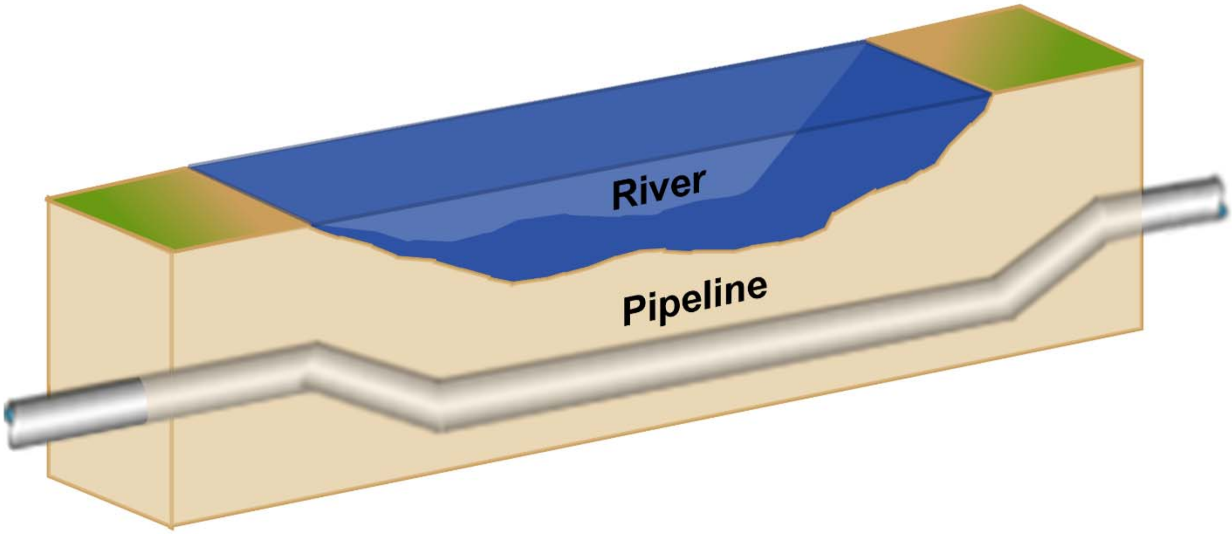
RECLAMATION

Managing Water in the West

Technical Service Center Manuals and Standards

Guidelines for Evaluating Pipeline Channel Crossing Hazards to Ensure Effective Burial



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Mission Statements

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Disclaimer

These guidelines for evaluating potential hazards for pipes and designing pipe burial depths are meant as a reference document to provide general guidance for Reclamation subject matter experts. Determining general scour; long-term degradation; and lateral migration for dynamic, natural channels is difficult to accomplish and highly uncertain due to a lack of widely applicable models. Professional judgement and expertise are required for effective pipe design. This guidance should not be construed as mandating a single method, as every situation has unique concerns.

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14. ABSTRACT
Proper analysis and design for buried pipes at water crossings can prevent future pipeline damage and reduce repair and replacement costs. These guidelines outline best practices for hydrologists, geomorphologists, engineers, and other subject matter experts to help determine the appropriate depth and lateral extent for pipeline burial to protect pipelines from stream-related hazards. The guidelines focus on ephemeral stream systems; however, these methods apply to any water-related crossing.

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Manuals and Standards

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Acronyms and Abbreviations

1D	one-dimensional
2D	two-dimensional
3DEP	3D Elevation Program
AEP	annual exceedance probability
ARS	Agricultural Research Service
ASCE	American Society of Civil Engineers
CONUS	continental U.S.
CN	curve number
EMA	Expected Moments Algorithm
ESRI	Environmental Systems Research Institute
FHWA	Federal Highway Administration
GIS	Geographical Information System
GCS	grade control structures
HDD	horizontal directional drilling
HDSC	Hydrometeorological Design Studies Center
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
IACWD	Interagency Committee on Water Data
IfSAR	Interferometric Synthetic Aperture Radar
LiDAR	Light Detection and Ranging
MGBT	Multiple Grubbs Becks Test
mi2	square miles
MRLC	Multi-Resolution Land Characteristics
NED	National Elevation Dataset
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	National Resources Conservation Service
NTSB	National Transportation Safety Board
NWIS	National Water Information System
NWS	National Weather Service
PHMSA	Pipeline and Hazardous Materials Safety Administration
psi	pounds per square inch
Reclamation	Bureau of Reclamation
SCS	Soil Conservation Service
SME	subject matter expert
SRH-2D	Reclamation’s Sedimentation and River Hydraulics two-dimensional numerical model
SSURGO	Soil Survey Geographic soils database
STATSGO2	State Soil Geographic Digital General Soil Map soils database
TR-55	Technical Release 55
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

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1. About These Guidelines

1.1. Purpose and Need for these Guidelines

This Technical Service Center Manual provides a better understanding and promotes consistent methods for assessing pipeline hazards and scour.

Pipelines are the most efficient way to transport and deliver potable water, gas, and oil, and there are more than 2.5 million miles of pipeline across the United States. Most pipelines are underground, and cross under rivers, streams, and lakes. In the United States, pipelines cross water bodies (crossings) at about 18,000 locations—many of these pipelines are only buried a few feet below the water (American Rivers, 2017).

Moreover, water bodies are dynamic, and buried pipelines can become exposed or damaged when stream and lake beds change. Therefore, understanding the potential hazards that crossings pose to pipelines and designing pipeline burials to avoid these hazards is critical to avoiding expensive repairs or even catastrophic failures.

To date, we are not aware of any comprehensive guidance for assessing and addressing these hazards in pipeline design. We have developed this guidance to provide Reclamation's subject matter experts with the tools needed to conduct effective assessments and design recommendations for buried pipe to help prevent pipeline failures at crossings in the future. Burial depth recommendations derived from these evaluations are used when designing or replacing a pipeline to protect the pipelines from damage at stream crossings.

Note that investigation recommendations for how to repair an exposed pipe are beyond the scope of this project.

1.2. Audience for These Guidelines

This Technical Service Center Manual is designed for subject matter experts who evaluate hazards at pipe crossings and recommend appropriate burial depths.

These guidelines are intended to help guide Bureau of Reclamation (Reclamation) teams of subject matter experts (SME) in evaluating potential pipeline hazards along proposed pipeline alignments and in determining appropriate burial depths to avoid these hazards. These guidelines assume that SMEs are familiar with alluvial and fluvial processes (e.g., channel planform and scour, dunes and antidunes), engineering principles and codes, and geomorphology.

This report presents a risk-based approach and outlines best practices to estimate the depth and lateral extent for pipeline burials to reduce the risk of pipeline exposure and failure at stream crossings. SMEs can use these guides as a reference document to conduct consistent and effective Reclamation pipeline hazard assessments to determine recommended pipeline burial depths.

Evaluating pipeline crossing fluvial hazards requires applying geomorphic field assessments, empirical scour depth estimates, and historical aerial photography inspection. Determining general scour; long-term degradation and lateral migration for dynamic, ephemeral channels is difficult to accomplish and highly uncertain. There are few widely applicable methods and models, and each proposed pipeline profile must be examined in an iterative fashion to understand the unique challenges posed for crossings at that location. Evaluating these pipeline crossing hazards requires using investigation techniques such as applying geomorphic field assessments, empirically estimating scour depth, and inspecting historical aerial photography.

1.3. Guideline Approach and Methods

To develop these guidelines, we compiled procedures used in multiple projects evaluating fluvial hazards where pipelines cross channels.

These guidelines modify and build on methods from American Society of Civil Engineers (ASCE) (2005), which adds together all three scour components (bend, general, and bedform) to long term degradation and then multiplies the total depth by a safety factor ranging from 1.1 to 1.5. One key modification these guidelines make from the ASCE (2005) methodology is that either bend or general scour calculations are applied—but not both—because bend scour equations include general scour estimates.

These guidelines update previous Reclamation guidelines for estimating degradation and local scour (Pemberton and Lara, 1984) for general, bend, dune, anti-dune, and confluence scour. In addition, a new degradation analysis methodology was developed because threshold channel methods found in Pemberton and Lara (1984) aren't typically applicable to alluvial ephemeral channel crossings. Historic channel morphology, anthropogenic alterations to the channel, and local geology are also investigated to offer insight into past and potential channel incision and migration.

2. Using this Guideline

These methods apply in general. Every study will have unique aspects to consider.

These guidelines were developed utilizing primarily ephemeral streams in the arid southwestern United States. However, these methods apply in assessing any water body crossing (e.g., ephemeral, intermittent, perennial channels) when the link between hydrology and stream erosion is not well documented or measured:

- **Ephemeral channels** are common in arid regions. They have flowing water for brief periods of time in response to rainfall runoff events, resulting in rapid channel bed and bank erosion. There are few stream gages installed on such systems, so the practices in this guide can help determine potential changes from floods.

- **Intermittent streams** have longer periods of seasonal flows; during wet periods (e.g. snow melt). On an annual basis, they convey more water than ephemeral streams.

- **Perennial channels** often do not experience as severe of channel bed and bank erosion as ephemeral channels. Yet without a history of cross section measurements over several decades at the crossing, these gradual changes need to be assessed with the practices outlined in this guide.

This guideline includes a description of:

- **Frequently asked questions.** Use this section for explanations to questions that stakeholders, partners, and decisionmakers without a detailed background in design or fluvial analyses may ask about the importance of proper pipe burial designs. This text can provide introductory material for reports and analyses summaries to explain channel-related hazards to pipelines and the rationale for recommending pipeline burial depths for planners, decisionmakers, and stakeholders.

- **Methods and analysis steps**. The rest of the guidance provides a practical outline for conducting a pipeline hazards evaluation. Once the initial list of crossing sites is determined (Section 4), every site is treated equally up through the final prioritization (low or high hazard). From there, the sites with a low hazard rating are directly assigned a total pipe burial depth and length based largely on field observations and prescriptive minimum requirements that are project dependent. Alternatively, sites with a high hazard rating are ran through a series of detailed analyses before settling on a total pipe burial depth and length. Figure 1 provides a flow chart of how each section in this guideline relates to one another, and the methods used for both low and high hazard crossings.

While each pipeline hazards evaluation is unique and requires professional judgment to determine appropriate levels and methods of analysis, SMEs will generally perform the following analysis tasks:

- Initially identify crossings, assess this list through a field review, and prioritize the list by assigning a hazard rating in determining its level of analysis.

- Analyze maps, historical imagery, and topography to estimate future lateral migration for moderate and high priority sites.

- Use the National Resources Conservation Service (NRCS) method of estimating peak flows for ungaged watersheds (U.S. Department of Agriculture [USDA], 1986) and use a risk-based approach (Federal Highway Administration [FHWA], 2012) to determine peak discharges associated with a return period of interest. For gaged watersheds a flood frequency analysis should be conducted (England et al., 2018).

- Conduct a hydraulic assessment and compute scour using the hydraulic results.

- Use field assessments and downstream channel bed slope changes to determine long term degradation potential.

- Add these components together (with a safety factor) to determine the total vertical scour that is used to set the burial depth to the top of the pipe. The burial length should extend far enough to adequately cover the potential channel widening and migration at the crossing.

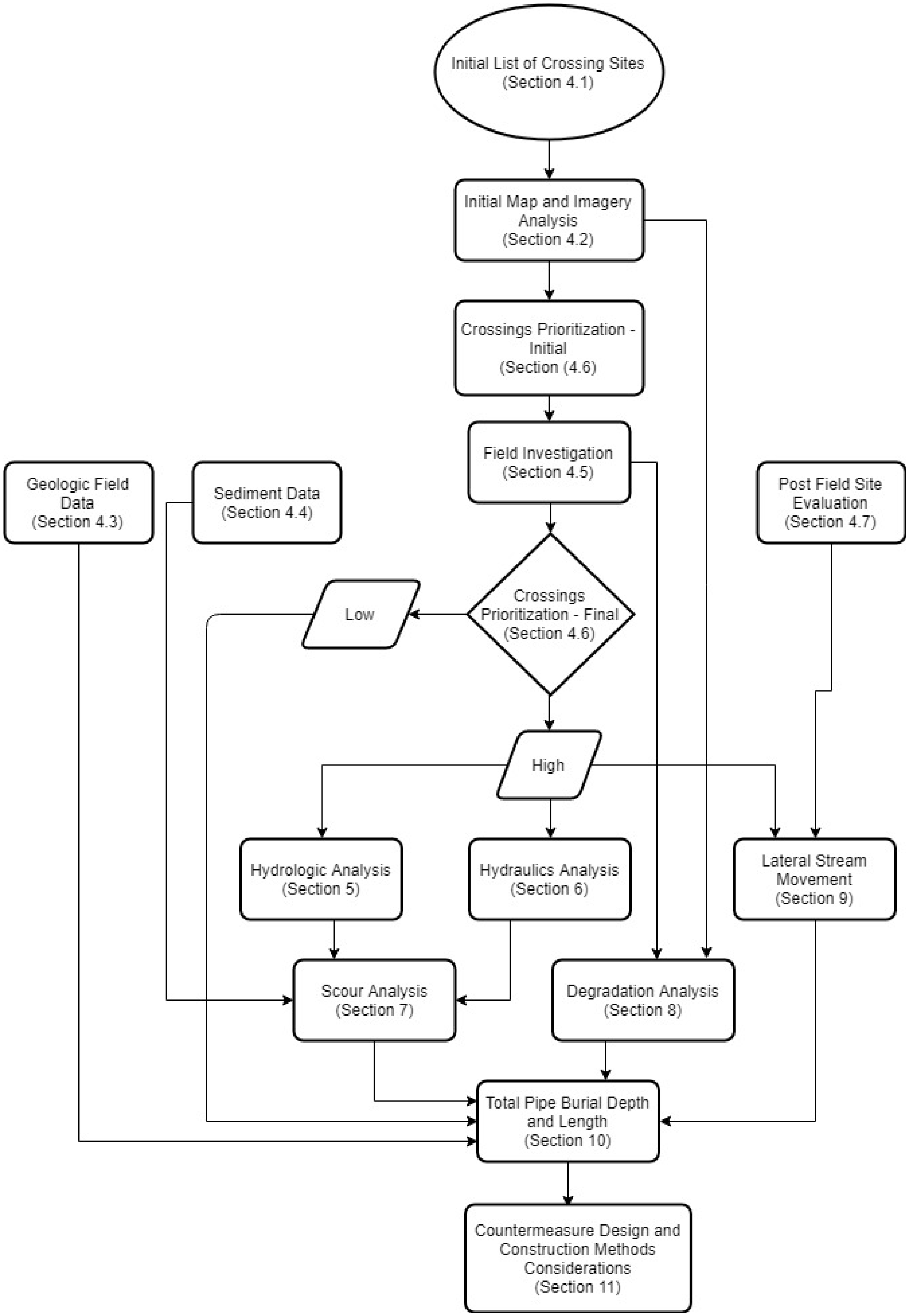


Figure 1. Flow chart of guidelines methods and application.

3. Frequently Asked Questions

3.1. How Important is Good Burial for Pipe Design?

Identifying and assessing stream hazards is critical to help maintain the life of the pipeline, prevent pipe exposure and minimize future operation and maintenance costs.

Underground pipelines containing water, natural gas, crude oil, and other petroleum products cross underneath channels with perennial (continuous) and ephemeral (intermittent) flow.

When these buried pipelines run under a waterway (i.e., a crossing), then designers must consider potential hazards such as scour and degradation to recommend an adequate burial depth. If pipelines are not buried deep enough below a crossing, then water movement can wear away soil and expose a pipeline. Pipelines are strong in compression and weak in tension; thus, an exposed, unsupported pipe is at an unacceptably high risk of rupturing. Moreover, exposed pipelines are vulnerable to long-term issues such as abrasion and corrosion and short-term issues such as direct attacks from hydraulic forces or debris during high flows.

For example, channel degradation exposed a series of gas lines at an arroyo crossing in west-central New Mexico, leaving the gas lines suspended above the channel (Figure 2). This pipeline was likely originally buried about 5 feet below the bed prior to the degradation shown.

Figure 2. Channel degradation exposed buried gas lines in New Mexico.

3.2. Why Not Just Use the Minimum Depths Required by Law?

Federal law only covers rivers larger than 100 feet wide. Pipelines buried twice as deep as the minimum requirements have been exposed.

Currently, Federal law mandates a minimum of 4 feet of cover below all rivers greater than 100 feet wide; there are no regulations for pipelines crossing smaller streams. Pipeline failures due to scour and the current state of inspected pipeline crossings have shown that burial depths greater than the minimum requirements are often necessary to prevent failures. A large, dynamic river can easily scour more than two to three times the minimum depth of 4 feet in a single flood. For example:

- The Poplar gas line underneath the Yellowstone River near Glendive, Montana had been buried at least 8 feet below the river bottom according to a 2011 survey (Douglass, 2015). Even though this was twice the Federal requirements, the gas line still became exposed due to scour in just 4 years. The pipelined ruptured in January 2015, releasing roughly 40,000 gallons of oil downstream (American Rivers, 2017)

- The USGS performed a study that found the Missouri riverbed had deepened by 9 to 41 feet in 27 places due to severe scouring during the 2011 floods (Douglass, 2015).

- More than 20 pipeline river crossings in Montana were found to be "dangerously close to exposure" during inspections of 90 crossings in 2011 (Nicas, 2012).

- Extreme flooding along the San Jacinto River in Texas in 1994 resulted in pipeline ruptures combining for a release of 1.47 million gallons of petroleum into the river (National Transportation Safety Board [NTSB], 1996).

Pipeline risks are compounded by the fact that a scour, degradation, and lateral movement risk assessments are seldom performed at most crossings: "…we still have a problem with operators not doing adequate risk assessments." Rebecca Craven (Pipeline Safety Trust quoted in Douglass, 2015). The many documented failures, a selection of which are summarized above, highlight the importance of conducting scour and channel stability assessments at pipeline crossings.

3.3. What Crossing Hazards Do We Need to Consider?

Water bodies are inherently dynamic. Changes in channel geometry at crossings can threaten a pipeline from streambed lowering (vertical), from the side (lateral), and along the alignment (longitudinal).

Changes in water flows can occur from anthropogenic interference, such as dams and increased urban runoff, or natural causes, such as variations in runoff, precipitation, and temperatures. These changes can cause scour, degradation, and lateral migration through bank erosion. These are the primary processes in dynamic fluvial channels that threaten exposing pipes at crossings (Figure 3).

Buried pipelines may be exposed by vertical, lateral, and longitudinal changes to the channel.

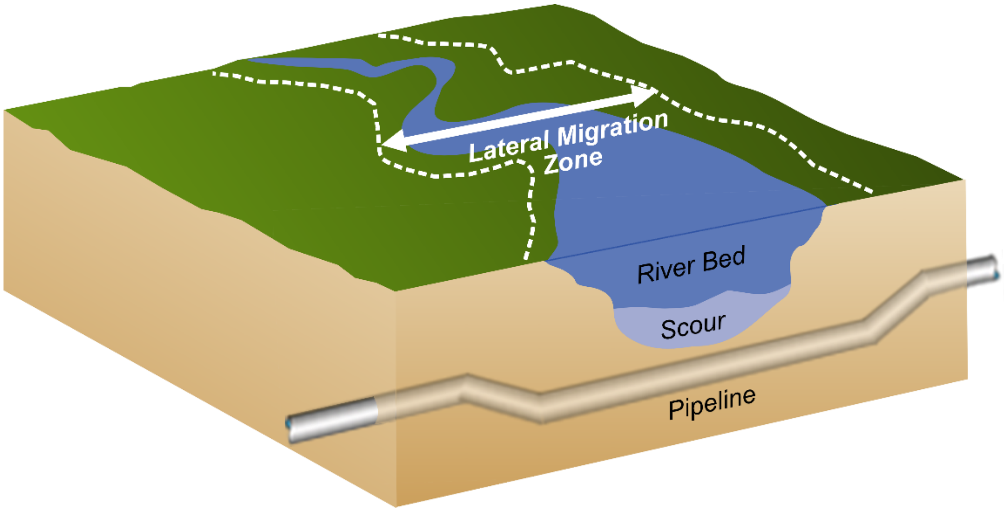


Figure 3. The main hazards impacting buried pipelines at crossings.

3.3.1. Scour

Scour is a primary hazard for buried pipelines. Scour is defined as the removal of sediment from the bed and banks of a channel by the flow of water (Warren, 2011 and FHWA, 2012). Scour may occur during the rising limb of a flood hydrograph, followed by deposition during the falling limb of the hydrograph. Scour may occur as:

- **General scour** naturally occurs when peak discharges remove sediment from the channel bed. This type of scour is not associated with bridge piers or abutments, bank stabilization or cross-channel structure scour.
- **Bend scour** is associated with the flow of water around a bend in a river.
- **Bedform scour** occurs as dunes and anti-dunes migrate through the process of erosion and deposition.

3.3.2. Degradation

Degradation is a general and progressive long-term lowering of the channel bed due to erosion over a relatively long channel length. The stream degrades because it is adjusting its bed slope toward a new equilibrium to match the changing sediment, runoff, or base level control. Channel beds can degrade in three common ways:

- **Along the channel bed.** Degradation is typically caused by a lowering of the stream's downstream bed elevation (base level), a reduction in upstream sediment supply, or an increase in surface runoff (FHWA, 2012a).

- **At a headcut.** Degradation can occur from the upstream propagation of a headcut; part of a river or channel where there is an abrupt vertical drop in the channel bed. Degradation from propagating headcuts along ephemeral channels in the arid southwest are especially common. As the streambed erodes and lowers the bed elevation, the downstream channel becomes incised. The channel upstream of the headcut remains unaffected until the headcut migrates upstream during floods.

- **Knickpoint.** Degradation can occur where there is a slope change with a lower downstream slope and a corresponding steeper upstream slope. Upstream of a knickpoint the channel bed can degrade as it assumes the downstream slope. Headcuts can also begin as knickpoints.

3.3.3. Channel Migration

Lateral migration shifts in channel planform, and widening can also threaten pipelines, causing scour at pipeline locations that were previously outside the limits of erosion during the original design. As a generalization, the risk of bank erosion is low on straight and anastomosing channels, moderate on meandering channels, and high on braided channels (Knighton and Nanson, 1993). However, sediment supply, water discharge and the erodibility of the bed and banks are key factors which control the lateral and vertical incision of channels and their subsequent channel planforms. Highly erodible bank material coupled with anthropogenic modifications to stream channels (e.g., removal of riparian vegetation) often result in the lateral movement of channels. Natural meander migration is also common. Additional pipe burial depth extending some lateral distance beyond the channel banks is needed.

3.4. What are the Levels of Hazards?

Reclamation classifies potential hazards for exposure into two categories (low and high) based on available data, field observations, and professional judgement. Low-hazard crossings have a lack of channel definition, presence of bedrock or other channel stability features and are assigned a prescribed burial depth. High-hazard crossings are assigned to crossings where the channel has a defined bed and banks and poses a risk of erosion. Individual channel scour, degradation and lateral migration assessments are performed.

3.5. How Do You Determine Appropriate Burial Depths and Lengths?

Pipelines should be installed below the total scour depth, calculated by totaling the degradation and scour, and then adding in a safety factor. This burial depth should extend along the alignment far enough to adequately cover the pipeline during the future in case of channel widening or migration at the crossing (Figure 4).

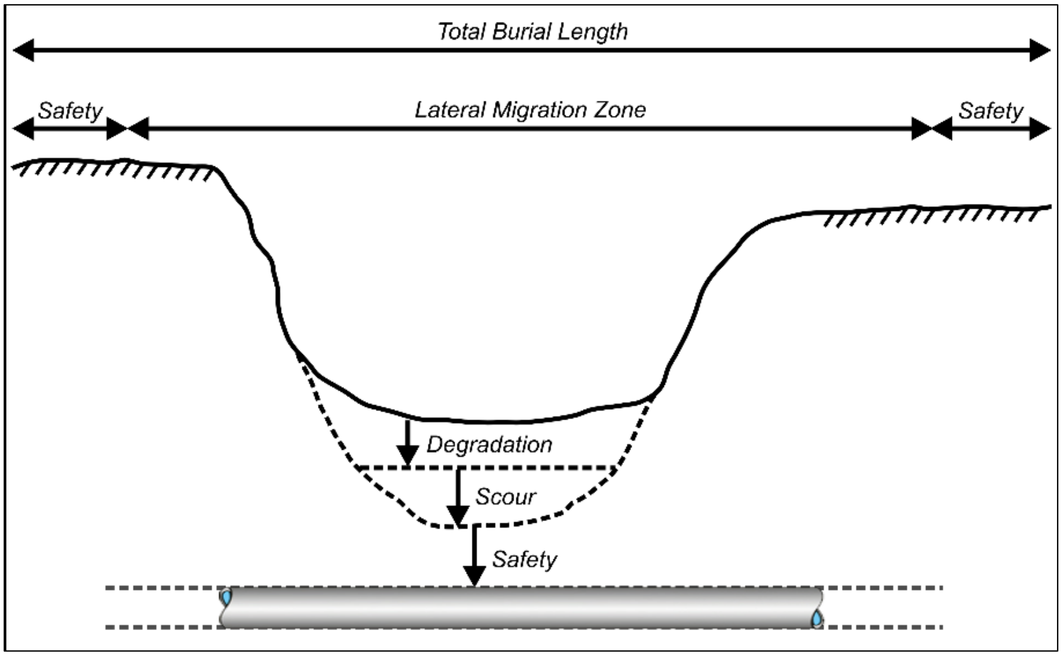


Figure 4. Schematic showing the considerations for determining pipeline burial depth.

4. Crossings Identification and Evaluation

4.1. Initial List of Crossing Sites

4.1.1. Office-Based Analysis of Potential Crossing Sites

Identifying and assembling all the crossing sites that may need to be analyzed is an important first step for any pipeline hazards evaluation. Identify potential crossings anywhere along the pipeline profile where surface water is currently concentrating or has concentrated in the historical record, including:

Make a list of crossings that will evolve as the study progresses. Determine potential crossings and their associated hazards.

- all USGS-mapped blue-line streams,
- areas immediately upstream or downstream from a culvert crossing underneath a road, even if a channel is not apparent on imagery,
- vegetated areas that appear to have active springs or wetlands, and
- defined stream channels or gullies (flow paths) with a defined bed and banks or defined channel vegetation.

This is usually done through an office-based analysis of available data. We recommend plotting the pipeline alignment in a platform such as Environmental Systems Research Institute (ESRI) ArcGIS or Google Earth and using modern aerial and satellite imagery to develop the initial list of stream crossing sites.

4.1.2. Opportunities for Realignments

As you identify potential crossings, you may note areas with potential issues which could require more detailed analyses, deeper burial depths, or other mitigation.

Point out these potential issue spots with the overall team and planners. If the project is in an early development stage, it may be possible to suggest pipeline realignments that would reduce overall stream hazards and burial cost; for example, moving the pipeline to cross a stream channel away from a meander bend or changing the angle at which the pipeline crosses a stream to reduce the overall length of pipeline within the stream channel.

4.1.3. Data Gap Identification

Once preliminary crossings are determined, assemble and assess available data to determine data gaps and to identify locations which may have additional sites that require more data to ultimately evaluate stream hazards.
Available data commonly include:

- pipeline alignment,
- detailed topography (surveyed cross sections and longitudinal profiles or high-quality digital elevation models derived from light detection and ranging [LiDAR] or photogrammetry),
- geologic and topographic maps,
- historical aerial photographs and satellite imagery,
- exploratory drill logs detailing subsurface material type and depth to bedrock, and
- surface and subsurface sampling and size gradation analysis for alluvial channel sediment.

Correlate the data by location and quality to determine any data needs. It is important to identify data gaps early in the process, as it may take time to acquire these data. In addition, an initial field reconnaissance evaluation is crucial to confirm, eliminate, or add additional crossing locations and aid in hazard prioritization.

4.2. Initial Map and Imagery Analysis

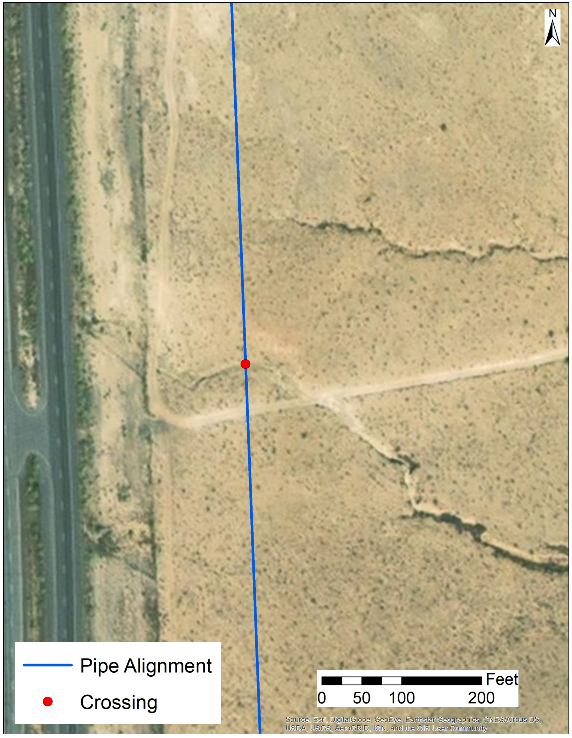
4.2.1. Aerial and Satellite Imagery Analysis

Analyze historical and current maps and imagery along the pipeline profile to identify potential crossings.

Basemaps derived from both modern aerial and satellite imagery are available from GoogleEarth and ESRI ArcGIS. Google Earth also provides historical basemaps for many areas with coverage extending back to the 1990s. Earlier historical imagery may be downloaded from the U.S. Geological Survey (USGS) Earth Explorer site (earthexplorer.usgs.gov). Historical coverage typically extends back to the 1960s and, in many cases, earlier datasets are available. In addition to digital images, stereo pairs of single frame photos may be available, but this level of detail is rarely required. Once data are acquired, digital imagery before the 1990s must often be georeferenced for use in Geographical Information Systems (GIS) software to allow comparison with more recent imagery.

First, map any additional crossings that were present in historical but not modern imagery. These sites are later checked during a field reconnaissance trip. The initial site list should include a Site ID, location coordinates, pipeline station, potential classification, and notes. This site list can provide a consistent reference for subsequent field visits, site elimination and prioritization, and site evaluation.

Begin the initial risk classification (described further in Section 4.6) by grouping channels by size and definition. For example, to help guide the field reconnaissance trip, you may initially classify crossings with no channel definition below road drain culverts as low hazard priority sites and identify large incised channels as high hazard priority sites. You can then conduct a cursory analysis for potential hazards to evaluate in the field, such as erosive banks or incisional areas as indicated from shading on the imagery. By comparing the shadow angles along the bed and banks of a channel (Figure 5), you can often detect evidence of vertical incision and bank erosion. Incision indicators are helpful in identifying downstream headcuts that may propagate upstream to the pipeline, which need to be confirmed in the field.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5. Stream channels shown on 2017 imagery from ESRI flowing from west to east. Shadows indicate stream channels are likely incised.

4.2.2. Topographic Map Analysis

Use topographic maps in your preliminary determination of crossings before the field reconnaissance trip. These maps should include USGS topographic maps, Light Detection and Ranging (LiDAR), ground survey data, or other detailed topography of the pipeline alignment. Add any pipeline crossing locations that cross USGS-mapped blue-line streams as well and any topographic expressions of swales or stream channels that were not previously identified on imagery to the site list. In many areas, stream channels may exist on topographic maps that have since been obliterated by road building or other infrastructure. In other cases, several streams can merge together and enter a road ditch then cross underneath the road through a single culvert or bridge.

The location of these rerouted channels needs to be identified so that they are accounted for in the hydrologic analysis of flood frequencies at pipeline crossings. Include any obliterated or abandoned stream channels on the site list, as the relict channel could accumulate flow during large floods.

In addition to site identification, check the downstream longitudinal stream profiles for evidence of degradation along stream channels. A longitudinal profile is a plot of the streambed elevation (y-axis) against the distance along the stream (x-axis)—demonstrating how streambed elevation changes with distance downstream. Degradation may take the form of a headcut or a more diffuse knickpoint, where there is a sharp increase in stream gradient upstream from a lower gradient reach. Also look for evidence of incised channels, where banks are over-steepened. These features can then be checked during a field reconnaissance to aid in stream prioritization.

4.2.3. Geologic Map Analysis

Use geologic maps and reports to note surficial bedrock and determine if there are any potential bedrock grade controls near stream crossings. Digital geologic maps are available from the USGS (http://ngmdb.usgs.gov/maps/mapview/). These maps can be used to determine geologic data and rock type which may provide useful information about the depth of alluvial cover and resistance to erosion at crossing locations. Hard bedrock can help stabilize channel banks or control channel alignment, while softer bedrock (e.g., mudstone, claystone, or unwelded tuff) is susceptible to erosion.

Surficial soil cover may vary throughout the area and influence erodibility. Soil maps from the NRCS may also provide information about grain size and soil characteristics (https://websoilsurvey.sc.egov.usda.gov/). Many of the sites Reclamation has analyzed were covered by Quaternary alluvium; therefore, the observed grain size in small channels may be a relict of Quaternary rather than modern processes, indicating greater stability, and important to recognize.

4.3. Geologic Data

Geologic mapping along or near the proposed alignment is part of the design data for Reclamation pipeline design and construction analyses. Drill log and test pit data are especially helpful to identify grain sizes and estimate the depth to bedrock. In many Reclamation locations, the depth to bedrock is frequently variable and cannot be predicted based on published map data. For example, Appendix B contains a geologic design data report from the Navajo Gallup Water Supply Project (Reclamation, 2017) that contains drill logs and test pit information. If possible, conduct a preliminary analysis of published maps to help inform the decision to acquire drill log and test pit data.

4.4. Sediment Data

Several scour analysis methods rely on bed sediment gradation estimates. Composite sediment samples are needed from the bed surface as well as through as much of the potential depth of scour as is practical (1-3 feet). Samples are analyzed to determine their grain size distribution following standard procedures

(ASTM D6913 and Bunte and Abt, 2001). Use the resultant median grain size values of surface bed samples and deeper samples at each site in the scour analyses. Appendix C contains a description of bed and bank sediment sample and size-gradation analysis.

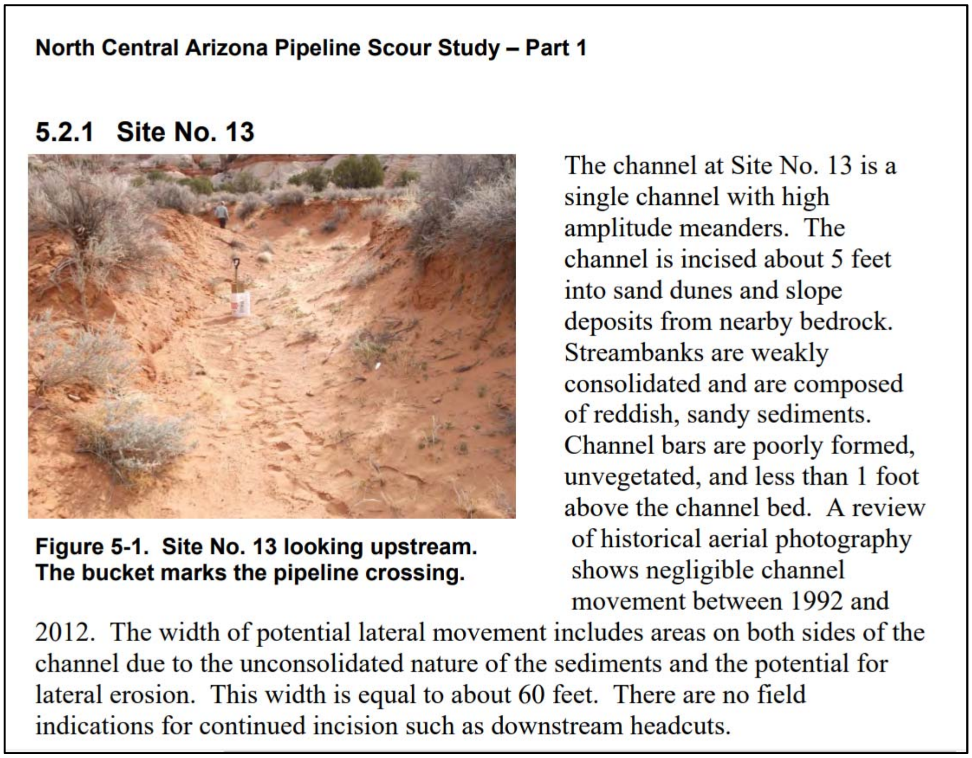
4.5. Field Investigation

The field reconnaissance should be used to confirm or modify potential hazards identified during preliminary analysis of digital imagery and topography.

Use the field reconnaissance visit to check the office-based identification of crossing sites and prioritize crossings into low or high hazard sites. Often, additional sites are added following the field assessment as evidence of crossings are found in the field. Sometime sites are eliminated as preliminary evidence turns out to be incorrect. Sometimes, for example, the shadowing or vegetation patterns on digital imagery may indicate a potential stream where it is not found in the field.

Walk every stream channel upstream and mostly downstream of each crossing site on the initial site list. All potential stream hazards should be documented and mapped. The length of stream channel that needs to be investigated cannot be standardized for each site as it depends on the potential for upstream and downstream features to impact the pipeline. If there are features that could erode and impact the channel stability of the pipeline, such as a downstream headcut, they should be investigated. Other features, such as a road crossing, can pose additional degradation risks in foreseeable scenarios. For example, if a dirt-fill road crossing washed out, it could result in scour and degradation that may propagate upstream. In other cases, nearby road crossings, grade control, or other engineered structures may provide stability and limit the scope of the investigation. For example, if the pipeline alignment is located immediately downstream from a large highway crossing, there is likely little risk of lateral migration (assuming the highway crossing is properly aligned and not at risk of failure).

Photographs clearly showing the crossings help designers understand the context for the pipeline hazards evaluation. Figure 6 provides an example of a description and photograph for a potential pipeline crossing used in the North Central Arizona Pipeline Scour Study – Part I (Reclamation, 2013).



North Central Arizona Pipeline Scour Study – Part 1

5.2.1 Site No. 13

Figure 5-1. Site No. 13 looking upstream. The bucket marks the pipeline crossing.

The channel at Site No. 13 is a single channel with high amplitude meanders. The channel is incised about 5 feet into sand dunes and slope deposits from nearby bedrock. Streambanks are weakly consolidated and are composed of reddish, sandy sediments. Channel bars are poorly formed, unvegetated, and less than 1 foot above the channel bed. A review of historical aerial photography shows negligible channel movement between 1992 and 2012. The width of potential lateral movement includes areas on both sides of the channel due to the unconsolidated nature of the sediments and the potential for lateral erosion. This width is equal to about 60 feet. There are no field indications for continued incision such as downstream headcuts.

Figure 6. Example of description for a channel crossing.

Complex sites may require additional data collection as the project develops. The field reconnaissance trip may be combined with or be separate from a data collection trip. Data collection includes detailed mapping of active erosion and deposition features. Note the channel's geomorphic planform near the pipeline (straight, anastomosing, meandering, braided) and map the geographic extent of floodplain and terraces, location of side channels, and presence of active or cut-off meanders. Also map, document, and measure features that can impact pipeline stability, such as:

- the height of headcuts may propagate upstream and affect the pipeline alignment;
- bedrock outcrops and characteristics (i.e., erodibility), noting how bedrock could limit the vertical scour, lateral migration, and degradation potential;
- active springs;
- gullies through channel banks;
- stream bank heights, gradients, and recent bank failures;
- channel and valley width; and
- any other signs of erosion and sediment transport.

Collect sediment samples for gradation analyses at all sites where you anticipate conducting scour assessments (described in Appendix C). As the hazard prioritization and required analyses are not finalized until after the field reconnaissance, it can be difficult to anticipate where these samples are needed, requiring another field trip.

Note preliminary estimates of lateral burial extent, which are finalized after hydrologic and lateral stability assessments.

4.6. Crossings Hazard Prioritization

Crossings are assigned a risk hazard in order to prioritization the hydrologic and hydraulic analyses that are needed for each site.

Once the crossings are identified (Section 4.1) field observations can be used to classify them into low and high hazard so that time allocated to analyzing (and designing) each crossing can be scaled according to hazard:

- **Low hazard crossings are** typically assigned a prescribed minimum burial depth that depends on the project location (e.g., frost depth + safe additional burial depth) and a length obtained from a cursory stability analysis using readily available historical aerial imagery and field observations.

- **High hazard crossings** are typically assigned a custom burial depth and length based on a full (quantitative) scour (Section 7), degradation (Section 8), and lateral migration (Section 9) analyses. These crossings could involve additional field visits and data collection.

Assignment of each crossing's category is based on available data, field observations, and professional judgement. Some of the initially identified crossings will fall off the list completely after evaluating field observations. As additional data become available the assigned hazard classification may be adjusted as the analysis and design process progresses.

4.6.1. Low Hazard Priority Crossings

Crossings are usually assigned a low hazard when field observations indicate a lack of channel definition, presence of channel stability features such as bedrock or another channel structures or determined to be depositional rather than erosional.

In addition, a full scour analysis cannot be performed when there was a lack of hydrologic and/or hydraulic data. Keep any historic stream channels and any crossings identified downstream of a road culvert (with no defined channel) as low priority sites.

4.6.2. High Hazard Priority Crossings

A high hazard rating is usually assigned to crossings where the channel has a defined bed and banks and poses a risk of erosion. These crossings show signs of instability as determined during the field investigation or preliminary (cursory) migration analysis and have field indicators of degradation (e.g., incision, knickpoints, or headcuts).

4.7. Post Field Site Evaluation

Following field verification and crossing prioritization, we conduct additional mapping and measurements with imagery and topographic data for high hazard sites. We use historical imagery to track changes in the channel planform through time. Features which should be mapped include:

- the active channel morphology,
- areas of past erosion that may be re-vegetated in more modern imagery,
- the presence or absence of terraces,
- lateral channel migration and movement of channel meanders,
- locations of alluvial fans,
- vertical incision, headcuts, or knickpoints, and
- the addition of upstream and downstream infrastructure which affects the channel alignment.

