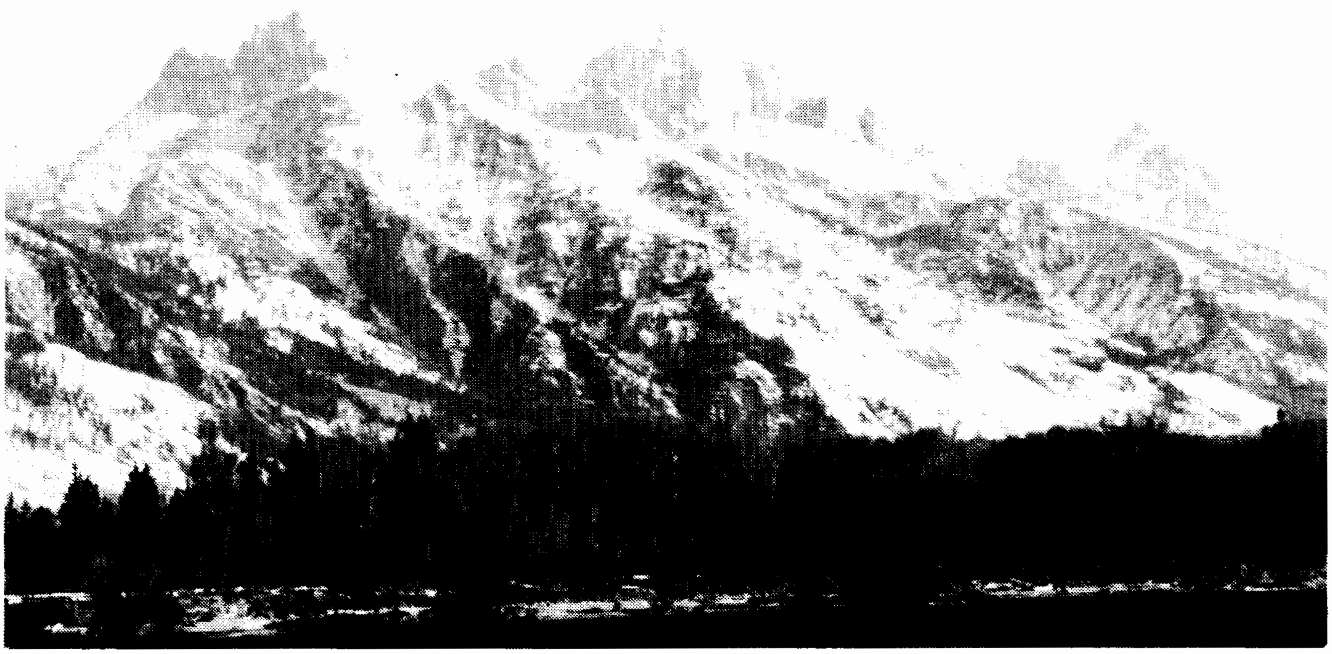
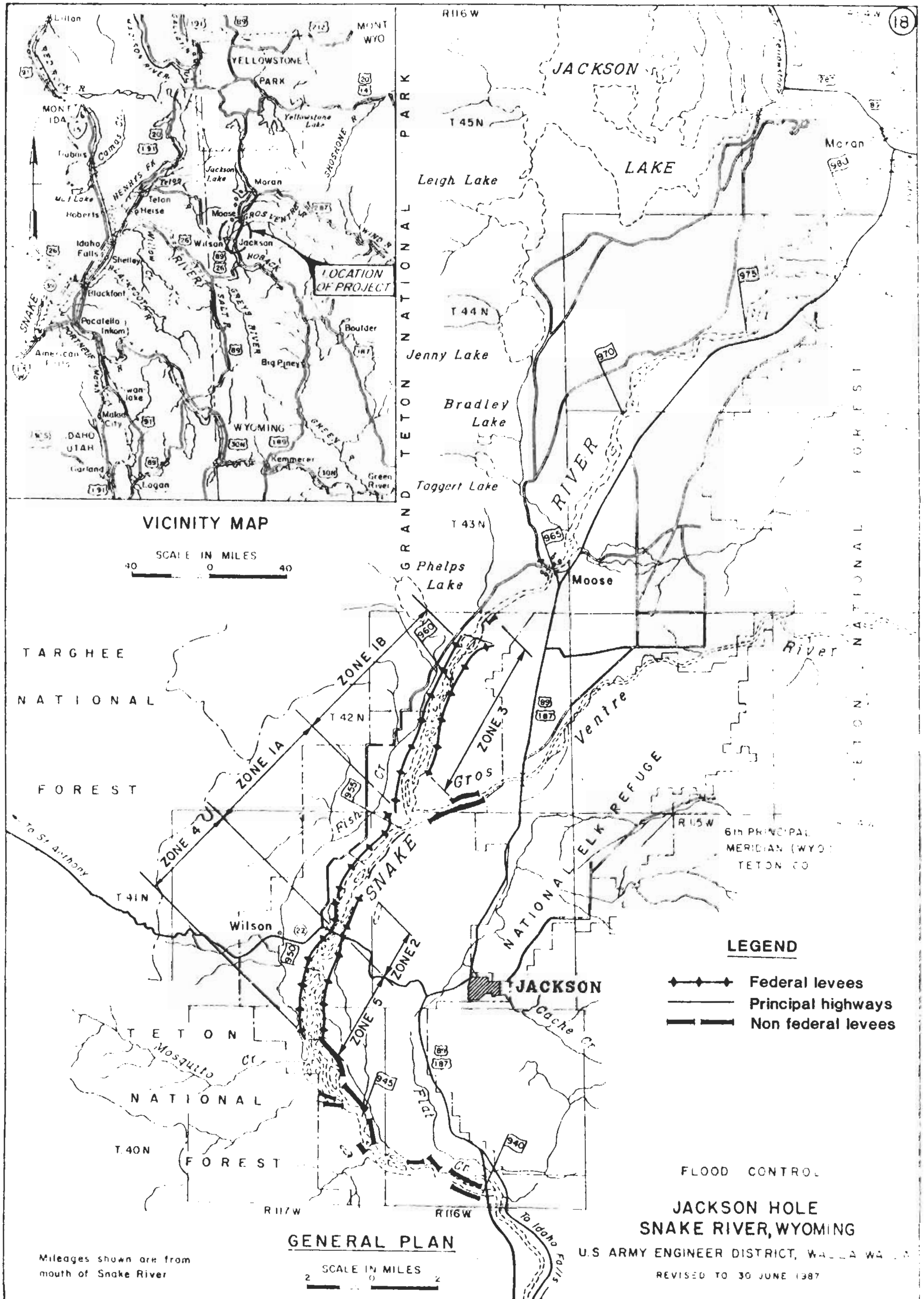
US Army Corps
of Engineers
Walla Walla District

Jackson Hole, Wyoming Flood Protection Project Letter Report



January 1988

CORPS OF ENGINEERS U.S. ARMY



Enclosure 1

JACKSON HOLE, WYOMING, FLOOD PROTECTION PROJECT LETTER REPORT

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JACKSON HOLE, WYOMING, FLOOD PROTECTION PROJECT LETTER REPORT

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DEPARTMENT OF THE ARMY
WALLA WALLA DISTRICT CORPS OF ENGINEERS
BUILDING 602, CITY-COUNTY AIRPORT
WALLA WALLA, WASHINGTON 99362-9265

REPLY TO
ATTENTION OF

CENPW-PL-PF (1110-2-1150a) 27 January 1988

MEMORANDUM FOR: Commander, North Pacific Division, ATTN: CENPD-CO-E

SUBJECT: Jackson Hole, Wyoming, Flood Protection Project Letter Report

1. Introduction.

a. Authority.

(1) The 1986 Water Resources Development Act (PL 99-662), dated 17 November 1986, designates that the Secretary of the Army shall have the responsibility of the operation and maintenance of Jackson Hole Snake River levees project. The specific section is found under Title VIII-Project Modifications, Section 840, Jackson Hole Snake River, Wyoming, as follows:

> "The project for Jackson Hole Snake River local protection and levees, Wyoming, authorized by the River and Harbors Act of 1950 (Public Law 81-516), is modified to provide that the operation and maintenance of the project, and additions and modifications thereto constructed by non-Federal sponsors, shall be the responsibility of the Secretary: Provided, that non-Federal sponsors shall pay the initial $35,000 in cash or materials of any such cost expended in any one year, plus inflation as of the date of enactment of this Act."

(2) Under the provisions of this act, the Corps of Engineers is responsible for the operation and maintenance of the project.

(3) This letter report is being submitted as requested by NPDCO-B letter, dated 4 February 1987, subject: FY 1987 O&M Requirements for Jackson Hole Snake River Project. The Jackson Hole Flood Protection Project is sponsored by Teton County. The Federal levees were authorized by Section 204 of the River and Harbors Act of 1950, PL 81-516.

b. Purpose and Scope.

(1) The purpose of this report is to identify the studies and measures which are necessary to develop a cost effective operations and maintenance plan for the Jackson Hole Snake River flood control project.

(2) The scope of the study is to show the need for plans to lessen the historically high operation and maintenance costs of the

Jackson Hole levee system and to justify the cost of recommended studies. The levee system may include both Federal and non-Federal levees. Background information is included to substantiate recommendations.

c. Background.

(1) Description of Area. The Jackson Hole area is a valley on the Snake River about 10 miles wide and 35 miles long at approximately 6,200 feet elevation near the western boundary of the State of Wyoming. The headwaters of the Snake River originate to the north in Yellowstone Park. Principal tributaries of the Snake River above the Jackson Hole area are Lewis River, Pacific Creek, and Buffalo Fork. The Gros Ventre River and several smaller drainages enter the Snake River in the project area. The Jackson Hole area is bounded by the rugged and scenic Teton Range on the west, the high plateaus of Yellowstone Park to the north, and the Gros Ventre Range to the east. The Teton and Gros Ventre Ranges converge to the south to constrict the flow of the Snake River to a narrow canyon downstream to Palisades Reservoir. Grand Teton National Park is the upstream end of the existing Federal flood control project and the downstream end is approximately 4 miles below the Jackson-Wilson (J-W) Bridge. The Snake River Basin drains 2,500 square miles above the J-W Bridge. The non-Federal levees are located downstream of the Federal levees on the Snake River and on the Gros Ventre River upstream from its mouth to the Grand Teton National Park boundary. (See Enclosure 1, area map, and Enclosure 5, Plate 1, Upper Snake River Basin.) The city of Jackson, Wyoming, is located outside the Snake River floodplain about 5 miles to the east of the river. The town of Wilson is in the floodplain and located on Fish Creek, a secondary tributary which parallels the Snake River.

(2) Flood Characteristics and Past Floods. Snake River flood events in the project area result primarily from snowmelt and occur in a rather regular pattern of prolonged high flows in May, June, and July. Annual flood peak discharges at the J-W Bridge have been estimated from records of the Snake River at Moran, Wyoming, and near Heise, Idaho, and for tributary streams. These estimates indicate that peak flows exceeding 20,000 cubic feet per second (cfs) have occurred 13 times between the years of 1904 and 1986. Peak discharges greater than 10,000 cfs have occurred 74 times. The largest known discharge (estimated at 41,000 cfs) occurred in 1894 and the second largest (estimated at 32,500 cfs) occurred in 1918. Enclosure 2, Table 1, lists the natural and actual peak discharges estimated at the J-W Bridge for the period of available records. Major floods (flows over 20,000 cfs) are indicated in the following tabulation:

Year	Peak Flow (cfs)
1894	41,000
1918	32,500
1904	28,500
1909	25,900
1986	25,600
1917	23,400
1927	22,900 *
1943	22,800
1911	21,900
1982	21,800
1913	21,200
1914	20,700
1928	20,700
1912	20,200

*Peak flows from normal snowmelt. In 1925, a landslide dammed the Gros Ventre River, forming a temporary lake. This dam broke in 1927, causing a peak flow in the Snake River greater than anything shown in this tabulation; however, a reliable estimate of that floodflow cannot be made.

No flood damage surveys or estimates of flood damages were conducted for any of the above-listed floods. The 1986 flood was contained in the project levees by an intensive flood fight effort.

(3) Preproject River Conditions. In the project area, prior to construction of the project, the Snake River flowed through a maze of braided channels with relatively shallow depths and with banks 1,000 to 4,000 feet apart. The Snake River's gradient in the project area is about 19 feet per mile. Therefore, relatively small flood stages resulted in high stream velocities. Damages began at flows as low as 5,000 cfs, and appreciable damages resulted from discharges of 8,000 cfs and above. Prior to construction of the flood control project, the spring floodflows caused extensive bedload movements and channel changes which endangered vast acreages of ranch land. Operation of upstream storage at Jackson Lake provided some benefits by reducing peak flood discharges in the project reach. However, the increased exposure of the riverbanks to erosion and possible avulsion from sustained moderately high reservoir releases was increased during the summer months. Bank protection was considered a necessity with the relatively high sustained summer flows that continued bank erosion. Construction of protective works consisting of cobble-filled timber cribs, gravel levees, and some stone revetment was undertaken by local interests (Teton County, the Wyoming Highway Department, and the Corps of Engineers) prior to 1955. While this construction prevented major avulsions, the work was not comprehensively planned or constructed to ultimately control the river. Early studies by the Corps of Engineers considered channel rectification by instream excavation and

a system of drop structures, groins, and revetted levees to control the Snake River in the project reach. While flood control could be maintained by instream excavation, an increase in stream velocities would result, aggravating bank and channel erosion. Drop structures would have reduced velocities, but would have been very expensive because of the width of the river. About six structures per mile would have been required to provide a drop of 3 feet per structure. Also, levees would have been required along both banks, and considerable maintenance would have been necessary to handle the bedload movement within the system. Use of a groin protection system would have required that it be supplemented by almost continuous levees to prevent flanking and overflow. The stabilization and stream confinement plan was recommended by the District and consisted of gravel levees protected with riprap. In 1955, the Corps of Engineers completed the study of flood control requirements for the area and formulated specific design criteria.

(4) Floodplain Development.

(a) The economy of the area was originally dependent upon cattle ranching. The lands within the floodplain were devoted to agricultural purposes, such as the production of hay for winter feed or for pasturing of cattle. In recent years, recreation and tourist trade has increased tremendously. The scenic beauty and recreational activities have lured many people to the Jackson Hole area. A sizable amount of the floodplain has been developed for rural residences. These residences are located primarily along the highway and between the J-W Bridge and the resort community of Teton Village. Seventy-five percent of the homes in the floodplain area are located north of the J-W highway and on the west side of the Snake River.

(b) Most of the floodplain is irrigated hay or pasture, but also contains numerous rural and farm residences, several small commercial businesses, a condominium complex that includes seven multifamily dwellings, and a few dude ranches. The total floodplain includes approximately 12,000 acres and is roughly 30 percent of the total private land in Teton County. Total value of the floodplain in 1974 was estimated by the Corps of Engineers to be $72.6 million, and in 1986 it had increased to nearly $200 million. Two highways are located in the floodplain, Highway 22 connecting Jackson and Wilson and the Teton Village Road (SR 390).

(c) The continued use of the floodplain is dependent on the integrity of the levee system. If the level of flood protection meets or exceeds the 100-year flood, the development of the floodplain area is expected to continue in much the same manner as it has in recent years.

(5) Significance of the Floodplain. The dramatic change in this area from a primarily agricultural economy, based on the production of livestock to an industry of tourism that continues to grow, emphasizes the importance of the floodplain area to the local economy. Thousands of visitors are drawn to this basin of scenic wonders for the summer

activities such as camping, golfing, fishing, boating, float trips, hiking, biking, horseback riding, and photography. The private economy of the area is largely based on supporting these activities. The combination of summer activities with the winter skiing and other seasonal activities provides a stability to all the support industries of transportation, food, lodging, and other basic services. Because of the limited land base, the floodplain area is needed to provide for development of homes for permanent residence as well as for development of facilities to accommodate tourism. Statistics maintained by the local chamber of commerce show projected population growth and tourist visitation as follows:

Population

	1960	1970	1980	1990	1995
Jackson	1,437	2,688	4,511	5,484	5,964
Teton County	3,062	4,823	9,355	16,594	20,743

Park Visitation - Recreational Only

Year	Grand Teton N. P.	Yellowstone N. P.	*Skier Days (3 Resorts)
1987	2,428,640	2,618,429	
1986	2,180,361	2,405,063	325,900
1985	2,130,210	2,262,455	290,000
1984	2,239,513	2,262,969	295,200
1983	2,571,204	2,405,653	287,900
1982	2,534,029	2,404,862	279,600
1981	2,653,381	2,544,242	240,200
1980	2,555,627	2,009,581	201,400
1975	2,807,027	2,246,132	195,000

* Represents season (Nov-Apr)

Note: The park services changed their method of visitation counting in 1983 or 1984 which accounts for most, if not all, of the decrease in visitations.

(6) Previous Studies. The flood-related problem on the Snake River in the Jackson Hole area has been the subject of several studies. The first survey report was published in 1942 and concluded there was no economically justifiable work. As a result of the increased development in floodplain areas, a 1947 survey report recommended the construction of the existing levee system. A general design memorandum proposing the existing levee system was published and approved in 1955. The levee system was constructed in six zones from 1959 to 1964 (Enclosure 1). A Rehabilitation Report for the existing system was submitted to higher authority in November 1969. The report was rejected in November 1972 by HQUSACE and a restudy was requested. This study was initiated in

July 1973, and a draft report was prepared by September 1975. A final report was not submitted to higher authority. Reviews of the draft report by NPD and HQUSACE concurred (with Walla Walla District) that the economic benefits could not support upgrading the total levee system, and there was no funding authorization to provide annual operation and maintenance funds. These O&M costs were left to the local sponsor, supported by Federal emergency funds as available.

(7) At the request of Teton County Commissioners, the Corps of Engineers is studying the non-Federal levees and unleveed reaches in the Jackson Hole area under the General Investigations program. A reconnaissance report furnishing results of preliminary studies is to be completed in May 1988.

d. Site Investigations.

(1) Project Familiarization Investigation. On 28 April 1987, a CENPW team consisting of the Chief, Plan Formulation Branch; Study Team Leader; and a representative from Geotechnical Branch visited the project for 2 days to review and become familiar with the project. This review included PL 84-99 rehabilitation of the levee system damaged by the 1986 flood.

(2) Conference on Jackson Hole Flood Protection Project. Walla Walla District hosted a 3-day conference at Jackson, Wyoming, with representatives from NPD and HQUSACE (1-3 June 1987) to discuss plans for implementing Section 840 of the Water Resources Development Act of 1986.

(3) Field Investigation with Hydraulic Consultants. On 30 June and 1 July 1987, District representatives met with hydraulic consultant Mr. C. R. Neill of Northwest Hydraulic Consultants; Mr. Sam Powell, Chairman of the Corps Committee on Channel Stabilization; and Mr. Howard Whittington, a member of the committee, to discuss the problems of the project and possible solutions relative to the river and a containment levee system. See final report, Enclosure 7, Appendix B.

(4) Meeting with the Committee on Channel Stabilization (CCS). District and NPD representatives met with members of the CCS during the week of 13-17 July 1987 to discuss methods of improving flood protection and reducing the maintenance cost of the project. See report in Enclosure 7, Appendix B.

2. Existing Flood Control Measures.

a. Overview. The original design of the Jackson Hole levee system provided for approximately 23 miles of revetted levee along the Snake River. The project begins 4 miles below the Snake River Bridge near Moose, Wyoming, and ends about 4 miles below the J-W Bridge. The levee design required the toe of the riprap to be 3 feet below the river thalweg, and the top of riprap was set on the basis of the performance of previously constructed gravel levees. (See Enclosure 5, Plate 10.) Subsequently, during flood fights and other emergency work, additional levees were built along the Gros Ventre River (between the mouth and the boundary of Grand Teton National Park), and the Imenson and Taylor Creek levees were built below the downstream end of the Federally constructed levees. These represent additions to the original project; however, they are intermittent, with unprotected gaps between the levee sections. See Enclosure 5, Plates 3 and 4, for levee locations.

b. PL 516 (FCA:1950) Authorized Levees.

(1) Construction of the Snake River flood control project at Jackson, Wyoming began in 1957, and it was completed in 1964. This project provided continuous levees on the right bank of the Snake River between River Mile (RM) 948 and RM 960.5. On the left bank, the project began at RM 948 and ended at RM 960.5 with no levees being constructed between RM 953 and 956.5. The revetted levees were intended to contain the standard project flood; 45,000 cfs below the mouth of the Gros Ventre River and 37,000 cfs above. The location of the levee system was generally adjacent to the main channel and slightly set back to avoid underwater excavation of the riprap toe trench. The distance between the levees was established at approximately 1,000 feet, as compared with the natural channel width of 1,000 to 4,000 feet.

(2) The levee section consisted of a lower riprap section with the upper portion of the levee protected by a cobble zone placed on a 1V on 4H slope. The typical project levee section is shown in Enclosure 5, Plate 10. The levees were designed with the intent of providing 3 feet of freeboard for the project flood. However, water surface measurements and studies performed by the District indicate that local anomalies in the water surface elevations caused by debris, divided flow, and bedload movements will result in little or no freeboard in localized areas. The intent of the original design was to match the water surface of the 15,000-cfs flow with the top of the riprap.

(3) The riprap toe was set 3 feet below the thalweg. The thalweg was established based on the lowest points of the stream as determined from preconstruction surveys. The riprap section consisted of stone having a minimum weight of 20 pounds, a maximum weight of 400 pounds, and at least 75 percent of the stones were to weigh 100 pounds or more. Between RM 948 and RM 951.3, on the left and right banks, the riprap was to have an average size of 250 pounds with 8-inch-minus material to be removed. A number of reaches have been observed where the weight of the riprap is significantly lighter than was required by the contract, and subsequent

erosion damage of these areas has been noted in previous reports 1 and 2 below. The riprap used in the original construction was obtained from two andesite porphyry sources which were located on the West Gros Ventre Butte. The principal quarry was located on the left bank of the Snake River adjacent to the J-W Bridge in the southwest quarter of Section 24, T. 41 N., R. 117 W. The second quarry was located on the left bank of the Gros Ventre River at its confluence with the Snake River in the southwest quarter of Section 5, T. 41 N., R. 116 W. Significant chemical and frost deterioration of the original riprap has been observed in some areas. The amount of deterioration varies considerably from one location to the next; but on the average, the deterioration amounts to approximately 5 percent of the riprap section.

c. Non-Federal Flood Control Projects.

(1) Non-Federal projects are projects in which either the entire project or a component thereof are constructed with other than Federal funds. A project constructed under Federal emergency disaster authorities, such as PL 84-99 or PL 93-228, is a non-Federal project unless it was constructed as a replacement for a damaged Federal project. Such a project is not constructed to the design standards imposed on a normal construction project.

(2) Many of the non-Federal levees along the Snake and Gros Ventre Rivers in Teton County were constructed by the Corps of Engineers during emergency operations under PL 84-99. Other Federal involvement has been by the Corps of Engineers' Operation Foresight and by the Soil Conservation Service. The Wyoming Department of Transportation, Department of Game and Fish, and Teton County also have contributed to the construction and/or improvement of the non-Federal levees described in the following paragraphs. Refer to Enclosure 5, Plates 2, 3, 4, and 9 for locations of the non-Federal levees.

(a) The 95 Ranch levee is on the left bank of the Snake River near RM 963. It is approximately 1,800 feet long with approximately 500 feet revetted. It was constructed by the Corps of Engineers and Teton County during a flood fight in May 1975.

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1. "Snake River Bank Stabilization, Idaho and Wyoming," by Leland B. Jones, a paper presented at the ASCE Transportation Engineering Conference, Minneapolis, Minnesota, May 1965.

2. "Rehabilitation Report, Jackson Hole Flood Control Project," U.S. Army Engineer District, Walla Walla, Washington, November 1969.

(b) In 1968, an unnamed non-Federal levee was built by the Corps of Engineers and Teton County as an extension downstream from RM 948 on the left bank. It is approximately 1,500 feet long and is revetted its entire length.

(c) The Upper Imenson levee was also constructed in 1968 by the Corps of Engineers and Teton County. It begins immediately downstream from the unnamed levee mentioned above and extends downstream for over a mile. Originally constructed as a setback levee, much of it was not revetted during construction. Over half of its length is currently revetted due to changes in the river channel which brought flows adjacent to the levee. Blue Crane Creek flows into the Snake River between the Upper and Middle Imenson levees.

(d) The lower 4,000 feet of the Middle Imenson levee was constructed by the Corps of Engineers as a clearing and snagging (Section 208) project in November 1967. Revetment was added to the upstream 1,800 feet in the spring of 1969 under Operation Foresight. In 1971, also under Operation Foresight, revetment was added to the remaining 2,200 feet. During a flood fight in 1972, this levee was extended and revetted for 1,000 feet on the upstream end. Crane Creek flows into the Snake River between the Middle and Lower Imenson levees.

(e) The Lower Imenson levee was constructed by the Corps of Engineers and Teton County during a flood fight in 1971. It is approximately 2,800 feet long and revetted its entire length.

(f) In 1956, 800 feet of the Upper Taylor Creek levee was constructed on the right bank by the Corps of Engineers and Teton County. The following year, it was extended 1,500 feet and revetted.

(g) Also in 1956, 1,500 feet of the Middle Taylor Creek levee was constructed on the right bank. During flood fights in 1975 and 1982, another 1,500 feet and 500 feet, respectively, were added. The lower 500 feet (the 1982 construction) has been destroyed and not replaced. All work on this levee was a joint effort between the Corps of Engineers and Teton County.

(h) The Lower Taylor Creek levee was constructed on the right bank by the Corps of Engineers and Teton County under Operation Foresight in 1971. It is 800 feet long and revetted its full length. The only return to this levee has been during a flood fight in 1973.

(i) In 1977, the Corps of Engineers was contracted by the Soil Conservation Service to place approximately 3,000 feet of bank protection along the right bank of the Snake River near RM 942. Very little of this project remains today.

(j) During a flood fight in 1975, the Spring Creek levee was constructed by the Corps of Engineers and Teton County. In 1977, it was reconstructed by the Corps under contract with the Soil Conservation Service. There has been no Corps involvement at this location since then.

(k) Very little is known about the State Game and Fish Intermittent levee. At one time, it was a continuous levee, believed to have been constructed by the Wyoming State Highway and Game and Fish Departments to protect the elk feed grounds and to prevent the Snake River from flowing into Flat Creek and threatening the Flat Creek highway bridge. There has been no Corps involvement on this levee.

(m) The South Park levee was constructed by the Corps of Engineers and Teton County during a flood fight in 1974. It has been repaired only once--during a flood fight in 1975. It is 1,000 feet long and revetted full length.

(n) The State Highway Department levee extends 400 feet upstream from the Snake River Bridge. There has been no Corps involvement on this levee.

(o) The upstream 3,000 feet of the Evans levee was constructed by Teton County in 1965. In 1969, it was extended 3,500 feet by the Corps and Teton County under Operation Foresight. In 1976, it was extended another 1,000 feet by the Corps under contract to the Soil Conservation Service. There has been no Corps involvement in this levee since then.

(p) The Nelson levee is situated along 5,000 feet of the right bank of the Gros Ventre River. It was constructed in 1956 and 1957 by the Corps of Engineers and Teton County.

(q) The Hansen and Lucas levees below the Cattleman's Bridge were also built in 1956 and 1957 by the Corps and Teton County along 9,000 feet of the left bank of the Gros Ventre River opposite the Nelson levee. The Lucas levee also was extended 300 feet upstream from the bridge. In 1971 and 1972, the Lucas levee was extended 3,500 feet to tie to high ground adjacent to Grand Teton National Park.

3. Project Adequacy.

a. Existing Levee Conditions.

(1) General. Erosion protection for the existing levee system was based on assumed channel velocities and water surface profiles which have proven to be inaccurate and have, therefore, resulted in inadequate riprap sections that have incurred substantial damage. Approximately one-third of the levee system has been damaged and has required repair at least one time. During a given flood event, the damage has generally occurred at several localized areas which extend up to 400 feet in length and are distributed throughout the entire levee system. The degree of

damage or the incidence of repeated damage varies over the length of the project. There are significant reaches of the levee system where little or no damage has occurred since construction. Tree growth on adjacent islands indicates that these reaches are relatively stable and protected. For example, the right bank of the levee section between stations 20 and 129 of the L_1 levee has not required repair. A portion of that levee section is effectively being protected by a groin. Other areas of the levee system have infrequent damage or the repair from one year may be followed in subsequent years by extensions of the earlier repair. Several reaches of the levee system have required repeated repair. The repair history of these areas indicates that although the river may temporarily shift its alignment away from the levees, it will repeatedly return and damage these sections. The recorded reaches of concentrated damage are as follows:

Left Bank Station	Right Bank Station
50-70	100 (L_1)
80-105	79-85
115-220	255-265
520-530	285-297
570-590	480-500
672-678	585-590
750-765	

Plates 2 through 9 (Enclosure 5) indicate the areas of rehabilitation work and the dates of repair.

(2) PL 84-99 Repair Work.

(a) Background. Following construction of the levee system, flood fighting and rehabilitation have been performed on a nearly annual basis. Small local areas of flood damage have been repaired year by year, as required. This results in a patchwork appearance in intensively repaired areas. For example, a 100-foot reach of levee may have been repaired in 1975 and have a riprap section and condition that was different from the adjacent 200 feet of levee which was repaired in 1985.

