SAND AND GRAVEL MINING IMPACTS ON LOCAL RIVERS - HISTORICAL DATA REVIEW AND ANALYSIS

Prepared for:

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JULY 13, 2011

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Date Signed 7/13/11
ARIZONA, U.S.A.

Expires 6/30/2013

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OVERVIEW

The purpose of this study is to evaluate the impacts due to the mining of sand and gravel from the major rivers in Maricopa County. This evaluation is designed to review the long term stability of the rivers in an effort to develop mining recommendations for rivers such as the Hassayampa that have not, as yet, been subjected to extensive, large mining operations.

Sand and gravel have been removed from the rivers in the Phoenix area for decades. Mining has become more prominent and important to the local economy as demand for concrete, asphalt, and gravel for roads and other uses have increased. Early in the 20th century – indeed even into the 1960's – a large flood event would readily fill the pits caused by the removal of sand and gravel from the river bed. As the demand increased and equipment became larger, the size of the pits also increased. Today pits are on the order of 40 ft to 60 ft and even 100+ ft deep with some covering several hundred acres. These pits are not readily filled with sediments during flood events and have been observed to cause significant head and tail cuts in their vicinity.

The major rivers in the Phoenix metropolitan area are also controlled by dams and reservoirs upstream from Phoenix which remove the inflow of sediment into the rivers near Phoenix – the notable exceptions being the Gila and the Hassayampa Rivers. The Gila, though dammed upstream by the Coolidge Dam, flows through a long relatively natural stretch but returns to sediment equilibrium prior to reaching the Phoenix area. Both of these rivers currently transport primarily sand in the Phoenix area rather than the gravels and cobbles (and boulders) that are transported in the Salt, Verde, and Agua Fria systems. The Gila is heavily infested with salt cedar just upstream from the Salt River confluence which appears to significantly reduce its sediment transport capacity at the confluence with the Salt River (WEST 2004).

The result of the extensive sand and gravel mining has been the lowering of river beds in the Phoenix area. There are numerous and widely varied estimates of how far the beds of the rivers have lowered over the years. These range from a few feet to estimates in the 40 to 60 ft range. As a result of the various estimates and the impact that the various pits might have if the higher estimates are correct, this study was commissioned to ascertain how much the rivers in Maricopa County have lowered and what impacts can be verified from the mining operations. This study was also designed to determine if channel lowering is due to the impacts of sand and gravel mining or due to some other cause such as the upstream dams on the Salt, Agua Fria, and Verde Rivers.

This effort is an attempt to better understand the long term impacts of mining on rivers in Maricopa County. It anticipated that it will also aid in the preparation of sand and gravel mining guidelines that will protect the rivers and associated infrastructure while encouraging continued sand and gravel mining to the extent the mining does not jeopardize the stability of the rivers and adjacent infrastructure.

DATA COLLECTION AND DISCUSSION

This effort involved the review of data collected in several studies that were previously performed by other consultants in Maricopa County. These include JE Fuller and Associates, WEST Consultants, Boyle Engineering, and others. The primary data source, however, was the Flood Control District of Maricopa County. The 1903 survey data was scanned from the original paper maps and provided by the Salt River Project (SRP) – assistance for which we are extremely grateful. Their data has provided the basis for the study and the absence of the SRP data would make conclusions difficult at best.

A summary of the main data used is listed below and the reference section contains an extensive list of the datasets reviewed for the study. Not all of the data listed in the reference section was actually used in the analysis but is included so the reader and later users of the report have a complete list of the data that was reviewed for this report.

1902-1903 Topographic maps (SRP, 1903) of the lands proposed for inclusion in the SRP project. This data was scanned by SRP and provided to the project by SRP. This data covered the Salt, Gila upstream of the Agua Fria Confluence and most of the Agua Fria River to just north of Union Hills. This data provided a base level comparison of conditions prior to significant mining being undertaken along the Salt and Agua Fria Rivers.

1965 HEC-2 model of the Agua Fria River (USACE 1965). This was provided by the District as a part of a sediment transport study for the Agua Fria River performed by WEST Consultants, Inc. These model data were provided by WEST Consultants (WEST 2002b).

1995 HEC-RAS model of the Agua Fria River (Coe & Van Loo 1995) and associated FEMA work maps were provided by Maricopa County. This model was based on a floodplain study performed by Coe & Van Loo Consultants, Inc

Latest available topographic data for the Salt, Gila and Agua Fria Rivers as well as some earlier data (primarily from the 1980's, 1990's and early 2000's) in digital form. These data allow the comparison with historic data to determine the impacts of mining and other factors over time. Data included topography from numerous aerial surveys of the Salt, Gila and Agua Fria Rivers. The County does have a 10 ft contour data set for the whole county but this data proved to be redundant for most of the area since more detailed mapping was available. The mapping was used for a portion of the Salt River through downtown Phoenix where it was the latest data available.

DISCUSSION OF DATA

Data for the Salt and Gila Rivers were primarily in digital form with the exception of the 1903 SRP data (SRP, 1903) which was provided by SRP as a digital scan of the original maps. The maps were georeferenced to the USGS digital raster data for the Phoenix area. This allowed the direct use of the more recent digital data in a comparison with the historical SRP data.

Salt River

A large number of partial data sets were available for the Salt and Gila Rivers but enough data was available to obtain four fairly complete data sets (including the SRP data) from Granite Reef Dam to the Agua Fria confluence. The mostly complete data sets consist of the following data sets:

1) **Salt River Topographic Data (SRP 1902-03).**

2) **1982-83 (Country Club to 116th Ave) (FCD 1984) combined with 1984 (Country Club to Granite Reef Dam), (Burgess & Niple, 1986).** The data sets for 1982 from Country Club Drive to 116th Avenue (FCD 1982) and for 1984 from Country Club to Granite Reef Dam were obtained from paper or velum map sets in the engineering files of the Flood Control District. These two data sets provide a complete set of coverage for the 1982-84 timeframe. This data set gives good coverage after the 1978, 1979, and 1980 floods on the Salt River. A few data points from the Hayden Road bridge study were also obtained and give data from 1972 for Scottsdale/Rural Rd, Mill Avenue and close enough to McClintock (Hayden) Rd to estimate the elevation at that road crossing.

3) **1990-97 (Recker to Country Club and I-10 to 99th Ave) (and post 1993 flood data (1993 – Country Club to between Mesa and Stapley and between Stapley and Gilbert to past Greenfield and 1997 - Country Club to I-10), (Baker 1991, 1993, 1997)** and

4) **2001 data from Granite Reef Dam to Loop 101 from the Va Shly' Ay Akimel Ecosystem Restoration Project (WEST 2002) combined with data from 2008 from McKellips Road to I-10 (FCD 2008) and a few cross sections near Gilbert Road (Chang 2009).**

The Hayden (McClintock) Road Bridge final design report (CRSS 1980) shows the elevation at the bridge due to a scour hole was 1137 ft. This can be compared with a 1972 elevation of 1155 ft and a final elevation after bridge reconstruction of 1150 ft. This is the only data that shows a lowered elevation at the McClintock Road crossing. All other surveys show the elevation as being similar to that observed in 1903. This lowering was due to the scour hole associated with the old bridge (see the aerial photos for 1969 and 1979 for Scottsdale/Rural Road as shown in Figure 1 and Figure 2). The profile for the reach indicates a bed elevation of approximately 1149 ft. A 12 ft deep change in the minimum bed elevation due to scour is significant but not unexpected at a substantial bridge constriction.

The Baker floodplain study (Michael Baker 1999) also provides a good data set for the entire reach but portions of the river were remapped due to changes that occurred during the 1993 flood. It was hoped that for this analysis the portions that were mapped pre-flood could be separated from the post-flood data to give a better picture of how the river changes during the flood event. The original (pre-1993 flood) data for the areas that were remapped could not be located so the extent of changes due to the 1993 flood alone could not be determined.

Two recent data sets give good coverage for the Salt River from the I-10 bridges to Granite Reef Dam. The Salt River Masterplan data set (FCD 2008) covers the river from I-10 to McKellips Road and the 2001 topography for the Va Shly' Ay Akimel Restoration Project (WEST 2002) covers from the Loop 101 Bridges to Granite Reef Dam.

These four relatively complete data sets described above give a good comparison of the behavior of the Salt River over the last 100 years but most of the data are concentrated within the last 30 years.

Large floods occurred on the Salt River in 1905, 1916, 1919, 1926, 1965-66, 1978, 1980, and 1993. The large floods through at least 1965-66 were likely sufficient to "reset" the river (i.e.fill any pits that had been formed and mostly restore sediment continuity in the river). The ability of the river to fill the pits was due in part to the relatively limited mining that had occurred on the river through about 1970 and due in part to the large supply of sediment in the river upstream from the mined pits. The large floods were also large enough to propagate any head cuts and tail cuts from pits which may have accounted for pier damages at bridges and low water crossings near pits. These earlier flows were also large enough to not only refill the pits but likely drowned out the headcuts caused by the pits in the early to middle stages of the floods. During the 1978 flood, however; damages occurred to the I-10 bridge over the Salt River and this was attributed to the sand and gravel mining both upstream and downstream from the bridge (Boyle 1980).

The Boyle report also cites a study by Aldridge (1970) that describes gravel mining damages from the floods in 1965. During the 1965 flood one pier of the Central Ave bridge failed, and about 1,000 feet of shoulder and one lane of I-10 were washed away in the flood but Aldridge did not lay blame for the damages and indicated that the gravel pits had "been filled" during the flood (p C23). The Boyle (1980) report states that complaints against sand and gravel miners were increasing at the time of their report. The 1981 Boyle Preliminary Design Report for the Hayden Road Bridge cites upstream mining as having impacts on the sediment transport for the Tempe reach of the Salt River.

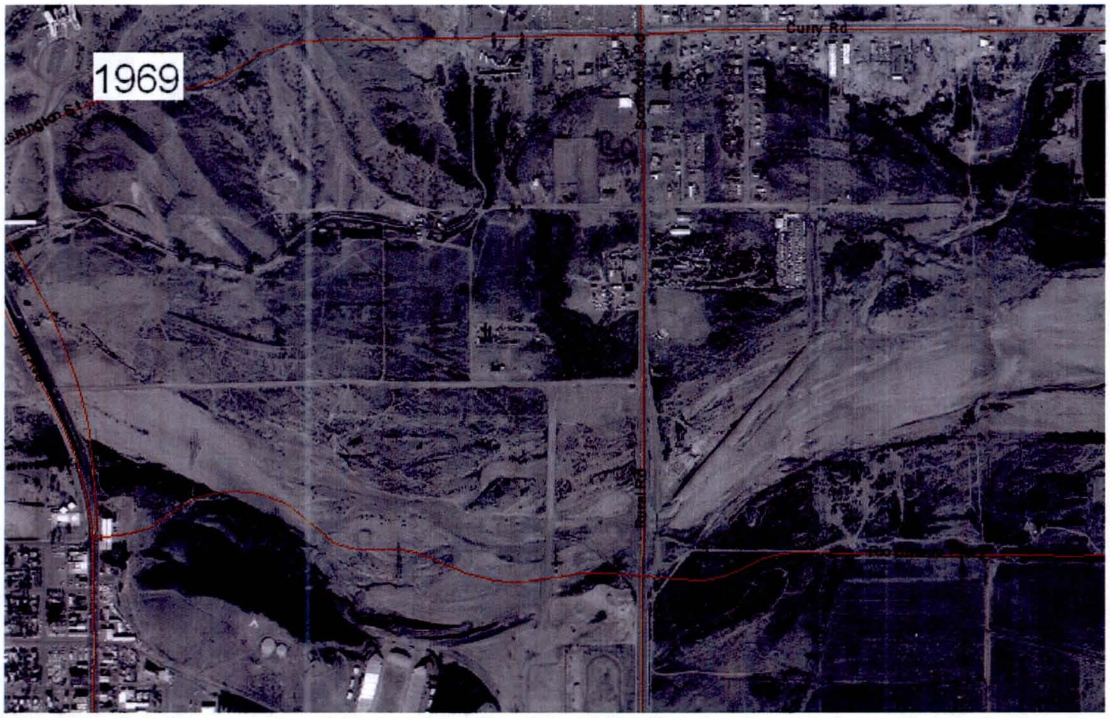

Figure 1. Salt River at Rural (Scottsdale) Road in 1969. Hayden Road is just off right in the photo.

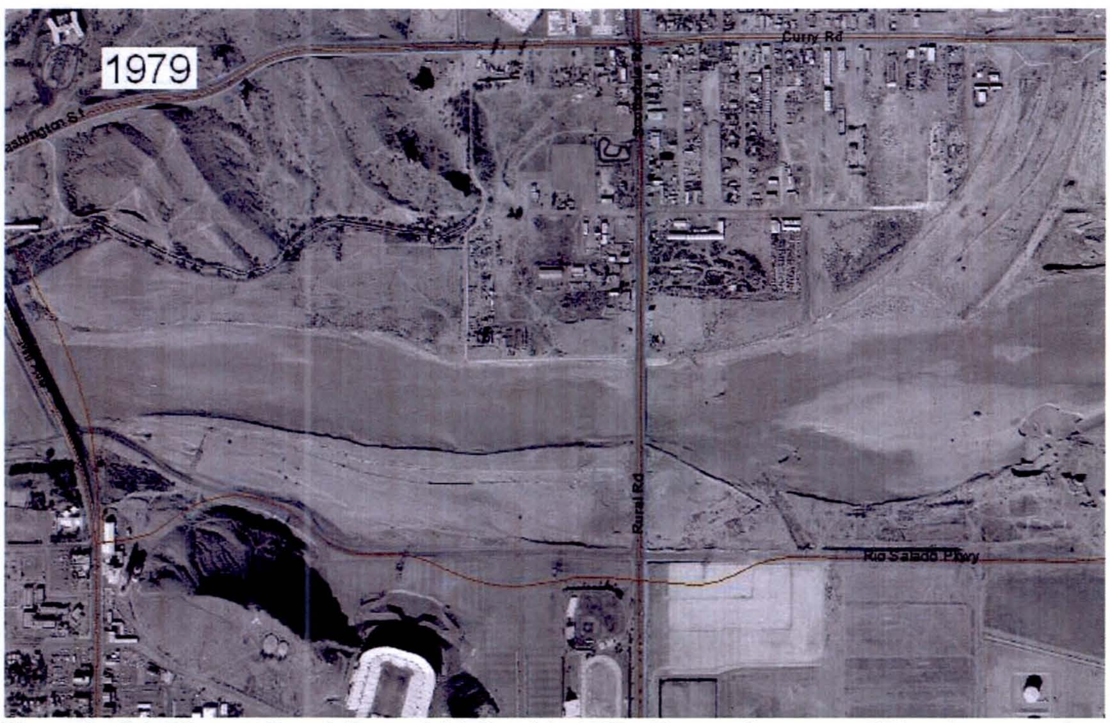

Figure 2. Salt River at Rural (Scottsdale) Road in 1979. Note realignment of River between photos.

