DUNVEGAN LOW-HEAD HYDRO PROJECT
HEADPOND SLOPE STABILITY ASSESSMENT
PEACE RIVER NEAR DUNVEGAN, ALBERTA

Submitted To:

GLACIER POWER LTD.
CALGARY, ALBERTA

Submitted By:

AGRA EARTH & ENVIRONMENTAL LIMITED

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File No. EG-08542

EXECUTIVE SUMMARY

The geologic conditions along the reach of the Peace River between the proposed low-head hydroelectric structure and Fourth Creek are favourable with respect to the stability of the valley slopes within the proposed headpond area. The geologic units/features that contribute to large-scale landsliding both upstream and downstream are not encountered within the reach of the Peace River in which the proposed headpond is located. It is considered that the types of slope processes (weathering, erosion, sliding/slumping) encountered in the headpond will be similar to those already existing in the reach at present. These processes are considered to be predominantly shallow and caused by a number of factors such as weathering, upslope land use and river erosion. It is considered that the impoundment of the headpond for the proposed low-head hydro structure will have the impact of a modest increase in the rate of these ongoing processes during the initial few years of operation of the structure. The increase in the rate of these processes is not expected to be visually noticeable to the general public. Over time, the rates of these slope processes would be expected to decrease to those levels presently observed.

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1.0 INTRODUCTION

AGRA Earth & Environmental Limited (AEE) was retained by Glacier Power Ltd. to undertake an assessment of the stability of the slopes and erosion potential of the shoreline along a 26-kilometre reach of the Peace River in northwestern Alberta. The purpose of the study was to assess the potential impacts of the operation of a low head hydro plant on the Peace River at Dunvegan, Alberta. The findings of this report are to be used to satisfy the Terms of Reference of the Environmental Impact Assessment (EIA) (Alberta Environment, 1999) as issued by Alberta Environment on October 21, 1999. This report specifically addresses the geotechnical issues with respect to slope stability and sediment generation potential due to landsliding along the proposed headpond.

Authorization to proceed was provided by Mr. Doug Main of Glacier Power Ltd. on October 4, 1999.

This assessment of the headpond slopes was undertaken in conjunction with studies of the river morphology (M.Miles and Associates Ltd., 2000a) and the river hydrology (UMA Engineering, 2000). Information from these studies has been incorporated into this report.

2.0 PROJECT DESCRIPTION

The following is the project description as outlined in the final terms of reference obtained from Alberta Environment on October 21, 1999.

The Dunvegan Project structure is located on the Peace River approximately two kilometers west of the Highway 2 bridge crossing at Dunvegan.

For the purposes of this review, the Project is considered to include the following low head (six meters) modular hydro facility and components:

- a powerhouse consisting of approximately 40 turbine units connected side-by-side across the main channel for a total distance of 168 m
- a fixed-crest control weir/spillway with inflatable rubber dam will extend from the powerhouse across the remaining 252 m of channel width to maintain water levels behind the powerhouse at 6 m above the tailwater level during low flow periods
- a navigational or alternative structure to accommodate river traffic
- a 138 kV transmission line to two potential interconnection points: alternative 1 interconnects with Alberta Power's 138 kV line approximately 5 kilometers to the southeast of the Project, and alternative 2 will interconnect at the Anderson Gas Plant approximately 14 kilometers northeast of the Project
- fishways
- a headpond – the size varies with the flows in the river
- shore-based facilities and access roads (two kilometers on each side).

The Project powerhouse and weir are all located in the wetted river channel except for the headworks abutments at both ends of the structure.

3.0 SETTING

The study area is encompassed in the Alberta plains physiographic unit of Alberta. Broad, gently sloping prairie, deeply incised by steep sided river valleys characterizes this area.

The Peace River is confined by a broad, u-shaped valley downcut into marine/non-marine bedrock of Cretaceous age. The valley itself was carved to its present configuration by a series of glaciers and meltwater channel flow and has an average width of between 1.5 km and 3 km at the top, is 0.4 km to 0.8 km wide at water level and has a depth from 150 m to 275 m below the upland prairie (Acres-Monenco, 1983). The upper river valley slopes have, in many places, a hummocky appearance caused by the slumping of the valley walls. Along some sections of the river, the valley sides are steep and bedrock is exposed.

Glacial processes have affected the physical features of the area. Erosion of the ground surface during the advance and retreat of the ice sheets was followed by further erosion and deposition during the interglacial and postglacial periods. Recent drainage has incised deeply through the glacial deposits and into the underlying bedrock. Sediment entering the upstream of the BC/Alberta border is largely cut off by the Bennett Dam. Studies by M.A. Carson & Associates (1992) have concluded that the majority of the sediment entering the Peace River downstream of the Bennett Dam originates from the tributary valleys, not from along the Peace River itself.

Many of the slopes along the Peace River have been shaped in the past by landsliding processes. These range from deep-seated landslides in valley infills, such as those found at the confluence of the Peace and Montagneuse Rivers and downstream of Dunvegan and towards the town of Peace River to sliding of the Kaskapau shales and Pleistocene sediments high on the valley slopes. The slopes in the vicinity of the headpond are considered to be comparatively unsusceptible with respect to deep-seated instability. There are no documented deep seated slides in the headpond reach and there were no signs of deep seated landsliding observed during this study. The slopes of the proposed headpond area have been shaped by toe erosion and shallow sliding and the gullying of the Dunvegan and overlying Kaskapau Formations. The regional landsliding types and controls are discussed in more detail in Section 3.2.

3.1. GEOLOGY

General

The slopes along the proposed headpond are dominated by the steep interbedded sandstone and shales of the Dunvegan Formation that outcrop within the lower 100 to 120 metres of the valley wall. The Dunvegan Formation is overlain by variable thicknesses of the silty Kaskapau which is in turn overlain by up to 35 metres of silts, clays, sand and till of Pleistocene age. Since the retreat of the last glaciers in the Peace Region the Kaskapau shales and the overlying Pleistocene drift have gradually failed back to the relatively gentle, hummocky slopes that are observed at this time overlying the contrasting steep slopes of the Dunvegan Formation. The following discussion will outline the geological conditions from oldest to youngest. Figure 3.1 provides a visual representation of the geologic units encountered along Peace River in the headpond.

Bedrock

The bedrock in the study area consists of a series of marine and non-marine sandstones, shales and siltstones of Cretaceous age. From Dunvegan to the upstream end of the head pond, the formations consist mainly of slide-prone Kaskapau Formation along the upper part of the valley walls. The Kaskapau overlies the Dunvegan Formation, which is much stronger and consists of greater amounts of sandstone strata. The Dunvegan, in turn overlies the very weak and failure-prone Shaftsbury Formation. The available geological information and borehole data indicates that the Shaftsbury Formation is a significant distance (20 to 30 metres) below the riverbed throughout the proposed headpond. At the location of the proposed head works structure, borehole data from the 1975 study the Shaftsbury Formation is located approximately 30 metres below the present river level and it is not considered that landsliding in the Shaftsbury would be probable based on this depth (Monenco, 1975).

The geological formations mentioned above are defined as follows, from oldest to youngest. The Shaftsbury Formation is not discussed as it is not exposed in the valley walls and does not present a landslide hazard in the headpond reach:

Dunvegan Formation: The Dunvegan formation consists of mainly fresh-water sandstones and shales outcropping prominently on the north side of the Peace River. Exposed bluff slopes of the Dunvegan Formation, near Dunvegan, are encountered up to 100 metres above the present river level. The contact with the overlying Kaskapau Formation was noted to range between 440 to 460 metres, based on borehole data from the 1975 drilling program (Monenco, 1975). From the drilling program for the 1975 Monenco Report, the sandstones comprise 30% to 50% and the shales 70% to 50% of the formation. The deposits comprise medium grey, medium to fine grained, micaceous and feldspathic, cemented sandstones interbedded with dark grey, fissile, silty shales and siltstones (Acres-Monenco, 1983). South facing slopes in the interbedded sandstone and shale range between 45° to 50° with north facing slopes ranging from 40° to 45°. Erosion, gullying and other forms of mechanical and chemical weathering are constantly affecting the slopes.

Kaskapau Formation: The Kaskapau Formation overlies the Dunvegan Formation and forms the upper valley slopes above elevations 450 +/- 10 metres. The formation comprises approximately 90% light and dark grey soft shale with thin sandstone interbeds comprising approximately 10 % of the formation. The upper beds of the strata are often weathered to highly plastic, soft clay (Acres-Monenco, 1983).

Quaternary Sediments

General: The Pleistocene tills and lake sediments encountered in the upper portion of the valley slopes form a relatively level plain that is dissected by variable sizes of gullies, which drain toward the Peace River. These deposits range in thickness typically between 15 to 35 metres based on published geology and the 1975 studies at Dunvegan (Monenco, 1976). The general stratigraphy on the upper slopes consists of silt and clay lake sediments overlying a medium plastic till, which in turn overlies the Kaskapau Formation bedrock. Along the base of the valley, sand and gravel deposited during deglaciation and in more recent times cover the bedrock surface and were noted to be up to 35 metres in thickness at the head works site (Monenco, 1976). The following is a discussion of the Pleistocene sediments from oldest to youngest.

Pleistocene Glacial Till: The glacial till encountered in the study area is described as a hard, dark brown, silty, sandy, medium plastic clay with some cobbles and gravel. In the literature thicknesses ranging from 6 metres to 35 metres are encountered on the right and left banks of at the location of the proposed head works structure (Acres-Monenco, 1983). The thicker sections of till, up to 35 metres, are hypothesized to consist of valley infill adjacent to Hines Creek and Dunvegan Creek. In these areas, the thick till deposits are found to directly overlay the Dunvegan Formation, indicating that the overlying Kaskapau shale was eroded by water or glacier activity during or prior to the last glaciation in the area.

Lacustrine Sediments: The upland is relatively level and is underlain by what is expected to be a highly variable thickness of glacial drift sediments. The uppermost of these materials is glacial lake silt and clay, locally reaching from tens to over 100 metres in thickness. Where these sediments happen to be thin along the upper valley sides, they commonly rest on glacial till, which is expected to be fairly dense and clay-rich in this region. The corehole logs from the 1975 Monenco study indicate that clay is described as silty and medium to high plastic with thicknesses of up to 5 metres in the vicinity of the dam centreline (Monenco, 1975).

Glaciofluvial/Fluvial: The valley bottom/flat just above the river level is underlain by floodplain deposits, mostly relatively thin (less than 2 metres) overbank silt, clayey silt, and fine sand which in turn rests on sediments consisting of generally coarser sands, gravel and boulders. Wherever the finer-grained top stratum has been eroded by river action or was never deposited in the first place, coarser granular alluvial materials occur at ground surface. These appear on exposed river bars and also occur on the channel bed beneath the river. Test holes at scattered locations and geophysical surveys undertaken during the 1975 study suggest the coarse fluvial sediments reach maximum depths 29 metres below the current river level (Monenco, 1975).

Colluvium: Lower valley slopes are typically covered by a chaotic mixture of slumped debris (varying proportions of bedrock and glacial drift materials), talus debris, and slopewash colluvium. These highly variable colluvial debris form isolated mounds in some places and long narrow coalescing fillet-like piles of reworked, unconsolidated materials in other localities. The materials that comprise the colluvial deposits are derived from the overlying Kaskapau shale, Dunvegan Formation, glacial till and lacustrine clays; therefore the grain sizes are expected to be a variable mixture of clay, silt, sand and boulders.

3.2. REGIONAL LANDSLIDING

There have been numerous, large magnitude landsliding events along the Peace River over the past 100 years which have led to temporary blockages of the Peace River and/or to damage/loss of property in inhabited areas. These landsliding events have been associated with two main geological factors, which have controlled the type and extent of landsliding. The following discussion outlines the main geologic factors that contribute to erosion and sliding process along the Peace River between the Alberta/B.C. border and the Town of Peace River. Taken from (J.D. Mollard and Associates, 1975).

Reach 1: Cherry Point to the Montagneuse River

The confluence of the Montagneuse and Peace Rivers is located where the Peace River takes an abrupt turn to the south, as shown as Reach 1 on Figure 3.2. Within this reach, the valley is comparatively wide at the top with shallow slopes and widespread large slides are associated with the existence of a large preglacial valley. Figure 3.2 shows the trend line of the thalweg of the large preglacial valley, and tributary valleys, which run along and across the present day Peace River. This valley was cut into the bedrock by meltwater, prior to the final glaciation of the Peace Region. During the advance and retreat of the Laurentide ice sheet across Alberta, this incised valley was then infilled with silt, clay, sand, and gravel and till and is therefore relatively weaker than the adjacent bedrock. Due to the high groundwater levels and often pre-sheared and weak nature of the materials infilling the valleys, these materials are highly susceptible to landsliding. Large slides such as the Attachie Slide (Evans et al, 1996), and slides at Montagneuse (Cruden et al, 1997) and at Dunvegan (Brooker, 1959) occur in the pre-glacial valley at locations where is crosses the Peace River.

Figure 3.3 shows a photo of the typical slopes encountered in valley sediments as observed at the confluence of the Peace and Montagneuse River and taken by the author during the field visit on October 7, 1999. A photo of the typical slopes along the proposed headpond is provided for comparison as well.

Reach 2: Montagneuse River to Dunvegan

From the confluence with the Montagneuse River, the thalweg of the pre-glacial valley trends to the north and east of the Peace River, intersecting the river again within a few kilometres downstream of Dunvegan. The slopes in this stretch of the Peace River are then characteristic of the bedrock, not the valley infill sediments.
The valley walls in this reach are typified by the steep, interbedded sandstones and shales of the Dunvegan Formation overlain by relatively weak Kaskapau clay shale and Pleistocene sediments. The silty, Kaskapau shales are relatively weak and often consist of old, compound slides that incorporate the overlying Pleistocene sediments. These slopes have developed over time and are considered to have reached their long-term angle of repose. Typical features in the Kaskapau Formation consist of relatively flat, hummocky slopes and old bowl features found overlying the more competent Dunvegan Formation, which comprises the lower 100 to 120 metres of the valley slopes along the headpond.

Landsliding in the interbedded sandstone and shale of the Dunvegan Formation is not common along the Peace River due to the thick, competent sandstone layers that are interbedded with silty shales.

Reach 3: Dunvegan to East of Saddle River

This portion of the Peace River lies to the east of the area near Dunvegan where the main pre-glacial valley crosses and continues to the south of the Peace River before crossing the Peace River again to the east of the confluence with the Saddle River. In this section of the valley, the Dunvegan Formation sandstone and shales are exposed in the valley sides and the valley is comparatively narrow at the top with few large slides. Slides are primarily confined to the Kaskapau shales and overlying Pleistocene sediments.

