PIPELINE RUPTURE FREQUENCY ANALYSIS

ATTACHMENT A

GEOTECHNICAL REPORT

PIPELINE GEOHAZARD ASSESSMENT AT

SELECT PIPELINE WATERCOURSE CROSSINGS

ENBRIDGE LINE 3 REPLACEMENT PROJECT

PREPARED FOR

DYNAMIC RISK ASSESSMENT SYSTEMS INC.

REVISION 1, 12 SEP 2016

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1.0 INTRODUCTION

1.1 GENERAL

The Line 3 Replacement Project (L3R) is a pipeline project that includes construction through the State of Minnesota. The L3R Project is proposed by Enbridge Energy Limited Partnership (Enbridge). Enbridge will also operate the pipeline. KGL understands that the project is under review by the Minnesota Public Utilities Commission (Commission).

This report provides the results of a geohazard assessment and semi-quantitative susceptibility calculation carried out by Kelly Geotechnical Ltd. (KGL) at select locations along preferred and optional project route for L3R within the State of Minnesota. The report was prepared for the use of Calgary, AB, based Dynamic Risk Assessment Systems Inc. (Dynamic) by KGL to support a failure frequency estimate calculation at prescribed watercourse crossing locations. The assessment locations were selected by the Commission and KGL understands that this work may form part of a pipeline regulatory submission in the State of Minnesota.

The assessment locations were provided to KGL by Dynamic. The work was carried out according to the terms of the existing subcontractor agreement between KGL and Dynamic.

1.2 SCOPE

Figure 1 is an overview map of the L3R project route within the areas of interest to this study. The map shows that the crossing locations do not occur on a single route, and thus a single MP reference is not available. The assessment area for the purposes of geohazard assessment covers the crossing area and approach slopes only. The assessment areas typically cover up to about 1 mile on either side of the crossing location. Table 1 provides overview data for the assessment locations shown on Figure 1.

Table 1 - Assessment Area and Pipeline Overview Details

Assessment Location	Crossing Type	Preliminary Design Available	Nominal Pipe Size (NPS)	Existing Pipeline Crossing (Y/N)
			L3R	
Red River	HDD	N	36	Y
Mosquito Creek	Open Cut	Y	36	Y
Shell River	HDD	N	36	N
Mississippi River at Little Falls	HDD	N	36	Y
Mississippi River at Ball Club	HDD	N	36	Y
Mississippi River at Palisade	HDD	Y	36	N
Sandy River	HDD	Y	36	N

For the purposes of the KGL study, the scope of the geohazard assessment is specific to the case for loss of containment only.

1.3 METHODOLOGY

Geohazards are a class of threats (in this context related to a pipeline system) related to external loading in response to the occurrence of a geological process. A geohazard assessment is defined as a process where the susceptibility of an area(s) to potential geohazards is examined and rated in a systematic way. For the purposes of this report geohazards are rated in a quantitative format to express annual probability of occurrence. The reader is directed to the discussions throughout this report related to the applicability and limitations of such data.

To establish susceptibility of the pipeline system to geohazards, the study area terrain and configuration of the pipeline system is compared against a list of potential geohazards. The comparison between the terrain conditions and the geohazard list, is used to define specific threat assessment areas (hazard impact zones). The hazard impact zones are numbered uniquely, defined spatially, and are assigned factors used to calculate susceptibility. The factors represent the potential for a geohazard to occur, the frequency of occurrence, and the potential damage to the pipeline system if the geohazard occurs. An additional factor is assigned to represent any beneficial effects that the planned construction methods or materials (i.e. mitigation) used in the hazard impact zone have in reducing the potential impacts or frequency of occurrence associated with the geohazard.

The process of establishing susceptibility noted above is described in the following formula and is based on the work by Rizkalla (2008)[1]. Note that susceptibility (S) at a line segment (j) is expressed for the purposes of this study as an equivalent to annual Failure Frequency (F_f), where over line segment j, failure frequency is defined as the product of the potential for the geohazard to occur $I(_j)$, the frequency of occurrence $F(_j)$, the unmitigated system vulnerability $V(_j)$, and the effects of the mitigations used in the segment $M(_j)$. The formula described is shown below.

$S_{(j)} = F_{f(j)} = I_{(j)} \times F_{(j)} \times V_{(j)} \times M_{(j)}$, where:

F_f = failure frequency (expressed in events per year)
I = Occurrence factor ranging from 0 to 1
F = Frequency of occurrence (expressed in events per year)
V = Vulnerability factor ranging from 0 to 1
M = Mitigation factor ranging from 0 to 1

Factors related to calculating susceptibility can be expressed in many ways, from relative rankings only (qualitatively) through to absolute rankings (quantitatively). For the purposes of this project the assessment was conducted in a quantitative fashion in order to align with non-geohazard threat assessment data used by Dynamic in the overall risk assessment.

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[1] Rizkalla, 2008. Pipeline Geo-Environmental Design and Geohazard Management. ASME, New York , NY.

It is important to note that quantitative geohazard data must be viewed in the correct context that it is used for this assessment. Comprehensive soil, bedrock and groundwater data, long-term slope stability performance records, and an accurate depiction of potential environmental influences from short and long term climate patterns, are a few of the variables that are typically not available to fully characterize the behavior of the terrain over the potential life of a project. As a result, engineering judgement plays a key role in the geohazard assessment process, and strict quantification of such methods is not always possible. Estimates of several attributes within the assessment are often made, based on evidence set out in the assessment report. An order-of-magnitude approach is adopted for the quantitative assessment outcomes for this project since it is best suited to adjust to the levels of precision typically present in geological data when evaluating various geohazard attributes.

In some cases geohazard impact areas overlap one another. Most often this is as a result of one geohazard triggering another, but it is not always the case. Examples of one triggering another could include ground shaking and liquefaction; or lateral migration and landsliding. It is also possible that they do not have a co-dependence, but are located in the same hazard space, an example could include ground shaking and scour. Where geohazards are present in the study areas and may have a co-dependency on an overlapping geohazard impact zone the relevant frequency and/or occurrence term of the failure frequency formula is adjusted (often matched) to reflect the co-dependency. Where they are located in the same hazard space with no co-dependency, there is no further consideration. This approach allows the overall quantitative assessment calculation to treat the susceptibility of each hazard (or threat) separately along a specific (and sometimes overlapping) segment of the pipeline system. The separate values of susceptibility are used as an input to the overall risk assessment framework by Dynamic.

2.0 DATA

The following background data was provided to KGL by the project team for the purposes of the assessment. The data was used to prepare detailed site plan maps showing the study areas (see Figures 2 through 8). Note that the detailed site plans shown on Figures 2 through 8 include an overview "Site Plan" layout (shown in "A" series Figures), and a "Terrain Analysis Summary" layout (shown in "B" series Figures). Initial data gathering was carried out during Dynamic's Threat Assessment Workshop held in Enbridge's Duluth, MN offices on Dec 9 and 10, 2015.

Digital Project Files

- Google Earth File (.kmz) showing proposed pipeline route(s) and assessment locations. (Updated Mosquito Creek location after initial delivery to reflect an error in original location).
- GIS (.shp) files setting out the pipeline route.
- Project supplied LiDAR survey data panels (*digital elevation model data*) for Shell River; Mississippi River at Palisade; and Sandy River.

Project Reports[2]

- Barr Engineering Co., 3 Aug 2015. Technical Memorandum. "Sandpiper Line Wide Desktop Geologic Assessment".
- Barr Engineering Co., February 2015. Geotechnical Data Report. Sandpiper Pipeline Project, Milepost 446, Hubbard County, Minnesota. (Shell River)
- Barr Engineering Co., March 2014, Revised January 2015. Geotechnical Data Report. Sandpiper Pipeline Project, Milepost 533. *(Mississippi River at Palisade)*
- Barr Engineering Co., July 2014. Geotechnical Data Report. Sandpiper Pipeline Project, Milepost 549. *(Sandy River)*

Reference Reports

- American Engineering Testing, Inc. May 2008. Report of Geotechnical Exploration and Review, Enbridge Pipeline, Alberta Clipper/Southern Lights Projects, Mississippi River Crossing Site, MP 986, Ball Club, Minnesota.
- Historical air photo imagery from online sources.

Published Data

- Footnote references are included in this report where KGL used existing published data sources such as regional geological mapping.

Publically Available Topography and Imagery

- Project data was supplemented by publically available LiDAR data obtained from the Minnesota Department of Natural Resources MnTOPO web application at: (http://arcgis.dnr.state.mn.us/maps/mntopo/).
- Imagery was available from online sources including Google and Bing open source files.

Field Visits

- Local terrain features were observed by KGL during a field visit to the study areas in March 2016.

[2] Sandpiper is a project that has since been cancelled; however, the data are still relevant.

3.0 TERRAIN ANALYSIS

3.1 TERRAIN ANALYSIS METHODOLOGY

The project data was reviewed and characterized within the study areas using methods as set out by Cruden and Thompson (1987)[3] where areas are "divided into units whose engineering characteristics are relatively uniform". This method allows for subsequent hazard zonation by a direct mapping methodology, similar to that as described in Soeters and van Westen (1996)[4].

Several aspects of the support data used to conduct the terrain analysis are shown on the "B" series figures included in this report (i.e. Figures 2B through 8B). The data shown includes cross-sections through key slopes, slope gradients, and slope direction together with hillshade imagery and aerial imagery.

The results of the terrain analysis are provided in descriptive form in the site descriptions in the following section.

3.2 SITE DESCRIPTIONS

3.2.1 Red River of the North

This crossing is located on the Red River of the North, about 54 miles north of Grand Forks, North Dakota. The study area is shown on Figures 2A and 2B.

This crossing would be constructed using HDD methods adjacent to several other Enbridge pipelines located in this corridor. It is understood that the modern adjacent pipelines were successfully installed using HDD methods.

The terrain in the crossing location is generally described as flat to gently sloping. Steeper slopes, up to about 20 degrees and 10' high are present adjacent to the main channel on the south side of the river. Similar slopes are also present adjacent to the main river channel on the north side, although they are higher, extending 20 to 25' high. Total relief in the crossing area is between about 25' and 30'.

The Red River of the North flows northward in a meandering channel incised into the surrounding plains. The channel banks and valley slopes are well vegetated, and in areas outside of agricultural development they typically have a significant tree cover. Using online sources, 20 years of imagery was reviewed. The imagery shows that the channel position has remained relatively static over the period, with apparently

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[3] Cruden, D.M. and Thompson, S. 1987. Exercises in Terrain Analysis. Pica Pica Press, Edmonton, AB, Canada.
[4] Soeters, R., and van Westen, C.J. (1996) Slope Instability Recognition, Analysis, and Zonation. Ch 8 In Landslides Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council. National Academy Press, Washington, DC.

only minor bank losses, although this period is relatively short in a geological and hydrotechnical context. It is understood that the flow varies considerably over the year and that widespread overbank flooding is typical in spring flood. Abandoned oxbows and channels are present in the imagery.

Soil conditions are assumed only and are based on the typical profile of the region that includes thin overbank deposits of silts and sands covering a thick sequence of high plastic clay. Observations at the south stream bank during the site visit suggest that the channel is incised into the high plastic clay deposits. High plasticity clays tend to provide for channel stability with respect to scour and lateral migration provided that excess undercutting erosion and landsliding does not occur.

3.2.2 Mississippi River at Ball Club

This crossing is located on the Mississippi River about 21 mi northwest of Grand Rapids, MN. The crossing is parallel to, and immediately downstream of Route 2 and a railway crossing of the Mississippi. The study area is shown in Figures 3A and 3B.

Photo - 1 taken looking north at the rail crossing at Mississippi River and Highway 2 near Ball Club Lake.

This crossing is assumed to be constructed using HDD methods, similar to other crossings completed successfully for modern Enbridge projects in this corridor.

The upland terrain is generally described as flat to gently sloping and is generally forested throughout. The upland terrain is separated from a broad lower river floodplain by short 15 to 20' high 15 to 20 degree terrace slopes that follow a sinuous path parallel to the main Mississippi River valley floodplain alignment.

The Mississippi River meanders in an underfit 100' to 150' wide stream located within a much larger floodplain channel area that is between about 2000' and 3000' wide. The overall channel crosses the project corridor at a nominal 45^{o} skew. Frequent river cut-off channels and oxbows are present throughout. Standing water, muskeg and poorly drained wetland terrain dominate throughout the full floodplain width.

The floodplain crossings for the highway and railway are immediately upstream of the proposed corridor and have spans of different lengths. The shortest is the highway crossing with a bridge length of about 150', and the longest is the 600' railway crossing (estimated from aerial photos). The bridge approaches are constructed through the floodplain channel area on embankment fills.

The American Engineering Testing Inc. (2008) report for a past Enbridge project at this location indicates that the area is underlain by relatively thin topsoil or peat deposits overlying a sequence of mixed silts and sands to depths of about 60'. The sands and silts overly till deposits to the maximum depth investigated (101)'.

3.2.3 Mississippi River at Palisade

This crossing is located on the Mississippi River about 1 mi south of Palisade, MN. The crossing is immediately east of Route 10 where it parallels the river on the west side. The study area is shown in Figures 4A and 4B.

This crossing would be constructed using HDD methods and is understood to be the first crossing on this alignment.

The upland terrain is generally flat to gently sloping toward the river. Total relief in the study area is between about 15' to 20'. The upland plain to the east of the study area is above about 1221' elevation, while the area to the west is lower, between about 1212' and 1216'.

Photo - 2 taken looking south at the crossing area

The existing western river bank is relatively steep at between about 20^0 and 30^0, and is much steeper than the eastern bank that includes typical slopes of between about 5^0 and 15^0. Stepped, or terraced patterns, are suggestive of long-term or ancient erosion sequences. These patterns are more prominent on the higher eastern banks. A small V-shaped gully is eroded between a back-sloped bench on the east side and the river immediately south of the proposed pipeline alignment.

The Mississippi River is contained within a single channel with well vegetated stream banks for several miles up and down stream. The channel is notably less sinuous through this area as compared to its more pronounced meandering character upstream and downstream. Abandoned oxbows are present, although they are well vegetated in this reach and do not appear recent. The orientation of the flow of the river, channel direction and slope morphology suggests the overall long-term direction of lateral migration is westward. The terrain above the existing river bank on the east is generally flat with some subdued steps associated with past (or ancient) fluvial erosion. The public road improvements on Route 10 upstream on the western banks appear to include erosion protection measures at the toe of the slope.

Soils are described in the Barr Engineering MP 533 (2015) report as mixtures of sands, silts and clays. The materials above the existing channel primarily consist of sandy clays; while the channel is incised through a lean clay. Underlying layers at depths greater than 20' below the riverbed include a thin layer of sand or fat clay alluvium covering glacial till to the maximum depth investigated of 90'. The V-shaped gully on the eastern bank is consistent with erosion patterns in sandy sediments.

3.2.4 Mississippi River at Little Falls

This crossing is located on the Mississippi River about 5 mi north of Little Falls, MN. The crossing study area extends between about Route 213 on the west side through to Route 371 on the east side. The study area is shown in Figures 5A and 5B.

Photo - 3 taken looking west along the proposed crossing alignment across the Mississippi River

This crossing would be constructed using HDD methods. The route is parallel to existing gas pipelines that cross the river at the same location.

The upland terrain appears generally flat to gently sloping toward the river. Total relief is estimated to be on the order of about 20' to 25'. The existing pipeline corridor through the area is cleared and vegetated and is generally parallel to existing roads and driveways approaching the river. Developed residential and agricultural land in the area is cleared, and areas along the banks of the river are predominantly forested. Project specific soil information was not available for the area. The terraced pattern of slopes present along the river and adjacent upland terrain, as well as the local drainage patterns are indicative of fine grained soils such as lean clays, silty clays or mixtures of silt, clay and sand.

The imagery available shows that the river has been relatively stable in the current position for a period of at least 20 years, with only minor differences visible due to different water stages at the time the photos were taken. The Mississippi River flows in a broad nominally 500' to 1000' wide meandering channel with frequent islands and braided character. Old grown-over oxbows are present in this reach.

The slopes along the river are relatively steep, with 10 to 15' high vegetated areas that maintain a gradient of between about 20 to 30 degrees. A significant amount of residential development is present along the river, as compared to other sites reviewed.

3.2.5 Mosquito Creek to Lower Rice Lake

This crossing is located on Mosquito Creek about 20 mi west of Bemidji, MN. The study area is parallel to, and east of, several existing pipelines. This crossing would be constructed using conventional trenched methods. The study area is shown on Figures 6A and 6B.

Photo - 4 taken looking northwest at the crossing area. Note that the proposed crossing is through the existing vegetated area to the east (top in photo) of the existing cleared pipeline right-of-way

The upland terrain is described as gently sloping toward the creek location from the north and south. Total relief is estimated to be on the order of about 20' near the crossing area. The existing pipeline corridor through the area is cleared and vegetated. Developed agricultural land exists to the west of the corridor, while areas to the east are predominantly forest or wetland terrain.

Site specific soil information was not available for the area. The Barr Engineering (2015) Line Wide Desktop Geologic Assessment indicates that the soils are anticipated to be *"predominantly clayey material. Soil types will be silty to sandy clay intermixed with some gravel, areas of silty to clayey sand may be present locally. Boulders may be encountered but are not expected to be common."*

The stream is poorly defined on the imagery in the study area. There was no visible flowing water at the time of the field assessment and the channel area as defined on the mapping was vegetated.

3.2.6 Shell River at Twin Lakes

This crossing is located on Shell River about 1.5 mi southwest of Hubbard, MN. The route is parallel to, and south of, an existing electrical transmission line. The study area is shown on Figures 7A and 7B. This crossing would be constructed using HDD methods.

Shell River flows in a nominal 100' wide underfit channel contained within the larger approximately 1500' wide floodplain incised between 20' to 40' below the adjacent upland terrain. The floodplain is generally described as wetland terrain with frequent grown-in back-channels, oxbows and meander cut-offs.

The upland terrain above the channel area is relatively flat, and predominantly agricultural land with forested areas within about 500 to 100' of the crest of the incised slopes. The forested slopes between the channel and the upland terrain are relatively steep at between about 22° and 25°, and are about 15' high on the east and 40' high on the west.

Photo - 5 taken looking east along the proposed route

Soils are described in the Barr Engineering MP 533 (2015) report as predominantly glacial outwash and glacial till deposits. Drill holes encountered mixtures of sand through the vertical sections of the east and west slopes above the floodplain. Sand deposits are shown in the report to extend between nominally about 10' and 40' below the elevation of the floodplain, underlain by lean clay (glacial till) and mixtures of sand, silts and clays (glacial till). Drilling extended to depths between about 70' and 100' below the floodplain.

