeasured sediment discharge was estimated to have been 5 percent of the total sediment discharge.

Data collected during the 4-year period of study show that sediment loads were higher than those recorded by V. G. Kaiser during the longer period 1939–65. Whereas Kaiser's study showed an average annual soil loss of 9.6 million tons, the average annual loss during the recent study was 14.2 million tons.

The factor that has had the greatest effect on the increase of sediment yields is land use. Lands once covered and protected by natural vegetation have been extensively cultivated, and much of the soil has become susceptible to erosion, particularly in areas mantled by loessal soils.

INTRODUCTION

PURPOSE AND SCOPE

This report presents the findings of a study of fluvial-sediment transport in the Palouse River basin during the period July 1961–June 1965. The study was made in cooperation with the Washington State Department of Water Resources. The purpose of the study was to determine generally the quantity and characteristics of sediment transported by streams in the basin and to understand better the factors that cause soil erosion and sediment discharge in various parts of the basin. This information will be of value to future planning and development of the water and soils resources of the watershed.

This report discusses the relative quantities and types of sediment transported by streams and the environmental factors of land use, precipitation, temperature, runoff, geology, and topography that influence erosion and determine the amount of fluvial sediment in a stream. Precise evaluation of these interrelated factors is beyond the scope of this report, as the study was a reconnaissance only.

PREVIOUS SEDIMENT STUDIES

Potter and Love (1942) investigated transport of fluvial sediment from three small watersheds near Pullman during the period 1934–40. The Soil Conservation Service, U.S. Department of Agriculture, used these data to help develop conservation plans for a number of farms in the Pullman area. Kaiser (1961; written commun., 1966) has been studying soil erosion in Whitman County since 1939. Some results of his studies are compared with data collected during the present study on page 16.

ACKNOWLEDGMENTS

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GENERAL FEATURES OF THE BASIN

PHYSIOGRAPHY

The Palouse River basin covers 3,283 square miles, of which about 2,730 square miles is in southeastern Washington and the remainder is in Idaho (pl. 1). The Palouse River drains into the Snake River 59.5 miles upstream from the mouth of the Snake River at Lake Wallula (Columbia River). Altitudes in the basin range from 5,334 feet at Bald Mountain in the Clearwater Mountains in Idaho to 480 feet at the mouth of the Palouse River in Washington.

The major tributaries of the Palouse River, in downstream order, are the South Fork Palouse River, Rebel Flat Creek, Rock Creek (which includes Pine Creek), Union Flat Creek, and Cow Creek. The reaches of these streams flowing through the eastern part of the basin flow northwest to west, and those in the western part flow west to southwest. Stream gradients are in part governed by outcrops of the underlying basalt and in part by aggradation of valley floors by deposition of sediment carried from higher lands. Kaiser (1961, p. 139–145) reported that increased overland flow (surface runoff) caused by removal of natural vegetation has accelerated erosion and has increased the amount of sediment deposited at the base of the slopes. Such conditions have resulted in the aggradation of valley floors and, thus, have changed the stream gradients.

For convenience in discussing sediment transport in the area, the Palouse River basin has been herein divided into three subareas (pl. 1).

Subarea A is the easternmost part of the basin, characterized by steptoes and foothills—areas generally above an altitude of 2,600 feet. Local relief is high, loess cover is thin, and precipitation is relatively heavy. The main stem of the Palouse, the South Fork Palouse, and Pine Creek head in this subarea.

Subarea B, the central part of the basin, is partly in the Palouse Hills. The Palouse Hills were characterized by Caldwell (1961, p. 115) as "a rolling surface of broad, asymmetric, wavelike swells of eolian loess-like materials, generally rising 20 to 80 feet above valleys that contain neither streams nor channels." In subarea B, stream channels are not well defined in the valley floors, and only the main courses have a distinct direction. According to Newcomb (1965, p. 24), erosion has been responsible for the "billowing rounded convex-upward hill slopes characteristic of the Palouse topography."

One factor responsible for the mechanical shaping of the loess hills, besides normal surface runoff and wind action, is the buildup of large banks of snow on the north and east faces of the hills. As these snowbanks melt, excess runoff causes deeper erosion of the soil on the north and east slopes. This is especially true in the Colfax-Pullman-Moscow area.

Subarea C is the westernmost, scabland, part of the basin. Lack of an integrated drainage system and little local relief are common physiographic features of this subarea; lakes such as Sprague and Rock Lakes are numerous and signify the lack of integrated drainage. Interchannel areas in the scabland are locally characterized by remnant mantles of loess. All of the Cow Creek basin and a major part of the Rock Creek basin are in this area.

GEOLOGY

For the purpose of this report, three basic geologic units are recognized in the Palouse basin. These units are (1) metamorphic and intrusive igneous rocks of pre-Tertiary age, (2) basalt of the Columbia River Group of Miocene and Pliocene age, and (3) loess of late Pliocene, Pleistocene, and Holocene (Recent) age. The areal extent of these units is illustrated on plate 1.

Pre-Tertiary rocks form the high buttes and steptoes of subarea A and are the basement rocks throughout the remainder of the basin. Much of the pre-Tertiary land surface has been covered by extensive flows of basalt of the Columbia River Group. The basalt ranges in thickness from several thousand feet to only a few feet; it is nonexistent in some places near the Clearwater Mountains.

The sand and gravel in subarea C were transported there during catastrophic floods that followed breakage of ice dams to the north. The floods occurred during the Wisconsin Glaciation in late Pleistocene time (Flint, 1938, p. 461–524; Bretz, 1928, 1959; Bretz and others, 1956, p. 957–1050).

The channeled scablands of eastern Washington are unique; at no other place in the world does this type of landscape exist. The basalt of the scablands is characterized by a deeply eroded and channeled surface, with interchannel areas locally mantled by loess that escaped the floodwaters. The area is marked by numerous dry coulees, by large closed basins occupied by lakes, and by isolated remnants of basalt not eroded by the floodwaters. Little soil has developed, and the surface materials consist mostly of boulders, cobbles, and gravel. Large quantities of sand and gravel cover isolated areas where ponded-backwater conditions existed during various stages of the flooding.

Loess (a fine-grained windblown deposit) of late Pliocene, Pleistocene, and Holocene age is the most important source of fluvial sediment in the basin. The loess is classified in this report as "older" and "younger." The older loess was laid down on top of the basalt prior to the extensive flooding that created the channeled scablands. The younger loess was deposited after the floods. The younger loess is not as extensive as the older loess and has a less-developed soil horizon. Silt and clay are dominant in both of the loess units. Locally, the aggregate thickness of the loess is 150 feet or more. In general, the thickness decreases toward the northeast.

The geology of specific areas in the Palouse River basin was studied by Bretz (1928, 1959), Flint (1938), Threasher (1925), Richmond, Fryxell, Neff, and Weis (1965), Fryxell and Cook (1964), Foxworthy and Washburn (1963), Walters and Glancy (1969), and others.

CLIMATE

The climate in the study area is arid to subhumid, with precipitation ranging from 12 inches in subarea C to more than 40 inches in subarea A (pl. 1). Only one-fourth of the precipitation occurs during the growing season, May to September.

The annual precipitation measured at Colfax for the years 1961–65 (table 1) indicates that it was below the long-term mean of 20.97 inches (U.S. Weather Bureau, 1962–66). The relationship of monthly precipitation to monthly mean runoff of the Palouse River, as recorded at the gaging station at Colfax, and the average maximum and minimum monthly temperatures are shown in figure 1.

TABLE 1.—*Summary of average annual precipitation at Colfax, 1961–65, and annual departure from the long-term mean (20.97 in.)*

[Climatological data from U.S. Weather Bureau (1962–66)]

Year (July 1–June 30)	Annual precipitation (inches)	Departure from long-term mean (inches)
1961–62	16.97	−4.00
1962–63	17.60	−3.37
1963–64	15.78	−5.19
1964–65	20.19	− .78
Average for study period (1961–65)	17.63	−3.34

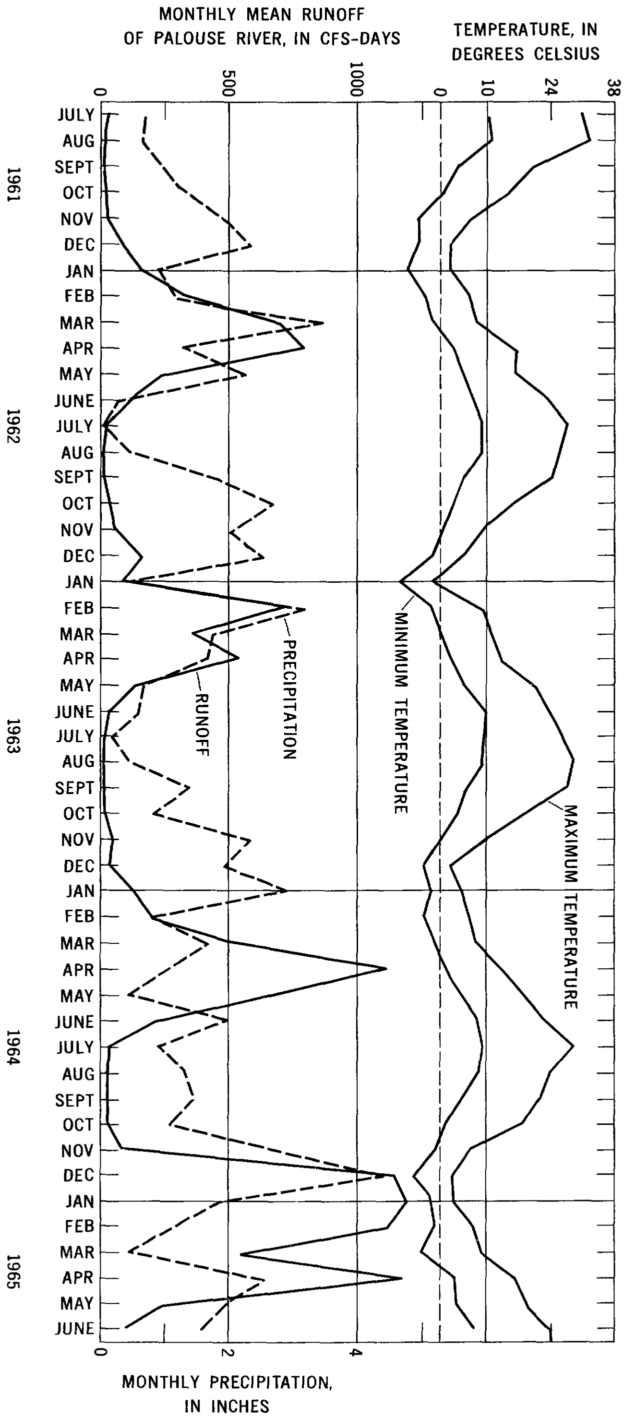

FIGURE 1.—Hydrograph showing monthly precipitation, monthly mean runoff of Palouse River, and monthly maximum and minimum temperatures, at Colfax, July 1, 1961–June 30, 1965.

