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FINAL ENVIRONMENTAL IMPACT STATEMENT

Volume II

NEXUS Gas Transmission Project and Texas Eastern Appalachian Lease Project

Source: State of Ohio Office of Information Technology

NEXUS Gas Transmission, LLC	**Docket Nos.:** CP16-22-000
Texas Eastern Transmission, LP	CP16-23-000
DTE Gas Company	CP16-24-000
Vector Pipeline L.P.	CP16-102-000

Federal Energy Regulatory Commission
Office of Energy Projects
Washington, DC 20426

Cooperating Agencies:

U.S. Environmental Protection Agency **U.S. Fish and Wildlife Service** **U.S. Army Corps of Engineers**

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NGT PROJECT BLASTING PLAN

NEXUS Gas Transmission, LLC

NEXUS Project

FERC Docket No. CP16-__-000

BLASTING PLAN

November 2015

NEXUS Project Blasting Plan

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ACRONYMS AND ABBREVIATIONS

amsl	above mean seal level
CFR	Code of Federal Regulation
CI	Chief Inspector
FERC	Federal Energy Regulatory Commission
ms	milliseconds
msl	mean sea level
NEXUS	NEXUS Gas Transmission, LLC
Project	NEXUS Project
ROW	right-of-way

1.0 INTRODUCTION

This Blasting Plan outlines the procedures and safety measures that NEXUS Gas Transmission, LLC's ("NEXUS") contractor will adhere to while implementing blasting activities, should they be required, during the construction of the NEXUS Project. The contractor will be required to submit a detailed blasting plan to NEXUS prior to construction that is consistent with the provisions in this Blasting Plan and construction specification CS-PL1-7.8 (Appendix A).

2.0 PRE-BLAST INSPECTION

As required by FERC, NEXUS will conduct pre-blast surveys, with landowner permission, to assess the conditions of structures, wells, springs, and utilities within 150 feet of the proposed construction right-of-way. Should local or state ordinances require inspections in excess of 150 feet from the work area, the local or state ordinances will prevail. The survey will include:

- Informal discussions to familiarize the adjacent property owners with blasting effects and planned precautions to be taken on this project;
- Determination of the existence and location of site specific structures, utilities, septic systems, and wells;
- Detailed examination, photographs, and/or video records of adjacent structures and utilities; and
- Detailed mapping and measurement of large cracks, crack patterns, and other evidence of structural distress.

The results will be summarized in a condition report that will include photographs and be completed prior to the commencement of blasting.

3.0 MONITORING OF BLASTING ACTIVITIES

During blasting, the NEXUS contractor will take precautions to minimize damage to adjacent areas and structures. Precautions include:

- Dissemination of blast warning signals in the area of blasting;
- Use of blasting mats or other suitable cover (such as subsoil) to prevent fly-rock and possible damage to public, adjacent structures and natural resources;
- Posting warning signals, flags, or barricades;
- Following federal and state procedures and regulations for safe storage, handling, loading, firing, and disposal of explosive materials; and Controlling excessive vibration by limiting the size of charges and by using charge delays, which stagger or sequence the detonation times for each charge.

If the contractor has to blast near buildings or wells, a qualified independent contractor will inspect structures and wells within 150 feet, or farther if required by local or state regulations, of the construction right-of-way prior to blasting, and with landowner permission. Post-blast inspections by a NEXUS representative will also be performed as warranted. All blasting will be performed by registered licensed blasters and monitored by experienced blasting inspectors. Recording seismographs will be installed by the contractor at selected monitoring stations under the observation of NEXUS personnel. During construction, the contractor will submit blast reports for each blast and keep detailed records as described in Section 4.7.

Ground vibration and air overpressure effects of each blast will be monitored by seismographs.

If a charge greater than eight pounds per delay is used, the distance of monitoring will be in accordance with the U.S. Bureau of Mines Report of Investigations 8507.

To maximize its responsiveness to the concerns of affected landowners, NEXUS will evaluate all complaints of well or structural damage associated with construction activities, including blasting. NEXUS will staff a landowner hotline to receive landowner questions or concerns. The toll-free landowner hotline is (844)589-3655. The landowner hotline will be staffed Monday through Friday from 7 A.M. to 5 P.M. and on Saturday from 7 A.M. to 12 P.M. by NEXUS ROW personnel. Outside of these hours, a call forwarding system will be available to receive calls and page the complaint resolution coordinator. All calls will be returned within 24 hours of receipt. In the unlikely event that blasting activities temporarily impair well water, NEXUS will provide alternative sources of water or otherwise compensate the owner. If well or structural damage is substantiated, NEXUS will either compensate the owner for damages or arrange for a new well to be drilled.

4.0 BLASTING SPECIFICATIONS

The potential for blasting along the pipeline segments to affect any wetland, municipal water supply, waste disposal site, well, septic system, spring, karst cavity or abandoned underground mine, will be minimized by controlled blasting techniques and by using mechanical methods for rock excavation as much as possible.

If blasting is required in proximity to these features, the blasting will be designed and controlled to focus the energy of the blasting to the rock within the trench and to limit ground accelerations outside the trench. This should minimize fracturing of the rock outside of the trench. However, even if new fractures do develop in the rock outside of the trench, the ground accelerations are not expected to be high enough to produce ground displacement along these fractures that would be high enough (a) to open these fractures and significantly increase the permeability of the rock in the vicinity of these features or (b) to cause subsidence around these features, particularly karst cavities and abandoned underground mines.

Controlled blasting techniques have been effectively employed by NEXUS and other companies to protect active gas pipelines up to within 25 feet of trench excavation. The following sections present details of procedures for powder blasting that will be implemented in blasting areas along the NEXUS Project route.

4.1 General Provisions

The contractor will provide all personnel, labor, and equipment to perform necessary blasting operations related to the work. The contractor will provide a permitted blaster possessing all permits required by the states in which blasting is required during construction, and having a working knowledge of state and local laws and regulations that pertain to explosives.

Project blasting will be done in accordance with all applicable state and local laws; and regulations applicable to obtaining, transporting, storing, handling, blast initiation, ground motion monitoring, and disposal of explosive materials and/or blasting agents.

Any failure to comply with the appropriate law and/or regulations is the sole liability of the contractor. The contractor and the contractor's permitted blaster shall be responsible for the conduct of all blasting operations, which shall be subject to inspection requirements.

Affected landowners will be contacted prior to any blasting activities.

4.2 Storage of Explosives and Related Materials

Explosives and related materials shall be stored in approved facilities required under the provisions contained in 27 CFR Part 55 and all other applicable regulations. The handling of explosives may be performed by the person holding a permit to use explosives or by other employees under his or her direct supervision provided that such employees are at least 21 years of age.

4.3 Pre-Blast Operations

The contractor is required to submit a planned schedule of blasting operations to the CI or his designated representative for approval, prior to commencement of any blasting or pre-blast operation, which indicates the maximum charge weight per delay, hole size, spacing, depth, and blast layout. If blasting is to be conducted adjacent to an existing utility, approval from the operator and NEXUS must be obtained in regard to blasting parameters. The contractor shall provide this schedule to the CI at least 3 working days prior to any pre-blast operation for approval and use. Where residences are within 50 feet of the blasting operation, the CI may require notification in excess of 5 days. The blasting schedule is to include the blast geometry, drill hole dimensions, type and size of charges, stemming, and delay patterns and should also include a location survey of any dwelling or structures that may be affected by the proposed operation. Face material shall be carefully examined before drilling to determine the possible presence of unfired explosive material. Drilling shall not be started until all remaining butts of old holes are examined for unexploded charges, and if any are found, they shall be re-fired before work proceeds. No person shall be allowed to deepen the drill holes that have contained explosives.

A maximum loading factor shall not exceed the site specific allowable pounds of explosive per cubic yard of rock. However, should the loading fail to effectively break up the rock, a higher loading factor may be allowed if the charge weight per delay is reduced by a proportional amount and approved by the CI.

4.4 Discharging Explosives

Persons authorized to prepare explosive charges or conduct blasting operations shall use every reasonable precaution, including, but not limited to, warning signals, flags, barricades, or woven wire mats to ensure the safety of the general public and workmen.

The contractor shall obtain NEXUS's approval and provide them at least 72-hour notice prior to the use of any explosives. The contractor shall comply with local and state requirements for pre-blast notifications, such as "One Call", which requires a 72-hour notice.

Whenever blasting is being conducted in the vicinity of gas, electric, water, fire alarm, telephone, telegraph and steam utilities, the blaster shall notify the appropriate representatives of such utilities a minimum of 24 hours in advance of blasting. Verbal notice shall be confirmed with written notice. In an emergency, the local authority issuing the original permit may waive this time limit.

Blasting operations, except by special permission of the authority having jurisdiction, shall be conducted during daylight hours.

When blasting is done in congested areas or in proximity to a significant natural resource, structure, railway, or highway or any other installation that may be damaged, the blast shall be backfilled before firing or covered with a mat, constructed so that it is capable of preventing fragments from being thrown. In addition, all other possible precautions shall be taken to prevent damage to livestock and other property and inconvenience to the property owner or tenant during blasting operation. Any rock scattered outside the right-of-way by blasting operations shall immediately be hauled off or returned to the right-of-way.

Precautions shall be taken to prevent accidental discharge of electric blasting caps from currents induced by radar and radio transmitters, lightning, adjacent power lines, dust and snow storms, or other sources of extraneous electricity. These precautions, per 29 CFR 1926.900(k), shall include:

- Detonators shall be short-circuited in holes which have been primed and shunted until wired into the blasting circuit;
- Suspension of all blasting operations and removal of all personnel from the blasting area during the approach and progress of an electrical storm;
- The posting of all signs warning against the use of mobile radio transmitters on all roads within 350 feet (107 m) of blasting operations;
- Ensuring that mobile radio transmitters which are less than 100 feet away from electric blasting caps, in other than original containers, shall be de-energized and effectively locked, and
- Observance of the latest recommendations with regard to blasting in the vicinity of radio transmitters or power lines, as set forth in the IME Safety Library Publication No. 20, Safety Guide for the Prevention of Radio Frequency Radiation Hazards in the Use of Electric Blasting Caps.

No blast shall be fired until the blaster in charge has made certain that all surplus explosive materials are in a safe place, all persons and equipment are at a safe distance or under sufficient cover, and that an adequate warning signal has been given.

Only the person making leading wire connections in electrical firing shall fire the shot. All connections should be made from the bore hole back to the source of firing current, and the leading wires shall remain shorted until the charge is to be fired. After firing an electric blast from a blasting machine, the leading wires shall be immediately disconnected from the machine and short-circuited. If there are any misfires while using cap and fuse, all persons shall remain away from the charge for at least one hour. If electrical blasting caps are used and a misfire occurs, this waiting period may be reduced to 30 minutes. Misfires shall be handled under the direction of the person in charge of the blasting and all wires shall be carefully traced in search for the unexploded charges.

Explosives shall not be extracted from a hole that has once been charged or has misfired unless it is impossible to detonate the unexploded charge by insertion of a fresh additional primer.

4.5 Waterbody Crossing Blasting Procedures

To facilitate planning for blasting activities for waterbody crossings, rock drills or test excavations may be used in waterbodies to test the ditch-line during mainline blasting operations to evaluate the presence of rock in the trench-line. The excavation of the test pit or rock drilling is not included in the time window requirements for completing the crossing. For testing and any subsequent blasting operations, stream flow will be maintained through the site. When blasting is required, FERC timeframes for completing in-stream construction begin when the removal of blast rock from the waterbody is started. If, after removing the blast rock, additional blasting is required, a new timing window will be determined in consultation with the Environmental Inspector. If blasting impedes the flow of the waterbody, the contractor can use a backhoe to restore the stream flow without triggering the timing window. During blasting operations, the contractor shall comply with the waterbody crossing procedures specified in the NEXUS Project Erosion and Sedimentation Control Plan as well as any project-specific permit conditions.

4.6 Disposal of Explosive Materials

All explosive materials that are obviously deteriorated or damaged shall not be used and shall be destroyed according to applicable local, state, and federal requirements.

Empty containers and packages, and paper on fiberboard packing materials that have previously contained explosive materials shall not be reused for any purpose. Such packaging materials shall be destroyed by burning at an approved outdoor location or by other approved method. All personnel shall remain at a safe distance from the disposal area.

All other explosive materials will be transported from the job site in approved magazines per local and/or state regulations.

4.7 Blasting Records

A record of each blast shall be made and submitted, along with seismograph reports, to the NEXUS CI. The record shall contain the following minimum data for each blast:

- Name of company or contractor;
- Location, date and time of blast;
- Name, signature, and license number of contractor and of blaster in charge;
- Type of material blasted;
- Number of holes, depth of burden and stemming, and spacing;
- Diameter and depth of holes;
- Volume of rock in shot;
- Types of explosives used, specific gravity, energy release, pounds of explosive per delay, and total pounds of explosive per shot;
- Delay type, interval, total number of delays, and holes per delay;
- Maximum amount of explosives per delay period of 17 ms or greater;
- Power factor;
- Method of firing and type of circuit;
- Direction and distance in feet to nearest structure and utility owned or leased by the person conducting the blasting;
- Weather conditions;
- Type and height or length of stemming;
- If mats or other protection were used; and
- Type of detonators used and delay periods used.

The person taking the seismograph reading shall accurately indicate exact location of the seismograph, if used, and shall also show the distance of the seismograph from the blast.

Seismograph records, where required, should include:

- Name of person and firm operating and analyzing the seismograph record;
- Seismograph serial number;

- Seismograph reading; and
- Maximum number of holes per delay period of 17 ms or greater.

5.0 POST-BLAST INSPECTION

NEXUS ROW representative in conjunction with the CI and/or an independent contractor, with landowner permission, will examine the condition of structures within 150 feet, or as required by state or local ordinances, of the construction area after completion of blasting operations to identify any changes in the conditions of these properties or confirm any damages noted by the landowner. The independent contractor with landowner approval will conduct a re-sampling of wells within 150 feet, or as required by state or local ordinances, of the construction area. Should any damage or change occur during the blasting operations, an additional survey of the affected property will be performed before the continuation of blasting operations.

6.0 REFERENCES

Occupational Safety and Health Administration blasting requirements 29 CFR 1926.900(k)

Ohio Fire Code – Section 1301:7-7.

Ohio Administrative Code (OAC) Chapter 4123:1-5-29 Explosives and Blasting.

APPENDIX A

- ***CONSTRUCTION SPECIFICATION – ONSHORE PIPELINES AND METER STATIONS - ROCK EXCAVATION***

Spectra Energy **Construction Specification**	Spec. Number: **CS-PL1-7.8**	
	Master Issue Date: **01/20/2014**	Section **I** of **I**
	Sub-Document Date: **01/20/2014**	Page **1** of **5**

Title: **ONSHORE PIPELINES AND METER STATIONS – ROCK EXCAVATION**

TITLE	APPROVAL
Accountable Group:	*Rick Crabtree 12/2/2013 3:54:18 PM*
Technical Champion:	*Robert W. Guerrero 1/20/2014 4:58:25 PM*
TITLE	**RATIFICATION**
SET-US Operating Company:	*Alan K Lambeth 1/17/2014 11:09:50 AM*
Union Gas Operating Company:	*N/A*
Westcoast (SET-WEST) Operating Company:	*N/A*

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7 ROCK EXCAVATION

7A Pre-requisites for Use of Explosives

Prior to the use of any explosives, the Contractor shall:

7A1 Submit a blasting procedure/plan a minimum of two (2) weeks prior to any blasting activities and receive Company approval. The blasting procedure shall take into account adjacent pipelines, power lines and specific requirements outlined in the Contract Documents and shall include as a minimum:

7A1.1 Storage of explosives

7A1.2 Transportation of explosives

7A1.3 Inspection of drilling areas

7A1.4 Loading of explosives

7A1.5 Non-electric detonation methods - Electric detonation methods are not acceptable.

7A1.6 Control of fly-rock during blasting, including mat placement if used

7A1.7 Security procedures

7A1.8 Sequence of events leading up the detonation of explosives

7A1.9 Proposed hours of blasting

7A1.10 True distances to buildings or operating pipelines

7A1.11 Maximum charge mass per delay interval

7A1.12 Borehole diameters

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7A1.18 Geology description

7A1.19 Borehole stemming depth

7A1.20 Special conditions or variations for grade rock, trench rock, underwater blasting, and blasting at undercrossings of existing utilities

7A1.21 Blast to open face

7A2 Obtain Company approval and provide a notice of 72 hours prior to detonation of any explosives.

7A3 Obtain approval from the Company if the blasting parameters vary from the requirements set out in this specification or the Contract Documents.

7B Use of Explosives

7B1 The Contractor shall secure and comply with all the applicable permits required for the handling, transportation, storage, and use of explosives.

7B2 The Contractor shall not endanger life, livestock, or adjacent properties.

7B3 The Contractor shall minimize inconveniences to the property owners or tenants during all phases of blasting.

7B4 The Contractor shall provide physical protection to any above-grade utilities and equipment in the area of the blast.

7B5 The Company is to be given the opportunity to set up any required monitoring equipment.

7B6 The Contractor shall provide monitoring equipment to ensure vibrations are limited to two inches per second (50 mm/s) PPV, when measured at dwellings, buildings, structures, and power line towers. For power line towers, this limit applies to the greatest of the three vectors; otherwise this limit is the vector sum of the three planes. The Contractor limits vibrations to one inch per second (25 mm/s) PPV for vibration-sensitive structures specified by the Company. In no case shall vibration amplitude exceed 0.004 in (0.15 mm).

7B7 Any blasting in close proximity to existing in-service piping is to be in accordance with the Contract Documents.

7B8 Charge loading is to be spread in order to obtain the optimum breakage of rock. The Contractor shall attempt to achieve a fragmentation rate of at least 75% of the trench rock to less than 6 in (150 mm) in diameter.

7B9 All delay connectors used shall have a delay interval of at least seventeen milliseconds.

7B10 There are to be no loaded holes left overnight, and the site is inspected after each blast for any un-detonated charges.

7B11 The Contractor shall discuss the blasting plan with the Company prior to each blast, including the maximum charge weight per delay, hole sizes, spacing, depths and layout. Upon completion of blasting each day, the Contractor shall provide the Company with the following for each blast:

7B11.1 Blasting Contractor license number

7B11.2 Date, time, and location of blast

7B11.3 Hole sizes, spacing, depths, layout, and volume of rock in blast

7B11.4 Delay type, interval, total number of delays, and holes per delay

7B11.5 Explosive type, specific gravity, energy release, weight of explosive per delay, and total weight of explosive per shot

7B11.6 Powder factor

7B11.7 Copies of any seismographic data

7C Evaluation of Close-In Blasts

The following additional limitations apply for blasting at distances of less than 25 feet from the pipeline. These criteria were extrapolated from a 1970 US Bureau of Mines Study on cratering in granite and refined based on a 2004 failure investigation.

7C1 Blasting on Pipeline Right-of-Way

Blasting should not be allowed on the pipeline right-of-way except when conducted for the benefit of the Company and under the supervision of a Company representative or qualified Blasting Inspector familiar with the Company's blasting requirements.

7C2 Minimum Offset From Blast Holes to Pipeline

7C2.1 No blast holes should be loaded at an offset of less than 25 feet from the centerline of an in-service pipeline except in cases where precise measurements are taken to ensure that the pipeline will have at least one foot of Clearance (C) from the theoretical area surrounding the blast hole in which the ground could be permanently deformed by the blast under worst case conditions.

7C2.2 This theoretical area is a conical shape originating at the bottom of the blast hole and extending out at an angle up to the ground surface as depicted in Figure BLAST1 below.

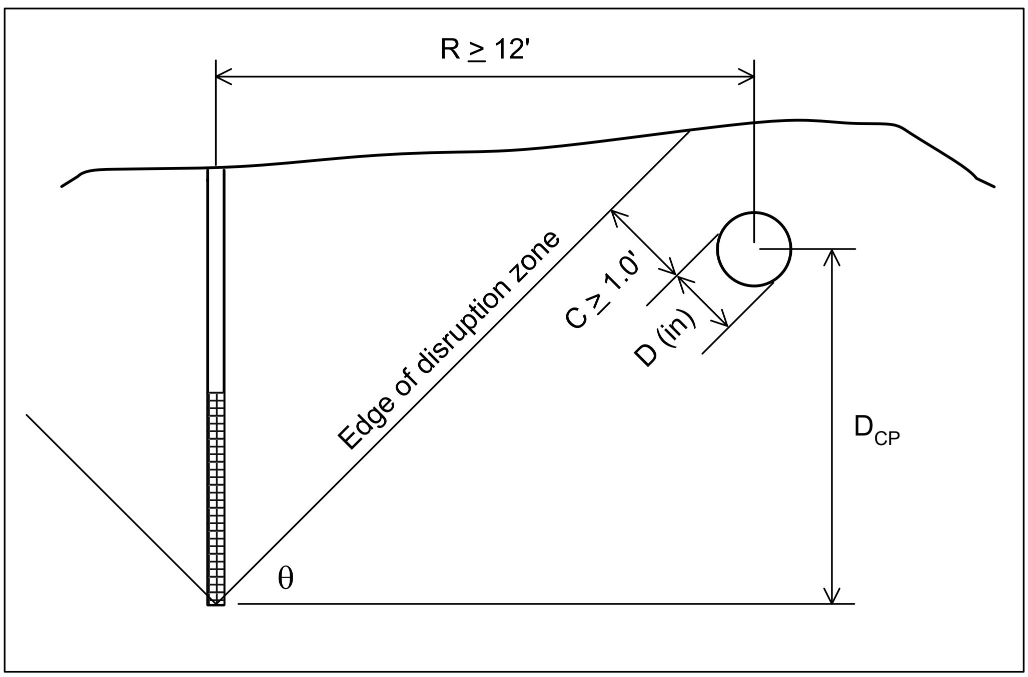

FIGURE BLAST1 – SEPARATION FROM BLAST HOLE

7C2.3 The clearance C can be calculated by:

$$C = R \times \sin\theta - D_{CP} \times \cos\theta - \frac{D}{24}$$

with D in inches and the other dimensions in feet, and where θ is the angle from the horizontal of the theoretical zone of permanent disruption.

7C2.4 The disruption zone angle θ shall be taken to be 32°, except when both of the following special circumstances hold. If both of these conditions hold, the disruption zone angle θ may be taken to be 45°.

7C2.4.1 Charge weight per delay does not exceed 0.9 times the ordinary maximum allowable charge weight <u>and</u>

7C2.4.2 Charge weight per delay in pounds must not be greater than effective hole depth in feet, divided by 2.5 lb/ft (Example: for 15-ft hole depth, maximum charge no greater than 15 ft / 2.5 lb/ft = 6 lb).

7C2.5 If the calculated clearance C would be less than 1 foot, the minimum offset distance must be increased accordingly. The minimum offset R to achieve 1 foot clearance is:

$$R = \frac{1\,ft}{\sin\theta} + \frac{D}{24 \times \sin\theta} + \frac{D_{cp}}{\tan\theta}$$, or:

- θ = 32°: $R = 1.887\,ft + \frac{D}{12.718} + 1.6 \times D_{cp}$
- θ = 45°: $R = 1.414\,ft + \frac{D}{16.971} + D_{cp}$

7C2.6 When blast holes are angled from the vertical, this can have the effect of directing the disruption from the blast in one direction (the surface acts as a free face, allowing movement in that direction). For this reason, blast holes within 25 feet of an existing pipeline must be drilled vertically or angled away from the pipeline as the hole gets deeper.

7C2.7 In all cases, the absolute minimum offset R is 12 feet.

7D Mechanical Rock Removal

7D1 Mechanical rock removal shall occur between the hours of 7:00 am and 7:00 pm, unless otherwise specified by the Company.

7D2 The Contractor shall achieve a fragmentation rate of at least 75% of the trench rock to less than 6 in (150 mm) in diameter.

APPENDIX E-2

TEAL PROJECT BLASTING PLAN

Spectra Energy Partners

TEXAS EASTERN APPALACHIAN LEASE PROJECT

BLASTING PLAN

November 2015

Texas Eastern Appalachian Lease Project
Blasting Plan

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ACRONYMS AND ABBREVIATIONS

amsl	above mean seal level
CFR	Code of Federal Regulation
CI	Chief Inspector
FERC	Federal Energy Regulatory Commission
ms	milliseconds
msl	mean sea level
NEXUS	NEXUS Gas Transmission, LP
Project	Texas Eastern Appalachian Lease Project
ROW	right-of-way
TEALP	Texas Eastern Appalachian Lease Project
TETLP	Texas Eastern Transmission, LP

1.0 INTRODUCTION

Texas Eastern Transmission, LP ("Texas Eastern"), an indirect wholly owned subsidiary of Spectra Energy Partners, LP. Blasting Plan outlines the procedures and safety measures that Texas Eastern, LP's ("Texas Eastern's") contractor will adhere to while implementing blasting activities, should they be required, during construction of the Texas Eastern Appalachian Lease Project ("TEAL Project" or "Project"). The contractor will be required to submit a detailed blasting plan to Texas Eastern prior to construction that is consistent with the provisions in this Blasting Plan and construction specifications CS-PL-1-7.7 (Appendix A).

2.0 PRE-BLAST INSPECTION

As required by FERC, Texas Eastern will conduct pre-blast surveys, with landowner permission, to assess the conditions of structures, wells, springs, and utilities within 150 feet of the proposed construction right-of-way. Should local or state ordinances require inspections in excess of 150 feet from the work area, the local or state ordinances will prevail. The survey will include:

- Informal discussions to familiarize the adjacent property owners with blasting effects and planned precautions to be taken on this project;
- Determination of the existence and location of site specific structures, utilities, septic systems, and wells;
- Detailed examination, photographs, and/or video records of adjacent structures and utilities; and
- Detailed mapping and measurement of large cracks, crack patterns, and other evidence of structural distress.

The results will be summarized in a condition report that will include photographs and be completed prior to the commencement of blasting.

3.0 MONITORING OF BLASTING ACTIVITIES

During blasting, the Texas Eastern contractor will take precautions to minimize damage to adjacent areas and structures. Precautions include:

- Dissemination of blast warning signals in the area of blasting;
- Use of blasting mats or other suitable cover (such as subsoil) to prevent fly-rock and possible damage to public, adjacent structures and natural resources;
- Posting warning signals, flags, or barricades;
- Following federal and state procedures and regulations for safe storage, handling, loading, firing, and disposal of explosive materials; and

Excessive vibration will be controlled by limiting the size of charges and by using charge delays, which stagger or sequence the detonation times for each charge.

If the contractor has to blast near buildings or wells, a qualified independent contractor will inspect structures and wells within 150 feet, or farther if required by local or state regulations, of the construction right-of-way prior to blasting, and with landowner permission. Post-blast inspections by a Texas Eastern representative will also be performed as warranted. All blasting will be performed by registered licensed blasters and monitored by experienced blasting inspectors. Recording seismographs will be installed by the contractor at selected monitoring stations under the observation of Texas Eastern personnel. During construction, the contractor will submit blast reports for each blast and keep detailed records as described in Section 4.7.

Ground vibration and air overpressure effects of each blast will be monitored by seismographs.

If a charge greater than eight pounds per delay is used, the distance of monitoring will be in accordance with the U.S. Bureau of Mines Report of Investigations 8507.

To maximize its responsiveness to the concerns of affected landowners, Texas Eastern will evaluate all complaints of well or structural damage associated with construction activities, including blasting. A toll-free landowner hotline will be established by Texas Eastern for landowners to use in reporting complaints or concerns. In the unlikely event that blasting activities temporarily impair well water, Texas Eastern will provide alternative sources of water or otherwise compensate the owner. If well or structural damage is substantiated, Texas Eastern will either compensate the owner for damages or arrange for a new well to be drilled.

4.0 BLASTING SPECIFICATIONS

The potential for blasting along the pipeline segments to affect any wetland, municipal water supply, waste disposal site, well, septic system, or spring will be minimized by controlled blasting techniques and by using mechanical methods for rock excavation as much as possible. Controlled blasting techniques have been effectively employed by Texas Eastern and other companies to protect active gas pipelines up to within 12 feet of trench excavation. The following sections present details of procedures for powder blasting that will be implemented in blasting areas along the Project route.

4.1 General Provisions

The contractor will provide all personnel, labor, and equipment to perform necessary blasting operations related to the work. The contractor will provide a permitted blaster possessing all permits required by the states in which blasting is required during construction, and having a working knowledge of state and local laws and regulations that pertain to explosives.

Project blasting will be done in accordance with all applicable state and local laws; and regulations applicable to obtaining, transporting, storing, handling, blast initiation, ground motion monitoring, and disposal of explosive materials and/or blasting agents.

Any failure to comply with the appropriate law and/or regulations is the sole liability of the contractor. The contractor and the contractor’s permitted blaster shall be responsible for the conduct of all blasting operations, which shall be subject to inspection requirements.

Affected landowners will be contacted prior to any blasting activities.

4.2 Storage of Explosives and Related Materials

Explosives and related materials shall be stored in approved facilities required under the provisions contained in 27 CFR Part 55 and all other applicable regulations. The handling of explosives may be performed by the person holding a permit to use explosives or by other employees under his or her direct supervision provided that such employees are at least 21 years of age.

4.3 Pre-Blast Operations

The contractor is required to submit a planned schedule of blasting operations to the CI or his designated representative for approval, prior to commencement of any blasting or pre-blast operation, which indicates the maximum charge weight per delay, hole size, spacing, depth, and blast layout. If blasting is to be conducted adjacent to an existing Texas Eastern Transmission, LP ("TETLP"), approval must be received from the TETLP Transmission Department. The contractor shall provide this schedule to the CI at least 3 working days prior to any pre-blast operation for approval and use. Where residences are within 50 feet of the blasting operation, the CI may require notification in excess of 5 days. The blasting schedule is to include the blast geometry, drill hole dimensions, type and size of charges, stemming, and delay patterns and should also include a location survey of any dwelling or structures that may be affected by the proposed operation. Face material shall be carefully examined before drilling to determine the possible presence of unfired explosive material. Drilling shall not be started until all remaining butts of old holes are examined for unexploded charges, and if any are found, they shall be re-fired before work proceeds. No person shall be allowed to deepen the drill holes that have contained explosives.

A maximum loading factor shall not exceed the site specific allowable pounds of explosive per cubic yard of rock. However, should the loading fail to effectively break up the rock, a higher loading factor may be allowed if the charge weight per delay is reduced by a proportional amount and approved by the CI.

4.4 Discharging Explosives

Persons authorized to prepare explosive charges or conduct blasting operations shall use every reasonable precaution, including, but not limited to, warning signals, flags, barricades, or woven wire mats to ensure the safety of the general public and workmen.

The contractor shall obtain Texas Eastern's approval and provide them at least 72-hour notice prior to the use of any explosives. The contractor shall comply with local and state requirements for pre-blast notifications, such as "One Call", which requires a 72-hour notice.

Whenever blasting is being conducted in the vicinity of gas, electric, water, fire alarm, telephone, telegraph and steam utilities, the blaster shall notify the appropriate representatives of such utilities a minimum of 24 hours in advance of blasting. Verbal notice shall be confirmed with written notice. In an emergency, the local authority issuing the original permit may waive this time limit.

Blasting operations, except by special permission of the authority having jurisdiction, shall be conducted during daylight hours.

When blasting is done in congested areas or in proximity to a significant natural resource, structure, railway, or highway or any other installation that may be damaged, the blast shall be backfilled before firing or covered with a mat, constructed so that it is capable of preventing fragments from being thrown. In addition, all other possible precautions shall be taken to prevent damage to livestock and other property and inconvenience to the property owner or tenant during blasting operation. Any rock scattered outside the right-of-way by blasting operations shall immediately be hauled off or returned to the right-of-way.

Precautions shall be taken to prevent accidental discharge of electric blasting caps from currents induced by radar and radio transmitters, lightning, adjacent power lines, dust and snow storms, or other sources of extraneous electricity. These precautions, per 29 CFR 1926.900(k), shall include:

- Detonators shall be short-circuited in holes which have been primed and shunted until wired into the blasting circuit;
- Suspension of all blasting operations and removal of all personnel from the blasting area during the approach and progress of an electrical storm;
- The posting of all signs warning against the use of mobile radio transmitters on all roads within 350 feet (107 m) of blasting operations;
- Ensuring that mobile radio transmitters which are less than 100 feet away from electric blasting caps, in other than original containers, shall be deenergized and effectively locked, and
- Observance of the latest recommendations with regard to blasting in the vicinity of radio transmitters or power lines, as set forth in the IME Safety Library Publication No. 20, Safety Guide for the Prevention of Radio Frequency Radiation Hazards in the Use of Electric Blasting Caps.

No blast shall be fired until the blaster in charge has made certain that all surplus explosive materials are in a safe place, all persons and equipment are at a safe distance or under sufficient cover, and that an adequate warning signal has been given.

Only the person making leading wire connections in electrical firing shall fire the shot. All connections should be made from the bore hole back to the source of firing current, and the leading wires shall remain shorted until the charge is to be fired. After firing an electric blast from a blasting machine, the leading wires shall be immediately disconnected from the machine and short-circuited. If there are any misfires while using cap and fuse, all persons shall remain away from the charge for at least one hour. If electrical blasting caps are used and a misfire occurs, this waiting period may be reduced to 30 minutes. Misfires shall be handled under the direction of the person in charge of the blasting and all wires shall be carefully traced in search for the unexploded charges.

Explosives shall not be extracted from a hole that has once been charged or has misfired unless it is impossible to detonate the unexploded charge by insertion of a fresh additional primer.

4.5 Waterbody Crossing Blasting Procedures

To facilitate planning for blasting activities for waterbody crossings, rock drills or test excavations may be used in waterbodies to test the ditch-line during mainline blasting operations to evaluate the presence of rock in the trench-line. The excavation of the test pit or rock drilling is not included in the time window requirements for completing the crossing. For testing and any subsequent blasting operations, stream flow will be maintained through the site. When blasting is required, FERC timeframes for completing in-stream construction begin when the removal of blast rock from the waterbody is started. If, after removing the blast rock, additional blasting is required, a new timing window will be determined in consultation with the Environmental Inspector. If blasting impedes the flow of the waterbody, the contractor can use a backhoe to restore the stream flow without triggering the timing window. During blasting operations, the contractor shall comply with the waterbody crossing procedures specified in the NEXUS Project Erosion and Sedimentation Control Plan as well as any project-specific permit conditions.

4.6 Disposal of Explosive Materials

All explosive materials that are obviously deteriorated or damaged shall not be used and shall be destroyed according to applicable local, state, and federal requirements.

Empty containers and packages, and paper on fiberboard packing materials that have previously contained explosive materials shall not be reused for any purpose. Such packaging materials shall be destroyed by burning at an approved outdoor location or by other approved method. All personnel shall remain at a safe distance from the disposal area.

All other explosive materials will be transported from the job site in approved magazines per local and/or state regulations.

4.7 Blasting Records

A record of each blast shall be made and submitted, along with seismograph reports, to the TETLP CI. The record shall contain the following minimum data for each blast:

- Name of company or contractor;
- Location, date and time of blast;
- Name, signature, and license number of contractor and of blaster in charge;
- Type of material blasted;
- Number of holes, depth of burden and stemming, and spacing;
- Diameter and depth of holes;
- Volume of rock in shot;
- Types of explosives used, specific gravity, energy release, pounds of explosive per delay, and total pounds of explosive per shot;

- Delay type, interval, total number of delays, and holes per delay;
- Maximum amount of explosives per delay period of 17 ms or greater;
- Power factor;
- Method of firing and type of circuit;
- Direction and distance in feet to nearest structure and utility owned or leased by the person conducting the blasting;
- Weather conditions;
- Type and height or length of stemming;
- If mats or other protection were used; and
- Type of detonators used and delay periods used.

The person taking the seismograph reading shall accurately indicate exact location of the seismograph, if used, and shall also show the distance of the seismograph from the blast.

Seismograph records, where required, should include:

- Name of person and firm operating and analyzing the seismograph record;
- Seismograph serial number;
- Seismograph reading; and
- Maximum number of holes per delay period of 17 ms or greater.

5.0 POST-BLAST INSPECTION

An independent contractor, with landowner permission, will examine the condition of structures within 150 feet, or as required by state or local ordinances, of the construction area after completion of blasting operations to identify any changes in the conditions of these properties or confirm any damages noted by the landowner. The independent contractor with landowner approval will conduct a re-sampling of wells within 150 feet, or as required by state or local ordinances, of the construction area. In the event that damage or change should occur during blasting operations, an additional survey of the affected property will be performed before the continuation of blasting operations.

6.0 REFERENCES

Occupational Safety and Health Administration blasting requirements 29 CFR 1926.900(k)

Ohio Fire Code – Section 1301:7-7.
Ohio Administrative Code (OAC) Chapter 4123:1-5-29 Explosives and Blasting.

APPENDIX A

- ***BLASTING SPECIFICATIONS***

TITLE	APPROVAL
Accountable Group:	*Rick Crabtree 12/2/2013 3:54:18 PM*
Technical Champion:	*Robert W. Guerrero 1/20/2014 4:58:25 PM*
TITLE	**RATIFICATION**
SET-US Operating Company:	*Alan K Lambeth 1/17/2014 11:09:50 AM*
Union Gas Operating Company:	*N/A*
Westcoast (SET-WEST) Operating Company:	*N/A*

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7 ROCK EXCAVATION

7A Pre-requisites for Use of Explosives

Prior to the use of any explosives, the Contractor shall:

7A1 Submit a blasting procedure/plan a minimum of two (2) weeks prior to any blasting activities and receive Company approval. The blasting procedure shall take into account adjacent pipelines, power lines and specific requirements outlined in the Contract Documents and shall include as a minimum:

7A1.1 Storage of explosives

7A1.2 Transportation of explosives

7A1.3 Inspection of drilling areas

7A1.4 Loading of explosives

7A1.5 Non-electric detonation methods - Electric detonation methods are not acceptable.

7A1.6 Control of fly-rock during blasting, including mat placement if used

7A1.7 Security procedures

7A1.8 Sequence of events leading up the detonation of explosives

7A1.9 Proposed hours of blasting

7A1.10 True distances to buildings or operating pipelines

7A1.11 Maximum charge mass per delay interval

7A1.12 Borehole diameters

7A1.13 Hole pattern, burden, and spacing

7A1.14 Borehole depth, subgrade depth, and unloaded collar length

7A1.15 Sketch showing borehole loading details

7A1.16 Explosive names, properties, and delay sequences

7A1.17 Calculated powder factor (weight per volume of rock), based on explosive energy of 1000 calories per gram

7A1.18 Geology description

7A1.19 Borehole stemming depth

7A1.20 Special conditions or variations for grade rock, trench rock, underwater blasting, and blasting at undercrossings of existing utilities

7A1.21 Blast to open face

7A2 Obtain Company approval and provide a notice of 72 hours prior to detonation of any explosives.

7A3 Obtain approval from the Company if the blasting parameters vary from the requirements set out in this specification or the Contract Documents.

7B Use of Explosives

7B1 The Contractor shall secure and comply with all the applicable permits required for the handling, transportation, storage, and use of explosives.

7B2 The Contractor shall not endanger life, livestock, or adjacent properties.

7B3 The Contractor shall minimize inconveniences to the property owners or tenants during all phases of blasting.

7B4 The Contractor shall provide physical protection to any above-grade utilities and equipment in the area of the blast.

7B5 The Company is to be given the opportunity to set up any required monitoring equipment.

7B6 The Contractor shall provide monitoring equipment to ensure vibrations are limited to two inches per second (50 mm/s) PPV, when measured at dwellings, buildings, structures, and power line towers. For power line towers, this limit applies to the greatest of the three vectors; otherwise this limit is the vector sum of the three planes. The Contractor limits vibrations to one inch per second (25 mm/s) PPV for vibration-sensitive structures specified by the Company. In no case shall vibration amplitude exceed 0.004 in (0.15 mm).

7B7 Any blasting in close proximity to existing in-service piping is to be in accordance with the Contract Documents.

7B8 Charge loading is to be spread in order to obtain the optimum breakage of rock. The Contractor shall attempt to achieve a fragmentation rate of at least 75% of the trench rock to less than 6 in (150 mm) in diameter.

7B9 All delay connectors used shall have a delay interval of at least seventeen milliseconds.

7B10 There are to be no loaded holes left overnight, and the site is inspected after each blast for any un-detonated charges.

7B11 The Contractor shall discuss the blasting plan with the Company prior to each blast, including the maximum charge weight per delay, hole sizes, spacing, depths and layout. Upon completion of blasting each day, the Contractor shall provide the Company with the following for each blast:

7B11.1 Blasting Contractor license number

7B11.2 Date, time, and location of blast

7B11.3 Hole sizes, spacing, depths, layout, and volume of rock in blast

7B11.4 Delay type, interval, total number of delays, and holes per delay

7B11.5 Explosive type, specific gravity, energy release, weight of explosive per delay, and total weight of explosive per shot

7B11.6 Powder factor

7B11.7 Copies of any seismographic data

7C Evaluation of Close-In Blasts

The following additional limitations apply for blasting at distances of less than 25 feet from the pipeline. These criteria were extrapolated from a 1970 US Bureau of Mines Study on cratering in granite and refined based on a 2004 failure investigation.

7C1 Blasting on Pipeline Right-of-Way

Blasting should not be allowed on the pipeline right-of-way except when conducted for the benefit of the Company and under the supervision of a Company representative or qualified Blasting Inspector familiar with the Company's blasting requirements.

7C2 Minimum Offset From Blast Holes to Pipeline

7C2.1 No blast holes should be loaded at an offset of less than 25 feet from the centerline of an in-service pipeline except in cases where precise measurements are taken to ensure that the pipeline will have at least one foot of Clearance (C) from the theoretical area surrounding the blast hole in which the ground could be permanently deformed by the blast under worst case conditions.

7C2.2 This theoretical area is a conical shape originating at the bottom of the blast hole and extending out at an angle up to the ground surface as depicted in Figure BLAST1 below.

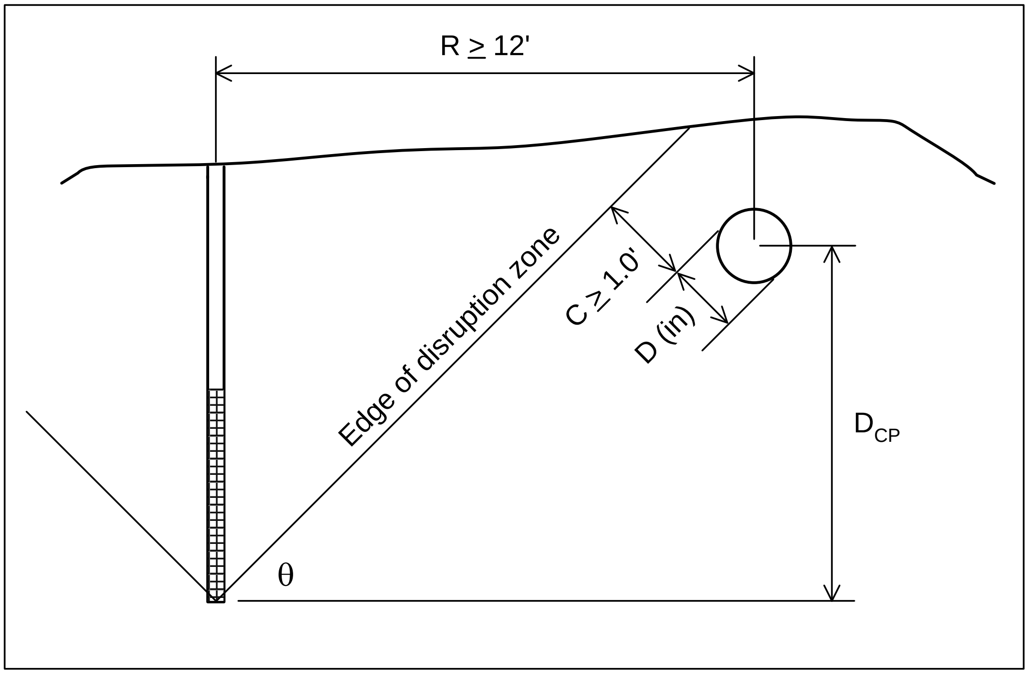

FIGURE BLAST1 – SEPARATION FROM BLAST HOLE

7C2.3 The clearance C can be calculated by:

$$C = R \times \sin\theta - D_{CP} \times \cos\theta - \frac{D}{24}$$

with D in inches and the other dimensions in feet, and where θ is the angle from the horizontal of the theoretical zone of permanent disruption.

7C2.4 The disruption zone angle θ shall be taken to be 32°, except when both of the following special circumstances hold. If both of these conditions hold, the disruption zone angle θ may be taken to be 45°.

7C2.4.1 Charge weight per delay does not exceed 0.9 times the ordinary maximum allowable charge weight and

7C2.4.2 Charge weight per delay in pounds must not be greater than effective hole depth in feet, divided by 2.5 lb/ft (Example: for 15-ft hole depth, maximum charge no greater than 15 ft / 2.5 lb/ft = 6 lb).

7C2.5 If the calculated clearance C would be less than 1 foot, the minimum offset distance must be increased accordingly. The minimum offset R to achieve 1 foot clearance is:

$$R = \frac{1\,ft}{\sin\theta} + \frac{D}{24 \times \sin\theta} + \frac{D_{cp}}{\tan\theta}$$, or:

- θ = 32°: $R = 1.887\,ft + \frac{D}{12.718} + 1.6 \times D_{cp}$
- θ = 45°: $R = 1.414\,ft + \frac{D}{16.971} + D_{cp}$

7C2.6 When blast holes are angled from the vertical, this can have the effect of directing the disruption from the blast in one direction (the surface acts as a free face, allowing movement in that direction). For this reason, blast holes within 25 feet of an existing pipeline must be drilled vertically or angled away from the pipeline as the hole gets deeper.

7C2.7 In all cases, the absolute minimum offset R is 12 feet.

7D Mechanical Rock Removal

7D1 Mechanical rock removal shall occur between the hours of 7:00 am and 7:00 pm, unless otherwise specified by the Company.

7D2 The Contractor shall achieve a fragmentation rate of at least 75% of the trench rock to less than 6 in (150 mm) in diameter.

APPENDIX E-3

NGT PROJECT DRAIN TILE MITIGATION PLAN

NEXUS
GAS TRANSMISSION

NEXUS Gas Transmission
Proposed Pipeline Project

DRAFT

Drain Tile Mitigation Plan

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LIST OF ACRONYMS

DSWR	Division of Soil and Water Resources
DTE	DTE Gas Company
DTMP	Drain Tile Mitigation Plan
HDPE	High-density polyethylene
NEXUS	NEXUS Gas Transmission, LLC
NRCS	Natural Resource Conservation Service
ODNR	Ohio Department of Natural Resources
PE	Polyethylene
PVC	Polyvinyl chloride
ROW	Right-of-Way
USDA	United States Department of Agriculture

1 INTRODUCTION

NEXUS Gas Transmission, LLC (NEXUS) is proposing construction of approximately 255 miles of new, 36-inch diameter natural gas transmission pipeline through Ohio and Michigan, known as the NEXUS Gas Transmission Project (Project or NEXUS Project). The mainline route originates in Columbiana County, Ohio and extends through Ohio and Michigan, connecting with facilities of DTE Gas Company (DTE) in Ypsilanti Township, Michigan. The proposed mainline route includes approximately 208 miles of new pipeline in Columbiana, Stark, Summit, Wayne, Medina, Lorain, Huron, Erie, Sandusky, Wood, Lucas, Henry, and Fulton Counties, Ohio; and approximately 47 miles of new pipeline in Lenawee, Monroe, Washtenaw and Wayne Counties, Michigan.

The proposed Project will cross agricultural fields that contain a widespread network of subsurface drainage systems, commonly known as drain tile systems. NEXUS is committed to working with Stakeholders and landowners to minimize the potential for impacts to drain tile systems and has developed this draft Drain Tile Mitigation Plan (DTMP) for use during planning, construction, and restoration of the proposed Project in order to manage, mitigate and repair drainage systems impacted by construction activities.

As outlined below, parcels crossed by the proposed Project will be individually reviewed and analyzed to determine the potential for drain tile impacts. Appropriate advance planning and mitigation work will be undertaken as practicable. This will be accomplished through communication with Stakeholders, landowners and subject matter experts. NEXUS will be responsible for the costs associated with mitigating and repairing drain tile impacts from construction-related activities so that drainage systems are at least equivalent to their pre-construction condition. This draft DTMP will be revised and expanded as appropriate as the proposed Project moves forward and additional site-specific information is obtained.

2 DEFINITIONS

A. Agricultural Land – Land which is presently under cultivation; land which has been previously cultivated and not subsequently developed for non-agriculture use; and cleared land which is capable of being cultivated. It includes land used for cropland, improved pasture, truck gardens, vineyards and orchards (ODNR).

B. Agricultural Inspector – A person qualified by education and experience for the purpose of evaluating pipeline construction in relation to soil removal and replacement, drainage repairs, and corridor restoration associated with agricultural land and cropland.

C. Cropland – A land use category that includes areas used for the production of crops for harvest, both cultivated and non-cultivated. Cultivated crops include row crops, close grown crops, vegetables and hay and pasture in rotation with the crops. Non-cultivated crops include lands used in conservation grassland programs, berries, horticultural plants and long stand vegetables.

D. Drain Tile – Any artificial sub-surface system designed to intercept, collect, and convey excess soil moisture to a suitable outlet. This may include systems constructed using clay, concrete, polyvinyl chloride (PVC), polyethylene (PE) materials, and high-density polyethylene (HDPE) plastic.

E. Drain Tile Inspector – A person qualified by experience for the purpose of evaluating pipeline construction in relation to drain tile removal and replacement, repairs and system restoration.

F. Drain Tile Contractor – A person qualified by experience for the purpose of drain tile installation, drainage repairs and drainage system restoration.

G. Landowner – Person(s) holding legal title to property on the pipeline route from whom NEXUS is seeking or has obtained a temporary or permanent easement, or any person(s) legally authorized by a landowner to make decisions regarding the mitigation or restoration of agricultural impacts to such landowner's property. This includes tenant farmers on the public or private properties

H. Stakeholders – Federal, state and local agencies, landowners and local citizens impacted by the proposed project activities.

I. Pipeline – The mainline pipeline and its related appurtenances (ODNR).

J. Right-of-Way (ROW) – The permanent and temporary easements that NEXUS acquires for the purpose of constructing and operating the pipeline.

K. Right-of-Way (ROW) Agent – A person to negotiate the buying and selling of private lands or land use rights (such as easements) between two or more parties.

L. Surface Drains – Any surface drainage system such as shallow surface field drains, grassed waterways, open ditches, or any other conveyance of surface water (ODNR).

M. Tenant – A person or persons lawfully residing on, or in operational control of the land.

N. Topsoil – The upper-most part of the soil commonly referred to as the plow layer, the A layer, or the A horizon, or its equivalent in uncultivated soils. It is the surface layer of the soil that has the darkest color or the highest content of organic matter (as Identified in the United States Department of Agriculture (USDA) County Soil Survey and verified with right-of-way samples) (ODNR).

3 GENERAL OVERVIEW OF DRAINAGE SYSTEMS

Drain tile is used in agricultural areas to improve drainage in soils with high groundwater or poor internal drainage. Drain tile typically removes excess water from the top 3 to 4 feet of soil and improves the potential for crop productivity. Pipeline construction activities, particularly trenching and heavy equipment traffic, can damage existing drain tile.

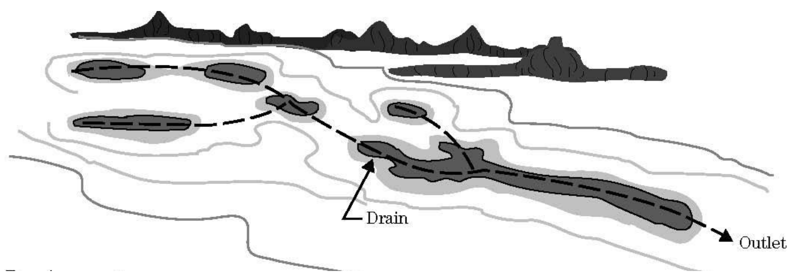
Conduits support the overall makeup of drain tile systems and are intended to facilitate water drainage. Laterals are smaller drain tile – typically 4" in diameter – aligned as much as possible with field contours in order to intercept or capture water as it flows down slope.

Mains and sub-mains are larger drain tile – typically 6" to 18" in diameter – positioned on steeper grades or in swales in order to facilitate the placement of laterals and to convey water to an outlet.

Historically, the most common materials used to manufacture drain tile have been clay, concrete, PVC, and PE. Practically all agricultural drain tile installed today is made from HDPE plastic. Drain tile made from HDPE plastic comes in various wall profiles (e.g. corrugated and smooth), diameters (e.g. 4" – 24" and larger), wall thicknesses (e.g. single and dual wall), and wall perforations (e.g. slotted and non-perforated).

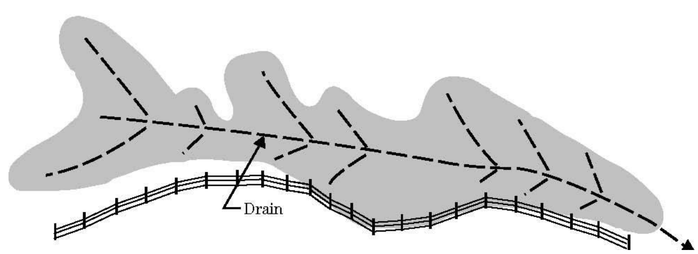
Because sub-surface drainage is used primarily to lower the water table or remove excess water percolating through the soil, drain tile is typically laid out in a pattern that best fits the soil and topography of the area. There are two basic ways to lay out drain tile: random and systematic. It is expected that the proposed NEXUS Project will encounter both layouts along the pipeline corridor.

The random system pattern is suitable for undulating or rolling land that contains isolated wet areas. The main drain is usually placed in the swales rather than in deep cuts through ridges. The laterals in this pattern are arranged according to the size of the isolated wet areas. Thus, the laterals may be arranged in a parallel or herringbone pattern or may be a single drain connected to a sub main or the main drain (NRCS).



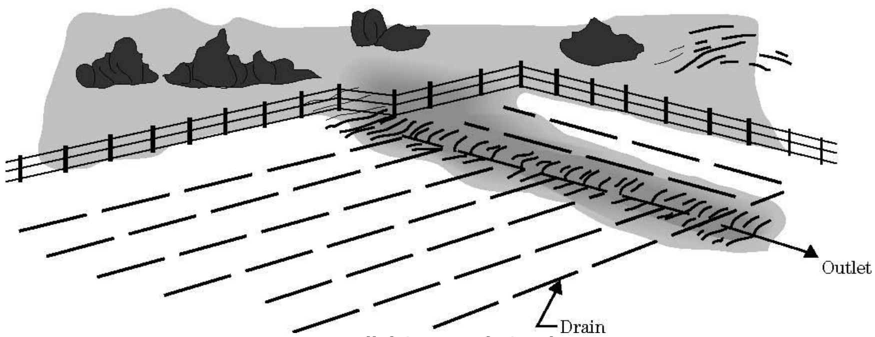
Random System (USDA)

The types of systematic systems expected to be encountered include the herringbone, parallel and double main system. The herringbone system consists of parallel laterals that enter the main at an angle, usually from both sides (USDA). The main is located on the major slope of the land, and the laterals are angled upstream on a grade. This pattern is often combined with other patterns to drain small or irregular areas. Its disadvantage is that it may cause double drainage (since two field laterals intercept the main at the same point). The herringbone pattern can provide the extra drainage needed for the less permeable soils that are found in narrow depressions.



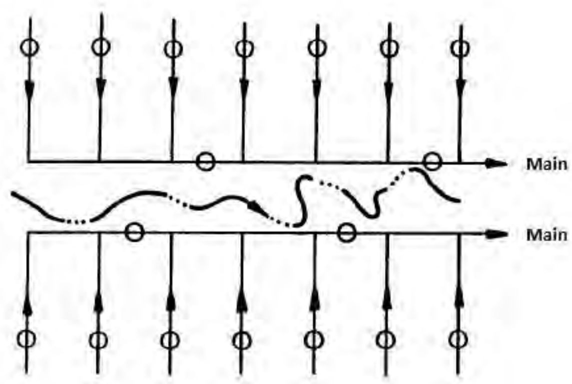
Herringbone System (USDA)

The parallel system consists of parallel lateral drains located perpendicular to the main drain. The laterals in the pattern may be spaced at any interval consistent with site conditions. This pattern is used on flat, regularly shaped fields and on uniform soil. Variations of this pattern are often combined with others (NRCS).



Parallel System (USDA)

The double main system is a modification of the parallel and herringbone patterns. It is applicable where a depression, frequently a grass waterway, divides the field in which drains are to be installed. This pattern is used where a depression area is wet because of seepage from higher ground. Placing a main on each side of the depression serves two purposes, it intercepts the seepage water, and it provides an outlet for the laterals. If the depression is deep and unusually wide, and if there is only one main in the center, a change in the grade line of each lateral may be required before it reaches the main. Locating a main on each side of depressions keeps the grade line of the laterals more uniform.



Double Main (NRCS)

Drain tile can be installed with a backhoe, tile plow, and chain machine or wheel trencher. Drain tile laterals are generally installed at a depth of three-to-five feet, and outlet tile is often installed five-to-six feet deep or deeper in some areas. Installation depths can vary dramatically based on the need to maintain grade through a hill slope and reach a desired outlet location and depth. The drain tile must be installed deep enough to effectively drain subsurface water from the property, minimizing the need to repair or install additional drain tile in the future.

4 PROPOSED NEXUS PROJECT AREA

The presence of drain tile along the proposed NEXUS pipeline route generally increases as the route traverses east to west. Beginning in Columbiana County and through Stark, Summit, Wayne, Medina and Lorain Counties in Ohio, the proposed pipeline route crosses agricultural land with minimal drain tile consisting mostly of random, with occasional systematic, layouts. Once into Erie County and continuing through Sandusky, Wood, Lucas, Henry and Fulton Counties in Ohio, drain tile becomes more prevalent and consists of mostly systematic layouts. As the proposed pipeline route crosses into Michigan, systematic drain tile layouts continue to be prevalent in Lenawee County. The presence of drain tile is less in Monroe and Washtenaw Counties, Michigan. There are no known drain tile systems along the proposed NEXUS pipeline route in Wayne County, Michigan.

As the frequency of systematic layouts increases, the drain tile spacing typically becomes tighter or "closer", increasing the intensity of drainage in that area. The counties in Ohio expected to have the greatest density of drain tile include Erie, Sandusky and Wood. In Michigan, Lenawee County is expected to have the greatest density of drain tile.

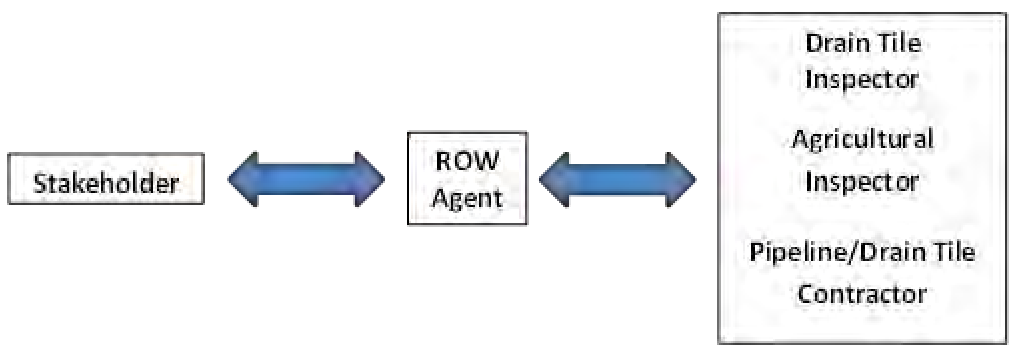
It is anticipated that many of the drainage systems in the proposed Project area are designed like a spider web: drain tile and surface drains funnel water to a main tile or area on or off the property, and the water is moved to a ditch, creek, or other waterbody.

5 PRE-CONSTRUCTION PHASE

5.1. Communication Protocol

NEXUS landowners will be enabled to easily communicate drain tile concerns before, during and following the construction process and for the life of the pipeline. The affected landowner's primary point of contact will be a NEXUS ROW Agent, who in turn will coordinate with appropriate Drain Tile Inspectors and Contractors to develop responses and solutions to landowner concerns. Landowner communication can also be facilitated through the use of NEXUS's toll-free telephone number (1-844-589-3655).

Flow Diagram for Communications



5.2. Preliminary Drain Tile Assessment

NEXUS ROW Agents will communicate with affected landowners in advance of construction activities to gain an understanding and knowledge of existing and planned drainage systems traversed by the proposed Project. NEXUS will use a structured landowner questionnaire (see Appendix 9.1) to collect information pertaining to drain tile layout, location, material, size, and depth of cover, etc. NEXUS will also gather information from the following additional sources, as needed and practicable:

- Interviews with various public agencies and entities (local Soil and Water Conservation Districts, County Engineers, Conservancy Districts and County Drain Commissioners, and Farm Bureaus)
- Interviews with local Drain Tile Contractors

- Review of existing drain tile plans, maps and as-built drawings
- Analysis of high resolution aerial imagery
- Field investigations

Where landowners have communicated plans to install future drain tile systems, NEXUS will endeavor to accommodate plans for future drain tile systems as provided by the landowner. NEXUS will construct the pipeline at a depth of approximately 6 to 12-inches below the planned drain tile to accommodate planned installation of drain tile systems. The location of planned drain tile systems will also be identified on the Project as-built alignment sheets.

