An Assessment of the Paleoflood Hydrology Methodology: Analysis of the 1993 Flood on Tonto Creek, Central Arizona

by
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Abstract

The flood of January 8, 1993 is the largest flood preserved in the paleoflood record for Tonto Creek, and probably was the largest flood in the past three hundred years on Tonto Creek. Deposits left by the flood provided an opportunity to calibrate the results of the previous paleoflood analysis of Tonto Creek completed by O'Connor and others, 1986). In addition, these deposits afforded a rare opportunity to test some of the basic assumptions of the paleoflood methodology, which has been applied on a variety of streams throughout the world.

Hydraulic modeling of the largest 1993 flood indicates that a peak discharge of about 1500 cubic meters per second (cms) (50,000 cfs) occurred on Tonto Creek at the study reach. Comparison of peak discharge estimates based on various of types of flood deposits left by 1993 floods indicates that peak discharge estimates based on slackwater sediment elevations alone underestimate maximum flood peaks by about 30 percent relative to peak discharge estimates based on flotsam elevations (House and others, 1995). The 325 year paleoflood record preserved in the study reach indicates that the largest peak discharges on Tonto Creek have occurred since 1941, the period of record of the USGS stream gage on Tonto Creek. Therefore, paleoflood data were used only to extend the length of record. Comparison of the historical peak discharge estimates at the paleoflood study reach and published gage estimates reveal a significant discrepancy between estimated flood magnitudes that cannot be explained by hydrologic routing or watershed area. The peak discharges gauged by the USGS and the length of record established by paleoflood data were used in the MAX program, a threshold exceedance statistical analysis model (Stedinger, 1988), to estimate a 100-year flood magnitude of about 1800 cms (63,000 cfs) at the USGS gage site on Tonto Creek.

The results of the Tonto Creek study are similar to the results of paleoflood assessments of the Salt River and Verde River previously completed for the Salt River Project (CH2M HILL, 1994; House and others, 1995). That is, except in the most ideal environments for slackwater sediment preservation, paleoflood discharge estimates based on slackwater sediments alone may be underestimated by about 30 percent.
Introduction

The January 8, 1993 flood was probably the peak discharge on Tonto Creek in the past three hundred years. Deposits left by the flood provided an opportunity to calibrate the results of the previous paleoflood analysis of Tonto Creek. In addition, the flood deposits afforded an opportunity to further test some of the basic assumptions of the paleoflood methodology, which has been applied on a variety of streams throughout the world. This report summarizes the results of an investigation of the 1993 flood deposits on Tonto Creek.

This report complements paleoflood studies previously prepared for the Salt River Project for the Salt River and Verde River (CH2M HILL, 1994; House and others, 1995).

Paleoflood Methodology

Paleoflood hydrology studies have been completed for rivers throughout the American Southwest (cf. Ely, 1992) and in semiarid climates worldwide (cf. Enzel and others, 1993; Baker and others, 1988). Paleoflood estimates have been used by various federal, state, and local agencies, as well as private organizations to calibrate hydrologic modeling, reconstruct flood flows, extend stream gage records, investigate dam safety, and evaluate anomalous indirect flood estimates.

The paleoflood reconstruction method used in this study employs flood deposits such as slackwater sediments (SWD) and other paleostage indicators (PSI) to estimate minimum water surface elevations of the floods which left the SWD or PSI deposits. Slackwater sediments are silt and sand material transported in high-velocity floodwater that settle out of suspension in areas of ineffective, low-velocity flow. Typical ineffective flow areas that favor SWD sedimentation include back-flooded tributary mouths, channel margins upstream of severe channel constrictions, and densely vegetated broad overbank areas. PSI include scour lines, flood debris, flood damaged vegetation, and flood related plant distributions (Hupp, 1988; O'Connor and others, 1986).