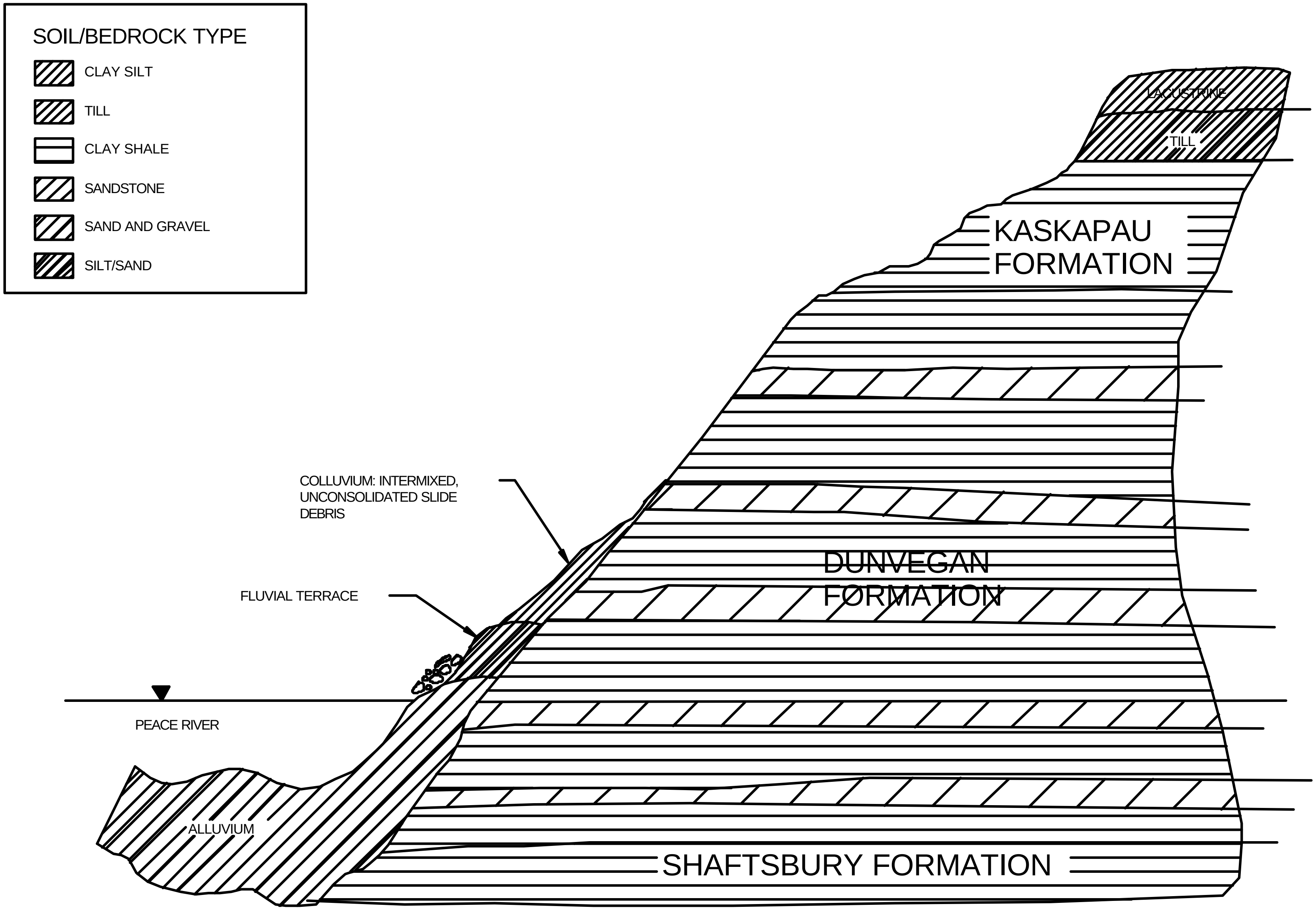
Reach 4: East of Saddle River to Town of Peace River

To the east of the confluence of the Saddle River, the slopes from this point are heavily influenced by the presence of the preglacial valley and by the occurrence of the weak slide prone Shaftsbury clay shale that occurs higher in the valley. To the west of this point the Shaftsbury Formation occurs a sufficient depth below the river that it does not contribute to large magnitude deep-seated landsliding. From this point, as shown on Figure 3.2, to the east, widespread large-scale landsliding controlled by the weak valley infill sediments and/or the weak Shaftsbury Formation are encountered. Landsliding in and around the Town of Peace River reported by Cruden et al (1990) occur within this reach of the river.

Summary

The reach of the river in which the three alternative dam heights were proposed in 1975 by the Alberta Hydro Committee were carefully chosen with respect to landsliding concerns. This section of the Peace River was chosen by the Alberta Hydro Committee because the Shaftsbury Formation and the weak pre-glacial valley materials did not form the slopes west of Dunvegan

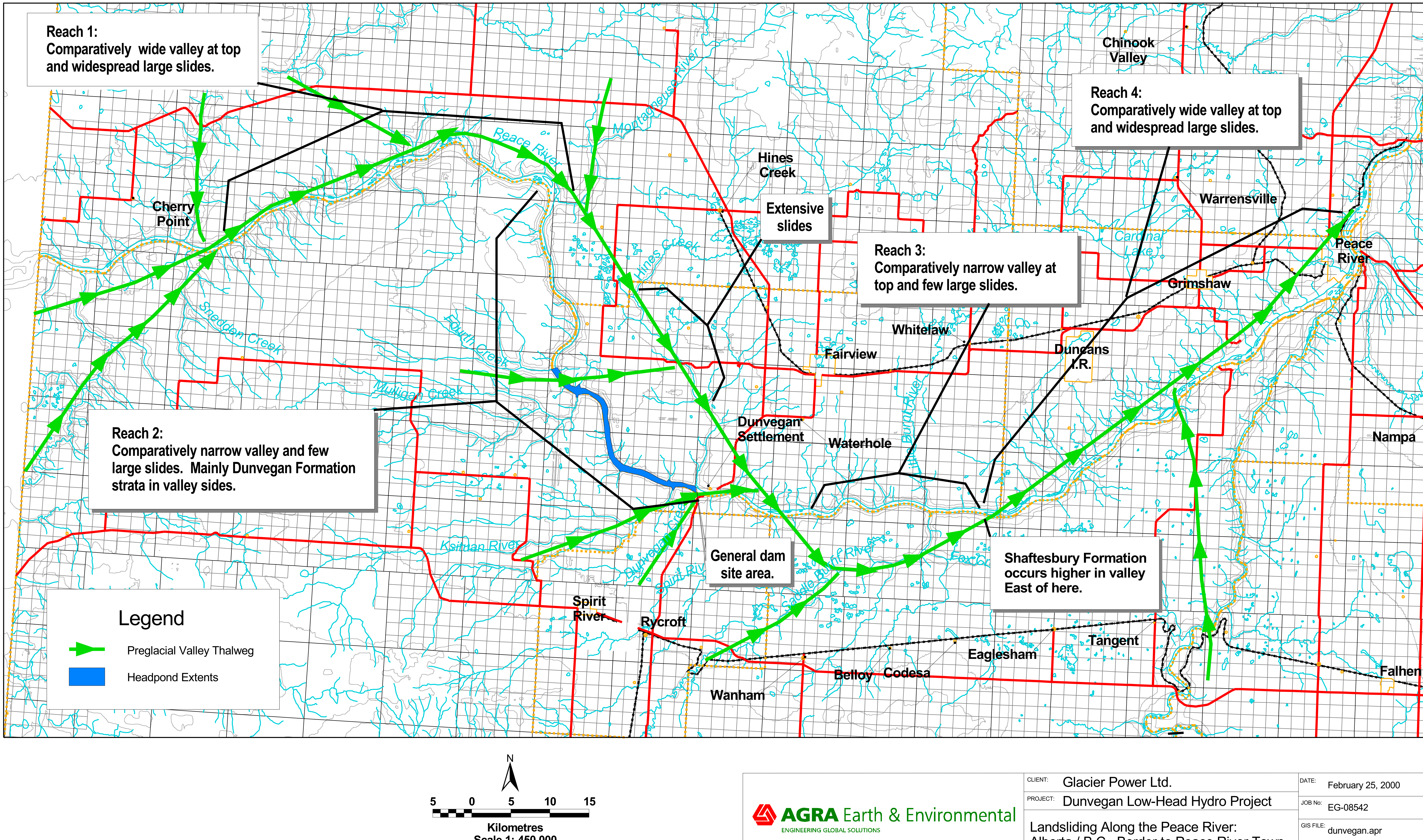
Regional studies of landsliding along the Peace River have indicated that the geological conditions encountered in the proposed headpond do not promote the initiation of a large deep-seated landslide into the headpond. The exposed Dunvegan Formation sandstone and shale slopes are considered to be very competent and stable, thus presenting a low likelihood of a large landslide originating in the bedrock along the presently proposed Dunvegan Project headpond.



CLIENT:	DWN BY: RSW	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: CRF	STRATIGRAPHY OF THE VALLEY WALLS IN THE DUNVEGAN PROJECT AREA	REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE: N.T.S.		
	DATE: MARCH, 2000		FIGURE 3.1

AGRA

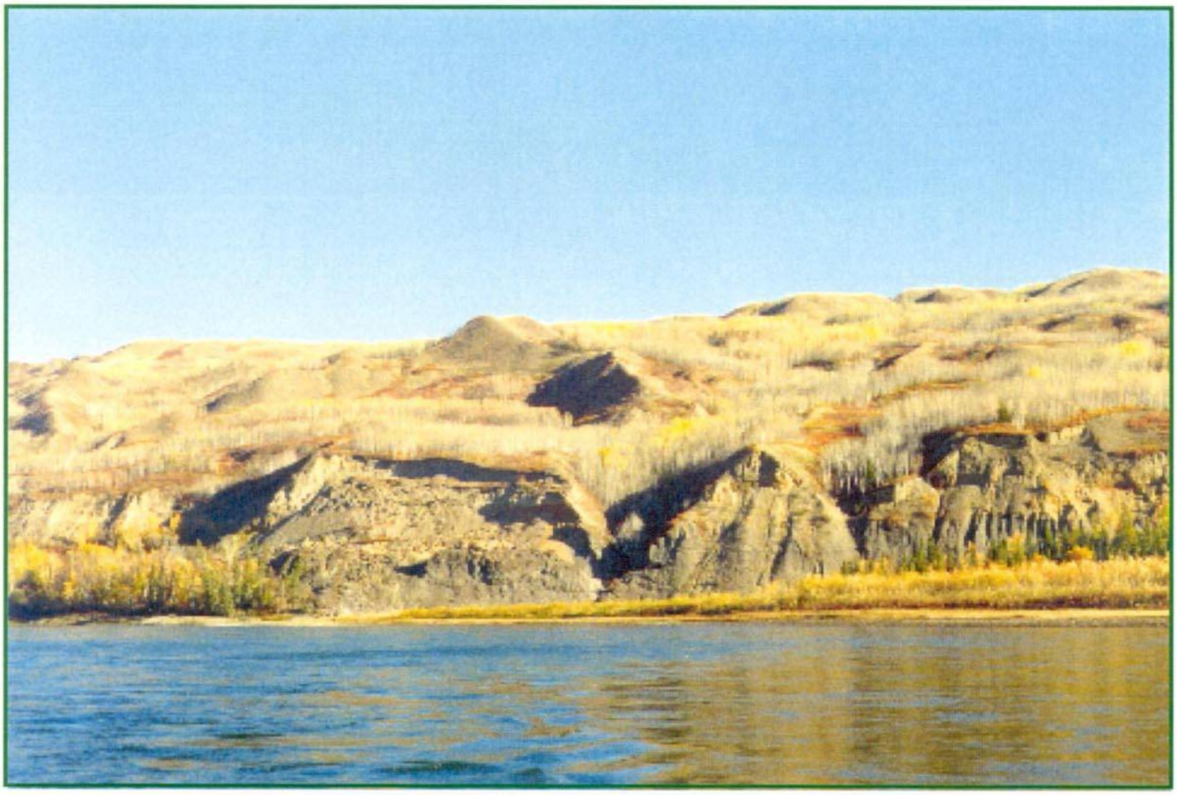
*PLOT 1:1=D S:\CADD\Geo\EG08500\eg08542\REPORT FIGURES\ fig-3-1.dwg Sun. Apr. 16 3:18pm 2000 SWilcox



Sources: Geologic interpretation based on J.D. Mollard Associates Ltd., 1975.

AGRA Earth & Environmental
ENGINEERING GLOBAL SOLUTIONS

CLIENT:	Glacier Power Ltd.	DATE:	February 25, 2000
PROJECT:	Dunvegan Low-Head Hydro Project	JOB No:	EG-08542
	Landsliding Along the Peace River: Alberta / B.C. Border to Peace River Town	GIS FILE:	dunvegan.apr
			FIGURE 3.2
		REV.	



SLOPES IN THE PRE-GLACIAL VALLEY FILL AT THE MONTAGNEUSE RIVER CONFLUENCE (~25km UPSTREAM OF HEADPOND)

TYPICAL VALLEY SLOPES WITHIN THE HEADPOND

CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: C.R.F.	HEADPOND SLOPE STABILITY ASSESSMENT COMPARISON OF PRE-GLACIAL VALLEY SLOPES AND HEADPOND SLOPES	REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE N.T.S.		
	DATE: MARCH, 2000		FIGURE 3.3

PLOT 1:1=D S:\CADD\Geo\EG08500\eg08542\REPORT FIGURES\ fig-3-3and4-11.dwg Sun. Apr. 16 3:17pm 2000 SWilcox

4.0 ASSESSMENT OF EXISTING SLOPE CONDITIONS

4.1. GENERAL

As discussed in Section 3.2 and shown on Figure 3.2, the regional geologic factors that contribute to deep seated landsliding along the Peace River are not encountered within the reach of the river in which the headpond is located. Based on these findings, as well as the findings of the airphoto and field review, it is considered that there is a low likelihood of a large magnitude/volume slide developing within the reach of the Peace River encompassing the proposed headpond for the low head project. Slope processes will likely consist of a modest acceleration of shallow/surficial landsliding at locations where it has historically occurred. A discussion of these processes is provided in Section 4.5.

4.2. REVIEW OF PREVIOUS STUDIES

In 1975, the Alberta Hydro Committee initiated feasibility studies to examined three alternative dam heights; a low (41 metre), intermediate (69 metres) and high head (120 metres) These alternatives were situated at the same site as the presently proposed Dunvegan low head (6m) project location and provide valuable information related to slope stability related to the Dunvegan Project.

The following points summarize the findings with respect to the stability of the slopes associated with the three alternative dam heights (Monenco, 1975):

1. Sliding and slumping of the valley slopes have occurred in the past, and will continue in the future under natural conditions. If a reservoir were formed, the sliding and slumping would be at an accelerated rate. However, the slides would be of a minor nature and would not pose a threat to a project at Dunvegan or the river regime. Nevertheless, project design intrinsically could accommodate a major flood wave generated by a major slide.
2. Frequent occurrence of new large slides, similar in size and volume to past failures (i.e. several tens of acres in extent), are not expected to develop as a result of proposed reservoir construction and operation because colluvium-covered, considerably less slide prone Dunvegan Formation forms the reservoir banks where reservoir waters are deepest; and unstable stratified sediments filling the preglacial valley bypass the lower end of the reservoir.
3. Many small slides (i.e. less than an acre in size) are likely to develop. These failures may be triggered by current and wave erosion at the toe of the slope and by reservoir level drawdown, or both. These activities might also re-activate creep movements in some of the larger old slides, especially those failures that happen to extend farther down the sides of the valley walls. However, most of these slides should develop during the first few years of reservoir operation.

It must be noted that the above findings pertain to the medium head option where the increase in water levels at the structure would be up to 69 metres and the reservoir would extend to the west of the Alberta/BC Border (approximately 390 kilometres upstream of Dunvegan). This influence would be significantly greater than the effects of the low head structure proposed by Glacier Power which proposes to increase water elevation 6 metres with a total headpond reach length of 22 to 26 kilometres.

4.3. AIRPHOTO ASSESSMENT

The airphoto assessment of the proposed headpond consisted of a two phase approach: a review of recent medium scale (1:20,000) and large scale (1:80,000) airphotos, followed by a review of the historical airphoto compilation provided by M.Miles and Associates Ltd. (2000b).

