UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



# POTENTIAL TRANSPORT OF SEDIMENT FROM ENLOE RESERVOIR BY THE SIMILKAMEEN AND OKANOGAN RIVERS, WASHINGTON

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Prepared in cooperation with the
State of Washington Department of Ecology

OPEN-FILE REPORT

Tacoma, Washington
1972

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# POTENTIAL TRANSPORT OF SEDIMENT FROM ENLOE RESERVOIR BY THE SIMILKAMEEN AND OKANOGAN RIVERS, WASHINGTON

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ABSTRACT

This study was undertaken to determine the probable effects on the Similkameen and Okanogan Rivers of the removal, transport, and deposition of sediment now deposited behind Enloe Dam on the Similkameen River, if the dam were removed.

Under existing conditions of sediment transport, the average annual suspended-sediment discharges at three streamflow-measuring sites are calculated to be 134,000 tons for the Similkameen River near Nighthawk, 175,000 tons for the Okanogan River near Tonasket, and 175,000 tons for the Okanogan River at Malott.

The volume of sediment in Enloe Reservoir was computed to be 1.79 million cubic yards (about 2.4 million tons). The sediment is largely sand. If the dam were removed the maximum amount of reservoir sand transportable (in addition to normal sediment discharge), under stated conditions of velocity and depth during any average 10-year period, would

range from about 17,000 to 580,000 cubic yards per year, with about 320,000 cubic yards being transported during a year of average water discharge. These volumes represent a range of 32 to less than 1 percent of the volume of sediment now deposited in the reservoir.

The reservoir deposits not carried to the mouth of the Okanogan River (at Columbia River) would be deposited largely in a 17-mile reach of the Okanogan River immediately downstream from its confluence with the Similkameen River. Deposition of the reservoir sediment would tend to reduce the capacity of the channel of the Okanogan River in this reach; also there possibly would be some long-term adjustments of the stream course to the temporary increase in the sediment load. Locally, the reduction in channel cross section probably would increase the depth of water and area of inundation during floods. Deposition of sediment in the Okanogan River channel and accompanying undesirable effects would be less severe if the dam were removed in segments over a period of several years.

If the dam is removed in segments the amount of sediment transported by the river could be monitored to evaluate (1) the timing of removal of the remaining segments of the dam, based on actual sediment-transport data, (2) the amount of sediment remaining in the reservoir, and (3) the impact of sediment deposition on channel configuration and flooding.

## INTRODUCTION

Enloe Dam and a hydroelectric-power plant were built in 1920 on the Similkameen River 5.2 miles upstream from the confluence with the Okanogan River (fig. 1). Fluvial sediment has been deposited in the reservoir until, as of 1971, the depth of water behind the 53-foot-high dam averaged less than 20 feet. Because the dam restricts the movement of salmonoid fish and has not been used for generation of power since 1958, a proposal has been made by several Federal and State agencies to remove the dam. This study was made in cooperation with the State of Washington Department of Ecology to determine the probable impact of the reservoir sediments on the Okanogan River if the dam is removed.

