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Risk to Structures Due to Mining Pits Between Bell Road and Grand Avenue on Agua Fria River, Arizona

Submitted to

Flood Control District of Maricopa County
2801 W. Durango Street
Phoenix, AZ 85009

Submitted by

PBSJ

9275 Sky Park Court, Suite 200
San Diego, CA 92123
David T. Williams, PhD., P.E., CPESC, DWRE
Leo R. Kreymborg, P.E., CFM

Registered Professional Engineer (Civil)
CERTIFICATE NO. 24349
DAVID T. WILLIAMS
Date Signed 4/14/06
ARIZONA U.S.A.

TABLE OF CONTENTS

Section		Page
1.0	Introduction	1
2.0	Acknowledgments	1
3.0	Background	1
4.0	Collection and Rectification of Workmaps	4
5.0	Channel Changes Due to Natural and Mining Activity	4
5.1	Channel Changes From 1964-1965 to November 2000	4
5.2	Mining Activity Since 2000	5
5.3	Adjustments to the Mining Pit Geometry for Analyses	6
6.0	Headcut Calculation Methodology	7
6.1	Arizona Department of Transportation Method	7
6.2	Simons, Li & Associates Method	8
6.3	W. J. Mckeever Method	9
6.4	Hydrographs and Return Frequencies	10
7.0	North Pit Evaluation	11
7.1	General Description of North Pit	11
7.2	Anticipated Headcut Path From the North Pit	13
7.3	Adot Method for Headcut	13
7.4	Simons & Li Associates Headcut Method	16
7.5	Mckeever Headcut Method	16
7.6	North Pit Bend Scour Potential	16
8.0	South Pit	16
8.1	South Pit Bend Scour Potential	20
9.0	Risk to Other Structures	21
10.0	Potential Obstructions to Flow	23
11.0	Status of Pits Compared With FCD Sand and Gravel Guidelines	24
12.0	Historical Bridge Impacts From Mining Activities	24
13.0	Summary	26
14.0	References	27

Figure **Page**

Figure 1. Site Map with major pit boundaries as of November 2000. Background photo is from November 2004. 3

Figure 2. Profiles along current baseline. Dips in the 1964-65 profiles at about 11,000 to12,000 feet along baseline are due to mining pits in the 1964-65 topography. 5

Figure 3. Expansion the of North Pit. Bell Road is at the top of the image. Agua Fria River flows from top to bottom. 6

Figure 4. Picture of north end of North Pit, looking northeast. Power lines in background are along the south side of Bell Road. Photo taken February 24, 2006....7

Figure 5. Schematic of headcut and tailcut for ADOT method. Streamflow is right to left. 8

Figure 6. Simons, Li & Associates graphs. 9

Figure 7. Illustration of McKeever technique. 10

Figure 8. North Pit. Colored outlines represent pit limits as of November 2000. Background image is from November 2004. 12

Figure 9. Profile of North Pit. The bottom of the black line representing Bell Road is the elevation of the bridge's pier footings at 1136.5 feet 14

Figure 10. South Pit....17

Figure 11. Cross-section of channel near upstream end of the south pit....19

Figure 12. Profile of South Pit along the assumed streamline through the South Pit 20

Figure 13. High tension power lines south of Bell Road, seen as faint lines. The pole in the river can be seen by the shadow it casts onto the bridge. 21

Figure 14. Possible headcut progression from east pit. 22

Figure 15. Possible headcut progression from southeast pits....23

Figure 16. Schnepf Road Bridge over Queen Creek in February 2005, after headcut reached the Queen Creek Bridge. 25

Figure 17. Schnepf Road Bridge over Queen Creek, 2006. 25

Tables **Page**

Table 1. Pit Data.... 11

Table 2. North Pit headcut, ADOT method, assuming 32.3 foot pit depth.... 15

Table 3. North Pit headcut, ADOT method, assuming 45 foot pit depth.... 15

Table 4. McKeever Method headcuts at Bell Road due to North Pit.... 16

Table 5. Major non-conformances with FCDMC Sand and Gravel Guidelines.... 24

1.0 INTRODUCTION

This study was performed for the Flood Control District of Maricopa County (the District) under contract 2005C031. Among its many duties, the District is responsible for health and safety issues related to any activities within the rivers and floodplains of Maricopa County. Of particular concern to the District is the presence of mining pits between Bell Road and Grand Avenue within the floodplain of the Agua Fria River. Floodwaters could enter these pits and "capture" the river. River capture by the pit just downstream of Bell Road could induce a headcut that would migrate upstream and cause the failure of the Bell Road Bridge or a high-tension power line pole which is just south of Bell Road. Also, if the river is captured by the pit just upstream of Grand Avenue, a tailcut would form, progress downstream, and could cause the failure of the Grand Avenue Bridge or the railroad bridge which is just north of Grand Avenue. There are also some mobile home and trailer parks which could potentially be endangered due to headcuts from pits along the eastern edge of the Agua Fria floodplain. This study documents an investigation to determine the potential of headcuts or tailcuts which could endanger these various structures.

2.0 ACKNOWLEDGMENTS

Dr. David T. Williams, P.E., was the Project Manager for this study and was responsible for the overall technical approach. He was assisted by Mr. Leo R. Kreymborg, P.E., who did most of the computations and spreadsheet development as well as wrote major portions of this report. Mr. Eric Coughlin, Ms. Heather Duarte, and Mr. Kyle McCarty assisted in digitizing and rectification of maps as well as GIS layouts. Ms. Debbie Surrell assisted in the development of the charts and figures. Mr. Joseph Tram, P.E., was the main contact for the District.

3.0 BACKGROUND

A number of mining pits have been excavated off the main banks of the Agua Fria River between Bell Road and Grand Avenue. The major pits in the region were identified and are shown in Figure 1. Left and right designations are in terms of looking in the downstream (approximately southern) direction of flow. These pits are referred to as:

(1) The North Pit, which is just downstream of Bell Road on the left (west) bank, parallels the Agua Fria River for about 1 mile.

(2) The South Pit, which is the pit upstream of Grand Avenue on the right (east) overbank of the river, parallels the Agua Fria River for over 3,000 feet.

(3) The West Pit.

(4) The East Pit.

(5) The Southeast Pits.

An inspection of the pits and topography identified the North Pit as a possible threat to Bell Road bridge and a pole supporting a power line (located just downstream of the bridge) due to the possible formation of a headcut which could migrate upstream of the North Pit. The South Pit was identified as a possible threat to the Grand Avenue bridge and a railroad bridge (located just upstream of Grand Avenue) due to the possible formation of a tailcut which could migrate downstream of the South Pit. The West Pit, East Pit, and Southeast Pits are considered a lesser danger to major structures, although the East Pit and Southeast Pits are fairly close to a mobile home park and trailer park. The potential threats posed by the East Pit and Southeast Pits are due to headcuts which could proceed upstream, which would then erode areas adjacent to the parks, and would then lead to bank failure. The conceptual descriptions of what are headcuts and tailcuts are presented later.

All elevations in this report are NGVD 1929, feet.

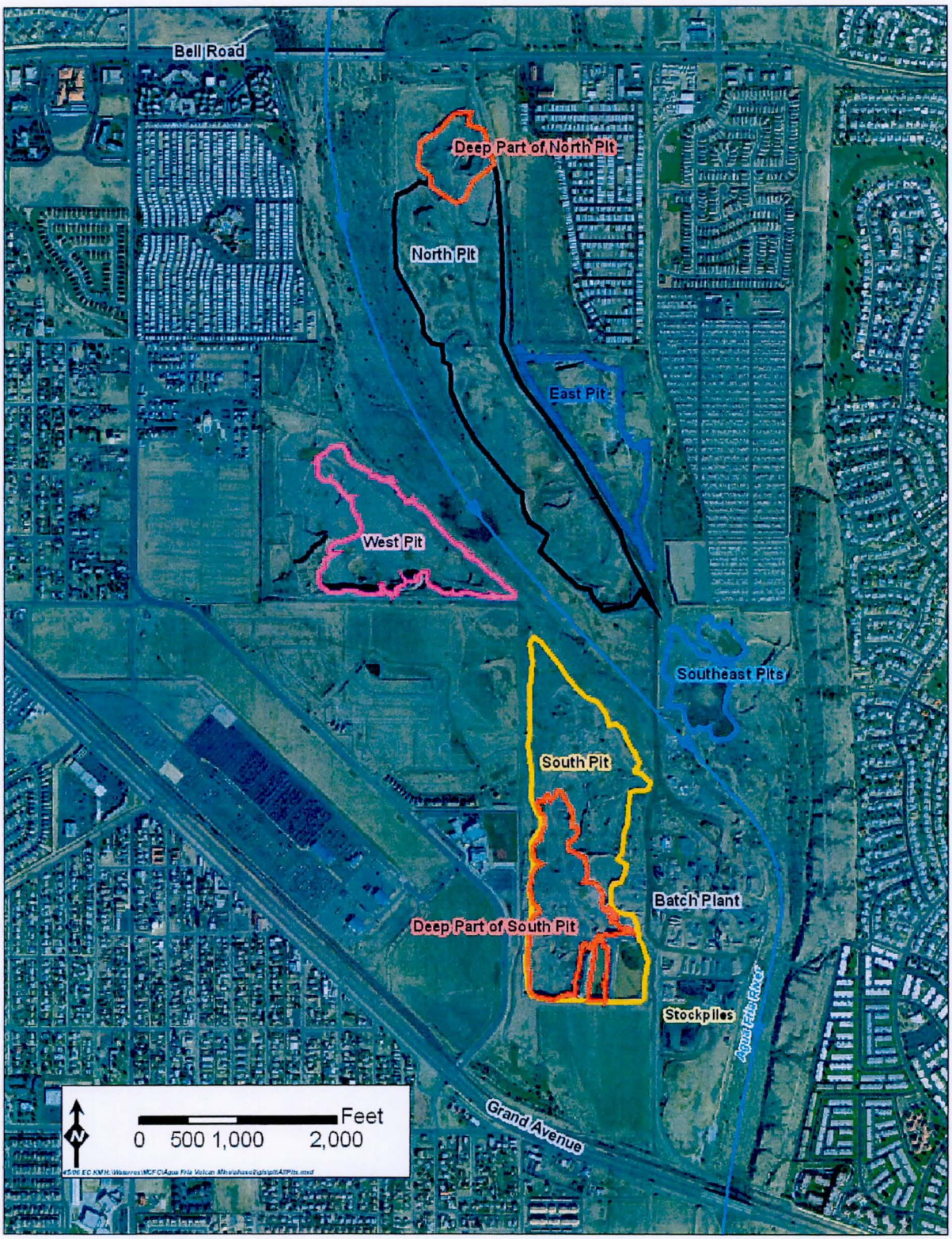

Figure 1. Site Map with major pit boundaries as of November 2000. Background photo is from November 2004.

