Table 8-1 Enbridge Line 6B Pipeline Release—Wildlife Response Summary from July 28, 2010, to December 31, 2013

Category	Individuals	Dead on Arrival	Died in Care	Euthanized	Released	In Care	Survival (%)
Birds	196	25	27	0	144	0	73.5%
Mammals	72	34	15	0	23	0	31.9%
Turtles	5,605	26	74	5	5,479[1]	21	98.1%
Snakes	23	4	2	1	16	0	69.6%
Amphibians	893	0	0	0	893	0	100.0%
Fish	6,715	290	0	0	6,425	0	95.7%
Crustaceans	549	5	2	0	542	0	98.7%
Total	14,053	384	120	6	13,522	21	96.4%

NOTE:
[1] Does not include 157 turtle hatchlings born in the wildlife center and released during 2011 and 2012.

Long-term studies evaluating the post-release survival of animals rehabilitated during the Enbridge Line 6B wildlife response are underway. Although complete quantitative analysis is not yet complete, data show that numerous turtles were recaptured over the course of four years and the successful captive reproduction from oiled female turtles suggest positive long-term survival results.

Wildlife rehabilitators have reported similar success from crude oil releases into freshwater and marine environments. Saba and Spotila (2003) reported on the Sun Pipeline Corporation crude oil pipeline release of approximately 4,800 barrels in the John Heinz National Wildlife Refuge in Pennsylvania in 2000. After tracking 66 rehabilitated turtles, the authors concluded that, "[r]ehabilitation of oil exposed freshwater turtles is effective in restoring these animals to normal behavior in nature." Golightly et al. (2002) studied the behavior and survival of a small set of western gulls after rehabilitation from the offshore 1997 Torch Operating Company crude oil release in south-central California. Approximately 170 barrels were released and 78 bbl recovered. All oiled and rehabilitated birds survived until their transmitters failed (127 to 235 days). Dunne and Miller (2007) studied the post-release survival of oiled, rehabilitated waterfowl from multiple release events throughout the U.S. using data from the USGS Bird Banding Laboratory and concluded that "contact with oil and subsequent rehabilitation is not an indicator of reduced post-release survivability in mallards and Canada geese, and that release location has a significant effect on longevity." More recently, Ziccardi et al. (2011) examined the behavior and survival of rehabilitated surf scoters oiled during the offshore 2007 cargo ship *Cosco Busan* (operated by Fleet Management Ltd.) event, which released 1,260 barrels of heavy fuel oil in San Francisco Bay. While survival rate estimates for the oiled birds were lower than for other non-oiled groups, the authors noted that the results exhibited, "possibly stronger effects based on captivity and/or rehabilitation versus overt effects of oiling." While Russell et al. (2003) correctly pointed out that each species may respond differently to the stress of being oiled, captured, and rehabilitated and the handling of animals at a given facility can influence survival, the overall rehabilitation goal of releasing healthy animals that can survive in the wild is being realized.

8.4.4 Restoration

When a release of crude oil or other contaminants occurs, the condition of the environment prior to the release is considered a "baseline" for evaluation of damages resulting from the event. The loss of ecosystem services, or "injury," reduces conditions below the baseline and then, as the crude oil is cleaned up, the affected ecosystem services begin to recover naturally (Figure 8-1). Restoration attempts to reduce the magnitude and duration of the injury by hastening the recovery of affected resources back to baseline conditions through active human intervention activities (French et al. 1996; OPA 1990).

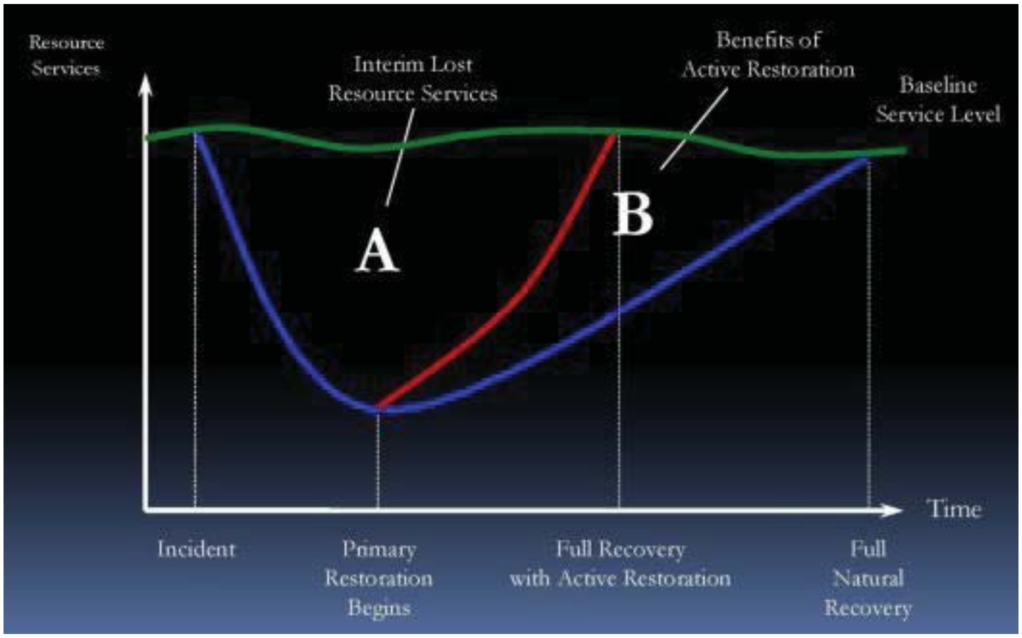

Figure 8-1 General Model of Ecosystem Service Loss Following a Petroleum Hydrocarbon Release

Examples of human intervention activities that can hasten recovery include removing contaminated soil and backfilling areas with appropriate soils, sediments, or other materials; seeding and planting disturbed habitats; treating invasive species; stocking fish or other species; augmenting soil mycorrhizae; and installing wildlife or fish habitat structures. The specific measures selected in a particular case are determined by the type, location, and abundance of resources affected.

During the Line 6B spill response in Michigan, Enbridge employed a variety of restoration techniques with the intent of reducing damages and the time necessary for affected areas to recover. Some of the techniques implemented included backfilling scraped and excavated areas, seeding and planting with native species, and controlling the spread of invasive species. Five years after the release, monitoring data submitted to the MI DEQ indicate that affected wetland areas are showing a comparable level of quality and function to similar unaffected areas and appear reasonably consistent with environmental conditions without crude oil disturbance (Enbridge 2015b, 2015c, 2016a, 2016b). Enbridge also provided multiple compensatory restoration projects, including removal of a dam, creation of 300 acres of wetlands, and construction of five recreation sites (USFWS et al. 2015a).

At Enbridge's 2002 Cohasset release site in Minnesota where 6,000 barrels of crude oil were released with 2,574 barrels recovered, wetland restoration efforts included reestablishing site topography and vegetation. Disturbed surfaces within the wetland were re-contoured to create pit and mound micro-topography; native wildflowers and grasses were seeded; emergent plants, unrooted cuttings (shrubs and trees) and tree seedlings were planted; and the area was treated to control the spread of invasive plants. Although removal of peat soil caused the site to be wetter than before the release, it is now a functional marsh-type wetland following restoration (USFWS et al. 2005). Enbridge also provided for the restoration of 30 acres of forested and scrub-shrub wetland and the retrofit of 10 school buses for particulate emission reductions as compensatory projects (USFWS et al. 2005).

Resource enhancement can also be conducted in conjunction with restoration efforts, raising the level of ecological function above baseline and providing greater service benefits. Following a 2003 release of approximately seven barrels of No. 6 Fuel Oil from its B.L. England Generating Station in Cape May, New Jersey, Conectiv Energy restored the area by replacing damaged invasive vegetation with native species. Project reports indicated that at the end of the first growing season, development of planted vegetation was progressing throughout most of the project area with vegetative cover by native species averaging 41% for the site, representing approximately half of the total 80% native vegetative cover required to be deemed successfully restored (Pfeifer and Hess 2005). The improved community diversity above baseline conditions provided greater benefits to marsh animals such as fiddler crabs, diamondback terrapins, egrets, butterflies, mummichog, and humans. Conectiv Energy restored additional habitat adjacent to the damaged area as a compensatory project to increase the benefits to marsh ecosystem services (Pfeifer and Hess 2005).

8.4.5 Summary

While recovery cannot eliminate the damages caused by a release of crude oil and associated response activities or achieve a full restoration of exactly what existed before a crude oil release, reports from past release events suggest that it can reduce the overall amount and extent of damages and substantially reduce the time necessary for natural resource recovery to occur. The remaining loss of ecosystem services can then be addressed through compensatory restoration (as identified by the applicable regulatory agency) to address interim losses (i.e., reduced ecosystem functions and human use of the resources during the time it takes the resources to recover).

8.5 DISCUSSION

When possible, the case studies selected for review of recovery of environmental receptors in the physical, biological and human environments focused on crude oil releases that occurred within the same or similar climatic conditions, ecosystems, and communities as those found in Minnesota. In some cases, recovery from releases in other regions was discussed to offer greater breadth of information on factors that influence recovery rates.

For biological and physical environments, the ability of environmental receptors to recover, the timeframe for recovery, and the factors affecting recovery rates were examined. For human environments, the processes by which human use and socio-economic conditions recover following crude oil releases and the factors influencing recovery also were addressed.

The case studies that were reviewed generally were large releases since these releases are better documented due to the severity or magnitude of the event. As the majority of pipeline releases tend to be relatively small with a median volume of three barrels (PHMSA 2016), the effects are expected to be less than for large releases and rates of recovery are expected to be more rapid.

8.5.1.1 Physical Environment

The recovery of the physical environment (e.g., surface water, groundwater, soil) from a crude oil release is determined by numerous factors including site-specific environmental conditions at the time of the release, the environmental material that is affected, the severity and areal extent of the release, the type of oil released, the speed and efficacy of emergency response, and methods for clean-up and site remediation.

8.5.1.1.1 Surface Water

The rate of recovery of surface water is measured by the rate at which petroleum hydrocarbons are removed from the environment, as well as the ability of the surface water to support aquatic life and meet drinking water standards protective of human health and the environment.

Based on PHMSA pipeline incident statistics[38], the vast majority of crude oil releases do not affect surface water resources. Even though 47% of pipeline releases occur completely within the operator's property, there were only 2.7% of hazardous liquid pipeline incidents that required surface water remediation and only 0.2% of the incidents that affected drinking water resources (PHMSA 2016).

Factors that accelerate the recovery of surface waters include:

- Prompt and efficient emergency response to remove crude oil from the environment
- Warm temperatures, sunlight, and nutrient availability to facilitate weathering and biodegradation
- High flow rates in rivers and inflow in ponds and lakes that dilute crude oil and flush the affected area of petroleum hydrocarbons
- Large waterbody size, which contributes to dilution of crude oil and crude oil constituents

[38] Incidents must be reported to PHMSA if the incident results in one or more of the following consequences: 1) a release of 5 gallons or more, 2) death or serious injury necessitating hospitalization, 3) fire or explosion not intentionally set by the operator, or 4) property damage of $50,000 or more (49 CFR 195.50).

8.5.1.1.2 Groundwater

For groundwater, the rate of recovery varies depending primarily on the amount of crude oil in the environment; the vulnerability of the groundwater (e.g., unconfined and confined aquifers); the physical and chemical characteristics of the crude oil; and attributes of the groundwater (e.g., oxygen and nutrient availability, microbial populations, physical, and chemical composition of the aquifer materials).

Based on PHMSA pipeline incident statistics, the vast majority of terrestrial crude oil releases do not affect groundwater resources. Even though 47% of pipeline releases occur completely within the operator's property, there were only 3% of hazardous liquid pipeline incidents that required groundwater remediation, and only 0.2% of the incidents that affected drinking water resources (PHMSA 2016).

Although contaminated groundwater may take decades to recover, petroleum hydrocarbon plumes tend to move slower than groundwater and generally move only tens of hundreds of feet (as opposed to thousands of feet). A review of petroleum hydrocarbon groundwater plumes throughout the U.S. found that the plume size was stable or shrinking at the majority of sites examined, indicating groundwater resources recover from petroleum hydrocarbon contamination (Newell and Connor 1998). The removal of residual oil from the environment is critically important for recovery of groundwater resources.

8.5.1.1.3 Soil

As discussed above, many pipeline incidents occur completely within the operator's property and most are small in volume (three barrels or less). Based on PHMSA statistics, pipeline incidents that occurred off the operator's property are small (20 barrels), and the majority of releases require soil remediation involving 100 cubic yards of soil or less. Only 3% of releases reported to PHMSA require soil remediation of 10,000 cubic yards or more (PHMSA 2016)

The speed of soil recovery is primarily related to release volume, type of oil released, the soil type, and the speed and efficacy of emergency response. While crude oil releases can adversely affect soils, there are a number of environment fate processes that can facilitate soil recovery. For example, microbial biodegradation, in combination with other environmental fate mechanisms, such as evaporation and photodegradation, facilitate the recovery of soils. In Minnesota, microbial biodegradation may be slower than more temperate areas with warmer soil temperatures, but remediation techniques that oxygenate and fertilize soils can be used to enhance soil recovery rates.

8.5.1.2 Terrestrial Ecosystems

Similar to the physical environment, the recovery of the biological environment from a crude oil release is determined by numerous factors including site-specific environmental conditions at the time of the release, the types of environmental receptors affected, the severity and areal extent of the release, the type of oil released, the speed and efficacy of emergency response, and methods for clean-up and site remediation.

8.5.1.2.1 Terrestrial Vegetation

In general, the recovery of plants is closely associated with the recovery of affected soils, though vegetation may also be directly affected by direct contact (oiling) or toxicological processes. Other factors accelerating the recovery of plants include the presence of nearby vegetation populations that act as sources for seeds and the use of active clean up and recovery strategies (e.g., removal of coated vegetation, reseeding, fertilization of soils). The timing of the release also is important as areas that are affected during periods of dormancy tend to recover more quickly. Recovery of terrestrial plants is variable and dependent on the severity and areal extent of effects, the recovery of soils, the techniques used during emergency response and clean up, and the successional stage of the community.

National pipeline incident data indicate that only 2.5% of pipeline incidents reported to PHMSA resulted in the need for active vegetation remediation (PHMSA 2016).

8.5.1.2.2 Terrestrial Biota

Terrestrial wildlife, including birds, mammals, and reptiles, may be affected in the event of a crude oil release. Recovery of wildlife depends upon the susceptibility, behaviors, and physical traits of the species affected. For example, case studies found that reptiles recovered more quickly from oiling compared to birds and mammals; this is attributed to the lack of fur or feathers that crude oil can adhere to, which helps reduce adverse effects due to physical contact. While individual organisms differ in their susceptibility and may experience adverse effects, effects to wildlife populations are influenced by life history strategies. The loss of multiple individuals may substantially affect some populations, while others may show minimal effects.

Active wildlife remediation programs are generally associated with the large, widespread releases and, consequently, are only reported in 0.4% of releases (PHMSA 2016).

Historical releases have demonstrated that individual animals, if captured and treated quickly following oiling, can survive and often be returned to the wild. If emergency response is prompt and strategies to reduce effects to wildlife (e.g., use of wildlife deterrents) are employed, recovery can be rapid. Active wildlife remediation programs are generally associated with the large, widespread releases and, consequently, are only reported in 0.4% of releases (PHMSA 2016).

8.5.1.3 Aquatic Ecosystems

The recovery of the aquatic ecosystem from a crude oil release is determined by numerous factors including site-specific environmental conditions at the time of the release, subsequent water flows through the affected area, the environmental media affected, the types of environmental receptors affected, the severity and areal extent of the release, the type of oil released, the speed and efficacy of emergency response, and methods for clean-up and site remediation.

8.5.1.3.1 Aquatic Biota

Aquatic ecosystems directly and indirectly support a myriad of organisms including aquatic and riparian vegetation, fish, amphibians, benthic invertebrates, birds, and mammals. Crude oil releases can have substantial effects on surface water and the ecosystems it supports. As described above in Section 8.5.1.1, Physical Environment, the recovery of surface waters is measured by the rate at which petroleum hydrocarbons are removed from the environment, as well as the biological recovery of organisms that rely on the affected surface water.

Factors facilitating the recovery of aquatic ecosystems closely mimic the factors affecting recovery of surface waters, including:

- Prompt and efficient emergency response to remove crude oil from the environment
- Warm temperatures and nutrient availability to facilitate weathering and biodegradation
- Presence of upstream populations of fish, wildlife, and invertebrates to facilitate recolonization
- High flows in rivers and inflow in ponds and lakes, which dilute crude oil and flush the affected area of hydrocarbons
- Large waterbody size, which contributes to dilution of crude oil and crude oil constituents

National PHMSA pipeline incident data show that approximately 1.2% of crude oil releases affect fish (PHMSA 2016).

In general, effects to aquatic ecosystems tend to be temporary and localized in extent. While rates of aquatic ecosystem recovery are variable, recovery in flowing systems can begin to occur soon after the release event as the crude oil is flushed from the system. Recovery in stationary or slow moving waters may take longer as recovery may be more dependent upon weathering and other degradation processes, rather than flushing flows.

8.5.1.4 Human Environment

Since the late 1960s and the emergence of the environmental movement, great strides have been made through the passing of laws and programs for safety and release preparedness, communication, and compensation. Three measures of socio-economic recovery from a crude oil release are: 1) restoration of daily life activities and monetary reimbursement; 2) the return of ecological functionality of affected land and resources; and 3) restoration of the well-being of individuals and communities adversely affected by a release through financial compensation for damages. Review of literature and case studies demonstrate that communities recover from socio-economic effects, and the speed and efficacy of spill response can limit the severity of effects to human uses and the area affected by a release, which facilitate recovery rates.