Continued cold weather in the Palouse River basin is unusual, but subfreezing temperatures are frequent, sometimes causing the soil to freeze to a depth of several inches. Commonly, warm moist air moving suddenly into the basin causes warm rains to occur while the ground is still frozen.

RUNOFF

Most of the precipitation, runoff, and peak flows in the study area occur during the winter and early spring. During the summer, the flow of the many perennial streams decreases gradually to base flow.

Surface runoff from the basin, for the 4-year period of study, averaged 408,000 acre-feet per year (table 2). Runoff during the 27-year period of record averaged 445,200 acre-feet per year for the Palouse River at Hooper (location shown on pl. 1). Most of the runoff comes from subarea A—the upper reaches of the Palouse River, Pine Creek, and South Fork Palouse River—where precipitation is 20 to 40 inches in the higher altitudes.

Streams such as Rebel Flat, Cottonwood, Union Flat, and Willow Creeks that drain mostly subarea B have less annual runoff than streams originating in subarea A, but peak flows of the streams in both subareas are about equal. Less precipitation (14–23 in.) in subarea B is the chief reason for less annual runoff. The runoff from subarea B is more closely associated with storm duration; streams are "flashy" and seldom sustain high rates of discharge for more than a few days each year.

The least runoff in the basin is from the scablands in subarea C, where precipitation ranges from 12 to 18 inches annually, the least in the basin. Streams in subarea C—for example, Cow Creek and Rock Creek that drain most of this subarea—tend to be less flashy than those in subarea A because the peak flows are stored temporarily in numerous lakes and depressions.

Three major storms occurred during the study period. The storm of February 4, 1963, produced the highest peak flow of record for the Palouse River at Hooper. The other two caused

TABLE 2.—*Summary of annual precipitation and estimated average annual runoff for the three subareas and for the entire Palouse River basin, 1961–65*

Subarea (pl. 1)	Range of annual precipitation (inches)	Estimated average annual runoff		Yield (acre-ft per sq mi)
		Acre-feet	Percentage of total	
A	20–40	224,000	55	301
B	14–23	151,000	37	110
C	12–18	33,000	8	28
Entire basin	12–40	408,000	100	124

peaks, much less in magnitude, on December 24, 1964, and January 30, 1965. Table 3 summarizes the annual runoff during the period of this investigation and runoff data for past years. The table lists only data for those stations in operation during the investigation.

LAND USE

All land in the Palouse River basin is cultivated where deposits of loess are sufficiently thick to sustain crops. Wheat, the principal crop, is supplemented by other grains and legumes.

Subarea A is characterized by forest range on the slopes of the Clearwater Mountains and by cropland in areas underlain by extensive loess and of moderate local relief. Forest range covers about 60 percent of subarea A in Idaho. Except for the steptoes and buttes, most of subarea A in Washington is cultivated.

Except for small areas in the northern part characterized by stands of ponderosa pine, nearly all of subarea B suitable for farming has been plowed. The only other uncultivated areas are those that are too steep or those where streams have removed the loess cover and exposed the underlying basalt.

Lands in subarea C are not widely cultivated, except where large islands of loess exist. Most of the vegetation is grass and sage, but large stands of ponderosa pine grow in the northernmost part of the subarea. Livestock grazing is important where cultivation is not extensive.

DATA COLLECTION

Collection and analysis of sediment samples were in accordance with standard techniques established by the U.S. Geological Survey. Most of the basic sediment data were published in one annual series (U.S. Geological Survey, 1964b, c; 1965b; 1966; and 1967). The stream-discharge data were published in another series (U.S. Geological Survey, 1962, 1963, 1964a, and 1965a).

During this study, fluvial-sediment data were collected at one daily station and at 15 reconnaissance sites (pl. 1). Samples at reconnaissance sites were collected frequently during selected high flows and infrequently during times of low flow.

The daily station was on the Palouse River at Hooper, where an observer obtained samples daily during low and medium flows and more often during high flows.

SEDIMENT CHARACTERISTICS IN THE BASIN

SOURCE OF SEDIMENT

The sediment transported by water in the Palouse River basin comes both from broad sheet erosion of hills, fields, and surround-

TABLE 3.—*Annual and average annual runoff at several stations in the Palouse River basin, 1962–65, and streamflow data for period of record*

[Runoff data from records of U.S. Geol. Survey]

Station number	Station name	Drainage area (sq mi)	Annual runoff for year ending June 30 (acre-ft per sq mi)				Average annual runoff 1963–65 (acre-ft per sq mi)	Percent of basin total	Period of record	Average annual runoff for period of record (acre-ft per sq mi)	Peak flow (cfs)	Date of peak flow
			1962	1963	1964	1965						
3461.	Palouse River at Colfax [1]	497	301	256	369	677	401	49.2	Sept. 1955–Sept. 1965	473	8,510	Dec. 24, 1964
3480.	South Fork Palouse River at Pullman.	132	134	103	168	314	180	5.9	Feb. 1934–Sept. 1942; Dec. 1959–Sept. 1965.	172	5,000	Feb. 26, 1948
3485.	Missouri Flat Creek at Pullman.	27.1	110	116	145	302	168	1.1	Feb. 1934–Sept. 1940; Jan. 1960–Sept. 1965.	179	1,500	Do.
3492.1.	Palouse River below South Fork at Colfax.	796	----	----	[2] 280	530	----	[2] 62.0	Oct. 1963–Sept. 1965	----	14,500	Feb. 3, 1963
3494.	Pine Creek at Pine City	302	[2] 71.5	111	72.9	209	[2] 116	[2] 8.7	Sept. 1961–Sept. 1965	----	10,800	Do.
3505.	Union Flat Creek near Colfax	189	86.8	93.6	77.6	215	118	5.5	July 1953–Sept. 1965	146	2,930	Jan. 29, 1965
3510.	Palouse River at Hooper	2,500	111	130	120	261	156	95.8	Sept. 1897–Dec. 1899; Apr. 1900–Apr. 1907; June 1908–July 1912; Mar. 1913–Mar. 1916; Feb. 1951–Sept. 1965.	178	33,500	Feb. 4, 1963
3525.	Cow Creek at Hooper	697	----	28.5	12.7	34.2	[3] 25.1	[2] 4.1	Feb. 1951–Dec. 1953; Mar. 1962–Sept. 1965.	----	1,150	Feb. 5, 1963

[1] Published as "Palouse River near Colfax" prior to 1964.
[2] Partly estimated.
[3] 3-year record.

ing areas and from channel erosion of streambanks and streambeds. Channel erosion is more dominant in subarea B, where steep banks of soft materials are prominent along many streams. The quantities of suspended-sediment discharge resulting from either sheet or channel erosion were not separately defined, but probably the greater contribution to the sediment load comes from sheet erosion.

SUSPENDED-SEDIMENT CONCENTRATION

Concentrations of suspended sediment in streams vary according to the soils and runoff characteristics of the source areas. Suspended-sediment concentrations in streams that originate in subarea B, which is underlain chiefly by loess, tend to be greater than concentrations in streams that originate in either subarea A or subarea C, which are characterized largely by loess-free mountains and scablands, respectively. In the latter two areas, streams originating in the mountains of subarea A, where precipitation and runoff are greater, carry higher concentrations of suspended sediment than streams flowing across the scablands of subarea C. The rate of soil removal also is directly related to the rate of runoff; short periods of high runoff during storms are responsible for the major sediment concentration and transport during the year.

For the period of record, the discharge-weighted mean concentration of suspended sediment in the Palouse River, as calculated for the station at Hooper, was 2,970 mg/l (milligrams per liter). This concentration near the outlet of the basin is not reflected by similar values for sampling sites upstream, however, owing to the great areal variations in precipitation and runoff, character of surface materials, type of land use, and vegetative cover.

The sediment concentrations in tributaries near the boundary between subareas A and B are greater than those in the upper reaches of the Palouse River in subarea A. However, the heavier runoff of nearly sediment free water from the upper tributaries in subarea A dilutes concentrations of the lower tributaries as they enter the main stem. This is reflected in samples taken near the boundary between the subareas. For example, the discharge-weighted mean concentration of 1,300 mg/l (table 4) in the Palouse River at Colfax, which represents runoff from a large mountainous area to the east, is low compared with the mean concentration of 2,900 mg/l in the South Fork Palouse River at Pullman, which represents runoff from a lower part of subarea A characterized by less precipitation but having a greater proportion of loess-mantled land. Sufficient data were not available to compute a discharge-weighted mean concentration for the Palouse River at Palouse, the drainage basin of which lies wholly in subarea A. However, the observed concentrations tended to be much lower than those in other streams draining subarea A because the river above Palouse drains a greater amount of forested land.

Sediment concentrations during storm periods are greater in subarea B than in the other subareas. For example, 85,000 mg/l was measured in the South Fork Palouse River at Colfax on February 4, 1963, and the maximum measured concentration in the Palouse River at Hooper, the daily station, was 69,100 mg/l on February 4, 1963. Also, the greatest discharge-weighted mean sediment concentration for a storm period was for a reconnaissance site in subarea B. There, 36,700 mg/l was recorded for Rebel Flat Creek at Winona for the period January 25–31, 1964. During the same period, the discharge-weighted mean concentration for nearly the entire Palouse River basin, as measured at Hooper, was only 3,700 mg/l. During the storm period of February 3–9, 1963, the concentration was 19,200 mg/l at the Hooper station, indicating that the concentration for Rebel Flat Creek was comparatively much greater than that during the January 25–31, 1964, period.

