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Pipeline Crossing
Scour Evaluations

Maricopa County, Arizona

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Water • Environmental • Sedimentation • Technology

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

Scour Evaluation for Pipeline Crossing of Wash 3 East at Deer Valley Road

Maricopa County, Arizona

Prepared for:

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Prepared by:

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August 2007

Registered Professional Engineer (Civil)
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BRIAN THOMAS
WAHLIN
Date Signed 8/15/07
ARIZONA, U.S.A.

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INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct the 100-year flow event scour evaluation for the 12-inch natural gas pipeline crossing of Wash 3 East at a location approximately 45 feet upstream of Deer Valley Road. The proposed pipeline crossing of Wash 3 East lies in the Sections 13 and 14 of T4N R2W in Maricopa County, Arizona. The project location is shown in Figure 1.

Wash 3 East is located in the Wittmann Wash subbasin as defined by the *Wittmann Area Drainage Master Study Update* (Entellus, 2005). Wash 3 East starts at the Central Arizona Project canal and flows in a southern direction until in drains into the Trilby Wash Basin just downstream of Deer Valley Road. The hydrology and the hydraulics for the site were developed by Entellus (2005) as part of the *Wittmann Area Drainage Master Study Update*. Low flows pass under Deer Valley Road through four sets of culverts. Each set of culverts consists of 3 barrels that are 10 feet wide by 3 feet high. One set of these culverts is shown in Figure 2. The 100-year discharge overtops Deer Valley Road.

Figure 2. One of the culvert crossings for Wash 3 East at Deer Valley Road

Figure 3. Wash 3 East bed material near the Deer Valley Road crossing

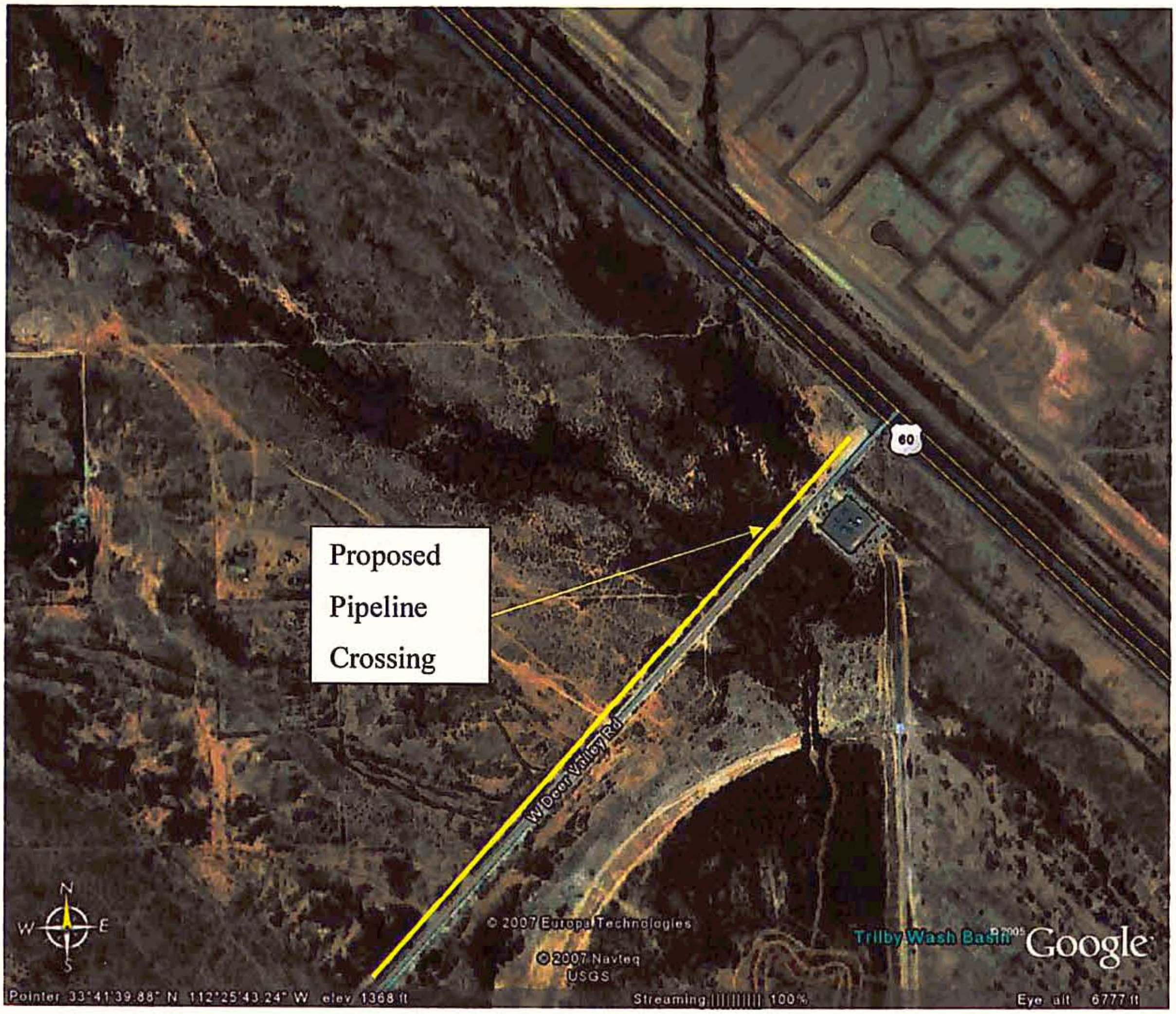

Figure 1. Project location map

DATA COLLECTION

A field reconnaissance was conducted on August 4, 2007 by personnel from WEST, Sunrise Engineering, and Southwest Gas. Wash 3 East is a sand and gravel bed channel (see Figure 3). A representative soil sample was obtained at the proposed pipeline crossing. Material testing of the sample was performed by Richer, Atkinson, McBee & Associates, Inc. (RAM) of Tempe, Arizona. The gradation data provided by RAM is included in the Appendix. The median grain size (D_{50}) for the soil sample is 0.15 mm. Based on field observations, the bed material in the study area ranges from small gravel to very fine sand (see Figure 3). Thus, the laboratory test results are consistent with field observation.

The banks of Wash 3 East near Deer Valley Road are not well defined, and the channel is heavily vegetated. The Manning's *n*-value used in the main channel in the hydraulic model of Wash 3 East is 0.093 while the overbanks, which have less vegetation than the main channel, are given an *n*-value of 0.063. Based on observations in the field, these *n*-values appear to be reasonable.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrology was based upon the *Wittmann Area Drainage Master Study Update (ADMSU) Hydrology Report* (Entellus, 2005). The hydrologic analysis for the Wittmann area ADMSU was performed using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Package. The precipitation runoff model was developed following the procedures and parameters recommended in the FCDMC's *Drainage Design Manual for Maricopa County, Arizona: Hydrology* (1995). The soil losses were estimated using the Green & Ampt method and the Clark Unit hydrograph and S-graphs were used to route excess runoff within the subbasins to their concentration points. Wash 3 East is located in the Wittmann Wash subbasin. The concentration point in the HEC-1 model just upstream of the Deer Valley Road crossing is CWI506. Originally, the 100-year peak discharge for CWI506 was 2,460 cfs. In Entellus' addendum to the hydrology, the 100-year peak discharge at this concentration point was reduced to 2,340 cfs. To be conservative, the original 100-year discharge of 2,460 cfs was used for this scour analysis.

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 model was originally developed by Entellus as part of the Wittmann ADSMU (Entellus, 2005), and it was provided by the Flood Control District of Maricopa County (FCDMC). At the request of Southwest Gas, they hydraulic model was not reviewed by WEST. Since the hydraulic model for Wash 3 East has been reviewed and accepted by the FCDMC, it was assumed for the scour evaluation that the model was adequate. Thus, no changes were made to the model. The Deer Valley Road crossing is structure RS 1.366 in the HEC-RAS model. The scour calculations were based on the cross-section just upstream of the Deer Valley Road crossing at RS 1.381.

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.

The proposed pipeline crossing of Wash 3 East is located in a straight section of the wash approximately 45 feet upstream of the Deer Valley Road crossing. Thus, there would be no bend scour near the pipeline crossing and this scour component was not considered in the determination of the total scour depth.

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. Local scour is not an issue at crossing site because the proposed pipeline crossing will be located approximately 45 feet upstream from the Deer Valley Road crossing. Thus, local scour was not considered in the determination of the total scour depth.

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 by 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. The Central Arizona Project canal is located upstream of the crossing. Since this structure may reduce the sediment inflow into Wash 3 East, Blench's equation was also examined. 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 0.25 for straight reaches.

For a median grain diameter of 0.15 mm, general scour was evaluated using the hydraulic parameters in the reach of Wash 3 East at the pipeline crossing (cross-section 1.381). The Lacey's silt factor at this location for the 100-year event was determined to be 0.68, and the corresponding general scour was calculated to be 1.8 feet:

$$y_{gs} = 0.25(0.47(\frac{2{,}460}{0.68})^{\frac{1}{3}}) = 1.80 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey equation was estimated to 2.3 feet.

The general scour was also calculated using Neill's equation (Neill, 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 0.5 for straight reaches;

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 2.82 feet. The design discharge per unit width (q_f) and bankfull discharge per unit width (q_i) are 1.79 cfs/ft and 2.80 cfs/ft, respectively. Therefore, the general scour was computed to be 1.04 feet:

$$d_s = 0.5(2.82(\frac{1.79}{2.80})^{0.67}) = 1.04 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to 1.4 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 straight reaches,

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 0.15 mm, F_{b0} was determined from Figure 4 to be about 0.7 ft/s^2. General scour was evaluated using the average hydraulic parameters in the reach of Wash 3 East at the pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 1.79 cfs/ft, and the corresponding general scour was be calculated to be 1.0 feet:

$$y_{gs} = (0.6)\left[\frac{(1.79)^{2/3}}{(0.7)^{1/3}}\right] = 1.00 \text{ feet}$$

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

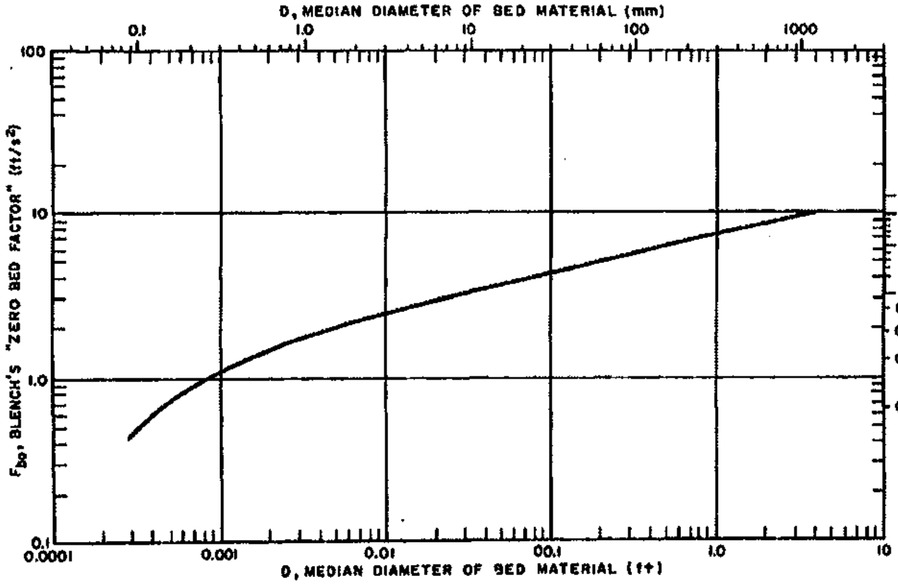

Figure 4. Blench's "zero bed factor" (from Pemberton and Lara (1984))

Since the general scour was greatest using Lacey's equation, the general scour depth was chosen to be 2.3 feet.

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 flow regime flow. A bedform trough is a component of total scour in this study. The Froude number in Wash 3 East at cross-section 1.381 for a 100-year event is approximately 0.1, which would indicate that the flow can be classified in the lower flow regime. The scour depth due to dunes is equal to one-half of the height of dunes.

$$y_{bedform} = 0.5d_h$$

Dune height is estimated using the following equation presented by Simons and Senturk (1992):

$$d_h = 0.066Y_h^{1.21}$$

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

d_h = dune height, in feet, and

Y_h = hydraulic depth of flow, in feet.

From the HEC-RAS model, the hydraulic depth of flow at the pipeline crossing is 1.95 feet. Therefore, the bedform scour was computed to be 0.07 feet.

$$y_{bedform} = 0.5(0.066(1.95)^{1.21}) = 0.074 \text{ feet}$$

Using a factor of safety of 1.3, the bedform scour was estimated to be 0.1 feet.

Long-Term Degradation

Long-term degradation can often be evaluated using equilibrium, or stable, slope analysis and/or historic cross-section data. The existing culvert crossing at the Deer Valley Road is the location of a stable or "pivot" point downstream of the proposed pipeline crossing since the culvert floor is concrete. Because the "pivot" point was located close to the proposed pipeline crossing, the long-term degradation was conservatively estimated by horizontally projecting the Deer Valley Road culvert invert elevation back to the location of the proposed pipeline crossing. The difference between the two elevations is an estimate of the long-term degradation. There is no difference in elevation between the invert of the culverts and the location of the proposed pipeline crossing. Thus, the long-term degradation should be zero. However, to be conservative, it was assumed that the long-term degradation was 0.5 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 near Deer Valley Road on Wash 3 East is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 5.5 feet (2.3 feet + 0.1 feet + 0.5 feet + 2.6 feet). Therefore, a burial depth of the crown of 5.5 feet below the thalweg of the channel is considered sufficient to protect the pipe from failure due to scour. Note that this evaluation does not take into account any local scour due to bridge piers and abutments that may exist in the future.

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:

$$M_{LS} = 1.0(Q_D)^{0.5}$$

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 (2,460 cfs). Using this information, the minimum "safe" setback distance necessary was calculated to be 49.6 feet:

$$M_{LS} = 1.0(2,460)^{0.5} = 49.60 \text{ feet}$$

Thus, a minimum setback distance of 50 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 50 feet beyond the main channel banks or the 100-year floodway, which ever is greater. In this case, the floodway controls and the total scour depth should be maintained at least 50 feet beyond the floodway on both sides of the channel. The floodway corresponds to the edges of the culverts. Thus, the entire scour depth of 5.5 feet should be maintained for at least 50 feet beyond the edges of the culverts. Using the road stationing for Deer Valley Road, the 5.5 feet deep trenching should start at station 07+75 and end at station 17+85.

SUMMARY

A scour analysis and lateral migration analysis for a 12-inch natural gas pipeline crossing of Wash 3 East at Deer Valley Road was conducted. The total scour depth at the proposed pipeline crossing was determined to be 5.5 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline at the proposed crossing be a minimum of 5.5 feet below the thalweg of the channel.

The minimum "safe" setback distance was calculated to be 50 feet from the existing unprotected banks. The entire scour depth of 5.5 feet should be maintained for at least 50 feet beyond the edges of the culverts. Using the road stationing for Deer Valley Road, the 5.5 feet deep trenching should start at station 07+75 and end at station 17+85. The crown of the gas pipeline should be at least 5.5 feet below the lowest ground elevation between road stations 07+75 and 17+85.

A schematic view of the pipeline crossing is shown in Figure 5.

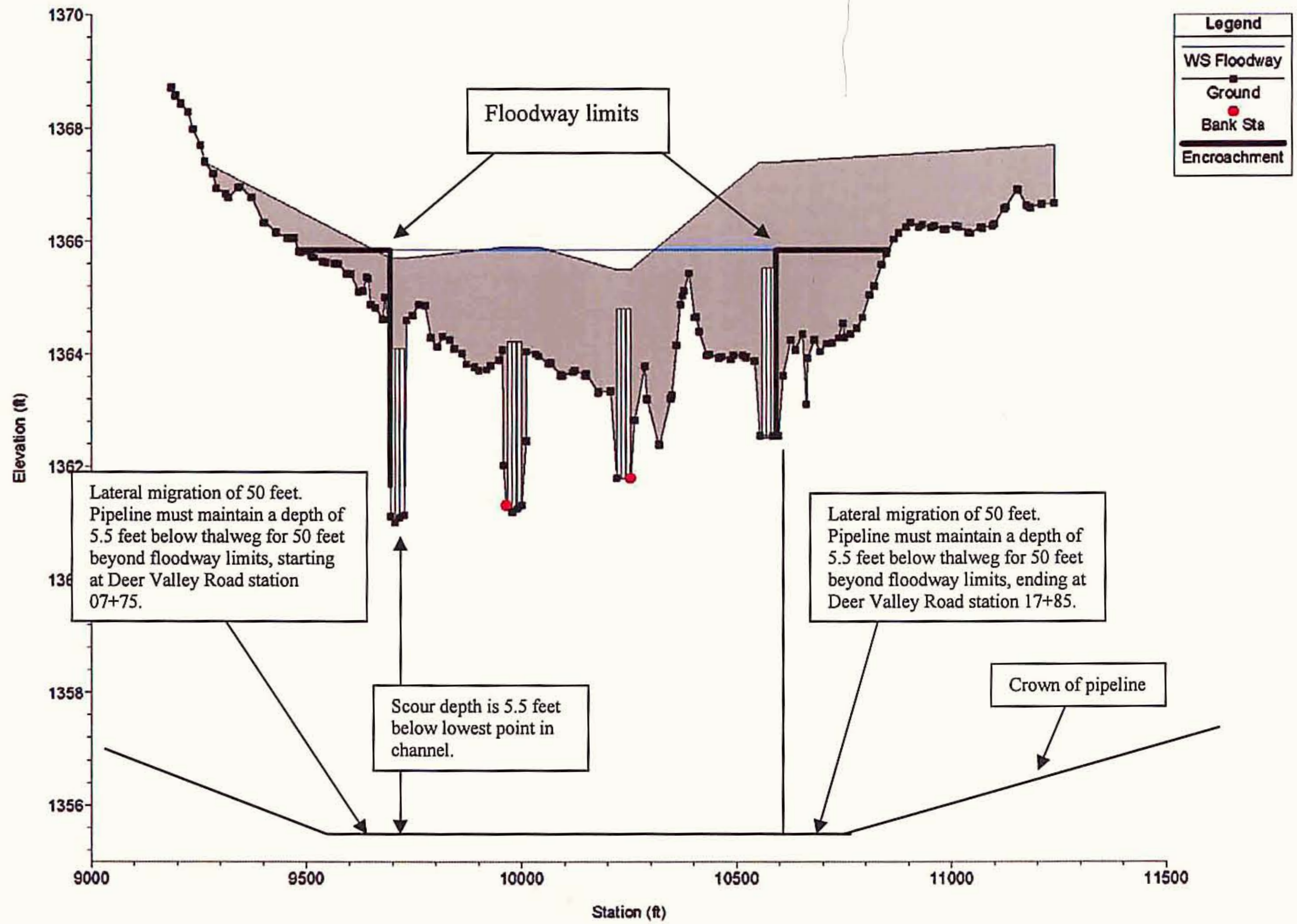

Figure 5. Schematic view of scour depths for pipeline crossing (drawing not to scale)

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APPENDIX: 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., Sta. 201
Tempe, AZ 85284

Project No.: L15034
Report Date: 8-Aug-07
Lab No.: 27739

Project: **Southwest Gas Scour Analysis**
Location:

Sampled By: Client
Date Sampled: 6-Aug-07
Submitted By: Client
Date Submitted: 6-Aug-07

Sample Source: Location #1

Material: Soil

Supplier:

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

Results:

Sieve Size	Percent Passing	Specifications	
		Minimum	Maximum
	100		
	100		
3"	100		
2"	100		
1-1/2"	100		
1"	100		
3/4"	100		
1/2"	98		
3/8"	94		
1/4"	90		
#4	88		
#8	81		
#10	80		
#16	74		
#30	67		
#40	62		
#50	58		
#100	49		
#200	41		

Remarks:

Distribution: Addressee (1)

AAP® AASHTO R18

Respectfully submitted,

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

LAB16 Rev.0

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INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct the 100-year flow event scour evaluation for a 12-inch natural gas pipeline crossing of Wash 1 West at a location approximately 60 feet upstream of Deer Valley Road. The proposed pipeline crossing of Wash 1 West lies in the Sections 13 and 14 of T4N R2W in Maricopa County, Arizona. The project location is shown in Figure 1.