Flood stage estimates derived from SWD-PSI elevations within a stream reach can then be compared to water surface profiles generated from hydraulic modeling of the reach. Many previous SWD-PSI studies have used the U.S. Army Corps of Engineers computer step-backwater model HEC-2, to develop water surface profiles (Hydraulic Engineering Center, 1985). A range of discharges are used in the hydraulic model; the discharge that produces water surface elevations which best match SWD-PSI elevation is assumed to be the minimum discharge that could have emplaced the flood deposit under consideration (O'Connor and Webb, 1988).

In some cases, numerical and relative age estimates can be assigned to paleoflood deposits. Numerical ages may be obtained from organic material entrained in flood sediments, which can be dated using radiocarbon ($^{14}$C) radiometric dating techniques (Baker and others, 1985; Ely and others, 1992). Age estimates can also be obtained from soil characteristics or soil profile development (cf. Gile and others, 1981), dendrochronology from damaged trees, or
stratigraphic relationships between flood deposits (Baker, 1987). Estimated ages for specific flood deposits can be used to develop a flood chronology, from which flood frequency estimates can be derived. Baker and others (1988), O’Connor and Webb (1988), Partridge (1985), and Ely (1985) provide more detailed descriptions of the SWD-PSI technique.

Assumptions. The SWD-PSI technique has several inherent assumptions, including:

(1) Predictable Hydraulics. Flood hydraulics can be adequately modeled using a step-backwater analysis. That is, flow is steady (discharge constant), gradually varied (depth and velocity vary gradually between cross section), one-dimensional (flow lines are parallel and turbulence can be accounted for by energy loss coefficients), and slope is small (<10%).

(2) Rigid Channel Geometry. Cross section geometry is stable. That is, no significant scour or fill of the channel bed and banks occurs during the flood, and the surveyed channel dimensions are essentially the same as the channel dimensions at the time SWD-PSI were emplaced (may be 1000's of years).

(3) "N" Values. Stream roughness can be reasonably estimated. That is, the flood channel and overbank roughness values are similar to conditions at the time of analysis, and roughness values can be adequately estimated at each cross section from field conditions.

(4) SWD Elevation vs. Peak Stage. Slackwater deposits approximate peak flood stage. That is, the elevation of slackwater deposits are close to, if not equal to the maximum water surface elevation achieved by the flood. Also, slackwater deposits and other PSI left by the same flood will plot close to the same water surface profile. SWD elevations are assumed to represent minimum water surface elevations.

This study examines assumption #4 in detail, and provides some information regarding assumption #1.

Previous Studies. The SWD-PSI technique has been applied to many streams in the Lower Colorado Basin (cf. Enzel and others, 1993; Ely and others, 1993). Previous studies prepared for the Salt River Project have included the following:

- Tonto Creek. O’Connor and others (1986);
- Verde River. Ely (1985), O’Connor and others (1986), CH2M HILL (1994); House and others (1995);

The previous paleoflood study of Tonto Creek relied primarily on SWD to estimate paleoflood magnitudes. Other PSI were noted in the previous study, but they were not been reliably matched with SWD. Therefore, the possible relationship between various types of PSI,
including SWD could not be established for specific floods. For this study, because the flood deposits were examined soon after the flood, a more definitive relationship between the different types of PSI could be established. The stream reach examined for this study was a portion of the reach analyzed by O'Connor and others (1986).

**Study Objectives**

This study had three objectives:

- **1993 Flood Peak Estimate.** Estimate the peak flood magnitude of the January 1993 flood based on the SWD-PSI found at each site.

- **Relative PSI Accuracy.** A range of discharges that matched each type of PSI was determined, and the magnitude relative to available PSI was estimated.

- **Paleoflood-Based Flood Frequency.** The effect of adding paleoflood data to statistical flood frequency analyses was assessed.

This study focused on the 1993 flood deposits at a site on Tonto Creek. The study site was located on Tonto Creek near Gisela, immediately downstream of the Rye Creek confluence. The scope of this study included four main objectives:

- Field Studies;
- Hydraulic Analysis;
- Hydrologic Analyses; application of the MAX flood frequency program;
- Final Report.

