ST. MARY DIVERSION FACILITIES GEOTECHNICAL STUDIES FOR THE HALL COULEE SIPHON CROSSING

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"Lifeline of the Hi-line"

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GEOTECHNICAL REPORT
HALL COULEE SIPHON CROSSING
ST. MARY DIVERSION AND CONVEYANCE FACILITIES

1.0 INTRODUCTION

1.1 Purpose and Scope

This report presents the results of our geotechnical studies for the replacement of the Hall Coulee Siphon crossing, part of the St. Mary Diversion Facilities located northeast of Babb, Montana. The purpose of the geotechnical studies was to determine the general surface and subsurface conditions at the siphon crossings and to develop preliminary geotechnical engineering recommendations to enhance long-term performance of the existing or replacement siphons. This report describes the fieldwork and laboratory analyses conducted for the investigation performed and instrumentation monitoring since 2006, the surface and subsurface conditions encountered, and presents our preliminary recommendations for the existing and future replacement siphon crossing. Any additional data which is collected after the time of this report may warrant modifications to the conclusions and recommendations contained herein. In addition, final design of the replacement siphon structure has not been initiated and a final alternative or layout has yet to be determined.

Our field work included drilling four soil borings, installing slope inclinometers in each completed boring and performing Cone Penetration Testing (CPT) probings adjacent to two of the borings. Samples were obtained from the borings and returned to our Great Falls laboratory for testing. Laboratory testing was performed on select soil samples to determine engineering properties of the subsurface materials. The information obtained during our field investigations and laboratory analyses was used to develop preliminary recommendations for the design of the replacement siphon.

1.2 Project Description

The Hall Coulee Siphon is one of three siphon structures along the 29 miles of the St. Mary River Diversion and Conveyance Facilities (Figure 1A). The Hall Coulee Siphon is similar to the St. Mary River Siphon crossing except smaller in size. The siphon carries water from the west side of Hall Coulee to the east side. The inverted siphon consists of two riveted steel pipes 78 inches in diameter. The overall siphon length from inlet to outlet is approximately 1,405 feet long. The design discharge capacity of each pipe is 425 cfs for a combined capacity of 850 cfs. The maximum static head is 102 feet (44.5 psi) which is the elevation difference between the inlet water level and the center of the pipes crossing the bottom of Hall Coulee. The siphon inlet and outlet are concrete transition structures.

Photo 1 Hall Coulee Siphon inlet transition looking downstream (eastward) (10/13/04).

Photo 2 Siphon crossing Hall Coulee, looking east (downstream) (05/16/06).

The following represents a brief summary of the siphon history, performance, repairs and on-going maintenance. This information was obtained from various USBR documents.

Similar to the St. Mary River Siphon, the left pipe, as viewed looking downstream, was constructed from 1912 to 1915, and the right pipe was constructed from 1925 to 1926. Most of the left, original pipe was placed underground with 3 to 5 feet of soil cover except that portion crossing the bottom of the Hall Coulee. Water diversion and conveyance started in June of 1916 with just the left pipe. Because of the problems experienced at the St. Mary River Siphon, it was decided that the right pipe should be constructed above ground on concrete saddles on 20-foot centers to support the pipe. This also facilitated maintenance of the exterior protective coating. It was also decided to use more expansion/contraction joints and increase the internal joint movement distance from 10 inches to 24 inches. A typical expansion/contraction joint with a cathodic continuity cable is shown in Photo 3.

The siphons at Hall Coulee are relatively stable compared to the St. Mary River Siphon crossing, but have experienced some minor problems with sliding, leakage and closure of expansion/contraction joints. Photos 4 and 5 show typical siphon repairs due to deflection and corrosion.

Photo 3 Typical Expansion/Contraction Joint, Including Cathodic Protection Continuity Cable (10/26/04).

Photo 4 Typical siphon repair due to compression forces and/or corrosion (10/13/04).

Photo 5 Typical siphon repair due to compression forces and/or corrosion (10/13/04).

Supporting the siphon on concrete saddles reduces the drag forces imposed by down slope ground movements. However, this causes the concrete supports to rotate downslope which creates a point-load bearing condition. This has resulted in up to 6-inch indentations in the pipe at the points of the concentrated load (Photo 6).

Photo 6 Photo shows right to left ground movements causing rotation of concrete support and point-loading of siphon which can lead to buckling (10/13/04).

The right siphon exhibits similar movement, but because this pipe was constructed with a different type of expansion joint, this allowed the pipe to accommodate more movement. In any event, several of the right siphon expansion joints also became entirely closed and were replaced in October 2007 (Photo 7).

In summary, the existing Hall Coulee Siphon, excluding the concrete transition structures, exhibits the following deficiencies:

- The exposed concrete pipe supports are deteriorating.
- Both conduits continue to move down the slope.
- Concrete supports under the conduit are rotating because of ground movements relative to the pipe. As the supports tip they buckle the bottom of the pipe.
- Portions of the conduit continually need to be removed at the expansion/contraction joints to keep them functional. Additional lengths of conduit need to be added to replace displaced sections.
- Most of the expansion/contraction joints leak and tend to saturate the supporting soils and the hillsides (see Photo 8).

Photo 7 Replacement of a contraction joint on the right siphon in November 2007. (10/17/07).

Photo 8 Leaking expansion/contraction joint on Hall Coulee Siphon. Note erosion of supporting soil. Rag being used to diffuse spray (10/13/04).

The Hall Coulee Siphon crossing is in fair to poor condition and represents one of the fragile components of the overall Diversion Facilities. Sudden rupture and progressive failure could cause both economic and environmental catastrophes. Current alternatives being considered by the Design Team for replacing the Hall Coulee Siphon include the various parameters and design alternatives:

- One large replacement pipe versus two smaller pipes,
- Above ground supported siphon versus direct bury construction with integrated drainage,
- Pipe materials, i.e. cast-in-place concrete, steel or other,
- Below coulee crossing or elevated above,
- New alignment and reduction of overall length,
- Need for and level of corrosion protection, and
- Slope stability issues and need for or level of stabilization corrective measures.

2.0 SUMMARY OF FIELD AND LABORATORY STUDIES

2.1 Field Explorations

The field exploration program was conducted from August 16 to the 19, 2006. Four soil borings were drilled to depths ranging from 27.3 to 40.8 feet at the locations shown on Figure 1B to observe subsurface soil and groundwater conditions. The borings were advanced through the subsurface soils using a truck-mounted, Longyear BK-80 drill rig equipped with 8-inch O.D. hollow stem augers. The drilling and sampling methods used are indicated on the Boring Logs. Rock coring was performed in one boring (ESI-2) and approximately 5 feet of HQ-size, rock core (2.375-inch diameter) was obtained. The borings were logged by Erling A. Juel, P.E. of Thomas, Dean & Hoskins, Inc. (TD&H). The locations and surface elevations of the exploratory soil borings shown on Figure 1B were determined by TD&H surveying personnel in the field.

In-situ soil parameters were measured adjacent to two of the four soil boring locations using an electric cone penetrometer. The cone penetration test with pore water measurements (CPTU) is described by ASTM D-5778. The CPTU probe measures cone tip resistance (q_c), sleeve friction (f_s), pore water pressure behind the cone tip (u_2) generated during penetration and tilt angle of the probe during the push. A depth synchronization unit tracks the probe depth and penetration rate as the CPTU probe is systematically pushed into the subsurface soils using 1-meter long rods. A target penetration rate of 20mm per second was utilized and data was electronically recorded every second.

Samples of the subsurface materials were taken using 1-3/8-inch I.D. split spoon samplers. The samplers were driven 18 inches, when possible, into the various strata using a 140-pound drop hammer falling 30 inches onto the drill rods. For each sample, the number of blows required to advance the sampler each successive six-inch increment is recorded, and the total number of blows required to advance the sampler the final 12 inches is termed the penetration resistance ("N value"). This test is known as the Standard Penetration Test (SPT) described by ASTM D-1586. Penetration resistance values indicate the relative density of granular soils and the relative consistency of fine-grained soils. The CPTU probe profiles and logs of all borings, which include soil descriptions, sample depths and penetration resistance values, are presented on the Figures 2 though 7.

Measurements to determine the presence and depth of groundwater were made in the borings by lowering an electronic water sounder through the open boring or auger shortly after the completion of drilling. The depths or elevations of the water levels measured, if encountered, and the date of measurement are shown on the borings logs.

The Hall Coulee Siphon crossing has been investigated previously by USBR staff in 2001 as part of the North Central Regional Feasibility Study. Five soil borings were drilled on the slopes and four of them were completed as piezometers for future water level measurements. Their locations are shown on Figure 1B. Logs of the previous USBR soil borings are included in the Appendix.

2.2 Instrumentation

For the TD&H study, each of the four soil borings were completed as slope inclinometers by installing 2.75-inch diameter, ABS plastic inclinometer casing which extends from the bottom of the boring to approximately 3 feet above the ground surface. The outside annulus was back-filled with a cement-lime-bentonite grout slurry. A protective steel monument casing was installed at the ground surface to protect the inclinometer casing. The protective casing was set using pre-mixed concrete.

Slope inclinometers are geotechnical devices used for monitoring soil deformation perpendicular to the casing axis. The casing serves as an alignment guide for an instrument probe containing gravity-sensing transducers. A change in casing inclination with respect to a previous measurement is an indication of lateral soil movements. Inclinometers are used primarily for monitoring and assessing slope stability parameters including soil mass movements and depths to failure planes.

2.3 Laboratory Testing

Samples obtained during the field exploration were returned to our materials laboratory where they were observed and visually classified in general accordance with ASTM D2487, which is based on the Unified Soil Classification System. Representative samples were selected for testing to determine the engineering and physical properties of the soils in general accordance with ASTM or other approved procedures.

Tests Conducted:	To determine:
Natural Moisture Content	Representative moisture content of soil at the time of sampling.
Grain-size Distribution	Particle size distribution of soil constituents describing the percentages of clay/silt, sand and gravel.
Atterberg Limits	A method of describing the effect of varying water content on the consistency and behavior of fine-grained soils.

UU Shear Strength (Field)	The undrained, unconfined shear strength (s_u) of cohesive soils as determined in the field by either a pocket penetrometer or a hand torvane.

The laboratory testing program for this project consisted of 52 visual classifications and moisture content determinations, 7 grain-size distributions, and 7 Atterberg limit analyses. The results of the water content analyses are presented on the boring logs, Figures 2 through 5. The grain-size distribution curves and Atterberg limits are presented on Figures 8 and 9. Numerous unconfined compressive strengths (q_u) were determined in the field using a pocket penetrometer. The results are shown on the boring logs at the depths the samples were tested.

3.0 SITE CONDITIONS

3.1 Geology and Physiography

The site is geologically characterized as consisting of Quaternary-aged alluvial and glacial deposits of clay, sand and gravel underlain by Cretaceous-aged sedimentary bedrock possibly of the Two Medicine Formation (K_{tm}). Glacial till/drift is the most predominant soil type which blankets the upper slopes at the project site. It is typically a clay soil with varying concentrations of sand and gravel. The glacial till/drift was most likely deposited by past widespread alpine glaciation. Alluvial deposits of sands and gravels were encountered at upper elevations. Alluvium is deposited by flowing water and most likely represents glacial outwash deposits. Sedimentary bedrock was encountered at depth in each boring. A geologic cross-section was prepared based on the USBR and TD&H soil borings and is presented on Figure 14 in the Appendix.

The appropriate 2009 International Building Code (IBC) seismic design parameters for the site include site coefficients of 1.20 and 1.69 for F_a and F_v, respectively. The Site Class for this site is C, and the mapped spectral response accelerations at short periods (S_s) and at 1-second period (S_1) are 0.49g and 0.18g, respectively. For slope masses, embankments and active landslides, risks from seismic activity includes increased driving forces from lateral acceleration and a significant reduction of the resisting shear strength forces. The likelihood of seismically-induced soil liquefaction or settlement for this project is not probable and does not warrant additional evaluation.

3.2 Surface Conditions

The existing siphon crossing is shown on Figure 1B. The site presently consists of native grasses, brush and bushes. Locally, the area has been disturbed due to initial construction of the siphon, numerous subsequent repairs, and three crude oil pipelines that cross under the siphon at the bottom of Hall Coulee. Maintenance access roads traverse each of the siphon slopes. On the west slope, site topography is such that the site slopes range from 24 to 35 percent. The topography is best described as strongly sloping to moderately steep and gently rolling. On the east slope, slopes range from 15 to 24 percent. In general, the terrain on the east side is described as slightly hummocky.

3.3 Subsurface Conditions

3.3.1 Soils.

The subsurface soil conditions appear to be relatively consistent based on our exploratory drilling and soil sampling. In general, the subsurface soil conditions encountered within the

soil borings on the east slope consist of approximately 7.0 to 19.5 feet of glacial till/drift and outwash soils. In ESI-1, soils consist of 19.5 feet of silty, clayey sand with gravel, silty, clayey gravel with sand, and clayey gravel with sand. For ESI-2, soils consist of 7 feet of clayey sand and sandy, lean clay. Shale bedrock was encountered below the soils.

On the west slope, subsurface conditions consist of 8.0 and 23.0 feet of glacial soils. In WSI-1, approximately 8 feet of clayey sand was observed. In WSI-2, up to 23 feet of lean clay with sand was encountered. Each boring on the west slope was terminated in the shale bedrock which extends down to a depth of at least 36.8 feet. The subsurface geologic conditions are illustrated on Figure 14 in the Appendix.

The subsurface soils are described in detail on the enclosed boring logs and are discussed below. The stratification lines shown on the logs represent approximate boundaries between soil types and the actual in situ transition may be gradual vertically or discontinuous laterally.

GLACIAL TILL/DRIFT AND OUTWASH

Glacially derived soil deposits blanket both slopes of the Hall Coulee Siphon crossing. These soil deposits consist predominantly of lean clay with sand and clayey gravel with sand. Lesser amounts of clayey sand, sandy lean clay and silty, clayey sand with gravel were encountered. These soils ranged in thickness from 8.0 to 23.0 feet. The soils are firm/medium dense to hard/very dense as indicated by penetration resistance values which ranged from 11 to 95 blows per foot (bpf) and averaged 32 bpf. Seven samples of the various soils obtained from the borings contained between 0 and 43 percent gravel, between 14 and 45 percent sand, and between 19 and 86 percent silt and clay. The samples exhibited liquid limits of 22 to 51 percent and plasticity indexes of 6 to 29 percent. The natural moisture contents measured varied from 8 to 31 percent and averaged 16 percent.

SEDIMENTARY BEDROCK

Sedimentary bedrock was encountered below the mantling soils in each of the four borings. The bedrock is a black to dark gray, thinly bedded to blocky, marine carbonaceous shale. The shale was generally weathered at the upper contact becoming less weathered with depth. The USBR soil borings identify the shale as the Cretaceous-aged Two Medicine Formation. The shale was generally very dense as indicated by penetration resistance values which ranged from 29 to greater than 50 bpf and averaged over 50 bpf. Natural moisture contents ranged from 8 to 28 percent and averaged 15 percent. A rock core was obtained from Boring ESI-2 (Figure 3). Due to the soft, fissile nature, the core recovery was 60 percent and the Rock Quality Designation (RQD) was 0.19.

3.3.2 Ground water

Ground water was encountered within two of the four soil borings during drilling. Specifically, water levels were measured at the time of drilling. The presence or absence of observed ground water may be directly related to the time of the subsurface investigation. Numerous factors contribute to seasonal ground water occurrences and fluctuations, and the evaluation of such factors is only possible with continuous monitoring of piezometers.

The slope inclinometers are not intended to serve as ground water monitoring wells due to the inherent nature of their construction and the annulus grout backfill. However, ground water may enter and collect in the inclinometer casing. When observed, water levels encountered in the inclinometer casing are recorded but should be treated with discernment. The USBR installed four piezometers on the slopes (DH01-HC2 through DH01-HC5) in 2001. Similar to our recent investigation, similar ground water conditions were encountered in the USBR-installed borings. The casing and ground surface elevations of the USBR piezometers and TD&H inclinometers were determined by TD&H surveying personnel. Specifics of each installation are summarized in Table 1 below. As part of our slope inclinometer monitoring program, readings were obtained from the USBR piezometers. Table 2 and the following graph (Exhibit 1) summarize the measured ground water elevations obtained since February 2006.

Table 1 – Summary of Instrumentation

West Side Installation	Top of Casing	Ground Surface	Installed By	Status
DH01–HC1	(1)	4427.60	USBR	(1)
DH01–HC2	4354.10	4351.50	USBR	(2)
WSI-1	4432.07	4428.85	TDH	(2)
WSI-2	4377.64	4375.80	TDH	(2)

East Side Installation	Top of Casing	Ground Surface	Installed By	Status
DH01-HC3	4340.72	4338.59	USBR	(2)
DH01-HC4	4373.44	4370.29	USBR	(2)
DH01-HC5	4405.49	4403.74	USBR	(2)
ESI-1	4407.16	4405.24	TDH	(2)
ESI-2	4367.82	4364.80	TDH	(2)

NE =Ground Water Not Encountered
(1) =Installation Not Completed as Piezometer
(2) =Ground Water Levels Monitored