If headcuts propagating upstream through time are documented in multiple imagery datasets, then past rates of headcut migration can be calculated. Rates of past meander movement, channel widening, and lateral migration may also be calculated from the imagery; however, this is often more difficult for small, ephemeral streams given the variations in georeferencing and image resolution. Degradation features, mapped changes in channel morphology, and field geology data are used to inform the scour, degradation, and lateral channel erosion analyses and inform decisions about the overall pipe burial depth and length (Section 10).

We use detailed topographic maps of the pipeline alignment to cross reference with features mapped on aerial imagery and mapped in the field. Topographic data analyses should indicate bank heights, the width of terraces, floodplain, and channel bars, width of any inset channels (along a cross section), the bottom channel width (across the channel, between the base of the right and left banks), and top channel width (between the tops of the right and left banks, above inset terraces or floodplains). In many cases, topographic data are collected up to several years before the site analysis. Depending on the data resolution, erosion and incision post-dating the topographic data collection can be quantified by comparing the topography with digital imagery and/or field measurements. We also note breaks-in-slope and cross reference the topography with valley margins mapped from aerial imagery. Topographic data should have enough detail to generate a stream channel cross section across the pipeline alignment; the pipeline may not cross perpendicular to the channel alignment and this information is needed to inform the burial length of the pipeline below all crossings.

Channels at risk for widening or migration should be given additional consideration. In these cases, professional judgement is used to determine the burial extent by incorporating analyses from map, aerial imagery, and field assessments. Historic rates of lateral migration may be applied to help predict future rates of migration over the design life of the pipeline (e.g., Lagasse et al., 2004). Rates of bank retreat may also be applied to predict channel widening. However, this assumes uniform movement of the stream channel when many channels experience periods of stasis punctuated by periods of channel movement that are usually in response to hydrologic events. In addition, channels cannot widen indefinitely under the same flow regime. For channels that appear to be widening or initiating braiding, you can use nearby channels with similar flow regimes and geologic settings to help inform the potential future channel width.

5. Hydrologic Analysis

As runoff from precipitation events serves as the primary driver of sediment transport, a hydrologic analysis is a necessary component in:

- evaluating scour at pipeline crossings of flow conveyance channels,
- developing design specifications, and
- selecting and/or appraising structure design life.

The hydrologic analysis provides peak flow frequencies for defined probabilities of occurrence. Frequency hydrographs can also be developed.

The hydrologic analysis typically provides flow magnitudes for defined recurrence intervals. Hydrographs associated with flood frequency magnitudes (i.e., frequency hydrographs) can be provided as needed for specific hydraulic and scour analyses.

Selecting an appropriate flood recurrence interval to evaluate scour is important with respect to design considerations and hazard assessment. Coupling flood recurrence intervals with the pipeline design life lets you use a risk-based approach for selecting the return period interval for scour determination as recommended by FHWA (2012a). A 50-year design life is used for many pipelines, and a 1% annual exceedance probability ([AEP], 100-year recurrence interval) peak discharge is typically selected for the analysis of scour depth (ASCE, 2005). To calculate the likelihood of a flood occurring during the design life of a crossing, use the compound risk equation solved in terms of the probability, P, of an event with an annual exceedance probability A (probability of event occurring within a given year), occurring over n years (Equation 1):

$$P = 1 - (1 - A)^n \tag{1}$$

Using Equation 1, a flood with a 2% AEP would have a 63.4% chance of occurring during a 50-year pipeline design life, whereas a flood with a 1% AEP would have a 39.5% chance of occurring during a 50-year design life.

Several methods are available to estimate frequency flow magnitudes; however, different methods are appropriate for different watersheds and engineering applications. Analytical methods can be generally grouped into rainfall-runoff modeling or statistical fitting of distributions to observed data (Reclamation, 2004). Apply experienced hydrologic engineering judgment in selecting the methods to use for your particular evaluation, considering: hydro-meteorological characteristics of the watershed, data availability, and specific requirements of the hydraulic/scour analysis. To provide greater confidence in flood frequency estimates and inform what results should be considered in the final evaluation, use multiple methods when applicable (Reclamation, 2006).

Depending on the type of hydraulic and/or scour analysis, peak discharges and/or frequency hydrographs will be developed. Hydrographs can be used to evaluate flood duration processes (e.g. overtopping), when volume is an important design/evaluation consideration, for storage and sediment routing, and when unsteady flow modeling is required (FHWA, 2012b).

5.1. Statistical Approaches

5.1.1. Flood Frequency Analysis (Bulletin 17C)

To assure uniformity in estimating flood frequency at locations with gage information, agencies concerned with flood risk should use Bulletin 17C guidelines for Federal planning decisions.

Where gage data of sufficient record length is available for a particular pipeline crossing, a statistical flood frequency analysis may be performed to determine peak flow estimates (see Bulletin 17C [England et al., 2018]). Site-specific gage data with a sufficient record (at least 10 years, with informative regional skew and/or record extension) can be fit using a log-Pearson Type III (LP-III) distribution to develop discharge frequency estimates following Bulletin 17C methodology (see England et al., 2018). Bulletin 17C updates the previous flood flow frequency guidelines (Interagency Committee on Water Data [IACWD], 1982) by:

- incorporating a new method, the Expected Moments Algorithm (EMA) (Cohn et al., 1997 and 2001);
- using Multiple Grubbs Becks Test (MGBT) to identify potentially influential low floods (Cohn et al., 2013); and
- improving computation of confidence intervals using the EMA method.

A primary source of streamflow data is through the USGS National Water Information System (NWIS)[1]. This database includes sub-daily, daily, and annual peak flow data as well as daily, monthly, and annual statistics. Additionally, streamflow data is collected by other Federal agencies including the U.S. Army Corps of Engineers (USACE) and the U.S. Forest Service. Information is also available from Reclamation, who is consolidating all of its current and historical streamflow data[2]. Other potential sources of data are state and local government agencies, utility companies, water-intensive industries, and academic institutions (FHWA, 2012b). When site-specific information is not available, estimates of unregulated peak discharge can be developed by combining and transposing gage data in the watershed (see Cudworth, 1992 and England et al., 2018).

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[1] waterdata.usgs.gov/nwis

[2] water.usbr.gov

EMA results describe the peak flow frequency for applicable AEPs of interest. The USGS program PeakFQ[3] (Veilleux et al., 2014) can be used to perform an EMA analysis. EMA:

- computes the moments of a Log Pearson Type III distribution using a time series of systematic, historic, and paleoflood data and perception thresholds;
- applying station, regional, or weighted skew weighting; and
- performing a MGBT to remove influential low outliers (England et al., 2018).

5.1.2. Regional Regression Equations

Regional regression equations transfer streamflow statistics from gaged to ungaged sites using an extrapolation of data from nearby watersheds with similar hydrologic, physiographic, and climatological characteristics. Regional flow-frequency regression equations can be used to estimate peak flow frequency, including sites with limited or no streamflow information. USGS has developed regional regression equations for estimating streamflow statistics. These equations transfer streamflow statistics from gaged to ungaged sites by applying watershed and climatic characteristics as predictor variables within defined homogeneous hydrogeologic regions (Ries et al., 2017).

Regional regression equations are used to transfer streamflow statistics from gaged to ungaged sites by using watershed and climatic characteristics as explanatory or predictor variables.

The USGS, often with state partners, has developed a comprehensive series of regional regression equations for most states in the United States and has published these studies as part of the National Streamflow Statistics Program[4] (Ries, 2006). The regression equations, developed using gage data and independent physical variables within a defined hydrogeologic region, provide peak flow estimates from 2-year floods to 500-year floods (1:2 to 1:500).

StreamStats[5] is a map-based web application that

- delineates watersheds for user-selected sites;
- provides watershed-specific basin and climatic characteristics; and

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[3] water.usgs.gov/software/PeakFQ/

[4] https://water.usgs.gov/osw/programs/nss/pubs.html

[5] https://streamstats.usgs.gov/ss/

- applies watershed characteristics in regional regression models to provide estimates of peak flow frequency and other flow statistics as available (Ries et al., 2017).

For pipeline crossings, regional regression equations should not be used as a single method to inform scour analysis and design. Rather, you can use regional regression to support evaluation and validation of rainfall-runoff modeling or an EMA analysis. Note that StreamStats can provide additional useful information (i.e., basin and climate characteristics) to better understand the hydrology of the site of interest.

When applying USGS state-level regional regression equations to estimate peak flow magnitude frequency for scour analysis and design at pipeline crossings, be sure to understand the limitations and the applicability of the method. Regional regression equations should only be applied where the basin of interest fits within in the range of the characteristics (i.e., independent variables) of the gaging stations used to develop the regression equations. When evaluating ephemeral streams, it is also important to understand whether any of the gages used in development of regression equations were ephemeral – if no ephemeral streams were included, then the regional regression equations may not be relevant.

5.2. Rainfall-Runoff Modeling

Applying precipitation frequency information in a rainfall-runoff model can provide flow frequency estimates at sites without gage data.

Streamflow frequency information can be developed by applying precipitation frequency information and a spatiotemporal pattern of a critical storm in a hydrologic model to simulate the runoff response of the watershed. The controlling assumption in this approach is that the frequency of the runoff will be equal to the frequency of the precipitation input (i.e., AEP neutral). This sub-section describes the data and inputs needed to perform rainfall-runoff modeling and the two hydrologic models that can be used to perform a hydrologic frequency analysis.

Changes to the watershed from forest fires, urbanization, channelization, and other natural and anthropogenic landscape-changing processes affect watershed hydrology. These changes can impact infiltration, storage, travel time, and other important hydrologic controls. Additionally, climatic changes may influence the precipitation inputs. Assess stationarity assumptions when developing streamflow frequency information using rainfall-runoff modeling. When performing rainfall-runoff modeling, it may be beneficial to consider non-stationarity and to perform multiple simulations varying the hydrometeorological parameters and inputs to provide a range of potential peak flows (i.e., sensitivity analysis) within the design life of the pipeline crossing.

5.2.1. Data and Inputs

To perform rainfall-runoff modeling, multiple data are required. Precipitation information is used to define the magnitude and timing of precipitation in the model. Geospatial data are used in the Geographical Information Systems (GIS) environment to physically characterize the watershed of interest to parameterize the hydrologic model. The primary data needed include:

- precipitation frequency information,
- spatiotemporal distribution of precipitation,
- physical basin and reach characteristics, and
- streamflow data for calibration.

5.2.1.1. Precipitation and Climate Data:

Precipitation information for flood rainfall-runoff modeling and flood frequency analysis is generally available from various agencies:

- **Point precipitation data and radar rainfall products** are available from the National Oceanic and Atmospheric Administration (NOAA) and the NOAA National Centers for Environmental Information.

    - ncdc.noaa.gov/cdo-web/
    - ncei.noaa.gov/access/search/index

- In watersheds where snowmelt plays a dominant flood mechanism, precipitation and temperature data (**snow telemetry and snow course data**) can be obtained from NRCS.

    - wcc.nrcs.usda.gov/snow/

- **Precipitation frequency estimates** and timeseries are available from the National Weather Service (NWS) Hydrometeorological Design Studies Center (HDSC). The NWS Precipitation Frequency Data Server provides precipitation depth-duration-frequency data across the U.S. This data can be obtained through a map-based web application, where a user can identify a location for which precipitation frequency estimates are needed.

    - NOAA Atlas 14 contains precipitation frequency estimates with associated 90% confidence bounds and supplementary information including the spatial ASCII grids of precipitation frequency estimates, temporal distributions for associated durations, and analyses of seasonality. For most states, these underlying data are from NOAA Atlas 14, Volumes 1-11. The Atlas is divided into volumes based on geographic sections of the country and is available for all states except for the Pacific Northwest.

    - In Washington, Oregon, Idaho, Montana, and Wyoming, more limited precipitation frequency data are available from the NWS HDSC:
        - Arkell and Richards (1986) for durations 1-hr and shorter;
        - NOAA Atlas 2 for 2-hr and 24-hr durations; and
        - Technical Paper 49 for durations greater than 1-day.

    - nws.noaa.gov/oh/hdsc/currentpf.html
    - hdsc.nws.noaa.gov/hdsc/pfds/index.html

- **Precipitation frequency estimates for Washington State** are also available from Schaefer et al. (2002).

    - wsdot.wa.gov/Research/Reports/500/544.1.htm

5.2.1.2. Elevation Data:

Elevation data are used to delineate basins and to calculate needed hydrologic geometry including: basin area, channel and flow-path lengths, and watershed and channel slopes. The finest resolution elevation data should typically be used.

- National Elevation Dataset (NED) and 3D Elevation Program (3DEP) data can be obtained through the USGS National Map Viewer. The 3DEP data, managed by the USGS, is an interagency program to provide high-quality topographic data (LiDAR, Interferometric Synthetic Aperture Radar [IfSAR]) for the U.S. by 2023—currently about 50% of the U.S. has available or in-progress elevation data to meet the 3DEP specification for high accuracy and resolution.

    - viewer.nationalmap.gov/basic/
    - usgs.gov/core-science-systems/ngp/3dep

- Elevation data are also available from various state and local agencies.

5.2.1.3. Soil Data:

Soil type information is needed for rainfall-runoff modeling to parameterize the loss parameters in the hydrologic model. The soil type information needed depends on the loss method used. The major source of information on soil types is available through the NRCS, which has prepared soil maps for most of the counties in the U.S. The two most used soils databases are the Soil Survey Geographic (SSURGO) and the State Soil Geographic Digital General Soil Map (STATSGO2). For hydrologic characterization of a watershed, use SSURGO when available.

- SSURGO and STATSGO2 data are available from the NRCS through the Geospatial Data Gateway or the Web Soil Survey.

  - gdg.sc.egov.usda.gov
  - websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

- **The SSURGO database** contains information about soil from NRCS field surveys and associated laboratory analyses generally at a 1:12,000 scale (some at a scale of 1:63,360). SSURGO datasets consist of map data, tabular data, and information about how the maps and tables were created. The soils database, containing information about the component soils and their properties, is linked to the map units. Some useful soil properties in the database, important for rainfall-runoff modeling, include hydrologic soil group, hydraulic conductivity, and soil depth.

  - nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627

- The **NRCS Soil Data Viewer ArcMap Add-In** can provide access to soil properties in an area of interest (i.e., within delineated basin), facilitating computation of a single value for a map unit without having to query the database, process that data, and link to spatial map.

  - nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/survey/geo/?cid=nrcs142p2_053620

- **STATSGO2** is a coarse resolution catalogue of soils and surficial geology at the 1:250,000 scale. The dataset was primarily created by generalizing more detailed soil survey maps, and consists of georeferenced, vector and tabular data of physical and chemical soil properties.

  - data.nal.usda.gov/dataset/united-states-general-soil-map-statsgo2

5.2.1.4. Land Cover Data:

Land use data are available in different forms, including aerial photographs and zoning maps.

- A useful source of land use data is the **National Land Cover Database (NLCD)** developed from decadal Landsat satellite imagery and other supplementary datasets by the Multi-Resolution Land Characteristics (MRLC) consortium. The NLCD 2016 Land Cover for the continental U.S. (CONUS) database is available for download from the MRLC consortium.

  - mrlc.gov/data?f%5B0%5D=category%3Aland%20cover

5.2.2. Rainfall-Runoff Models

There are many numerical hydrologic models that can be used to develop peak flow frequency estimates for pipeline design and evaluations of hazards. Two useful rainfall-runoff modeling platforms that Reclamation hydrologists use in pipeline hydrologic analyses include Technical Release 55 (TR-55) and Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS). These models, their applicability, and generalized overview of developing peak flow frequency estimates are discussed in this sub-section.

5.2.2.1. Technical Release 55 (TR-55):

5.2.2.1.1. Calculation Methods

The NRCS Technical Release 55 (TR-55), *Urban Hydrology for Small Watersheds*, provides two methods to calculate peak flows:

- **Graphical peak discharge method** (Soil Conservation Service [SCS][6], 1992) for homogeneous drainage areas with time of concentration less than 10 hours. The graphical peak discharge method is limited to watersheds with uniform runoff characteristics (whose soils, land use, and ground cover can be represented by a single CN) and only provides peak flows and not runoff hydrographs.

- **Curve Number (CN)** method (SCS, 1973) for watersheds with areas smaller than 25 mi^2 (SCS, 1986).

WinTR-55 Software for Small Watersheds: The WinTR-55 computer software package[7] was developed by NRCS to provide a tool to calculate peak flow for small watersheds. Peak flow for selected AEPs are computed using the CN method by applying precipitation frequency estimates to a dimensionless rainfall distribution curve for a 24-hour storm. Using the CN method, rainfall volume is converted to runoff volume using the watershed's CN, which is a function of soil type, vegetative cover, area of imperviousness, interception capacity, and surface storage (SCS, 1986). Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on travel time through the watershed (SCS, 1986).

To help users select the appropriate TR-55 procedures a specific project, SCS (1986) developed a workflow chart (Figure 7). For both methods, the basin/sub-basins need to be delineated, and information must be developed to assign CN to basin or sub-basins, calculate time of concentration and assign precipitation volumes and temporal pattern. The primary input data for this analysis include:

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[6] Soil Conservation Service (SCS) is now Natural Resources Conservation Service (NRCS).

[7] https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1042901

- elevation data to delineate the watershed and calculate watercourse length and slope,
- soil data to spatially map the hydrologic soil group,
- landcover data and aerial imagery to define the cover type,
- precipitation frequency volumes (if NOAA Atlas 14 information is available for the site, the TR-55 software will populate precipitation frequency volumes based on county and state), and
- 24-hour precipitation temporal distribution ordinates (if SCS synthetic rainfall distributions are selected for use, the rainfall distribution type can be selected in the TR-55 software – see SCS [1986] in Appendix C).

Procedures for performing a TR-55 analysis are described in SCS (1986), and detailed methodology are described in SCS (1973, 1992) and chapters of the NRCS National Engineering Handbook, Part 630 Hydrology (1997).

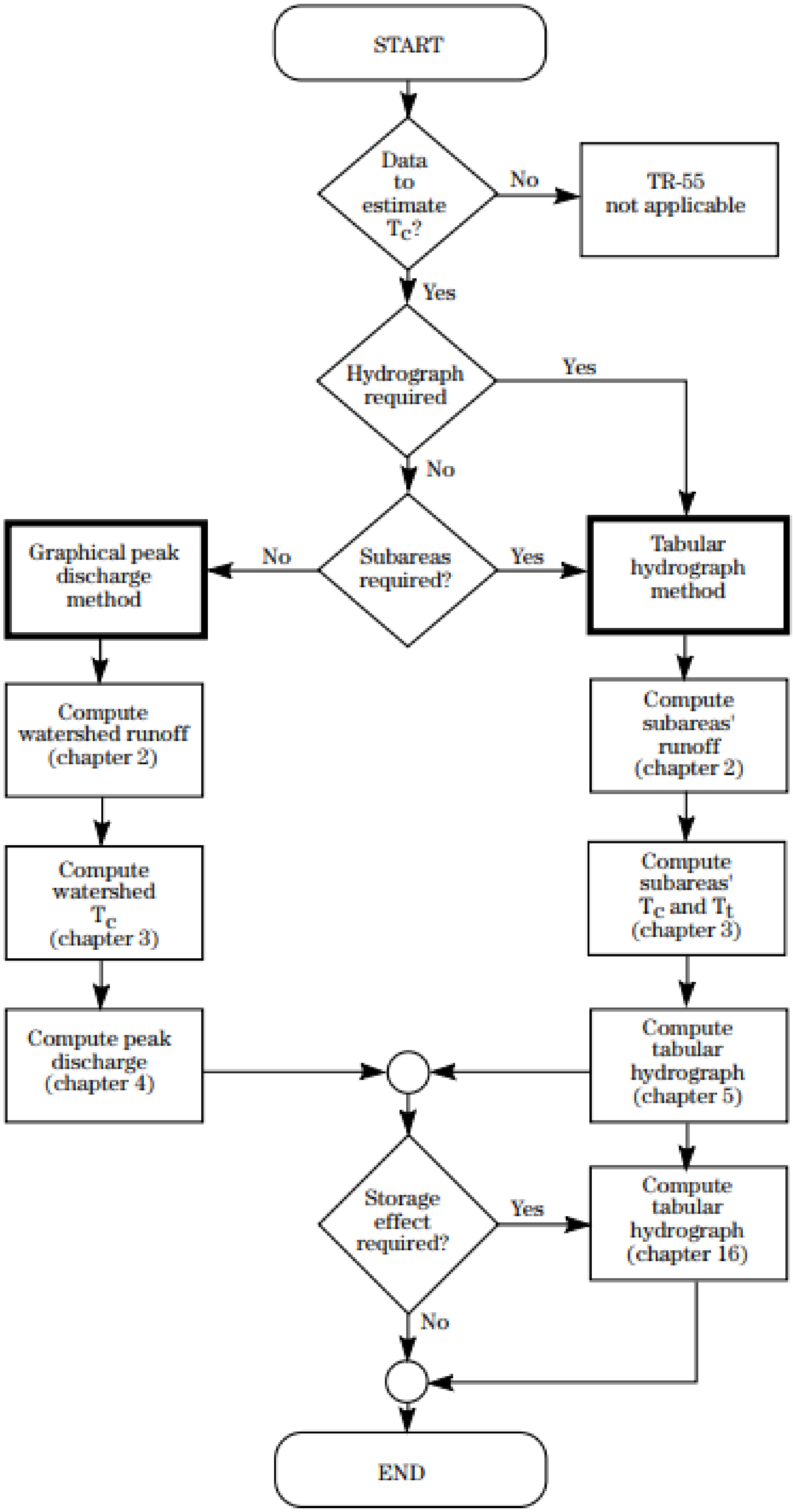

Figure 7. Workflow chart for selecting the appropriate procedures in TR-55 (SCS 1986).

5.2.2.2. Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS):

Rainfall-runoff modeling using HEC-HMS includes many hydrologic analysis methods (U.S. Army Corps of Engineers [USACE], 2018) and is a more robust and flexible software program than TR-55. It is a good alternative to TR-55 for calculating peak flows under these conditions:

- in large watersheds greater than 25 square miles (mi^2);
- in complex watersheds that necessitate alternative/advanced methods (canopy, surface, loss, transform, baseflow) and/or components (e.g. reservoirs, snow, gridded data); and
- when critical storm duration is much shorter or longer than 24 hours.

Similar to what was described previously for TR-55, the basin needs to be delineated and information must be developed to describe hydrologic characteristics of the watershed as well as the climatic inputs. Procedures for performing hydrologic simulations using HEC-HMS are comprehensively described in USACE (2018).

6. Hydraulics Analysis

Hydraulics analysis computations vary in involvedness, depending on channel complexity at the crossing.

Hydraulic parameters for scour estimation can be computed using peak discharge estimates from the design floods and a topographic survey of the crossing channel. The 10-meter resolution National Elevation Dataset (NED) topography data from the USGS are typically too coarse and should not be used in hydraulic analysis. Cross sections and a longitudinal profile of the channel may be acquired using both field survey data and high-resolution topographic data such as that collected from a LiDAR or photogrammetric survey.

A suitable channel roughness value should be estimated from bed material size and channel properties to represent stream channel roughness.

Hydraulic methods include at-a-station analysis, one-dimensional (1D) hydraulic modeling such as Hydrologic Engineering Center – River Analysis System (HEC-RAS) (USACE, 2016), or two-dimensional (2D) hydraulic model such as Reclamation's Sedimentation and River Hydraulics two-dimensional numerical model (SRH-2D) (Lai, 2008).

- For simple planform channels that are sand bedded or have some gravel, using an at-a-station analysis is usually sufficient as the bed slope and width tends to be relatively uniform during high flow events.

- For gravel bedded channels with more defined riffles and pools, a 1D gradually varied flow backwater model is more suitable given the longitudinal changes in slope and channel width associated with this morphology.

- For downstream culverts that create backwater at high flows, downstream bridge crossings, or other in channel structures, a 1D model is also needed.

- For more complex (multi-thread) channel planforms with non-uniform cross sections, systems with various side channels, flow concentrations, or complex contraction and/or expansion at bridges, a 2D model provides a more accurate representation of the flow field in such a way that you can focus on localized depths and velocities.

An at-a-station hydraulics (i.e., a normal depth calculation) requires a single cross section of the channel at the crossing where the average energy grade line slope through that cross section is assumed constant and equivalent to the bed slope. This method, which is applicable for relatively uniform cross section geometries, can be employed using a spreadsheet tool or commercial software, such as Bentley's FlowMaster® (2009). The current version of HEC-RAS (USACE,

2016) for at-a-station hydraulics, does not provide all the hydraulic variables necessary for scour calculations. Beware that using a single cross section to compute local hydraulics does not account for the backwater conditions, eddies, or secondary flow paths. This simplification can result in overestimating velocity and scour depth when backwater effects in the downstream channel are not accounted for. Moreover, the average cross-section velocity based on the uniform flow assumption can underestimate stream velocity and scour depth at locations where there is significant flow concentration.

One-dimensional, gradually-varied flow modeling generally requires at least four or five cross sections, downstream from the pipeline crossing. These cross sections should be spaced to represent major channel changes and should not be spaced more than about one channel width apart. Normal depth can be assumed at the downstream most cross section, which is also the downstream model boundary. These downstream cross sections give the model enough distance between the downstream model boundary and the pipeline crossing so the predicted water surface at the pipeline crossing is not influenced by the downstream boundary. 2D models require developing a topographic surface and using a downstream boundary water surface elevation generally from either an at-a-station or 1D hydraulic analysis.

Regardless of the method used to obtain the hydraulic variables, the calculated variables are used as input to the scour calculations. Key hydraulic variables include flow depth, cross sectional average velocity, unit discharge, and Froude number. Scour equations use hydraulic depth as an input value defined as the flow cross sectional area divided by the wetted top width. Some equations provide a more conservative estimate when using the normal depth from the at-a-station hydraulics. Overly conservative scour estimates can result if you use the 100-year flood peak discharge and its resulting at a station hydraulics where there is a backwater effect.

If culvert scour is needed (see Section 7.4), then culvert hydraulics will need to be computed. A complete analysis of culvert hydraulics can be difficult, and a description of this process is beyond the scope of these guidelines. Flow conditions vary over time for any given culvert; the barrel of the culvert may flow full or partly full depending on the upstream and downstream conditions, barrel characteristics, and inlet geometry. Typical culvert design methods are based either on the use of design charts and nomographs, or software programs (e.g., HY-8 or HEC-RAS). Using hydrologic estimates together with state-of-practice culvert design methodologies (FHWA, 2012c), you can estimate the discharge flowing through the culvert and use this in the culvert scour analysis.

7. Scour Analysis

Scour analysis for pipeline crossings underneath channels consists of evaluating general scour, bend scour and bed form scour.

To determine pipeline burial depth and length to prevent pipe exposure, use detailed scour analyses performed at each crossing site together with long-term degradation and estimate future channel bank erosion caused by channel migration.

Note that local scour analysis for bridge piers, abutments and associated channel contraction and other types of scour resulting from channel structures are not included in these guidelines. Methods for evaluating scour at bridges can be found in FHWA (2012a). Scour estimating methods for bank stabilization structures such as bendway weirs, spur dikes, vanes or barbs, stone toe with bio-engineering and riprap revetments are not included in this guideline but can be found in Baird et al. (2015). Scour associated with grade control structures and downstream of culvert are included later in Section 7.4. In the rare case of a pipeline crossing near a point where two channels join together (confluence), or for crossings under braided rivers confluences, perform the scour analysis using the methods of Ashmore and Parker (1983), and Amoafo (1985) as summarized in Melville and Coleman (2000). Methods for evaluating and protecting bank stabilization structures from scour can be found in Baird et al. (2015). Scour associated with grade control structures and downstream of culvert are included later in Section 7.4. In the rare case of a pipeline crossing near a point where two channels join (confluence), or for crossings under braided rivers confluences, perform the scour analysis using the methods of Ashmore and Parker (1983), and Amoafo (1985) as summarized in Melville and Coleman (2000).

Scour may occur as general, bend, or channel bedform, all of which occur in natural channels without the presence of structures. These types of scour occur into channel beds down to erosion resistant layers such as gravel, cobble, boulder, and bedrock. Section 4.2.3 contains a description of geologic data necessary to determine the presence and elevation of bedrock beneath channel crossing sites. Analysis methods for these types of scour are discussed in this section, and methods to be used for each type are listed in Table 1. Equations associated with these methods are in Appendix A. Table 1 also contains methods for degradation analysis for threshold channels covered in section 8.2.5.

Table 1. Equations Used to Evaluate Various Scour Types Along Channels that Are Distant from Structures

Scour Form	Equation	Source
General Scour	Zeller General Scour	Simons Li & Associates (1985)
	Neill Incised	Neill (1973)
	Neill Competent Velocity	Pemberton & Lara (1984)
	Blench Zero Bed Factor	Pemberton & Lara (1984)
	Lacey	ASCE, Predicting Bed Scour (2005)
	USBR Mean Velocity Method	Pemberton & Lara (1984)
	USBR Envelope Curve	Pemberton & Lara (1984)
Bend Scour	Zeller Bend Scour	Simons Li & Associates (1985)
	Maynord Bend Scour	Maynord (1996)
	Thorne Bend Scour	Thorne et al. (1995)
	USACE Bend Scour Design Curves – sand	EM 1110-2-1601, Plate B41, in USACE (1994)
Bedform Scour	Simons Li & Associates	Simons Li & Associates (1985)
	Dune Scour Equation	Flood Control District of Maricopa County (2003), as presented in the PBS&J Scour Spreadsheet (PBS&J, 2008)
Long-Term Bed Degradation:	Schoklitsh Method	Schoklitsh (1932) as adapted by Pemberton & Lara (1984)
	Meyer-Peter & Müller Method	Meyer-Peter & Müller (1948) as adapted by Pemberton & Lara (1984)
Stable Slope Equations	Lane's Tractive Force Method	Lane (1955) as adapted by Pemberton & Lara (1984)
	Shield's Diagram	Shields (1936), as adapted by Pemberton & Lara (1984)
Bed Armor Equation	Shield's Incipient Motion	Shields (1936) as adapted by Pemberton & Lara (1984

7.1. General Scour

General scour occurs in channels in their natural state without the presence of structures, Event based general scour is bed lowing observed in channels generated by peak discharges, not associated with bridge piers, abutments, culvert, bank stabilization or cross channel structure scour. General scour may occur on the streambed during the rising limb of a flood hydrograph, continuing until the erosive capacity of the water is lower than the ability of the channel

Event-based general scour occurs during the passage of flood peaks in mobile bed channels and often affects the entire cross section.

material to resist it. At that stage, the maximum extent of scour has been reached (Annandale 2006). Following the flood peak, sediments in transport may be deposited on the streambed, potentially infilling portions of the scoured bed. Therefore, a comparison of pre-and post-flood channel cross sections will not likely reveal the maximum extent of general scour. Consequently, the maximum extent of scour, rather than the net change in stream bed elevation, poses the greatest risk to pipelines.

As the flow level increases during the rising limb of the hydrograph, velocity and bed shear stress correspondingly increase, resulting in additional sediment transport capacity that generally lowers the channel bed. As the discharge incrementally increases, velocity and sediment transport capacity also increase. When the flood peak passes, velocity reduces, sediment transport capacity decreases, and the channel infills all or a portion of the scoured bed. Discharge waves travel faster downstream than their corresponding sediment waves, so erosion often occurs during the beginning and peak of the flood which is before upstream sediment loads have a chance to reach a given stream location. Deposition often occurs following the flood peak when the upstream sediment loads have arrived.

There are seven different methods for calculating general scour listed in Table 1. Each of the general scour methods are based on empirical data sets. Appendix A contains the range of conditions used for the development of each equation where available. Data on the range of applicability is not available for many methods. When these equations are applied there is often a wide range of scour estimates requiring professional judgement to determine which method or combinations of methods to use. One approach is to use a mean of all relevant results (not always including outlier results). If one method is significantly lower than other method results, it should not be used as it would skew results towards lesser scour. Another approach is to look for a grouping of equation results. For ephemeral channels in New Mexico, for example, results from the Blench Zero Bed Factor and Reclamation Envelope curve methods are often similar and averaged to estimate general scour.

General scour equations are based on field and laboratory measurements that require multiplying the results by a safety factor to account for uncertainty in the empirical methods and stream channel variability. Safety Factors are discussed in Section 10.

7.2. Bend Scour

Flow through channel bends creates scour because of secondary currents and higher velocity on the outside of the bend.

Bend scour is the process associated with the flow of water around a bend in a river without the presence of structures. Flow through channel meander bends moves in a helical pattern (secondary currents) that transports sediment from the outside (concave bank) to the inside of the bed where deposits often form a point bar. Secondary currents tend to move downstream with the flow in a helical motion: down along the outside bank of the channel bend, across the channel bottom toward the inside bend, and then back across the channel near the water surface. Secondary currents occur from the channel curvature and generally erode the outer bank and deposit sediment along the inside bank as a point bar. Because of the downstream movement of flow, the maximum bend scour typically occurs downstream from the maximum point of channel curvature (bend apex).

Considerable professional judgement should be exercised when determining how to interpret results. Evaluate scour depths from each method in Table 1 to determine what methods would be appropriate for your situation. You may determine that several methods would give similar results in this situation, and you could average the results from these methods together while not using the remaining method results. If you determine that there are not several methods that would give similar results, then either using the highest or a mean may be the most appropriate approach. If the lowest value is significantly less than others, do not include it in the average because including such a low value in the mean would skew results toward a lower scour value. Maynord (1996) and Thorne et al (1995) present regression equations which require a safety factor (Section 10) to account for uncertainty in the empirical methods. Appendix A contains guidelines for application of a factor of safety for the Maynard (1996) equation.

7.3. Bedform Scour

Mobile sand river beds develop dunes and anti-dunes that result in additional scour by the systematic process of erosion and deposition.

As sand size sediments are moved (transported) along the bed of a channel particles tend to move in groups as migrating bed forms such as ripples, dunes and anti-dunes. Ripples are too small to significantly contribute to channel scour.

The passage of dunes may increase local scour depths by as much as 30% (NRCS 2007). Bedform scour is estimated as the dune or anti-dune height (ASCE 2005, PBS&J 2008). The trough between crests of bedforms in sand bed streams also creates scour. More complete descriptions of bedforms can be found in Julien (2010) and Knighton (1998). Bedform equations require a safety factor (Section 10) to account for derivation data variability. The larger of the two bedform scour methods in Table 1 is used as part of the total scour depth calculation.

7.4. Culvert Scour

Culvert scour is local scour caused by the culvert structure and is not general scour. Culverts under roadway embankments convey cross drainage. As drainage waters are conveyed through the road embankment, flow discharges from the culvert act as impinging jets that transport bed sediments downstream, leading to the development of scour holes.

Downstream culvert scour and degradation analyses are needed where the pipeline alignment crosses close to the downstream end of a culvert, which typically conveys water under a road embankment. A scour hole may form where water exits the culvert like a jet and impacts the stream bottom. The scour hole dimensions from the impinging jet are shown in Figure 8 and Figure 9. The scour depth, width, and length are needed to design pipeline burial depth. Using culvert hydraulics for the unsubmerged outlet case allows you to estimate the maximum scour. To prevent exposure, the design burial depth for the pipe should either be the total of the scour depth, degradation estimate, and safety factor or the pipeline profile should be re-aligned to move the pipe downstream of the scour hole length plus a deemed safe distance to account for uncertainty. Similarly, pipe burial length (the length of pipe buried to the scour depth) should extend beyond the estimated dimensions of the scour hole width a deemed safe distance.

The methods for determining scour hole dimensions depend upon sediment size. Design equations to determine the maximum scour hole depth, width and length for various downstream channel bed sediment sizes are in Appendix Section A.4.

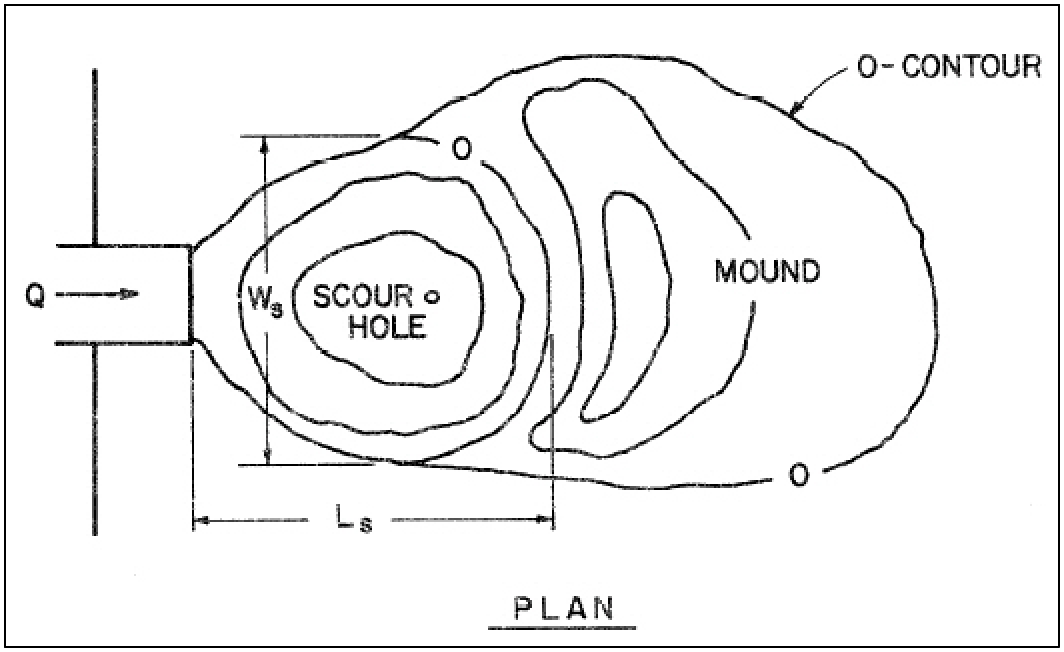

Figure 8. Definition of scour hole dimensions for design (plan view).

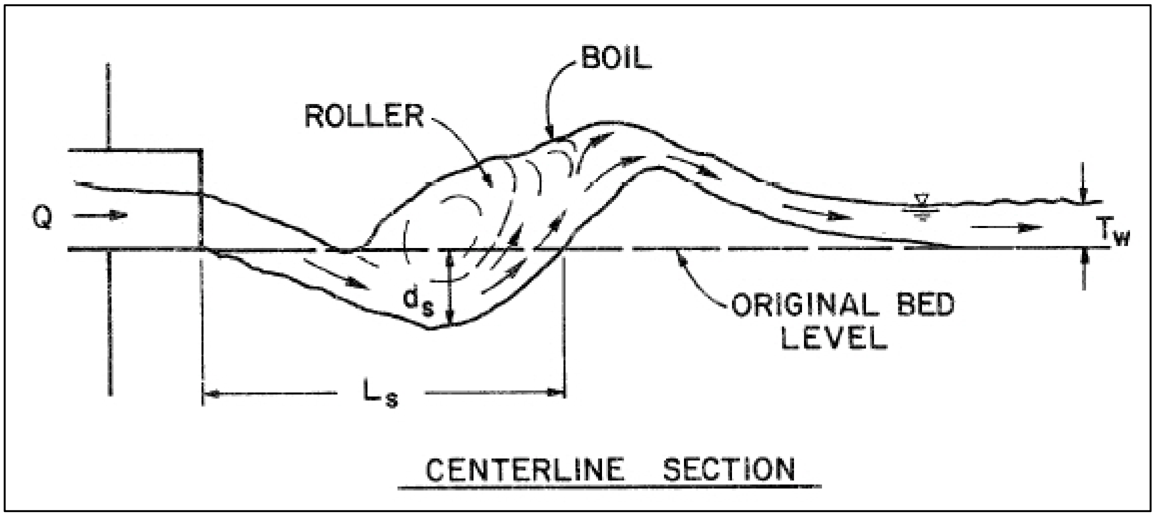

Figure 9. Definition of scour hole dimensions for design (centerline section) for channels without downstream degradation potential.

8. Degradation Analysis

Degradation is the long-term process where sediment removal from the bed lowers the streambed elevation.

Degradation should be accounted for as part of the total scour and degradation estimate so that the pipe can be buried deep enough to prevent the pipeline from being exposed. If there is a likelihood of advancing upstream channel degradation, the pipe can be buried deeper for added protection. Alternatively, the upstream degradation progression can be blocked by grade-control structures.

Channel degradation is often caused by a lowering of the base level that the stream flows drain to, a significant reduction in upstream sediment supply, or a significant increase in surface runoff (without additional sediment) usually due to added impervious surfaces associated with land development. Upstream sediment supply is significantly reduced downstream from large reservoir pools. Generally, channels downstream of surface runoff detention ponds do not experience degradation unless they are large enough to store sediment. Channels can also experience degradation as streams evolving over time (Schumm et al., 1984; Simon and Hupp, 1986; and Simon, 1989). Degradation occurs into channel beds down to erosion resistant layers such as coarse gravel, cobbles, boulders, and bedrock. Section 4.3 contains a description of geologic data necessary to determine the presence and the elevation of bedrock beneath channel crossing sites. For channels where sediment transport only occurs during high flows (threshold channel), use the degradation analysis in Section 8.2.5.

The following sections describe methods for estimating long-term degradation using long-term monitoring data, field evidence, milder channel slopes that may exist downstream, assessment of migrating headcuts, and streambed armoring for threshold channels. For channels where sediment is transported during most flows (alluvial channel), no degradation can be estimated if the following conditions are true:

- There isn’t any degradation evidence from long-term monitoring data (Section 8.1)
- There isn’t any field evidence of degradation (Sections 8.2.1 and 8.2.3)
- The downstream channel does not have a significantly milder slope (Section 8.2.2)

8.1. Long-Term Data

Field observations that identify and examine evidence of overall channel stability or instability are perhaps the most valuable tools in evaluating long-term degradation.

