Sediment Transport by Streams in the Walla Walla River Basin, Washington and Oregon July 1962–June 1965

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1868

Prepared in cooperation with the Washington State Department of Water Resources and the U.S. Army Corps of Engineers

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By B. E. Mapes

ABSTRACT

The Walla Walla River basin covers about 1,760 square miles in southeastern Washington and northeastern Oregon. From the 6,000-foot crest of the Blue Mountains on the east to the 340-foot altitude of Lake Wallula (Columbia River) on the west, the basin is drained by the Touchet River and Dry Creek, entirely within Washington, and by Mill Creek, North and South Forks Walla Walla River, and Pine Creek–Dry Creek, which all head in Oregon. The central lowland of the basin is bordered on the north by Eureka Flat, Touchet slope, and Skyrocket Hills, on the east by the Blue Mountains, and on the south by the Horse Heaven Hills.

The basin is underlain by basalt of the Columbia River Group, which is the only consolidated rock to crop out in the region. Various unconsolidated fluviatile, lacustrine, and eolian sediments cover the basalt. In the western part of the basin the basalt is overlain by lacustrine deposits of silt and sand which in places are mantled by varying thicknesses of loessal deposits. In the northern and central parts of the basin the loess is at least 100 feet thick. The mountainous eastern part of the basin is underlain at shallow depth by basalt which has a residual soil mantle weathered from the rock. The slopes of the mountains are characterized by alluvial fans and deeply cut stream valleys filled with alluvium of sand, gravel, and cobbles.

Average annual precipitation in the basin ranges from less than 10 inches in the desert-like areas of the west to more than 45 inches in the timbered mountains of the east; 65 percent of the precipitation occurs from October through March. The average runoff from the basin is about 4.8 inches per year. Most of the runoff occurs during late winter and early spring. Exceptionally high runoff generally results from rainfall and rapid melting of snow on partially frozen ground.

During the study period, July 1962–June 1965, average annual sediment yields in the basin ranged from 420 tons per square mile in the mountainous area to more than 4,000 tons per square mile in the extensively cultivated northern and central parts of the basin, which are drained by the Touchet River and Dry Creek. The Touchet River and Dry Creek transported approximately 80 percent of the total sediment load discharged from the Walla Walla River basin. The highest concentrations were contributed by the loessal deposits in the Dry Creek drainage. Two runoff events resulting from rain and snowmelt on partially frozen ground produced 76 percent of the suspended sediment discharged from the basin during

the study period. The maximum concentration measured, 316,000 milligrams per liter, was recorded for Dry Creek at Lowden on December 23, 1964.

Daily suspended-sediment concentrations for the Walla Walla River near Touchet exceeded 700 milligrams per liter about 10 percent of the time, and 14,000 milligrams per liter about 1 percent of the time. The discharge-weighted mean concentration for the 3-year period of study was 7,000 milligrams per liter.

Silt predominates in the suspended sediment transported by all streams in the basin. On the average, sediment from streams draining the Blue Mountains was composed of 20 percent sand, 60 percent silt, and 20 percent clay; for streams draining the Blue Mountains slope–Horse Heaven Hills area, the percentages are 9, 65, and 26, respectively; and for those draining the Skyrocket Hills–Touchet slope, the percentages are 5, 75, and 20, respectively.

The bedload in the mountain and upland streams was estimated to be about 5–12 percent as much as the suspended load. For the Walla Walla River and its tributaries in the lower basin area, the bedload was estimated to be only about 2–8 percent as much as the suspended load.

INTRODUCTION

Purpose and Scope.—To develop a better understanding of present fluvial-sediment conditions in the Walla Walla River basin, a study was begun in 1962 cooperatively between the U.S. Geological Survey and the Washington State Department of Water Resources. The purposes of the study were to (1) determine the approximate amount of sediment being transported by the Walla Walla River and its major tributaries; (2) evaluate the environmental factors that influence sediment yield and transport; and (3) establish a fluvial-sediment reference for use in future planning and development of the basin resources.

The limitations and degree of detail of the study were guided by the need for only a general evaluation of the sediment-transport problem during the 3-year project. On the basis of the short-term investigation, this report is therefore designed to determine the need for more detailed future studies of sediment problems in the basin.

Acknowledgments.—The investigation was expedited by the assistance provided both in the field and in the office by P. R. Boucher, C. J. Bartholet, and R. E. Lombard. A technical review of the manuscript by J. C. Mundorff and L. M. Nelson provided suggestions that were of benefit to the final report.

Previous Investigations.—During the period 1951–53 the U.S. Army Corps of Engineers obtained suspended-sediment data from the Walla Walla and Touchet Rivers to determine the effects of sedimentation on recreational development in the Walla Walla River arm of Lake Wallula, created by McNary Dam on the Columbia River (Ord and Cannon, 1965). Ord and Cannon (1965, p. 792) stated that a comparison of the amount of deposition with the average annual sediment discharge, estimated from suspended-sediment samples, indicates that 56 percent of the Walla Walla River sediment load is deposited in the Walla Walla River arm of the lake.

THE RIVER BASIN

LOCATION AND EXTENT

The Walla Walla River basin occupies most of Walla Walla County and part of Columbia County, in southeastern Washington, and parts of Umatilla and Wallowa Counties, in northeastern Oregon (fig. 1). The basin covers approximately 1,760 square miles and extends eastward for about 55 miles, from the mouth of the Walla Walla River at Lake Wallula to the crest of the Blue Mountains; the widest span from north to south is about 50 miles. Runoff and sediment discharge were measured on the Walla Walla River near Touchet, where the drainage basin area is 1,657 square miles.

TOPOGRAPHY

The following discussion of topography, particularly that of the Blue Mountains and the Walla Walla River valley, is based largely on information provided by Newcomb (1965, p. 9–14).

The Walla Walla River basin ranges in altitude from about 6,000 feet on the east to about 340 feet at the mouth of the Walla Walla River. The basin is characterized by four major topographic features. On the southwest is a ridge known as the Horse Heaven Hills, which originates in south-central Washington and extends southeastward across the State boundary into Oregon, where it abuts the foothills of the Blue Mountains. This ridge is broken by Wallula Gap, which contains the Columbia River (now Lake Wallula). Before Lake Wallula was formed, the mouth of the Walla Walla River was 1.5 miles upstream from Wallula Gap, but it is now about 4 miles farther east. The north slope of the Horse Heaven Hills descends sharply to the Walla Walla River within a few miles from altitudes of more than 1,500 feet, whereas the south slope descends gently into the Umatilla River basin in Oregon.

Eureka Flat, an upland between the Touchet and Snake River valleys, forms most of the northwestern basin boundary. It extends southwestward from about 8 miles north of Lamar to within 6 miles of the Columbia River. Eastward from Eureka Flat, a deeply eroded upland known as the Skyrocket Hills forms part of the northern boundary of the basin.

The Blue Mountains extend northward from Oregon into Columbia County, Wash., and form the eastern boundary of the basin. The altitude of the drainage divide ranges from 4,000 to 6,000 feet and is

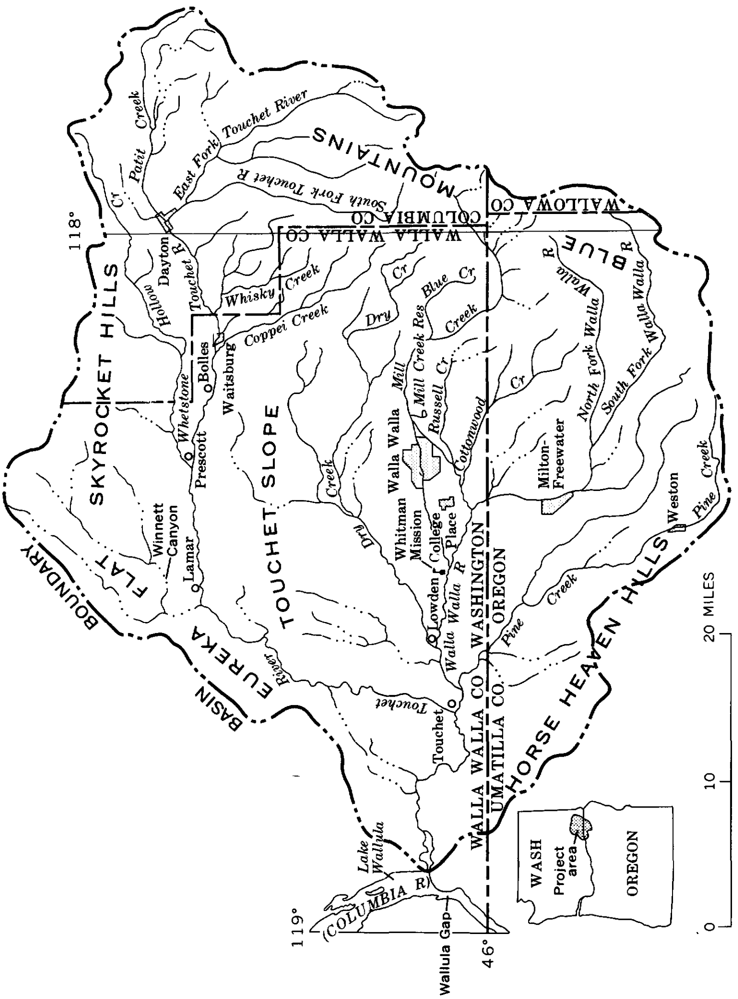

FIGURE 1.—Walla Walla River basin.

highest near the Washington-Oregon boundary. The Blue Mountains are an uplift of basalt of the Columbia River Group; the topography of this area shows the result of deep erosion by streams cutting into the basalt. In the uplands are narrow canyons with steep walls as much as 1,500 feet high.