TABLE 2 - Summary Of Ground Water Elevations
Hall Coulee Siphon Crossing

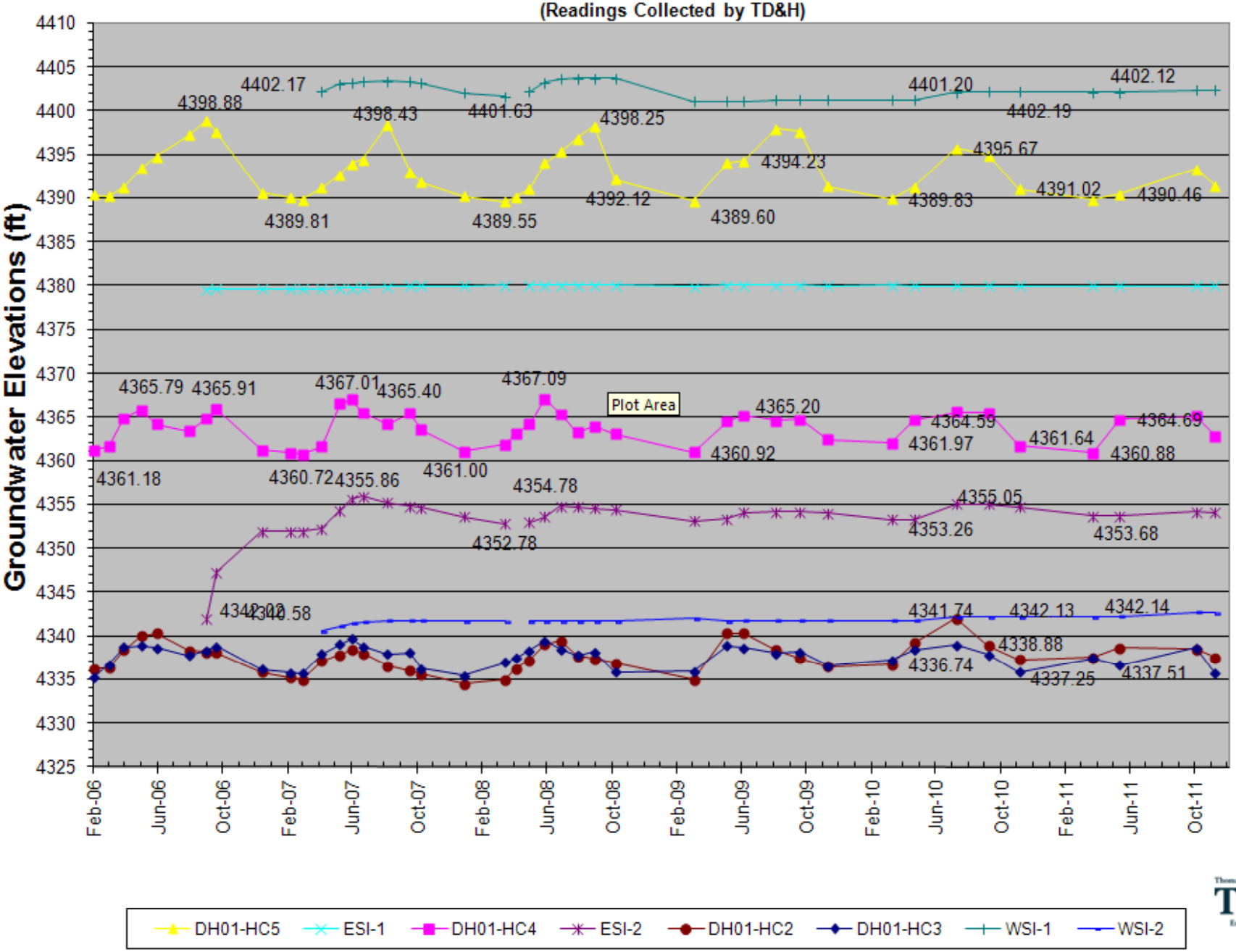
	West Slope			East Slope				
	DH01-HC2	WSI-1	WSI-2	DH01-HC3	DH01-HC4	DH01-HC5	ESI-1	ESI-2
Ground Elev.	4351.50	4428.85	4375.80	4338.59	4370.29	4403.74	4405.24	4364.80
Top Elevation	4354.10	4432.07	4377.64	4340.72	4373.44	4405.49	4407.16	4367.82
Bottom Elev.	4311.50	4399.40	4339.13	4318.62	4355.76	4382.19	4378.16	4326.30
Casing Length	42.60	32.67	38.51	22.10	17.68	23.30	29.00	41.52
2/7/2006	4336.22			4335.22	4361.18	4390.34		
3/8/2006	4336.29			4336.72	4361.57	4390.16		
4/5/2006	4338.36			4338.69	4364.81	4391.24		
5/8/2006	4339.98			4338.85	4365.79	4393.41		
6/5/2006	4340.33			4338.60	4364.15	4394.72		
8/5/2006	4338.31			4337.78	4363.29	4397.25		
9/7/2006	4338.12			4338.34	4364.77	4398.88	4379.54	4342.02
9/25/2006	4338.05			4338.80	4365.91	4397.54	4379.60	4347.26
12/20/2006	4335.85			4336.15	4361.21	4390.58	4379.66	4351.92
2/12/2007	4335.16			4335.77	4360.85	4390.04	4379.66	4351.92
3/6/2007	4334.95			4335.67	4360.72	4389.81	4379.66	4351.92
4/11/2007	4337.10	4402.17	4340.58	4337.88	4361.55	4391.16	4379.67	4352.22
5/15/2007	4337.86	4403.07	4341.09	4339.04	4366.52	4392.69	4379.70	4354.29
6/7/2007	4338.39	4403.14	4341.39	4339.63	4367.01	4393.98	4379.74	4355.61
6/27/2007	4337.95	4403.27	4341.56	4338.80	4365.51	4394.46	4379.76	4355.86
8/13/2007	4336.59	4403.34	4341.77	4337.90	4364.09	4398.43	4379.85	4355.15
9/24/2007	4335.96	4403.28	4341.75	4338.04	4365.40	4392.97	4379.93	4354.81
10/15/2007	4335.62	4403.16	4341.74	4336.23	4363.51	4391.77	4379.94	4354.65
1/3/2008	4334.51	4402.02	4341.69	4335.46	4361.00	4390.17	4379.99	4353.57
3/21/2008	4334.94	4401.63	4341.67	4336.97	4361.78	4389.55	4380.01	4352.78
4/9/2008	4336.23			4337.47	4363.04	4390.09		
5/5/2008	4337.20	4402.14	4341.67	4338.28	4364.12	4390.97	4380.01	4352.94

TABLE 2 Cont. - Summary Of Ground Water Elevations
Hall Coulee Siphon Crossing

	West Slope			East Slope				
	DH01-HC2	WSI-1	WSI-2	DH01-HC3	DH01-HC4	DH01-HC5	ESI-1	ESI-2
Ground Elev.	4351.50	4428.85	4375.80	4338.59	4370.29	4403.74	4405.24	4364.80
Top Elevation	4354.10	4432.07	4377.64	4340.72	4373.44	4405.49	4407.16	4367.82
Bottom Elev.	4311.50	4399.40	4339.13	4318.62	4355.76	4382.19	4378.16	4326.30
Casing Length	42.60	32.67	38.51	22.10	17.68	23.30	29.00	41.52
6/2/2008	4338.99	4403.18	4341.66	4339.42	4367.09	4393.99	4380.01	4353.60
7/3/2008	4339.39	4403.59	4341.68	4338.50	4365.34	4395.27	4380.07	4354.78
8/4/2008	4337.71	4403.72	4341.68	4337.76	4363.20	4396.84	4380.01	4354.72
9/4/2008	4337.38	4403.71	4341.67	4338.15	4363.88	4398.25	4380.01	4354.54
10/14/2008	4336.90	4403.72	4341.67	4335.82	4362.99	4392.12	4380.01	4354.38
3/10/2009	4334.96	4401.07	4341.96	4335.89	4360.92	4389.60	4379.91	4353.12
5/11/2009	4340.31	4401.04	4341.66	4338.90	4364.43	4394.04	4380.00	4353.36
6/12/2009	4340.30	4401.09	4341.72	4338.64	4365.20	4394.23	4380.01	4354.08
8/11/2009	4338.40	4401.21	4341.76	4338.00	4364.54	4397.98	4380.01	4354.17
9/25/2009	4337.40	4401.20	4341.75	4338.12	4364.71	4397.66	4380.00	4354.13
11/16/2009	4336.45	4401.19	4341.74	4336.58	4362.39	4391.32	4379.98	4354.00
3/16/2010	4336.74	4401.20	4341.74	4337.22	4361.97	4389.83	4380.00	4353.26
4/27/2010	4339.16	4401.19	4341.73	4338.35	4364.59	4391.24	4379.99	4353.28
7/16/2010	4341.96	4402.11	4342.12	4338.96	4365.60	4395.67	4379.99	4355.05
9/14/2010	4338.88	4402.19	4342.13	4337.82	4365.50	4394.92	4379.97	4355.01
11/11/2010	4337.25	4402.17	4342.12	4335.82	4361.64	4391.02	4379.97	4354.69
3/30/2011	4337.51	4402.12	4342.14	4337.42	4360.88	4389.82	4379.99	4353.68
5/19/2011	4338.63	4402.11	4342.21	4336.67	4364.69	4390.46	4379.96	4353.65
10/9/2011	4338.50	4402.34	4342.67	4338.60	4365.08	4393.31	4379.98	4354.15
11/14/2011	4337.52	4402.34	4342.65	4335.68	4362.74	4391.42	4379.97	4354.07

Note: DH01-HC1 not completed as ground water observation well
NE = Not Encountered

Exhibit 1 - Hall Coulee Siphon Both Slopes
Potentiometric Surface Elevations (PSE's)
(Readings Collected by TD&H)



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4.0 ENGINEERING ANALYSIS

4.1 Introduction

Both the east and west sides of the existing Hall Coulee Siphon crossing have a history of slope movements that have impacted siphon performance and necessitated numerous repairs. Repairs consisting of the installation of replacement expansion/contraction joints have been performed in the past as recently as the 2007 – 2008 off-season. Slope movements are on-going and can be characterized as follows:

- The left, older and buried siphon experiences more movement-related distress than the newer siphon which is supported above ground.
- The west slope exhibits more siphon movements than the east slope.

Translation and rotation of the concrete supports (Photo 6) tends to reduce the frictional drag imparted to the above ground siphon from the ground movements relative to the adjacent buried siphon. Also, leakage from the above ground supported siphon (Photo 8) tends to become runoff whereas leakage from the buried siphon tends to saturate the surrounding and supporting soils. These two combined observations result in the older, buried pipe (left side) being more prone to displacements than the elevated pipe.

Continual downward slope movements create internal stresses within the siphon barrels that tend to resist movements. The siphon barrel eventually buckles when the cumulative drag forces imposed from the moving soil exceed the internal strength of the siphon material itself. Tendency for buckling is enhanced when driving and resisting forces become eccentric. The use of expansion/contraction joints allow siphon movements to occur and reduces the buildup of resisting forces until full travel of the joint is realized. On the other hand, expansion/contraction joints offer little resistance to siphon movements and thereby facilitate movement.

Design of the replacement siphon structure must consider the current or potential slope stability issues in order to ensure acceptable long-term performance. The studies performed to date provide background information and recommendations to be considered during final design. The recommendations which follow should be reviewed once a final alignment for the replacement siphon(s) has been established.

4.2 Slope Inclinometers

Regular readings of the four slope inclinometers installed at the Hall Coulee Siphon crossing have been obtained since they were installed in August 2006. Initially, readings of the slope inclinometers were taken on a monthly basis and the frequency was gradually reduced since. The results of the slope inclinometers are shown on Figures 10 through 13.

Data obtained from the inclinometers indicate that the movements occurring on these slopes are minor and appear to be relatively shallow. No signs of deep-seated slope instabilities were observed during our monitoring period. A review of the data collected indicates that the movements observed are irregular and only one relatively clearly defined slide plain could be found. Slope inclinometer WSI-1 indicates that surficial slope movements are occurring and appear to extend to a maximum depth of approximately 10 feet. The maximum extent of the movements, since the installation of the inclinometer, is on the order of 1-inch. Shallow slope movements are likely being caused by the leaking siphons and do not appear to be related to an inherent instability of the existing slopes.

4.3 Slope Stability Issues

4.3.1 Introduction

The slope stability history of the siphon crossing prior to the original siphon construction in 1915 is not known. Hummocky terrain on the east slope suggests historical instability. The absence of this characteristic landform both north and south of the siphon on the same east slope suggests that this may be the result of the last 96 years of canal operation and not necessarily due to natural, pre-existing soil and ground water conditions.

4.3.2 Ground Water

Ground water levels have been measured by TD&H personnel in the USBR installed piezometers since February 2006 and the TD&H installed inclinometers since September 2006. Potential sources of ground water in the vicinity of the siphon crossing on both the east and west slopes include the following:

- Leakage from the unlined canal prism upstream and downstream of the siphon transition structures
- Leakage from the concrete to steel siphon interfaces at the transition structures
- Leakage from the siphon barrels and expansion/contraction joints

- Storm water infiltration due to surface irregularities on the slopes
- Natural occurring sources of ground water

In general, the glacial clay soils are relatively impervious; however, excavation and the construction of the buried siphon created a ready seepage path for upslope leakage to follow which increased shear strength softening directly below and adjacent to the buried siphon section. Also, as movements of the siphon occur, whether above or below ground, leakage tends to increase which further exacerbates slope instability.

The four ground water monitoring wells exhibit ground water fluctuations that reach seasonal highs in September and lows in March. This corresponds to the natural fluctuation of ground water levels as well as the seasonal operation of the canal facilities. The range of ground water levels to date for each observation well is shown on the geologic cross-section (Figure 14). Although not constructed as monitoring wells, as of April 11, 2007, each of the four inclinometers had exhibited the presence of ground water. As such, this data in our opinion, is not reliable as an accurate indication of ground water levels. The ground water levels are also summarized on Exhibit 1 of Section 3.3.2.

To date, the two piezometers near the bottom of the coulee, DH01-HC2 and DH01-HC3, have fluctuated seasonally from approximately 4.4 to 7.5 feet. DH01-HC4, mid slope on the east side, has fluctuated approximately 6.4 feet. The piezometer below the outlet of the transition structure , DH01-HC5, has exhibited the greatest seasonal fluctuation of nearly 9.3 feet. The fluctuations tend to decrease as you move down slope supporting the theory that ground water levels are being influenced by the operation of the canal system.

4.3.3 Soil Shear Strengths

Due to the granular nature and consistency of the subsurface soils, undisturbed samples for shear strength testing were not obtained. CPT testing was performed adjacent to ESI-1 and WSI-2. Our experience with similar glacial till soils indicates that the residual drained shear strength angle (ϕ) is commonly between 8 and 18 degrees. Residual shear strength in the clay would tend to develop with increasing displacements along a developed slide plane. The existing slopes vary from 15 to 24 percent (9 to 13 degrees) and from 24 to 35 percent (13 to 19 degrees) for the east and west slopes respectively.

4.4 Replacement Siphons

To reduce seepage and increases to the soil-moisture regime on the slopes, considerations should be given for lining portions of the canal prism both upstream and downstream of the siphon transition structures. In addition, attention should be given to the interface between the transition structure and the siphon to further reduce leakage and seepage.

Based on the findings from the investigation and monitoring performed, it is our opinion that the replacement siphon may be constructed as a buried installation. To enhance long-term performance, the buried alternative should incorporate a drainage system integral to the backfill zone to intercept and convey leakage, seepage, and infiltration away from the foundation soils. A conceptual detail of a buried installation utilizing a single replacement pipe is shown in Figure 15; however, a similar system which incorporates two pipes could also be used. The ground surface should be revegetated and sloped to drain away from the buried siphon to reduce infiltration. Also siphon anchorage, tied into the underlying bedrock, should also be included in the final design to provide additional resistance against potential sliding.

4.5 Slope Stability Enhancements

The slope instabilities and ground movements impacting the Hall Coulee siphon are relatively shallow and appear to be isolated to the area surrounding the siphon structure. This indicates that the localized instability is primarily due to increases in infiltration and soil moisture in proximity to the existing siphons. These increases in moisture lead to shear strength softening of the supporting soil and an overall loss of strength. Methods to improve the drainage around the existing siphon structure would tend to reduce pore pressures within the soil mass. The reduction in pore pressures would simultaneously increase the shear strength of the soil and decrease the total driving forces acting on the slope.

The main sources of the additional moisture are due to natural annual precipitation and the additional loss of water being conveyed through the siphon structure. Of these two factors, only the additional water being lost by the system is within our control; however, improved drainage surrounding the structure will help with the management of the naturally occurring precipitation. The monitoring wells along the slope show a strong correlation between ground water elevations and length of operation of the canal system. At the time of the seasonal canal start-up, the ground water levels are near their lowest elevation. The ground water levels gradually rise and reach their peak near the end of the operating season for the system. Once the canal is shut-down for the season, the ground water levels gradually return to the base values. This trend is readily seen on Exhibit 1 and the trend is more pronounced in years prior to 2009 in which more regular data collection was performed.

As discussed previously, the main sources of water infiltration from the siphon system are due to leaks from the pipes themselves and infiltration through the unlined canal prism upstream and downstream of the siphon. Reduction in these two factors will have a substantial influence on the overall stability of the slopes which support the siphon structure. This would include prompt repair and maintenance of the existing siphons to repair leaks and minimize water losses and potential lining of the upstream and downstream canal prism.

These potential improvements are considered relatively short-term in nature. These options will help to reduce the seepage volumes and minimize the potential for slope movements until a replacement siphon system can be designed, constructed, and placed into operation. These alternatives will require seasonal maintenance and/or repair which can be quite costly if implemented for a long-term fix of this system. Continued monitoring of slope movements and ground water elevations prior to and after the implementation of any improvements or replacement structure will help in gauging their effectiveness and functionality.

5.0 RECOMMENDATIONS

5.1 General

1. Periodic inclinometer and piezometer monitoring should be continued until final design of the replacement siphons has been completed. It is important to obtain and review this additional data to confirm or modify the recommendations provided in this report. In addition, collection of data will provide a baseline for evaluating the effectiveness of future improvements and/or replacement systems.

2. Once the alignment of the proposed replacement siphon system has been determined, additional inclinometers and piezometers should be constructed along the alignment. This will help with the evaluation of any existing slope instabilities and will provide a baseline to which post-construction data can be compared.

3. Future design considerations should be made for lining portions of the canal prism both upstream and downstream of the siphon transition structures to help reduce leakage and the introduction of ground water seepage to the siphon slopes. In addition, design of the transition structures should incorporate measures to reduce detrimental leakage at the interfaces of dissimilar materials.

5.2 Replacement Siphons

4. The corrosivity analyses on similar soils indicate that the soils are corrosive to bare metal and aggressive to normal concrete. Based on our past experience and laboratory testing and field observations, moderate concentrations of water-soluble sulfates are common in the local clay soils. The concentration of sulfates is considered detrimental causing deterioration of concrete. Sulfate resistant cement (Type V) or Type II cement with a maximum of 8 percent C_3A (tricalcium aluminate) content should be used in all concrete exposed to the native clay soils. Likewise, the native clay soils have a known propensity for moderate to severe corrosion activity towards unprotected, bare metal surfaces. Corrosion protection schemes should be incorporated into the designs where applicable.

5. It is our opinion that the replacement siphon may utilize a buried construction approach provided the backfill zone incorporates a passive drainage system to intercept and convey seepage, leakage, and ground water away from the foundation soils. A conceptual detail of a single pipe system is shown on Figure 15.

5.3 Slope Stability Enhancements

6. No slope stability enhancements to the existing siphon system are recommended at this time. Improvements discussed above to reduce potential infiltration should be considered if a substantial amount of time is anticipated prior to construction of a replacement system.

5.4 Continuing Services

7. Consultation between the geotechnical engineer and the design professionals during the design phases is highly recommended. This is important to ensure that the intentions of our recommendations are incorporated into the design, and that any changes in the design concept consider the geotechnical limitations dictated by the on-site subsurface soil and ground water conditions.

6.0 LIMITATIONS

This report has been prepared in accordance with generally accepted geotechnical engineering practices in this area for use by the client for design purposes. The findings, analyses, and recommendations contained in this report are based on site conditions encountered and further assume that the results of the exploratory borings are representative of the subsurface conditions throughout the site, that is, that the subsurface conditions everywhere are not significantly different from those disclosed by the subsurface study. If during construction, subsurface conditions appear different from those encountered during our study, this office should be advised at once so we can review these conditions and reconsider our recommendations, when necessary.

Unanticipated soil conditions are commonly encountered and cannot be fully determined by a limited number of soil borings and laboratory analyses. Such unexpected conditions frequently require that additional expenditures be made to obtain a properly constructed project. Therefore, some contingency fund is recommended to accommodate such potential extra costs.

If substantial time has elapsed between the submission of this report and the start of work at the site, or if conditions have changed because of natural causes or construction operations at or adjacent to the site, we recommend that this report be reviewed to determine the applicability of the conclusions and recommendations considering the time lapse or changed conditions.

If you desire, we will review those portions of the plans and specifications which pertain to earthwork and foundations to determine if they are consistent with our recommendations. In addition, we are available to observe construction, particularly the placement and compaction of all fill, preparation of all foundations and quality control testing of Portland cement concrete.

This report was prepared for the exclusive use of the owner and architect and/or engineer in the design of the subject facility. It should be made available to prospective contractors and/or the contractor for information on factual data only and not as a warranty of subsurface conditions such as those interpreted from the boring logs and presented in discussions of subsurface conditions included in this report.

