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The Arizona Floods of January and February 1993

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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).

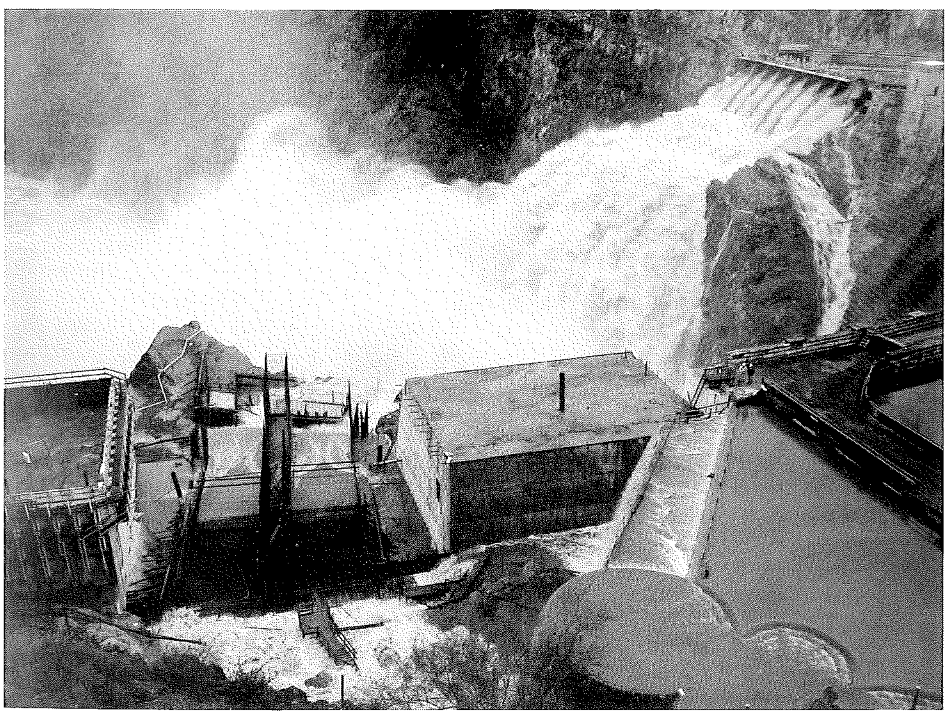

Figure 1. Close-up of the Roosevelt Dam spillway on January 19. The combined discharge of the Salt River over the spillway and coffer dam (foreground) was approximately 34,000 cubic feet per second (cfs) at the time the photograph was taken. This value is associated with the highest recorded level of 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.

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.

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

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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.

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.

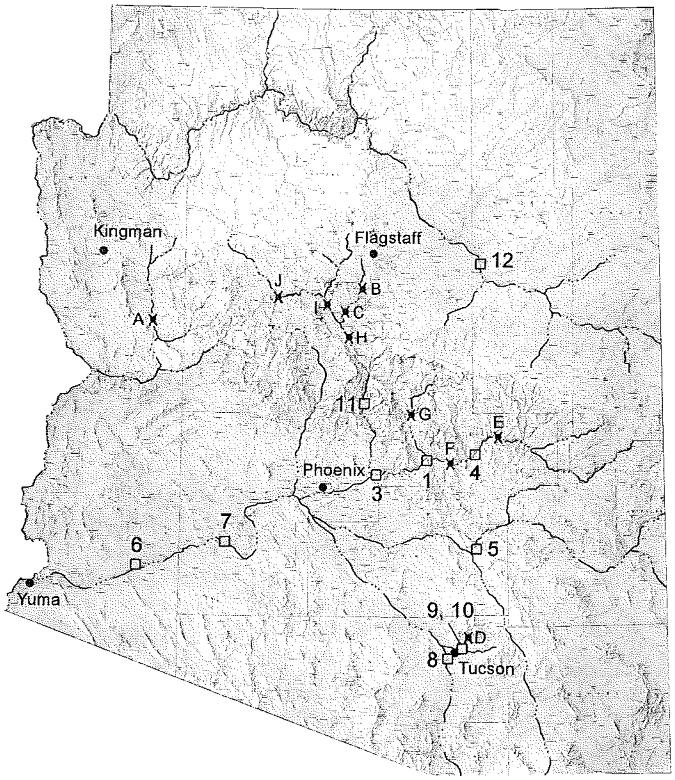


Figure 2. *Major streams, approximate sites of Figures 1 through 12, and locations of lettered stream gages listed in Table 1.*

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 (mi²)	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