Alluvial deposits that originate in the canyons of the Walla Walla River and Mill Creek form broad fans that slope westward from the 1,200- to 1,500-foot level down to the floor of the Walla Walla River valley. The Mill Creek alluvial fan extends westward beyond the city of Walla Walla to Whitman Mission. A similar alluvial fan formed by the Walla Walla River extends northwestward from Milton-Freewater to join the Mill Creek fan where the two spread across the upper part of the main valley floor.

Terraces, which are eroded remnants of older alluvial fans, also form parts of the upper valley floor. The terraces follow the broad plains of the Mill Creek and Walla Walla River drainages to the lower altitudes in the basin. Older terraces lie on both sides of Mill Creek above the alluvial fan and south of Dry Creek, and extend westward nearly to Lowden. They have been eroded to form a hilly topography similar to that of the Palouse country to the north. A less eroded lower terrace joins the older terrace at the 1,250-foot level, and extends downvalley from areas east of Walla Walla and northeast of Milton-Freewater to an altitude of 400 feet about 4 miles west of Touchet. The main part of this terrace, known as the Gardena Terrace, is south of both Pine Creek and Walla Walla River near Touchet. The terrace is identified by escarpments that rise as much as 150 feet above the flood plains of the Walla Walla River.

A hilly upland, which separates the Touchet River and Dry Creek drainages, originates in the lower part of the Blue Mountains between the headwaters of Coppei Creek and Dry Creek. The crest of this upland extends northwestward toward Bolles; from there, it is within 2–3 miles of the Touchet River throughout the river's course to the mouth at Touchet. The hilly upland descends from an altitude of about 2,000 feet south of Waitsburg to about 600 feet at Touchet. It is part of the greatest sediment-producing area in the basin; its southern slope is referred to by Newcomb as the "Touchet slope" (1965, p. 11).

GEOLOGY AND SOILS

Newcomb (1965, p. 1–2) described the geology of the Walla Walla River basin as follows:

The only consolidated rock in the basin is the Columbia River Basalt. [Under present usage, this is designated as basalt of the Columbia River Group.] These accordantly layered lava flows are the bedrock exposed in the canyons and other declivities.

* * * The basalt is overlain by unconsolidated deposits of Pleistocene and Recent age. The oldest, thickest, and most extensive unit of these deposits consists of the old clay, up to 500 feet or more thick, that partly fills the Walla Walla synclinal trough. The old clay is interfingered with the old gravel which descends in a tabular stratum from the mouths of the canyons. Successively younger deposits—the Palouse Formation, the deposits of the upper valley terraces, the Touchet beds, and the Recent alluvium—in places overlie the basalt as well as the old gravel and clay of Pleistocene age.

Soils of the Walla Walla Basin can be classified according to their general sources of origin, as discussed by Harrison, Donaldson, McCreary, Ness, and Krashevski (1964, p. 8–12). As defined by the above-named authors, the five following classifications are used: (1) soils of sandy terraces and outwash plains, (2) soils of loessal and lake-laid terraces, (3) soils of bottom lands and low terraces, (4) soils of loessal uplands, and (5) soils of the mountains.

Figure 2 shows the geographic distribution of the soil types in the basin.

On the extreme western, downstream end of the basin, soils of sandy terraces and outwash plains have developed from material deposited by the Columbia and Snake Rivers, most of which is basaltic sand and gravel with some silt. The porous, highly permeable soils developed from these deposits have been thoroughly reworked by the wind and are very dry most of the time. Except for a possible small contribution of these materials to the Touchet River, these soils are of little significance to the fluvial-sediment yield of the basin.

Well-drained loessal and lacustrine sediments cover the terraces of the lower Walla Walla River valley. The dominant soil-forming materials are stratified deposits of silt and sand, referred to by Flint (1938, p. 494) as the Touchet Beds. The Touchet Beds range from a patchy veneer above an altitude of 1,100 feet to a sequence that is more than 100 feet thick beneath the lower valley terraces. North of the Walla Walla River and on both sides of the Touchet River, the stratified materials are overlain by loessal deposits as much as 10 feet thick. These were derived largely by wind erosion of the Touchet Beds.

Most soils covering the bottom lands and low terraces have formed from material washed from adjacent uplands and deposited as alluvium on nearly level to gently sloping stream bottoms and flood plains. The soils are generally deep, well drained, and of medium texture. In the Mill Creek drainage system, some of the soils are shallow and overlie gravel or cobbles of basalt.

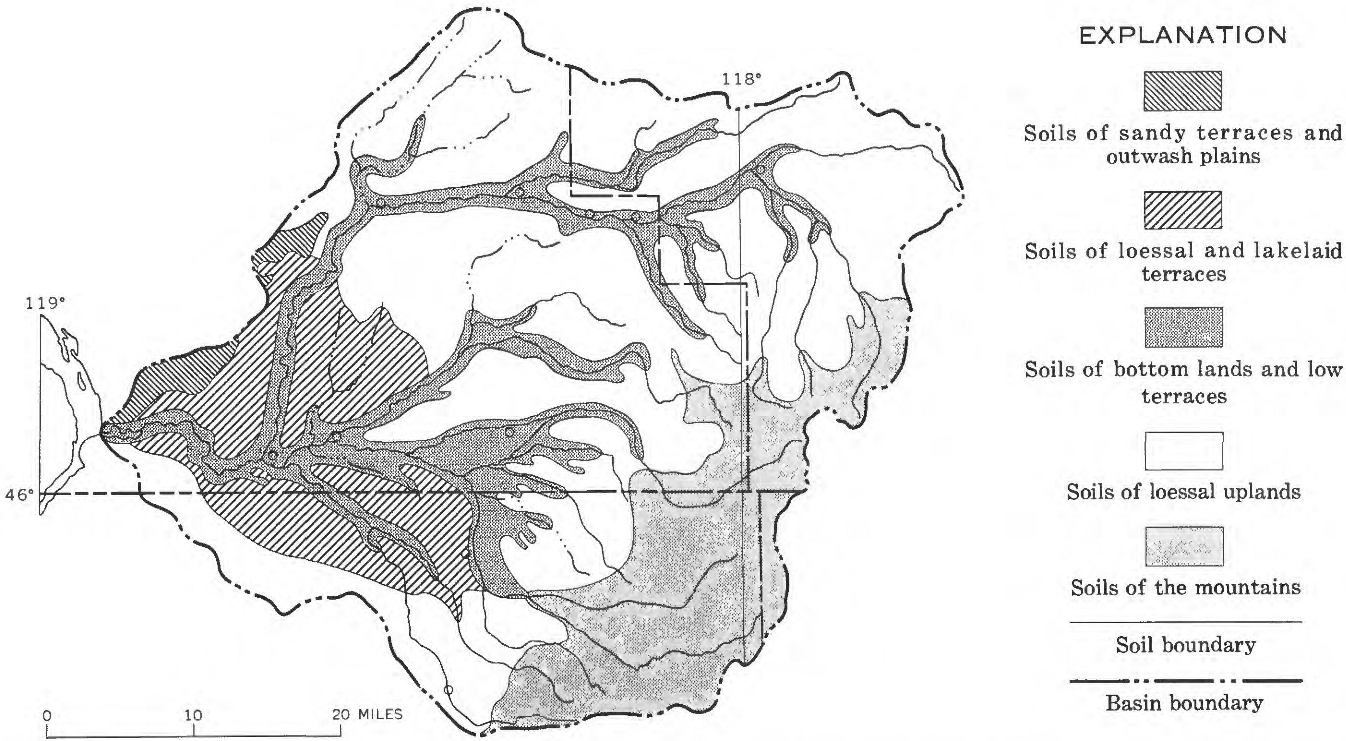

FIGURE 2.—Geographic distribution of soil types in the Walla Walla River basin. Data compiled from maps of Harrison, Donaldson, McCreary, Ness, and Krashevski (1964), Krashevski, Starr, and Sugden (1956), and Newcomb (1965).

Approximately 55 percent of the basin is loessal uplands, where the soil-forming materials consist principally of fine wind-blown deposits known as the Palouse Formation. The soils are well drained and range in thickness from less than 1 to 100 feet or more. The percentage of silt is fairly constant in the soils, but the percentage of very fine sand is highest in the west and decreases toward the east. In contrast, the percentage of clay is highest in the east and decreases toward the west.

On the slopes of the Blue Mountains, loess and residuum weathered from basalt are the chief soil materials. The soil is rocky and shallow to moderately deep. The soils that mantle the south-facing slopes in the valleys of the Blue Mountains consist of weathered basalt and a small amount of loess and are seldom more than 15 inches deep over solid basalt. The north-facing slopes are mantled by a larger percentage of loess than are the south slopes, and the soil is about a foot deeper. Soils on the ridge tops and on slopes above an altitude of 3,000 feet are as much as 5 feet deep over the basalt. These well-drained soils on steep slopes erode very rapidly once the surface layer of duff is removed.

CLIMATE

According to Phillips (1965), climate in and adjacent to the Walla Walla River basin is moderate owing to the influence of marine air from the Pacific Ocean. The lower, western part of the basin is generally warm and dry, whereas temperatures are cooler and precipitation is greater as the altitude increases eastward toward the Blue Mountains. The average annual precipitation ranges from less than 10 inches west of Touchet to more than 45 inches on the slopes of the Blue Mountains (fig. 3). Precipitation is light in the summer, gradually increases in the fall, reaches a peak in midwinter, and decreases sharply in late spring. Approximately 65 percent of the annual precipitation at Walla Walla occurs from October to March as both rain and snow. Snow seldom accumulates on the valley floor but may accumulate to depths of several feet in the Blue Mountains. Extremely heavy rains are infrequent, though a few thunderstorms may occur during the spring and summer.

