EROSION AND SEDIMENT YIELDS IN TWO SUBBASINS OF CONTRASTING LAND USE, RIO PUERCO, NEW MEXICO

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INTRODUCTION

The Rio Puerco basin (16,100 km^2) (fig. 1) is the largest tributary to the Rio Grande in New Mexico, draining more than 20% of its area at San Marcial (fig. 1). The Rio Puerco contributes only 4% of the Rio Grande's average annual runoff at San Marcial, from a combination of spring snow-melt and monsoonal storms, but contributes over 70% of the Rio Grande's average annual suspended-sediment load. Data compiled for world rivers by Milliman and Meade (1983) and Zhao and others (1992) show that the Rio Puerco has the fourth highest average annual suspended-sediment concentration (fig. 2).

Three major channels have cut and filled the Rio Puerco valley in the past 3,000 years (Love and Young, 1983; Love, 1986). An interesting aspect of these cut-and-fill cycles is that the Rio Puerco channel filled to the same level in the valley that it occupied prior to each cutting event. For example, by 1880 A.D. the Rio Puerco occupied the same level in the valley that it had before its incision around 600 B.P. (Love, 1986) but incision began again in 1885 (Bryan, 1925). Recent surveys indicate that the Rio Puerco is now in a cycle of aggradation (Elliott and others, 1998; Gellis and Elliott, in press). The cycle raises questions about the sediment source(s) for this filling and the process of aggradation independent of a change in the base level of the Rio Grande.

To examine sediment sources in the Rio Puerco basin, a study quantifying a sediment budget for two subbasins, Volcano Hill Wash (9.30 km^2) and Arroyo Chavez (2.28 km^2), began in 1995 and continued through 1998. The subbasins were selected on the basis of differences in geology and land use. Volcano Hill Wash drains Cenozoic basalt flows. Soil surface textures are dominantly silty clay loam. Mesa surfaces are topped with a basalt stone pavement and underlain with silty clay loam and silt loam. Eolian silt is an important component of the mesa surface sediment. Land use in the watershed is grazing and there are no dirt roads in the basin.

The Arroyo Chavez subbasin drains interbedded shales and sandstones. Soils are derived from underlying shales and sandstones of the Cretaceous Menefee Formation and from eolian silt. Surface soil textures range from silty clay loam to sandy clay loam, both containing about 30% clay. Surface clay content, found to be important to sediment yield from local test plots (Aguilar and Aldon, 1991), appears to be similar in the upland mesa surfaces of both Arroyo Chavez and Volcano Hill Wash, although Volcano Hill Wash has a denser accumulation of stony pavement. Land use in the basin is grazing and gas pipeline activity. Portions of the alluvial valley are sparsely vegetated, and gullies and soil piping are common.

Livestock numbers in both subbasins were obtained from the Bureau of Land Management in Albuquerque, New Mexico. The 930-hectare Volcano Hill subbasin is part of a larger 29,205-hectare grazing allotment. Between 1995 and 1998 the number of livestock on the allotment ranged from 0 to 682. The average number of livestock over this time period was 293 or 1.0 animal per 100 hectares. The grazing allotment received a grazing management award in the early 1990's. The 228-hectare Arroyo Chavez subbasin is part of a larger 4,456-hectare grazing allotment. The number of livestock on the allotment from 1995 to 1998 was steady at 325 or 7.3 animals per 100 hectares.

This paper describes preliminary results of erosion and sediment yields for the Volcano Hill Wash and Arroyo Chavez subbasins used to develop a preliminary sediment budget on sediment sources and sinks.

Figure 1. Location of Volcano Hill Wash and Arroyo Chavez basin in the Rio Puerco basin.

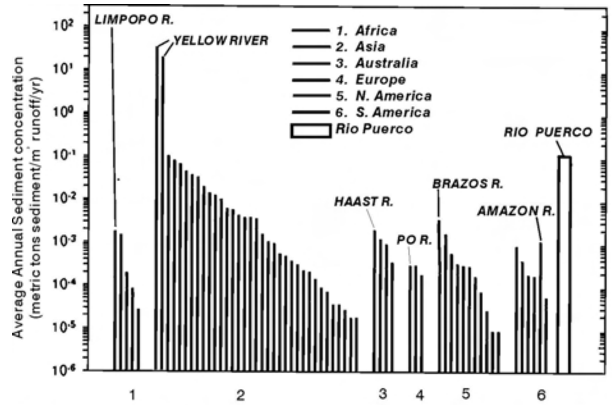

Figure 2. Average annual suspended-sedment concentrations of world rivers and the Rio Puerco, N. Mex (Milliman and Meade, 1983; Zhao and others, 1992).