5.3. Mitigation Planning and Process

If drain tile is determined to be present on a property, a meeting with a Drain Tile Contractor will be scheduled on-site to gather additional details to develop a drain tile mitigation plan in coordination with affected landowners. NEXUS will utilize the information gathered to identify mitigation options, taking into consideration drain tile size requirements and materials, if the drain tile is to be cut and capped, and/or if drain tile is to be removed and replaced.

NEXUS recognizes the amount of drain tile information from each landowner will vary. It is anticipated the information will range from detailed drain tile locations to unknown conditions. At the very least, drain tile information will be tabulated per property tract and utilized for construction planning. In the event detailed drain tile locations are known (i.e. existing maps, GPS data, imagery, etc.), the details will be illustrated on property drawings. The drawings will be utilized for pipeline construction planning and may be requested by the landowner before the construction process begins on their property. Appendix 9.2 provides a flow chart of this process.

The following mitigation measures will be implemented:

- NEXUS will be responsible for repairing drain tile damages that result from construction-related activities so that they are at least equivalent to their pre-construction condition. If the construction schedule impacts the landowner’s ability to grow crops during that season, appropriate compensation will be provided.

- If available during the time of construction, NEXUS will endeavor to use qualified local Drain Tile Contractors with experience in Ohio and Michigan to conduct drain tile repairs/replacements.

- The Drain Tile Contractor will work under the direction of, and with the direct involvement of, the pipeline construction contractor and the NEXUS construction management team.

- Repair materials will be equivalent to those currently in place for repairing the damaged drain tile and will be joined to existing drain tile by means of adapters or couplers manufactured for that purpose.

- During construction, damaged drain tile will be staked with lath using colored flagging in such a manner that they will remain visible to the construction crews until permanent repairs are completed. Damaged, unused, or discarded pieces of drain tile will be removed and disposed of promptly and properly.

- To the extent practicable, NEXUS will replace drain tile to the same location, depth, alignment, grade, and spacing as the pre-construction drain tile.

- GPS technology capable of 3-D survey grade accuracy, or other similarly accurate technology, will be used to document drain tile location, alignment and grade.

- The landowner will be given the opportunity to observe temporary and permanent repairs on their property. For safety concerns, the landowner shall request access with the ROW Agent to be properly escorted onto the construction ROW.

- The Agricultural Inspector and Drain Tile Inspector will inspect and approve the drain tile repairs prior to the commencement of final restoration.

- Permanent repairs to drain tile will be completed as soon as possible, based on, for example weather and soil conditions.

- NEXUS will collect as-built data of the restored and replaced drain tile. This will include the linear extent of the drain tile repairs and the location of adapter connections.

6 CONSTRUCTION PHASE

The following sets forth anticipated measures and techniques to be employed during mitigation activities (these may be subject to change depending on field conditions and other variables). NEXUS will have Agricultural Inspectors and Drain Tile Inspectors present during construction, to monitor the execution of the following measures and, as noted above, the landowner will be given the opportunity to observe temporary and permanent repairs on their property.

6.1 Drain Tile Identification

Using the information gathered during the drain tile assessment phase, known locations of existing drain tile will be staked with lath using colored flagging, after stripping the topsoil from the construction ROW. NEXUS will stake both sides of the trench, once the drain tile has been exposed. These locations will be surveyed to define the linear extent of each drain tile within the construction ROW.

In some cases, drain tile information may be limited or locations not known. Once the drain tile has been exposed during construction, NEXUS will communicate with the landowner based on field conditions as to how the drain tile will be repaired. If the drain tile location is not known, the drain tile will be staked with lath using colored flagging on both sides of the trench once it has been exposed during pipeline construction.

6.2 Drain Tile Repair

During construction, drain tile will be temporarily repaired in the trench until the pipe is lowered into the trench and permanent repairs are completed.

The following describes the typical pipeline construction process for drain tile repairs:

A. Pipeline Trench - Temporary Repair

As trenching equipment traverses across the landowner's property, temporary repairs will be completed at each drain tile location as it is being exposed. Drain tile that will be impacted by trenching will be:

- Cut and temporarily capped or screened, if water is not flowing in the drain tile.
- Cut and temporarily repaired, if water is flowing in the drain tile.

For temporary repairs, a rigid support or pipe will be laid across the full extent of the trench with a 1-foot minimum into undisturbed ground on both sides of the trench. Drain tile will be laid on the support and connected with adapters to the existing drain tile. This process will be utilized throughout the trenching phase to maintain drainage, where necessary.

The temporary drain tile will be disconnected as the pipe is lowered into the trench to approximately 6 to 12-inches below the drain tile. The drain tile connections will be re-established as quickly as possible to reduce the amount of water flowing into the trench.

B. Pipeline Trench - Permanent Repair

After the pipe is lowered into the trench but before the trench is backfilled, the drain tile will be permanently repaired:

- Where drain tile was temporarily capped or screened, the drain tile will be laid onto a rigid beam, high strength composite material, rigid outer casing pipe or other rigid support material that will keep the repaired drain tile supported the full length of the trench and approximately 3-feet into undisturbed ground on both sides of the trench. The rigid support will be stabilized and adapters or couplers will connect the repaired tile to existing drain tile on both sides of the trench.

- Where drain tile was temporarily repaired in the trench, the drain tile will be fortified based on the above mentioned requirements. The rigid support will be stabilized.

NEXUS will utilize sandbags in the trench to structurally support and prevent settling of the permanent repaired drain tile during or after the backfill process (see Appendix 9.3).

C. ROW - Permanent Repair

Before completing permanent drain tile repairs in the trench, the tile will be internally probed or examined by other suitable means on both sides of the trench for the entire width of the ROW. If damage has occurred, the drain tile will be repaired.

If Project construction activities damage drain tile outside the pipeline construction ROW, NEXUS will address the issue with the landowner on a case-by-case basis.

7 POST-CONSTRUCTION PHASE

After the replacement of topsoil in the ROW, drain tile repaired and replaced by NEXUS within the ROW will be monitored for three years, or until restoration is considered successful. Conditions to be monitored during this period include drain tile settling, crop production, and drainage. The monitoring period is intended to allow for effects of weather changes such as frost action, precipitation, settling and changes in growing seasons, from which various monitoring determinations can be made.

During and after the post-construction monitoring phase, the NEXUS ROW Agent will remain the landowner's point of contact and will coordinate with appropriate Drain Tile Inspectors and Contractors to develop responses and solutions to landowner concerns. Landowner communication can also be facilitated through the use of NEXUS's toll-free telephone number (**1-844-589-3655)**

8 SUMMARY

NEXUS appreciates the importance of agricultural drainage systems in the proposed Project area and is committed to minimizing the potential for impacts to drainage systems as a result of construction-related activities. NEXUS will work with landowners to identify the locations of existing drain tile and plans for developing drainage systems, and devise mitigation and repair strategies as necessary. NEXUS will be responsible for the costs associated with mitigating and repairing impacts from construction-related activities. Unless otherwise negotiated with the landowner, drain tile systems directly damaged by NEXUS will be repaired to at least equivalent to their pre-construction condition or replaced by NEXUS. If available during the time of construction, NEXUS will endeavor to use qualified local Drain Tile Contractors with experience in Ohio and Michigan to conduct and/or consult during drain tile repairs/replacements. Repairs and restoration to drain tile systems conducted by NEXUS will be monitored for three years, or until restoration is considered successful, to ensure the system functions properly.

This draft DTMP will be revised and expanded as the Project develops and additional site-specific information is obtained.

9 REFERENCES AND APPENDICES

ODNR - DSWR Pipeline Standard, December 3, 2013.

USDA NRCS Water Management Guide - Chapter 3 Subsurface Drainage, July 2007.

NRCS National Engineering Handbook - H_210_NEH_16, May 2008.

9.1. Drain Tile Questionnaire

Landowner Drain Tile Questionnaire

Tract# ___________________

Landowner

Name:

Address:

Best Phone#:

Tenant (if applicable)

Name:

Address:

Best Phone#:

1. Are you aware of any existing drain tile or recent drain tile installation (within past 30 years) on this tract? **Y or N**

   If yes, please describe the following:

   Drain Tile General Description (e.g. location within this tract, random, patterned, deep main, drains to NE corner, outlets in ditch, etc.):

   Drain Tile Operating Condition (e.g. unknown, poor – breaking down, fair, good, etc.)

   Drain Tile Spacing (e.g. unknown, 40' centers, varies within field, etc.):

   Drain Tile Size (e.g. unknown, 4", 6" and 8", etc.):

   Drain Tile Depth (e.g. unknown, laterals ~ 3' deep, mains ~ 5' deep, etc.):

   Drain Tile Material (e.g. unknown, corrugated plastic, clay, etc.):

2. Do you have any drain tile maps, as-built drawings, or GPS coordinates for this tract? **Y or N**

   If yes, please include/attach.

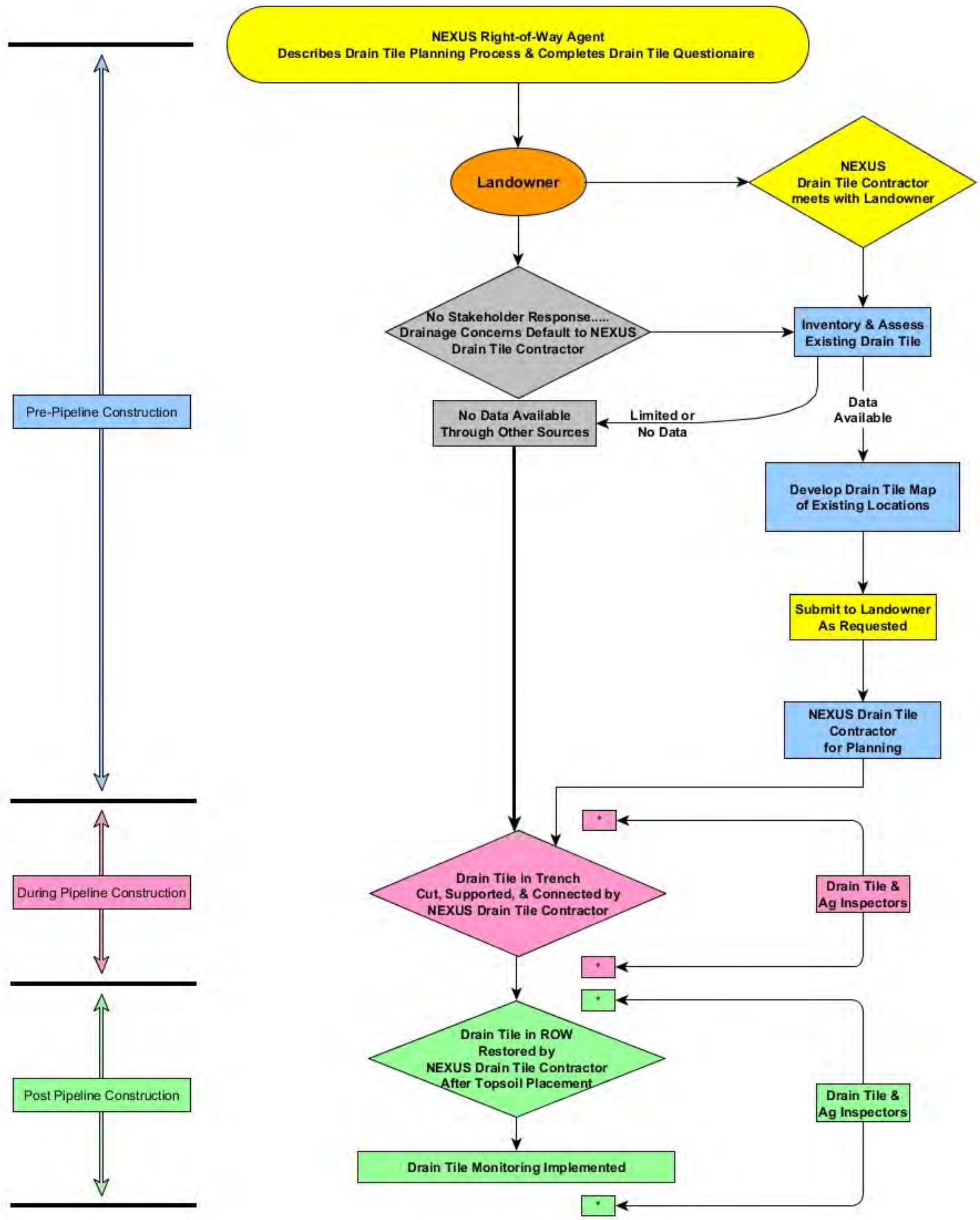
3. Are you aware of any multiple landowner (public or private group) drainage projects associated with this tract? **Y or N**

   If yes, please describe.

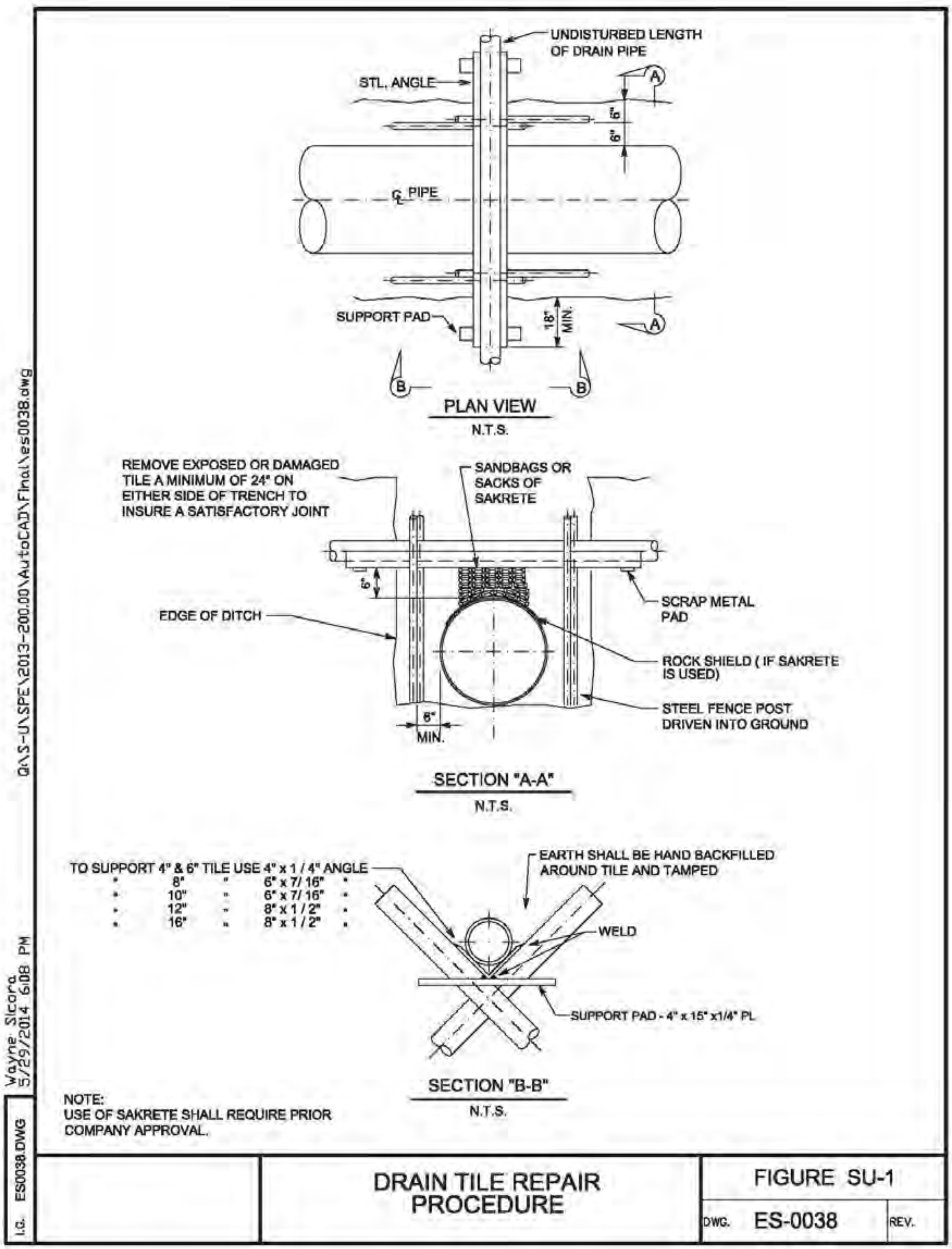
4. Who has done or is doing drain tile installation or maintenance/repair work on this tract?

5. Is there anything else you would like us to know about the drainage system on this tract? (e.g. surface inlets, pump/lift station, overloaded main, future drainage installation planned, etc.):

9.2. Mitigation Planning and Process



9.3. Typical Permanent Drain Tile Repair Procedures



APPENDIX E-4

HDD DESIGN REPORT AND HDD MONITORING AND INADVERTENT RETURN CONTINGENCY PLAN

HDD Design Report, Revision 2
Nexus Pipeline Project

March 2016

Prepared for:

FLUOR

FLUOR ENTERPRISES, INC.
1 Fluor Daniel Drive
Sugarland, Texas 77478

Prepared by

J.D. Hair & Associates, Inc.
2424 E 21st St, Suite 510
Tulsa, Oklahoma 74114-1723

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2424 East 21st Street
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Tulsa, Oklahoma 74114
Tel 918-747-9945
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www.jdhair.com

March 17, 2016

Fluor Enterprises, Inc.
1 Fluor Daniel Drive
Sugarland, TX 77478

Attention: Mr. Rollins Brown, P.E.

SUBJECT: HDD Design Report, Revision 2
Nexus Pipeline Project

Dear Mr. Brown:

J. D. Hair & Associates, Inc. (JDH&A) is pleased to submit the following report titled *HDD Design Report, Revision 2, Nexus Pipeline Project*. The report presents site-specific feasibility evaluations, design considerations, supporting calculations, and other details relative to obstacle crossings on the proposed Nexus Pipeline Project to be installed using horizontal directional drilling (HDD).

We appreciate your confidence in JDH&A. If you have any questions or need additional information, please do not hesitate to contact us.

Sincerely,

J. D. HAIR & ASSOCIATES, INC.

Jeffrey M. Scholl, P.E.
Engineering Manager

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APPENDIX - CROSSING SPECIFIC REPORTS

1. INTRODUCTION

This report provides a summary of design considerations and engineering calculations associated with horizontal directionally drilled (HDD) crossings on the 36-inch pipeline for the Nexus Gas Transmission Project. J. D. Hair & Associates, Inc. (JDH&A) has undertaken this report as part of the scope outlined in Fluor Enterprises, Inc. (FLUOR) Purchase Order No: GS15-337208.

The report is divided into two primary sections. The first section provides a general overview of the HDD construction method including a description of the HDD process, feasibility considerations, and details with respect to calculation methods used during the design process. The second section of the report contains site-specific crossing evaluations that include the following topics:

- General Site Descriptions
- Subsurface Conditions
- Design Geometry and Layout
- Assessment of Feasibility
- Risk Identification and Assessment
- Installation Loading Analysis
- Hydraulic Fracture Evaluation
- Estimated Construction Duration

HDD crossings proposed for the Nexus Project that served as the focus of this report are included in Table 1.

Table 1: Proposed HDD Crossings on the Nexus Project

Mile Post	Location	Crossing Name	Horizontal Length
7.9R	Columbiana County, Ohio	Wetland	2,931 feet
41.0R	Summit County, Ohio	Nimisila Reservoir	1,776 feet
47.8R	Summit County, Ohio	Tuscarawas River	3,263 feet
71.1	Median County, Ohio	Wetland	1,784 feet
86.9	Lorain County, Ohio	East Branch Black River	1,809 feet
92.5	Lorain County, Ohio	West Branch Black River	1,676 feet
104.1	Huron County, Ohio	Vermilion River	3,184 feet
110.3	Erie County, Ohio	Interstate 80	1,432 feet
116.8	Erie County, Ohio	Huron River	2,423 feet
146.3R	Sandusky County, Ohio	Sandusky River	2,586 feet
162.6R	Sandusky County, Ohio	Portage River	1,790 feet
180.1R	Wood County, Ohio	Findlay Road	1,522 feet
181.2	Wood and Lucas Counties, Ohio	Maumee River	3,999 feet
215.0	Lenawee County, Michigan	River Raisin	1,479 feet
237.4	Washtenaw County, Michigan	Saline River	1,315 feet
250.7	Washtenaw County, Michigan	Hydro Park	2,300 feet
251.5	Washtenaw County, Michigan	Interstate 94	1,359 feet
254.4R	Washtenaw County, Michigan	US-12	1,739 feet

2. HDD PROCESS DESCRIPTION

Installation of a pipeline by HDD is accomplished in three stages as illustrated in Figure 1. The first stage consists of directionally drilling a small diameter pilot hole along a designed directional path. The second stage involves enlarging this pilot hole to a diameter suitable for installation of the pipeline. The third stage consists of pulling the pipeline back into the enlarged hole.

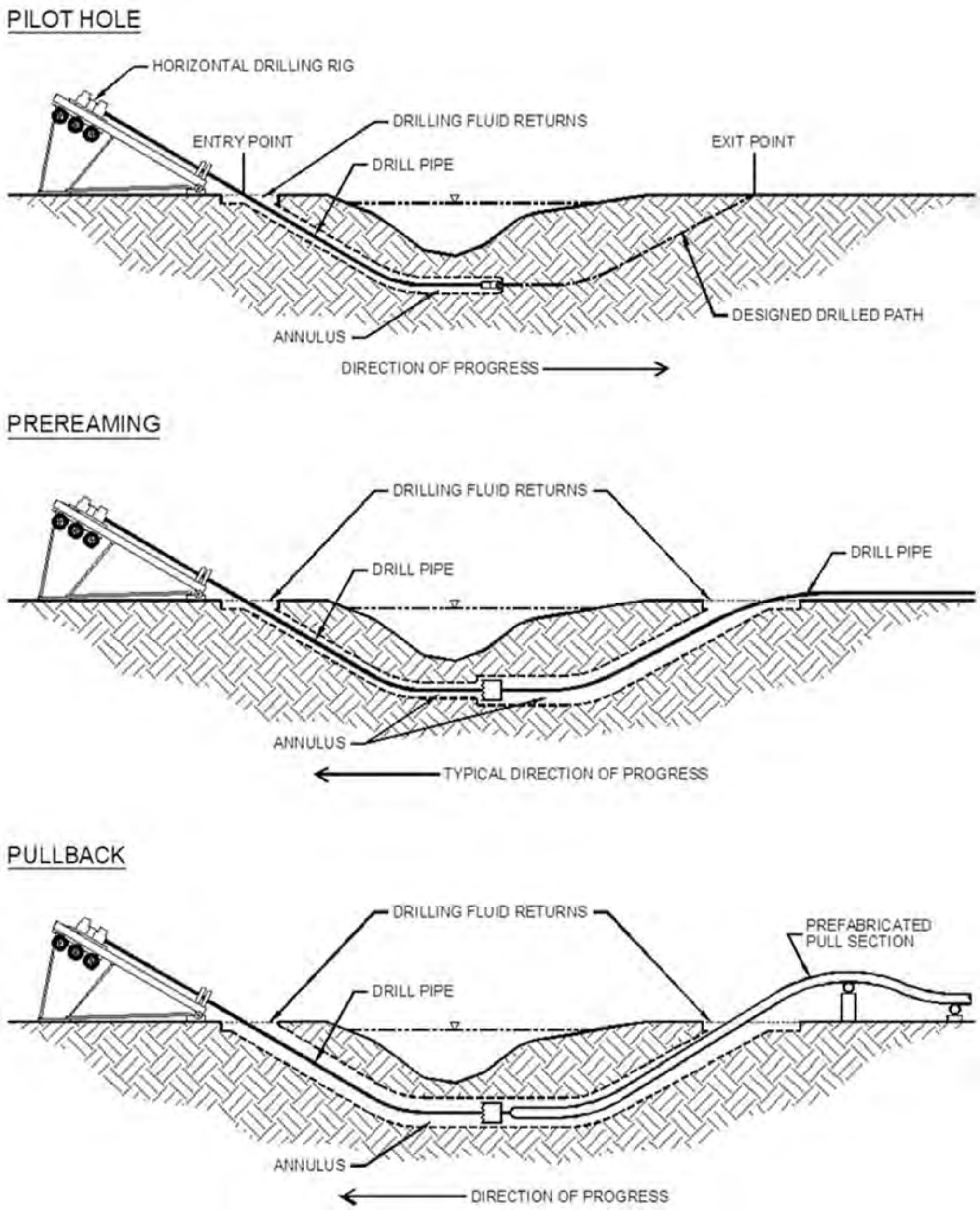

Figure 1: The HDD Process

2.1. Pilot Hole Directional Drilling

2.1.1. Pilot Hole

Pilot hole directional control is achieved by using a non-rotating drill string with an asymmetrical leading edge. The asymmetry of the leading edge creates a steering bias while the non-rotating aspect of the drill string allows the steering bias to be held in a specific position while drilling. If a change in direction is required, the drill string is rolled so that the direction of bias is the same as the desired change in direction. Leading edge asymmetry is typically accomplished with either a bent sub or a bent motor housing located behind the bit.

In loose soils, drilling progress may achieved by hydraulic cutting with a jet nozzle. If hard zones are encountered, the drill string may be rotated to drill without directional control until the hard zone has been penetrated. Mechanical cutting action required for harder soils and rock is provided by a mud motor, which converts hydraulic energy from drilling fluid to mechanical energy at the drill bit. This allows for bit rotation without drill string rotation.

The path of the pilot hole is monitored during drilling using a steering tool positioned near the bit. The steering tool provides continuous readings of the inclination and azimuth at the leading edge of the drill string. These readings, in conjunction with measurements of the distance drilled, are used to calculate the horizontal and vertical coordinates of the steering tool relative to the initial entry point on the surface. The path of the pilot hole can also be determined with a surface monitoring system that induces an artificial magnetic field using a wire placed on the surface. Measurements of this magnetic field's properties by instruments in the steering tool allow the position of the steering tool to be determined using triangulation. This provides data that can be used to correct downhole survey inaccuracy that results from inconsistencies in the earth's magnetic field.

2.1.2. Prereaming

Enlarging the pilot hole is accomplished using prereaming passes prior to pipe installation. Reaming tools generally consist of a circular array of cutters and drilling fluid jets and are often custom made by contractors for a particular hole size or type of soil. These tools are attached to the drill string and rotated and drawn along the pilot hole. Drill pipe is added behind the tools as they progress along the drilled path to ensure that a string of pipe always extends between the entry and exit points.

2.1.3. Pullback

Pipe installation is accomplished by attaching a pipeline pull section behind a reaming assembly at the exit point, then pulling the reaming assembly and pull section back to the drilling rig. This is undertaken after completion of prereaming or, for smaller diameter lines in loose soils, directly after completion of the pilot hole. A swivel is utilized to connect the pull section to the reaming assembly to minimize torsion transmitted to the pipe. The pull section is supported using some combination of roller stands and pipe handling equipment to minimize tension and prevent damage to the pipe.

3. TECHNICAL FEASIBILITY CONSIDERATIONS

For a pipeline to be installed by HDD, either an open hole must be cut into the subsurface material so that installation of a pipeline by the pullback method is possible, or the properties of the subsurface material must be modified so that the soil behaves in a fluid manner allowing a pipeline to pass through it.

In the open hole condition, a cylindrical hole is drilled through the subsurface. Drilling fluid flows to the surface in the annulus between the pipe and the wall of the hole. Drilled spoil is transported in the drilling fluid to the surface. This is generally applicable to rock and cohesive soils. It may also apply to some sandy or silty soils depending on the density of the material, the specific makeup of the coarse fraction, and the binding or structural capacity of the fine fraction.

The open hole condition is difficult to achieve in loose cohesionless soils over a long horizontally drilled length. Nevertheless, pipelines are routinely installed by HDD in loose soils. The mechanical agitation of the reaming tool coupled with the injection of drilling fluid will cause the soil to experience a decrease in shear strength. If the resulting shear strength is low enough, the soil will behave in a fluid manner allowing a pipe to be pulled through it.

3.1. Pilot Hole Limitations

A pilot hole must be drilled in compression. That is, weight on bit must be achieved by thrusting the drill pipe away from the drilling rig. Drill pipe buckling becomes a problem, depending on soil conditions, and the combination of pipe bending and rotation can lead to failure through low cycle fatigue. Pilot hole length is limited by the capacity of the drill pipe to withstand the combination of compressive, bending, and torsional loads.

Pilot holes are directionally drilled by orienting the asymmetry of the bottom hole assembly by rotating the drill string at the drilling rig. As pilot hole distances increase, the orientation of the bottom hole assembly becomes more difficult to control. Actions taken at the drilling rig several thousand feet behind the bottom hole assembly may not translate clearly to reactions at the leading edge. Pilot hole length is limited by the ability to accurately steer.

A pilot hole must achieve either an open hole or fluidized condition in the soil to allow penetration. Depending on the characteristics of the soil, these two conditions may be difficult to achieve over long horizontal lengths. Suspension of cuttings is difficult to maintain over long horizontal distances. Cuttings may accumulate around the pipe causing it to get stuck. Experience has shown that the fluidized condition degrades over time if the soil is not agitated and exposed to bentonite drilling fluid flow. Drill pipe, and pipelines, have become stuck during HDD operations and have been abandoned in place. Pilot hole length is limited by the ability to maintain a hole in the subsurface.

Despite the above limitations, experience in the HDD industry indicates that pilot holes up to approximately 7,000 feet are feasible when drilling with a single rig in one direction, and significantly longer lengths are possible through the use of the drilled intersect technique. A drilled intersect involves drilling a pilot hole with two rigs from opposite ends of a drilled segment. The pilot holes are essentially drilled into one another. The intersect technique theoretically doubles the maximum feasible length of a pilot hole from 7,000 feet to 14,000 feet.

The practical limits of the intersect technique may be closer to 12,500 feet to allow for some overlap as one pilot hole is sought out by another.

HDD crossings under consideration on the Nexus Project have proposed lengths ranging from 1,320 feet to 4,018 feet, easily within the lengths attainable using a single HDD rig. Therefore, utilization of the intersect technique is not envisioned.

3.2. Prereaming and Pullback Limitations

Since drill pipe is usually rotated in tension during prereaming and pullback, the length limitations associated with drill pipe compression and low cycle fatigue experienced in pilot hole drilling do not come into play. Concerns with steering are also not applicable. Horizontal length during prereaming and pullback is limited by the ability to maintain an open hole or fluid condition to such an extent that drill pipe, reaming tools, and product pipe can be moved along the drilled path without exceeding the capacity of the pipe or drilling rig.

Pipeline diameter is limited by the capacity of drill pipe for the transmission of torque to reaming tools. Commercially available drill pipe is limited to 7-5/8 inches in diameter. This limitation notwithstanding, experience in the HDD industry has demonstrated that installation of 56-inch diameter steel pipe is feasible in amenable subsurface conditions. HDD installation of 36-inch diameter steel pipe, once again in amenable subsurface conditions, is relatively common.

3.3. Subsurface Material

While length, diameter, and subsurface material work in combination to limit the technical feasibility of a HDD installation, technical feasibility is primarily limited by subsurface material. The problematic subsurface condition most often encountered in evaluating the feasibility of a HDD installation is large grain content in the form of gravel, cobbles, and boulders. Other subsurface conditions that can affect the feasibility of a HDD installation include excessive rock strength and abrasivity, poor rock quality, solution cavities, and artesian conditions.

3.3.1. Large Grained Formations

Soils consisting principally of coarse-grained material present a serious restriction on the feasibility of HDD. Coarse gravel, cobbles, and boulders, cannot be readily fluidized by the drilling fluid, nor are they stable enough to be cut and removed in a drilling fluid stream as is the case with a crossing installed in competent rock. A boulder or cluster of cobbles will remain in the drilled path and present an obstruction to a bit, reamer, or pipeline. Such obstructions must be mechanically displaced by drilling tools. If the characteristics of the coarse grained materials are such that mechanical displacement with HDD tools is not possible, HDD installation may not be technically feasible.

Fortunately, problematic coarse grained soils are normally encountered in limited quantities. Coarse overburden may overlay bedrock or a finer grained formation amenable to penetration by HDD. If the overburden is not too deep, it can be removed by excavation or penetrated with a surface casing. HDD can then proceed through the amenable formation.

3.3.2. Excessive Rock Strength and Abrasivity

Exceptionally strong and abrasive rock can hamper all phases of a HDD project. Slow penetration rates and frequent stoppages to replace worn bits and reamers can result in extended construction durations and unacceptable increases in construction cost. Excessive rock strength and abrasivity can also lead to tool or drill pipe failures downhole as a result of premature wear and excessive torque. Experience has shown that competent rock with unconfined compressive strengths as high as 50,000 psi can be negotiated with today's technology. However, entry of such materials at depth can be problematic, as the drill string may tend to deflect rather than penetrate.

3.3.3. Poor Rock Quality

A HDD installation through poor quality (extensively fractured or jointed) rock can present the same problems as coarse-grained deposits. Cutting a hole through such materials may cause the overlying rock to collapse, creating obstructions during subsequent passes.

3.3.4. Solution Cavities

Solution cavities present in karst formations can have a substantial impact on the feasibility of a HDD installation. While the wall of a competent rock hole serves to limit the deflection of the drill string, penetration of a void leaves the drill string unconstrained potentially allowing it to deflect laterally. Continued rotation of a drill string subjected to such a deflection can result in failure of the drill pipe due to low-cycle fatigue.

3.3.5. Artesian Conditions

Penetration of an artesian aquifer during drilling or reaming operations can result in a sustained flow of groundwater and fine soils into the drilled hole. This can cause several serious problems including degradation of drilling fluid, deterioration of the hole, drilling fluid storage and disposal issues, and stuck pipe or downhole tools.

4. DRILLING FLUIDS

4.1. Introduction

The primary impact of HDD on the environment revolves around the use of drilling fluids. Where regulatory problems are experienced, the majority of concerns and misunderstandings are associated with drilling fluids. An awareness of the function and composition of HDD drilling fluids is imperative in producing a permittable and constructible HDD design.

Drilling fluid is used in all phases of the HDD process. Figure 2 shows the relationship of the elements typically associated with a HDD drilling fluid system.

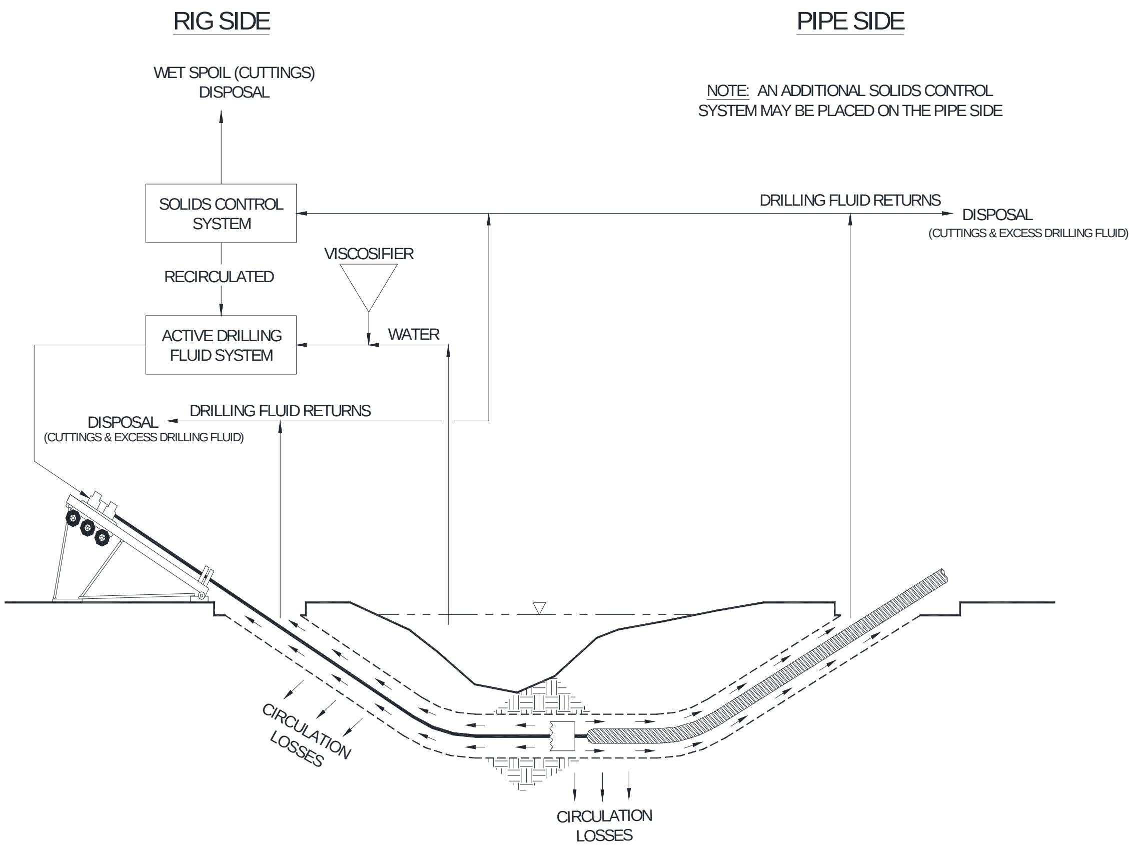

Figure 2: HDD Drilling Fluid Flow Schematic

4.2. Functions of Drilling Fluid

The principal functions of drilling fluid in HDD pipeline installation are as listed below:

- **Transportation of Spoil –** Drilled spoil, consisting of excavated soil or rock cuttings, is suspended in the fluid and carried to the surface by the fluid stream flowing in the annulus between the wall of the hole and the pipe.
- **Cooling and Cleaning of Cutters** – High velocity fluid streams directed at the cutters remove drilled spoil build-up on bit or reamer cutters. The fluid also cools the cutters.
- **Reduction of Friction** – Friction between the pipe and the wall of the hole is reduced by the lubricating properties of the drilling fluid.
- **Hole Stabilization** – The drilling fluid stabilizes the drilled or reamed hole. This is critical in HDD pipeline installation as holes are often in loose soil formations and are uncased. Stabilization is accomplished by the drilling fluid building up a wall cake and exerting a positive pressure on the hole wall. Ideally, the wall cake will seal pores and produce a bridging mechanism to hold soil particles in place.

- **Transmission of Hydraulic Power** – Power required to turn a bit and mechanically drill a hole is transmitted to a downhole motor by the drilling fluid.
- **Hydraulic Excavation –** Soil is excavated by erosion from high velocity fluid streams directed from jet nozzles on bits or reaming tools.
- **Soil Modification –** Mixing of the drilling fluid with the soil along the drilled path facilitates installation of a pipeline by reducing the shear strength of the soil to a near fluid condition. The resulting soil mixture can then be displaced as a pipeline is pulled into it.

4.3. Composition of Drilling Fluid

The major component of drilling fluid used in HDD pipeline installation is fresh water obtained at the crossing location. In order for water to perform the functions listed above, it is generally necessary to modify its properties by adding a viscosifier. The viscosifier used almost exclusively in HDD drilling fluids is naturally occurring clay in the form of bentonite mixed with small amounts of extending polymers to increase its yield (high yield bentonite).

Increasing the yield of bentonite allows more drilling fluid to be produced with less viscosifier (dry bentonite). For example, Wyoming bentonite yields in excess of 85 barrels of drilling fluid per US ton of dry viscosifier. Addition of polymers to produce high yield bentonite can increase the yield to more than 200 barrels of fluid per ton of viscosifier. Typical HDD drilling fluids are composed of less than 2% high yield bentonite by volume with the remaining components being water and drilled spoil. Solids control equipment should be utilized to remove drilled spoil from the fluid to the extent practical, maintaining total solids (high yield bentonite and drilled spoil) at around 6% by volume.

4.4. Inadvertent Returns

HDD involves the subsurface discharge of drilling fluids. Once discharged downhole, drilling fluid is uncontrolled and will flow in the path of least resistance. The annulus of the drilled hole is intended to provide a controlled path of least resistance. However, in some cases the drilling fluid will disperse into the surrounding soils or discharge to the surface at some random location, which may not be a critical problem in an undeveloped location. However, in an urban environment or a high profile recreational area, inadvertent returns can be a major problem. In addition to the obvious public nuisance, drilling fluid flow can buckle streets or wash out embankments.

Drilling parameters may be adjusted to maximize drilling fluid circulation and minimize the risk of inadvertent returns. However, the possibility of lost circulation and inadvertent returns cannot be eliminated. Contingency plans addressing possible remedial action should be made in advance of construction and regulatory bodies should be informed.

Inadvertent returns are more likely to occur in less permeable soils with existing flow paths. Examples are slickensided clay or fractured rock structures. Coarse grained, permeable soils exhibit a tendency to absorb circulation losses. Manmade features, such as exploratory boreholes or piles, may also serve as conduits to the surface for drilling fluids. Inadvertent drilling fluid returns in a waterway are shown in Figure 3 and drilling fluid returns surfacing through cracks in pavement along a roadway in Figure 4.

Research projects have been conducted in an attempt to identify the mechanisms that cause inadvertent returns and develop analytical methods for use in predicting their occurrence. Efforts have centered on predicting the point at which hydraulic fracture of the native soils will occur. These programs have met with limited success in providing a reliable prediction method. Engineering judgment and experience must be applied in utilizing hydraulic fracture models to predict the occurrence, or nonoccurrence, of inadvertent returns. Additional information relative to evaluating the potential for hydraulic fracture is presented in Section 5.

Figure 3: Inadvertent drilling fluid return in waterway

Figure 4: Inadvertent drilling fluid return surfacing through cracks in pavement

5. HYDRAULIC FRACTURE EVALUATION

As mentioned briefly above, hydraulic fracture, also known as hydrofracture, is a phenomenon that occurs when drilling fluid pressure in the annular space of the drilled hole exceeds the strength of the surrounding soil mass, resulting in deformation, cracking, and fracturing. The fractures may then serve as flow conduits for drilling fluid allowing the fluid to escape into the formation and possibly up to the ground surface. Drilling fluid that makes its way to the ground surface is known as an inadvertent drilling fluid return or, more commonly, a “frac-out.”

Although hydrofracture may be one mechanism by which frac-outs occur, it is not the only one. In fact, it is thought that frac-outs due to true hydrofracture occur in only a small percentage of cases. Drilling fluid flows in the path of least resistance. Ideally, the path of least resistance is through the annulus of the drilled hole and back to the fluid containment pits at the entry or exit points. However, the path of least resistance may also be through naturally occurring subsurface features such as fissures in the soil, shrinkage cracks, or porous deposits of gravel. Drilling fluid may also flow to the surface alongside piers, piles, utility poles, or other structures.

The risk of hydrofracture can be determined by comparing the formation limit pressure (confining capacity) of the subsurface soils to the estimated annular pressure necessary to conduct HDD operations. If the drilling fluid pressure in the annulus exceeds the confining capacity of the overlying soils, there is risk that inadvertent drilling fluid returns due to hydrofracture will occur. A discussion of the methods used to predict the formation limit pressure and the minimum required annular pressure on the Nexus Project is provided in the sections below.

5.1. Formation Limit Pressure

For HDD crossings on the Nexus Project that involve passing through uncemented soil (i.e. silt, sand, clay), the formation limit pressure was calculated using the "Delft Method." The Delft Method is described in Appendix A of an Army Corps of Engineers publication (CPAR-GL-98) titled *Recommended Guidelines for Installation of Pipelines beneath Levees using Horizontal Directional Drilling.*[1]

The Delft Method assumes uniform soil conditions in the soil column above the point along the drilled path that is being analyzed and requires engineering judgment with respect to the selection of geotechnical parameters that are used in the Delft equations. With respect to the Nexus Project, subsurface parameters were estimated based on site-specific standard penetration test (SPT) data presented in the geotechnical reports prepared by Fugro Consultants, Inc. Since the Delft Method assumes uniform soil conditions, weighted averages of the various material properties of the overburden soils were used in assessing the confining capacity.

5.2. Estimated Annular Pressure

The estimated minimum annular pressure necessary for HDD pilot hole operations was calculated using the Bingham Plastic Model. The Bingham Plastic Model is described in Chapter 4 of Society of Petroleum Engineer's *Applied Drilling Engineering*.[2] Variables with respect to drilling fluid rheology and tooling used in the annular pressure calculations are provided in Table 2.

Table 2: Drilling Fluid Parameters

Drilling Fluid Parameter	Value
Effective Pilot Hole Diameter	14 inches
Drill Pipe Diameter	6.625 inches
Drilling Fluid Weight	11 pounds per gallon
Pump Flow Rate	210 gallons per minute
Yield Point	29 pounds per 100 ft^2
Plastic Viscosity	15 centipoise

[1] *Recommended Guidelines for Installation of Pipelines beneath Levees using Horizontal Directional Drilling*, prepared for U.S. Army Corps of Engineers, Kimberlie Staheli [et al], April 1998

[2] *Applied Drilling Engineering,* Society of Petroleum Engineers, Richardson, Texas, A. T. Bourgoyne, Jr. [et al], 1991

5.3. Hydrofracture Risk Assessment

The results of the hydrofracture risk assessments for applicable crossings on the Nexus Project are included in the site-specific reports.

6. DESIGN CRITERIA

6.1. HDD Path Centerline

An HDD profile design is defined by the following six parameters:

- Entry Point
- Exit Point
- Entry Angle
- Exit Angle
- P.I. Elevation
- Radius Of Curvature

The relationship of these parameters to each other is illustrated in Figure 5.

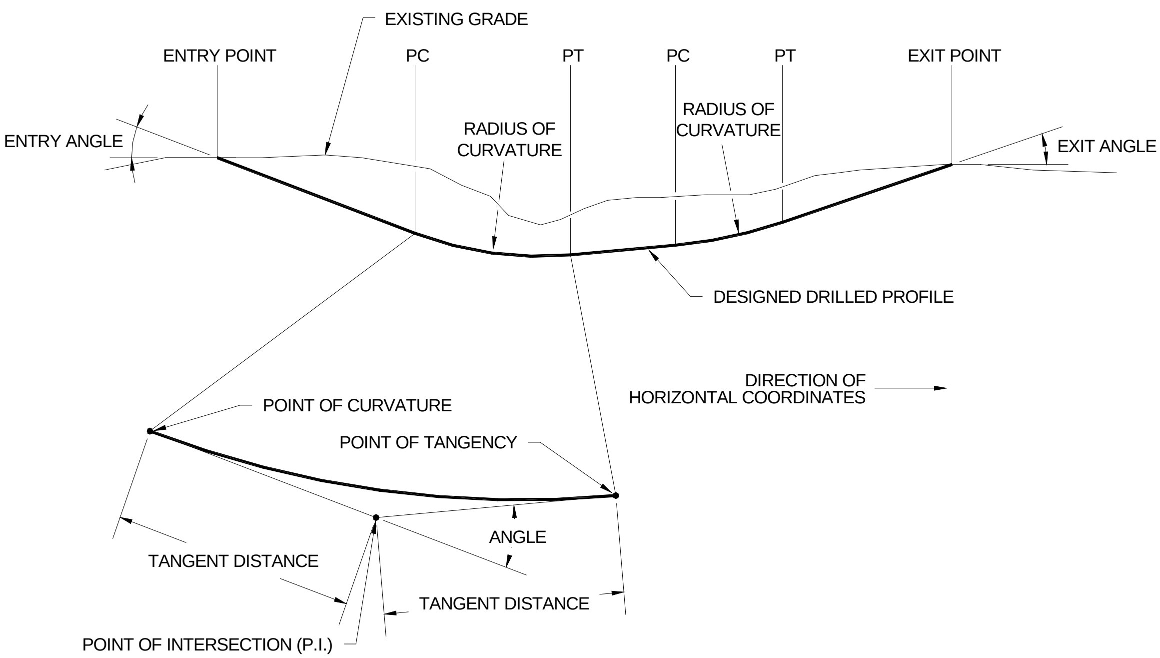

Figure 3: Horizontal Directional Drilling Terminology

6.2. Entry and Exit Points

The entry and exit points are the endpoints of the designed drilled segment on the ground surface. The drilling rig is positioned at the entry point and the pipeline is pulled into the drilled hole through the exit point. The relative locations of the entry and exit points, and consequently the direction of pilot hole drilling and pullback, should be established by the site's geotechnical and topographical conditions.

The following criteria were used as the basis for selecting entry and exit points on the Nexus Project: 1) steering precision and drilling effectiveness are greater near the drilling rig; 2) drilling fluid returns to the rig are enhanced if the entry point is lower than the exit point; 3) pullback operations are enhanced if there is sufficient work space in line with the drilled path to allow the pull section to be fabricated in one continuous string. It is also important to recognize that the position of the drilling rig may be changed during construction to facilitate operations and a dual rig scenario may be employed during prereaming. In a dual rig scenario rigs are positioned at both ends of the drilled segment and work in tandem.

6.3. Entry and Exit Angles

Ideal or target entry angles are between 8-degrees and 12-degrees, which accommodate most HDD drilling rigs. Target exit angles are between 8-degrees and 10-degrees to facilitate breakover support during pullback. These are consistent with HDD industry design standards.[3] In some cases, where topographic considerations or other site-specific conditions dictated, angles greater than the target values have been used.

6.4. P.I. Elevation

The P.I. elevation defines the depth of cover that the HDD installation will provide under the obstacle. Although experience and judgement with respect to depth of cover must be used on a crossing specific basis, it is generally thought that areas along the HDD alignment with less than 40 feet of cover have a greater susceptibility to inadvertent drilling fluid returns.[4] Standard practice with respect to design depth has slowly evolved over the years, primarily based on field experience and observations as opposed to theoretical methods. Therefore, in order to reduce the risk of drilling fluid impacts (heaving, settlement, and inadvertent returns) the majority of the HDD crossings on the Nexus Project were designed with 40 feet of cover at the target obstacle. However, in some cases, designs may involve less cover if adverse subsurface conditions or other site-specific constraints dictated otherwise.

6.5. Radius of Curvature

The design radius of curvature for HDD segments was set at 3,600 feet. This is consistent with the HDD industry standard design radius of 1,200 times the nominal outside diameter.[5] This relationship has been developed over a period of years in the HDD industry and is based on experience with constructability as opposed to any theoretical analysis.

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[3] *Manual of Practice No. 108, Pipeline Design for Installation by Horizontal Directional Drilling* (Reston, VA: American Society of Civil Engineers, 2005), 15.

[4] *Manual of Practice No. 108*, 50.

[5] *Manual of Practice No. 108*, 16.

7. INSTALLATION LOADS AND STRESSES

During HDD installation, a pipeline segment is subjected to tension, bending, and external pressure as it is pulled through a prereamed hole. The stresses in the pipe and its potential for failure are a result of the interaction of these loads.[6,7] In order to determine if a given pipe specification is adequate, HDD installation loads must first be estimated so that the stresses resulting from these loads can be calculated. A thorough design process requires examination of the stresses that result from each individual installation loading condition as well as an examination of the combined stresses that result from the interaction of these loads.

7.1. HDD Installation Stress Analysis

Calculation of the approximate tensile load required to install a pipeline by HDD is relatively complicated due to the fact that the geometry of the drilled path must be considered along with the properties of the pipe being installed and the subsurface conditions. Assumptions and simplifications are required. A method to accomplish this is presented in *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, published by the Pipeline Research Council International (PRCI).[8]

The PRCI Method involves modeling the drilled path as a series of segments to define its shape and properties during installation. The individual loads acting on each segment are then resolved to determine a resultant tensile load for each segment. The estimated force required to install the entire pull section in the reamed hole is equal to the sum of the tensile loads acting on all of the defined segments. When utilizing the PRCI Method, pulling loads are affected by numerous variables, many of which are dependent upon site-specific conditions and individual contractor practices. These include prereaming diameter, hole stability, removal of cuttings, soil and rock properties, drilling fluid properties, and the effectiveness of buoyancy control measures.[9]

It is important to keep in mind that the PRCI Method considers pulling tension, pipe bending, and external pressure. It does not consider point loads that may result from subsurface conditions such as a rock ledge or boulder. Indeed, we know of no way to analyze potential point loads that may develop due to subsurface conditions. Although this type of damage is relatively rare, several cases have been observed over the last ten years where pipelines suffered damage in the form of dents or pipe deformation due to point loads encountered during HDD installation.

Pulling load calculations for the Nexus Project were completed under two separate installation scenarios. The first is based on the exact design geometry shown on the preliminary plan and profile drawings. The second is based on an assumed worse case installation model in which the pilot hole is drilled 25 feet deeper and 50 feet longer than the designed path with a radius of curvature equal to 50 percent of the design radius (1,800 feet).

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[6] Fowler, J.R. and C.G. Langner. "Performance Limits for Deepwater Pipelines." Presentation, OTC 6757, 23rd Annual Offshore Technology Conference, Houston, TX, May 6-9, 1991.

[7] Loh, J.T. "A Unified Design Procedure for Tubular Members." Presentation, OTC 6310, 22nd Annual Offshore Technology Conference, Houston, TX, May 7-10, 1990.

[8] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide* (Arlington, VA: Pipeline Research Council International, Inc., 2008), 26-36.

[9] *Manual of Practice No. 108*, 42.

The installation stress calculations are based on several assumptions with respect to pipe/soil interaction, conditions of the hole, and drilling fluid properties. One variable, which plays a significant role in the calculated pulling load is the fluid drag coefficient. For pulling load calculations on the Nexus Project, a fluid drag coefficient of 0.025 was assumed. This value is based on research conducted by Jeffrey Puckett[10] and is referenced in the 2008 edition of the PRCI's *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide.* Another variable that has substantial impact on the calculated pulling load is the soil friction coefficient. In this case, a value of 0.30 was assumed, which is generally considered a conservative, upper bound, but reasonable value for pipe and soil interaction in a drilling fluid filled hole. For drilling fluid density, it was assumed the reamed hole would contain a heavy 12 pounds per gallon mixture of drilling fluid and soil cuttings during pullback. For conservative results, it was assumed the pipe will be installed empty, without ballast during pullback.

Anticipated pulling loads as well as the results of the pipe stress calculations can be found in the site-specific reports.

7.2. Operating Stress Analysis

As with a pipeline installed by conventional methods, a pipeline installed by HDD will be subjected to internal pressure, thermal expansion, and external pressure during normal operation. A welded pipeline installed by HDD will also be subjected to elastic bending. The operating loads imposed on a pipeline installed by either of these methods are addressed in Chapter 5 of *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide.*

With one exception, the operating stresses in a pipeline installed by HDD are not materially different from those experienced by pipelines installed by cut and cover techniques. As a result, past procedures for calculating and limiting stresses can be applied. However, unlike a cut and cover installation in which the pipe is bent to conform to the ditch, a pipeline installed by HDD will contain elastic bends.

Flexural stresses associated with elastic bends were analyzed in combination with longitudinal and hoop stresses that develop during hydrostatic testing and subsequent operation of the pipeline to verify that stresses conform to applicable limits specified in ASME B31.8 (2010).

Three scenarios were investigated for the Nexus Project. In the first two scenarios, it was assumed the pipeline would be fully restrained underground, with an initial restraint temperature of 55 °F and an operating temperature of 120 °F. The first scenario involved an elastic radius of 3,600 feet under an operating pressure 1,440 psig. The second scenario involved the same operating pressure but reduces the radius to 1,800 feet. The third scenario assumed that temperatures would be constant under a hydrostatic test pressure of 2,160 psig and a bending radius of 1,800 feet. A summary of the assumptions used in each loading scenario is provided in Table 3.

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10 Puckett, Jeffrey S. "Analysis of Theoretical Versus Actual HDD Pulling Loads." *Volume Two, New Pipeline Technologies, Security and Safety*, 1352. Presentation, Proceedings of the ASCE International Conference on Pipeline Engineering and Construction from The Technical Committee on Trenchless Installation of Pipelines (TIPS) of the Pipeline Division of ASCE, Baltimore, Maryland, July 13-16, 2003.

Table 3: Operational & Hydrotesting Parameters

Scenario	Radius (ft.)	Max. Pressure (psig)	Installation Temperature (ºF)	Max Operating Temperature (ºF)
Number 1 (Operation)	3,600 (Design)	1,440	55	120
Number 2 (Operation)	1,800 50% of Design	1,440	55	120
Number 3 (Hydrotesting)	1,800 50% of Design	2,160	50	50

In summary, pipe stress resulting from each of the loading scenarios is within acceptable limits as defined by B31.8 (2010). A summary of the results is provided in Table 4.

7.3. Minimum Radius

As mentioned previously in this report, the HDD design radius is 3,600 feet. However, since the pilot hole generally deviates from the exact design during construction, a minimum allowable radius has been specified as part of the allowable pilot hole tolerances called out on the drawings. The radius is typically analyzed over a distance of approximately 90 feet (three joints of range 2 drill pipe) during pilot hole drilling and compared against the allowable minimum. In order to facilitate pilot hole drilling and allow the contractor flexibility in the event that steering issues result due to subsurface conditions, JDH&A recommends setting the minimum radius to 50 percent of the design radius (1,800 feet). Operational stress calculations demonstrating the acceptability of the recommended minimum radius are provided in Table 4. Installation loading stresses associated with the minimum radius are provided with the site-specific reports included in the Appendix.

Table 4: Operational Stress Summary

Pipe Properties			
	Scenario 1	Scenario 2	Scenario 3
Pipe Outside Diameter =	36.000 in	36.000 in	36.000 in
Wall Thickness =	0.741 in	0.741 in	0.741 in
Specified Minimum Yield Strength =	70,000 psi	70,000 psi	70,000 psi
Young's Modulus =	2.9E+07 psi	2.9E+07 psi	2.9E+07 psi
Moment of Inertia =	12755.22 in^4	12755.22 in^4	12755.22 in^4
Pipe Face Surface Area =	82.08 in^2	82.08 in^2	82.08 in^2
Diameter to Wall Thickness Ratio, D/t =	49	49	49
Poisson's Ratio =	0.3	0.3	0.3
Coefficient of Thermal Expansion =	6.5E-06 in/in/°F	6.5E-06 in/in/°F	6.5E-06 in/in/°F
Pipe Weight in Air =	279.04 lb/ft	279.04 lb/ft	279.04 lb/ft
Pipe Interior Volume =	6.50 ft^3/ft	6.50 ft^3/ft	6.50 ft^3/ft
Pipe Exterior Volume =	7.07 ft^3/ft	7.07 ft^3/ft	7.07 ft^3/ft
Operating Parameters			
Maximum Allowable Operating Pressure =	1,440 psig	1,440 psig	2,160 psig
Radius of Curvature =	3,600 ft	1,800 ft	1,800 ft
Restraint Temperature =	55 °F	55 °F	55 °F
Operating Temperature =	120 °F	120 °F	55 °F
Groundwater Table Head =	0 ft	0 ft	0 ft
Operating Stress Check	Scenario 1	Scenario 2	Scenario 3
Hoop Stress =	34,980 psi	34,980 psi	52,470 psi
% SMYS =	50%	50%	75%
Longitudinal Stress from Internal Pressure =	10,494 psi	10,494 psi	15,741 psi
% SMYS =	15%	15%	22%
Longitudinal Stress from Temperature Change =	-12,253 psi	-12,253 psi	0 psi
% SMYS =	18%	18%	0%
Longitudinal Stress from Bending =	12,083 psi	24,167 psi	24,167 psi
% SMYS =	17%	35%	35%
Net Longitudinal Stress (taking bending in tension) =	10,325 psi	22,408 psi	39,908 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	15% ok	32% ok	57%
Net Longitudinal Stress (taking bending in compression) =	-13,842 psi	-25,925 psi	-8,426 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	20% ok	37% ok	12%
Combined Stress (NLS w/bending in tension) - Max Shear Stress Theory =	24,655 psi	12,572 psi	12,562 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	35% ok	18% ok	18%
Combined Stress (NLS w/bending in compression) - Max Shear Stress Theory =	48,822 psi	60,905 psi	60,895 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	70% ok	87% ok	87%
Combined Stress (NLS w/bending in tension) - Max. Distortion Energy Theory =	31,129 psi	30,690 psi	47,453 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	44% ok	44% ok	68%
Combined Stress (NLS w/bending in compress.) - Max. Distortion Energy Theory =	43,582 psi	52,939 psi	57,150 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	62% ok	76% ok	82%

8. CONSTRUCTION DURATION

Estimates of the duration of HDD activities at each crossing site have been prepared based on assumed production rates for the various phases of HDD operations taking into account the crossing lengths, the product line diameter, and subsurface conditions. The duration estimates cover drilling services only (pilot hole through pullback) and do not include installation of surface casings that may be installed at the contractor's option or support operations that are typically provided by a prime contractor (i.e. site preparation & restoration, pull section fabrication, hydrostatic testing). Additionally, the duration estimates do not include contingency to account for operational problems that may occur during construction. Bearing in mind that unanticipated operational problems are relatively common on HDD installations, actual construction durations can be expected to exceed the estimated durations by some amount. In some extreme cases, the duration may be increased by 50 to 100 percent.

Estimated durations for each crossing are presented in Table 5. Details with respect to the individual crossing estimates are provided in the site-specific reports.