Prepared by: Craig R. Nadeau

Craig R. Nadeau, P.E.
Geotechnical Engineer

Reviewed by: Erling A. Juel

Erling A. Juel, P.E.
President

St. Mary Diversion Facilities

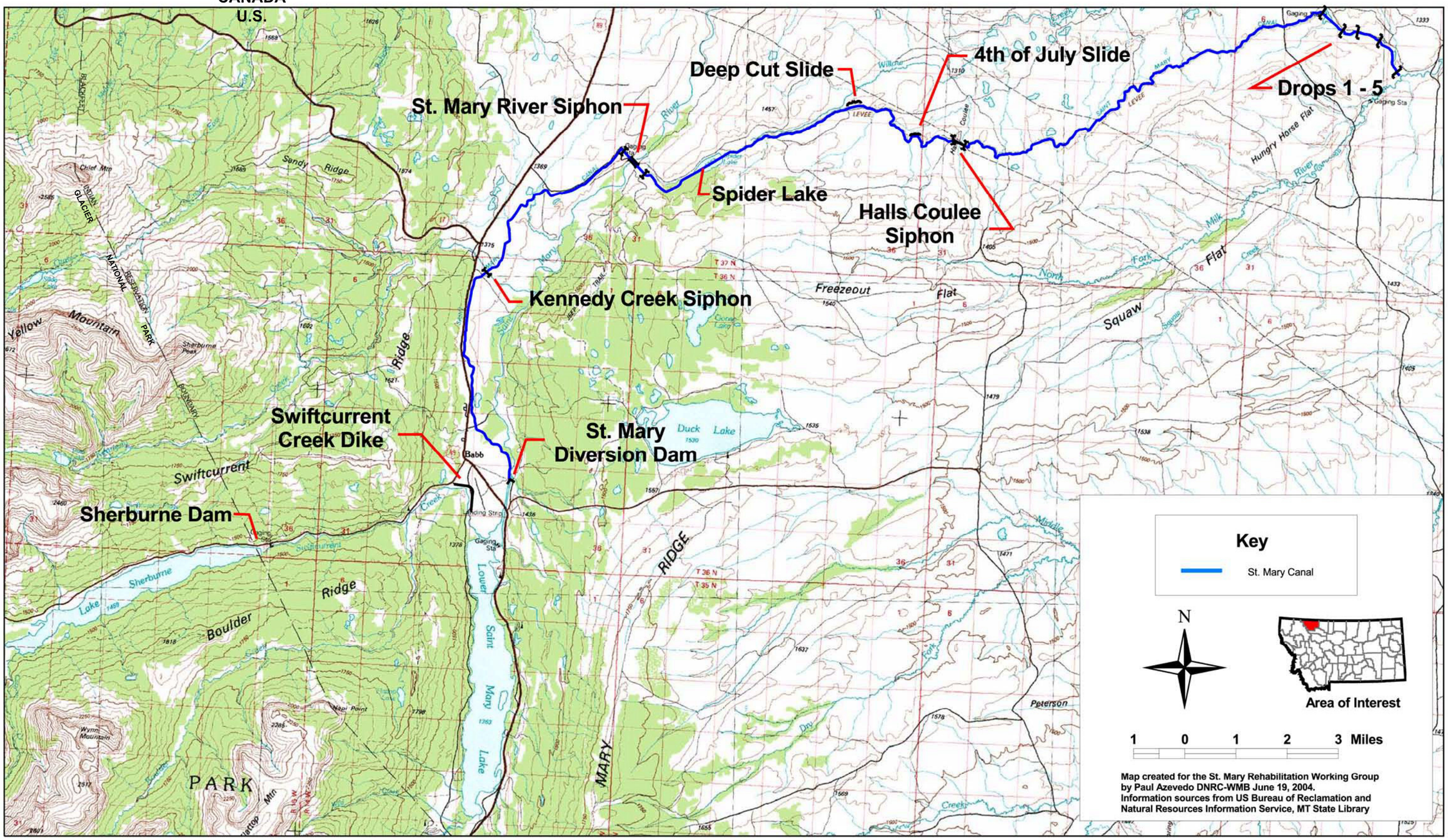


Figure 1A

LEGEND

- 3415 — CONTOUR
- CP — CONTROL POINT
- EDGE OF GRAVEL
- ELECTRICAL BOX
- FENCE – WIRE
- PP — PETROLEUM PIPELINES
- GUY WIRE
- E — OVERHEAD ELECTRIC
- POWER POLE
- SIPHON
- SLOPE INCLINOMETER
- USBR MONITORING WELL/BORING

INSTALLATION	TOP OF CASING	GROUND SURFACE
DH01–HC1	–	(1) 4427.60
DH01–HC2	4354.10	4351.50
DH01–HC3	4340.72	4338.59
DH01–HC4	4373.44	4370.29
DH01–HC5	4405.49	4403.74
ESI–1	4407.16	4405.24
ESI–2	4367.82	4364.80
WSI–1	4432.07	4428.85
WSI–2	4377.64	4375.80

BASED ON TD&H SURVEYS
(1) – NOT FOUND IN FIELD, APPROXIMATED BASED ON USBR LOGS
DH01–HC1 NOT COMPLETED AS MONITORING WELL

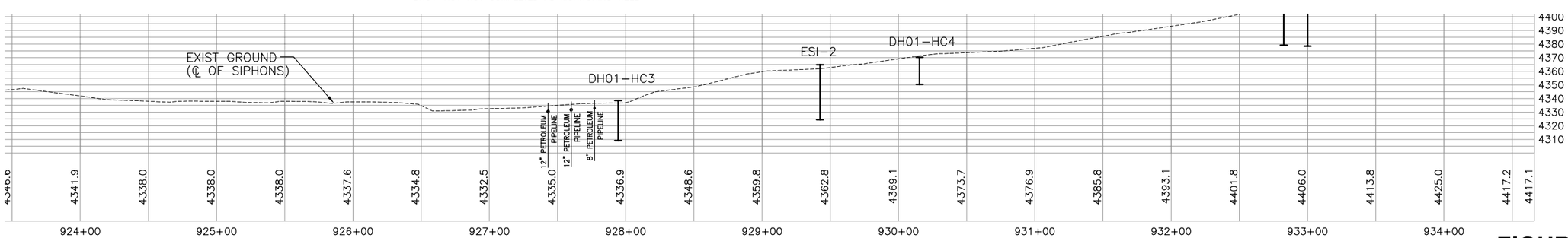


FIGURE 1B

REVISIONS
DESCR DATE BY
DESCR DATE BY
DESCR DATE BY

TD&H
THOMAS, DEAN & HOSKINS, INC.
ENGINEERING CONSULTANTS
GREAT FALLS–BOZEMAN–KALISPELL–HELENA
SPOKANE
LEWISTON
MONTANA
WASHINGTON
IDAHO

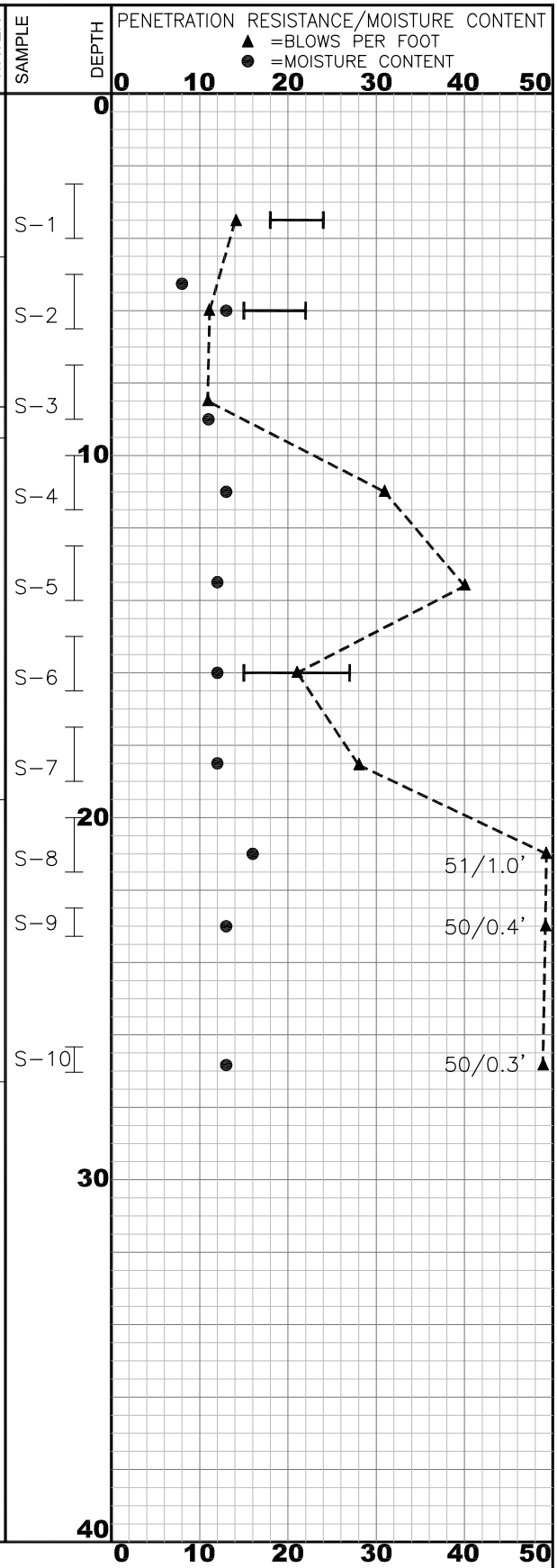
DRAWN BY: MWC
DESIGNED BY: EAJ
QUALITY CHECK:
DATE: 04.02.07
JOB NO. 04-167
FIELDBOOK

DNRC - CARDD
ST. MARY CANAL REHABILITATION

ST. MARY DIVERSION FACILITIES GEOTECHNICAL STUDIES
HALL COULEE SIPHON CROSSING
PLAN & PROFILE

CAD NO. 04167-HC-FIG1.DWG
SHEET 1 OF 1

GRAPHIC LOG	SURFACE: Cleared Pad – Disturbed Ground SURFACE ELEVATION: 4405.2 SOIL DESCRIPTION	DEPTH	GROUND WATER
	Silty, Clayey **SAND** with Gravel, medium dense, subangular, slightly moist to moist, grayish brown	4.5	
	Silty, Clayey **GRAVEL** with Sand, medium dense, slightly moist to moist, grayish brown	8.65 9.5	▼
	Clayey **GRAVEL** with Sand, medium dense to dense, subrounded to subangular, occasional sandy seams, moist to saturated, grayish brown	19.5	
	SHALE, very dense/hard, highly weathered, highly fractured, fissile, friable, noncalcareous, slightly moist, medium gray to black	27.3	
	Bottom of Boring: 27.3 feet Installed Slope Inclinometer Casing – Top of Casing Elevation: 4407.16 – Overall Length: 29.00 feet Construction: 2.75–inch I.D., ABS plastic inclinometer casing; cement/lime/bentonite annulus grout; steel, protective casing monument Logged by: Erling A. Juel, P.E. (08/17/06) Drilled by: Haztech Drilling using a truck-mounted BK-81 drill rig with 8-inch HSA.		**Groundwater Encountered During Drilling**

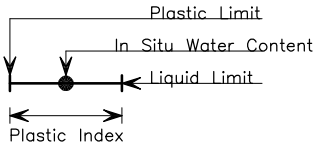


Note: The stratification lines represent approximate boundaries between soil types. Actual boundaries may be gradual or transitional.

LEGEND

- ▲ SPT blows per foot
- ● Field Moisture content
- ▼ Groundwater Level
- Grab/composite sample
- 1–3/8–inch I.D. split spoon
- 2–1/2–inch I.D. split spoon
- 2–1/2–inch I.D. ring sampler
- 3–inch I.D. thin–walled sampler
- * No sample recovery

Atterberg Limits



GNP = Granular and Nonplastic
H = Sample Heave

Log of Soil Boring ESI-1

Hall Coulee Siphon Crossing
St. Mary Rehabilitation Project
North of Babb, Montana

August 2006 04-167

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MONTANA WASHINGTON IDAHO

Figure No. 2
Sheet 1 of 1

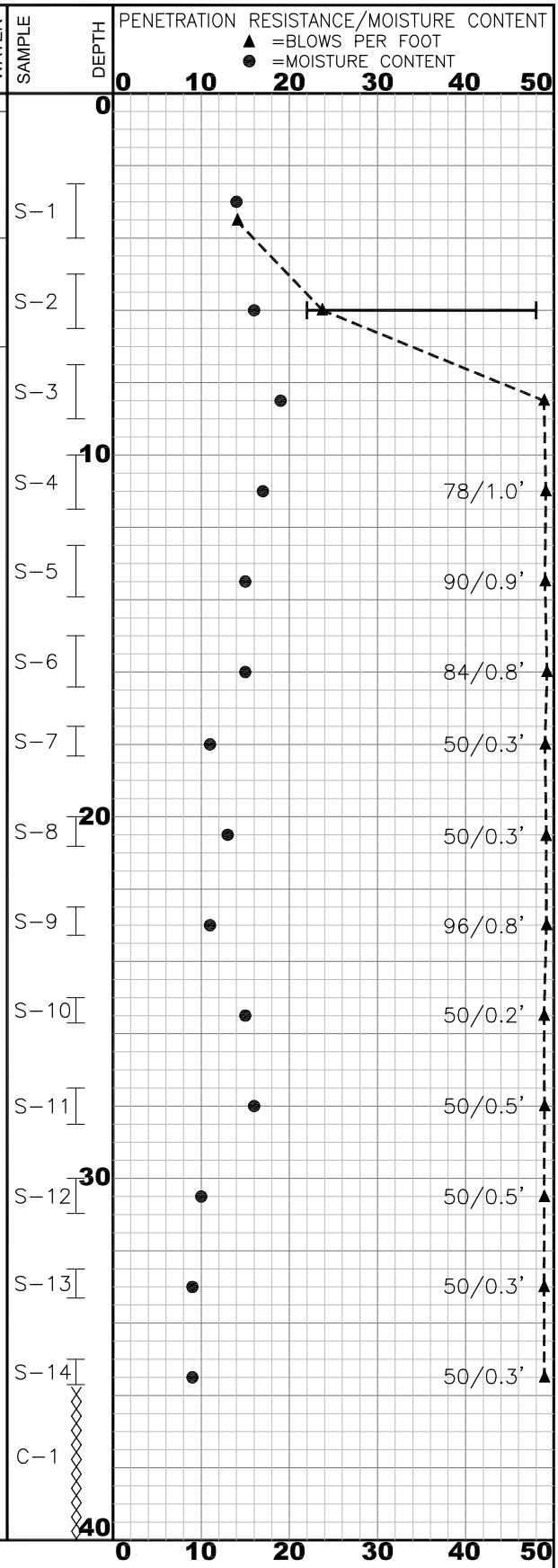
GRAPHIC LOG	SURFACE: Native Grasses SURFACE ELEVATION: 4364.8 SOIL DESCRIPTION	DEPTH	GROUND WATER
	TOPSOIL AND ORGANIC MATERIAL	0.5	
	Clayey **SAND**, medium dense, slightly moist, medium to dark gray	4.0	
	Sandy **LEAN CLAY**, very stiff, slightly moist to moist, gray	7.0	
	SHALE, very dense/hard, highly weathered, highly fractured, iron-staining, thinly bedded to blocky, noncalcareous, friable, dry to slightly moist, medium to dark gray		**Groundwater Not Encountered During Drilling**

Logged by: Erling A. Juel, P.E. (08/16/06)

Drilled by: Haztech Drilling using a truck-mounted BK-81 drill rig with 8-inch HSA.

Rock Core Run #1
Depth: 35.8' to 40.8'
Coring Rate: 6 min/ft.
Recovery: 60%
RQD: 0.19

(Continued on Following Sheet)

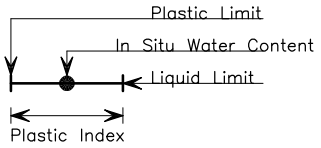


Note: The stratification lines represent approximate boundaries between soil types. Actual boundaries may be gradual or transitional.

LEGEND

- ▲ SPT blows per foot
- ● Field Moisture content
- ▼ Groundwater Level
- Grab/composite sample
- 1-3/8-inch I.D. split spoon
- 2-1/2-inch I.D. split spoon
- 2-1/2-inch I.D. ring sampler
- 3-inch I.D. thin-walled sampler
- * No sample recovery

Atterberg Limits



GNP = Granular and Nonplastic
H = Sample Heave

Log of Soil Boring ESI-2

Hall Coulee Siphon Crossing
St. Mary Rehabilitation Project
North of Babb, Montana

August 2006 04-167

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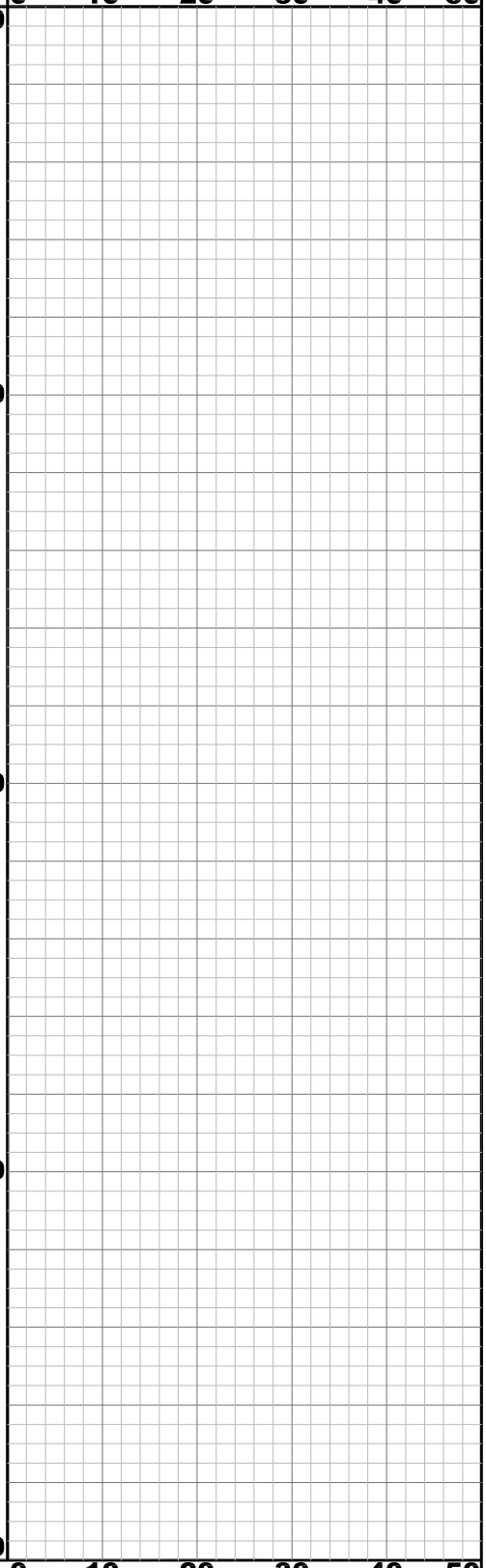
Figure No. 3
Sheet 1 of 3

GRAPHIC LOG	SURFACE: Native Grasses SURFACE ELEVATION: 4364.8 SOIL DESCRIPTION	DEPTH	GROUND WATER	SAMPLE	DEPTH
	(Continued from Previous Sheet)	40.8		X	40
	Bottom of Coring: 40.8 feet				
	Installed Slope Inclinometer Casing – Top of Casing Elevation: 4367.82 – Overall Length: 41.52 feet Construction: 2.75–inch I.D., ABS plastic inclinometer casing; cement/lime/bentonite annulus grout; steel, protective casing monument		**Groundwater Not Encountered During Drilling**		50 60 70 80

PENETRATION RESISTANCE/MOISTURE CONTENT
▲ =BLOWS PER FOOT
● =MOISTURE CONTENT

0 10 20 30 40 50



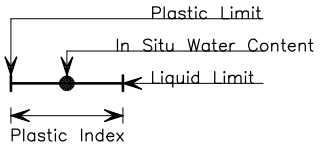
Logged by: Erling A. Juel, P.E. (08/16/06)

Drilled by: Haztech Drilling using a truck-mounted BK-81 drill rig with 8-inch HSA.

