MADISON RIVER, MONTANA
REPORT ON

# FLOOD EMERGENCY
# MADISON RIVER SLIDE

# VOLUME II
# APPENDIXES

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
SEPTEMBER 1960

# MADISON RIVER, MONTANA
# REPORT ON
# FLOOD EMERGENCY
# MADISON RIVER SLIDE

VOLUME II

APPENDIXES

SEPTEMBER 1960

PREPARED BY
U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

DISTRIBUTED BY
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

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BY WOODWARD, CLYDE, SHERARD AND ASSOCIATES
CONSULTING CIVIL ENGINEERS

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX I

Preliminary Studies of Madison Canyon
Slide and Hebgen Dam
By Woodward, Clyde, Sherard and Associates
Consulting Civil Engineers

August 28, 1959

Job No. 3527

Lt. Col. Hogrefe, District Engineer
Garrison District
Corps of Engineers, U. S. Army
Riverdale, North Dakota

SUBJECT: Report on Preliminary Studies of Madison Canyon Slide and Hebgen Dam Near West Yellowstone, Montana

Dear Sir:

In accordance with verbal instruction given to us on August 21, 1959 we have made preliminary studies of the Madison Canyon Slide and the Hebgen Dam which are located on the Madison River in the Counties of Gallatin and Madison in Montana. The purpose of the studies was to determine the stability of both the slide which has blocked the lower end of the Madison Canyon and of the Hebgen Dam which was damaged by the recent earthquake. The request and authorization for the studies were given verbally by Major General Keith Barney, Division Engineer, Missouri River Division, Omaha, Nebraska.

The scope of the studies is briefly outlined below in accordance with notes prepared by Mr. Wendell E. Johnson, Chief, Engineering Division, Missouri River Division, Omaha, Nebraska:

"To: Woodward, Clyde, Sherard & Associates

Preliminary report covering:

1. Your views and recommendations regarding

   a. Safety of Hebgen Dam and need for commencing drawdown.

b. Safety of slide area for impondment and probability of sudden failure.

c. Feasibility of removing a significant part of slide to provide a spillway which would not fail rapidly.

d. Further investigation recognizing that there may not be time for extended investigation.

JOHNSON"

Because of the need for quick action, an immediate reconnissance was made of the Hebgen Dam and the Madison Canyon Slide on August 21 and 22. A verbal report with recommendations and conclusions was presented to the Division Engineer and Chief of the Engineering Division, Missouri River Division, on the late afternoon of August 22, 1959. Present at this meeting with the Division Engineer were various personnel of the Garrison District and the Office of the Chief of Engineers.

LOCATION

Hebgen Dam is located in Sections 22 and 23, Township 11S, Range 3E, in Gallatin County, Montana. The Madison Canyon Slide is located in Section 36, Township 12S, Range 2E in Madison County, Montana. The slide is across the Madison River at the mouth of the Madison Canyon in the Madison Mountain Range. Immediately west of the slide is a broad valley of unconsolidated sediments deposited by the Madison River and its tributaries. Gallatin and Madison Counties are in the southwestern part of Montana immediately west of Yellowstone National Park. The Madison River flows northwestward from Yellowstone Park. Hebgen Lake, which stores about 350,000 acre feet of water behind Hebgen Dam, is about 17 miles long; it extends to the western boundary of Yellowstone Park.

CHRONOLOGY OF EVENTS

The exact time of the earthquake is a point of disagreement among local people. It is agreed, however, that the earthquake occurred between 11:35 and 11:40 MST on August 17, 1959. The earthquake was recorded at the University of California Seismological Station in Berkeley, at 11:39:56 P.M. on August 17, 1959 PDT. According to personnel at the station it would take about 1-1/2 minutes for the shock wave to travel from West Yellowstone, Montana to Berkeley, California. It appears, therefore, that the earthquake occurred at about 11:38 P.M. MST. Sharp after-shocks were recorded by the Berkeley Station the next day from 12:59 A.M. to 9:06 P.M.; these after-shocks varied in magnitude from 5.5 to 6.75 on the Richter Scale. A summary of the times and magnitudes of the major shock and after-shocks is given below:

| Date | Time at Berkeley, PDT | Magnitude (Richter Scale) |
|---|---|---|
| 8/17 | 11:39:56 P.M. | 7.5 to 7.75 |
| 8/18 | 12:59:05 A.M. | 6.5 |
| 8/18 | 1:44:37 A.M. | 6.0 |
| 8/18 | 4:06:45 A.M. | 5.5 to 5.75 |
| 8/18 | 8:28:52 A.M. | 6.75 |
| 8/18 | 9:06:42 P.M. | 5.75 to 6.0 |

Many additional after-shocks of lesser magnitude were recorded but they are not considered to be of major importance for purposes of this report.

The caretaker at Hebgen Dam saw a wave of water sweep at least 3 feet over the dam soon after the first major shock. This was followed at intervals of about 10 minutes with at least 3 more waves which were clearly visible in the bright moonlight. The top of the dam was visible between waves. The waves of water converged in the narrow channel below the dam and passed quickly downstream causing destruction and loss of life. Major faulting occurred along the right bank of the reservoir and in the canyon downstream from the dam. The right side of the reservoir area dropped 6 to 10 feet while the left side well upstream of the dam uplifted approximately 6 feet. Numerous slides along the edges of the reservoir severely damaged the upstream access road to the dam making it impassable for rescue vehicles. A huge slide at the mouth of Madison Canyon blocked the road from the downstream end. The large slide also blocked the Madison River completely with a mass of earth and rock debris slightly less than one mile long, one quarter to one third of a mile wide, and 150 to 400 feet high. A reservoir commenced to form immediately behind the slide mass or natural dam.

HEBGEN DAM

Hebgen Dam was built about 1915. The dam is a rock and soil fill dam with a central concrete core. It is approximately 720 feet long including a concrete spillway, 81 feet in width, located on the right bank. The embankment is about 90 ft high at its highest point. The central concrete core wall extends to bedrock which is found at a depth of about 115 feet below the top of the dam. The spillway has 8 openings, each 7 feet wide. The crest elevation of the dam was 6550.61 and that of the spillway slab 6536.24. Stoplogs placed across spillway openings were used to raise the reservoir level to elevation 6544.61. The concrete core wall beneath the dam was carried to bedrock; however, the core wall beneath the spillway extends only to a depth of about 15 feet below the bottom of the spillway. Storage behind the reservoir is about 350,000 acre feet at maximum pool.

At the time of the earthquake the reservoir surface was high. The earthquake caused considerable damage to the spillway and earth dam. Near the right abutment, where the embankment is the lowest in height, the downstream slope has dropped about 4 feet below the top of the concrete core wall. The entire upstream slope has dropped 4 to 6 feet below the top of the core wall. The greatest drop in the downstream zone is close to the spillway. The greatest drop in the upstream zone is near the middle of the dam. The concrete core wall has broken loose from the spillway wall. It appears that the core wall has moved slightly upstream from the spillway. There is a ground fault along the right bank of the reservoir which has caused the parking and boat loading area just upstream of the spillway to slip into the water. It appears that this fault may extend into the spillway. There are fractures along the ridge just downstream of the right abutment of the dam which may be a continuation of the fault. The spillway chute has been badly damaged. The concrete lining, which is about 4 inches thick, has been broken and water has leaked through the lining. Springs are observed just below the downstream slope near the right abutment. In this particular area considerable rock fill may be seen at the toe of the slope; it is possible that the lower portion of the downstream zone in this area was constructed of rock fill. The concrete core wall has broken vertically in four places near the right end of the dam. The first break is located 15 feet from the left spillway wall, the second break 30 feet, the third 63 feet and the fourth about 83 feet from the left spillway wall. The largest opening in these breaks is about 3 inches wide; in two of the breaks the concrete wall seems to be displaced from 1 to 3 inches. The crest of the downstream fill slope has dropped with respect to the core wall about 4 feet at the right end, tapering gradually towards the left end of the dam where the drop below the core wall is about 6 inches. A close examination of the toe of the downstream slope, in the highest portion of the dam, failed to reveal any major displacement of the slope; however a deep gully has been eroded near the outlet pipe where the water spilling over the right half of the dam converged into the old river channel. At the right end where the embankment is only about 15 to 20 feet high it is difficult to determine whether there is any bulging at the toe; the slope here is badly eroded and cracked and is covered with numerous pieces of rock. Seepage is observed in the rock fill near the right end of the dam. There are at least three major seeps which flow at a rate estimated at 300 gpm. There are also some seeps along a road about 100 to 200 feet downstream of the toe of the dam. This road parallels the spillway discharge channel and is located about 30 feet above the river level. The seeps seem to be emanating from the ridge downstream of the dam.

The upstream slope is badly cracked where exposed above the reservoir surface. The cracks are approximately parallel to the concrete core wall. Although it was not possible to determine conditions below the water surface it appears to us that most of the upstream slope has slumped downward and toward the reservoir. On both sides of the concrete core wall the earth fill near the surface has separated as much as 6 inches from the wall. Earth has been tamped in this opening to minimize infiltration of water.

Based on our observations of the damage to the spillway and the embankment we are of the opinion that the dam is not safe at the reservoir level of 22 August 1959 (Gage reading 42). Major repairs will definitely be required for future operation of the dam and reservoir. A decision should be made by the owner as to the scheme of repair and the work should commence as soon as possible. It is our recommendation that the present water level behind the dam be lowered to avoid the possibility of failure.

MADISON CANYON SLIDE

The Madison Canyon Slide is located at the west end of the Madison Canyon. Discussions with geologists who mapped the area prior to the slide reveal that the surface rock at the site consisted of a massive ledge of dolomite rock extending from the canyon bottom up the left side of the canyon to a ridge approximately 1300 feet above the river. There were numerous intermediate ledges which were developed from erosion by the river in the past. The dolomite layer had a dip of about 50 to 60 degrees toward the river. It had the greatest height near the mouth of the canyon and decreased in height towards the upstream end of the canyon. Immediately behind the dolomite layer were schist formations in various degrees of weathering and decomposition. Upstream of the dolomite ledge the schist formations were exposed to weathering. Over a period of years they have developed a slope approaching the angle of repose of this formation. All bedding of the schists and of the dolomites was approximately parallel and dipped toward the stream at an angle of about 50 to 60 degrees from the horizontal. In effect, the dolomite acted as a retaining wall holding the schist formations in place.

In order to help us in fulfilling our mission we questioned a number of geologists familiar with the site. Several of these geologists were in the process of mapping the area geologically; the others came in to study the slide for their own information. The names of several of the geologists are given below. We believe that they would be able to provide additional information on the geology of the slide.

| | |
|---|---|
| Mr. Jarvis Hadley, | USGS, Regional Geologist,<br>Ennis Hotel, Ennis, Montana<br>Mapping slide area. |
| Mr. William Long, | USGS, Field Assistant to Mr. Hadley,<br>Ennis, Montana<br>Mapping slide area. |
| Mr. Whitkind, | USGS, Denver. In charge of field<br>party mapping area upstream of<br>Hebgen Dam. |
| Mr. Dorsey Hager, | Consulting Geologist,<br>908-909 Continental Bank Bldg.<br>Salt Lake City, Utah |
| Prof. McManus, | Geologist, Montana State College,<br>Bozeman, Montana<br>Prepared a short report on the<br>slide for a college publication. |

Geologists are of the opinion that the earthquake buckled the dolomite ledge near the bottom causing the upper portion to slip downward; the support was thus taken away from the schist formation. The schist formation, unable to stand on the steep slope, slid rapidly down the left side of the Canyon. Reports indicate that the slide occurred in a matter of seconds. The slide mass pushed the dolomite along the bottom of the valley and up the right side. A second slide apparently occurred immediately after the first. The second slide consisted of the more weathered schist just upstream of the main slide. The schists of the second slide were deposited along the upstream portion of the natural dam,

In order to determine if the lake behind the natural dam would cause ponding against the toe of Hebgen Dam, which is about 6 miles upstream, Forestry Service personnel made elevation readings at various points on the slide mass in the river bottom and at the base of Hebgen Dam. The elevation readings were taken at various points in the area with altimeters in a helicopter. The altimeter readings indicated that the river bottom at the downstream toe of the natural dam had an elevation of approximately 6300. At the upstream toe of the slide the river bottom or canyon had an elevation of about 6320. In the lowest portion of the slide, where the reservoir will spill, the elevation was about 6460 or approximately 140 feet above the upstream toe of the natural dam. The elevation at the downstream toe of Hebgen Dam is 6470 according to the design drawings. This elevation checked out fairly well with altimeter readings made from helicopters. The top of the Hebgen Dam had an elevation of about 6550. The highest portion of the natural dam has an elevation of about 6700. Although these elevation readings were approximate they did indicate that the lowest portion of the crest on the natural dam was about 10 feet lower than the downstream toe of Hebgen Dam. Measurements by Bureau of Public Roads personnel, review of maps in this region, and other information indicate that it is unlikely that the lake ponded behind the slide will approach the toe of the Hebgen Dam.

It was estimated by Forestry Service personnel that the water had ponded to a depth of about 30 feet behing the natural dam on the 20th of August. On that day the water level was rising at the rate of about 6 inches per hour. Two days later it was rising at a rate of about 3 inches per hour. Area-capacity curves veloped by Garrison District personnel from rough topographic ps with large contour intervals indicated that the storage capacity behind the slide before overtopping is about 50,000 acre-feet. On the 21st of August water was being released from Hebgen Dam at a rate of 1,200 cubic feet per second according to the caretaker at the dam. A rough estimate of inflows from tributaries downstream of Hebgen Dam indicates that approximately 500 cubic feet per second of other inflows enter the reservoir behind the natural dam, giving a total of approximately 2,000 cubic feet per second or roughly 4,000 acre-feet per day. Observations at the downstream toe of the slide indicated that practically no water was passing through the slide. The slide was impervious on the 21st and 22nd of August. Assuming that inflows will be at the rate of 3,000 or 4,000 acre-feet per day, it is estimated that it will probably take 15 to 20 days from the 22nd of August to fill the reservoir behind the natural dam.

A detailed reconnaisance was made of the slide from a helicopter and on foot to determine the composition and distribution of materials in the slide mass blocking the canyon. Very rough estimates indicate that the slide mass or natural dam is three quarters to a mile long in the direction of the river flow. It is about a third to a half mile wide across the valley. The natural dam rises about 400 feet above the canyon bottom at its highest point and about 150 feet at the point, where water will probably spill. The highest mass is piled near the right side of the canyon. The lowest portion is located approximately over the old river channel. The slide mass in the canyon has effectively blocked the river flow. The slide is acting as a natural dam.

A detailed examination of the top of the entire natural dam indicates that the materials in the downstream one-third of the dam consist of very coarse, hard rock fragments varying in size from 1 to 10 feet in diameter. There are some materials smaller than one foot in diameter and some boulders as large as 20 feet in maximum dimension. The inclination of the material in the lower 1000 feet of the slope of the slide is approximately 1 vertical to 15 horizontal. There are three distinct ridges formed by the slide across the valley in the area where water may overflow. In addition to the larger blocks of rock the upstream portion of the ridge contains a considerable amount of finer materials developed from crushing of the weathered schist rocks. There are considerable amounts of hard rock varying in size from 6 inches to 3 feet in diameter overlying the entire lower areas of the natural dam. The upstream zone contains the surface mantle which covered the original slopes. Also lying on the surface of the upstream portion of the slide area or natural dam are the trees which originally stood on the slopes. The trees generally point their stumps towards the northwest or the upstream right abutment.

Because of the favorable distribution of materials in the slide mass, the flat inclination of the downstream slope, the presence of a natural spillway channel in the lowest portion of the mass, and the extremely wide section parallel to the river stream, we believe the slide will act as a stable natural dam. At the time of our inspection there was no evidence of seepage out of the downstream toe. It is very likely that as the water level rises there will be a considerable amount of seepage through the coarser materials which cover the right side of the valley. We do not believe that this will be harmful because of the very flat downstream slope.

The mass of dolomite blocks piled up along the right abutment is standing at an inclination of about 40 to 45 degrees in the steepest area. We believe that there will be some adjustment of this mass under the influence of heavy seepage and some undercutting by erosion in the spillway area. Although a considerable amount of water will seep through the dam, it is our opinion that there will be flows over the crest. As a result there will be some erosion of the surface of the lower portions of the slide area. Because of the presence of large amounts of coarse rock and the flat average slope of the downstream zone (about 4 percent) we feel that the danger of rapid undercutting or rapid erosion is low.

There are certain studies which should be initiated immediately in the slide area. First, a topographic survey should be made of the slide mass at contour intervals of about 2 feet to determine the volumes of materials, the elevations of the high and low points, and to form a basis for velocity and erosion studies in the spillway channel. In addition to the topographic surveys we recommend that a program of test borings be started at once. In the first phase several borings should be made in the river bottom at the downstream toe of the natural dam to determine the types and distribution of materials in the valley beneath the slide. The purpose of the foundation investigation is to determine whether there is a possibility of piping beneath the slide mass.

In addition to the above studies, which should commence immediately, we recommend that certain measures be taken to lower and widen the crest of the upstream ridge. The slide scarp along the top of the ridge about 1300 feet above the canyon bottom should also be removed.

It is recommended that bulldozers be utilized to excavate a spillway on the crest of the upstream portion of the natural dam where the reservoir will spill. The elevation of this area should be lowered as much as practicable within the time available and a wide crested spillway should be excavated. Bulldozers may be operated along the remainder of the spillway to form a rip-rapped spillway channel.

Hydraulic studies should be made to determine the rock size required to rip-rap the channel against the velocities anticipated in the spillway chute. We also recommend that explosive charges be used to remove the steep slide scarp high above the slide area. Observations from a helicopter disclosed that a number of wide cracks exist immediately above the scarp. These cracks indicate that the scarp will slide in the near future. Although the quantity of material involved is not great we believe it should be removed to avoid danger to personnel working below.

In addition to the immediate studies recommended above, such as topographic surveys and test borings in the river bottom, we recommend that observation wells be installed at suitable locations in the slide mass to measure subsurface water levels. Test borings should also be made to determine whether fine grained materials exist beneath the downstream zone of the dam. Although surface examinations indicate that coarse rock materials exist in the downstream portions of the dam and fine grained or impervious materials in the upstream portion, we believe that the surface examinations should be confirmed by test borings. The observation wells should be located high enough so that they will not be interrupted or damaged by flows over the spillway.

Confirming our verbal recommendation of August 22nd, we emphasize the desirability of maintaining 24-hour watch of the downstream portion of the dam for seepage and for possible movement. Records should be maintained of the rates of rise in the reservoir level and the estimates of storage behind the sliding mass confirmed by further studies.

For consideration in the future we recommend that some thought be given to the construction of a debris dam downstream of the present slide. The debris dam would serve the purpose of flattening out the crest of any flood that may develop due to break-out of certain portions of the sliding mass; discharges downstream in the Madison River Valley could be controlled by such a debris and detention dam. It is entirely conceivable that the flows over the slide will be stabilized in the form of a rapids so that no debris dam would be required downstream.

In summary, it is our opinion that the slide mass will be stable against rapid failure from the water accumulated behind the slide. We believe that the sliding mass has formed a natural dam. We recommend, however, that careful observations be made of subsurface flows to determine whether an accumulation of water pressures on the downstream slope develops.

Very truly yours,

WOODWARD-CLYDE-SHERARD & ASSOCIATES

BY /s/Dr. James L. Sherard
Dr. James L. Sherard
New York R.E. 30966

By /s/Stanley F. Gizienski
Stanley F. Gizienski
California R.E. 10352

MADISON RIVER, MONTANA
REPORT ON
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MADISON RIVER SLIDE

APPENDIX II

GEOLOGY OF HEBGEN DAMSITE
BY R. E. CURTISS

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX II

Geology of the Hebgen Damsite
by R. E. Curtiss

30 August 1959

## GEOLOGY OF THE HEBGEN DAMSITE

### INTRODUCTION:

Pertinent geologic conclusions and recommendations relative to the damage to Hebgen Dam and immediate vicinity are contained herein.

### MECHANICS OF EARTHQUAKE DAMAGE:

Initial shock waves in the form of sudden energy releases from the earthquake resulted in the formation of the Hebgen fault (See Plate 1) and concomitant damage to the spillway and the east end of the core wall.

Hebgen fault roughly parallels the northeast side of the reservoir and dips 65 to 75 degrees toward the dam. The fault originated in structurally weak surficial deposits of talus, terrace, and alluvial sediments about 850 feet east of the spillway near the competent east ridge composed largely of durable Madison limestone and associated rocks. The fault possibly is intercepted one or two miles downstream from the dam by the pre-quake Madison fault. Hebgen fault extends upstream from the dam toward the reputed epicenter of the earthquake in Yellowstone Park.

Regionally, the downthrown fault block of the Hebgen fault exhibits tilting and inundation of the shoreline, minor slides, tension cracks, and compaction of the loosely consolidated sediments along the northeast side of the lake.

In the immediate damsite area, with the formation of Hebgen fault, compressive shock waves were transmitted through the terrace and alluvial deposits, literally jolting the downthrown fault block some 850 feet horizontally between the fault scarp and the spillway (See Plate 2). The fault scarp is about 15 to 20 feet high directly opposite the spillway. This apparent vertical displacement decreases pregressively toward the rigid bedrock foundation of the dam about 250 feet lower than the fault scarp.

The quake moved the overburden horizontally by compression energy and vertically by tensional release and compaction. The jolt was transmitted in a westerly direction through the nonrigid overburden to the sector of the core-wall which is firmly attached to the structurally durable bedrock at Station 8 + 84. Between Stations 3 + 75 and 8 + 84 (509 feet), the foundation is rigid bedrock which is a part of the competent west or left valley wall.

The weakest structural foundation of the dam underlies the spillway which is superimposed on a terrace deposit. The jolt moved the overburden and spillway structure horizontally and slightly vertically against the rigid core wall. The core wall at station 8 + 84 imposed rigid restraint against compression forces. The spillway and about 85 feet of the core wall broke; greatest damage was sustained by the spillway.

The vertical component of displacement is believed much less than the horizontal component in the immediate damsite area. It is believed that if the fault vertically displaced the bedrock foundation, significant open joints and fractures in the bedrock would probably be reflected by extensive damage to the core-wall part of the dam, with conspicuous breakage and leakage.

Tension cracks developed between the spillway and the fault scarp. Random cracks are perceptible in the spillway and broken core-wall area and the broken area of the downstream curve of the spillway chute, across the highway, and up the slope toward the scarp. Many open cracks are conspicuous between the highway east of the spillway and the fault scarp, attesting to the fractured condition of the overburden materials. No water seeps or saturated zones have been noted to date; however, additional reconnaissance in the dam area is recommended.

CONDITION OF WEST (LEFT) VALLEY WALL:

Lithologically, metamorphic rocks, which comprise the west valley wall (left abutment) in the immediate dam area, are predominantly competent quartzite and dolomite, with lesser amounts of incompentent thin beds of sericite schist. These rocks are similar to those found in the Madison Valley slide area.

The beds generally strike N35°E and dip an average of 40° northwest or downstream. It is believed that the west wall is structurally stable. No slickensided surfaces, indicative of movement, were observed along bedding planes as a result of the earthquake. Several minor slides are evident along the shoreline. Based on the structural and lithologic characteristics of the materials, no large-scale slides which might damage Hebgen Dam are suggested.

## CONCLUSIONS AND RECOMMENDATIONS:

Conclusions and recommendations are as follows:

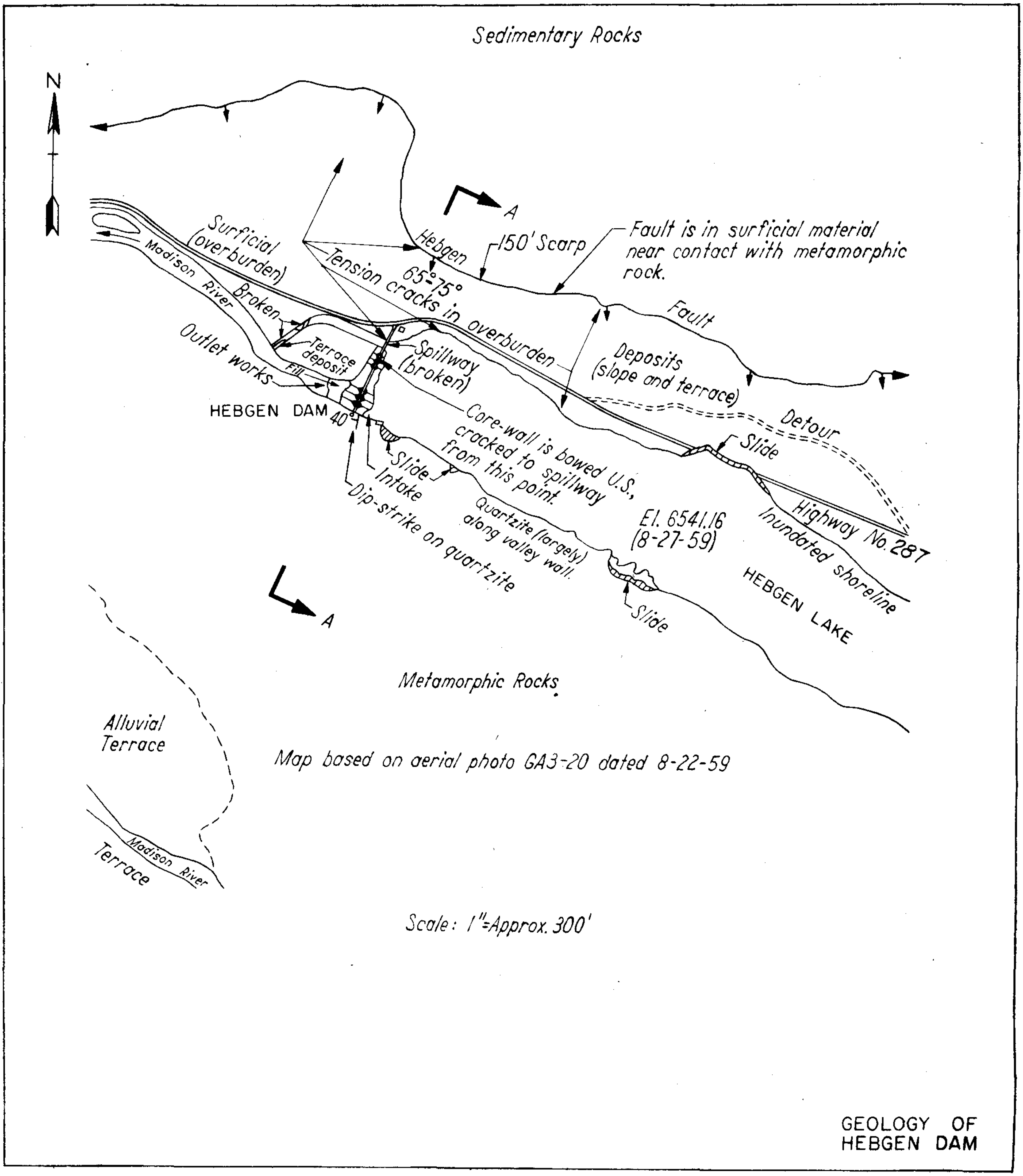
1. Tremors subsequent to the earthquake continue at erratic intervals. Any additional movement along the Hebgen Fault which might extend to the dam area could be ascertained by instrumentation.

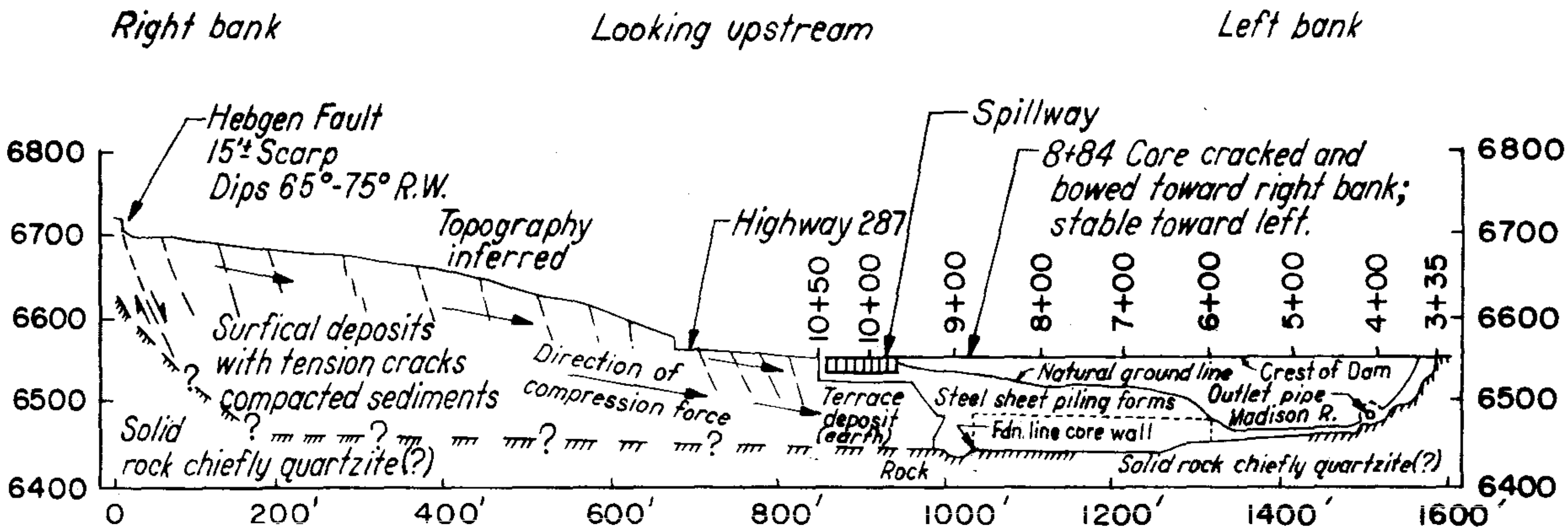
2. The main part of the dam between Stations 3 + 75 and 8 + 84 is attached to rigid bedrock. It is believed that additional tremors will not be deleterious to this sector of the dam.

3. Based on the structural and lithologic characteristics of the west or left valley wall, indications are that no large-scale slides are anticipated. The valley wall appears stable.

4. Additional reconnaissance of the tension-crack area on the right bank of the spillway is recommended. Water seepage and saturated zones might develop if extensive cracks developed through the surficial deposits to bedrock.

R. E. CURTISS


Sedimentary Rocks
N
A
Surficial (overburden)
Hebgen
150' Scarp
Fault is in surficial material near contact with metamorphic rock.
65°-75°
Tension cracks in overburden
Madison River
Broken
Fault
Terrace deposit
Spillway (broken)
Deposits (slope and terrace)
Outlet works
Fill
HEBGEN DAM
40°
Core-wall is bowed U.S. cracked to spillway from this point.
Detour
Slide
Slide
Intake
Dip-strike on quartzite
Quartzite (largely) along valley wall.
El. 6541.16 (8-27-59)
Highway No. 287
Inundated shoreline
HEBGEN LAKE
Slide
A
Metamorphic Rocks
Alluvial Terrace
Map based on aerial photo GA3-20 dated 8-22-59
Madison River
Terrace
Scale: 1"=Approx. 300'
GEOLOGY OF HEBGEN DAM




SECTION A-A

HEBGEN FAULT
AND EARTHQUAKE FORCES
THAT DAMAGED HEBGEN DAM
17 AUGUST 1959

MADISON RIVER, MONTANA
REPORT ON
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MADISON RIVER SLIDE

APPENDIX III

APPRAISAL OF THE CONDITION OF
HEBGEN DAM
BY P. T. BENNETT

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
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APPENDIX III

Appraisal of the Condition of Hebgen Dam
by P. T. Bennett

26 August 1959

## APPRAISAL OF THE CONDITION OF HEBGEN DAM

1. General. A description of the earth movements at and in the vicinity of Hebgen Dam, and a general statement of the effect on the dam, is contained in a separate report by Mr. Curtiss. This memorandum presents in somewhat more detail the effects of the quake on the dam, appraises the condition of the valley, terrace, and spillway areas of the project, and recommends a limited program of investigations considered necessary as a guide to sound engineering for reconstruction of the spillway. A more detailed description of the physical condition of the dam is given in a report by Mr. Carter Johnson. The necessary background data for this memo will be found in the report by Mr. Curtiss.

2. The dam can be divided into three sections for purposes of discussing its reaction to the earthquake movements.

a. Valley section--Extends from left abutment to about Station 6+50, where the original ground rises about 35 feet from the valley floor to the edge of the gently sloping right bank terrace. The core wall rests directly on bedrock, and the fill is practically on bedrock. This section is relatively immune to differential movements between bedrock and right terrace, as all elements are founded on rock and are in relatively poor contact with the overburden of the terrace.

b. Terrace section--(Stations 6+50 to 8+75) In this section, the embankment varies from 20 feet to 40 feet in height, and is founded on the terrace overburden which has a depth ranging from 90 feet to 60 feet. The core wall is founded on bedrock, and is approximately 110 feet high. With respect to longitudinal and vertical movements, the core wall can be considered as attached to the bedrock. The embankment in this section, as regards movement in any direction, is a part of the terrace.

c. Spillway section--The spillway and 30 foot cutoff wall both rest on terrace and will tend to move with it. Between the spillway proper and the terrace section there is a transition section about 100 feet long in which the core wall does not go to bedrock. This transition is considered to be part of the spillway section in the following discussion.

3. The general pattern of movement of the terrace was horizontal deformation toward the river, plus a vertical compaction. The valley section of the dam, being in excellent contact with bedrock and very little contact with the terrace, was virtually unaffected by the differential movement of terrace with respect to bedrock.

4. In the terrace section, the vertical compaction of the terrace lowered the fill with respect to the core wall. The vertical differential between fill and wall is roughly proportioned to the thickness of foundation soils, varying from zero at the left abutment to three or four feet at the spillway. (If the vertical deformation had resulted from subsidence of fill material, the differential would have been a minimum at the spillway, and a maximum in the valley.)

5. In the spillway section, the spillway crest structure and the transition section of the core wall tended to move with the terrace, restrained only by the thin cutoff wall in longitudinal compression, and as a very weak cantilever in the vertical direction. The transition section of the wall in this vulnerable area is cracked and offset in two locations, and is deformed in grade and alignment with respect to the portion of the wall founded on rock.

6. The riverward bay of the spillway was severely damaged by being thrust against the end of the transition section of the wall. The thin bottom and sidewalls of the chute, which show evidence of displacement prior to the quake, were almost completely destroyed by minor differential deformations within the terrace on which it rests.

7. On 26 August, minor amounts of seepage were emerging at the toe of the fill or a few feet up the slope, in the terrace section. At the junction of valley and terrace section, a very deep hole had been scoured in the toe of the dam and the toe of the terrace by a surge of surface water over the spillway stop logs and over the crest of the dam. The fill material on the side of this hole was damp, and appeared to be dryer in the interior. There was no seepage from the fill into this hole. The greatest part of the seepage observed on 26 August was emerging from the toe of the terrace and from a roadway ramp angling down the face of the terrace. It was limited to an extent of about 200 feet upstream and downstream.

8. All surface indications point toward the area of the spillway structure and the partial-depth section of the core wall as the probable origin of the seepage. A large part of it probably originated from the chute downstream from the stop logs, as Montana Power personnel stated that a very pronounced decrease of seepage was coincident with placing of additional stop logs in the structure.

9. Conclusions. It is concluded that the valley and terrace sections of the dam are structurally and functionally intact. The concrete core wall between Station 8+84 and the spillway, which does not penetrate to bedrock, is cracked and offset in line and grade. It cannot be determined by surface inspection whether the damage to the wall constitutes a hazard. The spillway crest structure and chute are severely damaged and non-functional.

10. Recommended investigations. To determine whether the damage to the core wall is functionally serious, it is desirable to know the nature of the backfill adjacent to the wall, and whether seepage is actually passing through the cracks. Information on both points can be had by drilling holes upstream and downstream from the wide open crack in the wall at Station 9+00, and subsequent installation of piezometers in both holes. As a control for comparison, make a similar pair of piezometers at Station 8+00. Drill all four holes 80 feet deep.

11. To determine the effects of future spillway repair on seepage in the terrace, install three piezometer tubes at the toe of the dam, located at Station 9+00, R 0+70D Station 8+00, R 1+00 D and Station 7+00, R 1+30 D. Recommended depth--30 feet.

12. To determine whether general cracking of the terrace has opened up any new paths of seepage, make a careful reconnaissance of the right bank of the river from toe of dam to spillway chute, from river level to crest of terrace. Repeat in a week or ten days. If any seepage is found, try to determine whether the condition existed prior to the quake.

13. Spillway repair. It is not considered necessary in the course of spillway repairs to restore the structural continuity of the cutoff wall between the spillway and the main cutoff to rock. As a matter of fact, restoration of this stiff but relatively fragile member would only invite a repetition of structural damage in the event of future earthquake deformations similar to those recently experienced. It would be desirable to replace a section of the wall, 25 to 50 feet in length, with impervious rolled fill.

