GEOQuébec 2015
Challenges from North to South
Des défis du Nord au Sud

Terrain analysis for high voltage transmission line routing using remote sensing techniques

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ABSTRACT
Remote sensing techniques offer cost effective tools for characterizing terrain conditions for geotechnical and environmental assessment of linear infrastructure routes. A routing study for a high-voltage overhead transmission line highlights the utility of remote sensing for evaluating slope stability, flood frequency at a major river crossing, and potential impacts to environmentally sensitive aeolian soils. Remote sensing tools used include black and white stereoscopic air photos, high-resolution colour orthoimagery, and digital elevation data generated from photogrammetric analysis and LiDAR data. Interpretation of these data sets was aided by ground and helicopter field reconnaissance and publically available information including water well logs, soils maps, and hydrologic data. Study results illustrate information that can be gained from remote sensing techniques, the value of integrating this information with other data sources, and examples of specific terrain features that can be studied using remote sensing products.

RÉSUMÉ
Les techniques de télédétection offrent des outils efficaces et peu coûteux pour procéder à la caractérisation géotechnique et environnementale des sites d'infrastructures routières linéaires. Une étude réalisée pour l'implantation d'une ligne de transmission électrique a démontré l'utilité de la méthode de télédétection afin d'évaluer la stabilité des pentes, la fréquence des inondations au point de la traversée d'une rivière importante, ainsi que les impacts potentiels sur les sols d'origine éolienne écologiquement sensibles. Les outils de télédétections incluent les photos aériennes stéréoscopiques en noir et blanc, l'ortho-imagerie en couleur à haute résolution, les données d'élévations numériques obtenues à partir d'une analyse photogrammétrique et des données LiDAR. L'interprétation des données a été bonifiée par des travaux de reconnaissance de terrain, au sol et héliportés, ainsi qu'au moyen d'informations disponibles au public, incluant des données hydrogéologiques, des cartes pédologiques et des données hydrologiques. Les résultats de l'étude font état du type d'information qui peut être obtenue par l'entremise de techniques de télédétection, l'intérêt d'intégrer ce type d'information aux données de base obtenues par d'autres sources, et fournit des exemples de terrains types qui peuvent être étudiés en utilisant ces méthodes de télédétection.

1 INTRODUCTION

Desktop studies and field reconnaissance were carried out to identify and evaluate terrain features that could potentially impact the design, construction, operation and environmental sensitivities of a high voltage transmission line in west-central Saskatchewan. A variety of remote sensing technologies were applied to maximize the types of terrain features that could be identified and the level of information that could be provided to guide transmission line routing and field reconnaissance. Of particular importance in this study were features related to slope stability at a major river crossing, potential damage to foundations and structures due to flooding, ice breakup and flotsam, and the environmental integrity of sensitive aeolian terrain. Remote sensing technologies included, high-resolution colour orthoimagery, large-scale stereoscopic aerial photography, and digital elevation models from different sources to characterize the terrain and identify geohazards.

2 STUDY AREA

The study area is located in west-central Saskatchewan near the Alberta border. It is bisected by the North Saskatchewan River, a large dominantly glacier-fed river originating in the Rocky Mountains in western Alberta. Figure 1 shows the location of the study area.

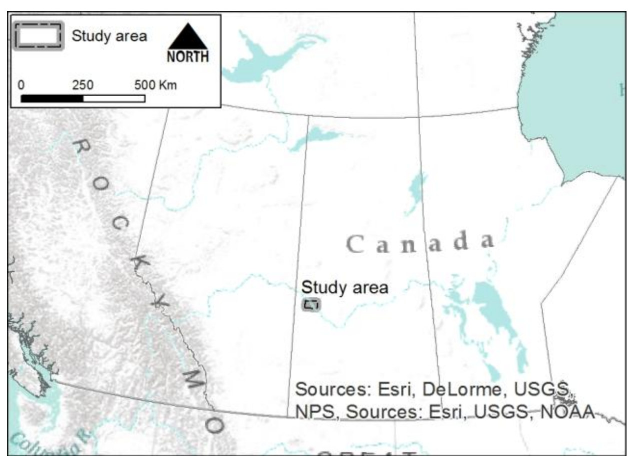

Figure 1. Study area

The surficial geology consists of extensive aeolian sediments deposited in a glaciolacustrine delta overlying multiple till and intertill units which overlie the Cretaceous

