Scour Evaluation for Pipeline Crossing of Cave Creek

Maricopa County, Arizona

WEST CONSULTANTS, INC.

Water • **E**nvironmental • **S**edimentation • **T**echnology

Hydraulics • Hydrology • Sedimentation • Water Quality • Erosion Control • Environmental Services

Scour Evaluation for Pipeline Crossing of Cave Creek

Maricopa County, Arizona

Prepared for:

Sunrise Engineering, Inc.
2152 South Vineyard, Suite 123
Mesa, AZ 85210

Prepared by:

WEST CONSULTANTS, INC.

WEST Consultants, Inc.
960 West Elliot Road, Suite 201
Tempe, AZ 85284

October 2007

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 10/30/07
ARIZONA, U.S.A.

TABLE OF CONTENTS

INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct a 100-year flow event scour evaluation for a 2-inch natural gas pipeline crossing in the left overbank of the floodplain to Cave Creek. The proposed pipeline crossing lies in the Sections 5 and 6 of T5N R4E in Maricopa County, Arizona. The proposed pipeline initially parallels a small tributary to Cave Creek before it enters the Cave Creek floodplain (blue hashed area in Figure 1). The proposed pipeline does not actually into the floodway of Cave Creek. The project location is shown in Figure 1. Cave Creek near the proposed gas pipeline crossing is shown in Figure 2.