14. If it is found that seepage is occurring through the cracks in the cutoff wall, or under the partial-penetration wall, it is recommended that chemical grouting be used to restore impermeability.

15. Summary. From the left abutment to Station 8+84, the dam and core wall show no sign of functional distress. The downstream curvature of the top of the wall, and the subsidence of the dam and its foundation relative to the wall are not considered indicative of any condition requiring remedial action.

16. Seepage at the toe of the terrace section of the dam and along the toe of the right bank terrace originates largely from the damaged spillway structure and possibly from the ruptured action of the partial-penetration

cutoff wall. The quantity of seepage does not indicate serious trouble, but it should be further investigated, and blocked off in connection with spillway repairs. Restoration of a rigid cutoff wall between the spillway and the deep section of the cutoff wall is undesirable.

P. T. Bennett

# MADISON RIVER, MONTANA
# REPORT ON
# FLOOD EMERGENCY
# MADISON RIVER SLIDE

## APPENDIX IV

## HEBGEN DAM INSPECTION
BY C. V. JOHNSON

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX IV

Hebgen Dam Inspection
By C. V. Johnson

26 August 1959

## HEBGEN DAM INSPECTION

1. General: A general inspection was made of the Hebgen Dam of the Montana Power Company to determine the damage sustained by the earthquake of 17 August 1959. The earthquake caused extensive damage to the spillway, general movement of earth at the right abutment, and a subsidence of the earth fill embankment. The surging of the reservoir caused the dam and spillway to be overtopped, which resulted in considerable washing of the downstream face of the dam and erosion of a large hole at the downstream toe at the junction of the embankment and the right bank terrace. The following paragraphs describe the condition of the dam as found by the inspection.

2. Abutment earth movement: There was a general movement of the right abutment toward the center of the valley along most of the reservoir area and also downstream of the dam. The dam offered restraint to the movement and there was considerable cracking of the right abutment area immediately adjacent to the dam. A few cracks also developed at the left abutment of the dam. The entire spillway structure was shifted toward the center of the valley approximately two feet with respect to the core wall of the dam which was assumed to be stationary. This movement was evident where the spillway structure had sheared past the core wall. The cracks in the abutment area indicate that the abutment in general moved more than the two feet indicated at the right end of the core wall and spillway.

3. Spillway damage: The entire spillway structure was shifted toward the center of the valley with respect to the core wall. This movement was probably greatest downstream from the dam and this differential movement caused damage to the spillway paving and walls. The surging of water after the quake overtopped the dam and taxed the spillway beyond its capacity. Sections of the floor and left channel wall were washed out and the water overtopped the left bank of the spillway channel.

This water along with the water which overtopped the dam washed out a hole at the toe of the dam. After the initial surges of water, the normal discharge of the spillway eroded considerable material from the area where the floor slab was removed. The spillway was damaged extensively and it is considered that the structure will have to be removed and rebuilt. The spillway stop logs were put in place and discharge through the spillway was discontinued after the quake to avert further eroding and damage. After the stop logs were in place it was found that a considerable amount of water was boiling up on the downstream side of the stop logs through cracks in the concrete. No sediment was carried by this flow. At the downstream end of the spillway structure slab there was a milky color to the water, indicating the underseepage under the slab was carrying a slight amount of sediment. The head carrying the water under the slab was approximately 5.5 feet at the start of observations; this will decrease as the reservoir is lowered. The underseepage is apparently not increasing at the present time.

4. Core wall movement and cracks: Data furnished by the Montana Power Company indicated that there was a differential vertical movement of one foot between the right and left ends of the concrete core wall. All but 0.2 feet of this movement took place in the 75 feet of core wall adjacent to the spillway. The spillway end of the core wall settled a total of one foot with respect to the left abutment end. There was also considerable horizontal movement of the core wall. A transit line run by Montana Power Company indicated that the core wall at the spillway structure had moved upstream 2.8 feet. The right abutment sight may have shifted so it is not certain as to the exact amount of movement. A check at the junction of the spillway and core wall indicated there was a differential movement of 1.8 feet between the spillway structure and the core wall. The core wall had moved upstream with respect to the spillway. The core wall was cracked at numerous locations, which are tabulated as follows:

| STATION | REMARKS |
|---|---|
| 3 + 94 -------------- | crack may be old with recent movement |
| 4 + 19 -------------- | old crack |
| 6 + 06 -------------- | diagonal crack (45° shear crack) |
| 7 + 04 -------------- | vertical crack |
| 8 + 06 -------------- | old crack, vertical, no movement |
| 8 + 43 -------------- | vertical crack |
| 8 + 81 -------------- | 1" opening, 1 3/4" transverse displacement |
| 9 + 01 -------------- | 5" opening, 3" transverse displacement |
| 9 + 35 -------------- | 1 3/4" opening |
| 9 + 50 -------------- | vertical crack. |

5. Embankment subsidence: There was considerable subsidence of the earth embankment due to the earthquake. This was quite evident by casual observation, as the core wall which was founded for the most part on bedrock was left protruding above the fill. A check was made of the amount of subsidence upstream and downstream of the core wall. The downstream subsidence varied quite uniformly from a maximum of 3.7 feet at Station 9 + 50 to 0.1 feet at Station 3 + 75 at the left abutment. On the upstream side of the core wall the maximum subsidence was approximately 5.6 feet at Station 7 + 50 and decreased to about 2.5 feet at the right abutment and about 1.5 at the left abutment. The maximum subsidence on the downstream side of the core wall was opposite where the wall had apparently moved the farthest upstream. The top of the embankment in this area was cracked a considerable amount. The amount of subsidence did not correlate with fill height, but it is probable that there was considerable backfill adjacent to the core wall in the area adjacent to the spillway.

6. Seepage conditions downstream of dam: Immediately after the quake it was reported that there was considerable seepage issuing from the natural terrace slope downstream from the dam. After the spillway discharge was closed off this seepage decreased to a small amount, so it was concluded that most of this seepage came from the spillway channel. A small amount of seepage was issuing from the natural ground slope at the point the fill had been eroded at the toe. Farther downstream along a berm considerable seepage was issuing from the natural ground. A probable source of this seepage is the water in the damaged spillway channel downstream of the spillway structure. At the downstream end of the outlet tunnel a considerable amount of seepage was flowing, but Montana Power Company employees reported that there had been no change in this seepage for years.

During the construction of the dam five piezometers were installed just downstream from the core wall. These pipes were last read in 1939 and the pipes were sealed off. The tops of these pipes were burned off and water surface readings taken. Immediately after this observation all the piezometers were water tested and two of the piezometers proved to be active, so the reading could be trusted. The saturation line downstream of the core wall was found to be about 52 feet below reservoir level and approximately 24 feet above the tailwater. This indicated that the core wall was functioning in the deep part of the fill. No piezometer reading was available adjacent to the spillway where the core wall was cracked.

7. Overflow damage to the embankment: At the time of the earthquake, waves were set up in the reservoir which overtopped the dam and spillway. This water tended to concentrate at the junction of the right abutment natural terrace and the embankment. An area about 30 feet in extent was eroded at the toe of the fill, leaving a vertical face 15 to 20 feet high. The exposed material was a sandy clay which was dry and stable at the time of the inspection. Mr. Jones, chief construction engineer of Montana Power Company, indicated it was their plan to fill this eroded area immediately. The crest of the embankment showed very little damage from the overflow water. There was some gullying but the main part of the embankment had resisted the erosion quite well.

8. Summary: An overall evaluation of the condition of the dam and recommended action has been made by Mr. P. T. Bennett in a separate report, so will not be repeated. This report has furnished a preliminary analysis of the effect of the earthquake on the dam. Further data is becoming available and a more comprehensive report will be made later when additional data becomes available.

C. V. Johnson

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX V

GEOLOGY OF MADISON VALLEY SLIDE

BY W. J. SAMUELSON AND R. E. CURTISS

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX V

Geology of Madison Valley Slide
By W. J. Samuelson and R. E. Curtiss

GEOLOGY OF MADISON VALLEY SLIDE

30 August 1959

## INTRODUCTION

The following geologic conclusions and recommendations pertinent to the recent Madison River slide cover the various structural and lithologic characteristics of the rock mass and their effect on the current flood control planning.

## MECHANICS OF SLIDE

Surficial and structural characteristics of the slide and resulting rock mass are illustrated on the attached geologic map and profiles. The slide is typical of movement within steepened valleys and the rocks included in the failure were structurally conditioned for movement prior to the earth shocks. (Refer to pre-slide aerial photos 9-19-56-ECI-1-128, 129 and 130.)* Petrographically, the rocks consist of quartzite and dolomite and lesser proportions of chlorite schist and hornblende gneiss. The quartzite and dolomite are hard and after failure disintegrated into angular fragments ranging in size from spalls to chunks in excess of 10 cubic yards. The schists and gneiss are quartz injected, but structurally weak, and during the failure disintegrated into thin platey pieces which are not conducive to a high degree of compaction.

Prior to the slide the in-place rocks were striking N 85° E and dipping approximately 45 to 50 degrees, placing the individual rock strata in a position dipping into the valley. The pre-slide south valley was very steep and apparently supported by a buttress of outcropping quartzite and dolomite. The quartzite and dolomite in turn was underlain by relatively incompetent schist and gneiss. As a result of the many earth shocks, the mass was triggered and slid out on a weathered, decomposed schist, moved across the valley and came to rest high on the north valley wall. In final position the rock mass has blocked the Madison Valley in essentially the

* Not reproduced.

attitude as shown on the attached surface geology map. A secondary slide which followed the described initial fall by an unknown time interval, possibly a few minutes, moved off the upstream end of the initial slide area and came to rest in the swale created by the toe of the initial slide. In its downward movement, the second slide created a terrace of disintegrated schist on the greater portion of the upstream face of the natural dam. The end result of these movements has been a complete blocking of the Madison Valley and creation of a natural dam on the Madison River. The material zoning which developed as a result of the slide is illustrated on the surface geology map and profiles.

## STABILITY OF THE NATURAL DAM

In consideration of the afore mentioned slide mechanics, the predominance of hard brittle quartzite and dolomite, and the high degree of compaction, it is felt that the natural dam is stable and will not experience any serious movements or displacements. The alluvial material which was included within the valley prior to the slide was relatively thin and was undoubtedly gouged from the valley floor and incorporated into the base of the rock during the slide. The abutment sections appear to be stable and are included between competent rock. In addition, the rock fill is constricted at the downstream toe which would tend to impede any downstream movement. The gradation of the rock is for the most part very good, with the exception of the incompetent slide terrace designated on the geology map as disintegrated schist. The downstream toe of the dam is also very competent, being comprised chiefly of well interlocking angular pieces of hard brittle quartzite and dolomite. No saturated areas or springs were noted along the north or south valley walls in the immediate slide area. The increment of slope stability is therefore increased.

## CONCLUSIONS AND RECOMMENDATIONS

The recommendations concerning the rock slide are as follows:

1. Indications are that no danger from additional rock slides of the magnitude of 17 August 1959 appears imminent on either the north or south valley slopes. Two additional minor slides are currently anticipated along the south wall (See Plate 1). The slide material consists primarily of incompetent chlorite schist, perhaps 10 to 20 feet thick. If these anticipated slides materialize and encroach on the crest of the natural dam, some maintenance will be required. However, pre-slide remedial measures are not recommended.

2. The berm or terrace, composed largely of chlorite schist and illustrated on Plate No. 2 is an incompetent loosely compacted mass. It is recommended that the discharge over the natural dam be diverted from the toe of this material to avoid the possibility of triggering slides. Materials necessary to fill in low areas across the upstream face and top of the rock-filled dam should be derived from the quartzite and dolomite ridge to the north.

3. Compressive forces during the rock slide compacted a well-graded quartzite and dolomite ridge against the north valley wall. Gneiss and schist, which are between the saddle and the south slope, are less compacted as a result of slump. However, this degree of compaction appears to be such that any flow from the reservoir will not erode the natural dam en masse.

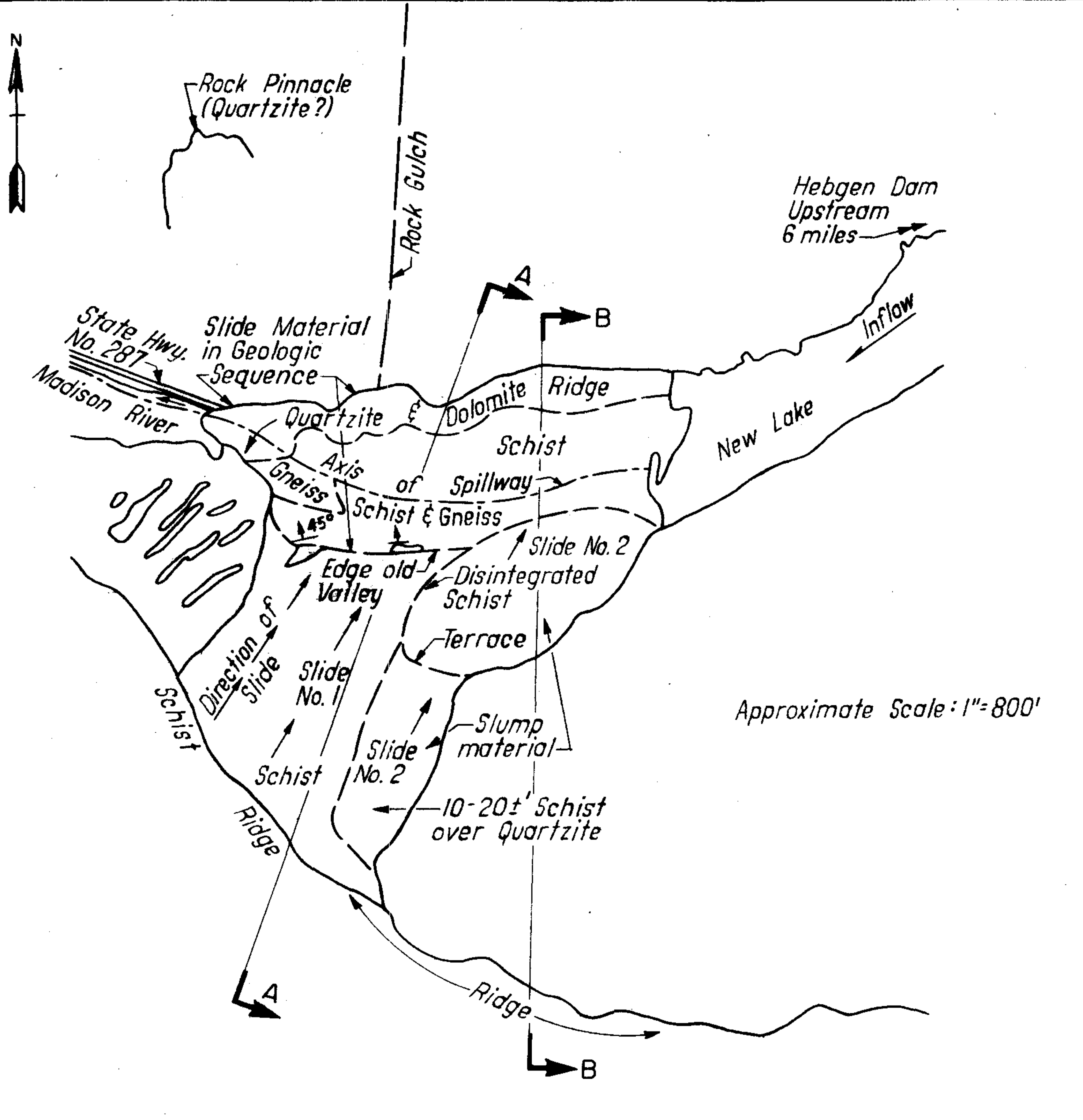
4. A pinnacle of rock composed largely of jointed quartzite and dolomite is high on the north valley wall. The pinnicle has drawn attention concerning the possibility of sliding into the valley. Dust swirls, which denote small rock falls, have been evident. This competent rock mass does not appear to be presently unstable. The bedding dips generally north into the north wall rather than into the Madison River Valley. Therefore, the pinnacle does not constitute an immediate element of danger. It is believed, however, that the rock mass, if subsequent detailed observations warrant, may be removed at a later date to obviate the possibility of sliding.

5. It is suggested that slide-movement instrumentation be established across the south valley wall to ascertain any movement along minor slides that might encroach on the crest area of the natural dam. Indications are that additional slide movements along the upstream south valley wall will be in successive stages rather than in major units.

W. J. Samuelson

R. E. Curtiss

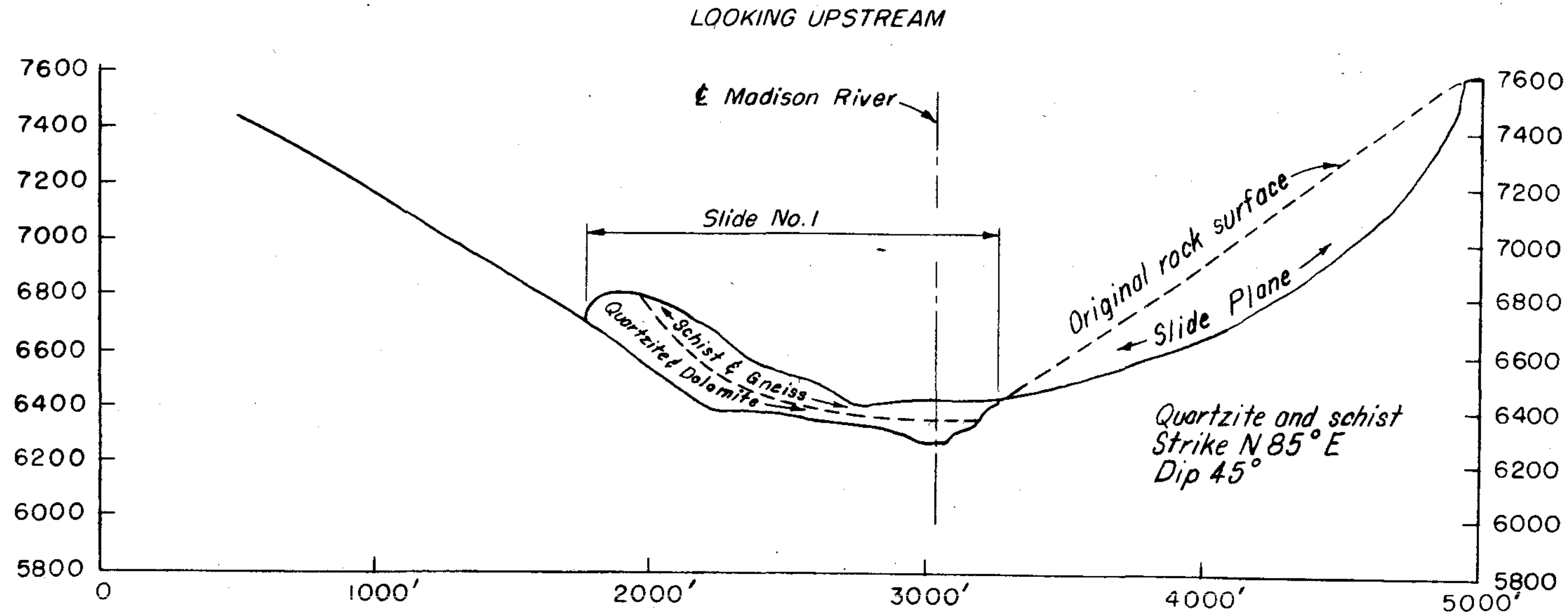
Plate No. 1 Surface Geology of Madison Valley Slide
Plate No. 2 Geologic Section A-A
Plate No. 3 Geologic Section B-B



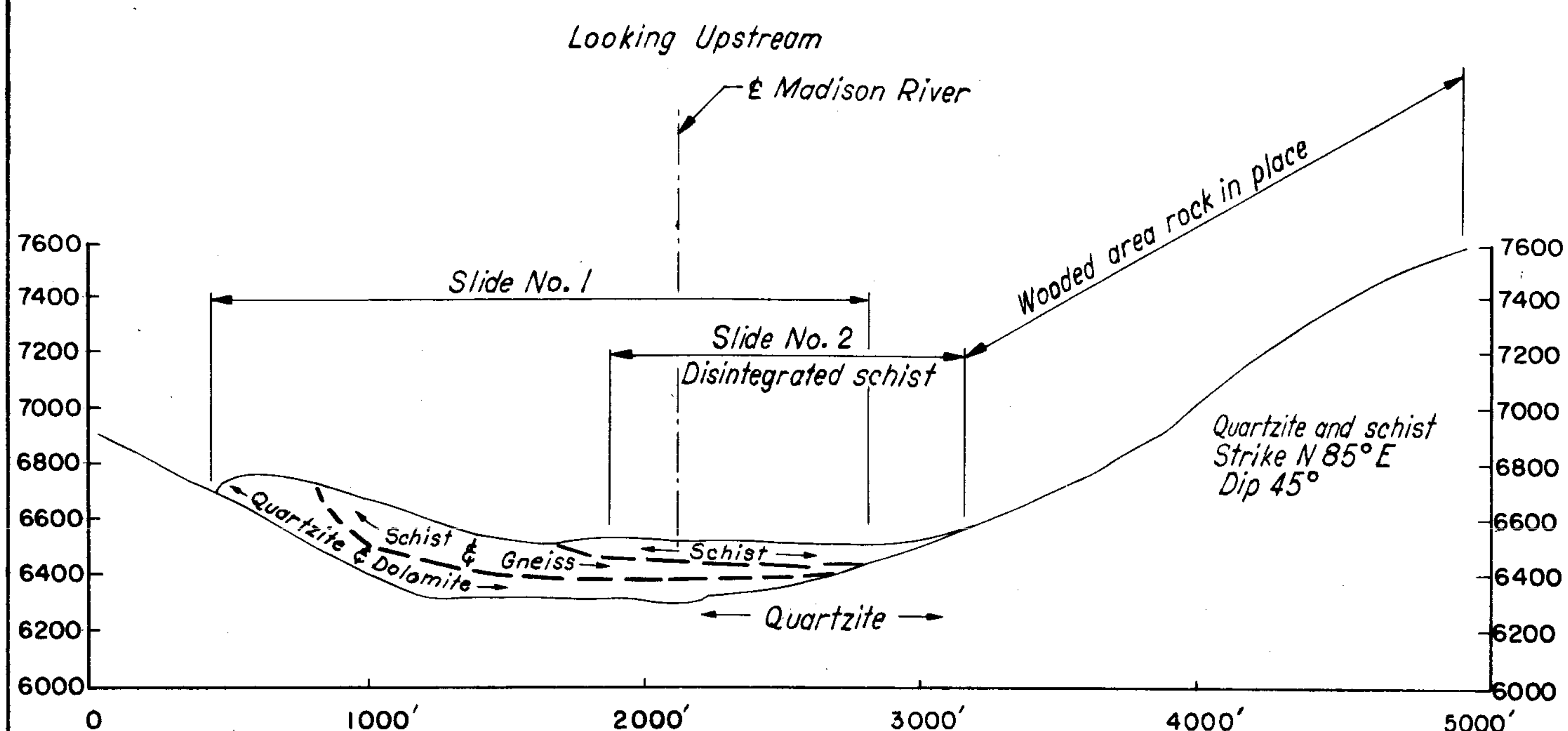

SURFACE GEOLOGY OF
MADISON VALLEY SLIDE
25 AUGUST 1959



APPENDIX V PLATE 1




GEOLOGIC SECTION A - A




GEOLOGIC SECTION B-B

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX VI

STABILITY OF SLIDE DAM
AND RECOMMENDATION ON DEVELOPMENT
OF OVERFLOW SPILLWAY
BY D. K. KNIGHT AND P. T. BENNETT

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX VI

Stability of Slide Dam
and Recommendations on Development
of Overflow Spillway
By D. K. Knight and P. T. Bennett

26 August 1959

## Stability of Slide Dam and Recommendation on Development of Overflow Spillway

### PURPOSE

1. The earthquake of 17 August 1959 created a rock fill dam across the Madison River near the mouth of Madison Canyon. The dam is about 200 feet high, and will impound perhaps 80,000 acre feet of water. If released suddenly, this volume of storage would produce severe flooding along the Madison River below the dam. The purpose of this report is to present an appraisal of the structural stability of the slide mass as a dam, its performance as an overflow spillway when the water reaches the crest, and to recommend emergency measures to be taken to insure satisfactory performance of the spillway.

### SCOPE

2. The geology of the region, and the stability of the canyon walls against further sliding, are covered in a separate report. This report will be restricted to consideration of the slide mass as an overflow dam, with particular reference to:

a. General dimensions.
b. Materials in the slide.
c. Stability as a dam.
d. Seepage through the dam.
e. General recommendation for development of a spillway over the dam.

## DIMENSIONS

3. The rock fill extends approximately 5000 feet from toe to toe in the valley floor. In profile, it is a series of major crests and depressions, the highest crest being upstream. In section, the slide mass is U-shaped, curving smoothly from the left bank talus remaining after the slide to a thick mass of rock which surged up the face of the right wall of the canyon, to an elevation approximately 200 feet above the low point of the cross section. The depth of slide material at the highest crest of the profile is approximately 220 feet above the original stream bed.

## MATERIALS

4. For a detailed description of the types and probable distribution of materials in the slide mass, see the separate geological report. As exposed on the surface, the sequence of materials along the "channel" thru the slide is:

Downstream Toe -- Massive quartzite, well graded, densely packed. Many massive blocks ranging up to 15' x 12' x 8' in size. This material lies downstream from the quartzite nose which split the slide into a small downstream mass and a much larger upstream mass.

Central Portion -- Schist and gneiss, principally gneiss. Angular blocks grading from spalls up to one cubic yard.

Upstream Crest Area -- Predominantly schist, grading from gravel to thin and slabby pieces of six to eight inch size. This material would be relatively unstable under high velocity flows, and would also break down from natural weathering action.

Upstream Toe -- A relatively thin layer of coarse quartzite lies against the right wall of the valley. With this exception, the rest of the upstream toe is made up of weathered gneiss and schist, with the voids almost completely filled with fine grained nonplastic soil. The upstream face of the slide appears to be made up of relatively impervious material up to an elevation in the vicinity of 6420. (The absence of seepage through the mass prior to 26 August indicates that the apparently continuous quartzite layer along the right abutment is either discontinuous below pool level, or is choked with fines.)

5. Along the entire length of the slide mass, its greatest height is on the right abutment. This rock, originating more deeply in the slide, is principally made up of quartzite, and is more competent than the rock in the existing low channel through the slide.

## STABILITY AS A DAM

6. Considering the mass as a dam, its base width is five to eight times as great as would have been used in building a rock fill dam of the same height. The downstream slope is extremely flat, averaging about 1 on 12. The upstream part of the mass consists of a crest section several hundred feet wide, and an upstream slope very roughly estimated at 1 on 7 average. The mass has roughly the characteristics of a composite earth and rock-fill dam section, with the relatively impervious earth fill upstream. The rock-fill was dynamically compacted by the earthquake shock, and is generally dense and well keyed together. The canyon walls tend to converge downstream, which would add to the longitudinal stability if there were any tendency toward movement downstream. Considering all these conditions, there is no question of the stability of the mass against a slide downstream. The possibility of transverse or upstream sliding is discussed in connection with recommendations on development of a safe spillway over the dam.

## SEEPAGE THROUGH THE DAM

7. Prior to the morning of 26 August, when a small quantity of seepage flow was observed, the sand in the original river bed was entirely dry at the toe of the slide. The pool level on the morning of the 26th, when seepage first appeared, was 6380 ±, or about 145 feet above the downstream toe. Since the pool was still on the relatively impervious upstream face, it is considered probable that the initial seepage was through the coarser and cleaner material lying on the face of the right abutment; the absence of seepage prior to 26 August indicates the probability that the quartzite layer is discontinuous, or choked with fines at levels below 6370 ±.

8. It is very difficult to estimate future seepage quantities, since the distribution of the relatively impervious material can only be estimated roughly from surface indications. Assuming the bulk of the impervious material to be located upstream and below elevation 6380 ±, it appears probable that the seepage may flow over the impervious mass as over a control weir, then drop sharply, and saturate only the lower levels of the rock mass. Considering the sectional area between elevation 6380 and 6450, the proposed spillway crest, and a possible range of gradients and effective permeabilities, it appears that seepage through the rock mass might be in the range between 200 and 1000 cfs at full pool, elevation 6450. Thus, at this early stage, it appears possible that normal river flows might pass through the rock fill without any surface flow over the spillway crest. It should be emphasized that this very rough estimate should be revised continually as actual seepage quantities are recorded in the future.

9. Whatever the quantity of seepage may ultimately prove to be, it cannot endanger the stability of the dam, since the very coarse rock of the downstream toe will easily pass almost unlimited flows.

10. There will undoubtedly be piping of fines out of the upstream dirt-choked rock into the cleaner central mass. Considering the extreme possibility of the fines being moved to the downstream region and deposited there, the stability would not be endangered, since the rock-to-rock structure of the dam would not be changed.

11. Summing up the seepage aspects, the quantity is highly uncertain at this time, but it appears possible that low to normal river flows may pass through the rock without overtopping it. Re-distribution of fines within the rock mass will undoubtedly occur, resulting in uneven settlements in the upstream, dirt choked area. Fines reaching the coarse rock of the downstream toe will probably be carried out of the rock mass, but will not disturb the strength of the rock-to-rock contact even if partially deposited within the mass.

## POTENTIAL SPILLWAY PROBLEMS

12. There appear to be three separate problems to be considered in developing and maintaining a reliable spillway over the slide dam.

a. Stability of crest against sliding -- Upstream from the highest saddle, the slide mass is made up of soil and weathered rock, the least stable material in the slide. Above and downstream from the area, the largest mass of potentially unstable material remains near the left abutment, along the upstream boundary of the slide scar. It is possible that saturation of the toe by the rising pool, and saturation of the remaining mass on the abutment by surface run off could reactivate a slide, and drop the spillway crest below pool level, releasing a fairly large volume from storage in a short time. Such an occurrence is not regarded as highly probable but it should be considered as possible.

b. The second source of spillway trouble is the possibility of blocking the spillway channel by debris from the existing slide slope. The additional material which might cause damage is relatively fine, and it might dam up several feet of surcharge, then wash out and release a minor flood.

c. The third and most obvious spillway problem is the possibility of scouring the crest or channel by high velocity flows, particularly in the crest area and upper part of the chute where the rock is relatively fine.

13. To minimize the possibility of losing control of the spillway crest by an upstream slide, it is recommended that an artificial crest be developed in the pocket immediately downstream from the existing saddle, which is now approximately 50 feet lower than the present high point. This hole should be filled, to an elevation about 20 feet below design crest level, with relatively fine rock dozed downstream in the course of lowering the saddle to design grade. The top 20 feet should be filled with heavy quartzite, borrowed from the layer lying against the right abutment. (See plan sketch) The left side of the crest should be constructed of heavy quartzite.

14. To avoid undercutting the possibly unstable left abutment and to minimize the possibility of blocking the spillway by a new slide, the spillway channel should be located as far as practicable toward the right side of the valley. A definite layout cannot be recommended until surveys are more nearly complete permitting estimate of quantity and cost.

15. To avoid uncontrolled scour of the spillway chute, the alignment should be kept as far to the right as is economically practicable where the rock is generally heavier and of better quality. In areas where the existing surface rock is fine, line the floor and left side of the chute with heavy rock borrowed from the high quartzite.

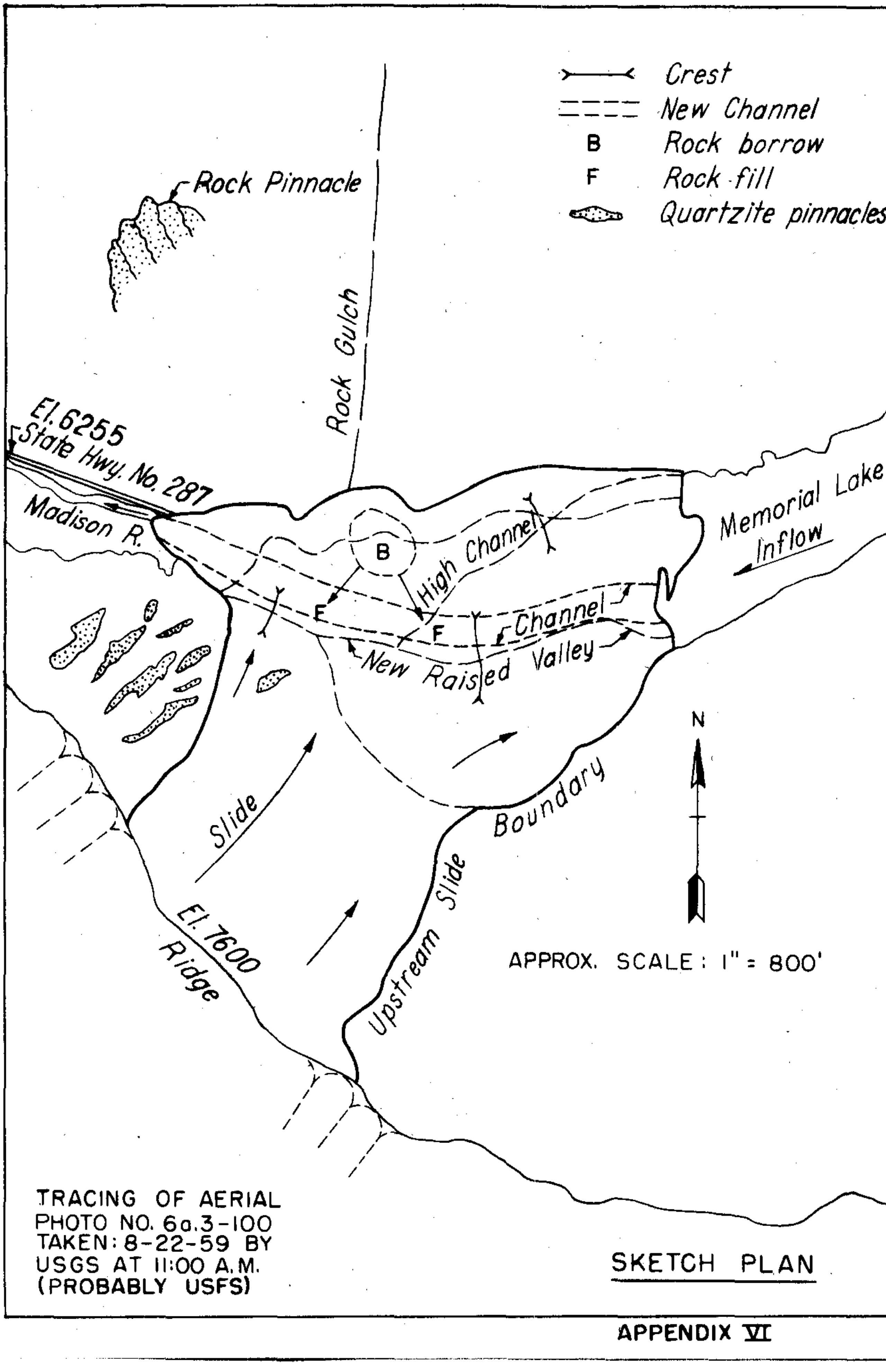
16. The spillway crest and chute should be shaped to avoid concentration of flow which might begin scouring deeply into the rock. The section should be designed to spread the flow out onto a thin sheet of as nearly uniform depth as is practicable with the size of rock to be handled. It is considered desirable to pass low and normal flows as seepage through the rock mass, reserving the spillway for high river discharges. If this condition can be obtained, the pool would have some degree of storage between normal pool and spillway crest. The probability of achieving this desirable condition increases with spillway crest elevation, and the cost of crest excavation decreases. It is therefore recommended that the spillway crest excavation be established at 6450 which is ten feet below the toe of Hebgen Dam.

Signed:

1 incl. Sketch Plan

D. K. Knight

P. T. Bennett




SKETCH PLAN

APPENDIX VI

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX VII

INSPECTION OF LOWER SLIDE
GROS VENTRE RIVER
BY P. T. BENNETT AND D. K. KNIGHT

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX VII

Inspection of Lower Slide, Gros Ventre River
By P. T. Bennett and D. K. Knight

3 September 1959

## INSPECTION OF LOWER SLIDE
## GROS VENTRE RIVER

1. The "lower slide" on the Gros Ventre River near Jackson, Wyoming, was inspected on 28 August 1959 by C. A. Burgtorf, D. K. Knight, and P. T. Bennett, primarily for the purpose of comparing the materials in the Gros Ventre slide with those of the slide into the Madison River which occurred as a result of an earthquake on 17 August. The party was fortunate in that Mr. Guilbert Huff, who was an eye-witness to the slide, acted as guide for the party.

2. The occurrence of the slide is described in Engineering News-Record of July 16, 1925, July , 1925, and September 17, 1925. Failure of the slide material as a dam is described in Engineering News-Record of May , 1927.