Table 5: Estimated HDD Construction Durations

Mile Post	Crossing Name	True Length (feet)	Construction Duration (days)
7.9R	Wetland	2,959	73
41.0R	Nimisila Reservoir	1,785	16*
47.8R	Tuscarawas River	3,309	88
71.1	Wetland	1,792	14
86.9	East Branch Black River	1,822	46
92.5	West Branch Black River	1,686	39*
104.1	Vermilion River	3,205	78
110.3	Interstate 80	1,439	38
116.8	Huron River	2,437	60
146.3R	Sandusky River	2,600	65
162.6R	Portage River	1,801	46
180.1R	Findlay Road	1,528	13
181.2	Maumee River	4,018	81
215.0	River Raisin	1,485	13
237.4	Saline River	1,320	12
250.7	Hydro Park	2,311	26
251.5	Interstate 94	1,366	12
254.4R	US-12	1,750	14*

*Based on assumed subsurface conditions

9. RISK ASSESSMENT

The relative risk associated with installation by HDD at each crossing location has been categorized as Low, Average, or High. This categorization is presented in the site specific reports under the sections titled Risk Identification and Assessment.

For the purposes of this report, risk is defined as the possibility of experiencing serious operational problems that result in significant delays or cost overruns. For example, an HDD pull section may become stuck during pull back requiring either remedial action to recover the partially installed pipeline or abandonment of the pipeline in place. The latter instance would require a new pilot hole to be drilled and reamed with a probable doubling of drilling duration and cost. This would be a significant delay and cost overrun.

Additional discussions relative to site-specific operational problems that may occur during HDD construction on the Nexus Project are in the site-specific reports included in the Appendix.

Further discussion concerning HDD operational problems and contingency planning is included in the project-specific document titled "Nexus Gas Transmission Project, HDD Monitoring and Contingency Plan."

APPENDIX

Crossing Specific Reports

MP 7.9R Wetland

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, In`c. titled "Geotechnical Data Report, Wetland No. 7 HDD Crossing, Nexus Gas Transmission Project, Columbiana County, Ohio" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The proposed 36-inch wetland crossing at pipeline Mile Post 7.9R is located near the intersection of Knox School Road and New Garden Avenue, about 5 miles northeast of Minerva, Ohio. The crossing involves passing beneath the wetland and Knox School Road. The wetland is approximately 450 feet wide and is located in a topographically low-lying area bound to the east by Knox School Road and open farm fields to the west. The east side of the crossing involves a mixture of wooded plots surrounding a commercial orchard. The west side of the crossing is primarily open farm fields. The topography in the area is gently rolling with steep slopes down to the wetland. The relief from the top of the slopes to the bottom of the valley where the wetland is located is about 150 feet. Figure 1 provides a general overview of the vicinity of the crossing.

Figure 1: Overview of the Wetland Crossing at M.P. 7.9R

Subsurface Conditions

Four geotechnical exploratory borings were taken as part of the site investigation conducted by Fugro Consultants, Inc. Borings WL7-01 and WL7-02 were taken on the east side of the wetland and borings WL7-03 and WL7-04 were taken on the west side of the wetland. Each of the borings encountered approximately 15 to 30 feet of overburden soil (sand, silty sand, clayey sand and some gravel) overlying sedimentary bedrock in the form of sandstone, siltstone, claystone, shale, and occasional coal beds. Unconfined compressive strength of the bedrock generally fell in the range of 2,000 psi to 6,000 psi. Rock quality designation (RQD) indicates good quality, competent bedrock overall.

Refer to the geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Wetland No. 7 HDD Crossing, Nexus Gas Transmission Project, Columbiana County, Ohio" and dated September 11, 2015 for detailed information relative to the subsurface layers.

Design Geometry & Layout

The proposed wetland crossing involves a horizontal length of 2,931 feet. It utilizes a 12-degree entry angle, an 8-degree exit angle, and a radius of curvature of 3,600 feet. The crossing design is based on obtaining a minimum of 40 feet of cover beneath the wetland and Knox School Road.

The exit point is located on the west side of the crossing to take advantage of available workspace for pull section fabrication, which will allow the pull section to be fabricated in a single segment, thus avoiding the potential risk of getting stuck during downtime associated with a tie-in weld during pullback. The entry point is located in an open field behind a commercial orchard.

The proposed HDD design, as well as available workspace for HDD operations, is shown on the preliminary HDD plan and profile drawing included at the end of this site-specific report.

Assessment of Feasibility

Based on a review of available geotechnical and other site-specific mapping, the proposed 36-inch wetland crossing is feasible. Although large diameter rock crossings do involve higher risk of HDD operational problems, given the proposed length and the fact that the crossing involves passing through relatively soft sedimentary rock formations, it is our opinion that with the right downhole tool selections and sound planning, skilled and experienced HDD contractors will not have significant difficulties.

Risk Identification and Assessment

Potential construction impacts resulting from installation by HDD include damage to Knox School Road in the form of heaving or settlement, as well as drilling fluid surfacing within the wetland. In this case, due to the topographic relief and relative depth of the crossing compared to the entry point (177 feet), annular pressure will be high due to the height of the drilling fluid column. Since the crossing will be installed through bedrock, drilling fluid may flow through existing fractures or joints and make its way to the ground surface. Therefore, the risk of inadvertent drilling fluid returns within the wetland is increased at this location. There is also increased risk of the development of sinkholes or surface settlement along the HDD alignment on the west end of the crossing during reaming operations. This is due to the 16 foot elevation differential between the entry and exit points. The risk of sinkholes is greatest within 115 feet of the exit point.

HDD construction and operational risks associated with the crossing include failure of large diameter rock reaming tools downhole, hole misalignment at the soil/rock interface which can lead to downhole tools or the pull section getting lodged, and loss of drilling fluid circulation through existing fractures which could negatively impact cuttings removal. In addition, sink holes (hole collapse) on the west side resulting from the elevation differential may increase the difficulty of reaming and cuttings removal.

The overall risk level associated with the proposed 36-inch wetland crossing is considered average.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the crossing, without ballast, is 492,725 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 521,640 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 2. Detailed calculations for each loading scenario are summarized in Figures 3 and 4.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 2: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D = 36.000 in
Pipe Weight, W = 279.0 lb/ft
Coefficient of Soil Friction, μ = 0.30

Fluid Drag Coefficient, C_d = 0.025 psi
Ballast Weight / ft Pipe, W_b = 405.5 lb (If Ballasted)
Drilling Mud Displaced / ft Pipe, W_m = 634.5 lb (If Submerged)
Above Ground Load = 0 lb

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L = 1131.7 ft
Exit Angle, θ = 8.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ cosθ = 119,497 lb

Fluidic Drag = 12 π D L C_d = 38,396 lb

Axial Segment Weight = W_e L sinθ = 55,981 lb

Pulling Load on Exit Tangent = 213,875 lb

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 502.7 ft
Segment Angle with Horizontal, θ = -8.0 °
Deflection Angle, α = -4.0 °

Average Tension, T = 270,090 lb
Radius of Curvature, R = 3,600 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

h = R [1 - cos(α/2)] = 8.77 ft

j = [(E I) / T]$^{1/2}$ = 1,170

Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] = 3.4E+06

X = (3 L) - [(j / 2) tanh(U/2)] = 929.55

U = (12 L) / j = 5.15

N = [(T h) - W_e cosθ (Y/144)] / (X / 12) = 138,187 lb

Bending Frictional Drag = 2 μ N = 82,912 lb

Fluidic Drag = 12 π D L C_d = 17,055 lb

Axial Segment Weight = W_e L sinθ = 12,463 lb

Pulling Load on Exit Sag Bend = 112,430 lb
Total Pulling Load = 326,305 lb

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L = 100.0 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ = 10,664 lb

Fluidic Drag = 12 π D L C_d = 3,393 lb

Axial Segment Weight = W_e L sinθ = 0 lb

Pulling Load on Bottom Tangent = 14,057 lb
Total Pulling Load = 340,362 lb

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 754.0 ft
Segment Angle with Horizontal, θ = 12.0 °
Deflection Angle, α = 6.0 °

Average Tension, T = 401,395 lb
Radius of Curvature, R = 3,600 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

h = R [1 - cos(α/2)] = 19.72 ft

j = [(E I) / T]$^{1/2}$ = 960

Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] = 9.3E+06

X = (3 L) - [(j / 2) tanh(U/2)] = 1782.04

U = (12 L) / j = 9.43

N = [(T h) - W_e cosθ (Y/144)] / (X / 12) = 207,497 lb

Bending Frictional Drag = 2 μ N = 124,498 lb

Fluidic Drag = 12 π D L C_d = 25,582 lb

Axial Segment Weight = W_e L sinθ = -28,013 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 122,067 lb
Total Pulling Load = 462,429 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 470.9 ft
Entry Angle, θ = 12.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ cosθ = 49,120 lb

Fluidic Drag = 12 π D L C_d = 15,979 lb

Axial Segment Weight = W_e L sinθ = -34,802 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 30,296 lb
Total Pulling Load = 492,725 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	6,003	ok	0	ok	0	ok	0.10	ok	0.01	ok
	5,634	ok	0	ok	1483	ok	0.09	ok	0.06	ok
PC										
	5,634	ok	12,083	ok	1483	ok	0.35	ok	0.17	ok
	4,147	ok	12,083	ok	2674	ok	0.33	ok	0.27	ok
PT										
	4,147	ok	0	ok	2674	ok	0.07	ok	0.15	ok
	3,975	ok	0	ok	2674	ok	0.06	ok	0.15	ok
PC										
	3,975	ok	12,083	ok	2674	ok	0.33	ok	0.27	ok
	2,606	ok	12,083	ok	2143	ok	0.31	ok	0.19	ok
PT										
	2,606	ok	0	ok	2143	ok	0.04	ok	0.09	ok
Exit Point	0	ok	0	ok	-242	ok	0.00	ok	0.00	ok

Figure 3: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1437.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	151,756	lb			
Fluidic Drag = 12 π D L C_d =	48,762	lb			
Axial Segment Weight = W_e L sinθ =	71,093	lb			
Pulling Load on Exit Tangent =	**271,612**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	313,529	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	j = [(E I) / T]$^{1/2}$ =	1,086	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	5.1E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	274.54	
U = (12 L) / j =	2.78		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	115,128	lb
Bending Frictional Drag = 2 μ N =	69,077	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**83,836**	**lb**			
Total Pulling Load =	**355,447**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	169.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	18,081	lb			
Fluidic Drag = 12 π D L C_d =	5,753	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**23,834**	**lb**			
Total Pulling Load =	**379,281**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	377.0	ft	Average Tension, T =	425,360	lb
Segment Angle with Horizontal, θ =	12.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	6.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	9.86	ft	j = [(E I) / T]$^{1/2}$ =	933	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	1.8E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	671.94	
U = (12 L) / j =	4.85		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	155,622	lb
Bending Frictional Drag = 2 μ N =	93,373	lb			
Fluidic Drag = 12 π D L C_d =	12,791	lb			
Axial Segment Weight = W_e L sinθ =	-14,007	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**92,158**	**lb**			
Total Pulling Load =	**471,439**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	780.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	12.0	°			
Frictional Drag = W_e L μ cosθ =	81,394	lb			
Fluidic Drag = 12 π D L C_d =	26,477	lb			
Axial Segment Weight = W_e L sinθ =	-57,669	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**50,202**	**lb**			
Total Pulling Load =	**521,640**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	6,355	ok	0	ok	0	ok	0.10	ok	0.01	ok
	5,744	ok	0	ok	2457	ok	0.09	ok	0.14	ok
PC										
	5,744	ok	24,167	ok	2457	ok	0.62	ok	0.48	ok
	4,621	ok	24,167	ok	3052	ok	0.60	ok	0.54	ok
PT										
	4,621	ok	0	ok	3052	ok	0.07	ok	0.20	ok
	4,330	ok	0	ok	3052	ok	0.07	ok	0.19	ok
PC										
	4,330	ok	24,167	ok	3052	ok	0.60	ok	0.53	ok
	3,309	ok	24,167	ok	2787	ok	0.58	ok	0.47	ok
PT										
	3,309	ok	0	ok	2787	ok	0.05	ok	0.16	ok
Exit Point	0	ok	0	ok	-242	ok	0.00	ok	0.00	ok

Figure 4: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The proposed wetland crossing will be installed almost entirely through sedimentary bedrock. Since the Delft Method (discussed previously in Section 5) is only applicable to uncemented subsurface material, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

The estimated duration of construction is 73 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as JDH&A's past experience in similar subsurface conditions. Refer to Figure 5 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Wetland Crossing (MP 7.9R)
days/week =	7.0	
Drilled Length, feet =	2,959	
Pilot Hole		
Production Rate, feet/hour =	20	
shifts/day =	1	
Drilling Duration, hours =	148.0	
shifts =	12.3	
Trips to change tools, shifts =	1.0	
Pilot Hole Duration, days =	13.3	

Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	200.4	200.4	200.4			9.3	11.4	622.1
shifts =	16.7	16.7	16.7			0.8	1.0	51.8
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	18.2	18.2	18.2			1.3	1.5	57.3

Summary				
HDD Duration at Site, days =	72.7			
Site Establishment	**Move in**	**Rig Up**	**Rig Down**	**Move Out**
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 5: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-31

HORIZONTAL LENGTH = 2,931'
TRUE LENGTH = 2,959'

PLAN

SCALE: 1" = 200'

EXIT POINT @ 8°
29+30.81, 1279.18
N 14815990.51, E 1629787.83

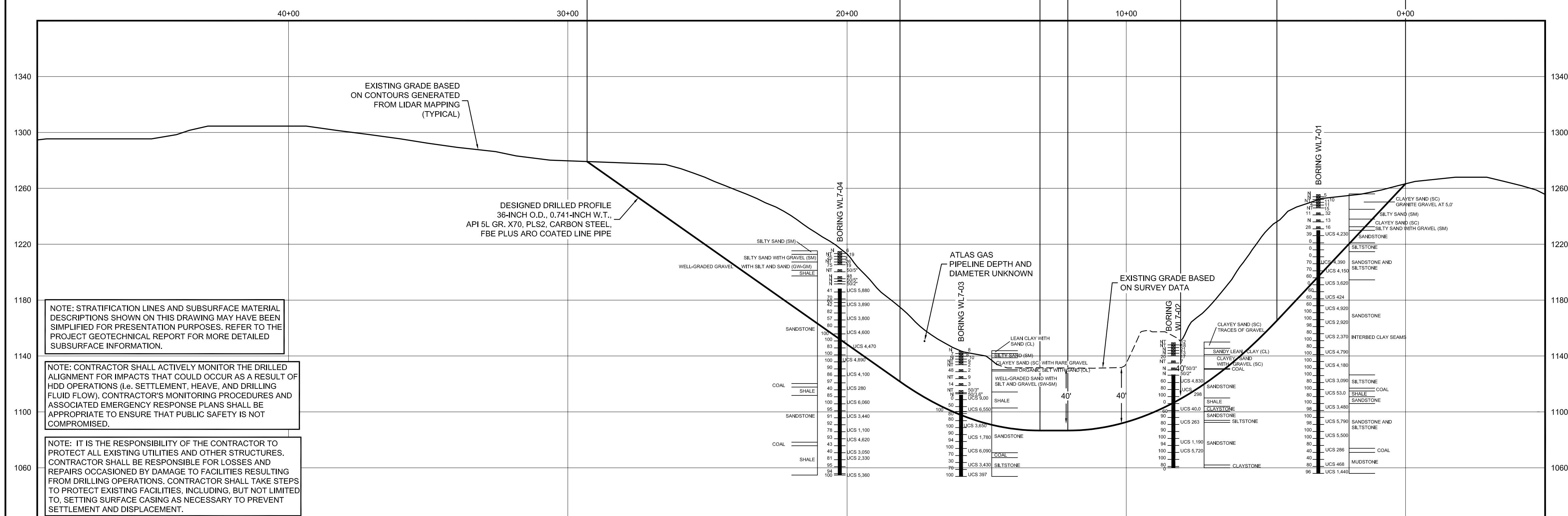
P.T. 8° SAG BEND
18+10.16, 1121.69

P.C. 8° SAG BEND
13+09.13, 1086.65
RADIUS = 3,600'

P.T. 12° SAG BEND
12+09.13, 1086.65

P.C. 12° SAG BEND
4+60.65, 1165.32
RADIUS = 3,600'

ENTRY POINT @ 12°
0+00.00, 1263.23
N 14814525.98, E 1632326.49



NOTE: STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING MAY HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES. REFER TO THE PROJECT GEOTECHNICAL REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.

NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

PROFILE

SCALE: 1" = 200' HORIZONTAL
1" = 40' VERTICAL

500 400 300 200 100 0

ALIGNMENT LEGEND

PIPELINE MILEPOST
PIPELINE
INTERCONNECTING PIPELINE
CONSTRUCTION LIMIT
STUDY CORRIDOR
STAGING AREA
WAREYARD
PERMANENT ROW
ADDITIONAL TEMPORARY WORKSPACE
METERING & REGULATION STATION (M&R)
COMPRESSOR STATION SITE
FACILITIES TEMPORARY WORKSPACE
FACILITIES PERMANENT WORKSPACE
DELINEATED WETLAND BOUNDARY
DELINEATED WATERBODY BANK
DELINEATED WATERBODY CENTERLINE
APPROXIMATE WETLAND BOUNDARY
APPROXIMATE WATERBODY BANK
APPROXIMATE WATERBODY CENTERLINE
PERMANENT ACCESS ROAD
TEMPORARY ACCESS ROAD
PARCEL TRACT NO
PROPERTY LINE
CONTOUR
MUNICIPALITY LINE
FENCE
FOREIGN PIPELINE
POWERLINE
WATER PIPELINE
RAILROAD TRACK
TELEPHONE
TEE TAP
UTILITY LINES
BLOW OFF VALVE
MAINLINE VALVE (MLV)
TOWER
MICROWAVE TOWER
HORIZONTAL DIRECTIONAL DRILLING
TANK
LIGHT POLE
FIRE HYDRANT
WELL: GAS WATER OIL UNKNOWN

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

Ⓑ BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
TSS 1,350 — TENSILE SPLITTING STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA/CENTERLINE AND REVISE ENTRY POINT LOCATION
HANO-A-1010	ALIGNMENT SHEET M.P. 7.97 TO M.P. 8.91	1	LKB	JMS	ISSUED FOR BID
HANO-A-1009	ALIGNMENT SHEET M.P. 7.02 TO M.P. 7.97	0	LKB	ACM	ISSUED FOR FERC

IG.#

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS

TITLE	PRELIMINARY SIGNATURE	PRELIMINARY DATE	CONSTRUCTION SIGNATURE	CONSTRUCTION DATE
DRAWN BY:	ACM	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	ACM	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH WETLAND CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

COLUMBIANA COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 7.9R	W.O.	SCALE: AS SHOWN	DWG. HANO-H-1001	REV. 3

MP 41.0R Nimisila Reservoir

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Nimisila Reservoir Crossing is located near the intersection of East Comet Road and Christman Road, just south of Akron, Ohio. The primary obstacles that will be crossed are Christman Road, an existing overhead powerline right of way, and the Nimisila Reservoir. The reservoir is approximately 700 feet wide, and based on hydrographic survey points, roughly 5 feet deep. The proposed HDD alignment crosses an existing overhead power corridor at an approximate 45-degree angle. Both ends of the crossing are within agricultural land. Residential homes exist directly to the north and southeast of the exit point with the nearest home being roughly 370 feet away. The topography in the area is gently rolling with a mixture of farm land and mature timber. Refer to Figure 1 for a general overview of the vicinity of the crossing.

Figure 1: Overview of the Nimisila Reservoir Crossing

Subsurface Conditions

At the time of this writing, site-specific subsurface information is not yet available.

Design Geometry & Layout

The proposed Nimisila Reservoir HDD design involves a horizontal length of 1,776 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature of 3,600 feet. The crossing design maintains 20 feet of cover beneath the slope on the west side of the reservoir, 53 feet of cover beneath Christman Road, 53 feet beneath the Reservoir, and 40 feet beneath the edge of wetland on the east side of the crossing.

The entry point is located on the east side of Christman Road in an open farm field. The exit point is located on the west side of the crossing, also within an open but slightly smaller farm field. An elevation difference of roughly 17 feet exists between the entry and exit points with the entry site existing at the lower elevation.

The proposed HDD design, as well as available workspace for HDD operations, is shown on the preliminary HDD plan and profile drawing included in this site-specific report.

Assessment of Feasibility

Overall, given the length and diameter of the proposed installation, it is within the range of what has been successfully completed using HDD in the past. However, the feasibility will need to be confirmed when site-specific geotechnical data is available.

Risk Identification and Assessment

Potential construction impact resulting from HDD operations include damage to Christman Road in the form of heaving or settlement, drilling fluid surfacing within the reservoir, or drilling fluid surfacing near the entry or exit point due to shallow cover within loose agricultural soil.

Based on the length of the proposed Nimisila Reservoir crossing, it is considered to have a low level of risk. However, risk should be re-evaluated after site-specific geotechnical information is available.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 311,607 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 338,943 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 2. Detailed calculations for each loading scenario are summarized in Figures 3 and 4.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 2: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in
Pipe Weight, W =	279.0	lb/ft
Coefficient of Soil Friction, μ =	0.30	
Fluid Drag Coefficient, C_d =	0.025	psi
Ballast Weight / ft Pipe, W_b =	405.5	lb (If Ballasted)
Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb (If Submerged)
Above Ground Load =	0	lb

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	323.4	ft
Exit Angle, θ =	8.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ cosθ =	34,154	lb
Fluidic Drag = 12 π D L C_d =	10,974	lb
Axial Segment Weight = W_e L sinθ =	16,000	lb
Pulling Load on Exit Tangent =	**61,129**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft
Segment Angle with Horizontal, θ =	-8.0	°
Deflection Angle, α =	-4.0	°
Average Tension, T =	114,139	lb
Radius of Curvature, R =	3,600	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft
j = [(E I) / T]$^{1/2}$ =	1,800	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	2.5E+06	
X = (3 L) - [(j / 2) tanh(U/2)] =	668.84	
U = (12 L) / j =	3.35	
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	127,506	lb
Bending Frictional Drag = 2 μ N =	76,504	lb
Fluidic Drag = 12 π D L C_d =	17,055	lb
Axial Segment Weight = W_e L sinθ =	12,463	lb
Pulling Load on Exit Sag Bend =	**106,021**	**lb**
Total Pulling Load =	**167,150**	**lb**

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	280.3	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	29,890	lb
Fluidic Drag = 12 π D L C_d =	9,511	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**39,401**	**lb**
Total Pulling Load =	**206,551**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft
Segment Angle with Horizontal, θ =	10.0	°
Deflection Angle, α =	5.0	°
Average Tension, T =	257,147	lb
Radius of Curvature, R =	3,600	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	13.70	ft
j = [(E I) / T]$^{1/2}$ =	1,199	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	5.8E+06	
X = (3 L) - [(j / 2) tanh(U/2)] =	1287.50	
U = (12 L) / j =	6.29	
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	165,565	lb
Bending Frictional Drag = 2 μ N =	99,339	lb
Fluidic Drag = 12 π D L C_d =	21,318	lb
Axial Segment Weight = W_e L sinθ =	-19,464	lb
Pulling Load on Entry Sag Bend =	**101,193**	**lb**
Total Pulling Load =	**307,744**	**lb**

Negative value indicates axial weight applied in direction of installation

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	50.0	ft
Entry Angle, θ =	10.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ cosθ =	5,254	lb
Fluidic Drag = 12 π D L C_d =	1,698	lb
Axial Segment Weight = W_e L sinθ =	-3,088	lb
Pulling Load on Entry Tangent =	**3,863**	**lb**
Total Pulling Load =	**311,607**	**lb**

Negative value indicates axial weight applied in direction of installation

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,796	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,749	ok	0	ok	132	ok	0.06	ok	0.01	ok
PC										
	3,749	ok	12,083	ok	132	ok	0.32	ok	0.08	ok
	2,516	ok	12,083	ok	960	ok	0.30	ok	0.10	ok
PT										
	2,516	ok	0	ok	960	ok	0.04	ok	0.02	ok
	2,036	ok	0	ok	960	ok	0.03	ok	0.02	ok
PC										
	2,036	ok	12,083	ok	960	ok	0.30	ok	0.10	ok
	745	ok	12,083	ok	429	ok	0.28	ok	0.06	ok
PT										
	745	ok	0	ok	429	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	-252	ok	0.00	ok	0.00	ok

Figure 3: Installation Loading and Stress Analysis (As-Designed Scenario)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in
Pipe Weight, W =	279.0	lb/ft
Coefficient of Soil Friction, μ =	0.30	
Fluid Drag Coefficient, C_d =	0.025	psi
Ballast Weight / ft Pipe, W_b =	405.5	lb (If Ballasted)
Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb (If Submerged)
Above Ground Load =	0	lb

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	628.9	ft
Exit Angle, θ =	8.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ cosθ =	66,413	lb
Fluidic Drag = 12 π D L C_d =	21,340	lb
Axial Segment Weight = W_e L sinθ =	31,113	lb
Pulling Load on Exit Tangent =	**118,866**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft
Segment Angle with Horizontal, θ =	-8.0	°
Deflection Angle, α =	-4.0	°
Average Tension, T =	156,994	lb
Radius of Curvature, R =	1,800	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft
j = [(E I) / T]$^{1/2}$ =	1,535	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	3.3E+05	
X = (3 L) - [(j / 2) tanh(U/2)] =	175.22	
U = (12 L) / j =	1.96	
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	102,498	lb
Bending Frictional Drag = 2 μ N =	61,499	lb
Fluidic Drag = 12 π D L C_d =	8,527	lb
Axial Segment Weight = W_e L sinθ =	6,231	lb
Pulling Load on Exit Sag Bend =	**76,258**	**lb**
Total Pulling Load =	**195,123**	**lb**

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	294.0	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	31,351	lb
Fluidic Drag = 12 π D L C_d =	9,976	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**41,327**	**lb**
Total Pulling Load =	**236,450**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft
Segment Angle with Horizontal, θ =	10.0	°
Deflection Angle, α =	5.0	°
Average Tension, T =	274,126	lb
Radius of Curvature, R =	1,800	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft
j = [(E I) / T]$^{1/2}$ =	1,162	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	9.4E+05	
X = (3 L) - [(j / 2) tanh(U/2)] =	405.22	
U = (12 L) / j =	3.25	
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	124,041	lb
Bending Frictional Drag = 2 μ N =	74,424	lb
Fluidic Drag = 12 π D L C_d =	10,659	lb
Axial Segment Weight = W_e L sinθ =	-9,732	lb
Pulling Load on Entry Sag Bend =	**75,351**	**lb**
Total Pulling Load =	**311,802**	**lb**

Negative value indicates axial weight applied in direction of installation

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	351.5	ft
Entry Angle, θ =	10.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ cosθ =	36,910	lb
Fluidic Drag = 12 π D L C_d =	11,925	lb
Axial Segment Weight = W_e L sinθ =	-21,694	lb
Pulling Load on Entry Tangent =	**27,141**	**lb**
Total Pulling Load =	**338,943**	**lb**

Negative value indicates axial weight applied in direction of installation

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,129	ok	0	ok	0	ok	0.07	ok	0.01	ok
	3,799	ok	0	ok	924	ok	0.06	ok	0.02	ok
PC										
	3,799	ok	24,167	ok	924	ok	0.59	ok	0.30	ok
	2,881	ok	24,167	ok	1338	ok	0.58	ok	0.31	ok
PT										
	2,881	ok	0	ok	1338	ok	0.05	ok	0.04	ok
	2,377	ok	0	ok	1338	ok	0.04	ok	0.04	ok
PC										
	2,377	ok	24,167	ok	1338	ok	0.57	ok	0.30	ok
	1,448	ok	24,167	ok	1073	ok	0.55	ok	0.26	ok
PT										
	1,448	ok	0	ok	1073	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	-252	ok	0.00	ok	0.00	ok

Figure 4: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

At the time of this writing, site-specific geotechnical data is not available. Therefore, a hydrofracture evaluation could not be completed.

Construction Duration

The estimated duration of construction is 16 days based on assumed subsurface conditions consisting of silt, sand, and clay. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as JDH&A's past experience in similar subsurface conditions. Refer to Figure 5 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Nimisila Reservoir Crossing. Subsurface assumed to consist of silt/sand/clay.
days/week =	7.0	
Drilled Length, feet =	1,785	
Pilot Hole		
Production Rate, feet/hour =	50	
shifts/day =	1	
Drilling Duration, hours =	35.7	
shifts =	3.0	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	3.5	

Ream and Pull Back								
Pass Description =	36-inch	48-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	1.0	1.0				8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0				15.0	15.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	31.7	31.7				5.6	6.9	75.9
shifts =	2.6	2.6				0.5	0.6	6.3
Rig up, shifts =	0.5	0.5				0.5	0.5	2.0
Trips to change tools, shifts =	1.0	1.0				0.0		2.0
Pass Duration, days =	4.1	4.1				1.0	1.1	10.3

Summary	
HDD Duration at Site, days =	15.8

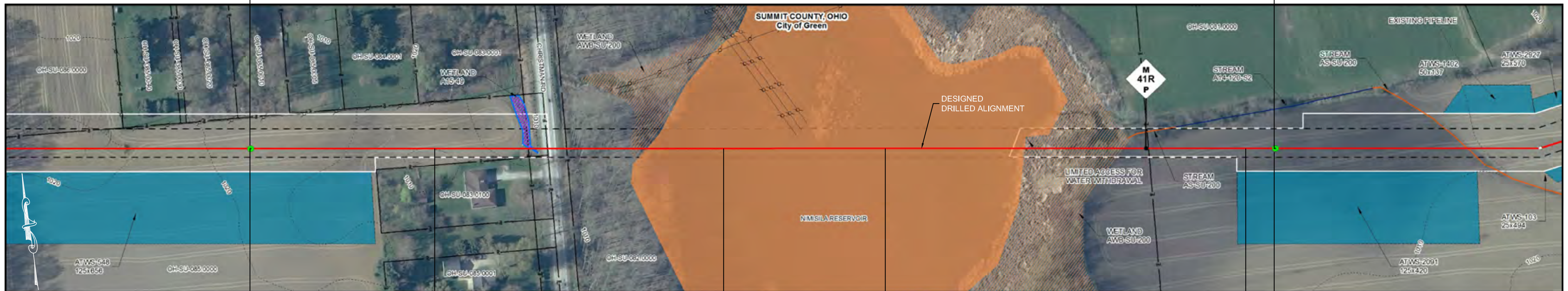
Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 5: Estimated Construction Duration

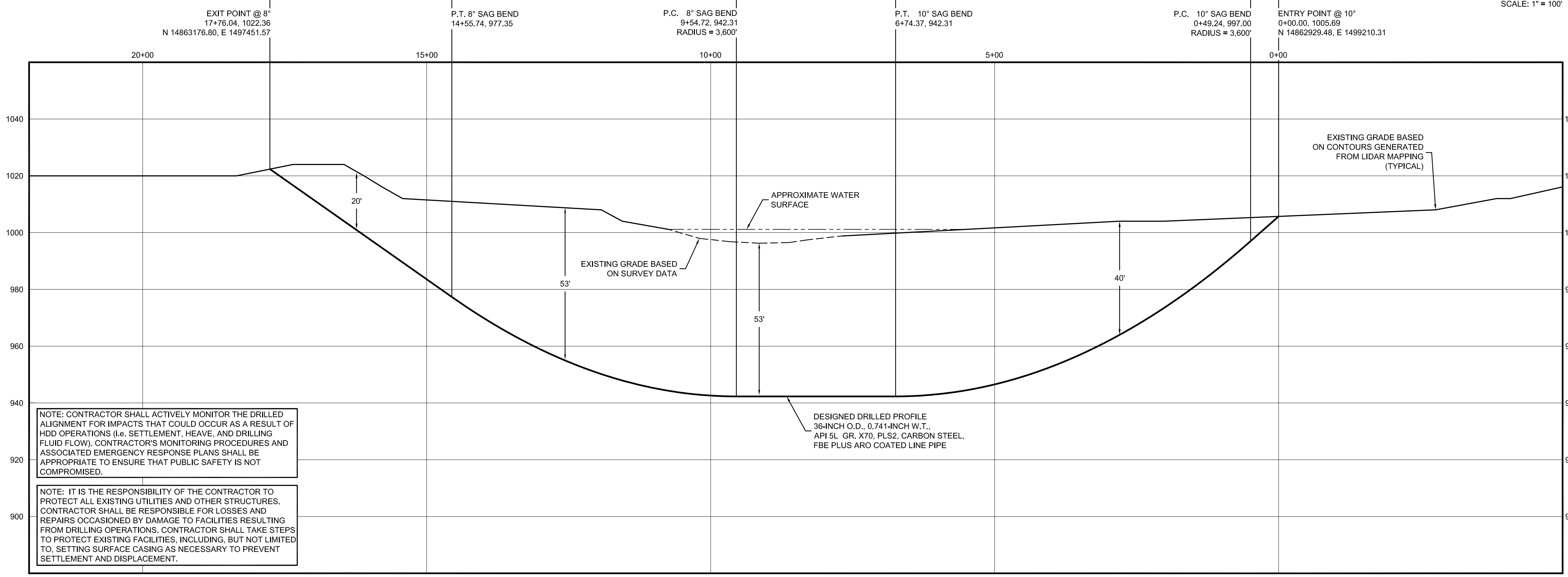
1 *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-39

HORIZONTAL LENGTH = 1,776'
TRUE LENGTH = 1,785'



PLAN
SCALE: 1" = 100'



NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

PROFILE
SCALE: 1" = 100' HORIZONTAL
1" = 20' VERTICAL

ALIGNMENT LEGEND

PIPELINE MILEPOST, PIPELINE, INTERCONNECTING PIPELINE, CONSTRUCTION LIMIT, STUDY CORRIDOR, STAGING AREA, WAREYARD, PERMANENT ROW, ADDITIONAL TEMPORARY WORKSPACE, METERING & REGULATION STATION (M&R), COMPRESSOR STATION SITE, FACILITIES TEMPORARY WORKSPACE, FACILITIES PERMANENT WORKSPACE

DELINEATED WETLAND BOUNDARY, DELINEATED WATERBODY BANK, DELINEATED WATERBODY CENTERLINE, APPROXIMATE WETLAND BOUNDARY, APPROXIMATE WATERBODY BANK, APPROXIMATE WATERBODY CENTERLINE, PERMANENT ACCESS ROAD, TEMPORARY ACCESS ROAD, PARCEL TRACT NO, PROPERTY LINE, CONTOUR, MUNICIPALITY LINE

FENCE, FOREIGN PIPELINE, POWERLINE, WATER PIPELINE, RAILROAD TRACK, TELEPHONE, TEE TAP, UTILITY LINES, BLOW OFF VALVE, MAINLINE VALVE (MLV), TOWER, MICROWAVE TOWER, HORIZONTAL DIRECTIONAL DRILLING, TANK, LIGHT POLE, FIRE HYDRANT, WELL: GAS, WATER, OIL, UNKNOWN

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA AND UPDATE WORKSPACE/CENTERLINE
		1	LKB	JMS	ISSUED FOR BID
HANO-A-1048	ALIGNMENT SHEET M.P. 40.41 TO M.P. 41.36	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	LKB	01/11		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB	01/11		
DESIGN CHECKER	JMS	01/12		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH NIMISILA RESERVOIR CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

SUMMIT COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 41.0R | W.O. | SCALE: AS SHOWN | DWG. HANO-H-1002 | REV. 3

MP 47.8R Tuscarawas River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical and Geophysical Data Report, Tuscarawas River HDD Crossing, Nexus Gas Transmission Project, Summit County, Ohio" and dated October 30, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Tuscarawas River Crossing is located near pipeline Mile Post 48, south of Barberton, Ohio. It involves passing beneath the Tuscarawas River, a railroad, and Van Buren Road. The Tuscarawas River is approximately 80 feet from bank to bank at the crossing location, and less than 2 feet deep at the deepest point. The proposed HDD alignment runs parallel to an existing power line corridor. The topography on each side of the crossing slopes moderately steeply toward the river. The elevation change east of Van Buren Road is approximately 155 feet. The land on each side of the river consists of a mixture of wooded patches and agricultural land. An overview of the proposed crossing location is provided in Figure 1 through Figure 3.

Figure 1: Overview of the Tuscarawas River Crossing

Figure 2: View west along proposed HDD alignment from Van Buren Road

Figure 3: View east from Van Buren Road. Topography extends upwards toward the proposed entry point

Subsurface Conditions

Three geotechnical borings were taken on the east side of the river as part of the geotechnical exploration program conducted by Fugro Consultants, Inc. Two of the borings, TUS-01 and TUS-02, were taken between Van Buren Road and the east edge of Tuscarawas River, and one of the borings, TUS-06, was taken near the proposed HDD entry point approximately 1,000 feet east of Van Buren Road. TUS-01 encountered mixtures of sand with silt, lean clay, and sandy lean clay, sand, and occasional gravel to the termination depth of 76 feet below grade. The second boring, TUS-02, taken near the bank of the river, encountered relatively sandy lean clay, sand, and silt until 20 feet below ground surface, followed by sandstone and siltstone bedrock to the termination of 100 feet. Rock quality designation (RQD) index values indicate good to excellent quality bedrock overall. Results for unconfined compressive strength (UCS) average 8,189 psi. Boring TUS-06 encountered clayey sand to a depth of 14 feet, followed by residual shale to a depth of 34 feet, interbedded siltstone, sandstone, and shale to a depth of 52 feet, and sandstone to the boring termination depth of 101 feet. RQD index values ranged from 23 to 95, with an average of 65 indicating fair quality bedrock. UCS test values ranged from 1,150 psi to 7,990 psi.

Geophysical methods were used in an attempt to characterize the bedrock surface between borings TUS-1 and TUS-2. Results of the seismic refraction study indicate the bedrock surface may dip to the east from boring TUS-2, falling from elevation 930 feet to 855 feet over a horizontal distance of 450 feet. From that point, the bedrock surface looks to be trending upwards toward boring TUS-1. The bedrock is estimated to fall somewhere in the range of elevation 860 feet and elevation 875 feet at the location of boring TUS-1.

Refer to the geotechnical data report prepared by Fugro Consultants, Inc. titled “Geotechnical and Geophysical Data Report, Tuscarawas River HDD Crossing, Nexus Gas Transmission Project, Summit County, Ohio” and dated October 30, 2015 for detailed information relative to the subsurface conditions.

Design Geometry & Layout

The proposed Tuscarawas River HDD design has a horizontal length of 3,263 feet. It utilizes a 16-degree entry angle, an 8-degree exit angle, and a design radius of curvature of 3,600 feet. The design maintains a minimum of 40 feet of cover at the west edge of the Tuscarawas River, 46 feet of cover beneath the railroad tracks, 66 feet beneath Van Buren Road, and approximately 42 feet of cover beneath the bottom of the hillside on the east side of the river. Due to a pipeline alignment point of intersection (P.I.) on the east side of the crossing, the entry point location was limited in how far east it could be located. Therefore, in order to maintain suitable cover along the hillside, a 16-degree entry angle was necessary.

An alternate entry point located at the bottom of the slope just east of Van Buren road was investigated during the initial design stages. However, the location was seen an unfavorable due to the inability to gain sufficient cover beneath Van Buren Road (less than 20 feet), as well as the large elevation differential between the entry and exit points (107 feet). A large elevation differential would result in drilling fluid flowing to the low side, leaving much of the reamed hole on the west side unsupported with drilling fluid, increasing the risk of sinkholes and HDD operational problems

Due to workspace considerations, the exit point is located on the west side of the crossing, which provides the better option for pull section fabrication across relatively open fields. The entry point on the east side is approximately 48 feet higher topographically. Some HDD contractors may elect to drill the pilot hole and ream from the exit (low) side since there are benefits with respect to drilling fluid flow and fluid handling, and then move the HDD rig spread over to west side for pullback.

A copy of the HDD design plan and profile drawing for crossing the Tuscarawas River is attached to this report for reference.

Assessment of Feasibility

Although the feasibility of the proposed crossing of the Tuscarawas cannot be ruled out, uncertainties with respect to subsurface conditions make it difficult to assess with any certainty. Based on the three site-specific geotechnical borings as well as geophysical studies, the bedrock surface is variable along the HDD alignment. Boring TUS-02, taken closes to the river, encountered bedrock at only 20 feet below the surface, whereas the other boring, TUS-01, taken roughly 800 feet to the east of TUS-02, was drilled to 77 feet and did not encounter bedrock. Boring TUS-06, taken approximately 1,200 feet east of TUS-01 near the proposed entry point, encountered bedrock at a depth of 14 feet.

Ideally, since borings TUS-02 and TUS-06 encountered bedrock at shallow depths, thus making it impossible to avoid bedrock, the HDD crossing should be designed to stay within bedrock over the majority of the length of the crossing. This minimizes the risk of HDD operational problems associated with passing in and out of bedrock, or skimming across the top of the bedrock surface. The current HDD design may present a challenging installation since because the bedrock surface is highly variable, it may involve drilling out of bedrock and into overburden, and then back into bedrock. This may result in downhole tooling or the product pipe getting lodged as it moves through the soil/bedrock interface.

Risk Identification and Assessment

Potential construction impacts resulting from installation by HDD are damage to Van Buren Road and the railroad due to heaving or settlement, as well as drilling fluid surfacing within the river channel. The risk of inadvertent drilling fluid returns is increased due to the topographic nature of the site and the relative pressure head associated with the depth of the HDD segment in relation to its entry and exit points.

The overall risk associated with installation by HDD is questionable due to uncertainties with respect to the bedrock surface. At a minimum, there is risk of briefly drilling out of bedrock and then, after a few hundred feet, drilling back into bedrock. Moving in and out of bedrock can result in numerous HDD operational problems.

Additional geotechnical data is necessary to better define the location of the bedrock surface so that the HDD design can be optimized and the level of risk better assessed.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 530,744 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 560,400 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 3. Detailed calculations for each scenario are summarized in Figures 4 and 5.

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	
HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1330.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	140,520	lb			
Fluidic Drag = 12 π D L C_d =	45,151	lb			
Axial Segment Weight = W_e L sinθ =	65,829	lb			
Pulling Load on Exit Tangent =	**251,501**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	308,517	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	j = [(E I) / T]$^{1/2}$ =	1,095	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	3.5E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	964.90	
U = (12 L) / j =	5.51		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	140,857	lb
Bending Frictional Drag = 2 μ N =	84,514	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**114,032**	**lb**			
Total Pulling Load =	**365,533**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	6	lb			
Fluidic Drag = 12 π D L C_d =	2	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**8**	**lb**			
Total Pulling Load =	**365,541**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	1005.3	ft	Average Tension, T =	439,102	lb	
Segment Angle with Horizontal, θ =	16.0	°	Radius of Curvature, R =	3,600	ft	
Deflection Angle, α =	8.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft	
h = R [1 - cos(α/2)] =	35.03	ft	j = [(E I) / T]$^{1/2}$ =	918		
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	1.7E+07		X = (3 L) - [(j / 2) tanh(U/2)] =	2557.02		
U = (12 L) / j =	13.14		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	271,238	lb	
Bending Frictional Drag = 2 μ N =	162,743	lb				
Fluidic Drag = 12 π D L C_d =	34,109	lb				
Axial Segment Weight = W_e L sinθ =	-49,730	lb	Negative value indicates axial weight applied in direction of installation			
Pulling Load on Entry Sag Bend =	**147,122**	**lb**				
Total Pulling Load =	**512,663**	**lb**				

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	470.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	16.0	°			
Frictional Drag = W_e L μ cosθ =	48,191	lb			
Fluidic Drag = 12 π D L C_d =	15,952	lb			
Axial Segment Weight = W_e L sinθ =	-46,062	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**18,081**	**lb**			
Total Pulling Load =	**530,744**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	6,466	ok	0	ok	0	ok	0.10	ok	0.01	ok
	6,246	ok	0	ok	1223	ok	0.10	ok	0.05	ok
PC										
	6,246	ok	12,083	ok	1223	ok	0.36	ok	0.16	ok
	4,453	ok	12,083	ok	3335	ok	0.34	ok	0.36	ok
PT										
	4,453	ok	0	ok	3335	ok	0.07	ok	0.23	ok
	4,453	ok	0	ok	3335	ok	0.07	ok	0.23	ok
PC										
	4,453	ok	12,083	ok	3335	ok	0.34	ok	0.36	ok
	3,064	ok	12,083	ok	2804	ok	0.31	ok	0.27	ok
PT										
	3,064	ok	0	ok	2804	ok	0.05	ok	0.16	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb (If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb (If Submerged)
			Above Ground Load =	0	lb

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1636.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	172,779	lb			
Fluidic Drag = 12 π D L C_d =	55,517	lb			
Axial Segment Weight = W_e L sinθ =	80,942	lb			
Pulling Load on Exit Tangent =	**309,238**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	352,086	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	$j = [(E I) / T]^{1/2}$ =	1,025	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	5.4E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	292.84	
U = (12 L) / j =	2.94		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	118,228	lb
Bending Frictional Drag = 2 μ N =	70,937	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**85,696**	**lb**			
Total Pulling Load =	**394,934**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	163.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	17,470	lb			
Fluidic Drag = 12 π D L C_d =	5,559	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**23,028**	**lb**			
Total Pulling Load =	**417,962**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	473,532	lb
Segment Angle with Horizontal, θ =	16.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	8.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	17.52	ft	$j = [(E I) / T]^{1/2}$ =	884	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.8E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1067.01	
U = (12 L) / j =	6.82		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	198,251	lb
Bending Frictional Drag = 2 μ N =	118,951	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	-24,865	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**111,140**	**lb**			
Total Pulling Load =	**529,102**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	813.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	16.0	°			
Frictional Drag = W_e L μ cosθ =	83,418	lb			
Fluidic Drag = 12 π D L C_d =	27,612	lb			
Axial Segment Weight = W_e L sinθ =	-79,733	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**31,298**	**lb**			
Total Pulling Load =	**560,400**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	6,827	ok	0	ok	0	ok	0.11	ok	0.01	ok
	6,446	ok	0	ok	2658	ok	0.10	ok	0.16	ok
PC										
	6,446	ok	24,167	ok	2658	ok	0.63	ok	0.53	ok
	5,092	ok	24,167	ok	3713	ok	0.61	ok	0.66	ok
PT										
	5,092	ok	0	ok	3713	ok	0.08	ok	0.29	ok
	4,812	ok	0	ok	3713	ok	0.08	ok	0.28	ok
PC										
	4,812	ok	24,167	ok	3713	ok	0.61	ok	0.65	ok
	3,768	ok	24,167	ok	3448	ok	0.59	ok	0.58	ok
PT										
	3,768	ok	0	ok	3448	ok	0.06	ok	0.24	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

Based on subsurface information available to date, the Tuscarawas River crossing will likely involve passing through bedrock over the portion of the crossing beneath the river that is of interest. Since the Delft Equation (Discussed previously in Section 5 of this report) is only applicable to uncemented subsurface material, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

The estimated duration of construction for the Tuscarawas River Crossing, assuming it is installed entirely through bedrock, is 88 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 7 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Tuscarawas Crossing
days/week =	7.0	
Drilled Length, feet =	3,309	
Pilot Hole		
Production Rate, feet/hour =	15	
shifts/day =	1	
Drilling Duration, hours =	220.6	
shifts =	18.4	
Trips to change tools, shifts =	1.0	
Pilot Hole Duration, days =	19.4	

Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	224.2	224.2	224.2			10.5	12.7	695.7
shifts =	18.7	18.7	18.7			0.9	1.1	58.0
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	2.0	2.0	2.0			0.0		6.0
Pass Duration, days =	21.2	21.2	21.2			1.4	1.6	66.5

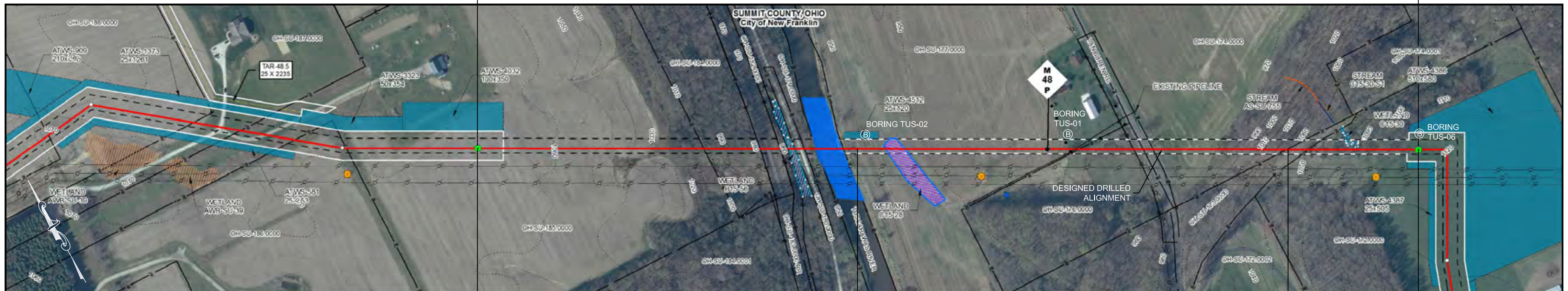
Summary				
HDD Duration at Site, days =	87.9			
Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-49

HORIZONTAL PLAN LENGTH = 3,263'
TRUE LENGTH = 3,309'



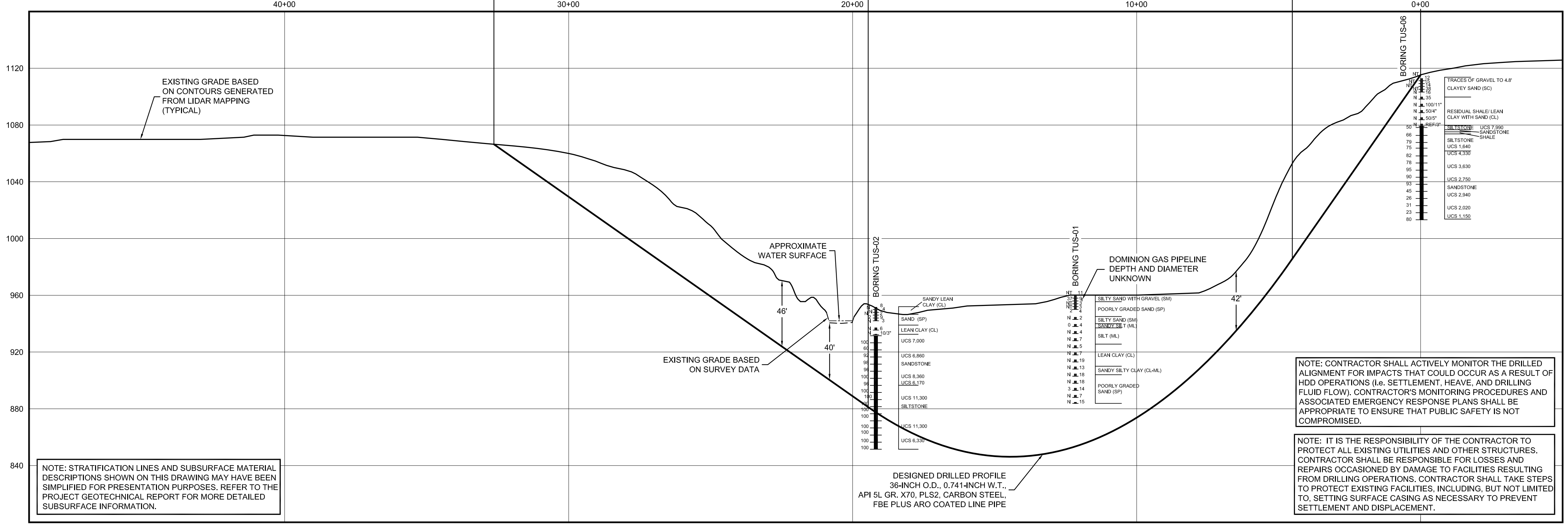
PLAN
SCALE: 1" = 200'

EXIT POINT @ 8°
32+63.12, 1066.45
N 14879218.12, E 1471002.64

P.T. 24° SAG BEND
19+45.27, 881.24

P.C. 24° SAG BEND
4+51.96, 985.66
RADIUS = 3,600'

ENTRY POINT @ 16°
0+00.00, 1115.26
N 14877609.45, E 1473841.67



NOTE: STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING MAY HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES. REFER TO THE PROJECT GEOTECHNICAL REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.

NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

PROFILE
SCALE: 1" = 200' HORIZONTAL
1" = 40' VERTICAL

500 400 300 200 100 0
40 20 0

ALIGNMENT LEGEND

PIPELINE MILEPOST
PIPELINE
INTERCONNECTING PIPELINE
CONSTRUCTION LIMIT
STUDY CORRIDOR
STAGING AREA
WAREYARD
PERMANENT ROW
ADDITIONAL TEMPORARY WORKSPACE
METERING & REGULATION STATION (M&R)
COMPRESSOR STATION SITE
FACILITIES TEMPORARY WORKSPACE
FACILITIES PERMANENT WORKSPACE
DELINEATED WETLAND BOUNDARY
DELINEATED WATERBODY BANK
DELINEATED WATERBODY CENTERLINE
APPROXIMATE WETLAND BOUNDARY
APPROXIMATE WATERBODY BANK
APPROXIMATE WATERBODY CENTERLINE
PERMANENT ACCESS ROAD — PAR-0.0
TEMPORARY ACCESS ROAD — TAR-0.0
PARCEL TRACT NO — OH-CO-011.0000-SC
PROPERTY LINE
CONTOUR
MUNICIPALITY LINE
FENCE
FOREIGN PIPELINE
POWERLINE
WATER PIPELINE
RAILROAD TRACK
TELEPHONE
TEE TAP — UTILITY LINES
BLOW OFF VALVE — MAINLINE VALVE (MLV)
TOWER — MICROWAVE TOWER
HORIZONTAL DIRECTIONAL DRILLING
TANK — LIGHT POLE — FIRE HYDRANT
WELL: GAS — WATER — OIL — UNKNOWN

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 — 23: PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES; PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
6 — MOHS HARDNESS
53 — ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC. BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED OCTOBER 30, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA AND UPDATE CENTERLINE
HANO-A-1056	ALIGNMENT SHEET M.P. 47.99 TO M.P. 48.93	1	LKB	JMS	ISSUED FOR BID
HANO-A-1055	ALIGNMENT SHEET M.P. 47.04 TO M.P. 47.99	0	LKB	AM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	KMN	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	KMN	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH TUSCARAWAS RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

SUMMIT COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 47.8R | W.O. | SCALE: AS SHOWN | DWG. HANO-H-1003 | REV. 3

MP 71.1 Wetland

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Wetland No. 68 HDD Crossing, Nexus Gas Transmission Project, Medina County, Ohio" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The proposed 36-inch category 3 wetland crossing at approximate pipeline Mile Post 71.1 is located about 4 miles south of Medina, Ohio near the intersection of Wedgewood Road and Lafayette Road. The crossing involves passing beneath a wooded wetland that is approximately 900 feet wide. Both sides of the crossing are open farm fields. The south side of the crossing is bound to the south by Wedgewood Road and to the north by Chippewa Inlet Trail. The topography in the area is flat. Figure 1 provides a general overview of the vicinity of the crossing. Figures 2 and 3 provide site photos showing the general vicinity of the entry and exit locations.

Figure 1: Overview of the Wetland Crossing at MP 71.1

Figure 2: View looking toward exit location

Figure 3: View toward entry location from Wedgewood Road

Subsurface Conditions

Two site-specific geotechnical borings were taken as part of the site investigation conducted by Fugro Consultants, Inc. One boring (WL68-02) was taken on the north side of the crossing near the tree line and the second (WL68-01) was taken on the south side of the crossing near the tree line. Both terminated at a depth of 100 feet below the ground surface. Boring WL68-02 encountered primarily sand and lean clay, with occasional gravel. Where encountered, gravel content ranged from 32% to 36% at depths of approximately 44 feet and 94 feet in boring WL68-01. Boring WL68-02 encountered similar soils. Where encountered, gravel content ranged from 3% to 18%.

Refer to the geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Wetland No. 68 HDD Crossing, Nexus Gas Transmission Project, Medina County, Ohio" and dated September 11, 2015 for additional information.

Design Geometry & Layout

The proposed wetland crossing involves a horizontal length of 1,784 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature of 3,600 feet. The crossing design maintains 40 feet of cover at the south edge of the wetland, 56 feet of cover at the north edge of the wetland, and just under 30 feet of cover beneath the small drainage ditch on the north side of the wetland.

The exit point is located on the north side of the crossing to take advantage of available workspace for pull section fabrication, which will allow the pull section to be fabricated in a single segment, and thus avoid the risk of getting stuck during downtime associated with a tie-in weld. The entry point is located in an open field south of Wedgewood Road.

The proposed HDD design, as well as available workspace, is shown on the preliminary plan and profile drawing included at the end of this site-specific report.

Assessment of Feasibility

Given the relatively short length of the crossing, as well as the anticipated subsurface conditions consisting of mixtures of sand and lean clay with minor gravel, the proposed wetland crossing is feasible and should be a straightforward installation.

Risk Identification and Assessment

Potential construction impacts that may result from installation by HDD include inadvertent drilling fluid returns surfacing within the wetland. Provided subsurface conditions across the site are consistent with those encountered in the site-specific geotechnical borings, the overall risk of HDD operational problems is considered low.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 308,072 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 335,211 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each loading scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	222.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	23,489	lb			
Fluidic Drag = 12 π D L C_d =	7,547	lb			
Axial Segment Weight = W_e L sinθ =	11,004	lb			
Pulling Load on Exit Tangent =	**42,041**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	94,657	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	$j = [(E I) / T]^{1/2}$ =	1,977	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.3E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	608.83	
U = (12 L) / j =	3.05		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	126,193	lb
Bending Frictional Drag = 2 μ N =	75,716	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**105,234**	**lb**			
Total Pulling Load =	**147,274**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	408.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	43,532	lb			
Fluidic Drag = 12 π D L C_d =	13,851	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**57,384**	**lb**			
Total Pulling Load =	**204,658**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	255,207	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	13.70	ft	$j = [(E I) / T]^{1/2}$ =	1,204	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	5.8E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1285.29	
U = (12 L) / j =	6.26		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	165,406	lb
Bending Frictional Drag = 2 μ N =	99,244	lb			
Fluidic Drag = 12 π D L C_d =	21,318	lb			
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**101,098**	**lb**			
Total Pulling Load =	**305,755**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	30.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	3,150	lb			
Fluidic Drag = 12 π D L C_d =	1,018	lb			
Axial Segment Weight = W_e L sinθ =	-1,852	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**2,317**	**lb**			
Total Pulling Load =	**308,072**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,753	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,725	ok	0	ok	79	ok	0.06	ok	0.00	ok
PC										
	3,725	ok	12,083	ok	79	ok	0.32	ok	0.08	ok
	2,493	ok	12,083	ok	907	ok	0.30	ok	0.10	ok
PT										
	2,493	ok	0	ok	907	ok	0.04	ok	0.02	ok
	1,794	ok	0	ok	907	ok	0.03	ok	0.02	ok
PC										
	1,794	ok	12,083	ok	907	ok	0.29	ok	0.09	ok
	512	ok	12,083	ok	376	ok	0.27	ok	0.06	ok
PT										
	512	ok	0	ok	376	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	-92	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	527.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	55,748	lb			
Fluidic Drag = 12 π D L C_d =	17,913	lb			
Axial Segment Weight = W_e L sinθ =	26,116	lb			
Pulling Load on Exit Tangent =	**99,777**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	137,431	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.39	ft	$j = [(E I) / T]^{1/2}$ =	1,641	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.0E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	158.87	
U = (12 L) / j =	1.84		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	100,915	lb
Bending Frictional Drag = 2 μ N =	60,549	lb			
Fluidic Drag = 12 π D L C_d =	8,528	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**75,308**	**lb**			
Total Pulling Load =	**175,085**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	421.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	44,993	lb			
Fluidic Drag = 12 π D L C_d =	14,316	lb			
Axial Segment Weight = W_e L sinθ =	-1	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Bottom Tangent =	**59,309**	**lb**			
Total Pulling Load =	**234,394**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	272,006	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	$j = [(E I) / T]^{1/2}$ =	1,166	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	9.4E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	403.64	
U = (12 L) / j =	3.23		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	123,829	lb
Bending Frictional Drag = 2 μ N =	74,298	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**75,224**	**lb**			
Total Pulling Load =	**309,618**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	331.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	34,804	lb			
Fluidic Drag = 12 π D L C_d =	11,245	lb			
Axial Segment Weight = W_e L sinθ =	-20,457	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**25,593**	**lb**			
Total Pulling Load =	**335,211**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,084	ok	0	ok	0	ok	0.06	ok	0.01	ok
	3,772	ok	0	ok	871	ok	0.06	ok	0.02	ok
PC										
	3,772	ok	24,167	ok	871	ok	0.59	ok	0.29	ok
	2,856	ok	24,167	ok	1285	ok	0.57	ok	0.30	ok
PT										
	2,856	ok	0	ok	1285	ok	0.05	ok	0.04	ok
	2,133	ok	0	ok	1285	ok	0.03	ok	0.04	ok
PC										
	2,133	ok	24,167	ok	1285	ok	0.56	ok	0.29	ok
	1,216	ok	24,167	ok	1020	ok	0.55	ok	0.26	ok
PT										
	1,216	ok	0	ok	1020	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	-92	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The risk of inadvertent drilling fluid returns due to hydrofracture was evaluated using the Delft Method. In summary, under normal drilling operations, the risk of inadvertent drilling fluid returns due to hydrofracture is low over the majority of the length of the crossing. The factor of safety remains above 2.0, with an estimated low risk of hydrofracture until the last 315 feet of the crossing. It is only as the bit begins making its way to the surface when depth of cover drops to 20 feet or less that the risk of hydrofracture is pronounced. Beginning at approximately station 14+70, the estimated annular pressure matches or exceeds the formation limit pressure, indicating a high risk of inadvertent drilling fluid returns. Refer to Figure 7 for results presented in graphical format.