Field studies included reconnaissance of the study site, topographic survey of 1993 flood deposits and channel geometry, and description of flood deposits. Hydraulic analyses included HEC-2 modeling of the study reach to estimate the discharge rates/water surface profiles that best fit elevations of SWD and PSI, and to estimate potential error in peak flow rate estimates based on SWD alone. Flood-frequency analyses were conducted using the MAX computer program (Stedinger, 1988) to determine the effect of including SWD-based discharge estimates and paleoflood record length on flood frequency estimates (e.g., the 100-year flood) based on stream gage data. Discharge estimates based on the HEC-2 modeling results were also compared to discharge estimates made at the USGS gage on Tonto Creek, which is located less than 2 miles downstream.
Description of Study Area

The Tonto Creek study site (Figure 1) is located within a small canyon cut into the Sierra Ancha range, approximately 45 km upstream of Roosevelt Lake. The study reach is located about six miles downstream of the Town of Gisela, and about three miles upstream of a USGS stream gage (Tonto Creek above Gun Creek) that has been in operation since 1941. There are no significant tributaries located between the study reach (1,666 km$^2$; 651 mi$^2$) and the USGS stream gage (1,728 km$^2$; 675 mi$^2$). The study reach consists of the middle portion of the 425 m (1400 ft) reach analyzed by O'Connor and others (1986).

The canyon ranges in width from about 55 to 80 m (180 to 270 feet). Canyon expansion areas form backwater or reverse currents, and have slackwater deposit sequences up to 4 m thick. Mesquite and salt cedar grow on the tops and sides of the silty sand slackwater accumulations. Vegetation on the canyon walls include Sonoran desert species such as saguaro, hedgehog, and prickly pear cacti, and brushy trees such as palo verde and creosote.

The study reach consisted of eight cross sections within a straight 250-m-long bedrock canyon reach. The canyon walls are steep to nearly vertical, and are composed of strongly deformed Precambrian metamorphic rocks and Tertiary-aged alluvial deposits found locally on the north side of the study reach. The canyon bottom and stream bed is composed of a pool and riffle sequence with a average slope of about 0.3 percent (0.003 m/m). Pool reaches typically have gravel and coarse sand bed material; riffles are comprised of cobbles and small to medium boulders. The active channel nearly fills the canyon bottom area, with some low flow channel bars at the base of the canyon walls. Bedrock crops out at several places along the canyon bottom, so canyon bottom alluvium is probably quite thin.

Additional SWD-PSI from the 1993 floods also were collected at a narrow bedrock constriction located about 300 m upstream of the slackwater study reach. The constriction consists of a 30-m-wide gap in a bedrock wall immediately downstream from a 250-m-wide floodplain. PSI observed on the constriction walls indicated that the constriction was not completely overtopped during the 1993 event, and therefore may be used to reconstruct flood hydraulics using critical depth relationships.

USGS stream gage records on Tonto Creek extend to 1941 (Tonto Creek above Gun Creek). Flood peaks reported for the gaging station on Tonto Creek are summarized in Table 1 and Figure 2. Flood peak estimates from the previous paleoflood study are summarized in Table 2. Flood recurrence intervals predicted by the USGS from stream gage records are summarized in Table 3.
Figure 1. Tonto Creek Study Site Location
Annual Flood Series: Tonto Creek

Figure 2. Reported flood peaks for the gage below Gun Creek on Tonto Creek
### Table 1

**Tonto Creek above Gun Creek, Reported Flood Peaks over 40,000 cfs**

<table>
<thead>
<tr>
<th>Year</th>
<th>Discharge (cms)</th>
<th>Discharge (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 18, 1952</td>
<td>1,297</td>
<td>45,400</td>
</tr>
<tr>
<td>December 22, 1965</td>
<td>1,277</td>
<td>44,700</td>
</tr>
<tr>
<td>September 5, 1970</td>
<td>1,514</td>
<td>53,000</td>
</tr>
<tr>
<td>March 2, 1978</td>
<td>1,634</td>
<td>57,200</td>
</tr>
<tr>
<td>February 15, 1980</td>
<td>1,754</td>
<td>61,400</td>
</tr>
<tr>
<td>December 24, 1984</td>
<td>1,237</td>
<td>43,300</td>
</tr>
<tr>
<td>January 9, 1993</td>
<td>2,071</td>
<td>72,500</td>
</tr>
</tbody>
</table>