Long-term degradation can be difficult to evaluate, given the time scale, the complexity of watershed geomorphology, and typically limited historical data. Where there is long-term stream gage data or where there are repeated cross section measurements over many years or decades, channel degradation can be assessed. When there are also corresponding discharge measurements, then it may be possible to determine the linkages between degradation and hydrology, land use changes, and the effects of other human impacts (e.g., channelization, and floodplain encroachments from roads, bridges, development, levees, and other infrastructure). For most pipeline crossings in remote areas, there is usually limited historical data. The next few sections describe methods to determine long-term degradation in the absence of historical data.

8.2. Estimating Channel Degradation

8.2.1. Field Evidence of Fluvial Processes

Long-term degradation is commonly estimated largely based on observed field conditions (Figure 2) and any historical information that may have been gleaned from the stability analysis.

Incised channels, headcuts, and land development in the upper watershed are typical indicators of channel instability where degradation can reasonably be expected. Land development causes increased runoff, increasing discharges in channels, which in turn increases sediment transport capacity. Without a corresponding increase in sediment supply, channels affected by land development degrade to reduce the energy gradient needed to balance sediment transport capacity with supply.

Information from observed field conditions and historical information are considered in conjunction with mitigating factors, such as downstream hard points where the vertical profile of a given channel cannot degrade in human time scales. Examples of hard points include culverts, grade control structures, paved or riprapped low-water road crossings and bedrock in the channel. Where headcut(s) are migrating upstream towards the crossing location, you can use the height(s) of the headcut(s) as the estimate for the depth of the long-term degradation.

8.2.2. Downstream Long Profile Slope Changes

Where field observations or historical evidence do not provide evidence of degradation, and there is a milder downstream channel slope, you can estimate the potential degradation depth the channel could achieve by extrapolating the milder slope at the knickpoint upstream to the crossing location. This extrapolation assumes that the channel will continue to degrade or incise downward until it achieves the milder slope of the downstream channel. This method assigns the milder downstream slope as the equilibrium slope at the arroyo crossing. Figure 10 shows the longitudinal profile of an ephemeral channel with a milder downstream slope used to estimate the upstream degradation potential. Degradation estimates are used as the last summation piece of the total scour estimate.

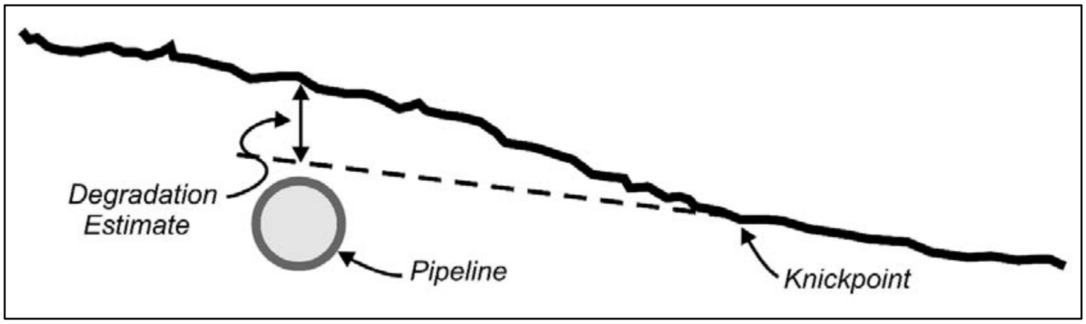

Figure 10. Schematic showing estimating channel bed degradation using a downstream milder bed slope.

8.2.3. Main Channel Migrating Headcuts

Headcuts migrating upstream can undermine and expose the pipeline (Figure 11 and Figure 12). Where headcuts are migrating upstream towards the crossing location, you can use the height of the headcut as the estimate for the depth of the long-term degradation. The maximum elevation difference should be used along with a safety factor (Section 10).

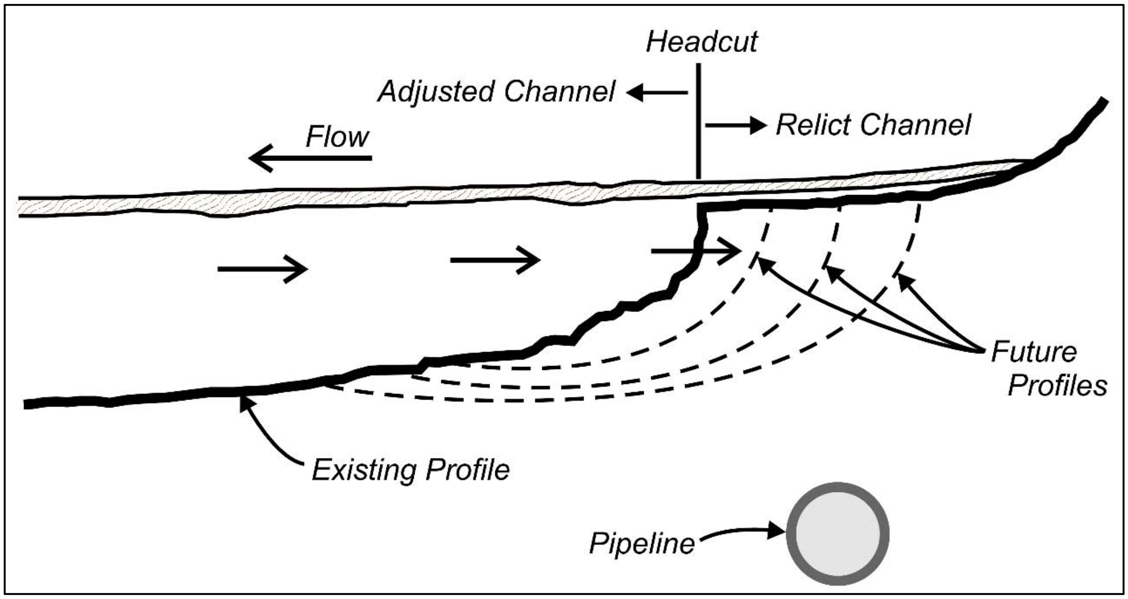

Figure 11. Schematic showing migrating headcut.

Figure 12. Active headcut in an ephemeral drainage channel in New Mexico.

8.2.4. Propagating Headcuts

Propagating headcuts that lack a defined channel upstream of the headcut pose another risk of degradation (Figure 13). When such headcuts are downslope from the pipe alignment, there is a risk that they will propagate to the pipe alignment and expose the pipeline. The propagation direction of these headcuts is especially difficult to predict. Historical photography may inform rates and directions of past propagation, and topographic data may indicate whether the headcuts are following a topographic swale or other feature. However, sometimes the direction of propagation may be influenced by irregularities in the water table or underlying alluvium, and bedrock. As it is uncertain where the pipeline may be impacted, a conservative design burial length is recommended to accommodate potential directions of future headcut propagation.

For the pipeline crossings near the propagating headcuts shown in Figure 13, this conservative design would include deep burial along any area directly west of the propagating headcuts with a buffer of deeper burial extending to the north and south. Determine the burial depth by adding the height of the headcut with a safety factor. In other cases where the area of impact is more difficult to predict, adaptive management coupled with preventative measures, such as installing armoring (riprap) along headcuts and monitoring their progress over time is recommended. Regular monitoring of both armored and unarmored headcuts is recommended during design life to enable protective measures if a headcut approaches the pipeline.

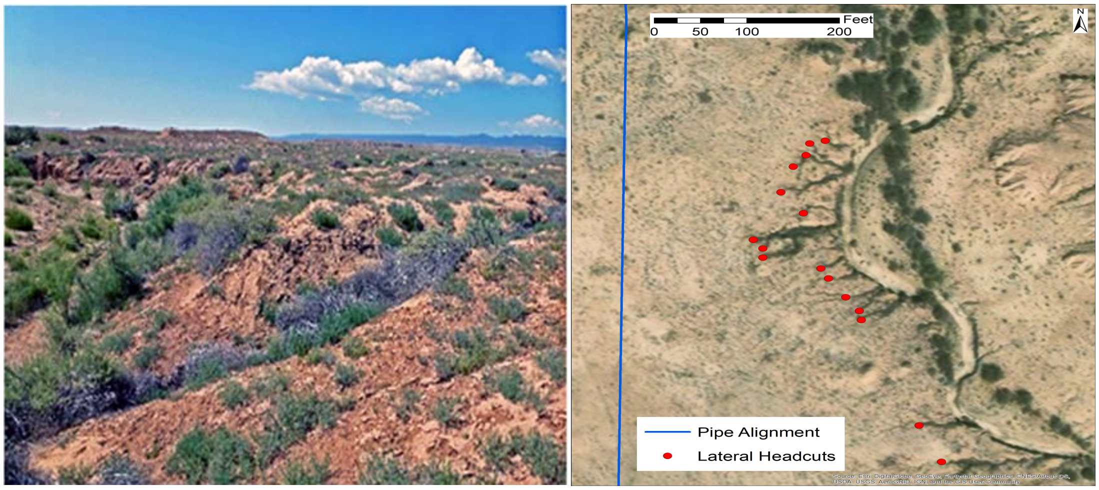

Figure 13. Lateral headcuts off the main channel propagating toward the pipe alignment. Field photograph (left) and 2017 imagery from ESRI (right).

8.2.5. Threshold Channels

Determining the channel's equilibrium (stable) slope based upon particle size assumes that channel degradation is limited by an armoring process or that the channel is a "threshold" channel. This is a commonly used practice to evaluate the potential for long-term degradation. The fundamental assumption is that all particles on the channel boundary are on the verge of motion at the bankfull discharge (Knighton, 1998). For incised channels the 2-year return period flow should be used instead of the bankfull discharge (not applicable for incised channels). Results from the hydraulic analysis serve as input data for empirical equations used to estimate potential channel degradation.

Threshold channels have relatively large sized bed material which is transported occasionally at high discharges.

You can use the Schoklitsh, Meyer-Peter & Muller, Lane's Tractive Force, and the two Shield's methods in Table 1 to estimate the slope at which bed particles are on the verge of motion. These estimated slopes can be compared to the existing slope. Where the existing slope is steeper there is potential for channel degradation. For the calculated slope to be used for estimating potential pipe cross degradation, a suitable downstream bed elevation control needs to be located. Controls could be bedrock, a tributary mouth with larger bed material, a downstream reach with larger bed material, a grade control structure or a culvert. Once a suitable downstream control is located then use its bed elevation to project the flatter slope upstream to the pipeline crossing location. The estimated degradation is the difference between projected and current bed elevation. This methodology assumes that degradation will occur until the milder slope is achieved. The threshold channel slope method may not be applicable if the computed stable slope is significantly less steep (milder) than the slope anywhere along the actual channel. In this case, assume the stable channel slope is equal to the milder slope of the downstream reach.

As with general and bend scour methods, the results from the methods listed in Table 1 should be evaluated. Groupings of results can be averaged. Results which are much lower or higher than the other methods should be eliminated from averaging to not bias the results to a very low value. For channels without a grouping or with much higher or lower results, a numerical average of all methods would be appropriate.

9. Lateral Stream Movement

Lateral channel migration is an equally important risk to unearthing pipelines in certain systems as scour and degradation (Figure 14). It’s important to synthesize information from the data analysis to determine the potential zone of lateral movement (Section 4.7).

The pipeline needs to be protected not just from vertical incision from scour and degradation, but also from lateral stream channel movements through the design life of the pipeline.

Figure 14. Exposure of a pipeline due to lateral stream movement. (Photo adapted from Fogg and Hadley, 2007).

9.1. Low Lateral Movement Risk

A crossing likely has a low risk of lateral movement if:

- The channel has a naturally straight morphology that has not experienced any historical lateral movement or bank erosion.
- The crossing is immediately downstream from culverts underneath highways (the case for many of the pipelines Reclamation teams have studied). In these cases, it is important to determine whether the pipeline is

properly located. For example, is the culvert centered along the stream axis or does the outlet preferentially direct flow into one stream bank, creating an erosional risk? If the culvert controls lateral movement, is well-located, and is not at risk to be undermined, then the site is likely at a low risk for future lateral migration.

At low-hazard priority crossings, as well as at high-hazard priority crossings with a low risk of lateral movement, the potential zone of lateral movement is defined as the top channel width, including any inset terraces and floodplains or other fluvial features, plus a buffer. Reclamation engineers typically apply a minimum buffer of at least 1-2 active channel widths. However, if erosion-resistant bedrock is present, this will limit the zone of potential lateral movement. If there is low risk of lateral movement but a potential for channel widening then we recommend using a model of bank retreat appropriate for the stream bank materials (e.g., USDA's Agricultural Research Service (ARS) Bank and Toe Stabilization Model[8], or similar). Potential for channel widening can be evaluated using a channel evolution model such as Schumm et. al (1984), Simon and Hupp (1986), and Simon (1989).

9.2. High Lateral Movement Risk

Stream channels at greater risk for lateral movement have:

- historical evidence of migration or bank erosion; or
- meandering, braided, or anastomosing channel morphologies.

At a minimum, the (channel migration) zone for lateral movement should be long enough to span the top channel width, including the alluvial plain, floodplain, side channels, and any vegetated islands. As necessary, the zone should be expanded to include all abandoned channel features such as cutoff meander bends.

Also consider the rate and location of historical channel movements. For especially dynamic channels, you may expand the zone of potential lateral movement to cover the entire valley that the stream is able to laterally migrate within. With small stream crossings, expand this zone to include abandoned stream features and areas where it appeared that a stream could potentially migrate. In all cases, the zone should also be expanded to include a buffer; you can typically use a larger buffer for sites at risk of lateral movement, determined by professional judgement. Note that the potential zone of lateral movement may also be limited by erosion-resistant bedrock or other features.

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[8] https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/bstem/overview/

10. Total Pipe Burial Depth and Length

The total burial depth and length of pipe is the culmination of the analysis contained in Sections 7, 8, and 9.

10.1. Total Pipe Burial Depth

Total recommended pipeline burial depth adds the potential for scour and degradation.

Total recommended pipeline cover depth is estimated as the summation of the event-based scour, degradation depth, and the application of a safety factor, *SF*. Given that bend scour equations include all scour processes in river bends it would be redundant to add bend scour to general scour and bed form scour. Therefore, the larger of general scour and bend scour is added to bedform scour to determine total scour.

Total event-based scour depth, Z_{event} is calculated as the summation of the maximum of the general and bend scour ($Z_{general}, Z_{bend}$) and the bedform scour, $Z_{bedform}$ as shown in Equation 2:

$$Z_{event} = MAX\left(Z_{general}, Z_{bend}\right) + Z_{bedform} \qquad (2)$$

Where the pipeline is constructed near culverts, then Z_{event} would be the estimated culvert scour. Event-based scour estimates use the peak design discharge (typically the 100-year event), for a 50-year design life often used for many pipelines.

Total pipeline cover depth is determined by adding event base scour, Z_{event} to long-term degradation depth, $Z_{degradation}$ and multiplying by an applicable safety factor. Equation 3 summarizes:

$$Z_{total} = (Z_{event} + Z_{degradation})SF \qquad (3)$$

Safety factors usually range from 1.1 to 1.5 (ASCE, 2005), depending upon the uncertainty of scour estimates and the effect of pipeline exposure and failure. Provide a larger safety factor for channels that show a potential for future degradation or that have migrating headcuts downstream of the alignment crossing. Also consider risks of potential failure, for example, provide a larger safety factor for larger transmission pipelines that supply municipal water as there are large adverse effects of the pipeline being out of service.

Total scour depth from Equation 2 is subtracted from the channel thalweg elevation to determine the elevation of the top of the pipe. When scour and degradation analysis topography are measured several years prior to construction, specify both the elevation of the top of pipe and a minimum cover depth. This will account for bed lowing during this period in incising channels. Where the computed total scour depth (Z_{total}) would be below the elevation of bedrock, limit the total scour depth to the elevation of the bedrock. See Section 11.3 on the appropriate modification to the burial depth design for bedrock. Check local, State or Federal regulations such as Pipeline and Hazardous Materials Safety Administration (PHMSA) (2019) to ensure all cover depth requirements are met.

10.2. Total Pipe Burial Length

The maximum burial depth is calculated along the bottom width of the active stream channel; however, this maximum burial depth must extend for some length on either side of the channel to accommodate the potential for migration (burial extent). Total burial length is the total of the channel top width, estimated long-term lateral migration, and a safety factor. For sites without a significant probability of lateral migration or channel widening, using the top channel width plus an additional safety factor extending from both channel margins may be used for this burial extent. This approach may cover any inset terraces or floodplain features that may be more prone to erosion.

The burial extent should cover the current channel top width and any foreseen potential movement due to channel migration or widening.

The proposed burial length (at maximum burial depth) should extend to cover the current channel's top width, $L_{top\,width}$ and any potential movement of the channel due to migration or widening, $L_{movement}$, plus a buffer that acts as a safety factor (Equation 4).

$$L_{total} = L_{top\,width} + L_{movement} + SF \tag{4}$$

The channel's top width for burial length should be expanded to the top width following excavation and reconstruction of the channel bank. For instance, if the existing channel bank is steeper than 2.5H:1V and is laid back to 2.5H:1V during pipeline installation, this would be the top width used in Equation 4. Determine the safety factor in Equation 4 by reviewing the historical migration rates.

When the burial length from one or more crossings overlaps into the zone of another nearby crossing, the $L_{top\,width}$ should extend through all overlapping crossings plus any potential movement of the channels due to migration or widening as determined from field and historical aerial photography analysis.

Pipelines require a series of miter bends to get underneath channel crossings; for multiple crossings close together it may be more practical to extend the burial length through all the crossings rather than have multiple miter bends close together (Figure 15).

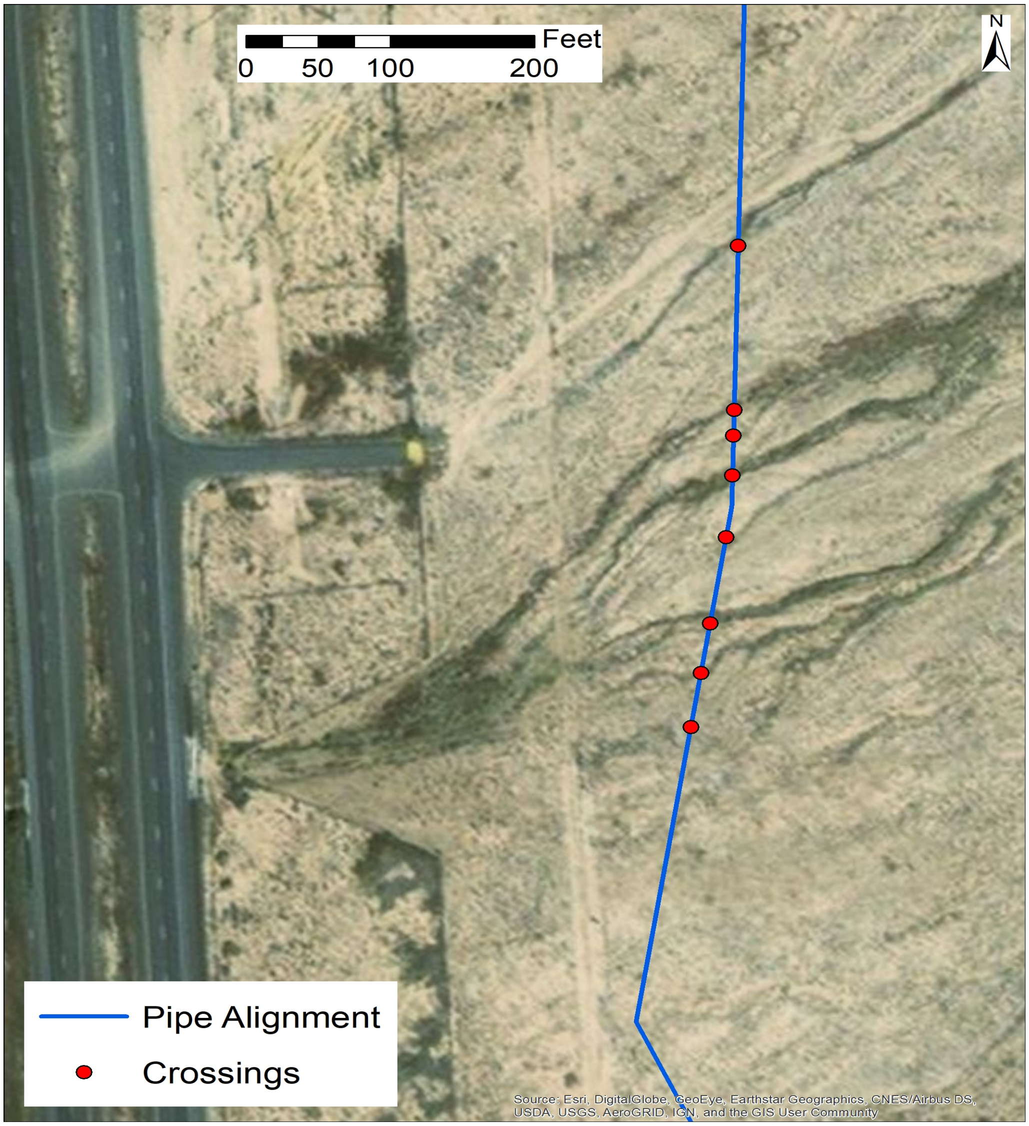

Figure 15. Multiple crossings shown against 2017 imagery, available from ESRI. Burial length should extend through all of these crossings with additional burial length to account for potential movement of the outmost channel (to the north and south) due to lateral migration or widening.

In cases where a channel parallels the proposed pipe alignment and where analysis of lateral stream movement shows potential lateral migration that would expose the pipeline without additional burial depth, recommendations to bury the pipeline to the depth of scour and degradation (multiplied by a safety factor) along the distance of the parallel channel reach are appropriate.

11. Construction Methods Considerations, Countermeasure Designs, and Inspections

Various construction scenarios require designs and countermeasures as discussed in this section. These situations include:

- Pipelines placed in bedrock need special construction methods, depending upon the bedrock properties.
- Trench excavation in high channel banks can experience piping after construction that erodes backfill along the axis of the pipeline
- Scour and future channel degradation may be so deep that an open trench placement method creates excessive land disturbance that can create construction rights-of-way issues.

Figure 16. Erosion of pipe backfill caused by surface runoff.

Construction methods considerations not presented in these guidelines include cofferdams and other dewatering methods for trench excavation, and countermeasures for potential flash floods when installing pipeline channel crossings.

11.1. Crossing Trench Backfill and Bank Treatment

Channel banks disturbed by pipeline placement will likely erode—even when compacted—and usually require some bank treatment for erosion protection and re-vegetation. In addition to naturally occurring streambank erosion, trench backfill can erode as well (Figure 16). Trenches that cross channels with banks that are flatter the 2.5H:1V are prescribed a lower level of bank treatment than steeper banks. Checking local, State, or Federal regulations is recommended to ensure all environmental requirements are met.

11.1.1. Components of Trench Backfill and Bank Treatment

The components of trench backfill and bank treatment are:

- **Compaction:** After trenching and placing the pipe and bedding at crossing sites the trench should be compacted to best mimic the density of the natural channel bank material and bed before trenching. Compacting trench backfill to natural density helps prevent seepage or piping paths along the longitudinal axis of the pipe line and down the stream crossing channel bank.
- **Grade to natural bank slope:** During compaction, the bank slope should be graded to the natural bank slope, but not steeper than 2.5H:1V.
- **Grade to 2.5H:1V:** For crossing channel banks steeper than 2.5H:1V trench backfill should be graded to 2.5H:1V during compaction to natural density.

Disturbed channel banks need erosion protection that is based on natural side slope. Banks steeper than 2.5H:1V need more bank treatment.

- **Slope transition to natural from 2.5H:1V:** For crossing channel bank slopes steeper than 2.5H:1 shape a transition between the compacted 2.5H:1V trench backfill and the native steeper slope. Determine the transition length by using about a 30-degree angle between the stream bank alignment of the top of the 2.5H:1V bank line and the undisturbed bank slope. The 30-degree angle minimizes turbulence as the flow expands into the trench cut and contracts downstream of the trench cut area back into the existing channel bank slope and top width (Figure 17). Where right-of-way or other concerns require a shorter transition distance than determined by a 30-degree expansion and contraction angle, a larger angle can be used. However, larger angles increase flow turbulence that may cause erosion and bank treatment maintenance until vegetation re-establishes on the disturbed trench alignment.

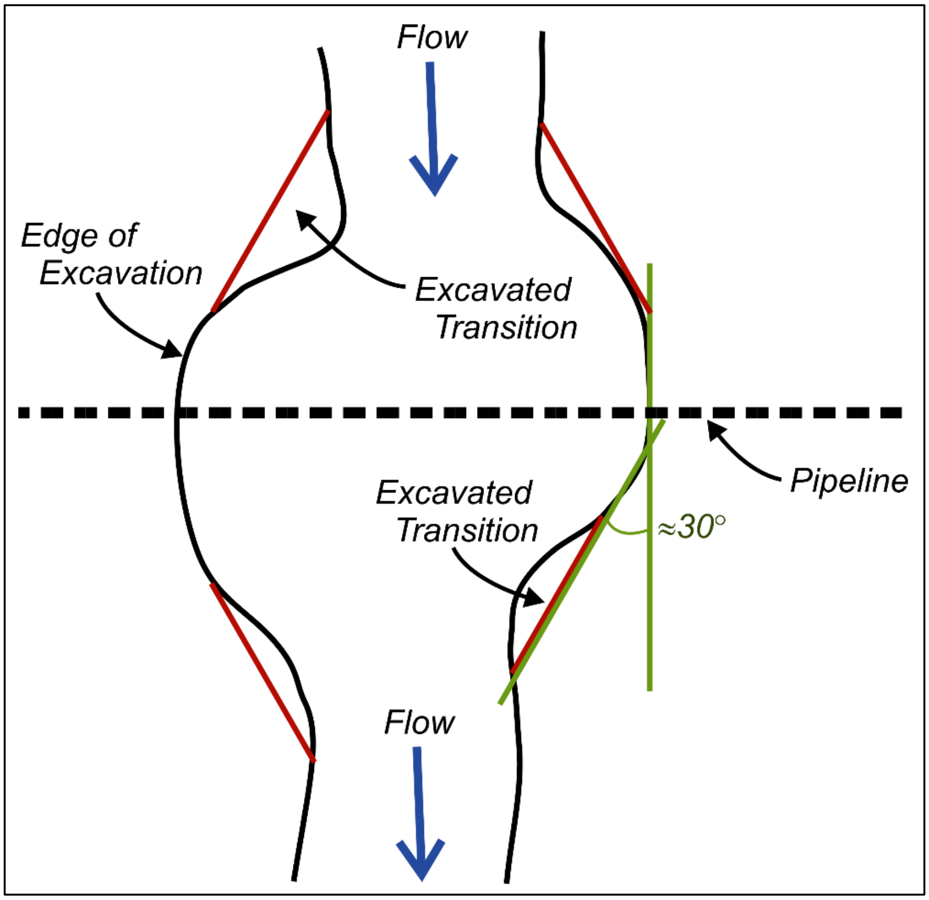

Figure 17. Transition, expansion, and contraction zones for banks steeper than 2.5H:1V.

- **Erosion Control Blanket:** Erosion control blankets help retain moisture to promote native vegetation re-growth and should be placed to cover the entire excavated bank. It should also extend a minimum of 5 feet along the bank line past the trench excavation for banks flatter than 2.5H:1V. For banks steeper than 2.5H:1V the erosion control blanket should extend along the bank line 5 feet past the transition zone (Figure 17) as much as practical. It is best for erosion control blankets to be made of bio-degradable fabric and fiber that will last between 3 to 5 years in arid climates. For more humid climates, hydroseeding and/or drill seeding using native grasses will help restore the disturbed channel bank to pre-existing conditions. For perennial channels, the adjacent riparian zone will be disturbed by trench excavation, therefore planting native shrub and tree species along with erosion control blankets will be needed. Bio-engineered bank protection may also be needed (Baird et al, 2019).

- **Biodegradable Coir Wattles:** Coir wattles placed on the disturbed bank and transitions between disturbed and undisturbed banks help prevent rills and gullies from forming. Bio-degradable wattles (9-inches in diameter) should to be placed on top of erosion control blankets to prevent the formation of erosion features down the bank such as the rills and gullies shown in Figure 16. Placement should be parallel to the bank top—extending a minimum of 5 feet past the edges of the trench excavation. Wattles should be placed at the top and toe of the bank and be spaced a minimum of 12 feet apart as measured along the longitudinal trench alignment of the bank slope. Use at least three wattles for lower bank heights (at the top, toe, and middle). Wattles constructed using coconut fiber (coir) bound by high strength bristle coir twine netting should provide about 5 years of erosion protection. An example installation of coir wattles is shown in Figure 18.

Figure 18. Example installation of biodegradable coir wattles (Photo courtesy of rolanka.com, all rights reserved).

- **Toe Riprap:** Riprap should be placed along the toe to prevent toe erosion due to turbulence in the upstream expansion and downstream contraction zones (Figure 19). Toe riprap is typically sized to withstand at least a 10-year return interval peak discharge. The bottom elevation of the toe rock beneath the channel bed is the scour elevation resulting from a 25-year return interval peak. The top elevation of the toe rock is usually the water surface of the 10-year return interval peak discharge in incised ephemeral channels. For intermittent and perennial channels top of the riprap should be the elevation where native vegetation grows on the bank. Bio-engineering may also be needed above the elevation of the riprap toe. Bio-engineering guidance can be found in Baird et al (2015). Toe rock of this size and placement elevations should provide toe stabilization until the disturbed bank line has returned as much as practical to a more natural state. But it is not intended to prevent long-term channel migration occurring in the future from reach scale channel processes.

- **Surface Diversion Berms:** Adding surface flow diversion berms is also recommended to help prevent the formation of rills, gullies and piping (Section 11.2).

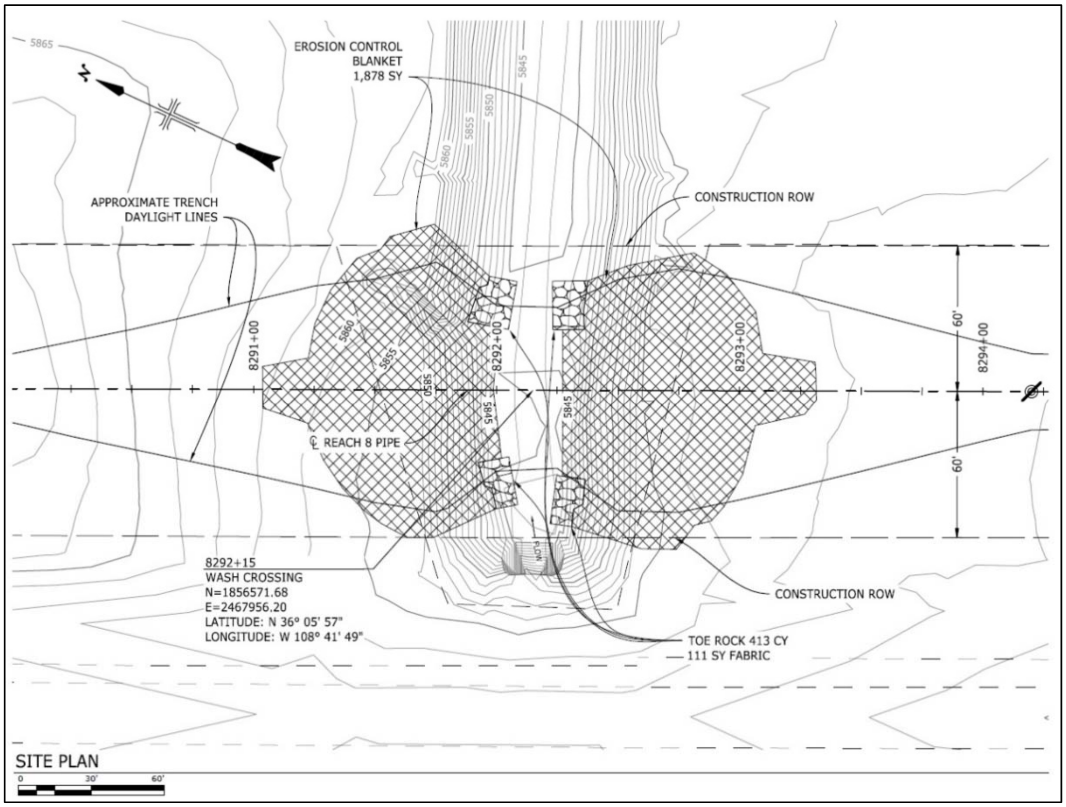

Figure 19. Typical bank treatment design at pipeline crossing for bank slopes steeper than 2.5H:1V. Note: surface diversion berms not shown.

Table 2 summarizes which bank treatment types apply to channel bank slopes flatter or steeper than 2.5H:1V.

Table 2. Types of bank treatment for crossings with natural bank slopes flatter and steeper than 2.5H:1V

Bank Treatment Type	**Natural Bank Flatter than 2.5H:1V**	**Natural Bank Steeper than 2.5H:1V**
Compaction	X	X
Grade bank to natural slope	X	
Grade bank to 2.5H:1V		X
Transition from 2.5H:1V Trench backfill to natural bank slope		X
Erosion Control Blanket	X	X
Biodegradable Coir Wattles	X	X
Toe Riprap		X
Surface Diversion Berms	X	X

11.1.2. Application Notes for Backfill and Bank Treatment

The purpose of bank treatment is to prevent bank erosion as a result of pipe installation and to put the crossing bank back to as natural state as possible. However, bank treatment is not intended to prevent channel migration occurring from reach-scale channel processes. For perennial channels, bio-engineering with stone toe is recommended, see Baird et al (2015) for design guidance.

The approaches in this section are ideally suited for a pipeline crossing immediately upstream of a roadway culvert, or where channel degradation or headcut migration processes are not expected to occur within approximately 10-years.

These applications are not recommended at locations that have exhibited extensive vertical instability and therefore have a large long-term scour depth. For example, this treatment would not be appropriate at or immediately upstream of a headcut as it could easily migrate upstream and expose the pipeline in the freshly excavated and backfilled trench. An alternative pipe alignment is recommended if the pipe alignment is immediately upstream of a headcut. If an alternate alignment is not practical, then installing the pipe underneath the channel using horizontal directional drilling (HDD) (Section 11.4) or stabilizing the headcut with a grade control structure (Section 11.5) is recommended. Where there is a migrating headcut for which analysis shows that the rate of headcut migration will not likely progress to the pipeline alignment during the design life, then some form of pipe protection may be warranted. This could be installing trench filled riprap (Baird et. al., 2015), which is a reasonably economic means to provide some level of pipeline protection to prevent complete pipeline exposure should the migration rate be faster than estimated. Trench filled riprap should provide enough short-term protection while longer term protection is designed and constructed.

11.2. Backfill Mounding and Surface Diversion Berms

Figure 20. Erosion of trench backfill just above the bank of a crossing site caused by internal erosion and piping. Note the exposed pipeline inside the trench.

After trenching and backfill on slopes, including channel bank slopes, voids can form within the backfill caused by the removal of soil material by seepage. Piping is an internal erosion that progresses and appears as a hole in the slope where water discharges to the surface. Continued piping erosion of the trench backfill can eventually expose the pipeline (Figure 20).

Coir wattles placed on the disturbed bank and transitions between disturbed and undisturbed banks help prevent rills and gullies from forming that can contribute to piping. Compaction and mounding of the trench backfill (Figure 21) and surface flow diversion berms (Figure 22) help divert surface runoff away from the trench alignment and help prevent piping and soil erosion. These features are needed when there are overland flow paths that cross the pipeline alignment as it approaches channel crossings and at the top of channel banks. Surface flow diversion berms, compaction and mounding are the only features in this guide that are applicable along the overall pipeline alignment.

Surface flow diversion berms consist of mounded backfill material and a coir wattle (Figure 22), constructed in an arc shape (Figure 23). At channel crossings they should be installed at the top of the excavated bank (Figure 24). In arid climate zones where there is minimal vegetation on the landscape, surface flow diversion berms are recommended to be placed every 100-200 feet when the slope of the land along the pipeline alignment exceeds about 4%. When the land slope along the alignment is more than 6% surface diversion berms should be placed more frequently. As the land slope increases, spacing between surface diversion berms should decrease accordingly. Surface diversion berms should be placed at the top of any slope and within 50 to 100 feet from the top since flows beginning near the slope top will cause the greatest erosion. The bank slopes and surface berm spacings are approximate, and there is no available guidance for these features. Any local experience and field observations that indicate the length and size of rill and gully erosion or piping processes should be used in lieu of these guidelines.

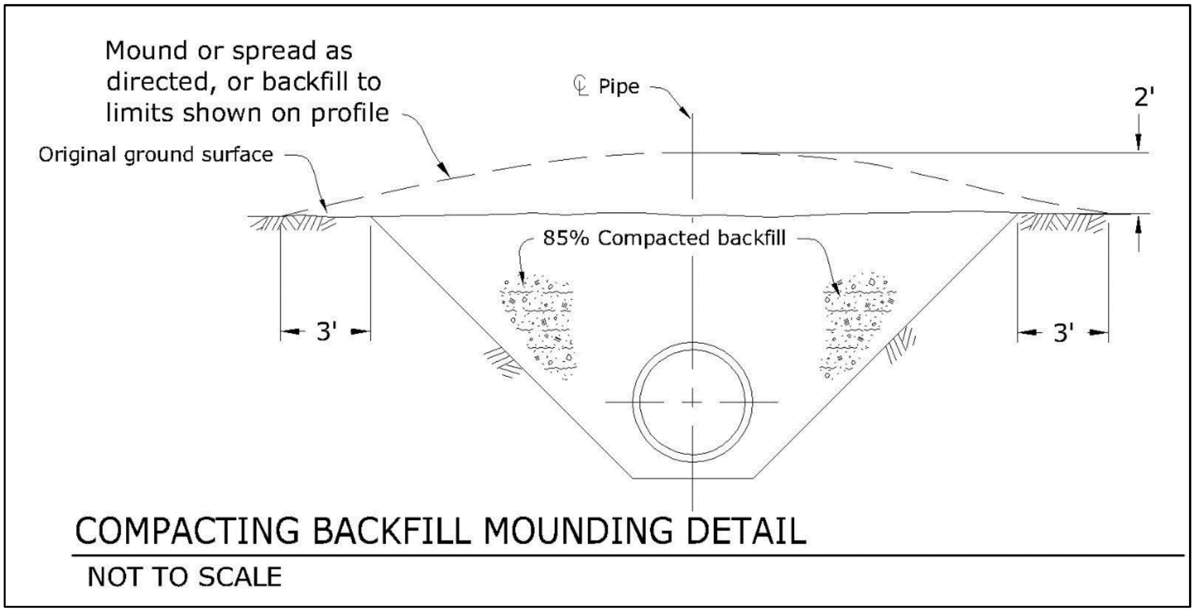

Figure 21. Compacting backfill mounding detail. Note for each pipeline project the insitu density will need to be determined. The 85% in this figure is for western New Mexico.

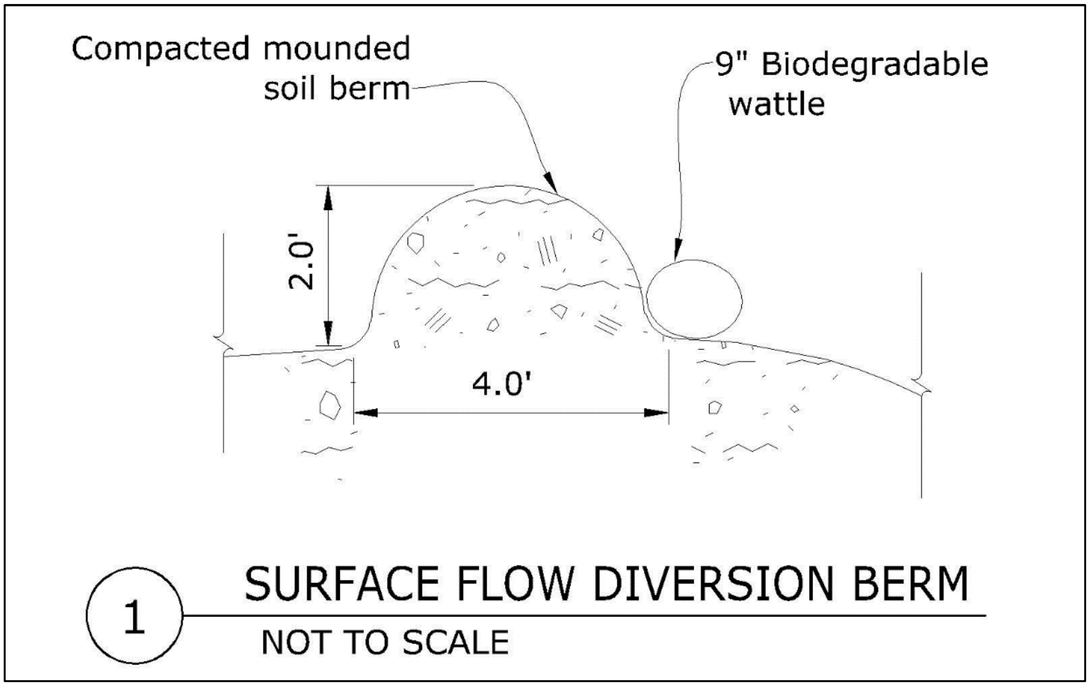

Figure 22. Surface flow diversion berm.