Agua Fria River

The data for the Agua Fria River consisted primarily of data from earlier HEC-2 and HEC-RAS studies of the river in addition to the SRP data. This complicated the analysis to some extent and required the referencing the river mile stations (RM) in the models to physical locations on the ground. Three models were available for use in the review. The 1985 model was heavily documented and called out each road or alignment in the model, the 1995 model with the associated floodplain work maps, and the 1975 model which had almost no documentation in the model. The 1985 model documentation missed only one road alignment from Bell Road to the Gila confluence while the 1975 model contained only four bridges and no other references as to the location of cross sections. The report for the 1985 study (USACE 1985) can be found in the FCD library as well but was not needed to identify section line data due to the excellent comments contained in the 1985 HEC-2 model. Available data also included a 1995 model developed by Coe & Van Loo Consultants. This model was updated by WEST (2002b) with new mapping from Bell Road to Cactus Road for and used for both hydraulic and sediment transport modeling.

The 1975 HEC-2 model (USACE 1975) required the most work to determine the location of each road and alignment. Bridge locations in the 1975 model were matched to the 1985 model as a starting point for alignment of the model. The bridges that existed at the time give some reference points to compare the model with the 1903 and 1985 data sets. The river mile values at the section lines were compared between the 1903, 1975 and 1985 data sets both numerically and graphically to obtain the locations of the section lines as discussed below. Values for the 1995 model were taken from the floodplain delineation work maps obtained from the FCD files.

The source of the topography used in the 1975 model is unreferenced and was used as representative of conditions along the river in approximately 1970-75. The Agua Fria River topography used in the 1985 Corps model (USACE 1985) is based on a number of data sets collected by several differing entities. The data sets are listed below:

- Gila to Camelback Rd -1981 Corps topography with a two foot contours
- Camelback to Northern – City of Glendale topography, 1982, 4 ft contour
- Northern to DS of Grand – July 1983 topography with four foot contours
- DS Grand to DS of Bell – American Engineering topo June 1982 with four foot contours
- Bell to Rose Garden – Cella Barr topography, June 1982 with four foot contours
- Rose Garden to Jomax – FCD topography, July 1983 with four foot contours

The scanned paper map data (i.e. the SRP 1903 data) were georeferenced and the values picked off the GIS maps using ARCMap. This data was compared with data from intermediate and current topography to determine what changes had occurred over time in the river. The differences in river lengths due to straightening or shifting of the river channels during floods was estimated by comparing the 1903 river length with the 1975 and 1985 river lengths as available in the HEC-2 models.

The data for the Agua Fria contains three relatively complete data sets (1975, 1985, and 1995) in addition to the SRP data (1902-03) although few floods have occurred in the period since 1975 when more detailed data are available for the Agua Fria. Major floods occurred on the Agua Fria in 1919, 1978, 1980 and with a couple of relatively small (5,000 cfs) flows in 1990 and 1993.

METHOD OF ANALYSIS

The primary method of analysis was to georeference the 1902-03 SRP topographic maps to the most recent USGS quadrangles and to pick off thalweg elevations at locations of interest (primarily section roads or road alignments, (i.e. section lines), which could be found relatively easily on all of the data layers). Since bridges and section lines could be identified easily in the model or map data, the use of locations fixed in space eliminated the need to adjust the various HEC-2 and HEC-RAS models (with the exception of the 1975 Agua Fria River model) to account for channel length changes over time. Most of the data were digital and were evaluated using ArcMAP by comparing elevations at the section line in the digital topography. The 1984-85 data for the Salt River were developed from the paper or velum workmaps in FCD files.

VERTICAL DATUMS

The vertical datums of the various data were compared. The newer topography was primarily in NGVD 29 but some data sets were in NAVD 88 for the Agua Fria River and the original SRP map was specified simply MSL (mean sea level) leaving some doubt as to its datum and the comparison to more recent vertical datums. A review of the map's benchmarks and a comparison to benchmarks that were located nearby appear to be reasonably close to the current datums and no adjustment was made between the 1902 mean sea level datum and more recent NGVD 29 datum. A benchmark included in both the 1903 data and the USGS quadrangle for Mesa is shown in Figure 3. Further the comparison of the 1902-03 data and the current bed elevations for the rivers away from the influence of mining activities indicate that the data sets are comparable. Data points were plotted to the nearest foot. All of the topographic data for the Salt River were thus in NGVD 29 and no datum adjustment was

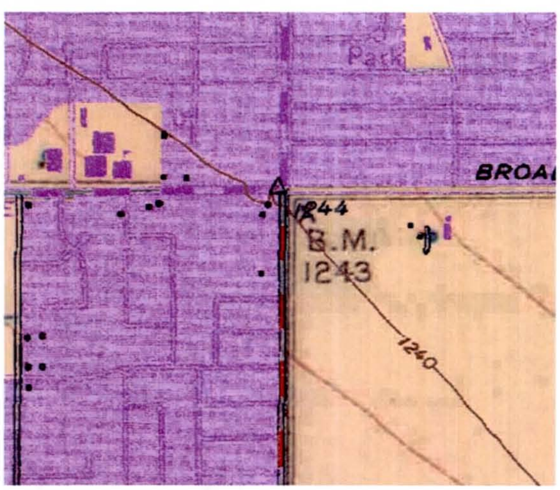

Figure 3. Benchmark at Broadway Road and Gilbert Road for 1902-03 Topo and USGS Quad for Mesa.

necessary.

The Agua Fria River data contained topographic data in both NAVD 88 and NGVD 29 datums. Benchmarks along the Agua Fria River were reviewed from the County GDACS system and the benchmarks were adjusted using NOAA's VERTCON program. Using these references it was determined that the average adjustment between the datums was approximately 2 ft. The NAVD 88 data was thus adjusted to NGVD 29 for the Agua Fria River by subtracting 2 ft from the NAVD 88 data. Data from two GDACS benchmarks in the area of the NAVD 88 topo data are shown in Table 1. The benchmarks were selected from those located on rock outcrops to reduce the impact of subsidence (if any) on datum adjustments.

Table 1. Vertical Datum Adjustments along North Agua Fria River where Topography was reported in NAVD 88. An adjustment of -2.0 ft was used to convert between the NAVD 88 and NGVD 29 datums.

Station	Stability	North Latitude	West Longitude	VERTCON Difference*
AJ3868-Jomax & 115th Ave	A	33 43 30.00123(N)	112 18 29.97484 (W)	0.621 m 2.04 Ft
AJ3856-Bell Rd and Agua Fria	A	33 38 21.67359(N)	112 18 58.59371(W)	0.581 m 1.91 ft
Average Adjustment				1.98 ft

*Positive difference indicates that NAVD88 is higher than NGVD 29

ANALYSIS OF DATA

The GIS data were obtained primarily from the Flood Control District of Maricopa County. Additional data were obtained from any available source as discussed in previous sections. The data were brought into ARCMap and overlaid on the georeferenced data to view the changes over time. Data sets were georeferenced using the top of hills or other readily identifiable points that would not have changed significantly during the intervening 100 years.

SALT RIVER

As previously discussed, the data available for the Salt River included the 1902-03 SRP topographic maps, and topography from a number of aerial mapping projects ranging from about 1980 to 2008. The elevation data at the major roads and sections lines were tabulated by the year of the survey for comparison. The surveys fell into some relatively good data ranges for analysis. A number of the surveys were prior to the 1993 flood on the Salt and Gila Rivers and provide a good picture of the before conditions. There were also a number of surveys showing conditions after the 1993 flood. Some areas had surveys of both before and after the flood event but most of the areas where significant changes occurred during the 1993 flood the immediate pre-flood data could not be located. Additional survey data were also obtained during or after the year 2000.

No large event has occurred after the 1993 event but a 6 year event occurred in 2005 and 2010 as well as some other minor flows. The thalweg data are shown in Figure 3 for the Salt and Gila Rivers from Granite Reef to the Agua Fria confluence with the Gila River. The minimum pit elevations are primarily only shown for the reach from Loop 101 to Granite Reef Dam. Most of the pits downstream from 19th Avenue were not included on the plot since they are filled with water and elevations are not readily available. This is also true of a pit just upstream from the Dobson Road alignment in the Salt River channel. The pit upstream of Dobson Road was estimated based on other pits in the area and from historical aerial photos with varying water elevations.

A prior study by Fuller (2000) determined the total change along the river by comparing data between 1903 and 1991-97. The current study used all readily available data including that used by Fuller. This data allowed a review of the response of the river from 1903 until as late as 2008 for a portion of the Salt River from I-10 to McKellips Road and at Gilbert Road. Additional topography has been obtained by the District since the Fuller report and was included in this analysis. A history of the flood events on the Gila prior to 1966 is shown in Figure 4 and was taken from Aldridge (1970). Major flows since 1965 are shown in Table 3.

Fuller found that the river's thalweg length has varied depending on the estimate which is not surprising given a length of approximately 40 miles from the Granite Reef Dam to the Gila River confluence. The estimates vary by a maximum of 2.55 miles as shown in Table 2. A plot of the data is shown in Figure 5 and it is interesting to note that all of the length estimates are approximately equal at 51st Avenue. If this holds it appears that meandering in the system may adjust to new pits and channelized reaches by meandering or straightening in other locations. This should be further investigated prior to making any conclusions, however.

Table 2. River Length Comparison from Fuller 2000.

	Data Sets			
Location	1902-3	USGS 82	G-9-87-S.x*	Baker 1999
Granite Reef Dam	0	0	0	0
McKellips Road	11.25	10.09	11.25	9.80
Rural Road	16.30	15.70	16.35	15.64
24th Street	22.85	21.38	24.21	21.92
Central Avenue	25.32	24.03	26.96	24.48
51st Avenue	29.95	29.85		30.25
91st Avenue	36.20	35.40		35.50
Gila River confluence	40.85	39.2		38.30

* Data taken from map set labeled Topography Along Channel of Salt River. Reference: G-8-87-S.x where x is sheet 1 through 9. (Flood Control District of Maricopa County)

TABLE 6.—*Discharge data for major floods, Salt River and main tributaries, 1888–1965*

[Peaks are those for which daily flow of the Salt River was computed to be more than 30,000 cfs at Roosevelt or more than 50,000 cfs below Verde River; sources of data given in table 7]

Date of flood	Peak discharge, in cfs					Peak discharge, in cfs—Con.	Maximum daily discharge associated with the flood, in cfs					
	Salt River near Roosevelt	Tonto Creek	Salt River at Roosevelt	Salt River above Verde River	Verde River	Salt River below Verde River	Salt River near Roosevelt	Tonto Creek	Salt River at Roosevelt	Salt River above Verde River	Verde River	Salt River below Verde River
Feb. 22–23, 1890									71,600		64,500	143,000
Feb. 19, 1891						[1] 267,000						[1] 225,000
Feb. 23–24, 1891 [2]			150,000			300,000					135,000	[1] 225,000
Jan. 17–18, 1895									46,800	49,800	33,200	83,000
Feb. 4–5, 1905			[3] 43,400						31,400	32,300	33,000	65,000
Feb. 28 to Mar. 1, 1905			[3] 36,400						27,600	29,100	25,100	54,000
Mar. 13–14, 1905			[3] 48,000						38,700	28,600	25,500	54,000
Mar. 17–18, 1905			[3] 54,000						39,800	34,800	29,400	64,000
Mar. 20–21, 1905			[3] 54,000						44,400	35,800	10,600	45,000
Apr. 12–13, 1905			[3] 68,000			[4] 115,000			45,500	60,600	32,100	87,000
Nov. 27, 1905			[3] 145,000	[5] 138 000	96,000	>200,000			97,700	[6] 90,000	61,500	[6] 150,000
Mar. 13–14, 1906									35,700	37,300	31,300	66,000
Mar. 27, 1906									28,200	28,200	30,400	58,000
Dec. 3–4, 1906									36,600	38,000	15,400	53,000
Mar. 6, 1907									14,200	18,600	32,200	51,000
Dec. 16–17, 1908										35,000	51,600	63,000
Jan. 30, 1915							37,500	11,000	48,500	79	15,700	16,000
Jan. 19–20, 1916	100,000		[7] 120,000		[8] 68,900	[4] 120,000	91,000	18,000	109,000	50,000	53,400	95,000
Jan. 29–30, 1916						[4] 105,000	69,500	8,690	78,200	50,000	22,600	73,000
Nov. 28, 1919							36,500	6,430	42,900	294	46,800	47,000
Dec. 6, 1919							50,600	8,920	59,500	508	16,900	17,000
Feb. 22–23, 1920						[4] 130,000	56,000	9,880	65,900	28,000	48,200	76,000
Dec. 28, 1923	43,000						32,200	20,000	52,200	0	40,800	41,000
Feb. 17–18, 1927	40,000				70,000	([9])	31,600	12,600	40,900	1,110	48,300	([9])
Feb. 10–11, 1932	57,000				53,000	([9])	35,200	8,000	42,200	25	41,500	([9])
Feb. 7–8, 1937	88,000		>100,000	28	63,000	([9])	35,000	18,000	49,000	23	39,200	([9])
Mar. 4, 1938	24,100			53	95,000	[1] 85,000	17,800	6,000	23,800	14	59,700	([9])
Mar. 14–15, 1941	117,000	32,000	136,000	29	45,800	([9])	60,200	16,500	76,700	29	32,700	([9])
Jan. 18–19, 1952	111,000	45,400	139,000	10	237		46,600	21,200	58,500	5	189	
Dec. 25–26, 1959	78,200	25,200	103,000	[10] 700	[10] 620	[8] 8,800	41,800	14,300	51,800	134	182	
Dec. 22–24, 1965	68,800	44,700	88,000	4.360	8,540	9,530	45,100	15,300	56,000	3,750	2,950	6,900
Dec. 30–31, 1965	59,900	22,100	66,000	50 100	31,300	67,000	30,600	11,200	40,400	37,200	30,200	64,000

[1] Data not previously published; from J. H. Gardiner and S. O. Decker (written commun., 1948).
[2] Figures for February 23-24, 1891, have been published previously as maxima and as daily mean discharges. J. H. Gardiner and S. O. Decker (written commun., 1948) have indicated that the published figures should be used as maxima; they gave a daily discharge of about 225,000 cfs at Arizona Dam. Daily mean discharge at Roosevelt not determined.
[3] Data not previously published; obtained by applying an extension of 1905 rating to maximum stage noted by observer.
[4] C. T. Newton (U.S. Army Corps of Engineers, written commun., 1957).
[5] Maximum observed; previously published as daily mean flow, but figure is inconsistent with records for Salt River at Roosevelt.
[6] Approximate; estimated from records for Salt River near Roosevelt and Verde River near McDowell.
[7] Approximate; estimated from records for Salt River near Roosevelt and Tonto Creek near Roosevelt.
[8] From Salt River Valley Water Users' Association.
[9] Discharge approximately equal to that in the Verde River but may differ slightly because of inflow, attenuation, and time of travel.
[10] Originated in tributaries below reservoir systems.

Figure 4. Table of Historic Flows from USGS WSP 1850-C, Aldridge (1970).

