Advances in the Planning, Design and Construction of a Major Pipeline Project in a Geohazards-Intensive Area.

TRANSMOUNTAIN

Indigenous Acknowledgement

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Agenda

INTRODUCTION

MODULE 1: Regulatory Conditions and Filings

MODULE 2: Advanced Design Methods

MODULE 3: Construction Techniques

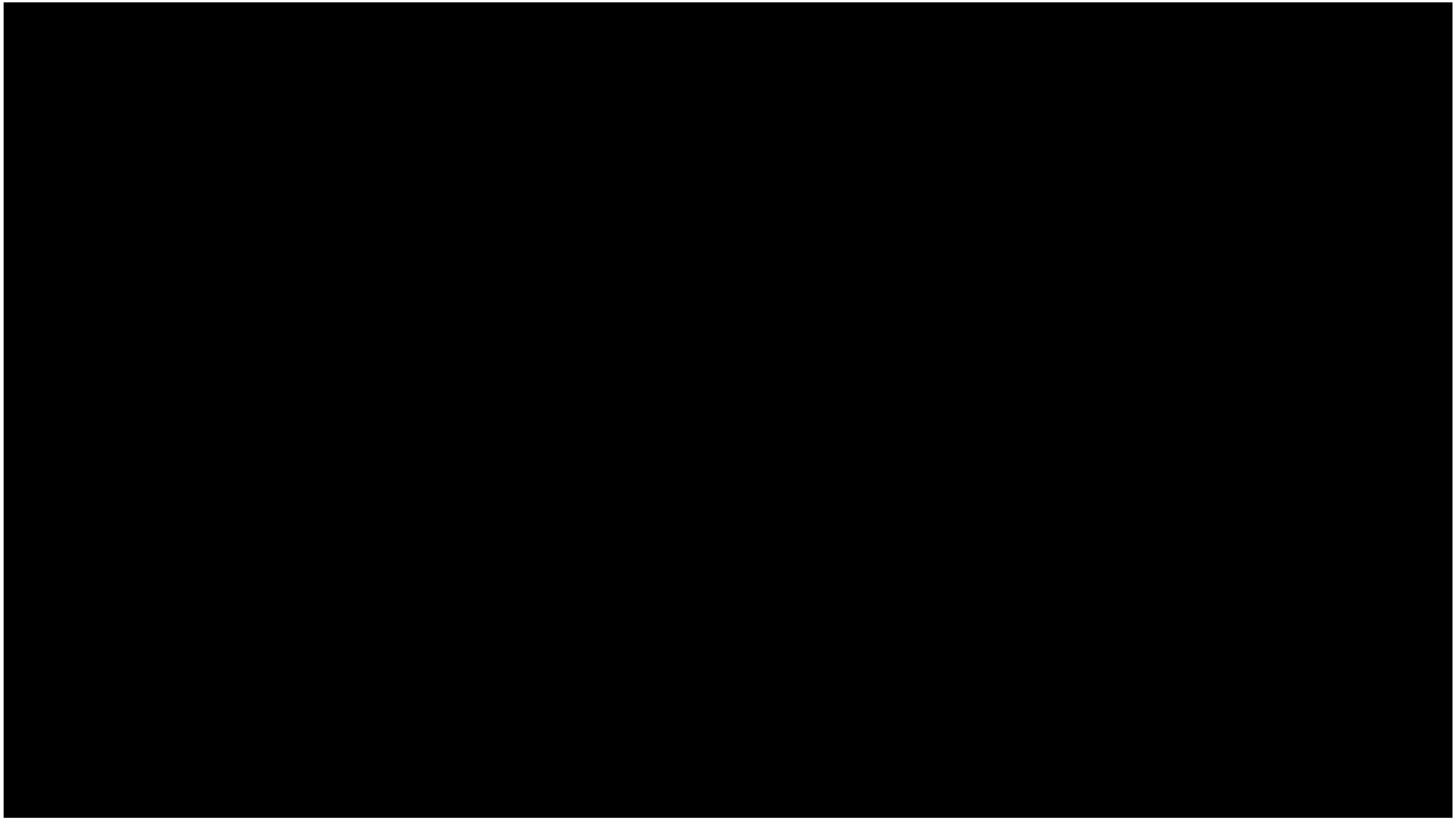
MODULE 4: Geohazards Management


Trans Mountain Expansion Project
CANADA
Vancouver
UNITED STATES
Toronto
Chicago
New York
San Francisco
Los Angeles
North Atlantic Ocean
MÉXICO
Mexico City
VENEZUELA
Bogotá
PERÚ
2,000 km
1,000 mi

Trans Mountain Line 1

- Construction began in 1952 following federal charter approval in March 1951, and took just over 30 months using multiple crews along its 1,150 km route across rugged terrain—including the Rocky Mountains and sensitive wetlands
- The pipeline entered service in October 1953, carrying approximately 150,000 barrels per day from Edmonton, Alberta to Burnaby, British Columbia, via four pump stations and a marine dock terminal

Trans Mountain Expansion Project



Trans Mountain Expansion Project

- The original Trans Mountain Pipeline, built in 1953, continues to operate safely.
- On June 18, 2019, the Government of Canada approved the Trans Mountain Expansion Project (TMEP), subject to 156 conditions enforced by the Canada Energy Regulator (CER).
- Key facts about the expansion:
  - 988 km of new pipeline constructed.
  - 74% of the route used the existing right-of-way.
  - 16% followed other linear infrastructure (telecommunications, hydro, highways).
  - 11% required new right-of-way.
  - 193 km of pipeline was reactivated.
- Unanticipated Challenges:
  - COVID
  - Major forest fires
  - Atmospheric river

Module 1: Planning and Regulatory Commitments

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Agenda

TRANS MOUNTAIN EXPANSION PROJECT

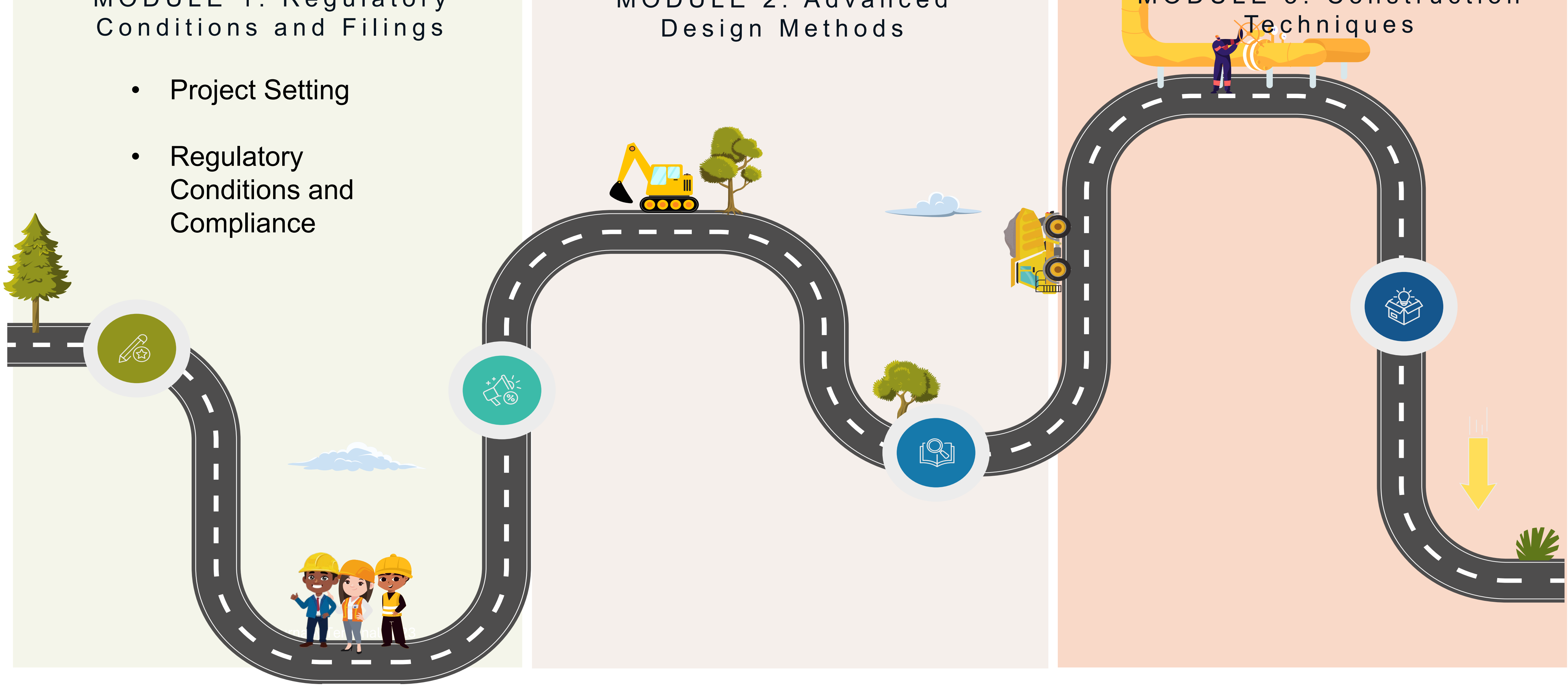
Pipeline Lifecycle Unveiled: Managing Pipeline Geohazards from Design to Operations

MODULE 1: Regulatory Conditions and Filings

- Project Setting
- Regulatory Conditions and Compliance

MODULE 2: Advanced Design Methods

MODULE 3: Construction Techniques



Trans Mountain Expansion Project

- Social and Economic Contributions:
  - >108 million hours worked during the project.
  - 35,500 individuals hired to support construction.
  - >20,000 days of Indigenous Monitoring work.
  - >$6 billion awarded in indigenous contracts.
  - >80,000 shovel tests, as part of an archaeological program, in areas identified as having potential to support heritage resources.
  - 1,181 km of fiber optic cable installed along the pipeline to support leak detection.

TMEP at a Glance

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199 permitted highway crossings

50 permitted railroad crossings

1,269 permitted road crossings

46 km (5%) steep slopes

101 km (10%) urban pipelines

TMEP at a Glance

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30 km of well point dewatering for high water table conditions

434 sites identified by TMEP terrain mapping based on geohazards inventory

0.2 to 1.1 water course crossings per kilometer

214 temporary bridges

73 km of trench blasting

TMEP at a Glance

584,495 m3 of grade rock blasting

632,495 m3 of metal leaching /acid rock drainage material disposed at licensed landfill

75 major trenchless crossings

557 Bored trenchless crossings

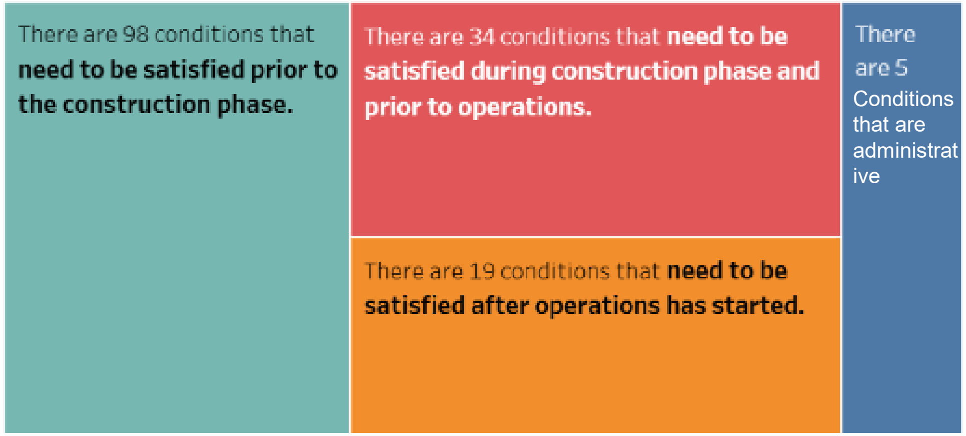
125 km (13%) of stove pipe construction

Trans Mountain Expansion Project

Regulatory Conditions and Compliance

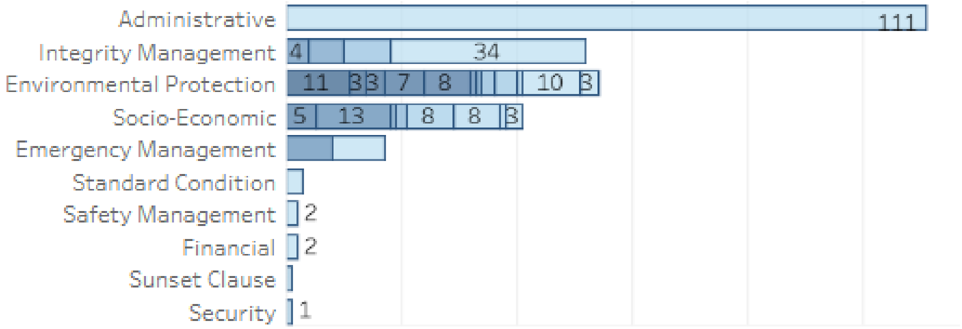
Conditions by Lifecycle Stage

Click on a lifecycle stage to filter the conditions list.



Conditions By Theme, Sub-Theme

Click on a theme to filter the conditions list.



- The Canada Energy Regulator (CER) issued and enforced several conditions directly **applicable or related to geotechnical and geohazards management** considerations.

- These conditions are categorized in terms of their implementation windows as follows:
  - Pre-construction:
  - Geotechnical/Geohazards Related (Conditions 16, 51, 66, 67, 68 and 69)
  - Pipeline Design Related (Conditions 15, 17, 70 and 104)
  - Environmental Protection Related (C72)
  - During Construction (C106)
  - Post-construction (C147)

Geotechnical Pre-Construction Regulatory Conditions

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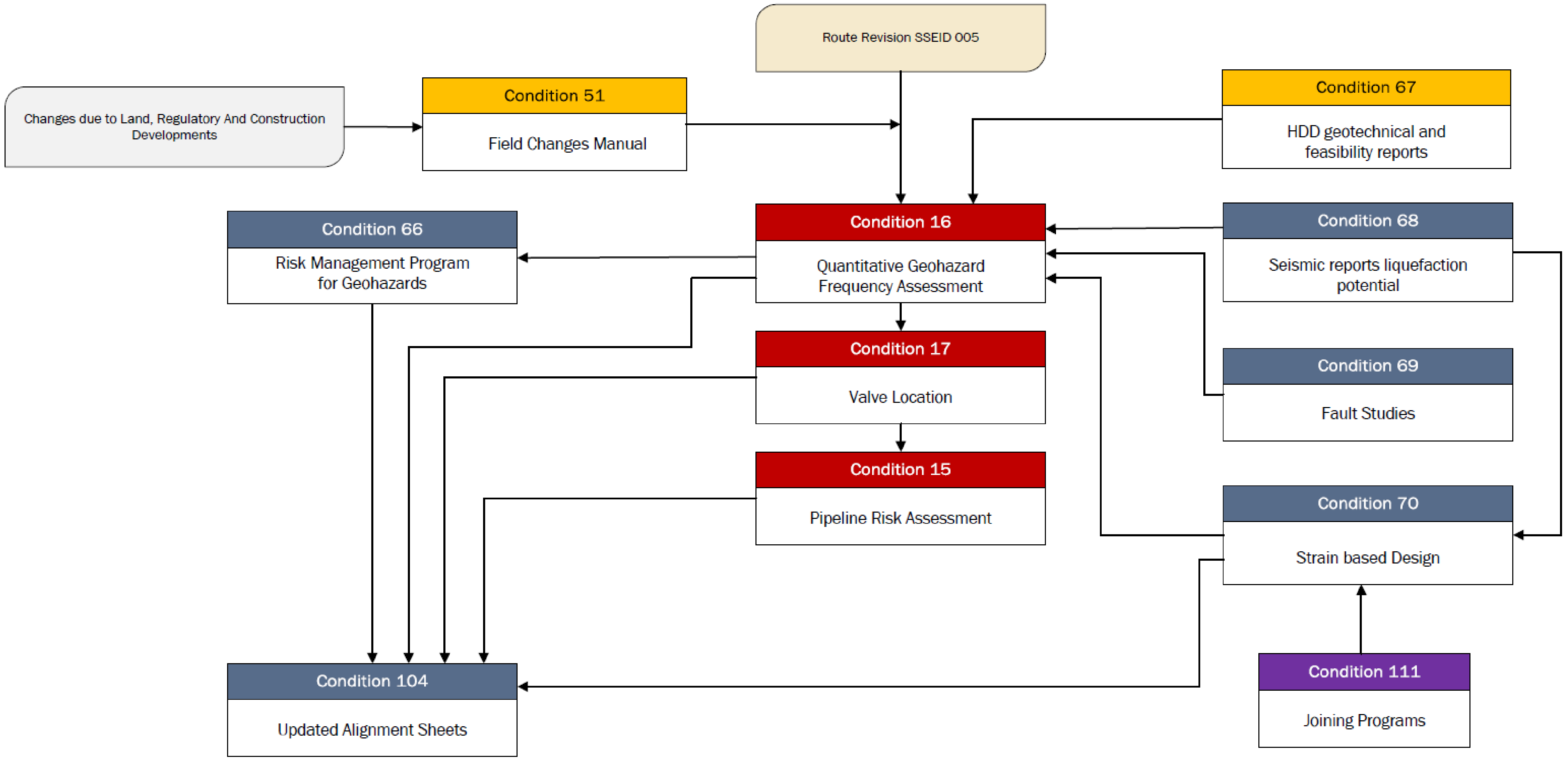


C16: Quantitative Geohazard Frequency Assessment

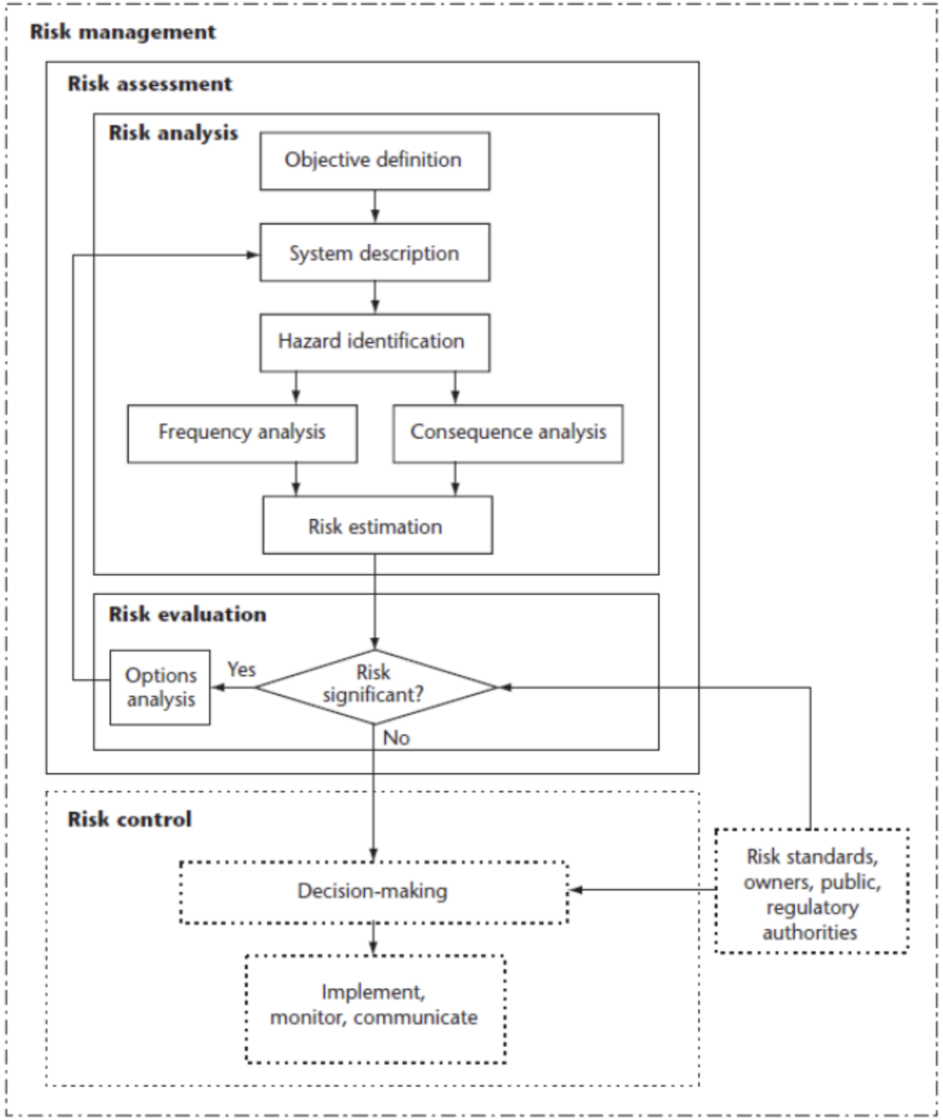


Figure 1. Risk Management Framework (from CSA Z662).

NEB Condition Requirement:

Trans Mountain must provide in the assessment a plan to manage and mitigate geohazards at any location where the FLoC value is greater than 10^{-5} events per year to reduce the level to as low as reasonably practicable (ALARP), including a detailed explanation of how the ALARP level has been attained at each location

C16: Quantitative Geohazard Frequency Assessment

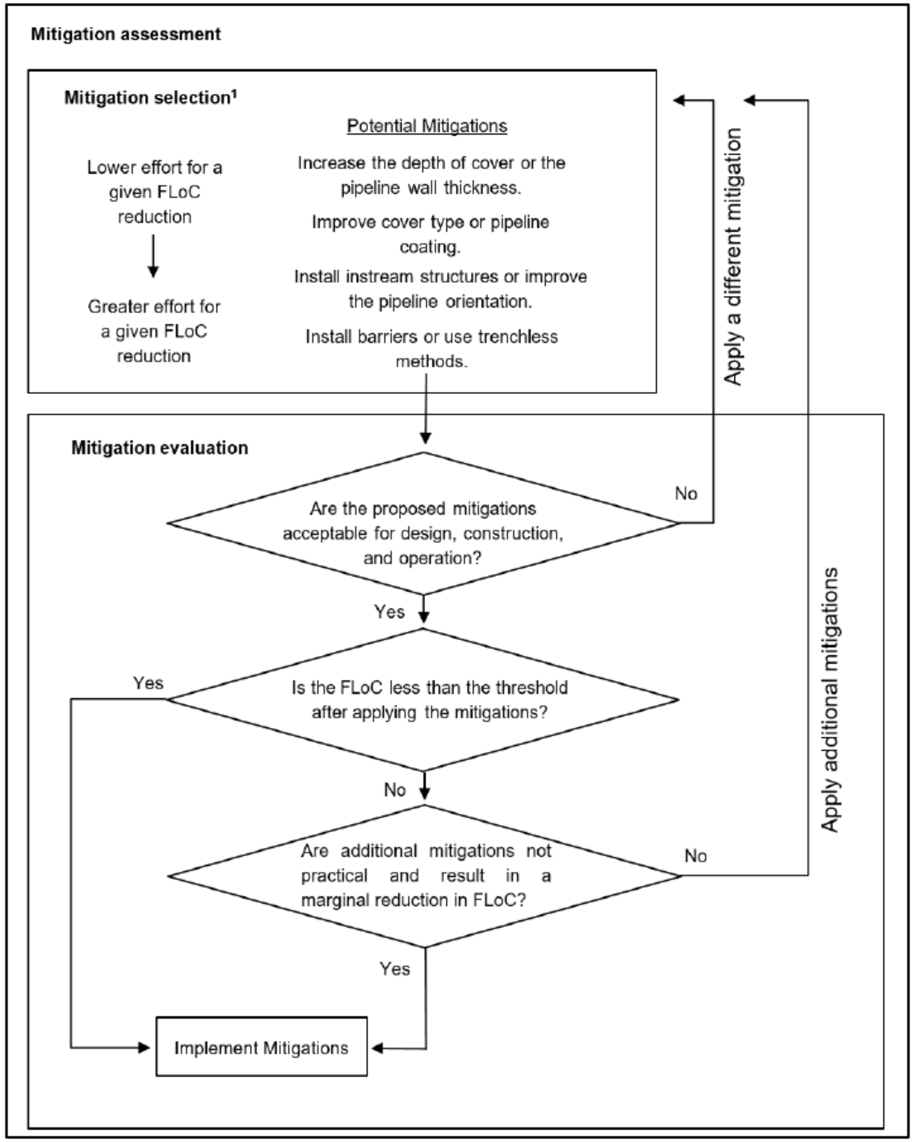


Figure 2. Mitigation assessment flow chart.

The FLoC from a geohazard in terms of events per year was calculated for specific locations along the pipeline (denoted with the subscript, "(i)") as follows:

$$FLoC(i) = I(i) \times F(i) \times SH(i) \times SV(i) \times V(i) \times M(i)$$

I(i) is the occurrence factor

F(i) is the frequency

SH(i) is the horizontal spatial probability

Sv(i) is the vertical spatial probability

V(i) is the vulnerability

M(i) is a mitigation reduction factor

The estimates for FLoC were compared against a 1×10^{-5} threshold to evaluate if the pipeline design met this geohazard frequency objective. Sites where FLoC exceeded the 1×10^{-5} geohazard threshold were further evaluated to identify if the pipeline design is "as low as reasonably practicable" (ALARP).