3.2.7 Sandy River

This crossing is located on Sandy River about 3 mi northeast of McGregor, MN. In this area the Sandy River runs roughly parallel to and north of an existing railroad and Route 210. The study area is shown on Figures 8A and 8B.

This crossing would be constructed using HDD methods to cross the stream, road and rail in one alignment.

Sandy River flows in a nominal 15' to 20' wide channel incised 5' to 6' into the adjacent upland terrain. The terrain adjacent to the stream banks is a mix of developed agricultural land, wetland and forested area, and is dissected frequently by abandoned meander channels. Several distinct channel patterns visible in the morphology of the area suggest that the river is, or has been, used for irrigation or flood control since the path of the stream has been excavated and realigned in several locations. Adjacent tributary streams have distinct meander patterns while the Sandy River in this location does not. At high flows many of the meander loops are flooded, as evidenced on some of the available historical photos.

Soils in the area are described in Barr Engineering MP 549 (2014) report. They include layered silt and sand alluvial soils from surface down to an underlying glacial till about 60' below surface that continued to the maximum depth investigated (91').

Photo - 6 taken looking south along the proposed alignment from the road crossing of Sandy River

4.0 GEOHAZARD ASSESSMENT

4.1 PROJECT GEOHAZARD LIST

Geohazards encompass a broad category of natural hazard processes. Table 2 presents the preliminary list of geohazard types reviewed for the project. Note that the list is general in nature and includes a broad range of hazards that could be theoretically present in the project geological setting. The list is used to systematically evaluate whether the hazard is credible at each site, and if so, a determination of the spatial extent of the hazard area can be made and the susceptibility calculated. The list does not include all possible natural hazards. Hazards not represented are associated with geological settings or conditions not present such as high relief and alpine terrain, and those typical of deserts, arctic, and volcanic settings.

Table 2 - Geohazard Categories and Types Evaluated for the Project

Category	Geohazard Type	Identifier	Geohazard Description
Hydrotechnical	Lateral Migration	LM	Lateral movement of a stream related to stream bank losses
	Scour	SC	Downward erosion of the stream bed
	Buoyancy	UP	Uplift of a pipeline related to buoyant conditions
	Erosion	ER	Erosion of cover and/or confining materials around the pipe
Mass Movement	Deep-seated Landslide	DS	Deep landslide with rotational or complex slide surface
	Creep	CR	Gradual downslope movement of soil or rock
	Shallow Landslide	SL	Skin flows and shallow slides
Tectonics	Liquefaction	LQ	Loss of soil strength due to dynamic loading
	Shaking	SK	Ground shaking due to seismic activity
	Fault Displacement	FD	Differential movement of ground due to fault breaks
Geochemical	Acid Rock Drainage	ARD	Oxidation of sulphide bearing materials
	Karst Collapse	KC	Collapse of ground into bedrock solution cavities
Freeze / Thaw	Frost Action	FA	Ground heave due to excess ice formations in frozen ground

4.2 GEOHAZARD IMPACT AREAS - SCREENING & DEFINITION

The following sections present a discussion of the process of comparing the geohazard list (Table 2), including the detailed geohazard description types (as applicable, and defined in Appendix A) and the terrain analysis. The results of the comparisons support establishing the hazard impact areas (geohazard polygons) shown on Figures 2A through 8A (excluding 6A). A total of 23 hazard impact areas were identified for the project. The polygons were numbered sequentially from 4 through 26, as listed on the maps noted above. The assessment basis for each hazard type is described in the detailed geohazard description tables provided in Appendix A.

Geohazards related to hydrotechnical and mass movement comprised the natural hazard threats identified in the study areas.

4.3 HYDROTECHNICAL GEOHAZARDS SUMMARY

4.3.1 Hydrotechnical - Lateral Migration and Scour

Geohazards associated with scour and lateral migration are present in all of the study areas with the exception of the Mosquito Creek to Lower Rice Lake assessment area. Details for the assessment of Lateral Migration and Scour are set out in pages A1 and A2 of Appendix A. For the purposes of simplification in this assessment, the hazards were combined and assessed as a single hazard impact area, expressing the condition that one or both modes of impact could occur anywhere throughout the polygon during a flood stage event.

While the potential for some degree of scour does exist at Mosquito Creek during extreme flow events, a hypothetical scour channel would be quite narrow, likely on the order of 10' in the extreme case. Considering this potential channel width and spanning of the relatively large diameter steel pipeline the hazard was discounted as having a credible potential to lead to a loss of containment event at this site.

4.3.2 Hydrotechnical - Erosion Geohazards Evaluation

In the context of pipeline geohazards assessment erosion is described as the loss of soil along the right-of-way or ditch associated with precipitation related upland drainage water and/or wind. It is distinguished separately (as per overland precipitation related flow) from potential sediment losses associated with hydrotechnical related erosion hazards at defined stream locations. Erosion is common throughout the construction phases and during the first few years of operations prior to re-vegetation of the work areas.

Erosion is visible on the surface, and is easily identified in regular line patrols where it becomes significant. Assuming that regular line patrols would lead to intervention on the ground by maintenance crews to control erosion and add cover if it is lost, erosion related geohazards are assessed as not having a credible potential to result in a loss of containment event in the defined study areas.

4.3.3 Hydrotechnical – Buoyancy

Buoyancy is described as pipe uplift as a result of unbalanced forces resulting from a combination of low cover forces associated with light-weight, thin and/or saturated cover soils or failed mechanical restraint systems. Pipe uplift can result in strain and bending in unrestrained segments of the pipeline, and can lead to pipe exposure at the surface. Buoyancy is an issue prevalent through areas of high water table, saturated organic terrain, and in shallow burial through streams or water bodies.

Buoyancy is typically a slow acting process and is often detected through field observations, routine line cover surveys, and can be detected in regular position-related ILI tool runs. Given the scope of the assessment, predominantly deep cover profiles in HDD, slow acting nature of buoyancy related hazards, and the regular inspection by position-related ILI tools, buoyancy is not assessed as having a credible potential to result in a loss of containment event.

4.4 MASS MOVEMENT GEOHAZARDS SUMMARY

Mass-movement geohazards are the group of geohazards associated with the downslope movement of earth materials. The hazard types are typically divided according to the type and scale of movement. Movements are typically described in accordance with classification systems set out in Cruden and Varnes (1996)[5]. Types considered in this assessment included shallow landslides, deep-seated landslides, and creep related movements. Flow slides and rock falls were not considered. Shallow landsliding is associated with small landslides typically less than several metres deep that have predominantly disaggregated failed soil masses. These slides are distinguished from deep-seated slides by the characteristics of the failed soil movements and shallow failure depths. Deep-seated landslide is associated with the movement of large masses of soil and/or rock on a rotational or complex failure surface. The sliding soil mass remains largely intact at initial sliding, but it may become disaggregated or blocky in complex failures. Retrogression above the initial slide limit is common. Creep is associated with the gradual downslope movement of soil and rock under constant stress and is most often associated with slopes where fluctuating groundwater pressures and/or frost action gradually transport particles downslope. Creep is not be used in the context of slow or very slow moving landslides. Creep movement is extremely slow.

[5] Cruden, D.M., and Varnes, D.J. (1996) Landslide Types and Processes. Ch 2 In Landslides Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council. National Academy Press, Washington, DC.

4.4.1 Mass Movement – Shallow and Deep-Seated Landslides

Geohazards associated with shallow and deep-seated landslides area have the potential to be present in many of the study areas, as shown on Figures 2A, 3A, 4A, 5A and 7A. Details for the assessment of Shallow Landslides and Deep-Seated Landslides are set out in pages A3 and A4 of Appendix A.

The landslide hazards are predominantly adjacent to the stream channels where the potential for undercutting the adjacent slopes can trigger failures. In addition to undermining, slope instability could be triggered in some cases where rapid river draw-down conditions following flooding result in failure associated with the elevated porewater pressures in the adjacent slopes developed during the flood stage rise in the water table. In many cases, such as at the Red River, localized shallow sliding was present and active adjacent to the stream, indicating that this is a routine process in the study areas. The slides associated with this mechanism of failure typically occur to depths consistent to or just below the bottom of the stream elevations, thus pipeline locations with significant cover depth between the stream bottom and top of pipe can be routed to avoid the hazard impact zone.

4.4.2 Mass Movement - Creep

As noted above, creep is described as a gradual downslope movement of soil and rock under constant stress. Creep is a slow acting process and can often be identified through ongoing operations related field observations, routine line patrols, and can be detected in differential plots using regular position-related ILI tool runs. Given the scope of the assessment, and the regularly planned inspection by position-related ILI tools, creep is not assessed as having a credible potential to result in a loss of containment event in the defined study areas.

4.5 TECTONIC GEOHAZARDS SUMMARY

Tectonic geohazards, including liquefaction, shaking, and fault displacement are assessed as not having a credible potential to impact the pipeline system in the defined study areas based on reviewing the results of the USGS - United States national seismic hazard maps by Petersen et al (2014)[6]. The report and associated mapping shows that the State of Minnesota is largely outside any significant areas of seismic activity. Using Figure 1 from Peterson et al (2014) "2% chance of exceedance in 50 years", giving overview hazard mapping for the 1 in 2475 year exceedance case assuming very dense soil and soft rock in the upper 30 m, it can be seen that the project lies predominantly within a zone with predicted Peak Ground Accelerations of between 0 and 0.04g. At such low values for the significant return period of 1 in 2475

[6] Petersen, MD, Moschetti, MP, Powers, PM, Mueller, CS, Haller, KM, Frankel, AD, Zeng, Yuehua, Rezaeian, Sanaz, Harmsen, SC, Boyd, OS, Field, Ned, Chen, Rui, Rukstales, KS, Luco, Nico, Wheeler, RL, Williams, RA, and Olsen, AH. 2014. Documentation for the 2014 update of the United States national seismic hazard maps: US Geological Survey Open-File Report 2014-1091, 243 p.

years, it is unlikely that potential seismic activity presents a credible hazard to the pipeline system, nor does it present a credible threat for triggering mechanisms for other geohazards such as landslides.

4.6 GEOCHEMICAL GEOHAZARDS SUMMARY

Two key mechanism are included in the geochemical geohazards summary, acid rock drainage and karst collapse. Acid rock drainage (excluding environmental effects that may result) can lead to increased rates of corrosion by lowering the contact water pH levels as acid is generated through weathering of sulphide bearing rocks. Karst collapse includes the potential for inducing strain as a result of settlement or spanning where loss of support occurs over a solution cavity (sinkhole).

For the purposes of acid rock drainage, if the planned pipe profile does not encounter bedrock, there is no potential to expose previously unweathered sulphide bearing minerals and thus no hazard exists. For karst collapse potential, the pipeline route would have to be located within or above bedrock units that could include solution cavities. For both potential hazards, knowledge of the type of bedrock and depth to bedrock is a useful first screening tool.

The 3 Aug 2015 Barr Engineering Co memorandum on the line wide desktop geological assessment was reviewed. The bedrock in Minnesota is reported to be greater than 30' deep in most areas with the exception of segment between MP 575 and 595 where shallow bedrock may be encountered sporadically. This area is located to the east of the study area along the L3R route. Areas along alternate routes are not discussed specifically in the report, although Figure 1 in the Barr report offers coverage of alternative crossings of the Mississippi at Ball Club and Little Falls. Table 3 presents a review of the bedrock types and depths taken from project reports and available online publications.

The bedrock types listed in Table 3 for the selected study areas are not considered to be susceptible to the development of solution cavities. Karst terrain is common in the southeastern part of Minnesota where carbonate rocks are common, however mapping (Gao, Y; Alexander, E.C., and Tipping, R.G, 2002)[7] indicates the potential karst area in the state is located south of the study areas. The potential for underlying rocks to develop solution cavities is estimated to be very low and therefore karst collapse is not considered a credible geohazard for this study.

[7] Gao, Y; Alexander, E.C., and Tipping, R.G, 2002. The Development of a Karst Feature Database for Southeastern Minnesota. Journal of Cave and Karst Studies. 64 (1) p. 51 – 57.

Table 3 – Bedrock Summary

Site	Bedrock Description	Bedrock Depth
Red River	Neoarchean mafic metavolcanic rocks with minor volcaniclastic and hypabyssal intrusions. (Jirsa, 2011)[8]	>30' See NOTE 1
Mosquito Creek	Neoarchean age granitic intrusive rocks of the Bemidji Intrusion. (Jirsa, 2011).	>30' See NOTE 1
Shell River	Proterozoic age slate and greywacke of the Nimrod Outlier. (Jirsa, 2011).	>100' See NOTE 1
Mississippi River at Little Falls	Paleoproterozoic age greywacke, mudstone, schist and slate of the Little Falls Formation. (Jirsa, 2011).	20' – 30' See NOTE 1
Mississippi River at Ball Club	Neoarchean age granite to granodiorite. (Jirsa, 2011).	>30' See NOTE 1
Mississippi River at Palisade	Shale of the Thompson Formation. (Barr MP 533 Report). Thompson Formation is of Paleoproterozoic age (Jirsa, 2011).	100' to 150' From Barr Report on MP 533
Sandy River	Graphitic schist of the Mille Lacs Group (Barr MP 549 Report).	100' to 150' From Barr Report on MP 549

NOTE 1: Bedrock depths taken from project geological assessment mapping and site specific reports where available.

Several of the bedrock types listed in Table 3 have the potential to include sulphide mineralization. Acid rock drainage occurs as a result of oxidation of previously unweathered minerals and can lower the pH significantly in contact water. Due to the relatively significant depths to bedrock predicted at the crossings it appears unlikely that the pipeline will be installed through rock, or in rock that is at or near a zone where oxidation could occur. It is important to note though that however unlikely it may be, if rock is encountered in the pipeline ditch or HDD alignments, it should be examined for the potential for ARD prior to disposal to examine the potential effects on the installed pipeline and on the environment where cuttings or excess rock excavation may be disposed.

4.7 FREEZE / THAW GEOHAZARDS SUMMARY

Frost action can impose differential vertical loads on the pipeline resulting in flexure of the pipe. The activity is associated with both freezing and subsequent thawing of the soils. During freezing uplift associated with the development of excess ice in freezing soils can impose loads, and during thawing a loss of soil strength associated with excess pore pressures can result in differential downward forces. Repeated cycles can result soil migration below the pipeline and relative uplift of the pipe. Freezing below a warm liquids pipeline will typically not occur, although it is theoretically possible under specific operating and environmental conditions.

[8] Jirsa, M A; Boerboom, Terrence J; Chandler, VW; Mossler, JH; Runkel, AC; Setterholm, DR. 2011. S-21 Geologic Map of Minnesota-Bedrock Geology. Minnesota Geological Survey. 1:500,000 scale.

Pipe loading related to frost action is a slow acting process often resulting in minor flexure of the pipeline only. The phenomenon can be observed over time through examination of line cover surveys, position related ILI data, and other such measurements and observations. Given that the scope of the study is specific to a loss of containment the slow acting nature of frost action on a pipeline system is assessed as not having a credible potential to impact the pipeline system in the defined study areas.

5.0 SUSCEPTIBILITY CALCULATIONS

As noted above, the 23 geohazard impact areas defined for the project are shown on Figures 2A through 8A, with the exception of Figure 6A (Mosquito Creek). The following sections briefly describe the failure mechanisms assessed in the study areas and provide a discussion of the issues leading to the selection of the susceptibility factors. The susceptibility values, calculated as per the methods set out in Section 1.3 are presented in Table 4, below.

Table 4 - Geohazard Susceptibility

Assessment Location	Geohazard Type	Geohazard Number	Occurrence (Factor)	Frequency (annual probability)	Vulnerability (Factor)	Mitigation (Factor)	Susceptibility (annual probability)
Red River	LM/SC	4	0.1	0.005	0.01	0.001	5.00E-09
	DS	5	0.01	0.005	1	0.001	5.00E-08
	DS	6	0.01	0.005	1	0.001	5.00E-08
	SL	7	1	0.005	0.01	0.001	5.00E-08
Mississippi River at Ball Club	LM/SC	8	1	0.005	0.01	0.001	5.00E-08
	SL	9	0.01	0.01	0.01	0.001	1.00E-09
	SL	10	0.01	0.01	0.01	0.001	1.00E-09
	SL	11	0.01	0.01	0.01	0.001	1.00E-09
	SL	12	0.01	0.01	0.01	0.001	1.00E-09
	SL	13	0.01	0.01	0.01	0.001	1.00E-09
	SL	14	0.01	0.01	0.01	0.001	1.00E-09
	SL	15	0.01	0.01	0.01	0.001	1.00E-09
Mississippi River at Palisade	LM/SC	16	1	0.005	0.01	0.001	5.00E-08
	SL	17	0.01	0.005	0.1	0.001	5.00E-09
	SL	18	0.01	0.005	0.1	0.001	5.00E-09
Mississippi River at Little Falls	LM/SC	19	1	0.005	0.01	0.001	5.00E-08
	SL	20	0.01	0.005	0.1	0.001	5.00E-09
	SL	21	0.01	0.005	0.1	0.001	5.00E-09
Shell River at Twin Lakes	LM/SC	22	0.01	0.005	0.01	0.001	5.00E-10
	DS	23	0.01	0.001	1	0.001	1.00E-08
	SL	24	0.1	0.01	0.1	0.001	1.00E-07
	SL	25	0.01	0.01	0.1	0.001	1.00E-08
Sandy River	LM/SC	26	0.1	0.005	0.01	0.001	5.00E-09

The guidance for factors generally follows the process as set out in the tables in Appendix A. Note that for the assessment of hydrotechnical hazards a baseline assumption of a damaging return period flood must be used to predict when routine scour or erosion exceeds typical design standards. For the purposes of this assessment, a 200 year flood return period is assumed.

5.1 RED RIVER OF THE NORTH (L3R)

The predominant failure mechanisms of the soils include shallow landslides and erosion of the overbank silts and sands near the channel as well as rotational failures in the high plastic clays adjacent to the channel. Triggers include rapid draw-down of the river or undercutting from lateral migration of the thalweg following major flood events.

HDD installation method is a significant mitigating factor at this location.