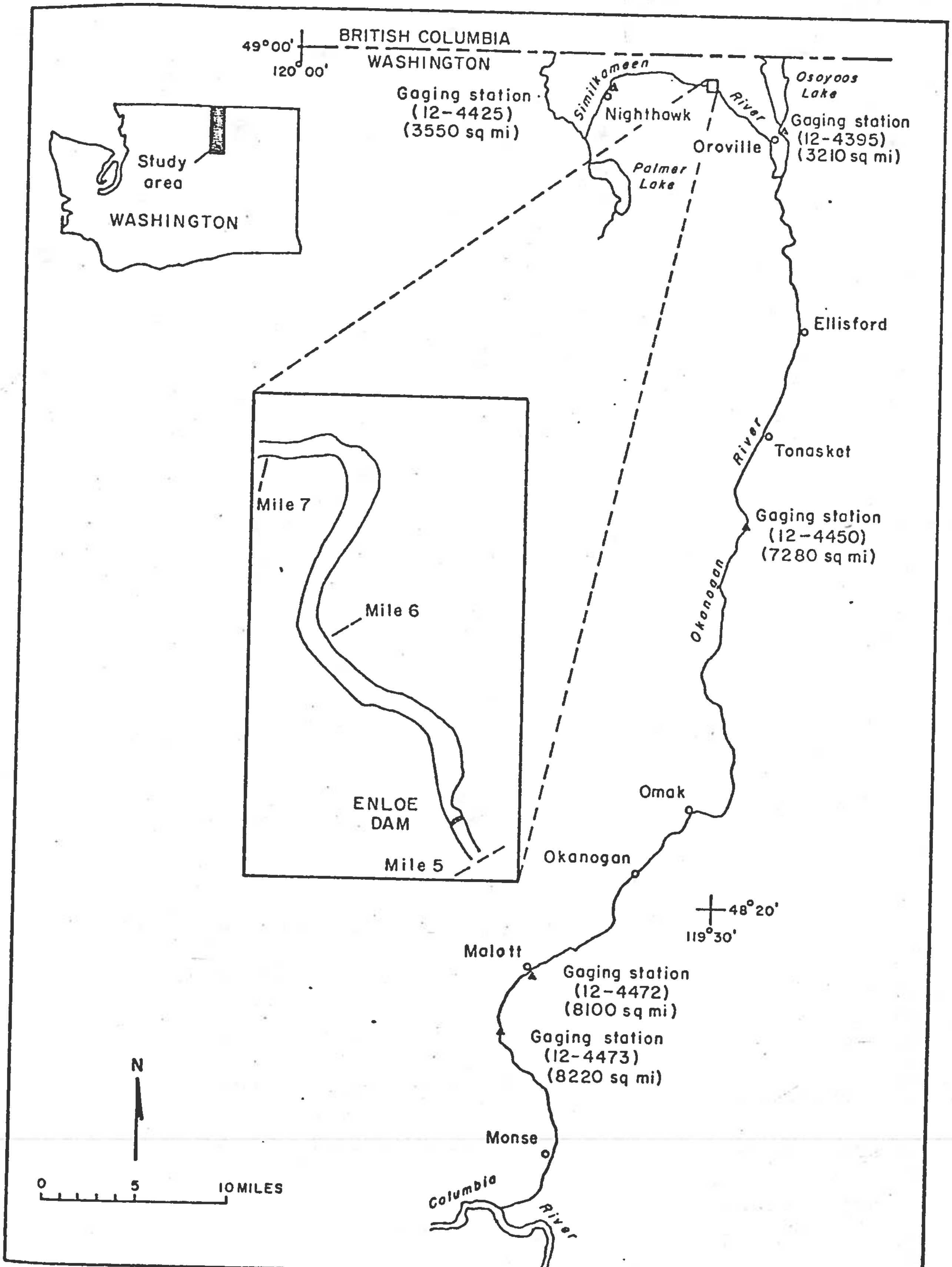


FIGURE 1.--Locations of Enloe Dam and study reach on the Similkameen and Okanogan Rivers.

## DATA COLLECTION

Prior to this study, the quantity and particle-size distribution of the sediment deposited in the reservoir was unknown. For the study, 41 cross sections were established on the reservoir (fig. 2, in pocket). Sections A through N were established by the U.S. Bureau of Reclamation November 9-12, 1971, and sections 1 through 26 were established by the U.S. Geological Survey November 28-December 1, 1971. The profile of each cross section was determined by sounding for water depth, and the configuration in reservoir profile between cross sections was determined by a recording sonic depth sounder. Recorded soundings provided continuous traces of the present reservoir profiles about 75 feet from each shoreline.

Samples for particle-size analysis were obtained from the sediment deposited at various cross sections in Enloe Reservoir and at five sites in the Okanogan River below its confluence with the Similkameen River (table 1). Core samples from the reservoir were obtained at sections where the sediment deposits were soft. At other reservoir sites samples were obtained at or near the surface of the deposits. In areas of boulders, cobbles, and gravel the particle sizes of sediments are described from visual observation. Sampling and examination of the bottom materials in the reservoir was facilitated by scuba diving.

## ANALYSIS OF DATA

The depth of sediment in the reservoir as of 1971 was determined by comparison of the 1971 profile with a longitudinal profile developed in 1934 by the U.S. Geological Survey (1938). The streambed level prior to installation of the dam was determined generally from a line drawn from the present profile of the river in bedrock at section 1 to the base of the dam (fig. 3). However, where a bedrock bottom was determined at a specific cross section the measured depth was used rather than the depth estimated from the generalized longitudinal profile. The volume of sediment entrapped in the reservoir was then determined as follows: (1) The 1971 cross-section profiles were plotted; (2) the channel profile before completion of the dam was estimated from the 1916 survey by Okanogan Valley Power Co. and from the projected pre-dam river profile shown in figure 3, and the area of sediment in each cross section was then planimetered; and (3) the volume of sediment between adjacent cross sections was calculated by using the average areas of the cross sections