Lea Park Formation. The North Saskatchewan River flows within a large post-glacial meltwater channel and experiences significant variations in discharge throughout the year, typically cresting in late June-early July for several days to weeks. The valley sides are highly susceptible to landslide activity where the contact between glacial sediments and underlying weak Cretaceous shale lies near or above the valley bottom, and due to groundwater seepage from permeable surficial aeolian and glaciofluvial sediments and intertill stratified units on the upper slopes. An extensive aeolian plain is present on both sides of the river. The aeolian plain is vegetated with grassland and seeded pasture in open areas with scattered wooded areas near wet depressions. Topographic relief on the aeolian plain ranges from gently undulating to hummocky and ridged where dunes and blowouts are present. Dunes and blowouts are mostly stabilized by vegetation but are susceptible to erosion where the vegetation has been disturbed. The primary economic activity in the study area consists of ranching in grassland areas, cereal crops around the perimeter of the aeolian plain and extensive oilfield development throughout much of the study area.

The study area receives approximately 416 mm of precipitation per year, with 315 mm falling as rain and 101 mm as snowfall. Average daily temperatures range from -15 to +17 °C with an average annual temperature of 2.3 °C.

3 DATA SOURCES

The following data sources were used for this study:

Natural Resources Canada (NRCAN). 2007. Canadian Digital Elevation Data, Level 1 Product Specifications Edition 3.0. Centre for Topographic Information, Natural Resources Canada, Sherbrooke, Quebec. Available from: http://www.geobase.ca/geobase/en/data/cded/description.html

Natural Resources Canada (NRCAN). 2013. Historical aerial photography. National Airphoto Library, Natural Resources Canada, Ottawa, Ontario. Available from: https://neodf.nrcan.gc.ca/

Saskatchewan Geospatial Imagery Collaborative (SGIC). 2012. Aerial imagery: FlySask 60cm orthoimagery. Data served by Saskatchewan Ministry of Environment. Available from: http://flysask.ca/

Saskatchewan Power Corporation. 2014. LiDAR 5m elevation data. Data processed by GeoDigital.

Saskatchewan Ministry of Agriculture (MOA). 2009. Soil zones in southern Saskatchewan. Government of Saskatchewan Geomatics Division. Regina, Saskatchewan.

Water Security Agency. 2015. Drillers Reports Water Well Logs. Online Drillers Logs, Water Security Agency, Moose Jaw, Saskatchewan. Available from: https://www.wsask.ca/Water-Info/Ground-Water/Information-Services/

Environment Canada. 2015. Hydrometric Water Discharge Data. Water Survey of Canada, Environment Canada, Ottawa, Ontario. Available from: https://wateroffice.ec.gc.ca/

Helicopter and ground field reconnaissance observations.

4 METHODOLOGY

Studies were carried out in three separate components: 1) a slope stability assessment; 2) a hydrometric analysis; and 3) an assessment of environmental sensitivity related to aeolian soils.

4.1 Slope stability

The slope stability assessment consisted of 3D examination of the valley slopes using 1:20,000 stereoscopic aerial photographs followed by ground and helicopter reconnaissance. Recent and past slope failures were delineated including failure bowls and backscarps, slump block ridges, debris path and debris deposits, where preserved. Possible contributing factors such as undercut slopes, ground and surface water sources and features impeding drainage were also identified. Helicopter reconnaissance covered a long reach of river downstream of the study area to gain a regional perspective as well as detailed examination of both valley sides within the immediate study area. Ground reconnaissance focussed on slopes near proposed valley crossing sites and consisted of walking traverses from the valley crest to the river shoreline.

