INTEGRATED REPORT

Canada's Oil Sands Innovation Alliance (COSIA)

Bioengineering and Conventional
Erosion and Sediment Control Solutions
for Oil Sands Operations

May 2018

ISO 9001 and 14001 Certified | An Associated Engineering Company

Executive Summary

Associated Environmental (Associated) was contracted by Canada's Oil Sands Innovation Alliance (COSIA) to prepare a report on Bioengineering and Conventional Erosion and Sediment Control Solutions for Oil Sands Operations. This document is not a prescriptive set of solutions meant to limit innovation.

A key component of this study was to document erosion and sediment control (ESC) approaches currently used by in-situ and mining companies in northern Alberta, and by some coal and forestry companies where their ESC experiences would be relevant to the geographic and ecological conditions encountered by the oil sands companies. Information was collected through interviews with 11 companies and documents acquired from operational personnel. Successes and lessons learned from failures of bioengineering ESC and of conventional engineered ESC were evaluated.

Conventional approaches are defined as techniques to control ESC using concrete, riprap, aggregate, nylon, geotextiles (commonly polypropylene or polyester), and wire (i.e., baskets and/or cages). Bioengineering is the use of living plant materials to perform some engineering function of ESC.

Bioengineering may improve environmental performance at oil sand operations and help meet the COSIA Land EPA goals of reducing footprint, more rapid reclamation, and optimizing biodiversity. These ESC techniques may:

- Reduce footprint intensity, in some cases, as vegetation can be re-established more rapidly and permanently during either operations or phased closure,
- Provide biodiversity benefits, as the bioengineered structures will lead to early successional ecosystems that will succeed to more mature ecosystems and provide a diversity of habitats, especially with phased reclamation,
- Support reclamation objectives for closure by helping create self-maintaining, self-healing ecosystems that mimic natural creeks, wetlands, and other landforms, and
- Result in cost savings during operations due to lower cost materials and lower maintenance needs with no requirement to remove synthetic materials/structures at closure.

The report documents the benefits and limitations of bioengineering and conventional ESC approaches as identified by operations personnel.

Nine factors were identified to be considered when determining the suitability of specific erosion control practices for a project:

- Risks or Consequences of Failure,
- Need for Immediacy,
- Water Flow and Velocity,
- Topography/Slopes,
- Soil Characteristics and Moisture,
- Accessibility,

- Weather and Season,
- Permanency of Techniques,
- Availability of Materials, and
- Cost.

Key high-level recommendations for ESC in the oil sands region that have been consolidated from across industrial sectors are:

- The integration of both bioengineering and conventional techniques within a single project has proven successful.
- Natural re-vegetation using rough and loose soil management with coarse woody material and the planting of shrub and tree seedlings is being used more commonly at some of the oil sand and coal mines for rapid revegetation. The use of the rough and loose technique will allow oil sand operators to move away from the practice of hydroseeding. Grasses and legumes reduce the survival of tree and shrub seedlings, and reduce the potential for ingress of native plant species from surrounding areas.
- Bioengineering techniques to establish vegetation is discouraged at higher risk operational sites where wildlife could increase human-wildlife conflicts, or where rapid or certain ESC is required to manage safety risks, or where vegetation would obscure visual integrity inspections.
- Bioengineering techniques using live plants are considered permanent ESC methods that require little maintenance once established. They are particularly successful along streambanks, drainways, and near groundwater seeps where the vegetation helps manage the water sources that can cause erosion and stabilize the slopes with their root masses. These techniques are particularly useful for operational projects away from high ESC risk areas such as at well pads, soil stock piles, bridges, roads and for the closure landscape.
- Bioengineering techniques may be challenging to implement for larger scale, landscape-level projects, due to the intense labour required for installation, and due to the limited availability of live cuttings. Live plant cuttings could be grown in stooling beds (cultivated in fields) or rooted in nurseries.
- Although erosion and control matting is used at several oil sand and coal operations, it can be challenging to install, maintain and remove at final reclamation, and can inhibit plant species diversity.

Three recommendations are proposed to encourage develop of bioengineering into a more common ESC practice in the oil sands region:

1. Increase Training on Bioengineering Techniques and Installation
2. Coordinate Live Plant Production for Bioengineering Installations
3. Coordinate and Expand Research on Bioengineering Techniques

Acknowledgements

The "Bioengineering and Conventional Erosion and Sediment Control Solutions for Oil Sands Operations" report required contributions from 12 companies and 34 individuals. Associated Environmental would like to acknowledge and thank all those individuals who participated in the interviews, provided documents or reviewed this report.