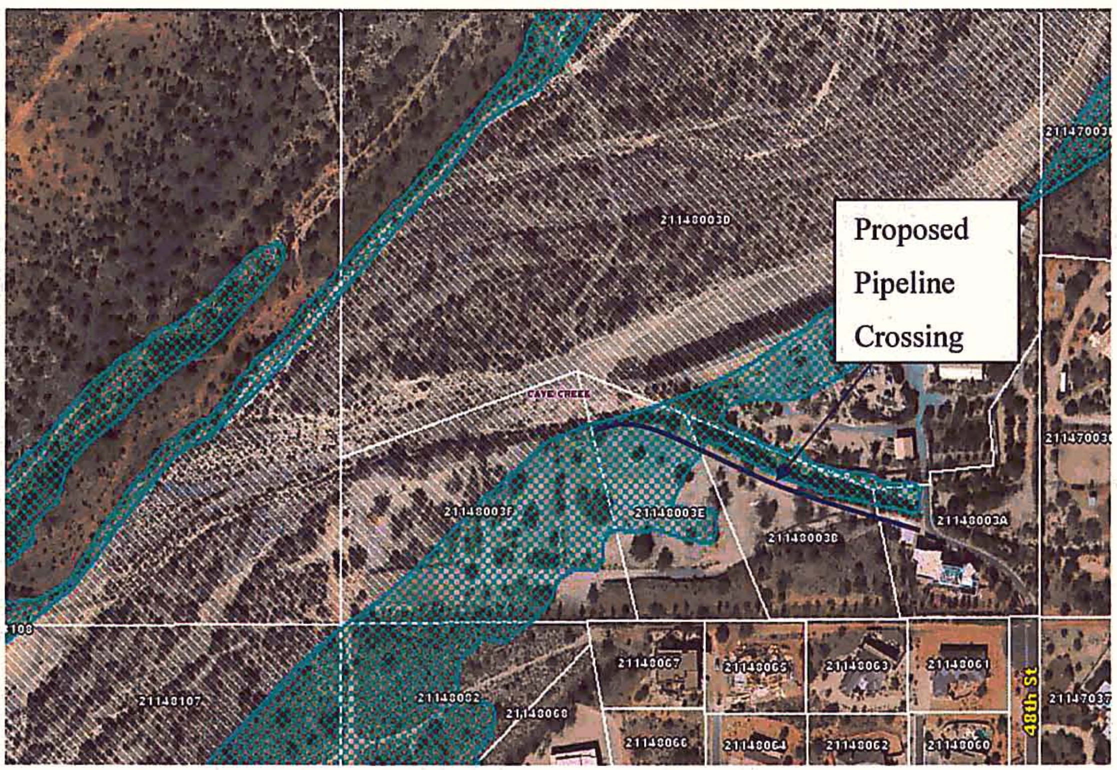

Figure 1. Project location map

Figure 2. Cave Creek near the proposed pipeline crossing

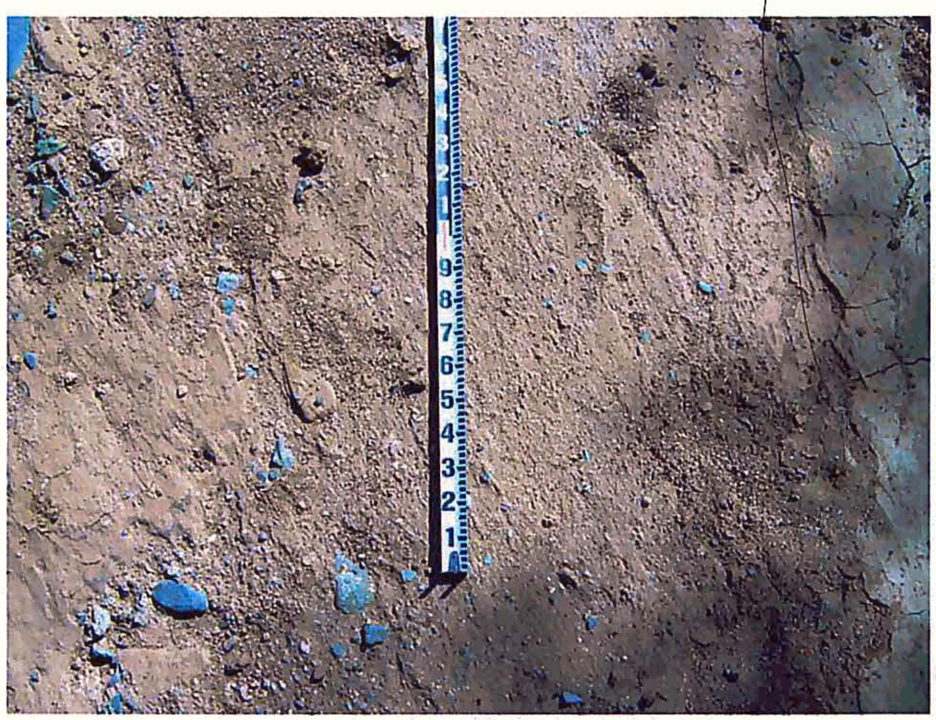

Figure 3. Channel material of Cave Creek near the proposed pipeline crossing

DATA COLLECTION

A field reconnaissance was conducted on October 19, 2007 by personnel from WEST. Cave Creek is a sand and gravel bed channel (see Figure 3). A representative soil sample was obtained at the proposed pipeline crossing site. Material testing of the sample was performed by Richer, Atkinson, McBee, Morman & Associates, Inc. (RAMM) of Tempe, Arizona. The gradation data provided by RAMM is included in Appendix 1. The median grain size (D_{50}) for the soil sample is 2.00 mm, and this median grain diameter was used for the scour calculations. Based on field observations, the bed material in the study area is gravel and sand. Thus, the laboratory test results are consistent with field observation.

Cave Creek is very flat channel near the proposed pipeline crossing and the banks are not well defined (see Figure 2). The Manning's n-value in the hydraulic model for the main channel is 0.05, while the Manning's n-value for the overbanks is 0.055. These values appear to be reasonable based on the field observations.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrologic analysis for the Cave Creek was conducted by George V. Sabol Consulting Engineers as part of the *Cave Creek Floodplain Delineation* (McLaughlin Kmetty Engineers, 1996). The hydrology was determined using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Software. The flow value for Cave Creek near the proposed pipeline crossing has been estimated to be 33,800 cfs, and this discharge was used to perform the scour analysis calculation.