LEGEND

- ▲ SPT blows per foot
- ● Field Moisture content
- ▼ Groundwater Level
- Grab/composite sample
- 1–3/8–inch I.D. split spoon
- 2–1/2–inch I.D. split spoon
- 2–1/2–inch I.D. ring sampler
- 3–inch I.D. thin–walled sampler
- * No sample recovery

Atterberg Limits



GNP = Granular and Nonplastic
H = Sample Heave

Note: The stratification lines represent approximate boundaries between soil types. Actual boundaries may be gradual or transitional.

Log of Soil Boring ESI-2 (cont.)

Hall Coulee Siphon Crossing
St. Mary Rehabilitation Project
North of Babb, Montana

August 2006 04-167

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Figure No. 3
Sheet 2 of 3

BORING ESI-2, ELEVATION 4364.8 FT., ROCK CORE RUN 1
CORE RUN 1: DEPTH=35.8' TO 40.8', RQD=19%, RECOVERY=60%

FIGURE 3

HALL COULEE SIPHON CROSSING
NORTH EAST OF BABB, MONTANA

PHOTO OF SOIL BORING ESI-2

CORE RUN 1

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DRAWN BY: TJR	DATE: SEPTEMBER 2005	SHEET 3 of 3
DESIGNED BY: EAJ	JOB NO. 04-167	
QUALITY CHECK:	CAD NO. 04167-ESI-2B .DWG	

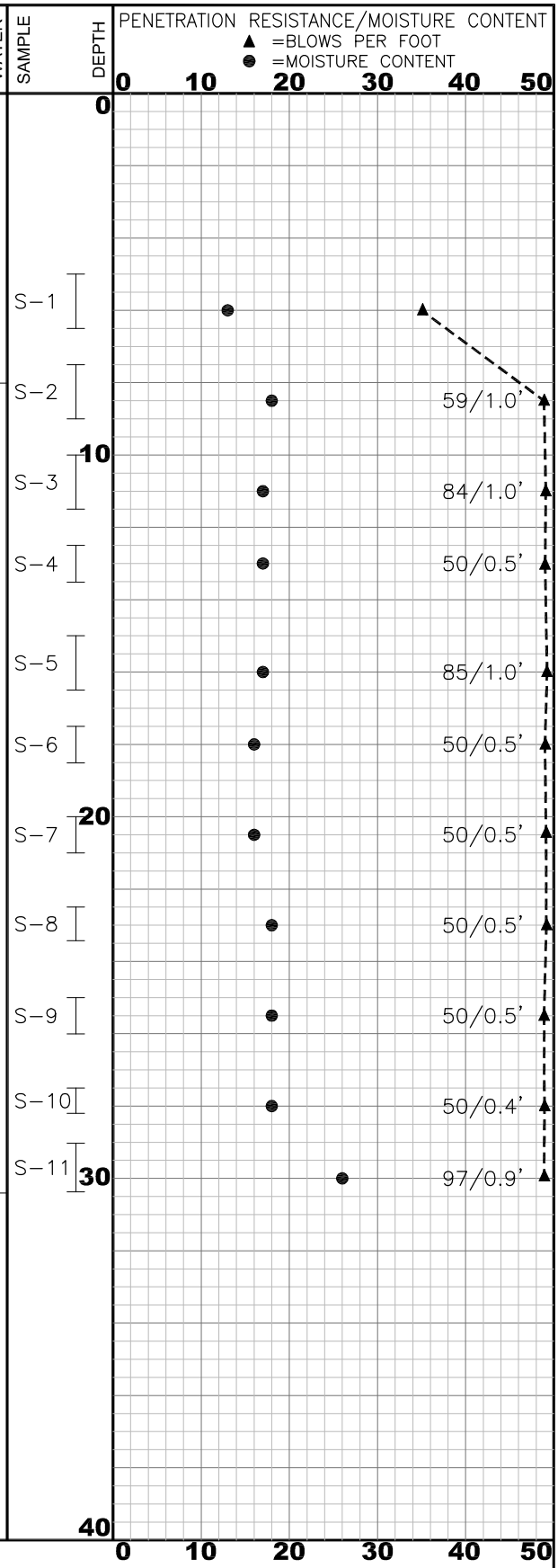
GRAPHIC LOG	SURFACE: Cleared Pad – Disturbed Ground SURFACE ELEVATION: 4428.8 SOIL DESCRIPTION	DEPTH	GROUND WATER
	Clayey **SAND,** dense, slightly moist, grayish brown	8.0	
	SHALE, very dense/hard, highly weathered at contact, less weathered with depth, highly fractured fissile, friable, iron–staining, slight moist to dry, medium gray		**Groundwater Encountered During Drilling**
	wet at 29.8 feet	30.4	
	Practical Auger Refusal @ 30.4 feet		

Logged by: Erling A. Juel, P.E. (08/19/06)

Drilled by: Haztech Drilling using a truck-mounted BK-81 drill rig with 8-inch HSA.

Installed Slope Inclinometer Casing
- Top of Casing Elevation: 4432.07
- Overall Length: 32.67 feet

Construction: 2.75–inch I.D., ABS plastic inclinometer casing; cement/lime/bentonite annulus grout; steel, protective casing monument

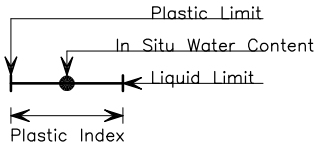


Note: The stratification lines represent approximate boundaries between soil types. Actual boundaries may be gradual or transitional.

LEGEND

- ▲ SPT blows per foot
- ● Field Moisture content
- ▼ Groundwater Level
- Grab/composite sample
- 1–3/8–inch I.D. split spoon
- 2–1/2–inch I.D. split spoon
- 2–1/2–inch I.D. ring sampler
- 3–inch I.D. thin–walled sampler
- * No sample recovery

Atterberg Limits



GNP = Granular and Nonplastic

H = Sample Heave

Log of Soil Boring WSI-1

Hall Coulee Siphon Crossing

St. Mary Rehabilitation Project

North of Babb, Montana

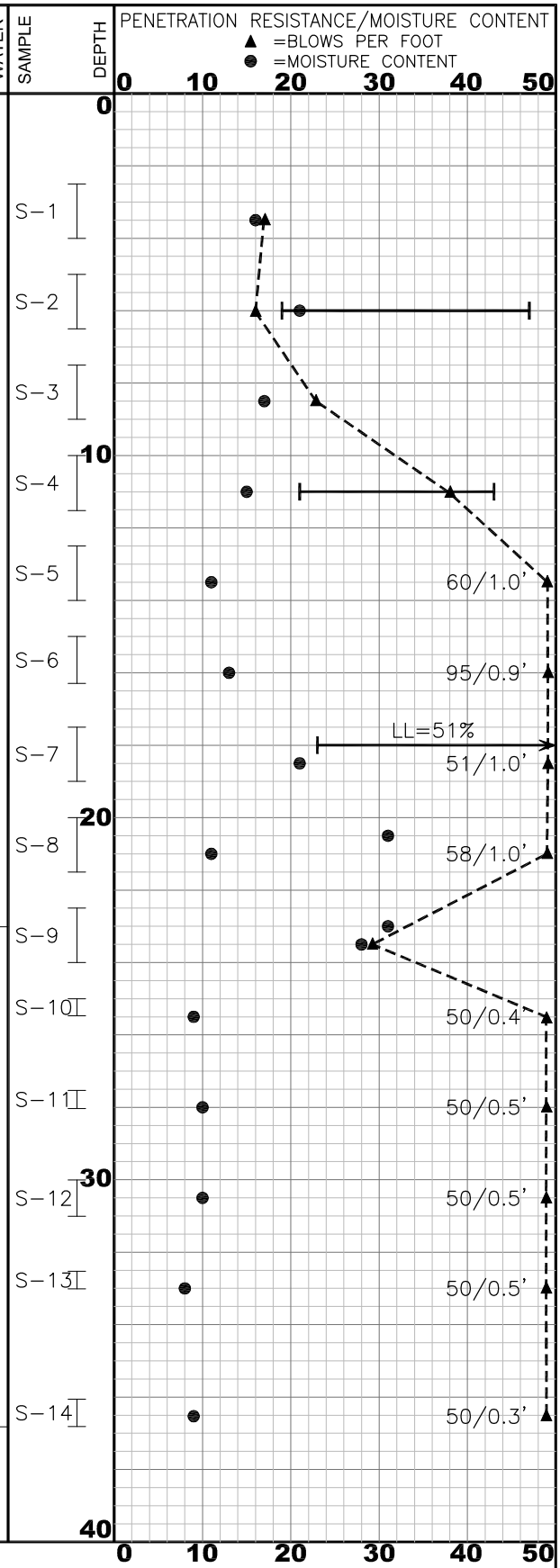
August 2006 04-167

TD&H THOMAS, DEAN & HOSKINS, INC. ENGINEERING CONSULTANTS GREAT FALLS–BOZEMAN–KALISPELL–HELENA SPOKANE LEWISTON MONTANA WASHINGTON IDAHO

Figure No. 4

Sheet 1 of 1

GRAPHIC LOG	SURFACE: Cleared Pad – Disturbed Ground SURFACE ELEVATION: 4375.8 SOIL DESCRIPTION	DEPTH	GROUND WATER
	LEAN CLAY with Sand, very stiff to hard, trace subrounded gravel, less gravel with depth, slightly moist, grayish brown q_u = 3.25–4.5 tsf Logged by: Erling A. Juel, P.E. (08/18/06) Drilled by: Haztech Drilling using a truck-mounted BK-81 drill rig with 8-inch HSA. q_u = > 4.5 tsf q_u = 4.0 to 4.5 tsf	23.0	Groundwater Not Encountered During Drilling
	SHALE, very dense/hard, highly weathered at upper contact, less weathered with depth, highly fractured, fissile, friable, slightly moist, medium gray Installed Slope Inclinometer Casing – Top of Casing Elevation: 4377.64 – Overall Length: 38.51 feet Construction: 2.75–inch I.D., ABS plastic inclinometer casing; cement/lime/bentonite annulus grout; steel, protective casing monument	36.8	
	Bottom of Boring: 36.8 feet		

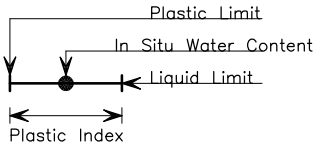


Note: The stratification lines represent approximate boundaries between soil types. Actual boundaries may be gradual or transitional.

LEGEND

- ▲ SPT blows per foot
- ● Field Moisture content
- ▼ Groundwater Level
- Grab/composite sample
- 1–3/8–inch I.D. split spoon
- 2–1/2–inch I.D. split spoon
- 2–1/2–inch I.D. ring sampler
- 3–inch I.D. thin–walled sampler
- * No sample recovery

Atterberg Limits



GNP = Granular and Nonplastic
H = Sample Heave

Log of Soil Boring WSI-2

Hall Coulee Siphon Crossing
St. Mary Rehabilitation Project
North of Babb, Montana

August 2006 04-167

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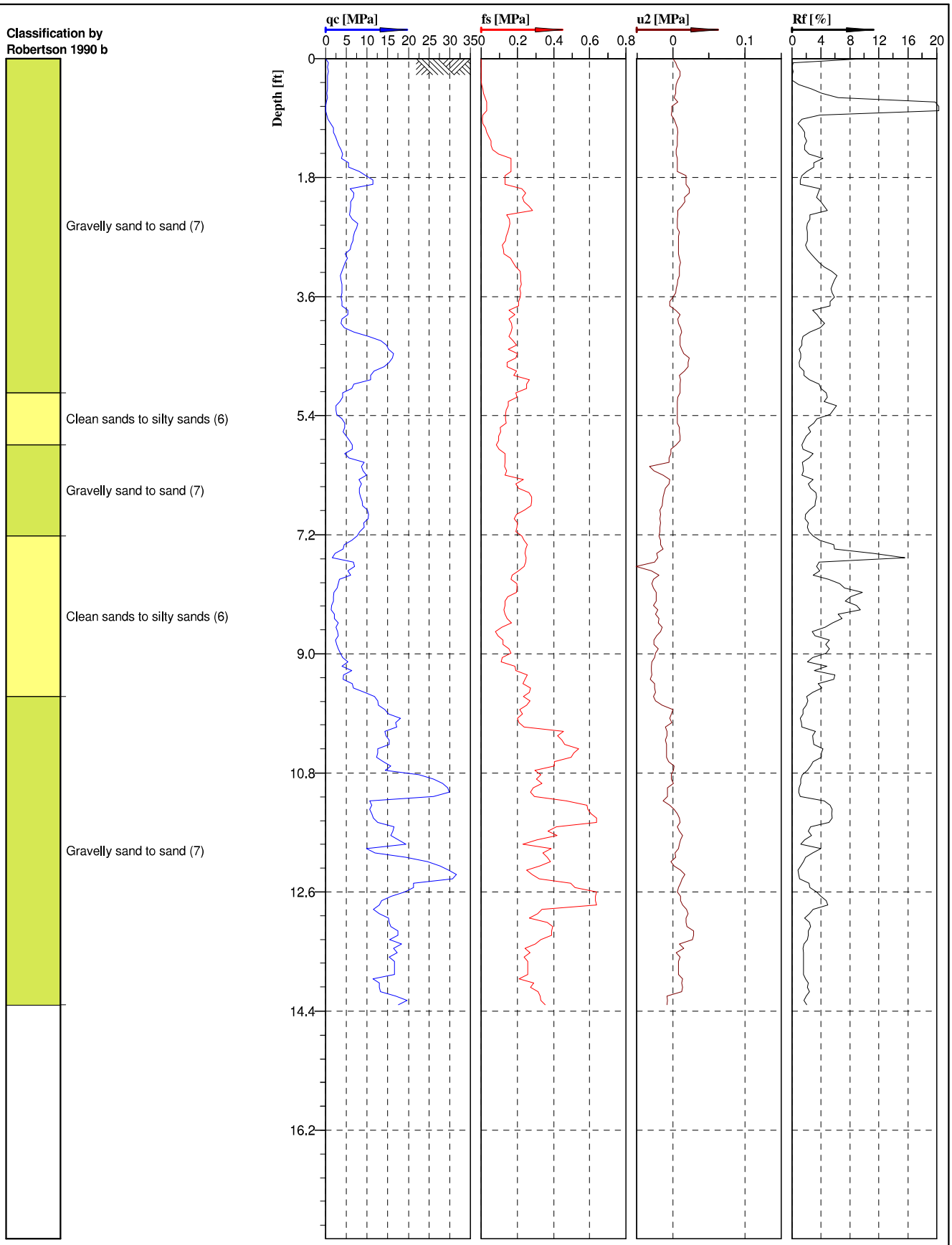
SPOKANE WASHINGTON
LEWISTON IDAHO

Figure No. 5
Sheet 1 of 1



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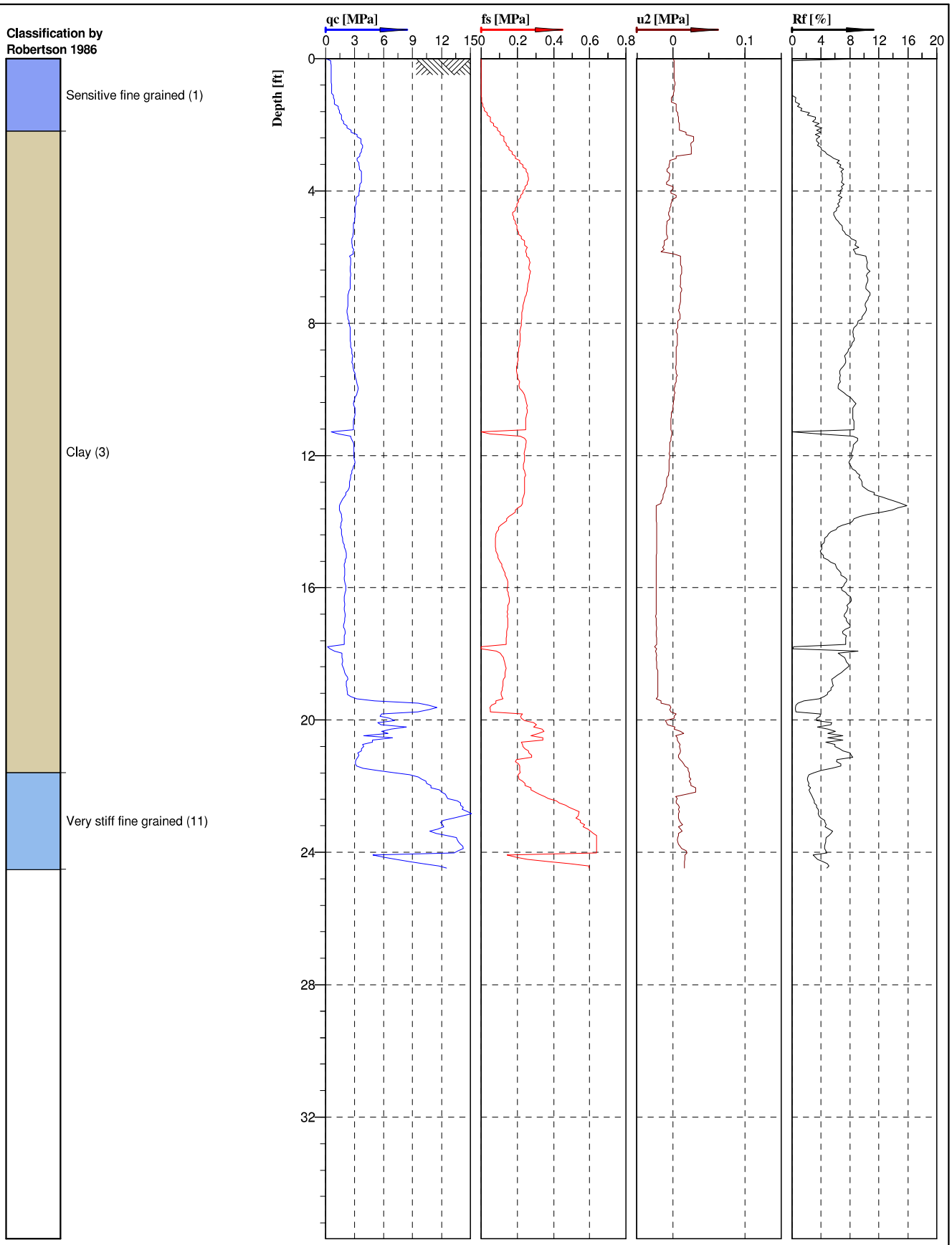
Engineering Consultants

U2

Cone No: 3561
Tip area [cm2]: 10
Sleeve area [cm2]: 150

Location: ESI-1, East Slope	Position:	Ground level: 4405.2	Test no: 1
Project ID: 04-167-002	Client: DNRS - CARDD	Date: 8/17/2006	Scale: 1 : 25
Project: Hall Coulee Siphon Crossing		Page: 1/1	Fig: 6
		File: 04-167-e1.CPT	