4.0 COLLECTION AND RECTIFICATION OF WORKMAPS

There were multiple sources of data from which the progression and extent of mining activity could be deduced:

(1) Paper topographic maps, one from 1964 and one from 1965 (referred to as the 1964-1965 workmaps). These maps were at 5-foot contour intervals and also had spot elevations called out on them. The 1965 workmap covers the southern part of the reach (in the region of Grand Avenue), while the 1964 workmap covers the region farther to the north.

(2) Detailed topography from November 2000 (FCDMC November 2000). This topography was available as 3-dimensional lines and breakpoints in GIS and was commissioned by the District. Of the various sources of topography for this reach, this was the highest quality topography available.

(3) Printed maps from Vulcan Material which reflects topography from December of 2003 (Vulcan December 2003). Presumably, this topography is available in digital (GIS or CAD) format, but the digital version could not be obtained in time for the preparation of this report.

(4) Color orthorectified aerial photographs from November of 2004.

(5) A field visit which was made in February of 2006.

The mining activity and other changes in the topography from 1964-65 until November 2000 was assessed by comparing the 1964-65 flood workmaps to the November 2000 topography. The 1964-65 workmaps were electronically scanned. These two scans were then georeferenced using the grid coordinates which were printed on the maps.

While the grid tic coordinates on the 1964 map appeared to be accurate, the 1965 map tics appears to be incorrectly registered by approximately 60 feet. The 1965 maps were georeferenced again using three visual topographic cues; Based on comparisons with features in the rectified images versus the November 2000 topography, the final rectified images are believed to be accurate typically within 10 to 25 feet, though they may be regions were the discrepancy is greater.

5.0 CHANNEL CHANGES DUE TO NATURAL AND MINING ACTIVITY

5.1 Channel Changes from 1964-1965 to November 2000

Examination of the channel (see Figure 2) shows that it has degraded in almost the entire reach, from 1964-65 to November of 2000, by approximately 5 to 10 feet. Elevations in the far west overbank were very similar between the 1964-65 topography and the November 2000 topography, so the differences in elevations appear to be confined to the channel and it is not the result of a datum error or settlement of the region.

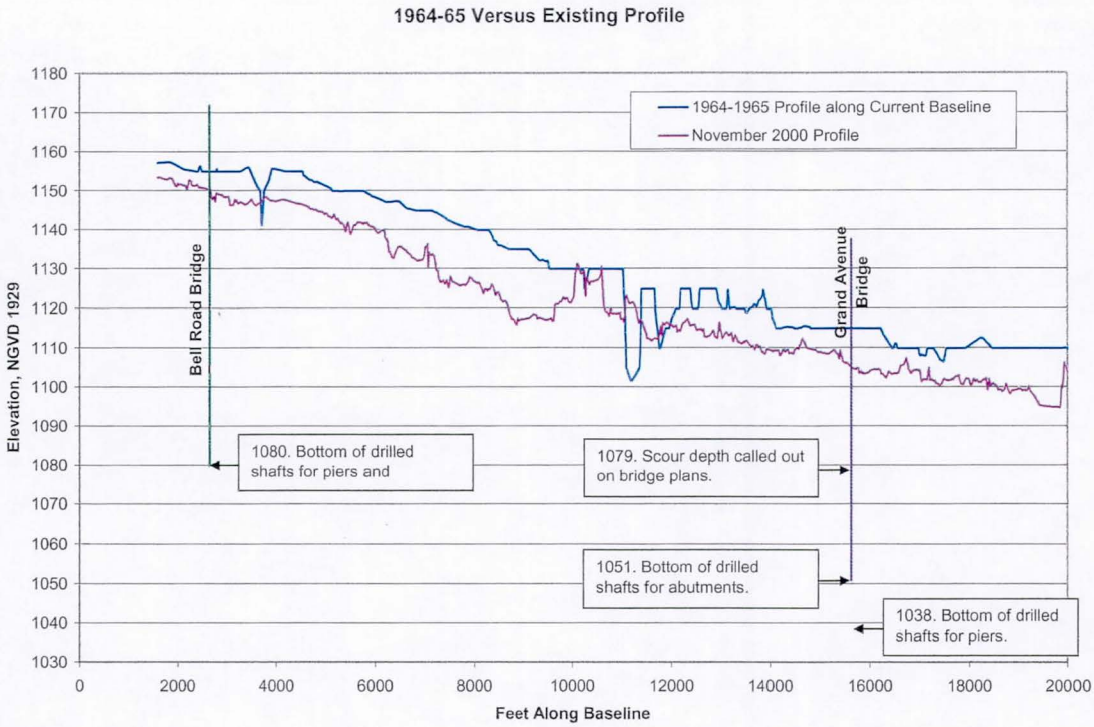

Figure 2. Profiles along current baseline. Dips in the 1964-65 profiles at about 11,000 to12,000 feet along baseline are due to mining pits in the 1964-65 topography.

5.2 Mining Activity Since 2000

The aerial photographs that are used as backgrounds for the figures were taken on November 29, 2004. The FCDMC topography was flown on November 28, 2000, almost exactly 4 years before the aerial photographs. The difference in dates between these two sources allows for some limited assessment of the mining activity between these dates. For example, the Southeast Pits have been extended farther to the east since 2000. The West Pit has extended farther to the west since 2000. These two changes can be seen in Figure 1. Most significantly, the North Pit has been extended farther north and, therefore, closer to Bell Road. The expansion of the North Pit is illustrated in Figure 3. The black line in the figure is the approximate pit boundary in November 2000. The red line is the pit boundary in December 2003 and was digitized from a rectified version of the Vulcan topographic maps. The background photograph is from November 2004. Note in particular the significant expansion to the north of the pit toward Bell Road in less than one year from December 2003 to November 2004. As of November 2004, the pit boundary is from 250 to 300 feet south of Bell Road.

Figure 3. Expansion the of North Pit. Bell Road is at the top of the image. Agua Fria River flows from top to bottom.

It is difficult to assess how much excavation has occurred since the November 2004 aerial imagery was taken. There was a field visit in February of 2006, but this visit was of limited usefulness in assessing progression of mining activity. Figure 4 shows a ground picture of the North Pit taken in February 2006, looking northeast toward Bell Road.

5.3 Adjustments to the Mining Pit Geometry for Analyses

For the purposes of headcut and tailcut calculations, the November 2000 topography was used for overall volumes and configurations of the pits. However, the distance from the upstream limit of the North Pit to the Bell Road Bridge (the anticipated path of the headcut) was reduced to more closely match the November 2004 aerial photographs.

Figure 4. Picture of north end of North Pit, looking northeast. Power lines in background are along the south side of Bell Road. Photo taken February 24, 2006.

6.0 HEADCUT CALCULATION METHODOLOGY

Headcutting is a complex phenomenon and analytical models such as sediment transport models are not well suited for the task. Most estimates of headcuts are empirically derived formulas or procedures based on the characteristics of previously observed headcuts. Three such methods were used to examine the potential depth and longitudinal extent of headcuts in the study reach.

6.1 Arizona Department of Transportation Method

The Arizona Department of Transportation (1989) describes a procedure developed for the estimation of short-term longitudinal channel response due to instream mining. This procedure was also published in Cotton and Ottozawa-Chatupron (1989). The procedures are hereafter referred to as the ADOT method. The procedure was developed using a simulation model formulated specifically for the hydraulic conditions typical of mined river reaches in Arizona. The model was calibrated using data from mined river reaches in sand bed and gravel bed

channels throughout Arizona. Simulations were then conducted to create several synthetic data sets from which general dimensionless relations were developed. Formulas for the maximum depth and distance of scour upstream and downstream of an instream excavation for a flood hydrograph could then be determined and applied. In the ADOT method, the regression equations for the case of a sand bed channel with a sediment gradation of D_{50} = 1 mm are presented. From the model simulations, limiting conditions for scour were found for headcutting. Headcutting is limited to no more than half the excavated depth due to deposition from the headcut erosion immediately downstream of the pit brink. The ADOT method also presents a methodology to calculate tailcutting. A schematic (taken from Cotton and Ottozawa-Chatupron) of the headcut and tailcuts is shown in Figure 5. Note that flow is from right to left.