According to U.S. Weather Bureau records, average air temperatures in the Walla Walla River valley range, in degrees Fahrenheit, from the lower 20's during the winter to the upper 80's during the summer. The average annual air temperature at Walla Walla for the period 1905–61 was 53.8°F (12°C).

A rapid fluctuation of air temperature during the winter months is one of the most critical factors contributing to fluvial-sediment movement in the basin. For example, prewetted soil, in subfreezing tem-

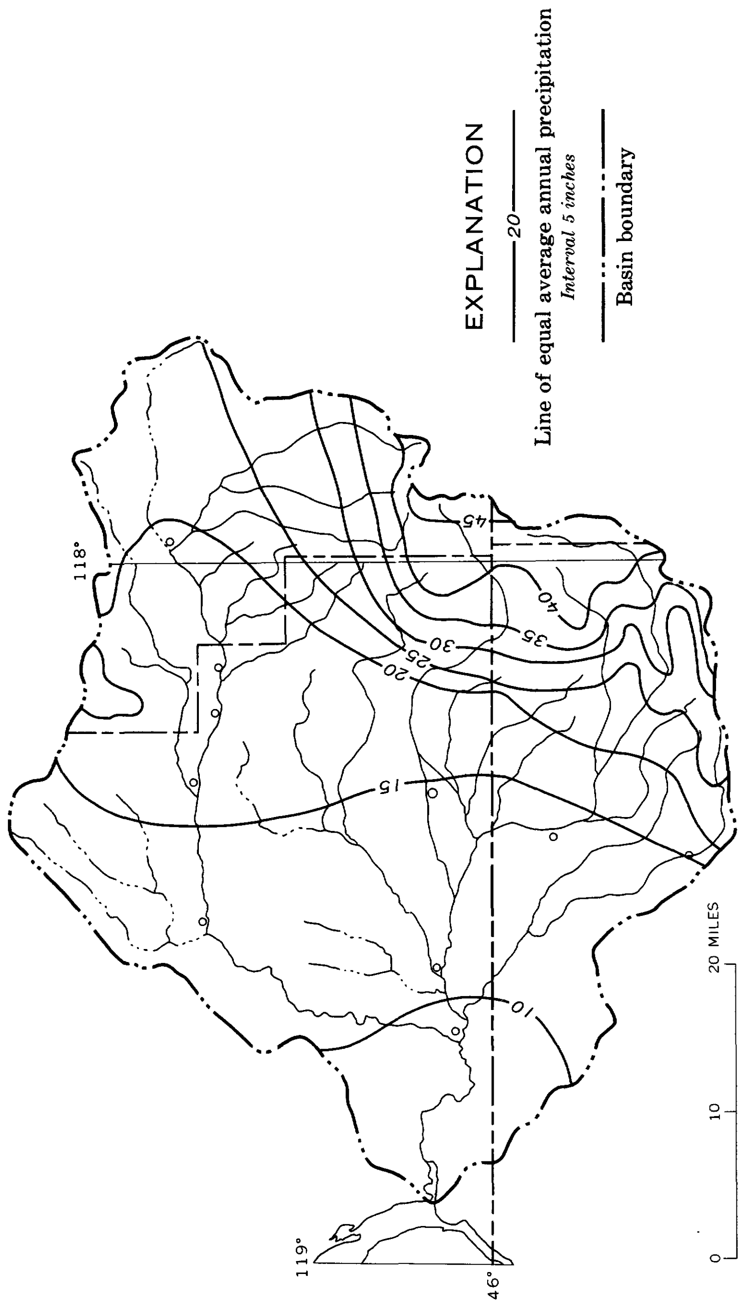

FIGURE 3.—Average annual precipitation. Based on maps prepared by the U.S. Weather Bureau.

peratures and covered by snow, may be frozen to depths of several inches in a few days. Occasionally, chinook winds as warm as 60°F (16°C) will suddenly terminate such periods of extremely cold weather. The inflow of warm air, often accompanied by rain, causes rapid melting of the snow, thawing and saturation of the upper few inches of the soil zone, and consequent severe runoff and erosion.

VEGETATION AND LAND USE

A century ago nearly all the Walla Walla River basin was protected by some type of natural vegetative cover. The valley was an expanse of grassland covered by blue bunch grass, beardless wheatgrass, and fescue on the medium-textured soils, and by needlegrasses on the sandy soils. In the drier, western part of the basin, the lowland grass cover was interspersed with sparse sagebrush and some palatable weeds. In the east the grassland joined the forests of the Blue Mountains.

The lush vegetation of the basin attracted early pioneers, who reported that streams were normally clear and that even the high flows carried little silt. In the latter years of the 19th century, however, stream conditions changed as large areas of the grasslands were grazed or plowed, and some acreages were converted to irrigation farming.

Since the advent of powered farming equipment, nearly all suitable land areas in the valley have been put under cultivation to produce small grain, alfalfa, and garden crops. Land areas not suitable for cultivation are used for grazing. Only a few small areas of the native grassland remain in the basin. These comprise fence corners and rights-of-way, enclosed areas such as cemeteries and monuments, and very steep or otherwise inaccessible areas.

Sagebrush has increased its range at the expense of some of the western grassland and occupies some abandoned croplands. Originally, the sage was more sparse in a rich stand of grass, but today it is thicker and may even appear to be dominant.

Man's activities have had less effect on vegetal cover in the forest areas than elsewhere in the basin. The mountains are clothed with trees of which ponderosa pine, Douglas-fir, white fir, and western larch are the more marketable species. At the higher altitudes the forests are more dense, and the undergrowth is thin. In the lower ridges and drier canyons, the stand of trees is more sparse, and the undergrowth of grass and bushes is heavier. Watershed-management practices in the forested areas have tended to control erosive runoff of the soil cover.

STREAMS

WALLA WALLA RIVER

The Walla Walla River originates on the western slope of the Blue Mountains in the southeastern part of the basin. South Fork, which is the continuation of the main stem, and North Fork originate high in the mountains at an altitude of about 5,000 feet. North and South Forks Walla Walla River flow westward through canyons, and their gradients decrease from about 200 feet or more per mile in the upper reaches to about 100 feet per mile at their confluence. At Milton-Freewater the Walla Walla River flows across its alluvial deposits at a gradient of about 50 feet per mile. Near Walla Walla the river is joined by Yellowhawk Creek, by many spring-fed streams, and by Mill Creek and its braided distributary channels. The river channel grows deeper, and the gradient decreases to about 25 feet per mile in the lower valley, where three major tributaries—Pine Creek, Dry Creek, and the Touchet River—discharge into the Walla Walla River. Backwater effects from McNary Dam on the Columbia River extend about 9 miles upstream from the mouth of the Walla Walla River.

MILL CREEK

Mill Creek heads in the Blue Mountains east of Walla Walla at an altitude of about 5,000 feet and flows through mountain canyons. Its course is controlled by the structure of the basalt. Downstream from the mountain front Mill Creek is met by its largest tributary, Blue Creek, whose headwaters originate in the mountains at an altitude of about 3,000 feet. Approximately 3 miles east of the city of Walla Walla, floodflow is diverted into Mill Creek Reservoir. As stream levels subside, the stored flood waters are released as regulated flow into Russell Creek. About 2 miles east of Walla Walla flow is diverted into Yellowhawk Creek for use in irrigation, Near Walla Walla, Mill Creek forms several distributary channels which flow across alluvial deposits to the Walla Walla River.

The gradient of Mill Creek averages about 150 feet per mile as it flows through its mountain canyons. Near Walla Walla the gradient averages about 60 feet per mile. Mill Creek drains approximately 6 percent of the Walla Walla River basin.

DRY CREEK

The headwaters of Dry Creek originate in the lower part of the Blue Mountains east of Walla Walla. Dry Creek descends from an altitude of about 4,000 feet to the valley floor in about 12 miles, a gradient of about 200 feet per mile. It flows generally northwestward around the city of Walla Walla and is joined by nonperennial tributaries that drain a large part of the Touchet slope. Dry Creek then turns southwestward and joins the Walla Walla River at Lowden at a gradient of about 30 feet per mile. Dry Creek drains about 15 percent of the Walla Walla River basin.

PINE CREEK

Pine Creek and its tributaries make up about 10 percent of the drainage area of the Walla Walla River basin. It originates in the Blue Mountains in the southernmost part of the basin and flows through the lower valley terraces of the Walla Walla River to join the main stem near Touchet. The gradient of Pine Creek decreases from about 200 feet per mile above Weston to about 25 feet per mile near Touchet.

Tributaries of Pine Creek which drain the Horse Heaven Hills flow only during periods of high runoff from heavy rainfall or snowmelt.

TOUCHET RIVER

The Touchet River, principal tributary to the Walla Walla River, drains about 45 percent of the Walla Walla River basin. It is formed in the northeastern part of the basin by the union of several creeks that drain the northern Blue Mountains. The South and East Forks Touchet River head at altitudes of 4,000 and 5,000 feet, respectively. East Fork, which is considered the upstream extension of the Touchet River, flows to its confluence with South Fork, just above Dayton, at a gradient of approximately 150 feet per mile. The Touchet River is joined by Patit Creek at Dayton and by Whisky and Coppei Creeks near Waitsburg. These three tributaries are similar to each other in drainage and head at an altitude of about 3,000 feet. Whetstone Hollow Creek, an intermittent stream, empties into the Touchet River at Prescott. Winnett Canyon contains an intermittent stream which drains the western part of the Skyrocket Hills and the north part of Eureka Flat. It meets the Touchet River just west of Lamar, where the Touchet River makes an abrupt change of course to flow southward to the Walla Walla River. The Touchet River is near the south edge of its drainage basin for much of its course between Bolles and Lamar, and no significant tributaries flow into the river from the south along this reach. The gradient of the Touchet River decreases from about 40 feet per mile between Dayton and Waitsburg to an average of 20 feet per mile closer to the Walla Walla River.