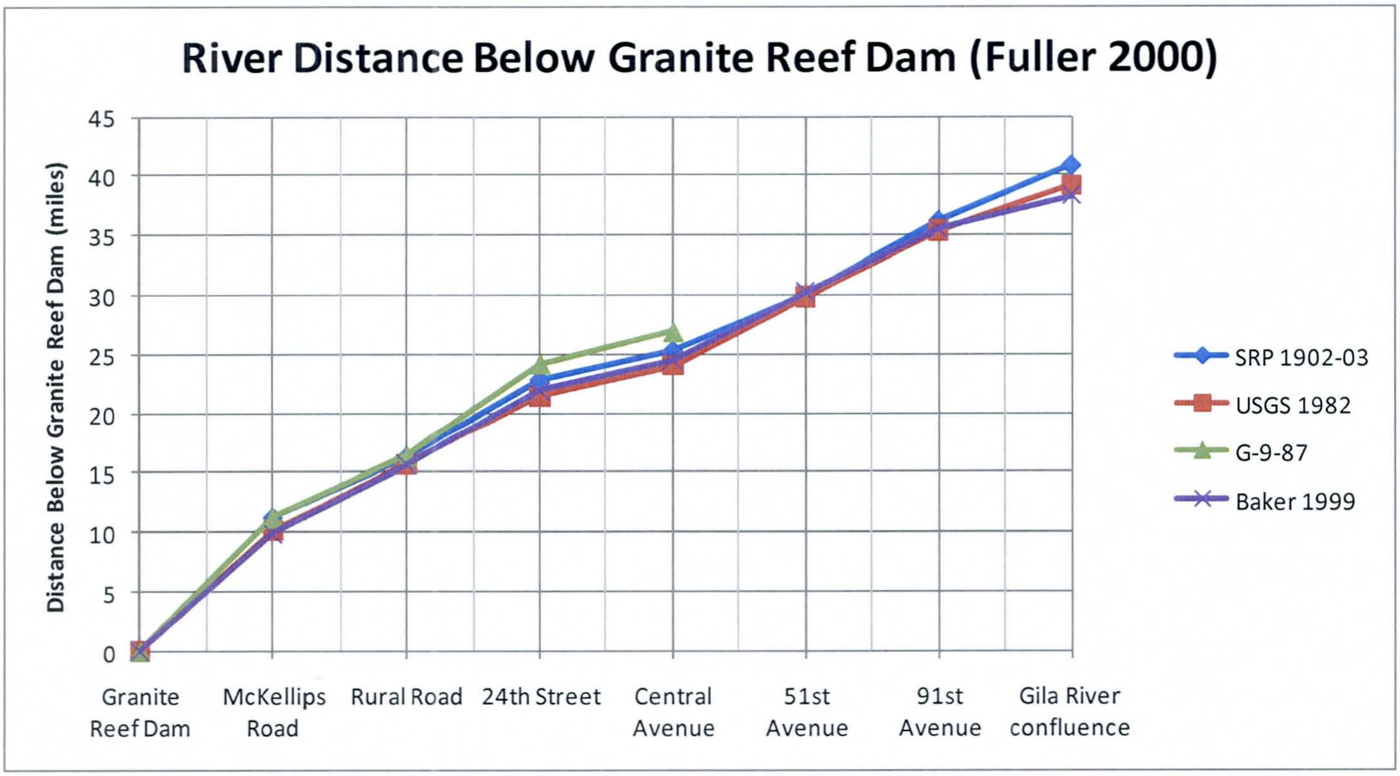

Figure 5. Fuller's Distance Comparisons for the Salt River from 1902 to 2000. Baker 1999 Data is Prior to 1993 Flood.

The data obtained for this report show that the Salt River had already lowered by up to 28 feet between 48th Street and 35th Avenue and the Aldridge (1970) report shows a very large gravel mine in the vicinity of 67th Avenue. Other mines are shown but are relatively minor in comparison. A review of the 1937 aerial photo on the Flood Control District Website shows a very wide meander belt to the south of downtown Phoenix that was subsequently narrowed. This channel narrowing alone could account for the lowering of the thalweg in this reach so it is not conclusive that mining caused this lowering. The reach of the River at Priest Avenue is also underlain by bedrock at a relatively shallow depth which is not the case in other portions of the river. (Tempe History Museum 2010 indicating that the 1905 bridge piers reach to bedrock.) This shallow bedrock limits changes in the elevation of the river bed above the outcrop – the area currently covered by the Tempe Town Lake.

The data evaluated for this study also clearly indicate that the lowering of the channel is not due to the impact of the dams but rather a result of mining activities in the river. The upper reach of the Salt River held its elevation from 1903 until mining activities approached the various areas. This is shown in the Fuller 2000 report as well as by current data. The absence of channel lowering in the upper reaches would not have been the case if the bed of the river was being impacted by the upstream dams. Gilbert Road, for example only lowered recently due to mining operations both upstream and downstream of the road crossing. Elevations upstream above Gilbert Road also held until mining operations began the removal of large amounts of material from the river channel. This is shown in Figure 6 by comparing the 1993 data with the 2003 data. It can be seen that the data prior to 2003 falls almost exactly on the line from the 1903 survey.

Some lowering is seen in the Salt River below Granite Reef Dam but this may be due to the impacts of the diversion dam. This impact may be due either to sediment capture upstream of the diversion dam or to concentration of flows below the dam. Fuller's 2000 and 2001 reports support the conclusion that the lowering at Granite Reef Dam is not due to the impacts of the upstream storage reservoirs since the reach above Granite Reef is also stable for the previous 100 years.

From this review of the data it does not appear that sand and gravel mining on the Salt River have impacted areas that are not immediately adjacent to the mining operations. The impacted areas surrounding the pits appear to be limited to lengths of less than a mile with perhaps the exception of Gilbert Road where an upstream and a downstream pit were connected by a lowered channel after an approximate 6 year event (See discussion below). This same phenomenon (scour between upstream and downstream pits) was blamed for the scour failure of the I-10 bridge pier in 1965-66 after the freeway bridge had only been open for about one month (Aldridge 1970).

Simons & Li (1989) obtained similar results in their analysis of the Salt River. They observed that the channel lowering in the Salt River compared directly with the amount of material removed by mining with only a small percentage being unaccounted for. This material that couldn't be accounted for was small enough to be either error in the analysis or a small amount of transport into the reach from upstream.

A number of headcuts along the Salt River can be seen in recent topography and aerial photos. Some of these can be seen in photos on Google Earth or in photos on the County's GIS server. Most of these headcuts, while significant (300-600+ ft) have not moved long distances up the river – primarily due to the lack of flows in the river. If the river were subject to more large flows the head cuts could be expected to move further up the river. Headcuts can be seen in Figure 7 – Figure 10 and are labeled although they are readily apparent.

Topography from 2001 showed a head cut upstream from Alma School reaching nearly to McKellips Road. This is absent in the 2008 topography – likely filled by the sediment transport associated with the 2005 flow event coupled with the new grade control structure at the Alma School Road Bridge. This indicates that sediment transport is still occurring to some extent in the river in spite of the upstream pits. The fact that the deep pits in the Dobson to Country Club reach did not fill significantly in the 2005 event indicates that the upstream sediment supply was deposited in the upstream pits or that sediment transport was not particularly high in the relatively small event. Material scoured from headcuts is usually deposited in the upstream end of the pit as can be seen clearly in Figure 9 where the headcut is shown and the delta can be noted to have displaced the water in the upstream portion of the pit immediately downstream of the headcut channel.

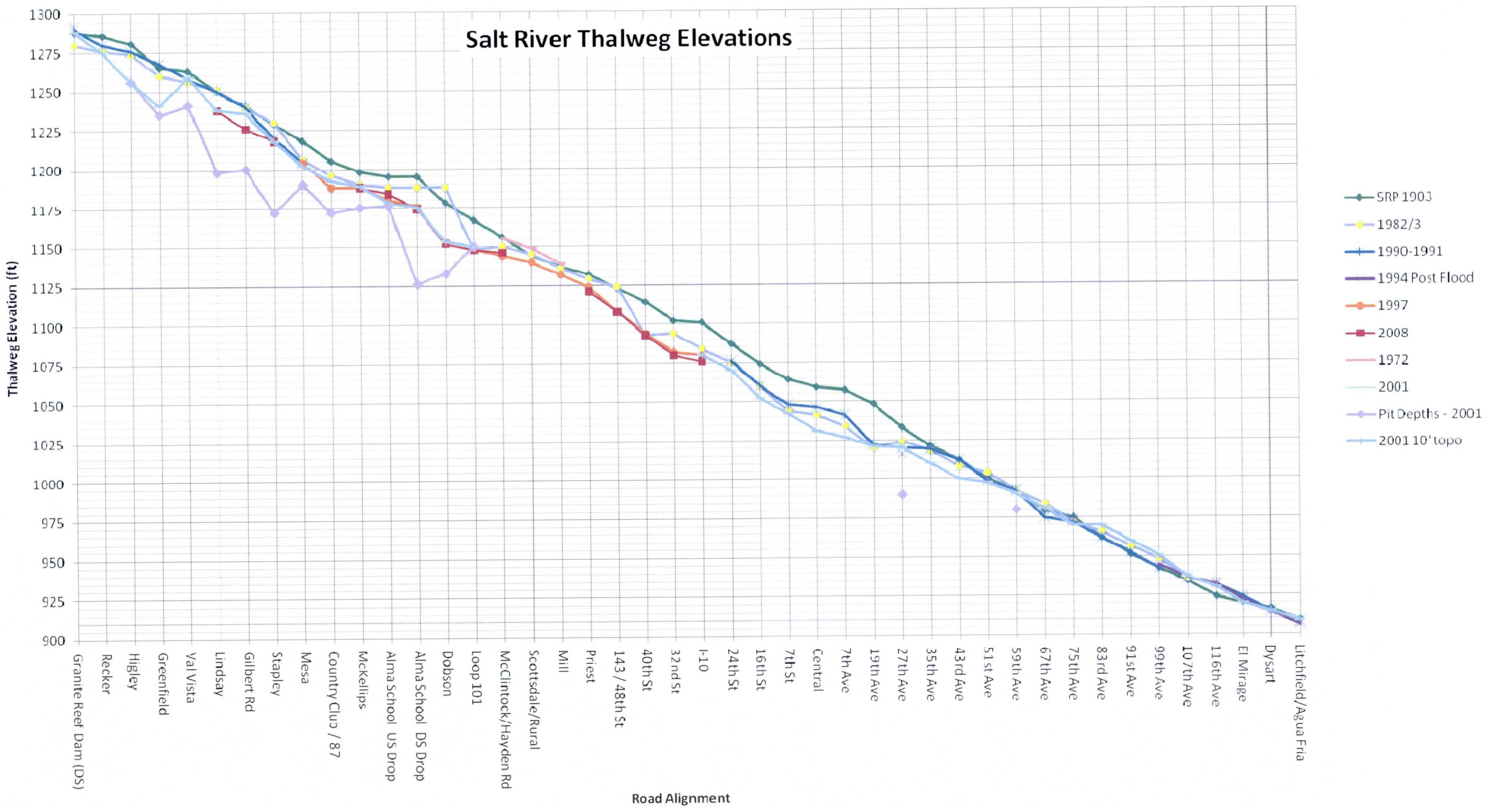

Figure 6. Historical Thalweg Elevations (min bed elevation) Salt and Gila Rivers from Granite Reef to Agua Fria Confluence. The pit depth at Dobson Road is estimated at approximately 20 ft below the outlet elevation from Aerial Photos and may be off by ±10 ft. Pit Elevations are only shown upstream from Loop 101. Pit Elevations area from latest available topography for subject reach. See Associated Table for Notes.

Table 3. Thalweg Elevations for Salt and Gila Rivers from Granite Reef Dam to Agua Fria Confluence by Year and Data Set. Recent Major Floods are shown at end of Table for Reference.

Road Crossing/Alignment	SRP Survey 1902-3 Original MSL	1903 Fuller (2000)	Bridge Study 1972	Eng Div 1982/1986 Paper Map NGS	Delta Bed Elev 1902-1982	SGRMP Baker 7/90-2/93 NGVD 29	Delta Bed Elev 1902-1992	SGRMP Post 93 Flood NGVD 29	Post 93 Apr-94 NGVD 29	Delta Bed Elev Post 93-02	Maryvale Mar-94	SGRMP Feb-97 Baker NGVD 29	Delta Bed Elev 1902-97	2001 Va Shly' +Co. 10'	2008 SRMP 6/21/2008 NGVD29	Delta Bed Elev 1902-2008	Delta Bed Elev Most Recent	Max Pit Depth Va Shly' Ay Akimel
Granite Reef Dam (DS)	1288	1289		1280	-8	1290	2		1292	4				1288			0	
Recker	1286	1285		1276	-10	1280	-6							1275			-11	
Higley	1281	1277		1274	-7	1276	-5							1256			-25	1256
Greenfield	1265	1265		1260	-5	1268	3							1241			-20	1235
Val Vista	1263	1257		1256	-7	1258	-5							1259			-22	1241
Lindsay	1250	1250		1251	1	1250	0							1238	1238		-11	1198
Gilbert Rd	1241	1241		1240	-1	1240	-1							1236	1226	-15	-15	1200
Stapley	1229	1229		1230	1	1220	-9							1218	1218		-11	1172
Mesa	1218	1218		1206	-12	1204	-14					1204	-14	1202			-16	1190
Country Club / 87	1205	1205		1196	-9							1188	-17	1192			-13	1172
McKellips	1198			1190	-8							1188	-10	1189	1188	-10	-10	1175
Alma School US Drop	1195	1195		1188	-7							1180	-15	1178	1184	-11	-11	1176
Alma School DS Drop	1195			1188	-7							1176	-19	1175	1174	-21	-21	1126
Dobson	1178	1178		1188	10							1152	-26	1153	1152	-26	-26	1133*
Loop 101	1167	1167		1148	-19							1148	-19	1150	1148	-19	-19	1150
McClintock/Hayden Rd	1156	1156	1155*	1150	-6							1144	-12		1146	-10	-10	
Scottsdale/Rural	1144	1144	1149	1145	1							1140	-4		**		-4	
Mill	1137	1137	1139	1136	-1							1132	-5		**		-5	
Priest	1132	1134		1129	-3							1124	-8		1121	-11	-11	
143 / 48th St	1123	1123		1124	1							1108	-15		1108	-15	-15	
40th St	1114	1114		1093	-21							1094	-20		1093	-21	-21	
32nd St	1102			1094	-8							1082	-20		1080	-22	-22	
I-10	1101	1101		1084	-17							1080	-21	1080	1076	-25	-25	
24th St	1087	1093		1075	-12	1076	-11							1070			-11	
16th St	1074	1074		1060	-14	1060	-14							1052			-14	
7th St	1064	1064		1044	-20	1048	-16							1042			-16	
Central	1059	1059		1041	-18	1046	-13							1031			-13	
7th Ave	1057	1057		1034	-23	1041	-16							1027			-16	
19th Ave	1048	1049		1020	-28	1022	-26							1021			-26	
27th Ave	1033	1033		1024	-9	1020	-13		1016	-17				1020			-17	990*
35th Ave	1021	1021		1018	-3	1019	-2							1010			-2	

