TECHNICAL SERVICE CENTER
Denver, Colorado

LITERATURE REVIEW OF THE HYDRAULIC AND GEOMORPHIC RELATIONSHIPS OF THE BIGHORN RIVER FISHERIES STUDY, MONTANA

Prepared by

Cassie C. Klumpp
Hydraulic Engineer
Sedimentation and River Hydraulics Group
WATER RESOURCES SERVICES

U.S. Department of the Interior
Bureau of Reclamation

May 1997

Literature Review of the Hydraulic and Geomorphic Relationships of the Bighorn River Fisheries Study, Montana

Introduction

The Montana Fish, Wildlife, and Parks (MFWP), the U. S. Bureau of Reclamation and the Western Area Power Administration are working together to study changes in the Bighorn River. Since the closure of Yellowtail Dam, the Bighorn River has become a trout stream of national significance and has been called "the world's finest trout stream". The purpose of this study is to document hydraulic and geomorphic changes in the river, any adverse changes in the river that may affect the trout fishery, and to help propose changes in the river system to maintain the high quality trout stream.

The MFWP developed an Upper Bighorn River Fisheries Management Plan (1987)_to help meet the demand for a high-quality wild trout fishing experience. As part of the plan, photos were made at the designated sites to provide visual documentation of river flow changes related to side channel dewatering. The MFWP created a series of test sites to document changes in island side channels (Figure 1). The sites (Figure 1) where the photos were taken ranged from the Afterbay Dam downstream to Saint (St.) Xavier Bridge (16 river miles). From the observations and ranges of flow in the river, the MFWP made recommendations about the volume of water in the river necessary to maintain and enhance trout fisheries. Absolute minimum flows during drought periods were 1500 cfs (cubic feet per second), 2200 cfs during normal periods and 2500 cfs for the first 10 river miles. The MWFP has noticed changes in stream morphology at two sampling sections since initiation of the plan. These include a decrease in the flow in side channel riffles since initiation of the plan.

This literature review of existing hydraulic and sediment data has been prepared to document the problems that have been noted in the Bighorn River since adoption of the Bighorn River Management Plan.

Basin Description

The Bighorn River and its tributaries drain an area of 19,000-sq. mi. (square miles) in Wyoming and 3,900 sq. mi. in south central Montana. The headwaters of the Bighorn start in Wyoming and join to form the Wind River. As the Wind River leaves Wind River Canyon, it becomes the Bighorn River and flows northward into the Bighorn Basin. Principal tributaries of this reach include the Greybull and Shoshone Rivers. Principal reservoirs include the Boysen Reservoir on the Wind River (in Wind River Canyon) and Buffalo Bill Dam and Reservoir on the Shoshone River. Boysen Reservoir was completed in 1951 and flows have been reduced to between 4,000 and 17,000 cfs.

Yellowtail and Afterbay Dams are located in south-central Montana on the Bighorn River and are within the Crow Indian Reservation, approximately 43 air miles from Hardin, Montana (Figure 2). The Yellowtail Dam was built between 1963 and 1966. The dam is 525 ft high and 1,450 ft long. Principal uses of Yellowtail Dam include power generation, irrigation, flood control, and fish and wildlife enhancement. The power plant is operated for peaking power (USBR, 1991 and USBR, 1994).

The after bay dam, which serves as a re-regulating structure, is 72 ft high. The spillway has a capacity of 20,000 cfs and is 160 ft wide with five radial gates and a sluiceway controlled by three slides gates. The sluiceway can release flow 22 feet below the radial gates.

Perennial streams that are tributary to the Bighorn include Beauvais, Rotten Grass, Soap, and the Little Bighorn River (Figure 2). The Little Bighorn River had an average discharge of 240 cfs during the period of record and spring floods ranging from 1,000 to 4,500 to cfs. The southern most diversion, just outside of the canyon, is the Big Horn Canal, with a headgate capacity of 720 cfs. The Two Leggins Canal, with a capacity of 400 cfs, diverts water from the Bighorn River at the mouth of Two Leggins Creek, 61 miles south of Hardin (Hamilton and Paulson, 1968).

Basin Geology

The Bighorn River is composed of tertiary sediment deposits including gravel. The Bighorn River cut the canyon to a depth of more than 2000 ft. and a width of 3/4 mile in its ancestral days. The lower Bighorn Valley is composed of six steplike broad, alluvial terraces. The river incised a channel through the 20 ft. to 40 ft. thick deposits of sandy gravel and the underlying shale. It then stopped downcutting and began cutting laterally and deposited a sandy gravel material in its newly established flood plain (Hamilton and Paulson, 1968).

Current drill logs show that gravel deposits, ranging in thickness from 10 ft to 30 ft,underlie the present river. Sandy gravel is exposed 100-150 ft. above the river along undercut bluffs and at numerous small gravel pits. These sandy gravel deposits are composed of thick beds of poorly sorted sand, cobble, and gravel and are interbedded with well-sorted sand. The gravel is rounded particles of basalt, andesite, granite, chert, quartzite, limestone, and dolomite (Hamilton and Paulson, 1968).

Strong winds have removed the silt, clay, and fine sand from the terrace surfaces leaving a pebbly desert pavement. This is interspersed with a layer of alluvial and colluvial gravel. Thin deposits of silty gravel underlie the floodplains of tributary streams. This gravel is mantled with deposits of silt or silty clay that are thicker than the underlying gravel. Tributary flash floods transport a heavy load of this fine material and deposit it at the mouths of the creeks as alluvial fans. Numerous alluvial fans created by steep-gradient creeks, draining badlands east of the valley, have forced the Bighorn River below Afterbay Dam to migrate slowly westward to its present position. (Hamilton and Paulson, 1968)

Basin Hydrolgy

Flood frequency analysis of annual peak discharges before and after construction of Yellowtail Dam are summarized in Table 1. Yellowtail Dam reduced the magnitude of flooding on the Bighorn River at St Xavier by about 50 percent for the 5-, 10-, 25-, 50-, and 100-year flood. Flood flows after completion of Yellowtail Dam for the 50- and 100-year flood increased by about 50 percent for the Little Bighorn River near Hardin, Montana, and the Bighorn River at Bighorn, Montana, because of the large flood that was recorded on the Little Bighorn River in 1978. Flood flows on the Little Bighorn River increased because of natural changes in hydrology, not Yellowtail Dam.

Table 1 Flood Frequency Analysis Before and After Construction of Yellowtail Dam

Before Construction[1]

Frequency (years)	Bighorn R. near. St. Xavier (cfs) (1934-1966)	Bighorn R. at Bighorn, Mt. (cfs) (1946-1966)	Little Bighorn R. near Hardin, Mt. (cfs) (1953-1966)
5	21,900	19,200	3,110
10	26,300	24,100	4,280
25	31,800	30,800	5,980
50	35,760	36,100	7,380
100	39,600	41,600	8,900

After Construction[1]

Frequency (years)	Bighorn R. near. St. Xavier, Mt. (cfs) (1967-1995)	Bighorn R. at Bighorn, Mt. (cfs) (1967-1995)	Little Bighorn R. near Hardin, Mt. (cfs) (1967-1995)
5	11,400	19,510	1,310
10	14,000	26,618	4,764
25	17,369	37,867	7,269
50	19,877	48,117	9,734
100	22,401	60,169	12,824

[1]USGS Watstore Computer Database, Reston, Va.

The average monthly discharge for the months of October through February is about the same for both the Yellowstone River at Billings, Mt. and the Bighorn River at Bighorn, Mt. The Bighorn River is providing about one-half of the flow to the Yellowstone River below their confluence. During the month of March, however, the flow in the Bighorn River is sometimes greater than the Yellowstone River. Heavy runoff from prairie drainages of the Bighorn River peak in March or April, causing the flows on the Bighorn River to exceed flows on the Yellowstone River.

Severe flooding occurred in May 1978 in southeastern Montana and Wyoming on the Bighorn River, the Tongue River and the Yellowstone River. Flooding on the Bighorn River began at the mouth of Soap Creek because of Yellowtail Dam (Figure 1). Extreme runoff from Soap Creek, Rotten Grass Creek, Beavais Creek and the Little Bighorn River caused record flooding on the Bighorn River. The event causing the flooding was a thunderstorm event, which occurred during snowmelt, when the ground was already saturated.

The peak discharge on the Bighorn River at Bighorn, Mt. during the May 1978 flood was more than twice the previous maximum record and exceeded the 100-year flood. The maximum discharge from the flood was approximately 60,000 cfs. However, releases out of Yellowtail Dam were held to between 2000 and 6000 cfs. Flows did not increase sharply until tributary inflow entered the river from Soap Creek, Rotten Grass Creek, Beauvais Creek and the Little Bighorn River reached the Bighorn River and traveled downstream below Hardin, Mt. The Yellowtail Dam reduced flooding on the Bighorn River during this storm by about 25,000 cfs.

Geomorphic Study

Many factors affect rivers but one of the most important changes can be the construction of dams and reservoirs. Reservoirs trap sediment and release clear water which has the potential to degrade the river channel downstream of the dam (Simons, 1975). Sediment is an important variable affecting slope, sinuosity, and cross-section shape (Schumm, 1972).

