w/ ltr. dtd. 4/29/88
2053 #49
To: Charlotte Abrams
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REPORTED EFFECTS OF SELECTED EARTHQUAKES IN THE WESTERN NORTH AMERICAN INTERMONTANE REGION, 1852-1983, ON UNDERGROUND WORKINGS AND LOCAL AND REGIONAL HYDROLOGY: A SUMMARY

Completed April, 1988

Prepared by

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Prepared for
Division of Waste Management
Office of Nuclear Material and Safeguards
Washington, D.C. 20555

NRC FIN D1018

8805030193 880429

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UNITS OF MEASURE ABBREVIATIONS USED IN THIS REPORT

^{o}F	degree Fahrenheit	in	inch
cfm	cubic feet per minute	mi	mile
cfs	cubic feet per second	min	minute
ft	foot	pct	percent
ft/h	feet per hour	s	second
gpm	gallon per minute	yr	year
h	hour		

ABSTRACT

Bureau of Mines personnel conducted a literature search for information pertaining to the effects on underground workings and hydrology of 28 specific earthquakes in the Western North American Intermontane Region.

Few data pertaining to damage in the subsurface are available; however, a number of conclusions may be reached:

1) Historically, seismic events (natural or induced) have had few significant effects on underground facilities such as mines, tunnels, and other excavations outside of the immediate epicentral area;

2) Underground workings within the epicentral area may experience moderate damage due to shaking, spalling of loose rocks, or increased water influx; and

3) Those workings in which fault movement occurs may sustain moderate to severe damage such as offset of adits, tunnels, and timbers, caving, and varyious degrees of flooding.

Hydrologic phenomena, on the other hand, are numerous in type and widespread in distribution. The most notable include increases, decreases, or cessations of flow or levels in springs, geysers, streams, and wells. Ephemeral or persistent springs or geysers may come into existence; others may disappear. Areas characterized by geysers and hot springs often exhibit great disturbances in the ground water regime. Mud, silt, or sand may be ejected from ground fissures to form sand boils, craterlets, cones, or "volcanoes". Other manifestations include reversal of stream direction, changes in water chemistry, and earthquake-induced artesian flow from wells.

INTRODUCTION

Purpose

The Bureau was directed by Nuclear Regulatory Commission (NRC) Work Directive 010 (subsequently expanded by Work Directive 014), Task Order 002, under Interagency Agreement NRC-0285-004,
". . . to examine well and mine data for western U.S. mines to determine any effect of regional earthquakes on ground water or underground mines. Hydrologic effects should include documented well fluctuations, flooding in mines or tunnels, or spring modifications. Mine data should be examined for any documentation of damage to openings or underground workings as a result of earthquakes. In addition, if there are any mining areas within the region where persistent induced seismicity has been observed or numerous rock bursts have been reported, these locations should be included in the mine damage summary."

The earthquakes selected by the NRC for this study represent some of the larger seismic events (6.0 magnitude or greater) that have occurred in North America. The geographic region under consideration mainly lies between the Rocky Mountains on the east and the Cascade-Sierra Nevadas on the west and extends from the Canadian border on the north to the State of Sonora, Mexico, on the south.

This report is presented to fulfill the requirements of the work directive.

Objectives

This document was designed to provide a quick reference to the effects of specific earthquakes on underground workings and local and regional hydrology. To this end, a table is provided that lists the earthquakes by primary and alternate name (where applicable), shows their approximate latitude and longitude coordinates, dates,1/ magnitude, and Mercalli Intensity, and summarizes their effects. An abstract for each event, providing more detailed or specific information in bullet form, is presented in appendix A. At the request of the NRC (Work Directive 014), abstracts for the Dixie Valley-Fairview, NV, Hebgen Lake, MT, and Borah Peak, ID, earthquakes have been expanded to include detailed quantitative data.

Methodology

The methodology for Work Directive 010 consisted of literature research and oral and written communications with Federal, State, and private agencies. Research efforts included visits to state mining bureaus in California, Nevada, and Washington, and the libraries of the University of Nevada, Reno, NV; Eastern Washington University, Cheney, WA;/and Washington State University, Pullman, WA.

1/Dates reported in Greenwich Civil Time.

Inquiries and requests for information were solicited from the sources listed below. Those sources indicated by an asterisk are perhaps the best for this type of information.

Arizona Bureau of Mines, Tucson, AZ.
California Division of Mines and Geology Library, Sacramento, CA.
Dr. Ernest Corp, Spokane Research Center, Bureau of Mines, Spokane, WA.
Department of Geology and Mineral Industries, Portland, OR.
Eastern California Museum, Independence, CA.
Idaho Bureau of Mines and Geology, Moscow, ID.
Dr. C. Dan Kealy, Spokane Research Center, Bureau of Mines, Spokane, WA.
Mid-Columbia Library, Kennewick, WA.
Mines Library, University of Nevada-Reno, Reno, NV.
Montana Bureau of Mines and Geology, Butte, MT.
National Geophysical Data Center, Boulder, CO. *
National Technical Information Service, Springfield, VA. *
Nevada Bureau of Mines and Geology, Reno, NV.
Nevada Historical Society, Reno, NV.
Nevada Mining Association, Reno, NV.
New Mexico Bureau of Mines and Mineral Resources, Socorro, NM
Owen Science and Engineering Library, Washington State University, Pullman, WA. *
Paul Sands, Spokane Research Center, Bureau of Mines, Spokane, WA.
Seismological Society of America, Berkeley, CA. *
Superintendent of Documents, Government Printing Office, Washington, DC.
Dr. Tousson Toppozada, California Division of Mines and Geology, Sacramento, CA.
U.S. Geological Survey, Water Resources Division, Reston, VA. *
Utah Geologic and Mineral Survey, Salt Lake City, UT.
Washington Division of Geology and Earth Resources, Olympia, WA.

Accounts of minor to moderate damage to underground workings have often been reported in local newspapers yet have failed to be included in professional or technical journals. The value of press accounts is demonstrated in the abstract of the Owens Valley, CA, event of 1872.2/ Time and funding constraints, however, prohibited visits to the offices of the many newspapers in and around the areas under consideration.

Many accounts contained herein are of a general nature. This is due, in most part, to generalities in the references cited. Site-specific data, when available, are included if such inclusion contributes to the user's overall understanding of the data and does not compromise the NRC's stated objective of a quick and concise reference.

2/Press accounts of the Owens Valley event were graciously provided by Dr. Tousson Toppozada of the California Division of Mines and Geology, Sacramento, CA, from his personal files.

Where possible, ambiguous terms used in the references such as "considerable", "significant", "period of time", etc., are qualified or quantified. However, such quantification and qualification are generally lacking in the references.

To maintain consistency, customary units of measure have used throughout the report.

EARTHQUAKE DAMAGE TO UNDERGROUND WORKINGS

Several recent studies conclude that there are very few available data on damage in the subsurface due to earthquakes (1, p. 2; 2, p. 17; 3)3/ and most earthquake accounts are based on the effects on surface structures; the same conclusion was reached in this study. This paucity of data may be due to several factors that include, but are not limited to:

- Failure to report damage where such was limited to minor rock falls or slight increases in mine water.
- Lack of communication, especially in the 19th and early 20th centuries, in sparsely populated areas.
- Lack of interest by newspaper editors or authors and/or editors of professional or technical journals.
- Little or no subsurface damage directly attributable to earthquakes.

Pratt (1, p. 2) states, "It is common knowledge in mining circles that the damage caused by earthquakes is significantly less in the subsurface than it is on the surface; mines have operated for a substantial period of time in some of the most seismically active regions of the world." This view is shared by Carpenter (2), Stevens (3), and Dowding and Rozen (4).

In an investigation of the Great Alaskan Earthquake of 1964, the U.S. Geological Survey (1, p. 32) found that although some rocks were shaken loose, no significant damage to mines, tunnels, or similar underground facilities was reported. The reports of non-damage, according to Pratt (2, p. 32), are significant, as this event was one of the largest (Magnitude 8.5 on Richter scale) to occur this century and surface damage was extreme.

3/Underlined numbers in parentheses refer to items in the list of references at the end of this report.

In many cases, earthquakes strongly felt on the surface are little felt in the subsurface. For instance, hundreds of miners in the workings at Butte, MT, were unaware of the 1959 Hebgen Lake shock although considerable shaking was reported on the surface. With regard to earthquake damage in the subsurface, Stevens (2, p. 20) draws the following conclusions:

> Severe damage is inevitable when a mine or tunnel intersects a fault along which movement occurs during an earthquake. Possible damage includes offset of the workings on either side of the fault, destruction of timbering, collapse of roof and walls of workings, and flooding of the mine--all of which could have disastrous consequences.
>
> Mines in the epicentral region of strong earthquakes, but not transected by fault movement, may suffer severe damage by shaking. Timbering may fall, and collapse of roof or walls and mine shafts and their linings may occur. Flooding of mine workings by enlargement and interconnection of joints or old fractures is possible.
>
> Mines outside of the epicentral region are likely to suffer little or no damage from a strong earthquake. Some spalling of rock, falling of loose or weak roof pendants, or some shaking, are the only effects to be expected, and in many cases the earthquake is not even noticed in mines so located.
>
> Other factors being equal, it appears reasonable that the severity of damage due to shaking would probably be least when the mine is located in highly competent, unweathered rock. Somewhat greater damage would probably be expected in a mine located in loose, unconsolidated, or incompetent rock. However, comparative data on this are inadequate.
>
> The intensity of shaking below ground is commonly less severe than on the surface due seemingly to rock type. In general, the progression of rock type upward from depth is from highly competent unweathered rock, through weathered rock, to loose, unconsolidated rock near the ground surface.

The overall lack of data pertaining to damage in the subsurface, it would appear, is due in most part to lessened effects of seismicity at depth.

EARTHQUAKE EFFECTS ON LOCAL AND REGIONAL HYDROLOGY

Hydrologic events, on the other hand, are ubiquitous. With few exceptions, large earthquakes (and some smaller ones in water-rich areas such as southwestern Montana) produce a variety of hydrologic phenomena such as:

- Well level fluctuations.
- Flooding of mines and other subterranean chambers.
- Variations in spring flow rates (temporary or permanent increases, decreases, or cessation of flow).
- Increases or decreases in spring or geyser temperature.
- Changes in water chemistry in wells, springs, geysers and streams.
- Changes in volume or flow direction of surface waters.
- Appearance of new springs, streams, or geysers.
- Artesian flow from previously non-flowing wells.
- Loss of artesian flow in wells.
- Rejuvenation of dry springs, wells, streams, or geysers.
- Sinkholes, both subareal and subaqueous.
- Sand boils; sand, silt, or mud "geysers", "volcanoes", or "craterlets."
- Large volumes of sediment in springs, wells, or geysers.
- Pronounced modifications of functional behavior of geysers.
- Water issuing, spouting, or gushing from fissures in the ground.
- Other rather bizarre phenomena such as oil, methane, and water gushing from an abandoned oil well; spring running "blood red" due to great influx of iron oxides; and previously sweet water wells or springs becoming salty or charged with sulfur compounds.

Hydrologic effects and reported damage to underground workings are summarized in table 1.

ROCK BURST

Deep mines in several mining districts in the western United States are subject to rock burst, most notably those in the Coeur d'Alene District of northern Idaho. Rock burst is a phenomenon that occurs in deep mines as a result of the removal (excavation) of confining material, rather than one necessarily related to seismic activity of a local or regional scale. Incipient rock bursts may, however, may be triggered as a result of modifications to the regional or local stress field caused by earthquakes.

TABLE 1. - Summary of effects of selected earthquakes on underground workings and on local and regional ground- and surface-water regime

Event	Date[1]	N lat	W long	Mag[2]	MMI[3]	Subsurface damage	Hydrologic effects
Near Fort Yuma, CA.....	11/09/1852	33.0	114.5	Und	VIII (?)	No damage reports located.	"Mud volcanoes in Mexico south of Ft. Yuma assumed great activity." Area was very sparsely populated.
Owens Valley, CA.....	03/26/1872	36.5	118.0	Und	X-XI	Cracked timbers, rock spalls.	Increases in stream and spring flow; new springs created; water issued from fissures; sand or mud spouts; flow from non-artesian wells; reversal of stream flow; new creek formed; new sulfur springs; fluctations in wells; large water spouts; changes in chemical composition of wells and springs; Owens and Kern Rivers reversed direction for short time.
Near Lake Chelan, WA...	12/15/1872	49.2	121.0	7.0 (?)	IX	No damage reports located.	No reports of hydrologic effects located.
Utah-Idaho Border.....	11/10/1884	41.5	111.2	Und	VIII	No damage reports located.	No reports of hydrologic effects located.
Sonora, Mexico.....	05/03/1887	31.0	109.0	Und	VIII-IX	Rock spall at Tombstone, AZ.	Waterholes became flowing streams; new springs created; water and sand issued from fissures; "remarkable" increase in flow of Yaqui River tributaries; increased volume in wells and springs.
Umatilla, OR.....	03/07/1893	45.9	119.3	Und	VII	No damage reports located.	No reports of hydrologic effects located.
31 mi E. of Milford, UT	11/14/1901	38.7	112.1	Und	VIII	No damage reports located.	Large volume of water ejected from cracks; local creeks increased in volume.
Pine Valley, UT.....	11/17/1902	37.4	113.5	Und	VIII	No damage reports located.	No reports of hydrologic effects located.
Socorro, NM.....	07/16/1906	34.0	107.0	Und	VIII	No damage reported from mines in Socorro or Magdalena Mts.	Hot springs near Socorro increased in temperature (?). See abstract.
Northeastern Arizona... (Coconino Forest).	09/24/1910	36.0	111.1	Und	VIII	No damage reports located.	No reports of hydrologic effects located.
Near Williams, AZ.....	08/18/1912	36.5	111.5	Und	VIII	No damage reports located.	No reports of hydrologic effects located.
Pleasant Valley, NV....	10/03/1915	40.5	117.5	7.7	X	Considerable portion of mine tunnels caved at Kennedy; no reported damage at Golconda or Elko.	Number of hot springs increased in temperature; some dormant springs reactivated; increases and decreases in spring flow; mud and water spouts; some wells and springs went dry; large increase in flow of streams and springs throughout Nevada.
Elsinore, UT.....	09/29 thru 10/01/1921	38.8	112.2	Und	VIII	No damage reports located.	Hot springs in Elsinore Valley ran "blood red" due to heavy influx of iron oxides.

See footnotes at end of table.

TABLE 1. - Summary of effects of selected earthquakes on underground workings and on local and regional ground- and surface-water regime--Continued

Event	Date[1]	N lat	W long	Mag[2]	MMI[3]	Subsurface damage	Hydrologic effects
East of Helena, MT.....	06/28/1925	46.0	111.2	6.7	VIII	No damage reports located.	Widespread effect on wells and springs within 50 mi of epicenter; increases in spring flow and well levels; some wells went dry, some turbid; new springs created; water supply for Toston, MT failed; mud, silt, and sand "geysers" reported; abandoned oil well near Cody, WY spouted oil, gas, and water for several days.
Cedar Mountain, NV.....	12/21/1932	38.7	117.8	7.3	X	"Damage done to mines," nature and extent of damage not reported.	Some wells and springs increased or decreased in volume, some unaffected; numerous reports of sand or silt "volcanoes."
SE of Hawthorne, NV....	01/30/1934	38.3	118.4	Und	VIII-IX	Reports of "considerable" damage at Quaily Mine. See abstract.	Some wells and springs showed level or flow changes.
Hansel Valley, UT.....	03/12/1934	41.7	112.8	6.6	VIII	No damage reports located.	Large quantities of water issued from fissures; mud "volcanoes" and craterlets; new springs; 40 new springs near Monument--had salty taste; artesian flow from wells for period of time; water under considerable hydrostatic head threw large pieces of sod into air; Locomotive Springs dried up then resumed with a 30 pct increase--flowed dark red for 8 h; oil seep near Promontory Point increased flow; sinkholes reported.
Near Helena, MT.....	10/19/1935	46.6	112.0	6.2	VIII	Some mines reported increase in mine water. No damage reports located.	Many sand or silt "volcanoes" reported throughout area; new springs; increase in spring and stream flow; cold spring flowed warm for short period; changes in well levels.
Near Helena, MT.....	11/01/1935	46.6	112.0	6.0	VIII	No damage reports located.	Essentially same as above.
Milton-Freewater, OR...	07/16/1936	46.2	118.2	5.7 (?)	VII	No damage report located.	Several dormant springs revived; an artesian well also revived and spouted water for a period of time.
Southwestern Montana... (Virginia City-Alder area).	11/23/1947	44.8	112.0	6.3	VIII	No damage reports located.	No reports of hydrologic effects located.
East of Fallon, NV..... (Fallon-Stillwater series).	07/06 thru 08/24/1954	39.4	118.5	6.6	VIII-IX	No damage reports located.	Water well level changes, also in hot water wells; several sand, mud or silt "volcanoes;" changes in water chemistry.
Dixie Valley, NV..... (Dixie Valley-Fairview)	12/16/1954	39.3	118.2	7.3	X	No damage reports located.	Mudflow due to soil saturation; artesian flow from previously non-flowing wells; water table raised in some valleys, lowered in others; mud and/or silt "volcanoes" along fissures in ground; changes in spring flow, well levels.

See footnotes at end of table.

TABLE 1. - Summary of effects of selected earthquakes on underground workings and on local and regional ground- and surface-water regime--Continued

Event	Date[1]	N lat	W long	Mag[2]	MMI[3]	Subsurface damage	Hydrologic effects
Hebgen Lake, MT.....	08/18/1959	44.8	111.1	6.0-7.1	VI-X	Flooding in Clayton Silver Mine, Custer Co., ID.	Great effect on surface and ground water regime; several new springs; springs, wells turbid; new thermal springs created; water spouts under considerable hydrostatic pressure; some wells became artesian; changes in well levels throughout the United States, including Puerto Rico and Hawaii; water spouted from fissures; large sinkholes developed; great changes in functional behavior of most thermal springs and geysers in Yellowstone National Park; scores of long-dormant geysers reactivated, new ones created; violent geyser eruptions.
Pocatello Valley, ID...	03/28/1975	42.1	112.5	6.1	VIII	No damage reports located.	No reports of hydrologic effects located.
Yellowstone National... Park, MT.	06/30/1975	44.7	110.6	6.4	VIII	No damage reports located.	Geysers greatly affected, many increased markedly in volume and activity, many ceased flow; several new geysers came into existence; Gibbon River became very turbid.
Mammoth Lakes, CA.....	05/25/1980	37.6	118.6	6.1	VII	No damage reports located.	Hot Creek area closed due to very high water temperatures; many sand boils; discharge of water from slump blocks; new hot spring created; some springs increased in flow, others decreased, some unaffected; wells and springs became turbid; steam and fumes issued from fissures.
Borah Peak, ID.....	10/28/1983	44.0	113.9	7.3	IX-X	Clayton Silver Mine flooded; Kraken Hill Mine badly damaged, nature and scope of damage proprietary.	Large increases in spring and stream discharge; ephemeral lake formed; some springs dried up; higher levels in many U.S. Geological Survey (USGS) observation wells; sand and water issued from fissures; some wells in Montana went dry, many turbid, some increased in iron oxide levels.

Und Undetermined.
(?) An uncertainty exists as to the actual value.
[1]Greenwich Civil Time (GCT).
[2]Magnitude--based on Richter scale.
[3]Based on Modified Mercalli Intensity scale, 1931.

According to Thrush (5, p. 932-933), rock bursts are: "The sudden yielding, sometimes with explosivelike violence, of the rock in pillars, in the bottoms of shafts being sunk, in stopes, or at the face of drifts being driven to develop the mine. They are not likely to occur until a depth of 1,500 to 3,000 ft below the surface is reached." The term is further defined (5) as "The occurrence of the rupture of a mass of strained rock in such a manner that a large portion of the local (emphasis added) accumulated strain energy is released in a short period of time. The types of failures vary from splitting off of small slabs of rock from a mine wall or face to the major collapse of large pillars, roofs, or other massive portions of the mine structure. The conditions which influence rock bursts in mines are: (1) The area of excavation; (2) the shortest roof span; (3) stress pattern and concentration; (4) types of rocks involved; (5) directions of planes of weakness in the rock; and (6) the dip of the mineral deposit. The heaviest (most intense, of an explosive nature) rock bursts are attributable to pillar failure."

Brady (6) has noted that local anomalous microseismicity changes (an increase followed by a decrease) were recorded prior to three moderate rock bursts in the Star mine, Burke, ID. Analyses of pre-and post- seismic activity are interpreted in terms of, and shown to be consistent with, the inclusion theory of failure. The rock bursts were not related to earthquakes.

During the course of this study, no reports of rock burst as the result of local or regional earthquakes were located.

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2. Carpenter, D. W. and D. Towse. Seismic Safety in Nuclear-Waste Disposal. Livermore, CA: Lawrence Livermore Natl. Lab., UCID-18125, 1979.

3. Stevens, P. R. A Review of the Effects of Earthquakes on Underground Mines. U.S. Geol. Surv. OFR 77-313, 1977.

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5. Thrush, P. W, and Staff, Bureau of Mines. A Dictionary of Mining, Mineral, and Related Terms. Washington, DC: U.S. Dept. Interior, Bureau of Mines, 1968, pp. 932-933.

6. Brady, B. T. Anomalous Seismicity Prior to Rock Bursts: Implications for Earthquake Prediction. Basel, Switzerland: Pageoph, v. 115, Birkhauser Verlag, 1977, pp. 357-374.

APPENDIX A.--EARTHQUAKE ABSTRACTS

The following earthquake abstracts are presented in bullet form for quick reference and easy reading.

For the user's convenience, references for individual earthquakes are included at the end of each abstract. Information followed by a number in parentheses relates that datum or data to a specific reference; data not so indicated were abstracted from one or more of the references listed.

In some cases, such as the Excelsior and the Dixie Valley-Fairview earthquakes in Nevada and the Hebgen Lake earthquakes in Montana, the principal- and aftershocks are treated as a single event as it is often impossible to distinguish from the literature which event is responsible for reported damage or hydrologic manifestations. The Montana earthquakes of 1935, for example, consisted of several large aftershocks and more than 2,000 smaller shocks.

An entry such as "No reports of damage located" should not be construed as "No damage occurred." Such entries do not necessarily preclude the existence of damage information, only that the investigator was unable to locate any relevant data. Data in quotes denote the words of the referenced author(s).

Location: Near Fort Yuma, CA (?)
Latitude: 33° N.
Longitude: 114.5° W.
Date: November 9, 1852
Intensity (Modified Mercalli scale): VIII (?)
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- ". . . there were fissures in the ground there and the mud volcanoes in Mexico south of Fort Yuma assumed great activity."

References

Townley, S. D. and M. W. Allen. Descriptive Catalog of the Earthquakes of the Pacific Coast of the United States, 1769-1928. Bull. Seism. Soc. Amer. v. 29, No. 1, 1939, p. 29.

(?) An uncertainty exists as to the actual location or value.

Location: Owens Valley, CA
Latitude: 36.5° N.
Longitude: 118° W.
Date: March 26, 1872
Intensity (Modified Mercalli scale): X-XI
Magnitude (Richter scale): Undetermined

Effects on Underground Mines 1/

- "Rumors of a few sets of timbers broken in some of the mines" in vicinity of Austin (NV) (1).

- Earthquake distinctly felt at Gold Hill (Virginia City, NV). Miner injured by fall of rock in Belcher Mine (2).

- Men in mine near Virginia City (Nevada) felt "very disagreeable sensations" (3).

- Earthquake "cracked timbers in some quartz mines" in vicinity of Jackson, Amador County, CA (4).

- Mining camp of Cerro Gordo severely damaged (5). No reported damage to underground workings.

- "None of the (silver/lead/zinc) mines at Cerro Gordo caved in" (6).

- At Hot Springs, several severe shocks were felt. Miners at 200 ft felt nothing (7).

- Heavy damage to railroad tracks, roads, and homes at Eclipse Mine. Kearsarge Mine and Mill felt severe shock; some damage to mill (8). No reported damage to underground workings at either mine; however, a miner at the Eclipse was injured by minor spalling of rock.

- Earthquake not felt in underground mines in vicinity of Bakersfield (9).

Hydrologic Effects 1/

- Temporary and/or permanent changes to watercourses, accumulations of water "where such were not known before," depressions filled with water. Owens River near Lone Pine went dry for several h following the first heavy shock. Earthquake waves on Owens Lake (10).

- Immense volume of water thrown out of well at Desert Spring. Water continued to flow (from March 26) until March 30 (11).

- "Water and quicksand thrown up from cracks up to 30 feet in depth" (12).

- "Nine-foot-high tidal wave" on Owens Lake (13).

1/Newspaper accounts from the personal files of Dr. Tousson Toppozada, CA Div. Mines and Geol., Sacramento, CA.

- "The recent earthquake let the bottom out of the well of Josiah Rogers near this place. The well has never been without water in the dryest season, but since the earthquake the water has disappeared until there is not a bucketful left" (14).

- "South of Fish Springs Slough water spouted out of the ground in many places. Several new springs (came into existence) in formerly desert places. In other places, streams and springs dried up" (15).

- "Water stopped running over Vernal Falls at Yo Semite (now Yosemite National Park) for several minutes" (16).

- "Old springs have dried up and new springs started" (17).

- "Spring flow increased four-fold; quality of water increased, (now) pure and sweet." Other springs in San Diego County increased flow (18).

- Large increase in flow at Oak Spring (19).

- "A wave about 1 foot high rolled up the Stockton Channel" (20).

- The Reno Journal (April 30, 1872) reports a hot spring east of Wadsworth commenced throwing water to a height of 25 ft after earthquake (21).

- "Columns of water were lifted into the air and created quite a stream" (22).

- Thirty new sulfur springs reported in Linn's Valley near Glenville (CA ?). Some fresh water springs increased two- to four-fold in volume; some changed from fresh water to sulfur water (23).

- "Important spring dries up . . attributed to earthquake" (24).

- "Spring, low in volume, becomes running stream with 15 inches of good, clear, water" (25).

- "Water in springs in Columbus, Esmeralda County (Nevada), spouted 12-15 feet" (26).

- "Owens River increases in volume. New creek makes appearance" (27).

- "Owens Lake has risen 4 feet since the earthquake. The Kerns and Owens rivers reversed course for several minutes. When they returned to normal flow (direction), they showed a large increase in volume" (28).

- "Owens Lake rising since earthquake; threatens to flood (mine) workings at Swansea" (29). 2/

2/No reports of actual flooding were located.

- "Inyo earthquake credited with having entirely stopped the flow of water in some of the artesian wells at Los Angeles; those still active are flowing at diminished rates" (3).

References

1. Reese River Reveille, Austin, NV, Mar. 26, 1872, p. 2.

2. Sacramento Daily Union, Sacramento, CA, Mar. 27, 1872, p. 5.

3. Sacramento Daily Record, Sacramento, CA, Mar. 30, 1872, p. 7.

4. Amador Dispatch, Jackson, CA, Mar. 30, 1872, p. 2.

5. Sacramento Daily Union, Sacramento, CA, Apr. 1, 1872, p. 2.

6. Evening Express, Los Angeles, CA, Apr. 5, 1872, p. 3.

7. Sacramento Daily Union, Sacramento, CA, Apr. 1, 1872, p. 2.

8. The Inyo Independent, Independence, CA, June 6, 1872, p. 3.

9. Kern County Weekly Courier, Bakersfield, CA, Apr. 13, 1872, No. 16, v. 3, p. 2.

10. Whitney, J. D. 8th Annual Report of the State Mineralogist. CA State Min. Bureau, 1888, pp. 288-298.

11. Evening Express, Los Angeles, CA, Mar. 30, 1872, p. 2.

12. _____, Apr. 15, 1872, p. 3.

13. _____, Apr. 16, 1872, p. 2.

14. Nevada Daily Transcript, Nevada City, NV, Apr. 3, 1872, p. 3.

15. Sacramento Daily Union, Sacramento, CA, Apr. 1, 1872, p. 2.

16. _____, Apr. 12, 1872, p. 3.

17. Sacramento Daily Record, Sacramento, CA, Mar. 28, 1872, p. 2.

18. Daily Morning Bulletin, San Diego, CA, Apr. 3, 1872, p. 3.

19. _____, Apr. 13, 1872, p. 3.

20. Daily San Joaquin Republican, Stockton, CA, Mar. 26, 1872, p. 3.

21. Stockton Daily Independent, Stockton, CA, Apr. 30, 1872, p. 2. See also NV State J., Reno, NV, Mar. 30, 1872, p. 3.

22. Visalia Weekly Delta, Visalia, CA, Mar. 28, 1872, p. 2.

23. _____, Apr. 4, 1872, p. 2. See also Oakland Daily News, Oakland, CA, Apr. 29, 1872, p. 2.

24. _____, May 16, 1872, p. 3.

25. Tuolumne Independent, Sonora, CA, Apr. 13, 1872, p. 3.

26. _____, May 4, 1872.

27. Sacramento Bee, Sacramento, CA, Apr. 3, 1872, p. 2.

28. Daily Bulletin, San Diego, CA, Apr. 5, 1872, p. 1.

29. Kern County Weekly Courier, Bakersfield, CA, May 4, 1872, No. 19, v. 3, p. 2.

30. The Inyo Independent, Independence, CA, Apr. 13, 1872, p. 3.

Location: Near Lake Chelan, WA 1/
Latitude: 49.2° N.
Longitude: 121.2° W.
Date: December 15, 1872
Intensity (Modified Mercalli scale): IX
Magnitude (Richter scale): 7.0 (?)

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- No reports of hydrologic effects located.

Reference

Townley, S. D. and M. W. Allen. Descriptive Catalog of the Earthquakes of the Pacific Coast of the United States, 1769-1928. Bull. Seism. Soc. Amer., v. 29, No. 1, 1939, pp. 259-260.

1/ Location uncertain; some sources place epicenter in British Columbia, others in Puget Sound (WA) area
(?) An uncertainty exists as to the actual value.

Location: Utah-Idaho Border
Latitude: 41.5° N.
Longitude: 111.2° W.
Date: November 10, 1884
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- No reports of hydrologic effects located.

Reference

Williams, J. S. and M. L. Tapper. Summary of Earthquakes in Utah. Bull. Seism. Soc. Amer. v. 43, No. 3, 1953, pp. 191-218.

Location: Sonora, Mexico
Latitude: 31° N.
Longitude: 109° W.
Date: May 3, 1887
Intensity (Modified Mercalli scale): VIII-IX
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- Mining town of Tepic, near Moctezuma, Sonora, Mexico, was totally demolished. However, the nearby Santa Ana Mine reported "no caving in any of the underground works" although "swaying" was distinctly felt on the 600 level (1).