Road Crossing/Alignment	SRP Survey 1902-3 Original MSL	1903 Fuller (2000)	Bridge Study 1972	Eng Div 1982/1986 Paper Map NGS	Delta Bed Elev 1902-1982	SGRMP Baker 7/90-2/93 NGVD 29	Delta Bed Elev 1902-1992	SGRMP Post 93 Flood NGVD 29	Post 93 Apr-94 NGVD 29	Delta Bed Elev Post 93-02	Maryvale Mar-94	SGRMP Feb-97 Baker NGVD 29	Delta Bed Elev 1902-97	2001 Va Shly' +Co. 10'	2008 SRMP 6/21/2008 NGVD29	Delta Bed Elev 1902-2008	Delta Bed Elev Most Recent	Max Pit Depth Va Shly' Ay Akimel
43rd Ave	1012	1012		1008	-4	1012	0							1000			0	
51st Ave	1000	1000		1004	4	998	-2		1000	0				997			0	````
59th Ave	992	992		992	0	992	0							990			0	980*
67th Ave	979	979		984	5	975	-4							981			-4	
75th Ave	975	975		972	-3	972	-3		974	-1				970			-1	
83rd Ave	962	962		966	4	962	0							970			0	
91st Ave	951	951		956	5	952	1							960			1	
99th Ave	942	942		948	6	942	0		944	2				950			2	
107th Ave	934	934		936	2			936	936	2	930			937			2	
116th Ave	924	924		931	7	932	8	932	932	8	928			930			8	
El Mirage	920					924	4		922	2	918			920			2	
Dysart	916					915	-1		914	-2				915			-2	
Litchfield/Agua Fria	909					908	-1	906	906	-3				909			-3	

Gilbert Road Survey 2007
Estimated from Downstream Topo
1986 Burgess & Niple 1984 Topo
* Water in Pit

*Hayden Scottsdale Road was shown at elev. 1137 for the scour hole from the old Scottsdale Road Bridge with averaged existing at 1149 and EL 1150 for designed channel for new bridge (Boyle 1981)
** Bed Elevations obscured by Tempe Town Lake

Values Disagree with Values in Fuller Report
However values were checked carefully on 1902-03 SRP Maps
Some differnces expected due to diffculty in reading map contours

Values from 2001 County 10 ft Data
Pits from Va Shly' Ah Akimel Data
Pits from 2008 Data

Gila River	Gage	Peak (cfs)	Daily Average (cfs)	Return Period (Yrs)**
Gila Flood - Jan 9, 1993	Estrella	162,000	132,000	46
Gila Flood - Jan 19, 1993	Estrella		103,000	25
Gila Flood - Feb 15, 1995	Estrella	74,900	51,400	17
Gila Flood - Feb 13, 2005	Estrella	38,900	29,900	8
Salt River				
Salt Flood - Jan 8, 1993	Alma School	129,000	96,600	42
Salt Flood - Jan 18, 1993	Alma School	106,000	87,900	28
Salt Flood - Feb 21, 1993	Alma School	75,200	44,600	15

** Return Period based on Corps' Modified Hydrology March 1996

Salt River Below Stuart Mtn Dam	Ave	Peak	Return Interval (Yrs)**
1/1/1966	38,600		20
1/19/1979	54,000		200
2/16/1980	64,000		260
3/22/1983	14,100		10
10/2/1983	33,300		17
1/18/1993	33,700	44,500	18
1/20/1993	34,500	35,600	

Verde River Below Bartlett Dam	Ave	Peak	Return Interval (Yrs)**	Ratio Peak/Ave Calculated	Ratio Estimated
3/4/1938	59700	95000	38	1.59129	1.4935
12/30/1965	28700	35600	8	1.240418	1.2455
3/2/1978	67600	101000	41	1.494083	1.5567
12/18/1978	58600	75800	25	1.293515	1.4847
2/15/1980	58800	97300	39	1.654762	1.4863
2/9/1983	13300	*14927*	*4.5*		1.1223
1/8/1993	84700	*143439*	*90*		1.6935
2/15/1995	64100	*97990*	*40*		1.5287
2/13/2005	25100	*30539*	*7*		1.2167

FCD Data
USGS Data
Estimated from Ave Data Using Peak/Ave Ratio

The 2005 event was only an approximate 6 year event and as such did not carry huge quantities of sediment. Larger floods will carry higher sediment loads and although some of the pits may partially fill, it is likely that the net result will be a general lowering of the river channel as it reaches more of an "average" elevation. This average elevation will represent an equilibrium between the higher sections of the channel and the lower pit elevations.

The elevations for the pits as shown in Figure 6 are for the minimum elevations and not any indication of what the final bed elevation would be in the vicinity of the pits after significant flow has occurred. The final river elevation will likely be between the existing thalweg elevation and the minimum pit elevation after a large flood. The pits will not recover to the existing thalweg elevation given the reduced sediment load from upstream. This reduction in sediment transport is due primarily to the upstream pits and reservoirs.

Salt River at Gilbert Road. The 2005 event caused significant scour at the Gilbert Road crossing of the Salt River with a portion of the channel lowering approximately 14 feet from the 2001 elevation at the bridge. It appears from site visits and from the data that the lowering was contained primarily between a large pit downstream and a smaller and older upstream pit. Based on site visits it is thought that the bed of the river armored during the event and prevented (or at least limited) additional down cutting through the reach under the bridge. The flow was swift and turbulent and would have continued to down cut to connect the pit upstream and the pit downstream if the bed had not armored. See Figure 11 - Figure 13 for flow conditions at Gilbert Road during the falling portion of the 2005 flood hydrograph (Q = approx 15,000 cfs).

The reason for the Gilbert Road lowering is clearly shown in Figure 6. The potential for channel lowering can be seen not only in the pit elevations upstream and downstream from Gilbert Road but also in the channel thalweg elevations upstream and downstream from the bridge. These lower elevations upstream and downstream of the road resulted in bed lowering to make the reach more uniform in terms of bed slope. The current bed elevation appears to be more in equilibrium with the downstream channel bed elevations. However, if the river again breaches the berm that keeps flow out of the downstream mining operation the bed in this reach can be expected to lower further – especially if the flow is high enough to mobilize the existing bed armor. If the destruction of the armor and the breach of the protection berm occur during a large event (perhaps greater than a 15 year event) an additional bed lowering of 5-10 feet (or more) could be expected at Gilbert Road.

The flow patterns at Gilbert Road during the 2005 event are relatively clear in Figure 11. It is evident that the flow made a right turn into the downstream pit and exited the pit about three quarters of a mile downstream. This capture of the river by the pit likely accounted for a significant portion of the channel lowering at Gilbert Road. The capture of the river may have only accelerated what would have occurred over a longer time period given the excavations in the river downstream of this pit. Figure 7 clearly shows a head cut in the main river channel just upstream from the point where the flow exited the pit. This headcut would be expected to move upstream towards the Gilbert Road Bridge and eventually merge with the tail cut from the pit upstream of Gilbert Road causing problems at the Gilbert Road Bridge similar to resulting from the pit capture. This can be seen in the 2000 thalweg data show in Figure 6.

The Gilbert Road lowering likely started as a headcut into the downstream pit that rapidly progressed upstream until it merged with the tail cut from the upstream pit. At this point the behavior of the channel at Gilbert Road is simply channel lowering in response to the lower elevations of the pits upstream and downstream. One of the headcuts from the downstream pit as well as the channel lowering near Gilbert Road can be seen in Figure 10.

From the 2009 County photo it is apparent that the material deposited in the pit downstream of Gilbert Road is being (or has been) removed. This will increase the depth of the headcut and channel lowering when the berm protecting the pit again fails during a large flood. This will occur unless the flow is not sufficient to break up the bed armor developed during the 2005 flood. When the bed armor is displaced the channel will again lower in an attempt to find a new equilibrium value. In the 2010 aerial photos it appears that the main channel has been lowered and reconstructed in an effort to convince the water to flow in the channel rather than breaching the pit protection berm.

Figure 7. Aerial Photo of Salt River below Gilbert Road after 2005 Flood Event. Note flow path through gravel pit (yellow arrows) vs. expected flow down channel (white arrow). Another headcut can be seen just upstream from where the 2005 flow exited the pit. This headcut is the result of another pit excavated downstream.

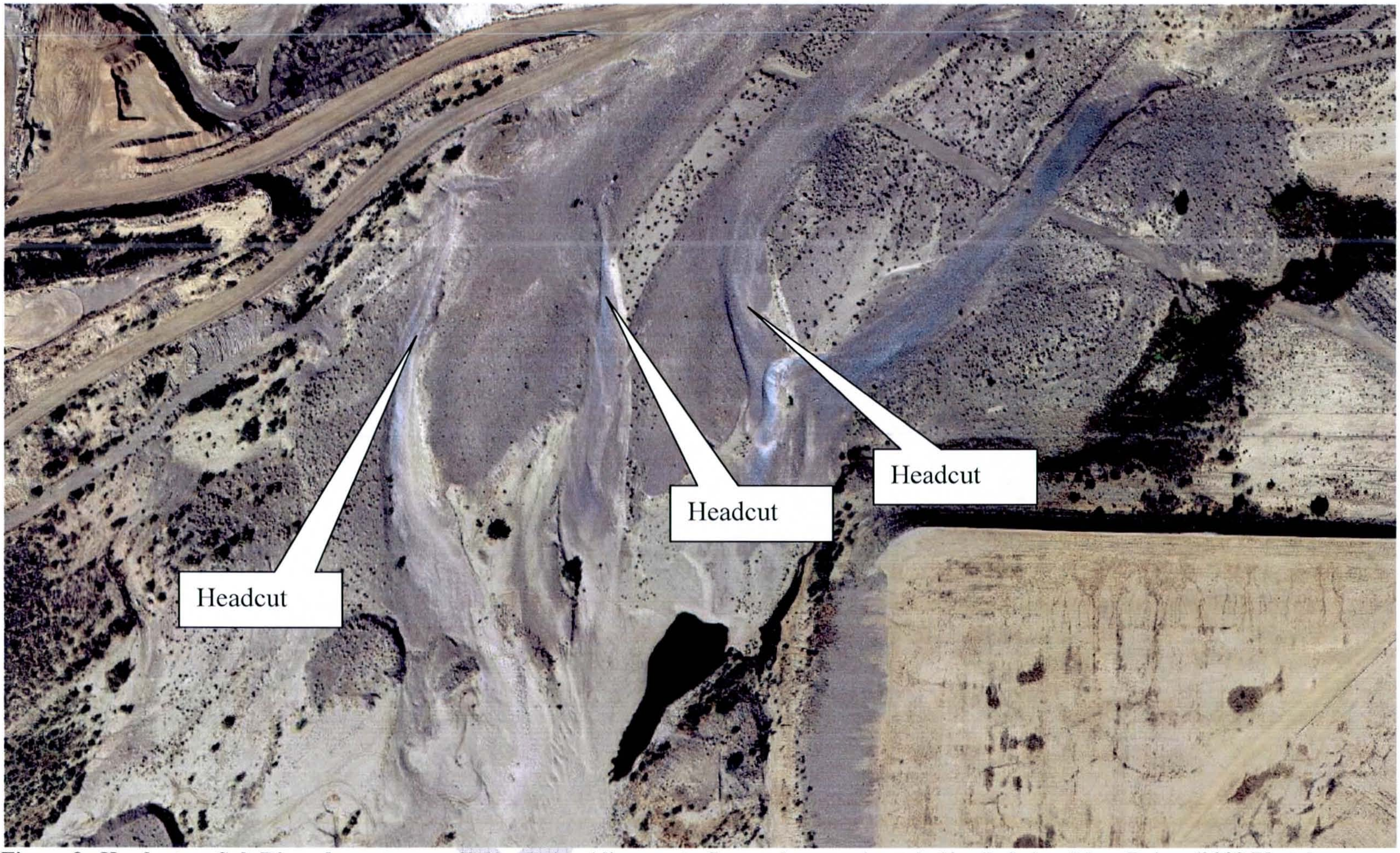

Figure 8. Headcut on Salt River downstream of Mesa Drive Alignment – Located approximately ½ mile below Mesa Drive. (2009 Photo)

Figure 9. Headcut downstream of Alma School Road (2009 Photo).

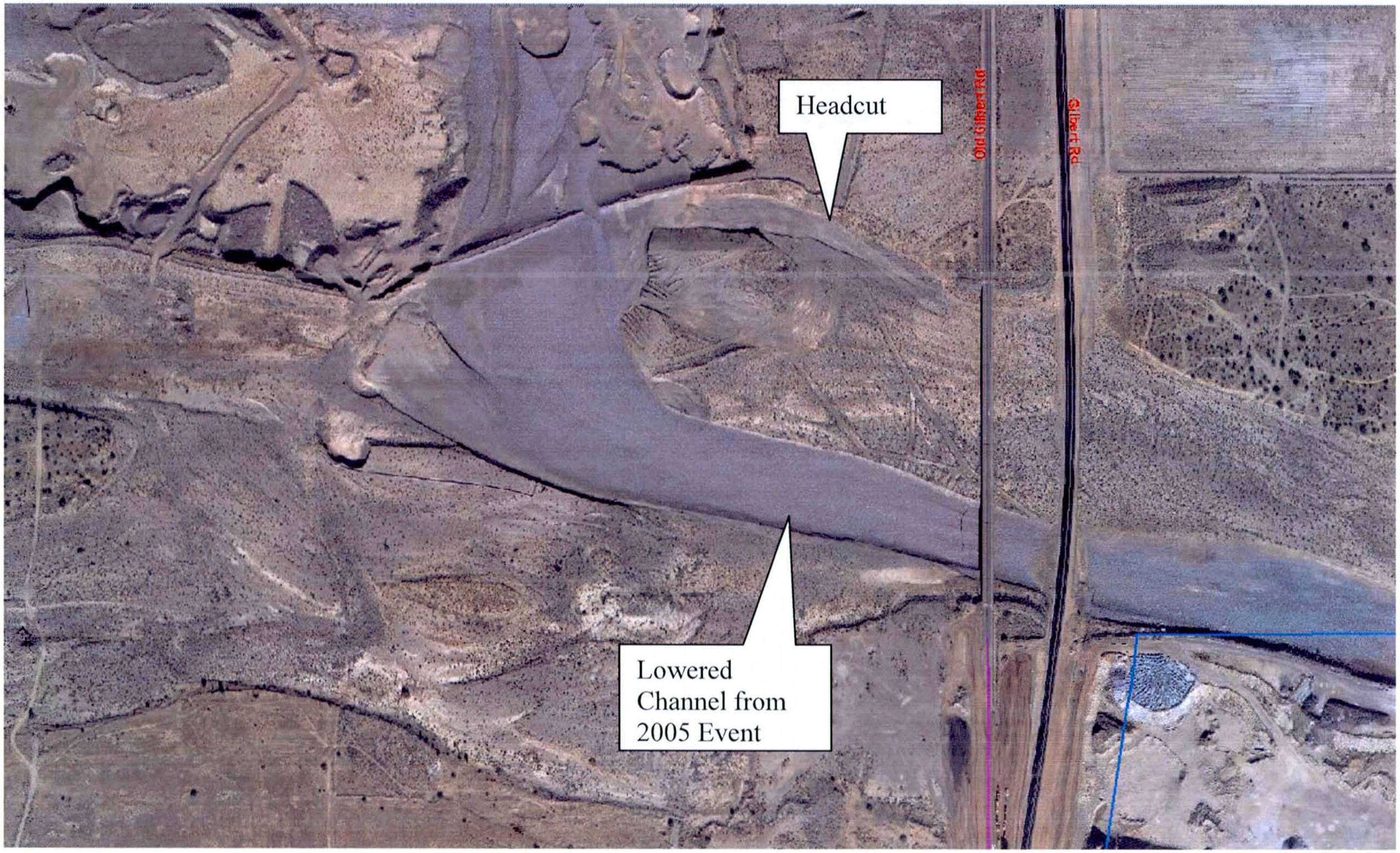

Figure 10. Headcut below Gilbert Road and Lowered Channel from 2005 Event.