4.2 Hydrometric analysis

A hydrometric analysis was carried out to determine the magnitude and frequency of flooding of the river banks in this part of the North Saskatchewan River. Determining flooding levels and frequency aided in the location and design of the transmission structures which will span a distance of approximately 1000 m across the river.

The desktop hydrometric analysis utilized a DEM created from high resolution stereo imagery and water survey data from the Water Survey of Canada (WSC). Discharge records and rating curves were obtained from the WSC. Flood frequency analysis was done using historical hydrometric data. River discharge values and the rating curve supplied by WSC were used to estimate stage height. Local bathymetric data are not available for the study area. The channel bottom elevation was estimated by subtracting the stage height from the water surface elevation determined from the FlySask DEM. The estimated channel bottom elevation provided a reference point from which higher stage heights could be measured. Water surface levels were generated in a GIS to show the flood surface under varying recurrence intervals of discharge.

A field visit to the site and discussion with local landowners helped validate the findings.

4.3 Environmentally sensitive aeolian soils

Environmental sensitivity associated with aeolian soils was assessed by mapping the distribution of surficial sand deposits from air photos, characterizing the relief and current stability of the aeolian deposits and ranking these areas in terms of susceptibility to wind erosion in the event that the vegetation cover is disturbed.

Stereoscopic air photos were used to map areas with characteristic dune forms and evidence of wind erosion. Aeolian deposits were then further subdivided on the basis of relief with higher relief areas having a greater likelihood of being disturbed by transmission line construction. Water well driller's reports were reviewed to support interpretation of air photos and to determine the depth of surficial sand deposits to help assess foundation and ground water conditions in aeolian areas. Wind sensitive soil polygons were extracted from the Saskatchewan Soils Resource Database (SSRD) (AAFC 2005). This information was overlaid on the air photo mapping to better constrain the likely distribution of wind susceptible soils. Lastly, the extent of sensitive sand dune areas was examined using field photographs and helicopter video to validate the mapping. Areas mapped as being sensitive to wind erosion were identified and included as part of the wind sensitive soils layer. Two classes were considered: high susceptibility and very-high susceptibility.

5 RESULTS

5.1 Slope stability

The most common slope failures in the study area are retrogressive slump failures. These failures are typically defined by an arcuate backscarp that is commonly located 250-500m back from the river shoreline. The valley side relief ranges up to approximately 40-60m above river level. The failures can occur as large single slump failures with multiple slump blocks but more commonly consist of landslide complexes with multiple adjoining slump failures extending continuously for several kilometres along the valley side (Figure 2).

Local borehole drilling indicates that the elevation of the clay shale bedrock surface beneath glacial drift is uneven, varying above and below the valley bottom. Therefore, it is thought that the primary failure mechanism is movement along zones of weakness in the Lea Park Formation mudstone, with slope instability being more prevalent where the drift-bedrock contact is above the valley bottom. A similar failure mechanism has been associated with large retrogressive failures described elsewhere along the North Saskatchewan River in this region (Sauer and Christiansen 1986, Sauer 1982, Christiansen 1982, Kelly et al. 1995, Eckel et al. 1987, Krahn et al. 1979, Misfeldt et al. 1991).

The importance of interactions with the groundwater regime has also been noted by others. Figure 2 is an air photo map showing an area of extensive retrogressive slump failure in the study area. These landslides are characterized by well-defined backscarps and a series of subarcuate slump block ridges that become progressively lower in elevation toward the river.

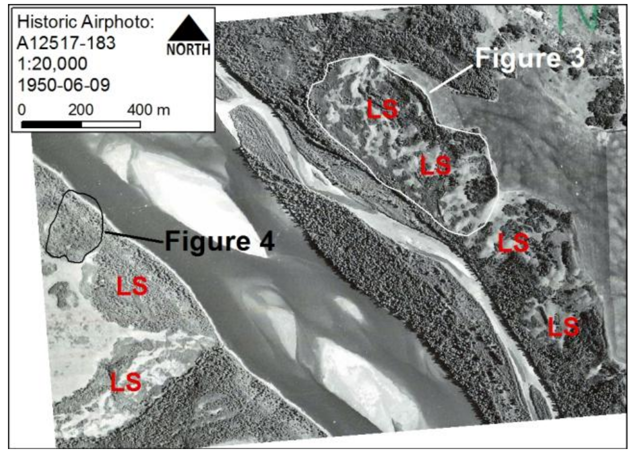

Figure 2. Airphoto showing landslides (LS)