HYDRAULICS

The US Army Corps of Engineers' River Analysis System standard-step backwater computer program (HEC-RAS, Version 3.1.3) was used to the compute channel hydraulics (USACE, 2005). The original HEC-2 model for Cave Creek was developed as part of *Cave Creek Floodplain Delineation* (McLaughlin Kmetty Engineers, 1996). This hydraulic model represents the existing condition of Cave Creek near the proposed pipeline crossing. The original HEC-2 model was imported into HEC-RAS. Since the hydraulic model for Cave Creek has been reviewed and accepted by the Flood Control District of Maricopa County (FCDMC), it was assumed that the model was adequate for the scour analysis. The scour calculations were based on the cross-section near the proposed pipeline crossing at RS 30.85 in the hydraulic model.

SCOUR CALCULATIONS

The proper consideration of scour at a site requires a determination of the total scour. Total scour refers to the total depth of scour at a given location and is the sum of all scour components that apply to the site of interest. These scour components can include:

- Bend scour
- Local scour
- General scour or contraction scour
- Bedform scour
- Long-term degradation
- Low-flow incisement scour

A factor of safety may be applied to account for uncertainty of the data, degree of variability of the channel conditions, level of risk, etc. The factor of safety may be applied to some or all of the scour components. In this study, a safety factor of 1.3 is used for all of the scour components. The total scour at a given location is the sum of the individual components that are applicable at that location.

Bend Scour

The proposed pipeline crossing of Cave Creek is located downstream of a moderate bend in the channel. The bend scour was accounted for indirectly by choosing the appropriate *Z* factor in the general scour calculations.

Local Scour

Local scour is the scour that results from an obstruction and abrupt change in the direction of flow. Local scour is caused by an acceleration of flow and resulting vortices induced by the obstruction. It occurs at bridge piers, abutments, embankments, and other structures obstructing the flow. Based on the field observation, there are no structures located near the location of the proposed pipeline crossing. Therefore, local scour will not be an issue at crossing site and was not considered in the determination of the total scour depth. Note that this analysis does not take into account any bridges or structures that may be present in the future.

General Scour

General scour is the lowering of the streambed across the channel or stream over relatively short time periods (e.g., the general scour in a given reach after the passage of a single flood event). The lowering may be uniform across the bed or non-uniform (i.e., the depth of scour may be deeper in some parts of the cross-section).

General scour may result from concentration of the flow when the flow area of a stream is decreased from the normal either by a natural constriction or a manmade constriction (i.e., local encroachment, bridge, etc.). With the decrease in flow area there is an increase in average velocity and bed shear stress.

In this study, the general scour was computed using Lacey's equation (1930), Neill's equation (1973), and Blench's equation (1969). Lacey's equation is applicable to natural river systems, while Neill's equation is applicable to channel constriction cases where there is a bridge or contraction structure (FCDMC, 2007). Blench's equation is applicable if there is a hydraulic structure upstream that may significantly reduce the sediment inflow to the reach (FCDMC, 2007). To be conservative, the largest scour depth among the three equations was assumed for the general scour.

Lacey's equation (1930) for general scour is given by:

$$y_{gs} = Zy_m = Z(0.47(\frac{Q}{f})^{\frac{1}{3}})$$

where: y_m = mean depth at design discharge;

Q = design discharge (cfs);

f = Lacey's silt factor = $1.76 \times D_m^{1/2}$;

D_m = mean grain size (mm);

y_{gs} = general scour depth (ft); and

Z = multiplying factor, taken to be 0.5 for a moderate bend.

For a median grain diameter of 2.00 mm (0.00656 ft), the Lacey's silt factor was determined to be 2.49 at the proposed pipeline crossing. Using the hydraulic parameters of Cave Creek near the proposed pipeline crossing (cross-section 30.85), the general scour was calculated to be 5.6 feet:

$$y_{gs} = 0.50(0.47(\frac{33{,}800}{2.59})^{\frac{1}{3}}) = 5.61 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey equation was estimated to 7.3 feet.