C16: Quantitative Geohazard Frequency Assessment

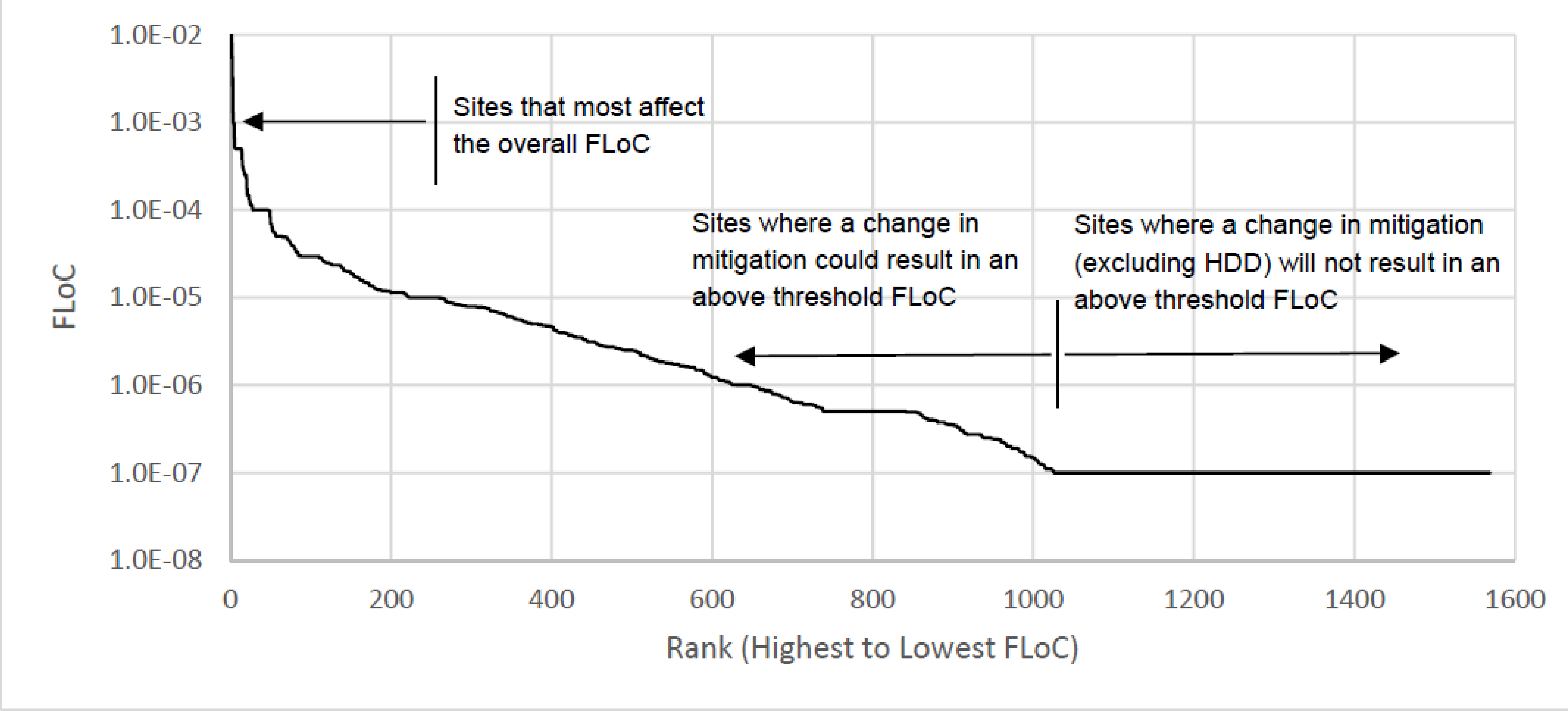
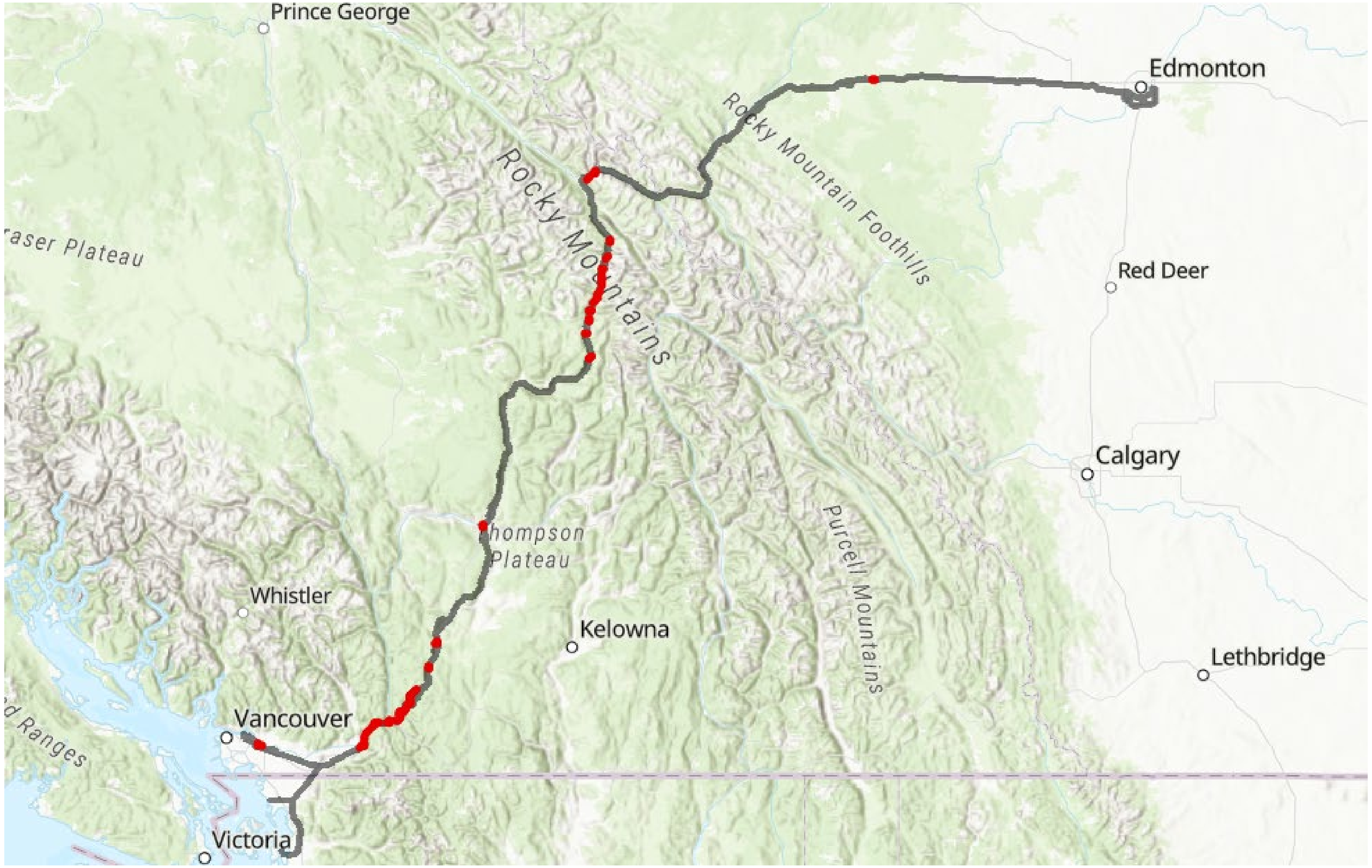


Figure 1-1. **Cumulative ranking of sites from highest to lowest FloC. The minimum FloC estimate was set to 1 × 10^{-7}.**

C16: Quantitative Geohazard Frequency Assessment



Sections with FLoC values exceeding 1x10-5

Summary Results:

- The number of geohazard segments with pre-mitigation FLoC estimates exceeding the 1×10^{-5} threshold is 222 (14% of all sites)
- The application of mitigation designs in the post-mitigated assessment has reduced the number of segments that are greater than 1×10^{-5} to 43 (2.7% of all sites)

C51: Field Changes Manual

NEB/CER Condition Requirement:

Trans Mountain must file with the NEB, for approval, ... a field changes manual for geohazards mitigations. This manual must include:

- Decision criteria for implementing mitigation for any geohazards identified during construction
- Specific criteria for implementing changes to the design, grading, special materials, protective structures, burial depth, installation procedures, erosion mitigation measures and monitoring
- Details regarding the required qualifications of the field staff that will implement the manual

C51: Field Changes Manual

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1. ESTABLISH
- Conduct regular site meetings with owner and contractor prior to and during construction
- Establish a collaborative approach with the contractor and owner during construction
- Develop a clear understanding of geohazards, geotechnical issues and design/mitigation elements by all construction participants

2. INSPECT & OBSERVE
- Complete a site inspection prior to construction and observe geotechnical conditions periodically during construction
- Confirm observed geohazards have been characterized in the geohazards inventory
- Confirm that observed geotechnical conditions are consistent with expected baseline geotechnical conditions

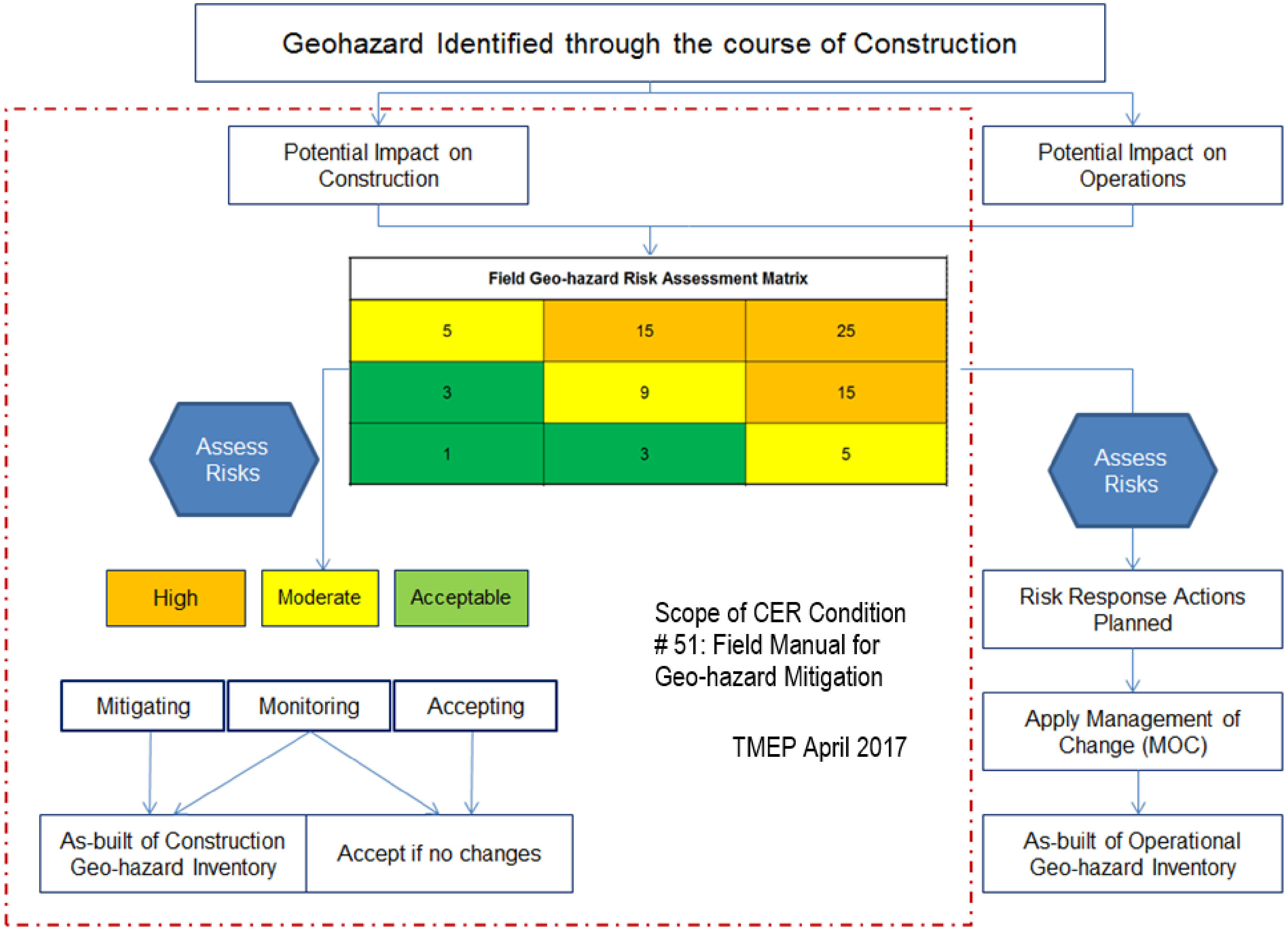
YES

NO

3. ASSESS & REVISE
- Assess observed new or different geotechnical conditions
- Revise the geohazard inventory and anticipated site geotechnical conditions
- Assess potential environmental triggers and thresholds that could impact observed conditions

4. SELECT & IMPLEMENT
- Appropriate construction mitigation from mitigation toolbox
- Communicate selected construction mitigation and any field changes to contractor and owner
- Monitor implementation of the selected mitigation

C51: Field Changes Manual



Summary Results:

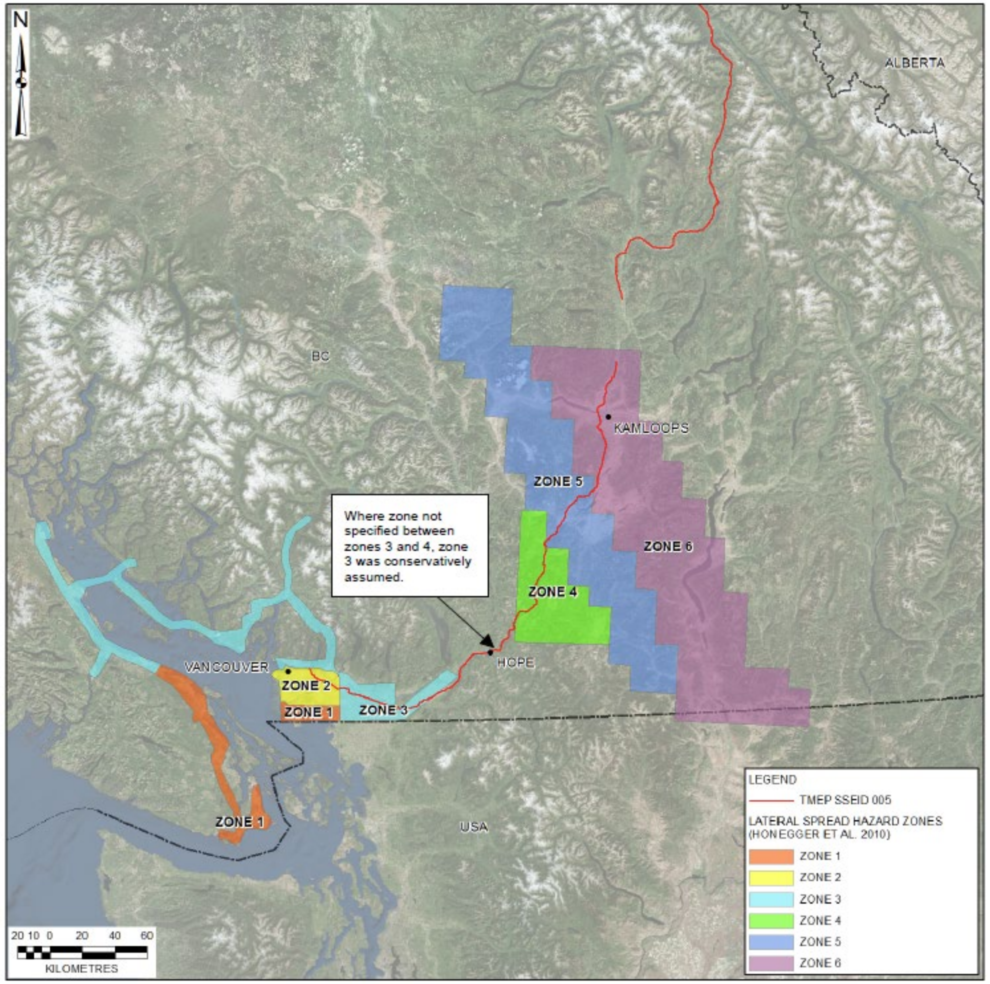
- Decision process was implemented during construction
- Field changes reported to CER as part of Condition 106 (monthly construction report)

C68: Field Changes Manual

Regulator's Condition Requirement:

Trans Mountain must file with the NEB … a final report that identifies all sites along the Project that have "Very High", "High" and "Moderate" liquefaction-triggered ground movement potential, and that describes how the potential for liquefaction-triggered movement will be mitigated at each site

C68: Liquefaction Potential



B) Approximate geographic extent of lateral spread hazard zones 1 through 6 (from Honegger et al. 2010), with TMEP proposed alignment.

- The seismic liquefaction and lateral spreading hazard assessment was performed in a staged approach starting with desktop remote sensing-based study followed by detailed geotechnical subsurface investigations at select sites including SPT, CPT and advanced lab testing.
- Liquefaction potential was assessed at test sites for the common design seismic hazard of 1:2,475 Annual Exceedance Probability (which refers to ground motion that has a 2% probability of being exceeded in a 50-year period)
- The estimated lateral displacements at each site were used to provide insight on the level of the anticipated imposed strains on the pipeline.
- The procedure used to assess liquefaction triggering followed that outlined in the Earthquake Engineering Research Institute (EERI) Monograph No. 12 by Idriss and Boulanger (2008) followed by the recommendations outlined in "Greater Vancouver Liquefaction Task Force Report (GVLTF 2007). Work reported by Honneger et. al. (2006) provided additional guidance.

C68: Summary Results

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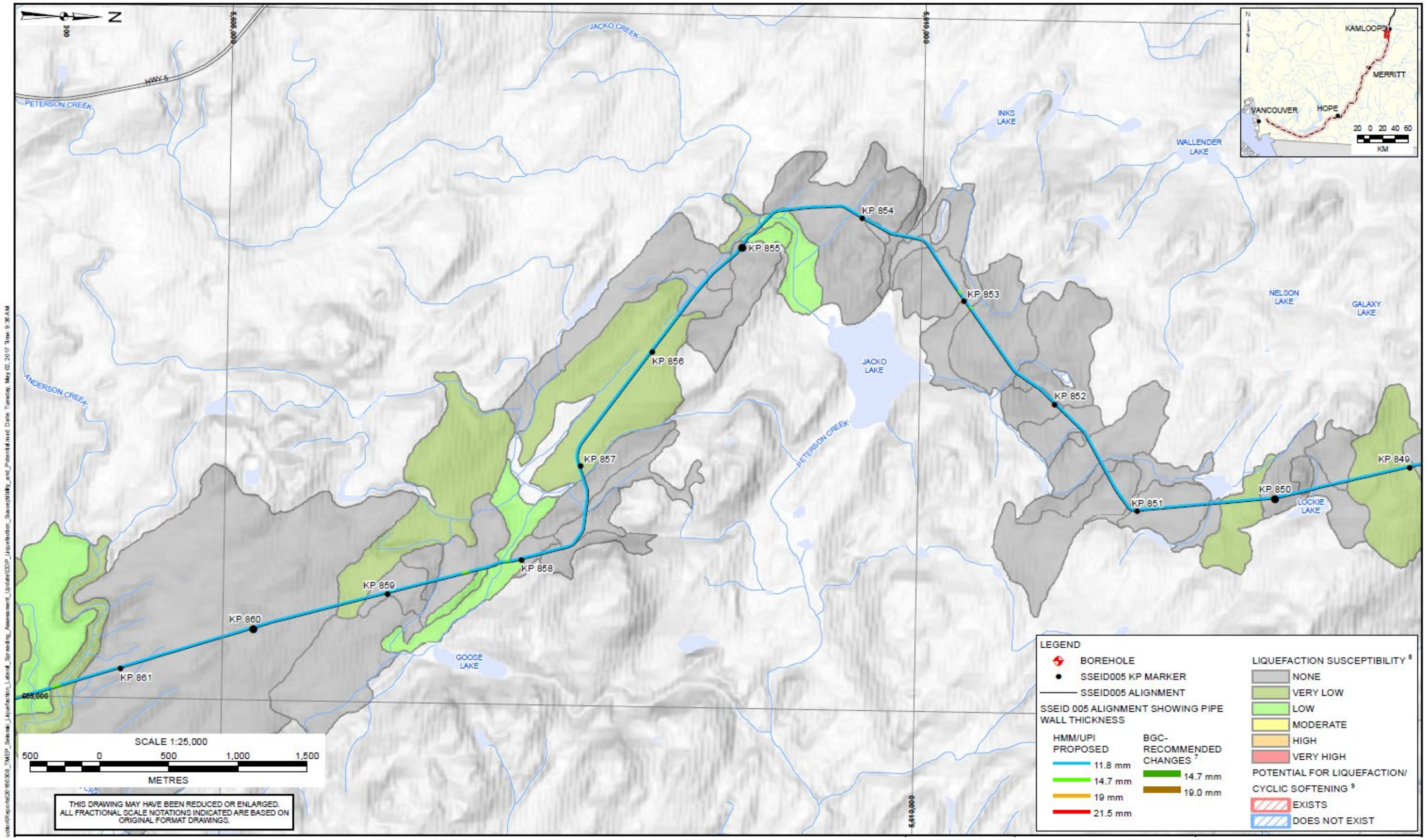
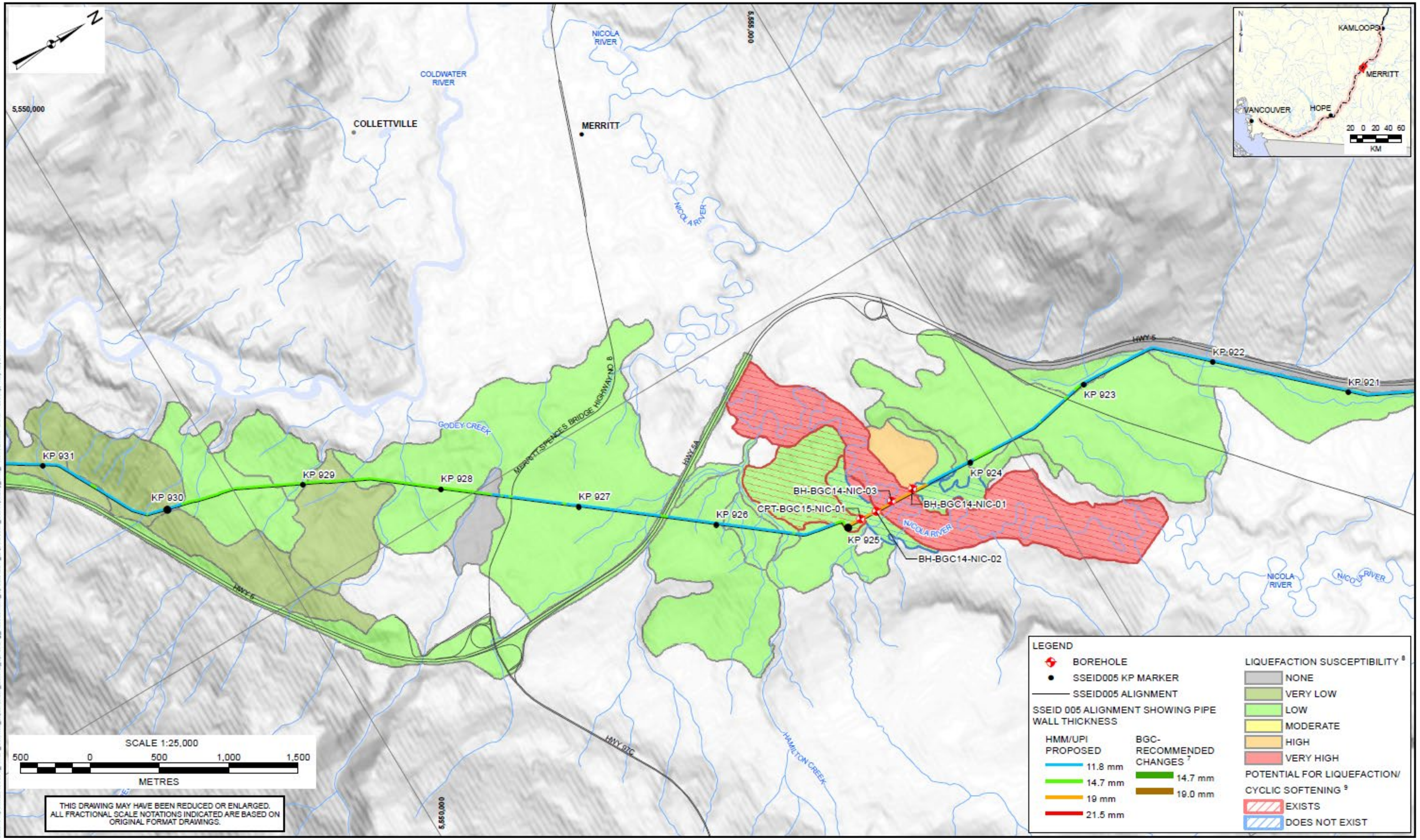
- The assessment demonstrated that out of 339.82 km length of potential interest, 327.41 km does not need mitigation to the pipe wall thickness beyond what has already been specificized to accommodate non-seismic hazards.
- For the remainder 12.41 km, various mitigations in the form of increasing pipeline wall thickness and/or grade was recommended to have seismic FLoC values less than the threshold of 1x10^-5.



C68: Summary Results

TRANSMOUNTAIN



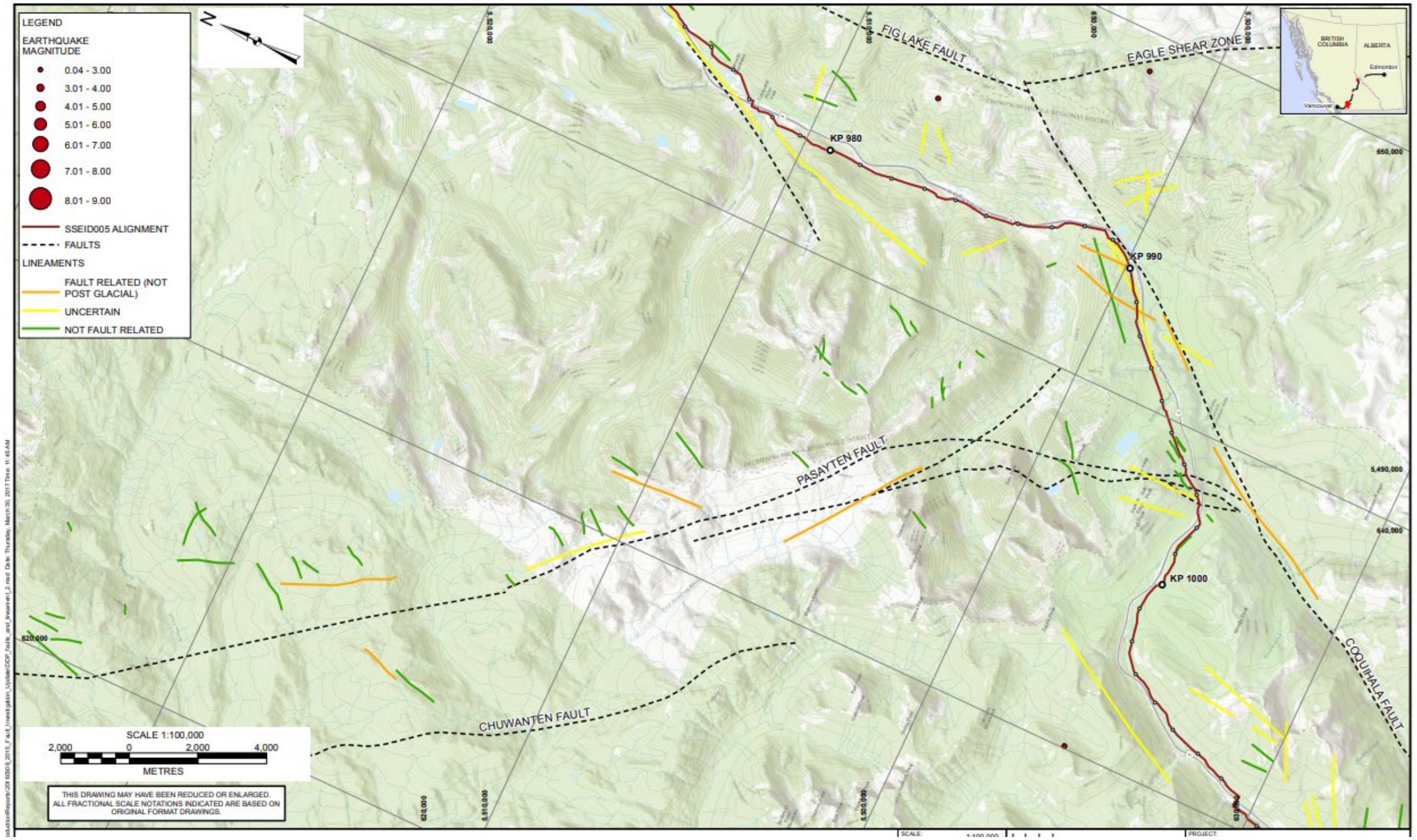
C69: Fault Studies

NEB Condition Requirement:

Trans Mountain must file with the NEB, at least 3 months prior to commencing construction, the results of fault-mapping studies that were ongoing during or undertaken after the OH-001-2014 proceeding, for use in the detailed design of the Project. This filing must include conclusions regarding possible seismic activity during the Holocene epoch for Sumas Fault, Vedder Mountain Fault, Fraser River-Straight Creek Fault and Rock Mountain Trench, and other possible hidden faults, as well as the potential for compounding risks due to the proximity of the Vedder Mountain and Sumas Faults

C69: Fault Studies

- Trans Mountain completed studies including a review of new information, field mapping, aerial photograph interpretation, and compiling historical earthquakes along the area of interest.
- The Project defines an active fault as one that has experienced demonstrable surface rupture within the Holocene epoch (about the past 11,600 years).
- The Project's fault investigations have not revealed evidence of Holocene-active faults across the right-of-way. However, the Project does cross seismically active terrain.



C70: Strain-based Design (SBD)

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NEB Condition Requirement:

Trans Mountain must file with the NEB … the following information related to strain-based design where it is applied:

a) the location and rationale for selecting strain-based design in each location

b) a report summarizing the adequacy of the strain-based design for various loading scenarios provided in a)
c) A list of standards and Project-specific specifications, including testing procedures, used in the strain-based design

C- 70: Strain-based Design (SBD)

- Pipe subjected to soil displacement loading can incur a loss of containment (LoC) through three failure mechanisms that define the limit states of the pipeline system. These are:
  1. Tensile failure of the pipe body,
  2. Tensile failure of a girth weld containing a flaw,
  3. Compressive strain induced buckle of sufficient severity as to produce a transverse through wall crack.

- The specification of High Strain Capacity (HSC) heavy wall pipe increases tensile strain capacity and ensures the pipe installed exhibits the proven material and weld properties required to achieve high strain capacity by applying SBD.

- The SBD approach was applied to areas subject to displacement controlled geohazards (landslides and seismic liquefaction induced lateral spreading) as identified in the response to Condition 16 “Quantitative Geohazard Frequency Assessment”.
  - Additionally, TMEP specified HSC pipe for the Westridge tunnel. Short sections of HSC pipe were specified for construction practicality.

C- 70: Summary Results

The total HSC pipe quantities utilized by TMEP were 28,935 m.

It is estimated that the change to heavy wall increases the tensile strain capacity (TSC) moderately (6%). However, the change to HSC and heavy wall pipe, with the accompanying modifications in weld and coating procedures increases, combined with an increase of TSC by 144%

Significant operational benefits are realized as the strain capacity permitted by code increases from 0.5% to 1.3% (or nearly 3 times the design allowable for stress-based design)

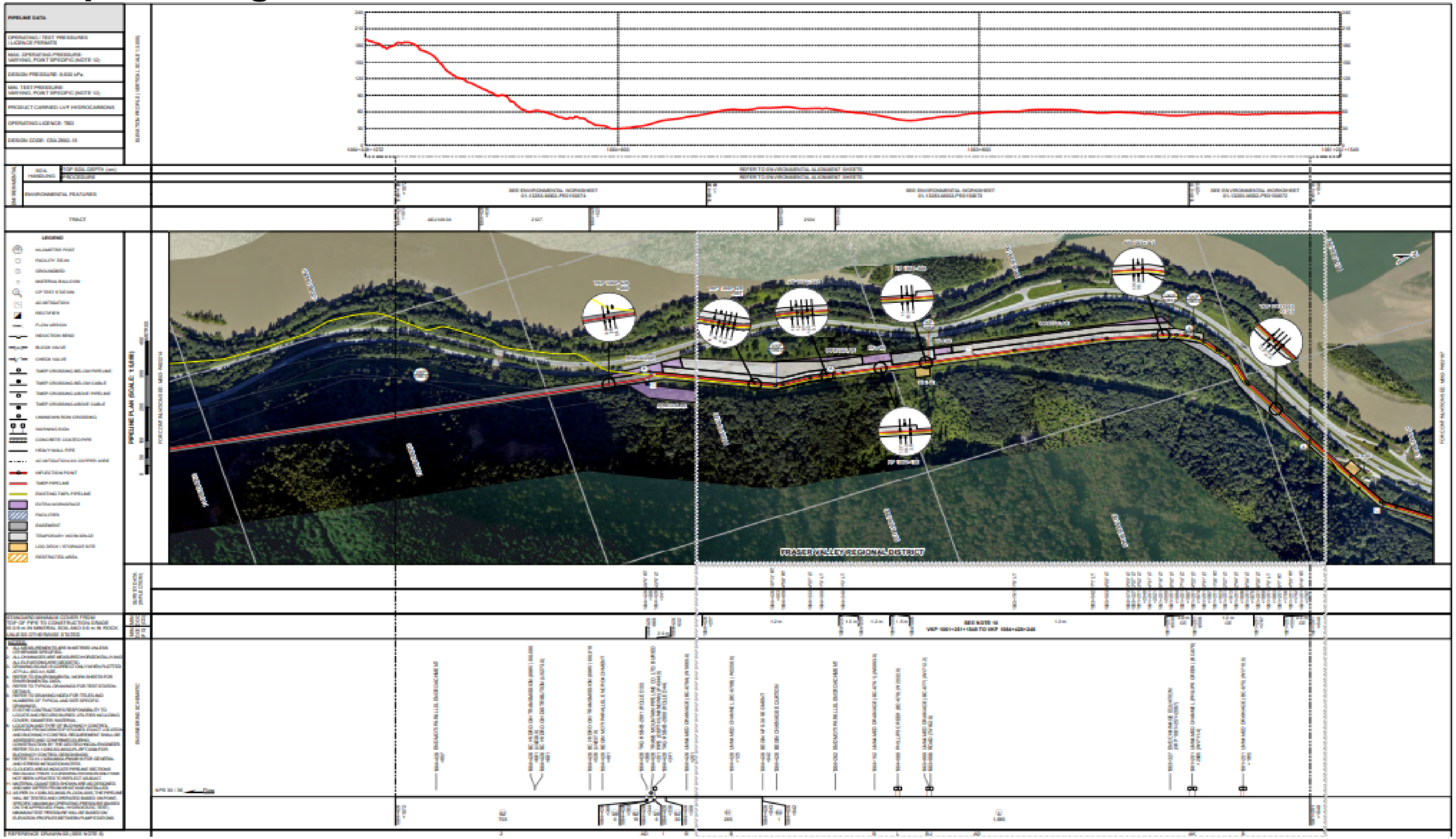
C104: Updated Engineering Alignment Sheets & Designs

NEB Condition Requirement:

Trans Mountain must file with the NEB … updated engineering alignment sheets and drawings and, as they become available and prior to their implementation, any modifications to those sheets and drawings.

C104: Updated Engineering Alignment Sheets & Designs

Example of alignment sheet



C104: Updated Engineering Alignment Sheets & Designs

Spread 5B Dominant Design table

Spread #	PXID	Geohazard Category	Geographic Location	SSEID005.24.2 (S5B) KP from	SSEID005.24.2 (S5B) KP to	Width (m)	Burial Depth (m)	Additional Cover (m)	Recommended Depth of Cover (m)	Pipeline Wall Thickness (mm)	Burial Type
5B	W1612.3	Scour	Unnamed Channel	992.142	992.145	3	1.5	0	1.5	As per UPI design	IB
5B		Rockfall	Dry Gulch East Slope - Coquihalla Summit	992.800	992.910	110	1.5	0.8	2.3	19	IB
5B		Rockfall	Dry Gulch - Coquihalla Summit	992.910	992.974	65	1.5	0.8	2.3	19	IB
5B		Rockfall	Dry Gulch West Slope - Coquihalla Summit	992.974	993.100	126	1.5	0.8	2.3	19	IB
5B	W1615.3	Scour	Fallslake Creek	994.228	994.258	30	1.5	0	1.5	14.7	CE
5B	W1618.3	Scour	Unnamed Channel	995.929	995.935	6	1.5	0	1.5	As per UPI design	IB
5B	W2088.1	Scour	Unnamed Channel	998.085	998.091	6	1.5	0	1.5	As per UPI design	IB
5B	W1621.4	Scour	Unnamed Channel	999.428	999.444	16	1.5	0	1.5	As per UPI design	IB
5B		Debris Flow	Markhor Peak Channel 3	999.513	999.518	5	1.2	0	1.2	As per UPI design	IB
5B	W1622.4	Scour	Boston Bar Creek	1000.059	1000.070	11	1.5	0	1.5	As per UPI design	IB
5B	W1623.5	Scour	Unnamed Channel	1001.635	1001.651	16	1.5	0	1.5	As per UPI design	IB
5B		Debris Slides	Flatiron - Coquihalla Valley	1001.649	1007.920	6271	1.5	1	2.5	As per UPI design	IB
5B	W1627.5	Scour	Boston Bar Creek	1007+810+372	1007+810+401	29	2.2	0	2.2	14.7	CE
5B		Debris Slides	Bombtram Mountain - Coquihalla Valley	1008.237	1008.354	117	1.5	1	2.5	As per UPI design	IB
5B	W1629.3	Debris Flow	Unnamed Channel	1008.354	1008.357	3	2.5	0	2.5	14.7	CE
5B		Debris Slides	Bombtram Mountain - Coquihalla Valley	1008.357	1008.667	309	1.5	1	2.5	As per UPI design	IB
5B		Debris Flow	Unnamed Channel	1008.667	1008.669	2	1.5	0	1.5	19	CE
5B		Debris Slides	Bombtram Mountain - Coquihalla Valley	1008.669	1008.707	39	1.5	1	2.5	As per UPI design	IB
5B		Debris Flow	Unnamed Channel	1008.707	1008.710	2	1.5	0	1.5	As per UPI design	CE
5B		Debris Slides	Bombtram Mountain - Coquihalla Valley	1008.710	1009.031	321	1.5	1	2.5	As per UPI design	IB
5B	W1630.3	Debris Flow	Unnamed Channel	1009.031	1009.035	4	1.5	0	1.5	19	CE
5B		Debris Slides	Bombtram Mountain - Coquihalla Valley	1009.035	1009.413	378	1.5	1	2.5	As per UPI design	IB
5B	W1631.3	Debris Flow	Unnamed Channel	1009.413	1009.433	20	1.5	0	1.5	19	CE
5B		Debris Slides	Bombtram Mountain - Coquihalla Valley	1009.433	1010.880	1447	1.5	1	2.5	As per UPI design	IB
5B	W1637.3	Debris Flow	Unnamed Channel	1010.880	1010.896	15	2	0	2	19	CE
5B		Debris Slides	Bombtram Mountain - Coquihalla Valley	1010.896	1010.943	48	1.5	1	2.5	As per UPI design	IB
5B	W1639.3	Debris Flow	Unnamed Channel	1010.943	1010.947	4	1.5		1.5	As per UPI design	CE

C106: Construction Progress Reports

NEB Condition Requirement:

Trans Mountain must file with the NEB, monthly construction progress reports from commencing construction until after commencing operations. The reports must include information on the progress of activities carried out during the reporting period, including:

a) safety, environmental and security issues, or non-compliances that occurred during the reporting.

b) measures undertaken to resolve safety and environmental issues or non-compliances identified in a);

c) confirmation that security issues identified in a) have been addressed;

d) a description and the location of any change made to geohazard mitigation measures pursuant to Condition 51; and

e) the location of any pressure tests carried out during the reporting period and a description of any unsuccessful pressure tests, including the reasons for the lack of success of each.

C106: Construction Progress Reports

Report example:

Location	Description of Geohazard	Description of Mitigation Measures
TCA 24B Zig Zag Road (KP1012+800 to KP1013+600)	Erosion/Slope Instability	- On April 24, 2024, TEL completed a field review of the Zig Zag Road section of the TMEP alignment between KP1012+800 and KP1013+600. The purpose of the review was to assess the stability of the cut slopes for worker access safety, and also to provide recommendations for final restoration of the grade cuts to provide long-term stable access for pipeline operations (TEL Document # GH_4984). -TEL assessed the interval to be safe for worker entry, provided several controls were followed as outlined in the above referenced Field Review Report, dated April 24, 2024. These controls included maintaining worker and vehicle distance from the cut as far as practicable, shutdown recommendations for adverse weather including heavy precipitation and wind events, recommendations for the positioning and use of a spotter for workers close to the cut, and the positioning of equipment or vehicles between workers and the cut if stationary work was necessary. -TEL also provided recommendations and construction details in the above report for restoration of extremely oversteepened cuts in a number of locations across the subject interval. Recommendations included the removal of mesh and canopy anchors in several locations, and the placement of lock block walls at the toe of several sections to be backfilled with approved rock or gravel to buttress the cuts. It was noted that the recommended lock block buttress configuration would not buttress the entire footprint of all oversteepened cuts along the road, but are intended to significantly reduce the rate and scale of slope retrogression such that the residual retrogression hazard can be reasonably managed using standard low volume access road maintenenance methods. TEL conducted a follow up review on September 9, 2024 to reaffirm all recommendations provided in the April 24, 2024 report (TEL Doc #: GH_5665). -TEL has been conducting ongoing daily site assessments since October 7, 2024, to monitor the implementation of the provided recommendations and the suitability of the final cut slope restoration. TEL will continue to monitor until restoration completion.

C147: Natural Hazard Assessment

NEB Condition Requirement:

Trans Mountain must file with the NEB, within 1 year after commencing operations:

a) the results of the baseline natural hazard assessment for the Project

b)confirmation that the natural hazard assessment will be:

- updated at intervals not exceeding 5 years
- integrated into the exiting Natural Hazard Management Program for the Trans Mountain Pipeline system

C147: Natural Hazard Assessment

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Condition 147 Pipeline Overview

Approach to Geohazards Identification

Pre-Construction

Condition 16: A total of 1,569 geohazard were identified along the alignment. These have been categorized into three risk-based groups:

KEY GEOHAZARDS	220 Geohazards
VERY LOW HAZARD GEOHAZARDS	429 Geohazards
NEGLIGIBLE HAZARD GEOHAZARDS.	930 Geohazards

Construction mitigations measures were developed for each of the key geohazards locations to reduce potential impacts on the pipeline.

Condition 68: Liquefaction potential was ranked using imagery and terrain data; only 3 high-risk sites required mitigation.

During-Construction

Field Identified or Project Triggered Geohazards

Identified either through Terrain Stability Field Assessments (TSFAs) or during the construction phase as work progressed. Field Geotechnical consultant managed these sites.

TOTAL SITES IDENTIFIED	197 Sites

Baseline Geohazards Assessment

The baseline geohazard assessment is considered complete once identified geohazard sites have been evaluated (or baselined) through office and/or field inspections , or mitigation measures have been implemented, with the associated information documented in CAMBIO™

Condition 16 listed geohazards by count, not location, allowing multiple hazards per pipeline segment. In the baseline assessment, hazards were grouped by location, and duplicates were removed from lower-risk categories to avoid overlap. Below is a summary of sites incorporated into the Geohazard Management Program.

Site Group	Number of Sites	Baseline Assessment
KEY GEOHAZARDS	354	A combination of key geohazards identified before and during construction.
Pre- Construction	157	A range of construction mitigations were applied, additionally both field and office inspections were conducted.
During-Construction	197	Field Geotechnical consultants provided site-specific recommendations. Sites will be monitored initially as per the EOR's advice, then integrated into Trans Mountain's geohazard management program.
VERY LOW HAZARD SITES	223	Ground or office inspections were conducted by internal specialists and a geotechnical consultant.
NEGLIGIBLE HAZARD SITES	241	These locations pose very low risk to pipeline integrity and will be monitored through aerial patrols and LiDAR change detection.

In addition to the baseline assessment notes in the table, all pipeline segments containing these sites have been baselined using IMU data, aerial patrol recordings, and collected LiDAR.

Re-Assesment

All geohazards identified before, during, and after construction have been incorporated into the Trans Mountain Geohazard Management Program. The assessment will be updated through the methods listed below, at intervals not exceeding five years.

Aerial Inspections: Conducted at least twice a year; geohazard engineers review site photos and aerial imagery to detect changes in site conditions.

Imagery Review: LiDAR is collected every two years for change detection; InSAR is used as needed for specific sites.

Office & Ground Inspections: Performed based on risk-based timelines outlined in Section 2.1.6.

In-Line Inspections (ILI): Used to detect pipeline movement and deformations; typically completed every five years or more frequently depending on risk.

Watercourse Crossing Surveys: Carried out by professional surveyors for detailed topography and pipeline profile data, especially at non-wadeable crossings.

Module 2: Advanced Design Methods

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Agenda

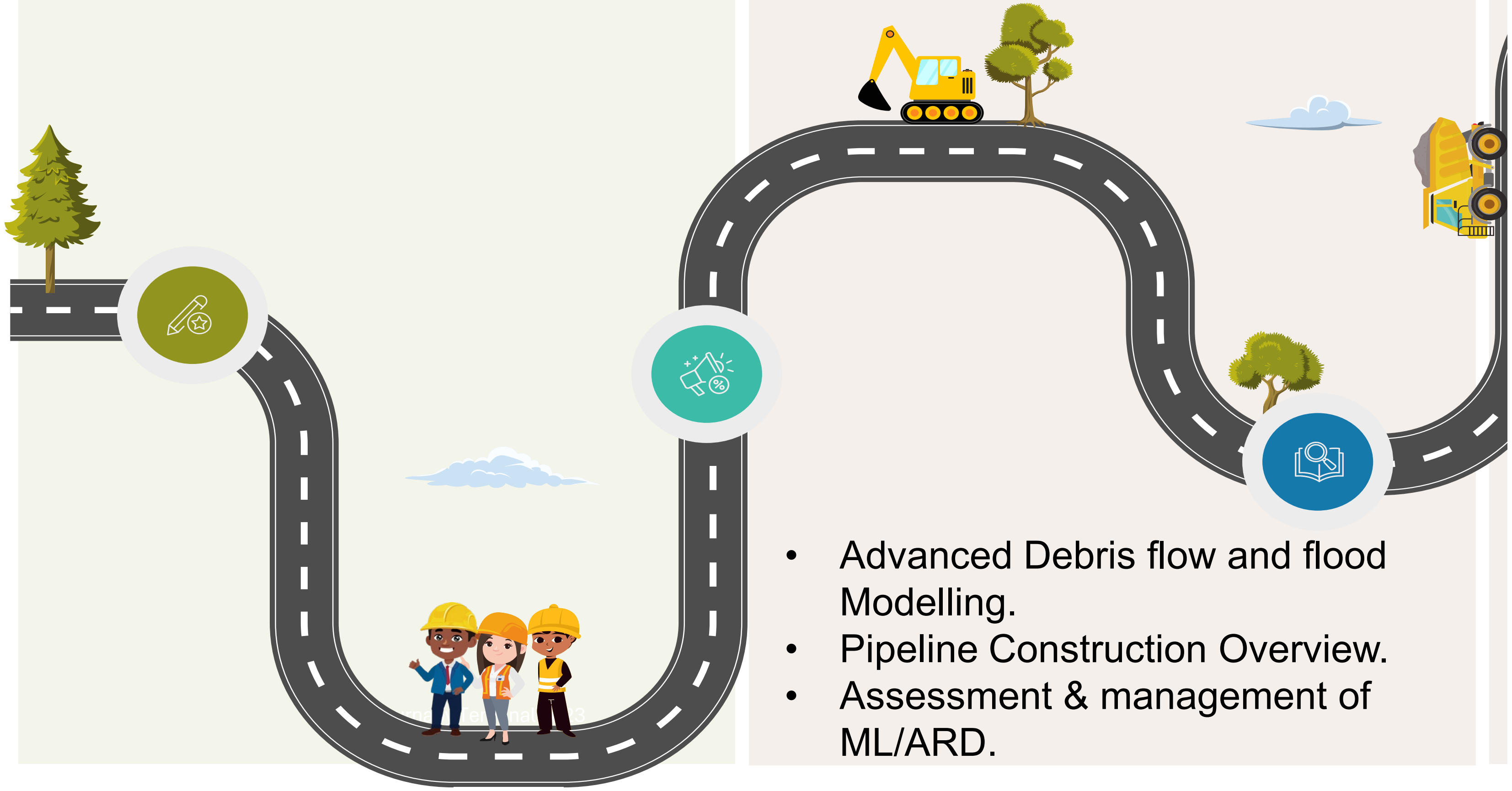
TRANS MOUNTAIN EXPANSION PROJECT

Pipeline Lifecycle Unveiled: Managing Pipeline Geohazards from Design to Operations

MODULE 1: Regulatory Conditions and Filings

MODULE 2: Advanced Design Methods

- Pipeline Corridor Selection
- Risk based design method



- Advanced Debris flow and flood Modelling.
- Pipeline Construction Overview.
- Assessment & management of ML/ARD.

Pipeline Corridor Selection

Pipeline Corridor Selection

Terrain Mapping

Topography and Geotechnical Properties

Groundwater and Drainage

Cultural and Environmental Constraints

Applications of Terrain Analysis

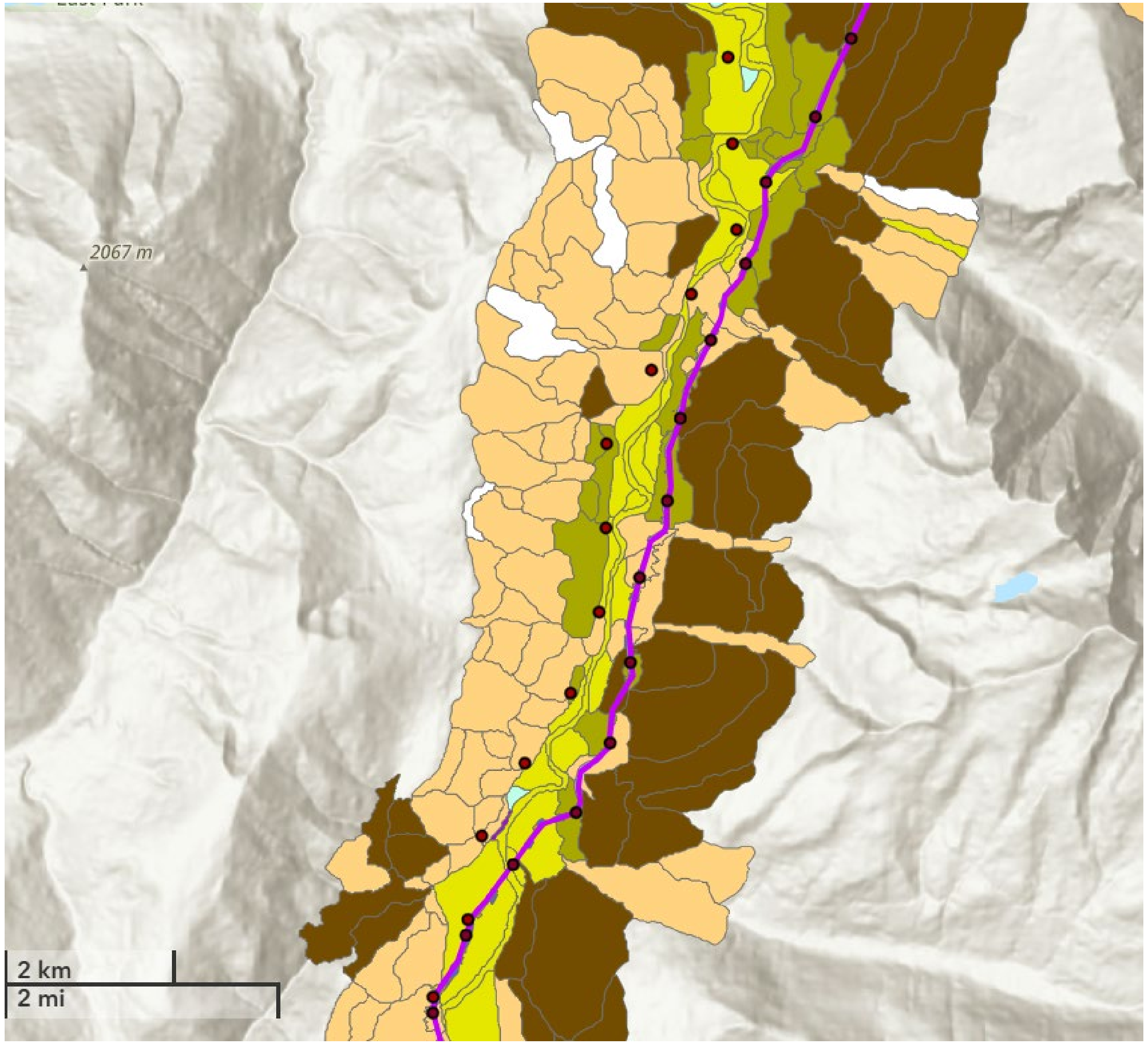
Adjacent Operating Pipelines

Pipeline Corridor Selection

Terrain Mapping

Terrain mapping involves the **delineation and classification of the landscape based on landforms, surficial materials, and geomorphic processes.**

While terrain analysis describes existing conditions, the information gathered can assist with evaluating **how conditions may change over different stages of the project** and with assessing potential environmental and social impacts of the Project.



Pipeline Corridor Selection

Terrain Mapping

Air Photo Interpretation

- Provides historical and current terrain views.
- Ideal for identifying slope changes, land use, riverbank erosion, channel migration and vegetation patterns.
- The historical photos serve as a valuable archive of past conditions and **providing evidence for changes in the landscape** within the study area.
- **Limitations:** Seasonal coverage and resolution variability.