(b) Riprap Section Configuration. The riprap material extends nearly to the top of the levee section in areas of flood fighting. Where rehabilitation has been performed, the lower riprap section, in some cases, has been extended to a higher elevation than the original riprap section. In recent years, the PL 84-99 rehabilitation work has attempted to place the toe of the riprap to a depth of 5 feet below the river thalweg. In some instances, the excavating equipment was not capable of excavating and placing to this depth because of the height of the levee. Additionally, when work was performed during flood fights, excavation of the toe trench was hindered by high water. In these areas, the toe of the riprap section may have been placed at the thalweg bottom. Until 1980, the PL 84-99 rehabilitation used riprap sizes similar to that used in the original construction work. The following table shows the riprap gradation cited in the PL 84-99 rehabilitation reports:

Percent Passing	Stone Size by Weight (lbs.)
100	400-700
50	200-300
15	60-200

In 1974, field measurements of local velocity and water surface elevations, taken at impingement locations, indicated that a substantially larger riprap size was necessary to resist the erosive forces. As a result of the 1974 investigation, recommendations were made to increase the size of riprap stone used in PL 84-99 repairs. The riprap gradation cited in the 1980 PL 84-99 reports was changed to the following gradation and the repair section as shown in Enclosure 5, Plate 11:

Percent Passing	Stone Size by Weight (lbs.)
100	2,200-880
50	400-650
15	140-320

(c) Riprap Variation from Specifications. The PL 84-99 riprap material does not necessarily correspond to the gradations shown above for three reasons: (1) inadequate quarry sources; (2) problems associated with placing material during high flows; and (3) intentional segregation of the riprap stones. It is very difficult to find good sources of high quality riprap material in the Jackson, Wyoming, area. The quarry areas used to produce riprap for the levee repair have often had zones of flow structure or natural cleavages which cause the material to break into smaller sizes. Additionally, large quantities of fine-grained materials are often present in the quarry areas (see Enclosure 4, Photograph 1). When work is being performed under inclement weather conditions (which typically is the case), the fine-grained materials freeze or clog the processing equipment. This condition results in the inclusion of substantial quantities of fine-grained or undersized rock materials in the riprap material (see Enclosure 4, Photographs 2 and 3). The variation in quality of the riprap material is made worse by the variation in the riprap source from one year to the next. The riprap quarry sources have changed a number of times as a result of depletion of a quarry area or because of the expense associated with the royalty payments for certain quarry areas. The inplace riprap also varies from the specified gradation because of segregation of the riprap stones during placement. The PL 84-99 rehabilitation work has placed very large stones (up to 5,000 pounds) in the toe area of the riprap section in an effort to achieve a more permanent repair in extremely severe impingement areas (see Enclosure 4, Photograph 4). The remaining smaller stones are placed on the upper portion of the slope. The larger stones are more difficult to place and rework to form a uniform, smooth riprap section; and, as a result, the PL 84-99 rehabilitation riprap section often has large voids and ragged slopes (see Enclosure 4, Photographs 5 and 6). While the toe section of some of the PL 84-99 rehabilitation work may have an average size of between 100 and 600 pounds, the majority of the riprap section consists of stones having an average size of 100 pounds or less.

(3) Typical Levee Damage.

(a) Impingement Conditions. The majority of damage to the levee section occurs on the recession of the flow peak when debris and gravel bedload restrictions clog the main channel and the riverflow is forced against the levee at sharp impingement angles. The impingement area typically is subjected to localized increased water surface elevation and increased velocities. Enclosure 2, Table 2, shows the measured velocities at impingement locations for a flow of 13,790 cfs. The measured velocities indicate that velocities of 10 feet per second (fps) are common at the impingement areas; and, in some cases, velocities of 10 fps have been observed immediately adjacent to the riprap toe. The velocities shown in Table 2 do not reflect the turbulent conditions present at the impingement locations. Instantaneous velocities of up to 16 fps have been observed at the impingement areas. These instantaneous velocities were sustained for 30 seconds or longer. It is not known if the instantaneous velocities adjacent to the riprap toe were as high as 16 fps, but observers who were present during the measurements indicate that the velocities adjacent to the toe were significantly higher than 10 fps.

(b) Cobble Zone. The riprap section has been overtopped in localized reaches. The locations of the overtopping vary depending on debris obstructions and divided flow channels of the river that can occur at relatively low flows. The levee's upper zone of cobble protection has been designed to protect against limited or intermittent riverflows (12,000 cfs above Gros Ventre and 15,000 cfs below Gros Ventre), and significant damage occurs when it is subjected to prolonged flooding. The extent of overtopping varies each year, but significant damage repairs have occurred since construction of the project. When the cobble zone is inundated, the 1V on 4H levee slope progressively erodes, leaving a flat, nearly horizontal bench at the top of the riprap section. This bench generally varies from 6 to 8 feet in width, with extremes of approximately 12 feet in areas of more severe impingement or prolonged flooding.

(c) Riprap Damage.

1. Three types of riprap damage have been observed for the original construction and the PL 84-99 rehabilitation work. Areas of riprap damage vary in condition or degree of riprap loss--from oversteepened slopes which are scarped abruptly at or below the low water line--to total loss of the slope protection which exposes the underlaying gravel embankment materials. In some areas, damage or failure of the riprap section

has been of a progressive nature. This type of riprap damage is typical of less severe impingement areas or of areas at which the riverflow is parallel to the levee section. The smaller individual riprap stones are moved out of the riprap section during floodflows, thinning the section and oversteepening the riprap toe. The undersized stones are first removed, leaving behind the larger stones. Because the undersized material often comprises a significant portion of the riprap section, the resulting riprap surface is left in a ragged and rough condition. This roughened surface increases the turbulence and shear stress on the riprap section and induces further erosion. Enclosure 4, Photograph 7, shows an originally constructed riprap section which has been progressively eroded and oversteepened at the toe.

2. The second type of riprap damage consists of severe erosion of the riprap section during the course of a single flood event. This type of damage is typical of direct impingement areas. As with the first case, the smaller stones are eroded first, leaving only the larger material. In some areas, the undersized materials or fine-grained materials have prevented adequate contact between the large stones; and, as the soil and undersized materials are removed by scour, the larger stones are undermined and allowed to move (see Enclosure 4, Photograph 8). A significant portion of the levee system having large stones placed at the levee toe incurred damage during the 1986 flood because of the undersized and fine-grained materials being included within the riprap section (see Enclosure 4, Photographs 9 through 11). These sections of riprap failures are believed to be the result of removal of smaller riprap stones from the levee slope rather than undermining of the levee toe by riverbed scour.

3. The third type of levee damage consists of the erosion of the riverbed materials from under the riprap toe. This erosion results in undermining and failure of the riprap section. The originally constructed riprap section was toed 3 feet below the river thalweg. The PL 84-99 rehabilitation has attempted to place the riprap toe section 5 feet below the channel bottom, but because of high water conditions or higher embankment sections, this has not always been accomplished. Therefore, it is likely that some of these riprap sections will be undermined during flood events. Also, 5 feet of toe burial depth may not be adequate at severe impingement locations. Thalweg measurements were taken at impingement points in the fall of 1967 and 1973 after a peak spring runoff of 13,000 and 15,900 cfs, respectively. The results of the thalweg measurements are summarized below and show depths below the average thalweg profile:

	1967 Measurements (ft.)	1973 Measurements (ft.)
Maximum Depth	12	6
Average Depth	4	3

The measurements were taken during low flows in the fall and some back-filling of the scour holes may have occurred following the spring flood event. The measurements indicate that the riprap section, as originally constructed, was not toed in sufficiently. The measurements also indicate that the PL 84-99 rehabilitation repairs may not be sufficiently toed in at severe impingement locations.

(4) Evaluation of Existing Riprap Sizes.

(a) The original contract specifications and the PL 84-99 construction required that the existing riprap material have an average size stone ranging from 200 to 650 pounds. However, the placement of significant quantities of undersized and fine-grained materials in the section has reduced the average size of the existing riprap material to approximately 100 pounds. The PL 84-99 construction since 1980 has attempted to place larger stones in the toe sections of the more critical areas. However, the effectiveness of these larger stones has, in many cases, been negated by including undersized and fine-grained materials which have prevented contact between the larger stones (see Enclosure 4, Photographs 12 and 13). In general, the use of undersized material has reduced the average size of the riprap or has reduced its effectiveness so that it is not adequate to withstand the erosive forces at severe impingement locations. Where the riverflows are parallel to the levee, the existing stone size appears to be adequate in most areas.

(b) The required riprap size, as determined by the design equations shown in ETL 1110-2-120, "Additional Guidance for Riprap Channel Protection," has a D_{50} minimum of 85 pounds. This was based on the observed point velocity at impingement locations of 10 fps, 1 foot above the riprap toe. The increased riprap size which would be required as a result of the turbulent conditions may be indicated by the instantaneous velocities, which are considered to be high. If they were 16 fps and were immediately adjacent to the riprap toe, a D_{50} minimum size would be 6,900 pounds. The CCS, during a recent site visit, stated that the design equations presented in ETL 1110-2-120 and EM 1110-2-1601 are not applicable because of the extremely turbulent conditions at the impingement locations. Therefore, the riprap sizes determined by these equations are in question.

(c) It is difficult to determine an adequate riprap size based on the observed performance of the existing riprap. The construction inspectors and the local flood control levee superintendent believe that the riprap material placed in the toe of the levee section in the severe impingement locations should be in the size range of 1,000 to 2,000 pounds. Remedial repairs have been made using stones up to 5,000 pounds. However, the roughness of the surface of these sections increases the turbulence and shear stresses on the riprap. Additionally, the riprap section often contains large quantities of undersized materials which prevent contact between the large stones. This type of construction facilitates the failure of the slope protection and gives a misleading indication that even larger stone sizes are required. A riprap section constructed of smaller stones of proper gradation sizes should perform better than the sections having extremely large stones in the toe (see Enclosure 7, Appendix B, CCS report). This statement is supported by the fact that existing riprap sections having D_{50} stone sizes of 350 pounds and having little undersized or fine-grained materials separating the larger stones have successfully survived moderate impingements with minor damage (see Enclosure 4, Photograph 14). Failures of riprap sections having larger stone sizes than 350 pounds do occur; however, in these areas, undersized and fine-grained materials have been present and have prevented interlock between the specification size stones. Because of the increased turbulence and shear stress associated with the larger riprap stone in the toe sections and the undersized and fine-grained materials which prevent contact between the proper sized stones, it is difficult to evaluate the performance of the existing riprap and precisely determine the required size. Based on the performance of the existing riprap, the D_{50} minus size should be between 350 and 2,000 pounds.

(d) In summary, the velocity measurements performed in 1974 indicate, on the average, that erosive conditions within the levee system are not severe. However, there may be instantaneous velocities that produce extremely erosive conditions. The areas of extreme erosive conditions is in agreement with the opinion of the PL 84-99 inspectors and the local levee officials who advocate using an average riprap stone size of 1,000 to 2,000 pounds in the toe of the riprap section. On the other hand, the existing riprap sections have significant quantities of undersized materials that decrease the effectiveness of the riprap section, and it has been observed that well constructed riprap sections having average riprap stone sizes of 350 pounds can successfully resist moderate impingement flows. Therefore, the average riprap size required to resist the erosive conditions at impingements is uncertain, but the existing riprap material is not adequately sized nor is the riprap section properly constructed to resist the erosive forces in areas of direct impingement. Also, the toe section of the existing riprap in some areas may not be of sufficient depth below the river thalweg to avoid undermining by scour.

b. <u>History of Levee Maintenance Costs</u>.

(1) Past project history has shown the high cost of the flood protection provided by emergency flood fights and rehabilitation after high flows. Total outlays by public agencies since 1964 have been $9,395,658 in 1986 dollars. More than $6.25 million has been paid by the Government.

(2) Enclosure 2, Table 3, lists all the known costs for flood fight, rehabilitation, and advance measures since the Federal levees were completed in 1964. Costs have been adjusted to 1986 dollars. Annual costs have averaged more than $400,000 over the past 23 years.

c. Flood Protection Levels.

(1) Original Design of Federal Levees. The Federal levees forming the Jackson Hole flood control project were originally designed for a standard project flood discharge of 37,000 cfs upstream of the Gros Ventre River and 45,000 cfs downstream. A 3-foot freeboard was included in the design. Top of riprap was designed for flow levels of 15,000 cfs below and 12,500 cfs above the Gros Ventre River. Since the levees were completed in 1964, there have been eight years when the flows exceeded 16,000 cfs, including 1982 (21,800 cfs) and 1986 (25,600 cfs); and, the levees have not been overtopped. There has been at least one levee failure caused by erosion and numerous flood fights to prevent additional levee failures.

(2) Non-Federal Levees.

(a) The exact level of protection provided by the non-Federal levees has not been determined. The levees are not continuous and are not designed to be at a consistent profile or orientation with respect to the active meander belt. Although the levees have provided protection for some areas, other areas have failed during past floods. Due to discontinuities and variations in construction, the protection provided by these levees depends, to some extent, on the location of the braided channels during a flood event.

(b) A General Investigations study is currently evaluating the flood protection levels of the non-Federal levees. This information will be used to determine the average annual benefits and the average annual costs of maintenance. This data will be used as the means to evaluate the specific levee reaches that will be recommended as additions to the Federal levee system for continued operation and maintenance funding.

(3) Current Conditions. The 1986 flood filled the channel area within the levees with undermined trees and other debris. Because of this debris, the risk of levee failure from impingement flows during floodflows is substantially increased. The problem of debris within the channel is considered to be a continuing major threat to the integrity of the levee system.

4. Flood Damages and Flood Control Benefits.

a. There are three distinct reaches that will be considered for Federal maintenance: (1) the original Corps-constructed levee project; (2) levees constructed by non-Federal interests on the lower Gros Ventre River; and (3) levees constructed by non-Federal interests on the Snake River downstream of the Corps project.

b. Information on areas protected by non-Federal levees is lacking. This information will be obtained in the current General Investigations study of Snake River in Wyoming. That information will be used to determine if the non-Federal levees, or parts thereof, should be included in a Federal maintenance program.

c. Property values and flood damages available from past studies of the Federally constructed levees have been updated to current price level and converted to average annual damage using the most recent flow-frequency curve. Value of property and average annual damage in various categories is shown below:

Table of Damages and Values
($1,000)

	Federal Levees	
Damage Category	Value	Average Annual Damage
Residential & Misc. Structures	$ 30,143	$2,531
Transportation & Utilities	4,210	668
Agriculture (Incl. Land)	125,385	1,146
Emergency	-	143
Other (Incl. Fish Habitat)	-	287
Total	$159,738	$4,775

d. Prior studies assumed that local efforts would provide protection against flows of approximately 12,000 cfs on the Snake River upstream of the Gros Ventre River and 15,000 cfs downstream of the Gros Ventre River in the absence of Federal assistance. This is the 2-year flood (exceedence probability 50 percent). This is assumed to be the without-project condition. Average annual remaining damage in the without-project condition for the Federal levee is $2,579,000. The original project for the Jackson Hole area was designed to provide standard project flood level protection (45,000 cfs on the Snake River below the Gros Ventre River and

37,000 cfs above the Gros Ventre River). If the levees were to be reconstructed and maintained to provide that level of protection and comparable levee capacity was provided at the non-Federal levees along the lower Gros Ventre River, essentially all flood damage would be prevented in those areas (up to the exceedence probability of 0.001). The average annual benefits of 50-year flood protection and 100-year flood protection are $2,070,000 and $2,492,000, respectively.

5. PL 99-662 Requirements.

a. Project Limits.

(1) General. The limits of the proposed project will be the Federally constructed levees and those additions that provide the needed flood flow protection and economic benefits to justify their inclusion. In discussions, the local sponsor (who was instrumental in the development of the law) insists the intent is to provide levee maintenance for the entire river reach from Grand Teton National Park to the (U.S. 89/187) highway bridge near the mouth of Flat Creek. The data to evaluate the benefits of additions to the Federal system will be provided by the ongoing General Investigations study.

(2) Federal Levees. The levees begin at the upstream end at approximate RM 960, which is approximately 4 miles downstream from the Moose, Wyoming, highway bridge crossing, thence downstream along the banks of the Snake River to approximate RM 948. This point is about 3.5 miles downstream of the J-W Bridge. This is the total levee system authorized in PL 81-516.

b. Non-Federal Requirements.

(1) Cost Sharing. The PL 99-662 legislation provides that the non-Federal sponsors shall pay the initial $35,000 in cash or materials of any such cost expended in any one year, plus inflation as of the date of enactment of the act (17 November 1986). It is proposed that inflation be indexed from the Corps of Engineers Civil Works Construction Cost Index, System Category 11-A Levees--all earthwork. The average FY 86 index for that category is 365.02. The same index for FY 87 is 370.07, resulting in an inflation factor of 1.01384.

(2) Real Estate. The county shall acquire all lands, easements, and rights-of-way including suitable borrow sites and dredged material disposal areas necessary to accomplish the work on the project.

(3) Local Cooperation Agreement (LCA). A draft LCA for the project will be included in the next study submitted. An interim LCA will be negotiated with Teton County that will support the continuing maintenance costs and be aligned to accomplish priority work items defined later in in this report.

6. Design Considerations.

a. Design Flow.

(1) Past experience has indicated that the existing Federal project levees can be expected to contain the 100-year flood with an effective maintenance program in conjunction with flood fight activities. Walla Walla District has assured FEMA that the Federal project levees are adequate for 100-year flood protection if they are adequately maintained. Largely because of the levees, the value of the floodplain area has risen very substantially. In comparing 100-year flood control benefits to original project design level benefits, there is less than 1 percent increase in benefits. This is because a relatively small increase in water surface profile occurs as the discharge increases near the 100-year flow level. For these reasons, it is recommended that the 100-year floodflows of 22,900 cfs above and 28,600 cfs below the Gros Ventre River be used for design flows for the Federal levees. For the non-Federal levees, additional data will be provided by the General Investigations study to identify the appropriate level of protection that might be expected.

(2) A stream gauging station is required on the Gros Ventre River to provide adequate information for project maintenance. Only 14 years of records (1945-1958) are available. In the future, a longer data base and continuous flow data records are needed to improve estimates on the present level of protection and future levee maintenance requirements, to analyze river morphology, to assist in the flood control operation of Jackson Lake, and to attempt to correlate damage from future floods with the river discharge. The CCS, in its 1987 report on Jackson Hole levees (Enclosure 7, Appendix B), recommended the maintenance of a stream gauging station on the Gros Ventre River.

b. Jackson Lake Regulation.

(1) General.

(a) Jackson Lake was originally a natural lake impounded behind the terminal moraine of an ancient glacier. In 1907, construction was completed on a temporary timber crib dam to provide 200,000 acre-feet of additional storage for irrigation. A permanent earthfill dam with a concrete section was completed in 1911; and in 1917, the dam was reconstructed to its present level. Rehabilitation of the earthfill portion of the dam is presently in progress. When completed, the project will operate at previously authorized levels. Between minimum (elevation 6730) and normal pool (elevation 6769), the reservoir will have a capacity of 847,000 acre-feet of storage. Both Jackson Lake and Palisades Reservoir (filled in 1958) are irrigation projects operated by the Bureau of Reclamation. Palisades has joint-use space allocated for flood control. Although the reservoirs can be drawn down for flood control during the winter, they generally are refilled during the early irrigation season. Between 1907 and 1956, Jackson Lake was used exclusively for irrigation storage with only incidental flood control regulation. In 1956, an agreement between the Bureau of Reclamation and the Corps of Engineers provided that 25 percent of the flood control space reserved in Palisades Reservoir was transferable to Jackson Lake to provide increased regulation of floods between the two projects. The objective of the present operation is: to provide specified flood protection below Palisades--while limiting flows to a maximum of 20,000 cfs, when possible. In Jackson Hole, flows can exceed this limit (increasing until they reach the level of the inflow) since the primary objective is below Palisades.

(b) Several factors limit the amount of flood regulation that can be achieved by Jackson Lake operation: (1) irrigation has priority over other uses, and the amount of flood control space available depends on the amount of carryover storage as well as the runoff forecasts; (2) an attempt to reduce flood peaks downstream of Henrys Fork in the Idaho Falls area is the primary objective which often results in less than optimum flood control in the Jackson area; and (3) only one-third of the area and an estimated maximum of one-half of the flow at the Flat Creek gauge in Jackson Hole are controlled by Jackson Lake. (The maximum flow of record at Moran is only 15,000 cfs, while the maximum flow at Jackson during the same period was 32,500 cfs.)

(2) Flow Duration. Regulation of floodflows reduces the peak discharge but increases the duration of high flows. Sustained high flows near bankfull (about 11,000 cfs) probably contribute significantly to bank erosion problems. Based on records from 1973 through 1986, sustained flows exceeding 11,000 cfs occur an average of 4 weeks each year (see Enclosure 2, Table 4).

(3) Frequency Curves. Regulated frequency curves were developed in 1975 using the regulation criteria and theoretical maximum reduction in natural peak flows that could be achieved through regulation of Jackson Lake. Actual experience has shown this degree of regulation was not achieved. Consequently, new frequency curves have been developed based on 31 years of experienced operations and realistic assumptions on how much reduction could be achieved by Jackson Lake during major floods. These curves are included in this report. It should be noted that the 1986 flood (25,600 cfs) was about a 50-year event. Discharges for the 100-year event are 22,900 cfs upstream (see Enclosure 3, Chart 1) and 28,600 cfs downstream (Enclosure 3, Chart 2) of the Gros Ventre confluence. Although a gauge does not presently exist on the Gros Ventre River, a frequency curve based on a 14-year record has been developed (see Enclosure 3, Chart 3). The 100-year flood discharge (7,400 cfs) is based on this record.

(4) Flood Control Agreement. Coordination between the Corps of Engineers and the Bureau of Reclamation concerning the operation of Jackson and Palisades is ongoing as part of the flood control process. There may be some opportunity to obtain better control on the moderately high floods as procedures and hydrologic data improve, but for the extreme events (50-year floods and above) there appears to be little opportunity

for improvement within the constraints of the authorized function of the Jackson Lake and Palisades projects. Consequently, without additional storage on the system there does not appear to be substantial potential for further reduction of major floods below those indicated on the frequency curves.

c. Channel Stabilization.

(1) The present channel is braided and unstable through the entire study reach, both on the Snake and Gros Ventre Rivers. The braided condition increases the difficulty of calculating both the design profile and the destructive hydraulic forces produced by impinging forces on the levee riprap protection. If the main river channels could either be stabilized or the points of impingement could be predicted, proper design of the levee protection would be much easier.

(2) The present valley floor consists of glacial outwash gravels and alluvial materials brought in by tributary streams. The underlying rock is faulted along the eastern face of the Teton Range and slopes downward toward the west. Since the surface terraces also appear to be sloped in the same direction, there is a possibility that the valley floor may still be tilting. The Snake River has entrenched deeply into the outwash deposits upstream of the project, while downstream convex valley cross sections and streams which turn abruptly downstream on entering the valley suggest aggradation. The effect of outwash from the Gros Ventre River is uncertain. Geomorphic indicators, such as changes in slope, bed material size, or fan-gravel encroachment at the confluence are either lacking or too small to demonstrate a significant influence from the Gros Ventre River. In 1925, a portion of the valley wall along the Gros Ventre River failed and the resulting slide dammed the river to form Lower Slide Lake. The slide dam failed in 1927 and the subsequent flood carried a considerable amount of debris into the Snake River.

(3) A large amount of literature has been written on the geomorphology of the region. A review of this material, combined with the opinions of experts in fluvial geomorphology may give additional understanding of the processes forming the valley and river. However, the primary concern is what is presently influencing the behavior of the Snake River within the limits of the Federal project and nearby non-Federal levees. Sediment ranges were established along the Federal levees in 1954 and were resurveyed in 1967 and 1973. A resurvey of these ranges after the large flood in 1986 would be useful in studying aggradation or degradation trends. Based on surveys performed between 1954 and 1973, there has been a small amount of degradation averaging less than 1 foot of bed depth, with the greatest amount occurring downstream of the Gros Ventre confluence. A tabulation of changes in selected sediment ranges is found in Enclosure 2, Table 5.

(4) Recently, Mr. Charles R. Neill, a consultant on gravel streambeds, was retained to review the overall situation. The Corps CCS also provided advice in 1974--and, again, in 1987.

(5) Several suggestions that were made are as follows:

- Review the reach of the river near Moose Bridge to determine why it is stable and confined to a single channel.

- Review past maps and photographs of the river to determine whether changes in the braided channel (impingement points particularly) can be predicted.

- Resurvey sediment ranges to determine if trends toward progressive aggradation or degradation can be identified.

(6) Past changes in the braided channel patterns are presently being reviewed. Observations to date, based on aerial photographs and U.S. Geological Survey maps dating back to 1899, depict a braided channel with randomly changing patterns. The channel appears to change course by avulsion or by a major channel shifting into a minor channel, rather than the progressive bank erosion and point bar building associated with a true meandering channel. Additional review will be required to determine whether the active meander belt is remaining in a relatively stable location.

(7) The District plans to initiate studies under the scheduled maintenance program to predict areas that will suffer damages from shifting impingement flows or other potentially damaging conditions. The District will also review the feasibility of attempting to force the river into a stable meandering pattern, or at least to direct the flow at specific locations with groins or other structures to limit the length of levee subject to damage.

(8) The CCS has suggested that we should collect samples of the bed material and perform grain size analysis (see Section 4.9 of their report). Representative bed material and armor layer samples are needed for any geomorphic analysis of the river system. Armor layer samples and bulk gradations are needed to determine the size of material being transported in different reaches and to determine potential depths of channel degradation for alternative levee designs.

d. <u>Relocation or Realignment of Non-Federal Levees.</u> Typically, the non-Federal levees on the Gros Ventre and downstream of the project have developed over the years from blocked channels, clearing and snagging projects, and flood fights. The majority of the levees are disconnected, and some of them are set at a sharp angle to the streamflows. In some cases, the levees appear to extend far into the active meander belt of the Snake River. The desirability of relocating or realigning the non-Federally constructed levees is being investigated in an ongoing reconnaissance study being conducted under the General Investigations program for this portion of the Snake River Basin. Normal non-Federal cost sharing and other requirements associated with flood control projects would be required for any levee relocation proposal that may result from that study.

e. Levee Protection.

(1) Improved Erosion Resistance.

(a) General. The existing riprap section provides reasonable protection for parallel flow conditions, but is considered to be inadequate for protection against erosion at direct impingement locations. The proposed studies will investigate various alternative designs to provide improved erosion resistance. Economic analysis of alternatives will be accomplished to determine the cost effectiveness of the different alternative designs. Both construction maintenance costs will be considered. The study will evaluate improving the entire levee system, as well as improving those areas which incur frequent damage. There may be more benefit to providing improved erosion resistance in those areas which are frequently damaged or which are the most critical for protection. Additionally, the cost effectiveness of repairing only the damaged portion of the levees following a flood event will be evaluated. The improved erosion resistance study will include the use of synthetic materials such as concrete, gabions, and grouted riprap, as well as a suitably graded riprap material.

(b) Improved Riprap Section. The erosion resistance of the riprap section can be improved by using a suitable sized riprap and by improved processing, placement, and keying of the riprap stones. As has been previously described, placing and keying of the riprap should be improved by performing the work under summer weather conditions and removing the soil and undersized materials. These simple construction changes will significantly improve erosion resistance of the riprap section; however, to eliminate future damage of a repaired section or reduce the costs of repeated repairs, additional improvements using the appropriate sized stones in the repair section will be required.

(c) Study Plan. The present design criteria are not applicable for sizing the riprap stones for turbulence conditions which exist at this project (see Enclosure 7, Appendix B, CCS report). The proposed plan of study for determining the appropriate riprap stone size will consist of observing the performance of existing riprap sections and evaluating the level of damage associated with a riprap stone size. To properly evaluate the performance, the properties of the existing riprap sections must be cataloged. This will include: size of the riprap, type of rock material, keying of individual riprap stones, and the presence of voids or soil which prevents contact between stones. Additionally, the history of flow impingements and the severity of those impingements will be studied from available photographs. The effectiveness of a particular riprap section will be evaluated by measuring the extent of damage against the impingement conditions and the properties of the riprap section. In addition to evaluating the existing riprap sections, the performance of future repair work will also be monitored and evaluated. The initial maintenance repair work will be performed using an average riprap stone size of 500 pounds. If this riprap section is observed to be inadequate, future repair work will use larger stone sizes. The effectiveness of this study is dependent upon the knowledge of existing riprap section properties and the accurate observation of subsequent damage; therefore, it is important that field observations be performed and data collected. Initially, the existing riprap sections will be cataloged during a low flow period when the toe of the riprap can be viewed and differences in gradation or stone sizes between the toe and upper slope of the riprap section may be noted. Field inspection of riprap damage should be conducted at the time of the flood event and during periods of low flow when the extent of the damage can be viewed.

(d) Alternate Test Section Study. The proposed method of study as outlined in the previous paragraph (c) is not considered the most accurate method for determining the appropriate stone size, but has the advantage of a low initial study cost. A more effective study would directly determine the riprap stone size by using a riprap test section (see Enclosure 7, Appendix B, CCS report). Several riprap sections would be constructed using selected stone sizes, and the damage would be observed for each size. This study should be effective and accurate because the construction and test conditions would be controlled. Also, all of the test sections could be observed simultaneously so that comparisons of the performance could readily be made. This is in contrast with "observing the existing riprap," where the performance of the riprap section is influenced by lack of adequate-sized riprap material and poor placement, as well as by the erosive forces of the river. The "observe the existing riprap" study requires many years to complete, and the interim repair work may have to be replaced if the study shows it to be undersized. The riprap test section method should determine the required riprap size within a short time so that subsequent repair work would avoid future repair. The cost of design and construction of the riprap test sections is estimated to be $240,000; and, this cost may be prohibitive in view of current funding availability. However, the riprap test section study should be seriously considered if funding can be made available, since this method could provide valuable design and analysis guidance for other Corps of Engineers projects which have similar turbulent flow conditions.

(e) Synthetic Materials to Improve Erosion Resistance. In addition to the studies to improve the riprap section, various synthetic material designs will be evaluated as alternate means of providing improved erosion protection. This study will consist of compiling a list of all potential alternatives and evaluating their cost and effectiveness. Some laboratory work or field investigations may be required to determine the constructibility and effectiveness of an alternative. These field investigations will be accomplished as a portion of the O&M repair work.

