Arizona Geological Survey
ARIZONA GEOLOGY

Vol. 23, No. 2 Investigations • Service • Information Summer 1993

The Arizona Floods of January and February 1993

P. Kyle House
Arizona Geological Survey

OVERVIEW

In January and February 1993, widespread flooding damaged homes, businesses, crops, roads, bridges, and many other facilities in Arizona. The total damage in the State may exceed $50 million. The floods revealed both strengths and weaknesses in flood-control measures statewide and provided geologists, hydrologists, and engineers with unprecedented opportunities for flood-related research.

These floods resulted from unusually large amounts of precipitation generated by persistent, anomalous, atmospheric circulation patterns involving complex interactions between "warm" storms of subtropical origin and "cold" storms of polar origin. Abnormally high sea-surface temperatures in the eastern equatorial Pacific Ocean, which were associated with the El Niño phenomenon, enhanced the anomalous circulation patterns that ultimately produced 3 months of abnormally high precipitation throughout most of Arizona. The high rainfall and snowfall amounts generated the largest floods on record for many rivers in the State (Table 1).

From early December through late February, atmospheric circulation patterns over the Pacific Ocean and the western United States carried approximately 16 storms through parts of Arizona. The spatial and temporal characteristics of these storms resulted in widespread flooding. The following factors were critical in producing the floods: (1) basin-wide soil saturation; (2) storage of water in snowpack; (3) release of water from storage due to rain on snowpack; (4) long periods of low- to moderate-intensity rainfall over large areas; and (5) short periods of very intense rainfall over small areas.

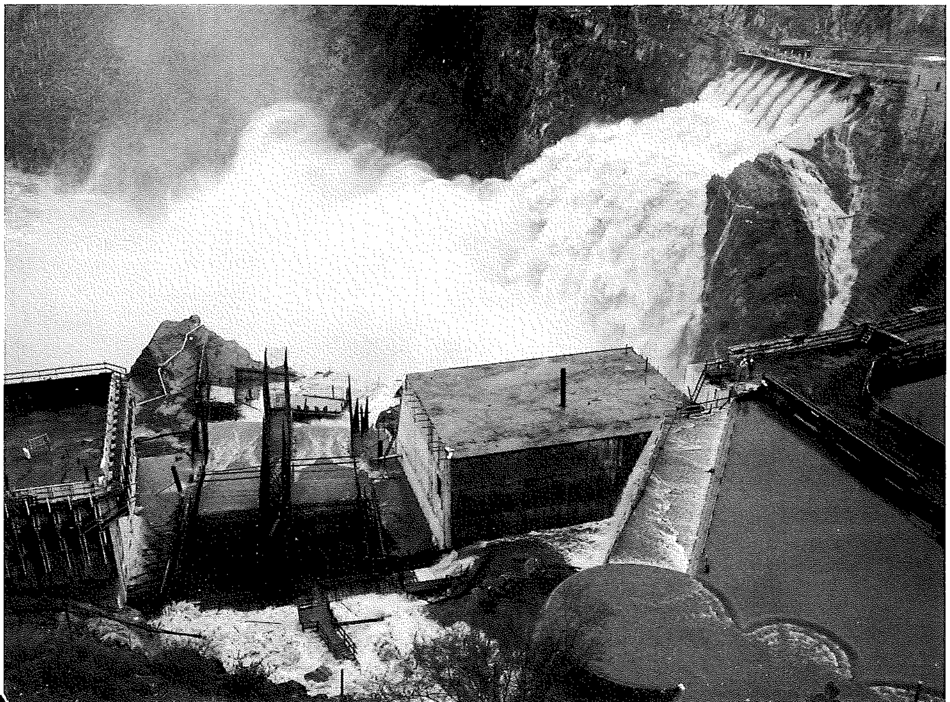

Figure 1. Close-up of the Roosevelt Dam spillway on January 19. The combined discharge of the Salt River over the spillway and coffer dam (foreground) was approximately 34,000 cubic feet per second (cfs) at the time the photograph was taken. This value is associated with the highest recorded level of Roosevelt Lake. The flooded area in the foreground is the construction site of a new spillway. Photo courtesy of the U.S. Bureau of Reclamation.

GENERAL STORM CHRONOLOGY

December

A series of wet storms that passed through Arizona in December set the stage for later flooding. December began with a Pacific storm that dropped more than 2 inches of rain in Tucson over a 3-day period. Similar amounts fell in Flagstaff and Phoenix. By the second week of December, a second storm moved through and dropped more than an inch in Phoenix and lesser amounts in Flagstaff and Tucson. Two additional storms affected Arizona during the next 2 weeks. Each of these first four storms was associated with a southern extension of the Pacific storm track that most frequently affects the

FLOODS continued on page 6

ALSO IN THIS ISSUE

Governor Establishes Earthquake-Safety Council

Many government agencies have responsibilities related to earthquake preparedness and safety. There is, therefore, a need to provide a consistent policy framework and a means for coordinating government programs and activities with those in the private sector. To accomplish this, Governor Fife Symington signed on February 17 Executive Order 93-3, which established the Arizona Council for Earthquake Safety (ACES). ACES will also provide policy, guidance, and direction for the implementation of Public Law 95-124, the Earthquake Hazard Reduction Act of 1977.

ACES is composed of 15 members who are appointed by the Governor and have expertise in areas such as geology, seismology, engineering, commerce, emergency management, government, education, medical services, utilities, insurance, and law enforcement. ACES members serve without compensation. The Division of Emergency Management (DEM) in the Arizona Department of Emergency and Military Affairs is responsible for earthquake preparedness and safety. R.A. (Reggie) Yates of the DEM is the ACES coordinator.

ACES has the following responsibilities related to earthquake safety:
1. Setting goals and priorities;
2. Requesting State agencies to devise criteria to assist in promoting earthquake safety;
3. Recommending program changes to improve earthquake safety to State and local agencies and the private sector;
4. Reviewing recovery and reconstruction efforts after damaging earthquakes;
5. Gathering, analyzing, and disseminating information;
6. Encouraging research;
7. Sponsoring training to improve the competence of specialized enforcement and other technical personnel;
8. Coordinating earthquake-safety and related government activities at all levels; and
9. Establishing and maintaining working relationships with boards, commissions, departments, agencies, and other public and private organizations.

Summary of Earthquake Activity in Arizona for 1992

Doug Bausch and Suzanne Morrison
Arizona Earthquake Information Center

The Grand Canyon area again appeared to be the most seismically active region in the State. Of the 74 earthquakes (Table 1) located within Arizona in 1992, 68 occurred in the South Rim area of the Grand Canyon (Figure 1). The South Rim activity included a sequence of earthquakes that peaked with a tremor of M_L* 4.5 on March 14 at 5:13 a.m. Universal Time Coordinated (on March 13 at 10:13 p.m. local time). This earthquake was widely felt by tourists, employees, and residents in Grand Canyon Village, Phantom Ranch, and Tusayan. Several foreshocks and aftershocks of this earthquake were also felt: an M_L 4.1 event about 1.5 minutes before the main shock, and tremors of M_L 3.9, 3.0, 3.1, and 3.9 on March 13, May 6, May 20, and July 5, respectively. No damage was reported, although observers noted rockfalls near the rim.

From March 17 through March 20, the Arizona Earthquake Information Center (AEIC) deployed a temporary network of seismograph stations around the epicentral area of the main shock. Approximately 90 earthquakes were detected by the temporary network during the 4-day period. Of those, 43 earthquakes were located. The magnitudes of these aftershocks ranged from M_L 0.3 to 2.1.

The Grand Canyon region is one of the more seismically active areas in Arizona. During recent years (1988, 1989, 1991, and 1992), swarms of earthquake activity have occurred there. With the exception of the March 1991 North Rim earthquake, all were located near the South Rim, several miles south of Grand Canyon Village. This recent activity is apparently not anomalous: nine felt earthquakes occurred in the same area from 1912 through 1948 (DuBois and others, 1982). The largest of these was the m_b* 6.2 shock on August 18, 1912 (Brumbaugh, 1991).