RUNOFF

Runoff from the Walla Walla River basin during the period 1962–65 was recorded at nine gaging stations. One station is on the Walla

Walla River, one each is on North and South Forks Walla Walla River, and the rest are on tributaries (table 1; pl. 1). Most streamflow data used in this report are published in the annual series by the U.S. Geological Survey (1963, 1964a, 1965a, 1966a). The gaging station on the Walla Walla River at Touchet is the farthest downstream and records the runoff from the basin. On the basis of the record from that station, the average annual runoff from the basin for the period 1951–65 is about 4.8 inches.

TABLE 1.—*Available streamflow records and average annual runoff at gaging stations in the Walla Walla River basin for several periods of record, and for period of study, July 1962–June 1965*

Station No.[1]	Station[2]	Drainage area (sq mi)	Average annual runoff			
			Periods of record	Inches	Acre-feet	Period of concurrent record, 1951–65 (acre-ft)
100	South Fork Walla Walla River near Milton, Oreg.	63	1907–17, 1931–65	37.9	127,400	131,000
110	North Fork Walla Walla River near Milton, Oreg.	42	1930–65	15.7	35,110	35,040
130	Mill Creek near Walla Walla	59.6	1913–17, 1939–65	22.3	70,800	70,660
135	Blue Creek near Walla Walla	17	1939–65	12.5	11,290	11,000
150	Mill Creek at Walla Walla	95.7	1941–65			
160	Dry Creek near Walla Walla	48.4	1949–65	6.4	16,510	15,490
[3] 165	East Fork Touchet River near Dayton.	102	1941–51, 1956–65	16.5	89,770	
170	Touchet River at Bolles	361	1924–29, 1951–65	8.3	160,700	162,900
185	Walla Walla River near Touchet	1,657	1951–65	4.8	426,400	426,400

[1] Number listed is part of the complete number that identifies each station in Part 14 (Part 14 includes Pacific Slope basins plus the Lower Columbia River basin). For example, the complete number for station 100 is 14-0100. All numbers in Part 14 are assigned in downstream order. Station locations are shown on plate 1.
[2] In Washington except as indicated.
[3] Since October 1964 published as 166.1 East Fork Touchet River below Hatley Creek near Dayton.

Annual runoff is low in the westernmost part of the basin, where the soil is highly permeable, and is highest in the mountain areas. Patterns of runoff and sediment yield are shown in figure 4. Runoff from the higher altitudes results from early winter and spring rains, snowmelt, and, occasionally, thunderstorms. Runoff increases during the late winter and early spring months and is sustained through June by the gradual melting of snow (fig. 4). Infrequent thunderstorms may cause significant increases in runoff during the summer months.

The most severe flooding in the basin results from heavy rainfall and rapid melting of snow on ground that has been frozen to depths of several inches during a period of extreme cold. These conditions produced two runoff events during the winter months of 1964–65. These two runoffs accounted for more than 20 percent of the water discharged from the basin in the 3-year study period.

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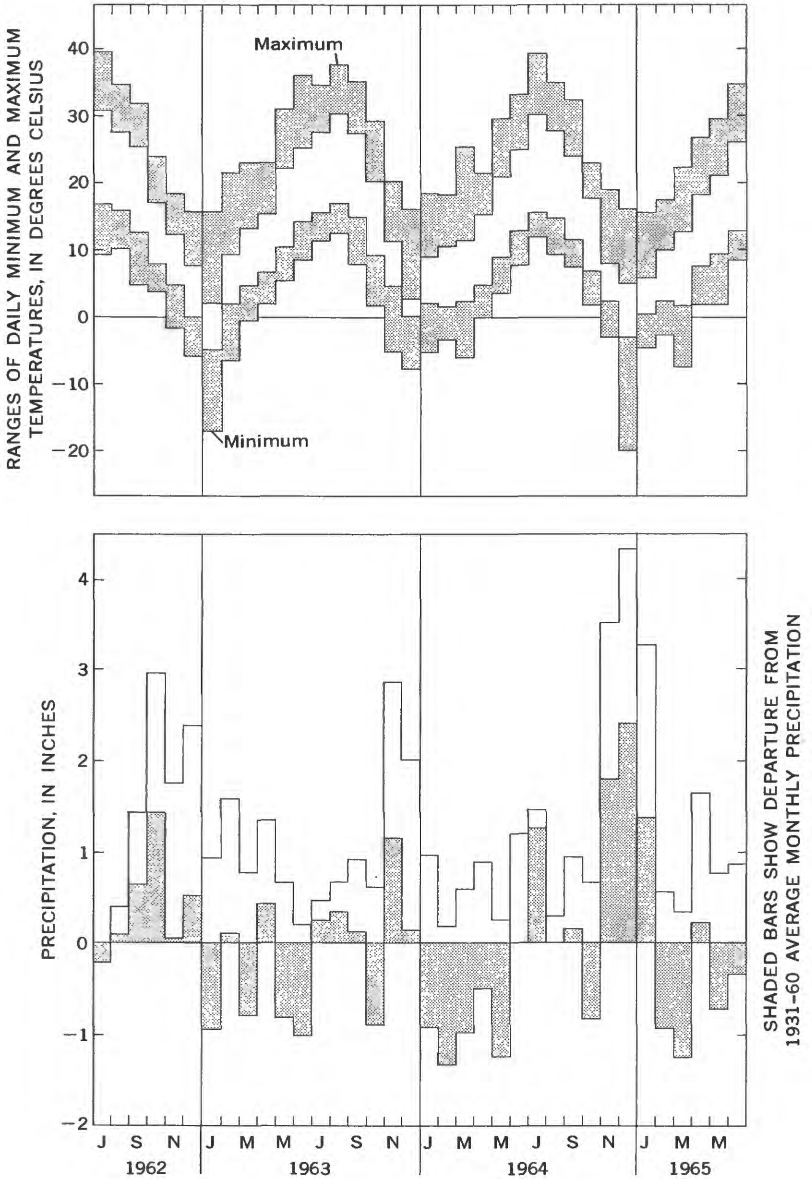
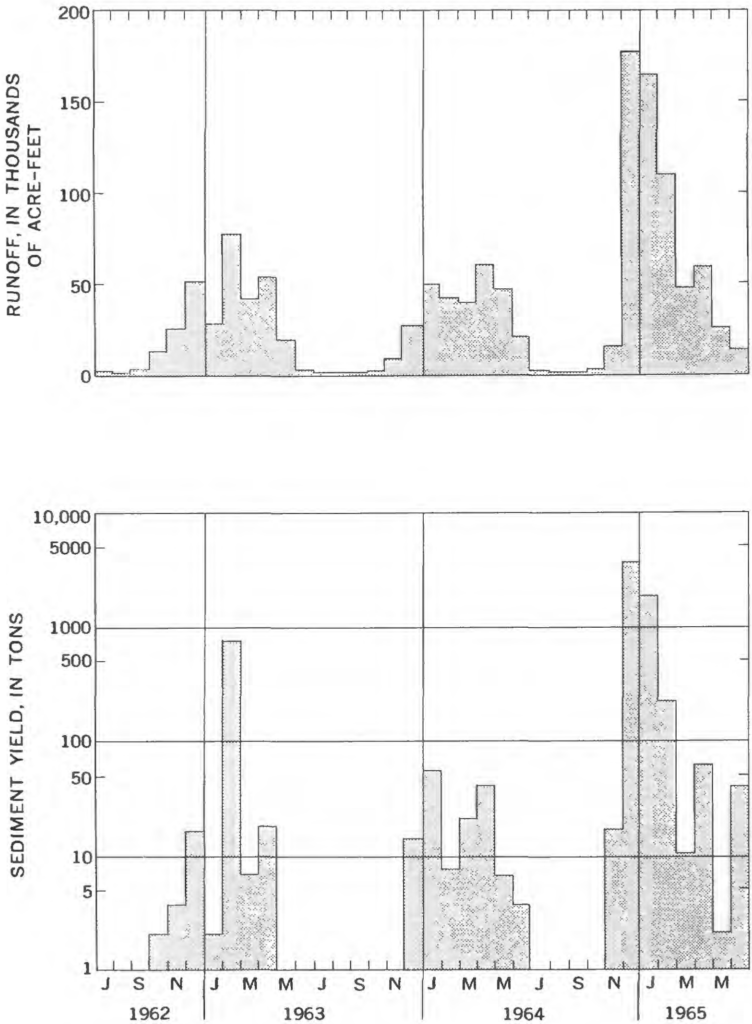


FIGURE 4.—Monthly runoff and sediment yield of Walla Walla River near Touchet and precipitation



as affected by seasonal changes in temperature and precipitation. Temperature recorded at Walla Walla.

The greatest flood during the study period was that of December 22–29, 1964, which resulted from heavy runoff in all areas of the basin. The flood produced a discharge in the Walla Walla River near Touchet that totaled 126,700 acre-feet. The average daily discharge increased from 850 cfs on December 21 to 20,300 cfs on December 23, and then decreased to 2,270 cfs on December 29.

The flood of January 27–February 4, 1965, resulted mostly from runoff in the upland and mountain areas of the basin. The average daily discharge of the Walla Walla River near Touchet increased from 2,320 cfs on January 26 to 14,500 cfs on January 30, and then decreased to 2,640 cfs on February 4. Total discharge from the Walla Walla River during this flood was 125,200 acre-feet.

Total runoff for the Walla Walla River near Touchet was comparable for the two flood periods, but maximum discharges were much higher and receded more rapidly during the December flood. This was due to a sudden inflow of warm air that resulted in rapid, heavy runoff followed by snow and a return of freezing temperatures that decelerated runoff.