- The shock was distinctly felt in Bisbee and Tombstone, AZ, but mine damage in the area was "trifling" and consisted of spalling of loose rock (2). "At this time, the mines of Bisbee and Tombstone were very extensively opened with many miles of underground workings and large stopes in limestone" (2).

- A mine in Tombstone reported spalling on the 150 level.

- Another mine reported tremor "definitely felt" on the 400 level and miners reported observing a "wave" or "deflection" in solid limestone (2).

- Miners at the 600 level in an unspecified mine felt shock "severely", many became sick--miners at the 150 level felt "less of a shock" (3).

Hydrologic Effects

In State of Sonora, Mexico

- Pre-existing "waterholes" (in Tepic-Moctezuma area) became flowing springs; some dried up (1).

- A new spring came into existence on the road to Santa Ana Mine (Tepic, Sonora).

- Aguilera (4) reports cracks near Baptiste, Sonora, "emitted water and fine sand" and commented on the "remarkable" increase in volume and rate of flow of the tributaries of the Yaqui River; new rivulets of water appeared while others disappeared. The volume of water in springs, wells, and surface drainages was "surprising" as the surrounding area was extremely dry (4).

References

1. MacDonald, B. Bull. Seism. Soc. Amer., v. 8, No. 1, 1911, pp. 74-78.

2. Staunton, W. F. Bull. Seism. Soc. Amer., v. 8, No. 1, 1918, pp. 25-27.

3. Townley, S. D. and M. W. Allen. Descriptive Catalog of the Earthquakes of the Pacific Coast of the United States, 1769-1928. Bull. Seism. Soc. Amer. v. 29, No. 1, 1939, p. 293.

4. Aguilera, J. G. Bull. Seism. Soc. of Amer., v. 10, No. 1, 1920, pp. 31-44.

Location: Umatilla, OR
Latitude: 45.9° N.
Longitude: 119.3° W.
Date: March 7, 1893
Intensity (Modified Mercalli scale): VII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- No reports of damage to underground mines located; reports of damage on surface "scanty--one wall of a stone building was thrown down".

Hydrologic Effects

- No reports of hydrologic effects located.

Reference

Townley, S. D. and M. W. Allen. Descriptive Catalog of the Earthquakes of the Pacific Coast of the United States, 1769-1928. Bull. Seism. Soc. Amer., v. 29, No. 1, 1939, p. 254.

Location: 31 mi east of Milford, UT
Latitude: 38.7° N.
Longitude: 112.1° W.
Date: November 14, 1901
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- Large volumes of water ejected from ground fissures.
- Local creeks increased flow volume.

Reference

Williams, J. S. and M. L. Tapper. Summary of Earthquakes in Utah. Bull. Seism. Soc. Amer., v. 43, No. 3, 1953, pp. 191-218.

Location: Pine Valley, UT
Latitude: 37.4° N.
Longitude: 113.5° W.
Date: November 17, 1902
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines (1, 2)

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects (1, 2)

- No reports of hydrologic effects located.

References

1. Townley, S. D. and M. W. Allen. Descriptive Catalog of the Earthquakes of the Pacific Coast of the United States, 1769-1928. Bull. Seism. Soc. Amer., v. 29, No. 1, 1939, p. 289.

2. Williams, J. S. and M. L. Tapper. Summary of Earthquakes in Utah. Bull. Seism. Soc. Amer., v. 43, No. 3, 1953, pp. 191-218.

Location: Socorro, NM
Latitude: 34° N.
Longitude: 107° W.
Date: July 16, 1906
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- Severe damage was sustained by adobe and masonry buildings in Socorro (School of Mines building undamaged). No damage, however, was reported by C. T. Brown (a mining engineer) in his inspection report of the mines in the nearby Socorro and Magdalena mountains.

Hydrologic Effects

- Hot springs near Socorro, according to various reports, increased in temperature; Reid (1), however, questions these reports.

Reference

1. Reid, H. F. Bull. Seism. Soc. Amer., v. 1, No. 1, 1911, pp. 10-16.

Location: Northeastern Arizona (Coconino Forest)
Latitude: 36° N.
Longitude: 111.1° W.
Date: September 24, 1910
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- No reports of hydrologic effects located.

Reference

Townley, S. D. and M. W. Allen. Descriptive Catalog of the Earthquakes of the Pacific Coast of the United States, 1769-1928. Bull. Seism. Soc. Amer., v. 29, No. 1, 1939, p. 275.

Location: Near Williams, AZ
Latitude: 36.5° N.
Longitude: 111.5° W.
Date: August 18, 1912
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- The area then was very sparsely populated; no reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- No reports of hydrologic effects located.

Reference

Tolman, C. F., Jr. Bull. Seism. Soc. Amer., v. 2, No. 3, 1912, pp. 209-210.

Location: Pleasant Valley, NV
Latitude: 40.5° N.
Longitude: 117.5° W.
Date: October 3, 1915
Intensity (Modified Mercalli scale): X
Magnitude (Richter scale): 7.7

Effects on Underground Mines

- At Kennedy (near the epicenter) . . ."A considerable portion of mine tunnels were caved."
- No reported mine damage at Golconda (103 mi from Kennedy) or Elko (44 mi from Kennedy).

Hydrologic Effects

- Increased flow in springs around Elko.
- "One of the most striking effects of the earthquake was the large increase in the flow of streams and springs throughout Nevada."
- In Pleasant Valley, all streams issuing from the Sonoma Range increased by a multiple of three to four; water stood on the (normally dry) playas.
- Mud spouts and "craterlets" came into existence.
- At Mud Springs, "water spouted to 2 to 3 feet with every lurch of the ground."
- Several hot springs increased flow; many went dry, many came into existence.
- A number of hot springs increased in temperature; several "extinct" hot springs renewed flow.
- Hot springs at Elko rose several in.
- Spring near Carson went dry; drilled to restore flow.

Reference

Jones, J. C. The Pleasant Valley, Nevada, Earthquake of October 2, 1915. Bull. Seism. Soc. Amer., v. 5, No. 4, 1915, pp. 190-205.

Location: Elsinore, UT
Latitude: 38.8° N.
Longitude: 112.2° W.
Date: September 29, 30, and October 1, 1921
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): Undetermined

Effects on Underground Mines

- No reported damage to underground workings although heavy damage sustained to brick and adobe structures, chimneys, plaster, glass, etc., at surface (1).

Hydrologic Effects

- Along east margin of Elsinore Valley near Monroe and Joseph, hot springs became "blood red" due to a heavy influx of iron oxides (2).

References

1. Pack, F. J. Bull. Seism. Soc. Amer., v. 11, Nos. 3 and 4, 1921, pp. 155-165.

2. Williams, J. S. and M. L. Tapper. Summary of Earthquakes in Utah. Bull. Seism. Soc. Amer., v. 43, No. 3, 1953, pp. 191-218.

Location: East of Helena, MT
Latitude: 46° N.
Longitude: 111.2° W.
Date: June 28, 1925
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): 6.7

Effects on Underground Mines (1, 2, 3)

- No reported mine damage. Miners at a mine in Barker, MT, working at a depth of 250 ft did not feel shock; miners in underground mines at Butte, MT (42 mi from Helena), were also unaware of earthquake.

Hydrologic Effects (1, 2, 3)

- Widespread effect on springs and wells within a 50 mi radius of epicenter.
- Both increases and decreases in spring flow and well levels were reported.
- Some wells went dry while others became turbid.
- Water supply for Toston, MT, failed.
- Several new springs came into existence; several went dry.
- Reported increased flow of hot water at White Sulphur Springs and Alhambra Springs at Clancy.
- An unidentified oil well near Cody, WY, unproductive for several years, spewed gas, oil, and water for several days. Flow started about noon of the day following the earthquake.
- Near Lewistown a spring "broke out" flowing at a rate of 126 gpm
- Several mud, silt, sand, and water "geysers" reported.

References

1. Byerly, P. Bull. Seism. Soc. Amer., v. 16, No. 4, 1926, pp. 209-265.

2. Pardee, J. T. The Montana Earthquake of June 27, 1925. U.S. Geol. Surv. Prof. Paper 147, 1926, pp. 7-23.

3. Willson, F. F. Bull. Seism. Soc. Amer., v. 16, No. 3, 1926, pp. 165-169.

Location: Cedar Mountain, NV
Latitude: 38.7° N.
Longitude: 117.8° W.
Date: December 21, 1932
Intensity (Modified Mercalli scale): X
Magnitude (Richter scale): 7.3

Effects on Underground Mines 1/

- " . . . a mill at one mine was considerably damaged (assume mill was on surface) and there was some underground sloughing in various mine workings" (1, p. 27).

- "Damage done to mines" (2)--nature and extent of damage not reported.

Hydrologic Effects (3)

- Several wells and springs experienced increases and/or decreases in flow rates; many remained unaffected.

- Spring flow at the Nevada Mine increased.

- Numerous reports of silt or sand "volcanoes" and craters.

References

1. Stevens, P. R. A Review of the Effects of Earthquakes on Underground Mines. U.S. Geol. Surv. Open-file Rep. 77-313, 1977.

2. U. S. Earthquakes, 1928-1935. U.S. Dep. Commerce, Environ. Sci. Service Admin., Coast and Geod. Surv., Washington, DC, 1968, p. 12.

3. Gianella, V. P. and E. Callaghan. The Cedar Mountain, Nevada Earthquake of December 20, 1932. Bull. Seism. Soc. Amer., v. 24, No. 4, 1934.

1/Richter (1958, in 1, p. 27) states (area of Cedar Mountain) " . . . is one the least inhabited parts of the U.S.; at the time of the earthquake hardly a dozen persons were in the region."

Location: Southeast of Hawthorne, NV (Excelsior Mountains earthquake sequence)
Latitude: 38.3° N.
Longitude: 118.4° W.
Date: January 30, 1934
Intensity (Modified Mercalli scale): VIII-IX
Magnitude (Richter scale): Undetermined

Effects on Underground Mines (both principal and aftershocks)

- Miners in a tunnel at Marietta (NV) " . . . felt obliged to steady themselves" but reported no damage.

- No damage was reported from the Silver Star Mine (Camp Douglass).

- Underground workers at the Silver Dike tungsten mine "scarcely noticed" shocks that were "acutely perceptible" to those on surface. No reported mine damage.

- Reports of "considerable damage" to the Quaily Mine. However, damage (according to the owner) may have been the result of the 1932 Cedar Mountain earthquake.

Hydrologic Effects

- Some wells and springs exhibited increases or decreases in levels or flow rates with no discernible pattern.

Reference

Gianella, V. P. and E. Callaghan. The Earthquake of January 30, 1934 at Excelsior Mountains, Nevada. Bull. Seism. Soc. Amer., v. 25, No. 2, 1935, pp. 161-168.

Location: Hansel Valley, UT (Kosmo)
Latitude: 41.7° N.
Longitude: 112.8° W.
Date: March 12, 1934
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): 6.6

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects (1, 2)

- Large quantities of water issued from ground fissures.
- Many new springs came into existence.
- Forty new springs at Monument--all had salty taste; water passed through several salt beds.
- Mud cone and "volcanoes" reported.
- Several sinkholes reported.
- Artesian flow from previously non-flowing wells--resumed normal flow after period of time.
- Large pieces of sod thrown into air by water spouts under considerable hydrostatic head.
- Large fluctuations in area wells.
- Locomotive Springs dried up, later resumed at 30 pct increase in flow--water ran dark red for 8 h.
- Oil seep near Promontory Point increased flow.

References

1. Shenon, P. J. "The Utah Earthquake of March 12, 1934". Paper in U.S. Earthquakes, 1928-1935. Washington, DC: U.S. Dep. Commerce, Environ. Sci. Service Admin., Coast and Geod. Surv., 1968, pp. 43-48.

2. U.S. Earthquakes, 1928-1935. Washington, DC: U.S. Dept. of Commerce, Environ. Sci. Service Admin., Coast and Geod. Surv., 1968, pp. 13-18.

Location: Near Helena, MT
Latitude: 46.6° N.
Longitude: 112° W.
Date: October 19, 1935
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): 6.2

Effects on Underground Workings

- No reported damage to underground workings within the State of Montana.
- Several mines (not identified by name) reported increase in water inflow.
- Mine officials at the Gould Mine, 28 mi northwest of Helena, reported minor spalling of rock on the 200 level; the shock was not felt below the 200 level.
- An unidentified mine, 30 mi southwest of Helena, reported no damage but the tremor was "felt slightly" on the 500 level.

Hydrologic Effects

- Many wells and springs in the region showed changes in level and/or flow volume.
- Most noticeable was increased spring flow and the development of new springs.
- Several creeks and rivers (not specified) reportedly showed significant increases in flow.
- A normally cold spring, 75 mi southwest of Helena, flowed warm; returned to normal "after a few days".
- Sand or silt "geysers" or "volcanoes" were reported throughout the region.

Reference

Scott, H. W. The Montana Earthquakes of 1935. MT Bur. Min. and Geol. Mem. 16, 1936.

Location: Near Helena, MT 1/
Latitude: 46.6° N.
Longitude: 112° W.
Date: November 1, 1935
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): 6.0

Effects on Underground Workings

- No reports of damage or other effects to underground mines or workings located.

- Tremor not felt below the 600 level at the Gould Mine (28 mi northwest of Helena); cars slightly shaken on the 600 level of an unspecified mine southwest of Helena.

Hydrologic Effects

- Effects on surface and ground waters were essentially the same as for the October 19 earthquake described on the preceeding page.

Reference

Scott, H. W. The Montana Earthquakes of 1935. MT Bur. Min. and Geol. Mem. 16, 1936.

1/Probable aftershock of October 19 earthquake.

Location: Milton-Freewater, OR
Latitude: 46.2° N.
Longitude: 118.2° W.
Date: July 16, 1936
Intensity (Modified Mercalli scale): VII
Magnitude (Richter scale): 5.7 (?)

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- Several dormant springs revived by tremor; a dry well also revived and spouted water for an unspecified period of time.

Reference

Anonymous. Bulletin of the Seismological Society of America. V. 27, No. 3, 1937, pp. 205-209.

(?) An uncertainty exists as to the actual value.

Location: Southwestern Montana (Virginia City-Alder area)
Latitude: 44.8° N.
Longitude: 111.8° W.
Date: November 23, 1947
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): 6.3

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- No reports of hydrologic effects located.

Reference

Qamar, A. I. and M. C. Stickney. Montana Earthquakes, 1869-1969. MT Bur. Mines and Geol. Mem. 51, 1983.

Location: East of Fallon, NV (Fallon-Stillwater Earthquakes)
Latitude: 39.4° N.
Longitude: 118.6° W.
Date: July 6 through August 24, 1954
Intensity (Modified Mercalli scale): VIII-IX
Magnitude (Richter scale): 6.6 to 6.8

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- Widespread "silt volcanoes."
- Water well levels in the general area increased or decreased with "no discernible pattern;" same phenomena noted in hot water wells.
- At Salt Wells, the water reportedly experienced a marked change in taste and odor.

Reference

Slemmons, D. B. Damage Caused by the Earthquakes of 1954. Bull. Seism. Soc. Amer., v. 46, No. 1, 1956.

Location: Dixie Valley, NV (Dixie Valley-Fairview)
Latitude: 39.3° N.
Longitude: 118.2° W.
Date: December 16, 1954
Intensity (Modified Mercalli scale): X
Magnitude (Richter scale): 7.1

The Dixie Valley-Fairview events of December 16, 1954, consisted of a magnitude 7.1 tremor north of Fairview Peak followed 4.3 min later by a magnitude 6.8 shock along the western margin of Dixie Valley 34 mi to the north. A map showing the Dixie Valley-Fairview epicenters and surface faulting is presented in figure 1.

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located. Water levels in the Stingaree Mine, however, declined by 1.4 ft following the tremor.

- Miners at Nevada Scheelite Mine reported "flashes of fire" on nearby mountain slopes but no damage at mine.

Hydrologic Effects

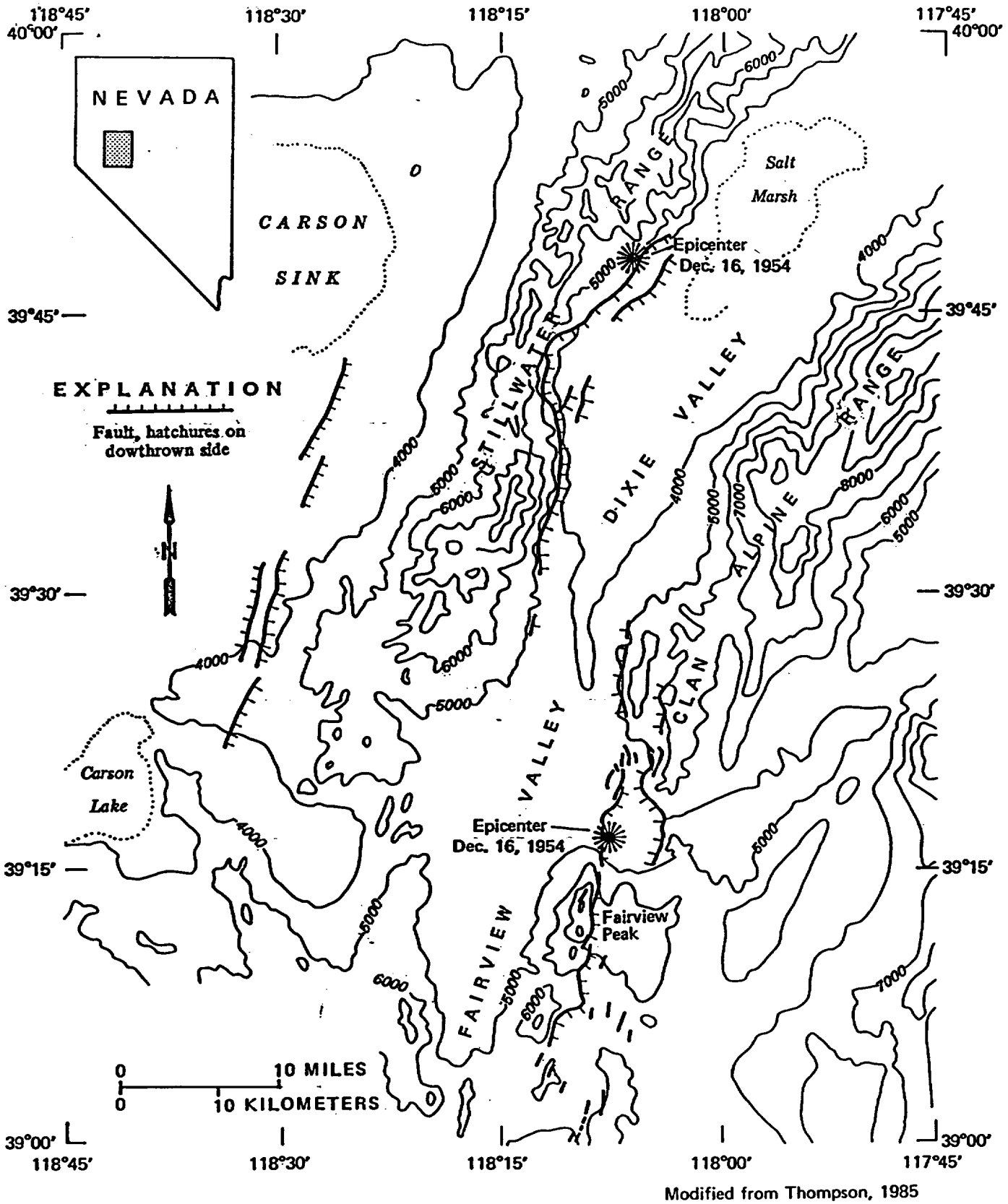
General

The following discussion pertaining to the overall hydrologic effects of the Dixie Valley-Fairview earthquakes is repeated from Zones (1).

The earthquake (author treats both shocks as a single event) of December 16, 1954, affected the hydrologic conditions in the Dixie Valley and Fairview Valley areas, NV. In Dixie Valley the rate of flow of water was temporarily increased and water flowed for more than a month from several wells that had not flowed before. Water levels in wells were higher after the earthquake, but the trend of water levels since the earthquake has varied locally. There is no evidence that ground-water temperatures were affected.

The flow of Mud Spring, which is on the main fault on the west side of Dixie Valley, increased substantially after the earthquake, but since has decreased to essentially its pre-earthquake rate.

The water level in Fairview Valley was about 4 feet higher after the earthquake. In East Gate Valley and West Gate Valley, ground-water levels were lower after the earthquake. In June 1956, the water level in East Gate Valley was 34 feet lower than the pre-earthquake level. At West Gate the water level was about 9 feet lower. In Stingaree Valley, the water level began to rise after an initial decline and reached a peak of about 11 feet higher than the pre-earthquake level.



Modified from Thompson, 1985

FIGURE 1. - Map showing epicenters and surface faulting, Dixie Valley-Fairview earthquakes

Possible causes for the rise in ground-water levels in Dixie and Fairview Valleys include tilting of the confined and semiconfined acquifers in the valleys, compaction of sediments of the valley fill, and increased upward leakage of ground water.

It is possible that opening of new fractures and widening of pre-existing fractures in the bedrock between East Gate, Cowkick, and Stingaree Valleys has accelerated the rate of movement of ground water between those valleys.

The temporary increase in the flow of water from Mud Spring may be due to the opening of fractures in the fault zone along which the water is rising, or to a possible lowering of the land surface at the springs with a resulting increase in artesian head at the spring orifices.

It is thought that any increase in the total discharge of ground water in the Dixie and Fairview Valleys areas is temporary because the increased discharge is probably from ground-water storage.

Fluctuations in water well levels, attributed to the Dixie Valley-Fairview earthquakes, were reported from the States of Arizona, California, Florida, Hawaii, Idaho, Illinois, Michigan, Nevada, New Jersey, New York, Tennessee, and Wisconsin (2).

Effects on Surface Water

As there are no perennial streams in the Dixie Valley-Fairview Valley areas, no surface hydrologic effects were noted. However, the southern part of the Humboldt Salt Marsh, north of the Dixie Valley settlement, was filled with water--an unusual occurrence for that time of year (December-January). Part of the standing water on the playa was attributed by Zones (1) to snowmelt, but a large portion was ". . . undoubtedly ground water that had flowed onto the playa from wells and springs and possibly from openings in the ground". Jones (3) noted a similar phenomenon in the playa in Pleasant Valley (Pleasant Valley earthquake of 1915), although he attributed the large volume of water to increases in local stream flow.

Effects on Springs

Two groups of springs in the Dixie Valley-Fairview Valley areas were examined by Zones (1) following the earthquake. Dixie Hot Springs, on the west side of Dixie Valley, exhibited no apparent change in flow or temperature between 1951 and January 1955.

Mud Spring, at the bedrock/alluvium contact at the base of the Stillwater Range, flowed at less than 1 gpm prior to the earthquake. However, a substantially larger flow was indicated by evapotranspiration. The area surrounding the springs (about 1 acre) received enough water to support the growth of grass, shrubs, and a few trees.

The main fissure of the earthquake transected the Mud Spring area and produced a fault-line graben about 20 ft wide and 5 ft deep. After the earthquake, water flowing from numerous small openings (few, if any, greater than 1 in. wide) filled the graben and overflowed onto the adjacent alluvial fan.

Spring flow in January 1955 was estimated at 220 gpm. By June 1956 flow had decreased to 16 gpm. Bell and Katzer (4) report spring flow ceased entirely during the summer of 1956 then apparently returned to pre-1954 earthquake conditions (less than 1 gpm).

Mud Spring resumed flow in the summer of 1984 and was discharging from several orifices on the west side of the 1954 graben by September. The estimated discharge rate was 15 to 25 gpm; the temperature was 76° F. On August 20, 1985, the discharge had increased by an estimated 15 to 20 pct and increased in temperature to 77° F. The increase in flow and temperature is attributed by Bell and Katzer (4) to a pressure head response to above-normal precipitation in Nevada during 1983 and 1984. A hydrograph of Mud Spring for the period December 1954 to August 1956 is presented in figure 2.

Mud Spring was also effected by the Pleasant Valley event of October 3, 1915 (see page 33 of this report).

Effects on Wells, Dixie Valley

The effects of the December 1954 earthquakes on wells in Dixie Valley were more pronounced than those for surface water or springs. These effects--changes in water level, flow, and temperature for 11 wells--are summarized in table 2; hydrographs for four additional wells are presented in figure 3. Well locations are presented in figure 4.

Water levels in every nonflowing well that was measured was higher after the earthquake (1). Levels ranged between less than 0.5 ft (well 11), and 4.6 ft (well 15). Flow from many wells temporarily ceased; several previously nonflowing wells commenced flow and maintained flow for more than a month. Well 7, which normally flowed at about 3 gpm, jetted water 1 ft above the casing at an estimated rate of 500 gpm; flow decreased to 15 gpm within 6 weeks. Well 3, previously non-artesian, flowed at a rate of "several hundreds of gallons per minute for a short period" (1). Six weeks later the flow decreased to 0.5 to 1 gpm. Wells 2 and 4, normally non-artesian, flowed at an unspecified rate for more than a month following the earthquake.

By June 1956, flow from most wells had returned to pre-earthquake rates. In some wells, number 5 in particular, flow rates declined to less than pre-earthquake values.

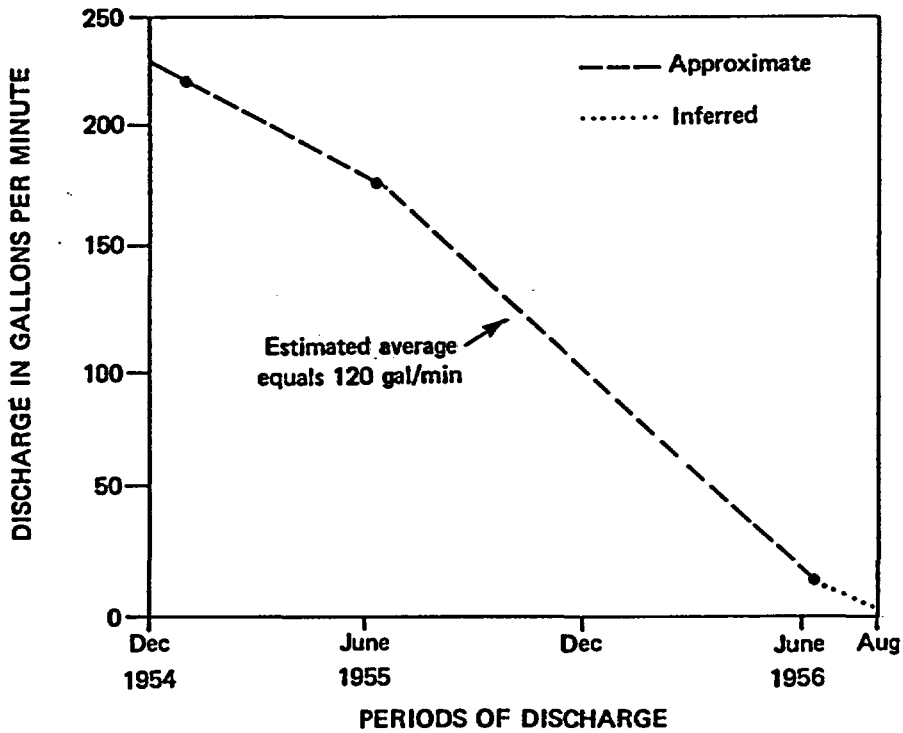


FIGURE 2. - Hydrograph of Mud Spring, December 1954 to August 1956, Dixie Valley-Fairview earthquakes

TABLE 2. - Summary of changes in well level, flow, and temperature, Dixie Valley. Dixie Valley-Fairview earthquakes

Well no.	Before earthquake	After earthquake		Remarks
1.....	8-22-51 est flow 3 to 5 gpm T. 68° F	1-26-55 est flow 2 to 3 gpm T. 68° F	6-25-56 flowing few gpm T. 68° F	
2.....	5- 1-51 WL - 1.73	1-14-55 flow 11 gpm 3-18-55 WL - 0.75	6-25-56 WL - 7.00	
3.....	4- 3-47 T. 64° F 5- 1-51 WL - 3.06 8-21-51 WL - 3.16	1-14-55 flow 1/2 to 1 gpm T. 62° F	6-25-56 WL - 3.93	Well partly filled with sand.
4.....	Reported not flowing	1-14-55 flow 2 to 3 gpm 3-18-55 WL + 0.62 6-13-55 WL - 0.60		Well filled with sand.
5.....	12-12-51 est flow 50 gpm T. 60-1/2° F	1-26-55 T.-60 1/2° F	6-25-56 est flow 5 gpm T. 60-1/2° F	
6.....	Reported flow 25 gpm	2- 1-55 WL - 0.7 (some seepage)	6-25-56 WL - 4.51 (no seepage)	Sand in bottom 16 feet of well.
7.....	8-24-51 est flow 3 gpm T. 62° F	2- 1-55 est flow 15 gpm T. 62° F	6-25-56 est flow 15 gpm T. 62° F	
8.....	8-22-51 flow 35 gpm T. 62-1/2° F	1-19-55 est flow 35 gpm T. 62-1/2° F	6-25-56 flow 33 gpm T. 62-1/2° F	
9.....	12-12-51 flow 37 gpm T. 62° F	1-19-55 flow 58 gpm T. 65° F	6-25-56 flow 35 gpm T. 65° F	
10.....	8-22-51 est flow 50 gpm WL + 8.7 T. 66° F	1-19-55 flow 58 gpm WL + 12.7 T. 66° F	6-25-56 flow 35 gpm WL + 9.2 T. 66° F	
11.....	8-23-51 WL - 127.36	1-19-55 WL -127.00		

T Temperature in degrees Fahrenheit.
WL Water level in feet.