COSIA Steering Committee

Robert Albricht – *ConocoPhillips Canada*
Audrey Lanoue – *Syncrude*
Michelle Young – *Imperial*

Canada's Oil Sands Innovation Alliance (COSIA)

Jack O'Neill – *Senior Technical Advisor - Land EPA*

Cenovus Energy

Jason Barrie

ConocoPhillips Canada

Brian Elaschuk
Brendan Hinzmann
Tyler Sellin

Canadian Natural

Clayton Dubyk

Daishowa-Marubeni International Ltd.

Gord Whitmore

Evergreen Learning and Innovation Centre

Doug Kulba

Imperial

Leanna Trefry

Northern Alberta Institute of Technology - Boreal Research Institute

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Suncor

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Christine Daily
Eric Kessel
Scott Ketcheson
Johann Mueller
Nancy O'Brien
Jonathan Price
Tom Wiebe

Syncrude

Eric Girard
Ana Manderson
Glen Miller

Teck Resources

Dan Bouillon
Dan Charest
Marsha Clarke
Moss Giasson
Karen Halwas
Neil Sandstrom
Marc Symbaluk

TransAlta

Dan Kuchmak

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1 Introduction

Associated Environmental (Associated) was contracted by Canada's Oil Sands Innovation Alliance (COSIA) to prepare a report on Bioengineering and Conventional Erosion and Sediment Control Solutions for Oil Sands Operations.

A key component of this study was to document erosion and sediment control (ESC) approaches currently used by in-situ and mining companies in northern Alberta, and some other industry sectors (e.g., coal mining) where their ESC experiences would be relevant to the geographic and ecological conditions encountered by the oil sands companies. Successes and lessons learned from failures of bioengineering ESC, focusing on the inclusion of live plant materials and of conventional engineered ESC such as rip rap, were evaluated. The opportunities and challenges with both types of ESC and recommendations on how to determine the suitable approach for ESC on different landscapes in the oil sands are discussed. This document is not a prescriptive set of solutions meant to limit innovation.

Bioengineering may improve environmental performance at oil sands operations and help meet the COSIA Land EPA goals of reducing footprint, more rapid reclamation, and optimizing biodiversity. These ESC techniques may:

- Reduce footprint intensity, in some cases, as vegetation can be re-established more rapidly and permanently during either operations, or phased closure,
- Provide biodiversity benefits, as the bioengineered structures will lead to early successional ecosystems that will succeed to more mature ecosystems, and provide a diversity of habitats, especially with phased reclamation,
- Support reclamation objectives for closure by helping create self-maintaining, self-healing ecosystems that mimic natural creeks, wetlands and other landforms, and
- Result in cost savings during operations due to lower cost materials and lower maintenance needs, and no requirement to remove synthetic materials/structures at closure.

Information was collected through interviews with, and documents acquired from operational personnel from oil sands mining and in-situ companies in northern Alberta, and from coal mining companies in Alberta and British Columbia, as well as case studies from some municipalities in Alberta. This study focused on obtaining details on case studies that provide examples of successful approaches to ESC, or situations that lead to lessons learned and the identification of approaches to be avoided.

This document has been structured to provide:

- Brief descriptions of general steps in erosion and sedimentation control and of conventional and bioengineering ESC techniques,
- A discussion on bioengineering and conventional ESC solutions for oil sands operations, including a summary of the benefits and limitations of each approach, and recommendations to move towards bioengineering,
- An annotated list of key reference documents on ESC in Appendix A, and
- Bioengineering and conventional ESC case studies for in-situ and mining oil sands operations, coal mining and municipalities in Appendix B.

2 Techniques and Steps in Erosion and Sedimentation Control

This section of the report provides brief descriptions of general steps in erosion and sedimentation control, and of conventional and bioengineering ESC techniques.

2.1 STEPS IN EROSION AND SEDIMENTATION CONTROL

Erosion control is the process whereby the potential for erosion (displacement of solids by wind, water, or ice) is minimized, and sediment control is the process whereby the potential for eroded soils being transported and/or deposited beyond the limits of the project site is minimized (Alberta Transportation 2011). Erosion control is the primary means for preventing the displacement of soils and the subsequent degradation of downstream aquatic resources, while sediment control addresses temporary measures that are used until erosion control has been established.

