KEYSTONE PIPELINE

HORIZONTAL DIRECTIONAL DRILL AT PEMBINA RIVER CROSSING MP 7.1

OCCURRENCE OF GROUND SUBSIDENCE (LOCALIZED SINKHOLES) AT COMPLETION OF DRILLING AND PIPE INSTALLATION

GENERAL DESCRIPTION OF THE SITUATION AND PLAN FOR INVESTIGATION AND REPAIRS

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Report re. Sink Holes at Pembina River HDD Site
TransCanada Keystone Pipeline, LP
Todd Kranda

TABLE OF CONTENTS

1. ANTECEDENTS

1.1 Introduction

In late 2008, Keystone installed a crude oil pipeline across the Pembina River in North Dakota utilizing the Horizontal Directional Drilling (HDD) technique.

The general location of the crossing is in the north east corner of the state, in the vicinity of the boundary between Cavalier and Pembina counties, approximately 7 miles from the Canadian border.

During the final stages of the installation and immediately following completion, subsidence was noted at the ground surface along the installed pipe alignment. This subsidence appeared in the form of progressive sinkholes located on the north side of the crossing near the exit point of the installation on the upper plateau.

Once subsidence was noted, an assessment of the scope and cause was initiated. The purpose of the assessment was to establish the likely cause of the subsidence in order to outline a course of action to further investigate the occurrence so a remediation plan can be developed. This report summarizes the efforts taken in this regard, the data reviewed, the observations made, and a brief assessment of the process involved and identification of additional assessment steps to be taken to evaluate the occurrence.

1.2 Background

The crossing of the Pembina River was conducted using HDD. The total length of the installation was approximately 4,000 feet. The total operation (drilling and pipe pulling) took place within the period of September 6, 2008 and January 29, 2009.

Subsidence at three well-defined locations was first noticed by the end of November 2008, while pre-reaming operations were in progress. Subsidence subsequently evolved into a total of five marked sinkholes. An intermediate zone between two of the original sinkholes that displayed marked settlement, eventually exhibited two additional sinkholes by mid February. The area affected is located over a portion of the pipe alignment that extends approximately 700 feet south, measured from the HDD exit point on the north side of the river. Initially, the dimension of each hole were reported to be on the order of 25 feet. Gradually, the openings have increased to values of approximately 55 feet.

The approximate locations of the sinkholes are at stations: 356+15; 356+50; 358+30; 362+50 and 363+00 feet. The southernmost sinkhole is located approximately 600 feet from the edge of the descent to the river. Locations of the holes are shown in Figure 1 which also depicts the as-built geometry of the installed pipeline.

1.3 Horizontal Directional Drill (HDD) at the Pembina River

Installation of pipelines by HDD is generally accomplished in three stages. The first stage consists of directionally drilling a small-diameter pilot hole along a designated directional path. The second stage involves enlarging this pilot hole to a diameter that will accommodate the pipeline by pre-reaming. The third stage involves pulling the prefabricated pipeline back into the enlarged hole as part of a final reaming process. Swabbing is often conducted prior to pipe pull-back to clear the hole of obstructions.

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. The direction of bias is referred to as the "tool face." Straight progress may be achieved by drilling with a series of offsetting tool face positions. The drill string may also be continually rotated where directional control is not required.

Down-hole hydraulic motors provide the mechanical cutting action required for harder soils by converting hydraulic energy from drilling mud pumped from the surface to mechanical energy at the bit. This allows for bit rotation without drill string rotation. Drilling mud consisting mainly of water and bentonite is utilized to power the hydraulic motors. Mud flow through the stator imparts rotation to the rotor, which is in turn connected though a linkage to the bit.

The actual path of the pilot hole is monitored during drilling by taking periodic readings of the inclination and azimuth of the leading edge. Readings are taken with an instrument commonly referred to as a probe, inserted in a drill collar as close as practicable to the drill bit. Down-hole probe survey readings are generally transmitted to the surface through a wire inside the drill string. These readings are used in conjunction with measurements of distance drilled to calculate the horizontal and vertical coordinates along the pilot hole relative to the initial entry point on the surface.

Once completed, the pilot hole is then reamed to a diameter approximately 12 inches greater than the diameter of the pipeline to be installed by running reaming tools of increasing diameters along the pilot hole. Reaming tools typically consist of a circular array of cutters and drilling fluid jets. Drilling fluid is pumped through the reamers to aid in cutting, to support the reamed hole, and to lubricate the trailing pipe.