Wash 1 West is located in the Wittmann Wash subbasin as defined by the *Wittmann Area Drainage Master Study Update* (Entellus, 2005). Wash 1 West starts at the Central Arizona Project canal and flows in a southern direction until in drains into the detention area behind McMicken Dam. The hydrology and the hydraulics for the site were developed by Entellus (2005) as part of the *Wittmann Area Drainage Master Study Update*. Low flows pass under Deer Valley Road through a bridge. The bridge has two sets of 3-foot wide piers as shown in Figure 2. High flows overtop Deer Valley Road.

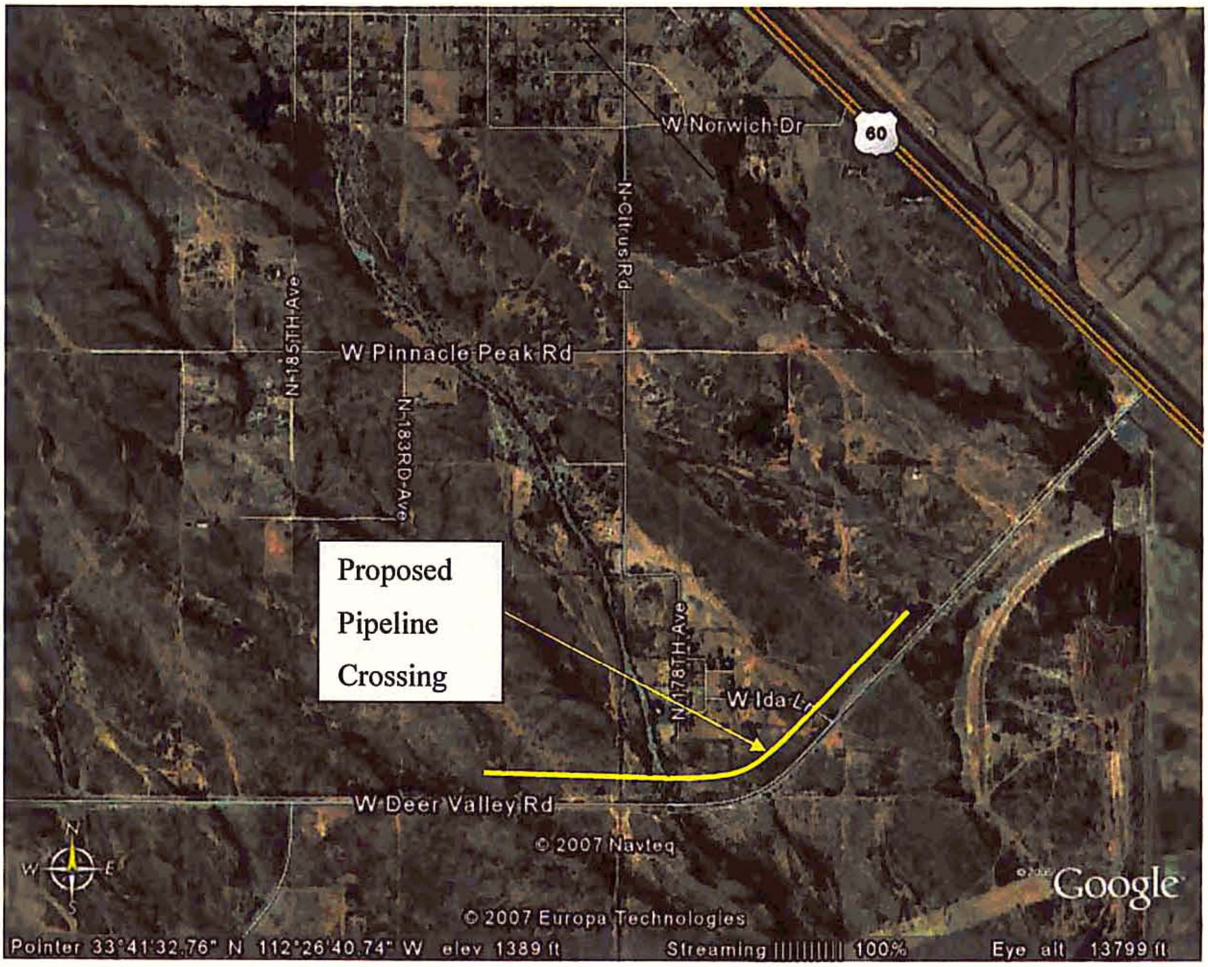

Figure 1. Project location map

Figure 2. The bridge crossings for Wash 1 West at Deer Valley Road

Figure 3. Wash 1 West bed material near the Deer Valley Road crossing

DATA COLLECTION

A field reconnaissance was conducted on August 4, 2007 by personnel from WEST, Sunrise Engineering, and Southwest Gas Corporation. Wash 1 West is a sand and gravel bed channel (see Figure 3). A representative soil sample was obtained at the proposed pipeline crossing. 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 0.15 mm. Based on field observations, the bed material in the study area ranges from coarse gravel to very fine sand (see Figure 3). Thus, the laboratory test results are consistent with field observation.

The banks of Wash 1 West near Deer Valley Road are not well defined, and the channel is heavily vegetated. The Manning's *n*-value used in the main channel in the hydraulic model of Wash 1 West is 0.055 while the overbanks, which have less vegetation than the main channel, are given *n*-values of 0.045 (left overbank) and 0.043 (right overbank). Based on observations in the field, these *n*-values appear to be reasonable.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrology was based upon the *Wittmann Area Drainage Master Study Update (ADMSU) Hydrology Report* (Entellus, 2005). The hydrologic analysis for the Wittmann area ADMSU was performed using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Package. The precipitation runoff model was developed following the procedures and parameters recommended in the FCDMC's *Drainage Design Manual for Maricopa County, Arizona: Hydrology* (1995). The soil losses were estimated using the Green & Ampt method and the Clark Unit hydrograph and S-graphs were used to route excess runoff within the subbasins to their concentration points. Wash 1 West is located in the Wittmann Wash subbasin. The concentration point in the HEC-1 model just upstream of the Deer Valley Road crossing is CWI510. Originally, the 100-year peak discharge for CWI510 was 6,160 cfs. In Entellus' addendum to the hydrology, the 100-year peak discharge at this concentration point was increased to 6,176 cfs.

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 model was originally developed by Entellus as part of the Wittmann ADSMU (Entellus, 2005), and it was provided by the Flood Control District of Maricopa County (FCDMC). At the request of Southwest Gas Corporation, the hydraulic model was not reviewed by WEST. Since the hydraulic model for Wash 1 West has been reviewed and accepted by the FCDMC, it was assumed for the scour evaluation that the model was adequate. The Deer Valley Road crossing is structure RS 1.0735 in the HEC-RAS model. The scour calculations were based on the cross-section just upstream of the Deer Valley Road crossing at RS 1.089.

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
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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.

The proposed pipeline crossing of Wash 1 West is located in a straight section of the wash approximately 60 feet upstream of the Deer Valley Road crossing. Thus, there would be no bend scour near the pipeline crossing and this scour component was not considered in the determination of the total scour depth.

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. The proposed pipeline crossing will be located approximately 60 feet from the Deer Valley Road Bridge face. The angle of attack of flow on a single pier in the upstream end of the bridge was considered to be zero degrees (i.e., piers are aligned parallel to the flow). Pier scour for the Deer Valley Road Bridge at Wash 1 West was estimated using the following equation documented in HEC-18 (FHWA, 2001):

$$y_s = y_1[2.0K_1K_2K_3K_4(\frac{a}{y_1})^{0.65}Fr_1^{0.43}]$$

where: y_s = scour depth;

y_1 = flow depth directly upstream of pier;

K_1 = correction factor for pier nose shape (1.0 for round shape);

K_2 = correction factor for angle of attack of flow (1.0 for zero degrees);

K_3 = correction factor for bed condition (1.1 for small dunes);

K_4 = correction factor for armoring by bed material size (1.0 for D_{50} = 0.15 mm);

a = pier width and debris width;

Fr_1 = Froude number.

From the HEC-RAS model, the flow depth directly upstream of pier was 6.26 feet, the pier width was 3 feet with no debris loading, and the Froude number was 0.04. Thus, the scour depth was calculated to be 2.1 feet:

$$y_s = 6.26[2.0(1.0)(1.0)(1.1)(1.0)(\frac{3}{6.26})^{0.65}(0.04)^{0.43}] = 2.14 \text{ feet}$$

HEC-18 indicates the top width of the scour hole from one side of the pier can vary from 1.07 to 2.8 times the scour depth or in the case of the Deer Valley Road crossing, from 2.3 to 6.0 feet. The 6.0 feet is based on the bottom width of the scour hole being equal to the depth of pier scour and material having an angle of repose 30 degrees. Since the distance of the proposed pipeline crossing upstream of the piers is approximately 60 feet, the local scour hole caused by piers will not extend to the proposed pipeline crossing location (see Figure 4) and there will be no local scour component for the proposed pipeline crossing.

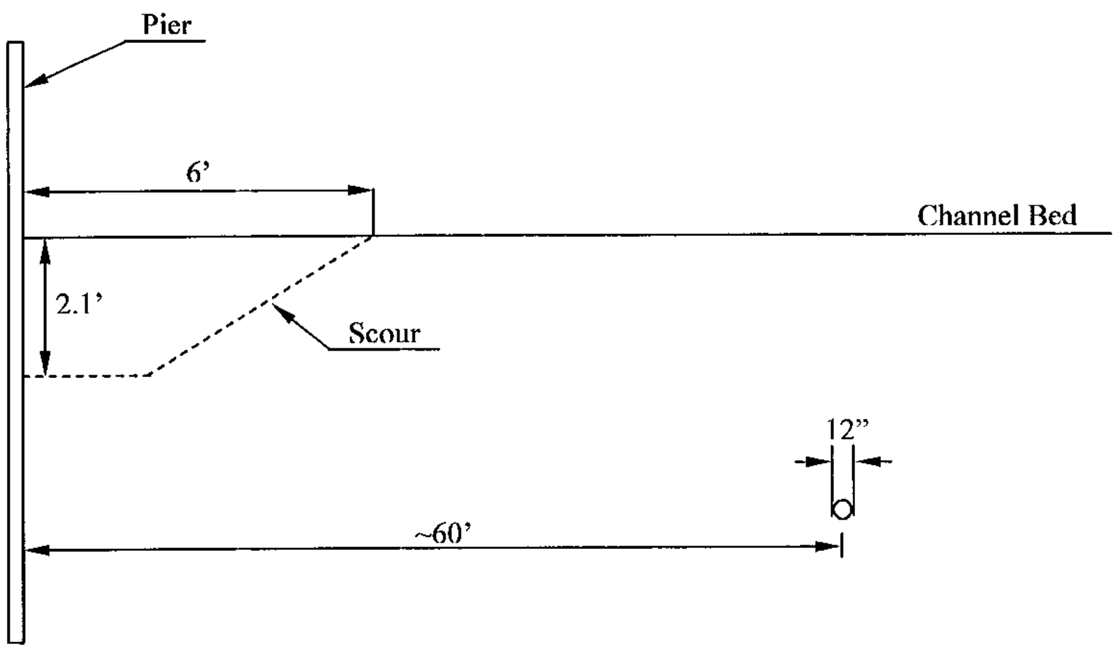

Figure 4. Local scour at pier

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 by 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. The Central Arizona Project canal is located upstream of the crossing. Since this structure may reduce the sediment inflow into Wash 1 West, Blench's equation was also examined. 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 0.25 for straight reaches.

For a median grain diameter of 0.15 mm (0.00049 ft), the Lacey's silt factor was determined to be 0.68. Using the hydraulic parameters in the reach of Wash 1 West at the pipeline crossing (cross-section 1.089), the general scour was calculated to be 2.5 feet:

$$y_{gs} = 0.25(0.47(\frac{6{,}176}{0.68})^{\frac{1}{3}}) = 2.45 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey equation was estimated to be 3.2 feet.

The general scour was also calculated using Neill's equation (Neill, 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 0.5 for straight reaches;

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 4.63 feet. The design discharge per unit width (q_f) is 1.96 cfs/ft and bankfull discharge per unit width (q_i) is 2.14 cfs/ft. Therefore, the general scour was computed to be 2.2 feet:

$$\mathrm{d_s} = 0.5(4.63(\frac{1.96}{2.14})^{0.67}) = 2.2 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to be 2.8 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 straight reaches,

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

F_{b0} = Blench's "zero bed factor" from Figure 5 (ft/s^2).

For a median grain diameter of 0.15 mm, F_{b0} was determined from Figure 5 to be about 0.7 ft/s^2. General scour was evaluated using the average hydraulic parameters in the reach of Wash 1 West at the pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 1.96 cfs/ft, and the corresponding general scour was be calculated to be 1.1 feet:

$$y_{gs} = (0.6)\left[\frac{(1.96)^{2/3}}{(0.7)^{1/3}}\right] = 1.06 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using Blench's equation was estimated to be 1.4 feet.

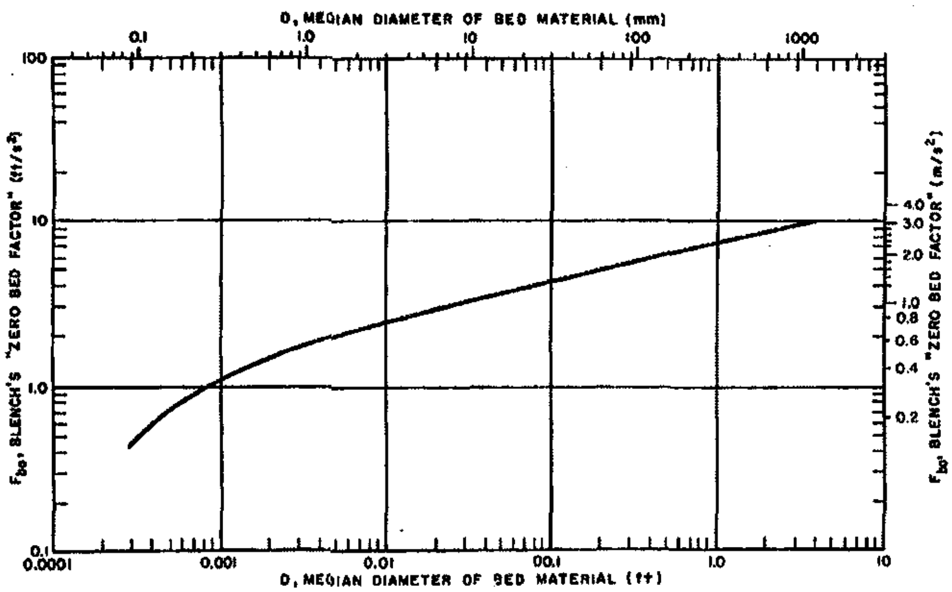

Figure 5. Blench's "zero bed factor" (from Pemberton and Lara (1984))

Since the general scour was greater using Lacey's equation, the general scour depth was chosen to be 3.2 feet.

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 in Wash 1 West at cross-section 1.089 for a 100-year event is approximately 0.04, which would indicate that the flow can be classified in the lower flow regime. The scour depth due to dunes is equal to one-half of the height of dunes.

$$y_{bedform} = 0.5d_h$$

Dune height is estimated using the following equation presented by Simons and Senturk (1992):

$$d_h = 0.066Y_h^{1.21}$$

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

d_h = dune height, in feet, and

Y_h = hydraulic depth of flow, in feet.

From the HEC-RAS model, the hydraulic depth of flow at the pipeline crossing is 7.11 feet. Therefore, the bedform scour was computed to be 0.35 feet.

$$y_{bedform} = 0.5(0.066(7.11)^{1.21}) = 0.35 \text{ feet}$$

Using a factor of safety of 1.3, the bedform scour was estimated to be 0.5 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. However, a field investigation revealed that the existing bridge at the Deer Valley Road does not have a fixed invert, so it can not be used as a "pivot" point. Thus, a stable slope analysis was not conducted since the location of a stable or "pivot" point could not be identified with any degree of certainty downstream of the Deer Valley Road crossing.

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 a 100-year discharge of 6,176 cfs, the long-term scour was calculated to be 3.8 feet:

$$y_{lts} = 0.02(6{,}176)^{0.6} = 3.76 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 4.9 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 near Deer Valley Road on Wash 1 West is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 11.2 feet (3.2 feet + 0.5 feet + 4.9 feet + 2.6 feet). Therefore, a burial depth of the crown of 11.2 feet below the thalweg of the channel is considered sufficient to protect the pipe from failure due to scour. Note that this evaluation does not take into account any local scour due to bridge piers and abutments that may exist in the future.