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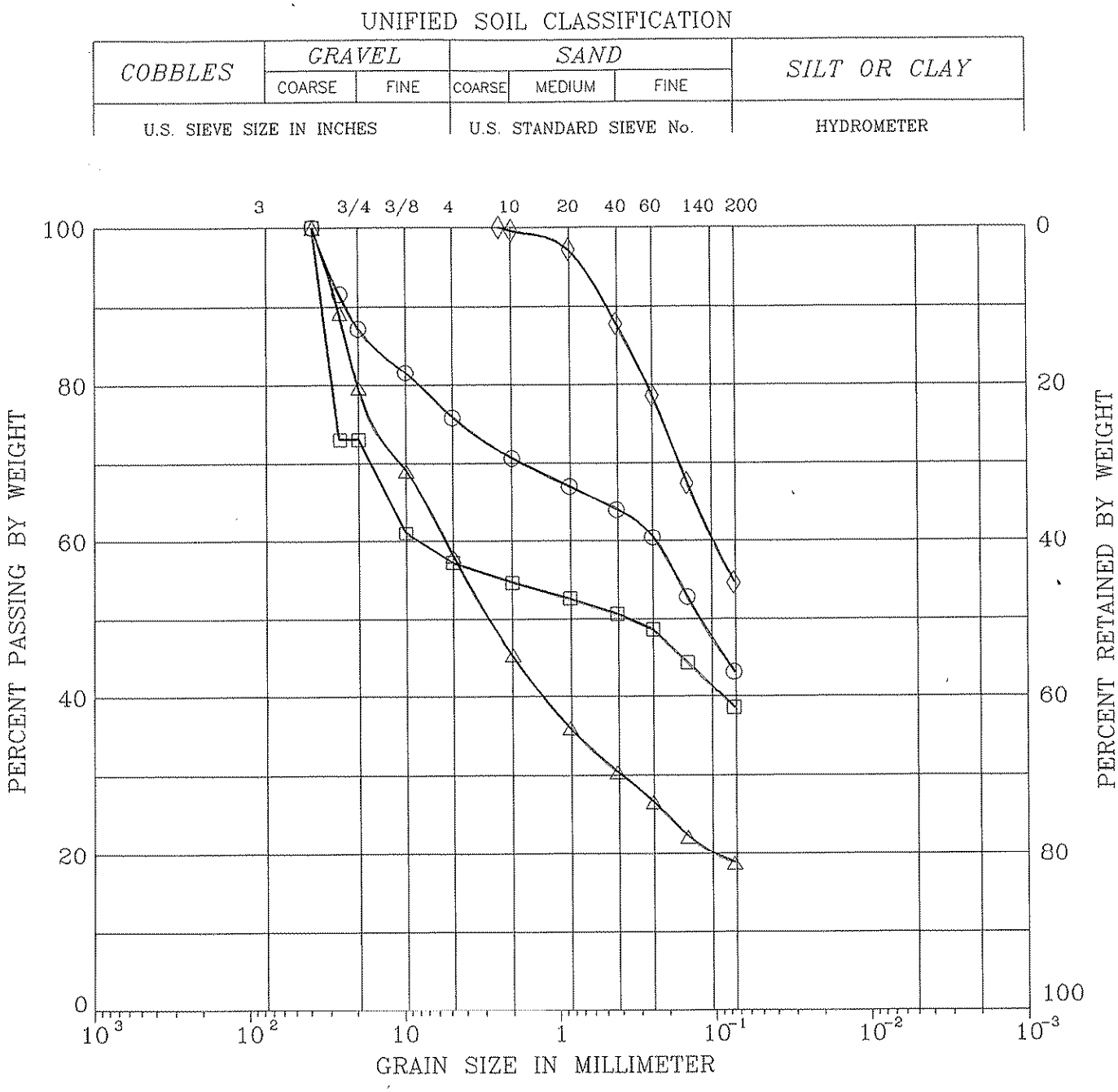
U2

Cone No: 3561
Tip area [cm2]: 10
Sleeve area [cm2]: 150

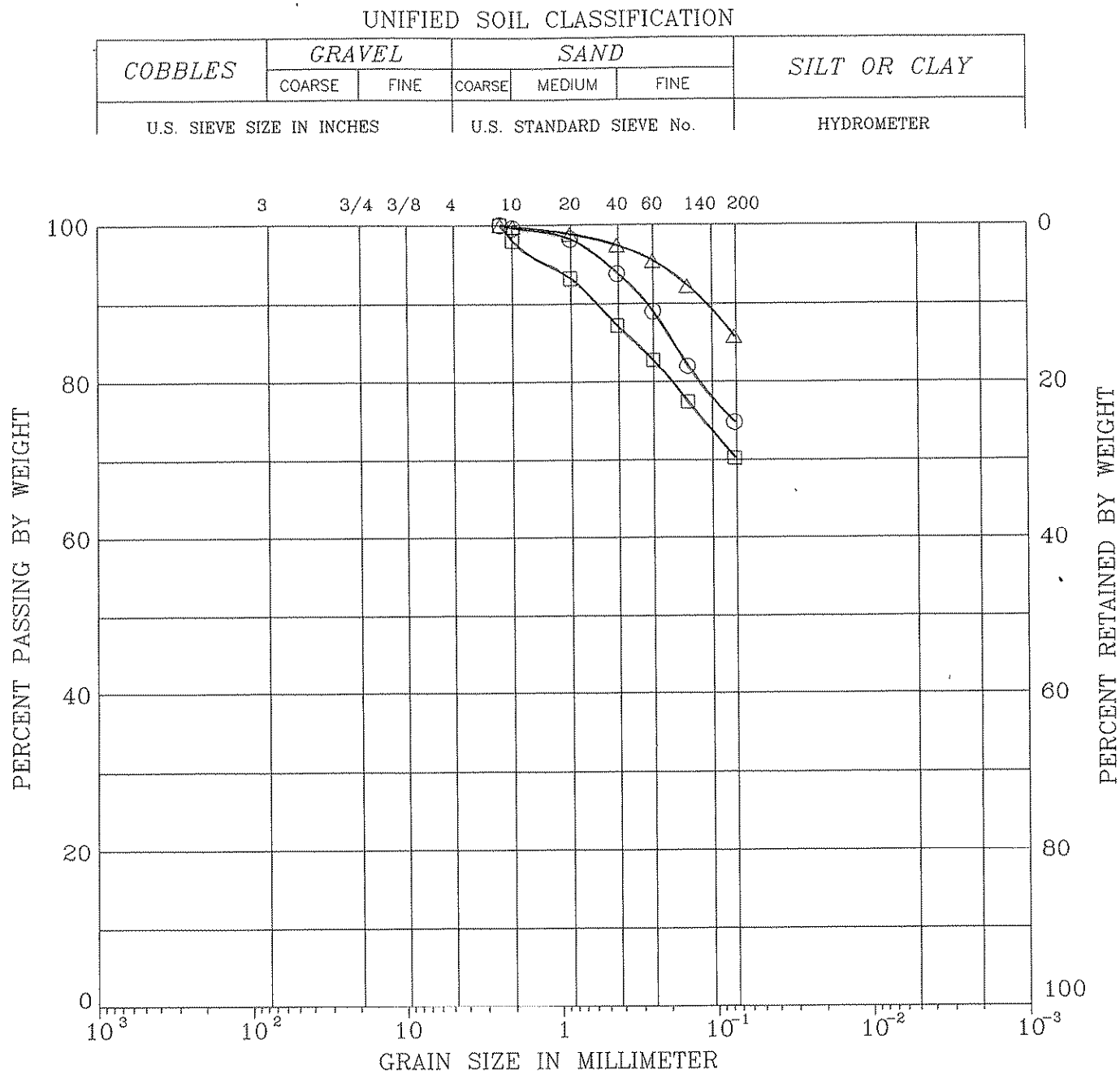
Location: WSI-2, West Slope	Position:	Ground level: 4375.8	Test no: 1
Project ID: 04-167-002	Client: DNRC - CARDD	Date: 8/18/2006	Scale: 1 : 50
Project: Hall Coulee Siphon Crossing		Page: 1/1	Fig: 7
		File: 04-167-wsi2.CPT	



SYMBOL	BORING	DEPTH (ft)	LL (%)	PI (%)	DESCRIPTION
○	ESI-1,S1	2.5-4.0	24	6	Silty, clayey SAND with Gravel (SC-SM)
□	ESI1,S2b	5.8-6.5	22	7	Silty, clayey GRAVEL with Sand (GC-GM)
△	ESI-1,S6	15-16.5	27	12	Clayey GRAVEL with Sand (GC)
◇	ESI-2,S2	5.0-6.5	48	26	Sandy LEAN CLAY (CL)

Remark : Hall Coulee Siphon Crossing

Project No. 04-167	St. Mary Diversion and Conveyance Facilities
THOMAS, DEAN & HOSKINS Engineering Consultants	GRAIN SIZE DISTRIBUTION Figure No. 8



SYMBOL	BORING	DEPTH (ft.)	LL (%)	PI (%)	DESCRIPTION
○	WSI-2,S2	5.0-6.5	47	28	LEAN CLAY with Sand (CL)
□	WSI-2,S4	10-11.5	43	22	LEAN CLAY with Sand (CL)
△	WSI-2,S7	17.5-19	51	28	FAT CLAY (CH)

Remark : Hall Coulee Siphon Crossing

Project No. 04-167	St. Mary Diversion and Conveyance Facilities
THOMAS, DEAN & HOSKINS Engineering Consultants	GRAIN SIZE DISTRIBUTION Figure No. 9

THOMAS, DEAN & HOSKINS
Engineering Consultants
Great Falls, Kalispell, Bozeman, Montana
Spokane, Washington, Lewiston, Idaho

SOIL CLASSIFICATION AND SAMPLING TERMINOLOGY FOR ENGINEERING PURPOSES

STANDARD PENETRATION TEST (ASTM D1586)

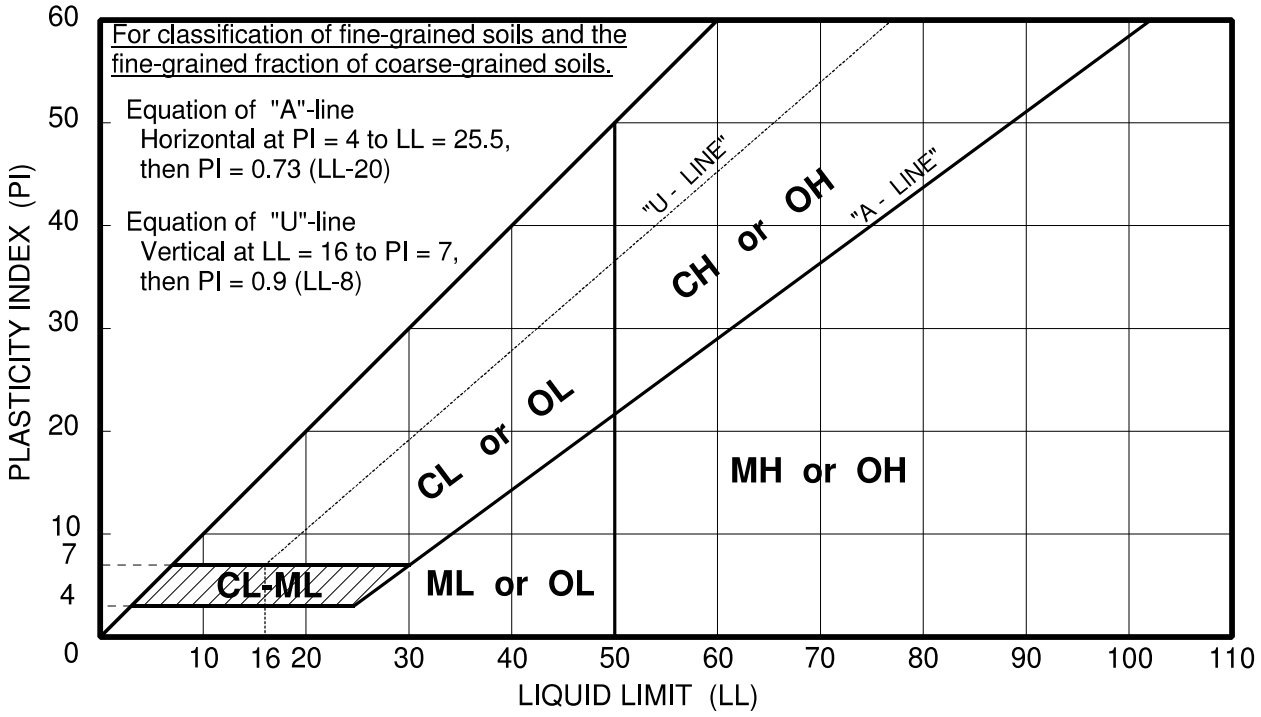
RELATIVE DENSITY*		RELATIVE CONSISTENCY*	
Granular, Noncohesive (Gravels, Sands, & Silts)	Standard Penetration Test (blows/foot)	Fine-Grained, Cohesive (Clays)	Standard Penetration Test (blows/foot)
Very Loose	0-4	Very Soft	0-2
Loose	5-10	Soft	3-4
Medium Dense	11-30	Firm	5-8
Dense	31-50	Stiff	9-15
Very Dense	+50	Very Stiff	15-30
		Hard	+30

*** Based on Sampler-Hammer Ratio of 8.929 E-06 ft/lbf and 4.185 E-05 ft^2/lbf for granular and cohesive soils, respectively (Terzaghi)**

PARTICLE SIZE RANGE

Sieve Openings (Inches)				Standard Sieve Sizes					
12"		3"	3/4"	No.4	No.10	No.40	No.200	<No.200	
BOULDERS	COBBLES	GRAVELS		SANDS			SILTS & CLAYS		
		Coarse	Fine	Coarse	Medium	Fine	(Distinguished By Atterberg Limits)		

PLASTICITY CHART



GW - Well-graded GRAVEL
GP - Poorly-graded GRAVEL
GM - Silty GRAVEL
GC - Clayey GRAVEL

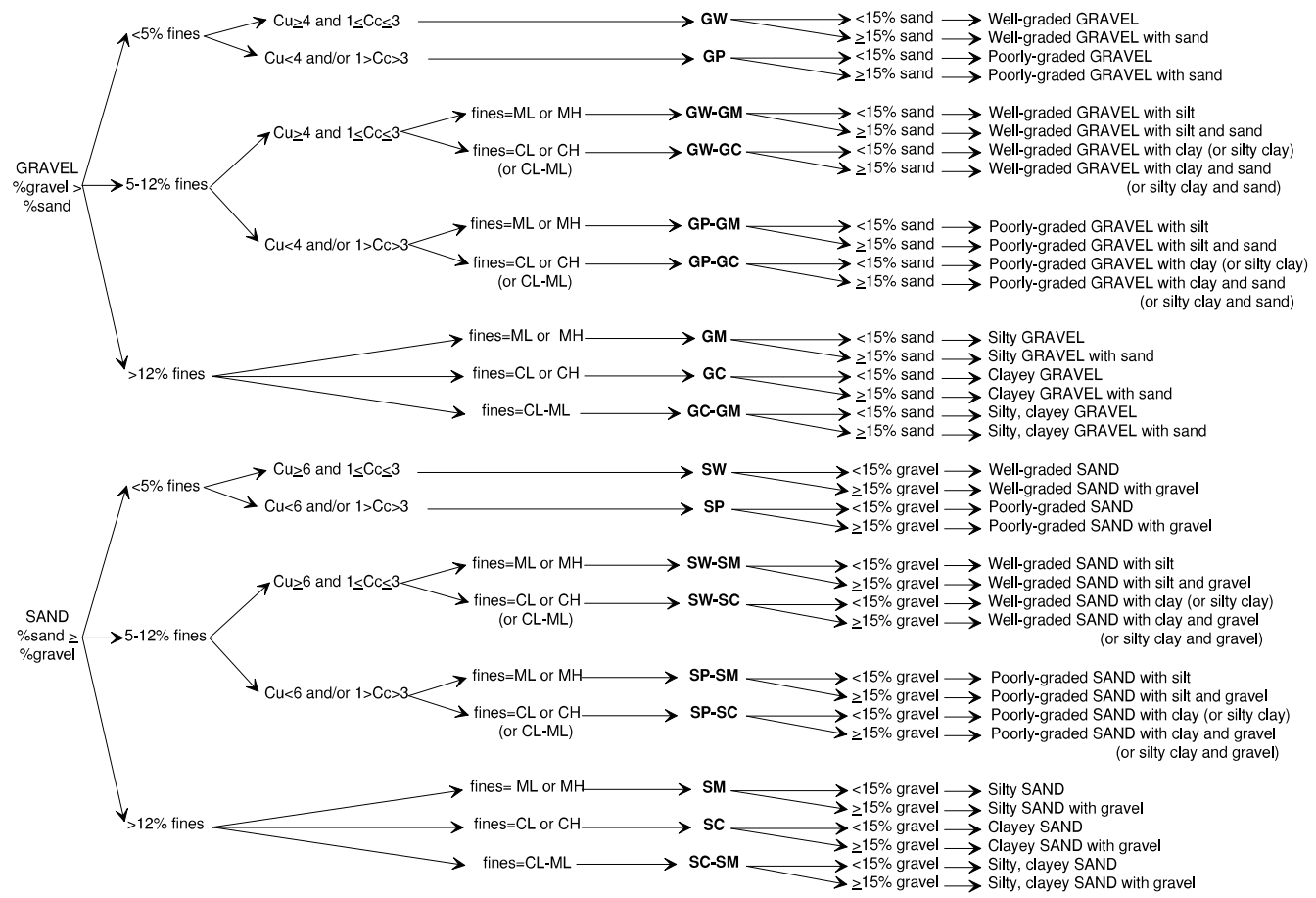
SW - Well-graded SAND
SP - Poorly-graded SAND
SM - Silty SAND
SC - Clayey SAND

CL - Lean CLAY
ML - SILT
OL - Organic SILT/CLAY
CH - Fat CLAY
MH - Elastic SILT
OH - Organic SILT/CLAY

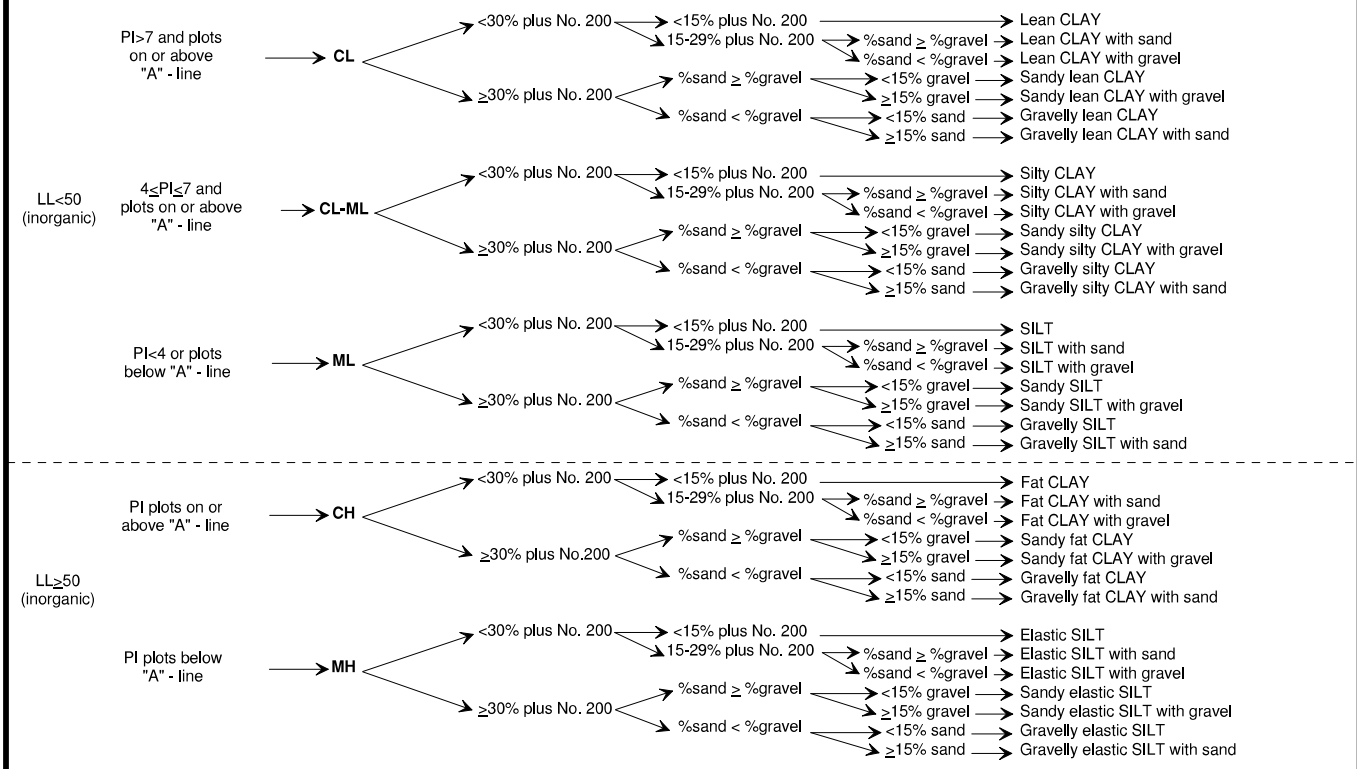
03/01

THOMAS, DEAN & HOSKINS
Engineering Consultants
Great Falls, Kalispell, Bozeman, Montana
Spokane, Washington, Lewiston, Idaho