1 Source: USGS, 1991
2 USGS, 1993

### Table 2

**Tonto Creek Paleoflood Estimates of Historical and Prehistoric Floods**

<table>
<thead>
<tr>
<th>Year</th>
<th>Discharge(^1) (cms)</th>
<th>Source of Discharge Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; ca. 1670 A.D.</td>
<td>715(^2)</td>
<td>O'Connor and others (1986)</td>
</tr>
<tr>
<td>1980</td>
<td>1,000 - Slackwater Technique, 1,754 - USGS Gage Data</td>
<td>O'Connor and others (1986), Garrett &amp; Gellenbeck (1991)</td>
</tr>
</tbody>
</table>

\(^1\) Paleoflood discharges from O'Connor and others not adjusted upward using SWD factor determined by this study.
\(^2\) Four to five events older than ca. 1670 A.D. and below the 25,000 cfs threshold are recorded in the SWD deposits.

### Table 3

**Tonto Creek**

**USGS Flood Recurrence Interval Estimates**

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Discharge (cms and cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1,717 60,100</td>
</tr>
<tr>
<td>50</td>
<td>2,260 79,100</td>
</tr>
<tr>
<td>100</td>
<td>2,886 101,000</td>
</tr>
</tbody>
</table>

Source: Garrett & Gellenbeck, 1991 (does not include 1993 event)
1993 Flood Deposits. 1993 flood deposits at the Tonto Creek site consisted of SWD, trimlines, and flotsam (Figure 3). SWD were draped over pre-existing slackwater deposits, and were identified by the lack of seasonal vegetation rooted in the sediment, an unconformable relation to vegetation rooted in lower deposits, and an overall fresh appearance. Abundant flotsam from 1993 was readily identified by its fresh appearance, and its elevation relative to SWD and other PSI. A trimline visible in several locations was identified and correlated to the 1993 flotsam at several locations. The channel characteristics were generally similar to conditions observed during the 1986 survey and paleoflood analysis.

Methodology

Technical methodologies employed for this study included the SWD-PSI technique outlined in the Introduction section earlier in this report, and threshold exceedance statistical analysis described below.

SWD-PSI Technique. The basic SWD-PSI methodology was applied with minor modifications to the Tonto Creek study area. This methodology is described in more detail in reports previously submitted to the Salt River Project (Partridge, 1985; Ely, 1985; O'Connor and others, 1986; Fuller, 1986). Application of the methodology to the study sites was refined by employing the following:

• Cross Section Location. Channel cross sections were surveyed at constricted portions of the canyon, rather than at expansions and embayments, to eliminate ineffective flow areas from hydraulic modeling.¹

• The hydraulically most simple portions of the O'Connor and others study site was chosen to maximize accuracy of HEC-2 modeling.

• SWD-PSI Points. SWD-PSI were surveyed between, as well as on cross section transects to maximize the number of data points available from which to match water surface profiles.

• SWD-PSI Profiles. Water surface profiles were matched to each type of PSI found and surveyed in the reach, as well as to SWD elevations.

• Calibration. HEC-2 calibration runs were used to test the sensitivity of water surface profiles to Mannings' n values (0.5 to 1.5 times chosen n), starting water surface elevation, starting water surface elevation method (slope-area, critical depth), flow regime (sub- and supercritical).