3. Data on the geology of the Gros Ventre slide area was obtained by a subsequent discussion with Dr. Frank A. Swenson of the U. S. Geological Survey. Dr. Swenson has written a paper on the geology of a large area which included the Gros Ventre valley. The attached rough geologic section has been prepared on the basis of this discussion. It should be noted that several years have passed since he prepared his paper and the section is necessarily based on memory. The Wells Sandstone formation is the predominating rock found in the remaining slide mass. It is believed to have been pervious enough to permit the passage of seepage waters down into the shale stratum, thus weakening the shale to the point of sliding. All of the beds overlying the shale were weakening by weathering action over a period of many years prior to the slide. The eye-witness account given in the Engineering News-Record states that seepage was showing at the base of the hill prior to the slide on 23 June 1925.

4. The materials of the Gros Ventre slide are now well exposed and easily inspected in the walls of the small canyon cut through the mass by outflow of the impounded water. The slide consisted

primarily of medium to very large blocks of massive, fine grained sandstone, mixed fairly uniformly with very fine grained materials, principally in the silt size range, but with appreciable deposits of very fine sand, and some slightly plastic silty clay. All the fines appear to be the product of weathering of sandstone, siltstone, and shaley bedrock making up the south or left abutment at the site.

5. The party also explored the area from which the slide mass moved to about one third or one fourth of its height. The slide scar differs from that at Madison Canyon in that a great amount of material similar to that which blocked the river still remains in the slide area. It is apparent that the north end of Sheep Mountain prior to the slide was capped near the crest with one or more massive ledges of hard durable sandstone, underlain by less competent sandstones, siltstones, and sandy shales. The lower beds were deeply weathered, producing large quantities of sand and silt, and lesser amounts of silty clay. A permanent lake exists in a pocket about half-way up the slide scar, indicating the generally impervious nature of the products of rock weathering in this vicinity. One concentration of extremely massive sandstones blocks, some of which are obviously from a weathered ledge outcrop, indicates that some of the sandstone blocks came from the upper portion of the slide, where similar outcrops can still be observed in the walls of the scar and on adjacent undisturbed slopes.

6. With the exception of a few isolated areas, the proportion of fines to rock in the slide mass is such that the rock fragments are in very poor contact, or are floating entirely in the matrix of fines. This condition was also observed in the slide mass which did not reach the river.

7. The following is quoted from a description of the slide by Frank B. Emerson, State Engineer of Cheyenne, Wyoming, published in ENR of September 17, 1925.

8. "The result of the slide was to shut off entirely the flow of the Gros Ventre River for about 12 days. Seepage then began to appear upon the lower face of the dam and this continued to increase as the water rose in the lake formed by the dam. On July 14 (three weeks after the slide occurred) a large increase in the flow was observed and practically the normal flow of the river was soon passing through the dam at a point near the center and about 30 feet below the top."

9. Elsewhere in the report it is stated that the downstream slope of the "dam" dropped off at a comparatively steep slope for a vertical distance of 60 feet. It therefore appears that the seepage found a relatively short path near the top of the "dam" and it emerged on a steep face.

10. The Gros Ventre slide appears to be made up of the same type of material for its full length, and this material is relatively impervious because of the large amount of fines. The emergency of seepage high on the slope is entirely consistent with the type of material involved. Furthermore, the silt and fine sand matrix is easily moved by piping, and the rock structure is not stable once the fines are removed. With all those conditions favorable to failure of the dam, it is surprising that it stood two years before failure occurred.

11. Comparing the Gros Ventre and Madison Canyon slides, it is found that their heights and base widths along the valley are nearly the same. The stream flow and storage capacities behind the dam are also very similar. In materials, the two slides are very dis-similar. The entire fill at Gros Ventre is made up of a mixture of very coarse rock fragments almost floating in semi-pervious silts and sands. There are no sandstone rocks in the Madison slide. At Madison Canyon, only the upstream section contains fines approaching the percentage observed at Gros Ventre. The central and downstream sections of the Madison slide are very much cleaner than at Gros Ventre, and the seepage gradient is expected to fall to a low level once the water emerges from the relatively impervious upstream section.

12. Further comparing the two slides, piping may move fines out of the upstream section at Madison, as apparently occurred at Gros Ventre, but the result will be different because of the relative quantities of rock and fines. The upstream section at Madison, although the rock is smaller in size than at Gros Ventre, appeared to have rock-to-rock contact. In the central and downstream sections at Madison, there is no doubt of the compact rock-to-rock structure. Movement of fines out of the upstream section at Madison may result in subsidence and possibly local sliding into the upstream pool, but any downstream movement of this section is blocked by the main mass of clean rock in the central and downstream sections. Partial filling of the voids in the clean rock of Madison will not affect its stability.

13. Concluding the comparison, the slide dam at Gros Ventre was susceptible to failure because of:

a. A steep downstream slope at the crest creating a short seepage path.

b. Fairly uniform distribution of a semi-impervious fill from upstream to downstream, which raised the seepage line to the short path near the crest.

c. A deficiency of rock in the mixture of rock and fines, such that the mass lost stability when fines were piped out.

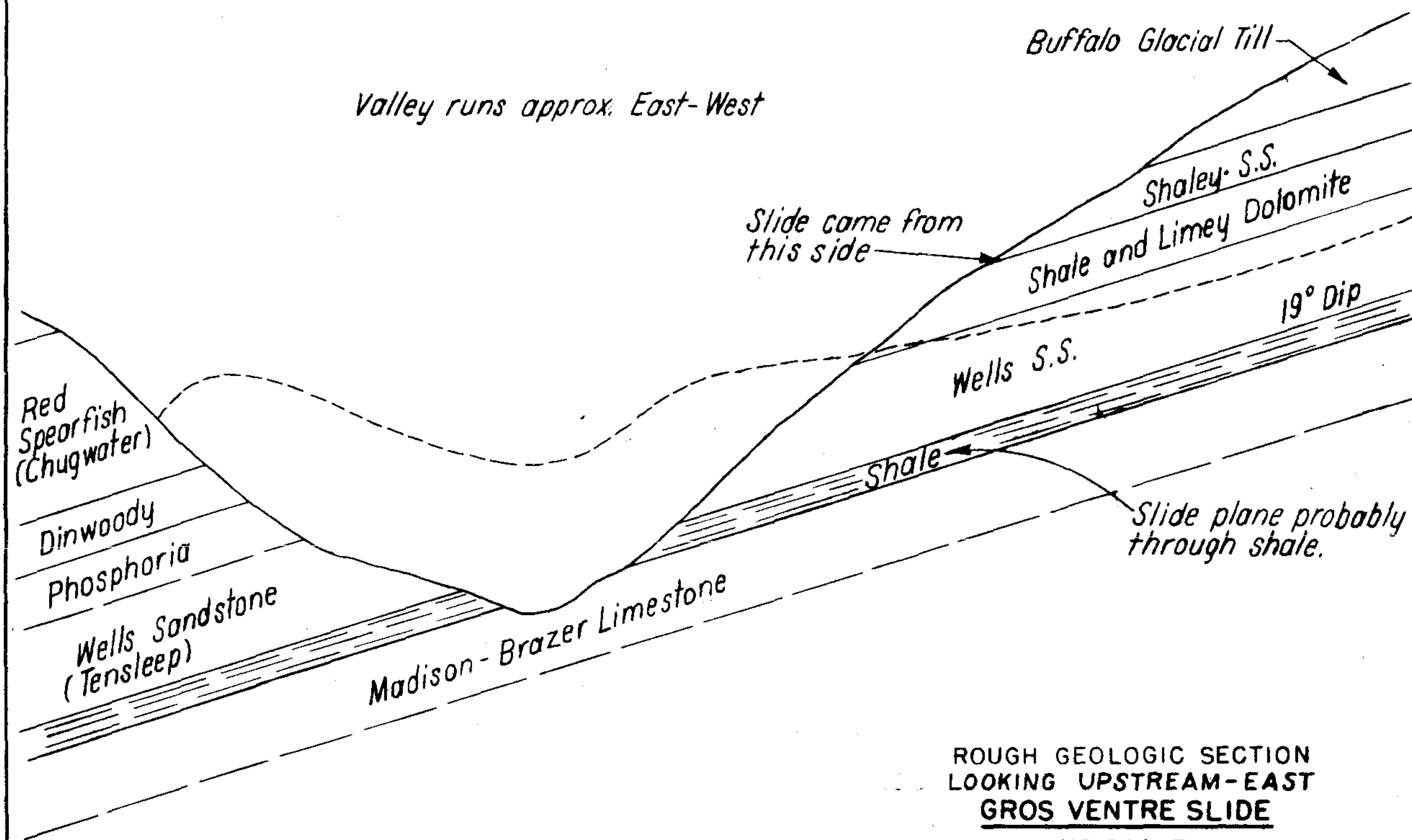
d. Much of the fine grained material was silt or very fine sand, which is very susceptible to movement by piping.

14. None of these adverse conditions is found at the Madison slide. The materials are graded from relatively impervious upstream to highly pervious downstream, providing immunity to all piping effects from seepage and providing great stability of the dam. It is concluded that the failure of the Gros Ventre slide dam, after a period of two years in which no effort was made to correct the adverse conditions, does not predict the future of the Madison Slide, where ideal if accidental initial conditions are being further improved as the pool rises.

Incl 1 Rough Geology Section

P. T. Bennett

D. K. Knight




ROUGH GEOLOGIC SECTION
LOOKING UPSTREAM-EAST
GROS VENTRE SLIDE
NO SCALE

APPENDIX VII

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX VIII

HYDROLOGY
BY C. A. BURGTORF

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX VIII

Hydrology
By C. A. Burgtorf

# HYDROLOGY

## HEBGEN RESERVOIR

Madison River at Hebgen Dam has an average mean daily flow between 900 and 1,000 c.f.s., with a maximum of record of a little less than 6,000 c.f.s. Prior to the earthquake on 17 August, Hebgen Reservoir pool was falling slowly with a release rate of about 1,000 c.f.s. and a pool elevation of 6542.8. No records are available of pool elevation or discharges for 18, 19, and 20 August.

On 21 August the pool elevation at the gage on the intake structure was 6541.9 or an apparent drop in pool level of 0.9 foot. This was the result of a change in storage-elevation relationship. A small amount of water flowed over the top of the dam as a result of seiches during the quake but was far less than the apparent change in storage in the lake.

Hebgen Lake was drawn down as rapidly as practicable following the quake for inspection of the dam and outlet and to lower the forces against the dam. The lake level was lowered to elevation 6539 on 4 September. Plates 1, 2, and 3 show the pool elevation, storage, inflow and outflow for Hebgen Reservoir from 16 August to 26 October. A storage capacity curve for Hebgen Reservoir is shown on plate 4.

## EARTHQUAKE LAKE

The quake and slide about 6.5 miles downstream from Hebgen Dam caused a wave of water immediately upstream and downstream from the slide. Evidence at the site showed that the water went over the banks with tremendous force but with very little volume as the water was all back in the channel in less than 1/4 mile.

The elevation of the channel bottom upstream from the slide is about 6260 feet. The pool which formed behind the slide rose rapidly and reached the crest of the spillway, elevation 6450 feet, on 10 September. Plates 5, 6, and 7 show the inflow, outflow, pool elevation and storage in the lake from 18 August to 27 October.

There was no evidence of seepage through the slide until 26 August. Following that date the seepage increased slowly and reached a flow of about 100 c.f.s. before flow started over the slide on 10 September. The lake has a capacity of 36,000 acre feet at elevation 6400 feet and a capacity of 82,600 acre feet at elevation 6453.4 feet, the maximum stage which occurred on 20 September. A storage capacity table of the lake is shown on plate 8.

STREAM FLOW

Gages were established by the U. S. Geological Survey on Duck, Cougar and Grayling Creeks and South Fork of Madison River, tributaries to Hebgen Reservoir, Cabin and Beaver Creeks, which empty into Earthquake Lake, and on Madison River at the toe of the slide, 1/2 mile downstream from the slide, Cliff Lake Bridge, Kirby Bridge and Varney Bridge near Cameron. Locations are shown on plate 9. Cableways were installed by the Geological Survey across the Madison River on top of the slide, at the toe, 1/2 mile downstream from the toe, and near Kirby Bridge.

Discharge measurements were made by the Geological Survey to determine rating curves for the streams upstream from the slide and from gage readings by U. S. Army Engineer personnel inflows to Hebgen Lake and Earthquake Lake were estimated.

Seepage through the slide prior to flows over the crest was measured daily by the Geological Survey. After the lake was filled measurements were made daily or more often by the Geological Survey on top of the slide and at the toe of the slide. Deposition of material from the slide forced the abandonment of the cableways near the slide and after 4 October all measurements of outflow from the lake were made at Kirby Bridge. Beginning on 26 September the measurements of outflow were increased to 6 to 8 per day and Army Engineer personnel supplemented the Geological Survey in doing the work. On 18 October the Engineers took over the measuring program except for occasional readings. The program was discontinued on 26 October.

CHANNEL AND BRIDGE CAPACITIES

Madison River from the slide to near Ennis and from the canyon downstream from the Madison Power Plant near Ennis to the mouth has a very uniform channel. It has a fall of 20 to 30 feet per mile except for the lower 10 to 15 miles where the slope is about 10 feet per mile. The channel width is usually 200 to 300 feet.

Cross sections at all bridges and valley sections at elevan locations between the slide and the mouth of Madison River were surveyed. Rating curves were developed and used to determine safe release rates from Earthquake Lake and to estimate possible water surface elevations which might result from failure of Hebgen Dam or the slide.

Three of the bridges, Cliff Lake, Shelton Ranch, and Wolf Creek Bridges, located about 5, 16.5, and 19 miles respectively, downstream from the slide, are timber structures supported by rock-filled cribs. Their open water capacities are about 6,000 c.f.s. The remainder of the bridges are of a more permanent type of construction and have capacities in excess of 10,000 c.f.s.

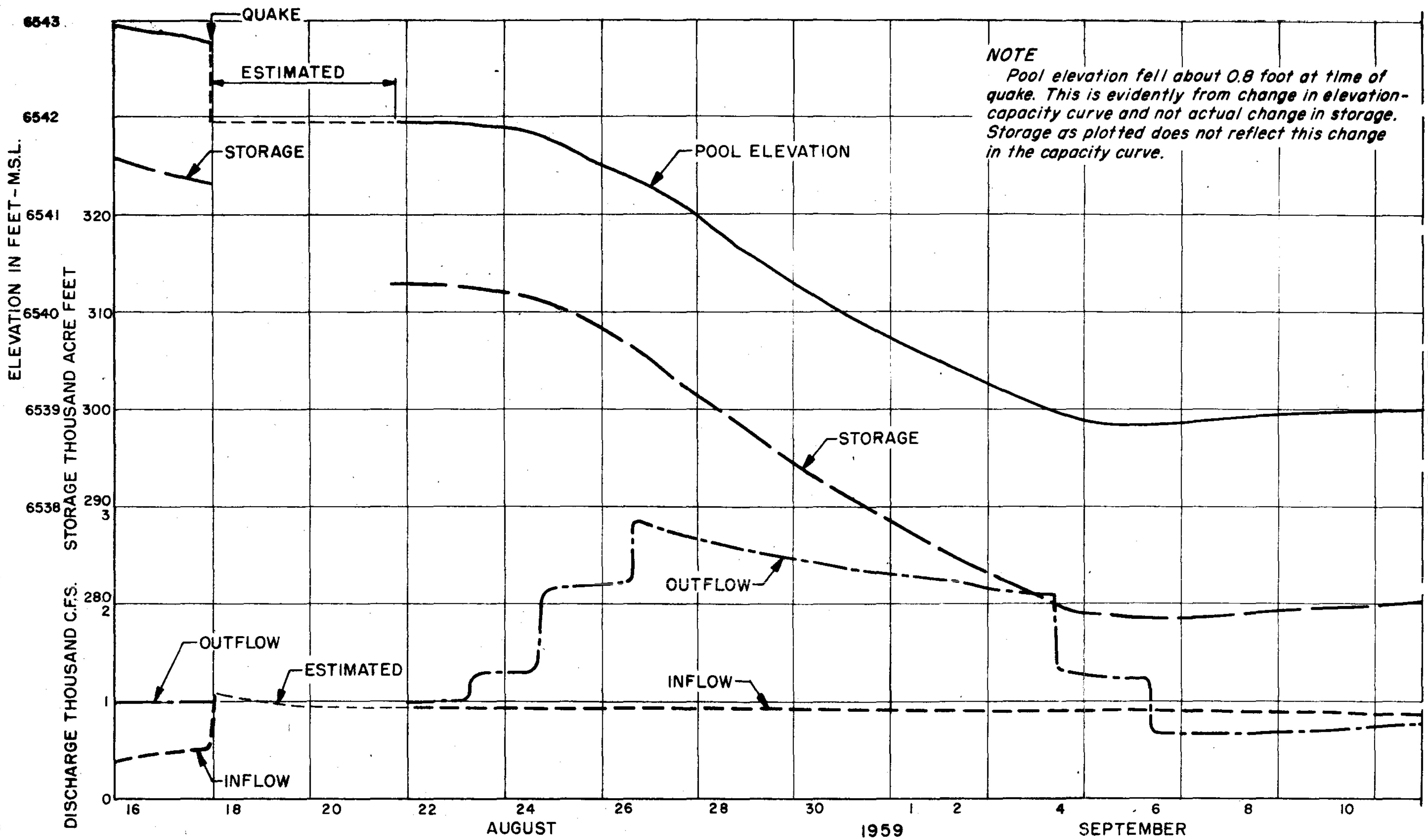
The spillway capacity of Ennis Lake is about 7,000 c.f.s. Flows of about that value have occurred past the Madison Power Plant without damage to the plant. Some pumping was required in the plant, but the generators did not get wet.

On the basis of these data it appeared that releases of 5,000 c.f.s. could be made from Earthquake Lake without significant damage to property downstream.

EVACUATION OF HEBGEN RESERVOIR

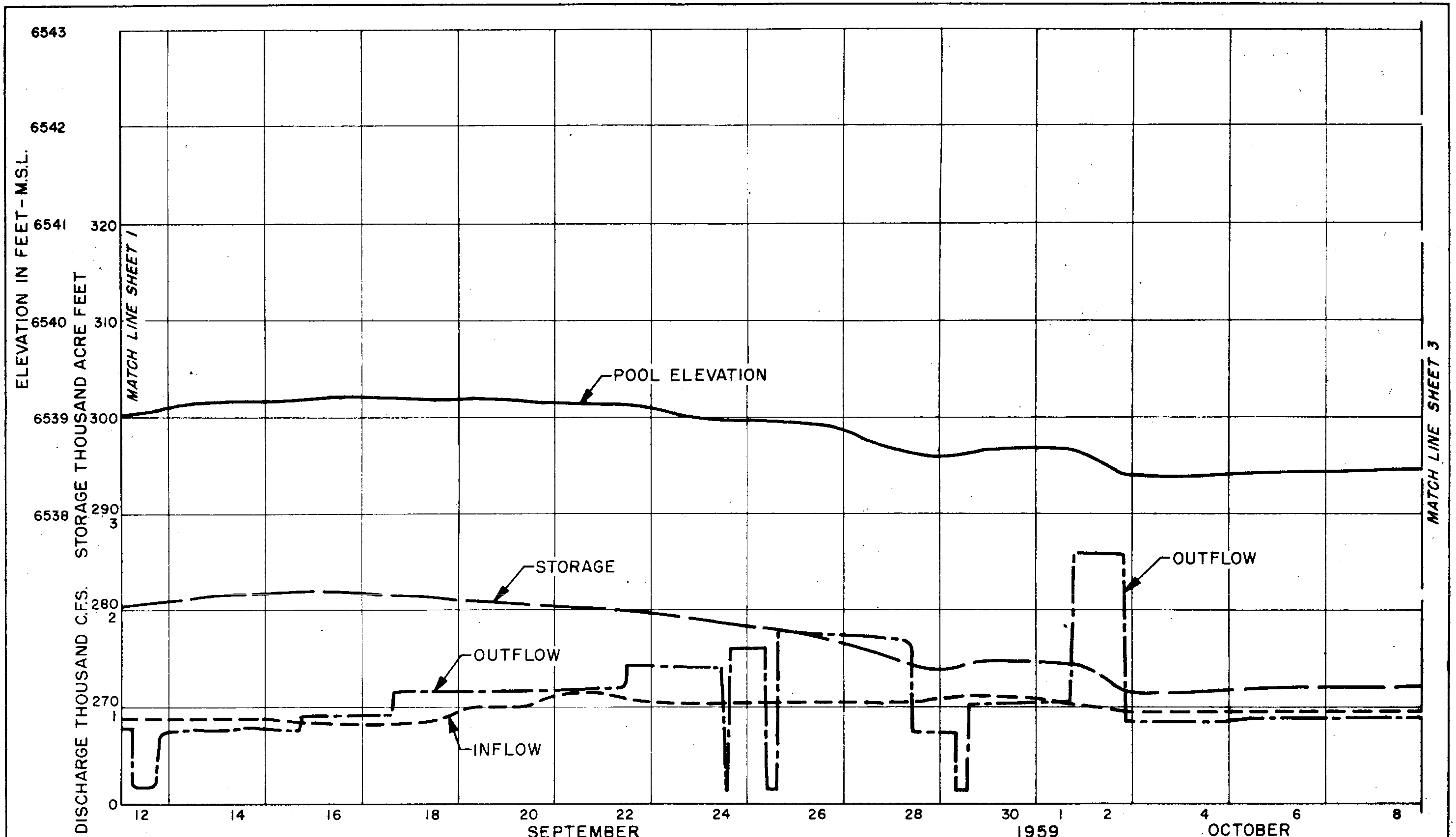
Hebgen Reservoir is usually filled during the spring runoff period, held steady during the summer and drawn down to a relatively low level beginning about 1 September. Extreme cold periods in December often cause anchor ice which breaks loose, blocks the channel and causes flooding. It was not possible to begin evacuation of Hebgen Reservoir in September because of the slide. Plans as of November 1959 were to evacuate Hebgen completely by 1 April for replacement of old stoplogs. With the beginning of drawdown of the reservoir being delayed there was a possibility that the ice problem during evacuation might be more serious than usual. However the presence of sediment in the water and high flows in the stream could combine to prevent the formation of anchor ice downstream and thus reduce the ice problem. The answer to this question could be determined only by experience and observation.

C. A. Burgtorf

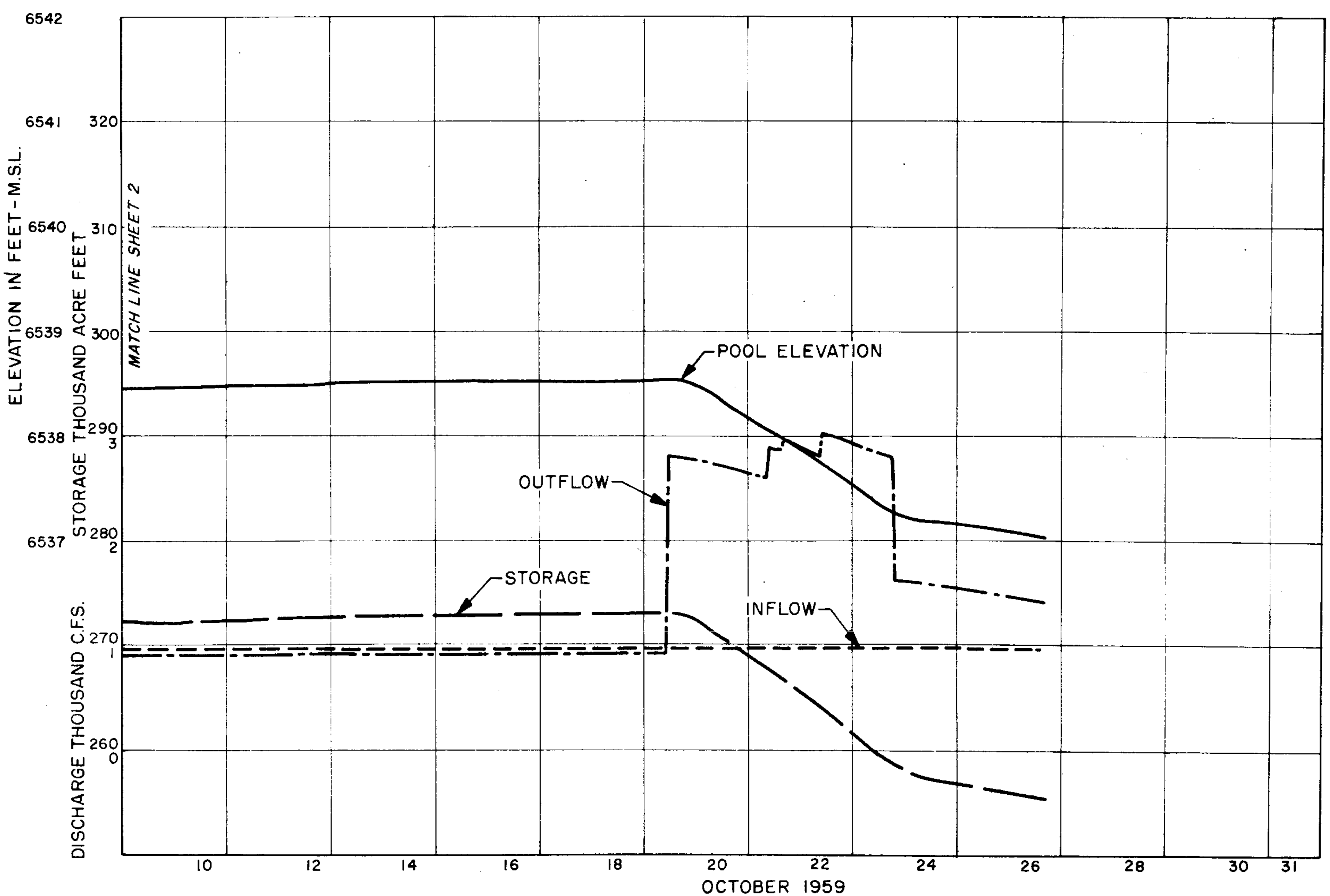



MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
HEBGEN RESERVOIR
REGULATION
CURVES

SHEET 1 OF 3



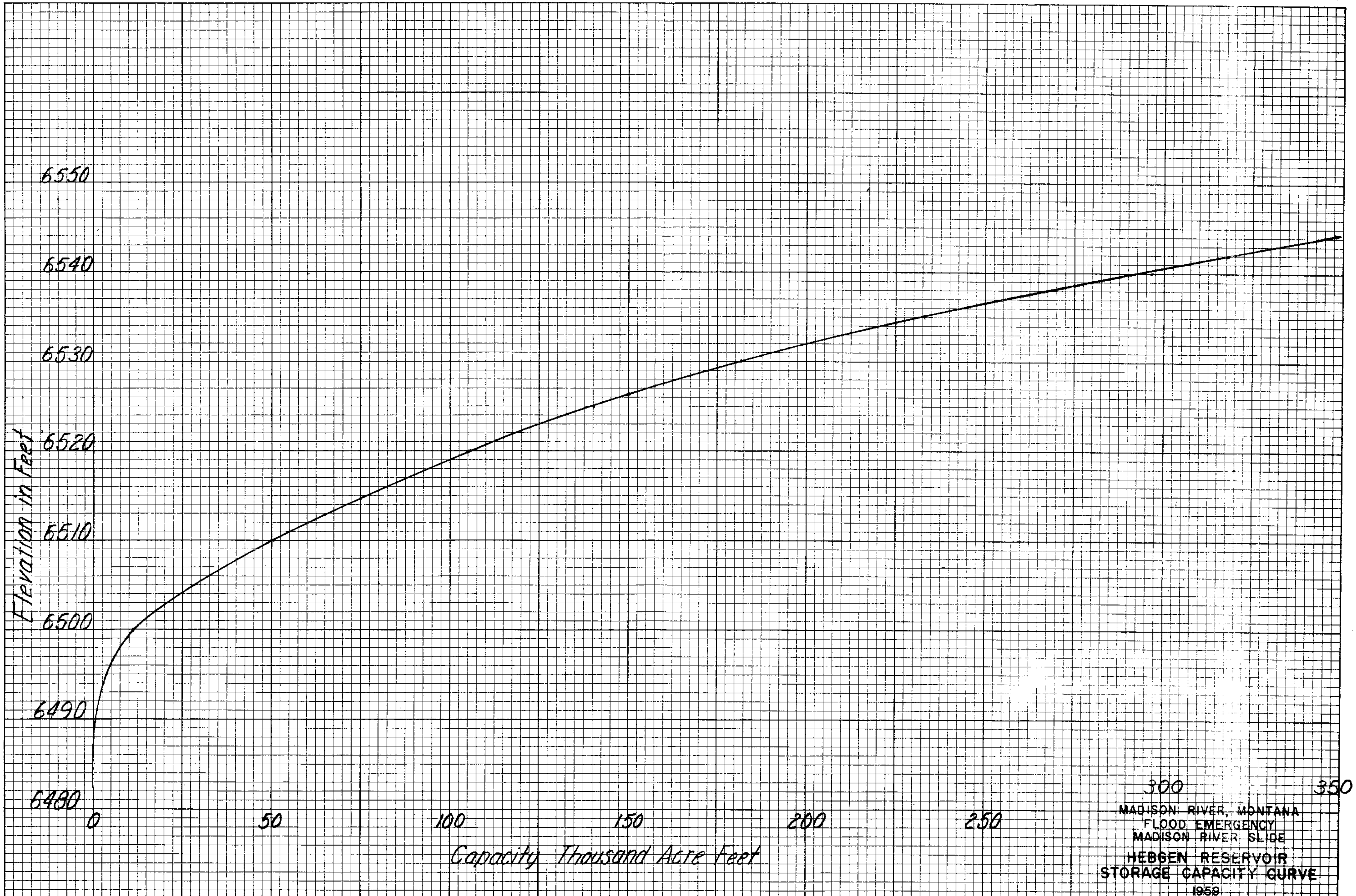

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
HEBGEN RESERVOIR
REGULATION
CURVES
SHEET 2 OF 3

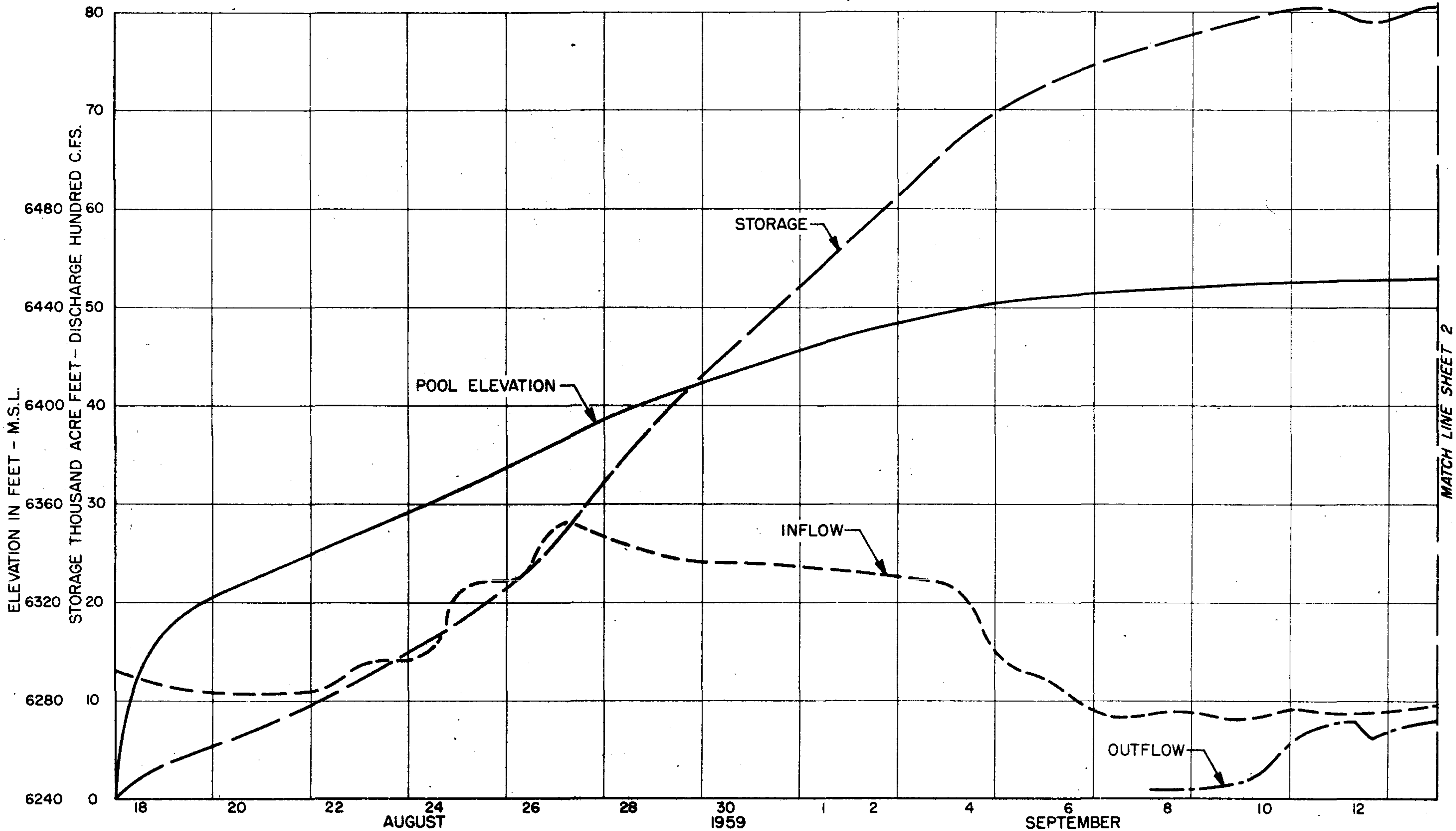



MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE

**HEBGEN RESERVOIR REGULATION CURVES**

SHEET 3 OF 3

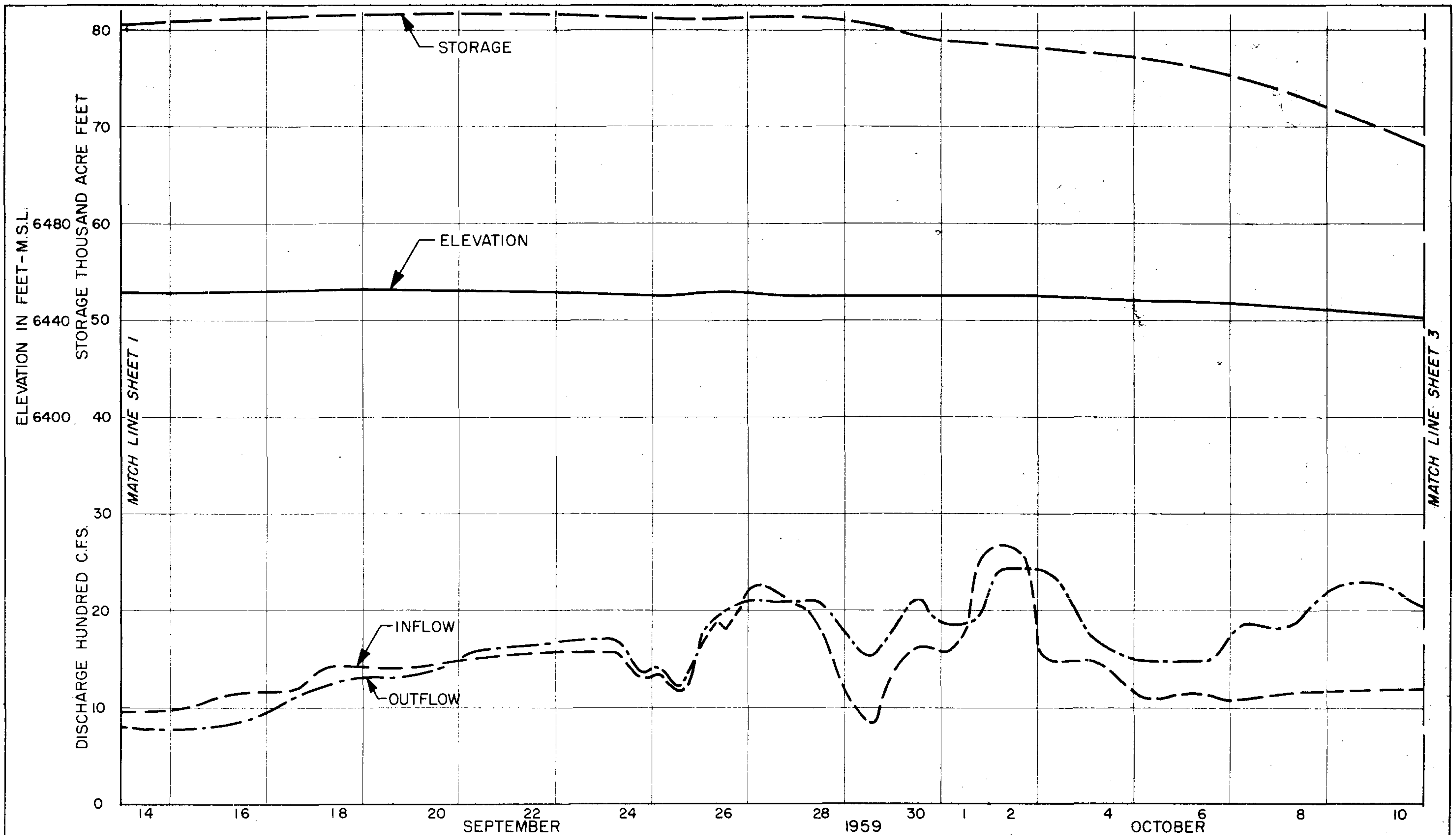

Elevation in Feet
6550
6540
6530
6520
6510
6500
6490
6480
0
50
100
150
200
250
300
350
Capacity Thousand Acre Feet
MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
HEBGEN RESERVOIR
STORAGE CAPACITY CURVE
1959




MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE

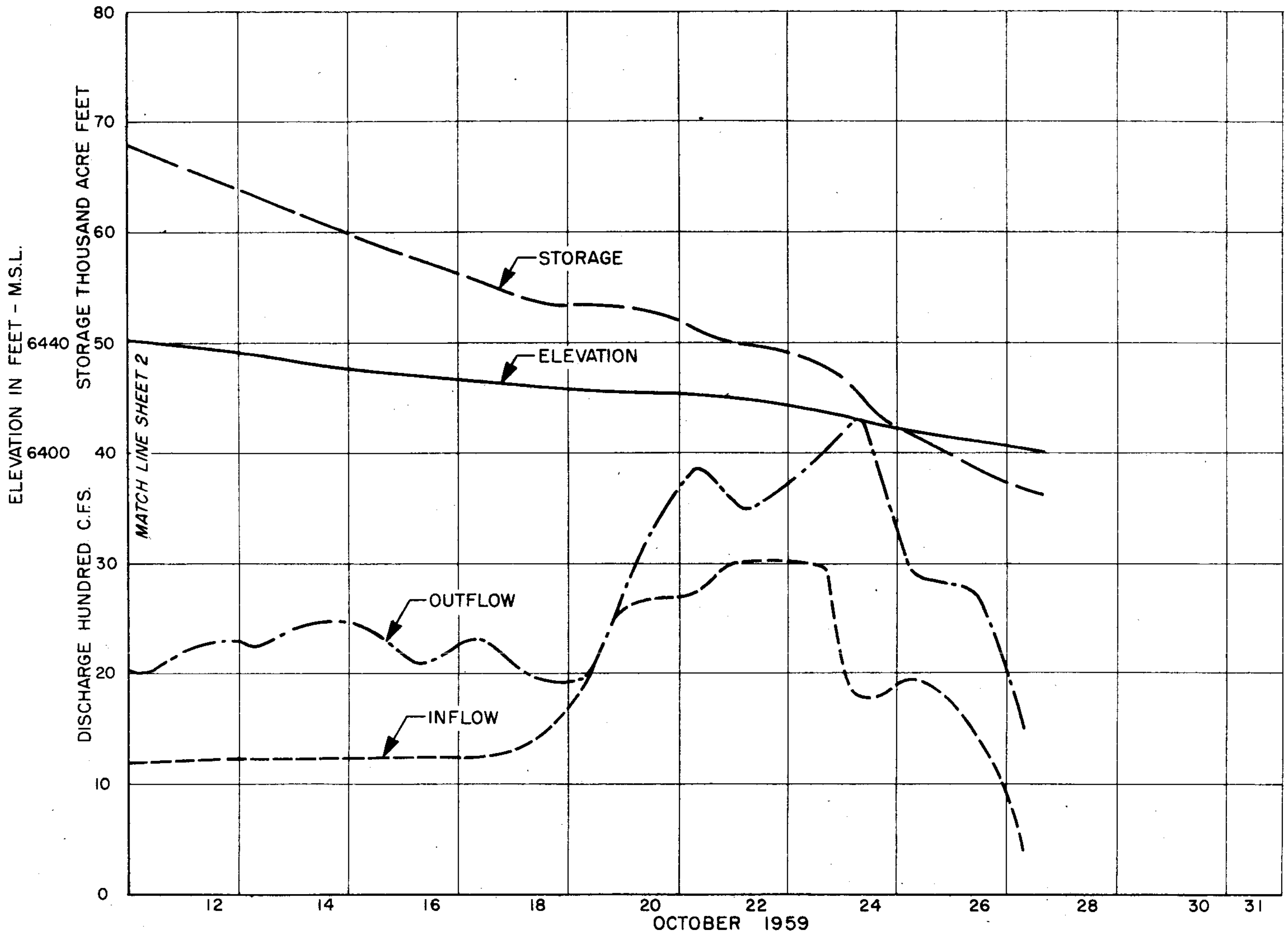
**EARTHQUAKE LAKE REGULATION CURVES**

SHEET 1 OF 3



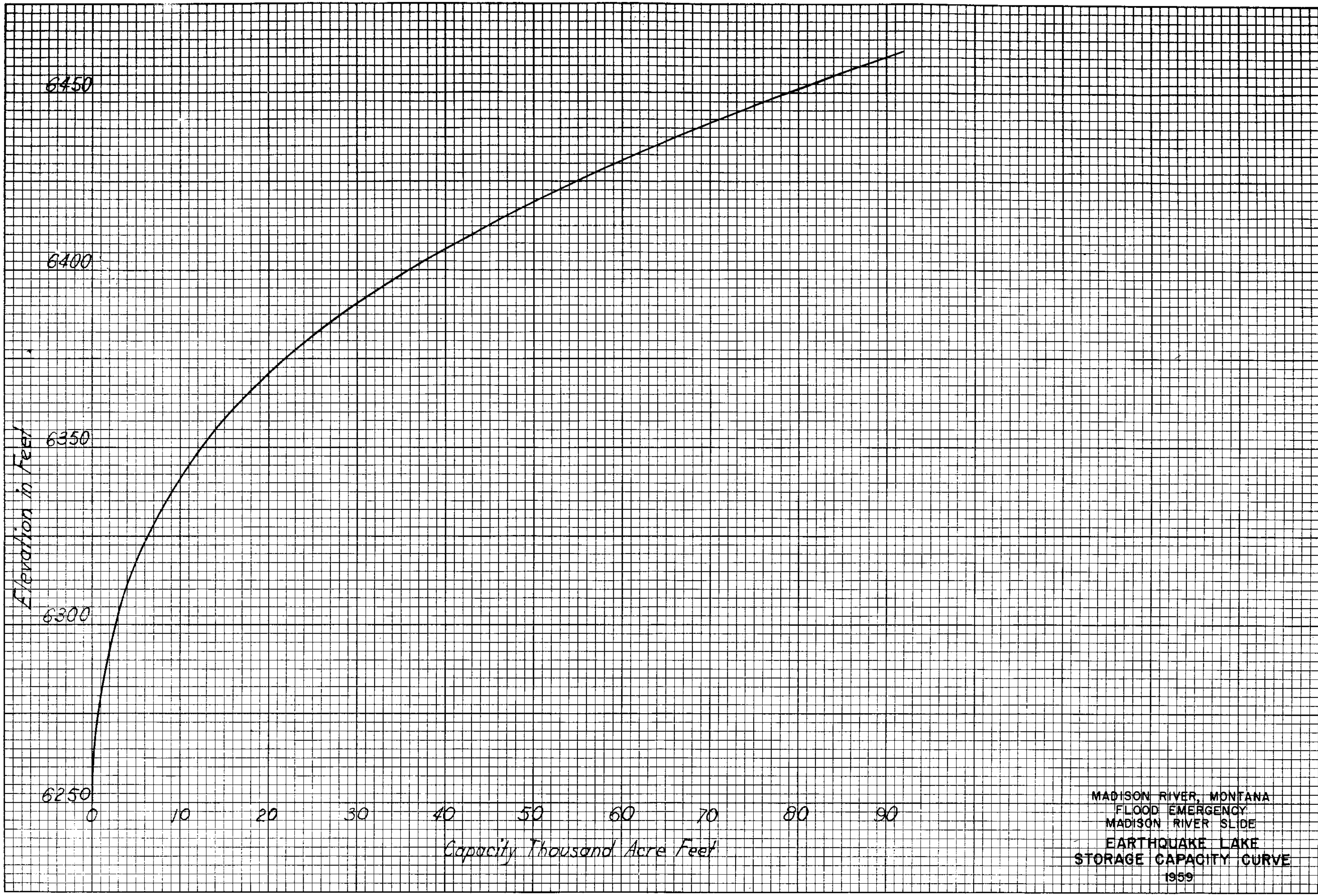

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
**EARTHQUAKE LAKE REGULATION CURVES**
SHEET 2 OF 3

**APPENDIX VIII-PLATE 6**

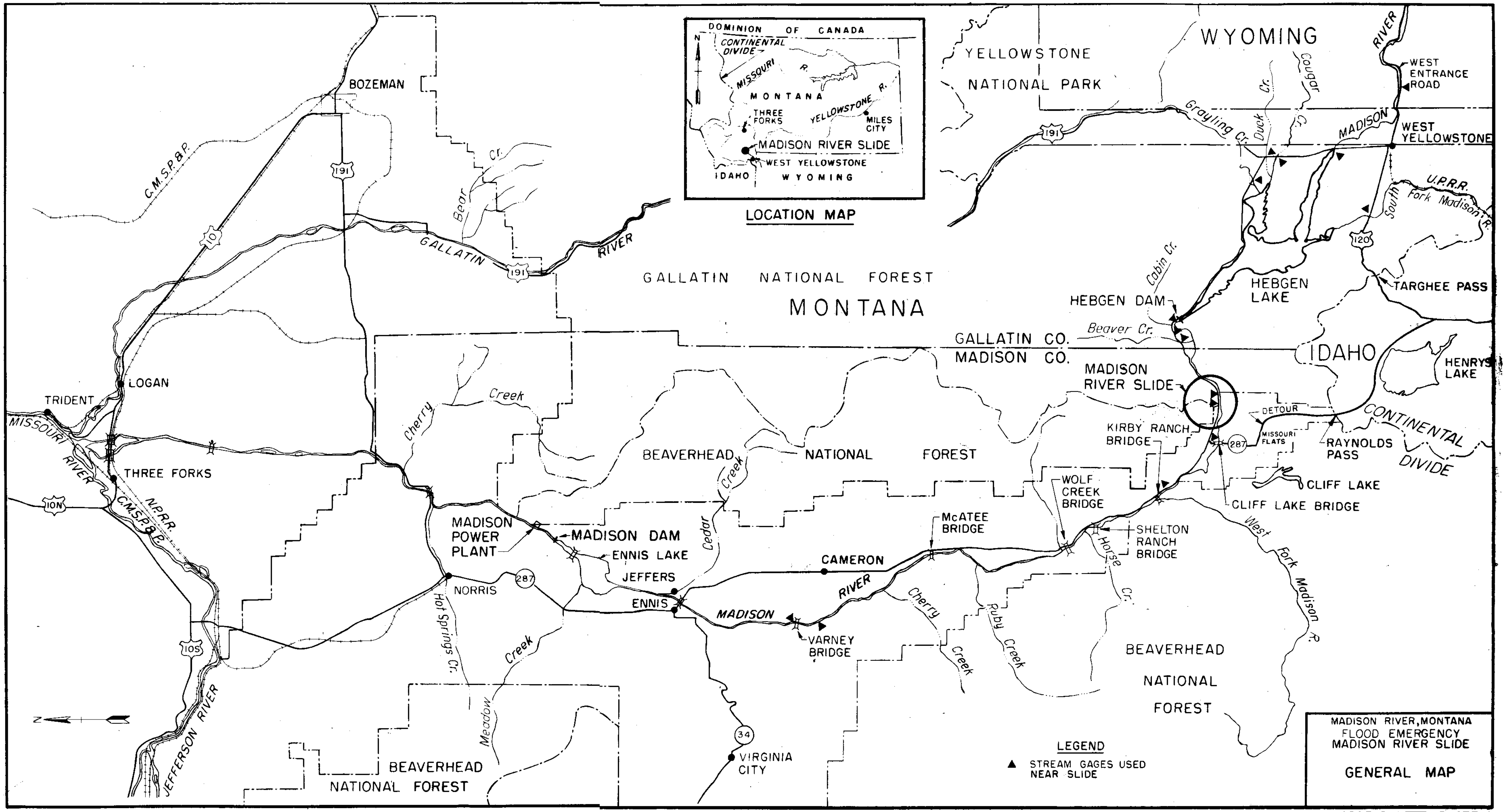



MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
**EARTHQUAKE LAKE**
**REGULATION**
**CURVES**

SHEET 3 OF 3




APPENDIX VIII PLATE 8




MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE

GENERAL MAP

APPENDIX VIII PLATE 9

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX IX

PRELIMINARY SLIDE-STABILITY STUDIES
BY R. E. CURTISS AND D. K. KNIGHT

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX IX

Preliminary Slide-Stability Studies
By R. E. Curtiss and D. K. Knight

## REPORT ON PRELIMINARY SLIDE-STABILITY STUDIES IN MADISON VALLEY SLIDE AREA WITH MISCELLANEOUS COMMENTS

### INTRODUCTION

1. Slide stability investigations in the Madison Valley rock slide area constitute an intensive, integrated program designed to ascertain the present and future safety of the crest area of the rock slide, a dolomite-quartzite-schist pinnacle on the north valley wall, and the relatively undisturbed dolomite-quartzite pinnacle in the south valley wall west of the slide area. Safety to personnel during the construction of the spillway has been of paramount importance.

2. Methods include slide-movement instrumentation that has been installed across cracks and displaced ground along the crest area of the slide. Additional investigations entail future slope safety factors which are based on rock volumes, slope angles, frictional resistances, and saturation loads. It is assumed the reader has read prior reports on the rock slide. Geology of slide area is shown on Figure 1.

3. Short-term and long-term safety factors are controlled by the unpredictability of possible reoccurring severe earthquakes and normal weathering processes, respectively, in the slide crest area.

4. Preliminary results and recommendations are contained herein. Miscellaneous observations, which include the Hebgen Dam area, are also included, as are general comments considered appropriate at the time of this report.

5. VOLUME OF MATERIAL INVOLVED. The length of the ridge above the slide scarp is approximately 1/2 mile in length. As can be noted on the aerial photographs taken of this area, the cracking behind the crest of the ridge which is visible today shows that two areas exhibit the most potential for movement, section I at the east end and section III at the west end of the ridge area. (See figure 1.)

6. Not knowing exactly what bedding or joint planes this material might break loose on, it is very difficult to estimate the volume of this material. Nevertheless, quantities have been computed using the dip of the beds as a general guide for possible fracture boundaries.

7. At the west end of the ridge, the volume of material susceptible to sliding has been estimated at slightly over one million cubic yards of material. At the east end (section I on figure 1 and photographs * No. 1, 2, and 3), the material which is already broken loose and lies on the upper portion of the slide face has been estimated at two-thirds of a million cubic yards. The large berm lying at a corresponding location below the east slide area, which would tend to resist the movement of downsliding material, has been estimated at two million yards (see figure 3).

8. For comparison, the following quantities have been computed from cross sections of the slide area before and after the occurrence of the slide in the Madison River. The total volume of rock and earth materials which now forms the natural dam across the canyon, has been computed at 43,400,000 cu. yds. Assuming a bulking factor of 20 percent from its natural position in the ridge, we can estimate the volume of material which was displaced from the ridge area by the quake at approximately 36,000,000 cu. yds. For comparison also, on the basis of the assumption that one cubic foot of natural dam is equal to 135 pounds, the weight of the slide material is 78,000,000 tons.

## INSTRUMENTATION

9. Three sets of slide-movement or strain gauges were installed on 29-30 August 1959 across cracked and displaced ground at the top or crest of the slide area (see figures 1 and 2 and photographs*). Eight wire-movement indicators were installed between gauge sets and in other areas of potential movement. (See figures 1 and 2 and photographs*.) Tables 1 and 2 show the results of gauge measurements and condition of wire indicators, respectively. Gauge sets are indicated as "A," "B," and "C." The "A" set of gauges, (see photo * 1) which consits of 4 gauges of 3/4-inch water pipe, is installed at the extreme east end of slide in Section I and is composed primarily of schist (see figure 1.). The "B" set of gauges (see photo * 3), which comprises 3 gauges of pipe, is located at the west end of Section I and is also underlain chiefly by schist. The "C" set of gauges (see photo * 10), which consists of 5 gauges of pipe, is installed at the west end of slide in Section III and consists essentially of schist. These gauges are marked with lathe and white flags, observable from both air and ground.

* Not reproduced.

10. Anchor gauges in the sets are reference gauges that were installed in presently firm blocks of ground. Cracked and broken ground (see photographs *) are between the anchor gauges and other gauges in the sets prefixed by "A," "B," and "C." Gauges are measured (see table 1) with a metal tape and hook-type anchor.

11. Eight wire-movement indicators have been installed in conjunction with the gauge sets to enable airborne observers to detect any significant displacement or movement. Certain of the gauges (see table 2) have wires attached. Yellow, red, and white squares of flagging are affixed to the wires. It is conjectured that any significant movement that would exert in the magnitude of 30 to 40 pounds of pressure would pull loose any wire indicator. A break in the wire would destroy the alignment of wire and show disturbance of flags. A break could be easily recognized by aerial observers. Detailed ground checks would follow to determine the reason for a wire break. Impending breakage of wire indicators would be reflected by slide-gauge readings indicating displacement.

## RESULTS OF SLIDE-GAUGE INSTRUMENTATION BETWEEN SETS "A" AND "B" IN SECTION I

12. Results of slide gauge readings between 30 August and 11 September 1959 and observations of wire indicators indicate that no significant movement has taken place along the entire crest area.

13. Gauge set A2-A4 has exhibited a total increase of 2 inches (see table 1), more than any other set on the top of the slide. This small change is considered negligible. Fluctuations in daily readings may be attributed to differences in wind and variable tensions applied to the tape. It should be noted, however, that an apparent vertical change of 1.12 feet has been noted along a 17-foot slide scarp at the extreme east end of the slide area. One foot of this vertical movement occurred prior to the installation of the "A" set of gauges. Early settling or compaction of loosely consolidated slump material consisting largely of schist and gneiss is indicated.

14. Horizontal check movement points J-7 and J-8 (see figure 1) were installed 9 September 1959 across the upstream toe of the left abutment of the slide at stations 48 + 71.2 and 52 + 96.8, respectively. The movement points were checked for alignment 14 September 1959. Points J-7 moved 1/2 inch north--negligible movement--while J-8 revealed no movement.

15. An increase of 1 1/2 inches--the maximum for the "B" set--has been recorded between gauges B-anchor and B2. It is believed that this apparent increase is negligible and is not indicative of significant movement.

* Not reproduced.

16. GEOLOGY. A geologic map of the slide area is shown on figure 1. The major lithologic units consist principally of chlorite schist with lesser amounts of hornblende gneiss. Bedding structure is obscured by slumped rock. However, weathered schist at the crest and immediately west of the "B" set of gauges revealed a N 70° E strike and a 62° NNW dip, approximating the bedding in the dolomite-quartzite pinnacles in the north and south valley slopes. The top 200 feet of the slide is treeless, representing a part of the south facing or back slope that slid. A sizable berm, which consists largely of schist, constitutes much of the upstream, left bank area of the natural dam. A 50-75 foot slide scarp is found about one-half way down the east boundary of the slide. No toe restraint is thus provided in this area for the presently stable timbered slope to the south.

17. CONCLUSIONS AND RECOMMENDATIONS. It appears tenable that slide 2 (Section I) offers no present endangerment to either construction or engineering personnel or the spillway structure, exclusive of a major reoccurring earthquake.

a. Since this ridge area was probably fractured and cracked as it is today immediately following the slide and has experienced the subsequent minor quakes and tremors, it is a strong indication that the material of the ridge area will remain in place for a period of a year or two at least. The two main factors which can influence the length of this period are as follows:

First: The occurrence of additional severe earthquake shocks.

Second: The weathering of the earth and rock mass along the ridge by natural moisture from rain and snow melt.

The second of these factors would of course take considerable time. It is estimated that two or more spring seasons would be necessary to saturate and weaken the slide materials sufficient to cause them to start moving from their natural position and slide or creep slowly into the area of the natural dam below. It is believed that the end of the scarp area (see aerial photos * 1, 2, and 3), is likely to absorb water at a much more rapid rate than other areas of the ridge, since a greater surface is exposed. At the time that the east slide mass becomes saturated sufficiently to lower the shear strength of the materials, it will slide or creep toward the natural dam and spillway below. The speed of this movement is difficult to predict but could possibly be very rapid and develop sufficient speed to move through the rather large and comprehensive berm which lies between the scarp and the spillway channel. Rapid sliding would be sufficient to block the spillway channel which has been constructed.

* Not reproduced.

b. A simple stability analysis was run on the loose slide material in Section I. The distorted section shown as figure 3 was used as the basis for the stability study. No water forces were assumed and the weight of the slide mass was taken as 120 lbs. per cubic foot. For a factor of safety of 1.00 the required shear strength along the slide plane was computed to be a frictional resistance of tangent $\phi = .55$. The effect of infiltrating rain water or snow melt was evaluated on the basis of 26 inches annual precipitation. The added weight of the water would be approximately 6%, or negligible. If this much moisture were added uniformly to the slide mass, the increase in moisture content would also be of no consequence. The most effect from moisture would result if the water seeped through the mass to accumulate at the slide plane or the surface of firm bedrock. It seems doubtful that this amount of moisture would have a major weakening effect along the slide plane. It is therefore concluded that the rate of sliding for the Section I area will be a slow creep and will not block the spillway channel.

c. Unloading the top of the slide, which might entail the removal of perhaps 2/3 million cubic yards of slimped material, would increase stability. Material could be removed to the back slope. Accessibility would present somewhat of an obstacle.

d. Continued observation is recommended.

## RESULTS OF SLIDE-GAUGE INSTRUMENTATION BETWEEN SETS "B" AND "C" IN SECTION II

18. Results of observations taken on wire indicator number 4 (see figure 2, table 2, and photo * No. 6) cite no movement thus far. Tight cracks are noted some 200 feet (slope distance) along the south facing or back slope (see photos * Nos. 3, 4, 5, and 6). Arcute cracks are conspicuous near the scarp.

19. GEOLOGY. Weathered schist bedding strikes N 70° E and dips 62° NNW into the rockslide area along a steep scarp (see photo * 4). The back slope dips about 32° south. The crest is therefore precipitous for several hundred horizontal feet and about 50 vertical feet.

20. CONCLUSIONS AND RECOMMENDATIONS. Section II appears somewhat more stable than Section I on the east or Section III on the west.

a. The central area, shown as Section II of the ridge on figure 1, is more steeply sloped and cleaner than the other ridge areas. For the top 50 feet the jagged scarp face follows alternately along the steeply dipping joint and bedding planes of the schist bedrock. Below this the slide face is on a much flatter slope.

* Not reproduced.

Although small cracks appear about 200 feet down the backslope, this section is considered generally stable, with only very small pieces on the face likely to fall off as weathering progresses. This conclusion is based on the fact that any fracture or slippage on either a joint or bedding plane whould be so steep as to pass under the present scarp face, thus developing tremendous resisting forces. Only quake forces of the maximum intensity would be sufficient to overcome this resistance.

b. Damage to the spillway is not anticipated.

c. Extended surveillance of the crack system is urged.

## RESULTS OF SLIDE-GAUGE INSTRUMENTSTION IN SET "C" AND SECTION III AREA

21. Slide-gauge measurements have recorded no significant movements to date. Arcute cracks are very conspicuous for approximately 450 feet along the extreme west edge of the slide scarp. This cracking extends about 125 feet back of the steep crest. One major crack, which is between $C_1$-$C_3$, $C_2$-$C_3$, and wire indicator 8, is at least six feet wide and 10 feet deep. The crack continues into the timbered north-facing slope about 75+ feet west of and parallel to the edge of the slide scarp. No significant cracks have been noted west of photo * 10. An increase of 5/8 inch was measured from C anchor to $C_1$ and $C_1$ to $C_3$ (see table 1). This change is considered negligible.

22. GEOLOGY. Schist constitutes the major rock type in the crest area. The south-facing slope is grass-covered with a thin soil mantle. Schist bedding, which is revealed in the aforementioned conspicuous crack, strikes about N 85° E and dips 57° NNW toward the Madison Valley rockslide (see figure 1). The crack appears to be locally joint controlled. A joint surface, which is at least 10 feet high, strikes N 25° W and dips 79° SW. Cross jointing was also noted.

23. Dolomite-quartzite pinnacles comprise a large proportion of the lower section of the timbered north-facing slope. A resistant nose of dolomite-quartzite is a remnant in the slide area. The nose, which is part of a pre-slide pinnacle, serves as a buttress, restraining the movement of slide material behind it in this section of the ridge. The easternmost dolomite-quartzite buttress has sustained periodic spalling of blocks. No extraordinarily large block has fallen. Bedding strikes N 80° E and dips 60° NNW. Dip and strike joints have developed extensively. Joint-controlled blocks in the magnitude of three or four feet in thickness have spalled subsequent to the major earthquake. The falling rocks have been arrested by the talus slope and timber. No deleterious affects have resulted to either personnel, equipment, or spillway.

* Not reproduced.

24. CONCLUSIONS AND RECOMMENDATIONS. The western end of the ridge in the area shown as Section III on figure 1 is considered stable over-all since it is well braced by a dolomite ridge remaining along the west edge of the slide. However, this area is also too weak to withstand severe earthquake shock.

a. Rather estensive deep cracking has taken place at the top of the ridge as shown on aerial photograph * number 10. It is expected that some large joint-controlled blocks will fall out of this area next year as nature's weathering forces act through the many wide cracks. These fallouts will endanger anyone in the areas below but are not expected to adversely effect the function of the spillway channel.

b. Preventive maintenance, which would consist of the removal of possibly 150,000 cubic yards of crest material, would substantially obviate the possibility of dangerous large block falls.

c. Continued observation is recommended.

## RESULTS OF INVESTIGATION OF AREAS EAST OF SLIDE AREA

25. Airborne and footborne reconnaissance detected disconnected and discontinuous cracks along the narrow ridge east of the rock slide crest. These cracks are not perceptible on standard sized aerial photographs. Most of the cracks are fairly tight. One crack, however, which is 1500± feet east of the slide scarp, apparently is strike (N 38° E) controlled (see figure 1). The crack displays about one foot of vertical displacement and six inches of horizontal displacement. It is open to a depth of at least three feet. It continues eastward for perhaps a hundred yards into the timbered area below the ridge.

26. Indications are that many of the small, relatively tight cracks are tension cracks resulting from the major quake. Such cracks are found on similar ridges on the top of other Madison Valley ridges and do not necessairly indicate slide movements.

27. A reconnaissance of the extreme end of the north-facing timbered slope west of the slide revealed cracking and broken, displaced ground immediately in juxtaposition with the east slide scarp. Extensive cracking does not appear to continue for any appreciable distance through the timbered slopes on either side of the slide scarp.

28. GEOLOGY. Bedrock exposures are restricted largely to the narrow crest. The north and south valley slopes are timbered and soil covered, respectively. Exposed rocks are relatively unweathered.

* Not reproduced.

The largest crack, which is described above, parallels the strike of the rocks. Gneiss with quartz-injected veins and lesser amounts of schist strike about N 38° E and dip 53° NW some 1500± feet east of the slide scarp. Dip joints are well developed. The apparent deviation in strike from the general strike N 80° E of the rocks in the slide area may indicate a fault whose alignment conforms with a fault scarp striking southwest in the general direction of Henry's Lake, Idaho. The same strike and dip of the rocks was observed about 3,000± feet east of the slide scarp.

29. CONCLUSION AND RECOMMENDATIONS. This area appears currently stable.

a. A major slide in this area would seriously endanger the upstream left abutment sector of the dam (see figure 1). The 50-75± foot slide scarp, which is midway along the east side of the slide area, exerts little toe restraint to a part of the timbered area adjacent to the slide area. On the other hand, the large mass of the slide provides considerable toe support.

b. It is believed that the discontinuous, disconnected cracks along the ridge do not imperil the stability of the ridge or the timbered slopes east of the scarp.

c. The narrow ridge and uniform slope indicate that the greater percentage of moisture will be runoff, with little absorbed in the bedrock.

d. Continued observations are strongly recommended for this area.

## RESULTS OF INVESTIGATIONS OF THE PINNACLE ON THE NORTH VALLEY WALL

30. Sloughed rocks and attendant dust swirls have focused attention on the prominent rock pinnacle (see photo * 11) on the north valley slope. Small rocks have sloughed from this pinnacle and corresponding ridges on the north slope in the wake of many tremors.

31. GEOLOGY. Rocks near the base of the pinnacle (see photo * 12) are composed principally of dolomite, quartzite, gneiss, schist and quartz-injected veins. Bedding strikes N 84° E and dips 54° NNW or into the north valley slope. Strike and dip joints are well developed. Rocks break along the joints. Rock-sloughed areas on the fairly massive dolomite and quartzite pinnacle (see photo * 11) have resulted in light colored scars in contrast to the dark

* Not reproduced.

colored weathered surfaces which have not sustained very recent sloughing. The fracture or joint in the pinnacle apparently was developed prior to the earthquake as attested by the dark colored, weathered surfaces. Less closely spaced jointing is evident on the pinnacle than in the lower rock ridges adjacent to the pinnacle. A well developed talus slope dips 30° S below the pinnacle and associated ridges. Most of the sloughed rocks come to rest on the talus slope above the highway and downstream from the natural dam.

32. CONCLUSIONS AND RECOMMENDATIONS. Present indications are that the pinnacle is relatively stable for an indefinite period. It has thus far withstood the earthquake and innumerable tremors. Surveillance should be maintained during the immediate future. In the event that the main joint or fracture is opened and the rock mass appears severed, the pinnacle should be removed by explosives thus eliminating any safety hazard.

## GENERAL CONCLUSIONS AND RECOMMENDATIONS

33. The inpending danger of potential rock slides dictates that public access to the slide area and concomitant establishment of highways, buildings, camp grounds, recreational areas and the like be denied until all safety hazards have been removed.

34. The following preventive measures are recommended:

a. Continued surveillance and observation of potential rock slide areas should be continued once or twice a week until fall, once a month through the winter, and once a week next spring, particularly during the snow-melt period about the last of April and during May and June.

b. The removal of perhaps 700,000 cubic yards from three specific crest areas designed to minimize safety hazards to personnel, equipment, and the spillway structure is suggested.

c. Observation of the rock pinnacle on the north valley wall should be continued.

d. It is strongly recommended that road construction be prohibited at the toe area of the rock slide. Any removal of the toe area might trigger additional slides that could endanger personnel, equipment, and the spillway.

e. A telemeter-type electronic warning device should be designed and installed in conjunction with the wire indicators near gauge sets "A" and "C" in the slide-crest area. If this is successfully done the frequency of observations recommended in paragraph a above may be reduced.

## MISCELLANEOUS OBSERVATIONS OR COMMENTS

35. SLIDE-STABILITY OBSERVATIONS AT HEBGEN DAM. The geology and effects of the earthquake at Hebgen Dam are treated in a prior report.

36. Surficial deposits of loosely consolidated overburden crop out between the spillway and Hebgen fault scarp. As a result of the earthquake, this material was broken and cracked. The overburden is highly receptive to moisture. This area receives about 26 inches of precipitation annually. An undertermined amount of sliding, perhaps of the slow, creeping type, may be anticipated in the distant future.

37. The quantity of anticipated moisture is expected to exert a negligible weight in the overburden. However, sliding may occur if the Hebgen fault scarp, which is a slide plane, becomes saturated--lubricated--or if the saturation line in the overburden equals the Hebgen Lake level. The slope between the spillway and Hebgen fault is not excessively steep, about 1 on 3.5. This slope, evaluated with the rather high shear strength of the gravelly overburden materials, is considered stable, except for subsequent earthquake shocks.

38. It is recommended that three sets of slide-movement gauges be installed across the Hebgen fault scarp and a similar number across open tension cracks east of the spillway. Subsequent observations should be permanently scheduled. (Mr. Jones, Montana Power Co. superintendent, has offered to read such gauges.) Any significant increase in general cracking or movement might be arrested by instituting a crack-sealing program to reduce saturation.

39. The left abutment area appears relatively stable. Slides of small magnitude resulted from the earthquake; slide scars are perceptible. Additional small quantities of jointed rock (dolomite, quartzite, and schist) are expected to slough periodically.

40. SLIDE OVERFLOW SPILLWAY STRUCTURE. For a permanent structure, two additional steps are envisioned; first, the crest elevation should be lowered 35 to 50 feet; second, the chute rock should be grouted with cement-sand grout for about 10 feet depth. If at least one of these can not be accomplished, it is doubtful that a permanent structure can be attained.