The lowest concentrations of suspended sediment in the basin are in the streams of subarea C. There, rainfall is less, runoff is low, and areas mantled by easily eroded loess are much smaller. The greatest observed concentration for Cow Creek at Hooper was 532 mg/l on February 6, 1963. The low concentrations in subarea C also may be due in part to the entrapment of sediment in the numerous lakes in the area. For example, the concentration of suspended sediment for Rock Creek at Ewan was relatively low during high flow (maximum observed, 471 mg/l on February 1, 1965), suggesting a high trap efficiency for Rock Lake, which is just above the sampling site. (See p. 21.)

High-flow concentrations of 2,600 mg/l were equaled or exceeded less than 2 percent of the time in the Palouse River at Hooper, whereas low-flow concentrations of 25 mg/l were equaled or exceeded 80 percent of the time (fig. 2). The discharge-weighted concentrations varied considerably from storm to storm. For example, the concentrations were 19,200 mg/l for the storm of February 3–9, 1963, and 4,800 mg/l for the storm of January 27–February 4, 1965. The smaller sediment concentration during the latter storm may have been due to different antecedent moisture conditions, to more deeply frozen ground, or, more probably, to a different pattern of precipitation in the various subareas.

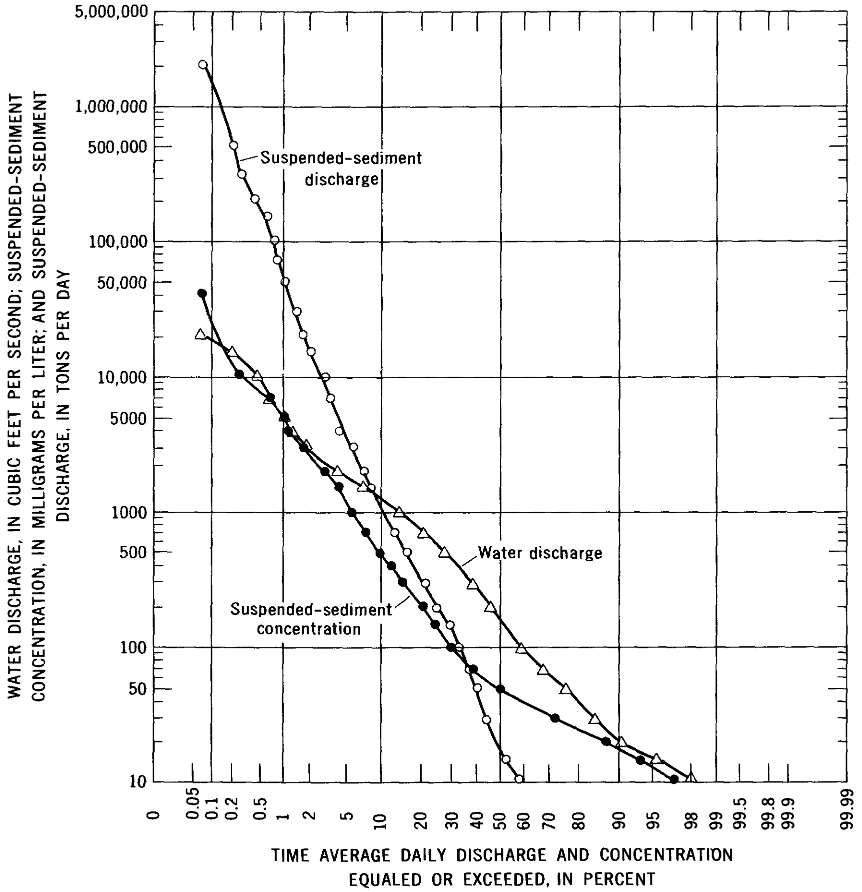

FIGURE 2.—Duration curves of daily flow, daily suspended-sediment concentration, and daily suspended-sediment discharge. Palouse River at Hooper, July 1, 1961–June 30, 1965.

SUSPENDED-SEDIMENT YIELDS AND DISCHARGE

Sediment yields follow the same pattern as suspended-sediment concentrations. The yields calculated during the period of study were slightly larger in the south-central part of the basin than in other parts, were lowest in the western part of subarea C and in the eastern part of subarea A, and were greatest through the southern part of subarea B (pl. 1).

The estimate of average annual discharge of the Palouse River at its mouth at the Snake River was based partly on annual discharges for Palouse River at Hooper and for Cow Creek at Hooper, and partly on estimates of suspended-sediment discharge below those stations. The average amount of sediment that passed each station annually is expressed as a percentage of that which passed the mouth of the Palouse River (table 4). The annual sedi-

TABLE 4.—*Average annual suspended-sediment discharges from drainage areas upstream from given stations in the Palouse River basin, July 1, 1961–June 30, 1965*

Station	Sediment-sampling station or drainage between stations	Drainage area above station (sq mi)	Average annual suspended-sediment discharge (tons)	Percentage of load of Palouse River at mouth [1]	Average annual sediment yield (tons per sq mi)	Discharge-weighted mean concentration (mg/l)	Method of computation [2]	Approximate percentage of drainage basin within indicated subarea		
								A	B	C
3454	Palouse River at Palouse	398	180,000	12	460		S	100	0	0
	Palouse to Colfax	99	180,000	12	1,800		D	35	65	0
3461 [3]	Palouse River at Colfax	497	360,000	23	730	1,300	*S*, F	87	13	0
3480 [3]	South Fork Palouse River at Pullman	132	93,000	5.9	700	2,900	S, F	82	18	0
3485 [3]	Missouri Flat Creek at Pullman	27.1	46,000	2.9	1,700	7,400	S, F	53	47	0
	Pullman to Colfax	69	86,000	5.4	1,200		D	41	59	0
3492	South Fork Palouse River at Colfax	228	220,000	14	980		S	66	34	0
	Colfax to Winona	261	260,000	16	1,000		D	1	95	4
3493.1	Palouse River at Winona	986	850,000	54	860		S	59	40	1
3493.2	Rebel Flat Creek at Winona	73.2	160,000	10	2,100		S, Ea	0	100	0
3494 [3]	Pine Creek at Pine City	302	160,000	10	600	3,400	F	39	61	0
3495	Rock Creek at Ewan	[4] 526	4,700	.3	9		S, *Ea*	22	49	29
3496.9	Cottonwood Creek below Pleasant Valley Creek near Ewan.	110	187,000	12	1,700		S, F_1, *Ea*	0	100	0
	Rock Creek below Ewan stations	318	72,000	4.6	230		E	0	41	59
3499	Rock Creek near Winona	[5] 954	260,000	17	280		E	12	52	36
		[6] 428	260,000	17	620		E			
3505 [3]	Union Flat Creek near Colfax	189	80,000	5.0	420	2,600	F	7	93	0
	Union Flat Creek below Colfax to LaCrosse	105	150,000	10	1,500		D	0	92	8
3507	Union Flat Creek near LaCrosse	294	230,000	15	800		*S*, F_2	4	93	3
3509	Willow Creek at Gordon	67.4	52,000	3.3	770		S	0	77	23
	Areas below Winona, LaCrosse, and Gordon stations	165	16,000	1.0	96		E	0	11	89
3510 [3]	Palouse River at Hooper	[5] 2,500	1,572,000	99.5	629	2,970	R	28	52	20
		[6] 1,974	1,568,000		796		R			
3525 [3]	Cow Creek at Hooper	697	3,200	.2	5	135	F	0	0	100
	Palouse River at mouth	3,283	1,580,000	100	480	2,850	Ea	21	40	39

[1] Percentage values based on unrounded loads.
[2] D, difference in sediment discharge between stations; E, estimated; Ea, partly estimated; F, sediment-transport flow-duration curve, discussed by Jordan, Jones, and Petri (1964, p. 60–63), Miller (1951), Wark and Keller (1963, p. 10–13); F_1, translation of flow-duration curves for Missouri Flat Creek at Pullman and Pine Creek at Pine City; F_2, translation of flow-duration curves for Union Flat Creek near Colfax; R, daily station record, Palouse River at Hooper; S, storm loads, discussed by Jones (1964, p. 63–69), Palouse River at Hooper; italic letters indicate computation given most weight or total weight.
[3] Site also is stream-gaging station.
[4] Outflow from Rock Lake.
[5] Includes drainage area of Rock Lake.
[6] Excludes drainage area of Rock Lake.

ment discharges and yields from some of the tributaries in the basin are shown on plate 1.

Much of the sediment was discharged during the major storms of February 3–9, 1963, December 22–27, 1964, and January 27–February 4, 1965 (fig. 3). These three storms accounted for 81 percent of the sediment discharged but only 22 percent of the runoff recorded during the entire study period (table 5). The storm of February 3–9, 1963, was the largest sediment contributor and produced nearly one-half of the 4-year yield.

Duration curves for flow, suspended-sediment concentration, and suspended-sediment discharge in the Palouse River at Hooper (fig. 2) indicate that high sediment transport occurred in a short period of time, inasmuch as the mean daily sediment discharge (4,300 tons) was equaled or exceeded only 4.3 percent of the time. In comparison, the mean daily water discharge was equaled or exceeded 28 percent of the time.