¹ Because HEC-2 assumes one-dimensional flow, a horizontal water surface elevation, and uniform velocity with channel segments, areas of ineffective flow should be deleted from the hydraulic model. Ineffective flow areas include backwater areas, eddies, and other zones where the principal flow direction is not oriented parallel to the channel centerline (or close).
Flood Frequency Analysis. The results of hydraulic reconstructions of the 1993 floods on Tonto Creek based on SWD-PSI data were used to prepare a flood frequency analyses using the Stedinger and others (1986) methodology. Stedinger and others (1986) previously prepared an analysis of the Salt-Verde River system for the Salt River Project, but did not consider Tonto Creek. Stedinger’s methodology uses an application of maximum likelihood techniques in the statistical analysis of both the gauged (systematic) and paleoflood (categorical) data. Categorical data is defined as data defined by the number of occurrences or non-occurrences above specific magnitude thresholds over specified amounts of time. These statistical techniques have proven to be superior in extracting information from compound data sets compared to the weighted moments technique recommended by the United States Water Resources Council Bulletin 17b (1982) (Stedinger and Baker, 1987; Lane, 1987, Condie and Lee, 1982).

The maximum likelihood approach is so named because it maximizes the agreement between the fitted distribution and what has actually been observed or recorded. That is, it maximizes the likelihood of observing what is believed to have occurred. The statistical details of this approach and its application to paleoflood data are provided by Stedinger and Cohn (1986), and Stedinger and others (1986).

Data analysis was performed using the computer program MAX (Stedinger and others, 1988) which facilitates the rapid analysis of compound data sets using maximum likelihood techniques. For the Tonto Creek study, the following approach was used for the MAX application: (1) annual peak discharges from the USGS gage record (1941-1995) were used without any correction factor, (2) an upper threshold of 70,000 cfs was used so that the 1993 event was the only exceedance, and (3) the length of record was based on a 14C date obtained from a basal unit of a SWD reported by O’Connor and others (1986). No paleoflood discharge magnitudes were used in the MAX analysis because none of the paleoflood discharges reported by O’Connor and others (1986) were larger than the largest gauged floods and therefore were below the highest threshold.

Three MAX modeling scenarios were considered. First, a 325 year length of record was used, based on the maximum potential age of the 14C date reported by O’Connor and others (1986). Second, the 325 year length of record was retained, but only the upper 30 percent of the flood series was fitted to the Log Pearson III distribution. Censoring the lower 70 percent of the data (i.e., the more frequent events) is appropriate for estimating the parameters of low-frequency events which may represent separate flood populations. This censoring approach was also applied in the previous SRP flood frequency analysis by Stedinger and others (1986). The third modeling scenario, assumed an arbitrary record length of 100 years, to test the sensitivity to record length based on the 14C date. The latter scenario was performed with no data censoring because censoring the data did not result in an optimal solution.
Results

1993 Discharge Estimates. Peak discharges for 1993 floods were estimated by comparing water surface profiles generated by HEC-2 modeling to the elevations of various types of SWD-PSI. Plots of a range of water surface profiles for Tonto Creek are shown in Figure 4. A certain degree of scatter is to be expected when comparing HEC-2 generated water surface profiles to surveyed elevations of SWD-PSI. Therefore, judgment is used to select the profile which best fits the elevations of each type of SWD-PSI and peak discharge estimates are reported as a range of discharges (Table 4). The lower value in the range represents the minimum reasonable fit of the data to a water surface profile. The upper value in the range of discharges represents the maximum reasonable discharge for the conditions modeled.

Estimates of 1993 peak flow rates based on HEC-2 modeling of the study reaches and different types of PSI are summarized in Table 4. By comparison, the discharge estimate made by the USGS for the January 8, 1993 flood on Tonto Creek is 2,071 cms (72,500 cfs) (Smith and others, 1994). Plots of water surface profiles and PSI's are shown in Figure 4.

<table>
<thead>
<tr>
<th>Site</th>
<th>Slackwater Profile</th>
<th>Flotsam Profile</th>
<th>Constriction</th>
<th>USGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonto Creek</td>
<td>850 - 1,000</td>
<td>1,285 - 1,430</td>
<td>1,430</td>
<td>2,071</td>
</tr>
<tr>
<td></td>
<td>30,000 - 35,000</td>
<td>45,000 - 50,000</td>
<td>50,000</td>
<td>72,500</td>
</tr>
</tbody>
</table>

Discharge estimates based solely on SWD are about 52 percent lower than the preliminary USGS flood peak estimates. SWD flood estimates were about 30 percent lower than flood estimates based on the more ephemeral flotsam and trimline PSI. Therefore, an adjustment factor of about 30 percent (1.3x) may be appropriate for Tonto Creek SWD-based paleoflood estimates reported by O’Connor and others (1986), based on comparison with PSI observed from the 1993 flood.  