(2) Protection of Levee by Sacrificial Structures. It may be more economical in some areas to place structures in the river to curtail the erosive force. Structures which will be considered for use are timber

piles, gabions, hard points, and large riprap volume toe sections. The study will consist of compiling a list of potential alternatives and evaluating their effectiveness, constructibility, and cost. Some laboratory work or field investigations may also be required to determine the constructibility and effectiveness of an alternative. These field investigations will be accomplished during the O&M repair work.

(3) Riprap Sources Investigation.

(a) District Experience. The PL 84-99 riprap production has had to deal with major problems in high quarry waste, difficult operating conditions, and poor quality quarry areas. The majority of the bedrock outcrops in the Jackson area consist of sedimentary formations which are not suitable for riprap. Generally, localized outcrops of igneous bedrock material have been used as the sources of riprap material. These formations are anomalies and their extent and structural composition are variable as well as undependable. Also, the igneous bedrock sources have contained flow structures or cleavage planes which cause the rock to fracture into smaller sizes than are desired and/or have extensive weathered zones or joints filled with soil. The bedrock material in the existing county quarry (which is presently used for riprap production) appears to have adequate durability and hardness, and can produce the required size stones. But this quarry has a high waste factor and an abundance of fine-grained material which significantly increases the production costs. It is anticipated that there is an ample supply of bedrock material for the extended future production requirements if the environmental concerns do not prohibit development. Because exploration information has not been available to guide previous development of quarry areas, quarry developments have not been efficient, and often areas having poor quality rock, with large quantities of soil and undersized materials, have been used. PL 84-99 work has not provided advance funding for exploration and, as a result, the amount of overburden and eventual drilling and blasting is based only on the rock outcrops which are visible on the surface. This method of developing any quarry area increases the amount of waste materials, as well as increasing the amount of undersized rock and soil materials into the riprap material. Because of the scarcity of suitable material for riprap, the production of riprap from the known quarries in the area is expensive and generally of poor quality. Development of a quality riprap source is a major requirement for the efficient maintenance of the levee system.

(b) Investigations by Other Agencies. The Bureau of Reclamation and the Wyoming Highway Department require quality riprap material in the area and have made extensive efforts to locate riprap sources. The Wyoming Highway Department at Jackson uses gabions for erosion protection because of the lack of large riprap material in the vicinity. The highway department personnel have indicated that the only available riprap source in the area is the source presently used for PL 84-99 work. The Bureau of Reclamation performed extensive quarry investigations in the Jackson Hole area as part of the dam safety rehabilitation of Jackson Dam. A number of potential sites were identified within the national park, but the National Park Service will not allow quarry operations within the park. The prohibition against borrowing extends to other lands within the national park boundary that are not controlled by the National Park Service. When the Bureau considered developing quarry areas within the pool area of Jackson Lake, which is within the national park boundary, the National Park Service filed a lawsuit against the Bureau. After prolonged legal discussions, the Bureau relented to avoid a public confrontation in court. The Bureau then identified two potential quarry sites which are located outside the national park boundary, but the haul distances made these sites economically infeasible. As a result of restrictions against quarry operations within the national park boundary and the long distances to the few potential quarries outside the park, the Bureau determined that soil cement was a more viable erosion protection material than riprap. The experience of the Government and local agencies within the Jackson Hole area indicates that the National Park Service will not permit quarry operations within the national park boundaries and that viable quarry sites outside the park boundaries are rare.

(c) Commercial Suppliers. Commercial suppliers have not supplied riprap for the project. Previously, all riprap material for the project has been obtained from Government designated or county quarries and not by commercial suppliers. It is proposed that a contract to produce an emergency stockpile of riprap (discussed later in paragraph 7.a.) be developed to test the ability of the commercial market to supply suitable riprap for the project.

(d) Riprap Supply and Quarry Investigation Study Plan.

1. The proposed program for identifying a suitable riprap source for the project will consist of an in-house quarry investigation to include a detailed evaluation of the existing quarry and a geologic reconnaissance of all potential quarry sites within a reasonable haul distance from the project. Concurrently, avenues will be pursued to test the viability of the commercial market to search out and produce adequate quality riprap. Primary emphasis of the study will be on the evaluation of the existing quarry. Teton County has engaged private A-E's to evaluate the quarry. Preliminary conversations with the A-E indicate that an ample supply of rock is available for extended use provided that any environmental issues can be overcome.

2. Approximately 5,000 cubic yards of riprap will be required in stockpile for use in flood emergencies by the spring of 1989. A contract will be awarded to produce, deliver, and stockpile the necessary quantity during the summer of 1988.

(4) Report Completion and Documentation. Depending upon the results of the hydrology studies, a number of studies which have not previously been described may be required. If the river morphology study indicates that the river could be trained into a single channel, the design and location of river training structures will be required.

7. Interim Operations and Maintenance Requirements.

a. Emergency Riprap Stockpile. In order to be responsive to flood emergencies, a quantity of stockpiled riprap is required to reinforce critical levee reaches during high flows. The quantity requested is 5,000 cubic yards at an estimated cost of $15 per cubic yard. If the riprap is produced from a remote quarry site which would require loading and hauling to be accessible, the riprap should be stockpiled at various locations along the levees to reduce hauling time during emergencies. It is proposed that alternatives be studied for up to eight different site locations. Requirements for the volume of riprap stockpiled should be increased to provide a minimum of 1,000 cubic yards at each site.

b. Improved Access to Levees. Improved access to the levees will permit quicker response to critical levee reaches threatened by floodflows. Under existing conditions, much of the levee access is single-lane traffic only, with few turnouts. In emergency situations, the inefficiencies of having loaded and empty trucks in a cycle from the levee roadway to turnouts can seriously impede critical repairs. Cost effective alternatives need to be identified along several long levee reaches, comparing the cost of additional access routes versus the cost of adding a lane for two-way traffic or numerous turnouts.

c. Recurrent O&M Activities.

(1) District Management. An O&M project requires scheduling of periodic and annual inspections, reviewing subsequent reports, and managing emergency preparedness and O&M activities. At least two local meetings called annually by an O&M project manager are necessary to maintain local coordination.

(2) Inspection. Periodic inspection of the levee system is required to see that the integrity of the system is maintained and to pinpoint hazards and areas of stress during high flows. Obviously, the frequency and intensity of this effort are related to quantity and duration of high flows.

(3) Access Maintenance. Levee access for maintenance and snow removal from the top of levees is required to prevent saturation of the roadbed materials. Removing the accumulated winter snows from the top of the levee at the end of the snow season assures a firm road surface to perform inspections and maintenance work.

(4) Clearing and Snagging. Teton County has requested Federal help in the removal of downed trees and debris from the Snake and Gros Ventre Rivers. A reconnaissance level study was initiated in FY 87 as part of the Section 208 clearing and snagging authority to evaluate the feasibility of removing the debris. The cost of the debris removal work was estimated at about $400,000, of which the local sponsor's share would be $100,000. It has since been determined that a Section 208 clearing and

snagging project cannot be implemented because of the operation and maintenance project status authorized by PL 99-662. NPD has directed that the 208 study be terminated and the work be accomplished as part of the operations and maintenance work. (See Enclosure 7, Appendix A, 1st End, dated 24 August 1987.) It is extremely important that funds be made available to allow clearing of the channel areas during the summer of 1988.

8. Real Estate Evaluations.

a. Since 1955, the Corps has been involved with Teton County in no less than eight projects for the repair and/or construction of levees along the Snake and Gros Ventre Rivers in Jackson Hole. In all cases, Teton County has been required to provide the lands, easements, and rights-of-way to accomplish the work. Generally, the county has acquired perpetual easements which provide for the right to construct and repair levees, embankments, revetments, canals, and incidental works within the specific areas described in the deeds.

b. Rights-of-way acquired for the Federal levees were of varying width, usually from 100 to 170 feet. Rights-of-way for some properties affected by the non-Federal levees proposed for inclusion in the project have not yet been acquired by the county.

c. The cost of real estate administrative activities related to the county land/easement acquisition (i.e., coordination, review of real estate instruments, verification of title, etc.) is estimated to be $10,000 in FY 88 and $10,000 in FY 89.

9. Future Studies and Associated Costs. (Individual work items and associated costs are shown in Enclosure 3, Chart 4, Project Study Schedule and Cost Projection.)

a. Hydrologic Requirements.

(1) Evaluation of Levee Freeboard, Alignment, and Toe Protection. The adequacy of the Federal levee freeboard at the 100-year flood level will be reviewed based on observed flood profiles and backwater computations. A hydraulic analysis of the non-Federal levees is also needed to establish the present level of protection, including upstream and downstream levee tie-off, and the preferred alignment for future emergency work. This review should include reduction and evaluation of the 1986 flood profile which was staked this fall, careful documentation and evaluation of profiles during high flow conditions in 1988 and 1989, and comparison with data available from previous floods and computed water surface profiles. The adequacy of levee toe protection will require additional surveys to define the present thalweg on both the Federal and non-Federal reaches, as well as field measurements of maximum scour depths and velocities during a future flood event.

(2) Geomorphic Study.

(a) A study of geomorphic conditions, including historic braided channel pattern changes, is needed to determine whether the stability of the channel can be improved and whether future impingement points can be predicted. A review of past aerial photographs and maps will be completed; and, a series of aerial photographs or video to document impingement flow patterns and changes occurring during a single flood event is planned.

(b) This study should include a resurvey of the existing sediment ranges to document channel bed changes and overall aggradation or degradation trends which have occurred since the last survey in 1973. This information may be particularly useful since the large flood of 1986 may have moved a considerable quantity of bed material. Sediment ranges should also be established on the non-Federal reaches to document future channel changes and erosion trends and to provide a basis for hydraulic computations.

(c) Channelbed grain size and armor layer grain size data should be collected. This information is needed to predict potential scour depths and sizes of material required for a stable channelbed.

(3) Improved Flood Regulation. Although little improvement appears possible, the available options will be reviewed and included in the final report. The Gros Ventre stream gauging station will be established to provide data for future studies and real-time operation.

b. Geotechnical Requirements.

(1) Improved Erosion Resistance. The riprap design for the project will be as outlined in Section 6.e.(1)(c) and will be determined by evaluating the effectiveness of the various existing riprap sections. Additionally, future repair work will be performed in accordance with a specified design, and field inspections will be performed annually to evaluate the effectiveness of that design. If the repair is observed to be inadequate, the design will be revised for future repair work. The proposed study requires funding for the field inspections and the evaluation of the existing riprap as well as for the monitoring and evaluation of future repairs.

(2) Synthetic Material Designs. In addition to the studies to improve the riprap section, various synthetic material designs will be studied as an alternative means of providing improved erosion protection. This study will consist of compiling a list of all potential alternatives and evaluating their cost and effectiveness. Some laboratory work or field investigations may be required to determine the constructibility of a particular alternative or to determine the cost of producing an alternative.

(3) Protection of Levee by Sacrificial Structures.

(a) If it is not feasible to economically provide a total erosion resistant revetment, it may be economical to place a structure in the riverbed in a manner to curtail erosive force. Structures which will be considered are timber piles, gabions, hard points, and riprap volume toe sections.

(b) The study will compile a list of potential alternatives and evaluation of their effectiveness, constructibility, and cost. Some laboratory work and/or field investigations will be performed to determine the constructibility of a particular alternative and to determine the cost of producing an alternative.

(4) Riprap Source Investigations. The proposed program for identifying a suitable riprap supply for the project will consist of a Government investigation for a quarry and a riprap supply contract to evaluate the viability of obtaining riprap commercially [see Section 6.e.(3)(d)].

c. Environmental Studies.

The Corps will be preparing an Environmental Assessment (EA) for the Jackson Hole levee O&M program rather than an Environmental Impact Statement since the Corps does not propose any new levee construction under this program. An integral part of the EA will be a review of the fish and wildlife resources of the project area, a determination of the impacts that O&M activities will have on the resources, and identification of any potential mitigation or enhancement activities that may be needed. The Corps will fully coordinate with appropriate Federal, state, and local agencies and interested parties in the preparation of the EA. As part of the preparation of the EA, the following acts and regulations will be complied with:

(1) Clean Water Act. The Corps will prepare a Section 404(b)(1) evaluation as required by this act for discharge of fill material below the line of ordinary high water. If required, a Section 401 Certificate will be obtained prior to actual construction.

(2) Clean Air Act. Pursuant to Section 176(C) and 309 of the Act, the EA will be provided to the Environmental Protection Agency.

(3) Endangered Species Act. The Corps will coordinate with the Fish and Wildlife Service Endangered Species Office as required under Section 7 of the Act.

(4) Fish and Wildlife Coordination Act. The Corps will coordinate with state and Federal fish and wildlife agencies as required by this Act.

(5) Wild and Scenic Rivers Act, Council on Environmental Quality (CEQ) Memorandum, 10 August 1980, Interagency Consultation to Avoid or Mitigate Adverse Effects on River in the Nationwide Inventory. The Corps will coordinate with other agencies to determine whether or not any of the project falls within any river section included in the nationwide inventory or is proposed for inclusion.

(6) Northwest Electric Power Planning and Conservation Act. The project will not conflict with the requirements of the Act or the Columbia Basin Fish and Wildlife Program which was developed in response to the Act.

(7) Reservoir Salvage Act of 1960; National Historic Preservation Act; Executive Order 11593, Protection and Enhancement of the Cultural Environment, 13 May 1971. The O&M program will be coordinated with the State Historic Preservation Officer to determine what effect the program will have on cultural resources and what mitigation, if any, is recommended.

(8) Executive Order 11990, Protection of Wetlands, 24 May 1977. The Corps will comply with this order to avoid any degradation of wetlands in the project area.

(9) Executive Order 11988, Flood Plain Management, 24 May 1977. The Corps, to the extent possible, will avoid long- and short-term adverse impacts associated with the occupancy and modification of the base floodplain and direct and indirect support of development in the base floodplain wherever there is a practicable alternative.

(10) CEQ Memorandum, 11 August 1980, Analysis of Impacts on Prime or Unique Agricultural Lands in Implementing NEPA. The Corps will coordinate with the Soil Conservation Service to minimize impacts on prime or unique farmlands in the project area.

d. Economic Studies. Average annual flood damages based on existing development in the floodplain and level of protection afforded by existing levees will be determined. Flood damage benefits measured on the reduction in the amount of flood damages or related costs will be estimated for each alternative plan. Benefits will be compared to project costs for each of the alternatives. Engineering design alternatives will be studied to determine life cycle costs to evaluate proposed designs.

e. Study Management. This includes planning, organizing, and control of work necessary to support preparation of the final report.

f. Plan Formulation. Effort will be to optimize plan features by incremental benefit and cost analysis to evaluate alternative plans for the report.

g. Report Preparation. This includes report writing, typing, and printing of report and EA documents. The draft report and draft EA are scheduled for submission to NPD in April 1989 and the final report and final EA are scheduled for submission in September 1989. This schedule is dependent upon receipt of FY 88 study funds no later than February 1988.

10. Conclusions.

a. The Jackson Hole Basin is a popular area for both national and international visitors. The valley has changed dramatically from an agricultural to a tourist-oriented society. These activities have significantly increased the economic base of the project area. With continued flood protection, it is projected that the population in Teton County will increase from the present 15,000 to about 26,000 by the year 2000. The floodplain comprises roughly 30 percent of the privately owned land in Teton County. Flood protection is essential for continued economic viability in the region. A properly maintained levee system will provide annual benefits on the order of $2.5 million.

b. The frequency of high flows and repairs to the levees in the past is uncontestable evidence the project area will continue to have the integrity of the levee system challenged. Past annual maintenance costs have been on the order of $400,000, which is very high. Part of the reason for the high maintenance costs is that the Corps has had no authority to undertake preventive measures when it was evident that sections of the levees were beginning to deteriorate.

c. Flood emergency authority contained in PL 84-99 permitted the Corps to take remedial action only during or immediately following high water. Thus, damages to the levees were more extensive and working conditions were more difficult than would have been the case if work could have been undertaken before the high water season. With proper planning, the maintenance quality will increase and the cost decrease.

d. The continuation of maintenance by the local sponsor, with Corps support for emergency needs using PL 84-99 authority, appears to be the worst option in terms of stabilizing the channel to reduce future maintenance costs. Implementing an annually funded operations and maintenance project under authority of PL 99-662 will improve the effectiveness of the Federal money invested because remedial work can be planned to take advantage of optimum weather and streamflow conditions.

e. Federal expenditures in the past under authority of PL 84-99 have occurred almost exclusively on the Federally constructed levees and on the non-Federal levees located on the lower end of the Gros Ventre River and on the Snake River below the Federal levees down to and including the Imenson and Taylor Creek levees. Non-Federal levees located in the reach below the Imenson and Taylor Creek levees down to the Highway 89/187 bridge do not provide a high level of flood protection.

f. It is imperative that the many downed trees in the leveed reach be removed as soon as possible to avoid damage to the levees and reduce the flood risk. It is also important that an emergency riprap stockpile be established and that quarry investigation be undertaken at an early date. If incremental funding is necessary, the other work items shown in Chart 4 should be subsequently accomplished in the following order: survey and mapping, real estate, hydrology, and environmental and economic studies.

11. Recommendations.

a. Clearing and snagging work be undertaken in the summer and fall of 1988 at a total estimated cost of $400,000. Fiscal year funding requirements for this work are estimated to be $250,000 in FY 88 and $150,000 in FY 89.

b. Riprap rock in the amount of 5,000 cubic yards be stockpiled prior to the 1989 flood season for emergency flood fight use. Funding requirement for this work is $100,000 in FY 88.

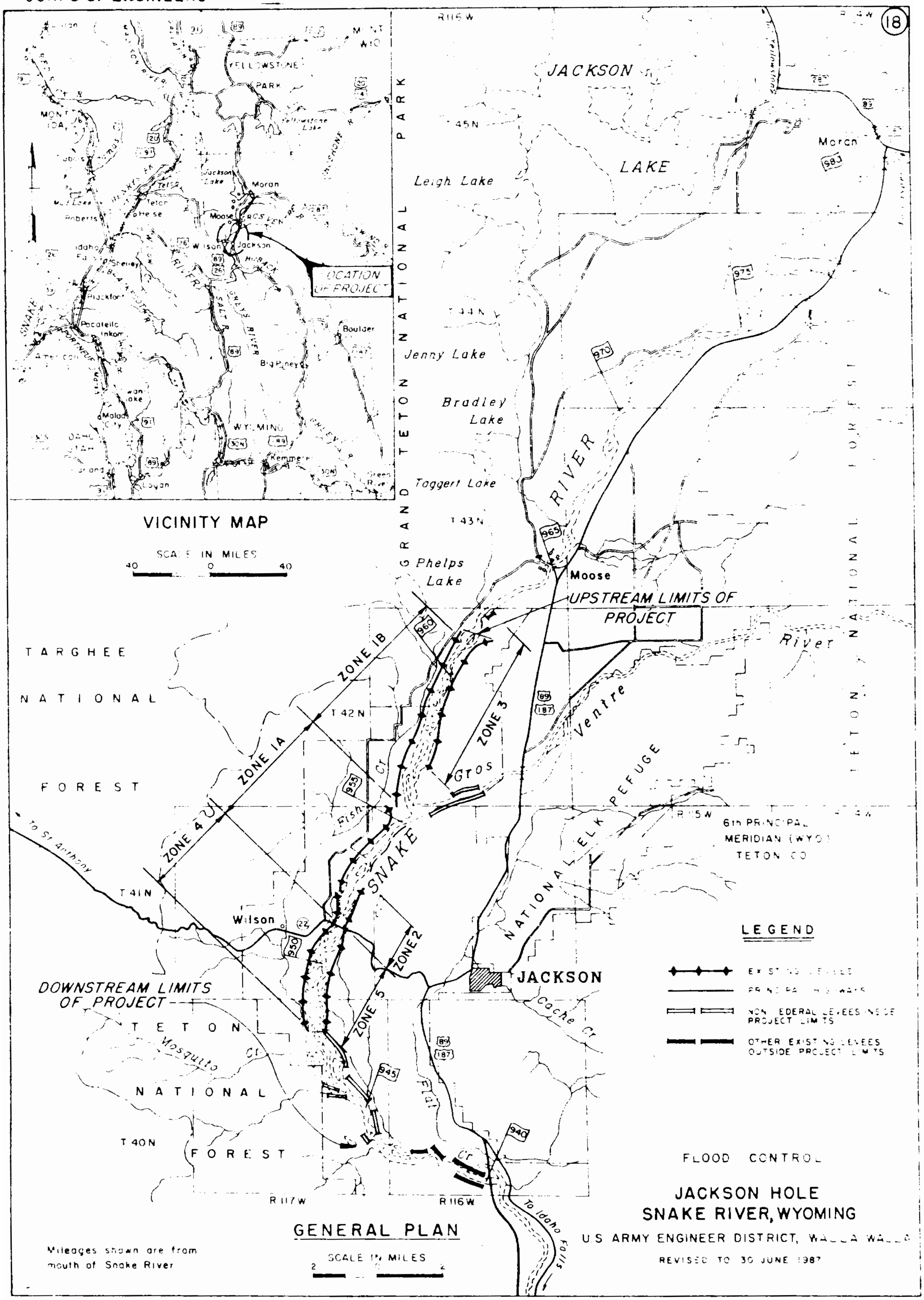
c. A study, as outlined in this report, be undertaken immediately to develop a cost effective maintenance plan for the Jackson Hole levees at an estimated cost of $782,000--$429,000 to be provided in FY 88 and $353,000 in FY 89.

d. Teton County be required to provide $35,000 annually, adjusted for inflation by the use of the Corps of Engineers Civil Works Construction Cost Index, System Category 11-A Levees--all earthwork.

\signed\
JAMES B. ROYCE
Colonel, CE
Commanding

6 Encls
1. Map
2. Tables
3. Charts
4. Photos
5. Plates
6. Appendixes

CORPS OF ENGINEERS U.S. ARMY



Enclosure 1

TABLE 1

Annual Peak Discharges of Snake River
At Jackson-Wilson Bridge
D.A. = 2500 Sq. Mi.

Water Year	Actual 1/ Cfs	Actual 1/ Date	Natural 2/ Cfs	Natural 2/ Date
1894			41,000	
1904	28,500	5/24	28,500	5/24
1905	10,400	6/8	10,400	6/8
1906	14,800	6/13	14,800	6/13
1907	18,300	6/21	18,300	6/21
1908	15,100	6/16	15,100	6/16
1909	25,900	6/18	30,000	6/18
1910	15,500	5/11	19,000	6/2
1911	21,900	6/20	29,000	6/14
1912	20,200	6/24	27,400	6/8
1913	21,200	6/5	28,100	5/27
1914	20,700	6/5	23,300	6/3
1915	12,200	6/27	11,700	[illegible]
1916	15,100	6/19	24,200	6/18
1917	23,400	6/17	23,500	6/17
1918	32,500	6/14	34,200	6/14
1919	14,100	6/16	13,800	5/29
1920	13,300	7/26	20,900	6/9
1921	18,100	6/14	24,100	6/13
1922	14,500	6/22	20,400	6/7
1923	12,600	8/10	19,300	5/26
1924	10,200	7/19	15,200	5/19
1925	14,600	6/30	22,900	5/22
1926	11,400	5/23	13,000	5/21
1927	22,900	6/25 3/	[illegible]	6/14 3/
1928	20,700	5/30	27,900	5/23
1929	14,600	6/17	15,600	6/15
1930	10,700	6/11-12	13,500	5/30
1931	8,460	7/20	7,200	5/15
1932	9,800	6/25	18,300	5/22
1933	14,700	6/15	19,100	6/17
1934	7,500	5/8	8,600	5/7
1935	10,100	6/13	20,000	6/14

Water Year	Actual 1/ Cfs	Actual 1/ Date	Natural 2/ Cfs	Natural 2/ Date
1936	14,000	6/1	23,600	6/1
1937	10,300	6/23	13,900	[illegible]
1938	14,100	6/18	19,700	6/7
1939	11,900	5/31	13,000	[illegible]
1940	9,150	7/14	11,500	[illegible]
1941	7,100	7/18	11,800	[illegible]
1942	9,500	6/25	16,600	6/9
1943	22,800	6/22	23,400	[illegible]
1944	12,000	6/2	13,200	6/2
1945	14,100	6/25	17,300	6/25
1946	16,700	6/6	17,100	6/6
1947	15,200	6/9	16,500	[illegible]
1948	18,000	6/3	20,400	[illegible]
1949	13,400	6/20	16,900	[illegible]
1950	17,100	6/30	21,300	[illegible]
1951	16,000	6/17-18	23,600	[illegible]
1952	15,300	6/7	22,600	[illegible]
1953	14,300	6/23	[illegible]	[illegible]
1954	14,000	5/23	24,300	[illegible]
1955	11,900	6/24	[illegible]	[illegible]
1956	16,400	6/3-5	28,700	[illegible]
1957	12,600	6/6	24,000	[illegible]
1958	13,100	5/22	18,300	[illegible]
1959	13,600	6/15-16	25,300	[illegible]
1960	6,700	12/4	12,900	[illegible]
1961	8,800	6/20	15,700	[illegible]
1962	8,500	6/13	16,700	[illegible]
1963	16,550	6/14	16,400	[illegible]
1964	15,700	6/5	19,870	[illegible]
1965	15,000	6/13	22,500	[illegible]
1966	12,000	5/9	16,200	[illegible]
1967	13,000	6/27	18,700	[illegible]
1968	13,800	6/23	16,300	[illegible]

TABLE 1 (Cont'd)

Water Year	Actual[1/] CFS	Actual[1/] Date	Natural[2/] CFS	Natural[2/] Date
1969	11,100	5/16	16,000	6/27
1970	14,900	6/29	20,200	6/8
1971	17,700	5/31	27,800	6/24
1972	15,900	6/9	27,400	6/9
1973	10,400	6/10	21,080	6/10
1974	19,200	6/18	29,640	6/18
1975	11,900	6/8	16,000	6/8
1976	15,800	6/4	21,100	6/4
1977	11,000	6/9	10,300	6/9
1978	19,000	6/10	23,600	6/10
1979	15,800	5/28	21,300	5/28
1980	15,500	5/24	21,500	5/24
1981	19,000	6/10	30,800	6/10
1982	21,800	6/29	29,000	6/29
1983	19,100	5/30	20,000	5/30
1984	19,300	6/1	22,900	6/1
1985	15,600	6/9	15,600	6/9
1986	25,600		35,174	6/6

NOTES:

1/ Estimated from records at other locations in many years.

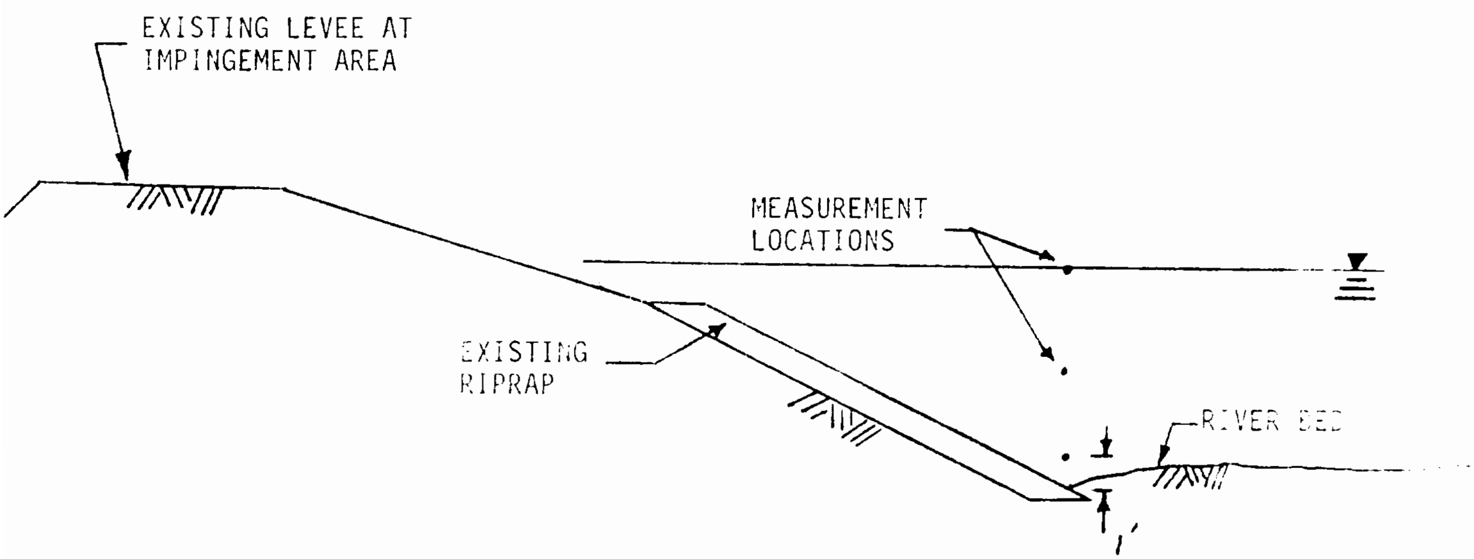
2/ Discharge without effect of Jackson Lake storage, which has regulated flows since 1909.

3/ Excludes effects of washout of landslide on Gros Ventre River. Peaks, including effect of washout, would be mucn larger than values shown.

TABLE 2

Point Velocity Measurements at Impingement Locations

Location of Measurement	Measurement Depth (ft.)	Point Velocity (fps)
Right Bank	Surface	10.93
Station	3	11.11
594+00	(1 ft. above toe) 6	10.41
Left Bank	Surface	10.17
Station	3	10.41
728+00	(1 ft. above toe) 6	9.94
Left Bank	Surface	10.41
Station	3	10.93
712+00	(1 ft. above toe) 6	10.41
Right Bank	Surface	10.41
Station	3	10.17
474+00	(1 ft. above toe) 6	8.93



NOTE: Velocity measurements were taken as shown above, during a flow of 13,790 cfs.