Following completion of pre-reaming, pipe installation is accomplished by attaching a prefabricated pipeline pull section behind a reaming assembly at the exit point and pulling the reaming assembly and pull section back to the drilling rig. A swivel is utilized to connect the pull section to the leading reaming assembly to minimize torsion transmitted to the pipe

All stages of HDD involve the circulation of drilling mud from the rig on the surface, through the drill pipe, and back to either the entry or exit points through the drilled annulus. Drilling mud is required to drive down-hole motors, create hydraulic cutting action, and transport spoil back to the surface. Drilling mud returns collected at the surface are processed through a solid control system that removes spoil from the drilling mud, allowing the mud to be reused. In order for water to perform the HDD functions required, it is generally necessary to modify its properties by adding a viscosifier. The viscosifier used almost exclusively in drilling muds is naturally occurring clay in the form of bentonite. Bentonite typically comes from Wyoming and consists principally of montmorillonite clay. Bentonite is not a hazardous material as defined by the EPA.

Details of the actual HDD performed at the Pembina River are provided on Figure 1. The Figure indicates the as built schedule for completion of the pilot hole; successive pre-reaming passes, swabbing attempts and the pipe pull back. The installation involved the completion of an approximately 4000-foot drill reamed to 42-inches. The 30-inch pipeline was constructed on the surface on the north side of the river and pulled into the exit point from the drill rig situated on the south side of the river.

Initially, the drilling contractor proposed a schedule that extended from September 20, 2008, through October 23, 2008, to complete the crossing. Construction actually started on September 6, 2008, and extended though January 29, 2009. It is understood that significant drilling fluid losses occurred downhole during the completion of the crossing. This however is currently being investigated and quantified.

1.4 Notification and Reporting

Since the subsidence was observed, Keystone has been communicating with several agencies and associations to inform them of the findings at the Pembina River. As we continue to assess the situation as detailed in this report, follow-up information will be communicated.

2. POST SUBSIDENCE ASSESSMENT

2.1 Field Reconnaissance and Observations

As part of this assessment a field reconnaissance was conducted on February 5th and 6th, 2009, by members of the Keystone team familiar with HDD operations and geotechnical processes. The reconnaissance involved the inspection of the general area where the sinkholes occurred, the area around the entry and exit points, and the banks of the river in the vicinity of the crossing. A representative of the North Dakota Public Service Commission, Mr. Dennis Markusen, also attended the visit.

Rough measurements of the size of the holes were obtained. Basically, the predominant "diameter" of the holes was noted to be on the order of 50 to 55 ft. The fifth hole (advancing to the south) is somewhat smaller. Assessing depth of any of the holes is difficult due to safety limitations and the uncertain extent to which spoil has cascaded into the openings. It is estimated that the sinkholes are open to a depth in the range of 30 to 55 feet.

The wall of each hole was noted to be quasi vertical. Sedimentary layers of predominantly granular soils (gravelly and sandy-silt) with cross bedding were observed. Given the unsupported height and soils present, instability and continuous retrogressive enlargement had occurred and is expected to progress. The area between the first three holes (advancing from the exit point) showed signs of subsidence; however, no localized sinkholes had developed at the time of the visit. As the snow cover and the frozen ground thaw, instability of the surficial layers may exacerbate.

A photographic summary of the sinkholes can be seen in Appendix A of this report.

2.2 Data Review

Data review commenced with an initial review of general geological information of the region including published geological information issued in 1975 for Pembina and Cavalier Counties. Based on the information, the site is generally underlain by alluvial and glacial deposits that overlie shale (silty clayey rock) of Cretaceous age. Rock outcrops are present on the banks of the river.

As part of the crossing design work, a geotechnical investigation was conducted in 2006 to determine subsurface conditions. The program originally comprised four boreholes. However, due to the terrain at the crossing, access could only readily be obtained for three boreholes. Each borehole was completed to a depth of 100 feet below ground surface. One borehole, borehole No. 1, was completed in the general vicinity of the subsidence as shown on Figure No. 1.

Construction and inspection personnel have provided basic as-built information consisting of as-built geometry, direction of operations, drilling operation sequence and schedule, drill progress observations, as well as a recount of the initial incidence of subsidence and subsequent progression. These data are reflected on Figure No. 1.

Additional efforts to gather and interpret daily construction data related to circulation loss and volumes are currently underway and will be utilized to refine additional assessment and remediation steps.

3. KEY FINDINGS AND INITIAL ASSESSMENT

3.1 Geotechnical Conditions

The information available indicated that the subsoil at the general site consists of alluvial and glacial deposits consisting of silts, sands and silty sands overlying rock.

In general terms, the boring logs of the exploration performed in 2006 for this crossing indicate that predominantly granular soils present on the north side of the river are loose to dense. Soils of similar nature and density were found to occur on the south side, overlying predominantly hard clayey soils. Cobbles and boulders were detected in the borings. Fissile, dark brown to black shale underlies the soils described.

The borehole that had been advanced in the general vicinity of where the subsidence ultimately occurred generally encountered approximately 90 feet of sand, silt and silty sand overlying clayey sand. The as-built drill path passed through the silty sand and clayey sand in this area. The subsidence has occurred within the silts, sands and silty sands.

3.2 Construction Process

The general construction process involved the following key steps:

GENERAL CONSTRUCTION PROCESS	
Activity	**Schedule**
Complete Pilot Hole	September 6 to October 16
Complete pre- reaming passes to 42-inch for north portion of crossing	October 18 to November 25
Complete pre-reaming passes to 42-inch for south portion of crossing	December 3 to January 6
Complete full 42-inch pre-reaming pass	January 6 to January 11
Swab passes attempted	January 12 to January 14
Complete additional full pre-reaming passes	January 14 to January 26
Complete pipe pull back (installation)	January 27 to January 29

The process was completed utilizing two drill rigs with one being located at the entry point and one at the exit point.

Relevant observations during construction include the following:

1. Swab passes attempted to clear the hole were continually obstructed in the vicinity of station 361 which is coincident with the area of eventual subsidence.
2. Drilling mud circulation was absent for extended period of time, indicating a loss of drilling mud into the subsurface formation.
3. Due to profile requirements and geotechnical conditions, the installation required HDD operations through both soils and bedrock.
4. Reamers were repeatedly lodged in the vicinity of the eventual subsidence during pre-reaming.

As noted above, the crossing required approximately 20 weeks to complete versus a planned 5 weeks.

3.3 Probable Causes of the Subsidence

Based on the above described initial review, it is suspected that the continual flow of drilling fluid over a protracted period resulted in the formation of subsurface voids in the soil formation. The incidence of this may have been greatest near the soil-rock interface where difficulty was experienced during reaming which would have resulted in prolonged exposure to flowing drilling mud. Due to the presence of clayey sand layers in the formation, these cavities may have been able to form without immediate expression of subsidence at the surface until the spanning capability of the cohesive layers was exceeded. Once the spanning capabilities of the cohesive layers were exceeded, this could result in a sudden collapse of the void(s) resulting in the sudden expression of sinkholes at the surface likely directly over the voids which formed.

The issue is compounded by the frequent loss of drilling fluid during the process. Not only does this imply that soils are being eroded and carried away, but the loss of circulation suggests lower mud pressures in the hole. Lower mud pressures will increase the incidence of collapse of the hole. Subsequent reaming operations to open the hole necessarily remove this material allowing further collapse and the creation of the voids described above.

3.4 On Going Risk

Given the unsupported depth of the subsidence and the nature of the soils present, instability and continuous retrogressive enlargement of the holes has occurred and will continue to progress. The situation will exacerbate as snow melt and runoff occurs and soils thaw. The continued collapse of the holes will increase the area of impact to the surface and could threaten stability of the slope.

Due to the presence of soils possessing some degree of cohesion, it is entirely possible that voids continue to exist at depth which have not yet collapsed. This could result in additional expressions at the surface or enlargement of existing ones.

It is not known to what extent subsidence has occurred below the pipe and accordingly to what extent the pipe has moved or may move in the future. Although the presence of rock at depth limits this risk, it cannot be ruled out completely without further review.

4. NEXT STEPS

The following sections summarize a Keystone plan to secure the site to ensure public and worker safety, further evaluate the nature and scope of the situation, and to design an appropriate remediation program. A schedule for the completion of these activities is also provided.

4.1 Safety Measures

The sinkholes have been secured with barricades and fencing as appropriate. Keystone will continue to monitor the area and maintain the barricades as necessary and provide additional barricades if necessitated by further subsidence. Additionally the Walhalla Snowmobiling Association has been advised of the holes as an established snowmobiling trail has been affected.

4.2 Complete Information Gathering

Additional drilling and inspection records are currently being reviewed. In particular, efforts are underway to quantify the duration and volume of drilling muds lost and the extent of spoil material recovered. Additional analysis of soil to rock transitions will be conducted to ascertain the potential for additional subsurface voids.

4.3 Monitoring Surveys of Sinkholes and Adjacent Areas

A procedure has been implemented to periodically survey the size and location of existing and any subsequent sinkholes. Additionally, points of known elevation have been established at other locations to allow the periodical monitoring for additional subsidence. These data will be recorded and assessed on a relative basis to evaluate any ongoing subsidence.

4.4 Subsurface Investigation

Keystone intends to implement a program of further investigation. The program could involve the use of techniques such as ground penetrating radar, gravimetric measurements, or electrical resistively methods.

A geophysical program would be able to identify the presence of significant subsurface voids or loose material. These data will be used to assess the possibility of future subsidence and to determine an appropriate remediation program.

5. SCHEDULE

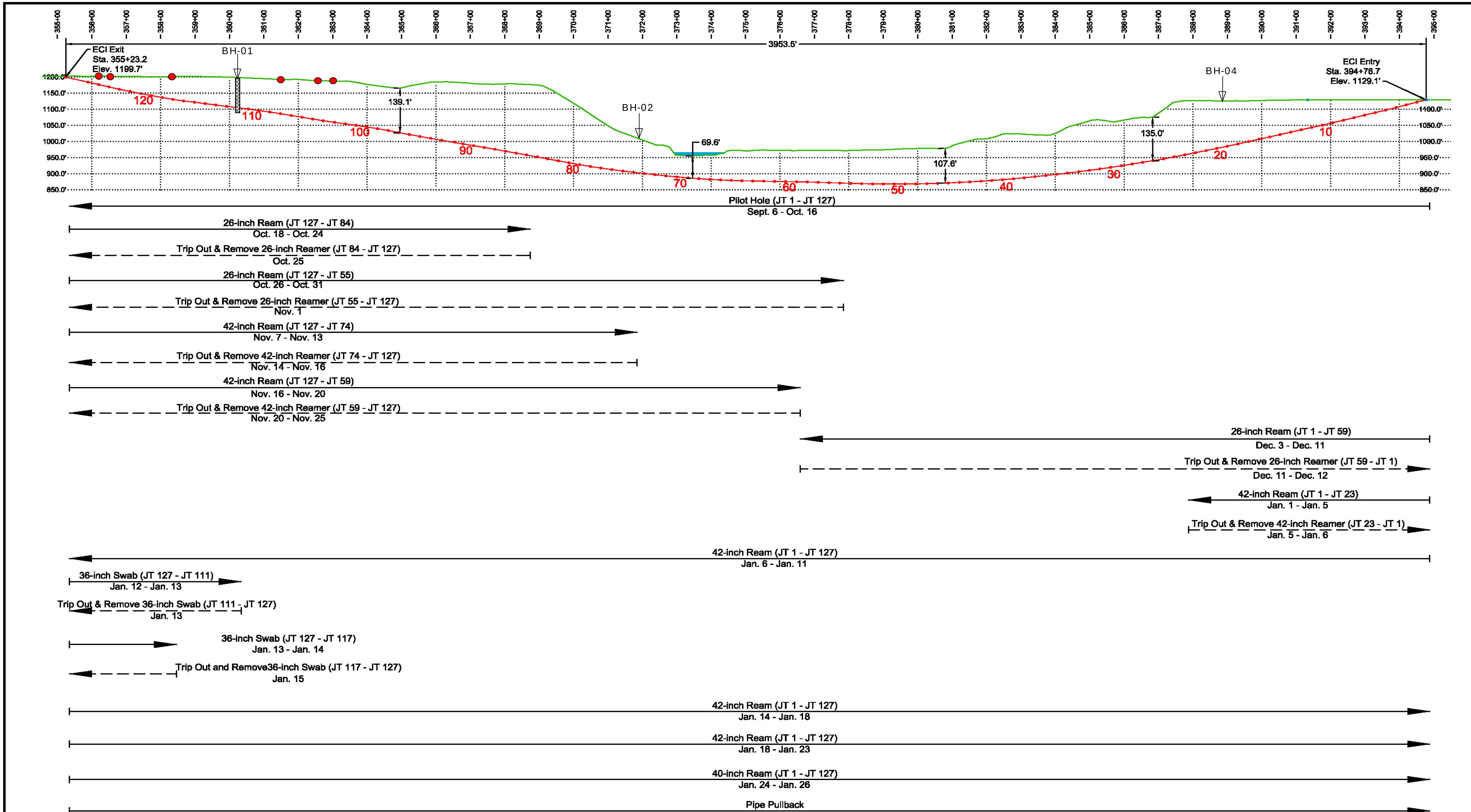
Sequence of activities and approximate durations can be seen in the following table.

SCHEDULE FOR CONTINUED EVALUATION AND REMEDIATION			
NO.	**ACTIVITY**	**DURATION**	**NOTES**
1.	Geophysical field surveys and report	4 weeks. Start date: March 2, 2009 End date: March 27, 2009	Proposals have been solicited from appropriate contractors.
2.	Analyze all information and subsequent Report	3 weeks. Start date: March 30, 2009 End date: April 17, 2009	
3.	Repairs	TBD – Schedule for remediation will be developed upon completion of assessment work.	A contractor with experience in the repair of subsidence associated with HDD and tunneling operations has been contacted to support development of a remediation program.

*Dates shown are approximations based on discussions with contractors.

6. SUMMARY

The crossing of the Pembina River for the Keystone Pipeline project with the HDD method resulted in subsidence in the form of sinkholes at the surface along the drill path. Such subsidence is not uncommon with HDD installations. This initial assessment has suggested that the subsidence is due to the formation of subsurface voids for various reasons during the drilling operation. A plan for further assessment has been outlined and a list of techniques which have all been used in the past to evaluate similar instances has been provided from which a remediation plan will be developed for implementation.



Legend

- Subsidence
- Approximate Borehole Location
- Ground Surface
- ECI As-Built Drill Path

BASE DRAWING PROVIDED BY: HENKELS & McCOY

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In business to deliver

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PEMBINA RIVER HDD INSTALLATION
30" KEYSTONE PIPELINE
AS-BUILT INFORMATION
PEMBINA & CAVALIER COUNTIES, NORTH DAKOTA

SCALE	DATE	DRAFTER	DRAWING NUMBER	REV.
NTS	2.20.09	DH	FIGURE 1	0

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FIGURE 2

SUBSURFACE BORING LOG

AET JOB NO: **09-00089** LOG OF BORING NO. **1 (p. 1 of 3)**

PROJECT: **Keystone Pipeline; Pembina River, Site 1.01; Walhalla, ND**

DEPTH IN FEET	SURFACE ELEVATION: 1312.3 NGVD MATERIAL DESCRIPTION	GEOLOGY	N	MC	SAMPLE TYPE	REC IN.	WC	DEN	LL	PL	%-#200
0–1	ORGANIC CLAY, surface roots, dark brown, firm (OL/OH)	TOPSOIL	6	M	SS	20					
1–2.5	LEAN CLAY WITH SAND, trace roots, black, firm (CL/OL)	MIXED ALLUVIUM	23	M	SS	18					
2.5–3	CLAYEY SAND, trace roots, firm, brown (SC)										
3–4.5	CLAYEY SAND, trace roots, brownish gray, very stiff (SC)										
4.5–6.5	SILTY SAND, fine to medium grained, brownish gray, moist, medium dense (SM)	COARSE ALLUVIUM	16	M	SS	18					
6.5–9	SAND, a little gravel, pieces of shale, fine grained, grayish brown, moist, medium dense (SP)		11	M	SS	16					
9–14	SAND WITH SILT, a little gravel, pieces of shale, medium to fine grained, brownish gray, moist, medium dense, lenses and laminations of shale (SP-SM)		16	M	SS	16					
			11	M	SS	16					
14–18	SAND WITH SILT, a little gravel, pieces of shale, medium grained, brownish gray, moist, loose (SP-SM)		9	M	SS	16					
18–28	SAND WITH SILT, a little gravel, pieces of shale, medium to fine grained, brownish gray, moist, loose to medium dense (SP-SM)		10	M	SS	16					22
			15	M	SS	16					
28–31+	SAND WITH SILT, a little gravel, medium to fine grained, brownish gray, moist, medium dense, lenses and laminations of shale (SP-SM)		19	M	SS	16					

DEPTH:	DRILLING METHOD	DATE	TIME	SAMPLED DEPTH	CASING DEPTH	CAVE-IN DEPTH	DRILLING FLUID LEVEL	WATER LEVEL
0-54½'	4.25" HSA							
54½'-99½'	RD w/DM							None

WATER LEVEL MEASUREMENTS

BORING COMPLETED: **10/20/06**

DR: **SS** LG: **BL** Rig: **69C**

NOTE: REFER TO THE ATTACHED SHEETS FOR AN EXPLANATION OF TERMINOLOGY ON THIS LOG

AMERICAN ENGINEERING TESTING, INC.

SUBSURFACE BORING LOG

AET JOB NO: **09-00089** LOG OF BORING NO. **1 (p. 2 of 3)**

PROJECT: **Keystone Pipeline; Pembina River, Site 1.01; Walhalla, ND**

DEPTH IN FEET	MATERIAL DESCRIPTION	GEOLOGY	N	MC	SAMPLE TYPE	REC IN.	WC	DEN	LL	PL	%-#200
33–38	GRAVELLY SAND WITH SILT, possible cobbles, pieces of shale, medium to fine grained, brownish gray, moist, dense (SP-SM)	COARSE ALLUVIUM	34	M	SS	16					
38–48	GRAVELLY SAND WITH SILT, pieces of shale, fine to medium grained, brownish gray, moist, dense, lenses of shale (SP-SM)		40	M	SS	16					
			22	M	SS	16					14
48–53	SAND WITH SILT AND GRAVEL, fine to medium grained, brownish gray, moist, medium dense (SP-SM)		27	M	SS	16					
53–58	SILTY SAND, fine to medium grained, brownish gray, moist, medium dense, lenses and laminations of clayey sand (SM)		24	M	SS	16					
58–63	CLAYEY SAND, brownish gray, very stiff, laminations of fine sand with silt (SC)	MIXED ALLUVIUM	27	M	SS	16	40				
63–68	SILTY SAND, fine to medium grained, brownish gray, moist, medium dense, laminations of clayey sand (SM)		26	M	SS	16					
68–	SILTY SAND, a little gravel, fine to medium grained, brownish gray, moist, dense (SM)	COARSE ALLUVIUM									

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SUBSURFACE BORING LOG

AET JOB NO: **09-00089** LOG OF BORING NO. **1 (p. 3 of 3)**

PROJECT: **Keystone Pipeline; Pembina River, Site 1.01; Walhalla, ND**

DEPTH IN FEET	MATERIAL DESCRIPTION	GEOLOGY	N	MC	SAMPLE TYPE	REC IN.	WC	DEN	LL	PL	%-#200
71 – 73	SILTY SAND, a little gravel, fine to medium grained, brownish gray, moist, dense (SM)	COARSE ALLUVIUM	32	M	SS	16					
73 – 83	SILTY SAND, fine to medium grained, brownish gray, moist, medium dense (SM)		26	M	SS	16					26
			27	M	SS	16					
83 – 88	SAND WITH SILT, medium to fine grained, brownish gray, moist, dense (SP-SM)		34	M	SS	16					
88 – 101	CLAYEY SAND, a little gravel, brownish gray, hard (SC)	MIXED ALLUVIUM	32	M	SS	18	34				
			34	M	SS	18	37				
			36	M	SS	18	37				
101	**END OF BORING**										

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APPENDIX A. PHOTOGRAPHS

Note: All photos courtesy of ENSR.


SN 356+15 Sink hole looking south


SN 356+50 Subsidence over ditch line looking south

SN 358+30 Sink hole looking into hole

SN 358+30 Sink hole looking north

SN 361+50 Sink hole looking north

Looking west at both sinkholes within Tetrault SF property 2009-01-29

SN 362+50 looking SE, Sinkhole near ROW centerline in pine plantation 2009-01-29

SN 363+00 looking W, Sinkhole near ROW centerline across Tetrault SF overlook road 2009-01-29