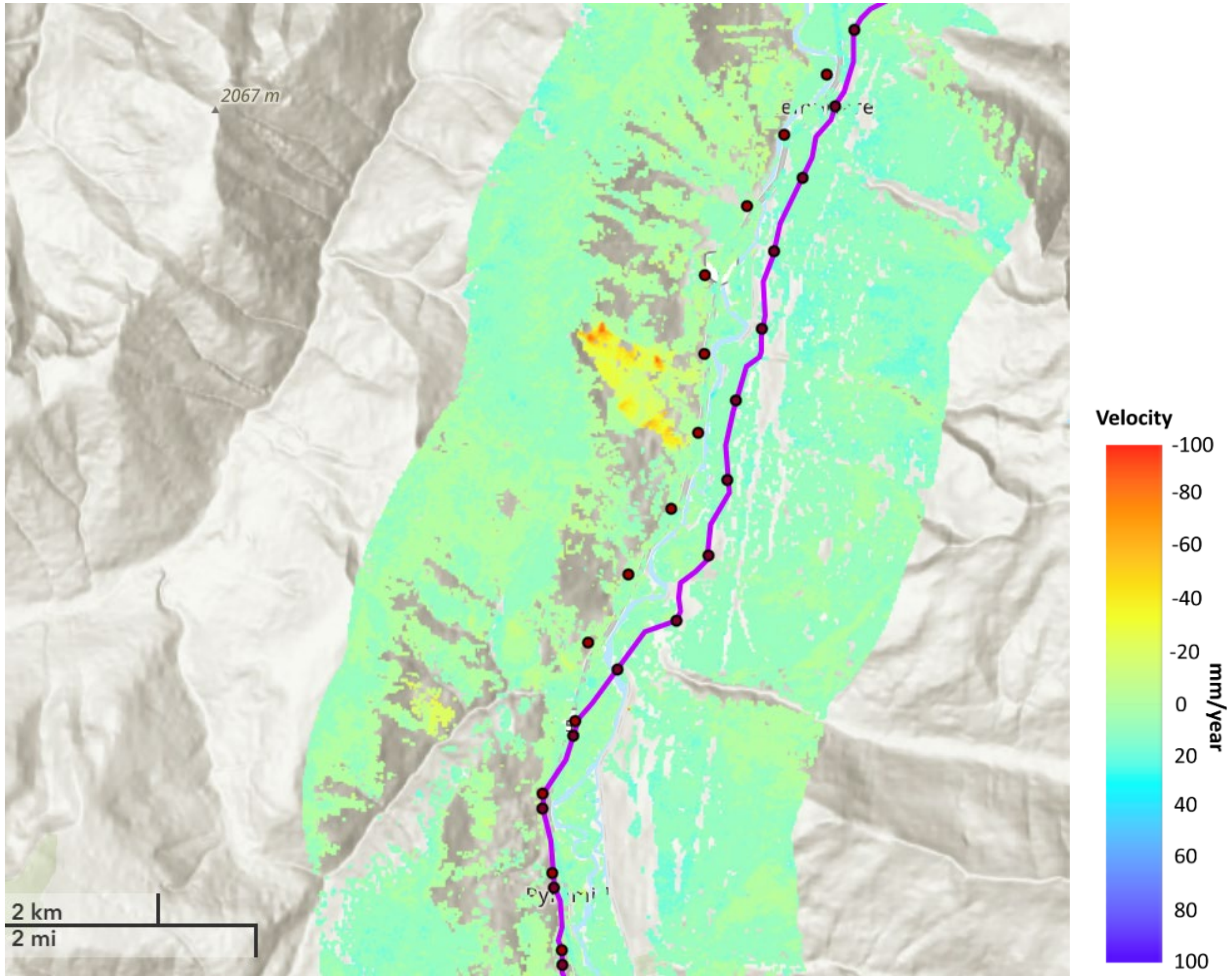
Rizkalla and Read 2019. Chapter 2.

Risk-Based Design Method

Terrain Mapping

Satellite Imagery

- Imagery acquired from satellite is often the preferred image type for large, regional-scale studies.
- Tracks changes over time (e.g., vegetation loss, erosion).
- Types: Optical, radar (InSAR), and thermal imagery.
- Advantage: Global coverage with repeatable monitoring.



Pipeline Corridor Selection

Terrain Mapping

Digital Surface Modelling (DSM)

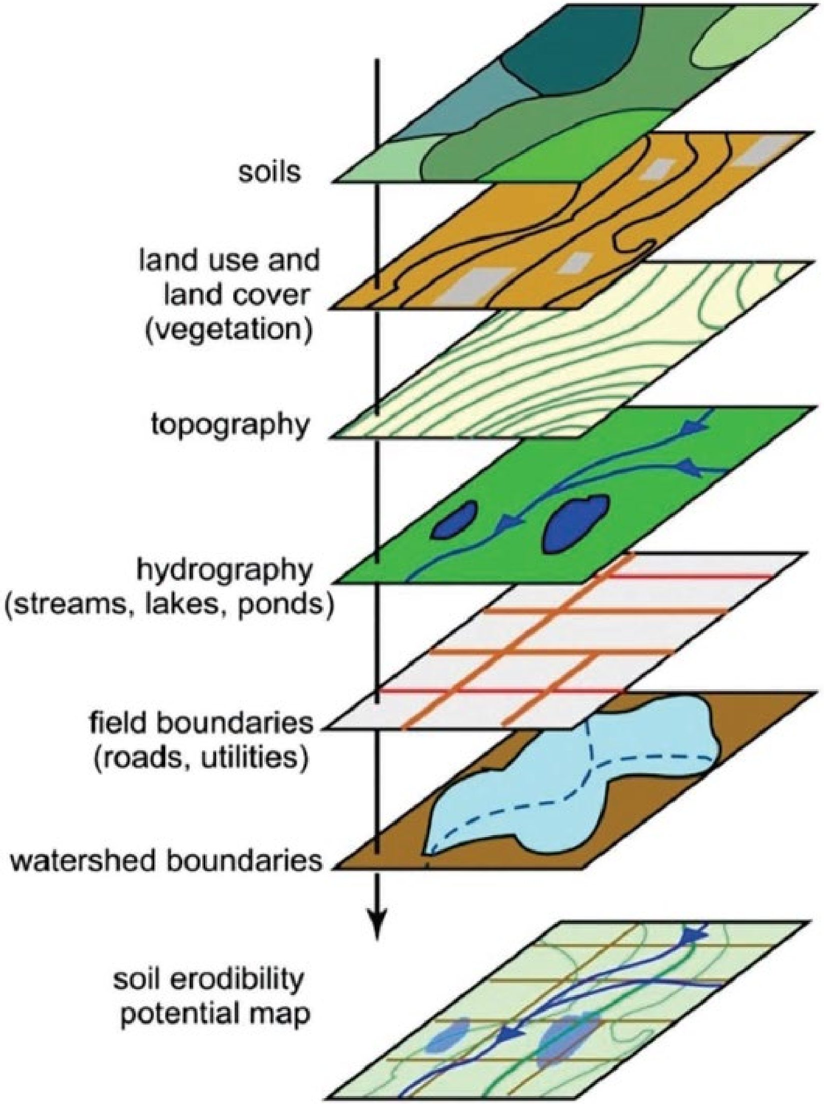
- 3D representation of terrain and surface features.
- Created using LiDAR, photogrammetry, or radar data.
- Applications: Slope stability analysis, hydrological modeling.
- High accuracy but requires specialized software and expertise.

Pipeline Corridor Selection

Terrain Mapping

Existing Maps and Reports

- Provide data on **soils, geology, topography**, and other physical/human factors.
- Guide and supplement air photo and satellite imagery analysis.
- Show **administrative areas and protected lands**, aiding early pipeline studies.
- Highlight existing **transportation and communication corridors** that impact pipeline decisions.
- Obtainable from **government agencies, universities, or commercial resellers**.



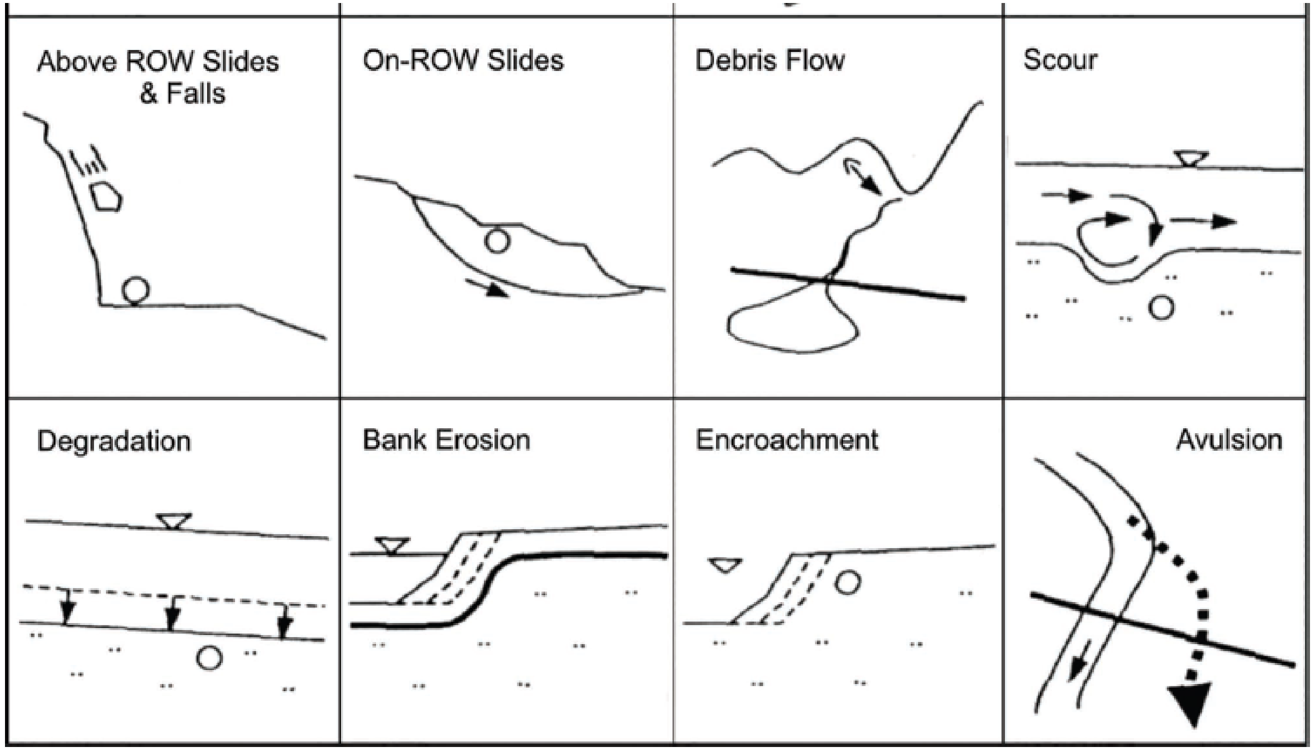
Rizkalla and Read 2019. Chapter 2.

Pipeline Corridor Selection

Topography and Geotechnical Properties

Geohazards

- Buried pipelines are susceptible to many geohazards. Assessing and managing the threat of these geohazards involves recognizing and **delineating specific geohazard mechanisms, estimating the frequency and magnitude of occurrence** of these processes and events and **assessing the vulnerability of the pipeline.**

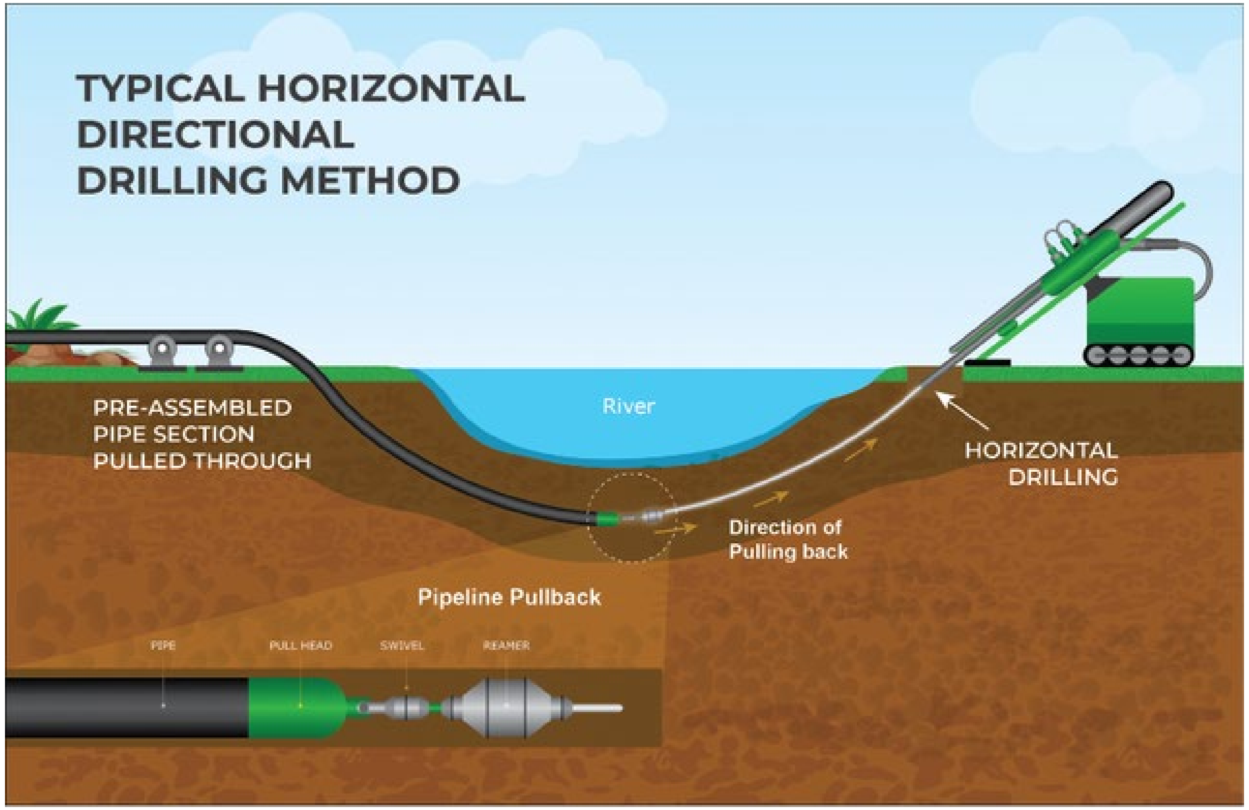


Rizkalla and Read 2019. Chapter 2.

Pipeline Corridor Selection

Ground Water and Drainage

- Hydrotechnical risks: **scour, bank erosion, slope instability, avulsion, and debris impact.**
- Key concern: Potential pipeline leakage **contaminating water resources**.
- Requires understanding shallow groundwater influenced by surface materials and drainage.
- Groundwater conditions are particularly. important for evaluating and planning **HDD crossings** to help select **drilling parameters and to ensure that aquifers are not contaminated** by drilling fluid.



Lawrence M. Slavin. ASTM F1962–22. 2023

Pipeline Corridor Selection

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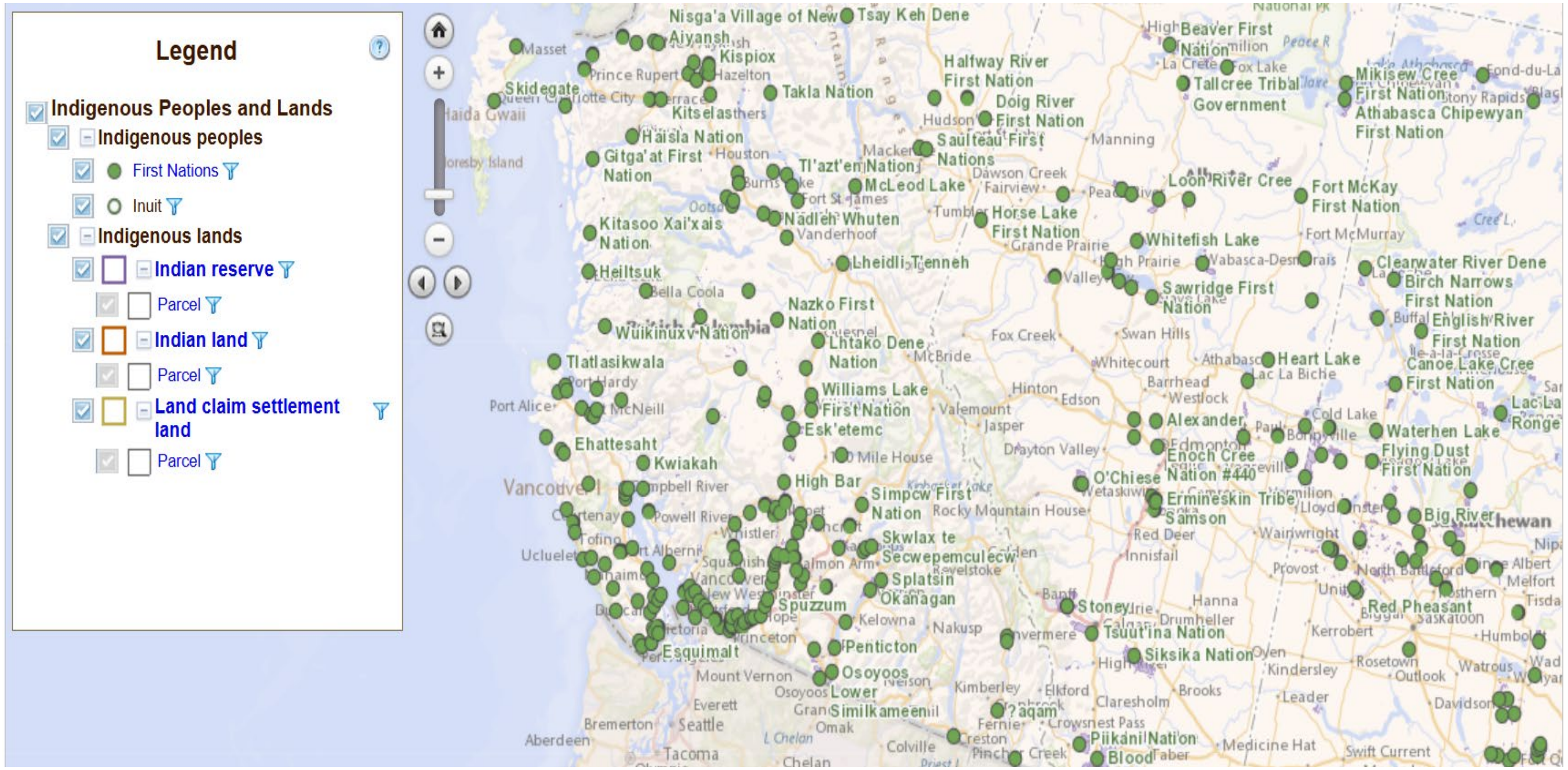
Cultural and Environmental Constraints

- Avoid sensitive areas or use terrain analysis to minimize effects.
  - Protected Environmental Zones
  - Water Resources
  - Indigenous Lands
  - Agricultural Lands
  - Urban and Residential Areas



Indigenous peoples and lands, Government of Canada. https://www.rcaanc-cirnac.gc.ca/eng/1605796533652/1605796625692

Pipeline Corridor Selection

Applications of Terrain Analysis

Corridor and Route Selection

- *Regional corridor studies, identify 2-3 competing, high-level corridors.*
- *Stakeholder engagement on high-level corridors.*
- *Detailed studies to select a preferred corridor.*

Design

- *Design must align with engineering criteria and adapt to terrain and geotechnical conditions.*
- *Detailed terrain data (e.g., LiDAR) informs the pipeline's horizontal and vertical alignments.*
- *Geotechnical studies (e.g., borehole drilling) help refine the design and manage terrain challenges.*

Construction

- *During construction, terrain-related issues can arise, but with proper data and design knowledge, they can be quickly addressed to keep projects on track and minimize environmental impacts.*

Operations

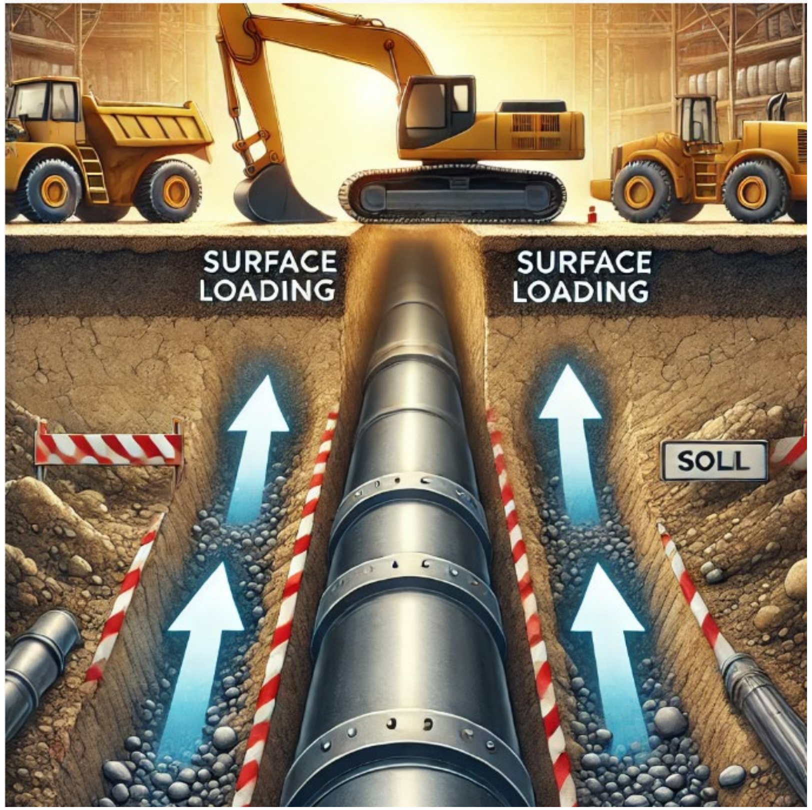
- *Data collected during routing, design, and construction helps with geohazard risk assessments, planning protective measures, and responding to emergencies in a timely and efficient manner.*

Pipeline Corridor Selection

Adjacent Operating Pipelines

Separation Distance

Surface Loading



Blasting

Risk Based Design Method

TRANSMOUNTAIN

Risk Based Design Method

Trans Mountain used a risk-based design combining annual failure frequency and consequence to estimate pipeline failure risk.

To support that overall risk assessment, **credible geohazards along the pipeline were identified** and the frequency of loss of containment was estimated at each geohazard site following the framework.

Frequency values expressed qualitatively or quantitatively

FLoC estimated using empirical analysis, deterministic assessment, and expert judgment for each hazard and location.

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Summary of Data Sources for Geohazard Assessment

01 Aerial Photos
Recent high-resolution images (1:15,000–1:20,000) plus historical photos for key sites (e.g., watercourses) to analyze changes over time.

02 Immersive Video
2012 helicopter flyover video used for corridor review from multiple angles.

03 Updated Terrain Mapping
2015–2016 updates using new surficial geology and borehole data.

04 LiDAR
High-resolution elevation data for the entire BC and Alberta corridor.

05 Google Earth
Supplemental imagery for cross-checking aerial photos.

Historical Records 06
Long-term geohazard and mitigation data from OPS Natural Hazard Management Program (since 1998).

Pipeline Design Info 07
HDD crossings, pipe wall thickness, and coating incorporated into frequency analysis.

Debris Flow/Flood 08
2015–2016 inventory and field validation of debris flow channels and fans.

Hydrotechnical Hazards 09
Desktop and field assessments of flood risk at watercourse crossings using LiDAR, satellite imagery, and surveys.

Rock & Soil Slopes 10
Site-specific slope hazard reviews with LiDAR and field checks to refine input data.

Risk Based Design Method

01 Threshold Defined

Canada Energy Regulator required Trans Mountain to reassess geohazard Frequency of Loss of Containment (FLoC) values before construction.

02 Threshold Value

Sites with FLoC > 1 in 100,000 per year (10^{-5} events/year) must have additional mitigation to reduce risk As Low As Reasonably Practicable (ALARP).

03 Required Plan

An updated Quantitative Geohazard Frequency Assessment must include:

- Site-specific field data.
- Mitigation actions for sites over threshold.
- Demonstration of how ALARP is achieved.

04 ALARP Principle

Mitigation continues until further risk reduction would be disproportionate to effort or cost — resources are then shifted to other higher-risk areas.

Risk Based Design Method

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Determine FLoC Values 01

FLoC value calculated based on: Occurrence (I), Frequency (F), Horizontal Spatial (SH), Vertical Spatial (SV), Vulnerability (V), and Mitigation (M).

$$FLoC_{(i)} = I_{(i)} \times F_{(i)} \times S_{H(i)}\ S_{V(i)} \times V_{(i)} \times M_{(I(i),F(i),SH(i),\ SV(i),V(i))}$$

02 Select sites above threshold: Pre-Mitigated results

- FLoC values were estimated assuming standard pipeline design and construction techniques would be employed.
- Sites segments with FLoC values above 10-5 were selected for further mitigation

03 Mitigation Selection

- Evaluated based on effort vs. risk reduction.
- Multiple options considered:
  - Increased Depth of Cover
  - Increased Wall Pipe Thickness
  - Horizontal Directional Drilling
  - Concrete Coating
- Reviewed for feasibility during planning, design, and construction.
- Iterative process until suitable solution found.

The mitigation measures reduce the FLoC value at each site by modifying one or more of the FLoC factors.

Post-Mitigation Results 04

- Where FLoC remained above threshold:
  - Further mitigation not added if impractical, disproportionate, or environmentally damaging.
  - ALARP principle applied — balance between additional benefit & feasibility.

Assessed Geohazards

- 11 key geohazard types were assessed, and engineering designs were implemented during construction to high-risk sites to mitigate their effects.

GEOTECHNICAL

1 Rock Slope Geohazards

- Rockfall
- Extremely rapid rockslides
- Extremely Rapid Rock Avalanches

2 Soil Slope Geohazards

- Debris Slides/Avalanches
- Earth landslides

HYDROTECHNICAL

3 Debris Hazards

- Debris Flows
- Debris Floods

4 Hydrotechnical Hazards

- Avulsion
- Scour
- Lateral Erosion
- Outburst-type floods

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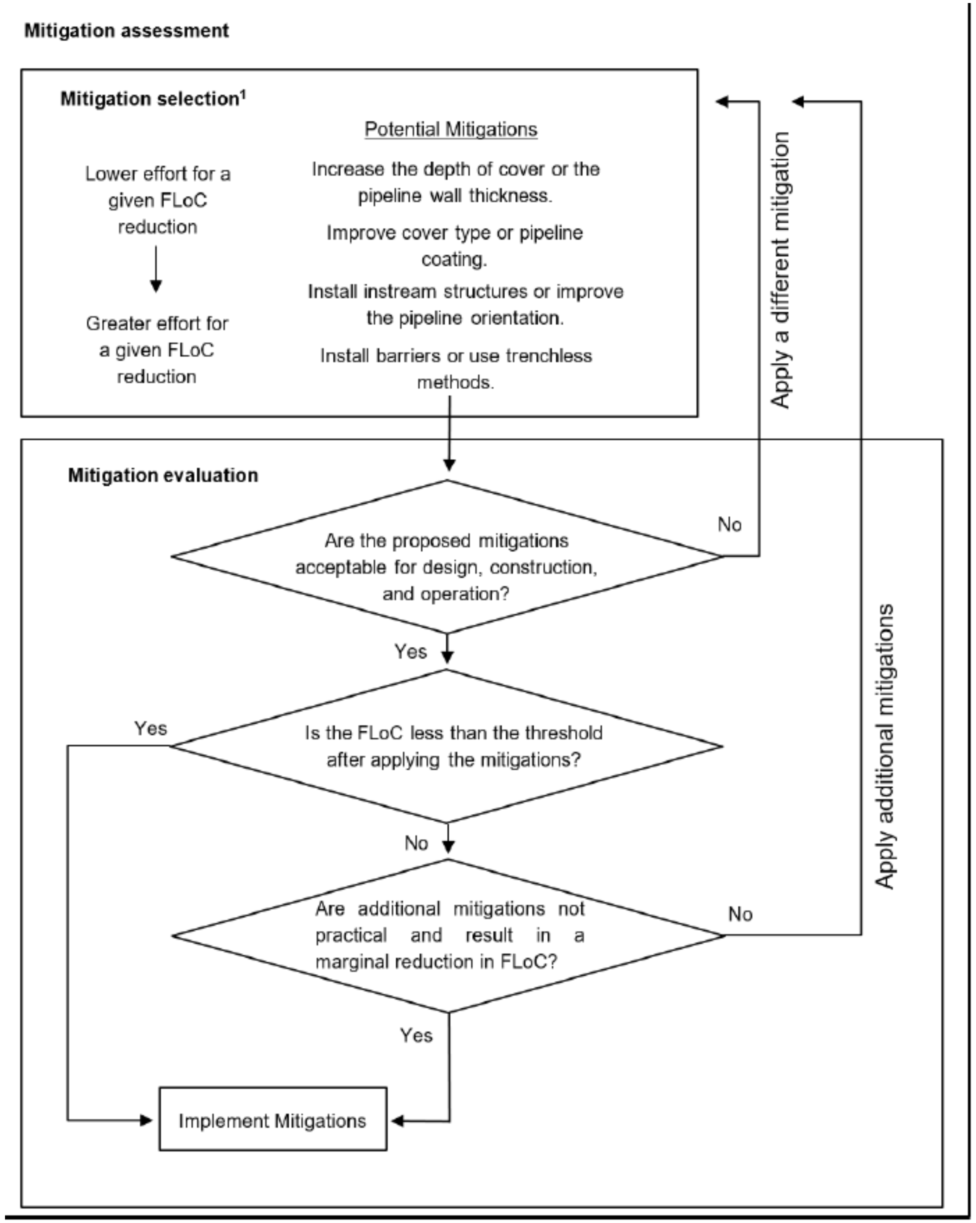
Mitigation Assessment



Assessment Results

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Assessment

- Quantitative Geohazard Frequency Assessment.
- TM must provide a plan to manage and mitigate geohazards at any location where the FLoC is greater than $1x10^{-5}$

1. A total of **<u>1,569</u>** credible geohazards segments were identified along the alignment.
2. **<u>220 (14%)</u>** sites were above the threshold set by the CER for the frequency of loss of containment **<u>Mitigation:</u>** Depth of Cover, Wall thickness, concrete coating, HDDs.
3. Out of the 429 geohazards identified as low-risk hazards, **<u>105 sites</u>** were evaluated by TM at the office and selected for baseline and ground inspections.
4. The remaining geohazards have a negligible hazard, and no further action was required.