Attachments:

- Table 1 Gauge Readings
- Table 2 Wire-Slide Indicators
- Figure 1 Plan of Slide
- Figure 2 Plan of Ridge Cracks
- Figure 3 Stability Section

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## TABLE 1. SLIDE-MOVEMENT GAUGES ON CREST OF MADISON VALLEY SLIDE

| PIPE GAUGES | DATE INSTALLED | DISTANCE | BRUNTON BEARING | 8-30-59 READING | TIME READ | TOTAL CHANGE | REMARKS |
|---|---|---|---|---|---|---|---|
| (A set has 5) | | | | | | | |
| A Anchor - A1 | 8-29-59 (6-7 PM) | 69' 2-3/8" | N.55° W. | 69' 2-3/8" | 10:45 AM | 0 | No Change |
| A Anchor - A2 | " | 86' 10-3/4" | H.75° W. | 86' 11-1/8" | 11:00 AM | +3/8" | Negligible Change |
| A Anchor - A3 | " | 94' 8-1/8" | S.74° W. | 94' 8-1/8" | 11:10 AM | 0 | No Change |
| A1 - A2 | " | 29' 6-1/4" | | 29' 6-3/8" | 11:20 AM | +1/8" | Negligible Change |
| A2 - A3 | " | 53' 1/2" | S.7° W. | 53' 1/2" | 11:30 AM | 0 | No Change |
| A2 - A4 | " | 96' 10" (1) | | 96' 10" | 11:55 AM | | |
| (B set has 3) | | | | | | | |
| B Anchor - B1 | 8-30-59 12:15-1:30PM | 94' 10-1/2" | N.31° E. | | | | |
| B Anchor - B2 | " | 97' 11" | N.4° W. | | | | |
| B1 - B2 | " | 66' 4" | N.82° W. | | | | |
| (C set has 5) | 8-30-59 12:15-3:20PM | 65' 4-1/2" | N.42° E. | | | | |
| C Anchor - C2 | " | 83' 6" | N.-S. | | | | |
| C1 - C2 | " | 64' 7" | N.77° W. | | | | |
| C1 - C3 | " | 50' 11-1/4" | N.5° E. | | | | |
| C2 - C4 | " | 44' 7-3/4" | N.2° E. | | | | |
| C3 - C4 | " | 72' 9-1/4" | N.69° W. | | | | |
| C1 - C4 | " | 99' 11-1/2"(2) | | | | | |

(1) Distance determined 8/30/59
(2) Distance determined 9/1/59

TABLE 1. SLIDE-MOVEMENT GAUGES ON CREST OF MADISON VALLEY SLIDE (Contd)

| PIPE GAUGES | 9-1-59 READING | TIME READ | TOTAL CHANGE | REMARKS | 9-2-59 READING | TIME READ | TOTAL CHANGE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| A Anchor - A1 | 69' 2-3/8" | 11:10 AM | 0 | No Change | 69' 2-3/8" | 5:15 PM | 0 | No Change |
| A Anchor - A2 | 86' 10-7/8" | 11:15 AM | +3/8" | Negligible Change | 86' 10-7/8" | 5:18 PM | +3/8" | Negligible Change |
| A Anchor - A3 | 94' 8-1/8" | 11:20 AM | 0 | No Change | 94' 8-1/8" | 5:20 PM | 0 | No Change |
| A1 - A2 | 29' 6-1/4" | 11:25 AM | 0 | No Change | 29' 6-1/4" | 5:23 PM | 0 | No Change |
| A2 - A3 | 53' 1/2" | 11:30 AM | 0 | No Change | 53' 1/2" | 5:25 PM | 0 | No Change |
| A2 - A4 | 96' 10-1/4" | 11:40 AM | +1/4" | Negligible Change | 96' 11" | 5:27 PM | +1" | Negligible Change |
| B Anchor - B1 | 94' 10-1/2" | 12:36 PM | 0 | No Change | 94' 11" | 5:35 PM | +1/2" | Negligible Change |
| B Anchor - B2 | 97' 11" | 12:45 PM | 0 | No Change | 97' 11-2/3" | 5:37 PM | +2/3" | Negligible Change |
| B1 - B2 | 66' 4" | 12:55 PM | 0 | No Change | 66' 4" | 5:41 PM | 0 | No Change |
| C Anchor - C1 | 65' 4-3/4" | 9:45 AM | +1/4" | Negligible Change | 65' 4-1/2" | 6:10 PM | 0 | No Change |
| C Anchor - C2 | 83' 6" | 9:55 AM | 0 | No Change | 83' 6" | 6:11 PM | 0 | No Change |
| C1 - C2 | 64' 7" | 10:05 AM | 0 | No Change | 64' 7-1/4" | 6:13 PM | +1/4" | Negligible Change |
| C1 - C3 | 50' 11-3/4" | 10:15 AM | +1/2" | Negligible Change | 50' 11-3/4" | 6:15 PM | +1/2" | Negligible Change |
| C2 - C4 | 44' 7-3/4" | 2:10 PM | 0 | No Change | 44' 7-3/4" | 6:18 PM | 0 | No Change |
| C3 - C4 | 72' 9-1/8" | 2:15 PM | -1/8" | Negligible Change | 72' 9-1/4" | 6:20 PM | 0 | No Change |
| C1 - C4 | 99' 11-1/2" | 2:20 PM | | Dist. Determined this date | Not Read | | | |

TABLE 1. SLIDE-MOVEMENT GAUGES ON CREST OF MADISON VALLEY SLIDE (Contd)

| PIPE GAUGES | 9-3-59 READING | TIME READ | TOTAL CHANGE | REMARKS | 9-4-59 READING | TIME READ | TOTAL CHANGE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| A Anchor - A1 | 69' 2-3/8" | 5:51 PM | 0 | No Change | 69' 2-1/2" | 3:43 PM | +1/8" | High Wind Negligible Change |
| A Anchor - A2 | 86' 10-3/4" | 5:55 PM | 0 | No Change | 86' 11" | 3:43 PM | +1/4" | Negligible Change |
| A Anchor - A3 | 94' 8-1/8" | 6:00 PM | 0 | No Change | 94' 8-1/8" | 3:45 PM | 0 | No Change |
| A1 - A2 | 29' 6-5/8" | 6:02 PM | +3/8" | Negligible Change | 29' 6-1/4" | 3:37 PM | 0 | No Change |
| A2 - A3 | 53' 1/2" | 6:10 PM | 0 | No Change | 53' 3/4" | 3:40 PM | +1/4" | Negligible Change |
| A2 - A4 | 96' 11" | 6:04 PM | +1" | Negligible Change | 96' 11" | 3:35 PM | +1" | Negligible Change |
| B Anchor - B1 | 94' 10-1/2" | 6:22 PM | 0 | No Change | 94' 11-1/4" | 3:47 PM | +3/4" | Negligible Change |
| B Anchor - B2 | 97' 11-1/2" | 6:24 PM | +1/2" | Negligible Change | 97' 11-7/8" | 3:48 PM | +7/8" | Negligible Change |
| B1 - B2 | 66' 4" | 6:26 PM | 0 | No Change | | | | |
| C Anchor - C1 | 65' 4-1/2" | 7:00 PM | 0 | No Change | 65' 4-3/4" | 3:14 PM | +1/4" | Negligible Change |
| C Anchor - C2 | 83' 5-1/4" | 7:04 PM | -3/4" | Negligible Change | 83' 6" | 3:16 PM | 0 | No Change |
| C1 - C2 | 64' 6-3/4" | 7:05 PM | +1/4" | Negligible Change | 64' 7-1/2" | 3:58 PM | +1/2" | Negligible Change |
| C1 - C3 | 50' 11-1/2" | 7:07 PM | +1/2" | Negligible Change | 50' 11-7/8" | 3:53 PM | +5/8" | Negligible Change |
| C2 - C4 | 44' 8-1/4" | 7:09 PM | +1/2" | Negligible Change | | | | |
| C3 - C4 | 72' 9-1/4" | 7:11 PM | 0 | No Change | | | | |
| C1 - C4 | 99' 10-1/4" | 7:14 PM | -1-1/4" | Negligible Change | | | | |

TABLE 1. SLIDE-MOVEMENT GAUGES ON CREST OF MADISON VALLEY SLIDE (Contd)

| PIPE GAUGES | 9-5-59 READING | TIME READ | TOTAL CHANGE | REMARKS | 9-7-59 READING | TIME READ | TOTAL CHANGE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| A Anchor - A1 | 69' 2-3/8" | 6:40 PM | 0 | No Change | 69' 2-1/2" | 9:30 AM | +1/8" | Negligible Change |
| A Anchor - A2 | 86' 11" | 6:42 PM | +1/4" | Negligible Change | 86' 11" | 9:32 AM | +1/4" | Negligible Change |
| A Anchor - A3 | 94' 8-1/8" | 6:44 PM | 0 | No Change | 94' 7-3/4" | 9:33 AM | -3/8" | Negligible Change |
| A1 - A2 | 29' 6-1/2" | 6:45 PM | +1/4" | Negligible Change | 29' 6-1/2" | 9:35 AM | +1/2" | Negligible Change |
| A2 - A3 | 53' 1/2" | 6:46 PM | 0 | No Change | 53' 1" | 9:37 AM | +1/2" | Negligible Change |
| A2 - A4 | 96' 11-3/8" | 6:49 PM | +1-3/8" | Negligible Change | 96' 11-1/2" | 9:40 AM | +1-1/2" | Negligible Change |
| B Anchor - B1 | 94' 11-1/4" | 6:52 PM | +3/4" | Negligible Change | 94' 11" | 9:45 AM | +1/2" | Negligible Change |
| B Anchor - B2 | 98' | 6:54 PM | +1" | Negligible Change | 98' 1/4" | 9:47 AM | +1-1/4" | Negligible Change |
| B1 - B2 | 66' 4" | 6:56 PM | 0 | No Change | 66' 3-3/4" | 9:50 AM | -1/4" | Negligible Change |
| C Anchor - C1 | 65' 4-1/2" | 7:10 PM | 0 | No Change | 65' 5" | 10:05 AM | +1/2" | Negligible Change |
| C Anchor - C2 | 83' 6" | 7:12 PM | 0 | No Change | 83' 5-3/4" | | -1/4" | Negligible Change |
| C1 - C2 | 64' 7" | 7:14 PM | 0 | No Change | 64' 6-3/4" | | -1/4" | Negligible Change |
| C1 - C3 | 50' 11-3/4" | 7:16 PM | +1/2" | Negligible Change | 50' 11-3/4" | | +1/2" | Negligible Change |
| C2 - C4 | 44' 8-1/4" | 7:20 PM | +1/2" | Negligible Change | 44' 8" | | +1/4" | Negligible Change |
| C3 - C4 | 72' 9-1/2" | 7:17 PM | +1/4" | Negligible Change | 72' 9-1/2" | | +1/4" | Negligible Change |
| C1 - C4 | 99' 11" | 7:15 PM | -1/2" | Negligible Change | 99' 11" | 10:20 AM | -1/2" | Negligible Change |

TABLE 1. SLIDE-MOVEMENT GAUGES ON CREST OF MADISON VALLEY SLIDE (Contd)

| PIPE GAUGES | 9-8-59 READING | TIME READ | TOTAL CHANGE | REMARKS | 9-11-59 READING | TIME READ | TOTAL CHANGE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| A Anchor - A1 | Not read | | | | 69' 2-5/8" | 9:33 AM | +1/4" | Negligible Change |
| A Anchor - A2 | " | | | | 86' 10-7/8" | 9:34 AM | +1/8" | Negligible Change |
| A Anchor - A3 | " | | | | 94' 7-5/8" | 9:35 AM | -1/2" | Negligible Change |
| A1 - A2 | " | | | | 29' 6-1/2" | 9:36 AM | +1/4" | Negligible Change |
| A2 - A3 | " | | | | 53' 5/8" | 9:37 AM | +1/8" | Negligible Change |
| A2 - A4 | 96' 11-1/2" | 12:40 PM | +1-1/2" | Negligible | 97' | 9:38 AM | +2" | Negligible Change |
| B Anchor - B1 | Not Read | | | | 94' 11" | 9:47 AM | +1/2" | Negligible Change |
| B Anchor - B2 | 98' | 12:50 PM | +1" | Negligible Change | 98' 1/2" | 9:49 AM | +1-1/2" | Negligible Change |
| B1 - B2 | Not Read | | | | 66' 4" | 9:54 AM | 0 | No Change |
| C Anchor - C1 | " | | | | 65' 5-1/8" | 10:45 AM | +5/8" | Negligible Change |
| C Anchor - C2 | " | | | | 83' 6" | 10:46 AM | 0 | No Change |
| C1 - C2 | " | | | | 64' 7" | 10:48 AM | 0 | No Change |
| C1 - C3 | 50' 11-7/8" | 1:10 PM | +5/8" | Negligible Change | 50' 11-7/8" | 10:44 AM | +5/8" | Negligible Change |
| C2 - C4 | Not Read | | | | 44' 8-1/4" | 10:41 AM | +1/2" | Negligible Change |
| C3 - C4 | " | | | | 72' 9-1/4" | 10:49 AM | 0 | No Change |
| C1 - C4 | " | | | | Not Read | | | |

TABLE 1. SLIDE-MOVEMENT GAUGES ON CREST OF MADISON VALLEY SLIDE (Contd)
(Data Added Subsequent to Report)

| PIPE GAUGES | 9-17-59 READING | TOTAL CHANGE | REMARKS | 10-21-59 READING | TOTAL CHANGE | REMARKS |
|---|---|---|---|---|---|---|
| A Anchor - A1 | 69' 3" | +5/8" | Negligible Change | 69' 4-3/4" | +2-3/8" | |
| A Anchor - A2 | 86' 11-1/2" | +3/4" | Negligible Change | 87' 5/8" | +1-7/8" | |
| A Anchor - A3 | 94' 7-7/8" | -1/4" | Negligible Change | 94' 9" | +7/8" | Negligible Change |
| A1 - A2 | 29' 6-5/8" | +3/8" | Negligible Change | 29' 8-1/8" | +1-7/8" | |
| A2 - A3 | 53' 5/8" | +1/8" | Negligible Change | 53' 1-1/2" | +1" | Negligible Change |
| A2 - A4 | 97' 1-1/4" | | | 97' 6" | +8" | |
| B Anchor - B1 | 94' 11-1/4" | +3/4" | Negligible Change | 95' 3" | +4-1/2" | |
| B Anchor - B2 | 98' 1-1/4" | +2-1/4" | | 98' 6" | +7" | |
| B1 - B2 | 66' 3-1/2" | -1/2" | Negligible Change | 66' 3-5/8" | -3/8" | Negligible Change |
| C Anchor - C1 | 65' 5" | +1/2" | Negligible Change | 65' 7-1/4" | +2-3/4" | |
| C Anchor - C2 | 83' 5-3/4" | -1/4" | Negligible Change | 83' 7-1/4" | +1-1/4" | |
| C1 - C2 | 64' 7" | 0 | No Change | 64' 8-3/8" | +1-3/8" | |
| C1 - C3 | 51' | +3/4" | Negligible Change | 51' 2" | +2-3/4" | |
| C2 - C4 | 44' 8" | +1/4" | Negligible Change | 44' 8" | +1/4" | Negligible Change |
| C3 - C4 | 72' 9-7/8" | +5/8" | Negligible Change | 73' 1/2" | +3-1/4" | |
| C1 - C4 | 99' 10" | -1-1/2" | | Not Read | | |

## TABLE 2. WIRE-SLIDE INDICATORS ON CREST OF MADISON VALLEY SLIDE

| WIRE NUMBER | DATE INSTALLED | LOCATION | REMARKS | 9-2-59 OBSERVATION | CONDITION OF WIRE & POINTS |
|---|---|---|---|---|---|
| 1 | 9-1-59 | Between A Anchor & Tree on Quartz mass at edge of slide. | 3 Yellow Flags N.17° W. Dist. 130 ± feet. | 5:15-6:20 PM Intact | No Change |
| 2 | " | A2 - A3 | Yellow Flag | Intact | No Change |
| 3 | " | B Anchor - B2 | Yellow Flag | Intact | No Change |
| 4 | " | Across crack between B & C gauge sets | Wire & White Flags | Intact | No Change |
| 5 | " | C Anchor - C1 | Yellow Flag | Intact | No Change |
| 6 | " | C1 - C3 | Yellow Flag | Intact | No Change |
| 7 | " | C2 - C4 | Yellow Flag | Intact | No Change |
| 8(1) | 9-8-59 | West of "C" set of gauges. Pipe and tree wire indicator | Yellow Flag | | |

(1) Across a major joint-controlled crack 42 ft. N. 70° W. from C4 to pipe; 58 ft. N 15° E. from C4 to tree.

TABLE 2. WIRE-SLIDE INDICATORS ON CREST OF MADISON VALLEY SLIDE (Contd)

| WIRE NUMBER | 9-3-59 OBSERVATION | CONDITION OF WIRE & POINTS | 9-4-59 OBSERVATION | CONDITION OF WIRE & POINTS | 9-5-59 OBSERVATION | CONDITION OF WIRE & POINTS |
|---|---|---|---|---|---|---|
| 1 | Intact | No Change | Intact | No Change | Intact | No Change |
| 2 | " | " | " | " | " | " |
| 3 | " | " | " | " | " | " |
| 4 | " | " | " | " | " | " |
| 5 | " | " | " | " | " | " |
| 6 | " | " | " | " | " | " |
| 7 | " | " | " | " | " | " |

TABLE 2. WIRE-SLIDE INDICATORS ON CREST OF MADISON VALLEY SLIDE (Contd)

| WIRE NUMBER | 9-6-59 OBSERVATION | CONDITION WIRE & POINTS | 9-7-59 OBSERVATION | CONDITION OF WIRE & POINTS | 9-8-59 OBSERVATION | CONDITION WIRE & POINTS |
|---|---|---|---|---|---|---|
| 1 | Intact (Aerial Observation) | No Change | Intact | No Change | Intact | No Change |
| 2 | | " | " | " | " | " |
| 3 | " | " | " | " | " | " |
| 4 | " | " | " | " | " | " |
| 5 | " | " | " | " | " | " |
| 6 | " | " | " | " | " | " |
| 7 | " | " | " | " | " | " |
| 8 | | | | | Installed | Installed |

TABLE 2. WIRE-SLIDE INDICATORS ON CREST OF MADISON VALLEY SLIDE (Contd)

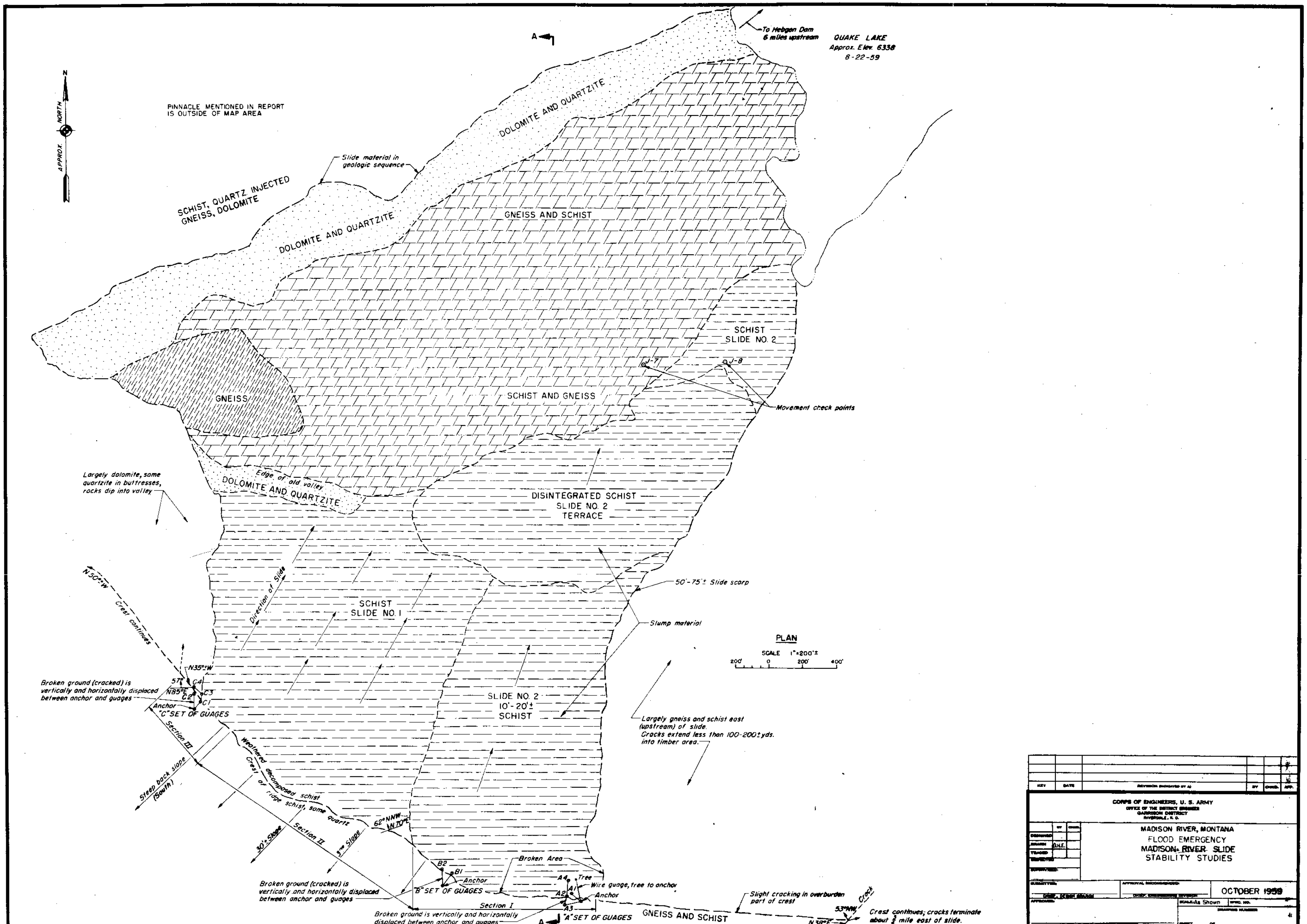
| WIRE NUMBER | 9-9-59 AERIAL OBSERVATION | CONDITION OF WIRE & POINTS | 9-10-59 AERIAL OBSERVATION | CONDITION OF WIRE & POINTS | 9-11-59 OBSERVATION | CONDITION OF WIRE & POINTS |
|---|---|---|---|---|---|---|
| 1 | Intact | No Change | Intact | No Change | Intact | No Change |
| 2 | " | " | " | " | " | " |
| 3 | " | " | " | " | " | " |
| 4 | " | " | " | " | " | " |
| 5 | " | " | " | " | " | " |
| 6 | " | " | " | " | " | " |
| 7 | " | " | " | " | " | " |
| 8 | " | " | " | " | " | " |

TABLE 2. WIRE-SLIDE INDICATORS ON CREST OF MADISON VALLEY SLIDE (Contd)

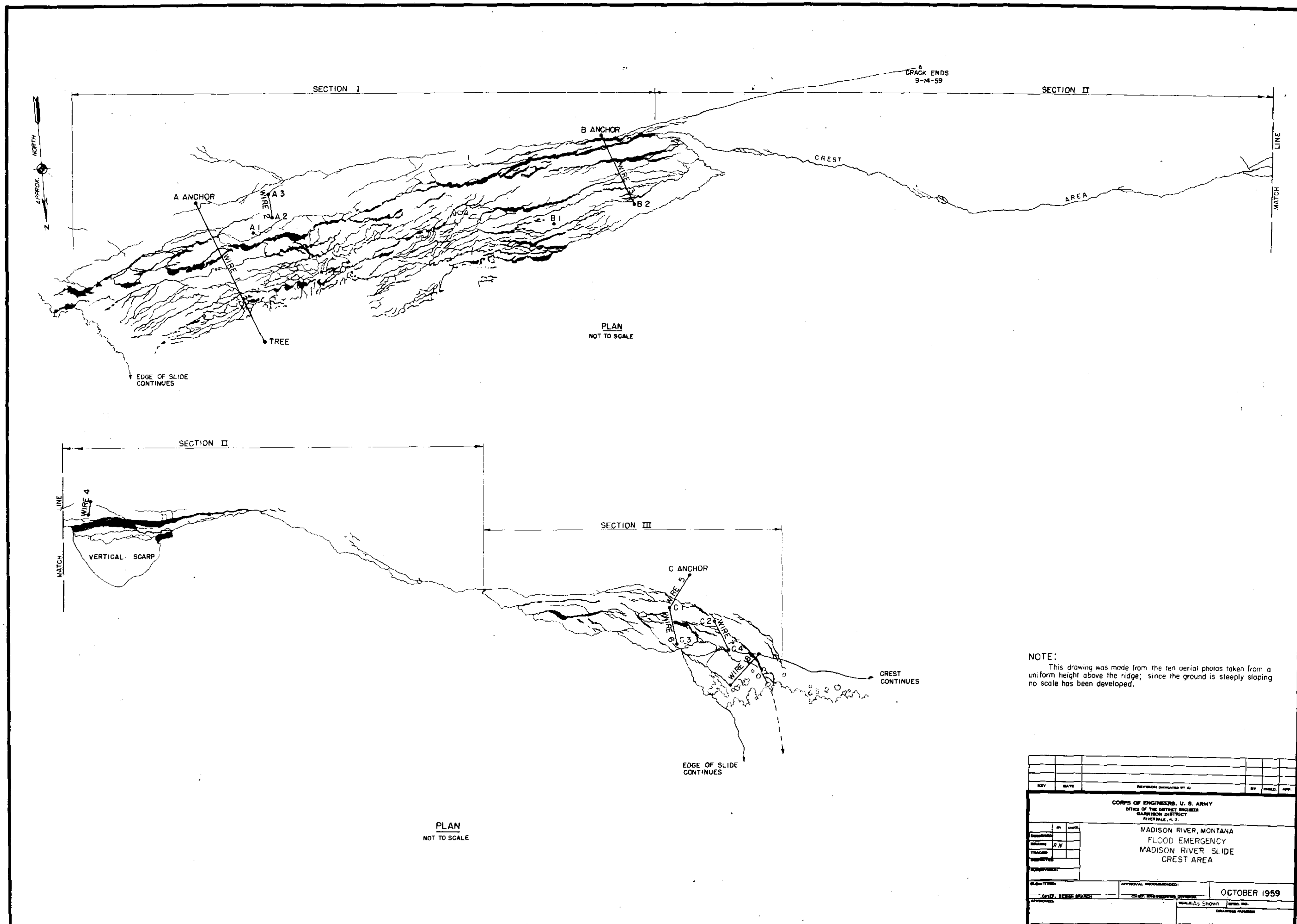
| WIRE NUMBER | 9-12-59 AERIAL OBSERVATION | CONDITION OF WIRES & POINTS | 9-13-59 AERIAL OBSERVATION | CONDITION OF WIRES & POINTS |
|---|---|---|---|---|
| 1 | Intact | No Change | Intact | No Change |
| 2 | " | " | " | " |
| 3 | " | " | " | " |
| 4 | " | " | " | " |
| 5 | " | " | " | " |
| 6 | " | " | " | " |
| 7 | " | " | " | " |
| 8 | " | " | " | " |

TABLE 2. WIRE-SLIDE INDICATORS ON CREST OF MADISON VALLEY SLIDE (Contd)
(Data Added Subsequent to Report)

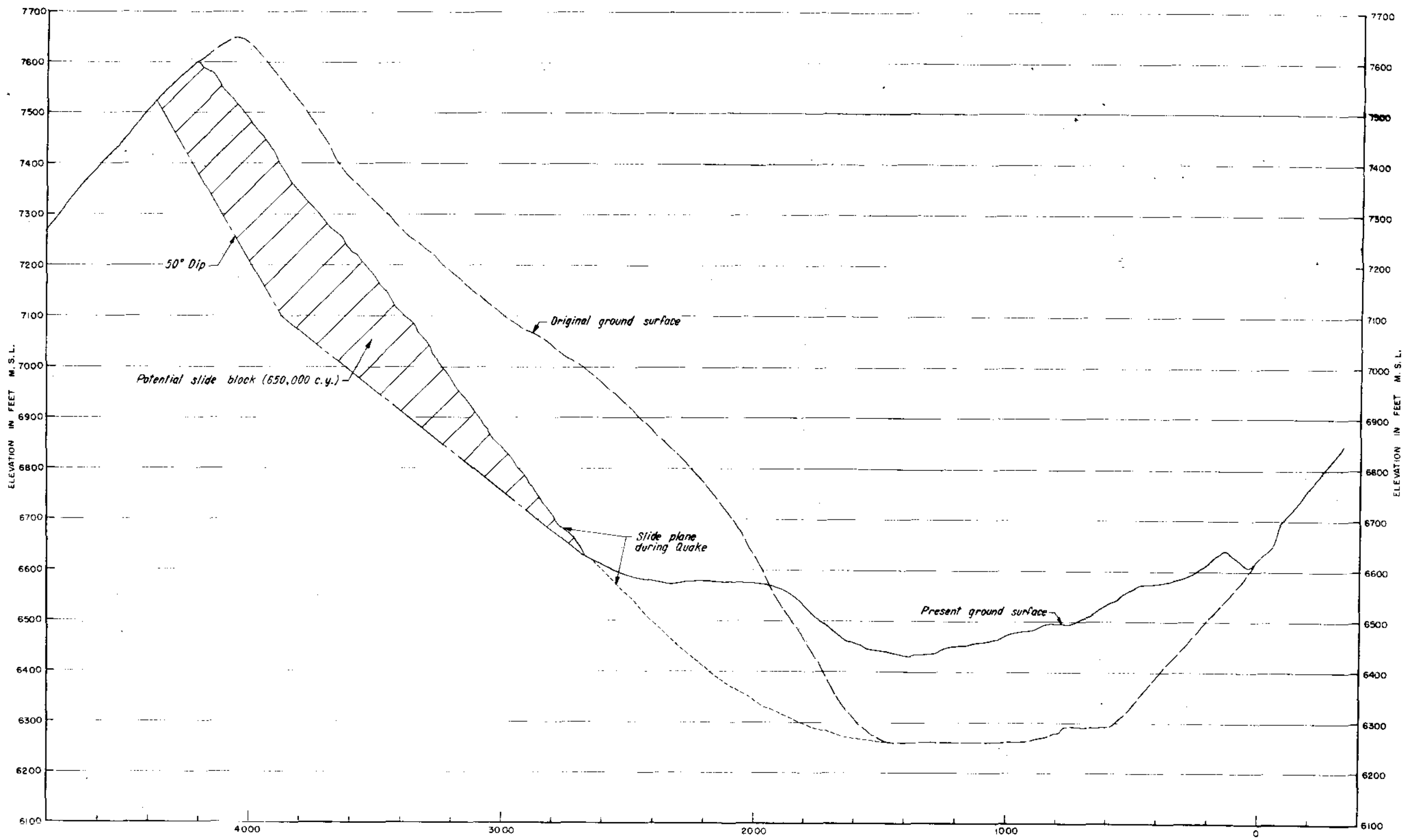
| WIRE NUMBER | 9-17-59 OBSERVATION | CONDITION OF WIRE & POINTS | 10-21-59 OBSERVATION | CONDITION OF WIRE & POINTS |
|---|---|---|---|---|
| 1 | Intact | No Change | Intact | Tight |
| 2 | " | " | " | Loose |
| 3 | " | " | " | Tight |
| 4 | | Not Checked | | Not Checked |
| 5 | " | No Change | " | Loose |
| 6 | " | " | " | Loose |
| 7 | " | " | " | Loose |
| 8 | " | " | Tight Offset to West | |




APPENDIX IX KNIGHT-CURTISS REPORT FIG. I




APPENDIX IX KNIGHT-CURTISS REPORT FIG. 2




SECTION A-A

SLIDE

SCALE HOR. 1" = 200'
VERT. 1" = 100'

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
GARRISON DISTRICT
RIVERDALE, N. D.

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
STABILITY STUDIES
SECTION A-A

DRAWN JPB

OCTOBER 1959

SCALE: As Shown

APPENDIX IX KNIGHT-CURTISS REPORT FIG. 3

# MADISON RIVER, MONTANA
# REPORT ON
# FLOOD EMERGENCY
# MADISON RIVER SLIDE

## APPENDIX X

## MADISON SLIDE SUBSURFACE EXPLORATION AND OBSERVATIONS

BY C. V. JOHNSON

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX X

Madison Slide Subsurface Exploration
And Observations
By C. V. Johnson

MADISON SLIDE SUBSURFACE EXPLORATION AND OBSERVATIONS

1. General. The earthquake of 17 August 1959 in southwestern Montana and the Yellowstone Park caused a rock and earth slide which completely blocked the narrow Madison River Canyon and formed a natural dam. The immediate problem at hand was to lower the crest of the slide and provide a spillway to safely conduct the overflow across the slide to the river below. Subsurface investigations usually precede construction, but in this emergency, construction work preceded investigations. The work of cutting down the crest of the slide was started immediately and the spillway alignment and grade was adjusted to meet field conditions as construction progressed. The slide, from surface observations, appeared to be predominantly rock but as work progressed the need for subsurface data became evident even though this data would not be available until emergency work was well along or complete. A program of subsurface exploration of the slide was decided upon on 31 August 1959. The purpose of the program was to determine if possible the type of subsurface material in the slide adjacent to the rock lined spillway and to determine the hydrostatic pressure gradient through the slide. It was considered that the drilling would be very difficult and the program, as originally set up, provided for drilling through the slide if possible, or at least 10 feet below the water surface level. One hole was located at the downstream toe of the slide; the purpose of this hole was to determine the depth to bedrock and the composition of the alluvial valley fill.

The materials encountered in the subsurface exploration of the slide were different than anticipated from surface observation. A considerable amount of soft disintegrated rock and earthy material was encountered which drilled very easily and the rock formations found were usually schist or gneiss which would break easily under impact. This rock appeared sound but must have been overstressed by the slide as it would break down under impact such as drilling or being moved by a dozer. Most of the rock was drilled and recovered by drive sample methods which furnished a complete record of all materials encountered. The samples were altered due to the impact of driving but by the proper interpretation of all drill data, such as difficulty in driving for sample or driving casing, the type and condition of the rock could be determined. Material containing considerable earth or disintegrated rock drilled easily while rock which had slid en masse and was fairly sound drilled very hard. Rock bits were used when the material was too hard to penetrate with a drive barrel or for drilling a considerable distance beyond the end of the drill casing. When drilling beyond the end of the casing mud was used to hold the hole open. The use of rock bits was held to a minimum because with this method of drilling, samples of the material were obtained only by bailing the mud sludge from the bottom of the hole.

2. Review of Drilling. The attached drawing plate 1 contains the drill logs of all the slide subsurface explorations. The following subparagraphs briefly review the actual drilling operation for each location and should be helpful in interpreting the drill logs.

a. Piezometer No. 1. Drilling was started on 3 September 1959 on piezometers No. 1, located at station 26+86 and 175 feet to the right of the spillway centerline. The initial drilling was in fractured and disintegrated schist and gneiss which drilled much more easily than anticipated. Water was encountered at 46.4 feet or approximately 15 feet below the lake level at the time. One of the purposes of drilling was to check the hydraulic gradient through the slide; therefore, after reaching a depth of 63 feet, drilling was discontinued so the drill rig could be moved to the next proposed location downstream.

b. Piezometer No. 3. Drilling started 4 September 1959 on piezometer No. 3 at station 19+00. The material at this location drilled harder than at the location of piezometer No. 1 upstream and appeared to be gneiss which had more strength but shattered under the impact of the drive barrel. More large pieces were encountered in this hole near the surface and the casing drove quite hard. At about 50 feet it was learned that the eight-inch casing had broken about 20 feet below and ground surface. This made progress difficult but drilling continued as far as possible in the hope of encountering the saturation line. At about 72 feet it was impossible to continue drilling, as the casing was becoming offset at the break. A two-inch piezometer pipe was installed and driven about three feet ahead of the eight-inch casing. The upper section of eight-inch casing was recovered and the drill rig moved to the next location at station 9+40. At the time the piezometer was installed at 11 a.m. on 6 September the hole was dry at elevation 6355.0. Six hours later, when the pipe was sounded, there was 0.8 foot of water in the pipe and by the next morning the water surface had risen another four feet.

c. Piezometer No. 2. The surface material at station 9+40 was composed of large angular pieces of rock. At a depth of about 20 feet a large boulder was encountered which necessitated the use of a rock bit. After this boulder was broken and passed, the material appeared to change to schist and gneiss which drilled about the same as in the previous hole. The color, however, was more yellow than at the other locations. The drive barrel broke up most of the material into rock flour and rock fragments, with rock flour predominating. The material drilled fairly hard until what appeared to be alluvial material was encountered at a depth of 70.5 feet or elevation 6372.3, which was slightly higher than anticipated (about 8 feet). The material encountered below the 70.5-foot depth appeared to be a mixture of slide and alluvium and was so confusing that the inspector saved samples of almost every drive for later analysis. It has since proved to be very difficult to analyze the materials in these samples. For example, the samples taken at 97.5 feet and 99.0 feet appeared to be definite slide material and were powder dry when recovered, while samples at 94.5 feet and 102 feet were completely saturated. The material at a depth of 102.0 feet appeared to be a sandy silt, very dark in color, resembling surface soil. Drilling continued to a depth of 105 feet which was 27 feet below original ground as interpreted from a topographic map of the area before the slide and several feet below the river bed at this location. A two-inch piezometer was installed with the screen in the coarse pervious material above the elevation where the apparently alluvial material was encountered.

d. Piezometer No. 4. Due to the large discharge of toe seepage it was advisable to move the proposed location of piezometer No. 4 downstream and locate it on the river bank along side of the road. The initial drilling was through road fill and talus material to the 17-foot depth, where alluvial material was encountered. The alluvial material consisted of gravels and sands which were in general angular with some rounded particles. Some cobbles up to five and one-half inches in size were encountered. The material appeared to be a mixture of quartz, schist, and gneiss particles. Occasionally a chunk of material would be found in which the gravel and sand were imbedded in a matrix of tough clay. At 89 feet a material was encountered which was probably disintegrated bed rock. The drive barrel would not penetrate, and it was very resistant to the rock bit. The material recovered in the bailer appeared to be a fine sandy material which furnished a cusion to the rock bit. At 93.5 feet solid bed rock was encountered which drilled faster and sharp angular cuttings were obtained when the hole was bailed. Drilling continued into bedrock to a depth of 105 feet to make sure it was not a large boulder. A piezometer with 10-foot screen was installed at this location to a depth of 63 feet, which coincided with some of the more pervious material encountered.

e. Piezometer No. 1A. At the completion of piezometer No. 4 the drill rig was moved to a location approximately 12 feet upstream from piezometer number 1 and a new hole was started using 10-inch casing initially, and reducing successively to 8-inch and finally 6-inch casing. The three sets of casing were necessary in order to drill to a depth at least equal to the original river valley. The first 60 feet was the same as the previous hole. The material to about 46 feet appeared to be a crushed rock. Below this depth there were traces of soil and from the 65-foot depth (elevation 6403.0) the material was mixed with considerable clay and soil. From a study of the talus slopes near the top of the slide it is believed this material was a talus alluvium. Pieces of rock were recovered that indicated water action and the gravel imbedded in the clay were somewhat rounded. This same general type of material continued to 181 feet (elevation 6287.0). At this depth a schist rock was encountered which acted as solid rock. Samples were obtained with a four-inch sample barrel but a rock bit was used for most of the drilling in this formation and it was drilled open hole. There was evidence of cracks and shattering but in general it drilled as solid rock except for five feet between 214 and 219 where a very compact dry reddish clay was encountered. After drilling through the clay with a drive barrel, drilling continued with rock bit to 237 feet which was the limit of the cable on the drill rig. This depth was approximately 15 feet below the river bed at this location and 25 feet below the original ground elevation as determined from a topography map of the area before the slide. It was evident that the slide had gouged out the original river valley alluvium, as the hole ended in what was presumed to be schist rock from the slide.