Based on recent national incidents reported to PHMSA, approximately 24% of reported incidents have occurred within populated areas (PHMSA 2016). Evacuations occurred in 2.3% of releases with an average evacuation of 101 evacuees per incident (PHMSA 2016).

8.5.1.5 Summary

Recovery rates are affected by numerous factors, including:

- Condition of the environment prior to disturbance, including natural variability and climatic conditions that can affect recovery rates
- Severity and spatial extent of the disturbance, including the type of crude oil; amount of residual crude oil left after initial response and clean up; and the persistence of residual crude oil in the environment
- Environmental conditions that affect crude oil evaporation and degradation rates (e.g., temperatures, nutrient and oxygen availability, sunlight)
- Resiliency and resistance of the ecosystem. Broadly, a species sensitivity to chemical exposure and its life history strategy (e.g., "r" or "K" strategists) can strongly influence the population's ability to withstand and recover from an oil release
- Proximity and mobility of nearby populations that can help quickly re-establish affected populations
- Speed and efficacy of emergency response and clean up

This review demonstrates that recovery of abiotic and biotic ecosystem components occurs after a crude oil release, though the timeframes for recovery are variable due to a variety of factors, as described above. Environmental conditions within the affected area, the types of environmental media and receptors affected, the severity and areal extent of the release, and the speed and efficacy of emergency response and clean up are major factors that affect the timeframes for recovery., Some very broad generalizations can be made about recovery rates from large crude oil releases as summarized in Table 8-2.

Table 8-2 Generalized Recovery Rates of Environmental Receptors After a Crude Oil Release with Significant Effects

Environmental Receptor	Unassisted Recovery Rates	Recovery Rates with Remediation	References
Terrestrial soil & vegetation	Months to years	Days to several years	Belsky 1982; De Jong 1980; Hemmings et al. 2015; Nieber 2013; Sparrow and Sparrow 1988; Wang et al. 1998; Wein and Bliss 1973
Terrestrial "r" strategists (species that tend to be short lived, reproduce quickly, abundant, and high mobility)	Months to several years	Weeks to months	Belsky 1982; Belsky 1975; CHMR et al. 1990; Robson et al. 2004

Table 8-2 Generalized Recovery Rates of Environmental Receptors After a Crude Oil Release with Significant Effects

Environmental Receptor	Unassisted Recovery Rates	Recovery Rates with Remediation	References
Terrestrial "K" strategists (species that are relatively long lived, slow to maturity, low reproduction rates)	Years to decades	Months to years	Bodkin et al. 2002; Hemmings et al. 2015; Saba and Spotila 2003; Stantec et al. 2012a
Surface water	Hours to days	Hours to days	Brown 2015; Hirji 2015.
Groundwater	Decades	Years to decades	Delin and Herkelrath 2014; Newell and Conner 1998
Aquatic sediments	Years to decades	Months to years	Fingas 2015; Guiney et al. 1987a; Hemmings et al. 2015; Poulton et al. 1997
Aquatic biota "r" strategists	Weeks to years	Weeks to months	Crunkilton and Duchrow 1990; Cushman and Goyert 1984; De Pennart et al. 2004; Lytle and Peckarsky 2001; Pontasch and Brusven 1988; Wallace 1990
Aquatic biota "k" strategists	Years to decades	Months to years	Goldberg 2011; Guiney et al. 1987a; Kubach et al. 2011
Socio-economic	Years to decades	Months to years	Arcadis 2011; Clarke and Hemphill 2002; Fall et al. 2001; Webler et al. 2010
Public perception (local)	Years to decades	Years to decades	Wooley 2002; Wooley 1995

9.0 SUMMARY AND CONCLUSIONS

As part of the route permitting process for L3RP, the DOC-EERA was directed to complete an environmental review. The review was required to include an assessment of large releases of crude oil, including the probability of such events, modeling of crude oil releases, and an assessment of the potential corresponding environmental effects. Pinhole leaks, which were identified as a concern by regulators and the public, are discussed in a separate report.

To complete this assessment, a number of factors and aspects have been discussed in this report, including:

- How a large release of crude oil might occur and the likelihood of such a release (i.e., a threat assessment and failure frequency analysis for the pipeline segments at each of the seven representative locations)
- Likely trajectory and fate (i.e., behavior) of unmitigated large releases (assuming no emergency responses within the first 24 hours) of several types of crude oil under different geographic, environmental, and seasonal conditions
- Range of potential effects that an unmitigated large release of crude oil may have on the natural and human environment
- Potential and timing for the recovery of the natural and human environments following a large release of crude oil, including how cleanup and remediation can influence recovery

Scientific studies and monitoring have documented that the effects of exposure to large releases of crude oil on freshwater and terrestrial ecosystems are adverse, and that human uses in the areas of a release can be negatively affected (Chapters 7.0 and 8.0). However, as discussed below, the extent and significance of these effects will depend on many factors, including the type and amount of crude oil, the sensitivity of the receptor to crude oil exposure, seasonal and environmental conditions, physical conditions such as river flow rates and shoreline types, and biological conditions such as shoreline or wetland vegetation cover.

While effects of exposure to crude oil can be adverse, incident records from past pipeline operations, as well as analyses of failure frequencies for the seven representative locations, demonstrate that a large release from a new and modern pipeline such as L3RP would be unlikely. Modern pipeline design includes a wide range of measures to reduce the likelihood of an oil release, including pipeline design, to directly address higher risk segments of the ROW; technical specifications for pipeline materials; construction techniques such as deeper burial in higher risk segments or HDD under watercourses; operational and emergency protocols for pipelines and pump stations; ongoing monitoring and inspection of pipelines; and preventive maintenance.

Further, pipeline operators such as Enbridge, are required to prepare emergency response plans, demonstrate response preparedness through regular inspections of response equipment, and regularly conduct drill exercises for hypothetical oil releases. As a result, if a release were to occur, emergency responders would be prepared and response actions would be taken swiftly (i.e., within hours) to help reduce immediate and long-term effects on the natural and human environment. Site remediation and restoration methods have advanced substantially over the past two decades, and would help reduce long-term effects on the biophysical and human environment and facilitate recovery of affected receptors.

As described in Chapter 8.0, evidence from actual oil releases demonstrates that biophysical and human receptors will recover following exposure to released crude oil, although the timeframes for recovery can vary. Effective clean-up of a release, combined with appropriate remediation and restoration methods will enhance recovery.

In reality, if an oil release were to occur, Enbridge would be expected to respond to the release within a matter of hours. Accordingly, the modeling of unmitigated large releases of crude oil constitutes an unlikely scenario for the proposed pipeline. As a result, the predicted trajectories, fates, and effects described here represent worst case scenarios.

In this chapter, results from the report are summarized with respect to:

- What is the likelihood of a large release of crude oil?
- How do different types of crude oil behave?
- How do seasonal flows and climate conditions influence possible outcomes?
- How do shoreline vegetation and water body types influence possible outcomes?
- What are the effects of crude oil exposure for various receptors?
- Will these receptors recover and how quickly?

9.1 WHAT IS THE LIKELIHOOD OF A LARGE RELEASE OF CRUDE OIL?

The primary purpose of this report is to provide quantitative and qualitative information regarding the risk of a crude oil release from the proposed L3RP. Risk is defined most concisely as the “chance of loss”. Accordingly, in the context of the risk associated with the operation of the L3RP pipeline, the term “risk” is used as a joint expression of chance (the annual probability of incurring a rupture in the L3RP pipeline), and loss (the consequences associated with such a rupture). The failure frequency analysis (Chapter 4.0) focuses on identifying potential threats for the seven representative locations along the proposed L3RP pipeline. For those threats that have the potential to contribute to the overall failure probability at each representative location, the annual probability (frequency) that a large release of crude oil will occur was assessed.

To address the probability of a large crude oil release, quantitative estimates of rupture frequency were determined for each of the seven representative locations. In linear infrastructure such as pipelines, the probability of failure over a given time period is proportional to segment length, with longer segments being associated with greater probabilities. Therefore, given that each of the seven representative sites were associated with river crossings, the length of the pipeline segment that was considered in the failure frequency analysis was established through a high resolution analysis of outflow and overland spill modeling for each modeled location. Full-bore rupture release scenarios were modeled in OILMAP Land as multiple individual releases at intervals of 32.8 ft (10 m) inland from each side of each river crossing. The model characterized site-specific local topography and land cover using a release volume specific to each crossing to determine whether spill plumes could reach the water body by means of overland flow. The length of pipeline defined by endpoints located inland from each river bank, over which the spill plume from a hypothetical full bore rupture could impact the water body (either directly, or by means of overland flow), was termed the "potential impact segment". The total length of the potential impact segment was the basis of estimating failure probability at each of the seven representative locations.

Having established the potential impact segment at each of the seven representative sites, quantitative estimates of rupture frequency for these segments were made, based on a two-step analysis. The first step involved a Threat Assessment in which the relevant threats for each impact segment were identified. As part of the Threat Assessment, approaches for quantifying threat-specific rupture frequency were selected, giving consideration to the threat attribute data, as well as best practice methodologies. Using these approaches, threat-specific quantitative estimates of rupture frequency were then generated for each potential impact segment in the second step of the analysis—the Frequency Analysis.

Potential threats to the L3RP that were examined included: external corrosion, internal corrosion, stress corrosion cracking, manufacturing defects, construction defects, equipment failure, third party damage, incorrect operations, weather related and outside force, and other threats. The threat assessment examined each of these potential threats to the specific segments of the L3RP in proximity to the seven representative locations, taking into account the design, materials, and construction and operational attributes for the pipeline.

The threat assessment showed that with the exception of "stress corrosion cracking" and "other threats", all of the remaining potential threats for the seven representative locations contributed to overall failure frequency. These potential threats were included in the quantitative assessment of failure frequency for that potential impact segment. Equipment failure (which addresses the failure of non-pipe components such as valves or equipment within pump stations) was not included in the failure frequency analysis, as none of the potential impact segments considered for the seven representative locations included non-pipe components.

To be consistent with the assessment of full bore ruptures in the consequence analysis, the frequency analysis focused on the occurrence of ruptures (as opposed to smaller leaks) within the potential impact segment. Based on the guidance provided in the Threat Assessment, the frequency analysis estimated rupture frequency for each of the seven representative locations using optimal approaches for each threat. These approaches included:

- Methods based on Industry Incident Data—PHMSA Hazardous Liquids Database, 2010-2015 (threats assessed using this method included manufacturing defects, construction defects and incorrect operations)

- Methods based on mechanistic, reliability approaches (external corrosion, internal corrosion, and third party damage)
- Site-specific evaluation of hydrotechnical and geotechnical hazards (weather related and outside forces)

The annual probability values, as well as the average annual return periods (defined as the inverse of the annual probability values) for each of the potential impact segments are summarized below:

Table 9-1 Annual Probability of Rupture and Average Return Period within the Potential Impact Segment for Each of the Seven Potential Impact Segments

	Annual Probability of Rupture	Average Return Period (yr)
Site Number	L3RP	L3RP
1—Mosquito Creek	3.402×10^{-06}	293,945
2—Mississippi River at Ball Club	3.961×10^{-07}	2,524,615
3—Sandy River	1.939×10^{-06}	515,730
4—Shell River	4.388×10^{-06}	227,894
5—Red River	2.781×10^{-06}	359,583
6—Mississippi River at Palisades	2.527×10^{-06}	395,726
7—Mississippi River at Little Falls	2.287×10^{-06}	437,254

As noted above, for linear infrastructure, such as pipelines, the likelihood of incurring a failure at some point along a pipeline segment increases as the length of the segment that is being considered increases. This is reflected in the above results, with the longest potential impact segment (the 2,543 ft-long segment associated with the Shell River crossing), having the greatest probability of failure.

The annual likelihood of a large crude oil release occurring within the seven potential impact segments for L3RP ranges from 4.388×10^{-06} to 3.961×10^{-07}. These failure frequencies are equivalent to average annual return periods from 227,894–2,524,615 years. Based on these values, large releases of crude oil from the proposed L3RP at any of the seven sites evaluated are considered to be unlikely.

9.2 HOW DO DIFFERENT TYPES OF CRUDE OIL BEHAVE?

Crude oils and refined petroleum products are complex mixtures of many thousands of different hydrocarbon compounds derived from naturally occurring geological formations. Each has physical and chemical properties (e.g., viscosity, density, solubility, volatility) that reflect its composition and affect its transport and fate, once released into the environment (NRC 2003).

When released into the environment, various weathering processes work to break down the hydrocarbons into primarily carbon dioxide and water. The rate of these natural weathering processes depends principally upon the type of crude oil (i.e., the specific mixture of hydrocarbon compounds present), and the characteristics of the receiving environment (e.g., location of the release, season, and weather conditions).

A range of product types are expected to be shipped in the L3RP pipeline, including heavier crude oils such as diluted bitumen and lighter crude oils such as Alberta Light Sweet Crude. To account for the differences in the types of crude oil that could be transported and the range of behaviors these oils would have within the environment, both a light crude oil (i.e., Bakken Crude) and two different blends of a single heavy crude oil (i.e., CLB) were considered in the risk analyses. The latter type of crude oil has a chemical composition that varies throughout the year, and was represented in the modeling as CLSB and CLWB. These two types of crude oil (Bakken Crude and CLB) represent products that exist within the spectrum of crude oil types commonly encountered in North America (Lee et al. 2015).

CLB is a diluted bitumen (often referred to as dilbit) with density and viscosity values that are in the upper range of values allowed by pipeline tariff specifications (typically less than 0.94 g/cm^3 at 15°C); both the modeled CLSB and CLWB have a density of approximately 0.92 g/cm^3 (Environment Canada 2016; Horn 2016). Because seasonal variations in environmental temperature affects the viscosity of diluted bitumen, the amount of condensate or other diluent added to the bitumen feedstock is adjusted through the year to meet shipping requirements to maintain the desired viscosity required for pumping. In turn, this also affects the density and viscosity of the crude oil, and the amount of soluble and volatile hydrocarbons present, which can result in slightly different behaviors.

Bakken crude is a light sweet crude oil with a sulfur content less than 0.2 wt.%; it is similar to many other light sweet crude oils produced and transported in the United States (Auers et al. 2014). The light end concentration of Bakken crude is between 3 and 9%, with 5% being typical (NDPC 2016). The Bakken crude oil used for modeling in this study had a density of 0.82 g/cm^3.

The time of year when a release occurs can have an important effect on the fate of crude oil due to differences in the temperature of the air, water, or soil; presence and depth of snow cover; presence and percent coverage of ice on water surfaces; and the depth of the active soil layer. During winter, cold air temperatures can increase the viscosity of released crude oil (i.e., make it thicker) so that it would spread more slowly, and potentially solidify. Temperature also affects the rate of evaporation of the volatile fraction of hydrocarbons; less of these fractions will evaporate, and will do so more slowly in colder temperatures than warmer temperatures. Frozen ground can limit the depth of penetration of any release. Variations in weather can also affect the ability of responders to detect, contain, or clean up a release (e.g., ice, torrential rains or flood events can make recovery of crude oil more challenging).

A large number of physical and chemical processes govern the fate of released crude oils (Figure 9-1). These same processes drive the potential for exposure and the types of effects that can occur to ecological, land cover, and human receptors.