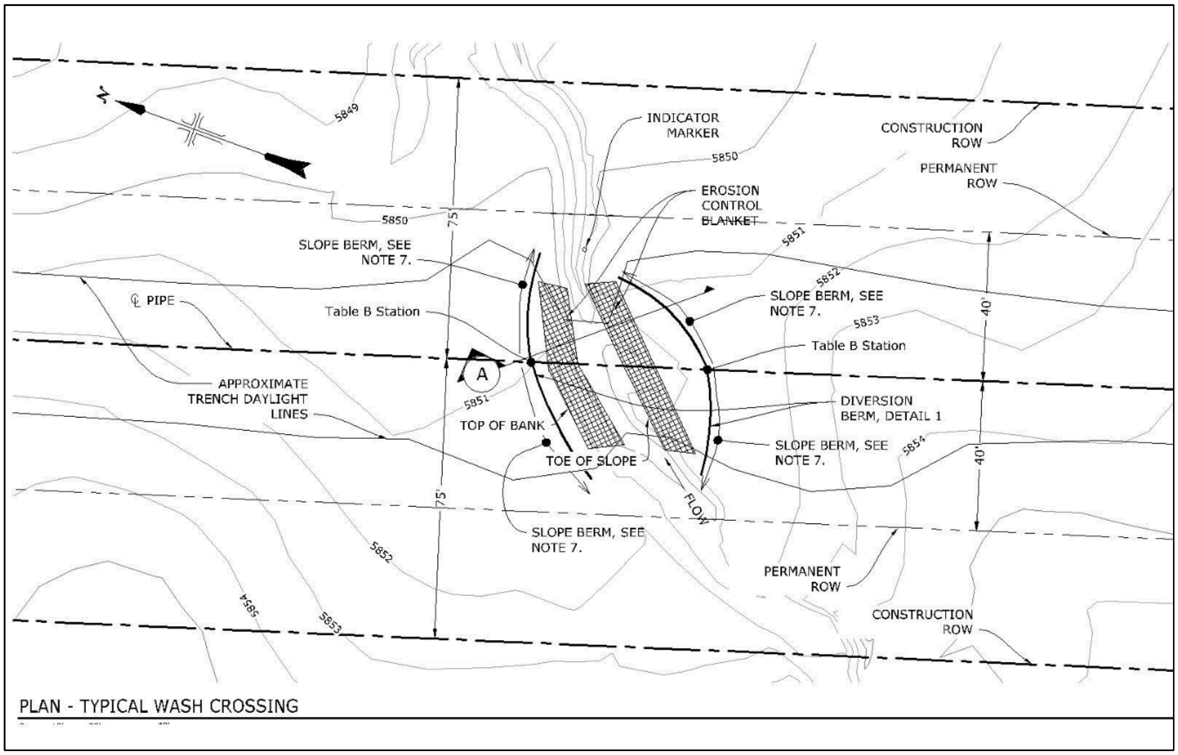

Figure 23. Plan of typical wash crossing for bank slopes flatter than 2.5H:1V.

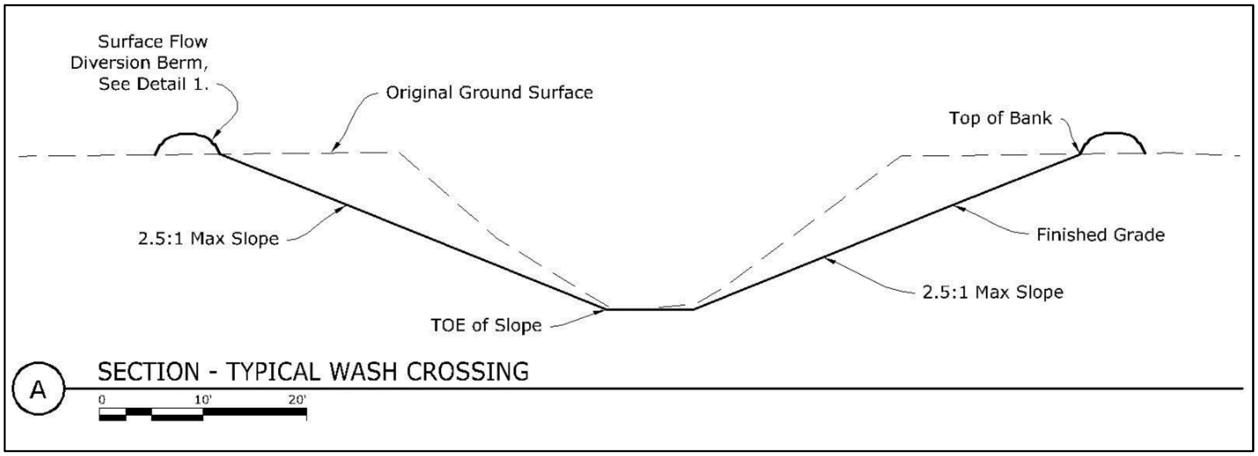

Figure 24. Detailed section of typical wash crossing for bank slopes greater than 2.5H:2V.

11.3. Trenching and Backfill in Bedrock

Examine the geology maps, drill logs, and test pits to determine if the estimated scour and degradation depth extends into bedrock. If so, then the bedrock should be excavated to provide at least 18 inches of cover over the pipe plus the minimum project frost burial depth. To prevent erosion of shallow backfill, pipe cover material should be lean concrete with a compressive strength of about 2,000 pounds per square inch (psi). Placing 18 inches of lean concrete is recommended to protect the pipe against exposure regardless of whether the bedrock can be excavated using a steel shank ripper attached to the rear of bulldozers, a pneumatic hammer attached to a hydraulic excavator, or blasting (in the case of very hard rock).

11.4. Horizontal Directional Drilling (HDD)

Occasionally, the standard trenching and backfilling approach may not be suitable for a variety of reasons including deep burial depth, long crossing length with active water conveyance, and environmental impacts. When these factors impact the constructability of a crossing to the point that a standard trenching approach cannot be used or is too expensive, horizontal directional drilling (HDD) should be considered. HDD allows for deep burial depths without a large surface cut — instead relying on entrance and receiving pits outside the ordinary high-water mark, where a prescribed horizontal bore path is drilled, and the pipe is then pulled back as the drill shaft is retrieved. HDD can more easily accommodate deeper burial depths than standard trenching and has the additional advantage of eliminating any channel bed and bank disturbance.

11.5. Grade Control Structures (GCS)

Grade control structures (GCS) are commonly used for in-stream structures that provide vertical stability for channels that might otherwise incise or degrade. These structures incorporate large changes in the vertical profile of a channel at a single location and can serve to stabilize the channel bed against degradation by providing an armored “hard point.” These structures can be constructed out of a variety of materials, including: cast-in-place concrete, loose rock, grouted rock, sheet pile, rock-filled gabion baskets, timber, etc. A GCS would typically be recommended at locations with unmitigated vertical instability and could be constructed immediately downstream of a pipeline crossing or at a site-specific downstream location (e.g. knickpoint, or narrow channel width). The crest elevation of the grade control structure will give the channel a “hard point” that will allow sediment to backfill behind the structure and stabilize the bed elevation at the pipeline immediately upstream. Guidelines for designing GCS are beyond the scope of this document. Occasionally there is a need for pipeline design to evaluate the scour potential of existing GCS, therefore Appendix A includes equations to determine scour downstream of GCS with both a vertical drop (concrete, sheet pile or gabion baskets), and with a downstream slope (concrete and loose or grouted rock).

11.6. Bank Stabilization for Channel Encroachment

See Reclamation’s Bank Stabilization Design Guidelines (Baird et al., 2015).

If the proposed pipeline alignment parallels the channel as opposed to crossing it, and if the channel is migrating laterally through bank erosion, then the pipe would be in jeopardy of becoming exposed if the channel were to migrate to the pipeline alignment. Burial depth can be increased using these guidelines to prevent exposure along the parallel length. Alternatively, bank stabilization measures could be installed along the channel to prevent channel migration.

11.7. Post Construction Crossing Inspections

Crossing inspections identify crossings with rapid degradation and lateral migration which may need countermeasures to ensure uninterrupted pipeline operation.

Regular office reviews and aerial and ground inspections should be conducted at a frequency that may vary for each site—depending on estimated risk and recent hydrologic (flooding) history and after large storm events. A simple early warning system is recommended for actively degrading crossing channels. The early warning device consists steel angle iron or pipe. The angle iron/pipe would be buried vertically into the stream bed on the downstream side of the pipeline and extend about 4 feet above the top of the pipe. Exposed top of angle iron/pipe would indicate that degradation is highly likely to be more than the design estimate and that degradation/scour countermeasure should be installed to prevent pipeline exposure.

The types of reviews and inspections include:

- **Office review** of as-built drawings, construction photographs and design documents to understand what was constructed and review of past monitoring reports to understand what has been happening.

- **Aerial inspections** can be made using current LiDAR or aerial photographs if there are enough present and historical images to assess channel changes through time. Small aircraft or unmanned aerial vehicles can be used for personnel trained in geomorphic hazard identification.

- **Ground inspections** can be used to inspect for the appearance of early warning steel angle irons or pipes and to conduct a visual assessment to subjectively assess if there are geomorphic activity warranting new or revised countermeasures.

- **Ground Surveys** can quantify the amount of topographic or bathymetric change.

Inspection interval may vary for each site depending on the estimated risk and recent hydrologic (flooding) history; should be inspected after a large storm.

12. Conclusion

Pipelines that cross perennial, intermittent, and ephemeral stream channels should be buried deep enough to remain undisturbed by scour and fill processes typically associated with passage of peak flows. Hydrologic and hydraulic analyses should be completed during the pipeline design phase to avoid failures, repeated maintenance of such crossings, and eliminate costly repairs and potential environmental degradation associated with pipeline breaks at stream crossings.

Following consistent guidelines for identifying, prioritizing, and evaluating the foreseen hazards at each pipeline crossing site will allow Reclamation Engineers to recommend appropriate burial depths and lengths for new and replacement pipe.

Buried pipelines encounter scour, long-term degradation, and lateral migration hazards when crossing underneath defined ephemeral, intermittent and perennial waterways. Identifying and evaluating which of these potential stream hazards are applicable at each crossing helps assign the most cost-effective counter measures to help maintain the life of the pipeline while minimizing future operation and maintenance costs. Without enough burial depth and burial length, pipelines can be exposed to hydraulic forces during high flows that often lead to exposure and ultimately failure.

Having a consistent methodology for assessing pipeline burial depth and length should help to ensure its use ultimately leading to fewer failures.

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14. Electronic Resources

Type	Source	Description	URL
Climate Data	NOAA	Point precipitation data and radar rainfall products	https://www.ncdc.noaa.gov/cdo-web/
Climate Data	NOAA National Centers for Environmental Information	Global coastal, oceanographic, geophysical, climate, and historical weather data	https://www.ncei.noaa.gov/access/search/index
Climate Data	NWS Hydro-meteorological Design Studies Center	Precipitation frequency publications	https://www.nws.noaa.gov/oh/dsc/currentpf.html
Climate Data	NWS	Precipitation depth-duration-frequency data across the U.S	https://hdsc.nws.noaa.gov/hdsc/pfds/
Geospatial Data	USGS	Earth Explorer - satellite, aircraft, and other remote sensing data	https://earthexplorer.usgs.gov
Geospatial Data	USGS	USGS National Map Viewer including National Elevation Dataset (NED) and 3D Elevation Program (3DEP) data	https://viewer.nationalmap.gov/basic/
Geospatial Data	NRCS	Soil Survey Geographic (SSURGO) and the State Soil Geographic Digital General Soil Map (STATSGO2) data	https://websoilsurvey.sc.egov.usda.gov/
Geospatial Data	MRLC consortium	NLCD Land Characteristics for the continental U.S. (CONUS) database	https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover
Hydrology and Climate Data	USBR	Water, hydropower, environmental, and infrastructure data	http://water.usbr.gov
Hydrology and Climate Data	NRCS	Precipitation and temperature data (snow telemetry and snow course data)	https://www.wcc.nrcs.usda.gov/snow/
Hydrology Data	USGS	National Water Information System (NWIS)	https://waterdata.usgs.gov/nwis
Programs	USGS	PeakFQ can be used to perform an EMA analysis	https://water.usgs.gov/software/PeakFQ/
Programs	USGS	StreamStats is a map-based web application for watershed analysis.	https://streamstats.usgs.gov/ss/
Programs	NRCS	WinTR-55 computer software package calculates peak flow for small watersheds	https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1042901
Programs	USDA ARS	Bank and Toe Stabilization Model	https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/bstem/overview/

Appendix A - Scour Equations

This appendix contains all the equations referred to in these guidelines. Nomenclature in this appendix is not consistent between equations but is defined. Many of the equations use bankfull flow hydraulic properties. For scour calculations we use the design event (e.g. 100-year flood) or the maximum discharge contained within the main channel whichever is highest in lieu of bankfull (e.g. incised channels). For braided or anastomosing channels, we recommend using a 2D model to determine the hydraulics in the largest braid or anastomose channel for scour calculations.

A.1. General Scour Equation

Zeller General Scour Equation

$$y_s = y_{max}\left[\frac{0.0685 * V^{0.8}}{y_h^{0.4} S_e^{0.3}} - 1\right]$$

Where:
y_s is scour depth below streambed (ft),
y_{max} is maximum depth of flow (ft),
V is average velocity of flow (ft/s),
y_h is hydraulic or mean depth of flow (ft), and
S_e is dimensionless energy slope.

Reference: Simons Li & Associates, 1985

Neill Incised

$$y_s = y_{bf}\, Z_N \left(\frac{q}{q_{bf}}\right)^m$$

Where:
y_s is scour depth below streambed (ft),
y_{bf} is average depth at bankfull discharge in incised reach (ft),
Z_N is the multiplying factor (Table A-1),
q is design flood unit discharge (ft^3/s per ft of width),
q_{bf} is bankfull unit discharge (ft^3/s per ft of width), and
m is the exponent, which varies from 0.67 for sand to 0.85 for coarse gravel.

Reference: Neill, 1973

Blench Zero Bed Factor

$$y_s = Z_B \left(\frac{q^{2/3}}{F_{b0}^{1/3}}\right)$$

Where:
y_s is scour depth below streambed (ft),
F_{b0} is Blench's "Zero Bed Factor," interpolated from Figure A-1. The Blench Zero Bed Factor curve (Figure C-1) shows an applicable range of bed sizes from sand (>0.0625mm) to medium boulder sizes (<1,000 mm).
q is design flood unit discharge (ft^3/s per ft of width) and
Z_B is the multiplying factor (Table A-1).

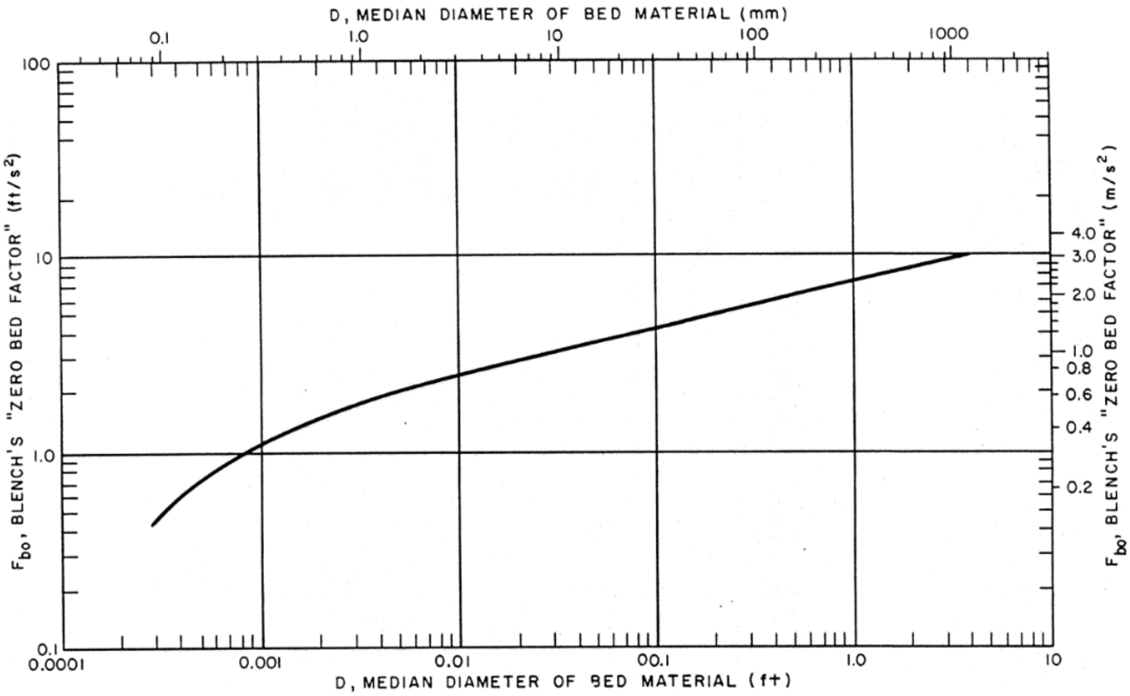


CHART FOR ESTIMATING F_{bo} (AFTER BLENCH)

Figure 9. - Chart for estimating F_{bo} (after Blench, 1969).

Figure A-1: Blench's "Zero Bed Factor"

Reference: Pemberton & Lara, 1984

Table A-1: Multiplying factors for Neill, Lacey, and Blench scour equations based on channel conditions. (after Table 7 in Pemberton and Lara, 1984)

Condition	Neill – Z_N	Lacey – Z_L	Blench – Z_B
Straight Reach	0.5	0.25	0.6
Moderate Bend	0.6	0.5	0.6
Severe Bend	0.7	0.75	0.6
Right angle bends	N/A	1	1.25
Vertical rock bank or wall	N/A	1.25	N/A

Lacey General Scour Equation

$$y_s = Z_L y_L$$

$$y_L = 0.47\left(\frac{Q}{1.76\sqrt{d_m}}\right)^{1/3}$$

Where:
y_s is scour depth below streambed (ft),
y_L is the mean depth using the Lacey regime equation (ft),
Q is the design discharge (cfs),
d_m is mean grain size (mm),

Z_L is the multiplying factor (Table 3) and
Note: PBS&J also uses $y_s = Z_L\, y_h$ where y_h=hydraulic depth

Reference: ASCE Prediction Bed Scour, 2005

Neill Competent Velocity

$$y_s = y_h \left(\frac{V}{V_c} - 1\right)$$

Where:
y_s is scour depth below streambed (ft),
y_h is mean depth (ft),
V is cross section mean velocity (ft/s),
V_c is competent mean velocity (ft/s) for sand and gravel interpolated from Figure A-2.
The competent velocity for erosion of cohesive sediments are presented in Table A-2.

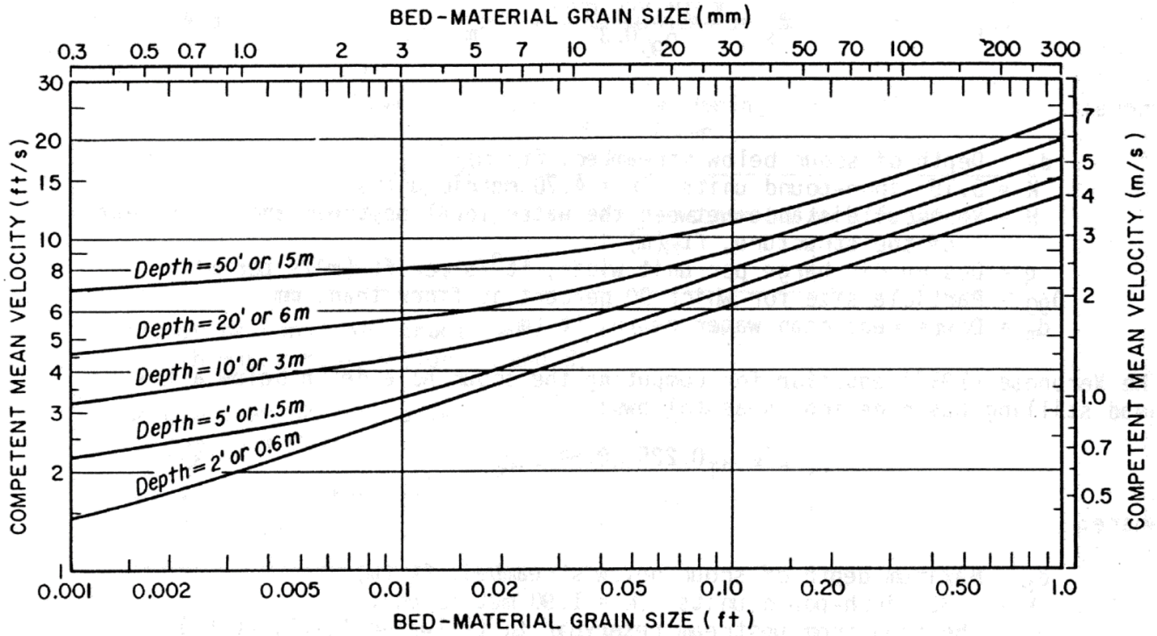


Figure A-2: Suggested competent mean velocities for significant bed movement of sand and gravel, in terms of grain size and depth of flow (after Neill, 1973).

Table A-2. Competent mean velocities for erosion of cohesive sediments (Table 8 Pemberton and Lara, 1984)

	Competent mean velocities (ft/s)		
Depth of flow (ft)	Low velocities for easily erodible sediments	Average velocities	High velocities for resistant sediments
5	1.9	3.4	5.9
10	2.1	3.9	6.6
20	2.3	4.3	7.4
50	2.7	5.0	8.6

Reference: Pemberton & Lara, 1984

USBR Envelope Curve

$$y_s = 0.937\left(\frac{q}{3.45}\right) + 2.47 \text{ if } q < 3.45$$

$$y_s = 2.45\, q^{0.24}, \text{if } q > 3.45$$

y_s is scour depth below streambed (ft) and
q is design flood unit discharge (ft^3/s per ft of width).
Where slope should be between 0.004 to 0.008 ft/ft, d_{50} should be between 0.5 to 0.7mm, and unit q should be less than or equal to 50 ft^3/s per ft width (Figure A-3). This method gives reasonable results for steeper slopes and coarser bed material sizes when unit q is less than or equal to 50 ft^3/s per ft width. This method was developed from field observations of ephemeral channel scour in the arid southwestern United States.

Reference: Pemberton & Lara, 1984 (adapted by PBS&J, 2008 for q < 3.45 ft^2/s)

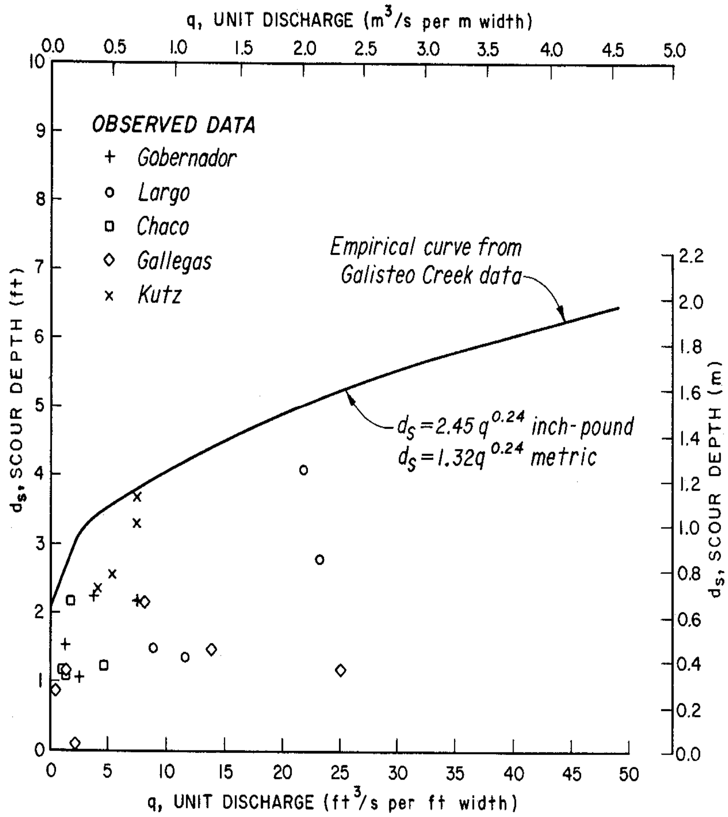


Figure A-3: USBR Envelope Chart for general scour calculations

USBR Mean Velocity Method

$$y_s = Z_L y_h$$

Where:
y_s is scour depth below streambed (ft),
y_h is mean depth (ft) and

Z_L is the multiplying factor (Table 3).

Reference: Pemberton & Lara, 1984

A.2. Bend Scour Equations

Zeller Bend Scour Equation

$$y_{bs} = \left(\frac{0.0685\, y_{max}\, V^{0.8}}{y_h^{0.4}\, S_e^{0.3}}\right)\left[2.1\left(\frac{W}{4\, R_c}\right) - 1\right]$$

$$X = \left(\frac{2.3\, C}{\sqrt{g}}\right)\left(\frac{V^2\, W_b}{g\, R_c} + y_{max}\right)$$

$$C = \frac{1.486}{n} R_h^{1/6}$$

$$X = \left(\frac{2.3\, \left(\frac{1.486}{n} R_h^{1/6}\right)}{\sqrt{g}}\right)\left(\frac{V^2\, W_b}{g\, R_c} + y_{max}\right)$$

Where:
y_{bs} is bend scour below thalweg (ft),
y_{max} is maximum flow depth at the design discharge (ft),
y_h is mean cross-section depth at the design discharge (ft),
S_e is dimensionless energy slope
V is average velocity of flow at the design discharge (ft/s),
W is channel top width (ft), and
R_c is the radius of curvature (ft).
X is the distance downstream from the end of curvature to where downstream currents have dissipated (ft),
C is the Chezy coefficient,
g is acceleration of gravity (32.17 ft/s^2),
W_b is channel top width at the bend (ft), and
R_h is the hydraulic radius (ft).

Reference: Simons Li & Associates, 1985 (page 5.105-5.106)

Maynord Bend Scour

Note: Not recommended where overbank depth exceeds 20% of channel depth.

$$y_{bs} = y_h\left[1.8 - 0.051\left(\frac{R_c}{W}\right) + 0.0084\,\left(\frac{W}{y_h}\right)\right] - y_h$$

Equation is limited to:

$\frac{R_c}{W} < 10$ and $\frac{R_c}{W} > 1.5$; if $\frac{R_c}{W} < 1.5$, ratio $\left(\frac{R_c}{W}\right)$ in equation is set to 1.5.

$\frac{W}{y_h} < 125$ and $\frac{W}{y_h} > 20$; if $\frac{W}{y_h} < 20$, ratio $\left(\frac{W}{y_h}\right)$ in equation is set to 20.

Where:
y_{bs} is bend scour below thalweg (ft),
y_h is the mean depth of the upstream crossing for this equation,
W is channel top width (ft), and
R_c is the radius of curvature (ft).

When y_{bs} is multiplied by a factor of safety (FS) of 1.00, 25% of the observed values of y_{bs} were underpredicted by more than 5%. When FS=1.10, only 2% of the observed values of y_{bs} were underpredicted by more than 5% (Maynord, 1996)

Reference: Maynord, 1996 via ASCE, 2005

Thorne Bend Scour

$$y_{bs} = y_h\left[2.07 - 0.19\log\left(\frac{R_c}{W} - 2\right)\right] - y_h$$

Equation is limited to:

$$\frac{R_c}{W} > 2$$

Where:
y_{bs} is bend scour below thalweg (ft),
W is channel top width (ft), and
R_c is the radius of curvature (ft).

Reference: Thorne et. al, 1995 via ASCE, 2005

USACE Bed Scour Design Curves

$$y_{bs} = y_h\left[-1.51\log\left(\frac{R_c}{W}\right) + 3.37\right] - y_{max} \text{ for sand} - \text{bed channels}$$

$$y_{bs} = y_h\left[-1.62703\log\left(\frac{R_c}{W}\right) + 3.375\right] - y_{max} \text{ for gravel} - \text{bed channels}$$

Where:
y_{bs} is bend scour below thalweg (ft),
W is channel top width (ft),
R_c is the radius of curvature (ft) and
y_{max} is the maximum depth at the design discharge (ft).

Reference: Corps of Engineers EM 1110-2-1601 Plate B41.

A.3. Bedform Scour Equations

ASCE Bedform Scour Equation

$$y_{bf} = DF * y_{max} \text{ for dunes}$$

$$y_{bf} = \frac{0.027}{2\,V^2} \text{ for antidunes}$$

$$y_{bf} = 0 \text{ for plane bed}$$

Where:
y_{bf} is bedform scour (ft),
DF is dune scour as a fraction of flow depth and
y_{max} is the maximum depth at the design discharge (ft).

Recommended values for DF are from 0.1 to 0.5 or 0.167 per Yalin (1964).

Reference: ASCE, Predicting Bed Scour, 2005

Antidune scour

$$y_{bf} = \frac{0.28\pi V^2}{g} \text{ for antidunes}$$

Where:
y_{bf} is bedform scour (ft),
V is average velocity of flow at the design discharge (ft/s) and
g is acceleration of gravity (32.17 ft/s^2)

Reference: Simons, Li & Associates 1982

Bedform Scour using Maricopa Co. Dune Scour Method

$$y_{bf} = \frac{0.066}{2}\, y_h^{1.21}$$

Where:
y_{bf} is bedform scour (ft) and
y_h is mean depth (ft)

Reference: Flood Control District of Maricopa County, Draft Drainage Design Manual, Hydraulics, September 2003

A.4. Equilibrium Slope Equations for Bankfull Discharge

Schoklitsh Method

$$S_L = 0.00174\left(\frac{d_{50}\,W}{Q_{bf}}\right)^{0.75}$$

Where:
S_L is equilibrium dimensionless slope for bankfull discharge,
W is channel width (ft)
d_{50} is mean grain size (mm) (50% finer particle size) and
Q_{bf} is bankfull discharge (ft^3/s).

Reference: Pemberton & Lara, 1984.

Meyer-Peter Muller Method

$$S_L = 0.19\left(\frac{n}{d_{90}^{1/6}}\right)^{1.5}\left(\frac{d_{50}}{y_{bf}}\right)$$

Where:
S_L is equilibrium dimensionless slope for bankfull discharge,
d_{90} is 90% finer particle size and
y_{bf} is mean flow depth at bankfull discharge (ft).

Reference: Pemberton & Lara, 1984.

Lane's Tractive Force Method

$$S_L = \frac{\tau_c}{\gamma_w\,R_h}$$

Where:
S_L is equilibrium dimensionless slope for bankfull discharge
τ_c is critical shear stress, based on d_{50} particle size, interpolated from Figure A-4
γ_w is the specific weight of water (62.4 lb/ft^3) and
R_h is the hydraulic radius (ft).

Reference: Pemberton & Lara, 1984

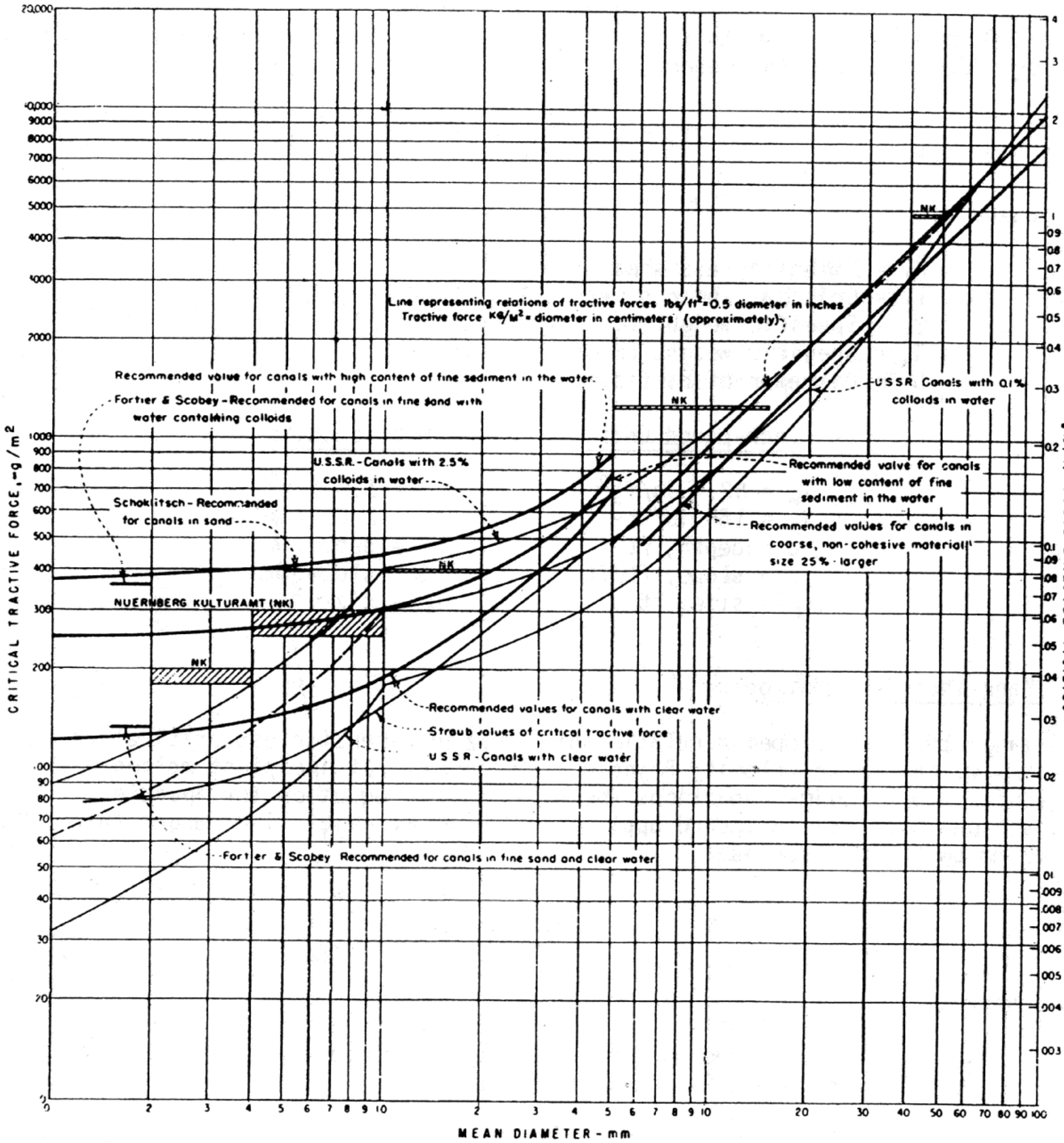


Figure A-4: Tractive force versus transportable sediment size (after Lane, 1952). Shield's Diagram Iterative Method

- $U^* = \sqrt{S_i\, R_h\, g}$
- $Re^* = U^* \left(\frac{d_{50}}{\nu}\right)$
- $S_f = \frac{\tau^* (\ _s - \gamma_w)\, d_{50}}{_w\, R_h}$

Where:

U^* is critical shear velocity (ft/s),
S_i is the initial guess for slope,
R_h is hydraulic radius of channel (ft),
g is acceleration of gravity (32.17 ft/s^2),
Re^* is critical Reynold's Number,
d_{50} is median particle size (ft),
ν is the kinematic viscosity of water based on temperature and interpolated from Table A-3,
$\tau^*$is dimensionless critical shear stress (see Figure A-5),
γ_s is the specific weight of sediment (165 lb/ft^3),
γ_w is the specific weight of water (62.4 lb/ft^3), and
S_f is the final slope calculated based on the Shield's diagram.

Table A-3: Water properties based on temperature

Temperature (deg. F)	μ, absolute viscosity (lbf-sec/ft^2)	ν, kinematic visocity (ft^2 / sec)
32	3.746E-05	1.931E-05
40	3.229E-05	1.664E-05
50	2.735E-05	1.410E-05
60	2.359E-05	1.217E-05
70	2.050E-05	1.059E-05
80	1.799E-05	9.300E-06
90	1.596E-05	8.260E-06

- The process for the iterative method is as follows:
  1) Guess initial slope, S_i
  2) Calculate critical velocity, U^*
  3) Calculation critical Reynold's Number, Re^*
  4) Look up critical shear stress, τ^*, from Shield's diagram (Figure A-5),
  5) Recalculate slope S_f, and
  6) Repeat until initial slope, S_i, is equal to final slope, S_f.

Reference: Pemberton & Lara, 1984

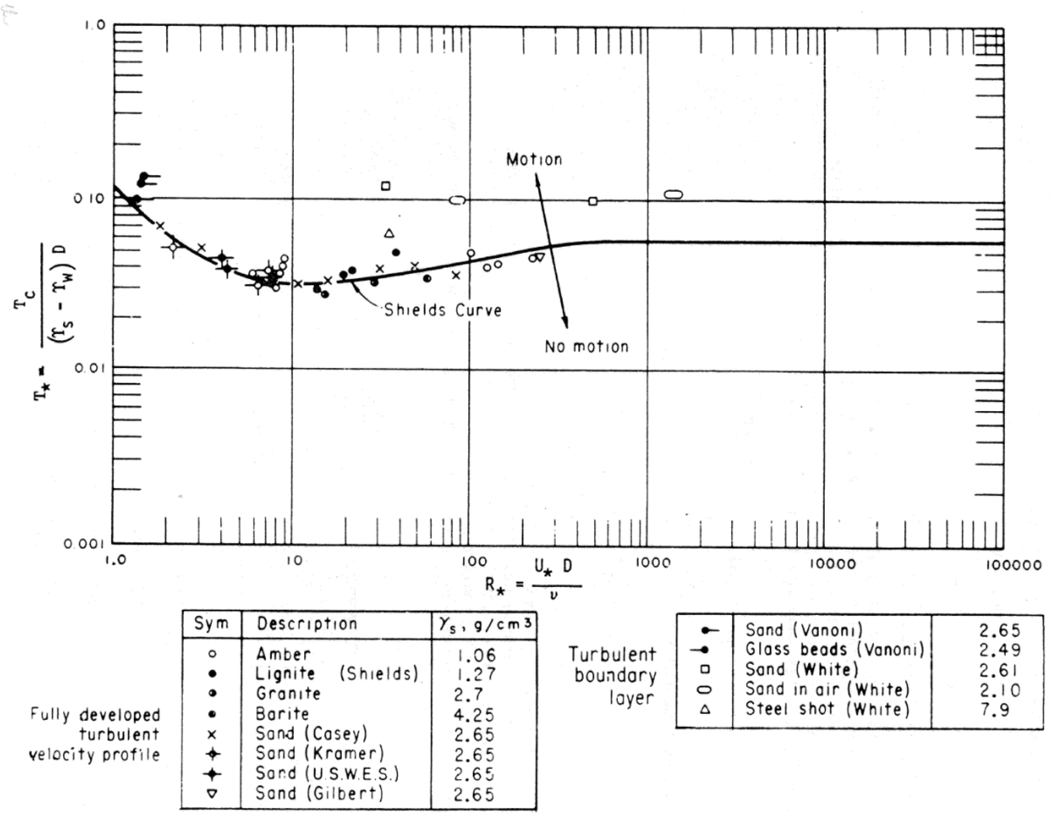


Figure A-5: Shield's diagram for initiation of bed material movement.

A.5 Culvert Outlet Scour (Local Scour)

Ruff el. al. equation

General form of the equation is:

$$d_s, W_s, L_s = a\ D\ \left(\frac{Q}{\sqrt{gD^5}}\right)^b$$

Where:

d_s is the scour hole depth (***Figure 9*** in Section 7.4. Culvert Scour),
W_s is the scour hole width,
L_s is the scour hole length,
Q is the discharge through the culvert,
D the culvert diameter,
g is gravitational acceleration of gravity (32.17 ft^2/s),
a is the equation coefficient,
b is the equation exponent.

The recommended values for coefficient *a* and exponent *b* are presented in Table A-4 for the scour hole dimensions and for a range of sediment sizes. For channels with median sand sizes (d_{50}) finer than 1.86mm, use the same coefficients and exponents for uniform sand (d_{50} = 1.86mm) as they are about the same or more conservative than those for cohesive material. We recommend increasing the safety factor applied to the scour hole depth, width and length for sand finer than 1.89mm by 20-30% to account for the likely increased scour hole dimensions.

Table A-4. Culvert scour equation parameters.

Material	Median sediment size, D_{50} (mm)	standard deviation[1] σ	Scour hole dimensions	Coefficient, a	Exponent, b
Uniform sand	1.86	1.33	d_s	2.07	0.45
			W_s	9.07	0.57
			L_s	20.87	0.51
Graded sand/gravel	2.00	4.38	d_s	1.24	0.32
			W_s	7.47	0.76
			L_s	12.77	0.41
Uniform gravel	7.62	1.32	d_s	1.80	0.45
			W_s	9.13	0.62
			L_s	14.22	0.95
Graded gravel	7.34	4.78	d_s	1.50	0.50
			W_s	8.67	0.89
			L_s	12.83	0.62
Cohesive material	0.15	N.A.	d_s	2.18	0.57
			W_s	8.91	0.35
			L_s	17.57	0.43

[1] $\sigma = (d_{84}/d_{16})^{0.5}$

Reference: Ruff, J.F., S.R. Abt, C. Mendoza, A. Shikh, and R. Kloberdanz. 1982

A.6 Grade Control Structure Scour (Local Scour)

Bormann and Julien equation

$$y_s = \left\{ 1.8 \left(\frac{\sin \emptyset}{\sin(\theta_j + \emptyset)} \right)^{0.8} \frac{q^{0.6} V_1 \sin \theta_j}{[(G-1)g]\,[(G-1)g]^{0.8}\, d_s^{0.4}} \right\} - D_p$$

Where:

y_s is the scour depth (Δz) (ft) downstream from the grade-control structure,
$\emptyset$ is the angle of repose of the streambed sediments,
θ_j is the jet angle for flow from the culvert into the stream bed (angle measured from horizontal),
q is design flood unit discharge (ft^3/s per ft of width),
V_1 is the approach velocity (ft/s),
G is the specific gravity of sediment (2.65),
g is the acceleration of gravity (32.17 ft^2/s)
d_s is the median particle diameter (mm),
D_p is the drop height of the grade-control structure (ft),

This equation applies where there is a downstream slope on the grade control structure (Figure C-6) for installations usually constructed of concrete and loose or grouted rock.

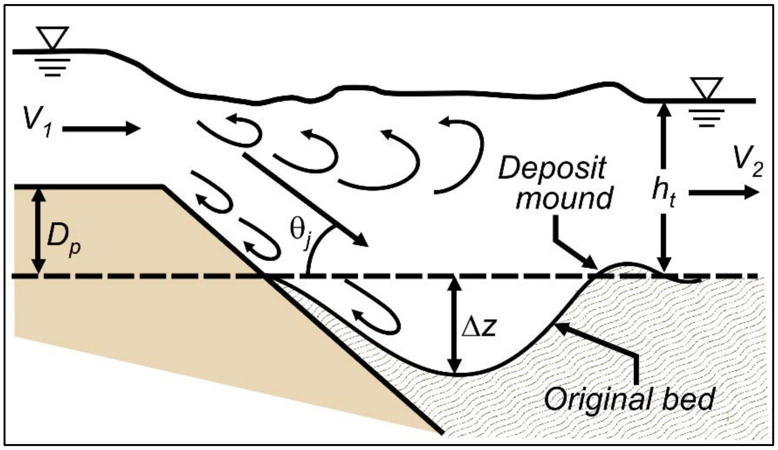


Figure C-6. Grade-control structure scour (modified from Julien, 2018).