Peak water discharges for the Walla Walla River and its three largest tributaries during the floods of December 22–29, 1964, and January 27–February 4, 1965, were as follows:

Station	Peak discharge (cfs)	
	Dec. 22, 1964	Jan. 30, 1965
Walla Walla River near Touchet	33, 400	15, 800
Touchet River at Touchet	11, 500	6, 100
Dry Creek at Lowden	10, 700	780
Pine Creek near Touchet	3, 770	2, 700

Runoff from the two floods resulted in an exceptionally high total runoff for the 1964–65 year of study. Table 2 shows that the annual runoff for the year ending June 1965 was about double that for each of the preceding 2 years of study and was nearly 50 percent greater than the long-term average.

Although the major source of annual flow from the Walla Walla River basin is direct runoff of precipitation, a significant contribution is made by water released from the ground-water reservoir through springs and subsurface seepage to streams. During seasons of low precipitation, the flow of Mill Creek and Walla Walla River is sustained by ground water discharged from aquifers beneath the middle and lower parts of the alluvial fans (Newcomb, 1965, p. 15–18).

TABLE 2.—*Average annual runoff of Walla Walla River near Touchet for July 1962–June 1965 and for total period of record 1951–65*

Period	Runoff	
	Inches	Acre-feet
Year ending June 1963	3.5	313,400
Year ending June 1964	3.4	296,500
Year ending June 1965	7.1	623,200
Average for 3-year period ending June 1965	4.7	411,000
Average for total period of streamflow record, 1951–65	4.8	426,400

SEDIMENT IN THE BASIN

RECORDS AVAILABLE

To compute total quantities of sediment discharged from a stream valley during a given period, information must be available on both runoff and the concentration of transported sediment. For the Walla Walla River basin, records of runoff are given in table 1. To determine sediment loads, two daily and 17 intermittent sampling stations were established in October 1962.

Of the two daily sediment-sampling stations, one was on the Walla Walla River near Touchet and the other was on Mill Creek below Blue Creek (pl. 1). The Walla Walla River sediment station is about 6 miles upstream from Lake Wallula. Records of water discharge were obtained at the stream-gaging station 1.7 miles upstream from the sampling site. The sediment station on Mill Creek was 2 miles below Blue Creek and about 4 miles above the flood-control diversion to Mill Creek Reservoir. Water discharge was based on records from the upper gaging station on Mill Creek and from the Blue Creek station near Walla Walla.

In addition to the two daily sediment-sampling stations, 17 intermittent sampling sites were established to determine the sediment discharge of tributaries in the basin (pl. 1); these included sampling sites at four existing stream-gaging stations. Occasional stage and water-discharge measurements were made to define stage-discharge curves for the 13 sites that had no continuous records of flow.

The sediment records for the two daily stations were extrapolated back to July 1, 1962 to permit computation of flow durations and to give equal weight to each of the 3 years in computing average annual loads. Any error introduced in extending the records is assumed to be very small because the sediment discharge during the summers of 1963 and 1964 was an insignificant part of the annual load for each of those years.

Information was collected at the 17 intermittent sampling sites only during selected storm periods. Sediment samples collected during the storm periods provided data in sufficient range for the methods used to determine average suspended-sediment discharges for the period 1962–65.

Suspended-sediment concentration, load, and particle-size data for the daily stations (Mill Creek below Blue Creek and Walla Walla River near Touchet), for the water year ending September 30, 1963, are published in the annual series entitled, "Quality of Surface Waters in the United States" (U.S. Geological Survey, 1966b); similar data for water years 1964 and 1965, and miscellaneous reconnaissance data for water years 1963–65, are published in an annual series by the U.S. Geological Survey (1964b, 1965b).

SUSPENDED-SEDIMENT CONCENTRATION

Sediment concentration is the ratio of the dry weight of sediment to the total volume of the water-sediment mixture; it is expressed as the ratio of sediment to water-sediment mixture, in milligrams per liter. Factors that affect the concentration of sediment in streams include physical properties of the soils, land-use practices, climatic conditions, and streamflow characteristics. Streams draining the high, timbered areas of the Blue Mountains have the lowest concentrations, whereas streams draining the cultivated soils of agricultural lowlands have the highest concentrations.

The minimum concentration measured in many streams of the subbasins was less than 1 mg/l. The maximum concentration measured during the study was 316,000 mg/l, in Dry Creek at Lowden on December 23, 1964.

In the Walla Walla River near Touchet during the period of study, the daily suspended-sediment concentration was more than 60 mg/l (milligrams per liter) about 50 percent of the time, 700 mg/l about 10 percent of the time, and 14,000 mg/l only 1 percent of the time (fig. 5). The maximum daily concentration was 61,200 mg/l on February 5, 1963, whereas the minimum daily concentration was 4 mg/l, on June 20, 1963. Instantaneous concentrations measured in the Walla Walla River during the study ranged from 4 mg/l to 114,000 mg/l.

Average sediment concentrations for selected periods of runoff are known as "discharge-weighted mean concentrations." The discharge-weighted mean concentration of the Walla Walla River near Touchet for the 3-year period of study was 7,000 mg/l (table 3). The maximum discharge-weighted mean concentration for a storm event at the same site was 35,300 mg/l, for the flood of December 22–29, 1964. The flood

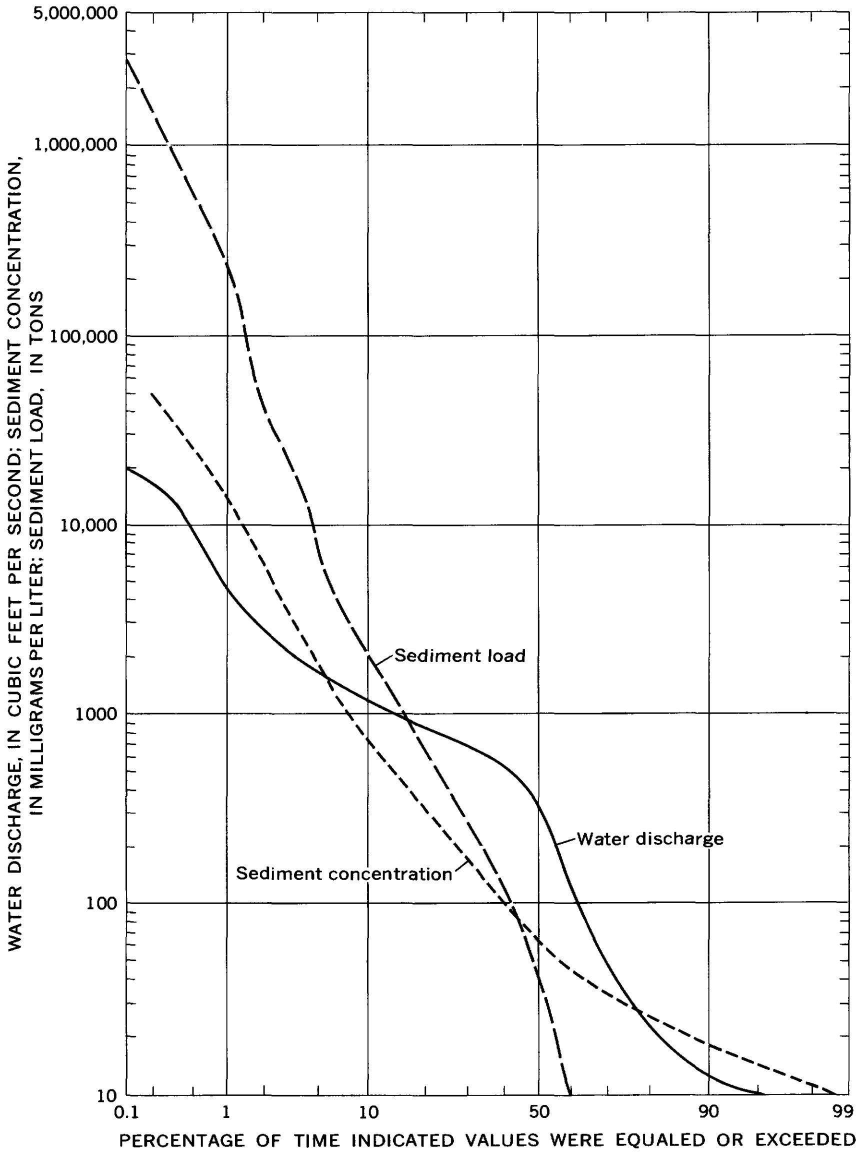


FIGURE 5.—Frequency curves for mean daily water discharge, sediment concentration, and sediment load, Walla Walla River near Touchet, July 1962–June 1965.

of January 27–February 4, 1965, produced a comparable volume of water discharge, but the discharge-weighted mean concentration was only 15,800 mg/l. The lower concentration for the latter flood was the result of less intense runoff at the lower altitudes and, consequently, of much less erosion in the major sediment-producing areas of the basin. The maximum discharge-weighted mean concentration at any station in the Walla Walla River basin was 165,000 mg/l, in Dry Creek at Lowden during the storm of December 22–29, 1964.