Figure 11. Gilbert Road Bridge during 2005 Flood showing Velocity in Channel and Rough Flow Patterns.

Figure 12. Salt River Downstream of Gilbert Road Bridge during 2005 Flood. Flow is approximately 15,000 cfs.

Figure 13. Flow Conditions in Salt River Downstream of Gilbert Road Bridge during 2005 Flood. Flow Rate is about 15,000 cfs.

AGUA FRIA RIVER

The data available for analysis for the Agua Fria River included the 1903 SRP data which shows the Agua Fria River as the western boundary of the maps. The fact that Agua Fria River was the western boundary of the SRP project and not of as great an interest is apparent since the western bank of the river is not, for the most part, shown on the SRP maps. The main channel of the river is also not shown for about 2 miles in the vicinity of Bethany Home Rd, Glendale Ave and Northern Ave. Thalweg elevation and river alignment at these section lines were estimated based on the data that was available for the other branch(es) of the channel for this area that were included on the SRP map.

The last large events on the Agua Fria River occurred in 1978 and 1980 with much smaller events in 1990 and 1993. Since that time all large flows have been captured in Lake Pleasant behind the New Waddell Dam. Thus any changes since that time are the result of either mining or local flows.

Data was collected and analyzed using the same pattern followed for the Salt River, i.e. for the locations where section lines or road alignments crossed the river. These were normally easily determined with the locations of the section lines (road alignments) for the 1975 model being the most challenging to determine. The 1985 model was highly documented and the SRP data was taken from the maps where the section lines / road alignments could be easily determined. The 1985 and 1995 models in conjunction with the SRP data provided a basis for aligning the 1975 model data. The 1975 model cross sections with bridges were taken as accurate and the alignments between the bridges in the HEC-2 model were interpolated based on the distances between the roads in the 1985 model. This was then visually checked for distance and fit with the 1903 (higher elevations) and 1985 (lower elevation) data. If river distances between two known bridge locations were estimated too long the thalweg elevation would fall below the 1985 data. Conversely if the distance was estimated too low the value would fall above the 1902-03 data. After initial estimates were made the estimated river mile values were adjusted by trial and error to keep the line for the 1975 model the equivalent distance between the 1903 and the 1985 lines based the distance between the thalweg elevation values at the bridges bounding the section. The result of this analysis can be seen in Figure 14 and Table 4.

The initial estimates of the river mile locations for road alignments were fairly accurate for most of the road alignments in the 1975 model. The estimated maximum adjustment of river mile locations of the road alignments was on the order of ±0.2 mile from a linear interpolation of the distance between the bridges. Given the slope of the river the resulting vertical error was on the order of ±2.5 feet. The distance in river mile error for the crossings was estimated visually and adjusted by trial and error using the spreadsheet associated with Figure 14. This error is not greatly different than that associated with a four foot contour elevation which is common in the 1985 model and assumed to be the accuracy of the topography used in the 1975 model.

Once the location of the road crossings was determined in the 1975 model the thalweg elevations for the various years could be compared. The results of the analysis are shown in Figure 15 and Table 5. A more detailed plot for the area with observable mining impacts in the data is shown in Figure 16. In reviewing the data it can be seen that while a number of changes on the order of 10-13 feet can be found in the data, most of the river changes are on the order of 8 feet or less. The areas with the highest degradation are also areas associated with large mining operations that have been impacted by large flood events.

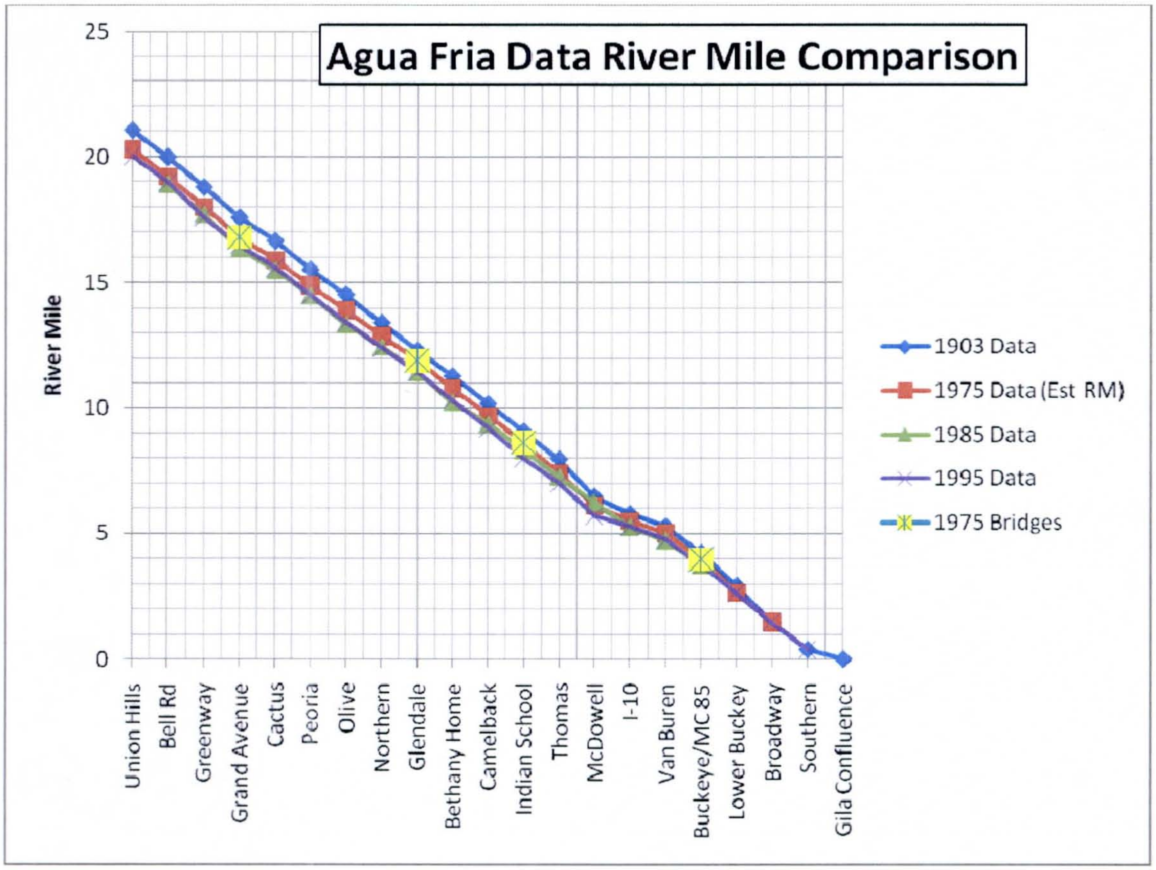

Figure 14. River Mile Data from HEC-2, HEC-RAS and Measured Data for Agua Fria River.

The Agua Fria is currently not mined to the same extent as the Salt River. This means that the river will still transport significant amounts of sediment and tend to fill shallow pits. As more and more of the river is mined with very large pits this will not be the case. The impacts to date are the lowering of the river by as much as 12 feet as shown in Table 5. The profiles for the river at the dates of the various topographic surveys are shown in Figure 15 and Figure 16.

The lowering noted along the Agua Fria River is significantly less than that observed on the Upper Salt River (about half at this point). The major difference is the lack of flood flows on the Agua Fria River and the lesser extent of mining to date on the Agua Fria. It is expected that during the next major flood that significant changes will occur in river channel. These changes will likely include both alignment as pits are captured, and lowering as the captured pits generate headcuts and tail cuts. The extent of these changes will depend on the extent to which pits are captured, filled with the sediment being transported down the river, and the peak and duration of the flows.

It is important to note that the Agua Fria River has both bank protection and grade control structures from Thomas Road to MC85. These structures limit any down cutting of the channel in this reach and immediately upstream. This reach has experienced only moderate changes since 1903 with changes ranging from +3 ft at Lower Buckeye Road to -7 ft at Van Buren St. These data are shown inTable 4.

Table 4. River Mile Stations for Various Years and Modeling Efforts. SRP Distances were Measured from Topographic Map.

		SRP 1903	1975 Bridges	1975 Estimated	1983	1995
Road/Alignment		RM	RM	RM	RM	RM
Union Hills		21.06		*20*		20.015
Bell Rd		19.99		*18.9*	18.906	18.97
Greenway		18.79		*17.9*	17.71	17.6
Grand Avenue		17.58	16.8		16.355	16.494
Cactus		16.66		*15.9*	*15.5*	15.6
Peoria		15.53		*14.9*	14.501	14.5
Olive		14.53		*13.9*	13.364	13.4585
Northern		13.42		*12.9*	12.47	12.42
Glendale		12.31	11.9		11.434	11.419
Bethany Home		11.28		*10.9*	10.25	10.343
Camelback		10.18		*9.8*	9.374	9.184
Indian School		9.07	8.62		8.327	8.005
Thomas		7.96		*7.4*	7.267	6.99
McDowell		6.47		*6.3*	6.235	5.6945
I-10		5.78		*5.6*	5.256	5.2975
Van Buren		5.27		*5*	4.741	4.7565
Buckeye/MC 85		4.23	3.985		3.741	3.7405
Lower Buckey		2.92		*2.65*		2.64
Broadway		1.46		*1.47*		1.46
Southern		0.39				0.39
Gila Confluence		0				
Estimated Values are in *italics* and highlighted in yellow						

Another important consideration is that the pit elevations shown are not continuous and the minimum depths are very localized. The average pit elevations are significantly less than the maximum depth shown and are likely more representative of potential scour depths. The pit depths in relation to the historical bed elevations are shown in Figure 16.

Table 5. Agua Fria Data from Historical Models and Topography. Negative values show lowering over time.

	SRP Data - 1902-03		1975 Corps			1983Corps			1995 - CVL			2008		NGVD	Most	Min Pit*	Comments
Location	RM	Thalweg	RM	Thalweg	Delta EL	RM	Thalweg	Delta EL	RM	Thalweg	Delta El	Thalweg		Delta El	Recent	Elevation	
		Elev (ft)	(Yellow =		1902-1975			1902-1984		Elev (ft)	1902-1995	NAVD88	NGVD 29		Del Elev	(ft)	
			Estimated)									NAVD88-2.0 =NGVD29					
Jomax						25.459	1254		25.5	1256		1256	1254	0	0	1256	
Happy Valley						24.152	1235		24.45	1236		1239	1237	2	2	1225.5	
Pinnacle Peak						23.205	1215		23.36	1218		1221	1219	1	1	1105	
Deer Valley						22.258	1198		22.2	1200		1196	1194	-6	-6	1131	Headcut from Pit
Rose Garden						21.681	1189		21.789	1184		1186	1184	-5	-5	1144	
Beardsley						21.24	1188		21.157	1180					-8	1136	
Union Hills	21.06	1164	20.3	1168	4	20.12	1172		20.015	1167	3				3	1167	
Bell Rd	19.99	1155	19.2	1152	-3	18.906	1147	-8	18.97	1147	-8				-8	1070	
Greenway	18.79	1133	18	1131	-2	17.71	1126	-7	17.6	1123	-10				-10	1100	
Grand Avenue/Thunderbird	17.58	1115	16.8	1114	-1	16.355	1112	-3	16.494	1105	-10	1107	1105	-10	-10	1100	
Cactus	16.66	1102	15.9	1101	-1	15.5	1093	-9	15.6	1095	-7	1099	1097	-5	-5	1093	
Peoria	15.53	1096	14.9	1087	-9	14.501	1084	-12	14.5	1083	-13	1086	1084	-12	-12	1084	
Olive	14.53	1075	13.9	1070	-5	13.364	1065	-10	13.4585	1064	-11	1066	1064	-11	-11	1038	
Northern	13.42	1062	12.9	1057	-5	12.47	1052	-10	12.42	1058	-4	1056	1054	-8	-8	1030	
Glendale	12.31	1048	11.9	1042	-6	11.434	1038	-10	11.419	1042	-6	1044	1042	-6	-6	1006	
Bethany Home	11.28	1034	10.8	1032	-2	10.25	1027	-7	10.343	1022	-12	1030	1028	-6	-6	958	
Camelback	10.18	1016	9.7	1022	6	9.374	1017	1	9.184	1011	-5	1010	1008	-8	-8	938	
Indian School	9.07	1004	8.62	1000	-4	8.327	1000	-4	8.005	999	-5	1002	1000	-4	-4	998	
Thomas	7.96	994	7.4	991	-3	7.267	988	-6	6.99	990	-4				-4		
McDowell	6.47	974	6.1	977	3	6.235	979	5	5.6945	974	0				0		
I-10	5.78	971	5.5	974	3	5.256	967	-5	5.2975	971	0				0		
Van Buren	5.27	967	5	966	-1	4.741	961	-7	4.7565	960	-7				-7		
Buckeye/MC 85	4.23	957	3.985	956	-1	3.741	954	-4	3.7405	952	-5				-5		
Lower Buckey	2.92	937	2.65	942	5				2.64	940	3				3		
Broadway	1.46	925	1.47	928	3				1.46	926	1				1		
Southern	0.39	914							0.39	912	-2				-2		
Gila Confluence	0	908								904	-4				-4		

Estimated River Alignment Locations
Deer Valley Road Topo - 2008
Pits - WEST Sediment Transport Study - 2000

***Minimum Pit Elevations are from Latest Available Topo and are Color Coded as to Origin**
Pit Elevations from 2008 Topo with Values Adjusted -2ft from NGVD 88

Agua Fria Floods	Date	Peak Flow Values El Mirage	Peak Flow Values Avondale	Source
Agua Fria at El Mirage	12/19/1978	58,400	29,300	USGS
Avondale Rd Gage	2/20/1980	41,800	44,200	USGS

Date	Peak Flow	Data Source	
9/3/1990	6,341	FCD	Buck. Rd
1/11/1993	5,329	FCD	Buck. Rd