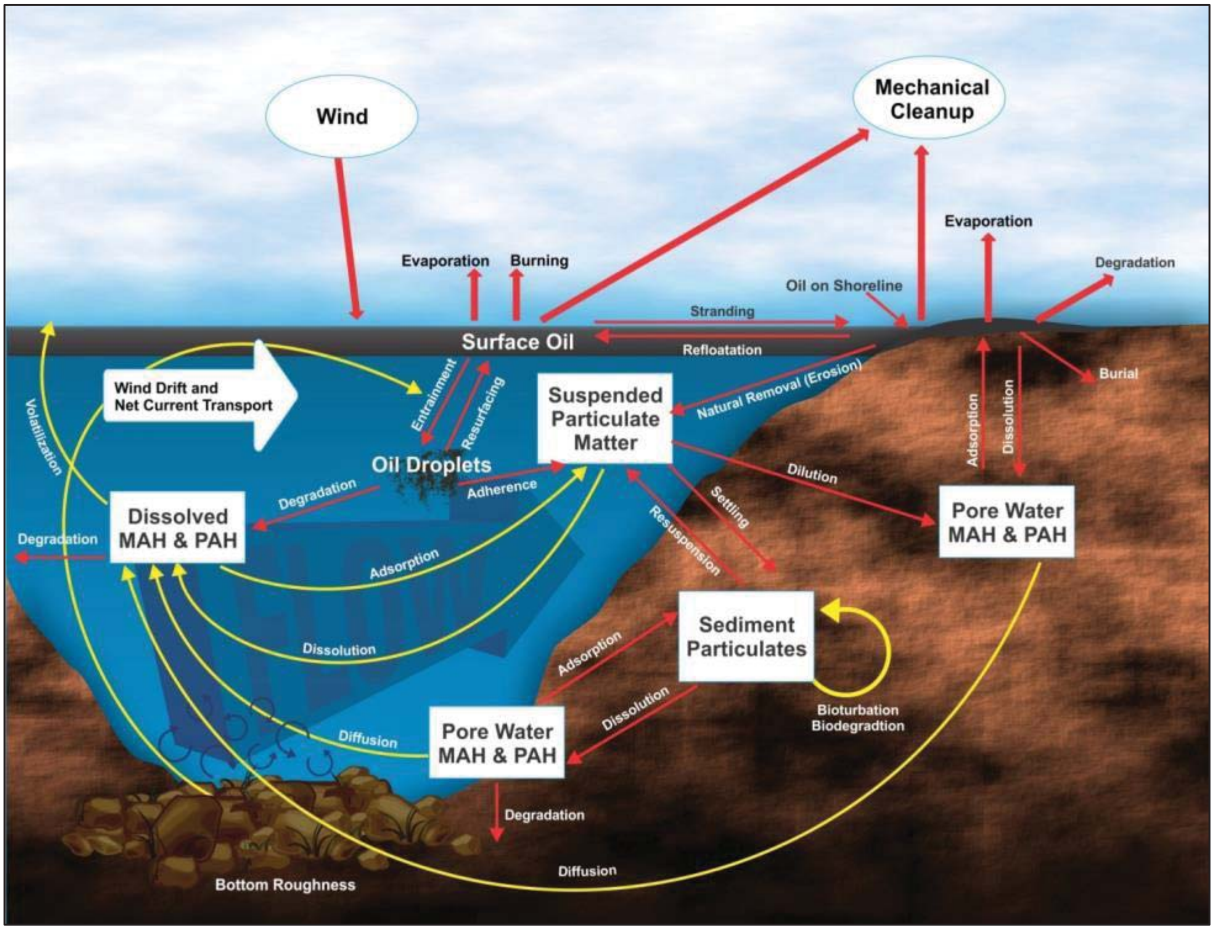

Figure 9-1 Crude Oil Fates Processes in Lakes and Rivers (Horn 2016)

Differences in the varying weathering processes for Bakken crude oil and CLB are summarized below:

Process	Comparison of Types of Crude Oil (Bakken, CLB and CLWB)
Spreading	Light crude oils such as Bakken are anticipated to spread more quickly due to their relatively low viscosity, when compared to heavier crude oils such as CLB.
Oil particle aggregation (binding of oil to sediment particles)	Any crude oil (including Bakken and CLB) can form OPAs, as they tend to adsorb to mineral and, especially, organic particles that are within the water column. The dispersion of crude oil into the water column as fine droplets, where it can interact with suspended sediment particles, is a necessary first step in this process for the formation of typical OPAs.
Evaporation	Losses through volatilization are greater in lighter crude oils such as Bakken, relative to CLB, as the composition of lighter crudes includes a larger proportion of volatile compounds.
Dispersion	Bakken crude will disperse more readily into the water column, when compared to CLB, due to its low viscosity and, therefore, the low amount of energy required to entrain this crude oil. This has implications for the potential formation of OPAs, as well as for the dissolution of relatively water soluble constituents of hydrocarbon and potential toxicity to aquatic life.
Dissolution	Bakken has a higher potential for dissolution, when compared to CLB, due to a larger percent composition of soluble lighter ends and lower viscosity. Due to the larger amount of condensate added, CLWB has more soluble compounds than CLSB.
Emulsification	In general, heavier crude oils emulsify more readily than lighter crude oils, although recent reports suggest that diluted bitumens do not readily emulsify (Fingas 2015).
Benthic deposition or sinking	Crude oils (including diluted bitumens) rarely weather sufficiently in the natural environment to result in a density greater than 1.0, so they tend to remain floating on the water surface unless other factors further modify the density. Formation of OPAs is the process most likely to result in released crude oil achieving a density (in combination with entrained or adhering mineral particles) that is greater than 1. The formation of an OPA and the density of the aggregation depends on a number of factors including the viscosity and density of the crude oil; the salinity and mixing energy available in the water body; and the concentration of suspended sediment present. Oil that strands along shorelines can also contact and bind to coarser sediment particles (e.g., sand and gravels) resulting in an aggregation that can sink if it enters the water body.
Photo-degradation	Bakken is likely subject to increased photo-oxidation relative to CLSB and CLWB. Diluted bitumens contain more resins and asphaltenes than lighter crude oils, and these hydrocarbons tend to be more resistant to weathering through photo-degradation.
Biodegradation	Accelerated in the presence of abundant oxygen and nutrients and at moderate temperatures; saturates and aromatics are expected to biodegrade within weeks (straight-chained aliphatics) to years (highly branched aliphatics to multi-ringed aromatics). Diluted bitumens contain more resins and asphaltenes than lighter crude oils, and these hydrocarbons tend to be more resistant to weathering through biodegradation.

Lighter crude oils such as Bakken tend to more readily evaporate, disperse and dissolve relative to diluted bitumen (diluent notwithstanding), resulting in a greater potential for toxic effects to the atmosphere, as well as biological communities residing in lakes and rivers. In addition, volatile compounds may result in potential inhalation exposure for human receptors.

Heavier crude oils tend to adhere to vegetation and soils along riparian banks and lakeshores that are within the predicted trajectory of an oil release, and tend to expose biological receptors that inhabit these areas. In general, heavier crude oils are more persistent and, as a result, may expose receptors over a longer period of time, relative to lighter crude oils.

Importantly, the specifics of any given incident will drive the fate and effects of released crude oil and refined petroleum products. Swift and effective containment of released crude oil, as well as cleanup, remediation and restoration will help to reduce the scale and magnitude of adverse effects (Lee et al. 2015). The influence of seasonal flows, climate condition, water body type and shoreline vegetation on the outcomes of a large release of crude oil is discussed below.

9.3 HOW DO SEASONAL FLOWS AND CLIMATE CONDITIONS INFLUENCE POSSIBLE OUTCOMES?

The downstream transport and fate of released crude oil is largely determined by river flow conditions and the type of crude oil. Three seasonal periods were considered in the modeling for L3RP: high river flow, coinciding with the spring freshet; average river flow, during summer or fall; and low river flow in winter, typified by freezing conditions and probable ice cover on the water surface.

Under high river flow conditions, the maximum downstream transport of released crude oil was predicted. Bakken crude oil is predicted to evaporate more, have a greater or equal proportion remaining on the river surface (or lake), and travel farther downstream, as compared to CLB. However, in the event of an actual release, it is expected that the downstream extents of both crude oils may be more similar, although the distribution of diluted bitumen may be patchier than light crude oils. Light oils such as Bakken crude oil are predicted to spread more thinly on the water surface with less adhering to riverbanks than heavy oils.

As a result of lower water velocities during average river flow conditions, both types of crude oil are predicted to travel a shorter distance downstream than during high flows. The fate of both crude oils during average flow conditions would be similar to those described for high flow conditions. However, evaporative losses could be greater in summer due to hotter ambient temperatures, or more comparable due to the lower surface area and the resulting reduction in evaporative surface due to less downstream transport. Evaporative losses would typically be higher for light crude oils such as Bakken, when compared to heavier crude oils such as CLB.

Under low river flow conditions, the predicted downstream extents of Bakken crude oil and CLWB was much less than during either the high flow or average flow period for most sites. The tendency for shorter downstream distances during the low flow period (i.e., winter) reflects the lower velocity of water in streams during the winter period, as well as adhesion to the undersurface of the ice (in SIMAP modeled cases). Ice cover on rivers and lakes during the winter would strongly limit or prevent evaporation to the atmosphere for both types of crude oil.

There was one exception in predicted downstream transport. Modeling for the Mississippi at Ball Club for both types of crude oil indicates that downstream transport was similar among all seasonal flows due to the large amount of shoreline oil retention.

As the primary objective of the modeling was to assess the trajectory, fate and effects of large releases of crude oil from a worst case perspective, only one of the seven representative locations (i.e., Mosquito Creek) included substantial overland flow of crude oil. The Mosquito Creek location was not a water crossing, but rather required overland flow to a seasonally variable, upper portion of the creek. At all other locations, overland flows of released crude oil and associated effects were generally not modeled because environmental effects of land releases of crude oil on soils, terrestrial vegetation and groundwater quality are limited in spatial extent (i.e., local), and readily remediated using conventional cleanup techniques (i.e., a release to land, or overland flow, is not a worst case event). Therefore, the environmental effects of a crude oil release on land cover receptors were not considered further in this assessment.

9.4 HOW DO SHORELINE VEGETATION AND WATERBODY TYPES INFLUENCE POSSIBLE OUTCOMES?

As noted above, differences in the downstream travel of crude oil are strongly influenced by river flow conditions (water volumes and resulting water velocity) and crude oil type. However, the type and density of shoreline vegetation and the waterbody type(s), also influence the downstream movement of crude oil.

Light crude oils such as Bakken would be expected to travel further downstream than the CLB due primarily to differences in shoreline oil retention. Larger amounts of CLB are predicted to strand as a thicker layer of oil on a given length of shoreline, than for the Bakken crude oil. Conversely, the same amount of Bakken crude oil could affect a greater length of shoreline, with a lesser thickness of oil.

As described in Chapter 5.0, the rate of oil loss to adhesion and puddle formation depends primarily on the physical characteristics of the land surface (vegetation type, land cover, slope) and the physical characteristics of the released product. Wetlands, including woody and herbaceous wetlands, have the highest oil retention values, followed by deciduous, evergreen and mixed forest (Table 5-1). Shrubland, grasslands and herbaceous cover, row crops and bare soil and rock have the lowest oil retention values. When comparing oil types, heavy crude oil will adhere more thickly to each of these surfaces than light crude oil (Table 5-2).

The type of water body and the associated river (or lake) flow conditions also affect the speed and distance that released crude oil may travel. The surface area of a water body and degree of mixing (e.g., turbulence or wave energy, especially sites such as waterfall or rapids) directly affects the rates of evaporation, dispersion (entrainment), dissolution, and photo-oxidation of released crude oil on the water surface, as well as the extent of spreading before crude oil reaches a shoreline or wetland (where adhesion could occur).

For the types of water bodies considered in this assessment, watercourses with well-defined channels and higher river flow rates tended to carry crude oil further and faster than sinuous and slower moving watercourses of a similar width and depth. This reflects not only the greater water velocity and volumes in well-defined water channels, but also the types of shorelines (i.e., typically dominated by shrublands, grass and herbaceous cover and bare substrates) and the lower oil retention value for these types of shorelines. In contrast, sinuous water courses have slower water flows and are typically associated with wetlands and riparian forests which have a high oil retention value.

As noted for the Mississippi River at Little Falls site, when crude oil releases move over turbulent water (e.g., rapids, tailraces, weirs or waterfalls), there could be substantial entrainment of crude oil into the water column. Entrained oil droplets in the water column would rise to the surface in downstream quiescent reaches of the watercourse. Downstream from the turbulent water areas, the dissolved aromatic hydrocarbon concentrations in the water column would increase, as the soluble portion of oil droplets forced into the water column dissolve into the water. Light oils such as Bakken crude oil that are exposed to such turbulent conditions would typically result in higher amounts of dissolved hydrocarbons in the water column, than would be the case for heavy crude oils such as CLB. Volatilization of the soluble compounds from the water would occur, as well as biodegradation.

When crude oil is mixed through the water column by turbulent mixing processes, there is also increased potential for small oil droplets that are suspended in the water column to interact with suspended sediments (i.e., the formation of oil-particle aggregations). This process is strongly influenced by the amount of suspended particulate matter in the water column. When diluted bitumen products (e.g., CLB) are dispersed in the water column and weather, they tend to adsorb to mineral and, especially, organic particles more than lighter crude oils. However, when diluted bitumen is on the water surface or along shorelines, natural weathering processes can actually increase the viscosity of heavy oils to a point where entrainment becomes less likely. Without this crude oil being in the water column, interactions between oil and suspended particulate matter may be reduced.

9.5 WHAT ARE THE EFFECTS OF CRUDE OIL EXPOSURE?

Overall, the effects of a release of light crude oil are expected to be similar to the effects of a heavy crude oil release, although at the level of the various ecological and human environment receptors, either type of crude oil may be predicted to have more or less spatially extensive or severe effects. For example, for sediment, shoreline and riparian areas, lighter crude oil is often predicted to have less severe but more spatially extensive effects than heavier crude oil, due to its lower viscosity and adherence to shoreline substrates and riparian vegetation. For the other receptors (e.g., river and lake habitat, aquatic plants, benthic invertebrates, fish, amphibians and reptiles, birds and semi-aquatic mammals, air quality, human receptors, and public use of natural resources), the relative magnitude of effects of lighter and heavier crude oils are variable, depending upon site-specific conditions, and also depending upon whether acute or chronic effects are being considered.

9.5.1 Aquatic Receptors

The effects of a crude oil release on benthic invertebrates and fish depend on the characteristics of the released crude oil and environmental conditions at the time of the release. Acute toxicity to fish is commonly but not always observed in association with crude oil releases, and is an indicator that, at least briefly, concentrations of dissolved hydrocarbons in the water column are sufficiently high to cause acute toxicity due to narcosis. Where water flow in rivers is sufficiently rapid and turbulent to entrain crude oil as small droplets in the water, the potential for acute toxicity to fish (including eggs and embryos) and benthic invertebrates could be greater for the light crude oil than for heavier crude oils. There is also potential for phototoxicity from a crude oil release in summer due to high light intensity and long day length, especially for small fish that are lightly pigmented or transparent.

Where they occur, floating aquatic plants would be expected to be killed if contacted by a crude oil slick. Submerged aquatic plants would be less vulnerable, as their exposure to dissolved hydrocarbons would be brief, and they are not considered to be among the most sensitive groups of aquatic biota. Mortality of aquatic and riparian vegetation could affect the biological integrity and productivity of the habitat, and potentially lead to erosion and further damage to the habitat.

During the winter (low flow) period, if a release of crude oil occurred onto the ice, the ice layer, as well as absorption of crude oil by snow, could substantially reduce the exposure of aquatic environments to oil. However, if crude oil was released directly to the river below the ice, or crude oil travelled along the ice surface and penetrated openings in the ice, the crude oil could travel downstream under the ice, accumulating in the narrow gap between the ice and the sediment along the river bank, or accumulating in hollows under the ice. For both types of crude oil, the winter ice would effectively inhibit evaporation, while providing greater potential for dissolution into the water column during the period of lowest dilution and water flow (i.e. lower volume of water moving through the river channel). Mortality of fish due to narcosis could occur and would be more likely for the light crude oil. The heavy crude oil would tend to remain in thicker localized accumulations, and rapid dissolution is less likely. As fish eggs and larvae would generally not be present during the winter, adult fish would be most affected. However, if crude oil residues in water and sediment remained, they could affect fish eggs and larvae in the following spawning season. Both crude oil types could be accumulated in sediment after a release in winter, and both crude oil types would be subject to re-mobilization with spring breakup of the ice, and increasing water flow rates.

9.5.2 Semi-Aquatic Wildlife Receptors

Amphibians (e.g., frogs, salamander), reptiles (e.g., turtles, snakes), birds (e.g., ducks, geese, shorebirds, raptors) and semi-aquatic mammals (e.g., muskrat, beaver, mink and otter) are present in many areas along the proposed pipeline route. If amphibians (adults, juveniles, or eggs) are directly exposed to crude oil, oiling effects, including mortality, could occur. Mortality of turtles is less likely, as these species appear to be relatively tolerant of external crude oil exposure. Reptiles like lizards and snakes are primarily terrestrial species and are less intimately associated with aquatic environments. During the winter (and likely up until April when winter ice is gone), amphibians and reptiles undergo a winter dormancy period and, as a result, would have a limited potential for exposure during the winter to released crude oil moving on the water surface or within the water column.

If exposed to external oiling, the ability of birds and mammals to maintain body temperature may be compromised, leading to death as a result of hypothermia. Birds and mammals that survive external oiling may experience toxicological stresses as a result of ingesting crude oil residues during preening/grooming or ingesting food. Birds can also transfer potentially lethal quantities of crude oil residue from their feathers to the external surface of eggs. Waterfowl and other semi-aquatic birds and mammals present in the affected rivers and lakes would be most affected. Animals upstream, farther downstream, or occupying other nearby habitats would likely be less affected, as it is assumed that emergency response measures to prevent or reduce further possible downstream transport of crude oil would be in place within 24 hours of the release. Timely capture and rehabilitation of oiled birds and mammals may help to mitigate the environmental effects of a crude oil release.

9.5.3 Human and Socio-Economic Receptors

Effects on air quality from a release of crude oils have the potential to temporarily disrupt human use and occupancy patterns. Light crude oils typically contain more VOCs than heavier crude oils, although the VOC content of diluted bitumen may be similar to that of light crude oil, depending on the type and quantity of diluent used in its manufacture. Air quality and subsequent human exposure to VOCs in the vicinity of the release of crude oil would be most affected within the first 24 hours of the oil release. In the event of an actual release, emergency response workers, in cooperation with public health and safety officials, would be active in isolating, containing and recovering released crude oil, as well as notifying the public about the release.

Light crude oil is typically expected to travel a similar or greater distance downstream under spring and summer conditions than heavy crude oil. As a result, environmental effects on air quality are predicted to be spatially similar for light and heavy crude oil types. Under winter conditions, cold temperatures, ice cover and absorption of crude oil into snow pack would strongly limit emissions of VOCs and human exposure, in addition to constraining the area of effects.

Some homes located along the trajectory of a predicted release could rely on groundwater as a drinking water source. In the event of a crude oil release, people would be notified and testing of wells would be completed to confirm the safety of the water supply. It is unlikely that a crude oil release to any of the modeled rivers/creeks/lakes would result in adverse health effects to consumers of drinking water. Where surface water is used as a source of water supply, the operators of such systems would be notified immediately upon the detection of a release, so that the situation could be monitored. Unprotected drinking water intakes in the path of a crude oil release would be temporarily closed until it was confirmed that the surface water was safe as a drinking water source.