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2 The Tonto Creek gage is located about three miles downstream of the study, but the drainage area is only about 24 square miles larger. The USGS estimate is rated as "fair."

3 The adjustment factor could be as high as 43%, since some flotsam elevations were as much as 43% higher than corresponding slackwater deposits.
Figure 4. HEC2 Profiles and SWD PSI Elevations
Evaluation of SWD-PSI Stages

Slackwater sediments generally are preserved at elevations substantially below PSI such as flotsam and trimlines. However, at ideal preservation sites on the Salt and Verde Rivers, 1993 SWD elevations were very close to 1993 flotsam and trimline elevations (House and others, 1995). Slackwater deposition areas on Tonto Creek were not ideal, and may have contributed to the greater difference between types of high-water marks. Table 5 shows the average relative relationship between the three types of flood deposits in the study reach (the elevation distance between types of PSI at a single location). The "top" of the SWD listed in Table 5 is a point on the main surface of the slackwater deposit. The "edge," by contrast, is the point where the SWD intersects the canyon wall, and was found to be higher in elevation, but not well preserved. Exposure of this "edge" of the SWD to slope wash and other weathering processes does not make it conducive to long-term preservation.

In general, the results shown in Table 5 indicate that if SWD sites are not carefully chosen and are not ideal sites for deposition and preservation, paleoflood estimates can be low. On average, surfaces of massive, thick slackwater sediment deposits, the most lasting of the types of PSI evidence, were about one to five feet lower than flotsam and trimline flood deposits.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Relative Elevations of PSI at the Tonto Creek Sites (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI Type</td>
<td>Relative Elevation</td>
</tr>
<tr>
<td>Slackwater Sediment</td>
<td>Top</td>
</tr>
<tr>
<td></td>
<td>Edge</td>
</tr>
<tr>
<td>Flotsam</td>
<td>+ 1 m</td>
</tr>
<tr>
<td>Trimline</td>
<td>+ 1.6 m</td>
</tr>
</tbody>
</table>

1 Based on a single data point.

Hydrologic Analysis

Flood Frequency Analysis. The Tonto Creek hydrologic data includes a 54 year period of record of gauged discharges, and a maximum known paleoflood record of about 325 years. The maximum ungauged paleoflood discharge estimated was about 715 cms⁴ (O'Connor and others, 1984: Table 6), a threshold which has been exceeded at least 13 times in the past 54 years, according to the USGS Tonto Creek gage record. Therefore, the best use of paleoflood information from the study site was to extend the length of record. Discharge magnitudes from

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⁴ Not adjusted for PSI vs. SWD factor estimated by this study.
the USGS gage record were used for the frequency analysis. The results of application of the MAX program to the modeling scenarios described above are summarized in Table 6.

<table>
<thead>
<tr>
<th>Case #</th>
<th>Q2</th>
<th>Q50</th>
<th>Q100</th>
<th>Q200</th>
<th>Q500</th>
<th>Q1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14,300</td>
<td>58,000</td>
<td>63,200</td>
<td>67,300</td>
<td>71,600</td>
<td>74,100</td>
</tr>
<tr>
<td>2</td>
<td>16,200</td>
<td>57,600</td>
<td>63,200</td>
<td>67,900</td>
<td>73,200</td>
<td>76,300</td>
</tr>
<tr>
<td>3</td>
<td>14,300</td>
<td>62,000</td>
<td>68,300</td>
<td>73,600</td>
<td>79,000</td>
<td>82,600</td>
</tr>
<tr>
<td>USGS Frequency</td>
<td>11,200</td>
<td>79,100</td>
<td>101,000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

As shown in Table 6, flood frequency discharge estimates based on application of the MAX program statistical procedures and including paleoflood data are significantly different than USGS estimates based on a shorter period of record. Comparison of case #2 and case #3 in Table show that the effect of censoring is not profound.