It is important to keep in mind that inadvertent drilling fluid returns may occur due to mechanisms unrelated to hydrofracture. It remains possible that inadvertent drilling fluid returns will occur by flowing to the ground surface through preexisting fractures or porous seams in the soil mass.

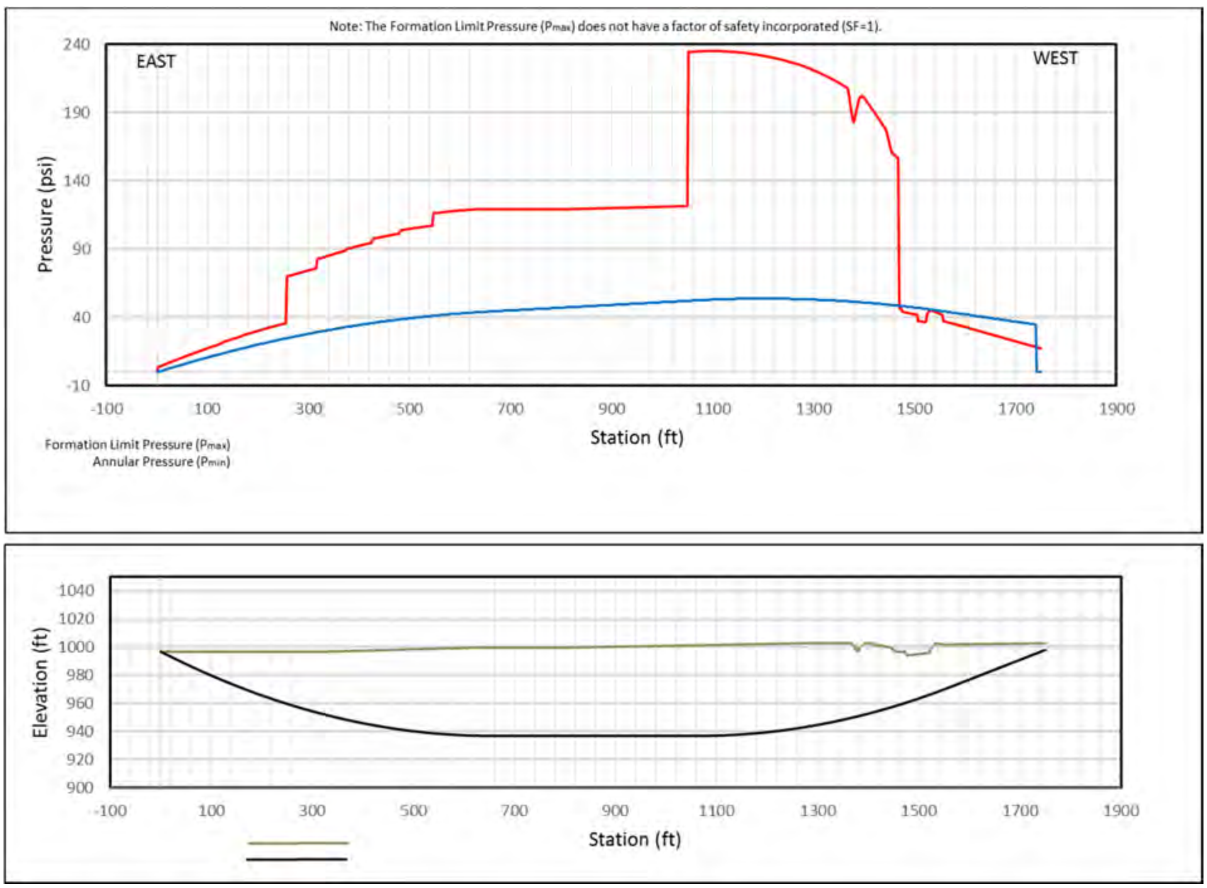


Figure 7: Hydrofracture Evaluation (Formation Limit Pressure -vs-Annular Pressure)

Construction Duration

The estimated duration of construction is 14 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 8 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Wetland Crossing (MP 71.1)
days/week =	7.0	
Drilled Length, feet =	1,792	
Pilot Hole		
Production Rate, feet/hour =	50	
shifts/day =	1	
Drilling Duration, hours =	35.8	
shifts =	3.0	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	3.5	

Ream and Pull Back								
Pass Description =	36-inch	48-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	2.0	2.0				8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0				15.0	15.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	16.9	16.9				5.7	6.9	46.3
shifts =	1.4	1.4				0.5	0.6	3.9
Rig up, shifts =	0.5	0.5				0.5	0.5	2.0
Trips to change tools, shifts =	1.0	1.0				0.0		2.0
Pass Duration, days =	2.9	2.9				1.0	1.1	7.9

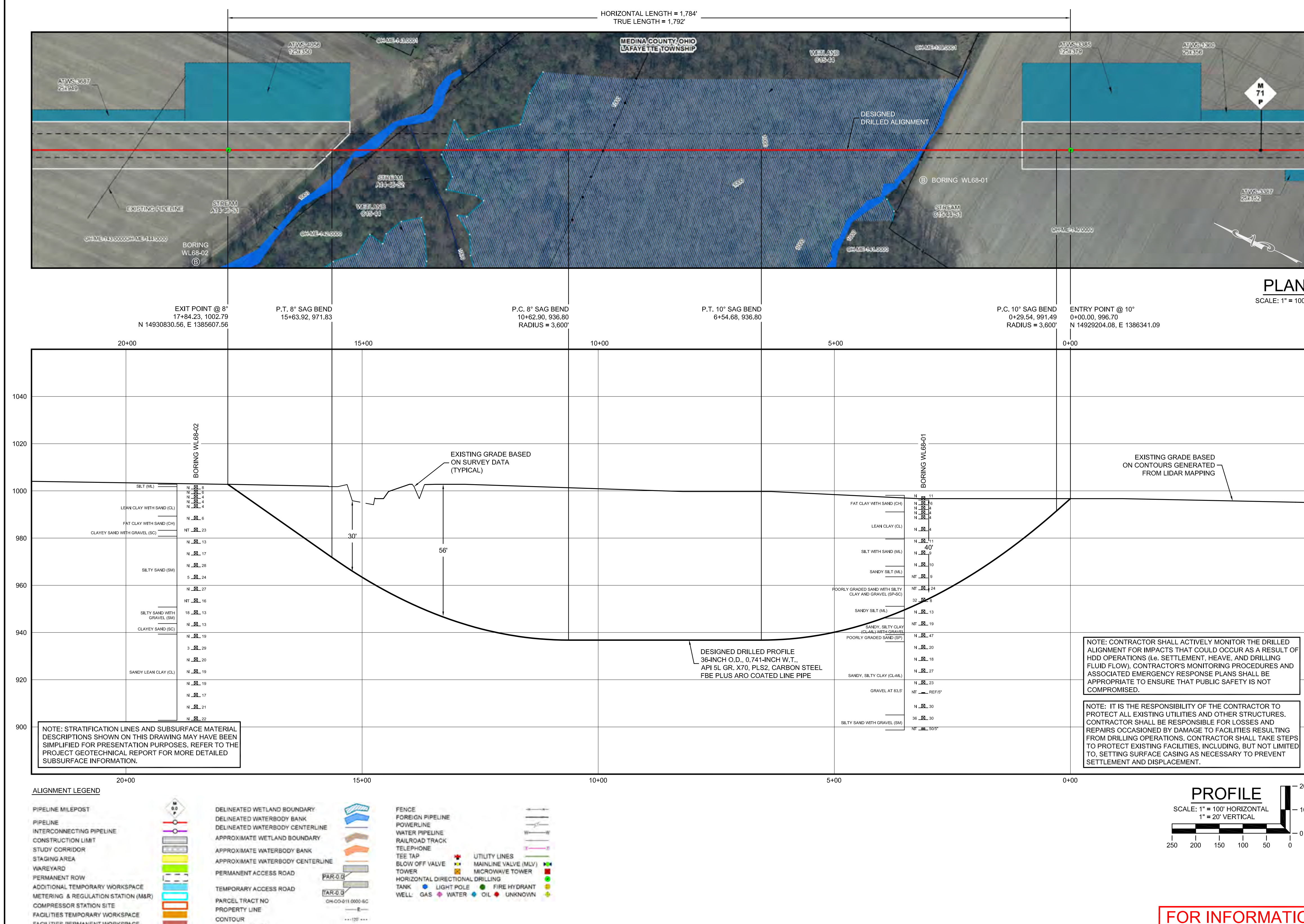
Summary	
HDD Duration at Site, days =	13.3

Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 8: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-58



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

Ⓑ BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA
		1	LKB	JMS	ISSUED FOR BID
WADS-A-1081	ALIGNMENT SHEET M.P. 71.07 TO M.P. 72.02	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

TITLE	PRELIMINARY SIGNATURE	DATE	CONSTRUCTION SIGNATURE	DATE
DRAWN BY:	DMP	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB	08/07		
DESIGN CHECKER	DLB	08/07		

ENGINEERING APPROVALS

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH WETLAND CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

MEDINA COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 71.1	W.O.	SCALE: AS SHOWN	DWG. WADS-H-1004	REV. 3

MP 86.9 East Branch Black River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical and Geophysical Data Report, East Branch Black River HDD Crossing, Nexus Gas Transmission Project, Lorain County Ohio" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch East Branch Black River Crossing is located just southwest of Grafton, Ohio near the intersection of Indian Hollow Road and Crook Street. The crossing involves passing beneath East Branch Black River, as well as wetland areas on both sides of the channel. The proposed pipeline alignment cuts perpendicularly across a cut bank/point bar at the crossing location. The topography in the vicinity of the crossing is essentially flat, but with the west side cut bank of the river approximately 22 feet higher than the east side and point bar deposit. Both sides of the river are open farmland surrounded by forest land. An overview of the crossing site is provided in Figure 1.

Figure 1: Overview of the East Branch Black River Crossing

Subsurface Conditions

Three geotechnical borings were drilled as part of the site investigation conducted by Fugro Consultants, Inc. Two of the borings (EBL-04, and EBL-03) were taken on the west side of the river and one of the borings (EBL-01) was taken on the east side of the river. The borings generally encountered lean clay, fat clay, silty sand, and clayey sand, with gravel, overlying sedimentary bedrock (sandstone and shale). Unconfined compressive strength tests were performed on select rock samples. The strength averaged 4,280 psi, with the lowest value recorded being 30 psi and highest being 11,300 psi. The rock quality designation (RQD) generally indicates good quality bedrock, with the exception of some of the shale cores recovered, which indicate poor quality.

Refer to the report titled "Geotechnical and Geophysical Data Report, East Branch Black River HDD Crossing, Nexus Gas Transmission Project, Lorain County Ohio" and dated September 11, 2015, for additional information.

Design Geometry & Layout

The East Branch Black River HDD design involves a horizontal length of 1,809 feet. The design entry point is located on the west side of the river near the pipeline point of intersection (P.I.). The location results from offsetting the entry point 60 feet from the P.I. This allows 28 feet of depth at the edge of the wetland with a 12-degree entry angle. The exit point location on the east side of the river is based on an 8-degree angle with 40 feet of cover at the edge of the east wetland. The design achieves 71 feet of clearance beneath the bottom of the river. The design employs a radius of curvature of 3,600 feet, the industry standard for a 36-inch pipeline installation.

The exit point is located on the east side of the crossing. This is to take advantage of the long linear stretch of available right-of-way (ROW) for pull section fabrication. In this case, the pull section can be fabricated in a single segment and thus avoid downtime associated with performing tie-in welds.

The preliminary HDD plan and profile design drawing for crossing the East Branch Black River is attached to this report for reference.

Assessment of Feasibility

Based on a review of available geotechnical information, the drilled path will pass thorough sedimentary sandstone and shale bedrock over the majority of the length of the crossing. Although the shale may involve significant fractures at depth as indicated by low RQD values, it is our experience that shale is typically conducive to the HDD process despite displaying what are often low RQD values. Therefore, given the proposed length of 1,822 feet and the anticipated subsurface conditions, the crossing is feasible.

Risk Identification and Assessment

Potential construction impacts associated with the proposed Black River Crossing are inadvertent drilling fluid returns surfacing within the wetlands or within the river. There is also risk that sink holes will develop during reaming operations on the west side of the crossing along the HDD alignment. This is due to the 22 foot elevation differential between the entry and exit points. The sinkholes are most likely to form within 100 feet of the entry point.

HDD construction and operational risks associated with a large diameter rock crossing include failure of large diameter rock reaming tools downhole; hole misalignment at the soil/rock interface; and loss of drilling fluid circulation through existing fractures which could negatively impact cuttings removal. In addition, sink holes and hole collapse on the west side resulting from the elevation differential may increase the difficulty of reaming and cuttings removal over the west segment of the crossing.

The overall level of risk associated with installation of the proposed 36-inch pipeline under the East Branch Black River by HDD is average.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 315,956 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 331,380 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 3. Detailed calculations for each loading scenario are summarized in Figures 4 and 5.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 3: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	360.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	38,092	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	12,240	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	17,845	lb			
Pulling Load on Exit Tangent =	**68,176**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	121,333	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R\ [1 - \cos(\alpha/2)]$ =	8.77	ft	$j = [(E\ I) / T]^{1/2}$ =	1,746	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	2.5E+06		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	688.43	
$U = (12\ L) / j$ =	3.45		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	127,992	lb
Bending Frictional Drag = $2\ \mu\ N$ =	76,795	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	17,055	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**106,313**	**lb**			
Total Pulling Load =	**174,489**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	67.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e\ L\ \mu$ =	7,191	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	2,288	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb			
Pulling Load on Bottom Tangent =	**9,479**	**lb**			
Total Pulling Load =	**183,969**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	754.0	ft	Average Tension, T =	240,350	lb
Segment Angle with Horizontal, θ =	12.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	6.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R\ [1 - \cos(\alpha/2)]$ =	19.72	ft	$j = [(E\ I) / T]^{1/2}$ =	1,241	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	8.8E+06		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	1642.51	
$U = (12\ L) / j$ =	7.29		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	191,989	lb
Bending Frictional Drag = $2\ \mu\ N$ =	115,193	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	25,582	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-28,013	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**112,762**	**lb**			
Total Pulling Load =	**296,731**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	137.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	279.0	lb/ft
Entry Angle, θ =	12.0	°			
Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	11,252	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	0	lb	Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input		
Axial Segment Weight = $W_e\ L \sin\theta$ =	7,972	lb			
Pulling Load on Entry Tangent =	**19,225**	**lb**			
Total Pulling Load =	**315,956**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,849	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,615	ok	0	ok	0	ok	0.06	ok	0.00	ok
PC										
	3,615	ok	12,083	ok	0	ok	0.32	ok	0.08	ok
	2,241	ok	12,083	ok	1291	ok	0.30	ok	0.12	ok
PT										
	2,241	ok	0	ok	1291	ok	0.04	ok	0.04	ok
	2,126	ok	0	ok	1291	ok	0.03	ok	0.04	ok
PC										
	2,126	ok	12,083	ok	1291	ok	0.30	ok	0.12	ok
	831	ok	12,083	ok	760	ok	0.28	ok	0.08	ok
PT										
	831	ok	0	ok	760	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 4: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Parameter	Value	Unit	Parameter	Value	Unit	
Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	666.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = $W_e L \mu \cos\theta$ =	70,351	lb			
Fluidic Drag = $12 \pi D L C_d$ =	22,605	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	32,957	lb			
Pulling Load on Exit Tangent =	**125,913**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	251.3	ft	Average Tension, T =	164,218	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	4.38	ft	$j = [(E I) / T]^{1/2}$ =	1,501	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1})]$ =	3.4E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	180.98	
$U = (12 L) / j$ =	2.01		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	103,082	lb
Bending Frictional Drag = $2 \mu N$ =	61,849	lb			
Fluidic Drag = $12 \pi D L C_d$ =	8,527	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**76,608**	**lb**			
Total Pulling Load =	**202,522**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	137.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e L \mu$ =	14,652	lb			
Fluidic Drag = $12 \pi D L C_d$ =	4,662	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	0	lb			
Pulling Load on Bottom Tangent =	**19,314**	**lb**			
Total Pulling Load =	**221,836**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	377.0	ft	Average Tension, T =	262,234	lb
Segment Angle with Horizontal, θ =	12.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	6.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	9.86	ft	$j = [(E I) / T]^{1/2}$ =	1,188	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1})]$ =	1.6E+06		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	562.89	
$U = (12 L) / j$ =	3.81		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	136,689	lb
Bending Frictional Drag = $2 \mu N$ =	82,013	lb			
Fluidic Drag = $12 \pi D L C_d$ =	12,791	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-14,007	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**80,798**	**lb**			
Total Pulling Load =	**302,633**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	446.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	12.0	°			
Frictional Drag = $W_e L \mu \cos\theta$ =	46,608	lb			
Fluidic Drag = $12 \pi D L C_d$ =	15,161	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-33,022	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**28,746**	**lb**			
Total Pulling Load =	**331,380**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,037	ok	0	ok	0	ok	0.06	ok	0.01	ok
	3,687	ok	0	ok	1074	ok	0.06	ok	0.03	ok
PC										
	3,687	ok	24,167	ok	1074	ok	0.59	ok	0.30	ok
	2,703	ok	24,167	ok	1669	ok	0.57	ok	0.33	ok
PT										
	2,703	ok	0	ok	1669	ok	0.04	ok	0.06	ok
	2,467	ok	0	ok	1669	ok	0.04	ok	0.06	ok
PC										
	2,467	ok	24,167	ok	1669	ok	0.57	ok	0.33	ok
	1,534	ok	24,167	ok	1404	ok	0.55	ok	0.29	ok
PT										
	1,534	ok	0	ok	1404	ok	0.02	ok	0.04	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The East Branch Black River crossing will be installed almost entirely through sedimentary bedrock. Since the Delft Equation (discussed in Section 5) is only applicable to uncemented subsurface material, an assessment of the risk of hydrofracture was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings. Instead, when passing through bedrock, inadvertent drilling fluid returns are more likely to occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

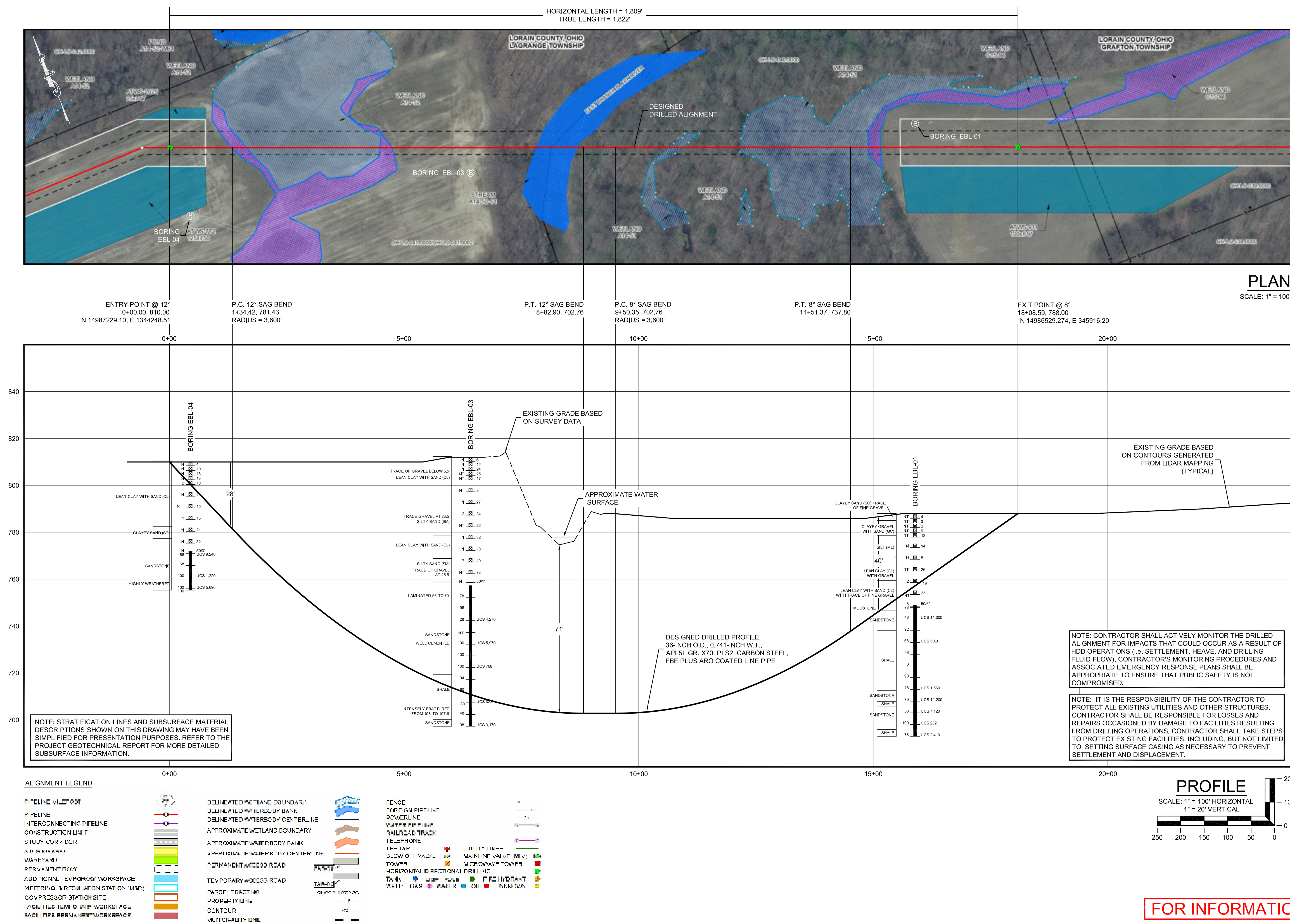
The estimated duration of construction for the East Branch Black River Crossing is 46 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated based on typical production rates for various subsurface materials outlined in the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as JDH&A's past experience in similar subsurface conditions. Details relative to the estimate are provided in Figure 6.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments						
Work Schedule, hours/shift =	12.0	36" East Branch Black River Crossing						
days/week =	7.0							
Drilled Length, feet =	1,822							
Pilot Hole								
Production Rate, feet/hour =	25							
shifts/day =	1							
Drilling Duration, hours =	72.9							
shifts =	6.1							
Trips to change tools, shifts =	0.5							
Pilot Hole Duration, days =	6.6							
Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	123.4	123.4	123.4			5.8	7.0	383.1
shifts =	10.3	10.3	10.3			0.5	0.6	31.9
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	11.8	11.8	11.8			1.0	1.1	37.4
Summary								
HDD Duration at Site, days =	46.0							
Site Establishment	Move in	Rig Up	Rig Down	Move Out				
shifts/day =	1	1	1	1				
shifts =	0.5	1.0	1.0	0.5				
days =	0.5	1.0	1.0	0.5				

Figure 6: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES

PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UNCONFINED COMPRESSIVE STRENGTH (PSI)

MOHS HARDNESS

ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC. BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA AND REVISE ENTRY POINT LOCATION
		1	LKB	JMS	ISSUED FOR BID
WADS-A-1097	ALIGNMENT SHEET M.P. 86.18 TO M.P. 87.13	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

TITLE	PRELIMINARY SIGNATURE	DATE	CONSTRUCTION SIGNATURE	DATE
DRAWN BY:	JMS	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB/ACM	08/07		
DESIGN CHECKER	ACM	08/07		

ENGINEERING APPROVALS

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH EAST BRANCH BLACK RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

LORAIN COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 86.5	W.O.	SCALE: AS SHOWN	DWG. WADS-H-1005	REV. 3

MP 92.5 West Branch Black River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch West Branch Black River Crossing is located approximately 2.5 miles southeast of Oberlin, Ohio near the intersection of West Road and Kipton Nickle Plate Road. The crossing involves passing beneath the meandering channel of the West Branch Black River, as well as West Road. The topography in the vicinity of the crossing is essentially flat, but with a topographic rise of approximately 20 feet conforming to the east bank of the river. Both sides of the river are mixtures of wooded patches and open farmland.

Figure 1: Overview of the West Branch Black River Crossing

Subsurface Conditions

At the time of this writing, site-specific subsurface information is not yet available.

Design Geometry & Layout

The West Branch Black River HDD design involves a horizontal length of 1,676 feet. The design geometry involves a 10-degree entry angle, an 8-degree exit angle, and radius of curvature of 3,600 feet. The HDD design achieves 40 feet of cover at the edge of the easternmost channel of the West Branch Black River, 55 feet beneath the western channel, and 56 feet of cover beneath West Road. The exit point is located in a farm field on the east side of West Branch Black River. There is approximately 1,739 feet of false right-of-way east of the exit point available for pull section fabrication.

The proposed HDD design for crossing the West Branch Black River, as well as available workspace for HDD operations, is shown on the preliminary HDD plan and profile drawing attached at the end of this report.

Assessment of Feasibility

Overall, given the length the proposed 36-inch installation, it is easily within the range of what has been successfully installed using HDD. It is anticipated the subsurface will consist of sedimentary bedrock conducive to the HDD process. However, the feasibility will need to be confirmed when site-specific geotechnical data is available.

Risk Identification and Assessment

Potential construction impacts due to installation by HDD include damage to West Road in the form of heaving or settlement, as well as drilling fluid surfacing within the West Branch Black River.

Based on the proposed length of the crossing, the overall risk of HDD operational problems and subsequent delays at this location are likely to be average. However, risk should be re-evaluated after site-specific geotechnical information is available.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 298,633 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 325,779 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 2. Detailed calculations for each loading scenario are summarized in Figures 3 and 4.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 2: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	405.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	42,830	lb			
Fluidic Drag = 12 π D L C_d =	13,762	lb			
Axial Segment Weight = W_e L sinθ =	20,064	lb			
Pulling Load on Exit Tangent =	**76,656**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	129,988	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	j = [(E I) / T]$^{1/2}$ =	1,687	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	2.6E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	710.45	
U = (12 L) / j =	3.58		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	128,578	lb
Bending Frictional Drag = 2 μ N =	77,147	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**106,665**	**lb**			
Total Pulling Load =	**183,320**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	53.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	5,646	lb			
Fluidic Drag = 12 π D L C_d =	1,797	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**7,443**	**lb**			
Total Pulling Load =	**190,763**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	240,964	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	13.70	ft	j = [(E I) / T]$^{1/2}$ =	1,239	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	5.7E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1268.28	
U = (12 L) / j =	6.09		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	164,247	lb
Bending Frictional Drag = 2 μ N =	98,548	lb			
Fluidic Drag = 12 π D L C_d =	21,318	lb			
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**100,402**	**lb**			
Total Pulling Load =	**291,165**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	96.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	10,155	lb			
Fluidic Drag = 12 π D L C_d =	3,281	lb			
Axial Segment Weight = W_e L sinθ =	-5,969	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**7,467**	**lb**			
Total Pulling Load =	**298,633**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,638	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,547	ok	0	ok	254	ok	0.06	ok	0.01	ok
PC										
	3,547	ok	12,083	ok	254	ok	0.32	ok	0.08	ok
	2,324	ok	12,083	ok	1082	ok	0.30	ok	0.11	ok
PT										
	2,324	ok	0	ok	1082	ok	0.04	ok	0.03	ok
	2,233	ok	0	ok	1082	ok	0.04	ok	0.03	ok
PC										
	2,233	ok	12,083	ok	1082	ok	0.30	ok	0.11	ok
	934	ok	12,083	ok	552	ok	0.28	ok	0.07	ok
PT										
	934	ok	0	ok	552	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	-303	ok	0.00	ok	0.00	ok

Figure 3: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D = 36.000 in
Pipe Weight, W = 279.0 lb/ft
Coefficient of Soil Friction, μ = 0.30

Fluid Drag Coefficient, C_d = 0.025 psi
Ballast Weight / ft Pipe, W_b = 405.5 lb (If Ballasted)
Drilling Mud Displaced / ft Pipe, W_m = 634.5 lb (If Submerged)
Above Ground Load = 0 lb

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L = 711.1 ft
Exit Angle, θ = 8.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ cosθ = 75,089 lb

Fluidic Drag = 12 π D L C_d = 24,127 lb

Axial Segment Weight = W_e L sinθ = 35,177 lb

Pulling Load on Exit Tangent = 134,393 lb

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 251.3 ft
Segment Angle with Horizontal, θ = -8.0 °
Deflection Angle, α = -4.0 °

Average Tension, T = 172,908 lb
Radius of Curvature, R = 1,800 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

h = R [1 - cos(α/2)] = 4.38 ft
j = [(E I) / T]$^{1/2}$ = 1,463

Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] = 3.5E+05
X = (3 L) - [(j / 2) tanh(U/2)] = 187.72

U = (12 L) / j = 2.06
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) = 103,785 lb

Bending Frictional Drag = 2 μ N = 62,271 lb

Fluidic Drag = 12 π D L C_d = 8,527 lb

Axial Segment Weight = W_e L sinθ = 6,231 lb

Pulling Load on Exit Sag Bend = 77,030 lb
Total Pulling Load = 211,423 lb

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L = 65.6 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ = 6,999 lb

Fluidic Drag = 12 π D L C_d = 2,227 lb

Axial Segment Weight = W_e L sinθ = 0 lb

Pulling Load on Bottom Tangent = 9,226 lb
Total Pulling Load = 220,648 lb

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 314.2 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 257,841 lb
Radius of Curvature, R = 1,800 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

h = R [1 - cos(α/2)] = 6.85 ft
j = [(E I) / T]$^{1/2}$ = 1,198

Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] = 9.1E+05
X = (3 L) - [(j / 2) tanh(U/2)] = 392.94

U = (12 L) / j = 3.15
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) = 122,430 lb

Bending Frictional Drag = 2 μ N = 73,458 lb

Fluidic Drag = 12 π D L C_d = 10,659 lb

Axial Segment Weight = W_e L sinθ = -9,732 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 74,385 lb
Total Pulling Load = 295,033 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 398.2 ft
Entry Angle, θ = 10.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ cosθ = 41,811 lb

Fluidic Drag = 12 π D L C_d = 13,509 lb

Axial Segment Weight = W_e L sinθ = -24,575 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 30,745 lb
Total Pulling Load = 325,779 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,969	ok	0	ok	0	ok	0.06	ok	0.01	ok
	3,594	ok	0	ok	1047	ok	0.06	ok	0.03	ok
PC										
	3,594	ok	24,167	ok	1047	ok	0.59	ok	0.30	ok
	2,688	ok	24,167	ok	1461	ok	0.57	ok	0.32	ok
PT										
	2,688	ok	0	ok	1461	ok	0.04	ok	0.05	ok
	2,576	ok	0	ok	1461	ok	0.04	ok	0.05	ok
PC										
	2,576	ok	24,167	ok	1461	ok	0.57	ok	0.31	ok
	1,637	ok	24,167	ok	1196	ok	0.56	ok	0.27	ok
PT										
	1,637	ok	0	ok	1196	ok	0.03	ok	0.03	ok
Exit Point	0	ok	0	ok	-303	ok	0.00	ok	0.00	ok

Figure 4: Installation Loading and Stress Analysis (Worse Case)

Hydrofracture Evaluation

At the time of this writing, site-specific geotechnical data is not available. Therefore, a hydrofracture evaluation could not be completed.

Construction Duration

The estimated duration of construction is 39 days based on assumed subsurface conditions consisting of sedimentary bedrock. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as JDH&A's past experience in similar subsurface conditions. Refer to Figure 5 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" West Branch Black River Crossing. Subsurface conditions assumed to consist of sedimentary bedrock.
days/week =	7.0	
Drilled Length, feet =	1,686	
Pilot Hole		
Production Rate, feet/hour =	25	
shifts/day =	1	
Drilling Duration, hours =	67.4	
shifts =	5.6	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	6.1	

Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	95.5	95.5	95.5			5.3	6.5	298.3
shifts =	8.0	8.0	8.0			0.4	0.5	24.9
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	9.5	9.5	9.5			0.9	1.0	30.4

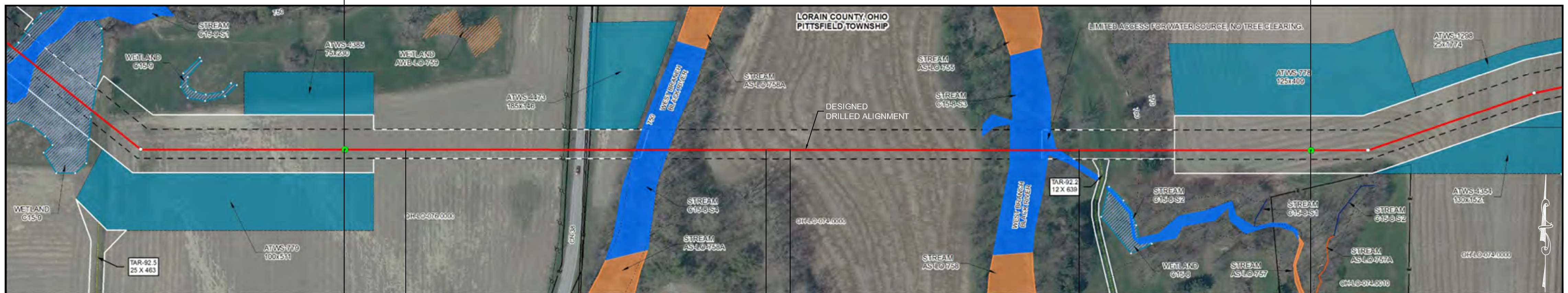
Summary				
HDD Duration at Site, days =	38.5			
Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 5: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-75

HORIZONTAL LENGTH = 1,676'
TRUE LENGTH = 1,686'



PLAN

SCALE: 1" = 100'

ENTRY POINT @ 10°
0+00.00, 756.00
N 14990296.18, E 1315898.33

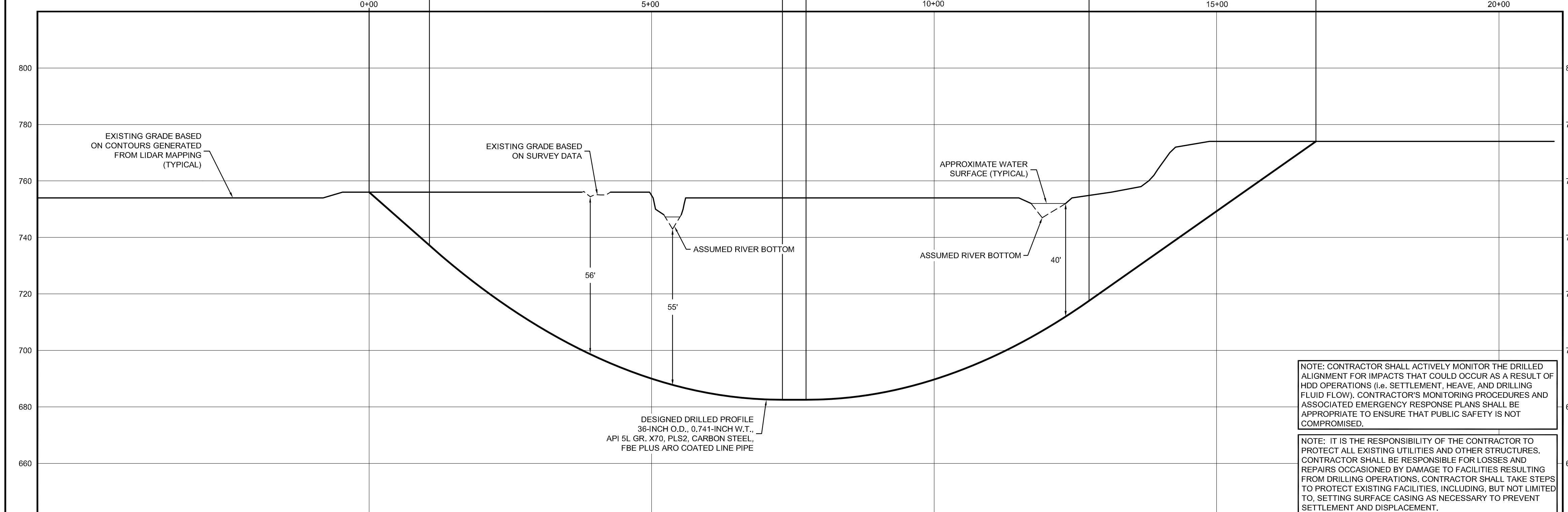
P.C. 10° SAG BEND
1+06.58, 737.21
RADIUS = 3,600'

P.C. 10° SAG BEND
7+31.71, 682.52

P.T. 8° SAG BEND
7+73.21, 682.51
RADIUS = 3,600'

P.C. 8° SAG BEND
12+74.24, 717.55

EXIT POINT @ 8°
16+75.89, 774.00
N 14990309.33, E 1317574.17



NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

PROFILE

SCALE: 1" = 100' HORIZONTAL
1" = 20' VERTICAL

250 200 150 100 50 0

20 10 0

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ALIGNMENT LEGEND

PIPELINE MILEPOST
PIPELINE
INTERCONNECTING PIPELINE
CONSTRUCTION LIMIT
STUDY CORRIDOR
STAGING AREA
WAREYARD
PERMANENT ROW
ADDITIONAL TEMPORARY WORKSPACE
METERING & REGULATION STATION (M&R)
COMPRESSOR STATION SITE
FACILITIES TEMPORARY WORKSPACE
FACILITIES PERMANENT WORKSPACE
DELINEATED WETLAND BOUNDARY
DELINEATED WATERBODY BANK
DELINEATED WATERBODY CENTERLINE
APPROXIMATE WETLAND BOUNDARY
APPROXIMATE WATERBODY BANK
APPROXIMATE WATERBODY CENTERLINE
PERMANENT ACCESS ROAD
TEMPORARY ACCESS ROAD
PARCEL TRACT NO
PROPERTY LINE
CONTOUR
MUNICIPALITY LINE
FENCE
FOREIGN PIPELINE
POWERLINE
WATER PIPELINE
RAILROAD TRACK
TELEPHONE
TEE TAP
BLOW OFF VALVE
TOWER
HORIZONTAL DIRECTIONAL DRILLING
TANK
WELL: GAS WATER OIL UNKNOWN
UTILITY LINES
MAINLINE VALVE (MLV)
MICROWAVE TOWER
LIGHT POLE
FIRE HYDRANT

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA/CENTERLINE AND REVISE ENTRY POINT LOCATION
		1	LKB	JMS	ISSUED FOR BID
WADS-A-1103	ALIGNMENT SHEET M.P. 91.86 TO M.P. 92.81	0	LKB	ACM	ISSUED FOR FERC
DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
DRAWN BY:	LKB	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB	08/07		
DESIGN CHECKER	DLB	08/07		
TITLE	SIGNATURE	DATE	SIGNATURE	DATE

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH WEST BRANCH BLACK RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

LORAIN COUNTY, OHIO

M.P. 92.2	W.O.	SCALE: AS SHOWN	DWG. WADS-H-1006	REV. 3

NEXUS GAS TRANSMISSION

MP 104.1 Vermilion River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled “Geotechnical and Geophysical Data Report, Vermilion River HDD Crossing (REV-1), Nexus Gas Transmission Project, Huron County, Ohio” and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch crossing of the Vermilion River is located near pipeline Mile Post 104.1, about two miles north of Wakeman, Ohio. Obstacles to be crossed include a shallow braided river and wetland complex, and Highway 62 (West Road). The area surrounding the river, approximately 800 feet on both sides, is wooded. In each direction beyond the woodlands are open farm fields. The topography on both sides is generally flat but drops off quickly toward the river. The elevation change is approximately 80 feet to the bottom of the river valley.

An overview of the proposed crossing location is provided in Figure 1. Photographs taken during the site reconnaissance are included as Figure 2 and Figure 3.

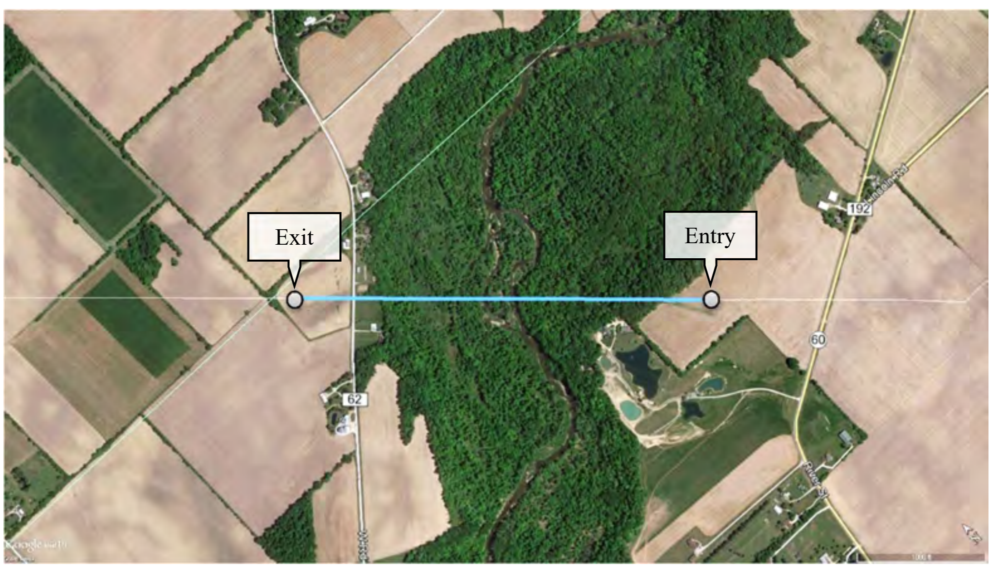


Figure 1: Overview of the Vermillion River Crossing

Figure 2: View west toward entry location

Figure 3: View west toward exit location from West Road

Subsurface Conditions

Four site-specific geotechnical borings were taken as part of the site investigation undertaken by Fugro Consultants, Inc. Two borings were taken on each side of the river. Each encountered approximately 20 feet of overburden soil (lean clay and sandy lean clay) overlying sedimentary bedrock consisting primarily of shale and siltstone, but with some claystone and sandstone. The unconfined compressive strength (UCS) of the bedrock ranged from 10 psi to 8,780 psi. In general, strength increases with depth. The majority of UCS values were less than 1,000 psi above elevation 760. Below elevation 760, UCS averaged 2,528 psi on the west side and 1,853 on the east side. Rock quality designation (RQD) index values generally indicate good quality bedrock, though the boring logs indicate several areas described as extremely fractured that did not necessarily correlate with the RQD values.

For detailed information relative to the subsurface investigation, refer to the geotechnical data report prepared by Fugro Consultants, Inc. titled “Geotechnical and Geophysical Data Report, Vermilion River HDD Crossing (REV-1), Nexus Gas Transmission Project, Huron County, Ohio” and dated September 11, 2015.

Design Geometry & Layout

The proposed crossing design involves a horizontal length of 3,184 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature of 3,600 feet. The crossing maintains 59 feet of cover beneath W Road, 40 feet of cover beneath the bottom of the slope on the west side of the crossing, just over 40 feet of cover beneath the Vermilion River, and 62 feet of cover beneath the slope on the east side of the crossing. Pull section fabrication will take place on the west side of the crossing since it provides sufficient unobstructed space for pull section stringing.

The proposed HDD design, as well as available workspace for HDD operations, is shown on the preliminary HDD plan and profile drawing included in this site-specific report.

Assessment of Feasibility

Based on available geotechnical data, it appears the crossing will be installed entirely through relatively weak sedimentary bedrock. HDD crossings with similar lengths and diameters have been installed through similar subsurface conditions in the past. Therefore, it is our opinion that with the right downhole tool selections and sound planning, skilled and experienced HDD contractors will be able to install the Vermilion River Crossing.

Risk Identification and Assessment

Notable risks associated with installation by HDD are the possibility of damage to West Road due to heaving or settlement, as well as inadvertent drilling fluid returns surfacing within the wetlands and river channels. The risk of inadvertent drilling fluid returns is elevated at this location due to the elevation differential of approximately 100 feet between the entry point and the bottom of the river valley. This requires a subsequently deep HDD segment which involves increased annular pressure associated with the static pressure head of the drilling fluid column.

Potential HDD construction and operational risks associated with the crossing include failure of large diameter rock reaming tools downhole, hole misalignment at the soil/rock interface, which may cause downhole tools to bind or the pull section to become lodged, and loss of drilling fluid circulation through existing joints and fractures within the sedimentary bedrock. Loss of circulation may negatively impact cuttings removal.

Overall, the proposed Vermilion River crossing is considered to have an average level of risk.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600'	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50' Depth: Increased by 25' Radius: 1,800'	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the "as-designed" crossing, without ballast, is 513,612 pounds. In the "worse-case" installation scenario, the anticipated pulling load without ballast is 543,187 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000 in	Fluid Drag Coefficient, C_d =	0.025 psi		
Pipe Weight, W =	279.0 lb/ft	Ballast Weight / ft Pipe, W_b =	405.5 lb	(If Ballasted)	
Coefficient of Soil Friction, μ =	0.30	Drilling Mud Displaced / ft Pipe, W_m =	634.5 lb	(If Submerged)	
		Above Ground Load =	0 lb		

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	791.6 ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
Exit Angle, θ =	8.0 °		
Frictional Drag = W_e L μ cosθ =	83,585 lb		
Fluidic Drag = 12 π D L C_d =	26,857 lb		
Axial Segment Weight = W_e L sinθ =	39,157 lb		
Pulling Load on Exit Tangent =	**149,600 lb**		

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7 ft	Average Tension, T =	204,456 lb
Segment Angle with Horizontal, θ =	-8.0 °	Radius of Curvature, R =	3,600 ft
Deflection Angle, α =	-4.0 °	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
h = R [1 - cos(α/2)] =	8.77 ft	$j = [(E\ I) / T]^{1/2}$ =	1,345
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.1E+06	X = (3 L) - [(j / 2) tanh(U/2)] =	850.44
U = (12 L) / j =	4.48	N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	133,659 lb
Bending Frictional Drag = 2 μ N =	80,195 lb		
Fluidic Drag = 12 π D L C_d =	17,055 lb		
Axial Segment Weight = W_e L sinθ =	12,463 lb		
Pulling Load on Exit Sag Bend =	**109,713 lb**		
Total Pulling Load =	**259,313 lb**		

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	728.6 ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
Frictional Drag = W_e L μ =	77,692 lb		
Fluidic Drag = 12 π D L C_d =	24,721 lb		
Axial Segment Weight = W_e L sinθ =	0 lb		
Pulling Load on Bottom Tangent =	**102,413 lb**		
Total Pulling Load =	**361,726 lb**		

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3 ft	Average Tension, T =	416,302 lb
Segment Angle with Horizontal, θ =	10.0 °	Radius of Curvature, R =	3,600 ft
Deflection Angle, α =	5.0 °	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
h = R [1 - cos(α/2)] =	13.70 ft	$j = [(E\ I) / T]^{1/2}$ =	943
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	6.3E+06	X = (3 L) - [(j / 2) tanh(U/2)] =	1413.96
U = (12 L) / j =	8.00	N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	178,831 lb
Bending Frictional Drag = 2 μ N =	107,299 lb		
Fluidic Drag = 12 π D L C_d =	21,318 lb		
Axial Segment Weight = W_e L sinθ =	-19,464 lb	Negative value indicates axial weight applied in direction of installation	
Pulling Load on Entry Sag Bend =	**109,153 lb**		
Total Pulling Load =	**470,878 lb**		

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	553.4 ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
Entry Angle, θ =	10.0 °		
Frictional Drag = W_e L μ cosθ =	58,114 lb		
Fluidic Drag = 12 π D L C_d =	18,777 lb		
Axial Segment Weight = W_e L sinθ =	-34,157 lb	Negative value indicates axial weight applied in direction of installation	
Pulling Load on Entry Tangent =	**42,734 lb**		
Total Pulling Load =	**513,612 lb**		

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	6,257	ok	0	ok	0	ok	0.10	ok	0.01	ok
	5,737	ok	0	ok	1370	ok	0.09	ok	0.05	ok
PC										
	5,737	ok	12,083	ok	1370	ok	0.36	ok	0.16	ok
	4,407	ok	12,083	ok	2199	ok	0.33	ok	0.22	ok
PT										
	4,407	ok	0	ok	2199	ok	0.07	ok	0.11	ok
	3,159	ok	0	ok	2199	ok	0.05	ok	0.10	ok
PC										
	3,159	ok	12,083	ok	2199	ok	0.31	ok	0.20	ok
	1,823	ok	12,083	ok	1668	ok	0.29	ok	0.14	ok
PT										
	1,823	ok	0	ok	1668	ok	0.03	ok	0.06	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Parameter	Value	Unit	Parameter	Value	Unit	
Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit
Segment Length, L =	1097.1	ft
Exit Angle, θ =	8.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ cosθ =	115,844	lb
Fluidic Drag = 12 π D L C_d =	37,223	lb
Axial Segment Weight = W_e L sinθ =	54,270	lb
Pulling Load on Exit Tangent =	**207,337**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit
Segment Length, L =	251.3	ft
Segment Angle with Horizontal, θ =	-8.0	°
Deflection Angle, α =	-4.0	°
Average Tension, T =	247,663	lb
Radius of Curvature, R =	1,800	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft
$j = [(E I) / T]^{1/2}$ =	1,222	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	4.5E+05	
X = (3 L) - [(j / 2) tanh(U/2)] =	238.43	
U = (12 L) / j =	2.47	
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	109,823	lb
Bending Frictional Drag = 2 μ N =	65,894	lb
Fluidic Drag = 12 π D L C_d =	8,527	lb
Axial Segment Weight = W_e L sinθ =	6,231	lb
Pulling Load on Exit Sag Bend =	**80,652**	**lb**
Total Pulling Load =	**287,989**	**lb**

Bottom Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit
Segment Length, L =	742.3	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	79,151	lb
Fluidic Drag = 12 π D L C_d =	25,185	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**104,336**	**lb**
Total Pulling Load =	**392,325**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit
Segment Length, L =	314.2	ft
Segment Angle with Horizontal, θ =	10.0	°
Deflection Angle, α =	5.0	°
Average Tension, T =	434,750	lb
Radius of Curvature, R =	1,800	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft
$j = [(E I) / T]^{1/2}$ =	922	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	1.1E+06	
X = (3 L) - [(j / 2) tanh(U/2)] =	496.50	
U = (12 L) / j =	4.09	
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	139,873	lb
Bending Frictional Drag = 2 μ N =	83,924	lb
Fluidic Drag = 12 π D L C_d =	10,659	lb
Axial Segment Weight = W_e L sinθ =	-9,732	lb
Pulling Load on Entry Sag Bend =	**84,851**	**lb**
Total Pulling Load =	**477,176**	**lb**

Negative value indicates axial weight applied in direction of installation

Entry Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit
Segment Length, L =	854.9	ft
Entry Angle, θ =	10.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ cosθ =	89,770	lb
Fluidic Drag = 12 π D L C_d =	29,005	lb
Axial Segment Weight = W_e L sinθ =	-52,763	lb
Pulling Load on Entry Tangent =	**66,012**	**lb**
Total Pulling Load =	**543,187**	**lb**

Negative value indicates axial weight applied in direction of installation

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	6,618	ok	0	ok	0	ok	0.11	ok	0.01	ok
	5,814	ok	0	ok	2163	ok	0.09	ok	0.11	ok
PC										
	5,814	ok	24,167	ok	2163	ok	0.62	ok	0.45	ok
	4,780	ok	24,167	ok	2577	ok	0.61	ok	0.48	ok
PT										
	4,780	ok	0	ok	2577	ok	0.08	ok	0.15	ok
	3,509	ok	0	ok	2577	ok	0.06	ok	0.14	ok
PC										
	3,509	ok	24,167	ok	2577	ok	0.59	ok	0.45	ok
	2,526	ok	24,167	ok	2312	ok	0.57	ok	0.40	ok
PT										
	2,526	ok	0	ok	2312	ok	0.04	ok	0.11	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

Based on available geotechnical information, it is anticipated that the proposed crossing will be installed almost entirely through sedimentary bedrock. Since the Delft Method (discussed previously in Section 5) is only applicable to soil, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

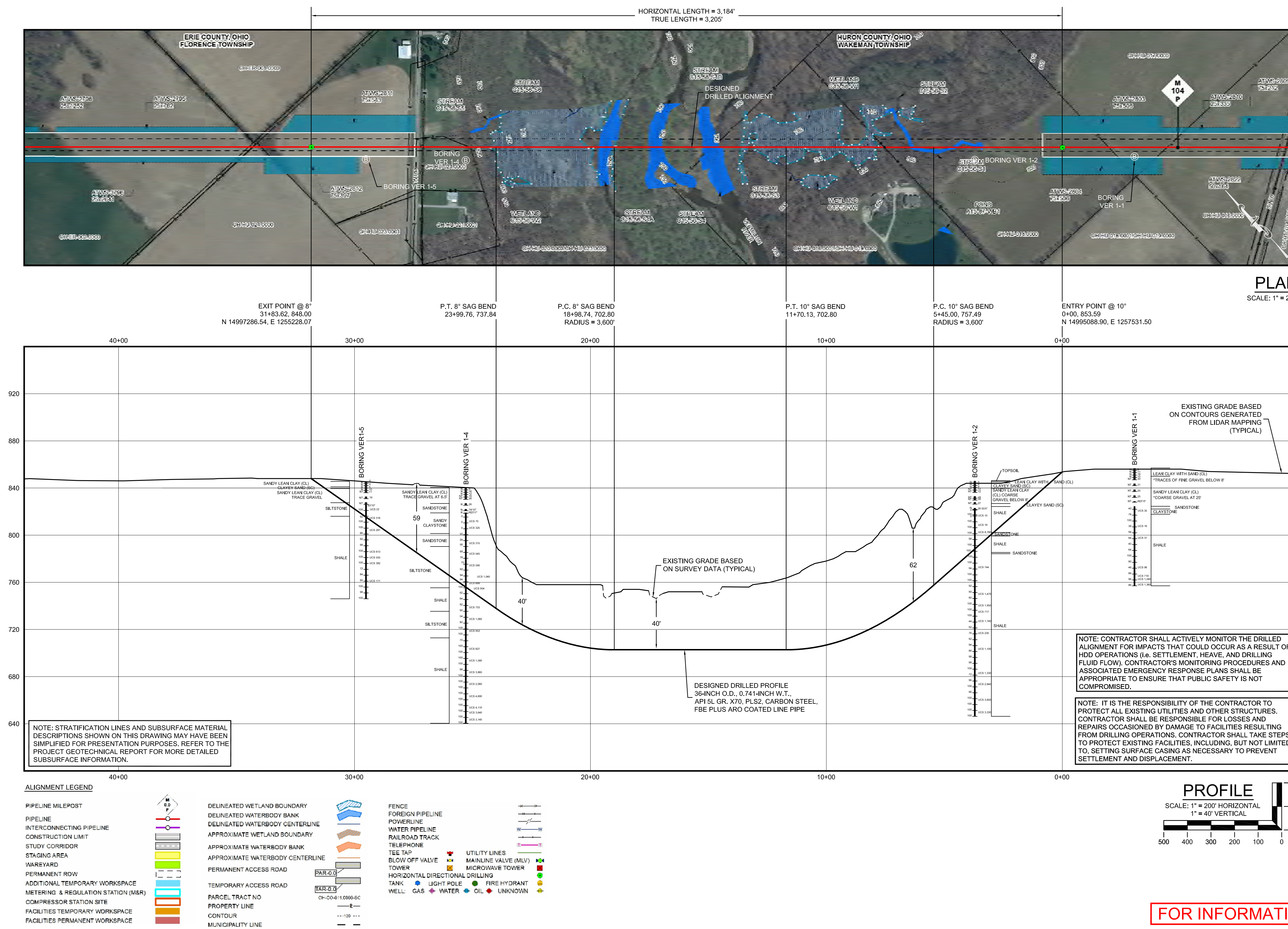
The estimated duration of construction for the proposed crossing is 78 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 7 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments						
Work Schedule, hours/shift =	12.0	36" Vermillion River Crossing						
days/week =	7.0							
Drilled Length, feet =	3,205							
Pilot Hole								
Production Rate, feet/hour =	20							
shifts/day =	1							
Drilling Duration, hours =	160.3							
shifts =	13.4							
Trips to change tools, shifts =	0.5							
Pilot Hole Duration, days =	13.9							
Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	7.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	217.1	217.1	217.1			10.1	12.3	673.8
shifts =	18.1	18.1	18.1			0.8	1.0	56.2
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	19.6	19.6	19.6			1.3	1.5	61.7
Summary								
HDD Duration at Site, days =	77.5							
Site Establishment	Move in	Rig Up	Rig Down	Move Out				
shifts/day =	1	1	1	1				
shifts =	0.5	1.0	1.0	0.5				
days =	0.5	1.0	1.0	0.5				

Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

(B) BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA
WADS-A-1116	ALIGNMENT SHEET M.P. 104.17 TO M.P. 105.12	1	LKB	JMS	ISSUED FOR BID
WADS-A-1115	ALIGNMENT SHEET M.P. 103.22 TO M.P. 104.17	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	JMS	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	ACM	08/07		
DESIGN CHECKER	DLB	08/05		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH VERMILION RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

HURON COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 104.1	W.O.	SCALE: AS SHOWN	DWG. WADS-H-1007	REV. 3

MP 110.3 Interstate 80

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Interstate 80 Road Crossing (Tract No. OH-ER-036.0000-RD), Nexus Gas Transmission Project, Lorain County Ohio" and dated October 26, 2015

General Site Description

The 36-inch Interstate 80 Crossing is located just east of Berlin Heights, Ohio. It involves passing beneath the eastbound and westbound lanes of I-80, as well as County Road 17 (Main Road), located immediately south of the interstate. Both sides of the interstate are open farm fields. The topography in the area is flat. An overview of the proposed crossing location is provided in Figure 1.

Figure 1: Overview of the Interstate 80 Crossing.

Subsurface Conditions

Two shallow borings to depths of approximately 30 feet were taken at the project site as part of a soils investigation for a previously planned conventional road bore crossing. The borings indicate mixtures of sand, silt, and clay, overlying shale sedimentary bedrock. Bedrock is estimated to begin around 29 feet below the ground surface.

Design Geometry & Layout

The proposed Interstate 80 Crossing has a horizontal length of 1,432 feet. It has been designed to achieve a minimum of 40 feet of cover beneath the bar ditch on the north side of Interstate 80. The design employs a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature equal to 3,600 feet. The exit point is located on the south side of the interstate to take advantage of a linear stretch of pipeline right-of-way (ROW), which will allow the pull section to be fabricated in a single segment and thus avoid downtime associated with tie-in welds.

The preliminary HDD plan and profile design for crossing Interstate 80 is attached to this report for reference.

Assessment of Feasibility

Numerous 36-inch pipelines have been installed using HDD over similar distances through similar sedimentary bedrock. Therefore, unless subsurface conditions at depth change significantly from that anticipated, the proposed crossing of Interstate 80 is feasible.

Risk Identification and Assessment

Potential construction impacts associated with installation of the proposed crossing by HDD are heaving or ground settlement along the HDD alignment, resulting in damage to Interstate 80.

HDD construction and operational risks associated the proposed crossing include failure of large diameter rock reaming tools downhole, hole misalignment at the soil/rock interface which can lead to tools or the product pipeline getting lodged, and problems resulting from circulation loss through existing fractures in the bedrock.