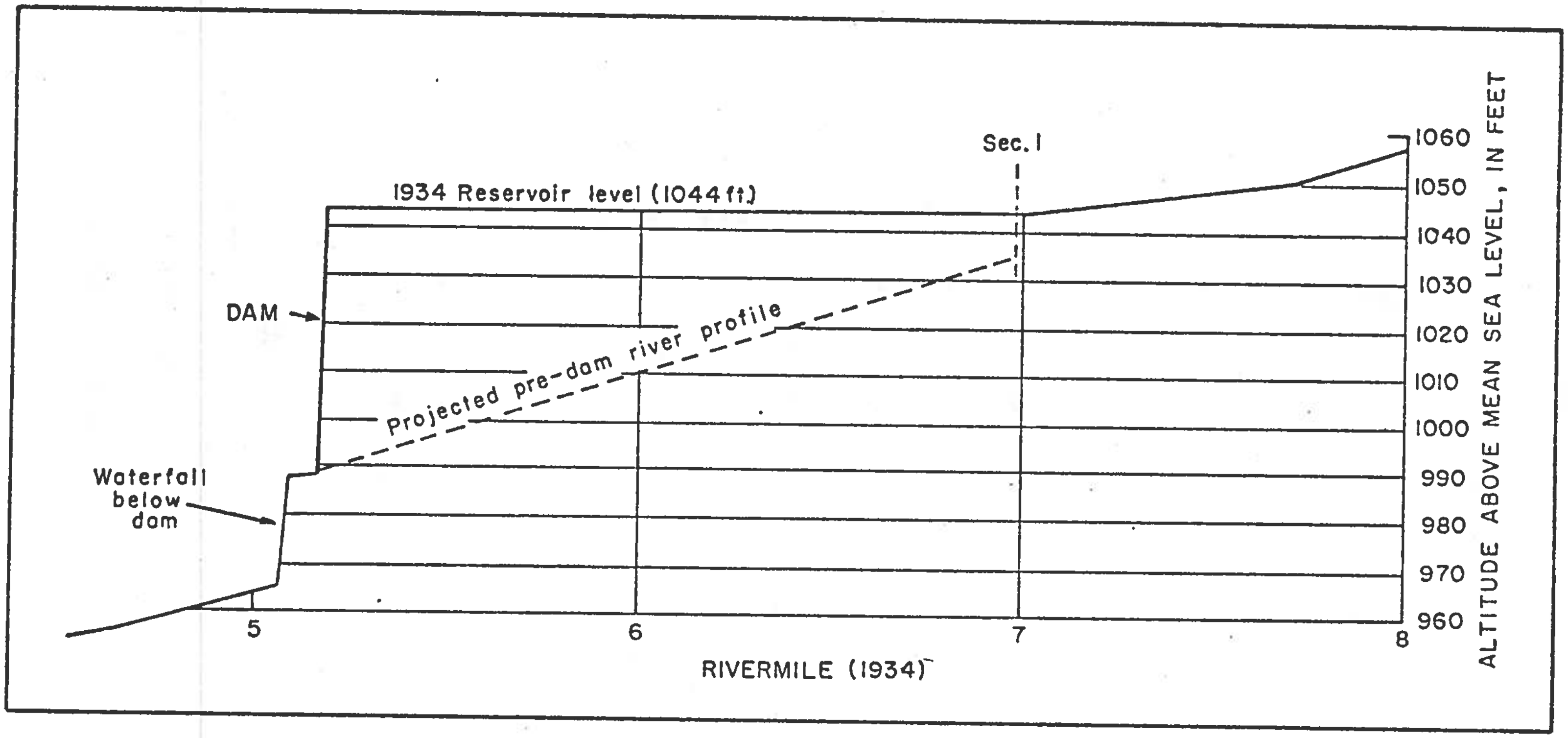


FIGURE 3.--Generalized longitudinal profile of Similkameen River in the vicinity of Enloe Dam. Adapted from a 1934 profile developed by the U.S. Geological Survey.

and the distance between cross sections measured from figure 2. By this method the volume of sediment in the reservoir was computed to be 1.79 million cubic yards.

Samples of deposited sediment generally were sieved into five particle-size classes (table 1). The streambed of the Similkameen River upstream from the reservoir consists largely of boulders and cobbles with some gravel and little sand. Very little sediment is deposited on the banks or in the channel immediately upstream from the reservoir. The bottom in the upstream part of the reservoir (upstream from sec. 4) is paved with cobbles and interstitial gravel. Some of these sediments will move downstream after the downstream part of the reservoir has been scoured but they would not immediately be carried to the streambed in the Similkameen River downstream from the dam. The particle-size distributions of sediments in the downstream part of the reservoir (downstream from sec. 9) are similar. In the area between section 4 and 9 (fig. 2) a large exposed bar, formed from deposited sediments, was calculated to contain about 48,000 cubic yards of sediment. Because the streamflow has shifted to the left side in this reach and because the particle size is large (table 1), the sediment on the right side probably would remain as a small terrace when the river level is lowered. This terrace probably would be subject to some erosion by subsequent high streamflows.

## TABLE 1.--Particle-size distribution of bed material in Enloe Reservoir and Okanogan River

| Cross section[1/] | Location | Percentage finer than indicated millimeter size | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.062 | 0.125 | 0.250 | 0.500 | 1.00 | 2.00 | 4.00 | 8.00 | 16.00 |
| | **Enloe Reservoir** | | | | | | | | | |
| 2 | | 8 | 37 | 92 | 99 | 100 | | | | |
| 6 | | -- | -- | 5 | 46 | 100 | | | | |
| 7 | Middle of slough | 1 | 3 | 9 | 70 | 90 | | | | |
| | Top of sandbar | -- | -- | 1 | 13 | 25 | 29 | 34 | 43 | 55 |
| | 25 ft left of sandbar | -- | 1 | 4 | 22 | 30 | 32 | 39 | 52 | 72 |
| 8 | Top of sandbar | -- | 2 | 21 | 88 | 99 | | | | |
| | Right ½ | 2 | 6 | 31 | 83 | 100 | | | | |
| | Left ½ | -- | 1 | 1 | 1 | 1 | 3 | 15 | 60 | 88 |
| 9 | Right ½ | 3 | 9 | 14 | 86 | 100 | | | | |
| | Left ½ | 11 | 12 | 56 | 97 | 100 | | | | |
| H | (1-ft core) | -- | 2 | 8 | 79 | 98 | | | | |
| F | Center of section | -- | -- | 6 | 64 | 92 | | | | |
| | Right 1/3 | -- | 1 | 4 | 67 | 97 | | | | |
| | Left 1/3 | 1 | 2 | 6 | 80 | 100 | | | | |
| 16 | Center of section | -- | -- | 5 | 64 | 96 | | | | |
| | Right 1/3 | 1 | 4 | 7 | 65 | 98 | | | | |
| | Left 1/3 | 1 | 2 | 13 | 30 | 96 | | | | |
| E | Right ½ | 5 | 8 | 13 | 76 | 100 | | | | |
| | Left ½ | -- | 1 | 10 | 94 | 100 | | | | |
| D | | 1 | 2 | 15 | 93 | 100 | | | | |
| 20 | 50 ft from right bank 15-ft core (0-8 ft) | 2 | 7 | 29 | 55 | 90 | | | | |
| | 50 ft from right bank 15-ft core (8-15 ft) | 1 | 2 | 14 | 40 | 91 | | | | |
| | 150 ft from right bank 6-ft core (0-3 ft) | -- | 1 | 9 | 75 | 98 | | | | |
| | 150 ft from right bank 6-ft core (3-6 ft) | -- | -- | 4 | 49 | 89 | | | | |
| | 150 ft from left bank 4-ft core | -- | -- | 6 | 70 | 89 | 92 | 92 | | |
| 21 | 50 ft from right bank (13-ft core) | -- | 1 | 9 | 58 | 92 | | | | |
| | Center of section (7-ft core) | 1 | 1 | 5 | 55 | 89 | | | | |
| | 150 ft from left bank (15-ft core) | 1 | 1 | 6 | 78 | 98 | | | | |
| | 100 ft from left bank (4-ft core) | -- | 1 | 7 | 74 | 98 | | | | |
| | **Okanogan River below confluence with Similkameen River** | | | | | | | | | |
| | 200 ft below confluence: Right bank | -- | 1 | 9 | 21 | 28 | 38 | 54 | 68 | 92 |
| | 200 ft below confluence: Left bank | -- | 1 | 5 | 21 | 27 | 32 | 41 | 55 | 86 |
| | ½ mile below confluence: Center of channel | -- | -- | 20 | 92 | 98 | 99 | | | |
| | ½ mile below confluence: 20 ft from right bank (deepest point in section) | -- | 1 | 29 | 94 | 100 | | | | |
| | 1¼ miles below confluence | 4 | 6 | 54 | 88 | 97 | 99 | | | |
| | 3¼ miles below confluence: Center of channel | -- | 2 | 9 | 65 | 97 | | | | |
| | 3¼ miles below confluence: On sandbar | -- | 1 | 15 | 96 | | | | | |
| | 5 miles below confluence | -- | 1 | 5 | 29 | 47 | 57 | 70 | 84 | 94 |
| | At Ellisford | -- | -- | 1 | 61 | 95 | | | | |