TABLE 2 (Continued)

Location of Measurement	Measurement Depth (ft.)	Point Velocity (fps)
Right Bank	Surface	11.31
Station	3	9.31
435+00	(1 ft. above toe) 6	7.82
Right Bank	Surface	7.82
Station	3	7.46
528+00		
Left Bank	Surface	10.17
Station	3	8.75
574+00	(1 ft. above toe) 6	3.82
Right Bank	Surface	7.63
Station	3	6.99
391+30	(1 ft. above toe) 6	3.30
Left Bank	Surface	8.01
Station	3	6.84
525+00	(1 ft. above toe) 6	3.82
Right Bank	Surface	7.14
Station	3	5.22
345+00		
Right Bank	Surface	10.41
Station	3	10.17
318+00	6	9.31
	(1 ft. above toe) 9	6.32
Right Bank	Surface	8.25
Station	3	7.63
295+00	(1 ft. above toe) 6	5.87
Right Bank	Surface	10.66
Station	3	9.11
265+00	(1 ft. above toe) 6	7.14
Right Bank	Surface	10.93
Levee L_2	3	9.82
Stat. 57+00		

<u>TABLE 2 (Continued)</u>

Location of Measurement	Measurement Depth (ft.)	Point Velocity (fps)
Right Bank	Surface	11.50
Levee L_2	3	10.66
STAT. 34+00	(1 ft. above toe) 6	8.41
Right Bank	Surface	9.31
Station	3	9.11
124+00	(1 ft. above toe) 6	7.46
Left Bank	Surface	8.75
Station	3	8.93
258+00	(1 ft. above toe) 6	7.82
Right Bank	Surface	8.75
Station	3	9.31
90+00	6	6.57
	(1 ft. above toe) 9	5.48
Left Bank	Surface	7.14
Station	3	7.30
220+00	(1 ft. above toe) 6	6.32
Left Bank	Surface	10.66
Station	3	10.66
177+00	(1 ft. above toe) 6	9.51
Right Bank	Surface	10.41
Levee L_1	3	8.21
Stat. 90+00		
Right Bank	Surface	9.51
Levee L_1	3	6.31
Stat. 98+00, end of groin		
Left Bank	Surface	10.93
Station	3	9.51
125+00	(1 ft. above toe) 6	7.82
Right Bank	Surface	6.44
Levee L_1		
Stat. 20+00		

TABLE 3

JACKSON HOLE, WYOMING
SNAKE RIVER LEVEE COSTS - 1964 THROUGH 1986

Flood Year	COE	State of Wyoming	Teton Co.	Total
1964	$ 223,045	$ 24,273	$ 52,221	$ 299,539
1965	No Cost	93,576	116,970	210,546
1966	No Cost	11,438	15,250	26,688
1967	No Cost	24,821	31,027	55,848
1968	80,867	34,514	146,187	261,568
1969	157,146	19,204	61,191	237,541
1970	216,472	61,666	74,118	352,256
1971	188,932	55,432	103,935	348,299
1972	120,089	49,951	112,277	282,317
1973	145,245	55,307	117,860	318,412
1974	506,033	76,744	102,291	685,068
1975	503,277	47,466	77,496	628,239
1976	171,298	47,702	35,616	254,616
1977	163,988	58,239	66,339	288,566
1978	367,113	114,428	212,297	693,838
1979	No Cost	26,556	49,269	75,825
1980	199,631	45,455	100,669	345,755
1981	487,335	54,725	111,955	654,015
1982	292,029	37,461	174,085	503,575
1983	159,283	26,359	98,475	284,117
1984	244,895	No Cost	50,677	295,572
1985	329,480	No Cost	52,017	381,497
1986	2,153,860	66,567	259,086	2,479,513
TOTAL	6,710,018	1,031,884	2,221,308	9,963,210

1. COSTS HAVE ADJUSTED TO REFLECT 1986 DOLLARS.

TABLE 4

DURATION OF HIGH FLOWS*

SNAKE RIVER AT JACKSON

YEAR	NUMBER OF DAYS MEAN DAILY FLOW EXCEEDS: 8000	10,000	12,000	14,000	18,000	20,000
1973	6	2	0	0	0	0
1974	70	43	34	22	4	0
1975	37	13	0	0	0	0
1976	76	43	28	10	0	0
1977	9	2	0	0	0	0
1978	62	41	28	19	0	0
1979	45	34	17	5	0	0
1980	51	31	15	1	0	0
1981	44	32	25	5	0	0
1982	77	65	49	31	8	4
1983	60	53	25	6	2	0
1984	69	45	22	5	1	0
1985	29	11	6	2	0	0
1986	58	45	40	36	19	16
AVERAGE	49.5	32.9	20.6	10.1	2.4	1.4

* Data based on records for gages "Snake River at Wilson Bridge near Jackson" (1973-1975) and "Snake River Below Flat Creek, near Jackson" (1976-1986). Discharges are given in CFS.

TABLE 5

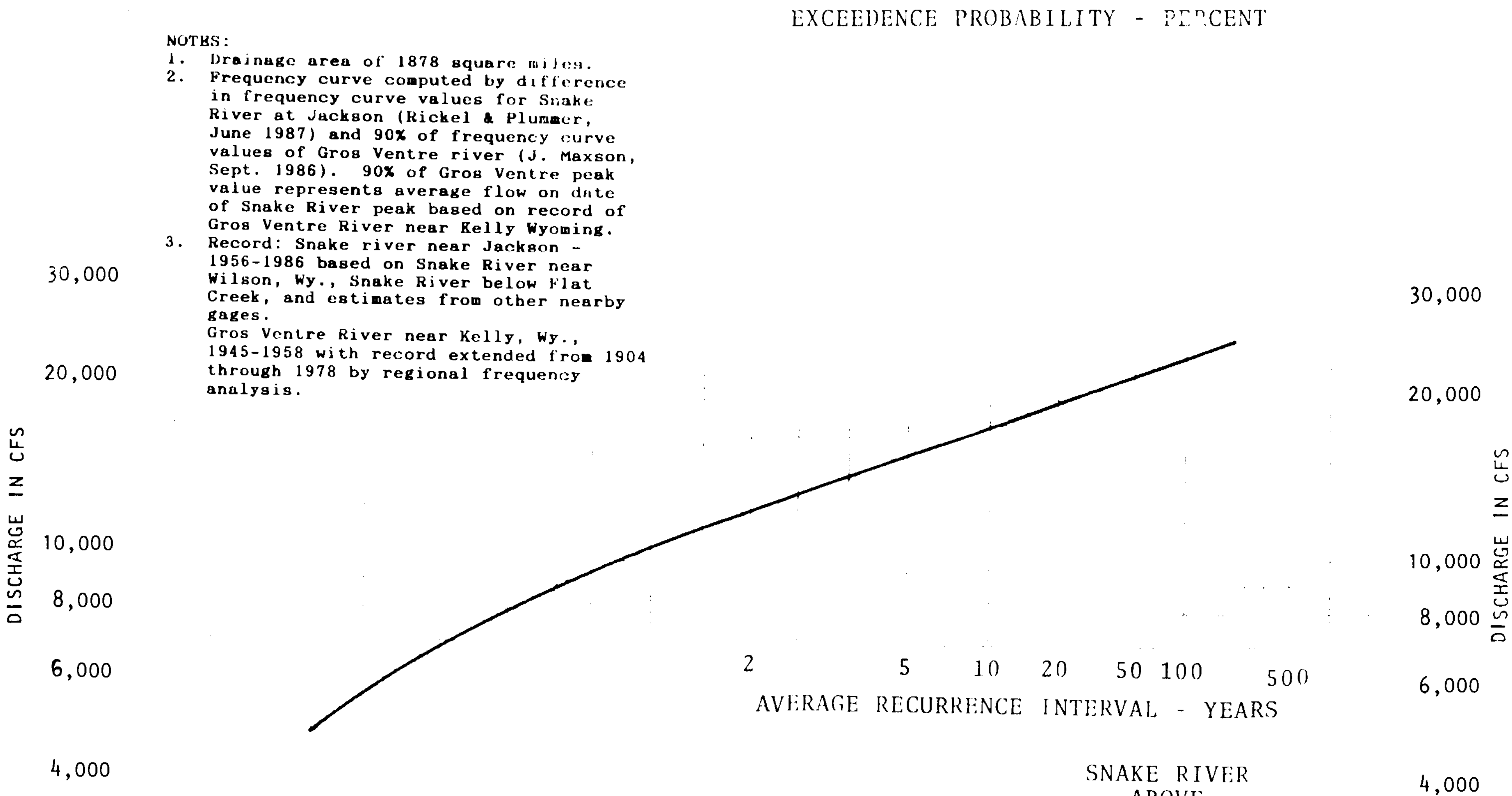
COMPARISON OF CHANGES IN FLOW AREA BETWEEN LEVEES FOR SNAKE RIVER SEDIMENT RANGES SURVEYED IN 1954, 1967, & 1973

RANGE	W.S.*	AREA 1954	AREA 1967	% CHANGE 1954-1967	AREA 1973	% CHANGE 1954-1973	% CHANGE 1967-1973
			Downstream End of Levee Project				
0.2	6090	5675	7226	+27%	7080	+25%	- 2%
0.1	6098	4833	5400	+12%	5101	+ 6%	- 6%
1.0	6104	3657	4827	+32%	4428	+21%	- 8%
2.0	6111	5085	5625	+11%	5518	+ 9%	- 2%
Average		4813	5770	+20%	5532	+15%	- 4%
			Just Downstream of Gros Ventre Confluence				
18	6213	3084	3270	+ 6%	3352	+ 9%	+ 3%
19	6219	2054	2874	+50%	4030	+96%	+40%
20	6226	2456	2870	+17%	3566	+45%	+24%
21	6233	3871	4375	+13%	4952	+30%	+13%
Average		2866	3347	+17%	3975	+39%	+19%
			Just Upstream of Gros Ventre Confluence				
29	6250	5057	4182	-17%	4768	- 6%	+ 14%
30	6255	4503	3499	-22%	4334	- 4%	+ 24%
31	6262	1810	1731	- 4%	3555	+ 96%	+105%
32	6270	2847	2482	-13%	3047	+ 7%	+ 23%
33	6274	635	777	+22%	1364	+115%	+ 76%
34	6282	1899	1538	-19%	1855	- 2%	+ 21%
Average		2791.8	2868	-15%	3151	+ 13%	+ 33%

* W.S. used was 100-year flood level rounded to neareast foot

NOTES:

1. Drainage area of 1878 square miles.
2. Frequency curve computed by difference in frequency curve values for Snake River at Jackson (Rickel & Plummer, June 1987) and 90% of frequency curve values of Gros Ventre river (J. Maxson, Sept. 1986). 90% of Gros Ventre peak value represents average flow on date of Snake River peak based on record of Gros Ventre River near Kelly Wyoming.
3. Record: Snake river near Jackson - 1956-1986 based on Snake River near Wilson, Wy., Snake River below Flat Creek, and estimates from other nearby gages.
   Gros Ventre River near Kelly, Wy., 1945-1958 with record extended from 1904 through 1978 by regional frequency analysis.



SNAKE RIVER
ABOVE
GROS VENTRE RIVER

ANNUAL PEAK DISCHARGE
FREQUENCY CURVE

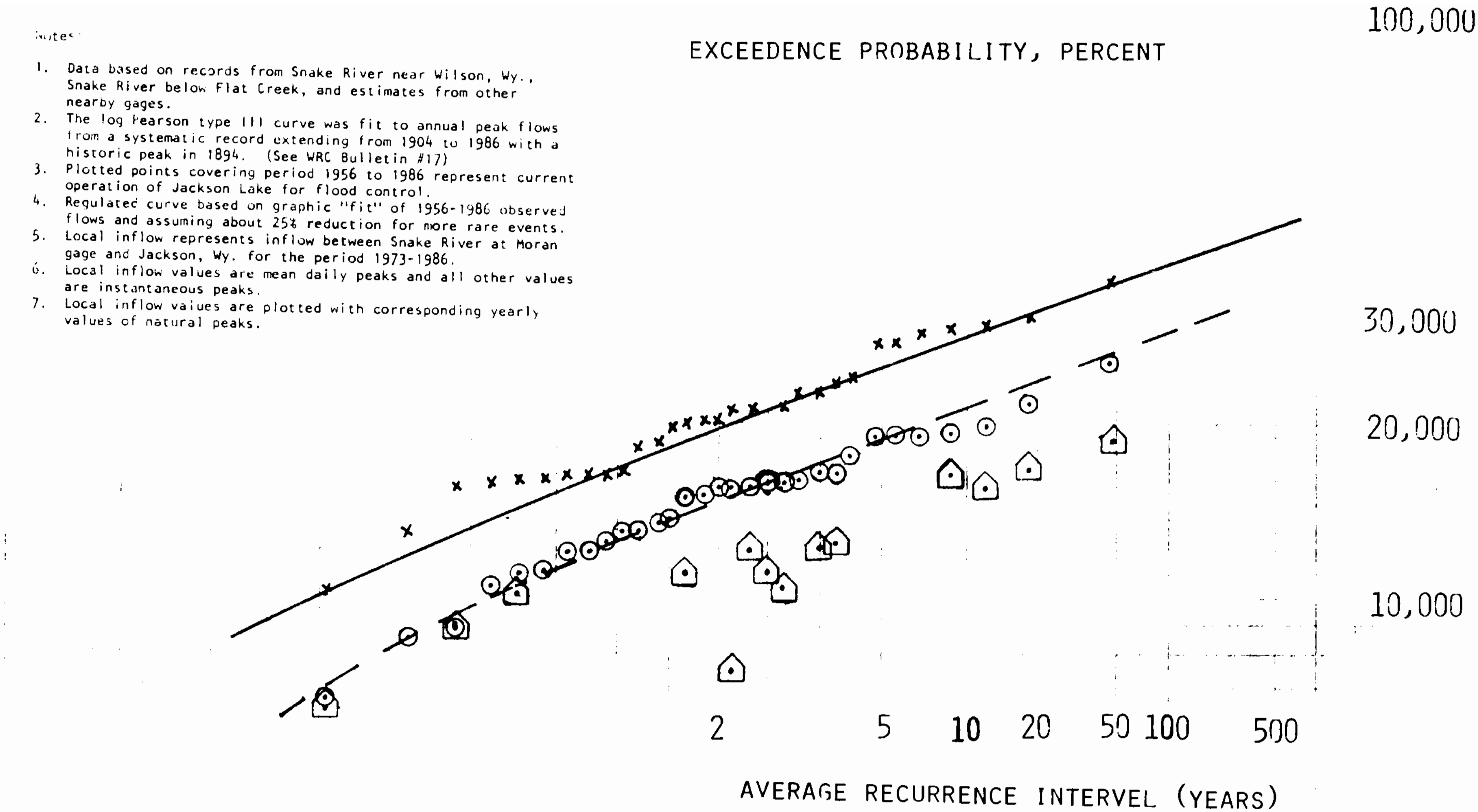
U.S. Army Engineer District
Walla Walla
Hydrology Branch

D. Plummer July

CHART

Notes:

1. Data based on records from Snake River near Wilson, Wy., Snake River below Flat Creek, and estimates from other nearby gages.
2. The log Pearson type III curve was fit to annual peak flows from a systematic record extending from 1904 to 1986 with a historic peak in 1894. (See WRC Bulletin #17)
3. Plotted points covering period 1956 to 1986 represent current operation of Jackson Lake for flood control.
4. Regulated curve based on graphic "fit" of 1956-1986 observed flows and assuming about 25% reduction for more rare events.
5. Local inflow represents inflow between Snake River at Moran gage and Jackson, Wy. for the period 1973-1986.
6. Local inflow values are mean daily peaks and all other values are instantaneous peaks.
7. Local inflow values are plotted with corresponding yearly values of natural peaks.



LEGEND

× × × × 1956-1986 RECORD, NATURAL PEAKS

⊙ ⊙ ⊙ ⊙ 1956-1986 RECORD, ACTUAL PEAKS

——— 1904-1986 RECORD, NATURAL FREQUENCY CURVE

— — —ESTIMATED REGULATED FREQUENCY CURVE

UNREGULATED LOCAL INFLOW BELOW JACKSON LAKE

SNAKE RIVER
NEAR JACKSON, WYOMING

FREQUENCY CURVES
NATURAL AND ACTUAL ANNUAL PEAKS

U. S. Army Corps of Engineers
Walla Walla District
Hydrology Branch

Rickel and Plummer June 1987

Notes:

1. The Gros Ventre River near Kelly, Wyoming has a drainage area of 622 square miles. The period of record at this location is from 1918, 1945 through 1968.

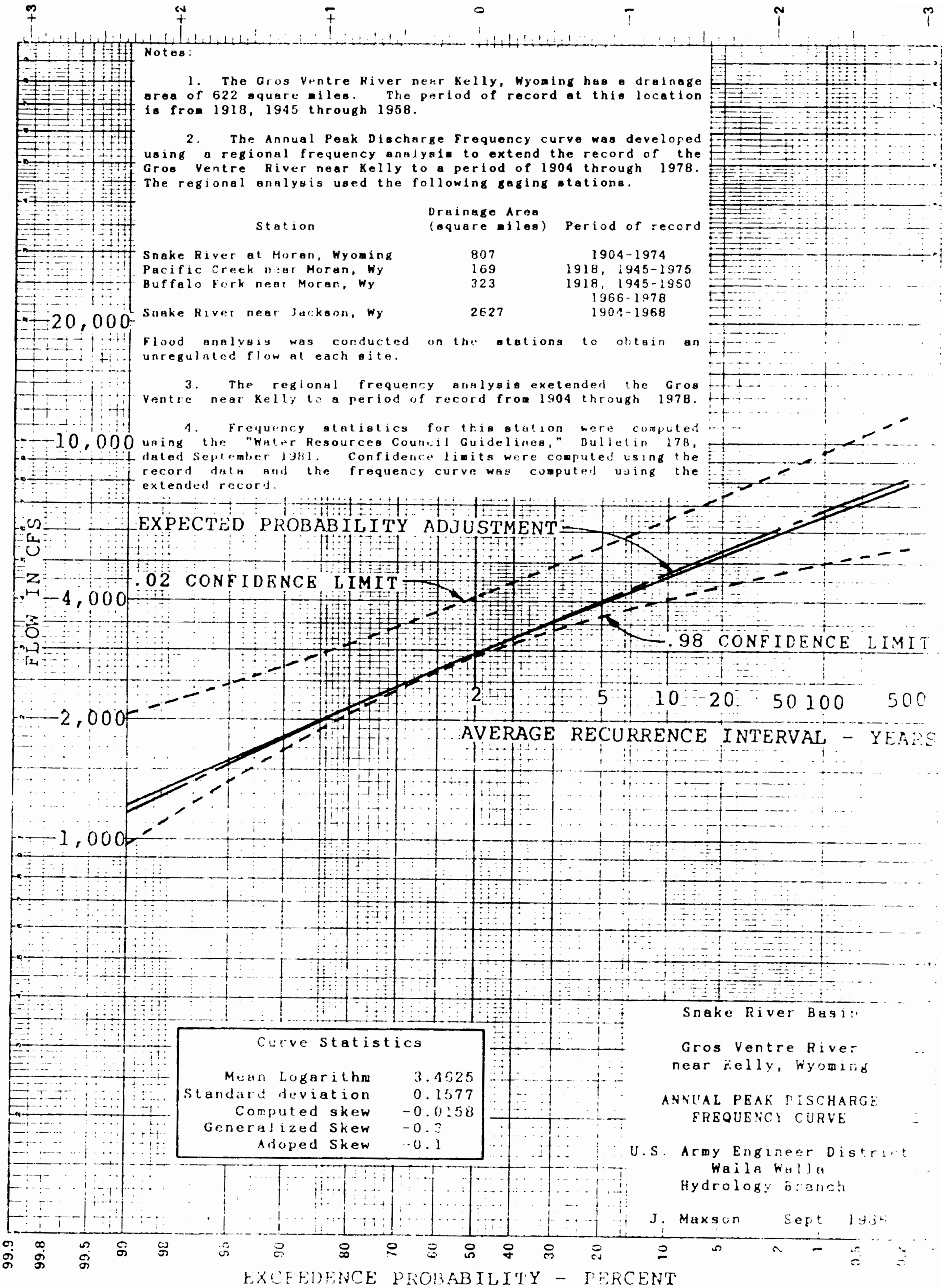
2. The Annual Peak Discharge Frequency curve was developed using a regional frequency analysis to extend the record of the Gros Ventre River near Kelly to a period of 1904 through 1978. The regional analysis used the following gaging stations.

Station	Drainage Area (square miles)	Period of record
Snake River at Moran, Wyoming	807	1904-1974
Pacific Creek near Moran, Wy	169	1918, 1945-1975
Buffalo Fork near Moran, Wy	323	1918, 1945-1960 1966-1978
Snake River near Jackson, Wy	2627	1904-1968

Flood analysis was conducted on the stations to obtain an unregulated flow at each site.

3. The regional frequency analysis exetended the Gros Ventre near Kelly to a period of record from 1904 through 1978.

4. Frequency statistics for this station were computed using the "Water Resources Council Guidelines," Bulletin 17B, dated September 1981. Confidence limits were computed using the record data and the frequency curve was computed using the extended record.



Curve Statistics	
Mean Logarithm	3.4625
Standard deviation	0.1577
Computed skew	-0.0158
Generalized Skew	-0.3
Adoped Skew	-0.1

Snake River Basin

Gros Ventre River near Kelly, Wyoming

ANNUAL PEAK DISCHARGE FREQUENCY CURVE

U.S. Army Engineer District Walla Walla Hydrology Branch

J. Maxson Sept 1988

JACKSON HOLE, SNAKE RIVER LEVEE PROJECT STUDY SCHEDULE AND COST PROJECTION CHART

ACTIVITY	PROJECT COSTS 1988	PROJECT COSTS 1989
Letter Report		
NPD/HQUSACE Review and Approval		
Study Report		
NPD/HQUSACE Review		
Survey and Mapping Total >>>>>>>>>>	$205,000	$25,000
a. Survey Thalweq Profile for Federal Levees	($25,000)	
b. Survey Thalweq Profile Non-Federal Levees	(35,000)	
c. Aerial Photography of High Flows	(5,000)	
d. Real Estate Property Survey Non-Federal Levees	(25,000)	
e. Mapping and Drafting Services	(5,000)	
f. Survey High-water Profile 1988	(20,000)	
g. Resurvey Existing Sediment Ranges	(60,000)	
h. Establish 12 New Sediment Ranges on Snake River & 10 New Ranges on Gros Ventre River	(30,000)	
i. Aerial Photos During High Flows 1989		(5,000)
j. Survey High-water Profile 1989		(20,000)
Geotechnical Total >>>>>>>>>>>	$100,000	$176,000
Quarry Investigations		
a. Office Investigation, Real Estate, Field Reconnaissance, and Riprap Contract Preparation	($40,000)	
b. Quarry Explorations		($150,000)
Riprap Size Based on Performance		
a. Catalog Existing Riprap	(6,000)	(6,000)
b. Record System Preparation	(10,000)	
c. Evaluate Impingement History	(5,000)	
d. Field Observations During High Flows	(3,000)	(3,000)
e. Rehabilitation & Damage Inspection		(3,000)
f. Evaluation of Riprap Performance & Damage	(10,000)	(2,000)
g. Design & Cost Estimate for Alternative Riprap Sections	(3,000)	
Synthetic Material & Sacrificial Structures Alternatives		
a. Evaluation of Alternatives, Plans, & Specifications, Cost Est. for Field Test	(20,000)	
b. River Management Structures		(7,000)
c. Construction Field Test		
d. Evaluate Performance		
Report Completion & Documentation	(3,000)	(5,000)
Hydrology Total >>>>>>>>>>>	$69,000	$30,000
a. Mark High-water Profile, Measure Impingement Velocity and Depths	($15,000)	
b. Hydrology Studies and Data Evaluation	(15,000)	
c. Mark High-water Profile, Measure Impingement Velocities and Scour Depths		($15,000)
d. Complete Hydrologic Studies and Report Preparation		(15,000)
e. Construct an Instrument Stream Gauging Station on the Gros Ventre River	(8,000)	
f. Operation, Maintenance, and Inclusion of Data for Gauging Station in USGS Publication	(6,000)	
g. Collect Channelbed Samples and Perform Grain Size Analysis	(25,000)	

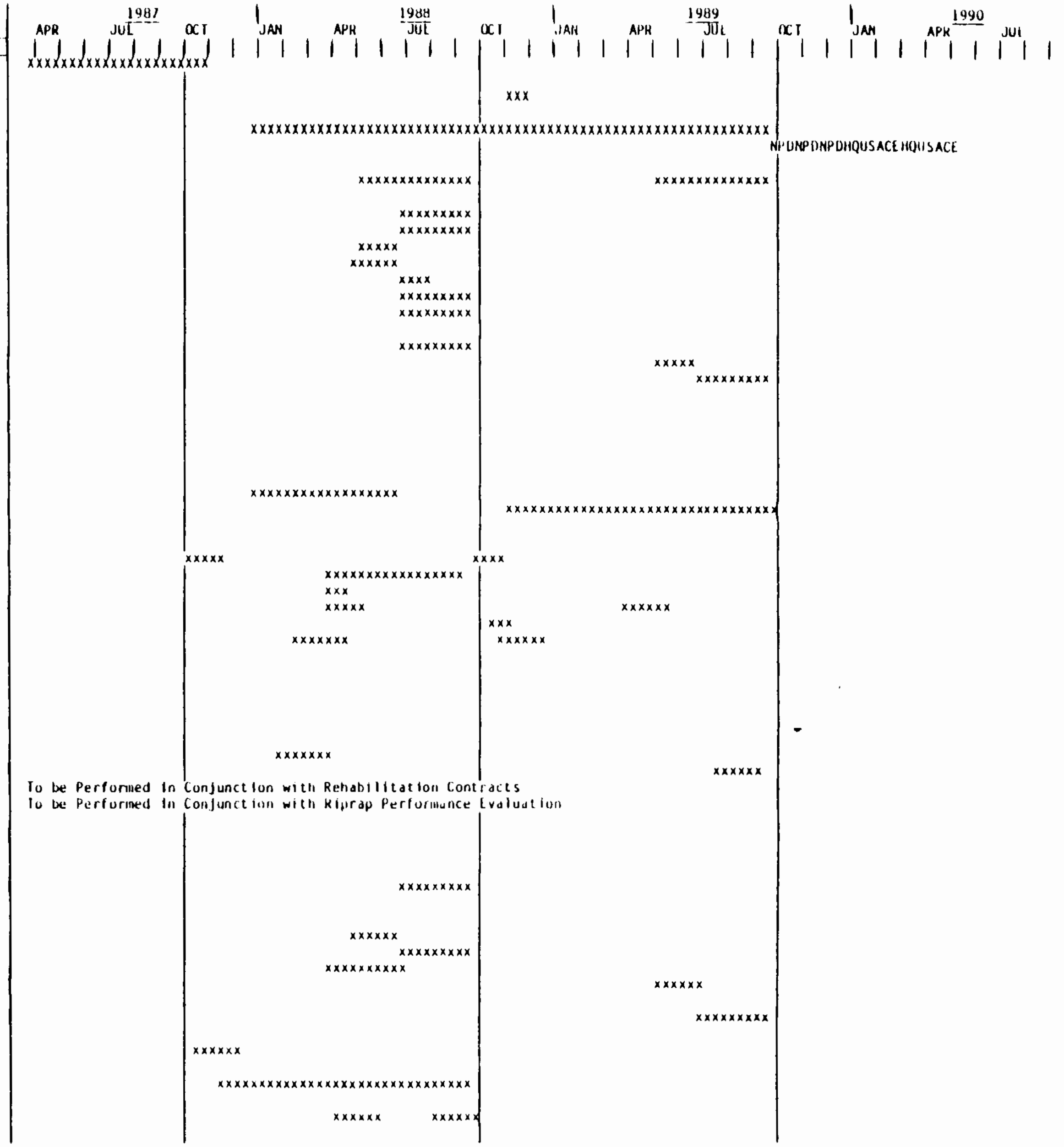


Chart 4
Sheet 1 of 2

JACKSON HOLE, SNAKE RIVER LEVEE PROJECT STUDY SCHEDULE AND COST PROJECTION CHART

ACTIVITY	PROJECT COSTS 1988	PROJECT COSTS 1989	SCHEDULE (1987: APR JUL OCT / 1988: JAN APR JUL OCT / 1989: JAN APR JUL OCT / 1990: JAN APR JUL)
Letter Report			XXXXXXXXXXXXXXXXXXXXX
NPD/HQUSACE Review and Approval			XXX
Study Report NPD/HQUSACE Review			XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX NPDNPDNPDHQUSACEHQUSACE
Economic Evaluation Total >>>>>>>>>>>	$15,000	$25,000	
a. Inventory of Damageable Property in Floodplains	($10,000)		xxxxxxxxxxx
b. Inventory of Damages Prevented by Project	(5,000)		xxxxxxxxx
c. Engineering Design Alternative Life Cycle Cost Comparisons		(25,000)	xxxxxxxxxxxxxxxxx
Environmental Studies Total >>>>>>>>>>	$3,000	$12,000	
- Environmental Assessment	($3,000)	($12,000)	xxx xxx xxx xxxxxxxxxxxxxxxxxxxxxxxxx
Real Estate Total >>>>>>>>>>	$15,000	$10,000	
a. Coordination of Land/Easement Acquisition and Appraisal Reviews with Teton County	($10,000)	($10,000)	x x x x xx x x x x xx x x x x xxxxxxxxxxxxxxxx
b. Admin. Costs for Quarry Site Acquisition	(5,000)		xxxxxxxxx
Study Management Total >>>>>>>>>>	$22,000	$75,000	
a. Management and Administration	($6,000)	($10,000)	x x x x xx x x x x x x x xx x x x xx x x x xx x x x xx x x x x
b. Public Meetings	(5,000)	(5,000)	xxx xxxxx
c. Plan Formulation	(6,000)	(15,000)	x x x x xx x x x xx x x x xx x x x xx x x x xxxxxxxx
d. Report Preparation	(5,000)	(10,000)	xxxxxxxxxxxxx xxxxxxxx
e. Word Processing		(10,000)	xxxxxxxxxx xxxxxxx
f. Printing		(25,000)	xxx xxxxxxxx
Summary of Annual Study Costs Total >>>>>	$429,000	$353,000	
Total Study Costs >>>>>>>>>>		$782,000	
Interim Operations and Maintenance Costs	$387,000	$187,000	
a. Clearing and Snagging	($250,000)	($150,000)	xxxxxxxxxxxxxxxxxx
b. Stockpile Emergency Riprap 5,000 Cubic Yards	(100,000)		xxxxxxxxxxxxxxx
c. District Management for Project O&M	(10,000)	(10,000)	x x x x x x x x x x x x x x x x x x x x x x x x x x x x x x x x
d. Maintenance of Access Roads and Tops of Levee	(5,000)	(5,000)	xx xx
e. Periodic Levee Inspection	(22,000)	(22,000)	x x x x x x x xxxxxxxxx x x x x x x x x x x x xxxxxxxxx x x x x x x x x x x x
Summary of Annual O&M Costs	$387,000	$187,000	
Total O&M Costs for 1988 and 1989		$574,000	
Total Annual Costs	$816,000	$540,000	
Summary Total Cost >>>>>>>>>>>>>>		$1,356,000	

Project Quarry - April 29, 1987

PHOTO 1

Left Bank Snake River, Quarry Access Road, River Mile 952.8
Note excessive quantity of undersized stones preventing contact between layer stones.

