

# Mitigation of the Belly River Landslide Using a Multidisciplinary Approach

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## ABSTRACT

The Belly River landslide, located adjacent to Highway 800 in the Blood Indian Reserve, posed an immediate risk to the highway. The landslide rapidly retrogressed as a result of river erosion and seasonal groundwater seepage discharge on the clay till slope. Protection of the highway, restoration of land for agricultural use, and development of a natural site appearance were key requirements identified by Alberta Transportation and the First Nations people. A team of geotechnical and hydrotechnical engineers, supported by environmental scientists and a bio-engineering consultant was assembled to design mitigation, obtain regulatory approval, and consult with stakeholders. Selected mitigation included geotechnical, hydrotechnical and bio-engineering components. Geotechnical engineering aspects of the remediation consisted of buttress fill construction to support the slope along with slope grading and drainage systems to control the groundwater. Hydrotechnical engineering components included channel realignment and bank armour. Bio-engineering techniques complemented the geotechnical and hydrotechnical designs. Deficiencies from a similar site repair were addressed in the Belly River design. The multidisciplinary approach yielded a successful design and is recommended for similar projects.

## RÉSUMÉ

Le glissement de terrain de la rivière Belly, situé près de la route 800 dans la réserve Blood Indian, posait un risque immédiat pour la chaussée. Ce glissement de terrain de nature rétrogressive a été causé par l'érosion des berges de la rivière et par la résurgence saisonnière des eaux souterraines dans la pente constituée de till argileux. Les principales exigences formulées par Transports Alberta et les Premières Nations pour les travaux incluent la protection de l'autoroute et la restauration du terrain à des fins agricoles tout en conservant un aspect naturel. Une équipe constituée d'ingénieurs en géotechnique et hydrotechnique, de scientifiques de l'environnement et d'un consultant en bio-ingénierie a été assemblée pour concevoir des mesures de restauration, obtenir l'approbation réglementaire et consulter les partis impliqués. La stratégie préconisée pour la restauration de la pente comporte des mesures de nature géotechnique, hydrotechnique et de bio- ingénierie. Les mesures géotechniques adoptées comprennent la construction d'un remblai en guise de contrefort, de même qu'un profilage de la pente et la mise en place d'un système de drainage pour le contrôle de l'eau souterraine. La partie ingénierie hydrotechnique inclus le réalignement de la rivière et le contrôle de l'érosion. Des techniques de bio-ingénierie ont été utilisées pour renforcer l'effet des mesures géotechniques et hydrotechniques adoptées. La conception a tenu compte des carences observées dans la restauration d'un site similaire à celui de la rivière Belly. L'approche multidisciplinaire adoptée a donné de bons résultats et son application est recommandée pour des projets similaires.

## 1 INTRODUCTION

The Belly River landslide site is located adjacent to Alberta Transportation's Highway 800 in the Blood Indian Reserve (Kainai Band), near Cardston in Southern Alberta, Canada. The site consisted of a landslide at a meander of the Belly River where the headscarp of the slide retrogressed towards the highway.

The Belly River has rapid flow that emanates from the nearby Rocky Mountains and is subject to large seasonal flow variations. The river channel at the site area was laterally mobile and in recent years the river had a high angle of attack at the site, which caused bank erosion. The undercut bank triggered instability of the 16 m high slope and presented a risk to the highway. Alberta Transportation (AT) contracted AMEC Environment & Infrastructure (AMEC) to design mitigative measures to protect the highway.

A team of geotechnical, hydrotechnical, environmental and bio-engineering specialists was assembled to design the mitigation. Several design options were prepared for consideration by the stakeholders and lessons learned from a similar project were applied. A weighted benefit analysis was used to select the best option. The final design included channel realignment and bank protection, a buttress fill and bio-engineering techniques. The multidisciplinary team provided a successful repair and demonstrated the value of using multiple techniques to repair this complex site.

Figure 1 illustrates the site location.

