Bronco Creek near Wikieup, Arizona

(Miscellaneous ungaged site in the Big Sandy basin, USGS Arizona Water Science Center)

Review of peak discharge for the flood of August 19, 1971

Location: This flood was located about 44 mi southeast of Kingman, Ariz., at 34.6764N and 113.5958W.

Published peak discharge: The published peak discharge for this flood is 73,500 ft^3/s and is rated poor. Other published discharge estimates are:

Publication	Discharge (ft^3/s)
Carmody (1980)	28,100
House and Pearthree (1995)	28,300
Hjalmarson and Phillips (1997)	96,800

Drainage area: 19 mi^2. The basin has three subbasins—Bronco Creek, Bronco Wash, and Greenwood Wash (so named in House and Pearthree, 1995).

Data for storm causing flood: A flashflood hit the Bronco Creek basin on August 19, 1971. About 3 in. of rain were measured in 45 minutes in Wikieup, Ariz., about 3 mi from the slope-area reach. This measurement seems to be the only local precipitation data for this storm. This flood is described as "virtually the largest known rainfall generated flood to come from a 50 square kilometer basin." Several investigators have attempted to analyze this flood using a variety of hydraulic and meteorological methods and have obtained a wide range of results. Historical photographs taken after the flood of August 19, 1971, and photographs taken during the 2003 review and described herein are provided in figures A179–A182.

Method of peak discharge determination: The original peak discharge estimate of 96,700 ft^3/s is based on a four-section slope-area measurement for a uniform reach. The discharge was reduced to 73,500 ft^3/s after roughness coefficients were increased during measurement review. The site was selected, and high-water marks flagged by H.W. Hjalmarson (USGS) on August 24, 1971. High-water marks and cross sections were surveyed on August 31, 1971. Byron Aldridge (USGS) did a contracted-opening computation for flow through the U.S. Highway 93 bridge to try to verify the computed discharge. Additional discharge estimates were made by several investigators using hydrometeorological methods, paleoflood techniques, and translatory wave theory. The original slope-area and the paleoflood (step-backwater) estimates probably are the most defensible. The occurrence of a series of large waves breaking over the highway bridge is supported by an eyewitness.

The original slope-area survey and bridge-contraction notes can not be found, but copies of the computations and review comments were available for use in this review. The slope-area reach is about 900-ft long and 400–500-ft wide and ends about 900 ft upstream of the U.S. Highway 93 bridge. The channel is an alluvial sand-bed channel. The original discharge computed by slope-area methods was reduced to 73,500 ft^3/s after roughness coefficients were increased from 0.030 to 0.040. Froude numbers ranged from 1.34 to 1.88. Tom Maddox (USGS), estimated velocities in the 25-ft/s range for the sediment sizes found in the slope-area reach. Velocity computed from the 73,500 ft^3/s discharge and the average 2.700-ft^2 cross-sectional area is about 27 ft/s.

Byron Aldridge (USGS) estimated a flood discharge that ranged from 54,000 to 61,000 ft^3/s by critical-depth calculation for a contracted opening through the bridge. Eyewitness accounts confirm that the opening was unobstructed at the time of the peak discharge. The drop in stage through the contraction was about 19 ft and was documented by high-water marks. The downstream marks were only 3 ft above the after-flood streambed. Aldridge reported that an average velocity of about 75 ft/s would be required to pass the computed discharge through the 160-ft wide bridge opening, thus bringing into question the validity of this contracted-opening estimate. Extensive erosion during and after the peak discharge reduce the reliability of this estimate. Reported deposits of approximately 40,000 yd^3 of new material on the delta at the mouth of Bronco Creek verify that extensive erosion did occur. It is not known if this is an artifact of the peak or of flow duration.

Channel slope in the basin ranges from 400 to 500 ft/mi. Two single cross-section slope-conveyance estimates and an approximation were made to try to confirm peak flow from each of the three subbasins comprising the Bronco Creek drainage. The results of these estimates are 9,100, 18,900, and 10,000 ft^3/s, respectively, for Bronco Wash (one-section slope conveyance), Bronco Creek (one-section slope conveyance), and Greenwood Wash (approximation based on similarity to Bronco Wash). The reported composite estimate is 38,000 ft^3/s.

Carmody (1980) (from House and Pearthree, 1995) used hydroclimatic techniques to estimate runoff in the Bronco Creek basin. He estimated that sustained precipitation of 10 in/hr for 35 minutes would be required to produce a discharge of 73,400 ft^3/s. The only precipitation data seem to be from nearby Wikieup, Ariz., where 3 in. of rainfall was measured in 45 minutes. This translates to about 4 in/hr. Transferring this rainfall data onto the Bronco Creek basin may stretch the technique depending on how widespread the most intense part of the storm was. The eyewitness account of the flood include a 2-hour observation by E. Fancher, Arizona Department of Transportation, of peak or near peak flow, which would support the theory of sustained intense precipitation over the basin.

House and Pearthree (1995) used paleoflood techniques to estimate peak discharge in each of the three subbasins. They combined these results to arrive at a new estimate for the 1971 peak discharge. To avoid the problem of unknown amounts of erosion and (or) fill, they selected bedrock reaches for their study. The study reaches in Bronco Creek, Bronco Wash, and Greenwood Wash were 45, 246, and 87 ft in length, respectively. Step-backwater techniques were used to try to match the slope of what are described as "unequivocal relic high-water marks" and slack-water deposits. The high-water marks are flotsam (woody debris) and were deposited on bedrock shelf-like features. There were from four to six high-water marks found in each reach. The computations were made with a variety of "*n*" values and discharges, and assumptions of subcritical and supercritical flow, until the computed profile matched the high-water mark profile. The cross sections ranged from about 9 ft apart to a maximum of about 30 ft apart. Cross-section widths ranged from about 24 ft for the Bronco Creek reach to about 45 ft for the Bronco Wash reach. The resulting discharge estimates are: Bronco Wash, 8,500 ft^3/s; Greenwood Wash, 3,900 ft^3/s; and Bronco Creek, 14,100 ft^3/s. The total discharge ranged from 26,500 to 30,000 ft^3/s and is considered an upper limit by the investigators.