5.2 MISSISSIPPI RIVER AT BALL CLUB

The relatively flat slopes and soil conditions in this area suggest that the potential for deep-seated rotational failures is negligible and this geohazard is ruled out as a credible threat. Shallow landsliding is possible where lateral migration undercuts the stream banks. The dominant geohazards in this segment are hydrotechnical and related to the activity of the Mississippi River. The broad channel area suggests that in the absence of the embankment fills and bridges upstream, the river has the potential to occupy positions throughout the overall channel in the future. For the purposes of analysis of lateral migration it is conservatively assumed that the upstream infrastructure could be removed or altered at any point and thus lateral confinement as a result of the existing bridge crossings is not assumed. For the purposes of scour, the assessment conservatively assumes the reverse, and includes the potential for increased scour as a result of upstream confinement through a bridge crossing. The scope of this assessment does not predict scour depth though, just relative potential for it to occur at this stage.

HDD installation method is a significant mitigating factor at this location.

5.3 MISSISSIPPI RIVER AT PALISADE

The fine grained nature of the soils and total relief suggest a potential for deep-seated landslides. Shallow slides are likely possible associated with continued river erosion at the toe of the steeper river banks.

While the channel position is relatively stable in the 20 years of imagery available for this review, the dominant geohazards in this study area are associated with hydrotechnical geohazards, including lateral migration, and scour. The existing stream bank morphology suggests an historic as well as present westward progression of the stream channel at this location.

HDD installation method is a significant mitigating factor at this location.

5.4 MISSISSIPPI RIVER AT LITTLE FALLS

The low topographic relief and relatively active nature of the Mississippi River channel indicate that the dominant geohazards for the study area are hydrotechnical in nature, specifically scour and lateral migration, with lateral migration dominating. The potential for landslides appears to be relatively low, although with active lateral migration and scour the adjacent stream banks could be subject to instability. The presence of a dam at Little Falls offers some control on the long-term downward scour potential and river level.

HDD installation method is a significant mitigating factor at this location.

5.5 SHELL RIVER AT TWIN LAKES

Based on the moderate topographic relief landslide geohazards are a potential threat in this study area, although the presence of relatively coarse grained outwash materials reduces the risk of sliding. Hydrotechnical geohazards including lateral migration and scour are also considered as credible threats in this study area, although the potential rates and magnitude are relatively small given the channel size and position in the floodplain.

HDD installation method is a significant mitigating factor at this location.

5.6 SANDY RIVER

The very low topographic relief in this area excludes the presence of landslide geohazards. The sand and silt mixtures near the surface have a high potential for erosion and therefore lateral migration and scour erosion are considered credible geohazards. The relatively small size of the stream relative to the size of the proposed pipelines reduces the potential for damage in a shallow cover or spanning situation.

HDD installation method is a significant mitigating factor at this location.

6.0 LIMITATIONS & CLOSURE

KGL appreciates the opportunity to provide the comments and recommendations in this report to assist Dynamic and their client Enbridge with the failure frequency estimates for the select locations along the L3R Project route.

The recommendations provided are necessarily limited to the understanding that this report was prepared using the referenced data only and a limited set of overview field reconnaissance observations, as set out in this report. The nature of interpreting geological data between measured data points is specifically noted to include the potential for different conditions than those described, owing to natural variability that is otherwise difficult or unable to be measured or predicted.

The information contained in this report has been prepared using generally accepted engineering practices. No warranty, whether implied or explicit is given. This report does not constitute an engineered design.

The report was prepared for the exclusive use of the clients named within and for the specific project site and conditions as set out. KGL accepts no responsibility for damages or losses related to any third party reliance on any information or recommendations included in this letter, either in whole or in part.

Please contact the undersigned if conditions change or are discovered to be otherwise different than those described herein.

Respectfully Submitted

Shane Kelly, M.Eng., P.Eng.
Senior Geotechnical Engineer

FIGURES

LEGEND:

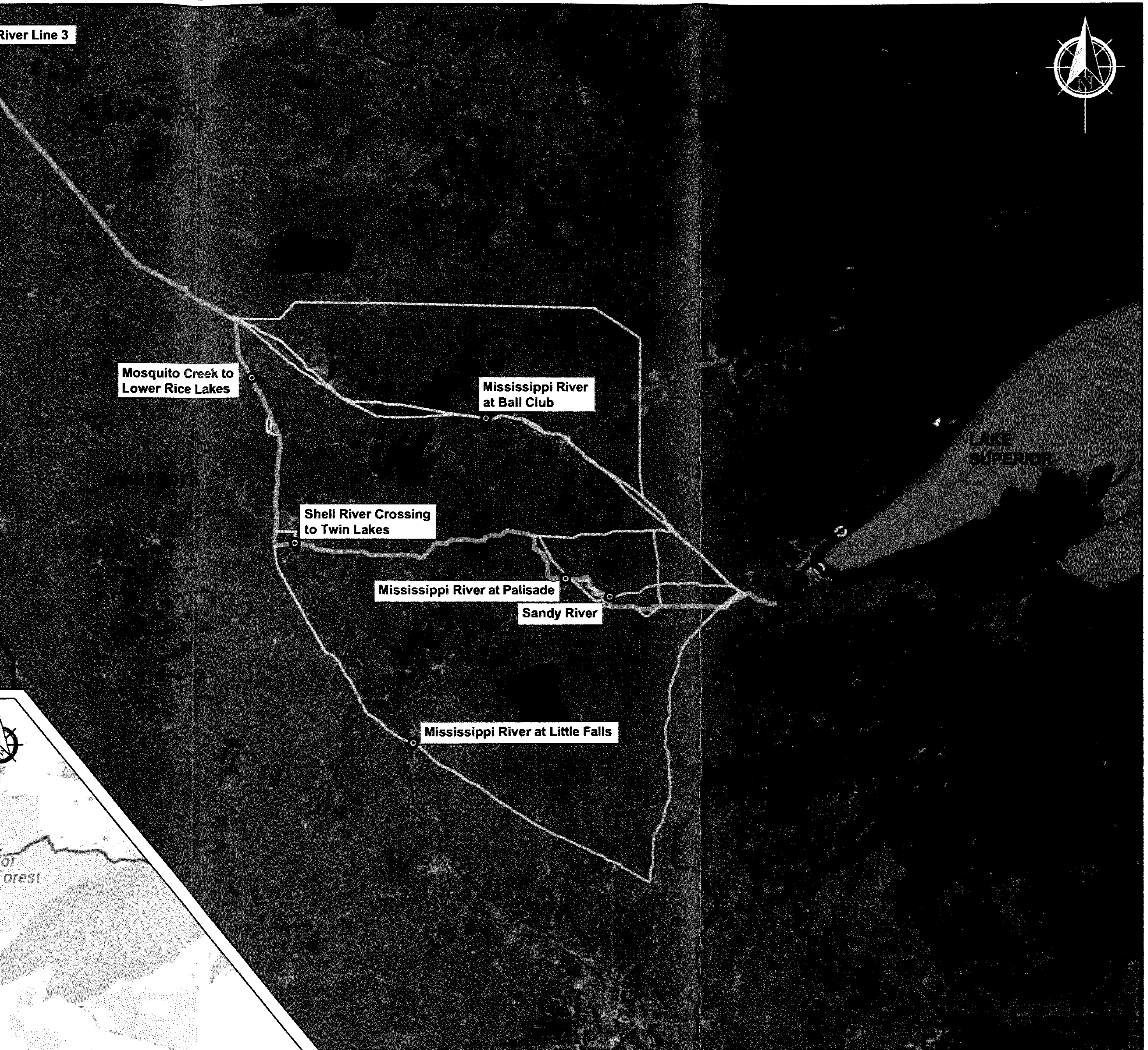
- Line 3 Preferred Route
- Alternate Routes
- Site Locations

NOTES:

1. Imagery obtained from online sources, Google Earth and Earth Explorer.

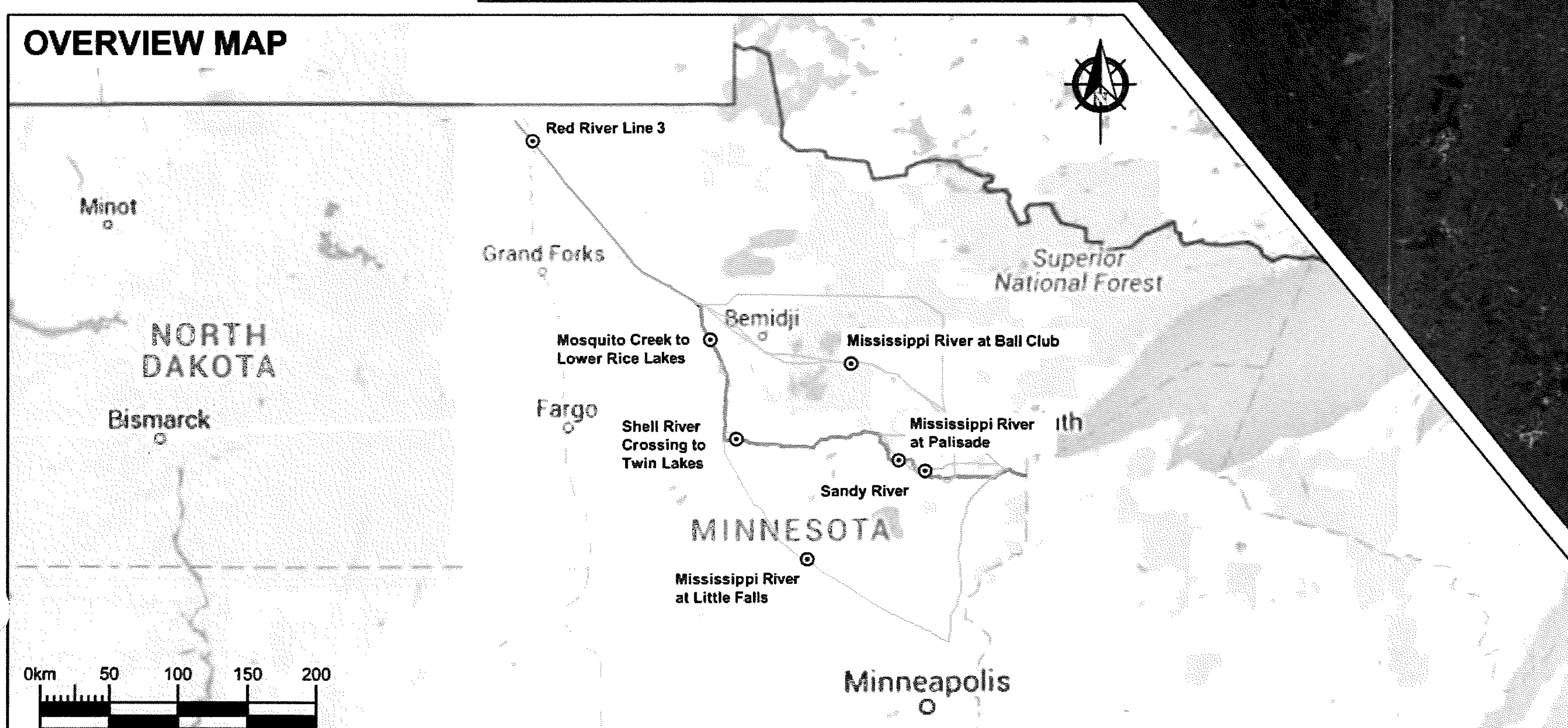
SITE CROSSINGS:

Red River Line 3
14U E:638693 N:5396412
Mississippi River at Ball Club
15T E:427493 N:5241534
Mississipi River at Palisade
15T E:462156 N:5171755
Mississippi River at Little Falls
15T E:396176 N:5100293
Mosquito Creek to Lower Rice Lakes
15T E: 326156 N:5258906
Shell River Crossing to Twin Lakes
15T E345543 N:5187125
Sandy River
15T E:481392 N:5163673



SITE CROSSING LOCATION PLAN

OVERVIEW MAP



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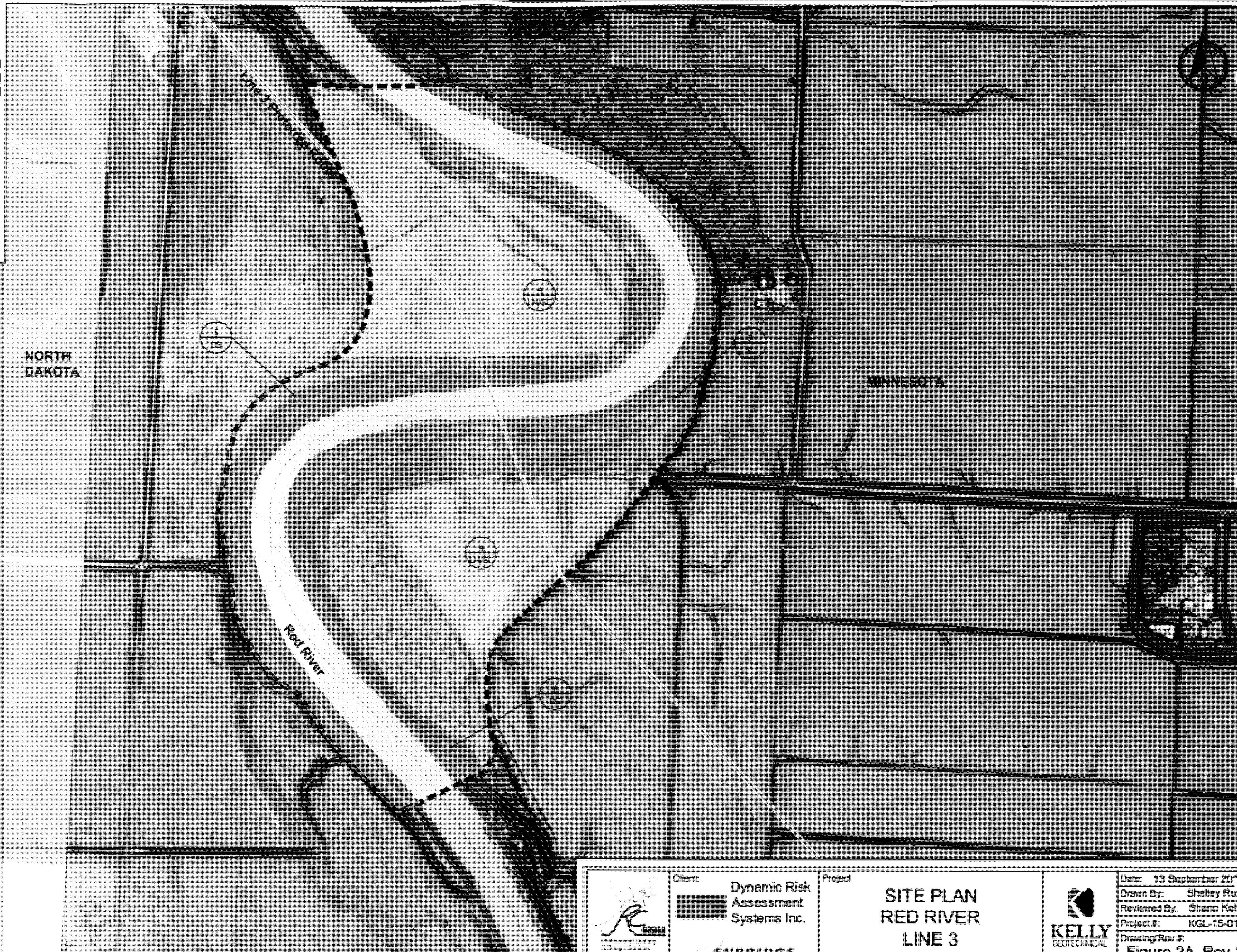
GEOHAZARD CATEGORY LEGEND

Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL

Legend:
Geohazard ID
Geohard Type



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Dynamic Risk Assessment Systems Inc. ENBRIDGE	SITE PLAN RED RIVER LINE 3	KELLY GEOTECHNICAL

Date: 13 September 20'
Drawn By: Shelley Ru.
Reviewed By: Shane Kelly
Project #: KGL-15-012
Drawing/Rev #: Figure 2A Rev 3

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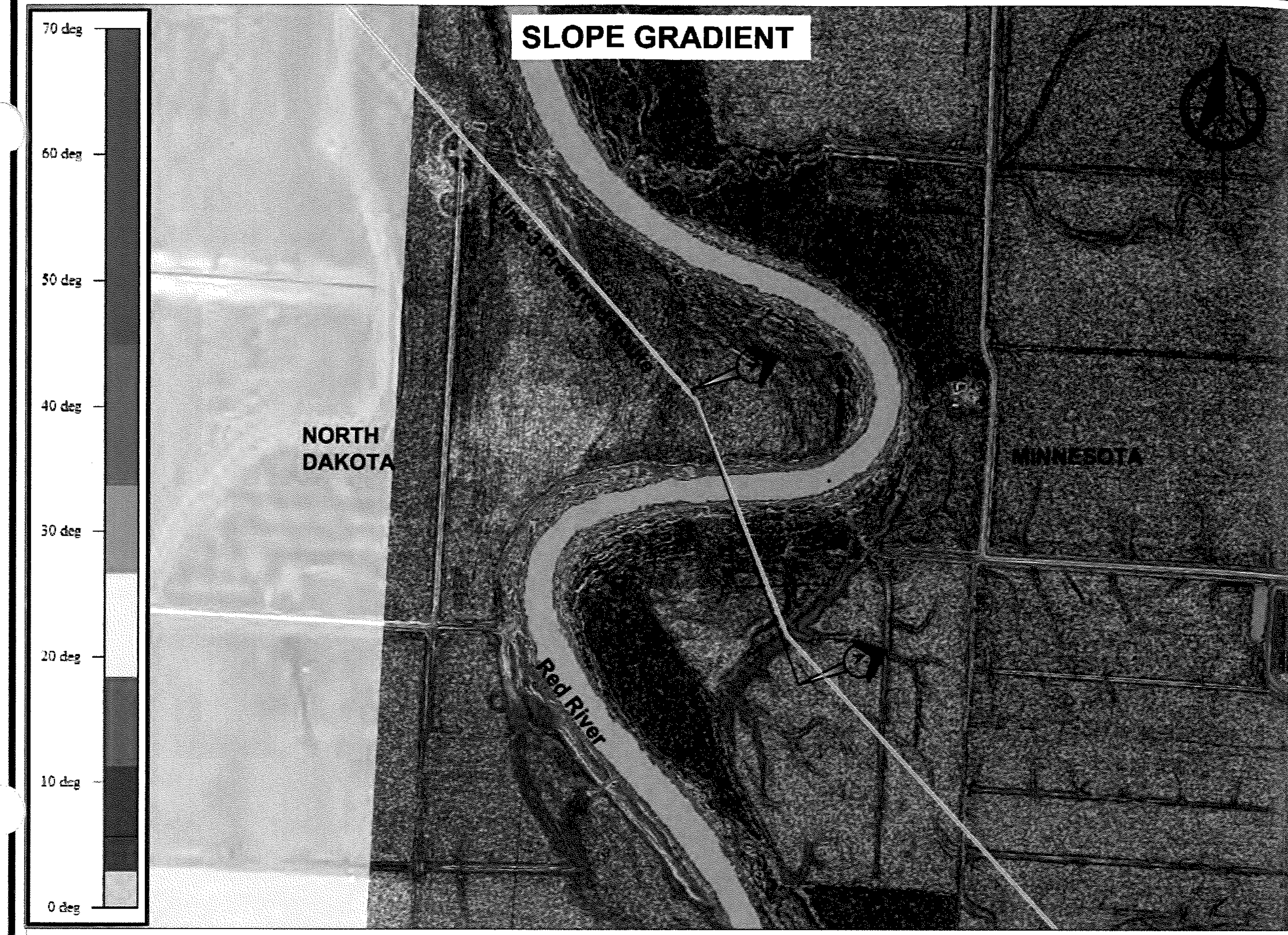