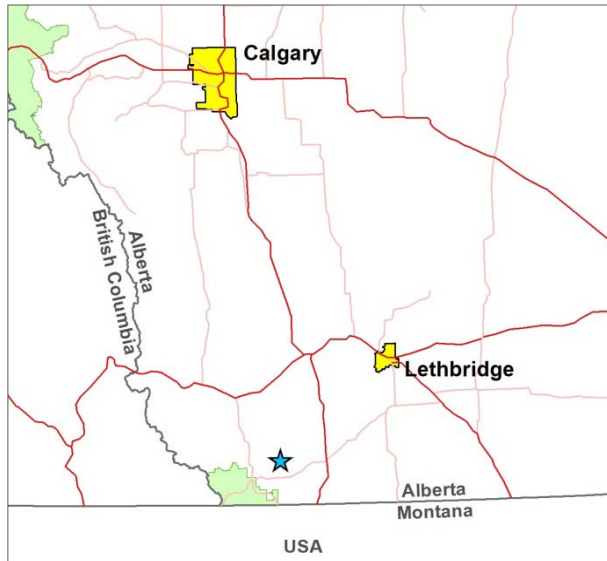


Figure 1. Site location.

## 2 INITIAL SITE ASSESSMENT

The site came to AT's attention in June 2009 after a significant increment of landslide retrogression towards the highway. AMEC undertook an emergency site assessment at AT's request.

The site area consisted of undulating grassland, used primarily for cattle grazing, with a 16 m deep incised river channel. The soil observed in the river valley was clay till, which was dry and stood vertical as 5 m high scarps in

the upper portion of the slope. The vertical scarps were likely due to over-consolidation, soil suction or possible light cementation, while the lower portion of the slope was wet and low-angled. The landslide was interpreted to be a complex slide mechanism triggered by river erosion.

The slope stood vertically when dry and protected from surface water by the grass vegetation. River erosion at the toe of the slope triggered metre-scale block topples, which in turn formed a colluvium mass on the lower slope. The blocks, then exposed to rain and groundwater seepage, weathered rapidly into a low-strength colluvium that was subject to rotational and flow landslides. River erosion continued to remove the colluvium mass, destabilized the slide mass and enabled further block topples at the slope crest. This cycle resulted in continued slope crest retrogression towards the highway, which apparently accelerated in the time frame around 2006 to 2009. At the time of the initial inspection in 2009, the headscarp of the slide was 12 m from the paved road surface but was not an immediate hazard to highway users.

The site was inspected again in May 2010. The headscarp had retrogressed significantly since June 2009 and was 5 to 6 m from the road surface along a 40 to 50 m length along the highway. The headscarp had intercepted the ditch invert, channelled surface water into the slide area and worsened the slope instability. Because the site was a hazard to vehicle safety, AT decided to proceed with mitigation to protect the highway. Refer to Figure 2 for an illustration of the site in 2010, and Figure 3 for an aerial image of the site in 2009.



Figure 2. Facing south at the area of main slide encroachment in May 2010. The highway embankment is visible at the left edge of the photo. Block topples and rotational or flow landslides are caused by river erosion and groundwater seepage.



Figure 3. Aerial image of the site area in 2009.

### 3 TEMPORARY MITIGATION AND 2010 MONITORING

Work to slow the landslide retrogression was initiated in May 2010. The near-vertical headscarp area was graded to a 1H:1V slope and launched soil nails were installed on a 1 m grid along the slope crest nearest the highway. Approximately 50 soil nails were installed to reduce block topples from the scarp. The ditch was also dammed upstream of the slide crest and a drainage pipe was installed to carry water beyond the slide area.

The site was inspected again in June 2010. The temporary remediation was observed to function well. High groundwater levels were indicated by seepage discharge approximately 2 m below ground surface, which was not observed during previous inspections. The seepage caused the vertical slope faces to collapse and flow and eroded the exposed soil. This observation emphasized the importance of seepage discharge management for any potential mitigation work.

### 4 STAKEHOLDERS AND REGULATORY APPROVAL

The project team began consultation with the First Nations and land occupant early in 2010, shortly after the temporary mitigation was installed. It was expected that the stakeholders' requirements for the project would be different than AT's and potentially incompatible. A Human Environment Specialist was assigned to the project at an early stage to serve as the stakeholder contact. Meetings were held at the site to identify concerns and communicate the plans in a culturally appropriate manner. Compensation for land use was required and the use of a specialist facilitated the process.

Following the initial stakeholder consultation, the archaeological, fisheries and vegetation assessments were completed. Since the regulatory process was expected to be potentially complex and slow, the required studies were performed early in the project to support the permit applications.