Data collected during the present study are compared with data collected for two other investigations. Suspended-sediment yields

TABLE 5.—*Summary of water and suspended-sediment discharge for selected storms, Palouse River at Hooper, July 1, 1961–June 30, 1965*

Storm	Water discharge		Suspended-sediment discharge (tons)	Sediment yield (tons per sq mi)	Discharge-weighted mean concentration (mg/l)	Percentage of load for entire period
	Acre-feet	Percentage of runoff for entire period				
1961						
Dec. 20–24	3,396	0.22	674	0.27	146	0.01
1962						
Feb. 14–18	9,076	.58	4,018	1.61	325	.06
Mar. 8–10	3,572	.23	10,100	4.04	2,080	.16
Mar. 24–30	52,120	3.34	341,060	136	4,810	5.4
Dec. 18–21	4,548	.29	2,299	.92	371	.04
1963						
Feb. 3–9	119,000	7.62	3,113,210	1,250	19,200	49.5
Feb. 18–22	15,010	.96	33,987	13.6	1,660	.54
Mar. 30–Apr. 4	18,360	1.18	34,447	13.8	1,380	.55
1964						
Jan. 25–31	10,900	.70	54,080	21.6	3,640	.86
Feb. 19–21	4,147	.27	2,981	1.19	528	.05
Mar. 11–14	7,093	.45	16,722	6.69	1,730	.27
Mar. 17–22	26,060	1.67	109,750	43.9	3,090	1.75
Mar. 30–Apr. 4	29,020	1.86	68,450	27.4	1,730	1.09
Nov. 25–29	3,283	.21	1,082	.43	242	.02
Dec. 22–27	73,980	4.72	991,570	396	9,880	15.8
1965						
Jan. 27–Feb. 4	148,100	9.49	959,160	387	4,800	15.4
Apr. 20–24	36,100	2.31	136,950	54.8	2,790	2.18
Total for runoff events	563,765	36.10	5,880,540	2,350	7,660	93.52
Total for entire period	1,552,621	100	[1] 6,287,691	2,520	2,970	100

[1] Discharge estimated for period of July 1, 1961–Sept. 30, 1961.

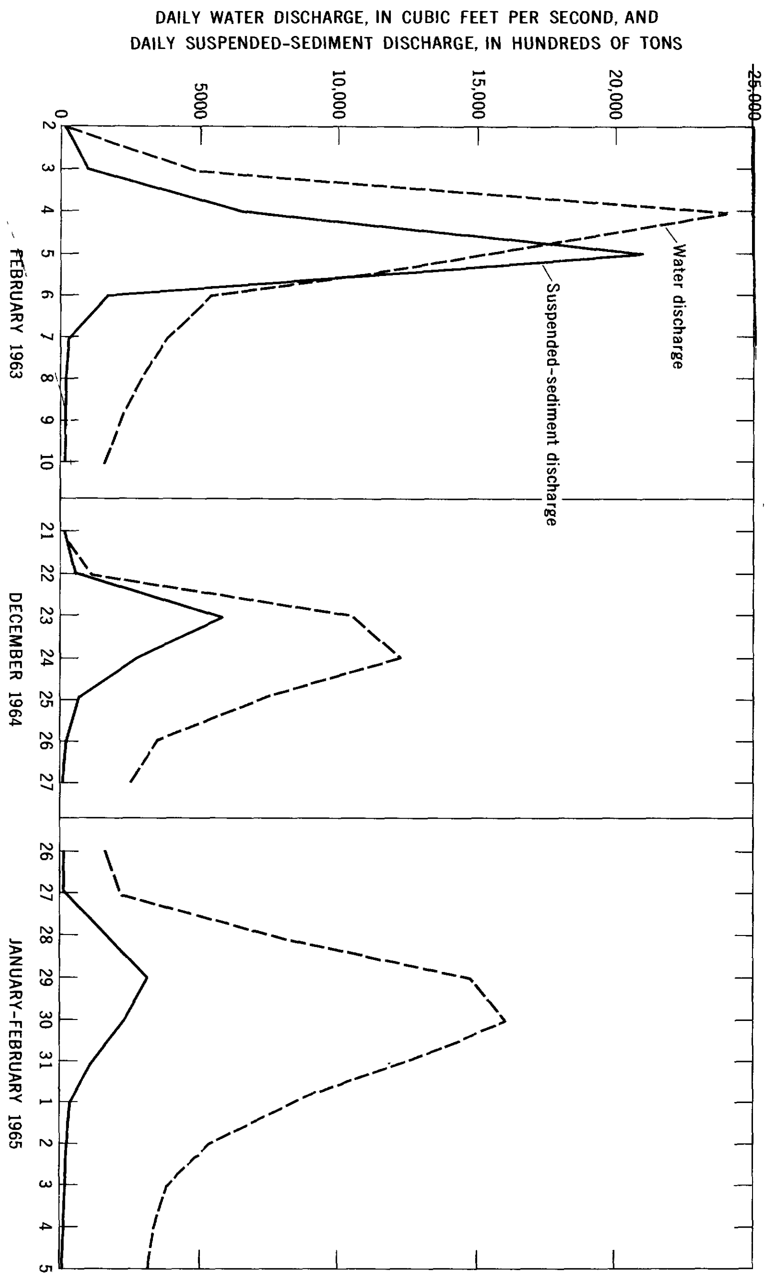

FIGURE 3.—Hydrographs of daily suspended-sediment discharge and daily water discharge for three storms, Palouse River at Hooper.

were measured at three stations near Pullman during 1934–40 and at two stations during 1961–65. Data for only one station, Missouri Flat Creek at Pullman, are available for both periods (table 6). Sediment yields in the Pullman area were much greater during 1961–65 than during 1934–40. During the later period, the yield from this drainage upstream from the gaging station at Pullman was 227 percent greater than that during the earlier period.

According to Kaiser (1961; written commun., 1966), soil loss from Whitman County by water erosion each year during the period 1939–65 ranged from 1,000,000 tons in 1946–47 to 21,900,000 tons in 1962–63 (table 7). The average annual loss during the 26-year period 1939–65 was 9,600,000 tons and during the 4-year period 1961–65 was 14,200,000 tons. This agrees with the earlier data, which showed that soil loss was probably greater for the period 1961–65 than for the long-term average. It should be pointed out that Kaiser's total soil-loss loads are much higher than stream loads, because soil loss includes all soil that has been moved, not only that reaching the stream channels.

For convenience, the suspended-sediment discharge in the basin is discussed by subareas. (See pl. 1.)

SUBAREA A

This area includes the upper reaches of the South Fork Palouse River, Missouri Flat Creek, Pine Creek, and the Palouse River main stem. The average annual sediment yield in this area is estimated to have been about 660 tons per square mile for the period 1961–65.

During the study, data from only one site, the Palouse River at Palouse, were typical of subarea A. This drainage was estimated to contribute about 12 percent of the sediment transported from the basin (table 4). The amount of sediment contributed by all of subarea A to other streams is not known. Due to the greater

TABLE 6.—*Suspended-sediment yields measured at three stations near Pullman for the period 1934–40, and at two stations for the period 1961–65*

[Data for period 1934–40 from Potter and Love (1942)]

Station	Sediment yield (tons per sq mi)	Period
South Fork Palouse River above Paradise Creek near Pullman	284	1934–40
Fourmile Creek at Shawnee	560	1934–40
Missouri Flat Creek at Pullman	520	1934–40
Do	1,700	1961–65
South Fork Palouse River at Pullman	700	1961–65

density of forests and other vegetal cover, the contribution from subarea A is assumed to be generally less than that from lands within subarea B, although unit runoff from subarea A is greater than that from subarea B. (See table 2.) The high steptoes and buttes typical of subarea A are composed of crystalline rocks that are less easily eroded than the loess hills at lower altitude. In small local areas of heavily cultivated loess in subarea A, the sediment yields are comparable to those of subarea B.

SUBAREA B

The Palouse River drainage area above Winona represents 30 percent of the total drainage area, but the sediment discharged past the Winona sampling site during the study period represented 54 percent of that from the entire basin. Sediment yields generally were greater in the Palouse Hills, or central part of the basin, than in the other areas. The annual average sediment yield in the subarea is estimated to have been about 970 tons per square mile for the period 1961–65. Moderate amounts of

TABLE 7.—*Annual soil loss by water erosion in Whitman County*

Erosion year [1]	Precipitation during runoff season [2] (inches)	Soil loss [3] (millions of tons)
1939–40	14.56	11.5
1940–41	18.10	8.0
1941–42	13.86	20.0
1942–43	18.88	12.0
1943–44	8.34	2.0
1944–45	12.96	2.0
1945–46	21.47	20.0
1946–47	12.58	1.0
1947–48	21.71	16.0
1948–49	16.46	5.0
1949–50	17.49	9.0
1950–51	17.31	10.0
1951–52	16.98	7.0
1952–53	17.77	7.5
1953–54	14.22	5.0
1954–55	10.68	6.0
1955–56	18.79	9.0
1956–57	12.14	5.0
1957–58	14.10	8.5
1958–59	16.14	9.5
1959–60	13.13	11.5
1960–61	16.23	8.5
1961–62	11.83	11.3
1962–63	14.19	21.9
1963–64	11.76	7.8
1964–65	12.91	15.9
26-year average	15.18	9.6

[1] Sept. 1–Mar. 31.
[2] U.S. Weather Bureau data for Colfax, Wash.
[3] Data compiled in field surveys by Kaiser (1961; written commun., 1966).

rainfall, moderate local relief with steeply sloping hills, fine-grained soils, and extensive cultivation all combine to account for the high sediment yields typical of this subarea.

From the approximate boundary between subareas A and B downstream, sediment yields from the Palouse River drainage area increased from 460 tons per square mile for the drainage area above Palouse to 1,800 tons per square mile for the area drained between Palouse and Colfax. This latter drainage area and the drainage areas of Missouri Flat Creek and the South Fork Palouse River between Pullman and Colfax, which yielded 1,700 and 1,200 tons per square mile, respectively, all exhibited high sediment yields as compared with most other parts of the basin. The sediment yield as measured in the South Fork Palouse River at Pullman was 700 tons per square mile, which probably is more typical of yields from subarea A.

Erosion along banks of the above-named streams is not nearly as noticeable as that along banks of streams farther west in this subarea. Vegetation generally is plentiful enough along these streams to provide protection and keep bank erosion from contributing greatly to the sediment load.

Sediment yields decrease in the intervening drainage area between the Colfax and Winona sampling sites and are less than those of adjoining drainage areas. The decrease from 1,800 tons per square mile for the Palouse-Colfax reach to 1,000 tons per square mile for the Colfax-Winona reach probably was due to one or more of the following factors: (1) Less extensive cultivation along the northern and southern slopes leading to the Palouse River, (2) less precipitation, and (3) erosion-resistant rocks along the stream channel and banks.

Of all the streams studied in the Palouse River basin, Rebel Flat Creek had the highest sediment yield, 2,100 tons per square mile. Although it represents only 2.2 percent of the total drainage area, Rebel Flat Creek drainage basin produces an estimated 10 percent of the annual sediment discharge from the Palouse River basin. Intensive cultivation, steep slopes, and fine-grained soils all contribute to the high sediment yield from the drainage area of Rebel Flat Creek. Much of the sediment transported in the creek during flood periods is deposited along its flood plain. Deposition continues with successive high flows although it decreases in the lower reaches and near the mouth of Rebel Flat Creek, where channel erosion takes place.