Recreational activities would be disrupted following a release of crude oil along the predicted downstream trajectory of the release. Fisheries regulators and public health officials typically close fisheries until it is confirmed through monitoring that fish consumption is not a threat to public health. This standard approach is an effective mitigation strategy to protect human receptors from contact with constituents in the crude oil.

9.6 WILL RECOVERY OCCUR?

The recovery of biophysical and human receptors from exposure to crude oil is affected by numerous factors, including:

- Condition of the environment prior to disturbance, including natural variability and climatic conditions that can affect recovery rates
- Severity and spatial extent of the disturbance, including the type of crude oil
- Amount of residual crude oil left after initial response and clean up
- Persistence of residual crude oil in the environment
- Environmental conditions that affect evaporation and weathering of crude oil (e.g., temperatures, nutrient and oxygen availability, sunlight)
- Resiliency and resistance of the ecosystem (broadly, a species' sensitivity to chemical exposure, as well as its life history strategy, can strongly influence the population's ability to withstand and recover from a crude oil release)
- Proximity and mobility of nearby populations that can help quickly re-establish affected populations
- Speed and efficacy of emergency response and clean up
- Use of remediation and restoration measures (if required)

As discussed in Chapter 8.0, recovery of abiotic and biotic ecosystem components occurs after a crude oil release, although the timeframes for recovery are variable due to a number of factors. Environmental conditions within the affected area, the types of environmental media and receptors affected, the severity and areal extent of the release, and the speed and efficacy of emergency response and cleanup are major factors that affect the timeframes for recovery.

9.7 CONCLUSIONS

The proposed L3RP will be built and operated to the standards for new and modern pipelines. The design, material specifications, construction methods, and operational protocols, including inspection and preventative maintenance, will help to reduce the likelihood of a crude oil release. Based on the failure frequency analyses for the seven representative locations, a large release of crude oil from the L3RP is considered unlikely.

While a large release of crude oil is unlikely, when freshwater or terrestrial ecosystems and human uses are exposed to a release of crude oil, effects are adverse. The significance of these effects can range from minor on local and regional receptor populations or uses, to substantial on a major portion of the exposed receptor population or uses. The significance of the effects of a crude oil release on a receptor will depend strongly on:

- Receptor itself in terms of its vulnerability to exposure to crude oil, and its sensitivity, if it is exposed to crude oil
- Type and volume of crude oil released
- Timing and location of the release relative to seasonal occurrences and locations of sensitive receptors and uses
- Climatic and site conditions at the time of the release
- Ability of responders to contain the release
- Speed, type and extent of cleanup, remediation, and restoration activities

This report assessed potential effects of an unmitigated large release of crude oil. In the unlikely event of an actual release of crude oil, swift and effective emergency response and cleanup measures would help reduce the extent of effects and help promote recovery of the affected receptors. Similarly, remedial actions and habitat restoration measures, as appropriate, would help further reduce many of the expected effects, while also aiding in recovery of freshwater and terrestrial environments, as well as human uses.

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ATTACHMENT A

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) L3R	Existing Pipeline Crossing (Y/N)
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.

[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^{0} 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.

Photo - 2 taken looking south at the crossing area

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'.

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.

Photo - 5 taken looking east along the proposed route

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^{0} and 25^{0}, and are about 15' high on the east and 40' high on the west.

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.

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[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

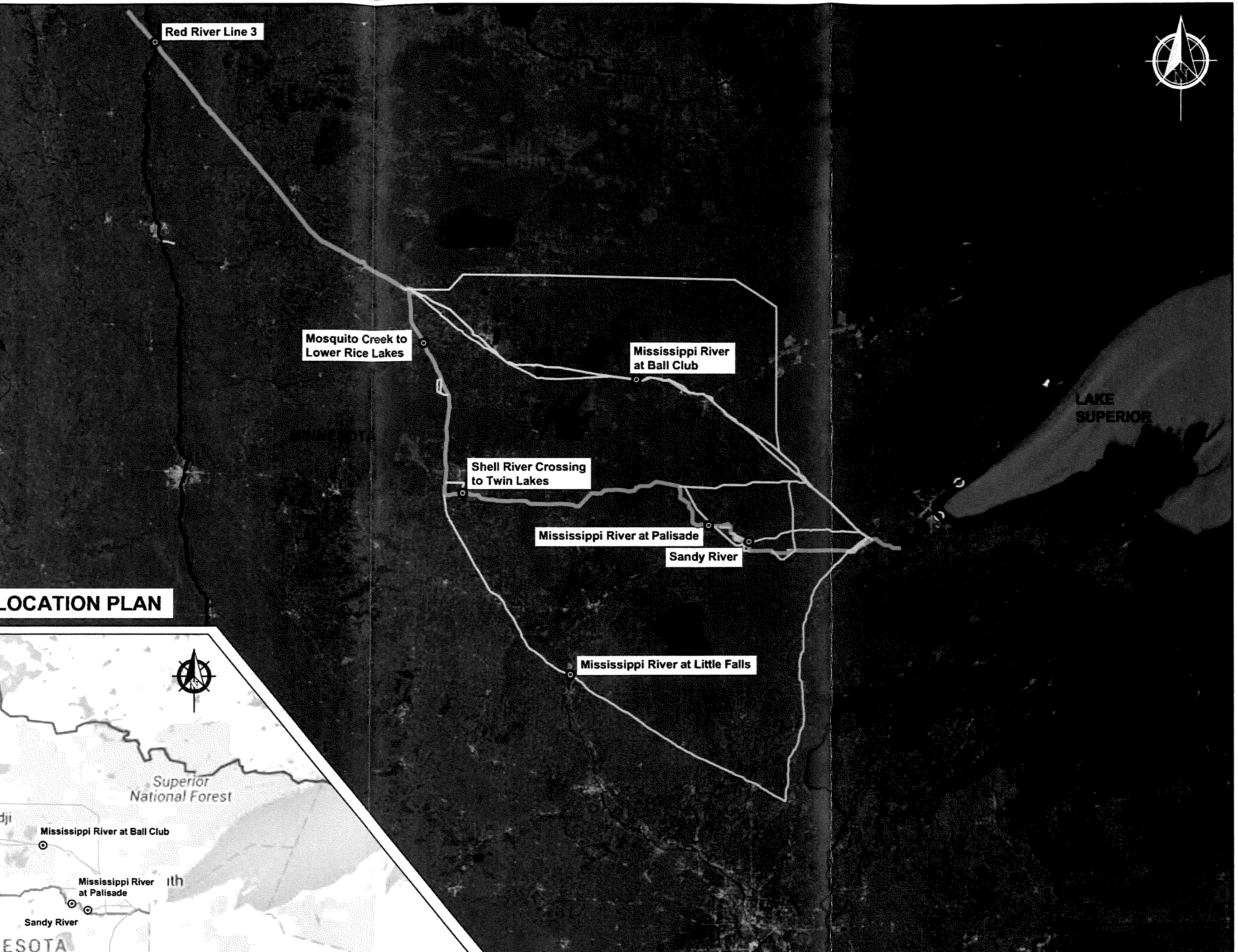
Mississipi River at Palisade
15T E:462156 N:5171755

Mississippi River at Little Falls
15T E:396176 N:5100293

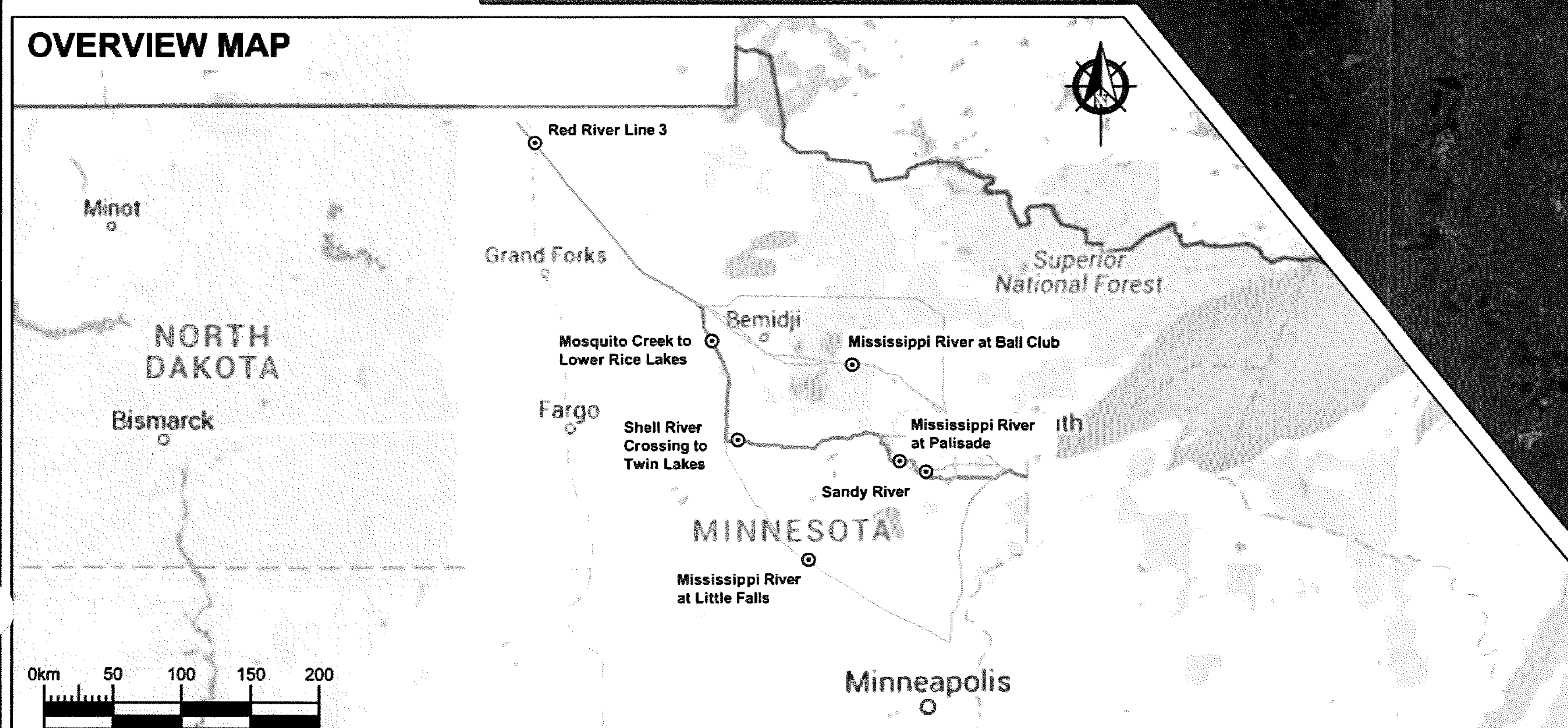
Mosquito Creek to Lower Rice Lakes
15T E: 326156 N:5258906

Shell River Crossing to Twin Lakes
15T E345543 N:5187125

Sandy River
15T E:481392 N:5163673



OVERVIEW MAP



RC DESIGN Professional Drafting & Design Services	Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project: SITE LOCATIONS OVERVIEW PLAN	KELLY GEOTECHNICAL	Date: 13 September 2016 Drawn By: Shelley Ruiz Reviewed By: Shane Kelly Project #: KGL-15-012 Drawing/Rev #: Figure 1 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

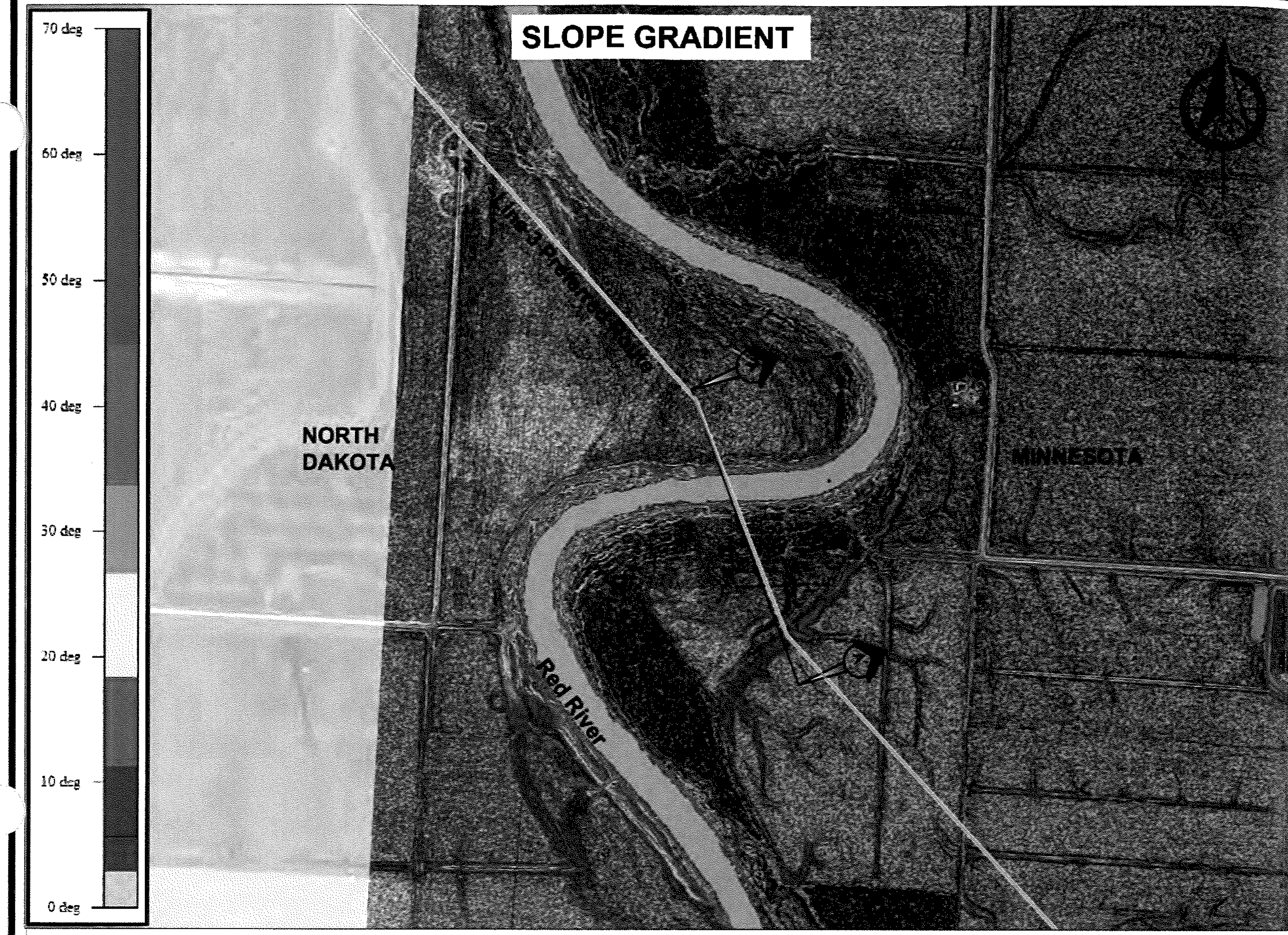
Legend:
Geohazard ID
Geohard Type

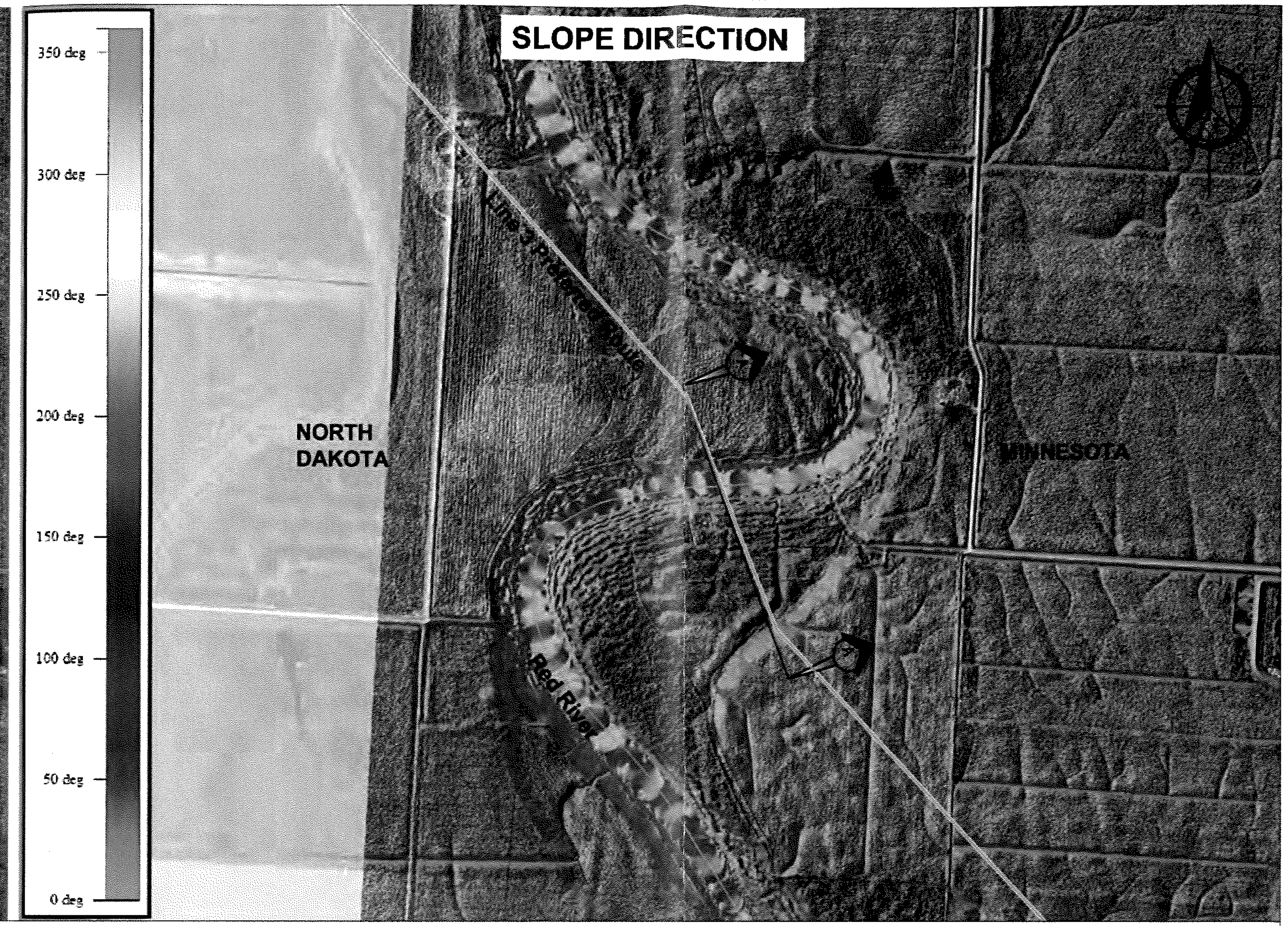
Client: Dynamic Risk Assessment Systems Inc.
ENBRIDGE