## 5 INVESTIGATION AND SITE UNDERSTANDING

The technical investigations were conducted early in the project after the stakeholder consultation was initiated.

### 5.1 Geotechnical Investigation

A geotechnical investigation was performed at the site in February 2011. Eight boreholes were advanced to depths of up to 26 m below ground surface along the length of the site and within the highway right-of-way. Slope inclinometers were installed in two of the boreholes to monitor for landslide movement and to provide post-construction monitoring of the highway. Vibrating wire piezometers were installed in the remaining six boreholes to determine the groundwater conditions.

Low-plastic clay till (basal till) was encountered in all boreholes to a depth of 16 m. The till was predominantly silt by grain size and was stiff to very stiff. A glaciolacustrine silt and clay, or possibly a water-sorted till unit, was encountered below 16 m to over 26 m depth. The piezometers measured hydrostatic water pressure, varying from 2 to 8 m deep seasonally, but typically below 6 m depth. The slope inclinometers did not detect landslide movement as was expected based on the interpreted slide mechanism.

### 5.2 Hydrotechnical Investigation

Historical aerial photographs were used to study the river mobility at the site. Approximately 70 m of channel migration occurred in 57 years at the landslide area, which indicated a highly mobile channel. Flood frequency analysis found that the 1:100 year flood event was 420 m<sup>3</sup>/s, with typical July flows of about 10 m<sup>3</sup>/s. The flood elevation and flow rates for the 1:2 year and 1:100 year flood events were selected for design of the various components of the mitigation.

### 5.3 Experience at a Similar Site

The project team was fortunate to have completed repair work at a similar site a few years before the Belly River site was identified. The Willow Creek site on Highway 2 also had a complex slide mechanism in similar soil with block topples and rotational movement driven by river erosion, much like the Belly River site. Mitigation work installed at Willow Creek included riverbank armour with Longitudinal Peaked Stone Toe Protection (LPSTP) and redirective vanes, slide mass grading, soil nails, and brush layering. Some of the components of the repair worked well; however, others did not function as intended. The slide was stabilized but with some continued headscarp retrogression. The mitigation was considered to be effective but with noted deficiencies.

A key finding from the Willow Creek repair was the importance of groundwater seepage control. Seepage that reached ground surface on the clay till slope (silt by

grain size) caused considerable loss of soil strength and resulted in the collapse of the vertical slope faces and flows on the graded slope. The flows, in turn, disturbed vegetation and erosion protection techniques. Launched soil nails were also found to be ineffective when installed below the seasonal high groundwater level, and were only useful for short-term stabilization unless they were in dry soil at all times throughout the year. Seepage caused the soil to erode around the nails. Slope benches were an effective technique to manage the drainage and minimize earth flows.

The bio-engineering techniques applied at Willow Creek were considered to be a trial application, and several types were used to determine the best methods for future projects. Brush layering, using live willow cuttings, was installed along the riverbank to provide natural erosion resistance. The willows did not survive, likely due to the willows being planted above the low-water level. Native grasses were planted using multiple techniques and Flexible Growth Medium (FGM) was the most successful.

The hydrotechnical design components, including bank armouring using LPSTP and vanes, were successful.

## 6 MITIGATIVE OPTIONS

The design of the mitigation was an iterative process which required teamwork amongst the technical disciplines. The design team generated requirements for a successful repair in consultation with the stakeholders. The preliminary design and consultation process was conducted through most of 2011.

### 6.1 Mitigation Requirements

Mitigation requirements were identified through consultation with AT and the stakeholders. AT required that the highway be protected from landslide retrogression and that the repair be easily constructible, using locally available fill if required.

The Kanai Band requested that any mitigation work maintain a natural appearance and use culturally appropriate plant species selected at their discretion. They also requested involvement throughout the project cycle.

The land occupant required that access for livestock be provided to enable grazing between pastures adjacent to the slide area.

### 6.2 Preliminary Mitigation Options

Three preliminary mitigation designs were prepared for review with AT. Figure 4 presents the designs.