The Bighorn River is characterized as having a fairly steep slope typical of a braided rather than a meandering stream (0.0014) with a sinuosity close to 1.2. Sinuosity is defined as the ratio of channel length to valley length. Sinuosity values can vary from 1 to greater than 4. When the sinuosity is greater than 1.5, a channel is called meandering, and when it is less than 1.5 it is called straight or sinuous. The bed material, with a median particle size of 20-40 mm, was composed mainly of gravel material. The bank full discharge was estimated to be 12,000 cfs for the Bighorn River at Bighorn, Mt. based on using the 1.5 year flood (Koch et. al, 1977). Upstream at the afterbay dam the estimated 1.5-year flood was 1700 cfs for the bankfull discharge. The increase in the 1.5-year flood peak is due to tributaries below Yellowtail Dam.

Many changes have affected the Bighorn River including the construction of two dams in Wyoming (Buffalo Bill and Boysen Reservoirs on the Shoshone and Wind Rivers which are tributary to the Bighorn River) and Yellowtail Dam and Bighorn Lake which are located in Montana. Peter Martin (Koch et. al., 1974) conducted a study to determine changes in channel morphology since the closure of Yellowtail Dam in 1965.

Photographs taken in 1939 below the Afterbay Dam for approximately 71 miles were compared to photographs taken in 1950 and 1974. Overlays of these photos showed changes in vegetated islands, gravel bars, agricultural development, and riparian vegetation on the river bottom from the Yellowtail Afterbay Dam to the Yellowstone River. Vegetated islands were defined as vegetated land separated from the valley floor by water or gravel bars. Gravel bars were classified as islands when separated from the valley floor by water and were classified as lateral deposits when they were adjacent to the valley floor (Koch et. al., 1977).

A summary of the changes in river length, riparian area, river area, vegetated island and gravel bar area, and total water area by reach are summarized in Tables 2-4 (Koch et. al., 1977). The river was divided into the following 5 reaches. The location of the reaches is shown on Figure 2.

[1] Yellowtail Afterbay dam to just above the mouth of Hay Creek
[2] Above Hay Creek to just above Two Leggins diversion dam,
[3] Above Two Leggins diversion dam to just below the mouth of dry Creek
[4] Below Dry Creek to above the mouth of Pocket Creek,
[5] Above Pocket Creek to mouth

Table 2 summarizes the changes in Bighorn River by river reach for bank riparian habitat, river area, water area, and islands before and after construction of Yellowtail Dam. Table 3 provides a detailed summary of changes in island gravel bars, lateral gravel bars, and vegetated islands by river reach. Table 4 provides an overall summary of the changes in the Bighorn River since construction of Yellowtail Dam.

The greatest percentage loss occurred in vegetated island and gravel bar areas (-35 %, Table 2). The first two reaches experienced a loss of 46-49 percent in vegetated islands and gravel bar areas. Reaches 3 and 4 experienced losses of 40 percent and 29 percent.

The greatest loss in percentage as shown in Table 3 occurred for island gravel bars. Elimination of flood flows of the river allowed the invasion of vegetation into the gravel bars. The total number of island gravel bars reduced from 619 islands before construction of the dam to 301 islands after construction of the dam. The total area reduction for the island gravel bars was 77 percent and 34 percent of lateral gravel bars were eliminated (Table 3).

The number of vegetated islands decreased from 414 to 287 and island areas decreased by 23 percent from 6360 to 4890 acres. Bank riparian area increased by 38 percent as former islands and gravel bars were eliminated. Total river areas decreased by 25 percent which includes the loss of island and gravel bars and water surface area (Tables 2 and 4). Island gravel bar losses seemed to be directly related to the distance from the dam with the greatest decrease in vegetated island and gravel bar areas occurring in the three reaches nearest to the dam. Reach 5, the furthest from the dam, showed a small increase in vegetated island and gravel bar areas since the closure of the dam (Table 3).

A plot of average daily discharges for two average flow years and two high flow years before and after closure of Yellowtail Dam are shown in Figures 3 and 4. These graphs demonstrate that dam releases have resulted in less flow variability during the year and a reduction in flood flow peak discharges.

Plots of bed material particle size distribution curves at the Test Sites 1 through 3 (Locations 1, 5 and 6, Figure 1), and bed material particle size distribution curves collected near Soap Creek are shown in Figures 5 through 12. These figures show the results of the bed material samples collected during the February 1997 field trip. River bed material is typically gravel with 7 to 25 percent sand size. Less than 1 percent of the material is silt or clay size.

A braided plan form is caused by a large sediment load relative to the river's hydraulic capacity. The Yellowstone River and the Bighorn River historically carried similar sediment loads and exhibited similar braided forms. Channel forming flows scour out a channel of accumulated sediment and deposit it downstream as bars. Channel forming flows also wash away or bury plants that have taken root on the banks and bars during low flow. The frequency of channel forming flow or bank full discharge has not been reduced on the Yellowstone River and the braided affect has been maintained (Montana Department of Natural Resources, 1981).

Table 5 summarizes the data collected on the Bighorn River during the field trip in February 1997. Test Sites 1-3, identified as Locations 1, 5, and 6, are shown in Figure 1. The median river bed material (D_{50}) averaged between 30 and 40 mm, and the maximum particle size was 100 mm or 4 inches. Deposition of sediment on the upstream side of islands and in the riffles that occurred in the divided flow areas tended to be much coarser with particle size D_{50} varying from 50-80mm and maximum sizes up to 120 mm. Measured suspended sediment concentration in the river was small, because of low flows that occur during winter months. As expected, approximately two-thirds of the material in suspension was composed of silt or clay size material.

The median particle (D_{50}) decreased in the main river channel with distance downstream. Data collected approximately 12 miles downstream of the Afterbay Dam at Soap Creek (Figure 1) was considerably finer than the material in the pools and riffles upstream near the dam. Evidence of silt and clay size material was also noted when the bed material was collected at Soap Creek. The D_{50} of the bed material collected on the bar near Soap Creek was 5mm and D_{90} of the bed material was only 11 mm. A comparison of the particle size D_{50} between Site 1 and Site 3 showed a decrease in the particle size D_{50} from 40 mm to 30 mm (Table 5).

The U.S. Bureau of Reclamation did not conduct a study to monitor the geomorphic changes of the Bighorn River since closure of the dam. Three reaches of the

Bighorn River below Yellowtail Dam (13 miles, 32 miles, and 52 miles) were monitored for evidence of channel degradation (U.S. Bureau of Reclamation, 1982). Each river reach only consisted of three channel cross-sections. However, the general conclusion of the study was that the monitored cross-sections showed no trends of degradation or aggradation. The most comprehensive study that has been completed to date was by Koch, which was based on aerial photo interpretation before and after construction of Yellowtail Dam.

Conclusions and Recommendations

1. Increases in bank riparian habitat have occurred since closure of the dam. Smaller gravel bar islands have been combined with other vegetated islands to form larger vegetated islands. These islands have been stabilized because of reduced peak flows and sediment load downstream. Although there are fewer vegetated islands and a general reduction in total island area, the average size of the remaining islands has increased.

2. The following hypothesis is proposed to explain the general decrease in area of gravel bars and vegetated islands: Bighorn River sediment deposits, such as island and lateral gravel bars, have decreased in both area and number due to the absence of large, sediment laden floods since the construction of Yellowtail and Afterbay dams. Prior to dam construction, these dynamic bars were naturally created and maintained by sediment laden floods. Gravel size sediments were transported in the river by the high stream velocities associated with flood flows and deposited as bars in eddies, such as those that were formed on the downstream side of islands, which have much lower velocities. In the dynamic river, these bars cyclically erode and redeposit over time. The gravel bars are becoming smaller in number and size because there is no mechanism for redeposition in the absence of sediment laden floods. Gravel bar area and number will decrease until the river reaches a new equilibrium in the post-dam environment.

3. The reach of the Bighorn River from Afterbay Dam to the confluence with Soap Creek has very little supply of gravel sized sediment, and there may be little opportunity for river island restoration. In fact, periodic controlled floods may not have a positive effect on the Bighorn River above Soap Creek. However, it may be possible to restore some of the predam gravel bars and islands in the reaches of the Bighorn River downstream from Soap Creek. Periodic controlled floods of short-duration may be able to transport gravels, that accumulate in the river channel during periods of low flow, and deposit it in eddies. This process would be very similar the beach/habitat-building flow that was released from Glen Canyon Dam during March/April 1996 to restore sandy beaches in Grand Canyon. For the Bighorn River, this hypothesis could be tested by a short-duration (2 to 3 days), controlled release of 15,000 to 20,000 cfs from Yellowtail and Afterbay Dam.