Figure 3 shows the typical appearance of slump block ridges in this type of failure. Many of the retrogressive failures in the study area appear to have been stable for a long period of time; however, air photo mapping and field reconnaissance confirmed that recent landslides have formed in retrogressive landslide terrain. Reactivated failures in the upper part of the slope (Figure 4) appear to be associated with groundwater seepage from overlying stratified sediments. In one instance a recent failure on the middle to lower slope is associated with bank erosion along the river shoreline.


Figure 3. Photograph of historical retrogressive landslide

Figure 4. Photograph of a recent upper slope landslide

Figure 5 shows the location selected for the North Saskatchewan River crossing, a corridor that is free of historical and recent landslide activity.

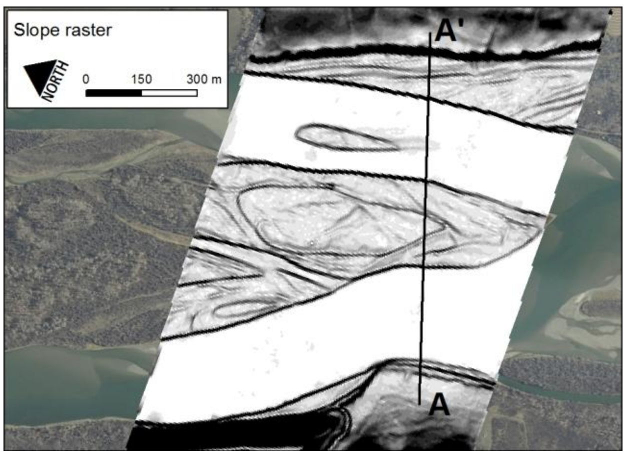

Figure 5. LiDAR slope raster of the river crossing

5.2 Hydrometric analysis

A flood frequency analysis was carried out to create a flood surface map for different recurrence intervals. Table 1 shows the river discharge and stage calculated for seven (7) recurrence intervals.

Table 1. River stage and discharge

Recurrence interval	Stage height (m) [1]	Discharge ($m^3 s^{-1}$)
2 years	3.7	1,055
5 years	4.6	1,631
10 years	5.2	2,108
25 years	5.9	2,837
50 years	6.4	3,480
100 years	7.0	4,221
200 years	7.6	5,073

[1]measured from bottom of river channel

Headwaters of the North Saskatchewan River are located in the Rocky Mountains in Alberta. The river flows eastward, passing through Edmonton, Alberta, and Prince Albert, Saskatchewan, before joining the South Saskatchewan River east of Prince Albert. East of the confluence the two rivers become the Saskatchewan River, flowing through Cedar Lake, Lake Winnipeg, and the Nelson River into Hudson Bay (Pomeroy et al. 2005). The North Saskatchewan River typically peaks in late June to early July in the study area. The majority of this flow is melt water from the Saskatchewan Glacier and alpine snow melt in the mountains and foothills of western Alberta (Pomeroy et al. 2005). Smaller peaks prior to mountain runoff can occur due to melting of the snowpack on the prairie, resulting in higher flows from tributary streams from April to May (Pomeroy et al. 2005). Typical peak flows usually last several days, however, in more extreme cases water levels may remain high for a week or longer.

The flood frequency analysis of the North Saskatchewan River in the study area found that the lower terraces and sandbars are subject to frequent flooding, often annually or biannually. Areas prone to frequent flooding tend to be unvegetated or sparsely vegetated. Higher terraces that are 4 m to 5 m above the riverbed may be subject to flooding every 5 to 10 years. Above this, there are higher terraces that do not appear to be subject to flooding within a statistical recurrence interval of 1:50 years. Figure 6 shows the calculated flood surface for the 1:50 year recurrence interval based on elevations taken from the FlySask DEM. The valley profile shown in Figure 7 was created from the FlySask DEM at A to A' in Figure 6.