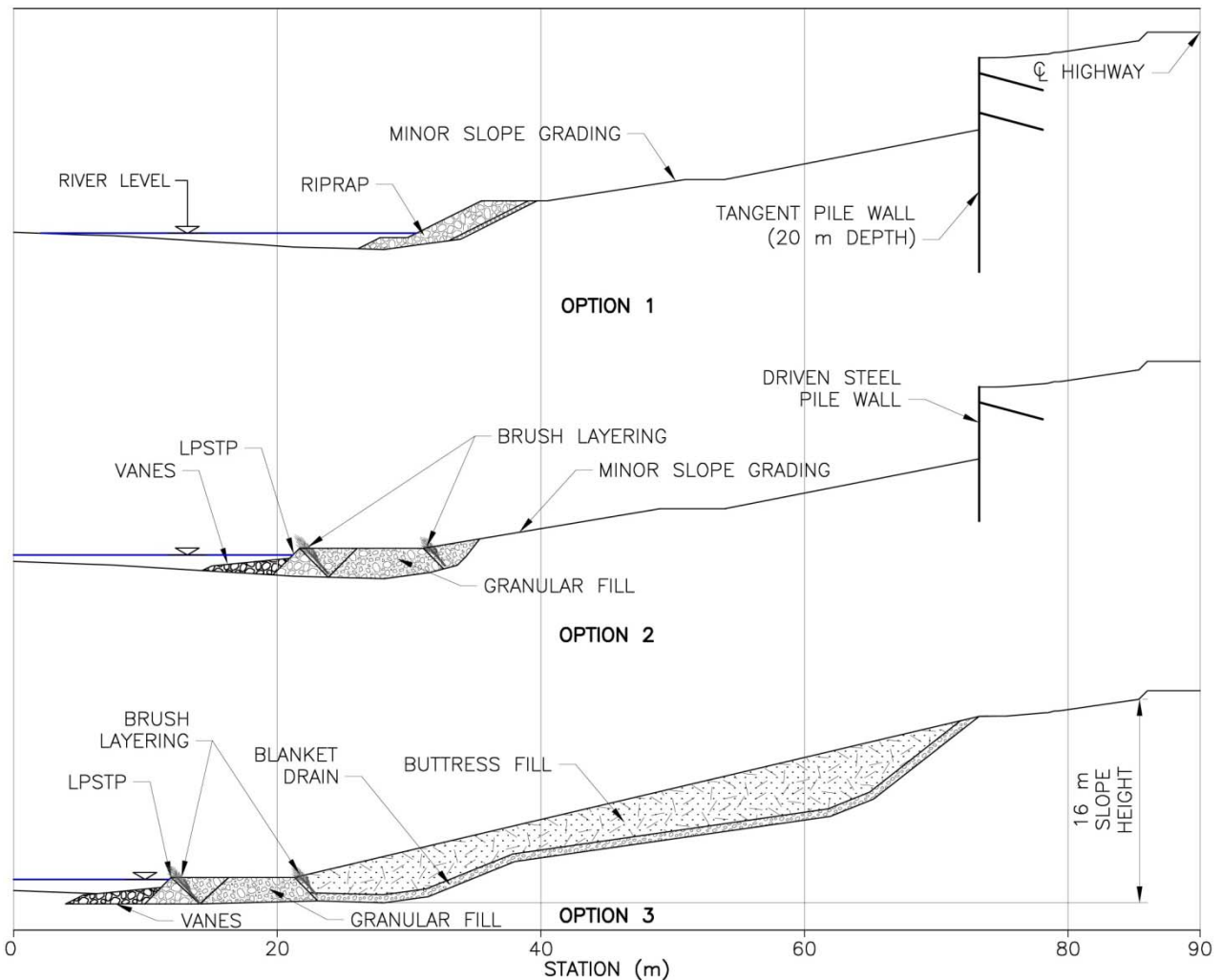


Figure 4. Cross-section of the preliminary mitigation options.

### 6.2.1 Option 1 – Maintain 2011 River Alignment

Option 1 included a relatively large, tangent, cast-in-place pile wall to 20 m depth along the highway right-of-way to support the highway as the slide mass continued to deform. The colluvium was to be graded to improve drainage and vegetation established to provide minor stability improvement of the slide mass. Rip-rap bank protection was to be installed along the existing channel alignment to protect against continued erosion. The design was considered a primarily geotechnical repair, with minimal input from the other disciplines. The design provided a high level of certainty that the highway would be protected but at a cost of roughly \$5.2 Million, which was higher than the other options. The design involved minimal interaction with the river; therefore, it could be constructed if regulatory approval was not obtained for work in the river. Poor aesthetics due to the exposed pile wall and high cost were the main disadvantages.