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:

$$M_{LS} = 1.0(Q_D)^{0.5}$$

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 (6,176 cfs). Using this information, the minimum "safe" setback distance necessary was calculated to be 78.6 feet:

$$M_{LS} = 1.0(6{,}176)^{0.5} = 78.58 \text{ feet}$$

Thus, a minimum setback distance of 80 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 80 feet beyond the main channel banks or the 100-year floodway, which ever is greater. In this case, the floodway controls and the total scour depth should be maintained at least 80 feet beyond the floodway on both sides of the channel. Using the road stationing for Deer Valley Road, the 11.2 feet deep trenching should start at station 64+70 and end at station 79+95.

SUMMARY

A scour analysis and lateral migration analysis for a 12-inch natural gas pipeline crossing of Wash 1 West at Deer Valley Road was conducted. The total scour depth at the proposed pipeline crossing was determined to be 11.2 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline at the proposed crossing be a minimum of 11.2 feet below the thalweg of the channel.

The minimum "safe" setback distance was calculated to be 80 feet from the edge of floodway. Using the road stationing for Deer Valley Road, the 11.2 feet deep trenching should start at station 64+70 and end at station 79+95.

A schematic view of the pipeline crossing is shown in Figure 6.

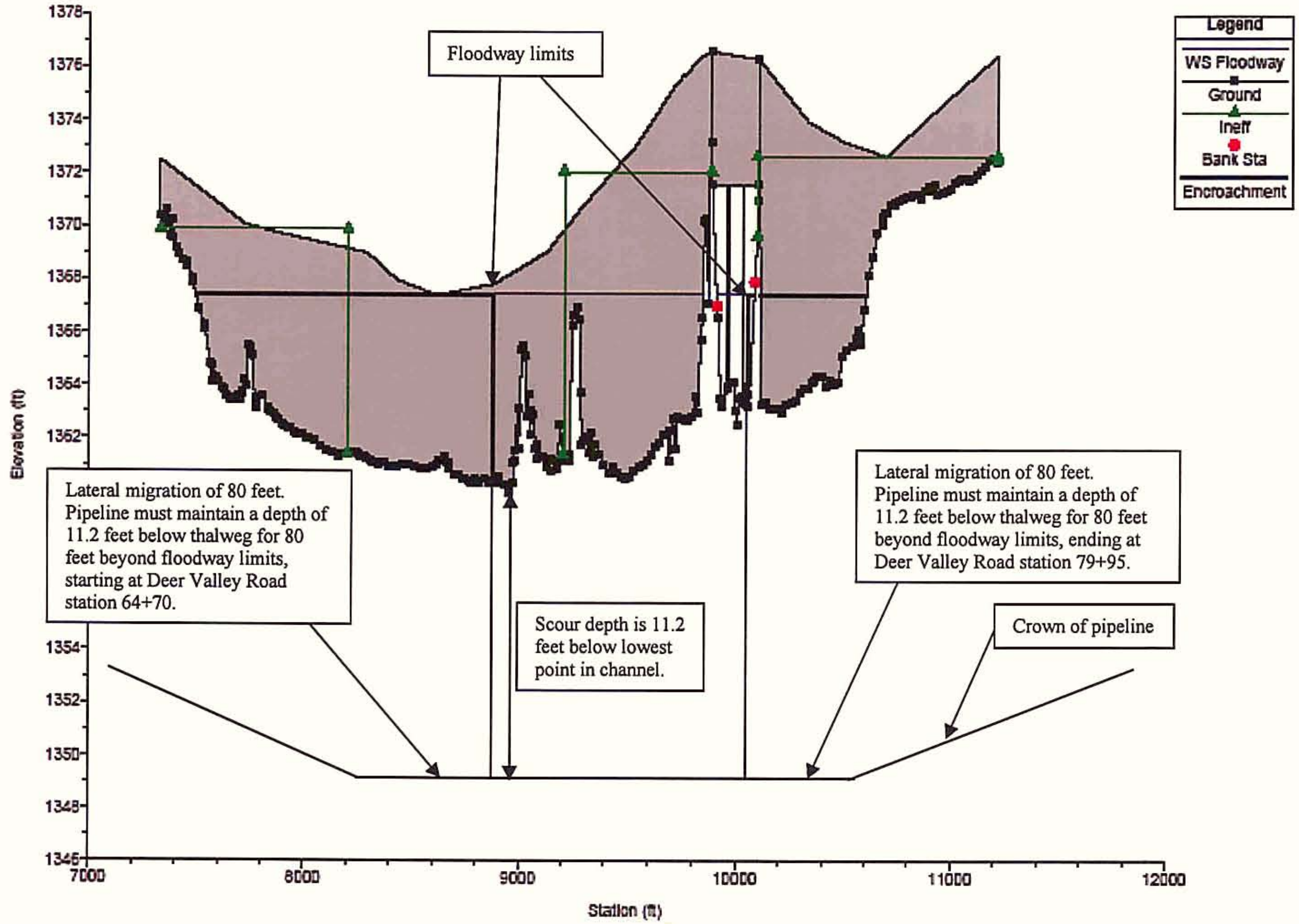

Figure 6. Schematic view of crown profile for the proposed pipeline crossing (drawing not to scale)

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APPENDIX 1: SOIL GRADATION INFORMATION

R·A·M·M

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

LABORATORY TEST RESULTS

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

Project No.: L15034
Report Date: 8-Aug-07
Lab No.: 27741

Project: **Southwest Gas Scour Analysis**
Location:

Sampled By: Client
Date Sampled: 6-Aug-07
Submitted By: Client
Date Submitted: 6-Aug-07

Sample Source: Location #2B

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"	98		
3/8"	95		
1/4"	90		
#4	86		
#8	76		
#10	74		
#16	69		
#30	66		
#40	64		
#50	62		
#100	46		
#200	26		

Remarks:

Distribution: Addressee (1)

AASHTO R18

Respectfully submitted,

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

LAB16 Rev.0

Scour Evaluation for Pipeline Crossing of Wash 2 West at Deer Valley Road

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
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August 2007

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 8/16/07
ARIZONA, U.S.A.

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INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct the 100-year flow event scour evaluation for a proposed 12-inch natural gas pipeline crossing of Wash 2 West at a location approximately 20 feet downstream of Deer Valley Road. The proposed pipeline crossing of Wash 2 West lies in the Sections 21 and 22 of T4N R2W in Maricopa County, Arizona. The project location is shown in Figure 1.

Wash 2 West is located in the Trilby Wash subbasin as defined by the *Wittmann Area Drainage Master Study Update* (Entellus, 2005). Wash 2 West starts at the Central Arizona Project canal and flows in a southern direction until in drains into the detention area behind McMicken Dam. The hydrology and the hydraulics for the site were developed by Entellus (2005) as part of the *Wittmann Area Drainage Master Study Update*. Both low and high flows pass under Deer Valley Road Bridge. The bridge has two sets of 3-foot wide piers as shown in Figure 2.

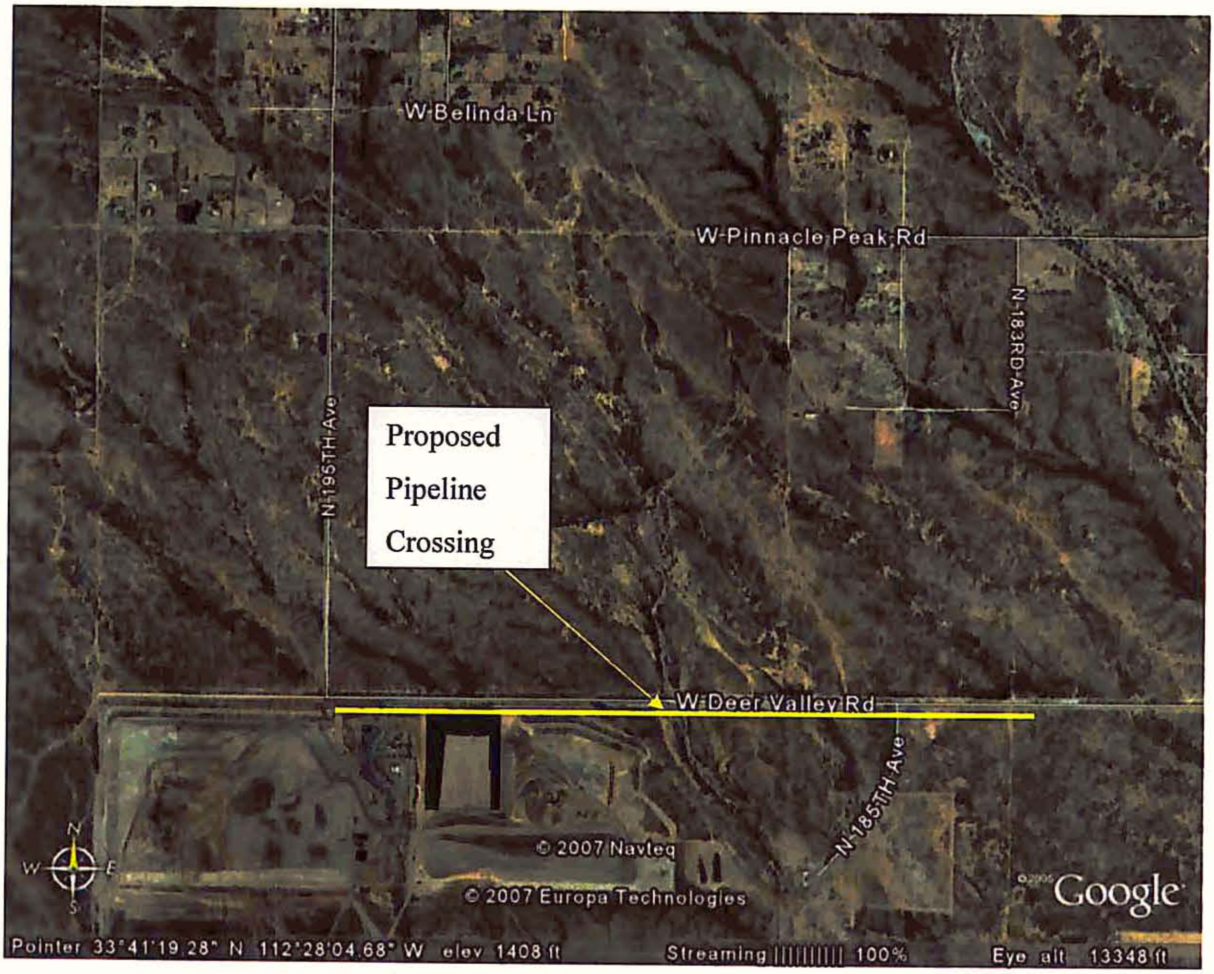

Figure 1. Project location map

Figure 2. The bridge crossings for Wash 2 West at Deer Valley Road

Figure 3. Wash 2 West bed material near the Deer Valley Road crossing

DATA COLLECTION

A field reconnaissance was conducted on August 4, 2007 by personnel from WEST, Sunrise Engineering, and Southwest Gas. Wash 2 West is a sand and gravel bed channel (see Figure 3). A representative soil sample was obtained at the proposed pipeline crossing. 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 1.18 mm, and the bed material in the study area ranges from very fine sand to coarse gravel (see Appendix 1 and Figure 3). Thus, the laboratory test results are consistent with field observation.

The banks for Wash 2 West near Deer Valley Road are well defined. The Manning's *n*-value used in the main channel in the hydraulic model of Wash 2 West is 0.038 while the overbanks, which have less vegetation than the main channel, are given an *n*-value of 0.032. Based on observations in the field, these *n*-values appear to be reasonable.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrology was based upon the *Wittmann Area Drainage Master Study Update (ADMSU) Hydrology Report* (Entellus, 2005). The hydrologic analysis for the Wittmann area ADMSU was performed using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Package. The precipitation runoff model was developed following the procedures and parameters recommended in the FCDMC's *Drainage Design Manual for Maricopa County, Arizona: Hydrology* (1995). The soil losses were estimated using the Green & Ampt method and the Clark Unit hydrograph and S-graphs were used to route excess runoff within the subbasins to their concentration points. Wash 2 West is located in the Trilby Wash subbasin. The concentration point in the HEC-1 model just upstream of the Deer Valley Road crossing is CTW422. Originally, the 100-year peak discharge for CTW422 was 2,970 cfs. In Entellus' addendum to the hydrology, the 100-year peak discharge at this concentration point was reduced to 2,842 cfs. To be conservative, the original 100-year discharge of 2,970 cfs was used for this scour analysis.

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 model was originally developed by Entellus as part of the Wittmann ADSMU (Entellus, 2005), and it was provided by the Flood Control District of Maricopa County (FCDMC). At the request of Southwest Gas, they hydraulic model was not thoroughly reviewed by WEST. Since the hydraulic model for Wash 2 West has been reviewed and accepted by the FCDMC, it was assumed for the scour evaluation that the model was adequate. The only change made to the model was that some of the bank stations were adjusted slightly so that they agreed with field observations. The scour calculations were based on the cross-section just downstream of the Deer Valley Road crossing at RS 2.163 in the HEC-RAS 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.

The proposed pipeline crossing of Wash 2 West is located in a straight section of the wash approximately 20 feet downstream of the Deer Valley Road crossing. Thus, there would be no bend scour near the pipeline crossing and this scour component was not considered in the determination of the total scour depth.

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. The proposed pipeline crossing will be located approximately 20 feet downstream from the Deer Valley Road bridge face. The angle of attack of flow on a single pier in the upstream end of the bridge was considered to be zero degrees (i.e., piers are aligned parallel to the flow). Pier scour for the Deer Valley Road Bridge at Wash 2 West was estimated using the following equation documented in HEC-18 (FHWA, 2001):

$$y_s = y_1[2.0K_1K_2K_3K_4(\frac{a}{y_1})^{0.65}Fr_1^{\ 0.43}]$$

where: y_s = scour depth;

y_1 = flow depth directly upstream of pier;

K_1 = correction factor for pier nose shape (1.0 for round shape);

K_2 = correction factor for angle of attack of flow (1.0 for zero degrees);

K_3 = correction factor for bed condition (1.1 for small dunes);

K_4 = correction factor for armoring by bed material size (1.0 for D_{50} = 1.18 mm);

a = pier width and debris width;

Fr_1 = Froude number.

From the HEC-RAS model, the flow depth directly upstream of pier was 6.17 feet, the pier width was 3 feet with no debris width, and the Froude number was 0.43. Thus, the scour depth was calculated to be 5.9 feet:

$$y_s = 6.17[2.0(1.0)(1.0)(1.1)(1.0)(\frac{3}{6.17})^{0.65}(0.43)^{0.43}] = 5.91 \text{ feet}$$

HEC-18 (FHWA, 2001) indicates the top width of the scour hole from one side of the pier can vary from 1.07 to 2.8 times the scour depth or in the case of the Deer Valley Road crossing, from 6.3 to 16.5 feet. The 16.5 feet is based on the bottom width of the scour hole being equal to the depth of pier scour and material having an angle of repose 30 degrees. A schematic of the scour hole dimensions downstream of the pier is shown in Figure 4. As shown in the figure, the proposed pipeline crossing will be located beyond the scour hole from the bridge piers. Thus, a local scour component was not considered for the proposed pipeline crossing.

The bridge deck itself is skewed about 26° with respect to the low flow channel. It appears that the piers are not skewed and that they are aligned with the flow. However, definite proof of how the piers are aligned was not available. To be conservative, a second pier scour analysis was performed assuming that the piers were skewed to the flow. The Deer Valley Road Bridge is 50 feet wide and there are three sets of 3-foot diameter piers under the bridge. Thus, the spacing between the piers is 20.5 feet, or 6.8 diameters. According to the HEC-18 (FHWA, 2001), the pier scour depth for skewed piers that are more than 5 diameters is 1.2 times greater than the pier scour depth calculated for a single pier. In this case, the pier scour depth would be 7.1 feet (i.e., 1.2*5.9). The top width of the scour hole would then be somewhere between 7.6 feet and 19.9 feet. Using the most conservative value for the scour hole top width would bring the scour hole to just about where the gas pipeline is to be buried. However, the scour depth at this point is essentially zero (see Figure 1). Thus, even if the piers are skewed to the flow, the local scour due to the piers will not impact the results of the analysis.

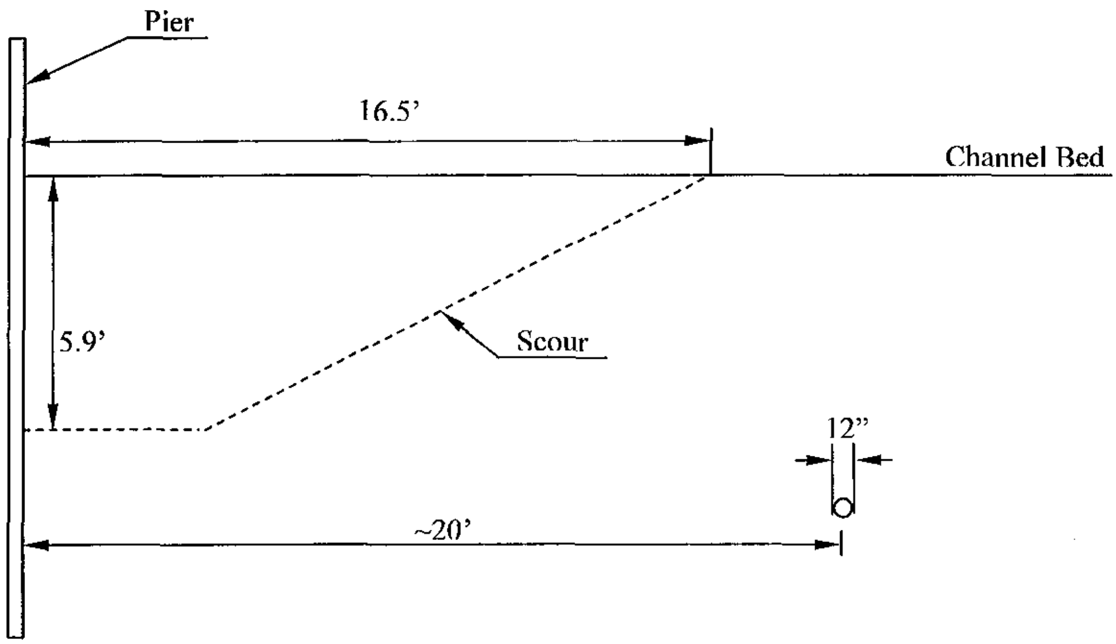

Figure 4. Local scour at pier

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 by 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. The Central Arizona Project canal is located upstream of the crossing. Since this structure may reduce the sediment inflow into Wash 2 West, Blench's equation was also examined. 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 0.25 for straight reaches.

For a median grain diameter of 1.18 mm (0.00387 ft), general scour was evaluated using the hydraulic parameters of Wash 2 West at the pipeline crossing (cross-section 2.163). The Lacey's silt factor at this location for the 100-year event was determined to be 1.91, and the corresponding general scour was calculated to be 1.4 feet:

$$y_{gs} = 0.25(0.47(\frac{2{,}970}{1.91})^{\frac{1}{3}}) = 1.36 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey equation was estimated to 1.8 feet.