Table 2 Changes in the Bighorn River after construction of Yellowtail Dam

Section	Before Construction	After Construction	Change	Percentage	
Length of Main Channel in Miles					
1	12.27	12.17	-0.10	-0.8	
2	19.55	19.82	+0.27	+1.4	
3	20.05	20.30	+0.25	+1.2	
4	19.48	18.91	-0.57	-2.9	
5	13.63	14.77	+1.14	+8.4	
Total	84.95	85.97	+1.02	+1.2	
Total Bank Riparian Area in acres					
1	1,552.04	2,232.25	+680.21	+43.8	
2	2,543.53	3,528.83	+985.30	+38.7	
3	1,910.02	2,761.91	+851.89	+44.6	
4	1,255.15	1,981.81	+726.66	+57.9	
5	1,590.59	1,675.96	+85.37	+5.4	
Total	8,851.33	12,180.76	+3,329.82	+37.6	
Total River Area in acres (includes water, island and gravel bars)					
1	1,342.23	985.16	-357.07	-26.6	
2	2,889.66	1,987.78	-901.88	-3102	
3	3,936.27	2,724.31	-1211.96	-30.8	
4	3,219.35	2,477.08	-742.27	-23.1	
5	1,956.10	1,794.46	-161.64	-8.3	
Total	13,343.61	9,948.79	-3394.82	-25.4	
Total vegetated island and gravel bar area in acres					
1	759.56	409.97	-349.59	-46.0	
2	1,921.15	979.29	-941.86	-49.0	
3	2,765.53	1,646.43	-1,119.10	-40.5	
4	2,090.37	1,465.63	-624.74	-29.9	
5	1,022.22	1,056.23	+34.01	+3.3	
Total	8,558.83	5,557.55	-3,001.28	-35.1	
Total water area in acres					
1	582.67	575.19	-7.48	-1.3	
2	968.51	1,008.49	+39.98	+4.1	
3	1,170.74	1,077.88	-82.86	-7.9	
4	1,128.98	1,011.45	-117.53	-10.4	
5	933.88	738.23	-195.65	-21.0	
Total	4,784.78	4,411.24	-373.54	-7.8	

[1]Koch et al, 1974

Table 2 Changes in the Bighorn River after construction of Yellowtail Dam

Section	Before Construction	After Construction	Change	Percentage	
Length of Main Channel in Miles					
1	12.27	12.17	-0.10	-0.8	
2	19.55	19.82	+0.27	+1.4	
3	20.05	20.30	+0.25	+1.2	
4	19.48	18.91	-0.57	-2.9	
5	13.63	14.77	+1.14	+8.4	
Total	84.95	85.97	+1.02	+1.2	
Total Bank Riparian Area in acres					
1	1,552.04	2,232.25	+680.21	+43.8	
2	2,543.53	3,528.83	+985.30	+38.7	
3	1,910.02	2,761.91	+851.89	+44.6	
4	1,255.15	1,981.81	+726.66	+57.9	
5	1,590.59	1,675.96	+85.37	+5.4	
Total	8,851.33	12,180.76	+3,329.82	+37.6	
Total River Area in acres (includes water, island and gravel bars)					
1	1,342.23	985.16	-357.07	-26.6	
2	2,889.66	1,987.78	-901.88	-3102	
3	3,936.27	2,724.31	-1211.96	-30.8	
4	3,219.35	2,477.08	-742.27	-23.1	
5	1,956.10	1,794.46	-161.64	-8.3	
Total	13,343.61	9,948.79	-3394.82	-25.4	
Total vegetated island and gravel bar area in acres					
1	759.56	409.97	-349.59	-46.0	
2	1,921.15	979.29	-941.86	-49.0	
3	2,765.53	1,646.43	-1,119.10	-40.5	
4	2,090.37	1,465.63	-624.74	-29.9	
5	1,022.22	1,056.23	+34.01	+3.3	
Total	8,558.83	5,557.55	-3,001.28	-35.1	
Total water area in acres					
1	582.67	575.19	-7.48	-1.3	
2	968.51	1,008.49	+39.98	+4.1	
3	1,170.74	1,077.88	-82.86	-7.9	
4	1,128.98	1,011.45	-117.53	-10.4	
5	933.88	738.23	-195.65	-21.0	
Total	4,784.78	4,411.24	-373.54	-7.8	

[1]Koch et al, 1974

Table 3 - Number, average area and total area of vegetated islands, island gravel bars, and lateral gravel bars on the Bighorn River before and after construction of Yellowtail Dam.

	Before Construction[a]			After Construction[b]			Area Change	
Section	Number	Average Area (ac)	Total Area (ac)	Number	Average Area (ac)	Total (ac)	Total (acres)	Percentages
Vegetated Islands								
1	54	8.5	459.2	42	8.5	355.2	-104	-22.6
2	85	15.2	1293.7	84	9.8	823.4	-470.3	-36.4
3	115	18.7	2155.2	56	25.8	1446.7	-708.5	-32.9
4	90	17.4	1567.3	66	20.1	1323.2	-244.1	-15.6
5	70	12.6	884.1	39	24.2	942.0	+57.9	+6.6
Total	414	15.4	6359.6	287	17.0	4890.6	-1469	-23.1
Island Gravel Bars								
1	79	2.8	219.4	42	0.7	30.1	-189.3	-86.3
2	131	3.9	507.9	75	1.3	94.6	-413.3	-81.4
3	183	3.0	548.3	77	1.5	118.6	-429.7	-78.4
4	113	3.8	432.5	61	1.7	102.8	-329.7	-76.2
5	113	0.9	106.0	46	1.5	66.6	-39.4	-37.2
Total	619	2.9	1814.2	301	1.4	412.8	-1401.4	-77.2
Lateral Gravel Bars								
1	26	3.1	81.0	20	1.2	24.6	-56.4	-69.6
2	40	3.0	119.6	23	2.7	61.3	-58.3	-48.7
3	16	3.9	62.0	28	2.9	81.1	+19.1	+30.8
4	21	4.3	90.5	22	1.8	39.6	-50.9	-56.2
5	19	1.7	32.1	18	2.7	47.7	+15.6	+48.6
Total	122	3.2	385.2	111	2.3	254.2	-131.0	-34.0

[a]Aerial photos of section 1-4 were taken in 1939, of section 5, in 1950.
[b]Aerial photos taken in 1974.

[1]Koch et al, 1974

Table 4 Loss in Bighorn River Area following construction of Yellowtail Dam

	Acreage Loss	Percentage Loss
Vegetated Islands	1,469	-23.1
Island Gravel Bars	1,401	-77.2
Lateral Gravel Bars	131	-34.0
Water Area	374	-7.8
Total River Area	3,374	-25.4

[1]Koch et al, 1974

Table 5 Sediment and Hydraulic Data Collected during Field Trip

Site	Discharge (cfs)	Velocity (ft/s)	Sediment Particle D50 (mm)	Sediment Particle D90 (mm	Suspended Sediment Concentration (mg/l)	Percent Finer than Sand Size
1 Pool Upstream	4050	3.23	40	80	3	58
1 Upstream of Island	4050	3.23	55	110	3	58
1 Downstream of Island	4050	3.23	20	50	3	58
2 Nose of Island	4310	3.36	20	60	4	59
3 Pool	4120	2.77	30	70	4	66
3 Riffle	4120	2.77	80	110	4	66
Bar near Soap Creek	4100	3.23	5.5	11		66
Just below Soap Creek	4100	3.23	45	80		