The overall level of risk associated with installation of the Interstate 80 Crossing using HDD is considered low.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the conservative analysis described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 252,580 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 279,019 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 2. Detailed calculations for each loading scenario are summarized in Figures 3 and 4.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 2: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	173.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	18,365	lb			
Fluidic Drag = 12 π D L C_d =	5,901	lb			
Axial Segment Weight = W_e L sinθ =	8,603	lb			
Pulling Load on Exit Tangent =	**32,869**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	85,298	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	$j = [(E I) / T]^{1/2}$ =	2,082	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.1E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	575.71	
U = (12 L) / j =	2.90		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	125,564	lb
Bending Frictional Drag = 2 μ N =	75,339	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**104,856**	**lb**			
Total Pulling Load =	**137,726**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	95.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	10,226	lb			
Fluidic Drag = 12 π D L C_d =	3,254	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**13,479**	**lb**			
Total Pulling Load =	**151,205**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	200,425	lb	
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft	
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft	
h = R [1 - cos(α/2)] =	13.70	ft	$j = [(E I) / T]^{1/2}$ =	1,359		
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	5.5E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1210.96		
U = (12 L) / j =	5.55		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	160,978	lb	
Bending Frictional Drag = 2 μ N =	96,587	lb				
Fluidic Drag = 12 π D L C_d =	21,318	lb				
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation			
Pulling Load on Entry Sag Bend =	**98,440**	**lb**				
Total Pulling Load =	**249,646**	**lb**				

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	38.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	3,990	lb			
Fluidic Drag = 12 π D L C_d =	1,289	lb			
Axial Segment Weight = W_e L sinθ =	-2,345	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**2,934**	**lb**			
Total Pulling Load =	**252,580**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,077	ok	0	ok	0	ok	0.05	ok	0.00	ok
	3,041	ok	0	ok	65	ok	0.05	ok	0.00	ok
PC										
	3,041	ok	12,083	ok	65	ok	0.31	ok	0.07	ok
	1,842	ok	12,083	ok	893	ok	0.29	ok	0.09	ok
PT										
	1,842	ok	0	ok	893	ok	0.03	ok	0.02	ok
	1,678	ok	0	ok	893	ok	0.03	ok	0.02	ok
PC										
	1,678	ok	12,083	ok	893	ok	0.29	ok	0.09	ok
	400	ok	12,083	ok	363	ok	0.27	ok	0.06	ok
PT										
	400	ok	0	ok	363	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	-4	ok	0.00	ok	0.00	ok

Figure 3: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	479.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	50,624	lb			
Fluidic Drag = 12 π D L C_d =	16,266	lb			
Axial Segment Weight = W_e L sinθ =	23,716	lb			
Pulling Load on Exit Tangent =	**90,606**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	128,032	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	j = [(E I) / T]$^{1/2}$ =	1,700	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	2.8E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	150.58	
U = (12 L) / j =	1.77		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	100,153	lb
Bending Frictional Drag = 2 μ N =	60,092	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**74,850**	**lb**			
Total Pulling Load =	**165,457**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	109.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	11,685	lb			
Fluidic Drag = 12 π D L C_d =	3,718	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**15,403**	**lb**			
Total Pulling Load =	**180,859**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	216,833	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	1,306	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	8.3E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	358.43	
U = (12 L) / j =	2.89		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	118,369	lb
Bending Frictional Drag = 2 μ N =	71,021	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**71,948**	**lb**			
Total Pulling Load =	**252,808**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	339.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	35,646	lb			
Fluidic Drag = 12 π D L C_d =	11,517	lb			
Axial Segment Weight = W_e L sinθ =	-20,951	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**26,212**	**lb**			
Total Pulling Load =	**279,019**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,399	ok	0	ok	0	ok	0.05	ok	0.00	ok
	3,080	ok	0	ok	858	ok	0.05	ok	0.02	ok
PC										
	3,080	ok	24,167	ok	858	ok	0.58	ok	0.28	ok
	2,203	ok	24,167	ok	1272	ok	0.56	ok	0.29	ok
PT										
	2,203	ok	0	ok	1272	ok	0.03	ok	0.03	ok
	2,016	ok	0	ok	1272	ok	0.03	ok	0.03	ok
PC										
	2,016	ok	24,167	ok	1272	ok	0.56	ok	0.29	ok
	1,104	ok	24,167	ok	1007	ok	0.55	ok	0.25	ok
PT										
	1,104	ok	0	ok	1007	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	-4	ok	0.00	ok	0.00	ok

Figure 4: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The Interstate 80 crossing will be installed almost entirely through bedrock. Since the Delft Equation (discussed previously in Section 5 of this report) is only applicable to uncemented subsurface material, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

The estimated duration of construction is 38 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as JDH&A's past experience in similar subsurface conditions. Refer to Figure 5 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Interstate 80 Crossing
days/week =	7.0	
Drilled Length, feet =	1,439	
Pilot Hole		
Production Rate, feet/hour =	25	
shifts/day =	1	
Drilling Duration, hours =	57.6	
shifts =	4.8	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	5.3	

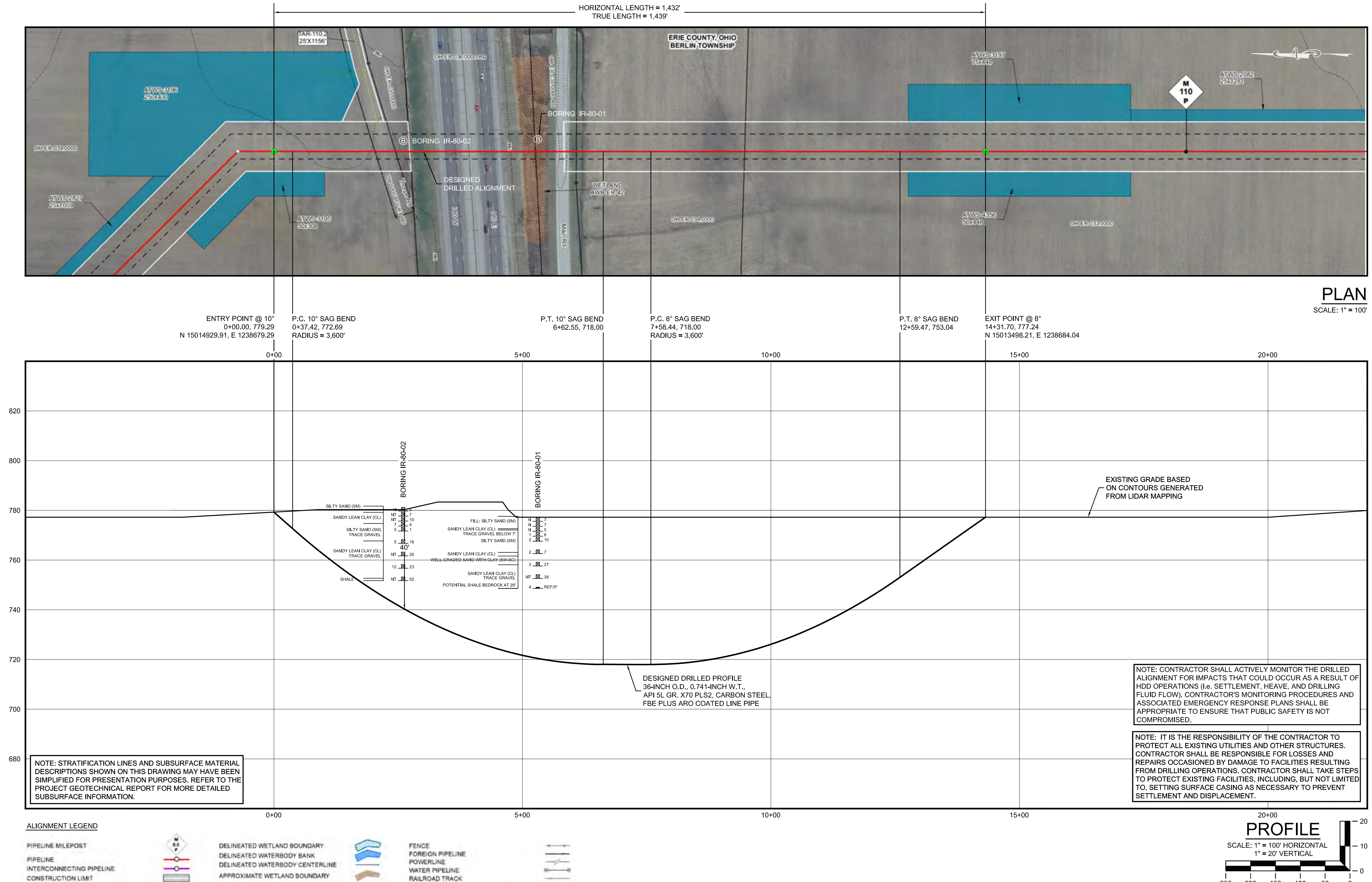
Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	97.5	97.5	97.5			4.5	5.5	302.5
shifts =	8.1	8.1	8.1			0.4	0.5	25.2
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	9.6	9.6	9.6			0.9	1.0	30.7

Summary				
HDD Duration at Site, days =	38.0			
Site Establishment	**Move in**	**Rig Up**	**Rig Down**	**Move Out**
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 5: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-93



ALIGNMENT LEGEND

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR AND SURVEY DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES

PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UNCONFINED COMPRESSIVE STRENGTH (PSI)

MOHS HARDNESS

ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC. BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED OCTOBER 26, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA
		1	LKB	JMS	ISSUED FOR BID
WADS-A-1123	ALIGNMENT SHEET M.P. 109.81 TO M.P. 110.57	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	DMP	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	DMP	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH INTERSTATE 80 CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

ERIE COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 110.1	W.O.	SCALE: AS SHOWN	DWG. WADS-H-1008	REV. 3

MP 116.8 Huron River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Huron River HDD Crossing, Nexus Gas Transmission Project, Erie County, Ohio" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch crossing of the Huron River is located near pipeline Mile Post 116.8, approximately 3 miles north of Milan, Ohio. The primary obstacles to be crossed are Highway 13 (Mudbrook Road) and the Huron River. The Huron River channel is approximately 200 feet wide at the crossing location, and based on hydrographic survey data, about 10 feet deep. The proposed HDD alignment is located north of, and runs parallel to, an existing overhead power corridor. Both sides of the crossing consist of wooded and agricultural land. Refer to Figure 1 for a general overview of the vicinity of the crossing. Figures 2 and 3 provide overviews of the entry and exit areas taken during the site reconnaissance.

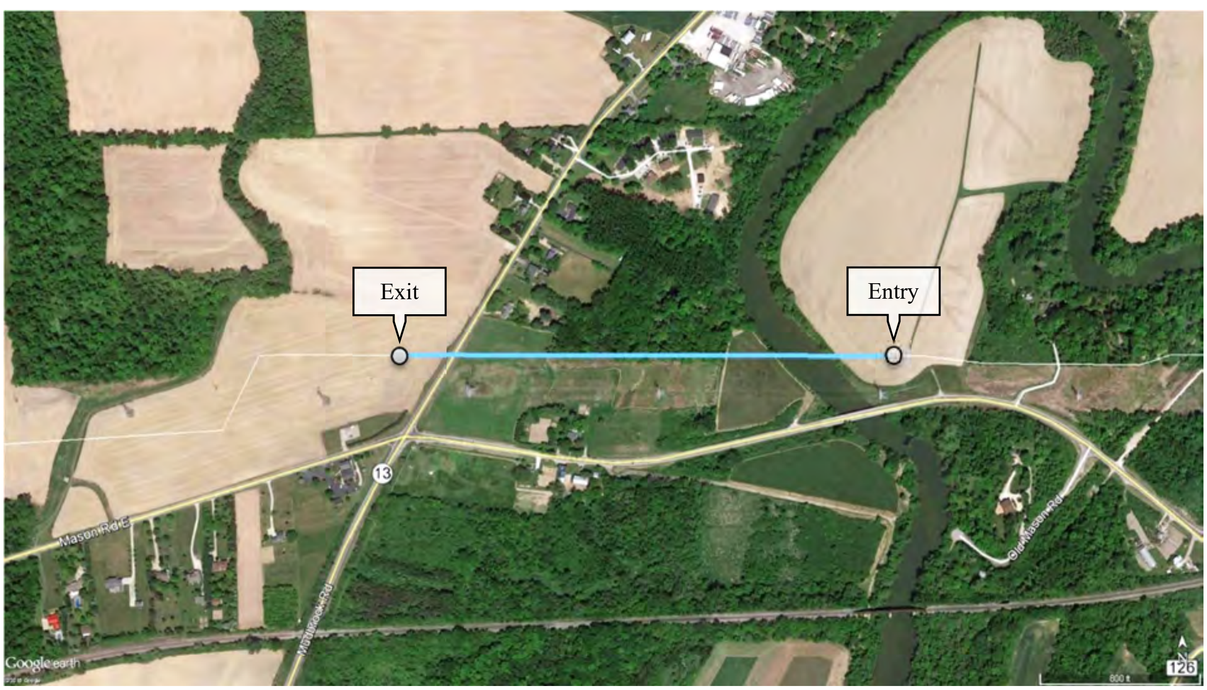


Figure 1: Overview of the Huron River Crossing

Figure 2: View looking north from Mason Road East toward entry point

Figure 3: View looking west from Mudbrook Road toward exit location

Subsurface Conditions

Four geotechnical borings were drilled at the proposed crossing site. Three of the borings were taken in a farm field on the east side of the river. One boring was taken west of Mudbrook Road. In general, the borings indicate mostly lean clay with increasing sand content with depth, overlying shale bedrock. The top of bedrock was encountered at approximately 30 feet below the ground surface on the east side and approximately 58 feet below the ground surface on the west side. In general, based on rock quality designation (RQD) index values, the bedrock is fair to good quality, with unconfined compressive strength (UCS) ranging from 4,070 psi to 13,600 psi. Methane gas was encountered at approximately 55 feet below the ground surface in boring HUR-02 and at approximately 53 feet below the surface in boring HUR-02A.

Refer to the Geotechnical data report prepared by Fugro Consultants, Inc. titled “Geotechnical Data Report, Huron River HDD Crossing, Nexus Gas Transmission Project, Erie County, Ohio” and dated September 11, 2015 for additional information.

Design Geometry & Layout

The proposed Huron River HDD design involves a horizontal length of 2,423 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and radius of curvature of 3,600 feet. The crossing design is based on obtaining 40 feet of cover beneath the river and 40 feet of cover beneath Mudbrook Road.

The entry point is located on the east side of the crossing in a farm field, approximately 400 feet from the centerline of Huron River. The exit point is located on the west side of the crossing, approximately 250 feet west of Mudbrook Road in a farm field. The exit point is located on the west side to make use of the open farm fields for pull section fabrication, which allows continuous stringing and avoids the necessity for a tie-in weld during pullback.

Workspace available for HDD operations is shown on the HDD plan and profile drawing included in this site-specific report.

Assessment of Feasibility

Based on a review of available geotechnical and other site-specific mapping, the proposed 36-inch crossing of the Huron River is feasible. Although large diameter crossings through rock have a higher risk of operational problems, with the right downhole tool selections and sound planning, skilled and experienced HDD contractors will be able to complete the crossing. This is not to say the crossing will be easy. It involves an elevation differential of 47 feet. This means that during reaming operations, approximately 400 feet of the reamed hole on the west side will be empty as the drilling fluid seeks equilibrium at lower elevations. This can make hole stabilization difficult which in turn can complicate reaming operations.

Risk Identification and Assessment

The most significant impact associated with HDD construction at this location involves damage to Mudbrook Road due to sinkhole formation. As mentioned previously, the reamed hole on the west side beneath Mudbrook Road will likely be empty and will be susceptible to inflow of loose soil, which eventually can result in sinkhole formation at the ground surface. The risk of sinkhole formation in the overburden is amplified by what are likely to be extended reaming durations associated with passing through hard rock. Temporary surface casing may be required to reduce the risk of settlement to Mudbrook Road. Inadvertent drilling fluid returns surfacing within the river are also a possibility. Given the depth of cover however, the risk of drilling fluid impact to the river is considered low.

HDD construction and operational problems involved with the Huron River Crossing include the possibility of failure of large diameter rock reaming tools downhole, hole misalignment at the soil/rock interface which can lead to tools binding or the product pipeline getting lodged, and operational problems resulting from circulation loss downhole. In addition, caving of the reamed hole on the west side resulting from lack of drilling fluid can complicate reaming operations. Finally, methane gas was detected in two of the borings. Although in JDH&A's experience it would be rare that a methane pocket would result in a failed HDD installation, there is the potential that methane gas, if the flow is great enough, could pose a safety risk during HDD operations. Prior to construction, HDD contractors should develop contingency measures to implement in the event that gas flow is encountered. Likewise, it also possible that the annulus surrounding the installed pipeline could serve as a conduit for continued gas flow to the surface. Therefore, a post-construction monitoring plan should be established so that remedial measures to control or eliminate gas flow, if needed, can be employed.

Based on the length of the crossing as well as the subsurface conditions, the risk level is considered average.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 368,009 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 467,524 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L = 406.0 ft — Effective Weight, $W_e = W + W_b - W_m$ = 279.0 lb/ft
Exit Angle, θ = 10.0 °

Frictional Drag = $W_e\ L\ \mu \cos\theta$ = 33,469 lb

Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 0 lb — Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input

Axial Segment Weight = $W_e\ L \sin\theta$ = -19,671 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Exit Tangent = 13,797 lb

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	79,670	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ = 13.70 ft — $j = [(E\ I) / T]^{1/2}$ = 2,155

$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ = 4.0E+06 — $X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ = 870.79

$U = (12\ L) / j$ = 3.50 — $N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ = 151,604 lb

Bending Frictional Drag = $2\ \mu\ N$ = 90,962 lb

Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 21,318 lb

Axial Segment Weight = $W_e\ L \sin\theta$ = 19,464 lb

Pulling Load on Exit Sag Bend = 131,745 lb
Total Pulling Load = 145,542 lb

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L = 762.3 ft — Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = $W_e\ L\ \mu$ = 81,290 lb

Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 25,866 lb

Axial Segment Weight = $W_e\ L \sin\theta$ = 0 lb

Pulling Load on Bottom Tangent = 107,156 lb
Total Pulling Load = 252,698 lb

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	304,462	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ = 13.70 ft — $j = [(E\ I) / T]^{1/2}$ = 1,102

$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ = 6.0E+06 — $X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ = 1335.01

$U = (12\ L) / j$ = 6.84 — $N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ = 169,456 lb

Bending Frictional Drag = $2\ \mu\ N$ = 101,673 lb

Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 21,318 lb

Axial Segment Weight = $W_e\ L \sin\theta$ = -19,464 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 103,527 lb
Total Pulling Load = 356,225 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 152.6 ft — Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft
Entry Angle, θ = 10.0 °

Frictional Drag = $W_e\ L\ \mu \cos\theta$ = 16,024 lb

Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 5,177 lb

Axial Segment Weight = $W_e\ L \sin\theta$ = -9,418 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 11,783 lb
Total Pulling Load = 368,009 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,484	ok	0	ok	0	ok	0.07	ok	0.01	ok
	4,340	ok	0	ok	401	ok	0.07	ok	0.01	ok
PC										
	4,340	ok	12,083	ok	401	ok	0.33	ok	0.10	ok
	3,079	ok	12,083	ok	1229	ok	0.31	ok	0.12	ok
PT										
	3,079	ok	0	ok	1229	ok	0.05	ok	0.04	ok
	1,773	ok	0	ok	1229	ok	0.03	ok	0.03	ok
PC										
	1,773	ok	12,083	ok	1229	ok	0.29	ok	0.11	ok
	168	ok	12,083	ok	401	ok	0.27	ok	0.06	ok
PT										
	168	ok	0	ok	401	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000 in	Fluid Drag Coefficient, C_d =	0.025 psi	
Pipe Weight, W =	279.0 lb/ft	Ballast Weight / ft Pipe, W_b =	405.5 lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30	Drilling Mud Displaced / ft Pipe, W_m =	634.5 lb	(If Submerged)
		Above Ground Load =	0 lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L = 707.4 ft
Exit Angle, θ = 10.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 74,289 lb
Fluidic Drag = $12 \pi D L C_d$ = 24,003 lb
Axial Segment Weight = $W_e L \sin\theta$ = 43,664 lb

Pulling Load on Exit Tangent = 141,955 lb

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 314.2 ft
Segment Angle with Horizontal, θ = -10.0 °
Deflection Angle, α = -5.0 °
Average Tension, T = 186,767 lb
Radius of Curvature, R = 1,800 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 6.85 ft
$j = [(E I) / T]^{1/2}$ = 1,407
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 7.7E+05
$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 329.22
$U = (12 L) / j$ = 2.68
$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 115,386 lb
Bending Frictional Drag = $2 \mu N$ = 69,232 lb
Fluidic Drag = $12 \pi D L C_d$ = 10,659 lb
Axial Segment Weight = $W_e L \sin\theta$ = 9,732 lb

Pulling Load on Exit Sag Bend = 89,623 lb
Total Pulling Load = 231,578 lb

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L = 843.7 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = $W_e L \mu$ = 89,970 lb
Fluidic Drag = $12 \pi D L C_d$ = 28,627 lb
Axial Segment Weight = $W_e L \sin\theta$ = 0 lb

Pulling Load on Bottom Tangent = 118,597 lb
Total Pulling Load = 350,175 lb

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 314.2 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °
Average Tension, T = 391,319 lb
Radius of Curvature, R = 1,800 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 6.85 ft
$j = [(E I) / T]^{1/2}$ = 972
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 1.1E+06
$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 476.07
$U = (12 L) / j$ = 3.88
$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 135,602 lb
Bending Frictional Drag = $2 \mu N$ = 81,361 lb
Fluidic Drag = $12 \pi D L C_d$ = 10,659 lb
Axial Segment Weight = $W_e L \sin\theta$ = -9,732 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 82,288 lb
Total Pulling Load = 432,463 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 454.0 ft
Entry Angle, θ = 10.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 47,680 lb
Fluidic Drag = $12 \pi D L C_d$ = 15,405 lb
Axial Segment Weight = $W_e L \sin\theta$ = -28,024 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 35,061 lb
Total Pulling Load = 467,524 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	5,696	ok	0	ok	0	ok	0.09	ok	0.01	ok
	5,269	ok	0	ok	1194	ok	0.08	ok	0.04	ok
PC										
	5,269	ok	24,167	ok	1194	ok	0.61	ok	0.34	ok
	4,266	ok	24,167	ok	1608	ok	0.60	ok	0.36	ok
PT										
	4,266	ok	0	ok	1608	ok	0.07	ok	0.06	ok
	2,821	ok	0	ok	1608	ok	0.04	ok	0.06	ok
PC										
	2,821	ok	24,167	ok	1608	ok	0.57	ok	0.33	ok
	1,729	ok	24,167	ok	1194	ok	0.56	ok	0.28	ok
PT										
	1,729	ok	0	ok	1194	ok	0.03	ok	0.03	ok
Exit Point	0	ok	0	ok	-666	ok	0.00	ok	0.01	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case Scenario)

Hydrofracture Evaluation

The Huron River Crossing will be installed almost entirely through bedrock. Since the Delft Equation (Discussed previously in Section 5 of this report) is only applicable to soil, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

The estimated duration of construction for the proposed crossing is 60 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 7 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Huron River Crossing.
days/week =	7.0	
Drilled Length, feet =	2,437	
Pilot Hole		
Production Rate, feet/hour =	25	
shifts/day =	1	
Drilling Duration, hours =	97.5	
shifts =	8.1	
Trips to change tools, shifts =	1.0	
Pilot Hole Duration, days =	9.1	

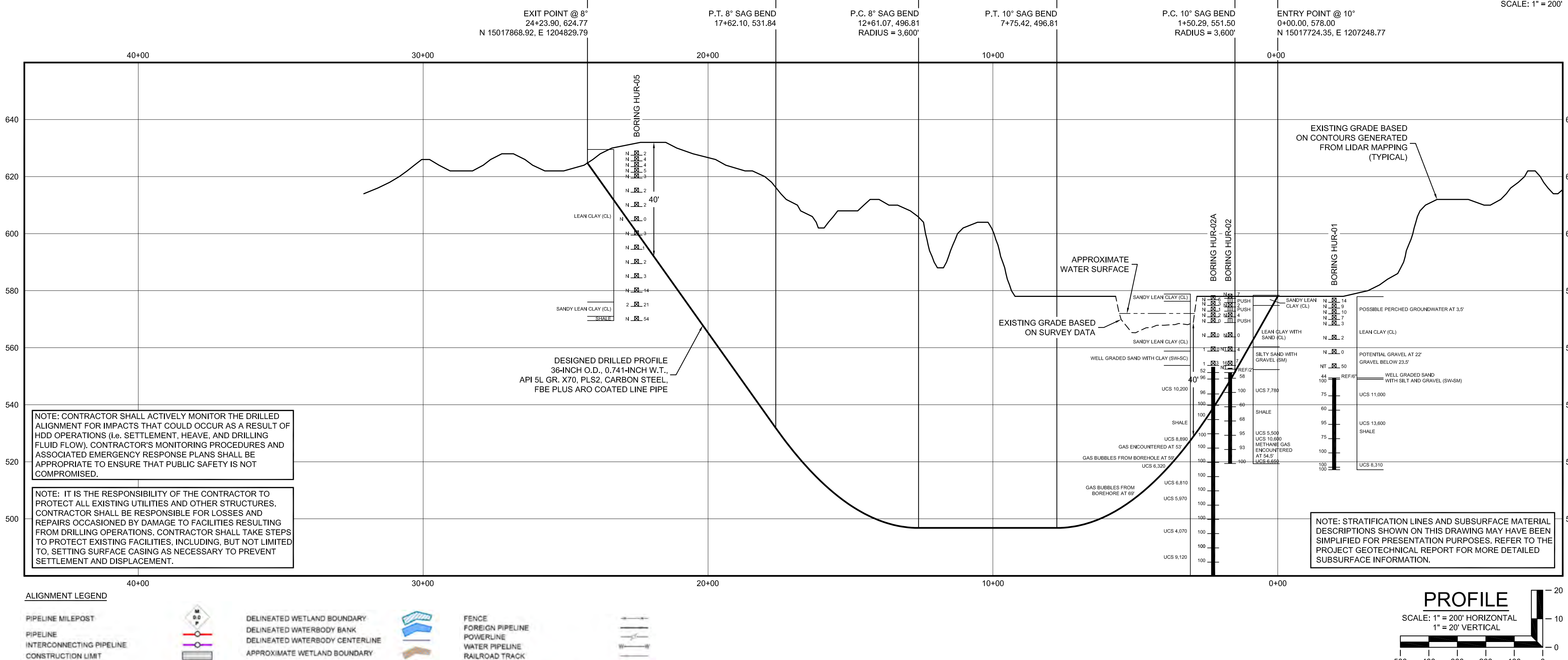
Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	7.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	165.1	165.1	165.1			7.7	9.4	512.3
shifts =	13.8	13.8	13.8			0.6	0.8	42.7
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	15.3	15.3	15.3			1.1	1.3	48.2

Summary				
HDD Duration at Site, days =	59.3			
Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

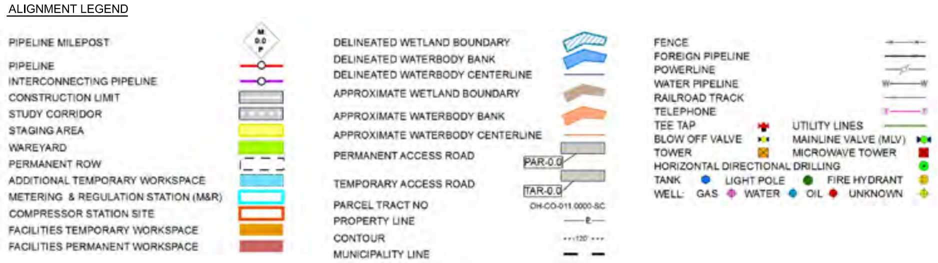
Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-103



ALIGNMENT LEGEND



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

Ⓑ BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		2	ACM	JMS	RE-ISSUED FOR FERC
WADS-A-1131	ALIGNMENT SHEET M.P. 117.20 TO M.P. 118.15	1	LKB	JMS	ISSUED FOR BID
WADS-A-1130	ALIGNMENT SHEET M.P. 116.25 TO M.P. 117.20	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	DMP	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	DMP	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH HURON RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

ERIE COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 116.8	W.O.	SCALE: AS SHOWN	DWG. WADS-H-1009	REV. 2

IG.#

MP 146.3R Sandusky River

Base Data

In performing the HDD design and engineering analysis, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Sandusky River HDD Crossing (REV-1), Nexus Gas Transmission Project, Sandusky County, Ohio" and dated October 2, 2015

General Site Description

The 36-inch Sandusky River Crossing is located near the intersection of State Highway 53 and Interstate 90 in Freemont, Ohio. The current revision of the HDD alignment has been shifted approximately 640 feet south of the original location (Revision 0) in order to avoid a municipal well protection zone and minimize the risk of impact to the wells. The primary obstacles to be crossed are the meandering Sandusky River as well as State Highway 53. The river is approximately 500 feet wide at the crossing location. Based on hydrographic data associated with the previous HDD alignment, the depth is approximately 15 feet. An overview of the proposed crossing location is provided in Figure 1.

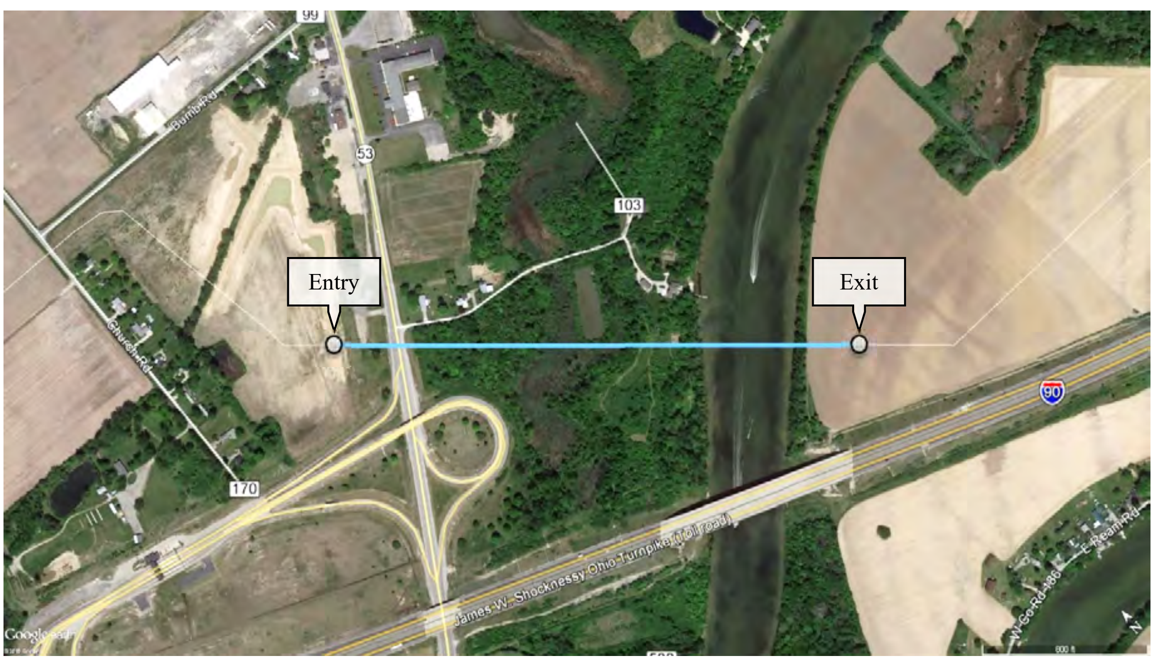


Figure 1: Overview of the Sandusky River Crossing

Subsurface Conditions

Three exploratory borings were taken as part of the geotechnical investigation conducted by Fugro Consultants, Inc. All of the borings are located on the west side of the river and approximately 500 to 600 feet north of the current alignment. SAN-1-4 encountered soft to very hard fat clay overlying dolomite bedrock. The top of bedrock was encountered at 60 feet. SAN-1-5 revealed loose to very loose fat clay to a depth of about 32 feet, and firm lean clay with gravel to 52 feet, overlying limestone bedrock. Boring SAN-1-2 encountered similar soils, with primarily clayey soils overlying limestone bedrock at approximately 75 feet. Rock quality designation (RQD) index values averaged 57 for SAN-1-4, 44 for SAN-1-5, and 86 for SAN-1-2 indicating fair to good quality rock. Small solution cavities are noted in all three borings. SAN-1-4 encountered voids from 101.5 feet to 103 feet and again at 105.5 feet. SAN-1-5 experienced small voids from 60.4 to 60.8 feet and SAN-1-2 from roughly 85 feet to termination at 135 feet. Unconfined compressive strength (UCS) of representative samples in borings SAN-1-2, SAN-1-4 and SAN-1-5 indicate values ranging from 5 psi to 11,400 psi, with an average of 4,689 psi.

In addition to the exploratory borings discussed above, four additional borings were taken as part of a subsurface investigation associated with a previous alignment located 800 to 1,500 feet to the southwest. The four additional borings encountered similar subsurface conditions to those described previously. Small voids or solution cavities were encountered in the dolomite/limestone bedrock in nearby borings SAN-02 and SAN-03 with similar loss of drilling fluids noted. UCS tests for bedrock ranged from 1,240 psi to 19,400 psi.

In addition to the possible voids in bedrock, other adverse soil conditions were encountered. Glacial till, while not revealed in the northern geotechnical borings, was observed in the four borings taken as part of the southern alignment, and therefore may be present at the crossing site. Cobble and boulders are commonly found in glacial deposits. Borings SAN-03 and SAN-05 revealed the presence of shale boulders but granite boulders were also suspected in the area.

Refer to the geotechnical data report prepared by Fugro Consultants, Inc. titled “Geotechnical Data Report, Sandusky River HDD Crossing (REV-1), Nexus Gas Transmission Project, Sandusky County, Ohio” and dated October 2, 2015 for additional information relative to the subsurface.

Design Geometry & Layout

The proposed crossing design involves a horizontal length of 2,586 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature of 3,600 feet. The crossing design maintains 40 feet of cover beneath the bottom of the east edge of the Sandusky River and 54 feet of cover beneath State Highway 53.

The exit point is located on the east side of the river in order to take advantage of an open farm field that can be used for pull section fabrication. Temporary workspace for pull section fabrication extends east and then curves to run parallel to Interstate 90, which allows for fabrication of the pull section in a single segment. The entry point is located on the west side of the river, just west of Ohio State Route 53 in an open field. A copy of the preliminary HDD plan and profile design drawing is included at the end of this section.

Assessment of Feasibility

Given solely the length and diameter of the proposed installation, it is within the range of what has been successfully completed using HDD. However, subsurface conditions have the potential to be problematic and increase the risk of HDD operational problems. More specifically, the boring logs indicate the presence of solution cavities in the limestone and dolomite bedrock. The risk of a twist-off during pilot hole drilling is magnified when large solution cavities are present. Penetration of a very large solution cavity during pilot hole drilling may leave the drill string and/or other tooling unconstrained potentially allowing it to deflect laterally. Continued rotation of a drill string when subjected to such deflection, particularly when it is under compression during pilot hole drilling, can result in failure of the drill pipe due to low-cycle fatigue.

Based on available geotechnical information, it appears that solution cavities are relatively small and limited in extent, and therefore should not prevent a successful installation. However, the risk of a encountering a large void that complicates HDD operations cannot be ruled out.

Risk Identification and Assessment

The primary construction impacts associated with installation by HDD at the Sandusky site are inadvertent drilling fluid returns surfacing within the river or within the topographically low marshy area near station 13+00. Likewise, drilling fluid impact to State Highway 53 in the form of heaving or settlement cannot be ruled out. Furthermore, due to karst features in the bedrock, there is a possibility that drilling fluid may impact water wells located within the municipal well protection zone. Although the risk is considered low given the distance (640 feet north of the current alignment), it is possible that drilling fluid could flow through a series of interconnected cavities and make its way into one of the wells.

Notable risks that may complicate HDD construction include encountering cobble or boulders, or as mentioned previously, penetrating karst features in bedrock, which may result in drill pipe failure. Other operational problems include failure of large diameter rock reaming tools downhole, hole misalignment at the soil/rock interface and operational problems resulting from loss of circulation.

Due to subsurface conditions, the risk level associated with the proposed crossing of the Sandusky River is average to high.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the conservative analysis described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 421,118 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 449,509. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each installation loading scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	435.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	45,983	lb			
Fluidic Drag = 12 π D L C_d =	14,775	lb			
Axial Segment Weight = W_e L sinθ =	21,541	lb			
Pulling Load on Exit Tangent =	**82,299**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	135,749	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	$j = [(E\ I) / T]^{1/2}$ =	1,651	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.7E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	724.25	
U = (12 L) / j =	3.65		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	128,969	lb
Bending Frictional Drag = 2 μ N =	77,381	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**106,899**	**lb**			
Total Pulling Load =	**189,198**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	735.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	78,403	lb			
Fluidic Drag = 12 π D L C_d =	24,947	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**103,350**	**lb**			
Total Pulling Load =	**292,548**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	345,331	lb	
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft	
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft	
h = R [1 - cos(α/2)] =	13.70	ft	$j = [(E\ I) / T]^{1/2}$ =	1,035		
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	6.1E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1368.18		
U = (12 L) / j =	7.29		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	172,856	lb	
Bending Frictional Drag = 2 μ N =	103,714	lb				
Fluidic Drag = 12 π D L C_d =	21,318	lb				
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation			
Pulling Load on Entry Sag Bend =	**105,567**	**lb**				
Total Pulling Load =	**398,115**	**lb**				

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	297.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	31,282	lb			
Fluidic Drag = 12 π D L C_d =	10,107	lb			
Axial Segment Weight = W_e L sinθ =	-18,386	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**23,003**	**lb**			
Total Pulling Load =	**421,118**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	5,131	ok	0	ok	0	ok	0.08	ok	0.01	ok
	4,850	ok	0	ok	619	ok	0.08	ok	0.02	ok
PC										
	4,850	ok	12,083	ok	619	ok	0.34	ok	0.11	ok
	3,564	ok	12,083	ok	1448	ok	0.32	ok	0.14	ok
PT										
	3,564	ok	0	ok	1448	ok	0.06	ok	0.05	ok
	2,305	ok	0	ok	1448	ok	0.04	ok	0.04	ok
PC										
	2,305	ok	12,083	ok	1448	ok	0.30	ok	0.13	ok
	1,003	ok	12,083	ok	917	ok	0.28	ok	0.08	ok
PT										
	1,003	ok	0	ok	917	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	-1	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	741.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = $W_e L \mu \cos\theta$ =	78,242	lb			
Fluidic Drag = $12 \pi D L C_d$ =	25,140	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	36,654	lb			
Pulling Load on Exit Tangent =	**140,036**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	178,692	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	4.38	ft	$j = [(E I) / T]^{1/2}$ =	1,439	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.6E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	192.10	
$U = (12 L) / j$ =	2.10		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	104,253	lb
Bending Frictional Drag = $2 \mu N$ =	62,552	lb			
Fluidic Drag = $12 \pi D L C_d$ =	8,527	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**77,311**	**lb**			
Total Pulling Load =	**217,347**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	748.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e L \mu$ =	79,860	lb			
Fluidic Drag = $12 \pi D L C_d$ =	25,411	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	0	lb			
Pulling Load on Bottom Tangent =	**105,271**	**lb**			
Total Pulling Load =	**322,618**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	362,923	lb	
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft	
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft	
$h = R [1 - \cos(\alpha/2)]$ =	6.85	ft	$j = [(E I) / T]^{1/2}$ =	1,010		
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	1.1E+06		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	461.25		
$U = (12 L) / j$ =	3.73		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	132,805	lb	
Bending Frictional Drag = $2 \mu N$ =	79,683	lb				
Fluidic Drag = $12 \pi D L C_d$ =	10,659	lb				
Axial Segment Weight = $W_e L \sin\theta$ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation			
Pulling Load on Entry Sag Bend =	**80,610**	**lb**				
Total Pulling Load =	**403,228**	**lb**				

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	599.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = $W_e L \mu \cos\theta$ =	62,938	lb			
Fluidic Drag = $12 \pi D L C_d$ =	20,335	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-36,992	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**46,281**	**lb**			
Total Pulling Load =	**449,509**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	5,476	ok	0	ok	0	ok	0.09	ok	0.01	ok
	4,913	ok	0	ok	1412	ok	0.08	ok	0.05	ok
PC										
	4,913	ok	24,167	ok	1412	ok	0.61	ok	0.35	ok
	3,931	ok	24,167	ok	1826	ok	0.59	ok	0.37	ok
PT										
	3,931	ok	0	ok	1826	ok	0.06	ok	0.08	ok
	2,648	ok	0	ok	1826	ok	0.04	ok	0.07	ok
PC										
	2,648	ok	24,167	ok	1826	ok	0.57	ok	0.35	ok
	1,706	ok	24,167	ok	1561	ok	0.56	ok	0.31	ok
PT										
	1,706	ok	0	ok	1561	ok	0.03	ok	0.05	ok
Exit Point	0	ok	0	ok	-1	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The Sandusky River crossing will be installed almost entirely through bedrock. Since the Delft Equation (Discussed previously in Section 5 of this report) is only applicable to uncemented subsurface materials, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fracture, joints, or solution cavities.

Construction Duration

The estimated duration of construction for the Sandusky River Crossing is 65 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "Installation of Pipelines by Horizontal Directional Drilling"[1], as well as past experience in similar subsurface conditions. Refer to Figure 7 for additional information relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

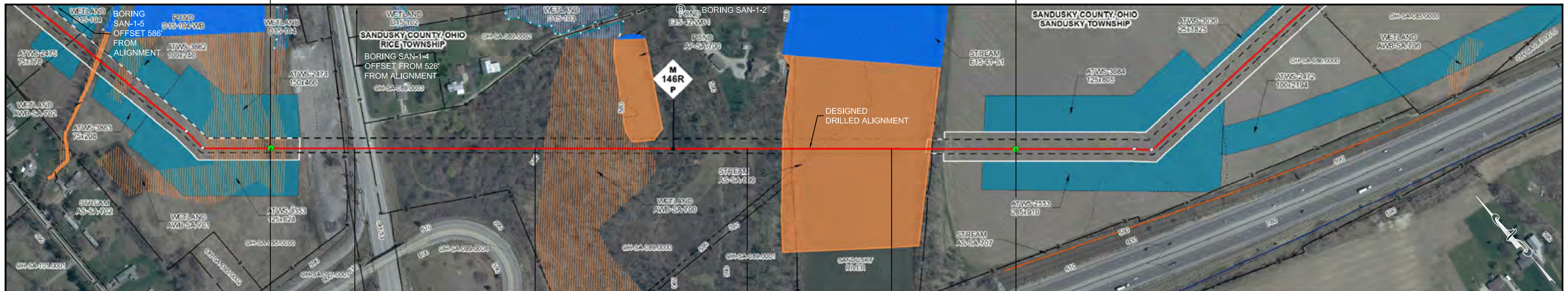
General Data		Comments						
Work Schedule, hours/shift =	12.0	36" Sandusky River Crossing						
days/week =	7.0							
Drilled Length, feet =	2,600							
Pilot Hole								
Production Rate, feet/hour =	20							
shifts/day =	1							
Drilling Duration, hours =	130.0							
shifts =	10.8							
Trips to change tools, shifts =	0.5							
Pilot Hole Duration, days =	11.3							
Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	176.1	176.1	176.1			8.2	10.0	546.6
shifts =	14.7	14.7	14.7			0.7	0.8	45.6
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	16.2	16.2	16.2			1.2	1.3	51.1
Summary								
HDD Duration at Site, days =	64.4							
Site Establishment	Move in	Rig Up	Rig Down	Move Out				
shifts/day =	1	1	1	1				
shifts =	0.5	1.0	1.0	0.5				
days =	0.5	1.0	1.0	0.5				

Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-112

HORIZONTAL PLAN LENGTH = 2,586'
TRUE LENGTH = 2,600'



PLAN
SCALE: 1" = 200'

ENTRY POINT @ 10° 0+00.00, 586.82 N 15044763.56, E 1063348.59

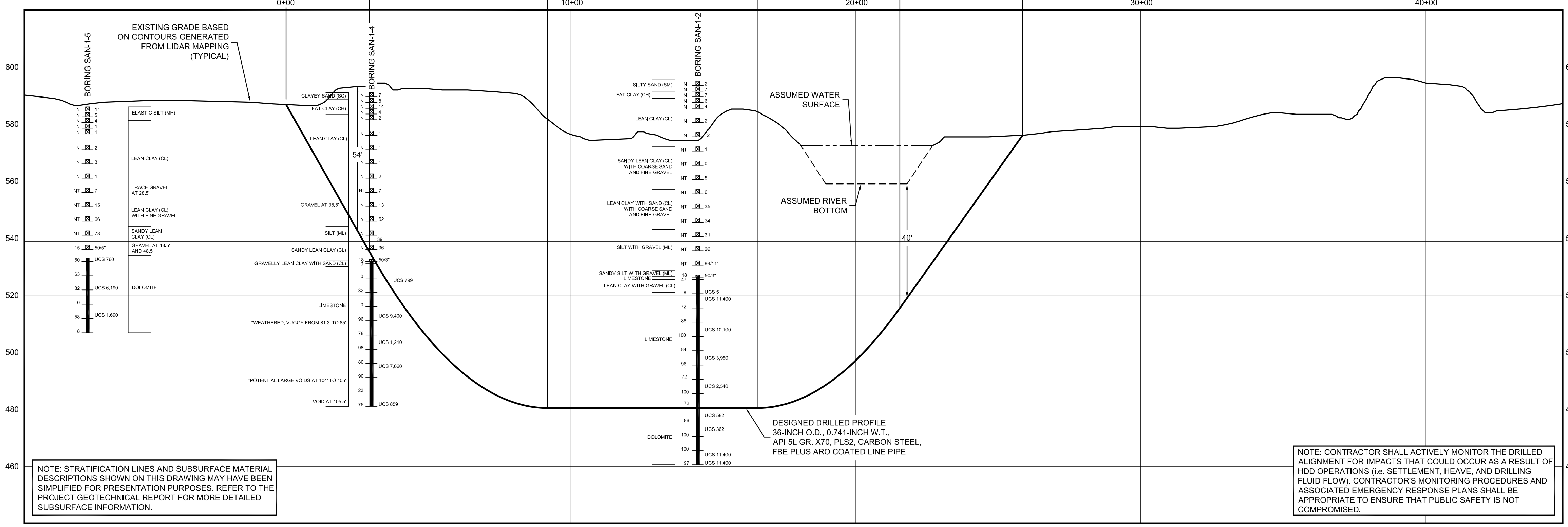
P.C. 10° SAG BEND 2+93.36,535.04 RADIUS = 3,600'

P.C. 10° SAG BEND 9+18.49, 480.40

P.C. 8° SAG BEND 16+53.79, 480.40 RADIUS = 3,600'

P.C. 8° SAG BEND 21+54.82, 515.44

EXIT POINT @ 8° 25+86.01, 576.04 N 15043014.34, E 1065253.24



NOTE: STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING MAY HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES. REFER TO THE PROJECT GEOTECHNICAL REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.

NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

PROFILE
SCALE: 1" = 200' HORIZONTAL
1" = 20' VERTICAL

ALIGNMENT LEGEND

PIPELINE MILEPOST
PIPELINE
INTERCONNECTING PIPELINE
CONSTRUCTION LIMIT
STUDY CORRIDOR
STAGING AREA
WAREYARD
PERMANENT ROW
ADDITIONAL TEMPORARY WORKSPACE
METERING & REGULATION STATION (M&R)
COMPRESSOR STATION SITE
FACILITIES TEMPORARY WORKSPACE
FACILITIES PERMANENT WORKSPACE
DELINEATED WETLAND BOUNDARY
DELINEATED WATERBODY BANK
DELINEATED WATERBODY CENTERLINE
APPROXIMATE WETLAND BOUNDARY
APPROXIMATE WATERBODY BANK
APPROXIMATE WATERBODY CENTERLINE
PERMANENT ACCESS ROAD
TEMPORARY ACCESS ROAD
PARCEL TRACT NO
PROPERTY LINE
CONTOUR
MUNICIPALITY LINE
FENCE
FOREIGN PIPELINE
POWERLINE
WATER PIPELINE
RAILROAD TRACK
TELEPHONE
TEE TAP
BLOW OFF VALVE
TOWER
UTILITY LINES
MAINLINE VALVE (MLV)
MICROWAVE TOWER
HORIZONTAL DIRECTIONAL DRILLING
TANK, LIGHT POLE, FIRE HYDRANT
WELL: GAS, WATER, OIL, UNKNOWN

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UNCONFINED COMPRESSIVE STRENGTH (PSI)
MOHS HARDNESS
ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC. BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED OCTOBER 2, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		2	LKB	JMS	RE-ISSUED FOR FERC
		1	LKB	JMS	SHIFT HDD ALIGNMENT SOUTH, REVISE DESIGN, ISSUED FOR BID
CLYD-A-1161	ALIGNMENT SHEET M.P. 145.34 TO M.P. 146.29	0	LKB	JMS	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	LKB	01/16		
PROJECT MANAGER	JMS	01/16		
DESIGN ENGINEER	LKB	01/16		
DESIGN CHECKER	JMS	01/28		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH SANDUSKY RIVER
BY HORIZONTAL DIRECTIONAL DRILLING
SANDUSKY COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 146.3R	W.O.	SCALE: AS SHOWN	DWG. CLYD-H-1010	REV. 2

MP 162.6R Portage River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. "Geotechnical Data Report, Portage River HDD Crossing, Nexus Gas Transmission Project, Sandusky County, Ohio" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Portage River Crossing is located near pipeline Mile Post 162.6R, southwest of Woodville, Ohio. The primary obstacles to be crossed are Pemberville Road, the channel of Portage River, and Fort Findlay Road. The land on each side of the river is essentially flat. Land use is agricultural. At the proposed crossing location, the Portage River is roughly 240 feet from bank to bank, and just over 4 feet deep at the deepest point based on hydrographic survey data. The topography slopes gently to the south toward Portage River, then rises approximately 20 feet up the south bank, and then flattens toward the south. An overview of the proposed crossing location is shown in Figure 1. Photographs taken during the site reconnaissance are provided in Figures 2 and 3.

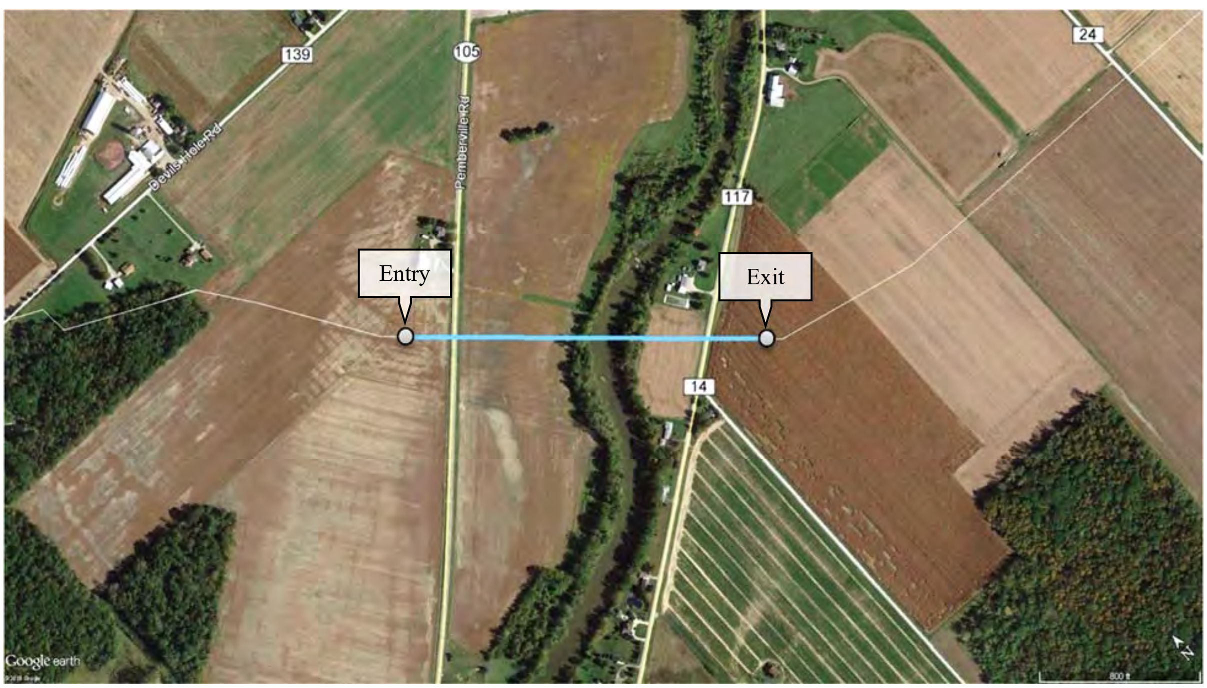


Figure 1: Overview of the Portage River Crossing

Figure 2: View looking west toward entry location

Figure 3: Portage River at proposed crossing location

Subsurface Conditions

Four geotechnical borings were taken at the proposed crossing site as part of the site-specific investigation conducted by Fugro Consultants, Inc. Two borings were taken on the north side of the river and two on the south side of the river. The borings generally encountered lean clay and gravel to depths of approximately 10 to 20 feet below the ground surface. Limestone was encountered beneath the clay at elevation 620 feet in all four borings. The boring logs indicate drilling fluid circulation was lost in two of the borings, with possible small voids encountered in all three of the borings. Unconfined compressive strength for the limestone ranged from 1,380 psi to 11,300 psi. Rock Quality Designation (RQD) index values indicate good quality, competent bedrock overall.

Refer to the geotechnical data report prepared by Fugro Consultants, Inc. "Geotechnical Data Report, Portage River HDD Crossing, Nexus Gas Transmission Project, Sandusky County, Ohio" and dated September 11, 2015 for additional information.

Design Geometry & Layout

The proposed Portage River HDD design has a horizontal length of 1,790 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and maintains 40 feet of cover beneath Pemberville Road and Fort Findlay Road. The crossing passes deep within limestone bedrock and maintains 67 feet of separation from the bottom of Portage River.

The entry point is located on the north side of the crossing in a farm field, approximately 262 feet from the centerline of Pemberville Road and 1,005 feet from the centerline of Portage River. The exit point is located on the south side of Fort Findlay Road in a farm field, approximately 270 feet from the centerline of Fort Findlay Road and 785 feet from the centerline of the river. The exit point is located on the south side to make use of the open farm fields for pull section fabrication, which allows continuous stringing and avoids the necessity for a tie-in weld during pullback.

The proposed HDD design, as well as available workspace for HDD operations, is shown on the preliminary HDD plan and profile drawing included at the end of this site-specific report.

Assessment of Feasibility

Given solely the length and diameter of the proposed installation, it is within the range of what has been successfully completed using HDD. However, subsurface conditions have the potential to be problematic and increase the risk of HDD operational problems. More specifically, the borings logs indicate solution cavities are present in the limestone and dolomite bedrock. The risk of a twist-off during pilot hole drilling is magnified when large solution cavities are present. Penetration of a very large solution cavity during pilot hole drilling may leave the drill string and/or other tooling unconstrained potentially allowing it to deflect laterally. Continued rotation of a drill string when subjected to such deflection, particularly when it is under compression during pilot hole drilling, can result in failure of the drill pipe due to low-cycle fatigue.

Based on available geotechnical information, it appears that solution cavities are relatively small and limited in overall extent. Therefore, the cavities should not prevent a successful installation. However, the risk of a encountering a large void cannot be ruled out.

Risk Identification and Assessment

Notable risks to consider at this crossing are impacts to both Pemberville and Fort Findlay Road resulting from drilling fluid flow (inadvertent returns, settlement, or heave), as well as inadvertent drilling fluid returns within the Portage River.

Construction risks associated with the Portage River Crossing include failure of large diameter rock reaming tools downhole, hole misalignment at the soil/rock interface which can lead to tools or the product pipeline getting lodged, and operational problems resulting from circulation loss through existing fractures or voids. Small solution cavities (voids) were noted in two of the borings. Although small voids can serve as a flow conduit for drilling fluid, they generally do not prevent a successful installation. However, a very large solution cavity, if encountered, can seriously restrict HDD operations.

Overall, the risk level for the Portage River crossing is considered average.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the conservative analysis described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 307,266 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 334,509 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each installation loading scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	357.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	37,697	lb			
Fluidic Drag = 12 π D L C_d =	12,113	lb			
Axial Segment Weight = W_e L sinθ =	17,660	lb			
Pulling Load on Exit Tangent =	**67,470**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	120,612	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	$j = [(E I) / T]^{1/2}$ =	1,751	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.5E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	686.52	
U = (12 L) / j =	3.44		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	127,943	lb
Bending Frictional Drag = 2 μ N =	76,766	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**106,284**	**lb**			
Total Pulling Load =	**173,754**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	139.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	14,873	lb			
Fluidic Drag = 12 π D L C_d =	4,732	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**19,605**	**lb**			
Total Pulling Load =	**193,359**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	243,625	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	13.70	ft	$j = [(E I) / T]^{1/2}$ =	1,232	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	5.7E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1271.56	
U = (12 L) / j =	6.12		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	164,463	lb
Bending Frictional Drag = 2 μ N =	98,678	lb			
Fluidic Drag = 12 π D L C_d =	21,318	lb			
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**100,532**	**lb**			
Total Pulling Load =	**293,890**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	173.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	18,189	lb			
Fluidic Drag = 12 π D L C_d =	5,877	lb			
Axial Segment Weight = W_e L sinθ =	-10,691	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**13,375**	**lb**			
Total Pulling Load =	**307,266**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,743	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,581	ok	0	ok	448	ok	0.06	ok	0.01	ok
PC										
	3,581	ok	12,083	ok	448	ok	0.32	ok	0.09	ok
	2,356	ok	12,083	ok	1276	ok	0.30	ok	0.12	ok
PT										
	2,356	ok	0	ok	1276	ok	0.04	ok	0.04	ok
	2,117	ok	0	ok	1276	ok	0.03	ok	0.03	ok
PC										
	2,117	ok	12,083	ok	1276	ok	0.30	ok	0.12	ok
	822	ok	12,083	ok	745	ok	0.28	ok	0.07	ok
PT										
	822	ok	0	ok	745	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	-7	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	662.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	69,957	lb			
Fluidic Drag = 12 π D L C_d =	22,478	lb			
Axial Segment Weight = W_e L sinθ =	32,773	lb			
Pulling Load on Exit Tangent =	**125,207**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	163,494	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	j = [(E I) / T]$^{1/2}$ =	1,504	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	3.4E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	180.41	
U = (12 L) / j =	2.01		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	103,024	lb
Bending Frictional Drag = 2 μ N =	61,814	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**76,573**	**lb**			
Total Pulling Load =	**201,780**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	153.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	16,331	lb			
Fluidic Drag = 12 π D L C_d =	5,197	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**21,528**	**lb**			
Total Pulling Load =	**223,308**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	260,582	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	1,191	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	9.2E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	395.06	
U = (12 L) / j =	3.16		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	122,701	lb
Bending Frictional Drag = 2 μ N =	73,621	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**74,548**	**lb**			
Total Pulling Load =	**297,856**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	474.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	49,845	lb			
Fluidic Drag = 12 π D L C_d =	16,105	lb			
Axial Segment Weight = W_e L sinθ =	-29,297	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**36,653**	**lb**			
Total Pulling Load =	**334,509**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,075	ok	0	ok	0	ok	0.06	ok	0.01	ok
	3,629	ok	0	ok	1240	ok	0.06	ok	0.04	ok
PC										
	3,629	ok	24,167	ok	1240	ok	0.59	ok	0.32	ok
	2,721	ok	24,167	ok	1654	ok	0.57	ok	0.33	ok
PT										
	2,721	ok	0	ok	1654	ok	0.04	ok	0.06	ok
	2,458	ok	0	ok	1654	ok	0.04	ok	0.06	ok
PC										
	2,458	ok	24,167	ok	1654	ok	0.57	ok	0.33	ok
	1,525	ok	24,167	ok	1389	ok	0.55	ok	0.29	ok
PT										
	1,525	ok	0	ok	1389	ok	0.02	ok	0.04	ok
Exit Point	0	ok	0	ok	-7	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The Portage River Crossing will be installed almost entirely through bedrock. Since the Delft Equation (Discussed previously in Section 5 of this report) is only applicable to soil, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

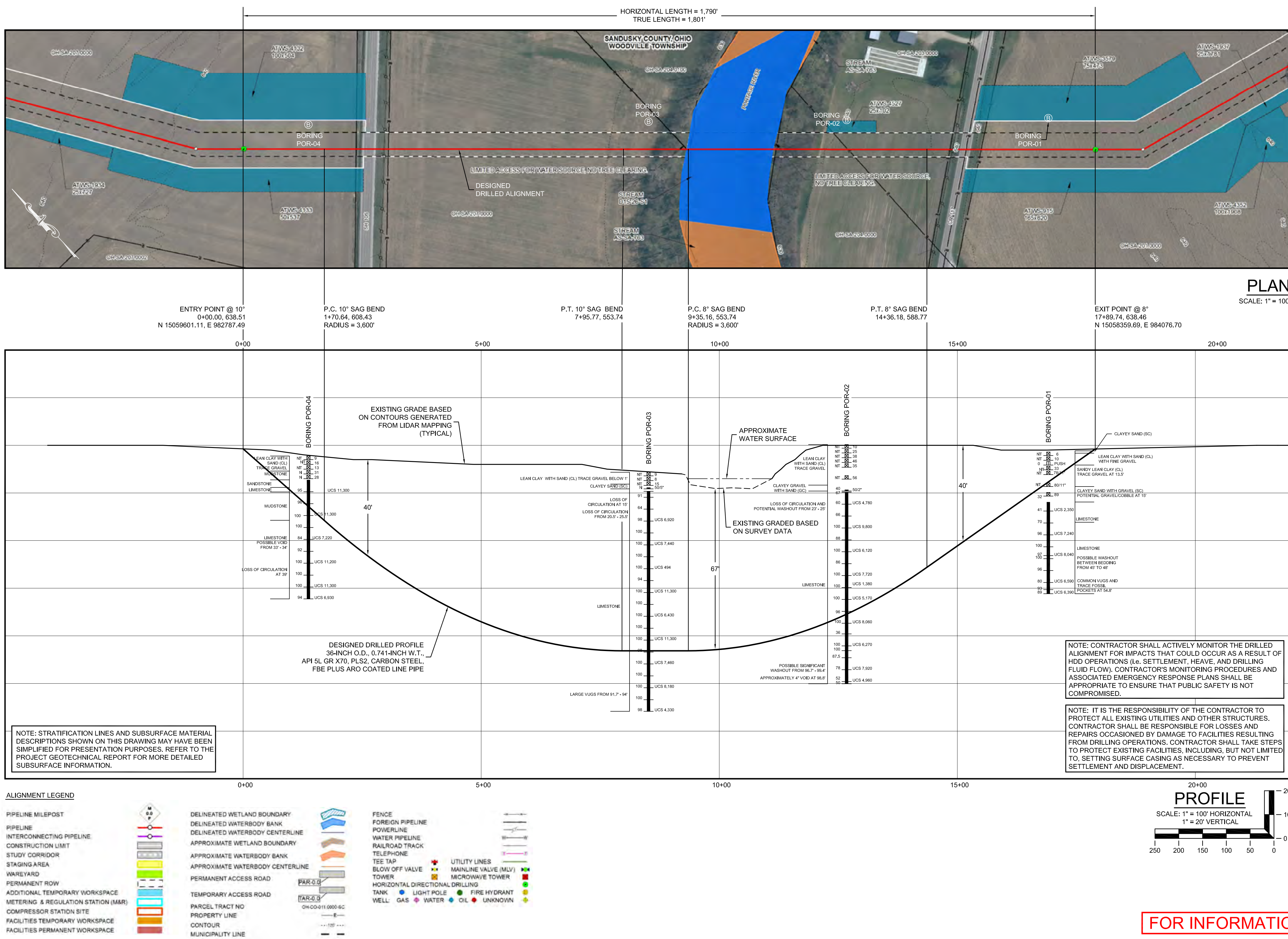
The estimated duration of construction for the Portage River Crossing is 46 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 7 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments						
Work Schedule, hours/shift =	12.0	36" Portage River Crossing						
days/week =	7.0							
Drilled Length, feet =	1,801							
Pilot Hole								
Production Rate, feet/hour =	25							
shifts/day =	1							
Drilling Duration, hours =	72.0							
shifts =	6.0							
Trips to change tools, shifts =	0.5							
Pilot Hole Duration, days =	6.5							
Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3	0.3			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	122.0	122.0	122.0			5.7	6.9	378.6
shifts =	10.2	10.2	10.2			0.5	0.6	31.6
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	11.7	11.7	11.7			1.0	1.1	37.1
Summary								
HDD Duration at Site, days =	45.6							
Site Establishment	Move in	Rig Up	Rig Down	Move Out				
shifts/day =	1	1	1	1				
shifts =	0.5	1.0	1.0	0.5				
days =	0.5	1.0	1.0	0.5				

Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.



FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

Ⓑ BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
TSS 1,350 — TENSILE SPLITTING STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA AND UPDATE CENTERLINE
		1	LKB	JMS	ISSUED FOR BID
CLYD-A-1179	ALIGNMENT SHEET M.P. 162.32 TO M.P. 163.27	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	ACM/DMP	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	DMP	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH PORTAGE RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

SANDUSKY COUNTY, OHIO

NEXUS GAS TRANSMISSION

M.P. 162.6R | W.O. | SCALE: AS SHOWN | DWG. CLYD-H-1011 | REV. 3

MP 180.1R Findlay Road

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, State Route No. 64 HDD Crossing, Nexus Gas Transmission Project, Wood County Ohio" and dated October 2, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch State Route 64 (Findlay Road) Crossing is located near pipeline Mile Post 180.1R, approximately 1 mile east of the proposed Maumee River Crossing, and just south of Waterville, Ohio. The primary obstacles to be crossed include Findlay Road and a small stream that runs parallel to the road on the west side. The stream is approximately 75 feet wide from the top of west bank to the top of the east bank. The topography in the area is flat. The land is partially wooded in the proximity of the road. The east side of the crossing consists of open farm fields bound by a wooded patch to the south. The west side of the crossing is an open farm field bound by woods to the north and west. Refer to Figure 1 for a general overview of the crossing location and Figure 2 for a photo showing the general location of the exit point.

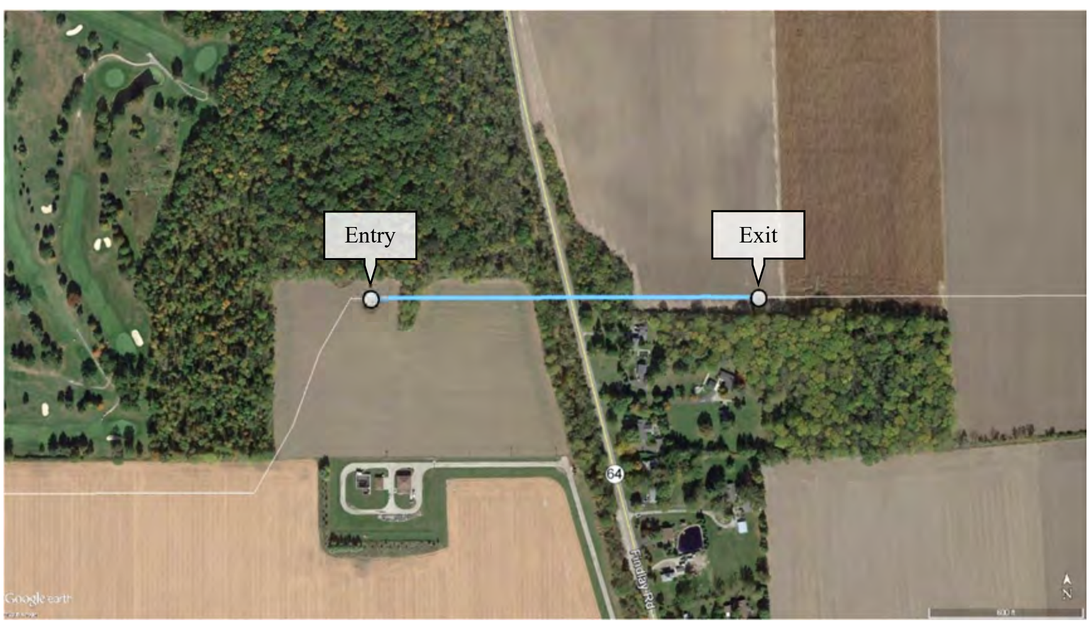


Figure 1: Overview of the State Route 64 (Findlay Road) Crossing

Figure 2: View looking east from tree line toward exit point

Subsurface Conditions

Four site-specific geotechnical borings were taken at the proposed crossing site as part of the site investigation conducted by Fugro Consultants, Inc. Borings SR-64-1 and SR-64-2 were taken on the east side of the Findlay Road and Borings SR-64-3 and SR-64-4 were taken on the west side. Two of the borings, SR-64-2 and SR-64-3, were terminated at a depth of 125 feet below the ground surface. The remaining were terminated at a depth of 75 feet below the ground surface. Each of the borings encountered mostly lean clay, silt, and sand overlying dolomite bedrock. The bedrock surface was encountered approximately 68 feet below the ground surface at approximate elevation 695.

For detailed information, refer to the geotechnical data report prepared by Fugro Consultants, Inc. titled “Geotechnical Data Report, State Route No. 64 HDD Crossing, Nexus Gas Transmission Project, Wood County Ohio” and dated October 2, 2015.

Design Geometry & Layout

The proposed Findlay Road HDD design involves a horizontal length of 1,522 feet. It is a minimum length design, which uses 8-degree entry and exit angles, and radius of curvature of 3,600 feet. The crossing design achieves a minimum of 30 feet of cover beneath the stream. In this case, the design utilizes a shallow entry angle and a reduced depth of cover beneath the stream to keep the HDD segment above bedrock, within the overburden soils.

The entry point is located on the west side of the crossing in a farm field, approximately 790 feet from the centerline of Findley Road. The exit point is located on the east side of the crossing, approximately 575 feet east of Findlay Road, also in a farm field. The exit point is located on the east side to make use of the open farm fields for pull section fabrication, which allows continuous stringing and avoids the necessity for a tie-in weld during pullback.

The preliminary HDD plan and profile drawing is included in this site-specific report for reference.

Assessment of Feasibility

Based on the design length, pipeline diameter, and subsurface conditions consisting primarily of clay, it is our opinion that installation by HDD is feasible.

Risk Identification and Assessment

The most significant risk of impact due to installation by HDD at this location is the possibility of damaging Findlay Road due to heaving or settlement, or drilling fluid surfacing with the stream.

Based on the length and the anticipated subsurface conditions, the level of risk associated with the proposed Findlay Road Crossing is low.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in **Error! Reference source not found.**1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 242,069 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 271,405 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 3. Detailed calculations for each loading scenario are summarized in Figures 4 and 5.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 3: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	158.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	16,734	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	5,377	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	7,839	lb			
Pulling Load on Exit Tangent =	**29,950**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	82,318	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R\ [1 - \cos(\alpha/2)]$ =	8.77	ft	$j = [(E\ I) / T]^{1/2}$ =	2,120	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	2.1E+06		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	564.47	
$U = (12\ L) / j$ =	2.85		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	125,365	lb
Bending Frictional Drag = $2\ \mu\ N$ =	75,219	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	17,055	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**104,736**	**lb**			
Total Pulling Load =	**134,686**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	69.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e\ L\ \mu$ =	7,444	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	2,369	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb			
Pulling Load on Bottom Tangent =	**9,812**	**lb**			
Total Pulling Load =	**144,499**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	186,523	lb
Segment Angle with Horizontal, θ =	8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R\ [1 - \cos(\alpha/2)]$ =	8.77	ft	$j = [(E\ I) / T]^{1/2}$ =	1,408	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	3.0E+06		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	823.01	
$U = (12\ L) / j$ =	4.28		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	132,429	lb
Bending Frictional Drag = $2\ \mu\ N$ =	79,458	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	17,055	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-12,463	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**84,049**	**lb**			
Total Pulling Load =	**228,548**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	150.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	8.0	°			
Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	15,854	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	5,094	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-7,427	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**13,521**	**lb**			
Total Pulling Load =	**242,069**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	2,949	ok	0	ok	0	ok	0.05	ok	0.00	ok
	2,784	ok	0	ok	316	ok	0.04	ok	0.01	ok
PC										
	2,784	ok	12,083	ok	316	ok	0.31	ok	0.08	ok
	1,760	ok	12,083	ok	847	ok	0.29	ok	0.09	ok
PT										
	1,760	ok	0	ok	847	ok	0.03	ok	0.02	ok
	1,641	ok	0	ok	847	ok	0.03	ok	0.02	ok
PC										
	1,641	ok	12,083	ok	847	ok	0.29	ok	0.09	ok
	365	ok	12,083	ok	316	ok	0.27	ok	0.06	ok
PT										
	365	ok	0	ok	316	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	-18	ok	0.00	ok	0.00	ok

Figure 4: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D = 36.000 in
Pipe Weight, W = 279.0 lb/ft
Coefficient of Soil Friction, μ = 0.30
Fluid Drag Coefficient, C_d = 0.025 psi
Ballast Weight / ft Pipe, W_b = 405.5 lb (If Ballasted)
Drilling Mud Displaced / ft Pipe, W_m = 634.5 lb (If Submerged)
Above Ground Load = 0 lb

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L = 464.5 ft
Exit Angle, θ = 8.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ cosθ = 49,046 lb
Fluidic Drag = 12 π D L C_d = 15,759 lb
Axial Segment Weight = W_e L sinθ = 22,977 lb
Pulling Load on Exit Tangent = 87,782 lb

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 251.3 ft
Segment Angle with Horizontal, θ = -8.0 °
Deflection Angle, α = -4.0 °
Average Tension, T = 125,137 lb
Radius of Curvature, R = 1,800 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

h = R [1 - cos(α/2)] = 4.38 ft
j = [(E I) / T]$^{1/2}$ = 1,719
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] = 2.8E+05
X = (3 L) - [(j / 2) tanh(U/2)] = 147.97
U = (12 L) / j = 1.75
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) = 99,918 lb
Bending Frictional Drag = 2 μ N = 59,951 lb
Fluidic Drag = 12 π D L C_d = 8,527 lb
Axial Segment Weight = W_e L sinθ = 6,231 lb
Pulling Load on Exit Sag Bend = 74,710 lb
Total Pulling Load = 162,492 lb

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L = 14.8 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ = 1,576 lb
Fluidic Drag = 12 π D L C_d = 501 lb
Axial Segment Weight = W_e L sinθ = 0 lb
Pulling Load on Bottom Tangent = 2,077 lb
Total Pulling Load = 164,569 lb

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 251.3 ft
Segment Angle with Horizontal, θ = 8.0 °
Deflection Angle, α = 4.0 °
Average Tension, T = 197,448 lb
Radius of Curvature, R = 1,800 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

h = R [1 - cos(α/2)] = 4.38 ft
j = [(E I) / T]$^{1/2}$ = 1,369
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] = 3.8E+05
X = (3 L) - [(j / 2) tanh(U/2)] = 205.73
U = (12 L) / j = 2.20
N = [(T h) - W_e cosθ (Y/144)] / (X / 12) = 105,769 lb
Bending Frictional Drag = 2 μ N = 63,461 lb
Fluidic Drag = 12 π D L C_d = 8,527 lb
Axial Segment Weight = W_e L sinθ = -6,231 lb — Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Sag Bend = 65,757 lb
Total Pulling Load = 230,326 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 456.1 ft
Entry Angle, θ = 8.0 °
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ cosθ = 48,166 lb
Fluidic Drag = 12 π D L C_d = 15,476 lb
Axial Segment Weight = W_e L sinθ = -22,564 lb — Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent = 41,078 lb
Total Pulling Load = 271,405 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,307	ok	0	ok	0	ok	0.05	ok	0.00	ok
	2,806	ok	0	ok	961	ok	0.04	ok	0.02	ok
PC										
	2,806	ok	24,167	ok	961	ok	0.57	ok	0.28	ok
	2,005	ok	24,167	ok	1226	ok	0.56	ok	0.28	ok
PT										
	2,005	ok	0	ok	1226	ok	0.03	ok	0.03	ok
	1,980	ok	0	ok	1226	ok	0.03	ok	0.03	ok
PC										
	1,980	ok	24,167	ok	1226	ok	0.56	ok	0.28	ok
	1,069	ok	24,167	ok	961	ok	0.55	ok	0.25	ok
PT										
	1,069	ok	0	ok	961	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	-18	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The risk of inadvertent drilling fluid returns due to hydrofracture was evaluated using the Delft Method. The Delft Method is described in Section 5 of the report. In summary, the risk of inadvertent drilling fluid returns due to hydrofracture is low over the majority of the length of the crossing. The factor of safety remains above 2.0 until station 13+93. Therefore, inadvertent drilling fluid returns due to hydrofracture are not anticipated under normal drilling operations through station 13+93. At station 14+58, approximately 65 feet from the exit point, the factor of safety drops below 1.0, indicating an increased risk of inadvertent drilling fluid returns due to hydrofracture. Inadvertent drilling fluid returns due to hydrofracture near the exit point, where cover is shallow, is a common occurrence in the HDD industry during pilot hole drilling. These returns typically occur within temporary workspace and are easily contained. Refer to Figure 6 for results presented in graphical format.

It is important to keep in mind that inadvertent drilling fluid returns may occur due to mechanisms unrelated to hydrofracture. It remains possible that inadvertent drilling fluid returns will occur by flowing to the ground surface through preexisting fractures or porous seams in the soil mass.

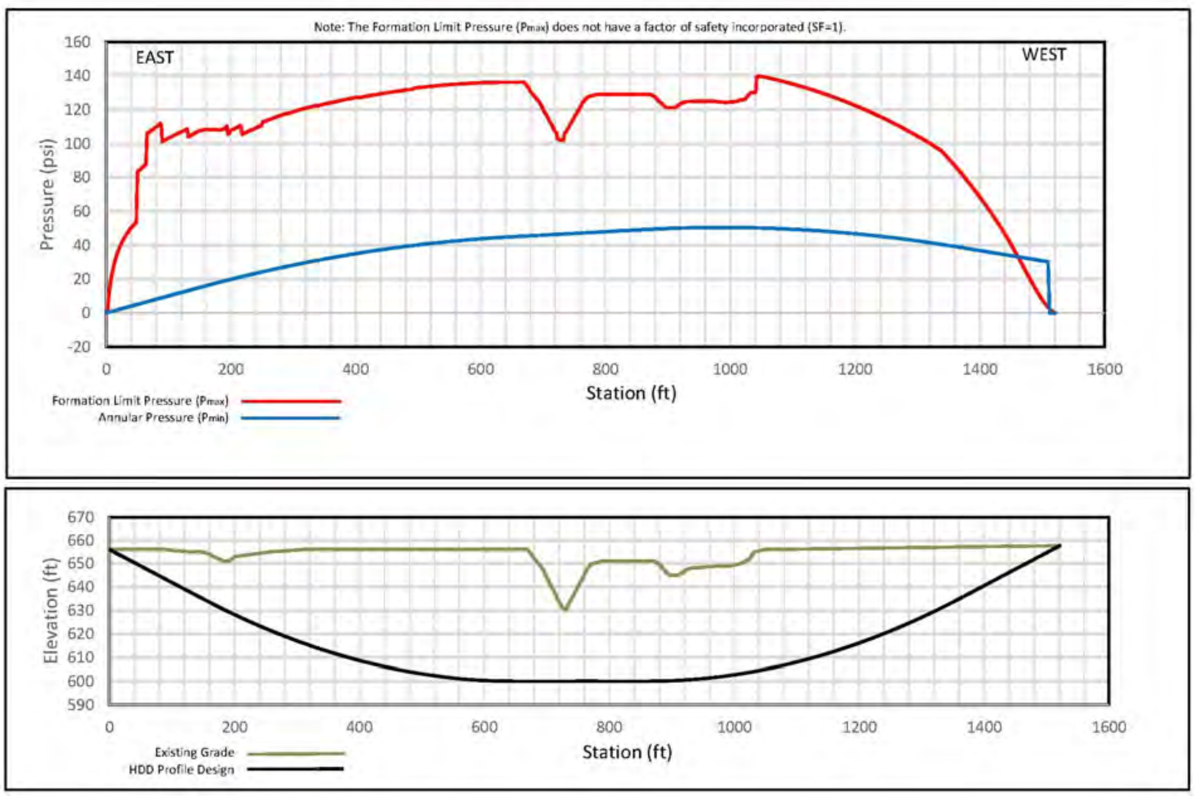


Figure 6: Hydrofracture Evaluation (Formation Limit Pressure –vs-Annular Pressure)

Construction Duration

The estimated duration of construction for the proposed crossing is 13 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 7 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Findlay Road Crossing
days/week =	7.0	
Drilled Length, feet =	1,528	
Pilot Hole		
Production Rate, feet/hour =	50	
shifts/day =	1	
Drilling Duration, hours =	30.6	
shifts =	2.5	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	3.0	

Ream and Pull Back								
Pass Description =	36-inch	48-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	2.0	2.0				8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0				15.0	15.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	14.4	14.4				4.8	5.9	39.5
shifts =	1.2	1.2				0.4	0.5	3.3
Rig up, shifts =	0.5	0.5				0.5	0.5	2.0
Trips to change tools, shifts =	1.0	1.0				0.0		2.0
Pass Duration, days =	2.7	2.7				0.9	1.0	7.3

Summary				
HDD Duration at Site, days =	12.3			
Site Establishment	**Move in**	**Rig Up**	**Rig Down**	**Move Out**
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

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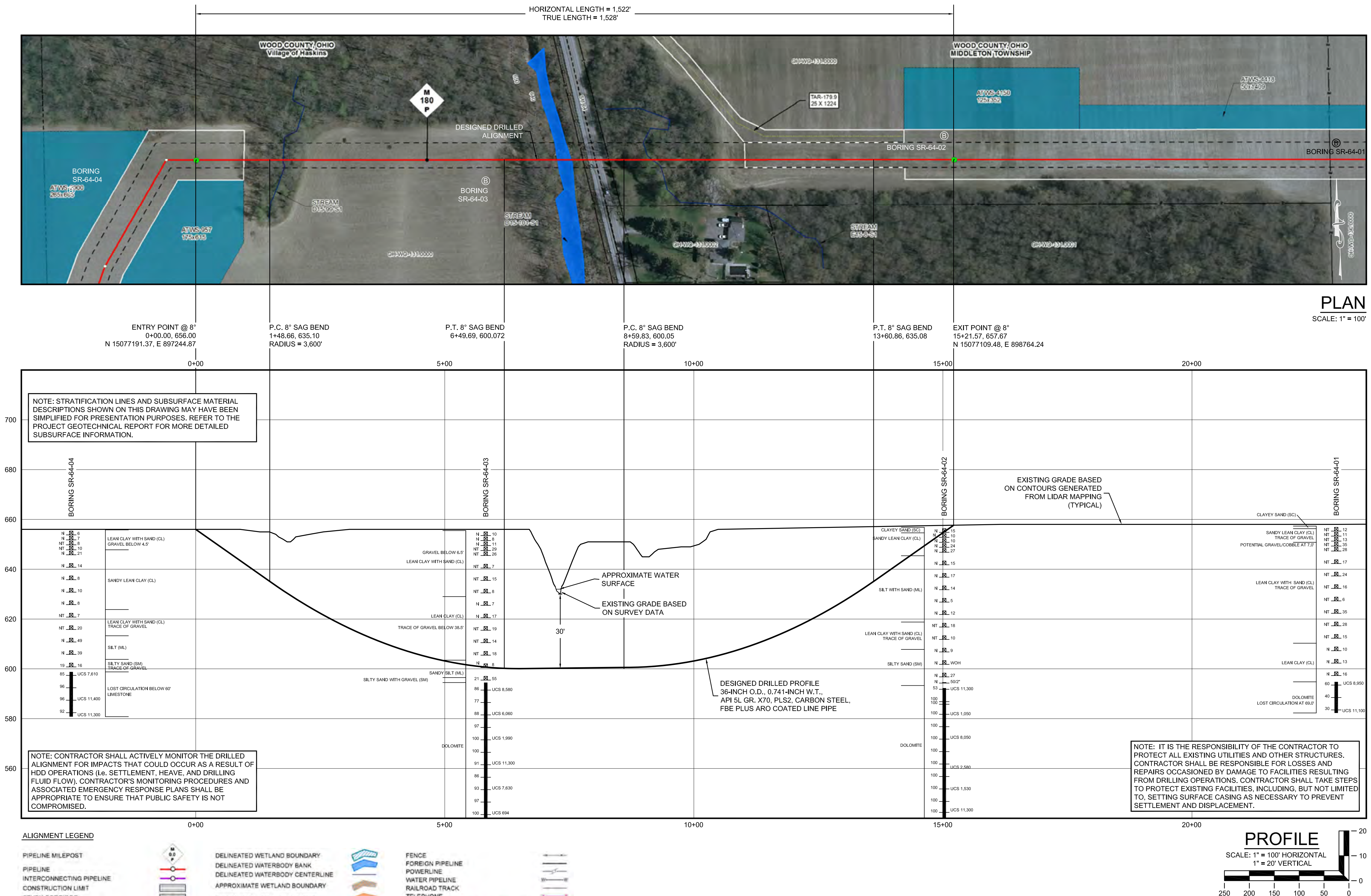


ALIGNMENT LEGEND

PIPELINE MILEPOST, PIPELINE, INTERCONNECTING PIPELINE, CONSTRUCTION LIMIT, STUDY CORRIDOR, STAGING AREA, WAREYARD, PERMANENT ROW, ADDITIONAL TEMPORARY WORKSPACE, METERING & REGULATION STATION (M&R), COMPRESSOR STATION SITE, FACILITIES TEMPORARY WORKSPACE, FACILITIES PERMANENT WORKSPACE

DELINEATED WETLAND BOUNDARY, DELINEATED WATERBODY BANK, DELINEATED WATERBODY CENTERLINE, APPROXIMATE WETLAND BOUNDARY, APPROXIMATE WATERBODY BANK, APPROXIMATE WATERBODY CENTERLINE, PERMANENT ACCESS ROAD, TEMPORARY ACCESS ROAD, PARCEL TRACT NO, PROPERTY LINE, CONTOUR, MUNICIPALITY LINE

FENCE, FOREIGN PIPELINE, POWERLINE, WATER PIPELINE, RAILROAD TRACK, TELEPHONE, TEE TAP, UTILITY LINES, BLOW OFF VALVE, MAINLINE VALVE (MLV), TOWER, MICROWAVE TOWER, HORIZONTAL DIRECTIONAL DRILLING, TANK, LIGHT POLE, FIRE HYDRANT, WELL: GAS, WATER, OIL, UNKNOWN

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES

PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UNCONFINED COMPRESSIVE STRENGTH (PSI)

TENSILE SPLITTING STRENGTH (PSI)

MOHS HARDNESS

ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED OCTOBER 2, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	LKB	JMS	RE-ISSUED FOR FERC
		2	LKB	JMS	REVISE HDD EXIT POINT AND UPDATE CENTERLINE
		1	LKB	JMS	ISSUED FOR BID
CLYD-A-1197	ALIGNMENT SHEET M.P. 179.37 TO M.P. 180.32	0	LKB	JMS	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS

TITLE	PRELIMINARY SIGNATURE	DATE	CONSTRUCTION SIGNATURE	DATE
DRAWN BY:	DMP	08/07		
PROJECT MANAGER	JSM	08/07		
DESIGN ENGINEER	DMP	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH FINDLAY ROAD CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

WOOD COUNTY, OHIO

M.P. 180.1R | W.O. | SCALE: AS SHOWN | DWG. CLYD-H-1012 | REV. 3

NEXUS GAS TRANSMISSION

MP 181.2 Maumee River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled “Geotechnical and Geophysical Data Report, Maumee River HDD Crossing, Nexus Gas Transmission Project, Lucas County, Ohio” and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Maumee River Crossing is located just south of Waterville, Ohio near the north edge of Missionary Island. The crossing involves passing beneath the Maumee River as well as US Highway 24 (Anthony Wayne Trail) on the west side of the West River Road on the east side of the river. The width of the river at the proposed crossing location is approximately 2,000 feet. The area is mostly comprised of agricultural land with a mix of woods. The terrain is relatively flat, but drops off near the Maumee River. From the plateaus on each side of the river, the elevation drops off about 40 to 50 feet from the upland farm fields on each side to the edge of water. An overview of the proposed crossing location is provided in Figures 1. Photos taken at the time of the site reconnaissance are included in Figures 2 and 3.

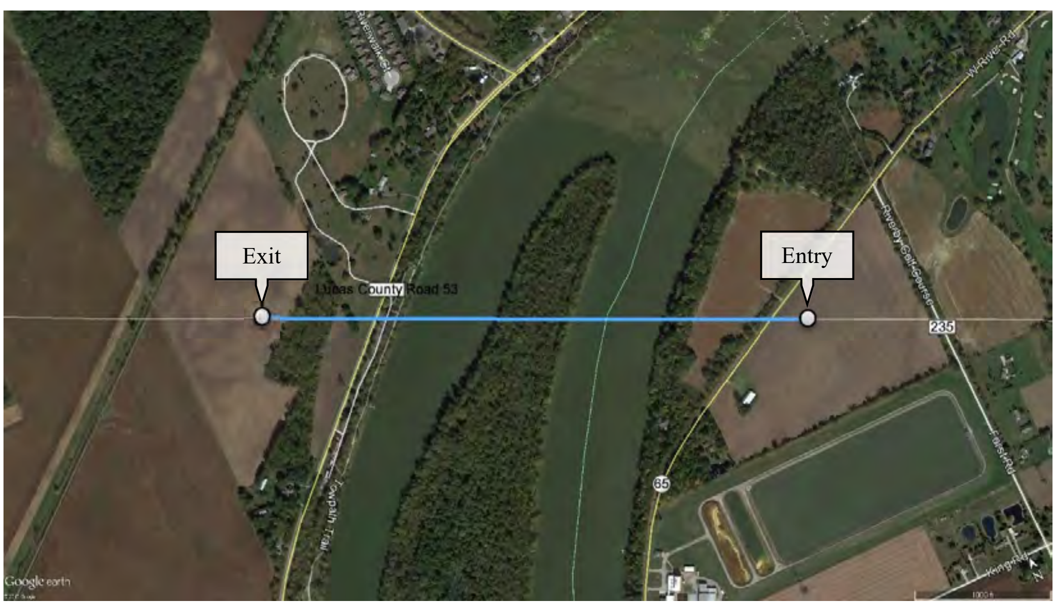


Figure 1: Overview of the Maumee River Crossing

Figure 2: View from West River Road toward entry location

Figure 3: Maumee River (west channel)

Subsurface Conditions

Four geotechnical borings have been taken as part of the site investigation conducted by Fugro Consultants, Inc. Two borings were taken on the west side of the river, both of which were drilled to a depth of 105 feet. Both borings encountered primarily lean clay to lean clay with sand overlying sedimentary bedrock. The top of bedrock was encountered at 85 feet in boring MAU-05 and 98 feet boring MAU-06. Borings MAU-01 and MAU-02 were drilled on the east side of the river. MAU-01 was drilled to 67 feet below the ground surface and encountered fat clay with occasional gravel and gravelly fat clay. Boring MAU-02 encountered mostly sandy lean clay with gravel to a depth of 78 feet. Sand with silt and gravel was encountered at 79 feet with sedimentary bedrock in the form of limestone and siltstone at a depth of 82 feet. The field logs indicate extensive fracturing in the limestone and siltstone. Rock quality designation (RQD) ranged from 0 to 66, with the average value being 12, indicating very poor quality bedrock. Unconfined compressive strength (UCS) of the bedrock averaged 5,988 psi.

Refer to the geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical and Geophysical Data Report, Maumee River HDD Crossing, Nexus Gas Transmission Project, Lucas County, Ohio" and dated September 11, 2015 for additional information.

Design Geometry & Layout

The Maumee River HDD design involves a horizontal length of 3,999 feet. The design length results from an entry angle of 12-degrees, an exit angle of 8-degrees, and a radius of curvature equal to 3,600 feet. In this case, it was not possible to maintain sufficient depth of cover beneath the river while staying above the bedrock surface. Therefore, the design is based on penetrating bedrock, which achieves 75 feet of cover beneath the Maumee River.

The west side of the crossing was chosen for the proposed exit point due to the open farm fields which are free of obstructions, which allow the pipeline pull section to be fabricated in a single segment and thus avoid tie-in welds during pullback.

The preliminary HDD plan and profile design drawing for the Maumee River Crossing is attached to this report for reference.

Assessment of Feasibility

Based on a review of available geotechnical information, the HDD segment must pass through approximately 325 feet of overburden soil containing occasional coarse granular material on the east side of the crossing, before penetrating sedimentary bedrock at a depth of approximately 75 feet. According to preliminary field logs, the bedrock is characterized by extreme fracturing, which in some cases can be problematic for installation by HDD. Although the feasibility of the Maumee River cannot be ruled out, subsurface conditions are present that increase the risk of HDD operational problems.

Risk Identification and Assessment

Potential construction impacts resulting from installation by HDD include possible damage to U.S. Highway 24 and West River Road due to heaving or settlement. In addition, there is risk that inadvertent drilling fluid returns will surface within the Maumee River.

HDD construction and operational risks associated with the crossing involve penetrating bedrock at depths in excess of 75 feet on the east side and almost 100 feet on the west side. Penetrating a deep bedrock surface during pilot hole drilling can sometimes be difficult due to bit deflection. The bit may deflect and skip across the top of the bedrock instead of penetrating it, resulting in unacceptable radius of curvature. A deep bedrock surface can be problematic during reaming and pullback operations due to misalignment at the soil/rock interface. Downhole reaming tools or the pull section may also hang up on the rock interface. Additional risks include failure of large diameter rock reaming tools downhole and operational problems associated with fractured bedrock, including loss of drilling fluid circulation.

Due to subsurface conditions, the risk level associated with the proposed crossing of the Maumee River is high.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 632,344 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 662,330 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	362.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	38,289	lb			
Fluidic Drag = 12 π D L C_d =	12,303	lb			
Axial Segment Weight = W_e L sinθ =	17,937	lb			
Pulling Load on Exit Tangent =	**68,529**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	121,693	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	$j = [(E I) / T]^{1/2}$ =	1,743	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.6E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	689.38	
U = (12 L) / j =	3.46		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	128,017	lb
Bending Frictional Drag = 2 μ N =	76,810	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**106,328**	**lb**			
Total Pulling Load =	**174,857**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	2316.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	246,962	lb			
Fluidic Drag = 12 π D L C_d =	78,581	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**325,543**	**lb**			
Total Pulling Load =	**500,400**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	558,632	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	13.70	ft	$j = [(E I) / T]^{1/2}$ =	814	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	6.5E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1478.17	
U = (12 L) / j =	9.27		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	191,018	lb
Bending Frictional Drag = 2 μ N =	114,611	lb			
Fluidic Drag = 12 π D L C_d =	21,318	lb			
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**116,465**	**lb**			
Total Pulling Load =	**616,865**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	200.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	21,050	lb			
Fluidic Drag = 12 π D L C_d =	6,801	lb			
Axial Segment Weight = W_e L sinθ =	-12,372	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**15,479**	**lb**			
Total Pulling Load =	**632,344**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	7,704	ok	0	ok	0	ok	0.12	ok	0.02	ok
	7,515	ok	0	ok	466	ok	0.12	ok	0.03	ok
PC										
	7,515	ok	12,083	ok	466	ok	0.38	ok	0.14	ok
	6,096	ok	12,083	ok	1295	ok	0.36	ok	0.16	ok
PT										
	6,096	ok	0	ok	1295	ok	0.10	ok	0.05	ok
	2,130	ok	0	ok	1295	ok	0.03	ok	0.04	ok
PC										
	2,130	ok	12,083	ok	1295	ok	0.30	ok	0.12	ok
	835	ok	12,083	ok	764	ok	0.28	ok	0.08	ok
PT										
	835	ok	0	ok	764	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Parameter	Value	Unit	Parameter	Value	Unit	
Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	668.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	70,548	lb			
Fluidic Drag = 12 π D L C_d =	22,668	lb			
Axial Segment Weight = W_e L sinθ =	33,050	lb			
Pulling Load on Exit Tangent =	**126,266**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	251.3	ft	Average Tension, T =	164,579	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	j = [(E I) / T]$^{1/2}$ =	1,499	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	3.4E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	181.26	
U = (12 L) / j =	2.01		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	103,112	lb
Bending Frictional Drag = 2 μ N =	61,867	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**76,626**	**lb**			
Total Pulling Load =	**202,892**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	2329.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	248,421	lb			
Fluidic Drag = 12 π D L C_d =	79,045	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**327,466**	**lb**			
Total Pulling Load =	**530,358**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	314.2	ft	Average Tension, T =	576,966	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	801	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	1.3E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	549.29	
U = (12 L) / j =	4.71		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	153,813	lb
Bending Frictional Drag = 2 μ N =	92,288	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**93,215**	**lb**			
Total Pulling Load =	**623,573**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	501.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	52,706	lb			
Fluidic Drag = 12 π D L C_d =	17,029	lb			
Axial Segment Weight = W_e L sinθ =	-30,978	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**38,757**	**lb**			
Total Pulling Load =	**662,330**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	8,069	ok	0	ok	0	ok	0.13	ok	0.02	ok
	7,597	ok	0	ok	1259	ok	0.12	ok	0.06	ok
PC										
	7,597	ok	24,167	ok	1259	ok	0.65	ok	0.40	ok
	6,461	ok	24,167	ok	1673	ok	0.63	ok	0.41	ok
PT										
	6,461	ok	0	ok	1673	ok	0.10	ok	0.08	ok
	2,472	ok	0	ok	1673	ok	0.04	ok	0.06	ok
PC										
	2,472	ok	24,167	ok	1673	ok	0.57	ok	0.33	ok
	1,538	ok	24,167	ok	1408	ok	0.55	ok	0.29	ok
PT										
	1,538	ok	0	ok	1408	ok	0.02	ok	0.04	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The majority of the Maumee River Crossing will be installed through bedrock. Since the Delft Method discussed in Section 5 of the report is only applicable to uncemented subsurface materials, a hydrofracture evaluation was not completed. In general, inadvertent drilling fluid returns due to hydrofracture do not typically occur on rock crossings, but instead occur by flowing through existing fractures, joints, or solution cavities.

Construction Duration

The estimated duration of construction for the Maumee River Crossing is 81 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Details relative to the estimate are provided in Figure 7.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Maumee River Crossing
days/week =	7.0	
Drilled Length, feet =	4,018	
Pilot Hole		
Production Rate, feet/hour =	20	
shifts/day =	1	
Drilling Duration, hours =	200.9	
shifts =	16.7	
Trips to change tools, shifts =	2.0	
Pilot Hole Duration, days =	18.7	

Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	0.4	0.4	0.4			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	195.7	195.7	195.7			12.7	15.5	615.1
shifts =	16.3	16.3	16.3			1.1	1.3	51.3
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	2.0	2.0	2.0			0.0		6.0
Pass Duration, days =	18.8	18.8	18.8			1.6	1.8	59.8

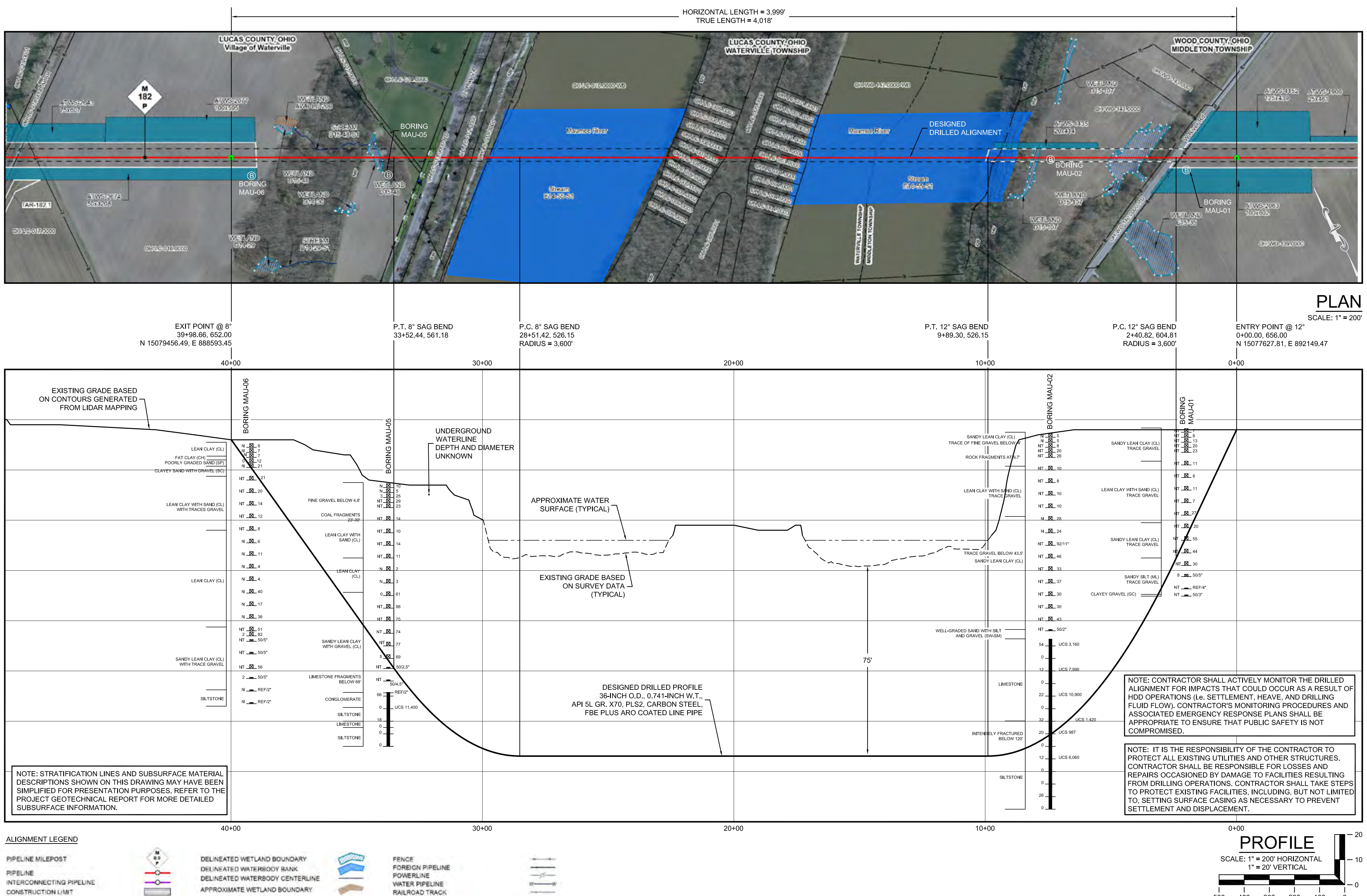
Summary	
HDD Duration at Site, days =	80.5

Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-141



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

Ⓑ BORING LOCATION

SPLIT SPOON SAMPLE

53 23 ← PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 ← UNCONFINED COMPRESSIVE STRENGTH (PSI)
TSS 1,350 ← TENSILE SPLITTING STRENGTH (PSI)
53 6 ← MOHS HARDNESS
ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		2	ACM	JMS	RE-ISSUED FOR FERC
CLYD-A-1199	ALIGNMENT SHEET M.P. 181.26 TO M.P. 182.21	1	LKB	JMS	ISSUED FOR BID
CLYD-A-1198	ALIGNMENT SHEET M.P. 180.32 TO M.P. 181.26	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS

TITLE	PRELIMINARY SIGNATURE	DATE	CONSTRUCTION SIGNATURE	DATE
DRAWN BY:	DMP	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB	08/26		
DESIGN CHECKER	AM	08/26		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH MAUMEE RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING
WOOD AND LUCAS COUNTIES, OHIO

NEXUS GAS TRANSMISSION

M.P. 181.2 | W.O. | SCALE: AS SHOWN | DWG. CLYD-H-1013 | REV. 2

MP 215.0 River Raisin

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Raisin River HDD Crossing (REV-1), Nexus Gas Transmission Project, Lenawee County, Ohio" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The proposed 36-inch River Raisin Crossing at approximately pipeline Mile Post 215.0, approximately 2 miles south of Blissfield, Michigan. The proposed crossing alignment trends in the north-south direction, cutting perpendicularly across Beamer Road. The river is approximately 100 feet wide at the crossing location. At the time of this writing, hydrographic survey shots indicating the depth of the river were not yet available. The land on the south side of the crossing consists of open farm fields. Immediately north of the river, the land is wooded. The wooded land is followed by open farm fields. An overview of the proposed crossing location is provided in Figures 1 through 3.

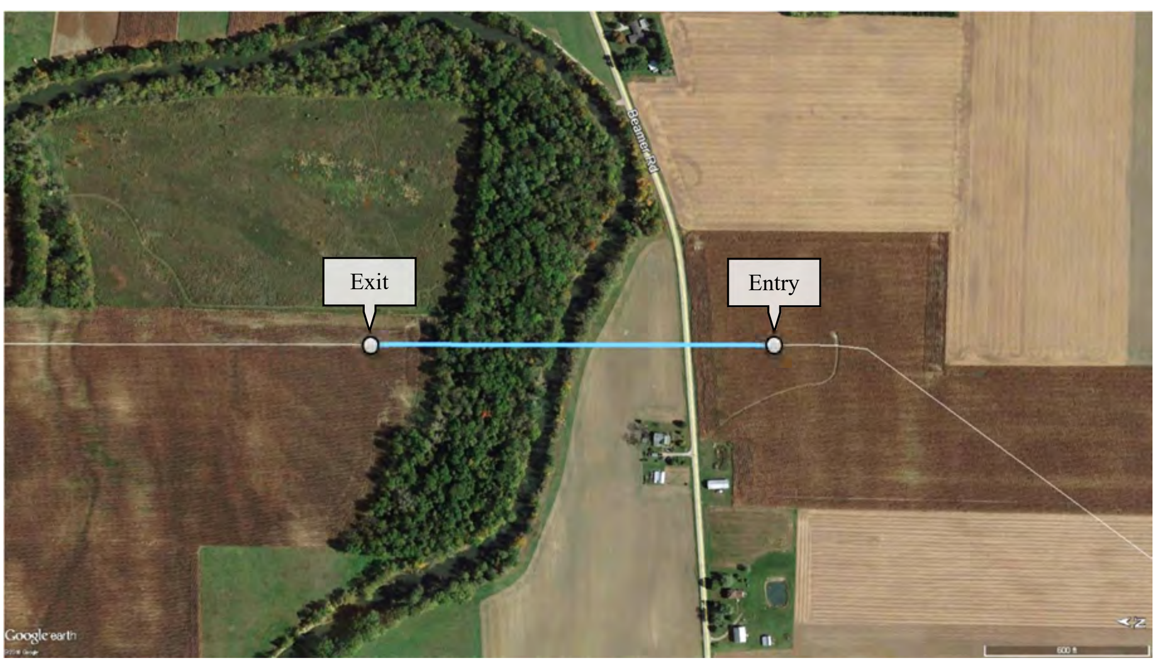


Figure 1: Overview of the River Raisin Crossing

Figure 2: View toward entry location from Beamer Road

Figure 3: View toward exit location

Subsurface Conditions

Three site-specific geotechnical borings were taken as part of the site-investigation conducted by Fugro Consultants, Inc. Borings RAI-1-1 and RAI-1-2, taken on the south side of the river, encountered primarily lean clay, lean clay with sand, sand, silt, and silt with clay and gravel. Boring RAI-1-3, taken on the north side of the river, primarily encountered lean clay, silty sand, and sand with silt.

Design Geometry & Layout

The proposed crossing involves a horizontal length of 1,479 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature of 3,600 feet. The crossing design is based on obtaining a minimum of 40 feet of cover at the edge of Beamer Road and tree line/slope on the north side of the crossing.

The exit point is located on the north side of the crossing to take advantage of available workspace for pull section fabrication, which will allow the pull section to be fabricated in a single segment. Pulling in a single segment will eliminate risk of getting the pull section stuck during downtime associated with a tie-in weld. The entry point is located in an open field on the south side of the river

The preliminary HDD design, as well as available workspace for HDD operations, is shown on the plan and profile drawing included in this site-specific report.

Assessment of Feasibility

The proposed River Raisin installation is feasible. With a horizontal length of 1,479 feet and subsurface conditions consisting of mixtures of lean clay and sand, the River Raisin crossing should be a straightforward installation. Numerous 36-inch HDD installations of similar distances through similar subsurface conditions have been completed.

Risk Identification and Assessment

Possible construction impacts associated with installation by HDD include damage to Beamer Road in the form of heaving or settlement, as well as drilling fluid surfacing in the river.

Based on the proposed length of the crossing and anticipated subsurface conditions, the overall risk level associated with installation by HDD is considered low.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600'	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50' Depth: Increased by 25' Radius: 1,800'	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the "as-designed" crossing, without ballast, is 259,367 pounds. In the "worse-case" installation scenario, the anticipated pulling load without ballast is 284,195 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each scenario are summarized in Figures 4 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	135.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	14,315	lb			
Fluidic Drag = 12 π D L C_d =	4,600	lb			
Axial Segment Weight = W_e L sinθ =	6,706	lb			
Pulling Load on Exit Tangent =	**25,620**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	77,899	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	$j = [(E\ I) / T]^{1/2}$ =	2,179	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.0E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	547.15	
U = (12 L) / j =	2.77		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	125,069	lb
Bending Frictional Drag = 2 μ N =	75,041	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**104,559**	**lb**			
Total Pulling Load =	**130,179**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	188.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	20,140	lb			
Fluidic Drag = 12 π D L C_d =	6,408	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**26,549**	**lb**			
Total Pulling Load =	**156,728**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	206,084	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	13.70	ft	$j = [(E\ I) / T]^{1/2}$ =	1,340	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	5.5E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1219.89	
U = (12 L) / j =	5.63		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	161,431	lb
Bending Frictional Drag = 2 μ N =	96,858	lb			
Fluidic Drag = 12 π D L C_d =	21,318	lb			
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**98,712**	**lb**			
Total Pulling Load =	**255,440**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	30.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	279.0	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	2,473	lb			
Fluidic Drag = 12 π D L C_d =	0	lb	Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input		
Axial Segment Weight = W_e L sinθ =	1,454	lb			
Pulling Load on Entry Tangent =	**3,927**	**lb**			
Total Pulling Load =	**259,367**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,160	ok	0	ok	0	ok	0.05	ok	0.00	ok
	3,112	ok	0	ok	0	ok	0.05	ok	0.00	ok
PC										
	3,112	ok	12,083	ok	0	ok	0.31	ok	0.07	ok
	1,909	ok	12,083	ok	816	ok	0.30	ok	0.09	ok
PT										
	1,909	ok	0	ok	816	ok	0.03	ok	0.02	ok
	1,586	ok	0	ok	816	ok	0.03	ok	0.01	ok
PC										
	1,586	ok	12,083	ok	816	ok	0.29	ok	0.08	ok
	312	ok	12,083	ok	286	ok	0.27	ok	0.05	ok
PT										
	312	ok	0	ok	286	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Parameter	Value	Unit	Parameter	Value	Unit	
Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	441.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	46,574	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	14,965	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	21,818	lb			
Pulling Load on Exit Tangent =	**83,357**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	251.3	ft	Average Tension, T =	120,602	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	4.38	ft	$j = [(E I) / T]^{1/2}$ =	1,751	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.7E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	143.83	
$U = (12 L) / j$ =	1.72		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	99,551	lb
Bending Frictional Drag = $2\ \mu\ N$ =	59,730	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	8,527	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**74,489**	**lb**			
Total Pulling Load =	**157,846**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	202.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e\ L\ \mu$ =	21,599	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	6,873	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb			
Pulling Load on Bottom Tangent =	**28,472**	**lb**			
Total Pulling Load =	**186,318**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	314.2	ft	Average Tension, T =	222,459	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	6.85	ft	$j = [(E I) / T]^{1/2}$ =	1,289	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	8.5E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	363.50	
$U = (12 L) / j$ =	2.92		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	118,926	lb
Bending Frictional Drag = $2\ \mu\ N$ =	71,356	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	10,659	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**72,283**	**lb**			
Total Pulling Load =	**258,601**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Parameter	Value	Unit	Parameter	Value	Unit
Segment Length, L =	331.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	34,806	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	11,246	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-20,458	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**25,594**	**lb**			
Total Pulling Load =	**284,195**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,462	ok	0	ok	0	ok	0.05	ok	0.00	ok
	3,151	ok	0	ok	781	ok	0.05	ok	0.02	ok
PC										
	3,151	ok	24,167	ok	781	ok	0.58	ok	0.27	ok
	2,270	ok	24,167	ok	1195	ok	0.57	ok	0.29	ok
PT										
	2,270	ok	0	ok	1195	ok	0.04	ok	0.03	ok
	1,923	ok	0	ok	1195	ok	0.03	ok	0.03	ok
PC										
	1,923	ok	24,167	ok	1195	ok	0.56	ok	0.28	ok
	1,016	ok	24,167	ok	929	ok	0.55	ok	0.25	ok
PT										
	1,016	ok	0	ok	929	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The risk of inadvertent drilling fluid returns due to hydrofracture was evaluated using the Delft Method. The Delft Method is described in Section 5 of the report. In summary, the risk of inadvertent drilling fluid returns due to hydrofracture is low over the first 1,000 feet of the crossing. However, after station 12+45, the factor of safety drops below 2.0, indicating a moderate risk of hydrofracture. By station 14+00, the factor of safety falls below 1.0, indicating an increased risk of hydrofracture over the remaining roughly 80 feet of the crossing. Inadvertent drilling fluid returns due to hydrofracture near the exit point, where cover is shallow, is a common occurrence in the HDD industry during pilot hole drilling. These returns typically occur within the temporary workspace and are easily contained. Refer to Figure 7 for results presented in graphical format.

It is important to keep in mind that inadvertent drilling fluid returns may occur due to mechanisms unrelated to hydrofracture. It remains possible that inadvertent drilling fluid returns will occur by flowing to the ground surface through preexisting fractures or porous seams in the soil mass.

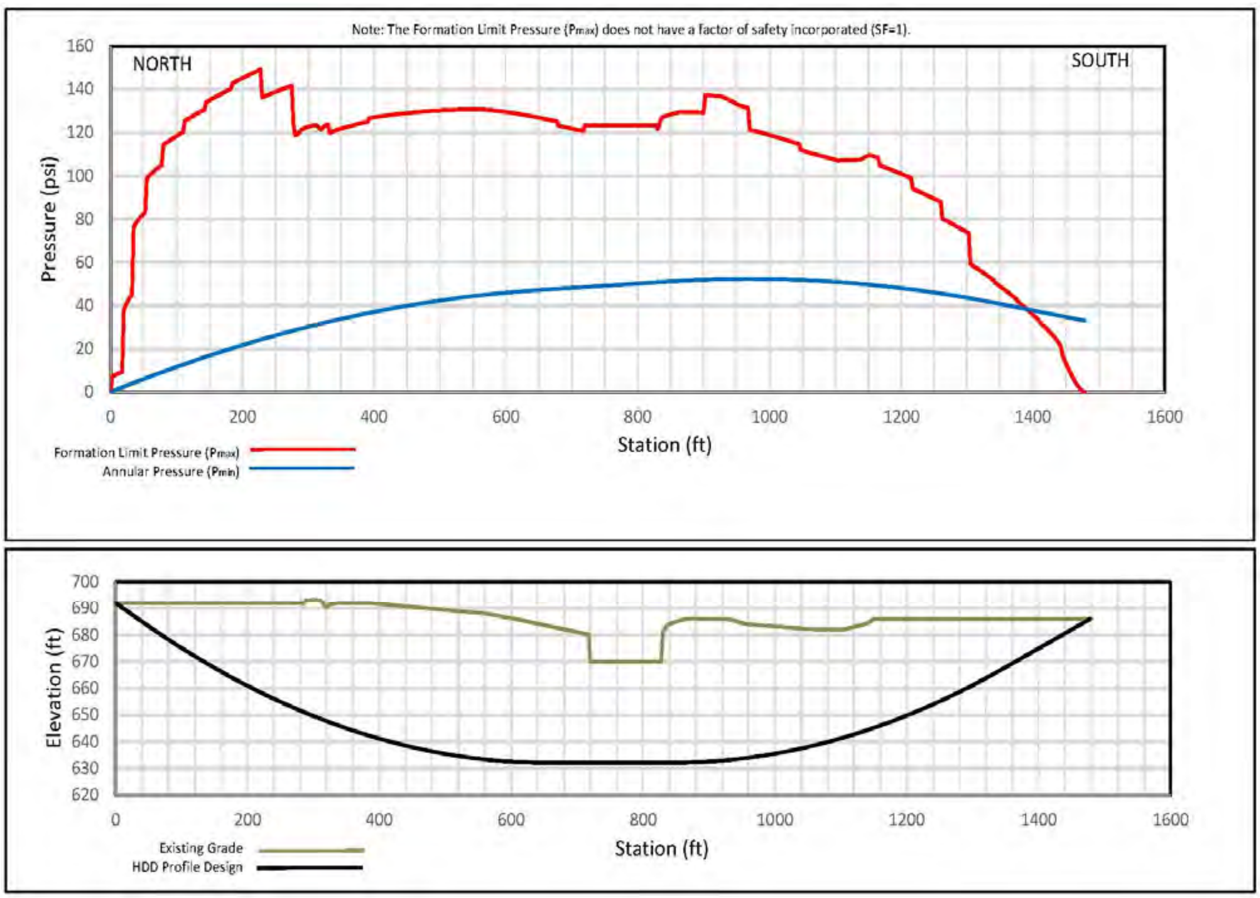


Figure 7: Hydrofracture Evaluation (Formation Limit Pressure - vs - Annular Pressure)

Construction Duration

The estimated duration of construction is 13 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated based on information contained within the Pipeline Research Council International's "Installation of Pipelines by Horizontal Directional Drilling", as well as JDH&A's previous experience in similar subsurface conditions. Refer to Figure 8 for details relative to the estimate.

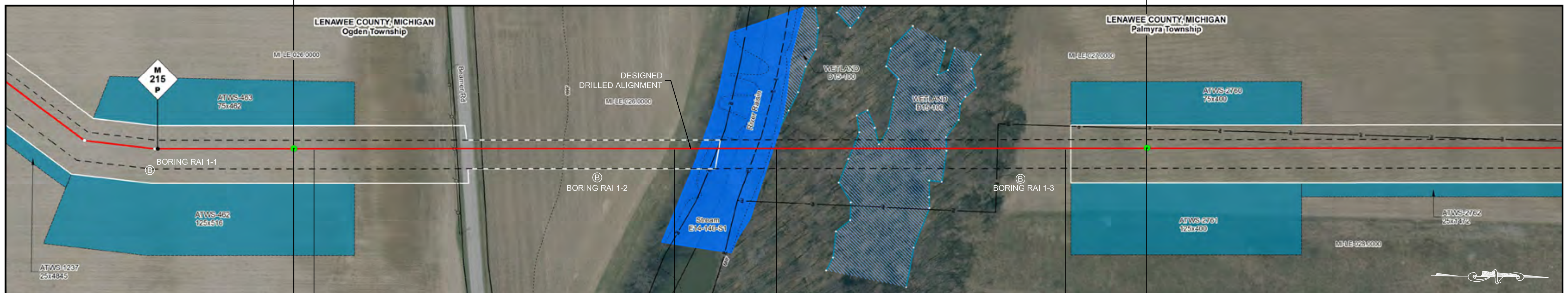
Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments						
Work Schedule, hours/shift =	12.0	36" Raisin River Crossing						
days/week =	7.0							
Drilled Length, feet =	1,485							
Pilot Hole								
Production Rate, feet/hour =	50							
shifts/day =	1							
Drilling Duration, hours =	29.7							
shifts =	2.5							
Trips to change tools, shifts =	0.5							
Pilot Hole Duration, days =	3.0							
Ream and Pull Back								
Pass Description =	36-ich	48-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	2.0	2.0				8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0				15.0	7.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	14.0	14.0				4.7	5.7	38.4
shifts =	1.2	1.2				0.4	0.5	3.2
Rig up, shifts =	0.5	0.5				0.5	0.5	2.0
Trips to change tools, shifts =	1.0	1.0				0.0		2.0
Pass Duration, days =	2.7	2.7				0.9	1.0	7.2
Summary								
HDD Duration at Site, days =	12.2							
Site Establishment	Move in	Rig Up	Rig Down	Move Out				
shifts/day =	1	1	1	1				
shifts =	0.5	1.0	1.0	0.5				
days =	0.5	1.0	1.0	0.5				

Figure 8: Estimated Construction Duration

E-4-150

HORIZONTAL LENGTH = 1,479'
TRUE LENGTH = 1,485'



ENTRY POINT @ 10°
0+00.00, 692.00
N 15201282.37, E 851878.97

P.C. 10° SAG BEND
0+34.87, 685.85
RADIUS = 3,600'

P.T. 10° SAG BEND
6+60.00, 631.16

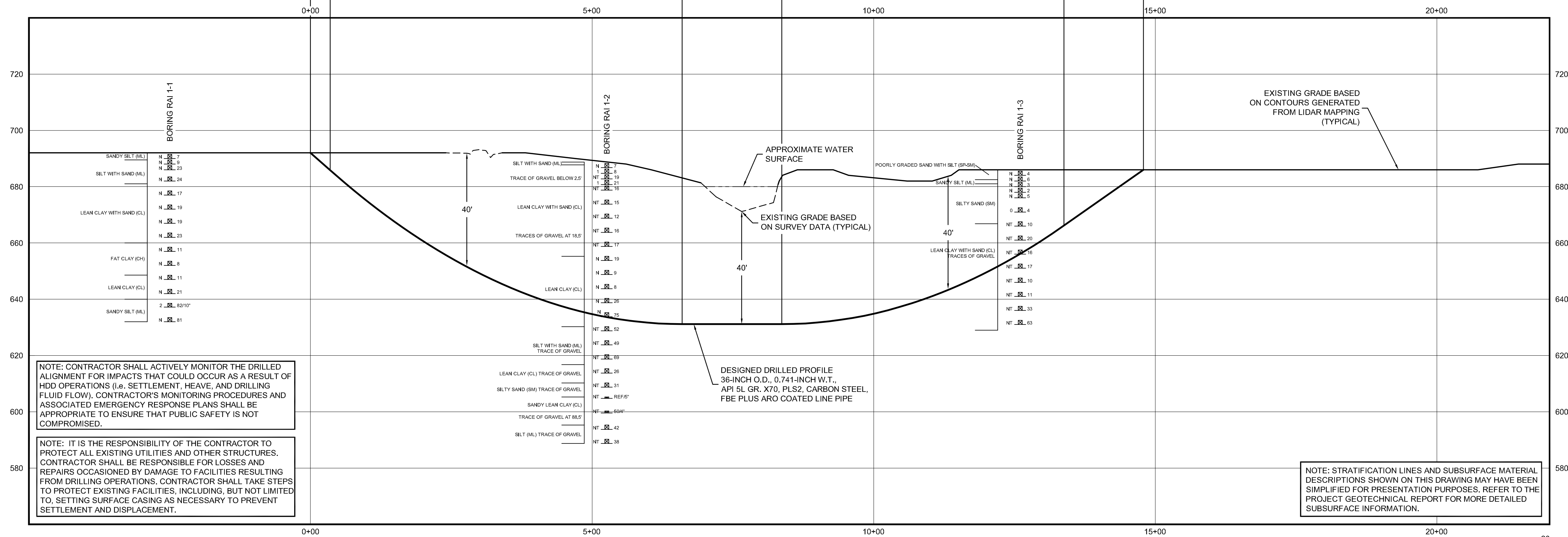
P.C. 8° SAG BEND
8+36.87, 631.16
RADIUS = 3,600'

P.T. 8° SAG BEND
13+37.89, 666.19

EXIT POINT @ 8°
14+78.82, 686.00
N 15202761.07, E 851860.29

PLAN

SCALE: 1" = 100'



NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

NOTE: STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING MAY HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES. REFER TO THE PROJECT GEOTECHNICAL REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.