The objective of erosion and sediment control is to limit or prevent the amount, and rate, of erosion occurring on disturbed sites and to capture eroded soil before it leaves the site. Wind and water are the driving natural erosive processes effecting disturbed lands.

Managing erosion and sedimentation begins by assessing the potential for, and risks of, erosion at a development site during the planning and design stage. The level of effort and the types of erosion and sedimentation control approaches are chosen based on the level of risk. The most effective strategy for managing erosion risk is in the planning and design phase of work to minimize the amount of land disturbed and retain as much of the natural vegetation as possible. Other aspects that should be considered in erosion and sedimentation control include:

- Water management,
- Stripping, grading and site preparation,
- Soil stabilization,
- Sediment control, and
- Implementation, inspection and maintenance of ESC sites.

Erosion and sedimentation control for the reclaimed mine closure landscapes should address risks posed by very long-term erosion/siltation by designing controls to mimic ESC of naturally analogous topographic features. For example, natural streams and creeks experience erosional events all the time and therefore a synthetic closure creek should have some allowance for some erosion.

2.1.1 Planning and Design: Site Assessment, Erosion Risk, and Level of ESC Effort

Assessing the risk or potential damages and consequences from uncontrolled erosion and/or sedimentation is required to determine the degree of ESC measures to be implemented into development planning.

Addressing these risks will demonstrate reasonable care was taken during project planning. Consequences of failing to control erosion and/or sedimentation may include (CoC 2011):

- Environmental damage: introduction of sediment into sensitive habitats (i.e., aquatic systems),
- Property/infrastructure damage (i.e., damage to critical operational facility),
- Operational consequences: time spent responding to damage and resulting labour and material costs with possible project delays,
- Legal consequences for potential violations, and
- Delay in getting reclamation certification and custodial transfer of the land to the Crown.

Oil sands activities can alter site erosion potential by changing soil cover, soil type, slope length/steepness, and drainage (Table 2-1). In mining operations, topsoil and subsoil are salvaged and used to reconstruct soil for reclamation; in in-situ operations, soil is removed and replaced upon final closure. ESC designers need to consider site conditions when assessing the erosion potential (Table 2 -1).

Table 2-1
Site Conditions to Consider for Project ESC Design

Site Conditions	Considerations
Soil	Soil erodibility is affected by several factors: grain size, grain size distribution, organic matter, structure, permeability, and soil chemistry.
Topography and Drainage	Includes slope length and gradient, drainage areas, existing drainage patterns, flowing water, and slope stability.
Downstream Sensitivities	Downstream sensitives may differ than those at a disturbed site, water can easily erode and transport sediment to more sensitive features (wetlands, key habitat areas etc.)

When determining the level of ESC required, a quantitative estimate of site conditions and erosion potential should be assessed, along with the consideration of potential negative downstream impacts. Table 2-2 outlines some typical levels of ESC effort required, given the erosion potential.

Table 2-2
Example of the Level of ESC Based on Risk Assessment

Erosion Potential	Consequences of Erosion and/or Sedimentation	Level of Erosion & Sediment Control				
		Structural Practices to Control for Erosion & Sedimentation	Water Management Practices	Staging Construction & Progressive Reclamation	Intensive Sediment Control Practices	Water Quality Monitoring
Low	Low	-	-	-	-	-
	High	Required	-	-	-	-
Medium	Low	-	-	-	-	-
	High	Required	Suggested	Suggested	Suggested	Suggested
High	Low	Required	Required	Required	Required	Suggested
	High	Required	Required	Required	Required	Required

2.1.2 Erosion Control: Water Management

A major focus of erosion and sedimentation control at oil sands operations is managing water by diverting existing streams and muskeg drainage away from potential operational sites prior to development.

The working landscape is then designed with gentle slopes to minimize erosion, and storm water run-off is managed by a system of ditches. The ditches take the water to sedimentation ponds, where levels of sediment are reduced to meet water quality requirements prior to water being released into the environment. The velocity, flow and quality of water in the drainage structures is usually managed through armouring the banks of the structures, slowing water flow, and improving water quality.

Some specific recommendations for water management that are based on work in municipalities can be modified to apply to oil sands operations, they include (CoC 2011, Alberta Transportation 2011):

- Ensure channels are designed and constructed to the necessary design discharge (i.e., areas with high water velocities and continuous flow may require extensive armouring);
- Convey run-off in stabilized channels with velocity controls (i.e., rock check dams, live staking, live silt fence, live gully breaks, or brush mattress);
- Protect channel inlet/outlets that are prone to scouring using riprap, or diffusers;
- Divert sediment-laden surface water to appropriate retention facilities (e.g., settling ponds); and
- Release water to the environment using diffusers, riprap or naturally vegetated areas.