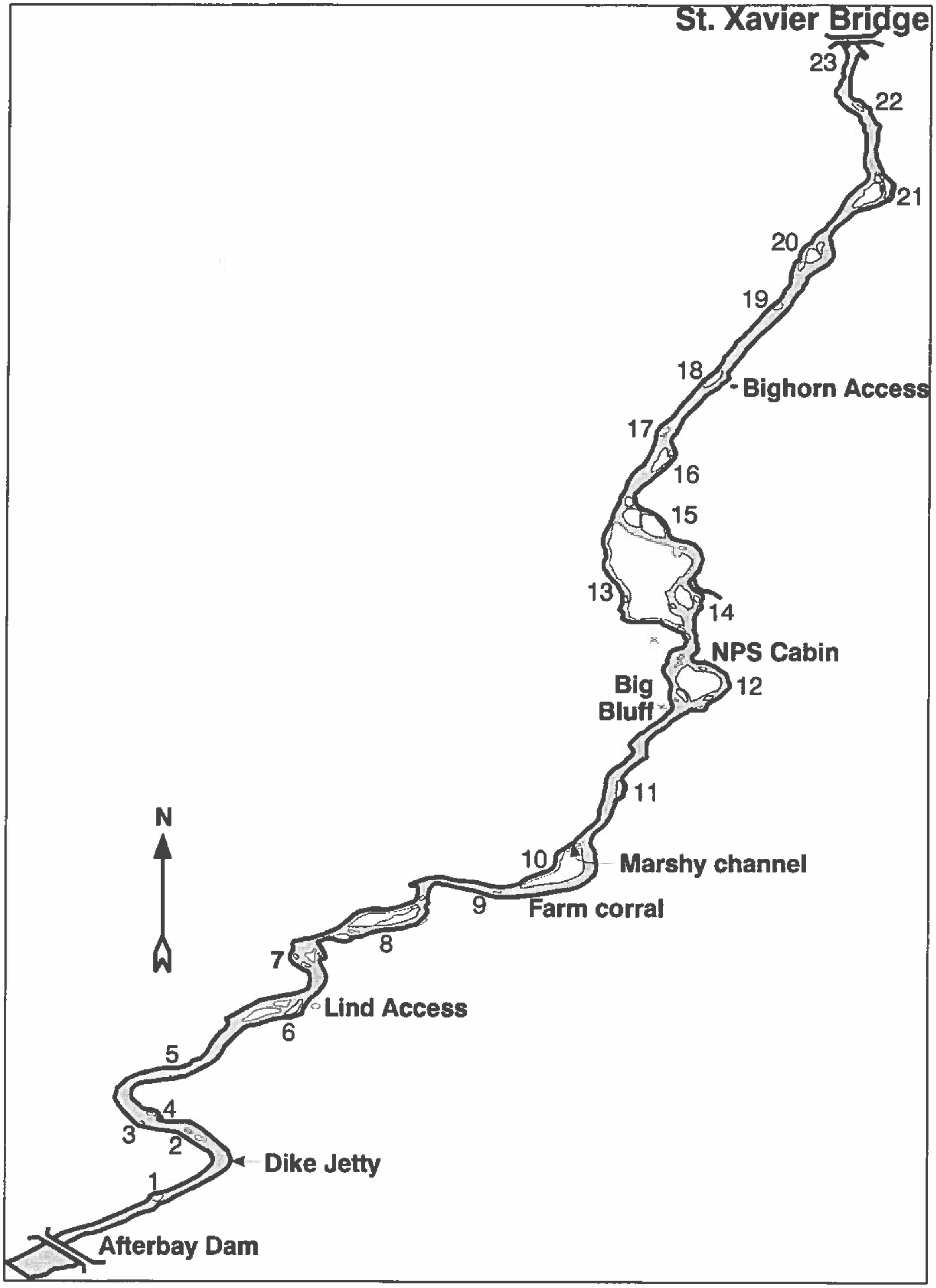

Figure 1 - Schematic of the Bighorn River

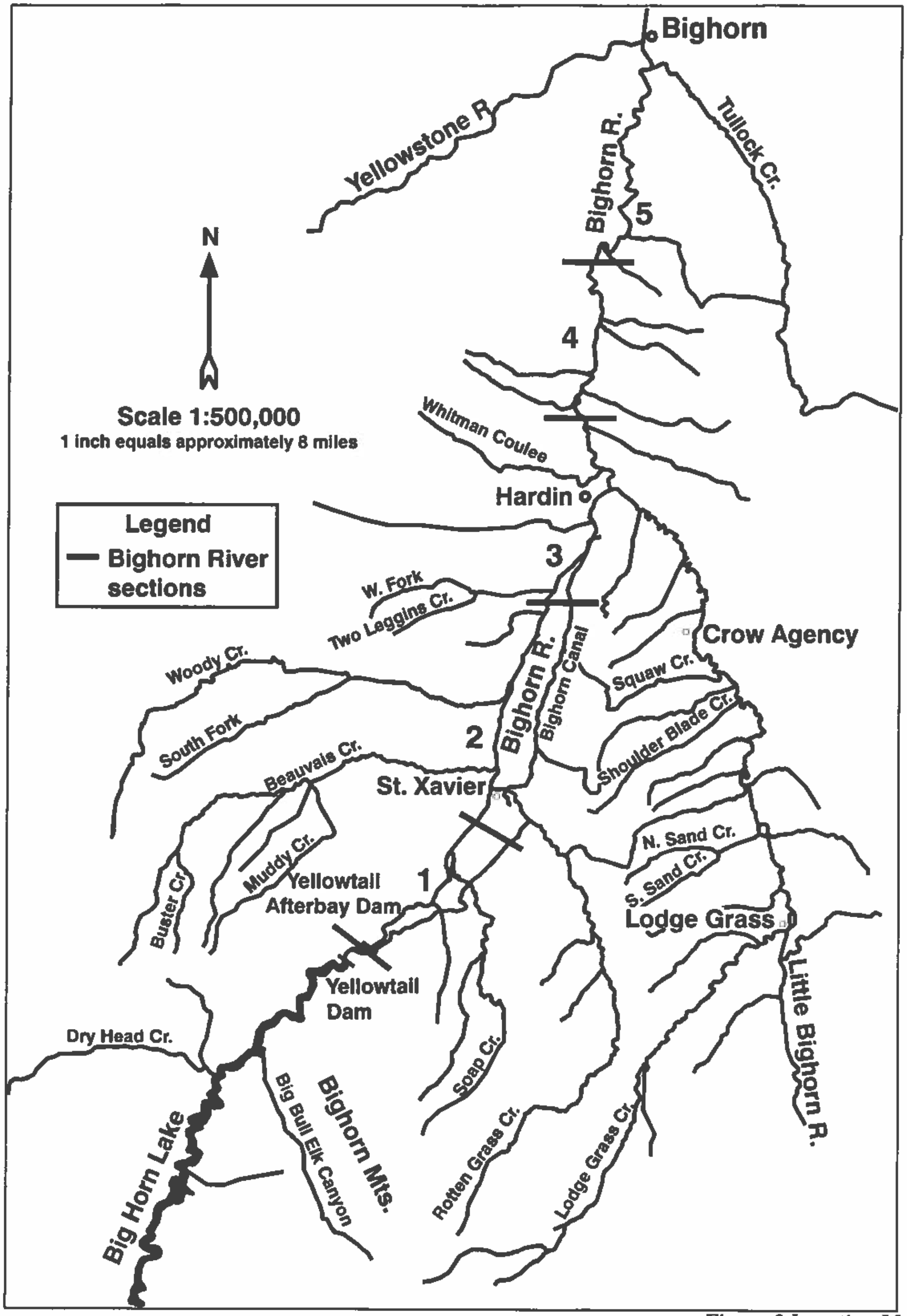

Figure 2 Location Map

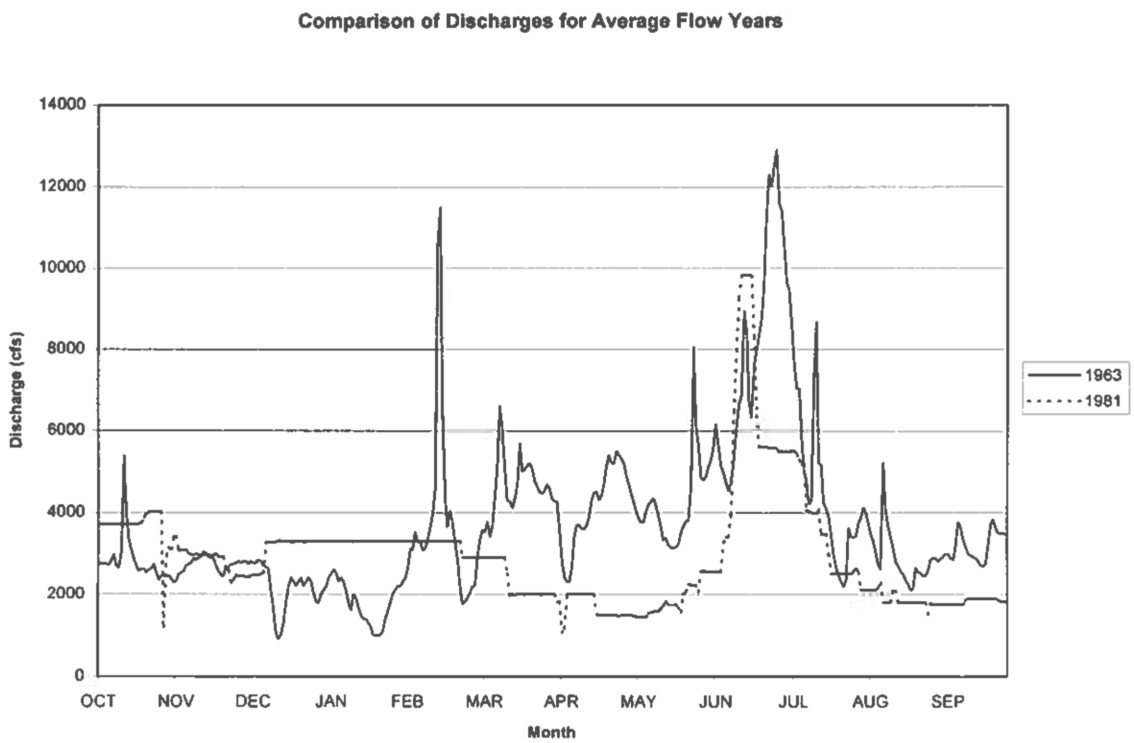

Figure 3 - Comparison of discharges for average flow years before and after construction of Yellowtail Dam

