WEATHER SITUATIONS ASSOCIATED WITH FLOODS DURING 1972

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Floods during 1972 resulted from a variety of meteorological causes, and some were only partially the result of extreme weather events. One flood that was not caused by a major weather event occurred on Buffalo Creek in West Virginia in February; and, although precipitation of moderate to heavy amounts occurred over a fairly large area, the major flooding resulted primarily from dam failure. Of the other major flood events, one resulted from snowmelt during extremely warm periods, four resulted from more or less isolated thunderstorm convective shower activity, three were the result of widespread precipitation associated with active frontal systems, one was the result of precipitation from a tropical storm, and a final one was the result of strong winds around the Great Lakes with possibly some supplemental flooding caused by the associated rain. Several flood events are discussed.

•THE WEATHER SITUATION on the morning of February 26 (the date the dam failure occurred on the middle fork of Buffalo Creek) caused general rain from eastern Kentucky and Tennessee, northeastward across West Virginia, into New England. On the 2 previous days, a band of frontal activity had stretched generally east-west through North and South Carolina and across northern Georgia, Alabama, and Mississippi just south of the Tennessee border. A cyclonic circulation developed on this front on the afternoon of the 25th and moved east-northeast across Tennessee and the southern tip of West Virginia. On the morning of the 26th, this low-pressure system was located over the boundary between Virginia and Maryland (Fig. 1). Heavy rainfall beginning on the 24th and continuing into the 26th, plus some snowmelt, caused considerable flooding of streams in West Virginia and Kentucky. Total rainfall for this 3-day period averaged about 3 to 4 in. at several locations. This much precipitation over very small areas would have an average recurrence interval of 2 to 5 years (6). Although precipitation from this system caused flooding throughout the West Virginia-Kentucky-Tennessee region, the magnitude of the disaster at Logan County was primarily a result of dam failure. Flooding in other portions of this region was characterized as generally minor to moderate.

The temperature conditions in the north-central part of Washington during the latter part of May and early June were more common for a period in mid to late summer. A high-pressure system off and along the Pacific coast brought a flow of air off the warm Pacific Ocean, across the Cascades, and down into the interior of the state. Through the Pacific Northwest, there were generally light winds and clear skies. These conditions were conducive to bright sunshine, which pushed the maximum temperatures into the 80s and low 90s over most of interior Washington and Oregon. Figure 2 shows the daily maximum and minimum temperatures at Omak, Washington. Such temperatures were not representative of this region for so early in the summer season and resulted in relatively rapid melting of heavy snowpack over the mountains of northern Washington, which was the primary cause of the heavy flooding through the Okanogan valley region.

During the afternoon of June 7, 1972, a severe thunderstorm occurred at Bakersfield, California, with little change in the basic weather pattern. During the first week in June, there was an unusually intense and persistent upper level low-pressure center located south and southwest of southern California. The circulation around this upper level low brought great quantities of tropical moisture into the Southwest from the Gulf of California and the warm Pacific Ocean southeast and southwest of Lower California. Scattered thunderstorms broke out in the interior mountains and deserts of southern California, Arizona, and Nevada during the early portion of this period and spread northward and westward during the latter days of the first week in June.