TABLE 3.—*Total runoff, suspended-sediment discharge, concentration, and yield for selected runoff events, Walla Walla River near Touchet, July 1962–June 1965*

Date of runoff	Total runoff		Suspended-sediment discharge		Discharge-weighted mean concentration (mg/l)	Suspended-sediment yield (tons per sq mi)
	Acre-feet	Percent of total for entire 3-year period	Tons	Percent of total for entire 3-year period		
1962						
Oct. 12–18	7,080	0.6	3,050	<0.1	316	2
Nov. 20–24	8,350	.7	4,480	<0.1	394	3
Dec. 2–5	8,500	.7	21,900	0.2	1,890	13
1963						
Feb. 2–8	35,170	2.9	1,270,000	10.9	27,000	766
Mar. 29–Apr. 3	10,730	.9	13,100	.1	897	8
Apr. 20–25	12,400	1.0	8,180	.1	483	5
Nov. 7–12	2,290	.2	780	<0.1	240	<0.5
Dec. 17–23	9,660	.8	11,900	.1	905	7
1964						
Jan. 25–29	14,900	1.2	71,500	.6	3,530	43
Mar. 30–Apr. 5	21,750	1.8	62,900	.5	2,120	38
May 17–22	12,360	1.0	5,110	<0.1	304	3
Nov. 25–27	7,800	.6	27,600	.2	2,600	17
Dec. 1–5	21,560	1.7	61,300	.5	2,090	37
Dec. 14–17	5,440	.4	22,900	.2	3,090	14
Dec. 22–29	126,700	10.3	6,190,000	52.9	35,300	3,740
1965						
Jan. 5–8	13,940	1.1	485,000	4.1	26,100	293
Jan. 27–Feb. 4	125,200	10.2	2,700,000	23.1	15,800	1,630
Apr. 20–23	18,780	1.5	83,600	.7	3,270	50
Total for runoff events (rounded)	462,800	37.6	11,000,000	94.2	17,800	6,670
Total for study period (rounded)	1,233,000	100.0	11,700,000	100.0	7,000	7,080

The highest sediment concentrations are associated with runoff resulting from rain and rapid melting of snow, so the high concentrations can be expected during the winter months, as shown in figure 6. However, occasional thunderstorms can cause high concentrations during the summer months.

SUSPENDED-SEDIMENT DISCHARGE DURING RUNOFF EVENTS

On the basis of data collected during the 3-year study, streams in the Walla Walla River basin characteristically discharge most of their annual sediment load during the period from November through April. Monthly and yearly suspended-sediment discharge of the Walla Walla River near Touchet are shown in table 4. Sediment discharge was exceptionally heavy in February 1963, December 1964, and January 1965. Sediment discharge during those 3 months comprised 92 percent of the total suspended-sediment discharge measured for the

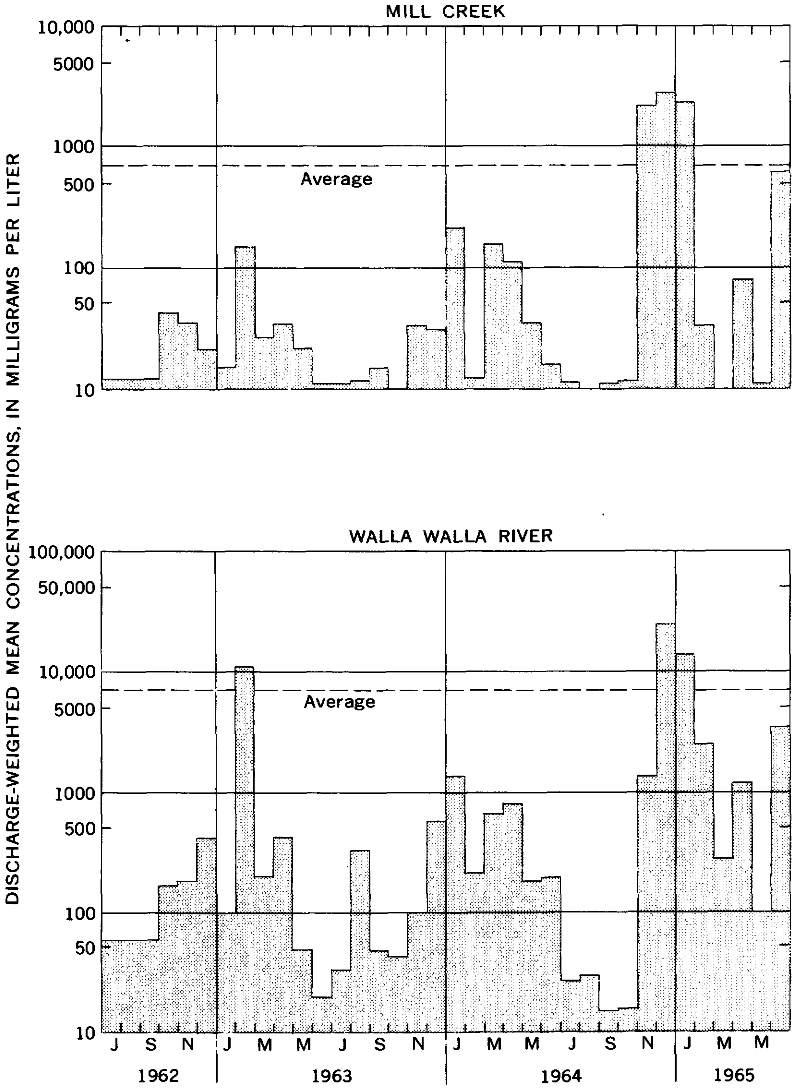


FIGURE 6.—Seasonal variations in suspended-sediment concentration, Mill Creek near Walla Walla and Walla Walla River near Touchet, July 1962–June 1965.

entire period of study, and resulted primarily from the runoff events during February 2–8, 1963; December 22–29, 1964; and January 27–February 4, 1965 (table 3). The latter two of these events produced 76 percent of the sediment discharged during the 3 years. The flood of December 22–29, 1964, was basin-wide and was greatest in magnitude of the three. Rapid runoff caused very pronounced rill-and-gully erosion throughout the basin. Sheet erosion, though extensive, was the less notable of the erosional processes. Sediment yields were the greatest from the Dry Creek drainage; this was due in part to severe erosion of the steep banks by the floodwaters. Bank and channel erosion in other streams of the basin were probably also the greatest in many years. Though sediment from the lower altitudes contributed most of the load, yields from higher altitudes were also considered much above average.

TABLE 4.—*Monthly and yearly suspended-sediment discharge, Walla Walla River near Touchet, July 1962–June 1965*

	Suspended-sediment discharge (tons)		
	1962–63	1963–64	1964–65
July	100	50	102
August	50	266	56
September	150	52	32
October	3, 270	75	76
November	6, 240	1, 250	28, 100
December	28, 900	22, 600	6, 290, 000
January	3, 540	91, 200	3, 220, 000
February	1, 300, 000	12, 400	373, 000
March	11, 100	35, 200	17, 600
April	31, 200	67, 600	107, 000
May	1, 260	11, 000	3, 540
June	42	5, 890	66, 000
Year	1, 380, 000	248, 000	10, 100, 000
Average annual discharge, July 1962–June 1965			3, 910, 000

Many of the maximum suspended-sediment discharges measured throughout the basin during the entire 3-year study occured during the December 1964 flood. The maximum daily sediment discharge of 3,230,000 tons occurred December 23 on the Walla Walla River near Touchet and was 28 percent of the total suspended-sediment discharged during the period of study. The maximum daily sediment discharge computed for a reconnaissance station during the study was 1,600,000 tons on December 22 for Dry Creek at Lowden. A maximum instantaneous discharge of 144 tons per second (equivalent to 12.4 million tons per day) also occurred on Dry Creek at Lowden, at 1800 hours on December 22. The maximum instantaneous discharge computed for the Walla Walla River near Touchet equaled 133 tons per second (11.5 million tons per day), at 2330 hours, December 22, 1964.

In the southern part of the basin, the flood of January 27–February 4, 1965, was greater than the December 1964 flood. Also, erosion was greater at higher altitudes in some areas, and much damage occurred to stream banks. Although the total runoff for the Walla Walla River near Touchet was comparable for the two floods (125,000 acre-ft and 127,000 acre-ft, respectively), suspended-sediment discharge of the January flood was less than half that of the December flood.

Though of less magnitude the flood of February 2–8, 1963, transported about 11 percent of the sediment discharged from the basin during the entire 3-year period. The three runoff events cited above were similar in that they were characterized by the sudden warming and rapid melting of snow and, together with rainfall, by a rapid runoff across ground that was thawed in only the upper few inches. The combination of these conditions is the greatest cause of erosion and sediment transport in the basin.

The total duration of selected storm events (table 3) composed only about 9 percent of the entire period of study. However, the combined runoff for selected storm events was about 38 percent of the total, and the sediment transported was about 94 percent of the total. As a result the total discharge-weighted mean concentration for the runoff events was 17,800 mg/l, or 254 percent of that for the 3-year period. Figure 5 shows how water discharge, sediment concentration, and daily sediment load were distributed with respect to time for the period of investigation.

SUSPENDED-SEDIMENT DISCHARGE BY SUBBASINS

Average annual suspended-sediment discharge and yields of areas upstream from the daily and intermittent stations are listed in table 5. The sediment yields, by subbasins, are shown graphically on plate 1. The annual suspended-sediment yields smaller than 1,500 tons per square mile are restricted generally to the mountainous, eastern part of the basin; yields in the 1,500- to 2,500-ton range are characteristic of the upland foothills; and most yields exceeding 2,500 tons per square mile are characteristic of the lower Touchet River and Dry Creek drainages.