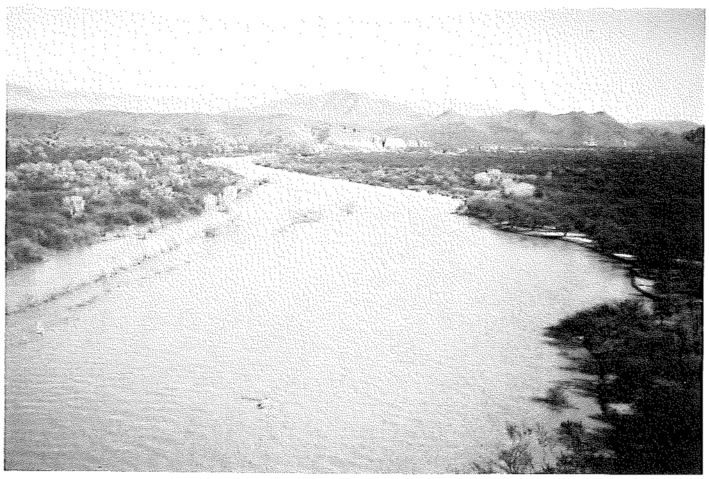
The most remarkable aspect of the January-February 1993 flooding in Arizona was its scale: it involved many flood events that were extremely large in volume, extent, and absolute magnitude. Almost every physiographic region in the State was affected, which is a rare circumstance. It is much more common 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.

SELECTED REFERENCES

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

Office of the State Climatologist, 1993, Arizona climate summary: Arizona State University, Department of Geography, v. 19, nos. 7, 8, and 9.



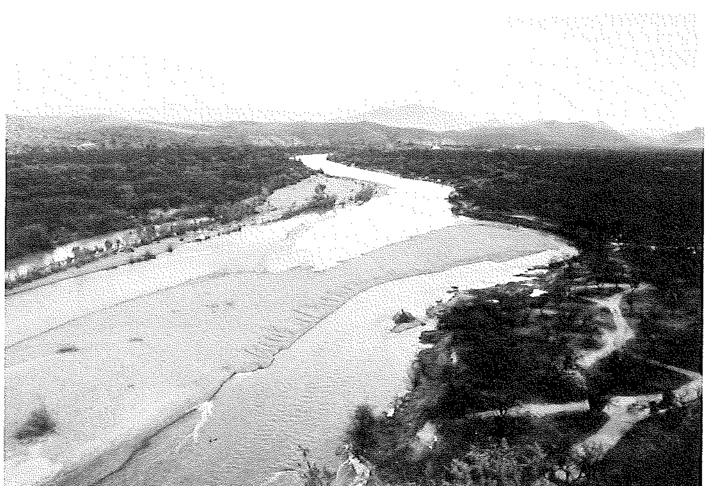


Figure 3 (a and b). Salt River below Stewart Mountain Dam. The first photograph was taken on January 20 following a peak discharge of 41,000 cfs. The second photograph of approximately the same site was taken on March 10. The peak discharge through this reach of the Salt River was significantly attenuated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

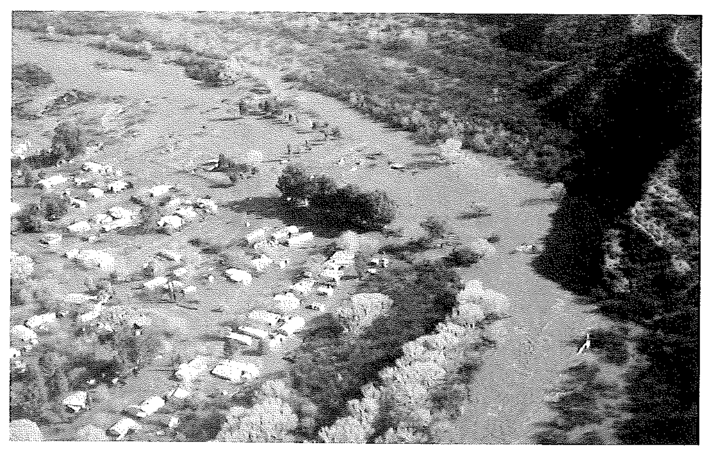


***Figure 4 (top).** View of the Salt River in Jump Off Canyon above Roosevelt Lake. A flood discharge of approximately 144,000 cfs passed through this reach on January 8. The flood removed all vegetation, soil, and weathered bedrock from the canyon walls and from the bedrock bench on the right bank. 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.*