Year	Peak	Source
1943	38,000	USGS WSP 2052

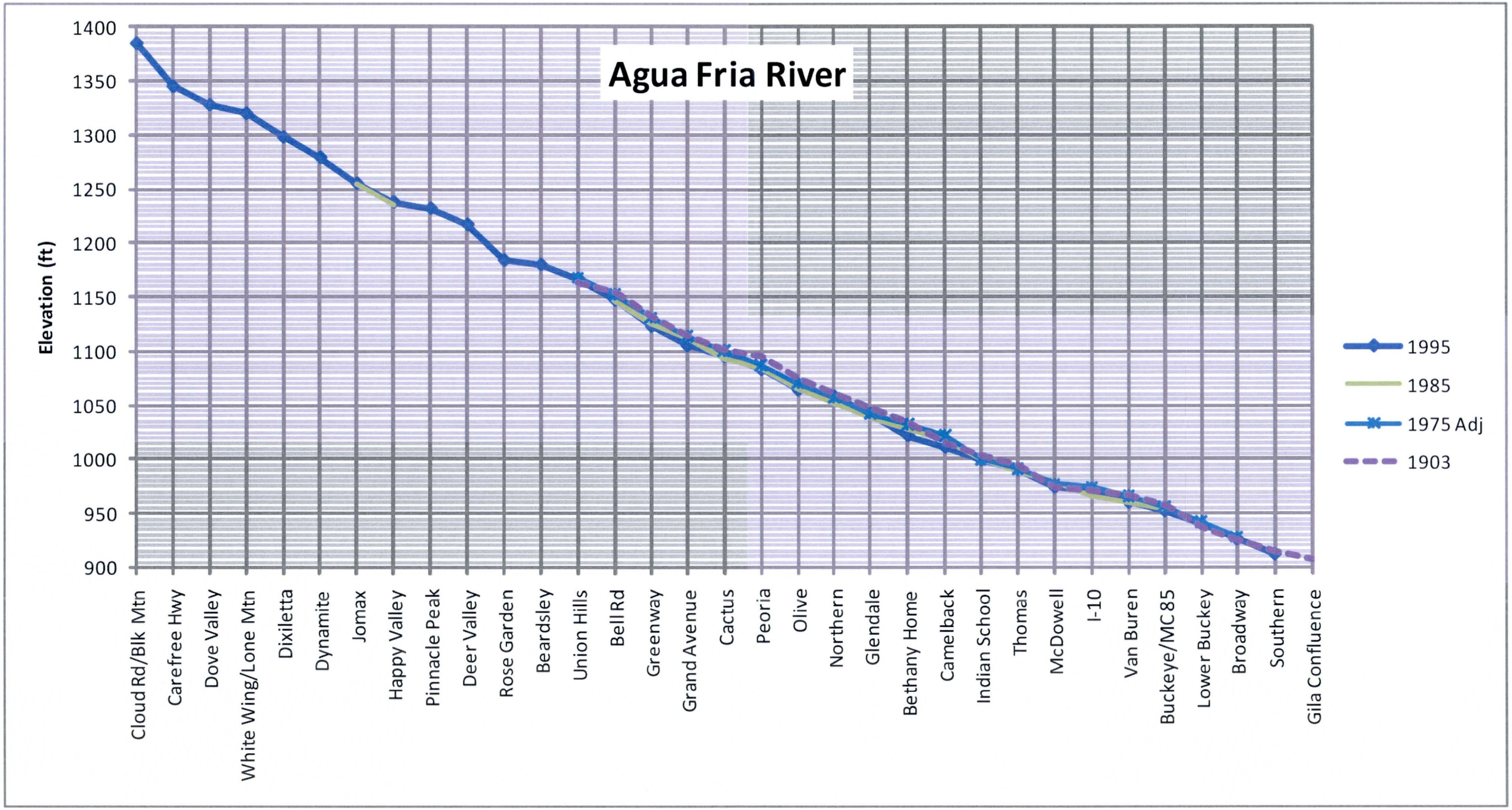

Figure 15. Thalweg Elevations for Agua Fria River from Gila River Confluence to SR 74.

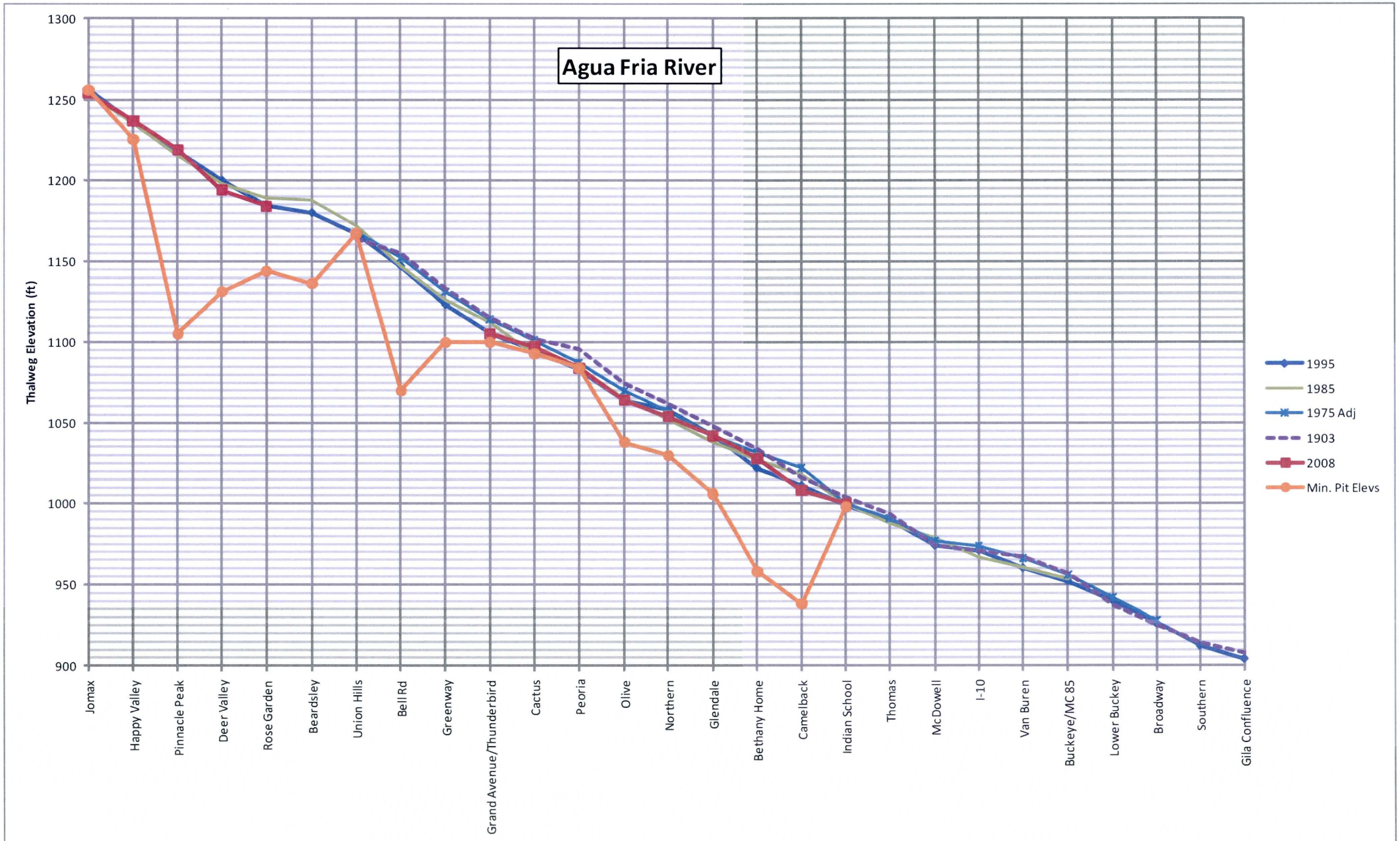

Figure 16. Thalweg Elevations for Agua Fria River 1903 through 1995 Showing Impacts of Mining Operations on River Bottom at Section Lines. Pit depths are from most recent topography – See Table 5 for more information.

SUMMARY AND CONCLUSIONS

The mining of sand and gravel from the rivers in Maricopa County in conjunction with channelization has lowered the Salt River profile by as much as 20-26 ft in some locations and caused both headcuts and tail cuts. Most of the river has lowered less than this amount with a more common lowering being on the order of 10-15 ft. The bed change along the Agua Fria River is currently significantly less than the Salt with most areas ranging from a few feet of deposition to about 12 ft of lowering. The lowering of the channels has, in some cases, reduced the floodplains and risk of flooding and therefore has not necessarily been a negative outcome. The problem occurs when the degradation has caused scour at bridges and other infrastructure and required expensive protection, repair, or replacement of the infrastructure. This scour / degradation has required the construction of grade control structures at Alma School Road, I-10, 19th Avenue, and other locations. The failure of the I-10 bridge just after opening was determined to be the result of the joining of a headcut from downstream with a tail cut from upstream.

SALT RIVER

The upper Salt River (above Loop 101) has experienced bed lowering ranging from 8 to 25 feet with the maximum being at the Dobson Road alignment. The average lowering for this reach is 15.5 feet. The middle portion of the Salt River (35th Ave to Loop 101) has also experienced significant lowering ranging from 0 to 25 feet. The average for this reach is 13.1 feet of lowering.

The lower Salt / Gila River (35th Ave to the Agua Fria confluence) has experienced less bed lowering than the other two sections analyzed. The bed change in this reach ranges from +2 ft to –7 feet with an average bed change of -1.8 feet. This limited lowering of the bed could be due to a number of reasons. These reasons could include the distance down the river from upstream mining operations, the fact that the river is still near its historical width, and/or mining may be reduced due to the difficulty of mining below the groundwater level. The inflowing sediment load from the Gila may also be preventing more bed reduction in this reach. The bed elevation in the confluence reach (99th and 107th Ave) has actually increased slightly (2 ft) while downstream of the confluence the bed elevations have decreased slightly (2 to 3 ft) over the 100 years of the data record. These changes are likely within the accuracy of the data, but may be due to vegetation growing in the channel causing deposition.

Numerous headcuts were noted along the Salt River above deep pits. Tail cuts were not noted but their location was not included in the scope of this report. The data is available such that tail cuts could be evaluated for the various pits along with the headcuts that were observed and noted in this report.

Based on the data obtained during this review it is our opinion that the amount of mining in the Salt River from 35th Avenue to Granite Reef Dam will preclude the river from resetting its bed to anything resembling its historic channel elevation. Any large future events will tend to average the bed to a new, significantly lower equilibrium level. Areas where drop structures have been constructed (Alma School Road to 19th Avenue) are not expected to undergo any significant change since the banks are protected to prevent lateral movement and drop structures will prevent further bed degradation.

AGUA FRIA RIVER

The Agua Fria River has experienced less channel lowering than the Salt River with the maximum channel lowering at the section lines being about 12 feet with the average lowering being on the order of 4.4 ft along the reach from Jomax to the Gila River confluence. The upper portion of the Agua Fria (Jomax to Bell Road) ranges from about a 2 ft increase to about an 8 ft lowering but this section is being actively mined and contains very deep pits. It is expected that the river will adjust after the next large flow event. The central portion of the river (Bell to Olive) has lowered the most of any reach along the river. The range for this reach is -5 to -12 ft with the average lowering being 9.6 feet.

GENERAL CONCLUSIONS

The lowering of the river systems in Maricopa County is obvious and can be seen in the data presented herein. The channel lowering has been a direct result of sand and gravel mining operations in the river channel and nearby. This has not been all detrimental, however; since flood risk has been reduced by the lowering of the channels and the construction of bank protection along some sections of the rivers.

The mining of sand and gravel from river deposits has had a significant impact on the stability and profile of the rivers in Maricopa County and will continue to have impacts into the foreseeable future even if mining in the rivers were to entirely cease. The unregulated mining along the various rivers can have extremely negative impacts on infrastructure (bridges, pipelines, bank protection, and other hard structures) as well as on the river profile itself. Even regulated mining can cause major problems with scour, deposition and bank erosion away from the property being mined if regulations and guidelines are improperly developed or applied.

This report is not designed or written to be anti-mining in its findings, explanation or summary. Regulated mining in accordance with a plan developed to consider all of the parties desire for development, flood control, recreation, and wildlife values can provide benefits for all the parties involved. This report is designed to present and discuss historical data from the perspective of developing better plans for the future that will aid the county and all other interested parties in developing the resources located along the

County's rivers and washes. The goal is to help provide an understanding of the impacts of the historical mining as a basis for decisions as to areas where the County and mining interests can work together in the development of sand and gravel mining guidelines that allow mining, promote the stability of the rivers, and protect adjacent property owners and infrastructure.

REFERENCES

Not all of the references cited in these lists were actually used in the analysis depending on the quantity, quality and applicability of the data. They are included here to provide a complete reference of the data sets that were found and available for use in this study. Some of the data was redundant or did not provide significant amounts of data in the areas of interest. Some data was redundant, such as portions of the County 10 ft contour data, since better data was available for most of the area reviewed. The 10' data was utilized for the central portion of the river and showed continued lowering of the river channel in the reach. Some data sets provided elevations at only one or two section lines and were thus utilized as necessary to assemble the best data set that was available for the study.

TOPOGRAPHY

Salt / Gila River (ordered by year)

Salt River Project 1903. Salt River Valley Arizona Topographic and Irrigation Map, Surveyed 1902-3, Sheet 1, Datum Mean Sea Level, Contour Interval 5 ft. Scanned and provided digitally by SRP.

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FCD 1990(1). White Tanks-Agua Fria ADMS, FCD 89-50, 2/10/1990, NAD27, Clarke 1986, NGVD29, Elvln-1003, North Bank and Channel, Agua Fria River to Dean Road.

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Baker 1991. Salt/Gila River Master Plan, FCD 92-01, 12/14/1991, NAD83, GRS1980, NGVD29, Full Coverage – Contour Interval = 4 ft). (See also Baker 1993, Baker 1997)

Scottsdale 1993. Scottsdale Mapping, IGA 93-07, 9/1/1993, NAD83, NAVD88, GRS 1980, Full Coverage – Between Rural and McClintock Drives (Not Used due to short section).

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FCD 1994. Maryvale ADMS, FCD 93-33, 3/28/1994, NAD27, Clarke 1866, NGVD29, Elvln-1005, Primarily North Bank and Some Channel at Agua Fria and Gila Rivers, 19th Ave to Agua Fria River.

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FCD 2000. Countywide 10 Food Contour Mapping, 12/17/2000, FCD xx-xx, NAD83, GRS 1980, NAVD88, Elvln-1208, Full Coverage- Above Granite Reef to Rainbow Road, Not Used due to wide contour spacing.

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FCD 2005. Rainbow Valley Mapping, 3/30/2005, FCD 03-67, NAD83, GRS 1980, NAVD88, Elvln-1226, West of Cotton Lane to Rainbow Road, South Bank and South Half Channel Data. Combine with El Rio for full Channel

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FCD 2008. Salt River Mapping, 6/21/2008, FCD 07-38, NAD83, GRS 1980, NGVD 29, Elvln-1289 – McKellips to I-10 (to Drop Structure) Primarily Channel Data.

Chang 2009. Fluvial-12 Simulation of Salt River near Gilbert Road Crossing, performed for The Flood Control District of Maricopa County.

Agua Fria River (ordered by year)

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USACE 1985. 1985 HEC-2 Study of the Agua Fria River, U.S. Army Corps of Engineers,

FCD 1985. White Tanks ADMS, FCD 95-05, 7/22/1987, Clarke 1866, NGVD29, West Bank of Agua Fria – Gila to Bell Road – No Channel Data – Not Used (Gila Channel Data Below Agua Fia).

FCD 1987. Agua Fria River FDS Re-Study, FCD 95-05, 2/22/1987, Clarke 1866, NGVD29, Gila River to Indian School Rd.

FCD 1991(1). AZ Canal Diversion Channel ADMS, FDC 90-10, 4/16/1991, Clarke 1866, NGVD29, East portion of channel/floodplain from one half mile south of Bethany Home to Glendale Road.

FCD 1991(2). Salt/Gila River Master Plan, FCD 92-01, 12/14/1991, NAD83, GRS1980, NGVD29, Gila River to one half mile north of Broadway Rd.

FCD 1994. Maryville ADMS, FCD 93-33, 3/28/1994, Clarke 1866, NGVD29, Agua Fria Channel and East Bank – Gila River to Approx Bethany Home Rd.