Project: SITE PLAN RED RIVER LINE 3

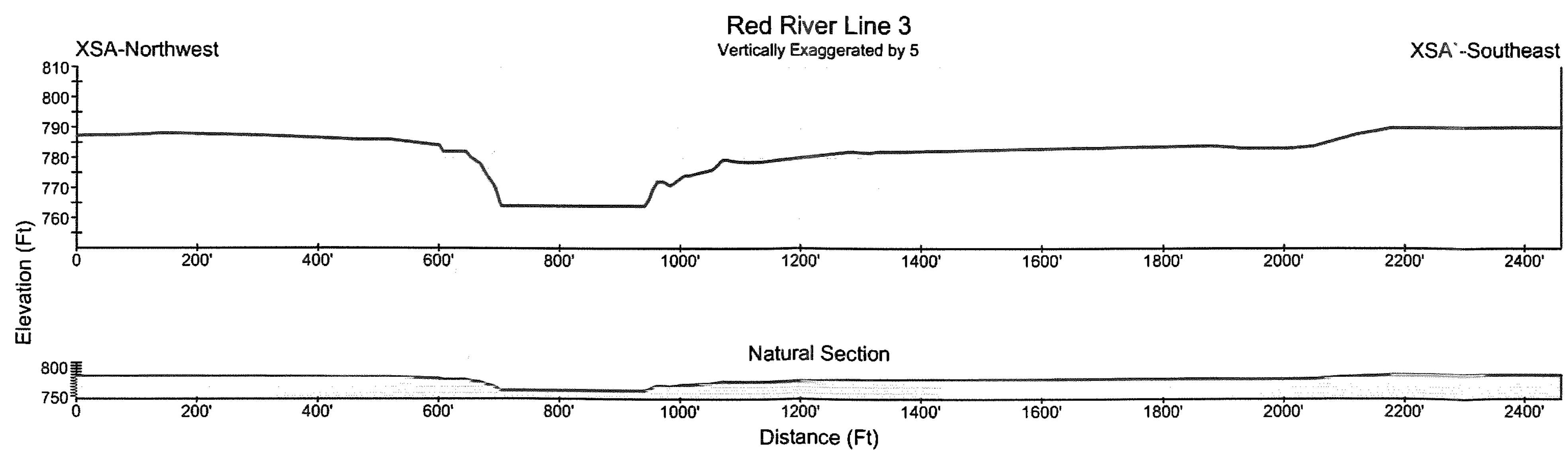
KELLY GEOTECHNICAL

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





CROSS SECTION A



Plan Scale

0ft 500' 1000' 1500' 2000'

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

RC DESIGN Professional Drafting & Design Services

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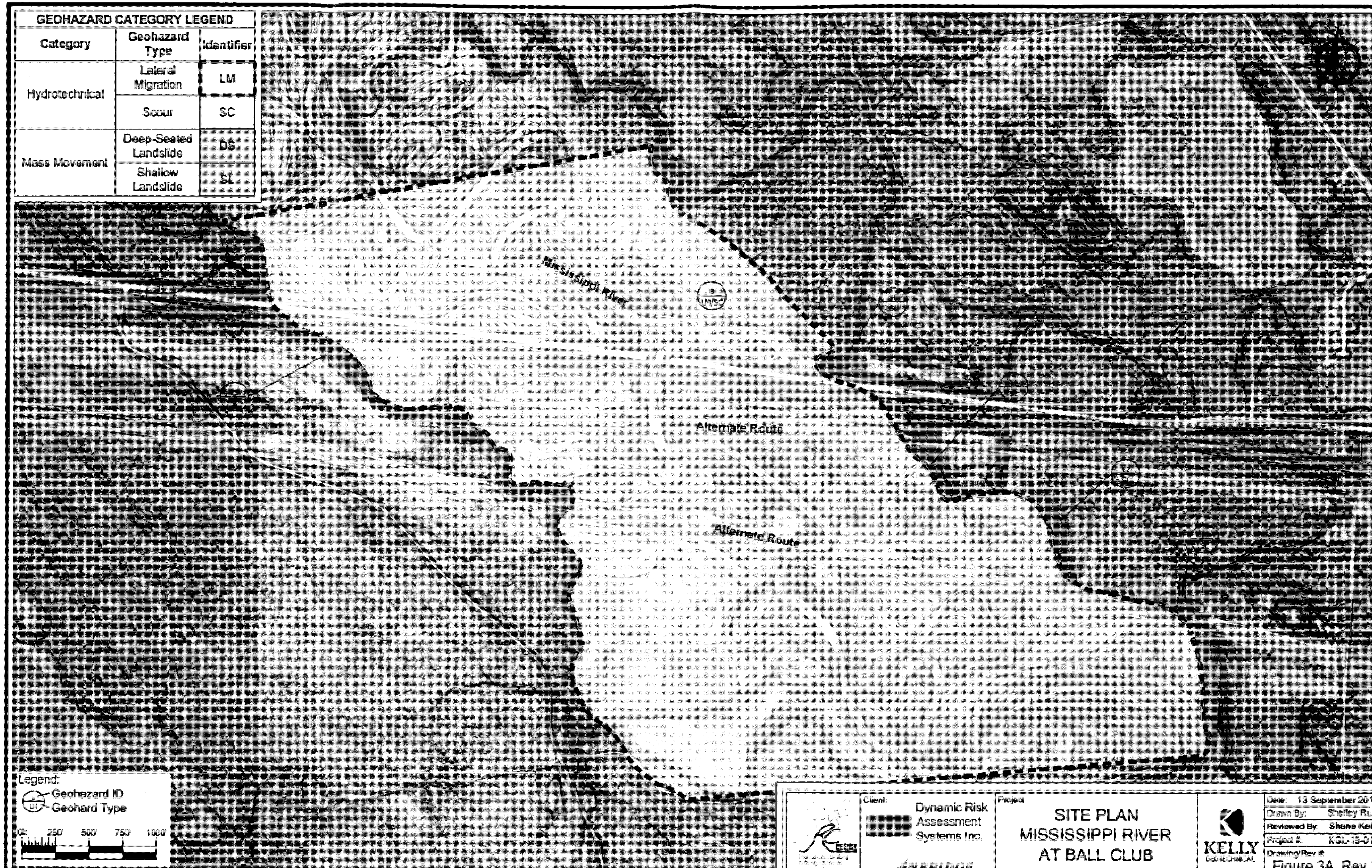
GEOHAZARD CATEGORY LEGEND		
Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



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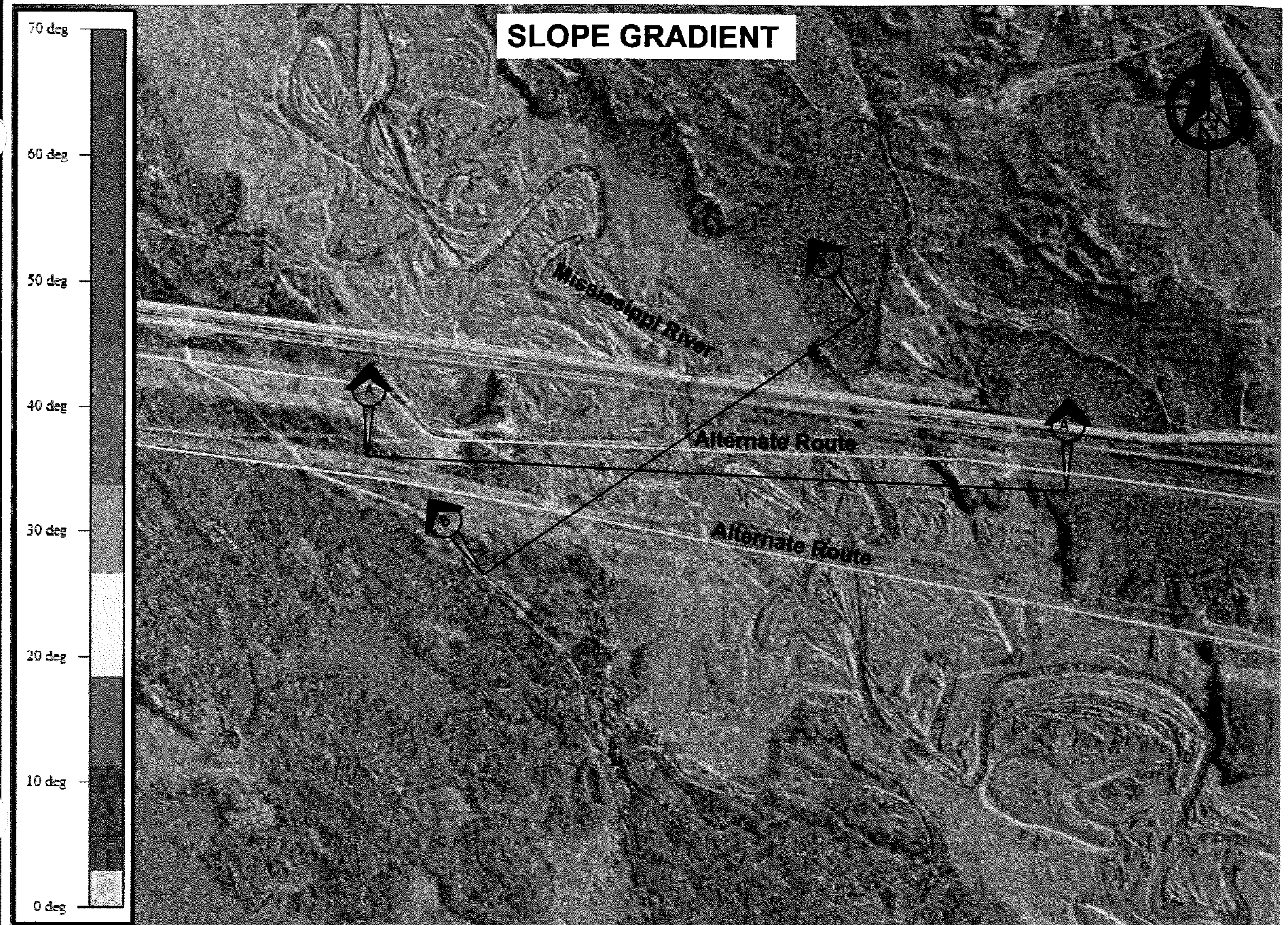

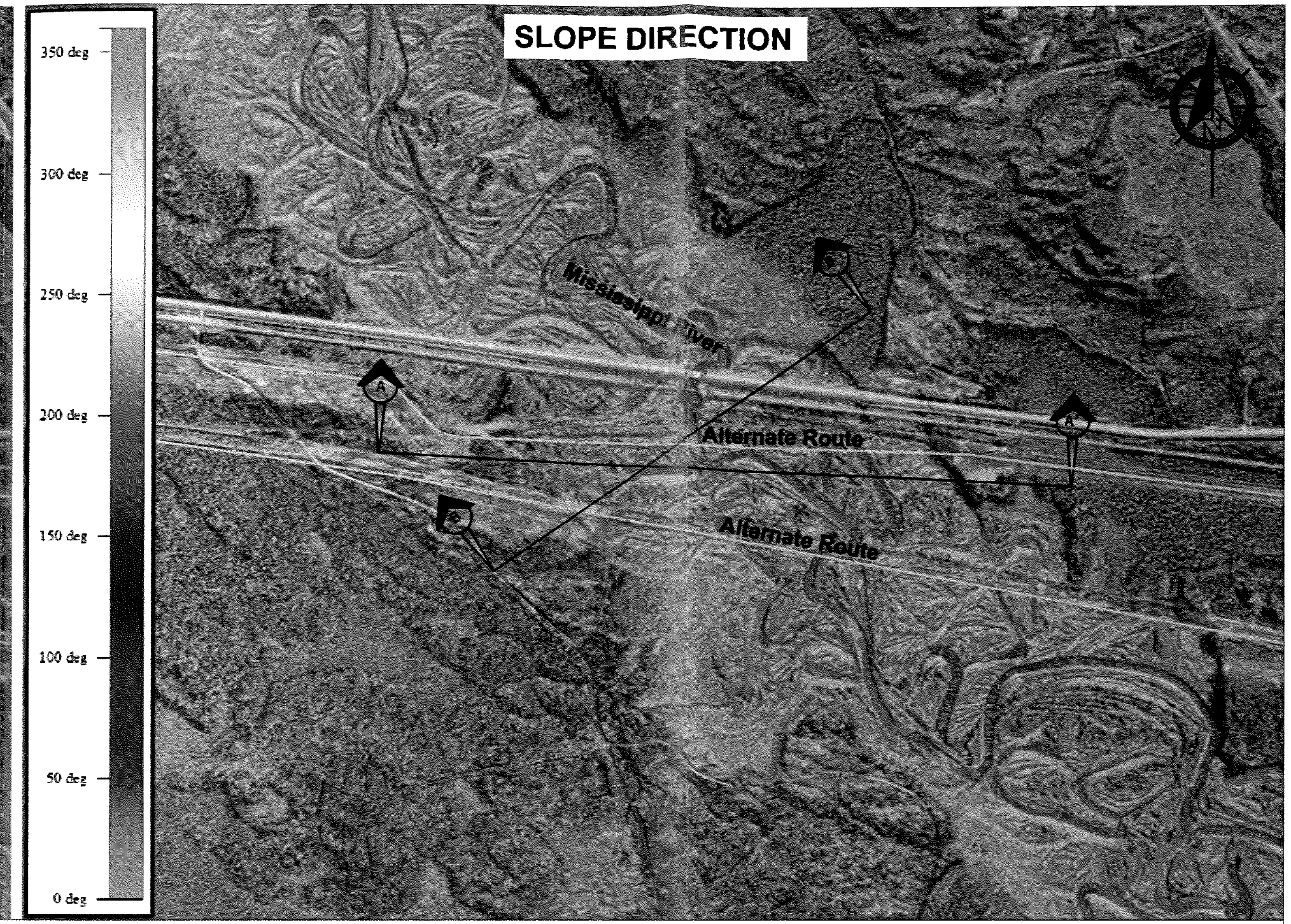

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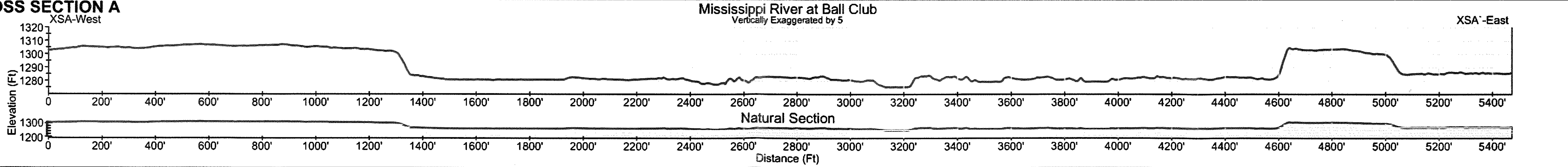

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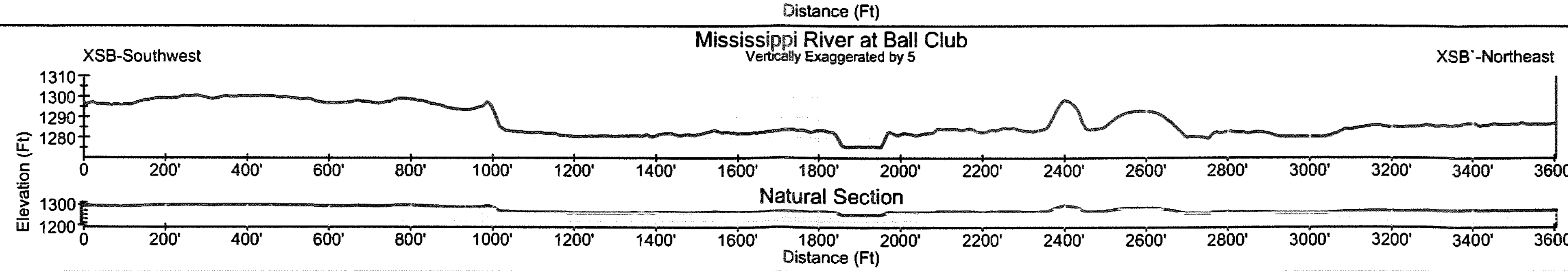