2.1.3 Stripping, Grading, and Site Preparation

Stripping, grading, and site preparation results in a significant exposure of soil and, generally, has the highest potential for erosion. Some best management practices identified for municipalities, but can be modified to apply to oil sands facilities, include (CoC 2011, Alberta Transportation 2011):

- Limit the duration of and stabilize exposed soils by applying suitable soil stabilization/cover (coconut matting, mulching, seeding/hydroseeding, geotextile matting, early revegetation and bioengineering, coarse woody material, riprap etc.);
- Create a rough and loose surface texture to promote filtration, reduce run-off, and provide microclimates for vegetation establishment; and
- Reduce slope length by intercepting run-off (i.e., brush wattles, terracing, compost socks and berms).

2.1.4 Erosion Control: Soil Stabilization

Exposed soils are at high risk of erosion as they can become easily detached from other surrounding soils particles by water or wind. They need to be covered and/or treated using soil stabilization techniques as soon as practical. Approaches to reduce soil erosion or stabilize soils can include (Alberta Transportation 2011):

- Avoid earthworks (i.e., soil stripping) during wet/windy periods,
- Revegetate as soon as practicable,
- Roughen the soil surface (i.e., rough and loose treatment),
- Avoid vehicle traffic on exposed soils, and
- Apply coarse woody material (Vinge and Pyper 2012).

2.1.5 Sedimentation Control

Water which contains excessive amounts of suspended sediment will require treatment to reduce the sediment levels prior to discharge off-site. Sediment control falls into two categories:

- **Filtering Controls:** Water is filtered through a porous material which traps sediment on the filter. This method does not filter out fine sediment reliably. Silt fences are often referred to as a filtering control, and while it does filter out some coarse sediment, it’s primary function is to detain run-off.
- **Settling Impoundments:** Water is detained, or water velocity is slowed, to allow for sediment to settle out of suspension.

Conventional and bioengineering techniques used for erosion and sediment control are outlined in Sections 2.2 and 2.3.

2.1.6 Implementation, Inspection, and Maintenance of ESC Sites

Erosion and sediment control on large, complex projects like oil sands facilities, involve multiple people and departments; hence good communication and appropriate delegation of tasks related to ESC measures is important. Several items to consider throughout the life of a project include:

- Implementing ESC measures according to the report/drawings developed during ESC planning and design to ensure management of risks;
- Implementing regular inspections and maintenance of ESC structure to ensure proper functioning;
- Implementing timely management of ESC structure failures based on prioritization of risks; and
- Documenting installation, inspection and maintenance of ESC structures, and making this information accessible to all relevant personnel.

When using bioengineering or live vegetation to stabilize soils, monitoring during the first few months is important as this is when bioengineering techniques are most likely to fail. Some re-application of seed or live stakes may be necessary to achieve the appropriate cover and some areas may require irrigation or protection from herbivory to ensure vegetation establishment.

2.2 BIOENGINEERING EROSION AND SEDIMENTATION CONTROL

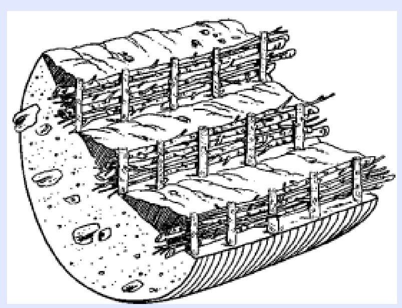
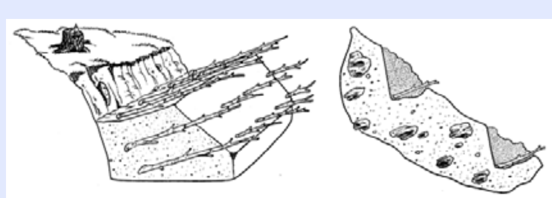
For the purposes of this document, soil bioengineering (bioengineering) is the use of living plant materials to perform some engineering function (Polster 1997). Table 2-3 summarizes various bioengineering techniques, their benefits, requirements for success, and limitations for use in ESC. This table also outlines various reclamation techniques and non-living plant materials that can be used for ESC at oil sands operations.