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Coe & Van Loo Consultants 1995. Agua Fria Floodplain Delineation, Model and Work Maps.

FCD 2000. Agua Fria FDS and Sediment Transport Study, FCD 99-48, 11/28/2000, GRS 1980, NGVD29, Cactus Road to Happy Valley Road.

FCD 2000-1. Glendale/Peoria Mapping, FCD 99-65, 1/10/2000, GRS 1980, NGVD29, one half mile south of Beardsley to Pinnacle Peak – East Bank – Not Used.

FCD 2002. Wittmann Mapping, FCD 01-21, 4/18/02, GRS 1980, NAVD88, West of Agua Fria River – Not Used.

FCD 2008, Pinnacle Peak Road Mapping, FCD 2007C038, NAVD 88, September 17, 2008 Photography. Not Used

FCD 2008, Agua Fria Boulevard Mapping, FCD 2007C038, NAVD 88, September 17, 2008 Photography, Jomax to Rose Garden and Grand to Indian School

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Aldridge, B.N., 1970. Floods of November 1965 to January 1966 in the Gila River Basin, Arizona and New Mexico, and the Adjacent Basins in Arizona, USGS Water Supply Paper 1850-C.

Hoffman and Miller Engineering (Hoffman), 1973. Salt River Channel, Tempe Bridge to Indian Bend Wash, Digital Hydraulic Model (Salt River Low Flow Channel, Mill Avenue to Hayden Road Hydraulic Report) (IBW)

Boyle Engineering Corps (Boyle), 1980. Central Arizona Water Control Study, Sand and Gravel Mining Guidelines, Prepared for the U.S. Army Corps of Engineers, Los Angeles District, FCD Call Number: A116.003

Boyle Engineering Corp. (Boyle), 1981. Preliminary Design Report for Hayden Road Bridge over the Salt River Hayden Road Bridge Scour Report. FCD Call Number: A125.601

CRSS Commercial Group (CRSS), 1980. Salt River Hydraulic Design Grade Control No. 4 to McClintock Drive Bridge, Draft Final Report. FCD Call Number: A125.603

Burgess and Niple, Inc., 1986, Upper Salt River Floodplain Delineation Study - Country Club Drive to Granite Reef Dam (HEC-2) (FDS), prepared for the Flood Control District of Maricopa County.

Simons, Li & Associates, Inc. (1989). Effects of In-Stream Mining on Channel Stability, Report HPR-PL-1-31 item 250, Prepared for Arizona Department of Transportation.

Michael Baker Jr., Inc. 1999. Salt-Gila River Floodplain Delineation Study, FCD-90-59, FCD 92-01. Topography from Granite Reef Dam to Gillespie Dam. Some pre-1993 flood (Granite Reef Dam to Mesa Drive and 24th St to Agua Fria Confluence) and some post-1993 flood (Mesa Drive to I-10 and 107th to 116th and other sections below Agua Fria).

JE Fuller/ Hydrology and Geomorphology, Inc. (Fuller), 2000, *Salt River Topographic Map Comparisons 1903 - 1993 (Includes Various Years Up to the Year 2000).*

JE Fuller/ Hydrology and Geomorphology, Inc. (Fuller), 2001, *Salt River Historic Channel Condition Maps 1934-2000 (Photo Comparisons); 1903-1997 (Topographic Map Comparisons)*, prepared for the Flood Control District of Maricopa County.

WEST, 2002, *Va Shly' Ay Akimel Hydraulic & Sediment Analysis – Final Without Project Analysis Report*, prepared for the Los Angeles District U.S. Army Corps of Engineers; September 20, 2002.

WEST 2002(b). *Modeling Sediment Transport in the Agua Fria River*, WEST Consultants, Inc., FCD 1999C048, Assignment #6.

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Chang, H. H., 2009, *FLUVIAL-12 Simulation of Salt River near Gilbert Road Crossing*, prepared for the Flood Control District of Maricopa County, August 2009. FCD Call Number: A126.969S

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Date Signed 7/13/11
ARIZONA, U.S.A.

Expires 6/30/2013

APPENDIX I

DISTRICT COMMENTS ON THE REPORT AND R2D RESPONSES

Flood Control District
of Maricopa County

MEMORANDUM

Date: December 13, 2010

To: Theresa Pinto, CFM, Project Manager, Planning Branch, Planning and Project Management Division

From: Richard Waskowsky, Hydrologist, Engineering Application Development and River Mechanics Branch, Engineering Division

CC: Bing Zhao, PhD, PE, Engineering Application Development and River Mechanics Branch Manager, Engineering Division

Subject: Sand and Gravel Mining Impacts: Historical Data Review and Analysis – by River Research and Design, Inc.

The Engineering Application Development and River Mechanics (EADRM) Branch received the revised submittal on December 13, 2010. The Branch has finished its review and has the following comments. The consultant should submit written responses (with digital copy) to these comments to the FCDMC. Comments that have been resolved have been shown in a gray font. All of the comments have been resolved.

1) **FCD Comment (September 10, 2009):** District staff would like the consultant to verify the Salt River thalweg change, which is given in previous studies (Fuller, 2000; Fuller, 2001).

   R_2D Response (November 20, 2009): The data from Fuller was taken as a starting point for the report. The Fuller data was added to the data table for the Salt River. Most values are very close if not identical. One of the data sets used by the Fuller review is the Baker data from 1995. This data includes both pre- and post-1993 flood data and was broken out for this study.

   R2D Submittal (February 16 and March 10, 2010)

   FCD Response (April 2, 2010): To compare the Fuller thalweg change and the thalweg change from the current study, please show the Fuller thalweg change on Table 1. Also, from the Fuller (2001) reference, the longitudinal channel length for the Salt River was much longer in 1903, than it was in 1999. Could the change in channel lengths from both studies be compared?

   R2D Response (April 26, 20010): The Fuller data was added to Table 1. The thalweg lengths from the Fuller Report from the Gila Confluence to Granite Reef Dam were 40.85 miles for the 1903 data and 38.3 miles for the 1999 data for a difference of 2.55 miles or about a 6% reduction in length over almost 100 years.

   The values for the Fuller study were located in a spreadsheet and compared with those obtained in this study. All of the values are now compared in Table 1. The only difference is at five locations which vary from 1 to 6 ft from the Fuller values. Based on the available maps our values disagree with the Fuller values at these locations. We have checked these values several times and think they are correct. (See Table 1 in the report.) Given the difficulty or reading the digital maps it may be that a review of the original paper maps may clarify the differences.

FCD Response (July 13, 2010): The Fuller-interpreted values from the 1902-03 SRP topography have been shown in Table 2 (Table 1 in previous submittals). However, the Salt River channel length comparison has not been provided in the current report. Please add a figure (similar to Figure 12) for the Salt River to document the channel length changes.

Also, was the 2001 Va Shly' Ay Akimel data taken from the HEC-RAS model or a TIN? From the 2001 HEC-RAS model, FCD estimates an elevation of ~1267 at Higley Road rather than 1256. Similarly, FDC estimates an elevation of ~1252 at Val Vista Road rather than 1241. Please verify the elevations in this Table.

Downstream of 24th Street, the latest topography is from 1994 and the majority of the topography is from 1990-1993. In this area should the 2001 10-foot contours be utilized?

R2D Response (November 29, 2010): The 2001 10 ft contours were added to the plot for areas identified and showed continued erosion in the area where more detailed and more recent data was not present. For the Salt River all elevation values were taken from contour data generated from the DEM data from the Fuller study. This data was checked and new cross sections cut along the road alignments. These cross sections showed very similar values to those in the report. Two values were updated slightly - Lindsay and Gilbert Roads which were 1238 (old 1239) and 1236 (old 1239) respectively. The values at Val Vista and Higley Road are for some deep low flow channels that show up clearly in the 2001 aerial photos. Whether the channels are natural or the result of mining is unclear but they were taken to be natural given the connectivity both upstream and downstream. It appears certain that the channel at Higley and Greenfield has been impacted by mining activities based on the 1902 elevations but the natural channel is no longer defined in those areas due to mining activities.

The channel length data from Fuller has been included in the report. No additional information was obtained regarding channel lengths on the Salt River during this study. A couple of numbers that were not shown in his spreadsheet were interpolated from the Fuller data to complete the new Table in the report (Table 2).

FCD Response (December 8, 2010): The Fuller Salt River channel length analysis has been included in the report. The FCD 10-foot contours have been utilized in the report. Comment resolved.

2) **FCD Comment (September 10, 2009):** Is the thalweg, which is reported in the R2D memorandum, the actual flow thalweg in the main channel or is it the bottom elevations of sand and gravel pits in the overbank area?

R2D Response (November 20, 2009): The data is the channel elevation. Elevations in floodplain gravel pits were ignored. At one cross section for one time period the section had been mined and after some thought the remnant of the natural channel was reported in the table and graphs. This was done to avoid a skew due to the single data point inside of the mine. Since the purpose of the study was to look at river behavior not mining depths this was thought to be an acceptable approach to the single point. Another line was added to the plot that shows the in-channel or near-channel mining depths where it is expected that the river will find a way (or has found a way) into the pits. Where the entire channel had been excavated and no natural channel could be found the bottom of the pit was used since that was now the channel bottom. The pit data is skewed near Dobson road as what appears to be a deep pit is filled with water. Aerial photos indicate this pit is likely well over 10 feet in depth but the actual depth is unknown.

The data for the minimum mine elevation does include some pits in the overbank, however; nearly all of the pits used were located in the river's active floodplain. The only exceptions were pits along the Agua Fria River in the lower portion of the mined reach near Indian School and Thomas Road where the pits may be in the overbank and possibly behind bank protection. All other pits were inside the active floodplain.

R2D Submittal (February 16 and March 10, 2010)

FCD Response (April 2, 2010): It appears that the data source for the minimum mine elevations taken was from 2001. Is this correct? In the picture (dated 1969) below, a gravel mine is in the middle of the channel (circled in red). For this example, the minimum elevation of the gravel should be included in the thalweg elevation.

R2D Response (June 2, 2010). It is apparent that numerous pits have been excavated along the river over time but the river thalweg was obtained at the road crossings to avoid the impacts of using pit elevations to determine the thalweg elevations. Only one pit was located at a crossing (Dobson Road) and only for one of the time periods where topography was available. All of the other pits were located away from the road alignments although they may have been very close to the alignment. The pit elevations were provided for comparison with the thalweg elevations. The pit elevations from either the 2001 or 2008 topography data (latest available) were used to illustrate the depth of the pits along the river. Other time frames could have been used for the pit depths but the most recent pit depths were used as indicative of potential future problems with channel lowering. The pit elevations were not intended to give historical perspective.

FCD Response (July 13, 2010): The method, which is used to analyze the bed change, is acceptable. However, for clarification, a note that explains the date (and source) of the maximum pit depth should be added to Table 2, Table 4, Figure 4 and Figure 14.

Additionally, the major floods that are listed in Tables 2 and 4 should be clarified. For example, the dates are not given for the Verde River flood data. The 1/21/1993 data for the Salt River below Stuart Mountain Dam is not the maximum for 1993, rather it appears that a 44,500 cfs peak occurred on 1/18/1993. Is the flood data that is listed at Alma School Road actually from Priest Road? It may be clearer if the only data that is shown for the Salt/Gila River are from gauges below Granite Reef Dam; and, if possible, more data from floods other than the 1993 and 2005 floods should be shown. Also, the source should be listed for the flood data in Table 4.

R2D Response (November 30, 2010): The note regarding where the pit depth data was obtained was added to Table 3, Figure 5, and and clarified in Figure 15. The source is color coded in Table 5 but a clarification was added to better emphasize the source data.

The dates were added to the Verde River Flood Data in Table 3. The source of the data used for the table was clarified by color coding. All of the data came from the USGS NWIS server with the exception of a few data points from the District server. The Salt River below Stuart Mountain Dam was selected to cover periods where data was not available further down the river. If data were available for all of the floods at Alma School or Priest those gages would have been used

since all of the flow was combined from the Salt and Verde Rivers at that point. The Priest Road data is from 1993 to present, Alma School 1991-1993, etc. with the only good gage data being below Stuart Mountain Dam for earlier periods which is why we included Verde flows as well.

FCD Response (December 8, 2010): The tables and figures have been clarified. Comment resolved.

3) **FCD Comment (September 10, 2009):** It seems that there are other reports that may be useful to determine the bed elevation change. Some examples of these reports are the bridge scour assessments by MCDOT (available in FCD library or from MCDOT) and the 1986 HEC-2 model by Burgess and Niple (1986).

R2D Response (November 20, 2009): We have contacted ADOT in regards to bridge information and it has been supplied but was not incorporated into the data for the draft. Information was obtained for the Mill Street to Scottsdale Road reach for 1972 and additional bridge information is being located. The topography from the Burgess and Niple (1986) study was incorporated into the report. The inclusion of the bridge reports would add value to the report but they obviously cover only one location and often do not provide additional data that would be beneficial. If the District desires additional bridge data could be included in the final report.

R2D Submittal (February 16 and March 10, 2010)

FCD Response (April 2, 2010): The additional topography data should be added to the report because any available data should be analyzed. However, since the data is localized, perhaps it would be better to have the localized data in a separate section, such as "Detailed Topography at Localized Locations."

R2D Response (June 2, 2010): As we discussed at a review meeting, it has been determined that the data would take more time to obtain and analyze than the value of the data to the study. The data requires the copying of each bridge inspection report, analyzing each report for the thalweg elevation, and insuring that the elevation is in the correct datum. Most of the bridges are relatively recent – especially in the area of interest and thus the data do not added a large amount of value to the analysis compared to the amount of time required to obtain and analyze the data. The topography covers most bridge locations back to 1982 for the Salt/Gila and 1975 for the Agua Fria. Only a few of the bridges pre-date this topographic data.

FCD Response (July 13, 2010): As was discussed in the review meeting, it was decided that including the localized data would require much more work without an appreciable gain in information. Therefore, the localized data was not included. Comment resolved.

4) **FCD Comment (September 10, 2009):** On page 2 of the memorandum, it is indicated that no data was found upstream of Mesa Drive subsequent to the 1993 flood. However, in JE Fuller (2008), it is indicated that a TIN, which was developed from data flown in December 2001, exists for the reach from Loop 101 to Granite Reef Dam. Therefore, it is recommended that the WEST (2002), JE Fuller (2008) and Chang (2009) reports be reviewed as part of this study.

   R2D Response (November 20, 2009): This data was located and incorporated into the report. The District's assistance in the location and inclusion of this data is appreciated.

   R2D Submittal (February 16 and March 10, 2010)

   FCD Response (April 2, 2010): The data has been added to the report. Comment resolved.

5) **FCD Comment (September 10, 2009):** For the data sources in the text, could citations be placed with them in order to more closely tie them to the Appendix? Also, in the Appendix, could the author and date be listed first for each data source?

   R2D Response (November 20, 2009): The data will be cited in the report and the author and date will be moved to the first position in the list of data references.

   R2D Submittal (February 16 and March 10, 2010)

   FCD Response (April 2, 2010): The author and date has been moved to the first position. However, not all data sources are listed in the REFERENCES section. For example, the USACE, 1965 reference is not shown in the REFERENCES section. Also, it appears that all the sources are not cited in the text. For example, the Baker study on page 4 does not have a citation. To help the readability of the report, please add all citations and references to the report.