Assessment Results

Table 2. Summary of the pre- and post-mitigated geohazard results.

Frequency of Loss of Containment (Events/Year)	Pre-Mitigated			Post-Mitigated		
	Total Number of Segments	% of Total	Length of Segment (km)	Total Number of Segments	% of Total	Length of Segment (km)
$>10^{-1}$	0	0	0	0	0	0
10^{-1} to $>10^{-2}$	0	0	0	0	0	0
10^{-2} to $>10^{-3}$	2	0.1	0.9	0	0	0
10^{-3} to $>10^{-4}$	25	1.6	17.1	1	0.1	0.6
10^{-4} to $>10^{-5}$	193	12.3	83.6	39	2.5	45.6
10^{-5} to $>10^{-6}$	407	25.9	152.3	475	30.3	180.8
10^{-6} to $>10^{-7}$	399	25.4	112.5	395	25.2	123.0
$<10^{-7}$	543	34.6	60.8	659	42.0	77.2
Total	**1,569**	**100**	**427.2**	**1,569**	**100**	**427.2**

Table 4. Summary of post mitigated geohazard FLoC greater than 10-5 events per year by geohazard class and category.

Frequency of Loss of Containment (Events/Year)	Rock Geohazards			Soil Geohazards		Hydrotechnical Hazards							
	Rockfall	Rock Slide	Rock Avalanches	Earth Landslides	Debris Slide	Debris Flow	Debris Flood	Scour	Flooding	Lateral Erosion	Encroachment	Avulsion	Outburst Floods
10^{-2} to $>10^{-3}$	0	0	0	0	0	0	0	0	0	0	0	0	0
10^{-3} to $>10^{-4}$	0	1	0	0	0	0	0	0	0	0	0	0	0
10^{-4} to $>2x10^{-5}$	0	1	9	0	0	1	0	3	0	1	0	0	0
$2x10^{-5}$ to $>10^{-5}$	4	4	8	1	0	0	1	2	0	4	0	0	0
Total	**4**	**6**	**17**	**1**	**0**	**1**	**1**	**5**	**0**	**5**	**0**	**0**	**0**

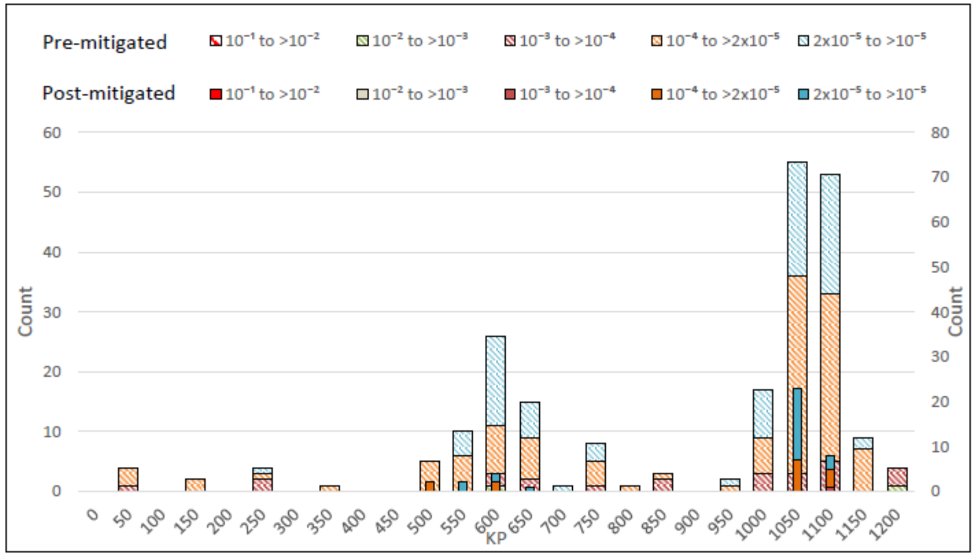
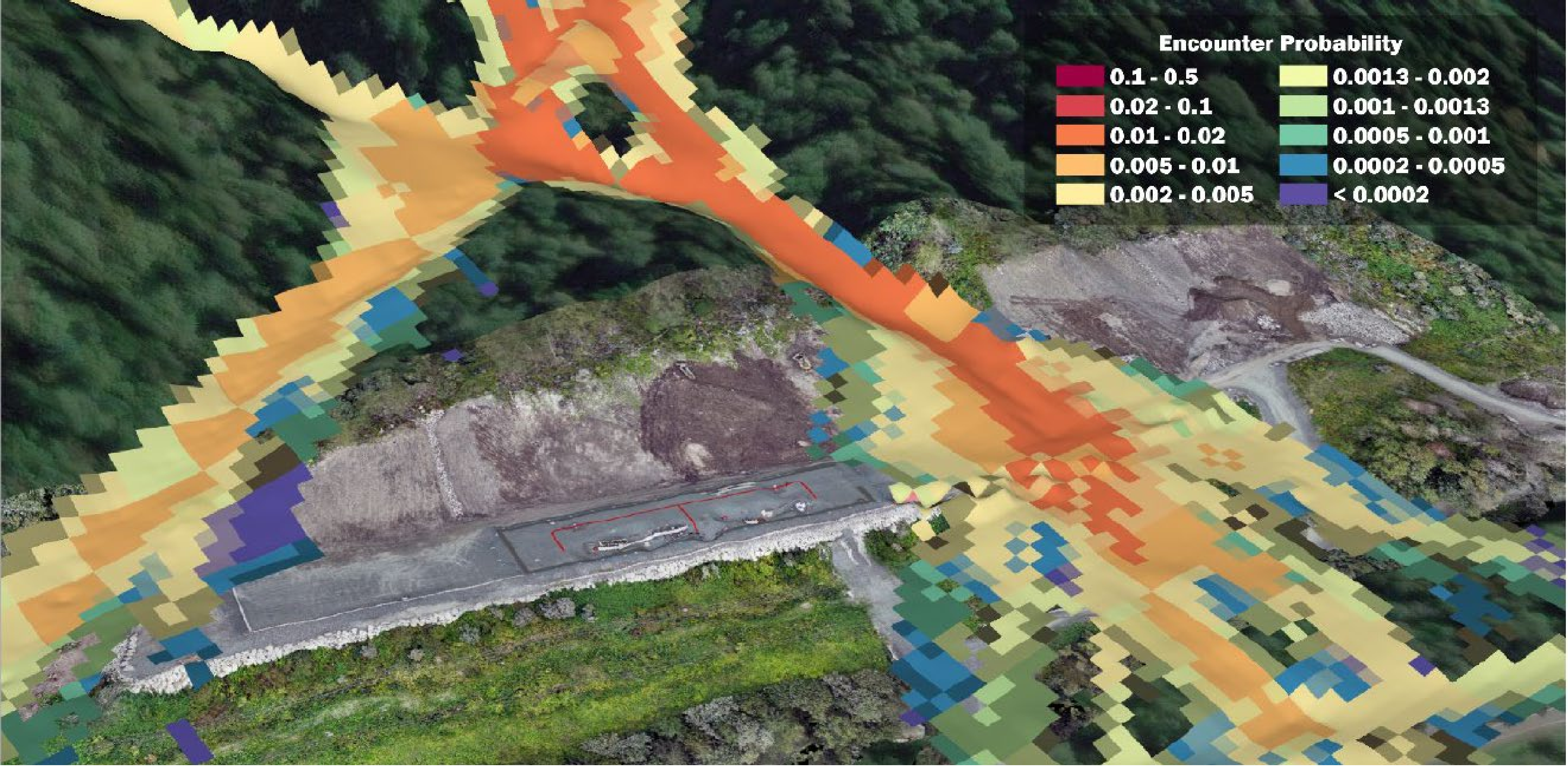


Figure 3. Number of pre- and post-mitigated geohazards along the proposed TMEP alignment with FLoC > 10^{-5} events per year.

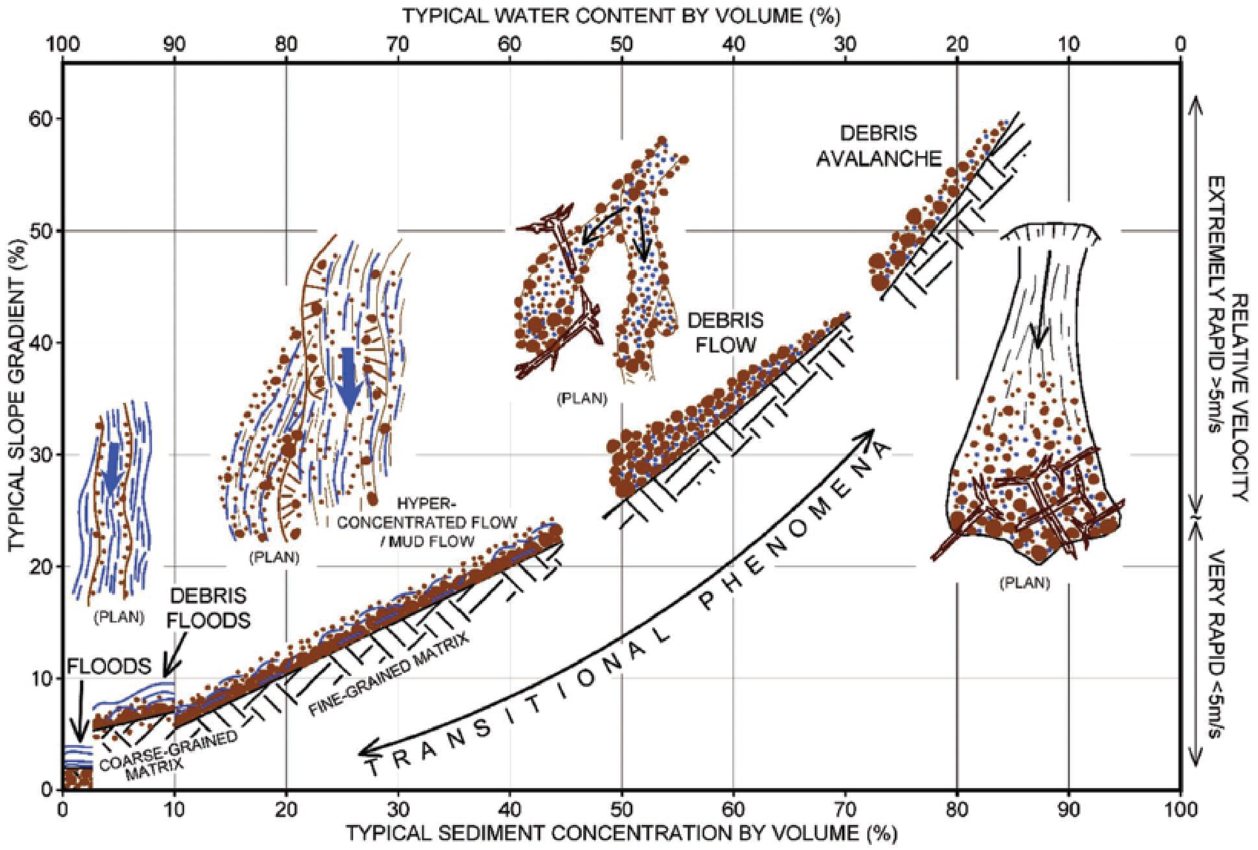


Advanced Debris Flow Modelling

TRANSMOUNTAIN

Debris Flow vs Debris Flood

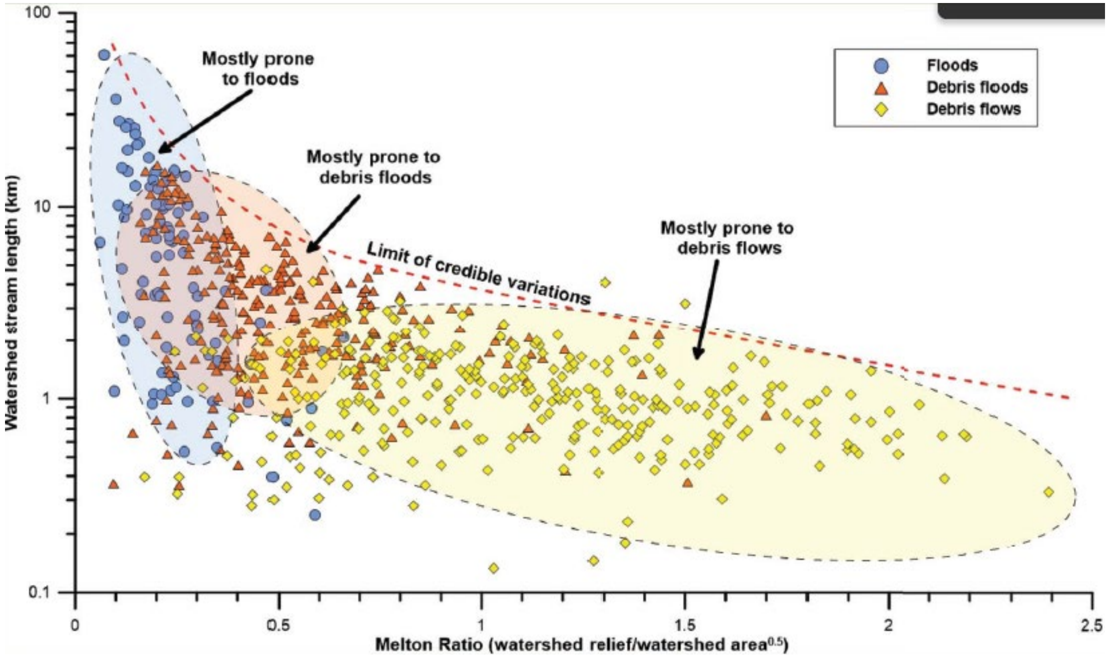
- **Debris flows:** Very rapid, water-saturated movement of debris in steep channels; sediment content **>50%**; can produce peak discharges up to **50× a major flood**.
- **Debris floods:** Similar process with lower sediment content (**3–50%**) and peak discharges up to **2–3× a major flood**.
- Occur in steep watersheds (**>3° gradient**) and confined channels with steep slopes.
- Paths include **initiation, transport, and deposition zones**; initiated by landslides or erosion from intense rain.
- Significant channel erosion and entrainment possible due to high energy and sediment loads.
- Common in steep gullies and small basins; larger basins may produce debris floods rather than flows.



Rizkalla and Read 2019. Chapter 13. BGC Engineering Inc.

Pipeline Crossings & Debris Flow Hazards

- Most mountain pipelines cross **alluvial or colluvial fans**, which are mainly depositional but can still **scour channels**, exposing pipelines to debris-flow impacts.
- **Avulsions** can occur when deposition blocks channels, forcing flows into new or old channels.
- In **transport zones**, debris flows are highly erosive and can strip overburden, exposing pipelines to direct impact.
- New or existing pipelines in these areas require hazard assessments:
  - Classify creek crossings (debris flow, debris flood, flood)
  - Map fans and avulsion paths
  - Evaluate channel scour potential
  - Use tools like **Melton Ratio** and watershed length for classification
- Where multiple hazards exist, design for the **most severe hazard**.
- Combined debris flood and debris flow risks can increase exposure and damage potential if scour exposes a buried line.



Rizkalla and Read 2019. Chapter 13. BGC Engineering Inc

Debris Flow Susceptibility

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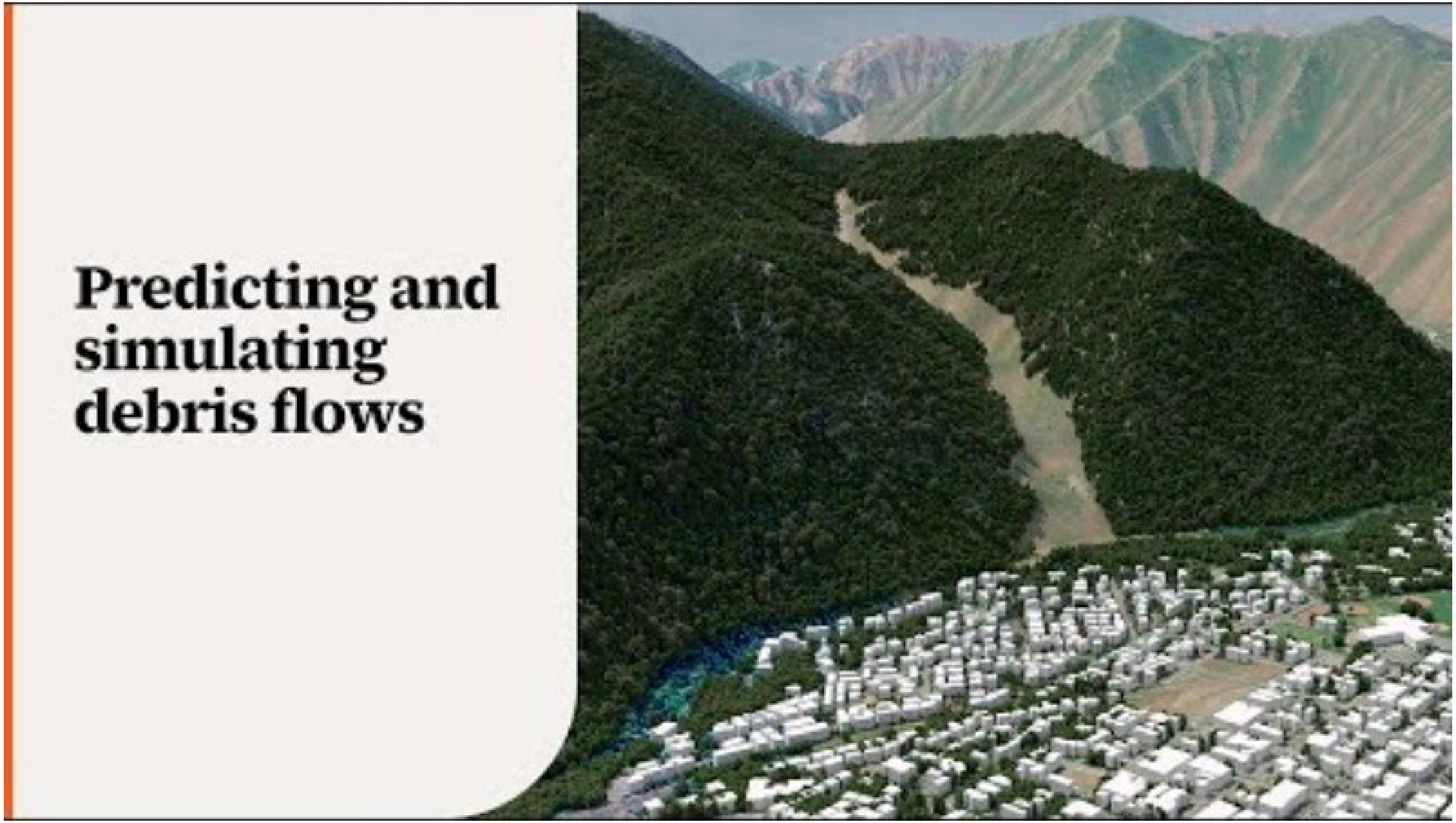
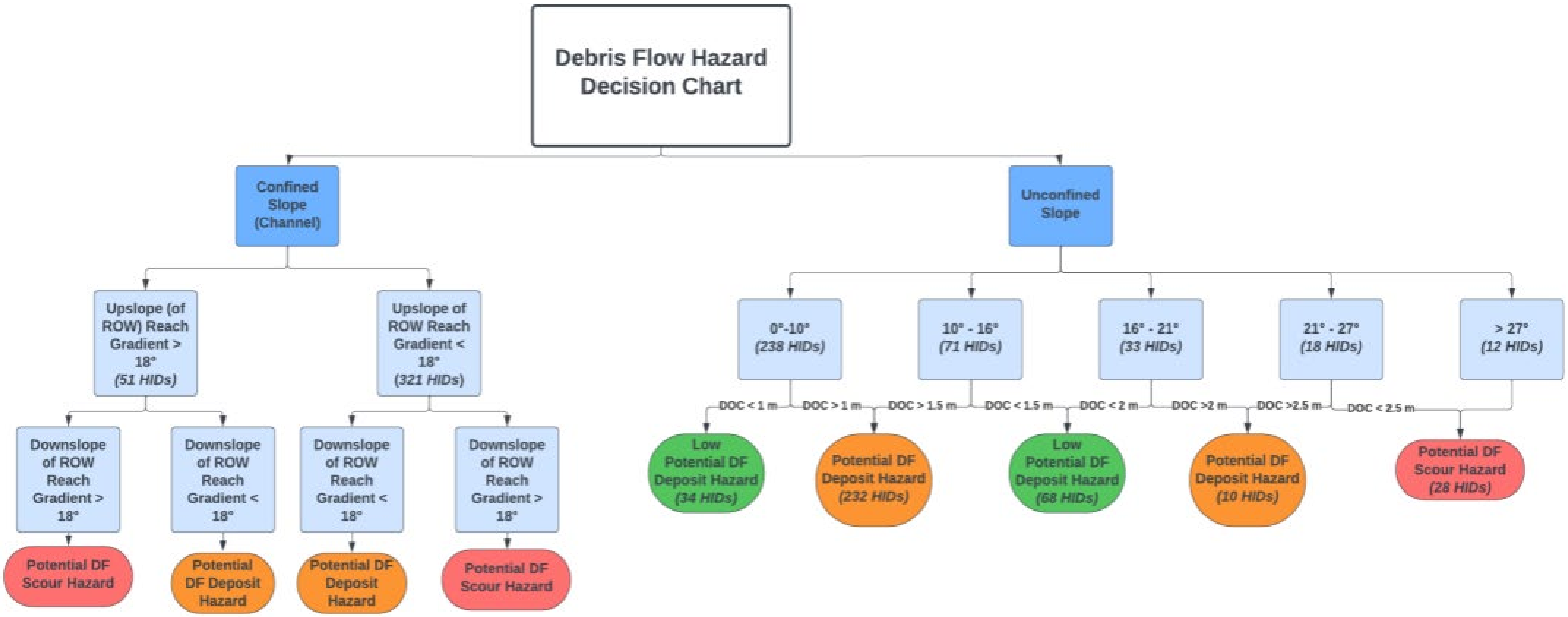
- **Objective:** Evaluate debris flow probability, vulnerability, and select mitigation.
- **Stability:** Assess initiation using historical evidence, basin conditions, sediment supply, channel gradient, and fan activity.
- **Trigger:** Estimate frequency from regional frequency-magnitude data, rainfall correlations, or expected discharge and return period.
- **Vulnerability:** Evaluate spatial/temporal probability of pipeline impact using proximity, orientation, GZI, and expected stress/strain on pipe.
- **Mitigation:** Select site-specific measures from toolbox:
  - *Construction:* Pipe protection, backfill, coatings, heavy wall pipe.
  - *Control:* Barriers, diversion, bank/channel protection.
  - *Isolation:* Aerial crossing, deep burial, trenchless methods.
  - *Monitoring:* Surveillance, ILI, climatic/seismic monitoring.
- **Practical Analysis:** Use GIS to map debris flow zones (basin, transport, channel, fan).
- **Key Inputs:** Catchment size/elevation, debris type/size/supply, channel morphology, rainfall, flow, velocity, pipe specs, and location.