Plan Scale

0ft 500' 1000' 1500' 2000'

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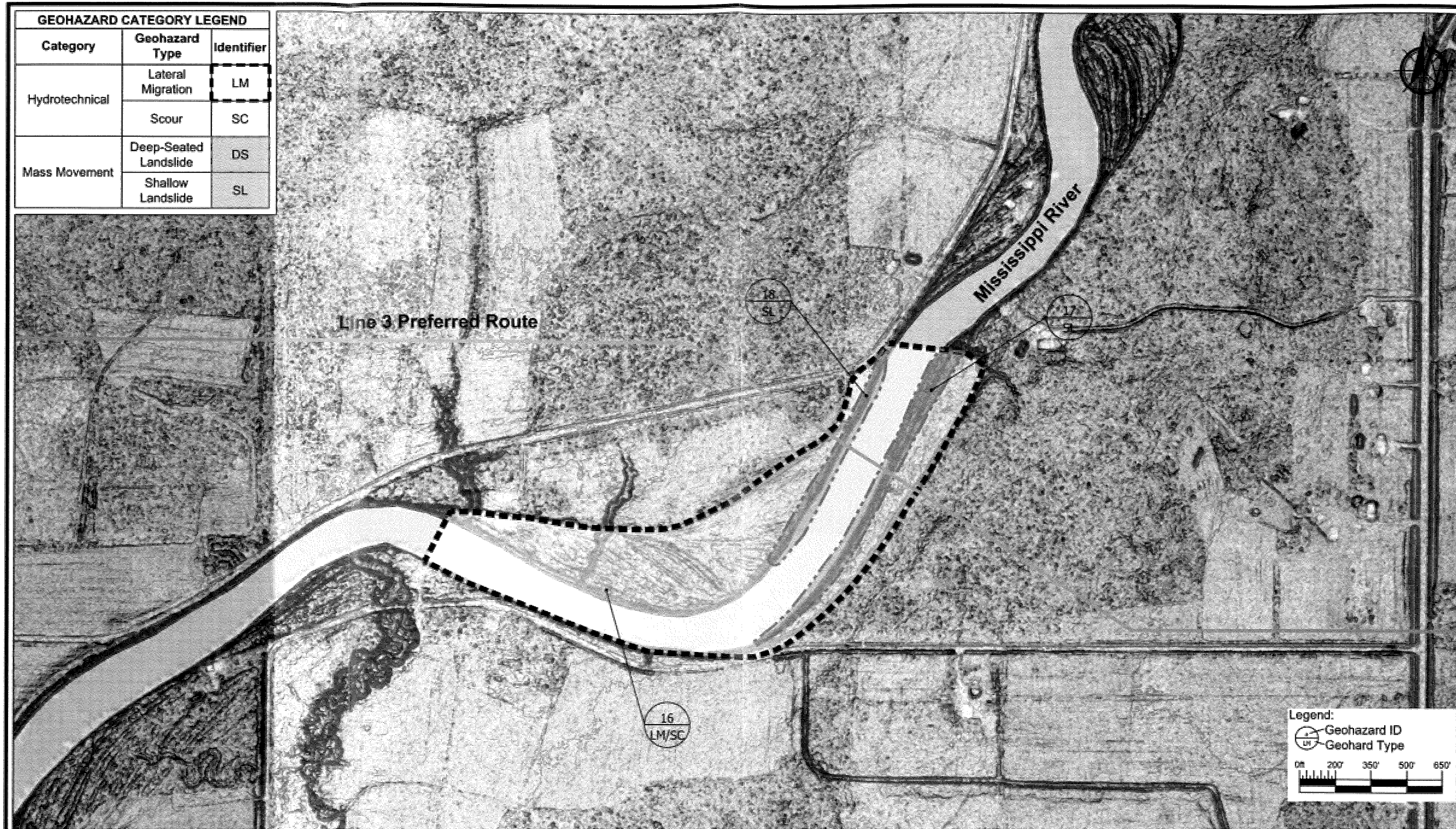
GEOHAZARD CATEGORY LEGEND		
Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



Client: Dynamic Risk Assessment Systems Inc.

ENBRIDGE

Project: SITE PLAN MISSISSIPPI RIVER AT 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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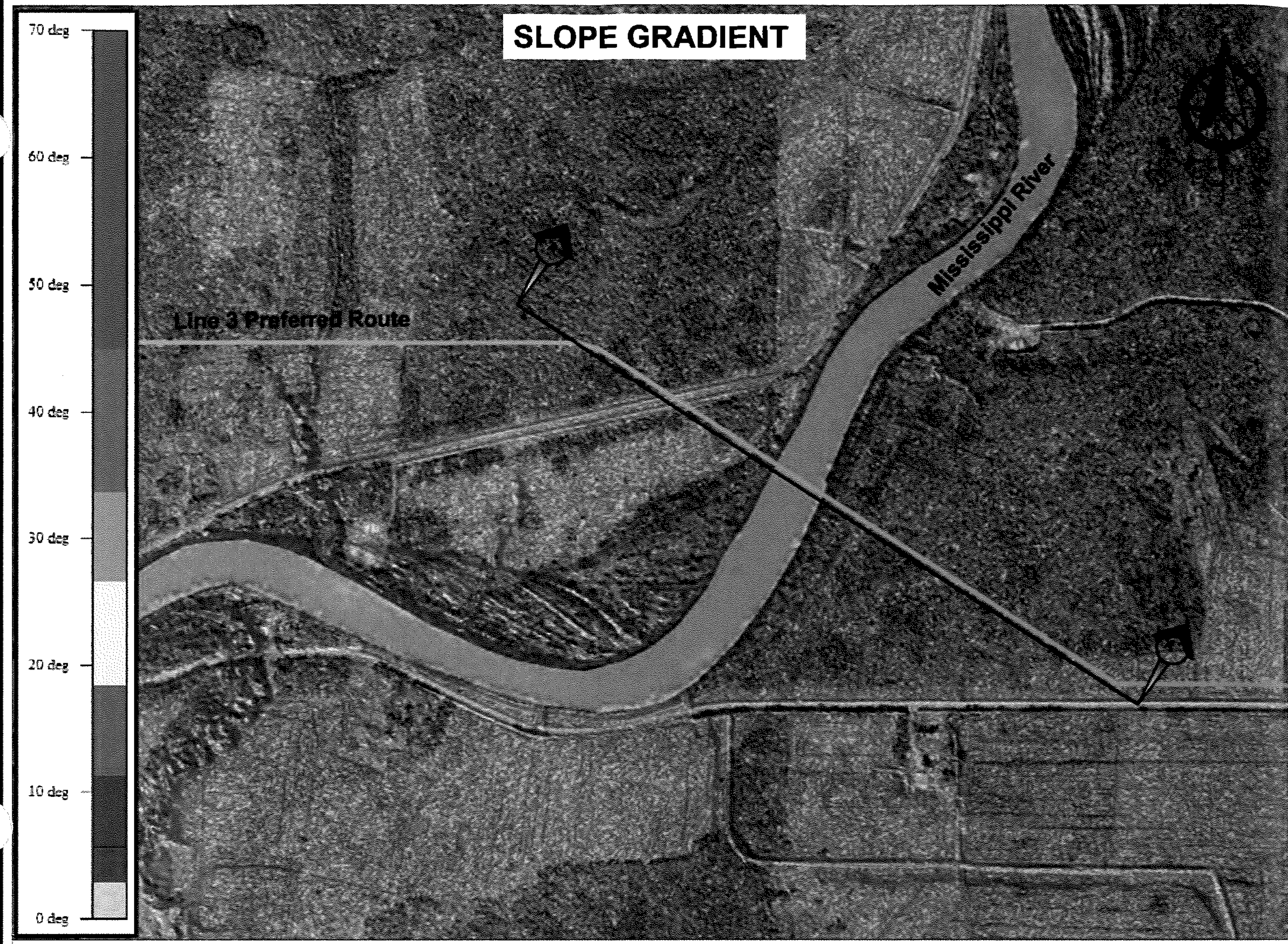

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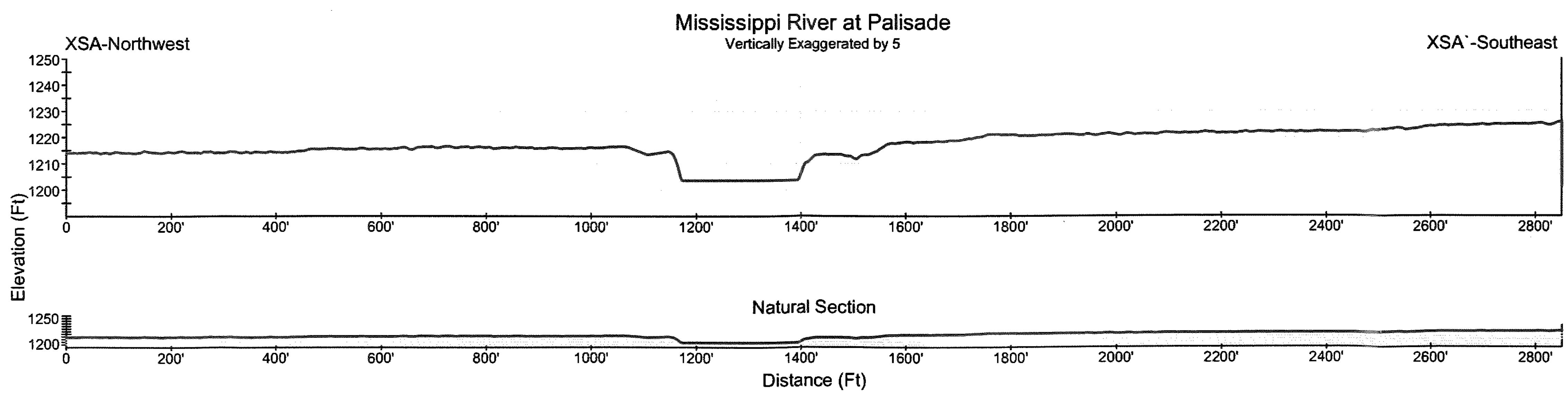

Plan Scale

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

RC DESIGN Professional Drafting & Design Services

KELLY GEOTECHNICAL

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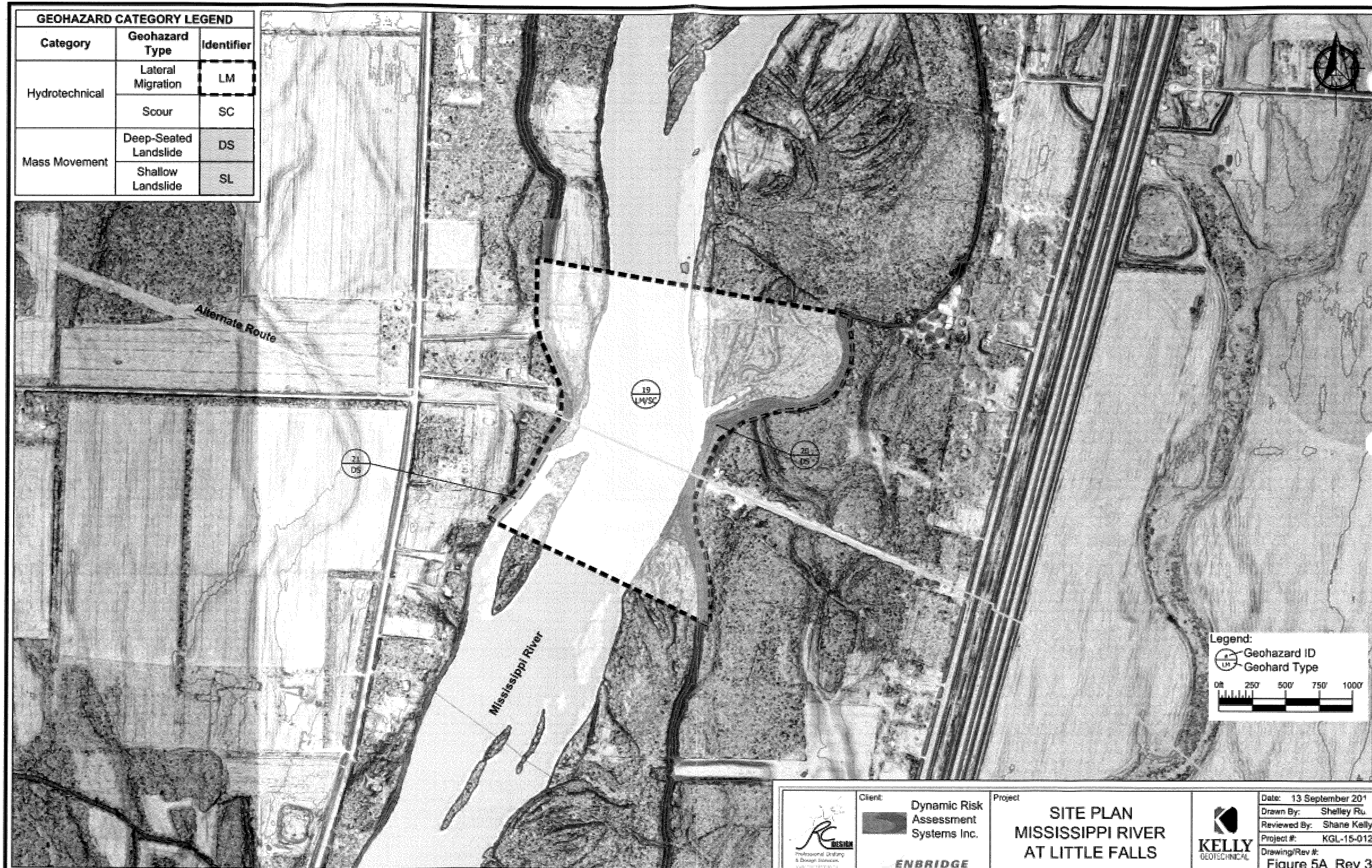
GEOHAZARD CATEGORY LEGEND		
Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project SITE PLAN MISSISSIPPI RIVER AT LITTLE FALLS	KELLY GEOTECHNICAL	Date: 13 September 201	Drawn By: Shelley Ru.
			Reviewed By: Shane Kelly	Project #: KGL-15-012
			Drawing/Rev #: Figure 5A Rev 3	

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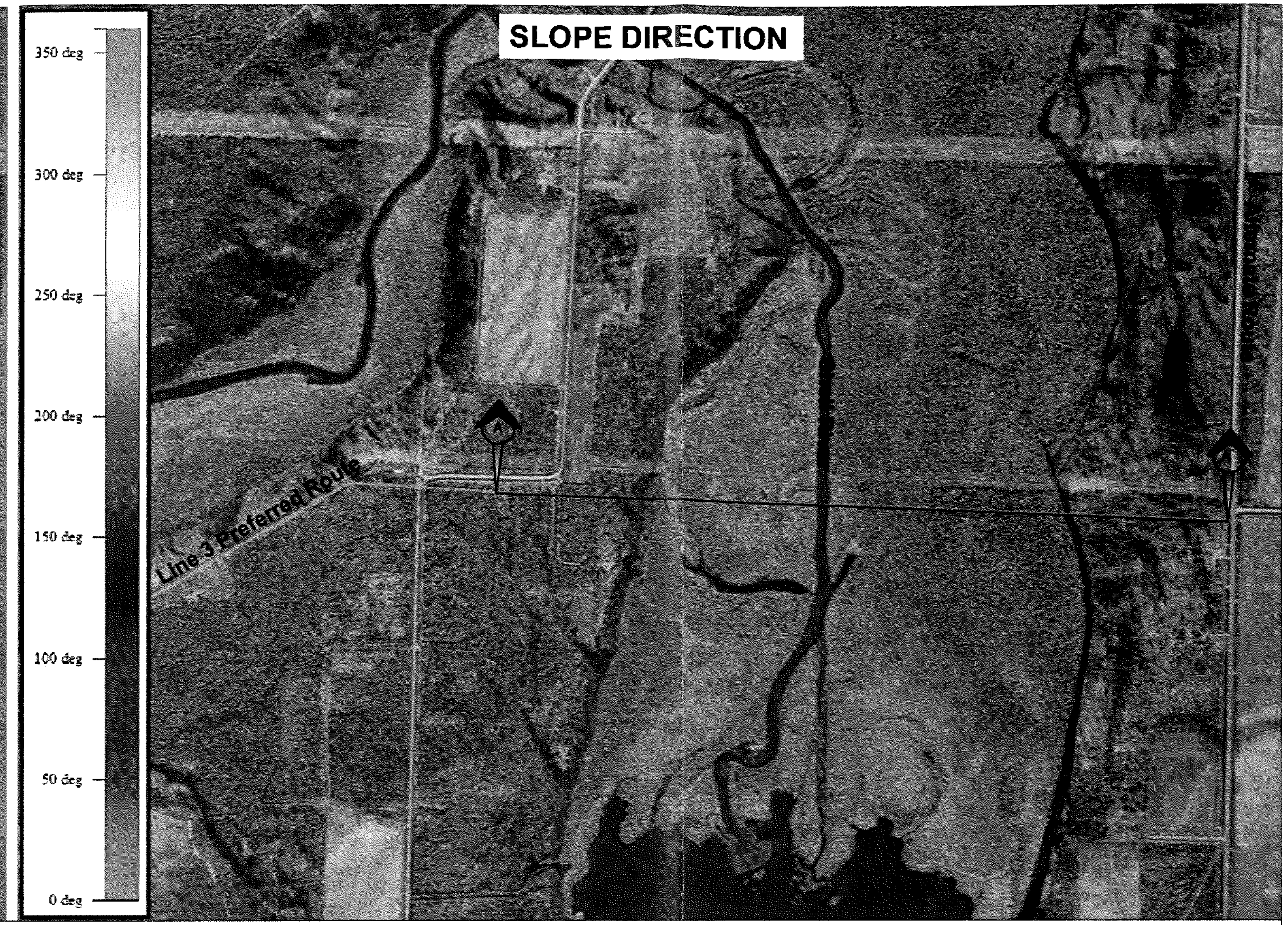