Schoklitsch equation

$$y_s = \left(\frac{3.15H^{0.2}q^{0.57}}{d_{90}^{0.32}}\right) - D_m$$

Where:

y_s is the scour depth (ft) downstream from the grade-control structure,
H is the vertical distance between the water level upstream and downstream of the structure (ft),
q is design flood unit discharge (ft^3/s per ft of width),

d_{90} is the particle size for which 90 percent is finer than (mm), and
D_m is the downstream mean water depth (ft).

This equation is used to estimate scour downstream of vertical drops usually constructed of sheet pile, or gabion baskets where there is no downstream slope on the grade control structure.

Reference: Pemberton & Lara, 1984

Appendix B - Example Geologic Design Data Report, Navajo Gallup Water Supply Project

Contents

APPENDIX 1

LOGS OF EXPLORATION

Drill Holes:

DHR4C-17-1, DHR4C-17-2, DHR4C-17-3, DHR4C-17-4, DHR4C-17-5.

Test Pits:

TPR4C-17-1, TPR4C-17-2, TPR4C-17-3, TPR4C-17-4, TPR4C-17-5, TPR4C-17-6, TPR4C-17-7, TPR4C-17-8, TPR4C-17-9, TPR4C-17-10, TPR4C-17-11, TPR4C-17-12, TPR4C-17-13, TPR6-17-1.

Cone Penetrometer Tests (CPT):

CPT5-14-1, CPT5-14-2, CPT5-14-3, CPT5-14-4, CPT5-14-5, CPT5-14-6.

APPENDIX 2

LABORATORY DATA

APPENDIX 3

PHOTOGRAPHS

APPENDIX 4

DRAWINGS

Dwg No. 1695-529-60161 General Map.

Dwg No. 1695-529-60146 Location Map.

Dwg No. 1695-529-60162 General Geologic Legend, Explanation and Notes.

Dwg No. 1695-529-60065 Location of Exploration.

Dwg No. 1695-529-60140 through 1695-529-60143 Surface Geology.

1.0 INTRODUCTION

The Navajo-Gallup Water Supply Project (NGWSP) is a major infrastructure project that is anticipated to feature approximately 280 miles of pipeline, several pumping plants and two water treatment plants. The NGWSP is divided into two segments, the Eastern phase (Cutter Lateral) and the Western phase (San Juan Lateral).

1.1 PURPOSE

The purpose of this report is to summarize geologic design data investigations for Reach 4C that is a feature on the San Juan Lateral of the NGWSP. Investigations were performed to collect site specific design data for line pipe. This report presents the data collected from July 2014 through July of 2017 from subsurface explorations and geologic mapping.

1.2 PROPOSED STRUCTURES

Reach 4C is approximately 4 miles of line pipe on the San Juan Lateral. The alignment starts about 3 miles north of Little Water and ends at the beginning of Reach 6, located in Little Water, New Mexico. The alignment is anticipated to begin at Pumping Plant 3 indicated on the General Map and may be designed with a Sanostee/Burnham Turnout, located near the end of the reach. Alignment adjustments within this area have been required due to cultural resource issues.

1.3 TOPOGRAPHICAL DATA BASE

Arial photography was flown on April 6th 2010 by Woolpert Inc. GPS survey equipment was used by Reclamation survey crews to locate panel points and the area was flown from approximately 3,600 feet above ground level. The topography collected from Woolpert Inc. consists of 2-foot contours using NAD-83 datum. Test pits and drill holes from investigations were located by the Four Corners Construction Office (FCCO) survey crew, utilizing survey quality GPS instruments. The coordinates are expressed in 1983 State Plane, New Mexico, West Zone.

2.0 GEOLOGIC INVESTIGATIONS

Geologic surface mapping at a scale of 1 inch to 200 feet was performed in 2014. Subsurface investigations began in 2014 and consisted of six Cone Penetrometer Tests (CPT) (CPT5-14-1, CPT5-14-2, CPT5-14-3, CPT5-14-4, CPT5-14-5 and CPT5-14-6), fourteen test pits (TPR4C-17-1,

TPR4C-17-2, TPR4C-17-3, TPR4C-17-4, TPR4C-17-5, TPR4C-17-6, TPR4C-17-7, TPR4C-17-8, TPR4C-17-9, TPR4C-17-10, TPR4C-17-11, TPR4C-17-12, TPR4C-17-13 and TPR6-17-1) and five drill holes (DHR4C-17-1, DHR4C-17-2, DHR4C-17-3, DHR4C-17-4 and DHR4C-17-5). The CPT's were performed using the Reclamation Pacific Northwest CPT truck. Test pits were conducted by the FCCO geology group with a backhoe operator and laboratory personnel. Drill holes were conducted by the FCCO geology group and the Reclamation Upper Colorado Drill Crew. Geologic logs, CPT diagrams, lab results, photos and drawings are included in the appendices.

2.1 TESTING AND SAMPLING

All soils recovered from test pits and drill holes were logged and visually classified using methods described in USBR 5005 [Earth Manual, Part 2, Third Edition, and the Unified Soil Classification System (USCS)]. Testing conducted by the FCCO Materials Laboratory included in-place density, Proctor, Atterberg Limits, specific gravity, gradation analysis and laboratory soil classification.

CPT's were performed at road crossings. Data parameters for CPT's consist of tip resistance, local friction, friction ratio, pore pressure, inclination, soil behavior type and SPT N-Values. Generally, CPT's reached refusal due to lithified or partially lithified soil behavior type that may be interpreted as bedrock or as coarse grained soil deposits that exceed the diameter of the cone. All CPT holes were conducted using an electronic cone penetrometer and hydraulic push system. The CPT push system was manufactured by Vertek/Applied Research Associates, Inc., in 2006. The digital data acquisition system was an Electronic Field Computer System (EFCS4) originally manufactured by Hogentogler (currently Vertek). CPT data is included in Appendix 1.

Test pits were excavated using a Case 580N rubber tire backhoe with a 24 inch bucket except for test pit TPR6-17-1 that was accomplished using a Deer 310K rubber tire backhoe with a 24 inch bucket. Excavation, testing and sampling was performed to the limit of the equipment or to refusal. Soil testing was conducted by the FCCO Materials Laboratory. In-place densities were performed by the sand cone method in test pits within alluvial deposits where bedrock was not encountered above seven feet in depth. Results from in-place densities are shown on the test pit logs in Appendix 1 and are included on the summary of test results in Appendix 2.

Drilling was achieved using a Central Mining Equipment (CME) 85 truck mounted and a CME 850 track mounted drill rig. Drill hole testing utilized a hollow stem auger and the Standard Penetration Test (SPT) for soil and HQ3 diamond bit coring methods for bedrock. Drilling was conducted using a 4.25 inch outside and 3.25 inch inside diameter by 5 foot-long hollow stem auger with a split tube type sampler. Standard Penetration Testing was accomplished using a 2.0 inch outside and 1.375 inch inside diameter by 2.5 foot-long split spoon sampler. A 140 pound auto hammer was used to drive the sampler. The SPT sampler was advanced 1.5 feet with blow counts reported per 0.5 foot of advancement. Representative samples were sent to the FCCO Materials Laboratory for laboratory soil classification. Rock core recovered from the drill holes were visually classified using methods described in the USBR, Engineering Geology Field Manual, Second addition, Volume 1. Rock core recovered from some drill holes were sealed with wax and sent to the Reclamation Technical Service Center (TSC) Concrete, Geotechnical and Structural Laboratory for further analysis. Drill hole logs are included in Appendix 1.

Representative samples from the bed and banks of wash crossings were collected for laboratory testing to determine pipeline burial depth and wash crossing stabilization design. Wash crossing samples were processed through the FCCO laboratory for consistency limits and gradation analysis using U.S. Alternative sieve sizes. The geology of these drainages and surrounding conditions are to be addressed in a separate report from the TSC Sedimentation and River Hydraulics Group.

Corrosion samples were collected approximately every one mile at a depth of 7 to 10 feet in test pits. Corrosion samples were sent to the TSC Materials and Corrosion Laboratory to determine design requirements for cathodic protection for buried structures. Corrosion data results are to be presented in a separate report from the TSC Materials and Corrosion Laboratory.

3.0 REGIONAL GEOLOGY

The San Juan Basin is a broad basin that is surrounded by many mountain ranges with distinct geologies including the Chuska Mountains, the La Plata Mountains, the San Juan Mountains, the San Pedro Mountains, the Zuni Mountains and Mt. Taylor. The San Juan Basin is a structural depression that contains Quaternary alluvium, resting on rocks of Cretaceous age which crop out around the margins of the basin, characterized by plateaus, mesas and dry-wash canyons presently being eroded in an arid climate. The NGWSP San Juan Lateral is located on the eastern slope of the Chuska Mountains, near the southwestern margin of the basin, south of Shiprock, New Mexico.

4.0 SITE GEOLOGY

The Reach 4C alignment begins north of Little Water, New Mexico, and crosses alluvium, mudflats, a dry arroyo, and terminates on a flood plain. The alignment is oriented north to south across cuestas and vales surrounding the Tocito Dome structural feature. The arroyo of the Sanostee Wash will be crossed in the southern margin of Little Water.

The bedrock underlying the Reach 4C alignment is comprised of Cretaceous Mancos Shale Formation and Cretaceous Gallup Sandstone and are the only bedrock units encountered in investigations. The sandstone generally forms hill tops and the softer claystone and shale units form the lower slopes of hills. The bedrock is relatively flat lying with shallow dips to the east. Bedrock inclination increases to approximately 45 degrees and dips to the north as the alignment nears the margins of the Tocito Dome.

4.1 STRATIGRAPHY

The Mancos Shale is a marine deposit divided into an upper and lower unit by the transgression and regression of the Gallup Sandstone. The upper and lower units of the Mancos Shale Formation will not be differentiated in this report. The Mancos Shale Formation and Gallup Sandstone is typically covered by varying amounts of surficial deposits mapped as Quaternary Alluvium. For more detail, see geologic logs in Appendix 1.

4.1.1 SURFICIAL DEPOSITS

Quaternary Alluvium (Qal)

Alluvial soil types encountered include Silty Sand (SM), Clayey Sand (SC), Lean Clay (CL), Lean Clay with Sand (CL)s, Sandy Lean Clay s(CL), Poorly Graded Sand (SP), Poorly Graded Sand with Silt (SP-SM), Poorly Graded Sand with Clay (SP-SC) and Poorly Graded Sand with Gravel and Cobbles (SP)g. All soil types occasionally contain gravel. Alluvium is derived from a variety of sources including eolian, slope wash, colluvium and alluvial deposition as well as weathering and decomposition of in-place claystone, shale and sandstone. Quaternary Alluvium is used to describe all surficial deposits along the Reach 4C alignment regardless of origin. The alluvium was observed to range from a few inches to 25.5 feet in depth.

Quaternary alluvium of Lean Clay and Clayey Sand found in test pit TPR4C-17-8.
Image for reference only. Photo taken 5-16-2017 by C. Beyer.

4.1.2 BEDROCK

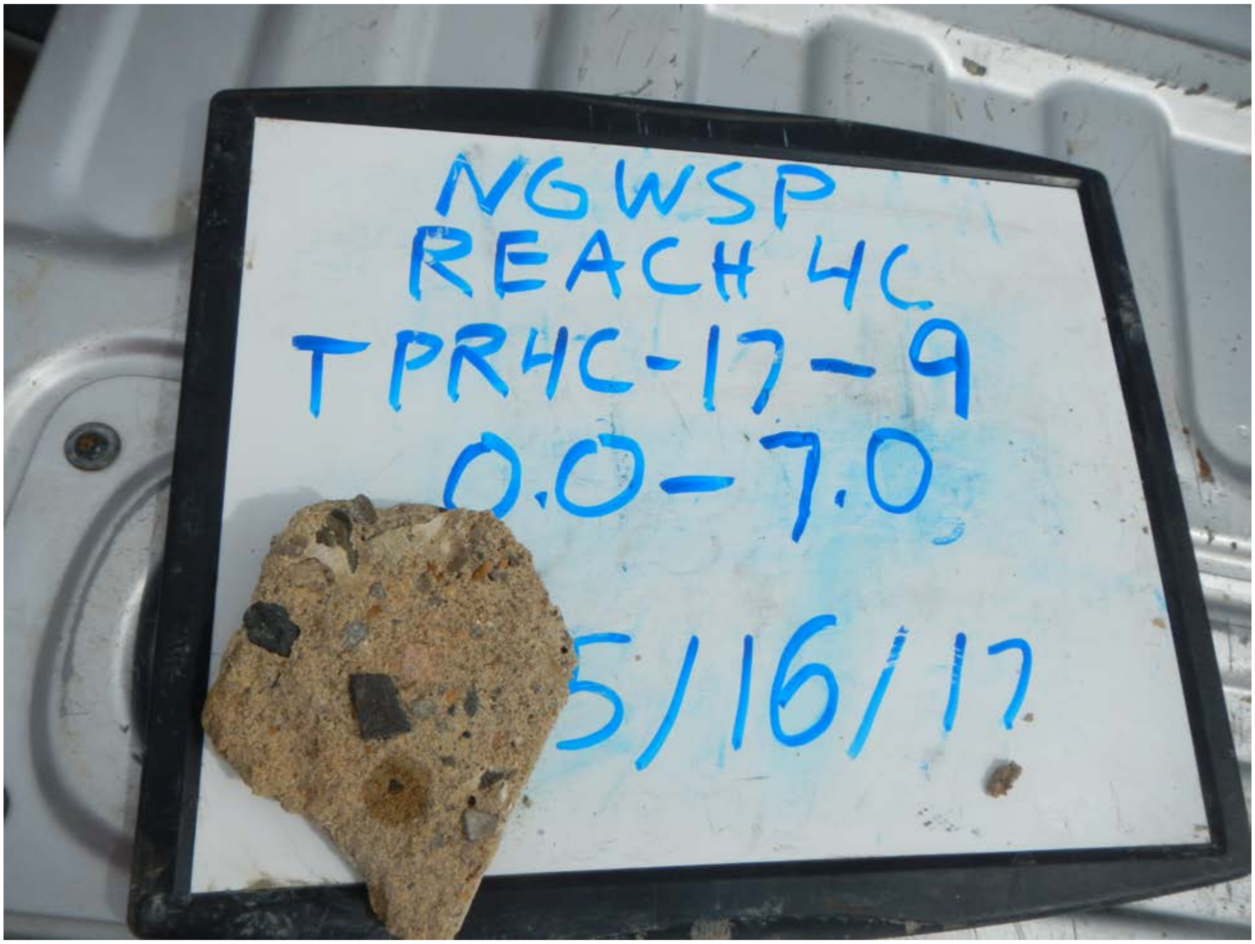
Cretaceous Mancos Shale (Km)

The Cretaceous Mancos Shale encountered on Reach 4C consists of interbedded fine-grained, mixed clastic laminations to moderate beds of sandstone, claystone, mudstone and shale that are carbonaceous and may contain lenses of coal. The shale is calcareous, sandy, fissile, gray to dark gray, light to dark brown to black in color and banded in places. Generally, the shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The sandstone is tan to brown, fine grained and laminated to moderately bedded. Sandstone interbeds are moderately soft (H5) and moderately weathered (W5). The claystone is light to dark brown or gray, sandy and laminated to moderately bedded. Claystone interbeds are very soft (H7) and intensely weathered (W7). The claystone is carbonaceous, contains calcium carbonate, mica and has thin to moderately thick gypsum infilling in joints.

Excavation of alluvium and the Mancos Shale found in test pit TPR4C-17-1.
Image for reference only. Photo taken 5-16-2017 by C. Beyer.

Cretaceous Gallup Sandstone (Kg)

The Cretaceous Gallup Sandstone is a shoreface, shoreline and offshore deposit. The sandstone is tan, brown to reddish brown and gray in color. The sandstone is thinly to moderately bedded, indurated by cementing material, and grades from coarse grain conglomerate to fine grained mixed clastic sandstone. The sandstone is typically moderately hard (H4) and moderately weathered (W5) to decomposed (W9).



Excavation sample of the Gallup Sandstone found in test pit TPR4C-17-9.
Image for reference only. **Photo taken 5-15-2017 by C. Beyer**

4.2 STATION TO STATION GEOLOGY

Stations are approximated and were used to locate periodic subsurface investigations. Investigations are roughly spaced at 1000 feet along the alignment where equipment access was possible. Realignments due to cultural resource restrictions have resulted in some investigations being located off centerline. Some planned investigations were not performed due to difficult access or cultural resource restrictions. Actual subsurface conditions and depth to bedrock along the alignment centerline may not be reflected in the individual logs. Conditions will vary between explorations.

Station 42000+00 to 42035+00: Qal/Km

Excavation in this area will be within alluvium and shale. The alignment crosses an overhead utility near Station 42011+00, a dirt road and buried gas line near Station 42019+00. Subsurface explorations include three test pits and one drill hole.

- Test pit TPR4C-17-2 encountered Poorly Graded Sand with Clay (SP-SC) from 0.0 to 2.5 feet and shale from 2.5 to 7.3 feet of depth. The shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The test pit met with refusal on shale bedrock at 7.3 feet of depth.
- Test pit TPR4C-17-3 encountered Poorly Graded Sand with Clay (SP-SC) from 0.0 to 2.3 feet and shale from 2.3 to 5.0 feet of depth. The shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The test pit met with refusal on shale bedrock at 5.0 feet of depth.
- Test pit TPR4C-17-4 encountered Poorly Graded Sand (SP) from 0.0 to 2.5 feet and Shale from 2.5 to 5.0 feet of depth. The shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The test pit met with refusal on shale bedrock at 5.0 feet of depth.
- Drill hole DH4C-17-2 encountered Poorly Graded Sand with Silt (SP-SM) from 0.0 to 2.3 feet, claystone from 2.3 to 19.0 feet and shale from 19.0 to 25.0 feet of depth. The claystone is soft (H6) and intensely to moderately weathered (W6). The shale is moderately soft (H5) and moderately weathered (W5). N-Values were acquired in bedrock and ranged from 66 to refusal per foot of advancement.

Station 42035+00 to 42040+00: Km

Excavation is expected to encounter sandstone of the Mancos Shale, based on surface geologic mapping. There were no subsurface explorations performed between these Stations. The sandstone of the Mancos Shale is moderately soft (H5), intensely weathered (W7) and fractured.

Station 42040+00 to 42066+00: Qal/Km

Excavation in this area will be within alluvium and shale. Subsurface explorations include three test pits.

- Test pit TPR4C-17-5 encountered Poorly Graded Sand (SP) from 0.0 to 1.7 feet and shale from 1.7 to 3.3 feet of depth. The shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The test pit met with refusal on shale bedrock at 3.3 feet of depth.
- Test pit TPR4C-17-6 encountered Poorly Graded Sand (SP) from 0.0 to 0.7 feet and shale from 0.7 to 3.0 feet of depth. The shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The test pit met with refusal on shale bedrock at 3.0 feet of depth.
- Test pit TPR4C-17-7 encountered Poorly Graded Sand (SP) from 0.0 to 0.8 feet and shale from 0.8 to 5.0 feet of depth. The shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The test pit met with refusal on shale bedrock at 5.0 feet of depth.

Station 42066+00 to 42080+00: Qal

Excavation in this area will be within alluvium. The alignment crosses a dirt road, Indian Service Route 5018, near Stations 42066+00 and 42067+50. Subsurface explorations include one CPT and one test pit.

- CPT hole CPT5-14-1 met refusal at 14.7 feet of depth.
- Test pit TPR4C-17-8 encountered Lean Clay (CL) from 0.0 to 9.0 feet and Clayey Sand (SC) from 9.0 to 13.5 feet of depth. The test pit was discontinued due to the limit of the equipment.
    - The in-place density reported 67.0% compaction, a dry density of 78.0 lbf/ft^3, a maximum dry density of 116.5 lbf/ft^3 and optimum moisture of 14.8% at approximately 7.0 feet of depth.

Station 42080+00 to 42110+00: Qal/Kg/Km

Excavation in this area will be within alluvium, sandstone, claystone and shale. The alignment crosses a dirt road near Station 42082+00. Subsurface explorations include one drill hole, one CPT and two test pits.

- Drill hole DHR4C-17-3 encountered Clayey Sand (SC) from 0.0 to 1.8 feet, Lean Clay (CL) from 1.8 to 10.3 feet, claystone from 10.3 to 23.3 feet and shale from 23.3 to 25.0 feet of depth. The claystone is soft (H6) and intensely weathered (W7). The shale is moderately hard (H4) to moderately soft (H5) and moderately weathered (W5). Blow counts ranged from 19 to 25 blows per foot of advancement in soils and 60 to refusal in bedrock.
- CPT hole CPT5-14-2 met refusal at 9.5 feet of depth.
- Test pit TPR4C-17-9 encountered Poorly Graded Sand (SP) from 0.0 to 3.7 feet, Poorly Graded Sand with Gravel and Cobbles (SP)g from 3.7 to 5.2 feet and sandstone from 5.2 to 7.0 feet of depth. The sandstone is moderately hard (H4) and moderately weathered (W5). The test pit met with refusal on sandstone bedrock at 7.0 feet of depth.
- Test pit TPR4C-17-10 encountered Poorly Graded Sand with Cobbles (SP) from 0.0 to 3.7 feet, sandstone from 3.7 to 9.5 feet and shale from 9.5 to 10.5 feet of depth. The sandstone is very soft (H7) and decomposed (W9). The shale is moderately soft (H5) to moderately hard (H4) and intensely to moderately weathered (W6). The test pit met with refusal on shale bedrock at 10.5 feet of depth.
    - The in-place density reported 86.1% compaction, a dry density of 102.7 lbf/ft^3, a maximum dry density of 119.3 lbf/ft^3 and optimum moisture of 11.0% at approximately 7.0 feet of depth.

Station 42110+00 to 42145+00: Qal

Excavation in this area will be within alluvium. The alignment crosses an overhead utility near Station 42137+00 and a dirt road near Station 42116+50, 42136+00 and 42138+50. The Sanostee Wash will be crossed near Stations 42142+00 to 42144+00. Subsurface explorations include two test pits and one drill hole.

- Test pit TPR4C-17-11 encountered Poorly Graded Sand (SP) from 0.0 to 6.0 feet, Clayey Sand (SC) from 6.0 to 9.5 feet and Poorly Graded Sand (SP) from 9.5 to 13.0 feet of depth. The test pit was discontinued due to the limit of the equipment.
    - The in-place density reported 83.7% compaction, a dry density of 88.1 lbf/ft^3, a maximum dry density of 105.3 lbf/ft^3 and optimum moisture of 17.8% at approximately 7.0 feet of depth.

- Test pit TPR4C-17-12 encountered Poorly Graded Sand with Clay (SP-SC) from 0.0 to 13.5 feet of depth. The test pit was discontinued due to the limit of the equipment.
    - The in-place density reported 79.0% compaction, a dry density of 83.2 lbf/ft^3, a maximum dry density of 105.3 lbf/ft^3 and optimum moisture of 17.2% at approximately 7.0 feet of depth.
- Drill hole DHR4C-17-4 encountered Clayey Sand (SC) from 0.0 to 2.8 feet, Poorly Graded Sand with Silt (SP-SM) from 2.8 to 5.4 feet, Silty Sand (SM) from 5.4 to 10.8 feet, Lean Clay with Sand (CL)s from 10.8 to 22.5 feet, claystone from 22.5 to 32.0 feet and shale from 32.0 to 49.1 feet of depth. The claystone is soft (H6) and intensely weathered (W7). The shale is moderately soft (H5) and moderately weathered (W5). Blow counts ranged from 6 to 91 blows per foot of advancement.

Station 42145+00 to 42160+00: Qal/Km

Excavation in this area will be within alluvium, shale and sandstone. The alignment crosses a retention basin next to a swale to the west along the highway near Station 42150+00 to 42153+00. A dirt road, Indian Service Route 5092, will be crossed near Station 42154+00. Subsurface explorations include one CPT and one test pit.

- CPT hole CPT5-14-4 met with refusal at 8.7 feet of depth.
- Test pit TPR4C-17-13 encountered Clayey Sand (SC) from 0.0 to 4.0 feet, Lean Clay with Sand (CL)s from 4.0 to 5.0 feet, Poorly Graded Sand with Clay (SP-SC) from 5.0 to 6.6 feet, shale from 6.6 to 8.0 feet and sandstone from 8.0 to 9.0 feet of depth. The shale is soft (H6) and intensely weathered (W7). The sandstone is moderately soft (H5) and moderately weathered (W5). The test pit was discontinued due to refusal on sandstone bedrock at 9.0 feet of depth.

Station 42160+00 to 42179+58: Qal

Excavation in this area will be within alluvium. Subsurface explorations include one drill hole and one test pit. Two CPT tests were performed at locations away from the centerline of the alignment.

- Drill hole DHR4C-17-5 encountered Lean Clay with Sand (CL)s from 0.0 to 7.2 feet, Sandy Lean Clay s(CL) from 7.2 to 22.0 feet and claystone from 22.0 to 25.0 feet of depth. The claystone is soft (H6) and intensely weathered (W7). Blow counts ranged from 12 to refusal per foot of advancement.
- CPT hole CPT5-14-5 met with refusal at 17.1 feet of depth.
- CPT hole CPT5-14-6 met with refusal at 22.5 feet of depth.
- Test pit TPR6-17-1 encountered Silty Sand (SM) from 0.0 to 8.2 feet, Lean Clay with Sand (CL)s from 8.2 to 9.4 feet, Silty Sand (SM) from 9.4 to 11.3 feet and Lean Clay with Sand (CL)s from 11.3 to 16.2 feet of depth. The test pit was discontinued due to the limit of the equipment.
    - The in-place density reported 78.9% compaction, a dry density of 82.2 lbf/ft^3, a maximum dry density of 104.2 lbf/ft^3 and optimum moisture of 18.3% at approximately 7.0 feet of depth.

5.0 GEOLOGIC CONSIDERATIONS

Concerns about the safety surrounding the geologic environment range from the stability of slopes in excavations to the excavation methods. Specific situations are addressed below.

Test pit investigations were conducted using a light duty backhoe. The majority of test pits were easily excavated using common methods. Typically, the backhoe met with refusal on shale or sandstone bedrock. Larger industrial equipment should be expected to accomplish trenching for pipe installation through the alignment.

Surface drainages that cross the pipeline alignment may have some potential for scour and will likely require some level of protection during pipeline construction. Surface and shallow subsurface samples were collected at the Sanostee Wash to determine gradations and physical properties of the soil. The surface drainages table shows approximate drainage locations and conditions that were apparent on the surface. General notations are found in the Surface Drainage Table located at the end of this report and Station to Station geology section above.

5.1 STABILITY OF EARTH MATERIALS

This section includes information on natural slope stability and recommends temporary and permanent cut slopes for both surficial deposits and bedrock. The stability of cut slopes is dependent upon the soil classification, composition of materials and moisture conditions. Recommended slope classification uses a method of categorizing soil and rock deposits in a hierarchy of Stable Rock, Type A, Type B, and Type C, in decreasing order of stability. The categories are determined based on an analysis of the properties and performance characteristics of the deposits and the environmental conditions of exposure.

5.1.1 NATURAL SLOPE STABILITY

The stability of surficial deposits in the Reach 4C area is dependent primarily on material composition. Natural slopes in unconsolidated alluvium are generally stable at approximately 1.5:1 or sometimes flatter in sandy materials. Bedrock exposures in the area are typically stable at about 1.5:1 or steeper in claystone and shale and 1:1 to vertical in sandstone.

5.1.2 TEMPORARY AND PERMANENT CUT SLOPES

Recommendations for cut slopes in surficial deposits are based on material type and texture. All cut slopes shall be constructed in accordance with the Reclamation Safety and Health Standards and OSHA standards. Recommendations are for dry or adequately dewatered materials. Cut slopes in materials with excessive moisture will require further flattening for stability. Recommended cut slopes for type C soils, including granular soils such as Poorly Graded Gravel (GP), Poorly Graded Sand (SP), Poorly Graded Sand with Silt (SP-SM), and Silty Sand (SM), are 1.5:1. Cut slopes in oversized material such as cobbles and boulders will also need to be sloped accordingly. Recommended cut slopes for type B soils, including Silty Clayey Sand (SC/SM) and Clayey Sand (SC) are 1:1. Lean Clay (CL) to Fat Clay (CH) soils are classified as type B soils due to the presence of construction traffic, and should have cut slopes of 1:1 or flatter.

Cut slopes in bedrock will be dependent upon the rock type and degree of weathering. All decomposed to intensely weathered, very soft bedrock will be classified as a type B or type C soils depending upon the composition of the rock. Moderately weathered to fresh, moderately soft to hard bedrock can be classified as Stable Rock, if all requirements of the Reclamation Safety and Health Standards are met. Sloping or benching for excavations greater than 20 feet deep shall be designed by a registered professional engineer.

5.2 EXCAVATION CONSIDERATIONS

Unconsolidated soils and weathered bedrock can be excavated using common methods. The depth of weathering is generally less than 2 feet in the claystone and is less than 1 foot in sandstone units. Degree of weathering may vary from decomposed (W9) to slightly weathered to fresh (W2). Excavation of the bedrock may be difficult and could require rock excavation methods locally, particularly where the trench excavation becomes constricted in width. Low density soils were encountered in three test pits on or near the alignment. Low density soils exhibited D-values below 85% and were encountered in test pits TPR4C-17-8, TPR4C-17-11 and TPR4C-17-12.

Horizontal Directional Drilling (HDD) may be an option or required for the crossing of the Sanostee Wash near the end of the reach alignment in Little Water. Investigation at this wash crossing are limited due to cultural resource restrictions. Subsurface conditions are not characterized in the Station to Station geology at the depth required for HDD.

Proper drainage should be provided during construction to prevent water from ponding near trenching operations or contaminating the line pipe.

5.3 GROUNDWATER OCCURENCE

Investigations along Reach 4C, using dry drilling methods, encountered a wet interval in DHR4C-17-3 between 20.0 and 21.7 feet of depth under perched conditions. Reach 4C lies entirely on the Chaco Slope which is a catchment basin for the Chaco River. Springs found to the west in the Chuska Mountains and the occasional flow of the Chaco River indicate that the water table fluctuates seasonally. Substantial rainfall, snowmelt or irrigation may produce shallow groundwater occurrence. In general, ground water is not anticipated during the majority of trenching operations but may be anticipated near the Sanostee wash crossing.

5.4 DRAINAGE CROSSINGS

Surface drainages exist along the Reach 4C alignment through Little Water. The geology of these drainages and surrounding conditions were investigated to gain an understanding of the potential for continued erosion and channel scour. The Surface Drainage Table 5.4.1, shows drainage locations and conditions.

Photo of wash crossing looking east across the alignment through the Sanostee Wash. Image for reference only. Photo taken 8-25-2017 by P. Gardner.

5.4.1 SURFACE DRAINAGE TABLE

STATION (Approx.)	DRAINAGE DIMENSIONS	DISTANCE FROM CULVERT	SURFACE MATERIAL TYPE	NOTES
42080+00	No defined width and flat.	>200 ft from culvert.	Clayey Sand.	Flat and depositional. No bank stabilization anticipated. Perched water table encountered in drill hole.
42142+50	Top width ~40 ft. Depth ~16' ft.	>200 ft from bridge.	Poorly Graded Sand.	Alignment crosses arroyo. Bank stabilization anticipated. Sanostee Wash.

6.0 REFERENCES

USBR 5005 [Earth Manual, Part 2, Third Edition, and the Unified Soil Classification System (USCS)].

USBR, Engineering Geology Field Manual, Second Edition, volume 1.

APPENDIX 1

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GEOLOGIC LOG OF DRILL HOLE NO. DHR4C-17-1

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
BEGUN: 7/19/17 FINISHED: 7/19/17
DEPTH AND ELEVATION OF WATER LEVEL: NE
DATE MEASURED: 7/19/2017

PROJECT: Navajo Gallup Water Supply Project
COORDINATES: N 1,997,056.6 E 2,461,233.2
TOTAL DEPTH: 25.5 ft
DEPTH TO BEDROCK: 3.0

STATE: New Mexico
GROUND ELEVATION: 5590.0 ft NAD 83
ANGLE FROM HORIZONTAL: -90°
HOLE LOGGED BY: P. Gardner
REVIEWED BY: J. Gilbert

NOTES

All measurements are from ground level and are the same as those used by the driller.

DRILLED BY:
Upper Colorado Drill Crew
DRILLER: B. Lane
HELPER: M. Butler, R. Matheson

PURPOSE:
Preconstuction soil and bedrock linepipe investigation.

DRILL EQUIPMENT:
CME MODEL 85 truck mounted rotary drill rig.

DRILL METHOD:
0.0 to 5.0 ft: 4.25 inch HSA with pilot bit.
5.0 to 10.0 ft: 4.25 inch HSA with split tube sampler and SPT.
10.0 to 25.5 ft: HQ3 diamond core methods with split spoon sampler.

DRILLING MEDIUM:
0.0 to 10.0 ft: None.
10.0 to 25.5 ft: Water.

DRILLING NOTES:
0.0 to 25.5 ft: Easy and smooth.

HOLE COMPLETION:
Backfilled with bentonite and auger cuttings.

SAMPLING:
5.0 to 6.5 ft: SPT
7.5 to 9.0 ft: SPT
10.0 to 25.5 ft: HQ3>0.5 ft preserved

DEPTH	GEOLOGIC SYMBOL	% CORE RECOVERY	% RQD	HARDNESS	WEATHERING	LABORATORY DATA						LABORATORY CLASSIFICATION	BLOWS / 0.5 FT	VISUAL CLASSIFICATION
						% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT			
0.0–3.0	Qal	NR												s(CL) 5587.0
3.0–5.0	Km			7	7									CLSTN
5.0–6.5		44				34.1	65.9	0.0	34.6	21.0	5.7	s(CL)	12/21/18	
6.5–7.5														
7.5–9.0		68				11.3	88.7	0.0	38.1	20.0	7.1	CL	23/50/NA	5581.0
9.0–10.0				5	5									SS
10.0–10.6		91	0											5579.4
10.6–15.5				7										SHALE
15.5–20.5		96	0											
20.5–25.5		100	64											5564.5

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 3.0 ft QUATERNARY ALLUVIUM

0.0 to 3.0 ft SANDY LEAN CLAY s(CL): About 60% fines with medium plasticity, medium toughness, medium dry strength and no dilatancy; about 40% fine to coarse, moderately soft subangular sand; maximum size, coarse sand; brown and dry; strong reaction with HCl.

3.0 to 25.5 ft CRETACEOUS MANCOS SHALE

3.0 to 9.0 ft CLAYSTONE: Light to dark brown color, sandy and laminated to very thinly bedded. Bedding planes near horizontal. Very soft (H7) and intensely weathered (W7). Gypsum, CaCOx and carbon blebs present. Weak reaction with HCl.

9.0 to 10.6 ft SANDSTONE: Brown, fine grained and laminated to thinly bedded. Bedding planes near horizontal to 30° from horizontal. Moderately soft (H5) and moderately weathered (W5). Gypsum, CaCOx and carbon blebs present. Claystone and gypsum interbeds from 0.25 to 0.5 inches thick; no reaction with HCl.

10.6 to 25.5 ft SHALE: Light to dark brown, dark gray and black color. Laminated to very thinly bedded. Claystone and sandstone laminations. Bedding planes near horizontal to 37° from horizontal. Easily separates on bedding planes. Very soft (H7) and moderately weathered (W5). Gypsum, FeOx, MnOx and carbon leaf fossils present.

JOINT MEASUREMENTS:

DEPTH	INCL	R	O	T	HL	INFILLING
12.0	60°	4	0	4	6	Gypsum
13.0	90°	4	0	3	6	Gypsum
14.3	60°	4	0	3	6	Gypsum
17.2	63°-75°	4	0	3	5	Gypsum
17.4	71°	4	0	4	6	Gypsum
17.9	55°	4	0	3	6	Gypsum
18.6	81°	4	0	3	6	Gypsum
19.1	74°	4	0	3	6	Gypsum
19.4	57°-79°	4	0	4	5	Gypsum
19.8	59°	4	0	3	6	Gypsum
21.3	60°	4	0	3	6	Gypsum
22.5	60°	4	0	3	6	Gypsum
22.9	53°-67°	4	0	3	5	Gypsum
23.5	80°	4	0	3	6	Gypsum
24.6	60°	4	0	4	6	Gypsum

STRATIGRAPHY:
0.0 to 3.0 ft QUATERNARY ALLUVIUM (Qal)
3.0 to 25.5 ft CRETACEOUS MANCOS SHALE (Km)

COMMENTS:

HSA= hollow stem auger NA= not available ft= feet NE= not encountered NP= non plastic NR= no recovery HCl= hydrochloric acid FeOx= iron oxide CaCOx= calcium carbonate MnOx= manganese oxide SPT= standard penetration test HQ3= coring system SS= sandstone CLSTN= claystone

The data for the center column and "classification and physical conditions" column are based on Bureau of Reclamation Geology Field Manual and drawings titled Geology for Design and Specification as follows "Drawing No. 40-D-6493 Standard Descriptions and Descriptive Criteria for Rock. Drawing No. 40-D-6499 Standard Descriptors and Descriptive Criteria for Discontinuities."

All angles measured from core axis at zero degrees unless otherwise noted.

GEOLOGIC LOG OF DRILL HOLE NO. DHR4C-17-2

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
BEGUN: 7/18/17 FINISHED: 7/18/17
DEPTH AND ELEVATION OF WATER LEVEL: NE
DATE MEASURED: 7/18/2017

PROJECT: Navajo Gallup Water Supply Project
COORDINATES: N 1,991,409.9 E 2,461,450.1
TOTAL DEPTH: 25.0 ft
DEPTH TO BEDROCK: 2.3

STATE: New Mexico
GROUND ELEVATION: 5579.7 ft NAD 83
ANGLE FROM HORIZONTAL: -90°
HOLE LOGGED BY: P. Gardner
REVIEWED BY: J. Gilbert

NOTES

All measurements are from ground level and are the same as those used by the driller.

DRILLED BY:
Upper Colorado Drill Crew
DRILLER: B. Lane
HELPER: M. Butler, R. Matheson

PURPOSE:
Preconstuction soil and bedrock linepipe investigation.

DRILL EQUIPMENT:
CME MODEL 85 truck mounted rotary drill rig.

DRILL METHOD:
0.0 to 5.0 ft: 4.25 inch HSA with pilot bit.
5.0 to 11.5 ft: 4.25 inch HSA with split tube sampler and SPT.
11.5 to 25.0 ft: 4.25 inch HSA with split tube sampler.

DRILLING MEDIUM:
0.0 to 25.0 ft: None.

DRILLING NOTES:
0.0 to 25.0 ft: Easy and smooth.

HOLE COMPLETION:
Backfilled with bentonite and auger cuttings.

SAMPLING:
5.0 to 6.5 ft: SPT
7.5 to 9.0 ft: SPT
10.0 to 11.5 ft: SPT

DEPTH	GEOLOGIC SYMBOL	% CORE RECOVERY	% RQD	HARDNESS	WEATHERING	LABORATORY DATA % FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION	BLOWS / 0.5 FT	VISUAL CLASSIFICATION
0.0 to 2.3	Qal	NR												SP-SM 5577.4
2.3 to 5	Km		0	6	6									CLSTN
5 to 6.5		64				27.1	72.9	0.0	25.0	8.5	3.5	(CL)s	19/25/41	
7.5 to 9.0		72				12.6	87.4	0.0	27.1	9.4	3.3	CL	38/50/NA	
10 to 11.5		46				18.3	81.7	0.0	30.4	13.9	3.8	(CL)s	36/50/NA	
15 to 20		74												
19 to 25														SHALE
20 to 25		94												5554.7

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 2.3 ft QUATERNARY ALLUVIUM

0.0 to 2.3 ft POORLY GRADED SAND WITH SILT (SP-SM): About 90% fine sand; about 10% fines with no plasticity, no dry strength and rapid dilatancy; maximum size, fine sand; brown and dry; strong reaction with HCl.

2.3 to 25.0 ft CRETACEOUS MANCOS SHALE

2.3 to 19.0 ft CLAYSTONE: Light to dark brown color, sandy and laminated to thinly bedded. Bedding planes near horizontal. Soft (H6) and intensely to moderately weathered (W6). CaCOx, MnOx and carbon blebs present. Grades to shale at 19.0 ft. Strong reaction with HCl.

19.0 to 25.0 ft SHALE: Brown and light to dark gray color, fissile, sandy and laminated. Bedding planes near horizontal. Moderately soft (H5) and moderately weathered (W5). Gypsum, FeOx, CaCOx, MnOx and carbon blebs present. Weak reaction with HCl.

STRATIGRAPHY:
0.0 to 2.3 ft QUATERNARY ALLUVIUM (Qal)
2.3 to 25.0 ft CRETACEOUS MANCOS SHALE (Km)

COMMENTS:

HSA= hollow stem auger NA= not available ft= feet NE= not encountered NP= non plastic NR= no recovery HCl= hydrochloric acid FeOx= iron oxide CaCOx= calcium carbonate MnOx= manganese oxide SPT= standard penetration test HQ3= coring system SS= sandstone CLSTN= claystone

The data for the center column and "classification and physical conditions" column are based on Bureau of Reclamation Geology Field Manual and drawings titled Geology for Design and Specification as follows "Drawing No. 40-D-6493 Standard Descriptions and Descriptive Criteria for Rock. Drawing No. 40-D-6499 Standard Descriptors and Descriptive Criteria for Discontinuities."

