Hydrology and Geomorphology of the Santa Maria and Big Sandy Rivers and Burro Creek, Western Arizona

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EXECUTIVE SUMMARY

This report provides hydrologic and geomorphic information to aid in the evaluation of the navigability of the Big Sandy River, Santa Maria River, and Burro Creek. These streams flow through rugged mountainous terrain of Mohave, Yavapai, and La Paz counties in western Arizona and join to form the Bill Williams River at what is now Alamo Dam and Reservoir. The rivers reflect a diversity of channel patterns, and include the mainly wide and braided sandy alluvial channels of the Big Sandy River, the narrow bouldery channels in bedrock canyons of Burro Creek, and a mix of bedrock canyons and wide alluvial channels on the Santa Maria River.

Although none of these tributaries has an abundant water supply, the relative surface-water flow of each river does vary. For most of its length, Burro Creek contains water that flows year round or is relegated to discontinuous pools during the dry portions of the year. The Big Sandy River maintains perennial flow along some portions of its length and is fed by upper watershed perennial streams such as Trout Creek. The Santa Maria is the driest of all three rivers, with most of its surface-water flow produced by tributaries in the upper watershed and in the main channel for 10-15 miles near its mouth. Low flow discharge measurements of each river are generally less than 10 cfs. Flood events are dramatic in comparison. Historical peak flow estimates for these rivers have been estimated at 68,700 cubic feet per second (cfs) (2/9/93) for the Big Sandy River, 47,400 cfs (2/14/80) for Burro Creek, and 23,100 cfs (3/1/78) for the Santa Maria River. The largest flow events have occurred during the winter months when meteorological conditions cause a series of storms to pass through the region, frequently generating multiple floods within a given year. All three rivers in many cases record the same flood events, reflecting the regional extent of the storms.

Substantial channel changes have occurred along the alluvial reaches of these rivers in the past 100 years. Most channel changes have occurred during large floods. Channel changes typically have involved erosion of stream terraces and tributary fans around outside bends, removal of vegetation within the channel, and in some cases, channel widening. Analysis of channel change spans the 20th century. Based on historical accounts, dramatic channel changes occurred around the turn of the century; based on interpretation of aerial photographs of the rivers, dramatic channel changes also occurred during floods from 1978 to 1995.
INTRODUCTION

This report summarizes the geomorphology and hydrology of the three principal tributary streams of the Bill Williams River in western Arizona. The Bill Williams River basin drains most of west-central Arizona, straddling Mohave, Yavapai and La Paz counties (Figure 1). The principal tributaries of the Bill Williams are Big Sandy River, which heads east of Kingman, and Santa Maria River, which heads near Hillside. These tributaries join to form the Bill Williams River at what is now Alamo Lake. Burro Creek is the largest tributary of Big Sandy River, entering south of Wikieup.

The rugged terrain of the Bill Williams River basin has limited human habitation to a few small towns and land development to irrigation agriculture and ranching mainly in the Big Sandy Valley and along the Bill Williams. Although the area was host to many mines which sought gold, silver, copper, and other associated minerals, the rugged terrain and limited water resources in the area impeded the development of large-scale enterprises. A notable exception is the Bagdad copper mine in the Santa Maria River drainage basin. Thus, for the most part, this area remains a remote location in Arizona.

Purpose and Scope

This section provides hydrologic and geologic information to aid in the determination of navigable versus non-navigable status for the major tributaries of the Bill Williams River in western Arizona. It begins with a brief introduction to the geology, climate, and physiography of the region. Hydrologic information is the focus of the paragraphs which follow introductory information and includes the history of stream gages within the basin and analysis of their surface water records. Selected floods from this century are discussed in some detail in order to understand the meteorology and hydrology of the largest flows in the gage record. Pre-gage historical documents and paleoflood records provide additional information on the hydrologic behavior of the Bill Williams River basin. Following the hydrologic discussions, channel characteristics are described as well as channel changes that may have occurred within the last century. Because of the extensive length of each river, specific reaches were selected and studied using aerial photographs, topographic maps, and general land office surveys from the early 1900’s. Appendices include a list of contacts, rating curves for primary stream gages, and photo documentation of river reaches.

Acknowledgments

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Geologic Setting

The Bill Williams River basin is located in the Basin and Range and Transition Zone geologic provinces in west-central Arizona. The Basin and Range province extends from the Snake River Plain in Idaho through southern Arizona and into Mexico. The Basin and Range province is characterized by generally north-trending mountain ranges (Spencer and Reynolds, 1989) which are separated by basins formed by normal faulting along mountain fronts. In southern and western Arizona, basins are deep, well-defined grabens which trend north to northeast, and have fairly regular
Figure 1. Location of the Big Sandy and Santa Maria rivers and Burro Creek in western Arizona.
spacings of 25 to 50 km (Menges and Pearthree, 1989). The Big Sandy Valley is the most prominent basin in the study area and is composed of basin fill over 3000 ft in depth (Davidson, 1973). The Transition Zone is the rugged, mountainous country between the Basin and Range and the Colorado Plateau. It has geologic and physiographic characteristics that are transitional between the highly deformed Basin and Range and the relatively undeformed, fairly high Colorado Plateau to the northeast.

The geology of the Bill Williams River basin reflects the complex history of the Basin and Range province, with several periods of magmatism and overprinting of compressional and extensional terranes in the past 80 million years. A period of wide-reaching magmatism and crustal shortening associated with the Laramide orogeny occurred in middle to late Cretaceous to early Tertiary period, about 80 to 60 million years ago. This same area was extended in the middle Tertiary between about 20 and 10 million years ago, forming major low-angle normal faults trending east-northeast-west-southwest. Large amounts of extension occurred in the area south and west of the Big Sandy - Santa Maria confluence, resulting in the exposure of rocks in the Buckskin, Rawhide, and Harquavar mountains that were buried beneath many miles of rock prior to the period of extension. Lesser amounts of middle Tertiary extension occurred in the Transition Zone to the northeast. As a result of this extension, the region experienced a reversal of surface drainage direction from north-flowing to south-flowing streams as the extended part of the crust subsided. Relatively modest late Tertiary extension in an east-west to east-southeast-west-northwest direction was accommodated by higher-angle normal faults (Zoback and others, 1981). The change in extension direction and style in the late Tertiary was accompanied by magmatic composition changes from primarily silicic to intermediate volcanism to predominantly basaltic volcanism.

Sediments that filled the structural basins formed by regional extension can be grouped into upper and lower basin fill, and Quaternary deposits. Lower basin fill ranges in age from middle to late Miocene, was deposited as normal faulting continued, and has a thickness of at least 3,000 ft in the Big Sandy Valley. Upper basin fill is as much as 300 ft thick and was deposited in the waning stages of deformation during the Pliocene and early Quaternary. Pedimentation along mountain fronts was begun in this period and continued into the middle Quaternary along with the deposition of thin coarse-grained fans. Through the Quaternary, alluvial fans and terraces have been deposited, modified, and eroded through processes which are for the most part driven by climate changes. The oldest and highest alluvial fans in the Big Sandy Valley occur in the upper watershed of Tule Wash and are about 200 ft thick. The bedrock mountains and alluvial basins have continued to be dissected during the Pliocene and Quaternary as regional drainage systems have continued to downcut. Sediments from coalescing drainages, deposited in the floodplains and streams of the study area, usually amount to no more than 40 ft in thickness (Menges and Pearthree, 1989; Davidson, 1973).