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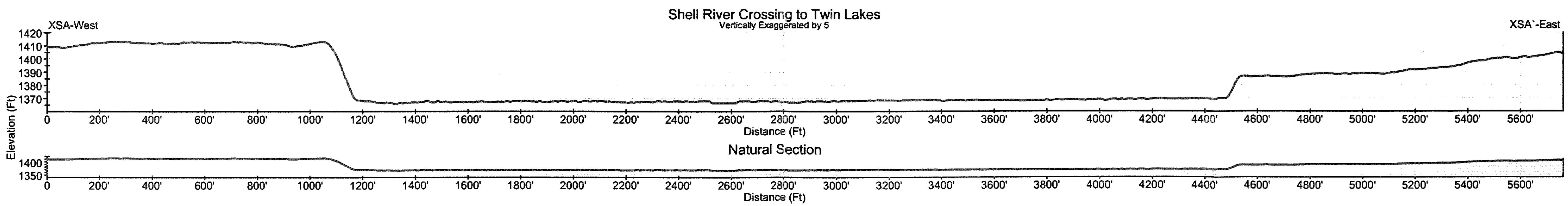

Plan Scale

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RC DESIGN
Professional Drafting & Design Services

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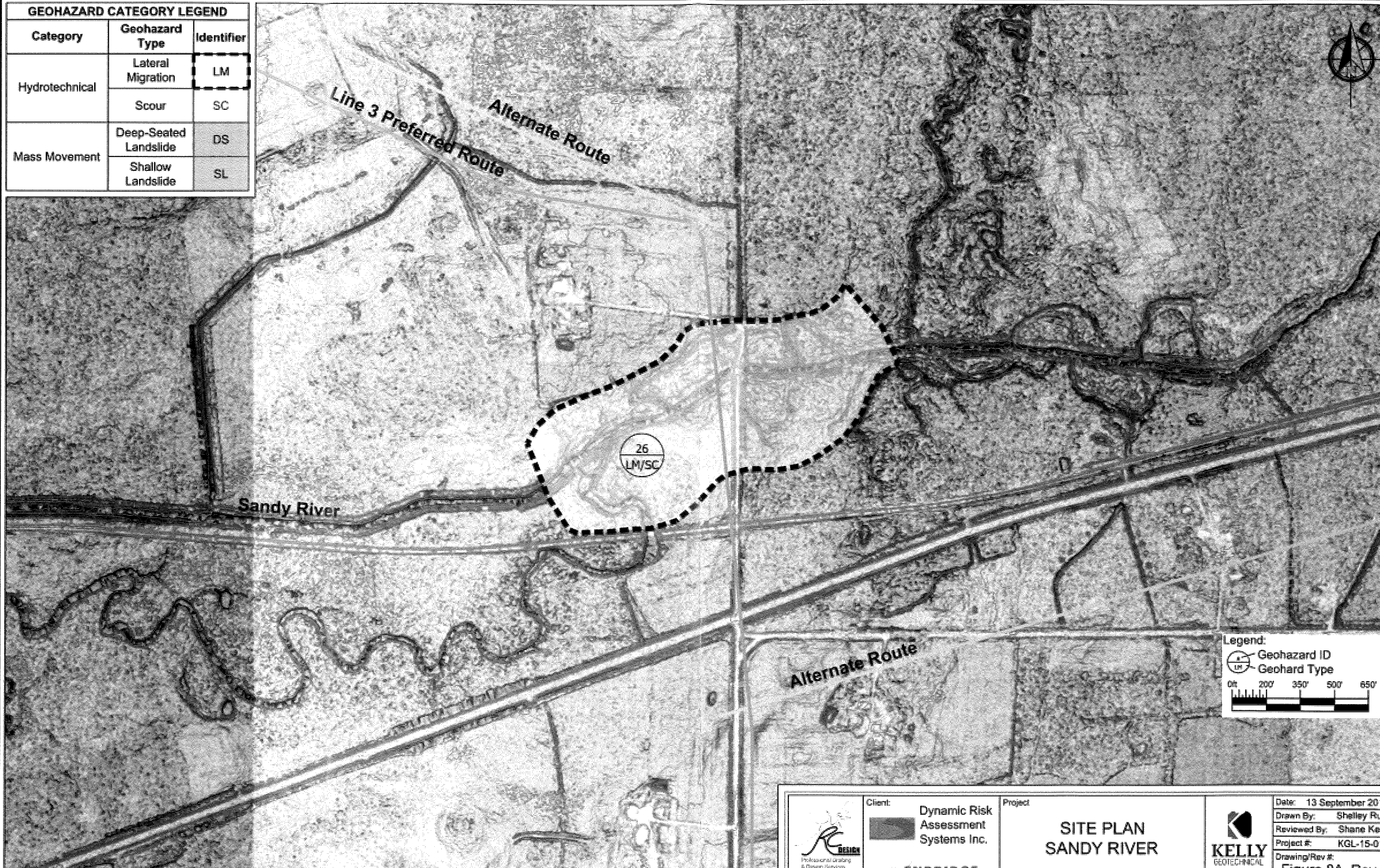
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



Client:	Project		
Dynamic Risk Assessment Systems Inc. ENBRIDGE	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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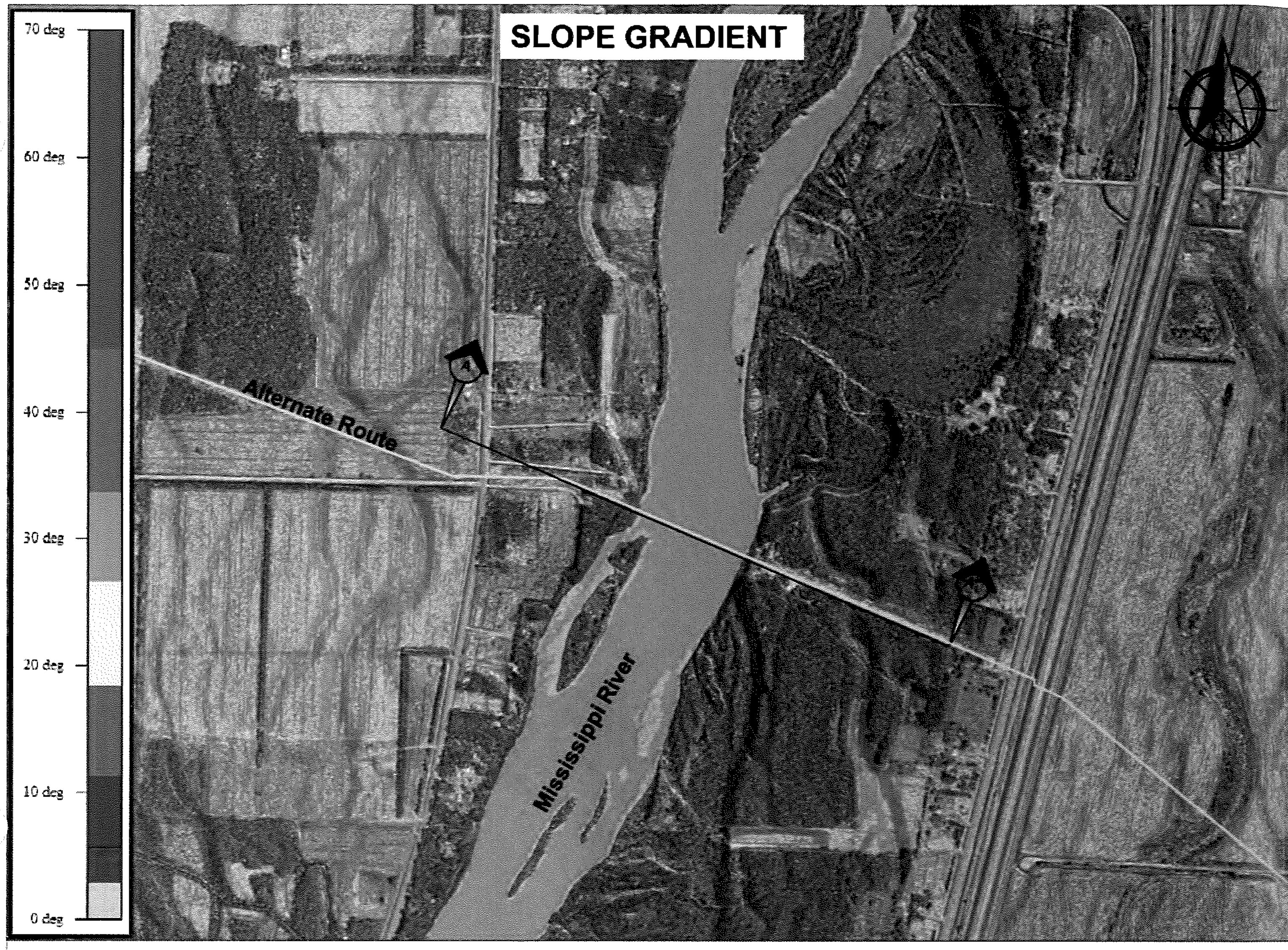

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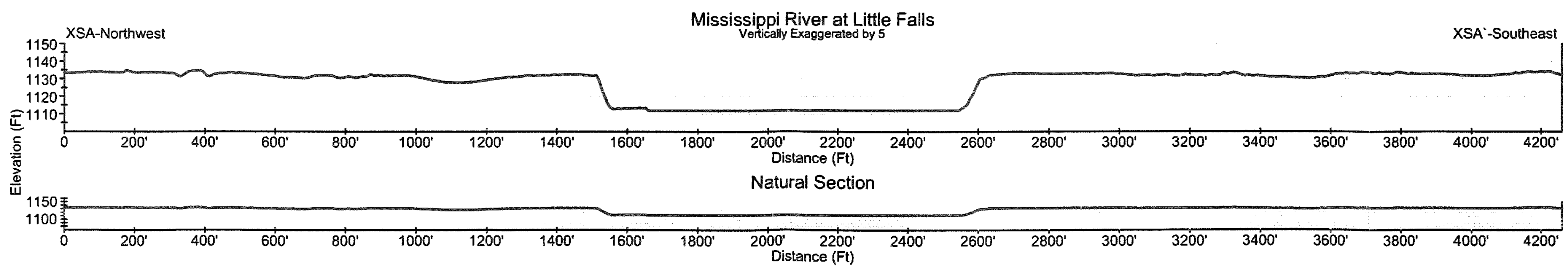

Plan Scale

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RC DESIGN
Professional Drafting & Design Services

Client: Dynamic Risk Assessment Systems Inc.

ENBRIDGE

Project: TERRAIN ANALYSIS SUMMARY MISSISSIPPI RIVER AT LITTLE FALLS

KELLY GEOTECHNICAL

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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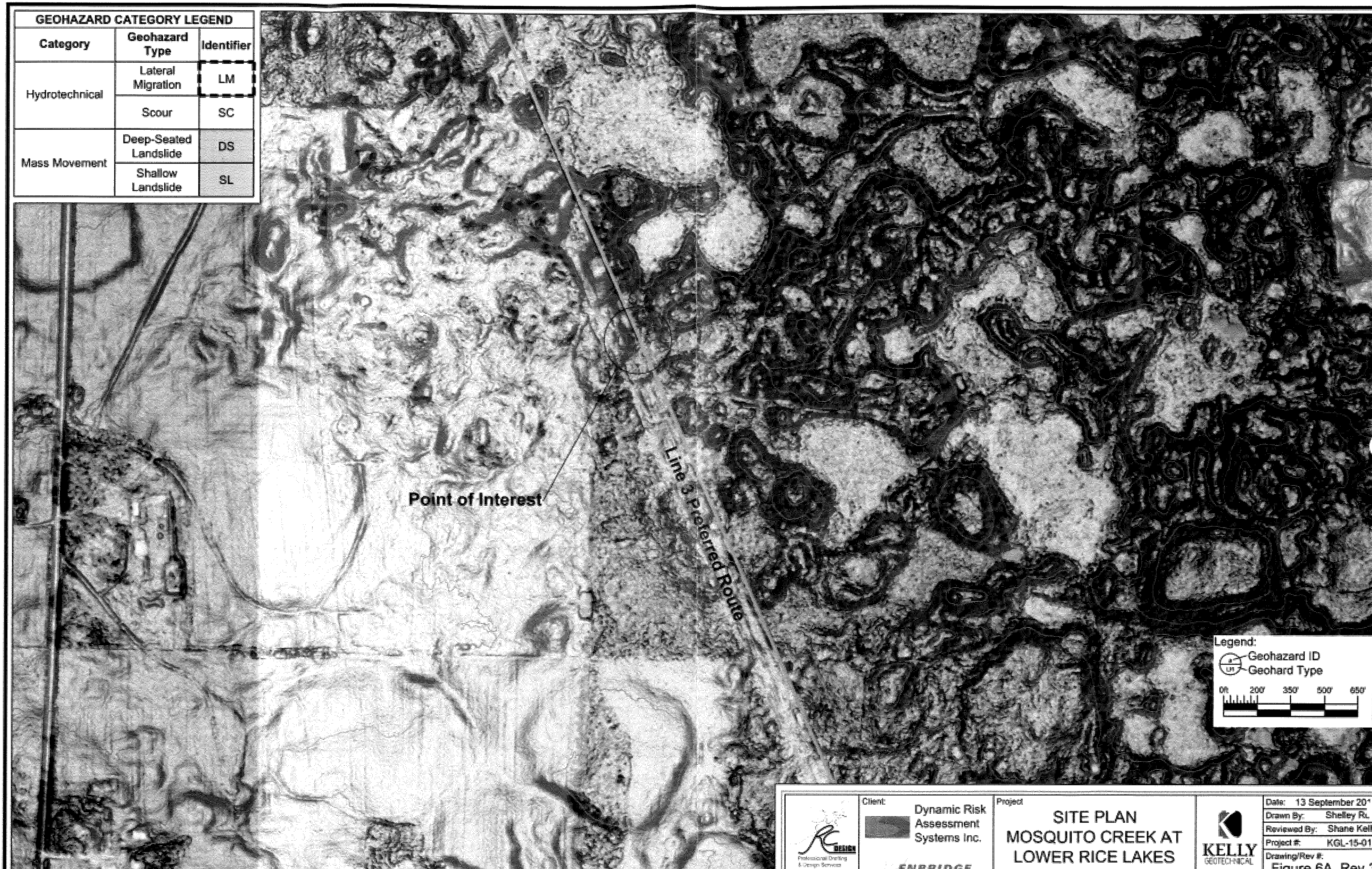
GEOHAZARD CATEGORY LEGEND

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 MOSQUITO CREEK AT LOWER RICE LAKES	KELLY GEOTECHNICAL	Date: 13 September 20' Drawn By: Shelley Ru Reviewed By: Shane Kelly Project #: KGL-15-012 Drawing/Rev #: Figure 6A Rev 3

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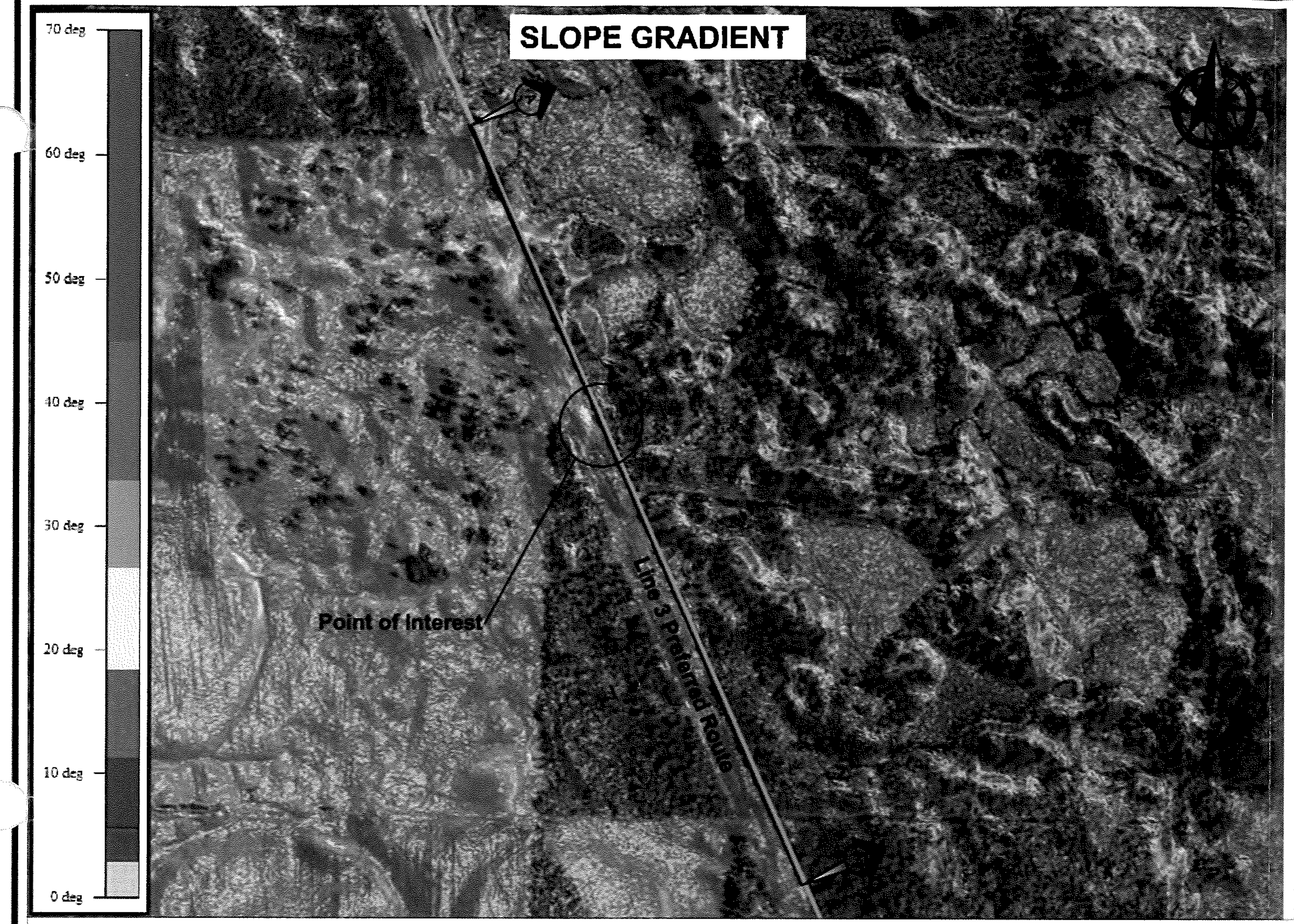