METHODS

A sediment budget for a drainage basin is based on the amount of sediment leaving that basin and an accounting of the sources of that sediment (Leopold and others, 1966; Dietrich and Dunne, 1978; Swanson and others, 1982). An essential feature of a sediment budget is to define transport processes, storage elements, and linkages between the two (Swanson and others, 1982). In the Volcano Hill Wash basin, the sediment budget was generalized for five geomorphic surfaces: mesa, steep colluvial slopes, alluvium/colluvium, eolian/alluvium, and alluvium. In the Arroyo Chavez basin, seven geomorphic surfaces were identified: mesa, steep colluvial slopes, moderate sloping hillslopes, gently sloping hillslopes, alluvial fans, well-vegetated alluvium, and sparsely vegetated alluvium. The geomorphic surfaces for both basins were delineated from color aerial photographs (1:24,000 scale) and entered into a geographical information system (GIS). The GIS was used to determine the area of each geomorphic surface in each subbasin.

Both subbasins were instrumented at the basin outlets with a streamflow-gaging station and an automatic suspended-sediment sampler. Rainfall was measured at 5 and 15 minute increments at each gaging station and various areas in each basin (fig. 3). Deposition from upslope erosion was measured using sediment traps and the volume of sediment deposited behind small dams. Sediment trap design was based on a modified Gerlach Trough (Gerlach, 1967; Gellis, 1998). The traps were 68 to 85 cm long and 13 cm wide. The traps were installed flush to the ground surface with the opening parallel to the slope contour. One to three 1.27 cm diameter holes were drilled into the side of the trap and were connected by tubing to 18.9 liter collection buckets. The contributing area to each trap was bounded with metal edging.

Samples of runoff and sediment were collected in the buckets after each rainfall event. Buckets were weighed in the laboratory to determine total sediment and water (runoff). The samples were stored in the laboratory for 1 month to allow the suspended sediment to settle. Water was then decanted from the buckets and the sediment was oven dried for 24 hours at 98 ^{0}C. Samples of the water were taken to determine the amount of sediment still in suspension.

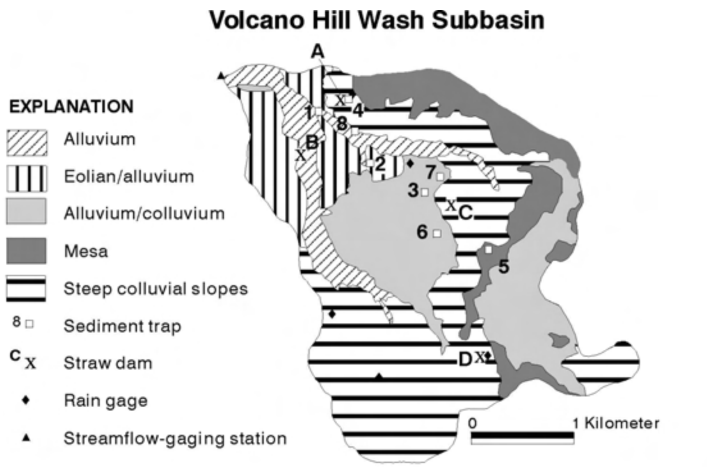

Figure 3. (A) Geomorphic surface for Volcano Hill Wash including sediment traps, straw dams, rain gages, and streamflow-gaging station.