On June 7, this moisture, mostly in the level between 5,000 and 25,000 ft, spread over the Tehachapi Mountains and into the San Joaquin Valley. At the same time, a new upper level low was moving toward the West Coast from the north Pacific. Its approach may have contributed to the vertical lift that helped to trigger the invading tropical moisture, producing large showers. In the upper level flow pattern, a very minor trough that moved around the larger low-pressure system across California, through Nevada, and toward the east during this period can be detected. The intense afternoon heating of the sun, which caused temperatures of over 100 deg during this period around Bakersfield, also helped to provide the instability in the atmosphere that promoted the intense thunderstorm development. During the morning and afternoon of the 7th, hourly weather reports showed middle and high clouds spreading northward from the Tehachapi Mountains across the southern San Joaquin Valley. There was no precipitation in the early afternoon, but shortly after 3 p.m. rain began at Bakersfield. By 3:45 p.m., thunder was heard. The wind at this time was from the south-southeast at 36 knots, with gusts to 46 knots. The intense period of rainfall lasted about 70 min, from shortly before 4 p.m. until near 5 p.m. The area covered in this storm by the 1-in. isohyet was approximately 50 square miles (Fig. 3), whereas the most intense portion, that with more than 2½ in. of precipitation, covered only about 3 square miles. The precipitation in this storm was about six times the 100-year recurrence value for this location (3). It was also about two-thirds the probable maximum precipitation (PMP) from thunderstorms estimated by the National Weather Service. PMP is an estimate of the physical upper limit of precipitation that could occur for a particular duration and size of area (1). It is interesting to note that the weather summary for California for June 1972 (2) states: "Drought conditions continued over the State.... Seasonal precipitation was near or slightly above normal only in the northern tier counties and in the higher elevations of the Sierra...." Thus, these cloud bursts—flash-flood types of storms—can occur even with drought conditions.

The next storm to be discussed occurred in northwestern Nevada on June 8, 1972 (Fig. 4). This region is relatively unsettled, and our data on small-scale occurrences for it are probably the poorest of any of the storms mentioned in this paper. It is interesting to speculate that perhaps the same meteorological impulse that caused thunderstorm activity in the San Joaquin Valley and flash flooding conditions at Bakersfield on the previous day caused this storm. The minor trough in the upper air circulation mentioned earlier appeared to have continued to progress through a long-wave trough position off the west coast of California to a position over northwestern Nevada. This, together with the high moisture conditions that persisted throughout the entire region and in coincidence with the heating of these regions in the late afternoon, appeared again to set off the thunderstorm activity. The precipitation measured at regular weather reporting stations of National Weather Service offices and by cooperative observers did not indicate any extremely large amounts, and the population density in this region is such that bucket surveys were not conducted. Thus, there is no knowledge of the precipitation amounts in these showers. Flooding on small streams provides indirect knowledge of the existence of large showers. The regular cooperative observers and reporting stations did report some amounts near or slightly over an inch from showers on the afternoon of the 8th.

The rainfall that occurred on June 9 in the vicinity of Rapid City, South Dakota, was among the most severe precipitation and flood events to occur in the Black Hills region. Prior to the South Dakota rain, a large high-pressure system in Canada was pushing slowly southward. Early on the 9th, the leading edge of the colder air mass stretched from a weak low over northeastern Vermont, west-southwestward across southern Lake Michigan, and then westward into South Dakota.

The main feature of the low-level flow over South Dakota was its easterly direction through most of the 9th, thus giving upslope motion due to both the large-scale slope of the Great Plains and the local and pronounced terrain of the Black Hills. To the south of this cooler air mass, the prevailing weather systems were quite weak. The weakness of the systems to the south of the leading edge of the cooler air meant weak gradients and light winds. Warm, moderately moist air was characteristically present over a large region. Detailed study indicates that there was an influx of moisture near maximum conditions in a rather narrow band on the mesoscale. These conditions appear to have been an important low-level feature contributing to the heavy rainfall. The upper air flow prior to the storm shows a prominent, fairly stationary long-wave ridge over the Great Plains, with the ridge line at 500 mb (approximately 18,000 ft) just to the east of Rapid City. There was also a very weak smaller scale trough oriented northwest-southeast through southwest Wyoming. An important characteristic of these high-level charts is the prevalence of light winds through the Dakotas and westward. These light winds aloft, indicative of a lack of a strong steering current, were apparently important in keeping the massive thunderstorms in approximately the same area for several hours. At the lower levels of the atmosphere, but still above the surface, some features that could be of significance might be noted. Reflecting the surface synoptic features, the 850-mb charts (approximately 5,000 ft) show a large Canadian high-pressure system centered well north of the North Dakota border and a weak low-pressure system centered near the Colorado-Wyoming border, which moved southward in the 12 hours just prior to the storm. These two broad-scale features provided a flow of air also from a generally southeasterly direction over South Dakota. An interesting feature is that at this level the maximum low-level moisture did not extend southward over Nebraska.