### 6.2.2 Option 2A and 2B – Intermediate River Alignment

Option 2A included a 10 m deep, driven, steel pile wall to support the headscarp near the highway. The shallow pile wall required support from the slide mass below, which was to be achieved by drainage improvement of the slide mass with trench drains and bio-engineering techniques to consume water, and an interceptor trench upslope of the headscarp. In addition, the channel was to be shifted 20 m into the river and armoured by LPSTP and redirective vanes. The design was multidisciplinary with contributions from each component required for the success of the entire design. The cost was estimated to be \$2.9 Million.

A variation of this design, Option 2B, was also considered and included a buttress fill at a 4H:1V slope to replace the pile wall. This option had approximately the same cost as Option 2A and was easier to construct but had higher uncertainty of slope stability until evaluation of the borrow source for the buttress fill could be completed. For preliminary purposes, it was assumed that fill would be imported if required. Both options had relatively low

cost and were simple to build but required encroachment into the river with regulatory approval.

### 6.2.3 Option 3 – Restore 1995 River Alignment

Option 3 included a 30 m encroachment into the river channel to restore the 1995 channel alignment and bank armour with LPSTP and vanes. A buttress fill was to be constructed at 5H:1V to support the landslide headscarp. The estimated cost was \$2.8 Million. Although the cost and constructability were advantageous, the encroachment into the river was perceived to be a significant disadvantage due to the major channel realignment.

### 6.3 Selection of Mitigation

Selection of the most suitable mitigative option was complex due to multiple evaluation criteria. A weighted benefit system was used to guide the process. The evaluation criteria included technical suitability, constructability, environmental concerns, landowner considerations and cost. The technical suitability considered how well the mitigation stabilized the slide. The environmental concern criteria included anticipated regulatory approval difficulties as well as the final condition of the site and river.

Each mitigative option was assigned a score from 1 to 3 for the evaluation criteria, which corresponded to a rating of low to high benefit, respectively. A low rating meant that the scenario offered little benefit and possibly had negative implications; moderate meant that the option did not offer significant advantages or disadvantages compared to the other scenarios; high benefit had definite advantages over others. Refer to Table 1 for the ratings for each option.

Weightings were assigned to each criteria in consultation with AT, as indicated by the percentages under each heading in Table 1. A total weighted score was obtained by multiplying the score by the weighting for each option and summing for all criteria. The score for each option is listed in Table 2.

Option 2B, which involved a shift of the river to an intermediate alignment and construction of a buttress fill, was determined to be the best option and was selected for construction. The cost for this option included the use of imported fill, which was a significant portion of the cost. The moderate encroachment into the river allowed the construction of a stable buttress fill and created favourable flow conditions for the river. Option 2B was also relatively simple to design and construct, and in addition it was cost-effective, accommodated livestock access and maintained a fairly natural site appearance.

Table 1. Mitigative Option Benefit Analysis

Option	Technical Suitability (35%)	Constructability (20%)	Environmental Considerations (10%)	Land Occupant Considerations (10%)	Capital Cost (25%)
1	Moderate	Low	Moderate	Moderate	Low
2A	Moderate	Moderate	Moderate	Moderate	Moderate
2B	Moderate	High	Moderate	Moderate	Moderate
3	Moderate	Moderate	Low	Moderate	Moderate

Table 2. Mitigative Option Weighted Score

Option	Total Weighted Score
1	1.6
2A	2.0
2B	2.2
3	1.9

## 7 DESIGN

The final design of Option 2B, prepared in early 2012, can be divided into hydrotechnical, geotechnical and bio-engineering components. These are described in further detail in the following sections.

### 7.1 Geotechnical Components

The primary component of the geotechnical design was a 4H:1V buttress fill intended to stabilize the landslide area and support the highway. Ease of construction was important. All aspects of the geotechnical design were intended to be easily achieved to allow rapid construction.

Stability analysis was performed with assumed reasonably conservative strength parameters for the fill. The factor of safety (FoS) for global stability was 1.5 for an effective friction angle of 25 degrees, while the FoS for a 20 degree effective friction angle soil was 1.2, which indicated that the design would likely remain serviceable even if the borrow source was inadequate. Good drainage of the buttress fill was required to maintain adequate stability.