**Physiography**

Most of the Bill Williams River basin is in the Basin and Range province and the rugged Transition Zone along the margin of the high elevation Colorado Plateau (Figure 2). The Big Sandy River basin has a total relief of 7297 ft and an area of ~2810 mi² (House, 1997), which includes 687 mi² (Markman, 1996) of the Burro Creek watershed. The Big Sandy River begins at the confluence of Knight and Trout creeks in the Pilgrim Wash Quadrangle and flows south through Big Sandy Valley, then...
Figure 2. USGS 7.5’ topographic quadrangles covering the study area and active stream gages. These tributaries of the Bill Williams River flow south to the confluence of the Big Sandy and Santa Maria rivers, where they combine to form the Bill Williams River.
cuts through the mountainous terrain of Greenwood Peak, Signal Mountain, Ararastra Mountain, and Artillery Peak to its mouth, where it converges with the Santa Maria River. It has a main channel gradient of 0.008 (Garrett and Gellenbeck, 1991) above the gaging station 17 miles south of Wikieup; other calculated gradients include 0.011 north of Cane Springs Wash and 0.006 in the southern portion of Big Sandy Valley (Davidson, 1973). Burro Creek heads in western Yavapai county between the Mohon and Santa Maria Mountains near the Luis Maria Baca Float No. 5, flows southwest through Bozarth Mesa and the rugged terrain of the Poachie Range, and joins the Big Sandy River approximately 12 miles south of Wikieup. Total relief from its source to its mouth is 5979 ft. Selected stream reaches located below the confluence with Boulder Creek and an 11-mile-long stretch that begins 15 miles above the confluence with the Big Sandy River, have gradients of 0.006 (Markman, 1996). The Santa Maria River heads in the Santa Maria Mountains near the Luis Maria Baca Float No. 5 and has a watershed area of 1520 mi² (House, 1997). It has a gradient of 0.009 above the gaging station near Bagdad and a lower gradient of 0.008 (Garrett and Gellenbeck, 1991) upstream from the gaging station near Alamo, which includes a gradual alluvial reach downstream from the Bagdad gage. From its source, the drainage flows to the southwest past Grayback Mountain and Ives Peak and turns to the west to meet the Big Sandy River near Alamo. With the highest elevation in the watershed at 7626 ft in the headwaters of Kirkland Creek subbasin, and the lowest on the order of 1120 ft at its confluence with the Big Sandy, the Santa Maria River watershed has a total relief of 6506 ft.

Climate
The climate of the Bill Williams River basin is semi-arid to arid. Temperature and precipitation values as well as dominant vegetation vary substantially within the basin, with pinyon-juniper woodlands in the mountain ranges and cacti and riparian species in the intervening valleys. Average January temperatures range from 35° to 45° F at higher elevations to 45°-50° F at lower elevations. Average July temperatures range from 65°-75° F at higher elevations to 80°-90° F at lower elevations in the watershed (Sellers and Hill, 1974).

Precipitation also varies considerably within the Bill Williams River basin. Annual precipitation is generally between 10 and 15 inches for valleys and low elevations, dropping as low as 6 inches near the mouth of Bill Williams River (United States Army, Office of the Chief Engineer, 1944), and 15-20 inches in the mountainous high-elevation areas (Sellers and Hill, 1974).

Precipitation falls mainly in summer and winter rainy seasons. Summer rains occur primarily during the afternoons and evenings in July and August and also in some valleys between 6 and 9 am. Summer storms are for the most part generated by convection, in which moisture from the Pacific Ocean and the Gulf of Mexico encounters heated mountainous terrain, which causes the air to increase in temperature and rise. These unstable air masses lead to high intensity rainstorms of short duration often accompanied by thunder, lightning, and strong winds (Sellers and Hill, 1974).

Dissipating tropical storms from the eastern Pacific occasionally bring heavy precipitation to portions of western Arizona during the late summer and early fall. For these storms to cross Arizona, the jet stream is rerouted to the northeast and commonly interacts with a cutoff low or low pressure trough (House, 1997). The largest floods recorded at the Santa Maria River gage near Alamo occurred in the late summer and early fall during the 1939, 1951 and 1964 water years. In his investigations in western Arizona, House
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(1997) found that large late summer and early fall floods occurred in 1939 and 1951, as well as 1970 and 1976. It is not possible to know if the gage on the Santa Maria River near Alamo also experienced large floods during 1970 and 1976 as it was discontinued in 1966.

In the upper Bill Williams River basin, stream gages have recorded high peak flows in the late summer-early fall months that presumably resulted from dissipating tropical storm precipitation events. Their magnitudes are smaller in comparison to winter flood events at the same gages, however. The largest flood of this type was 15,200 cfs recorded at the Santa Maria River gage near Bagdad on September 24, 1983; this discharge is among the top ten largest floods recorded at this gage. Large flows were also recorded on this date at Burro Creek (11,900 cfs) and Big Sandy River near Wikieup (12,900 cfs).

Although winter rains are generally lighter and longer lasting than summer rains, unusual meteorological phenomena may bring abundant precipitation across the Bill Williams River basin during the winter months. These storms result from the westward displacement of the ridge of high pressure in the Pacific Ocean and the formation of a semi-permanent low-pressure trough over the western United States. In this situation, storms tend to move south along the west coast instead of through Washington and Oregon. They then travel east from the coast through California and Arizona. Usually this storm track may produce precipitation in Arizona for a couple of days and continue to the east; this pattern tends to recur and may produce several precipitation events within a short time interval. However, if the high-pressure system in the north becomes especially well developed, the low pressure cell tends to become isolated from the track and may stagnate and intensify off the coast. By the time the storm reaches Arizona, it is fully developed and capable of producing large-magnitude events. In fact, when the flood records of large drainages of western and central Arizona are analyzed, it is almost always the case that the largest floods on record have occurred during the winter season (House and Hirschboeck, 1997).

This subsection summarizes various aspects of the hydrology of the Big Sandy and Santa Maria rivers and Burro Creek. I briefly discuss reaches with perennial flow on each of these streams, summarize historical flow records, and discuss in more detail the genesis of a few of the largest floods that have occurred in this drainage system.

Areas of Perennial Flow

The Big Sandy, Santa Maria Rivers, and Burro Creek all have perennial reaches along their lengths (Figure 3). In this report, a reach is perennial if it usually flows year round; however, some reaches included in the perennial category run dry during periods of extreme drought (Brown, et al, 1978). Reaches that are termed perennial by Brown et al (1978) and Freehely and Anderson (1986) are described as having a base flow of less than 10 cfs. In its headwaters, the Big Sandy River is supplied by perennial reaches of Willow Creek and the Trout Creek basin. The main stem perennial reaches stretch from Wikieup downstream to the Burro Creek confluence and from Signal to
Figure 3. Perennial stream reaches in the upper Bill Williams River basin (data from Brown, et al., 1978, and Freethey and Anderson, 1986).
Figure 4. Active and discontinued stream gages in the Bill Williams River basin. Discontinued gages typically have short records from the 1960’s and 1970’s. Exceptions are of the gage on Burro Creek, which records flow through the 1980’s, and the Santa Maria gage near Alamo, which began in 1939 and was discontinued when Alamo Dam was completed and a new gaging station was established upstream.
Alamo Lake. The Whipple expedition, which traveled through this area during 1853 and 1854, described the Big Sandy as having a water source which sinks and rises in the sandy channel along the length of the river (Foreman, 1941). Perennial flow in the Wikieup reach averaged 2.52 cfs from 21 miscellaneous measurements taken between 1959 and 1964 (Davidson, 1973). Burro Creek is perennial along most of its length with the exception of the reach near U.S. Route 93 bridge crossing. Tributaries of Burro Creek that are perennial include sections of Francis Creek, Boulder Creek, and Pine Creek. The reaches in these tributaries are all located within the first five miles upstream of the river mouth. The Santa Maria River basin has perennial reaches in the headwater tributaries of Cottonwood, Smith, and Sycamore creeks. The main stem Santa Maria is perennial approximately 5 miles above and below Bridle Creek, and 5 to 10 miles upstream from Alamo Lake. Portions of Kirkland Creek and Date Creek also flow year round.