All angles measured from core axis at zero degrees unless otherwise noted.

GEOLOGIC LOG OF DRILL HOLE NO. DHR4C-17-3

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
BEGUN: 7/18/17 FINISHED: 7/18/17
DEPTH AND ELEVATION OF WATER LEVEL: NE
DATE MEASURED: 7/18/2017

PROJECT: Navajo Gallup Water Supply Project
COORDINATES: N 1,986,741.4 E 2,461,811.1
TOTAL DEPTH: 25.0 ft
DEPTH TO BEDROCK: 10.3

STATE: New Mexico
GROUND ELEVATION: 5544.4 ft NAD 83
ANGLE FROM HORIZONTAL: -90°
HOLE LOGGED BY: P. Gardner
REVIEWED BY: J. Gilbert

NOTES

All measurements are from ground level and are the same as those used by the driller.

DRILLED BY:
Upper Colorado Drill Crew
DRILLER: B. Lane
HELPER: M. Butler, R. Matheson

PURPOSE:
Preconstuction soil and bedrock linepipe investigation.

DRILL EQUIPMENT:
CME MODEL 85 truck mounted rotary drill rig.

DRILL METHOD:
0.0 to 5.0 ft: 4.25 inch HSA with pilot bit.
5.0 to 16.5 ft: 4.25 inch HSA with split tube sampler and SPT.
16.5 to 25.0 ft: 4.25 inch HSA with split tube sampler.

DRILLING MEDIUM:
0.0 to 25.0 ft: None.

DRILLING NOTES:
0.0 to 25.0 ft: Easy and smooth.

HOLE COMPLETION:
Backfilled with bentonite and auger cuttings.

SAMPLING:
5.0 to 6.5 ft: SPT
7.5 to 9.0 ft: SPT
10.0 to 11.5 ft: SPT
12.5 to 14.0 ft: SPT
15.0 to 16.5 ft: SPT

DEPTH	GEOLOGIC SYMBOL	% CORE RECOVERY	% RQD	HARDNESS	WEATHERING	LABORATORY DATA % FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION	BLOWS / 0.5 FT	VISUAL CLASSIFICATION
														SC 5542.6
	Qal	NR												CL
5		28				16.5	83.5	0.0	24.3	9.6	7.5	(CL)s	4/8/11	
		32				21.5	78.5	0.0	19.8	3.4	3.5	(ML)s	9/11/14	
10														5534.1
	Km	28	NA			21.4	78.6	0.0	24.2	4.7	4.2	(CL-ML)s	7/15/45	
		12				8.7	91.3	0.0	26.1	9.8	6.9	CL	23/50/NA	
15		64		6	7	18.8	81.2	0.0	26.0	11.4	8.5	(CL)s	20/40/50	CLSTN
20		100												5521.1
				4	5									SHALE
				5										
25														5519.4

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 10.3 ft QUATERNARY ALLUVIUM

0.0 to 1.8 ft CLAYEY SAND (SC): About 75% fine sand; about 25% fines with low plasticity, low toughness, medium dry strength and slow dilatancy; maximum size, fine sand; brown and dry; strong reaction with HCl.

1.8 to 10.3 ft LEAN CLAY (CL): About 90% fines with medium plasticity, medium toughness, medium dry strength and no dilatancy; about 10% fine to medium sand; maximum size, medium sand; light brown, dry, CaCOx stringers and nodules; strong reaction with HCl.

10.3 to 25.0 ft CRETACEOUS MANCOS SHALE

10.3 to 23.3 ft CLAYSTONE: Light to dark brown color, sandy and laminated to very thinly bedded. Sandstone laminations present. Bedding planes near horizontal. Soft (H6) and intensely weathered (W7). CaCOx, FeOx and carbon blebs present. Wet between 20.0 and 21.7 ft. Weak to strong reaction with HCl.

23.3 to 25.0 ft SHALE: Brown and light to dark gray color, fissile, sandy and laminated. Bedding planes near horizontal to 14° from horizontal. Moderately hard (H4) between 23.3 and 23.7 ft. Moderately soft (H5) and moderately weathered (W5). Gypsum, FeOx, CaCOx, MnOx and carbon blebs present. Weak reaction with HCl.

STRATIGRAPHY:
0.0 to 10.3 ft QUATERNARY ALLUVIUM (Qal)
10.3 to 25.0 ft CRETACEOUS MANCOS SHALE (Km)

COMMENTS:

HSA= hollow stem auger NA= not available ft= feet NE= not encountered NP= non plastic NR= no recovery HCl= hydrochloric acid FeOx= iron oxide CaCOx= calcium carbonate MnOx= manganese oxide SPT= standard penetration test HQ3= coring system SS= sandstone CLSTN= claystone

The data for the center column and "classification and physical conditions" column are based on Bureau of Reclamation Geology Field Manual and drawings titled Geology for Design and Specification as follows "Drawing No. 40-D-6493 Standard Descriptions and Descriptive Criteria for Rock. Drawing No. 40-D-6499 Standard Descriptors and Descriptive Criteria for Discontinuities."

All angles measured from core axis at zero degrees unless otherwise noted.

U.S. DEPARTMENT OF THE INTERIOR · BUREAU OF RECLAMATION

GEOLOGIC LOG OF DRILL HOLE NO. DHR4C-17-4

SHEET 1 OF 1

FEATURE: Reach 4C	PROJECT: Navajo Gallup Water Supply Project	STATE: New Mexico
LOCATION: Pipe Alignment	COORDINATES: N 1,980,551.5 E 2,462,112.9	GROUND ELEVATION: 5545.3 ft NAD 83
BEGUN: 7/16/17 FINISHED: 7/17/17	TOTAL DEPTH: 49.1 ft	ANGLE FROM HORIZONTAL: -90°
DEPTH AND ELEVATION OF WATER LEVEL: NA	DEPTH TO BEDROCK: 22.5	HOLE LOGGED BY: P. Gardner
DATE MEASURED: 7/16/2017		REVIEWED BY: J. Gilbert

NOTES

All measurements are from ground level and are the same as those used by the driller.

DRILLED BY:
Upper Colorado Drill Crew
DRILLER: B. Lane
HELPER: M. Butler, R. Matheson

PURPOSE:
Preconstuction soil and bedrock linepipe investigation.

DRILL EQUIPMENT:
CME MODEL 850 track mounted rotary drill rig.

DRILL METHOD:
0.0 to 5.0 ft: 4.25 inch HSA with pilot bit.
5.0 to 25.0 ft: 4.25 inch HSA with split tube sampler and SPT.
25.0 to 49.1 ft: HQ3 diamond core methods with split spoon sampler.

DRILLING MEDIUM:
0.0 to 25.0 ft: None.
25.0 to 49.1 ft: Water.

DRILLING NOTES:
0.0 to 49.1 ft: Easy and smooth.
Stuck at 49.1ft, leave 20 ft of HQ3 and Barrell in hole.

HOLE COMPLETION:
Backfilled with bentonite and auger cuttings.

SAMPLING:
5.0 to 6.5 ft: SPT
7.5 to 9.0 ft: SPT
10.0 to 11.5 ft: SPT
12.5 to 14.0 ft: SPT
15.0 to 16.5 ft: SPT
20.0 to 21.5 ft: SPT
25.0 to 49.1 ft: HQ3>0.5 ft preserved

DEPTH	GEOLOGIC SYMBOL	% CORE RECOVERY	% RQD	HARDNESS	WEATHERING	LABORATORY DATA % FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION	BLOWS / 0.5 FT	VISUAL CLASSIFICATION
	Qal	NR												SC 5542.5
														SP-SM 5539.9
5		NR				21.5	78.5	0.0	NA	NP	1.2	SM	3/4/5	
		32				18.2	81.8	0.0	NA	NP	2.4	SM	4/4/6	SM 5534.5
10		96				82.7	15.9	1.4	25.9	9.8	4.6	(CL)s	3/3/4	
		84				79.9	20.1	0.0	24.7	5.9	9.6	(CL-ML)s	7/4/2	
15		14				89.5	10.5	0.0	27.9	10.6	10.6	CL	5/13/33	(CL)s
20		18				88.7	11.3	0.7	29.5	12.7	8.5	CL	31/41/50	5522.8
25	Km	100	36	6	7									CLSTN 5513.3
30		100	76											
35		100	95											
		92	77											
40		100	76	5	5									SHALE
45		83	56											5496.2

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 22.5 ft QUATERNARY ALLUVIUM

0.0 to 2.8 ft CLAYEY SAND (SC): About 65% fine sand; about 35% fines with low plasticity, low toughness, medium dry strength and no dilatancy; maximum size, fine sand; brown and dry; strong reaction with HCl.

2.8 to 5.4 ft POORLY GRADED SAND WITH SILT (SP-SM): About 90% fine sand; about 10% fines with no plasticity, no dry strength and rapid dilatancy; maximum size, fine sand; brown and dry; strong reaction with HCl.

5.4 to 10.8 ft SILTY SAND (SM): About 75% fine sand; about 25% fines with no plasticity, low dry strength and rapid dilatancy; brown and dry; strong reaction with HCl.

10.8 to 22.5 ft LEAN CLAY WTIH SAND (CL)s: About 85% fines with medium plasticity, medium toughness, medium dry strength and no dilatancy; about 15% fine to medium sand; maximum size, fine sand; light to dark brown, mottled with gray clay and moist; lenses of POORLY GRADED SAND 1 inch thick; MnOx and carbon blebs below 16.2 ft; strong reaction with HCl.

22.5 to 49.1 ft CRETACEOUS MANCOS SHALE

22.5 to 32.0 ft CLAYSTONE: Light to dark brown, tan, gray and black color. Laminated to moderately bedded. Bedding planes from horizontal to 20° from horizontal. Soft (H6) and intensely weathered (W7). CaCOx, Mica and MnOx present. Strong reaction with HCl.

32.0 to 49.1 ft SHALE: Light to dark gray, fissile and laminated. Moderately soft (H5) and moderately weathered (W5). Bedding planes from horizontal to 16° from horizontal. Weak reaction with HCl.

STRATIGRAPHY:
0.0 to 22.5 ft QUATERNARY ALLUVIUM (Qal)
22.5 to 49.1 ft CRETACEOUS MANCOS SHALE (Km)

COMMENTS:

HSA= hollow stem auger NA= not available ft= feet NE= not encountered NP= non plastic NR= no recovery HCl= hydrochloric acid FeOx= iron oxide CaCOx= calcium carbonate MnOx= manganese oxide SPT= standard penetration test HQ3= coring system SS= sandstone CLSTN= claystone

The data for the center column and "classification and physical conditions" column are based on Bureau of Reclamation Geology Field Manual and drawings titled Geology for Design and Specification as follows "Drawing No. 40-D-6493 Standard Descriptions and Descriptive Criteria for Rock. Drawing No. 40-D-6499 Standard Descriptors and Descriptive Criteria for Discontinuities."

All angles measured from core axis at zero degrees unless otherwise noted.

GEOLOGIC LOG OF DRILL HOLE NO. DHR4C-17-5

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
BEGUN: 7/15/17 FINISHED: 7/15/17
DEPTH AND ELEVATION OF WATER LEVEL: NE
DATE MEASURED: 7/15/2017

PROJECT: Navajo Gallup Water Supply Project
COORDINATES: N 1,978,292.1 E 2,462,191.2
TOTAL DEPTH: 25.0 ft
DEPTH TO BEDROCK: 22.0

STATE: New Mexico
GROUND ELEVATION: 5558.4 ft NAD 83
ANGLE FROM HORIZONTAL: -90°
HOLE LOGGED BY: P. Gardner
REVIEWED BY: J. Gilbert

NOTES

All measurements are from ground level and are the same as those used by the driller.

DRILLED BY:
Upper Colorado Drill Crew
DRILLER: B. Lane
HELPER: M. Butler, R. Matheson

PURPOSE:
Preconstruction soil and bedrock linepipe investigation.

DRILL EQUIPMENT:
CME MODEL 850 track mounted rotary drill rig.

DRILL METHOD:
0.0 to 5.0 ft: 4.25 inch HSA with pilot bit.
5.0 to 25.0 ft: 4.25 inch HSA with split tube sampler and SPT.

DRILLING MEDIUM:
0.0 to 25.0 ft: None.

DRILLING NOTES:
0.0 to 23.7: Easy and smooth.
23.7 to 25.0: Augers hung up, work 10' up, down, forward & reverse until free, clean out and finish hole.

HOLE COMPLETION:
Backfilled with bentonite and auger cuttings.

SAMPLING:
5.0 to 6.5 ft: SPT
7.5 to 9.0 ft: SPT
10.0 to 11.5 ft: SPT
12.5 to 14.0 ft: SPT
15.0 to 16.5 ft: SPT
20.0 to 21.5 ft: SPT

DEPTH	GEOLOGIC SYMBOL	% CORE RECOVERY	% RQD	HARDNESS	WEATHERING	LABORATORY DATA						LABORATORY CLASSIFICATION	BLOWS / 0.5 FT	VISUAL CLASSIFICATION
						% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT			
	Qal	NR												(CL)s
5		56				97.4	2.6	0.0	47.9	29.7	9.8	CL	5/8/11	5551.2
		48				54.2	45.8	0.0	26.2	13.8	6.5	s(CL)	7/5/7	
10		64				86.4	13.6	0.0	24.3	10.9	7.0	CL	6/11/11	
		44				69.8	17.5	12.7	29.2	13.2	4.9	s(CL)	13/10/5	s(CL)
15		22				92.4	7.6	0.0	29.1	14.6	8.2	CL	23/28/38	
20		70				92.5	7.5	0.0	NA	NP	7.9	ML	50/50/NA	5536.4
25	Km	54	0	6	7									CLSTN 5533.4

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 22.0 ft QUATERNARY ALLUVIUM

0.0 to 7.2 ft LEAN CLAY WITH SAND (CL)s: About 75% fines with medium plasticity, medium toughness, high dry strength and no dilatancy; about 25% fine to medium sand; maximum size, medium sand; gray, dry, CaCOx stringers present; lenses of LEAN CLAY; strong reaction with HCl.

7.2 to 22.0 ft SANDY LEAN CLAY s(CL): About 70% fines with low plasticity, low toughness, high dry strength and no dilatancy; about 30% fine sand; trace of coarse, hard, subangular gravel; maximum size, 40mm; brown, dry, CaCOx stringers, FeOx and carbon blebs at 13.5 ft; 2-inch lenses of LEAN CLAY between 14.9 and 19.4 ft; strong reaction with HCl.

22.0 to 25.0 ft CRETACEOUS MANCOS SHALE

22.0 to 25.0 ft CLAYSTONE: Gray to dark brown color and laminated to very thinly bedded. Soft (H6) and intensely weathered (W7). Mica, MnOx and carbon blebs present. Weak reaction with HCl.

STRATIGRAPHY:
0.0 to 22.0 ft QUATERNARY ALLUVIUM (Qal)
22.0 to 25.0 ft CRETACEOUS MANCOS SHALE (Km)

COMMENTS:

HSA= hollow stem auger NA= not available ft= feet NE= not encountered NP= non plastic NR= no recovery HCl= hydrochloric acid FeOx= iron oxide CaCOx= calcium carbonate MnOx= manganese oxide SPT= standard penetration test HQ3= coring system SS= sandstone CLSTN= claystone

The data for the center column and "classification and physical conditions" column are based on Bureau of Reclamation Geology Field Manual and drawings titled Geology for Designs and Specification as follows "Drawing No. 40-D-6493 Standard Descriptions and Descriptive Criteria for Rock. Drawing No. 40-D-6499 Standard Descriptors and Descriptive Criteria for Discontinuities."

All angles measured from core axis at zero degrees unless otherwise noted.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 1

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
COORDINATES: N 1,996,022 E 2,461,275
APPROXIMATE DIMENSIONS: 6'X10'X7' ft
DEPTH TO WATER: WLNE DATE: 5/17/2017

PROJECT: Navajo Gallup Water Supply Project
GROUND ELEVATION: 5591.22 ft
METHOD OF EXPLORATION: Case 580N Backhoe
LOGGED BY: C. Beyer
DATE EXCAVATED: 5/17/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME) 3 - 5 in	5 - 12 in	PLUS 12 in
1 2 3 4	SC 4.0 ft (5587.2)	0.0 to 4.0 ft CLAYEY SAND: About 80% fine sand; about 20% fines with low plasticity, low dry strength and low toughness; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist in top 1.0 ft, dry below 1.0 ft, homogeneous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
5 6 7	SHALE 7.0 ft (5584.2)	4.0 to 7.0 ft SHALE: Light brown to gray in color, soft (H6) to moderately hard (H4), moderately to intensely weathered (W6), laminated to thinly bedded, sandy, fissile, strong reaction with HCl. Recovered in bucket as 2 to 6-inch subangular fragments. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:
Surface vegetated with grass. Discontinued excavation due to refusal in shale bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 2

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
COORDINATES: N 1,994,835 E 2,461,323
APPROXIMATE DIMENSIONS: 4'X12'X7.3' ft
DEPTH TO WATER: WLNE DATE: 5/17/2017

PROJECT: Navajo Gallup Water Supply Project
GROUND ELEVATION: 5597.74 ft
METHOD OF EXPLORATION: Case 580N Backhoe
LOGGED BY: C. Beyer
DATE EXCAVATED: 5/17/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2	SP-SC 2.5 ft (5595.2)	0.0 to 2.5 ft POORLY GRADED SAND WITH CLAY: About 90% predominately fine sand, trace medium to coarse sand; about 10% fines with low plasticity, low dry strength, and low toughness; trace gravel, maximum size, 25mm; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist below 0.5 ft, homogeneous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
3 4 5 6 7	SHALE 7.3 ft (5590.4)	2.5 to 7.3 ft SHALE: Light brown to gray in color, soft (H6) to moderately hard (H4), moderately to intensely weathered (W6), laminated to thinly bedded, sandy, fissile, strong reaction with HCl. Recovered as 2 to 4-inch subangular fragments. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:
Surface barren. Discontinued excavation due to refusal in shale bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 3

SHEET 1 OF 1

FEATURE: Reach 4C
PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipe Alignment
GROUND ELEVATION: 5592.20 ft
COORDINATES: N 1,993,641 E 2,461,372
METHOD OF EXPLORATION: Case 580N Backhoe
APPROXIMATE DIMENSIONS: 4'X10'X2.3' ft
LOGGED BY: C. Beyer
DEPTH TO WATER: WLNE DATE: 5/17/2017
DATE EXCAVATED: 5/17/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2	SP-SC 2.3 ft (5589.9)	0.0 to 2.3 ft POORLY GRADED SAND WITH CLAY: About 90% predominately fine sand, trace medium to coarse sand and gravel; about 10% fines with low plasticity, low dry strength, and low toughness; maximum size, 25mm; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist below 0.5 ft, homogeneous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
3 4 5	SHALE 5.0 ft (5587.2)	2.3 to 5.0 ft SHALE: Light brown to gray in color, soft (H6) to moderately hard (H4), moderately to intensely weathered (W6), laminated to thinly bedded, sandy, fissile, strong reaction with HCl. Recovered in bucket as 2 to 4-inch subangular fragments. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:
Surface barren. Discontinued excavation due to refusal in shale bedrock.

U.S. DEPARTMENT OF THE INTERIOR · BUREAU OF RECLAMATION

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 4

SHEET 1 OF 1

FEATURE: Reach 4C
PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipe Alignment
GROUND ELEVATION: 5584.87 ft
COORDINATES: N 1,992,411 E 2,461,411
METHOD OF EXPLORATION: Case 580N Backhoe
APPROXIMATE DIMENSIONS: 4'X10'X5' ft
LOGGED BY: C. Beyer
DEPTH TO WATER: WLNE DATE: 5/16/2017
DATE EXCAVATED: 5/16/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2	SP 2.5 ft (5582.4)	0.0 to 2.5 ft POORLY GRADED SAND: About 95% fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist in top 1.0 ft, dry below 1.0 ft, homogeneous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
3 4 5	SHALE 5.0 ft (5579.9)	2.5 to 5.0 ft SHALE: Light brown to gray in color, soft (H6) to moderately hard (H4), moderately to intensely weathered (W6), laminated to thinly bedded, sandy, fissile, strong reaction with HCl. Recovered in bucket as 2 to 4-inch subangular fragments. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:
Surface sparsely vegetated with weeds. Discontinued excavation due to refusal in shale bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 5

SHEET 1 OF 1

FEATURE: Reach 4C	PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipe Alignment	GROUND ELEVATION: 5571.01 ft
COORDINATES: N 1,990,453 E 2,461,483	METHOD OF EXPLORATION: Case 580N Backhoe
APPROXIMATE DIMENSIONS: 4'X10'X3.3' ft	LOGGED BY: C. Beyer
DEPTH TO WATER: WLNE DATE: 5/16/2017	DATE EXCAVATED: 5/16/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1	SP 1.7 ft (5569.3)	0.0 to 1.7 ft POORLY GRADED SAND: About 95% fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist in top 1.0 ft, dry below 1.0 ft, homogeneous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
2 3	SHALE 3.3 ft (5567.7)	1.7 to 3.3 ft SHALE: Light brown to gray in color, soft (H6) to moderately hard (H4), moderately to intensely weathered (W6), thin sandstone interbeds, laminated to moderately bedded, fissile, strong reaction with HCl. Recovered in bucket as 2 to 4-inch subangular fragments. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:
Surface sparsely vegetated with weeds. Discontinued excavation due to refusal in shale bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 6

SHEET 1 OF 1

FEATURE: Reach 4C

PROJECT: Navajo Gallup Water Supply Project

LOCATION: Pipe Alignment

GROUND ELEVATION: 5557.33 ft

COORDINATES: N 1,989,481 E 2,461,517

METHOD OF EXPLORATION: Case 580N Backhoe

APPROXIMATE DIMENSIONS: 3'X10'X3' ft

LOGGED BY: C. Beyer

DEPTH TO WATER: WLNE DATE: 5/16/2017

DATE EXCAVATED: 5/16/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
	SP 0.7 ft (5556.6)	0.0 to 0.7 ft POORLY GRADED SAND: About 95% fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
1 2 3	SHALE 3.0 ft (5554.3)	0.7 to 3.0 ft SHALE: Light brown to gray in color, soft (H6) to moderately hard (H4), moderately to intensely weathered (W6), sandstone interbeds, laminated to moderately bedded, fissile, strong reaction with HCl. Recovered in bucket as 2 to 6-inch subangular fragments. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:

Surface sparsely vegetated with grass and brush. Discontinued excavation due to refusal in shale bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 7

SHEET 1 OF 1

FEATURE: Reach 4C	PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipe Alignment	GROUND ELEVATION: 5550.92 ft
COORDINATES: N 1,988,687 E 2,461,546	METHOD OF EXPLORATION: Case 580N Backhoe
APPROXIMATE DIMENSIONS: 3'X10'X5' ft	LOGGED BY: C. Beyer
DEPTH TO WATER: WLNE DATE: 5/16/2017	DATE EXCAVATED: 5/16/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
	SP 0.8 ft (5550.1)	0.0 to 0.8 ft POORLY GRADED SAND: About 95% fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
1 2 3 4 5	SHALE 5.0 ft (5545.9)	0.8 to 5.0 ft SHALE: Light brown to gray in color, soft (H6) to moderately hard (H4), moderately to intensely weathered (W6), sandstone interbeds, laminated to moderately bedded, fissile, strong reaction with HCl. Recovered in bucket as 2 to 10-inch flat, subangular fragments. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:
Surface barren. Discontinued excavation due to refusal in shale bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 8

SHEET 1 OF 1

FEATURE: Reach 4C	PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipe Alignment	GROUND ELEVATION: 5545.12 ft
COORDINATES: N 1,987,444 E 2,461,709	METHOD OF EXPLORATION: Case 580N Backhoe
APPROXIMATE DIMENSIONS: 8'X15'X13.5' ft	LOGGED BY: C. Beyer
DEPTH TO WATER: WLNE DATE: 5/16/2017	DATE EXCAVATED: 5/16/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2 3 4 5 6 7 8	CL (visual) s(CL) (lab class) In-place density, 50 Lb sample and corrosivity sample taken from 7.0 to 8.0 ft. 9.0 ft (5536.1)	0.0 to 9.0 ft LEAN CLAY: About 90% fines with medium plasticity, medium toughness, and medium dry strength; about 10% fine sand; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist, homogeneous, calcareous. Calcite precipitated out on surface of dry strength sample. IN-PLACE UNIT WEIGHT AND MOISTURE FROM 7.0 to 8.0 ft. Total: 78.0 lb/ft³, 14.8 % (67.0% compaction) LAB TEST DATA: 65.2 % fines, 34.8 % sand, LL= 25.6 PI= 11.7 SPG= 2.71 Maximum dry density: 116.5 lb/ft³, optimum water content= 14.8% Laboratory classification is SANDY LEAN CLAY. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
9 10 11 12 13	SC 13.5 ft (5531.6)	9.0 to 13.5 ft CLAYEY SAND: About 85% fine sand; About 15% fines with low plasticity, low dry strength, and low toughness; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist, homogenous, calcareous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			

COMMENTS:
Surface scarcely vegetated with grass. Discontinued excavation due to the limit of equipment.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17- 9

SHEET 1 OF 1

FEATURE: Reach 4C
PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipe Alignment
GROUND ELEVATION: 5581.42 ft
COORDINATES: N 1,985,880 E 2,461,940
METHOD OF EXPLORATION: Case 580N Backhoe
APPROXIMATE DIMENSIONS: 4'X12'X7' ft
LOGGED BY: C. Beyer
DEPTH TO WATER: WLNE DATE: 5/16/2017
DATE EXCAVATED: 5/16/2017

CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME) 3 - 5 in	5 - 12 in	PLUS 12 in
SP 3.7 ft (5577.7)	0.0 to 3.7 ft POORLY GRADED SAND: About 95% fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, trace subangular gravel on the surface, moist. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
(SP)g 5.2 ft (5576.2)	3.7 to 5.2 ft POORLY GRADED SAND WITH GRAVEL AND COBBLES: About 60% predominately fine sand, trace medium to coarse sand; about 35% fine to coarse subrounded to subangular gravel; about 5% fines with no plasticity, no dry strength and rapid dilatancy; trace subangular sandstone cobbles; maximum size, 150mm; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)	t	t	
CONGLOMERATE SS 7.0 ft (5574.4)	5.2 to 7.0 ft CONGLOMERATIC SANDSTONE: Gray in color, moderately hard (H4), moderately weathered (W5), fine to coarse grained with subangular pebbles. Thinly to moderately bedded; strong reaction with HCl. GEOLOGIC INTERPRETATION: Cretaceous Gallup Sandstone (Kg)			

COMMENTS:
Surface barren. Discontinued excavation due to refusal in sandstone bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17-10

SHEET 1 OF 1

FEATURE: Reach 4C
PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipe Alignment
GROUND ELEVATION: 5562.11 ft
COORDINATES: N 1,984,688 E 2,462,051
METHOD OF EXPLORATION: Case 580N Backhoe
APPROXIMATE DIMENSIONS: 6'X12'X10.5' ft
LOGGED BY: C. Beyer
DEPTH TO WATER: WLNE DATE: 5/16/2017
DATE EXCAVATED: 5/16/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2 3	SP 3.7 ft (5558.4)	0.0 to 3.7 ft POORLY GRADED SAND WITH COBBLES: About 95% predominately fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; trace medium to coarse sand, gravel and cobbles; maximum size, 150mm; strong reaction with HCl. IN-PLACE CONDITION: Brownish red, in color, dry. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)	t	t	
4 5 6 7 8 9	SS In-place density and 50 Lb sample taken from 7.0 to 8.0 ft. 9.5 ft (5552.6)	3.7 to 9.5 ft SANDSTONE: Brown in color, fine grained, decomposed (W9), very soft (H7), thinly to moderately bedded. Classified as a soil: POORLY GRADED SAND (SP): About 95% predominately fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; trace medium to coarse sand, gravel; maximum size 25mm; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, dry. IN-PLACE UNIT WEIGHT AND MOISTURE FROM 7.0 to 8.0 ft. Total: 102.7 lb/ft^3, 2.7 % (86.1 % compaction) LAB TEST DATA: 66.1% sand, 25.0 % fines, 8.9 % gravel, LL= NA PI= NP SPG= 2.68 Maximum dry density: 119.3 lb/ft^3, optimum water content= 11.0% Laboratory classification is SILTY SAND. GEOLOGIC INTERPRETATION: Cretaceous Gallup Sandstone (Kg)			
10	SHALE 10.5 ft (5551.6)	9.5 to 10.5 ft SHALE: Brownish gray in color, moderately soft (H5), to moderately hard (H4), intensely to moderately weathered (W6), laminated, slightly fissile and sandy; strong reaction with HCl.			
		GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			

COMMENTS:
Surface vegetated with grass and brush. Discontinued excavation due to refusal in shale bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17-11

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
COORDINATES: N 1,983,483 E 2,462,054
APPROXIMATE DIMENSIONS: 8'X15'X13' ft
DEPTH TO WATER: WLNE DATE: 5/15/2017

PROJECT: Navajo Gallup Water Supply Project
GROUND ELEVATION: 5560.65 ft
METHOD OF EXPLORATION: Case 580N Backhoe
LOGGED BY: C. Beyer
DATE EXCAVATED: 5/15/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2 3 4 5	SP 6.0 ft (5554.7)	0.0 to 6.0 ft POORLY GRADED SAND: About 95% fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, trace subangular gravel on the surface, moist. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
6 7 8 9	SC In-place density and 50 Lb sample taken from 7.0 to 8.0 ft. 9.5 ft (5551.2)	6.0 to 9.5 ft CLAYEY SAND: About 80% fine sand; about 20% fines with low plasticity, low dry strength and low toughness; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist in top 1.0 ft, dry below 1.0 ft, homogenous. IN-PLACE UNIT WEIGHT AND MOISTURE FROM 7.0 to 8.0 ft. Total: 88.1 lb/ft³, 11.7 % (83.7 % compaction) LAB TEST DATA: 90.4 % fines, 9.6 % sand, LL= 40.3 PI= 20.4 SPG= 2.70 Maximum dry density: 105.3 lb/ft³, optimum water content= 17.8 % Laboratory classification is LEAN CLAY. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
10 11 12 13	SP 13.0 ft (5547.7)	9.5 to 13.0 ft POORLY GRADED SAND: About 95% fine sand; about 5% fines with no plasticity, no dry strength and rapid dilatancy; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, moist. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			

COMMENTS:

Surface vegetated with grass and buck brush. Discontinued excavation due to limit of equipment.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17-12

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
COORDINATES: N 1,981,630 E 2,462,010
APPROXIMATE DIMENSIONS: 8'X15'X13.5' ft
DEPTH TO WATER: WLNE DATE: 5/15/2017

PROJECT: Navajo Gallup Water Supply Project
GROUND ELEVATION: 5557.24 ft
METHOD OF EXPLORATION: Case 580N Backhoe
LOGGED BY: C. Beyer
DATE EXCAVATED: 5/15/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2 3 4 5 6 7 8 9 10 11 12 13	SP-SC (visual) CL-ML (lab class) In-place density and 50 Lb sample taken from 7.0 to 8.0 ft. Corrosivity sample collected at 10ft. 13.5 ft (5543.7)	0.0 to 13.5 ft POORLY GRADED SAND WITH CLAY: About 90% fine sand; about 10% fines with low plasticity, low dry strength and slow dilatancy; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, dry, homogeneous. IN-PLACE UNIT WEIGHT AND MOISTURE FROM 7.0 to 8.0 ft. Total: 83.2 lb/ft³, 6.6% (79.0% compaction) LAB TEST DATA: 93.3% fines, 6.7% sand, LL= 29.2 PI= 6.4 SPG= 2.70 Maximum dry density: 105.3 lb/ft³, optimum water content= 17.2% Laboratory classification is SILTY CLAY. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			

COMMENTS:
Surface vegetated with weeds. Discontinued excavation due to limit of equipment.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR4C-17-13

SHEET 1 OF 1

FEATURE: Reach 4C
LOCATION: Pipe Alignment
COORDINATES: N 1,979,256 E 2,462,250
APPROXIMATE DIMENSIONS: 6'X12'X9' ft
DEPTH TO WATER: WLNE DATE: 5/15/2017

PROJECT: Navajo Gallup Water Supply Project
GROUND ELEVATION: 5554.27 ft
METHOD OF EXPLORATION: Case 580N Backhoe
LOGGED BY: C. Beyer
DATE EXCAVATED: 5/15/2017

DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2 3	SC 4.0 ft (5550.3)	0.0 to 4.0 ft CLAYEY SAND: About 80% fine sand; about 20% fines with medium plasticity, medium dry strength and medium toughness; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Light brown in color, dry, homogeneous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
4	(CL)s 5.0 ft (5549.3)	4.0 to 5.0 ft LEAN CLAY WITH SAND: About 75% fines with medium to high plasticity, medium to high dry strength and medium toughness; about 25% fine sand; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Dark brown in color, dry, homogeneous. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
5 6	SP-SC 6.6 ft (5547.7)	5.0 to 6.6 ft POORLY GRADED SAND WITH CLAY: About 90% predominately fine sand; about 10% fines with low plasticity, low dry strength, low toughness and slow dilatancy; maximum size; fine sand; strong reaction with HCl. IN-PLACE CONDITION: Pink in color, dry. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
7	SHALE 8.0 ft (5546.3)	6.6 to 8.0 ft SHALE: Brownish gray in color, soft (H6), intensely weathered (W7), laminated, slightly fissile and sandy; strong reaction with HCl. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			
8	SS 9.0 ft (5545.3)	8.0 to 9.0 ft SANDSTONE: Brown in color, fine grained, moderately soft (H5), moderately weathered (W5), thinly bedded to laminated. GEOLOGIC INTERPRETATION: Cretaceous Mancos Shale (Km)			
9					

COMMENTS:
Surface vegetated with grass and brush. Discontinued excavation due to refusal in sandstone bedrock.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT NO. TPR6-17- 1

SHEET 1 OF 1

FEATURE: Reach 6
PROJECT: Navajo Gallup Water Supply Project
LOCATION: Pipeline Alignment
GROUND ELEVATION: 5562.4
COORDINATES: N 1,977,102 E 2,462,173
METHOD OF EXPLORATION: Deere 310 K Backhoe
APPROXIMATE DIMENSIONS: 15'x8'x16.2'
LOGGED BY: P. Gardner
DEPTH TO WATER: WLNE DATE: 1/24/2017
DATE EXCAVATED: 1/24/2017

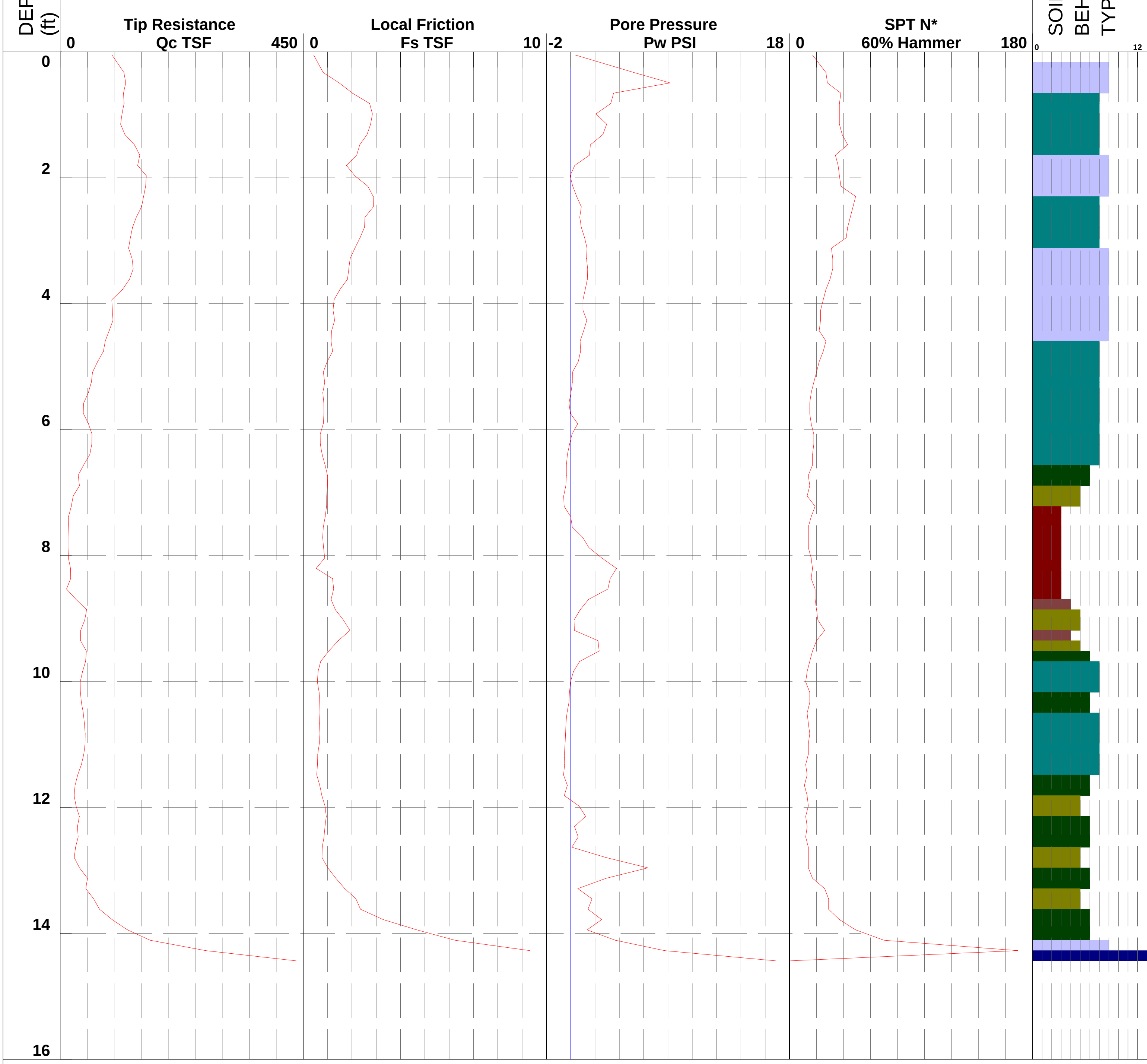
DEPTH	CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME)		
			3 - 5 in	5 - 12 in	PLUS 12 in
1 2 3 4 5 6 7 8	SM (Visual) CL (Lab classif) In-place density and 50 Lb sample taken from 7.0 to 8.0 ft. 8.2 ft (5554.2)	0.0 to 8.2 ft SILTY SAND: About 85% predominately fine sand, trace medium to coarse sand; about 15% nonplastic fines with rapid dilatancy and low dry strength; trace hard, subrounded gravel; maximum size, 25mm; weak reaction with HCl. IN-PLACE CONDITION: Light brown in color, dry, moderate cementation, cross stratified, clay lenses 5 inches thick. IN-PLACE UNIT WEIGHT AND MOISTURE FROM 7.0 to 8.0 ft. Total: 82.2 lbf/ft^3, 10.4% (78.9% compaction) LAB TEST DATA: 92.4% fines, 7.6% sand, LL= 34.1 PI= 18.2 SPG= 2.67 Maximum dry density: 104.2 lbf/ft^3, optimum water content= 18.3 % Laboratory classification is LEAN CLAY. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
9	(CL)s 9.4 ft (5553.0)	8.2 to 9.4 ft LEAN CLAY WITH SAND: About 80% fines with medium plasticity, medium dry strength and medium toughness; about 20% fine sand; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown to gray in color, dry, homogenous, hard, calcite stringers and nodules. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
10 11	SM 11.3 ft (5551.1)	9.4 to 11.3 ft SILTY SAND: About 60% fine sand; about 40% nonplastic fines with slow dilatancy and low dry strength; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, dry, moderate cementation. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			
12 13 14 15 16	(CL)s 16.2 ft (5546.2)	11.3 to 16.2 ft LEAN CLAY WITH SAND: About 65% fines with medium plasticity, medium dry strength and medium toughness; about 35% fine sand; maximum size, fine sand; strong reaction with HCl. IN-PLACE CONDITION: Brown in color, dry, homogenous, hard, calcite stringers and nodules. GEOLOGIC INTERPRETATION: Quaternary Alluvium (Qal)			

COMMENTS: Surface vegetated with grass. Discontinued excavation due to limit of equipment.