PHOTO 2

Left Bank Snake River, Station 134+00
Note excessive quantity of undersized stones preventing contact between larger stones.

PHOTO 3

Left Bank Snake River, Quarry Access Road, River Mile 953.2

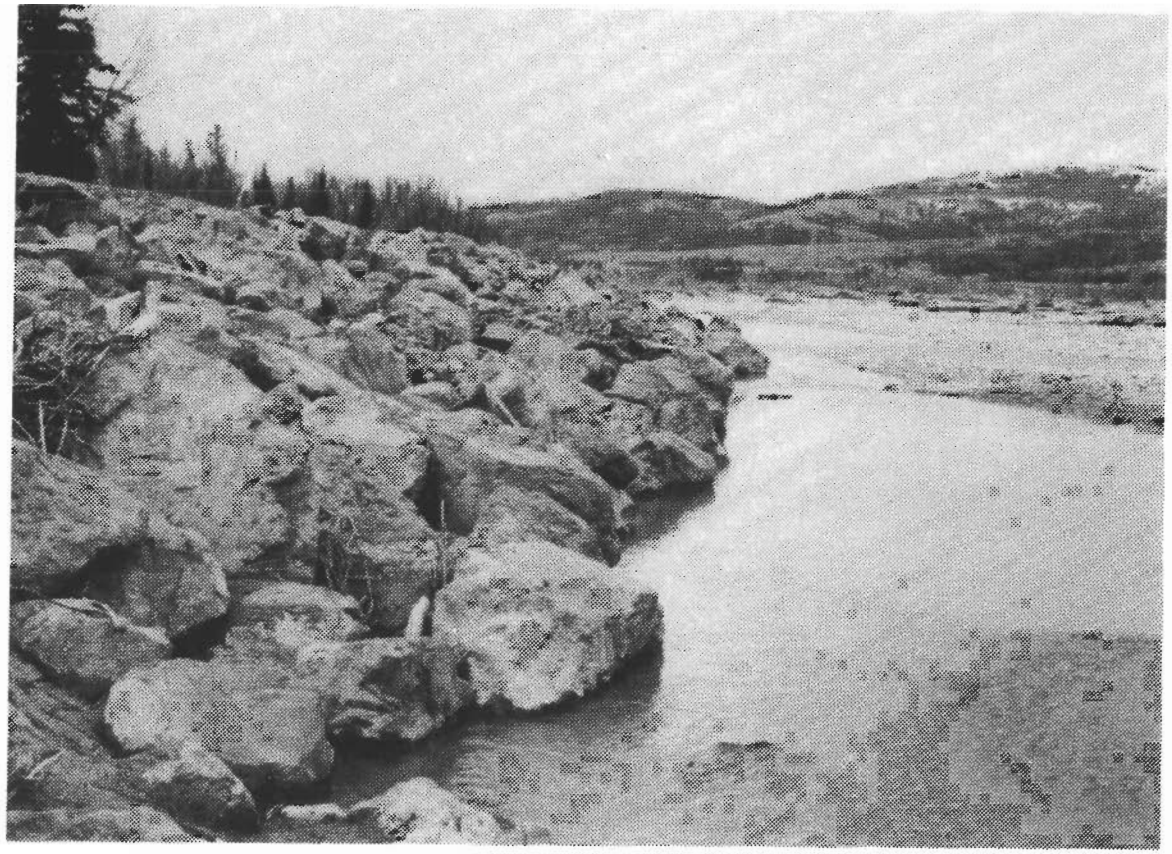
Note excessive quantity of undersized stones preventing contact between larger stones. Also, note large stones at toe.

PHOTO 4

Right Bank Snake River, Station 81+00

Undersized stone which previously supported large stones and filled voids has been removed by scour. The large stones which remain form a very rough surface.

PHOTO 5



Left Bank Snake River, Station 713+00

Note large stones at toe. Also, note that undersized stones have been removed by scour and the remaining revetment surface is very rough.

PHOTO 6

Left Bank Snake River, Station 691+00
Original riprap section which has been thinned and over-steepened by progressive erosion.

PHOTO 7

Left Bank Snake River, Station 140+00

Undersized stone which previously supported the large stones have been removed by scour and resulted in the large stones shifting and failing.

PHOTO 8

Right Bank Snake River, Station 265+00

Thinning of section and over-steepening of toe despite larger stone sizes at toe.

PHOTO 9

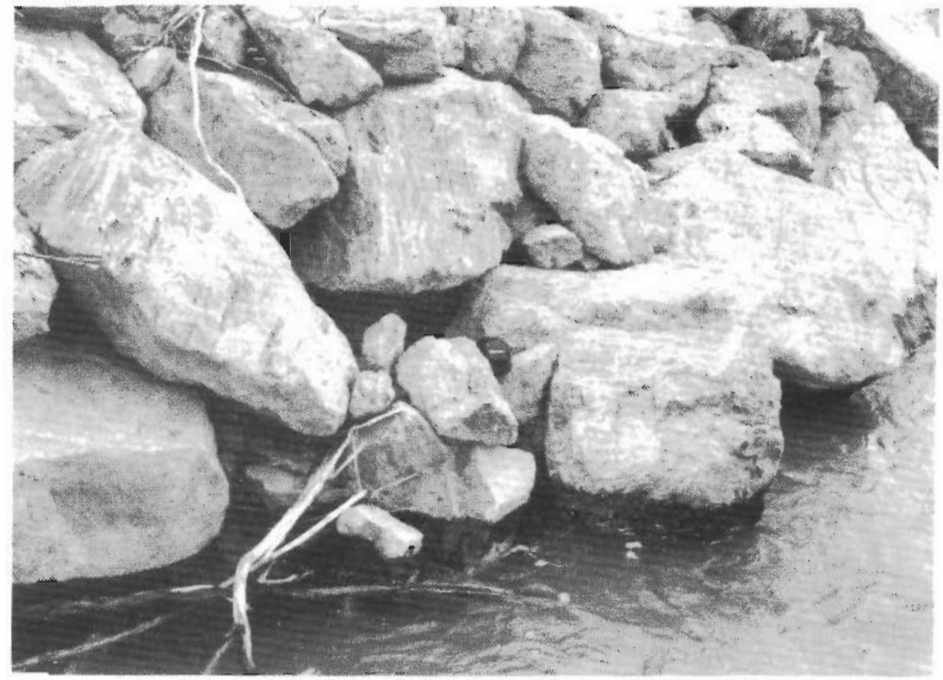
Left Bank Snake River, Station 713+00

Note erosion of toe area has exposed large stones. The undersized stones have been removed by scour and the remaining revetment surface is very rough.

PHOTO 10

Right Bank Snake River, Station 257+00
Thinning and over-steepening of toe despite larger stone sizes at toe.

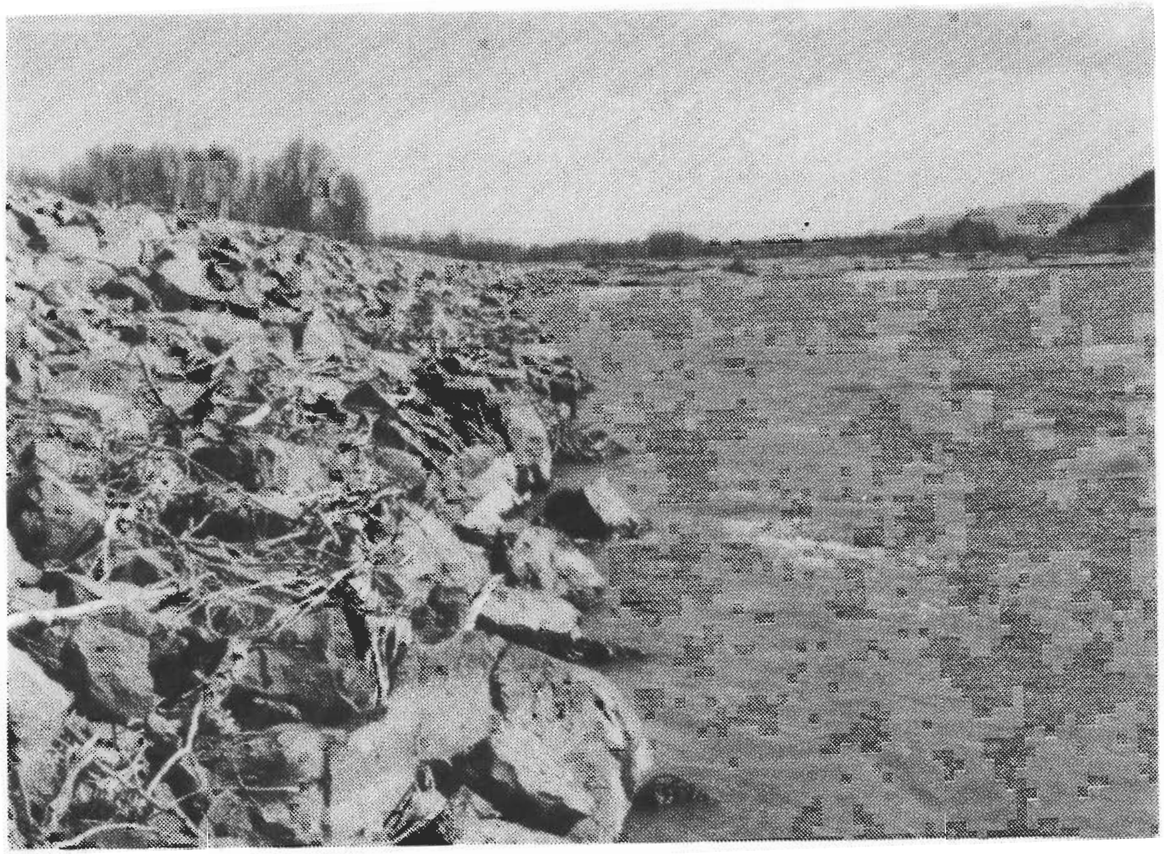
PHOTO 11



Right Bank Snake River, Station 79+00

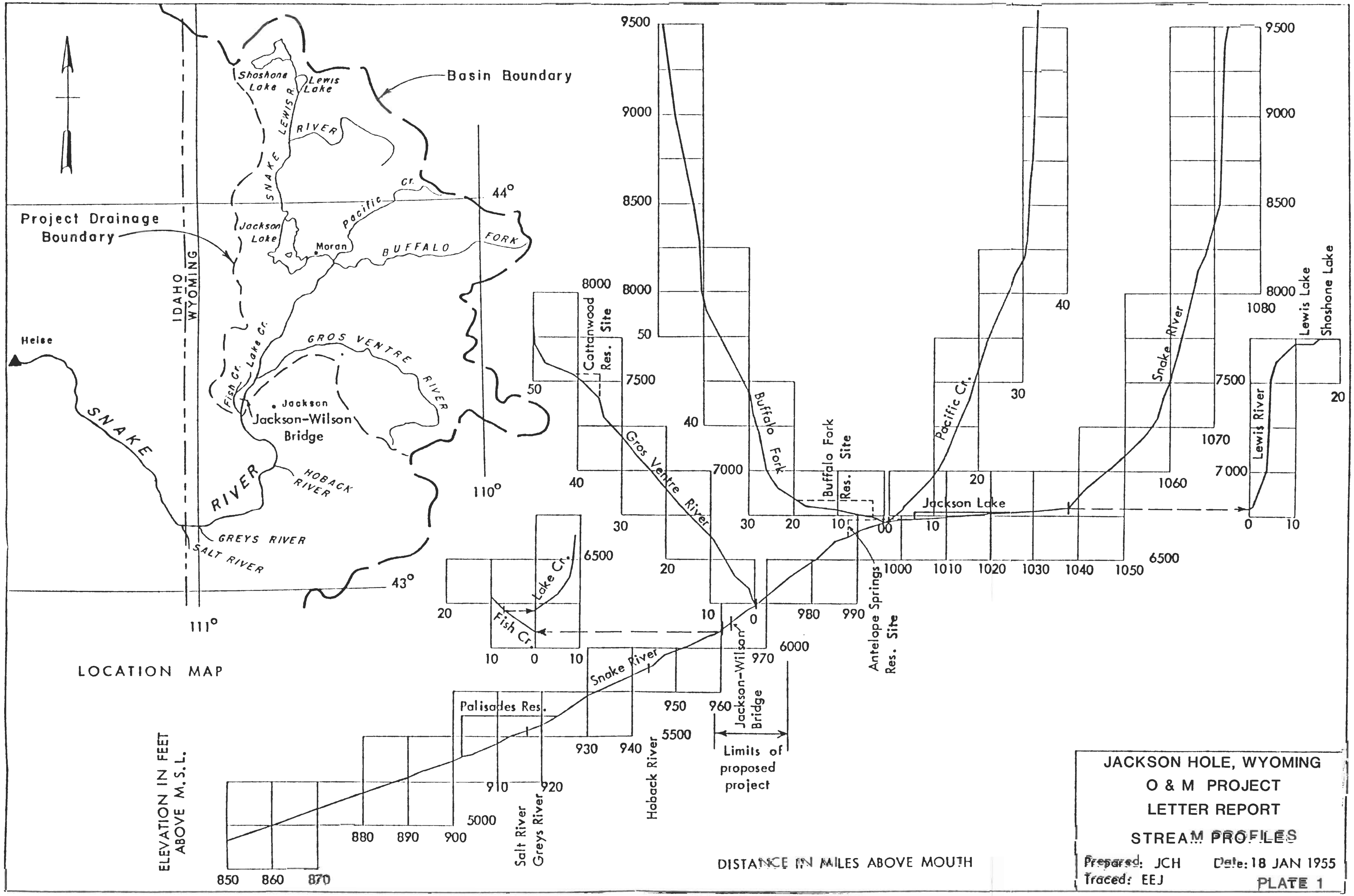
Photo 12 - Thinning and over-steepening of toe despite large stone sizes at toe.
Photo 13 - Closeup photograph of riprap.

PHOTOS 12 & 13

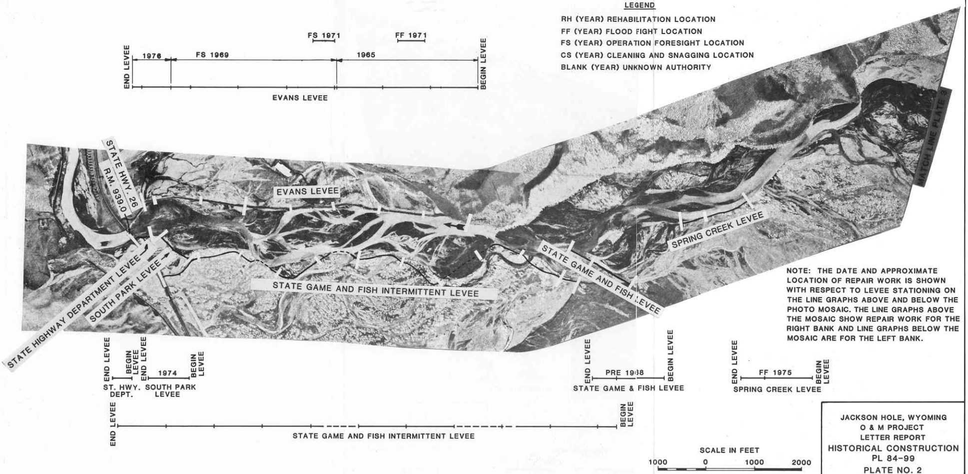


Right Bank Snake River, Station 316+00
Undersized material has been removed by scour but majority of the stone has remained in place.

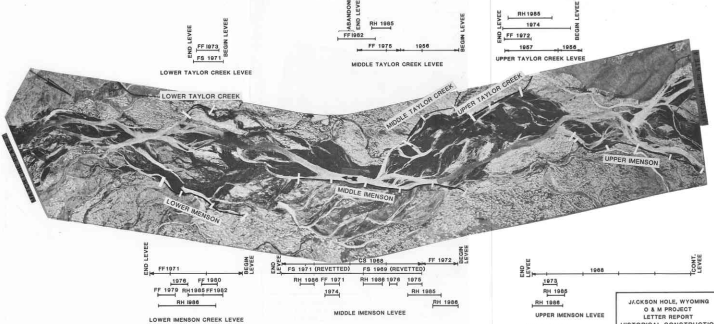
PHOTO 14



Basin Boundary
Shoshone Lake
Lewis Lake
LEWIS R.
RIVER
SNAKE
Cr.
Pacific
44°
Project Drainage Boundary
Jackson Lake
Moran
BUFFALO
FORK
IDAHO
WYOMING
Heise
Fish Cr.
Lake Cr.
GROS VENTRE
RIVER
Jackson
Jackson-Wilson Bridge
SNAKE
RIVER
HOBACK RIVER
110°
GREYS RIVER
SALT RIVER
43°
111°
LOCATION MAP
Cottonwood Res. Site
Gros Ventre River
Buffalo Fork
Buffalo Fork Res. Site
Pacific Cr.
Jackson Lake
Snake River
Lewis River
Lewis Lake
Shoshone Lake
Lake Cr.
Fish Cr.
Antelope Springs Res. Site
Palisades Res.
Jackson-Wilson Bridge
Limits of proposed project
Salt River
Greys River
Hoback River
ELEVATION IN FEET ABOVE M.S.L.
DISTANCE IN MILES ABOVE MOUTH
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
STREAM PROFILES
Prepared: JCH
Date: 18 JAN 1955
Traced: EEJ
PLATE 1



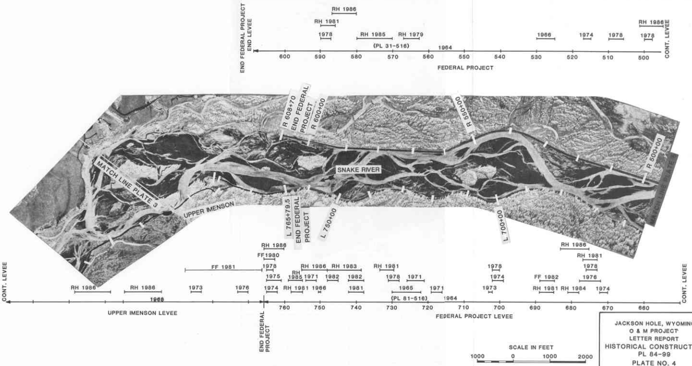
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 2



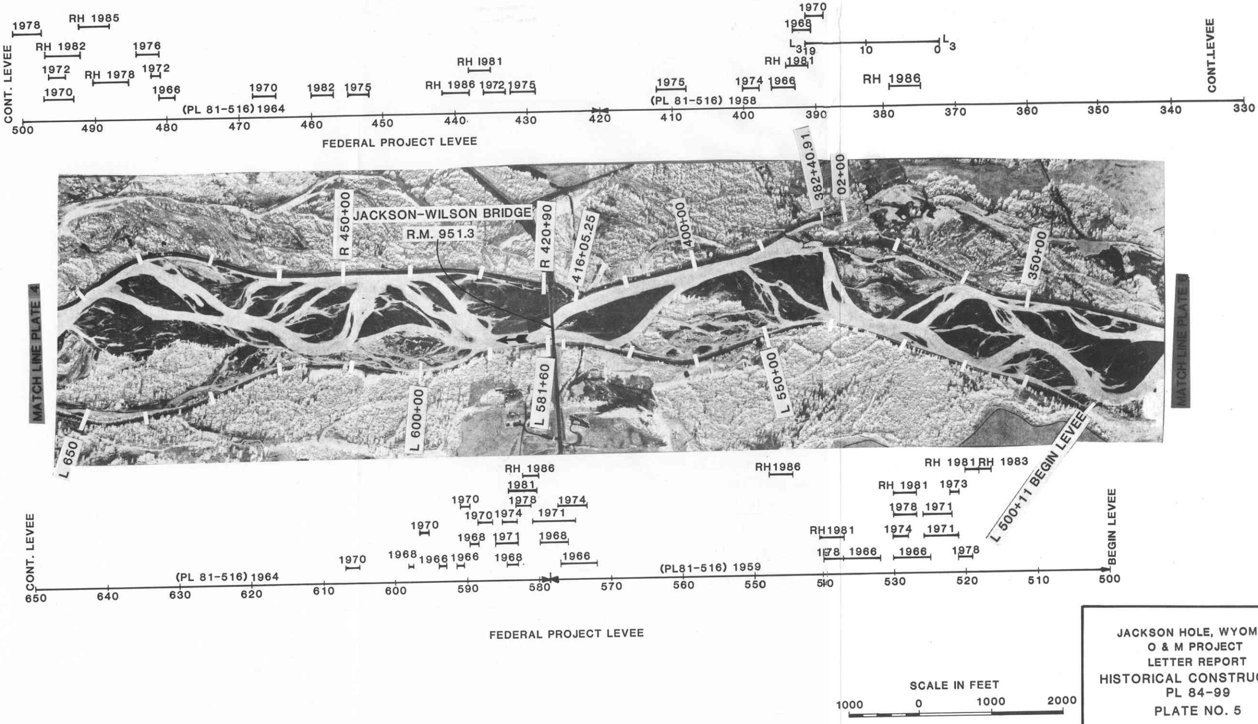
SCALE IN FEET

1000 0 1000 2000

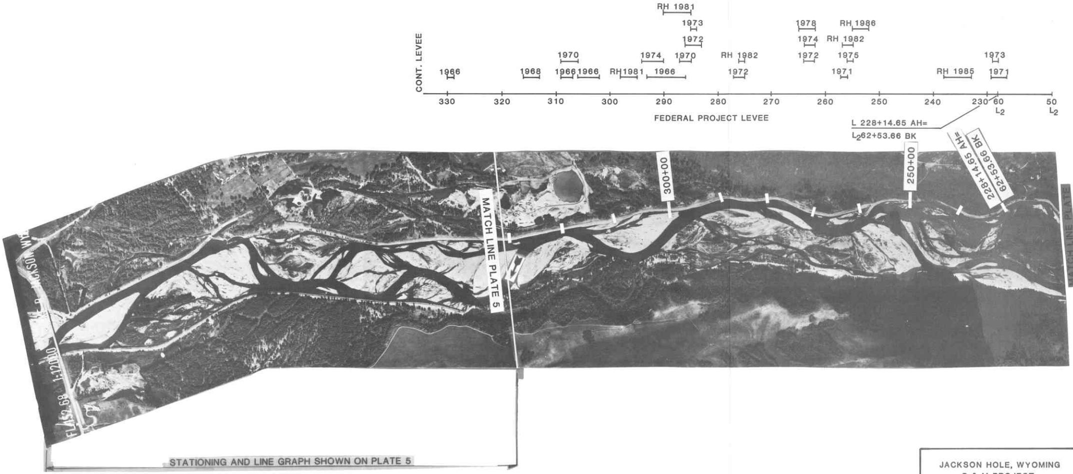
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 3



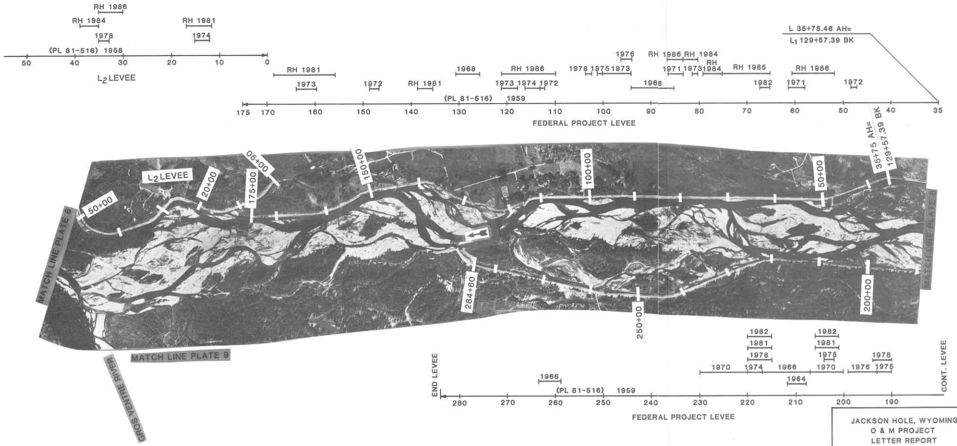
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 4



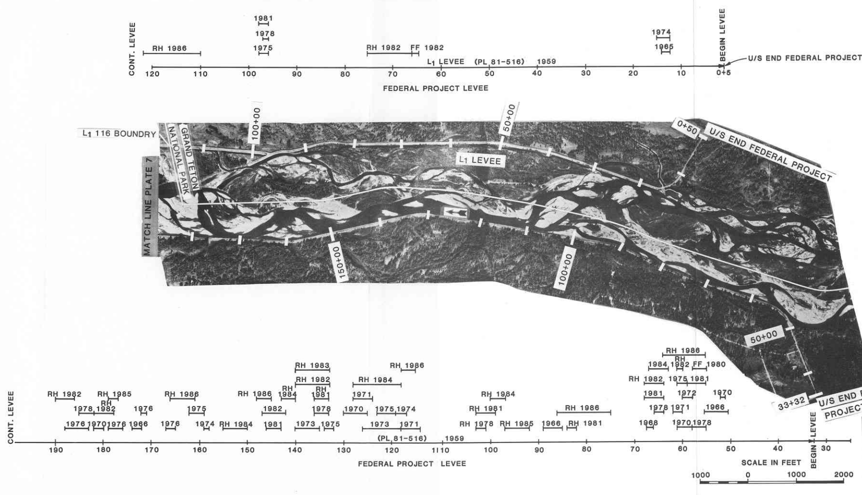
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 5



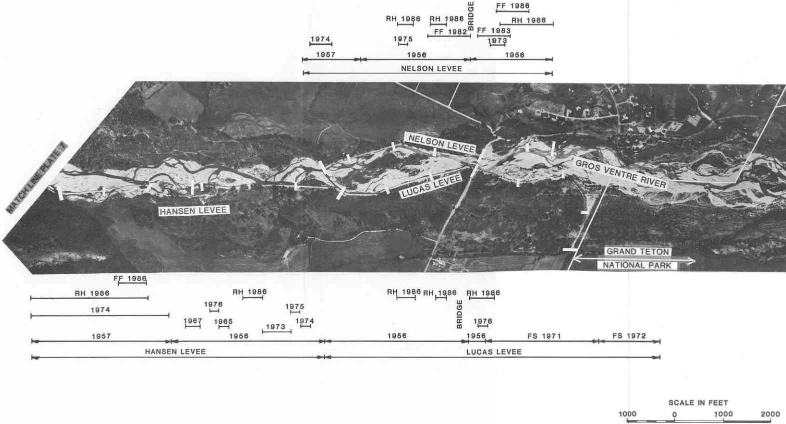
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 6



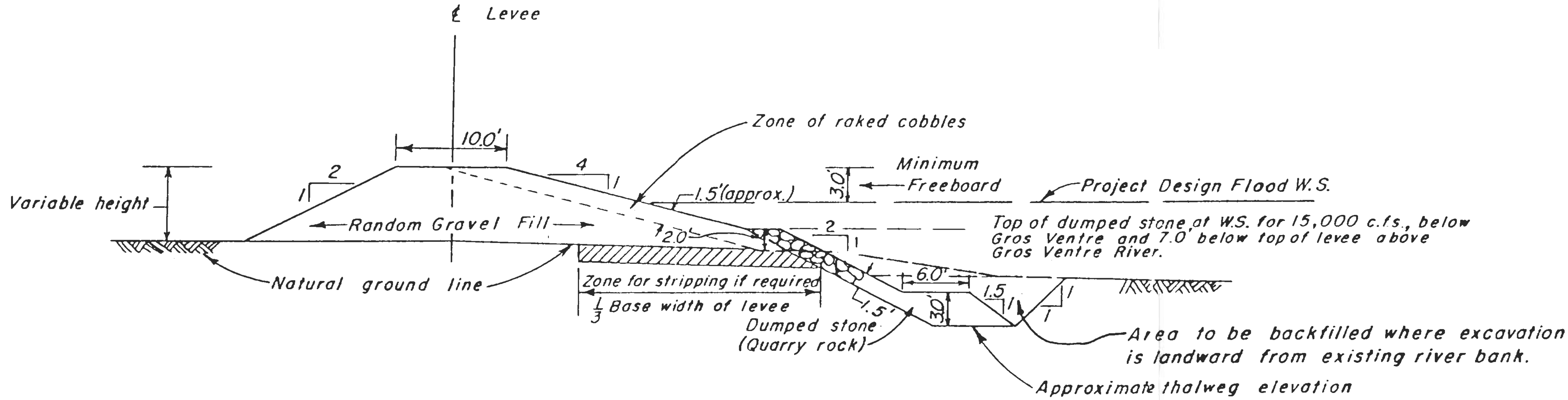
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 7



JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 8



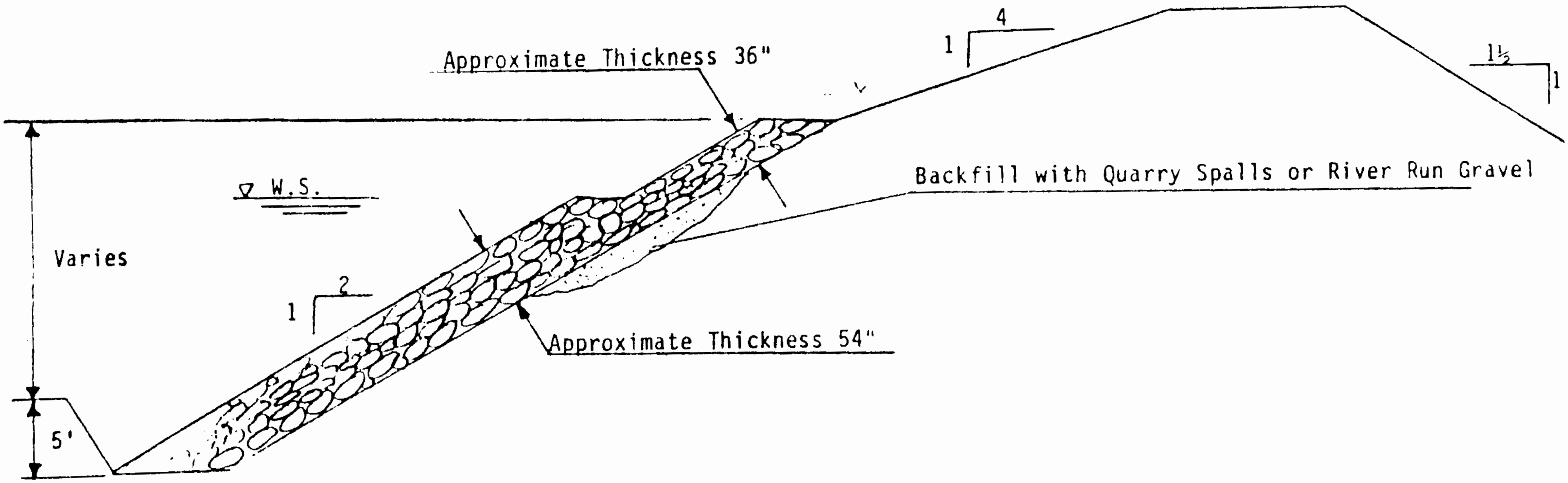
JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT
HISTORICAL CONSTRUCTION
PL 84-99
PLATE NO. 9



TYPICAL LEVEE SECTION

JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT

TYPICAL LEVEE SECTION



JACKSON HOLE, WYOMING
O & M PROJECT
LETTER REPORT

PL-99 REHABILITATION, 1980
TYPICAL REPAIR SECTION

PLATE 11

DEPARTMENT OF THE ARMY
WALLA WALLA DISTRICT, CORPS OF ENGINEERS
BUILDING 602, CITY-COUNTY AIRPORT
WALLA WALLA, WASHINGTON 99362

FS

REPLY TO
ATTENTION OF

CENPW-PL-PP (1110-2-1150a) 21 July 1987

MEMORANDUM FOR: Commander, North Pacific Division, ATTN: CENPD-PL-FS (Clyde Barnhill)

SUBJECT: Section 208 Clearing and Snagging Project, Snake River, Jackson, Wyoming (CWIS# 89272)

1. A study is currently underway to evaluate the feasibility of clearing debris from 23 miles of the Snake and Gros Ventre Rivers near Jackson, Wyoming. A work allowance amounting to $7,500 has been allocated for this study.