PROFILE

SCALE: 1" = 100' HORIZONTAL
1" = 20' VERTICAL

ALIGNMENT LEGEND

PIPELINE MILEPOST, PIPELINE, INTERCONNECTING PIPELINE, CONSTRUCTION LIMIT, STUDY CORRIDOR, STAGING AREA, WAREYARD, PERMANENT ROW, ADDITIONAL TEMPORARY WORKSPACE, METERING & REGULATION STATION (M&R), COMPRESSOR STATION SITE, FACILITIES TEMPORARY WORKSPACE, FACILITIES PERMANENT WORKSPACE

DELINEATED WETLAND BOUNDARY, DELINEATED WATERBODY BANK, DELINEATED WATERBODY CENTERLINE, APPROXIMATE WETLAND BOUNDARY, APPROXIMATE WATERBODY BANK, APPROXIMATE WATERBODY CENTERLINE, PERMANENT ACCESS ROAD, TEMPORARY ACCESS ROAD, PARCEL TRACT NO, PROPERTY LINE, CONTOUR, MUNICIPALITY LINE

FENCE, FOREIGN PIPELINE, POWERLINE, WATER PIPELINE, RAILROAD TRACK, TELEPHONE, TEE TAP, UTILITY LINES, BLOW OFF VALVE, MAINLINE VALVE (MLV), TOWER, MICROWAVE TOWER, HORIZONTAL DIRECTIONAL DRILLING, TANK, LIGHT POLE, FIRE HYDRANT, WELL: GAS, WATER, OIL, UNKNOWN

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR AND SURVEY DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UNCONFINED COMPRESSIVE STRENGTH (PSI)
TENSILE SPLITTING STRENGTH (PSI)
MOHS HARDNESS
ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC. BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		2	ACM	JMS	RE-ISSUED FOR FERC
		1	LKB	JMS	ISSUED FOR BID
WATE-A-1236	ALIGNMENT SHEET M.P. 214.93 TO M.P. 215.88	0	LKB	ACM	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS

TITLE	PRELIMINARY SIGNATURE	DATE	CONSTRUCTION SIGNATURE	DATE
DRAWN BY:	LKB	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH RIVER RAISIN CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

LENAWEE COUNTY, MICHIGAN

NEXUS GAS TRANSMISSION

M.P. 215.0 | W.O. | SCALE: AS SHOWN | DWG. WATE-H-1014 | REV. 1

MP 237.4 Saline River

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. "Geotechnical Data Report, Saline HDD Crossing, Nexus Gas Transmission Project, Washtenaw County, Michigan" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Saline River Crossing is located just northwest of Milan, Michigan near pipeline Mile Post 237.4. The crossing involves passing beneath the channel of Saline River as well as Mooreville Road, which is located just east of the river. The Saline River is roughly 60 feet from bank to bank, and about 7 feet deep based on hydrographic survey data. Both sides of the river are relatively flat and currently in use for agricultural purposes. The topography rises with the northeast bank of the river, and then levels off on the northeast side Mooreville Road. The elevation change is approximately 20 feet. An overview of the crossing location is provided in Figure 1 and Figure 2.

Figure 1: Overview of the Saline River Crossing

Figure 2: Looking south at proposed entry location from treeline near river

Subsurface Conditions

Four geotechnical borings were taken as part of the site investigation conducted by Fugro Consultants, Inc. Two borings were taken on the southwest side of the river and two on the northeast side of the river. The borings generally encountered lean clay, sandy lean clay, and gravelly lean clay overlying shale and limestone bedrock. Two of the borings on the southwest side of the river encountered potential cobbles/bounders at depths ranging from 34 feet to 43 feet. The top of the bedrock surface was encountered near elevation 590 to 600 feet (90 to 110 feet below the ground surface) in Borings SAL-01 through SAL-03. Boring SAL-04 was drilled to a depth of 75 feet without encountering the top of bedrock. Unconfined compressive strength on representative rock samples ranged from 5,420 psi to 11,000 psi for the shale in Boring SAL-03 and from 4,520 psi to 11,200 psi for the limestone encountered in Boring SAL-02.

Refer to the report titled “Geotechnical Data Report, Saline River HDD Crossing, Nexus Gas Transmission Project, Washtenaw County Michigan” and dated September 11, 2015, for additional information.

Design Geometry & Layout

The proposed HDD design for crossing Saline River has a horizontal length of 1,315 feet. The entry point is located in an open field on the southwest side of the river, the topographically lower side. This has benefits from a drilling fluid flow and handling perspective. The entry point is located approximately 600 feet from the southwest bank of the river. The exit point is located on the high side of the crossing, approximately 710 feet northeast of Mooreville Roads. Pull section fabrication will take place along the proposed pipeline right-of-way (ROW), which will allow pulling in a single continuous segment, and thus avoids the requirement for a tie-in weld.

Shallow angles (8-degree entry and exit angles) and a reduced depth of cover beneath the river (30 feet) have been utilized in an attempt reduce the risk of HDD operational problems by minimizing exposure to potentially adverse gravel/cobbles/boulders noted in Borings SAL-01 and SAL-02. A radius of curvature equal to 3,600 feet is used.

Assessment of Feasibility

Based on a review of available geotechnical information, the HDD segment must pass through coarse granular material in the form of gravel, and possibly cobbles and boulders on the southwest side of the crossing. As mentioned previously in this report, coarse granular material such as gravel, and cobbles, and boulders can be problematic to HDD operations. That said, given the relatively short length of the crossing (1,320 feet), skilled HDD contractors should be able to overcome the adverse conditions and successfully install the crossing.

Risk Identification and Assessment

Notable risks associated with pipeline installation by HDD include potential damage to Mooreville Road resulting from drilling fluid flow (inadvertent returns, settlement, or heave).

Although there is risk of HDD operational problems resulting from random gravel, cobbles and boulders, given the short length of the crossing, the overall risk level is considered average.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 212,230 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 270,033 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 3. Detailed calculations for each installation loading scenario are summarized in Figures 4 and 5.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 3: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000 in	Fluid Drag Coefficient, C_d =	0.025 psi		
Pipe Weight, W =	279.0 lb/ft	Ballast Weight / ft Pipe, W_b =	405.5 lb	(If Ballasted)	
Coefficient of Soil Friction, μ =	0.30	Drilling Mud Displaced / ft Pipe, W_m =	634.5 lb	(If Submerged)	
		Above Ground Load =	0 lb		

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	180.5 ft	Effective Weight, $W_e = W + W_b - W_m$ =	279.0 lb/ft
Exit Angle, θ =	8.0 °		
Frictional Drag = $W_e L \mu \cos\theta$ =	14,959 lb		
Fluidic Drag = $12 \pi D L C_d$ =	0 lb	Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input	
Axial Segment Weight = $W_e L \sin\theta$ =	-7,008 lb	Negative value indicates axial weight applied in direction of installation	
Pulling Load on Exit Tangent =	**7,951 lb**		

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7 ft	Average Tension, T =	59,869 lb
Segment Angle with Horizontal, θ =	-8.0 °	Radius of Curvature, R =	3,600 ft
Deflection Angle, α =	-4.0 °	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	8.77 ft	$j = [(E I) / T]^{1/2}$ =	2,486
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	1.7E+06	$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	466.88
$U = (12 L) / j$ =	2.43	$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	123,864 lb
Bending Frictional Drag = $2 \mu N$ =	74,318 lb		
Fluidic Drag = $12 \pi D L C_d$ =	17,055 lb		
Axial Segment Weight = $W_e L \sin\theta$ =	12,463 lb		
Pulling Load on Exit Sag Bend =	**103,836 lb**		
Total Pulling Load =	**111,787 lb**		

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	100.1 ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
Frictional Drag = $W_e L \mu$ =	10,670 lb		
Fluidic Drag = $12 \pi D L C_d$ =	3,395 lb		
Axial Segment Weight = $W_e L \sin\theta$ =	0 lb		
Pulling Load on Bottom Tangent =	**14,065 lb**		
Total Pulling Load =	**125,852 lb**		

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7 ft	Average Tension, T =	167,486 lb
Segment Angle with Horizontal, θ =	8.0 °	Radius of Curvature, R =	3,600 ft
Deflection Angle, α =	4.0 °	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	8.77 ft	$j = [(E I) / T]^{1/2}$ =	1,486
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.9E+06	$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	790.13
$U = (12 L) / j$ =	4.06	$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	131,128 lb
Bending Frictional Drag = $2 \mu N$ =	78,677 lb		
Fluidic Drag = $12 \pi D L C_d$ =	17,055 lb		
Axial Segment Weight = $W_e L \sin\theta$ =	-12,463 lb	Negative value indicates axial weight applied in direction of installation	
Pulling Load on Entry Sag Bend =	**83,269 lb**		
Total Pulling Load =	**209,121 lb**		

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	34.5 ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4 lb/ft
Entry Angle, θ =	8.0 °		
Frictional Drag = $W_e L \mu \cos\theta$ =	3,646 lb		
Fluidic Drag = $12 \pi D L C_d$ =	1,171 lb		
Axial Segment Weight = $W_e L \sin\theta$ =	-1,708 lb	Negative value indicates axial weight applied in direction of installation	
Pulling Load on Entry Tangent =	**3,109 lb**		
Total Pulling Load =	**212,230 lb**		

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	2,586	ok	0	ok	0	ok	0.04	ok	0.00	ok
	2,548	ok	0	ok	73	ok	0.04	ok	0.00	ok
PC										
	2,548	ok	12,083	ok	73	ok	0.31	ok	0.07	ok
	1,533	ok	12,083	ok	603	ok	0.29	ok	0.08	ok
PT										
	1,533	ok	0	ok	603	ok	0.02	ok	0.01	ok
	1,362	ok	0	ok	603	ok	0.02	ok	0.01	ok
PC										
	1,362	ok	12,083	ok	603	ok	0.29	ok	0.07	ok
	97	ok	12,083	ok	73	ok	0.27	ok	0.05	ok
PT										
	97	ok	0	ok	73	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 4: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	486.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	51,315	lb			
Fluidic Drag = 12 π D L C_d =	16,488	lb			
Axial Segment Weight = W_e L sinθ =	24,039	lb			
Pulling Load on Exit Tangent =	**91,842**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	129,298	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	j = [(E I) / T]$^{1/2}$ =	1,691	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	2.8E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	151.71	
U = (12 L) / j =	1.78		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	100,255	lb
Bending Frictional Drag = 2 μ N =	60,153	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**74,912**	**lb**			
Total Pulling Load =	**166,754**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	46.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	4,908	lb			
Fluidic Drag = 12 π D L C_d =	1,562	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**6,470**	**lb**			
Total Pulling Load =	**173,224**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	206,318	lb
Segment Angle with Horizontal, θ =	8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	j = [(E I) / T]$^{1/2}$ =	1,339	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	4.0E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	211.89	
U = (12 L) / j =	2.25		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	106,486	lb
Bending Frictional Drag = 2 μ N =	63,891	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	-6,231	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**66,187**	**lb**			
Total Pulling Load =	**239,411**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	340.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	35,905	lb			
Fluidic Drag = 12 π D L C_d =	11,537	lb			
Axial Segment Weight = W_e L sinθ =	-16,820	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**30,621**	**lb**			
Total Pulling Load =	**270,033**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,290	ok	0	ok	0	ok	0.05	ok	0.00	ok
	2,917	ok	0	ok	717	ok	0.05	ok	0.01	ok
PC										
	2,917	ok	24,167	ok	717	ok	0.58	ok	0.27	ok
	2,110	ok	24,167	ok	982	ok	0.56	ok	0.27	ok
PT										
	2,110	ok	0	ok	982	ok	0.03	ok	0.02	ok
	2,032	ok	0	ok	982	ok	0.03	ok	0.02	ok
PC										
	2,032	ok	24,167	ok	982	ok	0.56	ok	0.27	ok
	1,119	ok	24,167	ok	717	ok	0.55	ok	0.23	ok
PT										
	1,119	ok	0	ok	717	ok	0.02	ok	0.01	ok
Exit Point	0	ok	0	ok	-308	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The risk of inadvertent drilling fluid returns due to hydrofracture was evaluated using the Delft Method described previously in Section 5 of the report. In summary, the risk of inadvertent drilling fluid returns due to hydrofracture is low over the majority of the length of the crossing, with the exception of the first and last 50 feet of the installation, near the entry and exit points. Therefore, under normal drilling operations, inadvertent drilling fluid returns due to hydrofracture are not anticipated. Refer to Figure 6 for results presented in graphical format

It is important to keep in mind that inadvertent drilling fluid returns may occur due to mechanisms unrelated to hydrofracture. It remains possible that inadvertent drilling fluid returns will occur by flowing to the ground surface through preexisting fractures or porous seams in the soil mass.

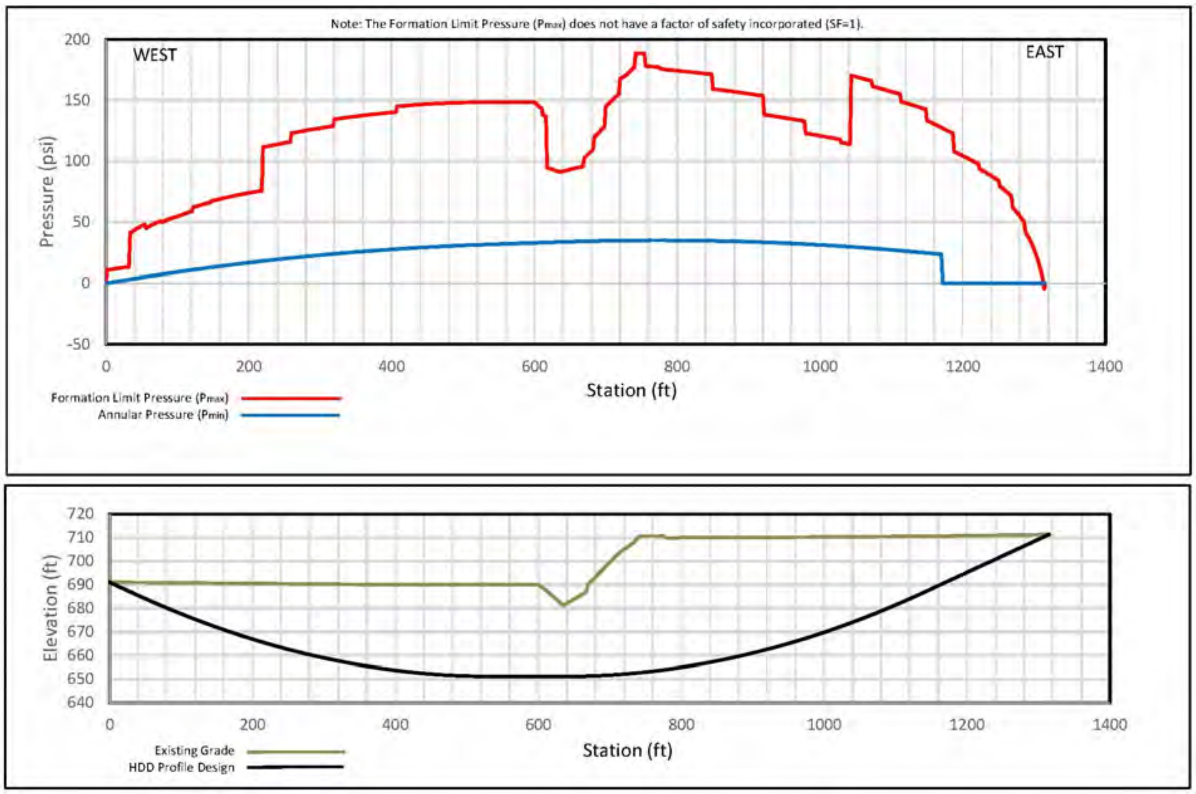


Figure 6: Hydrofracture Evaluation (Formation Limit Pressure –vs-Annular Pressure)

Construction Duration

The estimated duration of construction for the Saline River Crossing is 12 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 7 for additional information relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Saline River Crossing
days/week =	7.0	
Drilled Length, feet =	1,320	
Pilot Hole		
Production Rate, feet/hour =	50	
shifts/day =	1	
Drilling Duration, hours =	26.4	
shifts =	2.2	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	2.7	

Ream and Pull Back								
Pass Description =	36-inch	48-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	2.0	2.0				8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0				15.0	15.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	12.4	12.4				4.2	5.1	34.1
shifts =	1.0	1.0				0.3	0.4	2.8
Rig up, shifts =	0.5	0.5				0.5	0.5	2.0
Trips to change tools, shifts =	1.0	1.0				0.0		2.0
Pass Duration, days =	2.5	2.5				0.8	0.9	6.8

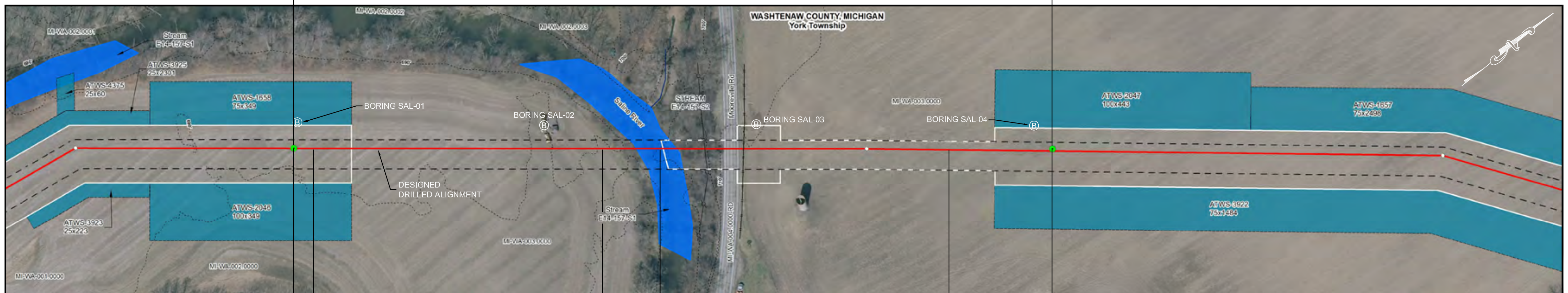
Summary				
HDD Duration at Site, days =	11.5			
Site Establishment	**Move in**	**Rig Up**	**Rig Down**	**Move Out**
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 7: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-159

HORIZONTAL LENGTH = 1,315'
TRUE LENGTH = 1,320'



PLAN
SCALE: 1" = 100'

ENTRY POINT @ 8°
0+00.00, 691.05
N 15300350.01, E 906066.89

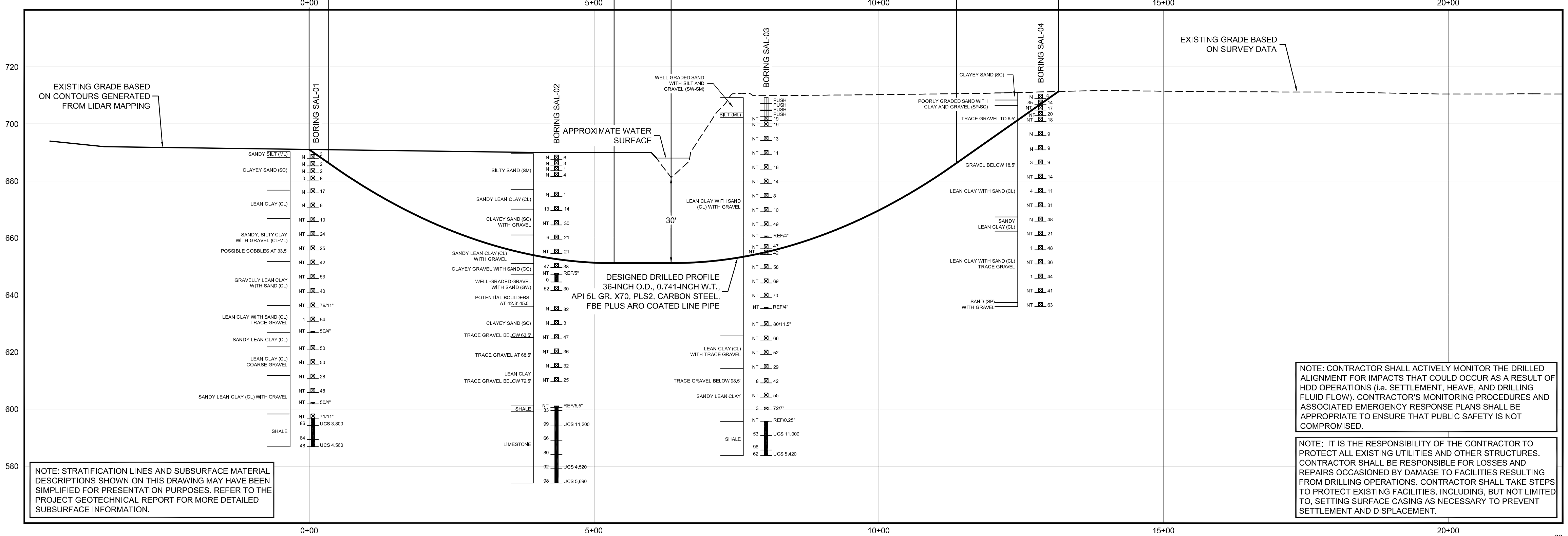
P.C. 8° SAG BEND
0+34.21, 686.24
RADIUS = 3,600'

P.T. 8° SAG BEND
5+35.23, 651.21

P.C. 8° SAG BEND
6+35.23, 651.21
RADIUS = 3,600'

P.T. 8° SAG BEND
11+36.25, 686.24

EXIT POINT @ 8°
13+15.00, 711.36
N 15301378.37, E 906886.46



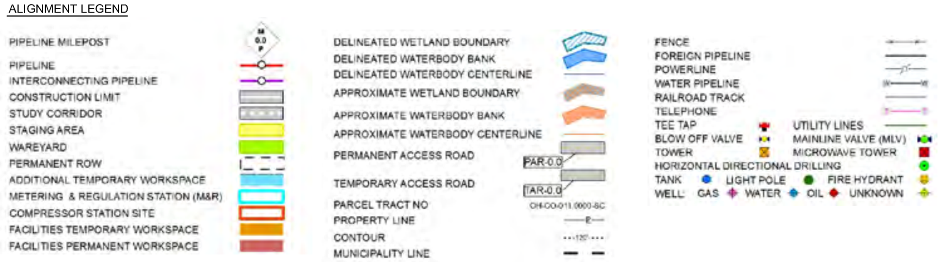
NOTE: STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING MAY HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES. REFER TO THE PROJECT GEOTECHNICAL REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.

NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

PROFILE
SCALE: 1" = 100' HORIZONTAL
1" = 20' VERTICAL

ALIGNMENT LEGEND



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
TSS 1,350 — TENSILE SPLITTING STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC. BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		2	ACM	JMS	RE-ISSUED FOR FERC
WATE-A-1260	ALIGNMENT SHEET M.P. 237.66 TO M.P. 238.60	1	LKB	JMS	ISSUED FOR BID
WATE-A-1259	ALIGNMENT SHEET M.P. 236.71 TO M.P. 237.66	0	LKB	JMS	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	DMP	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	DMP	08/07		
DESIGN CHECKER	ACM	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH SALINE RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING
WASHTENAW COUNTY, MICHIGAN

M.P. 237.4 | W.O. | SCALE: AS SHOWN | DWG. WATE-H-1015 | REV. 2

NEXUS GAS TRANSMISSION

MP 250.7 Hydro Park

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- LiDAR and survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. "Geotechnical and Geophysical Data Report, Hydro Park Ford River HDD Crossing, Nexus Gas Transmission Project, Washtenaw County Michigan" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Hydro Park Crossing is located near pipeline Mile Post 250.7 just south of Ypsilanti, Michigan. The primary obstacles that will be crossed are a meandering river just downstream of Ford Lake Dam, as well as Bridge Road. The river is approximately 175 feet wide at the crossing location and about 5 feet deep. Both sides of the crossing are wooded. The proposed HDD alignment crosses perpendicularly to Bridge Road, extends across the river cut-bank, and onto the point bar within South Hydro Park. An overview of the proposed crossing location is provided in Figure 1. Additional site photos taken during the reconnaissance are provided in Figures 2 and 3.

Figure 1: Overview of the Hydro Park Crossing

Figure 2: View looking east from approximate exit point

Figure 3: View looking south at water body from approximately 150 feet south of entry point

Subsurface Conditions

Four geotechnical borings were drilled at the proposed crossing site as part of the site investigation conducted by Fugro Consultants, Inc. Boring HYD-01, taken near the proposed entry point on the east side of the crossing, encountered layers of silty sand, lean clay with sand, sandy lean clay, sand with clay, and gravel with clay, overlying dolomite and shale bedrock. Top of bedrock was at approximately 99 feet below the ground surface. Grain size curves indicate gravel content as high as 71 percent. Boring HYD-02, taken approximately 614 feet south of the HDD alignment, was drilled to a depth of 79 feet and encountered mixtures of sandy lean clay, silty sand, clayey gravel, sand, with silt and gravel, gravel with silt and gravel with sand. A possible cobble was noted at about 65 feet. Grain size curves indicate gravel as high as 73 percent. Bedrock was not encountered in Boring HYD-02. Boring HYD-03 was located on the west side of the crossing, approximately 400 feet east of Bridge Road. Conditions encountered were consistent with the other borings. Top of bedrock occurred at a depth of 103 feet. Grain size curves indicate up to 41 percent gravel. Boring HYD-04, taken near the proposed HDD exit point, also encountered mixtures of clay, silt, sand, and gravel, but with less gravel after about 35 feet. Grain size curves indicate a gravel content of 72 percent at a depth of about 19 feet.

Design Geometry & Layout

The proposed crossing design involves a horizontal length of 2,300 feet. It utilizes 10-degree entry and exit angles, and a radius of curvature of 3,600 feet. The crossing design is based on offsetting the entry point 60 feet west of the P.I. on the east side of the crossing, obtaining 33 feet of cover beneath the slope on the east end of the crossing, 40 feet of cover at the centerline of Bridge Road, and 40 feet of cover beneath the river.

Due to workspace considerations, the exit point is located on the west side of the crossing to take advantage of open space parallel to Lakeshore Boulevard for pull section fabrication. The entry point is located on the east side of the crossing.

A copy of the preliminary HDD plan and profile drawing is included at the end of this report.

Assessment of Feasibility

Although the feasibility of the Hydro Park crossing cannot be ruled out, adverse subsurface conditions in the form of coarse granular material are present. Passing through significant coarse granular material (gravel) will increase the risk of HDD operational problems.

Risk Identification and Assessment

Notable risks at this location include damage to Bridge Road in the form of heaving or settlement, as well as drilling fluid surfacing with the water body.

The overall risk of constructional operational problems and delays is considered high due to an abundance of coarse granular material over the duration of the crossing.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse-case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 386,303 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 410,143 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each installation loading scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in
Pipe Weight, W =	279.0	lb/ft
Coefficient of Soil Friction, μ =	0.30	
Fluid Drag Coefficient, C_d =	0.025	psi
Ballast Weight / ft Pipe, W_b =	405.5	lb (If Ballasted)
Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb (If Submerged)
Above Ground Load =	0	lb

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	179.2	ft
Exit Angle, θ =	10.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e L \mu \cos\theta$ =	18,818	lb
Fluidic Drag = $12 \pi D L C_d$ =	6,080	lb
Axial Segment Weight = $W_e L \sin\theta$ =	11,061	lb
Pulling Load on Exit Tangent =	**35,959**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft
Segment Angle with Horizontal, θ =	-10.0	°
Deflection Angle, α =	-5.0	°
Average Tension, T =	102,344	lb
Radius of Curvature, R =	3,600	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	13.70	ft
$j = [(E I) / T]^{1/2}$ =	1,901	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	4.5E+06	
$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	969.75	
$U = (12 L) / j$ =	3.97	
$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	153,313	lb
Bending Frictional Drag = $2 \mu N$ =	91,988	lb
Fluidic Drag = $12 \pi D L C_d$ =	21,318	lb
Axial Segment Weight = $W_e L \sin\theta$ =	19,464	lb
Pulling Load on Exit Sag Bend =	**132,770**	**lb**
Total Pulling Load =	**168,729**	**lb**

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	719.5	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e L \mu$ =	76,721	lb
Fluidic Drag = $12 \pi D L C_d$ =	24,412	lb
Axial Segment Weight = $W_e L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**101,133**	**lb**
Total Pulling Load =	**269,863**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft
Segment Angle with Horizontal, θ =	10.0	°
Deflection Angle, α =	5.0	°
Average Tension, T =	322,064	lb
Radius of Curvature, R =	3,600	ft
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R [1 - \cos(\alpha/2)]$ =	13.70	ft
$j = [(E I) / T]^{1/2}$ =	1,072	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	6.0E+06	
$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	1350.05	
$U = (12 L) / j$ =	7.04	
$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	170,916	lb
Bending Frictional Drag = $2 \mu N$ =	102,550	lb
Fluidic Drag = $12 \pi D L C_d$ =	21,318	lb
Axial Segment Weight = $W_e L \sin\theta$ =	-19,464	lb
Pulling Load on Entry Sag Bend =	**104,404**	**lb**
Total Pulling Load =	**374,266**	**lb**

Negative value indicates axial weight applied in direction of installation

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	155.9	ft
Entry Angle, θ =	10.0	°
Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e L \mu \cos\theta$ =	16,369	lb
Fluidic Drag = $12 \pi D L C_d$ =	5,289	lb
Axial Segment Weight = $W_e L \sin\theta$ =	-9,621	lb
Pulling Load on Entry Tangent =	**12,037**	**lb**
Total Pulling Load =	**386,303**	**lb**

Negative value indicates axial weight applied in direction of installation

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,706	ok	0	ok	0	ok	0.07	ok	0.01	ok
	4,560	ok	0	ok	395	ok	0.07	ok	0.01	ok
PC										
	4,560	ok	12,083	ok	395	ok	0.34	ok	0.10	ok
	3,288	ok	12,083	ok	1224	ok	0.32	ok	0.13	ok
PT										
	3,288	ok	0	ok	1224	ok	0.05	ok	0.04	ok
	2,056	ok	0	ok	1224	ok	0.03	ok	0.03	ok
PC										
	2,056	ok	12,083	ok	1224	ok	0.30	ok	0.11	ok
	438	ok	12,083	ok	395	ok	0.27	ok	0.06	ok
PT										
	438	ok	0	ok	395	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	-76	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	480.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	50,474	lb			
Fluidic Drag = 12 π D L C_d =	16,308	lb			
Axial Segment Weight = W_e L sinθ =	29,666	lb			
Pulling Load on Exit Tangent =	**96,449**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	139,862	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	1,626	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	6.4E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	275.11	
U = (12 L) / j =	2.32		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	110,726	lb
Bending Frictional Drag = 2 μ N =	66,435	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	9,732	lb			
Pulling Load on Exit Sag Bend =	**86,827**	**lb**			
Total Pulling Load =	**183,275**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	800.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	85,401	lb			
Fluidic Drag = 12 π D L C_d =	27,174	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**112,574**	**lb**			
Total Pulling Load =	**295,850**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	335,339	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	1,050	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	1.0E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	445.56	
U = (12 L) / j =	3.59		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	130,086	lb
Bending Frictional Drag = 2 μ N =	78,052	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**78,979**	**lb**			
Total Pulling Load =	**374,828**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	457.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	48,025	lb			
Fluidic Drag = 12 π D L C_d =	15,517	lb			
Axial Segment Weight = W_e L sinθ =	-28,227	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**35,315**	**lb**			
Total Pulling Load =	**410,143**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,997	ok	0	ok	0	ok	0.08	ok	0.01	ok
	4,567	ok	0	ok	1188	ok	0.07	ok	0.04	ok
PC										
	4,567	ok	24,167	ok	1188	ok	0.60	ok	0.33	ok
	3,604	ok	24,167	ok	1602	ok	0.59	ok	0.35	ok
PT										
	3,604	ok	0	ok	1602	ok	0.06	ok	0.06	ok
	2,233	ok	0	ok	1602	ok	0.04	ok	0.05	ok
PC										
	2,233	ok	24,167	ok	1602	ok	0.56	ok	0.32	ok
	1,175	ok	24,167	ok	1188	ok	0.55	ok	0.27	ok
PT										
	1,175	ok	0	ok	1188	ok	0.02	ok	0.03	ok
Exit Point	0	ok	0	ok	-76	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading and Stress Analysis (Worse-Case)

Hydrofracture Evaluation

The risk of inadvertent drilling fluid returns due to hydrofracture was reviewed using the Delft Method. The Delft Method is described in Section 5 of the report. In summary, under normal drilling operations, the risk of inadvertent drilling fluid returns due to hydrofracture is low over the majority of the length of the crossing with the exception of the last 60 feet of the drill where cover is shallow as the bit begins to make its way to the surface. The factor of safety remains above 2.0 until station 22+12 indicating a low risk of hydrofracture. After station 22+12, the factor of safety begins dropping until reaching 1.0 at station 22+22, approximately 58 feet from the exit point, indicating an increased risk inadvertent drilling fluid returns. Inadvertent drilling fluid returns due to hydrofracture near the exit point, where cover is shallow, is a common occurrence in the HDD industry during pilot hole drilling. These returns typically occur within the project right-of-way and are easily contained and collected. Refer to Figure 7 for results presented in graphical format.

It is important to keep in mind that inadvertent drilling fluid returns may occur due to mechanisms unrelated to hydrofracture. It remains possible that inadvertent drilling fluid returns will occur by flowing to the ground surface through preexisting fractures or porous seams in the soil mass.

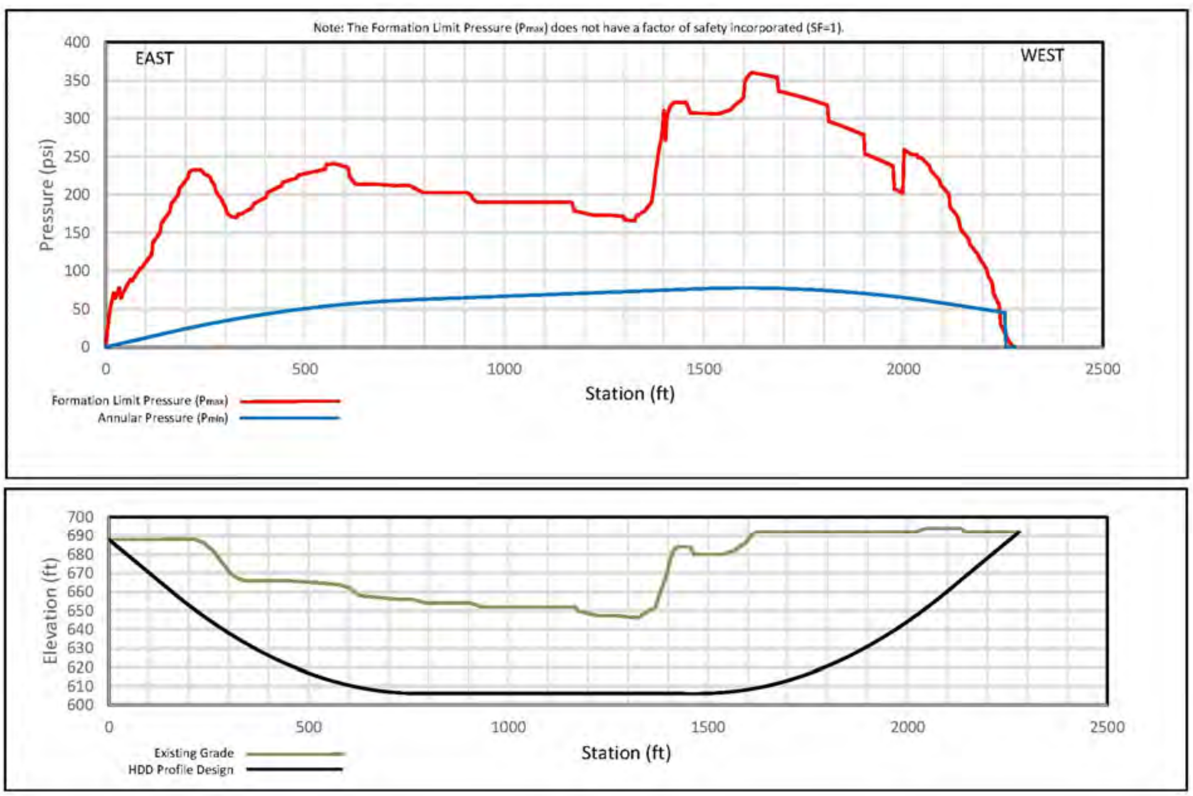


Figure 7: Hydrofracture Evaluation (Formation Limit Pressure –vs-Annular Pressure)

Construction Duration

The estimated duration of construction for the proposed crossing is 26 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 8 for additional information relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" Hydro Park Crossing
days/week =	7.0	
Drilled Length, feet =	2,311	
Pilot Hole		
Production Rate, feet/hour =	30	
shifts/day =	1	
Drilling Duration, hours =	77.0	
shifts =	6.4	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	6.9	

Ream and Pull Back								
Pass Description =	24-inch	36-inch	48-inch			Swab	Pull Back	Total
Travel Speed, feet/minute =	1.0	1.0	1.0			8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0	15.0			15.0	15.0	
shifts/day =	1	1	1			1	1	
Reaming Duration, hours =	41.0	41.0	41.0			7.3	8.9	139.2
shifts =	3.4	3.4	3.4			0.6	0.7	11.6
Rig up, shifts =	0.5	0.5	0.5			0.5	0.5	2.5
Trips to change tools, shifts =	1.0	1.0	1.0			0.0		3.0
Pass Duration, days =	4.9	4.9	4.9			1.1	1.2	17.1

Summary				
HDD Duration at Site, days =	26.0			
Site Establishment	**Move in**	**Rig Up**	**Rig Down**	**Move Out**
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 8: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

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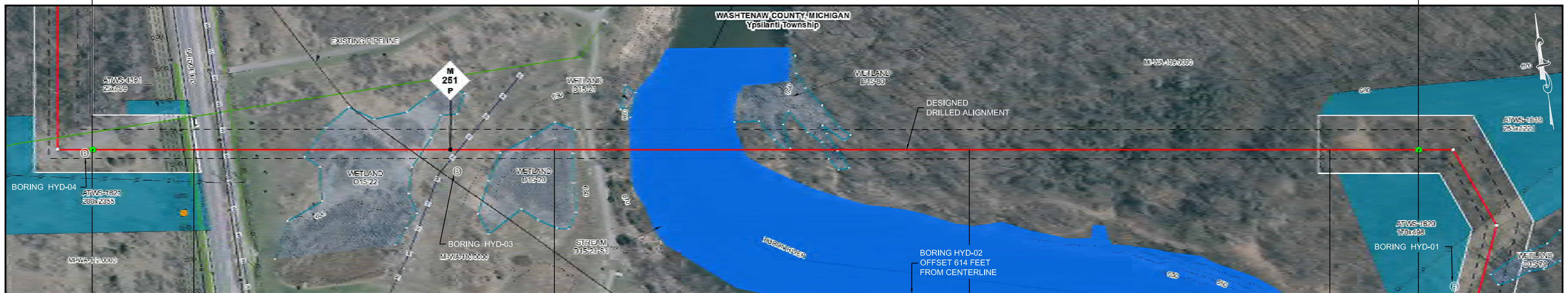
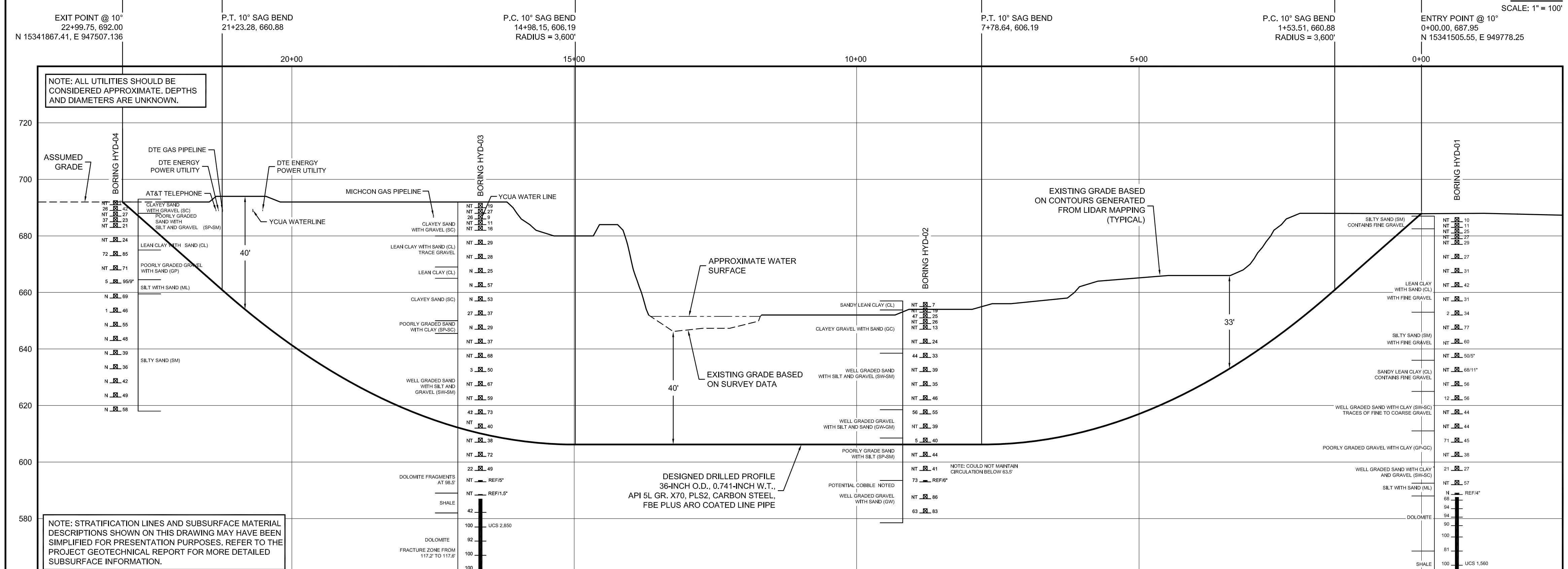
HORIZONTAL LENGTH = 2,300'
TRUE LENGTH = 2,311'



PLAN

SCALE: 1" = 100'



PROFILE

SCALE: 1" = 100' HORIZONTAL
1" = 20' VERTICAL

ALIGNMENT LEGEND

PIPELINE MILEPOST; PIPELINE; INTERCONNECTING PIPELINE; CONSTRUCTION LIMIT; STUDY CORRIDOR; STAGING AREA; WAREYARD; PERMANENT ROW; ADDITIONAL TEMPORARY WORKSPACE; METERING & REGULATION STATION (M&R); COMPRESSOR STATION SITE; FACILITIES TEMPORARY WORKSPACE; FACILITIES PERMANENT WORKSPACE

DELINEATED WETLAND BOUNDARY; DELINEATED WATERBODY BANK; DELINEATED WATERBODY CENTERLINE; APPROXIMATE WETLAND BOUNDARY; APPROXIMATE WATERBODY BANK; APPROXIMATE WATERBODY CENTERLINE; PERMANENT ACCESS ROAD; TEMPORARY ACCESS ROAD; PARCEL TRACT NO; PROPERTY LINE; CONTOUR; MUNICIPALITY LINE

FENCE; FOREIGN PIPELINE; POWERLINE; WATER PIPELINE; RAILROAD TRACK; TELEPHONE; TEE TAP; BLOW OFF VALVE; TOWER; HORIZONTAL DIRECTIONAL DRILLING; TANK; WELL: GAS, WATER, OIL, UNKNOWN; UTILITY LINES; MAINLINE VALVE (MLV); MICROWAVE TOWER; LIGHT POLE; FIRE HYDRANT

NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE
- PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
- PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE
- UNCONFINED COMPRESSIVE STRENGTH (PSI)
- MOHS HARDNESS
- ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC. BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	ACM	JMS	RE-ISSUED FOR FERC
		2	LKB	JMS	REVISE HDD ENTRY POINT LOCATION AND UPDATE CENTERLINE
WATE-A-1274	ALIGNMENT SHEET M.P. 250.89 TO M.P. 251.84	1	LKB	JMS	ISSUED FOR BID
WATE-A-1273	ALIGNMENT SHEET M.P. 249.49 TO M.P. 250.89	0	LKB	JMS	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	LKB	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB	08/07		
DESIGN CHECKER	DLB	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH HYDRO PARK CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

WASHTENAW COUNTY, MICHIGAN

NEXUS GAS TRANSMISSION

M.P. 250.7 | W.O. | SCALE: AS SHOWN | DWG. WATE-H-1016 | REV. 3

MP 251.5 Interstate 94

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- A geotechnical data report prepared by Fugro Consultants, Inc. titled "Geotechnical Data Report, Interstate 94 HDD Crossing, Nexus Gas Transmission Project, Washtenaw County Michigan" and dated September 11, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Interstate 94 Crossing is located in Rawsonville, Michigan. It involves passing beneath the eastbound and westbound lanes of Interstate 94, as well as the northbound and southbound lanes of the access roads (Ward Road and Lakeview Avenue). The proposed HDD alignment is located within an existing power line easement, which also contains an existing water line and an existing gas pipeline. An overview of the proposed crossing location is provided in Figures 1 through 3.

Figure 1 – Overview of the Interstate 94 Crossing

Figure 2: View looking west toward entry location

Figure 3: View looking east along power line ROW toward exit point

Subsurface Conditions

Four geotechnical borings were taken as part of the site investigation conducted by Fugro Consultants, Inc. Two of the borings were taken on the north side of the interstate and two of the borings were taken on the south side of the interstate. The borings generally encountered sand with some gravel to depths of approximately 15 to 20 feet below the ground surface, overlying mixtures of lean clay and sand to the termination depths of the borings.

Refer to the report titled "Geotechnical Data Report, Interstate 94 HDD Crossing, Nexus Gas Transmission Project, Washtenaw County Michigan" and dated September 11, 2015, for additional information.

Design Geometry & Layout

The proposed Interstate 94 Crossing has a horizontal length of 1,359 feet. It has been designed to achieve a minimum of 40 feet of cover beneath Interstate 94 and the associated access roads. The design employs a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature equal to 3,600 feet. The exit point is located on the north side of the interstate to take advantage of greater available workspace for pull section fabrication. The exit point on the north side of the crossing was positioned to be as far south as possible while still maintaining adequate cover beneath the access road. This provides the HDD contractor with approximately 1,000 feet of workspace for pull section fabrication. A copy of the proposed HDD design for Interstate 94 is included at the end of this section.

Workspace on both sides of the crossing runs along the existing power line easement and extends from just east of the existing gas pipeline for a distance of approximately 180 feet, providing ample working area for HDD rig side and pipe side activities. The power line easement crosses a residential street to the north approximately 1,150 feet from the point of exit. Therefore, the 36-inch pull section segment will have to be fabricated in two segments and welded during pullback.

The proposed HDD design, as well as available workspace for HDD operations, is shown on the HDD plan and profile drawing included in this site-specific report.

Assessment of Feasibility

Based on a review of available geotechnical information, subsurface conditions are conducive to the HDD process. Given the length, the proposed 36-inch diameter Interstate 94 Crossing is feasible.

Risk Identification and Assessment

Notable risks and potential construction impact associated with installation by HDD include impact to Interstate 94, Ward Road, and Lakeview Avenue in the form of heave, settlement, or inadvertent drilling fluid returns. In addition, because the crossing involves a tie-in weld during pullback, there is a chance the pull section could become silted or sanded in place while down for the weld, making it difficult to get the pipe moving again.

Overall, the level of risk associated with the proposed Interstate 94 Crossing is considered low.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 242,597 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 268,806 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each scenario are summarized in Figures 5 and 6.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in^4
Pipe Face Surface Area =	82.08	in^2
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft^3/ft
Pipe Exterior Volume =	7.07	ft^3/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft^3
Ballast Density =	62.4	lb/ft^3
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	176.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	18,631	lb			
Fluidic Drag = 12 π D L C_d =	5,986	lb			
Axial Segment Weight = W_e L sinθ =	8,728	lb			
Pulling Load on Exit Tangent =	**33,345**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	502.7	ft	Average Tension, T =	85,783	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	8.77	ft	$j = [(E I) / T]^{1/2}$ =	2,077	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.1E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	577.50	
U = (12 L) / j =	2.90		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	125,597	lb
Bending Frictional Drag = 2 μ N =	75,358	lb			
Fluidic Drag = 12 π D L C_d =	17,055	lb			
Axial Segment Weight = W_e L sinθ =	12,463	lb			
Pulling Load on Exit Sag Bend =	**104,876**	**lb**			
Total Pulling Load =	**138,221**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	29.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	3,104	lb			
Fluidic Drag = 12 π D L C_d =	988	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**4,092**	**lb**			
Total Pulling Load =	**142,313**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	191,315	lb	
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft	
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft	
h = R [1 - cos(α/2)] =	13.70	ft	$j = [(E I) / T]^{1/2}$ =	1,390		
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	5.4E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	1195.82		
U = (12 L) / j =	5.42		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	160,250	lb	
Bending Frictional Drag = 2 μ N =	96,150	lb				
Fluidic Drag = 12 π D L C_d =	21,318	lb				
Axial Segment Weight = W_e L sinθ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation			
Pulling Load on Entry Sag Bend =	**98,004**	**lb**				
Total Pulling Load =	**240,317**	**lb**				

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	29.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	3,101	lb			
Fluidic Drag = 12 π D L C_d =	1,002	lb			
Axial Segment Weight = W_e L sinθ =	-1,823	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**2,280**	**lb**			
Total Pulling Load =	**242,597**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	2,956	ok	0	ok	0	ok	0.05	ok	0.00	ok
	2,928	ok	0	ok	74	ok	0.05	ok	0.00	ok
PC										
	2,928	ok	12,083	ok	74	ok	0.31	ok	0.07	ok
	1,734	ok	12,083	ok	902	ok	0.29	ok	0.09	ok
PT										
	1,734	ok	0	ok	902	ok	0.03	ok	0.02	ok
	1,684	ok	0	ok	902	ok	0.03	ok	0.02	ok
PC										
	1,684	ok	12,083	ok	902	ok	0.29	ok	0.09	ok
	406	ok	12,083	ok	372	ok	0.27	ok	0.06	ok
PT										
	406	ok	0	ok	372	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	480.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			
Frictional Drag = W_e L μ cosθ =	50,730	lb			
Fluidic Drag = 12 π D L C_d =	16,301	lb			
Axial Segment Weight = W_e L sinθ =	23,766	lb			
Pulling Load on Exit Tangent =	**90,797**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	251.3	ft	Average Tension, T =	128,227	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	4.38	ft	j = [(E I) / T]$^{1/2}$ =	1,698	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	2.8E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	150.75	
U = (12 L) / j =	1.78		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	100,168	lb
Bending Frictional Drag = 2 μ N =	60,101	lb			
Fluidic Drag = 12 π D L C_d =	8,527	lb			
Axial Segment Weight = W_e L sinθ =	6,231	lb			
Pulling Load on Exit Sag Bend =	**74,860**	**lb**			
Total Pulling Load =	**165,656**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	43.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	4,674	lb			
Fluidic Drag = 12 π D L C_d =	1,487	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**6,162**	**lb**			
Total Pulling Load =	**171,818**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	207,515	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	1,335	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	8.1E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	349.77	
U = (12 L) / j =	2.82		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	117,445	lb
Bending Frictional Drag = 2 μ N =	70,467	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**71,394**	**lb**			
Total Pulling Load =	**243,212**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	331.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	34,805	lb			
Fluidic Drag = 12 π D L C_d =	11,245	lb			
Axial Segment Weight = W_e L sinθ =	-20,457	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**25,594**	**lb**			
Total Pulling Load =	**268,806**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,275	ok	0	ok	0	ok	0.05	ok	0.00	ok
	2,963	ok	0	ok	864	ok	0.05	ok	0.02	ok
PC										
	2,963	ok	24,167	ok	864	ok	0.58	ok	0.28	ok
	2,093	ok	24,167	ok	1278	ok	0.56	ok	0.29	ok
PT										
	2,093	ok	0	ok	1278	ok	0.03	ok	0.03	ok
	2,018	ok	0	ok	1278	ok	0.03	ok	0.03	ok
PC										
	2,018	ok	24,167	ok	1278	ok	0.56	ok	0.29	ok
	1,106	ok	24,167	ok	1012	ok	0.55	ok	0.25	ok
PT										
	1,106	ok	0	ok	1012	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading (Worse-Case)

Hydrofracture Evaluation

The risk of inadvertent drilling fluid returns due to hydrofracture was evaluated using the Delft Method. The Delft Method is described in Section 5 of the report. In summary, the risk of inadvertent drilling fluid returns due to hydrofracture is low over the majority of the length of the crossing. The factor of safety remains above 2.0 until the last 60 feet of the crossing where cover is shallow as the bit begins to make its way to the surface. Therefore, inadvertent drilling fluid returns due to hydrofracture are not anticipated under normal drilling operations at this location. Refer to Figure 7 for results presented in graphical format.

It is important to keep in mind that inadvertent drilling fluid returns may occur due to mechanisms unrelated to hydrofracture. It remains possible that inadvertent drilling fluid returns will occur by flowing to the ground surface through preexisting fractures or porous seams in the soil mass.

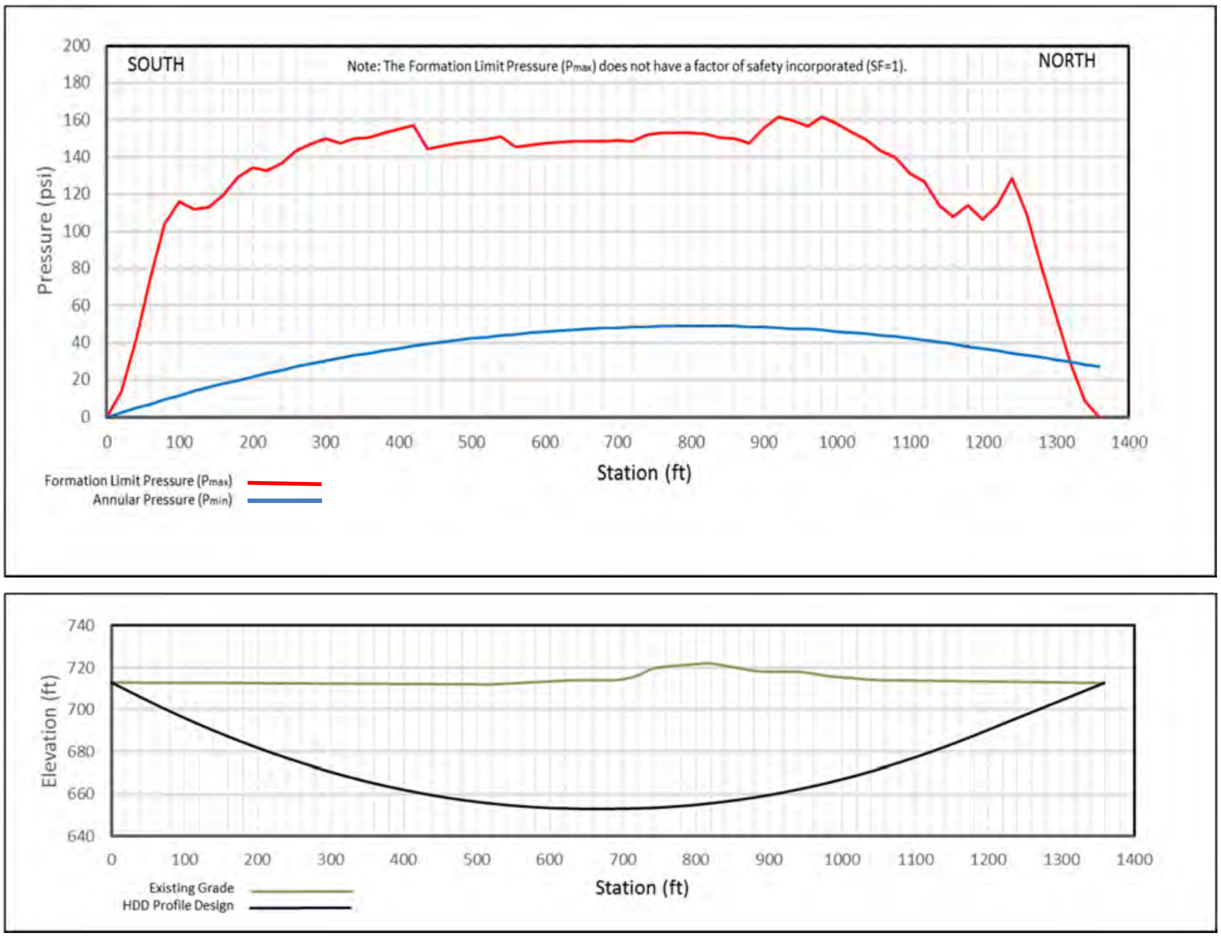


Figure 7: Hydrofracture Evaluation (Formation Limit Pressure - vs - Annular Pressure)

Construction Duration

The estimated duration of construction for the I-94 Crossing is 12 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 8 for additional information relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

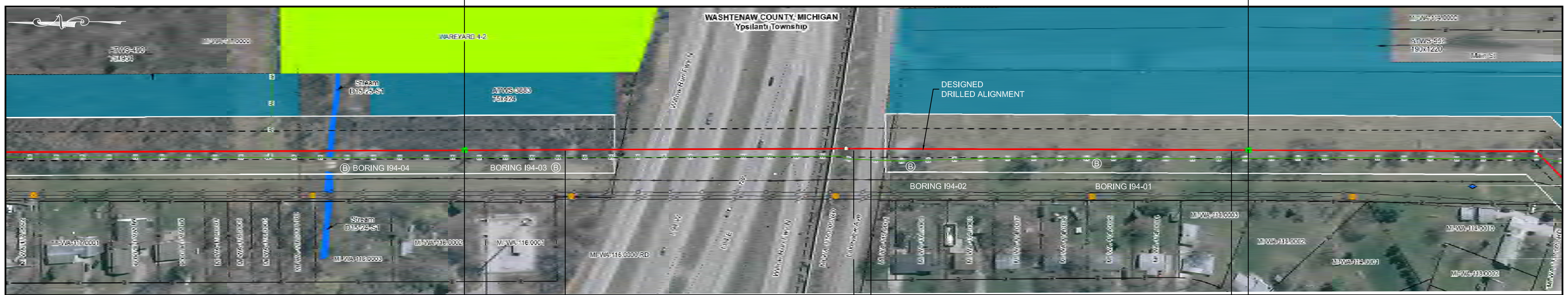
General Data		Comments						
Work Schedule, hours/shift =	12.0	36" Interstate 94 Crossing						
days/week =	7.0							
Drilled Length, feet =	1,366							
Pilot Hole								
Production Rate, feet/hour =	50							
shifts/day =	1							
Drilling Duration, hours =	27.3							
shifts =	2.3							
Trips to change tools, shifts =	0.5							
Pilot Hole Duration, days =	2.8							
Ream and Pull Back								
Pass Description =	36-inch	48-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	2.0	2.0				8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0				15.0	15.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	12.9	12.9				4.3	5.3	35.3
shifts =	1.1	1.1				0.4	0.4	2.9
Rig up, shifts =	0.5	0.5				0.5	0.5	2.0
Trips to change tools, shifts =	1.0	1.0				0.0		2.0
Pass Duration, days =	2.6	2.6				0.9	0.9	6.9
Summary								
HDD Duration at Site, days =	11.7							
Site Establishment	Move in	Rig Up	Rig Down	Move Out				
shifts/day =	1	1	1	1				
shifts =	0.5	1.0	1.0	0.5				
days =	0.5	1.0	1.0	0.5				

Figure 8: Estimated Construction Duration

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-177

HORIZONTAL LENGTH = 1,359'
TRUE LENGTH = 1,366'



PLAN
SCALE: 1" = 100'

EXIT POINT @ 8°
13+59.07, 712.67
N 15345325.30, E 947790.22

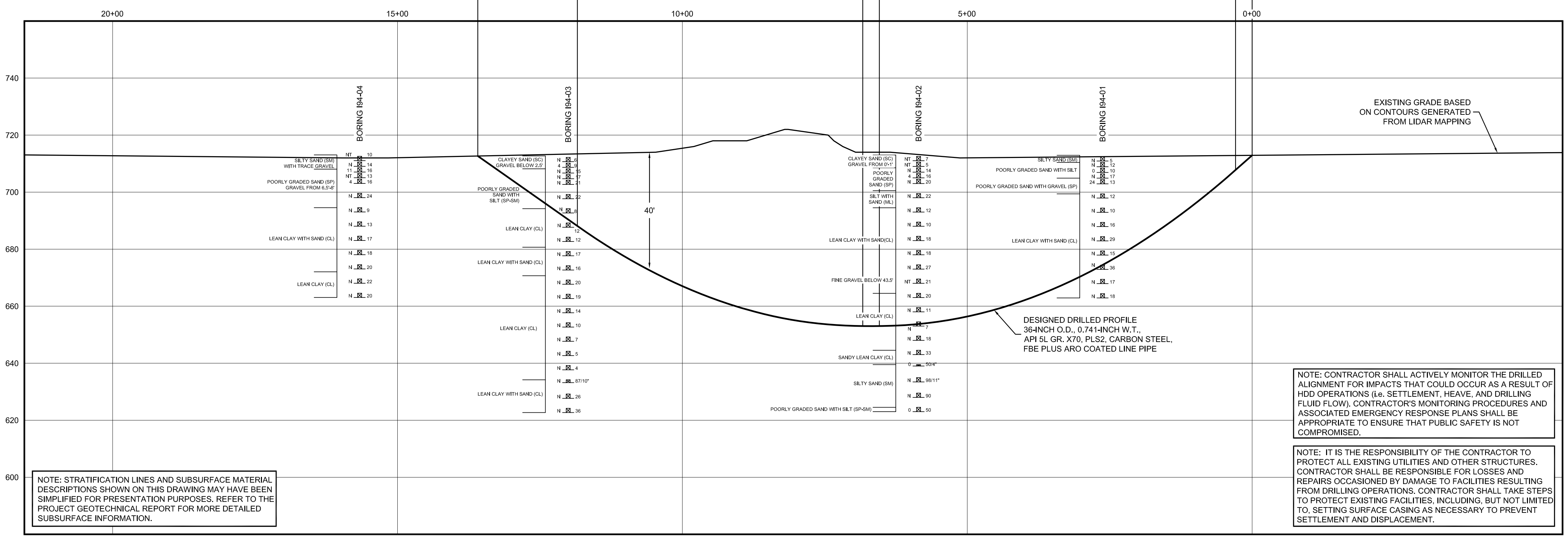
P.T. 8° SAG BEND
11+84.36, 688.12

P.C. 8° SAG BEND
6+83.34, 653.08
RADIUS = 3,600'

P.T. 10° SAG BEND
6+54.22, 653.08

P.C. 10° SAG BEND
0+29.09, 707.77
RADIUS = 3,600'

ENTRY POINT @ 10°
0+00.00, 712.90
N 15343966.30, E 947777.36



NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO PROTECT ALL EXISTING UTILITIES AND OTHER STRUCTURES. CONTRACTOR SHALL BE RESPONSIBLE FOR LOSSES AND REPAIRS OCCASIONED BY DAMAGE TO FACILITIES RESULTING FROM DRILLING OPERATIONS. CONTRACTOR SHALL TAKE STEPS TO PROTECT EXISTING FACILITIES, INCLUDING, BUT NOT LIMITED TO, SETTING SURFACE CASING AS NECESSARY TO PREVENT SETTLEMENT AND DISPLACEMENT.