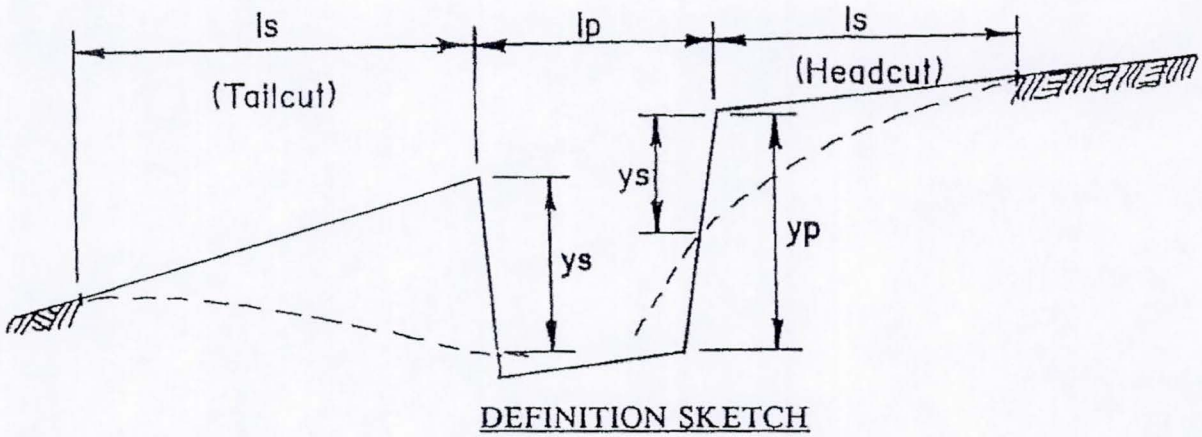

Figure 5. Schematic of headcut and tailcut for ADOT method. Streamflow is right to left.

6.2 Simons, Li & Associates Method

Simons, Li & Associates, Inc. (SLA, 1982) developed a guideline for the engineering analysis of sand and gravel mining. SLA modified and utilized the water and sediment routing method developed by Simons and Li (1979) to analyze erosion and deposition problems associated with instream or floodplain mining operation. The model was applied to predict the headcutting profile induced by the instream mining operations in San Juan Creek and Bell Canyon of Orange County, California, as well as in Rillito Creek in Tucson, Arizona. Model predictions were found to be in good agreement with the measured values for the gravel pit in San Juan Creek. Similar studies were also conducted for the proposed Columbia pit for sand and gravel mining in the Santa Cruz River floodplain, Pima County, Arizona. The study also shows that the pit depth significantly influences the severity of the headcut effect. In the study, the 100-year flood hydrograph for the proposed pit and the associated headcut distance and headcut depth were presented graphically for different pit depths up to 30 feet. The figures developed for headcut distance and head cut depth are shown in Figure 6. The analysis reveals that headcutting should

practically cease after the drown-out time, which is when the water in the pit starts to significantly dissipate the energy from the cascading water falling into the pit. To provide a factor of safety, a 1.5 multiplier to the computed distance was recommended to obtain the ultimate headcutting migration distance.

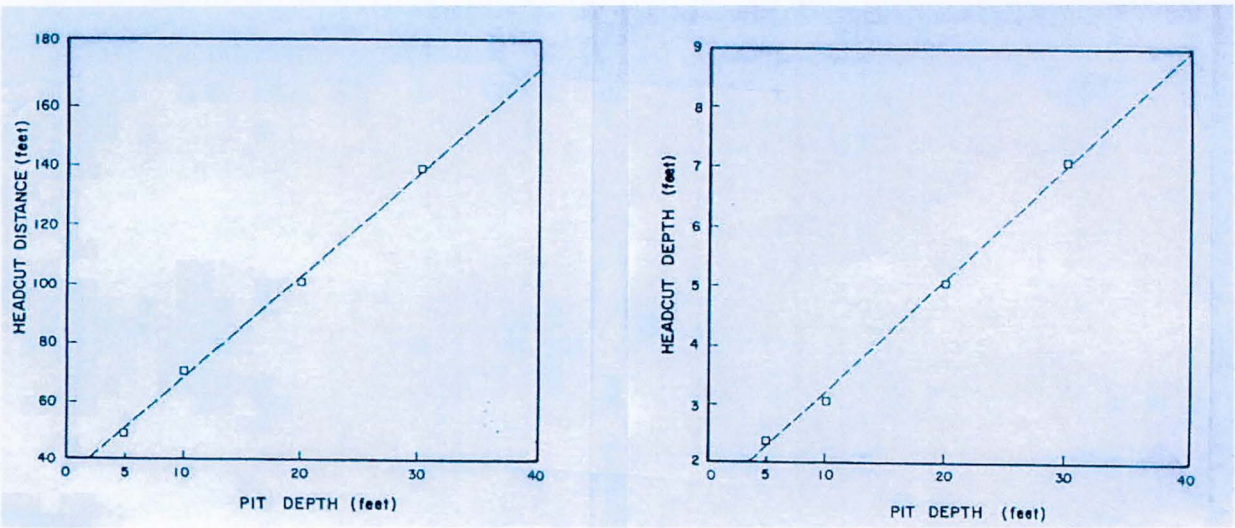

Figure 6. Simons, Li & Associates graphs.

6.3 W. J. McKeever Method

W. J. McKeever, Inc. (unpublished) provided an estimated headcutting profile for the proposed mining pit in their study area. The profile was determined using a slope twice the natural ground slope down to half the pit depth, as illustrated in Figure 7. Thus, the maximum headcutting depth is also half the pit depth. For the McKeever method, the available headcutting profiles from Anderson-Nichols and SLA for different conditions were analyzed. All the maximum headcutting depths were found to be less than, but close to, half the mining pit depth. However, the slope of the headcutting profile was much larger than the slope determined using the rule-of-thumb above. Therefore, the headcutting profile calculated using this engineering rule-of-thumb might provide the limiting envelope for the longitudinal extent of headcut migration.

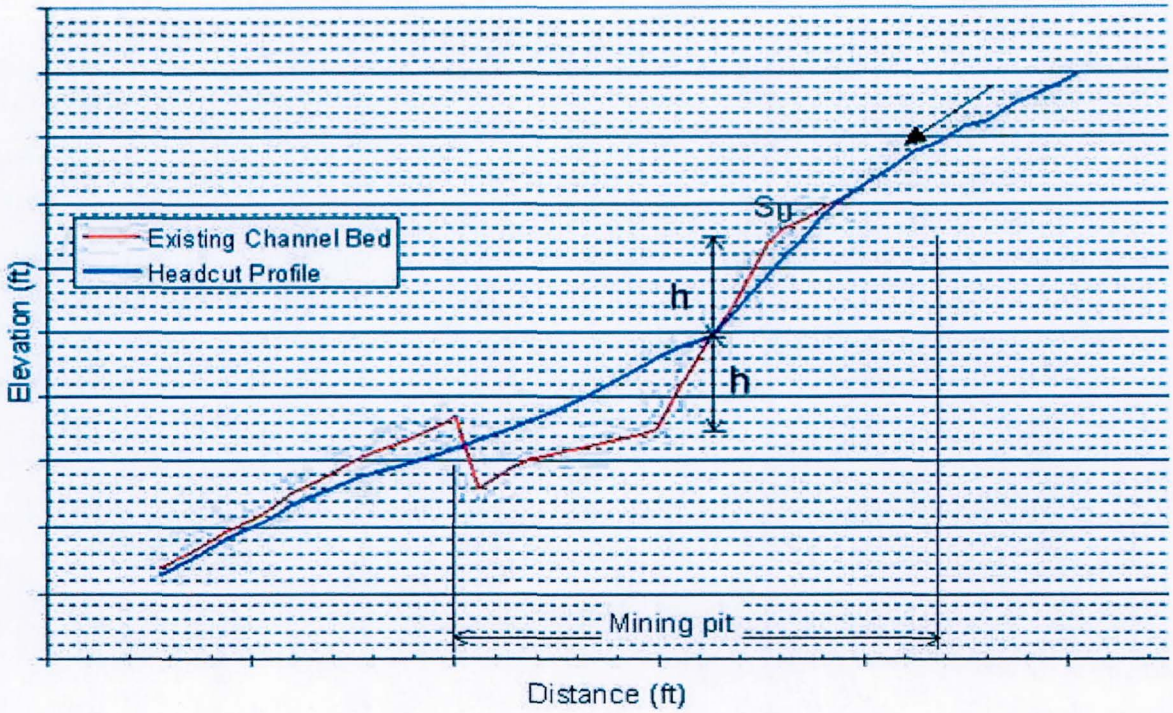

Figure 7. Illustration of McKeever technique.

6.4 Hydrographs and Return Frequencies

The hydrographs necessary for the ADOT method were obtained from the WEST Consultants Sediment Transport Study (WEST Consultants, March 2002). These were based on a 1995 Corps study (U.S. Army Corps of Engineers, 1995) which provided the peak flows. The peak discharges in the WEST hydrographs are slightly less than Corps peak discharges. This is because the Corps peak discharges are instantaneous discharges, while the WEST Consultants peak discharges are averaged over an hour or portions of an hour. The hydrographs from the 1995 Corps report take into consideration the construction of New Waddell Dam upstream in 1992.

It was found that for the North Pit and South Pit analysis, each pit would be filled just a few hours after the beginning the 100-year hydrograph. The total volume of the 100-year hydrograph is over 13,000 acre-feet, which is many times the volume of any of the individual pits. The pit volumes and other relevant dimensions are provided in Table 1.

Table 1. Pit Data

Pit	North Pit (for headcut O&C)	North Pit, Deep Part	South Pit (for O&C headcut)	South Pit, (for O&C tailcut)	East Pit	West Pit	Southeast Pits
Reference Flooding Elevation	1150	1150	1140	1127 (at overflow)	1130 (at overflow)	1133 (at overflow)	1121 (at overflow)
Water Volume at Flooding Elevation, Acre-Feet	2994	421	2636	1687	321	636	98
Approx Length, Feet	5300	650	3000 (average), (3600 along assumed streamline)	3000	-	-	-
Approx Width, Feet	730	750	1030	1030	-	-	-
Average Depth Feet*	32.3	37.4	35.9	23.7 (23 was used for tailcut analysis)	13.8	20.4	7.2
Maximum Depth, Feet	61	81	63	50	34	63	15.7

* Average Depth is from GIS grid calculations.

7.0 NORTH PIT EVALUATION

7.1 General Description of North Pit

The North Pit is located downstream (south) of Bell Road, on the left (east) bank. The black outline in Figure 8 shows the location of the North Pit. The red outline shows a much deeper portion of the pit at the northern end of the North Pit. The predominant elevation just upstream (north) of the North Pit is about 1,150 feet (NGVD 1929). Therefore, water should begin flowing into the North Pit when the adjacent river reaches an elevation of 1150 feet. According to the WEST LOMR HEC-RAS model (WEST Consultants, 2002), the water surface at cross-section 18.839, which is just upstream of the pit, would reach this 1050 elevation at 5,200 cfs. This is less than half of the 10-year flood peak of 11,000 cfs and is just a fraction of the 100-year flood peak of 37,500 cfs (both floods reported in the WEST Consultants, March 2002 study, which referenced the Corps of Engineers 1995 study as the source). The Flood Control District of Maricopa County maintains a gage at Grand Avenue, which has been in operation since April 27, 1994. The highest discharge recorded since that time is 5,952 cfs, which was recorded on October 27, 2000. Since this is just barely larger than the 5,200 cfs needed to begin entering the pit, the peak discharge from the October 27, 2000 event may not have been sufficient to enter the North Pit.

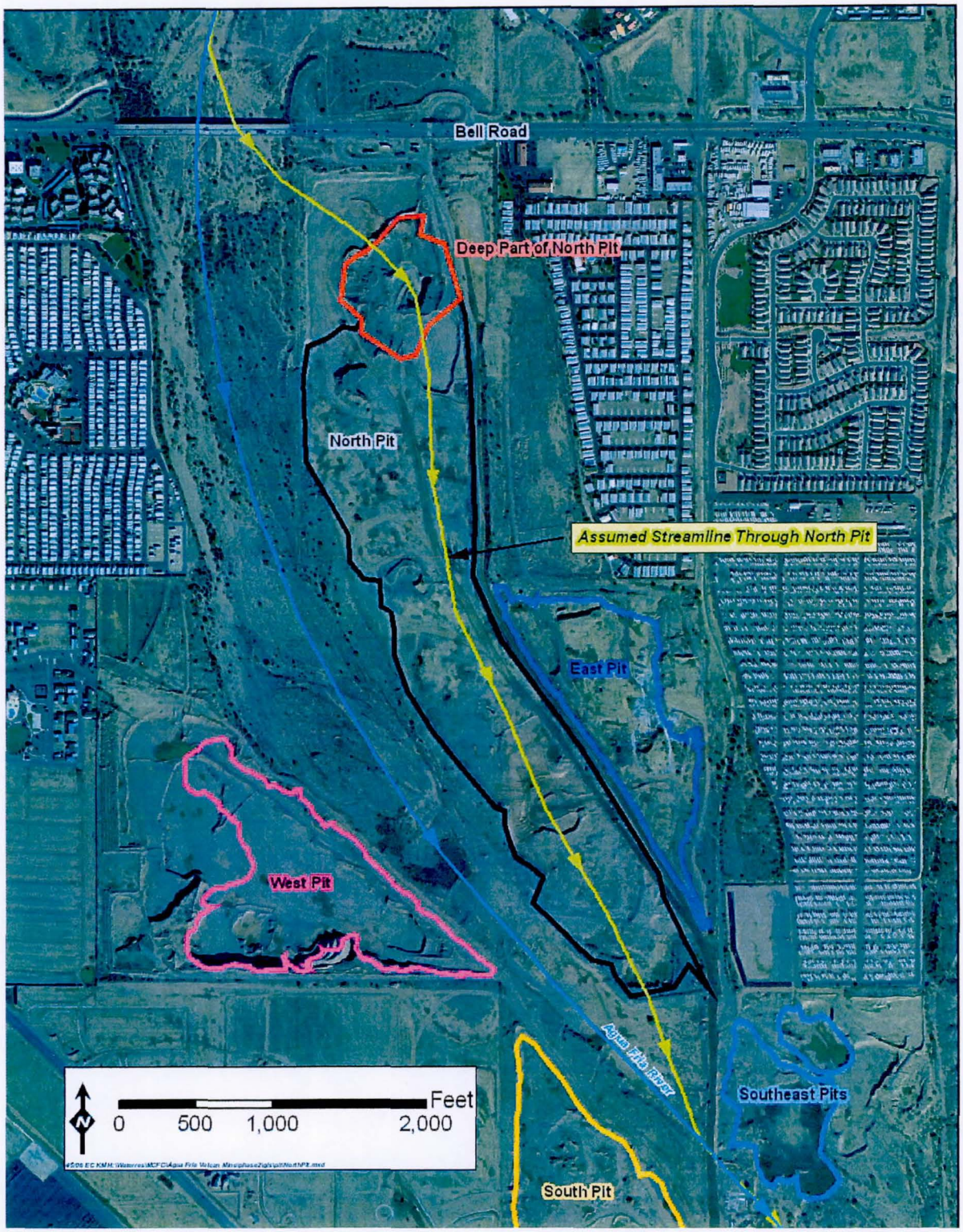

Figure 8. North Pit. Colored outlines represent pit limits as of November 2000. Background image is from November 2004.

It should also be noted that there is an access road under Bell Road that leads to the mining pits. This road can be seen in Figure 8 near the label "Bell Road." According to the WEST HEC-RAS model (WEST Consultants March 2002), the flooding elevation is lower than this road. However, there is considerable ground upstream and adjacent to the road which is higher than the 100-year flooding elevation; therefore, the road would not likely be overtopped in the 100-year event.

7.2 Anticipated Headcut Path from the North Pit

If water should begin flowing into the North Pit, then a headcut would start at the upstream edge of the pit and move toward the north and northwest. Should this headcut develop sufficiently, it is possible that the North Pit would capture all or nearly all of the flow from the Agua Fria River. For the headcut analysis, it is assumed that the pit would capture all the flow. Considering the large drop from the upstream limit of the pit to the bottom and the low discharge needed to enter the pit, this is a reasonable assumption.

If the North Pit should capture the flow, the streamline would shift to the left (east). For the purpose of the analysis, it is assumed that the new centerline would veer to the left, go through the approximate center of the pit, then continue downstream along the current left bank. The assumed streamline (in yellow) for this river capture by the North Pit is shown in Figure 8.

Figure 9 shows the profile of the assumed "pit capture" centerline of the channel should the North Pit capture the Agua Fria River. The elevation of the baseline of the existing streamline, when projected onto the new baseline, is also shown for comparison. The profile in Figure 9 is based on the November 2000 topography. In this topography, the upper limit of the North Pit, as measured along the assumed streamline through the North Pit, is about 1100 feet from Bell Road. Based on the November 2004 aerial photographs, however, the upper limit of the pit, when measured along the assumed streamline, was 580 feet from Bell Road. However, the east abutment is actually slightly closer to the pit, just 340 feet away at it closest point. Therefore, for the purposes of the headcut calculations, the 580 feet was rounded down and it was assumed the downstream face of Bell Road was 500 feet upstream of the pit.

7.3 ADOT Method for Headcut

For the ADOT method, a depth, width, and length of excavation are required. The ADOT method assumes a pit which is approximately rectangular with the bottom of the pit dropping gradually in the downstream direction. The North Pit has a sharp drop at the upstream end, descends into a very deep pit, then rises to about elevation 1120, then descends gradually along the rest of the pit. The profile can be seen in Figure 9.

For the ADOT method analysis, the use of the depth to the deepest part of the pit, about elevation 1070, was considered to be excessively conservative, i.e., would lead to headcuts depths that were unrealistically large.

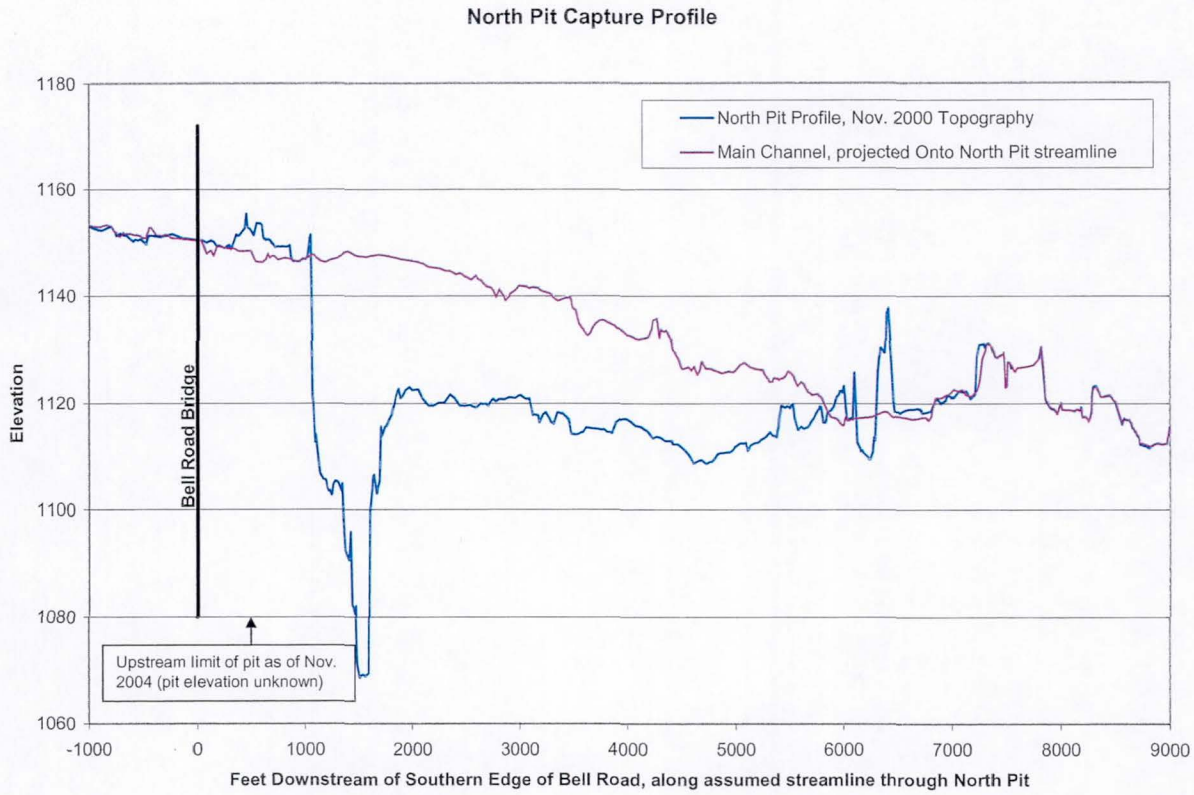

Figure 9. Profile of North Pit. The black line representing Bell Road. The elevation of the bridge's pier footings are at 1136.5 feet

Two alternative depths for the North Pit were used for the analysis. The first depth of the excavation was taken as 45 feet, which is the elevation of the region just upstream of the pit (1150) to the first major shelf at elevation 1105. An alternative, less conservative depth (leading to smaller headcuts), was derived by using the average depth of the entire pit at elevation 1117.7 feet. This resulted in a depth of 32.3 feet for the pit.

In order to calculate the ADOT method headcuts, a spreadsheet was developed where the appropriate parameters and the hydrographs were entered. The headcut for the North Pit was calculated for the 10-, 100-, and 500-year hydrographs with the results shown in Table 2. The hydrographs themselves were obtained the WEST Sediment Transport Study (WEST Consultants March 2002).

As mentioned before, the ADOT method headcut maximizes out at half of the pit depth. But the ADOT method also predicts how far the headcut will propagate upstream. For the 100-year flood and the 32.3 foot depth (average depth of the pit), the ADOT method predicts the headcut will have a maximum depth of 16.15 feet (32.3 feet / 2) and propagate upstream 2,200 feet at which point the headcut depth would be 5% of the maximum value. For the purposes of interpolation, the upstream limit was assumed to taper to zero headcut depth. With the bridge

being 500 feet away from the upstream limit of the North Pit in November 2004, along the anticipated rerouted channel, the interpolated headcut depth at the bridge would be about 12.5 feet (16.15 feet * 1700 feet / 2200 feet). The 500 year flood was presented because ADOT requires that a state designed bridge not catastrophically fail up to the 500 year flood.

Table 2. North Pit headcut, ADOT method, assuming 32.3 foot pit depth.

Event	10-year	100-year	500-year
Assumed Pit Depth	32.3	32.3	32.3
Maximum Headcut Depth	16.15	16.15	16.15
Longitudinal Extent of Headcut	1329 feet	2219 feet	2680 feet
Headcut Depth at Bell Road, 500 feet upstream	10.0 feet	12.5 feet	13.1 feet

If the assumed depth for the ADOT method equation is 45 feet (first major ledge in pit) rather than 32.7 feet, the values are as follows:

Table 3. North Pit headcut, ADOT method, assuming 45 foot pit depth.

Event	10-year	100-year	500-year
Assumed Pit Depth	45 feet	45 feet	45 feet
Maximum Headcut Depth	22.5	22.5	22.5
Longitudinal Extent of Headcut	1329 feet	2219 feet	2680 feet
Headcut Depth at Bell Road, 500 feet upstream	13.9 feet	17.4 feet	18.2 feet

In an analysis of the total scour depth at Bell Road, the headcut depth would need to be considered as part of a complete scour analysis. WEST Consultants had previously calculated a headcut depth for a pipeline just downstream of Bell Road in a report for Southwest Gas (WEST Consultants, May 2005). In their analysis, they used the ADOT method and located the pipeline 1,500 feet upstream of the pit. Their computed headcut distance only extended (tapered) upstream by 1,554 feet. Based on this, WEST calculated virtually no headcut depth by time the headcut reached the pipeline. The differences between the WEST analysis and this one are:

(1) The topography used in the April 2002 WEST study was the November 2000 topography. The 2004 aerial photographs show that the North Pit has been further excavated and is now at least 500 feet closer to Bell Road.

(2) WEST took the distance from the approximate center point of the bridge to the pit, and measured the distance from the bridge to the pit at a line approximately 45 degrees from the existing streamline. In this report, the assumed streamline is closer to the east abutment, which places the measured distance from the bridge much closer to the pit.

(3) The WEST study stated that the pit length was "about 4,000" feet long. The pit is 5,300 feet long according to this study's measurements.

(4) The WEST study used 40 feet as the pit depth.

7.4 Simons & Li Associates Headcut Method

The Simons & Li Associates graphs only extend to a pit depth of 40 feet. For this pit depth, the computed headcut extends upstream 170 feet and has a headcut depth of 9 feet. Using the recommended 1.5 factor of safety for the headcutting distance yields a headcut distance of 255 feet. Even if the 45 foot depth of the pit is assumed, and the headcut distance and depth are extrapolated, they will not reach the bridge (which is 500 feet away) according the Simons Li graphs. This method gives the shortest headcut distance.

7.5 McKeever Headcut Method

The channel slope averages approximately 0.003 feet in this reach, although this is quite variable. The McKeever method is to double the slope and assume that the headcut is projected upstream at this doubled slope, beginning at half the pit depth. This is illustrated in Figure 9 and the results are shown in Table 4.

Table 4. McKeever Method headcuts at Bell Road due to North Pit.

Assumed Pit Depth	Half Pit Depth (below 1150 elevation)	Less 0.006 x 500 feet (projected slope)	Headcut Depth at downstream face of Bell Road
32.3 feet	16.1	Less 3 feet	13.1 feet
45 feet	22.5	Less 3 feet	19.5 feet

In an analysis of the total scour depth at Bell Road, the headcut depth would need to be considered as part of a complete scour analysis.

7.6 North Pit Bend Scour Potential

In addition to the potential headcut created by the capture of the Agua Fria River by the North Pit, additional bend scour potential would be introduced by the re-routing of the river by the pit capture. The capture of the Agua Fria River by the North Pit would cause the river to bend to the left in order to veer into the pit. It is estimated that this bend radius would be 1,350 feet, possibly adding additional scour to the headcut scour depth at Bell Road Bridge. However, due to the likely straightening of the channel during a large event, the bend scour potential was not quantified.

8.0 SOUTH PIT

The South Pit is on the right (west) bank of the Agua Fria, just upstream of Grand Avenue. It is about 3,000 feet long and 1,000 feet wide. There is a deeper portion of the pit which is toward the southern part of the pit. The pit and deeper portion of the pit (in red) are illustrated in Figure 10.

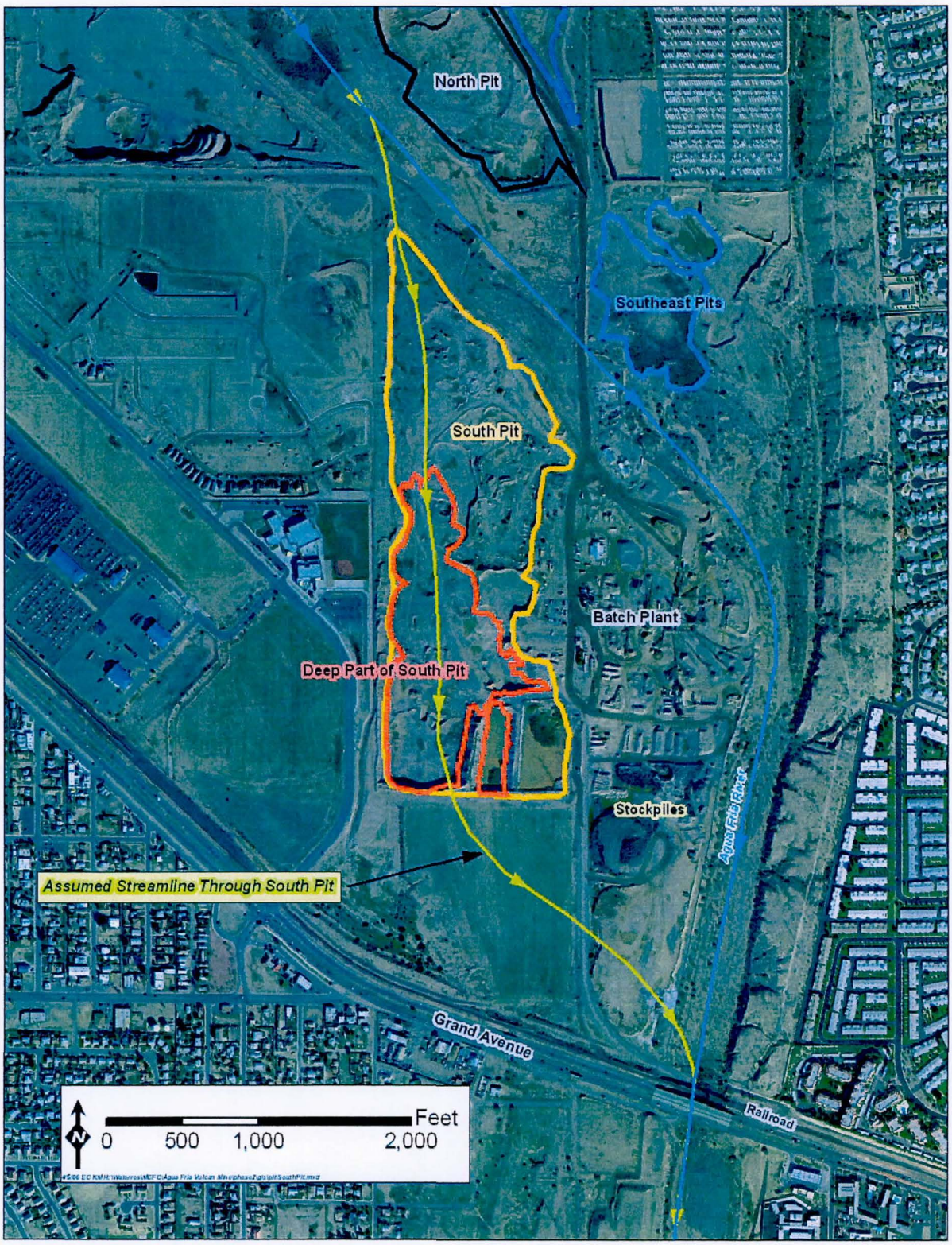

Figure 10. South Pit.

In order for a tailcut to develop, the river must be capture by the South Pit and this possibility was investigated. The WEST LOMR (WEST Consultants, 2002) discusses a flow breakout into the South Pit near the upstream limit and that at the 100-year flood of 37,500 cfs, this breakout overtops the bank by 1.5 feet. According the WEST calculations, a flow of 846 cfs would flow into the pit for a maximum of 5 hours. Due to this overtopping, the entire South Pit, as well as areas to the south and east, was mapped as FEMA Zone A in the WEST study.

The WEST study does not cover the likelihood that the overtopping could increase due to cutting in and widening of the overtopping area. This overtopping could be worse if the 100-year flood were underestimated, the water surface elevation was underestimated by the model (these uncertainties are the motivator for the FEMA requirement of 3 feet of freeboard on levees), and by the potential for geotechnical piping and failure of the division between the channel and South Pit. It was therefore assumed that a major portion the 100-year flood flows greater than the 846 cfs called out in the WEST study could flow into the South Pit.

As can be seen in Figure 11, which is a cross section just at the upstream end of the pit, the pit is substantially deeper than the channel itself. However, the exact amount of flow that would enter the South Pit would be a complex calculation and would depend on the amount of headcut / piping failure caused by the overtopping as well as the outflow elevation of the South Pit itself. According to the topography, without any tailcut, the South Pit would begin to outflow at about elevation 1127 near the downstream end of the pit. Since this 1127 outflow elevation is slightly higher than the channel bed at the upstream end (see Figure 11), the ponding effect may somewhat limit the amount of flow that would enter the South Pit. However, the creation of a tailcut at the downstream end could, in turn, lower this outflow elevation, resulting in more water entering the pit at the upstream locations.

To calculate the tailcut potential of the South Pit, the recommended method for a detailed study would be to develop a sediment transport model which includes both the South Pit and the main channel. Although sediment transport models are not well suited for headcut estimates, due to the rapid flow and cascading that occurs in a headcut, the models do well for estimates of tailcuts. The amount of diversion of flow into the South Pit, including a possible split flow calculation with part of the flow diverting into the South Pit, should also be modeled. However, such a model is complex and time-consuming to develop. Time limitations on the production of this report did not allow a sediment transport model to be developed. If and when measures are considered to protect infrastructure against the tailcut, the use of a sediment model would be the recommended procedure.

As a more approximate alternative method, the tailcut potential was calculated using the tailcut methodology described in the ADOT 1989 document and Cotton and Ottazawa-Chatupron paper from 1990. As a worst-case scenario, it was assumed that the entire 100-year flood enters the South Pit.

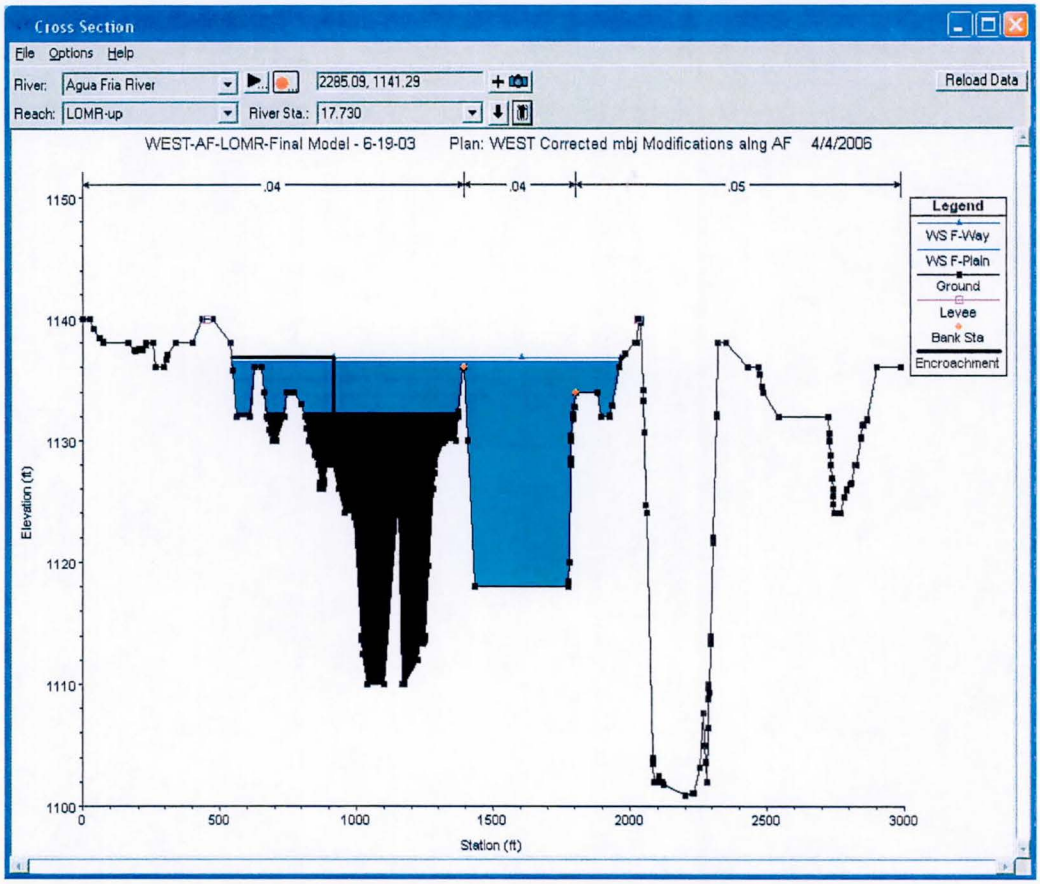

Figure 11. Cross-section of channel near upstream end of the south pit.

A spreadsheet was set up to calculate the tailcut as described in the ADOT (1989) document. Because the tailcut would need to go through the overbank area and then back into the channel, to assume the top of the pit at the overbank elevation of about 1125 to 1127 would lead to unreasonably large tailcuts. Instead, the top of assumed to be at the elevation of the channel where the tailcut would re-enter the channel, about elevation 1,110. From this elevation, the depth to the bottom of the pit at the downstream end is about 23 feet. Using the ADOT methodology, this results in a tailcut having a maximum depth of 10.0 feet which tapers out at 3,950 feet beyond the downstream limit of the pit. Interpolating linearly at the Grand Avenue Bridge, which is 2,000 feet downstream, this would result in 5 feet of tailcut at the Grand Avenue Bridge for the 100-year hydrograph.

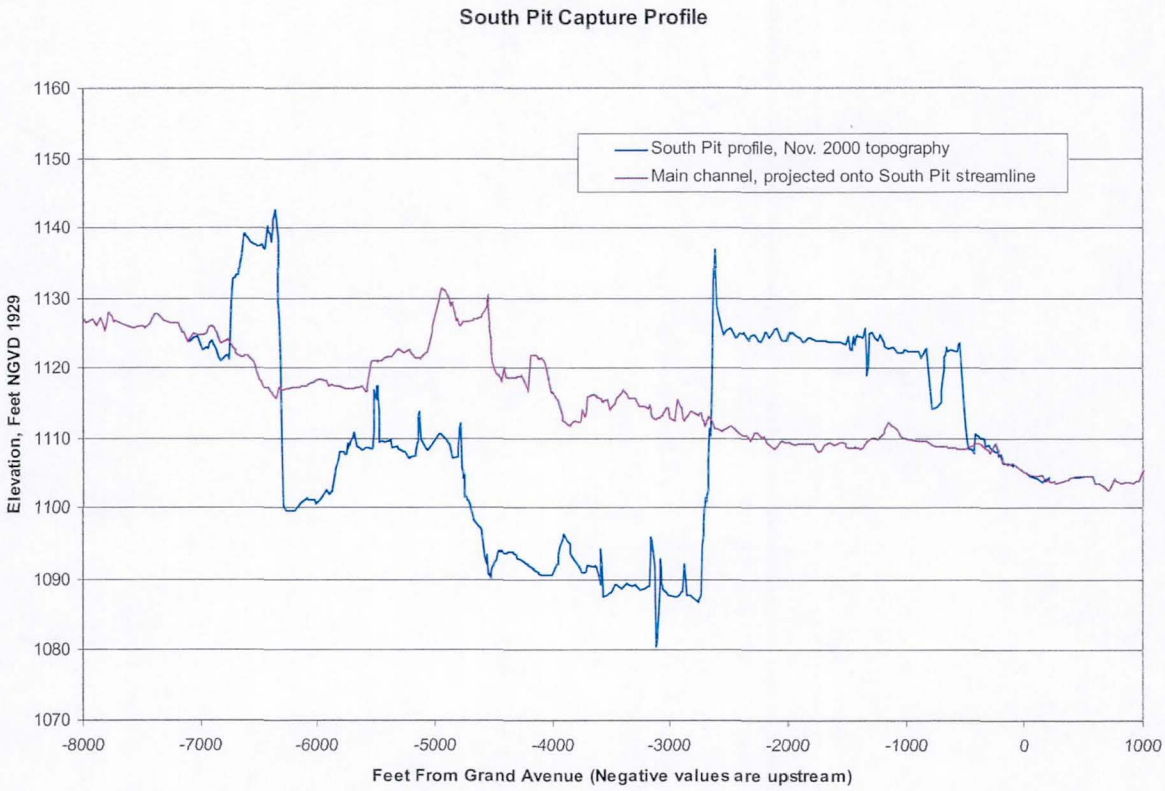

Figure 12. Profile of South Pit along the assumed streamline through the South Pit