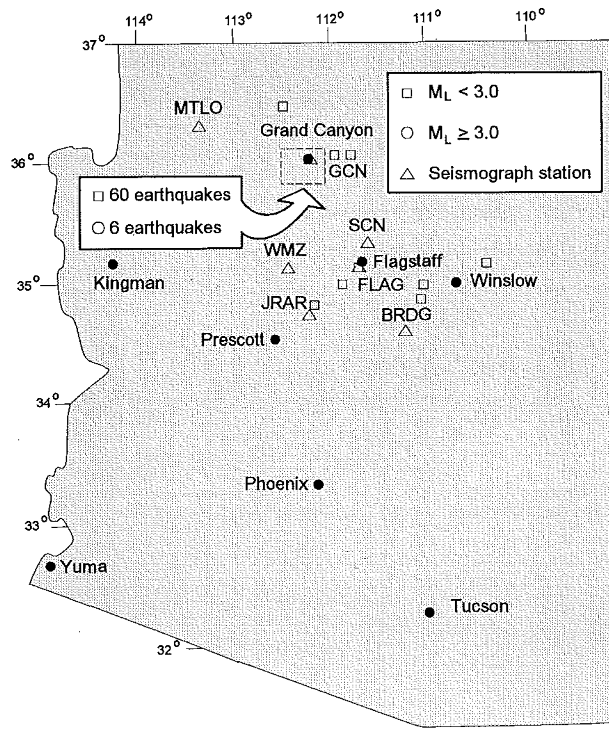

Figure 1. Arizona earthquakes located in 1992 by the AEIC network. Open triangles represent seismograph stations operated by the AEIC: MTLO = Mount Logan; GCN = Grand Canyon; SCN = Sunset Crater; FLAG = Flagstaff; WMZ = Williams; JRAR = Jerome; and BRDG = Blue Ridge Reservoir.

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* M_L is local magnitude or Richter magnitude, which is based on the logarithm of the largest ground motion recorded at the seismograph station. M_L is defined for a particular region and a particular seismograph network. Body-wave magnitude (m_b) is based on the amplitude of seismic waves that travel through the interior of the Earth. These two magnitude scales are roughly equivalent for small and moderate earthquakes.

Geothermal Test Hole Drilled

The Arizona Geological Survey issued a permit on May 18 to Tonto Drilling Services, Inc., to drill a geothermal test hole about 6 miles north of Alpine. The #1 Alpine-Federal well is in sec. 23, T. 6 N., R. 30 E., has a proposed total depth of 4,500 feet, and is being drilled to determine the hot-dry-rock geothermal potential in the granitic basement rocks. Tonto Drilling Services, Inc., will core the hole from about 500 feet to total depth and will measure subsurface temperatures, temperature gradients, and heat flow. Several shallower geothermal test holes drilled near the #1 Alpine-Federal well in the early 1980's revealed a higher-than-normal geothermal gradient in the area between Springerville and Alpine. None of these holes, however, penetrated the granitic basement rocks.

Several faults, including the Hermit and Bright Angel, are near the area of seismic activity. It is unclear, however, which of these surface faults, if any, are responsible for this activity. The earthquake epicenters do not appear to align along the mapped fault traces. The earthquakes may be caused by a fault or fault system that does not reach the surface of the Colorado Plateau. The AEIC continues to record and study Grand Canyon seismicity.

Several shocks occurred elsewhere in Arizona during 1992. An M_L 2.2 earthquake occurred on March 11 northeast of Winslow; M_L 1.7 and 1.9 events occurred near Sunset Mountain on March 19 and October 26, respectively. Other shocks included an M_L 2.1 tremor near Sycamore Canyon on May 8, an M_L 2.6 event within the Kaibab Plateau on May 22, and an M_L 1.9 earthquake near Lower Lake Mary, several miles south of Flagstaff, on October 20.

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Brumbaugh, D.S., 1991, Instrumental magnitudes of early Arizona earthquakes: Seismological Research Letters, v. 62, p. 51.

DuBois, S.M., Smith, A.W., Nye, N.K., and Nowak, T.A., Jr., 1982, Arizona earthquakes, 1776-1980: Arizona Bureau of Geology and Mineral Technology Bulletin 193, 456 p., scale 1:1,000,000.

Table 1. Arizona earthquakes located in 1992 by the AEIC network.

Date[1]	Epicenter[2]		Depth[3]	Origin Time[4]	M_L[5]	Location
	Lat (°N)	Long (°W)	(km)	(UTC)		
3-2	35.95	112.17	25	23:06:33	2.7	South Rim
3-11	35.18	110.39	4	08:06:16	2.2	northeast of Winslow
3-13	35.97	112.17	11	11:28:36	3.9	South Rim
3-13	35.96	112.07	10	11:31:08	2.2	South Rim
3-13	36.00	112.17	10	13:55:13	2.3	South Rim
3-13	36.08	111.86	10	16:05:50	2.2	South Rim
3-14	35.95	112.20	12	05:12:08	4.1	South Rim
3-14	35.89	112.17	4	05:13:36	4.5	South Rim, main shock
3-14	36.00	112.06	10	06:23:16	2.6	South Rim
3-14	35.95	112.02	10	06:47:46	2.3	South Rim
3-14	35.89	112.03	18	07:12:01	2.5	South Rim
3-14	35.95	112.10	14	14:09:10	2.2	South Rim
3-15	36.08	111.70	9	14:13:25	2.9	South Rim
3-17 through 3-20, South Rim aftershock survey, 43 locations, M_L 0.3 to 2.1						
3-19	35.00	111.00	2	10:45:10	1.7	Sunset Mountain
3-30	35.01	111.80	14	20:46:14	2.0	South Rim
4-17	36.00	112.17	10	15:13:55	2.1	South Rim
5-2	36.00	112.17	10	23:37:59	2.1	South Rim
5-6	36.03	112.21	13	01:37:33	2.3	South Rim
5-6	36.00	112.18	6	01:40:58	3.0	South Rim
5-6	36.00	112.08	10	03:12:10	1.9	South Rim
5-6	36.00	112.17	10	04:03:26	2.4	South Rim
5-8	34.84	112.07	16	15:30:25	2.1	Sycamore Canyon
5-20	36.02	112.17	9	21:46:05	3.1	South Rim
5-22	36.48	112.37	4	01:04:20	2.6	Kaibab Plateau
7-5	36.00	112.17	6	14:38:46	2.3	South Rim
7-5	36.00	112.17	6	14:43:54	2.6	South Rim
7-5	35.93	112.32	10	18:18:33	3.9	South Rim
7-5	36.00	112.30	6	18:20:28	2.2	South Rim
8-1	36.00	112.17	10	05:03:14	2.2	South Rim
10-20	35.15	111.63	8	14:32:22	1.9	Lower Lake Mary
10-26	34.88	111.03	6	10:28:12	1.9	Sunset Mountain

[1] Date = month-day
[2] Lat = latitude; Long = longitude
[3] km = kilometers
[4] UTC = Universal Time Coordinated; hour:minute:second
[5] M_L = local magnitude

LARGEST EARTHQUAKE IN ARIZONA SINCE 1959

On April 29, 1993, an m_b 5.4 earthquake shook most of northern Arizona. This is the largest earthquake in Arizona since the M_L 5.5 event that rocked Fredonia in 1959. The 1993 Cataract Creek earthquake occurred at 1:21 a.m. local time. It was located about 3 miles northwest of Valle, Arizona (population 75), and about 25 miles south of Grand Canyon Village. The main shock was preceded by an m_b 4.9 foreshock on April 25 at 2:29 a.m. local time. No injuries or significant structural damage were reported in this sparsely populated region.

The earthquake sequence was located within the Cataract Creek fault system, which consists of a northwest-trending zone of predominantly normal faults that extends from Stoneman Lake south of Flagstaff to the Grand Canyon. The AEIC recorded approximately 300 to 400 events of $m_b \geq 0.3$ during a 15-day period, beginning with the m_b 4.9 foreshock on April 25. An m_b 6.2 earthquake that shook Flagstaff in 1906 was located within the southeastern portion of the Cataract Creek fault system. This fault system and the most recent series of earthquakes warrant further study.

Seismic-Hazard Mapping in Arizona

Doug Bausch
Arizona Earthquake Information Center

In 1985, the Arizona Earthquake Information Center (AEIC) was established at Northern Arizona University in Flagstaff. Since that time, the AEIC has compiled data, responded to requests for information from agencies and individuals, and published several documents related to seismic-hazard mapping in Arizona. These publications are described below and may be purchased from the AEIC.