Debris Flow Modelling



Stantec Debris Flow Predictor: A tool that simulates the complex behavior of debris flows

Debris Flow Hazard Decision Chart

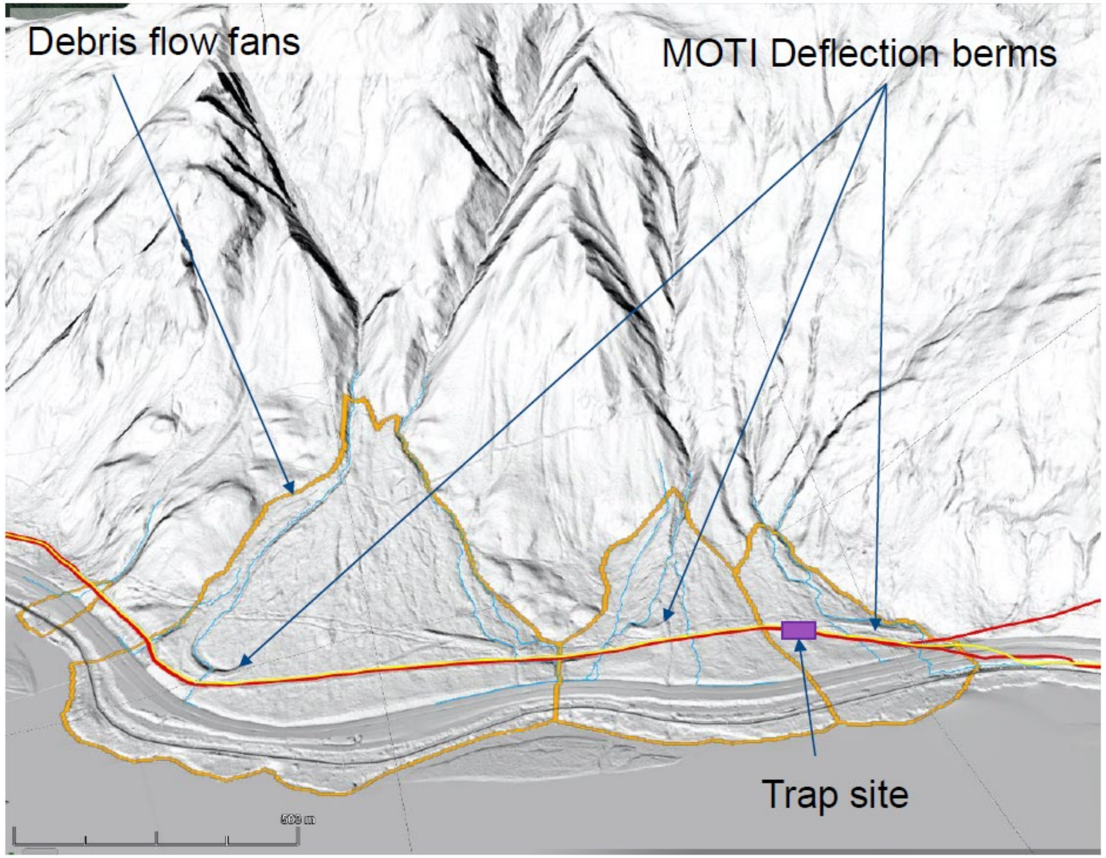


Stantec 2024 Debris Flow Screening Citeria - Scour and depositional Hazard Screening

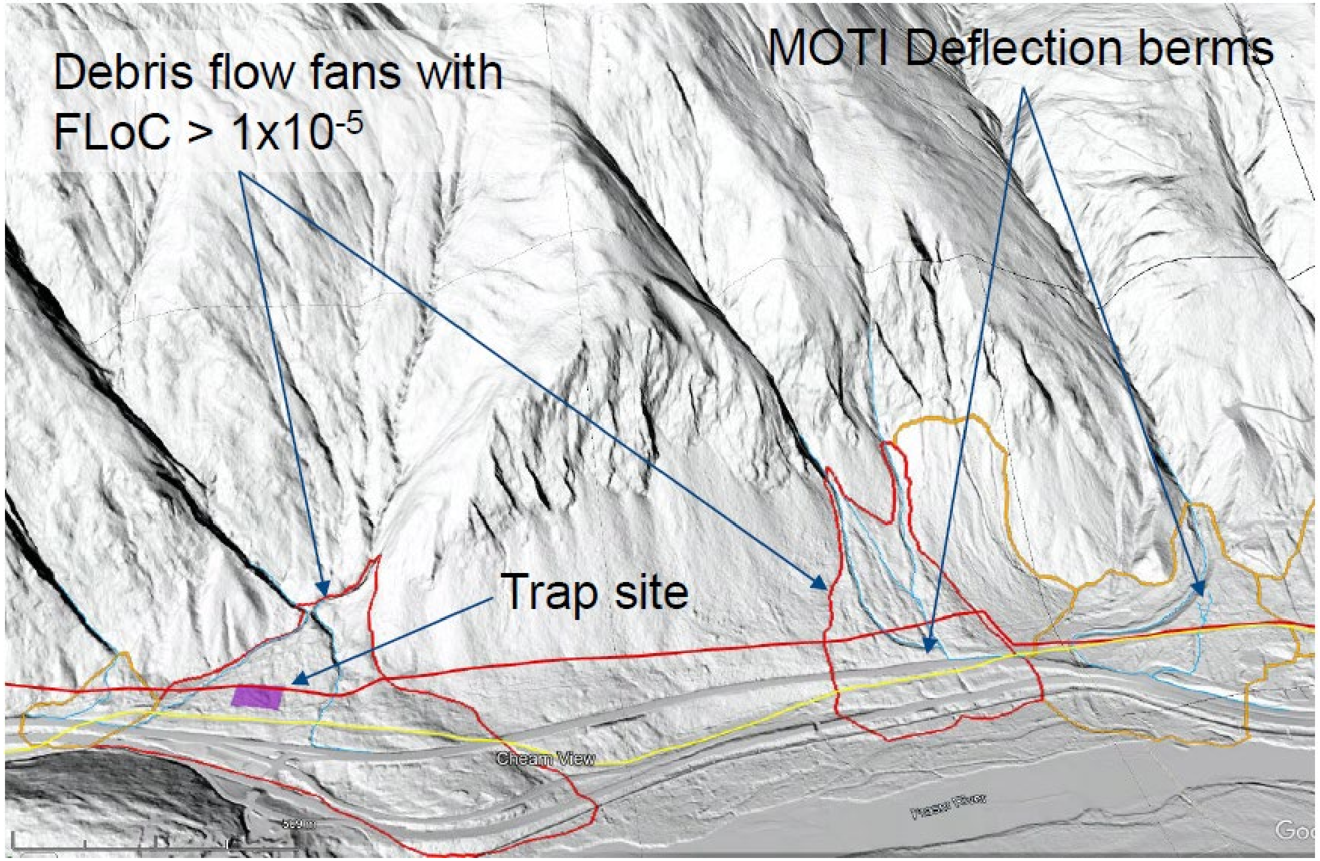
Debris Flow TMEP Modelling

An overview of the assessed area (yellow). The extents of the upstream and downstream pads are shown in white. The valve sites within these pads are depicted in red.

Debris Flow TMEP Modelling



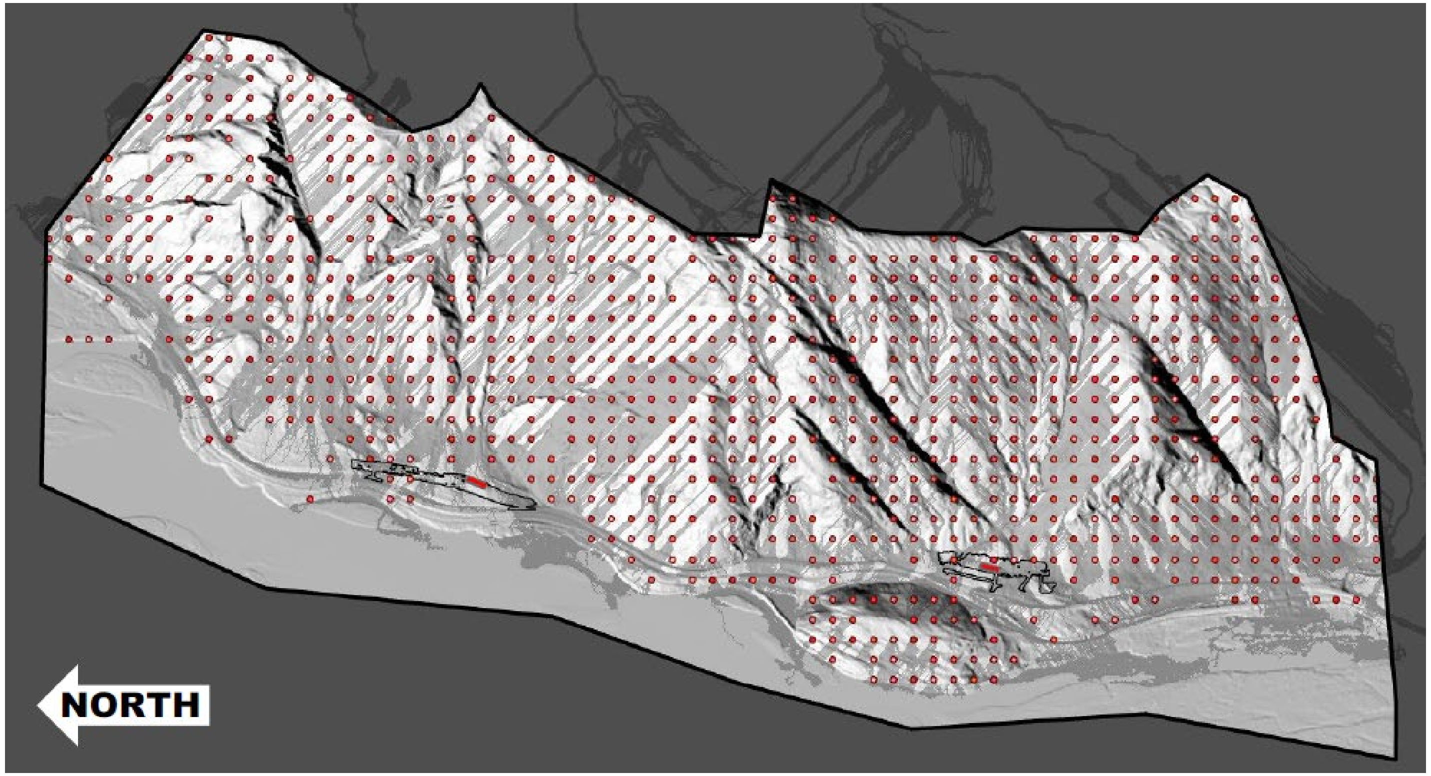
Lidar for Trap Site #1



Lidar for Trap Site #2

Debris Flow TMEP Modelling

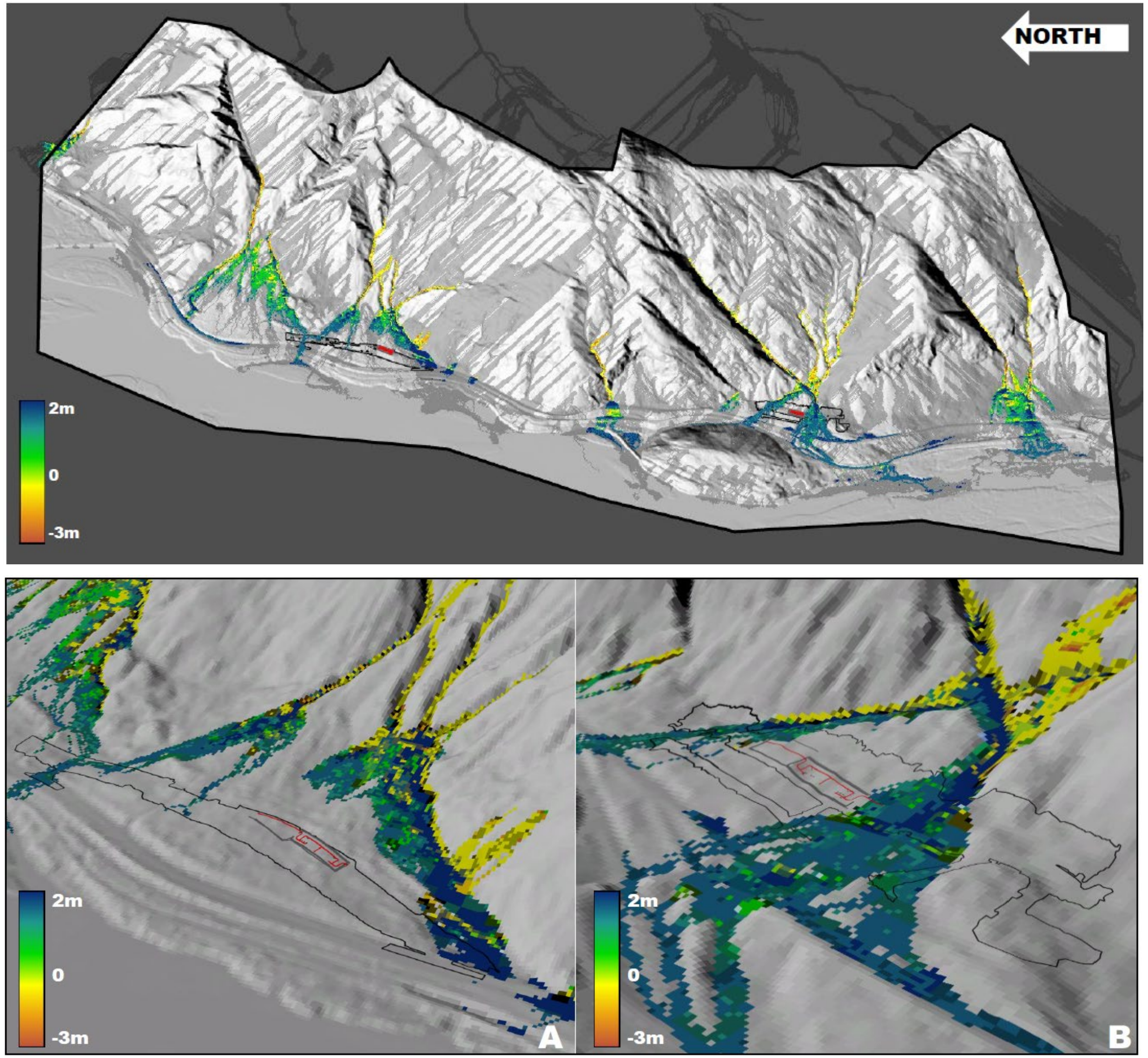
- DEM imported into Debris Flow Predictor.
- Method:
  - 50 initiation configurations upslope of valve sites.
  - ~20 initiation points per configuration.
  - 100 simulation loops.
- Output: ~93,800 probabilistic debris flow runout simulations.



Systematic distribution of debris flow initiation locations in the assessed area. The resulting model debris flows that resulted from these initiation locations is also shown (semi-transparent dark grey).

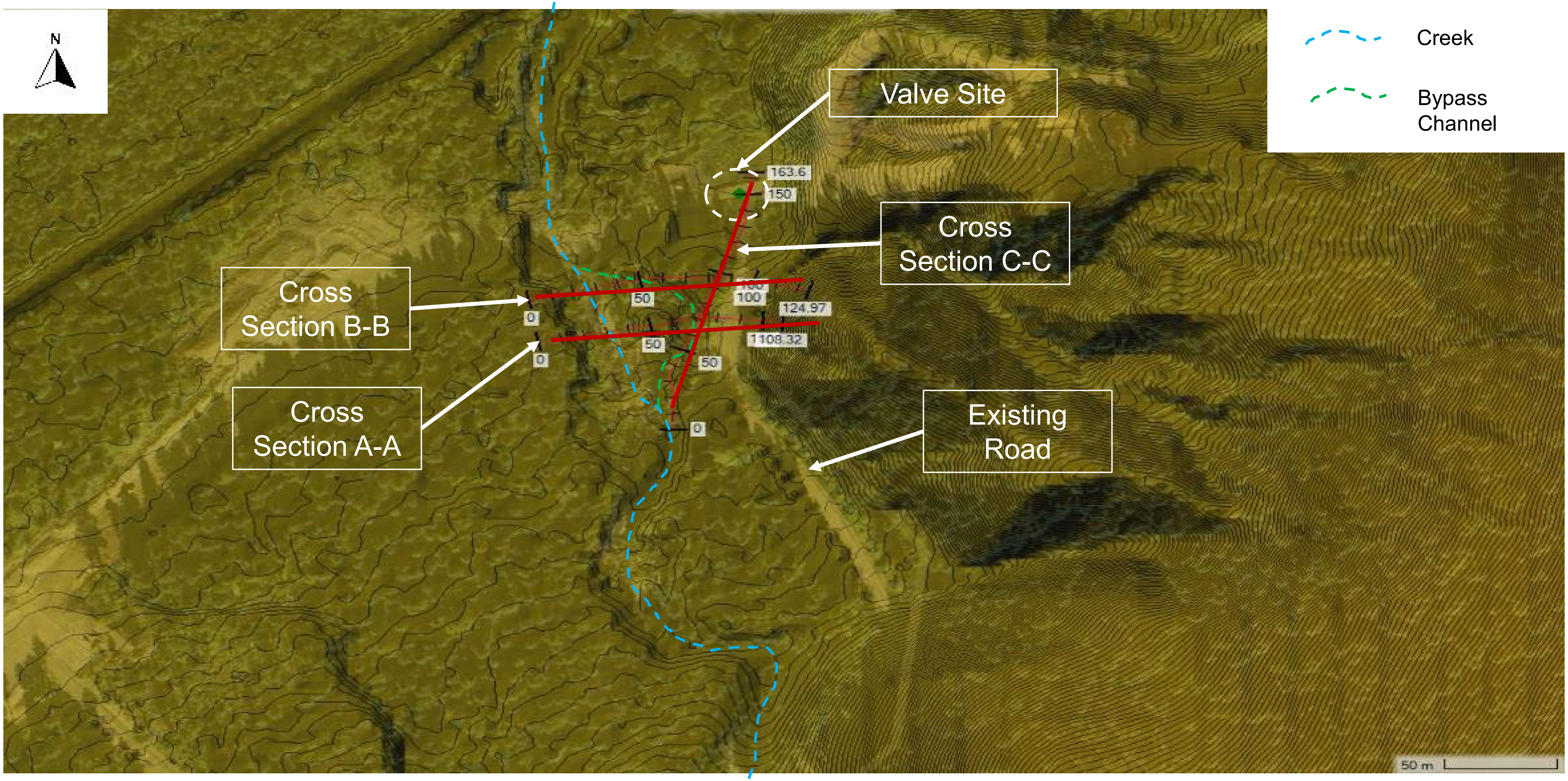
Debris Flow TMEP Modelling

- **Event Counts:** Exported from DebrisFlow Predictor → indicate how often debris flows reach points → used to calculate runout hazard (HR).
- **Scaling:** Simulations corrected to real-world debris flow frequency using Area-Based Probability-Intensity (PI) curves (Stantec 2023; Guthrie et al. 2023).
- **PI Curves:** Link rainfall intensity to landslide likelihood.
- **Conditions Considered:**
  - 2021 Atmospheric River (~1:200-year event) — up to 177 mm in 24h
  - Annual Probability — Calculated with CDF plots (IDF_CC tool) for various rainfall scenarios and years.
  - 50-Year Design Life — Exceedance probability estimated by combining annual probabilities.
- **Climate Note:** Probabilities vary with climate change scenarios (RCPs).



Mean depth of net scour and deposition. Total model debris flow coverage shown in dark grey.

Debris Flood Modelling



Debris Flood Modelling

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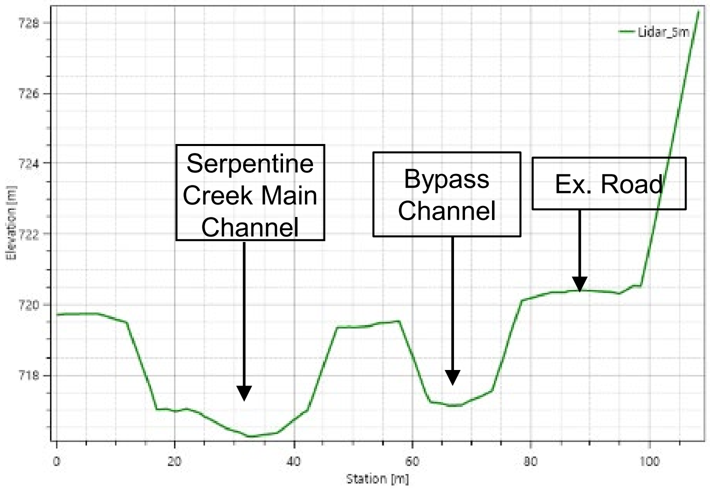
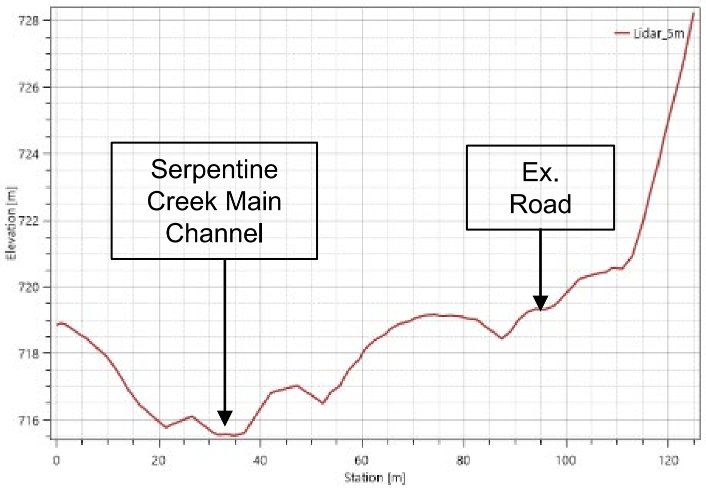
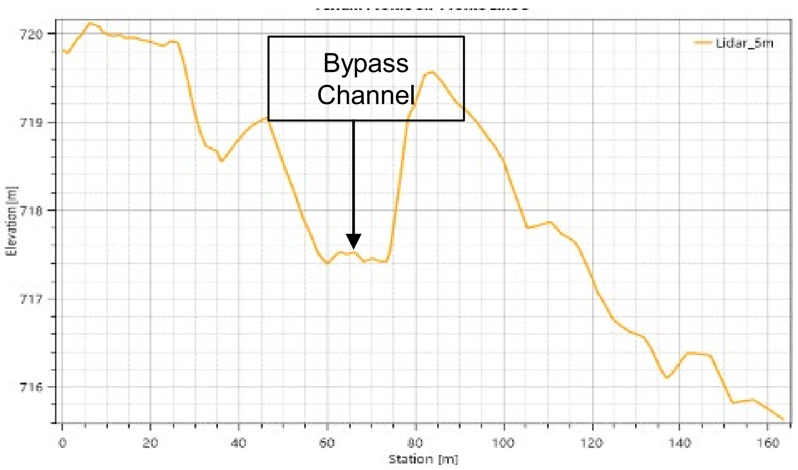
Cross Sections