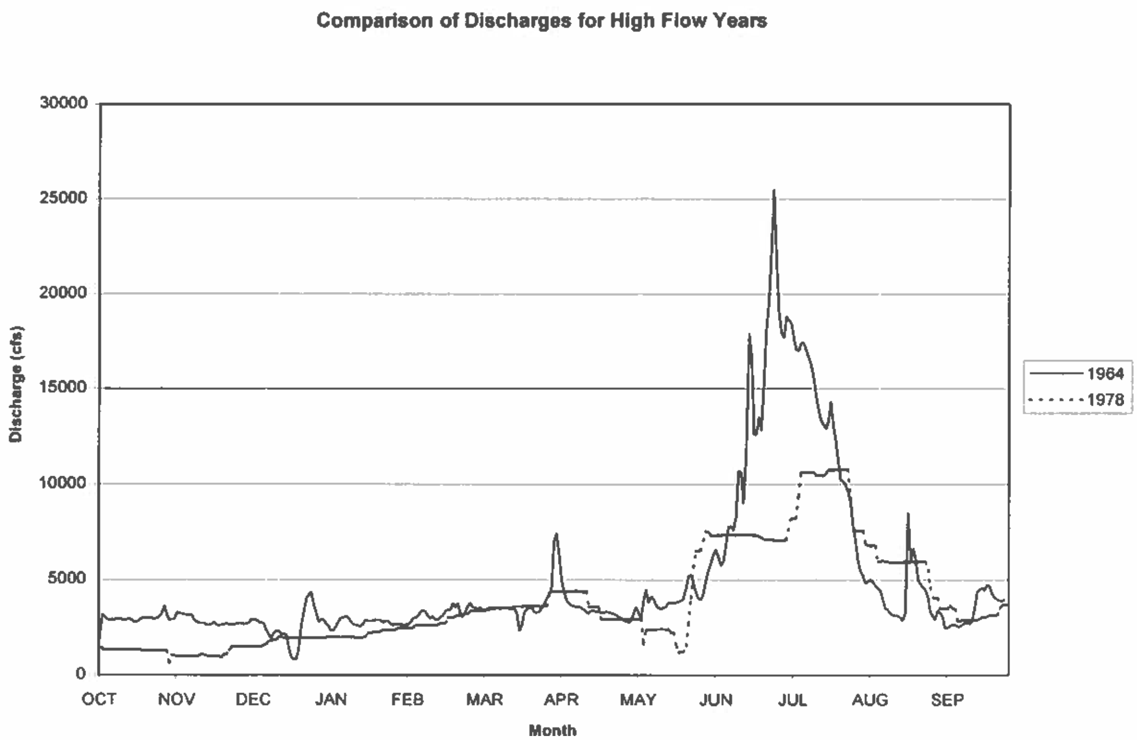

Figure 4 - Comparison of discharges for high flow years before and after construction of Yellowtail dam.

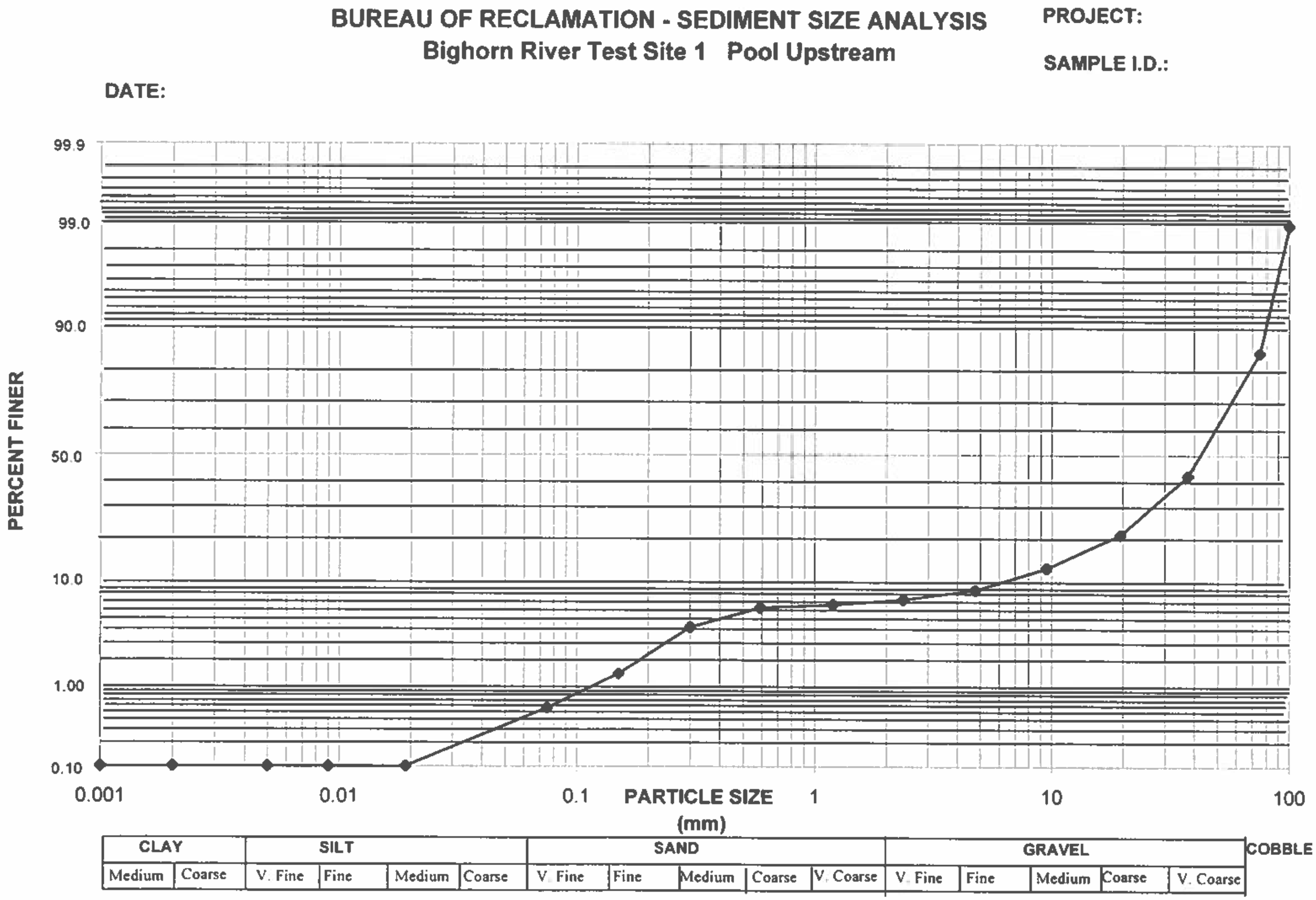

Figure 5- Particle size distribution, Bighorn River, Test Site 1, pool upstream.

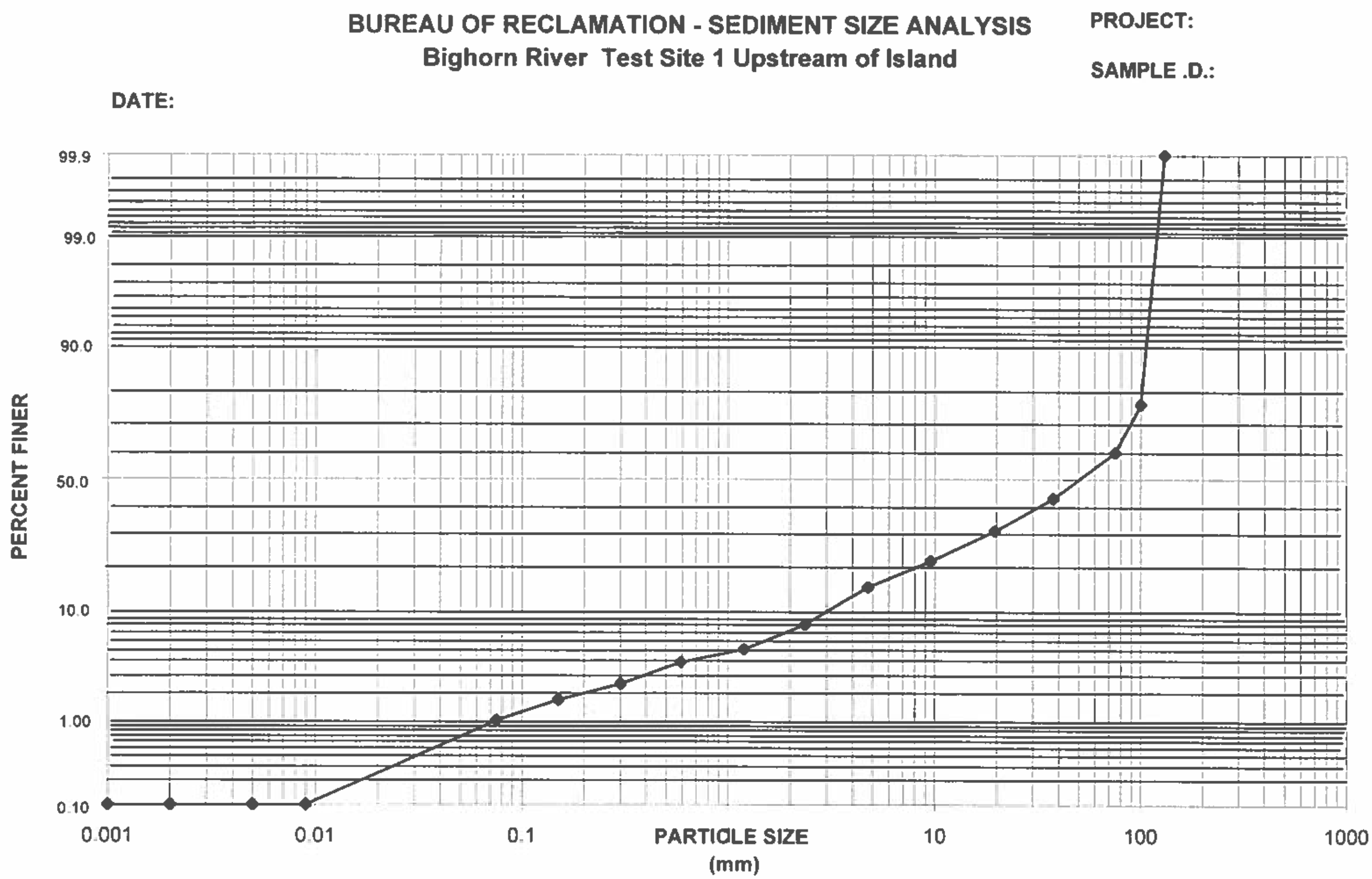

Figure 6 - Particle size distribution, Bighorn River, Test Site 1, upstream of island