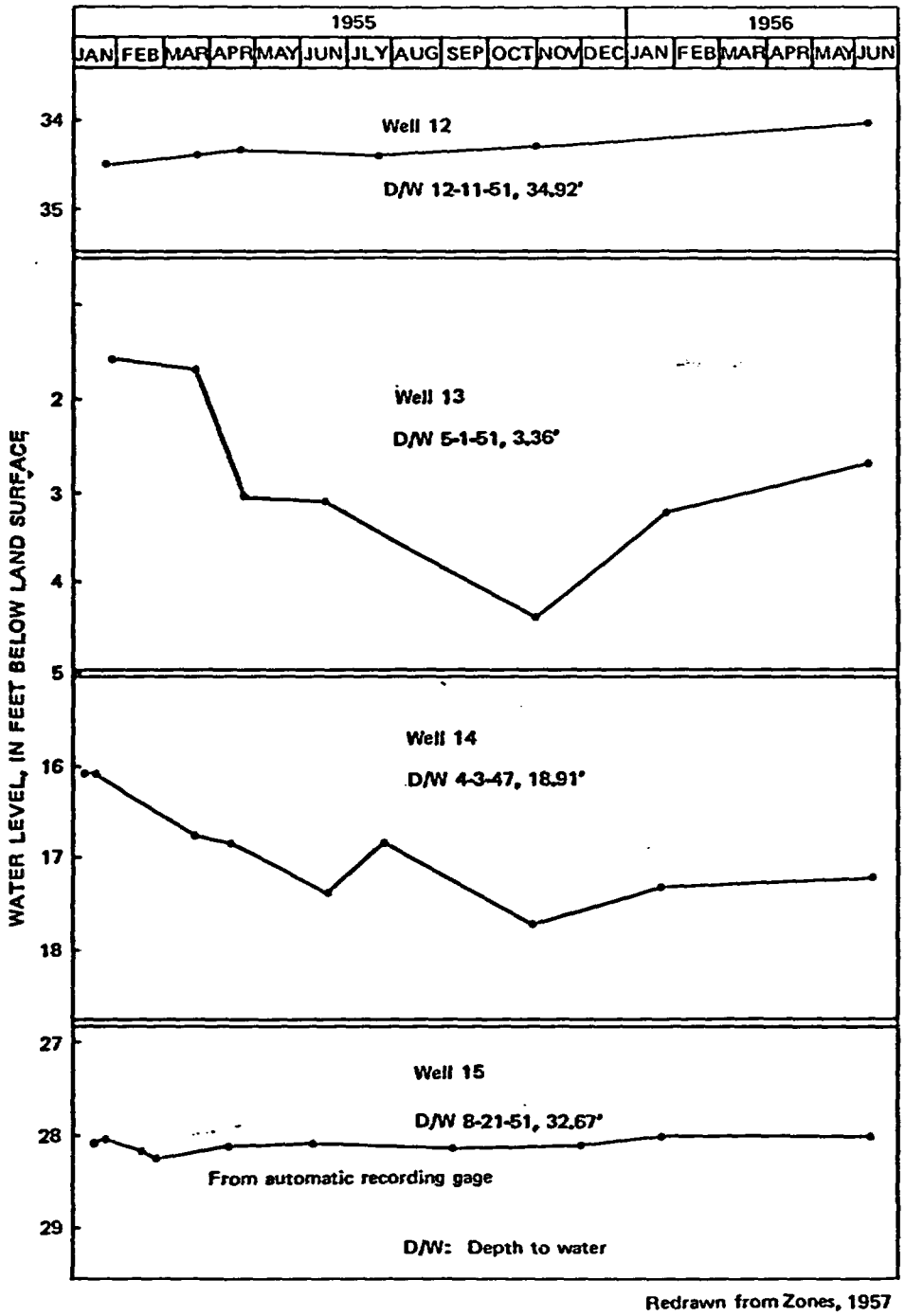
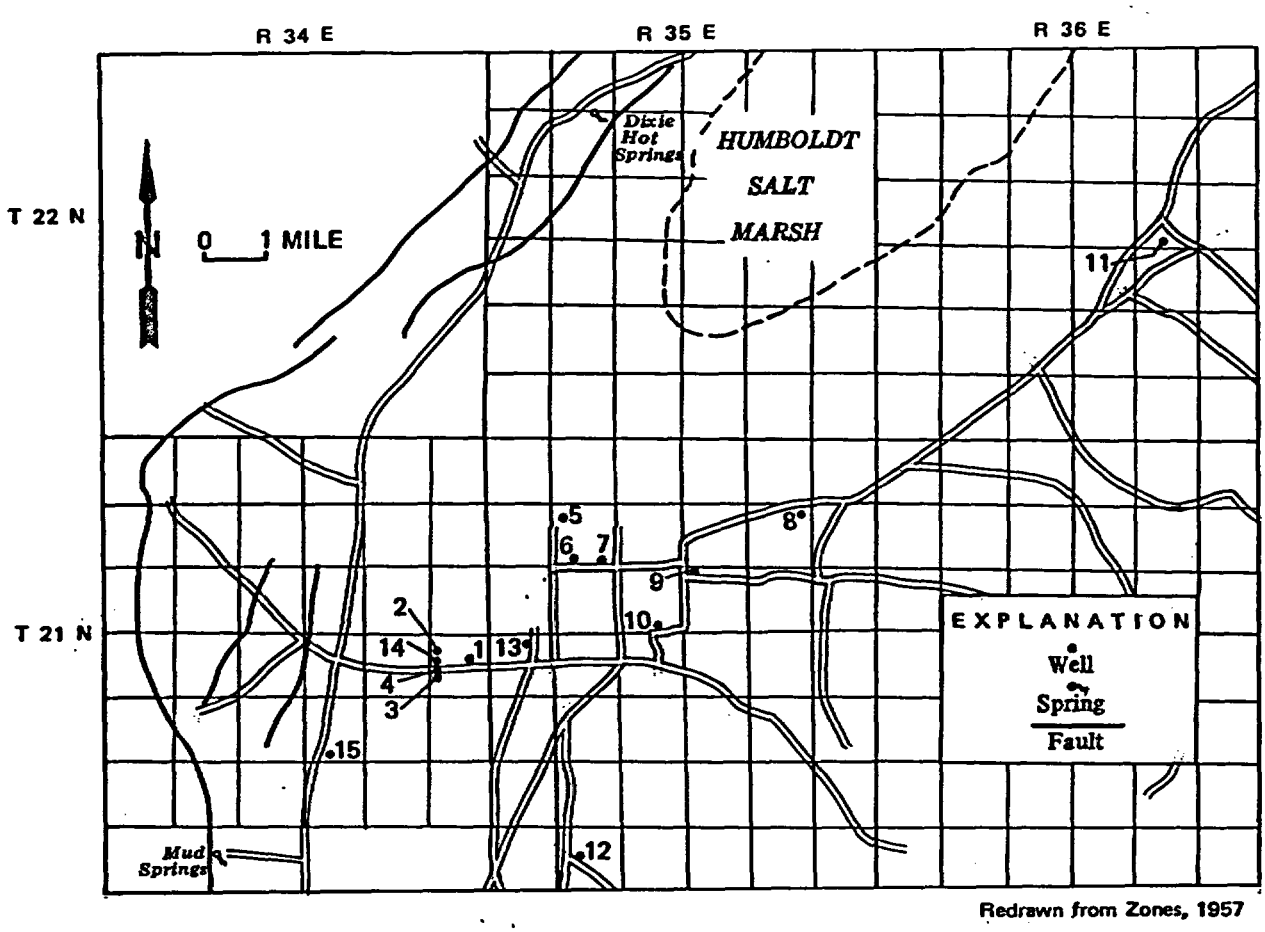


FIGURE 3. - Hydrographs of selected wells in Dixie Valley, Dixie Valley-Fairview earthquakes



Redrawn from Zones, 1957

FIGURE 4. - Map showing location of measured wells in Dixie Valley, Dixie Valley-Fairview earthquakes

Although some variation in well temperatures was noted, the weight of evidence indicates that there has been no change in the temperature of the ground water in Dixie Valley (1).

Effects on Wells, Fairview Valley

Hydrographs of four selected wells in Fairview Valley are presented in figure 5 and keyed to locations in figure 6.

About a month following the earthquake, the water level in well 16 in Fairview Valley was 4.4 ft higher than in June 1950; between January 1955 and June 1956, the level dropped 1 ft. In the three small valleys east of Fairview Valley (Stingaree, East Gate, and West Gate), however, the water table dropped after the earthquake. The Stingaree Mine, in Stingaree Valley 120 ft from one of the major ground ruptures, showed a decline in mine water levels of 1.4 ft; a decline of 3 ft was noted in well 17. The water level in well 18 (in West Gate Valley) dropped 6 ft; well 19 in East Gate Valley dropped 11 ft.

The water level in well 17 rose sharply for several months after the initial drop following the tremor. By October 1955 the level had reached 11 ft above December 1951 levels. Water levels in well 19 continued to decline reaching a low of 34 ft below pre-earthquake levels (June 1956). Zones (1) concluded that water drained at an accelerated rate from East Gate and Cowkick Valleys into Dixie and Fairview Valleys.

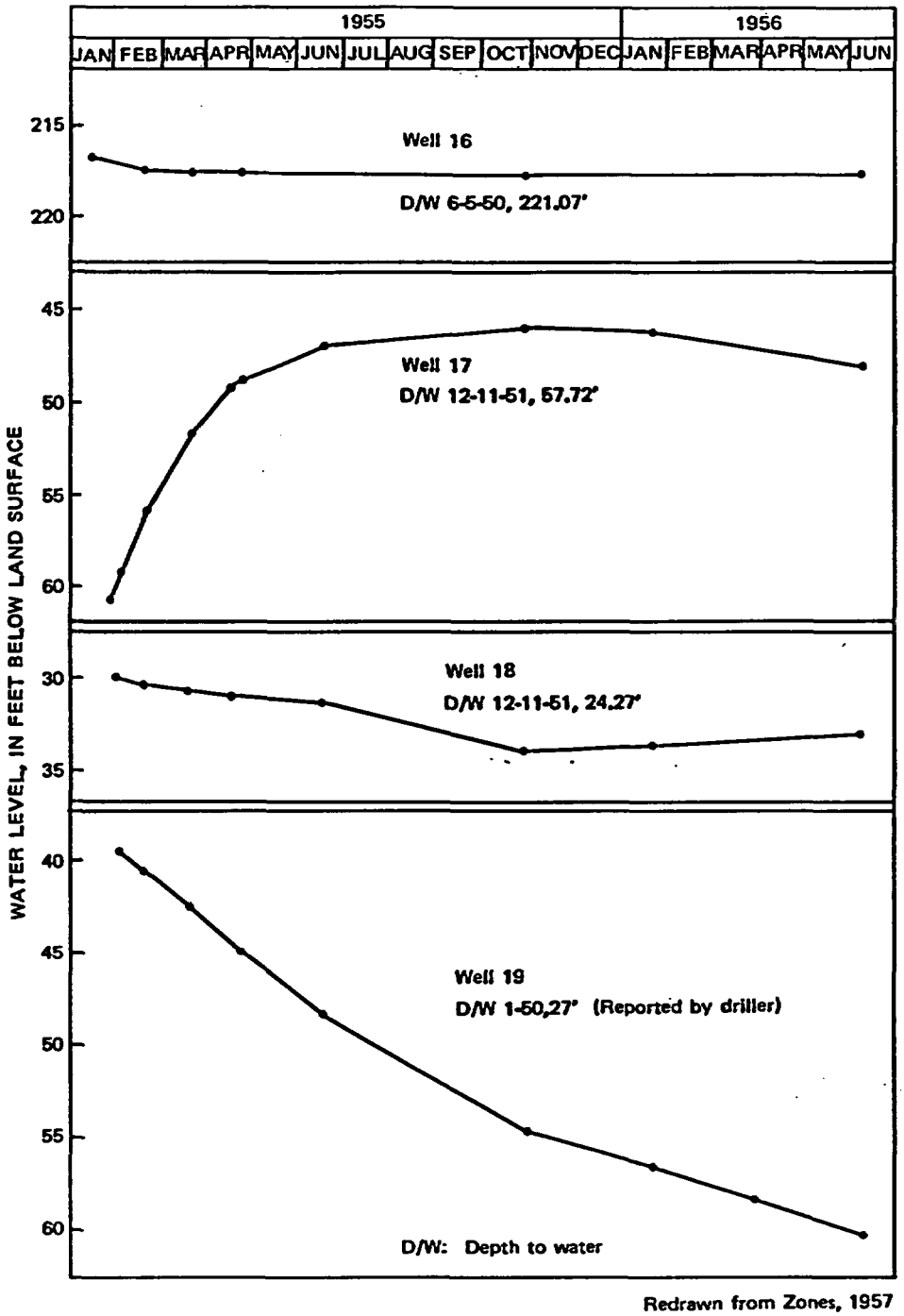
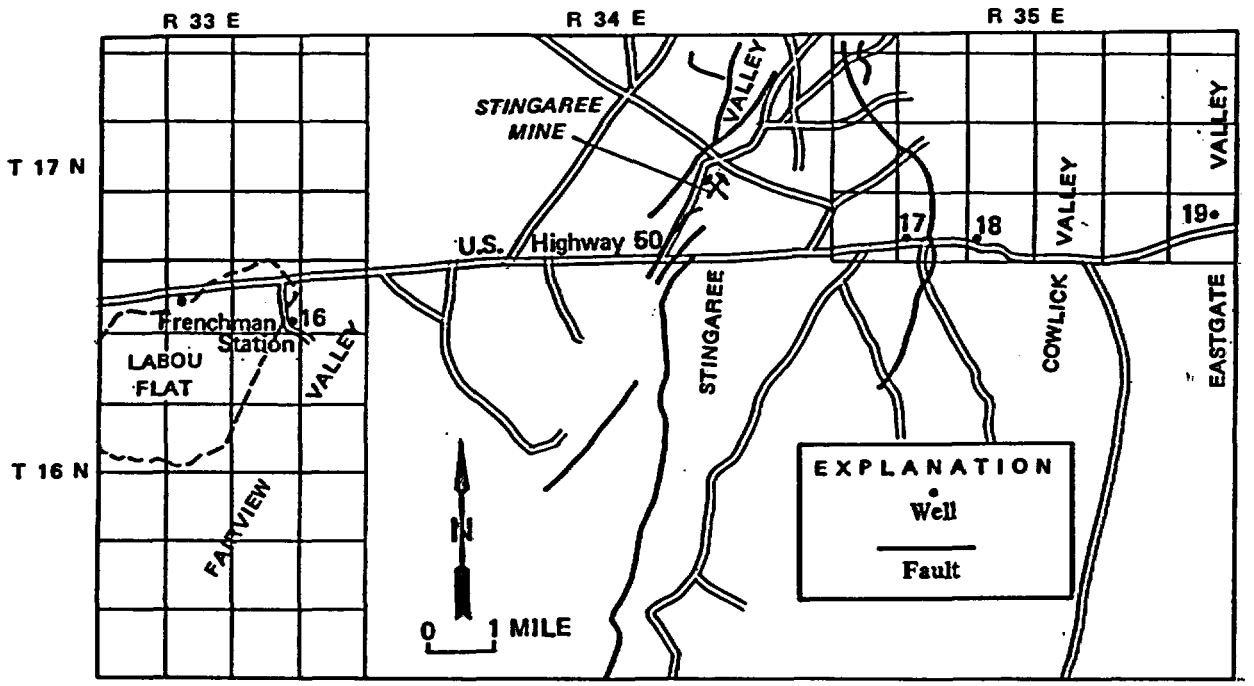


FIGURE 5. - Hydrographs of selected wells in Fairview Valley, Dixie Valley-Fairview earthquakes



Redrawn from Zones, 1957

FIGURE 6. - Map showing location of measured wells in Fairview Valley, Dixie Valley-Fairview earthquakes

References

1. Zones, C. P. Changes in Hydrologic Conditions in the Dixie Valley and Fairview Valley Areas, Nevada, After the Earthquake of December 16, 1954. Bull. Seism. Soc. Amer., Vol. 47, no. 4, 1957, pp. 387-396.

2. Murphy, L. M. and W. K. Cloud. United States Earthquakes, 1954. Washington, DC: U. S. Department of Commerce, Coast and Geodetic Survey Serial No. 793, 1956, pp. 57-71.

3. Jones, C. The Pleasant Valley, Nevada, Earthquake of October 2, 1915. Bull. Seism. Soc. Amer., Vol. 5, 1915, pp. 190-205.

4. Bell, J. W. and T. Katzer. Surficial Geology, Hydrology, and Late Quaternary Tectonics of the IXL Canyon Area, Nevada, as Related to the 1954 Dixie Valley Earthquake. NV Bur. Mines and Geol. Bull. 102 (prepared in cooperation with the USGS), 1987.

Location: Hebgen Lake, MT (principal earthquake and aftershocks)
Latitude: 44.8° N.
Longitude: 111.1° W.
Date: August 18, 1959
Intensity (Modified Mercalli scale):VI-X
Magnitude (Richter scale): 6.0 to 7.1

A map showing the epicenters of the Hebgen Lake earthquakes is presented in figure 7.

Effects on Underground Mines

Clayton Silver Mine, Custer County, ID, reported flooding; flow returned to normal (about 980 gpm) in about 8 months. This mine was also flooded as a result of the Borah Peak, ID, earthquake of October 28, 1983 (see page 94 of this report).

Hydrologic Effects

General

The Hebgen Lake earthquake had profound effects on the ground- and surface-water regime of the epicentral and West Yellowstone areas. Streams, most of which are spring fed, became very turbid and displayed a general increase in flow. Several new springs came into existence while others ceased to flow; many springs showed an increase or decrease in flow. Water well fluctuations were recorded throughout the conterminous United States and in Puerto Rico and Hawaii. Artesian flow began, or flow pressures increased, in a number of wells within 125 mi of the epicenter.

Water under considerable pressure issued from ground fissures and formed numerous sand boils. Large sinkholes were formed in alluvium underlain by cavernous bedrock.

Effects on Surface Water

A number of gaging stations in the area of the earthquake recorded increases in streamflow as early as August 18 (the day following the main shock). Those streams particularly affected were the Madison and Gallatin Rivers; lesser effects were noted on the upper Red Rock, Gardiner, Henry's Fork, and Ruby Rivers. Blacktail Creek, near Dillon, MT, showed marked and sustained increases. Gaging station locations for these and other streams are shown in figure 8.

Annual precipitation in the region averages more than 20 in, mostly in the form of snow. Precipitation is relatively well distributed over the year with the period of July to September the driest. Most streams in the epicentral area were at base-flow levels at the time of the earthquake, and there was little precipitation for nearly a month thereafter. The effects of precipitation were varied, however, and did not, in most instances, mask the effects of the earthquake on streamflow (1).

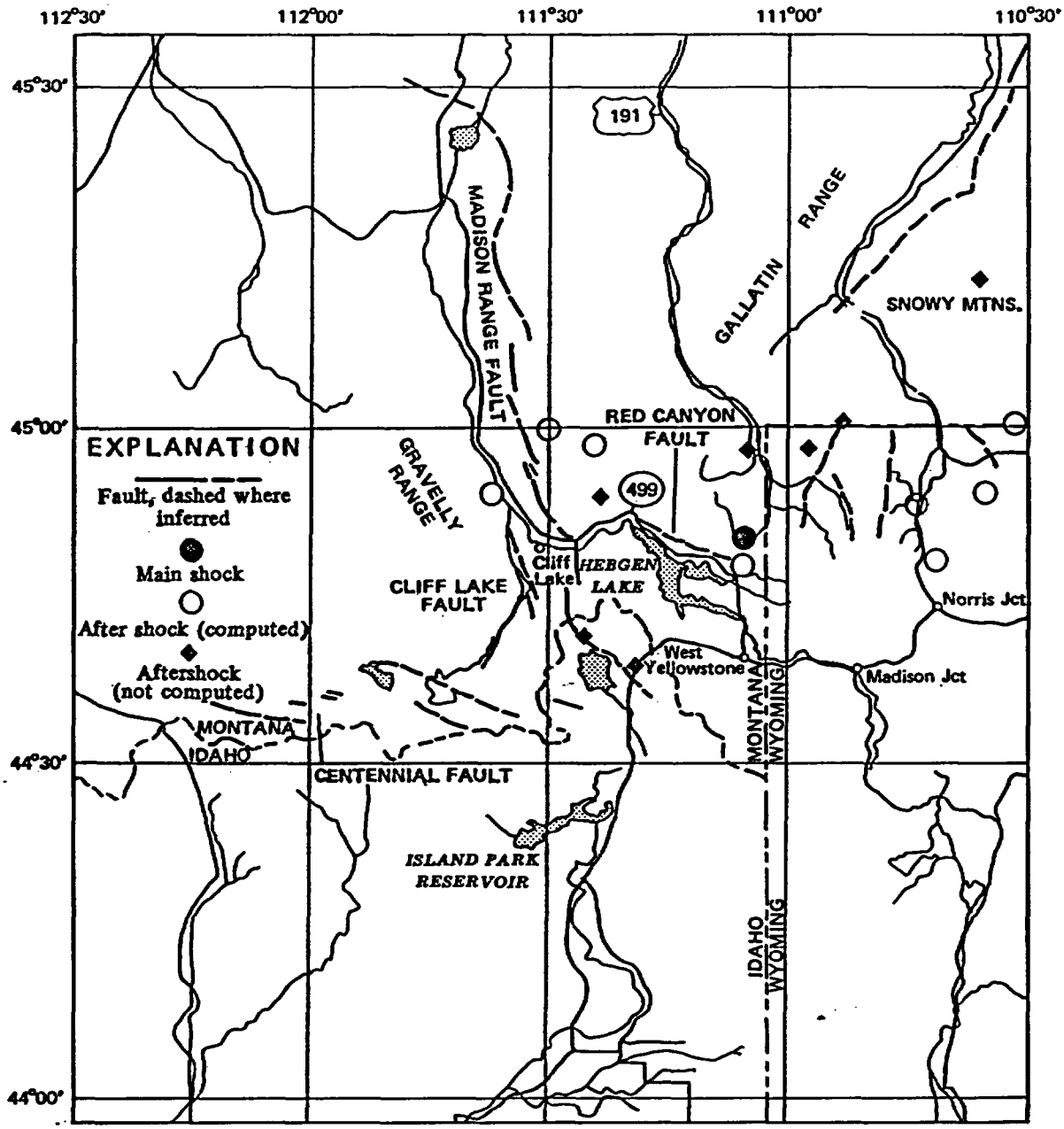


FIGURE 7. - Map showing epicenters of the Hebgen lake earthquakes.

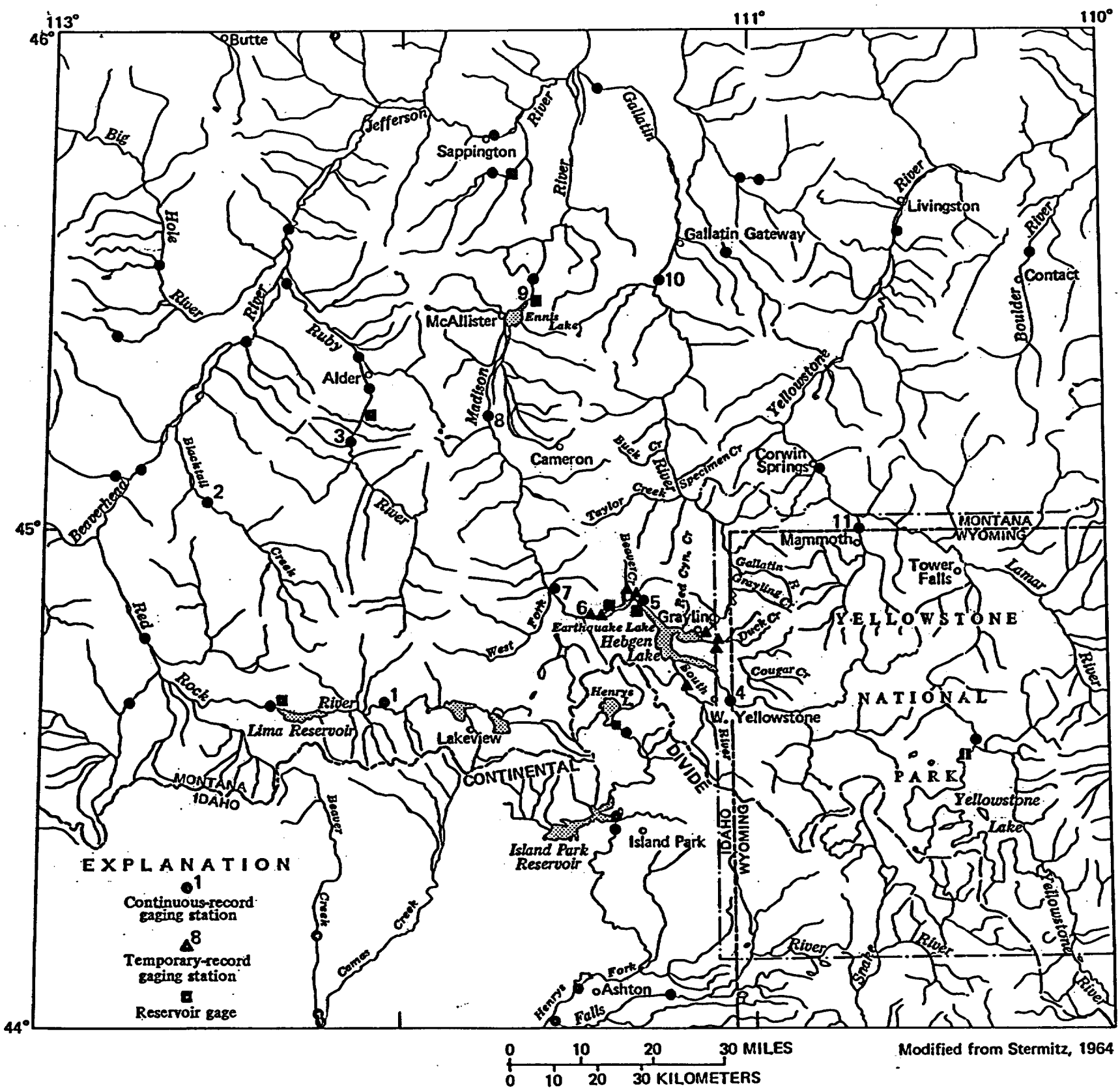


FIGURE 8. - Map showing surface drainage and gaging station locations, Hebgen Lake earthquakes

Daily discharge records of several streams in the area for the period August 1 through October 22, 1959, are graphically displayed in figures 9 through 20. The figures are correlated to gaging station locations shown on figure 8. Data employed in construction of the hydrographs (1) are included in appendix C.

Effects on Springs

Little quantitative data are available on the effects of the Hebgen Lake earthquake on springs outside of Yellowstone National Park because of a general lack of comparative pre-earthquake spring flow rate, chemistry, and temperature data. While many springs were reported to have increased or decreased in flow or exhibited a change in temperature, very few reports include quantitative information.

Considerable quantitative data, however, are available for thermal springs and geysers in West Yellowstone as these springs and geysers have been the subject of intensive study for many years. Earthquake effects on thermal springs and geysers in the park are discussed in the following section.

Effects on Thermal Springs and Geysers of the Firehole Geyser Basins, Yellowstone National Park

The following discussion and tables are summarized from Marler (2) who conducted a survey of the thermal springs and geysers in the Firehole Geyser Basins (Lower, Midway, and Upper Geyser Basins) between August and December 1959. The 173 springs considered by Marler are but a small portion of the springs and geysers within Yellowstone National Park; however, they are the only ones for which comparable pre-earthquake data are available.

An overview of the earthquake's effects in the Firehole Basins is provided by Marler in his abstract, a portion of which is repeated here:

> The 1959 Hebgen Lake earthquake resulted in great changes in the functional behavior of most of the thermal springs along the Firehole and Gibbon Rivers in the Yellowstone National Park. The effects were particularly marked along the Firehole drainage. This is the region of Yellowstone's most famous geysers and hot springs. The initial tremors served as an impetus to bring about eruptive activity in scores of geysers and quiescent springs. Many long-dormant geysers erupted; a few new geysers were born. Some hot springs seemed to be affected adversely, but on the whole there was a noticeable increase in thermal energy that, with the passing of time, gave evidence of persisting.