The general scour was also calculated using Neill's equation (Neill, 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 0.5 for straight reaches;

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 0.72 was assumed for this study.

From the HEC-RAS model, the average depth for bankfull discharge was 4.13 feet. The design discharge per unit width (q_f) is 20.51 cfs/ft and bankfull discharge per unit width (q_i) is 20.51 cfs/ft. Therefore, the general scour was computed to be 2.1 feet:

$$d_s = 0.5(4.13(\frac{20.51}{20.51})^{0.72}) = 2.07 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to 2.7 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 straight reaches,

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

F_{b0} = Blench's "zero bed factor" from Figure 5 (ft/s^2).

For a median grain diameter of 1.18 mm, F_{b0} was determined from Figure 5 to be about 1.9 ft/s^2. General scour was evaluated using the average hydraulic parameters in the reach of Wash 2 West at the pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 20.51 cfs/ft, and the corresponding general scour was be calculated to be 3.6 feet:

$$y_{gs} = (0.6)\left[\frac{(20.51)^{2/3}}{(1.9)^{1/3}}\right] = 3.63 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using Blench's equation was estimated to be 4.7 feet.

Since the general scour was greater using Blench's equation, the general scour depth was chosen to be 4.7 feet.

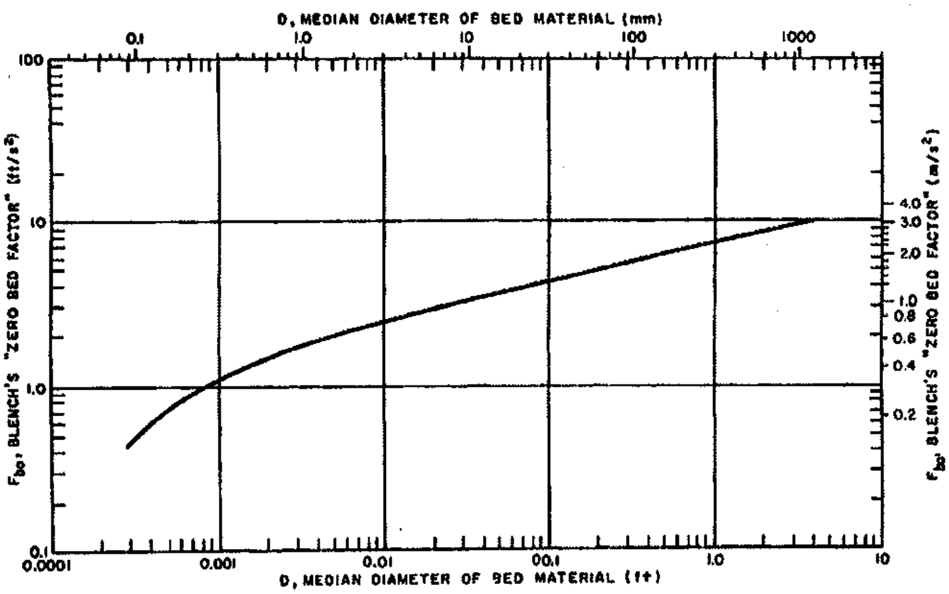

Figure 5. Blench's "zero bed factor" (from Pemberton and Lara (1984))

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 in Wash 2 West at cross-section 2.163 for a 100-year event is approximately 0.4, which would indicate that the flow can be classified in the lower flow regime. The scour depth due to dunes is equal to one-half of the height of dunes.

$$y_{bedform} = 0.5 d_h$$

Dune height is estimated using the following equation presented by Simons and Senturk (1992):

$$d_h = 0.066 Y_h^{1.21}$$

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

d_h = dune height, in feet, and

Y_h = hydraulic depth of flow, in feet.

From the HEC-RAS model, the hydraulic depth of flow at the pipeline crossing is 4.13 feet. Therefore, the bedform scour was computed to be 0.2 feet.

$$y_{bedform} = 0.5(0.066(4.13)^{1.21}) = 0.18 \text{ feet}$$

Using a factor of safety of 1.3, the bedform scour was estimated to be 0.3 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. However, a field investigation revealed that the location of a stable or "pivot" point could not be identified with any degree of certainty downstream of the Deer Valley Road crossing, 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 a 100-year discharge of 2,970cfs, the long-term scour was calculated to be 2.4 feet:

$$y_{lts} = 0.02(2{,}970)^{0.6} = 2.42 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 3.2 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 near Deer Valley Road on Wash 2 West is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 10.8 feet (4.7 feet + 0.3 feet + 3.2 feet + 2.6 feet). Therefore, a burial depth of the crown of 10.8 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:

$$M_{LS} = 1.0(Q_D)^{0.5}$$

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 (2,970 cfs). Using this information, the minimum "safe" setback distance necessary was calculated to be 54.5 feet:

$$M_{LS} = 1.0(2{,}970)^{0.5} = 54.50 \text{ feet}$$

Thus, a minimum setback distance of 55 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 55 feet beyond the main channel banks or the 100-year floodway, which ever is greater. In this case, the bank stations control and the total scour depth should be maintained at least 55 feet beyond banks on both sides of the channel. Using the road stationing for Deer Valley Road, the 10.8 feet deep trenching should start at station 147+35 and end at station 149+95.

SUMMARY

A scour analysis and lateral migration analysis for a 12-inch natural gas pipeline crossing of Wash 2 West at Deer Valley Road was conducted. The total scour depth at the proposed pipeline crossing was determined to be 10.8 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline at the proposed crossing be a minimum of 10.8 feet below the thalweg of the channel.

The minimum "safe" setback distance was calculated to be 55 feet from the existing unprotected banks. The entire scour depth of 10.8 feet should be maintained for at least 55 feet beyond the banks of Wash 2 West. Using the road stationing for Deer Valley Road, the 10.8 feet deep trenching should start at station 147+35 and end at station 149+95.

A schematic view of the pipeline crossing is shown in Figure 6.

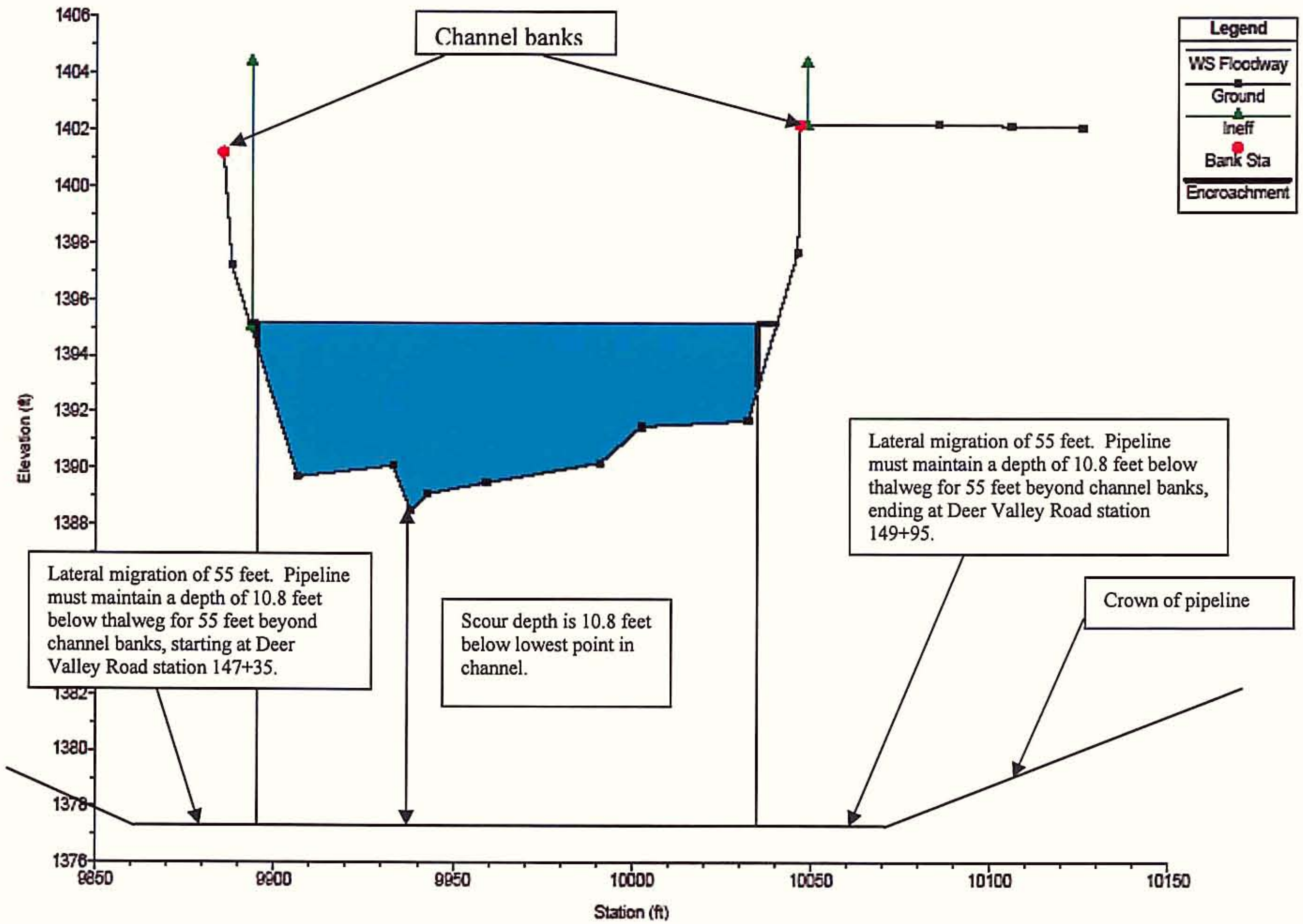

Figure 6. Schematic view of crown profile for the proposed pipeline crossing (drawing not to scale)

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APPENDIX 1: SOIL GRADATION INFORMATION

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R·A·M·M

LABORATORY TEST RESULTS

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

Project No.: L15034
Report Date: 8-Aug-07
Lab No.: 27742

Project: **Southwest Gas Scour Analysis**
Location:

Sampled By: Client
Date Sampled: 6-Aug-07
Submitted By: Client
Date Submitted: 6-Aug-07

Sample Source: Location #3

Material: Sand with Gravel

Supplier:

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

Results:

Sieve Size	Percent Passing	Specifications	
		Minimum	Maximum
	100		
	100		
3"	100		
2"	100		
1-1/2"	100		
1"	96		
3/4"	92		
1/2"	86		
3/8"	82		
1/4"	76		
#4	72		
#8	60		
#10	56		
#16	42		
#30	21		
#40	12		
#50	5		
#100	1		
#200	0.8		

Remarks:

Distribution: Addressee (1)

Respectfully submitted,

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

AASHTO R18

LAB16 Rev.0

Scour Evaluation for Pipeline Crossing of Trilby Wash at Deer Valley Road Alignment

Maricopa County, Arizona

Prepared for:

Sunrise Engineering, Inc.
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Prepared by:

WEST
CONSULTANTS, INC.

WEST Consultants, Inc.
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August 2007

Registered Professional Engineer (Civil)
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BRIAN THOMAS
WAHLIN
Date Signed 8/27/07
ARIZONA, U.S.A.

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INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct the 100-year flow event scour evaluation for the 12-inch natural gas pipeline crossing of Trilby Wash at a location approximately 130 feet downstream of centerline of the Deer Valley Road alignment. The proposed pipeline crossing of Trilby Wash lies in Sections 13, 14, and 24 of T4N R3W in Maricopa County, Arizona. The project location is shown in Figure 1.

Trilby Wash is located in the Iona Wash subbasin as defined by the *Wittmann Area Drainage Master Study Update* (Entellus, 2005). Trilby Wash starts at the Central Arizona Project (CAP) canal and flows in a southern direction until it drains into the detention area behind McMicken Dam. The hydrology for the site was developed by Entellus (2005) as part of the *Wittmann Area Drainage Master Study Update*. The hydraulic model of Trilby Wash was originally developed as part of the original Wittmann Area Drainage Master Study (WLB Group, 1988). Trilby Wash at Deer Valley Road alignment is shown in Figure 2.

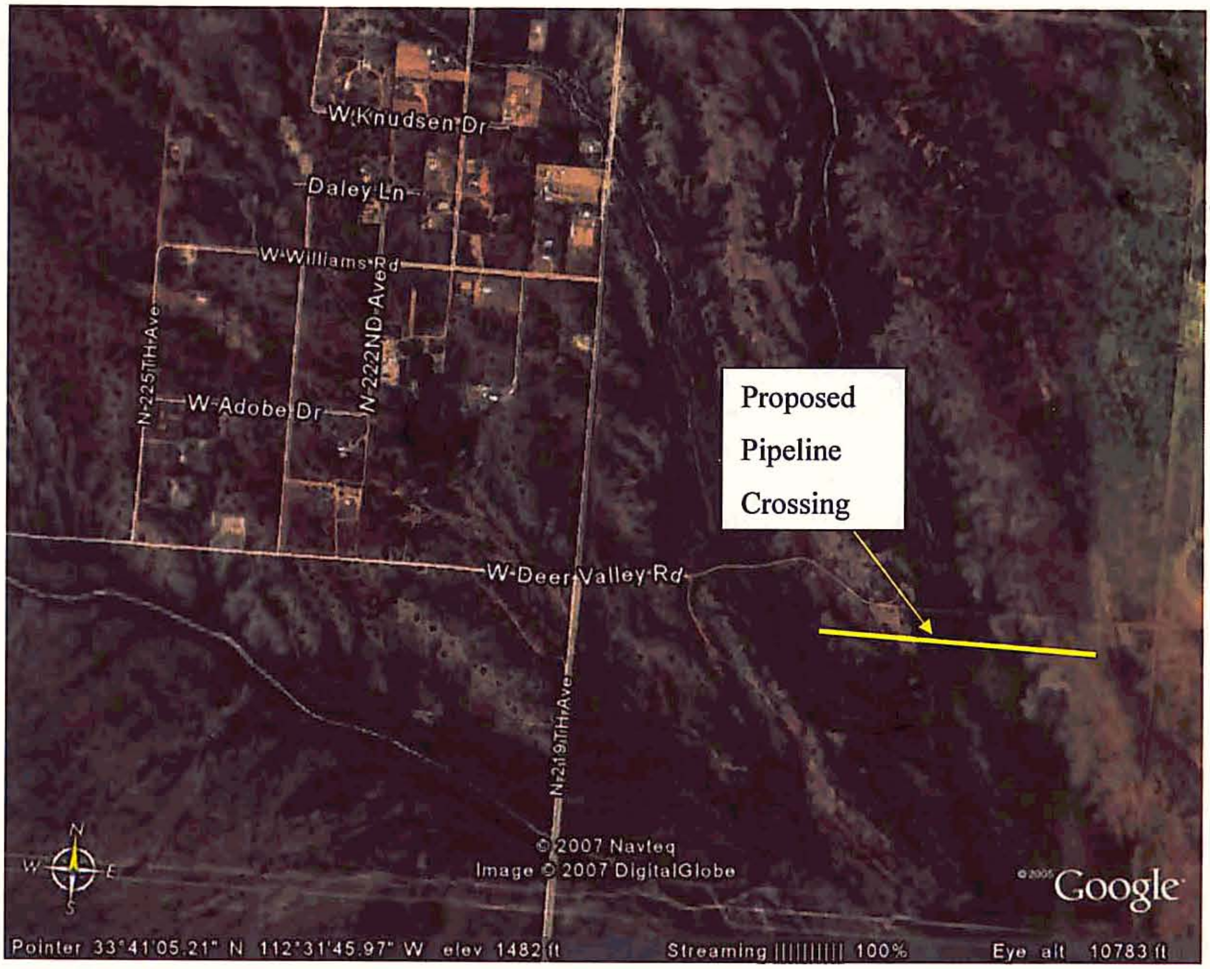

Figure 1. Project location map

Figure 2. Trilby Wash at Deer Valley Road alignment

DATA COLLECTION

A field reconnaissance was conducted on August 4, 2007 by personnel from WEST, Sunrise Engineering, and Southwest Gas. Trilby Wash is a sand and gravel bed channel. A representative soil sample was obtained at the site of the proposed pipeline crossing. 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 0.15 mm. Based on field observations, the bed material in the study area is very fine sand. Thus, the laboratory test results are consistent with field observation.

The banks for Trilby Wash near Deer Valley Road alignment are not well defined. The channel and banks of Trilby Wash are covered with thick vegetation as shown in Figure 2 The Manning's *n*-values used in the main channel and the overbanks in the hydraulic model of Trilby Wash are all set to 0.1. Based on observations in the field, these *n*-values appear to be reasonable.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrology was based upon the *Wittmann Area Drainage Master Study Update (ADMSU) Hydrology Report* (Entellus, 2005). The hydrologic analysis for the Wittmann area ADMSU was performed using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Package. The precipitation runoff model was developed following the procedures and parameters recommended in the FCDMC's *Drainage Design Manual for Maricopa County, Arizona: Hydrology* (1995). The soil losses were estimated using the Green & Ampt method and the Clark Unit hydrograph and S-graphs were used to route excess runoff within the subbasins to their concentration points. Trilby Wash is located in the Iona Wash subbasin. The hydrology used for Trilby Wash is shown in Table 1. Note that the river stationing corresponds to the river stationing used in the hydraulic model for Trilby Wash.

Table 1. Hydrology for Trilby Wash

River Station	100-Year Peak Discharge (cfs)
10.444	5,078
7.134	10,663
6.645	14,084
5.579	14,102

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 hydraulic model of Trilby Wash was originally developed as part of the original Wittmann Area Drainage Master Study (WLB Group, 1988), and it was provided by the Flood Control District of Maricopa County (FCDMC). The hydraulic model of Trilby Wash was developed using HEC-2. This model was imported into HEC-RAS to perform the scour analysis. At the request of Southwest Gas, the hydraulic model was not thoroughly reviewed by WEST. Since the hydraulic model for Trilby Wash has been reviewed and accepted by the FCDMC, it was assumed for the scour evaluation that the model was adequate. The scour calculations were based on the cross-section just downstream of the Deer Valley Road alignment crossing at RS 7.262 in the Trilby Wash hydraulic model. The peak discharge at this location is 5,078 cfs.