NOTE: STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING MAY HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES. REFER TO THE PROJECT GEOTECHNICAL REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.

PROFILE
SCALE: 1" = 100' HORIZONTAL
1" = 20' VERTICAL

ALIGNMENT LEGEND

GENERAL LEGEND
DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES
1. LIDAR AND SURVEY DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.

2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES
1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.

2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

GEOTECHNICAL LEGEND
BORING LOCATION

SPLIT SPOON SAMPLE
- PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
- PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

PUSH SAMPLE

CORE BARREL SAMPLE
- UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
- TSS 1,350 — TENSILE SPLITTING STRENGTH (PSI)
- MOHS HARDNESS
- ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES
1. GEOTECHNICAL DATA PROVIDED BY FUGRO CONSULTANTS, INC, BATON ROUGE, LOUISIANA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 11, 2015 FOR ADDITIONAL INFORMATION.

2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TESTS WERE PERFORMED.

3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

PILOT HOLE TOLERANCES
THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.

4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.

5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF UNDERGROUND FACILITIES
CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.

2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.

3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

DWG. NO.	REFERENCE DWG.	REV	DSN	CK	DESCRIPTION
		3	ACM	JMS	RE-ISSUED FOR FERC
		2	DLB	JMS	ADD DEPTH CRITERIA
WATE-A-1275	ALIGNMENT SHEET M.P. 251.84 TO M.P. 252.78	1	LKB	JMS	ISSUED FOR BID
WATE-A-1274	ALIGNMENT SHEET M.P. 250.89 TO M.P. 251.84	0	LKB	JMS	ISSUED FOR FERC

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS	PRELIMINARY		CONSTRUCTION	
TITLE	SIGNATURE	DATE	SIGNATURE	DATE
DRAWN BY:	LKB	08/07		
PROJECT MANAGER	JMS	08/07		
DESIGN ENGINEER	LKB	08/07		
DESIGN CHECKER	ACM	08/07		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH INTERSTATE 94 CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING
WASHTENAW COUNTY, MICHIGAN

NEXUS GAS TRANSMISSION

M.P. 251.5 | W.O. | SCALE: AS SHOWN | DWG. WATE-H-1017 | REV. 3

MP 254.4R US-12

Base Data

In performing the HDD design and engineering analysis presented in this report, we have relied upon the following information:

- A combination of LiDAR and traditional hydrographic survey data covering the proposed crossing location

General Site Description

The 36-inch US-12 Crossing is located in East Ypsilanti, Michigan. It involves passing beneath a railway loop, the eastbound and westbound lanes of State Highway 12, as well as several access ramps to the highway. The proposed HDD alignment deviates slightly from the existing power line easement and crosses beneath easement at an angle. The topography in the area is generally flat with the only exceptions being the raised subgrade for the highway and access roads.

An overview of the proposed crossing location is provided in Figures 1 through 3.

Figure 1 – Overview of the US-12 Crossing

Subsurface Conditions

At the time of this writing, site-specific subsurface information is not available.

Design Geometry & Layout

The proposed US-12 Crossing has a horizontal length of 1,739 feet. It has been designed to achieve a minimum of 40 feet of cover at the northern edge of the railroad loop as well as 40 feet beneath the exit ramp at the south end of the crossing. The design employs a 10-degree entry/exit angles and a radius of curvature equal to 3,600 feet. In addition to allowing a shorter horizontal length, a 10-degree exit angle was employed to achieve the desired cover criteria. The exit point is located on the south side of the highway. Here it can take advantage of derelict parking lots for pull section fabrication. In an effort to minimize the total length of the crossing, the entry point on the north side was positioned in front of the nearest PI and within a wooded area, giving the design adequate cover beneath the railroad loop. A clearing exists further to the north of the designed entry point which also could serve as an option for the entry if impact on the existing vegetation/trees is a concern.

Workspace at the south end of the crossing exists within a clearing near the eastbound exit ramp of US-12 and could extend into nearby former parking lots and derelict roads which exist further south. The unoccupied areas could serve well for pull section fabrication and layout. Workspace on the north side exists in a wooded area north of the railway loop. The proposed pipeline centerline reveals a hard PI roughly 185 feet from the exit point. Clearing of vegetation and some medium/large trees for workspace would be necessary at the entry point. The proposed HDD design as well as available workspace for HDD operations is shown on the HDD plan and profile drawing included in this site-specific report.

Assessment of Feasibility

Overall, given the length the proposed 36-inch installation, it is easily within the range of what has been successfully installed using HDD. It is anticipated the subsurface will consist of mixtures of sand, silt, and clay, similar to those encountered at the Interstate 94 crossing, which are conducive to the HDD process. However, the feasibility will need to be confirmed when site-specific geotechnical data is available.

Risk Identification and Assessment

Notable risks and potential construction impact associated with installation by HDD include impact to US-12 and the railway loop in the form of heave, settlement, or inadvertent drilling fluid returns.

Overall, the level of risk associated with the proposed US-12 crossing is considered low. However, risk should be re-evaluated after site-specific geotechnical information is available.

Installation Loading Analysis

Two installation scenarios were evaluated for the proposed crossing. The first scenario assumed the pilot hole would be drilled to the exact design centerline shown on the plan and profile drawing. The second scenario assumed a worse case model in which the pilot hole is drilled 25 feet deeper than the design profile with a radius of curvature reduced to 50 percent of the design radius. A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 3,600’	12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: Increased by 50’ Depth: Increased by 25’ Radius: 1,800’	12 ppg	Empty	Assumed Negligible

Based on the loading scenarios described above, the estimated pulling load for the “as-designed” crossing, without ballast, is 301,008 pounds. In the “worse-case” installation scenario, the anticipated pulling load without ballast is 323,924 pounds. In both cases, loads and stresses fall within acceptable limits as defined by the PRCI method. Pipe parameters and other installation properties are provided in Figure 4. Detailed calculations for each scenario are summarized in Figures 5 and 7.

Line Pipe Properties		
Pipe Outside Diameter =	36.000	in
Wall Thickness =	0.741	in
Specified Minimum Yield Strength =	70,000	psi
Young's Modulus =	2.9E+07	psi
Moment of Inertia =	12755.22	in⁴
Pipe Face Surface Area =	82.08	in²
Diameter to Wall Thickness Ratio, D/t =	49	
Poisson's Ratio =	0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F
Pipe Weight in Air =	279.04	lb/ft
Pipe Interior Volume =	6.50	ft³/ft
Pipe Exterior Volume =	7.07	ft³/ft
HDD Installation Properties		
Drilling Mud Density =	12.0	ppg
=	89.8	lb/ft³
Ballast Density =	62.4	lb/ft³
Coefficient of Soil Friction =	0.30	
Fluid Drag Coefficient =	0.025	psi
Ballast Weight =	405.51	lb/ft
Displaced Mud Weight =	634.48	lb/ft

Figure 4: Pipe and Installation Properties

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	161.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	10.0	°			
Frictional Drag = $W_e\ L\ \mu\ \cos\theta$ =	16,987	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	5,489	lb			
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	9,984	lb			
Pulling Load on Exit Tangent =	**32,460**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	98,764	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R\ [1 - \cos(\alpha/2)]$ =	13.70	ft	$j = [(E\ I) / T]^{1/2}$ =	1,935	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	4.4E+06		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	955.86	
$U = (12\ L) / j$ =	3.90		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	153,041	lb
Bending Frictional Drag = $2\ \mu\ N$ =	91,825	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	21,318	lb			
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	19,464	lb			
Pulling Load on Exit Sag Bend =	**132,607**	**lb**			
Total Pulling Load =	**165,068**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	159.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = $W_e\ L\ \mu$ =	16,953	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	5,394	lb			
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	0	lb			
Pulling Load on Bottom Tangent =	**22,347**	**lb**			
Total Pulling Load =	**187,415**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	628.3	ft	Average Tension, T =	237,532	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	3,600	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
$h = R\ [1 - \cos(\alpha/2)]$ =	13.70	ft	$j = [(E\ I) / T]^{1/2}$ =	1,248	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	5.7E+06		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	1263.96	
$U = (12\ L) / j$ =	6.04		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	163,968	lb
Bending Frictional Drag = $2\ \mu\ N$ =	98,381	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	21,318	lb			
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	-19,464	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**100,235**	**lb**			
Total Pulling Load =	**287,649**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	173.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = $W_e\ L\ \mu\ \cos\theta$ =	18,166	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	5,869	lb			
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	-10,677	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**13,358**	**lb**			
Total Pulling Load =	**301,008**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,667	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,504	ok	0	ok	416	ok	0.06	ok	0.01	ok
PC										
	3,504	ok	12,083	ok	416	ok	0.32	ok	0.09	ok
	2,283	ok	12,083	ok	1244	ok	0.30	ok	0.12	ok
PT										
	2,283	ok	0	ok	1244	ok	0.04	ok	0.03	ok
	2,011	ok	0	ok	1244	ok	0.03	ok	0.03	ok
PC										
	2,011	ok	12,083	ok	1244	ok	0.30	ok	0.11	ok
	395	ok	12,083	ok	416	ok	0.27	ok	0.06	ok
PT										
	395	ok	0	ok	416	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	-9	ok	0.00	ok	0.00	ok

Figure 5: Installation Loading and Stress Analysis (As-Designed)

Pipe and Installation Properties

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
Pipe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	463.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	48,643	lb			
Fluidic Drag = 12 π D L C_d =	15,716	lb			
Axial Segment Weight = W_e L sinθ =	28,590	lb			
Pulling Load on Exit Tangent =	**92,950**	**lb**			

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	136,256	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	1,648	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	6.3E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	270.43	
U = (12 L) / j =	2.29		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	110,367	lb
Bending Frictional Drag = 2 μ N =	66,220	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	9,732	lb			
Pulling Load on Exit Sag Bend =	**86,611**	**lb**			
Total Pulling Load =	**179,561**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	240.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Frictional Drag = W_e L μ =	25,632	lb			
Fluidic Drag = 12 π D L C_d =	8,156	lb			
Axial Segment Weight = W_e L sinθ =	0	lb			
Pulling Load on Bottom Tangent =	**33,788**	**lb**			
Total Pulling Load =	**213,349**	**lb**			

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	314.2	ft	Average Tension, T =	250,319	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
h = R [1 - cos(α/2)] =	6.85	ft	j = [(E I) / T]$^{1/2}$ =	1,216	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	9.0E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	387.01	
U = (12 L) / j =	3.10		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	121,686	lb
Bending Frictional Drag = 2 μ N =	73,011	lb			
Fluidic Drag = 12 π D L C_d =	10,659	lb			
Axial Segment Weight = W_e L sinθ =	-9,732	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**73,938**	**lb**			
Total Pulling Load =	**287,288**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	474.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			
Frictional Drag = W_e L μ cosθ =	49,822	lb			
Fluidic Drag = 12 π D L C_d =	16,097	lb			
Axial Segment Weight = W_e L sinθ =	-29,283	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Tangent =	**36,636**	**lb**			
Total Pulling Load =	**323,924**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,946	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,500	ok	0	ok	1208	ok	0.06	ok	0.04	ok
PC										
	3,500	ok	24,167	ok	1208	ok	0.59	ok	0.31	ok
	2,599	ok	24,167	ok	1623	ok	0.57	ok	0.33	ok
PT										
	2,599	ok	0	ok	1623	ok	0.04	ok	0.06	ok
	2,188	ok	0	ok	1623	ok	0.03	ok	0.05	ok
PC										
	2,188	ok	24,167	ok	1623	ok	0.56	ok	0.32	ok
	1,132	ok	24,167	ok	1208	ok	0.55	ok	0.27	ok
PT										
	1,132	ok	0	ok	1208	ok	0.02	ok	0.03	ok
Exit Point	0	ok	0	ok	-9	ok	0.00	ok	0.00	ok

Figure 6: Installation Loading (Worse-Case)

Hydrofracture Evaluation

At the time of this writing, site-specific geotechnical data is not available; therefore, a hydrofracture evaluation could not be completed.

Construction Duration

The estimated duration of construction for the US-12 Crossing is 14 days. The estimate assumes single 12-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speed were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[1], as well as past experience in similar subsurface conditions. Refer to Figure 8 for additional information relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

General Data		Comments
Work Schedule, hours/shift =	12.0	36" US-12 Crossing
days/week =	7.0	
Drilled Length, feet =	1,750	
Pilot Hole		
Production Rate, feet/hour =	50	
shifts/day =	1	
Drilling Duration, hours =	35.0	
shifts =	2.9	
Trips to change tools, shifts =	0.5	
Pilot Hole Duration, days =	3.4	

Ream and Pull Back								
Pass Description =	36-inch	48-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	2.0	2.0				8.0	6.0	
Mud Flow Rate, barrels/minute =	15.0	15.0				15.0	15.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	16.5	16.5				5.5	6.7	45.2
shifts =	1.4	1.4				0.5	0.6	3.8
Rig up, shifts =	0.5	0.5				0.5	0.5	2.0
Trips to change tools, shifts =	1.0	1.0				0.0		2.0
Pass Duration, days =	2.9	2.9				1.0	1.1	7.8

Summary				
HDD Duration at Site, days =	13.2			
Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.5	1.0	1.0	0.5
days =	0.5	1.0	1.0	0.5

Figure 8: Estimated Construction Duration

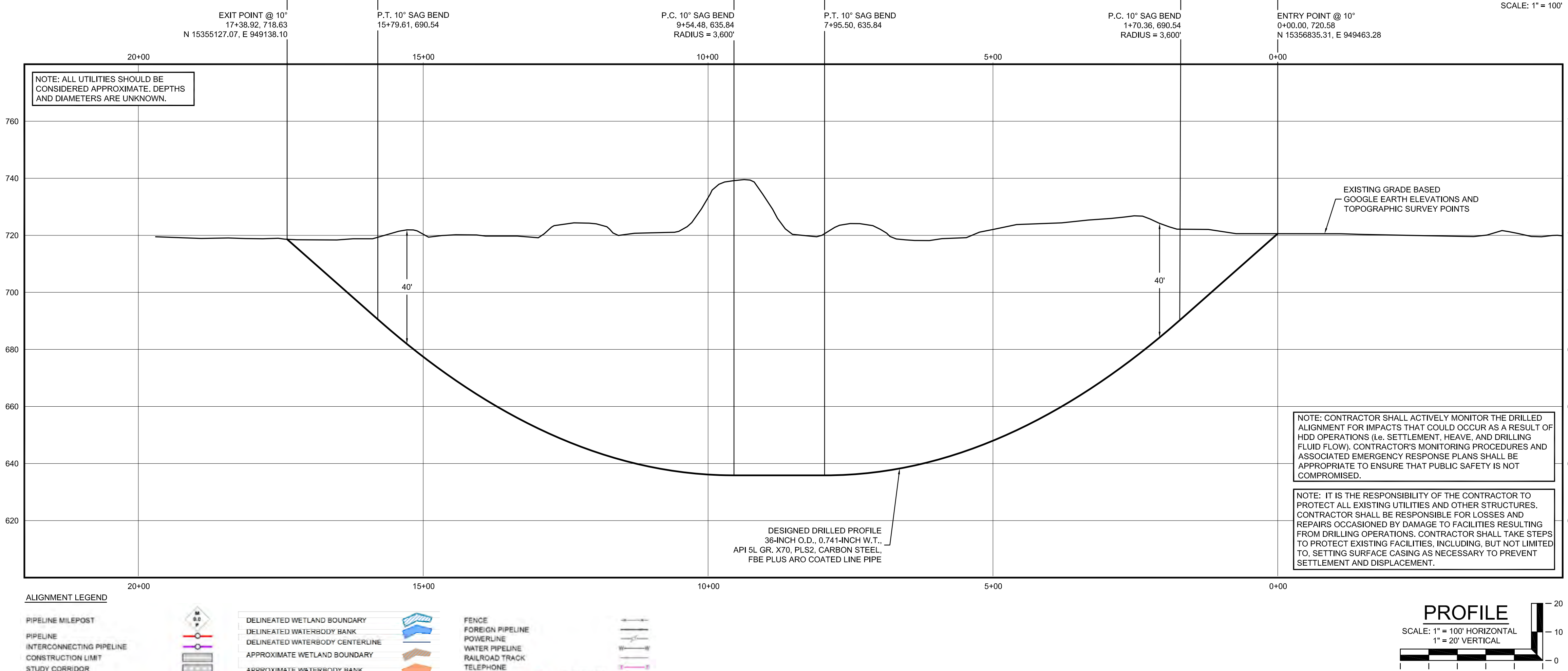
[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

E-4-185

HORIZONTAL LENGTH = 1,739'
TRUE LENGTH = 1,750'

PLAN

SCALE: 1" = 100'



PROFILE

SCALE: 1" = 100' HORIZONTAL
1" = 20' VERTICAL

ALIGNMENT LEGEND

PIPELINE MILEPOST
PIPELINE
INTERCONNECTING PIPELINE
CONSTRUCTION LIMIT
STUDY CORRIDOR
STAGING AREA
WAREYARD
PERMANENT ROW
ADDITIONAL TEMPORARY WORKSPACE
METERING & REGULATION STATION (M&R)
COMPRESSOR STATION SITE
FACILITIES TEMPORARY WORKSPACE
FACILITIES PERMANENT WORKSPACE
DELINEATED WETLAND BOUNDARY
DELINEATED WATERBODY BANK
DELINEATED WATERBODY CENTERLINE
APPROXIMATE WETLAND BOUNDARY
APPROXIMATE WATERBODY BANK
APPROXIMATE WATERBODY CENTERLINE
PERMANENT ACCESS ROAD
TEMPORARY ACCESS ROAD
PARCEL TRACT NO
PROPERTY LINE
CONTOUR
MUNICIPALITY LINE
FENCE
FOREIGN PIPELINE
POWERLINE
WATER PIPELINE
RAILROAD TRACK
TELEPHONE
TEE TAP
UTILITY LINES
BLOW OFF VALVE
MAINLINE VALVE (MLV)
TOWER
MICROWAVE TOWER
HORIZONTAL DIRECTIONAL DRILLING
TANK
LIGHT POLE
FIRE HYDRANT
WELL: GAS WATER OIL UNKNOWN

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. LIDAR, SURVEY, AND HYDROGRAPHIC DATA PROVIDED BY FLUOR ENTERPRISES, INC., SUGARLAND, TEXAS.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 17N, NAD83.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 1 FOOT RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
2. EXIT POINT: UP TO 5 FEET SHORT OR 20 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE.
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT.
5. CURVE RADIUS: NO LESS THAN 1,800 FEET BASED ON A 3-JOINT AVERAGE.

PROTECTION OF UNDERGROUND FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

FOR INFORMATION ONLY - NOT FOR CONSTRUCTION

REV	DSN	CK	DESCRIPTION
2	ACM	JMS	RE-ISSUED FOR FERC
1	LKB	JMS	UPDATE CENTERLINE
0	LKB	JMS	ISSUED FOR BID

DWG. NO. | REFERENCE DWG.

John D. Hair, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

ENGINEERING APPROVALS

TITLE	PRELIMINARY SIGNATURE	DATE	CONSTRUCTION SIGNATURE	DATE
DRAWN BY:	LKB	12/15		
PROJECT MANAGER	JMS	01/16		
DESIGN ENGINEER	LKB	01/16		
DESIGN CHECKER	LKB	08/16		

PLAN AND PROFILE
NEXUS PROPOSED MAINLINE PIPELINE
36-INCH US-12 MICHIGAN AVE CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

WASHTENAW COUNTY, MICHIGAN

NEXUS GAS TRANSMISSION

M.P. 254 | W.O. | SCALE: AS SHOWN | DWG. | REV. 2

SUPPLEMENT TO HDD DESIGN REPORT

Geotechnical Feasibility Study
Nimisila Reservoir HDD

Base Data

In performing this geotechnical feasibility study for the proposed Horizontal Directional Drill ("HDD") of the Nimisilla Reservoir, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- Surficial geologic mapping of the Canton 30 x 60 Minute Quadrangles, Ohio Department of Natural Resources, Division of Geological Survey, 2002
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of J. D. Hair & Associates, Inc. (JDHA).

General Site Description

The 36-inch Nimisila Reservoir Crossing is located near the intersection of East Comet Road and Christman Road, just south of Akron, Ohio. The primary obstacles that will be crossed are Christman Road, an existing overhead powerline right of way, and the Nimisila Reservoir. The reservoir is approximately 700 feet wide, and based on hydrographic survey points, roughly 5 feet deep. The proposed HDD alignment crosses an existing overhead power corridor at an approximate 45-degree angle. Both ends of the crossing are within agricultural land. Residential homes exist directly to the north and southeast of the exit point with the nearest home being roughly 370 feet away. The topography in the area is gently rolling with a mixture of farm land and mature timber. Refer to Figure 1 for a general overview of the vicinity of the crossing.

Figure 1: Overview of the Nimisila Reservoir Crossing

Subsurface Conditions

Surficial geologic mapping indicates the subsurface at the site of the proposed Nimisila Reservoir crossing will consist of unconsolidated sediments in the form of poorly sorted sand with inclusions of gravel, silt, sand, and till. In addition, mapping indicates localized zones of organic deposits throughout the study area. The top of sedimentary bedrock (interbedded shale, sandstone, and siltstone) is in excess of 100 feet in depth.

Design Geometry & Layout

The proposed Nimisila Reservoir HDD design involves a horizontal length of 1,776 feet. It utilizes a 10-degree entry angle, an 8-degree exit angle, and a radius of curvature of 3,600 feet. The crossing design maintains 20 feet of cover beneath the slope on the west side of the reservoir, 53 feet of cover beneath Christman Road, 53 feet beneath the Reservoir, and 40 feet beneath the edge of wetland on the east side of the crossing.

The entry point is located on the east side of Christman Road in an open farm field. The exit point is located on the west side of the crossing, also within an open but slightly smaller farm field. An elevation difference of roughly 17 feet exists between the entry and exit points with the entry site existing at the lower elevation.

The proposed HDD design, as well as plan and profile drawings, were included in the *HDD Design Report NEXUS Pipeline Project, Revision 2* filed with the NEXUS Response to FERC Environmental Information Request 1 in March 2016.

Assessment of Feasibility

With a proposed length of 1,776 feet, and a diameter of 36-inches, the proposed HDD installation is well within the range of what has been successfully installed in years past through similar subsurface conditions. Therefore, based on available information, we see no reason to rule out installation by HDD at the proposed Nimisila crossing location. Although subsurface conditions exhibit coarse granular material such as gravel or cobbles, given the length of the crossing and the current state-of-the-art in the HDD industry, these subsurface conditions are unlikely to prevent a successful installation.

Geotechnical Feasibility Study
Tuscarawas River HDD

Base Data

In performing the following evaluation, we have relied upon the following information:

- A combination of LiDAR, hydrographic, and traditional survey data covering the proposed crossing location
- Geotechnical data gathered by Fugro Consultants, Inc. between May 12, 2015 and July 30, 2015
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch Tuscarawas River Crossing is located near pipeline Mile Post 48, south of Barberton, Ohio. It involves passing beneath the Tuscarawas River, a railroad, and Van Buren Road. The Tuscarawas River is approximately 80 feet from bank to bank at the crossing location, and less than 2 feet deep at the deepest point. The proposed HDD alignment runs parallel to an existing power line corridor. The topography on each side of the crossing slopes moderately steeply toward the river. The elevation change east of Van Buren Road is approximately 155 feet. The land on each side of the river consists of a mixture of wooded patches and agricultural land. An overview of the proposed crossing location is provided in Figure 1 and Photos 1 and 2.

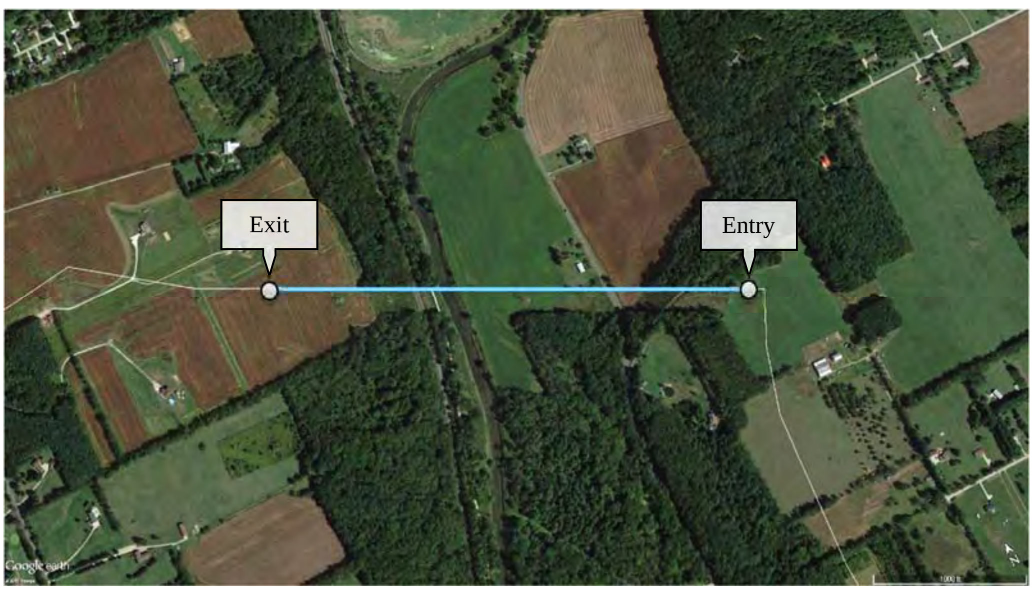


Figure 1: Overview of the Tuscarawas River Crossing

Photo 1: View west along proposed HDD alignment from Van Buren Road

Photo 2: View east from Van Buren Road. Topography extends upwards toward the proposed entry point

Subsurface Conditions

Three geotechnical borings were taken on the east side of the river as part of the geotechnical exploration program conducted by Fugro Consultants, Inc. Two of the borings, TUS-01 and TUS-02, were taken between Van Buren Road and the east edge of Tuscarawas River, and one of the borings, TUS-06, was taken near the proposed HDD entry point approximately 1,000 feet east of Van Buren Road. TUS-01 encountered mixtures of sand with silt, lean clay, and sandy lean clay, sand, and occasional gravel to the termination depth of 76 feet below grade. The second boring, TUS-02, taken near the bank of the river, encountered relatively sandy lean clay, sand, and silt until 20 feet below ground surface, followed by sandstone and siltstone bedrock to the termination of 100 feet. Rock quality designation (RQD) index values indicate good to excellent quality bedrock overall. Results for unconfined compressive strength (UCS) average 8,189 psi. Boring TUS-06 encountered clayey sand to a depth of 14 feet, followed by residual shale to a depth of 34 feet, interbedded siltstone, sandstone, and shale to a depth of 52 feet, and sandstone to the boring termination depth of 101 feet. RQD index values ranged from 23 to 95, with an average of 65 indicating fair quality bedrock. UCS test values ranged from 1,150 psi to 7,990 psi.

Geophysical methods were used to further characterize the top of the bedrock surface between borings TUS-1 and TUS-2. Results of the seismic refraction study indicate the bedrock surface may dip to the east from boring TUS-2, falling from elevation 930 feet to 855 feet over a horizontal distance of 450 feet. From that point, the bedrock surface looks to be trending upwards toward boring TUS-1. The top of bedrock is estimated to fall somewhere in the range of elevation 860 feet and elevation 875 feet at the location of boring TUS-1.

Design Geometry & Layout

The proposed Tuscarawas River HDD design has a horizontal length of 3,263 feet. It utilizes a 16-degree entry angle, an 8-degree exit angle, and a design radius of curvature of 3,600 feet. The design maintains a minimum of 40 feet of cover at the west edge of the Tuscarawas River, 46 feet of cover beneath the railroad tracks, 66 feet beneath Van Buren Road, and approximately 42 feet of cover beneath the bottom of the hillside on the east side of the river. Due to a pipeline alignment point of intersection (P.I.) on the east side of the crossing, the entry point location was limited in how far east it could be located. Therefore, in order to maintain suitable cover along the hillside, a 16-degree entry angle was necessary.

Due to workspace considerations, the exit point is located on the west side of the crossing, which provides the better option for pull section fabrication across relatively open fields. The entry point on the east side is approximately 48 feet higher topographically.

The proposed HDD design, as well as plan and profile drawings, were included in the *HDD Design Report NEXUS Pipeline Project, Revision 2* filed with the NEXUS Response to FERC Environmental Information Request 1 in March 2016.

Assessment of Feasibility

The data we have reviewed suggests that the proposed crossing can be completed using HDD. The crossing is designed to pass through bedrock conducive to installation by HDD over the duration of the crossing. Due to the variable nature of the bedrock surface, however, there is risk that the HDD segment will pass out of bedrock and into overburden, and then back into bedrock. Although a scenario such as this would be unlikely to prevent a successful HDD installation, it could result in HDD operational problems and delays. The *NEXUS HDD Monitoring and Inadvertent Return Contingency Plan*, filed with the Certificate Application in November 2015, has been developed to address and mitigate these types of issues.

Geotechnical Feasibility Study
West Branch Black River HDD

Base Data

In performing the geotechnical feasibility study, we have relied upon the following information:

- A combination of LiDAR and traditional survey data covering the proposed crossing location
- Surficial geologic mapping of the Lorain and Put-In-Bay 30x60 Minute Quadrangles, Ohio Department of Natural Resources, Division of Geological Survey, Draft 6, June 14, 2005
- Geotechnical data gathered by Fugro Consultants, Inc. between April 8, 2015 and August 11, 2015 at the site of the proposed East Branch Black River
- A reconnaissance of the proposed crossing location conducted in July of 2015 by a representative of JDH&A

General Site Description

The 36-inch West Branch Black River Crossing is located approximately 2.5 miles southeast of Oberlin, Ohio near the intersection of West Road and Kipton Nickle Plate Road. The crossing involves passing beneath the meandering channel of the West Branch Black River, as well as West Road. The topography in the vicinity of the crossing is essentially flat, but with a topographic rise of approximately 20 feet conforming to the east bank of the river. Both sides of the river are mixtures of wooded patches and open farmland.

Figure 1: Overview of the West Branch Black River Crossing

Subsurface Conditions

Based on surficial geological mapping, the subsurface at the proposed crossing site consists of unconsolidated sediments overlying sedimentary bedrock. More specifically, it is anticipated that the west side of the crossing will consist of approximately 40 feet of alluvium (silt, sand, clay, with some gravel and possible cobbles/boulders) resting above interbedded sandstone and shale. The east side of the crossing will likely consist of glacial till, which typically consists of unsorted silt, sand, clay, gravel, and possible random cobbles and boulders. Depth to bedrock on the east side is expected to be around 40 feet. The surficial mapping is generally consistent with site-specific borings taken at the East Branch of the Black River crossing, located approximately five miles east, where similar unconsolidated sediments and sedimentary bedrock were encountered. Depth to bedrock ranged from 40 to 50 feet. The sandstone and siltstone bedrock samples taken at the East Branch Black River had unconfined compressive strength (UCS) values that averaged approximately 4,280 psi, with the lowest value recorded being 30 psi and highest being 11,300 psi. Similar engineering properties are anticipated for the sandstone and shale beneath the West Branch Black River.

Design Geometry & Layout

The West Branch Black River HDD design involves a horizontal length of 1,676 feet. The design geometry involves a 10-degree entry angle, an 8-degree exit angle, and radius of curvature of 3,600 feet. The HDD design achieves 40 feet of cover at the edge of the easternmost channel of the West Branch Black River, 55 feet beneath the western channel, and 56 feet of cover beneath West Road. The exit point is located in a farm field on the east side of West Branch Black River. There is approximately 1,739 feet of false right-of-way east of the exit point available for pull section fabrication.

The proposed HDD design, as well as plan and profile drawings, were included in the *HDD Design Report NEXUS Pipeline Project, Revision 2* filed with the NEXUS Response to FERC Environmental Information Request 1 in March 2016.

Assessment of Feasibility

Given the length of the proposed 36-inch installation, it is easily within the range of what has been successfully installed using HDD. Likewise, the anticipated subsurface conditions are also conducive to the HDD process. Although there is risk of encountering random cobbles and boulders in the overburden soils, mitigation measures such as setting surface casing down to bedrock can be employed to bridge past these adverse materials and allow for a successful installation.

Geotechnical Feasibility Study
US-12 HDD

Base Data

In performing the geotechnical feasibility study for the proposed horizontal directional drill ("HDD") crossing of US-12, we have relied upon the following information:

- A combination of LiDAR and traditional topographic survey data covering the proposed crossing location
- Geotechnical data collected by Fugro Consultants, Inc. from March 17, 2016 to April 1, 2016

General Site Description

The 36-inch US-12 Crossing is located in East Ypsilanti, Michigan. It involves passing beneath a railway loop, the eastbound and westbound lanes of State Highway 12, as well as several access ramps to the highway. The north side of the crossing is wooded with adjacent commercial development. The south side consists of parking lots and abandoned sections of Willow Run Airport. The topography in the area is generally flat with the only exceptions being the raised subgrade for the highway and access roads.

An overview of the proposed crossing location is provided in Figure 1.

Figure 1 – Overview of the US-12 Crossing

Subsurface Conditions

Four geotechnical borings were taken as part of the site investigation conducted by Fugro Consultants, Inc. Two of the borings were taken south of U.S. Highway 12, one boring was taken in between the eastbound and westbound lanes of U.S. Highway 12, and the remaining boring was drilled north of U.S. Highway 12. Each boring was drilled to depths ranging from 60 feet to 100 feet below the ground surface.

All four borings encountered primarily lean clay with varying mixtures of silt, sand, and gravel. Approximately 25 percent of the samples contained gravel. Based on gradation tests of select samples, the gravel content was 10 percent or less. However, based on soil sample descriptions in intervals that were not tested, it would appear that there might be zones with up to 25 percent gravel.

Standard Penetration Test (SPT) values ranged from 0 to 30 blows along most of the designed HDD path. At a depth of approximately 75 feet below the ground surface, blow counts increase to about 40 blows per foot, before reaching very hard soils at about 85 feet with blow counts in excess of 50 blows for less than 6 inches.

Random cobbles and/or coarse gravel were suspected in three of the four borings. The potential cobble in Boring US-12-2 was encountered near the termination depth of the boring and below the designed path. Boring US-12-1 encountered a potential cobble at 54 feet and Boring US-12-4 encountered a cobble at 27.5 feet. During drilling of Boring US-12-3A, the logs indicate a possible artesian aquifer was encountered at a depth of roughly 30 to 35 feet. The water was under some pressure but did not flow uncontrollably.

Design Geometry & Layout

The proposed US-12 crossing has a horizontal length of 1,739 feet. It has been designed to achieve 40 feet of cover at the northern edge of the railroad loop and just over 30 feet beneath the exit ramp at the south end of the crossing. The design employs a 10-degree entry, an 8-degree exit angle, and a radius of curvature equal to 3,600 feet. The exit point is located on the south side of the highway where open derelict parking lots can be used for pull section fabrication. The entry point on the north side of the crossing was positioned to maintain a design depth of cover of 40 feet beneath the railroad loop.

The proposed HDD design, as well as plan and profile drawings, were included in the *HDD Design Report NEXUS Pipeline Project, Revision 2* filed with the NEXUS Response to FERC Environmental Information Request 1 in March 2016.

Assessment of Feasibility

Based on available data, we see no reason to rule out installation by HDD at the proposed U.S. 12 crossing site. The proposed length is easily within the range of what has been successfully installed for 36-inch pipelines. Likewise, subsurface conditions are generally conducive to the HDD process. Although random gravel and cobbles are present in the subsurface, they do not appear to be present in high enough percentages to prevent a successful installation.

NEXUS Gas Transmission, LLC

NEXUS Project

FERC Docket No. CP16-__-000

HDD Monitoring and Inadvertent Return Contingency Plan

November 2015

NEXUS Project HDD Monitoring and Inadvertent Return Contingency Plan

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1 INTRODUCTION

NEXUS proposes to install multiple pipeline crossings on the proposed 36-inch NEXUS Gas Transmission Project by horizontal directional drilling (HDD). HDD is a widely used trenchless construction method which accomplishes the installation of pipelines and buried utilities with minimal impact to the obstacle being crossed. However, HDD is not totally without impact. The primary impact associated with HDD revolves around the use of drilling fluids. Additionally, the HDD installation method involves the risk of failure when certain adverse subsurface conditions are encountered. The purpose of this document is to present contingency plans that may be implemented, in the event that problems develop during HDD operations, in order to complete the crossings successfully while minimizing potential associated impact.

1.1 Background

The tools and techniques used in the HDD process are an outgrowth of the oil well drilling industry. The components of a horizontal drilling rig used for pipeline construction are similar to those of an oil well drilling rig with the major exception being that a horizontal drilling rig is equipped with an inclined ramp as opposed to a vertical mast. HDD pilot hole operations are not unlike those involved in drilling a directional oil well. Drill pipe and downhole tools are generally interchangeable and drilling fluid is used throughout the operation to transport drilled spoil, reduce friction, stabilize the hole, etc. Because of these similarities, the process is generally referred to as drilling as opposed to boring.

Installation of a pipeline by HDD is generally accomplished in three stages. The first stage consists of directionally drilling a small diameter pilot hole along a designed directional path. The second stage involves enlarging this pilot hole to a diameter suitable for installation of the pipeline. The third stage consists of pulling a prefabricated pipeline segment into the enlarged hole.

The major component of drilling fluid used in HDD pipeline installation is fresh water obtained at the crossing location. In order for water to perform the required functions, it is generally necessary to modify its properties by adding a viscosifier. The viscosifier used almost exclusively in HDD drilling fluids is a naturally occurring bentonite clay typically mined by “open pit” methods from locations in Wyoming and South Dakota. Bentonite is a soft clay, formed by the weathering of volcanic ash, with the unique characteristic of swelling to several times its original volume when in contact with water. It is not a hazardous material as defined by the U.S. Environmental Protection Agency's characteristics of ignitability, corrosivity, reactivity, or commercial chemicals. It is also used to seal earth structures such as ponds or dams and as a suspending component in livestock feeds.

1.2 Technical Team

In order to ensure the highest probability of success on the proposed HDD installation, NEXUS has assembled a technical team which includes consultants having expertise in HDD design and construction and environmental issues specific to the proposed HDD crossing locations. This approach enhances the prospect of a successful HDD installation by bringing together more resources than those available to any single team member working independently.

1.3 Anticipated Subsurface Conditions

An extensive geotechnical exploration program was undertaken to aid in assessing the feasibility of HDD crossings on the NEXUS Project. Between the beginning of March and the end of August, 2015, exploratory borings were performed at those HDD crossing locations where access was available. In addition, geophysical techniques were used at select HDD crossing locations to supplement the exploratory borings. Based on the subsurface data collected to date, none of the sites have subsurface conditions that are expected to prevent installation by HDD.

2 FAILURE SCENARIOS

It is difficult to define a set of circumstances in advance that define "failure" of the HDD method as the decision to abandon HDD should take into account the conditions encountered on a given crossing. Following is a discussion of serious operational problems that might ultimately lead to abandoning the HDD installation method.

2.1 Problems During Pilot Hole Drilling

Problems during pilot hole drilling generally occur in the form of high compressive or torsional loads on the drill string. Loads such as these typically result from unconsolidated or coarse-grained material packing around the drill pipe as it is advanced. As friction on the drill string increases, the rig must apply greater torque and thrust. If the torque applied by the rig exceeds the strength of the drill pipe, the pipe will be sheared into two pieces, commonly referred to as "twisting off". Ultimately, friction can increase to the point that the drill string cannot be advanced or retracted, at which point it may be abandoned in place or parted by some means including intentionally twisting it off with the rig.

A skilled contractor will not continue drilling the pilot hole until it becomes stuck. As loads on the drill string increase, the contractor will adjust drilling fluid properties and work the hole by tripping the drill string out and back in. These measures are generally successful and abandonment of an HDD crossing due to excessive loads during pilot hole drilling is very rare.

Another problem that can occur during pilot hole drilling is a lack of directional control resulting in either a violation of pilot hole position tolerances or an unacceptable angular change. This can occur when the drill bit is deflected off a boulder or cobble lens or when attempting to penetrate a hard bedrock formation at depth. If left uncorrected, an unacceptable angular change can result in failure of the drill pipe due to a combination of excessive bending stress and rotation. However, redrilling efforts are usually successful and abandonment of an HDD crossing due to a lack of directional control is very rare.

Solution cavities, occasionally present in limestone and dolomite formations, can cause serious problems on an HDD installation, especially during pilot hole drilling when the drill string is in compression. While the wall of a competent borehole serves to limit the deflection of the drill string, penetration of a void leaves the drill string unconstrained, potentially allowing it to deflect substantially. Continued rotation of a drill string subjected to such a deflection often results in failure of the drill pipe due to low-cycle fatigue. If efforts to avoid extensive solution cavities are unsuccessful, the HDD installation method is typically abandoned. Limestone and dolomite are present on some of the proposed vertical alignments. However, the size of the cavities encountered in the exploratory borings is not expected to prevent installation by HDD.

2.2 Problems During Prereaming

Problems during prereaming generally involve excessive tensile or torsional loads when enlarging a hole through either hard rock or discontinuous materials such as fractured rock or glacial till. In this situation, application of excessive torque from the rig can easily result in the drill pipe being twisted off downhole. Accumulation of cuttings in the hole can cause tensile loads to become excessive, ultimately resulting in the reamer becoming stuck. If the reamer cannot be freed, the drill pipe is generally twisted off, either intentionally or unintentionally, and both the reamer and some amount of drill pipe are abandoned downhole.

A skilled contractor can typically avoid getting the reamer stuck downhole. As loads increase, the contractor will adjust drilling fluid properties and trip the reamer out of the hole to mechanically displace material. A stuck reamer is more difficult to free up than a pilot hole drill bit. Reamers are generally designed to move forward, not backward.

Prereaming through hard or unusually abrasive rock can lead to failure of reaming tools downhole due to excessive wear. This often results in roller cones or other portions of the reaming tool being lost downhole where they can present an obstacle to subsequent reaming passes or installation of the pipeline. Fishing operations to retrieve pieces of a reaming tool lost downhole are time consuming and often unsuccessful.

Penetration of an artesian aquifer on an HDD installation can cause significant problems, especially during prereaming operations when attempting to move a large volume of material out of the hole. A steady flow of groundwater into the hole from an aquifer tends to bring in fine soils, which eventually accumulate in the hole and can cause the reamer or drill pipe to bind. Additionally, a significant flow of water into the reamed hole can have a negative effect on drilling fluid properties. If drilling fluid returns to the HDD endpoints are maintained, the additional water returning to the surface can become overwhelming, resulting in drilling fluid storage and disposal issues.

2.3 Problems During Pullback

As with prereaming, problems during pullback generally involve excessive tensile or torsional loads which can ultimately result in the pull section becoming stuck. Excessive torque and pulling forces applied in an attempt to free the pipe can result in twisting off downhole. Removal of the pull section from the hole can be difficult and is sometimes impossible. If a partially installed pull section cannot not be withdrawn, the contractor’s only option is to start over, offsetting to one side and drilling a new pilot hole. Pipe left in the hole has to be replaced and a new pull section has to be fabricated.

Stuck pipe can also occur due to the relative stiffness of the pull section. During prereaming operations, it is possible for the reaming tool to "walk" around a boulder since it is being pulled and followed by a slender 5-inch drill pipe. However, when the same boulder is encountered during pullback, the reamer is forced to cut through it by the relatively rigid pull section.

Another issue that may occur during pullback, specific to installations through bedrock, is difficulties associated with transitioning from the overburden soil into the rock hole. Misalignment of the pull section as it moved into the reamed rock hole can result in the product line becoming lodged.

3 CONTINGENCY PLANS

Courses of action to consider if serious operational problems occur are outlined below. These contingency plans are meant to serve as guidelines and tools for advanced planning. The actual course of action to be employed will be based on an analysis of the conditions encountered during construction. In the event that a re-drill is necessary, the horizontal offset distance will be based on an analysis of the cause of failure and the as-built position of existing drilled hole. In most cases, the horizontal offset will be within 10 feet to 20 feet of the original alignment.

3.1 Twist Off During Pilot Hole

If there is a reasonable chance that the bottom hole assembly and/or drill pipe lost downhole can be retrieved using fishing tools, commence fishing operations. Otherwise, offset and redrill the pilot hole around the twisted off segment.

3.2 Solution Cavity Encountered During Pilot Hole

If the solution cavity is not extensive (i.e. extending no more than a few feet along the drilled path) and the bit successfully reenters the formation after passing through the void, proceed with the pilot hole at the contractor's discretion. If the solution cavity is extensive, offset and begin a new pilot hole in an effort to avoid the solution cavity.

3.3 Twist Off During Prereaming

If the failure is to the pipe side of the reamer, trip the reamer out with the rig, trip out the failed drill pipe with pipe side equipment, and trip back through the partially reamed pilot hole with a directional drilling assembly. If the failure is to the rig side of the reamer, trip out the failed pipe on the rig side. Attempt to separate the drill pipe on the pipe side of the reamer from the reamer and recover the drill pipe using pipe side equipment. If it is possible to redrill around the reamer and reenter the completed pilot hole without violating pilot hole tolerances, do so. If not, offset and drill a new pilot hole.

3.4 Twist Off During Pullback

If possible, recover the pull section using pipe side equipment or other means as available. Trip out the failed drill pipe and trip back through the reamed hole with a directional drilling assembly. Otherwise, salvage as much pipe as possible, offset, and begin a new pilot hole.

3.5 Failed Installation

A single occurrence of the problem scenarios described previously would not constitute a failure. Typically, there would have to be at least two occurrences resulting in stuck or twisted off drill pipe before an HDD contractor would consider abandoning the crossing. If it is ultimately determined that an HDD installation cannot be completed at any of the proposed crossing locations, NEXUS's contingency plan will be to install the crossing on the current alignment using a method other than HDD or, where this is not possible, install the crossing on a new alignment using HDD or another method, with the selected method being dependent on the topographic, hydrographic and geotechnical conditions on the new alignment. Any drilled or reamed hole which is abandoned will be filled with a mixture of drilling fluid and drilled spoil.

4 DRILLING FLUID IMPACT

All stages of HDD involve circulating drilling fluid from equipment on the surface, through a drill pipe to a downhole bit or reamer, and back to the surface through the annular space between the pipe and the wall of the hole. Drilling fluid returns collected at the entry and exit points are stored in steel tanks and processed through a solids control system which removes spoil from the drilling fluid allowing the fluid to be reused. The basic method used by the solids control system is mechanical separation using shakers, desanders, and desilters. Excess spoil and drilling fluid are transported to, and disposed of, at an approved disposal site.

Under ideal circumstances, drilling fluid exhausted at the bit or reamer will flow back to the entry or exit point through the drilled annulus. Under actual conditions, this happens inconsistently. Drilling fluid expended downhole will flow in the path of least resistance. In the drilled annulus, this path may be an existing fracture or fissure in the soil. This can result in dispersal of drilling fluid into the surrounding soils (lost circulation) or discharge to the surface at some random location (inadvertent returns). Lost circulation and inadvertent returns are common occurrences in pipeline installation by HDD and do not prevent completion. However, the environment may be temporarily impacted if drilling fluid inadvertently returns to the surface at a location on a waterway's banks or within a waterway. Drilling parameters may be adjusted to maximize circulation and minimize the risk of inadvertent returns. However, the possibility of lost circulation and inadvertent returns cannot be eliminated.

4.1 The Principal Functions of Drilling Fluid in HDD Pipeline Installation are Listed Below:

- **Hydraulic Excavation.** On crossings through soft soils, soil is excavated by erosion from high velocity fluid streams through jet nozzles on bits or reaming tools.
- **Transmission of Hydraulic Power**. On crossings through harder soils or rock, power required to turn a bit and mechanically drill a hole is transmitted to a downhole motor by the drilling fluid.
- **Transportation of Spoil**. Drilled spoil, consisting of excavated soil or rock cuttings, is suspended in the fluid and carried to the surface by the fluid stream flowing in the annulus between the pipe and the wall of the hole.
- **Hole Stabilization.** Stabilization of the drilled hole is accomplished by the drilling fluid building up a "wall cake" which seals pores and holds soil particles in place. This is critical in HDD pipeline installation as holes are often in unconsolidated formations and are uncased.
- **Cooling and Cleaning of Cutters.** Drilled spoil build-up on bit or reamer cutters is removed by high velocity fluid streams directed at the cutters. Cutters are also cooled by the fluid.
- **Reduction of Friction**. Friction between the pipe and the wall of the hole is reduced by the lubricating properties of the drilling fluid.
- **Modification of Soil Properties.** Mixing of the drilling fluid with the soil along the drilled path facilitates installation of a pipeline by reducing the shear strength of the soil to a near fluid condition. The resulting soil mixture can then be displaced as a pipeline is pulled into it.

4.2 Drilling Fluid Composition

The major component of drilling fluid used in HDD pipeline installation is fresh water. In order for water to perform the required functions, it is generally necessary to modify its properties by adding a viscosifier. The viscosifier used almost exclusively in HDD drilling fluids is a naturally occurring bentonite clay typically mined by "open pit" methods from locations in Wyoming and South Dakota. Bentonite is a soft clay, formed by the weathering of volcanic ash, with the unique characteristic of swelling to several times its original volume when in contact with water. It is not a hazardous material as defined by the U.S. Environmental Protection Agency's characteristics of ignitability, corrosivity, reactivity, or commercial chemicals. It is also used to seal earth structures such as ponds or dams and as a suspending component in livestock feeds.

The properties of bentonite used in drilling fluids are often enhanced by the addition of polymers. This enhancement typically involves increasing the yield. That is, reducing the amount of dry bentonite required to produce a given amount of drilling fluid. Untreated bentonite yields in excess of 85 barrels (3,570 gallons) of drilling fluid per ton of material. Addition of polymers to produce high yield bentonite can increase the yield to more than 200 barrels (8,400 gallons) per ton of material. Typical HDD drilling fluids are made with high yield bentonite and are composed of less than 4% viscosifier by volume, with the remaining components being water and drilled spoil.

4.3 Disposal Of Excess Drilling Fluid

Disposal of excess drilling fluid will be the responsibility of the selected HDD contractor. Prior to beginning HDD operations, the contractor will be required to submit their proposed drilling fluid disposal procedures to NEXUS for approval. NEXUS will review these procedures and verify that they comply with all environmental regulations, right-of-way and workspace agreements, and permit requirements.

The method of disposal applied to each crossing will be dependent upon applicable regulations. Potential disposal methods include transportation to a remote disposal site and land farming on the construction right-of-way or an adjacent property. Land farming involves distributing the excess drilling fluid evenly over an open area and mechanically incorporating it into the soil. Where land farming is employed, the condition of the land farming site will be governed by NEXUS's standard clean up and site restoration specifications.

4.4 Minimization Of Environmental Impact

The most effective way to minimize environmental impact associated with HDD drilling fluids is to maintain drilling fluid circulation to the extent practical. However, resources spent in an effort to maintain circulation should be weighed against the potential benefits achieved through full circulation. It should be recognized that in subsurface conditions which are not conducive to annular flow, restoration of circulation may not be practical or possible. In such cases, environmental impact can often be minimized most effectively by completing HDD operations in the shortest possible amount of time.

Steps which may be taken by the contractor to either prevent lost circulation or regain circulation include, but are not limited to, the following:

- Size the hole frequently by advancing and retracting the drill string in order to keep the annulus clean and unobstructed.

- When drilling fluid flow has been suspended, establish circulation slowly and before advancing.

- Minimize annular pressures by minimizing density and flow losses. Viscosity should be minimized, consistent with hole cleaning and stabilization requirements.

- Minimize gel strength.

- Control balling of material on bits, reaming tools, and pipe in order to prevent a plunger effect from occurring.

- Control penetration rates and travel speeds in order to prevent a plunger effect from occurring.

- Seal a zone of lost circulation using a high viscosity bentonite plug.

- Seal a zone of lost circulation using lost circulation materials. Note that any lost circulation materials proposed for use must be approved by NEXUS prior to utilization.

- Suspend drilling activities for a period of six to eight hours.

If inadvertent surface returns occur on dry land, it will be the responsibility of the HDD contractor to contain, collect, and restore the disturbed area in accordance with the requirements of NEXUS's construction specifications. Should inadvertent returns occur within a waterway, NEXUS will notify appropriate parties and evaluate the potential impact of the returns in order to determine an appropriate course of action. In general, NEXUS does not believe that it is environmentally beneficial to try to contain and collect drilling fluid returns in a waterway. HDD drilling fluids are nontoxic and discharge of the amounts normally associated with inadvertent returns, in most cases, do not pose a threat to the environment or public health and safety. Placement of containment structures and attempts to collect drilling fluid within a waterway often result in greater environmental impact than simply allowing the drilling fluid returns to dissipate naturally.

4.5 Requirements of HDD Contractor

The requirements that will be placed on the HDD contractor with respect to drilling fluid related issues are included in NEXUS's construction specifications. Excerpts from the HDD technical specification defining the contractor's responsibilities are presented below.

- **Instrumentation.** CONTRACTOR shall at all times provide and maintain instrumentation which will accurately locate the pilot hole, measure drill string axial and torsional loads, and measure drilling fluid discharge rate and pressure. NEXUS will have access to these instruments and their readings at all times. A log of all recorded readings shall be maintained and will become a part of the "As-Built" information to be supplied by CONTRACTOR.

- **Composition.** The composition of all drilling fluids proposed for use shall be submitted to NEXUS for approval. No fluid will be approved or utilized that does not comply with permit requirements and environmental regulations.

- **Recirculation.** CONTRACTOR shall maximize recirculation of drilling fluid surface returns. CONTRACTOR shall provide solids control and fluid cleaning equipment of a configuration and capacity that can process surface returns and produce drilling fluid suitable for reuse. NEXUS may specify standards for solids control and cleaning equipment performance or for treatment of excess drilling fluid and drilled spoil. NEXUS specified standards, if any, are listed in the General Requirements.

- **Loss of Circulation.** CONTRACTOR shall employ his best efforts to maintain full annular circulation of drilling fluids. Drilling fluid returns at locations other than the entry and exit points shall be minimized. In the event that annular circulation is lost, CONTRACTOR shall take steps to restore circulation.

- **Inadvertent Returns.** If inadvertent surface returns of drilling fluids occur, they shall be immediately contained with hand placed barriers (i.e. hay bales, sand bags, silt fences, etc.) and collected using pumps as practical. If the amount of the surface return is not great enough to allow practical collection, the affected area shall be diluted with fresh water and the fluid will be allowed to dry and dissipate naturally. If the amount of the surface return exceeds that which can be contained with hand placed barriers, small collection sumps (less than 5 cubic yards) may be used. If the amount of the surface return exceeds that which can be contained and collected using small sumps, drilling operations shall be suspended until surface return volumes can be brought under control.

- **Disposal.** Disposal of excess drilling fluids is the responsibility of the CONTRACTOR and shall be conducted in compliance with all environmental regulations, right-of-way and workspace agreements, and permit requirements. Drilling fluid disposal procedures proposed for use shall be submitted to NEXUS for approval. No procedure may be used which has not been approved by NEXUS. NEXUS, at its option, may secure an excess drilling fluid disposal site for CONTRACTOR. Excess drilling fluid disposal sites secured by NEXUS are listed in the General Requirements.

5 MONITORING

In order to ensure that HDD operations are conducted in accordance with established requirements and standard HDD industry practice, NEXUS will provide an inspector experienced in HDD construction to monitor the HDD contractor's performance at the jobsite. The primary functions of NEXUS's environmental inspector will be to document construction activities, report on the HDD contractor's performance, and notify the NEXUS Environmental Project Manager if the HDD contractor fails to conform to established requirements. Established requirements to which the HDD contractor must conform include, but are not limited to, the construction drawings, technical specifications, permits, easement agreements, and contractor submittals. The monitoring protocol which will be applied by NEXUS's environmental inspector relative to drilling fluid related issues is described in detail on the following pages.

5.1 Drilling Fluid Monitoring Protocol

The drilling fluid monitoring protocol to be applied will vary depending upon the following operational conditions.

Condition 1: Full Circulation

Condition 2: Loss of Circulation

Condition 3: Inadvertent Returns

5.1.1 Monitoring Protocol for Condition 1 – Full Circulation

When HDD operations are in progress and full drilling fluid circulation is being maintained at one or both of the HDD endpoints, the following monitoring protocol will be implemented.

- The presence of drilling fluid returns at one or both of the HDD endpoints will be periodically documented.
- Land-based portions of the drilled alignment will be periodically walked and visually inspected for signs of inadvertent drilling fluid returns as well as surface heaving and settlement. Waterways will be visually inspected from the banks for a visible drilling fluid plume.
- Drilling fluid products present at the jobsite will be documented.

If an inadvertent drilling fluid return is detected during routine monitoring, the monitoring protocol associated with Condition 3 will immediately be implemented.

5.1.2 Monitoring Protocol for Condition 2 – Loss of Circulation

When HDD operations are in progress and drilling fluid circulation to the HDD endpoints is lost or severely diminished, the following monitoring protocol will be implemented. It should be noted that lost circulation is common and anticipated during HDD installation and does not necessarily indicate that drilling fluid is inadvertently returning to a point on the surface.

- NEXUS's environmental inspector will notify the Environmental Project Manager that drilling fluid circulation to the HDD endpoints has been lost or severely diminished.
- NEXUS's environmental inspector will document steps taken by the HDD contractor to restore circulation. Should the contractor fail to comply with the requirements of the HDD Specification, NEXUS's environmental inspector will notify the Environmental Project Manager so that appropriate actions can be taken.
- If circulation is regained, NEXUS's environmental inspector will inform the Environmental Project Manager and resume the monitoring protocol associated with Condition 1.

- If circulation is not re-established, NEXUS's environmental inspector will increase the frequency of visual inspection along the drilled path alignment as appropriate. Additionally, NEXUS's environmental inspector will document periods of contractor downtime (during which no drilling fluid is pumped) and the contractor's drilling fluid pumping rate in case it should become necessary to estimate lost circulation volumes.

5.1.3 Monitoring Protocol for Condition 3 – Inadvertent Returns

If an inadvertent return of drilling fluids is detected, the following monitoring protocol will be implemented.

- NEXUS's environmental inspector will inform the Environmental Project Manager that an inadvertent drilling fluid return has occurred and provide documentation with respect to the location, magnitude, and potential impact of the return.

- If the inadvertent return occurs on land, NEXUS's environmental inspector will document steps taken by the HDD contractor to contain and collect the return. Should the contractor fail to comply with the requirements of the HDD Specification, NEXUS's environmental inspector will notify the Environmental Project Manager so that appropriate actions can be taken.

- If the inadvertent return occurs in a waterway, NEXUS, in consultation with appropriate parties, will determine if the return poses a threat to the environment or public health and safety.

- If it is determined that the return does not pose a threat to the environment or public health and safety, HDD operations will continue. NEXUS's environmental inspector will monitor and document the inadvertent return as well as periods of contractor downtime and the contractor's drilling fluid pumping rate in case it should become necessary to estimate inadvertent return volumes.

- If it is determined that the return does pose a threat to the environment or public health and safety, drilling operations will be suspended until containment measures can be implemented by the contractor. Documentation of any containment measures employed will be provided by NEXUS's environmental inspector. Once adequate containment measures are in place, the contractor will be permitted to resume drilling operations subject to the condition that drilling operations will again be suspended immediately should the containment measures fail. NEXUS's environmental inspector will periodically monitor and document both the inadvertent return and the effectiveness of the containment measures. Periods of contractor downtime and the contractor's drilling fluid pumping rate will also be documented in case it should become necessary to estimate inadvertent return volumes. Upon completion of the HDD installation, NEXUS will ensure that the inadvertent drilling fluid returns are cleaned up to the satisfaction of governing agencies and any affected parties.

6 NOTIFICATION

In the event of an inadvertent drilling fluid return within a waterway, NEXUS will immediately contact applicable agencies by telephone and/or e-mail detailing:

- the location and nature of the inadvertent return,
- corrective actions being taken, and
- whether the inadvertent return poses any threat to the environment or public health and safety.