An isohyetal analysis for the Black Hills storm shows several 12-in. centers of precipitation (Fig. 5). The maximum reported storm amount of nearly 15 in. fell in 6 hours near Nemo, South Dakota, about 16 miles northwest of Rapid City. All rainfall greater than 4 in. occurred on the eastern slopes of the Black Hills. The elongated, irregularly shaped, 8-in. isohyet, in general, lies between the 4,000- and 5,000-ft contours. Numerous and various-sized centers are scattered within the 8-in. isohyet. The largest, approximately 39 square miles, is about 15 miles west-northwest of Rapid City. There does not appear to be a simple or direct relation between maximum rainfall centers and terrain features of these locations. There is a slight indication that east-facing valleys may have contributed to some forced convergence of the prevailing low-level winds. The heaviest precipitation occurred in a period of about 5 to 6 hours. This heavy precipitation averaged about four times the 100-year 6-hour amount. The precipitation at the centers is also about two-thirds of the probable maximum precipitation for these locations (4).

In June 1972, there were unusually large amounts of precipitation in many portions of Arizona. This is a time of year when the probability of precipitation is relatively low in that state. Moist air entered Arizona from the south during this month with a frequency not usually prevalent until July or August. On June 21 and 22, unusually severe thunderstorm activity affected much of central and southern Arizona, with tornadoes and rain occurring in the Phoenix region. About mid-afternoon on the 21st, thunderstorms developed in a hot, moist tropical air mass over south-central Arizona, causing heavy rains and local flooding through the northeastern section of the Phoenix metropolitan area. The following morning at about 6 a.m., another severe thunderstorm system developed southwest of the Phoenix area in this relatively stagnant weather system (Fig. 6) and moved northeastward across Phoenix in the Scottsdale-Paradise valley area. This latter storm produced unusually heavy rains over a period of a few hours. The heaviest rains were about 4 to 4½ in., which is between two and three times the 100-year rainfall value (5) and about one-third to one-half the probable maximum precipitation (4) for this region. The exact multiple or ratio depends on the location and exact duration of the rainfall at the various points in and near the Phoenix area.

During the period from June 14 through 17, a low-pressure system moved across Canada just south of the Hudson Bay, crossing the James Bay on the 15th. A cold front

Figure 1. Weather situation on February 26, 1972 (star shows approximate location of flood event; cross-hatched area indicates extent of precipitation at 7:00 a.m. EST).

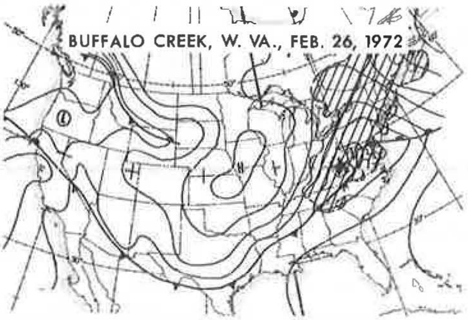


Figure 3. Total storm isohyetal map for the thunderstorm of June 7, 1972.