### Surface Water Records

Gage History. Stream flow volumes were first recorded in 1939 in the Bill Williams River basin, beginning with stream gages on the Bill Williams River and Santa Maria River near Alamo, Arizona (Figure 4; Table 1). These gages evolved as Alamo Dam near Alamo, AZ was proposed and built, and Alamo Lake

### Table 1. List of stream gages of the Bill Williams River Basin above Alamo Dam.

<table>
<thead>
<tr>
<th>Stream Gage Name</th>
<th>Number</th>
<th>Drainage area (mi²)</th>
<th>Period of Record (water year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Sandy River near Wikieup, AZ</td>
<td>09424450</td>
<td>2,742</td>
<td>1966-</td>
</tr>
<tr>
<td>Bill Williams River below Alamo Dam**</td>
<td>09426000</td>
<td>4,633</td>
<td>1939-</td>
</tr>
<tr>
<td>Santa Maria River near Bagdad, AZ</td>
<td>09424900</td>
<td>1,129</td>
<td>1966-85; 1988-</td>
</tr>
<tr>
<td><strong>Discontinued gages</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santa Maria River near Alamo, AZ</td>
<td>09425500</td>
<td>1,439</td>
<td>1939-93</td>
</tr>
<tr>
<td>Burro Creek near Old U.S. 93 Bridge</td>
<td>09424447</td>
<td>611</td>
<td>1980-93</td>
</tr>
<tr>
<td>Francis Creek near Bagdad, AZ*</td>
<td>09424432</td>
<td>134</td>
<td>1985-93</td>
</tr>
<tr>
<td>Kirkland Creek near Kirkland, AZ</td>
<td>09424470</td>
<td>109</td>
<td>1973-83</td>
</tr>
<tr>
<td>Big Sandy River Tributary near Kingman, AZ</td>
<td>09424410</td>
<td>2</td>
<td>1963-78</td>
</tr>
<tr>
<td>Kaiser Spring Tributary near Wikieup, AZ</td>
<td>09424430</td>
<td>1.7</td>
<td>1963-78</td>
</tr>
<tr>
<td>Iron Spring Wash Tributary near Bagdad, AZ</td>
<td>09424470</td>
<td>0.64</td>
<td>1964-79</td>
</tr>
<tr>
<td>Ash Creek near Kirkland, AZ</td>
<td>09424480</td>
<td>7</td>
<td>1960-78</td>
</tr>
<tr>
<td>Cottonwood Wash No. 1 near Kingman, AZ</td>
<td>09424200</td>
<td>143</td>
<td>1964-78</td>
</tr>
<tr>
<td>Date Creek near Congress, AZ</td>
<td>09425000</td>
<td>127</td>
<td>1939-43</td>
</tr>
</tbody>
</table>

*operated only as a low flow station prior to 1988 water year

**published as “Williams River near Alamo” prior to October 1943; published as “Bill Williams River near Alamo” from October 1943 to September 1967
developed behind it. The gage near Alamo on the Santa Maria was discontinued in 1966 because it was within the area of Alamo Lake; it was replaced by a new gage located about 10 miles upstream (Santa Maria near Bagdad gage). The USGS first began measuring streamflow on the Big Sandy River and Burro Creek in 1966 and 1980, respectively, but they discontinued the Burro Creek station following the 1993 water year. Stream gages were also installed on a number of tributaries to the Big Sandy, Santa Maria and Burro Creek; however, these gages were short-lived and mainly record stream flow from the early 1960’s to the late 1970’s. Active stations in the Bill Williams River basin upstream from Alamo Dam include the Big Sandy River near Wikieup, AZ, Santa Maria River near Bagdad, AZ, and the Bill Williams River below Alamo Dam.

Pre-gage Flood Records. Gage records give a picture of the past 60 years, at best; other accounts of pre-gage late 19th century to early 20th century flooding suggest that this was a wet period with many floods, some of which probably exceeded the floods in the gage record. Years that have been noted to have large floods on the Bill Williams River include 1884, 1891, 1905, 1906, 1910, 1911, 1915, 1916, 1920, 1923, 1927, 1930, 1931, 1932, 1937, 1938, and 1939. Although the magnitudes of these most of these floods are not known, indirect estimates were made for the largest of these, which include the flood of February 1891 estimated at 200,000 cfs and January 1916 at 185,000 cfs. This is in contrast to the largest recorded discharge measurement of 92,500 cfs which was made on February 7, 1937 at the Bill Williams River near Alamo (United States Army, Office of the Chief Engineer, 1944). Historic accounts of this period by Irene Cornwall Cofer who lived in the Big Sandy Valley at the turn of the century relate that prior to the 1880’s, the Big Sandy River channel was narrow, allowing for wide agricultural fields, orchards, and ranch houses. Many of these properties were washed away during floods in the 1880’s and early 1900’s. Cofer describes her experience of one of these floods on New Year’s Eve, 1908:

“The first really big flood that I saw in the Sandy River; one that cleaned the trees and brush from the river bottom and took cottonwood trees from the banks that were perhaps a hundred years old and tossed them end over end like they were two by fours.” [Cofer 1969:76]

Paleoflood Records. Paleoflood hydrology is an interdisciplinary approach used to study historic and prehistoric records of floods in river systems around the globe and is applicable to a wide range of scientific topics and practical problems. By extending the flood record beyond a relatively short historical data set, geologists are able to extract more representative samples of the largest floods for flood frequency analysis and to address long-term issues such as aggradation and degradation in the fluvial system, as well as flood-climate linkages for a particular region. The method produces results that are very useful and needed in urban planning, flood control procedures, and reservoir operation (Stedinger and Cohn, 1986; Hereford, et al., 1996; Graf, et al., 1991; Patton, 1977; Costa, 1978; Macklin, et al., 1992).

The slackwater deposit-paleostage indicator (SWD-PSI) technique in paleoflood hydrology allows for indirect discharge measurements following a flood by using features which record the height of the flood waters (Baker, 1987; Kochel and Baker, 1982; Patton, et al., 1979). Slackwater deposits are fine-grained deposits, typically composed of silt and sand, which accumulate in backwater zones where reduced velocities allow fine particles to fall from suspension. Reaches most conducive for preserving slackwater deposits include those that have fixed channel boundaries and features which initiate flow separation, such as alcoves, channel constrictions,
minor tributary mouths, or bedrock obstructions. Paleostage indicators include all other high water marks such as flotsam piles and mats, scour lines, non-exceedance indicators, water stains on trees and bedrock, and tree scars.