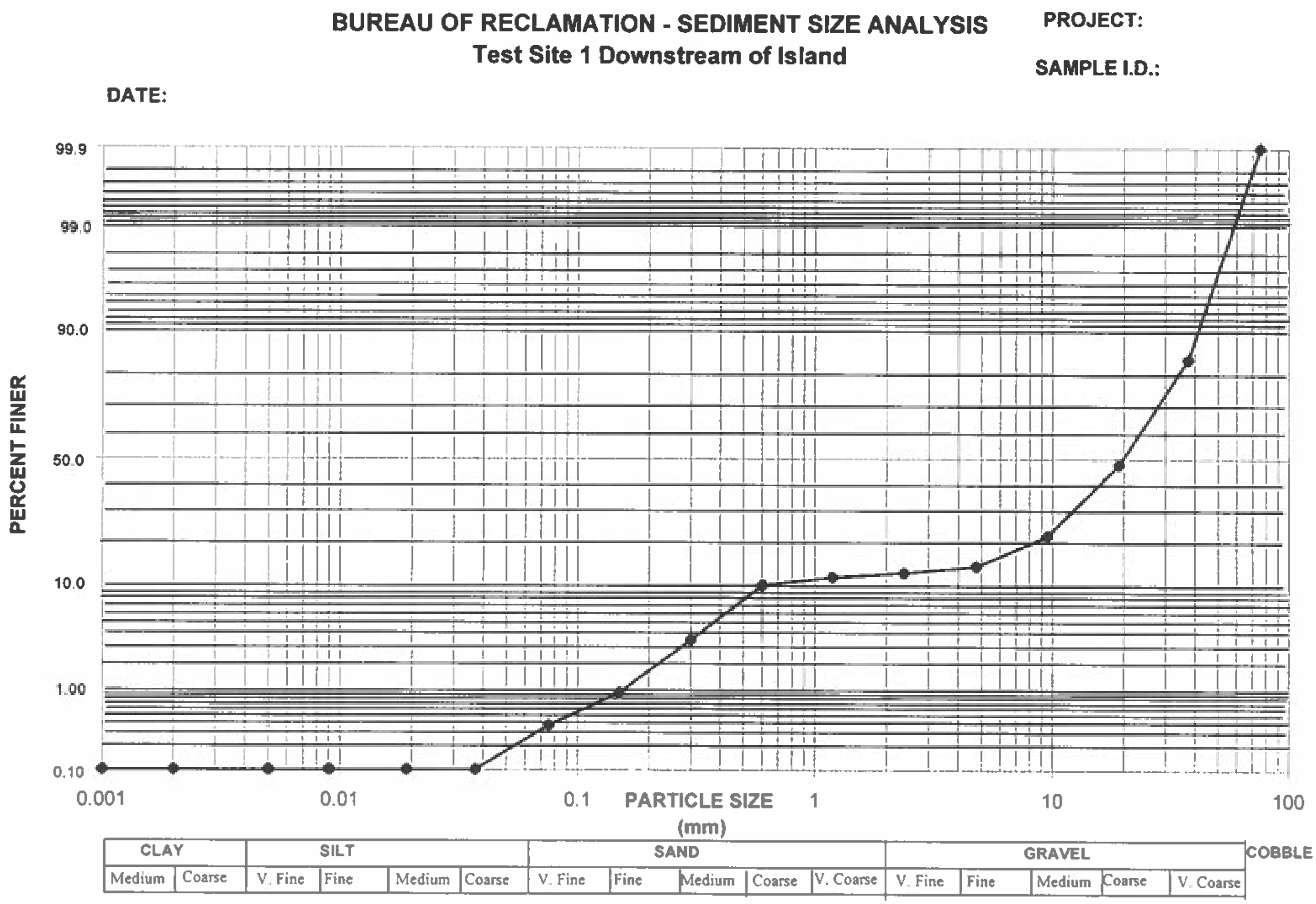

Figure 7 - Particle size distribution, Bighorn River, Test Site 1, downstream of island