Recent Photos

The following airphotos were reviewed for this assessment:

Scale	Year	Project	Photo Numbers
1:20,000	1992	92-158	Line 1: 1-5 Line 2: 28-37 Line 3: 61-68 Line 4: 96-98 Line 5: 130-134
1:80,000	1970	70-322	Line 54: 329-332

A review of air photos did not reveal any signs of features consistent with deep seated/large magnitude landsliding along the proposed head pond. Specific medium sized (estimated to be less than 0.2 million cubic metres of material) features noted on the photos were flagged for further investigation either during the field reconnaissance or with available geological and borehole information. The following specific features were identified and assessed with respect the deep seated landsliding:

Large Gullies (Left and Right Slopes – Kilometres 9 to 12): Figure 4.1 provides both an aerial view and a view from river level of some of the large gullies with relatively thick, gently sloped colluvium infill. These features were highlighted due to their anomalous appearance with respect to the other slopes found in the valley. Subsequent investigation of these features in the field indicated that they were well drained and at relatively flat and stable slope angles and presented a low likelihood of sliding into the Peace River. These gully features are discussed in more detail in the discussion of slope types and processes in Section 4.5.

Ribbed Features in Pleistocene Till (Left Slope – Kilometre 1 to 2): The review of airphotos highlighted anomalous lineations along the left (north) slope within the section between 1 to 2 kilometres upstream of the proposed Dunvegan head works structure. Figure 4.2 shows this feature both on the airphoto and from the river. Borehole data within this stretch of slope taken from the Hardy (1975) indicated that there is over 35 metres of Pleistocene sand and till overlying the Dunvegan Formation and possibly thin Kaskapau Formation at this location. Based on this data and the regional geology of the area it is considered that this relatively thick zone of Pleistocene sediments is located in an area where the Kaskapau Formation was either scoured by ice or eroded by water during early glaciation or prior to glaciation. The features identified on the photos and during the field assessment indicated that the linear features are relatively small block slides incorporating the till and sand and do not appear to be active or of large extent. The area upslope of these features has also remained cleared over the past 50 years and did not exhibit any signs of measurable movement based on a review of the airphotos from 1950 to 1992.

Historical Review

A compilation of historical airphotos covering the extents of the proposed headpond was completed by M.Miles and Associates Ltd. (M.Miles and Associates Ltd., 2000b). The following comments pertain to the review of those historical photos:

- **Lateral Erosion:** At the scale of the available airphotos (1:20,000) there was no measurable lateral erosion of the riverbanks along the headpond. Reasons for this are partially due to the scale of the photos and the fact that the majority of the photos used were taken after the regulation of the Peace River by Bennett Dam. Therefore flows are now significantly regulated, seasonally less varied, and lower than pre-Bennett Dam flows. The river, after 1970, would be located within the channel established prior to river regulation by Bennett Dam. In areas where erosion was active it is considered that the minor lateral erosion of the riverbanks would not be detectable on the available scale of airphotos. As well, the Peace River is an entrenched and laterally confined mature river within the headpond reach and is expected to be stable.

- **Impacts of Upslope Land Use:** During the 42 year period that was covered by the airphotos there were minor examples of the influence on the removal and/or establishment of vegetation on the stability of the slopes along the valley. Figures 6a through 6f of the M. Miles and Associates Ltd. (2000b) historical air photo compilation shows a specific example of the impacts of the removal and re-establishment of vegetation at the crest of the left slope approximately 16 kilometres upstream of the proposed Dunvegan Project head works structure. As can be seen on these photos shallow landsliding in the Pleistocene sediments has developed in the period prior to 1961 in a time period when there is little to no indication of mature tree cover at and beyond the crest of the slope. In the years between 1961 and 1992, as tree cover is established, the slopes begin to stabilize, likely due to the effect of the transpiration of moisture and ground reinforcement by the tree roots. This series of airphotos is considered to be representative of the shallow landsliding that may be expected to develop along slopes where the tree cover is removed by either man or natural processes.

4.4. FIELD ASSESSMENT

The field assessment was undertaken on October 7 and 8, 1999 by Corey Froese, M.Sc., P.Eng. of the AEE Edmonton office. The field assessment consisted of a traverse of the entire length of the reservoir using a jet boat supplied by a local contractor. The traverse began at the upstream end of the proposed head pond at Fourth Creek (chainage 26+000) and continued downstream over the two-day period. During the assessment, observations of typical slope types and processes were made and specific locations were inspected at representative slope zones. As well, photographs were taken of the slopes along the proposed headpond for the entire 26 kilometres. These photographs were referenced with notes and compiled in a photo album upon returning from the field assessment.

Observations recorded at the specific observation locations are as follows:

- Slope angles
- Soil types
- Observations of instability
- Seepage observations
- Locations of surveyed full supply level markers

In addition to assessing the slopes in the proposed headpond, the jet boat trip extended approximately 25 kilometres upstream of Fourth Creek to the confluence of the Montagneuse River with the Peace River. A large slide in the Montagneuse area several years ago had blocked one of the channels in the Peace River. The purpose of this trip was to assess the similarities/differences of the slope types and landsliding in this area to the types of slopes in the proposed headpond. A large slide at the confluence of the Peace and Montagneuse Rivers (Figure 3.2), the pre-glacial valley, runs parallel to the left (north) slope. Figure 3.3 shows the slopes observed at this location in comparison to the slopes in the Dunvegan Formation that are encountered along the proposed headpond. The preglacial valleys are infilled with weak till, clay and high groundwater levels that make these units highly susceptible to landsliding.

4.5. SLOPE TYPES AND PROCESSES

The four main slope processes/types as observed in the field reconnaissance are described below:

- Type 1: Bluff Slopes
- Type 2: Valley Slopes
- Type 3a: Large Gullies with Gently Sloping Colluvium
- Type 3b: Steep Gullies with Shallow Colluvium

The total length of the four slope types assigned during the initial review of the airphotos are presented in Table 4.1.

Table 4.1
Slope Types and Lengths along the Headpond

Slope Type	North Slope (kilometres)	South Slope (kilometres)	Total	% of Total
Bluff	6.4	0.0	6.4	12.3
Valley	9.0	24.8	33.8	65.0
Large Gullies	0.3	1.1	1.4	2.7
Shallow Gullies	10.3	0.1	10.4	20.0
Total Length	26.0	26.0	52.0	100.0

The locations of the different slope types, along with the current likelihood for shallow sliding and erosion, are shown on Figures 4.3 through 4.7. The likelihood for sliding/erosion is based on factors such as the current state of activity of the slope processes along the valley walls, aspect, upslope land use and current state of erosion at the toe of the slope. An assessment of the potential effects of the headpond on sliding/erosion will be addressed in Section 5.

Detailed descriptions of these four main slope types and the active processes are described below:

4.5.1. Type 1: Bluff Slopes

The term “Bluff slopes” is used to describe the slopes found predominantly within the lower 3.5 to 6.5 kilometres of the headpond on the north (left) slope of the Peace River. These types of slopes consist of intact exposures of interbedded sandstone and shale of the Dunvegan Formation that are periodically being eroded by the Peace River with minimal flood plain or debris protecting the toe of the slope. Figure 4.8a shows typical bluff slopes along the Peace River near Dunvegan. Typically the bluff slopes were an average of 100 metres high along the headpond with slopes at 45 ° to 50 °. The slope in the overlying Kaskapau shale and Pleistocene till and lacustrine sediments are relatively shallow and undulating, indicative of previous landsliding activity.

The landsliding types encountered on the bluff slopes are as shown on Figure 4.8.b. As can be seen on the photos, sliding on the bluff slopes consists primarily of the surficial weathered layer on the slope. Over time as the weathering progresses, the rock within approximately the top 0.3 metres of the exposed face becomes almost soil-like (unconsolidated) in consistency. This softening combined with the effects of the erosion of the river at the toe and any upslope water flow contribute to sliding of the weathered layer.

4.5.2. Type 2: Valley Slopes

The slopes designated as “Valley Slopes” are characterized by a small terrace and/or fan below the toe of the outcropping sandstone beds of the Dunvegan Formation. Figure 4.9.b. provides a good example of this type of section with the distinct layer of sandstone visible above the fan at the toe of the slope. Above the sandstone outcrop are slopes consisting of weathered bedrock, covered with a well-established growth of mature trees and ground cover. Slopes in the weathered bedrock typically are found to sit at approximately 40° on north facing slopes and up to 45° on south facing slopes.

Above the weathered Dunvegan slopes, relatively shallow sloping/undulating deposits of Kaskapau shale and Pleistocene sediments are encountered. Several large bowl shaped features are also noted to overlay the Dunvegan slopes, particularly along the south slopes between kilometres 3 and 9 of the headpond. These features are indicative of previous debris flow activity and are considered to be old features with no signs of recent movement in the past 40 years. In the historical air photo compilation (M. Miles and Associates Ltd, 2000b) two debris flows originating in these bowls were noted but these areas are now well vegetated and no activity was noted in the recent air photos.

Photo 6 on Figure 4.4 shows the development of a slide at the base of a typical valley slope. The slope at this location (~7.0 kilometres, right bank) occurs within an area of active lateral erosion on an outer bend of the Peace River. This particular slope failure appears to have developed due to undercutting and oversteepening of the slope by river erosion, combined with the effects of mechanical and biological (root growth and burrowing) weathering of the bedrock.

4.5.3. Type 3: Large Gullies with Gently Sloping Colluvium

At various locations (predominantly between kilometres 9 to 12) along the proposed headpond, large gullies containing gently sloping fans of colluvium (slide debris) are encountered that extend from near the crest of the slope to the river (Figure 4.1). These materials consist of earth flow deposits that have infilled existing gullies that were cut through the Dunvegan by meltwater. The infill material consists of debris from the upslope areas and gullies sides that have slid/slumped into the gully and then travelled down the existing gullies reaching the Peace River. Visual observations of the types of colluvium indicate that they are comprised of a mixture of clayey silt, fine sand and scattered angular gravel, cobbles and boulders. The colluvium itself is believed to have originated from the lacustrine silt/clay, silty till and silty shale that overly the more competent Dunvegan Formation

Field observations of representative fans indicated that slope angles ranged typically between 25 to 30 ° with well-established gullies either cutting through the centre or along one of the flanks of the gully infill material/colluvium. Due to the well-established drainage, the colluvium was typically found to be relatively dry and gully side slopes stood almost vertical. Based on these observed characteristics, the colluvium is considered to be in a dormant state of activity (i.e. do not exhibit any signs of active movement).
As is it considered that there is a low likelihood that a sudden, large volume slide will be initiated in the colluvium, the expected slope development/landsliding mechanisms should be a gradual deterioration and shallow sliding of the material at the rivers edge.

4.5.4. Type 3b: Steep Gullies with Shallow Colluvium

Although shallow gully slides are located at numerous locations, particularly on the North Slope, a large section of shallow gullies are located between 12 and 19 kilometres on the north/east slope. Figure 4.10 shows a section of slope with numerous shallow gullies. Figure 4.10.b. shows a more recent and active shallow gully slide. These gullies are typically over 100 metres in length, up to 30 metres wide and are estimated to be an average of 1 metre in thickness higher on the slope and thicker at the base. It is considered that these features consist of reworked and weathered silty shales and Pleistocene clays and tills that are relatively loose. These features are expected to continue to develop as they have in the past and deposit relatively small volumes of material into the Peace River, regardless of the impoundment of the river by the proposed structure.

In the section of the river along the left (north) bank between 6.0 and 7.0 kilometre two large debris flows entered the river with volume estimates ranging from 10,000 to 30,000 m^3 were noted to originate between 1950 and 1961, based on the historical airphoto compilation (M. Miles and Associates Ltd., 2000b). These slides did not appear to have a significant impact on river navigation or the overall river regime and were considered to have been triggered by a combination of weathering and upslope drainage.

4.6. CONTRIBUTING FACTORS

The types of landsliding/erosion discussed in the previous section are impacted at the same time by one or more processes that contribute to the destabilization of the slope material. The following is a discussion of these contributing factors, based on AEE's regional experience and the observations made during the field reconnaissance.

4.6.1. Weathering/Softening

The sedimentary bedrock encountered along the Peace River is subject to a gradual weakening of the surficial layer by the effects of mechanical and chemical weathering. Natural processes such as cycles of wetting/drying and freezing/thawing will lead to cracking and gradual breakdown of the surficial layer of the bedrock. The depth of the weathered zone will depend on climatic conditions such as the length of exposure to freezing, temperature variations as well as the properties of the bedrock. Upon exposure to these conditions, the upper layer of the bedrock will degrade to a soil, which is much weaker (unconsolidated) than the underlying bedrock. This weakened soil layer will tend to slide once it becomes weak enough that it can no longer stand at the relatively steep angle at which the underlying bedrock stands. Typically the depth of sliding in the weathered zone was found to be up to 0.5 metres thick in the Dunvegan Formation slopes. Figure 4.8.b. shows sliding of the weathered zone of material on bluff slopes along the proposed headpond.

4.6.2. Upslope Land use

The alteration of land upslope of the river valley slopes may have a detrimental effect on the slopes by increasing the amount of moisture that is available to infiltrate into the weathered bedrock. The removal of trees to create agricultural land or by fire will reduce the amount of moisture that is removed from the ground by transpiration by tree roots. The diversion of upslope water onto areas of the slope may also be detrimental to the slope. The addition of water onto the slope has the effect of decreasing the shear strength of the weathered bedrock, thus making the slopes more susceptible to shallow sliding into the headpond. The photos presented on Figure 4.11 show the north (left) slope between 7 and 8 kilometres upstream of the proposed structure. This area is below active agricultural land-use and cattle grazing. Cattle grazing will have an impact on the stability of the slopes by removing vegetative cover from the slope as well as diverting water along the cattle trails to concentrated flow paths on the slope. The area shown on Figure 4.11 was noted to be the most active area with respect to landsliding, also corresponding to the most active land-use.

4.6.3. Toe Erosion/Inundation

In general, the effects of the river on slopes can also contribute to slope instability in the following ways:

- **Lateral erosion:** Ongoing cutting of the toe of the slope can lead to the removal of material and loss of support at the base of the slope. This can have the influence of lowering the forces in the slope that resist the movement of upper portions of the slope, thus reducing the overall stability. The erosion can be caused by two mechanisms; riverbank erosion (due to water velocities along the river) and wave erosion. In general, bank erosion can be expected to decrease slightly due to lower water velocities in the headpond, and wave erosion may increase slightly due to higher water levels and consequently slightly longer fetches. As indicated, these are generalities, and in fact, the increase in fetch length is expected to be negligible in the headpond.

- **Toe of Slope Inundation/ Water Level Fluctuation:** Rapid water level fluctuations can have a detrimental impact on the stability of the gully type slopes. Stability concerns are greater where complex, interlayered pervious and weak impervious strata exist, and where the drawdown range is large and occurs at a rapid rate. In these situations, excess porewater pressures may develop and dissipate rather slowly, thus reducing the shear strength of the material and overall stability of the submerged portion of the slope. The effects of the headpond on slope stability is specifically addressed in Section 4.7.

4.6.4. Aspect

The direction that a slope faces can also have an impact on the stability of the slopes along the headpond. North facing slopes are often wetter and have more established vegetation (trees), while south facing slopes are considerably drier and are covered predominantly with grass. As the north facing slopes are typically wetter, they exhibit slope angles that are flatter than those noted on the south facing slopes as the higher moisture content in the rock will weaken the rock and lead to the development of the flatter slopes.

Although south facing slopes are typically drier, they will be more sensitive to increases in moisture as there is a lack of vegetation to remove moisture by transpiration. This fact and the lack of root strength reinforcement make the south facing slopes more susceptible to shallow landsliding. During the field reconnaissance the amount of surficial sliding was significantly more pronounced on the south facing (left) slopes.