Except for the drainage area above the site near Colfax, which had the lowest sediment yield of any measured in subarea B (table 7), the Union Flat Creek drainage area is similar to the drainage areas of other streams in subarea B. The low yields above Union Flat Creek near Colfax may be attributable in part to the drainage area having characteristics similar to those of subarea A. From the sampling site near Colfax to that near La Crosse, the sediment yield increased sharply from 420 tons per square mile for the area drained by Union Flat Creek near Colfax to 1,500 tons per square mile for the area from Colfax to La Crosse. This lower part of the Union Flat Creek drainage area borders Rebel Flat Creek drainage area and has a high yield similar to that of the adjoining basin.

Willow Creek, the southernmost stream studied in subarea B, flows through both scablands and loess hills. The estimated sediment yield from this drainage is 770 tons per square mile, and most of the sediment comes from this subarea. No study was made to determine the amount of bank erosion along the stream, but the presence of many deep erosional cuts suggests that a large part of the sediment discharge comes from bank erosion.

Of the sediment transported in the part of Pine Creek above Pine City, most is assumed to come from lands in subarea B. Channel erosion probably is not severe, because the channel in most places appears rather stable. All the sediment transported from this drainage area flows into Rock Lake, where much of it settles out. This sediment entrapment becomes the major factor in reducing the sediment load below the lake.

Cottonwood Creek, which adjoins Pine Creek downstream from Rock Lake, drains an area that yields 1,700 tons of sediment per square mile, more than double the yield to Pine Creek. Precipitation is slightly less over the Cottonwood Creek drainage area, and the higher yield probably is due to more intense cultivation and less vegetal cover. Like Rebel Flat Creek, Cottonwood Creek is overburdened with water and sediment during high flows, and overbank flooding occurs easily. During February 1963, severe flooding occurred in the town of St. John on Pleasant Valley Creek, tributary to Cottonwood Creek. Channel erosion is very noticeable along the lower reaches near Ewan. Sediment-discharge data are not available to determine the amount of sediment contributed between the sampling site and Ewan, but erosion below the site is probably not critical compared with that in the upper reaches.

No estimate of sediment discharge is available for the large area mantled by loess just west of Ewan and Rock Lake (pl. 1). Observed sediment yields probably were many times the yield of the surrounding scablands.

The greatest daily sediment discharge measured at a reconnaissance station at any time during the study was 265,000 tons on February 5, 1963, at Union Flat Creek near La Crosse. The greatest discharge of the Palouse River at Hooper was 2,110,000 tons, recorded on the same date. This discharge at Hooper represents 33.6 percent of the total discharge of the Palouse River basin for the period of study. Minimum daily discharge at each station was 1 ton per day or less.

During the storm of February 3–9, 1963, the greatest sediment yield recorded at any of the reconnaissance sampling sites was 1,800 tons per square mile for that part of the drainage basin of the South Fork Palouse River above Colfax. This yield probably was less than that from other drainage areas, such as those of Rebel Flat Creek or Cottonwood Creek, inasmuch as those areas underwent extremely severe erosion. (Rebel Flat and Cottonwood Creeks were not sampled during this flood.)

SUBAREA C

Data representative of sediment transport in subarea C were available from only one site, Cow Creek at Hooper. The sites on Rock Creek at Ewan and near Winona obtain data on water that comes mainly from lands in subareas A and B. The sites on Willow Creek at Gordon and Union Flat Creek near La Crosse record data largely representative of subarea B.

Sediment transported in subarea C is much less than that transported in subareas A and B owing to less rainfall and to the erosion-resistant character of the scablands. The total amount of sediment contributed by the scablands to the Palouse River basin during the study period 1961–65, is estimated to have been about 2 percent, or about 30,000 tons per year.

The greatest sediment movement from the subarea probably is from the loess islands between scabland channels. However, much of the loess is transported and deposited in local depressions and lakes without reaching the streams.

Sediment yields differ widely throughout subarea C, and data were insufficient to adequately determine local yields from the scablands. However, available data indicate that the sediment yield of about 5 tons per square mile from the Cow Creek drainage contrasts greatly with yields from lands adjoining subarea C. Even though rainfall is greater in the northern half of the subarea, sediment yields probably are less there than in the southern half of the subarea. Sediment yields in the northern half are, however, reduced by the large number of lakes there that entrap sediment and by the more dense vegetation that provides greater protection against erosion. For example, data collected near Rock Lake indicate that the trap efficiency of the lake is about 98 percent; although an estimated 200,000 tons of sediment per year discharges into Rock Lake, the annual sediment discharge of Rock Creek at Ewan is only about 4,700 tons per year. Of the estimated 200,000 tons of sediment entering Rock Lake, 160,000 tons is carried from subareas A and B by Pine Creek, and an estimated 40,000 tons comes from unsampled locations below the Pine City station.

PARTICLE SIZE OF SUSPENDED SEDIMENT

Caldwell (1961, p. 115–116), stated that soils in the Palouse area are composed of clay-sized particles that tend to become coarser in a westerly direction. Fluvial sediment in the Palouse basin generally also becomes coarser in a westerly direction, according to the particle-size data collected during this study (table 8) and to data tabulated for Palouse River at Hooper in annual publications on the quality of water (U.S. Geological Survey, 1964b, c; 1965b; 1966; and 1967).

In figure 4, discharge-weighted averages of particle size are shown rather than simple averages because the major part of each year's sediment load is transported during times of highest streamflow. The relationship between distribution and rate of flow is discussed below.

The percentage of clay in sediment from subarea A is greatest in the drainages of Missouri Flat Creek and the South Fork Palouse River. Silt particles predominate in the northern parts of the subarea, as shown in figure 4 by data from the Palouse River at Palouse and from Pine Creek at Pine City. (About 39 percent of the Pine Creek drainage comes from subarea A.)

The percentage of silt and sand in sediment from subarea B increases in a westerly direction, although the increase of sand is not as obvious as that of silt. Rebel Flat Creek, Willow Creek, and Cottonwood Creek below Pleasant Valley Creek all contain a high percentage of silt compared with that carried by other streams in the basin.

The one sample analyzed from Cow Creek at Hooper in subarea C, obtained during a medium flow, contained a large proportion of clay, as did the one collected from Rock Creek near Winona. This suggests entrapment of coarser particles in the many lakes and depressions in the subarea.

In the Palouse River at Hooper, silt is the largest part of the suspended-sediment load during higher flows (when most of the annual loads are transported), and clay is the largest part during

TABLE 8.—*Particle-size analyses of suspended-sediment samples*

[e, estimated. Method of analysis: C, chemically dispersed; N, in native water; P, pipet; V, visual accumulation tube; W, in distilled water]

Date of collection	Hour	Discharge (cfs)	Water temperature (°C)	Sediment concentration (mg/l)	Percent finer than indicated size, in millimeters										Method of analysis
					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.350	0.500	
3454. Palouse River at Palouse															
3- 9-62	1035	87	2	466	71	99	99	100	--	--	--	--	--	--	PWC
3-31-64	0840	1,860	4	1,240	21	26	39	55	77	95	99	100	--	--	VPWC
4-20-65	0650	2,980	7	2,670	27	35	47	63	84	e 95	--	--	--	--	PWC
3461. Palouse River at Colfax															
3- 9-62	0910	168	1	1,480	50	70	88	98	99	100	--	--	--	--	PWC
3-27-62	1415	3,790	5	2,130	34	42	55	72	93	95	--	--	--	--	PWC
12-18-62	1640	575	5	556	29	36	51	60	76	89	96	100	--	--	VPWC
2- 5-63	0815	2,540	2	12,100	36	44	60	77	94	99	100	--	--	--	VPWC
3-30-63	1230	1,530	6	1,670	23	30	41	58	80	97	99	100	--	--	VPWC
3-30-63	1735	1,980	4	3,580	24	29	42	60	84	98	100	--	--	--	VPWC
3-31-63	1815	2,310	5	1,450	19	27	38	52	81	95	99	100	--	--	VPWC
3-31-64	1520	1,920	7	2,010	18	25	37	54	79	95	100	--	--	--	VPWC
11-25-64	1500	822	4	958	33	42	59	80	97	--	--	--	--	--	PWC
4-20-65	1440	3,280	10	2,970	26	36	49	64	82	e 93	--	--	--	--	PWC
3480. South Fork Palouse River at Pullman															
3-30-63	0750	91	5	1,910	71	80	90	100	--	--	--	--	--	--	PWC
4- 1-64	1700	365	6	1,530	35	43	60	75	91	99	100	--	--	--	VPWC
12-22-74	1705	700	1	3,530	41	53	65	79	92	98	99	100	--	--	VPWC
3485. Missouri Flat Creek at Pullman															
3-30-63	1535	33	6	3,130	51	62	74	87	98	--	--	--	--	--	PWC
12-22-64	1730	399	1	5,530	43	53	66	79	94	99	100	--	--	--	VPWC