The original hydrology developed by the WLB Group for the Wittmann ADMS was significantly lower than the hydrology developed by Entellus for the Wittmann ADMSU. As a result, several cross-sections, including cross-section 7.262 where the scour analysis was performed, overtop and the ends of the channels have to be extended vertically. Normally, new topography should be added to the cross-sections so they are not vertically extended. However, in this case, the vertically extended cross-sections lead to higher velocities in the channel and a more conservative estimate of the scour depth. To be conservative, the original topography in the HEC-2 model was left unchanged.

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 Trilby Wash 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. There are no structures near the proposed pipeline crossing that would cause local scour. Thus, local scour 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 when Deer Valley Road is extended into this area.

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 by 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. The Central Arizona Project canal is located several miles upstream of the proposed pipeline crossing. Since this structure may reduce the sediment inflow into Trilby Wash, Blench's equation was also examined. 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 0.15 mm (0.00049 ft), general scour was evaluated using the hydraulic parameters of Trilby Wash at the proposed pipeline crossing (cross-section 7.262). The Lacey's silt factor at this location for the 100-year event was determined to be 0.68, and the corresponding general scour was calculated to be 4.6 feet:

$$y_{gs} = 0.5(0.47(\frac{5,078}{0.68})^{\frac{1}{3}}) = 4.59 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey *equation was estimated to 6.0* feet.

The general scour was also calculated using Neill's equation (Neill, 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 4.16 feet. The design discharge per unit width (q_f) is 4.65 cfs/ft and bankfull discharge per unit width (q_i) is 7.45 cfs/ft. Therefore, the general scour was computed to be 1.9 feet:

$$y_{gs} = 0.6(4.16(\frac{4.65}{7.45})^{0.67}) = 1.82 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to 2.4 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 3 (ft/s^2).

For a median grain diameter of 0.15 mm, F_{b0} was determined from Figure 3 to be about 0.7 ft/s^2. General scour was evaluated using the average hydraulic parameters in the reach of Trilby Wash at the pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 4.65 cfs/ft, and the corresponding general scour was be calculated to be 1.9 feet:

$$y_{gs} = (0.6)\left[\frac{(4.65)^{2/3}}{(0.7)^{1/3}}\right] = 1.86 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using Blench's equation was estimated to be 2.4 feet.

Since the general scour was greater using Lacey's equation, the general scour depth was chosen to be 6.0 feet.

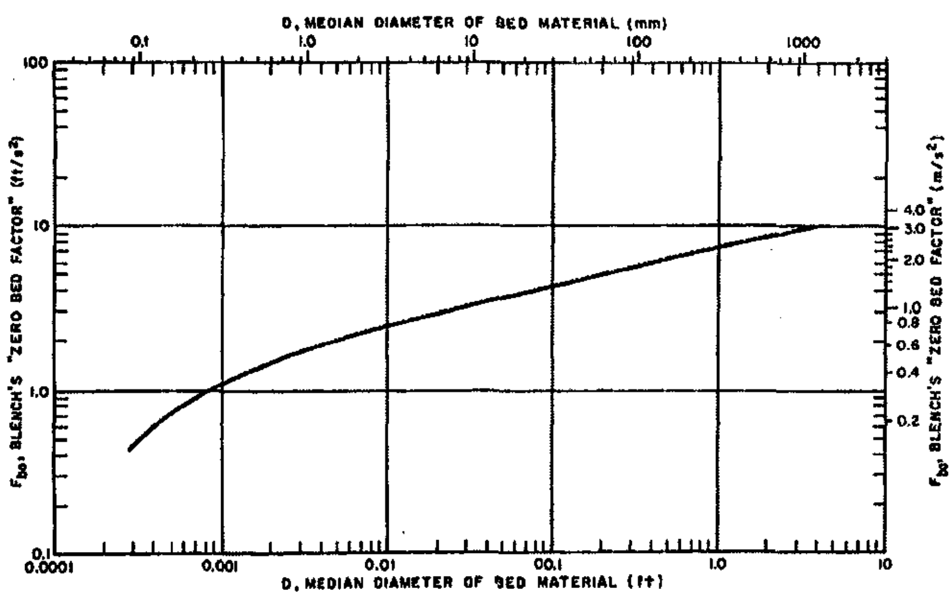

Figure 3. Blench's "zero bed factor" (from Pemberton and Lara (1984))

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 in Trilby Wash at cross-section 7.262 for a 100-year event is approximately 0.3, which would indicate that the flow can be classified in the lower flow regime. The scour depth due to dunes is equal to one-half of the height of dunes.

$$y_{bedform} = 0.5d_h$$

Dune height is estimated using the following equation presented by Simons and Senturk (1992):

$$d_h = 0.066Y_h^{1.21}$$

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

d_h = dune height, in feet, and

Y_h = hydraulic depth of flow, in feet.

From the HEC-RAS model, the hydraulic depth at the pipeline crossing is 4.16 feet. Therefore, the bedform scour was computed to be 0.2 feet.

$$y_{bedform} = 0.5(0.066(4.16)^{1.21}) = 0.19 \text{ feet}$$

Using a factor of safety of 1.3, the bedform scour was estimated to be 0.3 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. However, a field investigation revealed that the location of a stable or "pivot" point could not be identified with any degree of certainty downstream of the Deer Valley Road alignment crossing, 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. Since the 100-year discharge increases from 5,078 cfs to 10,663 cfs one cross-section downstream of the proposed pipeline crossing, it was assumed that the long-term scour from the higher flow would be more appropriate value to use. Using a 100-year discharge of 10,663 cfs, the long-term scour was calculated to be 5.2 feet:

$$y_{lts} = 0.02(10{,}663)^{0.6} = 5.22 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 6.8 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 near Deer Valley Road alignment on Trilby Wash is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 15.7 feet (6.0 feet + 0.3 feet + 6.8 feet + 2.6 feet).

Therefore, a burial depth of the crown of 15.7 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 channels with obvious 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. To be conservative, the large flow just downstream of the crossing (10,663 cfs) was chosen to be the 100-year discharge. Using this information, the minimum "safe" setback distance necessary was calculated to be 259 feet:

$$M_{LS} = 2.5(10{,}663)^{0.5} = 258.2 \text{ feet}$$

Thus, a minimum setback distance of 259 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 259 feet beyond the main channel banks or the 100-year floodway, which ever is greater. In this case, the channel bank controls and the total scour depth should be maintained at least 259 feet beyond the channel banks. Using the road stationing for Deer Valley Road alignment, the 15.7 feet deep trenching should start at station 307+20 and end at station 319+50.

SUMMARY

A scour analysis and lateral migration analysis for a 12-inch natural gas pipeline crossing of Trilby Wash at Deer Valley Road alignment was conducted. The total scour depth at the *proposed pipeline crossing* was determined to be 15.7 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline at the proposed crossing be a minimum of 15.7 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 when Deer Valley Road is extended into this area.

The minimum "safe" setback distance was calculated to be 259 feet from the channel banks. Using the road stationing for Deer Valley Road alignment, the 15.7 feet deep trenching should start at station 307+20 and end at station 319+50.

A schematic view of the pipeline crossing is shown in Figure 4.

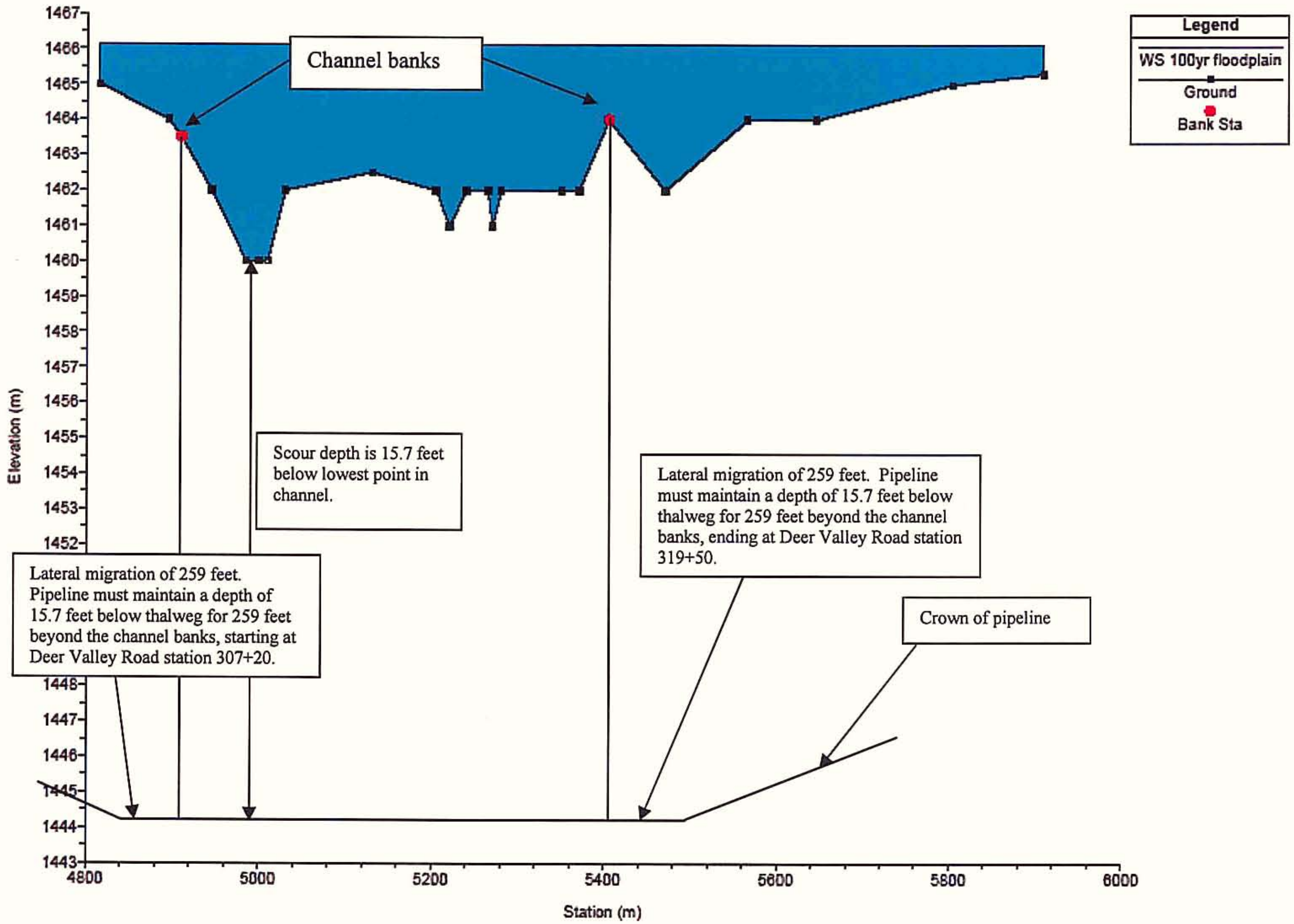

Figure 4. Schematic view of crown profile for the proposed pipeline crossing (drawing not to scale)

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LABORATORY TEST RESULTS

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

Project No.: L15034
Report Date: 8-Aug-07
Lab No.: 27743

Project: **Southwest Gas Scour Analysis**
Location:

Sampled By: Client
Date Sampled: 6-Aug-07
Submitted By: Client
Date Submitted: 6-Aug-07

Sample Source: Location #4

Material: Soil

Supplier:

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

Results:

Sieve Size	Percent Passing	Specifications	
		Minimum	Maximum
	100		
	100		
3"	100		
2"	100		
1-1/2"	100		
1"	100		
3/4"	97		
1/2"	96		
3/8"	94		
1/4"	91		
#4	89		
#8	84		
#10	82		
#16	75		
#30	65		
#40	58		
#50	53		
#100	45		
#200	36		

Remarks:

Distribution: Addressee (1)

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Respectfully submitted,

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

LAB16 Rev.0

Scour Evaluation for Pipeline Crossing of Iona East at Deer Valley Road Alignment

Maricopa County, Arizona

Prepared for:

Sunrise Engineering, Inc.
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Prepared by:

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August 2007

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 8/23/07
ARIZONA, U.S.A.

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INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct the 100-year flow event scour evaluation for a proposed 12-inch natural gas pipeline crossing of Iona East at a location approximately 130 feet downstream of centerline of the Deer Valley Road alignment. The proposed pipeline crossing of Iona East lies in Sections 13, 14, and 24 of T4N R3W in Maricopa County, Arizona. The project location is shown in Figure 1.

Iona East is located in the Iona Wash subbasin as defined by the *Wittmann Area Drainage Master Study Update* (Entellus, 2005). Iona East starts at the Central Arizona Project (CAP) canal and flows in a southern direction until in drains into the Trilby Wash. The hydrology and the hydraulics for Iona East were developed by Entellus (2005) as part of the *Wittmann Area Drainage Master Study Update*. Iona East at Deer Valley Road alignment is shown in Figure 2, while the bed material of the wash in shown in Figure 3.

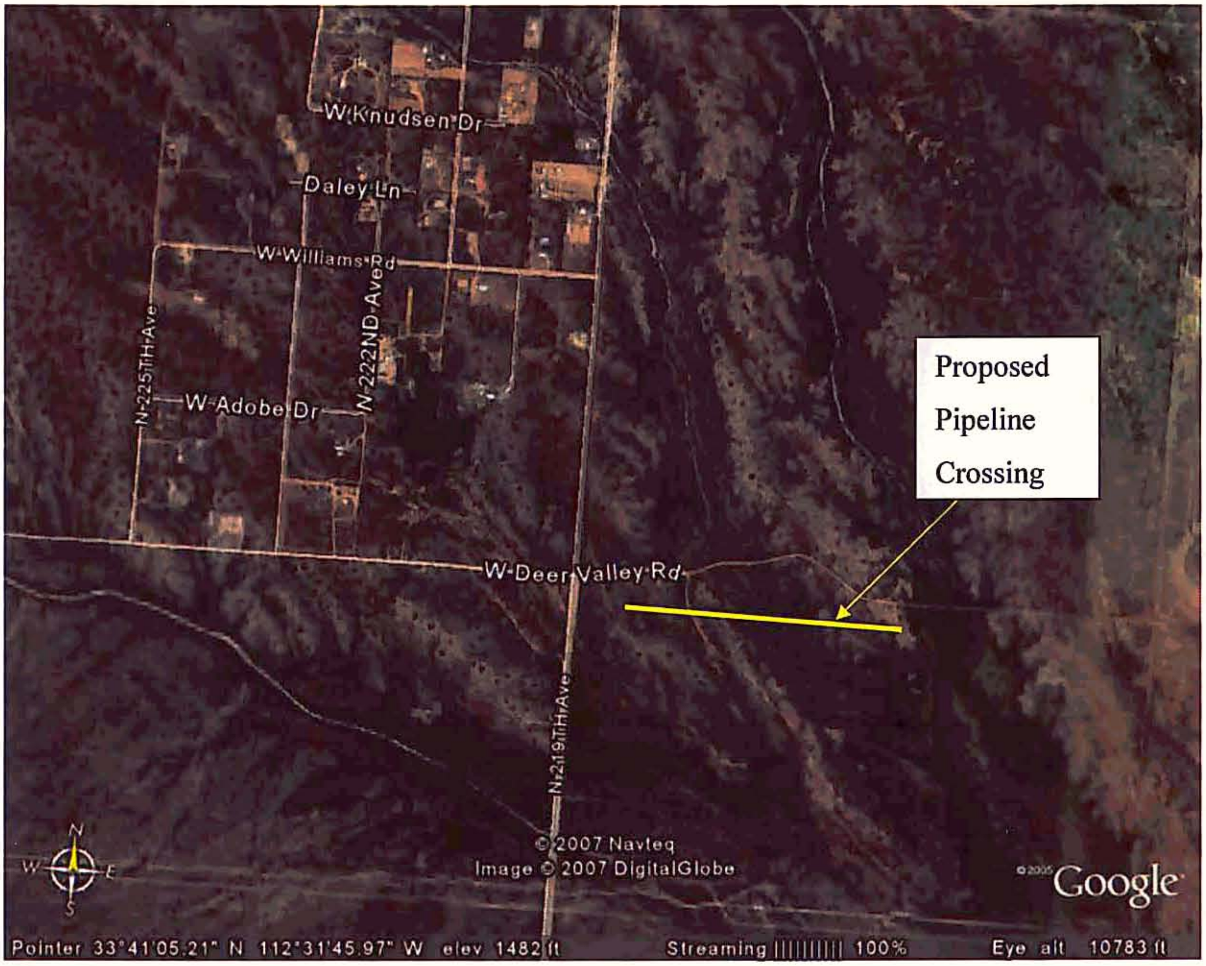

Figure 1. Project location map

Figure 2. Iona East at Deer Valley Road alignment

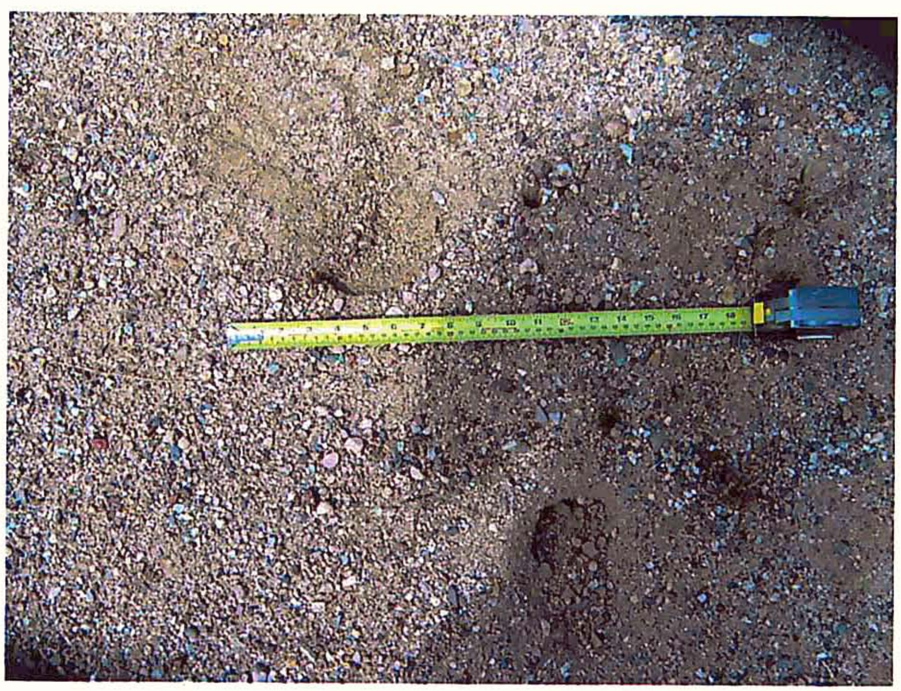

Figure 3. Iona East bed material near the Deer Valley Road alignment crossing

DATA COLLECTION

A field reconnaissance was conducted on August 4, 2007 by personnel from WEST, Sunrise Engineering, and Southwest Gas. Iona East is a sand and gravel bed channel (see Figure 3). A representative soil sample was obtained at the site of the proposed pipeline crossing. 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 1.18 mm. Based on field observations, the bed material in the study area ranges from coarse gravel to very fine sand (see Figure 3). Thus, the laboratory test results are consistent with field observation.