The general scour was also calculated using Neill's equation (1973), which is applicable to channel constriction cases where there is a bridge or contraction structure. Neill's equation (1973) for general scour is given by:

$$y_{gs} = Zd_f = Zd_i(\frac{q_f}{q_i})^m$$

where, y_{gs} = general scour depth (ft);

Z = multiplying factor, taken to be 0.6 for moderate bends;

d_f = scoured depth below design floodwater level (ft);

d_i = average depth at bankfull discharge in incised reach;

q_f = design flood discharge per unit width;

q_i = bankfull discharge in incised reach per unit width;

m = exponent varying from 0.67 for sand to 0.85 for coarse gravel, a value of 0.67 was assumed for this study.

From the HEC-RAS model, the average depth for bankfull discharge was 8.65 feet. The design discharge per unit width (q_f) is 42.71 cfs/ft and bankfull discharge per unit width (q_i) is 103.32 cfs/ft. Therefore, the general scour was computed to be 2.9 feet:

$$d_s = 0.6(8.65(\frac{42.71}{103.32})^{0.67}) = 2.87 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to 3.7 feet.

Blench's equation (1969) for general scour is given by:

$$y_{gs} = Z\left(\frac{q_f^{2/3}}{F_{b0}^{1/3}}\right)$$

where: y_{gs} = general scour depth (ft),

Z = multiplying factor, taken to be 0.6 for moderate bends,

q_f = design discharge per unit width (cfs/ft), and

F_{b0} = Blench's "zero bed factor" from Figure 4 (ft/s^2).

For a median grain diameter of 2.00 mm, F_{b0} was determined from Figure 4 to be about 2.1 ft/s^2. General scour was evaluated using the average hydraulic parameters in the Cave Creek near the proposed pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 42.71 cfs/ft, and the corresponding general scour was be calculated to be 5.7 feet:

$$y_{gs} = (0.6)\left[\frac{(42.71)^{2/3}}{(2.1)^{1/3}}\right] = 5.72 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using Blench's equation was estimated to be 7.4 feet.

Since the general scour was greater using Blench's equation, the general scour depth was chosen to be 7.4 feet.

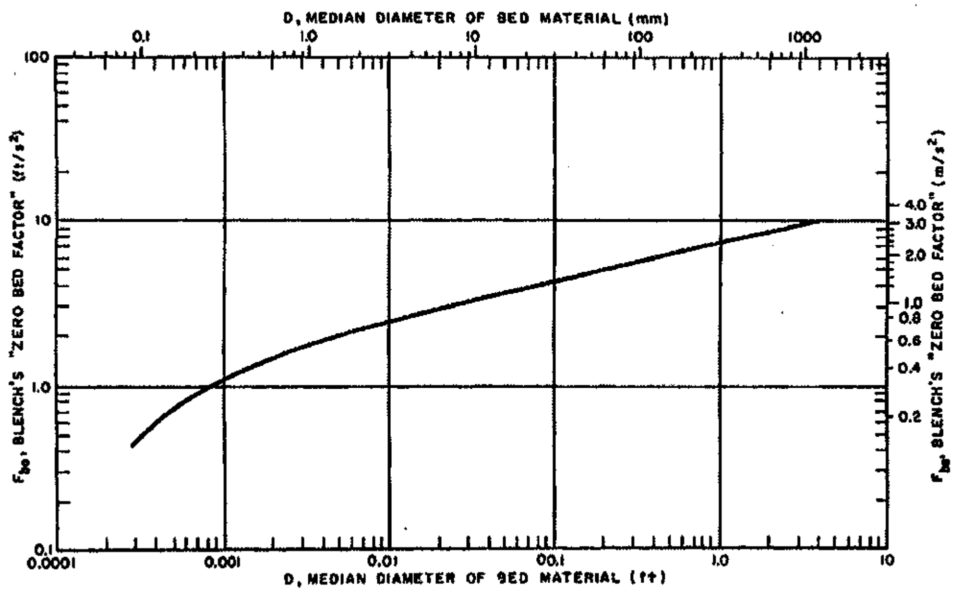

Figure 4. Blench's "zero bed factor" (from Pemberton and Lara (1984))

Bedform Scour

For sand bed channels, natural or manmade, it is necessary to estimate the height of the bedforms moving through the channel. Dunes form in lower regime flow with antidunes forming in transitional or upper regime flow. A bedform trough is a component of total scour in this study. The Froude number of Cave Creek near the proposed pipeline crossing for the 100-year event is 0.72, which would indicate that the flow can be classified in the upper flow regime. The scour depth due to antidunes is equal to one-half of the height of antidune.

$$y_{bedform} = 0.5d_h$$

Antidune height is estimated using the Kennedy's equation (Simons, Li and Associates, 1985):

$$d_h = 0.027V^2$$

where, $y_{bedform}$ = bedform scour;

d_h = antidune height, in feet, and

V = channel average velocity, in feet per second.