AEIC PUBLICATIONS

Bausch, D.B., Brumbaugh, D.S., Morrison, S.J., and Daughton, T., 1993, State ground-acceleration map, 100-year conditional probability: scale 1:1,000,000.

In 1991, the Arizona Division of Emergency Management contracted with the AEIC to prepare seismic-acceleration maps for Arizona. This project was part of the Arizona Earthquake Preparedness Program, which was established to build a foundation for earthquake-hazard mitigation and preparation in Arizona (Yates, 1992). The maps provide emergency planners, engineers, public officials, and others with guidelines to evaluate these hazards.

Seismic-acceleration contour maps show the force of ground shaking that may occur during an earthquake. The contour lines define ground motion of a certain level that will probably occur within a specific time (Euge, 1993). The AEIC determined the level of ground shaking that has a 90-percent chance of not being exceeded (or a 10-percent chance of occurring) within the next 100 years (Figure 1). Euge (1993) described the development of acceleration contour maps based on 50- and 250-year intervals.

The AEIC divided regions in Arizona and adjacent areas into **seismic source zones** (zones that are capable of producing earthquakes) based upon differing seismic characteristics. For example, the Colorado Plateau and Basin and Range Province are separate source zones. The most recent catalog of Arizona earthquakes published by the AEIC was used to define rates of earthquake occurrence within each source zone. The rate of occurrence is based on an observed number of earthquakes of a given magnitude per time period and was determined for each fault and seismic source zone. Where data were limited, the rates of occurrence were based on interpretation.

The high values for the Yuma area (Figure 1) are the result of high earthquake-occurrence rates for the faults that form the boundary of the North American and Pacific Plates within southern California and northern Mexico. Although the Yuma region has the highest acceleration values within Arizona (100-year acceleration of 60 percent of the force of gravity), two other areas of the State also have relatively high values: (1) southeastern Arizona, near the 1887 Sonoran

Figure 1. Earthquake acceleration contour map of Arizona and adjacent regions as a percentage of the force of gravity; contour intervals are 4 percent of gravity. Gravity is the acceleration of a freely falling body due to the attraction by the Earth and to the Earth's rotation about its axis. The acceleration level that is generally accepted as sufficient to damage weakly constructed structures is 10 percent of gravity (Richter, 1958). Contours are based on a 100-year conditional probability, defined as a 90-percent chance of not being exceeded within 100 years. For example, a value of 64 percent of the force of gravity in Yuma has a 90-percent chance of not being exceeded (or a 10-percent chance of occurring) during the next 100 years.

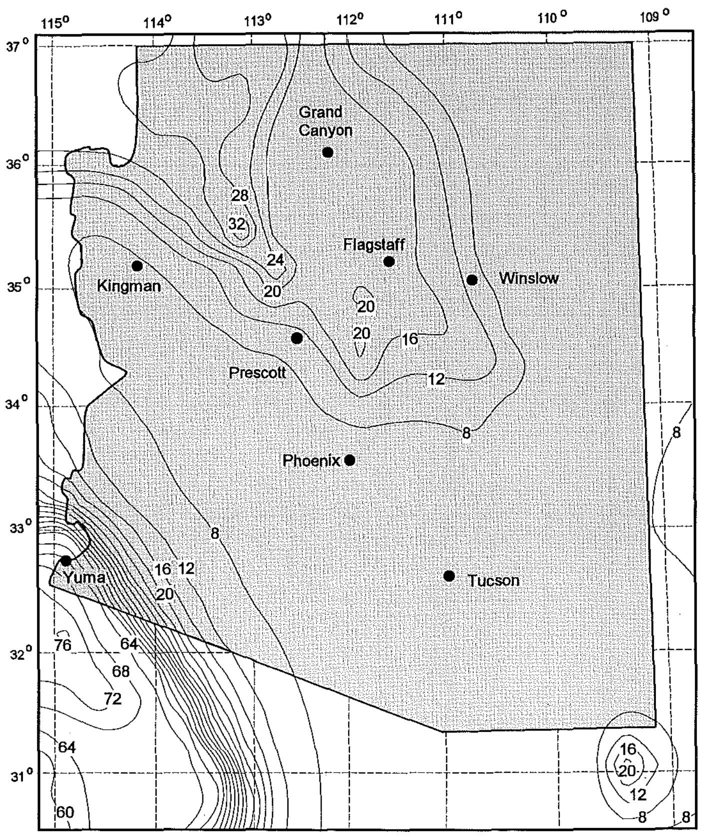
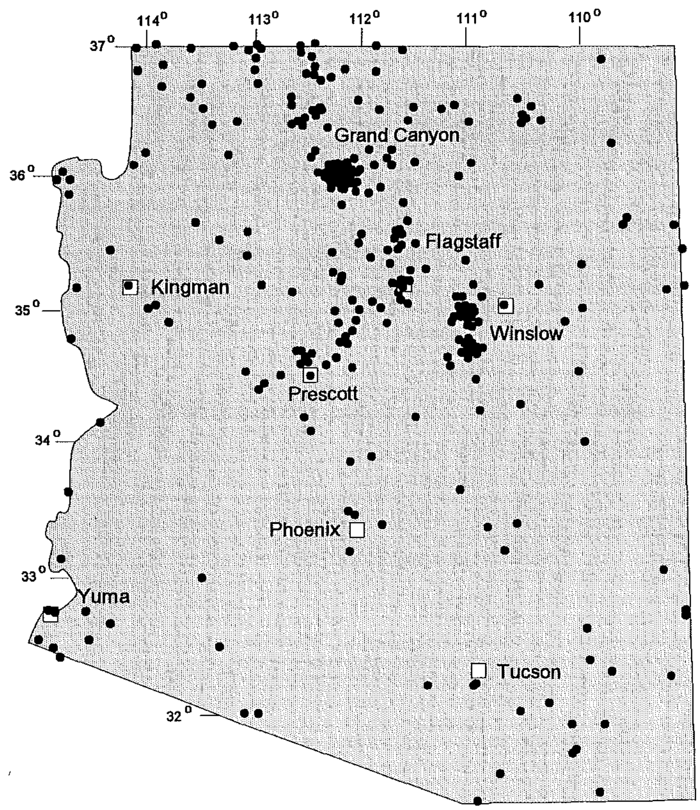


Figure 2. Epicenters of earthquakes (magnitude 0.5 to 6.2) that occurred in Arizona from 1830 through 1992, based on the most current AEIC catalog. Earthquake epicenters are represented by dots.



earthquake epicenter (DuBois and Smith, 1980); and (2) a zone that extends from the Prescott-Flagstaff area through northwestern Arizona. The latter zone includes the Verde, Big Chino, Aubrey, and Hurricane fault systems, as well as a northwest-trending belt of earthquake epicenters.

The 100-year conditional-probability map is published as a color plot at a scale of 1:1,000,000. General 50-, 100- and 250-year acceleration contour maps are also available at small scales printed on 8.5" x 11" sheets. Because the database for these maps contains approximately 4,000 data points, sorting techniques may be used to produce enlarged regional and areal maps.

Morrison, S.J., Brumbaugh, D.S., and Daughton, T., 1991, State of Arizona maximum-intensity ground-shaking map (1887-1987): scale 1:1,000,000.

This map illustrates the maximum Modified Mercalli Intensity levels for Arizona during the period between 1887 and 1987. These levels range from V to IX. The highest levels are near Yuma and in southeastern Arizona because of California earthquakes and the 1887 Sonoran earthquake, respectively (DuBois and Smith, 1980). The primary source of intensity data was DuBois and others (1982).

Acceleration describes the force of an earthquake, generally measured on bedrock, whereas intensity describes actual earthquake effects on human structures. Acceleration typically decreases with distance from an earthquake; intensity, however, may be influenced by unfavorable local geologic conditions, such as loose sandy soils or high ground water. This influence was clearly demonstrated by the devastation in the San Francisco Marina District about 60 miles north of the epicenter of the 1989 Loma Prieta earthquake (Bonilla, 1991). Similar geologic conditions in Yuma Valley increased the damage due to liquefaction and ground settlement during the 1940 Imperial Valley earthquake (U.S. Bureau of Reclamation, 1976). In populated areas that are underlain by high ground water and loose sandy soils, intensity maps may represent earthquake hazards more accurately than bedrock acceleration maps. A color plot of this map is available at a scale of 1:1,000,000.