[1/] Enloe Reservoir cross sections designated by letter were established by U.S. Bureau of Reclamation, 1971; cross sections designated by number were established by U.S. Geological Survey, 1971.

The bed of the Okanogan River, from its confluence with the Similkameen River to a point about 17 miles downstream near Ellisford, consists mostly of sand particles. The sand is generally several feet in depth, but may locally attain depths of 8-10 feet. This 17-mile reach of the Okanogan River is of gentle gradient (fig. 4; about 1.5 ft per mile) and contains many meanders, with adjacent old meander channels, as compared to that of the Similkameen River (gradient of about 15 ft per mile in the lower 15 miles), which flows through a narrow rock canyon. Downstream from the 17-mile reach, the average gradient of the Okanogan River is about 2.3 feet per mile to the mouth (fig. 4), and there are only a few meanders. The bed in this downstream reach consists of cobbles and gravel where the gradient is high, and gravel and sand where the gradient is lower.

Using a method developed by Nelson (1970), a relation of suspended-sediment discharge to annual peak and mean water discharges for various stations was defined from sediment data collected periodically during 1969-71 (fig. 5). The average annual suspended-sediment discharge thus estimated for three stations are as follows:

Similkameen River near Nighthawk-- 134,000 tons
Okanogan River near Tonasket------ 175,000 tons
Okanogan River at Malott---------- 175,000 tons