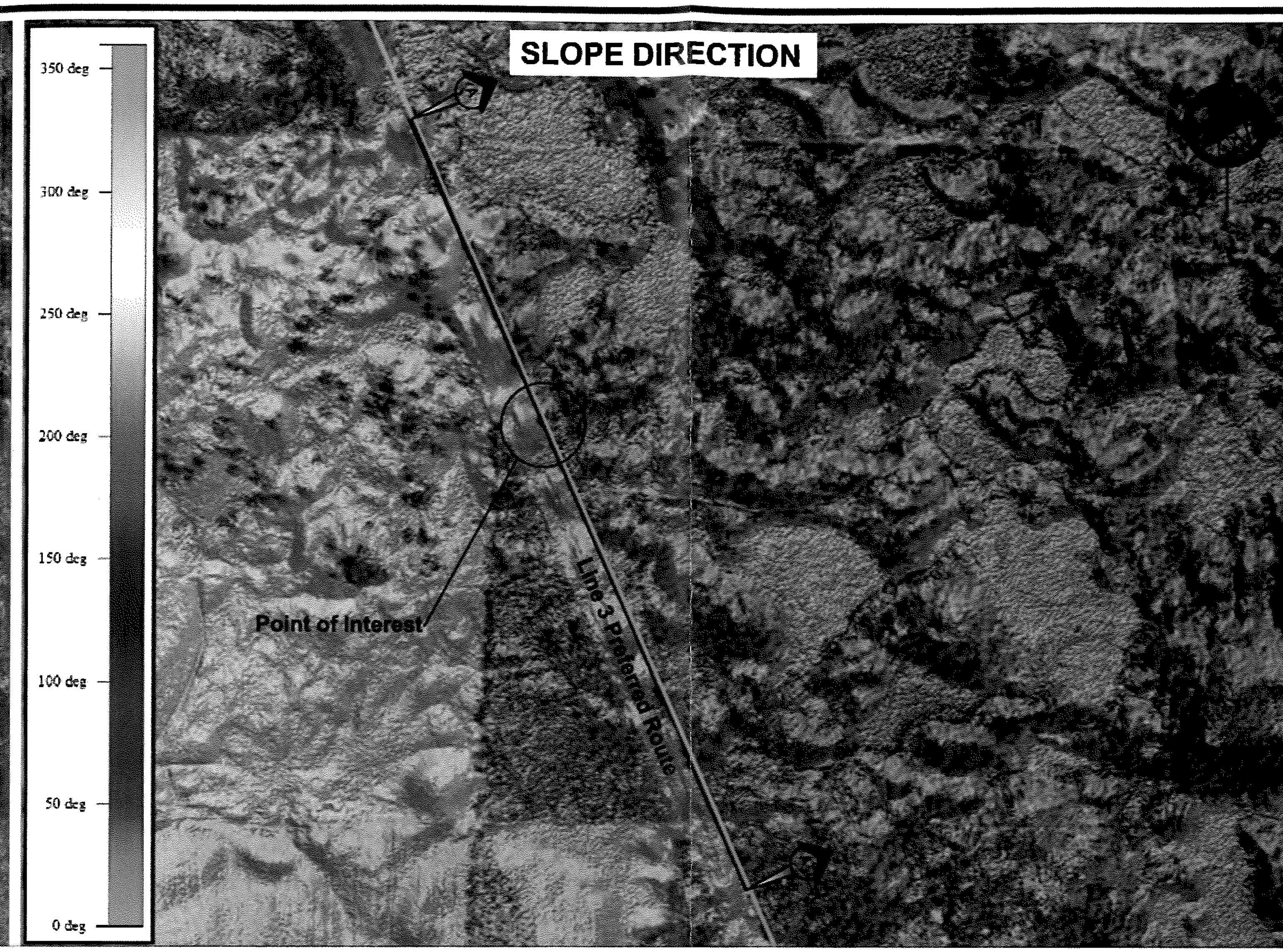

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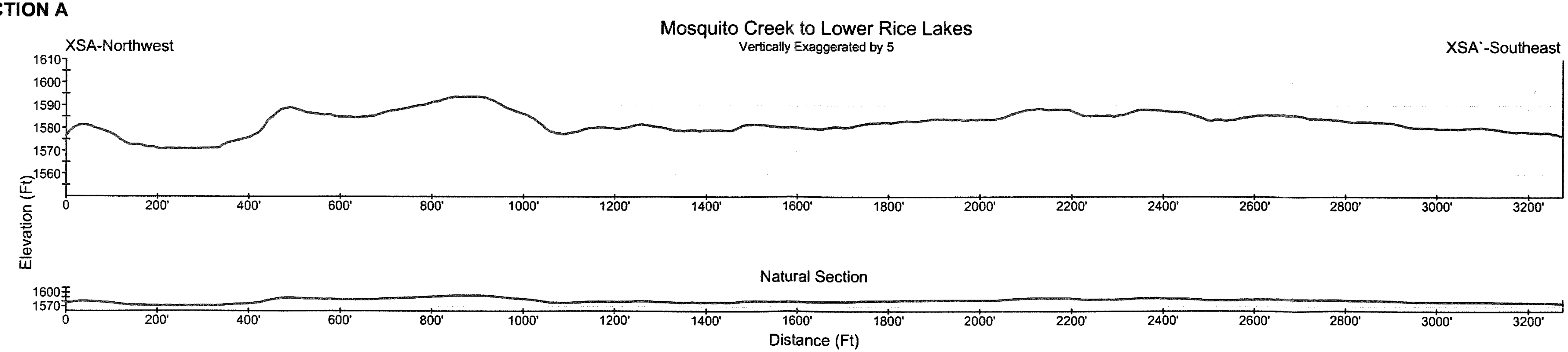

Plan Scale

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RC DESIGN Professional Drafting & Design Services	Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project: TERRAIN ANALYSIS SUMMARY 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

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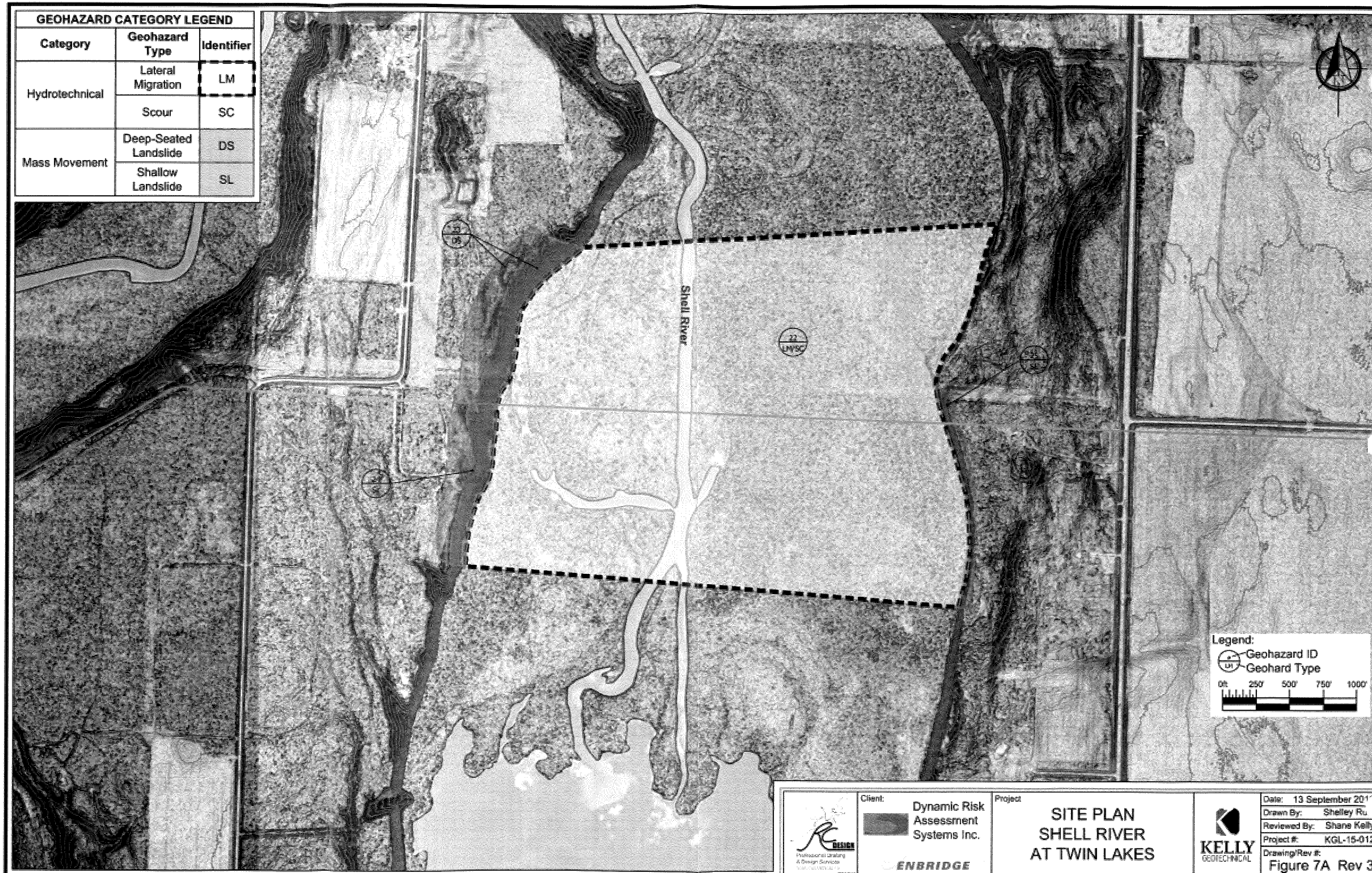
GEOHAZARD CATEGORY LEGEND		
Category	Geohazard Type	Identifier
Hydrotechnical	Lateral Migration	LM
	Scour	SC
Mass Movement	Deep-Seated Landslide	DS
	Shallow Landslide	SL



Client: Dynamic Risk Assessment Systems Inc.
ENBRIDGE

Project: SITE PLAN
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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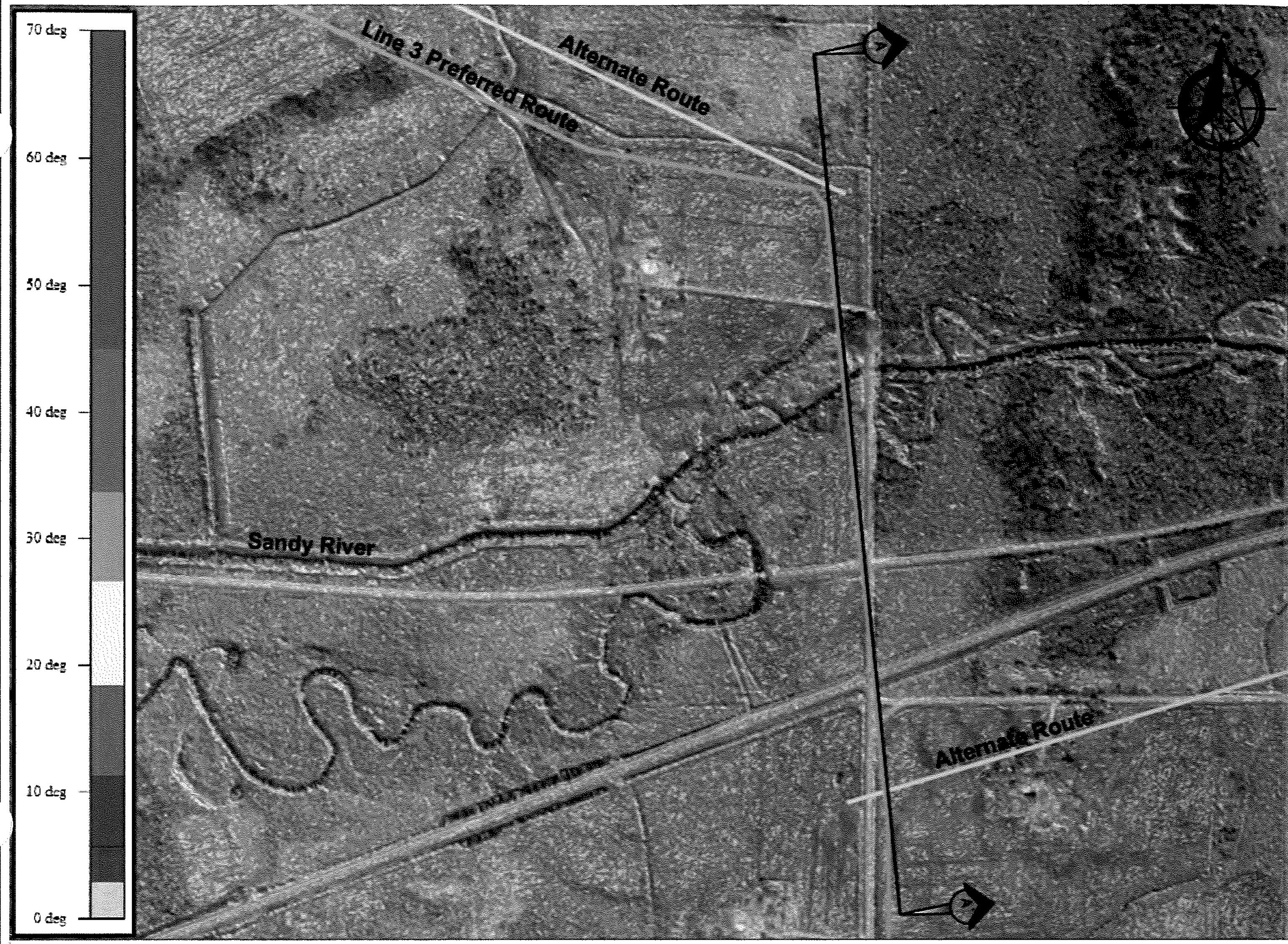

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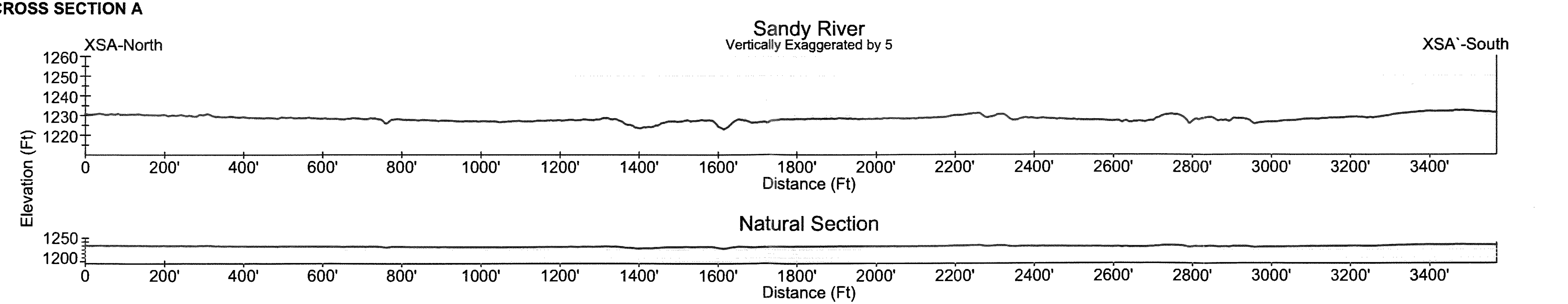

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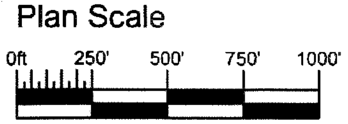

RC DESIGN Professional Drafting & Design Services	Client: Dynamic Risk Assessment Systems Inc. ENBRIDGE	Project TERRAIN ANALYSIS SUMMARY SANDY RIVER	KELLY GEOTECHNICAL	Date: 13 September 2016 Drawn By: Shelley Ruiz Reviewed By: Shane Kelly Project #: KGL-15-012 Drawing/Rev #: Figure 8B Rev 3

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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.	**Use the flood return period used to establish the burial depth and cover requirements in the watercourse crossing design. 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.