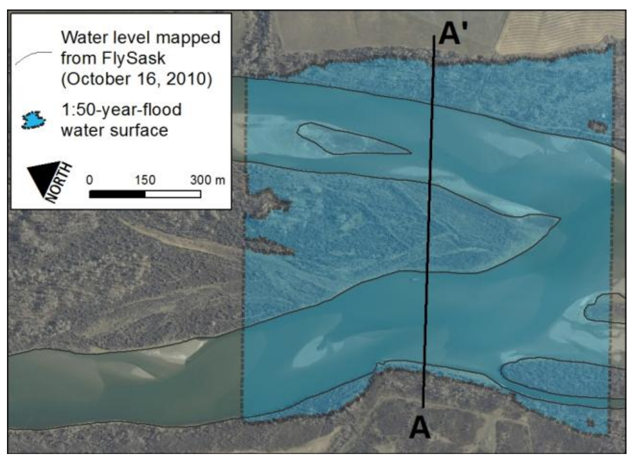

Figure 6. 1:50 year flood water surface

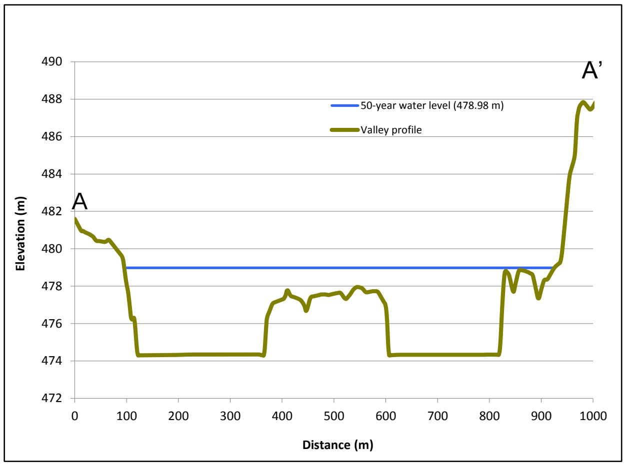

Figure 7: Cross section of valley profile.

A field visit confirmed the general accuracy of the FlySask DEM. The low terraces are unvegetated or sparsely vegetated with herbaceous plants. Drift wood is present in large amounts in backwater areas behind the low terraces. Slighter higher terraces have small trees with large amounts of driftwood and flotsam caught in them. Even higher terraces have large mature trees with very little evidence of flotsam in them. Public consultation with local landowners also revealed that some of the lower areas experience significant flooding and only in very large discharge years have water levels exceeded the lower terraces and flooded out surrounding land. Figure 8 shows a photograph of the river bank of the North Saskatchewan River. Driftwood and flotsam seen in Figure 9 were observed in the trees above the slope.

Figure 8. Photograph of river bank. Driftwood is located above the bank at location 'A'.


Figure 9. Photograph of driftwood. See location 'B' (Figure 5).

LiDAR data were acquired for transmission line design after desktop terrain studies had been completed. While comparison of the FlySask and LiDAR DEM profiles (Figure 10) shows a good general correspondence between the datasets, the LiDAR elevations are consistently higher than the FlySask elevations by approximately 1.5m. The difference is mainly a result of regional ground control having been used for the FlySask DEM whereas more accurate local ground control was used for the LiDAR DEM. The LiDAR DEM also captures the elevation of the ground surface more accurately in vegetated areas. Note, also, that the water surface elevation differed by more than 1.5m on the dates these data sets were acquired. The comparison of data sets supports the use of FlySask DEMs in preliminary desktops studies yet also highlights the importance of validating preliminary DEMs with higher accuracy data sets such as LiDAR and field surveys.