3492. South Fork Palouse River at Colfax															
3- 9-62	0930	94	1	882	63	83	97	100	--	--	--	--	--	--	PWC
3-27-62	0640	1,180	--	3,790	29	36	49	67	93	99	100	--	--	--	VPWC
2- 3-63	2000	2,410	1	10,800	35	46	60	77	93	99	100	--	--	--	VPWC
2- 5-63	0910	1,130	2	32,900	41	53	68	86	100	--	--	--	--	--	VPWC
6-18-63	1530	12	24	8,240	83	94	98	100	--	--	--	--	--	--	PWC
6-19-63	0740	11	19	6,440	96	100	--	--	--	--	--	--	--	--	PWC
9-23-63	1205	5.6	14	3,850	78	96	100	--	--	--	--	--	--	--	PWC
3-31-64	1640	352	10	1,680	47	60	75	92	99	--	--	--	--	--	PWC
4-20-65	1520	601	12	5,220	52	68	81	94	100	--	--	--	--	--	PWC
3493. Palouse River at Winona															
3- 9-62	1510	390	4	1,230	8	80	93	100	--	--	--	--	--	--	PWC
3-27-62	0900	4,730	5	5,600	22	28	40	56	86	97	99	100	--	--	VPWC
12-19-62	1125	665	6	430	46	61	84	97	100	--	--	--	--	--	PWC
2-20-63	1710	1,830	4	3,490	44	54	73	86	100	--	--	--	--	--	PWC
1-26-64	1240	292	1	4,840	47	71	87	97	100	--	--	--	--	--	PWC
1-27-65	1550	2,250	1	1,960	18	25	35	52	78	98	100	--	--	--	VPWC
1-29-65	1140	7,900	2	4,700	29	37	48	60	79	92	95	98	99	100	VPWC
3493.2. Rebel Flat Creek at Winona															
1-19-64	1145	5.6	0	2,600	58	83	85	91	98	100	--	--	--	--	
1-25-64	2310	84	1	33,300	24	36	53	75	91	97	99	100	--	--	VPWC
1-27-65	1520	515	1	32,300	10	14	20	30	54	90	98	100	--	--	VPWC
3494. Pine Creek at Pine City															
2- 6-63	2315	795	3	14,000	22	30	45	66	86	99	100	--	--	--	VPWC
2- 6-63	2315	795	3	14,000	0	10	29	61	86	99	100	--	--	--	VPN
3-19-64	0640	347	3	1,900	43	52	69	86	98	100	--	--	--	--	PWC
3-31-64	1310	184	12	1,200	57	77	91	97	98	100	--	--	--	--	VPWC
1-27-65	2140	990	1	4,030	25	33	36	56	82	98	100	--	--	--	VPWC
1-28-65	1920	2,620	1	6,920	22	28	36	50	73	96	99	100	--	--	VPWC
3496.9. Cottonwood Creek below Pleasant Valley Creek near Ewan															
1-30-64	1450	24	1	2,590	43	53	72	85	98	100	--	--	--	--	PWC
2-19-64	1040	27	2	3,380	31	46	64	68	93	100	--	--	--	--	PWC
1-27-65	1310	555	1	8,880	18	22	30	44	67	96	100	--	--	--	VPWC
1-28-65	1640	1,120	1	19,500	16	23	32	47	67	94	98	100	--	--	VPWC
1-30-65	1430	500	6	25,300	18	24	36	58	84	98	100	--	--	--	VPWC

TABLE 8.—*Particle-size analyses of suspended-sediment samples*—Continued

Date of collection	Hour	Discharge (cfs)	Water temperature (°C)	Sediment concentration (mg/l)	Percent finer than indicated size, in millimeters										Method of analysis
					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.350	0.500	
3499. Rock Creek near Winona															
1-28-64	1305	67	2	3,140	52	76	92	97	100	--	--	--	--	--	PWC
3505. Union Flat Creek near Colfax															
3- 9-62	1200	70	2	887	28	42	44	70	92	98	--	--	--	--	PWC
3-27-62	1620	422	6	7,170	34	44	56	72	91	98	--	--	--	--	PWC
6-18-63	1400	3.9	28	3,640	97	97	97	99	100	--	--	--	--	--	PWC
6-19-63	0810	3.9	19	3,670	95	100	--	--	--	--	--	--	--	--	PWC
1-28-65	1550	1,540	4	8,330	28	33	42	57	76	97	99	100	--	--	VPWC
3507. Union Flat Creek near Lacrosse															
2- 4-63	1655	2,6[illegible]	2	11,500	30	41	57	73	90	98	100	--	--	--	VPWC
1-19-64	0845	[illegible]6	0	2,270	71	89	99	100	--	--	--	--	--	--	PWC
1-25-64	1840	450	1	33,600	19	28	42	60	76	99	100	--	--	--	PWC
4-20-65	1230	380	13	5,980	23	31	41	56	79	99	100	--	--	--	VPWC
3509. Willow Creek at Gordon															
2- 4-63	1350	495	6	29,100	9	16	27	46	74	96	98	99	100	100	VPWC
1-25-64	1920	74	3	22,400	24	40	61	84	94	100	--	--	--	--	PWC
3525. Cow Creek at Hooper															
2- 6-63	0735	357	1	532	46	61	89	89	96	--	--	--	--	--	PWC

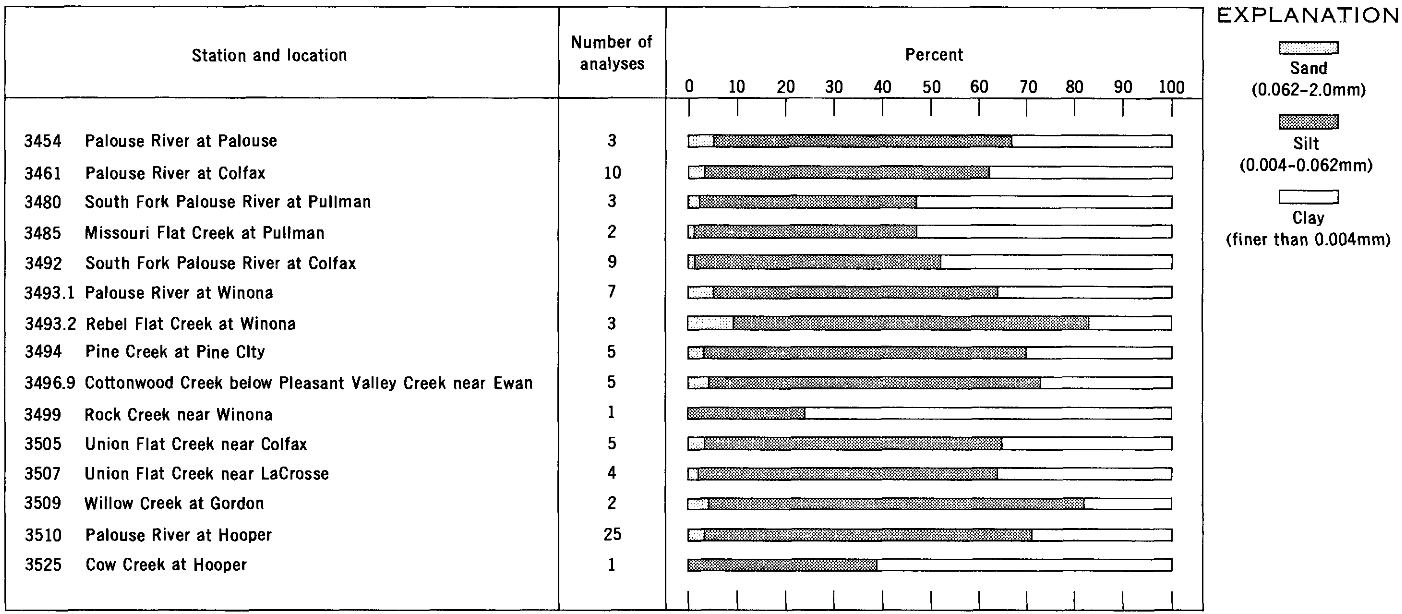

FIGURE 4.—Percentage distribution of sand, silt, and clay in suspended-sediment samples, Palouse River basin. Values are averages weighted by sediment discharge.

lower flows (fig. 5). The proportion of sand is low in the streams of the Palouse River basin regardless of flow magnitude. However, the presence of even small amounts of sand in a stream is important because these particles are the first to settle out when stream velocity is decreased, as in a reservoir. Sand-size particles also are much more difficult to collect than silt and clay particles because sand-size particles tend to move near the streambed. To the extent that the records for the Hooper station are representative, sand-size particles do not appear to move appreciably in suspension until the streamflow (fig. 6) is well above 1,000 cfs (cubic feet per second).

Two samples of stream water from Palouse River at Hooper and one from Pine Creek at Pine City were analyzed to observe the degree of flocculation (or aggregation of small particles into masses) of the fine suspended sediments. Results of the analyses show that flocculation is a fairly important factor to consider because it accounts for the percentage of clay-size particles being reduced 20 percent at Pine Creek and 1 and 8 percent at Hooper. Many more data would be needed to accurately determine the degree of flocculation.

UNMEASURED SEDIMENT DISCHARGE

The sediment samplers used during this investigation did not sample the vertical section of a stream nearer than 3 to 5 inches above the bottom. The amount of sediment transported below this depth, therefore, could not be determined by direct measurement. In computing the suspended-sediment discharge, however, the total water discharge was used so that at least a part of the sediment transported in the unsampled zone would be included in the computation. The suspended-sediment discharge not included in the foregoing computation constitutes a part of what is here called the unmeasured sediment discharge. Sediment rolling, skipping, or sliding on and near the streambed constitute the remaining part of the unmeasured sediment discharge.

Colby (1963, p. 49, 50) discussed the major factors affecting transport of unmeasured sediment discharge per foot of width:

> The bedload discharge depends mainly on the velocity of the water near the streambed and on the particle sizes of the bed sediment. The concentration of the suspended bed material both near the bed and higher in the flow is determined by such major factors as the velocity near the bed, particle size of the bed sediment, configuration of the bed, turbulence of the flow, and water temperature.