The Bill Williams River basin has not been extensively studied from a paleoflood perspective, although a paleoflood project is currently underway in this basin (House, oral communication, 1998). Ely (1992) studied selected paleoflood sites along the Bill Williams River, Big Sandy River and Burro Creek in order to extract regional information about variations in large-flood frequency in Arizona and southern Utah within the past 5000 years and their relation to long-term meteorological patterns and other paleoclimatic indicators. Ely’s Big Sandy River paleoflood site is located 9 miles downstream from the confluence with Burro Creek at 34°27′14″ N, 113°37′33″ W, and is composed of 3 inset stacks of deposits, the highest of which is covered by mesquite trees. Although a radiocarbon date from this uppermost deposit suggests that the entire package of floods is relatively young, the lack of flood evidence on the top surface indicates that the highest extent of deposits had not been overtopped in the historic period prior to 1992 and thus that larger floods than those measured historically have occurred. Ely’s paleoflood site at Burro Creek near Andy’s Hole (34°32′43″ N, 113°29′14″ W) is similarly young, with 5 or 6 flood deposits preserved.

Hydrologic data

Mean daily flow series. The magnitudes of mean daily flow values fluctuate seasonally and annually on rivers in the Bill Williams River basin. The largest flow volumes occur during the winter (December through March) and early fall (August through September) and arrive in the form of floods as well as sustained high flow for periods of days. The driest periods for these rivers occur during early summer (June and July) and late fall (October and November), in which flow may cease or drop to a few cfs.

The three rivers in this study exhibit records of daily flow values that differ in magnitude and seasonal variability according to the hydrologic characteristics of each river. The Big Sandy River near Wikieup, supported by a shallow aquifer in the Big Sandy Valley alluvium as well as several springs in the area, continues to flow year round. Daily flow values are generally less than 10 cfs during the drier months; wetter months have slightly higher daily flow values and sharp flood peaks during storms. No flow days (i.e., days which no flow is recorded) have not occurred at this particular gage, meaning that this reach of the Big Sandy River is consistently perennial. Burro Creek experienced sustained flow for most of the gage period of 1984-1993, although many times flow was less than 1 cfs during the dry months of the year. During some years, however, especially in the late 1980’s and early 1990’s, no flow days were recorded. These totaled 388 out of 4922 days in the gage record; in other words, approximately 8% of the total gage record measured mean daily flow values of 0 cfs. The Santa Maria at the gage near Bagdad has experienced seasonal variability similar to the Big Sandy River and Burro Creek, but there is a greater difference in magnitude between high flow periods and low flow periods during the year. For example, 7,112 of 10,393 or 68% of daily flow values have been no flow days on the Santa Maria River. Thus, the Santa Maria River in its upper reaches is more sensitive to fluctuations in precipitation, whereas the other gage locations discussed above have alternate ground water sources that sustain flow during the drier portions of the year.

The Santa Maria River near Alamo, located near the river’s mouth, had a strikingly
Figure 5. Mean annual flow at the USGS stream gage on Big Sandy River near Wikieup, Arizona.

Figure 6. Mean annual flow at the USGS stream gage on Burro Creek at Old U.S. 93 Bridge.
different record than the gage upstream. Only 1.6% of the gage near Alamo record is composed of no flow days compared to 68% at the gage near Bagdad. While this gage does record a completely separate time interval than the upstream gage, the difference in records is almost certainly due to the change of location on the river rather than a change in the overall hydrology of the system. The larger drainage area above the gage near Alamo may contribute to the larger peak discharge values recorded there. The maximum peak discharge recorded near Alamo (August 29, 1951) is approximately 10,000 cfs greater than any peak discharge recorded more recently at the upstream gage. The two gage records also differ markedly in the seasonality of the largest floods. The largest floods at Alamo (1939-65) occurred during the late summer-early fall, while those floods which dominate the Bagdad record (1966-present) occurred during the winter months. Based on the time of year in which they occurred, the late summer-early fall floods were generated by summer monsoonal storms or dissipating tropical storms. Hydrologic data for the Santa Cruz River in southern Arizona exhibit a somewhat similar trend (Webb and Betancourt, 1992). From 1930-59, the Santa Cruz flood record is dominated by summer monsoonal floods, none of which were very large, while the record from 1960-86 is dominated by fall and winter floods caused by dissipating tropical storms and regional winter storms. Webb and Betancourt point to a trend in meteorological phenomena, in which an increased number of dissipating tropical storms are brought into the southwestern United States during ENSO (El Nino-Southern Oscillation) conditions (Webb and Betancourt, 1992). On the Santa Maria River, only one large winter flood occurred between 1939 and 1965 (3/14/41). A number of dissipating tropical storms generated floods during this interval, however, including the largest flood of the gage record (8/29/51).

Mean annual flow series. The mean annual flow series, the arithmetic average of mean daily flow values for each year in the period of record, is best used to identify high flow and low flow years on record for a given gage. The Big Sandy River near Wikieup experienced its record high flow year in 1993, which includes the flood of record (68,700 cfs, 2/9/93) and a number of other large flood peaks during the winter of 1992-93 (Figure 5). The record low flow year for the gage was in 1996, when its largest flow value amounted to 275 cfs on 9/9/96. For Burro Creek, the record high flow year was again 1993 with the flood of record estimated at 55,300 cfs on February 8, 1993 (Figure 6). The record low flow year for Burro Creek was 1987, which had a peak discharge of 565 cfs on 3/5/87. The Big Sandy gage also recorded a low flow year in 1987. On the Santa Maria River, the record low flow year occurred in 1956 at the Santa Maria River near Alamo, in which mean annual discharge measured 2 cfs and the peak flow value measured 107 cfs (Figure 7). The record high flow year occurred in 1941, in which multiple flood peaks through the winter contributed to a high mean discharge for the given water year. The largest peak of this year measured 20,600 cfs on 3/14/41. The Santa Maria River near Bagdad experienced comparable high flow years in 1979 and 1980, both of which included a number of flood peaks during the winter months (Figure 8). The record low flow year for this gage was 1996, in which the gage recorded no flow during the entire year.

Annual flood series. Annual flood series of the Bill Williams tributaries represent the maximum peak flow volume for each year of record which have occurred during the last 50 years at each USGS gaging station (Figures 9-12). Years of extreme flooding on the rivers in the study area, with record flows and multiple large floods during winter months include 1978, 1980 and 1993, among others. Figure 13
Figure 7. Mean annual flow at the former USGS stream gage on the Santa Maria River near Alamo, Arizona.

Figure 8. Mean annual flow at the current USGS stream gage on the Santa Maria River near Bagdad, Arizona.
Figure 9. Annual flood series for the USGS stream gage on the Big Sandy River near Wikieup, Arizona.

Figure 10. Annual flood series for the USGS stream gage on Burro Creek at Old U.S. 93 Bridge, Arizona.
Figure 11. Annual flood series for the former USGS stream gage on the Santa Maria River near Alamo, Arizona. The period of record is 1939-1967.

Figure 12. Annual flood series for the USGS stream gage on the Santa Maria River near Bagdad, Arizona. The period of record is 1966-1995.
Figure 13. Peak discharges during 1978, 1980, and 1993. Gages on these streams record multiple flood peaks and are the result of a series of storms during the winter months.

*Flood peaks also occurred at the Big Sandy and Santa Maria stream gages on February 15, 1980; however, they are of unknown magnitude and therefore were not included in the chart.

Figure 14. Precipitation values for the storm of February 27-March 3, 1978.
displays the largest peak flows occurring for the above years on Burro Creek, Big Sandy River and Santa Maria River. Most of these floods appear to have been felt throughout the Bill Williams River basin, since stream gages on all three rivers typically record large flows. For the sake of brevity, only the most extreme event for each year will be discussed in the paragraphs to follow.