While dolomite rock was being hauled from the high ridge on the north side of the slide, great quantities of sand and gravel were noted which seemed to be alluvial in character. It was presumed that the slide had gouged out at least a portion of the valley alluvials and carried them up to the high ridge on the north side of the valley. This presumption tends to be confirmed by the fact that slide material was found below the elevation where natural ground should have been found, (if undisturbed). A piezometer pipe was installed at P-1A site with bottom of screen at elevation 6341 (127-foot depth). This piezometer gave water surface readings which were about 10 feet higher than piezometer No. 1 which was installed at elevation 6405 (63-foot depth), at this same location.

f. Piezometer No. 3A. Piezometer No. 3A was started at station 20+40 and 214 feet right of centerline to replace piezometer No. 3 which had been destroyed, and to obtain subsurface information through the entire slide. The initial material encountered was essentially the same as in piezometer No. 3 and continued to about elevation 6339.2 (109-foot depth). From 109 to 153 feet the material was clay, sand, and gravel which had alluvial characteristics and was probably from talus slopes. Below this depth to 209 feet the material consisted mainly of clay conglomerates of green and red decomposed schists. From 209 to 215 feet clayey gravels and sands were encountered which seemed to be alluvial in character, and were presumed to be from the original river flood plain. The last 30 feet of the hole had been drilled open hole and as this material would not stand open the hole was considered complete at 215 feet (elevation 6233.2 or 32 feet below the estimated original ground surface). A piezometer pipe was installed to elevation 6300.6 which was above the clays and in pervious gravelly material.

g. Intake Channel Test Holes. During the initial excavation for the intake channel for the spillway considerable rock material was encountered. As the spillway lowering operation was started this material was again encountered and as a result it was decided to drill three shallow test holes to determine the depth and extent of this formation. The tentative locations decided upon were at stations 29+50, 31+50, and 32+50. A berm for drilling was excavated as close to the channel as possible and the holes at 29+50 and 32+50 were drilled from this berm. This drilling was more difficult than at any of the other locations drilled. The rock formation for the most part seemed to be quite continuous and was judged to be a mass of schist and gneiss rock which was shattered but had not been disturbed enough to produce a bulking effect. It was difficult to drive ahead of the casing as the drive barrel tended to deflect and follow the fractures of the rock. The hole at 32+50 drilled harder than any hole drilled. At a depth of 50 feet the eight-inch casing drove so hard that it was necessary to change to six-inch casing to complete the hole. The drilling seemed to ease up below 60 feet (elevation 6404.8) but the rock formation was continuous to the depth drilled, elevation 6382.8. The hole at 29+50 was drilled to a depth of 80.5 feet, (elevation 6379.5) using eight-inch casing and six-inch drive barrel. The material drilled through was all judged to be shattered schist and gneiss with some fairly large pieces encountered at times.

After completing the holes at 29+50 and 32+50, construction activities made it necessary to offset the hole at 31+50 a total of 300 feet to the right of the channel centerline. Prior to moving to this location it had been noted that the surface rock at 31+50 was large and blocky and it was anticipated that the initial drilling would be very difficult. At the new location the material was entirely different and it was estimated that 80 percent of the material above a depth of 40 feet was earthy material and below this depth the material was mainly schist and gneiss which drilled easily. This drilling furnished evidence that the rock formation extended to the right at the lower elevations but it was not the resistant rock encountered in the vicinity of the spillway. The above drilling indicated that at the location of the spillway channel a fairly resistant rock formation would be encountered to the depth of the contemplated channel lowering.

3. Channel Face Studies. As the lowering of the spillway progressed observations made of the material excavated and the side slopes of the channel furnished a record of the rock formation encountered. The channel was excavated by draglines working on a berm on the right side of the channel. The left channel wall was washed clean as excavation progressed and prior to bank sloughing the rock formations were clearly visible. As discharges increased and the side slopes became higher bank scour on the left became excessive and this bank receded as much as 50 to 100 feet in places. After the sloughing started much of the formation was covered by a thin covering of earthy material. The right bank was excavated in the dry with shovels, and in general most of the slope was covered with an overlay of shattered rock and soil which made it difficult to determine the type and characteristics of the rock formation encountered. During the lowering operation maps were made every few days of the left channel formations, and notes were made of the type of rock excavated from the channel and the right bank. As the spillway lowering operation neared completion a study was made of all the data collected and a generalized geologic map was made showing the rock formations encountered in the spillway channel (attached drawing plate 2). The water surface profile for 25 October indicates the lower limit for which data was available for plotting the actual rock and soil conditions encountered. Record pictures of the channel walls were taken on 23 October when the channel was within 15 feet of ultimate lowering. Bank sloughing was quite severe at this time and the rock formation was partially obscured by a covering of dirt. At this time it was evident that the rock formation was probably being flanked to the left at one location. This was noted at 31+50 where earthy material was exposed where rock had been noted prior to excessive sloughing. There are included with this report record pictures taken on 23 October 1959, which show the material exposed in the channel walls as the spillway lowering operation was nearing completion. These pictures and the inclosed profile indicate that in general rocky material prevails in the upstream one-fourth of the spillway which should resist erosion and act as a control and prevent future rapid scour of the upstream spillway area, while the downstream area consists of earthy material with numerous boulders intermixed.

4. Mechanical Analysis of Slide Material. There is inclosed a mechanical analysis of typical earthy material obtained along the spillway channel. (Attached drawing plate 3.) This sample was intended to represent only the material under the 12-inch size.

A Michigan loader was used to obtain the sample and a representative portion weighing 1,370 pounds was analyzed for size. This sample indicated that over 50 percent of the material considered earthy would pass a 1-1/2-inch screen. This sample was probably fairly representative of the material in the downstream portion of the slide, which eroded very easily when subjected to water action.

5. Observation of Piezometers. Piezometer pipes were installed in all the initial drill holes to determine the hydraulic gradient through the slide. There is inclosed a drawing (plate 4) which summarizes piezometer observations through 22 October 1959. The individual record of each pipe is indicated on individual graphs and the hydraulic gradient for two different dates is indicated on the profile. The profile for 7 September 1959 was the earliest date that data was available to determine the gradient through the entire slide. This hydraulic gradient is of more value for studying and analyzing the composition of the slide than later profiles after the water started flowing over the spillway. After the flow started over the spillway water entered the slide along the entire length of the channel and tended to raise the gradient.

A study of the initial hydraulic gradient through the slide indicates that the upstream portion was more pervious than the lower portion of the slide. The hydraulic gradient had very little slope from the lake to the piezometer at station 26+86 and beyond this point the slope was steeper. Later during channel lowering operations it was verified that the upstream portion of the spillway was rock which had slid en masse and was crushed and fractured to make it very pervious. The downstream portion of the slide was composed of material described as earthy which was less pervious than the rocky material upstream. The hydraulic gradient through the lower portion of the slide indicated that there were no radical changes in the slide material, such as areas of clay which would act as a core.

Measurements were made of the seepage through the slide prior to and after discharge through the spillway. The seepage discharge increased very rapidly the last two days before discharge over the spillway indicating that it had taken approximately 20 days to soak up the material and establish seepage equilibrium through the slide. Measurements after this date indicated the seepage discharge probably averaged about 150 c.f.s. The seepage flows were clear and no movement of fines was observed. The observation of piezometers during the spillway lowering operation showed that the saturation line lowering coincided with the reduction in lake elevation, indicating that the slide material was free draining.

6. <u>Movement Observations</u>. A movement observation program was decided upon on 28 August 1959 at the same time that the drilling program was formulated. There was a difference of 300 feet in vertical elevation between the proposed spillway channel and the high point of the slide. It was conceivable that some movement could still be taking place in the slide and also it was desired to check for movement when water was first discharged over the spillway and the mass became saturated. There is attached a summary drawing, plate 5, which shows the movement points as installed. This drawing also contains the tabulated results of all observations made to the end of spillway lowering operations.

The reference points for the movement survey were located on stable ground upstream and downstream from the slide. The movement point J-4 ("key point") was the only point on the slide where both reference targets were visible. The movement program was designed to use the monument at this location as the "key point," and it was necessary to "wiggle in" with a transit to establish this point on line. After establishing the "key point" on line the movement points in each direction were set by sighting on the target at that end of the line. For all subsequent checks for transverse movement it was necessary to "wiggle in" on line at the location of the "key point" and then check the points in the same manner they were established. The program was designed so that any major movement would show up as transverse movement. However, elevations were run to all monuments and the distances between them were chained. The purpose of this was to furnish a check on the actual movement if the transverse movement check should show that significant movement was occurring.

The total transverse movement of the "key point" from the time observations started on 7 September 1959 to 23 October 1959 was 0.55 feet downslope (south) toward the spillway. This movement was not considered excessive, as it was only natural that consolidation of the slide mass and settlement of the foundation alluvium should take place after the disturbance and change of loading that took place with the slide. Definite plans were made to have a level check of all monuments before the end of construction, but engineering activities were phased out before this was possible. On 29 October 1959, which was the last day of operations, a check level run was made from BM 45A-1 to a temporary BM on the slide that represented the datum in use on the slide at the end of operations. The check elevation was 0.69 foot lower than the datum elevation in use. This could be interpreted as the average settlement of the slide from the time the original slide datum was established to the time of the check. The level run was not closed back to the starting point so can be used only as in indication of the probable settlement that occurred.

7. Stability Observations. No analytical calculations or tests of materials were made to determine the stability of the slide. Observations made are merely a record of the actual physical conditions of the slide during the many phases of construction, which serve as an indication of the probably stability of the slide. During the spillway lowering operation the left side of the channel was eroded down as steeply as the banks would stand. Lateral erosion caused the banks to recede as much as 100 feet in some locations. During this operation the material tended to slough off in thin slivers and no major failure of a section of bank was observed. The final cross sections show that most of the side slopes on the left side were steeper than 1 on 1 and in some cases (station 29) the slope was 1/2 foot horizontal to 1 foot vertical and the height of the bank exceeded 80 feet. Most of the slopes were between these two limits.

During the early part of October considerable erosion took place on the right side of the channel when the water bypassed the rock terraces in the channel and slopes over 100 feet in vertical height were exposed, which were judged to be steeper than 1 on 1. This erosion took place so fast that seepage water was observed issuing from the slope 10 to 20 feet above the base. This seepage would tend to reduce the stability of the slope but no major sloughs were observed. The material caved rapidly but came down in thin slivers. After the erosion was arrested these bluffs stood for several weeks with no further major sloughing.

The so-called earthy material composing a large share of the slide appears to act as a granular material and can be compared to the talus slopes on the nearby mountains which stand on steep angles of repose. Seepage discharge observations indicate that this material must stabilize into a natural filter very quickly as no fines are carried by established seepage sources. As a result of these observations it is believed that the slide is relatively stable and the danger of slides which could block the spillway channel are quite remote.

8. Summary.

a. The materials encountered in the subsurface explorations of the slide indicated that the slide was composed of more earthy material and soft weak rock than had been anticipated from surface observations.

b. Most of the rock encountered in drill holes adjacent to the spillway was schist and gneiss. Most of the rock could be drilled with a churn drill using a drive barrel for sampling. The rock appeared to have been stressed to the point where additional impact caused it to shatter.

c. The upstream one-fourth of the spillway (intake portion) was composed of massive schist and gneiss rock which had moved en masse. The rock was badly cracked and fractured but had not been disturbed enough to produce bulking and was resistant to water erosion. A great share of this material had to be removed by mechanical means during the spillway lowering operation.

d. The material in the downstream portion of the spillway consisted of a considerable portion of earthy or disintegrated rock which was very susceptible to water erosion. Numerous boulders were intermixed with this material, and tended to pave the channel as erosion progressed.

e. Piezometer observations indicated that the slide material was free draining with no impervious cores or blocks. The saturation line was well below the surface of the slide. The hydraulic gradient indicated that the upstream portion of the slide was more pervious than the lower section and this was verified in the spillway lowering operation.

f. Movement observations made on the slide indicated some downslope transverse movement and a level check indicated some vertical settlement. In comparison to the movement experienced after completion of construction on large dams such as Garrison and Fort Peck, this movement was probably the normal movement to be expected after the change in foundation loading and the disturbance of material caused by the slide.

g. During the spillway lowering operation high vertical banks standing on slopes steeper than 1 on 1 were observed. These banks tended to slough off in thin slivers of material as lateral erosion progressed and no major sloughing was observed. It is believed that the spillway channel will be quite stable and chances of a major slough are very remote.

C. V. Johnson

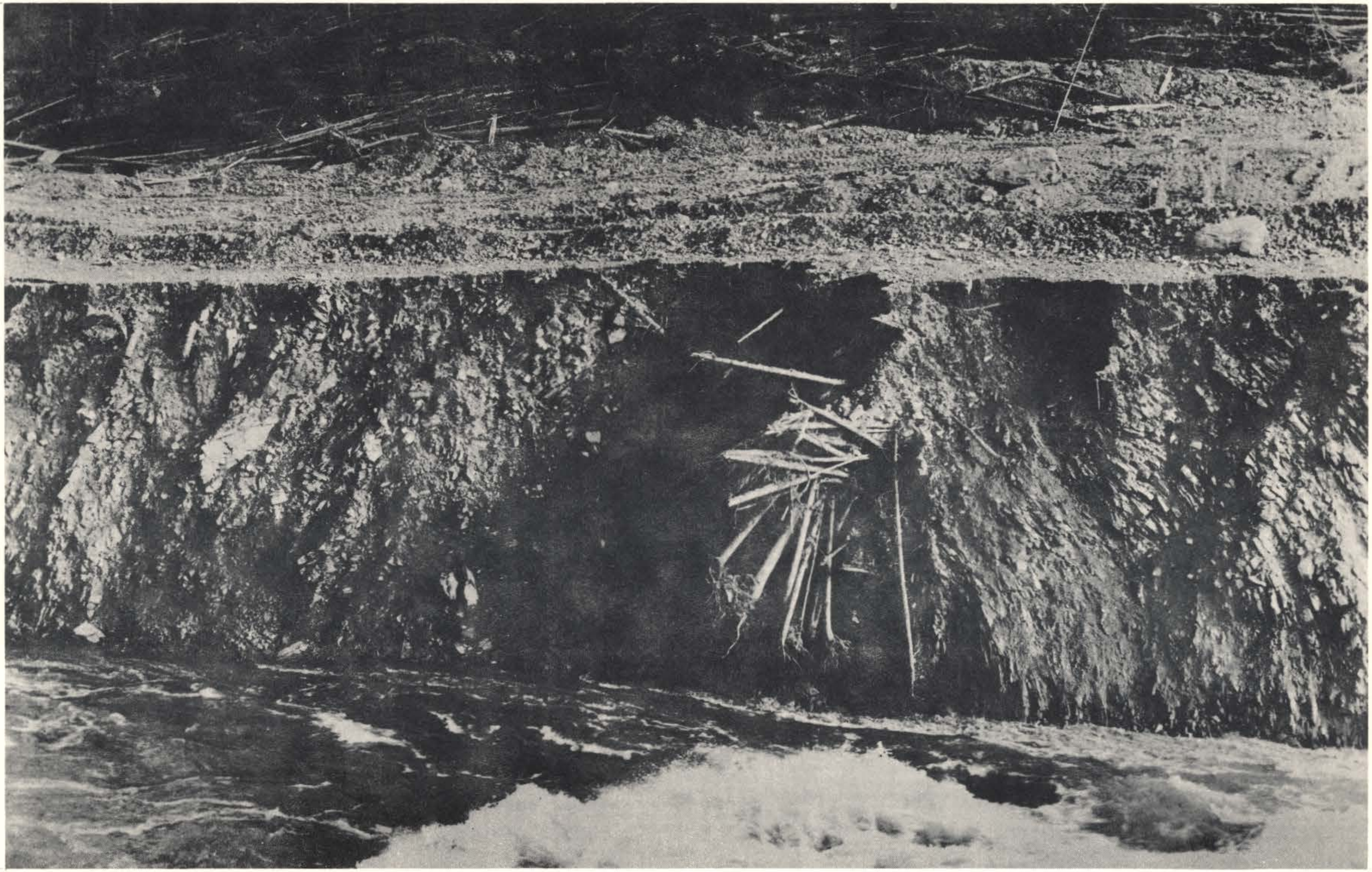

**FLOOD EMERGENCY — MADISON RIVER SLIDE**
U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA

View of slide from station 12 upstream to earthquake lake taken 21 October 1959. Number and arrows indicate the area covered by photos on the following pages. (Photo #1)

**FLOOD EMERGENCY — MADISON RIVER SLIDE**

**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

Oblique view of slide spillway taken from waters edge at station 35 looking upstream to lake entrance. View shows the rock and soil conditions of the left bank at this location before the start of bank sloughing from lateral erosion. Water surface of lake approximately 6412. Photo taken 23 October 1959. (Photo #2)



**FLOOD EMERGENCY — MADISON RIVER SLIDE**

**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

Oblique view of slide spillway taken from station 33 right bank looking upstream showing soil and rock formation of left bank. Water surface approximately elevation 6404, (top of bank 6450). Photo taken 23 October 1959. (Photo #3)


**FLOOD EMERGENCY — MADISON RIVER SLIDE**

**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

Oblique view of slide spillway taken from station 32 right bank looking upstream to station 34 left bank, showing the rock and soil conditions. Top earthy material tended to cover the rock formation as lateral erosion progressed. Water surface at station 34 approximately 6404. Photo taken 23 October 1959. (Photo #4)

**FLOOD EMERGENCY — MADISON RIVER SLIDE**

**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

View looking at station 30 on left bank of slide spillway showing typical rock formations encountered in the upstream area during early stages of spillway lowering operations. Photo taken 13 October 1959. See photo #6 taken 23 October 1959 at same location, which shows massive rock formation becoming less apparent as lateral erosion progressed. **(Photo #5)**

**FLOOD EMERGENCY — MADISON RIVER SLIDE**

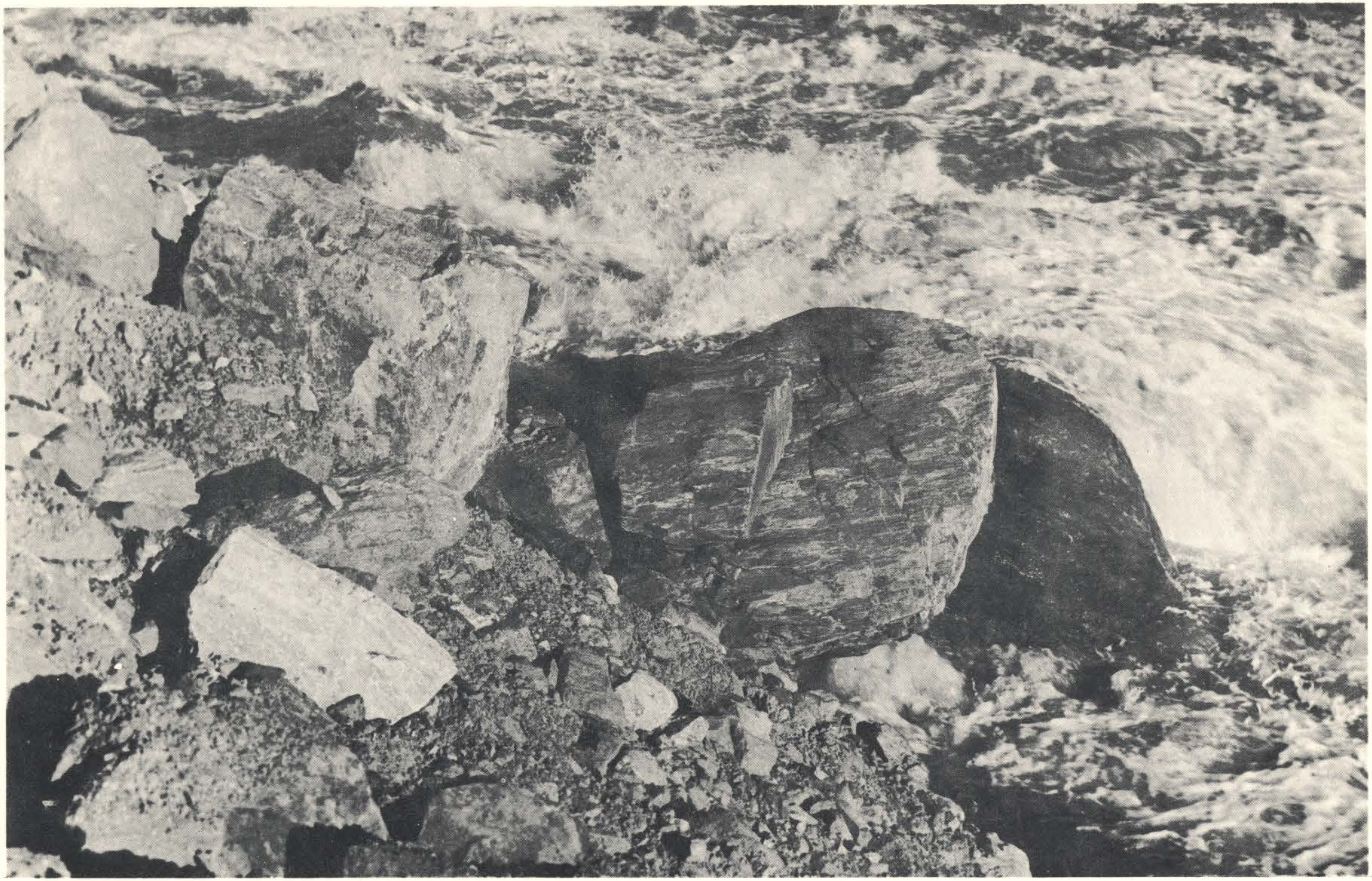
**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

Oblique view of slide spillway taken from station 30 right bank at waters edge looking upstream showing rock and soil conditions of left bank. Lateral erosion was extensive at this location and rock formation became less apparent as erosion progressed. Photo taken 23 October 1959. (Photo #6)

## FLOOD EMERGENCY — MADISON RIVER SLIDE

U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA

Oblique view of slide spillway taken from station 28 right bank at waters edge looking upstream with station 32 marker showing in picture. Picture shows rock and soil conditions of left bank. Rock formation shows through the light covering of dirt in the foreground. Water surface at station 30 approximately 6397 at time of picture. Photo taken 23 October 1959. (Photo #7)



**FLOOD EMERGENCY — MADISON RIVER SLIDE**
**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

View showing the large gneiss rock which were dragged out of channel at station 26 to 26+50. Channel constricted at this location. Photo taken 23 October 1959. (Photo #8)

**FLOOD EMERGENCY — MADISON RIVER SLIDE**
**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

View of right bank at station 26 showing the blocky rock encountered at this location. Photo taken 23 October 1959. (Photo #9)


**FLOOD EMERGENCY — MADISON RIVER SLIDE**
**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

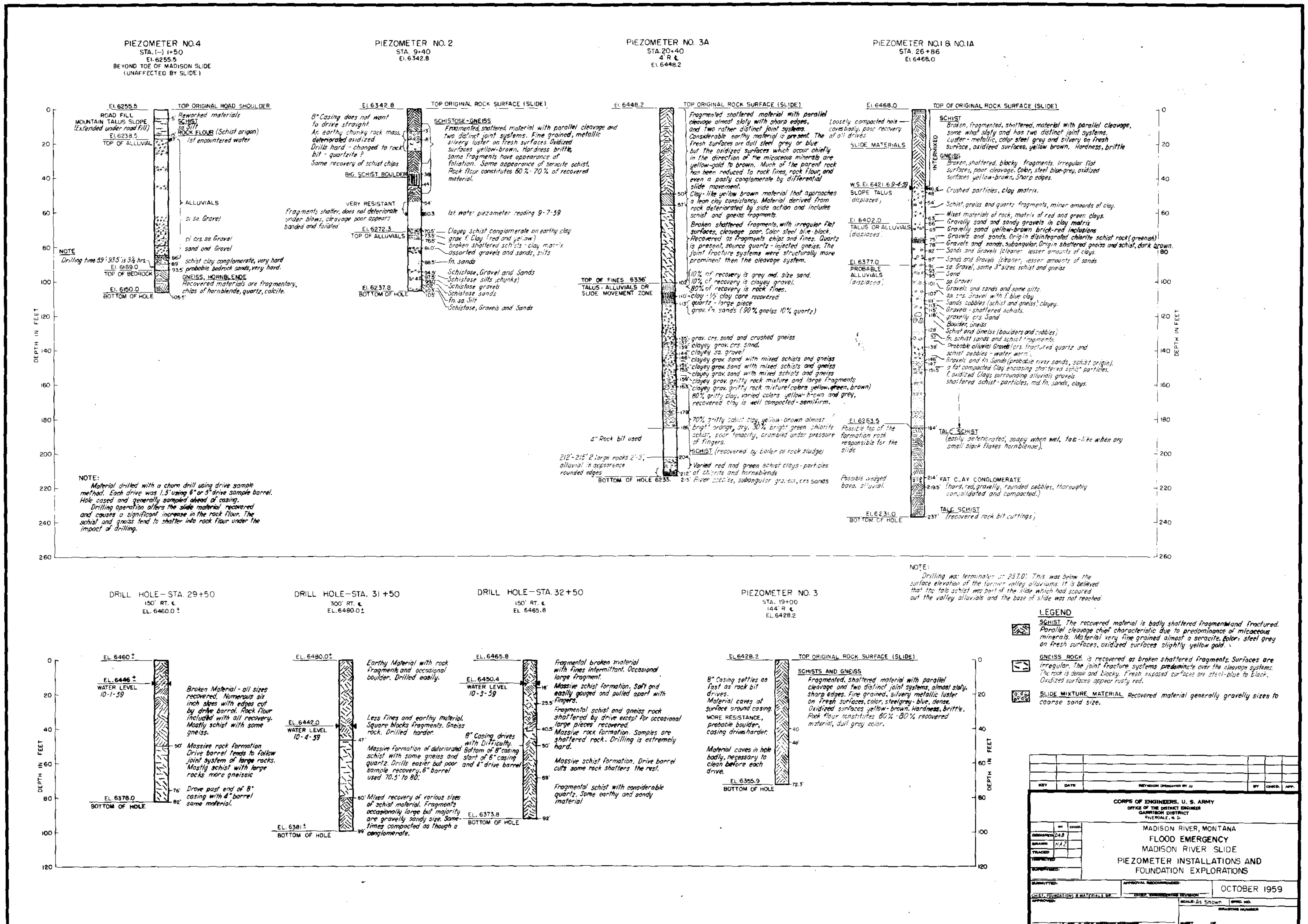
Oblique view of slide spillway taken from station 31 right bank at waters edge looking downstream at station 30 marker showing rock and soil conditions of right bank. Right bank was shovel excavated and most of rock formation covered with layer of loose rock and dirt. Note rock formation visible in several locations. Photo taken 23 October 1959. (Photo #10)

**FLOOD EMERGENCY — MADISON RIVER SLIDE**
**U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA**

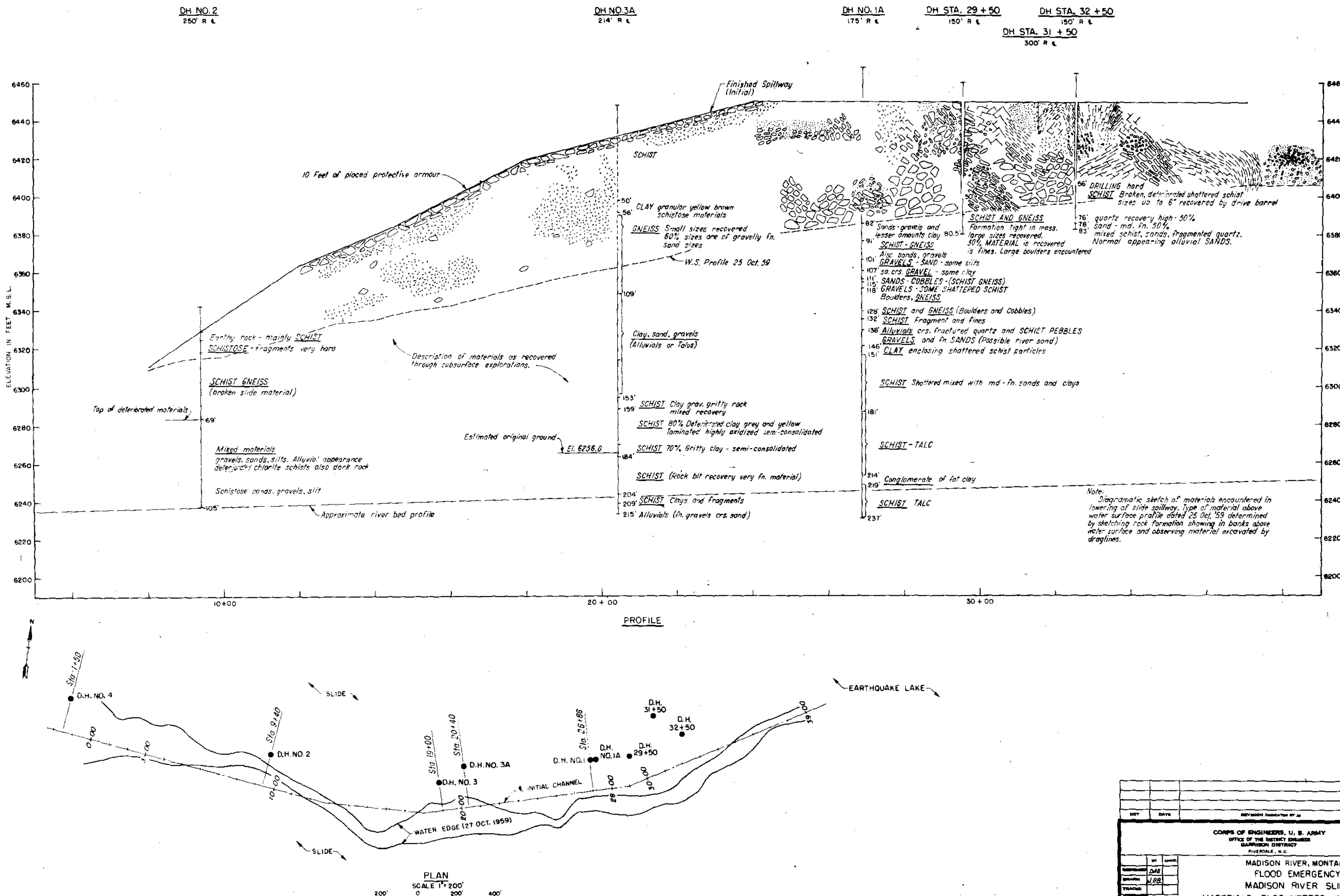
Panoramic view of right bank of slide spillway channel walls from approximately station 16 and downstream. Excessive lateral erosion occurred on right bank when water bypassed rock terraces in channel. Typical of material encountered in downstream reach of s.illway. Photo taken 13 October 1959. **(Photo #11)**

**FLOOD EMERGENCY — MADISON RIVER SLIDE**
U.S. ARMY ENGINEER DISTRICT, GARRISON, CORPS OF ENGINEERS, RIVERDALE, NORTH DAKOTA

Oblique view of slide spillway taken from station 19 right bank looking upstream showing rock and soil conditions of left bank. Material "Earthy" with occasional boulders and very susceptible to erosion. Typical of downstream reach of spillway. Light bank at top the original 10 foot rock lining of spillway. Photo taken 23 October 1959. (Photo #12)




APPENDIX X PLATE I




| KEY | DATE | REVISION INDICATED BY | BY | CHKD. | APP. |
|---|---|---|---|---|---|

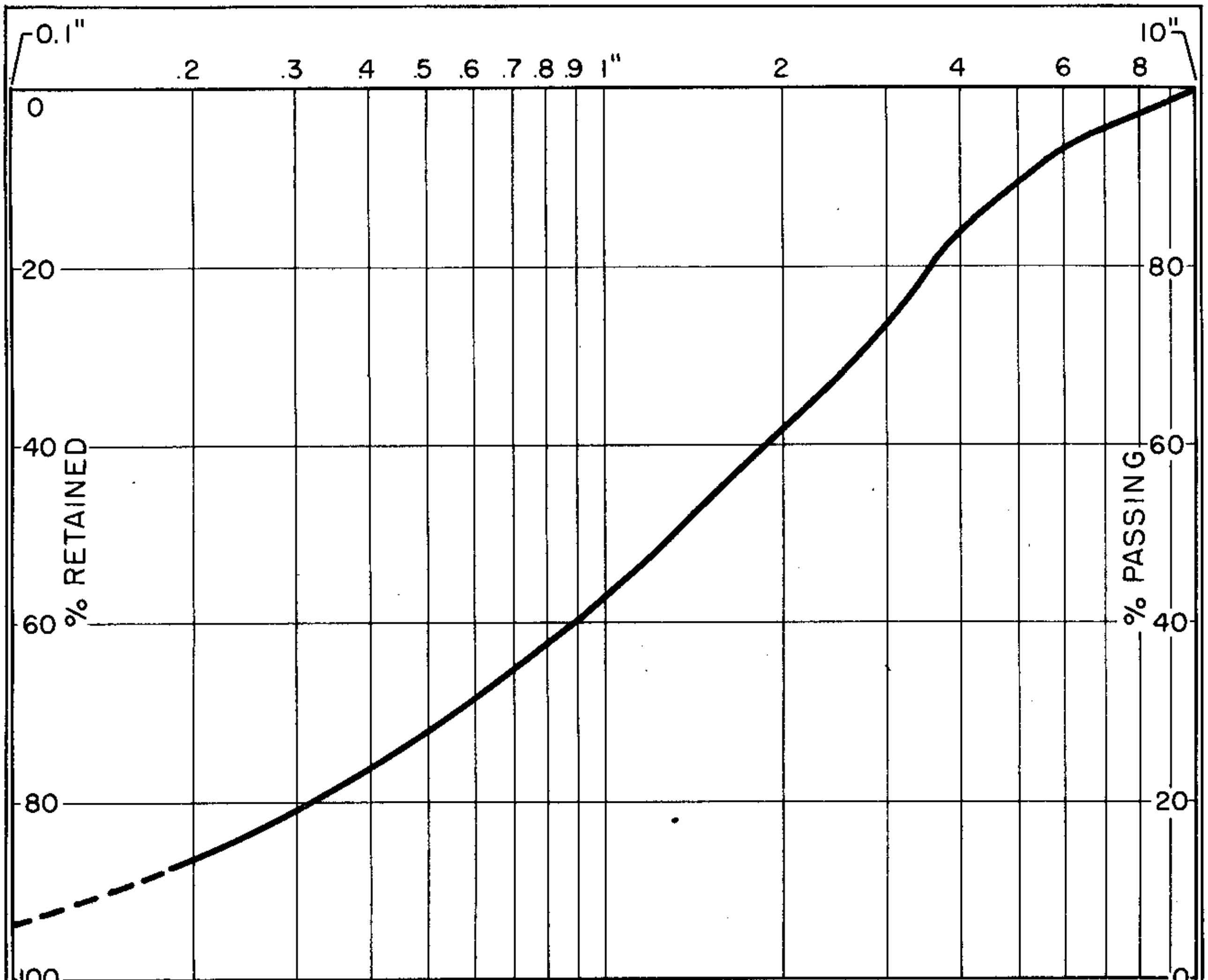
CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
GARRISON DISTRICT
RIVERDALE, N.D.

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
MATERIALS ENCOUNTERED IN SPILLWAY AND DRILL HOLES

DESIGNED DAS
DRAWN JRB

SCALE: As Shown

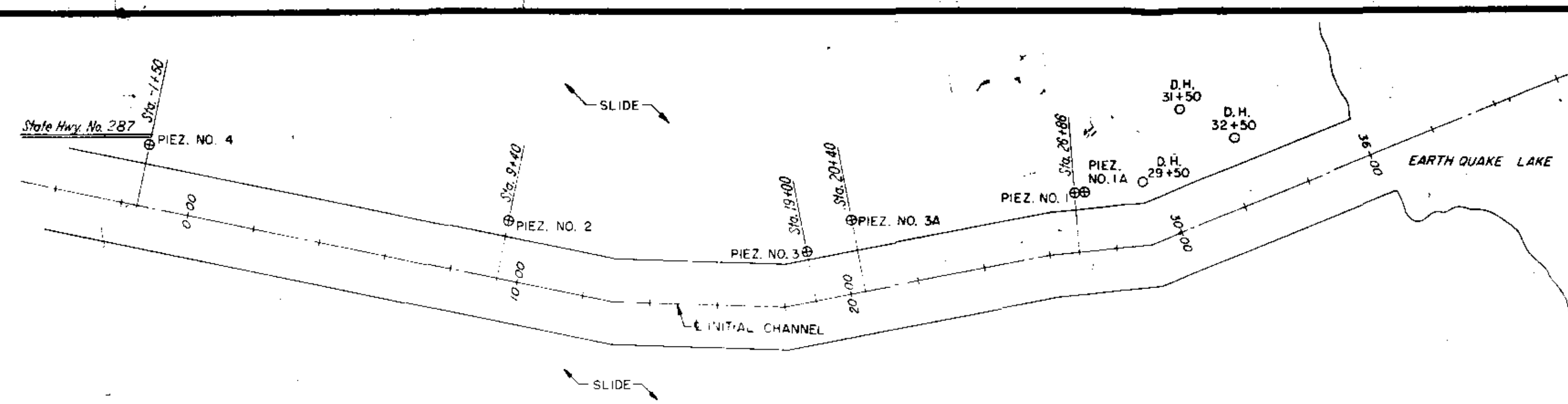
APPENDIX X PLATE 2




NOTE

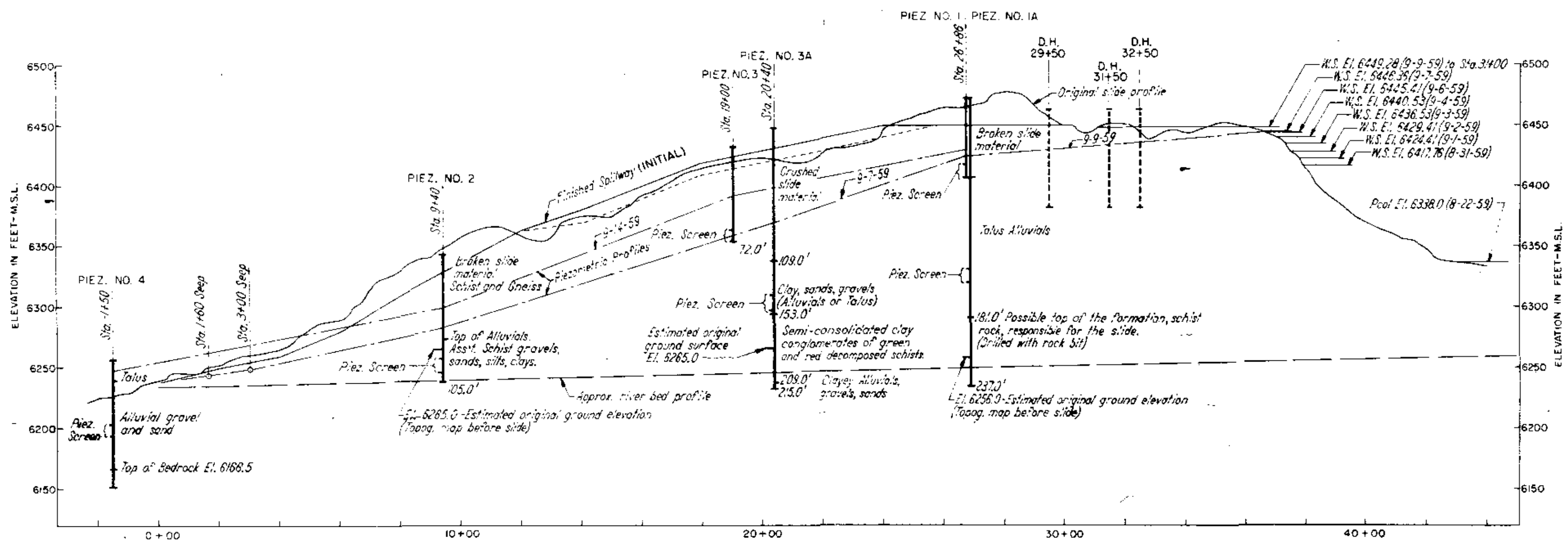
1370 Pound sample represents material smaller than ten inch size. Tested 9-20-59.