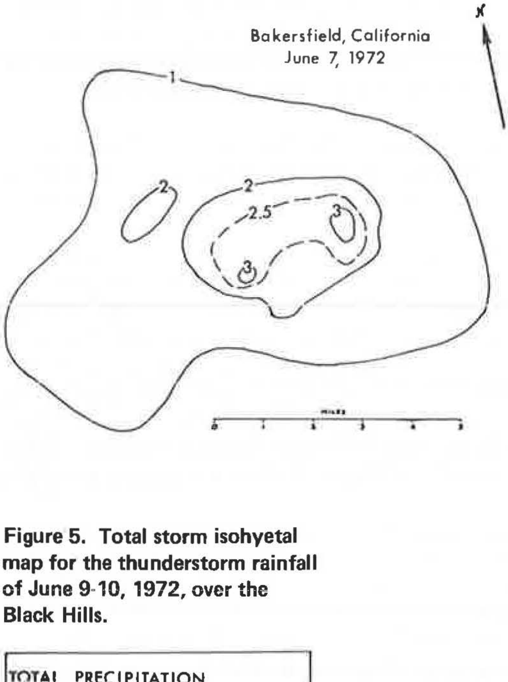


Figure 5. Total storm isohyetal map for the thunderstorm rainfall of June 9-10, 1972, over the Black Hills.

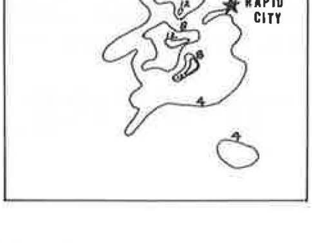


Figure 2. Maximum and minimum temperatures at Omak, Washington, during latter part of May and early June 1972.

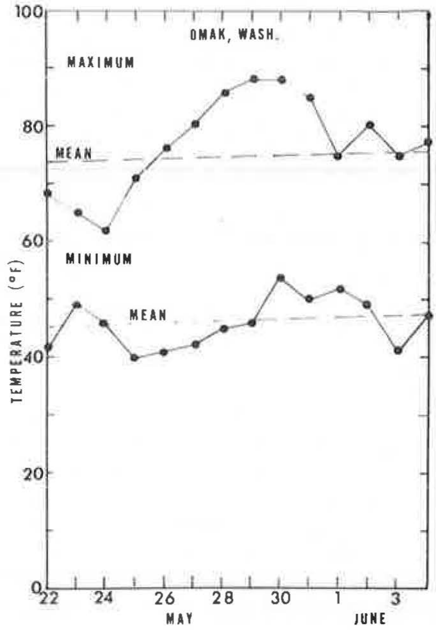
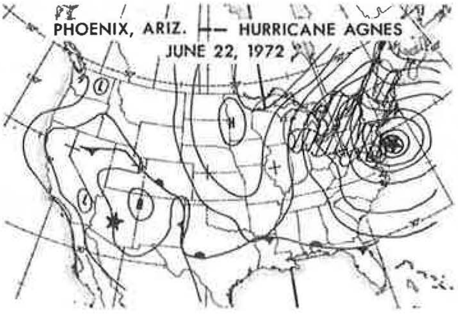


Figure 4. Weather situation on the morning of June 8, 1972 (star shows approximate location of flash flooding; cross-hatched area indicates extent of precipitation at 4:00 a.m. PST).

Figure 6. Weather situation on the morning of June 22, 1972 (stars show Phoenix and Hurricane Agnes at 7:00 a.m. EST).



extended southward from this system through the Great Lakes region and Indiana and into Arkansas. This frontal system continued to move eastward across the Northeast as the low moved into the Davis Straits. This frontal system passed through the New York-Connecticut area on June 17 and 18, causing considerable rainfall. Rainfall amounts reported were from 4 to 7 in. from New York City northward through Westchester County and the rest of Connecticut. Precipitation was in the form of showers on 4 consecutive days, the 16th through the 19th. The individual showers at the heaviest portion had recurrence intervals of approximately 5 to 10 years, and the total storm had a recurrence interval of about 5 to 10 years (5). One of the important aspects of this storm, as far as the northeastern portion of the country is concerned, is the wetting of the soil prior to the heavy rainfall that came from Hurricane Agnes in the succeeding days.