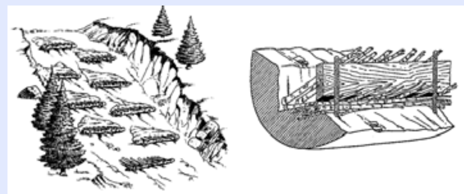
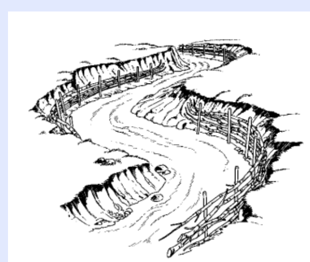
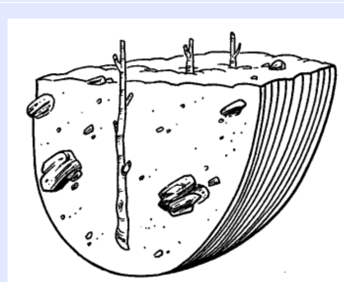
Pioneering species that will take root from untreated cuttings include willows, dogwood, and poplar. These pioneer species are ideally suited to be the initial species on disturbed sites. They help build productive soils and ameliorate the adverse conditions that are often found on disturbed sites (e.g., exposed conditions). The use of pioneering species in bioengineering treatments help ensure there will be an effective vegetation cover on the disturbed site into the future, as the natural plant community successional processes (Polster 1989) ensure a site is well vegetated (Figure 2-1).

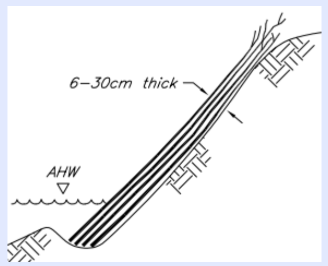
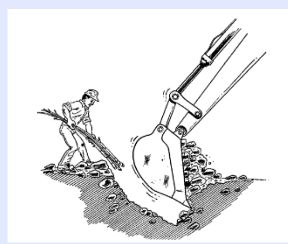
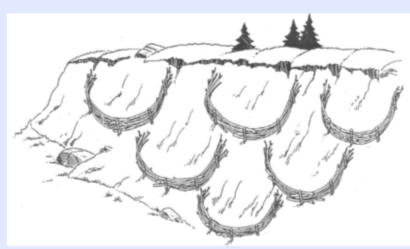
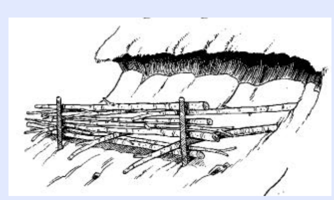
A requirement that applies to all techniques utilizing live plant material is that plant material must be harvested during the dormant season for best results. Limitations that apply broadly to all ESC techniques utilizing live plant material are:

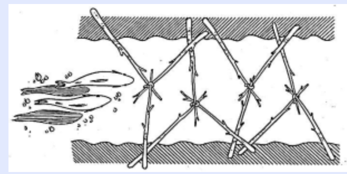
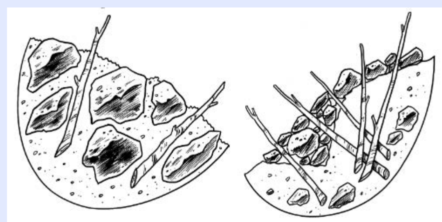
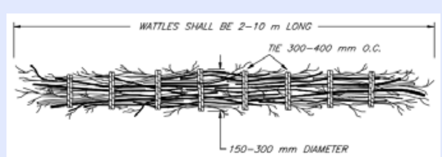
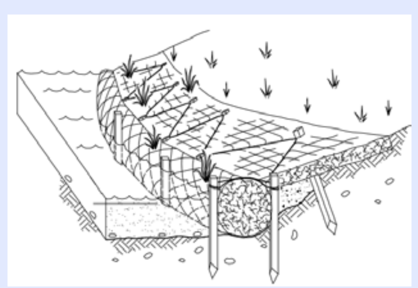
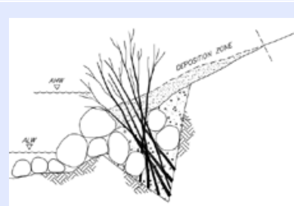
- Live cutting availability may be locally limited in some areas,
- Installation can be labour intensive,
- Plant growth success varies depending on site conditions, and
- Plants not protected by fencing during the establishment period may be damaged by wildlife browsing (herbivory).