2. Due to substantial coordination required as a result of P.L. 99-662, additional funds amounting to $15,000 are needed. The major portion of the added costs are the direct result of the long distance of travel required and other additional effort required to down scope the project to accommodate local funds available for a project.

FOR THE COMMANDER:

\signed\
L. V. ARMACOST, P.E.
Chief, Planning Division

CF:
Ed Estenson

CENPD-PL-FS (CENPW-PL-PP/21 Jul 87)(1105-2-10c)1st End Mr. Barnhill/kh/221-3823
SUBJECT: Section 208 Clearing and Snagging Project, Snake River, Jackson, Wyoming (CWIS #89272)

DA, North Pacific Division, Corps of Engineers, P.O. Box 2870, Portland, Oregon 97208-2870   24 August 1987

FOR: Commander, Walla Walla District

As discussed between Messrs. Armacost and Barnhill, we believe the authority contained in P.L. 99-662 to be the appropriate means to pursue the subject work. The Section 208 investigation should be terminated and the proposed project added to the FY 88 operation and maintenance work plan under Section 840 of P.L. 99-662.

FOR THE COMMANDER:

\signed\
D.E. OLSON
Chief, Planning Division

FORTY-SIXTH MEETING OF THE COMMITTEE ON CHANNEL STABILIZATION
JACKSON HOLE, WYOMING
JULY 13 TO 17, 1987

EXECUTIVE SUMMARY: The committee and guests met with Walla Walla District people to discuss causes of and possible solutions to the maintenance and repair problems experienced by the Snake River levee system in Jackson Hole almost continuously since its completion in 1964. Public Law 99-662 directed the Corps to take over operation and maintenance of the Federally constructed project along with local additions. This has provided an opportunity for a reassessment of the project design and for correcting the root causes of the continual expenditure of local and P.L. 99 money for repairs and flood fights.
The Committee:
a. at the request of Teton County, created a prioritized list of clearing and snagging actions for the county's use.
b. provided suggestions for interim operation, maintenance and flood fight procedures to be used until redesign work on the project is completed.
c. made recommendations for hydraulic and hydrologic studies and field measurments.
d. discussed possible solutions for repair and maintenance problems. Among solutions suggested were improved levee slope protection (riprap) design, minor river management techniques and selected levee setbacks.

Appendix B

CONTENTS

* Removed

** Note: Snake River at Jackson Hole, Wyoming: Field Inspection and Stability Assessment, dated September 1987, is inserted in lieu of preliminary report.

Forty-sixth Meeting of the Committee on Channel Stabilization
Jackson Hole, Wyoming

> The valley of Jackson Hole lies here snugly among the mountains that rise on every side. The scenery, the game herds, the wild flowers, the entire ensemble of natural attributes has combined to produce a recreational environment that gives satisfaction and inspiration to hundreds of thousands of people each year.
>
> from <u>Wapiti Wilderness</u> by Margaret and Olaus Murie

I. <u>Introduction</u>. Jackson Hole is a high (6000 ft.) valley in northwestern Wyoming. Grand Teton National Park is here. Yellowstone National Park is immediately to the north. Jackson is a town of about 4500 people at the southern end of Jackson Hole. The meeting of the Committee on Channel Stabilization (CCS), Walla Walla District (NPW) and North Pacific Division (NPD) people and guests (Attachment 1) was held in the basement meeting room of the Antler Motel in Jackson. The Snake River, the problem channel for this meeting, flows through Jackson Hole (the valley) and does not threaten the town of Jackson.

History and design details of the project are contained in the briefing book by NPW dated 10 July 1987 (Attachment 2). Pages in this book were numbered sequentially by the CCS Executive Secretary starting from the cover letter dated 10 July 1987 (page 1). Every page, drawing or chart that was not blank received a number. In order to readily find referenced (by the CCS numbering system) pages in NPW's briefing book (Attachment 2), readers should similarly number their pages in Attachment 2. The last page in the report is numbered 132. To check your numbering, note that this last page should correspond in the briefing book to page 13 of Technical Report No. 11 by the 1974 CCS.

The Corps of Engineers constructed levees along the Snake River in Jackson Hole between 1957 and 1964 (Attachment 2, Project History, page 23) and turned the project over to Teton County to operate. Numerous local levees have also been built along the Snake. Maintenance, repair and flood fight costs since 1964 have totalled $9.4 million (Attachment 2, Project History, pg. 27). No residential flood damage has occurred during that time; but the cost of keeping the levees intact has been a burden on Corps Emergency Operations and the local sponsor. Public Law 99-662, section 840, directs the Corps to assume operation and maintenance (O&M) responsibility for the Federal project and local additions (Attachment 2, O&M Project vs. PL 84-99, page 18). NPW asked the CCS to assess the project's performance and to recommend ways to reduce O&M costs.

Participants in this meeting used Monday afternoon (July 13), all day Tuesday, and Thursday afternoon to view the project. Project presentations and discussions occupied all day Wednesday and Thursday morning. The downstream limit of the group's project tour was the Lower Imerson Levee. The tour's upstream limits were bounded by Lower Slide Lake on the Gros Ventre River, Jackson Lake Dam on the Snake River and the top of the Rendezvous Mountain aerial tramway at Teton Village.

Because of the short time span between the fixing of the meeting date and the meeting itself, four CCS members could not attend the July 13 meeting; however, a supplementary meeting was held on June 30 with two CCS members and Charlie Neill of Northwest Hydraulic Consultants, Ltd. of Edmonton, Alberta attending. The conclusions of this supplementary group are incorporated in this report, and Mr. Neill's *preliminary report on the project is Attachment 3.

II. <u>Items Specifically Addressed by Each CCS Member</u>.

1. Prioritized Areas for Clearing and Snagging Operations - Teton County expects to get funds for clearing and snagging operations along the Snake River this year; but, if money to clear and snag the entire project is not forthcoming, the county wants to do the most critical areas first. At the request of the county, the CCS prioritized the order of work, as follows:

* Note: Snake River at Jackson Hole, Wyoming: Field Inspection and Stability Assessment, dated September 1987, is inserted in lieu of preliminary report.

a. Start at the upstream end of the project and work downstream towards the Wilson bridge . Remove snags from the levee face and from upstream of bridge piers first.

b. Remove all large debris from low bars, especially trees with root balls.

c. Remove debris downstream of heavily treed bars. Consider removing all down timber from bars within the leveed reach.

d. If possible, the above order of work should also be followed from the end of the project upstream on the Snake to Jackson Dam and upstream on the Gros Ventre to Lower Slide Lake.

e. If environmentally acceptable, consider sawing up trees into reasonable lengths in place and allowing them to float out. In particular, separate the trunks from the root balls.

2. Interim Procedures for O&M Until Redesign Work on Project (if any) Is Completed -

The CCS could not improve much on the emergency repair methods currently being used by the county and NPW Emergency Management people. Some suggestions for supporting work, assuming that Federal O&M money becomes available, are:

a. Keep a formal record of repairs and problem areas. Record locations of impinging flow areas and associated scour hole depths and velocities. Record the time of occurrance of significant events, such as start of failure, shift of impingement points and end of failure process and correlate these with stream gage readings, flood duration, etc. Repetitive aerial photography will record impingement shifts, can refine flood stages and can become a data base for significant improvements in design. In lieu of repetitive photos and good stage readings, consider a survey of the high water line immediately after the flood. Some sort of high water recorders that would not be knocked out during flood fight operations are desirable. Dale Hart's Prototype Evaluation Branch at WES can help out here.

b. Advance stockpiling of riprap and construction in the summer low water season immediately after the spring freshet, as suggested by NPW, would be notable improvements on present procedures.

c. Between flood periods, redirect bar crossings to flatten the stream impingement angle on the riprap face. Consider constructing sacrificial groins from stream-bed material. This effort may encourage deposits between the groins against the levees or, at least, will provide an erosional source during floods in lieu of levee material.

d. Construct weighted toes (buried or unburied) of graded rather than extremely large ungraded material; that is, the largest sizes need to be contained within the mass of the material. For this project, previous construction records of gradation, thickness, burial depth, toe width, etc. will prove very valuable for determining the most effective toe protection design. Note that during flood fight fight operations, the ability to place graded riprap may be diminished and large stone could be required.

3. Long-term Solutions to Assure the Design Level of Protection, to Reduce Levee Maintenance and to Eliminate Annual Flood Fights - a. Development of flows and anticipated maximum stages - The present design discharge is 45,000 cfs, but none of the CCS believes the current levee heights are likely to contain this flow. The CCS also does not believe that present or achievable levee erosion protection can withstand 45,000 cfs without unacceptable damage. The 100-year flood discharge is currently about 28,000 cfs, but this value is a function of the USBR flood control storage at Jackson Lake and is not firm (See Attachment 2, Stream Flow Characteristics, page 42.) With some adjustments in freeboard at selected locations, the project should be able to contain a 100-year flood discharge. The 1986 flood peak was 26,000 cfs, and no overtopping occurred, although areas with less than three feet of freeboard were observed. Two approaches to freeboard design can be considered:

(1). Freeboard can be designed to be a distance "x" above the maximum or design water surface profile (WSP) with appropriate additional allowances to force initial levee overtopping in the least hazardous location(s). See ETL 1110-2-299. Intermediate levee tiebacks to high ground, especially on the right (west) side, may also aid in preventing large flood damages; however, this solution should be aproached with caution, since local topography may cause deep flooding.

(2). The WSP along the levees will be of sinusoidal form, composed of a series of flat and steep reaches relative to one another. This pattern changes slowly from year to year and reflects a long term migration of bed position (not a sediment wave of material which moves noticably in a single event; this sort of movement does not take place at this location). By assuming minimum freeboard at the peaks of this sinusoidal pattern and connecting the peaks, NPW can provide a levee which will retain its freeboard even after long-term major shifts in the material deposition pattern and resulting design WSP. The Tanana River levee at Fairbanks, Alaska was designed this way. Design for least hazardous overtopping is needed in this approach, also.

b. Possible solutions to the repair and maintenance problems -

(1). Continue more or less as has been done in the past. This can only be done if prior experience has refined the county's and NPW's Emergency Operations repair efforts to the point that they now know with reasonable certainty what material to put in the river and where to put it, and are certain the system is now close to being stable because of past efforts. This stability is not presently apparent in the system, and some minor areas of impingement and resultant erosion have been observed this year despite the absence of high flows.

The CCS believes that one or more of the following schemes for project modification may have the potential for large O&M savings.

(2). Improve the design of the slope protection placed along the existing levee alignment - Present Corps riprap design criteria may not be applicable in this case. Recent WES studies have indicated that COE procedures break down when the riprap size is equal to or greater than 10% of the flow depth. In addition, impinging flows have a flow curvature which cannot be predicted using present methods. Carry the riprap section to the crest of the levee. Observation of what works along this reach and elsewhere under similar conditions may be the best present design guide. Starting in FY 88, the WES research work unit on riprap design will begin to look at the effects of impinging flow on riprap. Steve Maynord, principal investigator for this work unit, will be contacting NPW for prototype input from the Jackson Hole project and possibly others. There seems to be only minor riprap damage due to ice impingement, and no riprap displacement due to ice adherance. If riprap costs begin to escalate beyond economic feasibility, alternative methods of bank protection should be examined.

(3). Minor river management - The nearly perpendicular impingements of river flow on the levee face, identified as the principal cause of bank protection failure, could be redirected during annual low water by minor excavation work in the river. On a more ambitious scale, the possibility exists that the present braiding pattern is controllable. If conditions are not now dominated by factors that force braid formation, minor work in the river, including blocking some of the minor braids or back channels which impinge on the levee, to redirect the Snake River into a single or, at least, less braided channel could be sucessful. The single, stable river channel existing in the vicinity of the Moose bridge lends credibilty to this idea. A test reach on some historic problem area near the upstream end of the project should be attempted first with design, review and direction by river engineers. Environmental problems inherent in any in-channel work may also be a factor in this scheme.

(4). Selected levee setbacks - At locations where the lack of development allows, set back the levee out of the active braiding zone. At most locations, however, where development (or potential development) precludes large setbacks, move back at least to the landward toe of the existing levee and provide a sacrificial berm of erosion resistant material (and a modified weighted toe) that the river would have to erode before it could attack the levee itself.

(5). Short groins at selected locations - Construct groins upstream of zones of inadequate bank protection, in a manner similar to what has already been done at some points along the Snake, in order to deflect flow towards the river and away from the bank downstream.

(6). Increased upstream reservoir storage - Increased flood storage in Jackson Lake and/or new reservoir storage on the Gros Ventre River should be looked at. The COE/USBR interagency agreement for Jackson Lake (Attachment 2, Stream Flow Characteristics, page 42) should be reassessed to determine if all permissible flood control storage is being used.

(7). Allow controlled gravel extraction from the project reach to increase capacity and to nudge the river in desired directions - Environmental problems with this approach may be insurmountable.

4. Recommendations for Hydraulic and Hydrologic Studies and Field Measurments -

a. Hydraulic and geomorphic analyses - The first step is an analysis of chronological aerial photos. From this and other data sources, determine, to the extent possible, why the river is braided and to what degree this tendency is still present. Perform a low-cost (±$10,000) sediment assessment. Examine well-behaved river reaches (e.g. Moose bridge reach) for clues to maintaining desired regime. Determine if there is a main channel meander sequence and if it is migrating. Study the effect COE and local projects have had on the stream's morphological parameters of width, depth, slope, and planform of the main channel. Study reach should extend from Snake River Canyon entrance upstream to Jackson Lake dam and to the Gros Ventre slide.

b. Recover the 1986 high water profile and measure any subsequent profiles - Put in vertical control along the levee to make measurments easier. High water gages placed at locations which would not be damaged during flood fights would be useful. In a river this steep, with a highly variable water surface, the spacing of measuring points must be fairly close. This spacing should be determined by NPW hydraulic engineers.

c. Plot the river thalweg (low point) and measure scour at impingements during floods - Scour measurments by impulse radar or sonar may be a quick and easy way to do it (see Attachment 5).

d. Survey and resurvey cross-sections to define volumetric changes to the bed and long-term aggradation and degradation trends - this may be done on a relatively infrequent basis.

e. Obtain gradation of bed material (using a low-cost method and limited sampling), determine if bed is armored and if so, what flow conditions cause this armoring - See Attachment 4 for an economical method of bed sampling.

f. Obtain aerial photography on at least an annual basis - An alternative to aerial photography is vertical aerial video. See Attachment 6 for more information on this topic.

g. Install a stream gage on the Gros Ventre River.

h. Examine the gage records at Moran since they could be productive in determining aggradation trends.

i. Consider a mobile bed physical model study of a typical reach.

III. Previous CCS Report. The CCS met in Jackson in September 1973 to discuss the Snake River levees with NPW. The results of that meeting were published as CCS Technical Report No. 11, March 1974 (Attachment 2, page 115). The present CCS concurs with the views of the 1973 CCS as expressed in T.R. No. 11, except as follows:

-Unlike the 1974 CCS, the present CCS does not believe the existing project is capable of passing a design flood of 45,000 cfs without a major upgrading and is assuming that the design flood will eventually be revised to a value around 28,000 cfs.

-Question No. 2 (Attachment 2, page 124) - The 1974 CCS felt the river was aggrading and that the channel was not likely to stabilize naturally. The present CCS recommends a hydraulic and geomorphological analysis to determine (among other things) if the present braid system is a relic and if aggradation is no longer taking place. If this is true, it may be possible to maintain an acceptable and reasonably stable channel between the levees.

-Recommendations (Attachment 2, page 131) - The present CCS has deferred recommending any single project alternative until necessary field data, hydraulic and geomorphic studies and other vital information are developed.

IV. Conclusions.

1. The levees are located within the active braid belt of the river so that a river channel running along the face of at least one levee at any given cross-section is almost inevitable. On the other hand, the levees are not close enough together to force the river into a single channel running parallel to the levees; hence, the near-right-angle impingement of flow on the levee face. Further setbacks of the levee would reduce, but probably not totally eliminate, the frequency of impingements.

2. The present levee spacing has both favorable and unfavorable aspects:

Unfavorable - It is extremely difficult to protect the levees in this location from the erosive force of the river.

Favorable - With the present approximately 2000 foot spacing between levees, stage increases associated with extreme events should be relatively minor and may be confined within the levee freeboard if this freeboard is designed as recommended in paragraph II.3.a. Since stage increases due to levee confinement have been minor, no detrimental effects on seepage or interior flood control requirements have been noted.

The present levee locations allow the possibility of developing a non-impinging regime channel, if the river is susceptible to river management.

3. No solutions which involve in-river work should be attempted

without a thorough study of the problem, including a geomorphic analysis. Any "uninformed" bed or bank alterations within the active braid zone could upset the present equilibrium and result in unanticipated and unwanted physical changes.

3. No local additions of levees to Federal maintenance should be accepted without such additions meeting rigid criteria for alignment, set-back, rock protection, etc.

V. Recommendations.

Top Ten Action List - Prioritized list of NPW actions recommended by the CCS:

One - Define the design discharge and return interval.

two - Recover the 1986 flood profile and recompute the design profile.

three - Determine quarry source(s) for bank protection material.

four - Proceed with management strategy of debris removal, riprap stockpiling and braid control as interim measures.

five - Perform a sediment assessment and fluvial geomorphic analysis.

six - At flow impingement points, record locations and measure scour depths.

seven - Determine gradation of bed material.

eight - Attempt to discover long-term trends in bed elevations.

nine - Coordinate with WES in developing riprap design procedures for impingement points.

ten - Develop test reach for a comprehensive minor river management plan.

VI. Other Committee Actions.

1. Steve Maynord gave the group an update on progress within the riprap research work unit. He also informed us that the 200 cfs riprap test facility at WES is now operational.

2. Bob Brown and Terry Waller updated us on progress in the

stable channel research unit. Detailed analysis of the stability of selected streams before and after construction is continuing with the aid of Charlie Neill of Northwest Hydraulics. Drafts of the nationwide channel inventory and ETL on channel protection using soil cement, prepared by Andy Reese of MCI, were made available for perusal.

3. The committee members welcomed Tom Prokrefke (replacing Ed Glover) as a new committee member.

4. The committee members recommended and the committee chairman confirmed the selection of Glenn Drummond of ORD to fill the space on the committee vacated by Dick DiBuono. Subsequent to this confirmation, however, Mr. Drummond accepted a position in OCE's Hydraulic Design Section replacing Bruce McCartney, who is transfering to NPD. Mr. Drummond will therefore not join the committee , and a new member selection will be made during the next committee meeting.

VII. Closing.

The Committee thanks the people of Walla Walla District and Teton County for the support and hospitality given to us during our stay in Jackson. Next CCS meeting: Alaska in September.

Samuel B. Powell
Chairman,
Committee on Channel Stabilization

Thomas E. Munsey
Executive Secretary,
Committee on Channel Stabilization

Attendance List (week of 13 July 1987)
46th Meeting of the Committee on Channel Stabilization
Jackson Hole, Wyoming

COMMITTEE MEMBERS

Larry Banks	LMKED-H	601/634-5946
Al Harrison	MRDED-T	402/221-7303
Col. Jim Lyles (substituting for Ed Hecker)	CECW-O	202/272-0196
Tom Munsey	CEEC-EH-D	202/272-8504
Tom Pokrefke	WESHR	601/634-2650
Dick Regan	NPSEN-HH-HC	206/764-3595
Tony Thomas	WESHP	601/634-2511

Committee members Frank Coppinger and Tasso Schmidgall were not present. (see NOTE)

WALLA WALLA DISTRICT HOSTS

Larry Cheney	CENPW-SA-VE	509/522-6797
Les Cunningham	CENPW-PL-H	509/522-6598
Wendell Greenwald	CENPW-EN-GB-SC	509/522-6769
Jim Wood	CENPW-OP-EM	509/522-6726

NORTH PACIFIC DIVISION

Duane Bankofier	CENPD-EN-G	503/221-3868
Lewis Gustafson	CENPD-EN-G	503/221-3867
John Oliver	CENPD-EN-TE	503/221-3859

GUESTS

Don Barney	Teton County Road and Levee Supv.	307/733-7190
Bob Brown	WESHP-D	601/634-2608
Michael Gee	WRSC-HEC	916/551-1748
Steve Maynord	WESHS-H	601/634-3284
Terry Waller	WESHP-D	601/634-3731
Jon Zufelt	CRREL	603/646-4325

NOTE: Committee members Sam Powell and Howard Whittington, Charlie Neill of Northwest Hydraulic Consultants and Walla Walla District people met for an ancillary Committee meeting in Jackson Hole on June 29th and 30th.

SNAKE RIVER AT JACKSON HOLE, WYOMING: FIELD INSPECTION AND STABILITY ASSESSMENT

Prepared for:

U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT

Prepared by:

NORTHWEST HYDRAULIC CONSULTANTS INC.
KENT, WASHINGTON

September 1987

87:5097/526R

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1. PURPOSE AND SCOPE

This report is submitted in accordance with a contract issued in June 1987 by Seattle District, Corps of Engineers, to Northwest Hydraulic Consultants Inc. The Scope of Work called for a field inspection, analysis and report on the channel stability and sediment processes of the Snake River in the vicinity of Jackson Hole, Wyoming, in Walla Walla District.

The inspection was conducted on 30 June and 1 July 1987 by Mr. C.R. Neill of Northwest Hydraulic Consultants along with Mr. S.B. Powell of Office of Chief of Engineers, Mr. Lester Cunningham of Walla Walla District, and Mr. Howard Whittington of Mobile District. During part of the field trip, the group was accompanied by Mr. Don Barney of the local County Road Department. Following the field inspection, a meeting was held in Jackson to review available information and to discuss questions raised by Walla Walla District.

Information provided to the consultants included the following:

- briefing book of May 1987 on Jackson Hole Flood Protection Project, and expanded version of July 1987;
- compilation "Special flood hazard information, Snake River" dated February 1976;
- aerial mosaic plans of 1986;
- 1:24000 scale topographic maps showing existing and proposed levees.

The present report amplifies and supersedes a preliminary letter report dated 8 July 1987. In accordance with the intent of the contract, it constitutes a series of reactions to features observed and responses to questions raised, rather than an in-depth analysis of extensive data.

2. FIELD INSPECTION AND PROBLEM ASSESSMENT

The length of river under discussion is shown in Figure 1. The Snake River was inspected on the ground at various accessible points between Moose (upstream) and the state highway bridge (downstream). The Gros Ventre River was also viewed at several points. Photos 1 through 6, selected from about 30 photographs taken by the consultant, illustrate some typical features of the rivers. Problems facing the Corps of Engineers over maintenance and extension of the Jackson Hole Flood Protection Project were discussed during and after the field inspections. Our understanding of these problems is outlined below.

The Snake River over a length of approximately 25 miles upstream and downstream of Jackson and Wilson, Wyoming, is a braided gravel stream in a wide floodplain. Upstream of Jackson, the active braided system is more or less continuously confined between levees built in the 1960s under the federal flood control acts. Downstream of Jackson, there is an intermittent system of relatively short levees and other flood protection works built under various authorities. Both systems have been partly re-armored and/or extended under emergency flood legislation.

The main problems faced by the Corps at present are (i) how to reduce the heavy annual costs of emergency "flood-fight" maintenance of the existing system, and (ii) how to design for downstream extension of a continuous levee system, given the existing intermittent system.

The main tributary in the reach of interest is the Gros Ventre River, which joins the Snake about 4 miles upstream of the Jackson-Wilson bridge. Its drainage area is about 45% of that of the Snake upstream of the confluence.

The principal costs of maintenance arise from emergency placement of riprap bank protection on the levees during and immediately after flood events that threaten to breach them. The Corps levees were designed with riprap protection on the lower slope 1.5 ft thick and with toe trench protection 6 ft wide and 3 ft thick (Figure 2), but this has proved inadequate in many places. Repair and maintenance costs have averaged over $300,000 per year over 20 years and in 1986, when a severe flood occurred, were approximately $2.5 million. Riprap used for repair work is generally larger in size, is thicker and extends farther up the bank than the original riprap, but due to the emergency nature of the work special toe protection work appears to be generally lacking (Photo 3).

It appears that flood damage is normally caused by the main channel of the river striking the levee at a severe angle of attack rather than flowing parallel to it. Even in the upstream part where the river is to some extent controlled between parallel levees approximately 2000 ft apart, the main channel is still free to wander between them and develop sharp bends. Heavy driftwood in the form of tree trunks etc. is said to add to the force of the attack. Problems with the riprap protection as designed include insufficiently large stone size and thickness, insufficient depth or volume in the toe trench to provide for maximum scour, and lack of protection on the upper bank.

3. ANALYSIS OF RIVER CHARACTERISTICS

3.1 Flood Hydrology

Plotted frequency data for the Snake River below the Gros Ventre, as regulated by Jackson Lake Dam, indicate approximately as follows for the period 1956-86:

2	- year	flood	15,000 cfs
5	"	"	18,500
10	"	"	21,000
20	"	"	23,000
50	"	"	25,000
100	"	"	26,500
200	"	"	28,000
500	"	"	30,000

The 1986 flood was of approximately 50-year magnitude. A design flood of 45,000 cfs had been proposed for the levee continuation and upgrading project, but the practicability and economic justification of such a high figure has been questioned. On the basis of the above estimates, a design flood of 30,000 cfs would appear to be adequate.