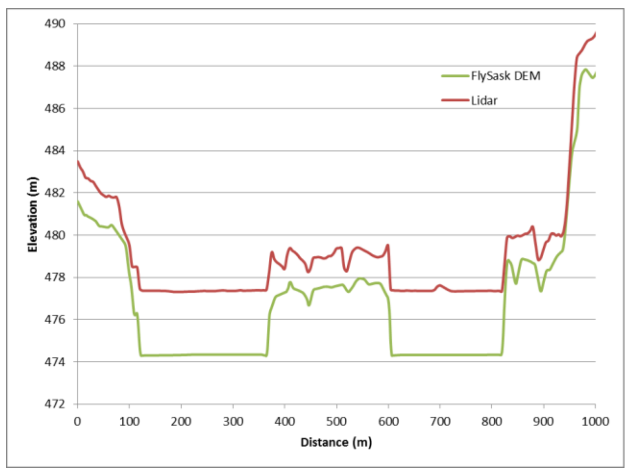

Figure 10. Comparison of FlySask and LiDAR cross-sections.

5.3 Environmentally sensitive aeolian soils

Glaciodeltaic sandy-soil covering a large part of the study area is susceptible to wind erosion where the protective vegetation and soil horizon are disturbed. Once the soil horizon is broken, it can be very difficult for vegetation to re-establish because wind tends to further disturb and mobilize the uniform fine-grained sand. For this reason, areas that are susceptible to wind erosion were mapped to identify areas which are at highest risk and may require special construction practices, monitoring and mitigation.

Ground water well logs showed that surficial sand is present in 25 of 37 wells examined. The average depth of surficial sand in these wells is 5.7 m, ranging from 1.2 m to 20.4 m. Surficial sand typically overlies till. Clay is the next most common surficial material, occurring in 10 of 37 wells. The average depth of surficial clay is 4.3 m, ranging from 0.9m to 12.2 m. The clay typically overlies sand. Till occurred at the surface in 2 of 37 records, with depths of 3.4 m and 20.1 m. In these wells till overlies sand. The surface soils in the dominantly sandy areas are classified as sand, fine-sand, loamy-sand, sandy loam, and fine sandy loam (AAFC 2005).

Figure 11 shows the areas of wind susceptible soil as delineated in the Saskatchewan Soil Resource Database. Examination of stereoscopic air photos and field reconnaissance confirmed that these areas are associated with dune forms ranging in relief up to 5-6m and with localized occurrences of active wind erosion.

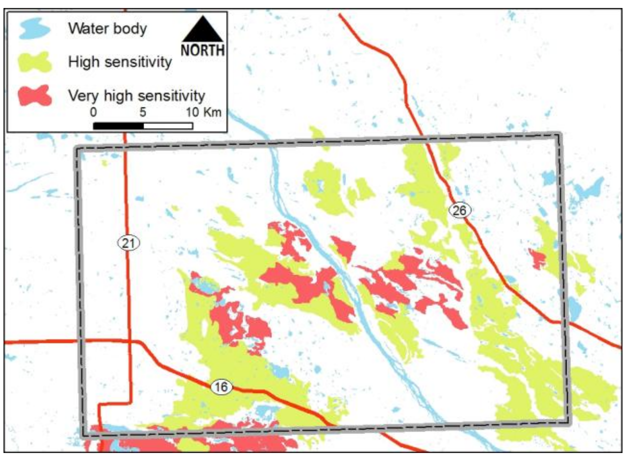

Figure 11. Location of wind sensitive soils

Figure 12 shows a LiDAR slope raster in an area of aeolian terrain. Dune forms and blowouts are visible as narrow steep-sided ridges and hollows. Figures 13 and 14 show photographs of aeolian soils in the study area.