Hjalmarson and Phillips (1996) used translatory wave theory to estimate discharge for the 1971 Bronco Creek flood in Arizona and the 1974 Eldorado Canyon flood in Nevada. Both basins have steep-gradient, alluvial channels and both have produced extraordinarily high peak discharges. Eyewitness reports of the Bronco Creek flood document a wave extending bank-to-bank about every 4 to 5 minutes. Waves 1,200 to 1,500 ft upstream of the bridge would take from 30 to 45 seconds to reach the bridge. The largest of these waves were 4–5 ft high. There is speculation that these waves deposited the high-water marks used to define the profiles used for the slope-area computation and represented only a transitory peak stage. This phenomenon has been documented in steep, rectangular channels by other investigators (for example, Holmes, 1936), usually where the channel gradient begins to flatten.

Possible sources of error: There are several sources of error in slope-area indirect flow measurements in steep-gradient alluvial channels, particularly for "flashflood" type events. Because of the instability of the bed, it is difficult to know the geometry of the cross sections at the time of the peak discharge or whether the sand was transport like a conveyor belt with minimal net change in cross-sectional area. It is also difficult to estimate what bed forms were present during the peak making assignments of roughness coefficients more difficult than usual.

For the Bronco Creek flood, even the high-water mark data that were used to develop the high-water profile is questionable because of the eyewitness report of bank-to-bank waves. There is speculation that wave crests, reported to be "100 percent" higher than the water surface, deposited the marks. The flow probably contained a high sediment concentration.

Sources of error associated with the contracted-opening (critical-depth) computation at the bridge primarily are due to unknown bed scour during the peak discharge. The bridge does not appear to provide much of a contraction. The hydrometeorologic analysis is burdened with the complexity of no precipitation data in the basin. Errors associated with transporting precipitation intensity data from outside the basin probably are much greater for convection storms than for area-wide storms. There is some evidence from the eyewitness reports of the flood peak at the U.S. Highway 93 bridge that indicates the intense rainfall may have lasted longer than originally thought.

The step-backwater analyses of stable reaches in the three branches of the Bronco Creek drainage were run through reaches as short as 45 ft. Step-backwater analysis does not have much sensitivity when applied to such short reaches of channel; however, for the critical-depth method, this reach length may be sufficient. When analyzing tributary flow, it is always difficult to know if each tributary peaked at the same time. The channel has a steep gradient and is alluvial upstream of the selected reaches so non-Newtonian flow is a possibility, but there is no evidence of a debris flow. The eyewitness account of bank-to-bank waves prompted an analysis of the flood using translatory wave theory. Flow probably was unstable or waves would not have developed. These kinds of flow instabilities need further work because they likely occurred in several of the floods reported herein. This is especially important because guidance in USGS documents about how to handle waves in peak discharge determinations is ambiguous (Benson and Dalrymple, 1967; Rantz, 1982).

Recommendations of what could have been done differently: Given a good reach with good high-water marks, the first approach would still be to make a slope-area measurement. Consultation with the best river mechanics and hydraulics professionals should have been part of the review process as soon as the original computation resulted in an unreasonably high unit discharge. If this team approach had been used, methods such as those of House and Pearthree (1995) might have been done earlier when more and better high-flow evidence was available. The USGS Arizona Water Science Center did a good job of trying to verify peak discharge with flow estimates at the bridge, for individual subbasins, and by using translatory wave theory.

Site visit and review: The site was visited on August 27, 2003, by John Costa (USGS Office of Surface Water), Terry Kenney (USGS Utah Water Science Center), Kenneth Wahl and Gary Gallino (USGS retired), and Kyle House (Nevada Bureau of Mines and Geology). The review team discussed the differences in the peak flow estimates. They agreed that there probably was a base peak flow represented by the House and Pearthree (1995) computations and roughly verified by the individual basin estimates by the USGS. They also agreed that it is difficult to refute the eyewitness account of large waves moving through the slope-area reach. These waves, and the high-water mark evidence, support an estimate of a high instantaneous peak flow with a low volume.

Recommendations: Qualify peak flow as representing two kinds of peak discharges—a base flood peak related to the runoff from the rainfall and a much larger instantaneous peak discharge related to large translatory waves caused by instability in the floodwater.

Eyewitness accounts verify a base floodflow with periodic bank-to-bank waves superposed on the surface of the flow. Estimates of the base (steady) floodflow range from about 28,000 to 38,000 ft^3/s. This peak is associated with the rainfall-runoff and would produce a unit discharge of 1,470–2,000 $(ft^3/s)/mi^2$. The instantaneous peak should be reported as 96,800 ft^3/s as computed by Hjalmarson and Phillips (1997) using wave theory—a discharge that was caused by the steep channel and erodible bed material. Both peaks should be rated as an estimate.

Figure A179. View looking downstream at cross section 1, Bronco Creek near Wikieup, Arizona, August 1971.

Figure A180. View looking upstream toward slope-area reach from U.S. Highway 93 bridge. Bronco Creek near Wikieup, Arizona, August 2003.

Figure A181. View from right bank to left bank near cross section 1, Bronco Creek near Wikieup, Arizona, August 2003.

Figure A182. View toward right bank at cross section 1, Bronco Creek near Wikieup, Arizona, August 2003.

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