The banks for Iona East near Deer Valley Road are well defined. The Manning's *n*-value used in the main channel in the hydraulic model of Iona East is 0.049 while the overbanks, which have less vegetation than the main channel, are given *n*-values of 0.034 and 0.038. Based on observations in the field, these *n*-values appear to be reasonable.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrology was based upon the *Wittmann Area Drainage Master Study Update (ADMSU) Hydrology Report* (Entellus, 2005). The hydrologic analysis for the Wittmann area ADMSU was performed using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Package. The precipitation runoff model was developed following the procedures and parameters recommended in the FCDMC's *Drainage Design Manual for Maricopa County, Arizona: Hydrology* (1995). The soil losses were estimated using the Green & Ampt method and the Clark Unit hydrograph and S-graphs were used to route excess runoff within the subbasins to their concentration points. Iona East is located in the Iona Wash subbasin. In Entellus' addendum to the hydrology, the 100-year peak discharge for Iona East at the CAP canal is 7,170 cfs. Entellus performed a split flow analysis for Iona East and Iona West. The split percentages used by Entellus were assumed to be 75% for Iona East and 25% for Iona West. Thus, the 100-year peak discharges entering Iona East and Iona West are 5,380 cfs and 1,790 cfs, respectively. The hydrology used for Iona East is shown in Table 1. Note that the river stationing corresponds to the river stationing used in the hydraulic model for Iona East.

Table 1. Hydrology for Iona East

River Station	100-Year Peak Discharge (cfs)
3.683	7,170
2.860	5,380
2.471	5,460
1.775	5,540

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 hydraulic model of Iona East was originally developed by Entellus as part of the Wittmann ADSMU (Entellus, 2005), and it was provided by the Flood Control District of Maricopa County (FCDMC). At the request of Southwest Gas, they hydraulic model was not thoroughly reviewed by WEST. Since the hydraulic model for Iona East has been reviewed and accepted by the FCDMC, it was assumed for the scour evaluation that the model was adequate. The scour calculations were based on the cross-section just downstream of the Deer Valley Road alignment crossing at RS 0.983 in the HEC-RAS model. The peak discharge at this location is 5,540 cfs.

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 Iona East is located along a moderate bend in the channel approximately 130 feet downstream of the Deer Valley Road alignment. 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. There are no structures near the proposed pipeline crossing that would cause local scour. Thus, local scour 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 when Deer Valley Road is extended into this area.

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 by 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. The Central Arizona Project canal is located several miles upstream of the proposed pipeline crossing. Since this structure may reduce the sediment inflow into Iona East, Blench's equation was also examined. 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 1.18 mm (0.00387 ft), the Lacey's silt factor at this location was determined to be 1.91. Using the hydraulic parameters of Iona East at the proposed pipeline crossing (cross-section 0.983), the general scour was calculated to be 3.35 feet:

$$y_{gs} = 0.5(0.47(\frac{5,540}{1.91})^{\frac{1}{3}}) = 3.35 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey equation was estimated to be 4.4 feet.

The general scour was also calculated using Neill's equation (Neill, 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 0.72 was assumed for this study.

From the HEC-RAS model, the average depth for bankfull discharge was 2.12 feet. The design discharge per unit width (q_f) is 4.36 cfs/ft and bankfull discharge per unit width (q_i) is 7.46 cfs/ft. Therefore, the general scour was computed to be 0.86 feet:

$$d_s = 0.5(2.12(\frac{4.36}{7.46})^{0.72}) = 0.86 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to 1.1 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 1.18 mm, F_{b0} was determined from Figure 4 to be about 1.9 ft/s^2. General scour was evaluated using the average hydraulic parameters in the reach of Iona East at the pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 4.36 cfs/ft, and the corresponding general scour was be calculated to be 1.3 feet:

$$y_{gs} = (0.6)\left[\frac{(4.36)^{2/3}}{(1.9)^{1/3}}\right] = 1.29 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using Blench's equation was estimated to be 1.7 feet.

Since the general scour was greater using Lacey's equation, the general scour depth was chosen to be 4.4 feet.

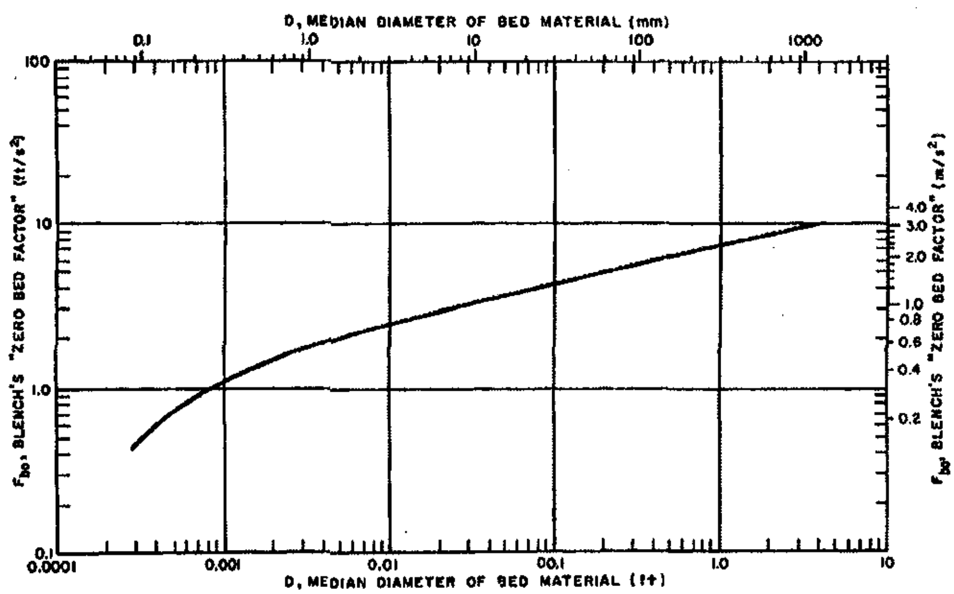

Figure 4. Blench's "zero bed factor" (from Pemberton and Lara (1984))

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 in Iona East at cross-section 0.983 for a 100-year event is approximately 0.4, which would indicate that the flow can be classified in the lower flow regime. The scour depth due to dunes is equal to one-half of the height of dunes.

$$y_{bedform} = 0.5d_h$$

Dune height is estimated using the following equation presented by Simons and Senturk (1992):

$$d_h = 0.066Y_h^{1.21}$$

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

d_h = dune height, in feet, and

Y_h = hydraulic depth of flow, in feet.

From the HEC-RAS model, the hydraulic depth of the channel at the pipeline crossing is 2.12 feet. Therefore, the bedform scour was computed to be 0.08 feet.

$$y_{bedform} = 0.5(0.066(2.12)^{1.21}) = 0.08 \text{ feet}$$

Using a factor of safety of 1.3, the bedform scour was estimated to be 0.1 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. However, a field investigation revealed that the location of a stable or "pivot" point could not be identified with any degree of certainty downstream of the Deer Valley Road alignment crossing, 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. The ADWR State Standard equation was applied under two scenarios. The first scenario uses the flows directly from the Iona East model to estimate the long-term scour. Since the proposed pipeline crossing will be near the confluence with Trilby Wash, the second scenario considers the possibility of the long-term scour in Trilby Wash migrating upstream to the proposed crossing.

For the first scenario, the 100-year discharge for Iona East is 5,540 cfs and the long-term scour is calculated to be 3.5 feet:

$$y_{lts} = 0.02(5{,}540)^{0.6} = 3.52 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 4.6 feet.

According to the hydrology developed by Entellus (2005), flow in the Trilby Wash just downstream of the confluence with Iona East is 10,663 cfs (from concentration point C302*). Using this discharge, the long-term scour in Trilby Wash is estimated to be 5.2 feet:

$$y_{lts} = 0.02(10{,}663)^{0.6} = 5.22 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 6.8 feet. The thalweg elevation for the last cross-section (RS 0.741) in the Iona East model is 1457.51 feet, which means that the long-term scour depth from Trilby Wash would extend down to an elevation of 1450.71 feet. The slope at the downstream end of Iona East is approximately 0.0055 and the proposed pipeline crossing is approximately 1,275 feet upstream from this cross-section. Projecting the scour elevation of 1450.71 feet upstream to the proposed pipeline crossing with the slope of 0.0055 yields a long-term scour elevation of 1457.72 feet. The thalweg elevation at proposed pipeline crossing is 1465.09 feet. Thus, long-term scour depth at the proposed pipeline crossing from the Trilby Wash would be 7.37 feet.

Since the second scenario yields a larger long-term scour depth, this scenario was assumed to control and the long-term scour depth was estimated to be 7.4 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 near Deer Valley Road alignment on Iona East is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 14.5 feet (4.4 feet + 0.1 feet + 7.4 feet + 2.6 feet). Therefore, a burial depth of the crown of 14.5 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 channels with obvious 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 (5,540 cfs). Using this information, the minimum "safe" setback distance necessary was calculated to be 186.1 feet:

$$M_{LS} = 2.5(5{,}540)^{0.5} = 186.1 \text{ feet}$$

Thus, a minimum setback distance of 187 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 187 feet beyond the main channel banks or the 100-year floodway, which ever is greater. In this case, the floodway controls and the total scour depth should be maintained at least 187 feet beyond floodway on both sides of the channel. Using the road stationing for Deer Valley Road alignment, the 14.5 feet deep trenching should start at station 323+60 and end at station 335+40.

SUMMARY

A scour analysis and lateral migration analysis for a proposed 12-inch natural gas pipeline crossing of Iona East at Deer Valley Road alignment was conducted. The total scour depth at the proposed pipeline crossing was determined to be 14.5 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline at the proposed crossing be a minimum of 14.5 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 when Deer Valley Road is extended into this area.

The minimum "safe" setback distance was calculated to be 187 feet from the edge of floodway. Using the road stationing for Deer Valley Road alignment, the 14.5 feet deep trenching should start at station 323+60 and end at station 335+40.

A schematic view of the pipeline crossing is shown in Figure 5.

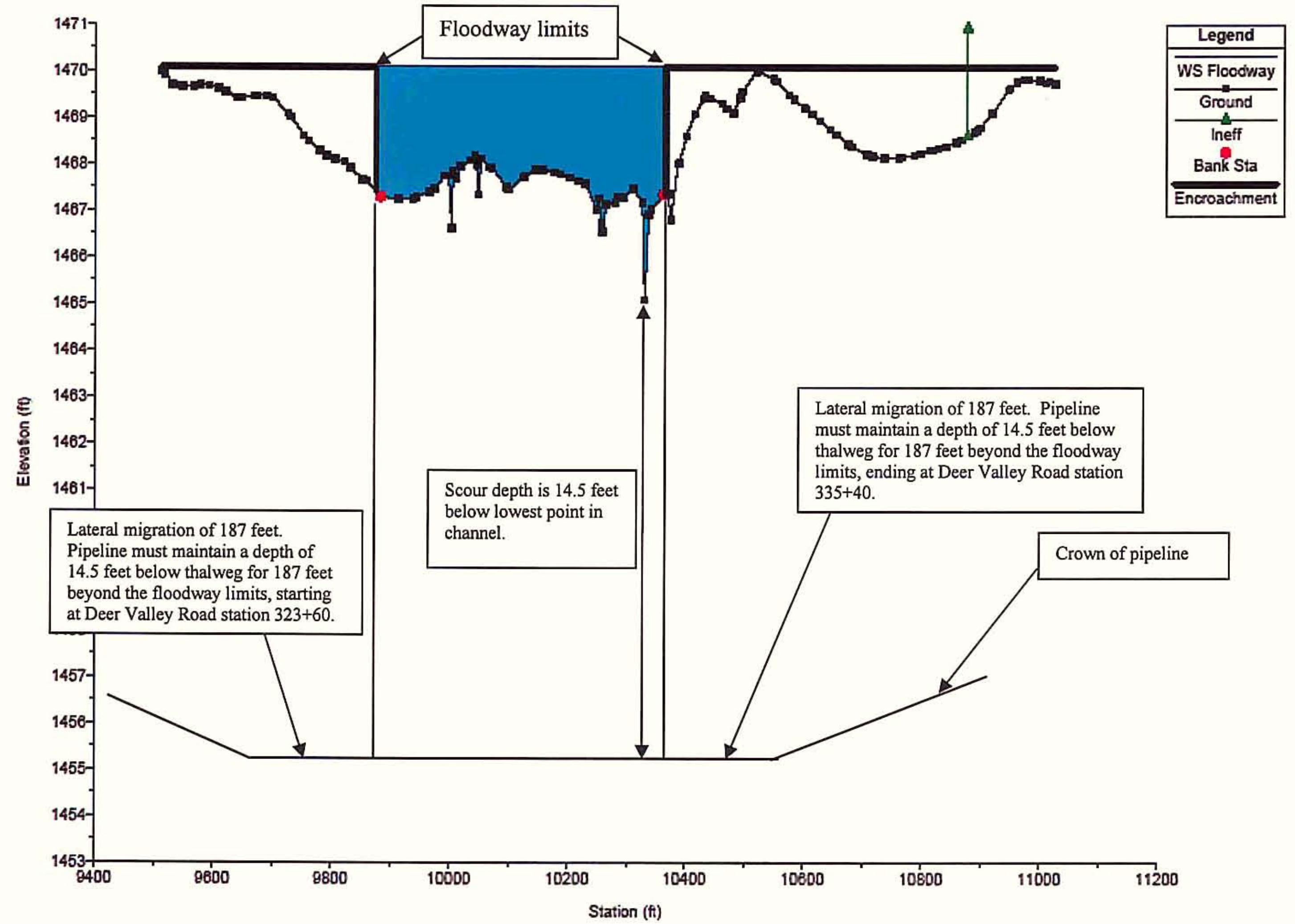

Figure 5. Schematic view of crown profile for the proposed pipeline crossing (drawing not to scale)

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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

LABORATORY TEST RESULTS

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

Project No.: L15034
Report Date: 8-Aug-07
Lab No.: 27744

Project: **Southwest Gas Scour Analysis**
Location:

Sampled By: Client
Date Sampled: 6-Aug-07
Submitted By: Client
Date Submitted: 6-Aug-07

Sample Source: Location #5

Material: Sand with Gravel

Supplier:

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

Results:

Sieve Size	Percent Passing	Specifications	
		Minimum	Maximum
	100		
	100		
3"	100		
2"	100		
1-1/2"	100		
1"	100		
3/4"	100		
1/2"	95		
3/8"	93		
1/4"	87		
#4	83		
#8	69		
#10	64		
#16	48		
#30	27		
#40	15		
#50	7		
#100	2		
#200	1.4		

Remarks:

Distribution: Addressee (1)

AASHTO R18

Respectfully submitted,

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

LAB16 Rev.0

Scour Evaluation for Pipeline Crossing of Iona West at 219th Avenue

Maricopa County, Arizona

Prepared for:

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2152 South Vineyard, Suite 123
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INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct the 100-year flow event scour evaluation for the 12-inch natural gas pipeline crossing of Iona West at a location approximately 70 feet downstream of centerline of the 219th Avenue. The proposed pipeline crossing of Iona West lies in the Sections 14, 23 and 24 of T4N R3W in Maricopa County, Arizona. The project location is shown in Figure 1.

Iona West is located in the Iona Wash subbasin as defined by the *Wittmann Area Drainage Master Study Update* (Entellus, 2005). Iona West splits off from Iona East approximately 4,700 feet below the Central Arizona Project (CAP) canal and flows in a southern direction until in drains into Trilby Wash. The hydrology and the hydraulics for the site were developed by Entellus (2005) as part of the *Wittmann Area Drainage Master Study Update*. Iona West at the 219th Avenue is shown in Figure 2.

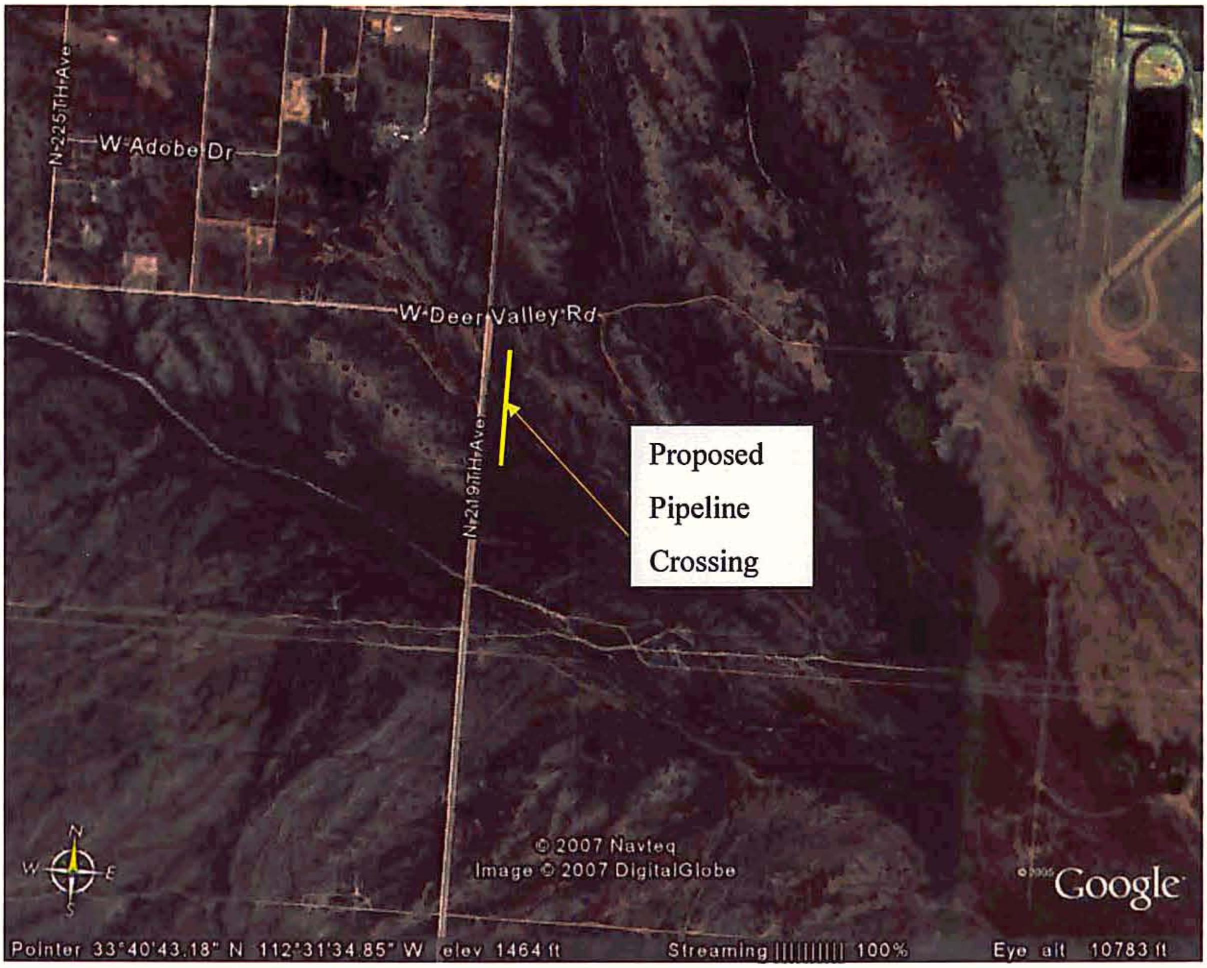

Figure 1. Project location map

Figure 2. Iona West at the 219th Avenue

DATA COLLECTION

A field reconnaissance was conducted on August 4, 2007 by personnel from WEST, Sunrise Engineering, and Southwest Gas. Iona West is a sand and gravel bed channel. A representative soil sample was obtained at the proposed pipeline crossing. 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 0.075 mm. Based on field observations, the bed material in the study area is very fine sand. Thus, the laboratory test results are consistent with field observation.