3.2 Planform

Over most of the length of interest, the river has a braided pattern consisting of one principal channel and a number of secondary channels. At the upstream end, near Moose, and at the downstream end near the highway crossing, the river transitions into essentially a single sinuous channel. The width of the natural braided system including inactive floodplain parts is in the order of 8000 ft, but upstream of the Jackson-Wilson bridge the parallel levees controlling the river are approximately 2000 ft apart. In the braided reaches, the principal channel appears to follow a roughly meandering path with a wavelength of perhaps 4000 to 5000 ft.

3.3 Slope

The slope of the Snake River is approximately 19 ft/mile or 3.6/1000. The slope of the Gros Ventre River is over 30 ft/mile or approximately 6/1000. It is said that successive surveys indicate slight degradation in the upstream reaches and aggradation downstream in the last 20 years. This may represent a response to partial confinement between levees upstream.

These slope data are plotted in Figure 3 on the slope-discharge-grainsize chart contained in a 1984 NHC report to the Corps of Engineers that presented tentative guidelines for preliminary design of stable channels.[1] The "dominant" discharge is taken as equivalent to the 5-year flood for plotting purposes. Assuming the median size of bed material to be in the 50 to 75 mm range in the absence of reliable data, the slopes plot at 2 to 3 times the "low transport" values. In terms of tentative adjustment factors suggested in the report, this would correspond to a moderate to high bed transport condition.

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1 Northwest Hydraulic Consultants, 1984. "Hydraulic design of stable flood control channels, II-draft guidelines for preliminary design". Report to Seattle District Corps of Engineers.

3.4 Cross-sections

The Snake River's channel width in essentially single-channel reaches appears to be in the range of 250 to 350 ft. Again assuming a dominant discharge equivalent to the 5-year flood, these widths are plotted in Figure 4 on the appropriate chart from the above-mentioned 1984 NHC report, and appear to fit reasonably well. The majority of cross-sections, however, exhibit two or more channels and a considerably greater total width.

On plotted cross-sections, maximum depths show as about 12 ft below the general floodplain level, but it is likely that scour depths at sharp turns and hard points are much greater in large floods. Existing levee heights appear to be generally in the range of 6 to 12 ft above floodplain level.

3.5 Materials

The bed material in the Snake River consists mainly of gravel with some content of sand and some material up to cobble or small boulder size, especially upstream of the Gros Ventre. The material in the Gros Ventre may be somewhat finer and have a higher sand content - it is said to be "looser". It has been suggested that the Gros Ventre brings in a disproportionate quantity of bed load but there appears to be no direct evidence of this in the form of a fan or other deposit at the confluence. Generally, the planforms of the two rivers are quite similar.

4. CONCLUSIONS AND RECOMMENDATIONS

Basically, the discussion below is provided in the form of responses to specific questions posed by Walla Walla District.

4.1 Appropriate Width Between Levees

It might be argued that the existing distance of approximately 2000 ft between parallel levees upstream of Jackson is neither narrow enough to create a single-channel river on a stable sinuous planform, nor wide enough to maintain sufficient setback from the main channel. As a result, the main channel continually impinges on the levees at one point or another; as soon as one weak point is reinforced, the river attack shifts to some other point. Furthermore, the river tries to develop main-channel meanders between the levees and thereby attacks them at severe angles rather than flowing parallel to them.

Arguments could be made for considering the extreme alternatives of (i) channelization in a meandering planform with continuous parallel levees in the order of a few hundred feet apart; or (ii) a much wider spacing than the existing, designed to maintain wide setbacks from the main channel and protected by groins where and when necessary. In an ideal case, the relative advantages of these approaches would depend greatly on land utilization. In the present case, the options for altering the levee spacing appear to be quite restricted.

4.2 Possibility of Predicting Future Points of Impingement

The river appears to be subject to sudden changes of channel pattern and main channel location in large floods, therefore it appears at first thought unlikely that future points of impingement can be predicted with any confidence. However, a study should be made of past channel shifts using historical airphotography to see if a pattern of main channel migration emerges. Such a study done by Alaska District for the braided Tanana River at Fairbanks[2] showed a definite pattern of down-valley migration of principal channel meanders.

4.3 Methods for Sizing Riprap Against Direct Impingement

It might seem self-evident that riprap has to be larger to resist a given velocity approaching at right angles to the bank than to resist the same velocity in parallel flow. Research data bearing on this problem appear, however, to be rather limited.

Appendix A contains an extract from a California Highways publication that gives a rough method of allowing for direct impingement. According to the guidance indicated, the effective velocity for sizing riprap at a direct impingement site might be twice that for parallel flow. Since stone size is roughly proportional to the square of velocity, this would imply that a size suitable for parallel flow should be roughly quadrupled for direct impingement, other things being equal. On the Snake River, the sizes used for floodfight repairs appear to be in the order of twice those in the original federal levees.

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2 Corps of Engineers, 1979. "Design Memo No. 27, Fairbanks Flood Control Project", Alaska District, Anchorage.

A somewhat different viewpoint is that the critical factor in riprap design is provision of sufficient stone volume to armor the bank down to the bottom of the scour that develops along an armoured slope and especially at points of impingement. Empirical factors have been recommended by proponents of the regime approach, for estimation of maximum scour in various situations: basically these involve estimation of a regime depth for the given flood discharge and boundary materials, and multiplication by a factor dependent on location or planform geometry - such as direct impingement. The regime depth can be looked on as an average depth under design flood conditions in "regime" or single-channel reaches. Typical multiplying factors quoted are 1.5 for a moderate bend, 2.0 for an abrupt bends, and 2.25 for direct impingement. In an analysis of observations in a gravel river of somewhat similar characteristics to the Snake, the present writer found multiplying factors of up to 2.5 in abrupt bends with more or less direct impingement on hard banks. An extract from the relevant paper is given in Appendix B.

4.4 Determination of Top and Bottom Profiles Along Levees

With regard to top profiles, we do not have much confidence in non-uniform flow computations using HEC-2 or equivalent in such shifting 3-D situations. In our experience, it is almost equally reliable to develop an average cross-section, estimate or calibrate a global roughness, and compute uniform flow. Non-uniform computations based on low-water surveys are apt to create a spurious impression of accuracy for high flood conditions when the whole river bed topography will be different from surveyed, and generally tend to over-predict the longitudinal irregularity of the flood profile. Being onedimensional, however, they do not provide for cross slopes due to flow curvature and impingement.

The suggestion by Mr. Powell to join up all the computed high points seems reasonable. The necessity for high flow calibration is paramount: efforts should therefore be made to pick up 1986 high water elevations along the Snake River if at all possible.

With regard to bottom-of-riprap profiles, it could be argued that if the river is to be left free to attack at severe angles almost anywhere, the whole bottom profile should follow worst-scour elevations. This is, however, likely to be extremely expensive. The concept of providing greater setback, and perhaps of using sacrificial groins, therefore seems an attractive alternative.

4.5 Regime Width

As noted in Section 3.4, the range of actual widths in existing single-channel reaches of the Snake River (250 to 350 ft) appears to be in line with a regime width of about 300 ft for a dominant discharge of about 18,500 cfs (5-year flood). For a 100-year flood of 26,500 cfs, the regime width would be about 350 ft. It is evident that simply to carry the floods, the river does not need anything like the width that has been provided between levees.

With respect to the capacity of a more confined river for bed-material transport, it is possible that the external supply of material is not as high as the channel pattern might suggest and that much of the transport is simply a short-distance exchange process. A greater degree of confinement would probably lead to some degradation, but the range of available stone sizes is large and bed armouring would probably ensue. However, there may be overwhelming environmental arguments against tight confinement, perhaps even against the moderate confinement already in place.

4.6 Groin protection

It seems likely that a system of unarmoured levees, set farther back than the existing federal levees and with groins where needed to maintain setback, is worth investigating as a more economical alternative to duplicating the upstream system in the downstream reach. It may also be possible to use groins to discourage the meander shift pattern of the principal channel, thereby limiting the locations of levee attack. It appears, however, that design alternatives are somewhat constrained by the need to incorporate into an extended federal system lengths of levee already constructed by non-federal agencies.

Photos 4 and 5 illustrate two types of short groins on existing non-federal levees. These appear to have had moderate success.

4.7 Levee Alignment

If the levees are well set back from the active river, the alignment can follow the general alignment of the braided system, as has in fact been done upstream. If closely spaced levees are used to create a channelization, they should be on a sinuous course compatible with a natural meander wavelength for the confined river.

4.8 Snake River Stability Upstream vs. Downstream of Gros Ventre River

It is possible, as has been suggested by others, that the Gros Ventre supplies a disproportionate amount of the bedload in the Snake downstream of the confluence. In that case the potential for channel instability would be greater downstream of the Gros Ventre confluence. Airphoto study of historical channel pattern changes should throw light on this. Other obvious sources of bed-material supply are located where the Snake River is impinging on higher terrace banks; instability may also be increased downstream of these locations.

4.9 Survey and study needs

The following items are suggested for inclusion in survey and study programs directed towards design of future flood control works:

- survey of 1986 high water marks;
- survey of maximum depths of scour holes at bends, obstructions etc.;
- superposition of main channel planforms based on historic airphotography;
- bulk sampling and grainsize analysis of river bed materials;
- determination of apparent volumes of degradation and aggradation based on available cross-sectional surveys.

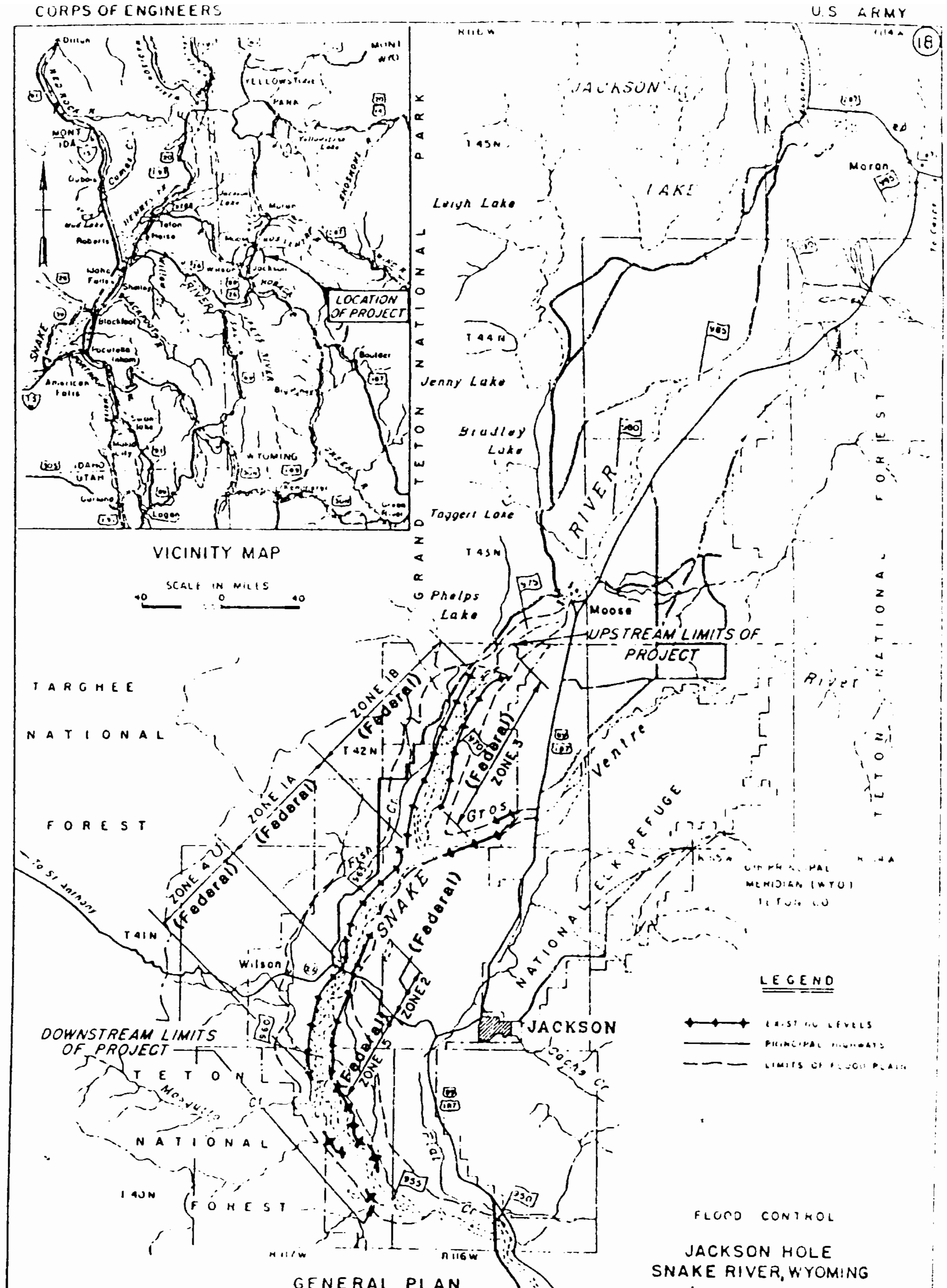
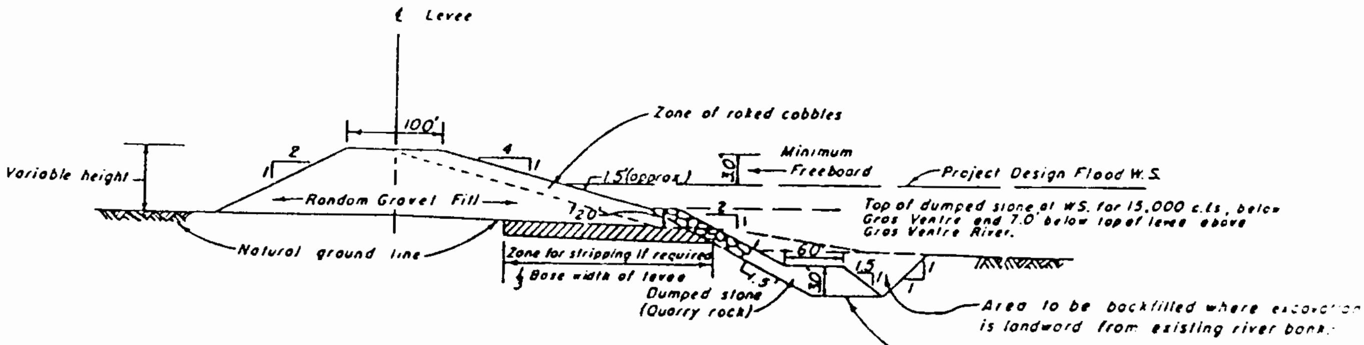


Figure 1. Location map



TYPICAL LEVEE SECTION

Figure 2. Original Corps of Engineers levee design

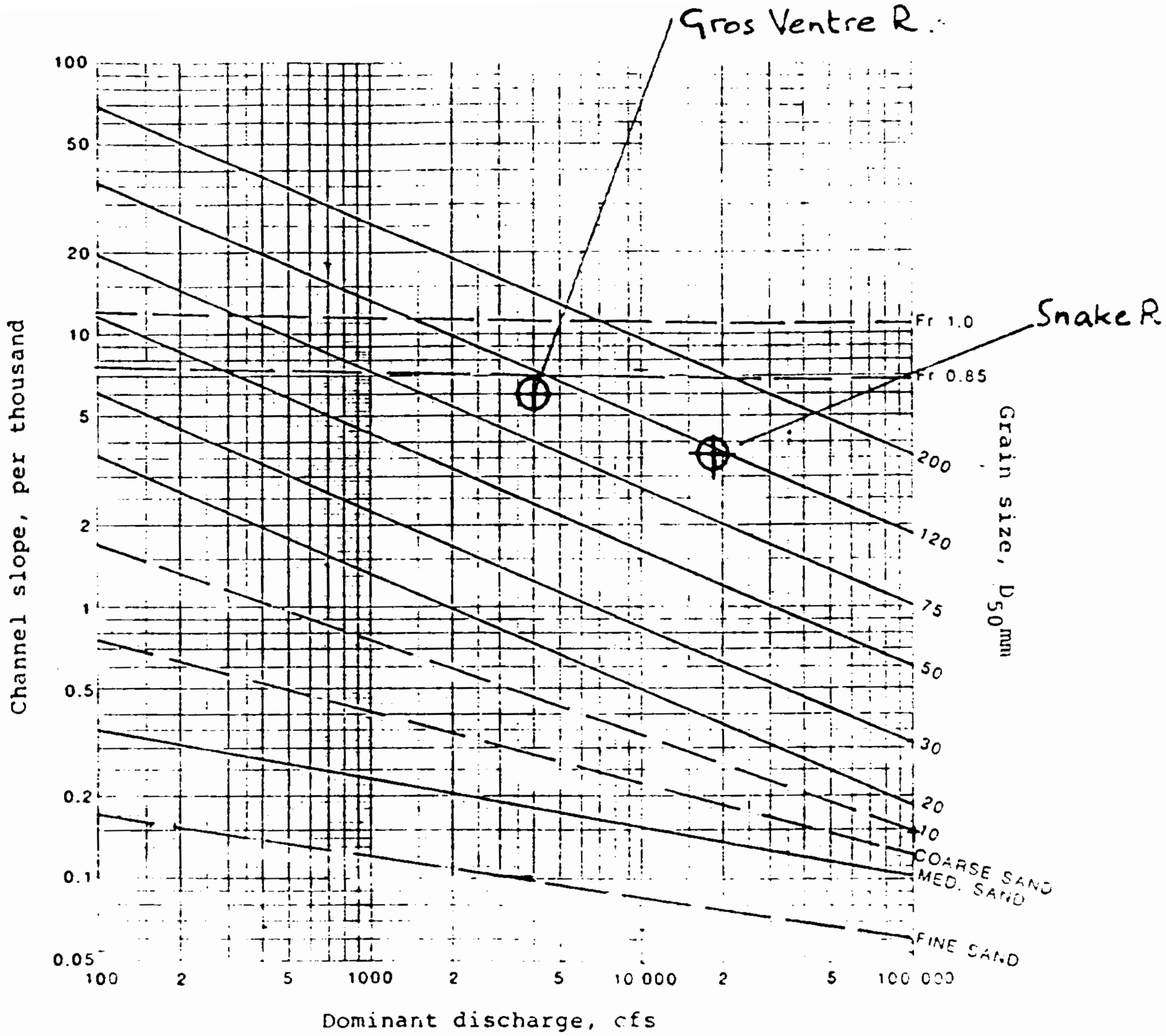
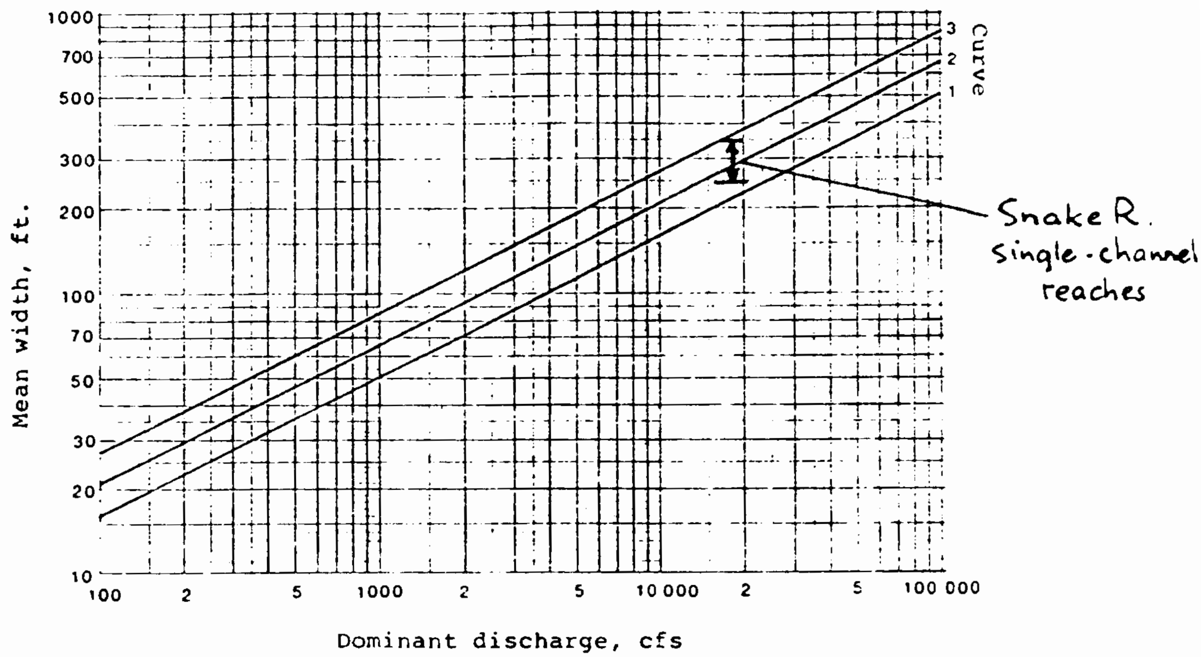


Figure 3.5 Limiting slopes for stability of channels in granular materials: low transport condition.

For assumptions and derivation see Appendix III. Curves shown as broken lines are tentative.

Figure 3. Slope-discharge-grainsize relation (from NHC 1984 report - see text)



Curve 1: high bank resistance to erosion
2: moderate bank resistance to erosion
3: low bank resistance to erosion

Figure 3.4 Mean width vs. dominant discharge for channels in erodible materials.

Assumption: trapezoidal cross-section
Equation: $b = CQ^{1/2}$, C=1.6 to 2.7

Figure 4. Width-discharge relation (from NHC 1984 report - see text)

Photo 1. Gros Ventre River 3 miles upstream of Jackson-Moose highway crossing.

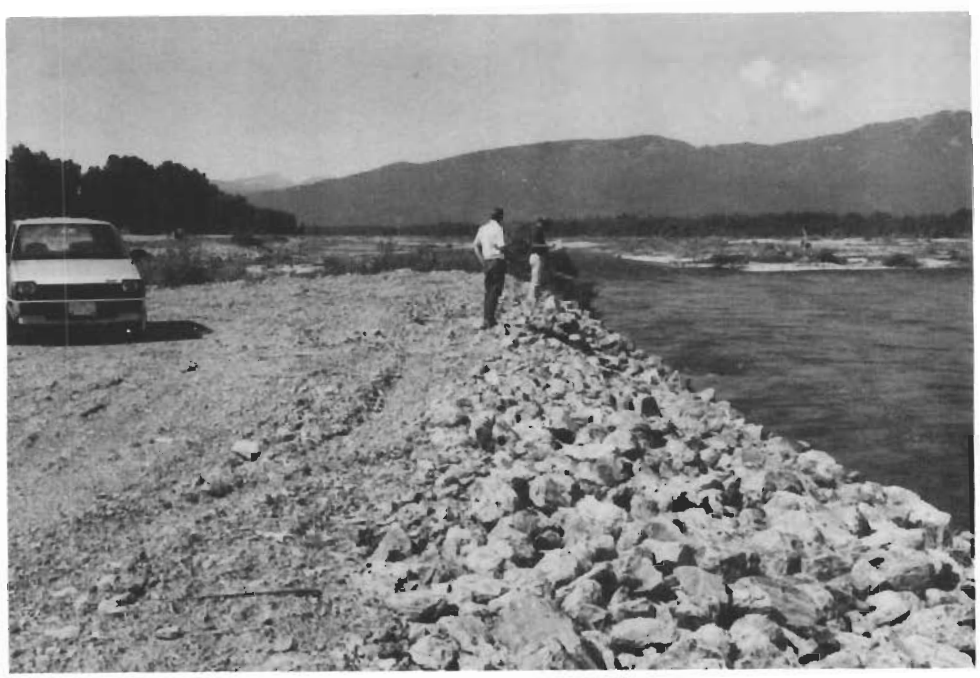


Photo 2. Snake River with federal levee upstream of Jackson-Wilson bridge.

Photo 3. Snake River with upgraded federal levee downstream of Jackson-Wilson bridge.

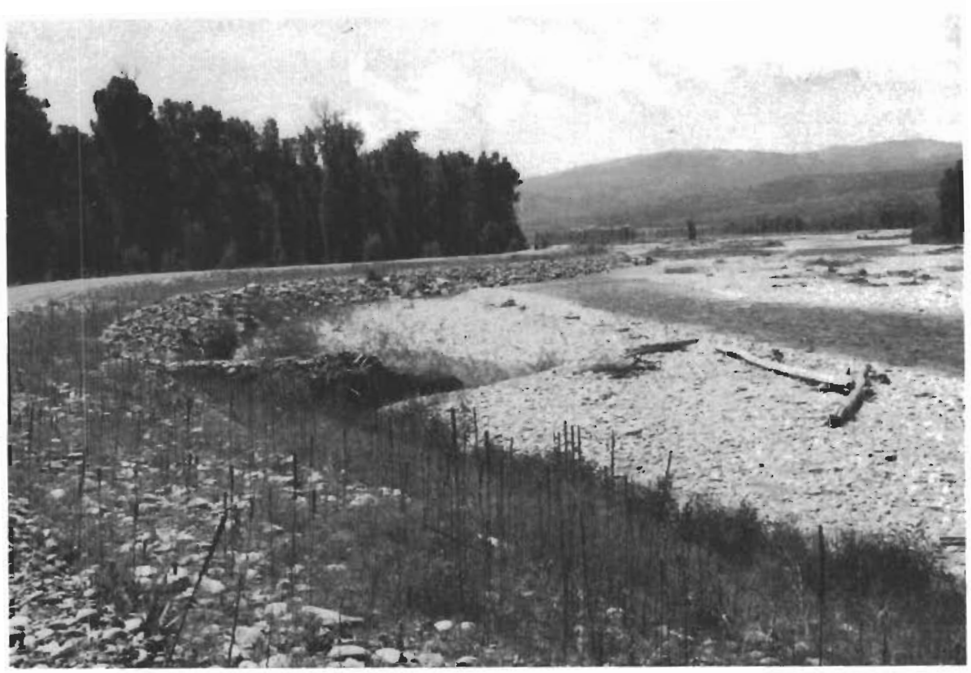


Photo 4. Non-federal levee and short gabion groins approx. 4 miles downstream of Jackson-Wilson bridge.

Photo 5. Non-federal levee with short rock spurs approx. 5 miles downstream of Jackson-Wilson bridge.

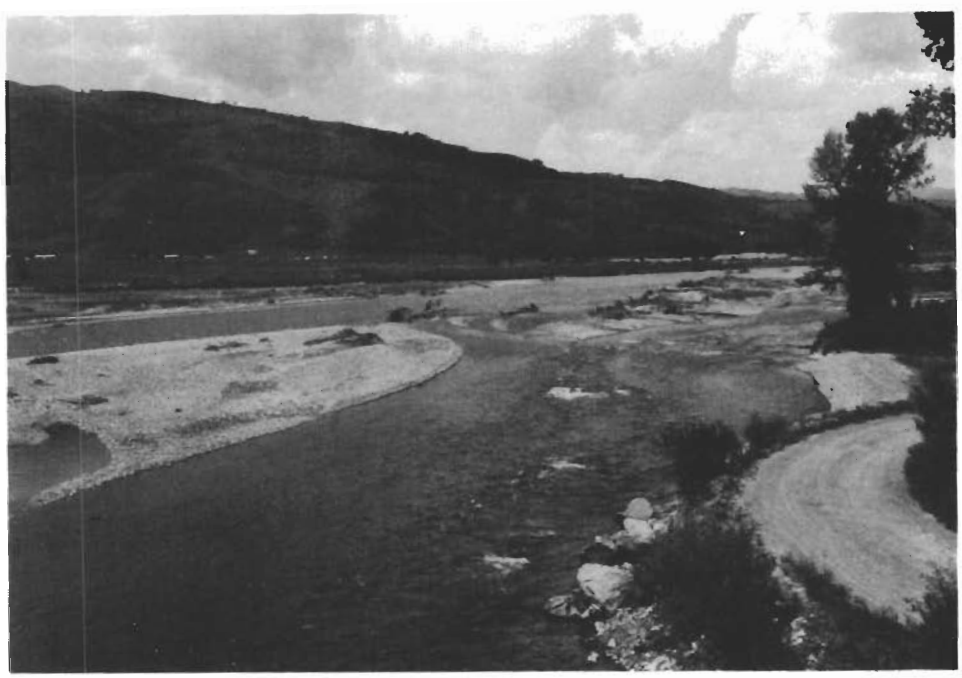


Photo 6. Snake River from highway bridge at downstream end of braided length.

[Trans. AGU, V. 35 - 6]

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Transactions, American Geophysical Union Volume 35, Number 6 December 1954

A METHOD OF SAMPLING COARSE RIVER-BED MATERIAL

M. Gordon Wolman

Abstract--This determination of the size of material on the bed of a stream is based upon an analysis of the relative area covered by particles of given sizes. The method is applicable to those rivers which flow on coarse material and may be waded during periods of low water. Sampling consists of measuring the intermediate axis of 100 pebbles picked from the bed of the channel on the basis of a grid system. From this sample a frequency distribution is drawn from which the desired size parameters are read. The advantages of the areal sampling procedure over bulk sampling are (1) that it is applicable to very coarse materials, and (2) that it provides a more representative sample of an entire reach of a stream.

Both hydraulic and physiographic studies of rivers often require some measure of rugosity of the channel. To provide an adequate description of bed material, as it affects rugosity, a consistent method of sampling is necessary. The method described here, though applicable only to coarse material, has several advantages over the usual bulk-sample method. The present method can satisfactorily integrate the enormous range in grain size often present in a river bed, as well as the non-random areal distribution of material in pools, riffles, and bars. The author believes this method of sampling described below produces a more representative picture of the bed of the stream, as well as a better measurement of the effective plane of roughness which directly affects the flow within the channel.