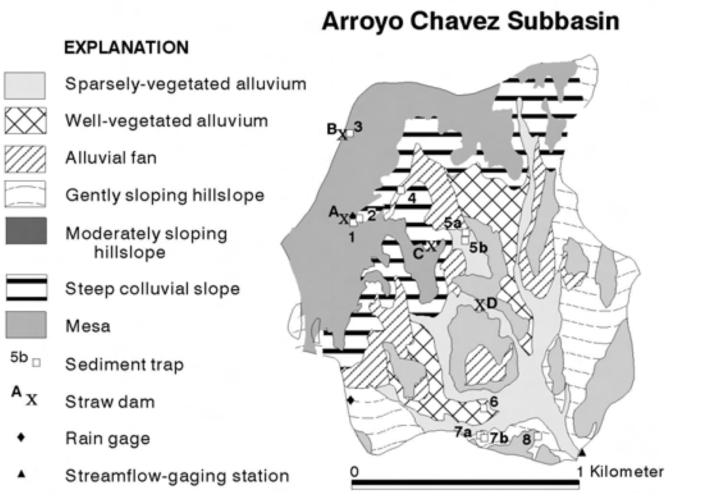

Figure 3. (B) Geomorphic surface for Arroyo Chavez including sediment traps, straw dams, rain gages, and streamflow-gaging station.

Four straw dams in each subbasin were constructed in first- and second-order channels. A notch approximately 1 m deep was dug in the channel and filled with straw bales. The bales were reinforced into the ground with steel rebar, and large rocks were piled on the downstream side, next to the straw bales to prevent the bales from toppling. The sediment pool on the upstream side of the straw bales was dug out, and four to six cross sections were monumented in the pool using steel rebar on either end. The cross sections were surveyed periodically to quantify sediment deposition.

Eight sediment traps were installed in the Volcano Hill Wash subbasin and 10 in the Arroyo Chavez subbasin (fig. 3). The contributing area to the sediment traps and the straw dams were surveyed using a total station. Drainage areas for the sediment traps ranged from 0.76 to 37 m^2; the straw dams ranged from 405 to 5,170 m^2. Contributing areas for two traps in the Arroyo Chavez subbasin, 5b and 7b (fig. 3B), were purposefully constructed at a small area, 0.76 and 1.7 m^2, respectively, to determine the effect of contributing area on sediment yield. Runoff was not recorded in these traps.

RESULTS

Streamflow and Suspended Sediment

Rainfall, runoff, and suspended sediment measured at the gaging stations are presented for water years 1996-98. A water year is October 1 of the previous year to September 30 of the current year. Volcano Hill Wash and Arroyo Chavez are ephemeral channels. Between October 1, 1995, and September 30, 1998, 31 runoff events were recorded at Volcano Hill Wash and 41 events were recorded at Arroyo Chavez.

The average annual sediment yield, water years 1996-98, for the Volcano Hill Wash subbasin was 405 tonnes/km^2/yr and for Arroyo Chavez subbasin was 981 tonnes/km^2/yr. By summing runoff and suspended-sediment load for the 3 years of collection, the total discharge-weighted sediment concentration for Volcano Hill Wash is 34,000 mg/L and for the Arroyo Chavez was 92,500 mg/L. Discharge-weighted sediment concentration is an informative way to look at sediment transport because it normalizes total sediment transport by the total amount of runoff transporting the sediment (Guy, 1964).

Dams and Sediment Traps

The sediment traps for Volcano Hill Wash operated between June 6, 1996, and August 12, 1998. The sediment traps for Arroyo Chavez operated between June 13, 1996, and October 2, 1998, except for traps 5b and 7b, which operated between March 5, 1997, and October 2, 1998. To calculate an annual sediment yield for each trap (kg/m^2/365 days), the total sediment load in grams (g), was divided by the total number of days the trap was operating and multiplied by 365 days. The volume-weighted sediment concentration, in parts per million (ppm), for each trap was calculated by dividing the sum of the dry weight of sediment (g) for the period of collection, by the weight of sediment and water (g), and multiplied by 10^6.

The highest sediment yield and sediment concentrations recorded from the sediment traps and dams in both subbasins occur on alluvium (Table 1). Based on the sediment trap results for Volcano Hill Wash, the highest sediment yield was 0.975 kg/m^2/365 days and the highest volume-weighted sediment concentration was 25,300 ppm for the alluvium (Table 1). Based on sediment trap results for Arroyo Chavez, the highest sediment yield was 3.35 kg/m^2/365 days and the highest volume-weighted sediment concentration was 140,000 ppm for the sparsely vegetated alluvium (Table 1). In both basins the alluvial valley floor is grazed. In the Arroyo Chavez basin the portion of the alluvial valley floor that is grazed is sparsely vegetated is a gullied, soil-piped surface with many headcuts.