Cross Section A-A



Cross Section B-B

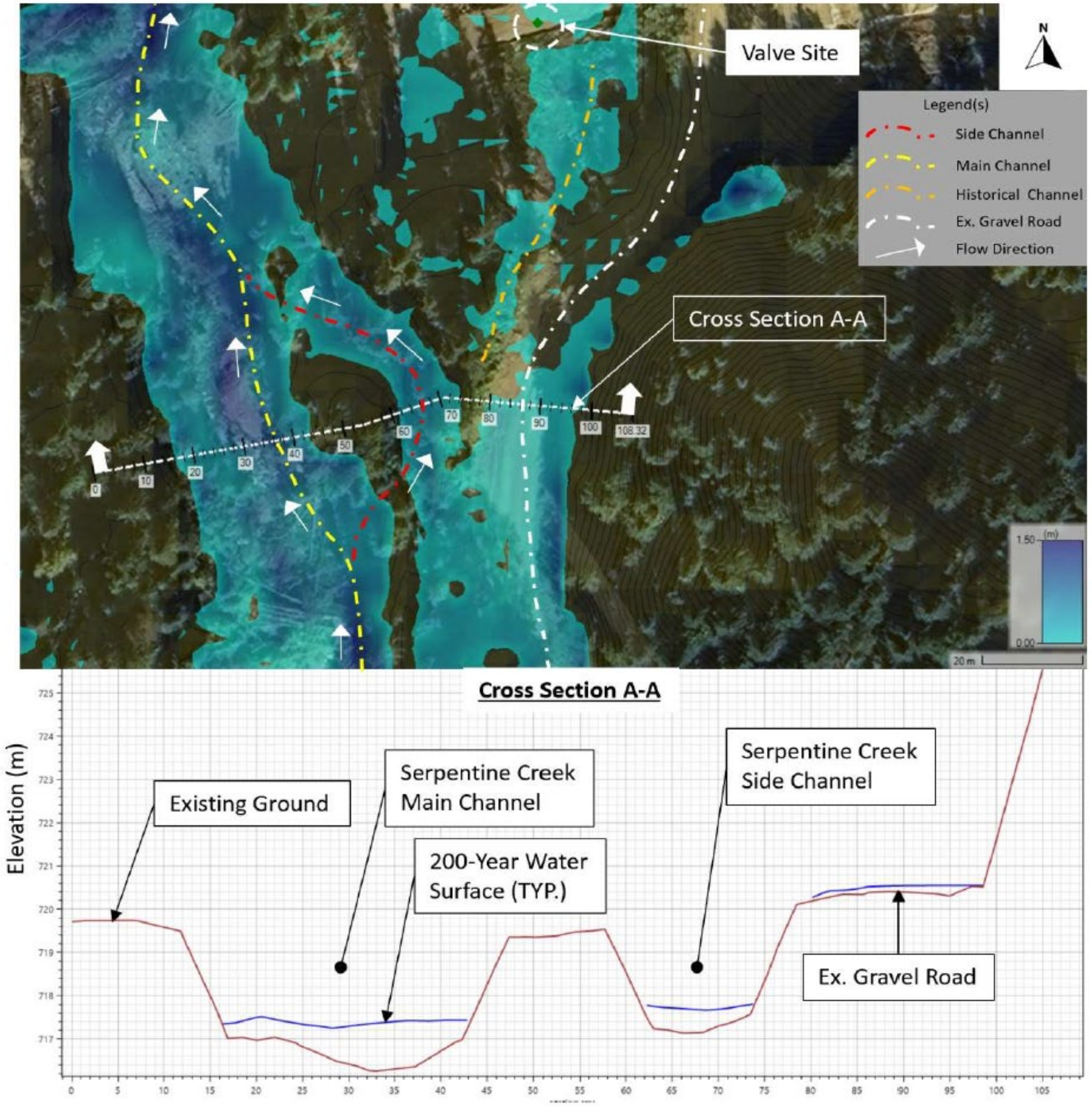


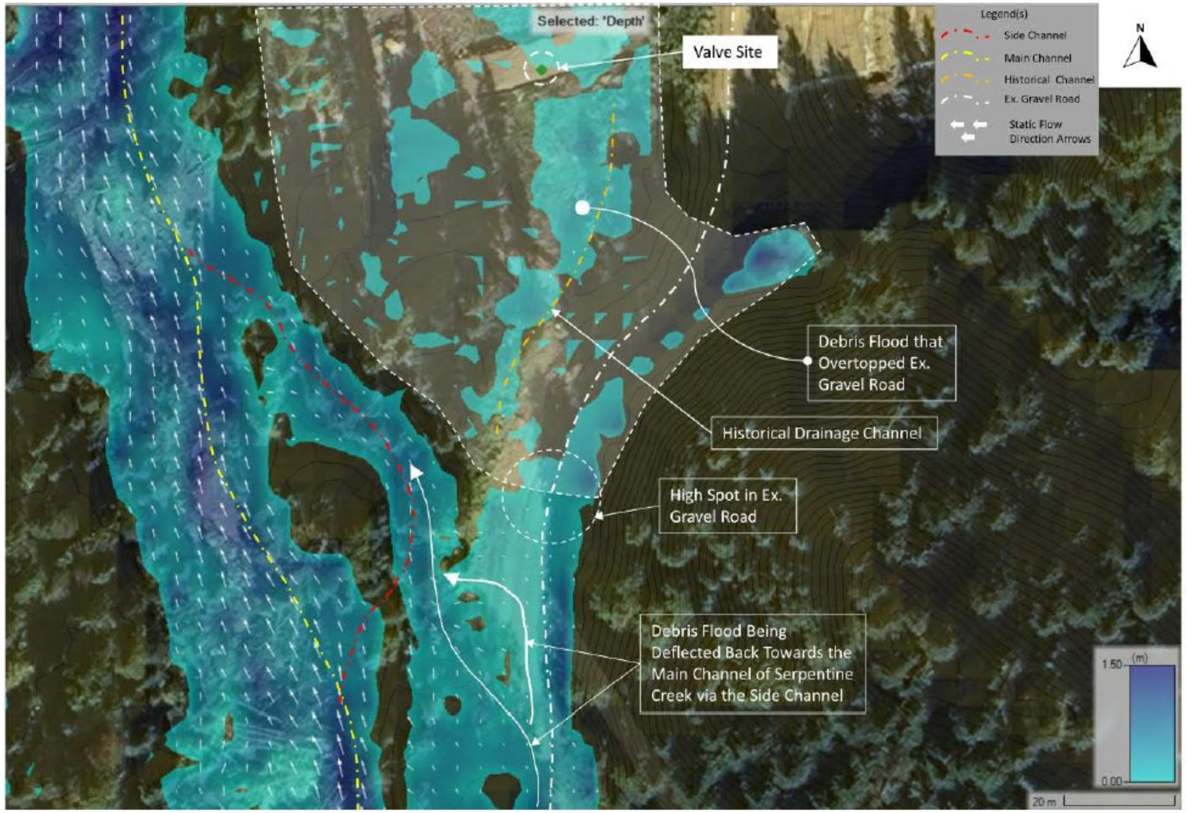
Cross Section C-C

Table 5 – Summary of Design Flows During Different Return Periods

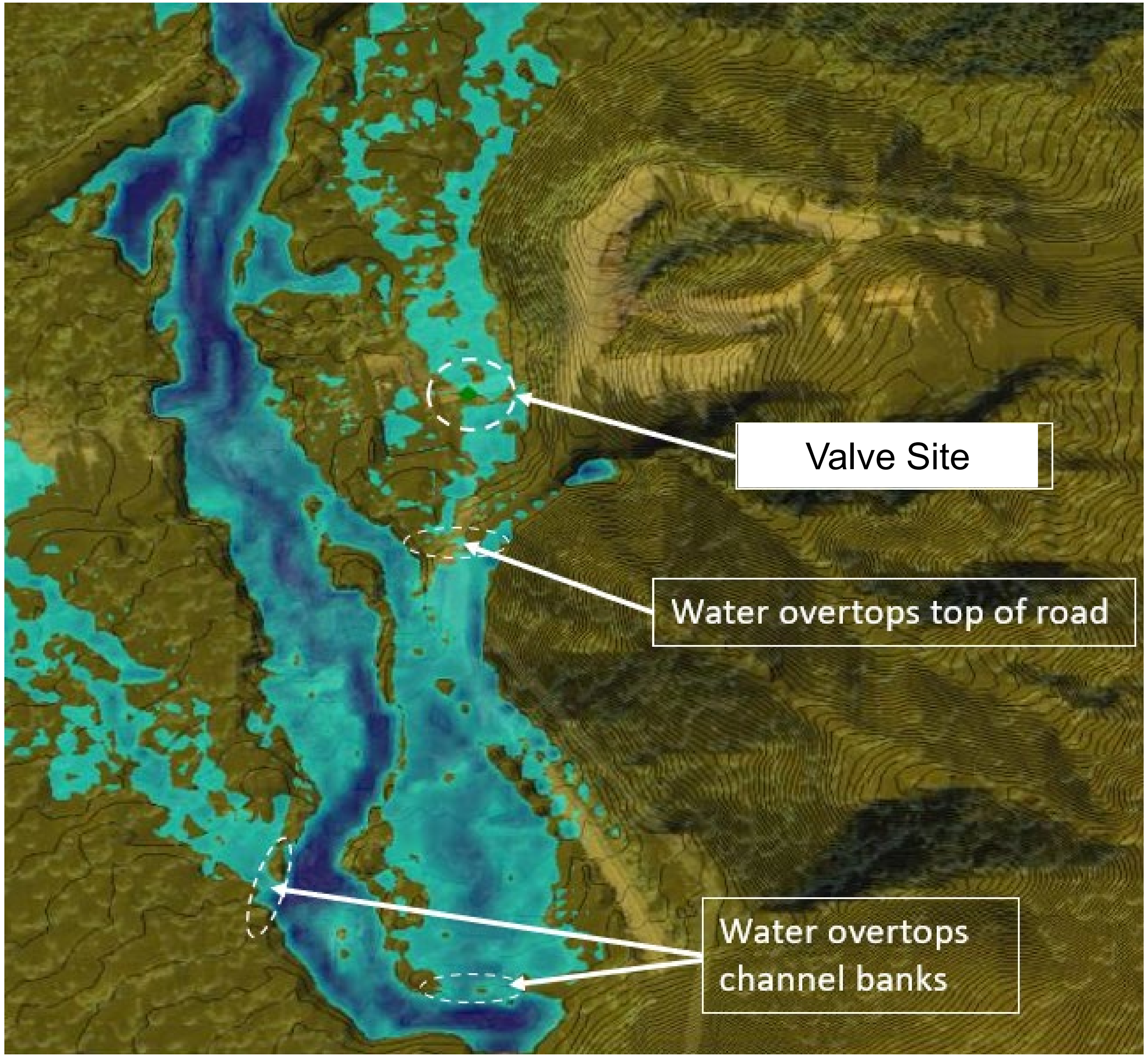
Return Periods	Peak Clearwater Flow (m^3/s)	Design Flow (with Climate Change Adaptation and Bulking Factor Applied) (m^3/s)
200-Year	33	73
100-Year	30	67
20-Year	25	54
2-Year	17	38

Debris Flood Modelling





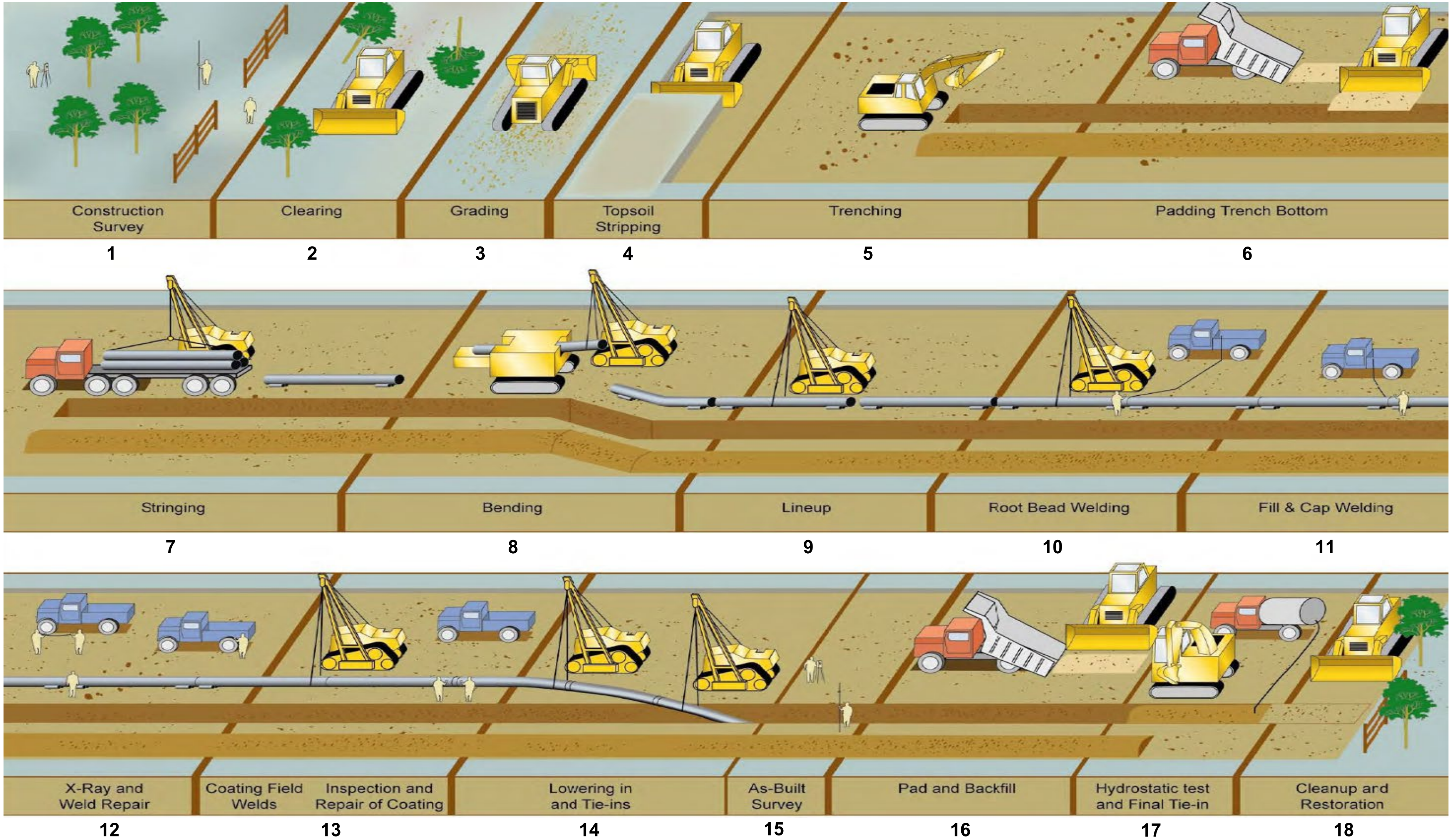
2K576 Debris-Flood Deflection Berm



Pipeline Construction Overview

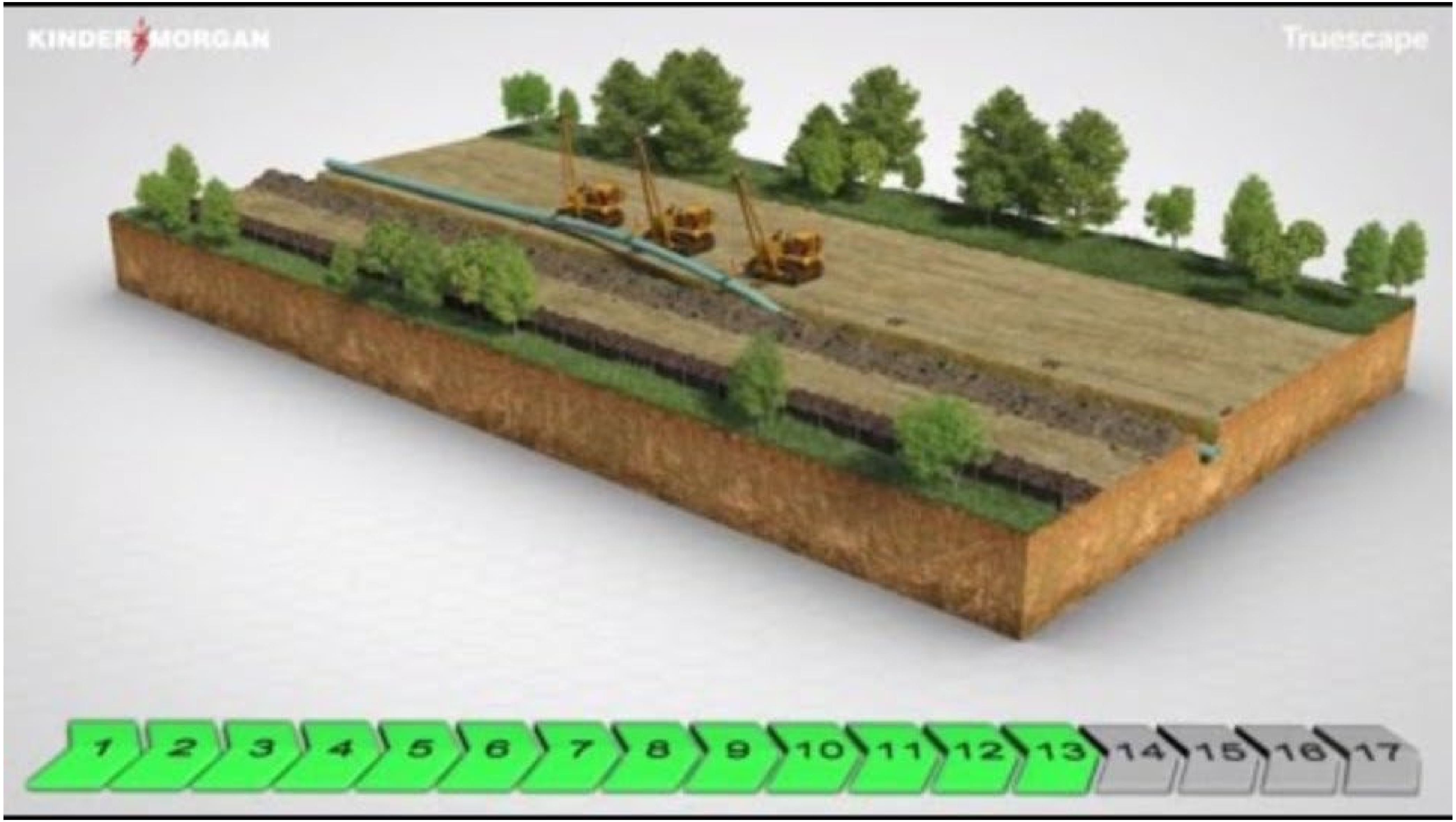
TRANSMOUNTAIN

Pipeline Construction Overview



For illustration purposes and not to represent TMEP in particular

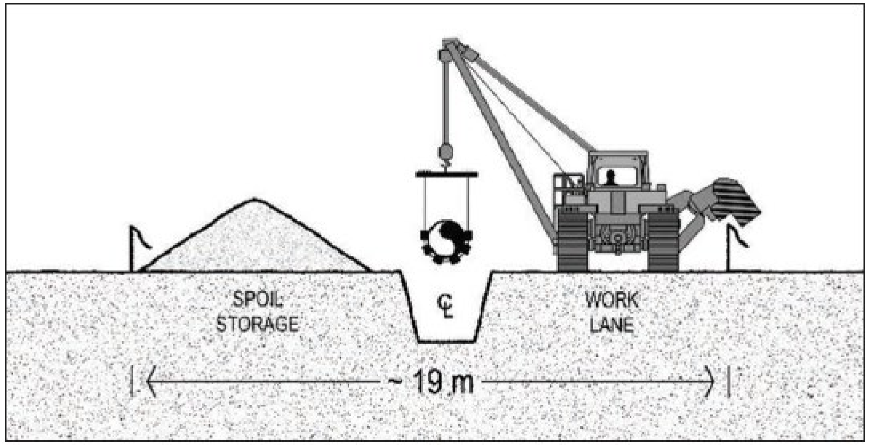
Pipeline Construction Overview



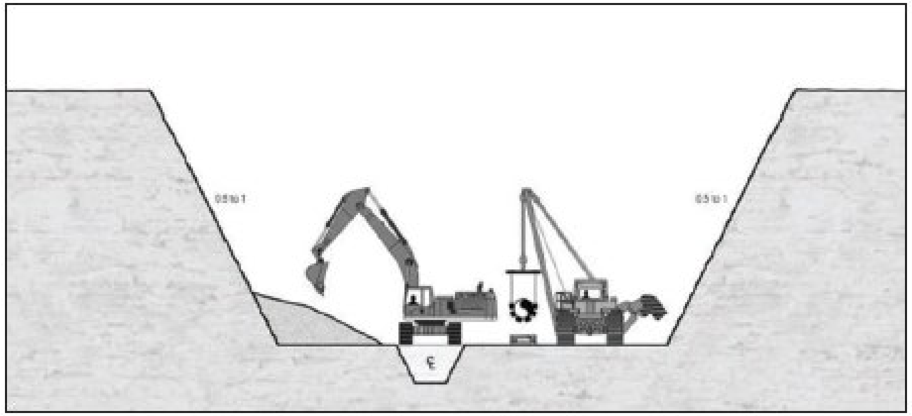
Pipeline Construction Overview

Grading – ROW Configurations

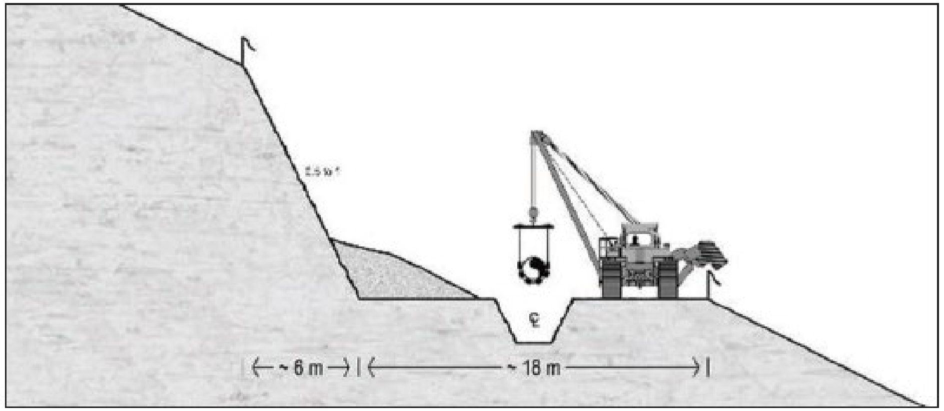
Flat Terrain



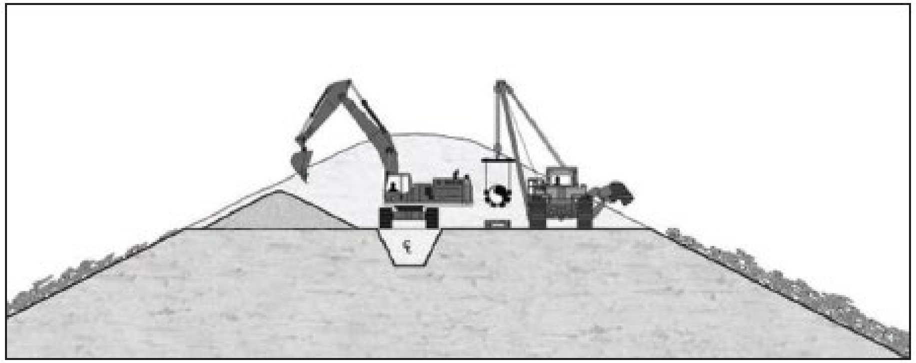
Thru-Cut



Side Cut Slope



Ridges

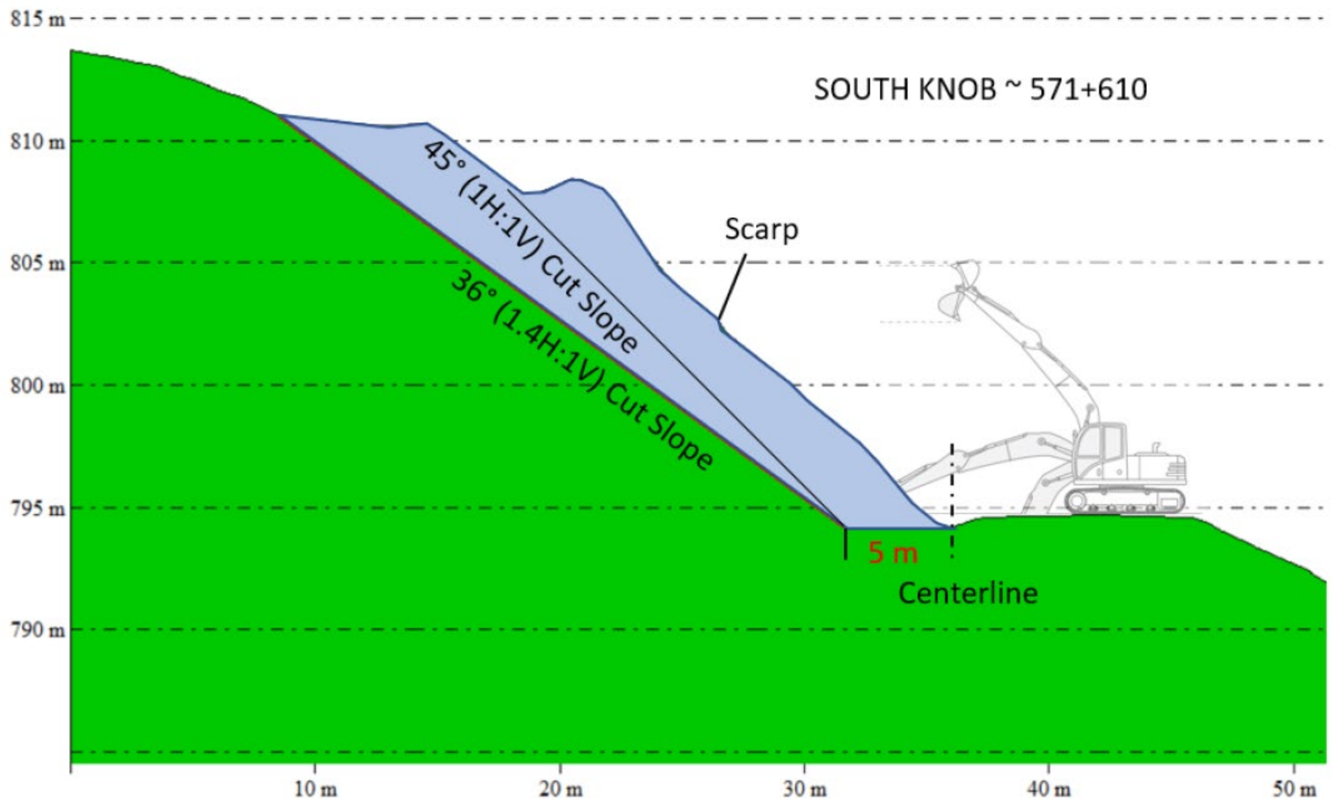


Pipeline Construction Overview

Side Cut Geotechnical Considerations

The stability of the graded cut and fill slopes is determined by the type of material being excavated.

- Competent bedrock may allow for cuts at 0.25H:1V.
- Fractured rock may require a 0.5H:1V angle. Surficial materials like glacial till are only temporarily stable at 1H:1V.
- Coarse soils may be stable at 1.5H:1V or 2H:1V.



Pipeline Construction Overview

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Grading Methods


Excavator


Blasting

ROW Configurations Examples


Side Cut Slope


Flat Terrain

Pipeline Construction Overview

TRANSMOUNTAIN

Pipeline Construction Overview

Trenching

Pipeline Construction Overview

Blasting

- Controlled blasting is used to break up hard rock to achieve required trench depth and grading.
- Enables efficient excavation in areas where conventional digging is impractical.
- Requires careful planning, safety controls, and monitoring to protect the pipeline corridor and surrounding environment.

Assessment & Management of ML/ARD

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Metal Leaching / Acid Rock Drainage

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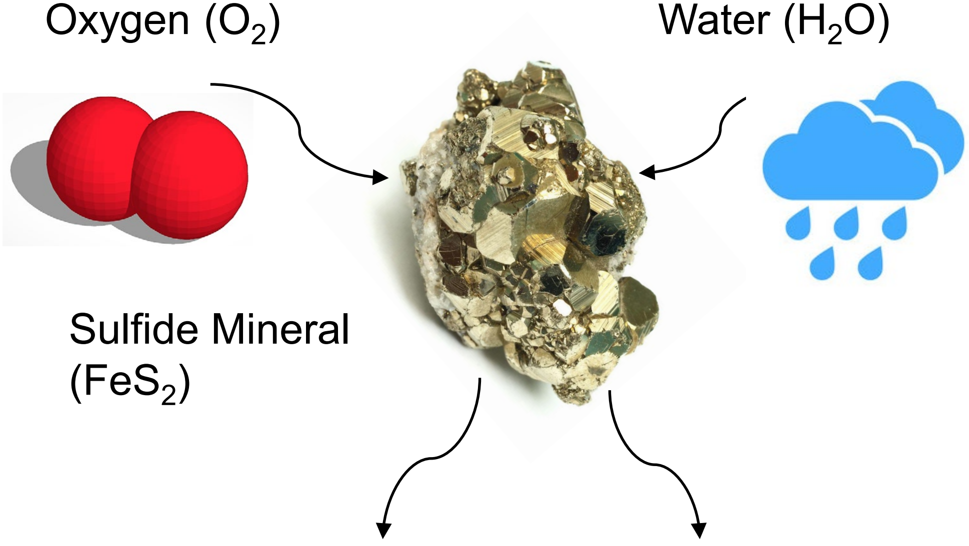
ML/ARD – What is it

Acid Rock Drainage (ARD) is a geochemical process that occurs when **sulfide minerals**, especially **pyrite (FeS_2)**, are exposed to **oxygen and water**—typically during construction, mining, or excavation. The reaction produces **sulfuric acid**, which lowers the pH of surrounding water and can lead to the **leaching of metals** from surrounding rock.

This reaction continues with further oxidation, especially in the presence of iron-oxidizing bacteria, producing **more acidity and dissolved metals**, which can contaminate groundwater and surface water.

Primary ARD Reaction



Metal Leaching / Acid Rock Drainage

Photo by Taylor Roades, 2023. The Guardian, June 18, 2024

HWY 1 Kicking Horse Canyon (Google Earth)

Understanding ML/ARD: What You Need to Know

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- Serious ARD can occur in rock with relatively low concentrations of susceptible minerals.
- Contamination can occur immediately after bedrock disturbance or might take months or years to develop after the bedrock disturbance has occurred.
- May be no visual evidence of ML contamination other than a lack of healthy aquatic biodiversity due to high dissolved metals contents in the water.
- Can occur in rock fills and exposed rock cut slopes.
- Once started, can last for centuries.
- ML/ARD is challenging to control and manage.

Observed water in the CMC 4 trench.

ML/ARD in Pipeline Corridor

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- **Identify susceptible rock material** in areas with variable geology along linear corridors.
- **Segregate or minimize volumes of ML/ARD-prone rock** to reduce handling and management costs.
- **Use phased rock exposure and disturbance** (e.g., access, clearing, grading, trenching) to limit early contact with bedrock where possible.
- **Multiple work fronts** may require continuous assessment and delineation when unassessed bedrock is uncovered during grading or trenching, which can lead to delays while waiting for assessment results.
- **Avoid double handling** by planning excavation and storage to account for limited working space and to manage ML/ARD-prone material efficiently.
- **Assess imported rock material** to ensure it does not introduce additional ML/ARD risks.

Pipeline Construction Workflow

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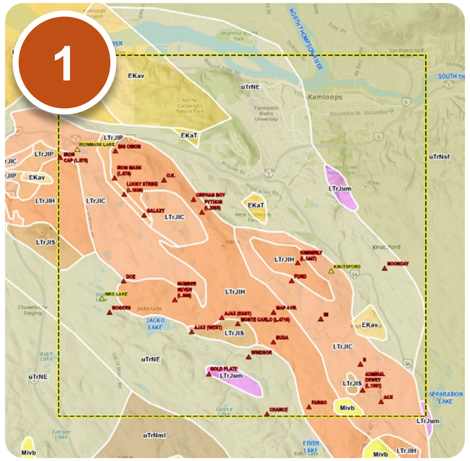


Project Planning
Tasks
- Desktop ML/ARD assessments.
- Develop ML/ARD Management Plan.

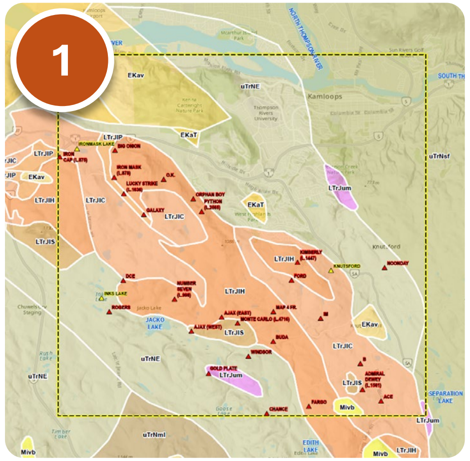
Pre-Construction
Tasks
- Monitor initial implementation of the ML/ARD management plan.
- Sample accessible rock outcrops.
- Conduct static geochemical testing.
- Perform laboratory kinetic tests.
- Develop rapid on-site assessment criteria.
- Pre-assess the ML/ARD potential of rock material.
- Characterize baseline surface water quality.