Description of sampling method--The determination of grain size is based upon an analysis of the relative area covered by given sizes rather than upon their relative weights. It is essentially an adaptation of suggestions made by J. C. Griffiths, Pennsylvania State University, for obtaining representative samples of heterogeneous materials. These suggestions the author gratefully acknowledges. The method consists of the following steps:

(1) In the desired reach of the stream a grid system is established either by pacing or with actual lines. The size of the grid is determined by the length of reach which the sampler desires to describe. This may include both a riffle and a pool, a riffle alone, or a pool alone. If comparisons are to be made between reaches, the sampler must obviously be consistent in his choice of the length of reach to be included in the sample.

(2) After establishing the grid, which can be done by a pacing traverse as the sampler picks up each pebble, 100 individual pebbles are picked up from the bed. (The sampling is probably less subjective when lines or tapes rather than pacing are used to fix the individual sampling points.) Randomness in the selection of each pebble can only be obtained if the sampler tries not to look at the bed as he picks up each pebble. The author's practice is to draw each pebble from beneath the tip of the toe of his boot.

(3) The intermediate axis of each pebble is measured. The limitations of measuring small individual pebbles such as sand sizes will be discussed below.

(4) Unless the actual diameters are of interest, a rule or scale can be designed showing class limits only and each pebble tallied within a grade class immediately. For this purpose the Wentworth scale is probably the most useful.

(5) With the pebbles placed in the proper classes, it is a simple matter to plot a frequency distribution of the sample. This plot is further simplified if the Wentworth size classes are denoted by the ϕ notation [KRUMBEIN, 1936] in which $\phi = -\log_2$ diameter in mm. Using this logarithmic scale the frequency distribution can be plotted on arithmetic coordinate paper (Fig. 1). Having plotted cumulative frequency curves for the distribution, the median diameter or other desired parameters can readily be determined in the field [INMAN, 1952].

The paragraphs which follow include observations on the present range of the experimental data, a comparison of the results of this procedure with the results produced by other sampling methods, and a brief analysis of the reproducibility of the sample obtained from a given reach by one or more operators.

ATTACHMENT 4

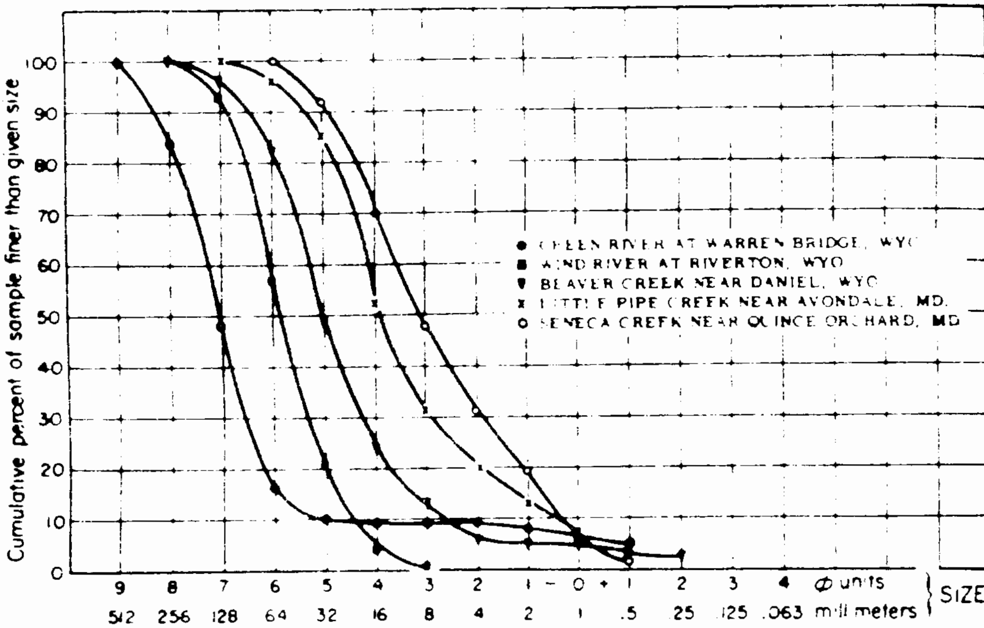

Fig. 1--Size analyses of river-bed gravels

Range of experimental data - The illustrative examples shown in Figures 1 and 2 from a large number of rivers flowing in diverse geographic regions indicate that the cumulative frequency curves of these samples resemble the distributions often shown by river gravels. Figure 2 compares these coarse bed materials with the normally distributed river-bed sands described by BLENCH [1952]. The median diameters of the samples range from 8 to 120 mm. Sorting, as measured by the φ standard deviations [INMAN, 1952, p. 135], ranges from 0.85 to 2.95 in the samples studied. These sorting values are lower on the whole than those listed by KRUMBEIN [1942] for comparable (possibly finer) gravels. Although it is conceivable that this method of sampling produces an apparent uniformity in the sample, the range of sorting found in the sediments thus far studied indicates that such a bias, if present, is not significant.

Comparison with other methods of sampling and analysis - It is interesting to compare samples determined from pebble counts with samples of the same material analyzed by sieving and weighing. As the example in Figure 3 shows, although the shapes of the curves are similar, the median diameter of the sample determined by the author's number frequency method is considerably larger than the median diameter of the sieved sample. The consistency of this relationship has been demonstrated by several analyses. The relationship is the reverse of the one we would expect if the comparison consisted simply of counting pebbles versus weighing the amounts of material in each sieve class from precisely the same sample. In the present instance, however, it is apparently the sampling procedure rather than the method of analysis which produces the discrepancy in median grain size.

The sample obtained from the grid represents the areal distribution of material on the bed. Each point sample actually represents a portion of the bed surface. If, for example, the sample of 100 stones contains ten in class 32-64 mm, the plotted frequency distribution actually shows that ten per cent of the surface area sampled is covered by material in the class 32-64 mm.

The distributions in Figure 3, therefore, represent analyses of samples taken from the same reach by two entirely different methods. The difference stems from the fact that the sieved sample represents a scoop of material obtained from one or more locations on the bed. If the bed contains coarse material, to be representative each sample must weigh in the neighborhood of 200-300 pounds. As a rule, in the absence of a dredge capable of obtaining a huge sample covering a wide surface area of the bed, we obtain for sieve analysis a non-representative sample from selected spots which contains a preponderance of fine material. It is the author's opinion that in most instances this defect in sampling is insurmountable if a volumetric analysis is made

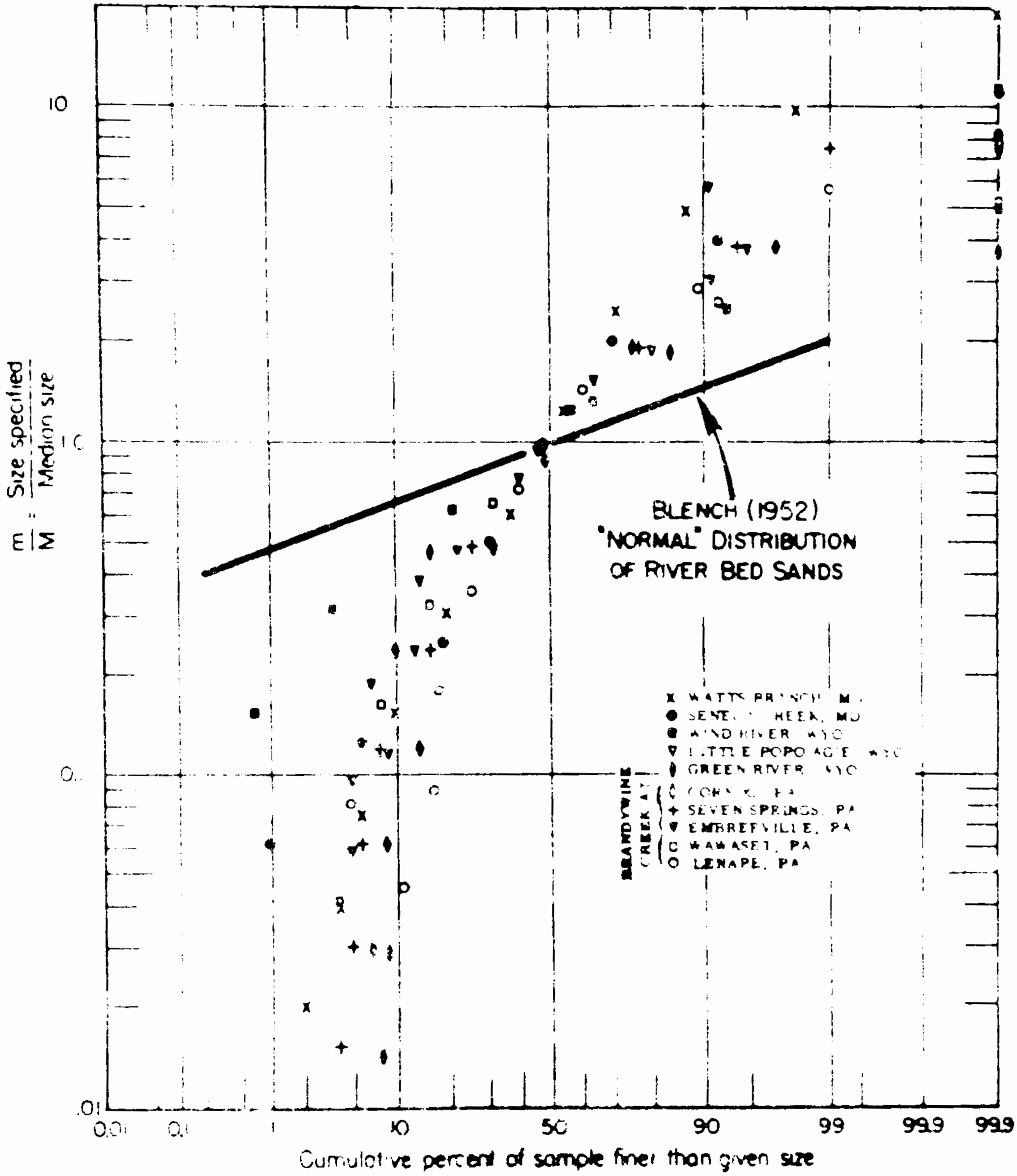

Fig. 2--Dimensionless size distribution for ten samples of river-bed gravels illustrating range of sorting and deviations from a normal distribution

Reproducibility of results--The reproducibility of results of the sampling at a given location is illustrated by the data presented in Tables 1 and 2. The three samples from Watts Branch (Table 1) were taken on separate days by the same sampler. In each case the distribution described by the cumulative frequency curves is much the same, although on one occasion the median diameter was considerably larger than on the other two. In all three samples the variance of the number of particles within the individual grades or size classes showed no systematic variation with grain size. The data from Mines Run (Table 2), a dry channel in a sandstone region in the Shenandoah Valley of Virginia, show the small amount of variation encountered at a given locality when a single operator samples 900 pebbles in groups of 100 pebbles. The standard deviation of the median diameters of these groups of 100 pebbles is 6.7 mm.

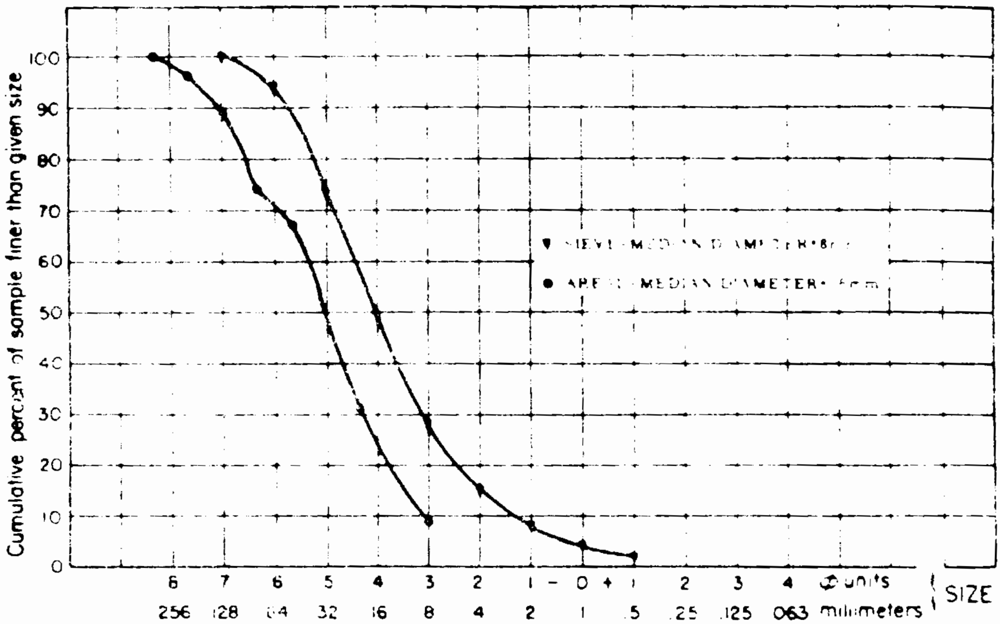

Fig. 3--Comparison of samples obtained from sieve and areal analysis

Table 1--Size distributions of three river-bed samples obtained at Watts Branch near Rockville, Maryland

Size		1953		
mm	Φ	June 19	August 25	October 1
0.5	1	....	3	2
1	0	4	0	2
2	-1	5	3	2
4	-2	11	3	4
8	-3	8	5	10
16	-4	8	17	17
32	-5	16	15	[illegible]
64	-6	16	26	17
128	-7	17	21	16
256	-8	10	6	11
512	-9	....	1	3
Median diameter, mm	....	25	37	26

In addition to illustrating the reproducibility of the sample, the data from Mines Run (Table 2) also suggest the minimum number of pebbles which should be counted to produce the described result. It can be seen from the table that 100 pebbles was sufficient to describe this distribution. Using the observed standard deviation, Student's t test suggests that one sample of 100 pebbles would be required to obtain a mean median diameter within plus or minus ten mm (12 pct of the median), with a likelihood of being correct approximately two-thirds of the time. Although it is conceivable that in larger rivers a greater number would be desirable, the use of 100 pebbles makes the computation of cumulative percentages and plotting of the distribution in the field extremely easy. Pending evidence to the contrary, this method appears reasonable.

Natural river channels possess small depositional 'provinces' such as occur on bars and riffles or in pools. If there is a distinct difference in the statistical variability of the individual deposits, those having the greater variability should be more intensively sampled than those of less variability

Table 2--Size distribution of nine samples obtained by one sampler from Mines Run, Virginia, July, 1953

Size	B2	B4	B6	B8	OA	A2	A4	A6	A8
mm									
4	1	1	2	2	...	1	1	2	...
10	2	1	2	3	3	3	4	2	...
25	6	11	9	12	14	4	7	9	8
40	6	10	8	7	8	11	11	11	9
63	15	16	16	7	9	18	14	23	17
100	22	22	18	23	26	22	26	13	20
160	19	21	27	21	19	18	15	17	23
250	19	13	14	16	15	17	13	13	12
400	5	3	1	7	4	5	6	4	9
630	3	1	3	2	2	1	2	4	1
1000	...	...	...	...	...	...	1	2	1
Median diameter, mm	94	80	82	84	83	80	79	69	87

Published data on river gravels from these depositional 'provinces,' however, show no marked differences in variability, and hence the random sampling proposed here appears to give the most significant results.

In obtaining samples from Mines Run the grid system was moved upstream and downstream at two-foot intervals in order to determine the effect of minor changes in the position of the grid on the reproducibility of the results. No systematic differences with position were observed, and, as before, the data showed no systematic variation within individual size classes; that is, the error of variation in sampling did not change systematically with change in grain sizes. The data from Watts Branch and from Mines Run suggest that an individual operator can repeat his sampling performance. Whether or not the accuracy of this repetition is sufficient for a given problem depends upon the results desired by the investigator.

The evidence available indicates that the results obtained by different operators on the same reach of channel do not differ appreciably. The three analyses obtained by different samplers from the Wind River at Riverton, Wyoming (Table 3), show extremely little variation in their median diameters and sorting. As the table shows, the median diameters were 51, 49, and 51 mm. The cumulative frequency curves for each of the samples are very similar. Data from Garner Run at Leading Ridge Gap, Pennsylvania, also show the consistent results obtained by different operators (Table 4). Although of limited value, five additional analyses indicate little variation in the results obtained by only two samplers.

Table 3--Size distribution of three samples obtained by different operators from Wind River at Riverton, Wyoming, August 6, 1953

Size		Operator		
mm	ϕ	A	B	C
8	-3	1	0	0
16	-4	4	1	3
32	-5	24	28	33
64	-6	51	55	53
128	-7	50	49	36
256	-8	10	8	10
Median diameter, mm	...	51	51	49

Table 4--Size distributions of three samples obtained by different operators from Garner Run at Leading Ridge Gap, Pennsylvania, September 31, 1953

Size		Operator		
mm	ϕ	A	B	C
2	-1	1	0	0
4	-2	4	0	0
8	-3	1	5	1
16	-4	4	6	4
32	-5	4	3	5
64	-6	16	13	17
128	-7	15	13	16
256	-8	11	13	13
512	-9	4	7	4
Median diameter, mm	...	64	77	77

Within the range of roundness normally encountered in river studies, there is little or no error introduced by the possibility of different samplers measuring different intermediate axes.

Limitations of the sampling procedure--The principal limitation thus far encountered in practice is the inability to measure accurately the fine particles. Two to four mm is about the smallest size which can be measured in the field. When the proportion of fine material is small, the smallest sizes may be lumped together or measured roughly in separate grades. Either system produces little change in the final result. Where fine material predominates, a sampling method such as this, which provides an areal coverage of the bed, requires both a sampler capable of drawing a single or a limited number of grains from the stream bed, and a calibrated magnifying glass which will permit measurements of fine particles in the field.

The difficulty of bed sampling by hand in deep water is a second limitation of the method. Thus far no satisfactory mechanical sampler has been developed for coarse material. The method is workable, however, where the water is several feet deep, and thus the importance of this limitation, which is common to all kinds of sampling beneath flowing water, is at least reduced.

Although it may not be a permanent one, the fact that the areal sampling procedure described here produces results, which are not directly comparable to the results previously obtained by bulk sampling and analysis of samples by weight, is something of a drawback. Additional work along the lines described by MARSCHNER [1953] may make it possible to convert from one system to another. It is important to remember, however, that conversion is only possible, or for that matter useful, where the samples themselves have equal validity. The primary significance of the sampling procedure suggested here is the fact that it gives a more representative sample, and hence a different one from those customarily obtained from river beds.

Conclusion--The principal advantages and disadvantages of the areal sampling procedure described here can be summarized as follows. In its favor are: (1) it is simple to perform, and indeed it is 'possible' in situations where flowing water and coarse material make other methods almost impossible; (2) the sampling method provides a reasonably representative sample of an entire reach of the stream; and (3) a sufficient range of sizes can be measured to permit some standardization of methods, making possible comparison of results obtained in studies of hydraulic roughness in one place with those obtained elsewhere. Its primary disadvantage at present is the inability to handle fine material.

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MARSCHNER, A. W., A method for the size analysis of sand on a number frequency basis, J. Sed. Pet., v. 23, pp. 49-59, 1953.

U. S. Geological Survey,
Washington 25, D. C.

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IMPULSE RADAR FOR RIVER BOTTOM MEASURMENTS

Current impulse radar technology exists for the determination of bed topography in rivers. Recent experiments tested several antenna configurations for investigating scour around bridge piers on the Connecticut River near Hartford, CT. The average water depth was approximately 10 feet. Signals received from the antennae varied according to their focus width and output power. One antenna, placed on the water surface, gave excellent readings, clearly showing pier scour to depths of 10 feet below the bed. The signal also contained reflections from subsurface changes in density. This information could be used by a trained observer to determine if filling of scour holes has taken place.

SONAR FOR RIVER BOTTOM MEASURMENTS

The USGS currently uses several types of sonar transducers and fathometers for measuring depth. A fathometer system was recently tested at the above bridge and was found to give excellent readings of scour holes up to a depth of 25 feet. The fathometer also provided information up to 15 feet into the bed sediments. The system used was a color video-type system with different colors signifying various densities of sediment. The sonar type systems have an advantage over radar systems in being about 1/5 as costly. The depth of penetration of the sonar systems may be limited in zones of high turbicity.

SAMPLE CONTRACT FOR AERIAL VIDEO OF RIVER

Aerial Video Tape Acquisition for Ice Monitoring in the Ohio River Basin Scope of Work

Purpose

The purpose of this work is to obtain color video tapes from aircraft to document river ice conditions on a one-time basis in parts of the Ohio River Basin (portions of the Allegheny, Monongahela, and Ohio Rivers) during the 1986-87 winter season. These tapes would be obtained during a low-altitude aircraft flight. The video tapes are intended to show the varying extent and distribution of ice cover and open water, ice jams, broken and unbroken ice, ice-surface characteristics, and navigation tracks through the ice on the date of flight.

Area of Coverage

The area to be covered in the video tapes is described as follows:

-Allegheny River - Mile 31 (just upstream of Lock and Dam No. 5 near Freeport, PA) downstream to Mile 0 (Pittsburgh Point at Pittsburgh, PA),

-Monongahela River - Mile 43 (upstream of Lock and Dam No. 4 near Belle Vernon, PA) downstream to Mile 0 (Pittsburgh Point), totaling 74 river miles, and

-Ohio River - Mile 0 (Pittsburgh Point at Pittsburgh, PA) downstream to Mile 266 (just downstream of confluence of Kanawha River at Point Pleasant, WV), 266 river miles.

Product Acquisition

The vendor shall be responsible for providing all video taping equipment, video tapes, aircraft, and flight personnel to accomplish the proposed work. Exposed video tapes obtained under the terms of this contract shall become the property of the U. S. Government. The color video tape used shall be "1/2-inch VHS" tape, in lengths not less than 60 min. nor more than 120 min. Video equipment used shall be "Industrial Grade" having precision tape speed control. The video tapes obtained during flight shall provide continuous coverage of the entire specified length of each river, as specified under Area of Coverage, weather conditions permitting. If tapes changes are made, the new tape shall resume coverage prior to the point where the previous tape ended, so as to maintain continuous coverage of the river and assure overlap for determining locations.

Video Procedures for Vertical Viewing

Potential vendors are instructed to prepare bids for the following vertical video taping procedures:

The video camera shall point vertically downward, and the top of the camera shall face forward in the aircraft camera mount, so that the scene shall enter the top of a viewing screen and exit at the bottom. The field of view, described in detail below, shall include the river width and sufficient amounts of land on the banks to allow identification of features (such as buildings, communities, bridges, highways, or tributary streams). This is required to permit locating ground features on tapes, and hence river locations, by reference to published maps and charts. To further aid in location determination, the video tape audio channel shall be used by the vendor during flight to identify features such as locks and dams, bridges, tributary streams, islands, and, in particular, river miles with a frequency of at least once every two miles. In addition, the audio channel shall be used to record flight data (date, altitude, etc.), breaks in flight lines, tape changes, and scale changes (where applicable). Turns in flight lines to follow curves in the river shall be flat turns insofar as practical. Where the river curvature is sharp enough to require banked turns, there shall be breaks in the video flight lines so that there are no gaps in video coverage. The aircraft speed during video taping shall not exceed a nominal ground speed of 200 mph (175 knots).

Field of View and Scale Information

Allegheny and Monongahela Rivers

The width of the subject rivers varies between 600ft and a localized maximum width of 2200ft. The predominant or average width is estimated to be about 800ft to 1000ft, with a nominal maximum width of 1500ft. In view of such large variations in river width, there is no single, precise scale requirement. It is anticipated that actual scale will vary according to operation of a zoom lens on the video camera, and according to flight altitude variations. Changes in lens focal length and flight altitude will be documented on the audio channel.

The primary requirement is that the field of view shall always have both river banks in view. Thus the actual scale and the actual scene width will vary and are of secondary importance, as long as the river width occupies no less than about 30% and generally more than 50% of the scene width.

As stated, the nominal maximum width of this river is 1500ft. Providing for approximately 500ft of land on each side of the river, the maximum normal video scene width will be about 2500ft (at the river surface level). Thus the minimum normal scale will be 1:30,000, assuming a 1-in. television tube in the video camera.

Ohio River

The width of the subject river varies between 900ft and,
with certain exceptions associated with islands and discussed in later paragraphs, a localized maximum width of 2200ft. The predominant or average width is estimated to be about 1300ft to 1600ft, with a nominal maximum width of 1800ft. In view of such large variations in river width, there is no single, precise scale requirement. It is anticipated that actual scale will vary according to operation of a zoom lens on the video camera, and according to flight altitude variations. Changes in lens focal

length and flight altitude will be documented on the audio channel.

The primary requirement (subject to exceptions cited in the following paragraphs) is that the field of view shall always have both river banks in view. Thus the actual scale and the actual scene width will vary and are of secondary importance, as long as the river width occupies no less than about 30% and generally more than 50% of the scene width.

As stated, the nominal maximum width of this river is 1800ft. Providing for approximately 500ft of land on each side of the river, the maximum normal video scene width will be about 2800ft (at the river surface level). Thus the minimum normal scale will be 1:33,600, assuming a 1-in. television tube in the video camera.

There are two groups of exceptions to the above paragraph. In the first group are locations where small islands make the river slightly wider, and a change in scale during flight (by varying focal length and/or altitude) will be required. In the second group are locations where large islands divide the river into a main channel and a secondary channel. These secondary channels will not require scale changes, but will require separate flight lines in addition to the primary flight line following the main channel.

Scale-change locations. Generally these locations will be flown with a video scene width of about 3500ft (at the river surface level). The corresponding scale will be 1:42,000 (1-in. television tube) within the reaches identified below.

Site	Location (River Miles)
Phillis Island	34.8 - 35.8
Cluster Islands	51.5 - 52.5
Fish Creek Island	112.8 - 113.9
Paden and Williamson Islands	131.7 - 136.0
Wells Island	138.7 - 139.7
Bat or Grape Island	151.3 - 152.3
Middle Brothers or Broadback Island	158.2 - 159.2
Marietta or Kerr Island	168.8 - 171.8
Muskingum Island	175.2 - 177.1
Neal Island	181.0 - 182.6
Letart Island	234.5 - 235.5
Eight Mile Island	257.6 - 258.1

Secondary flight-line locations. Generally these locations will be flown at the same scale as the primary flight lines, and will be taken after first completing the adjacent main channel and then returning to take the secondary channel in the same river direction (i.e., upstream or downstream).

Site	Secondary Channel Location *	Location (River Miles)
Brunot Island	Left (southwest)	1.5 - 3.0
Neville Island	Left (southwest)	4.5 - 10.2
Browns Island	Right (west)	60.6 - 63.5

Wheeling Island	Right (west)	89.3 - 91.4
Blennerhassett Island	Left (south)	185.7 - 189.9
Buffington Island	Right (west)	216.4 - 217.9

* Left or right when facing downstream.

General

Continuous monitoring by flight personnel shall be required to insure that the river banks remain in view at all times. If a bank goes out of the field of view, the flight line shall be terminated and the aircraft will return to the point where the bank last appeared. Video taping will then resume on an acceptable flight line containing both banks within the field of view. Such instances will be properly annotated on the audio channel.

Scheduling

The aircraft flight(s) for video acquisition under this procurement shall be scheduled at the direction of a representative of U. S. Army CRREL. The vendor shall initiate such flight(s) within 24 hours of such notice, weather conditions permitting. If the video coverage of the entire Area of Coverage cannot be obtained in one day, the remainder may be obtained on the following day. However, all video coverage is expected to be completed within 48 hours of the original order to begin video acquisition, weather conditions permitting. In accordance with normal aviation practice, flight personnel shall have final decision authority over initiating, terminating, or modifying any flight, based on weather conditions or any other safety considerations. The video acquisition portion of the flight(s) shall be accomplished between the local times of 0900 and 1500 hours.

Interrupted Video Coverage due to Adverse Weather

It shall be the vendor's responsibility to complete the flight(s) for video acquisition as ordered, weather conditions permitting. If a flight is initiated and weather conditions interrupt obtaining complete video coverage for the entire Area of Coverage, the vendor shall receive no payment unless within 48 hours of the interruption it is able to obtain the remaining video coverage.

Product Delivery

The video tapes acquired under this procurement shall be sent to U. S. Army CRREL, Hanover, NH. Duplicate copies of the video tapes acquired during each flight shall be sent to:

U. S. Army Engineer District, Operations Division, Pittsburgh, PA, for the Allegheny, Monongahela, and the portion of the Ohio River from Mile 0 to Mile 127 (downstream of Hannibal Locks and Dam).

U. S. Army Engineer District, Operations Division, Huntington, WV for the portion of the Ohio River from Mile 127 to Mile 266.

These products shall be sent by the best available means so as to be received at their destinations within 24 hours after completion of the flight.

Acceptability of Product

The product obtained under this procurement must be of an acceptable quality such as would be obtained by experienced and competent aerial surveying firms using properly functioning and suitable aircraft and video equipment operated by trained flight personnel using professional judgement in meeting the needs of the procurement.

Bid Basis

Bids on this work shall be on the basis of an estimated cost for completed video-acquisition flight(s) over the complete Area of Coverage, and for delivery of the video tape products from such flight(s).

Information Requested

To evaluate the qualifications of vendors and the suitability of their equipment and operations for accomplishing this work, vendors are asked to provide brief descriptions and information as follows:

Video Equipment: Furnish names, model numbers, and brief specifications of video camera and lens, video tape recorder, in-flight video monitor (if any), and remote controller (if any). Describe the power supply for the video equipment during airborne operations. Provide brand names and types for video tape proposed to be used.

Aerial Equipment: Furnish make and model of aircraft proposed to be used,and describe any features or modifications of the aircraft making it suitable for the proposed video acquisition. Provide a description and/or pictures or drawings of the camera mount that would be employed.

Operations: Give the name and location of the airport(s) that will be used as an operational base. Briefly list and describe any previous aerial imagery acquisition experience (video and/or photo), giving dates, imagery types, locations, and clients. If such a list would be lengthy, five representative typical entries will be sufficient.