Iona West is very small near 219th Avenue and the banks are not well defined (see Figure 2). The Manning's *n*-value used in the main channel in the hydraulic model of Iona West is 0.073

while the overbanks, which have less vegetation than the main channel, are given *n*-values of 0.035 and 0.040. Based on observations in the field, these *n*-values appear to be reasonable.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrology was based upon the *Wittmann Area Drainage Master Study Update (ADMSU) Hydrology Report* (Entellus, 2005). The hydrologic analysis for the Wittmann area ADMSU was performed using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Package. The precipitation runoff model was developed following the procedures and parameters recommended in the FCDMC's *Drainage Design Manual for Maricopa County, Arizona: Hydrology* (1995). The soil losses were estimated using the Green & Ampt method and the Clark Unit hydrograph and S-graphs were used to route excess runoff within the subbasins to their concentration points. Iona West is located in the Iona Wash subbasin. In Entellus' addendum to the hydrology, the 100-year peak discharge for Iona East at the CAP canal is 7,170 cfs. Entellus performed a split flow analysis for Iona East and Iona West. The split percentages used by Entellus were assumed to be 75% for Iona East and 25% for Iona West. Thus, the 100-year peak discharges entering Iona East and Iona West are 5,380 cfs and 1,790 cfs, respectively. The hydrology used for Iona West is shown in Table 1. Note that the river stationing corresponds to the river stationing used in the hydraulic model for Iona West.

Table 1. Hydrology for Iona West

River Station	100-Year Peak Discharge (cfs)
2.991	7,170
2.914	1,790
2.659	1,830
2.126	2,100

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 model was originally developed by Entellus as part of the Wittmann ADSMU (Entellus, 2005), and it was provided by the Flood Control District of Maricopa County (FCDMC). At the request of Southwest Gas, they hydraulic model was not thoroughly reviewed by WEST. Since the hydraulic model for Iona West has been reviewed and accepted by the FCDMC, it was assumed for the scour evaluation that the model was adequate. The scour calculations were based on the cross-section just downstream of the 219th Avenue crossing at RS 1.156 in the HEC-RAS model. The peak discharge at this location is 2,100 cfs.

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.

The proposed pipeline crossing of Iona West is located in a straight section of the wash approximately 70 feet downstream of the 219th Avenue crossing. Thus, there would be no bend scour near the pipeline crossing and this scour component was not considered in the determination of the total scour depth.

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 is no structure 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 by 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. The Central Arizona Project canal is located several miles upstream of the proposed crossing. Since this structure may reduce the sediment inflow into Iona West, Blench's equation was also examined. 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 0.25 for straight reaches.

For a median grain diameter of 0.075 mm (0.000246 ft), general scour was evaluated using the hydraulic parameters of Iona West at the pipeline crossing (cross-section 1.156). The Lacey's silt factor at this location for the 100-year event was determined to be 0.48, and the corresponding general scour was calculated to be 1.9 feet:

$$y_{gs} = 0.25(0.47(\frac{2{,}100}{0.48})^{\frac{1}{3}}) = 1.92 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey equation was estimated to 2.5 feet.

The general scour was also calculated using Neill's equation (Neill, 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 0.5 for straight reaches;

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 1.54 feet. The design discharge per unit width (q_f) is 2.70 cfs/ft and bankfull discharge per unit width (q_i) is 2.39 cfs/ft. Therefore, the general scour was computed to be 0.8 feet:

$$d_s = 0.5(1.54(\frac{2.70}{2.39})^{0.67}) = 0.84 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to 1.1 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 straight reaches,

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

F_{b0} = Blench's "zero bed factor" from Figure 3 (ft/s^2).

For a median grain diameter of 0.075 mm, F_{b0} was determined from Figure 3 to be about 0.4 ft/s^2. General scour was evaluated using the average hydraulic parameters in the reach of Iona West at the pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 2.70 cfs/ft, and the corresponding general scour was be calculated to be 1.6 feet:

$$y_{gs} = (0.6)\left[\frac{(2.70)^{2/3}}{(0.4)^{1/3}}\right] = 1.58 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using Blench's equation was estimated to be 2.1 feet.

Since the general scour was greater using Lacey's equation, the general scour depth was chosen to be 2.5 feet.

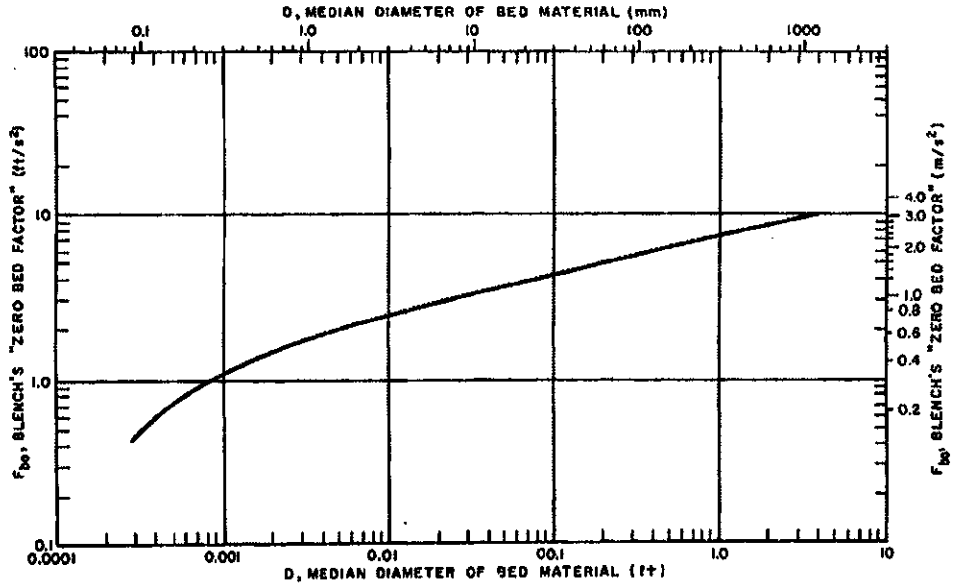

Figure 3. Blench's "zero bed factor" (from Pemberton and Lara (1984))

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 in Iona West at cross-section 1.156 for a 100-year event is approximately 0.22, which would indicate that the flow can be classified in the lower flow regime. The scour depth due to dunes is equal to one-half of the height of dunes.

$$y_{bedform} = 0.5d_h$$

Dune height is estimated using the following equation presented by Simons and Senturk (1992):

$d_h = 0.066 Y_h^{1.21}$

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

d_h = dune height, in feet, and

Y_h = hydraulic depth of flow, in feet.

From the HEC-RAS model, the hydraulic depth of the channel at the pipeline crossing is 1.54 feet. Therefore, the bedform scour was computed to be 0.06 feet.

$y_{bedform} = 0.5(0.066(1.54)^{1.21}) = 0.06$ feet

Using a factor of safety of 1.3, the bedform scour was estimated to be 0.1 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. However, a field investigation revealed that the location of a stable or "pivot" point could not be identified with any degree of certainty downstream of the 219th Avenue crossing, 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. The ADWR State Standard equation was applied under two scenarios. The first scenario uses the flows directly from the Iona West model to estimate the long-term scour. Since the proposed pipeline crossing is near the confluence with Trilby Wash, the second scenario considers the possibility of the long-term scour in Trilby Wash migrating upstream to the proposed crossing.

For the first scenario, the 100-year discharge for Iona West is 2,100 cfs and the long-term scour is calculated to be 2.0 feet:

$$y_{lts} = 0.02(2{,}100)^{0.6} = 1.97 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 2.6 feet.

According to the hydrology developed by Entellus (2005), flow in the Trilby Wash just downstream of the confluence with Iona East is 10,663 cfs (from concentration point C302*). Using this discharge, the long-term scour in Trilby Wash was estimated to be 5.2 feet:

$$y_{lts} = 0.02(10{,}663)^{0.6} = 5.22 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 6.8 feet. The thalweg elevation for the Iona West cross-section at the confluence with Trilby Wash (RS 0.521) is 1452.25 feet, which means that the long-term scour depth from Trilby Wash would extend down to an elevation of 1445.45 feet. The slope at the downstream end of Iona West is approximately 0.00392 and the proposed pipeline crossing is approximately 3,360 feet upstream from this cross-section. Projecting the scour elevation of 1445.45 feet upstream to the proposed pipeline crossing with the slope of 0.00392 yields a long-term scour elevation of 1458.62 feet at the proposed crossing. The thalweg elevation at proposed pipeline crossing is 1467.43 feet. Thus, long-term scour depth at the proposed pipeline crossing from the Trilby Wash would be 8.81 feet.

Since the second scenario yields a larger long-term scour depth, this scenario was assumed to control and the long-term scour depth was estimated to be 8.8 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 near the 219th Avenue on Iona West is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 14.0 feet (2.5 feet + 0.1 feet + 8.8 feet + 2.6 feet). Therefore, a burial depth of the crown of 14.0 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:

$$M_{LS} = 1.0(Q_D)^{0.5}$$

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 (2,100 cfs). Using this information, the minimum "safe" setback distance necessary was calculated to be 45.8 feet:

$$M_{LS} = 1.0(2{,}100)^{0.5} = 45.83 \text{ feet}$$

Thus, a minimum setback distance of 46 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 46 feet beyond the main channel banks or the 100-year floodway, which ever is greater. In this case, the floodway controls and the total scour depth should be maintained at least 46 feet beyond floodway on both sides of the channel. Using the road stationing for the 219th Avenue, the 7.8 feet deep trenching should start at station 351+65 and end at station 357+30.

SUMMARY

A scour analysis and lateral migration analysis for a 12-inch natural gas pipeline crossing of Iona West at the 219th Avenue was conducted. The total scour depth at the proposed pipeline crossing was determined to be 14.0 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline at the proposed crossing be a minimum of 14.0 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 minimum "safe" setback distance was calculated to be 46 feet from the edge of floodway. Using the road stationing for the 219th Avenue, the 14.0 feet deep trenching should start at station 351+65 and end at station 357+30.

A schematic view of the pipeline crossing is shown in Figure 4.

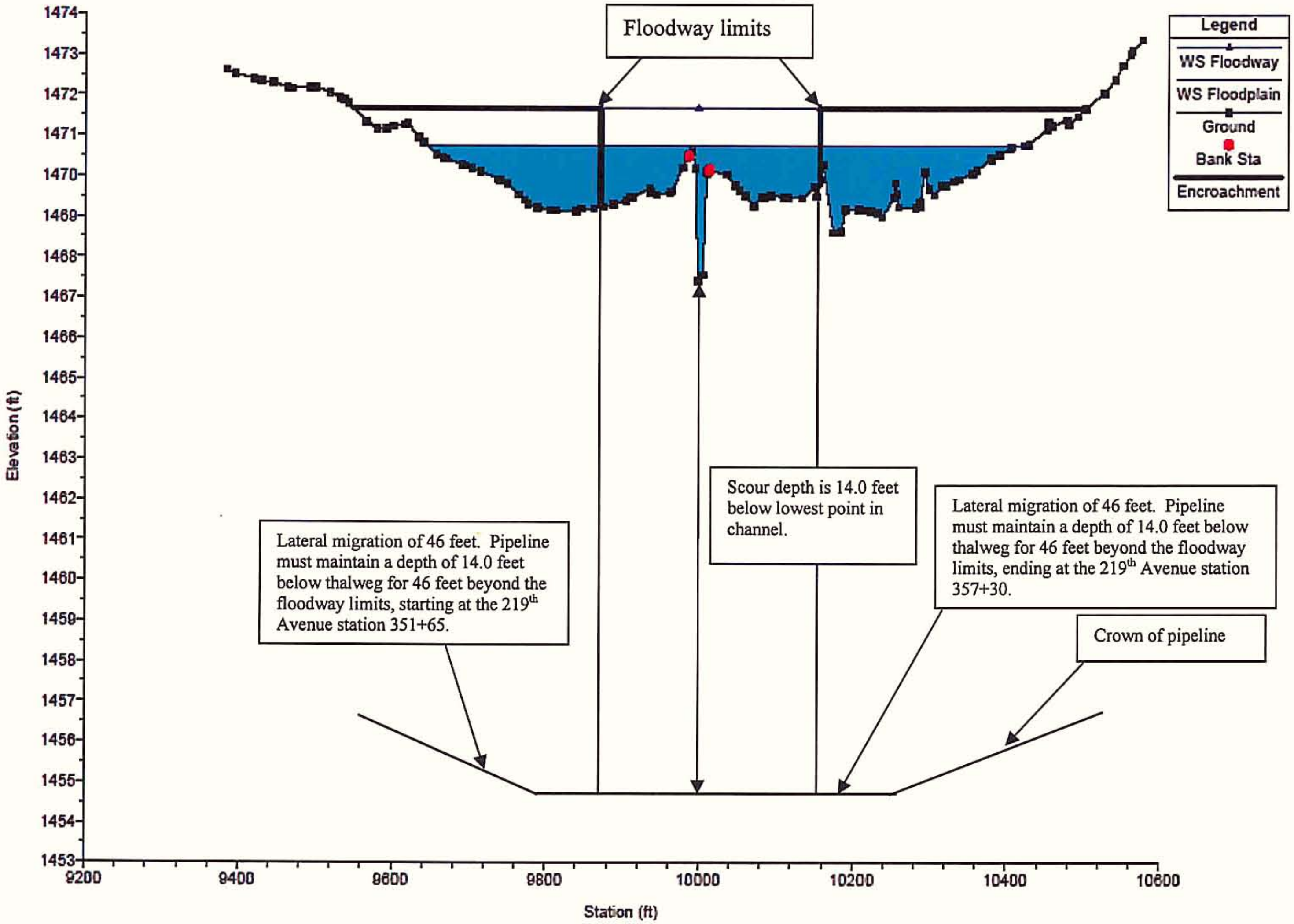

Figure 4. Schematic view of crown profile for the proposed pipeline crossing (drawing not to scale)

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APPENDIX 1: SOIL GRADATION INFORMATION

R·A·M·M

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

LABORATORY TEST RESULTS

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

Project No.: L15034
Report Date: 14-Aug-07
Lab No.: 27864

Project: **Southwest Gas Scour Analysis**
Location:

Sampled By: Client
Date Sampled: 13-Aug-07
Submitted By: Client
Date Submitted: 13-Aug-07

Sample Source: Location #6

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"	100		
3/8"	100		
1/4"	99		
#4	97		
#8	94		
#10	93		
#16	90		
#30	82		
#40	77		
#50	72		
#100	63		
#200	56		

Remarks:

Distribution: Addressee (1)

Respectfully submitted,

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

AASHTO R18

Scour Evaluation for Pipeline Crossing of Wash 5 West at 219th Avenue

Maricopa County, Arizona

Prepared for:

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

Prepared by:

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

August 2007

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 8/29/07
ARIZONA, U.S.A.

TABLE OF CONTENTS

Registered Professional Engineer (Civil)
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WAHLIN
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ARIZONA, U.S.A.

INTRODUCTION

WEST Consultants, Inc. (WEST) was retained by Sunrise Engineering, Inc. to conduct the 100-year flow event scour evaluation for a proposed 12-inch natural gas pipeline crossing of Wash 5 West at a location approximately 70 feet downstream of centerline of the 219th Avenue. The proposed pipeline crossing of Wash 5 West lies in the Sections 15, 23 and 24 of T4N R3W in Maricopa County, Arizona. The project location is shown in Figure 1.

Wash 5 West is located in the Sun Valley Parkway subbasin as defined by the *Wittmann Area Drainage Master Study Update* (Entellus, 2005). Wash 5 West starts at the Central Arizona Project (CAP) canal and flows in an eastern direction until in drains into Trilby Wash. The hydrology for the site was developed by Entellus (2005) as part of the *Wittmann Area Drainage Master Study Update*. The hydraulic model of Wash 5 West was developed as part of the original Wittmann Area Drainage Master Study (WLB Group, 1988). Wash 5 West at the 219th Avenue is shown in Figure 2.

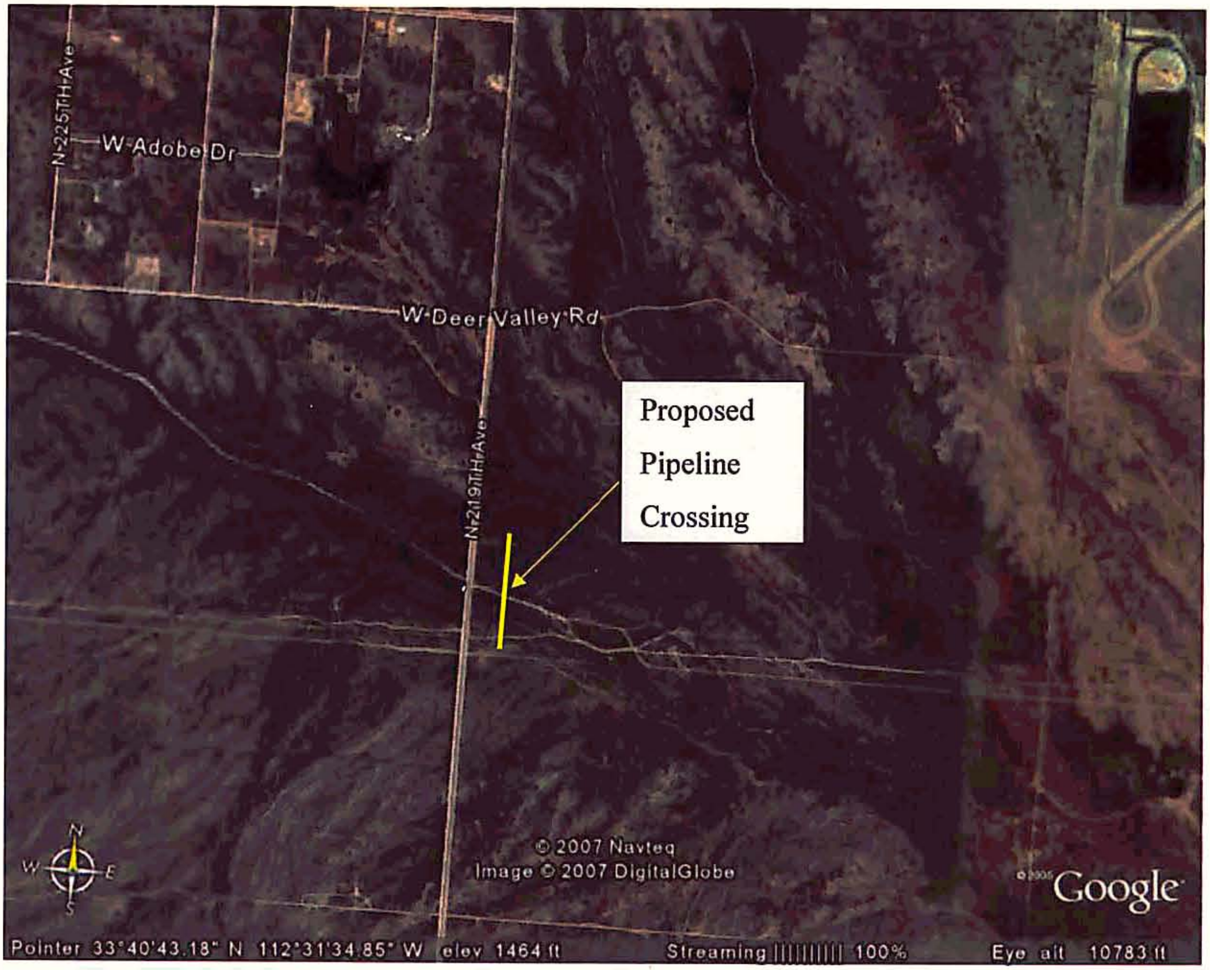

Figure 1. Project location map

Figure 2. Wash 5 West at the 219th Avenue

Figure 3. Wash 5 West bed material near the 219th Avenue crossing

DATA COLLECTION

A field reconnaissance was conducted on August 4, 2007 by personnel from WEST, Sunrise Engineering, and Southwest Gas. Wash 5 West is a sand and gravel bed channel (see Figure 3). A representative soil sample was obtained at the proposed pipeline crossing. 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 0.60 mm. Based on field observations, the bed material in the study area ranges from coarse gravel to very fine sand (see Appendix 1 and Figure 3). Thus, the laboratory test results are consistent with field observation.

The banks for Wash 5 West near 219th Avenue are not well defined (see Figure 2). The Manning's *n*-value used in the main channel and overbanks in the hydraulic model of Wash 5 West is 0.09. Based on observations in the field, these *n*-values appear to be reasonable.

HYDROLOGY

The scour analysis for this study was conducted only for the 100-year discharge. The hydrology was based upon the *Wittmann Area Drainage Master Study Update (ADMSU) Hydrology Report* (Entellus, 2005). The hydrologic analysis for the Wittmann area ADMSU was performed using the US Army Corps of Engineer's HEC-1 Flood Hydrograph Package. The precipitation runoff model was developed following the procedures and parameters recommended in the FCDMC's *Drainage Design Manual for Maricopa County, Arizona: Hydrology* (1995). The soil losses were estimated using the Green & Ampt method and the Clark Unit hydrograph and S-graphs were used to route excess runoff within the subbasins to their concentration points. Wash 5 West is located in the Sun Valley Parkway subbasin. The hydrology used for Wash 5 West is shown in Table 1. Note that the river stationing corresponds to the river stationing used in the hydraulic model for Wash 5 West.

Table 1. Hydrology for Wash 5 West

River Station	100-Year Peak Discharge (cfs)
1.492	6,753
0.434	7,363
0.114	7,445

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 hydraulic model of Wash 5 West was developed as part of the original Wittmann Area Drainage Master Study (WLB Group, 1988), and it was provided by the Flood Control District of Maricopa County (FCDMC). At the request of Southwest Gas, the hydraulic model was not thoroughly reviewed by WEST. Since the hydraulic model for Wash 5 West has been reviewed and accepted by the FCDMC, it was assumed for the scour evaluation that the model was adequate. The scour calculations were based on the cross-section just downstream of the 219th Avenue crossing at RS 0.214 in the HEC-RAS model. The peak discharge at this location is 7,363 cfs.

The original HEC-2 model developed by the WLB Group started at the CAP canal, which is at river station (RS) 3.378. A HEC-RAS model was developed for this study by importing the HEC-2 model into HEC-RAS computer program. Because of uncertainty surround the hydrology to the west of the 227th Avenue extension and the results at the proposed pipeline crossing are not influenced by this upstream reach, all of the cross sections west of the 227th Avenue extension at RS 1.907 were eliminated. Thus, the HEC-RAS model starts at RS 1.907 and ends at the confluence with Trilby Wash.

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.

The proposed pipeline crossing of Wash 5 West is located in a straight section of the wash approximately 70 feet downstream of the 219th Avenue crossing. Thus, there would be no bend scour near the pipeline crossing and this scour component was not considered in the determination of the total scour depth.

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 is no structure 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 by 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. The CAP canal is located several miles upstream of the proposed crossing. Since this structure may reduce the sediment inflow into Wash 5 West, Blench's equation was also examined. 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 0.25 for straight reaches.

For a median grain diameter of 0.60 mm (0.00197 ft), the Lacey's silt factor at this location was determined to be 1.36. Using the hydraulic parameters of Wash 5 West at the pipeline crossing (cross-section 0.214), the corresponding general scour was calculated to be 2.1 feet:

$$y_{gs} = 0.25(0.47(\frac{7{,}363}{1.36})^{\frac{1}{3}}) = 2.06 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using the Lacey equation was estimated to 2.7 feet.

The general scour was also calculated using Neill's equation (Neill, 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 0.5 for straight reaches;

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 1.98 feet. The design discharge per unit width (q_f) is 3.35 cfs/ft and bankfull discharge per unit width (q_i) is 3.05 cfs/ft. Therefore, the general scour was computed to be 1.1 feet:

$$\mathrm{d_s} = 0.5(1.98(\frac{3.35}{3.05})^{0.67}) = 1.05 \text{ feet}$$

Using a factor of safety of 1.3, the general scour from Neill's equation was estimated to 1.4 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 straight reaches,

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 0.600 mm, F_{b0} was determined from Figure 4 to be about 1.5 ft/s^2. General scour was evaluated using the average hydraulic parameters in the reach of Wash 5 West at the pipeline crossing. The unit discharge (q_f) at this location for the 100-year event was determined to be 3.35 cfs/ft, and the corresponding general scour was be calculated to be 1.2 feet:

$$y_{gs} = (0.6)\left[\frac{(3.35)^{2/3}}{(1.5)^{1/3}}\right] = 1.17 \text{ feet}$$

Using a factor of safety of 1.3, the general scour using Blench's equation was estimated to be 1.5 feet.

Since the general scour was greater using Lacey's equation, the general scour depth was chosen to be 2.7 feet.

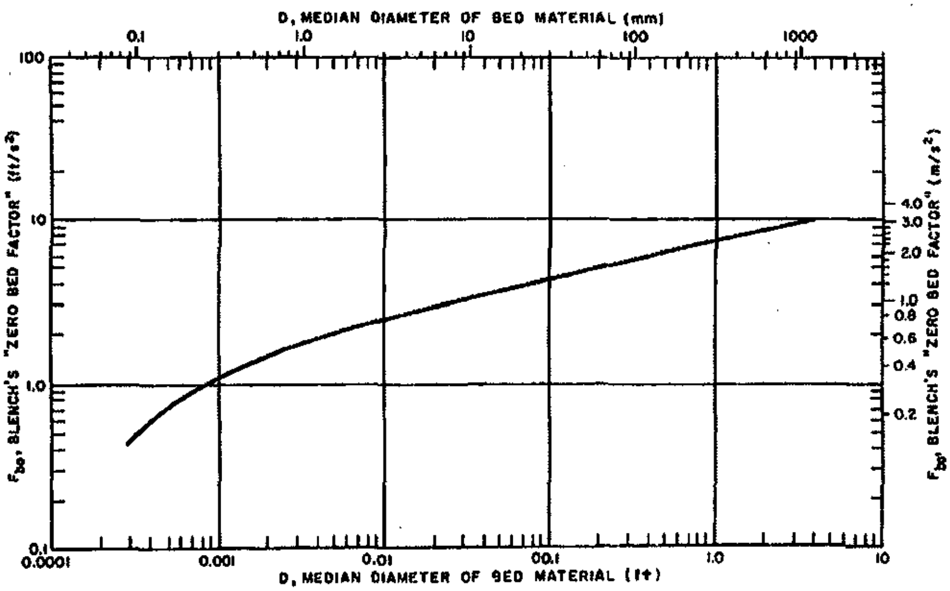

Figure 4. Blench's "zero bed factor" (from Pemberton and Lara (1984))

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 in Wash 5 West at cross-section 0.214 for a 100-year event is approximately 0.19, which would indicate that the flow can be classified in the lower flow regime. The scour depth due to dunes is equal to one-half of the height of dunes.

$$y_{bedform} = 0.5d_h$$

Dune height is estimated using the following equation presented by Simons and Senturk (1992):

$$d_h = 0.066Y_h^{1.21}$$

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

d_h = dune height, in feet, and

Y_h = hydraulic depth of flow, in feet.

From the HEC-RAS model, the hydraulic depth of flow at the pipeline crossing is 1.98 feet. Therefore, the bedform scour was computed to be 0.08 feet.

$$y_{\text{bedform}} = 0.5(0.066(1.98)^{1.21}) = 0.08 \text{ feet}$$

Using a factor of safety of 1.3, the bedform scour was estimated to be 0.1 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. However, a field investigation revealed that the location of a stable or "pivot" point could not be identified with any degree of certainty downstream of the 219th Avenue crossing, 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. The ADWR State Standard equation was applied under two scenarios. The first scenario uses the flows directly from the Wash 5 West model to estimate the long-term scour. Since the proposed pipeline crossing will be near the confluence with Trilby Wash, the second scenario considers the possibility of the long-term scour in Trilby Wash migrating upstream to the proposed crossing.

For the first scenario, the 100-year discharge for Wash 5 West is 7,363 cfs and the long-term scour is calculated to be 4.2 feet:

$$y_{lts} = 0.02(7{,}363)^{0.6} = 4.18 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 5.4 feet.

According to the hydrology developed by Entellus (2005), flow in the Trilby Wash just downstream of the confluence with Wash 5 West is 10,663 cfs (from concentration point C302*). Using this discharge, the long-term scour in Trilby Wash is estimated to be 5.2 feet:

$$y_{lts} = 0.02(10{,}663)^{0.6} = 5.22 \text{ feet}$$

Using a factor of safety of 1.3, the long-term degradation was estimated to be 6.8 feet. The thalweg elevation for the last cross-section (RS 0.001) in the Wash 5 West model is 1455.00 feet, which means that the long-term scour depth from Trilby Wash would extend down to an elevation of 1448.20 feet. The slope at the downstream end of Wash 5 West is approximately 0.004 and the proposed pipeline crossing is approximately 1,090 feet upstream from this cross-section. Projecting the scour elevation of 1448.20 feet upstream to the proposed pipeline crossing with the slope of 0.004 yields a long-term scour elevation of 1452.56 feet. The thalweg elevation at proposed pipeline crossing is 1459.50 feet. Thus, long-term scour depth at the proposed pipeline crossing from the Trilby Wash would be 6.94 feet.

Since the second scenario yields a larger long-term scour depth, this scenario was assumed to control and the long-term scour depth was estimated to be 7.0 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 near the 219th Avenue on Wash 5 West is the sum of the general scour, bedform scour, long-term degradation, and low-flow incisement scour, and it is estimated to be 12.4 feet (2.7 feet + 0.1 feet + 7.0 feet + 2.6 feet). Therefore, a burial depth of the crown of 12.4 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:

$$M_{LS} = 1.0(Q_D)^{0.5}$$

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 (7,363 cfs). Using this information, the minimum "safe" setback distance necessary was calculated to be 85.8 feet:

$$M_{LS} = 1.0(7{,}363)^{0.5} = 85.81 \text{ feet}$$

Thus, a minimum setback distance of 86 feet is required at the proposed pipeline crossing. Note that the recommended scour depth should be maintained from 86 feet beyond the main channel banks or the 100-year floodway, which ever is greater. However, in this case, there is no floodway analysis existing and the channel banks are not well defined. To be conservative, the floodplain is used instead of floodway in this case. Thus, the total scour depth should be maintained at least 86 feet beyond floodplain on both sides of the channel. Using the road stationing for the 219th Avenue, the 12.4 feet deep trenching should start at station 360+00 and end at station 398+60.

SUMMARY

A scour analysis and lateral migration analysis for a proposed 12-inch natural gas pipeline crossing of Wash 5 West at the 219th Avenue was conducted. The total scour depth at the proposed pipeline crossing was determined to be 12.4 feet for the 100-year event. Therefore, it is recommended that the crown of the pipeline at the proposed crossing be a minimum of 12.4 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 minimum "safe" setback distance was calculated to be 86 feet from the edge of floodplain. Using the road stationing for the 219th Avenue, the 12.4 feet deep trenching should start at station 360+00 and end at station 398+60.

A schematic view of the pipeline crossing is shown in Figure 5.

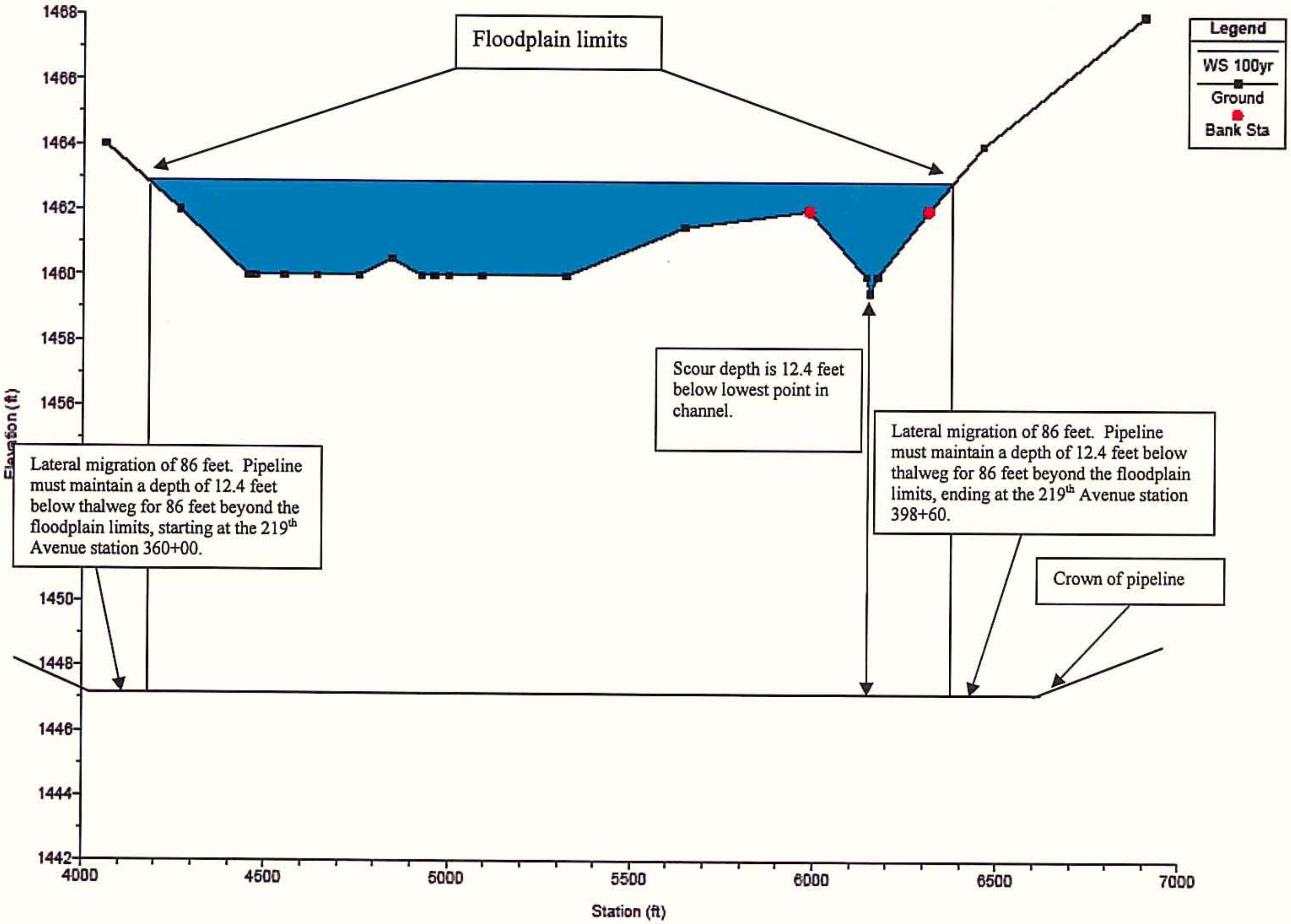

Figure 5. Schematic view of crown profile for the proposed pipeline crossing (drawing not to scale)

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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., Sta. 201
Tempe, AZ 85284

Project No.: L15034
Report Date: 8-Aug-07
Lab No.: 27745

Project: **Southwest Gas Scour Analysis**
Location:

Sampled By: Client
Date Sampled: 6-Aug-07
Submitted By: Client
Date Submitted: 6-Aug-07

Sample Source: Location #7

Material: Sand

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"	96		
1/4"	93		
#4	90		
#8	80		
#10	77		
#16	59		
#30	30		
#40	18		
#50	8		
#100	2		
#200	1.6		

Remarks:

Distribution: Addressee (1)

Respectfully submitted,

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

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