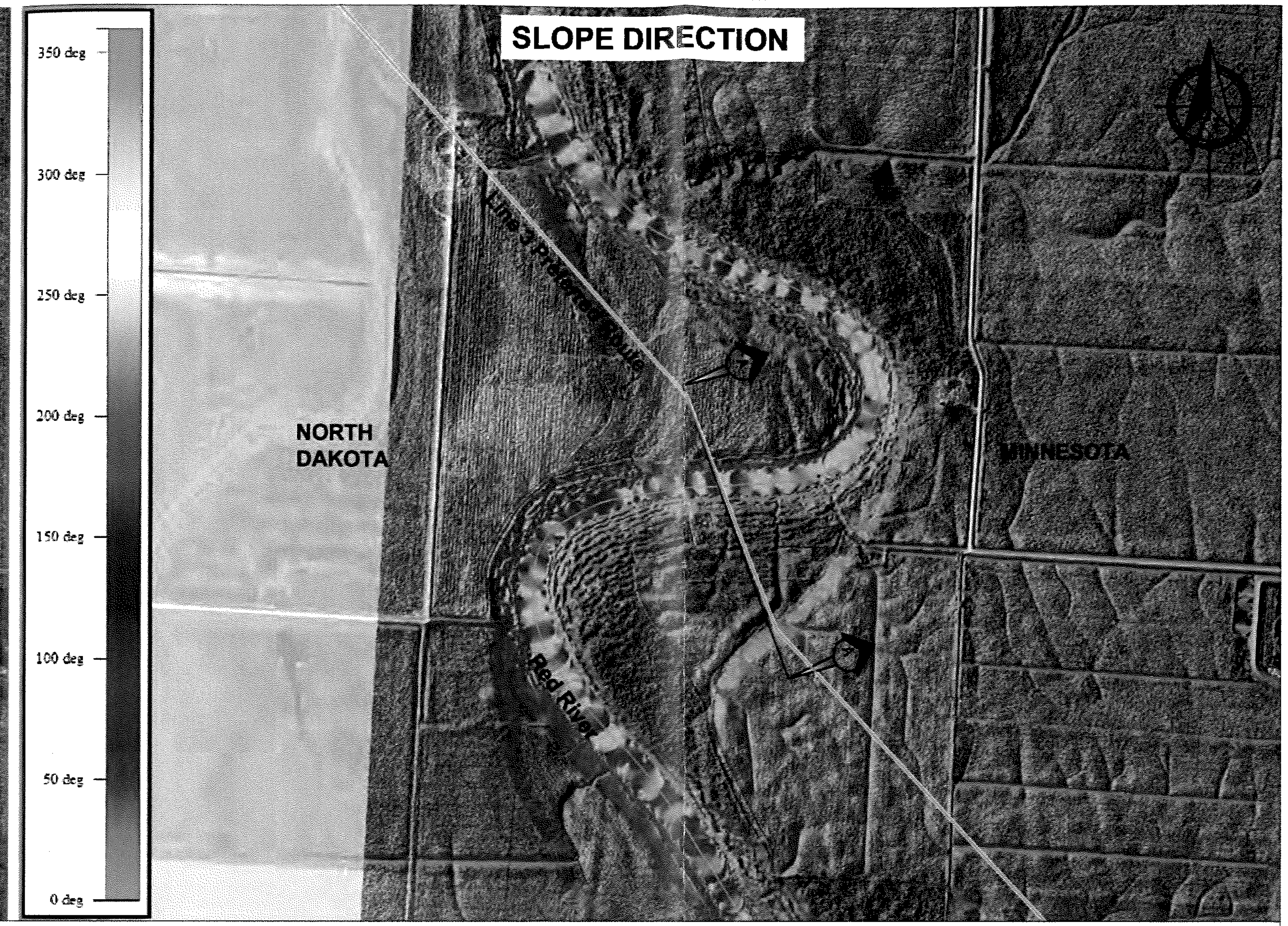

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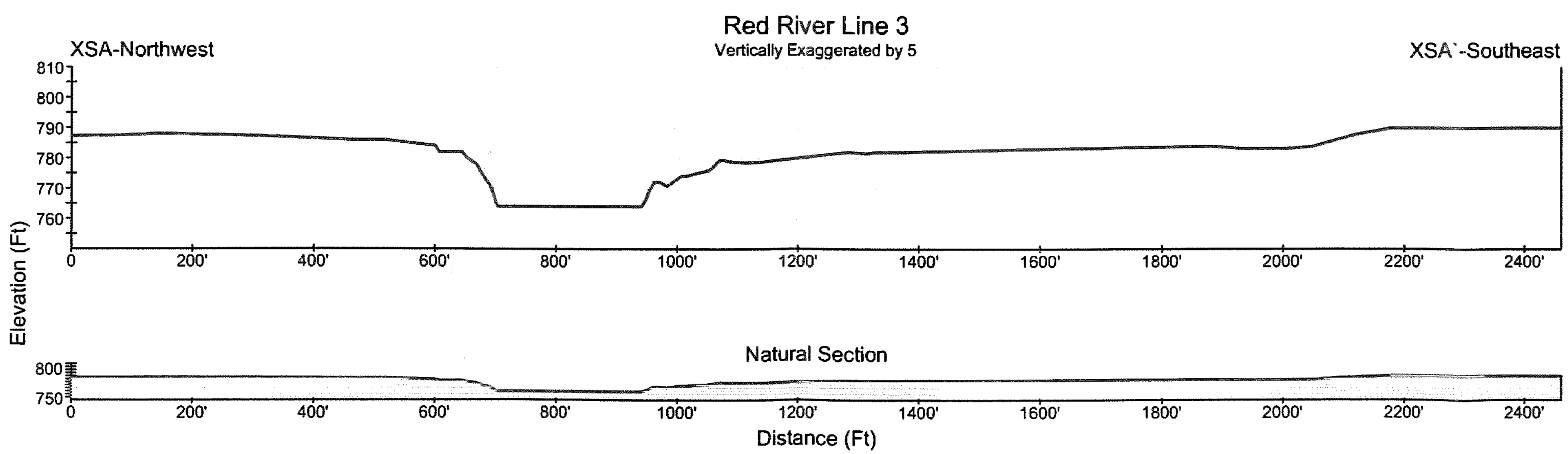

Plan Scale

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Client:	Project	
Dynamic Risk Assessment Systems Inc. ENBRIDGE	TERRAIN ANALYSIS SUMMARY RED RIVER LINE 3	Date: 13 September 2016 Drawn By: Shelley Ruiz Reviewed By: Shane Kelly Project #: KGL-15-012 Drawing/Rev #: Figure 2B Rev 3

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KELLY GEOTECHNICAL

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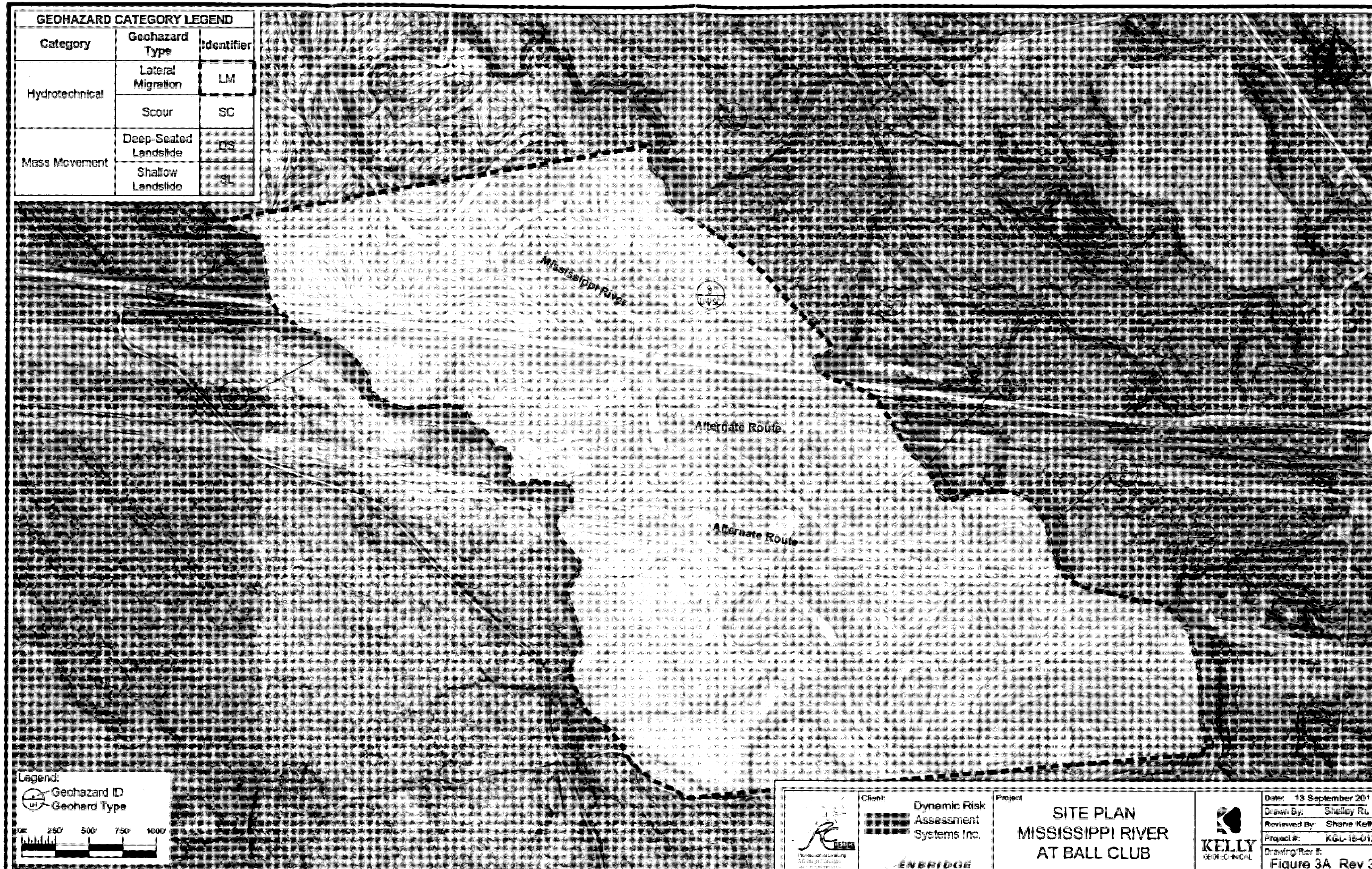

GEOHAZARD CATEGORY LEGEND		
Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL

Client: Dynamic Risk Assessment Systems Inc.

ENBRIDGE

Project: SITE PLAN MISSISSIPPI RIVER AT BALL CLUB

KELLY GEOTECHNICAL

Date:	13 September 201
Drawn By:	Shelley R.
Reviewed By:	Shane Kelly
Project #:	KGL-15-012
Drawing/Rev #:	Figure 3A Rev 3

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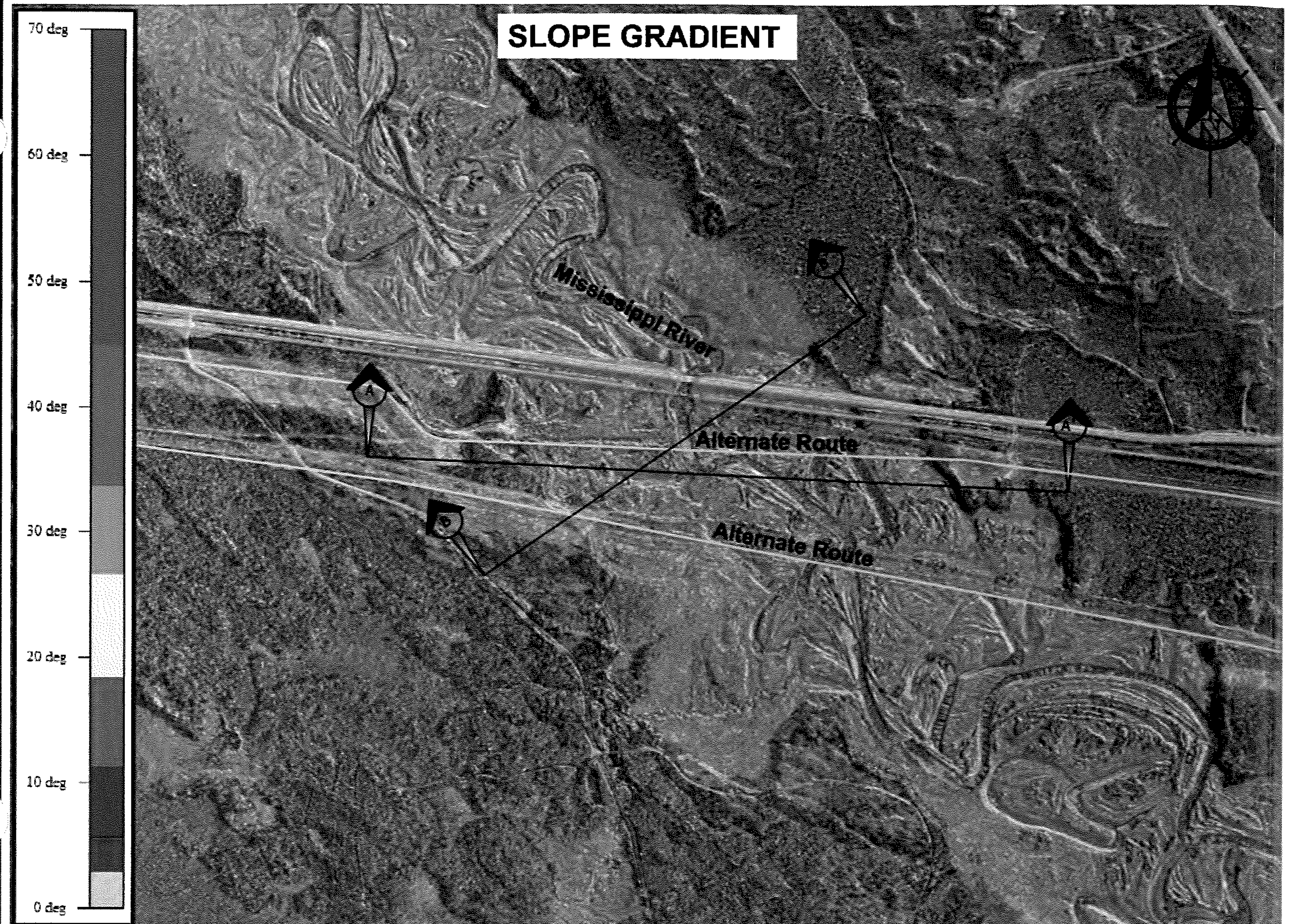
SLOPE GRADIENT



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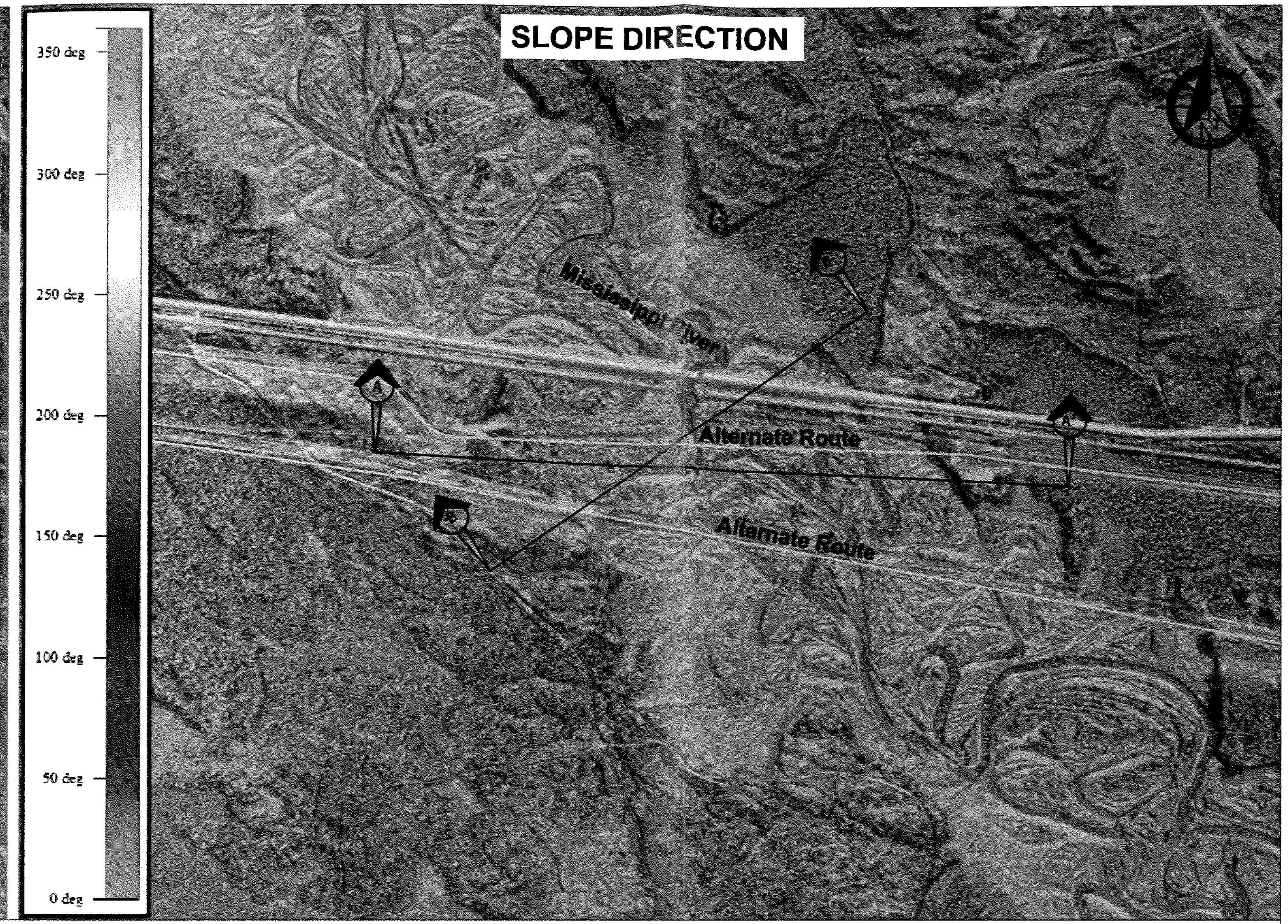