**Analysis of Selected Large Floods**

Regional meteorological and hydrological data from storms that have impacted the Bill Williams River basin show similar large-scale mechanisms and basin responses to large-magnitude precipitation events. The largest floods are generated from frontal and convective winter storms occurring in the winter months that carry above-normal amounts of moisture into the southwest. In this region, precipitation is enhanced by orographic effects from the Mogollon Rim, which serves as a barrier to northeastward-moving moist air. The storms are generally characterized by anomalous hydroclimatological conditions, in which a blocking high pressure ridge creates split westerly flow such that a jet stream track occurs further south than normal, and allows moisture to be delivered to the Southwest. This track becomes strengthened as the trough deepens and may become stationary, allowing precipitation to fall over the region for a number of consecutive days. This jet stream condition may occur many times throughout the winter to steer storms over the region. Rapid warming and cooling trends create antecedent conditions conducive to flooding as subsequent storms develop. Some of the antecedent conditions that have been present in the studied floods include: high soil moisture content, above average precipitation preceding the event, and high water content in snow (Aldridge and Eychaner, 1984; Aldridge and Hales, 1984; Chin, et al., 1991; House and Hirshboeck, 1997).

Although gages in the Bill Williams River basin recorded large peaks for several years at each gage, I selected three floods that were recorded as large-magnitude floods that were felt basin-wide.

**Storm of February 27-March 4, 1978.** The storm pattern for 2/27-3/4/78 follows the general scenario outlined above. The winter storm track was displaced further south than it would normally occur and included warming and cooling trends which delivered precipitation during January 15-24 and February 6-16 and increased soil moisture content. Significant antecedent moisture in the form of above average rainfall occurred for many gages in the region. On February 27, a low-pressure trough was situated across Arizona, and brought showers to the Bill Williams River basin; moisture trailing behind a high-pressure ridge continued the precipitation trend. On March 1, warm, moist air from the tropics traveling northeast collided with cold air over Arizona and the mountain fronts of the transition zone, and produced the greatest precipitation of the storm event for the gages in western Arizona. Areas with the largest precipitation totals on March 1st include the Bagdad (3.08 in) and Wikieup (1.91 in) precipitation gages (Figure 14). Total precipitation from February 27-March 4, 1978 for gages in this region range from 3.01 in. at Prescott to 6.51 in. at Bagdad (Aldridge and Eychaner, 1984). Large discharges were recorded on March 1 at stream gages in the basin; a discharge of 36,500 cfs at the Big Sandy River near Wikieup was the third largest in the gage record. A discharge of 23,100 cfs recorded at the Santa Maria River near Bagdad was the peak of record. Peak discharge in Burro Creek is unknown since the gage was not installed until 1980.

**Storm of February 13-21, 1980.** The storm of February 13-21, 1980 was characterized by a
series of six storms, which originated off the coast of California and moved across central Arizona carrying warm moist air from the Pacific. This event was preceded by above average rainfall during the month of January due to the southerly displaced storm track; sizable floods of 19,800 cfs at the Big Sandy and Santa Maria stream gages occurred on January 30, 1980. The result was that the available water holding capacity of the soil was decreased by the time the February storms arrived. High flows were recorded throughout the basin and were reflected in the level of Alamo Lake, which was higher than normal due to prior flood events in 1978 and 1979 (Chin, et al., 1991). The largest flood peak during the storm of February 13-21 occurred on February 14th at the Burro Creek gage and measured 47,400 cfs. The Big Sandy and Santa Maria gages record flood peaks of unknown magnitude on February 15th and estimated at 38,500 and 19,500 cfs, respectively, on the 20th. These peaks rank as the second largest discharges in the gage record of all three tributaries.

Storm of February 7-10, 1993. The general circulation pattern during the winter of 1993 was characterized by the development of a high-pressure area in the eastern North Pacific Ocean that persisted through the winter. This persistent high pressure caused a branching of the polar jet stream and forced the associated Pacific storm tracks further north and south than they would normally occur. This brought greater cyclonic storm activity across the state of Arizona. Sea surface temperatures (SST’s) remained above normal from December 1992 through February 1993 such that warm moist air from the eastern Pacific was delivered to Arizona, increasing rainfall totals during the winter months. Persistence of the large scale circulation anomaly and the repeated occurrence of split westerly flow also acted to increase precipitation above average levels, create antecedent conditions conducive to flooding, and bring frontal passages through the area, initiating alternating cooling and warming trends. Storms occurred during both warm and cool episodes; rainfall was the dominant precipitation type during warm events while some snowpack accumulated at higher elevations during cool events. Four major storms occurred in Arizona during the winter of 1993 that were responsible for flooding in Arizona: (1) January 6-9; (2) January 13-19; (3) February 7-10; (4) February 18-21 (House and Hirshboeck, 1997). Although all four storms produced flood peaks in the Bill Williams River basin, the storm of February 7-10 produced the largest peaks for the 1993 water year and peaks of record for select gages.

Meteorological conditions for this event were such that moisture directed north behind a warm front was quickly followed by a cold front from the west, a scenario which provided abundant precipitation for the flood event. Precipitation ranged from approximately 60 to 80 mm with >80 mm at the highest elevations in the watershed. Flood peaks were produced on February 8-9, 1993 in the Bill Williams River basin. Burro Creek experienced its peak of record on February 8th at 2300 hrs. Burro Creek experienced its peak of record on February 8th at 2300 hrs. Three hours later, the Big Sandy near Wikieup also experienced its peak of record measuring 68,700 cfs on February 9th at 0200 hrs. Santa Maria near Bagdad measured a flow of 15,700 cfs at 0300 hrs, which is the fifth largest discharge on record for this site.
In order to characterize the geomorphology of the channels and document any changes in channel position, I first conducted an aerial photo search for coverage of the Bill Williams River basin through the 20th century. Aerial photo sets that were used included sets from 1953-54, 1963, 1972, 1976, 1978, 1980, 1985, 1987, 1990, 1992 and 1995. Other sources of information include General Land Office Surveys from the early 1900’s and 7.5’ USGS topographic maps (Table 2). Because of the length of the three rivers and the prevalence of canyon reaches that experience negligible channel change over short time periods, I selected specific alluvial reaches to study in detail. Reach selection was based on aerial photo reconnaissance using 1:60,000 Army Map Service (AMS) photos from 1953-54 to identify alluvial reaches which have the potential for channel change and the availability of photos for alluvial reaches. Reaches were then mapped by aerial photo interpretation, delineating active channels, terraces, and older alluvium, and then comparing mapped reaches from different years to identify channel changes. Field checking and ground photos provide additional documentation for recent channel changes.

Channel Characterization

The Big Sandy River, Burro Creek, and Santa Maria River have channel configurations that range from narrow steep-walled canyons to wide alluvial reaches. Confined reaches in canyons typically contain a single channel and have little space for lateral channel migration. Alluvial reaches may also maintain a single primary flow channel; however, secondary channels commonly are used during large magnitude flow events. Some reaches must be characterized as an intermediate type between these two end members, as they are confined within canyon walls relatively close to channel margins but are wide enough such that sedimentation occurs along channel margins and secondary channels can develop. Channel bedload sediments are composed mainly of cobbles, gravel and sand with some boulders, which are transported mainly during flood events. Sand, silt and clay size particles make up the suspended load during flood events.

The Big Sandy River is mainly a wide and braided alluvial system in Big Sandy Valley with incision of less than 20 ft into higher terraces and alluvial surfaces when they are present. In its lower reaches, the river enters into a series of alternating confined and alluvial segments. Confined reaches stretch from Section 25, T15N R13W, to the north side of Burro Peak and through Signal Canyon in the Signal Mountain Quadrangle.

In contrast to the Big Sandy, Burro Creek contains proportionately more confined reaches rather than alluvial reaches. Alluvial reaches that do exist are narrower and more limited in extent than those of the Big Sandy. Alluvial reaches may also contain “bottlenecks”, or abrupt contractions and expansions in channel width. Alluvial reaches include: Happy Hollow Canyon to Salt Creek; Boulder Creek to Six Mile Crossing; U.S. Route 93 bridge crossing; and confluence with Big Sandy River to ~1 mile above that confluence.

The Santa Maria River in its upper reaches exhibits confined narrow canyons and intermediate reaches that are composed of alluvial channels which narrow to bottlenecks in places. The intermediate reaches extend from Quail Spring to sec 25 of T13N R9W and from Santa Maria Ranch to Black Canyon. The lower Santa Maria River, from the gaging station to Alamo Lake, is a wide alluvial reach similar to the Big Sandy River in Big Sandy Valley.
Channel Change

The purpose of this section is to document the nature and magnitude of channel changes that have occurred during the 20th century. For each reach, channels were delineated by aerial photo interpretation and were designated by the prevalence of channel sediment and the absence of thick vegetation. Areas that contained channels with significant vegetation were not designated as the main channel but instead were included as channel bars and overflow areas within the floodplain. Some mid-channel vegetated bars that were between channels are not represented in order to simplify the figures.

Big Sandy River, Burro Creek Confluence to Wikieup. The Big Sandy River from Wikieup to Burro Creek confluence is highly varied in its channel character. On the Wikieup 7 ½’ quadrangle, the channel is wide and braided, but abruptly narrows as it flows south through a narrow canyon with tight bends. The low flow channel in straight reaches of the canyon is moderately sinuous and slightly incised into alluvium; around the bends the channel is wide and shallow and supports wetland vegetation. From its crossing with Signal Canyon road, the Big Sandy River returns to a wide alluvial channel to the confluence with Burro Creek. The greatest potential for channel change lies in alluvial reaches; for this reason as well as photo availability, the reach from Wikieup to its narrowing point serves as an illustration of channel changes that have occurred on this river reach of the Big Sandy. Two subreaches will be discussed: the Wikieup reach is located in the northern half of the Wikieup quadrangle (Figure 15) and the Hopewell Ranch reach is located in the southern half of the Wikieup quadrangle (Figure 16). Data sets used in this study include General Land Office (GLO) cadastral surveys and aerial photos from 1953, 1963, 1978, 1990, and 1995.

Channel changes have been expressed primarily in the form of changes in vegetation.

Table 2. List of aerial photo sources used for this geomorphologic study of the Big Sandy River, Santa Maria River and Burro Creek.

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<tr>
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<tr>
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<td>CLR</td>
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<td>1:4000</td>
<td>CLR/IR</td>
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<tr>
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<td>1:24000</td>
<td>CLR</td>
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<tr>
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<td>1:40000</td>
<td>B/W</td>
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<tr>
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<td>ADOT</td>
<td>1:24000</td>
<td>B/W</td>
<td>ADOT Office, Phoenix</td>
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</tbody>
</table>

B/W = black and white; CLR = color; CLR/IR = color infrared
Figure 15. Historical channel changes on the Big Sandy River, Wikieup reach.

Figure 16. Historical channel changes on the Big Sandy River, Hopewell Ranch reach.
density and channel width and position, presumably in response to flood flows. GLO surveys completed in 1912 and 1917 show a channel markedly different from that of 1953 and later in the historic record. In general, the channel delineated by GLO surveyors was wide compared to later channel patterns of 1953 and 1963 and had greater sinuosity than any later channel documented by aerial photos. This is especially true of the Wikieup study reach. Although GLO survey data is less reliable than photo documentation, channel positions seem reasonable by the following arguments: (1) The greatest bends in the channel occurred at the intersection of the channel with section lines, which should accurately depict channel position. (2) Large floods are known to have occurred in the late 1800’s and early 1900’s. Because surveying followed this interval, it seems reasonable that the channel was wide and sinuous, reflecting the influence of large flows on channel pattern. In fact, according to historic accounts, the late 19th century to early 20th century was a time period in which many channel changes were occurring. Many homesteads that had existed along the Big Sandy River in these reaches and in northern Big Sandy Valley were washed away during the 1880’s and later. Landholdings that are specifically noted include: the Cornwall Ranch (see Figure 16), the Boner Ranch, the Scott Place, and the town of Greenwood (Cofer, 1969). Channel incision of 5-10 ft and channel widening in the Big Sandy River since the 1860’s was also noted by Kam through written communication to Davidson in 1966 (Davidson, 1973). In 1953, multiple low-flow channels existed within the reach and were generally confined to a small portion of the larger channel. Photos from 1963 show an increase in vegetation in portions of active channels of 1953 and abandonment of a right bank meander near Wikieup in the Wikieup reach; generally, flow routes were very similar to that of 1953, but occupied a smaller portion of the channel.

The 1978 photos post-date major floods during the winter of 1977-1978 and reflect changes caused by large flows. Although the channel occupied a similar position to the channel of 1963 deposition on the Big Sandy River floodplain obstructed the pre-flood channel and effectively in many cases, its width changed dramatically, and in some places diverged to flow around vegetated channel bars. In the Wikieup reach, channel widening generally followed the 1963 channels north of Wikieup and reoccupied and accentuated the 1953 meander near Wikeup. South of Wikieup, channel changes occurred in the form of right bank erosion along agricultural fields. Split flow existed downstream of the left bank erosion in which flow occupied the 1963 channel and initiated a new channel that diverged toward the left bank and utilized a road oblique to flow to widen its channel even further. The two channels rejoined approximately ½ mile downstream from their split.

The Hopewell Ranch reach also displays prominent channel changes, the most spectacular of which occurred at the Bronco Creek confluence and downstream from the confluence. On August 19, 1971, Bronco Creek experienced a flood estimated at 26,000 to 30,000 cfs (House and Pearthree, 1995). This flood caused major channel changes in Bronco Creek and deposition of fan material at the junction of Bronco Creek and Big Sandy River. The Bronco Creek fan rerouted it toward the left bank, narrowing the new channel. This change in channel position is reflected in the position of the river channel in 1978 and the direct abutment of the Bronco Creek fan against this new channel. Rerouting toward the left bank was followed downstream by right bank cutting along the agricultural fields of the bridge terrace and erosion on the opposite bank. Downstream of the U.S. Route 93 bridge, right bank cutting occurred, eroding vegetated channel bars and low terraces to bedrock.
Photos from 1990 capture a channel that was very similar to that of 1978 in both width and position. However, the 1990 channel was overall more vegetated and one channel had become dominant over another in areas of split channel flow. For example, the eastern channel was dominant whereas the western channel was semi-vegetated. In the Hopewell Ranch reach, the channel that had eroded agricultural fields to accommodate large flow volumes was heavily vegetated.

In 1995, the channel was reduced in sinuosity and increased in width in the Wikieup reach with noticeable erosion on the outside bends of the main channel, especially along the agricultural fields on the right bank in Wikieup. In the Hopewell Ranch reach, the 1995 channel was actually more sinuous than that of 1978 or 1990; channel width was variable with some reaches being wider and some narrower than previous channel configurations. The most noticeable channel changes occurred upstream of Bronco Creek, where the channel widened and migrated toward the right bank, and in the vicinity of the U.S. Route 93 bridge, where bank erosion is evident along the outside bends and the channel narrows as it flows underneath the highway bridge. The channel bends in this reach are nearly at 90 degree angles. It is most likely that channel differences between 1990 and 1995 aerial photos are largely a result of the floods of 1991 and 1993.

Burro Creek, U.S. 93 Bridge Site. Burro Creek at the U.S. 93 bridge is located in the Kaiser Spring 7 ½’ quadrangle in T14N R11W and is characterized by channel bends with point bars and minor terraces in conjunction with a narrow canyon reach below the 93 bridge. This reach is not perennial but typically contains water for a good portion of the year. The channel itself is characterized by pools and riffles typical of the creek as a whole. Two major tributaries join Burro Creek within this reach; Raster Wash enters upstream of the bridge, while Black Canyon enters downstream. In contrast with the selected reaches on the other rivers, bedrock control affords less potential for channel change. This is especially true in the vicinity of the bridge, where channel position has changed minimally during the 20th century. However, around tight bends in the canyon, channel widening has occurred such that point bars and alluvial terraces have developed. In these reaches the channel has experienced lateral scour during floods which have repeatedly truncated Black Canyon fan and exaggerated meander patterns on Burro Creek upstream of Raster Wash (Reach 1). Reach 1 is the focus of the following paragraphs as it demonstrates the most pronounced channel changes that have occurred within the study site. Aerial photos used to document Reach 1 were taken in 1953, 1963, 1976, 1980, 1990, and 1995. GLO surveys and topographic maps completed in 1980 also provide information on channel position.

Reach 1 is characterized by a meandering channel with low sinuosity issuing from a left bend in upper Burro Creek (Figure 17). Two large terraces (A; B) joined by a narrow strip are located on right bank on the outside bend of the channel meander while smaller terraces occupy the left bank. An overflow channel (C) carved into an alcove curves along the right bank immediately upstream of Raster Wash. In 1953, the channel was positioned centrally in Reach 1, and skirted the left bank at C. Vegetation was sparse in overbank area C, indicating that it must have experienced recent flow. In 1963, the channel appeared very similar. By 1976, however, lateral erosion had begun on the right bank of terraces A and B, with continued use of overflow area C. By 1990, the channel had eroded the right bank to bedrock so that terraces A and B were no longer connected. Left bank terraces downstream were also eroded, though not as dramatically. This effectively routed flow toward the left bank,
Figure 17. Historical channel changes on Burro Creek just upstream of the U.S. Route 93 bridge.
isolating overbank area C and depositing sediment at its opening. Area C also experienced bank cutting along the edge adjacent to the main channel. Low relief bars decreased in vegetation density from 1976, while vegetation in area C increased in density. Reach 1 appears very similar in photos taken in 1995 with minimal reduction in vegetation density at the upper end of the reach. These changes are minimal given the fact that the 1993 flood was the peak of record. Thus, most channel changes occurred between 1976 and 1990, and most likely resulted from the floods of 1978 and 1980.

**Santa Maria River, U.S. 93 Bridge Site.** The Santa Maria River channel at the U.S. 93 bridge is an alluvial reach that issues from a more confined setting in Section 10 T12N R9W and reenters a confined setting downstream of the U.S. 93 bridge in Section 21 T12N R9W. In this reach, the Santa Maria River is bordered by bedrock, Pleistocene terraces greater than 50 ft above the modern channel, Holocene terraces, and active gravel bars. Changes have occurred in both channel position and vegetation density on terraces and bars; a few of these features will be used to highlight areas of change. These include the bridge terrace, located north of and underneath the U.S. 93 bridge on the right bank and the left bank terrace in a minor alcove on the left bank downstream of the bridge (Figure 18). Site A designates the channel upstream of the bridge while site B represents the channel downstream of the bridge. Photo sets used for this analysis include 1953, 1963, 1978, 1990, and 1995.

1953: A single low flow channel was present in area A along the left bank, and split in area B to form two channels which reconnected at the abrupt left bend downstream; low relief bars were not vegetated and appear to have experienced a recent flood event, possibly that of 1951.

1963: Channel configuration was very similar to that of 1953; the low flow channel along the left bank was vegetated on its margins, and additional vegetation had grown on bars.

1978: Channel configuration was very similar to 1963 photos.

1990: Channel in area A remained very similar to past channel positions; however, vegetation along the low flow channel in area B had been partly removed and a new channel cut more abruptly from left to right; vegetation continued to increase on the bridge terrace and terrace A. Multiple channels had developed where previously only two could be defined.

1995: Channel formed in 1990 was vegetated and cross cut by a new low flow channel down the center of the river. The channel on the left bank in area A had become a minor flow path. Bars had become more vegetated since 1990; however, the main channel was very clear of vegetation. In area B, split low flow channels were evident once again.

The Santa Maria River channel upstream from the U.S. 93 Bridge has been relatively stable during the past century, but the downstream reach has experienced channel migration from left to right and morphologies ranging from braided to split flow. Changes that have occurred are reflected in differences in channel position from 1978 to 1995. Channel changes correspond to a time period in which large magnitude floods were recorded on this drainage; these floods were likely responsible for much of the lateral migration and erosion.

**Santa Maria River near Bagdad Gaging Station to Alamo Lake.** The Santa Maria River in its lower reaches is an alluvial channel
Figure 18. Historical channel changes on the Santa Maria River at U.S. Route 93 bridge.
Figure 19. Historical channel changes on the Santa Maria River near Valencia Wash.
Figure 20. Historical channel changes on the Santa Maria River near Date Creek.
comparable in morphology and scale to alluvial reaches of the upper Big Sandy River. Channel widths range from less than ¼ mile at the gage near Bagdad to nearly one mile at its widest in Section 15 T11N R11W. Channel morphology is best described as a braided system with semi-vegetated bars between channels. This section reviews the general channel changes that are evident in this reach and highlights a few areas that show dramatic changes for this photo set. General channel changes include decreases in channel width and increases in sinuosity from 1953 to 1976, and increases in channel width and decreases in sinuosity from 1987 to 1992 (Shafroth, written communication).

Figures 19 and 20 highlight two areas on the Santa Maria alluvial reach that have experienced changes in channel width and sinuosity. The first area is located in the vicinity of Valencia Wash and demonstrates the trend in channel width (Figure 19). In the early 1900’s, surveyors recorded the position of the main channel as they surveyed section lines for the Township and Range grid. Along the west section line of sec 13 T11N R11W, the Santa Maria River was positioned in what is now a semi-vegetated bar. By 1953, channel position remained relatively stable near the gage but had shifted toward the left and right (north and south) of its previous position along the western border of section 13 (Figure 18). In 1953, the active flow area was wide with multiple channels transporting flow. Photos from 1979 show an overflow of sediments onto cultivated land on the right bank immediately downstream of the gage, and abandonment of the southernmost channel upstream of Valencia Wash. In general, channels within the braided system were diminished in size and partly vegetated when compared to those that existed in 1953, while the active channels were less vegetated. By 1992, the channels upstream had widened to incorporate more of the bottomland into the primary flow path, but did not reach the extent of the 1953 flow pattern.

Near Date Creek, channel position differs markedly during the 20th century (Figure 20). In 1917, the main channel as noted by the surveyor was located along the right bank of the Santa Maria River. In 1953, the channel in the vicinity of Date Creek was composed of two channels occupying the left and right banks. Major channel changes are evident on the 1967 topographic base, where the northerly channel is dominant and cuts to the left bank near the mouth of Date Creek. This pattern is accentuated in 1979. By 1987, the dominant channel upstream of Date Creek had shifted to a more central position; continued left bank cutting shifted the channel bend downstream of Date Creek. This trend continued into 1992 and in effect, decreased the sinuosity of this reach.

In summary, the most prominent channel changes occurred from 1953 to 1979, when channel width decreased near Valencia Wash and sinuosity increased near Date Creek, and from 1979 to 1987, when the channel experienced left bank lateral erosion near Date Creek and channel widening near Valencia Wash. The largest floods in the historic record at the Bagdad gage occurred during the winters of 1978, 1980, 1991, and 1993 and seem to be the most obvious catalysts for channel change on the Santa Maria River. Generally, changes on the Santa Maria River took the form of channel widening, increased sinuosity, and decreased vegetation density in response to large floods. Study reaches on the Big Sandy River and Burro Creek show similar records of channel change, both in the type of change and occurrence during periods of large floods.
The Big Sandy River, Santa Maria River, and Burro Creek flow through rugged terrain of some of the most remote lands in Arizona. Although the three rivers do not have abundant water resources, they all contain perennial reaches along their lengths. The Big Sandy River has perennial surface water along some portions of its length and is fed by upper watershed perennial streams such as Trout Creek. Burro Creek maintains perennial surface water along most of its length, which during the driest intervals exists as discontinuous pools of standing water. The Santa Maria is the driest of all three rivers, with most of its surface water supplied by tributaries in the upper watershed and in the main channel for 10-15 miles near its mouth. Low flow discharge measurements of each river are generally less than 10 cfs. Flood events are dramatic in comparison. Peak flow estimates for these rivers are estimated at 68,700 (2/9/93) for the Big Sandy River, 53,300 cfs (2/8/93) for Burro Creek, and 23,100 cfs (3/1/78) for the Santa Maria River. The largest storm events resulted in heavy, basin-wide precipitation events that caused floods of varying magnitudes at all three gages.

Substantial channel changes have occurred in response to large floods during the historical period. Channel changes typically have involved erosion of stream terraces and tributary fans around outside bends, removal of vegetation within the channel, and channel widening. Analysis of channel change spans the 20th century; according to historic accounts, severe channel changes occurred around the turn of the century, when large floods washed away farmlands and the old mining town of Greenwood along the Big Sandy River. The most dramatic channel changes documented by aerial photo interpretation occurred from 1978 to 1995.
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APPENDIX A

Stage-discharge rating curves for USGS stream gages

Figure A1. Composite rating curve for the Big Sandy River near Wikieup, Arizona.

Figure A2. Rating curve for Burro Creek at Old US 93 Bridge, Arizona. rating table 4; start date (time): 9-30-90 (2400)
Figure A3. Rating curve for Santa Maria River near Bagdad, Arizona.
rating table 4; start date/time: 9/30/90 (2400)

Figure A4. Rating curve for Francis Creek near Bagdad, Arizona.
rating table 5; start date (time): 10-01-92 (0001)
APPENDIX B

*Photo documentation of river reaches*

Photographs in this appendix are not a comprehensive set that document river morphology but rather provide a glimpse of selected reaches for each river. The Big Sandy River and Burro Creek photo sets also contain comparative photos, the first photo most likely taken in the early 1960’s and the second in 1998. A photo index describes the location and characteristics for each photo in the following paragraphs.
A historical photo (top) taken by Carlos Elmer, who was active in Mohave County between 1948 and 1975, depicts an autumn flood on the Big Sandy. The lower photo taken in 1998 by J. Klawon illustrates channel morphology of the Big Sandy in low flow conditions. During periods of low flow, the Big Sandy occupies a narrow semi-entrenched channel and is bounded by an extensive floodplain of fine sediments and full-grown trees outside of what is presumably the high flow channel. Extreme events occupy a greater portion of the floodplain; in the Elmer photo, floodwaters are seen inundated even well vegetated portions of the floodplain and dislodging some of this debris to carry downstream.

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Figure B2. Big Sandy River downstream of Trout Creek  
Location: NE ¼ sec 35 T18N R13W

Sandy and gravelly wide alluvial channel with low mid-channel terraces infrequently inundated.

Figure B3. Big Sandy River near Signal  
Location: NW ¼ SE ¼ sec 25 T15N R13W

Entrenched moderately sinuous channel of fine-grained sediment with abundant vegetation along channel margins and filling the channel in some locations.
The high bridge over Burro Creek on U.S. Route 93 was completed sometime between 1963 and 1976. The photograph on the top by Carlos Elmer was most likely that the photo was taken soon after the bridge’s completion; The high flow event shown in this photo narrows the probably dates to August or September of 1963, 64 or 71. The photo on the right was taken in the fall of 1998 by J. Klawon. Comparison between the two photos demonstrates the differences and similarities between high flow and low flow channel patterns. Floodwater occupies 2 channels in the foreground of Elmer’s photo, with the channel along the right bank as the main channel and the channel along the left bank as an overflow channel with a noninundated bar separating the two. Channel configuration in 1998 is very similar with the low flow channel hugging the right bank and a vegetated channel bar on the left. Much of the existing vegetation along the left bank is inundated by the floodwaters of the Elmer photo; generally there is less vegetation in the channel than that of 1998 (note the absence of species on the downstream gravel bar on the left bank). The early photo may have been taken in the waning stages of this particular flood, shown by the evidence of recent flow on the gravel bar to the far right on the photo.

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2 Carlos Elmer, “Low Bridge at Burro Creek.” CP Photographs Collection (CP SPC 214A: 2958), Dept. of Archives and Manuscripts, University Libraries, Arizona State University, Tempe.
The low bridge at Burro Creek was in use as the primary traffic route over Burro Creek for U.S. Route 93 until the completion of the high bridge. After this, the low bridge continued to be maintained and in 1980, a USGS stream gage was installed on its downstream side. Note that this gage can be seen in the 1998 (bottom) photo but not in Elmer’s (top) photo. Possible dates for this photo range from 1948 to 1975; the truck on the bridge appears to be a make and model from the early 1960’s (Ferguson, personal communication). Although channel position in both photos is very similar, vegetation density had decreased from the Elmer’s photo to 1998. Major differences in vegetation occurred in the main channel downstream of the low bridge, and on the left bank low terrace upstream of the bridge.

Carlos Elmer, “Low Bridge at Burro Creek.” CP Photographs Collection (CP SPC 214A: 2958). Dept. of Archives and Manuscripts, University Libraries, Arizona State University, Tempe.
Figure B6. Burro Creek near Big Sandy River confluence
Location: sec 19 T12N R9W
Sandy and gravelly wide alluvial channel with low fine-grained to gravelly Holocene terraces (center of photo) and higher Pleistocene terraces (banks on sides of photo).

Figure B7. Santa Maria River near U.S. Route 93 bridge
Location: NW ¼ NE ¼ sec 22 T12N R9W
This photo was taken looking west-northwest (upstream) from a high Pleistocene terrace on the left bank. The river bends from right to left on the photo around the low terrace of Santa Maria Ranch and turns sharply to the southwest off the bottom of the photo. In this reach, the river channel is composed mainly of sand and gravel with vegetation along channel margins and low terraces. The low flow channel occupied the outside bend of the river in this photo.
The Santa Maria River channel issues from the upstream reach of intermediate width to a wide alluvial braided channel of mainly sands and gravels. The gaging station for the Santa Maria is situated on the bedrock protrusion to the left of the photo. Although it is not evident in this particular photograph, most portions of the alluvial reach from the gage to Alamo Lake contain relatively stable vegetated channel bars.