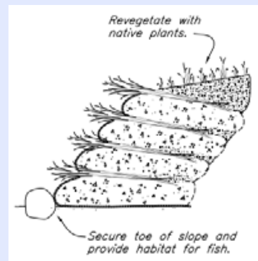
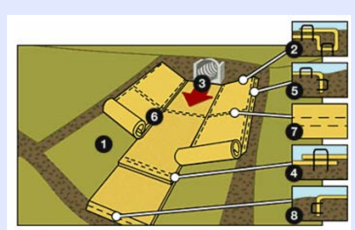
Table 2-3
Benefits, Requirements and Limitations of Soil Bioengineering Techniques and Reclamation with Living and Non-Living Plant Material

Method	Benefits	Requirements	Limitations
Soil Bioengineering (Living Plant Materials)			
Requirements/limitations for all living plant materials	• N/A	• Harvest/plant during dormant season • Requires adequate moisture	• Plant growth success varies depending on site conditions • Plants not protected by fence during establishment period may be damaged by wildlife browsing (herbivory) • Live cutting availability may be locally limited in some areas • Vulnerable to failure prior to root establishment
Wattle fences[5] *Short retaining walls built of live cuttings backfilled with soils from the slope above* 	• Changes slope angle so the vertical part of the slope is the wattle fence and the horizontal part is flattened • Establishes vegetation growth on over-steepened slopes • Live cutting sprouts and stabilizes soil • Reduces erosion • Protects vegetation damage from falling debris • Self healing • Starts successional trajectory to vegetate site	• Fences approximately 30 cm height • Suitable for slopes < 70 degrees • Fencing and watering may be required until established[1]	• Vegetation may not establish if debris continuously fall into fences • Can be labour intensive to install • Must be strong enough to support the slope prior to root establishment
Live pole drains[5] *Tight bundles of living cuttings partially buried aligned towards desired drainage path* 	• Create a preferred path for subsurface flow • Immediate drainage after installation • Used to drain excessive moisture • Drainage pathway establishes water loving vegetation communities • Stabilize soil slumps • Economical	• Moisture drains towards lower end • Avoid over-burial • Careful trimming of cuttings to allow for tight bundling • Leave 6 to 8 cm opening at the top and bottom of the bundle to allow light to reach the cuttings	• If over-buried, subsurface flow may not follow the preferred pathway
Brush layer[1,5] *Horizontal rows of live cuttings buried in fill or cut slopes* 	• Reduces surface erosion • Stabilizes steep slopes • Promotes vegetation growth • Increases slope roughness reducing flow and promotes sediment deposition • Becomes stronger overtime • Self-healing • Acts as horizontal drainage after flood events • Economical • Flexible strengthening to fill slopes	• Slope up to 27 degrees • Steep slopes may require support from geotextiles, wire, or geogrids	• Can be labour intensive to install

Method	Benefits	Requirements	Limitations
Modified brush layers[5] *Brush layers supported on a short log or board* 	• Catches rocks from rolling downslope • Protects slope vegetation • Backfills and aids in vegetation establishment • Used on slopes too dry for wattle fencing • Stabilizes slopes • Can use locally sourced materials (logs) • Self-healing	• Logs ~ 2m in length and 30 cm in diameter • Logs/boards must be staked into place (live stakes or rebar) • Stagger multiple layers over the area (2 – 3 m apart)	• Multiple, staggered, layers are required • Large debris can destroy a layer
Live gully breaks[5] *Wattle fences built within gullies to control erosion and debris torrents* 	• Slow water velocity • Reduces potential for torrents to initiate • Strengthen with age (as vegetation establishes) • Live smiles within gullies backfill with accumulation of flowing materials	• Establish slope breaks high in the channel • 5 – 10 m between breaks • Stake wattle fencing using live stakes or rebar •	• See general living plant material limitations
Live bank protection[5] *Wattle fences constructed on cutbanks in streams* 	• Protects against scouring • Promote vegetation growth in riparian areas • Reduce amount of material moving within the water • Reduce erosion on toe of steep banks • Stabilize over-steepened banks	• Construct along stream cut banks • Construct several tiers to accommodate large water level fluctuations	• Can be labour intensive to install
Live silt fences[5] *Rows of live cuttings installed into drainage channels to slow flow velocities and allow sediment to drop out* 	• Slow water velocity • Allow for sediment deposition • Trap floating debris • Strengthens overtime • Self-healing	• Designed for small (or ephemeral) low velocity drainage channels	• See general living plant material limitations
Live staking[1,5] *Live cuttings inserted into the soil* 	• Root system stabilizes soil • Increase channel roughness that reduces flow velocity and promotes sediment deposition • Becomes stronger overtime • Enhance site conditions and encourage successional vegetation • Self-healing • Used in a variety of different bioengineering approaches	• 80% of the cutting must be inserted into the soil • Cutting must be at least 60 cm long • Vertical or diagonal installation • Plant in areas with little or no competition (not in established grasses or sod)[7] • Harvest willow from lowland habitats for greater staking survival (under ideal conditions)[7]	• See general living plant material limitations