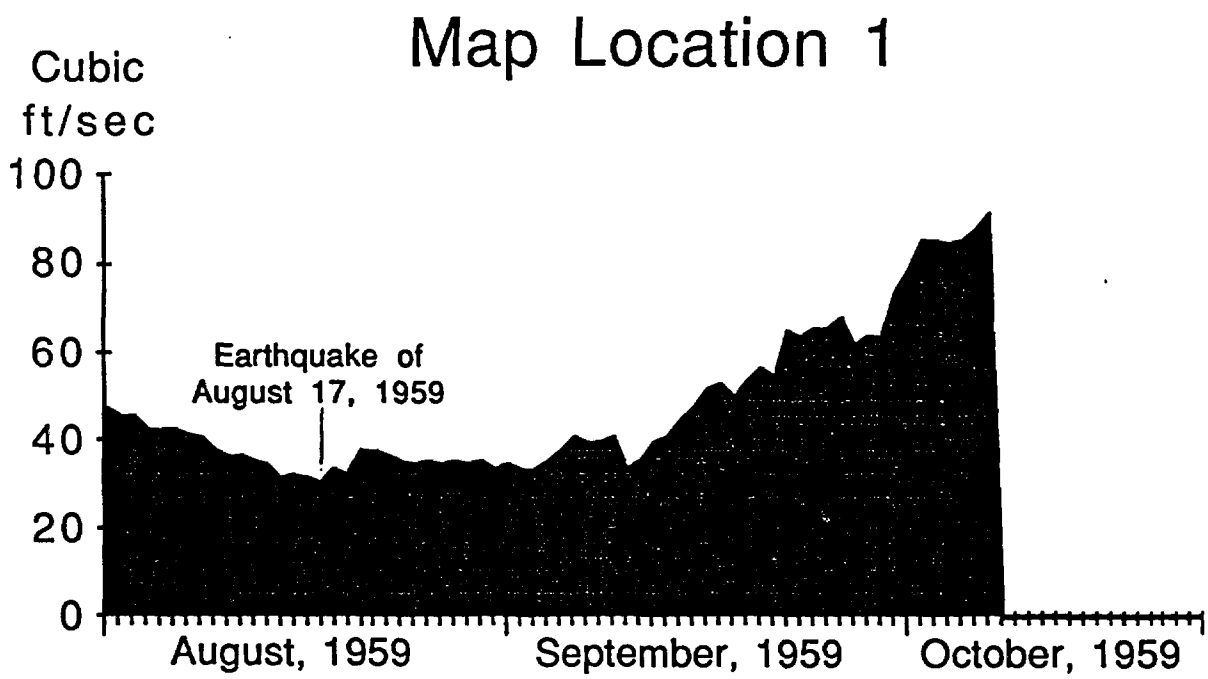


FIGURE 9. - Daily discharge, Red Rock River at Kennedy Ranch near Lakeview, MT, Hebgen Lake earthquakes

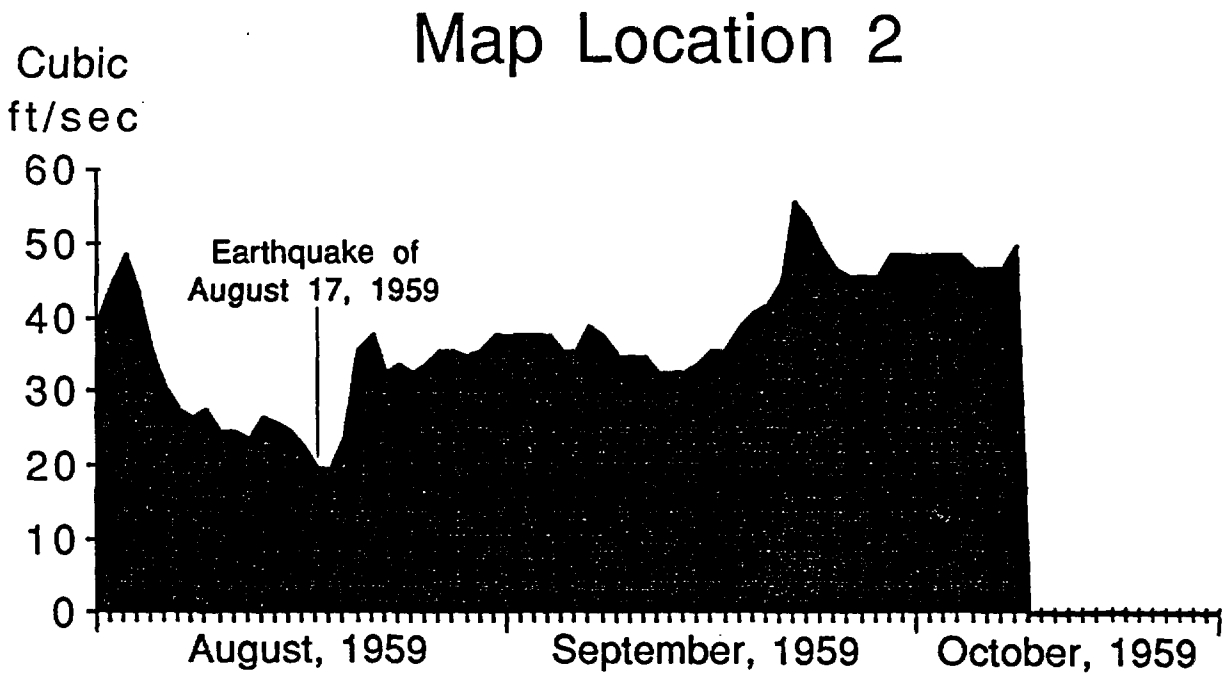


FIGURE 10. - Daily discharge, Blacktail Creek near Dillon, MT, Hebgen Lake earthquakes

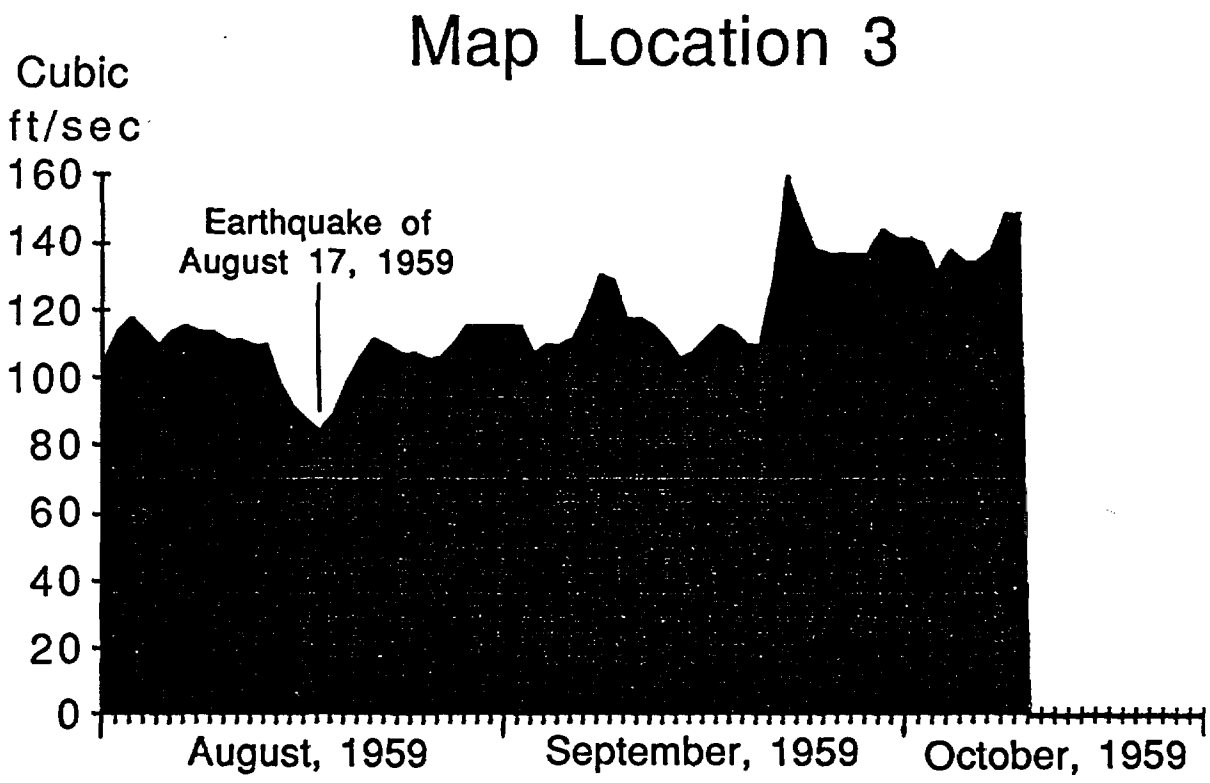


FIGURE 11. - Daily discharge, Ruby River above reservoir near Alder, MT
Hebgen Lake earthquakes

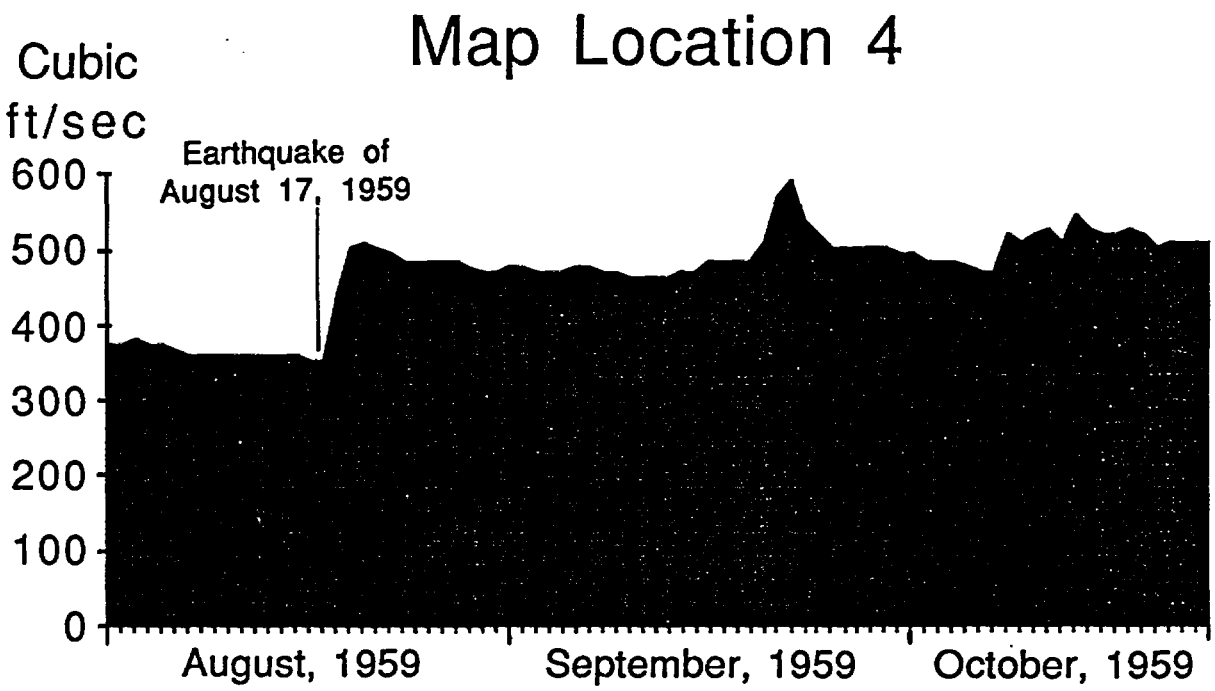


FIGURE 12. - Daily discharge, Madison River near West Yellowstone, MT, Hebgen Lake earthquakes

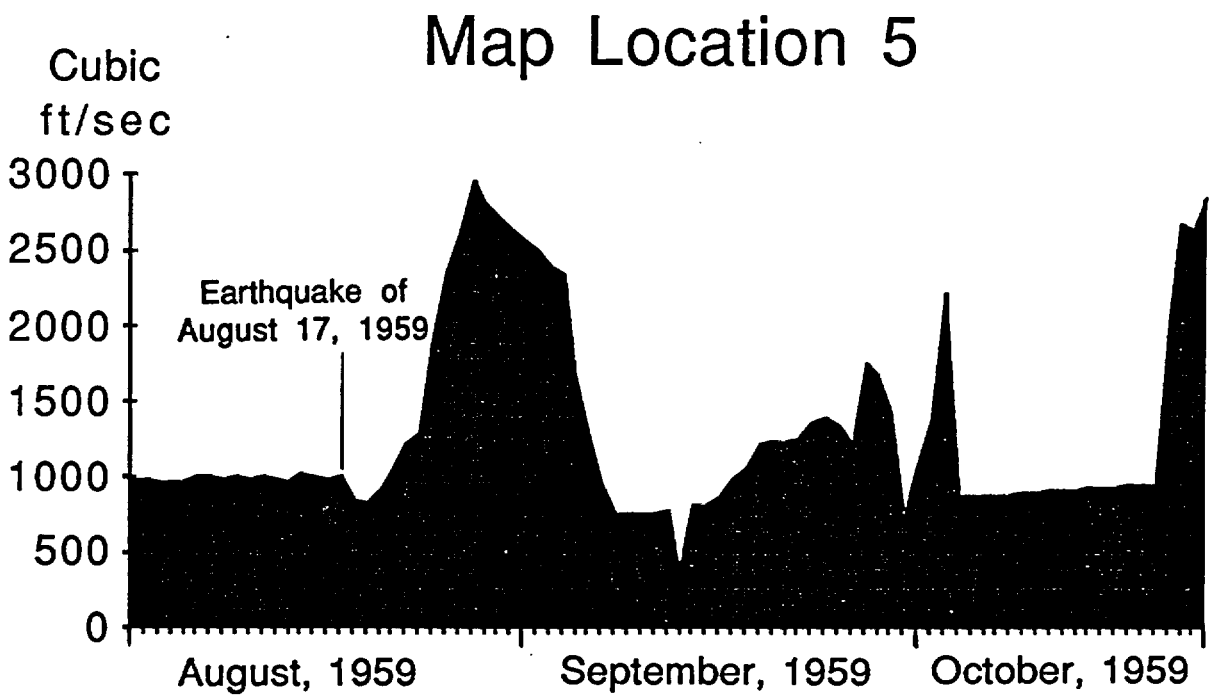


FIGURE 13. - Daily discharge, Madison River below Hebgen Lake near Grayling, MT, Hebgen Lake earthquakes

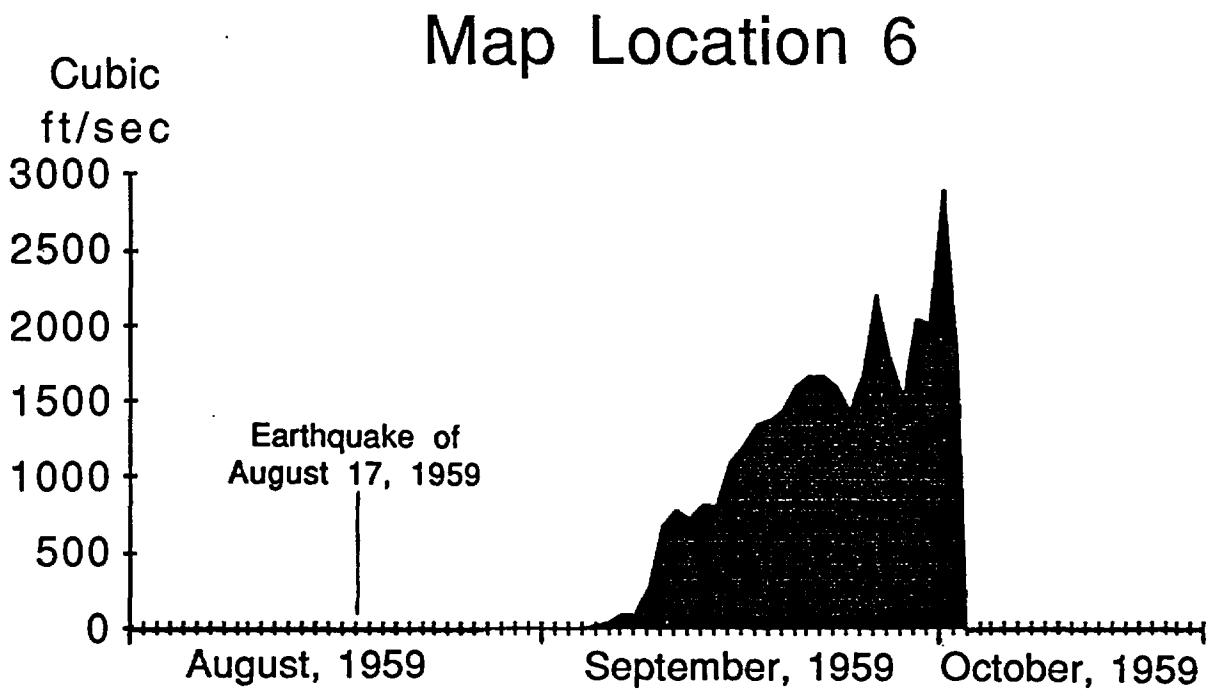


FIGURE 14. - Daily Discharge, Madison River above Sheep Creek northwest of West Yellowstone, MT, Hebgen Lake earthquakes

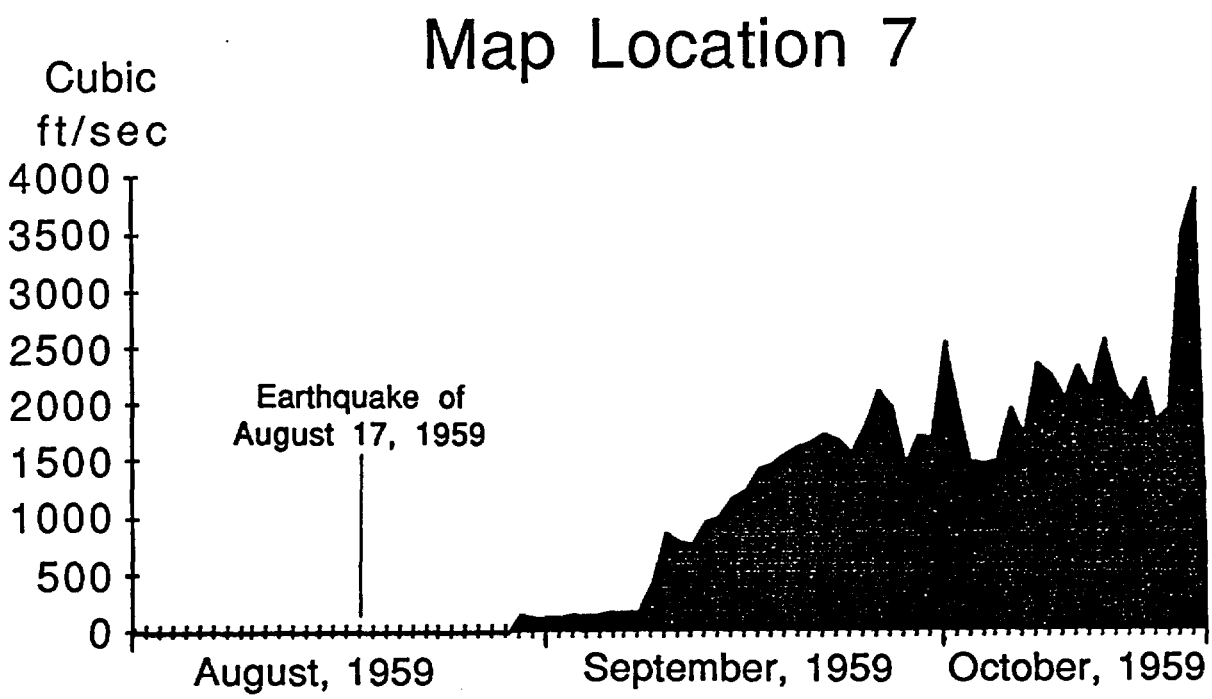


FIGURE 15. - Daily discharge, Madison River at Kirby Ranch near Cameron, MT, Hebgen Lake earthquakes

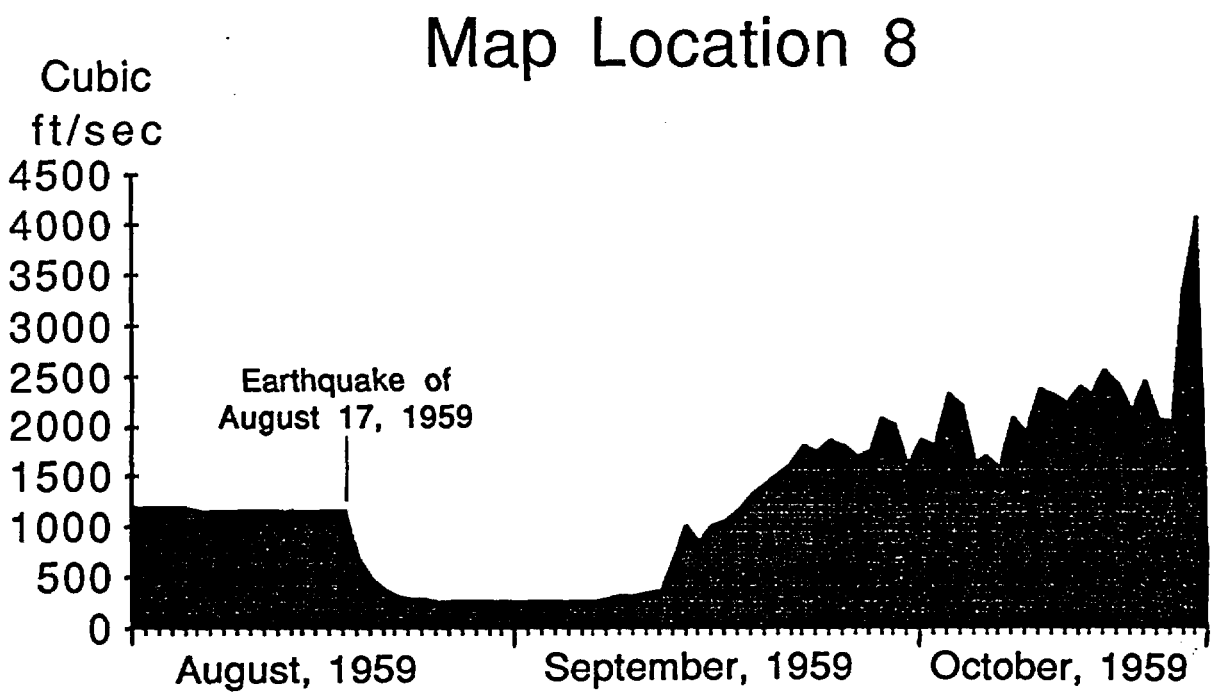


FIGURE 16. - Daily discharge, Madison River near Cameron, MT, Hebgen Lake earthquakes

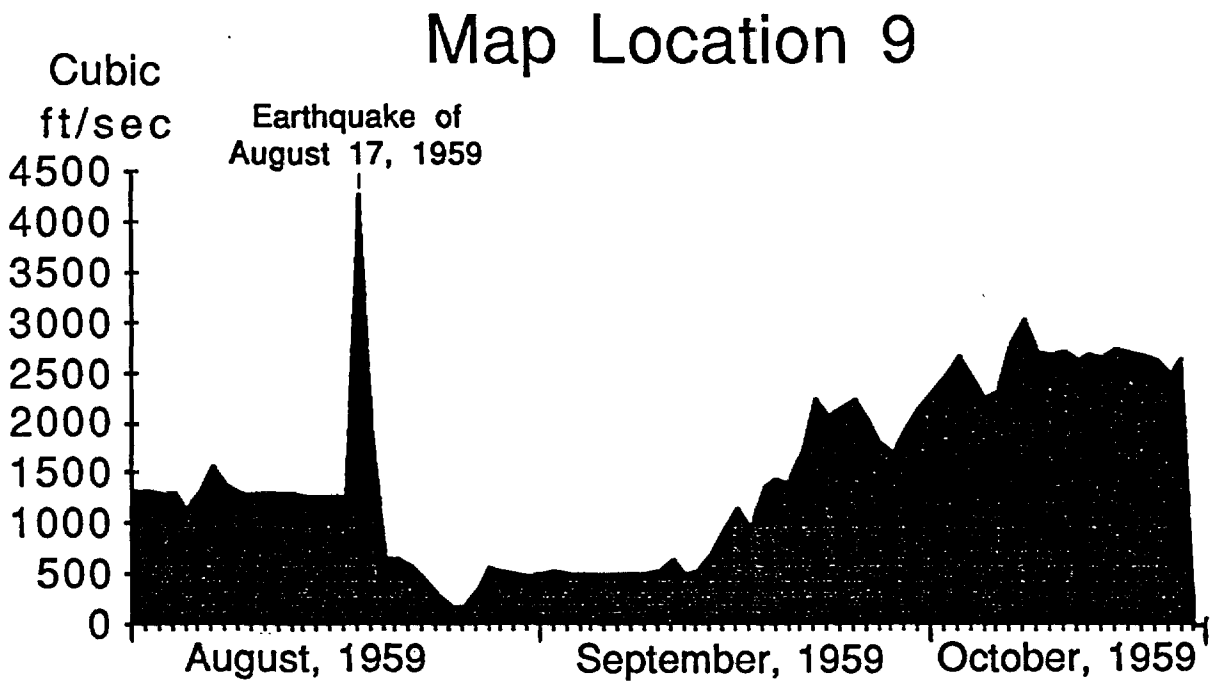


FIGURE 17. - Daily discharge, Madison River below Ennis Lake near McAllister, MT, Hebgen Lake earthquakes

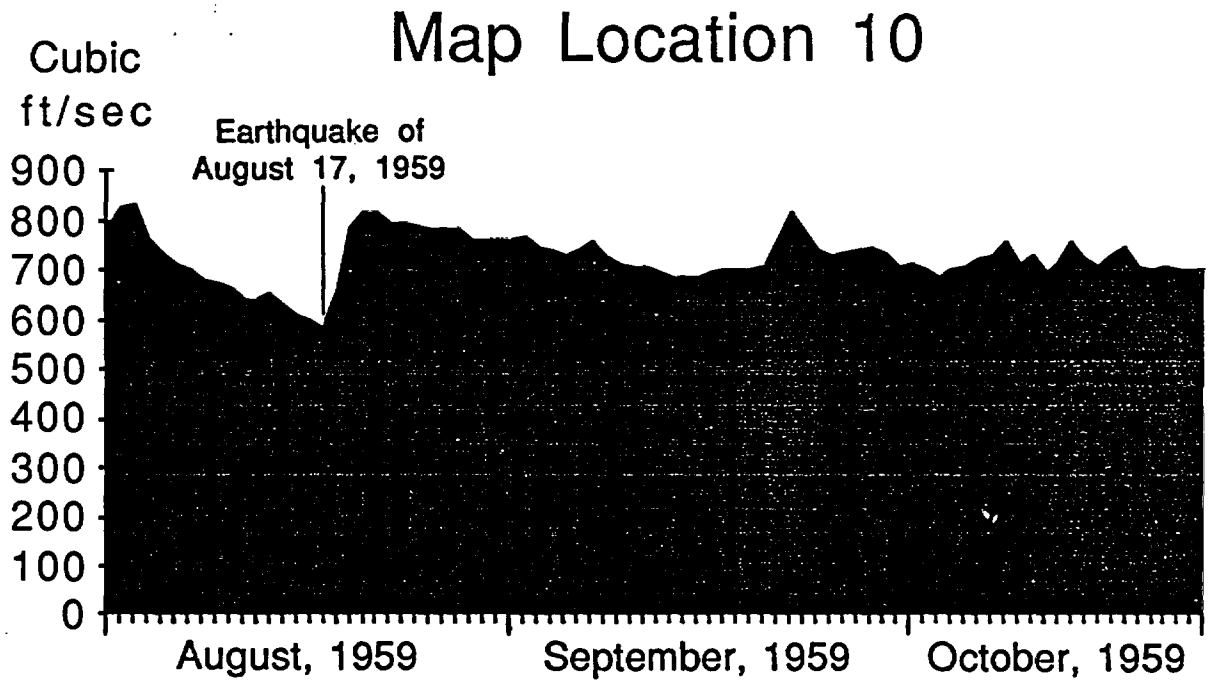


FIGURE 18. - Daily discharge, Gallatin River near Gallatin Gateway, MT, Hebgen Lake earthquakes

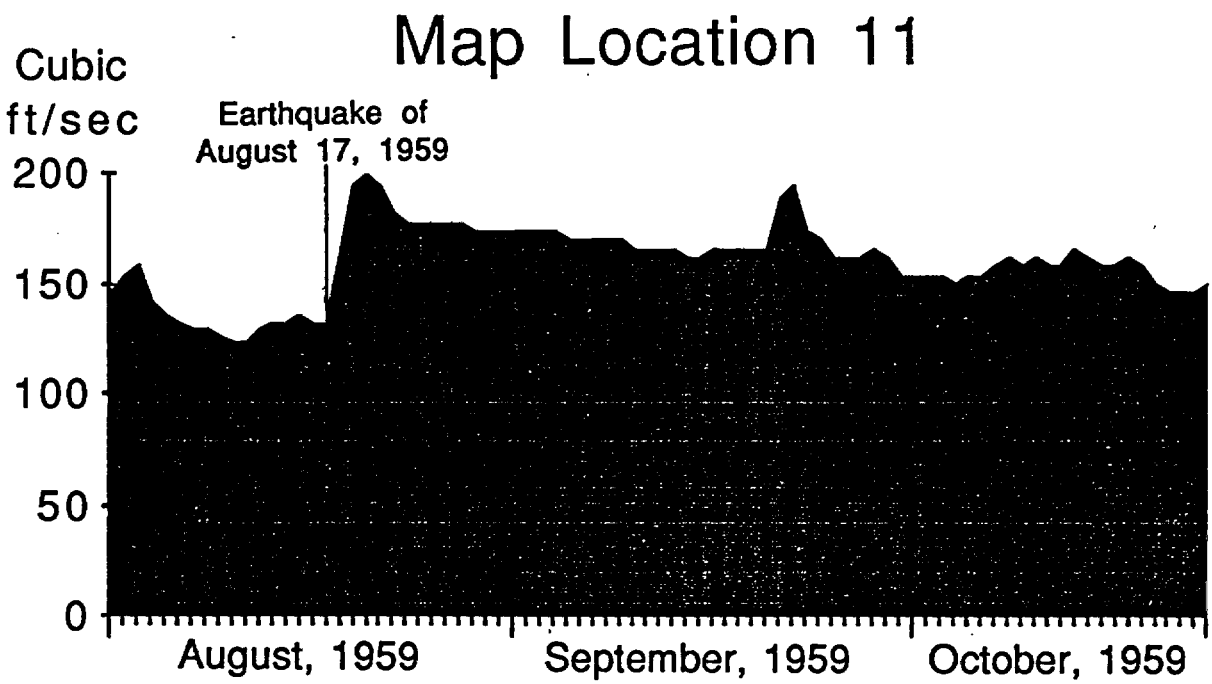


FIGURE 19. - Daily discharge, Gardiner River near Mammoth, Yellowstone National Park, MT, Hebgen Lake earthquakes

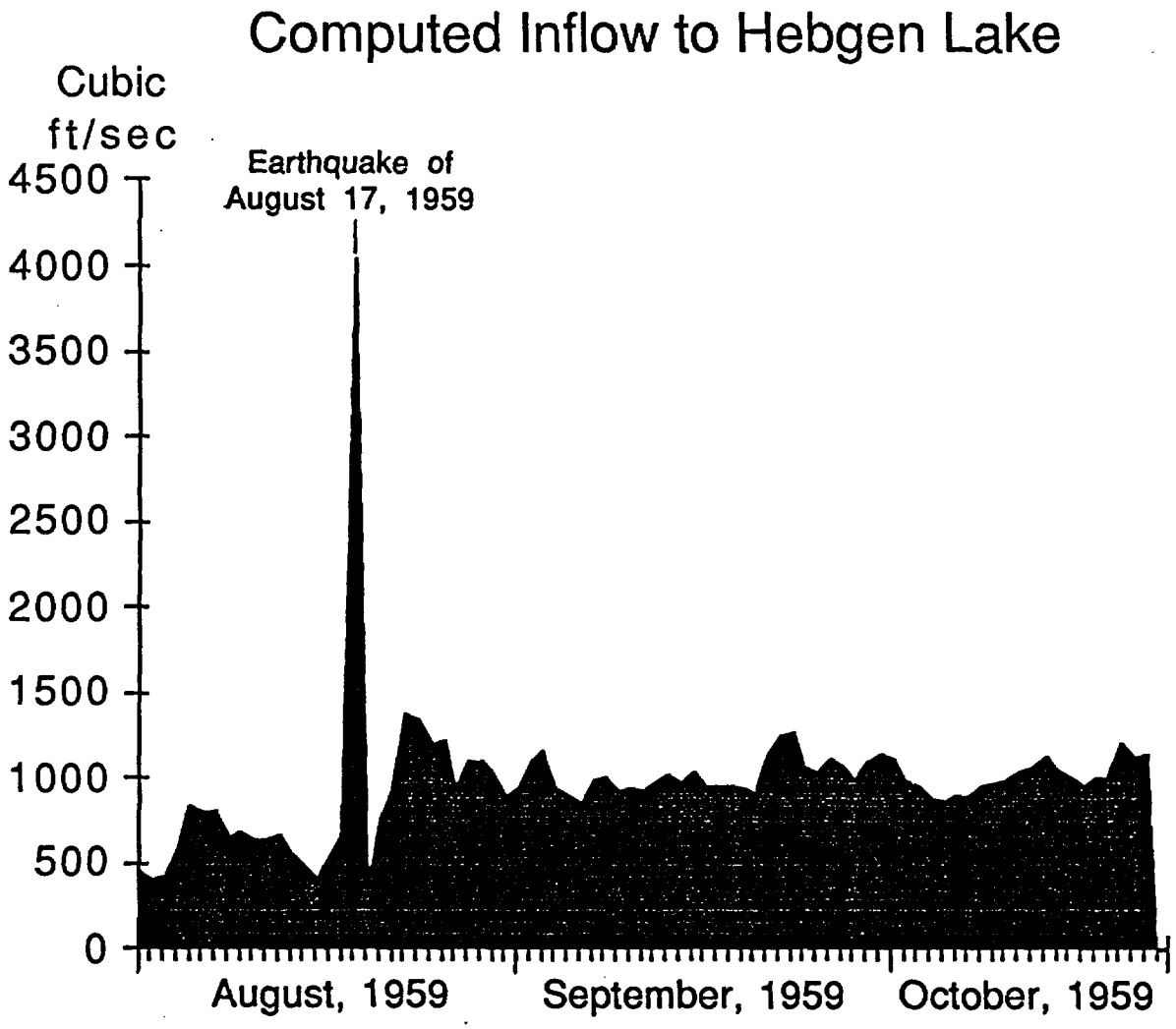


FIGURE 20. - Computed inflow to Hebgen Lake (3-day average), Hebgen Lake earthquakes

The effects of the earthquake on geysers in the Firehole Basins and effects on springs and pools in the same area are summarized in tables 3 and 4, respectively.