Colby devised a simple method for estimating unmeasured sediment discharge for sand-bed streams; the method requires only

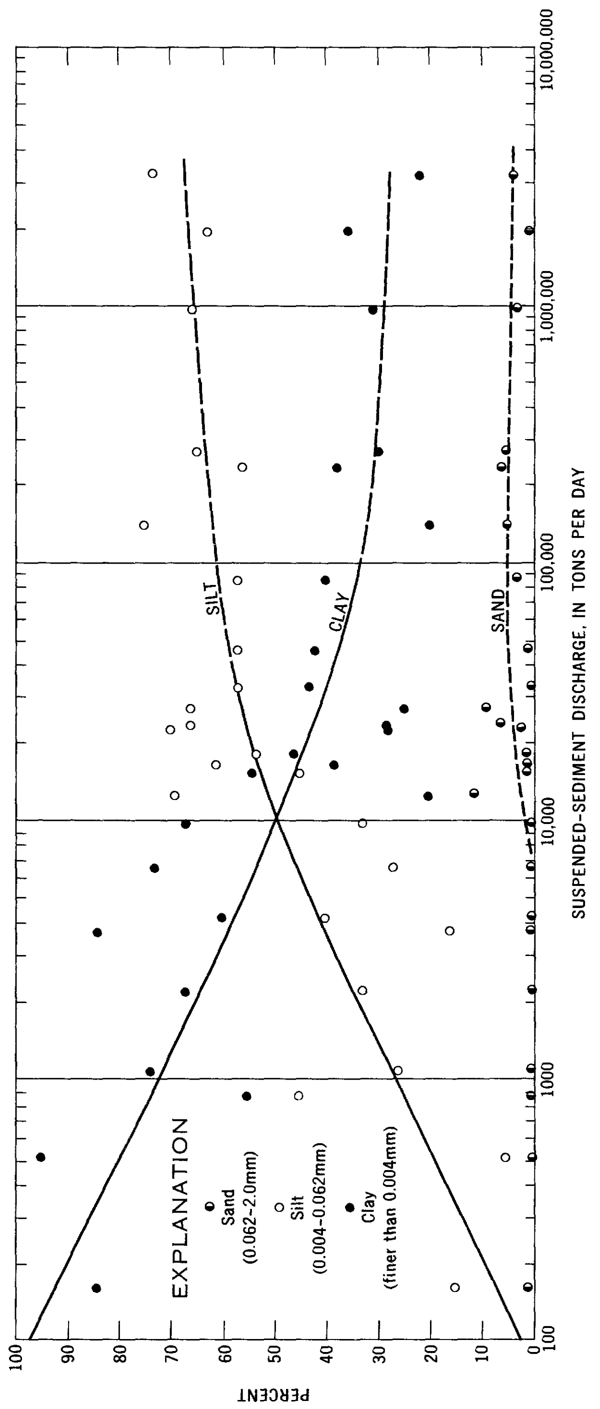

FIGURE 5.—Relation between suspended-sediment discharge and percentage of sand, silt, and clay in Palouse River at Hooper.

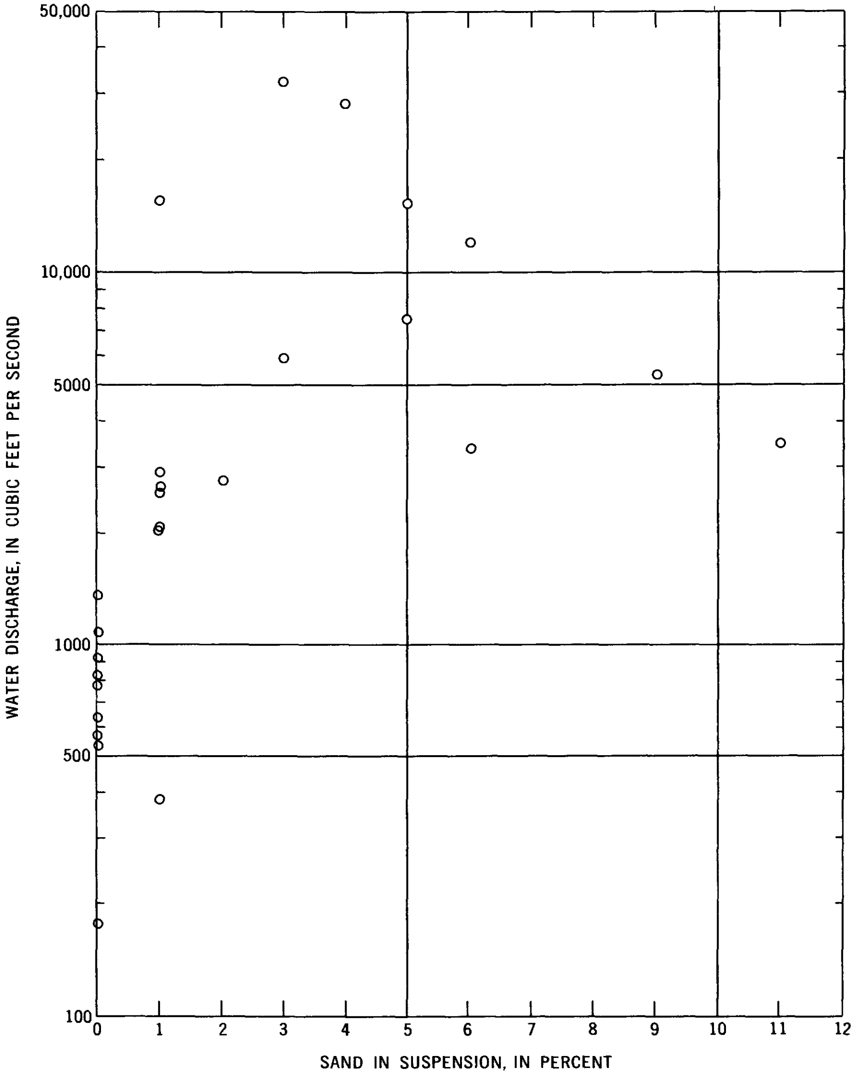

FIGURE 6.—Relation between water discharge and percentage of sand in suspension, Palouse River at Hooper.

measurements of stream width, mean depth, mean velocity, and concentration of suspended sand. For each of the sediment-sampling locations in the study area where all these parameters were available, computed data (table 9) show in general that unmeasured sediment discharge composes 2 to 8 percent of the total sediment discharge. The unmeasured sediment discharge is considered to be of nearly the same magnitude in all streams in

TABLE 9.—*A comparison of measured suspended-sediment discharge with unmeasured sediment discharge at selected sites in the Palouse River basin*

Station number and name		Date	Hour	Water discharge (cfs)	Mean velocity (fps)	Mean depth (ft)	Suspended-sediment discharge (tons per day)	Unmeasured sediment discharge (computed by the Colby method)	
								Tons per day	Percentage of total
3454.	Palouse River at Palouse	Mar. 31, 1964	0840	1,860	2.99	5.31	6,230	480	7.2
		Apr. 20, 1965	0650	2,980	3.70	6.60	21,500	1,850	7.9
3480.	South Fork Palouse River at Pullman	Apr. 1, 1964	1700	365	3.20	2.4	1,510	99	6.2
		Dec. 22, 1964	1705	700	4.30	2.9	6,670	486	6.8
3485.	Missouri Flat Creek at Pullman	Dec. 22, 1964	1730	399	5.10	3.0	5,960	300	4.8
3492.	South Fork Palouse River at Colfax	Mar. 27, 1962	0640	1,180	6.10	5.5	12,100	1,010	7.8
		Feb. 3, 1963	2000	2,410	8.00	9.1	221,000	4,850	2.2
3493.1.	Palouse River at Winona	Mar. 27, 1962	0900	4,730	4.90	7.1	71,500	2,480	3.4
		Jan. 27, 1965	1550	2,250	3.20	5.5	11,900	512	4.1
		Jan. 29, 1965	1140	7,900	7.20	8.8	100,000	8,050	8.0
3493.2.	Rebel Flat Creek at Winona	Jan. 25, 1964	[1]2110	[2]99.8	[2]1.47	[2]2.5	7,660	27	.3
		Jan. 27, 1965	[1]1650	[2]533	[2]2.39	[2]4.7	44,000	855	1.9
3496.9.	Cottonwood Creek below Pleasant Valley Creek, near Ewan.	Jan. 28, 1965	1640	1,120	4.06	5.7	57,800	1,880	3.1
3510.	Palouse River at Hooper	Dec. 22, 1961	1225	387	.73	5.4	160	49	23.4
		Mar. 27, 1962	1120	5,980	5.3	8.5	87,800	2,800	3.1
		Feb. 4, 1963	0925	32,300	12.8	9.2	977,000	37,000	3.7
		Feb. 5, 1963	0515	18,400	10.0	8.9	3,240,000	60,000	1.8
		Feb. 5, 1963	1445	15,700	9.2	8.8	1,970,000	21,000	1.1
		Feb. 20, 1963	1140	2,060	2.6	7.1	15,400	220	1.4
		Mar. 31, 1963	1555	2,790	3.2	7.7	23,000	570	2.4
		Apr. 1, 1963	1040	2,560	3.0	7.5	18,500	340	1.8
		Mar. 19, 1964	0935	2,950	3.3	7.8	46,400	570	1.2
		Apr. 1, 1964	1230	2,650	3.1	7.7	16,900	340	2.0
		Apr. 2, 1964	2000	3,410	3.7	8.1	23,700	2,400	9.2
		Dec. 24, 1964	1400	12,100	8.0	8.8	238,000	18,000	7.0
		Dec. 26, 1964	1145	3,500	3.7	8.1	12,700	1,300	9.3
		Jan. 28, 1965	1110	7,600	6.2	8.7	141,000	7,300	4.9
		Jan. 29, 1965	1410	15,400	9.1	8.8	271,000	17,000	5.9
		Feb. 1, 1965	1345	8,660	6.7	8.6	44,900	3,100	6.5

[1] Time when water-discharge measurement was made.
[2] From actual water-discharge measurement.

the Palouse River basin. However, no definite conclusions can be drawn as to the exact unmeasured discharge by any one stream, as shown by table 9, because streams in the Palouse River basin generally would not be classified as sand bed, and most figures shown in table 6 would tend to exaggerate the percentage of bed-load discharge. Streambed material was obtained at four sites, and the results of particle-size analyses are listed in table 10. The streambeds are composed of materials ranging in size from very fine (less than 0.062 millimeter) to very large (cobbles and boulders). Beds appear rather stable, with only moderate shifting of stream channels. Rocks are large and angular and are cemented together, and in places the Palouse River flows directly on basalt. Also, because sand-size particles constitute a small part of the suspended load, this further indicates the small amount of sand available in the streambeds.

FACTORS AFFECTING SEDIMENT YIELD

The principal factors that affect sediment yield are land use, precipitation, temperature, runoff, geology, and topography.

LAND USE

Changing land use is considered to be the most important factor affecting sediment yields in the Palouse River basin. Its effects on the accelerated rate of erosion in the basin are discussed in a paper by Victor (1935). Victor stated that the streams ran almost free of sediment before the development of an agricultural economy but that the sediment load increased rapidly after cultivation became intense. By 1934, channels had widened, and headward erosion had increased at a rate of 20 to 100 feet per year.