ASTM D2487 CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES

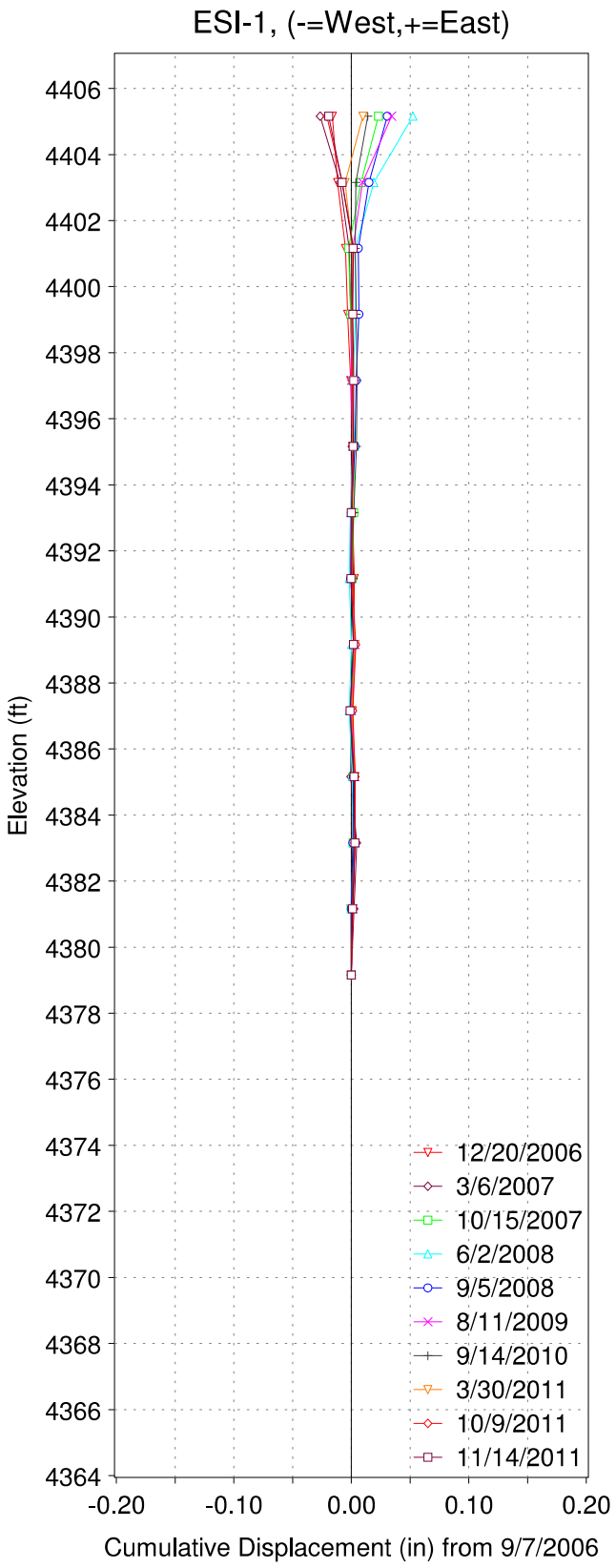


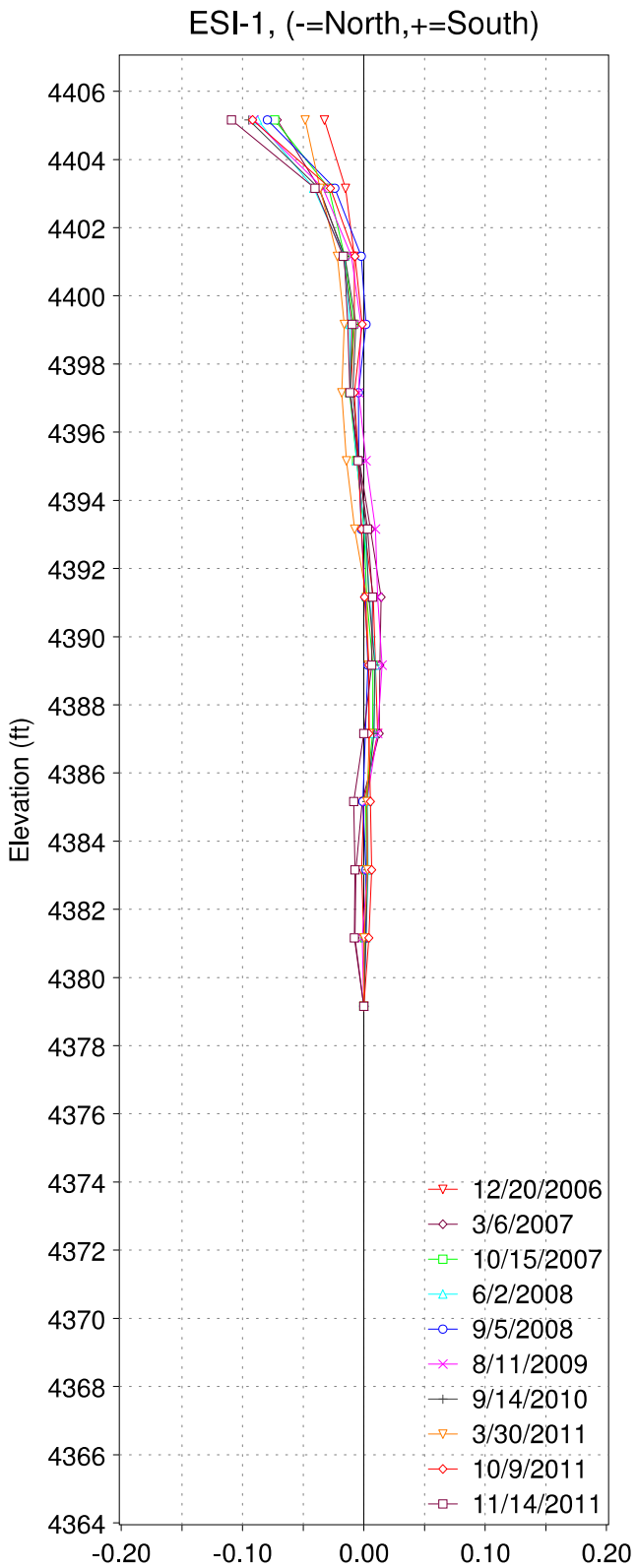
Flow Chart For Classifying Coarse-Grained Soils (More Than 50 % Retained On The No. 200 Sieve)



Flow Chart For Classifying Fine-Grained Soils (50 % Or More Passes The No. 200 Sieve)

03/98





Thomas, Dean & Hoskins, Inc.
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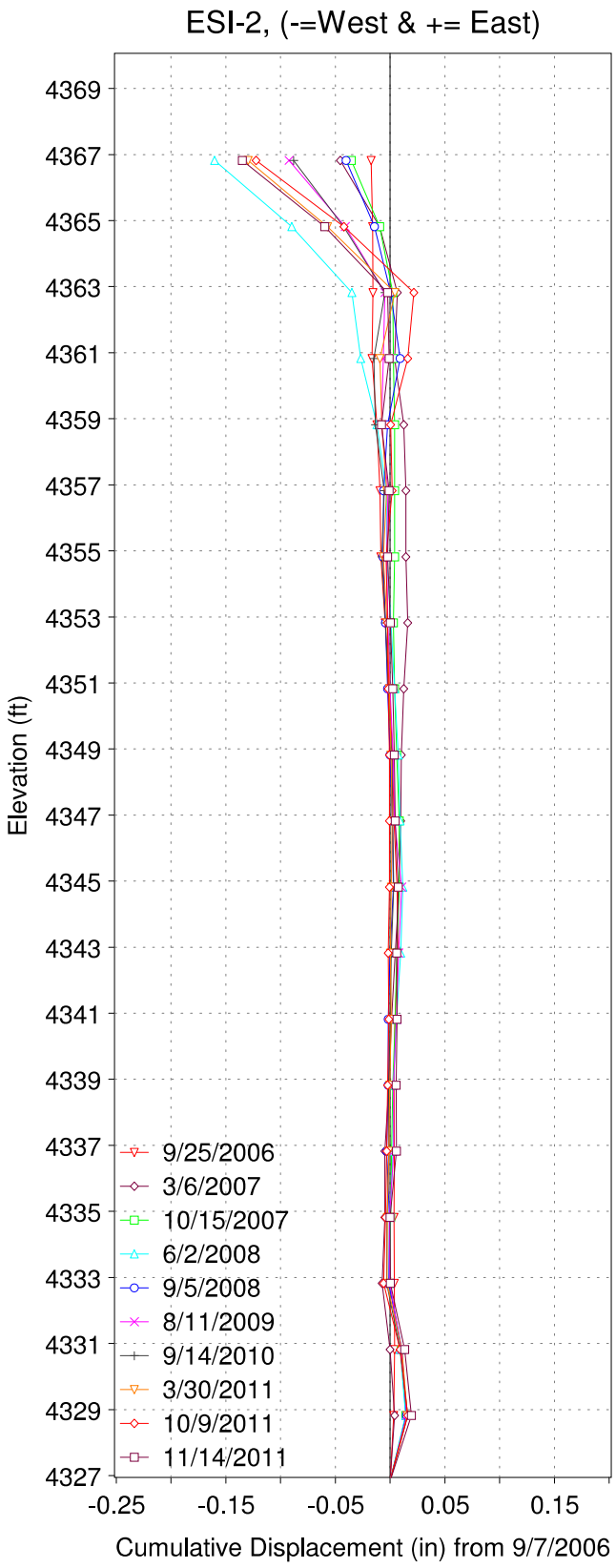
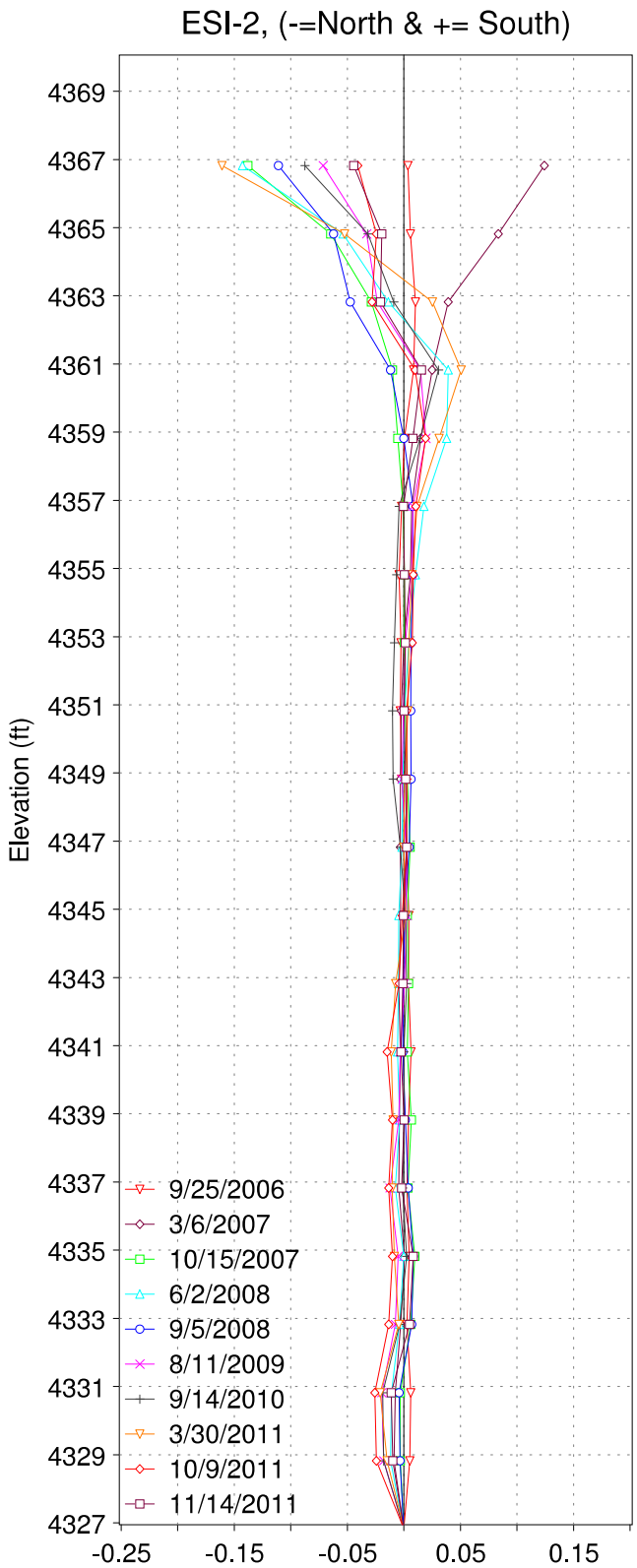
Engineering Consultants

St. Mary River Diversion & Conveyance Facilities, Near Babb, MT
Hall Coulee Siphon Crossing, East Slope

Ground Elevation: 4405.2

Figure 10





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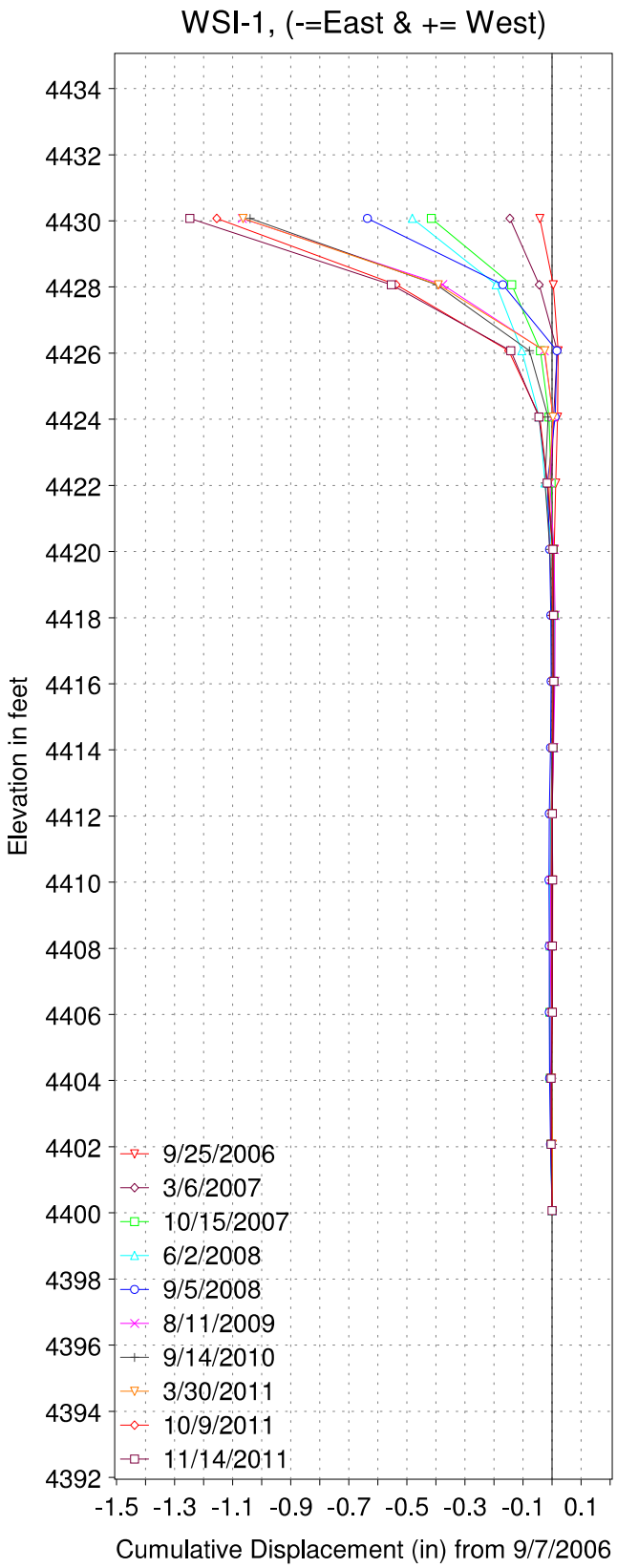
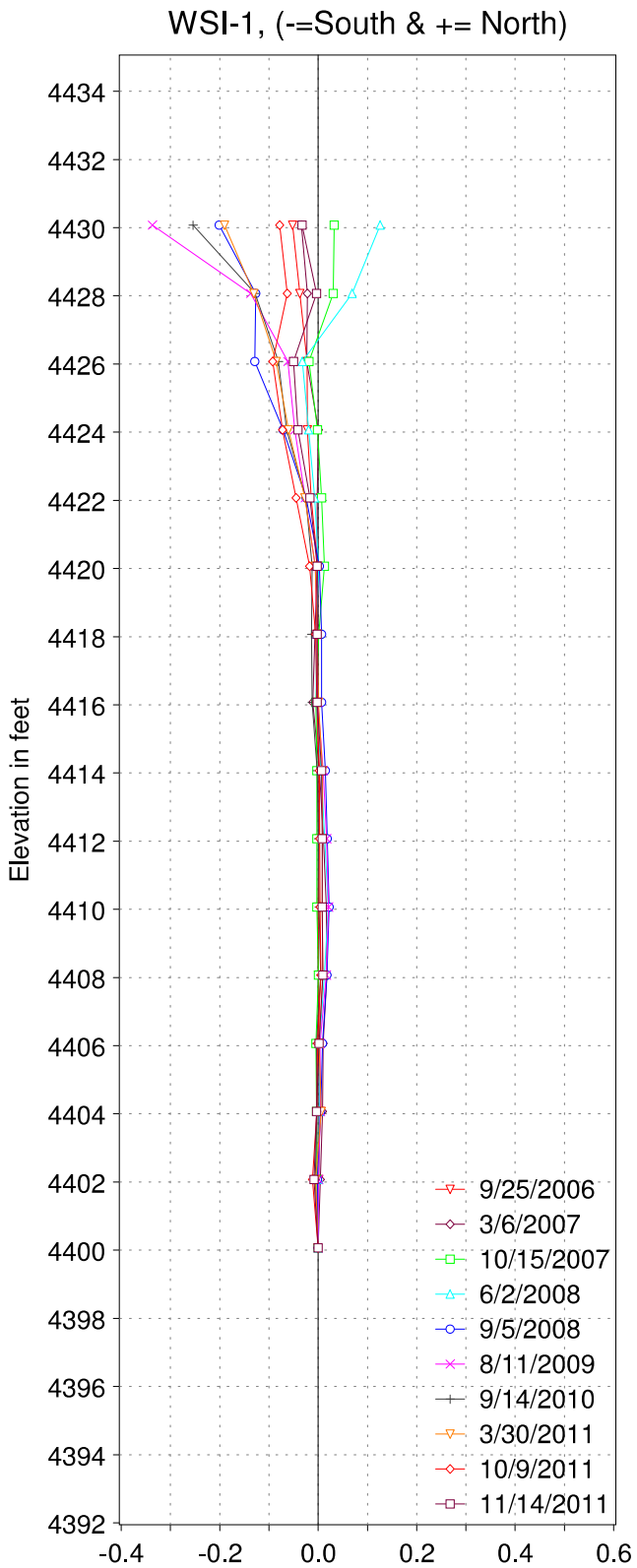
St. Mary River Diversion & Conveyance Facilities, Near Babb, MT
Hall Coulee Siphon Crossing, East Slope