Hurricane Agnes formed on the 15th of June as a tropical depression off the Yucatan Peninsula. During the next 24 hours, the storm intensified and became a tropical storm. Agnes was revealed by satellite to have an unusually large circulation. On Saturday, June 17, Agnes began moving northward at about 10 mph. The following morning, hurricane-force winds were found near its center, which was some 250 miles west of the Florida Keys. By Sunday, winds were gusting from 40 to 50 mph along the Florida coast, strengthening first in the Keys and then by evening as far north as Orlando. Agnes had an unusually large circulation that brought in an easterly to southeasterly flow over Florida. As a result, winds along the east coast were often as strong as or stronger than those along the west coast. Precipitation spread over the entire Florida region.

By the afternoon of the 18th, two things were obvious: Agnes would cross the coast along the Florida panhandle, and the most destructive blow in this region would be storm tides along the west coast. Agnes moved ashore near Panama City late Monday afternoon, the 19th. It crossed northwestern Florida and weakened as it moved through Georgia. Near the 20th, the large weak depression moved northeastward across Georgia and into South Carolina. The principal effect of this storm then was rain. It was heaviest in the south in Georgia. The Carolina mountain areas were drenched, whereas in the central and coastal areas rain was light. The system continued to move northeastward across the Carolinas on Wednesday. The storm intensified again as it moved closer to the Atlantic Ocean. Cape Hatteras reported a 37-mph wind and gusts of 62 mph. Agnes reached Norfolk as a rejuvenated tropical storm on Wednesday night. It was, however, an unusual system. At one time on the 22nd, surface pressures were below 1,000 mb over an area from upstate New York to the North Carolina capes, whereas the lowest pressure hovered near 990 mb. Normal sea-level pressure is about 1,013 mb. This large region of low pressure was due in part to a quasi-stationary trough in the Ohio valley. The moisture-laden gulf air in Agnes was replenished by the Atlantic. This moist air encountered the Appalachians and triggered torrential rains over river basins from South Carolina to New York. As mentioned previously, many of these river basins were already soaked by heavy rains from the storm of June 17 and 18. Agnes moved off the Virginia capes and back out to sea late Wednesday. During the 22nd (Fig. 6), the broad system moved up the East Coast, across western Long Island, and inland near New York City. The storm became extratropical, moved westward across New York, and became nearly stationary before it turned toward the northeast again. On the 25th, it moved east-northeastward across Lake Ontario, southern New York, southern Quebec, Maine, New Brunswick, and Nova Scotia. Heavy rains continued from the 20th through the 25th over much of the northeastern United States.

The total precipitation (in inches) from Hurricane Agnes over the northeastern United States is shown in Figure 7. This is a preliminary map. It does include, through the New York-Connecticut-Pennsylvania region, some of the precipitation from the previous storm. Detailed studies of this storm are under way, but the final maps are not yet available for this period. The largest observed amounts of precipitation from Virginia through Maryland, Pennsylvania, and New York were all about twice the values for the 100-year return period where they occurred (5). The heaviest centers occurred through southeastern Pennsylvania, with regions of precipitation in excess of 16 in. Heavy rainfall centers, with precipitation depths of over 12 in., occurred from central Virginia through New York.

Figure 7. Preliminary total storm isohyetal map for Hurricane Agnes.