The lowest sediment yield recorded from the traps at Volcano Hill Wash was 0.046 kg/m^2/365 days, recorded on a steep colluvial slope (Table 1). The lowest sediment yield for Arroyo Chavez was 0.139 kg/m^2/365 days, recorded for the well-vegetated alluvium (Table 1). The lowest volume-weighted sediment concentration recorded from the traps at Volcano Hill Wash was 4,170 ppm recorded on the eolian/alluvium surface (Table 1). The lowest volume-weighted sediment concentration recorded from the traps at Arroyo Chavez was 13,800 ppm on steep colluvial slopes (Table 1).

Sediment Budget

The sediment budgets are based on the time period that the gaging stations and sediment traps operated in each subbasin. The straw dams operated over a different time period than the sediment traps. To normalize for this difference, sediment deposition in the dams was divided by the number of days in operation and multiplied by the number of days the sediment traps were operating. The traps operated for 797 days in Volcano Hill Wash (June 6, 1996, to August 12, 1998) and 841 days in Arroyo Chavez (June 13, 1996, to October 2, 1998). Two traps in Arroyo Chavez, 5b and 7b, were installed later in the project, and sediment collected at these traps was normalized in the same manner as the straw dams. The sediment yield for each geomorphic surface was calculated using the results from the sediment traps and straw dams and averaged. The average sediment yield for each geomorphic surface was multiplied by the area of each geomorphic surface to obtain total erosion in kg.

For Volcano Hill Wash the highest average erosion rate for the five geomorphic surfaces occurred on alluvium (1.145 kg/m^2), followed by mesa (0.742 kg/m^2), alluvium/colluvium (0.397 kg/m^2), steep colluvial slopes (0.166 kg/m^2), and eolian/alluvium (0.145 kg/m^2) (fig. 4; Table 2). In the subbasin, 3,630,000 kg of sediment was eroded from the landscape and 11,300,000 kg of sediment was transported out of the basin (Table 2A). Thus, 7,670,000 kg (68%) of sediment was transported out of the basin that cannot be accounted for by measured upland erosion.

For Arroyo Chavez the highest average erosion rate for the seven geomorphic surfaces occurred on sparsely vegetated alluvium (6.53 kg/m^2), followed by alluvial fan (2.16 kg/m^2), steep colluvial slopes (1.37 kg/m^2), mesa (0.899 kg/m^2), gently sloping hillslopes (0.419 kg/m^2), moderately sloping hillslopes (0.334 kg/m^2), and well-vegetated alluvium (0.321 kg/m^2) (fig. 4; Table 2). More than 3,590,000 kg of sediment was eroded from the landscape and 6,710,000 kg of sediment was transported out of the basin (Table 2B). Thus, 3,120,000 kg (46%) of sediment was transported out of the basin that cannot be accounted for by measured upland erosion.

The unaccounted sediment in both subbasins may be contributions of sediment from bed and bank erosion or from important source areas of upland sediment (such as landslides noted on steep slopes in Volcano Hill Wash) that were not measured. The amount of sediment that may be originating from sources not measured in Volcano Hill Wash is 68%. The amount of sediment that may be originating from sources not measured in Arroyo Chavez is 46%. In addition, the amount of sediment removed from both subbasins is based on suspended-sediment load computations, which do not include bedload. If bedload were measured, the amount of sediment from unreported sources would increase. Kondolf and Matthews (1991) reported that the unmeasured residuals in sediment budgets can range from 1 to more than 100%.