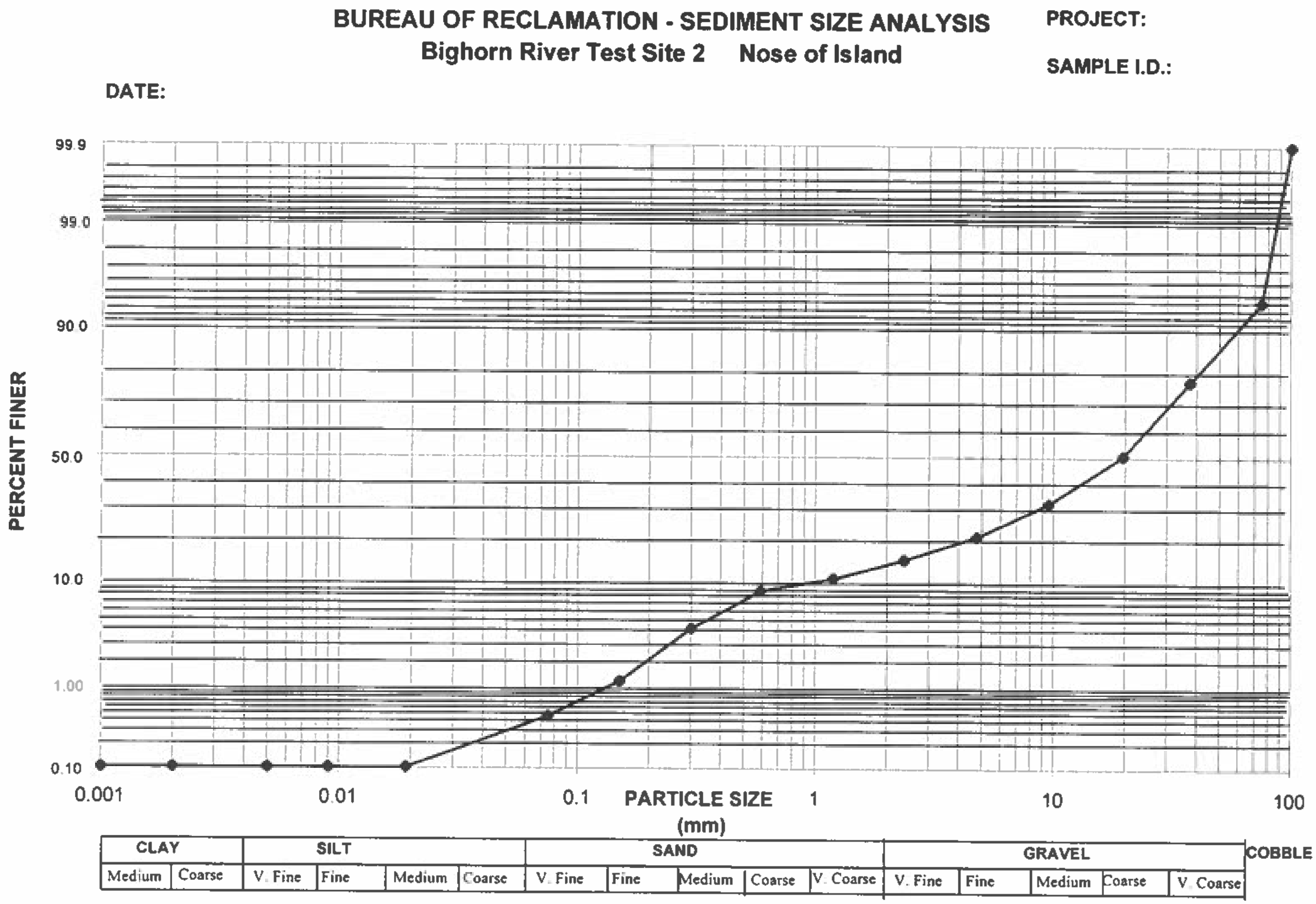

Figure 8-Particle size distribution, Bighorn RiverTest Site 2, nose of island

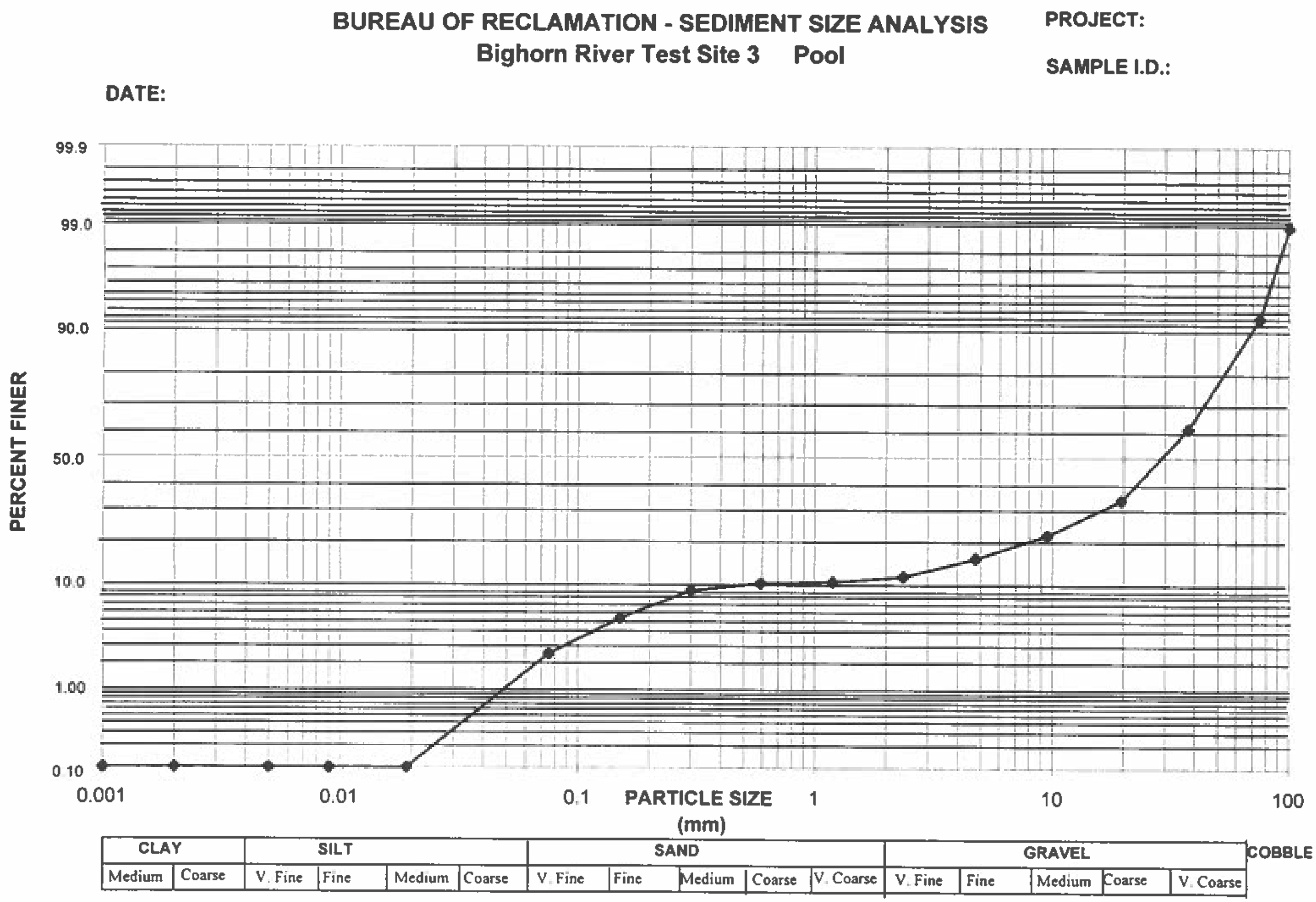

Figure 9 - Particle size distribution, Bighorn River, Test Site 3, pool.