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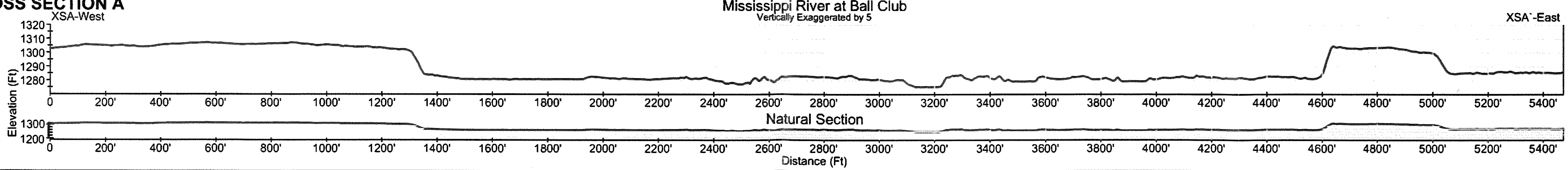

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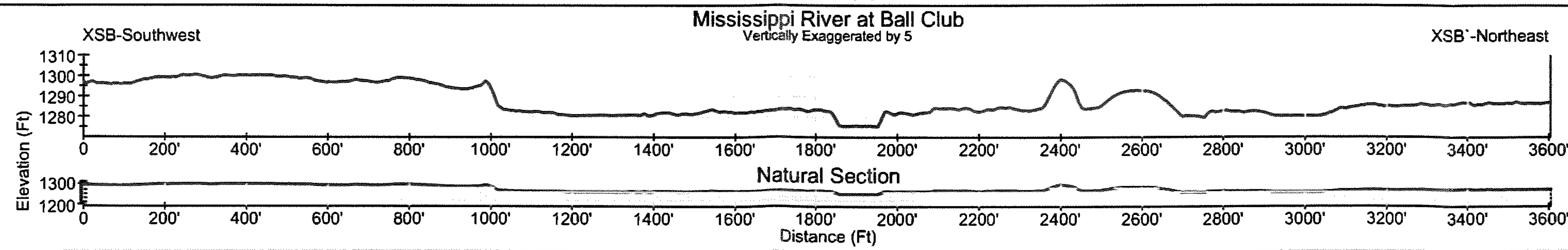

Plan Scale

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RC DESIGN Professional Drafting & Design Services	Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project TERRAIN ANALYSIS SUMMARY MISSISSIPPI RIVER AT BALL CLUB	KELLY GEOTECHNICAL

Date:	13 September 2016
Drawn By:	Shelley Ruiz
Reviewed By:	Shane Kelly
Project #:	KGL-15-012
Drawing/Rev #:	Figure 3B Rev 3

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GEOHAZARD CATEGORY LEGEND		
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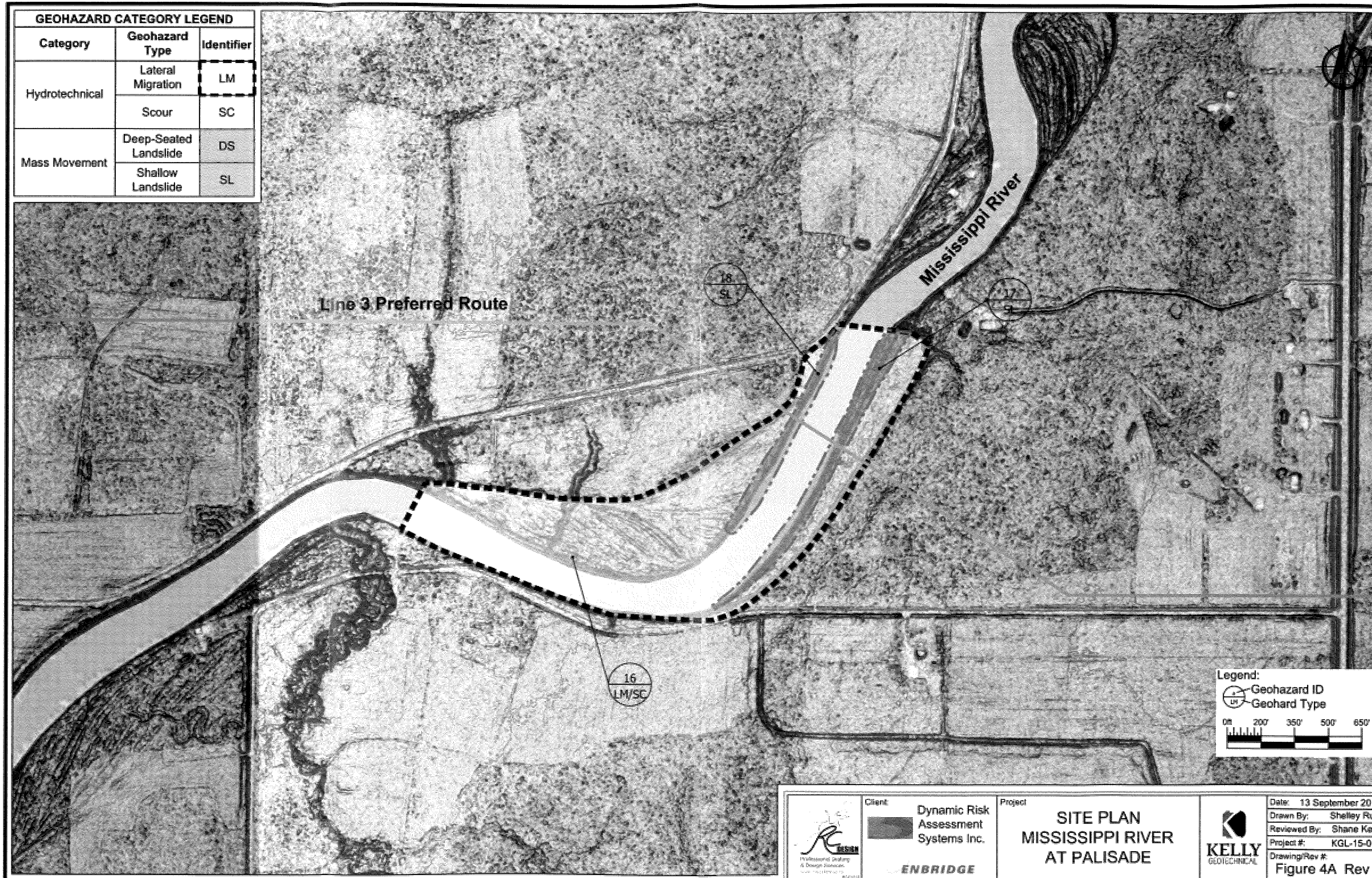
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



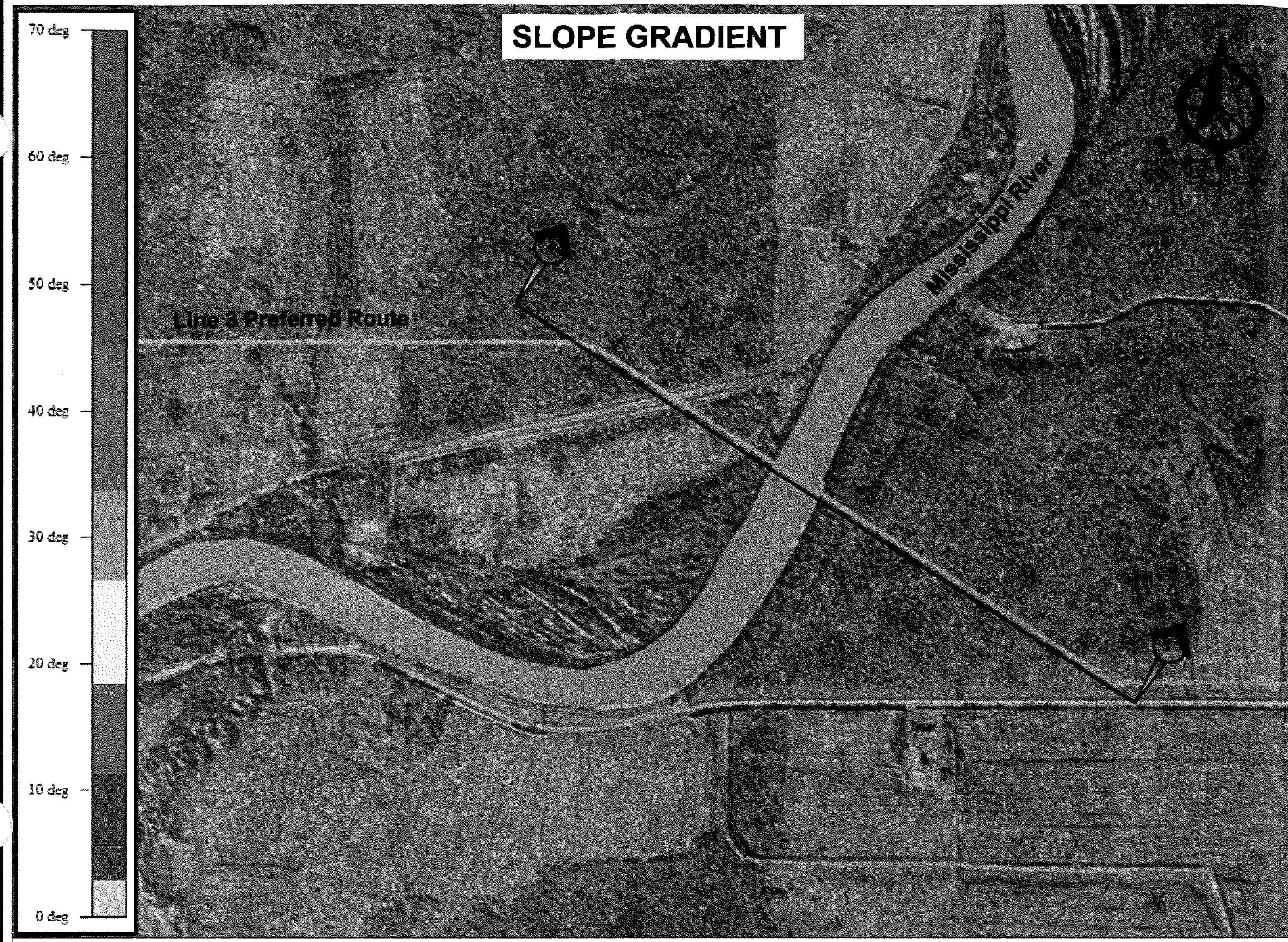
Client: Dynamic Risk Assessment Systems Inc.

ENBRIDGE

Project: SITE PLAN MISSISSIPPI RIVER AT PALISADE

KELLY GEOTECHNICAL

Date:	13 September 201
Drawn By:	Shelley Ru
Reviewed By:	Shane Kelly
Project #:	KGL-15-012
Drawing/Rev #:	Figure 4A Rev 3



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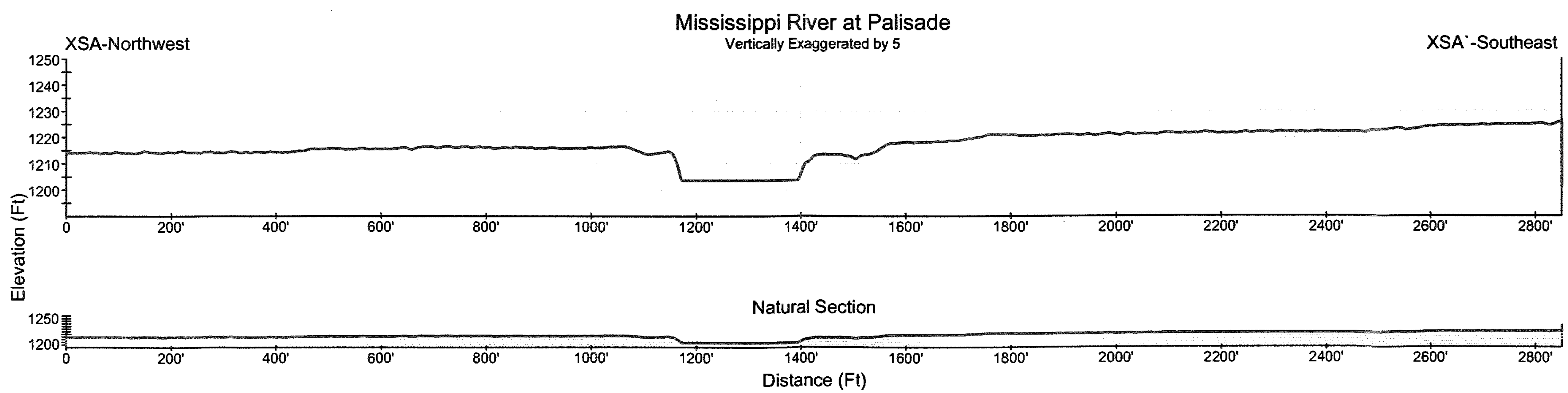

Plan Scale

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Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project: TERRAIN ANALYSIS SUMMARY MISSISSIPPI RIVER AT PALISADE	KELLY GEOTECHNICAL	Date: 13 September 2016
			Drawn By: Shelley Ruiz
			Reviewed By: Shane Kelly
			Project #: KGL-15-012
			Drawing/Rev #: Figure 4B Rev 3

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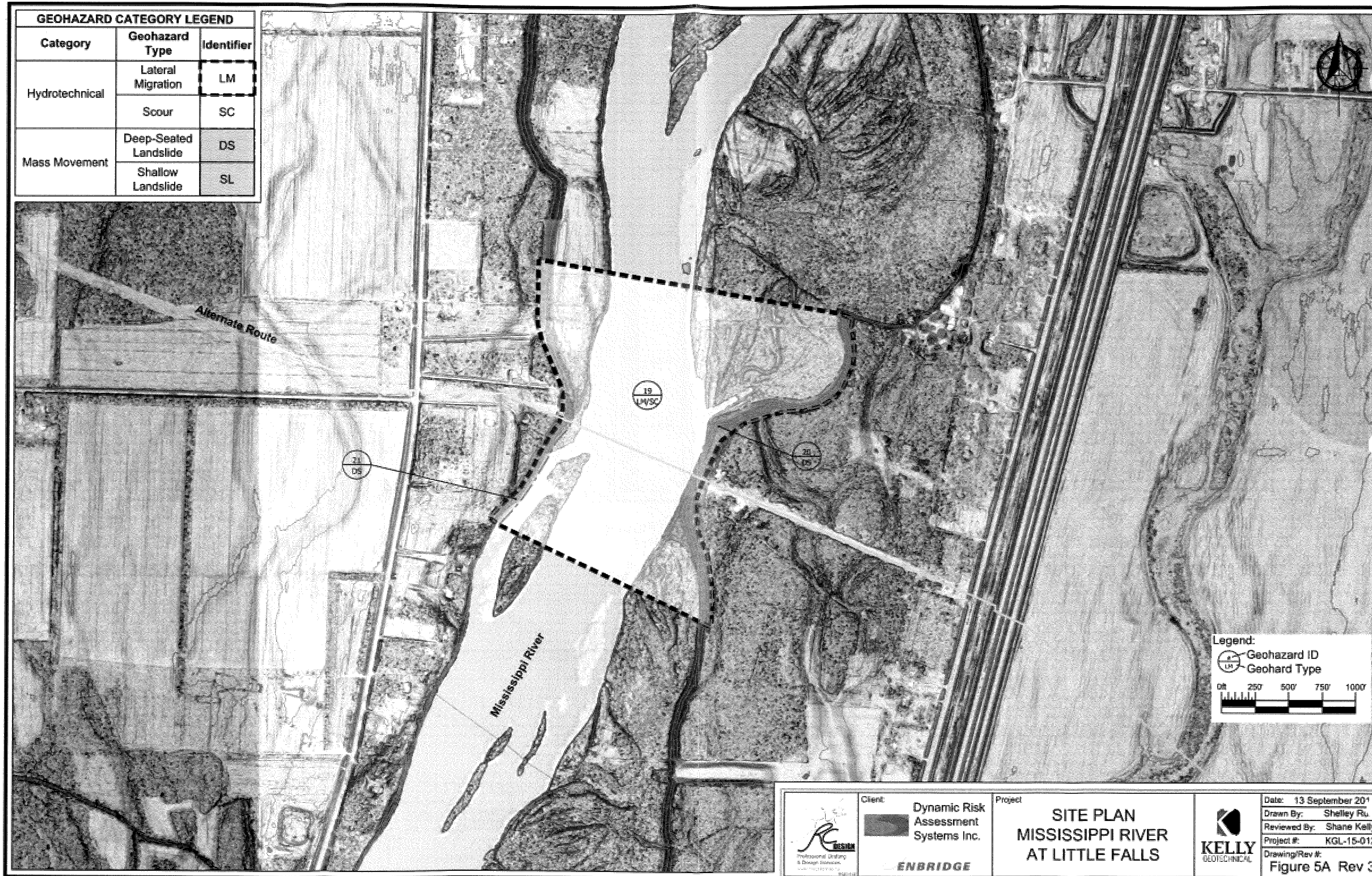

GEOHAZARD CATEGORY LEGEND		
Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL

Client:	Project		
Dynamic Risk Assessment Systems Inc. ENBRIDGE	SITE PLAN MISSISSIPPI RIVER AT LITTLE FALLS	KELLY GEOTECHNICAL	Date: 13 September 20 Drawn By: Shelley Ru Reviewed By: Shane Kelly Project #: KGL-15-012 Drawing/Rev #: Figure 5A Rev 3

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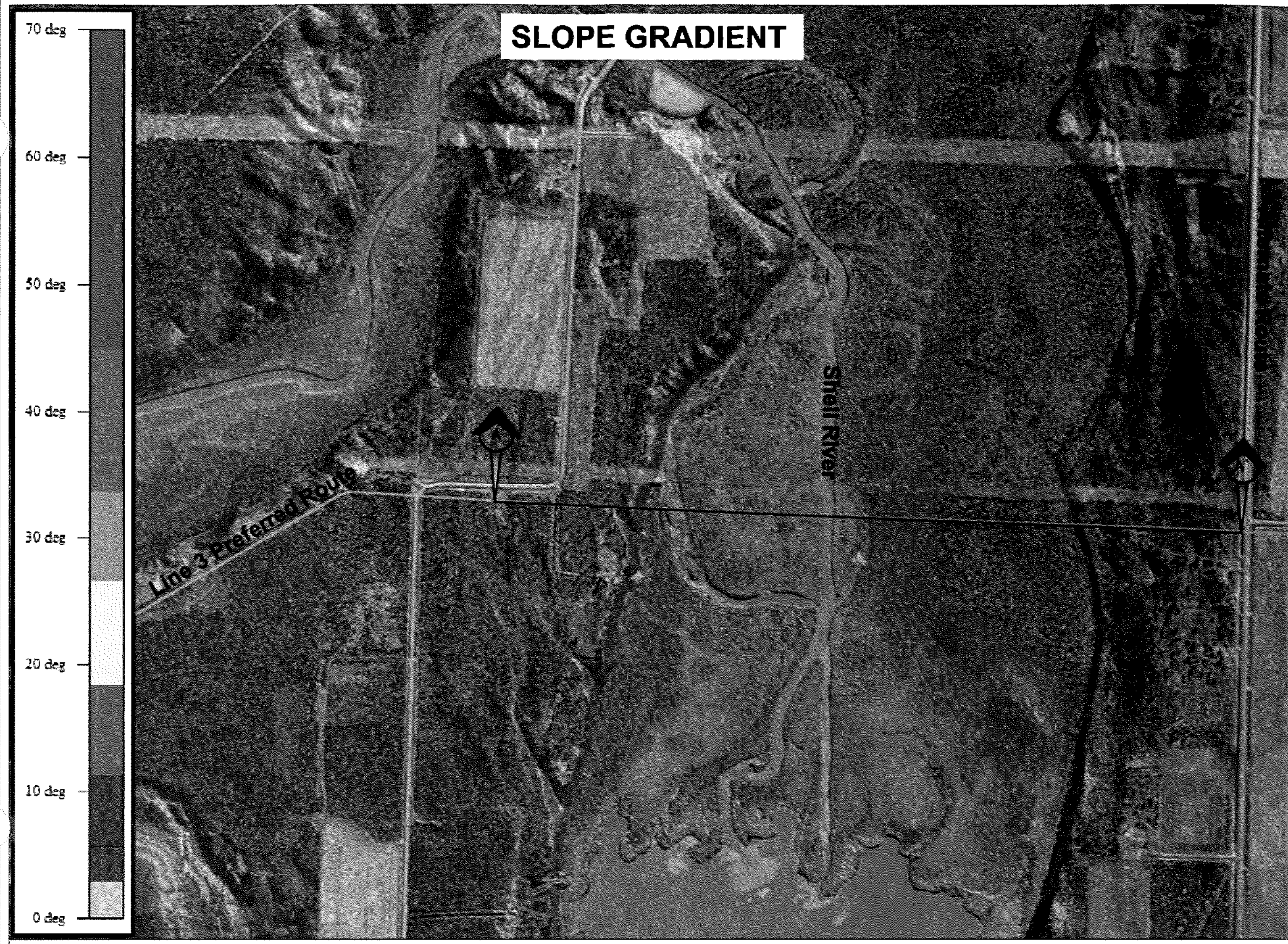

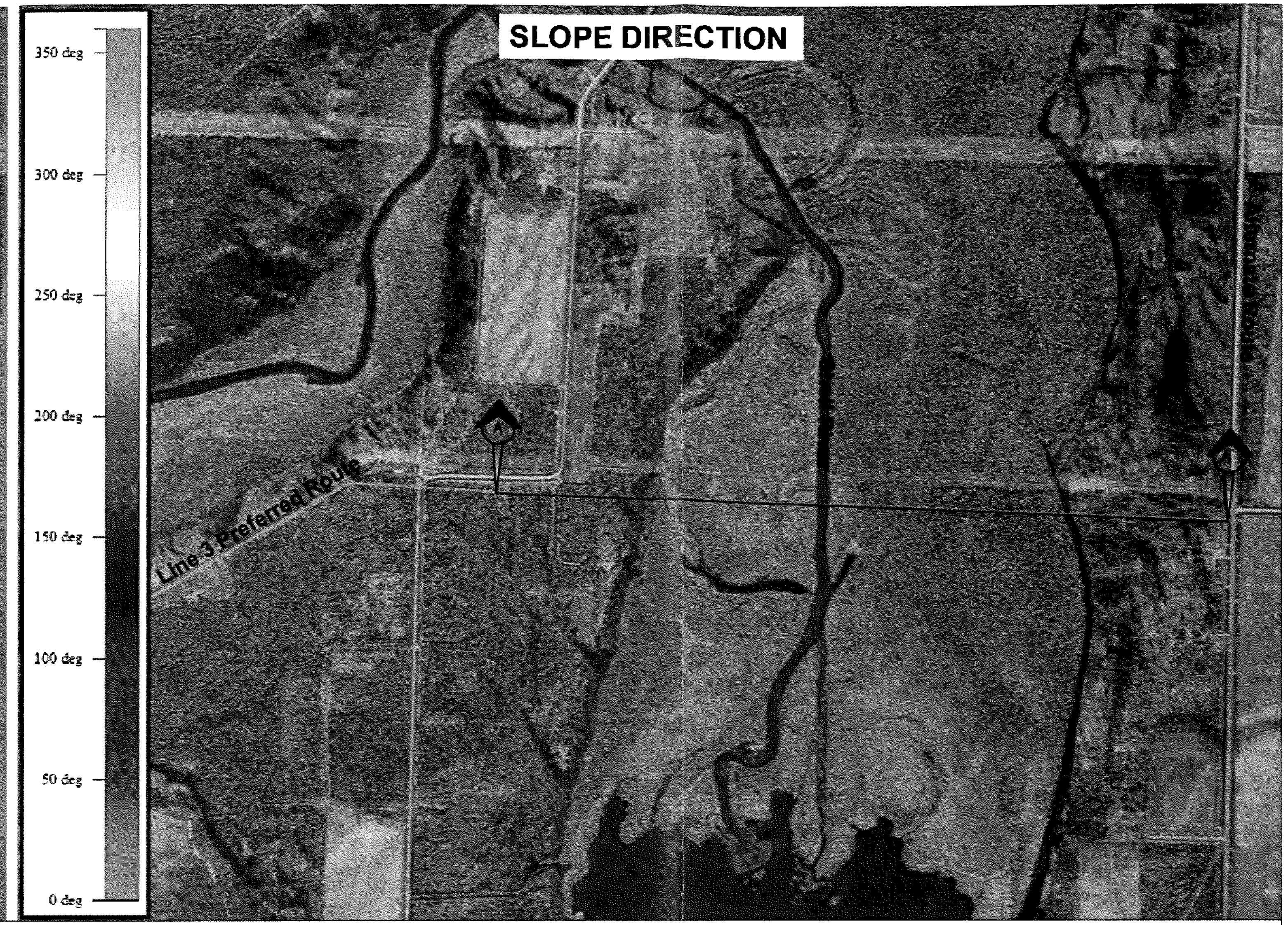

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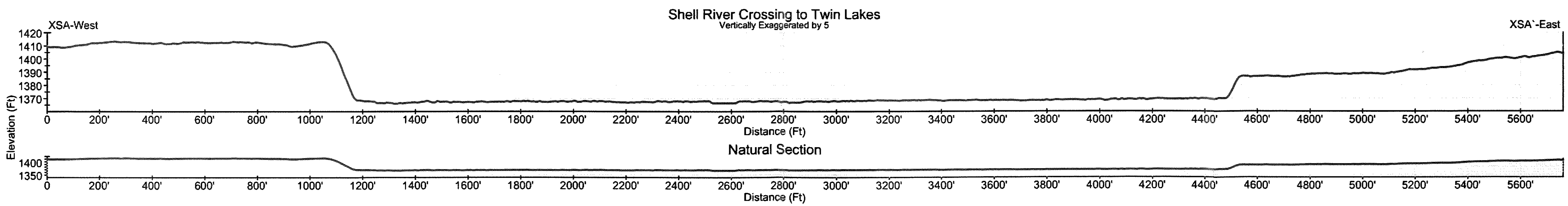

Plan Scale

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Client: Dynamic Risk Assessment Systems Inc.

ENBRIDGE

Project: TERRAIN ANALYSIS SUMMARY SHELL RIVER AT TWIN LAKES

KELLY GEOTECHNICAL

Date:	13 September 2016
Drawn By:	Shelley Ruiz
Reviewed By:	Shane Kelly
Project #:	KGL-15-012
Drawing/Rev #:	Figure 7B Rev 3

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GEOHAZARD CATEGORY LEGEND		
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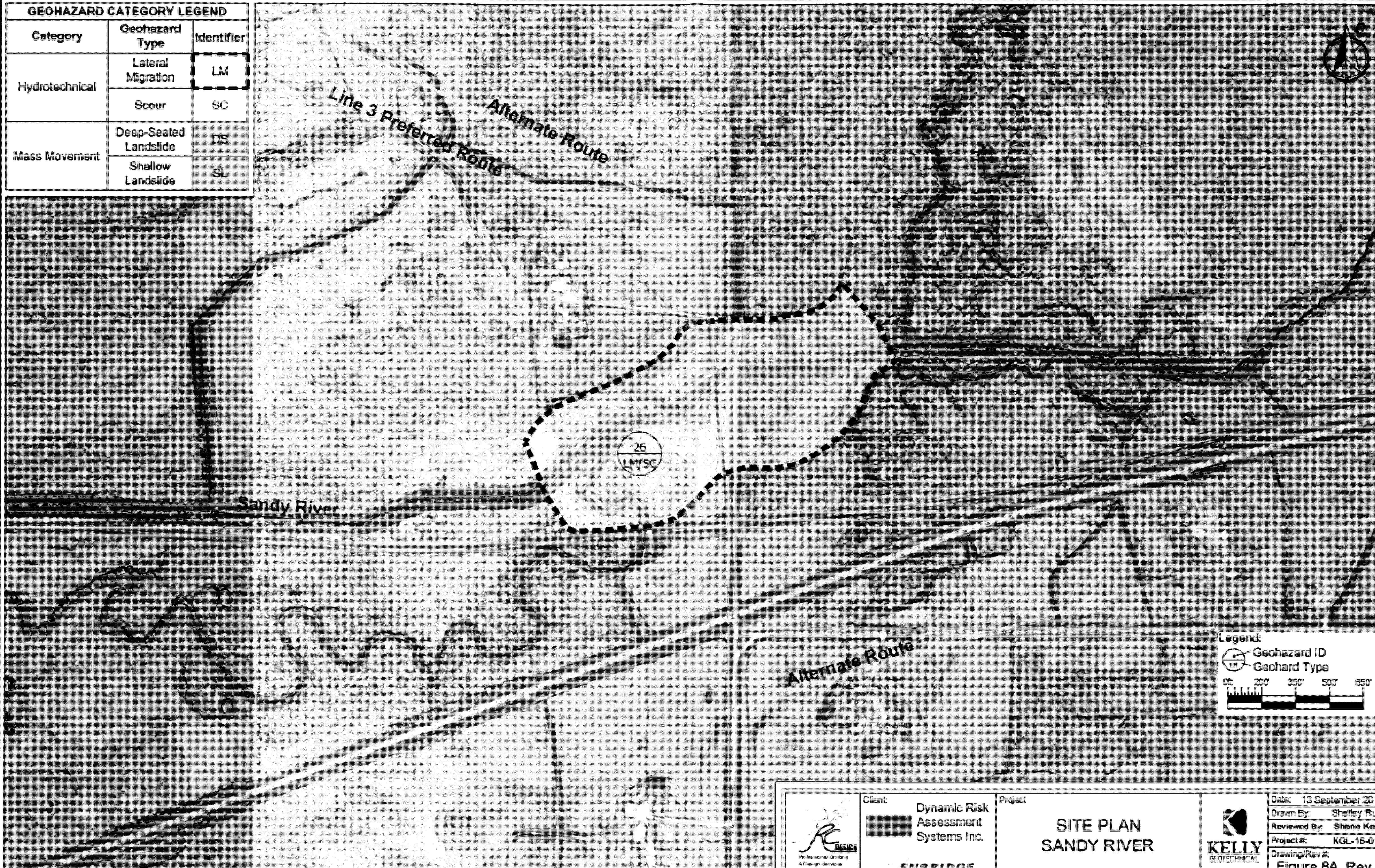
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



Client: Dynamic Risk Assessment Systems Inc.
ENBRIDGE

Project: SITE PLAN SANDY RIVER

KELLY GEOTECHNICAL

Date: 13 September 201
Drawn By: Shelley Ru.
Reviewed By: Shane Kelly
Project #: KGL-15-012
Drawing/Rev #: Figure 8A Rev 3

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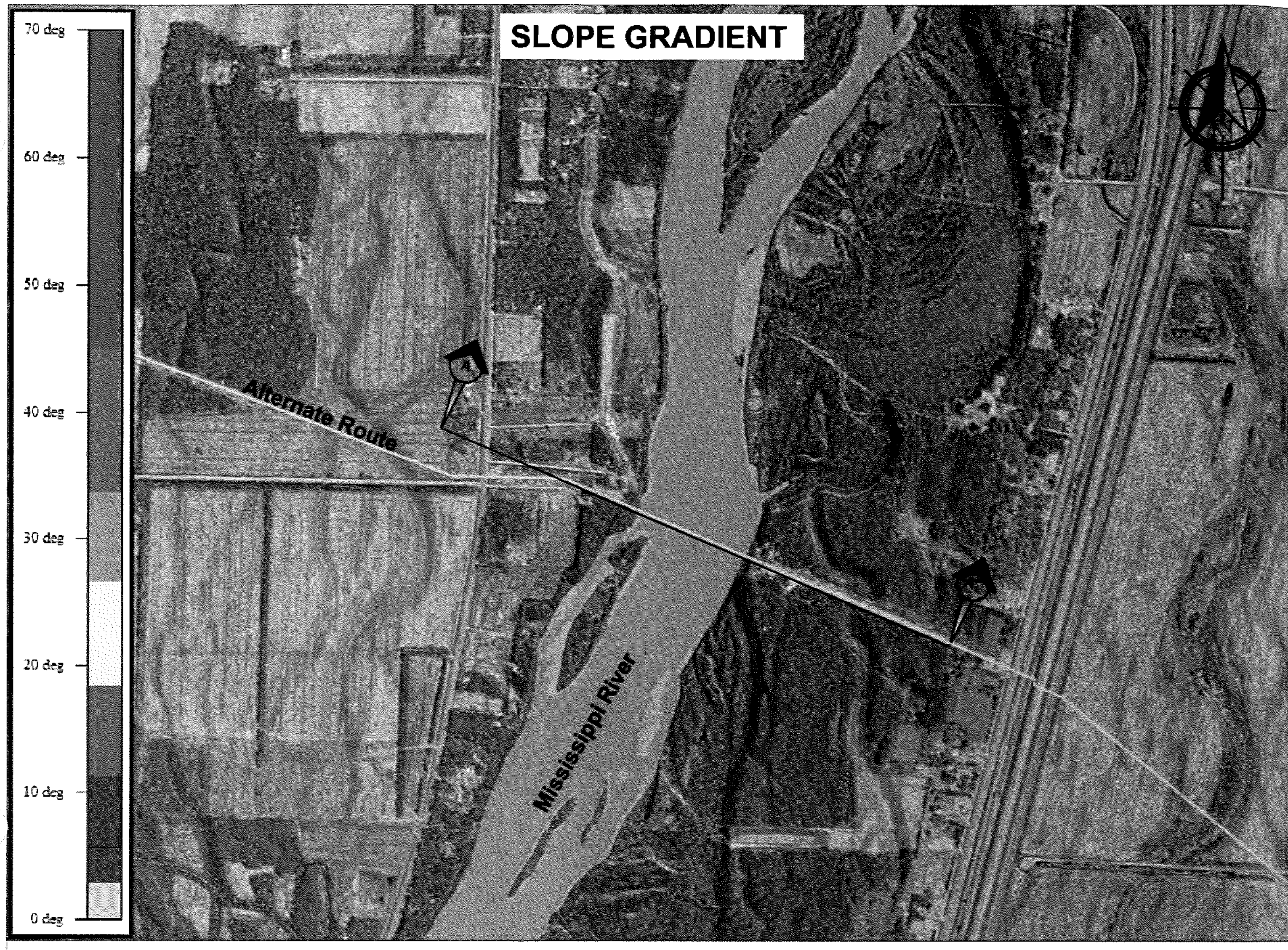

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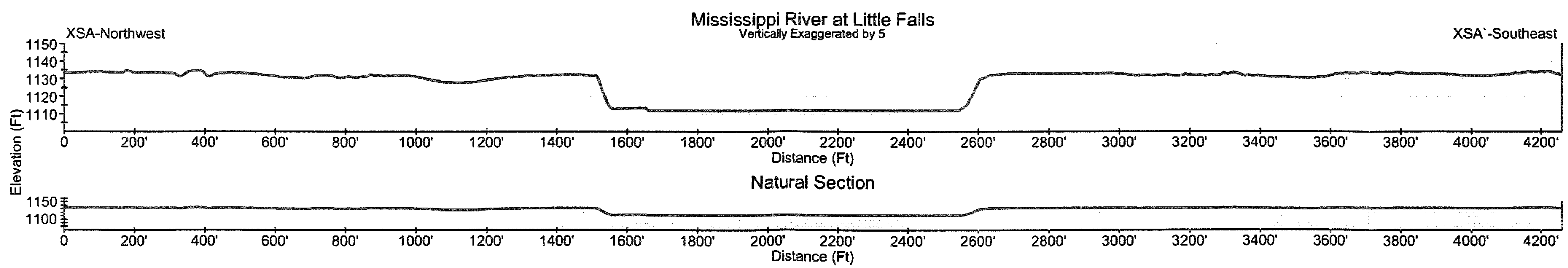

Plan Scale
0ft 500' 1000' 1500' 2000'

Client:	Project		
Dynamic Risk Assessment Systems Inc. / ENBRIDGE	TERRAIN ANALYSIS SUMMARY MISSISSIPPI RIVER AT LITTLE FALLS	Date:	13 September 2016
		Drawn By:	Shelley Ruiz
		Reviewed By:	Shane Kelly
		Project #:	KGL-15-012
		Drawing/Rev #:	Figure 5B Rev 3

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KELLY GEOTECHNICAL

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GEOHAZARD CATEGORY LEGEND		
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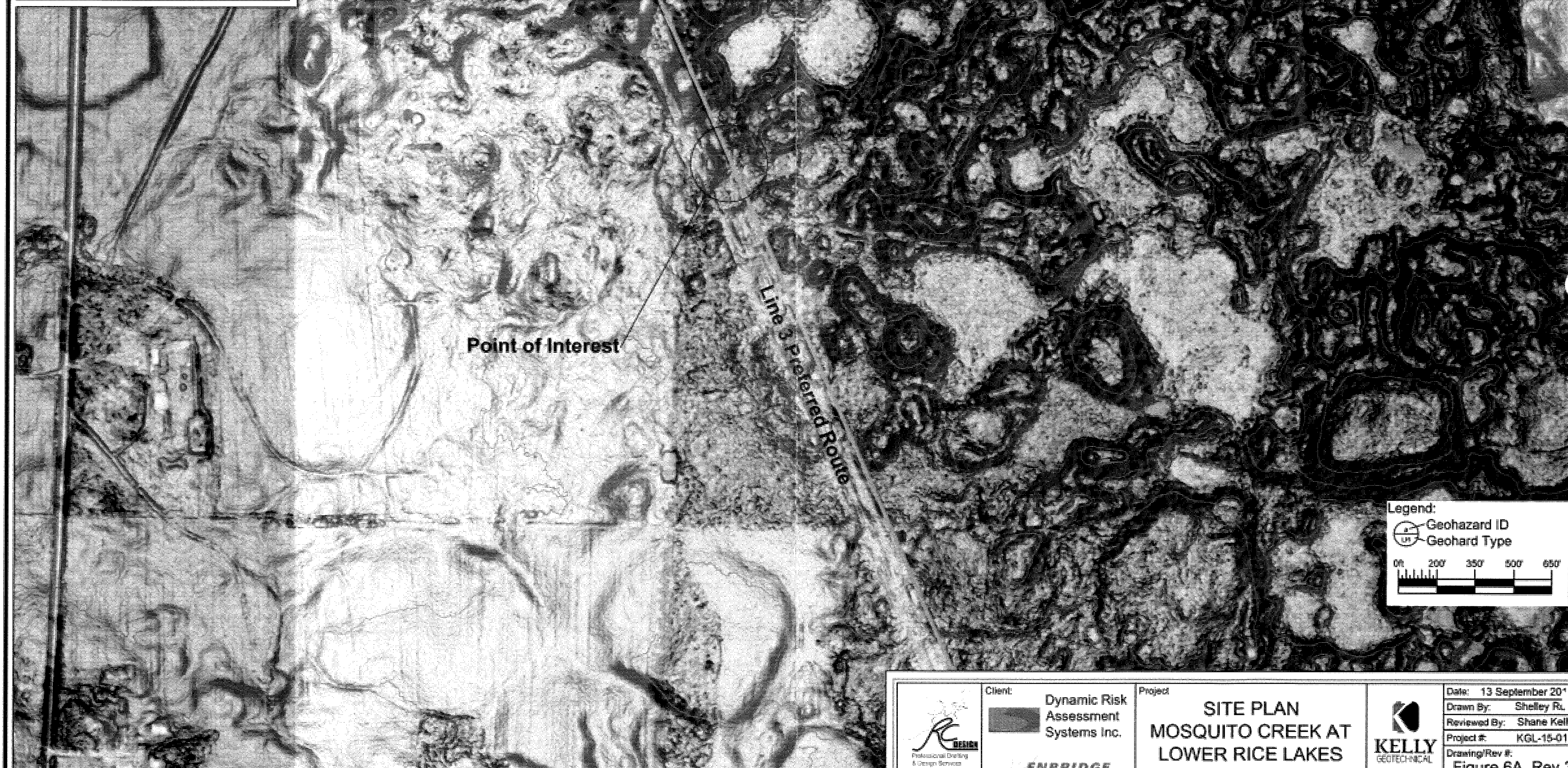
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project: SITE PLAN MOSQUITO CREEK AT LOWER RICE LAKES	KELLY GEOTECHNICAL	Date: 13 September 20'
			Drawn By: Shelley R.
			Reviewed By: Shane Kelly
			Project #: KGL-15-012
			Drawing/Rev #: Figure 6A Rev 3

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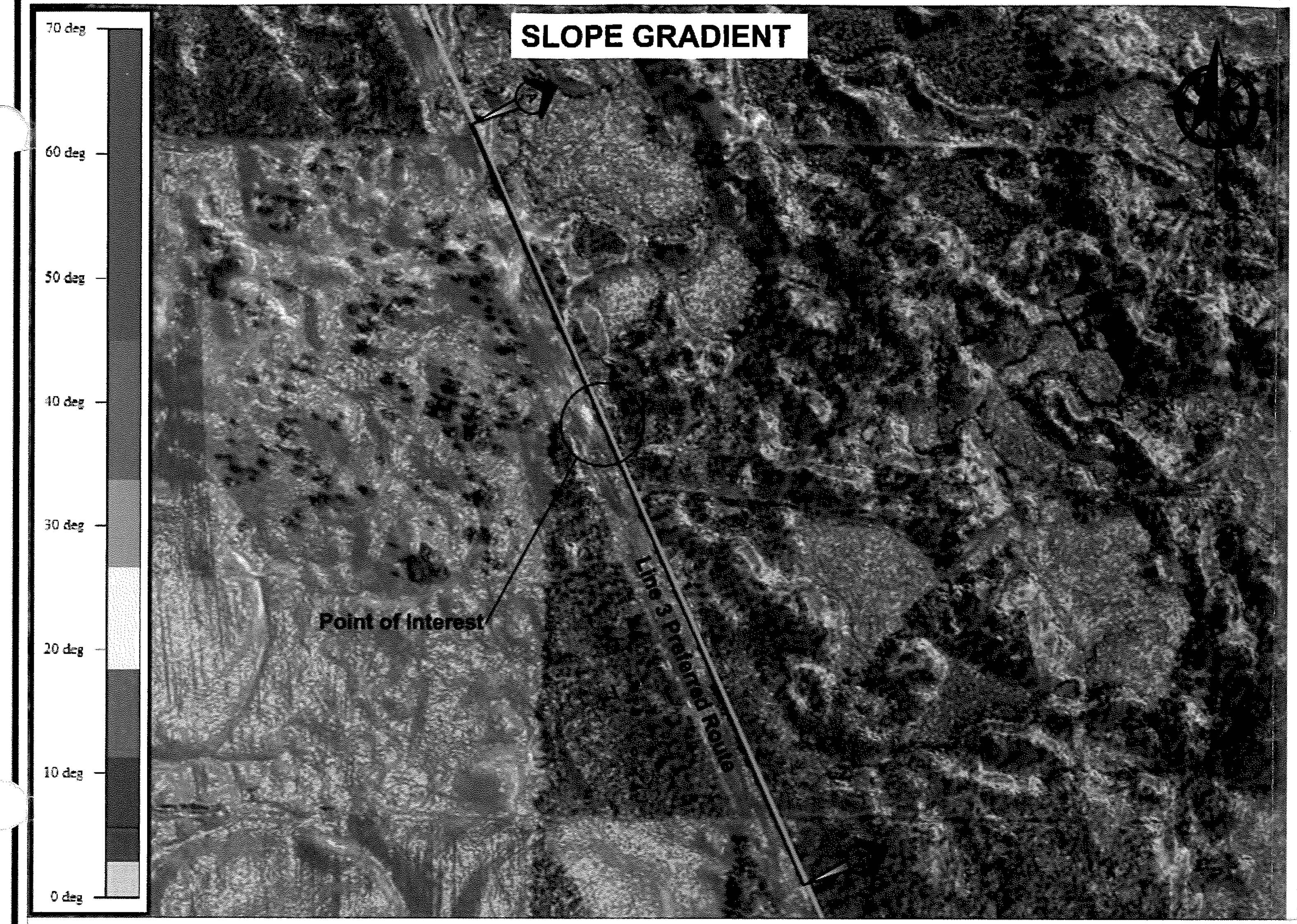

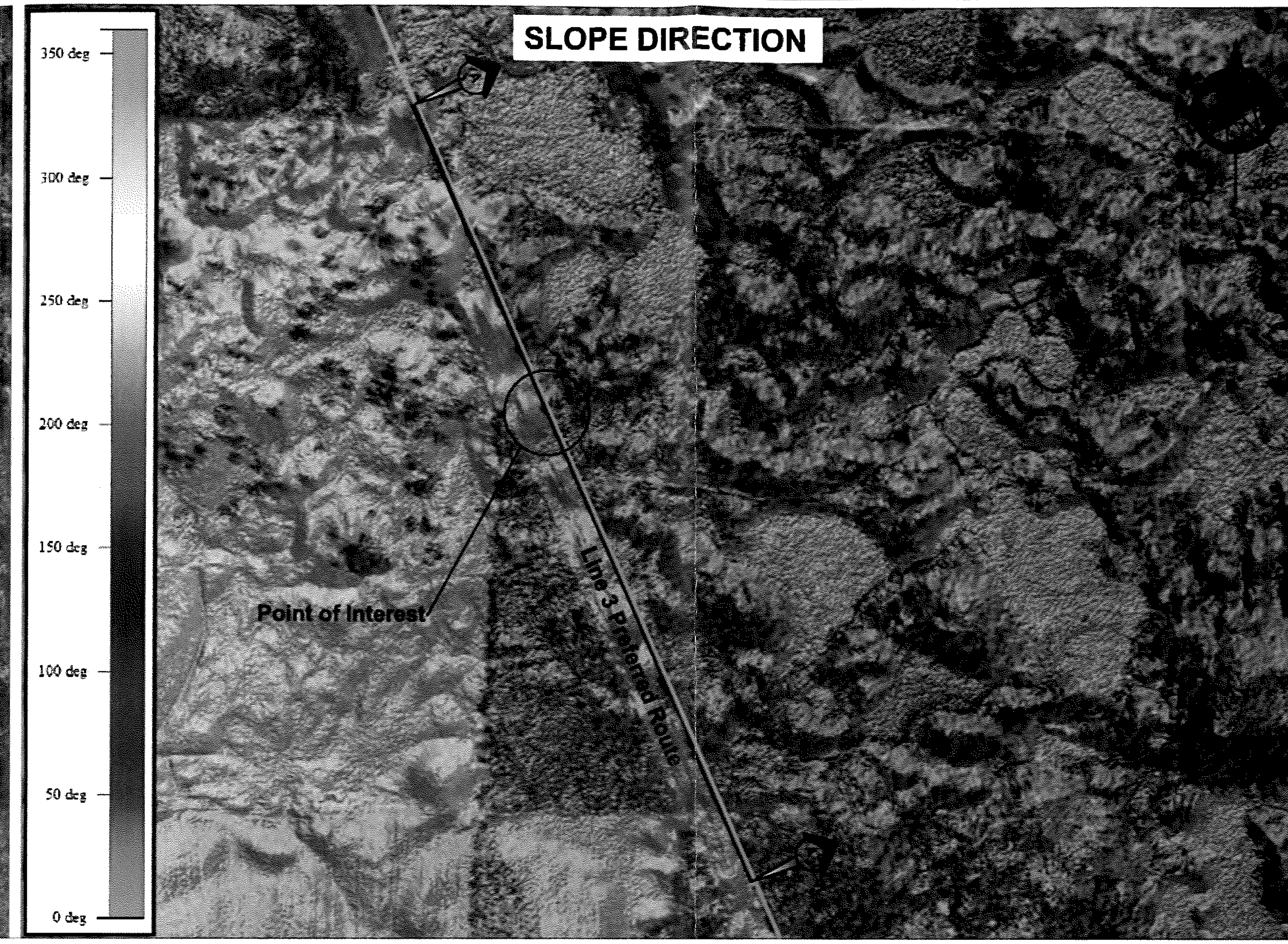

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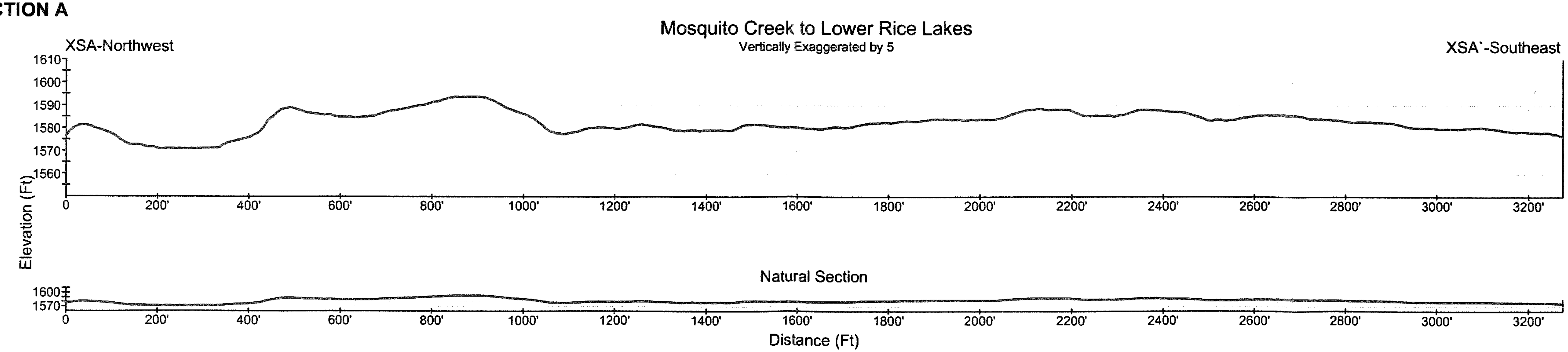

Plan Scale

0ft 250' 500' 750' 1000'

Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project: TERRAIN ANALYSIS SUMMARY MOSQUITO CREEK TO LOWER RICE LAKES	KELLY GEOTECHNICAL	Date: 13 September 2016
			Drawn By: Shelley Ruiz
			Reviewed By: Shane Kelly
			Project #: KGL-15-012
			Drawing/Rev #: Figure 6B Rev 3

RC DESIGN Professional Drafting & Design Services

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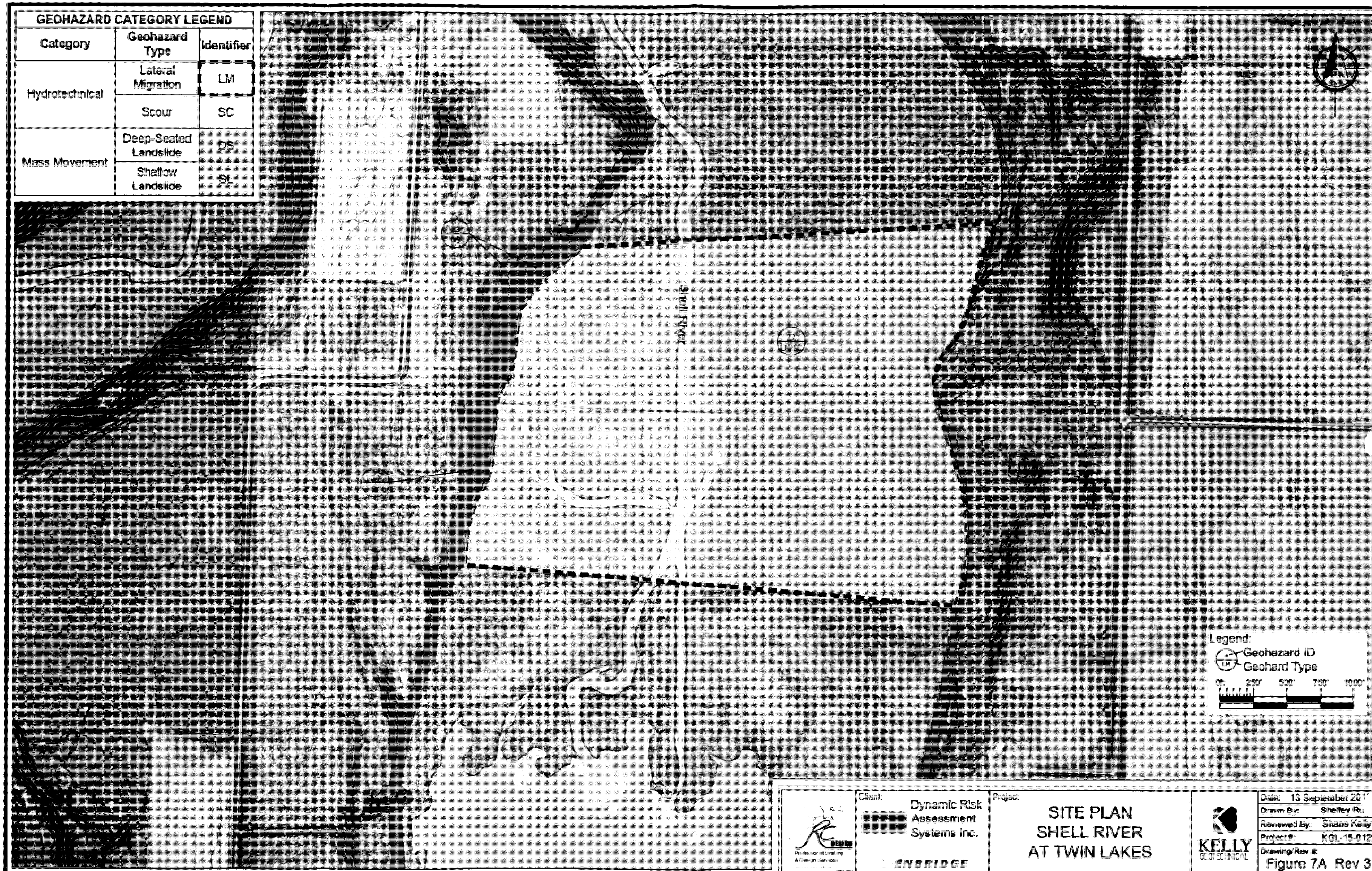
GEOHAZARD CATEGORY LEGEND		
Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