From the HEC-RAS model, the average velocity of Cave Creek near the pipeline crossing is 11.95 ft/s. Therefore, the bedform scour was computed to be 1.9 feet.

$$y_{bedform} = 0.5(0.027(11.95)^2) = 1.93 \text{ feet}$$

Using a factor of safety of 1.3, the bedform scour was estimated to be 2.5 feet.

Long-Term Degradation

Long-term degradation can often be evaluated using equilibrium, or stable, slope analysis and/or historic cross-section data. A stable slope analysis can be utilized if there is an appropriate "pivot" point located a short distance downstream. A field investigation revealed that the location of a stable or "pivot" point could not be identified, thus a stable slope analysis was not utilized in this study.

Arizona State Standard 5-96 (ADWR, 1996) provides an equation for computing long-term degradation when no downstream controls exist within the channel system. The long-term degradation can be conservatively computed as follows:

$$y_{lts} = 0.02(Q_{100})^{0.6}$$

where: y_{lts} = long-term scour depth, in feet, and

Q_{100} = 100-year discharge, in cubic feet per second.

This equation should only be used for long-term degradation when no downstream controls exist within the channel. Using the 100-year discharge of 33,800 cfs results a long-term scour estimate of 13.6 ft and a total scour depth of 26.1 ft, including the factor of safety of 1.3. Since the proposed pipeline does not actually cross the main Cave Creek channel, this scour depth appears to be overly excessive. To obtain a more reasonable estimate of the long-term scour, the discharge in the main Cave Creek channel (i.e., 10,952 cfs) was used instead of the full 100-year discharge. The main channel of Cave Creek will transport most of the sediment and thus, will be responsible for most of the long-term scour. Using the 100-year main channel discharge of 10,952 cfs, the long-term scour was calculated to be 5.31 feet:

$$y_{lts} = (0.02)(10{,}952)^{0.6} = 5.31 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation, y_{lts}, was estimated to be 6.9 feet.

Low-flow Incisement Scour

The normal irregularities in the bed of a watercourse could result in a low-flow channel. That channel is formed by the predominance of a low-flow condition or due to low-flows that persist after a flood. The magnitude of low-flow incisement scour can be estimated as no less than 1 foot and possibly in excess of 2 feet (FCDMC, 2007). In this study, the low-flow incisement scour was assumed to be 2.0 feet. Using a factor of safety of 1.3, this scour component is computed as 2.6 feet.

Total Scour

The total scour at the proposed pipeline crossing on Cave Creek is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 19.4 feet (7.4 feet + 2.5 feet + 6.9 feet + 2.6 feet). Therefore, a burial depth of the crown of 19.4 feet below the thalweg of the channel is considered sufficient to protect the pipe from failure due to scour.

LATERAL MIGRATION

The Arizona Department of Water Resources' (ADWR) State Standard for Watercourse System Sediment Balance (ADWR 1996) provides a procedure for estimating the "safe" setback or distance beyond the existing stream banks that the pipeline should remain at the design burial depth to prevent scour due to lateral migration of the channel. The equation recommended for straight channels with minor curvature is:

$$M_{LS} = 2.5(Q_D)^{0.5}$$

where: M_{LS} = minimum "safe" setback distance necessary, in feet, and

Q_D = design discharge, in cubic feet per second.