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
**MECHANICAL ANALYSIS**
**SLIDE MATERIAL**
**STA. 28+00**



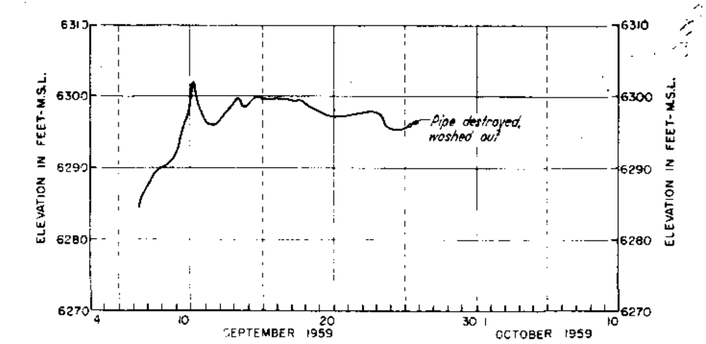

PLAN

SCALE 1"=200'

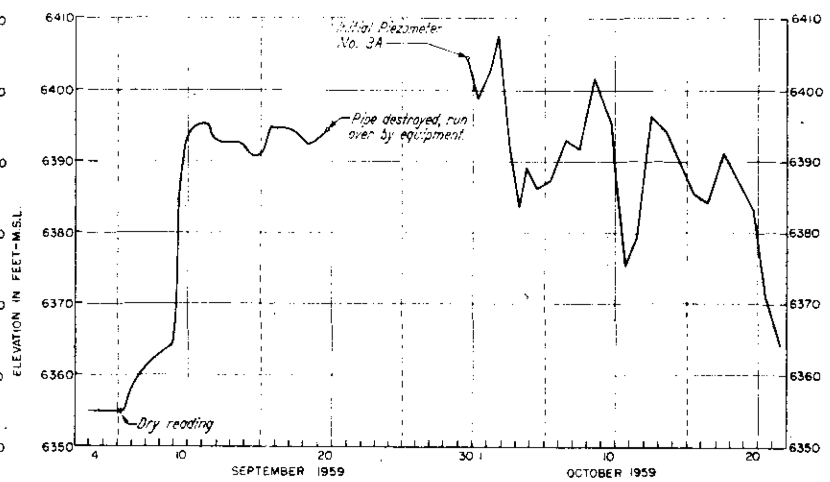



PROFILE

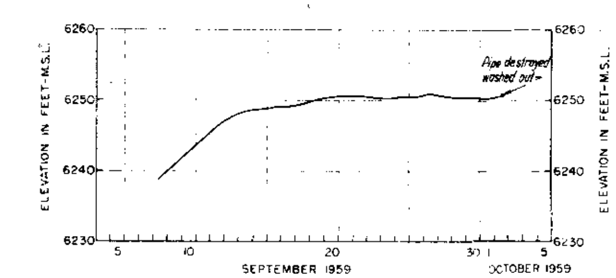
SCALE HOR. 1"=200' VERT. 1"=50'



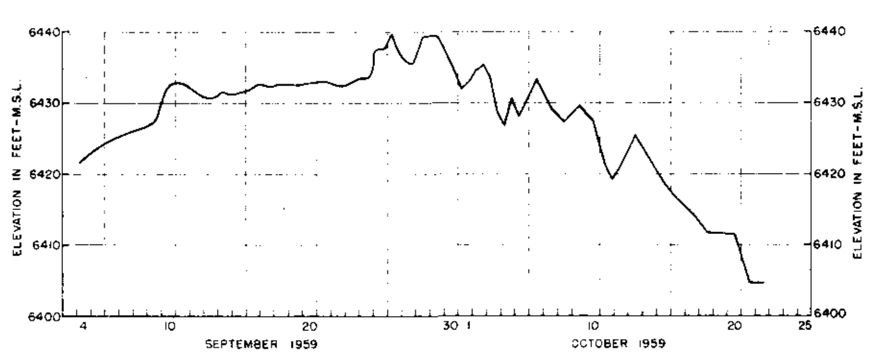

PIEZOMETER NO. 2



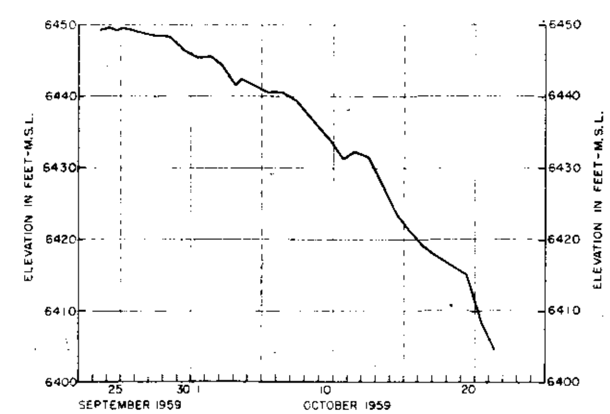

PIEZOMETER NO. 3 AND 3A




PIEZOMETER NO. 4




PIEZOMETER NO. 1



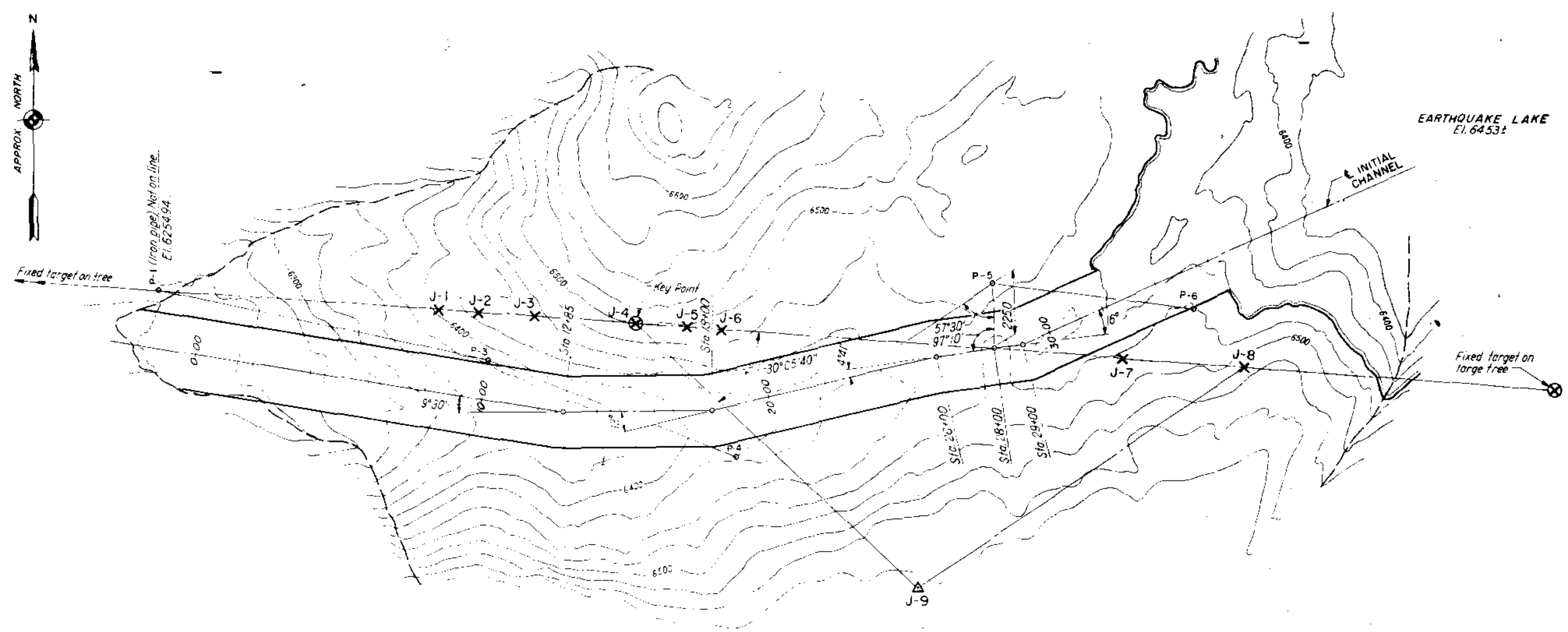

PIEZOMETER NO. 1A

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
GARRISON DISTRICT
RIVERDALE, N. D.

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
PIEZOMETERS
PLAN, PROFILE AND RECORD OF OBSERVATIONS

SCALE: As Shown

APPENDIX X PLATE 4




## PLAN

SCALE 1" = 200'

200' 0 200' 400'

| SLIDE MOVEMENT POINTS | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TRAVERSE MOVEMENT CHECK | | | | | | | | | | | | |
| MOVEMENT POINTS | SEPT 7,8,8,1959 | 9-9-59 | 9-10-59 | 9-14-59 | 9-19-59 | 9-23-59 | 9-28-59 | 10-19-59 | 10-23-59 | | | |
| J-1 | 0 | .3S | .05N | .17S | Destroyed | — | | | | | | |
| J-2 | 0 | 0 | .12N | .06S | .08S | .09S | .08S | | | | | |
| J-3 | 0 | 0 | 0 | 0 | .10S | .10S | .14S | | | | | |
| J-4 | 0 | .11S | .15S | .33S | .42S | .42S | 0.35S | 0.50(S) | 0.55(S) | | | |
| J-5 | 0 | .28S | .07S | .21S | Destroyed | Destroyed | — | | | | | |
| J-6 | 0 | .36S | .11S | .30S | Destroyed | Destroyed | — | | | | | |
| J-7 | 0 | 0 | 0 | .04N | 0.00 | 0.00 | 0.00 | [illegible] | [illegible] | | | |
| J-8 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | |
| J-8, J-4, J-9 | 30°05'40" | | | | | | | 30°05' | | | | |
| OBSERVER | Perry | Perry | Perry | Perry | Best | Best | Best | Best | Best | | | |

| SLIDE MOVEMENT POINTS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LONGITUDINAL MOVEMENT CHECK | | | | | | | | |
| | | 9-10-59 | | | | | | |
| MOVEMENT POINTS | INITIAL STATION | DISTANCE | CURRENT CHANGE | ACC. CHANGE | DISTANCE | CURRENT CHANGE | ACC. CHANGE |
| IRON PIPE | 0+00 * | | | | | | |
| | | 300.0 | 0 | 0 | | | |
| RED HEAD | 3+00 | | | | | | |
| | | 300.0 | 0 | 0 | | | |
| RED HEAD | 6+00 | | | | | | |
| | | 700.0 | 0 | 0 | | | |
| HUB | 13+00 | | | | | | |
| | | 1196.5 | 0 | 0 | | | |
| J-1 | 24+96.5 | | | | | | |
| | | 136.1 | 0 | 0 | | | |
| J-2 | 26+32.6 | | | | | | |
| | | 195.8 | 0 | 0 | | | |
| J-3 | 28+28.4 | | | | | | |
| | | 350.0 | 0 | 0 | | | |
| J-4 | 31+78.4 | | | | | | |
| | | 174.8 | 0 | 0 | | | |
| J-5 | 33+53.2 | | | | | | |
| | | 124.0 | 0 | 0 | | | |
| J-6 | 34+77.2 | | | | | | |
| | | 1334.0 | 0 | 0 | | | |
| J-7 | 48+71.2 | | | | | | |
| | | 485.6 | 0 | 0 | | | |
| J-8 | 52+96.8 | | | | | | |

* 0+00 on Movement Line not shown on sheet.

| SLIDE MOVEMENT POINTS | | | | |
|---|---|---|---|---|
| MOVEMENT POINTS | 9-10-59 INITIAL ELEV. | ELEV. | CURRENT CHANGE | ACC CHANGE |
| BM 45A-1 | 6195.24 | | | |
| P-1 | 6254.94 | | | |
| 0+00 * | 6269.00 | | | |
| J-1 | 6398.80 | | | |
| J-2 | 6425.50 | | | |
| J-3 | 6440.80 | | | |
| J-4 | 6504.47 | | | |
| J-5 | 6497.73 | | | |
| J-6 | 6490.66 | | | |
| J-7 | 6472.30 | | | |
| J-8 | 6515.58 | | | |

| KEY | DATE | REVISION (INDICATED BY Δ) | BY | CHKD. | APP. |
|---|---|---|---|---|---|

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
GARRISON DISTRICT
RIVERDALE, N. D.

| | BY | CHKD. |
|---|---|---|
| DESIGNED | C.V.J. | |
| DRAWN | D.H.E. | |
| TRACED | | |

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
MOVEMENT POINTS

SCALE: 1" = 200'

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX XI

EQUIPMENT RENTAL CONTRACTS
BY K. C. FISCHER

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX XI

Equipment Rental Contracts
By K. C. Fischer

MRGVS 28 August 1959

MEMORANDUM FOR RECORD

SUBJECT: Equipment Rental Contracts for Hebgen Lake Earthquake Disaster Area

1. On 17 August 1959 an earthquake in western Montana caused a landslide across the Madison River below the Hebgen Dam. Waters from the Madison River and other tributary streams caused a lake to form rapidly behind the landslide which imposed an imminent threat of flood, endangering the lives and property of ranchers and townspeople in the Madison Valley. By teletype dated 22 August 1959, under Public Law 99 dated 22 June 1959, the Office, Chief of Engineers authorized and directed the Division Engineer, Missouri River Division and the District Engineer, Garrison District to proceed with immediate survey and to take steps necessary to prevent future damage to life and property from incipient flooding below the landslide blocking the Madison River.

2. The landslide and potential flood problems were surveyed by experts, consultants and Corps personnel and it was determine necessary to construct a rock plated spillway through the slide to provide a means of releasing the water impounding behind the slide. Because of the need to take remedial action as expeditiously as possible in order to avoid any further damage or danger to life and property and because of the many intangibles surrounding the content of the material in the slide, the lack of contour information to determine quantities for removal, handling and disposal, it was considered virtually impossible to prepare specifications or other data and information to permit contracting the work on a unit price or a fixed-fee basis. For this reason, it was determined necessary to accomplish the work by hiring equipment on equipment rental contracts. Lt. Colonel Hogrefe briefly discussed the method of contracting with General Barney who agreed that equipment rental was the only practicable method of performing the necessary remedial work under the existing emergency conditions. Therefore, all remedial work will be accomplished by equipment rental contracts, using the appropriate contract forms set forth in Appendix A, ER 1180-1-1. All contracts to include equipment with operator and operating supplies.

3. In cooperation with the Civil Defense, the Montana Chapter of the Associated General Contractors of America has organized a disaster plan called operation "Bulldozer" which is administered by the A.G.C. Thus, arrangements for the hire of the equipment needed were made under this plan and the rental rates were negotiated by the undersigned, representing the Government and Mr. J. W. Marlow, Secretary, Montana Chapter, A.G.C., Administrator of the operation "Bulldozer" plan and Mr. F. L. Oliver, Member of the Board of Directors, A.G.C. In computing the rates the undersigned used as a guideline, the rental rates set forth in the Garrison District Disaster Manual which were adjusted upward to allow for the fact that the equipment rental rates in the State of Montana were increased by 10% in June 1959, plus allowance for overtime on labor, said overtime being directed by the Government. (7 each, 10 hour days = 70 hours per week). Generally, the A.G.C. representatives based their negotiations on the rental rates established by the Montana State Highway Department, said rates adjusted upward to include the aforementioned 10% rate increase; labor at rates set forth in the Department of Labor Wage Determination, plus 12% on labor to cover employee additives and benefits as provided in the 1958-1961 International Union of Operating Engineers Labor Contract and overtime allowance based on a 70 hour work week, computed as follows: 85 straight time hours (40 regular + 30 @ time and $\frac{1}{2}$ = 85) x the hourly rate ÷ by 70 = the average hourly rate. (Example: Straight hourly rate = $3.20 x 85 = $272.00 ÷ 70 = $3.88 per hour). For comparison purposes there follows a tabulation of rates computed by the Government (excluding the 12% for additives and the allowance for overtime), the rates computed by the A.G.C. and the final rates agreed to. These rates include operators, oilers and all operating fuels, supplies and equipment but not expense for mobilization.

| | | GOVT. | AGC | AGREED RATE PER HOUR |
|---|---|---|---|---|
| 1. | Tractor, crawler w/dozer and power control attachment, Model A-D-8, Z U series | $19.04 | $19.78 | $19.50 |
| 2. | Tractor, crawler w/dozer and power control attachments, B-D8-Series 13A thru 15A | 22.00 | 23.76 | 23.00 |
| 3. | Tractor, crawler w/dozer and power control attachments C Model D-9 | 27.07 | 25.51 | 25.50 |
| 4. | Shovel, crawler, w/2 yd. bucket | 32.47 | 33.00 | 32.00 |
| 5. | Shovel, crawler, w/2½ yd. bucket | 35.83 | 35.00 | 35.00 |

| | | GOVT. | AGC | AGREED RATE PER HOUR |
|---|---|---|---|---|
| 6. | Shovel, crawler, w/3 yd. bucket | $43.81 | $38.00 | $38.00 |
| 7. | Truck, Diesel End Dump 13.5-16 cu. yd. (22 ton) | 22.42 | 20.00 | 20.00 |
| 8. | Truck, butane, end dump, 16-18 cu. yd. - 26 ton | Not listed in disaster manual | 25.00 | 23.00 |
| 9. | Motor Patrol, caterpillar Model 14 | 15.58 | 15.00 | 14.00 |
| 10. | Loader (shovel) Tractor, crawler type, 2½ cu. yd. | 15.12 | 15.00 | 14.00 |
| 11. | Water truck, 38,000 gal. capacity w/pump | Not listed in disaster manual | *15.08 | 12.00 |
| 12. | Generator, light plant | | | |
| | A. 5kw | No rates were set forth in either the disaster manual or the Montana Highway manual - rates were based on normal charge for contractor's rental. 150 kw rate includes wages of tender. | | 2.50 |
| | B. 150 kw | | | 14.00 |
| 13. | Draglines, crawler | | | |
| | A. 4 cu. yd. -87' boom | 54.79 | 38.00 | 38.00 |
| | B. 6 Cu. yd.-120' boom | Not listed in disaster manual | 50.00 | 48.00 |
| 14. | Loaders, front end, rubber tired, Michigan | | | |
| | A. 4 yd. | 34.20 | 34.20 | 33.00 |
| | B. 6 yd. | 36.00 | 36.00 | 36.00 |

*AGC computed pump at $2.75 and added price to truck rate. Govt. contended pump should be included as part of water truck - AGC reluctantly agreed - thus rate reduced to $12.00

| | GOVT. | AGC | AGREED RATE PER HOUR |
|---|---|---|---|
| 15. Cranes, lifting, truck mounted w/2 choker setter each crane, 20' boom | | | |
| A. 25 ton | $33.51 | $33.84 | $33.00 |
| B. 30 ton | 38.20 | 37.87 | 37.00 |
| 16. Drill "cat," consisting of D-8 "cat" tractor, 600 cfm compressor and "cat" mounted drill | No rates in disaster manual | 37.42 | 36.00 |

In addition to the foregoing, equipment sufficient to accomplish a complete drilling and blasting operation was hired under a price per hour contract. The hourly rental rate of $22.50 per hour for all equipment with operators, etc., was arrived at as follows:

| ITEM | RATE PER HOUR |
|---|---|
| a. Compressor | $ 3.50 |
| b. Pneumatic drill | 1.50 |
| c. Air hose, couplings & drill steel | 3.00 |
| d. Pickup truck | 3.00 |
| e. Powder Man (salary) | 3.70 (with overtime) |
| f. Driller | 3.60 (with overtime) |
| g. Insurance | 2.70 |
| h. Mobilization & demobilization | 1.50 |
| Total | $22.50 |

The charges were computed by the undersigned and agreed to by the contractor. This rate was not coordinated with the AGC but was negotiated directly with the contractor.

In establishing the rates, an attempt was made to negotiate a lower rate for equipment working a second shift since the contractor's operating costs and insurance costs go down as the number of work hours increase. The AGC people said they might be agreeable to such an arrangement if they could be guaranteed a minimum of say 30 days work. When advised we could guarantee no definite period, they would not agree to a lower second shift rate. They did, however, recognize the fact that the longer the equipment worked, the lower the cost to the contractor, particularly with respect to supervision and indirect costs. For this reason in some instances I was able to negotiate a lower rate than the rate computed by the AGC. The one major exception to this was the rates on the crawler tractors. Because of the type of material (sharp broken rock, etc.) in which the equipment was to work and the anticipated high maintenance and repair costs, the AGC was not agreeable to any rate lower than that shown. At one stage during negotiations, two contractors (Kiely and Zook) were reluctant to accept the rates agreed to but relented after the AGC people advised them that all other contracts would accept the rates as negotiated.

4. Neither the Garrison District nor the Montana State Highway schedule included any provisions for payment of mobilization and demobilization. Mr. Marlow stated a common rate in the State of Montana was $21.00 per hour loaded and $15.00 per hour deadheading. I told him that, in addition to the fact that the rate seemed high, I was not in favor of such an arrangement as it gave the contractor the opportunity to move slowly and that the Government would be subjected to payment for breakdowns and/or delays in transit, which may be caused by the fault or negligence of the contractor. I was more in favor of a flat rate per load mile. After some checking with his directors and other contractors, Marlow suggested a rate of $2.00 per load mile, which rate would also include deadheading back to the point of origin. I suggested $1.00 per load mile, which would allow $0.60 per mile in and $0.40 per mile out. Marlow said this was too low and would not agree. After some investigation, I found that the rate for commerical haulers ran from a minimum of $1.25 per hour to a maximum of $1.75 per mile. Long Construction showed figures where a one year operation on one low boy running 48,000 miles resulted in an actual cost, without profit or office overhead of $1.10 per load mile. Long stated that study was made prior to the last labor and equipment rental rate increases. I then suggested a medium rate of $1.50 per load mile. After some consultation between Marlow and Oliver, they agreed to the rate. This rate was to cover all charges incidental to the movement, such as flag cars, but would not cover the contractor's cost of disassembly and assembly of cranes, draglines and other equipment which could not otherwise be moved in one piece. Since such was an actual out-of-pocket expense to the contractor, it was agreed that the Government would reimburse for actual costs. No rate was available on end dump trucks or other self-propelled equipment that was normally moved "over the road" under its own power; however, F & S Construction, who has about 30 end dumps, advised that their standard rate for standby or in transit time was 75% of the regular hourly rate, which in this instance would be 75% of $20.00 = $15.00. The rate appeared to be reasonable and was agreed to. During the 1949 "Operations Snowbound," a standby rate of 75% was also used. Thus the mobilization and demobilization rates were established as follows:

| | |
|---|---|
| Rail shipment | - Actual costs as shown on bill of lading |
| Truck transport | - $1.50 per load mile plus actual assembly and disassembly costs |
| Self-propelled | - 75% of regular hourly rate |

The mileage from Ennis to the slide area is computed, for mileage payment purposes, as 40 miles.

/s/Kenneth C. Fischer
KENNETH C. FISCHER
Chief, Supply Division

At the time the rental rates were negotiated and the contracts prepared, it was not considered necessary to establish standby rates, as it was intended that when an item of plant became surplus to the needs of the Government it would be released upon one day's advance notice, as provided in the contract. It has now been found that in cutting the crest of the spillway, all plant, especially tractors and trucks, are not constantly needed. However, it is considered essential that a certain amount of such equipment be held in standby status to help combat excessive erosion or other problems that may arise during the period the crest is being lowered. Standby status is defined as being on the job, ready for operation, complete with operator and operating supplies, but not actually working.

On 28 September 1959, negotiations for standby rates were conducted with Mr. F. L. Oliver, AGC, representing the contractors and Mr. Wayne L. Likes, District Auditor and myself representing the Government. To commence the negotiations, a breakdown, showing all costs considered in determining the rate, was made on a D-8 Tractor and a 4-yard dragline. (See Inclosure 1). This breakdown was made for the purpose of determining what costs, normally included in the hourly rate, could be deducted while the equipment was in standby. It was determined that fuel, oil, and grease; repairs and profit should be excluded. The total of these items amounted to approximately 25% of the hourly rate; thus, Mr. Oliver suggested that the standby rate be 75% of the hourly rate. I felt that this was a little high on the basis that the equipment would not depreciate as fast in standby as it would if it were working. Mr. Oliver contended that this was not so, that equipment depreciated at the same rate whether or not it was working. He did say, however, that the salvage value of a unit in standby would be higher than on a unit working, especially one working under conditions such as those that existed at the slide. Considerable discussion followed on the propriety of the 75% proposal, at which point, I suggested an alternate proposal. I suggested that in lieu of a percentage of the hourly rate, in order to facilitate time checking and cost accounting, we establish a guaranteed number of hours per shift which would be somewhat commensurate with the 75% and would allow the contractor his due costs. For example: for each $11\frac{1}{2}$ hour shift, the contractor would receive 8 hours at full pay, but if he worked 8 hours and was shut down he would stand by the remaining $3\frac{1}{2}$ hours of the shift at no charge. If he worked less than 8 hours (say 3 hours), the contractor would receive 8 hours pay but would stand by for $11\frac{1}{2}$ hours. There follows a comparison of the two methods proposed, both based on an $11\frac{1}{2}$ hour shift, using a D-8, series 14-A tractor:

75% of \$23.00 = \$17.25 x 11.5 hours = \$198.38
8 hours guarantee at full rate of
\$23.00 per hour = \$184.00

It should be noted that the hourly proposal actually amounts to approximately 70% of the full rate on an 11½ hour shift basis. I felt that this was more equitable than the 75% suggested by Oliver. Mr. Oliver was reluctant to agree to anything less than 75%, but admitted that the guaranteed hourly proposal was much easier to administer than the percentage arrangement. He then stated he would be agreeable but first wanted to check with some of the other contractors to get their reaction. Mr. Oliver then contacted Mr. Anderson, F & S Contracting Co. and Mr. Bill Kiely, Kiely Construction Co. After some discussion of the matter, Mr. Oliver advised that the contractors would accept the 8 hour guarantee in lieu of the 75%. Since Colonel Hogrefe expressed the desire to go from 2 each 11½ hour shifts to 3 each 8 hour shifts, it was necessary to apply the same formula to an 8 hour shift. For this purpose, I took the figure of 5½ hours at full rate in lieu of 75% of full rate for the entire 8 hour shift. This comparison, based on a D-8 tractor, series 14-A is as follows:

75% of \$23.00 = \$17.25 x 8 hours = \$138.00
5.5 hrs. guarantee at full rate
of \$23.00 per hour = \$126.50

Based on these negotiations and agreements, a memorandum was prepared and issued to all field units, establishing the procedure for equipment on standby. A copy of this memorandum is attached. (See Inclosure 2).

/s/Kenneth C. Fischer
KENNETH C. FISCHER
Chief, Supply Division

2 Incl
1. Equip Rental Rate Breakdown
2. Memo on Standby Time

# EQUIPMENT RENTAL RATE BREAKDOWN

28 September 1959

D8 - 14 - A SERIES W DOZER & PCU AGC

| | |
|---|---|
| Depr | 9.90 |
| F.O.G. | 3.60 |
| Rep | 5.00 |
| Opr 70 Hr Wk | 4.20 |
| TOTAL | 22.70 |

| | ESTIMATED | ACTUAL | | |
|---|---|---|---|---|
| Depr | 8.63 | 8.63 | 8.63 | |
| F.O.G. | 2.10 | 2.10 | | |
| Rep | 3.60 | 3.60 | | |
| Oper 70 Hr | 4.20 | 4.34 | 4.34 | |
| | 18.53 | 18.67 | | |
| +10% Field O.H. Mech, Serv - Supv | 1.85 | 3.49 | 3.49 | |
| | 20.38 | 22.16 | | |
| +4% Home Office | .82 | .89 | .89 | |
| | | 23.05 | | |
| | 21.20 | | 17.35 | 75.4% |
| +10% Profit | 2.12 | 2.30 | | |
| | 23.32 | 25.35 | | |
| 4 C. R. Dragline | | | | |
| Depr | 14.60 | 14.60 | 14.60 | |
| F.O.G. | 3.00 | 3.00 | | |
| Rep | 4.50 | 4.50 | | |
| Oper | 4.43 | 4.56 | 4.56 | |
| Oiler | 3.18 | 3.67 | 3.67 | |
| | 29.71 | 30.33 | | |
| +10% F.O.H. | 2.97 | 5.67 | 5.67 | |
| | 32.68 | 36.00 | | |
| +4% B.O. | 1.31 | 1.44 | 1.44 | |
| | 33.99 | 37.44 | 29.94 | 78.8% |
| +10% Prof | 3.40 | 3.74 | | |
| | $37.39 | 41.18 | | |

Standby Time

Field Units District Engineer 29 Sep 59 K. Fischer

1. The following procedure shall apply for equipment placed on standby time.

a. $11\frac{1}{2}$ hour shifts: Equipment which normally works $11\frac{1}{2}$ hour shifts and is placed on standby for the entire shift will be credited with 8 hours time. Equipment working a part shift (less than 8 hours) and then placed on standby will be credited with a total of 8 hours time. Equipment working 8 hours or more and then placed on standby for the remainder of the shift will be credited with only the actual hours worked and no time will be given for standby.

b. 8 hour shifts: The same procedure as set forth in paragraph 1a above will apply for equipment working on 8 hour shifts except that equipment will be credited with $5\frac{1}{2}$ hours in lieu of 8 hours.

c. In summary, each piece of equipment, except light generating plants, equipment down for repairs or equipment released from the job but not removed from the worksite, will be guaranteed 8 hours pay for each $11\frac{1}{2}$ hour shift or $5\frac{1}{2}$ hours pay for each 8 hour shift.

WALTER W. HOGREFE
District Engineer

# MADISON RIVER, MONTANA
# REPORT ON
# FLOOD EMERGENCY
# MADISON RIVER SLIDE

## APPENDIX XII

## CONSULTANTS' REPORT

BY MR. EDWARD B. BURWELL, JR.
DR. ARTHUR CASAGRANDE
MR. I. C. STEELE
DR. LORENZ G. STRAUB

MARCH 1960

U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

MADISON RIVER, MONTANA
REPORT ON
FLOOD EMERGENCY
MADISON RIVER SLIDE

APPENDIX XII

Consultants' Report
By Mr. Edward B. Burwell, Jr.,
Dr. Arthur Casagrande, Mr. I. C.
Steele, and Dr. Lorenz G. Straub

REPORT OF BOARD OF CONSULTANTS
MADISON CANYON EARTHQUAKE EMERGENCY PROJECT

## Introduction

The Board of Consultants was appointed in early September, 1959, to consider the potential hazard and recommend remedial measures in connection with the rock fill dam created by the earthquake in the Madison River area immediately west of Yellowstone National Park. The members of the Board were requested to report either as individuals or jointly. Visits to the site by individual Board members were made at different times and variously in association with principals of the Office of the Chief of Engineers, Office of the Division Engineer, and of the District.

The rock slide which formed the dam occurred shortly before midnight on August 17, 1959, and involved an estimated 80 million tons of material obstructing the narrow canyon about six miles downstream of Hebgen Dam. In the following several weeks the dam created by the slide resulted in the progressive formation of a lake over 200 ft deep at the dam.

In the initial phase of emergency operations by the Garrison District of the Corps of Engineers prior to appointment of the Board of Consultants, steps toward stabilization were taken by the building of a 250 ft. wide spillway over the rock fill by the use of dozers and other earth moving equipment. Details of this operation have been described elsewhere in reports of the District Engineer. This first phase of the operation was considered terminated on 10 September 1959 when flow over the spillway took place.

Visits by members of the Board to the site were made as follows: 18 September 1959 - Arthur Casagrande, I. C. Steele; 23-25 September 1959 - E. B. Burwell, Lorenz G. Straub; 30 September - 1 October 1959 - Lorenz G. Straub; 12 October 1959 - Lorenz G. Straub; 29 October 1959 - E. B. Burwell, I. C. Steele, Lorenz G. Straub.

Appraisals of the Board

Based upon field observations and a review of data made available by the District Engineer to members of the Board and as a result of individual special studies, a number of conclusions were drawn from various points of view of the individual Board members with special reference to dealing with the flood hazard.

1. Holding of the originally established spillway which had been prepared by emergency earth moving operations would be impossible without continued costly maintenance.

2. In order to provide a reasonably stable and safe condition at the slide, the elevation of the cut through the rock fill should be lowered an amount to permit the lake level to be drawn down from approximately elevation 6453 to about elevation 6400, that is a lowering of about 50 ft.

3. Considerable uncertainty existed as regards the mechanical composition of the slide material, but on the south side particularly the rock appeared to be fine enough to be very erodible. Also, since there was only of the order of 200 cfs or less seepage flow through the dam, the rock fill for the most part was recognized as being relatively fine. A mechanical composition determination of a large specimen which was presumed to be approximately typical indicated a median size of less than 3 in. diameter particles. Based upon the erodibility of materials as large as 9 in. effective diameter, calculations by one of the members of the Board indicated that with the reservoir at the then existing elevation of 6450 uncontrolled normal flow of 2,500 cfs could result in a break-through reaching a maximum possible discharge of about 85,000 cfs within less than one day, whereas on the same basis of calculations for the reservoir lowered 50 ft., the peak flow in case of a break-through would amount to only of the order of 15,000 second ft. and would require an initial flow rate of about 4,000 cfs to start the crevasse. The Madison River channel capacity at bank-full stage was estimated at about 5,000 cfs in some regions of the channel, possibly as much as 8,000 cfs in others. There was thus strong indication of a serious flood hazard.

The foregoing were among the principal considerations in proposals for recommendations of minimum requirements in concluding emergency field operations against a potential flood hazard.

Observed Conditions at Final Inspection

The final inspection of the Board of Consultants made jointly with principals of the Office of the Chief of Engineers, the Division Engineer, and the District Engineer indicated syst matic accomplishment of the objectives of the emergency project. These observations, in conjunction with the data and charts of the progress of the work, showed typically the following results.

1. The channel through the slide area had been lowered sufficiently to reduce the lake level by approximately 50 ft.

2. A maximum degradation of the channel through the slide area of a much as 80 ft. had taken place, while immediately downstream aggradation of the channel of the order of a maximum of 30 ft. had taken place.

3. The average slope of gradient from the lake to the normal channel of the river downstream had been reduced to about 3 per cent, while the steepest gradient through the cut was of the order of 5 per cent. In comparison to these figures, the steepest gradient over a distance of about 200 ft. or more prior to the field operations amounted to as much as 20 per cent with precariously rapid erosion taking place at times under these conditions.

4. The side slopes of the cut appear to be stable except for some rock slides where undercutting by the stream will take place.

Concluding Comments

The Board is in agreement that the mission undertaken by the Corps of Engineers in the Madison Canyon Earthquake Emergency Project has been accomplished, and expresses itself in more detail as follows:

1. An acceptable factor of safety against failure or rapid erosion which could cause serious floods downstream has been provided by lowering the capacity of the reservoir from 80,000 acre-feet to 36,000 acre-feet and by reducing the average gradient of the spillway channel across the dam to about 3 per cent.