Method	Benefits	Requirements	Limitations
	• Effective at preventing erosion on toe of watercourse banks when planted densely	• Longer willows cuttings with diameters > 0.5 cm have higher success rates[7] • Paint exposed/cut tops using (non-toxic) latex to prevent desiccation[7]	
Brush mattress[1] *Live cuttings laid over gravel banks* 	• Can tolerate high water velocities (up to 5 m/s)[6] • Branches slow flow velocity and quickly stabilize slope/streambank • Captures sediment in flood events; rebuilds banks • Produces riparian vegetation rapidly • Greatly reduces water velocity • Self-healing	• Layer live cuttings in a thick (15-30 cm) blanket • Select species which grow well from cuttings	• Low success where basal ends cannot be kept in water
Gravel bar staking *Live cuttings installed in the gravel bed within a stream* 	• Acts as pioneering vegetation cover on gravel bars • Will stabilize underlying soil and bind the gravel together with established root systems • Used where excess gravel is causing stream instability • Reduces flow velocity allowing deposition of sediment carried by the water. • Starts the successional processes on gravel bars that eventually result in productive forests.	• Cutting to be angled downstream • At least 80% of the cutting is underground • In drier areas (i.e., higher gravel bars) >85% of the cutting is underground	• See general living plant material limitations
Live smiles[5] *Bowed fences constructed from live plant cuttings* 	• Use on slopes with flowing silts (causes wattle fences and modified brush layers to fail) • Uses a catenary curve to support the mud on the slope, allowing moisture to drain out • High tensile strength • Live smiles are porous and drain flowing silts stabilizing the slope • Allows for root development in weak soils	• Fences configured in bowed shapes • Stagger across slope face • Smiles should be 2 – 5 m wide and 40 cm tall • Stakes must be firmly established (50 – 60 cm long)	• Can be labour intensive to install
Live reinforced earth walls (LaREWs)[5] *Wattle fences with long cuttings inserted into the face of the fence* 	• Addresses overhanging areas associated with piping failure • Allows for backfilling and prevents slumping • Provides shear resistance • Becomes more stable overtime • Can be used to treat large cavities	• Treat cavities as large as 3 m deep x 3 m high x 5 m wide • Use in conjunction with live pole drains for additional groundwater management	• Can be labour intensive to install
Live shade[5]	• Creates canopy cover fish habitat and improves shading along watercourses • Used in areas where riparian vegetation is sparse	• Tripod design over the stream, securing the tops together • Basal ends of cuttings must be inserted 75 cm into the soil	• See general living plant material limitations