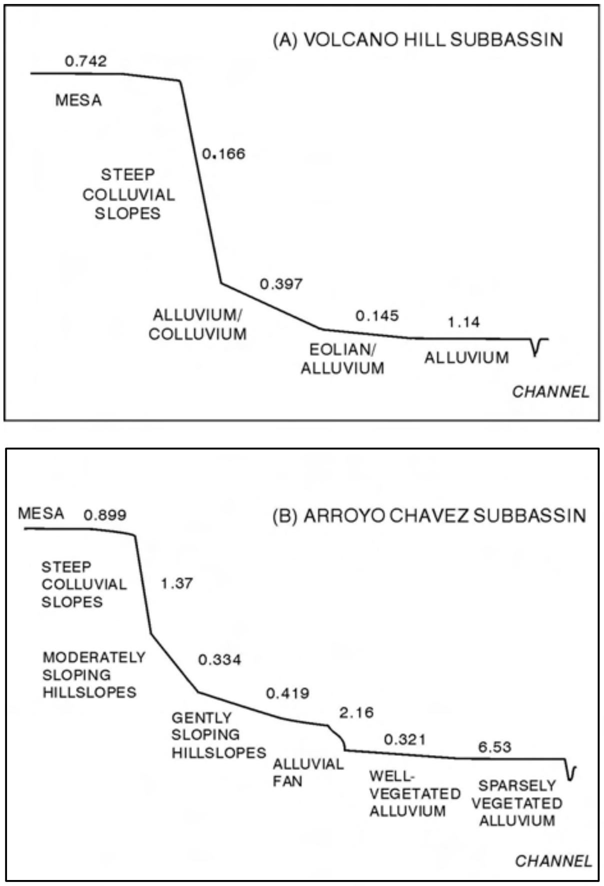

Figure 4. Erosion rates, in kilograms per square meter, on the geomorphic surfaces defined for the sediment budget in (a) Volcano Hill Wash subbasin and (b) Arroyo Chavez subbasin.

DISCUSSION

Erosion was measured in two subbasins of the Rio Puerco, each having different geology and land use. Erosion and sediment yields are higher in Arroyo Chavez subbasin compared to Volcano Hill Wash subbasin. Because geology and land use are different, these basins may represent end-members in the larger Rio Puerco drainage. The average annual sediment yield measured at the outlet of Arroyo Chavez subbasin (981 tonnes/km^2 /yr) is more than twice the sediment yield of Volcano Hill Wash (405 tonnes/km^2 /yr). The total discharge-weighted sediment concentration for the period of study at Arroyo Chavez (92,500 mg/L) was more than twice the concentration at Volcano Hill Wash (34,000 mg/L). By averaging the sediment yields and volume-weighted sediment concentrations from all sediment traps, the sediment yield for Arroyo Chavez (0.683 kg/m^2 /365 days) is more than twice the average sediment yield for all traps at Volcano Hill Wash (0.274 kg/m^2 /365 days) and the volume-weighted sediment concentration averaged for all traps at Arroyo Chavez (49,300 ppm) is more than three times greater than that at Volcano Hill Wash (11,500 ppm). The Volcano Hill Wash subbasin drains Cenozoic basalt flows with a silty eolian mantle that is protected by a basalt stone pavement.

Grazing is commonly cited as a contributor to increased erosion rates. The Arroyo Chavez subbasin is part of a grazing allotment that has livestock per 100 hectares seven times higher than Volcano Hill Wash. Visually most portions of the basin support a healthy vegetative cover. In both subbasins the major contribution of sediment is from the alluvial-valley floor. Grazing is expected to have a major effect along the valley floor where animals seek water and shade, thus grazing may play a role in differences in erosion. Other land-use factors that may be contributing to higher erosion and sediment yield in Arroyo Chavez are gas pipeline activity, including dirt roads, and trenching for the pipeline. Visually the basin is gullied with many areas of bare ground.

There are, however, observations that argue against the role of grazing as the sole factor influencing rates of erosion.

1. Storage of sediment in the alluvial valleys predates the intense grazing of the late 19th century. Alluvium in Arroyo Chavez and in the Rio Puerco yields radiocarbon dates greater than 5,000 B.P. (Pavich and others, 1997).

2. Differences in basin sediment yields are simply not due to differences in land use and upland erosion. The proportion of sediment exported from Volcano Hill Wash does not decrease in proportion to decreases in upland erosion. This may imply that sediment is being extracted from storage as upland sources are depleted and the channel attempts to maintain an equilibrium condition of sediment transport. Similar occurrences were noted for channels in the eastern United States as they maintained a stable sediment transport rate over time while upland erosion rates decreased as a result of soil conservation (Trimble and Lund, 1982).

Unraveling the complex responses of sediment transport to rainfall requires study periods longer than are possible by instrumental methods. The instrumented records do allow us to conclude, however, that erosion and sediment yields differ markedly due to geologic and land-use factors.

Table 1. Summary of data from sediment traps and straw dams for (A) Volcano Hill Wash and (B) Arroyo Chavez subbasins.