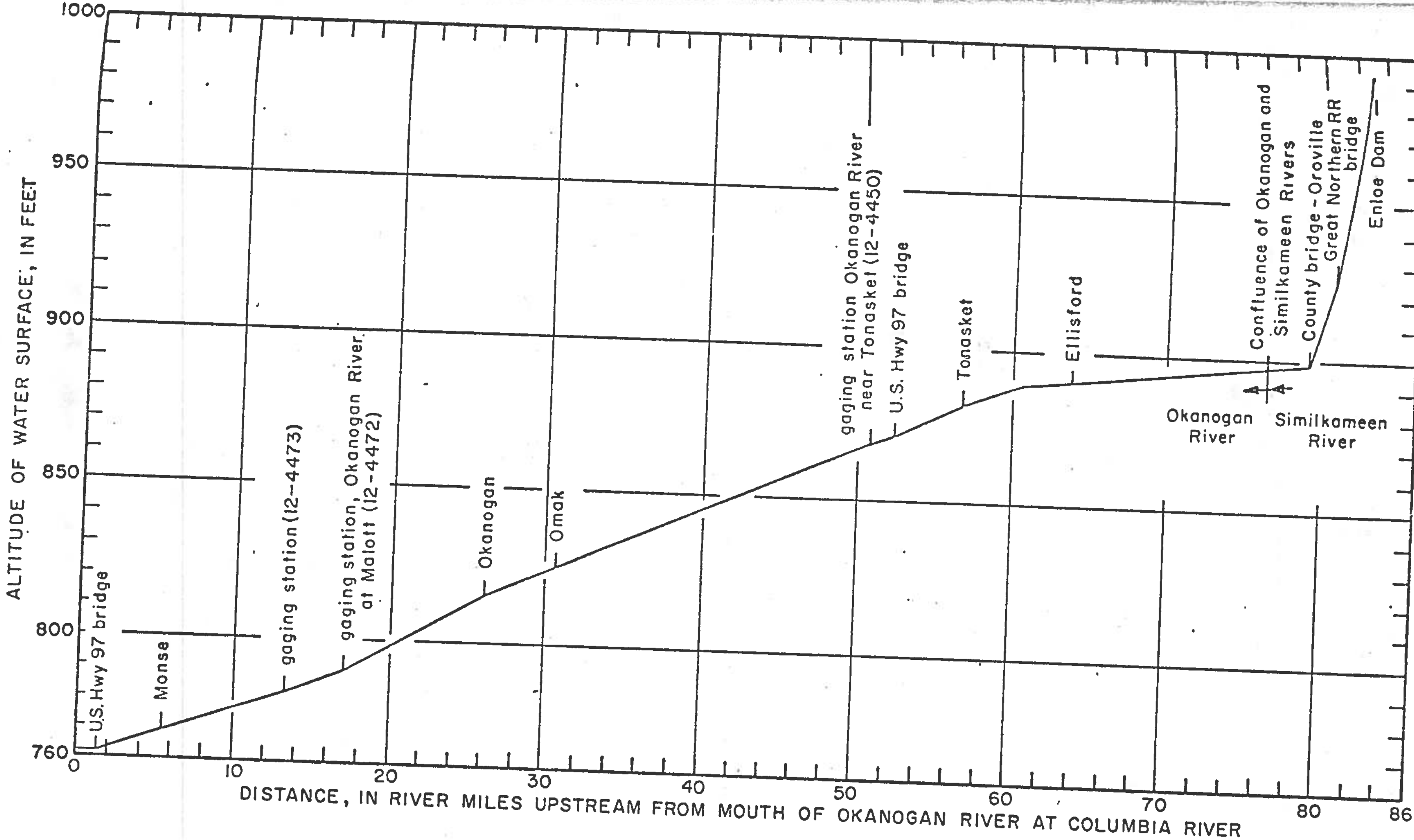


FIGURE 4.--Generalized longitudinal profile of Similkameen-Okanogan Rivers downstream from Enloe Dam. Altitude of water determined by Pacific Northwest River Basins Commission (1968).

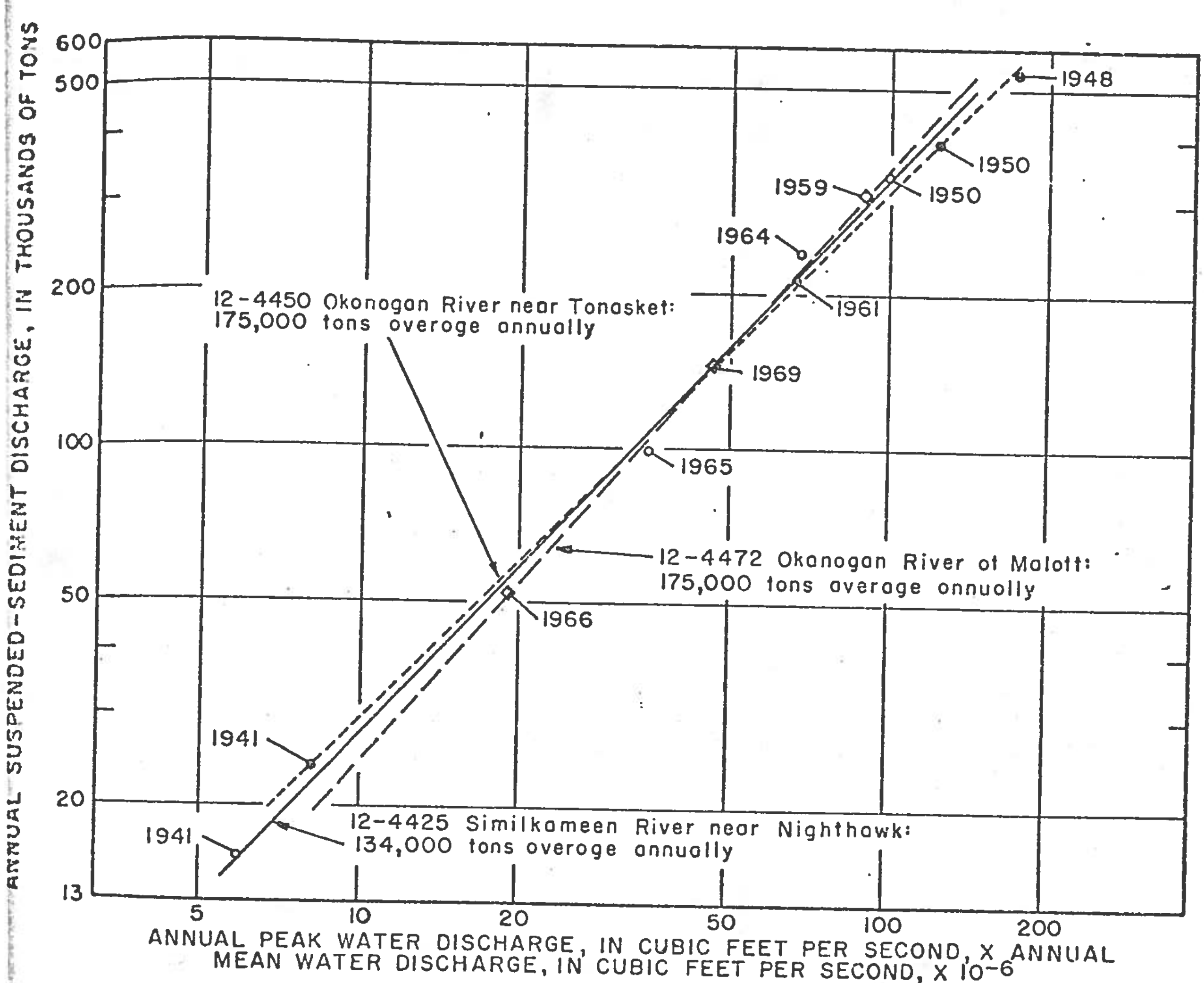


FIGURE 5.--Relations of annual suspended-sediment discharge to annual peak and mean water discharges.