RC Design Professional Drafting & Design Services	Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project: SITE PLAN SHELL RIVER AT TWIN LAKES	KELLY GEOTECHNICAL	Date: 13 September 201' Drawn By: Shelley Ru Reviewed By: Shane Kelly Project #: KGL-15-012 Drawing/Rev #: Figure 7A Rev 3

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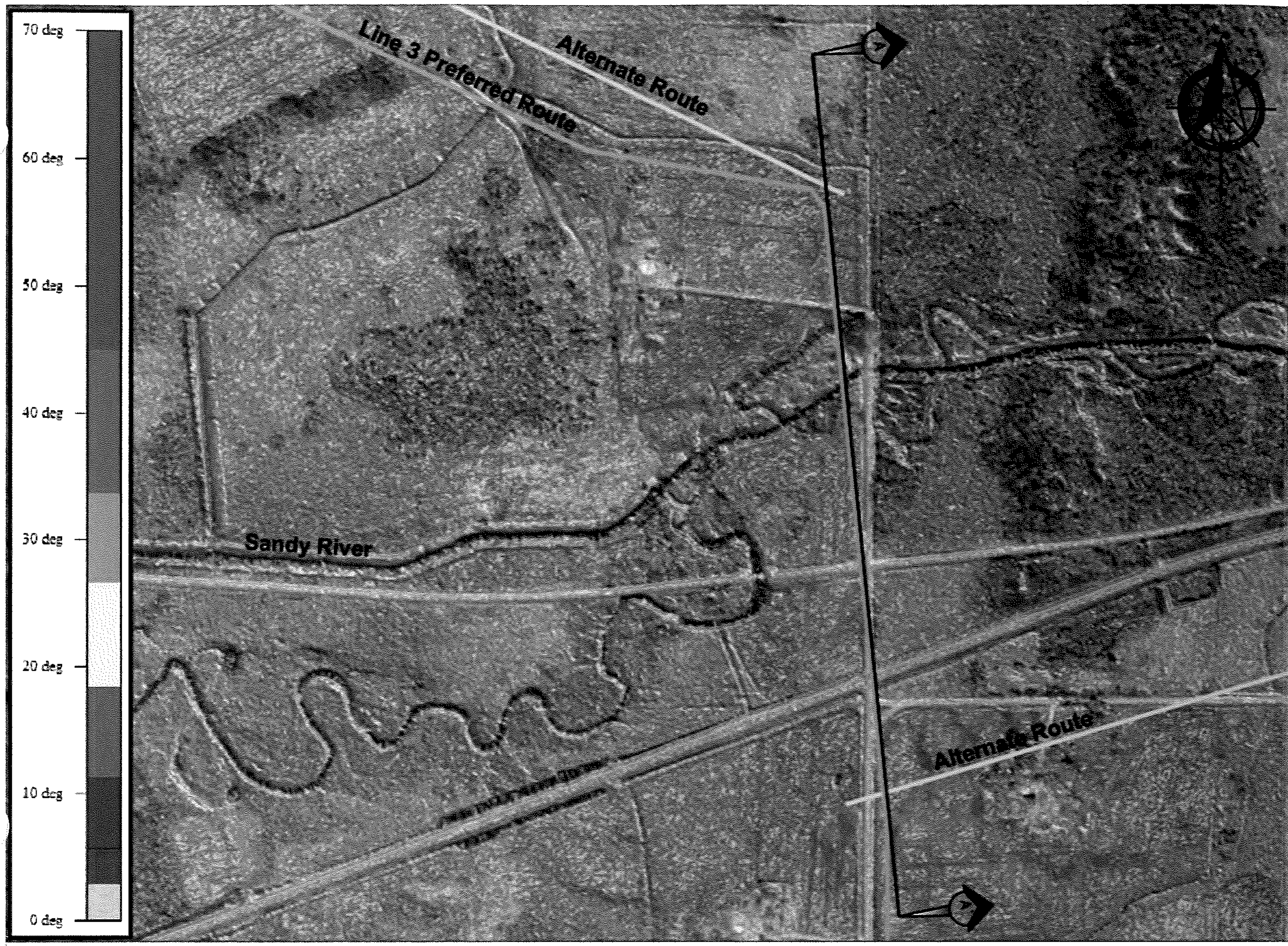

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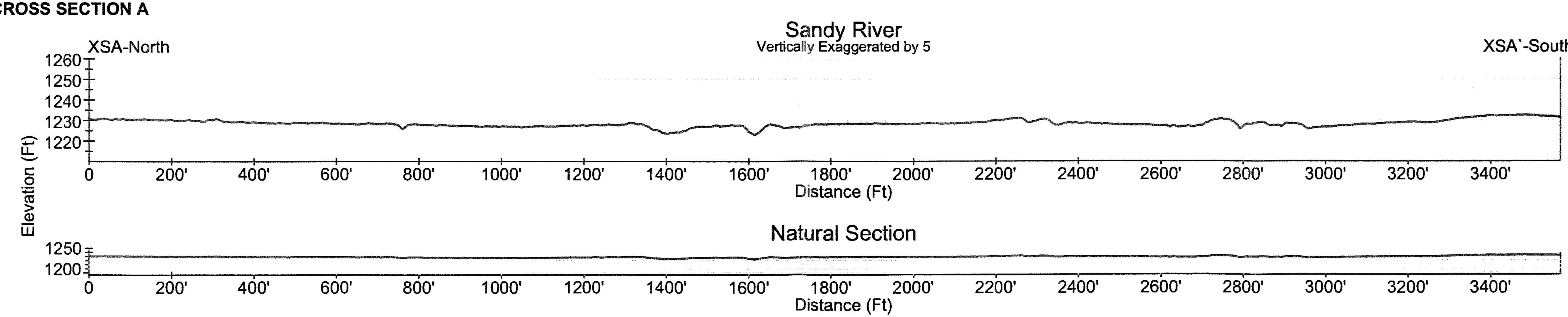
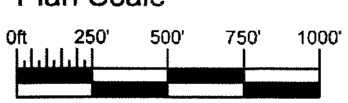


Plan Scale



RC DESIGN Professional Drafting & Design Services	Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project: TERRAIN ANALYSIS SUMMARY SANDY RIVER	KELLY GEOTECHNICAL	Date: 13 September 2016 Drawn By: Shelley Ruiz Reviewed By: Shane Kelly Project #: KGL-15-012 Drawing/Rev #: Figure 8B Rev 3

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APPENDIX A

Geohazard Type	**Lateral Migration**	Lateral migration is associated with the lateral scouring and movement of a stream channel due to erosion of stream banks. This hazard requires the presence of a stream channel and the presence of erodible soils on the banks, or both.
Geohazard Category	Hydrotechnical	
Hazard Identifier	LM	

Factor	Comments / Considerations	Values
I	This hazard is generally applicable to all stream channels and occurrence is adjusted for site conditions.	0 Not possible (only use for areas where controls are in place to prevent natural erosion). 0.01 Theoretically possible only 0.1 Credible. In region with evidence of past occurrence but not directly at site. 1 Evidence of past occurrence at site
F	Frequency of occurrence is based on the flow conditions in the stream that generate significant erosion. Generally this is related to season fluctuations or flooding at a defined return period.	**In absence of defined site-specific frequency of occurrence information apply the following** 0.001 once every 1000 years 0.01 once every 100 years 0.1 once every 10 years 1 once every 1 year
V	Lateral migration can lead to the removal of soil cover, or even pipe support below the pipeline where channel migration extends in-shore past the sag-bend at the limit of a deep burial segment of the watercourse crossing. Potential effects can vary from exposure of the pipeline through to rupture in the extreme case where an unsupported pipeline segment is exposed to vibration induced from moving water and impacts from debris.	**For the effect(s) being assessed as part of the work use the following as a basis** 0 Hazard occurrence would not result in effect(s). 0.001 1 in 1,000 occurrences would result in effect(s). 0.01 1 in 100 occurrences would result in effect(s). 0.1 1 in 10 occurrences would result in effects(s). 1 Every occurrence results in effect(s).
M	Mitigation options that act to reduce the frequency, or occurrence of this geohazard include elements installed to protect the stream banks from erosion or to attenuate flow. Mitigation options that act to reduce vulnerability of the pipeline to potential effects could include the use of additional pipeline wall thickness or protective coatings, or deep trenchless installation methods such as HDD.	**Chose only ONE factor** 0.001 Deep burial construction using trenchless methods with entry/exit beyond the limits of erosion as defined by detailed, site-specific hydrotechnical design. 0.01 Sag bend locations for trenched or isolated crossing installation are located beyond the limits of long-term erosion as defined by detailed, site-specific hydrotechnical design. 0.01 Armoured river banks, flow attenuation, or stream training to be maintained throughout life of the pipeline. 0.1 Use heavy wall pipe and/or concrete coated pipe.

Susceptibility (S) to the geohazard within the hazard impact zone along pipeline route segment (j) is calculated as: $S_{(j)} = I_{(j)} \times F_{(j)} \times V_{(j)} \times M_{(j)}$	I =	Occurrence factor. Factor from 0 to 1.
	F =	Frequency of Occurrence. Expressed in events per year.
	V =	Vulnerability factor. Factor expressing potential damage during occurrence.
	M =	Mitigation Factor. Reduction factor for use of a specific design mitigation.

Geohazard Type	**Scour**	Scour is associated with vertical scouring within an existing stream channel. This hazard is present in all flowing stream channels and is generally controlled by the shape of the channel, rate of flow and the type of stream bed materials.
Geohazard Category	Hydrotechnical	
Hazard Identifier	SC	

Factor	Comments / Considerations	Values
I	This hazard is generally applicable to all stream channels and occurrence is adjusted for site conditions.	0 Not possible (only use for areas where controls are in place to prevent natural erosion). 0.01 Theoretically possible only 0.1 Credible. In region with evidence of past occurrence but not directly at site. 1 Evidence of past occurrence at site
F	Frequency of occurrence is related directly to the potential for occurrence of scour at any point in the hazard area to a depth less than the minimum cover requirements as set out in the pipeline design requirements.	**<u>Use the flood return period used to establish the burial depth and cover requirements in the watercourse crossing design.</u> In absence of defined return periods the following can be used as a guide** 0.001 once every 1000 years 0.01 once every 100 years 0.1 once every 10 years 1 once every 1 year
V	Scour can lead to the removal of soil cover, or even pipe support below the pipeline within the deep burial segment of the watercourse crossing. Potential effects can vary from exposure of the pipeline through to rupture in the extreme case where an unsupported pipeline segment is exposed to vibration induced from moving water and impacts from debris.	**The basis of this value should be based on documented system performance over time, or developed from datasets of hazard occurrences and effects in comparable area. In the absence of such data use the following as a basis:** 0 Hazard occurrence would not result in effect(s). 0.001 1 in 1,000 occurrences would result in effect(s). 0.01 1 in 100 occurrences would result in effect(s). 0.1 1 in 10 occurrences would result in effects(s). 1 Every occurrence results in effect(s).
M	Mitigation options that act to reduce the frequency, or occurrence of this geohazard include elements installed to protect the stream bed from erosion or to attenuate flow. Mitigation options that act to reduce vulnerability of the pipeline to potential effects could include the use of additional pipeline wall thickness or protective coatings, or deep trenchless installation methods such as HDD.	**Chose only ONE factor** 0.001 Deep burial construction using trenchless methods that results in a minimum cover depth at least 10x required depth for a standard trenched cover depth within the hazard area. 0.01 Armoured channel, flow attenuation, or stream training to be maintained throughout life of the pipeline. 0.1 Use heavy wall pipe and/or concrete coated pipe.

Susceptibility (S) to the geohazard within the hazard impact zone along pipeline route segment (j) is calculated as: $S_{(j)} = I_{(j)} \times F_{(j)} \times V_{(j)} \times M_{(j)}$	I =	Occurrence factor. Factor from 0 to 1.
	F =	Frequency of Occurrence. Expressed in events per year.
	V =	Vulnerability factor. Factor expressing potential damage during occurrence.
	M =	Mitigation Factor. Reduction factor for use of a specific design mitigation.

Geohazard Type	**Deep-seated Landslide**	Deep-seated landslide is associated with the movement of large masses of soil and/or rock on a rotational or complex failure surface. The sliding soil mass remains largely intact at initial sliding, but it may become disaggregated or blocky in complex failures. Retrogression above the initial slide limit is common.
Geohazard Category	Mass Movement	
Hazard Identifier	DS	

Factor	Comments / Considerations	Values
I	This hazard is present on slopes where soil or rock materials have insufficient strength to resist downward forces and/or where high or changing groundwater pressures may exist.	0 Not possible 0.01 Theoretically possible only. 0.1 Credible. In poorly drained region near standing water sources or near the water table, but trench soils are typically unsaturated. 1 Trench soils are wet, organic, or within a body of water.
F	Frequency of occurrence is related directly to the potential for weak geological units to be present on a slope combined with the potential for the slopes to become steeper, the slopes to become loaded; and/or the potential for significant and/or rapid fluctuations in the groundwater table to exist. These conditions are typical in river valleys as a result of flooding or changes in long term precipitation patterns; on slopes as a result of construction or other anthropogenic activities, or as a result of weakening geological units or reactivation of old slides.	**In absence of defined site-specific frequency of occurrence for triggering mechanisms apply the following** 0.001 once every 1000 years 0.01 once every 100 years 0.1 once every 10 years 1 once every 1 year (use as a minimum for active slides)
V	Sliding of large blocks or segments of intact ground can impose significant forces on the pipeline in the direction of movement. In addition to the slide mass, there is considerable shear forces generated at the boundaries of the slide where the pipeline may cross. Effects are generally significant where buried pipelines are restrained in the sliding mass unless the rate of movement is very slow and strain relief is possible either mechanically or passively by relative movement of the pipeline through the soil mass. Effects are dependent on the location of the pipeline in the slide mass and direction of sliding relative to pipeline direction. The high strains typically imposed can lead to bending, buckling, and rupture.	**The basis of this value should be based on documented system performance over time, or developed from datasets of hazard occurrences and effects in comparable area. In the absence of such data use the following as a basis:** 0 Hazard occurrence would not result in effect(s). 0.001 1 in 1,000 occurrences would result in effect(s). 0.01 1 in 100 occurrences would result in effect(s). 0.1 1 in 10 occurrences would result in effects(s). 1 Every occurrence results in effect(s).
M	Mitigation options that act to reduce the frequency, or occurrence of this geohazard include slide stabilization measures including drainage, slope flattening, and slope buttressing. Mitigation options that act to reduce vulnerability could include deep burial below the slide limits; monitoring and strain relief for very slow moving slides; surface installation on sliding supports; and/or shallow burial and monitoring.	Chose only **ONE** factor or base choices on performance of assessed systems and conditions in comparable area 0.001 Deep burial to depths below potential slide. 0.01 Slide stabilization including designed buttresses, flattening and monitoring. 0.1 Slide stabilization using drainage measures only, or shallow burial. 0.5 Monitoring of pipeline movement through soil with strain relief program.

Susceptibility (S) to the geohazard within the hazard impact zone along pipeline route segment (j) is calculated as: $S_{(j)} = I_{(j)} \times F_{(j)} \times V_{(j)} \times M_{(j)}$	I =	Occurrence factor. Factor from 0 to 1.
	F =	Frequency of Occurrence. Expressed in events per year.
	V =	Vulnerability factor. Factor expressing potential damage during occurrence.
	M =	Mitigation Factor. Reduction factor for use of a specific design mitigation.

Geohazard Type	**Shallow Landslide**	Shallow landsliding is associated with small landslides typically less than several metres deep that have predominantly disaggregated failed soil masses. These slides are distinguished from deep-seated slides by the characteristics of the failed soil movements and shallow failure depths.
Geohazard Category	Mass Movement	
Hazard Identifier	SL	

Factor	Comments / Considerations	Values
I	This hazard is generally applicable to slopes in geological materials that are weak and/or subject to high groundwater pressures.	0 Not possible. 0.01 Theoretically possible only 0.1 Credible. In region with evidence of past occurrence but not directly at site. 1 Evidence of past occurrence at site
F	Frequency of occurrence is related directly to the potential for weak geological units to be present on a slope combined with the potential for the slopes to become steeper, the slopes to become loaded; and/or the potential for significant and/or rapid fluctuations in the groundwater table to exist. These conditions are typical in river valleys as a result of flooding or changes in long term precipitation patterns; on slopes as a result of construction or other anthropogenic activities, or as a result of weakening geological units or reactivation of old slides.	**<u>Use the triggering return period.</u> In absence of defined return periods the following can be used as a guide** 0.001 once every 1000 years 0.01 once every 100 years 0.1 once every 10 years 1 once every 1 year (use as a minimum for active slides)
V	Shallow land sliding can impose significant forces on a pipeline system where the span of pipe through the slide mass is unable to resist bending or shear. Effects are dependent on the location and orientation of the pipeline relative to slide movement. Shallow sliding may result in loss of cover or exposure of the pipe, and in larger slide extents or rapid failure can lead to bending, buckling, and rupture.	**The basis of this value should be based on documented system performance over time, or developed from datasets of hazard occurrences and effects in comparable area. In the absence of such data use the following as a basis:** 0 Hazard occurrence would not result in effect(s). 0.001 1 in 1,000 occurrences would result in effect(s). 0.01 1 in 100 occurrences would result in effect(s). 0.1 1 in 10 occurrences would result in effects(s). 1 Every occurrence results in effect(s).
M	Mitigation options that act to reduce the frequency, or occurrence of this geohazard include slide stabilization measures with drainage, slope flattening, and slope buttressing. Mitigation options that act to reduce vulnerability could include deep burial below the slide limits; monitoring and strain relief for very slow moving slides; surface installation on sliding supports; and/or shallow burial with low friction wrap and monitoring.	**Chose only ONE factor** 0.001 Deep burial to depths below potential slide. 0.01 Slide stabilization including designed buttresses, flattening and monitoring. 0.1 Slide stabilization using drainage measures only, or monitoring with shallow burial and low friction pipe wrap. 0.5 Monitoring of potential landslide areas only.

Susceptibility (S) to the geohazard within the hazard impact zone along pipeline route segment (j) is calculated as: $S_{(j)} = I_{(j)} \times F_{(j)} \times V_{(j)} \times M_{(j)}$	I =	Occurrence factor. Factor from 0 to 1.
	F =	Frequency of Occurrence. Expressed in events per year.
	V =	Vulnerability factor. Factor expressing potential damage during occurrence.
	M =	Mitigation Factor. Reduction factor for use of a specific design mitigation.