For this study, the design discharge, Q_D, was equal to the 100-year discharge (33,800 cfs). Using this information, the minimum "safe" setback distance necessary was calculated to be 459.6 feet:

$$M_{LS} = 2.5(33{,}800)^{0.5} = 459.58 \text{ feet}$$

Thus, a minimum setback distance of 460 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 460 feet beyond the main channel banks or the 100-year floodway, whichever is greater. In this case, the channel banks controls and the total scour depth should be maintained at least 460 feet beyond the channel banks. A lateral migration setback distance of 460 feet extends almost to the start of the proposed pipeline. To be conservative, the whole proposed pipeline crossing (approximately 600 feet) should be considered to be buried 19.4 feet below the thalweg of the channel. Doing this will protect the pipeline from any scour and/or lateral migration that could occur along the small tributary that the proposed pipeline parallels.

SUMMARY

A scour analysis and lateral migration analysis was conducted for a 2-inch natural gas pipeline crossing of Cave Creek. The total scour depth at the proposed pipeline crossing was determined to be 19.4 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline be buried a minimum of 19.4 feet below the thalweg of the channel. Note that this analysis does not take into account any bridges or structures that may be present in the future.

The "safe" setback distance was set to be 600 feet from the edge of the left bank. A schematic view of the pipeline crossing is shown in Figure 5.

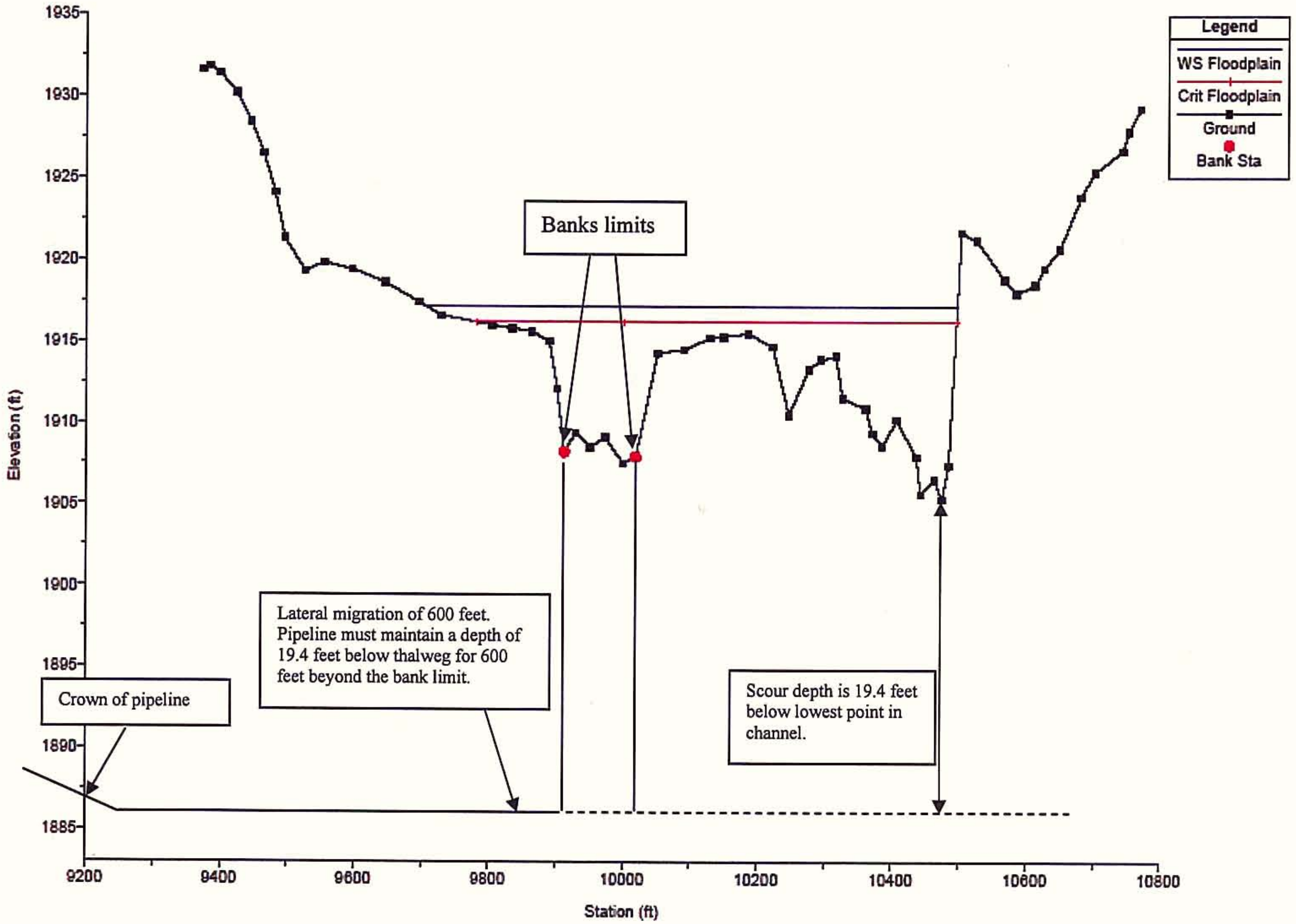

Figure 5. Schematic view of crown profile for the proposed pipeline crossing (drawing not to scale)

REFERENCES

Arizona Department of Water Resources. (1996). *Watercourse System Sediment Balance*, State Standard 5-96, September 1996, Phoenix, AZ.

Blench, T. (1969). *Mobile-Bed Fluviology*. University of Alberta Press, Edmonton, Canada.

Flood Control District of Maricopa County. (1995). *Drainage Design Manual for Maricopa County, Arizona: Hydrology*, Phoenix, AZ.

Flood Control District of Maricopa County. (2007). *Drainage Design Manual for Maricopa County, Arizona: Hydraulics (DRAFT)*, Phoenix, AZ.

Lacey, G. (1930). "Stable Channels in Alluvium." *Proceedings of the Institution of Civil Engineers*, v. 229.

McLaughlin Kmetty Engineers, Ltd. (1996). *Cave Creek Floodplain Delineation*, Flood Control District of Maricopa County, Phoenix, AZ.

Neill, C.R. (1973). *Guide to Bridge Hydraulics*, published for Roads and Transportation Association of Canada.

Pemberton, E. L. and J. M. Lara. (1984). *Computing Degradation and Local Scour*, USBR, Denver, Colorado, January 1984.

Simons, Li and Associate. (1985). *Design Manual for Engineering Analysis of Fluvial Systems*, Arizona Department of Water Resources, Phoenix, Arizona.

U.S. Army Corps of Engineers. (2005). *HEC-RAS River Analysis System, User's Manual*, version 3.1.3, May 2005.

APPENDIX 1: SOIL GRADATION INFORMATION

Ricker • Atkinson • McBee • Morman & Associates, Inc.
Geotechnical Engineering • Construction Materials Testing
2105 S. Hardy Drive, Suite 13, Tempe, AZ 85282-1924
Telephone (480) 921-8100 • Facsimile (480) 921-4081

R·A·M·M

LABORATORY TEST RESULTS

Client: West Consultants
Attn: Brian Wahlin
960 W. Elliot Rd., Ste. 201
Tempe, AZ 85284

Project No.: L15344
Report Date: 22-Oct-07
Lab No.: 28824

Project: **Laboratory Testing**
Location: Cave Creek

Sampled By: Client
Date Sampled: 19-Oct-07
Submitted By: Client
Date Submitted: 19-Oct-07

Sample Source: South Side

Material: Soil

Supplier:

Test Method(s): Sieve Analysis (ASTM C117, C136)

Results:

Sieve Size	Percent Passing	Specifications Minimum	Specifications Maximum
	100		
	100		
3"	100		
2"	100		
1-1/2"	100		
1"	100		
3/4"	100		
1/2"	97		
3/8"	95		
1/4"	87		
#4	79		
#8	55		
#10	50		
#16	34		
#30	19		
#40	15		
#50	12		
#100	9		
#200	6.3		

Remarks:

Distribution: Addressee (1)

AAP® AASHTO R18

Respectfully submitted,

Shawn C. Morman, E.I.T.
Vice President