Where the Okanogan River flows from Osoyoos Lake (fig. 1), it contains very little sediment but, in the reach between the confluence with the Similkameen and the gaging station near Tonasket, it has an increase in average annual discharge of suspended sediment of about 40,000 tons. This increase in sediment discharge is nearly all caused by bank and channel erosion as there is little inflow to the river in this reach except during extremely high streamflows.

Sediment discharge cannot be estimated in the 17-mile reach of the Okanogan River immediately downstream from the Similkameen because streamflow data are not available. However, data are available at two downstream gaging stations, Okanogan River near Tonasket and Okanogan River at Malott. Velocity and depth data at these two stations were used to estimate the transport of sands. Using figure 6, which is from the graph developed by Colby (1964), and under the stated conditions of velocity and depth, an estimate was made of the maximum amount of sand transportable by the streamflow through a sand channel. The estimated discharges of sand by the Okanogan River near Tonasket and at Malott are shown in figure 7. Because the channel of the Okanogan River near Tonasket is not a sand channel, the curve shown in figure 7 is not as accurate as that indicated by Colby. However,

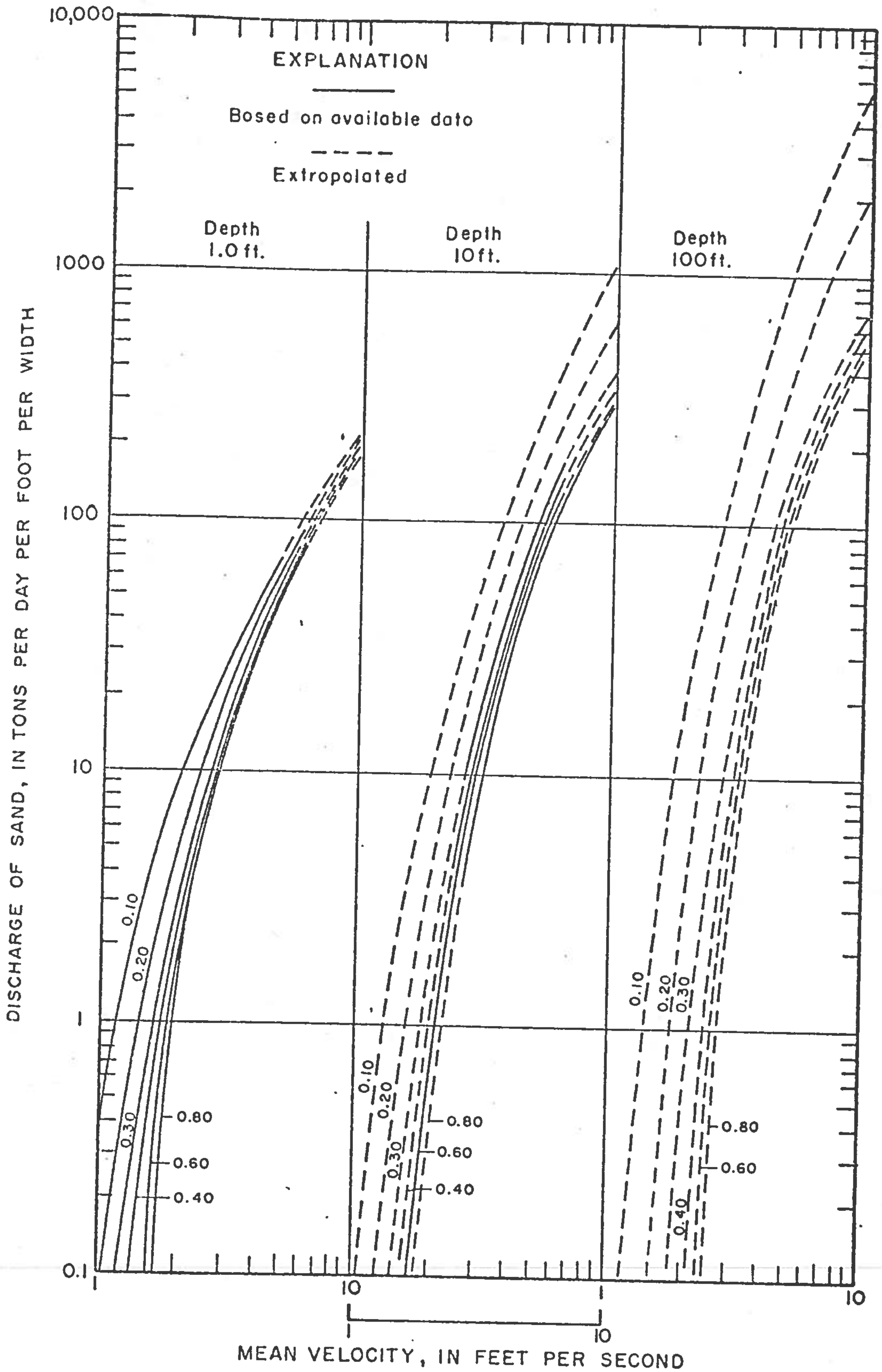


FIGURE 6.--Relationship of discharge of sands to mean velocity, for six median sizes of bed sands, three depths of flow, and a water temperature of 15.5°C (60°F), as defined by Colby (1964, p. A36).