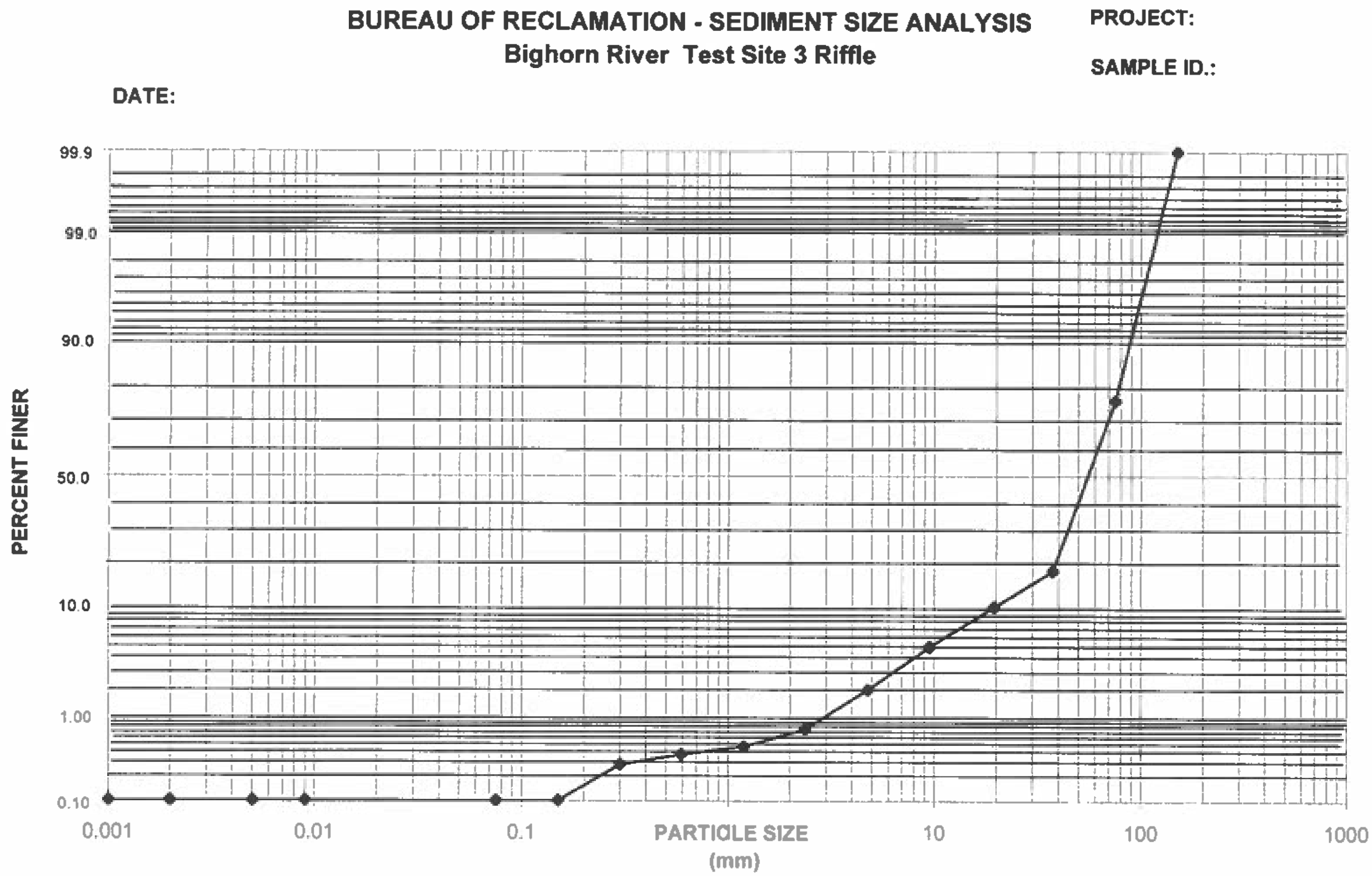

Figure 10 - Particle size distribution, Bighorn River, Test Site 3, Riffle

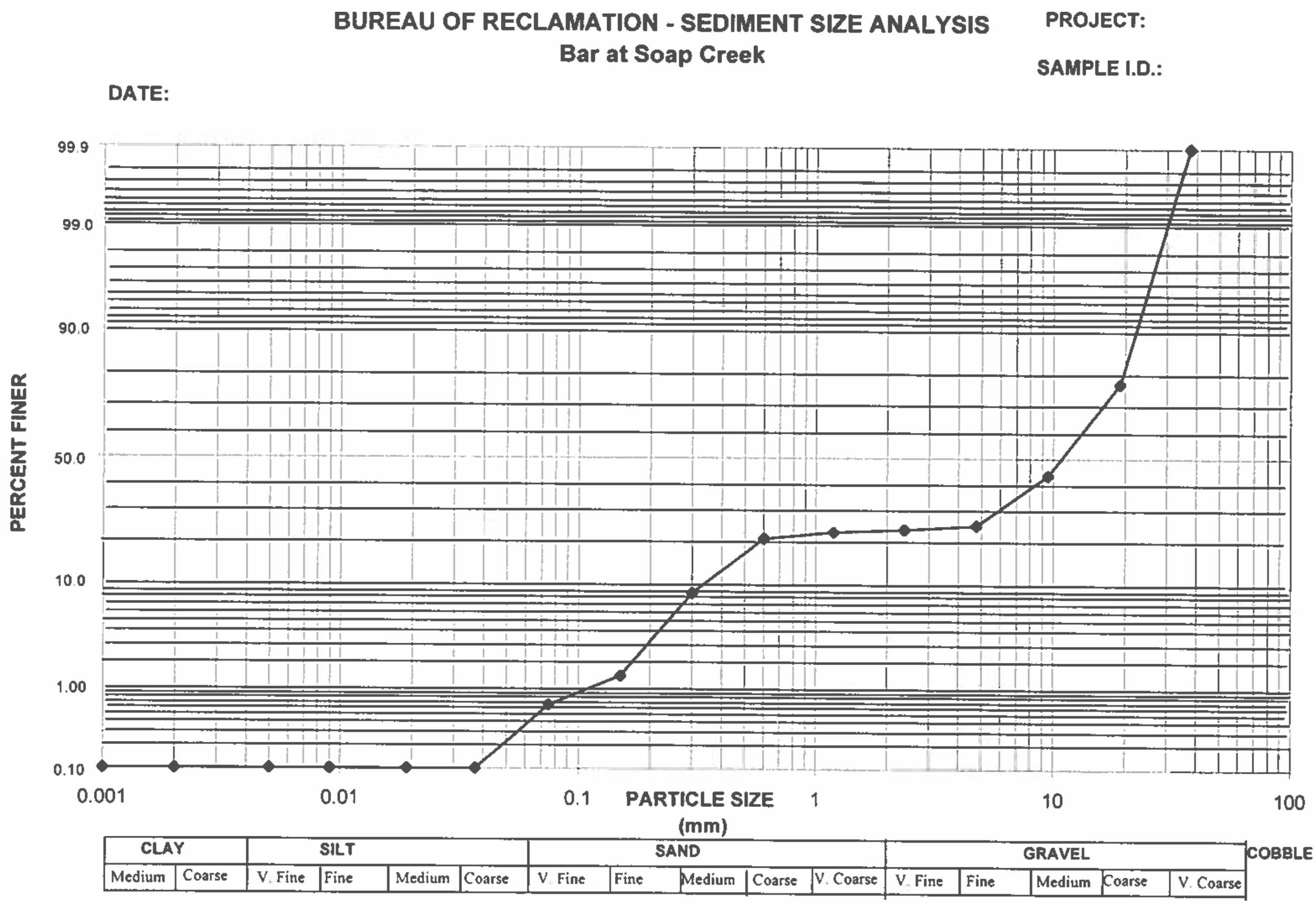

Figure 11 - Particle size distribution, Bighorn River Gravel Bar at Soap Creek

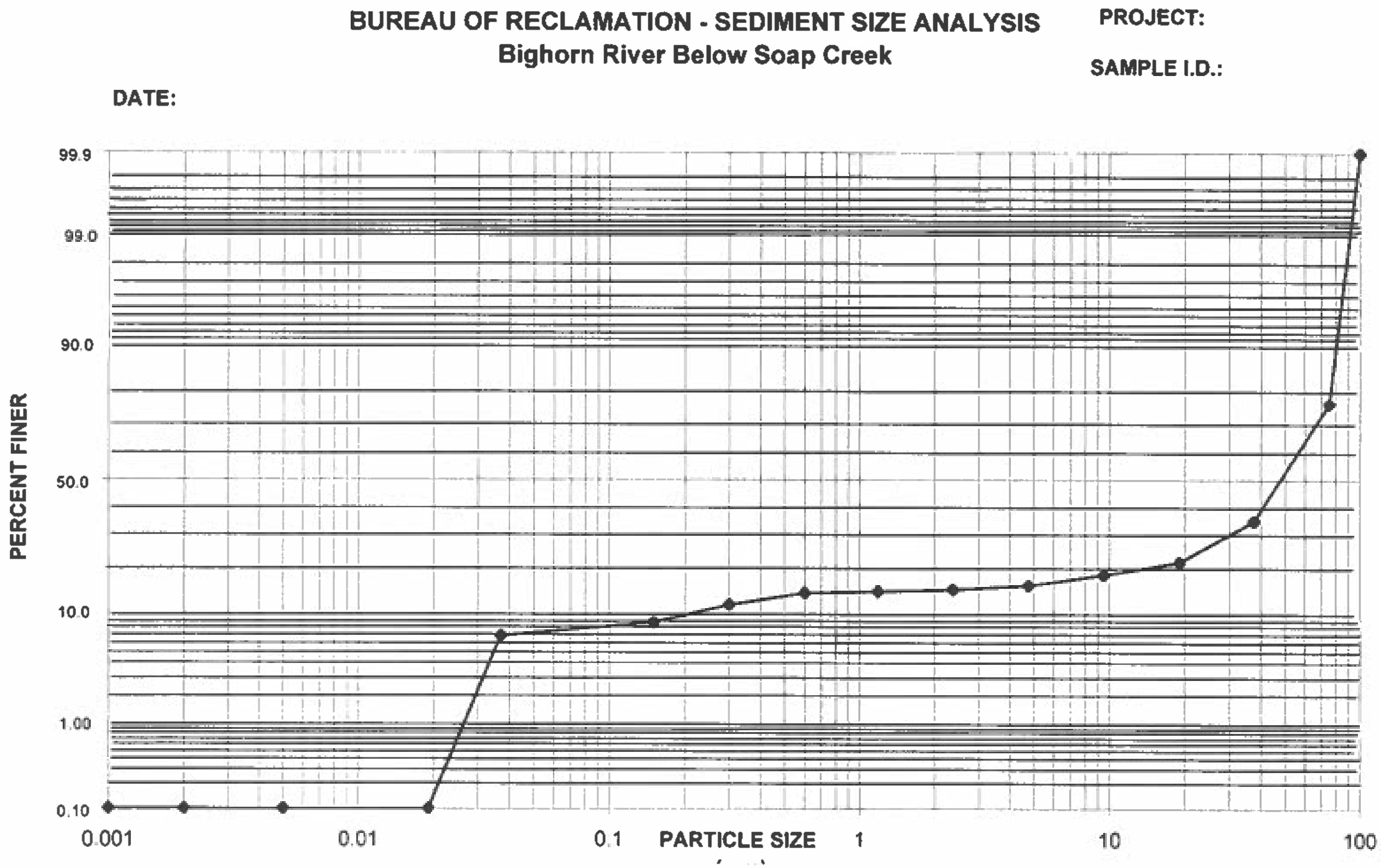

Figure 12 – Particle Size Distribution, Bighorn River just below Soap Creek

References

Agard, Sherry S., 1087, "Geomorphic evolution of the lower Bighorn River," Montana, U.S. Geological Survey

Hamilton, L.J. and Paulson, Q. F., 1968, "Geology and Ground water Resources of the Lower Bighorn Valley, Montana," Water Resources Paper 1876, U.S. Geological Survey, 1968.

Koch, Roy, Curry, R. and Weber, M., 1977, "The Effect of Altered Streamflow on the Hydrology and Geomorphology of the Yellowstone River Basin," Montana, Technical Report No. 2, Montana Department of Natural Resources and Conservation.

Montana Department of Fish, Wildlife & Parks, 1987, "Upper Bighorn River Fisheries Management Plan," August.

Missouri River Basin Commission, 1978, "Report on the Yellowstone Basin Adjacent Coal Area Level B Study, Clarks Fork-Bighorn and Lower Yellowstone, Montana," Omaha, Nebraska.

Montana Department of Natural Resources, 1981, "How the River Runs," a study of potential changes in the Yellowstone River Basin; Yellowstone impact study; final report, Water Resources Division, Helena, Montana.

Moore, L. G. and Shields, R. R., 1976, "Streamflow Characteristics of the Yellowstone River Basin, Montana through 1976," U. S. Geological Survey, Water Resources Investigations 80-41.

Parrett, C., Carlson, D. D., Craig, G. S., and E. H. Chin, "Floods of May 1978 in Southeastern Montana and Northeastern Wyoming," U. S. Geological Survey , Water Resources Division, Helena, Mt.

Pederson, D. A., 1987, "Hydrology of Area 51, Rocky Mountain Coal Province, Wyoming and Montana," U. S. Geological Survey.

Shumm, S. A., 1972, "River Morphology," Dowden, Hutchinson, and Ross, Inc., Strousburg, Pa.

Simons, D.B., P.F. Lagasse, and Y. H. Chen, and S.A. Schumm, 1975, "The River Environment, A Reference Document," Colorado State University, Fort Collins, Co.

Soltero, R. A., Wright, J. C. and Horpestad, A. A., 1973, "Effects of Impoundment on the Water Quality of Bighorn River," Montana State University.

U. S. Department of Interior, Bureau of Reclamation, 1982, Memorandum on the Bighorn River Degradation Study Below Yellowtail Reservoir, Billings, Montana.

U. S. Department of Interior, Bureau of Reclamation, 1991, "Effects of Supersaturation of Dissolved Gases on the Fishery of the Bighorn River Downstream of the Yellowtail Afterbay Dam," Completion Report.

U.S. Department of Interior, Bureau of Reclamation, 1994, "Appendix Material for Status Report on the Identification and Preliminary Evaluation of Alternatives," Yellowtail Afterbay Dam.

Wright, John C. and Soltero, Raymond, 1973, "Limnology of Yellowtail Reservoir and the Bighorn River," EPA-R3-73-002, Montana State University.