BUREAU OF RECLAMATION

Hole # CPT5-14-1
Cone # DSA0739
Date/Time 7/9/2014 9:56:19 AM
Project NGWSP
Location REACH 5
Operator L ROBINSON
Station
Offset
Elevation 5545.6
Northing 1988087.048
Easting 2461666.218

CPT DATA



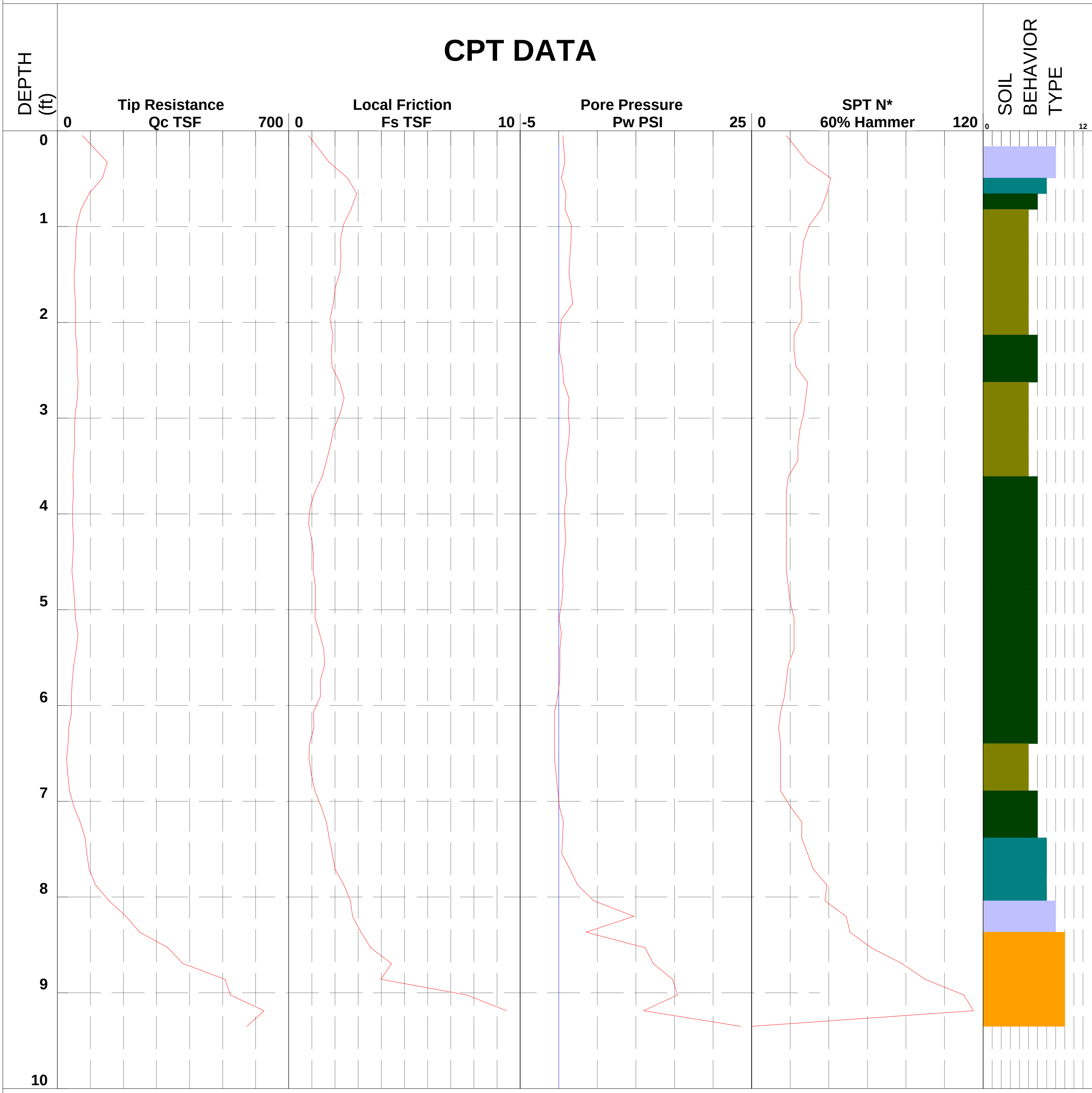
■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

Total Depth 14.7' Qc>450 Fs>12

BUREAU OF RECLAMATION

Hole # CPT5-14-2
Cone # DSA0739
Date/Time 7/9/2014 8:48:15 AM
Project NGWSP
Location REACH 5
Operator L ROBINSON
Station
Offset
Elevation 5544.8

Northing 1986623.061
Easting 2461855.374

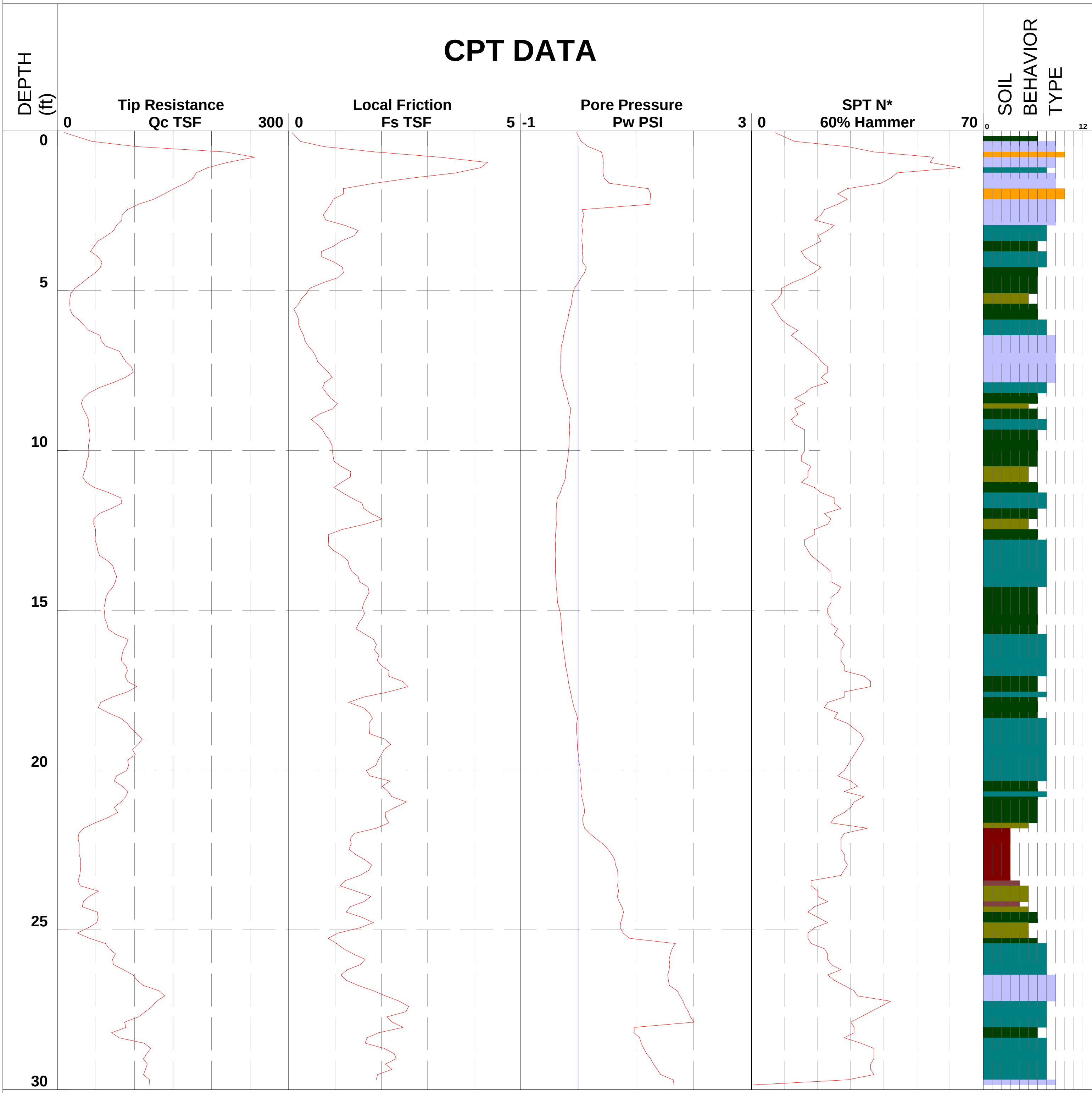


■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

Total Depth 9.5' Qc>650 Fs>10

BUREAU OF RECLAMATION

Hole #	CPT5-14-3	Cone #	DSG1028	Date/Time	7/9/2014 10:54:04 AM
Project	NGWSP	Location	REACH 5	Operator	L ROBINSON
Station		Offset		Elevation	5556.9
		Northing	1983477.004	Easting	2462273.514



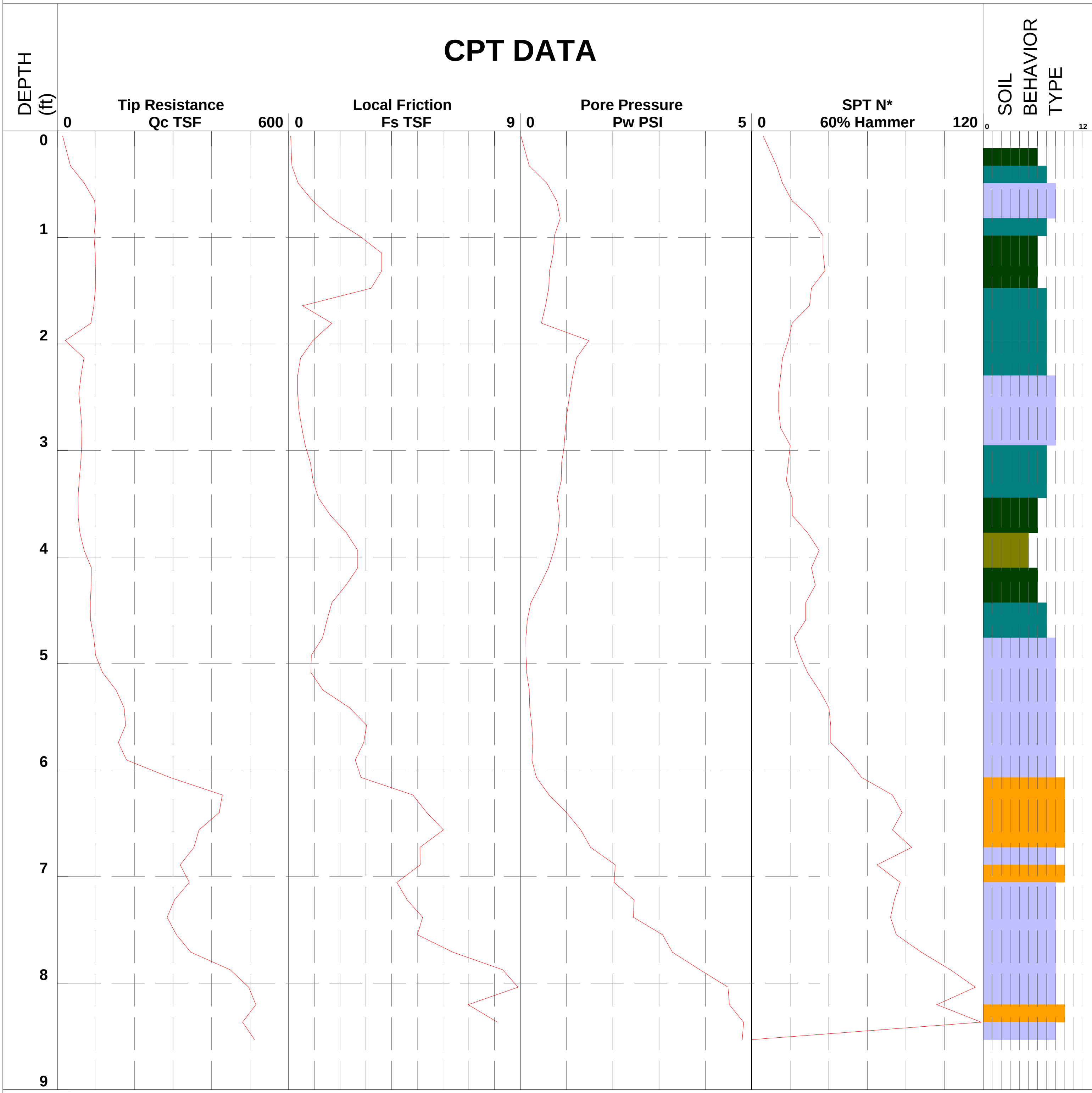
■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

Total Depth 30'

BUREAU OF RECLAMATION

Hole # CPT5-14-4
Cone # DSG1028
Date/Time 7/9/2014 12:32:34 PM
Project NGWSP
Location REACH 5
Operator L ROBINSON
Station
Offset
Elevation 5555.2
Northing 1979525.473
Easting 2462035.457

CPT DATA



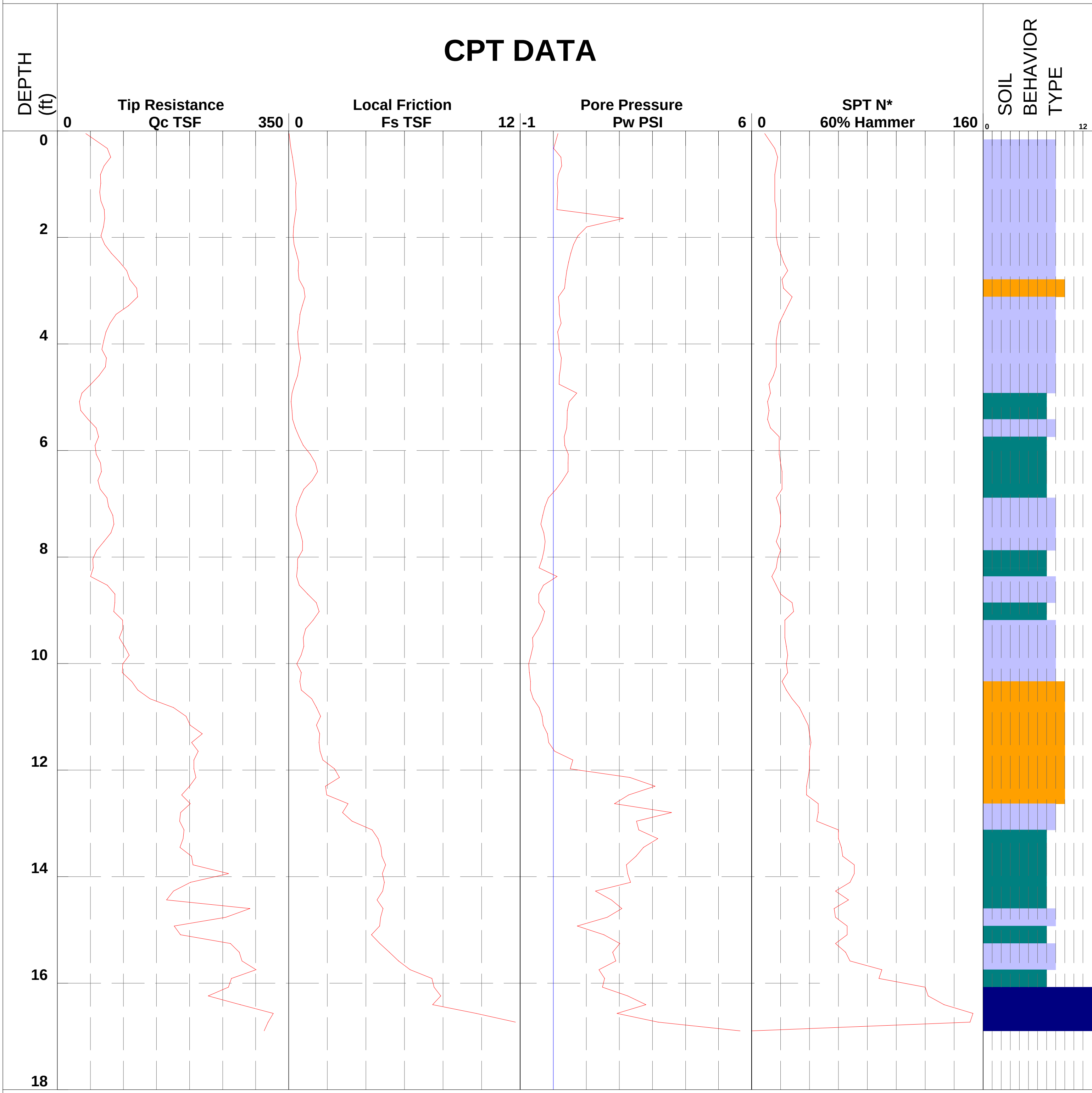
■ 1 - sensitive fine grained	■ 4 - silty clay to clay	■ 7 - silty sand to sandy silt	■ 10 - gravelly sand to sand
■ 2 - organic material	■ 5 - clayey silt to silty clay	■ 8 - sand to silty sand	■ 11 - very stiff fine grained (*)
■ 3 - clay	■ 6 - sandy silt to clayey silt	■ 9 - sand	■ 12 - sand to clayey sand (*)

Total Depth 8.7' Qc>500 Fs>9

BUREAU OF RECLAMATION

Hole # CPT5-14-5
Cone # DSG1028
Date/Time 7/9/2014 1:06:45 PM
Project NGWSP
Location REACH 5
Operator L ROBINSON
Station
Offset
Elevation 5559.6
Northing 1978270.650
Easting 2461908.639

CPT DATA

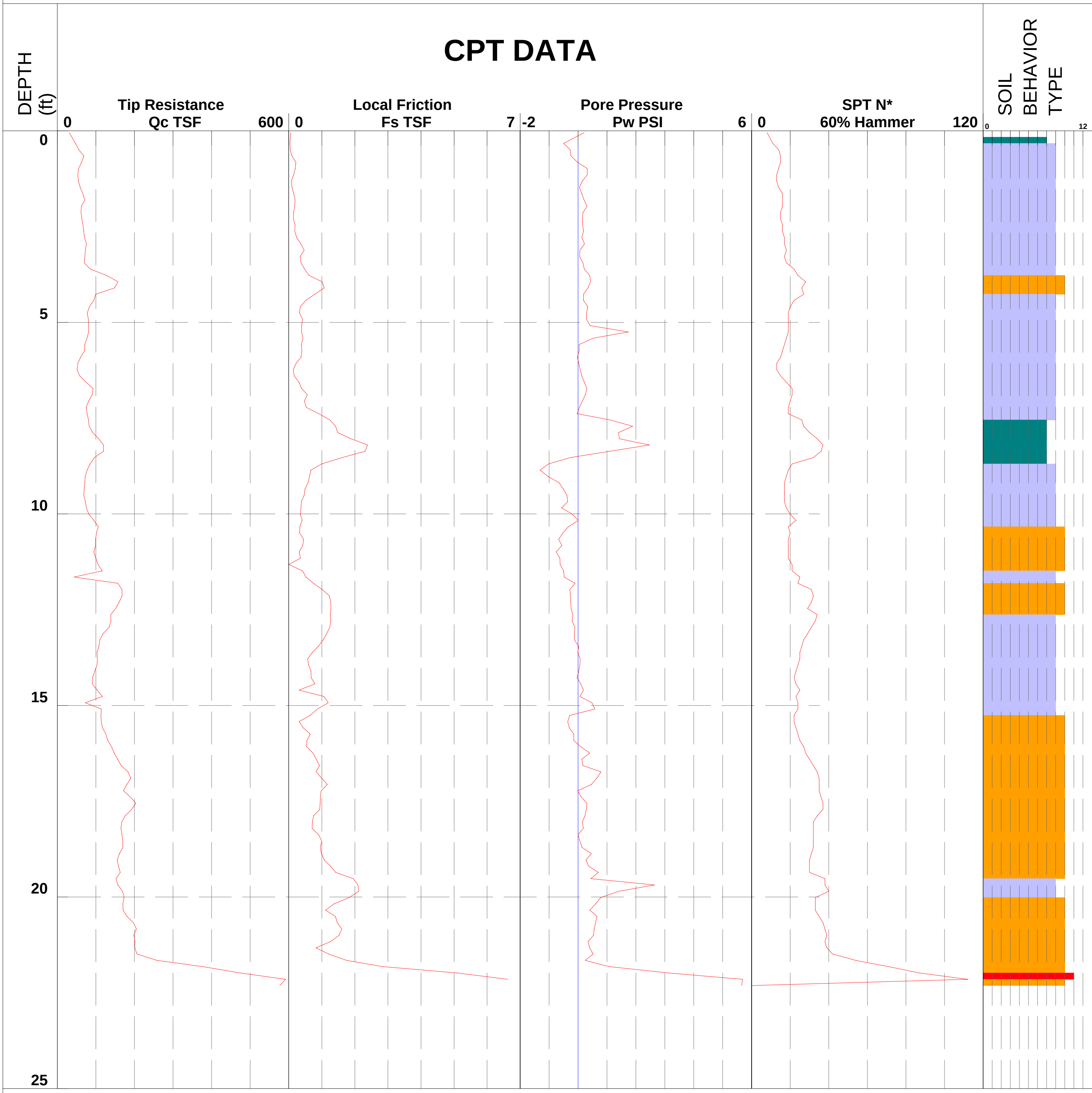


■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

Total Depth 17.1' Qc>500 Fs>12

BUREAU OF RECLAMATION

Hole #	CPT5-14-6	Cone #	DSG1028	Date/Time	7/9/2014 1:39:17 PM
Project	NGWSP	Location	REACH 5	Operator	L ROBINSON
Station		Offset		Elevation	5564.3
		Northing	1977174.900	Easting	2461926.383



⬜ 1 - sensitive fine grained

⬛ 2 - organic material

🟥 3 - clay

🟫 4 - silty clay to clay

🟨 5 - clayey silt to silty clay

🟩 6 - sandy silt to clayey silt

🟩 7 - silty sand to sandy silt

🟪 8 - sand to silty sand

🟧 9 - sand

🟥 10 - gravelly sand to sand

🟦 11 - very stiff fine grained (*)

🟦 12 - sand to clayey sand (*)

Total Depth 22.5' Qc>650 Fs>6

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APPENDIX 2

IDENTIFICATION			PARTICLE SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			IN-PLACE DENSITY				COMPACTION TESTS			
			<u>FINES</u>																
TEST PIT NUMBER	DEPTH - feet	CLASSIFICATION SYMBOL	SMALLER THAN 0.005mm	0.005 to 0.074mm	<u>SAND</u> #200 (0.074mm) to 3" (4.76mm)	<u>GRAVEL</u> #4 (4.76mm) to 3" (76.2mm)	<u>COBBLES</u> 3" (76.2mm) to 5" (127mm)	<u>OVERSIZE</u> Larger than 5" (127mm)	LIQUID LIMIT - %	PLASTICITY INDEX - %	SHRINKAGE LIMIT - %	DRY DENSITY- pcf	FILL MOISTURE CONTENT- %	SPECIFIC GRAVITY PLUS No. 4	SPECIFIC GRAVITY MINUS No. 4	MAXIMUM DRY DENSITY - pcf	OPTIMUM MOISTURE CONTENT - %	PENETRATION RESISTANCE - psi	D-VALUE - %
SPT-1	5.0 - 6.5	s(CL)	37.8	28.1	34.1	0	0	0	34.6	21.0	-	-	5.7	-	2.65	--	--	--	--
SPT-2	7.5 - 9.0	CL	43.8	44.9	11.3	0	0	0	38.1	20.0	-	-	7.1	-	2.67	--	--	--	--

NOTE: Numbers in parentheses are metric equivalents of numbers directly above.
**Denotes In-place density and 5-point curve.*

IDENTIFICATION			PARTICLE SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			IN-PLACE DENSITY				COMPACTION TESTS			
			FINES																
TEST PIT NUMBER	DEPTH - feet	CLASSIFICATION SYMBOL	SMALLER THAN 0.005mm	0.005 to 0.074mm	SAND #200 (0.074mm) to 3” (4.76mm)	GRAVEL #4 (4.76mm) to 3” (76.2mm)	COBBLES 3” (76.2mm) to 5” (127mm)	OVERSIZE Larger than 5” (127mm)	LIQUID LIMIT - %	PLASTICITY INDEX - %	SHRINKAGE LIMIT - %	DRY DENSITY- pcf	FILL MOISTURE CONTENT- %	SPECIFIC GRAVITY PLUS No. 4	SPECIFIC GRAVITY MINUS No. 4	MAXIMUM DRY DENSITY - pcf	OPTIMUM MOISTURE CONTENT - %	PENETRATION RESISTANCE - psi	D-VALUE - %
SPT-1	5.0 - 6.5	(CL)s	26.8	46.1	27.1	0	0	0	25.0	8.5	-	-	3.5	-	2.69	--	--	--	--
SPT-2	7.5 - 9.0	CL	27.2	60.2	12.6	0	0	0	27.1	9.4	-	-	3.3	-	2.70	--	--	--	--
SPT-3	10.0 - 11.5	(CL)s	31.3	50.4	18.3	0	0	0	30.4	13.9	-	-	3.8	-	2.70	--	--	--	--

NOTE: Numbers in parentheses are metric equivalents of numbers directly above.
**Denotes In-place density and 5-point curve.*

IDENTIFICATION			PARTICLE SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			IN-PLACE DENSITY				COMPACTION TESTS			
			FINES																
TEST NUMBER	DEPTH - feet	CLASSIFICATION SYMBOL	SMALLER THAN 0.005mm	0.005 to 0.074mm	SAND #200 (0.074mm) to 3" (4.76mm)	GRAVEL #4 (4.76mm) to 3" (76.2mm)	COBBLES 3" (76.2mm) to 5" (127mm)	OVERSIZE Larger than 5" (127mm)	LIQUID LIMIT - %	PLASTICITY INDEX - %	SHRINKAGE LIMIT - %	DRY DENSITY- pcf	FILL MOISTURE CONTENT- %	SPECIFIC GRAVITY PLUS No. 4	SPECIFIC GRAVITY MINUS No. 4	MAXIMUM DRY DENSITY - pcf	OPTIMUM MOISTURE CONTENT - %	PENETRATION RESISTANCE - psi	D-VALUE - %
SPT-1	5.0 - 6.5	(CL)s	42.5	41.0	16.5	0	0	0	24.3	9.6	-	-	7.5	-	2.73	--	--	--	--
SPT-2	7.5 - 9.0	(ML)s	24.2	54.3	21.5	0	0	0	19.8	3.4	-	-	3.5	-	2.71	--	--	--	--
SPT-3	10.0 - 11.5	(CL-ML)s	23.3	55.3	21.4	0	0	0	24.2	4.7	-	-	4.2	-	2.69	--	--	--	--
SPT-4	12.5 - 14.0	CL	34.5	56.8	8.7	0	0	0	26.1	9.8	-	-	6.9	-	2.80	--	--	--	--
SPT-5	15.0 - 16.5	(CL)s	27.1	54.1	18.8	0	0	0	26.0	11.4	-	-	8.5	-	2.70	--	--	--	--

NOTE: Numbers in parentheses are metric equivalents of numbers directly above.

**Denotes In-place density and 5-point curve.*

IDENTIFICATION			PARTICLE SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			IN-PLACE DENSITY				COMPACTION TESTS			
			FINES																
TEST NUMBER	**DEPTH - feet**	**CLASSIFICATION SYMBOL**	**SMALLER THAN 0.005mm**	**0.005 to 0.074mm**	**SAND #200 (0.074mm) to 3” (4.76mm)**	**GRAVEL #4 (4.76mm) to 3” (76.2mm)**	**COBBLES 3” (76.2mm) to 5” (127mm)**	**OVERSIZE Larger than 5” (127mm)**	**LIQUID LIMIT - %**	**PLASTICITY INDEX - %**	**SHRINKAGE LIMIT - %**	**DRY DENSITY- pcf**	**FILL MOISTURE CONTENT- %**	**SPECIFIC GRAVITY PLUS No. 4**	**SPECIFIC GRAVITY MINUS No. 4**	**MAXIMUM DRY DENSITY - pcf**	**OPTIMUM MOISTURE CONTENT - %**	**PENETRATION RESISTANCE - psi**	**D-VALUE - %**
SPT-1	5.0 - 6.5	SM	7.0	14.5	78.5	0	0	0	-	-	-	-	1.2	-	2.63	--	--	--	--
SPT-2	7.5 - 9.0	SM	7.0	11.2	81.8	0	0	0	-	-	-	-	2.4	-	2.65	--	--	--	--
SPT-3	10.0 - 11.5	(CL)s	35.2	47.5	15.9	1.4	0	0	25.9	9.8	-	-	4.6	2.53	2.64	--	--	--	--
SPT-4	12.5 - 14.0	(CL-ML)s	23.7	56.2	20.1	0	0	0	24.7	5.9	-	-	9.6	-	2.66	--	--	--	--
SPT-5	15.0 - 16.5	CL	31.8	57.7	10.5	0	0	0	27.9	10.6	-	-	10.6	-	2.68	--	--	--	--
SPT-6	20.0 - 21.5	CL	35.0	53.0	11.3	0.7	0	0	29.5	12.7	-	-	8.5	2.58	2.64	--	--	--	--

NOTE: Numbers in parentheses are metric equivalents of numbers directly above.
**Denotes In-place density and 5-point curve.*

IDENTIFICATION			PARTICLE SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			IN-PLACE DENSITY				COMPACTION TESTS			
			FINES																
TEST NUMBER	DEPTH - feet	CLASSIFICATION SYMBOL	SMALLER THAN 0.005mm	0.005 to 0.074mm	SAND #200 (0.074mm) to 3" (4.76mm)	GRAVEL #4 (4.76mm) to 3" (76.2mm)	COBBLES 3" (76.2mm) to 5" (127mm)	OVERSIZE Larger than 5" (127mm)	LIQUID LIMIT - %	PLASTICITY INDEX - %	SHRINKAGE LIMIT - %	DRY DENSITY- pcf	FILL MOISTURE CONTENT- %	SPECIFIC GRAVITY PLUS No. 4	SPECIFIC GRAVITY MINUS No. 4	MAXIMUM DRY DENSITY - pcf	OPTIMUM MOISTURE CONTENT - %	PENETRATION RESISTANCE - psi	D-VALUE - %
SPT-1	5.0 - 6.5	CL	74.0	23.4	2.6	0	0	0	47.9	29.7	12.4	-	9.8	-	2.50	--	--	--	--
SPT-2	7.5 - 9.0	s(CL)	33.7	20.5	45.8	0	0	0	26.2	13.8	-	-	6.5	-	2.58	--	--	--	--
SPT-3	10.0 - 11.5	CL	41.3	45.1	13.6	0	0	0	24.3	10.9	-	-	7.0	-	2.62	--	--	--	--
SPT-4	12.5 - 14.0	s(CL)	21.3	48.5	17.5	12.7	0	0	29.2	13.2	-	-	4.9	2.56	2.66	--	--	--	--
SPT-5	15.0 - 16.5	CL	36.7	55.7	7.6	0	0	0	29.1	14.6	-	-	8.2	-	2.67	--	--	--	--
SPT-6	20.0 - 21.5	ML	30.7	61.8	7.5	0	0	0	NA	NP	-	-	7.9	-	2.74	--	--	--	--

NOTE: Numbers in parentheses are metric equivalents of numbers directly above.

**Denotes In-place density and 5-point curve.*

IDENTIFICATION			PARTICLE SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			IN-PLACE DENSITY				COMPACTION TESTS				
			FINES																	
TEST PIT NUMBER	**DEPTH – feet**	**CLASSIFICATION SYMBOL**	**SMALLER THAN 0.005 mm**	**0.005 to 0.074 mm**	**SAND #200 (.074mm) to #4 (4.76mm)**	**GRAVEL #4 (4.76mm) to 3" (76.2mm)**	**COBBLES 3" (76.2mm) to 5" (127mm)**	**OVERSIZE Larger than 5" (127mm)**	**LIQUID LIMIT - %**	**PLASTICITY INDEX - %**	**SHRINKAGE LIMIT - %**	**DRY DENSITY - pcf**	**FILL WATER CONTENT - %**	**SPECIFIC GRAVITY PLUS No. 4**	**SPECIFIC GRAVITY MINUS No. 4**	**MAXIMUM DRY DENSITY - pcf**	**OPTIMUM WATER CONTENT - %**	**PENETRATION RESISTANCE - psi**	**D-VALUE - %**	**RELATIVE COMPACTION - %**
TPR4C-17-8	7.0	s(CL)	34.6	30.6	34.8	0	0	0	25.6	11.7	-	78.0	14.8	-	2.71	116.5	14.8	600	67.0	-
TPR4C-17-10	7.0	SM	10.9	14.1	66.1	8.9	0	0	NA	NP	-	102.7	2.7	2.50	2.68	119.3	11.0	400	86.1	-
TPR4C-17-11	7.0	CL	50.9	39.5	9.6	0	0	0	40.3	20.4	6.26	88.1	11.7	-	2.70	105.3	17.8	750	83.7	-
TPR4C-17-12	7.0	CL-ML	25.0	68.3	6.7	0	0	0	29.2	6.4	-	83.2	6.6	-	2.70	105.3	17.2	850	79.0	-

** Denotes In-place density and 5-point curve*

APPENDIX 3

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Navajo Gallup Water Supply Project

San Juan Lateral, Reach 4C, Drill Core Photos

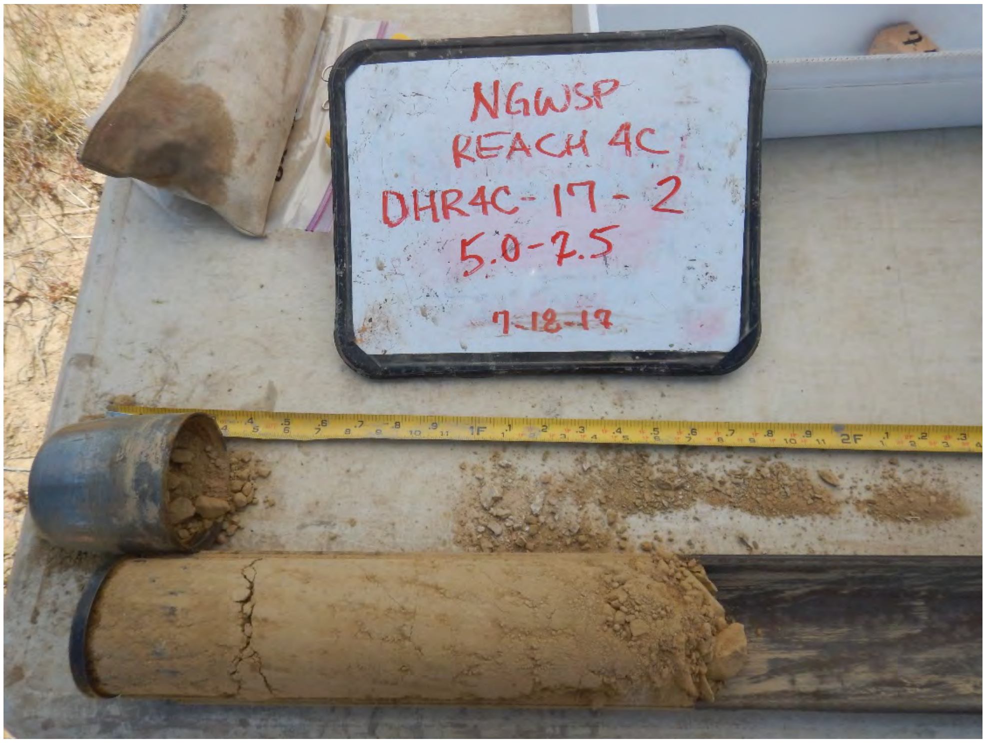

NGWSP
REACH 4C
DHR4C-17-1
5.0-10.0
7-19-17
1/2


NGWSP
REACH 4C
DHR4C-17-1
10.0-15.5
7-19-17


NGWSP
REACH 4C
DHR4C-17-1
15.5-20.5
7-19-17
NGWSP
REACH 4C & 6
DH & TP


NGWSP
REACH 4C
DHR4C-17-1
20.5-25.5
7-19-17


NGWSP
REACH 4C
DHR4C-17-1
10.0-25.5
7-19-17
2/2
10.0
15.5
20.5
25.5


NGWSP
REACH 4C
DHR4C-17-2
5.0-7.5
7-18-17


NGWSP
REACH 4C
DHR4C-17-2
7.5-10.0
7-18-17
NGWSP
REACH 4C
DH & TP


NGWSP
REACH 4C
DHR4C-17-2
10.0-15.0
7-18-17


NGWSP
REACH4C
DHR4C-17-2
5.0-15.0
1/2
7-18-17
7.5
5.0
10.0
15.0


NGWSP
REACH 4C
DHR4C-17-2
15.0-20.0
7-18-17


NGWSP
REACH 4C
DHR4C-17-2
20.0-25.0
7-18-17


NGWSP
REACH 4C
DHR4C-17-2
15.0-25.0
7-18-17
2/2
15.0
20.0
25.0


NGWSP
REACH 4C
DHR4C-17-3
5.0-7.5
7-18-17


NGWSP
REACH 4C
DHR4C-17-3
7.5-10.0
7-18-17
NGWSP
REACH 4C


NGWSP
REACH 4C
DHR4C-17-3
10.0-12.5
7-18-17

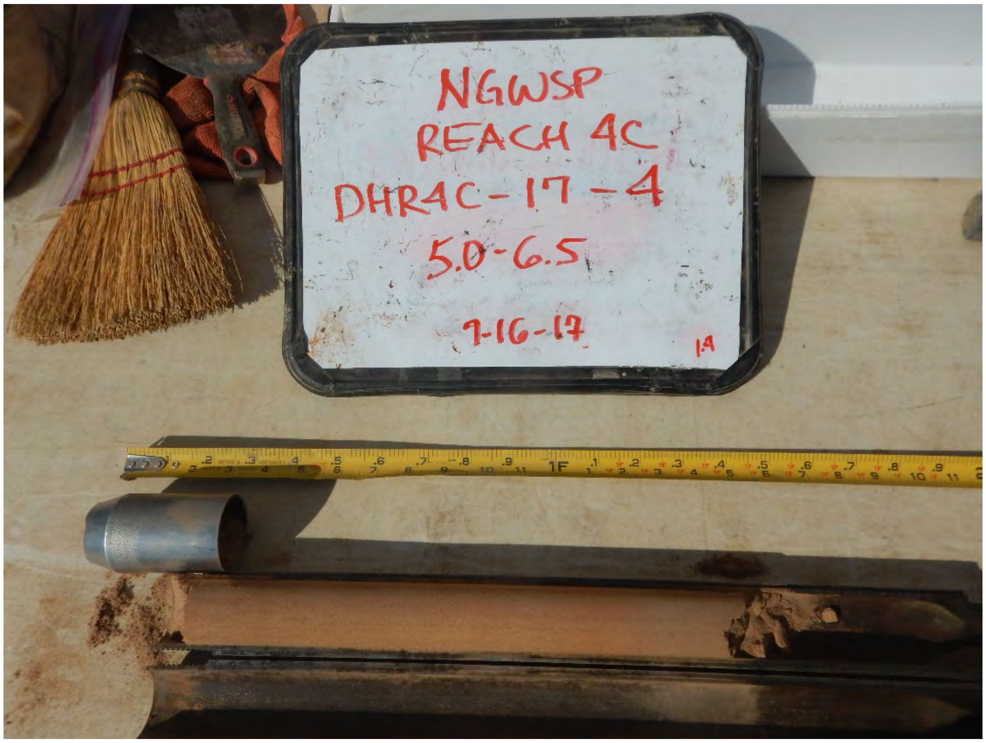

NGWSP
REACH 4C
DHR4C-17-3
12.5-15.0
7-18-17
5139


NGWSP
REACH 4C
DHR4C-17-3
5.0-15.0
7-18-17
1/2
5.0
7.5
10.0
12.5
15.0


NGWSP
REACH 4C
DHR4C-17-3
15.0-20.0
7-18-17


NGWSP
REACH 4C
DHR4C-17-3
20.0-25.0
7-18-17


NGWSP
REACH 4C
DHR4C-17-3
15.0 - 25.0
7-18-17
2/2
15.0
20.0
25.0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REACH 4C
DHR4C-17-4
5.0-6.5
7-16-17
1.4


NGWSP
REACH 4C
DHR4C-17-4
7.5-10.0
7-16-17
0.8


NGWSP
REACH 4C
DHR4C-17-4
10.0-12.5
7-16-17
2.4


NGWSP
REACH 4C
DHR4C-17-4
12.5-15.0
7-16-17
2.1


NGWSP
REACH 4C
DHR4C-17-4
15.0-20.0
7-16-17
1F
2F


NGWSP
REACH 4C
DHR4C-17-4
7.5-20.0
7-16-17
10.0
15.0


NGWSP
REACH 4C
DHR4C-17-4
20.0-25.0
7-16-17
0.9


NGWSP
REACH 4C
DHR4C-17-4
20.0-25.0
7-16-17
2/
20.0


NGWSP
REACH 4C
DHR4C-17-4
25.0-30.0
7-16-17
5A


NGWSP
REACH 4C
DHR4C-17-4
30.0-35.0
7-16-17
5B


NGWSP
REACH 4C
DHR4C-17-4
25.0-38.7
7-16-17
3/4
25.0
30.0
35.0
38.7
NGWSP


NGWSP
REACH 4C
DHR4C-17-4
38.7-40.0
7-16-17
5.0
BOARD MARKER


NGWSP
REACH 4C
DHR4C-17-4
40.0-45.0
2-16-17
NGWSP
REACH 4C & 6
DH & TP


NGWSP
REACH 4C
DHR4C-17-4
45.0-49.1
2-16-17


NGWSP
REACH 4C
DH R4C-17-4
38.7-49.1
4/4
7-16-17
45.0
NGWSP
REACH 4 & 6
DH & TP


NGWSP
REACH 4C
DHR4C-17-5
5.0-7.5
7-15-17
1A
1F


NGWSP
REACH 4C
DHR4C-17-5
7.5-10.0
7-15-17
1.2
7-15-17


NGWSP
REACH 4C
DHR4C-17-5
10.0-12.5
7-15-17
1.6
7-15-17


NGWSP
REACH 4C
DHR4C-17-5
12.5-15.0
7-15-17
NGWSP
BOARD MARKER
HUSKY


NGWSP
REACH 4C
DHR4C-17-5
5.0-15.0
1/2
7-15-17
7.5
12.5
5.0
10.0
15.0


NGWSP
REACH 4C
DHR4C-17-5
15.0-20.0
7-15-17


NGWSP
REACH 4C
DHR4C-17-5
20.0-23.7
7-15-17


NGWSP
REACH 4C
DHR4C-17-5
23.7-25.0
7-15-17
0.7
1F
2F


NGWSP
REACH 4C
DHR4C-17-5
15.0-25.0
7-15-17
2/2
15.0
20.0
22.0
23.7
25.0

Navajo Gallup Water Supply Project

San Juan Lateral, Reach 4C, Test Pit Photos


NGWSP
REACH 4C
TPR4C-17-2
0.0-7.3
5/16/17


NGWSP
REACH 4C
TPR4C-17-2
0.0-7.3
5/16/17

TPR4C-17-3


NGWSP
REACH 4C
TPR4C-17-4
0.0-5.0
5/16/17


NGWSP
REACH 4C
TPR4C-17-4
0.0-5.0
5/16/17


NGWSP
REACH 4C
TPR4C-17-5
0.0-3.3
5/16/17


NGWSP
REACH 4C
TPR4C-17-5
0.0-3.3
5/16/17


NGWSP
REACH 4C
TPR4C-17-6
0.0-3.0
5/16/17


NGWSP
REACH 4C
TPR4C-17-6
0.0-3.0
5/16/17


NGWSP
REACH 4C
TPR4C-17-7
0.0-5.0
5/16/17


NGWSP
REACH 4C
TPR4C-17-7
0.0-5.0
5/16/17


TPR4C-17-8


NGWSP
REACH 4C
TPR4C-17-8
0.0-13.5
5/16/17


TPR4C-17-9


NGWSP
REACH 4C
TPR4C-17-9
0.0-7.0
5/16/17


TPR4C-17-10


NGWSP
REACH 4C
TPR4C-17-10
0.0-10.5
5/16/17


TPR4C-17-11


NGWSP
REACH 4C
TPR4C-17-11
0.0-13.0
5/15/17

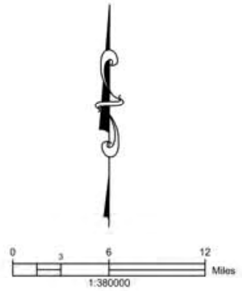

TPR4C-17-12


NGWSP
REACH 4C
TPR4C-17-12
0.0-13.5
5/15/17
extendahoe


TPR4C-17-13

APPENDIX 4

KEY MAP



LEGEND

- 🟥 Pipeline (Varied by Reach)
- 🟩 Water Treatment Plant
- ● Pumping Plant Location
- ◆ Turnout Location
- ▨ Jicarilla Indian Reservation
- ▨ Navajo Nation Indian Reservation (Chapters)
- — Highway (as designated)
- -·- County Line