2. It is recognized that lateral erosion and shifting of the channel will occur and may induce slides of inconsequential magnitude.

3. In general vertical erosion at the crest and in the upper approaches of the channel are expected to be slow due to the resistant character of the channel bottom.

4. On the south side of the slide there exists along the ridge for a distance of about ½ mile substantial volumes of schist (possibly several million cubic

yards) which are severely cracked and disturbed. Further deterioration of the stability of this ridge, resulting from weathering, ice wedging, and hydrostatic forces, will occur and will in time produce additional rock falls and slides. However, as the dip of the schist toward the valley is about 70 degrees and the lower portion of the mass is confined by a massive berm of slide material, it appears unlikely that a slide will occur of sufficient magnitude to cause serious blockage of the spillway channel unless the area is again subjected to a severe seismic shock. Therefore, the decision not to undertake any remedial treatment of the ridge and to assume the calculated risk of possible future slides is considered warranted.

5. Concerning the stability of the high cliffs on the north side of the dam, no serious damage appears to have been done by the earthquake. As the rocks on this side of the valley dip into the mountain mass, no danger of slides exists.

6. Inasmuch as the process of bank erosion, degradation of the upper channel, and further aggradation and changes in the channel downstream of the slide may be expected to take place for some years and more actively in the immediate future, it is suggested that a yearly survey of the profile and lateral displacement of the spillway be obtained so as to have record of further developments. In view of the interest of local organizations in this situation, including for example the Montana Power Company, it is suggested that the Corps of Engineers encourage these interests to undertake such surveys, perhaps as a cooperative effort.

Finally, the Board commends the Corps of Engineers in its efficiency and effectiveness in the performance of this most difficult and urgent emergency assignment.

BOARD OF CONSULTANTS

Edward B. Burwell, Jr.
Arthur Casagrande
I. C. Steele
Lorenz G. Straub

# MADISON RIVER, MONTANA

# REPORT ON

# FLOOD EMERGENCY

# MADISON RIVER SLIDE

## APPENDIX XIII

## HYDRAULIC STUDIES
BY ADOLFS MARKUS

SEPTEMBER 1960

PREPARED BY
U. S. ARMY ENGINEER DISTRICT, GARRISON
CORPS OF ENGINEERS
RIVERDALE, NORTH DAKOTA

PUBLISHED BY
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

Madison River, Montana
Report on
Madison River Slide

Appendix XIII

HYDRAULIC STUDIES

by Adolfs Markus

1. A rock spillway was selected as the most logical way to pass overflow discharges and construction work began before any detailed hydraulic computations were made. The water level in Earthquake Lake rose so fast that there was not enough time for complete grading of the channel's bottom to a flatter slope nor for paving the downstream portion of the channel with large sized rock. The computations were based on the existing bottom slopes and a 250-foot width to determine expected performance of the proposed rock spillway.

2. While construction operations were in progress, studies were made to determine velocities to be expected in the proposed spillway channel at each station, and the sizes of rock that would be required for stability. Velocities at normal depths were computed for each slope and for various discharges up to 10,000 c.f.s., using Manning's formula with "N" values of 0.03 and 0.04. Corresponding rock sizes were taken from WES Chart 712-1, published by the Waterways Experiment Station. The values were plotted above each stationing, so that the relationships between discharge, depth, velocity, and required rock size could be readily determined. The chart for a "N" value of 0.03 is shown on Plate 1.

3. A discharge rating curve for the initial spillway was computed and routings were made to determine the time lag between changes of discharge from Hebgen Lake and equal changes in discharge from Earthquake Lake.

4. When it became evident that the initial spillway as constructed could not be held, studies were made to determine the sizes and quantities of rock that would be required to pave the downstream slope of the channel and the sizes of rock-fill drop structures that would be required to prevent erosion.

5. When the decision was made to lower the spillway, it was necessary to know how rapidly the lowering could proceed without permitting the discharge from Earthquake Lake to exceed the limits of safety. The maximum discharge that each bridge across the Madison River downstream from the slide could pass was computed from measured cross sections and slopes. The curves on Plate 2 show the relationship between the rate of lowering of the lake elevation and discharge

from the lake, both with Hebgen Lake outlet gates closed and with Hebgen Lake discharge approximately equal to inflow, or 900 c.f.s., as well as the rate of rise of Hebgen Lake with the outlet gates closed.

6. Any practical method of lowering the spillway would result in a progressive decrease in the width of the channel. Hydraulic computations were made and charts were prepared showing simultaneously the relationships between discharge, bottom width, slope, normal depth, velocity, and required rock size. Such charts were prepared for Manning's "N" values of 0.04 and 0.05. The chart for a "N" value of 0.04 is shown on Plate 3.

7. The chart on Plate 3 is applicable when slopes are mild and do not influence the stability of the rock, when the size of rock in the channel bottom corresponds to the "N" value and there is no scouring of the bottom. When the slope becomes steeper and scouring occurs, the stability of the rock is a function of slope and velocity. If the channel bed consists of rock of all sizes, the smaller sizes will be removed, leaving the larger sizes, until equilibrium is reached. At this point depth, velocity, rock size, and Manning's "N" are functions of discharge per linear foot and of slope, discharge per linear foot and slope being independent variables. The relationships between those variables are shown on Plate 4.

8. Approximate measurements were made of depths, velocities, and rock sizes in the spillway channel to check the computed relationships. Because of the high velocities, turbulent flow, and lack of instruments, exact measurements were not possible. However, within the limit of error, the results showed reasonable agreement with the values by Isbash.

9. The spillway channel upstream from the initial crest was excavated in increments of depth approximating ten feet, starting at the lake and reaching zero depth on the channel slope near the crest. When the final plug or crest was excavated, the discharge increased considerably. For ready determination of the safe depth of cut, a set of curves was prepared, showing the relationships between initial discharge, bottom width, depth of cut, and final discharge. The curves are shown on Plate 5.

10. When stream gaging was transferred to the Kirby Ranch bridge, measurements were no longer responsive immediately to changes in discharge through the spillway. To provide information without delay, the Earthquake Lake discharge rating curve shown on Plate 6 was developed. This curve shows the relationship between water surface elevation in the lake and discharge from lake storage in c.f.s. per 0.01

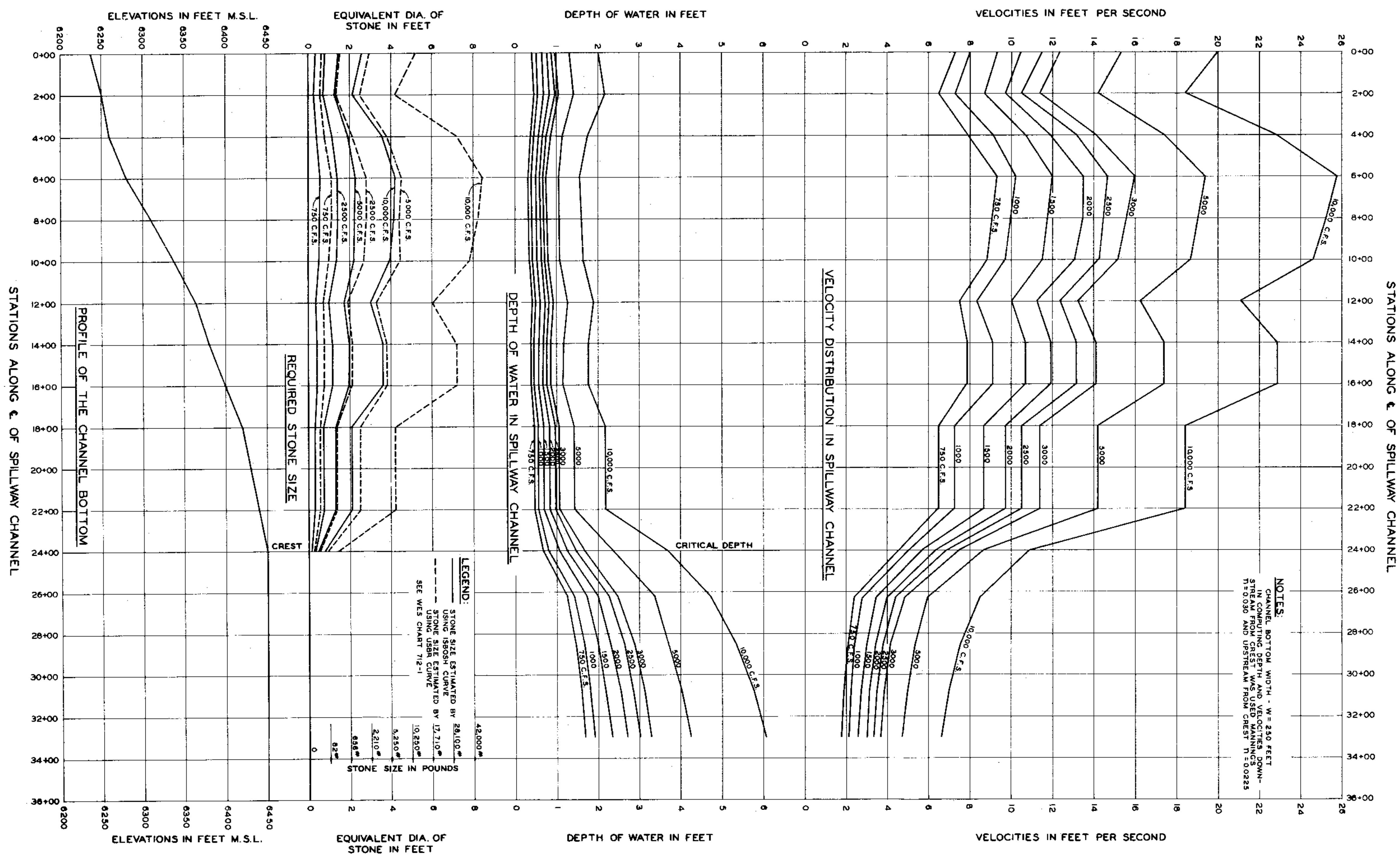
foot of water surface drop per hour. By use of this curve, knowing the discharge from Hebgen Lake, the water surface elevation in Earthquake Lake and the rate of fall per hour, it was possible to estimate instantaneous discharge through the spillway. The Earthquake Lake water surface was measured each half an hour and the computed discharge actually was the average discharge in each half-hour period.

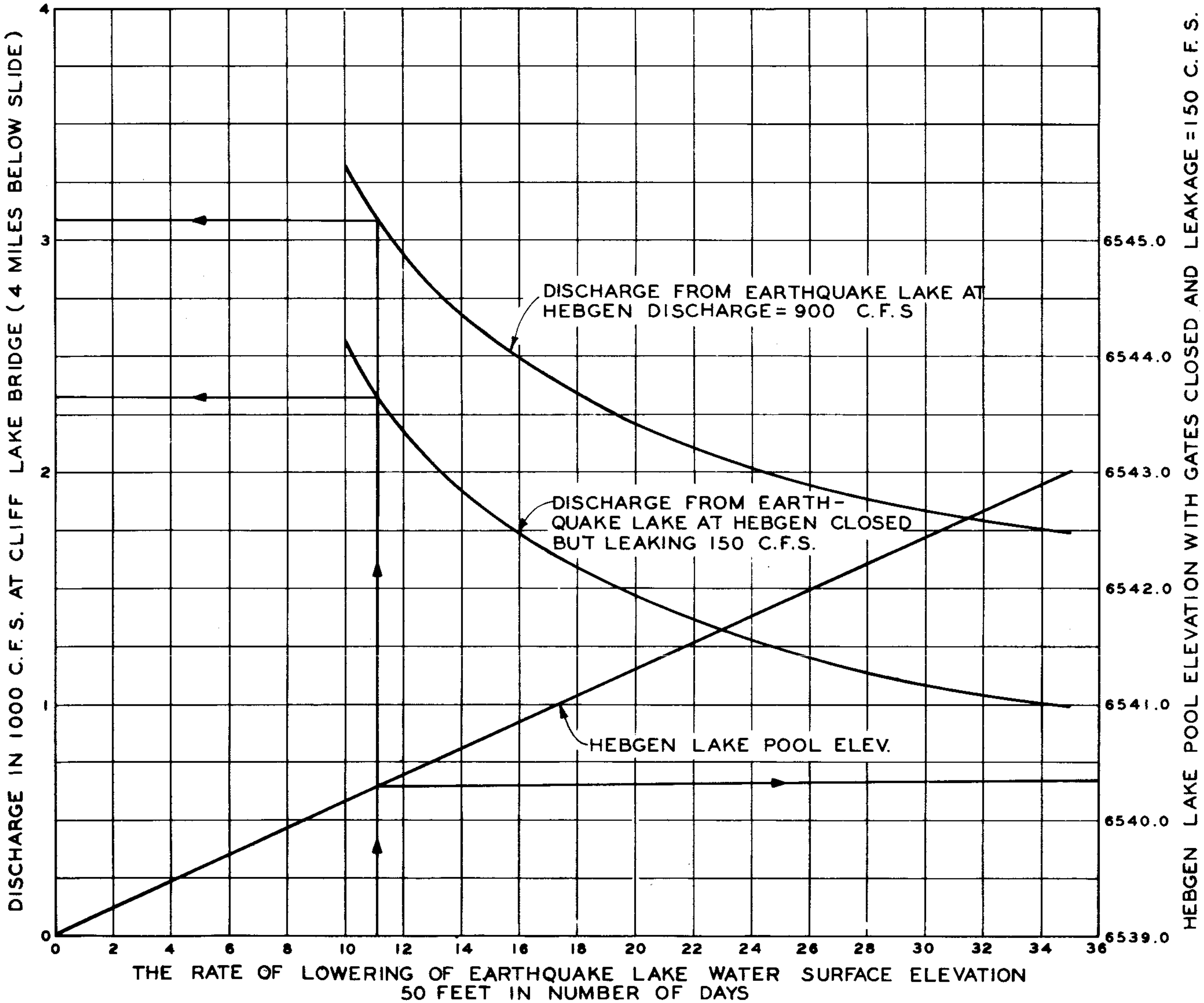
11. Discharge rating curves were computed for the Hebgen Lake outlet works and spillway. Assuming the gates fully open, routings were made to determine the maximum possible rate of drawdown of Hebgen Lake storage. The results of the routings are shown on Plate 7. It was found that, starting with a water surface elevation of 6540, it would be possible to drain the lake completely in 50 days.

ADOLFS MARKUS

MADISON RIVER, MONTANA
FLOOD EMERGENCY
**MADISON RIVER SLIDE**
VARIATION OF DEPTH, VELOCITIES AND STONE SIZE ALONG THE SPILLWAY CHANNEL AT DIFFERENT DISCHARGES
SEPT. 1960

THIS DRAWING HAS BEEN REDUCED TO THREE EIGHTHS THE ORIGINAL SCALE






NOTES:

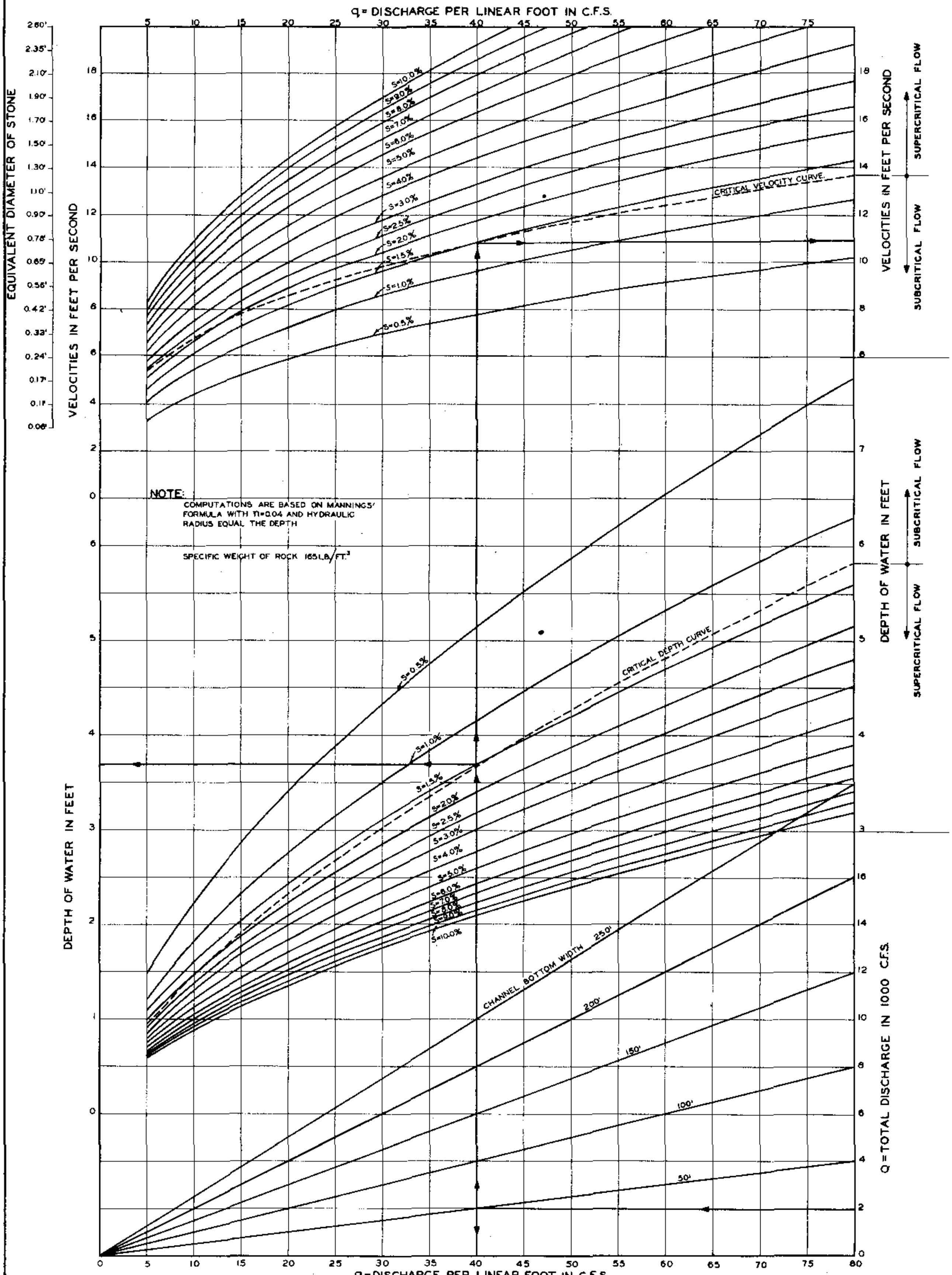
1. INFLOW INTO EARTHQUAKE LAKE
   FROM HEBGEN---------- 150 & 900 C.F.S.
   FROM CABIN & BEAVER CREEKS=100 C.F.S.
2. INFLOW BETWEEN EARTHQUAKE LAKE AND CLIFF LAKE BRIDGE -----------=100 C.F.S.
3. CLOSED HEBGEN OUTLETWORKS ARE LEAKING AT RATE 150 C.F.S.
4. HEBGEN INFLOW = 950 C.F.S.
5. STARTING ELEVATION OF HEBGEN LAKE WATER SURFACE COMPUTATIONS = 6539.0

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE

**EARTHQUAKE LAKE SPILLWAY**

LOWERING OF EARTHQUAKE LAKE WATER SURFACE ELEVATION FROM EL. 6453.0 TO EL. 6403.0 OR TOTAL 50 FEET

SEPT. 1960




MADISON RIVER

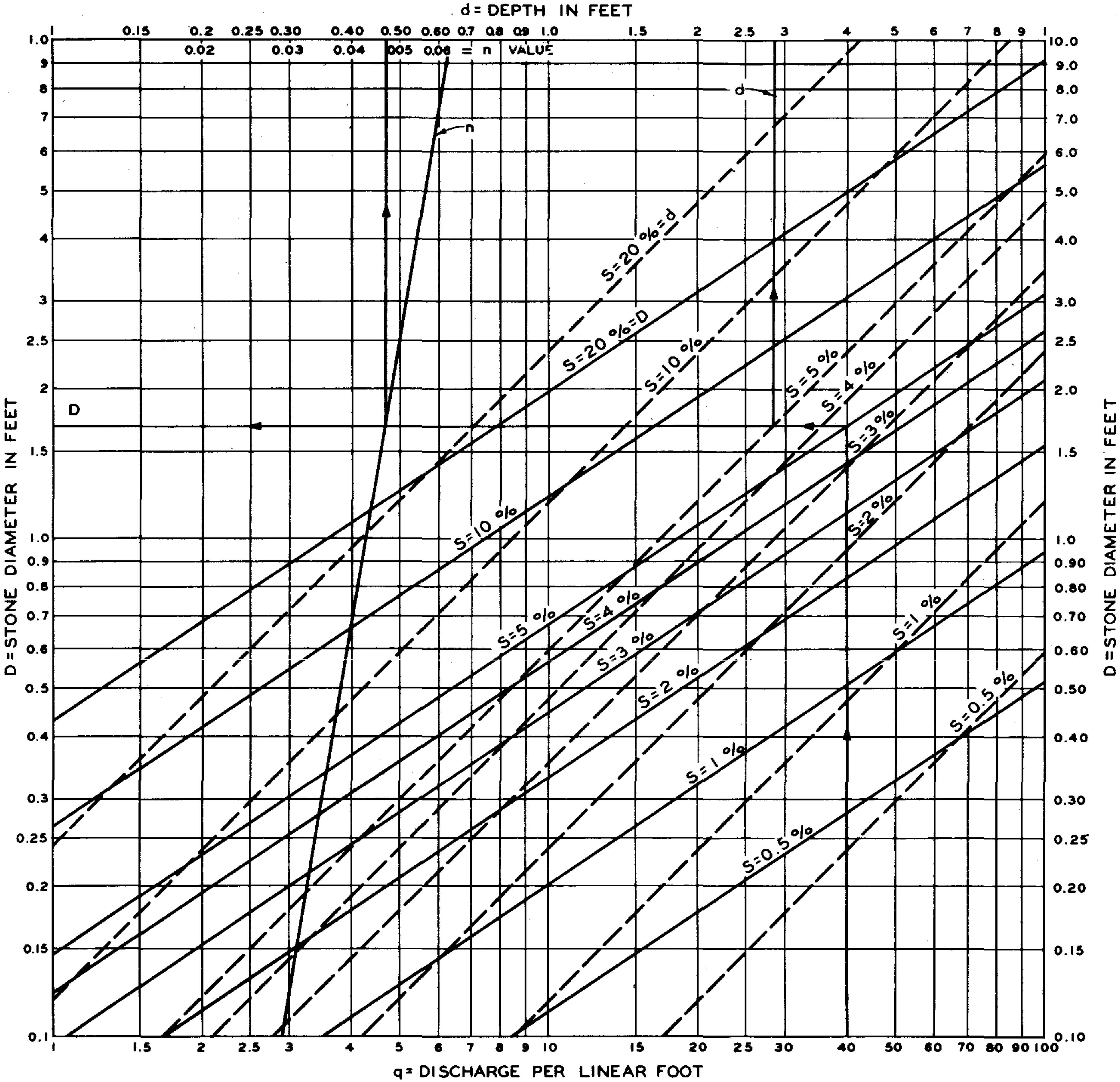
FLOOD EMERGENCY

**MADISON RIVER SLIDE**

EARTHQUAKE LAKE SPILLWAY

NORMAL DEPTH AND VELOCITIES VS. DISCHARGE SLOPE AND CHANNEL WIDTH

SEPT. 1960




1. $n = 0.043\, D^{1/6}$
2. $D = 0.0228\, S^{1/3} v^2$
3. $v = \frac{1.486}{n} S^{1/2} d^{2/3}$
4. $v = \frac{q}{d}$

LIMITS: $d \geqq D$

SOLUTION GIVES:

$D = 1.48\, S^{2/9} q^{2/3}$

$d = \frac{D}{11.9 S}$

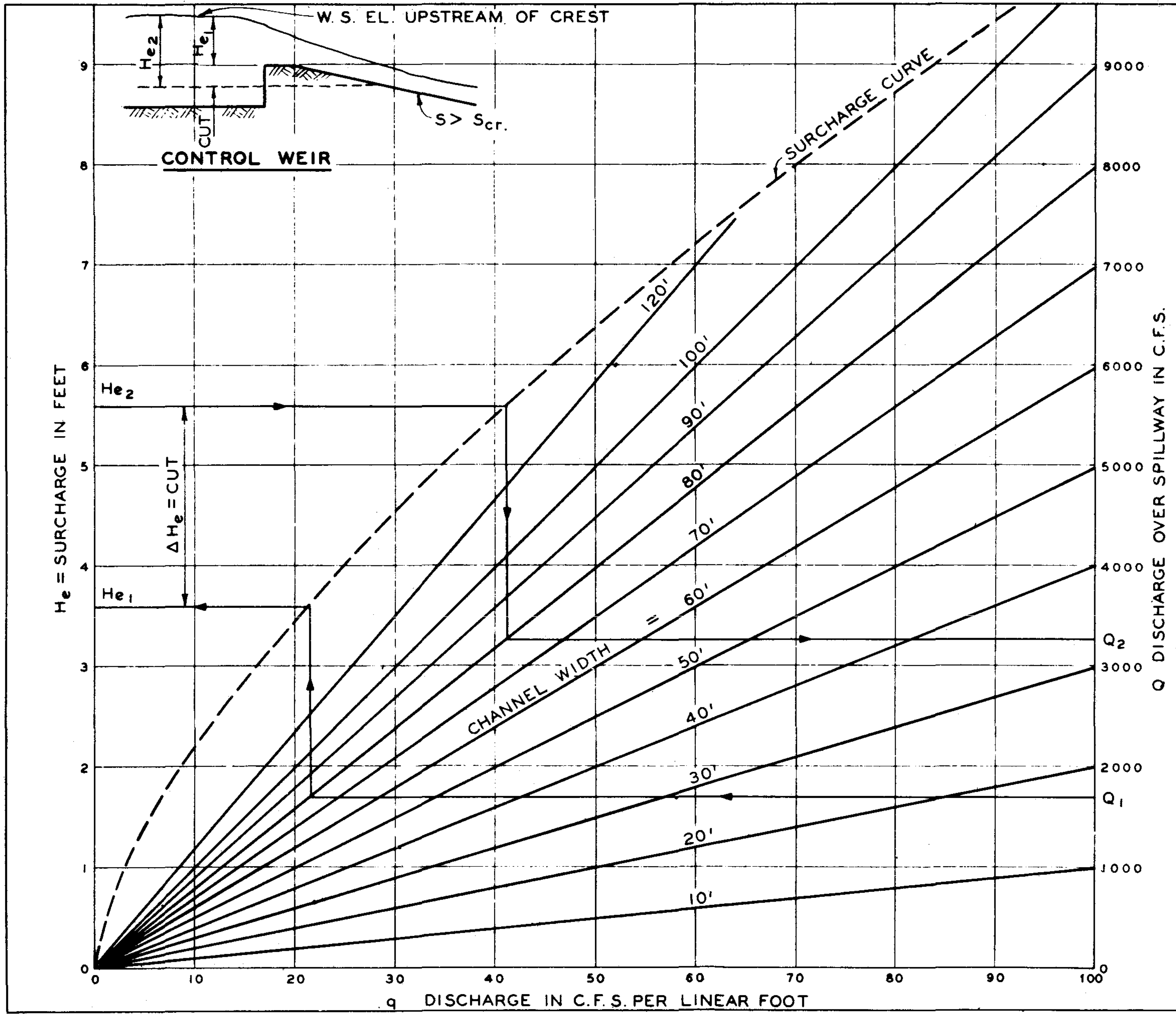
MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE

**EARTHQUAKE LAKE SPILLWAY**

**ISBASH CURVES**

SIZE OF ROCK
VERSUS
SLOPE AND DISCHARGE PER FOOT

SEPT. 1960



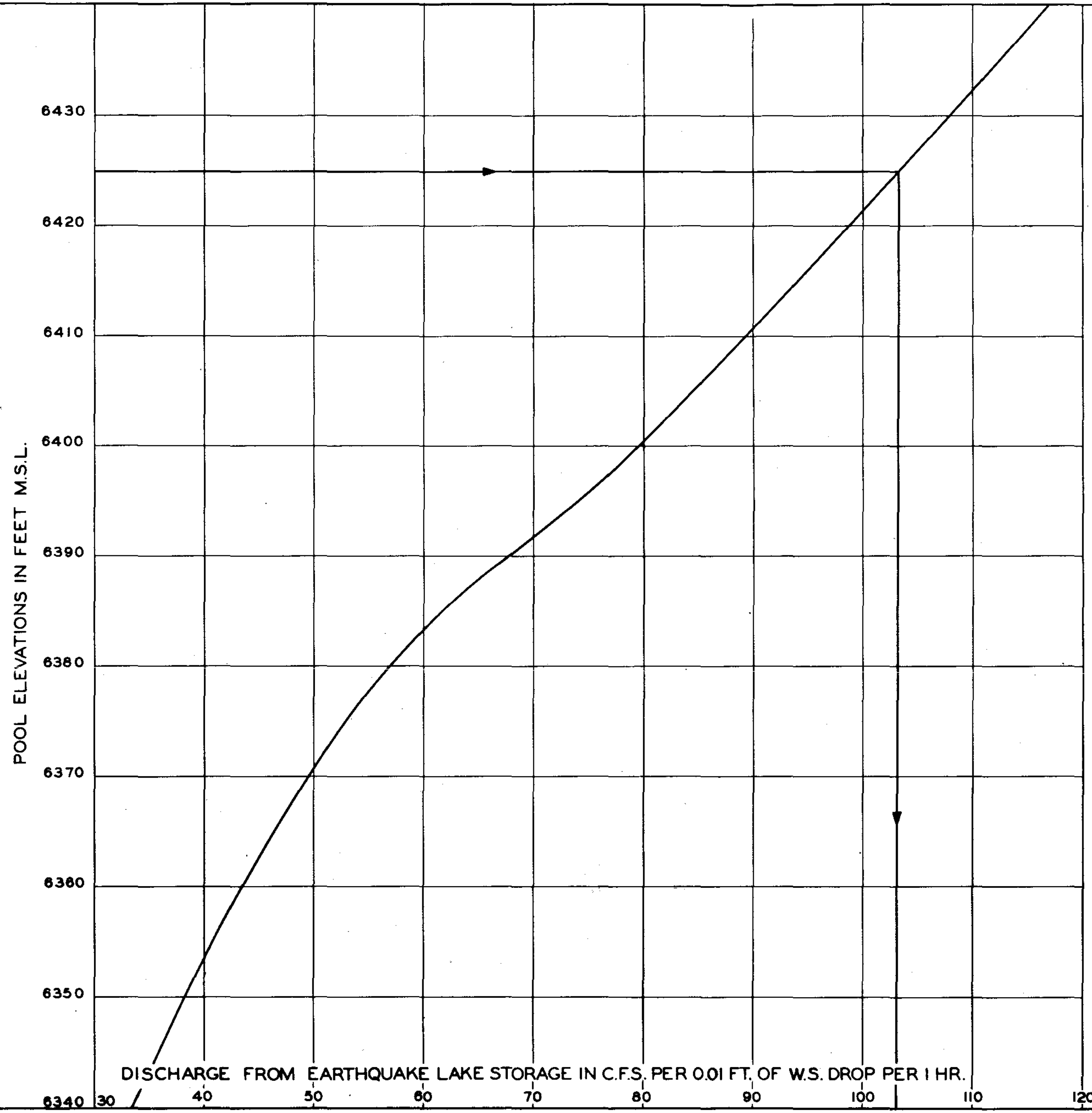

NOTE:
THE PROCEDURE OF HOW TO FIND THE NEW DISCHARGE IS SHOWN ON THE CHART. THE APPROXIMATE WIDTH OF CHANNEL, THE PREVIOUS DISCHARGE AND THE DEPTH OF CUT ARE ASSUMED AS KNOWN VALUES. LOSSES ARE NEGLECTED.

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE

**EARTHQUAKE LAKE SPILLWAY**

DISCHARGE INCREASE
BY CUTTING OF THE
CREST

SEPT. 1960




EXAMPLE:

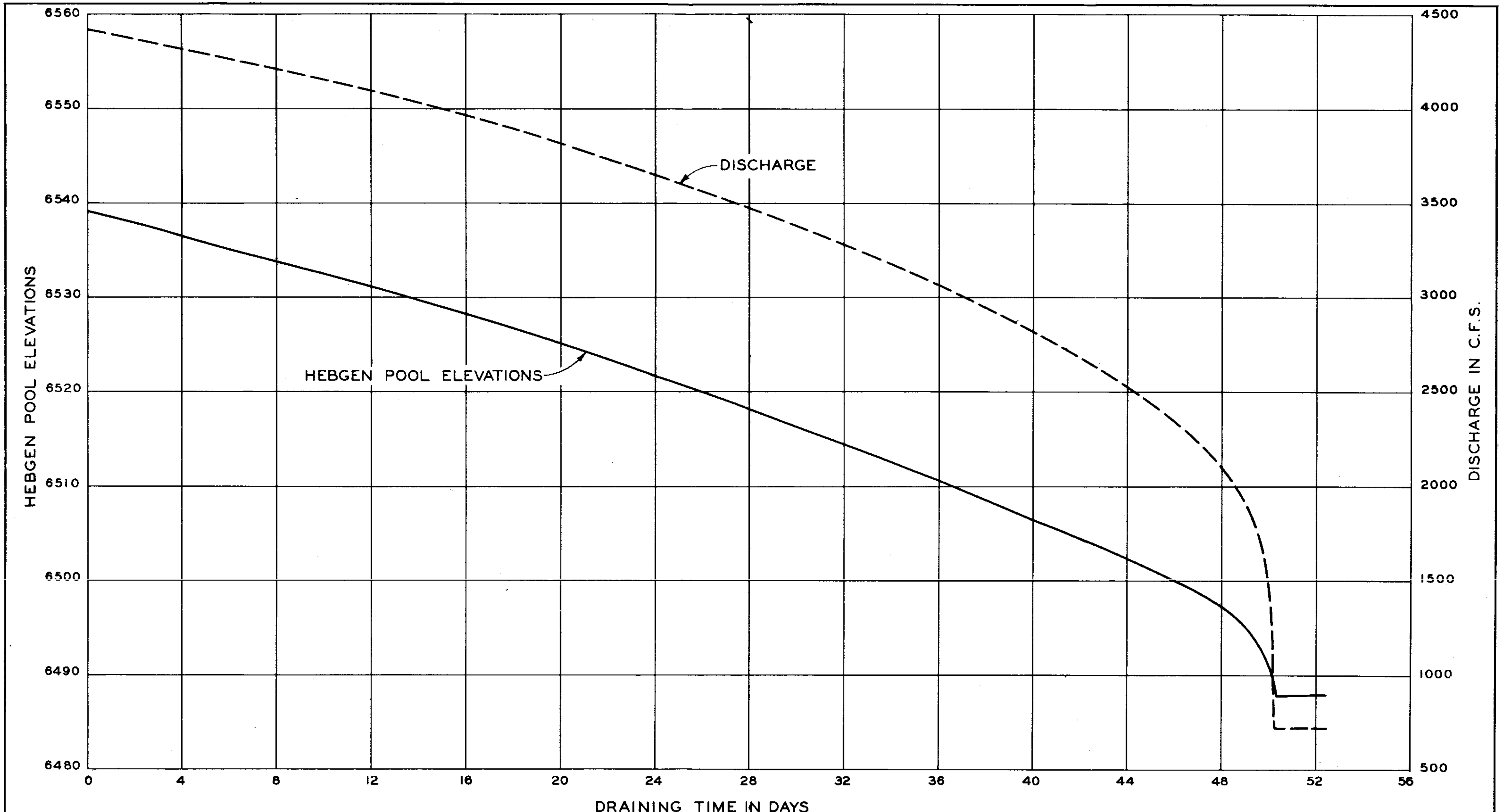
GIVEN: EARTHQUAKE LAKE POOL ELEVATION = 6425
DROP OF POOL ELEVATION = 0.20 FT. PER. HR.
INFLOW FROM HEBGEN = 900 C. F. S.

COMPUTE: FROM CHART: $Q_{0.01} = 103.5 \frac{\text{C.F.S.}}{\text{0.01 FT. PER. HR.}}$

DISCHARGE FROM STORAGE:
$Q_0 = 103.5 \times 20 = 2070$ C.F.S

DISCHARGE OVER CREST:
$Q = 2070 + 900 = 2970$ C.F.S.

MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE
**EARTHQUAKE LAKE SPILLWAY**
EARTHQUAKE LAKE DISCHARGE
RATING CURVE
SEPT. 1960




MADISON RIVER, MONTANA
FLOOD EMERGENCY
MADISON RIVER SLIDE

**HEBGEN LAKE POOL ELEVATIONS**

FULLY OPEN CONDUIT
SEPT. 1960