4.7. EFFECTS OF THE HEADPOND

Raising Peace River water levels by 6 metres (~ 20 feet) at the head works structure will have the effect of increasing the areas of the valley wall subject to inundation, reducing the flow velocity along the river edge and aggrading of existing sand and gravel bars. The latter effect may increase the lateral erosion at specific areas due to the deflection of the river by the bars. The specific impacts are discussed below:

River Level Changes: Figure 4.12 provides an indication of the projected changes in water levels caused by the Dunvegan Project as compared to the river levels prior to regulation of the Peace River by Bennett Dam. The figure has been divided into three zones, 1 through 3 which reflect the types of shoreline features which would occur at the elevated water levels. The main areas of focus are those in which the average annual flows and flood events are within or higher than the upper range of pre-Bennett Dam flows and therefore not confined to the banks of the pre-Bennett Dam channel. Using these inundation levels, flow is expected to act on slopes that have historically not been subjected to prolonged flows or extreme flood events. The main effects will be in zones of unvegetated, unconsolidated sediments at specific locations.

- **Zone 1** represents the length of the headpond (0.0 to 6.1 kilometres) in which the average annual river flow levels will be higher than the average annual river levels that acted on the slopes prior to the regulation of the river by Bennett Dam. As well, the flood events will be higher than those prior to regulation. The 1:50 year return period for a flood was selected as a reasonable, mid-range event. The portions of the slope that will be affected the most are the isolated shallow gullies containing shallow colluvium within the lower 6 kilometres of the headpond along the north (left) slope.

  The main effects on slope stability will be the submergence and softening of weathered bedrock and slope debris that is currently above water. As the water level is increased in this area the flow velocities along the bank will decrease.

  The impacts of wave erosion are expected to be negligible within this reach. Based on conversations with locals at Dunvegan it is understood that high winds in the valley are infrequent and therefore it is considered that the erosive effects of wave action will be minimal. As well, provincial wind isotach maps indicate that the Peace Region has the lowest wind velocities in the province of Alberta (ESBI Alberta Ltd, 1999).

- **Zone 2** represents the reach of the headpond (6.1 to 17.1 kilometres) in which the average annual post-Dunvegan river levels will be within the upper range of average annual pre-Bennett flow levels. The flood events are considered to have the greatest effect on the non-vegetated, unconsolidated materials in the debris fans between kilometres 6.0 and 7.0. In this area, fans of unconsolidated debris along the slope would be highly susceptible to erosion by a flood event. This is an area with previously active slope processes. River levels associated with flood events (1:50 year and less) are also calculated to be higher than those prior to regulation (UMA, 2000). The implication of this is that the river levels will be acting on slopes on which the river levels did act on in the past. Although river levels will be higher than present regulated levels they will be expected to act in an area in which high pre-Bennett water levels have acted on the slopes prior to 1968. The effects will likely be confined to the reworking, and softening of the fine silty fluvial terraces encountered at the base of the majority of the slopes within this reach. The areas of the highest potential to be affected by flood events would be the section of the reach along the left bank from 12 to 17 kilometres in which numerous steep gullies containing shallow colluvium terminate at the edge of the river.

- **Zone 3** (17.1 kilometre to 26.0 kilometre) represents the reach in which the post-Dunvegan river levels will act in the mid to lower range of pre-Bennett flow levels. It is considered that the impact on the materials at the slope toe will be minimal throughout this stretch of the headpond. A slight increase of the river levels above those presently encountered will be expect to lead to a slight reworking and redistribution of the fluvial sediments encountered along the river's edge throughout this reach.

Toe Erosion: The impoundment of the headpond will have the positive effect of decreasing the overall flow velocity along the edge of the river and the negative effect of increasing erosive attack on specific areas by the increased rate of aggradation of sand bars and resulting deflection of flows into banks on the opposite side of the river. This increase in lateral erosion will occur in areas in which bars have been forming on an ongoing basis, especially since regulation of the flows by the WAC Bennett Dam in 1968 to 1972. A more detailed discussion of the long-term river past and future river morphology issues are addressed by Mike Miles and Associates Ltd. (2000a). The areas in which erosion rates will be increased are highlighted on the sediment delivery potential maps in Section 5 and in the discussion in Appendix A.

River Level Fluctuations/Dam Break:

In order to assess the potential effects of a failure of the dam structure or the rubber weir, the following information has been provided (personal communication, Paul Kemp, Canadian Projects):

- Rapid drawdown upon dam break (low potential even under an extreme flood event) will cause the headpond to drop from Dunvegan levels to post-Bennett (present) levels.
- A failure of the rubber weir could rapidly lower the head pond level by about 2 metres at the head works and proportionally less progressing upstream from the structure. This is considered to be a lesser event but with a higher potential frequency than that of a dam break.

It is considered that the areas affected by the river level fluctuations generated by either of these scenarios will have minimal effect on the competent sandstones and shales of the Dunvegan Formation. The highest potential for the river fluctuations initiating landsliding into the headpond would be for the shallow colluvium filled gullies situated on the slopes in the lower 7 kilometres of the headpond. The areas affected would be along the north (left) slope between kilometres 6 and 7. This is an area where the steep fans of colluvium enter the river from the slopes above. The effect of a sudden drawdown of up to 6 metres on these features could potentially mobilize shallow failures at the toes of these fans, which in turn could possibly mobilize the upslope portions of these fans as well. Based on a visual estimate of the volume of sediment available there is less than 15,000 m^3 of material that could be mobilized in such a scenario. Two historic debris flows in this area observed on the 1961 airphotos, delivered between 10,000 to 30,000 m^3 of debris into the river. It is considered that this type of failure would not be rapid and would not be detrimental to the operation of the proposed structure or the river regime. This would be considered to be a low magnitude, low frequency event.

CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: C.R.F.	HEADPOND SLOPE STABILITY ASSESSMENT LARGE GULLY FEATURES (12-19km)	REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE N.T.S.		
	DATE: MARCH, 2000		FIGURE 4.1

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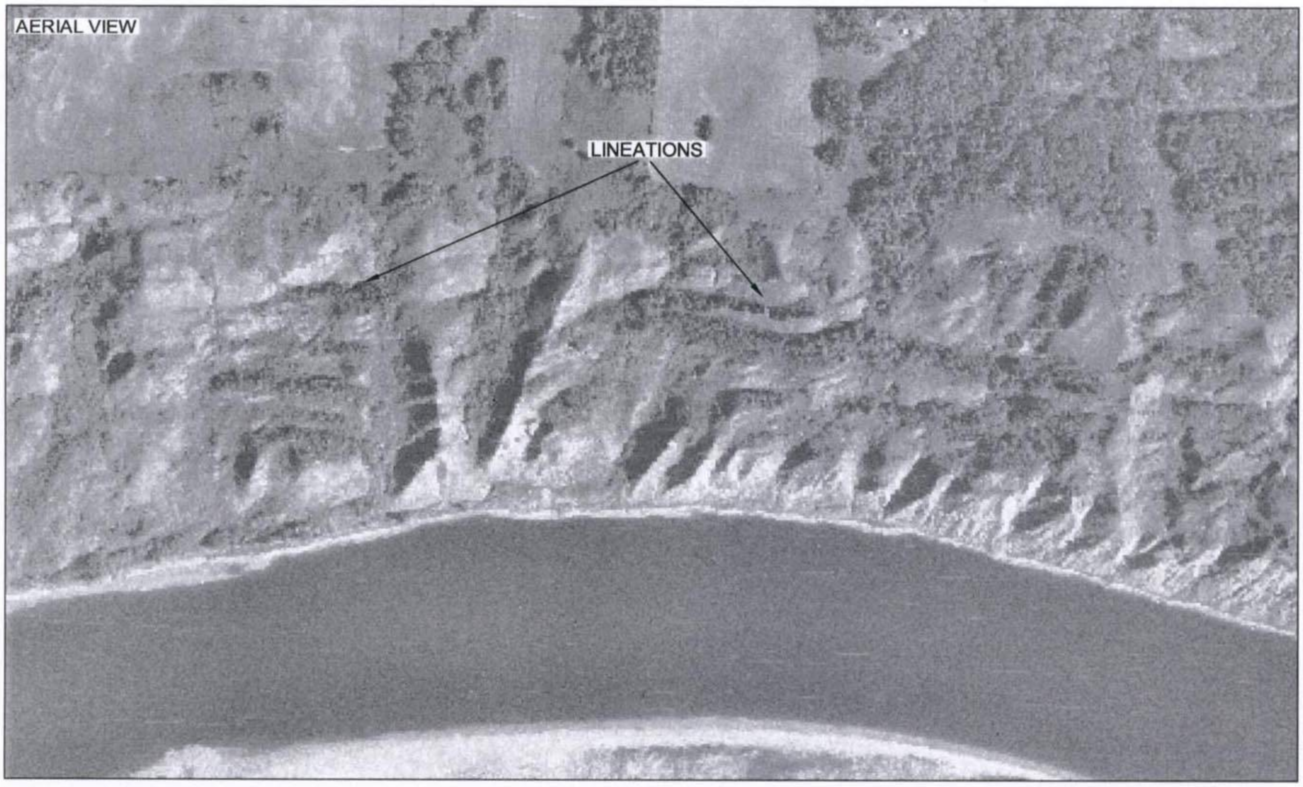

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	CHK'D BY: C.R.F.	HEADPOND SLOPE STABILITY ASSESSMENT LINEAR FEATURES (1.0-2.0km)	REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE N.T.S.		
	DATE: MARCH, 2000		FIGURE 4.2

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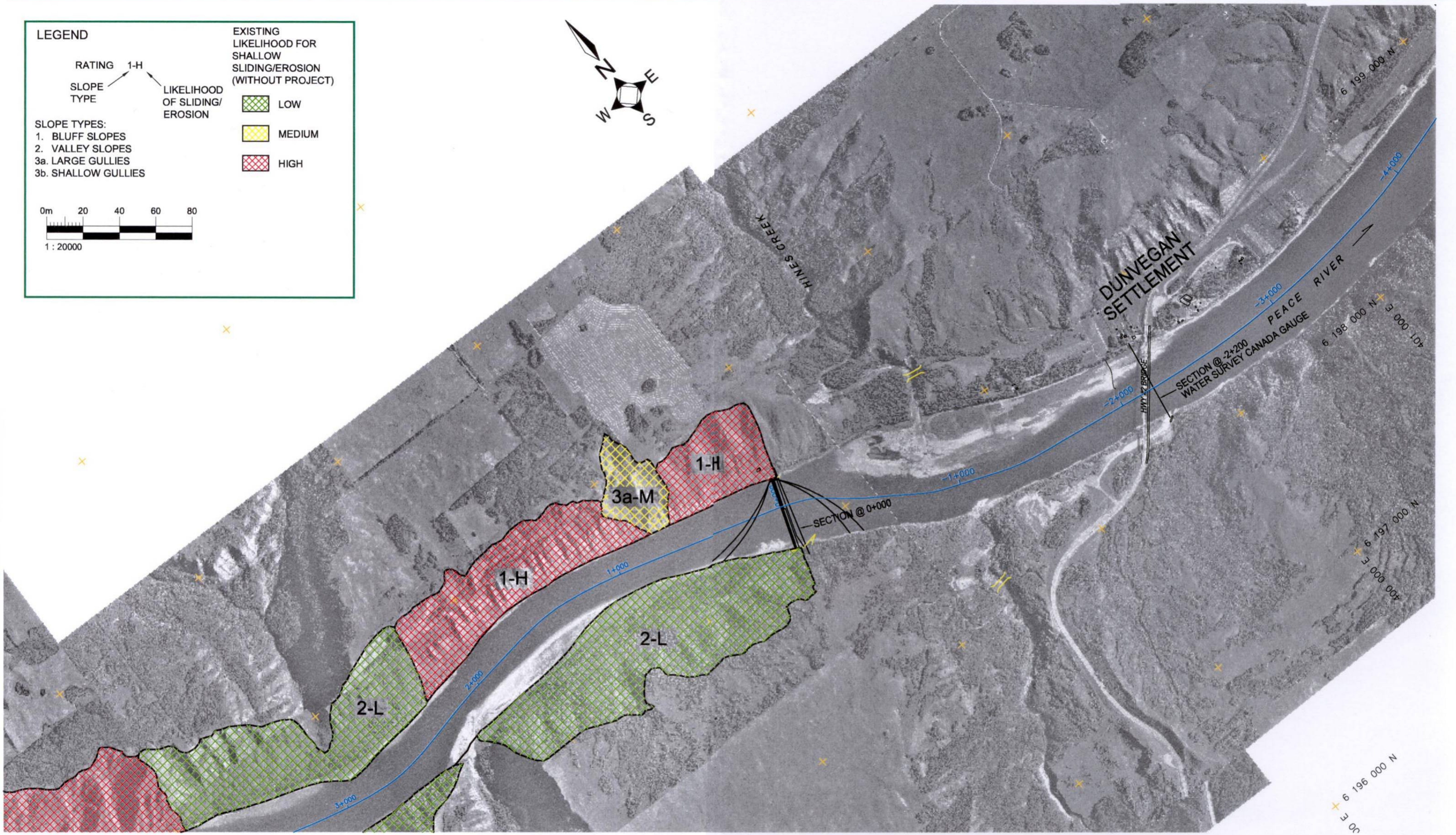

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AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	CHK'D BY: C.R.F.	HEADPOND SLOPE STABILITY ASSESSMENT EXISTING SLIDING/EROSION LIKELIHOOD	REV. NO.: -
	SCALE 1 : 20000		
	DATE: MARCH, 2000		FIGURE 4.3