Effects on Water Well Levels

The effect of the Hebgen Lake earthquake on water levels in wells is the most pronounced ever recorded in the United States (3). Water level fluctuations were recorded in USGS observation wells in 30 states, including Alaska, Hawaii, and the Territory of the Commonwealth of Puerto Rico.

The maximum recorded well fluctuation exceeded 10 ft in Lincoln County, ID. In nine states, recorded fluctuations were more than 1 ft; fluctuations between 0.5 and 1 ft were recorded in five states.

Changes in water levels and pressure heads compiled by da Costa (3) are presented in table 5. Data for three wells in Pennsylvania were omitted from this report due to lack of locational information.

The Madison Landslide and Earthquake Lake

The earthquake of August 17, 1959, aided by local unstable structural and geomorphic conditions, caused a massive landslide in the Madison River Canyon, 6 miles downstream from Hebgen Dam that buried the river to depths ranging between 100 and 200 ft over a distance of 1 mile. An estimated 37 million yd^3 of broken rock slid into the river forming a natural dam. Shortly after the landslide, more than 80,000 acre-ft of water had accumulated behind the rock mass and had backed up to within 500 ft of the damaged toe of Hebgen Dam. The resulting lake was aptly named "Earthquake Lake."

The U.S. Army Corps of Engineers, under its emergency flood-control powers, took immediate measures to lower the level of Earthquake Lake. It was felt that if water had been allowed to rise to the top of the natural dam, failure of Hebgen Dam was probable. By October 27, the lake volume had been reduced to about 45,000 acre-ft through a narrow spillway excavated by the Corps of Engineers and the passage of water of the Madison River through the channel had reached a safe level.

TABLE 3. - Summary of characteristics of geysers affected by Hebgen Lake earthquake

Name	Observations prior to August 17, 1959						Observations after August 17, 1959					
	Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature °F Sept. 1951	Temperature °F Summers 1958-59	Characteristics	Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (°F) Sept. 1959	Characteristics
UPPER GEYSER BASIN												
Daisy Group:												
Daisy.....	128 min.	1,250[1]	75- 80	196	196	Plays at angle; has preliminary overflow.	Aug.-Dec..	58 min..	1,250[1]	75- 80	200	Earthquake doubled frequency of activity; no preliminary overflow.
Comet.....	4 min..	0	4- 5	200	200	Water of equption falls into crater...	..do.....	Constant	0	4- 5	202	Water level ebbed 12 in.
Splendid.....	Infrequent.	4,160[1]	125	200	200	Series of eruptions when in active phase.	..do.....	One eruption.	4,160[1]	125	202	Played following quake, increased boiling since.
Daisy's Thief..	..do....	80[1]	20	199	199	When active, eruption precedes and stops Daisy.	..do.....	None....	0	0	200	12-in ebb in water level.
Morning Glory Group:												
Fan.....	..do....	8	100-125	199	199	Several vents in cracked sinter.	..do.....	..do....	10	0	202	Increased boiling and temperature.
Mortar.....	..do....	U	30- 40	199	199	Plays in concert with Fan.	..do.....	..do....	0	0	200	Water in crater level higher; hotter.
Sentinel.....	Dormant.	25	0	200	200	Constant boiling.....	..do.....	..do....	25	0	202	Erupted after quake.
Grotto Group:												
Riverside.....	7 h 32 min.	U	75- 80	200	200	Plays at angle, preliminary overflow.	..do.....	6 h 28 min.	U	75- 80	200	5 to 6 h intervals first few days following earthquake.
Link.....	Dormant.	0	0	202	157	Had ebbed below overflow.	..do.....	None....	35	0	163	Murky; increased temperature and discharge.
Culvert.....	Steady..	0	2	198	200	Steady boiling from road shoulder.	..do.....	Steady..	0	3	202	Increased temperature and vigor of boiling.
Grotto and Rocket (function as single unit).	8 h.....	470[1]	10- 50	200	200	Active about half of the time; longest eruption 12 h.	..do.....	4-10 h..	470[1]	10- 50	201	Active at times for more than 30 h.
Grotto Fountain	8-24 h..	430[1]	50	200	200	Precedes Grotto's eruptions.	..do.....	Occasional.	430[1]	50	198	Rejuvenated, 8 to 24 h, in October.
Spa.....	8 h.....	45[1]	1-ft surge	182	183	Action follows Grotto	..do.....	4-10 h..	45[1]	1	183	Murky following earthquake.
Giant Group:												
Giant.....	Dormant cycle.	0	0	203	202	Periodic cycles.....	..do.....	None....	0	0	203	More sloshing in crater since earthquake.
Catfish.....	Dormant.	0	0	200	198	Active and dormant cycles.	..do.....	Dormant.	0	0	202	More vigorous boiling.
Mastiff.....	..do....	0	0	204	203	Active when Giant is hot.	..do.....	..do....	0	0	205	Increased boiling.
Turtle.....	..do....	0	0	199	200	Active during active cycle of Giant.	..do.....	..do....	U	0	200	Periodic overflow following earthquake.
Oblong.....	6-8 h...	U	20	197	198	Voluminous discharge.	..do.....	3-5 h...	NM	20	200	Murky, more frequent activity.
Black Sand Basin:												
Whistle.....	Dormant	0.04	0	199	143	When active has long and violent steam phase.	..do.....	Dormant.	0.05	0	144	Murky first week after earthquake.
Cliff.....	Infrequent..	NM	25- 30	198	197	Three eruptions in 1959.	..do.....	Active daily..	NM	25- 30	200	Erupts 3- to 10 h periods daily.
Spouter.....	Near constant..	80	3- 4	197	198	Erupts most of the time.	..do.....	Nearly constant..	80	3- 4	200	Increase in temperature; murky August 18.

See footnotes at end of table.

TABLE 3. - Summary of characteristics of geysers affected by Hebgen Lake earthquake--Continued

Name	Observations prior to August 17, 1959						Observations after August 17, 1959					
	Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature °F Sept. 1951	Temperature °F Summers 1958-59	Characteristics	Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (°F) Sept. 1959	Characteristics
UPPER GEYSER BASIN--Continued												
Castle Group:												
Castle.....	14-17 h...	U	75-100	200	200	Steam phase eruptions.	Aug.-Dec..	4-9 h....	U	75-100	201	Eruptions about twice as frequent.
Sprinkler.....	80-100 h..	U	3	194	194	Splashing eruptions...	..do.....	50-60 h..	U	3	198	Increased frequency.
Deleted Tea-kettle.	Dormant...	0	0	200	200	Rarely erupts.....	..do.....	Dormant..	6.5	25	199	Erupted following earthquake; flowing.
Churn.....	..do.....	0	0	151	155	..do.....	..do.....	Occa-sional.	3[1]	Boiling eruption	161	Did not rejuvenate until November.
Sawmill.....	2-3 h.....	190[1]	20- 40	167	189	Plays at about time of overflow.	..do.....	1-3 h....	190[1]	20- 40	194	Erupted almost continuously for 4 days following earthquake.
Tardy.....	..do.....	25[1]	6- 10	194	194	Connected with Sawmill	..do.....	..do.....	25[1]	6- 10	196	Increased activity following earthquake.
Spasmodic.....	U.....	45[1]	1- 2	199	199	Boiling-type activity.	..do.....	2-4 h....	45[1]	6- 10	203	Boiling more vigorous.
Grand Group:												
Old Tardy.....	Infre-quent.	35[1]	6	201	200	Jet-type operation....	..do.....	1 or more times daily.	35[1]	6	202	Increased activity since earth-quake.
Bulger.....	Daily.....	30[1]	6- 8	198	199	..do.....	..do.....	..do.....	30[1]	6- 8	202	More frequent activity.
Triplet.....	8-12 times daily.	25[1]	2- 3	184	185	Boiling-type eruption.	..do.....	Dormant..	6 PF	0	182	Dormant since earthquake.
Grand.....	3 times daily.	60 (quiet phase)	150-180	169	176	Rocket-type eruption..	..do.....	..do.....	70	0	165	One eruption following quake; increased flow.
Turban.....	15-25 min.	60 (quiet phase)	3- 6	196	197	Boiling-type eruption.	..do.....	..do.....	25	1	187	Partial rejuvenation since September.
Economic.....	Dormant...	0	0	144	154	Jet-type eruption.....	Aug.-Sept. 15.	5-20 min.	7.5	6- 10	200	Dormant since September 15.
Geyser Hill Group:												
Infant.....	Only with Giantess.	0.4	1	199	198	Boiling-type eruption.	Aug. 17...	Played for 100 h.	3	2	201	Has played occasionally since August 17; usual level--3 in.
Giantess.....	Infrequent	U	20- 50	200	198	Rocket-type eruption..	Aug.-Dec..	1 erup-tion.	U	20-150	200	Triggered by earthquake, erup-tion lasting 3 times normal duration; increased boiling; inactive in January 1960.
Vault.....	5-7 days..	1.3 (quiet phase)	8- 10	198	184	Dome-type eruption....	Oct.-Dec..	Most days several erup-ions.	1.3 (quiet phase)	8- 10	197	Inactive August and September; marked rejuvenation since September.
Cone.....	Dormant...	0	0	193	191	.....	Nov.-Dec..	Several daily.	U	25- 30	194	No previous record of activity.
Aurum.....	Cyclic....	0	0	201	201	Was in dormant period.	Aug.-Dec..	U.....	35	12- 15	201	Rejuvenated to active geyser by earthquake.
Sponge.....	45 s-1 min	3[1]	0.5	202	202	Boiling-type eruption.	Aug.-Sept. Oct.-Dec..	Dormant.. 45 s-.... 1 min.	0 3	0 2/3	200 203	Water ebbed 6 ft; no activity. Increased boiling.
Model.....	Dormant...	U	3- 5	192	192	Jet-type eruption.....	Aug.-Dec..	U.....	U	3- 5	194	Occasionally active since quake.
Lion.....	4 times weekly.	U	50- 60	201	200	..do.....	Aug.-Nov..	Very in-frequent	U	50- 60	200	Fewer eruptions following earthquake, partial rejuvena-tion in December.
Big Cub.....	Dormant...	U	40	200	200	..do.....	Aug.-Dec..	Dormant..	0	0	203	Water level, +4 in; increased boiling.
Lioness.....	..do.....	U	20- 30	200	200	Dome-type eruption....	..do.....	..do.....	0	0	201	Water level, +6 in; increased boiling.

See footnotes at end of table.

TABLE 3. - Summary of characteristics of geysers affected by Hebgen Lake earthquake--Continued

Name	Observations prior to August 17, 1959: Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature °F Sept. 1951	Temperature °F Summers 1958-59	Characteristics	Observations after August 17, 1959: Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (°F) Sept. 1959	Characteristics
UPPER GEYSER BASIN--Continued												
Little Cub.....	1-4 h.....	1	2- 3; occasionally 10	200	200	Jet-type eruption.....	Aug.-Dec..	10 m to 4 h.	1.5	3- 10	200	More 10-ft eruptions than preceding earthquake.
Depression.....	2-3 h.....	62[1]	3	182	186	Splash-type eruption..	..do.....	1-2 h....	62[1]	3	188	Increased frequency of activity. One eruption following earthquake.
Beehive.....	1-2 times weekly.	NM	150-180	203	203	Powerful cone-type eruption.	Aug.-Sept. Oct.-Dec..	Dormant.. 3-4 eruptions weekly.	0 NM	0 150-180	203 ...	Rejuvenation and marked increase in activity from October to December.
Cascade.....	Dormant...	0	0	186	186	No known activity in more than 40 yr.	Aug.-Sept.	20-60 min..	400 approx	20- 30	200	Marked rejuvenation by earthquake; dormant since Sept. 11.
Plume.....	60-70 min.	50[1]	20- 25	195	197	Cyclic, active since 1942.	Aug.-Dec..	42-46 min..	50[1]	20- 25	201	New spring flowing into crater slows activity; when checked, interval shows increase noted.
North Anemone..	Every 9-11 min.	20[1]	3	197	198	Erupting water drained into north vent.	..do.....	Infrequent.	25[1]	3	198	Most of energy shifted to South Anemone vent.
South Anemone..	..do.....	1.5[1]	1.5	197	197	Chain action, eruption followed North Anemone.	..do.....	Almost constant..	2[1]	2	197	Chain action in Anemone group has not been characteristic since quake.
Old Faithful...	61.8 min..	2,750[1]	130	200	200	Average 61.8 min (based on check of 1,158 eruptions be- May 1 and August 18, 1959).	Aug.....	62.1 for 175 intervals.	2,750[1]	130	200	
							Sept.....	65.0 for 239 intervals.	.....	.....	...	There has been a somewhat steady increase in length of interval since quake. No observations for length of interval were made in November.
							Oct.....	66.8 for 47 intervals.	.....	.....	...	
							Dec.....	67.4 for 255 intervals.	.....	.....	...	
Cascade Group:												
Hillside.....	1-2 h.....	200[1]	2- 3	200	200	Was in minor eruption cycle.	Aug.-Sept.	20 min-1 h.	1,300[1]	20- 30	202	Earthquake initiated major eruption cycle.
Cauliflower....	50 min....	63[1]	1	192	190	Quite regular.....	Aug.-Dec..	50-60 min..	63[1]	1	192	Eruption a rolling boil; murky after earthquake.
Sapphire Group:												
Black Pearl....	Dormant...	0	0	199	199	Cyclic.....	..do.....	Steady.....	0	3	200	Ebbed 12 in; steady boiling.
Shell.....	Irregular.	4.5[1]	1	198	198	Boiling-type eruption	..do.....	2-50 min...	4.5[1]	1	202	Most of the water flows back into crater.
MIDWAY GEYSER BASIN												
Excelsior Group:												
Excelsior.....	Dormant...	3,600	0	199	199	Large steady discharge.	..do.....	None.....	3,600	0	190	Muddy first few days after earthquake.
LOWER GEYSER BASIN												
Great Fountain Group:												
Great Fountain.	12 h.....	U	100	202	202	Eruption readily predictable.	..do.....	3-9 h.....	U	100	203	Change in pre-eruption sympotoms; more frequent activity.
White Dome.....	15-90 min.	U	20- 25	199	199	Shift in pattern of length of interval...	Aug. 17-21 Aug. 21-Dec.	Dormant.... 15-60 min..	0 U	0 20- 25	199 ...	Dormant first 3 days after quake; then resumed normal function.
Pink Cone Group:												
Pink Cone.....	2-3 times weekly.	35[1]	12- 15	200	200	Jet-type eruption.....	Aug.-Dec..	1-4 h.....	35[1]	12- 15	201	Tremendous increase in activity.
Bead.....	32-33 min.	45[1]	15	182	183	Very regular.....	Aug.-Sept. Oct.-Dec..	55-60 min.. 15-16 min..	45[1] 45[1]	15 15	177 ...	Longer interval; shortened to 15 or 16 min after September.
Narcissus.....	4-5 h.....	80[1]	12	171	171	Easy to predict.....	Aug.-Dec..	5-6 h.....	80[1]	12	168	Slightly longer interval.

See footnotes at end of table.

TABLE 3. - Summary of characteristics of geysers affected by Hebgen Lake earthquake--Continued

Name	Observations prior to August 17, 1959						Observations after August 17, 1959					
	Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature °F Sept. 1951	Temperature °F Summers 1958-59	Characteristics	Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (°F) Sept. 1959	Characteristics
LOWER GEYSER BASIN--Continued												
Firehole Lake Group:												
Artesia.....	Dormant...	0	0	200	200	Cyclic.....	Aug.-Oct..	Steady.....	50	3	201	Rejuvenated by earthquake; ceased in October, but steady flow continued.
Fountain Group:												
Jelly.....	Irregular.	81[1]	2- 10	193	192	Different types of eruptions.	Aug.-Dec..	Nearly steady first few days.	81[1]	10- 15	193	Increased frequency and vigor of activity.
							Aug.-Sept.	30 min-1 h.	U	20- 30	200	Eruptions accompanied by pronounced steam phase never observed before.
Spasm.....	30 min to 2 h.	U	20- 30	196	196	Two types of activity..	Sept. 10-Dec.	Dormant...	0	0	0	Crater emptied and stayed empty.
Bellefontaine..	Dormant...	0	0	198	198	Splash-type eruption...	Aug.-Dec..	30 min-1 h.	25	5- 6	200	Rejuvenated by earthquake.
Fountain.....	2 eruptions in 1959.	U	.....	157	159	Fountain-type eruption; duration 45 min.	Aug. 18... Aug.19-Dec	All day.... Dormant....	U 0	20- 50 0	159 ...	Played in concert with Morning and Clepsydra; no such previous record.
Morning.....	1-2 eruptions weekly.	170	50-150	189	188	Powerful fountain-type eruption.	Aug. 18-31	Almost constant.	170	50-150	193	Activity started by quake; dormant since September 1, with steady overflow.
Clepsydra.....	1-2 wild-phase eruptions weekly.	150[1]	.....	198	196	Activity initiated by Morning.	Aug.-Dec..	Constant...	200	20- 30	201	Wild phase initiated by earthquake; has not ceased playing (January 1960).
Sub.....	Dormant...	0	0	184	188	Nearly empty crater...	..do.....	Steady.....	12	0	196	Has not ceased playing (January 1960).
Jet.....	4-5 min when in active period.	25[1]	10- 15	198	199	Jet-type eruption.....	..do.....	5-12 min...	25[1]	10- 15	199	Action less frequent since Morning and Fountain ceased playing.
Hotel Group:												
Thud.....	Dormant...	0	0	180	180	Cyclic, infrequent....	Aug. 18...	None.....	0	12- 15	183	Erupted following quake; dormant since; murky.
Total of maximum rates observed.	.....	14,400	.....	.....	.....	.....	.....	.....	16,000	.....	.....	
Average temperatures.	.....	.....	.....	193.8	192.8	.....	.....	.....	.....	.....	195.1	

NM Not readily measurable.
PF Periodic flow.
U Undetermined.
[1]In eruption.

TABLE 4. - Summary of characteristics of springs and pools affected by Hebgen Lake earthquake

Name	Observations prior to August 17, 1959						Observations after August 17, 1959					
	Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1951	Temperature (° F) Summers 1958-59	Characteristics	Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1959	Characteristics
UPPER GEYSER BASIN												
Morning Glory Group:												
Morning Glory Pool.	.....	25	.....	169	163	Steady overflow.....	Aug.-Dec.	.....	0	.....	169	Murky first few days, water 2 to 6 in. below rim of crater.
Spiteful Spring	.....	1.3	.....	198	199	.....	..do.....	.....	1.5	.....	200	Murky first few days.
Grotto Group:												
Bottomless Pit.	.....	U	.....	140	195	Discharges into Chain Lake; sudden temperature increase in July	..do.....	.....	U	.....	198	Discharges into Chain Lake; murky; increase in temperature.
Square Spring..	.....	0	.....	201	199	Active geyser in 1950.	..do.....	.....	0	.....	200	Murky first few days.
No. 7 Grotto Group.	.....	5	.....	177	175	Steady overflow.....	..do.....	.....	16	.....	184	Increase in temperature and overflow.
Giant Group:												
South Purple Pool.	.....	15	.....	140	145	Algal-lined pool.....	..do.....	.....	0	.....	182	Murky first few days, sharp increase in temperature.
East Purple Pool.	.....	5	.....	196	196	Ebbs 3 ft following Giant's eruptions.	..do.....	.....	NF	.....	196	Murky first few days.
North Purple Pool.	.....	0	.....	196	197	..do.....	..do.....	.....	0	.....	197	Do.
Chromatic Spring.	.....	0	.....	171	164	Exchange of flow with Beauty Pool.	..do.....	.....	0	.....	164	1-in. ebb following quake.
Beauty Pool....	.....	30	.....	161	164	Exchange of flow with Chromatic.	..do.....	.....	58	.....	169	Increase in flow and temperature.
Inkwell Spring.	.....	20	.....	200	200	Steady boiling.....	..do.....	.....	22	.....	201	Increase in boiling and temperature.
Daisy Group:												
Bonita Pool....	.....	I	.....	140	104	Ebbs with eruptions of Daisy and Spendid.	..do.....	.....	0	.....	105	No overflow since quake; usual level -3 in.
Brilliant Pool.	Erupts following Spendid.	PU	3- 20	194	194	Ebbs 1 ft following Daisy's activity.	..do.....	.....	0	.....	203	Ebbed 1 to 3 ft; boiling most of the time.
Punch Bowl Spring	.....	3.3	.....	201	201	Steady boiling.....	..do.....	.....	3.8	.....	202	Increased temperature and boiling.
Black Sand Basin:												
Black Sand Pool	.....	95	.....	197	197	Clear, deep blue.....	..do.....	4-6 min...	117	1, surge	200	Geyser activity, plus increased temperature.
Green Spring...	Cyclic....	125	3	159	177	Periodic variation in temperature.	..do.....	.....	125	.....	179	Murky first few days.
Emerald Pool...	.....	10	.....	155	147	Bowl lined with yellow algae.	..do.....	.....	10	.....	150	Do.
Handkerchief Pool.	.....	0	3- 4	176	177	Occasional eruptive activity.	..do.....	.....	0	.....	165	3-in ebb following quake.
Rainbow Pool...	Cyclic....	U	20-100	166	166	Occasional seasonal eruptions.	..do.....	.....	0	.....	163	6-in. ebb following quake; murky.
Sunset Lake....	.....	NM	.....	185	183	Heavy overflow color rings.	..do.....	.....	Heavy	.....	190	Eruption following quake, not observed, murky several days.
Myriad Group:												
North Three Sisters.	Cyclic....	15	0	181	182	Shift of activity in main bowl.	Aug.-Nov..	18-20 min.	0	15-20	198	Murky, 3-ft ebb.
							Dec.....	18-20 min.	0	15-20	...	Jet-type activity.
							Aug. 17-31	.....	0	.....	185	3-ft ebb, murky.
Middle Three Sisters.	.....	U	.....	171	171	Constant level; flowed into North Bowl.	Sept.....	Occasional	U	15	199	Sudden heavy surge into eruption.
							Oct.-Dec..	.....	0	.....	...	3-ft ebb.
							Aug. 17-31	.....	0	0	185	
South Three Sisters.	.....	U	.....	183	183	..do.....	Sept.....	Occasional	U	15	...	Active through September.
							Oct.-Dec..	.....	0	0	...	

See footnotes at end of table.

TABLE 4. - Summary of characteristics of springs and pools affected by Hebgen Lake earthquake--Continued

Name	Observations prior to August 17, 1959						Observations after August 17, 1959					
	Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1951	Temperature (° F) Summers 1958-59	Characteristics	Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1959	Characteristics
UPPER GEYSER BASIN--Continued												
Orange Spring Group:												
Orange Spring...	Cyclic..	0	0	138	139	Eruptions frequent when in active cycle.	Aug.-Dec..	Near constant spouting	U	3	180	Active cycle following quake.
No. 22.....	.....	Seep....	.....	137	137	Slight steady flow.....	Aug.-Nov..	.....	0	.....	141	6-in. ebb; murky first few days.
							Dec.....	.....	0	.....	...	2-in. ebb.
Round Spring Group:												
Round Spring...	.....	0	.....	178	137	No flow in 1959 preceding quake.	Aug.-Dec..	.....	0	.....	142	Increase in temperature plus 4-in. rise in water level from mid-1959 level.
North Round Spring.	.....	0	.....	151	150	Infrequent overflow...	..do.....	.....	0	.....	165	Same as Round Spring.
Pear Spring.....	.....	0	.....	166	165	Algal-lined spring....	do.....	.....	0	.....	194	Erupted following quake.
West Round Spring.	.....	0	.....	142	142	Lined with brown algae	..do.....	.....	0	.....	160	Erupted violently following quake.
Castle Group:												
Castle Group No. 26.	.....	0	.....	199	199	Steady boiling, no overflow.	..do.....	.....	0	.....	200	Murky first few days; steady boiling.
Crested Pool....	Rare....	15	3	200	200	Normally steadily flowing spring.	..do.....	.....	0	.....	155	Water level -12 in.; large drop in temperature.
									0	.....	200	Steam vent steady with development of new spring on side of chimney.
Chimney Fumarole	.....	0	.....	200	200	Steady steam vent.....	..do.....	.....	10	.....	200	
South Scalloped Spring.	.....	0	.....	198	198	3-in. ebb below rim...	..do.....	.....	5	.....	202	Increase in temperature and discharge.
Scalloped Spring	.....	0	.....	200	198	34-in. ebb in crater..	..do.....	.....	0	.....	201	24 in. ebb, and increase in temperature.
Frog Spring.....	.....	0	.....	64	64	Frogs in spring.....	..do.....	.....	2.3	..U....	196	Erupted following quake; has remained hot with overflow.
Liberty Pool....	.....	Seep....	.....	132	133	Pool lined with brown algae.	..do.....	.....	0.9	.....	163	One known eruption following quake; big increase in temperature.
Oval Spring.....	.....	0	.....	199	199	1-ft ebb in water level.	..do.....	.....	0	.....	201	Erupted following quake.
Belgian Pool....	.....	0	.....	164	163	..do.....	..do.....	.....	0	.....	161	Murky, ebb 18 in.
Terra Cotta Spring.	Cyclic..	2	0	196	196	Dormant before quake..	..do.....	U.....	15	6-8	197	Active cycle initiated by quake.
Grand Group:												
Wave Spring.....	.....	5	.....	131	134	Steady overflow.....	..do.....	.....	12.6	.....	163	Erupted following earthquake; hotter with increased flow.
Calida Spring...	.....	0	.....	183	183	1-in. ebb below rim...	..do.....	.....	1	.....	192	Murky plus overflow, increase in temperature.
Witches Cauldron	.....	80	.....	200	200	Steady boiling overflow.	..do.....	.....	80	.....	200	Murky water, only observed effect.
Milk Cauldron...	.....	0	.....	190	194	28-in. ebb in crater..	..do.....	.....	0	.....	200	Increase in temperature and boiling plus 20 in. ebb.
Geyser Hill Group:												
Teakettle Spring	.....	0	.....	199	199	1-ft ebb; crater empties when Giantess plays.	..do.....	.....	0	.....	203	Increase in temperature and ebb 30 in.
Rock Pool.....	.....	Seep....	.....	198	198	Constant level, clear water.	..do.....	.....	0	.....	198	4 in. ebb plus murky water.
Dragon Spring...	.....	5	.....	198	198	Steadily flowing spring.	..do.....	.....	0	.....	200	Erupted following quake; water then stayed at 35 in. ebb.

See footnotes at end of table.

TABLE 4. - Summary of characteristics of springs and pools affected by Hebgen Lake earthquake--Continued

Name	Observations prior to Aug. 17, 1959						Observations after Aug. 17, 1959					
	Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1951	Temperature (° F) Summers 1958-59	Characteristics	Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1959	Characteristics
UPPER GEYSER BASIN--Continued												
West Doublet Pool.	.....	20-40	.....	178	180	Increased flow with East Doublet surge.	Aug.-Dec....	.....	20- 40	.....	193	Murky following quake, increase in temperature.
East Doublet Pool.	.....	U	.....	193	193	Surge about every 5 min; flowed into West Doublet.	..do.....	.....	U	.....	196	Murky following quake; increase in temperature; flowed into West Doublet.
Beach Spring....	U.....	0.5[1]	1- 3	178	185	Cyclic in activity....	..do.....	Several daily.	0.5[1]	1- 3	201	Increase in temperature and frequency.
Ear Spring.....	.....	30	.....	200	200	Superheated.....	..do.....	Rare.....	125[1]	1	202	Erupted following quake; increase in temperature.
West Goggle Spring.	Intermittent	4	Quiet overflow	196	196	Periodic overflow.....	..do.....	Overflow every 20 to 30 min	4- 5	Surge...	200	Increased temperature and overflow.
Heart Spring....	.....	5	.....	200	199	Steady flow.....	..do.....	.....	0	.....	200	Murky, ebb 1 in. below overflow.
Arrowhead Spring	.....	0	.....	177	175	Water 4 in. below rim.	Aug.-Sept...	30 min-1 h	54[1]	3	200	Became eruptive following quake.
							Oct.-Dec....	.....	1.5	.....	...	Overflow but not eruptive.
Old Faithful Group:												
Chinaman Spring.	.....	.5	.....	200	200	Constant boiling.....	Aug.-Dec....	.....	.5	20- 30	201	Erupted following quake.
East Chinaman Spring.	.....	.3	.....	196	196	..do.....	..do.....	.....	.3	.....	198	Murky, increased temperature.
Blue Star Spring	.....	7	.....	184	185	Clear, shelved spring.	..do.....	.....	7	.....	186	Murky following quake.
Cascade Group:												
Gem Pool.....	.....	85	.....	188	189	Blue, constant level..	..do.....	.....	88	.....	194	Murky; increase in temperature.
Sprite Pool.....	.....	0	.....	167	164	Water 2 in. below rim.	..do.....	.....	.8	.....	181	Murky; discharge; increased temperature.
							Aug.-Nov....	.....	0	.....	195	Erupted following quake; became hotter in December.
Calthos Spring..	.....	0	.....	184	184	Water 6 in. below rim.	Dec.....	2 known eruptions	100	U.....	...	
Pulcher Spring..	.....	0	.....	199	199	Water level 3 ft below rim.	Aug.-Oct....	.....	150	.....	201	Murky, overflowing.
							Nov.-Dec....	.....	0	.....	...	Water 6 in. below rim.
Mirror Pool.....	.....	22	.....	183	183	Constant overflow.....	Nov.-Dec....	.....	24	.....	184	Murky following quake.
Sapphire Group:												
Black Opal Spring.	.....	175	.....	172	172	Erupts on rare occasions.	Aug.-Dec....	.....	175 (approx)	.....	173	Has stayed murky since quake.
							Aug.17-Sept. 4.	.....	125	6- 8	204	Constant surging.
Sapphire Pool..	15 min.	75 (approx)	3- 6	202	202	Deep blue color; true geyser, superheated.	Sept. 5-13..	2 h.....	2,250[1]	100-150	204	Major geyser activity.
							Sept.13-28..	.....	125	6- 8	204	Constant surging.
							Sept.29-Dec	30 min-2 h	1,000-3,000[1]	60-150	204	Major geyser activity.
West Mustard Spring.	.....	0	.....	164	163	Pool lined with yellow algae.	Aug.-Dec...	.....	U	3	200	Constant spouter following quake; loss by splashing.
East Mustard Spring.	.....	0	.....	136	157	..do.....	..do.....	.....	U	3	200	Do.
Avoca Spring.....	.....	3	.....	198	198	Constant boiling.....	..do.....	.....	0	.....	202	Water -4 ft; steam vent activity.