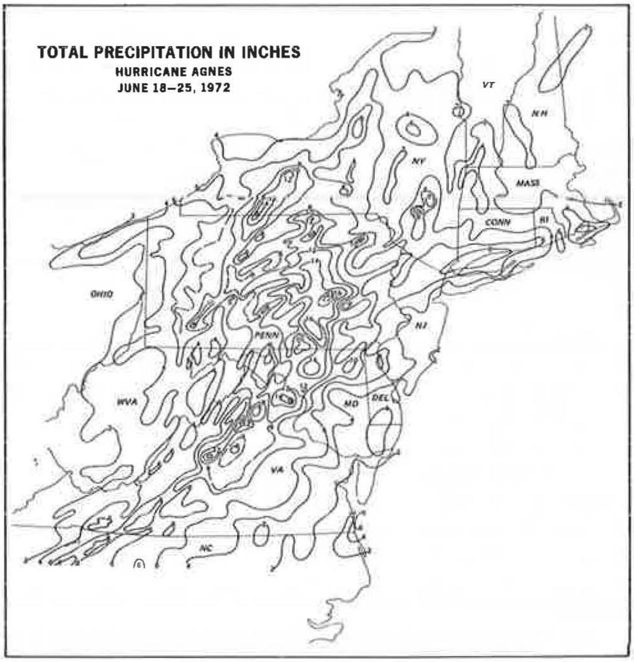


Figure 8. Weather situation on the morning of August 1, 1972 (star shows approximate location of flooding; cross-hatched area indicates extent of precipitation at 6:00 a.m. CST).

Figure 9. Weather situation on the morning of September 11, 1972 (star shows approximate location of flooding; cross-hatched area indicates extent of precipitation at 6:00 a.m. CST).

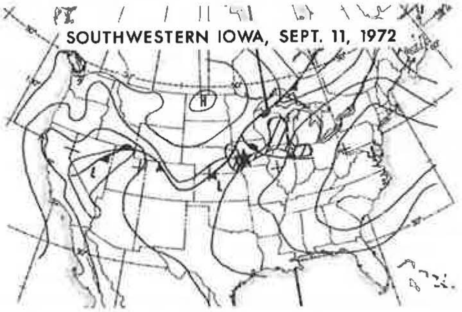
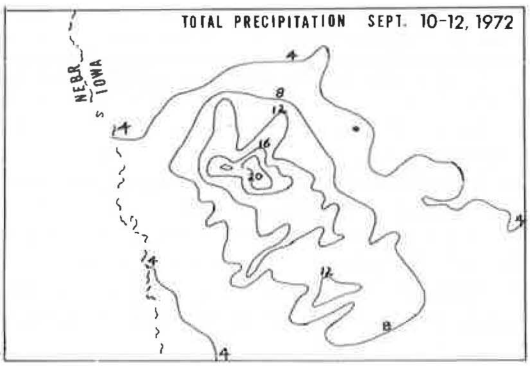


Figure 10. Total storm isohyetal map for western Iowa.



The flooding in northeastern Iowa in early August 1972 was caused by a weather system similar to that causing the flooding on June 17 and 18 in the New York-Connecticut region (Fig. 8). A low-pressure system moved across Canada through the Hudson Bay-James Bay vicinity, while a cold front trailed southeastward through the Great Lakes region into the United States. A weak low-pressure system was located just east of the Rocky Mountains, but this was not the primary cause of the precipitation. Moist air around a high centered off the southeastern U.S. coast fed moisture up across the Great Plains into the Iowa region. As the cold front moved southeastward through central United States, this warm, moist air was lifted, and numerous showers occurred. The heavy rainfall over Iowa resulted from this lifting as the cold front moved southeastward.

The situation in September 1972 was again typical of the storms that caused flooding over much of the central and eastern United States in summer and early fall. A well-organized low-pressure system moved eastward in the prevailing westerlies across Canada, while a frontal system trailed down through the United States (Fig. 9). A low developed over the eastern Colorado-western Kansas-Nebraska region on the 10th and 11th. It moved northeastward along the front, deepening as it moved. The convergence around this system and the instability in the warm, moist air feeding northward over the Great Plains were primary causes of large amounts of precipitation over Iowa. In this storm, precipitation was extremely intense. At Harland, Iowa, approximately $12\frac{1}{2}$ in. fell on the 11th, and the 3-day total was more than 20 in. The 1-day amount is about twice the 100-year value, and the 3-day total was about 2.5 times the 100-year value (6). As shown in Figure 10, the 8-in. area of precipitation is quite large. The occurrence of 8 in. in 1 day at a point in this region has a recurrence interval of approximately once in 100 years. No studies have been done that would permit an estimate of the recurrence interval of precipitation over an area this large with an average depth well over 8 in. Probably, the recurrence interval would be much greater than 100 years.

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