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NAVAJO-GALLUP WATER SUPPLY PROJECT
NEW MEXICO

SAN JUAN LATERAL

REACH 4C

D. Thornburg
DESIGNED
D. THORNBURG
DRAWN
GARDNER, PAUL
CHECKED
Gilbert, Justin J
TECH. APPR.
Longwell, Barry D
APPROVED
ADMIN APPROVAL - Project Construction Engineer

FARMINGTON, NM 2017-11-14

GENERAL MAP

1695-529-60161

SHEET 1

DATE AND TIME PLOTTED
NOVEMBER 14, 2017 13:11
PLOTTED BY
DTHORNBURG

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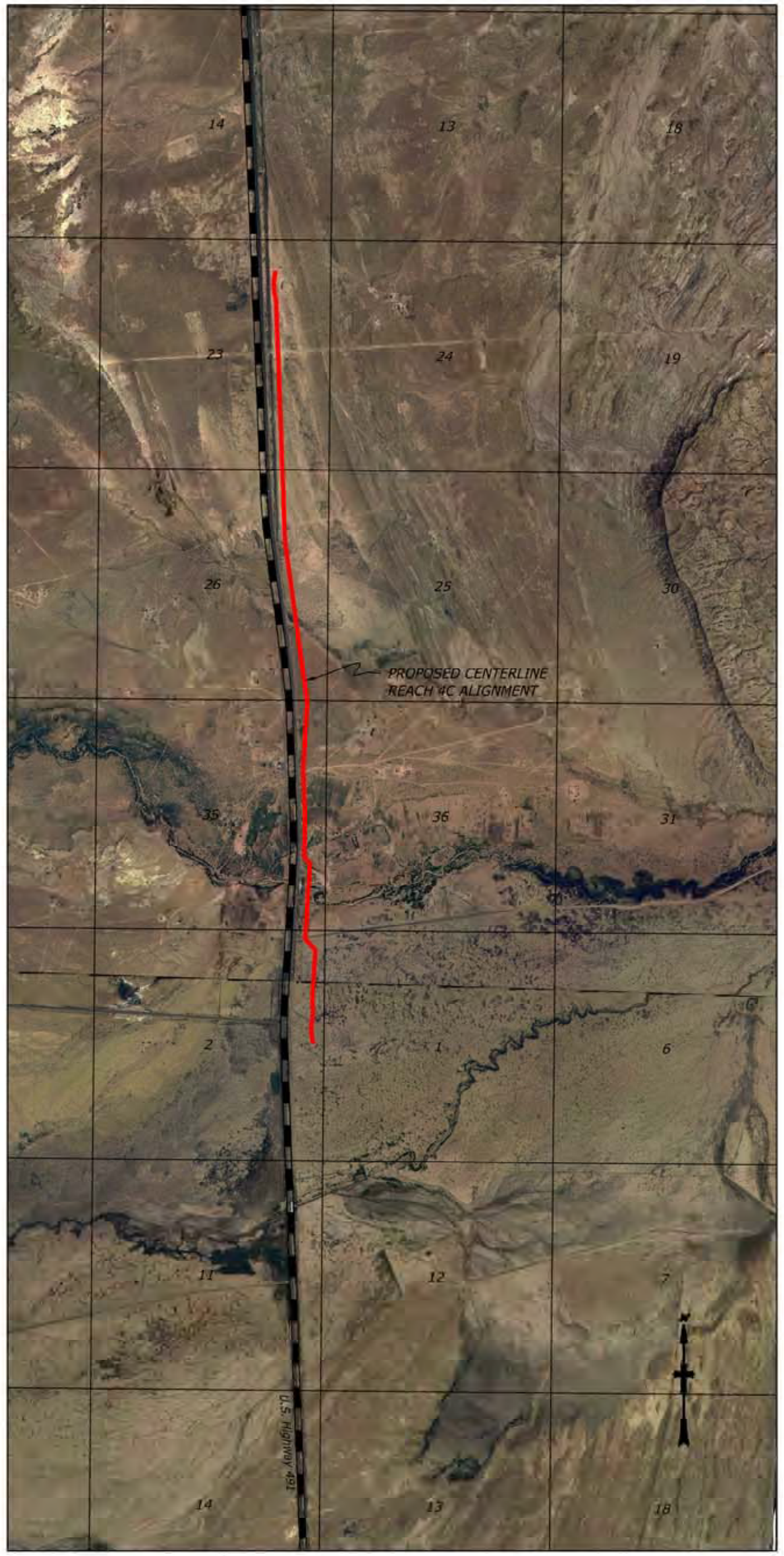

LOCATION MAP

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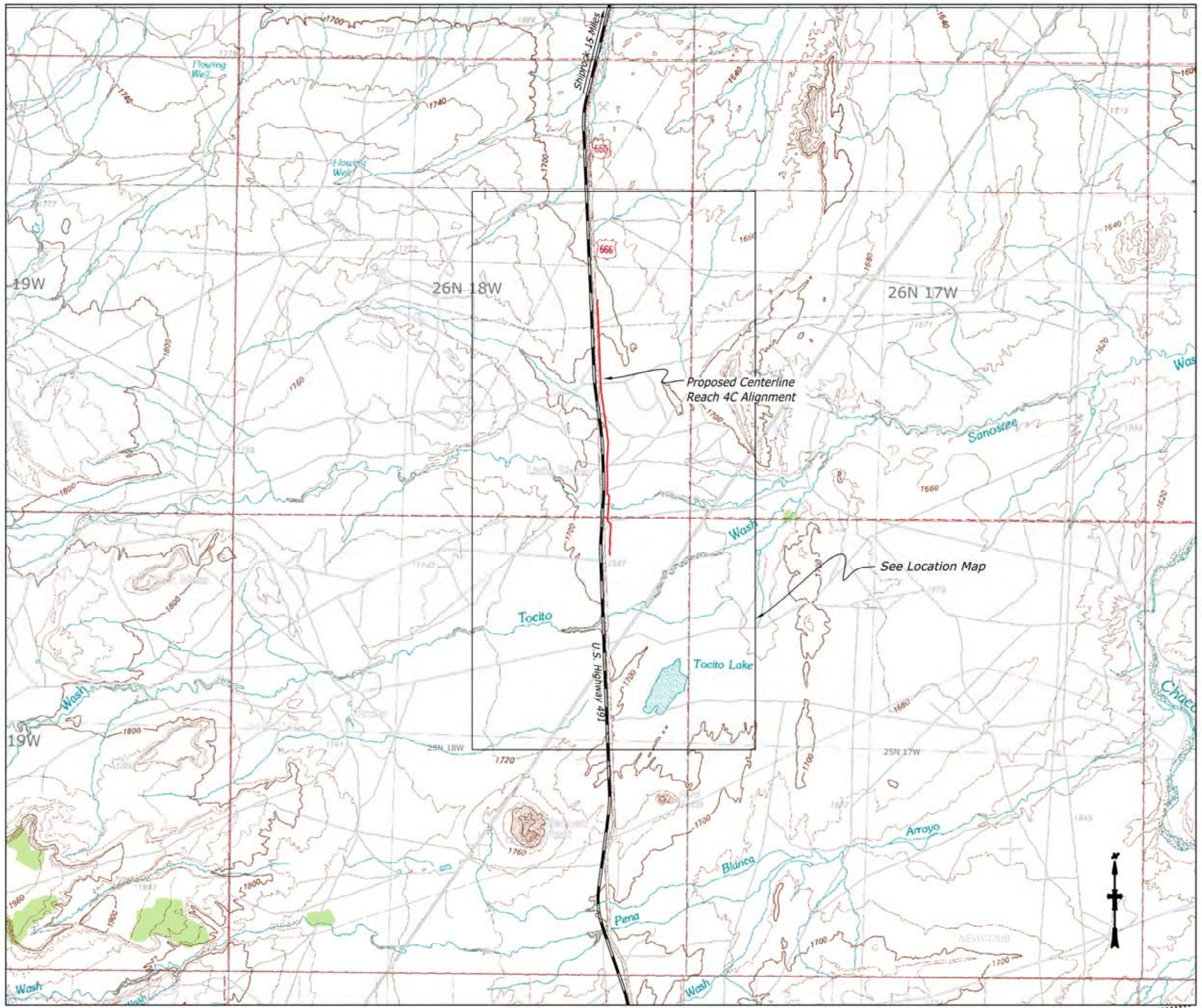

VICINITY MAP

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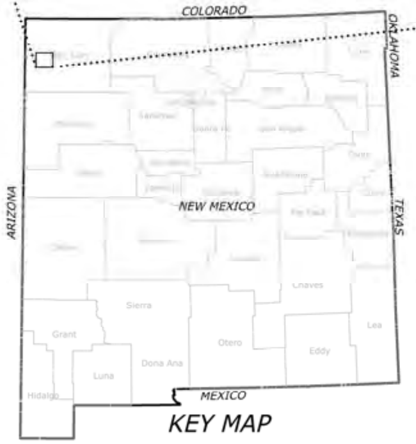

KEY MAP

LEGEND

- U.S. Highway
- State Highway
- Navajo Nation Chapter
- County Boundary Line
- Township, Range and Section Lines

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NAVAJO-GALLUP WATER SUPPLY PROJECT
NEW MEXICO

SAN JUAN LATERAL
REACH 4C

D. THORNBURG
DESIGNED
D. THORNBURG
DRAWN
PAUL GARDNER
CHECKED
Gilbert, Justin J
TECH. APPR.
Longwell, Barry D
APPROVED
ADMIN APPROVAL Project Construction Engineer

FARMINGTON, NM 2017-11-14

LOCATION MAP

1695-529-60146

SHEET 1

DATE AND TIME PLOTTED
NOVEMBER 14, 2017 13:16
PLOTTED BY
DTHORNBURG

CAD SYSTEM
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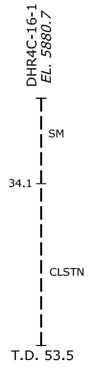
RECLAMATION
Managing Water in the West

GENERAL EXPLANATION
STRATIGRAPHY

Qal	*Quaternary Alluvium* *Alluvial soil types encountered include Silty Sand (SM), Clayey Sand (SC), Lean Clay (CL), Lean Clay with Sand (CL)s, Sandy Lean Clay s(CL), Poorly Graded Sand (SP), Poorly Graded Sand with Silt (SP-SM), Poorly Graded Sand with Clay (SP-SC) and Poorly Graded Sand with Gravel and Cobbles (SP)g. All soil types occasionally contain gravel. For more detail, see each specific geologic log. Alluvium is derived from a variety of sources including eolian, slope wash, colluvium and alluvial deposition as well as weathering and decomposition of inplace claystone, shale and sandstone. Quaternary Alluvium is used to describe all surficial deposits along the Reach 4C alignment regardless of origin. The alluvium was observed to range from a few inches to 25.5 feet thick.*
Kpl	*Cretaceous Point Lookout Sandstone* *The Point Lookout Sandstone is dark to light gray, brown and pinkish, fine grained sandstone with interbedded claystone. The sandstone is moderately soft (H5) to moderately hard (H4), moderately weathered (W5), laminated to thinly bedded and has no reaction with HCl. The sandstone has gypsum veins and manganese oxide staining. The claystone is dark brown, gray mottled with orange, soft (H6) to very soft (H7), intensely to moderately weathered (W6) and friable. The claystone has gypsum veins, iron oxide staining and has no reaction with HCl.*
Km	*Cretaceous Mancos Shale* *The Cretaceous Mancos Shale is gray to dark gray, light to dark brown to black in color and banded in places. The shale is a calcareous marine claystone that is sandy and fissile. Generally, the shale is soft (H6) to moderately hard (H4) and moderately to intensely weathered (W6). The Mancos Shale is interbedded with fine-grained mixed clastic laminations to moderate beds of sandstone and claystone. The sandstone is tan to brown, fine grained and laminated to moderately bedded. Sandstone interbeds are moderately soft (H5) and moderately weathered (W5). The claystone is light to dark brown or gray, sandy and laminated to moderately bedded. Claystone interbeds are very soft (H7) and intensely weathered (W7). The claystone is carbonaceous, contains calcium carbonate, mica and has thin to moderately thick gypsum infilling in joints.*
Kg	*Cretaceous Gallup Sandstone* *The Cretaceous Gallup Sandstone is tan, brown to reddish brown and gray in color. The sandstone is fine to coarse grained, moderately hard (H4) and moderately weathered (W5) to decomposed (W9). The sandstone is thinly to moderately bedded and grades from coarse grain conglomerate to fine grained mixed clastic sandstone to the Mancos Shale.*

GENERAL GEOLOGIC LEGEND

CPT4C-16-2 ⊗	*Proposed Cone Penetration Test with identification number*
CPT4C-16-2 ⊗	*Cone Penetration Test with identification number*
DHR4C-16-10 ○	*Proposed Drill Hole location with identification number*
DHR4C-16-10 ●	*Drill Hole location with identification number*
TPR4C-16-10 ☐	*Proposed Test Pit location with Identification number*
TPR4C-16-10 ■	*Test Pit location with Identification number*
Qal Km	*Geologic Unit Contact*
— — Qal — Km	*Dashed where approximate*
— ? — Qal — ? — Km	*Queried where inferred*



Drill Hole or Test Pit on profile (dashed where projected)

GENERAL GEOLOGIC NOTES

Geologic standards and definitions used for rock quality and rock discontinuities are based on Bureau of Reclamation Engineering Geology Field Manual and drawing numbers 40-D-6493 and 40-D-6499.

Soil classification and descriptions are based on the Unified Soil Classification System (USCS) and Bureau of Reclamation procedures and guidelines as described in Geotechnical Branch Training Manuals Nos. 4, 5, 6, and Designations USBR 5000 (laboratory classification) and USBR 5005 (visual classification). These procedures are similar to ASTM D2487-11 and ASTM D2488-09A respectively.

Interpretations shown on geologic profiles are based on Test Pit, Drill Hole, outcrop, and field mapping data. Interpretations suggest general trends between data points and do not depict localized irregularities.

For the entire description of material, drilling or excavation method and conditions, exact locations of the hole, etc., see complete log.

BEDROCK ABBREVIATIONS:

SS - SANDSTONE
SH - SHALE
CLSTN - CLAYSTONE

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U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NAVAJO-GALLUP WATER SUPPLY PROJECT
NEW MEXICO

SAN JUAN LATERAL
REACH 4C

Paul Gardner
DESIGNED
D. Thornburg
DRAWN
Paul Gardner
CHECKED
Gilbert, Justin J
TECH. APPR.
Longwell, Barry D
APPROVED
ADMIN APPROVAL - Project Construction Engineer

FARMINGTON, NM *2017-11-14*

GENERAL GEOLOGIC LEGEND, EXPLANATION, AND NOTES

1695-529-60162

SHEET 1

DATE AND TIME PLOTTED
NOVEMBER 14, 2017 13:18
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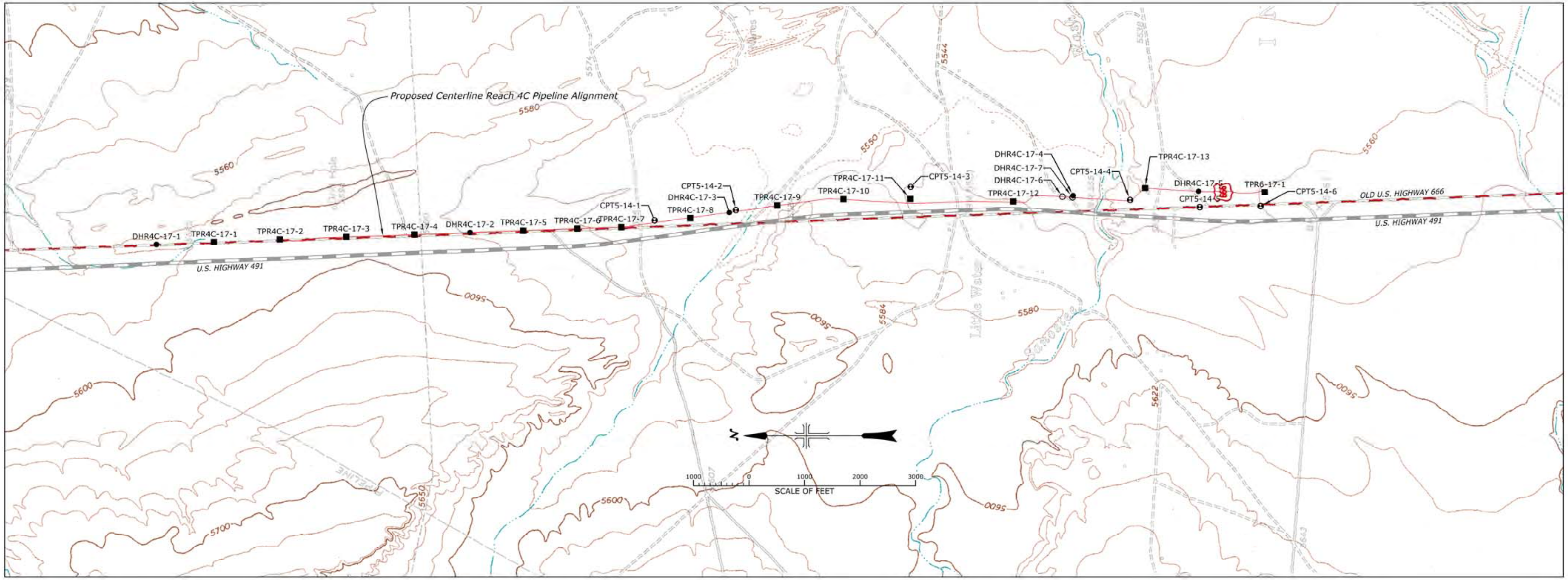
RECLAMATION
Managing Water in the West



Point Table

	Description	Northing	Easting	Elevation
	CPT5-14-1	1988087.05	2461666.22	5545.60
	CPT5-14-2	1986623.06	2461855.37	5544.81
	CPT5-14-3	1983477.00	2462273.51	5556.95
	CPT5-14-4	1979525.47	2462035.46	5555.20
	CPT5-14-5	1978270.65	2461908.64	5559.61
	CPT5-14-6	1977174.90	2461926.38	5564.27
	DHR4C-17-1	1997056.61	2461233.18	5590.02
	DHR4C-17-2	1991409.87	2461450.11	5579.69
	DHR4C-17-3	1986741.44	2461811.09	5544.40
	DHR4C-17-4	1980551.48	2462112.94	5545.33
	DHR4C-17-5	1978292.10	2462191.17	5558.36
	DHR4C-17-6	1980744.54	2462093.91	NO DATA
	DHR4C-17-7	1980561.98	2462080.97	NO DATA
	TPR4C-17-1	1996022.12	2461275.18	5591.22

Point Table

	Description	Northing	Easting	Elevation
	TPR4C-17-2	1994835.16	2461323.09	5597.74
	TPR4C-17-3	1993640.52	2461371.72	5592.20
	TPR4C-17-4	1992411.06	2461410.75	5584.87
	TPR4C-17-5	1990452.89	2461482.71	5571.01
	TPR4C-17-6	1989480.52	2461516.95	5557.33
	TPR4C-17-7	1988687.04	2461546.25	5550.92
	TPR4C-17-8	1987443.63	2461708.72	5545.12
	TPR4C-17-9	1985879.78	2461939.52	5581.42
	TPR4C-17-10	1984687.72	2462050.67	5562.11
	TPR4C-17-11	1983483.17	2462054.02	5560.65
	TPR4C-17-12	1981630.31	2462009.67	5557.24
	TPR4C-17-13	1979256.17	2462250.22	5554.27
	TPR6-17-1	1977101.99	2462173.30	5562.42

GENERAL NOTES

1. Coordinates based on New Mexico State Plane West Zone, feet. (NAD83).
2. The Ground to New Mexico State Plane West Zone Grid conversion factor is 0.999734970999.

REFERENCE DRAWINGS

General Map..1695-529-60161.
Location Map...1695-529-60146.

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FARMINGTON, NM 2017-09-20

LOCATION OF
EXPLORATION

1695-529-60065

SHEET 1

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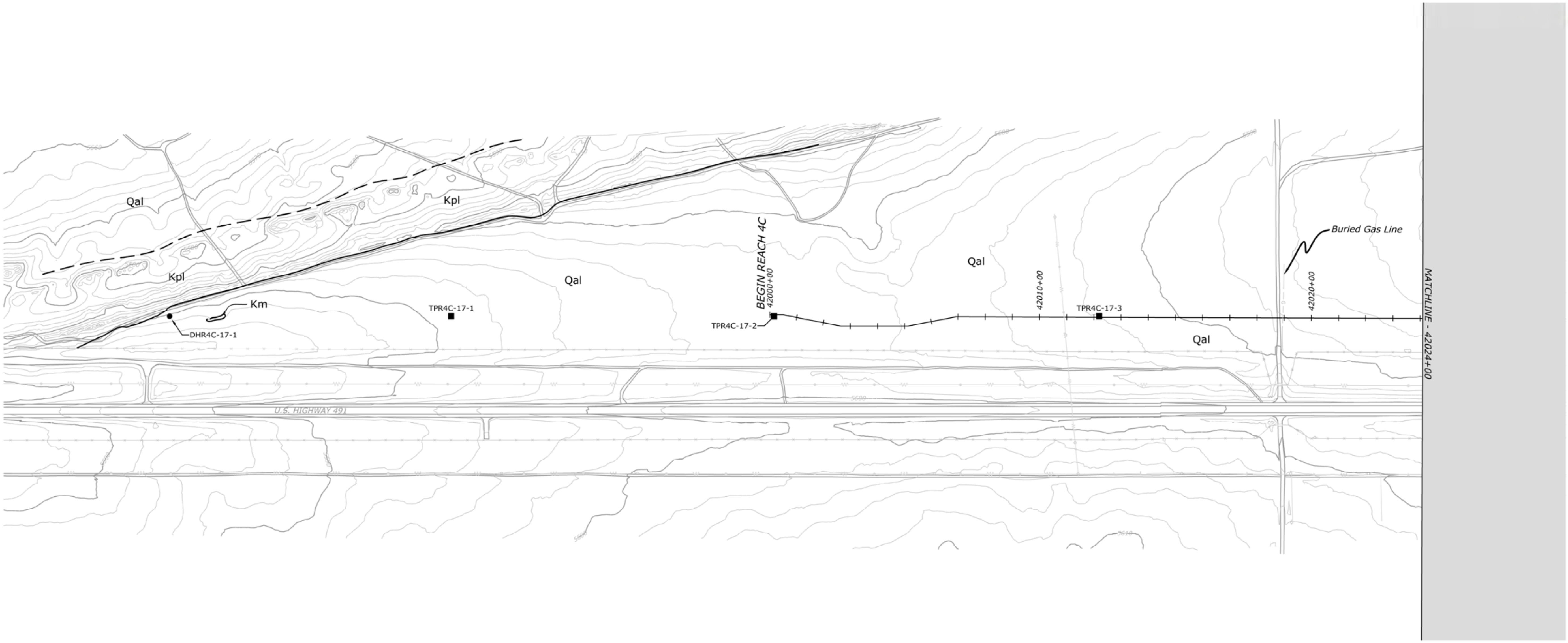
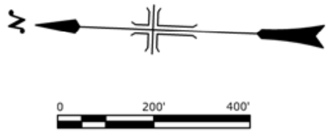
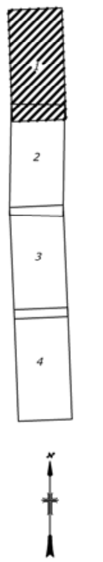


SURFACE GEOLOGY PLAN VIEW





SHEET INDEX

GENERAL NOTES

1. Coordinates based on New Mexico State Plane West Zone, feet. (NAD83).

2. The Ground to New Mexico State Plane West Zone Grid conversion factor is 0.999734970999.

3. Contour interval is 2 feet.

REFERENCE DRAWINGS

General Map..	1695-529-60161.
Location Map...	1695-529-60146.
General Geologic Legend, Explanation and Notes........	1695-529-60162.
Location of Exploration..	1695-529-60065.

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SAN JUAN LATERAL

REACH 4C

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SURFACE GEOLOGY

1695-529-60140

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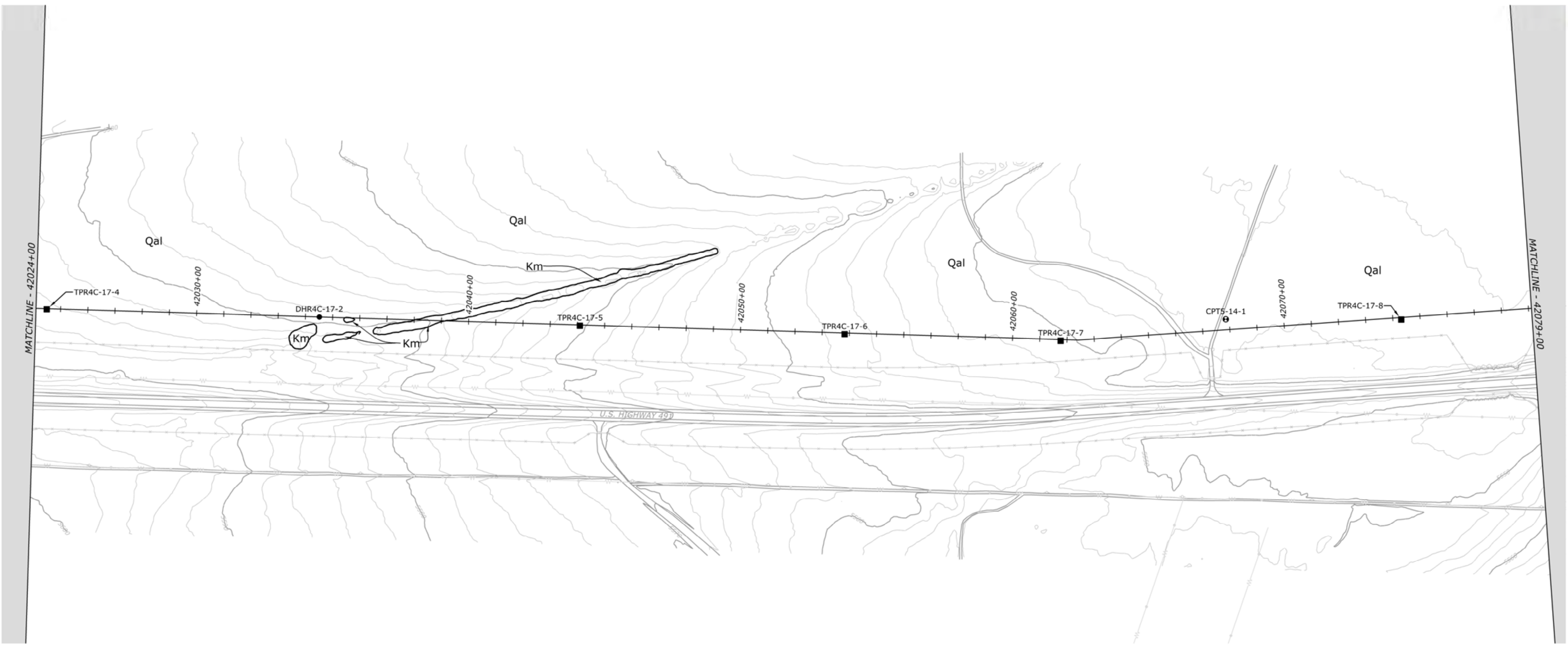

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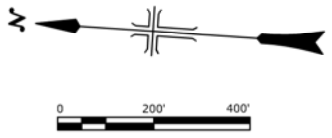

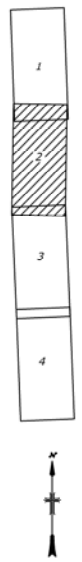

SHEET INDEX

GENERAL NOTES

1. Coordinates based on New Mexico State Plane West Zone, feet. (NAD83).
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SAN JUAN LATERAL

REACH 4C

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SURFACE GEOLOGY

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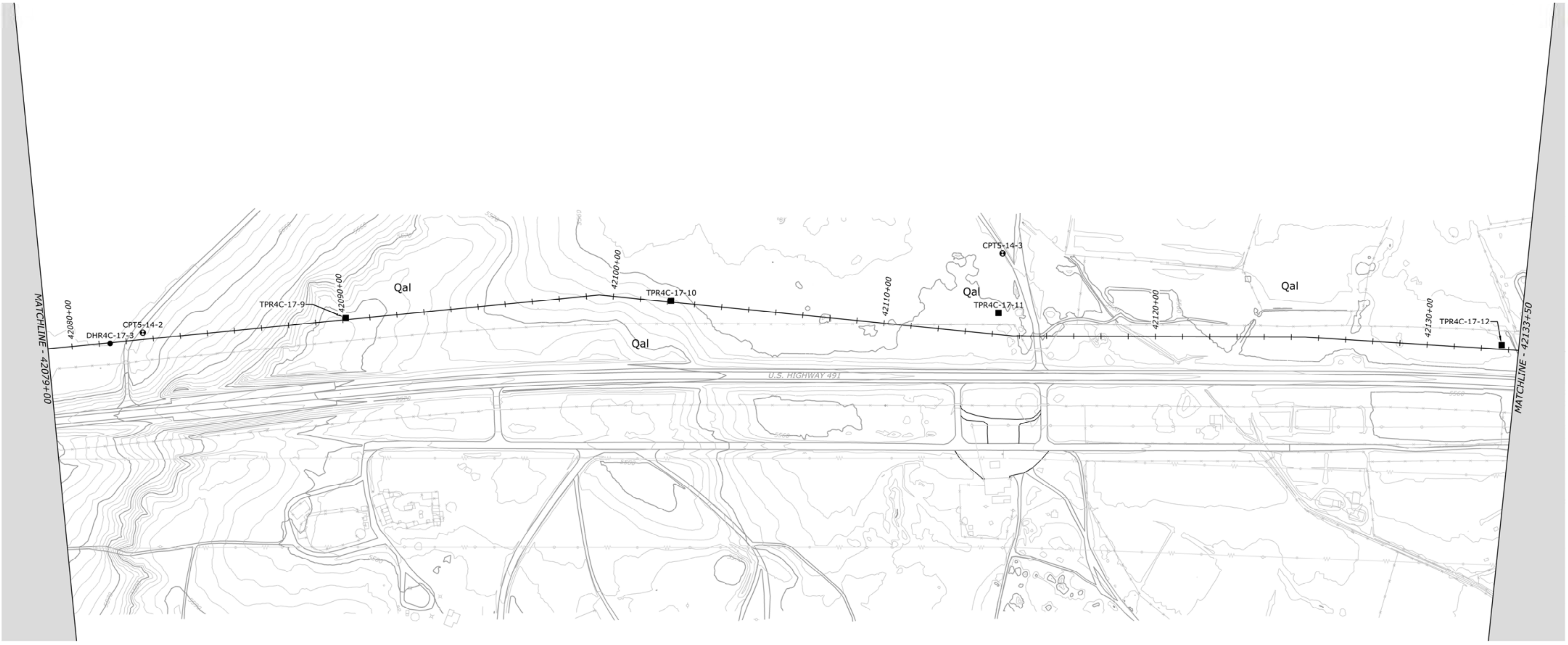

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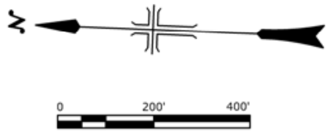

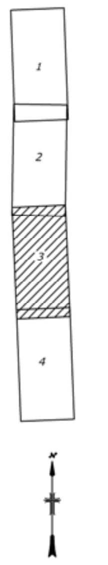

SHEET INDEX

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SURFACE GEOLOGY

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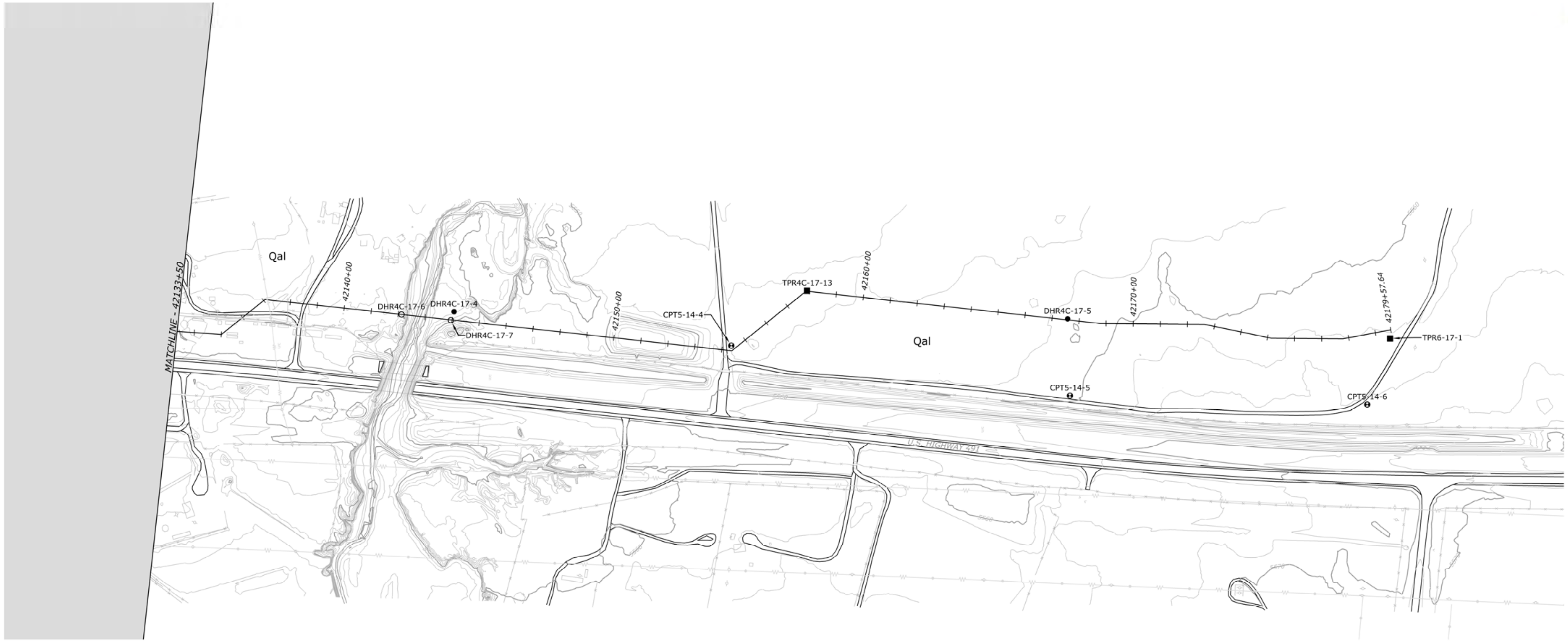

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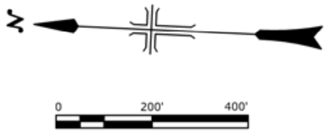

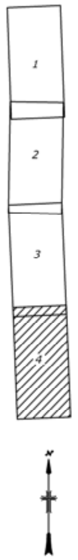

SHEET INDEX

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Location of Exploration..1695-529-60065.

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SURFACE GEOLOGY

1695-529-60143

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Appendix C - Bed and Bank Material Soil Property Sample Collection and Laboratory Measurements

C.1. Streambed Samples

Streambed samples will consist of two types, surface and subsurface. At all sites, a surface and subsurface sample is needed for pipe burial depth, and bank and bed treatment design. The surface sample generally represents the size of sediment being supplied to the channel, being transported through, or depositing. While the subsurface sample(s) represents the size of material effecting potential for future bed incision, and local scour. Subsurface samples should be retrieved at a minimum range of depth of 1.5 to 2 feet beneath the surface using a shovel or hand auger. An auger may be needed for deeper depths than 2 feet if there are different strata (color, size, and resistance to auguring) within 1.5 to 2 feet beneath the surface, then sample each and note depth below the bed. Where nearby drill logs or exploratory test pits indicate changes in stratigraphy that may affect scour, sediment samples may need to be retrieved at deeper depths. If there is an augur resistant layer or clay stone, then auguring another to 3-4 feet should be performed to determine the thickness of the erosion resistant layer to assess long term incision and scour properties. If there is a known erosion resistant layer present, then auguring to this depth would be useful. Note the presence of any auger resistant layers and sample if possible. Samples locations should be generally about 50 feet downstream of the pipeline alignment as this is the most likely location of potential bed treatment for stabilization. At some crossings, streambed samples will be collected from along the crossing alignment.

Take photographs of all sediment sample locations and include photographs looking upstream, downstream, and across the stream channel.

C.2. Bank Samples

Sediment sizes from stream bank samples can be used to estimate bank erodibility, critical bank height if needed, and bank treatment design. Samples should be representative of the entire bank height. There may be ephemeral pipeline crossing locations where both banks have about the same visual sediment size. For these channels a single sample that is representative of both banks may be collected. Where there is any visual observation of grain size or erodibility changes between banks then a sample for each bank should be collected. For banks with distinctively different sediment layers (different grain sizes or erodibility characteristics), collect samples from each layer and note elevations above the streambed. At some crossings, as noted below, there is a vertical bank with a sloping bank upstream and downstream of the pipeline crossing. Samples should be obtained from the upstream and downstream sloped sections, since the bank would be graded to these slopes, and the stratigraphy would be entirely disturbed. The same criteria should be used for upstream and downstream as for opposite banks when deciding how many samples to collect for laboratory analysis.

Where soil layers or bedrock exist, layers with notable change in grain size and erodibility should be documented as the height above the bed and sampled separately. Where the banks are relatively homogeneous, one sample per bank is sufficient that is representative of the entire bank height. Even though the pipeline excavation will mix together the various layers, if present, documenting layers and sampling will assist with the upstream and downstream transition design.

C.3. Large Sediment Sizes

Where there are sediment sizes greater than 2.5-inch (64 mm) diameter then the field methods described by Bunte and Abt (2001) should be used to determine sediment sizes.

C.4. Soils Laboratory Testing

For each sample the following should be done:

1) Gradation, using U.S. Alternate sieve sizes (American Geophysical Union Scale). Sediment analysis methods use U.S. Alternate sieve sizes instead of U.S. standard if possible (Table C-1).

2) Atterberg Limits.

3) Provide size analysis results sheets.

Table C.1. Example of bed and bank sample size analysis using the U.S. Alternative Sieve Sizes.

Identification		Particle Size Percent Passing																		Consistency Limits		
		Cobble	Gravel					Sand					Silt				Clay			Liquid Limit %	Plasticity Index %	Shrinkage Limit %
Sample Number	Depth-ft.	5"	2.5"	1.25"	5/8"	5/16"	No. 5	No. 10	No. 18	No. 35	No. 60	No. 120	No. 230									
		128mm	64mm	32mm	16mm	8mm	4mm	2mm	1mm	0.5mm	0.25mm	0.125mm	0.0625mm	0.037mm	0.019mm	0.009mm	0.005mm	0.002mm	0.001mm			
SITE 1																						
Bed Surface			100	96.5	92.6	83.6	73.9	66.9	63.5	51.3	24.7	8.5	3.9	3.6	3.2	2.9	2.2			NA	NP	-
Banks			100	97.7	97.7	97.3	97.1	97.0	96.8	94.9	78.0	35.0	11.0	10.6	9.7	7.2	5.8			NA	NP	-
Bed	1.5 - 2.0		100	97.4	92.5	84.5	75.3	69.8	66.4	58.3	33.1	13.6	8.1	7.9	6.4	4.9	3.8			NA	NP	-
SITE 2																						
Bed Surface			100	99.0	96.2	93.8	91.3	88.8	86.8	74.9	32.1	9.3	3.6	3.6	2.7	1.8	1.4			NA	NP	-
Banks			100	100.0	100.0	100.0	100.0	99.9	99.8	98.7	80.4	35.2	11.6	10.4	9.4	7.5	5.7			NA	NP	-
Bed	1.5 - 2.0		100	100.0	95.2	86.7	77.5	71.3	68.0	55.3	21.6	8.1	4.5	4.2	4.2	3.0	2.3			NA	NP	-
SITE 3																						
Bed Surface			100	100.0	100.0	100.0	100.0	99.9	99.7	98.5	90.5	73.3	54.0	52.4	50.0	43.4	38.5			27.1	13.6	-
Banks			100	100.0	99.3	98.8	98.4	98.0	97.7	96.0	84.9	63.7	43.6	41.6	35.0	29.3	25.3			22.4	7.2	-
SITE 6																						
Banks			100	100.0	99.0	98.6	97.9	96.3	95.2	91.6	76.0	57.0	38.4	35.6	31.8	27.0	24.2			20.9	5.9	

Bunte, K. and S.R. Abt, 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-bed Streams for Analyses in Sediment Transport, Hydraulics and Streambed Monitoring. USD A-Rocky Mountain Research Station, General Technical Report RMRS-GTR-74. 74.