(A) Volcano Hill Wash

Sediment trap	Geomorphic surface	Number of events	Drainage area (m^2)	Runoff (g)	Sediment load (g)	Rainfall (mm)	Sediment yield (kg/m^2/365 days)	Volume-weighted sediment concentration (ppm)
1	Alluvium	39	7.2	547,240	15,220	526	0.975	25,300
2	Eolian/alluvium	28	8.3	289,820	1,210	526	0.067	4,170
3	Alluvium/colluvium	35	9.7	335,620	4,560	572	0.215	13,600
4	Steep colluvial slopes	33	4.8	64,560	490	604	0.046	7,500
5	Mesa	35	5.8	292,000	4,340	634	0.340	14,800
6	Alluvium/colluvium	34	6.6	249,550	1,830	572	0.128	7,300
7	Alluvium/colluvium	38	4.7	302,200	2,070	572	0.202	6,900
8	Alluvium	35	6.4	245,000	3,080	526	0.220	12,600

Straw dam	Days in operation	Geomorphic surface	Drainage area (m^2)	Sediment deposition (kg)	Sediment yield (kg/m^2/365 days)
A	1224	Steep colluvial slopes	5,000	1,560	0.093
B	1202	Alluvium	422	530	0.378
C	1203	Steep colluvial slopes	5,170	2,300	0.135
D	1224	Steep colluvial slopes	2,510	250	0.30

(B) Arroyo Chavez

Sediment trap	Geomorphic surface	Number of events	Drainage Area (m^2)	Runoff (g)	Sediment load (g)	Rainfall (mm)	Sediment yield (kg/m^2/365) days	Volume-weighted sediment concentration (ppm)
1	Mesa	46	37	692,390	19,000	688	0.228	27,800
2	Steep colluvial slopes	39	7.9	232,590	3,200	688	0.175	13,800
3	Mesa	47	35	487,880	29,000	701	0.353	58,900
4	Alluvial fan	52	27	726,130	59,000	688	0.937	81,400
5a	Sparsely vegetated alluvium	58	27	1,509,500	210,000	790	3.35	140,000
5b	Sparsely vegetated alluvium	34	0.76		1,300	602	1.06	
6	Well-vegetated alluvium	31	6.4	64,450	2,000	917	0.139	31,800
7a	Gently sloping hillslopes	46	28	807,660	12,000	894	0.198	15,600

7b	Gently sloping hillslopes	29	1.7		660	790	0.243	
8	Moderately sloping hillslopes	43	22	286,380	7,300	1,016	0.145	25,400

Straw dam	Days in operation	Geomorphic surface	Drainage area (m^2)	Sediment deposition (kg)	Sediment yield (kg/m^2/365 days)
A	1207	Steep colluvial slopes	2,280	2,760	0.367
B	1171	Mesa	1,420	2,690	0.590
C	1172	Steep colluvial slopes	541	2,150	1.24
D	931	Sparsely vegetated alluvium	405	4,570	4.43

Table 2. Sediment budget for (A) Volcano Hill Wash and (B) Arroyo Chavez.

(A) Volcano Hill Wash (June 6, 1996, to August 12, 1998)

	Streamflow-gaging station	Mesa	Eolian/alluvium	Alluvium/colluvium	Steep colluvial slopes	Alluvium
Sediment yield, kg/m^2	1.22	0.742	0.145	0.397	0.166	1.145
Area, m^2	9,299,309	1,260,737	991,207	2,303,337	3,878,763	865,264
Total erosion, kg	11,300,000	935,000	144,000	914,000	644,000	991,000

Total upland erosion = 3,630,000 kg
Total suspended-sediment transport = 11,300,000 kg
Difference = -7,670,000 kg

(B) Arroyo Chavez (June 13 1996, to October 2, 1998)

	Streamflow-gaging Station	Mesa	Alluvial fan	Sparsely vegetated alluvium	Well-vegetated alluvium	Gently sloping hillslopes	Moderately sloping hillslopes	Steep colluvial slopes
Sediment yield, kg/m^2	2.94	0.899	2.16	6.53	0.321	0.419	0.334	1.37
Area, m^2	2,280,679	592,593	235,198	275,445	182,117	335,654	341,173	318,499
Total erosion, kg	6,710,000	533,000	508,000	1,800,000	58,500	141,000	114,000	436,000

Total upland erosion = 3,590,000 kg
Total suspended-sediment transport = 6,710,000 kg
\ Difference = -3,120,000 kg

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