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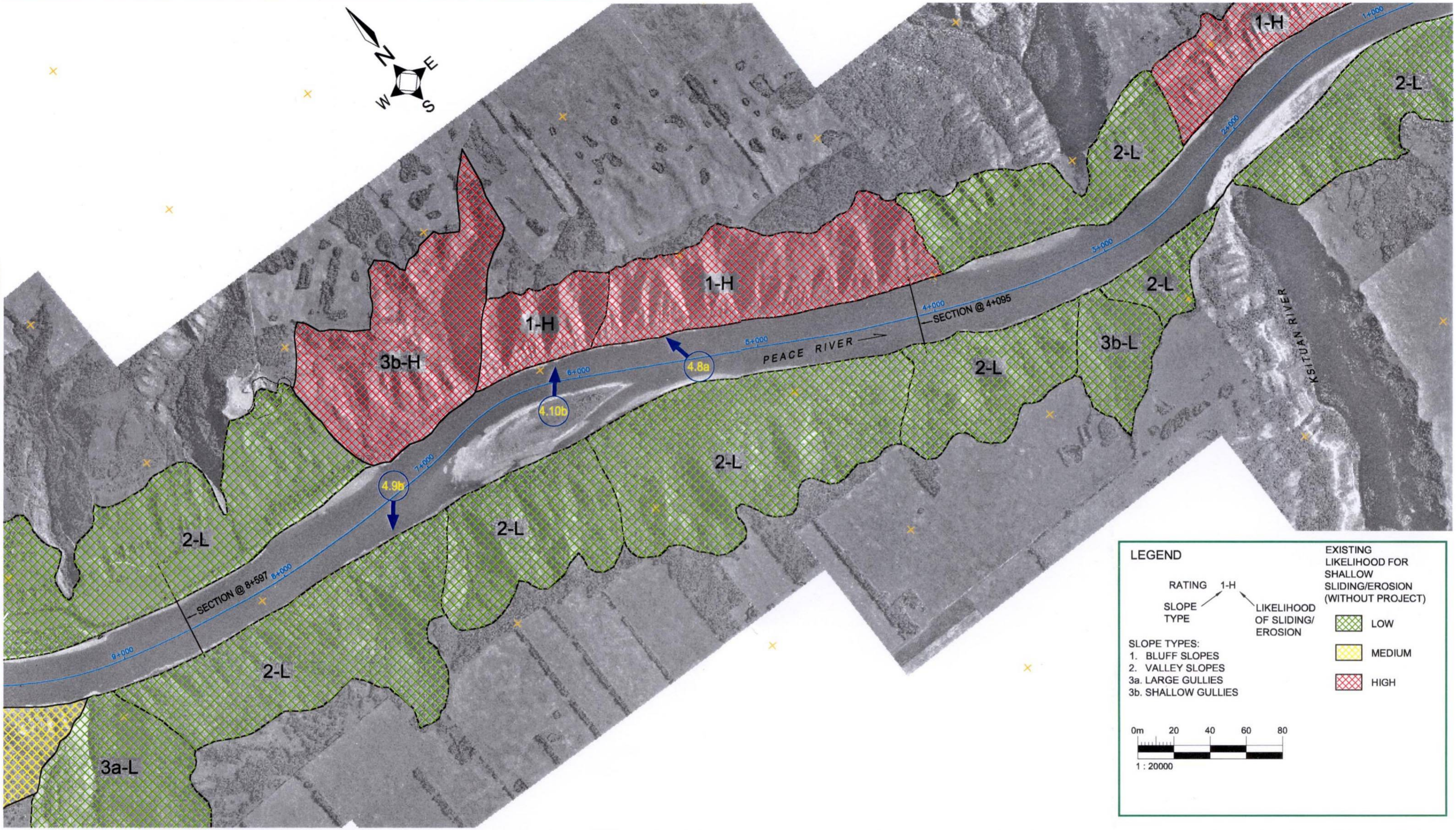
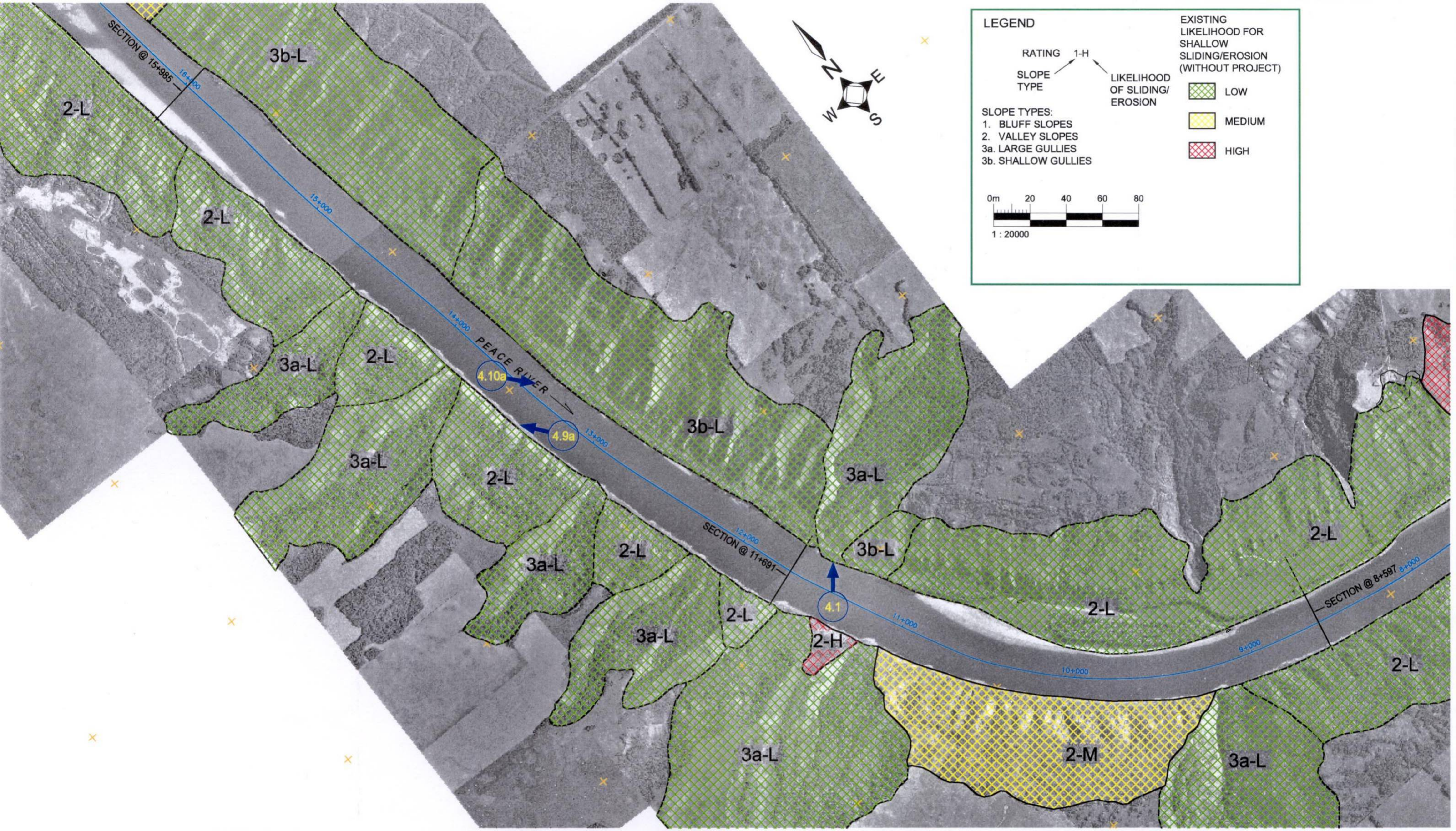


DRAWING SOURCE: 1001-002-4.3.3.052.DWG FROM CANADIAN PROJECTS LIMITED

CLIENT: GLACIER POWER LTD AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	DWN BY: R.S.W. CHK'D BY: C.R.F. SCALE 1 : 20000 DATE: MARCH, 2000	DUNVEGAN LOW HEAD HYDRO PROJECT HEAD POND SLOPE STABILITY ASSESSMENT EXISTING SLIDING/EROSION LIKELIHOOD	AEE PROJECT NO: EG08542 REV. NO.: - FIGURE 4.4



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CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	CHK'D BY: C.R.F.	HEAD POND SLOPE STABILITY ASSESSMENT EXISTING SLIDING/EROSION LIKELIHOOD	REV. NO.: -
	SCALE 1 : 20000		
	DATE: MARCH, 2000		FIGURE 4.5

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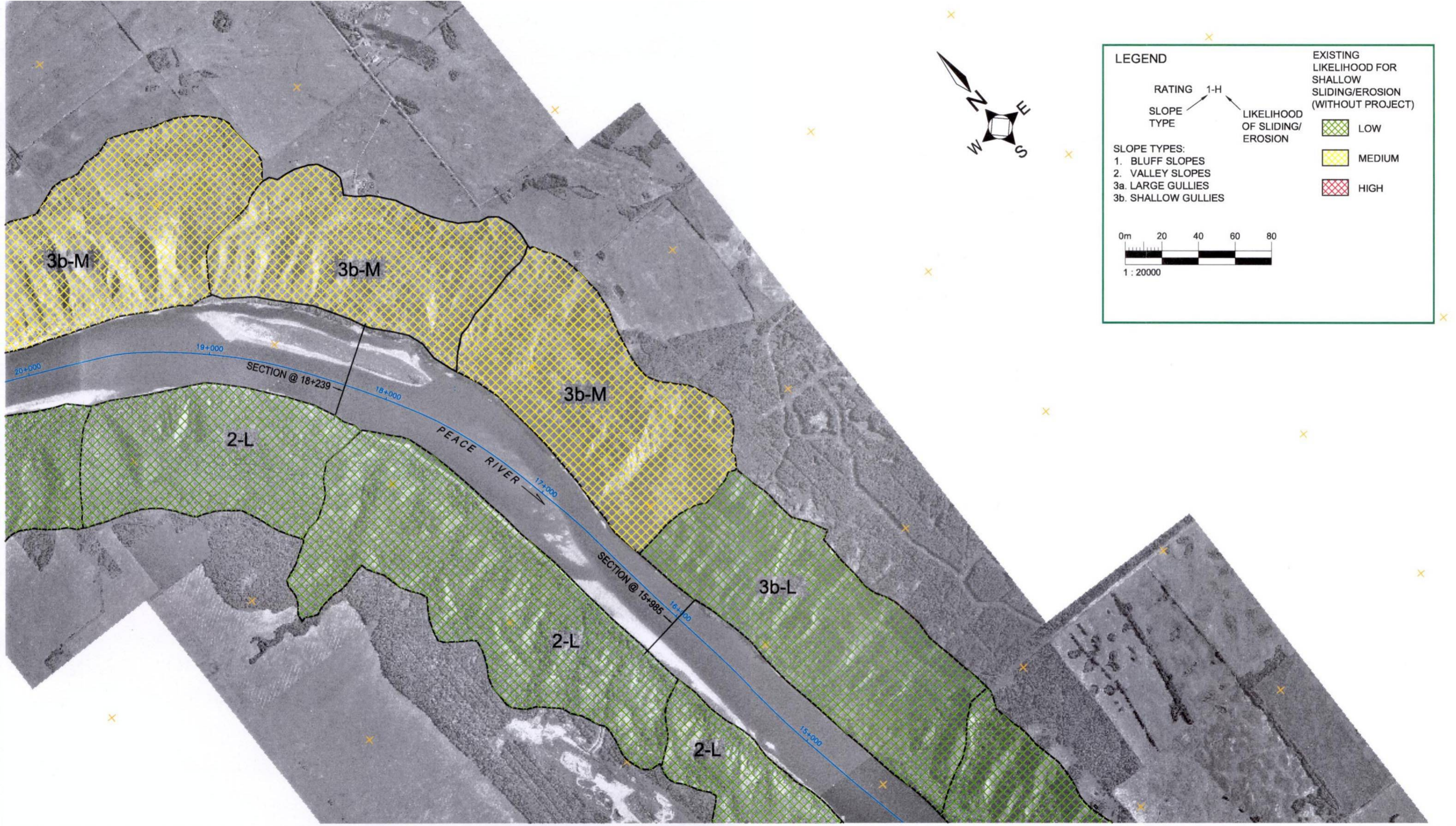

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AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	CHK'D BY: C.R.F.	HEAD POND SLOPE STABILITY EXISTING SLIDING/EROSION LIKELIHOOD	REV. NO.: -
	SCALE 1 : 20000		FIGURE 4.6
	DATE: MARCH, 2000		

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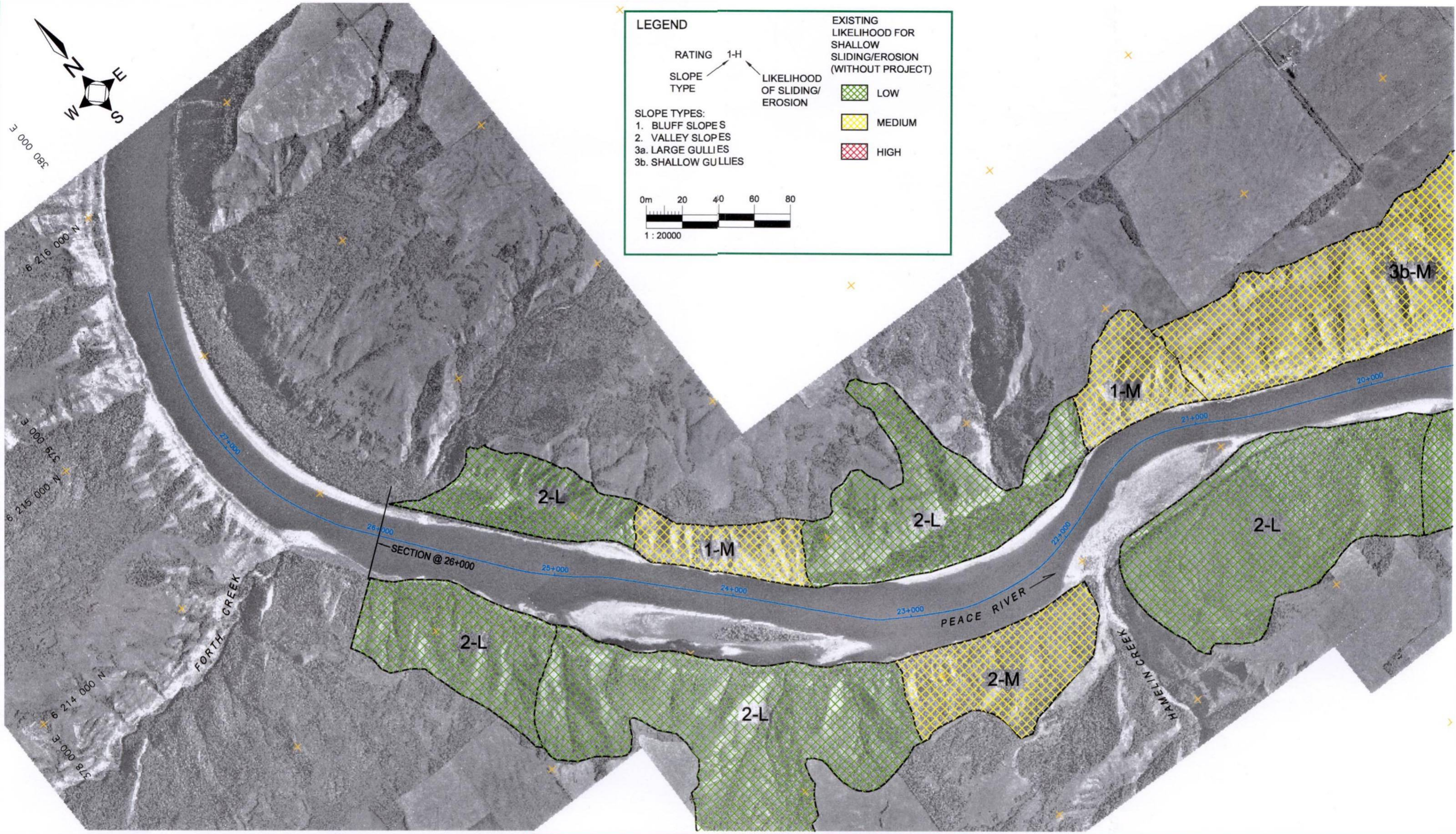

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CLIENT: GLACIER POWER LTD / AGRA Earth & Environmental — ENGINEERING GLOBAL SOLUTIONS	DWN BY: R.S.W. CHK'D BY: C.R.F. SCALE 1 : 20000 DATE: MARCH, 2000	DUNVEGAN LOW HEAD HYDRO PROJECT HEAD POND SLOPE STABILITY ASSESSMENT EXISTING SLIDING/EROSION LIKELIHOOD	AEE PROJECT NO: EG08542 REV. NO.: - FIGURE 4.7

4.8a TYPICAL BLUFF SLOPES (LEFT SLOPE AT 5+100km)

4.8b BEDROCK TOPPLES WITH UNDERMINED SANDSTONE ON BLUFF SLOPE AT 5+800km

CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: C.R.F.	BLUFF-TYPE SLOPES ALONG HEAD POND	REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE N.T.S.		
	DATE: MARCH, 2000		FIGURE 4.8

AGRA EDMONTON

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4.9a VALLEY TYPE SLOPE WITH INCISED GULLY AT 13+500 km

4.9b SLIDING IN VALLEY TYPE SLOPE IN AREA OF ACTIVE LATERAL EROSION AT 7+000km

CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: C.R.F.	"VALLEY-TYPE" SLOPES ALONG HEAD POND	REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE N.T.S.		
	DATE: MARCH, 2000		FIGURE 4.9