The preliminary design noted that imported fill might be required if the borrow source at site did not meet the 25 degree effective friction angle requirement. Subsequent tests of a borrow source on site proved that the local fill was suitable for construction of the 4H:1V buttress. This resulted in significant cost-savings over the initial estimate.

Prior to placement of the buttress fill, the slide mass was graded to a minimum of 2 percent to promote drainage towards the river with light compaction from tracked equipment travel.

A granular blanket drain was constructed on the graded slide mass along the entire slide area from the slope crest to the riverbank armour. The intent was to convey the seasonally high groundwater seepage and

drain the buttress fill. The blanket drain intercepted the granular fill and bank armour at river level, which served as the drain outlet. The drain consisted of a 500 mm thick layer of AT Designation 6 – Class 80 pit run gravel, separated from the native soil and buttress fill by non-woven geotextile. The design satisfied permeability and filtration requirements and was intended to be simple to construct on the potentially soft slide mass surface.

A 150 mm diameter, perforated, flexible drainage pipe was installed in the drainage blanket immediately above the 1:100 year flood level through the slide area, with outlets to the slope face. The drainage pipe system provided an outlet for the blanket drain during floods, and a visual means to monitor for blockage of the drain outlet. Vibrating wire piezometers were also installed at the base of the blanket drain at four locations to monitor for drain blockage, with all piezometers terminated at an easily accessible junction box at the highway right-of-way.

The buttress fill was constructed along an approximately 100 m wide portion of the slide at the area of main encroachment. To improve ease of construction, relatively low compaction was specified by tracked construction equipment. A specification for the compaction method with periodic density checks was recommended. The buttress fill was designed as a benched slope, with the bench platforms nearly flat with 500 mm thick topsoil to hold moisture for vegetation. An erosion resistant drainage channel was included to intercept surficial flow and overflow from the bench platforms. One of the benches was aligned diagonally along the slope from the crest to river level, with fencing on both sides to provide livestock access through the site.

## 7.2 Hydrotechnical Components

The hydrotechnical works included riverbank erosion protection along the entire 210 m length of the landslide area with LPSTP and redirectional vanes. The bank armour was installed along an intermediate channel alignment that encroached into the river by approximately 20 m. Granular fill was placed in the river to restore the channel alignment and provide construction access.

LPSTP is a free-standing rip-rap structure that reduces encroachment compared to traditional rip-rap because it can be constructed steeper and does not require a key-in at the toe. It also allows the incorporation of live willow plantings behind the rip-rap, which were part of the bio-engineering strategy. The LPSTP was built to the elevation of the 1:2 year return period peak discharge.

Vanes are redirective structures constructed from rock fill that project upstream into the channel flow and dip gently from the top of the LPSTP to stream bed elevation. They alter flow direction, induce deposition and reduce flow velocity along the bank. The applicability of redirective structures depends greatly on the stream type and configuration, but they were judged to be well-suited for the Belly River. Sediment deposition adjacent to the vanes allows future riparian plantings to be placed in order to promote stabilization of the area in concert with improved fish habitat. Vanes also result in the thalweg (deepest part of the channel) being shifted away from the stream bank towards the middle of the channel. Pools were also excavated at the tip of the vanes for fish habitat improvement.

## 7.3 Bio-Engineering Components

Bio-engineering components were included to complement the hydrotechnical and geotechnical designs. Brush layering, which uses live willow cuttings placed along the upslope side of the LPSTP, was used to provide natural erosion protection and enhancement of the habitat along the shore, both on land and in the water. Live pole plantings were included near the shoreline to create natural bank vegetation conditions.

A combination of native trees, shrubs, and grasses were planted on the slope to improve the erosion resistance of the buttress fill and disturbed soils with their root systems. Containerized plantings were used on the benched slope platforms and FGM with a native seed mix was used across the site. A rolled erosion control product was installed at areas with high erosion susceptibility.

Refer to Figures 5 and 6 for a cross-section and site plan of the final design.