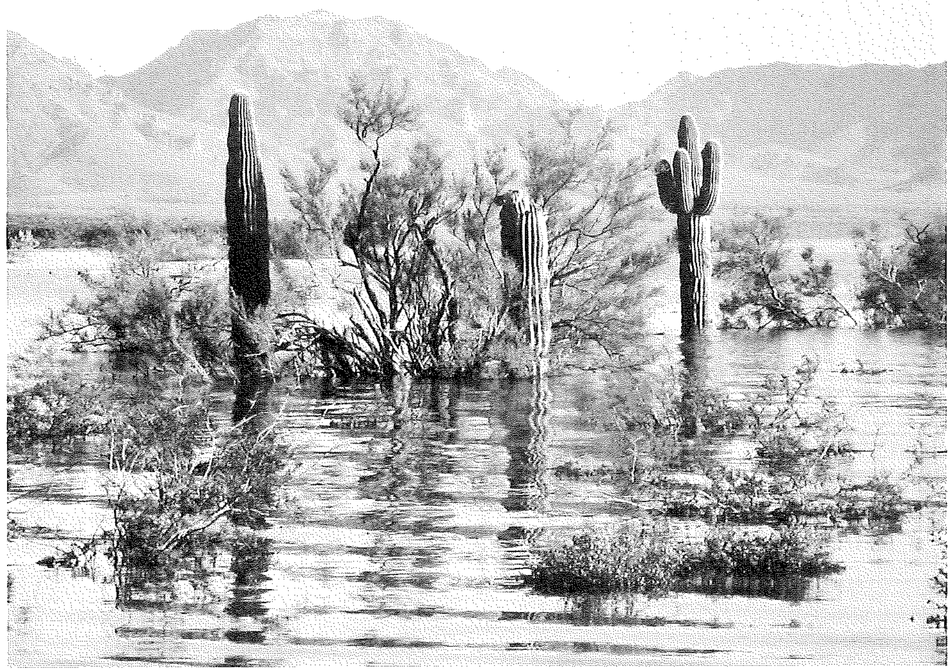


Figure 7 (right). *Native Sonoran Desert vegetation flooded along the margins of Painted Rock Reservoir in southwestern Arizona. This reservoir, fed by the Gila River, filled to a capacity of 2.8 million acre-feet for the first time since its completion in 1961. Photo taken on March 16 by Steven J. Skotnicki,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

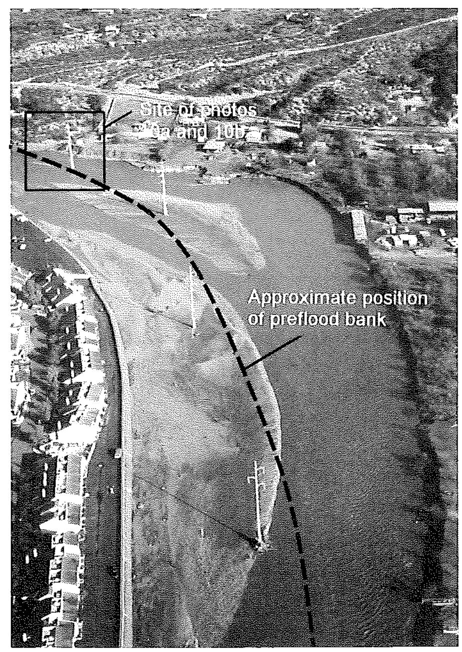


Figure 9 (above). *Severe bank erosion along Rillito Creek near N. Country Club Blvd., Tucson. This photograph was taken on January 20, 12 days after the peak discharge. Line on photo shows former position of bank. Photo by Victor R. Baker, University of Arizona.*

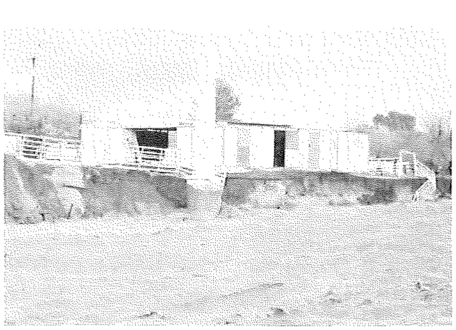


Figure 10 (a and b, left). *Sequential photographs of site within Figure 9 showing horse stables being destroyed by bank erosion along Rillito Creek near N. Country Club Blvd., Tucson. The photos were taken at 11:33 a.m. and 11:50 a.m. on January 8. The peak discharge on Rillito Creek was between 20,000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

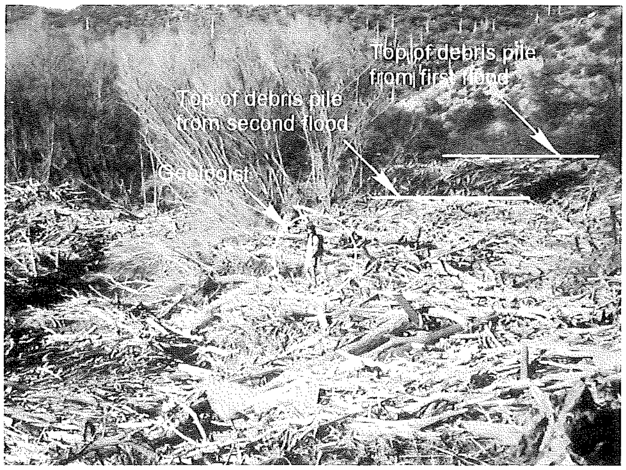


Figure 11. Massive pile of flood debris on the lower Verde River above Horseshoe Reservoir. This photograph, taken on April 10, shows two levels of debris that correspond to the peak discharges of January 8 (127,000 cfs) and February 20 (111,000 cfs). Note arrow pointing to person for scale. Photo by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

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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