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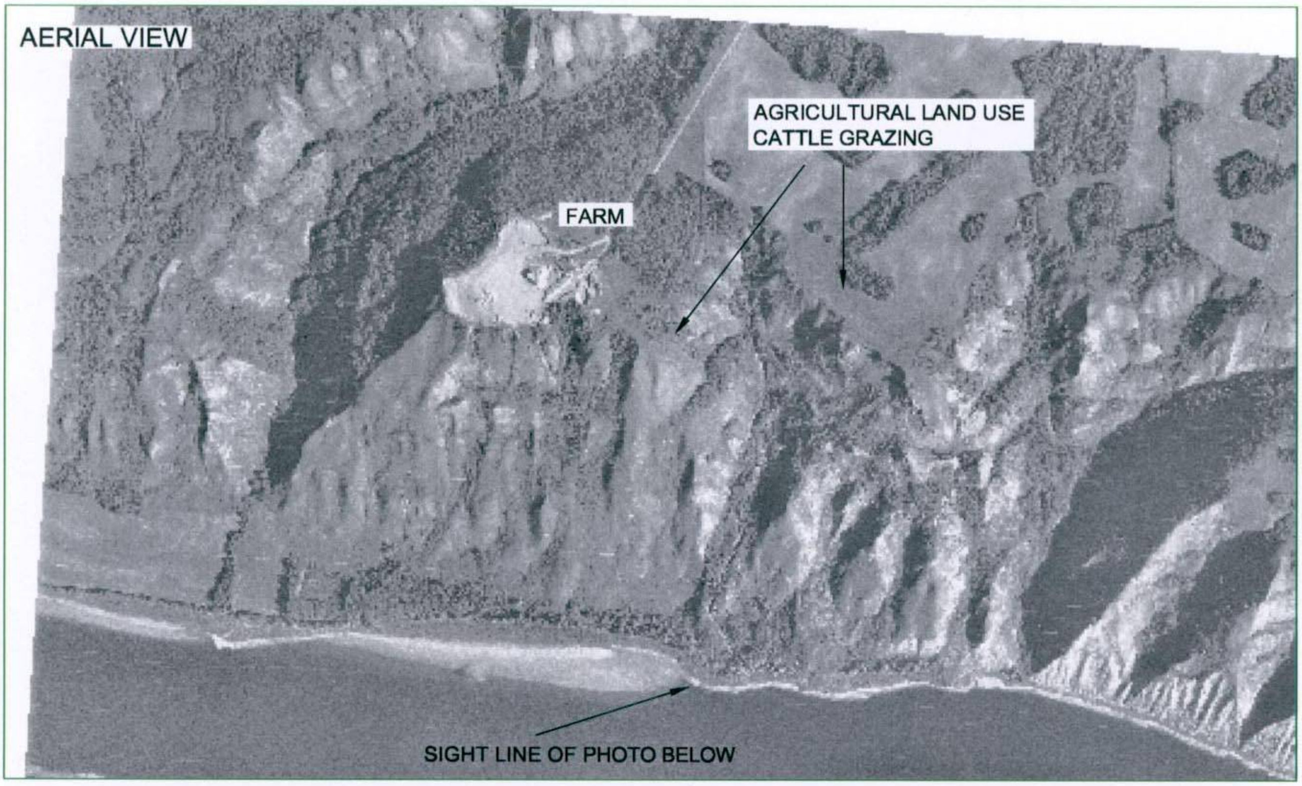
4.10a SECTIONS OF VALLEY WALL WITH NUMEROUS STEEP GULLIES CONTAINING SHALLOW COLLUVIUM (13+500km)

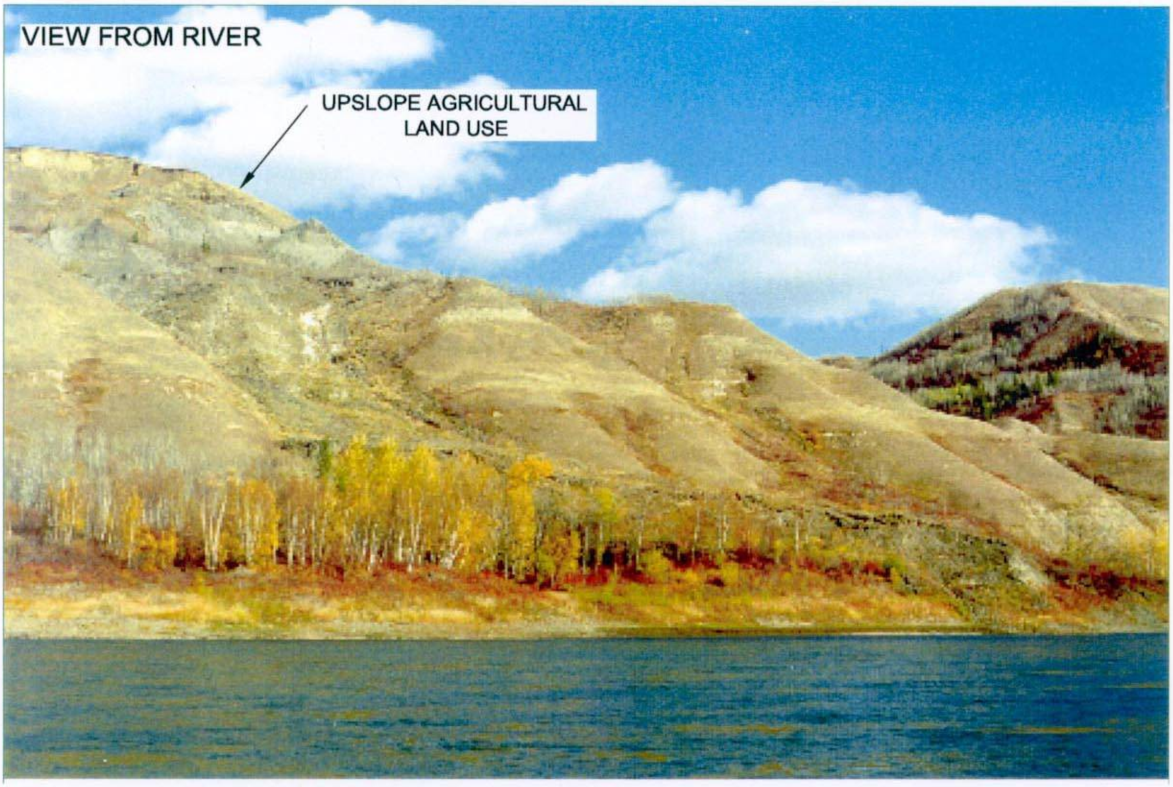
4.10b ACTIVE SLIDING IN STEEP GULLY WITH SHALLOW COLLUVIUM AT 5+800km

CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: C.R.F.		REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE N.T.S.	STEEP GULLIES WITH SHALLOW COLLUVIUM	
	DATE: MARCH, 2000		FIGURE 4.10

AGRA EDMONTON

*PLOT 1:1=D S:\CADD\Geo\EG08500\eg08542\REPORT FIGURES\ fig-4-8-9-10.dwg Sun. Apr. 16 3:35pm 2000 SWilcox





CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: C.R.F.	HEADPOND SLOPE STABILITY ASSESSMENT LANDSLIDING DUE TO UPSLOPE LAND USE	REV. NO.: -
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	SCALE N.T.S.		
	DATE: MARCH, 2000		FIGURE 4.11

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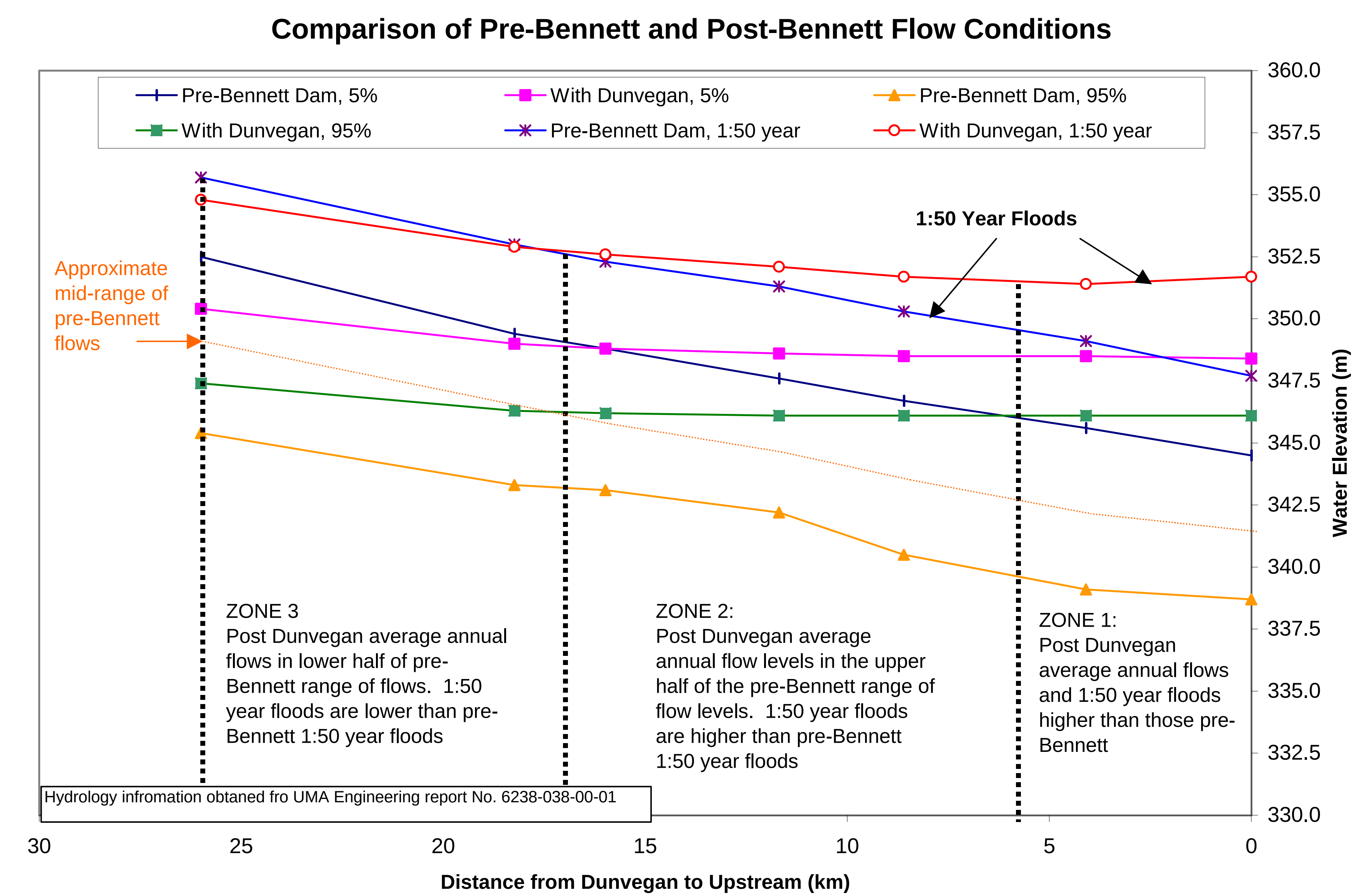

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Figure 4.12

5.0 MAPPING OF POST PROJECT SLOPE CONDITIONS

5.1. APPROACH

In order to assess where the proposed headpond would be expected to effect the existing slope processes, the entire length of the headpond was assessed as to where there would be a increase in the rate of the existing, ongoing slope processes due to the effects of the headpond. In order to complete this task, a review of the slopes along the headpond was undertaken incorporating the results of the field assessment, the airphoto review, the UMA hydrology report and AEE experience with similar geological conditions in the region. This type of review is qualitative in nature and is not used as an exact prediction tool for estimating specific landslide volumes and frequencies.

A detailed listing of the issues considered in the assessment of sediment delivery is included in Appendix A.

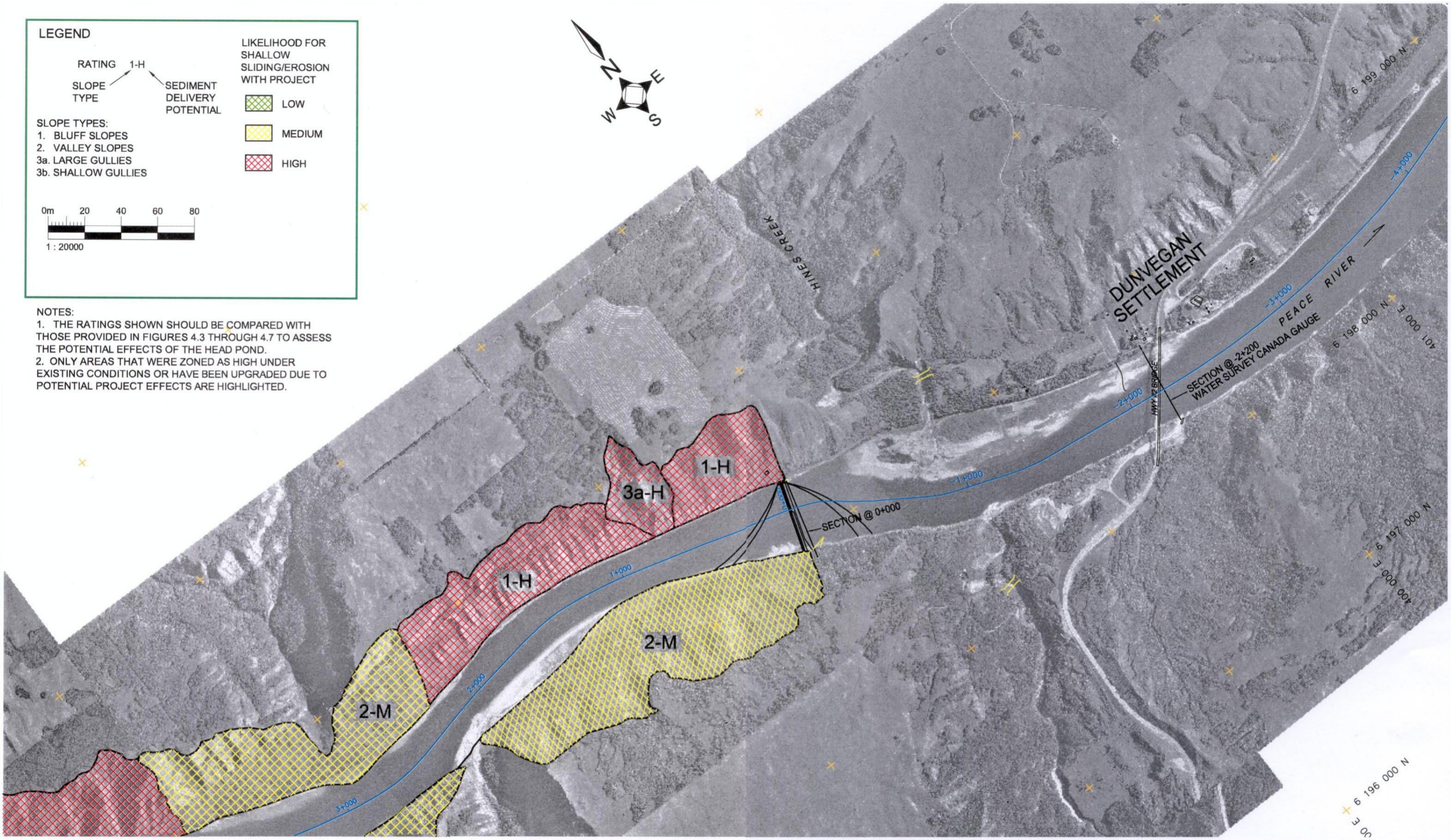
5.2. LIKELIHOOD OF SLIDING/EROSION

Figures 5.1 through 5.5 provide the zoning of the slopes along the entire length of the headpond to illustrate the increase in the rate of slope process development (sliding/slumping and erosion) along the headpond. The factors that contribute to sliding and the types of slopes that have been zones were discussed in Section 4.0. All slopes have been classified as high, medium or low potential for shallow sliding and erosion based on regional experience and judgement based on the following factors:

- Slope type
- River level
- Effects of lateral erosion
- Slope Aspect
- Upslope land use
- Evidence of landsliding

The zoning shown on Figures 5.1 through 5.5 only reflects the areas that were classified as a high likelihood (due to existing active slope processes) and those areas that the likelihood would be expected to increase due to the potential effects of the project.