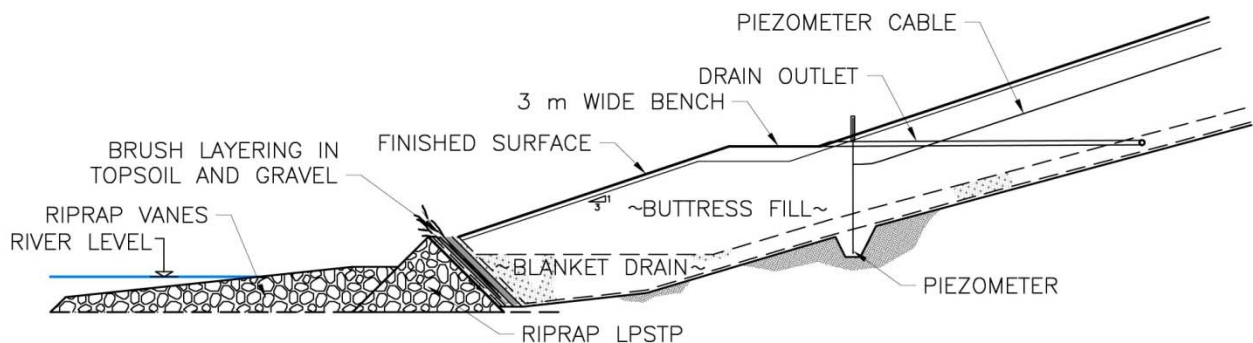


Figure 5. Cross-section of the mitigation design at the toe of the slope showing the main hydrotechnical and geotechnical design components.