**Conclusions**

Based on the results of this study, 1993 peak flow rates and 100-year discharge rates can be estimated, as shown in Table 7. These data indicate that Tonto Creek experienced a flood with a recurrence interval between a 25- and 50-year event at the study site. By comparison, the USGS gage estimate of 72,500 cfs would be about a 200- to 500-year event using the results of the MAX flood frequency analysis, but only a 25- to 50-year event using the USGS flood frequency analysis.

<table>
<thead>
<tr>
<th>River</th>
<th>1993 Peak Discharge (cms/cfs)</th>
<th>100-Year Discharge (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonto Creek</td>
<td>1,430 / 50,000</td>
<td>63,200</td>
</tr>
</tbody>
</table>

Also, it can be concluded that use of SWD rather than more ephemeral PSI results in underpredicting peak discharge rates by about 30 percent, with stages underestimated by 1 to 1.5 m. This conclusion supports the relationship found between types of SWD-PSI and
estimated flood magnitude in the studies of the 1993 floods on the Salt River and Verde River (House and others, 1995).

Data in Table 8 shows the relative magnitudes of predicted peak flow rates for Tonto Creek estimated by other methods. The 100-year discharge predicted from the MAX program and SWD-PSI yield significantly lower flood estimates than many other empirical or hydrologic methods.

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Tonto Creek (cms/efs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993 Peak Discharge: This Study</td>
<td>1,430 / 50,000</td>
</tr>
<tr>
<td>1993 Peak Discharge: USGS</td>
<td>2,070 / 72,500</td>
</tr>
<tr>
<td>Q100: This Study</td>
<td>1,820 / 63,200</td>
</tr>
<tr>
<td>Q100: USGS</td>
<td>2,890 / 101,000</td>
</tr>
<tr>
<td>USGS (1994) Q100 Regression Equation</td>
<td>1,380 / 48,300</td>
</tr>
<tr>
<td>Roeske’s Equation (Q100)</td>
<td>2,400 / 84,000</td>
</tr>
<tr>
<td>Malvick’s Maximum Expected Flood¹</td>
<td>2,720 / 95,000</td>
</tr>
<tr>
<td>Maximum flood from regional envelope</td>
<td>3,150 / 110,000</td>
</tr>
</tbody>
</table>

¹ From O’Connor and others, 1986

Other conclusions that may be reached as a result of this investigation include the following:

- The 1993 event probably was the largest flood in the past 325+ years. SWD-PSI from the 1993 event was found well above all the slackwater deposits observed in and near the study reach.

- The results of this study suggest that the USGS gage estimate for the 1993 flood may be too high, given the very small difference in drainage area, and the similarity of peak discharge estimates based on HEC-2 modeling of the study reach and the discharge estimate at the constriction upstream of the HEC-2 modeling reach. This conclusion supports the findings of O’Connor and others (1986) regarding possible inaccuracies in the USGS gage estimates.
References Cited


Approximate Location of Constriction

EXPLANATION:
- LOW FLOW CHANNEL
- CANYON WALL
- SLACKWATER-SEDIMENT ACCUMULATION
- TC-1 STUDY SITE

View looking upstream
March 11, 1994

Figure 3. Tonto Creek Study Reach
Approximate Location of Constriction

Approximate 1995 Study Limits

ExPLANATION:
- LOW FLOW CHANNEL
- CANYON WALL
- SLACKWATER-SEDIMENT ACCUMULATION
- TC-1 STUDY SITE

View looking upstream
March 11, 1994

Figure 3. Tonto Creek Study Reach
EXPLANATION:

- LOW FLOW CHANNEL
- CANYON WALL
- SLACKWATER-SEDIMENT ACCUMULATION
- TC-1 STUDY SITE

Approximate Location of Constriction

Approximate 1995 Study Limits

View looking upstream
March 11, 1994

Figure 3. Tonto Creek Study Reach