The zoning criteria tables, based on the above criteria, from which the ratings were derived, are included in Appendix A along with a more detailed discussion of the zoning criteria.



NOTES:
1. THE RATINGS SHOWN SHOULD BE COMPARED WITH THOSE PROVIDED IN FIGURES 4.3 THROUGH 4.7 TO ASSESS THE POTENTIAL EFFECTS OF THE HEAD POND.
2. ONLY AREAS THAT WERE ZONED AS HIGH UNDER EXISTING CONDITIONS OR HAVE BEEN UPGRADED DUE TO POTENTIAL PROJECT EFFECTS ARE HIGHLIGHTED.

DRAWING SOURCE: 1001-002-4.3.3.052.DWG FROM CANADIAN PROJECTS LIMITED

CLIENT: GLACIER POWER LTD / AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
	CHK'D BY: C.R.F.	HEAD POND SLOPE STABILITY LIKELIHOOD FOR SHALLOW SLIDING/EROSION WITH PROJECT	REV. NO.: -
	SCALE 1 : 20000		
	DATE: MARCH, 2000		FIGURE 5.1

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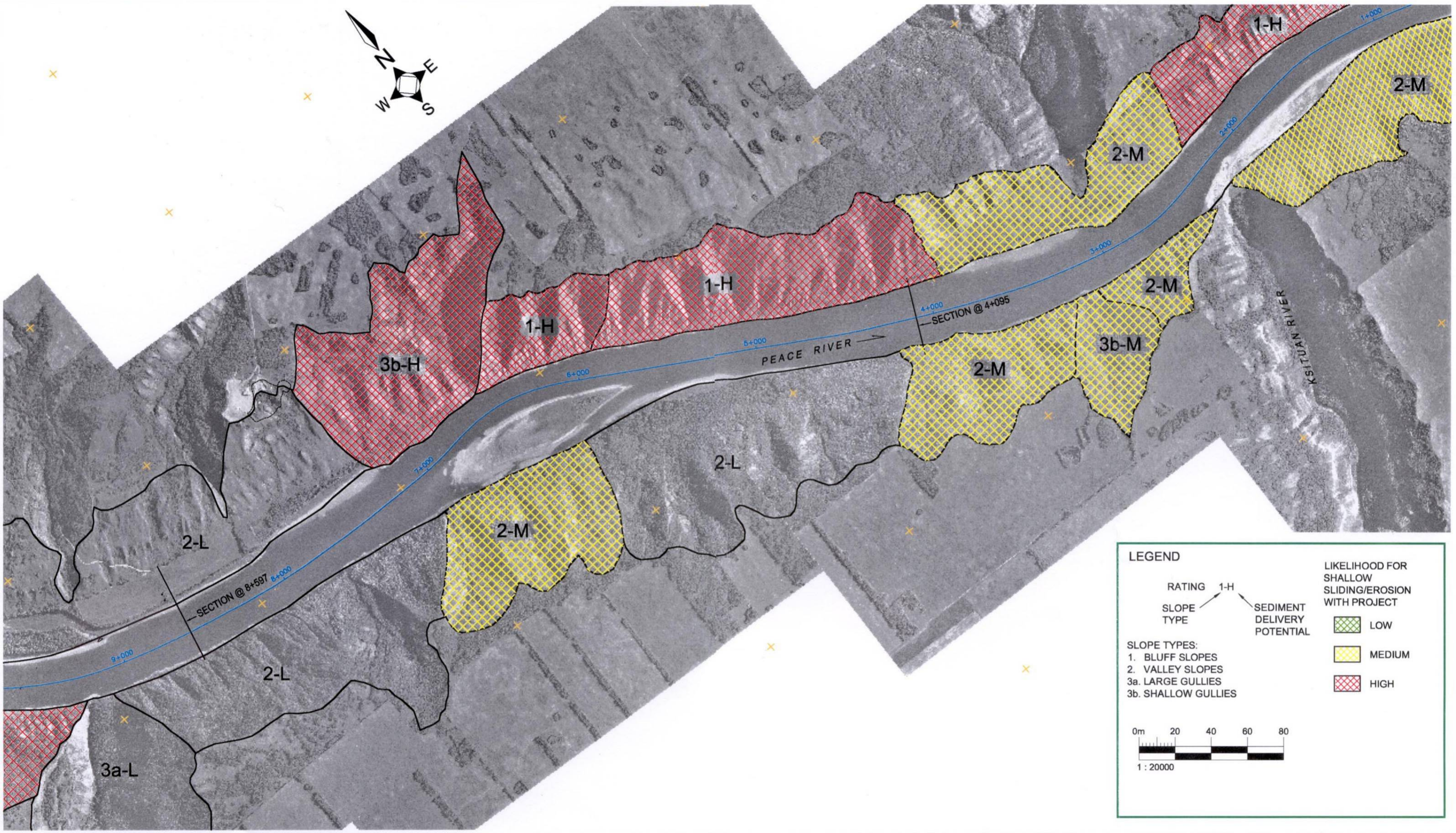


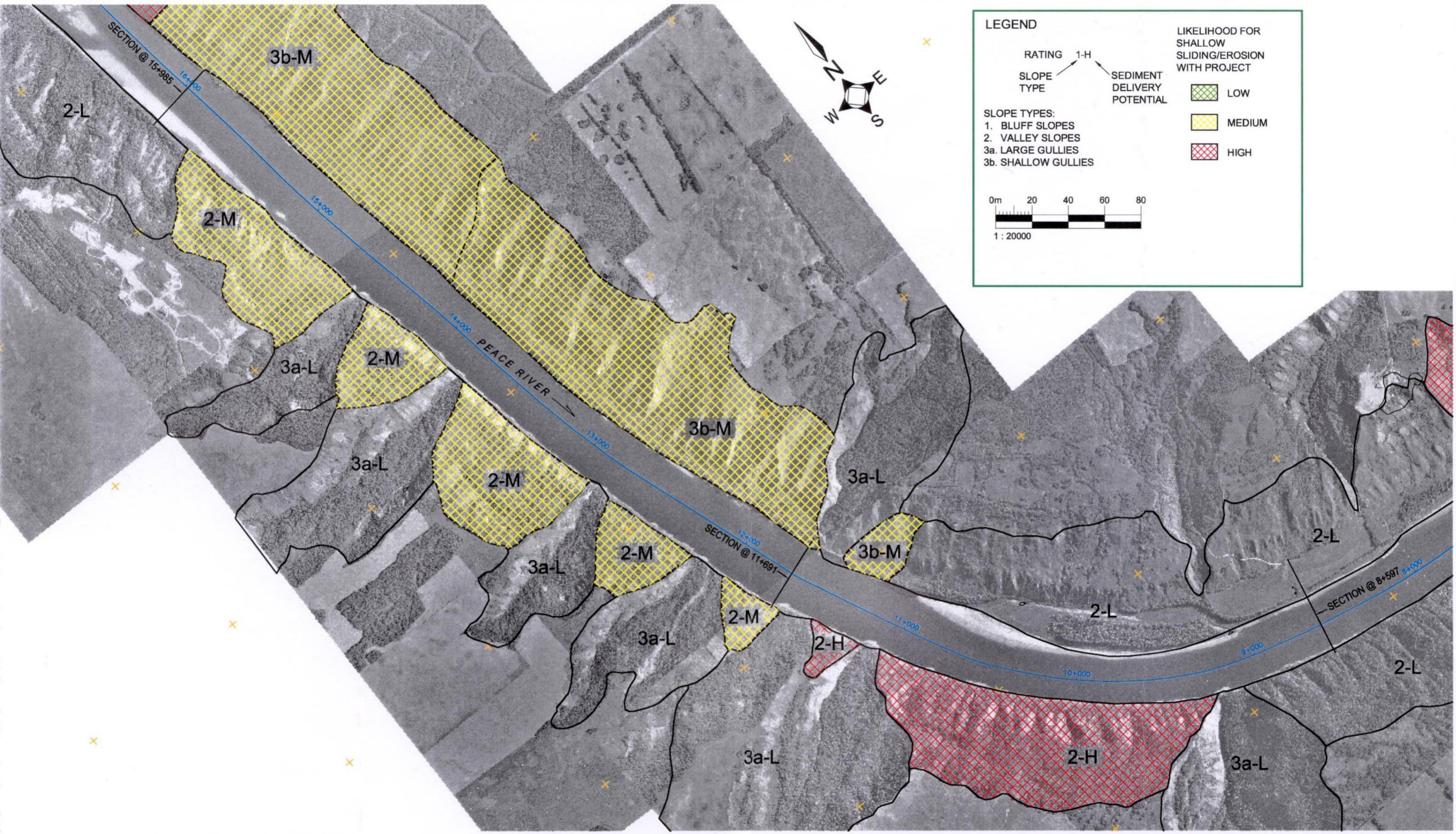
DRAWING SOURCE: 1001-002-4.3.3.052.DWG FROM CANADIAN PROJECTS LIMITED

NOTES:

1. THE RATINGS SHOWN SHOULD BE COMPARED WITH THOSE PROVIDED IN FIGURES 4.3 THROUGH 4.7 TO ASSESS THE POTENTIAL EFFECTS OF THE HEAD POND.
2. ONLY AREAS THAT WERE ZONED AS HIGH UNDER EXISTING CONDITIONS OR HAVE BEEN UPGRADED DUE TO POTENTIAL PROJECT EFFECTS ARE HIGHLIGHTED.

CLIENT: GLACIER POWER LTD AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	DWN BY: R.S.W. CHK'D BY: C.R.F. SCALE 1 : 20000 DATE: MARCH, 2000	DUNVEGAN LOW HEAD HYDRO PROJECT HEAD POND SLOPE STABILITY LIKELIHOOD FOR SHALLOW SLIDING/EROSION WITH PROJECT	AEE PROJECT NO: EG08542 REV. NO.: - FIGURE 5.2

PLOT 1:1=D S:\CADD\Geo\EG08500\eg08542\orthophotos\ 8462-001-A2000.dwg Sun. Apr. 16 3:31pm 2000 SWilcox



DRAWING SOURCE: 1001-002-4.3.3.052.DWG FROM CANADIAN PROJECTS LIMITED

NOTES:

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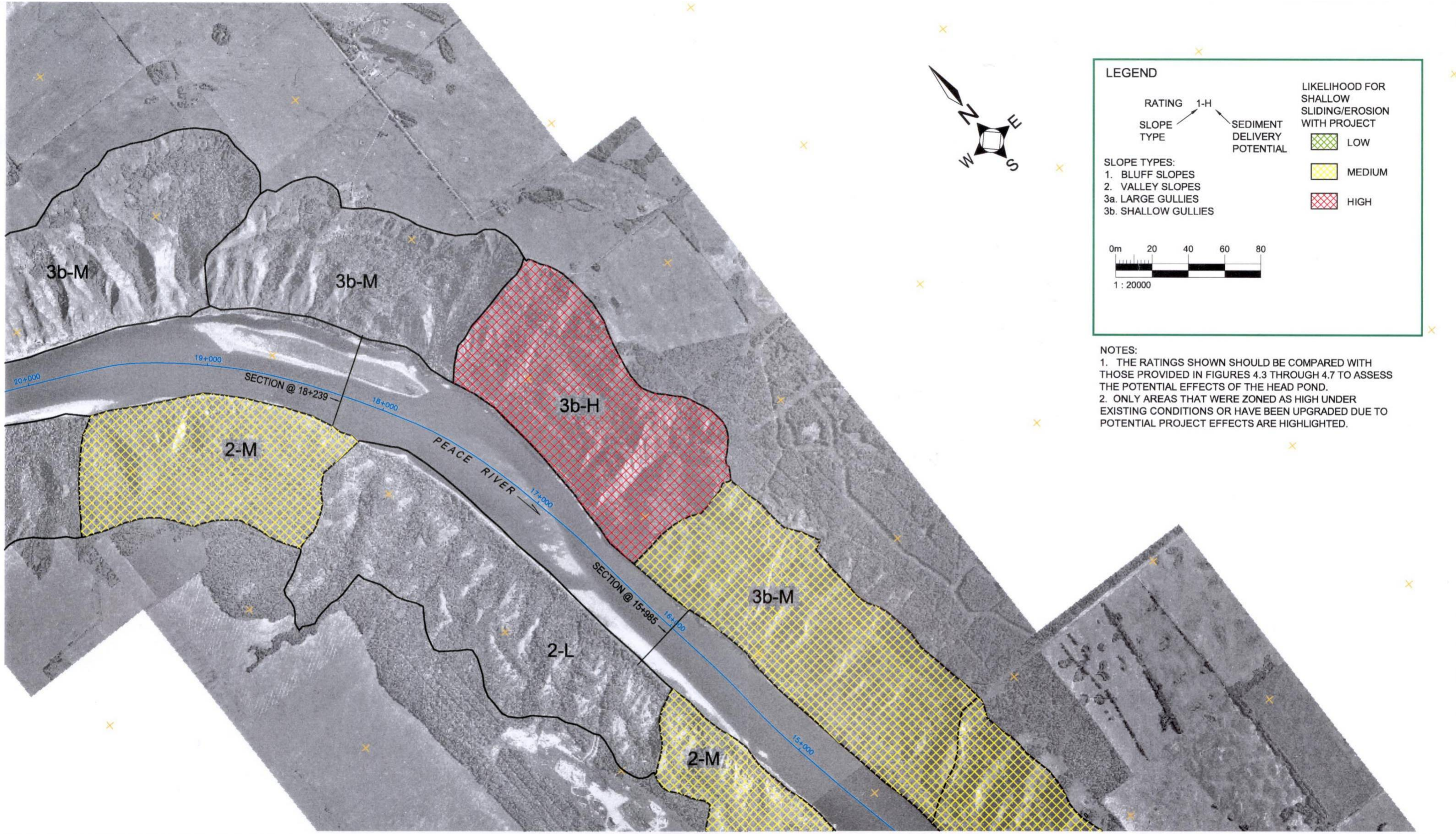
CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	CHK'D BY: C.R.F.	HEAD POND SLOPE STABILITY LIKELIHOOD FOR SHALLOW SLIDING/EROSION WITH PROJECT	REV. NO.: -
	SCALE 1 : 20000		
	DATE: MARCH, 2000		FIGURE 5.3

LOT 1:1=D S:\CADD\Geo\EG08500\eg08542\orthophotos\ 8462-001-A2000.dwg Sun. Apr. 16 3:31pm 2000 SWilcox