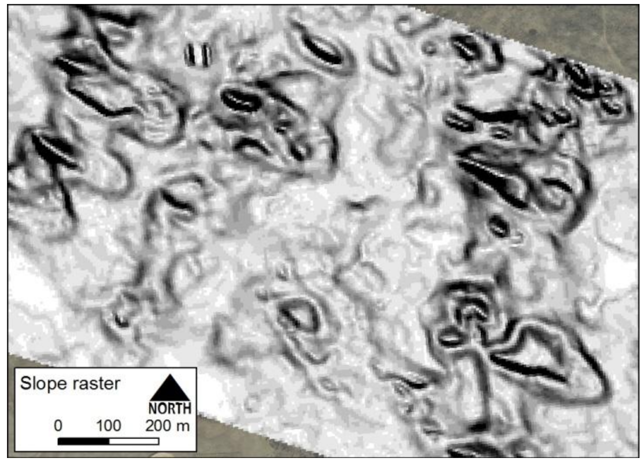

Figure 12: LiDAR slope raster of dune areas. Dunes are approximately 4 metres in height.

Figure 13: Blowout in a dune ridge on the east side of the river. This blowout is located in an area rated as having very high sensitivity to wind erosion.

Figure 14: Blowouts on a gently undulating sand plain on the east side of the river. These blowouts are located in an area rated as having very high sensitivity to wind erosion.

There are approximately 40,000 ha of wind sensitive soils in the study area, of which 31,000 ha are rated highly susceptible, and 9,000 ha are very highly susceptible. This includes soils within polygons mapped as wind sensitive which are principally sand, fine-sand, and loamy-sand. Terrain within the preferred corridor on the east side of the North Saskatchewan River is generally lower in relief than the west side (approximately 1-3 m) with longer gentler slopes. Although relatively infrequent and small in area, active blow outs occur in wind susceptible soils on both sides of the river. Even so, almost all of the dunes are well vegetated and stable.

6 DISCUSSION AND CONCLUSIONS

Desktop remote sensing techniques proved to be cost effective for assessing a range of terrain-related issues during geotechnical characterization and environmental assessment studies for routing a high-voltage overhead transmission line in west-central Saskatchewan. Study results highlight the utility of remote sensing for identifying and evaluating terrain issues related to slope stability, flood frequency at a major river crossing and minimizing impacts to environmentally sensitive aeolian soils. Remote sensing tools included various scales of black and white stereoscopic air photos, high-resolution colour aerial imagery, digital elevation data generated from photogrammetric analysis, and LiDAR digital elevation data. Interpretation of these data sets was aided by ground and helicopter field reconnaissance and publically available information including water well logs, soils maps, and hydrologic data. Terrain interpretation from stereoscopic air photos identified a number of recently active and historical landslides in the study area. Large retrogressive slumps are believed to have failure planes in the underlying clay shale of the Cretaceous Lea Park Formation. Drilling results indicated that the top of the Lea Park Formation is located above the riverbed elevation in places within the study area. Small recent slumps on the upper valley side appear to be associated with ground water seepage. The locations and nature of landslides was confirmed by helicopter reconnaissance and ground observations, allowing routes to be selected that avoid areas of past slope movements.

A desktop hydrometric study, supported by field observations, was conducted to estimate the magnitude of staging and flood frequency at potential river crossing sites, and was based on historical discharge data and rating curves obtained from Environment Canada, combined with topographic profiles generated from stereoscopic digital aerial imagery. Lands subject to flooding range from non-vegetated sandbars and low (1- 2 m high) willow-covered terraces that often flood annually, to elevated terraces (up to 4 – 5 m high) that flood approximately once every 5 to 10 years. Analytical results were supported by field observations and anecdotal evidence from landowners.

Wind-sensitive sandy soil exists extensively throughout the study area. Wind sensitivity soil polygons were extracted from published data sources and were further assessed using vertical air photos, field photographs, helicopter video and LiDAR data. The degree of soil sensitivity to disturbance and erosion was mapped based on relief, vegetation and soil texture. Imagery showing the location of existing access roads and trails was also used to assess the potential for impacts during construction.

In summary, remote sensing data and methods provided timely and cost-effective information for transmission line route planning, allowing for the selection of a route that minimized environmental impacts, potential geohazards and undesirable foundation conditions related to slope stability, flood frequency and wind sensitive soils, while still minimizing impacts to landowners and resource development companies.

ACKNOWLEDGEMENTS

The authors thank SaskPower for providing permission to publish this paper.

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