Brumbaugh, D.S., Morrison, S.J., and Bausch, D.B., 1993, Arizona earthquakes, 1830-1992, catalog and map: 10 p., scale 1:1,000,000.

The catalog of earthquakes maintained by the AEIC contains locations, origin times, and magnitudes for 475 Arizona earthquakes (Figure 2). The catalog's database format allows sorting by date, time, location, or magnitude. In addition to locating Arizona earthquakes each year (see article on pages 2 and 3), the AEIC relocates earthquakes that occurred before the seismic network was established. The AEIC completes this task by retrieving the raw data (e.g., seismograms and phase arrival times) from various regional sources (e.g., the California Institute of Technology and the U.S. Geological Survey), combining these data with the network data, and using the most current crustal-velocity model. Last year, about a dozen earthquakes that occurred during the 1950's and 1960's were relocated. Many of the epicenters were relocated from Arizona to California or Mexico.

A color plot of this map is available at a scale of 1:1,000,000. A printout of the complete catalog with a small-scale, 8.5" x 11" map may also be purchased.

ORDERING INSTRUCTIONS

The color plots of the three 1:1,000,000-scale maps discussed above are available for $20 each; the current catalog of Arizona earthquakes may be ordered for $5; all prices include shipping costs. Earthquake- or acceleration-data sorting, such as epicenters by date, location, or magnitude, and enlarged regional acceleration maps may also be purchased. Send requests to the Arizona Earthquake Information Center, Northern Arizona University, P.O. Box 4099, Flagstaff, AZ 86011; tel: (602) 523-7197.

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Richter, C.F., 1958, Elementary seismology: San Francisco, W.H. Freeman and Co., 768 p.

U.S. Bureau of Reclamation, 1976, Record of earthquakes in the Yuma area, 1776-1976: Special Report, 191 p.

Yates, R.A., 1992, Arizona Earthquake Preparedness Program: Arizona Geology, v. 22, no. 3, p. 4-5.

Arizonan Confirmed for Key Interior Position

Elizabeth Ann Rieke, Director of the Arizona Department of Water Resources since April 1991, has been confirmed as Assistant Secretary for Water and Science, one of six Assistant Secretary positions in the U.S. Department of the Interior. Former Arizona Governor Bruce Babbitt was recently confirmed as Secretary of the Interior.

Rieke began work on March 8. She administers the U.S. Geological Survey, U.S. Bureau of Mines, and U.S. Bureau of Reclamation.

From January 1987 to April 1991, Rieke worked for the law firm of Jennings, Strouss and Salmon. From 1982 through 1986, she served in the Legal Division of the Arizona Department of Water Resources as Deputy Counsel and Chief Counsel. She has participated in Colorado River negotiations, statewide water-planning activities, and negotiations that led to significant legislation affecting water management in Arizona. She recently served as Chair of the Governor's Task Force on Central Arizona Project issues.

Rieke graduated from Oberlin College in 1965 and received her law degree from the University of Arizona in 1981.

FLOODS continued from page 1

Pacific Northwest. The storms were relatively cold and dropped snow in areas above about 6,000 feet. Consequently, they saturated the lower portions of watersheds and increased the snowpack in higher areas.

Conditions in the atmosphere changed considerably during the last week of December. Storms entrained in the Pacific storm track began to interact vigorously with disturbances in the subtropical jet stream, which was farther north than usual because of El Niño. Moisture from the subtropical jet stream had influenced previous storms, but its effect increased dramatically in late December and through most of January. By late December, a high-pressure ridge began to develop over the Gulf of Alaska, and a strong low-pressure trough intensified off the western coast of North America. The last storm of December was enhanced significantly by these circumstances. It was steered down the western coast, gathered moisture from the subtropical jet stream, and passed directly through Arizona. Phoenix and Tucson received 0.89 and 0.72 inches of rain, respectively, whereas areas at higher elevations in Arizona received significantly more (e.g., Flagstaff, 2.16 inches; Miami, 2.37 inches). Because of the influence of the subtropical jet stream, the storm was relatively warm and raised the snow level above 8,500 feet. The storm saturated watersheds at all elevations and increased base flow in streams throughout much of the State, making flooding imminent.

January

During the first 3 weeks of January, the atmospheric circulation over the Pacific Ocean and the western United States provided a continuous supply of rain and snow to Arizona. Furthermore, the dynamic interplay between the Pacific storm track and the subtropical jet stream maximized the potential for flooding by spacing the warm and cold storms, thus allowing water stored in the snowpack to be released by subsequent rainfall. A profound example of this occurred at the end of the first week in January. The late December storm that primed the watersheds was followed by a colder storm that built up the snowpack above 6,000 feet.

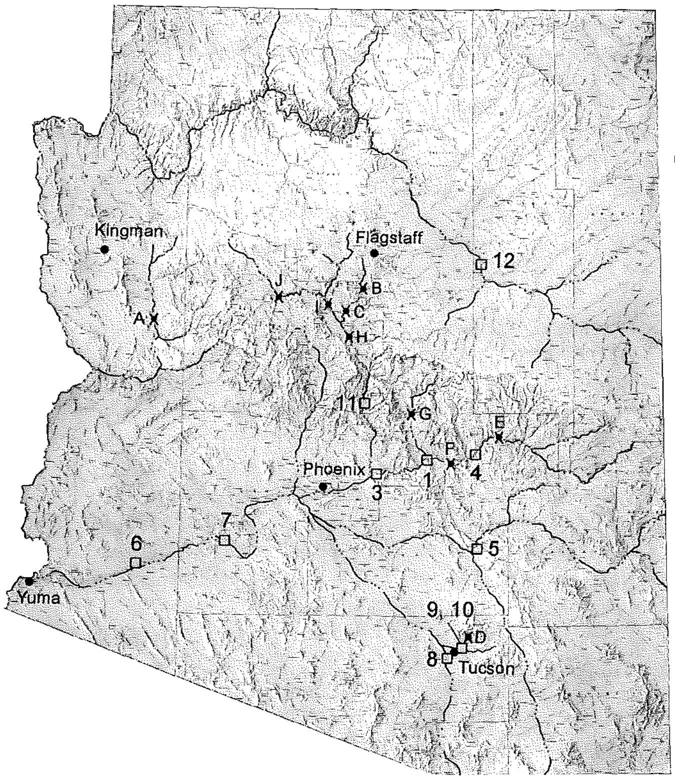

Figure 2. Major streams, approximate sites of Figures 1 through 12, and locations of lettered stream gages listed in Table 1.

Three days later, a massive storm with subtropical air and moisture entered the State, pushed the snow level back above 8,000 feet, and dropped large quantities of rainfall over much of Arizona for 3 days. Some of this rainfall was intense. From January 6 to 9, Tucson received 2.16 inches, Phoenix received 2.01 inches, Flagstaff received 2.88 inches, and Kingman received 3.88 inches of rainfall. This storm generated record and near-record floods statewide (Table 1).

From January 9 through 19, snow levels remained above 7,000 feet, and three more storms passed through Arizona. The third storm resulted in major flooding on the Santa Cruz River north of Tucson, and increased flooding on the Gila River. The passage of this storm marked the onset of a relatively dry period for the State and the beginning of the end of serious flooding in southern Arizona, except along the Gila River.

Table 1. Record floods in Arizona during the winter of 1993. Locations of gages are identified by letter on Figure 2. Discharge estimates for 1993 were supplied by the U.S. Geological Survey and are considered preliminary and subject to revision.

Site	Drainage Area (mi^2)	Largest Measured Discharges (cfs) Winter 93	Date	Previous	Date
A) Big Sandy River near Wikieup	2,742	65,600	2/9/93	38,500	2/20/80
B) Oak Creek at Sedona	233	28,500	2/19/93	9,460	11/30/82
C) Oak Creek near Cornville	355	38,900	2/20/93	26,400	2/19/80
D) Sabino Creek near Tucson	36	10,820	1/8/93	7,730	9/6/70
E) Salt River near Chrysotile	2,849	76,600	1/8/93	74,000	1/16/16
F) Salt River near Roosevelt	4,306	144,000	1/8/93	117,000	3/14/41
G) Tonto Creek above Gun Creek	675	61,600	1/8/93	61,400	2/15/80
H) Verde River near Camp Verde	5,010	105,000	2/20/93	97,000	3/3/38
I) Verde River near Clarkdale	3,503	63,140	2/20/93	50,600	2/21/20
J) Verde River near Paulden	2,507	20,800	2/20/93	15,700	2/20/80

February

At the end of January and through most of February, portions of north-central and northwestern Arizona were affected by small disturbances in the jet stream and by the southern extensions of fronts moving through the western United States. From February 8 to 10, parts of northwestern Arizona received more than 4 inches of rain. On February 9, the Big Sandy River near Wikieup had its largest recorded flood.

Another storm from February 14 to 16 brought rain to low elevations statewide and snow to areas above 6,000 feet. Two small disturbances on February 19 and 20 brought intense rainfall to north-central and northwestern Arizona (5 inches in Flagstaff) and pushed the snow level back up to 8,000 feet. These final storms caused flooding in the Flagstaff area and generated record floods on Oak Creek and the upper portions of the Verde River. Portions of communities in the Verde River floodplain in central Arizona received significant amounts of damage from the February floods.

SUMMARY

The most remarkable aspect of the January-February 1993 flooding in Arizona was its scale: it involved many flood events that were extremely large in volume, extent, and absolute magnitude. Almost every physiographic region in the State was affected, which is a rare circumstance. It is much more common for only relatively small portions of Arizona to be affected by large, synchronous episodes of flooding. The winter floods of 1993 attest to the significance of the unusual and persistent characteristics of the atmospheric circulation patterns that produced them. Understanding the frequency of these patterns is critical to understanding the frequency of the related floods.

Although many unfortunate consequences resulted from the floods in Arizona this winter, floods should not be characterized as solely destructive phenomena to be controlled and abated. They should also be understood for what they are: natural, intrinsic components of the physical environment. The 1993 floods offered enormous research potential. Engineers are reconsidering flood-control alternatives and improvements, hydrologists now have a remarkable data set for analyzing flood rainfall-runoff relationships, geologists have an unprecedented opportunity to study the effect of extreme floods on the landscape, and some property owners have a chance to reconsider the risks of living on the floodplain.

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National Oceanic and Atmospheric Administration and National Weather Service, 1993, Daily weather maps for December, January, and February.

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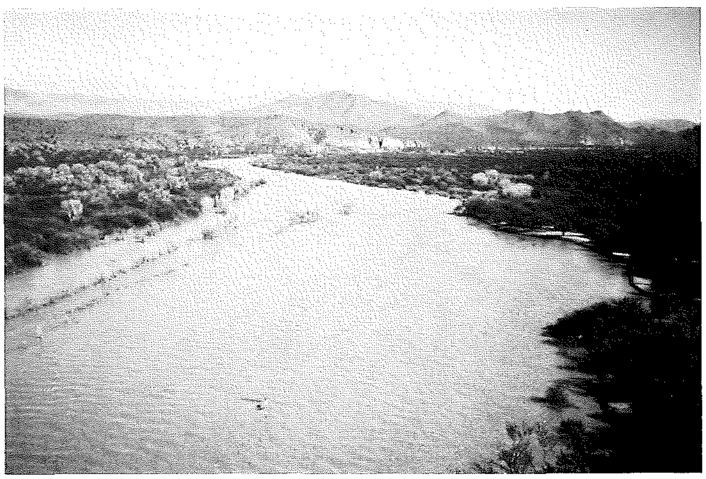


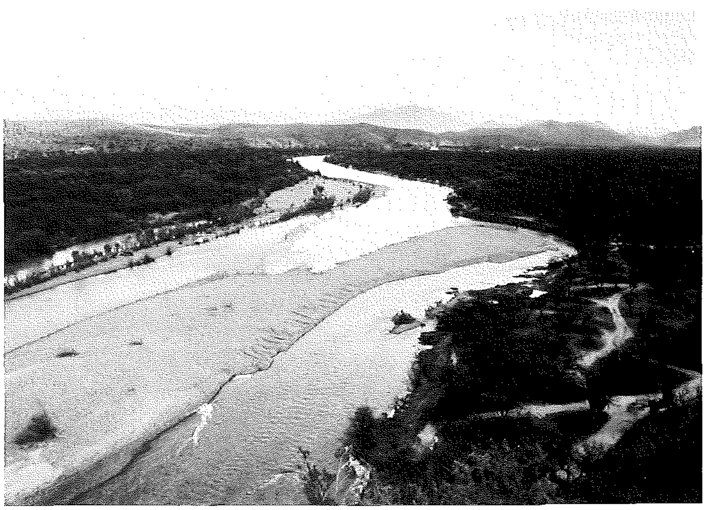
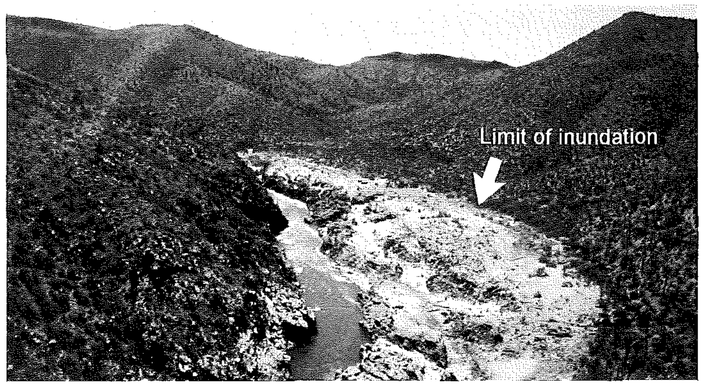


Figure 3 (a and b). Salt River below Stewart Mountain Dam. The first photograph was taken on January 20 following a peak discharge of 41,000 cfs. The second photograph of approximately the same site was taken on March 10. The peak discharge through this reach of the Salt River was significantly attenuated by storage upstream in Saguaro, Canyon, Apache, and Roosevelt Lakes. Photos by P. Kyle House, Arizona Geological Survey.



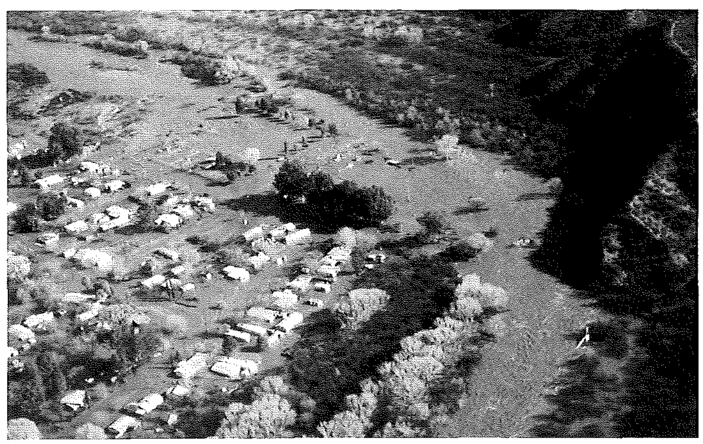


Figure 4 (top). View of the Salt River in Jump Off Canyon above Roosevelt Lake. A flood discharge of approximately 144,000 cfs passed through this reach on January 8. The flood removed all vegetation, soil, and weathered bedrock from the canyon walls and from the bedrock bench on the right bank. The flow depth exceeded 40 feet at this site. Photo by P. Kyle House, Arizona Geological Survey.

Figure 5 (bottom). Aerial view of the Winkelman Flats in Winkelman, showing inundation by the Gila River below Coolidge Dam. This photograph was taken on January 20. The peak discharge on the Gila River 20 miles downstream at Kelvin reached 74,200 cfs on the afternoon of January 19. Photo by Victor R. Baker, University of Arizona.

Figure 6 (above). Flooded agricultural land along the lower Gila River. This photograph was taken on March 3. This flood resulted from unprecedented releases (peak discharge: 25,920 cfs) from Painted Rock Reservoir. Photo © 1993 Peter L. Kresan, University of Arizona.

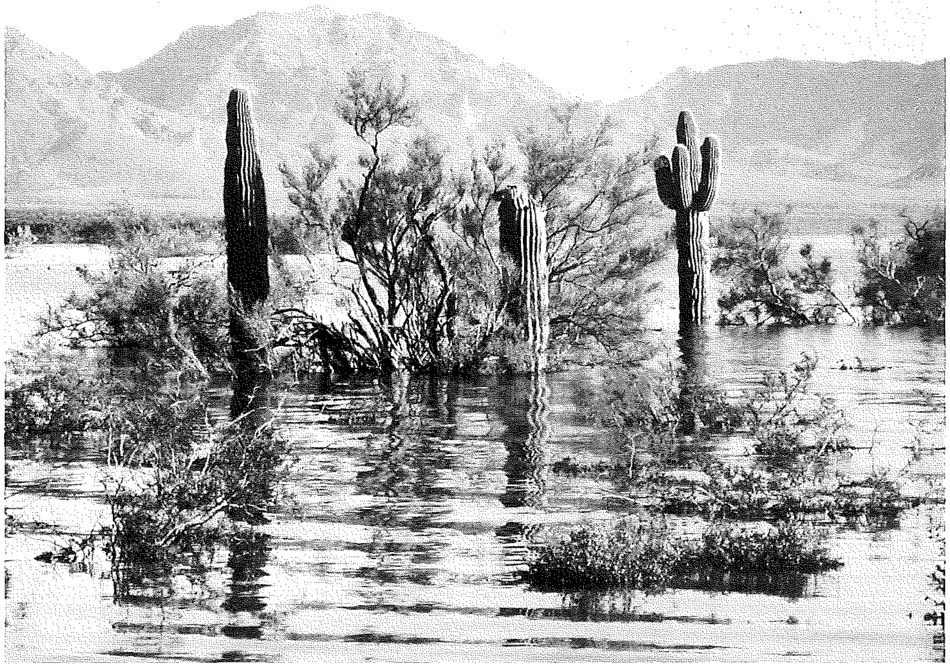


Figure 7 (right). Native Sonoran Desert vegetation flooded along the margins of Painted Rock Reservoir in southwestern Arizona. This reservoir, fed by the Gila River, filled to a capacity of 2.8 million acre-feet for the first time since its completion in 1961. Photo taken on March 16 by Steven J. Skotnicki, Arizona Geological Survey.

Figure 8 (above). Large standing waves on the Santa Cruz River near downtown Tucson. This photograph was taken on January 19 at approximately 9:30 a.m. The peak discharge in this reach was between 25,000 and 35,000 cfs that morning. Photo by P. Kyle House, Arizona Geological Survey.

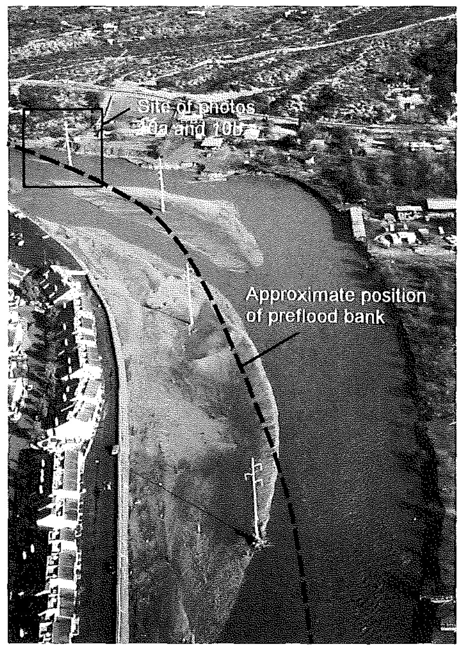


Figure 9 (above). Severe bank erosion along Rillito Creek near N. Country Club Blvd., Tucson. This photograph was taken on January 20, 12 days after the peak discharge. Line on photo shows former position of bank. Photo by Victor R. Baker, University of Arizona.

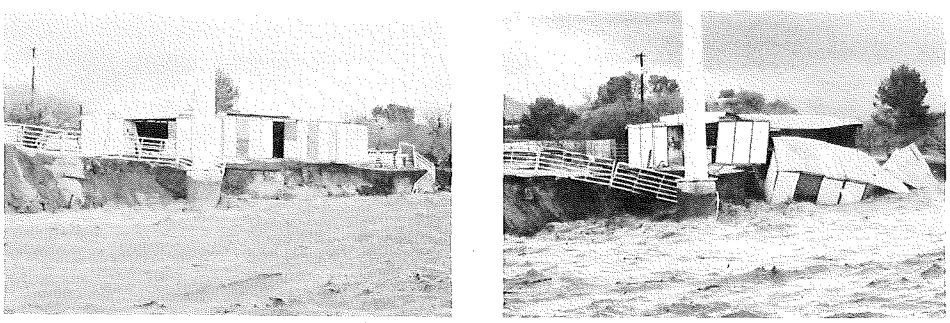


Figure 10 (a and b, left). Sequential photographs of site within Figure 9 showing horse stables being destroyed by bank erosion along Rillito Creek near N. Country Club Blvd., Tucson. The photos were taken at 11:33 a.m. and 11:50 a.m. on January 8. The peak discharge on Rillito Creek was between 20,000 and 30,000 cfs earlier that morning. Photos by H. Wesley Peirce, Arizona Geological Survey.

ACKNOWLEDGMENTS

Thanks to Chris Smith, Frank Brewsaugh, and Greg Pope of the U.S. Geological Survey for providing preliminary flood-discharge estimates; Cliff Schlueter and Bill Rohwer of the U.S. Bureau of Reclamation for providing dam-release data and photographs; Charlie Ester of the Salt River Project for providing flood-discharge estimates and dam-release data; and Terri Miller of the Arizona Department of Water Resources for providing preliminary flood-damage estimates.

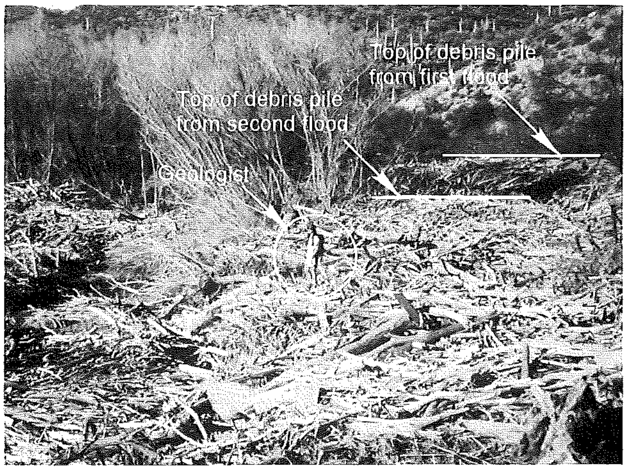


Figure 11. Massive pile of flood debris on the lower Verde River above Horseshoe Reservoir. This photograph, taken on April 10, shows two levels of debris that correspond to the peak discharges of January 8 (127,000 cfs) and February 20 (111,000 cfs). Note arrow pointing to person for scale. Photo by Philip A. Pearthree, Arizona Geological Survey.

Figure 12. Breach in an artificial levee on the Little Colorado River near Winslow on January 7. The breach was closed on January 14 before another series of storms caused flooding that came within 2 feet of the crest of the repaired levee. Photo by Chuck Williams, Navajo County Flood Control District.

New AZGS Publications

These publications may be purchased from the Arizona Geological Survey, 845 N. Park Ave., #100, Tucson, AZ 85719. Orders are shipped by UPS; a street address is required for delivery. All orders must be prepaid by check or money order payable in U.S. dollars to the Arizona Geological Survey. Add these shipping charges to your total order:

In the United States:	20.01 - 30.00, add 5.75	50.01 - 100.00, add 10.25
$1.01 - $5.00, add $2.00	30.01 - 40.00, add 6.50	Over 100.00, add 12%
5.01 - 10.00, add 3.00	40.01 - 50.00, add 8.00	Other countries: Request
10.01 - 20.00, add 4.50		price quotation.

Slaff, Steven, 1993, Gravity and magnetic surveys at Brady earth fissure, Picacho Basin, Pinal County, Arizona: Open-File Report 93-1a, 29 p., scale 1:24,000. $7.00

Brady fissure is an active earth fissure that trends roughly north-south 0.6 mile west of the Tucson Aqueduct of the Central Arizona Project. The fissure, which has approximately doubled its length during the past 12 years, is currently more than 1 mile long, up to 10 feet wide, and up to 10 feet deep. If it continues to lengthen, it could damage the Tucson Aqueduct.

The principal goal of the project was to determine whether the location of Brady fissure is controlled by subsurface geologic structure, such as a pediment edge or buried, inactive normal fault. The results indicate that this could be the case, but further investigation is required to verify the interpretations. Rather than a single normal fault, the fissure's position may be controlled by the location of a group of subparallel, buried inactive faults. The results of the study and their interpretations are summarized in this report.

Slaff, Steven, 1993, Gravity and magnetic surveys at Brady earth fissure, Picacho Basin, Pinal County, Arizona: Raw data: Open-File Report 93-1b, 15 p. $2.50

This computer printout includes the raw data obtained during the geophysical surveys described in Open-File Report 93-1a.

Duncan, J.T., and Spencer, J.E., 1993, The AZGS core repository: Open-File Report 93-2, 29 p. $4.50

See description under "AZGS Core Repository Reorganized," which is printed on pages 11 and 12.

Huckleberry, Gary, 1993, Surficial geology of the middle Gila River area, north-central Pinal County, Arizona: Open-File Report 93-3, 52 p., 5 sheets, scale 1:24,000. $16.50

Recent developments in geologic dating techniques and increased understanding of weathering processes have improved geologists' ability to distinguish and map unconsolidated sediments into genetic and temporal units. The need for surficial geologic mapping in Arizona has risen along with concerns about ground-water management, environmental protection, and geologic hazards, such as flooding, land subsidence, and earth fissures. Five alluvial-fan surfaces and 12 stream-terrace surfaces have been identified in the middle Gila River area. These surfaces are the product of alternating erosion and deposition by the river and its tributaries from the late Pliocene to the present. The youngest surfaces may still be aggrading and are subject to flooding about every 100 years. This project was funded by the COGEOMAP program.

Pearthree, P.A., 1993, Geologic and geomorphic setting of the Verde River from Sullivan Lake to Horseshoe Reservoir: Open-File Report 93-4, 25 p., 5 sheets, scale 1:24,000. $20.00

The Verde River is one of the primary perennial streams in Arizona. The free-flowing reach of the river, which extends from Sullivan Lake to Horseshoe Reservoir, supports diverse riparian environments and provides habitats for fish and wildlife. Portions of the river, however, have been significantly affected by human activities, including diversion of water for agricultural purposes and extraction of aggregate for construction projects. The U.S. Environmental Protection Agency (EPA) proposed an Advanced Identification (ADID) project to identify sites that may be suitable or are generally unsuitable for disposal of dredged or fill material. The Arizona Geological Survey received an EPA grant to evaluate and map the geologic units along the central Verde River. This report summarizes the geologic and geomorphic setting of those riparian areas. The report includes 1:24,000-scale strip maps that depict the surficial geology and generalized bedrock geology along the Verde River.

Gilbert, W.G., and Skotnicki, S.J., 1993, Geologic map of the west-central Gila Bend Mountains, Maricopa County, Arizona: Open-File Report 93-5, 16 p., scale 1:24,000. $4.50

The study area consists of Proterozoic metamorphic rocks overlain by an extensive sequence of Miocene mafic and intermediate volcanic rocks and continental clastic rocks. Late Oligocene to early Miocene granitoid plutonic rocks intrude Proterozoic rocks in the northwestern part of the map area. Tertiary extension and magmatism occurred in the study area, which is characterized by felsic and mafic volcanic rocks and by northwest-trending normal faults. A low-angle detachment fault exists south and east of Cortez Peak and is broken into en echelon patterns by younger faults. Numerous prospects are scattered throughout the area, although no mineral production has been recorded.

Ort, M.H., and Skotnicki, S.J., 1993, Geologic map of Saddle Mountain, Maricopa County, Arizona: Open-File Report 93-6, 11 p., scale 1:24,000. $3.75

The Saddle Mountain area is dominated by middle Tertiary, felsic to intermediate volcanic rocks, and underlying, less abundant, Proterozoic crystalline rocks. The Lower Proterozoic rocks consist of metavolcanic rocks and thin beds of chemical, sedimentary, iron-rich rocks (banded iron formation). Great thicknesses of monolithologic breccias are associated with lavas of the same composition. The study area includes only a few faults, none of which appear to have slipped significantly.

Dickinson, W.R., 1993, Summary geologic map of Black Hills, near Mammoth, Pinal County, Arizona: Contributed Map CM-93-B, scale 1:24,000. $3.00

The Black Hills are a structurally complex area that encompasses the San Manuel and Mammoth mineral districts. Low- and high-angle normal faults, including the San Manuel fault that separated the originally contiguous San Manuel and Kalamazoo porphyry copper deposits, displace a variety of Tertiary volcanic and sedimentary rocks and pre-Tertiary igneous rocks.

Knapp, J.H., 1993, Geologic map of the Moon Mtns., Colorado River Indian Reservation, La Paz Co., Arizona: Contributed Map CM-93-C, scale 1:24,000. $3.00

The Moon Mountains, located northwest of Quartzsite, consist of granitic rocks of uncertain age and Paleozoic and Mesozoic sedimentary and volcanic rocks that have been metamorphosed, penetratively deformed, cut by low- and high-angle faults, and intruded by Tertiary granitic rocks. The Copper Peak detachment fault at the northwestern edge of the range projects beneath the Copperstone Mine and may have been an important conduit for ore-forming fluids.

RADON PUBLICATIONS

Radon in Arizona, edited by Jon E. Spencer and published by the Arizona Geological Survey, is a comprehensive summary of current knowledge on radon in the State. This collection of 11 technical articles and 2 folded maps defines the distribution of radon and describes its relationship to the geology and hydrology of Arizona. Studies focus on the following areas: Tucson, Phoenix, Prescott, Verde Valley, southeastern Arizona, and the Navajo Nation Indian Reservation. Two articles summarize studies of radon in ground water. The two maps show areas of elevated uranium concentrations in Arizona. This 96-page book may be purchased from the Arizona Geological Survey for $29.00, plus shipping. (See previous page for ordering instructions.)

The Geology of Radon, written by James K. Otton and published by the U.S. Geological Survey, is a 29-page nontechnical booklet that answers key questions about this geologic hazard: what it is, how it forms, how it moves through soil and water, how it enters homes and other buildings, how it is measured, how maps may help in locating potentially high radon areas, and where to obtain additional information on radon. An excellent overview of this potential health risk, this free booklet may be obtained from the Tucson Earth Science Information Center, 340 N. 6th Ave., Tucson, AZ 85705-8325; tel: (602) 670-5584; fax: (602) 670-5591; or from Book and Open-File Report Sales, U.S. Geological Survey, Federal Center, Box 25286, Denver, CO 80225; tel: (303) 236-7477; fax: (303) 236-1972.

Radon Gas: A Geologic Hazard in Arizona, by Jon E. Spencer, answers many of the same questions posed in the booklet listed above. This 17-page nontechnical publication, however, also includes information specific to Arizona. For example, it lists the areas in the State that contain anomalous concentrations of uranium (greater than 6 parts per million) and, thus, potentially high concentrations of radon. It also specifies how residents of Arizona can reduce radon levels in their homes. Based on original research by the author and other geologists, this easy-to-read booklet is available for $2.50, plus shipping, from the Arizona Geological Survey. (See previous page for ordering instructions.)

Knapp, J.H., 1993, Geologic map of Mesquite Mtn., Colorado River Indian Reservation, La Paz Co., Arizona: Contributed Map CM-93-D, scale 1:24,000. $3.00

Mesquite Mountain, located south of Parker, consists of gneissic and granitic crystalline rocks that were deformed in Cenozoic and possibly Mesozoic time. Crystalline rocks are flanked by the Miocene to Pliocene Bouse Formation, and both are cut by a high-angle fault.

Chenoweth, W.L., 1993, Geology and production history of the Bootjack uranium mine, Navajo County, Arizona: Contributed Report CR-93-A, 8 p. $1.50

The Bootjack Mine, located approximately 13 miles north of Kayenta, Arizona, was one of several large uranium deposits in the Oljeto syncline area of Monument Valley. It was the deepest (400 feet) of these deposits and had one of the highest ore grades (0.46% U_3O_8). This report, which includes a map of the underground mine workings, describes the geologic setting and production history of the Bootjack Mine. Most of the information is from U.S. Atomic Energy Commission documents.

Tips for Earthquake Preparedness

BEFORE AN EARTHQUAKE:

Check your home for potential hazards.

- Repair defective electrical wiring, leaky gas pipes, and inflexible connections. Bolt down water heaters and gas appliances.
- Know where and how to shut off electricity, gas, and water at main switches and valves. Check with local utility companies for instructions.
- Place large and heavy objects on lower shelves. Securely fasten shelves to walls. Brace or anchor high or top-heavy objects.
- Store bottled goods, glass, china, and other breakables in low or closed cabinets.
- Fasten overhead lighting fixtures, such as chandeliers, with wiring or an anchoring sill.
- Repair deep plaster cracks in ceilings and foundations.
- Hold occasional drills so that each family member knows what to do in an earthquake.
- Teach responsible family members how to turn off electricity, gas, and water at main switches and valves.

Have on hand:

- A flashlight and battery-powered radio in case power is cut off.
- A supply of drinking water and nonperishable foods that may be prepared without cooking.
- A fire extinguisher and first-aid kit.

DURING AN EARTHQUAKE:

- Most important: **STAY CALM.** Think through the consequences of any action you take.
- If you are indoors, stay indoors; if you are outdoors, stay there. During earthquakes, most injuries occur as people enter or leave buildings.
- If you are indoors, take cover under a heavy desk, table, bench, in a supported doorway, or along an inside wall. Stay away from glass and fireplaces. Do not use candles, matches, or other flame either during or after the tremor because of possible gas leaks. Douse all fires.
- If you are in a high-rise building, get under a desk or similar heavy furniture. Do not dash for exits because stairways may be broken or jammed with people. Never use elevators because power may fail.
- If you are outdoors, move away from buildings and utility wires. The greatest danger from falling debris is just outside doorways and close to outer walls. Once in the open, stay there until the shaking stops.
- If you are in a moving car, stop as quickly as safety permits, but stay in the vehicle and keep low. A car may jiggle violently on its springs, but it is a good place to stay until the shaking stops. When you resume driving, watch for hazards created by the earthquake, such as fallen or falling objects, downed electrical wires, or broken or undermined roadways.

AFTER AN EARTHQUAKE:

- Be prepared for additional earthquake tremors, or "aftershocks." Although most of these are smaller than the main shock, some may be large enough to cause additional damage or bring weakened structures down.
- Check for injuries. Do not attempt to move seriously injured persons unless they are in immediate danger of further injury.
- Turn on your radio or television to get the latest emergency information from local authorities.
- Check your utilities. The earthquake may have broken gas, electrical, and water lines. If you smell gas, open windows and shut off the main gas valve. Then leave the building and report the leakage to authorities. Do not reenter the building until a utility official says it is safe. If electrical wiring is shorting out, shut off the current at the main meter box. If water pipes are damaged, shut off the supply at the main valve. Emergency water may be obtained from hot-water tanks, toilet tanks (not bowls), and melted ice cubes.
- Check the entire height of your chimney carefully for cracks. Unnoticed damage could lead to a fire. The initial check should be done from a distance. Approach chimneys with caution.
- Check to see that sewage lines are intact before using sanitary facilities.
- Do not touch downed power lines or objects in contact with downed lines.
- Immediately clean up spilled medicines, drugs, flammable liquids, and other potentially hazardous materials.
- Use the telephone only for genuine emergency calls. Do not spread rumors; they often do great harm after disasters.
- Stay away from damaged areas. Your presence could hamper emergency relief efforts, and you could be putting yourself in personal danger. Cooperate fully with public-safety officials. Respond to requests for volunteer assistance from police and fire-fighting, civil-defense, and relief organizations, but do not go into damaged areas unless your assistance has been requested.

AZGS Core Repository Reorganized

The Arizona Geological Survey (AZGS) has statutory responsibility to maintain a repository of rock cuttings and core samples. Diamond-drill core samples have been donated to the AZGS over many years, but until recently these samples had not been completely organized and cataloged. In 1992, the AZGS organized a core repository now housed in the basement of the State Building at 416 W. Congress in downtown Tucson. Financial donations from Magma Copper Company and Homestake Mining Company ($1,000 each) were used to cover the costs of moving and skeletonizing the core collection. Core boxes donated by ASARCO were used to organize the samples, many of which were in crumbling boxes that had been stored outside.

Core samples in the new facility represent almost 300 individual drill holes and approximately 150,000 linear feet of drill core. The samples have been skeletonized (either by the donor or by AZGS geologists) to varying degrees; 20 percent to less than 1 percent of the original material has been retained. All 14 Arizona counties are represented in the storage facility by at least one drill hole; Apache, Cochise, Maricopa, and Mohave Counties are represented by the most individual holes. The samples represent various projects ranging from geotechnical site assessments to metallic mineral exploration.

A new AZGS open-file report (OFR 93-2), titled *The AZGS Core Repository,* contains a complete inventory of AZGS

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Arizona Geographic Information Council

As much as 90 percent of the work of government agencies relates to geography, i.e., where people, places, and things are located. During the last 20 years, scientists have developed a powerful new technology to create, manage, and analyze location-related data with the aid of computers. This technology, known as geographic information systems or GIS, combines traditional database management with sophisticated spatial data processing. GIS technology allows humans to communicate and understand information in ways that were never before possible.

Use of GIS technology in the public and private sectors has grown rapidly in the United States. Almost 60 GIS's have already been established in Arizona. By the year 2000, virtually all of the Federal, State, county, and large municipal agencies in Arizona are expected to have a GIS. Usage in the private sector is also exploding.

GIS differs from traditional data processing because of the common need among organizations for the same location-related data. For example, several public and private organizations could use parcel, road, land-use, drainage, and population data to support their operations. Creating digital GIS data is expensive. Without coordination, the potential for duplication of effort at taxpayers' expense is tremendous.

In 1982, the Arizona Legislature established the Arizona Land Resource Information System (ALRIS). The goals of the ALRIS program, which is under the auspices of the State Land Department, are as follows: (1) to design, develop, and maintain statewide, multipurpose, digital, spatial databases for use by public agencies; (2) to develop and conduct GIS training programs for public employees; and (3) to serve as a clearinghouse for digital spatial data to help reduce GIS costs.

To aid the cooperative development and management of GIS, ALRIS works through the Arizona Geographic Information Council (AGIC), which was created by Governor's Executive Order in 1988. AGIC's 29-member Executive Management Board is composed of representatives from Federal, State, and local governments, as well as regional GIS consortia, universities, and the private sector.

In October 1992, AGIC released a strategic plan to guide the development of GIS in Arizona. The plan focuses on five main issues: administrative and legal, data resources, technology, information exchange, and education. The cornerstone of Arizona's GIS plan is the hiring of a State Cartographer, who would coordinate the ALRIS program at the State Land Department. The Arizona Legislature has authorized this position but has not yet funded it. A copy of the AGIC strategic plan may be examined in the Arizona Geological Survey library or obtained from AGIC, 1616 W. Adams St., Phoenix, AZ 85007.

Arizona Geology

Vol. 23, No. 2 — **Summer 1993**

State of Arizona: Governor Fife Symington

Arizona Geological Survey

Director & State Geologist: Larry D. Fellows

Illustrator: Peter F. Corrao

ISSN 1045-4802

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core holdings and includes maps of drill-hole locations. Core samples drilled and donated by the U.S. Bureau of Mines and Bendix Field Engineering Corporation are described in nine published reports, which are listed in OFR 93-2. AZGS files contain unpublished reports and drill logs for other samples, but many are undocumented, except for the location information given in OFR 93-2. Anyone who would like to purchase this 29-page report for \$6.50 (including shipping) or inspect core samples should contact the AZGS by telephone at (602) 882-4795 or by mail at 845 N. Park Ave., #100, Tucson, AZ 85719-4816.

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Arizona Geological Survey
845 N. Park Ave., Suite 100
Tucson, AZ 85719-4816
Tel: (602) 882-4795

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