The effect of land use on erosion was discussed by Kaiser (1961) and related to the major flood events of 1894 and 1910. Kaiser reported that little damage from sedimentation occurred as a result of the 1894 flood, and "only slight siltation [sedimentation damage] accompanied the 1910 flood," although it was considered to be the greatest on record at Hooper until 1963.

After 1910, an intensification of farming in the Palouse country was accompanied by an increase in soil erosion. The sediment-yield maps on plate 1 indicate that at the present time subarea B, where farming is more concentrated, produces the largest amount of sediment. The high yields from Rebel Flat, Missouri Flat, and Cottonwood Creeks also are due largely to land-use practices in these basins. In contrast, although higher runoff occurs in the eastern part of the basin, cultivation is less intensive, and the sediment yield consequently is much lower. Also, much of the eastern subarea is mountainous and is well protected by natural vegetation.

The detrimental effects of accelerated erosion in past years have been reduced locally by soil-conservation practices such as contour plowing and terracing and cross-slope seeding.

PRECIPITATION, TEMPERATURE, AND RUNOFF

The heaviest precipitation, lowest temperature, and highest runoff occur during the winter and early spring months (fig. 1). Owing to the combination of these factors, sediment discharges also are highest during these months. A major part of the annual sediment discharge is transported when events occur in the following sequence: (1) Low temperatures freeze the soil, (2) snow falls on top of frozen ground, and (3) an abrupt rise in temperature occurs and, accompanied by warm rains, melts the snow and partially thaws the soil. This sudden increase in liquid moisture on top of ground frozen below a shallow depth causes a sudden increase in runoff, erosion of the top few inches of the thawed soil, and consequent high sediment discharge in the streams. The three major storms that occurred during this study (fig. 3) produced this type of runoff and are described below.

On February 2, 1963, the soil in the Palouse River basin was covered by 4 to 8 inches of snow and was frozen to a depth of 20 to 30 inches. Temperature increased from near freezing on February 2 to about 7°C on February 3, when nearly 0.90 inch of rain fell. The rainfall and warm temperatures caused almost complete melting of the snow in a few hours. Runoff resulted in maximum discharges being recorded for the Palouse River at Hooper and for several gaging stations in the basin (table 3). Temperature increased to about 16°C on February 4. An additional 0.50 inch of rain fell during the afternoon and evening on soil which had thawed to about 4 inches below the surface but which was still frozen at depth. Severe erosion resulted from the rainfall on the thawed surface. Runoff from the rainfall on February 4 was estimated to be about 10–16 percent less than runoff from the rainfall of the preceding day. However, an estimated sediment load of nearly 2 million tons was transported past the Hooper station as a result of the rainfall on February 4, compared with an estimated load of 1 million tons on February 3.

The storm of December 22–27, 1964, resulted from climatic conditions somewhat similar to those of February 3–9, 1963. Before the storm, about 5 inches of snow covered the ground, and the soil was frozen to a depth of about 10 inches. A sudden inflow of warm air was accompanied by warm rains, and the tempera-

TABLE 10.—*Particle-size analyses of bed material at four sites in the Palouse River basin*

[Method of analysis: B, bottom-withdrawal tube; C, chemically dispersed; D, decantation; N, native water; P, pipet; S, sieve; V, visual accumulation tube; W, in distilled water]

Date of collection	Hour	Discharge (cfs)	Water temperature (°C)	Percent finer than indicated size, in millimeters																Method of analysis
				0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.350	0.500	1.000	2.000	4.000	8.000	16.000	32.000	
3480. South Fork Palouse River at Pullman																				
Feb. 18, 1964	1440	38	4	13	19	30	45	67	86	94	98	99	99	100	--	--	--	--	--	VPSWC
				8	13	22	33	44	54	59	70	75	79	94	95	98	100	--	--	VPSWC
				11	14	26	47	76	88	--	--	--	--	--	100	--	--	--	--	SPWC
				24	31	45	68	90	99	100	--	--	--	--	--	--	--	--	--	VPSWC
Average				17	24	36	54	73	84	88	92	94	94	98	99	100	--	--	--	
3494. Pine Creek at Pine City																				
Feb. 19, 1964	1200	62	3	0	0	1	1	2	2	4	5	6	7	19	35	66	86	100	--	VPSWC
3496.9. Cottonwood Creek below Pleasant Valley Creek near Ewan																				
Feb. 19, 1964	1040	27	2	7	9	12	20	40	66	87	97	98	98	99	100	--	--	--	--	VPSWC
				5	7	12	22	47	73	84	92	95	96	99	100	--	--	--	--	VPSWC
				4	6	8	13	31	83	98	99	100	--	--	--	--	--	--	--	VPWC
				7	8	13	20	45	92	100	--	--	--	--	--	--	--	--	--	VPWC
Average				6	8	12	19	41	78	92	97	98	98	100	--	--	--	--	--	
3510. Palouse River at Hooper																				
Dec. 19, 1963	1800	123	2	--	--	--	--	--	11	14	28	45	66	84	98	100	--	--	--	VSW
				4	5	6	7	11	16	23	36	46	55	76	87	95	97	100	--	VPSWC
				2	3	3	4	6	8	12	18	24	30	52	59	68	74	83	100	VPSWC
				36	45	50	62	78	92	95	98	99	100	--	--	--	--	--	--	VPWC
				32	35	46	57	71	88	96	99	99	100	--	--	--	--	--	--	VPWC
				18	23	29	37	55	69	84	89	91	93	94	100	--	--	--	--	VPWC
Average				18	22	27	33	44	55	62	68	72	76	84	89	93	94	97	100	

Apr. 4, 1964	1110	1960	6	--	--	--	0	1	1	3	16	49	85	91	94	95	99	100	--	VPSWC
				--	--	--	--	--	--	--	4	17	55	100	--	--	--	--	--	V
				--	--	--	--	--	--	--	0	3	11	42	46	51	54	64	100	V
				--	--	--	--	--	--	--	0	1	2	10	14	21	26	37	100	V
Average				--	--	--	--	--	--	1	5	18	38	61	64	67	70	75	100	

ture rose from about −5°C on December 21 to about 12°C on December 23. About 1.5 inches of rain fell during the same period. Severe erosion occurred, although it was less intense than that resulting from the 1963 storm. Less sediment was transported in the Palouse River at Hooper during the December storm than during the storm of February 1963 partly because (1) the soil mantle was frozen to great depths, and it was readily thawed by the warm temperatures, allowing water to percolate into the subsoil; (2) a lighter snowpack existed; (3) an inflow of cool air closely followed the initial rainfall and caused the runoff rate to decrease in some places; and (4) little rain fell on bare soil after the snowpack had been removed.

The storm of January 27 to February 4, 1965, also produced large sediment discharges. Antecedent moisture had been very high prior to the storm, and more runoff resulted than from the December 1964 storm; but less fluvial sediment was transported from the basin. Sediment discharge was lower partly because (1) rainfall intensity was less during the storm and (2) the soil was not uniformly frozen to depth, and it thawed easily and allowed additional moisture to be retained. Because much moisture could be stored in the soil, runoff rates, and thus erosion, were reduced. The hydrograph (fig. 3) shows that runoff from this storm occurred over a longer period of time than did the runoff from either the 1963 or the 1964 storm.

The relations between sediment discharge and storm runoff during the three major storms and between monthly sediment discharge and monthly runoff are shown in figure 7. Most sediment discharge is transported during the short periods of storms, whereas runoff occurs over longer periods because it is sustained by ground-water seepage and bank storage.

The years during which precipitation is heavy are not necessarily those during which the sediment discharge is high. For example, the sediment load transported past Hooper in 1962–63 was higher than that in 1964–65, even though more precipitation occurred during the latter period.

GEOLOGY AND TOPOGRAPHY

The areas characterized by loess-covered hills contribute the greatest amount of sediment per unit area (pl. 1), and the steeper northern and eastern slopes are eroded faster than the southern and western slopes. The higher erosion rates on the northeast-facing hillsides are the result of greater runoff from melting of larger snowbanks on these leeward slopes. As the snow melts,

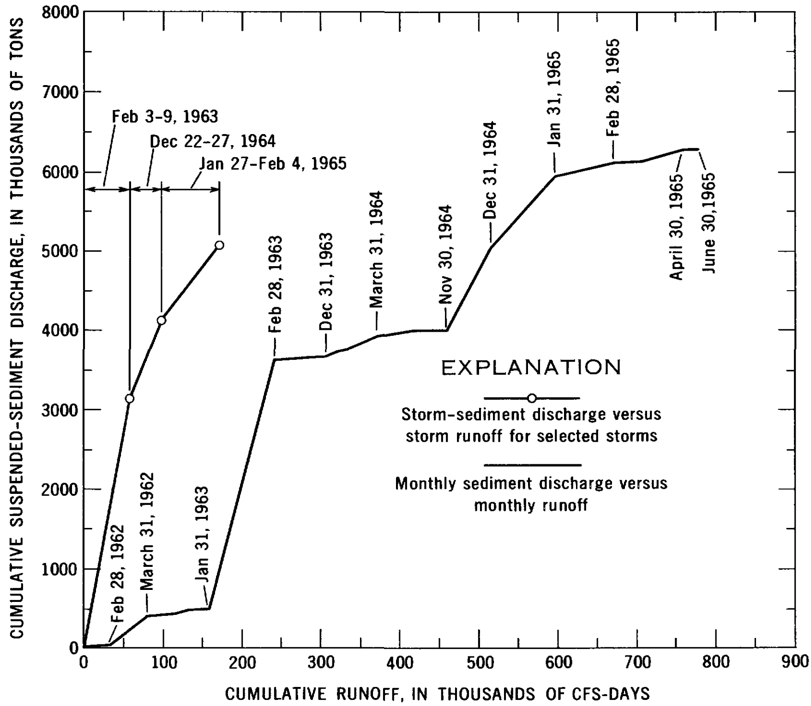

FIGURE 7.—Double-mass relation between suspended-sediment discharge and runoff, Palouse River at Hooper.

soil moisture becomes very high, and after a time the saturated soil becomes a mudflow as it is removed by surface runoff.

In the scablands of subarea C, where topography is relatively flat and basalt is near the surface, sediment yields are low. In subarea A, the consolidated basalt and pre-Tertiary rocks are low sediment producers.

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