See footnotes at end of table.

TABLE 4. - Summary of characteristics of springs and pools affected by Hebgen Lake earthquake--Continued

Name	Observations prior to Aug. 17, 1959						Observations after Aug. 17, 1959					
	Eruption frequency	Discharge 1959 (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1951	Temperature (° F) Summers 1958-59	Characteristics	Date	Eruption frequency	Discharge (gpm)	Normal height of eruption (ft)	Temperature (° F) Sept. 1959	Characteristics
MIDWAY GEYSER BASIN												
Midway Geyser Basin Group:												
Indigo Spring...	.....	90	.....	199	199	Steady flowing.....	Aug.-Dec....	.....	0	.....	201	Murky; ebb 18 in. below overflow.
Grand Prismatic Spring.	.....	U	.....	...	...	..do.....	..do.....	.....	U	.....	...	Ebbed 8 ft first few hours following quake; crater slightly tilted to northeast.
Opal Spring.....	.....	0	.....	162	162	Infrequent eruptions..	..do.....	.....	0	.....	180	Murky, hotter.
Turquoise Pool..	.....	0	.....	54	54	Filled by overflow from Prismatic.	..do.....	.....	0	.....	132	8 ft ebb; increase in temperature; murky.
LOWER GEYSER BASIN												
Great Fountain Group:												
Lemon Spring....	.....	2.2	.....	147	143	Algal-lined pool.....	..do.....	.....	2.2	.....	137	Murky following quake.
Broken Egg Spring.	.....	1	.....	151	152	Constant level.....	..do.....	.....	0	.....	187	Murky, 15 in. ebb, refilled in December.
Firehole Pool...	.....	40	.....	196	196	Constant boiling.....	..do.....	.....	40	.....	196	Murky following quake.
Surprise Pool...	.....	25	.....	200	200	Superheated spring....	Aug.-Sept...	.....	25	.....	202	Murky; hotter.
							Oct-.Dec....	U.....	40	1	...	Periodically active.
Pink Cone Group:												
Shelf Spring...	.....	85	.....	199	199	Superheated.....	Aug.....	4 h.....	350	10-12	202	Activated by quake.
							Sept.-Dec...	.....	85	.....	201	No further eruptions.
Firehole Lake Group:												
Zomar Spring...	.....	800	.....	166	166	Steady flowing spring.	Aug.-Dec....	.....	80	.....	167	Very turbid following quake.
Black Warrior Spring.	.....	U	.....	195	195	..do.....	..do.....	.....	0	.....	177	Erupted following quake; ebbed 12 in.
East end Firehole Lake.	.....	0	.....	165	165	Flame-like ascent of gas bubbles.	..do.....	.....	0	.....	174	Water murky and hotter.
East side Firehole Lake.	.....	0	.....	150	151	..do.....	..do.....	.....	0	.....	148	Water murky and cooler.
Fountain Group:												
Silex Spring....	.....	13	.....	190	190	Occasional overflow..	Aug.-Sept.15	Constant.	0	3- 4	200	Water muddy, steady spouting; ebbed 3 ft.
							Sept.15-Dec.	.....	13	0	196	Crater refilled, steady overflow.
Celestine Spring	.....	66	.....	196	196	Steady overflow, clear blue spring.	Aug. 17-28..	None.....	0	0	200	Water ebbed 50 in.; muddy.
							Aug. 28-Sept. 14.	Constant.	0	6- 8	202	Steady jetting of muddy water. Crater refilled with steady overflow.
							Sept.15-Dec.	.....	65	.....	199	
							Aug. 17-21..	.....	0	.....	198	Slow rise in level, mud volcano action.
							Aug. 21-28..	.....	0	.....	200	
Fountain Paint Pot.	.....	0	.....	188	192	Active mud pots at south end of crater.						New mud pots at north end; new fumaroles outside main crater.
							Aug. 29-Dec.	.....	0	.....	196	Mud volcano action subsided; new mud pots and fumaroles persisted.
Hotel Group:												
Thud Spring (Fungoid).	.....	8.5	.....	179	179	Steady flowing spring	Aug.-Dec....	.....	8.5	.....	189	Murky, erupted night of quake.
Stirrup Spring..	.....	6	.....	191	190	do.....	..do.....	.....	0	.....	191	Do.
Gourd Spring....	.....	0	.....	158	157	Algae-lined pool.....	..do.....	.....	12	.....	186	Murky, erupted night of quake; steady discharge thereafter.
Jug Spring.....	.....	Slight..	.....	163	163	Seep overflow.....	..do.....	.....	Seep.....	.....	161	Murky after quake.
Cliff Spring....	.....	1.3	.....	197	197	Steady flow.....	..do.....	.....	1.3	.....	196	Murky, erupted night of quake.
Oak Leaf Spring.	.....	Seep....	.....	196	196	Quiescent spring.....	..do.....	.....	0	.....	196	Murky, erupted night of quake; ebbed 6 in.
Kidney Spring...	25 min.	12[1]	3-4	195	198	Periodically eruptive	..do.....	25 min...	12[1]	3- 4	199	Murky following quake.
Total maximum discharge.	.....	1,250	.....	.....	.....	.....	.....	.....	1,970	.....	.....	
Average temperature.	.....	.....	.....	176.7	176.9	.....	.....	.....	.....	.....	185.57	

I Infrequent.
NF No flow since quake.
NM Not readily measurable.
PU Periodic, undetermined.
U Undetermined.
[1] In eruption.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Alabama				
Jef-1.....	15 S.,3 W.,29.....	Jefferson.....	140	Bangor Limestone.....	M	6:40	43.4	1.3
COL-1.....	3 S., 10 W., 30....	Colbert.....	265	Fort Payne Chert and Tuscumbia Limestone.	M	6:40	28.50	.73
ELM-1.....	19 N., 20 W., 14...	Elmore.....	402	Augen gneiss.....	PC	6:40	9.06	.60
MAR-1.....	12 S., 13 W., 32...	Marion.....	520	Pottsville Sandstone.....	P	6:40	7.82	.20
TW-7.....	14 S., 8 E., 23....	Calhoun.....	95	Conasauga Limestone.....	C	6:40	13.51	>1.0
						*16:00	13.55	.06
TW-14.....	15 S., 8 E., 6.....	..do.....	213	..do.....	C	6:40	50.65	.85
						*16:00	50.69	.05
TW-2.....	16 S., 7 E., 32....	..do.....	355	Shale, streaks of limestone....	C	6:40	20.44	.64
TW-9.....	13 S., 10 E., 7....	..do.....	145	Rome Formation; limestone.....	C	6:40	11.79	.09
C-33-T.....	5 S., 4 W., 21.....	Morgan.....	295	Fort Payne Chert.....	M	6:40	13.41	.1
J-OBS-1.....	3 S., 4 W, 5.....	Limestone.....	142	..do.....	M	6:40	17.55	.4
CT-2.....	3 S., 4 W., 5.....	..do.....	133	..do.....	M	6:40	13.55	.5
TW-11.....	2 S., 11 W., 33....	Lauderdale....	227	..do.....	M	6:40	14.14	>1.0
TW-42.....	4 S., 11 W., 22....	Colbert.....	325	Tuscumbia Limestone.....	M	6:40	28.80	.65
TW-16.....	4 S., 11 W., 4.....	..do.....	327	Fort Payne Chert.....	M	6:40	74.29	.23
TW-24.....	4 S., 11 W., 15....	..do.....	352	Tuscumbia Limestone.....	M	6:40	60.40	.42
TW-15.....	4 S., 11 W., 9.....	..do.....	286	..do.....	M	6:40	21.42	.04
W-6.....	5 S., 1 W., 12.....	Madison.....	---	----------	---	6:40	11.90	.93
CT-79.....	3 S., 1 W., 32.....	..do.....	146	Fort Payne Chert.....	M	6:40	11.89	.35
MT-3.....	5 S., 1 E., 29.....	..do.....	356	Tuscumbia Limestone.....	M	6:40	16.87	.29
D-3.....	3 S., 1 W., 25.....	..do.....	---	..do.....	M	6:40	35.01	.15
				Arizona				
(D-4-2) 13bcc...	4 S., 2 E., 13.....	Pinal.....	534	Alluvium.....	Q	7:00	73.73	0.05
(D-5-8) 16dda...	5 S., 8 E., 16.....	..do.....	200	..do.....	Q	7:00	129.08	.06
(D-6-5) 25ccc...	6 S., 5 E., 25.....	..do.....	102	..do.....	Q	7:00	54.25	.30
				Arkansas				
6S-5W-21cab.....	6 S., 5 W., 21.....	Jefferson.....	75	Alluvium: coarse sand.....	Q	6:30	11.86	0.01
6S-7W-32ccc.....	6 S., 7 W., 32.....	..do.....	115	Terrace dep: medium to coarse sand.	Q	7:15	19.48	.02
7S-3W-6ddd.....	7 S., 3 W., 6.....	Arkansas.....	113	Very coarse sand.....	Q	6:50	52.14	.01
8S-3W-tract 2286	8 S., 3 W.....	..do.....	125	Terrace deposit: medium sand...	Q	6:30	19.03	.01
8S-3W-33abd.....	8 S., 3 W.....	Desha.....	60	Terrace deposit: medium sand, gravel.	Q	6:50	11.83	.01
11S-2W-3cca.....	11 S., 2 W.....	..do.....	754	Claiborne Group: sand.....	T	7:00	14.84	.06
				California				
2N/7E-2C1	2 N., 7 E., 2.....	San Bernardino	400	Gravel, sand, and clay lenses..	T and Q	7:00	40.96	0.56
								.22
2N/7E-4H1	2 N., 7 E., 4.....	..do.....	500	Alluvium: gravel, sand and clay lenses.	---	7:00	191.36	.12

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				California--Continued				
3N/8E-29C1.....	3 N., 8 E., 29.....	San Bernardino	800	Alluvium: sand, gravel, and clay lenses.	---	7:30	88.97	0.14
8S/2W-20L1.....	8 S., 2 W., 20.....	Riverside.....	524	Alluvium.....	Q	7:00	40.35	.06
8S/2W-20B2.....	8 S., 2 W., 20.....	..do.....	213	Older alluvium.....	Pt	7:00	25.98	.22
26/40-17N1.....	26 S., 40 E., 17...	Kern.....	178	Alluvium: gravel, sand, and clay.	Pt	7:00	100.90	.06 [2]
26/40-22N1.....	26 S., 40 E., 22...	..do.....	203	Sand, silt, and clay.....	Q	7:30	72.21	.08
26/40-22P1.....	26 S., 40 E., 22...	..do.....	850	Alluvium: sand and clay.....	Pt	7:00	67.96	.19
17/17-21N1.....	17 S., 17 E., 21...	Fresno.....	1005	Alluvium.....	Pt(?) and R	8:00	295.03	.10
23/25-16N3.....	23 S., 25 E., 16...	Tulare.....	430	..do.....	Pt and R	8:00	237.64	.50
23/25-16N4.....	23 S., 25 E., 16...	..do.....	250	..do.....	Pt(?) and R	6:00	118.62	.10
23/25-17Q3.....	23 S., 25 E., 17...	..do.....	355	..do.....	Pt(?) and R	6:00	121.71	1.07
12/12-16H5.....	12 S., 12 E., 16...	Fresno.....	720	..do.....	Pt(?) and R	6:00	130.00	.27
14/14-5H1.....	14 S., 14 E., 5....	..do.....	401	..do.....	Pt(?) and R	7:00	94.88	.04
15/16-20R1.....	15 S., 16 E., 20...	..do.....	350	..do.....	Pt(?) and R	8:00	79.93	1.11
						*18:00	79.91	.04
15/16-34E1.....	15 S., 16 E., 34...	..do.....	500+	..do.....	Pt(?) and R	7:00	179.99	.16
16/16-2M1.....	16 S., 16 E., 2....	..do.....	1047	..do.....	Pt(?) and R	6:00	184.94	.43
26/26-10R1.....	26 S., 26 E., 10...	Kern.....	1000	Older alluvium.....	Pl and Pt(?)	6:00	373.88	.39
						13:00	373.96	.04
6/30-29D3.....	34°34'25",120°04'15"	Santa Barbara.	43	Aluvium: coarse sand and gravel.	R	6:30	14.18	.04
7/34-12E1.....	7 N., 34 W., 12....	..do.....	385	Careaga Sand: massive, fine to coarse sand.	Pl	7:00	305.50	.02
7/35-22N2.....	7 N., 35 W., 22....	..do.....	194	Alluvium: sandy gravel.....	R	6:30	6.34	.70
7/35-33R1.....	34°38'47",120°33'54"	..do.....	420	Careaga Sand: coarse gravel...	Pl	6:30	109.70	.06
11/9-13L1.....	11 N., 9 E., 13....	Kern.....	462	Sand, clay, and gravel; basalt	---	7:00	152.37	.67
11/9-36C2.....	11 N., 9 E., 36....	..do.....	372	Sand, silt, clay, and gravel..	---	7:00	107.86	.34
				Colorado				
C-23-42-13.....	23 S., 42 W., 13...	Prowers.....	47	Alluvium: sand and gravel.....	Pt and R	3:18	7.09	0.03

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Florida				
Col-9.....	4 S., 17 E., 5.....	Columbia.....	836	Limestone.....	T	6:45	87.28	0.01
H-13.....	27 S., 18 E., 21...	Hillsborough..	300	..do.....	T	6:30	6.43	.04
H-30.....	31 S., 19 E., 32...	..do.....	500	..do.....	T	6:15	+9.40 [3]	.06
H-500.....	32 S., 20 E., 9....	..do.....	330	..do.....	T	6:30	49.19	.12
Pasco 16.....	25 S., 21 E., 34...	Pasco.....	1008	..do.....	T	6:45	59.09	.19
Volusia 31.....	18 S., 32 E., 11...	Volusia.....	113	..do.....	T	6:15	4.61	.08
V-909-106-4.....	15 S., 32 E., 33...	..do.....	234	..do.....	T	6:30	5.28	.14
V-910-105-1.....	15 S., 32 E., 27...	..do.....	498	..do.....	T	6:15	14.26	.18
P-45.....	28 S., 23 E., 36...	Polk.....	768	..do.....	T	6:55	62.56	.13
F-210.....	53 S., 41 E., 13...	Dade.....	112	..do.....	T	6:50	2.37 [4]	.19
G-553.....	55 S., 40 E., 16...	..do.....	91	..do.....	T	6:50	6.75 [4]	.14
G-580.....	55 S., 40 E., 11...	..do.....	100	..do.....	T	6:50	3.95 [4]	.23
S-19.....	53 S., 40 E., 25...	..do.....	95	..do.....	T	6:50	1.45 [4]	.48
S-68.....	53 S., 41 E., 19...	..do.....	61	..do.....	T	6:50	.52 [4]	.23
G-820.....	49 S., 42 E., 9....	Broward.....	224	..do.....	T	6:50	5.35 [4]	.17
				Georgia				
7.....	32°08'17",81°22'54"	Effingham.....	431	Ocala Limestone.....	E	6:00	14.74	0.18
17.....	32°03'30",81°05'45"	Chatham.....	505	..do.....	E	6:00	108.50	.23
63.....	32°05'07",81°05'49"	..do.....	525	..do.....	E	6:00	103.25	.22
82.....	32°06'10",81°07'55"	..do.....	332	..do.....	E	6:00	104.42	.10
99.....	32°04'30",81°03'30"	..do.....	500	..do.....	E	6:00	74.20	.27
317.....	32°02'00",80°54'15"	..do.....	354	..do.....	E	5:30	22.50	.37
382.....	32°06'10",81°08'55"	..do.....	---	..do.....	E	6:00	92.66	.35
				Hawaii				
83.....	21°18'20",157°51'05"	Honolulu.....	509	Koolau Volcanic Series: basalt.	Pl(?)	5:00	1.31	0.0 (sic)
193.....	21°23'37",157°56'52"	..do.....	363	..do.....	Pl(?)	6:00	5.36	.10
T-24.....	21°21'27",157°53'10"	..do.....	115	..do.....	Pl(?)	7:30	---	Trace
T-52.....	21°24'20",157°55'45"	..do.....	321	..do.....	Pl(?)	7:30	148.41	.06
				Idaho				
7N-36E-22ac2....	7 N., 36 E., 22....	Jefferson.....	35	Snake River basalt.....	Pl to R	7:00	8.02	3.35 [5]
						8:30	8.00	.22
						9:00	7.98	.04
						15:30	7.95	.42 [5]
						*4:30	7.98	.05
7N-35E-20cb1....	7 N., 35 E., 20....	..do.....	65	..do.....	Pl to R	6:00	50.75	.24
						7:00	50.76	.05
						14:00	50.79	.03
7N-34E-4cd1.....	7 N., 34 E., 4.....	..do.....	57	..do.....	Pl to R	6:30	24.94	4.91
						8:00	24.94	.68
						9:00	24.94	.22 [6]
						11:00	24.95	.16
						15:30	24.95	1.76 [7]
						*4:00	24.96	.30

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Idaho--Continued				
5N-34E-9bd1.....	5 N., 34 E., 9.....	Jefferson.....	553	Basalt.....	Pt	6:30	258.95	4.67
						8:00	258.95	.17
						15:30	258.96	.55
53N-2W-9aa1.....	53 N., 2 W., 9.....	Kootenai.....	351	Fluvioglacial gravel and sand.	Pt	6:30	230.99	.26
						15:30	231.01	.05
						*4:00	231.02	.02
5S-17E-26ac1....	5 S., 17 E., 26....	Lincoln.....	255	Snake River Basalt.....	Pl to R	6:00	186.62	>10.0 [8]
						7:00	186.62	.10
						15:00	186.71	.24
5S-33E-35cc1....	5 S., 33 E., 35....	Power.....	60	Gravel.....	Pl to R	6:00	24.25	.10
4N-45E-13ad1....	4 N., 45 E., 13....	Teton.....	304	Alluvium.....	Pl to R	7:00	172.93	>5.00 [8]
						7:30	173.02	.11
						8:00	173.07	.38
						9:00	173.08	.20
						11:30	173.15	.10
						15:30	173.25	.63
						*4:00	173.52	.21
4N-1W-35aa1.....	4 N., 1 W., 35.....	Ada.....	44	Sand and gravel.....	Pl to R	18:00	5.18	.16
3N-2E-25bb2.....	3 N., 2 E., 25.....	..do.....	52	..do.....	Pl to R	17:00	9.17	.09
1S-30E-156bc1...	1 S., 30 E., 15....	Bingham.....	752	Basalt.....	Pt	7:30	712.90	.69
5S-31E-27ab1....	5 S., 31 E., 27....	..do.....	46	..do.....	Pt	8:00	12.23	.03
1S-19E-3cc2.....	1 S., 19 E., 3.....	Blaine.....	51	Clay, silt, sand, and gravel..	Q	7:00	13.24	1.68
						8:00	13.24	.10
						15:00	13.26	.30
						18:00	13.29	.04
2S-20E-1ac2.....	2 S., 20 E., 1.....	..do.....	209	Snake River Basalt and alluvium	Pl to R	6:00	143.32	.95
						14:00	143.33	.12
						*3:00	143.36	(?).04
						**24:00	143.36	.09
						**17:00	143.44	(?).06
6N-31E-13db1....	6 N., 31 E., 13....	Butte.....	326	Snake River Basalt.....	Pl to R	5:00	215.14	>2.00 [8]
						6:00	215.14	.62
						9:00	215.13	.12
						13:00	215.20	>2.00 [8]
						*3:00	215.20	.27
5N-29E-23cd1....	5 N., 29 E., 23....	..do.....	401	..do.....	Pl to R	7:30	272.31	3.82
						8:30	272.30	.09
						9:00	272.30	.05
						16:00	272.28	.36
						*4:30	272.27	.05
3N-29E-14ad1....	3 N., 29 E., 14....	..do.....	588	Basalt.....	Pl to R	4:00	452.06	>2.00 [8]
						6:00	452.06	>2.00 [8]
						8:00	452.04	.11
						13:00	452.04	>2.00 [8]
						*2:00	452.03	.17
2N-27E-33ac2....	2 N., 27 E., 33....	..do.....	1200	Snake River Basalt.....	Pl to R	*7:00	985.56	.04

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Illinois				
ANL-9.....	37 N., 11 E., 9....	DuPage.....	140	Niagara Dolomite.....	S	6:30	94.61	0.14
ANL-10.....	37 N., 11 E., 9....	..do.....	198	..do.....	S	6:30	79.85	.96
ANL-20.....	37 N., 11 E., 10...	..do.....	168	..do.....	S	6:30	42.74	.11
ANL-38.....	37 N., 11 E., 5....	..do.....	173	..do.....	S	6:30	101.76	.02
				Indiana				
Cs.(25/3-10A1)..	25 N., 3 E., 10....	Cass.....	130	Limestone.....	S	6:45	20.96	0.11
Md 8.....	21 N., 6 E., 15....	Madison.....	415	..do.....	S	7:00	30.77	.07
Ma 31.....	16 N., 5 E., 6.....	Marion.....	347	Niagara Dolomite.....	S	7:00	102.1	.56
Ma 32.....	17 N., 3 E., 36....	..do.....	322	..do.....	S	4:00	13.05	.05
Mi(25/3-1H1)....	25 N., 3 E., 1.....	Miami.....	182	Limestone.....	S	6:30	21.06	.49
						15:30	21.04	.03
Mi(25/3-1H2)....	25 N., 3 E., 1.....	..do.....	183	..do.....	S	6:30	18.09	.17
						15:30	18.08	.01
Mi(25/3-1H4)....	25 N., 3 E., 1.....	..do.....	182	..do.....	S	6:45	23.20	.35
Mi(26/3-35C1)...	26 N., 3 E., 35....	..do.....	143	..do.....	S	6:30	35.55	.30
						15:30	29.70	.03
Pu 6(29/4W-4L1).	29 N., 4 W., 4.....	Pulaski.....	663	Niagara Dolomite.....	S	6:45	16.15	.20
				Kentucky				
8245-3745-404...	37°46',82°45'.....	Johnson.....	115	Breathitt Formation: sandstone	P	9:00	28.25	0.28
8400-3705-40....	37°07',84°04'.....	Laurel.....	400	Lee Formation: sandstone.....	P	*3:00	48.14	.06
				Maryland				
Cal-GD6.....	38°19'58",76°27'08"	Calvert.....	493	Aquia Greensand.....	E	9:00	34.44	(?)0.04
						12:40	34.75	(?).05
				Michigan				
7N7E17-1.....	7 N., 7 E., 17.....	Genessee.....	222	Saginaw Formation: sandstone, shale, coal, and limestone.	P	6:45	35.68	0.60
						15:45	35.83	.06
						*4:15	36.13	.07
2N4E9-1.....	2 N., 4 E., 9.....	Livingston....	280	Saginaw Formation: Parma Sandstone, shale, coal and limestone.	P	6:45	112.04	.21
3N10E32-1.....	3 N., 10 E., 32....	Oakland.....	160	Alluvium: sand and gravel.....	Pt	6:45	116.40	.14
39N23W28-3.....	39 N., 23 W., 28...	Delta.....	530	Munising Sandstone.....	C	7:00	3.11	.26
41N5W23-1.....	41 N., 5 W., 23....	Mackinac.....	47	Salina Formation: limestone...	S	7:00	14.45	.13

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Minnesota				
28.22.22bdd1....	28 N., 22 W., 22...	Dakota.....	264	Jordan (?) Sandstone.....	C	7:00	----	0.16
117.22.5abd2....	117 N., 22 W., 5...	Hennepin.....	483	Jordan Sandstone.....	C	6:30	----	.93
117.22.8dbd2....	117 N., 22 W., 8...	..do.....	503	..do.....	C	6:30	----	.27
117.23.11bbd1...	117 N., 23 W., 11..	..do.....	437	..do.....	C	6:30	----	.20
117.23.34daa2...	117 N., 23 W., 34..	..do.....	467	..do.....	C	6:30	----	.67
58.17.7daa1.....	58 N., 17 W., 7....	St. Louis.....	357	Biwabik Iron Formation.....	PC	15:30	----	(?).05
58.17.18ccc1....	58 N., 17 W., 18...	..do.....	118	Virginia shale: fractured argillite.	PC	(?)6:00	----	.33
						6:30	----	.16
				Montana				
6-20-8aa.....	6 N., 20 W., 8.....	Ravalli.....	20.5	Fluvial sand and gravel.....	Q	6:45	4.96	0.12
7-20-21cd.....	7 N., 20 W., 21....	..do.....	13.7	..do.....	Q	6:45	4.45	.14
						15:30	4.46	.03
						19:00	4.50	.01
						20:30	4.51	.01
						*4:00	4.54	.01
8-20-19ba3.....	8 N., 20 W., 19....	..do.....	52.0	Sandy clay.....	T	6:45	13.19	>.01
9-20-12bb.....	9 N., 20 W., 12....	..do.....	19.7	Alluvium.....	Q	6:45	5.46	.18
9-20-26ba1.....	9 N., 20 W., 26....	..do.....	22.7	..do.....	Q	6:45	4.22	.40
						15:30	4.25	.08
						*4:00	4.29	.04
10-20-14ba1.....	10 N., 20 W., 14...	..do.....	43.8	Glaciofluvial deposit.....	Q	6:45	24.99	.16
13-19-8cc.....	13 N., 19 W., 8....	Missoula.....	112.3	Sand, gravel, and silt.....	Q	6:45	38.13	.65
						15:30	38.21	.12
						*4:00	38.28	.05
13-19-29da.....	13 N., 19 W., 29...	..do.....	--	..do.....	Q	6:45	39.39	1.76
						8:00	39.40	.05
						8:45	39.40	.01
						15:30	39.42	.15
						*4:00	39.48	.14
14-21-13bb.....	14 N., 21 W., 13...	..do.....	25	Sand and gravel.....	Q	6:45	10.91	.55
						8:00	10.91	.01
						8:45	10.90	.01
						15:30	10.89	.03
						*4:00	10.87	.04
35-24-9bd.....	35 N., 24 E., 9....	Blaine.....	35	Flaxville formation.....	Mi or Pl	7:00	33.63	.14
						10:50	33.62	.12
						*2:00	33.62	.04
				Nebraska				
A10-6-36cdd.....	----------	Lancaster.....	170	Dakota sandstone.....	K	----	67.31	0.23

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Nevada				
S19/60-9bccl....	19 S., 60 E., 9....	Clark.....	830	Alluvium.....	Pl and Pt(?)	7:00 [9]	99.56	>1.00
						8:30 [9]	99.70	.03
S19/60-33baal...	19 S., 60 E., 33...	..do.....	1008	..do.....	Pl and Pt(?)	7:00 [9]	21.86	.45 [10]
S22/61-4bccl....	22 S., 61 E., 4....	..do.....	355	..do.....	Pl and Pt(?)	7:00 [9]	99.0	(?) .29 [11]
				New Jersey				
25.14.8.2.2.....	----------	Morris.....	181	Wisconsin Drift: coarse sand and gravel.	Pt	7:00	189.64 [4]	0.08
25.14.9.4.1.....	----------	..do.....	100	Wisconsin Drift: sand, gravel, and clay.	Pt	7:00	174.18	.09
26.22.4.4.4.....	----------	Union.....	400	Brunswick Formation: red shale.	Tr	7:00	24.42	.72
						16:00	24.57	.06
31.1.6.4.8.....	----------	Camden.....	300	Raritan Formation: sand and gravel.	K	7:00	+8.80 [3]	.09
25.14.3.5.5.....	----------	Morris.....	170	Wisconsin Drift: sand, gravel and clay.	Pt	7:00	175.89	.02
26.21.5.4.6.....	----------	Union.....	290	Brunswick Formation.....	Tr	7:00	60.15	.04
				New Mexico				
10.24.9.333.....	10 S. 24 E., 9.....	Chaves.....	258	San Andres Limestone.....	Pe	6:40	48.67	0.22
10.24.21.212....	10 S., 24 E., 21...	..do.....	324	..do.....	Pe	6:40	47.37	.75
13.26.27.211....	13 S., 25 E., 27...	..do.....	880	..do.....	Pe	6:40	145.43	1.34
11.23.3.342.....	11 S., 23 E., 3....	..do.....	595	..do.....	Pe	6:40	181.71	.04
20.26.17.334....	20 S., 26 E., 17...	Eddy.....	70	Seven Rivers Formation.....	Pe	6:40	55.18	.05
22.26.2.242.....	22 S., 26 E., 2....	..do.....	---	Capitan Limestone.....	Pe	6:40	57.47	.09
24.29.17.444....	24 S., 29 E., 17...	..do.....	246	Rustler Formation.....	Pe	6:40	2.88	.02
24.29.30.414....	24 S., 29 E., 30...	..do.....	66	do.....	Pe	6:40	18.34	.14
12.11.9.221.....	12 N., 11 W., 9....	Valencia.....	500	San Andres Limestone.....	Pe	6:40	168.19	.59
6	14 S., 4 W., 4.....	Sierra.....	105	Magdalena Group.....	P and Pe	6:40	+.66 [3]	(?)1.34
				New York				
SA 529.....	43°03'27",73°47'53"	Saratoga.....	189	Little Falls Dolomite.....	C	7:15 [9]	51.44	0.28
Cu 10.....	42°08'07",79°12'14"	Chautaugua....	150	Gravel.....	Pt	7:00 [9]	48.14	.22
				Ohio				
Cl-1.....	39°55'50",83°51'12"	Clark.....	57	Glacial outwash gravel.....	Pt	---	4.57	0.24
Dl-3.....	40°21'42",83°04'00"	Delaware.....	135	Columbus Limestone.....	D	---	30.00	.11
Ge-3a.....	41°25',81°22'.....	Geauga.....	120	Cuyahoga Formation.....	M	---	20.41	.08
Gr-3.....	30°49',83°53'.....	Greene.....	116	Brassfield Limestone.....	S	---	57.54	.10
Ho-1.....	40°36',81°55'.....	Holmes.....	43	Logan Formation.....	M	---	4.86	.04
Mu-2.....	39°57',82°02'.....	Muskingum.....	53	Glacial outwash.....	Pt	---	8.40	.02
R-2.....	40°41',82°35'.....	Richland.....	129	Black Hand Sandstone.....	M	---	26.89	.02

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Oklahoma				
66.....	4 N., 8 W., 33.....	Grady.....	254	Rush Springs Sandstone.....	Pe	6:00	85.67	0.28
						14:00	------	(?).05
				Puerto Rico				
24-66.3-2.....	----------	----------	105	Alluvial deposit.....	---	11:20	1.86	(?)0.01
				South Carolina				
BFT-119(M-2)....	32°26'15",80°46'30"	Beaufort.....	93	Limestone.....	E	7:00	24.10	0.10
46.....	32°18'05",81°58'10"	Jasper.....	334	..do.....	E	5:30	20.67	.29
BFT-121M-4).....	32°28',80°44'.....	Beaufort.....	105	..do.....	E	7:00	14.17	.15
BFT-113(P1-25)..	32°27'30",80°45'...	..do.....	107	..do.....	E	7:00	25.20	.15
				Tennessee				
7:1-6.....	36°35',84°04'.....	Campbell.....	620	Limestone and sandstone.....	P	7:00	76.09	0.34
						16:00	76.14	.03
				Texas				
B-166.....	----------	Lamb.....	202	Ogallala Formation.....	Pl	6:50	37.56	0.15
436.....	----------	Bexar.....	756	Edwards Limestone.....	K	6:45	61.87	.60
S1-18.....	----------	Dimmit.....	320	Carrizo Sand.....	E	6:55	131.35	.20
				Utah				
(B-2-1)24bad-3..	----------	Davis.....	386	Valley fill.....	Cz	6:50	+24.6	3.8
(C-16-7)12dcd-5.	----------	Millard.....	480	..do.....	Cz	7:10	+22.2	5.1
(C-7-8)10cbd-1..	----------	Tooele.....	175	Gravel.....	Cz	6:40	88.30	.55
(C-2-4)33add-1..	----------	..do.....	165	Sand and gravel.....	Cz	6:40	11.76	>1.00 [8]
(C-35-11)33dbc-1	----------	Iron.....	140	Gravel.....	Cz	6:55	---	.78
				Washington				
20/3-18-C1.....	20 N., 3 E., 18....	Pierce--------	185	Sand and gravel.....	Pt	6:45	96.23	1.15
						8:00	96.22	.09
						8:30	96.22	.03
						15:30	96.25	.27
						*16:10	96.23	.00
20/25-21A2.....	20 N., 25 E., 21...	Grant.....	652	Columbia River Basalt.....	M	6:00	19.54	.29
22/27-19N2.....	22 N., 27 E., 19...	..do.....	275	..do.....	M	1:00	35.69	.05 [9]
10/17-5E2.....	10 N., 17 E., 5....	Yakima.....	15	Alluvium: sand and gravel.....	R	6:15	7.05	.04
						14:30	7.06	.03
						*14:15	7.08	.14
10/19-1N1.....	10 N., 19 E., 1....	..do.....	21	..do.....	R	6:45	6.52	.03
26/45-32J2.....	26 N., 45 E., 32...	Spokane.....	155	Sand and gravel.....	Pt	7:15	123.29	.35
						14:00	123.33	.03

See footnotes at end of table.

TABLE 5. - Fluctuations of water levels and pressure heads, Hebgen Lake earthquake--Continued

Well	Location [1] (T,R,S)	County	Depth of well (ft)	Water-bearing formation and (or) type of material	Age	Time	Depth to water before disturbance (ft)	Double amplitude of fluctuation (ft)
				Wisconsin				
Lf-57.....	1 N., 2 E., 33.....	Lafayette.....	265	Galena Dolomite.....	O	6:30	134.57	>1.00
						8:45	134.53	.03
						15:30	134.54	.18
						*4:00	134.47	.04
Lf-121.....	1 N., 2 E., 35.....	..do.....	300	..do.....	O	7:00	74.64	.55
						16:30	74.80	.03
						*5:00	74.80	.02
Lf-183.....	1 N., 1 E., 34.....	..do.....	268	..do.....	O	6:00	91.47	.46
						7:00	91.48	.01
						14:30	91.49	.02
Ml-121.....	5 N., 22 E., 13....	Milwaukee.....	268	Niagara Dolomite.....	S	6:00	67.82	.07
Fl-12.....	15 N., 17 E., 11...	Fond du Lac...	817	Galena, Platteville, and St. Peter Formations.	C and O	6:00	69.25	.10

Age: PC-Precambrian; C-Cambrian; O-Ordovician; S-Silurian; D-Devonian; M-Mississippian; P-Pennsylvanian; Pe-Permian; Tr-Triassic; K-Cretaceous; CZ-Cenozoic; T-Tertiary; E-Eocene; Mi-Miocene; Pl-Pliocene; Q-Quaternary; Pt-Pleistocene; R-Recent

Time: The Greenwich civil times refer to August 18, the day of the main earthquake except those marked *(asterisk), which refer to August 19, and those marked **(double asterisk), which refer to August 20. Where no figures are given, time was not available.

1 Where section, township, and range are not given, figures refer to latitude north and longitude west.
2 Single-amplitude fluctuation.
3 Water level is plus when piezometric surface is above land surface.
4 Water levels are referred to mean sea level.
6 Small fluctuations about 30 minutes later.
7 Two small fluctuations about 15 and 30 minutes later.
8 Complete revolution of chart; pen retraced mark; unable to determine highest and lowest points of fluction.
9 Within half an hour, more or less.
10 Float sticks occasionally. Residual change in water level may be due to malfunction of instrument.
11 Float rubs on casing; double amplitude probably greater than 0.29 foot.

References

1. Stermitz, F. Effects of the Hebgen Lake Earthquake on Surface Water. U.S. Geol. Surv. Prof. Paper 435-L, 1964, pp. 139-150.

2. Marler, G. D. Effects of the Hebgen Lake Earthquake of August 17, 1959, on the Hot Springs of the Firehole Geyser Basins, Yellowstone National Park. U.S. Geol. Surv. Prof. Paper 435-Q, 1964, pp. 185-197.

3. da Costa, J. A. Effect of Hebgen Lake Earthquake on Water Levels in Wells in the United States. U.S. Geol. Surv. Prof. Paper 435-O, 1964, pp. 167-178.

Reference not cited

Eppley, R. A. and W. K. Cloud. United States Earthquakes, 1959. Washington, DC: U.S. Department of Commerce, Coast and Geodetic Survey, 1961, pp. 65-75. (pertains to well level fluctuations)

Location: Pocatello Valley, ID
Latitude: 42.1° N.
Longitude: 112.5° W.
Date: March 28, 1975
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): 6.1

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- No reports of hydrologic effects located.

Reference

Coffman, J. L. and C. W. Stover. U.S. Earthquakes, 1975. Boulder, CO: U.S. Dep. Commerce, Natl. Oceanic and Atmospheric Administration, and U.S. Geol. Surv., 1976, pp. 20-24.

Location: Yellowstone National Park, MT
Latitude: 44.7° N.
Longitude: 110.6° W.
Date: June 30, 1975
Intensity (Modified Mercalli scale): VIII
Magnitude (Richter scale): 6.4

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- Geysers (generally) greatly affected; many increased flow and became more active.
- Several new geysers came into existence.
- Gibbon River became very turbid.

Reference

Coffman, J. L. and C. W. Stover. U.S. Earthquakes, 1975. Boulder, CO: U.S. Dep. of Commerce, Natl. Oceanic and Atmospheric Administration, and U.S. Geol. Surv., 1976.

Location: Mammoth Lakes, CA
Latitude: 37.6° N.
Longitude: 118.8° W.
Date: May 25, 1980
Intensity (Modified Mercalli scale): VII
Magnitude (Richter scale): 6.1

Effects on Underground Mines

- No reports of damage or other effects to underground mines or workings located.

Hydrologic Effects

- Discharge of water from slump blocks and ground cracks.
- Sand boils widespread.
- Hot Creek recreational area closed for period of time due to dangerously high water temperature.
- Reports of mud ejected from fissures.
- Increase flow in creek north of Mammoth School.
- One spring reportedly increased flow rate (rate not specified) immediately before and after shock of May 25.
- Steam and fumes reported issuing from ground cracks.
- Fumaroles reported (number, location not reported in reference).
- New hot spring started developing at Hot Creek the <u>day before</u> (emphasis added) the May 25 event.
- Wells at the Mammoth fish hatchery, Casa Diablo, and Hot Creek above the hot springs became turbid.

References

1. Anonymous. California Geology. V. 33, No. 9.

2. Sherburne, R. W. <u>Mammoth Lakes, California Earthquakes of May, 1980</u>. CA Div. Mines and Geol. Spec. Publ. 150, 1980.

Location: Borah Peak, ID
Latitude: 44.0° N.
Longitude: 113.9° W.
Date: October 28, 1983
Intensity (Modified Mercalli scale): IX-X
Magnitude (Richter scale): 7.3

A map showing the earthquake epicenter and general geographic features is presented in figure 21.

Effects on Underground Mines

Clayton Silver Mine

The Clayton Silver Mine, located about 20 mi southwest of Challis, ID, sustained flooding in its No.2 shaft for 3 h following the earthquake. No physical damage to the underground workings or mine surface facilities, however, was reported. The following account of the flooding and measures taken to mitigate same, is summarized from Wood (1); the information was provided by Clayton Mine management.

Water had been maintained at the 1,100-ft level prior to the earthquake by continuous pumping of 980 gpm. Three hours after the tremor, water began to rise at the rate of 6 ft/h; by 10:40 p.m. on the 28th, workings at the 1,100-ft level were flooded. By November 7, water had risen 245 ft to the 963-ft level. (Mine level is referenced to a datum elevation of about 5,890 ft at creek level below No. 1 shaft.) At that point, the water level stabilized then started to decline slightly by pumping 930 gpm. By November 15, a 2,000-gpm pump was installed and water levels began to decline at a greater rate; the water was down to the 1,080-ft level by December 17.

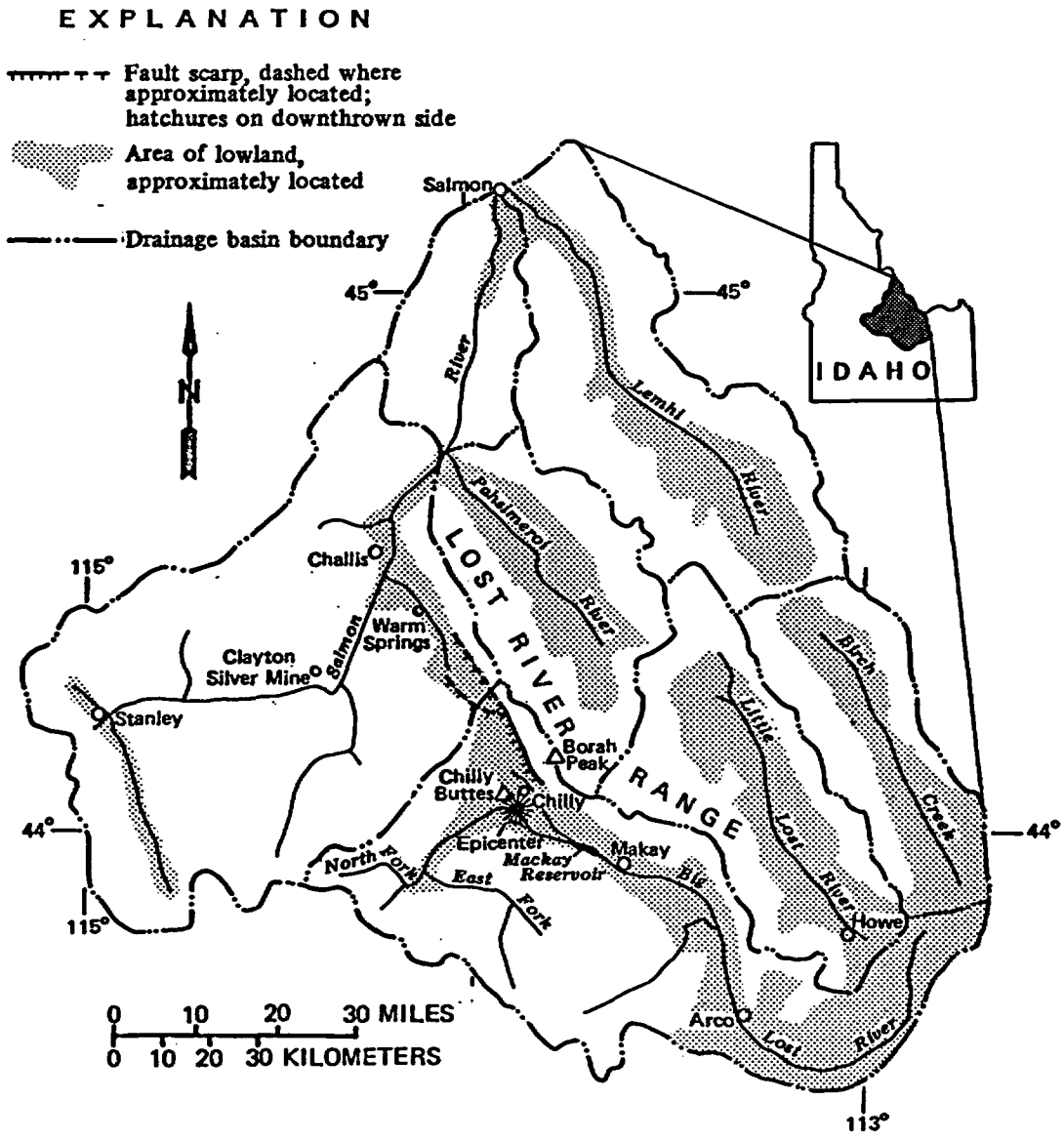
Irregularities in the drawdown curve (fig. 22) reflect periods when the pumps were operated at reduced rates or shut down for repairs. During the early portion of the curve, water levels rose at a rate of 0.7 ft/h when pumps were off; during later portions of the curve, water levels rose at 2.7 ft/h. Mine water inflow returned to pre-earthquake levels after about 8 months.

Clayton Mine was also flooded following the Hebgen Lake earthquake of August 17, 1959.

Kraken Hill Mine

Kraken Hill Mine, also located near Challis, ID, reported heavy damage the nature and extent of which is proprietary.1/

1/Confidential report from Kraken Hill Mine management to Bureau of Mines, Western Field Operations Center, Spokane, WA, and U.S. Small Business Administration, Disaster Assistance - Area 4, Sacramento, CA.



Modified from Whitehead, 1985

FIGURE 21. - Map showing earthquake epicenter and general geographic features, Borah Peak earthquake

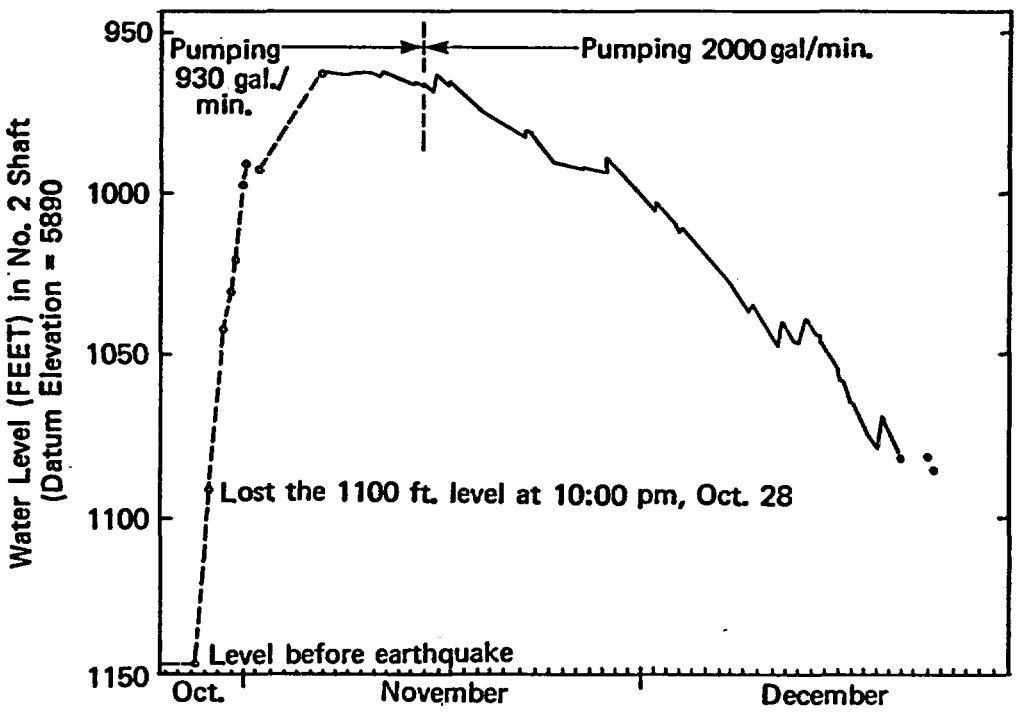


FIGURE 22. - Water levels in Clayton Silver Mine following Borah Peak earthquake

Hydrologic Effects

General

Following the Borah Peak earthquake, significant hydrologic changes were observed and/or reported. In one observation well near the epicenter, ground water rose as much as 13 ft then declined over a period of several months to stabilize at about 5 ft above pre-earthquake levels. Several wells in the area exhibited artesian flow for a brief period. New springs developed and many existing springs showed discharge increases. Ingram's Warm Springs, near Challis, ceased flow for several days then resumed at an increased flow rate. Ground water erupted from fissures near Chilly Butte (north of the epicenter) and formed numerous large sand boils on the adjacent valley floor. Many streams in the area showed increases in discharge, some as much as 100 pct. Generally, stream flows remained at high levels for 2 weeks before declining to near, but still above, original rates. Analyses of water samples (both cold- and thermal-water) by the USGS and others, indicated no significant changes in water chemistry.

Effects on Surface Water (2)

According to Whitehead (2), most streams in the epicentral area and surrounding basins were at or above maximum average discharge prior to the tremor. Following the earthquake, significant increases were measured at several USGS gaging stations. Hydrographs of the Salmon River, Herd Creek, and the Big and Little Lost Rivers at various locations are presented in figures 23 and 24. The hydrographs are keyed to locations shown in figure 25.

The following discussion of surface water effects is summarized from Whitehead (2).

Streamflow increased more than 100 pct in North Fork Big Lost River and in Big Lost River, about 14 mi and 9 mi southwest, respectively, of the epicenter. North Fork flow increased from about 3,000 cfm prior to the earthquake to more than 7,200 cfm. Big Lost River flow increased from 10,500 cfm to 23,900 cfm. Flow in Big Lost River had declined to about 19,500 cfm by December 1983.

At Larson Creek, discharge increased to 1,790 cfm (pre-earthquake discharge rate not available); Sulphur Creek discharge increased from its 1971 rate of 930 cfm to 1,600 cfm after earthquake.

No major precipitation occurred in the area during October (National Weather Service data) that would account for the increased discharge. Rainstorms before and after the earthquake are indicated on the hydrographs.

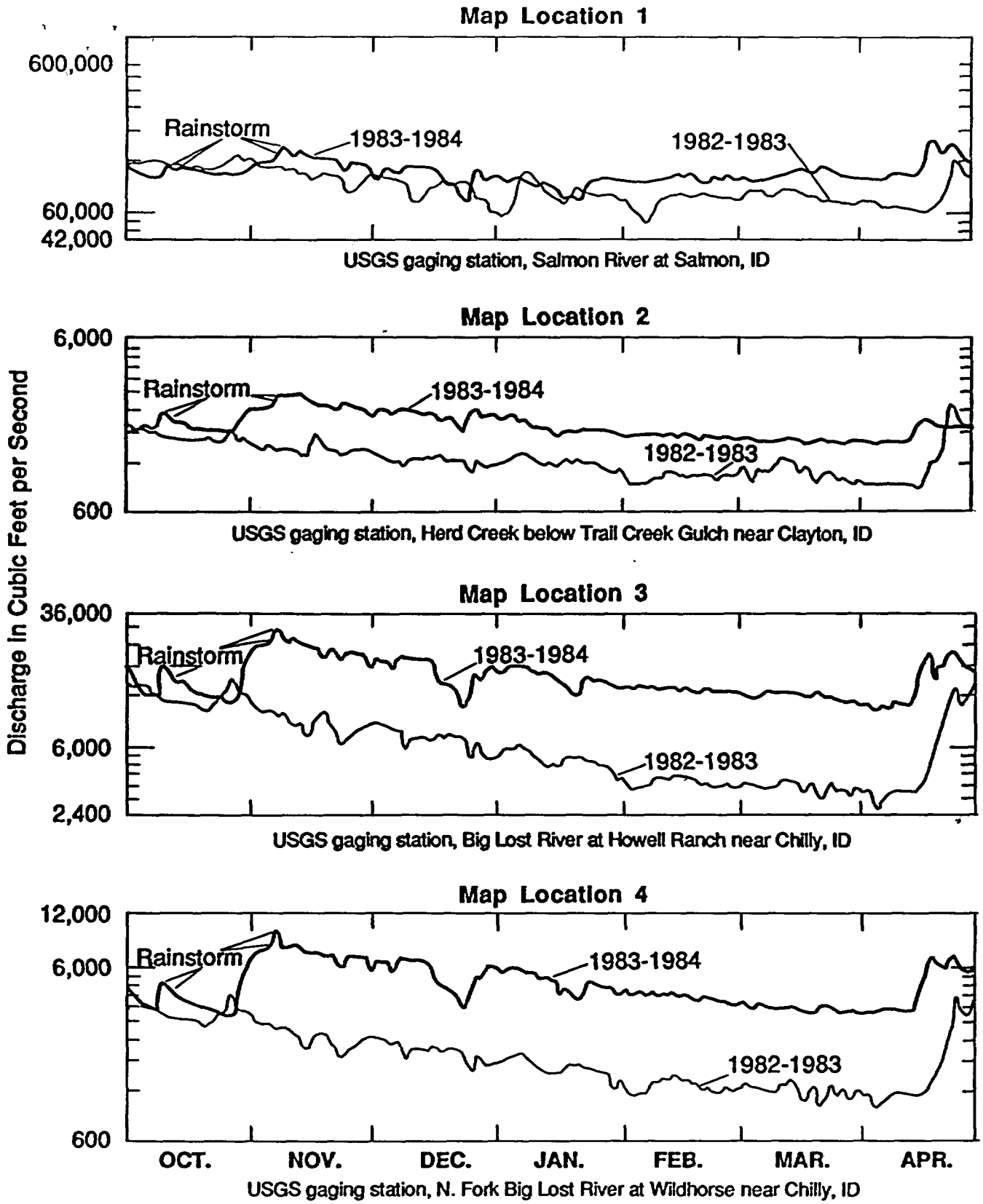


FIGURE 23. - Selected stream hydrographs, Borah Peak earthquake

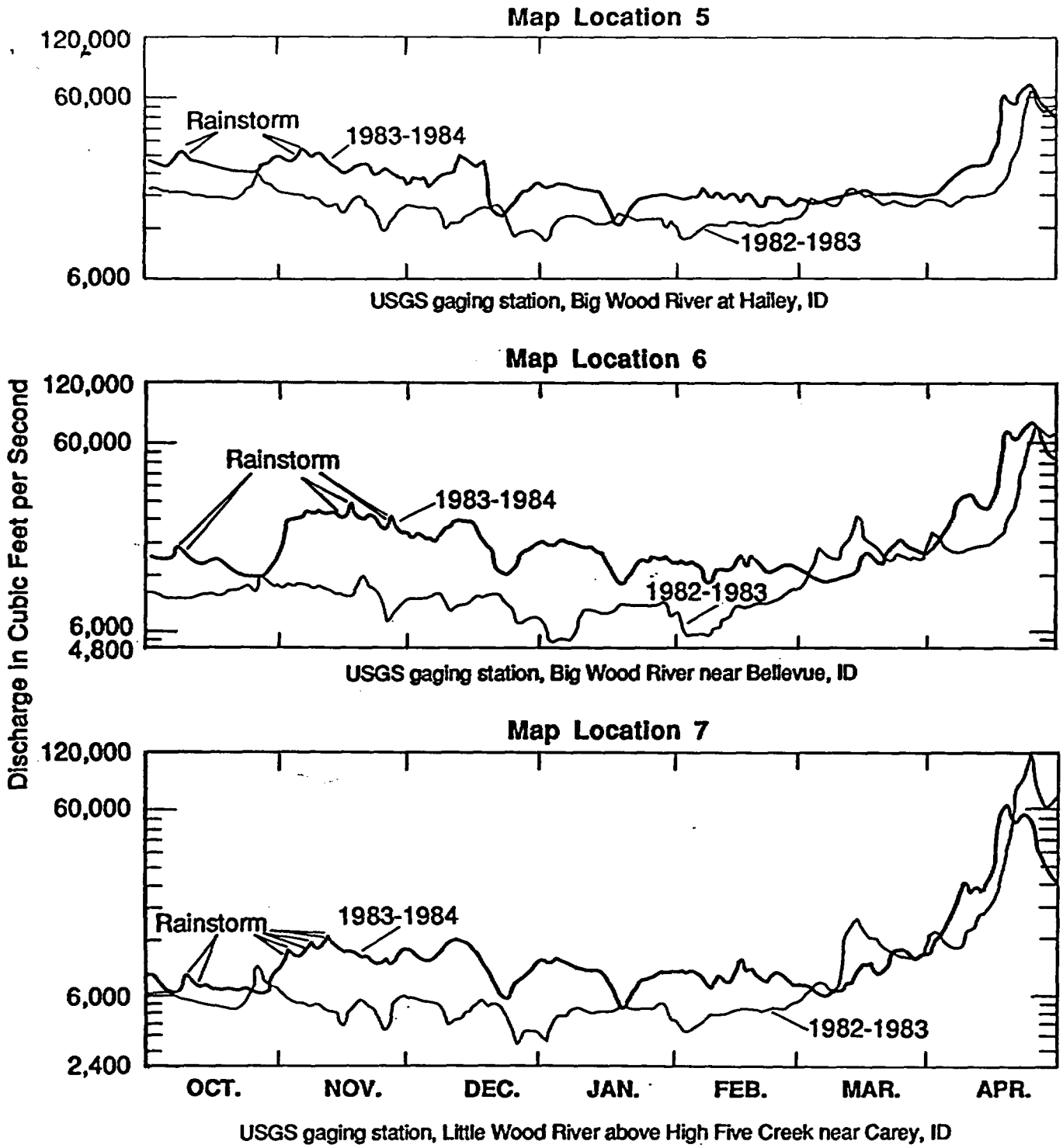


FIGURE 24. - Selected stream hydrographs, Borah Peak earthquake

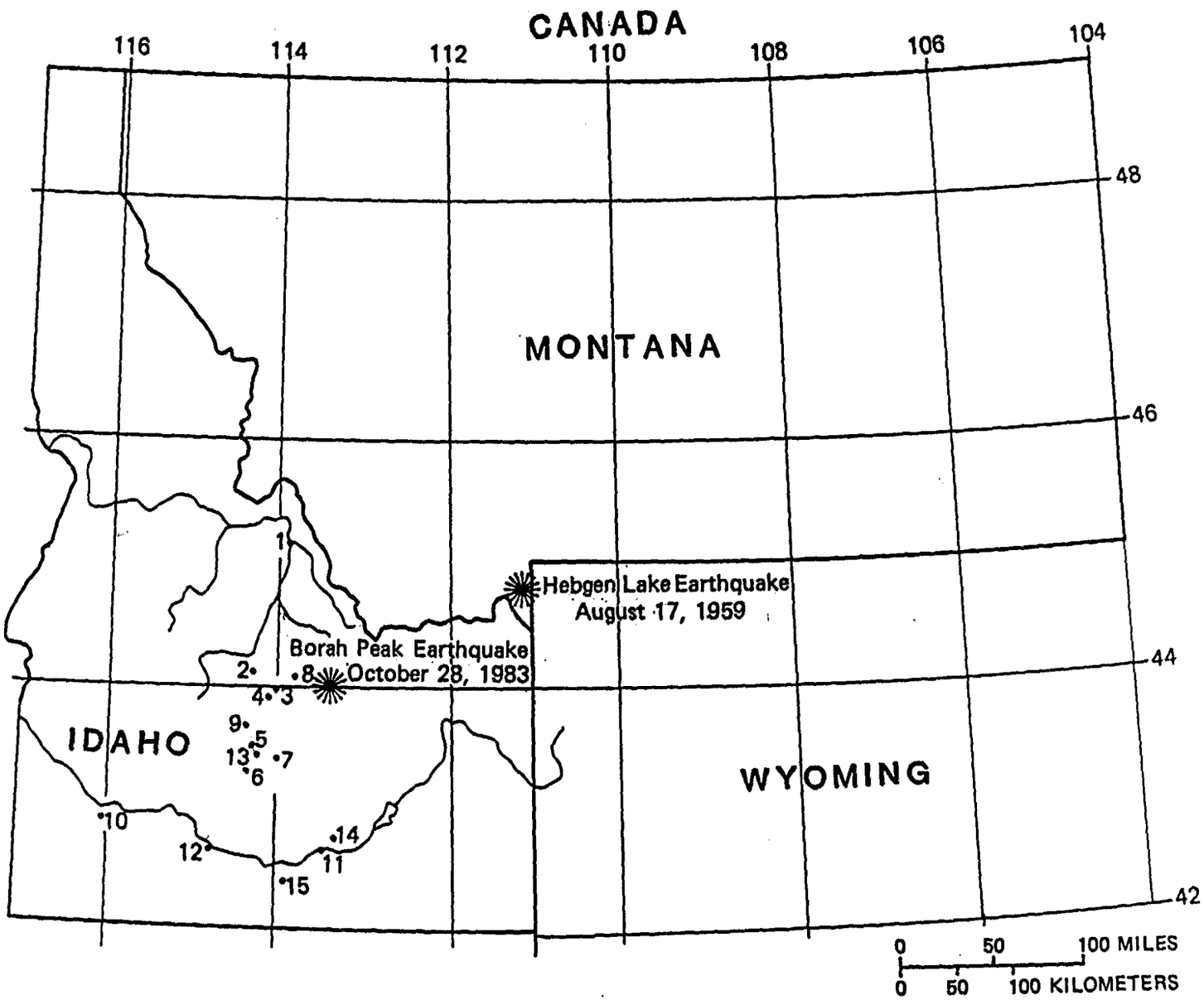


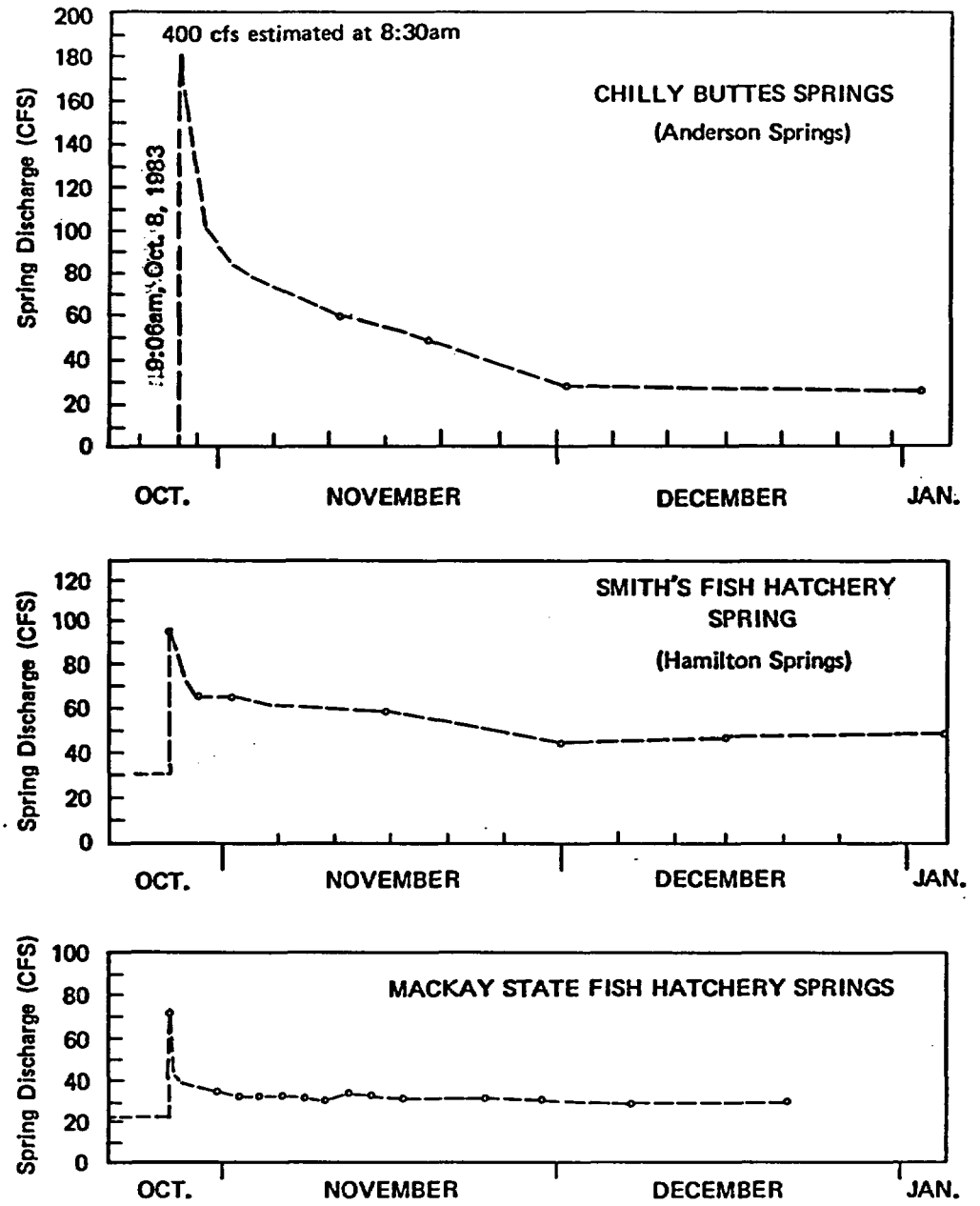
FIGURE 25. - Location map of observation stations--Borah Peak earthquake

The earthquake was directly responsible for the formation of two temporary lakes. A lake at Chilly Butte drained within 2 weeks; the other, in the Pahsimeroi River Basin, was reported by the U.S. Forest Service to have drained by the summer of 1984.