Ground Elevation: 4364.8

Figure 11





Thomas, Dean & Hoskins, Inc.
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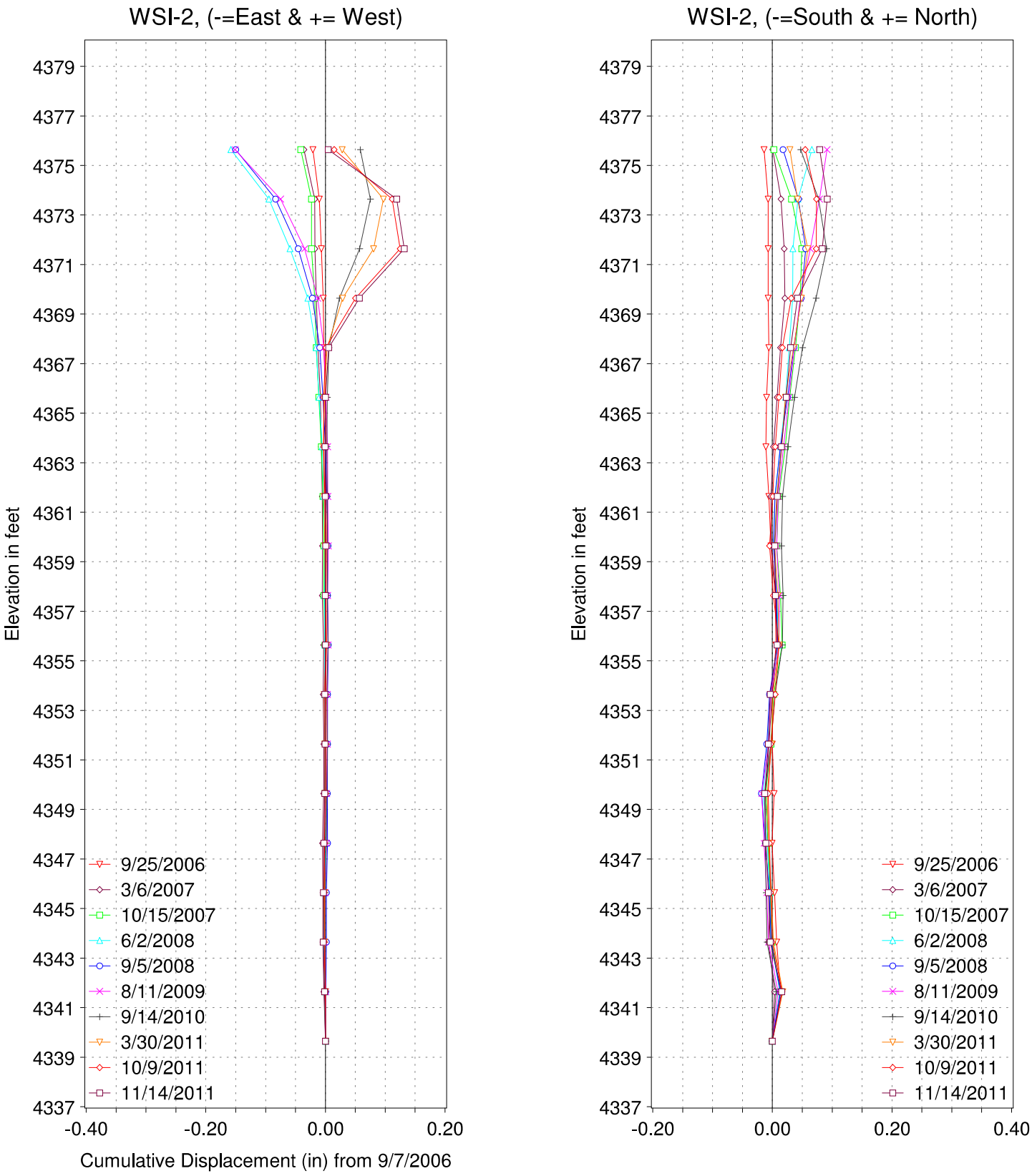
St. Mary River Diversion & Conveyance Facilities, Near Babb, MT
Hall Coulee Siphon Crossing, West Slope

Ground Elevation: 4428.8

Figure 12



Thomas, Dean & Hoskins, Inc.
TD&H
Engineering Consultants

St. Mary River Diversion & Conveyance Facilities, Near Babb, MT
Hall Coulee Siphon Crossing, West Slope

Ground Elevation: 4375.8

Figure 13

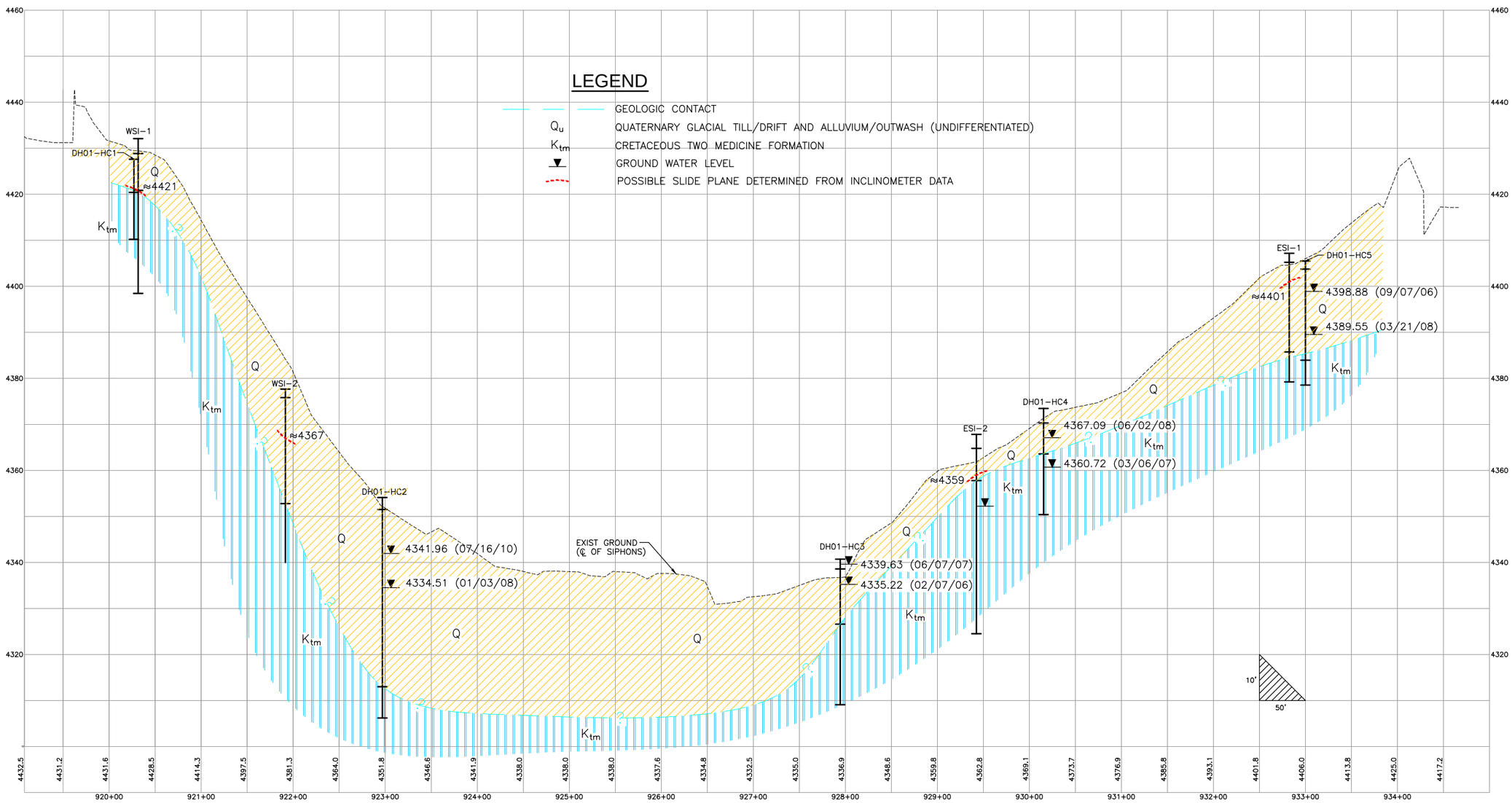


FIGURE 14

REVISIONS

BY	DATE	DESCR
BY	DATE	DESCR
BY	DATE	DESCR

THOMAS, DEAN & HOSKINS, INC.
ENGINEERING CONSULTANTS
GREAT FALLS–BOZEMAN–KALISPELL–HELENA
SPOKANE–LEWISTON
MONTANA
WASHINGTON
IDAHO

TD&H

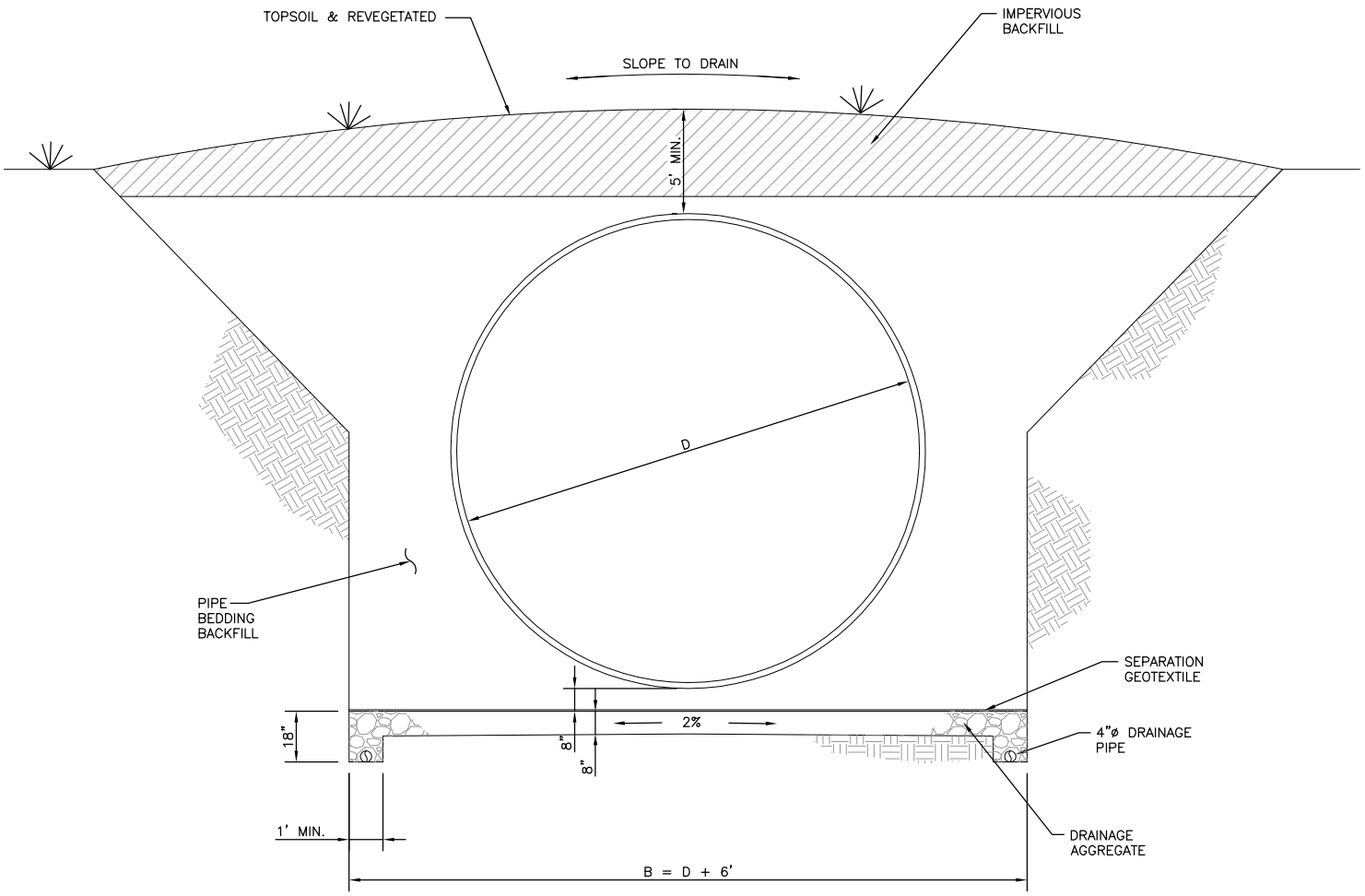
DRAWN BY:	MWC
DESIGNED BY:	EAJ
QUALITY CHECK:	
DATE:	04.02.07
JOB NO.	04-167
FIELDBOOK	

DNRC - CARDD
ST. MARY CANAL REHABILITATION

ST. MARY DIVERSION FACILITIES GEOTECHNICAL STUDIES
HALL COULEE SIPHON CROSSING
GEOLOGIC CROSS SECTION

CAD NO.04167-HC-FIG14.DWG

SHEET 1 OF 1



NO SCALE

NOTES

1. DRAIN PIPE SHALL CONSIST OF A MINIMUM 4–INCH DIAMETER, GEOTEXTILE–WRAPPED, FLEXIBLE, SLOTTED PIPE, ADVANCED DRAINAGE SYSTEMS (ADS) WITH DRAIN GUARD OR APPROVED EQUIVALENT.
2. SEPARATION GEOTEXTILE SHALL BE GEOTEX 401, MIRAFI 140NC, DALCO 1040 OR APPROVED EQUIVALENT.
3. DRAINAGE AGGREGATE SHALL BE WASHED OR SCREENED GRAVEL CONFORMING TO THE FOLLOWING GRADATION:

SIEVE SIZE	PERCENT PASSING
1½–INCH	100
¾–INCH	75 – 95
⅜–INCH	10 – 20
NO. 4	0 – 5

4. DRAINS SHALL HAVE A POSITIVE SLOPE.

ST. MARY DIVERSION FACILITIES
HALL COULEE SIPHON CROSSING

BURIED SIPHON
CONCEPTUAL DETAIL

TD&H

THOMAS, DEAN & HOSKINS, INC.
ENGINEERING CONSULTANTS
GREAT FALLS–BOZEMAN–KALISPELL–HELENA MONTANA
SPOKANE WASHINGTON
LEWISTON IDAHO

DRAWN BY:	RLR	DATE:	01/10/06
DESIGNED BY:	EAJ	JOB NO.	04-167
QUALITY CHECK:		CAD NO.	04167Fig15.DWG

FIGURE 15

GEOLOGIC LOG OF DRILL HOLE: DH01-HC1

FEATURE: No. Central Montana Regional Feasibility Study
LOCATION: Hall Coulee Siphon
BEGUN: 6/21/01 **FINISHED:** 6/21/01
DEPTH AND ELEV OF WATER LEVEL AND DATE MEASURED: N.R.

PROJECT: Milk River Project
COORDINATES: N 1,736,442.5 E 1,071,956.1
TOTAL DEPTH: 17.4
DEPTH TO BEDROCK: 7.2

STATE: Montana
GROUND ELEVATION: 4427.5
ANGLE FROM HORIZONTAL: -90 **AZIMUTH:** 0
HOLE LOGGED BY: C. Clark
REVIEWED BY: L. Crutchfield

NOTES

NOTES: All measurements are given in feet and taken from the ground surface unless otherwise noted.
N.M. = Not Measured
N.R. = Not Reached

LOCATION: Approximately 30' North of the siphon's west end, and approximately 10' below the top of siphon. Hall Coulee Siphon, Montana. Near station 918+98.

PURPOSE OF THE HOLE: Investigate the foundation conditions for a proposed siphon replacement across Hall Coulee, St. Mary Canal.

DRILLING EQUIPMENT: Truck mounted CME-85 drill, 4-1/4" Hollow Stem Augers with split sample barrel; CME automatic hammer with 2' long Standard Penetration Test (SPT) barrel on NWJ rods.

DRILLING METHODS: HSA with split sample barrel from 0.0' to 4.9' and cleanout intervals; continuous SPT's at 2.5' intervals from 4.9' to 17.4'.

DRILLER: Mike Kocian -USBR

WATER LEVEL: N.R.

HOLE COMPLETION: Hole was backfilled with cuttings from 17.4' to 2.0'; placed 3/8" bentonite chips from 2.0' to 0.0'. Hole marked with T-post.

DEPTH	FLD. CLASS/LITH.	% CORE RECOVERY	GEOL. UNIT SYM.	SPT (BLOWS/FT) 0–50
	SC	29	Qow	
5		73		30
		100		
	mdst	67	Ktm	44
		100		
10		53		50 / 50
		100		
		92		50 / 50
		100		
15		87		50 / 50
		100		

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

0.0' to 7.2' - QUATERNARY GLACIAL OUTWASH (Qowl):

0.0' to 7.2' - CLAYEY SAND (SC): About 80% fine to medium sand; about 20% medium plasticity fines; maximum size recovered, medium sand; medium to dark brown; medium toughness; dry; roots throughout interval; weak reaction with HCl.

0.6' to 1.2' - LEAN CLAY WITH SAND (CL): About 80% low to medium plasticity fines; about 10% fine sand; about 10% fine to coarse, hard, rounded to subrounded gravel; maximum size recovered, 2"; tough; dark brown; weak reaction with HCl.

7.2' to 17.4' CRETACEOUS TWO MEDICINE FORMATION (Ktm):

7.2' to 17.4' Mudstone: Dark gray to black; very intensly weathered to decomposed; soft; very intensely fractured; oxidized sand seams throughout; weak to no reaction with HCl.

12.8' to 13.2' - white to tan orange bentonitic clay interbed.

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE: DH01-HC2

FEATURE: No. Central Montana Regional Feasibility Study
PROJECT: Milk River Project
STATE: Montana
LOCATION: Hall Coulee Siphon
COORDINATES: N 1,736,319.2 E 1,072,195.8
GROUND ELEVATION: 4354.3
BEGUN: 6/21/01 FINISHED: 6/22/01
TOTAL DEPTH: 45.3
ANGLE FROM HORIZONTAL: -90 AZIMUTH: 0
DEPTH AND ELEV OF WATER LEVEL AND DATE MEASURED: -13.2 (4341.10) 06/22/2001
DEPTH TO BEDROCK: 38.5
HOLE LOGGED BY: C. Clark
REVIEWED BY: L. Crutchfield

NOTES

NOTES: All measurements are given in feet and taken from the ground surface unless otherwise noted.
N.M. = Not Measured
N.R. = Not Reached

LOCATION: Approximately 30' North of Hall Coulee Siphon, and approximately 105' West of the bottom of the hill along St. Mary Canal, Montana. Near station 926+50.