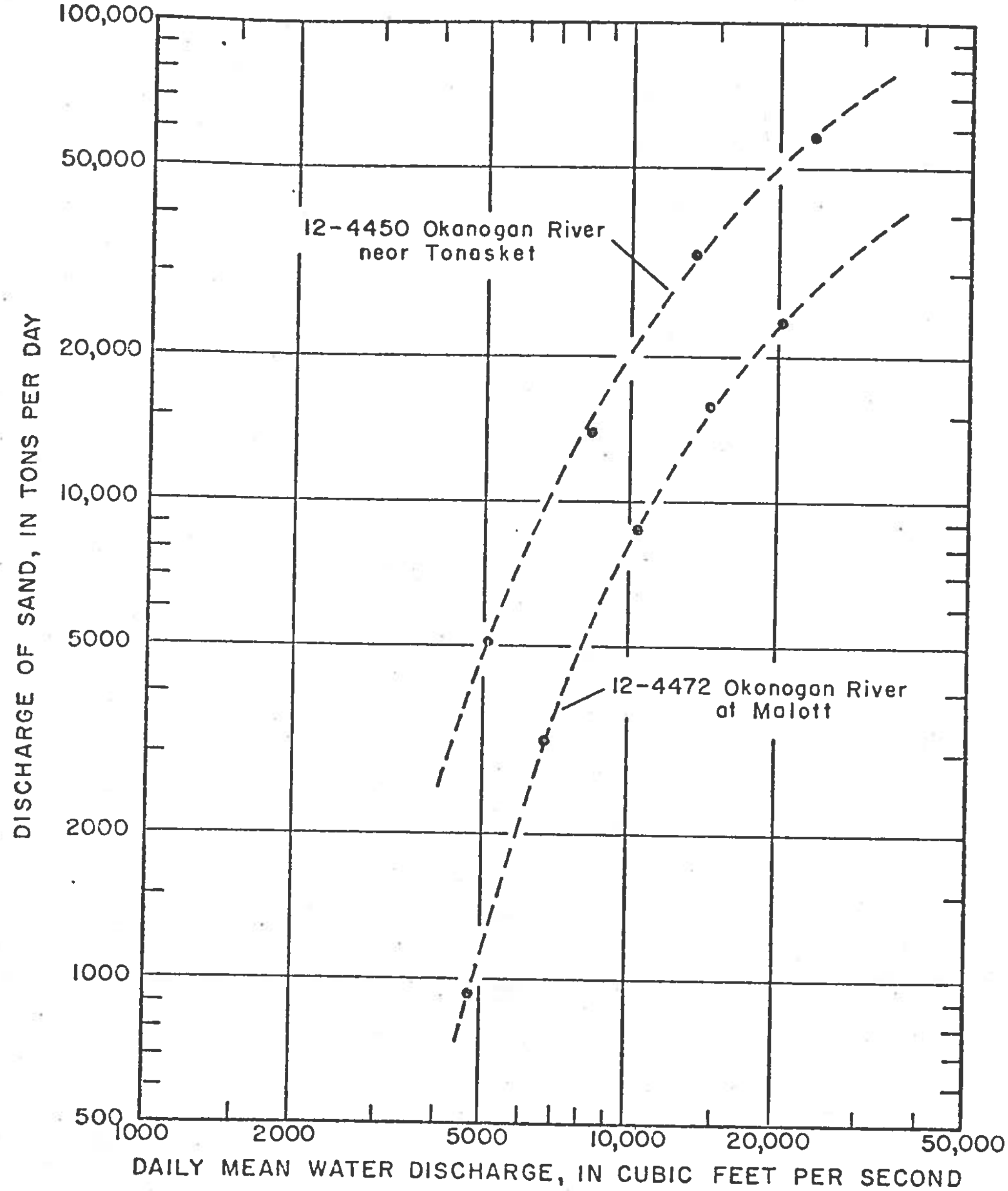


FIGURE 7.--Relation of daily mean water discharges to discharges of sand, Okanogan River near Tonasket and at Malott.

the theoretical quantity of sand transported by the Okanogan River near Tonasket is greater than the quantity available in the river.

The suspended-sediment discharge of the Okanogan River, under present hydraulic and hydrologic conditions, has been estimated as shown in figure 5, using the method given by Nelson (1970). From figure 7 and flow-duration curves, the theoretical sand discharge was estimated for Okanogan River at Malott for 5 years. Because the percentage of sand in the annual suspended-sediment discharge shown in figure 5 is unknown, an annual suspended-sediment discharge of 50 percent sand was estimated. By subtracting 50 percent of the estimated suspended-sediment discharge (see fig. 5) from the theoretical sand discharge, a relation between annual runoff and transportable reservoir sand was established (fig. 8). Because the gradient of the Okanogan River between Oroville and Tonasket is less than at Malott, probably more sand would be moved at Malott--that is, the velocity and power to transport sediment is much greater downstream from Tonasket and, therefore, little sand would remain in the downstream reaches of the river.