Effects on Springs

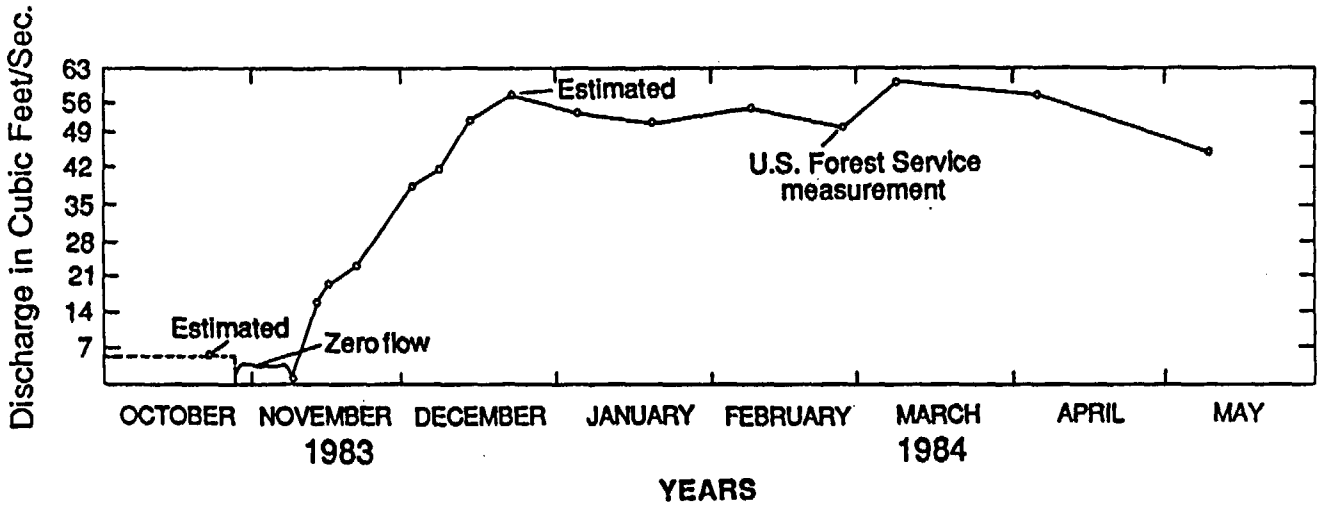
The Borah Peak earthquake was responsible for the formation of several new (albeit short-lived) springs and caused short-term increases, decreases, or cessation of flow in existing springs. Spring flow increase was the most widespread phenomenon. Perhaps the most significant increase in spring flow was at Ingram's Warm Springs, southeast of Challis. Prior to the tremor, the springs flowed at about 6 cfs. The springs ceased to flow after the earthquake but resumed flow on November 4. Flow increased steadily to peak on December 20 at 58 cfs. Discharge remained reasonably steady during January and February 1984, ranging between 52 and 55 cfs. By early March, discharge peaked at 62 cfs then declined to 58 cfs and 46 cfs on April 5 and May 9, respectively. Flow was measured in August 1984 at 53 cfs.

Hydrographs for Chilly Butte Springs (near Chilly, ID), Smith's Fish Hatchery Spring (northwest of Mackay, ID), and the springs at Mackay State Fish Hatchery (near Mackay, ID) are presented in figure 26. Figure 27 is a hydrograph of Ingram's Hot Springs.



Modified from Wood, 1985

FIGURE 26. - Selected spring hydrographs, Borah Peak earthquake



Modified from Whitehead, 1985

FIGURE 27. - Hydrograph of Ingram's Hot Springs, Borah Peak earthquake

Effects on Thermal Springs and Geysers, Yellowstone National Park

Unlike the August 17, 1959, Hebgen Lake earthquake, the Borah Peak tremor had no apparent significant effect on ground water flow and eruptive activity of thermal springs and geysers within Yellowstone National Park (3). This may be due, in part, to the greater distance between the park and the earthquake epicenter (150 mi; the Hebgen Lake epicenter was about 20 mi from Yellowstone), and the lack of personnel to make observations and perform tests (3). A summary of changes in spring and geyser behavior observed after the earthquake are presented in table 6.

Effects on Water Well Levels

The most pronounced water level fluctuations and/or changes in turbidity occurred in the epicentral area although some changes were noted in wells in Montana as far away as 435 mi. Near the epicenter, well levels rose rapidly following the earthquake and occasionally overtopped their casings. Often the water was muddy or sand-laden and caused many pump failures. Well level increases were noted throughout southern Idaho; most, however, returned to pre-earthquake levels within a relatively short period of time (2 weeks to 2 months).

An observation well near Chilly recorded the greatest water-level change (fig. 28). The recorder malfunctioned on September 15, 1983, and when it was restarted on November 4, the water level had risen 13 ft. Subsequently, it declined steadily until January then leveled off about 5 ft above its pre-earthquake stage.

Hydrographs of eight selected wells showing water-level changes following the earthquake are shown in figure 29. The hydrographs are keyed to locations shown in figure 25.

References

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2. Whitehead, R. L. "Hydrologic Changes Following the Borah Peak Earthquake." Paper in Proceedings of Workshop XXVIII on the Borah Peak, Idaho, Earthquake. U.S. Geol. Surv. Open-file Rep. 85-290 A, 1985, pp. 556-572.

3. Hutchinson, R. A. "Hydrothermal Changes in the Upper Geyser Basin, Yellowstone National Park, After the 1983 Borah Peak, Idaho, Earthquake." Paper in Proceedings of Workshop XXVIII on the Borah Peak, Idaho, Earthquake. U.S. Geol. Surv. Open-file Rep. 85-290 A, 1985, pp. 612-619.

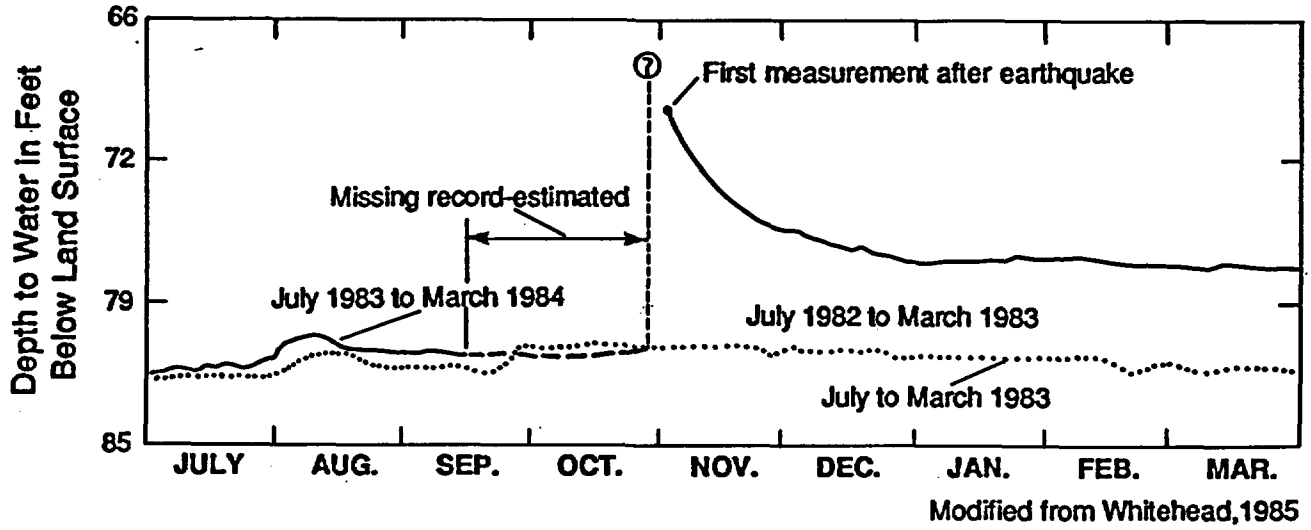

FIGURE 28. - Hydrograph of observation well near Chilly, ID, Borah Peak earthquake

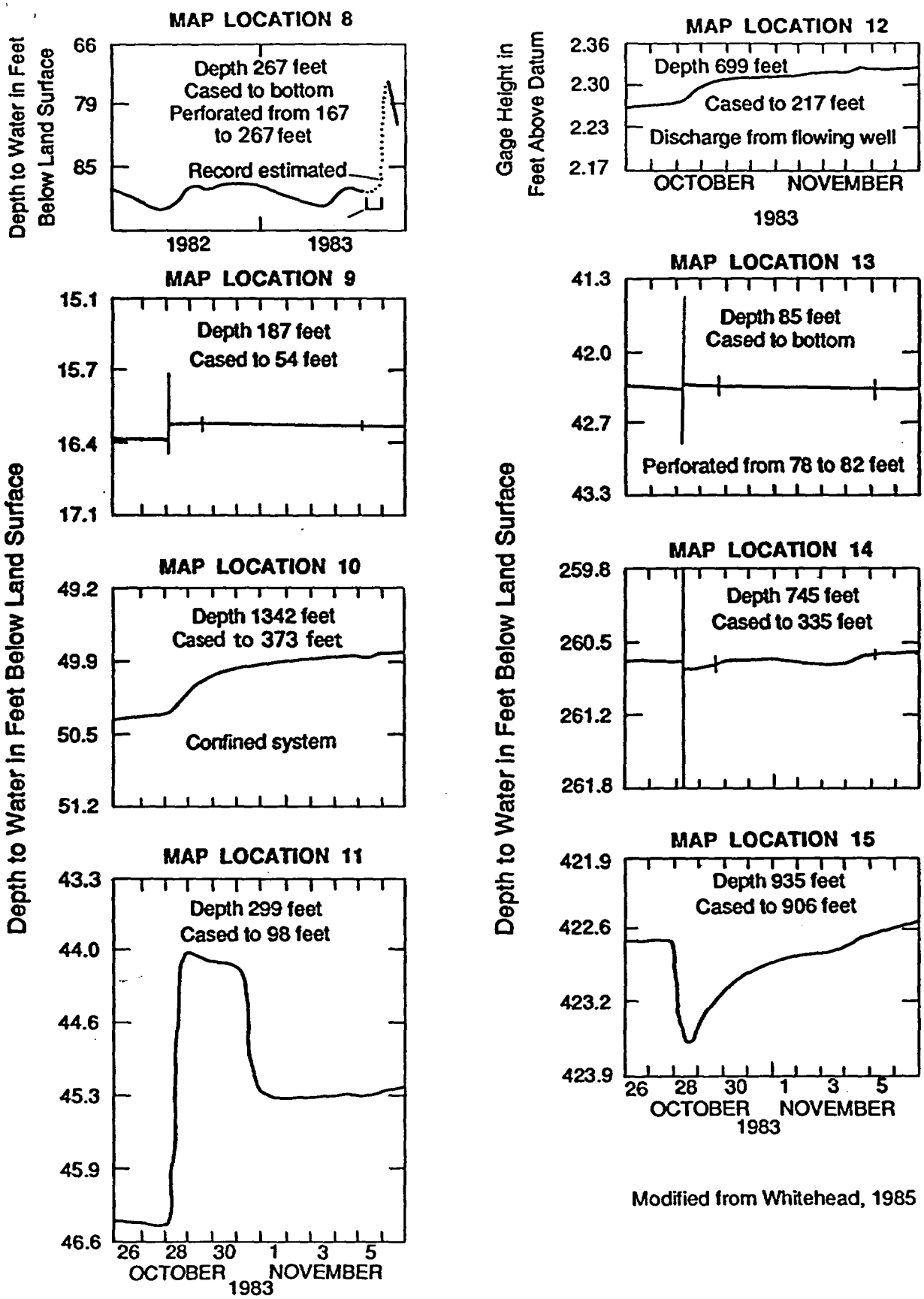

FIGURE 29. - Hydrographs of selected wells, Borah Peak earthquake

TABLE 6. - Summary of thermal changes in Upper Geyser Basin, Yellowstone National Park, resulting from the October 28, 1983 Borah Peak, ID earthquake

Thermal Feature	Comments
Anemone Geyser.....	Eruptions more powerful; water ejected on boardwalk.
Aurum Geyser.....	Durations increased from 10 s to near 2 min; maximum height up, with water reaching boardwalk laterally 25 ft.
Beehive Geyser.....	New regularity established after prior erratic eruption pattern; now predictable with 15-h average interval.
Bench Geyser.....	24-in diam and 20-in deep funnel formed in Giantess Geyser's loose sinter alluvium. Prior to quake, vent had been totally buried.
Bronze Spring.....	Discharge reduced to a mere seep by January 1984; ebbed 2 in. more by July. Significant color change due to temperature drop to 74° F.
Cascade Geyser.....	One major eruption at unknown date late fall or early winter; width of wash--47.5 ft.
Depression Geyser.....	Average interval decreased from more than 6 h to 2-3 h.
Dome Geyser.....	Exchange of function now seen with Vault Geyser instead of Giantess.
Dragon Spring.....	Discharge decreased, shown by about half of algae mat in runoff channels drying up and dying.
Unnamed geyser southeast of Dragon Spring.	Rejuvenated into frequent, 3.3 to 6.6 ft performing geyser.
Ear Spring.....	Discharge increased from small point outlet on east to frequent overflow in all directions. Sinter wash to west suggests heavy boil or small eruption in November or December.
Unnamed spring northwest of Ear Spring.	Height of "spouting" activity noticeably greater for 5 months.
Giantess Geyser.....	Became dormant on November 10, 1983, ending the series of 112 eruptions which began February 19, 1980. In contrast, only 108 eruptions were recorded during the 50-yr period of 1927-76.
Heart Spring.....	Increased gas discharge and temperature.
Infant Geyser.....	Water level ebbed more than 15.7 in.
Inverted Geyser.....	Sinter sheet ruptured over an area approximately 8.9 ft in diameter, causing geyser to be destroyed.

TABLE 6. - Summary of thermal changes in Upper Geyser Basin--Continued

Thermal Feature	Comments
Lion Geyser.....	Dormant from time of quake for about 15 months. The only prior time Lion Geyser has been known to be dormant was for a 2-1/2 month period following the 1959 Hebgen Lake quake.
Little Squirt Geyser.....	Rejuvenated from rare eruptions to long periods of play almost daily.
Pendant Geyser.....	Rejuvenated from long-dormant, quiet spring to almost continuous spouter, 0.33 to 6.2 ft high by early December, but nearly dormant again by July 31, 1984.
Plate Geyser.....	Eruptive activity increased from very rare in 1983 to around 3 to 4 h intervals. Geyser crater enlarged to 13 by 11.9 ft.
Unnamed blowouts east of Plate Geyser.	Fresh, unweathered sinter chips torn out and vegetation killed around each of these vents.
Plume Geyser.....	Before quake in 1983, Plume would initiate eruption with water level 2.8 to 3.9 in. below lower rim; behavior has changed since then in that it overflows heavily for 15 or more minutes before erupting. Average intervals have decreased from near 40 min to 30 min, and are strongly influenced by eruptive series of Vault Geyser in place of Giantess.
Unnamed vent near Plume Geyser.	Continuous boiling and heavy overflow since the Borah Peak event until July 1984, when pool level dropped 15.7 in. Area of vent increased by factor of 9 from vigorous surging.
Pump Geyser.....	Discharge apparently diminished as suggested by virtual disappearance of the active algae mat.
Roof Geyser.....	Eruptions more powerful after the quake as shown by new wash; changes in intervals or durations, if any, are unknown.
Scissors Springs.....	Eruptive activity and runoff from West Scissors ceased; water level down 3.9 to 7.8 in. in both vents.
Sponge Geyser.....	Water level in vent rose more than 6.6 ft; eruptive activity similar to that before the 1959 earthquake has returned.

TABLE 6. - Summary of thermal changes in Upper Geyser Basin--Continued

Thermal Feature	Comments
Surge Geyser.....	Frequent eruptive activity rejuvenated after October 28, 1983, until late winter. Fresh siliceous sinter eroded from pool and vent.
Vault Geyser.....	Serial-type eruptions very similar to those between 1947 and 1959 resumed; more powerful than the displays associated with Giantess eruptions of at least the last 10 yr.
Unnamed white halo blowout vent.	Fresh unweathered white siliceous sinter ejecta rim deposited around vent. Dimensions--5.8 by 5.6 ft.
Unnamed vent east of Arrowhead Spring.	New enlargement of vent and heavy wash 7.3 ft to the south. Dimensions--11.3 by 5 ft.

APPENDIX B.(1)--Modified Mercalli Intensity Scale of 1931 (Abridged) 1/

I. Not felt, except by a very few under especially favorable conditions.

II. Felt by only a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III.
Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize motion as an earthquake. Standing motor cars may rock slightly. Vibration similar to that of a passing truck.

IV. During the day felt indoors by many; felt outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation similar to that of a heavy truck striking building. Standing motor cars rock noticeably.

V. Felt by nearly everyone; many awakened. Some dishes and windows broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of falling plaster or damaged chimneys. Damage slight.

VII.
Everyone runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built, ordinary structures; considerable in poorly-built or badly designed structures. Some chimneys broken. Noticed by persons driving motor cars.

VIII.
Damage slight in specially designed structures; considerable in ordinary, substantial buildings, with partial collapse; great in poorly-built structures. Panel walls thrown out of frame structures. Destruction of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected from ground in small amounts. Changes in well water. Persons driving motor cars disturbed.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame buildings destroyed with foundations. Ground badly cracked. Rails bent. Considerable amount of landslides from river banks and steep slopes. Shifted sand and mud. Water splashed over banks.

1/For an unabridged version of the Modified Mercalli Intensity Scale of 1931, see reference (2).

XI. Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

References

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2. Coffman, J. L. and C. W. Stover. United States Earthquakes, 1976. Boulder, CO: U.S. Dep. Commerce, Natl. Oceanic. and Atmospheric Administration, and U.S. Geol. Surv., 1978.

APPENDIX C.--Daily discharge at selected gaging stations, Hebgen Lake earthquake

[Cubic feet per second, at selected stations]

Date	(1)[1] Red Rock River at Kennedy Ranch, near Lakeview, MT	(2) Blacktail Creek near Dillon, MT	(3) Ruby River above reservoir near Alder, MT	(4) Madison River near West Yellowstone, MT	Computed inflow to Hebgen Lake (3-day average)	(5) Madison River below Hebgen Lake, near Grayling, MT	(6) Madison River above Sheep Creek, near West Yellowstone, MT	(7) Madison River at Kirby Ranch, near Cameron, MT	(8) Madison River near Cameron, MT	(9) Madison River below Ennis Lake, near McAllister, MT	(10) Gallatin River near Gallatin Gateway, MT	(11) Gardiner River near Mammoth, Yellowstone National Park
AUGUST 1959												
1.....	48	39	106	378	469	1,000	.....	.....		1,340	794	147
2.....	46	45	114	378	412	1,000	.....	.....		1,350	830	155
3.....	46	49	118	384	438	989	.....	.....	1,220[2]	1,330	838	159
4.....	43	44	114	378	594	989	.....	.....		1,330	766	143
5.....	43	36	110	378	851	989	.....	.....		1,150	738	136
6.....	43	31	114	371	810	1,020	.....	.....		1,330	719	133
7.....	42	28	116	364	814	1,020	.....	.....		1,580	706	130
8.....	41	27	114	364	660	1,000	.....	.....	1,200[2]	1,400	686	130
9.....	38	28	114	364	688	1,020	.....	.....		1,310	680	127
10.....	37	25	112	364	646	1,000	.....	.....		1,310	667	124
11.....	37	25	112	364	640	1,030	.....	.....		1,320	648	124
12.....	36	24	110	364	677	1,000	.....	.....		1,320	648	130
13.....	35	27	110	364	566	989	.....	.....		1,310	660	133
14.....	32	26	99	364	497	1,040	.....	.....	1,180[2]	1,300	634	133
15.....	33	25	92	364	411	1,020	.....	.....		1,300	615	136
16.....	32	23	88	357	552	1,000	.....	.....		1,290	602	133
17.....	31	20	85	357	667[3]	1,030	.....	.....		1,290	589	133
18.....	34	20	90	442	4,048[3]	859	.....	.....	700[2]	4,300	660	163
19.....	33	24	99	505	385[3]	847	.....	.....	500[2]	1,880	787	195
20.....	38	36	106	514	765[3]	928	.....	.....	400[2]	678	822	200
21.....	38	38	112	505	935	1,060	.....	.....	350[2]	671	822	195
22.....	37	33	110	497	1,390	1,240	.....	.....	300[2]	593	801	184
23.....	36	34	108	488	1,360	1,310	.....	.....	300[2]	482	801	179
24.....	35	33	108	488	1,220	1,920	.....	.....	290[2]	324	794	179
25.....	36	34	106	488	1,230	2,370	.....	.....	280[2]	210	787	179
26.....	35	36	106	488	960	2,640	1.1	.....	280	210	787	179
27.....	36	36	110	488	1,110	2,970	2.5	.....	280	360	787	179
28.....	35	35	116	480	1,100	2,820	3.7	.....	280	586	766	175
29.....	36	36	116	473	1,050	2,740	9.4	.....	280	560	766	175
30.....	34	38	116	473	912	2,660	10	.....	280	515	766	175
31.....	35	38	116	480	960	2,580	13	148	275	508	766	175
SEPTEMBER 1959												
1.....	34	38	116	480	1,100	2,500	12	139	280	522	773	175
2.....	34	38	108	473	1,170	2,410	15	139	285	541	752	175
3.....	36	38	110	473	951	2,350	17	139	290	534	745	175
4.....	38	36	110	473	902	1,690	18	166	290	528	732	171
5.....	41	36	112	480	867	1,300	19	155	297	528	745	171

See footnotes at end of table.

APPENDIX C.--Daily discharge at selected gaging stations, Hebgen Lake earthquake--Continued

[Cubic feet per second, at selected stations]

Date	(1)[1] Red Rock River at Kennedy Ranch, near Lakeview, MT	(2) Blacktail Creek near Dillon, MT	(3) Ruby River above reservoir near Alder, MT	(4) Madison River near West Yellowstone, MT	Computed inflow to Hebgen Lake (3-day average)	(5) Madison River below Hebgen Lake, near Grayling, MT	(6) Madison River above Sheep Creek, near West Yellowstone, MT	(7) Madison River at Kirby Ranch, near Cameron, MT	(8) Madison River near Cameron, MT	(9) Madison River below Ennis Lake, near McAllister, MT	(10) Gallatin River near Gallatin Gateway, MT	(11) Gardiner River near Mammoth, Yellowstone National Park
SEPTEMBER 1959												
6.....	40	39	120	480	999	969	29	148	318	528	759	171
7.....	40	38	131	473	1,020	770	57[4]	175	325	528	732	171
8.....	41	35	129	473	939	770	108	184	346	522	719	171
9.....	34	35	118	465	956	770	110	184	360	515	712	167
10.....	36	35	118	465	942	781	271	416	384	554	712	167
11.....	40	33	116	465	980	792	690	868	725	658	700	167
12.....	41	33	112	465	1,030	378	792	804	1,020	534	693	167
13.....	45	33	106	473	981	825	738	780	874	541	693	163
14.....	48	34	108	473	1,040	825	820	954	1,040	710	693	163
15.....	52	36	112	488	963	880	834	1,000	1,080	962	700	167
16.....	53	36	116	488	975	1,000	1,110	1,180	1,180	1,150	706	167
17.....	50	39	114	488	969	1,080	1,220	1,240	1,350	983	706	167
18.....	54	41	110	488	958	1,240	1,360	1,440	1,460	1,380	706	167
19.....	57	42	110	514	930	1,260	1,390	1,480	1,530	1,450	712	167
20.....	55	45	129	574	1,150	1,260	1,440	1,560	1,650	1,440	766	190
21.....	65	56	160	593	1,260	1,270	1,600	1,620	1,820	1,730	822	195
22.....	64	54	148	540	1,270	1,380	1,680	1,680	1,760	2,260	780	175
23.....	66	50	139	522	1,080	1,410	1,680	1,750	1,890	2,090	745	171
24.....	66	47	137	505	1,050	1,350	1,600	1,700	1,830	2,160	732	163
25.....	68	46	137	505	1,120	1,230	1,450	1,580	1,730	2,260	738	163
26.....	62	46	137	505	1,070	1,770	1,680	1,790	1,760	2,040	745	163
27.....	64	46	137	505	1,000	1,700	2,210	2,120	2,100	1,820	752	167
28.....	64	49	144	505	1,100	1,440	1,810	1,970	2,040	1,730	738	163
29.....	74	49	142	497	1,160	752	1,540	1,480	1,640	1,970	712	155
30.....	79	49	142	497	1,120	1,100	2,050	1,720	1,890	2,170	719	155
OCTOBER 1959												
1.....	86	49	140	488	1,000	1,400	2,030	1,720	1,830	2,340	706	155
2.....	86	49	132	488	967	2,220	2,900	2,540	2,320	2,500	693	155
3.....	85	49	138	488	891	892	1,850	1,940	2,220	2,670	706	151
4.....	86	47	135	480	877	892	.....	1,510	1,670	2,470	712	155
5.....	88	47	135	473	900	904	.....	1,490	1,730	2,280	726	155
6.....	92	47	138	473	904	904	.....	1,510	1,620	2,340	732	159
7.....	..	50	149	522	964	904	.....	1,950	2,080	2,800	759	163
8.....	..	..	149	514	986	916	.....	1,740	1,960	3,050	719	159
9.....	..	..	...	522	994	916	.....	2,360	2,380	2,730	732	163
10.....	..	..	...	531	1,050	928	.....	2,260	2,340	2,690	700	159

See footnotes at end of table.

APPENDIX C.--Daily discharge at selected gaging stations, Hebgen Lake earthquake--Continued

[Cubic feet per second, at selected stations]

Date	(1)[1] Red Rock River at Kennedy Ranch, near Lakeview, MT	(2) Blacktail Creek near Dillon, MT	(3) Ruby River above reservoir near Alder, MT	(4) Madison River near West Yellowstone, MT	Computed inflow to Hebgen Lake (3-day average)	(5) Madison River below Hebgen Lake, near Grayling, MT	(6) Madison River above Sheep Creek, near West Yellowstone, MT	(7) Madison River at Kirby Ranch, near Cameron, MT	(8) Madison River near Cameron, MT	(9) Madison River below Ennis Lake, near McAllister, MT	(10) Gallatin River near Gallatin Gateway, MT	(11) Gardiner River near Mammoth, Yellowstone National Park
OCTOBER 1959												
11.....	..	..	...	514	1,080	928	.....	2,040	2,260	2,730	719	159
12.....	..	..	...	548	1,140	940	.....	2,340	2,400	2,650	759	167
13.....	..	..	...	531	1,060	952	.....	2,120	2,320	2,700	726	163
14.....	..	..	...	522	1,010	952	.....	2,560	2,560	2,680	712	159
15.....	..	..	...	522	975	952	.....	2,140	2,430	2,760	732	159
16.....	..	..	...	531	1,020	964	.....	2,010	2,160	2,720	752	163
17.....	..	..	...	522	1,020	964	.....	2,220	2,470	2,700	712	159
18.....	..	..	...	505	1,210	964	.....	1,870	2,080	2,650	706	151
19.....	..	..	...	514	1,140	2,040	.....	1,950	2,060	2,520	712	147
20.....	..	..	...	514	1,150	2,680	.....	3,480	3,330	2,660	706	147
21.....	..	..	...	514	.....	2,660	.....	3,890	4,090	.....	706	147
22.....	..	..	...	514	.....	2,860	.....	.....	.....	.....	706	151

[1]Numbers refer to gaging stations in figure 8.
[2]Estimated on basis of records for Madison River below Hebgen Lake and relations in prior years.
[3]Not averaged with adjacent daily discharge; data for August 17-20 reflect changes in capacity of Hebgen Lake.
[4]Flow prior to September 8 near toe of slide with about 10 cfs inflow between sites.