PURPOSE OF HOLE: Investigate the foundation condtions for a proposed siphon replacement across Hall Coulee on St. Mary Canal.

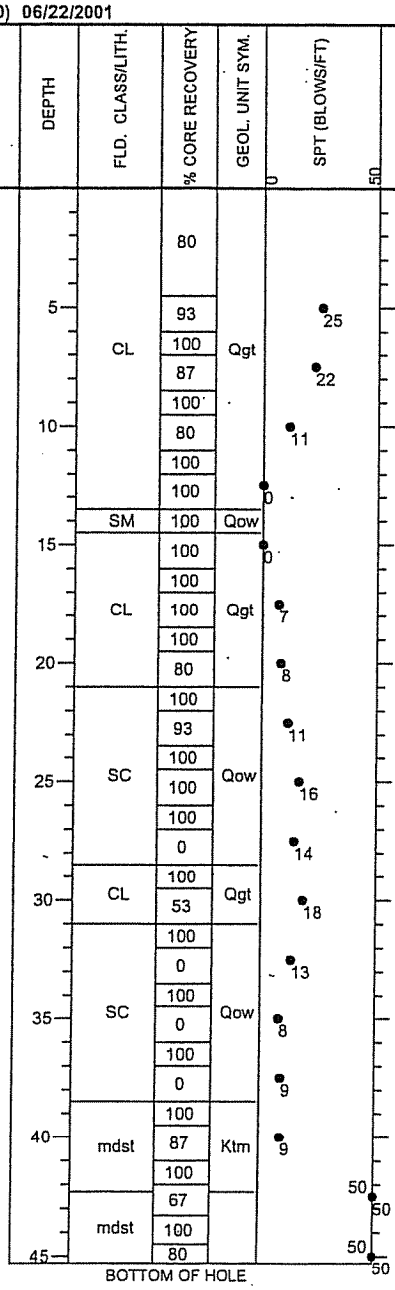
DRILLING EQUIPMENT: Truck mounted CME-85 drill; 4-1/4" Hollow Stem Augers (HSA) with split sample barrel; CME automatic hammer with 2' long Standard Penetration Test (SPT) barrel on NWJ rods.

DRILLING METHODS: HSA with split sample barrel from 0.0' to 4.5' and cleanout intervals; continuous SPT's at 2.5' intervals from 4.5' to 45.3'.

DRILLER: Mike Kocian - USBR

WATER LEVEL: 13.2' on 6/22/01

HOLE COMPLETION: Hole caved from 45.3' to 42.3'; set porous tube piezometer from 39.8' to 37.8' with 1.0" PVC riser pipe to 2.7' above ground surface; placed 8/12 graded sand from 42.3' to 30.2'; placed 3/8" bentonite chip hole plug from 30.2' to 2.0'; set 5' long 4" steel protective standpipe with locking cap to 3.0' above ground surface in neat cement grout.



CLASSIFICATION AND PHYSICAL CONDITION

0.0' to 13.5' - QUATERNARY GLACIAL TILL (Qgt):

0.0' to 13.5' - LEAN CLAY WITH SAND (CL): About 85% low to medium plasticity fines; about 15% fine sand; trace of gravel; maximum size recovered 1"; dark brown, grades to brown; moist to wet at 13.2'; roots from 0.0' to 0.4'; weak reaction with HCl grading to strong reaction with HCl at 13.5'.

13.5' TO 14.5' - QUATERNARY GLACIAL OUTWASH (Qow):

13.5' to 14.5' - SILTY SAND (SM): About 75% fine, subrounded sand; about 25% nonplastic fines; maximum size recovered, fine sand; dark brown, wet, very soft; strong reaction with HCl.

14.5 to 21.0' - QUATERNARY GLACIAL TILL (Qgt):

14.5' to 21.0' - SANDY LEAN CLAY (CL): About 65 to 70% low to medium plasticity fines; about 30 to 35% fine subangular and subrounded sand; trace of gravel maximum size recovered 1-1/2"; brown, wet, soft; strong reaction with HCl.

21.0' to 28.5' - QUATERNARY GLACIAL OUTWASH (Qow):

21.0' to 28.5' - CLAYEY SAND WITH GRAVEL (SC): About 45 to 55% fine to coarse sand, predominately fine sand; about 35% medium to high plasticity fines; about 10 to 20% fine to coarse, hard gravel; maximum size recovered 3"; brown, soft, wet, weak reaction with HCl.

28.5' to 31.0' - QUATERNARY GLACIAL TILL (Qgt):

28.5' to 31.0' - SANDY LEAN CLAY (CL): About 70% medium to high plasticity fines; about 25% fine to medium sand; about 5% fine to coarse, subangular, hard gravel; maximum size recovered, 1"; brown, medium to high toughness, wet; no reaction with HCl.

COMMENTS:

Continued next page

GEOLOGIC LOG OF DRILL HOLE: DH01-HC2

FEATURE: No. Central Montana Regional Feasibility Study
PROJECT: Milk River Project
STATE: Montana
LOCATION: Hall Coulee Siphon
COORDINATES: N 1,736,319.2 E 1,072,195.8
GROUND ELEVATION: 4354.3
BEGUN: 6/21/01 FINISHED: 6/22/01
TOTAL DEPTH: 45.3
ANGLE FROM HORIZONTAL: -90 AZIMUTH: 0
DEPTH AND ELEV. OF WATER
DEPTH TO BEDROCK: 38.5
HOLE LOGGED BY: C. Clark
LEVEL AND DATE MEASURED: -13.2 (4341.10) 06/22/2001
REVIEWED BY: L. Crutchfield

NOTES	DEPTH	FLD. CLASS/LITH.	% CORE RECOVERY	GEOL. UNIT SYM.	SPT (BLOWS/FT) 0 50	CLASSIFICATION AND PHYSICAL CONDITION
						31.0' to 38.5' - QUATERNARY GLACIAL OUTWASH (Qow):
						31.0 to 38.5' - CLAYEY SAND (SC): About 55 to 60% fine to coarse, subangular sand; about 40% high plasticity fines; trace to 5% fine to coarse, hard gravel; maximum size recovered, 3"; brown to gray, medium toughness, wet; no reaction with HCl.
						38.5' to 45.3' - CRETACEOUS TWO MEDICINE FORMATION (Ktm):
						38.5' to 42.3' - Mudstone: gray to dark gray; soft; wet. Mudstone is decomposed, if logged as soil: About 70 to 75% fine to coarse, soft, subangular sand; about 20% medium to high plasticity fines; about 5 to 10% soft gravel; maximum size recovered, 2.0".
						42.3' to 45.3' - Mudstone: dark gray; soft; wet; Intensly to very intensly weathered, structure not discernible; no reaction with HCl.

GEOLOGIC LOG OF DRILL HOLE: DH01-HC3

FEATURE: No. Central Montana Regional Feasibility Study
LOCATION: Hall Coulee Siphon
BEGUN: 6/23/01 FINISHED: 6/23/01
DEPTH AND ELEV OF WATER LEVEL AND DATE MEASURED: N.R.

PROJECT: Milk River Project
COORDINATES: N 1,736,110.3 E 1,072,648.4
TOTAL DEPTH: 29.5
DEPTH TO BEDROCK: 12.0

STATE: Montana
GROUND ELEVATION: 4340.2
ANGLE FROM HORIZONTAL: -90 AZIMUTH: 0
HOLE LOGGED BY: C. Clark
REVIEWED BY: L. Crutchfield

NOTES

NOTES: All measurements are given in feet and taken from the ground surface unless otherwise noted.
N.M. = Not Measured
N.R. = Not Reached

LOCATION: Approximately 40' North of siphon near bottom of canyon, and approximately 100' East of creek. Hall Coulee on St. Mary Canal, Montana. Near 920+80.

PURPOSE OF HOLE: Investigate the foundation conditions for a proposed siphon replacement across Hall Coulee, St. Mary Canal.

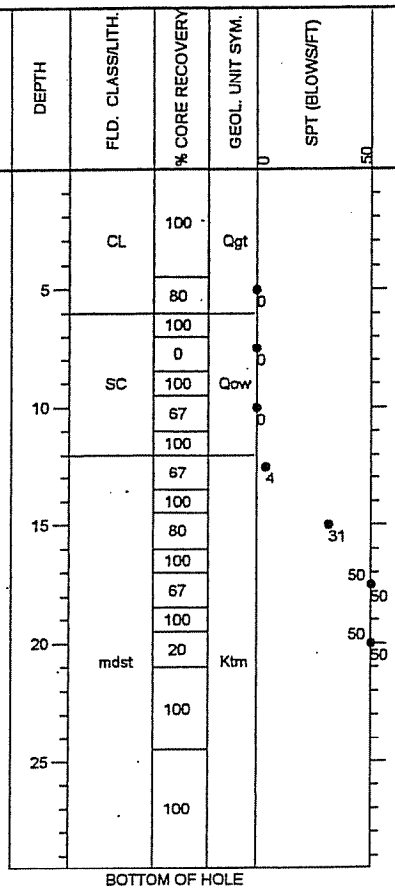
DRILLING EQUIPMENT: Truck mounted CME-85 drill; 4-1/4" Hollow Stem Augers (HSA) with split sample barrel; CME automatic hammer with 2.0' long Standard Penetration Test (SPT) barrel on NWJ rods.

DRILLING METHODS: HSA with split sample barrel from 0.0' to 4.5' and cleanout intervals, continuous SPT's at 2.5' intervals from 4.5' to 29.5'.

DRILLER: Mike Kocian - USBR

WATER LEVEL: N.R.

HOLE COMPLETION: Placed 3/8" bentonite chip hole plug from 29.5' to 20.5'; set porous tube piezometer from 19.5' to 17.5' with 1.0" PVC riser pipe to 2.5' above ground surface; placed 8/12 graded sand from 20.5' to 9.5'; placed 3/8" bentonite chip hole plug from 9.5' to 1.5'; set 5.0' long 4.0" steel protective standpipe with locking cap from 2.0' to 3.0' above ground surface in neat cement grout.



CLASSIFICATION AND PHYSICAL CONDITION

0.0' to 6.0' - QUATERNARY GLACIAL TILL (Qgt):

0.0' to 6.0' - LEAN CLAY WITH SAND (CL): About 75% low to medium plasticity fines; about 25% fine to coarse sand; trace of fine to coarse gravel; trace of cobbles; maximum size recovered, 3-1/2"; medium brown; soft; very moist to wet; weak reaction with HCl.

6.0' to 12.0' - QUATERNARY GLACIAL OUTWASH (Qow):

6.0' to 7.0' - CLAYEY SAND (SC): About 65% fine to coarse sand; about 35% low plasticity fines; trace of fine to coarse, hard gravel; maximum size recovered, 3"; light brown; wet; very soft; weak reaction with HCl.

7.0' to 12.0' - CLAYEY SAND (SC): About 80 to 85% fine to coarse, predominately fine, sand; about 15 to 20% medium plasticity fines; maximum size recovered, coarse sand; light brown to gray; soft; wet; weak to no reaction with HCl.

12.0' to 29.5' - CRETACEOUS TWO MEDICINE FORMATION (Ktm):

12.0' to 29.5' - Mudstone: Gray to dark gray; very intensly weathered to decomposed, bedding not discernible; soft; moist; very intensely fractured, joints dipping at 50 degrees and 30 degrees; weak reaction with HCl.

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE: DH01-HC4

FEATURE: No. Central Montana Regional Feasibility Study
LOCATION: Hall Coulee Siphon
BEGUN: 6/23/01 FINISHED: 6/23/01
DEPTH AND ELEV OF WATER LEVEL AND DATE MEASURED: N.R.

PROJECT: Milk River Project
COORDINATES: N 1,736,000.2 E 1,072,840.2
TOTAL DEPTH: 19.9
DEPTH TO BEDROCK: 6.7

STATE: Montana
GROUND ELEVATION: 4373.4
ANGLE FROM HORIZONTAL: -90 AZIMUTH: 0
HOLE LOGGED BY: C. Clark
REVIEWED BY: L. Crutchfield

NOTES

NOTES: All measurements are given in feet and taken from the ground surface unless otherwise noted.
N.M. = Not Measured
N.R. = Not Reached

LOCATION: About halfway up the east side of Hall Coulee Siphon, St. Mary Canal, Montana. Near station 925+68.

PURPOSE OF HOLE: Investigate the foundation conditions for a proposed siphon replacement across Hall Coulee, St. Mary Canal.

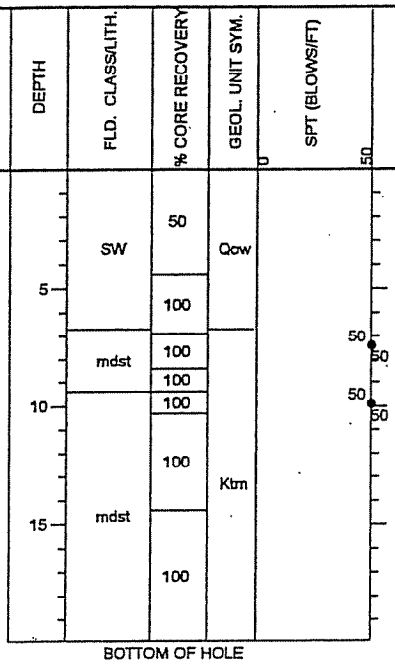
DRILLING EQUIPMENT: Truck mounted CME-85 drill; 4-1/4" Hollow Stem Augers (HSA) with split sample barrel; CME automatic hammer with 2' long Standard Penetration Test (SPT) barrel on NWJ rods.

DRILLING METHOD: HSA with split sample barrel from 0.0' to 4.4' and cleanout intervals; continuous SPT's at 2.5' intervals from 4.4' to 19.9'.

DRILLER: Mike Kocian - USBR

WATER LEVEL: N.R.

HOLE COMPLETION: Backfilled with cuttings to 15.0'; set porous tube piezometer from 15.0' to 13.0' with 1" PVC riser pipe to 3.4' above ground surface; placed 8/12 graded sand from 15.0' to 7.0'; placed 3/8" bentonite chip hole plug from 7.0' to 1.5'; set 5' long 4" steel protective standpipe with locking cap from 2.0' to 3.0' above ground surface in neat cement grout.



CLASSIFICATION AND PHYSICAL CONDITION

0.0' to 6.7' - QUATERNARY GLACIAL OUTWASH (Qow):

0.0' to 6.7' - WELL GRADED SAND WITH GRAVEL (SW): About 55% fine to coarse, angular to subrounded sand; about 40% fine to coarse, hard, subangulargravel; about 5% nonplastic fines; trace of cobbles; max size recovered, 4"; light brown; moist; soft; some iron oxidation stains; strong reaction with HCl.

6.7' to 19.9' - CRETACEOUS TWO MEDICINE FORMATION (Ktm):

6.7' to 9.4' - Mudstone is decomposed. If described as soil: About 85 to 95% low to medium plasticity fines; about 5 to 15% soft, fine sand; brown to light brown; moist; soft; weak reaction with HCl.

9.4' to 19.9' - Mudstone: Gray to dark gray; intensely to very intensely weathered; intensely fractured; soft; moist, wet in joints; oxidized; slickenslided joints at about 30 degrees; weak to no reaction with HCl.

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE: DH01-HC5

FEATURE: No. Central Montana Regional Feasibility Study
LOCATION: Hall Coulee Siphon
BEGUN: 6/24/01 **FINISHED:** 6/24/01
DEPTH AND ELEV OF WATER LEVEL AND DATE MEASURED: N.R.

PROJECT: Milk River Project
COORDINATES: N 1,735,874.8 E 1,073,095.6
TOTAL DEPTH: 25.2
DEPTH TO BEDROCK: 19.8

STATE: Montana
GROUND ELEVATION: 4405.4
ANGLE FROM HORIZONTAL: -90 **AZIMUTH:** 0
HOLE LOGGED BY: C. Clark
REVIEWED BY: L. Crutchfield

NOTES

NOTES: All measurements are given in feet and taken from the ground surface unless otherwise noted.
N.M. = Not Measured
N.R. = Not Reached

LOCATION: 60' West of east end of siphon and 40' North of siphon. Hall Coulee Siphon, St. Mary Canal, Montana. Near station 933+40.

PURPOSE OF HOLE: Investigate the foundation conditions for a proposed siphon replacement across Hall Coulee, St. Mary Canal.

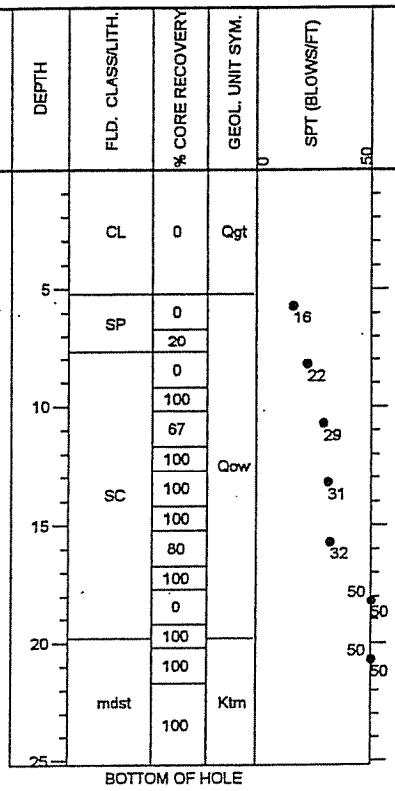
DRILLING EQUIPMENT: Truck mounted CME-85 drill; 4-1/4" Hollow Stem Augers (HSA) with split sample barrel; CME automatic hammer with 2' long Standard Penetration Test (SPT) barrel on NWJ rods.

DRILLING METHODS: HSA with split barrel sampler from 0.0' to 5.2' and cleanout intervals; continuous SPT's at 2.5' intervals from 5.2' to 25.2'.

DRILLER: Mike Kocian - USBR

WATER LEVELS: N.R.

HOLE COMPLETION: Hole caved from 25.2' to 21.4' when augers were pulled; set porous tube piezometer from 21.4' to 19.4' with 1" PVC riser pipe to 2.9' above ground surface; placed 8/12 graded sand from 21.4' to 11.0'; placed 3/8" bentonite chip hole plug from 11.0' to 4.5'; placed hole cuttings from 4.5' to 1.5'; set 5' long 4" steel protective standpipe with locking cap from 2.0' to 3.0' above ground surface in neat cement grout.



CLASSIFICATION AND PHYSICAL CONDITION

0.0' to 5.2' - QUATERNARY GLACIAL TILL (Qgt):

0.0' to 5.2' - SANDY LEAN CLAY (CL): About 60% low plasticity fines; about 30% fine to coarse sand; about 10% fine to coarse, hard, angular gravel; maximum size recovered, 1-1/2"; light brown to brown; moist; strong reaction with HCl.

5.2' to 19.8' - QUATERNARY GLACIAL OUTWASH (Qow):

5.2' to 7.7' - POORLY GRADED SAND WITH GRAVEL (SP): About 75% fine to coarse, predominately fine, sand; about 25% fine to coarse, hard, subangular to rounded gravel; trace of nonplastic fines; maximum size recovered, 2-1/2"; light brown to brown; moist; moderate reaction with HCl.

7.7' to 19.8' - CLAYEY SAND WITH GRAVEL (SC): About 65% fine to coarse sand; about 20% fine to coarse, hard, subangular gravel; about 15% medium plasticitiy fines; maximum size recovered, 3"; light brown to brown; moist; soft; weak reaction with HCl.

19.8' to 25.2' - CRETACEOUS TWO MEDICINE FORMATION (Ktm):

19.8' to 25.2' - Mudstone: Dark gray; very intensly weathered; soft; very intensely fractured; moisture and oxidation in joints and along bedding planes; weak reaction with HCl.

COMMENTS: