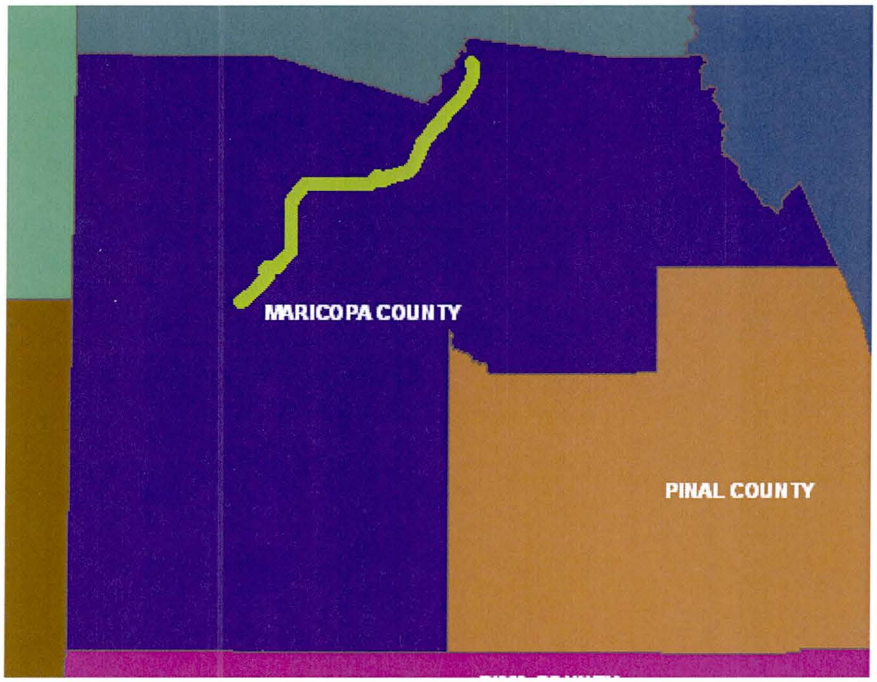
Riverine Scour and Lateral Migration Assessment at Select Sites for a 36" Natural Gas Pipeline



Prepared for:

Terracon
Consulting Engineers & Scientists
4685 South Ash Avenue
Suite H-4 I
Tempe, AZ 85282

Provided By:

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC
8400 S Kyrene Road
Suite 201
Tempe, AZ 85284
480-752-2124

Table of Contents:

Index of Figures:

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Index of Tables:

Appendix A: Calculations

Appendix B: Supporting Documentation

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Introduction

Terracon Consulting Engineers and Scientists, Inc. (Terracon) have been hired by Transwestern Pipeline, LLC to design a natural gas pipeline system extending from an existing pipeline in Ash Fork (Yavapai County) to near Coolidge (Pinal County). The proposed pipeline alignment will pass through the western Phoenix-metro area in Maricopa County. Terracon has retained JE Fuller Hydrology & Geomorphology, Inc. (JEF) to calculate appropriate scour depths and extents at select watercourse crossings in Maricopa County.

Purpose

This report documents scour and lateral erosion calculations performed in support of pipeline design. The information presented is intended to support floodplain use permitting for the pipeline within Flood Control District of Maricopa County right-of-way.

Study Areas

Generally, this study has been divided into two geographic regions. The first region contains six individual study areas and is located in the vicinity of the McMicken Dam, McMicken Outlet Channel, and McMicken Outlet Wash. The second region contains the remaining three study areas which are located near the western boundary of Buckeye FRS#1 adjacent to the Hassayampa River.

Figure 1 shows the location of the two regions relative to the Phoenix metro area. Figure 2 shows the study areas in the vicinity of McMicken Dam. Figure 3 illustrates the three study areas in the vicinity of Buckeye Flood Retarding Structure (FRS) #1.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

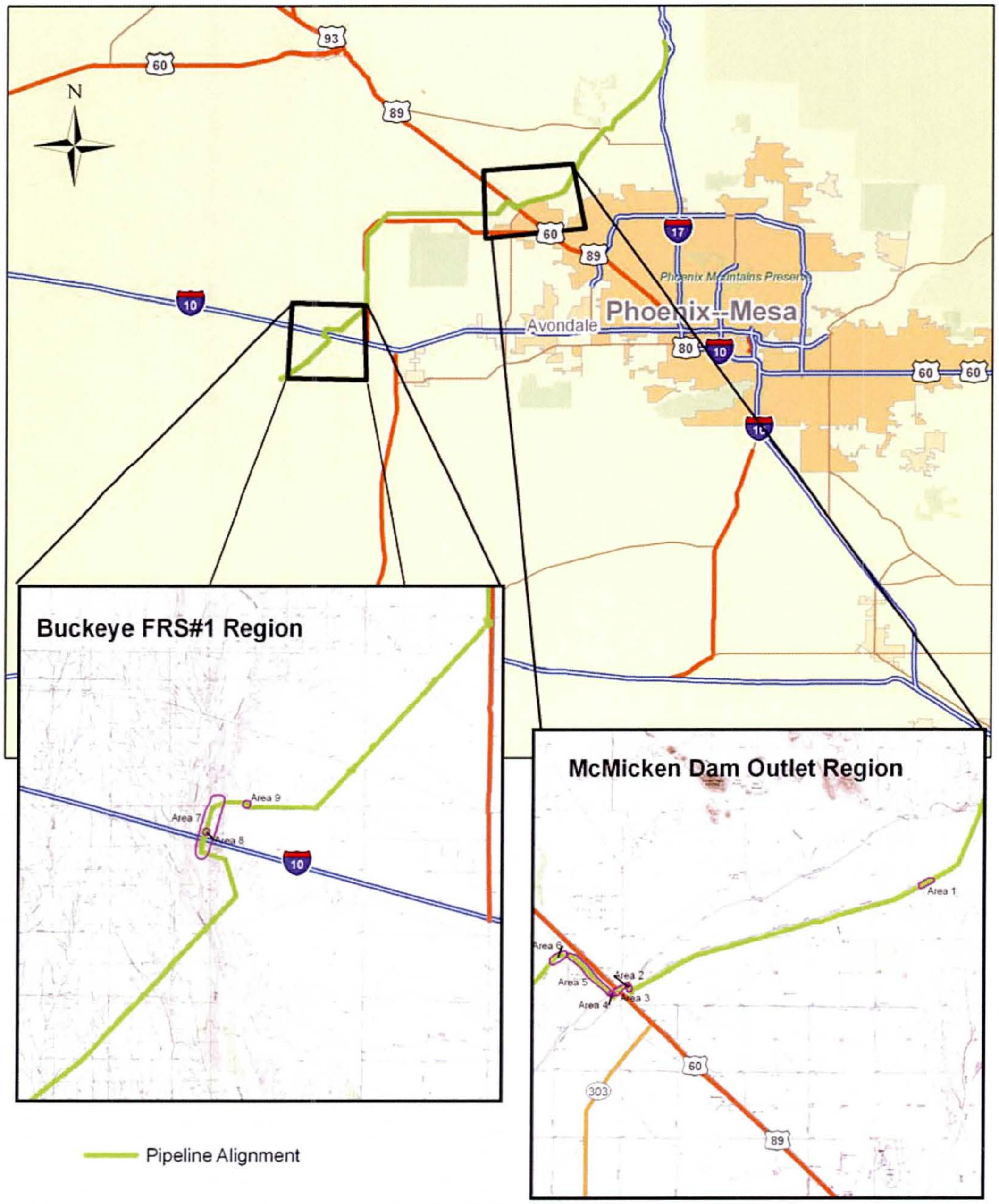


Figure 1 - Study Region Vicinity Map

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

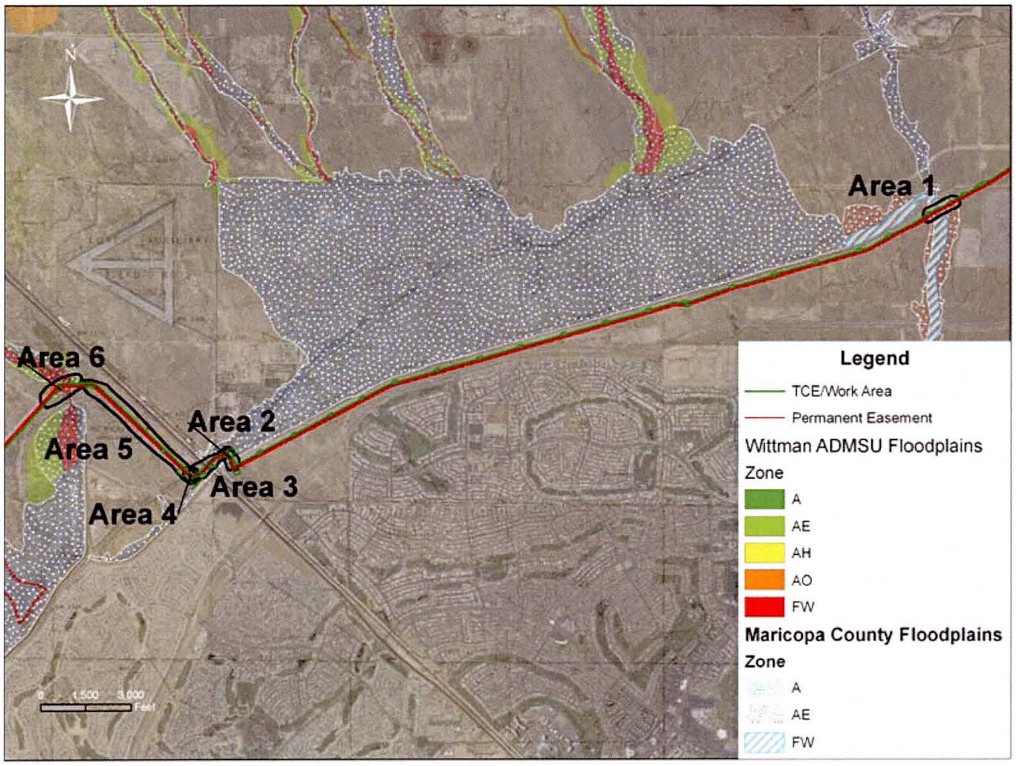


Figure 2 - McMicken Study Areas

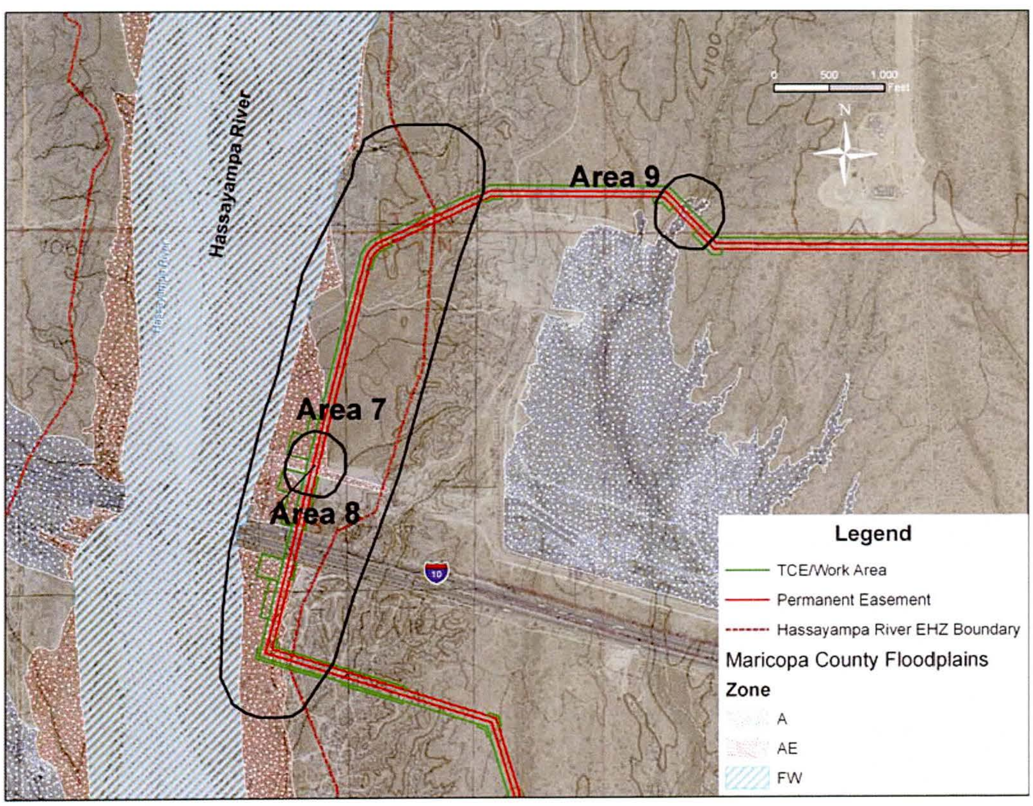


Figure 3 - Buckeye FRS#1 Study Areas

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Methodology

Scour equations conforming to Flood Control District of Maricopa County guidance were applied at all locations. A description of each site, riverine erosion hazards, available information, and analysis methodology for each location is presented below.

A meeting was held with Bing Zhao, Ph.D., P.E., Manager Engineering Application Development Branch, Engineering Division, Flood Control District of Maricopa County, to develop acceptable analysis approaches for the various scenarios encountered in the study areas. Methods conforming to the approaches agreed to have been followed as described below. The approved methodology is described below and is included as Appendix B.

A second meeting was held with FCDMC staff to discuss options for scour mitigation in the vicinity of the pipeline on 12-6-07. Scour analysis results in several locations were discussed at this meeting. Tom Renckly, PE, FCDMC Dam Safety Branch Manager, indicated that standard project flood (SPF) design is required for all dam-related features such as the McMicken Outlet Channel and wash.

<u>Vertical Scour</u> – Scour was evaluated in a site-specific manner, although a general methodology was used as described above. For riverine applications, vertical scour is typically described as the sum of components associated with specific design events, long-term channel evolution, and miscellaneous components. A description of the analysis used for each follows.

At most areas, a 100-year flow event was utilized for event-scour, although the presence of emergency spillways for Buckeye FRS#1 and McMicken Dam resulted in application of probable maximum flood (PMF) events in emergency spillway areas. Standard project flood analysis was performed at the crossings of the McMicken Dam Outlet Channel and the McMicken Dam Outlet Wash.

General scour (event-based) was evaluated using Bureau of Reclamation methodology approved by FCDMC (FCDMC, 2003). Following the FCDMC guidance, the Blench equation was to be used for clear water scour and the Lacey equation for live-bed scour (Pemberton and Lara, 1984). The distinction between clear-water and live-bed scour is based upon the sediment concentration of flow entering the study reach. If incoming flow is "sediment-lean," increased sediment uptake is anticipated whereas "sediment-laden" flow is expected to uptake less sediment. This behavior is useful in comparing the reasonableness of results from equations for both scour types. For the locations and soil types analyzed, the Lacey equation almost uniformly produced greater scour depths than the Blench equation. As clear-water scour is typically assumed to be of greater magnitude than live-bed scour, this result was puzzling. To present the most conservative results, the Lacey equation has been applied for all areas except Area 2.

Low flow incisement was evaluated for each site. Values for this scour component were selected following guidance in Chapter 11 of the FCDMC Draft Hydraulics Manual (FCDMC, 2003).

Other local event-based scour calculations were conducted as needed. These calculations include analysis for sill scour and culvert outlet scour.

Long term scour was evaluated using the Arizona Department of Water Resources Level I methodology in State Standard 5-96 (ADWR, 1996). Several locations are not subject to traditional long term scour. Also, several locations possess previous equilibrium slope analyses which have been applied if a downstream "hinge" point exists. For analysis of recurrence intervals other than 100-years, the 100-year discharge has been applied in this equation per the State Standard definition.

For all channel scour types, a safety factor of 1.3 has been applied to the calculated values to determine the design scour depth. All scour depths listed are relative to the existing channel thalweg.

Overbank Vertical Scour

Per comments from Bing Zhao at a meeting held on January 16, 2008, scour within the special-project-flood-floodplain was evaluated for Area 1 as a proof of concept.

Shallow, broad, relatively low-velocity flow is not well studied in scour literature. Due to a lack of guidance associated with flow of this character, a number of scour methodologies were applied and compared for reasonableness. The FCDMC's total scour methodology was applied for the overbank scour. Values for scour calculations were taken from the SPF-modified HEC-RAS model for the McMicken Dam Outlet Channel and Wash.

Long-term scour was taken as zero given the low incidence of flow in the overbanks at the crossing location. Low flow incisement was not considered for the same rationale.

Bedform scour was evaluated using the methodology described in the Draft FCDMC Hydraulics Manual (FCDMC, 2003).

Selection of an appropriate general scour methodology entailed review of multiple scour equations. The general scour calculations methods outlined in the FCDMC Hydraulics Manual (FCDMC, 2003) from the Bureau of Reclamation guidance (Pemberton and Lara, 1984) are not well conditioned for the condition to be modeled. These equations were developed for application in channelized situations and typically incorporate bedload transport. Bedload is not applicable for floodplain flow given the velocities involved. Additionally, given the small median diameter present in this area, transport as suspended load is a more probable mechanism. Suspended load concentrations are likely high approaching the site given the long flow-path from the McMicken Dam outlets. Given this behavior, the Blench equation was selected as the most applicable. Still, due to the

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

unconfined nature of flow in the overbank, Blench is not a strictly appropriate method and likely overestimates the scour depth. Due to this over-estimation, a safety factor of 1.1 has been applied to the calculation. Other methods investigated include Lacey, Permissible Velocity, Field Measurements of Scour method (Pemberton and Lara, 1984), Depth to Armor (Meyer-Peter Muller, Lane, Shields, Yang, Competent Bottom Velocity), and the Zeller-Fullerton equation.

Risk due to exposure of the pipe is also minimal in the overbank as velocities are minimal and unlikely to damage the pipe or associated infrastructure.

For this location, this analysis yields a total design scour depth of 3.1 feet. Results are presented in Appendix A with the Area 1 calculations. Due to the relatively high velocities present for overbank flow conditions and the small median sediment diameter at this location, these results are assumed to be more conservative than those for other study areas within the project.

Lateral Migration – Lateral migration analysis of crossing locations was accomplished using the modified Bishop's method. Several assumptions were necessary to perform the calculations.

1. The total design scour depth (with factor of safety) plus the pre-scour channel depth were assumed to equal the bank height.
2. A non-vertical slope was assumed in the post-scour condition due to an assumption of cohesionless soils.
3. Internal friction angle, ϕ, can be inferred from soil texture class and particle angularity as listed in boring log data or soil survey data.
4. No soil cohesion was assumed due to the uncertain and irregular nature of calcification.
5. A dry soil condition was assumed. The presence of water within the channel increases the safety factor for an analysis of otherwise identical geometry and geotechnical parameters. In an environment without base flow or a water table which intersects the channel, the pore water pressure gradient peaks in the channel and dissipates into the banks. Due to this gradient, an increased safety factor is generated by the increased water depth normal to the bank face.
6. The failure surface is described as having a factor of safety (against rotational failure) of less than 1.3. While the failure surface which generates the greatest lateral offset may have a lower factor of safety than 1.3, this method ensures that all values below the threshold of 1.3 are considered. .
7. A single soil type is assumed for each analysis. Homogeneous soil conditions likely do not exist natively, but the extent of failure areas considered and imprecise nature of scour calculations suggest such detail is not necessary for prudent design. Values representative of the least stable soil in the vicinity of the analysis have been used in calculations.
8. Soil unit weights were estimated based upon textural class and soil descriptions. For the simplified form of the Bishop method employed in this analysis, soil unit

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

weight does not affect the calculations. If pore water pressure, external hydraulic forces, or cohesion were considered, this would not be the case.

In applying the Bishop Method, an iterative computational scheme was developed following guidance in the US Army Corps of Engineers' EM 1110-2-1902 – Engineering and Design Slope Stability (USACE, 2003). This scheme varies the coordinates of the center and radius of the failure arch while implementing an iterative method to calculate the factor of safety for each failure geometry. Results are then reviewed through a two-stage constrained maximum function intended to produce the maximum horizontal failure distance for a given factor of safety.

Figure 4 shows typical geometry for the assumed conditions and a graphical depiction of the trial search method.

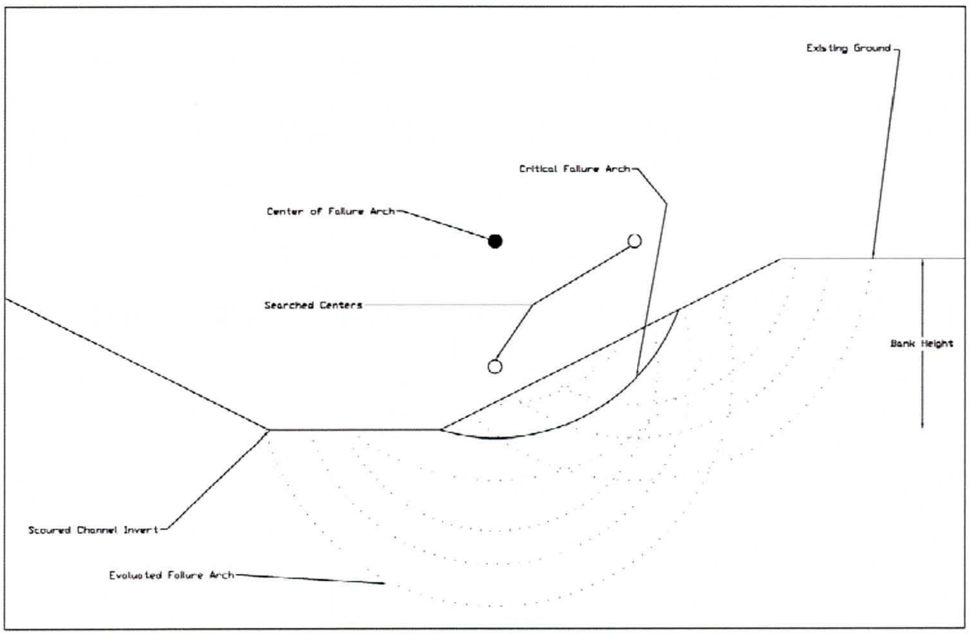


Figure 4 - Modified Bishop's Method Search Algorithm Geometry

Analysis

Scour and lateral migration have been evaluated for the purpose of designing the pipeline along the proposed alignment. Results of this analysis may not be applicable to changes in alignment and should not be applied for other purposes.

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 1: McMicken Outlet Wash Crossing

Site Description

Area 1 is located roughly 500 feet downstream of the confluence of the McMicken Outlet Channel and McMicken Outlet Wash. The proposed pipeline alignment crosses McMicken Outlet Wash approximately 500 feet downstream of the confluence. The alignment is located within a FEMA Zone AE floodway and fringe.

Figure 5 - Area 1 Location

Available Information

Hydrologic data for the area is available from the Wittmann Area Drainage Master Study Update (ADMSU) developed for the Flood Control District of Maricopa County (FCDMC) by Entellus (2005). Hydrologic modeling for the Wittmann ADMSU was conducted using FCDMC methodology and HEC-1 analysis for the existing and future condition land-use 100-year, 24-hour storm event. Hydrologic data for the SPF discharge is available from the Wittmann Area Drainage Master Study (ADMS) by the WLB Group (1989).

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Discharges corresponding to two rainfall depths are presented in the Wittmann ADMS; a depth of 8.6 inches corresponds to the 247 square mile contributing area for McMicken Dam and a depth of 7.4 inches corresponds to the 320 square mile contributing area associated with McMicken Dam, the McMicken Dam Outlet Channel, and McMicken Dam Outlet Wash. Discharges corresponding to a rainfall depth of 7.4 inches were used for analysis.

Hydraulic data for the area is available from a compilation HEC-RAS analysis of the McMicken Outlet Channel and McMicken Outlet Wash developed by JEF (2007) for the Wittmann Area Drainage Master Plan (ADMP). The HEC-RAS model is a compilation of geometry from three previous studies of the washes and Wittmann ADMSU existing-condition, 100-year hydrology.

Sediment data has been compiled by AMEC in the vicinity of the dam and is summarized in the McMicken Dam Geotechnical Appraisal Report included in the Wittmann ADMP (Entellus, 2007). Additional soils data was available through the NRCS soil survey (Maricopa County, Arizona, Central Part, AZ651).

Results

Vertical Scour – In the reach upstream of the crossing site, no barriers to sediment transport are present in the McMicken Outlet Channel or McMicken Outlet Wash. Due to the likelihood of sediment-laden flow, the Lacey equation was applied. In the vicinity of the pipeline crossing, test-pit 06-30 was dug by AMEC on December 4, 2006. The soil log for the test-pit logged clayey-sand to sandy-clay soil textures up to a depth of 9.5 feet in the McMicken Outlet Channel. A median soil diameter of 0.42 mm was inferred from the soils information and input into the Lacey equation.

Vertical scour analysis was performed for the 100-year and SPF events. In both cases, hydraulic parameters were generated using a HEC-RAS model originally developed for analysis of the 100-year event.

Application of SPF discharges from the Wittmann ADMS results in overtopping of the outlet channel and probable discharge to the south. However, no discharge is diverted out of the channel in the HEC-1 model. In the Wittmann ADMS SPF HEC-1 model, the outlet channel receives discharge from the principal outlet and approximately 8500 cfs overtops the emergency spillway and enters the outlet channel. A review of HEC-RAS cross sections of the outlet channel near Grand Avenue indicates the channel capacity is approximately 11,000 cfs. While the ADMS hydrology does not reflect this condition, discharges in excess of 11,000 cfs upstream of the US60 bridge will exit the channel. Within the HEC-RAS model, the bridge at US60 overtops, which occurs due to limitations in the HEC-RAS model; in reality, flows in excess of the channel capacity will exit the channel to the south. Because the Wittmann ADMS hydrology represents the most recent FCDMC-accepted SPF hydrology for the dam, it has been applied for scour design as described below.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

A "Z" factor associated with moderate channel curvature was incorporated into the Lacey equation. Additional calculations for bend scour were not performed.

Anti-dune scour was computed following guidance in the FCDMC's Draft Drainage Design Manual – Hydraulics (FCDMC, 2003). Hydraulic information was taken from the HEC-RAS analysis of McMicken Outlet Channel and McMicken Outlet Wash (JEF, 2007).

Long term scour was estimated with ADWR State Standard 5-96 Level I methodology.

Low flow incisement was estimated at 1 foot in the absence of better information. McMicken Outlet Wash is a natural wash with a pronounced thalweg in 2-foot topography which suggests 1 foot is a conservative value.

Summary results for the 100-year discharge and SPF discharge are presented below. Values associated with the SPF discharge have been used for design following instruction from FCDMC.

Table 1 - Area 1 100-year Scour Summary

Summary		
Type	Method	Result
General	Lacey	5.31
Bedform	FCDMC Manual	0.41
Thalweg/Low Flow	FCDMC Manual	1.00
Bend	-	-
Long-Term	SS5-96 Level I	4.10
Other	-	-
	Total	10.82
	Total w/ SF	14

Table 2 - Area 1 SPF Scour Summary

Summary		
Type	Method	Result
General	Lacey	7.01
Bedform	FCDMC Manual	0.51
Thalweg/Low Flow	FCDMC Manual	1.00
Bend	-	-
Long-Term	SS5-96 Level I	4.10
Other	-	-
	Total	12.62
	Total w/ SF	16.4

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

<u>Lateral Scour</u> - For McMicken Outlet Wash, a total design scour depth of 18 ft was calculated. A typical bank height of 7 ft was estimated from FCDMC Wittmann ADMSU 2-foot topography. These values yield a total scoured bank height of 23.4 ft. This height was applied as the bank height for the modified Bishop's method analysis. Other input parameters and results are listed below.

Table 3 - Area 1 Lateral Migration Data

Bank Slope	ϕ (deg)	c (lb/ft^2)	γ_s (lb/ft^3)	Distance from top of bank (ft)	Distance from toe of slope (ft)
2H:1V	20	0	110	42	89

<u>Summary</u>

The pipeline should be buried a minimum of 16.4 feet below the McMicken Outlet Wash thalweg for a distance of 178 feet.

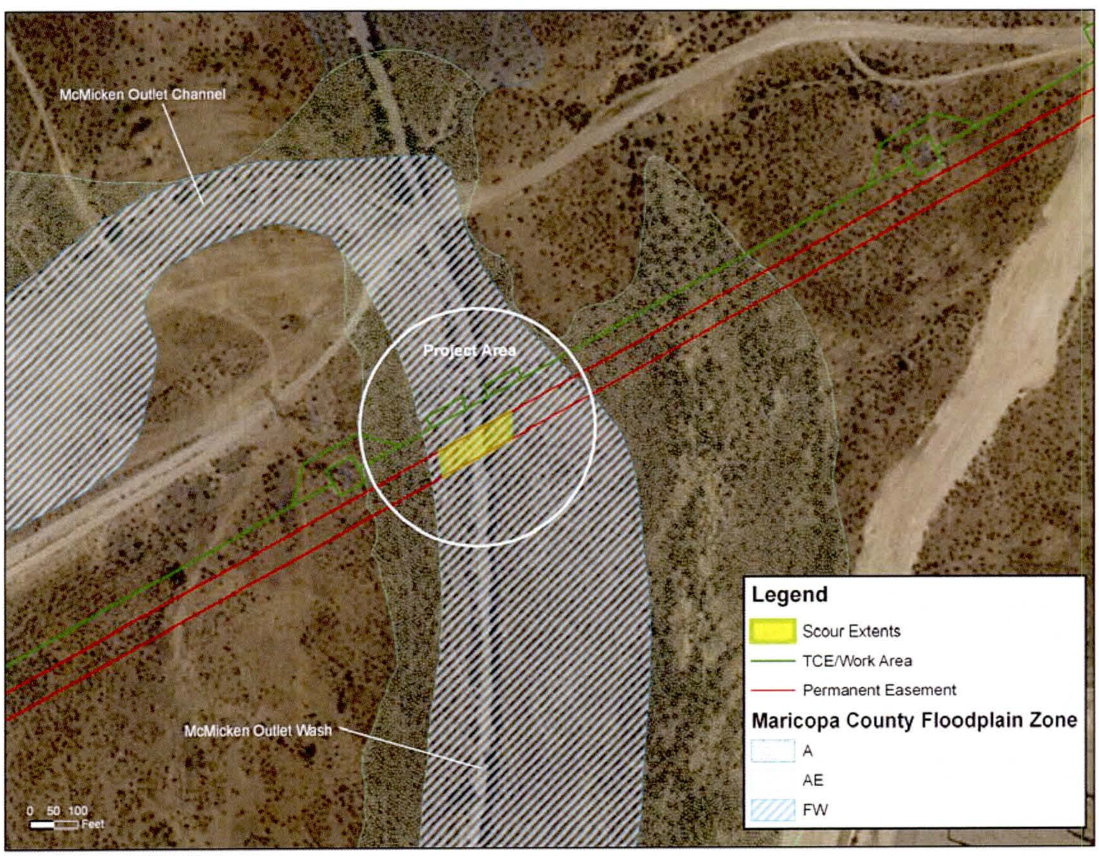


Figure 6 - Area 1 Scour Limits

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 2: McMicken Outlet Channel Crossing

Site Description

Area 2 is located northeast of the crossing of the Burlington Northern & Sante Fe railroad over the McMicken Outlet Channel. At this location, the pipeline alignment turns 90° to the southeast and crosses beneath the McMicken Outlet Channel perpendicularly. In this area, the alignment is located within a FEMA Zone A floodplain.

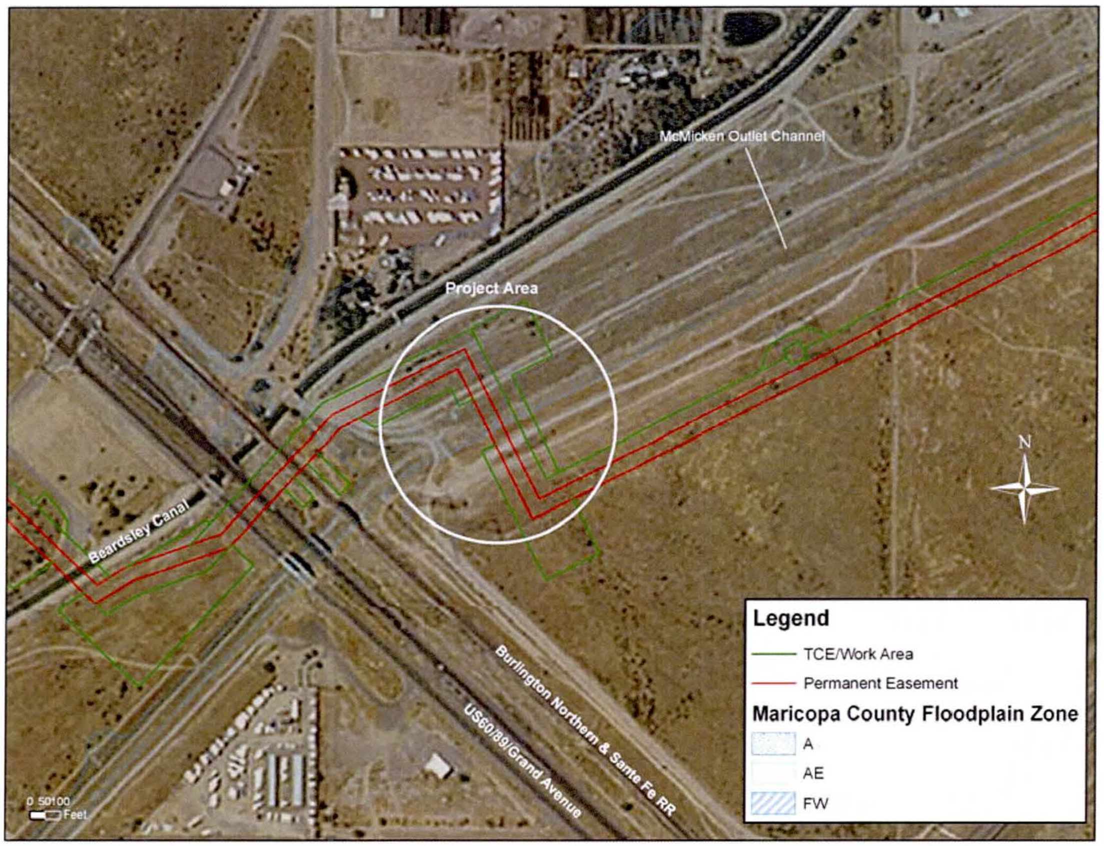


Figure 7 - Area 2 Location

Available Information

Hydrologic information for the area is available from the Wittmann ADMSU. Hydrologic modeling for the Wittmann ADMSU was conducted using FCDMC methodology and HEC-1 analysis for the existing and future condition land-use 100-year, 24-hour storm event. Hydrologic information for the SPF event was taken from the Wittmann ADMS by the WLB Group (1989).

Hydraulic data for the area is available from the previously mentioned compilation HEC-RAS analysis of the McMicken Outlet Channel and McMicken Outlet Wash developed by JEF (2007) for the Wittmann ADMP.

Sediment data has been compiled by AMEC in the vicinity of the dam and is summarized in the McMicken Dam Geotechnical Appraisal report included in the Wittmann Area Drainage Master Plan (Entellus, 2007). Additional soils data was available from the NRCS soil survey (AZ651).

Results

Vertical Scour – Vertical scour was computed for the 100-year and SPF discharges. Per instruction from FCDMC, SPF values have been used for design.

Due to the likelihood of sediment-laden flow, the Lacey equation was applied. In the vicinity of the pipeline crossing, test-pit 06-7 was dug by AMEC on December 4, 2006. The soil log for the test-pit logged sand and gravel with silt and clay soil textures up to a depth of 13 feet in the McMicken Outlet Channel. For the 100-year event, a median soil diameter of 0.42 mm was inferred from the soils information and input into the Blench equation. The Blench equation was used due to the upstream presence of McMicken Dam, which may act to settle sediment. For the SPF event, the same median sediment diameter was used, but the Lacey equation was selected for application due to the apparent overtopping of the emergency spillway and co-mingling with discharge from the principal spillway.

Anti-dune scour was computed following guidance in the FCDMC's Draft Drainage Design Manual – Hydraulics (FCDMC, 2003). Hydraulic information was taken from the HEC-RAS analysis of McMicken Outlet Channel and McMicken Outlet Wash (JEF, 2007).

Long term scour was estimated with State Standard 5-96 Level I methodology.

Site reconnaissance photos indicate the channel is trapezoidal with an evenly graded, semi-vegetated bottom. Figure 8 shows the channel at the crossing site. The Outlet Channel is regularly maintained and not subject to the cyclic low flows which are characteristic of natural washes. Because of the frequency of maintenance, no low-flow incision has been included for calculations based upon multi-year return interval events.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Figure 8 - McMicken Outlet Channel Near Crossing Site (Photo Date: March 28, 2007)

Table 4 - Area 2 100-yr Scour Summary

Summary		
Type	Method	Result
General	Blench	5.6
Bedform	FCDMC Manual	0.32
Thalweg/Low Flow	FCDMC Manual	0
Bend	-	-
Long-Term	SS5-96 Level I	2.4
Other	-	-
	Total	8.32
	Total w/ SF	11

Table 5 - Area 2 SPF Scour Summary

Summary		
Type	Method	Result
General	Lacey	5.45
Bedform	FCDMC Manual	0.69
Thalweg/Low Flow	FCDMC Manual	-

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Bend	-	-
Long-Term	SS5-96 Level I	2.40
Other	-	-
	Total	8.53
	Total w/ SF	11

Lateral Scour – Input and results of the modified Bishop's method for slope failure are presented below. Lateral erosion offsets were based upon the top of banks which were defined using 2-ft FCDMC topography developed for the Wittmann ADMSU. Figure 9 shows the lateral migration extents and scour depths in the vicinity of Area 2.

Table 6 - Area 2 Lateral Migration Data

Bank Slope	ϕ (deg)	c (lb/ft^2)	γ_s (lb/ft^3)	Distance from top of bank (ft)	Distance from toe of slope (ft)
2.5H:1V	20	0	110	48	113

Summary

At the McMicken Outfall Channel, the pipeline should be buried 11 feet below the channel invert for a distance of 221 feet.

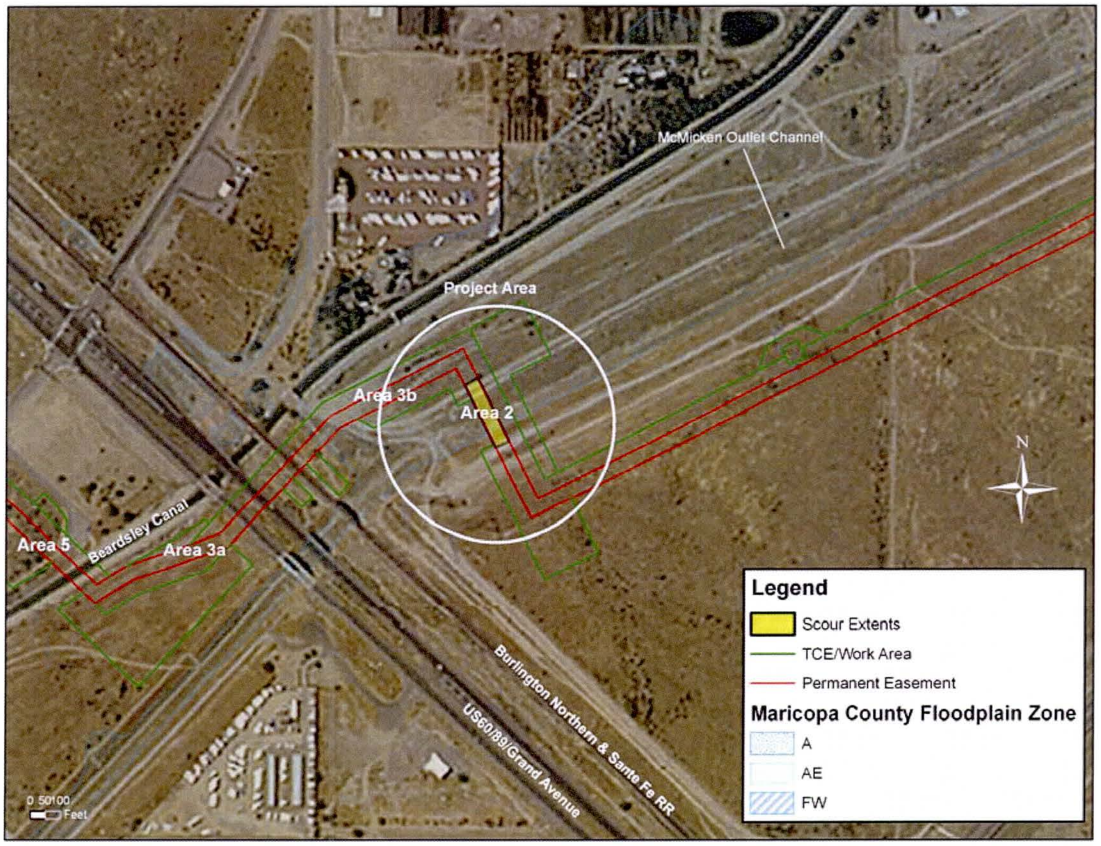


Figure 9 - Area 2 Scour Extents

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 3: McMicken Outlet Channel Floodplain

Site Description

Area 3 is located east of the intersection of the McMicken Dam Outlet Channel and US60/US89/Grand Avenue/Burlington Northern & Santa Fe Railroad. At this location, the proposed pipeline alignment turns 90° to the northwest to cross the channel at a near-perpendicular angle. The pipeline alignment then turns another 90° to the southwest and continues under US60/US89/Grand Avenue/Burlington Northern & Santa Fe Railroad. This area is located within a FEMA Zone A floodplain. The area west of US60/89/Grand Avenue is referred to as Area 3a and the area east of US60/89/Grand Avenue is referred to as Area 3b.

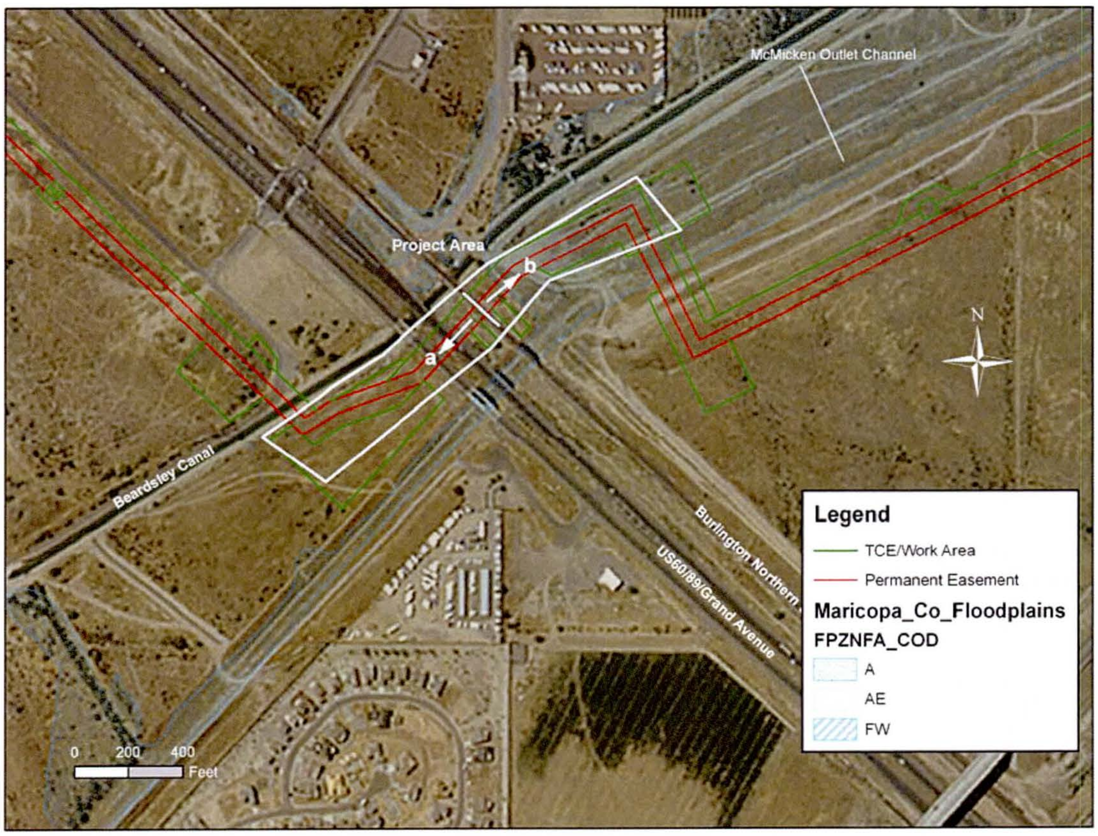


Figure 10 - Area 3 Location

Available Information

Hydrologic and hydraulic information for the 100-year event was taken from the previously mentioned hydraulic analysis of the outlet channel performed by JEF (2007).

Discharge data associated with the probable maximum flood (PMF) was taken from an unsteady-flow HEC-RAS modeled developed by Kimley-Horn (2004).

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Soils information is available from previous work by AMEC for the Wittmann ADMP and from NRCS soil surveys. Soil textural information from the AMEC test pit log is consistent with the NRCS soil information for the area.

Results

Vertical Scour – Area 3 is not subject to 100-year discharges from confined flow.

While the Area 3b is partially within a Zone A floodplain, it is not currently subject to riverine scour elements. The Zone A floodplain which intersects Area 3 is an artifact related to the Beardsley Canal dike which is not a FEMA-certified levee (Philips, 2007). A review of the recent HEC-RAS model of McMicken Outlet Channel shows containment of the 100-year discharge within the channel. As such, the scour hazard from the McMicken Outlet Channel in this area is minimal. Analysis of the crossing of the active conveyance portion of McMicken Outlet Channel is addressed in Area 2. The lateral migration offset for the McMicken Outlet Channel does not intersect the proposed pipeline alignment within Area 3 (see the lateral erosion analysis for Area 2 for the McMicken Outlet Channel lateral erosion extents).

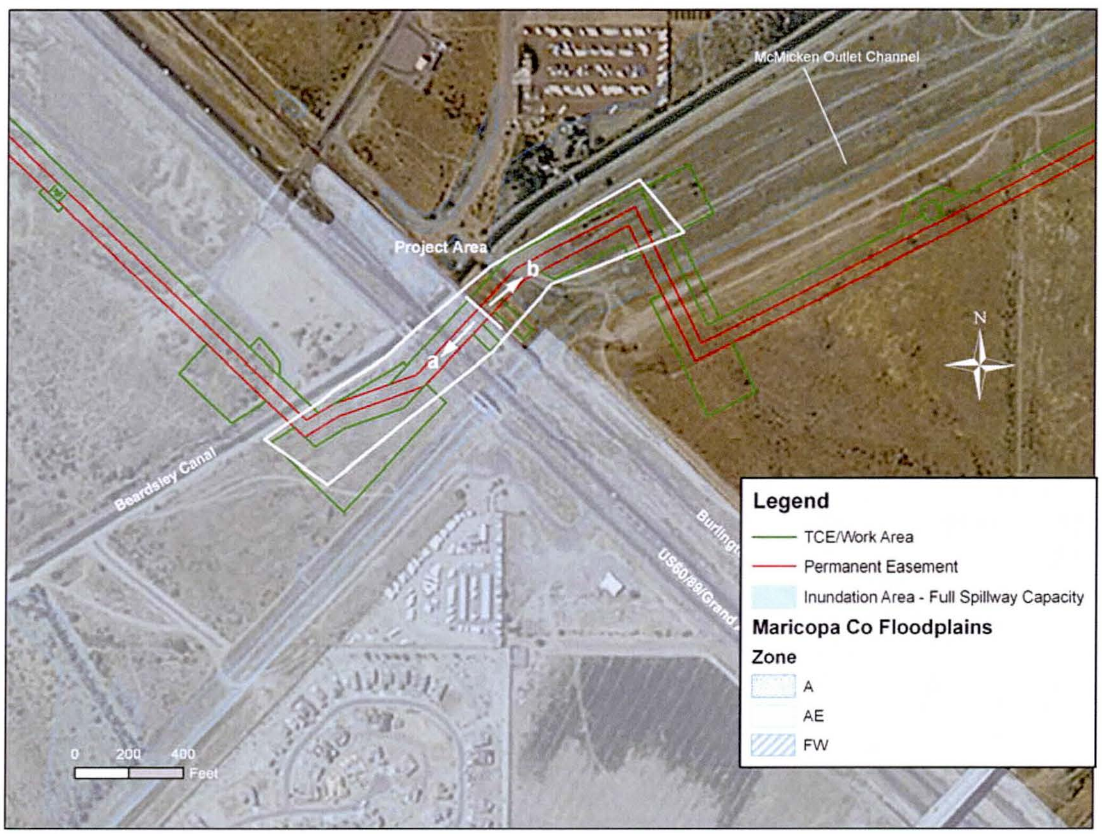


Figure 11 - Full Spillway Inundation Near Beardsley Canal

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 3a is subject to PMF discharges over Beardsley Canal via the emergency spillway. Analysis of this type of scour is discussed in Area 4. Due to the hazard present from the PMF discharge, use of the typical pipeline trench section, which details 3 feet of cover, is not recommended. Selection of an appropriate scour depth requires inspection of adjacent scour analyses. Inundation mapping for flow over the McMicken Dam emergency spillway has been provided by FCDMC and is shown in Figure 11. The inundation limits shown correspond to the full spillway discharge of 90,000 cfs, which is approximately equal to the 89,000 cfs modeled in the Kimley-Horn PMF unsteady HEC-RAS model of the McMicken Dam spillway. The inundation limits for the full spillway discharge correspond to the division between Area 3a and 3b.

In Area 3b, because no 100-year or PMF scour hazard exists from the emergency spillway or primary outlet channel, additional depth of placement for scour is not required. However, the high-hazard nature of the location and imprecise nature of hydrologic calculations suggests some cover is necessary. As such, minimally, the pipeline should be placed below the adjacent thalweg of the McMicken Outlet Channel through Area 3b. Were the Beardsley Canal levee to fail, a headcut could propagate upstream from the McMicken Outlet Channel at some positive slope. This differs from the PMF headcut discussion included in Area 4 because the contributing area upstream of the Beardsley Canal levee in this area is independent from McMicken Dam. Due to the distinct watersheds, the McMicken Outlet Channel may not have significant depth of flow prior to the arrival of the flow through the levee and a headcut will develop.

In Area 3a, scour depth corresponding to the values presented for Area 5 should be applied due to the hazard represented by PMF discharges over the McMicken Dam emergency spillway. For the 100-year, 200-year, 500-year, and SPF discharges, no hazard is present from flow through the McMicken Dam emergency spillway or flow within the McMicken Dam Outlet Channel.

<u>Lateral Scour</u> –No discharge is present in Area 3a or 3b during the 100-year event and lateral migration from the McMicken Outfall Channel for this return interval is addressed in Area 2. A review of the limits shown for Area 2 indicates the segment through Area 3 is beyond the lateral migration limits for the SPF.

Summary

Summary results for Area 3a are included in the analysis of Area 5. In Area 3b, it is recommended that the pipeline be buried below the invert elevation of the McMicken Outlet Channel for approximately 730 feet.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 4: Beardsley Canal Crossing

Site Description

Area 4 is the crossing of the alignment at the Beardsley Canal. The area is located southwest of the intersection of the Beardsley Canal and US60/89/Grand Avenue. At this location, the pipeline alignment turns approximately 90° to the northwest across the Beardsley Canal. To the northwest, the pipeline parallels the US60/89/Grand Avenue alignment.

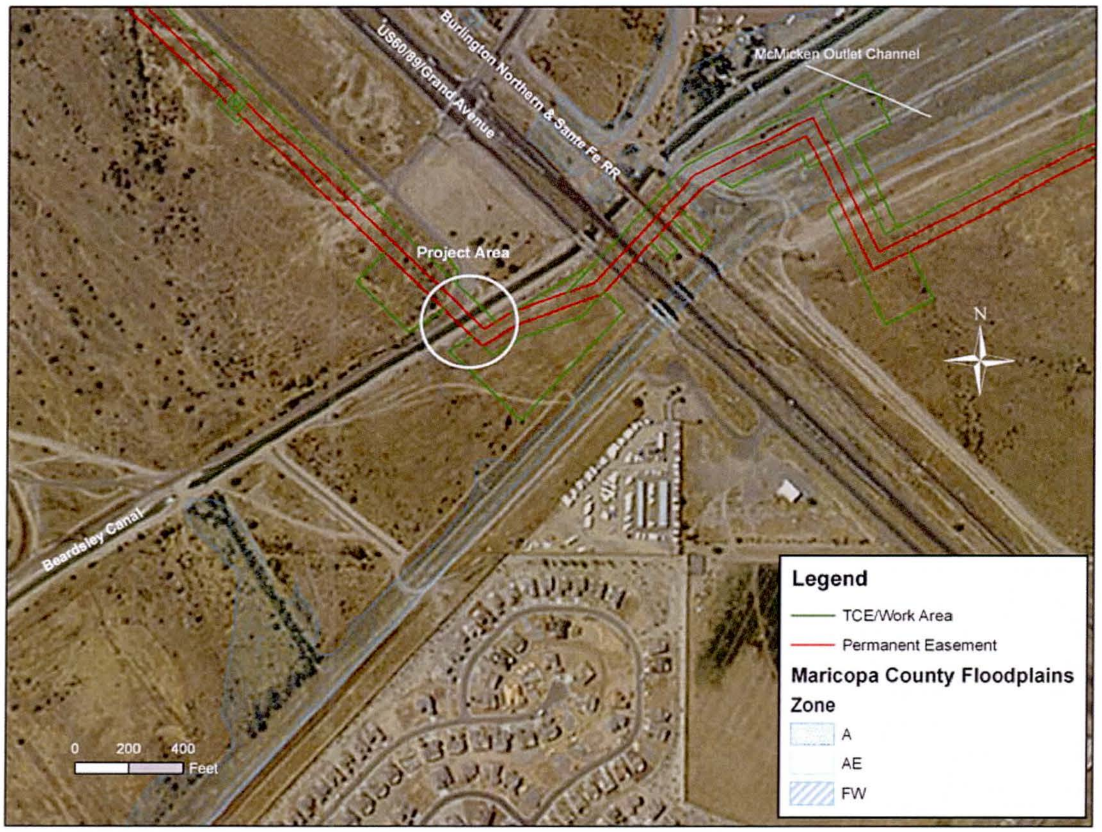


Figure 12 - Area 4 Location

Available Information

Hydrologic data was taken from the Emergency Action Plan (EAP) for McMicken Dam by Kimley Horn and Associates (2004). The unsteady-flow HEC-RAS model developed for this study indicates approximately 89,000 cfs overtops the emergency spillway during the PMF event.

Hydraulic data was developed using 2-foot contour interval topography produced for the Wittmann ADMSU. A normal depth analysis using Flowmaster (ver. 7) with Manning's

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

n values typical of the Kimley Horn HEC-RAS model produced values shown in the analysis for Area 5 in Appendix A.

The most comprehensive, readily-available sediment data in this vicinity of the Beardsley Canal crossing location is NRCS soil survey data. Several AMEC test pits have been dug in the McMicken Outlet Channel in the vicinity of the canal and are of similar character as the soils indicated by the NRCS soil survey.

Results

Vertical Scour - The Beardsley Canal crosses the McMicken Dam emergency spillway channel nearly perpendicularly. Conventional open-channel scour analysis is not capable of accounting for scour beneath a transverse, monolithic structure.

Multiple flood events were evaluated for this location. Notably, the 100-year, 500-year, PMF, and SPF events were investigated. Inundation limits developed for the emergency spillway and provided by FCDMC indicate that discharges less than 25,000 cfs do not cause inundation in this area. Unsteady-flow analysis of the routing along McMicken dam indicates that inundation of this area also do not occur during the 500-year event (this analysis is described in greater detail in Area 5).

Scour results from the analysis for Area 5 indicate the canal would be undermined by the spillway discharge from the PMF event if the design scour depth is achieved at the canal. In reality, the likelihood of this eventuality is minimal. The large size and extent of the Beardsley Canal suggest it will function as a vertical grade-control structure. While the general scour depth calculated for Area 5 may be realized, it will be localized upstream of the canal.

If upstream PMF scour were to continue to Beardsley Canal, it is unlikely the canal structure would remain intact. While the entire length across the emergency spillway could be compromised, a dam-break-type failure is far more likely given the topographically defined thalweg of the spillway area. Under this scenario, the likely point of failure of Beardsley Canal would be near the topographic low point located approximately 1200 feet from the pipeline crossing. Extension of the canal failure for 1200 feet is extremely unlikely and no depth adjustment for this eventuality is necessary.

An additional hazard is present in the form of headcutting from the McMicken Outlet Channel. In practicality, however, headcutting impacts will be minimal. The McMicken Outlet channel is supplied by the McMicken Dam primary spillway. The primary spillway conveys flow during sizeable events upstream of the dam including the 100-year flow event and the PMF. While the emergency spillway is not overtopped during the 100-year event, the McMicken Outlet Channel flows nearly full. During the PMF event, when the emergency spillway is overtopped, greater discharge will reach the outlet channel from the primary spillway and fill the channel to a greater extent than the 100-year event. Equations developed for the modeling of headcutting from sand and gravel extraction areas (Li et al, 1993) reflect a decrease in headcutting for pits with high initial

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

water surface elevations. Additionally, a headcut would propagate upstream with a positive slope resulting in a decreasing scour depth as the headcut approaches Beardsley Canal. However, as no substantial vertical drop will occur from emergency spillway flow into the channel and the Outlet Channel will be flowing nearly full, a headcut is not expected to propagate from the McMicken Outlet Channel to Beardsley Canal. Therefore we recommend no additional scour be added for this action.

Minimally, the top of the pipeline must be placed 10 feet below the invert of the Beardsley Canal to satisfy Maricopa Water District requirements. Based upon FCDMC 2-foot topography, this results in a minimum burial depth of 14 feet below the surrounding ground.

As described in Area 3 and Area 5, total scour (with safety factor) from the PMF discharge produces a scour depth of 28 feet, relative to the thalweg of the emergency spillway channel. This depth is far greater than that required by the Maricopa Water District (owner of the Beardsley Canal) and has been adopted for design to remain conservative.

Lateral Scour – Lateral scour is not necessary for design at this location as it is a continuation of the upstream and downstream scour depths.

Summary

Summary results for Area 4 are included in Area 5.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 5: McMicken Dam Spillway

Site Description

Area 5 is bounded by McMicken Dam to the west, the McMicken Dam Emergency Spillway to the northwest, US60/89/Grand Avenue to the east, and Beardsley Canal to the southeast. This area is the outlet of the McMicken Dam Emergency Spillway. This area is not located in a delineated floodplain.

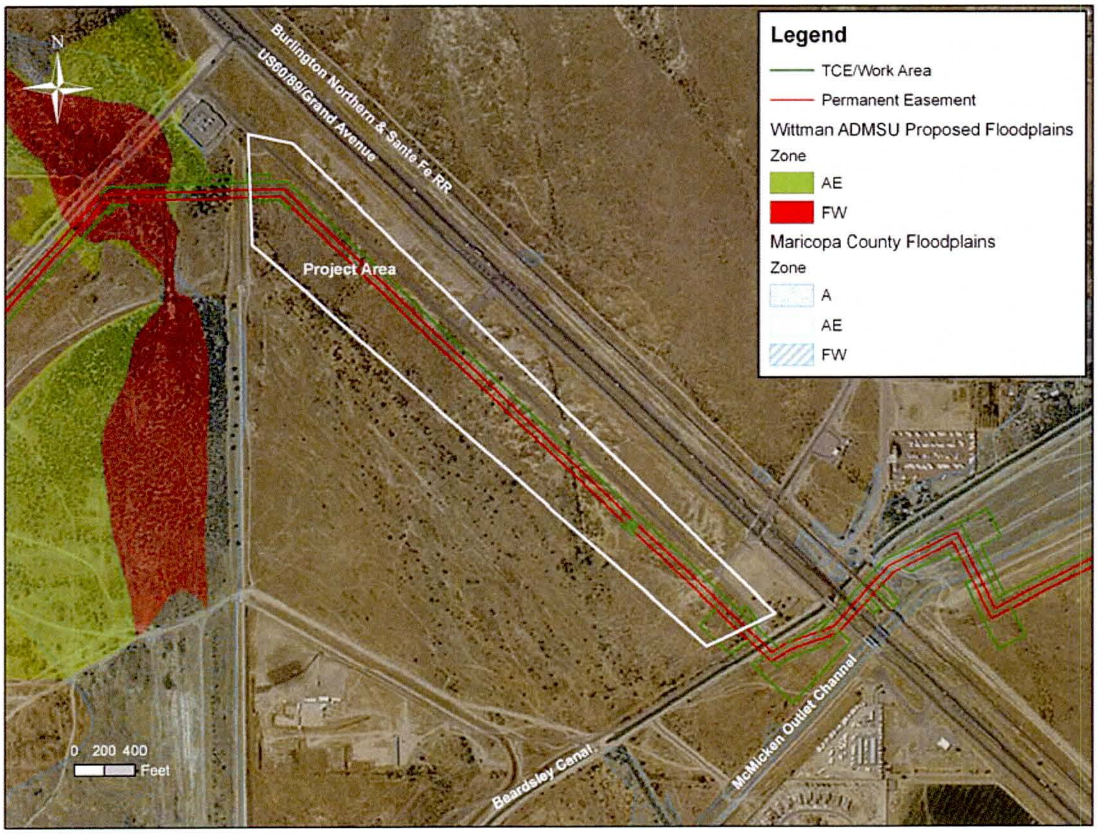


Figure 13 - Area 5 Location

Available Information

Hydrologic information has been taken from the Kimley-Horn (2004) unsteady-flow HEC-RAS model. Entellus Inc is currently in the process of modifying the Kimley-Horn model to more accurately match existing flow conditions and structures and may incorporate Wittmann ADMSU hydrology as well. The study is currently in-progress and is not available for use in this study.

As part of this analysis, JEF modified the Kimley-Horn unsteady-flow HEC-RAS model to model multiple flood events. The base hydrology for the Kimley-Horn model was taken from the Wittmann ADMSU McMicken Dam Hydrology report by Entellus (2004).

As part of their study, Entellus developed hydrology for multiple events including the 100, 200, and 500-year events as well as the 6 and 72-hour PMF events. Hydrographs were exported from the corresponding subbasins in each model to generate a multi-plan unsteady-flow HEC-RAS model for each event. Because the original Kimley-Horn model incorporated PMF discharges, only the future condition 100-year 24-hour, 200-year 24-hour, and 500-year 24-hour storms were analyzed by JEF. Output from these models was compared to inundation limits for the McMicken Dam emergency spillway associated with the 1/3, 2/3, and full spillway discharges of 25,000; 55,000; and 90,000 cfs respectively. Table 7 illustrates the results of HEC-RAS unsteady-flow routing along the upstream side of McMicken Dam. Storm depths for the 100, 200, and 500-year storms are point values. Direct comparison between these values and the SPF values shown in Table 8 is tenuous due to the uncertain areal reduction method of the storm depth and the difference in analysis method for the emergency spillway discharge (the SPF spillway discharge was computed via a HEC-1 rating curve).

Table 7 - Storm Information at McMicken Dam

Freq/ID	Storm Depth (inches)	Storm Duration (hours)	Peak Emergency Spillway Discharge (cfs)
100-yr	4.159	24	1800
200-yr	4.66	24	5700
500-yr	5.26	24	12500
PMF	15.7	72	89300

Table 8 - SPF Storm Information at McMicken Dam (WLB Group, 1989)

Freq/ID	Storm Depth (inches)	Storm Duration (hours)	Peak Emergency Spillway Discharge (cfs)
SPF	8.6	72	10977

Of the emergency spillway discharges studied, only the PMF discharge causes inundation or presents a lateral migration risk to the pipeline alignment. The other discharges studied produce peak discharges over the emergency spillway of less than the 1/3 spillway capacity discharge, which has defined inundation limits and does not come within 150 feet of the pipeline alignment. Additionally, FCDMC is currently considering moving the emergency spillway on McMicken Dam to the south which would further separate the pipeline alignment and emergency spillway flows.

In support of PMF scour analysis, hydraulic data for the study area has been established using normal depth computations in Flowmaster (ver. 7.0). Topographic information was taken from FCDMC 2-foot interval mapping for the Wittmann ADMSU. Manning's roughness values were estimated from aerial photography and compare well with those in the Kimley Horn dam break study (2004).

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Sediment data was taken from NRCS soil surveys (AZ651). No recent sediment data was available in the emergency spillway outlet area. Generally, soils appear to be fine grained for the scour depths computed.

Results

Normal depth hydraulic calculations were performed using an irregular cross-section (station-elevation data) in Flowmaster with the PMF overtopping discharge from the Kimley-Horn unsteady HEC-RAS analysis previously mentioned. Based upon this analysis, flow downstream of the spillway spreads with a top width of approximately 2300 ft.

Vertical Scour - Due to the length of the area studied and the width of the spillway, flow has been assumed to be fully expanded for scour analysis. The Lacey equation was selected for general scour, although sediment "lean" water likely is discharged over the spillway. Flow near the dam may be subject to clear water scour, but downstream areas will be subject to live-bed scour. Because a sediment transport model has not been conducted for the dam during a PMF event, live-bed scour, which produces a greater scour depth, has been assumed to be applicable for the entire area.

Normal depth flow parameters were input into the bedform scour equations listed in FCDMC's Hydraulics Manual (FCDMC, 2003). The bedform component was the smallest magnitude contributing scour element.

Long term scour has not been considered for this location due to several factors. Substantial flow is only present during extreme events, such as the PMF, with now flow with events up to the 100-year event. The downstream presence of the Beardsley Canal creates acts as a vertical grade control structure. "Local" long term scour may occur in the vicinity of the Beardsley Canal overchute, however, the pipeline alignment is not in the vicinity of the overshoot. Low-flow incisement has not been considered for similar reasons.

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Inundation limits for the PMF event are shown in Figure 14.

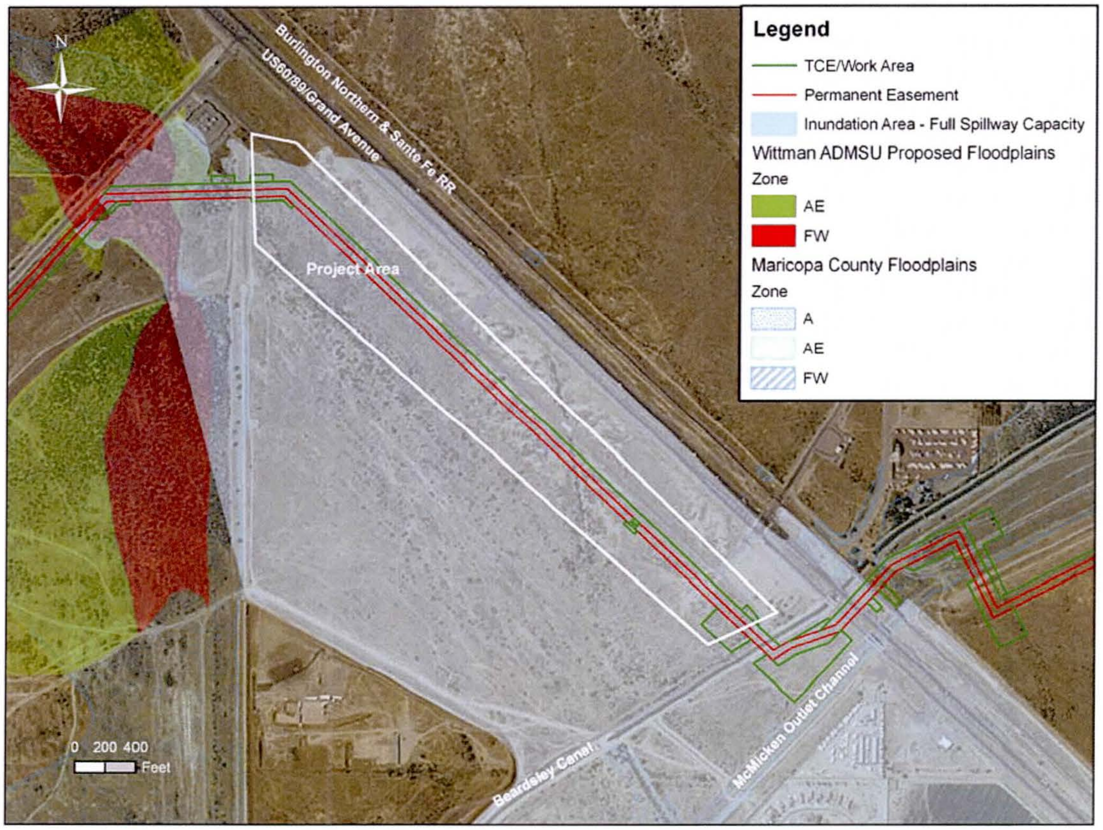


Figure 14 - Area 5 PMF Inundation Area

Upstream of the emergency spillway, scour depth is difficult to calculate. While substantial flow overtops the spillway crest, ponding occurs upstream of the crest which limits flow velocities. In the region between Area 5 and Area 6, the design scour burial depth will vary linearly between the scour depth for Area 5, 27.6 feet and Area 6, 17 feet.

Table 9 - Area 5 PMF Scour Data

Summary		
Type	Method	Result
General	Lacey	20.14
Bedform	FCDMC Method	0.25
Thalweg/Low Flow	n/a	-
Bend	n/a	-
Long-Term	n/a	-
	Total	20.4
	Total w/ SF	27

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Lateral Scour – Lateral migration analysis for this area is not necessary. The proposed alignment parallels the drainage alignment and is within the limits of PMF inundation through the entire study area, as shown in Figure 14.

Summary

The pipeline should be buried 27.6 feet below the emergency spillway channel invert for a distance of approximately 5525 feet to prevent scour during the PMF event. This distance includes Areas 3a, 4, and 5. For non-PMF events, no scour protection is required in Areas 3a, 4, and 5. Transwestern and FCDMC are currently discussing what level of design and scour protection is appropriate for Area 5. The final design scour depth may be less than required for the PMF event.

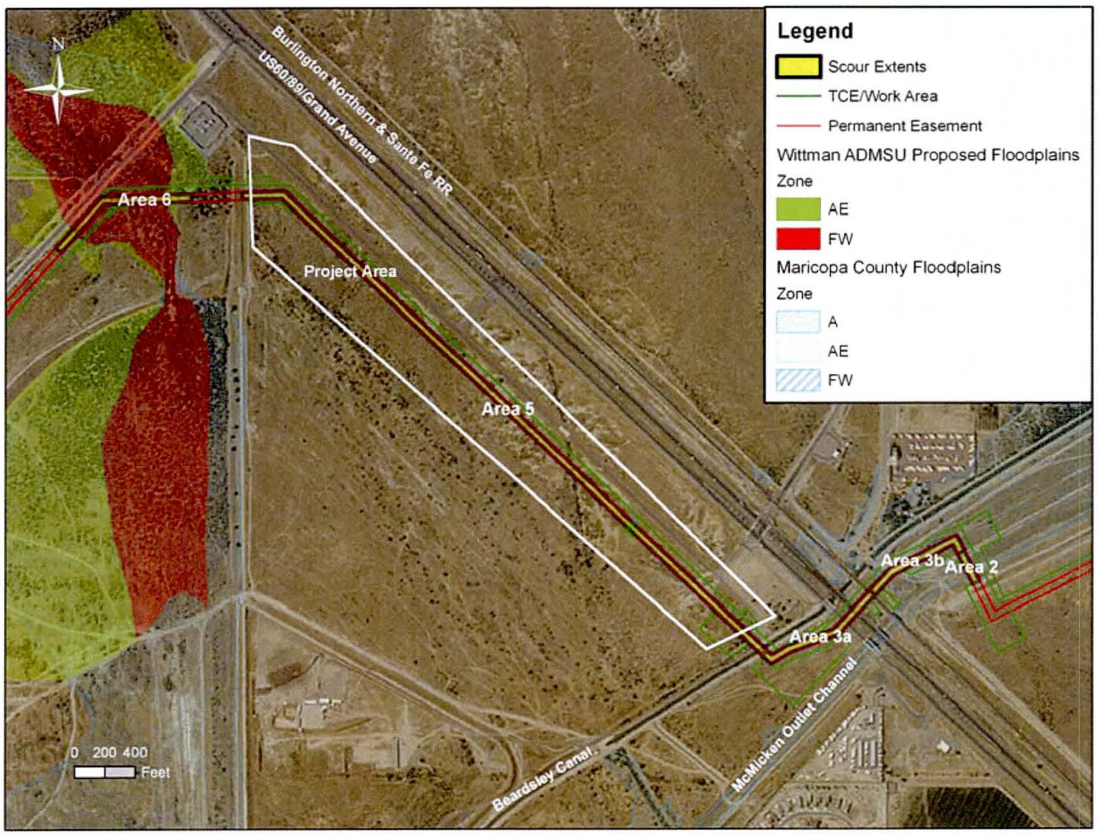


Figure 15 - Area 3a, 4, and 5 Scour Extents

Area 6: Wash 3E

Site Description

Area 6 is located southwest of the intersection of Deer Valley Road and US60/89/Grand Avenue. Along the western portion of this area, the pipeline alignment parallels Deer Valley Road. A wash, identified as Wash 3 East from the Wittmann ADMSU, crosses Deer Valley Road at this location and enters the McMicken Dam flood pool. The effective FEMA floodplain is Zone A, although floodplain delineations performed for the Wittmann ADMSU have defined a Zone AE floodway and fringe through the proposed pipeline alignment.

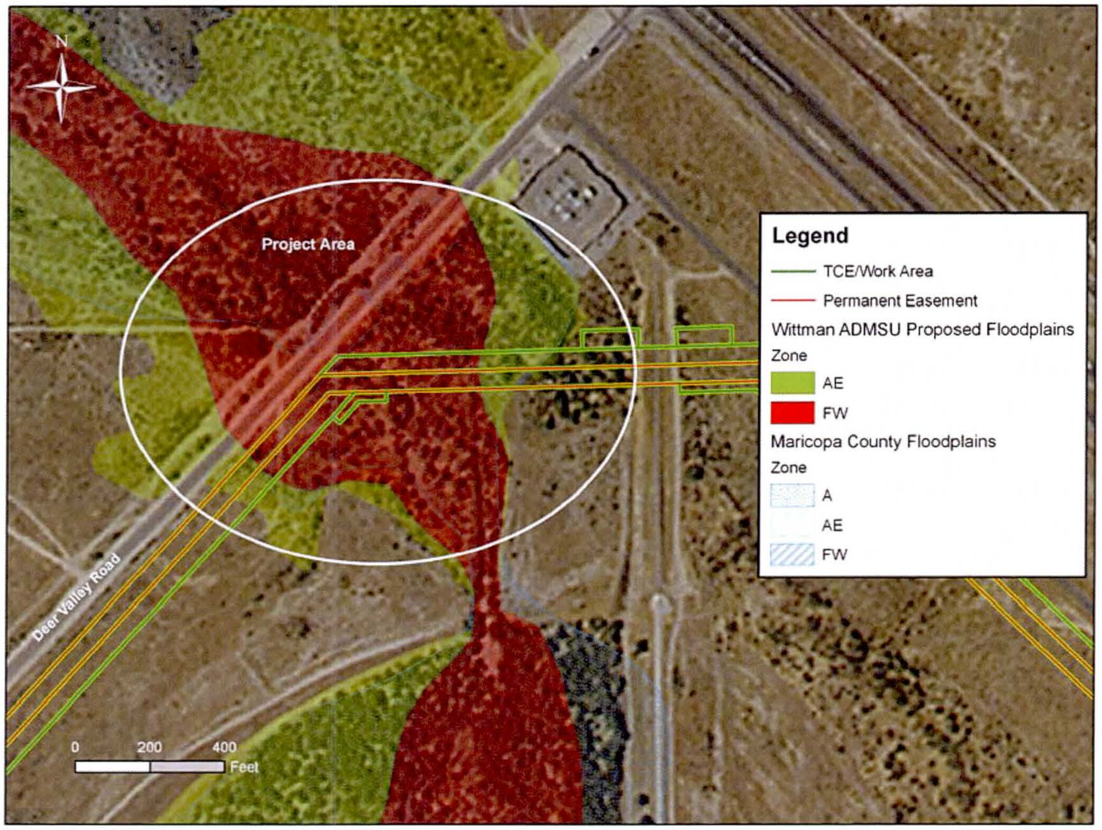


Figure 16 - Area 6 Location

Available Information

Hydrology for Wash 3E is available from the Wittmann ADMSU by Entellus (2007). For this study, hydrology found in the Wash 3E HEC-RAS model used for floodplain delineation has been used (Entellus, 2007). As part of the Wittmann ADMSU, HEC-1 analysis was conducted for existing and future conditions also.

Hydraulic information has been taken from the Wash 3E floodplain delineation HEC-RAS model.

Soils data has been taken from the NRCS soil survey. For scour analysis, the minimum median soil diameter for the area has been used.

Results

Vertical Scour – PMF inundation mapping shown in Figure 14 illustrates the mixed hazard present at this location. Design scour depths have been based upon 100-year discharge through Wash 3E due to the backwater nature of PMF inundation at the pipeline alignment. Comparison between the FCDMC floodplain and PMF inundation limits show excellent agreement with respect to the limits of inundation. This suggests that either similar discharges result at this location from both events, or the resultant backwater is similar for both discharges.

Input into scour equations has been based partially upon existing condition hydrology and partially upon future condition hydrology. The floodplain delineations performed by Entellus (2007) for the Wittmann ADMP utilize existing condition hydrology which possesses a lower peak discharge than similar modeling based upon a future, "developed" condition rainfall-runoff response. While detailed hydraulic parameters such as water surface top-width and Froude number are based upon output from the Wittmann floodplain HEC-RAS model, scour calculations methodologies which incorporate a discharge parameters have been calculated using the peak value from the 100-year, 24-hour, future condition HEC-1 model. The intent of this practice is to develop the most appropriate scour value for long term hydrologic trends in the watershed.

Area 6 is located downstream of Deer Valley Road, which impedes flow. While Deer Valley Road creates a minor settling pond, the extents do not appear to justify use of clear water scour equations. Also, the Lacey equation (general, live-bed scour) produces a more conservative scour value at this location. The Lacey equation was selected to evaluate live bed scour.

At Deer Valley Road, flow is passed via 4 sets of 2-10'x3' reinforced concrete box culverts (RCBCs). Outlet scour at the culverts was calculated using the methodology presented in HEC-14 for cohesionless soils (Thompson and Kilgore, 2006) with input taken from the Wittmann ADMSU floodplain analysis HEC-RAS model. This analysis suggests the scour holes formed at the outlets of the two eastern-most RCBC arrays do not reach the pipeline alignment. However, the full scour-hole depth from the western culverts will extends to the pipeline alignment. Therefore, the scour-hole depth has been included in Table 10.

HEC-RAS results from the Wittmann ADMSU floodplain analysis were input into bedform equations listed in the FCDMC's Draft Drainage Design Manual – Hydraulics.

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Long term scour was assessed using the Level I methodology presented in State Standard 5-96. This method determines long term scour using 100-year discharge as the only input. Application of this component is somewhat nebulous given the calculation of the culvert outlet scour-hole depth. Long term scour has been incorporated to develop a conservative scour estimate.

Results are summarized in Table 10 below.

Table 10 - Area 6 100-year Scour Summary

Summary		
Type	Method	Result
General	Lacey	4.35
Bedform	FCDMC Manual	0.16
Thalweg/Low Flow	-	-
Bend	-	-
Long-Term	SS5-96 Level I	2.50
Other	Culvert - HEC-14	6.26
	Total	13.27
	Total w/ SF	17.3

Lateral Scour – Lateral migration was assessed using the modified Bishop's method of slope failure at the design scour depth. In the vicinity of the crossing, no single defined channel is apparent in the FCDMC 2-foot contour mapping. Rather, multiple, ill-defined channels are apparent in the topography. From the Wash 3E floodplain delineation HEC-RAS model, 4 culvert arrays pass flow from Wash 3E under Deer Valley Road. The arrays span nearly the entire floodway width. Given the uncertainty present in the exact direction of existing flow, the lateral offset has been based upon setting the edge of the Zone AE floodplain, defined in the Wittmann ADMSU, as the top of the scoured bank. Offsets were measured using the values in the table below.

Table 11 - Area 6 Lateral Migration Data

Bank Slope	ϕ (deg)	c (lb/ft^2)	γ_s (lb/ft^3)	Distance from top of bank (ft)	Distance from toe of slope (ft)
2H:1V	25	0	100	28	65

Summary

The pipeline should be placed 17.3 feet below the channel thalweg of Wash 3E for a distance of 1010 feet. The scour depths are not shown as continuous between areas 5 and 6 due to the presence of the McMicken Dam emergency spillway structure which directs flow from Wash 3E westward, away from the spillway. Flows from behind the dam pond until the spillway overflows creating a minimal scour environment at the pipeline alignment. The appropriate scour depth in this transition area is that of Area 5; see the discussion in that section for details regarding the design scour depth.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

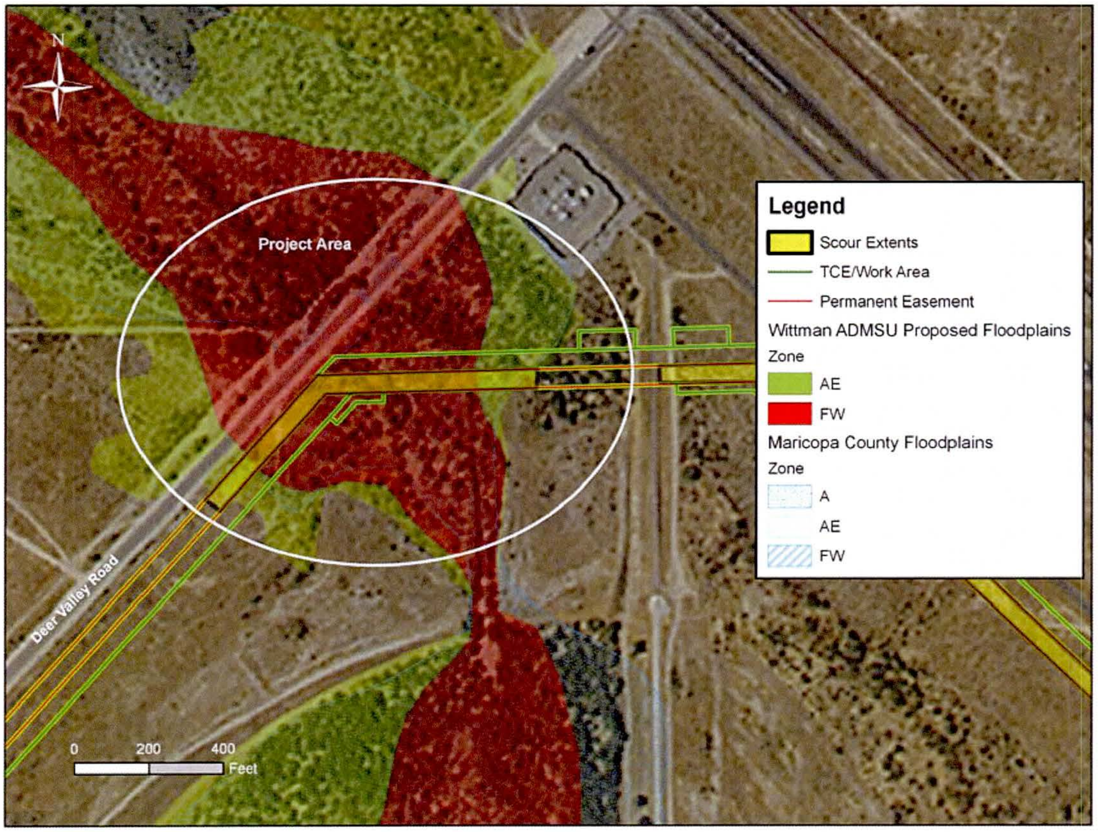


Figure 17 - Area 6 Scour Extents

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 7: Hassayampa Erosion Hazard Zone

Site Description

Area 7 is located east of the Hassayampa River, west of Buckeye FRS#1 and north of Interstate 10. In this area, the pipeline alignment travels roughly NE-SW while entering and exiting the area from the east.

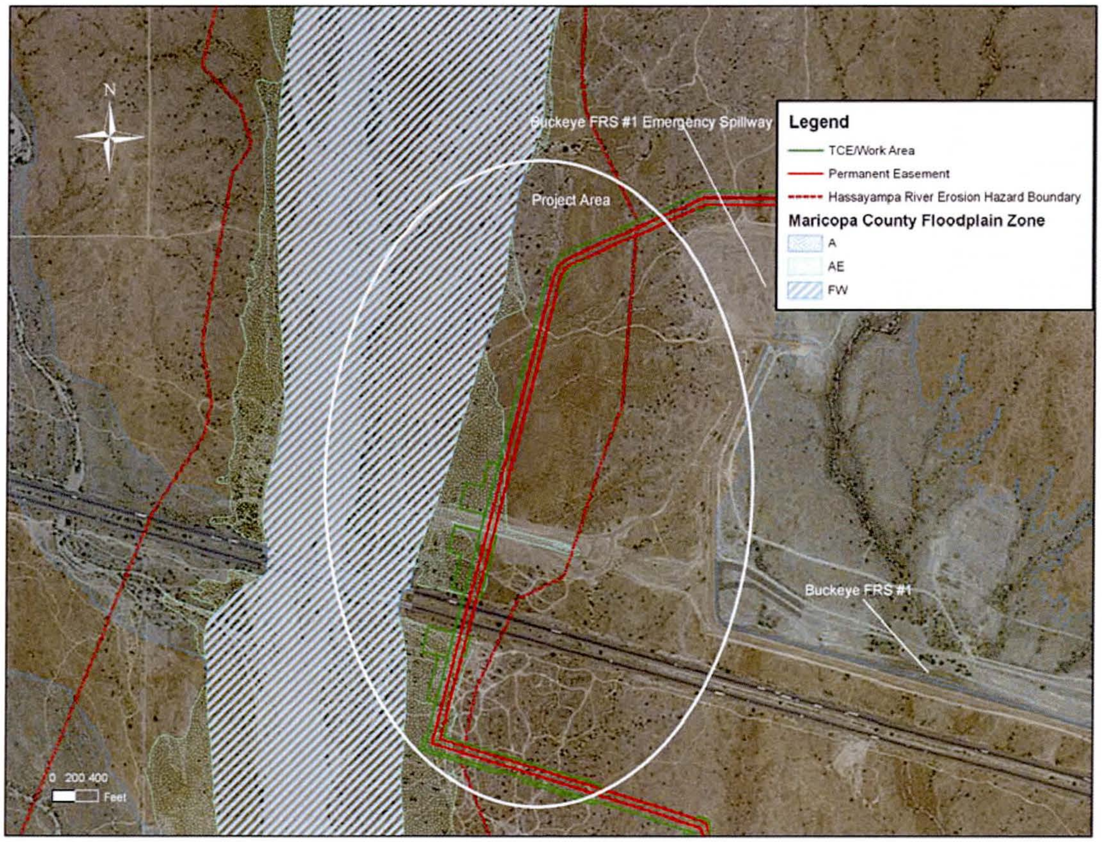


Figure 18 - Area 7 Location

Available Information

Hydrologic information for the Hassayampa River in this reach was taken from the Lower Hassayampa Watercourse Master Plan (JEF, 2006). Specifically, 100-year discharge data was extracted from the project erosion hazard zone HEC-RAS model. The 100-year discharge of 75,164 cfs was originally reported by Cella Barr and Associates in the floodplain delineation study (FDS) for the Hassayampa River (1988). Hydrologic information for the Buckeye FRS#1 emergency spillway was taken from the Buckeye ADMS unsteady flow model by PBS&J (2006).

Hydraulic information was taken from the Lower Hassayampa Watercourse Master Plan erosion hazard zone HEC-RAS model. Hydraulic parameters associated with the FDS discharge were utilized.

Sediment data in the vicinity were taken from NRCS soil survey data and the LHWCMP. Median sediment particles in this vicinity were retained on the #40 sieve.

Results

<u>Vertical Scour</u> – Scour was assessed for each hazard individually.

The PMF discharge routing behind Buckeye FRS#1 was modeled in the Buckeye ADMS using an unsteady HEC-RAS model. From this, a peak discharge of 18,651 cfs was modeled from the 6-hour PMF event. Compared to the 100-year discharge from the Hassayampa River, the PMF emergency spillway discharge is approximately 25% as large volumetrically. Given that most approximate scour calculation methods are based upon the design discharge, the predominance of the Hassayampa 100-year discharge will dictate the design scour depth. Figure 19 shows the inundation extents for a full spillway

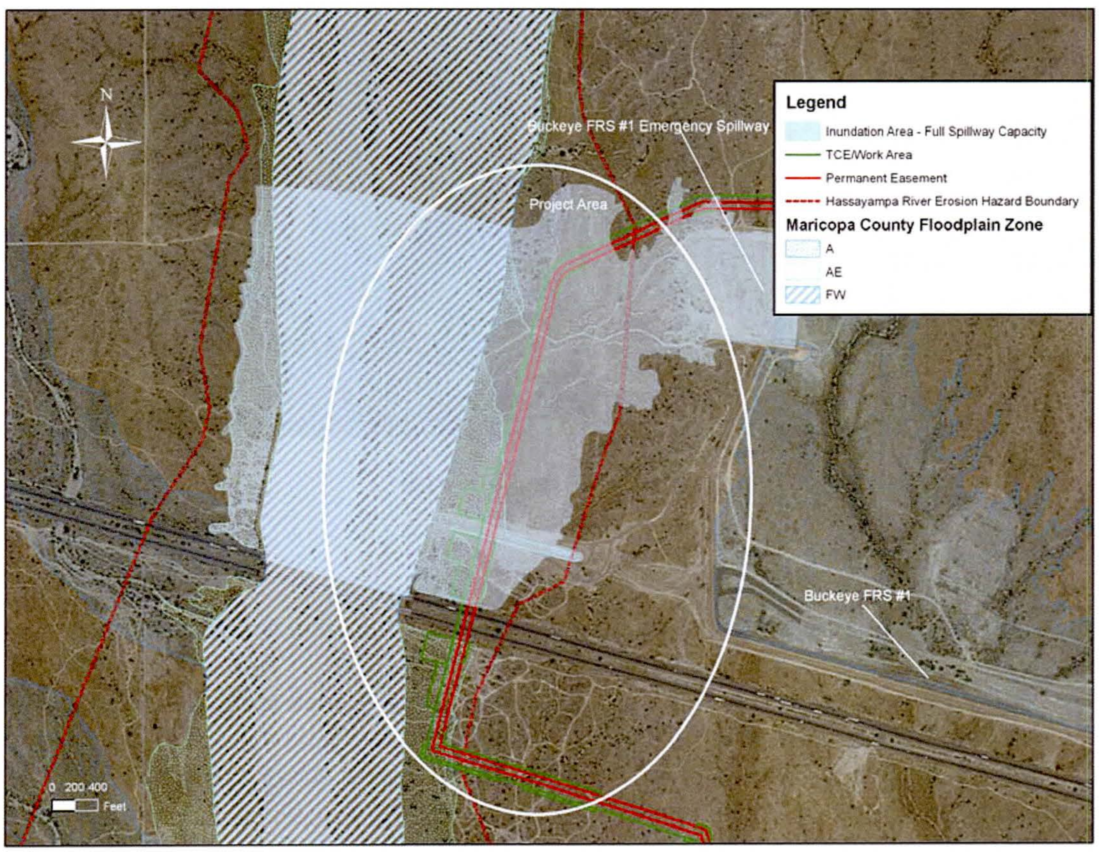


Figure 19 - Emergency Spillway Inundation Near Buckeye FRS#1

discharge from the Buckeye FRS#1 emergency spillway. In two locations the inundation extents intersect the alignment outside of the Hassayampa River erosion hazard zone.

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

This locations are not areas of active conveyance, as evidenced by topography, and do not present a significant scour risk to the pipeline. Scour results for the PMF analysis of the Buckeye FRS#1 emergency spillway are presented in Table 12. While long-term scour is not applicable for the PMF discharge due to the infrequent nature of flows from the spillway, application of the long-term scour from the Hassayampa River, associated with the 100-year discharge in that watercourse, would be applicable at this location. Application of the Hassayampa River long-term scour in conjunction with the PMF discharges results in a design scour depth, included safety factor, of 8.73 feet. More discussion of long-term scour in the Hassayampa River is provided below.

Table 12 - Buckeye FRS#1 Emergency Spillway PMF Scour Summary

Summary		
Type	Method	Result
General	Blench	4.30
Bedform	FCDMC Manual	0.18
Thalweg/Low Flow	-	-
Bend	-	-
Long-Term	-	-
Other	-	-
	Total	4.48
	Total w/ SF	5.8

For the Hassayampa River, no upstream barrier to sediment transport is present near this analysis area and sediment is readily available within the Hassayampa River channel. Accordingly, local scour was evaluated using the Lacey equation due to the presence of live-bed scour. Bend scour has been incorporated into the general scour calculation.

Bedform scour was evaluated using output from the erosion hazard zone HEC-RAS model developed for the LHWCMP. Data for multiple sections was used as bedform development is a transitory event.

Long term channel degradation was determined using State Standard 5-96 Level I methodology. Scour results are summarized below.

Low flow incisement has not been included as the Hassayampa River is a natural watercourse with a distinct thalweg.

Table 13 - Area 7 Hassyampa River 100-year Scour Summary

Summary		
Type	Method	Result
General	Lacey	9.18
Bedform	FCDMC Manual	1.75
Thalweg/Low Flow	-	-
Bend	-	-
Long-Term	SS5-96 Level I	16.90

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Other	-	-
	Total	27.8
	Total w/ SF	36

At an initial meeting with FCDMC staff, SS5-96 was specified as the acceptable means of calculating long-term scour for these applications. At a meeting held on 12-6-07 with FCDMC, Bing Zhao indicated the long-term scour component for the Hassayampa River was excessive. FCDMC staff has provided data from HEC-6 modeling from the LHWCMP (JEF, 2006) for use as the long-term scour component. HEC-6 modeling performed for the LHWMP indicates scour of 1 foot is expected under existing conditions based upon average daily discharges for the period of record from upstream gages.

Table 14 – Hassayampa 100-year Scour Summary following FCDMC Directions

Summary		
Type	Method	Result
General	Lacey	9.18
Bedform	FCDMC Manual	1.75
Thalweg/Low Flow	-	-
Bend	-	-
Long-Term	LHWCMP HEC-6	1
Other	-	-
	Total	11.9
	Total w/ SF	15.5

While this long-term scour depth has been suggested by FCDMC, JEF does not feel the assumptions inherent in the LHWCMP HEC-6 analysis represent future development within the Hassayampa River watershed, particularly with respect to sand-and-gravel excavation operations and potential urbanization impacts.

Rather than placing the pipeline to the full scour depth outside of the Hassayampa channel and within the Hassayampa EHZ, the client has requested structural alternatives to prevent lateral migration of the channel to the pipeline alignment. Regardless of the alternative implemented, the pipeline JEF recommends the pipeline be placed with the top of pipe below the Hassayampa River invert at the alignment of the future channel, which has yet to be determined, to facilitate the potential future construction of a channel to replace Buckeye FRS#1.

Lateral Scour – An existing erosion hazard zone has been delineated for the Hassayampa River in this reach for the LHWCMP (JEF, 2006). The results of that study have been applied at this site.

Summary

In Area 7, the pipeline should be placed a minimum of 17.6 feet below the Hassayampa River thalweg for a distance of 4570 feet.

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

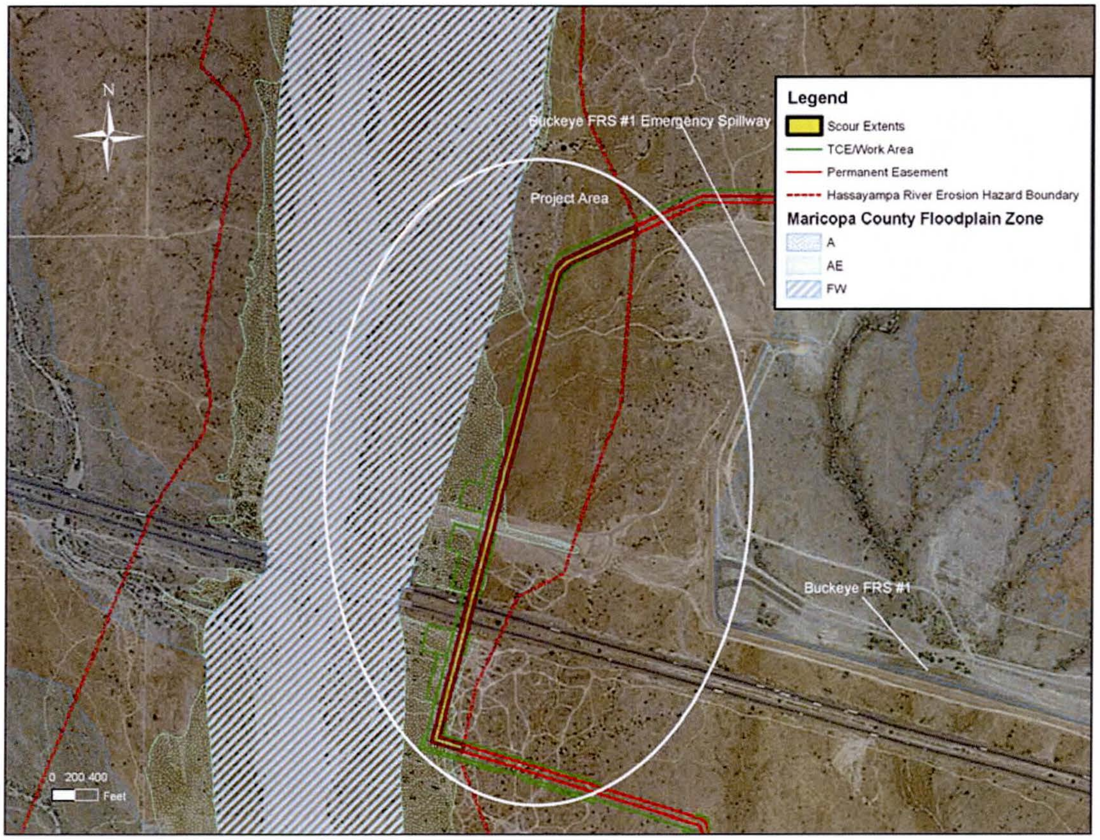


Figure 20 - Scour Extents for Areas 7 and 8
(See Figure 21 for Area 8 Location)

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 8: Buckeye FRS#1 Principal Spillway

Site Description

Area 8 is located within the Buckeye FRS#1 principal spillway near the Hassayampa River. The pipeline crossing of the Buckeye FRS#1 principal spillway is located entirely within the Hassayampa River erosion hazard zone.

Figure 21 - Area 8 Location

Available Information

Sediment data is available from the NRCS soil survey and LHWCMP.

Hydraulic data is available from the "Technical Data Notebook Buckeye Flood Retarding Structures Probable Maximum Flood (PMF) Hydrology & Hydraulics" (PMF TDN) by PBS&J (2006). An unsteady-flow HEC-RAS model was developed as part of the study to analyze the routed characteristics of the dam during multiple storm events including the 100-year, 500-year, and probable maximum precipitation (PMP).

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Normal depth computations for the principal outlet channel were performed with Flowmaster (v. 7). A manning's roughness of 0.035 and a triangular cross section with 3.5H:1V cross slopes were estimated.

Results

Vertical Scour - Analysis was completed using output from the unsteady HEC-RAS analysis of the FRS and spillways. Maximum 100-year discharge through the principal spillway was achieved during the 24-hour event. A peak discharge of 352 cfs passes through the principal outlet culvert during this event. The maximum discharge during a PMF event is achieved during the 6-hour PMP storm and generates a peak discharge of 474 cfs through the principal outlet. Results for the PMF discharge are summarized in Table 15. As the downstream vertical control, long-term scour for the Hassayampa River would supplant the principal spillway long-term scour if this analysis were used for design. However, the principal spillway discharge does not produce significant scour when compared to the 100-year discharge in the Hassayampa River as shown in Table 13. Accordingly, the analysis described for Area 7 has been applied in this location.

While the standard project flood would normally dictate design for dam related structures, PMF information was not readily available for this location. Instead, PMF results, which are generated by a storm of greater depth and more conservative hydrologic conditions, have been presented.

Table 15 - Buckeye FRS#1 Principal Outlet PMF Scour Summary

Summary		
Type	Method	Result
General	Blench	3.11
Bedform	FCDMC Manual	0.1
Thalweg/Low Flow	FCDMC Manual	1.00
Bend	-	-
Long-Term	SS5-96 Level I	0.70
Other	-	-
	Total	4.91
	Total w/ SF	6.4

Lateral Scour – Given the dominance of the Hassayampa River's scour, the Hassayampa River has also been selected as the reference for lateral migration. As with Area 7, the existing erosion hazard zone has been adopted for the lateral migration boundary.

Summary

Results have been presented with Area 7.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Area 9: Unnamed Tributary to Buckeye FRS#1

Site Description

Area 9 is located upstream of Buckeye FRS#1 near the western boundary of the FRS. The pipeline alignment crosses an un-named wash at this location. An effective Zone A floodplain is present at the crossing site. The floodplain originates from routing/ponding of flood flows along the Buckeye FRS#1 rather than from the wash itself.

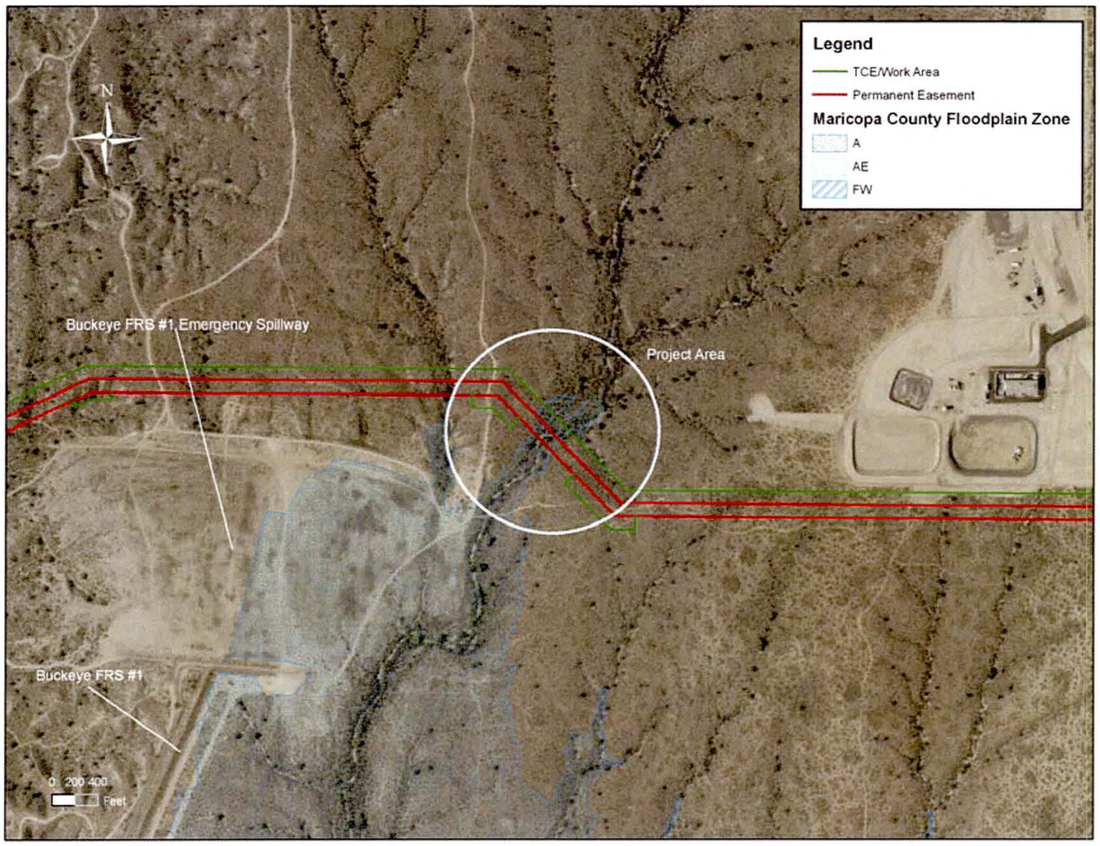


Figure 22 - Area 9 Location

Available Information

The Buckeye FRS#1 unsteady HEC-RAS model was used to evaluate impacts from flow over the emergency spillway during the PMF. Hydrology for the wash was taken from HEC-1 analysis for the area was available in the PMF TDN.

Hydraulic information for the un-named wash was unavailable.

Sediment data was taken from NRCS soil survey data. Generally, the median diameter soil particles in the vicinity were retained on the #40 sieve.

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Results

Vertical Scour - A review of the HEC-RAS unsteady-flow model for Buckeye FRS#1 shows a maximum ponding depth of approximately 2 feet at Area 9 during the PMF. Given this relatively shallow depth and the limited PMF inundation area upstream of the pipeline crossing, discharge to this point from the PMF is insignificant. Scour design is based upon the 100-year discharge.

The PMF TDN provided a peak 100-year discharge of 820 cfs (24 hour precipitation) for the un-named wash at Buckeye FRS#1. Although this discharge incorporates contributing area downstream of the crossing location, it is the finest resolution hydrologic data immediately available.

Using the 100-year peak discharge, a normal depth section was constructed using FCDMC 2-foot topography for the area. Manning's roughness values for the section were estimated based upon aerial photography and a comparison to the previously developed HEC-RAS model for the Lower Hassayampa Watercourse Master Plan. Haestad Methods' Flowmaster (v 7.0) was then used to calculate flow characteristics for normal depth. These values were input into the Lacey and anti-dune scour equations. The peak 100-year discharge was input into the State Standard 5-96 long term scour equation. Low flow incisement was estimated at 1 foot due to the 2-foot contours utilized. Summary results of the scour analysis are presented in Table 16.

Table 16 - Area 9 Scour Data

Summary		
Type	Method	Result
General	Lacey	2.04
Bedform	FCDMC Manual	0.18
Thalweg/Low Flow	-	1.00
Bend	-	-
Long-Term	SS5-96 Level I	1.20
Other	-	-
	Total	4.42
	Total w/ SF	6

Lateral Scour – No previous lateral migration analysis was found for this location. Analysis was undertaken using the modified Bishop's method of slope failure and simplified geometry as explained earlier in this report.

A total scoured bank height of 24 feet was used for the slope failure analysis. This value results from a bank height of 18 feet and a calculated scour depth of 6 feet. The existing left and right banks are sloped at approximately 12H:1V and 20H:1V, respectively. At these grades, the slopes are very stable and will likely remain so after 5 feet of scour. Analysis using the modified Bishop's method yielded a failure surface near the top of bank rather than the toe where no hazard to the pipeline is present from flow. Given this

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

behavior, no explicit lateral offset has been applied and the scour limits have been set 2 feet above the limits of the Zone A floodplain limits.

Table 17 - Area 9 Lateral Migration Data

Bank Slope	ϕ (deg)	c (lb/ft^2)	γ_s (lb/ft^3)	Distance from top of bank (ft)	Distance from toe of slope (ft)
2H:1V	25	0	120	44	284

Summary

Through Area 9, the pipeline should be placed 6 feet below the channel thalweg for a distance of 155 feet.

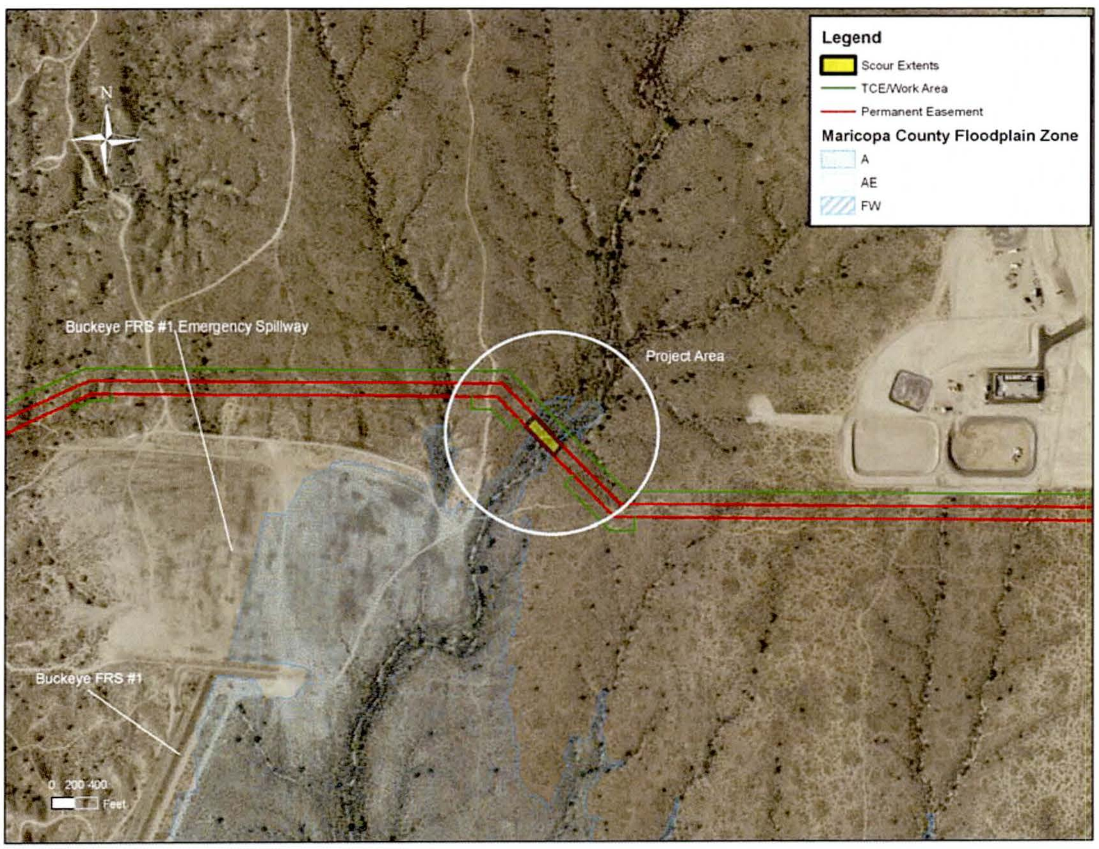


Figure 23 - Area 9 Scour Extents

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

References

ADWR, 1996. "State Standard for Watercourse System Sediment Balance." SS5-96. Arizona Department of Water Resources.

AMEC, 2007. Wittmann Area Drainage Master Plan Volume GA: McMicken Dam Geotechnical Appraisal Report. Flood Control District of Maricopa County Contract FCD 2004C060. Prepared for Entellus, Inc.

Cella Barr and Associates, 1988. Hydrologic Analysis of the Hassayampa River in Maricopa County, Arizona. Federal Emergency Management Agency.

Entellus, Inc, 2005. Wittmann Area Drainage Master Study Update. Prepared for Flood Control District of Maricopa County.

Flood Control District of Maricopa County, 2003. "Draft Drainage Design Manual for Maricopa County – Hydraulics." Flood Control District of Maricopa County.

Flood Control District of Maricopa County (Stewart Geo Technologies), 2005. Mapping for Wittmann Area Drainage Master Study Update.

JEF, 2006. Lower Hassayampa Watercourse Master Plan. Prepared for Flood Control District of Maricopa County.

JEF, 2007. McMicken Dam Outlet Channel Erosion and Sedimentation Analysis. Flood Control District of Maricopa County. Prepared for Entellus, Inc.

Li, Ruh-Ming, George K. Cotton, Michael E. Zeller, Daryl B. Simons, and Patricia Q. Deschamps, 1989. Effects of In-Stream Mining on Channel Stability, Final Report. Arizona Department of Transportation. FHWA-AZ89-250.

Hoskin Engineering Consult, Inc, 2001. "McMicken Dam Spillway Delineation Study, Report and Technical Data Notebook." Prepared for Flood Control District of Maricopa County.

Kimley-Horn and Associates, 2004. Dambreak Study for McMicken Dam Fissure Risk Zone Remediation Project. Prepared for Flood Control District of Maricopa County.

NRCS, 2003. Soil Survey Database for Maricopa County, Arizona, Central Part, AZ651. Natural Resources Conservation Service. United States Department of Agriculture.

NRCS, 2007. Soil Survey Database for Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona, AZ645. Natural Resources Conservation Service. United Stated Department of Agriculture.

8400 South Kyrene Road, Suite 201, Tempe, Arizona 85284
Phone: 480-752-2124 Fax: 480-839-2193

Pemberton, Ernest L, and Lara, Joseph M., 1984. "Computing Degradation and Local Scour." United State Bureau of Reclamation.

PBS&J, 2006. Buckeye/Sun Valley Area Drainage Master Study. Prepared for Flood Control District of Maricopa County.

Philips, Tim, 2007. Personal Communication.

Thompson, Philip and Kilgore, Roger, 2006. "Hydraulic Design of Energy Dissipators for Culverts and Channels. Hydraulic Engineering Circular Number 14, Third Edition." HEC-14. Federal Highways Administration.

USACE, 2003. Engineering and Design Slope Stability. EM 1110-2-1902.

WLB Group, 1989. Wittmann Area Drainage Master Study. FCD 86-24. Prepared for Flood Control District of Maricopa County.

Appendix A:

Calculations

Area #		Bank Height (ft)	Bank Slope (xH:1V)	ϕ	C	γ_s	Dist at a FS of 1.3 from top of bank	@ FS of 1.3 Distance from toe of slope	Radius	Xc	Yc
	Example:	40	1.5	25	0	120	58	118	90	19.73333	85.6
1	McMicken Outlet Wash (SPF)	23.4	2	20	0	110	42	89	51.714	5.616	43.056
2	McMicken Outlet (SPF)	24	2.5	20	0	110	46	106	54.48	4.32	45.84
3	Floodplain near US60/83	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
4	Beardsley Canal Crossing (SPF)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5	McMicken Spillway (SPF)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	Wash 3E (100yr)	18.3	2	25	0	100	28	65	42.273	7.32	40.809
7	Hassayampa EHZ (100yr)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
8	Buckeye FRS#1 Principal Outlet (PMF)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9	Unnamed Trib to Buckeye FRS#1 (100yr)	24	10	25	0	120	44	284	54.48	2.352	53.28

Notes:
- Bank height is based upon total design scour depth
- Bank slope is assumed based upon a "launched" slope following scour
- ϕ is an estimate inferred from soil boring textural data
- The simplified Bishop's method of analysis has been used to determine slope failure extents. To remain conservative, a dry condition has been assumed in the calculations
- A safety factor of 1.3 has been assumed for slope failure. Distances shown reflect the maximum distance for failure archs of safety-factors below this threshold.

Area 1

Calculation Summary

Scour Summary
100-year Discharge

SS5-96

Long Term	4.1 ft
General	8.0 ft

USBR

Blench	4.28 ft
Lacey	5.31 ft

Other

Bedform	0.41 ft
Low Flow Incisement	1.00 ft

Selected Methods

General - Lacey	5.31 ft
Bedform	0.41 ft
Low Flow Incisement	1.00 ft
Long Term - SS5-96	4.10 ft
Total	10.82 ft
Safety Factor	1.3
Design Scour Depth	14 ft

Bank Height	7 ft
Scour Depth	14 ft

Total Depth	**21 ft**

Notes:
- Scour depth is measured from the existing channel bed
- Lacey equation selected for general scour due to live-bed scour conditions
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Future condition HEC-1 output has been used for all scour calculations except for the bedform component

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimatic

Q_{100}	7038 cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs}	4.1 ft

Notes:
- Q100 from McMicken Outfall HEC-RAS model (JEF, 2007) for Wittman ADMSU (Entellus, 2007)

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-McMicken Dam Outfall Wash

Date 10/9/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $$d_S = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

Lacey Equation: $$d_S = 0.47Z\left(\frac{Q}{1.76D_m^{1/2}}\right)^{1/3}$$

Competent Velocity Equation: $$d_S = d_m\left(\frac{V_m}{V_C} - 1\right)$$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.12	mm
Q	7038	cfs
Fbo	0.59	ft/s^2
Top Width	480.62	ft

Notes:
Top width from HEC-RAS model.
Mean grain size from AMEC (2007) test pit data
Moderate bend assumed for migrated channel

Scour Depths (from Channel Bottom)

Lacey	5.31	ft
Average	5.31	ft
Safety Factor	1.3	
Design Depth	7	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/12/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

McMicken Outlet Channel/Wash								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
3.879	1300.94	1313.19	8.16	0.61	Dune	0.84	2.67	0.42
3.816	1298.44	1311.74	9.55	0.51	Dune	1.01	2.19	0.51

Note:
- Values taken from SPF HEC-RAS model
- Yh is based upon the HEC-RAS channel hydraulic depth

Scour Summary
SPF Discharge

SS5-96

Long Term	4.1 ft
General	11.0 ft

USBR

Blench	4.35 ft
Lacey	7.01 ft

Other

Bedform	0.51 ft
Low Flow Incisement	1.00 ft

Selected Methods

General - Lacey	7.01 ft
Bedform	0.51 ft
Low Flow Incisement	1.00 ft
Long Term - SS5-96	4.10 ft
Total	12.62 ft
Safety Factor	1.3
Design Scour Depth	16 ft

Bank Height	7 ft
Scour Depth	16 ft

Total Depth	**23 ft**

Notes:
- Scour depth is measured from the existing channel bed
- Lacey equation selected for general scour due to live-bed scour conditions
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Long-term scour based upon 100-year discharge

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimatic

Q_{100}	7038 cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs}	4.1 ft

Notes:
- Q100 from McMicken Outfall HEC-RAS model (JEF, 2007) for Wittman ADMSU (Entellus, 2007)

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-McMicken Dam Outfall Wash

Date 10/9/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $$d_S = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

Lacey Equation: $$d_S = 0.47Z\left(\frac{Q}{1.76D_m^{1/2}}\right)^{1/3}$$

Competent Velocity Equation: $$d_S = d_m\left(\frac{V_m}{V_C} - 1\right)$$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.12	mm
Q	7038	cfs
Fbo	0.59	ft/s^2
Top Width	480.62	ft

Notes:
Top width from HEC-RAS model.
Mean grain size from AMEC (2007) test pit data
Moderate bend assumed for migrated channel

Scour Depths (from Channel Bottom)

Lacey	5.31	ft
Average	5.31	ft
Safety Factor	1.3	
Design Depth	7	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/12/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

McMicken Outlet Channel/Wash								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
3.879	1300.94	1311.32	6.3	0.48	Dune	0.61	1.28	0.31
3.816	1298.44	1310.16	7.97	0.43	Dune	0.81	1.30	0.41

Note:
- HEC-RAS Qs were used for this analysis, although higher discharges were found for future land-use conditions
- PMF analysis was not performed for this area

Scour Summary
SPF Discharge

SS5-96

Long Term	4.1 ft
General	11.0 ft

USBR

Blench	4.35 ft
Lacey	7.01 ft

Other

Bedform	2.00 ft
Low Flow Incisement	1.00 ft

Selected Methods

General - Lacey	7.01 ft
Bedform	2.00 ft
Low Flow Incisement	1.00 ft
Long Term - SS5-96	4.10 ft
Total	14.12 ft
Safety Factor	1.3
Design Scour Depth	18 ft

Bank Height	7 ft
Scour Depth	18 ft

Total Depth	**25 ft**

Notes:
- Scour depth is measured from the existing channel bed
- Lacey equation selected for general scour due to live-bed scour conditions
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Long-term scour based upon 100-year discharge

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100}	7038 cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs}	4.1 ft

Notes:
- Q100 from McMicken Outfall HEC-RAS model (JEF, 2007) for Wittman ADMSU (Entellus, 2007)

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-McMicken Dam Outfall Wash

Date 10/9/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $$d_S = Z\frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

Lacey Equation: $$d_S = 0.47Z\left(\frac{Q}{1.76D_m^{1/2}}\right)^{1/3}$$

Competent Velocity Equation: $$d_S = d_m\left(\frac{V_m}{V_C} - 1\right)$$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.12	mm
Q	16190	cfs
Fbo	0.59	ft/s^2
Top Width	1080.2	ft

Notes:
Top width from HEC-RAS model.
Top width based upon channel width due to overtopping.
Mean grain size from AMEC (2007) test pit data
Moderate bend assumed for migrated channel

Scour Depths (from Channel Bottom)

Lacey	7.01	ft
Average	7.01	ft
Safety Factor	1.3	
Design Depth	9	ft

Dune and Anti-Dune Scour Height

Calc'd:	NDV	Date	10/12/2007
Checked:	JAD	Date	10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

McMicken Outlet Channel/Wash								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
3.879	1300.94	1313.19	8.16	0.61	Dune	0.84	2.67	0.42
3.816	1298.44	1311.74	9.55	0.51	Dune	1.01	2.19	0.51

Note:
- Values taken from SPF HEC-RAS model
- Yh is based upon the HEC-RAS channel hydraulic depth

Area 2

Calculation Summary

Scour Summary
100-year Discharge

SS5-96

Long Term	2.4 ft
General	8.4 ft

USBR

Blench	5.60 ft
Lacey	3.21 ft

Other

Bedform	0.32 ft
Low Flow Incisement	1.00 ft

Selected Methods

General - Blench	5.60 ft
Bedform	0.32 ft
Long Term	2.40 ft
Total	8.32 ft
Safety Factor	1.3
Design Scour Depth	11 ft

Bank Height	13 ft
Scour Depth	11 ft

Total Height	24 ft

Notes:
- Scour depth is measured from the existing channel bed
- Blench equation selected for general scour due to potential clear water scour conditions
- Low flow incisement not considered due to wide channel relative to flow magnitude - no distinct low-flow channel is present and substantial vegetation is present
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100} 2908 cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs} 2.4 ft

Notes:
- Q100 from Wittman ADMSU (Entellus, 2007)

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-McMicken Outlet Channel

Date 10/3/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $$d_s = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

Lacey Equation: $$d_s = 0.47Z \left(\frac{Q}{1.76 D_m^{1/2}} \right)^{1/3}$$

Competent Velocity Equation: $$d_s = d_m \left(\frac{V_m}{V_c} - 1 \right)$$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.42	mm
Q	2908	cfs
Fbo	1.29	ft/s^2
Top Width	89.81	ft

Notes:
Top width from normal depth section
Mean grain size inferred
from TP06-7 (AMEC, 2007)
Moderate bend assumed during
channel migration

Scour Depths (from Channel Bottom)

Blench	5.60	ft
Average	5.60	ft
Safety Factor	1.3	
Design Depth	7	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/11/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

McMicken Outlet Channel								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
24.5	1324.72	1333.86	6.55	0.33	Dune	0.64	0.63	0.32
22.48	1324.55	1333.57	6.32	0.36	Dune	0.61	0.72	0.31
20.15	1324.85	1333.3	6.54	0.34	Dune	0.64	0.67	0.32
17.1	1324.51	1333.08	6.22	0.29	Dune	0.60	0.46	0.30
14.35	1324.48	1332.91	6.11	0.26	Dune	0.59	0.36	0.29

Scour Summary

SPF Discharge

SS5-96

Long Term	2.4 ft
General	17.3 ft

USBR

Blench	12.36 ft
Lacey	5.45 ft

Other

Bedform	0.69	ft

Selected Methods

General - Lacey	5.45 ft
Bedform	0.69 ft
Long Term	2.40 ft
Total	8.53 ft
Safety Factor	1.3
Design Scour Depth	11 ft

Bank Height	13 ft
Scour Depth	11 ft

Total Height	24 ft

Notes:
- Scour depth is measured from the existing channel bed
- Lacey equation selected due to a greater calculated scour depth
- Low flow incisement not considered due to wide channel relative to flow magnitude - no distinct low-flow channel is present and substantial vegetation is present
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100} 2908 cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs} 2.4 ft

Notes:
- Q100 from Wittman ADMSU (Entellus, 2007)

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-McMicken Outlet Channel

Date 10/3/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $$d_S = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

Lacey Equation: $$d_S = 0.47Z \left(\frac{Q}{1.76 D_m^{1/2}} \right)^{1/3}$$

Competent Velocity Equation: $$d_S = d_m \left(\frac{V_m}{V_C} - 1 \right)$$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.42	mm
Q	14213	cfs
Fbo	1.29	ft/s^2
Top Width	1339.82	ft

Notes:
Top width based upon channel width due to overtopping during event
Mean grain size inferred from TP06-7 (AMEC, 2007)
Moderate bend assumed during channel migration

Scour Depths (from Channel Bottom)

Lacey	5.45	ft
Average	2.66	ft
Safety Factor	1.3	
Design Depth	3	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/11/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

McMicken Outlet Channel								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
24.5	1324.72	1342.34	12.27	0.4	Dune	1.37	1.73	0.69
22.48	1324.55	1341.43	11.91	0.51	Dune	1.32	2.72	0.66
20.15	1324.85	1340.96	10.94	0.52	Dune	1.19	2.60	0.60
17.1	1324.51	1340.76	10.18	0.42	Dune	1.09	1.58	0.55
14.35	1324.48	1340.52	10.11	0.38	Dune	1.08	1.28	0.54

Area 3

Calculation Summary

No calculations are included for this area.

Area 4

Calculation Summary

No calculations are included for this area.

Area 5

Calculation Summary

Scour Summary

PMF Discharge

SS5-96

Long Term	18.7 ft
General	39.7 ft

USBR

Blench	11.82 ft
Lacey	20.14 ft

Other

Bedform	0.25 ft

Selected Methods

General - Lacey	20.14 ft
Bedform	0.25 ft
Long Term	n/a ft
Total	20.39 ft
Safety Factor	1.3
Design Scour Depth	27 ft

Existing Bank Height
9 ft

Design Scour Depth
28 ft

Total Bank Height
37 ft

Notes:

- Scour depth is measured from the existing channel bed
- Lacey equation selected for general scour due to live-bed scour conditions
- Low flow incisement not considered due to absence of flow below PMF
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Manning's roughness estimated based upon recent aerial photography and values from the Kimley-Horn HEC-RAS model
- Long term scour not applicable due to absence of flow below the PMF and downstream control (Beardsley Canal).
- Typical banks are not present at this location - the left bank is defined by the embankment of Grand Avenue and the right bank is defined by McMicken Dam.

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-McMicken Dam Emergency Spillway

Date 10/3/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $$d_s = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

Lacey Equation: $$d_s = 0.47Z \left(\frac{Q}{1.76 D_m^{1/2}} \right)^{1/3}$$

Competent Velocity Equation: $$d_s = d_m \left(\frac{V_m}{V_c} - 1 \right)$$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.074	mm
Q	89295.59	cfs
Fbo	0.2	ft/s^2
Top Width	2283.17	ft

Notes:
Top width from normal depth section
Mean grain size inferred
from BH-19 (AMEC, 2003a) & NRCS
Severe bend assumed during
channel migration
Discharge from Kimley-Horn EAP Study

Scour Depths (from Channel Bottom)

Lacey	20.14	ft
Average	20.14	ft
Safety Factor	1.3	
Design Depth	26	ft

Dune and Anti-Dune Scour Height

Calc'd:	NDV	Date	10/11/2007
Checked:	JAD	Date	10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

McMicken Dam Emergency Spillway								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
Normal	-	-	5.27	0.57	Dune	0.49	1.51	0.25

Notes:
- Yh is based upon hydraulic depth, calculated as Flow Area/Top Width
- Values from normal depth calculation with Flowmaster, v 7.0

Flow Area	12033.5 sq ft
Top Width	2283.17 ft

Worksheet
Worksheet for Irregular Channel

Project Description	
Worksheet	Area 5 Channe
Flow Element	Irregular Chan
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Channel Sl(	.005510	ft/ft
Discharge	),295.59	cfs

Options	
Current Roughness Methc	›ved Lotter's Method
Open Channel Weighting	›ved Lotter's Method
Closed Channel Weightin(	Horton's Method

Results		
Mannings Coefficie	0.045	
Water Surface Elev	1,348.77	ft
Elevation Range	‡1.00 to 1,350.00	
Flow Area	12,033.5	ft²
Wetted Perimeter	2,284.42	ft
Top Width	2,283.17	ft
Actual Depth	7.77	ft
Critical Elevation	1,346.97	ft
Critical Slope	0.018850	ft/ft
Velocity	7.42	ft/s
Velocity Head	0.86	ft
Specific Energy	1,349.63	ft
Froude Number	0.57	
Flow Type	Subcritical	

Roughness Segments

Start Station	End Station	Mannings Coefficient
0+00	22+93	0.045

Natural Channel Points

Station (ft)	Elevation (ft)
0+00	1,350.00
0+12	1,348.00
3+66	1,346.00
3+96	1,347.00
4+25	1,346.00
7+27	1,344.00
12+45	1,342.00
16+25	1,341.00
20+05	1,342.00
22+81	1,344.00
22+85	1,346.00
22+89	1,348.00
22+93	1,350.00

Area 6

Calculation Summary

Scour Summary

100-year Discharge

SS5-96

Long Term	2.5 ft
General	8.5 ft

USBR

Blench	3.29 ft
Lacey	4.35 ft

Other

Bedform	0.16 ft
Culvert Outlet	6.26 ft

Selected Methods

General - Lacey	4.35 ft
Bedform	0.16 ft
Long Term - SS5-96	2.50 ft
Culvert - HEC-14	6.26 ft
Total	13.27 ft
Safety Factor	1.3
Design Scour Depth	17 ft

Bank Height	1 ft
Scour Depth	17 ft
Total Depth	18.3 ft

Notes:
- Scour depth is measured from the existing channel bed
- Lacey equation selected for general scour due to live-bed scour conditions
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Future condition HEC-1 output has been used for all scour calculations except for the bedform component

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100}	2956	cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs}	2.5	ft

Notes:
- Q100 from Future Land-Use HEC-1 modeling (24 hr) from Wittman ADMSU by Entellus, Inc.

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-Wash 3E from Wittman ADMSU

Date 10/9/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $d_S = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$

Lacey Equation: $d_S = 0.47Z \left(\frac{Q}{1.76 D_m^{1/2}} \right)^{1/3}$

Competent Velocity Equation: $d_S = d_m \left(\frac{V_m}{V_C} - 1 \right)$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.07	mm
Q	2956	cfs
Fbo	0.2	ft/s^2
Top Width	514.9	ft

Notes:
Top width from HEC-RAS model.
Mean grain size from AMEC (2003) boring data
Mean grain size inferred from textural information from test boring.
Moderate bend assumed for migrated channel
Discharge taken from "future condition" HEC-1 model.

Scour Depths (from Channel Bottom)

Lacey	4.35	ft
Average	4.35	ft
Safety Factor	1.3	
Design Depth	6	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/9/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

Wash 3E								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
1.351	1360.79	1363.77	1.55	0.24	Dune	0.11	0.08	0.06
1.284	1359.74	1363.25	2.24	0.14	Dune	0.18	0.04	0.09
1.233	1358.16	1362.57	3.65	0.19	Dune	0.32	0.12	0.16

Note:
- Values are from Wash 3E HEC-RAS Model from Wittman ADMSU by Entellus Inc.
- HEC-RAS Qs were used for this analysis, although higher discharges were found for future land-use conditions
- Yh is based upon the HEC-RAS channel hydraulic depth

Area 7

Calculation Summary

Scour Summary
100-year Event

SS5-96

Long Term	16.9 ft
General	20 ft

USBR

Blench	6.32 ft
Lacey	9.18 ft

Other

Bedform	1.75 ft

Selected Methods

General - Lacey	9.18 ft
Bedform	1.75 ft
Long Term - SS5-96 Level I	16.90 ft
Total	27.83 ft
Safety Factor	1.3
Design Scour Depth	36.2 ft

Existing Bank Height
12 ft

Scour Depth
36 ft

Design Bank Height
48 ft

Notes:
- Scour depth is measured from the existing channel bed
- Lacey equation selected for general scour due to live-bed scour conditions
- Low flow incisement not considered due to placement in lateral migration hazard
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Summary reflects JEF recommended values; FCDMC has directed that 1 foot of long term scour be applied at this location

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100}	75164	cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs}	16.9	ft

Notes:
- Q100 from Lower Hassayampa Watercourse Master Plan

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-Hassayampa River near Buckeye FRS#1

Date 10/3/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $d_S = Z\frac{q_f^{2/3}}{F_{bo}^{1/3}}$

Lacey Equation: $d_S = 0.47Z\left(\frac{Q}{1.76D_m^{1/2}}\right)^{1/3}$

Competent Velocity Equation: $d_S = d_m\left(\frac{V_m}{V_C} - 1\right)$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.514	mm
Q	75164	cfs
Fbo	1.42	ft/s^2
Top Width	1844.66	ft

Notes:
Top width from HEC-RAS model.
Mean grain size from LHWCMP channel sieve analysis
Moderate bend assumed during channel migration

Scour Depths (from Channel Bottom)

Lacey	9.18	ft
Average	9.18	ft
Safety Factor	1.3	
Design Depth	12	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/4/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

	Hassayampa River							
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
11.71	1035.64	1044.02	4.19	0.66	Dune	0.37	1.61	0.19
11.62	1033.39	1041.56	4.2	0.8	Anti-Dune	0.37	2.36	1.18
11.52	1031.12	1040.35	4.68	0.62	Dune	0.43	1.58	0.21
11.43	1029.8	1037.66	4.15	0.98	Anti-Dune	0.37	3.51	1.75
11.33	1028.26	1036.52	5.06	0.7	Anti-Dune	0.47	2.18	1.09
11.24	1026.79	1034.83	4.61	0.79	Anti-Dune	0.42	2.53	1.27
11.16	1025.43	1032.82	4.68	0.88	Anti-Dune	0.43	3.19	1.59
11.09	1022.98	1031.34	6.19	0.76	Anti-Dune	0.60	3.15	1.57
11.01	1020.38	1030.1	7.22	0.59	Dune	0.72	2.21	0.36

Notes:
- Values are from Lower Hassayampa Water Course Master Plan Erosion Hazard Zone HEC-RAS model.
- Yh based upon HEC-RAS hydraulic depth

Scour Summary
PMF Analysis

SS5-96

Long Term	7.4 ft
General	19.4 ft

USBR

Blench	4.30 ft
Lacey	2.88 ft

Other

Bedform	0.18 ft

Selected Methods

General - Blench	4.30	ft
Bedform	0.18	ft
Long Term	n/a	ft
Low Flow Incisement	n/a	ft
Total	4.48	ft

Safety Factor
1.3

Design Scour Depth
5.8 ft

Notes:
- Scour depth is measured from the existing channel bed
- Blench equation selected for general scour due to clear-water scour conditions
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Low flow incisement not considered due to absence of flow up to PMF
- Long term scour not relevent for this location; no discharge up to 100-year event

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100} 18651.07 cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs} 7.4 ft

Notes:
- QPMF from Buckeye FRS Unsteady Flow model by PBS&J

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-Buckeye FRS#1 Emergency Spillway

Date 10/3/2007
Computed By: NDV
Checked By:

Blench Equation: $d_S = Z\frac{q_f^{2/3}}{F_{bo}^{1/3}}$

Lacey Equation: $d_S = 0.47Z\left(\frac{Q}{1.76D_m^{1/2}}\right)^{1/3}$

Competent Velocity Equation: $d_S = d_m\left(\frac{V_m}{V_C} - 1\right)$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.514	mm
Q	18651.07	cfs
Fbo	1.42	ft/s^2
Top Width	816.96	ft

Notes:
Top width from HEC-RAS model.
Mean grain size from LHWCMP channel sieve analysis

Scour Depths (from Channel Bottom)

Blench	4.30	ft
Average	4.30	ft
Safety Factor	1.3	
Design Depth	6	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/4/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

Buckeye FRS #1 Emergency Spillway								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
Spillway			4.15	0.475886	Dune	0.37	0.83	0.18

Note:
- Values taken from Buckeye FRS#1 Spillway
- Values from PBS&J HEC-RAS Unsteady Analysis of Buckeye FRS#1 (6hr PMF)

Area 8

Calculation Summary

Scour Summary

PMF Analysis

SS5-96

Long Term	0.7 ft
General	3.9 ft

USBR

Blench	3.11 ft
Lacey	0.85 ft

Other

Bedform	0.10 ft
Low Flow Incisement	1.00 ft

Selected Methods

General - Blench	3.11	ft
Bedform	0.10	ft
Low Flow Incisement	1.00	ft
Long Term - SS5-96	0.70	ft
Total	4.91	ft
Safety Factor		
	1.3	
Design Scour Depth		
	6.4 ft	

Notes:
- Scour depth is measured from the existing channel bed
- Blench equation selected for general scour due to potential clear-water conditions
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.
- Long-term scour based upon 100-year discharge

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100}	352.21	cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs}	0.7	ft

Notes:

- Q100 from Buckeye FRS Unsteady Flow model by PBS&J

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-Buckeye FRS#1 Principal Spillway

Date 10/3/2007
Computed By: NDV
Checked By:

Blench Equation: $$d_S = Z\frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

Lacey Equation: $$d_S = 0.47Z\left(\frac{Q}{1.76D_m^{1/2}}\right)^{1/3}$$

Competent Velocity Equation: $$d_S = d_m\left(\frac{V_m}{V_C}-1\right)$$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.514	mm
Q	474.21	cfs
Fbo	1.42	ft/s^2
Top Width	33.7	ft

Notes:
Top width from HEC-RAS model.
Mean grain size from LHWCMP channel sieve analysis

Scour Depths (from Channel Bottom)

Lacey	0.85	ft
Average	0.85	ft
Safety Factor	1.3	
Design Depth	1	ft

Dune and Anti-Dune Scour Height

Calc'd: NDV Date 10/4/2007
Checked: JAD Date 10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

Buckeye FRS #1 Principal								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
Spillway			2.41	0.66	Dune	0.19	0.92	0.10

Note:
- Values based upon normal depth analysis using FlowMaster (v. 7)
- Discharge from PBS&J HEC-RAS Unsteady Analysis of Buckeye FRS#1 (PMF 6-hour)
- Yh calculated as hydraulic depth equal to Flow Area/Top Width

Flow Area 81.1 sq ft
Top Width 33.7 ft

Worksheet
Worksheet for Triangular Channel

Project Description	
Worksheet	Triangular Channe
Flow Element	Triangular Channe
Method	Manning's Formula
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Channel Slope	006190	ft/ft
Left Side Slope	3.50	H : V
Right Side Slope	3.50	H : V
Discharge	352.21	cfs

Results		
Depth	4.31	ft
Flow Area	64.9	ft^2
Wetted Perim	31.35	ft
Top Width	30.15	ft
Critical Depth	3.63	ft
Critical Slope	0.015422	ft/ft
Velocity	5.43	ft/s
Velocity Head	0.46	ft
Specific Energ	4.76	ft
Froude Numb	0.65	
Flow Type	Subcritical	

Area 9

Calculation Summary

Scour Summary

100-year Discharge

SS5-96

Long Term	1.2 ft
General	5.2 ft

USBR

Blench	1.01 ft
Lacey	2.04 ft

Other

Bedform	0.18 ft
Low Flow Incisement	1.00 ft

Selected Methods

General - Lacey	2.04 ft
Bedform	0.18 ft
Low Flow Incisement	1.00 ft
Long Term	1.20 ft
Total	4.42 ft
Safety Factor	1.3
Design Scour Depth	6 ft

Exist Bank Height
18 ft
Design Scour Depth
6 ft

Total Depth of Cover
24 ft

Notes:

- Scour depth is measured from the existing channel bed
- Lacey equation selected for general scour due to live-bed scour conditions
- Low flow incisement not considered due to placement in lateral migration hazard
- Bend scour has not been explicity calculated, but channel curvature has been incorporated into the Blench and Lacey local scour equations.

Long Term Degradation Calculation

- Method from State Standard 5-96, "System Sediment Balance" Level I Channel Degradation Estimation

Q_{100} 820 cfs

$$d_{gs} = 0.02(Q_{100})^{0.6}$$

d_{gs} 1.2 ft

Notes:
- Q100 from Buckeye/Sun Valley ADMS by PBS&J

General Scour Calculations

Methodology from US Bureau of Reclamation, "Computing Degradation and Local Scour", 1984
-Unnamed Wash near west Buckeye FRS#1 Boundary

Date 10/3/2007
Computed By: NDV
Checked By: JAD

Blench Equation: $d_S = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$

Lacey Equation: $d_S = 0.47Z \left(\frac{Q}{1.76 D_m^{1/2}} \right)^{1/3}$

Competent Velocity Equation: $d_S = d_m \left(\frac{V_m}{V_C} - 1 \right)$

Where:
d_S = Scour Depth Below Streambed (ft)
Z = Regime Modifier (See Table Below)
F_{bo} = Blench's "zero bed factor" (ft/s^2)
Q = Design Discharge (cfs)
D_m = Mean Grain Size of Bed Material (mm)
V_m = Mean Channel Velocity (ft/s)
V_c = Channel Competent Velocity (ft/s)
d_m = Mean Depth (ft)

Input Parameters

Mean Grain Size	0.514	mm
Q	820	cfs
Fbo	1.42	ft/s^2
Top Width	317.05	ft

Notes:
Top width from HEC-RAS model.
Mean grain size from NRCS Soil Survey
Moderate bend assumed during channel migration

Scour Depths (from Channel Bottom)

Lacey	2.04	ft
Average	2.04	ft
Safety Factor	1.3	
Design Depth	3	ft

Dune and Anti-Dune Scour Height

Calc'd:	NDV	Date	10/5/2007
Checked:	JAD	Date	10/24/2007

From Equations 10.13 and 10.14 in Draft Flood Control District of Maricopa County Drainage Design Manual Hydrualics

Unnamed Tributary to Buckeye FRS#1								
River Sta	Min Ch El	WSE	Yh	Fr	Controlling:	Dune Height	Anti-Dune Height	Scour Component
	ft	ft	ft			ft	ft	ft
Normal	-	-	0.71	0.76	Anti-Dune	0.04	0.36	0.18

Notes:
- Input is from normal depth calculation using Flowmaster v 7.0
- Yh is based upon hydraulic depth calculated as Flow Area/Top Width

Flow Area	225.9 sq ft
Top Width	317.05 ft

Worksheet
Worksheet for Irregular Channel

Project Description	
Worksheet	Area 9 Chann
Flow Element	Irregular Chan
Method	Manning's Forr
Solve For	Channel Deptr

Input Data		
Channel Sl	018986	ft/ft
Discharge	820.00	cfs

Options	
Current Roughness Meth	›ved Lotter's Method
Open Channel Weighting	›ved Lotter's Method
Closed Channel Weightin	Horton's Method

Results		
Mannings Coefficie	0.045	
Water Surface Elev	1,081.17	ft
Elevation Range	30.00 to 1,094.00	
Flow Area	225.9	ft²
Wetted Perimeter	317.07	ft
Top Width	317.05	ft
Actual Depth	1.17	ft
Critical Elevation	1,081.02	ft
Critical Slope	0.034320	ft/ft
Velocity	3.63	ft/s
Velocity Head	0.20	ft
Specific Energy	1,081.38	ft
Froude Number	0.76	
Flow Type	Subcritical	

Roughness Segments

Start Station	End Station	Mannings Coefficient
0+00	8+88	0.030
8+88	13+81	0.045
13+81	37+52	0.030

Natural Channel Points

Station (ft)	Elevation (ft)
0+00	1,094.00
2+56	1,092.00
3+44	1,090.00
4+32	1,088.00
5+20	1,086.00
6+80	1,084.00
8+88	1,082.00
12+00	1,080.00
12+69	1,080.00
13+81	1,082.00
17+57	1,084.00
19+25	1,086.00
23+84	1,088.00

Worksheet
Worksheet for Irregular Channel

Natural Channel Points	
Station (ft)	Elevation (ft)
25+44	1,090.00
33+68	1,090.00
37+52	1,090.00

Appendix B:

Supporting Documentation

Transwestern Pipeline Scour Analysis
Methodology Overview

1. Objective: Meet District requirement for vertical and lateral scour analysis in support of a floodplain use permit for all crossings of regulatory floodplains along proposed alignment.

2. Floodplain – Regulatory BFE. The pipeline will be buried below existing grade and will therefore have no impact on regulatory BFEs. No LOMR/CLOMR is required and no HEC-RAS documentation of BFE will be conducted by JEF.

3. Vertical Scour
    a. Methodology
        i. Event Scour:
            1. ADWR Equations for bend & antidune scour
            2. Use BUREC (Pemberton & Lara, 1984) general scour
                a. Clear water condition: Blench equation
                b. Sediment laden condition: Lacey equation
            3. Low flow incisement
                a. Not used if stable low flow channel present (natural channels) if justified by field observation & engineering judgment
                b. Use FCDMC Hydraulics Manual Chapter 11 elsewhere
        ii. Other Scour Types (if any)
            1. HEC-18 Equations at bridge structures
            2. Outlet scour downstream of culverts
            3. FCDMC Hydraulics Manual method used @ culverts
            4. BUREC (Pemberton & Lara, 1984) @ drop structures
            5. ADOT Method for headcut/tailcut near mines
        iii. Long-Term Scour
            1. Flow calculations based on bankfull discharge (natural washes)
            2. Riverine Crossings (and Inactive Alluvial Fans)
                a. If hinge points exist (unlikely)
                    i. Equilibrium slope method in ADWR Manual for sediment laden condition
                    ii. Limiting slope method for clear water (Pemberton & Lara, 1984)
                b. If no hinge points exist (most common)
                    i. SS5-96 Level 1
                    ii. Field observations
            3. Active Alluvial Fans
                a. SS5-96 Level 1 using bankfull discharge
                b. SVADMP corridors – use SVADMP results
                    i. Long-term scour calc's
                    ii. Grade control assumed as designed

iv. Total Scour
1. Measured from thalweg elevation
2. Sum of scour elements above

b. Data Input

i. Scenario #1: FIS Floodplains, Detailed Study
1. Hydraulics – Use RAS
2. Topo – Use FIS workmaps or RAS sections
3. Discharge – Use RAS Q100
4. Sediment – sieve sample

ii. Scenario #2: FIS Floodplain, Approximate Study
1. Hydraulics –Mannings rating at crossing alignment
2. Topo – Use District 10-ft mapping or best available topo
3. Discharge
a. ADMP HEC1 at nearest concentration point
b. USGS regression Q100 if no ADMP hydrology available
4. Sediment – sieve sample

iii. Scenario #3: FIS Alluvial Fans (Active Fans only)
1. Hydraulics
a. Mannings rating at largest fan channel on contour
i. Use bankfull discharge for design
b. SVADMP Mannings ratings @ corridor alignments
2. Topo – District 10 ft or best available
3. Discharge –
a. Full apex Q in AFHH/AFUFD, or corridor design
b. Below AFUFD, use bankfull discharge
4. Sediment – sieve at defined channels
5. Scour depth
a. Assume avulsion occurs in AFHH/AFUFD zone
b. Use scour depth from largest channel on contour across fan limits in AFHH/AFUFD zone
c. SS5-96 Level 1 with Qbankfull for long-term scour
6. SVADMP Corridors
a. Use design parameters from SVADMP at corridor crossing locations

4. Lateral Erosion

a. Methodology

i. Modified Bishops Method
1. Q100 design discharge
2. Supplement width with landform interpretation

b. Data Input

i. Bank Height/slope – field observation

ii. Bank material type/internal angle of friction
1. Field observation
2. NRCS soils reports

iii. Hydraulics & hydrology (same as for vertical scour above)

5. Submittal Format
   a. McMicken Dam & Buckeye FRS#1 area crossings in first submittal
   b. Group remaining crossings in reaches & submit reaches separately, staggered in time to ease review burden.
   c. Submit to Lynn Thomas @ FCDMC

Flood Control District of Maricopa County

Date 12-6-07

PERMIT 2006P068-
Transwestern

Name	Business	Phone	E-mail
Angie Hudecky	FCDMC	602-506-5476	alh@mail.maricopa.gov
Camp Mehrens	Universal/Ensco	281-415-5949	camp.mehrens@universalensco.com
David Runte	Transwestern	281-714-2304	Dave.Runte@EnergyTransfer.com
Jim Fisher	Transwestern	602.614.8979	Jim.Fisher@EnergyTransfer.c
John Chua	NRCS	602-280-8838	John.Chua@az.usda.gov
TIM PHILLIPS	FCD	602-506-4701	tsp@mail.maricopa.go
BING ZHAO	FCD	602-506-3293	biz@mail.maricopa.gov
TOM RENCKLY	FCDMC	602-506-8610	tm@mail.maricopa.gov
J David Deatherage	Copper State	480 368 1551	david@copperstate-eng.com
Mike Greenslade	FCD	602-506-5426	mdg@mail.maricopa.gov
Jon Fuller	JEF/H&G	480 222 5710	jon@jefuller.com

Flood Control District
of Maricopa County

INTEROFFICE MEMORANDUM

Date: January 11, 2008

To: Lynn Thomas, PE, Principal Engineer, Floodplain Management and Services Division

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

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

Subject: Transwestern Pipeline Floodplain Use Permit; Permit Number 2006P048

The Engineering Application Development and River Mechanics Branch (EADRM) has finished its review of your 12/31/2007 review request and has the following comments. The consultant should submit written responses (and digital copy) to these comments to the FCD.

1) On page 35, the report indicates that structural alternatives will be used in the Hassayampa River Erosion Hazard Zone regardless of the scour depth. It is unclear in the report about the structural alternative. The District needs to review and approve the final alternative.

   The District staff sent an email to Nathanael Vaughan of JE Fuller to clarify this issue. The response email on January 9, 2008 sent to Richard Waskowsky and Bing Zhao of the District from Nathanael Vaughan of JE Fuller is as follows:

   "Within the Hassayampa EHZ we are designing a riprap barrier with a launchable component. We had intended to submit the scour computations for your review separately prior to fully designing the riprap barrier because the vertical scour depth is necessary for design of the riprap barrier. At the meeting which you and Jon attended in December, I believe they showed a rough-order-of-magnitude design we'd put together. We had intended to supply those calculations in a design report whereas the scour report you are currently reviewing was intended to be a support document for the design. In the Area 7 discussion, we wanted to state clearly that the pipeline should be placed below the Hassayampa invert in the vicinity of the potential channel alternative to replace Buckeye FRS 1 to limit future conflict, otherwise there would be no mention of the structural alternative in the scour analysis" (Vaughan, 2008).

Based on above response email, it seems that the total scour depth calculated in the report will be used to design the riprap barrier toe-down. It should be noted that JE Fuller recommended 38 feet of total scour depth of which the long term scour is 16.9 feet based on Arizona State Standard Level 1 method (a conservative estimate). However, the 18 feet of total scour is acceptable to the District based on a much smaller long-term scour depth predicted by a HEC-6 model developed in Lower Hassayampa River Watercourse Master Plan (JE Fuller, 2006).

2) On page 27, the final scour depth is given as 27.6 ft, but the report indicates that a lesser value may be used. The final design scour depth should be the full scour depth.

3) For Area 2, the Blench general scour may be underestimated due to the large top width used in the SPF calculations. Since the deepest scour will occur in the Outlet Channel, the full channel flow rate and top width is recommended for the scour analysis.

4) The bedform scour for Area 1 does not match the calculations given in Appendix A for both the 100-year flood and the SPF flood. Please correct the bedform scour for Area 1, and check other areas for consistency. This error occurs because the maximum value is used for bedform scour even when the lesser scour is the controlling scour as defined by the Froude number. For example, in Area 1 the dune scour controls but the antidune scour is used.

5) In all bedform scour calculations, the maximum channel depth was used for dune height calculation, when it should be the hydraulic depth. Please use the hydraulic depth.

6) For area 3b, the burial depth is recommended as "below the invert elevation of the McMicken Outlet Channel." What is the exact burial depth? It should be buried at the total scour depth below the invert.

7) On page 30, the last sentence indicates that "the appropriate scour depth in this transition area [between Areas 5 and 6] is discussed in Area 5." However, this discussion was not found in Area 5. What is the recommended scour depth for this transition area?

8) In Appendix A, the calculations for Areas 3 and 4 are not provided because there are no explicit calculations for these areas. To avoid confusion, a note, which indicates that there are no calculations for these areas, should be placed in the appendix.

9) Table 7 on page 18 indicates a 15 ft cover depth for Area 3a, but the scour depth recommended for this same area is said (in the third paragraph on page 18) to be the value for Area 5, which is 28 ft (shown on page 22 and 27). What is the correct depth for Area 3a?

10) For Area 5, the Earth Spillway Erosion Model (USDA, 1997), which is implemented in the SITES model (USDA, 2007), is more applicable for spillway erosion than the Lacey equation. Therefore, the use of this model may reduce the scour estimate for this area, and subsequently Areas 3a and 4. However, the consultant may use the previously calculated value of 28 ft.

11) For Area 5, the use of the severe bend "z" coefficient may over-predict scour in this region. The use of the moderate bend "z" coefficient may be more applicable and will reduce the scour estimate for this area, and subsequently Areas 3a and 4. However, the consultant may use the previously calculated value of 28 ft.

12) On page 14 of the report, it is indicated that Figure 7 shows the lateral migration extents and the scour depths; however, these are not shown in the figure. Please show the depths and extents on the figure.

13) The scour extents, shown on Figure 9 on page 15 of the report, appear to be incorrect. They show the scour extents for areas 2, 3a, 3b, 4 and 5. Please correct the scour extents on Figure 9.

14) The scour extents, shown on Figure 12 on page 19 of the report, appear to be incorrect. They show the scour extents for areas 2, 3a, 3b, 4 and 5. Please correct the scour extents on Figure 9.

15) The date listed for the "McMicken Dam Outlet Channel Erosion and Sedimentation Analysis" is listed as 2006, rather it should be 2007.

16) The AMEC, 2003 reference is not included in the Reference section. Please include this reference.

References:

JE Fuller, 2006. Lower Hassayampa River Watercourse Master Plan. Prepared for Flood Control District of Maricopa County.

U.S. Department of Agriculture, Natural Resources Conservation Service, 1997. Earth Spillway Erosion Model. National Engineering Handbook, part 628, ch. 51. August 1997.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2007. SITES 2005 Water Resource Site Analysis Computer Program: User Guide, October 2007.

Vaughan, Nathanael, 2008. Email Communication to Bing Zhao, CC: jon@jefuller, Richard Waskowsky of FCDMC (7:46 AM, January 9, 2008).

FCDMC Comments and Responses

1) *On page 35, the report indicates that structural alternatives will be used in the Hassayampa River Erosion Hazard Zone regardless of the scour depth. It is unclear in the report about the structural alternative. The District needs to review and approve the final alternative.*

The District staff sent an email to Nathanael Vaughan of JE Fuller to clarify this issue. The response email on January 9, 2008 sent to Richard Waskowsky and Bing Zhao of the District from Nathanael Vaughan of JE Fuller is as follows:

"Within the Hassayampa EHZ we are designing a riprap barrier with a launchable component. We had intended to submit the scour computations for your review separately prior to fully designing the riprap barrier because the vertical scour depth is necessary for design of the riprap barrier. At the meeting which you and Jon attended in December, I believe they showed a rough-order-of-magnitude design we'd put together. We had intended to supply those calculations in a design report whereas the scour report you are currently reviewing was intended to be a support document for the design. In the Area 7 discussion, we wanted to state clearly that the pipeline should be placed below the Hassayampa invert in the vicinity of the potential channel alternative to replace Buckeye FRS 1 to limit future conflict, otherwise there would be no mention of the structural alternative in the scour analysis" (Vaughan, 2008).

Based on above response email, it seems that the total scour depth calculated in the report will be used to design the riprap barrier toe-down. It should be noted that JE Fuller recommended 38 feet of total scour depth of which the long term scour is 16.9 feet based on Arizona State Standard Level 1 method (a conservative estimate). However, the 18 feet of total scour is acceptable to the District based on a much smaller long-term scour depth predicted by a HEC-6 model developed in Lower Hassayampa River Watercourse Master Plan (JE Fuller, 2006).

- Agreed. The client has indicated 17.6 feet of total scour should be used for design of structural lateral migration protection. As stated in the report under Area 7, the HEC-6 model which predicts 1 foot of long-term degradation is based upon FCDMC dictated, present-condition hydrology and does not account for anticipated urbanization or sand/gravel extraction from the channel. JEF feels the Arizona State Standard Level 1 method more accurately captures the effects of these changes and recommends 38 feet of total scour be applied. The client has indicated that the 17.6 feet of total scour, as accepted by the FCDMC, is the depth to be used for design.

2) *On page 27, the final scour depth is given as 27.6 ft, but the report indicates that a lesser value may be used. The final design scour depth should be the full scour depth.*

- During a comment resolution meeting held on January 16, 2008, FCDMC staff including Bing Zhao and Tom Renckley agreed to a proposal to draft a letter to Tom which would be forwarded to his manager to address the lack of FCDMC policy regarding this type of utility placement. This activity is ongoing.

3) *For Area 2, the Blench general scour may be underestimated due to the large top width used in the SPF calculations. Since the deepest scour will occur in the Outlet Channel, the full channel flow rate and top width is recommended for the scour analysis.*

   - **Due to the fact that the crossing is located over a mile downstream of the principal outlet and the design event is the SPF, which overtops the emergency spillway, sediment laden flow may be expected. Because of this the Lacey equation has been used for SPF design. The Lacey equation does not rely upon unit discharge or top-width for calculation of general scour and thus this comment does not influence the design scour depth. The 100-year scour event, which is shown for illustrative purposes in the text, utilizes the Blench equation and varies with unit discharge, however flow is contained within the channel at this discharge and this comment is not applicable.**

4) *The bedform scour for Area 1 does not match the calculations given in Appendix A for both the 100-year flood and the SPF flood. Please correct the bedform scour for Area 1, and check other areas for consistency. This error occurs because the maximum value is used for bedform scour even when the lesser scour is the controlling scour as defined by the Froude number. For example, in Area 1 the dune scour controls but the antidune scour is used.*

   - This inconsistency has been addressed. The previous calculations assumed a worst-case assumption for general scour due to the relatively uncertain hydraulics of a meandered channel. Lower values have been applied per this comment and subsequent comments. The same explanation applies regarding use of maximum channel depth rather than hydraulic depth, although hydraulic depth is now used for all bedform scour computations.

5) *In all bedform scour calculations, the maximum channel depth was used for dune height calculation, when it should be the hydraulic depth. Please use the hydraulic depth.*

   - **See response to comment 4.**

6) *For area 3b, the burial depth is recommended as "below the invert elevation of the McMicken Outlet Channel." What is the exact burial depth? It should be buried at the total scour depth below the invert.*

- **As stated on page 18, no scour hazard exists from the 100-year or PMF discharges in Area 3b due to flow within the McMicken Dam emergency**

spillway or the McMicken Dam Outfall Channel. The *required* burial depth for scour protection is 0 feet; the *recommended* burial depth varies with the depth of the McMicken Outlet channel which parallels the pipeline alignment, but is approximately 12 feet.

7) *On page 30, the last sentence indicates that "the appropriate scour depth in this transition area [between Areas 5 and 6] is discussed in Area 5." However, this discussion was not found in Area 5. What is the recommended scour depth for this transition area?*

- **This discussion was not explicitly stated. The Area 5 scour depth is the scour depth in the transition.**

8) *In Appendix A, the calculations for Areas 3 and 4 are not provided because there are no explicit calculations for these areas. To avoid confusion, a note, which indicates that there are no calculations for these areas, should be placed in the appendix.*

- **A note has been added.**

9) *Table 7 on page 18 indicates a 15 ft cover depth for Area 3a, but the scour depth recommended for this same area is said (in the third paragraph on page 18) to be the value for Area 5, which is 28 ft (shown on page 22 and 27). What is the correct depth for Area 3a?*

- **This section has been reworded to reflect the following: for PMF design, the upstream PMF scour depth should be carried through Area 3a because it is subjected to a similar flow environment. For 100-year, 200-year, 500-year, and SPF design, the design scour depth is 0 feet. However, the recommended placement depth is below the invert of the McMicken Dam Outlet Channel.**

10) *For Area 5, the Earth Spillway Erosion Model (USDA, 1997), which is implemented in the SITES model (USDA, 2007), is more applicable for spillway erosion than the Lacey equation. Therefore, the use of this model may reduce the scour estimate for this area, and subsequently Areas 3a and 4. However, the consultant may use the previously calculated value of 28 ft.*

    - **While this area is described as a "spillway" the area of primary interest is subject to open-channel flow, although it is described by a very wide channel. Additionally, the intent of the analysis is not to model the failure of the McMicken Dam emergency spillway, but rather un-disturbed function of the spillway.**

11) *For Area 5, the use of the severe bend "z" coefficient may over-predict scour in this region. The use of the moderate bend "z" coefficient may be more applicable and will reduce the scour estimate for this area, and subsequently Areas 3a and 4. However, the consultant may use the previously calculated value of 28 ft.*

- **Definitions of "moderate" and "severe" are not defined technically in Pemberton and Lara. Given the unknown nature of channel migration and the orientation of the emergency spillway, "severe" curvature was assumed for analysis. Use of the "moderate bend" coefficient reduces the total design scour depth by 9 feet to a value of 18 feet. See the response to comment 2 for more information on Area 5.**

12) *On page 14 of the report, it is indicated that Figure 7 shows the lateral migration extents and the scour depths; however, these are not shown in the figure. Please show the depths and extents on the figure.*

- **The wrong figure was referenced. The reference has been changed to Figure 9 which shows the extents for multiple areas including Area 2. The extents for Area 3 have been removed from the figure for clarity.**

13) *The scour extents, shown on Figure 9 on page 15 of the report, appear to be incorrect. They show the scour extents for areas 2, 3a, 3b, 4 and 5. Please correct the scour extents on Figure 9.*

- **See the response to the previous comment.**

14) *The scour extents, shown on Figure 12 on page 19 of the report, appear to be incorrect. They show the scour extents for areas 2, 3a, 3b, 4 and 5. Please correct the scour extents on Figure 9.*

- **See the responses to the previous two comments. Figure 12 has been removed.**

15) *The date listed for the "McMicken Dam Outlet Channel Erosion and Sedimentation Analysis" is listed as 2006, rather it should be 2007.*

- **The date has been changed.**

16) *The AMEC, 2003 reference is not included in the Reference section. Please include this reference.*

- **The reference could not be found in the text. The AMEC contribution to the Wittmann ADMPU has been included explicitly in the references section of the report.**

References:

JE Fuller, 2006. Lower Hassayampa River Watercourse Master Plan. Prepared for Flood Control District of Maricopa County.

U.S. Department of Agriculture, Natural Resources Conservation Service, 1997. Earth Spillway Erosion Model. National Engineering Handbook, part 628, ch. 51. August 1997.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2007. SITES 2005 Water Resource Site Analysis Computer Program: User Guide, October 2007.

Vaughan, Nathanael, 2008. Email Communication to Bing Zhao, CC: jon@jefuller, Richard Waskowsky of FCDMC (7:46 AM, January 9, 2008).