There is also another potential water pathway under Grand Avenue, called in the WEST LOMR (WEST Consultants, 2002) the "AT&SF Channel." This channel goes under Grand Avenue at approximately the location of the last letter in the "Grand Avenue" label in Figure 10. The bottom of this ATS&F channel is fairly high, so it is assumed that the tailcut would not proceed through this channel.

8.1 South Pit Bend Scour Potential

In addition to the potential tailcut created by the capture of the Agua Fria River by the South Pit, additional bend scour potential is introduced by the re-routing of the river by the river capture. The capture of the Agua Fria River by the South Pit could cause the river to bend to the left and then to the right in order to pass under the Grand Avenue bridge. Both of these bends are about 1,300 feet in radius. However, some straightening is likely during a large flood event. Therefore, the bend scour potential was not included in the analysis.

9.0 RISK TO OTHER STRUCTURES

In addition to the Bell Road Bridge upstream, and Grand Avenue Bridge downstream, there are two other structures crossing the reach. There is a high-tension electrical line which runs across the river just downstream of Bell Road and has one of its poles in the middle of the river. This line can be seen in Figure 13. In the figure, the blue line is the approximate current Agua Fria streamline, and the yellow line is the assumed streampath through the North Pit. The headcut at this pole would be very similar to the calculated headcut for the Bell Road Bridge.

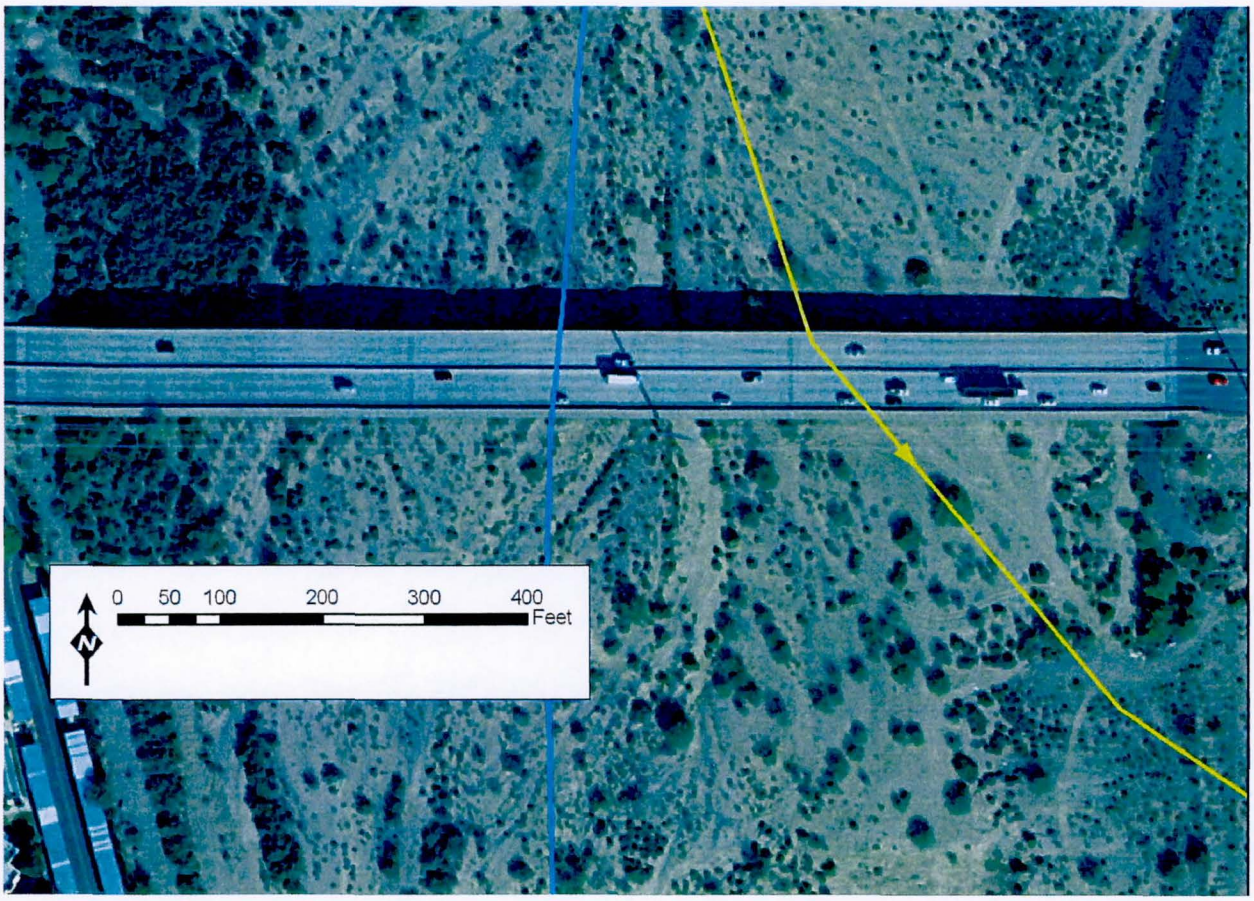

Figure 13. High tension power lines south of Bell Road, seen as faint lines. The pole in the river can be seen by the shadow it casts onto the bridge.

There is also the issue of the Southwest Gas line for which the WEST Consultants 2005 study was conducted. It appears that this line has already been constructed, and has been placed 50 feet below the surface (personal communication with Brian Wahlin of WEST Consultants, April 13, 2006). If this considerable depth is correct, then presumably it should be sufficient to withstand the additional scour due to the potential headcut. However, since no headcut was considered in the WEST study, it is nevertheless necessary that the a separate scour calculation including all components be conducted for this pipeline to insure its safety, especially in light of the expansion of the North Pit closer to Bell Road.

There is also a railroad bridge just upstream of Grand Avenue. The engineering drawings for this bridge were not available for this study. The railroad bridge would be subject to approximately the same additional impact, due to tailcut scour from the South Pit, as the Grand Avenue Bridge.

Also at risk are what appear to be a mobile home park near the east pit, and a trailer park near the southeast pits. These are just outside the floodplain and just upstream of the pits. These are illustrated in Figure 14 and Figure 15. For the Southeast Pit, in aerial photos from November 2004, there are no trailers parked in the region at risk, but the lot is graded, a new road has just been paved on the western edge, and it is reasonable to assume the intent was to park trailers there.

Since the East Pit and Southeast Pits are in the floodplain, a headcut from each of them could then proceed upstream. Both lots are at risk since they are only a few hundred feet from the upstream limit of the pits. The east pit appears to pose a greater risk because of its greater depth (an average depth of about 14 feet) and close proximity to the mobile home lot. The western banks of the mobile home and trailer lots would become considerable steeper as the headcuts proceeded upstream, increasing the risk of bank failure.