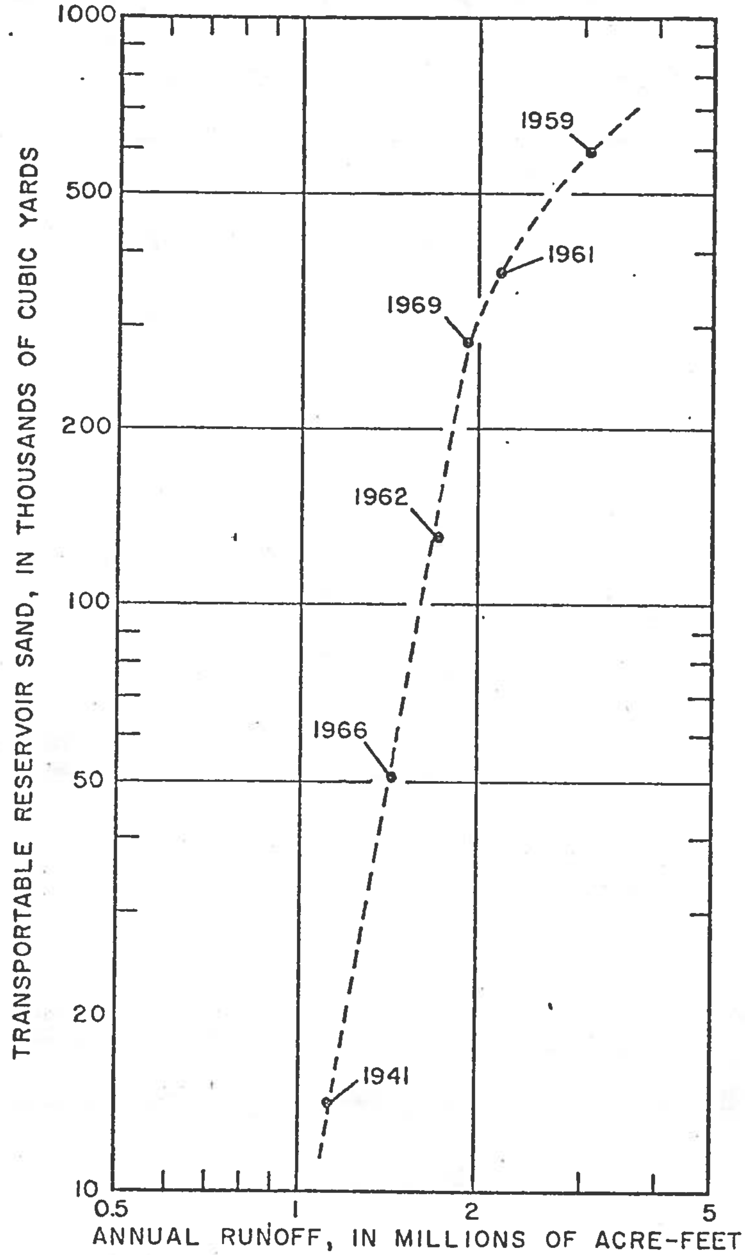


FIGURE 8.--Relation between annual runoff and transportable reservoir sand, Okanogan River at Malott.

The relation between runoff and transportable reservoir sand (fig. 8) can be used as a guide to estimate the probable transport of the sands. Analysis of the 40-year streamflow record indicates that during any 10-year period, on the average, the probable annual discharge of transportable reservoir sand (in addition to normal sediment discharge) in the Okanogan River at Malott would range from about 17,000 to 580,000 cubic yards. The estimated specific weight of the reservoir sand is 100 pounds per cubic foot. During a year of average flow the discharge of transportable reservoir sand would be about 320,000 cubic yards. Thus, if the Enloe Dam were removed in a year of average streamflow, less than 18 percent of the reservoir sediment would move completely through the Similkameen-Okanogan River system; the variation in streamflow to be expected in a 10-year period would result in removal of the reservoir's deposits ranging from less than 1 percent to 32 percent per year. During a year of occurrence of an extremely large flood, such as that of 1948, more transportable sand than that indicated by the curve in figure 8 probably would be transported. Such a flood could deposit some sand in the low areas and old oxbows on the flood plain.

The higher gradient of the Similkameen River normally produces much greater water velocities than those occurring in the Okanogan River. Thus, if the dam were removed, most of the sediment now trapped behind the dam would be carried to the confluence with the Okanogan. From there, the sediment that is not carried completely to the mouth of the Okanogan River would be deposited largely in the low-gradient 17-mile reach below the confluence, with the largest deposition probably occurring in the upstream part of that reach, near the confluence of the two rivers.

The reduction in channel cross section resulting from the deposition of sediment in the upstream part of the 17-mile reach would tend to raise the river level and, during high streamflows, to increase overbank flooding and areas of flood inundation. Also, there might be some long-term adjustments of the stream channel locally, such as new and larger sandbars or shifts in stream meanders. Such changes are virtually unpredictable in detail.

The rate of movement of the sand from the reservoir would depend largely upon the method of removal of the dam and on the streamflow prevailing at the time. The impact on the Okanogan River channel would be less severe and the potential of floods would be less if the dam were removed in segments over a period of several years. The lowering of the dam height during a period of low streamflow would decrease the probability of large quantities of sediment being carried downstream immediately. Also, there would be a greater probability of large quantities of sand--as much as one-third--remaining in the reservoir. Later, during periods of high streamflow, a considerable volume of the sand remaining in the reservoir as terraces would be moved downstream. However, such high discharges probably would transport much of the sand through the entire river system and to the Columbia River.

The amount of sediment moved by the rivers could be monitored following the removal of the first segments of the dam to determine (1) the timing of progressive removal of the remaining segments of the dam, based on actual sediment-transport data, (2) the amount of sand remaining in the reservoir, and (3) the impact of the sediment deposition on the channel configuration and flooding.

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