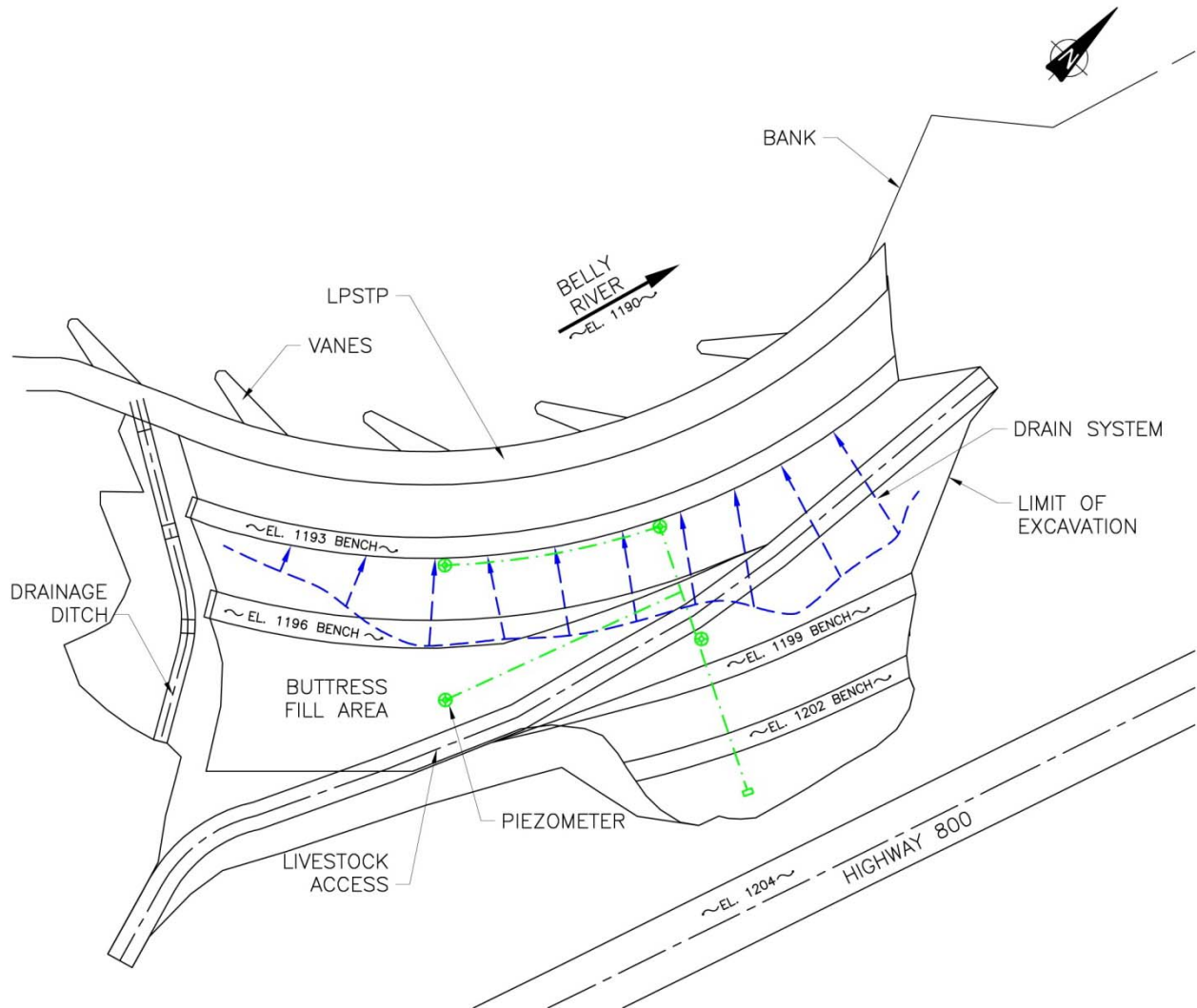


Figure 6. Site plan of the mitigation design showing the main design components.

#### 7.4 Multidisciplinary Approach Issues

Use of a multidisciplinary design necessitated collaboration through the design process. Some components required compromises from other disciplines, while some created benefits.

The most critical compromise was the channel alignment, which controlled the geometry of the buttress fill. The alignment was selected early in the design before strength parameters for the buttress fill were known. This required the use of assumed design parameters for the fill, which were later determined to be conservative and resulted in a larger buttress than would have been required if channel alignment was not considered.

Benefits were achieved when multiple design components complemented each other. The use of the granular fill and LPSTP along the riverbank as an outlet for the blanket drain is an example. Similarly, slope

benches were installed to reduce erosion but were also beneficial for plantings. The benches were covered with a thick topsoil and mulch layer to retain moisture for the plantings. The amount of moisture to retain was a compromise between the bio-engineering and slope stability disciplines.

Although the multidisciplinary approach was challenging, the benefit was demonstrated by a design that met the stakeholder requirements and was constructed at a reasonable cost.

## 8 CONSTRUCTION

In-stream construction of the hydrotechnical components began in August 2012 when the river level was low and to comply with fish protection restrictions. The worksite was



isolated by water-filled dams while the granular access platform was built and the bank protection was installed.

The remaining earthwork at the slide area was constructed later into the fall when the slide mass was driest, with all major work completed by November. Trafficability of the slide mass was better than expected, and light, tracked equipment was able to grade the slide mass and construct the blanket drain continuously, rather than incrementally as the buttress fill was placed from the river level upwards, as was initially planned.

Willow cuttings were harvested and planted in mid-October, while the remaining planting and seeding was conducted in the spring of 2013.

The mitigation work functioned well through 2013 with no deformation of the slide mass, highway or riverbank, and no significant erosion. The vegetation growth was quite aggressive. All deficiencies noted from the Willow Creek mitigation were successfully addressed.

The actual cost of the mitigation was \$1.7 Million, which was significantly lower than anticipated; mostly due to the use of a local borrow source, trafficable slide mass and design optimizations achieved during the final design.

Refer to Figure 7 for a post-construction photograph of the site from August 2013.



Figure 7. Facing north at the main buttress fill area in August 2013, showing the benched fill slope and livestock access path with vegetation becoming well-established.

## 9 CONCLUSIONS

The Belly River mitigation project was considered to be a success by all stakeholders. The mitigation criteria were identified early in the project cycle and the team selected a design that met these requirements with the aid of a weighted benefit analysis. The project was completed at a relatively low cost and in a reasonable time. The highway was protected from landslide damage, land was restored for agricultural use, and a natural site appearance was created.

The project demonstrated the value of a multidisciplinary approach. It would have been difficult or impossible for a single discipline to have met all the mitigation criteria. Additionally, some of the design components complemented each other, such as the use of the bank armour as a drain outlet and slope benches for plantings.

Lessons learned from a similar site repair, which did not perform as well, were incorporated in the Belly River design and demonstrated that case studies that document failures or deficiencies are important. The importance of

seepage discharge control and drainage, as well as the effective use of bio-engineering techniques were the key findings. It is hoped that this case study will be useful for the design of repair works at similar sites.

## ACKNOWLEDGEMENTS

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## REFERENCES

AMEC Environment & Infrastructure, 2012. Hwy 800:02 – Belly River Site, Design of Streambank Protection and Slope Stabilization. File No. LT106510.