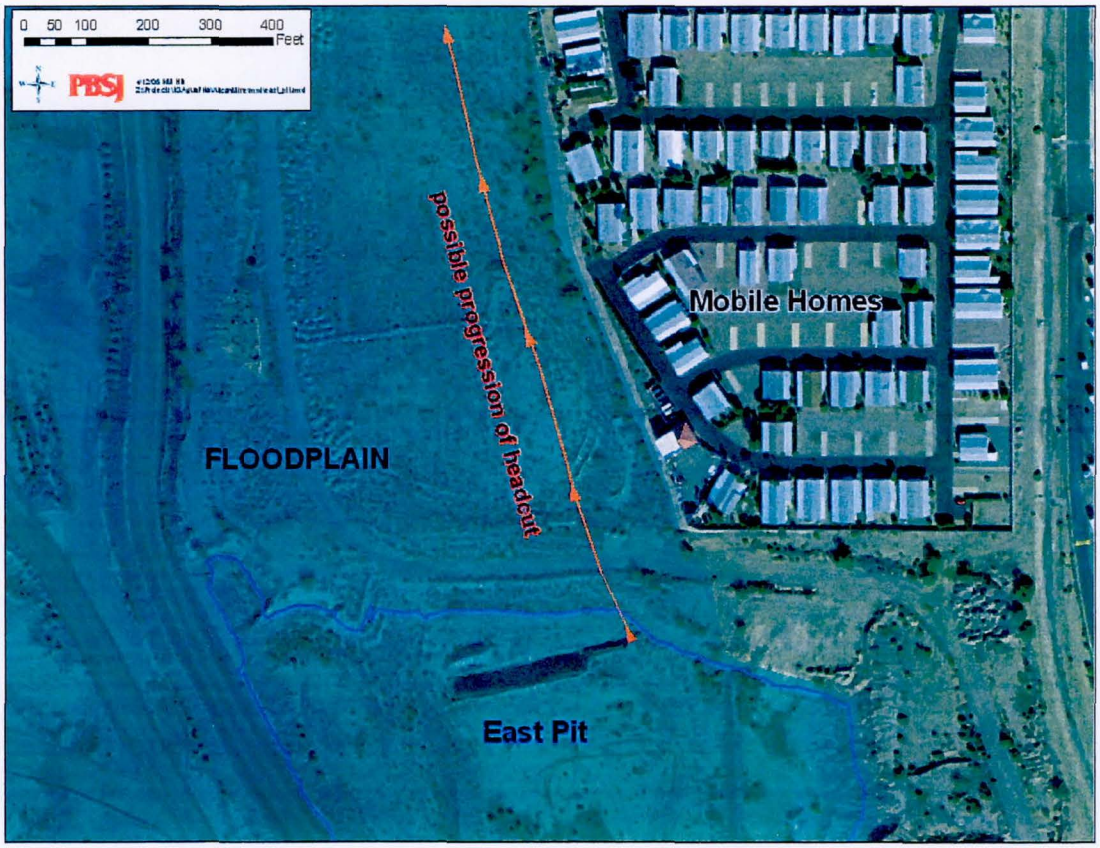

Figure 14. Possible headcut progression from east pit.

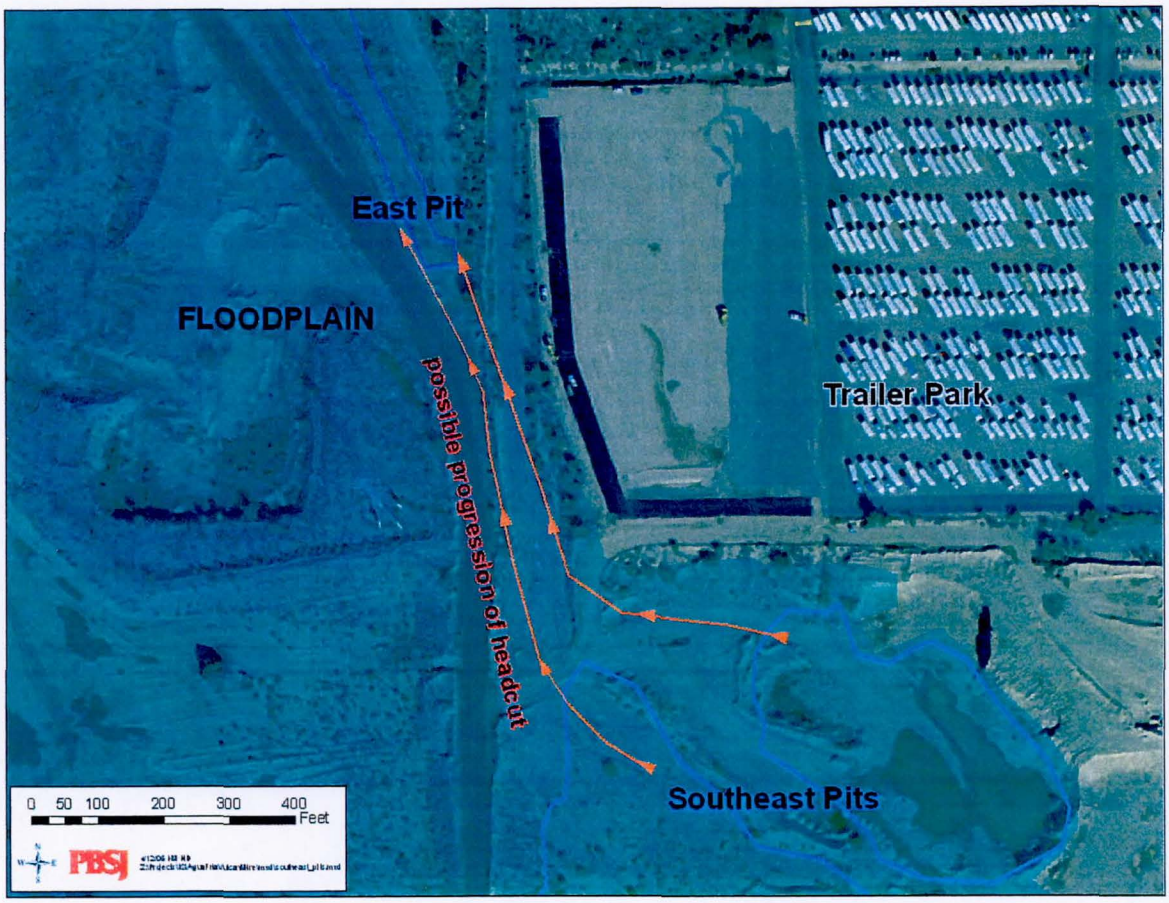

Figure 15. Possible headcut progression from southeast pits.

10.0 POTENTIAL OBSTRUCTIONS TO FLOW

In Figure 10, the batch plant and various stockpiles of material can be seen. Although these regions are in the floodplain, they are not in the active flow area. The stockpile and batch plants are within a Zone A approximate flood zone that was delineated due to the presence and possible flooding of the adjacent pit, and the possible future expansion of that pit (WEST Consultants, April 2002). At the 100-year flood elevation, these areas would not obstruct the flow since the 100-year flood is completely contained inside the channel.

11.0 STATUS OF PITS COMPARED WITH FCD SAND AND GRAVEL GUIDELINES

Almost the entire surface of the identified major pits is within the District's Erosion Hazard Zone for the Agua Fria River. For sand and gravel excavations that are within the District's jurisdiction, the District requires a floodplain use permit. The pits do not conform to the District's Sand and Gravel Mining Floodplain Use Permit Guidelines (FCDMC 2004). The major non-conformities are summarized in Table 5.

Table 5. Major non-conformances with FCDMC Sand and Gravel Guidelines.

Guideline	Specified Value FCD Guidelines	Measured Value	Notes
Minimum Upstream Setback to Bridge or Utility	500 feet	340 feet to Bell Road Bridge East Abutment	
		250 feet to a high tension power pole just south of Bell Road	
Minimum Upstream Setback to Property Line	50 times pit depth	250 from Bell Road at closest point	Estimated pit depth is 20 to 45 feet at upstream end, so FCD setback would be 1,000 to 2,250 feet
Depth of Excavation	Above natural channel thalweg elevation	As much as 80 feet below natural thalweg elevation (in the North Pit)	

12.0 HISTORICAL BRIDGE IMPACTS FROM MINING ACTIVITIES

The results of the analyses presented are not unusual for areas impacted by mining activities. In 1989, Simons & Li Associates prepared an extensive report for ADOT on the impact of mining activities (Arizona Department of Transportation, 1989). Numerous problems due to mining activity are documented. One example was a headcut of about 20 feet at the Country Club Road Bridge over the Salt River due to downstream mining activities. The ADOT report cites mining activity as a major contributing factor to bridge failure.

More recently, in Pinal County, the Schnepf Road Bridge over Queen Creek had to be shut down in early 2005. A headcut from a downstream mining operation developed during the February 14, 2005 storm and caused 10 feet of degradation of the channel bed Figure 16 shows the headcut starting to develop during the flood and Figure 17 shows the bridge as it stands in 2006 (Pinal County PowerPoint presentations, 2006). The drastic reduction in the buried depth of the shafts, which hold up the bridge by frictional support of the adjacent soil, resulted in a calculated insufficient bearing capacity. The bridge was therefore deemed unsafe and closed. The closure of this bridge has caused significant disruption to traffic in the region.

Figure 16. Schnepf Road Bridge over Queen Creek in February 2005, after headcut reached the Queen Creek Bridge.

Figure 17. Schnepf Road Bridge over Queen Creek, 2006.

13.0 SUMMARY

Two of the three methods used to estimate headcut formation show that for a 100-year flood, the North Pit would initiate a headcut 13 to 20 feet deep that could have a catastrophic impact on the Bell Road Bridge and the pole supporting the high tension power line just downstream. This flood is less than the 500-year flood, which is an ADOT standard for preventing a catastrophic failure. For a flood as low as the 10-year flood, the North Pit could initiate a headcut 10 to 144 feet deep. This headcut, in conjunction with other traditional components of scour, could result in scour depths that could compromise the structural integrity of the bridge and power pole. The scour depth need not reach the bottom of the bridge pier supporting shafts, but only to the depth where the remaining bearing capacity of the shafts is not sufficient to safely support the bridge. The lack of safe bearing capacity after degradation was the reason for the shutdown of the Schnepf Road bridge in neighboring Pinal County. The headcut could also undermine the bridge abutment protection on both sides of the bridge. In addition, it could cause failure of the upstream and downstream streambank protection (adjacent to the abutments) that is an integral part of the abutment protection. In an even worse scenario, if the scour depth is deep enough, the structure can fail catastrophically during a flood event and fall into the Agua Fria.

The tailcut potential due to river capture by the South Pit is 5 feet at the Grand Avenue Bridge and the railroad bridge. This tailcut, in conjunction with the other traditional components of scour, could result in a scour depth that would compromise the structural integrity of these structures.

Furthermore, there is additional risk associated with the East Pit and Southeast Pits. If headcuts from these pits develop, they may put nearby mobile home and trailer parks at risk.

The conditions described are dangerous and constitute public safety hazards. To mitigate this threat to life and property, the mining pits must be filled up to the ambient original surface or sufficient river training structures, such as levees, must be constructed to prevent river capture by the pits.

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