Construction
Tasks
- Monitor implementation of the Plan.
- Ongoing assessment of accessible bedrock using rapid assessment.
- Field marking / delineation.
- Stockpile / mitigation tracking.
- Maintain data management system and provision of mitigation recommendations.
- Monitoring surface water quality.

Grade Reinstatement and Mitigation
Tasks
- Assess site-specific cut slope mitigation designs and permanent drainage controls.
- Monitoring and tracking of mitigation implementation.
- Monitoring surface water quality.

Post Construction
Tasks
- Monitoring effectiveness of applied mitigations.
- Monitoring surface water quality.

Project Planning



- Review available geological mapping.
- Identify geological units that may be prone to hosting ML/ARD.
- Identify known mineral occurrences and metal mine sites from provincial databases to assist with the geological characterization.
- Look for opportunities for ML/ARD-based route optimization.
- Work with the client to develop a project ML/ARD Management Plan based on:
  - Anticipated project scale
  - Site conditions
  - Pipeline owner’s tolerance for risk

Bedrock Geology and ML/ARD

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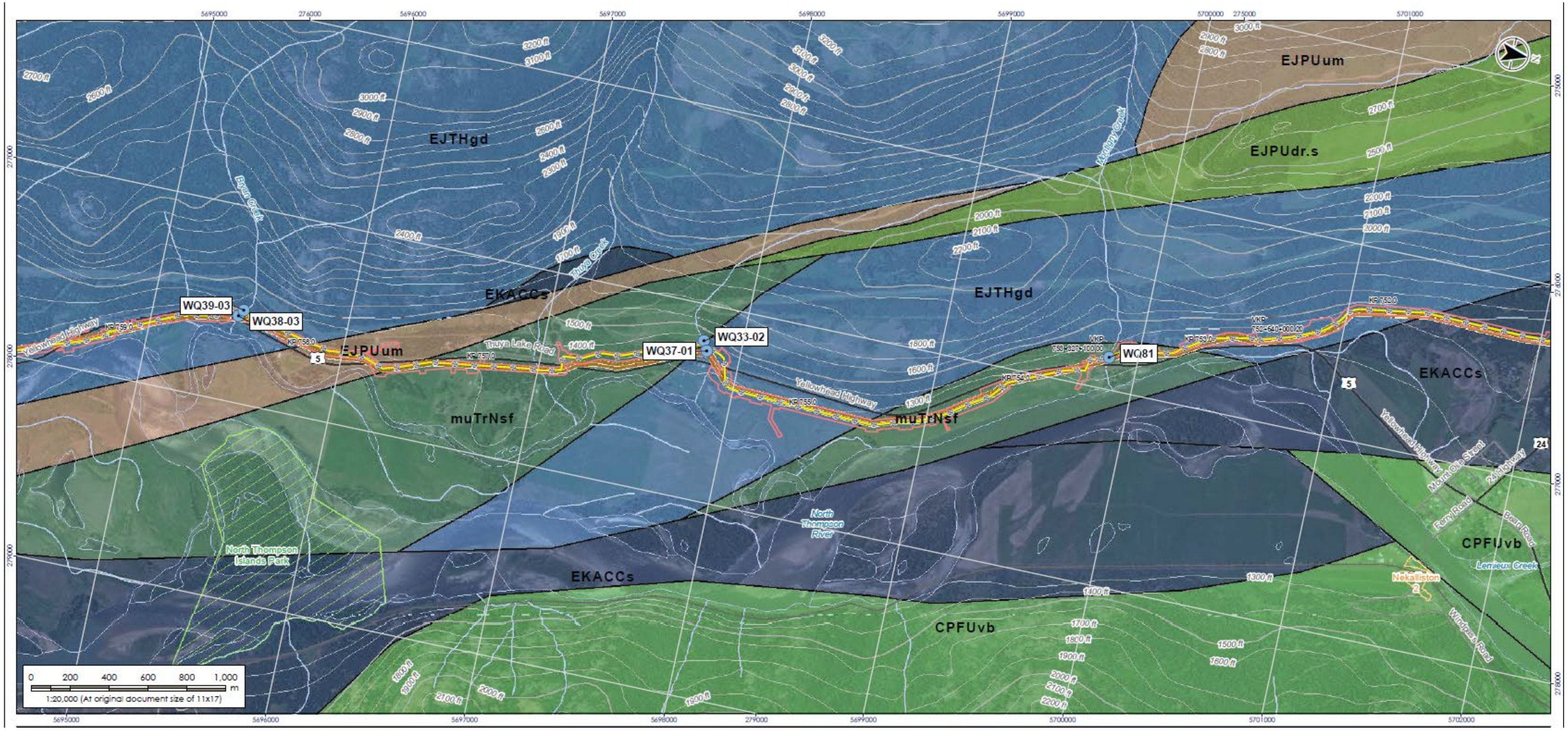


- Highway
- Road
- Minor Road
- Railway
- Major Topographic Contour (ft)
- Topographic Contour (ft)
- Watercourse
- Waterbody
- First Nations Reserve
- Park, Ecological Reserve, Protected Area, or Conservancy
- Water Quality Sample
- Kilometre Post
- Centreline
- Footprint
- Existing RoW

CPFUvb	Clinopyroxenite, hornblendite, wehrlite, dunite, serpentinite; local gabbro, diorite, intrusion breccia
EJPUdr.s	Conglomerate, sandstone, siltstone, shale, coal
EJPUum	Hornblende-biotite granodiorite, quartz monzodiorite, quartz diorite
EJTHgd	Microdiorite, quartz diorite, mafic schist, skarn
EKACCs	Pillowed and massive basalt; local chert, diabase, gabbro
muTrNsf	Siltstone, argillite, slate; local limestone, volcanic sandstone and basalt

Pre-Construction

- Bedrock samples collected from within proposed construction footprint:
  - On-site geology mapping conducted, looking for: **Geological contacts, Evidence of susceptibility.**
  - Where practical, subsurface investigation can be conducted, which can also determine depth of bedrock (e.g., test pits, test holes).
- Rock samples sent for static (and sometimes) kinetic testing **– this data is critical for developing rapid assessment criteria for use in future phases of project.**
- ML/ARD testing / assessment completed on known source material quarries to prevent import of susceptible material onto project.
- Surface water sampling and testing conducted pre-construction to determine background surface water quality.

Construction

ML/ARD Data Collection and Management System

- Integrated digital data collection in the field.
- On-site lab
- Rapid testing – Portable X-Ray Fluorescence Spectrometer (pXRF).
- Decision-ready data in 24 hours.
- Deliverables that can be used by all members of the project team.

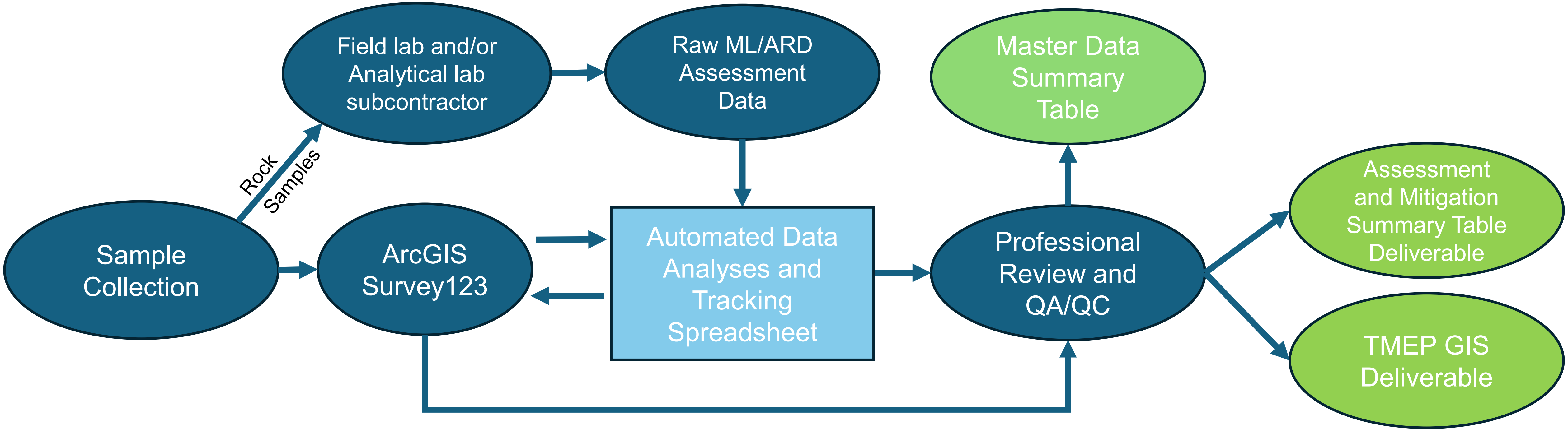
Kinetic testing

- Can be conducted on site in the field where appropriate.

Marking, Tracking, and Monitoring

- Review classification and mark exposed rock.
- Track rock stockpiles and applied mitigation.
- Conduct surface water sampling and assessment.

Construction



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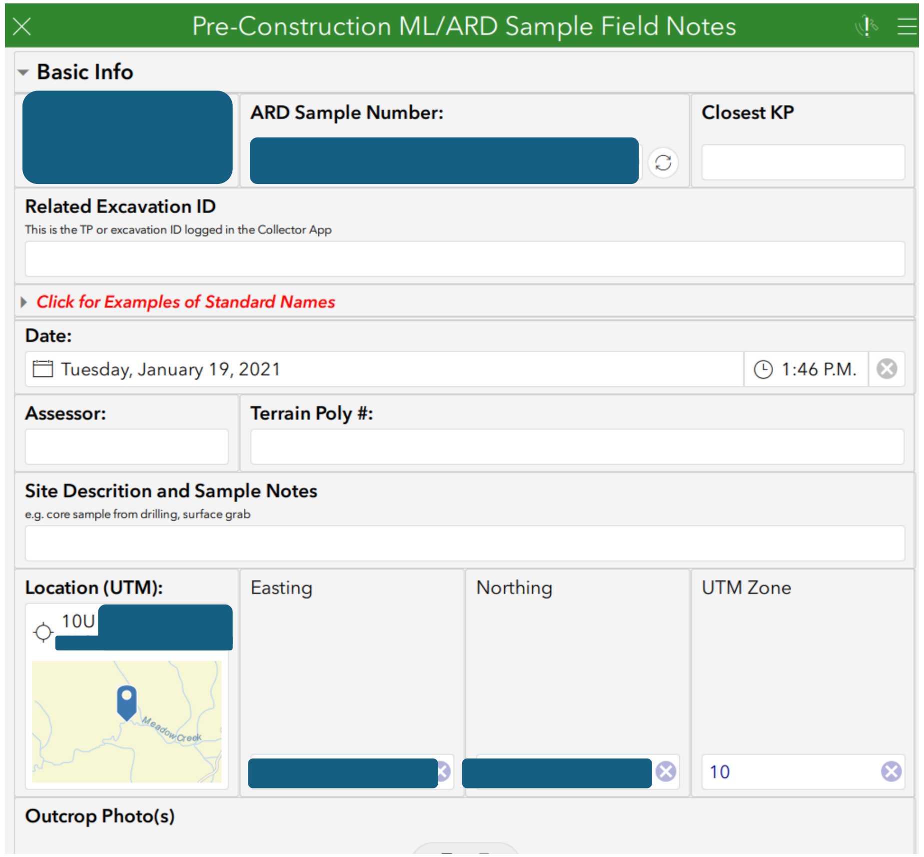
Digital Field Data and Sample Collection

- Field staff complete field forms on digital tablets for sample collection and geological observations. They have field-access to up-to-date assessment data to support decision making.

Digital Field Data Collection and pXRF Assessment

Using tablets and Survey 123 application. Field crews have access to assessment data within 24 hours to assist with field-based decision making.



GIS platform for sample collection

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On-Site Lab Trailer

- Set up on-site for rock crushing (with power) and pXRF testing.

Photos by Thurber, Spread 5B TMEP.

Construction

Rapid Testing – Portable X-Ray Fluorescence Spectrometer (pXRF)

- Determines elemental composition of crushed rock samples in minutes; can be used to predict ML/ARD potential.
- Quantitative and repeatable assessment method that can be used in the field (in most cases, likely not as accurate as static testing).
- Requires calibration with static data from samples collected pre-construction.
- Faster results than static testing.
- **A cornerstone tool in ML/ARD assessment methodology.**

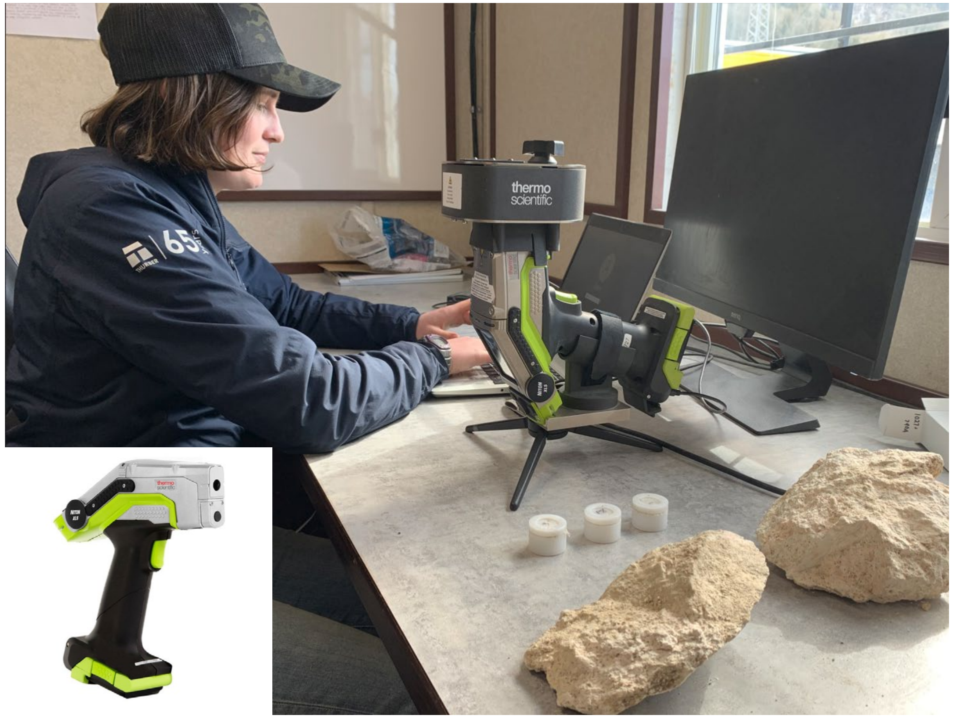

Photo by Thurber, Spread 5B TMEP

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Construction Management Category (CMC) Definitions and Mitigation Methods

Category 1 - "Normal" rock with no ML/ARD-related restrictions on the handling and use of this rock material.

Category 2 - "Low Sulfur PAG" Rock. This material will be re-used on the project RoW provided it is tracked, monitored, and kept 25m away from waterbodies.

Category 3 – "High Metal-Leaching (ML) Potential" Rock. This material will be removed from the project RoW and taken to licensed, off-site disposal facilities.

Category 4 – "High Sulfur PAG" Rock. This material will be removed from the project RoW and taken to licensed, off-site disposal facilities.

Category 5 – "Low Metal-Leaching Potential" Rock. This material will be re-used on the project RoW provided it is tracked, monitored, and kept 25m away from waterbodies.

CMC	DESCRIPTION	SPECIAL HANDLING AND MONITORING	RE-USE AND MONITORING	LICENSED OFF-SITE DISPOSAL	MITIGATION OF EXPOSED ROCK CUTS AND MONITORING
1	"Normal" Rock	No Mitigation required			
2	Low Sulfur PAG	✓	✓		
3	High ML	✓		✓	✓
4	High Sulfur PAG	✓		✓	✓
5	Low ML	✓	✓		

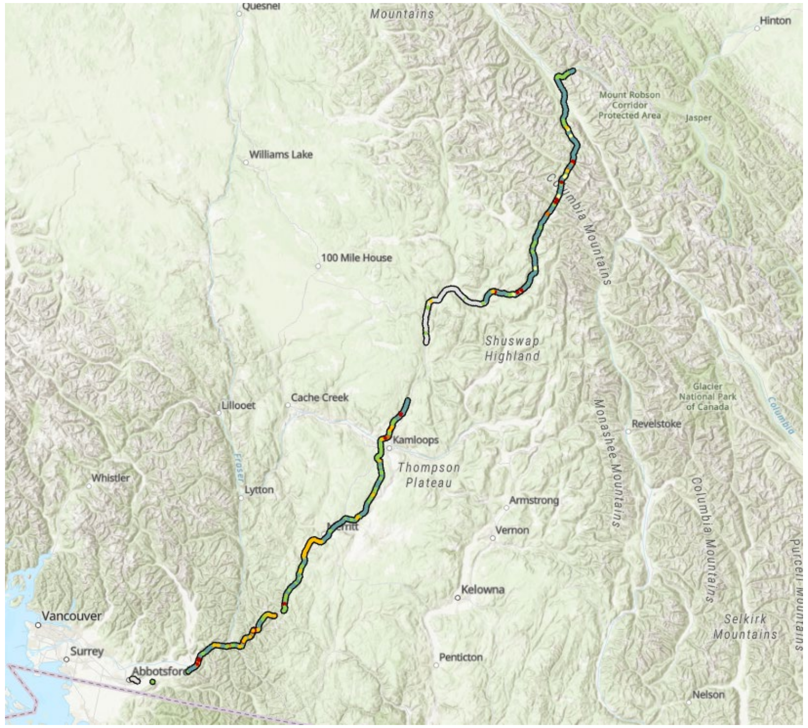
Construction

ML/ARD Mapping and Characterization

- Digital mapping products are an indispensable tool to work with ML/ARD rock efficiently and effectively.

Spread	Total Spread Length (Km)	Km of RoW Assessed		Characterization of Rock (%) based on Km of Rock Assessed [1]				
		Rock	Thick Soil	CMC 1	CMC 2	CMC 4	CMC 3	CMC 5
3/4A	201.5	24.16	177.34	63%	11%	6%	19%	0%
4B	74.0	10.6	63.4	87%	0%	1%	4%	8%
5A	186.7	50.72	135.69	87%	0%	2%	2%	9%
5B	85.76	28.4	57.3	53%	2%	18%	6%	20%
6	69.3	2.15	67.16	49%	9%	7%	1%	2%

[1] Percent characterization of rock for each CMC category represents the Km of rock characterized in the given category to date with respect to the length of characterized rock.



ML/ARD Risk Characterization — Bedrock Delineation

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Field Kinetic Testing

- Kinetic testing is the gold standard for ML susceptibility and timing of metal release:
  - Rapid testing (pXRF) → Static testing → Kinetic testing.
  - May support lower rock classification.
  - Data collected could be available in as little as 2-3+ months.
- In-field kinetic testing systems:
  - ROW space was available for rock storage.
  - Field kinetic testing is relatively lost cost compared.
    to potential savings if large volumes are considered.

Construction

Marking, Tracking, and Monitoring

- Review classification and mark exposed rock
- Track rock stockpiles and applied mitigation
- Conduct surface water sampling and assessment

Grade Reinstatement and Mitigation

- It is common for grade reinstatement and mitigation to be ongoing through the life of a pipeline project.
- Sites are individually assessed to provide mitigation and grade reinstatement based on several factors.
- Mitigation tracking and observation is typically part of the project ML/ARD management plan.

Disturbed Material

- **CMC2** and **CMC5** material was determined to be suitable **for reuse and was therefore retained and repurposed on site** as part of the project works.

- **CMC3** and **CMC4** material was **transported off site for disposal at a licensed specialized facility** in accordance with regulatory requirements.

Cut slope

Permanent mitigations included:

- Shotcrete the cut slope.

- Use of fine-grained soil material to cap the cut face.

- Slope recontouring using CMC1.

- Leave rock cuts exposed.

Grade Reinstatement and Mitigation

Mitigation – Disturbed Rock: Permanent off-site disposal

Volume control is critical – no mixing of rock and soil.

Require the provision of landfill characterization data (separate from ML/ARD assessment) weeks in advance in order to facilitate approvals.

ML/ARD Consultant collects the samples and provides the landfill characterization data to the TMEP ML/ARD Coordinators.

Disposal volumes tracked by the Contractor and TMEP ML/ARD Coordinator.

Typical maximum rock size is 300 mm but varies by receiver. Larger rock material was broken up by the Contractor.

Drainage controls and covers recommended for temporary stockpiles of CMC 3 and CMC 4.

Grade Reinstatement and Mitigation

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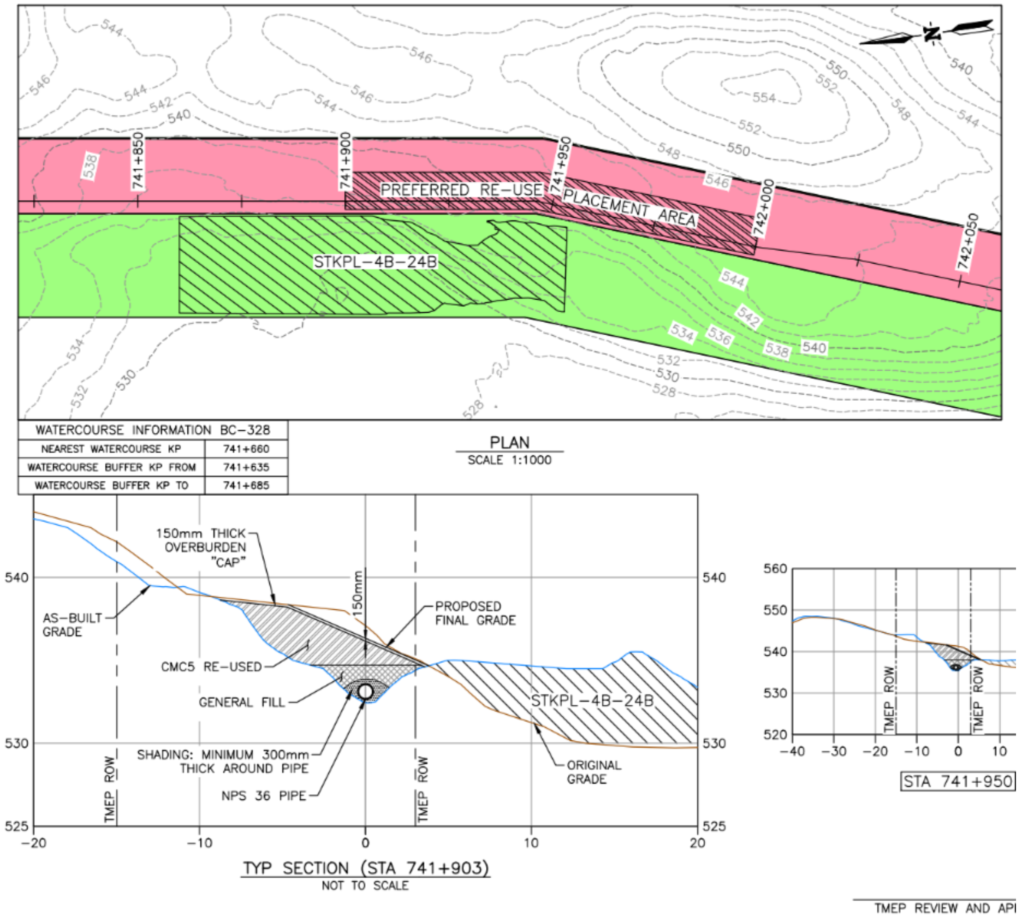
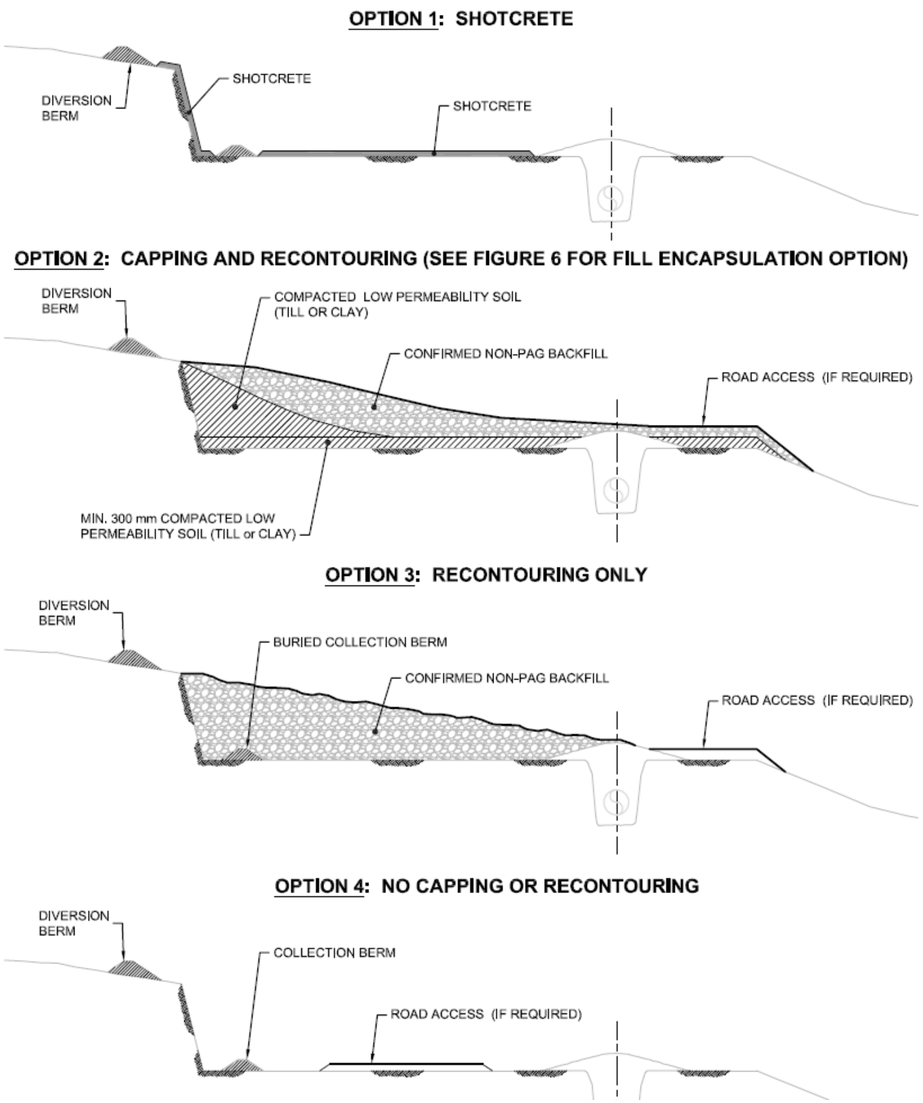
Mitigation – Disturbed Rock: Use in Construction

- Create Reuse Plans.
- Survey location of the reused material.



Grade Reinstatement and Mitigation

Mitigation – Cut Slope Mitigation



Grade Reinstatement and Mitigation

Mitigation – Cut Slope Mitigation

Cut Face Mitigation at a tunnel portal