TOUCHET RIVER AND DRY CREEK SUBBASINS

The combined drainage areas of Touchet River and Dry Creek constitute 60 percent of the Walla Walla River basin. These streams drain the area of greatest sediment yield (pl. 1) and discharge about 80 percent of the sediment load that passes the daily station on the Walla Walla River at Touchet. Although the quantity of sediment discharged by the Touchet River at Touchet was considerably greater than that of Dry Creek at Lowden, the sediment yield per square mile was much smaller. The lower yield of the Touchet River was due to dilution by tributary streams that head in timbered areas above Bolles. These streams produced an average of only 1,700 tons of sedi-

TABLE 5.—*Average annual suspended-sediment discharges and yields from areas in the Walla Walla River basin, July 1962–June 1965*

Station No.[1]	Station location or area [2]	Drainage area (sq mi)	Average annual sediment discharge [3] (tons)	Average annual sediment yield (tons per sq mi)	Percent of load for Walla Walla River near Touchet
120	Walla Walla River at Milton-Freewater, Oreg	163.0	(B)98,000	600	2.5
*130	Mill Creek near Walla Walla	59.6	(B)25,000	420	.6
*135	Blue Creek near Walla Walla	17.0	(B)37,000	2,200	.9
	Other area above station 136	14.4	(D)16,000	1,100	.4
136	Mill Creek below Blue Creek near Walla Walla	91.0	(R)77,800	855	2.0
144	Yellowhawk Creek near College Place	69.6	(B)110,000	1,600	2.8
*160	Dry Creek near Walla Walla	48.4	(B)120,000	2,500	3.1
	Dry Creek drainage between Walla Walla and Lowden	197.6	(D)790,000	4,000	20
160.5	Dry Creek at Lowden	246	(B)910,000	3,700	23
160.8	Pine Creek near Weston, Oreg	16.8	(B)19,000	1,100	.5
	Pine Creek drainage between Weston, Oreg., and Touchet	153.2	(D)310,000	2,000	7.9
161	Pine Creek near Touchet	170	(B)330,000	1,900	8.4
166.4	East Fork Touchet River at Dayton	108	(A)140,000	1,300	3.6
167	South Fork Touchet River near Dayton	39	(A)69,000	1,800	1.8
168	Patit Creek near Dayton	53.5	(A)98,000	1,800	2.5
169	Whisky Creek near Waitsburg	16.4	(B)27,000	1,600	.7
169.5	Coppei Creek at Waitsburg	34.1	(B)59,000	1,700	1.5
	Other area above Touchet River at Bolles	110	(D)230,000	2,100	5.9
*170	Touchet River at Bolles	361	(B)620,000	1,700	16
171	Whetstone Hollow Creek at Prescott	101	(E)430,000	4,300	11
	Other area between Bolles and Lamar	58	(D)250,000	4,300	6.4
171.2	Touchet River at Lamar	520	(B)1,300,000	2,500	33
	Touchet River drainage between Lamar and Touchet	227	(D)900,000	4,000	23
176	Touchet River at Touchet	747	(B)2,200,000	2,900	56
	Unsampled areas tributary to Walla Walla River	170	(E)300,000	1,800	7.7
*185	Walla Walla River near Touchet	1,657	(R)3,910,000	2,360	100

[1] See footnote 1, table 1, p. 13. Asterisk indicates site that is both a stream-gaging station and a sediment-sampling station.
[2] All towns are in Washington, except as noted.
[3] Method of computation used: A, flow-duration curve and sediment-transport curve, discussed by Jordan, Jones, and Petri (1964, p. 60–63), Miller (1951), Wark and Keller (1963, p. 10–13), and Searcy (1959); B, relation to storm loads for nearby sediment station, discussed by Jones (1964, p. 63–69); R, daily sediment station record; E, estimated load based on loads for nearby sediment stations; D, difference in loads between stations or areas.

ment per square mile annually. Low-sediment-yield timbered areas amount to 48 percent of the entire Touchet River drainage.

Between Bolles and Lamar the yield of the Touchet River increased abruptly to more than 4,000 tons per square mile, and was sustained at that rate through the lower part of the drainage. The yield of the Dry Creek subbasin was comparable to that of the Touchet River subbasin downstream from Bolles.

The area of heavy sediment yield drained by Touchet River and Dry Creek—from Eureka Flat eastward to Waitsburg, and from Walla Walla northward to the basin boundary—is underlain by soils that are highly susceptible to erosion. The soils consist of well-drained silt loams and very fine sandy loams. Precipitation ranges from 10 inches to about 18 inches per year; runoff is medium to high; and the likelihood of erosion is high. Since the original grassland was put under cultivation, nearly all the surface soil, about 5–8 inches, has been lost through erosion on some of the steep slopes (Harrison and others, 1964, p. 35). Pronounced rilling and gullying occurs in soils that mantle the long steep uniform slopes of the Skyrocket Hills.

PINE CREEK SUBBASIN

Pine Creek, like its neighboring tributaries to the north, drains an area whose soil is composed of silt and very fine sandy loam. Land use includes farming and grazing. Runoff is medium to rapid, and severe erosion can occur on the steeper slopes. The sediment discharge, mostly from Oregon, was 8.4 percent of that from the Walla Walla River basin; it produced an average annual yield of 1,900 tons per square mile.

MILL CREEK SUBBASIN

As described here the Mill Creek subbasin includes the drainages of Mill Creek above Blue Creek, Blue Creek, Mill Creek below Blue Creek, and Yellowhawk Creek.

The lowest sediment yield in the report area, 420 tons per square mile, was from Mill Creek above Blue Creek. Mill Creek drains the higher parts of the mountainous area underlain by soils of weathered basalt and small amounts of loess (silty clay loam). Runoff from the steep slopes can be rapid, but the dense stands of timber and brush tend to control erosion.

Blue Creek produced most of the sediment measured at Mill Creek below Blue Creek. The headwaters of Blue Creek drain timbered areas, but the lower reaches flow locally across loess-covered areas that have been cleared and put under cultivation. These lower areas are eroded easily during heavy runoff. The annual sediment yield of the Blue Creek drainage averaged 2,200 tons per square mile.

Sediment from the area below the daily station on Mill Creek is transported by the main stem and braided distributary channels and by diversions to Yellowhawk Creek. Mill Creek flows in a concrete-lined channel through the city of Walla Walla and, from there, in a natural channel to its confluence with the Walla Walla River. Soils of the drainage consists of basaltic material from the mountainous areas and of some loessal soils from the uplands. Erosion is assumed to be minimal in the urban area and moderate in the cultivated rural area, where slopes are slight and streambank cutting occurs. The sediment yield from this area was estimated to be about 1,000 tons per square mile.

The sediment yield of the Yellowhawk Creek drainage may have been affected by diversions of flow from Mill Creek during times of heavy runoff. The effect of such diversions from another drainage area was not determined during this study. Sediment samples were obtained near the mouth of Yellowhawk Creek, which therefore included runoff from areas drained by Russell Creek and Cottonwood Creek. The computed yield was about 1,600 tons per square mile. Soil types in these areas are similar to those of the Mill Creek basin. They range from basaltic material in the mountains to alluvial deposits on the upper valley floor. Erosion occurs mostly on the cultivated steep slopes near the mountains.

UPPER WALLA WALLA RIVER SUBBASIN

In the upper Walla Walla River drainage above Milton-Freewater, the annual sediment yield averaged only 600 tons per square mile and is comparable to that of Mill Creek. Sources of the sediments are also similar. At the higher altitudes the North and South Forks Walla Walla River drain great areas of basaltic soils mantled by forest, but on the lower mountain slopes the streams drain cultivated areas of loess, gravel, cobbles and deposits of basaltic soils. The larger area of forest land tributary to the Walla Walla River above Milton-Freewater may account for the smaller yield from that area than from the area tributary to Mill Creek above the daily station.

Annual sediment yield of the unsampled lower Walla Walla River valley—between the Touchet River and Milton-Freewater—was estimated, on the basis of yields from surounding areas, to be about 1,800 tons per square mile. The nearly level to gently sloping area is mantled by silt loams and very fine sandy loams which are cultivated, used for grazing, or left to native grasses. Runoff is generally light, and erosion is moderate.

Ord and Cannon (1965, p. 789) stated that the average annual runoff during 1951–53 was only slightly below the long-term average, and that the average annual sediment discharge determined for those years may therefore be fairly representative of the average sediment discharge for a long-term period. Although the average annual runoff for the period 1962–65 was only slightly less than that of 1951–53 (table 6), the sediment discharge was more than 50 percent greater. The more severe erosion occurred during the 1962–65 period, as the result of the floods of December 1964 and January–February 1965.

TABLE 6.—*Average annual runoff and sediment discharge from the Walla Walla River basin for the periods 1951–53 and 1962–65*

	Average runoff (acre-feet)	Average sediment discharge		Discharge-weighted mean concentration (mg/l)
		Acre-feet	Tons	
Jan. 1951–Dec. 1953	[1] 413,800	[1] 1,540	[2] 2,500,000	4,500
July 1962–June 1965	411,000	[3] 2,390	3,910,000	7,000

[1] Data from Ord and Cannon (1965, p. 789); sediment discharge includes 10 percent bedload.
[2] Estimated data from J. C. Cannon (U.S. Army Corps of Engineers, oral commun., 1966).
[3] Based on sediment density of 75 per cu ft; does not include bedload.

PARTICLE SIZE

The transportation and deposition of sediments are largely functions of particle size. Fine particles are usually kept in suspension by the turbulence of the moving water and may thus be transported from the basin. Coarse particles may travel in suspension, may roll or skip along the streambed, or may travel by a combination of the methods. They are likely to be deposited temporarily along the stream.

The concentration of silt and clay usually increases as flow increases because most highflows result from rainfall or snowmelt that easily erodes silt and clay from the land surface. Concentration of silt and clay does not necessarily decrease as flow decreases, however, because even low flows may be sufficient to carry fine sediment in suspension. The concentration of sand, however, is more dependent upon velocity and turbulence than is that of silt and clay. Hence, the concentration of coarse sediment usually increases or decreases as velocity increases or decreases (Colby, 1963, p. A10–A11).

A summary of the percent composition by weight of clay (less than 0.004 mm), silt (0.004–0.062 mm), and sand (0.062–2.0 mm) in suspended-sediment samples collected in the Walla Walla River basin is given in table 7. The number of analyses for each station is also given to indicate how representative the percentages are of the particle-size distribution for the stream at the sampling station.

Most of the samples were collected during periods of high runoff, when sediment discharge was high. The percentage of sediment in each particle-size class therefore does not necessarily represent average distribution with respect to time. Load-weighted values, however, should be fairly representative of the suspended sediment discharged by the streams in a few high-runoff events.