NOTES:
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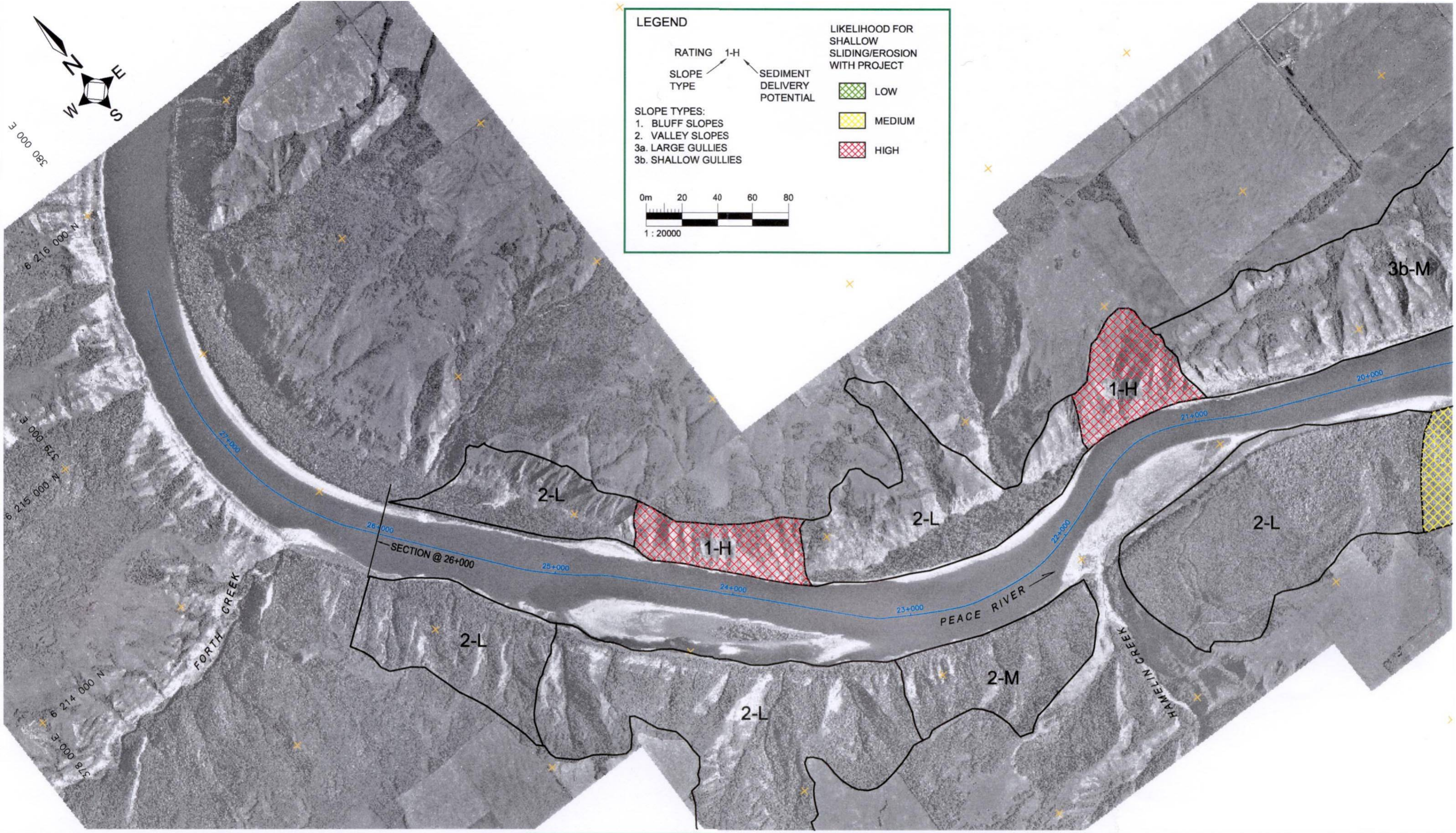
CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	CHK'D BY: C.R.F.	HEAD POND SLOPE STABILITY LIKELIHOOD FOR SHALLOW SLIDING/EROSION WITH PROJECT	REV. NO.: -
	SCALE 1 : 20000		
	DATE: MARCH, 2000		FIGURE 5.4

PLOT 1:1=D S:\CADD\Geo\EG08500\eg08542\orthophotos\ 8462-001-A2000.dwg Sun. Apr. 16 3:31pm 2000 SWilcox



DRAWING SOURCE: 1001-002-4.3.3.052.DWG FROM CANADIAN PROJECTS LIMITED

NOTES:

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CLIENT: GLACIER POWER LTD	DWN BY: R.S.W.	DUNVEGAN LOW HEAD HYDRO PROJECT	AEE PROJECT NO: EG08542
AGRA Earth & Environmental ENGINEERING GLOBAL SOLUTIONS	CHK'D BY: C.R.F.	HEAD POND SLOPE STABILITY LIKELIHOOD FOR SHALLOW SLIDING/EROSION WITH PROJECT	REV. NO.: -
	SCALE 1 : 20000		
	DATE: MARCH, 2000		FIGURE 5.5

PLOT 1:1=D S:\CADD\Geo\EG08500\eg08542\orthophotos\ 8462-001-A2000.dwg Sun. Apr. 16 3:31pm 2000 SWilcox

6.0 SUMMARY AND CONCLUSIONS

The geologic conditions along the reach of the Peace River between the proposed head works structure and Fourth Creek are favourable with respect to the stability of the valley slopes within the proposed headpond area. The geologic units/features that contribute to large-scale landsliding both upstream and downstream are not encountered within the proposed headpond section of the Peace River. The types of slope processes (weathering, erosion, sliding/slumping) encountered within the headpond will be similar to those already existing at present. These processes are considered to be predominantly shallow and caused by a number of factors such as weathering, upslope land use and river erosion. The headpond will result in a modest increase in the rate of these ongoing processes during the initial few years of operation. The increase in the rate of these processes is not expected to be observable, rather it will occur in a geologic process timeframe. Over time the rates of these slope processes would be expected to decrease to those levels presently taking place.

7.0 CLOSURE

This report has been prepared for the exclusive use of Glacier Power Limited and their agents for application to the proposed low head hydro project at Dunvegan.

Respectfully submitted,

AGRA Earth & Environmental Limited

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APPENDIX A: DETERMINATION OF THE LIKELIHOOD OF SLIDING/EROSION

Existing Conditions

In Section 4 of the main body of the report, maps showing the existing likelihood for shallow sliding and erosion along the proposed headpond were presented. The zoning was presented on Figures 4.3 through 4.7 to show the existing conditions along the headpond with respect to ongoing slope processes.

Potential Effects of Project

In Section 5 of the main body of the report, maps showing the potential effects on likelihood for shallow sliding and erosion with the proposed project were presented as Figures 5.1 through 5.5. In these figures, the entire length of the headpond has been zoned as a high, medium or low likelihood of shallow sliding/erosion. On these maps, only zones that already had a high likelihood for sliding/erosion (processes ongoing at present) and those ratings that were upgraded from the ratings shown on Figures 4.3 through 4.7 were shown in Figures 5.1 through 5.5.

The following provides a summary of the criteria used in the determination used in both sets of zoning as presented in Table A.1.

Slope Type: Slopes were zoned on the airphotos based on the types of slopes and the active processes noted on the airphotos and in the field. Slopes were classified as bluff slopes, valley slopes, large gullies and shallow gullies. The specific types of slopes corresponding to this nomenclature are outlined in Section 4.5 in the main body of the report.

Toe Buffer: During the field assessment, there were areas noted where debris from shallow slides remained on the slope, separated from the river by small terraces or benches at the river's edge. For large flood plains, such as the homestead terrace (kilometres 8 to 11 on the left bank) fans of debris originating from the slopes above were found to rest on or upslope of these features, thus not entering the river. Areas with large terraces at the base (greater than 5 metres in width) were then considered to have a low potential of landslide debris entering the river. The bluff slopes would be at the other end of the scale as the river cuts directly at the toe of the slope. These areas were considered to have a higher potential for sediment entering the river from upslope landsliding and erosion.

Upslope Land Use: The impacts of the removal of vegetation on the slopes were discussed in detail in the main body of the report. Due to these impacts, the presence or absence of tree cover at the crest of the slope was used as a criterion. Slopes with no tree cover at and back of the crest were considered to have a higher potential for slope instability than those that were forested.

Aspect: As discussed in the main body of the report, the slope aspect is seen to have a significant impact on slope instability. Slopes on the north side (left) are considered to be more susceptible to the initiation of shallow landsliding into the headpond due to the factors discussed in Section 4.6.4.

Landslide Activity: The state of activity was used as a criterion to assess the susceptibility of a slope to shallow landsliding. Areas with existing landsliding were given a rating of high, while areas with no visible signs of landsliding were rated as low potential for landsliding. Areas with dormant landsliding features, that could be re-initiated by factors as listed in Section 4.6, were rated anywhere from a low to high potential depending on the above criterion that may be acting on the slope.

Flow Level: The level at which the post-Dunvegan Peace River will act on the slopes and the potential impact was discussed in detail in Section 4.12 of the main body of the report. The river levels were determined using hydrology data presented by UMA Engineering (2000) and have been presented on Figure 4.7 in the main body of the report. Slopes were given a rating from I to III representing the three zones shown on Figure 4.12.

Lateral Erosion: An assessment of the potential increases in the rate of lateral erosion on the banks of the headpond were assessed based on the perspective of overall river morphology provided in personal communication with Mike Miles of M. Miles and Associates Ltd. The following is a summary table of the classification criteria used to rate the erosion potential. The ratings in this summary table were based on river water level changes as a result of Dunvegan, morphological changes as a result of Bennett, and site specific geometry (i.e. river angle of attack, etc.)

Table A.1 - Reaches Affected By Lateral Erosion

Reach (km)	Bank	Comments	Erosion Potential rating[1]
1.2 to 1.8	left	Deflection by alluvial fan at mouth of Ksituan River will direct the flow against the left bank; however, the flow velocities will be low because of the higher water levels induced by the head works structure .	low
6.0 to 7.0	left	The ongoing sedimentation within the south side channel resulting from the regulated flow regime may increase the flow concentration within the main channel to the north.	low
9.0 to 11.5	right	The ongoing sedimentation within the side channel upstream of the creek mouth resulting from the regulated flow regime may increase the flow concentration within the main channel.	low
16.5 to 17.8	left	As bar along right bank at km 16 builds and the flow is deflected by the mid-channel extension of this bar, the flow will be deflected against the left bank.	low
18.3 to 19	right	Over the next 5 to 10 decades, the north side channel is expected to close off due to channel narrowing and sedimentation resulting from flow upstream regulation, which may force the flow against the right bank.	low
21 to 21.5	left	As the bar/alluvial fan at the mouth of Hamelin Creek (at km 22.0) stabilizes, the flow against the left bank will be accentuated.	high
21.5 to 23.0	right	The point bar along the left bank in this reach may build over time, and promote erosion of the right bank and alluvial fan at km 22.0. However, as the Hamelin Creek fan already constitutes sediment that resides in the headpond (the foot of the fan is approximately only 1.5 m high) erosion of sediment from the fan was not considered in the sediment budget.	high
23.0 to 25.0	left	Over the next 5 to 10 decades the side channel along the right side of the channel may close off due to the channel narrowing and sedimentation resulting from flow upstream regulation, however, as the channel is straight in this reach, the effect on erosion of the left bank will likely be small.	low

[1] Qualitative assessment of river erosion based on water levels, flow velocities, angle of attack, etc.

Rating System

Based on the above criteria, each segment of the slope was rated as high, medium, or low likelihood for shallow sliding/erosion along the headpond. The rating table used to select the overall rating is provided as Table A.1. For example, a valley slope with no evidence of landsliding, minor changes in water level at the toe, no increase in lateral erosion, on a north facing slope with a large toe buffer would be rated as a low potential area. An area such as a south facing bluff slope with elevated water levels, increased lateral erosion and no toe buffer would be rated as a high potential area. The factors for each area that has been designated on the slope were taken into account and a judgement based rating was given.

EG08542: DUNVEGAN HYDRO PROJECT

Sediment Delivery Potential Map Zoning Criteria

Polygon	Bank (Facing Downstream)	From	To	Shore Length (Metres)	Slope Type 1. Bluff 2. Valley 3a. Large Gully 3b. Shallow Gully	Flow Level (I) GPrB - >Pre Bennett (II) GPoB - > Post Bennett (III) MC - Minimal Change	Increased Lateral Erosion (I) Low Potential (II) Moderate Potential (III) High Potential (-) No Change	Toe Buffer (I) No Buffer (II) <5 metres (III)>5 metres	Upslope Landuse (I) Cleared (II) Forested	Aspect (I) South (II) North	Landslide Activity (I) Active sliding (II) Dormant Sliding (III) Non-Evident	Existing Conditions	Post Project Conditions
1	Left	0+000	0+600	600	1	I	-	I	I	I	I	High	High
2	Left	0+600	0+670	70	3a	I	-	I	I	I	I	Moderate	High
3	Left	0+670	2+200	1530	1	I	I	I	I	I	I	High	High
4	Left	2+200	3+800	1600	2	I	-	III	I	I	II	Low	Moderate
5	Left	3+800	5+900	2100	1	I	-	I	II	I	I	High	High
6	Left	5+900	6+500	600	1	I	I	I	I	I	I	High	High
7	Left	6+500	7+200	700	3b	II	I	I	I	I	I	High	High
8	Left	7+200	11+200	4000	2	II	-	III	I	I	I	Low	Low
9	Left	11+200	11+400	200	3b	II	-	II	I	I	II	Low	Moderate
10	Left	11+400	11+600	200	3a	II	-	I	I	I	II	Low	Low
11	Left	11+600	14+150	2550	3b	II	-	II	I	I	II	Low	Moderate
12	Left	14+150	16+400	2250	3b	II	-	II	II	I	II	Low	Moderate
13	Left	16+400	17+700	1300	3b	II	II	II	I	I	II	Moderate	High
14	Left	17+700	19+000	1300	3b	III	-	II	I	I	II	Moderate	Moderate
15	Left	19+000	21+000	2000	3b	III	-	II	I	I	I	Moderate	Moderate
16	Left	21+000	21+500	500	1	III	I	I	I	I	I	Moderate	High
17	Left	21+500	23+500	2000	2	III	-	III	I	I	II	Low	Low
18	Left	23+500	24+600	1100	1	III	I	I	I	I	I	Moderate	High
19	Left	24+600	26+000	1400	2	III	-	III	I	I	II	Low	Low
20	Right	26+000	25+000	1000	2	III	-	II	II	II	II	Low	Low
21	Right	25+000	23+200	1800	2	III	-	II	I	II	II	Low	Low
22	Right	23+200	22+100	1100	2	III	III	I	II	II	II	Moderate	Moderate
23	Right	22+100	19+700	2400	2	III	III	III	I	II	III	Low	Low
24	Right	19+700	18+000	1700	2	III	I	II	I	II	II	Low	Moderate
25	Right	18+000	15+800	2200	2	II	-	III	I	II	II	Low	Low
26	Right	15+800	14+500	1300	2	II	-	II	I	II	II	Low	Moderate
27	Right	14+500	14+400	100	3a	II	-	II	I	II	II	Low	Low
28	Right	14+400	13+900	500	2	II	-	II	I	II	II	Low	Moderate
29	Right	13+900	13+800	100	3a	II	-	II	I	II	II	Low	Low
30	Right	13+800	12+900	900	2	II	-	II	I	II	II	Low	Moderate
31	Right	12+900	12+800	100	3a	II	-	II	I	II	II	Low	Low
32	Right	12+800	12+200	600	2	II	-	II	I	II	II	Low	Moderate
33	Right	12+200	12+000	200	3a	II	-	II	I	II	II	Low	Low
34	Right	12+000	11+650	350	2	II	-	II	I	II	II	Low	Moderate
35	Right	11+650	11+450	200	3a	II	II	II	I	II	II	Low	Low
36	Right	11+450	11+200	250	2	II	II	I	I	II	I	High	High
37	Right	11+200	11+050	150	3a	II	II	II	I	II	II	Low	Low
38	Right	11+050	9+300	1750	2	II	II	I	I	II	I	Moderate	High
39	Right	9+300	9+100	200	3a	II	II	I	I	II	II	Low	Low
40	Right	9+100	7+000	2100	2	II	-	III	I	II	II	Low	Low
41	Right	7+000	6+000	1000	2	II	-	II	I	II	II	Low	Moderate
42	Right	6+000	4+200	2200	2	I	-	III	I	II	II	Low	Low
43	Right	4+200	3+200	1000	2	I	-	II	I	II	II	Low	Moderate
44	Right	3+200	3+100	100	3b	I	-	II	I	II	II	Low	Moderate
45	Right	3+100	2+400	700	2	I	-	II	I	II	II	Low	Moderate
46	Right	2+400	0+000	2400	2	I	-	III	I	II	II	Low	Moderate