   R2D Response (June 2, 2010): The REFERENCES section includes a lot of data sources that were reviewed and the sources may or may not have been actually used in the final analysis. The removal of these items from the lists would leave a future reader uncertain if the data was available for use or was found. This could lead to future researchers reanalyzing significant amounts of data that were not helpful in this review. R2D would prefer to leave the data that has not been cited in the report in the references section to avoid this confusion in the future. A statement to this effect has been added in the References section.

FCD Response (July 13, 2010): A statement that clarifies how the data sources have been used has been added at the beginning of the REFERENCES section. Comment resolved.

6) **FCD Comment (September 10, 2009):** At the bottom of page 3 of the memorandum, it is indicated that the "maximum estimated error being on the order of ±0.2 miles and a vertical error of perhaps ±2 feet." Could a table, which supports how these estimates were developed, be added to the text? Similarly, on page 4, could a table that supports the vertical datum comparison be added to the text?

R2D Response (November 20, 2009): An explanation of the derivation of these estimates was included in the text.

R2D Submittal (February 16 and March 10, 2010)

FCD Response (April 2, 2010): The numerical estimates of error have been removed. However, having these numerical estimates gives the reader an idea on the accuracy of the bed change estimates. Could these estimates, as well as a table, which supports how these estimates were developed, be added to the report?

R2D Response (June 2, 2010): The estimates of error were comparable with the error associated with the topography (4 ft contours). The data used developed to estimate River Miles for the Agua Fria River is included in the report but since initial estimates were based on using an estimate of the river mile at the road section based on the distance between the upstream and downstream bridges any error in the initial estimate is not directly related to the error of the data and results. The estimate of adjustments in the river mile location is intended to show that while some adjustment was required the errors are on the same order as the errors in the underlying data. A table of how the river mile data varied from the original estimate does not exist as it was lost during the adjustment process.

A table was also developed for the conversion of the elevation datums and included in the vertical datum discussion on page 9 of the report.

FCD Response (July 13, 2010): The datum conversion has been clarified on pages 7 and 8, and more discussion has been added about the error estimates for the Agua Fria River. Comment resolved.

7) **FCD Comment (September 10, 2009):** The 2001 countywide 10-foot contours should also be given at least a cursory analysis to either supplement more detailed data or give an estimate of bed change when more detailed data does not exist.

R2D Response (November 20, 2009): The data was reviewed but for most areas more detailed data was available. For areas where more detailed data doesn't exist the countywide 10' contour will be utilized.

R2D Submittal (February 16 and March 10, 2010)

FCD Response (April 2, 2010): In the November R2D response, it is indicated that the countywide 10' contours will be utilized. However, on page 28 of the report, it is indicated that these contours were not used. Were these contours utilized? Please add a brief discussion about this data in the DATA COLLLECTED section, and why (or why not) this data was used.

R2D Response (June 2, 2010): In reviewing the data it became apparent that the 10 ft contours did not provide any data that was not available from other sources and thus was not utilized. A statement to this effect was added to the report.

FCD Response (July 13, 2010): The use/non-use of the references has been clarified in both the DATA COLLECTION AND DISCUSSION section and the REFERENCES section. Comment resolved.

8) **FCD Comment (September 10, 2009):** For the Agua Fria River, much of the reach downstream of Indian School Road has grade control structures in it, and therefore a lot of bed change is not expected. More discussion that documents this condition should be added to the memorandum.

R2D Response (November 20, 2009): Additional discussion will be added to the report to clarify this factor and discuss the implications for river stability in this reach.

R2D Submittal (February 16 and March 10, 2010)

FCD Response (April 2, 2010): Additional discussion has been added. Comment resolved.

9) **FCD Comment (September 10, 2009):** Based on the two aerial photographs below, it appears that significant bed degradation occurred at Rural Road. However, from Table 2 of the memorandum, it is indicated that 5 feet of aggradation occurred at Rural Road from 1902-1982.

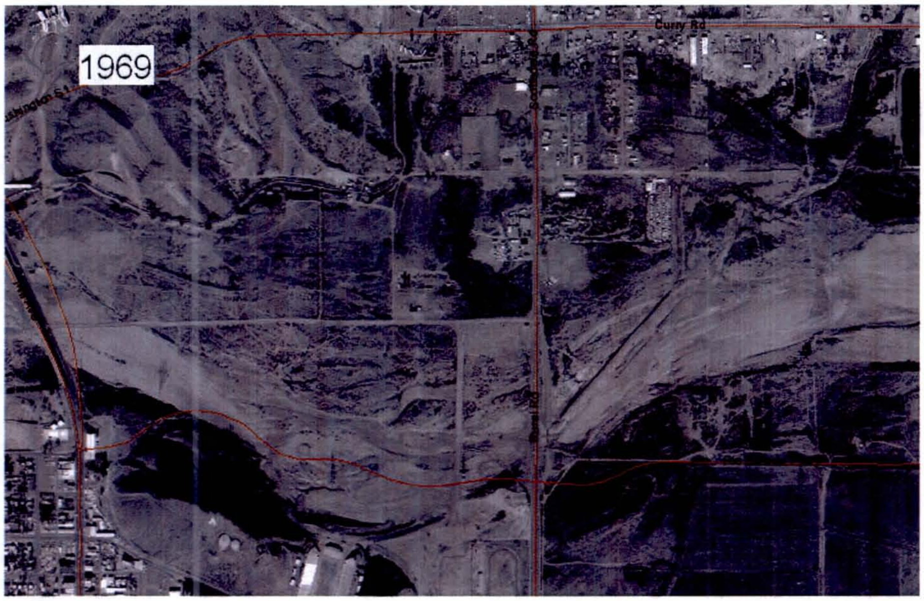
R2D Response (November 20, 2009): This was investigated further to check the data and make sure the data used for this location is correct. From the photos it is apparent that significant lateral movement of the channel occurred in this period. The 1969 photo would indicate that the channel had moved very far south and should show a lowered thalweg near the ASU stadium when compared with the more channelized appearing 1970 photo. The thalweg of both configurations would likely be close to the same since river seemed to be in dynamic equilibrium with the exception of the gravel mining impacts.

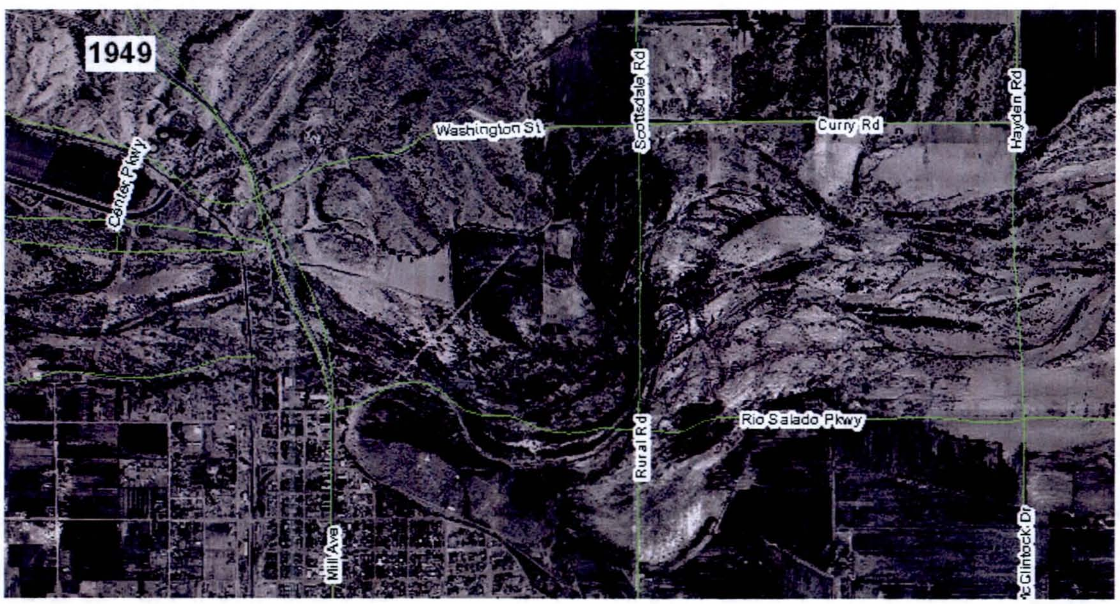
R2D Submittal (February 16 and March 10, 2010)

FCD Response (April 2, 2010): From the additional picture below (dated 1949), the statement that the river is in "dynamic equilibrium" seems hard to believe. Before 1949, the river appears much wider and much more sinuous. After 1979, it appears the river became much straighter and much more incised. Were the changes in the river from the early part of the century to the latter part of the century mainly from gravel mining impacts or were they from the upstream dams? Either way, the statement that the river is in dynamic equilibrium (at least at this location) seems suspect. Please clarify the overall changes in the river from the 1903 SRP topography to present day.

R2D Response (June 22, 2010): The use of the term dynamic equilibrium was indicated to indicate that the river is relatively stable in terms of channel profile rather than width and alignment. Even though the river has exhibited significant lateral changes in alignment and width it can still be in dynamic equilibrium. The behavior noted above occurs regularly in rivers in the southwest and does not necessarily mean they are not in dynamic equilibrium. The changes noted are not inconsistent with channel changes noted in historical aerial photos of the Salt River through the Phoenix area. The changes may have had more to do with impacts other than mining. For example the 1969 photo shows a significant berm directing flow to what appears to be a bridge on the south end of the Rural Road crossing. This would account for the 12 ft of scour noted in the report as well as directing the flows into the south bank which would further erode the south bank downstream from the bridge. The changes between the 1949 and 1969 photos clearly show the encroachment of development into the area. Even in the 1969 photos you can still see the meander loop from the 1949 photo but homes and/or businesses have been constructed in what was, in 1949, river channel. These changes have nothing to do with gravel mining. Whether the river was in dynamic equilibrium for this period cannot be absolutely determined from the available data but given the long term stability of the river channel in the vicinity of Scottsdale/Rural Road the river would appear to be in dynamic equilibrium even though it has undergone substantial changes in planform and width in the area.

FCD Response (July 13, 2010): The historical bed changes of the Agua Fria and the Salt Rivers have been clarified in Tables 2 and 4, as well as in the summary. Comment resolved.





10) **FCD Comment (April 2, 2010):** In the second paragraph on page 6, there are conclusions, which state that most of the floods filled the pits and any headcut/tailcuts were propagated. More discussion, which explains what these conclusions actually mean, should be added. More data, which supports the conclusions, should be provided. Since the Boyle reference does not seem to agree with the conclusions, more explanation about the inclusion of the Boyle reference (in this location) should be provided. Please also list the magnitude of the floods as well as the year.

R2D Response (June 22, 2010): The statement was revised and clarified. A reference to the Boyle report was included and additional discussion added including a statement (with the reference) that the existing pits filled during the 1965-66 flood.

FCD Response (July 13, 2010): The section on page 6 (page 4 in June 2010 report) has been expanded and clarified. Comment resolved.

11) **FCD Comment (April 2, 2010):** On some pages (e.g., page 16), the footer line did not print. Because of the text in the footer, the report would be clearer if the foot line was shown.

R2D Comment (June 22, 2010): The formatting was reviewed in order to correct issues with readability and consistency.

FCD Response (July 13, 2010): The footer line has been shown on all pages. However, there are some minor spelling and grammatical errors in the report. Some examples are listed below.

1) On page 2 in the first paragraph, "the" does not need to be capitalized before Salt River Project,
2) In the last paragraph on page 2, "a" is not necessary before digital form.
3) In the last paragraph on page 3, "ft" should be added after the elevations and the 12 ft elevation change.
4) In last sentence of the second paragraph on page 6, "delineation" is misspelled.
5) In the first sentence of the third paragraph on page 10, "his" should be "this."
6) In the first paragraph on page 18, it appears "Figures 8 – 10" should be either "Figures 8 – 11" or "Figures 9 – 11."
7) In the last sentence of the second paragraph on page 18, Figure 11 should be referenced rather than Figure 10.
8) In the first paragraph on page 22, the second sentence is unclear and should be revised.
9) In the first sentence of the second paragraph on page 22, there should be a space between "and" and "1993."
10) In the fourth sentence of the third paragraph on page 22, "conjunction" is misspelled.
11) On page 24, both references to Table 3 (in the first and second paragraphs) should actually reference Table 4.
12) In the first paragraph on page 28, the third sentence is confusing because the subject indicates lowering of the Agua Fria River but then deposition is also mentioned. This sentence may be clarified by changing "lowering" to "bed change."
13) In the second paragraph on page 28, the minus symbols (before 15.5 feet and 25 feet) are not necessary since the bed change is already classified as lowering. However, the

average of 13.1 feet should be clarified as an average lowering. Basically, in this section, the use (or non-use) of the minus symbol should be consistent.

14) Figure 13 should include a label on the y-axis.

Please make the above corrections and, if necessary, check the report for other errors.

R2D Response (November 30, 2010): The requested corrections were made and the document checked for other spelling and grammar errors.

FCD Response (December 8, 2010): Most of the corrections have been made. However, there are a few minor errors that should be corrected. They are:

a) The caption for Figure 6 indicates that pit elevations are only shown upstream of Loop 101. However, it appears that pit elevations are shown at 27th Avenue and 59th Avenue.

b) In the first sentence of the last paragraph on page 17, it appears the Figure 11 should be either Figure 7 or Figure 10.

c) The footer line should be shown on pages 19, 20 – 24.

d) In the last sentence of the last paragraph on page 27, it appears that Table 4 should be Table 5.

e) In the second sentence of the last paragraph on page 32, should this sentence read "Tail cuts were noted…"?

Please correct these minor errors.

R2D Response (December 13, 2010): The minor corrections were made as requested.

FCD Response (December 13, 2010): All of the revisions have been made. Comment resolved.

References:

Burgess and Niple, Inc., 1986, Upper Salt River Floodplain Delineation Study - Country Club Drive to Granite Reef Dam (HEC-2) (FDS), prepared for the Flood Control District of Maricopa County

Chang, H. H., 2009, *FLUVIAL-12 Simulation of Salt River near Gilbert Road Crossing*, prepared for the Flood Control District of Maricopa County, August 2009. FCD Call Number: A126.969S

JE Fuller/ Hydrology and Geomorphology, Inc. (Fuller), 2000, *Salt River Topographic Map Comparisons 1903 - 1993 (Includes Various Years Up to the Year 2000)*.

JE Fuller/ Hydrology and Geomorphology, Inc. (Fuller), 2001, *Salt River Historic Channel Condition Maps 1934-2000 (Photo Comparisons); 1903-1997 (Topographic Map Comparisons)*, prepared for the Flood Control District of Maricopa County.

JE Fuller/ Hydrology & Geomorphology, Inc. (Fuller), 2008, *Va Shly' Ay Akimel Salt River Ecosystem Restoration Project – Phase I: DRAFT Design Documentation Report Hydrologic and Hydraulic Analysis Appendix*, May 2008.

WEST, 2002, *Va Shly' Ay Akimel Hydraulic & Sediment Analysis – Final Without Project Analysis Report*, prepared for the Los Angeles District U.S. Army Corps of Engineers; September 20, 2002.