To further define the nature of the sediments in the basin, the values for each station (except those with fewer than three analyses) are shown in figure 7. The stations are symbolized and plotted accord-

TABLE 7.—*Average particle-size distribution of suspended sediment at gaging stations in the Walla Walla River basin, July 1962–June 1965*

Station No.[1]	Station[2]	Symbol No. in fig. 7	Clay (particles <0.004 mm) (percent[3])	Silt (particles 0.004–0.062 mm) (percent[3])	Sand (particles 0.062–2.00 mm) (percent[3])	Number of analyses
120	Walla Walla River at Milton-Freewater, Oreg	1	18	56	26	4
130	Mill Creek near Walla Walla	2	25	55	20	3
135	Blue Creek near Walla Walla	3	27	65	8	5
136	Mill Creek below Blue Creek	4	22	65	13	9
144	Yellowhawk Creek near College Place	5	32	61	7	4
160	Dry Creek near Walla Walla	6	22	72	6	7
160.5	Dry Creek near Lowden	7	18	77	5	11
160.8	Pine Creek at Weston, Oreg		30	68	2	2
161	Pine Creek near Touchet	9	20	65	15	12
166.4	East Fork Touchet River at Dayton	10	16	65	19	5
167	South Fork Touchet River near Dayton	11	22	60	18	2
168	Patit Creek near Dayton		27	71	2	4
169	Whisky Creek near Waitsburg	13	19	59	22	5
169.5	Coppei Creek at Waitsburg		30	62	8	4
170	Touchet River at Bolles		26	71	3	12
171	Whetstone Hollow Creek at Prescott		[4] 16	[4] 80	[4] 4	2
171.2	Touchet River at Lamar	17	20	71	9	7
176	Touchet River at Touchet	18	21	73	6	16
185	Walla Walla River near Touchet		28	69	3	32

[1] See footnote 1, table 1, p. 13.
[2] Gaging stations are all in the State of Washington except as indicated.
[3] Load-weighted values.
[4] Arithmetical average—no instantaneous load data available.

ing to sediment yield. The average particle-size composition of suspended sediments from the three areas of generally differing yields is given below, and data are in percent.

	Clay	*Silt*	*Sand*
Blue Mountains	20	60	20
Horse Heaven Hills–Blue Mountains slope	26	65	9
Skyrocket Hills–Touchet slope	20	75	5

A comparison between the particle-size composition of suspended-sediment samples from the mountains and from lower basin areas indicates equal percentages of clay, but 15 percent more sand from the mountain area and 15 percent more silt from the lower areas. A greater proportion of sand in the samples obtained from the mountain areas can be expected because the steeper stream gradients provide the velocities and turbulence that keep the coarse particles in suspension. A transition in the percentages of clay, silt, and sand occurs in the suspended sediments in the area between the mountains and lower basins.

BEDLOAD

Suspended-sediment samplers used in this investigation sample only that part of the vertical profile from the water surface to about 0.3

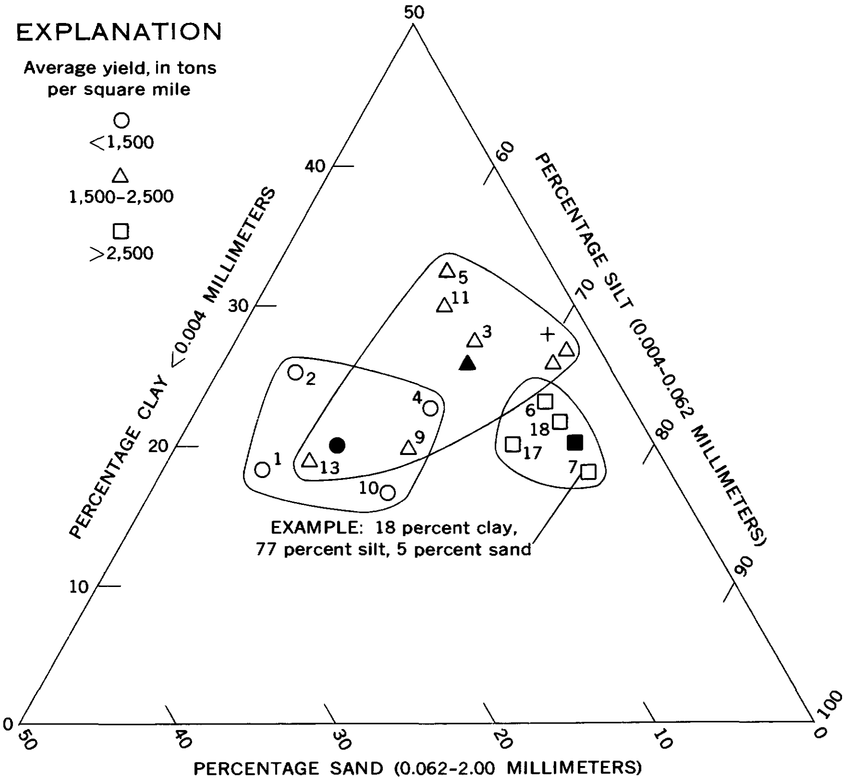


FIGURE 7.—Percentages of sand, silt, and clay in suspended sediment in streams in the Walla Walla River basin. Symbols indicate average annual sediment yield. Numbers refer to stations listed in table 7. Solid symbols, average values for stations in each group; and +, composition of sediment for Walla Walla River near Touchet (2,360 tons per sq mi).

foot above the streambed. Measured suspended-sediment discharge, then, does not represent total sediment discharge because the particles that move in nearly continuous contact with the streambed and those that bounce just above the streambed are not sampled. For purposes of discussion in this report, sediment transported in the lower 0.3 foot of the stream is considered to be bedload.

Whereas sediment particles finer than sand may be fairly well distributed vertically in a stream, most sand and coarser material is concentrated near the bed (Colby, 1963, p. A25). Bedload is composed mostly of these particles. It may be a negligible or a substantial percentage of the total sediment discharge, depending mainly upon such factors as stream velocity, the amount of material in suspension, particle size of bed material, and channel configuration. Bedload may be an appreciable percentage of the total sediment discharge in those streams whose beds are composed mostly of sand or whose suspended-sediment concentrations are low. Conversely, bedload may be only a small percentage of the total sediment discharge in those streams whose beds are rock, gravel, or consolidated clay or whose suspended-sediment concentrations are high. Although the percentage of bedload may decrease while the total sediment discharge increases, the bedload tonnage is greater for high flow than for low flow.

Accurate determinations of bedload require measurements of channel width, mean depth, mean velocity, temperature, suspended-sediment discharge, and particle size of both the bed material and the suspended sediment. Because such data were lacking for most streams in the Walla Walla River basin, bedload was estimated largely on the basis of data observed and collected from runoff events during the study and on observations of the streambed material at low flow. A discussion and table presented by Lane and Borland (1951) were used as a guide for the estimations.

The bedload for mountain and upland streams in the Walla Walla River basin is an estimated 5–12 percent of the suspended load. In the mountain streams, suspended sediment of generally low concentration—less than 1,000 mg/l—and averaging about 20 percent sand is transported through shallow channels. The channel beds of such streams are composed of coarse gravel to large cobbles that are intermixed with sand and small amounts of silt and clay from the loess. The gradient of the mountain streams is steep, and velocities at high flow are sufficient for the water to move large cobbles. For example, the streambeds shifted considerably during the floods of December 1964 and January 1965, which indicates that an appreciable amount of bedload movement occurred during those runoff events.

Below the steeper gradients of the mountains, the shallow channels become wider. Some of the streams deposit much of the coarse material they carry during floods, thereby building up their channels. Although the channel-bed material of streams on the lower slopes of the mountains is much the same as that of streams at higher altitudes and with steeper gradients, it consists of increased amounts of material finer than sand. The bed sediments are derived from older alluvium through which the streams have cut their channels and from loess of the uplands.

The bedload for Walla Walla River near Touchet and for its tributaries in the lower basin area is estimated to be about 2–8 percent as much as the suspended load. The suspended sediment discharged by streams during high flow consists principally of fine materials from the land surface and from channel erosion. The amount of bedload is therefore likely to be proportionately small. During these periods of high flow, suspended-sediment concentrations consist predominantly of silt and clay with an average of only 5 percent sand. Channels of the lower basin streams are fairly deep; in fact, in some places they have been cut deeply enough to expose the underlying basalt. The bed material is composed of very fine sand to medium gravel intermixed with large quantities of silt. Large cobbles and small boulders also litter the channel beds, but they move a very short distance, if at all, during high flow, and are therefore considered permanent rather than transportable material.

SUMMARY

Suspended-sediment data obtained from 1962 to 1965 indicate that the streams in the Walla Walla River basin discharge most of their annual loads during winter. Two runoff events, resulting from rain and rapid melting of snow that eroded away the thawed upper few inches of frozen ground, produced 76 percent of the sediment discharged by the Walla Walla River near Touchet during the 3 years. The maximum daily suspended-sediment discharge of about 3.2 million tons was 28 percent of the total suspended-sediment discharged during the period of study. Average annual sediment yields in the basin ranged from 420 tons per square mile in a forested, mountainous area to more than 4,000 tons per square mile in extensively cultivated areas.

Suspended-sediment concentrations varied widely. The minimum concentration measured in many streams was less than 1 mg/l; the maximum was 316,000 mg/l for Dry Creek at Lowden.

Silt was prevalent in the suspended sediments transported by all streams in the basin. The proportion of sand to total suspended sediment was greatest for mountain streams.

Bedload in the mountain and upland streams was estimated to be 5–12 percent of the suspended load. For the Walla Walla River and its tributaries in the lower basin area, the bedload was estimated to be 2–8 percent of the suspended load.

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