Method	Benefits	Requirements	Limitations
Live cuttings planted over newly created fish habitat 		• Cuttings over 4 m are too flexible (unless large and stout) • Overlap basal end for additional root support	
Pocket planting and joint planting[5] *Cuttings planted in the soil between boulders or riprap on streambanks (also known as Vegetated Riprap)* 	• Woody vegetation in riprap develop a deep, dense root structure to support eroded streambanks • Establishment of cuttings without additional soils. • Locks riprap into place • Prevents soil loss from behind riprap • Strengthen riprap by slowing water velocity promoting sediment deposition • Anchor riprap and gouging from ice and debris • Self-healing • Provided aquatic and wildlife habitat • Aesthetically pleasing	• Cuttings must by 4 cm in diameter at the tip • Any fabric below the riprap is breached to allow access to underlying substrate • Riprap layer is shallow • 80% of live plant material must be in contact with native ground soil • Plant ends must be 30 cm below the water table	• May requiring irrigation for up to 2 years
Live fascines (Wattles)[1] *Bundles of live fascine to stake into the soil along slope contours* 	• Grade break measure • Reduces sheet and rill erosion • Suitable for steep slopes • Functions well in freeze-thaw environments • Traps sediment and seeds	• Staking is needed to anchor wattles • Suitable for slopes up to 45 degrees	• Labour intensive to install • Limited to low sheet velocities • Susceptible to failure if installed incorrectly
Fibre rolls (pre-seeded)[1,6] *Cylindrical rolls composed of coconut fibres, or other materials (may be pre-seeded and wrapped in coir)* 	• Rolls pre-seeded with native riparian species • Either unplanted or pre-established mature plants • Allow for rapid establishment of riparian habitat • Accumulates sediment • Fibre rolls encourage siltation and wetland/floodplain creation • Last 5-7 years • Fibre rolls are installed across slope contours as a grade breaks	• Rolls must be anchored (can use live staking) • Link rolls together to form long chains • Suitable on steep/confined slopes, and channel banks less than 45 degrees • Rolls must be in continuous contact with the soil • Fibre rolls used on slopes with low sheet flow velocities • Install fibre rolls during dormancy period	• Established rolls with mature plants require a lot of shipment space • Expensive and labour intensive to install • Rolls have a 5 to 7-year lifespan • Susceptible to undermining failure if installed improperly • Rolls may have a plastic mesh framework that is expensive to recover from reclaimed sites
Live siltation[1] *A thick layer of live cuttings installed in a v-shaped trench along the toe of the streambank* 	• Stabilizes the toe of a streambank • Provides scour and toe protection • Traps sediment • Creates fish habitat • Self-healing	• Cuttings buried 1/3 in v-shaped trench • Angle towards the stream • Cuttings must be 1 – 1.5 m long • Must be planted at the water's edge • Minimum of 40 branches per trench	• See general living plant material limitations

Method	Benefits	Requirements	Limitations
Vegetated mechanical stabilized earth (VMSE)[1] *Brush layers interspersed between lifts of soil wrapped in natural fabric* 	• Vertical retaining structures • Act as a drainage layer or conduits to relieve pore pressure • Aids in long term seepage • Modify groundwater flow regime • Visually appealing	• Applicable on slopes as steep as 63 degrees • Begin at the base of the slope moving upwards • Soil lift thickness from 30 – 76 cm • Structures to be built during periods of low water	• More expensive than brush layering • Labour intensive to construct soil lifts
Reclamation and Non-Living Plant Materials			
Rough and Loose[5] *Alter soil to create a rough and loose surface modelling conditions created when trees fall over* 	• Reduces erosion • Creates micro ecosystem variability • Promotes diverse vegetation establishment • Inexpensive • Effective in confined and open spaces • Can be combined with live staking and coarse woody material application • Is much less expensive than traditional seeding to control erosion	• Significant erosion reduction with the addition of coarse woody material • Excavator opens holes on site, dumping material in mounds in-between holes	• Care must be taken when excavating soils • Site must be accessible to excavators • If used with live staking, site may require fencing to prevent wildlife browsing (herbivory)
Riparian Zone Preservation[1]	• Natural buffer to filter and slow surface runoff • Most effective natural sediment control measure • Reduces volume of runoff on slopes • Self-healing	• Fence off preserved areas to prevent vehicle or foot traffic in the area • Use along project site boundaries	• May interfere with construction efficiency • Careful planning is required to work around riparian areas
Rolled Erosion Control Products (RECP)[1] 	• Immediate protection to exposed soils prior to vegetation establishment • Biodegradable • Promotes vegetation growth • Suitable for steep slopes[3] • Lasts longer than mulch	• Suitable for slopes less than 21 degrees • Complete contact with soil surface required • Must be installed on non-frozen soils	• Installation labour intensive • Not suitable for rocky or icy surfaces • May need to replace if slope is not at final grade. • Commonly used with grass seed that has less root strength than woody vegetation • Associated with high rates of failure

Seeding/hydroseeding[1]
Hydroseeding is a slurry of water, seed, fertilizer, and tackifier sprayed onto exposed soils

	• Root systems prevent soil erosion
	• Rapid growth
	• Various planting methods (broadcasting, furrowing, hydroseeding)
	• Economical
	• Hydroseeding:
	  • Efficient application to large areas
	  • Wind/erosion protection
	  • Suitable for use on slopes
	  • Can be used on steep/rocky/gravelly surfaces
		• Application to areas with surface runoff, wind erosion or on slopes requiring supplemental materials:
		  • Tackifiers
		  • Mulch
		  • RECPs
		• Equipment may limit distance from a road to ~ 150 m
			• Dry, uncut grass can pose a fire risk near construction activities
			• Hydroseeding has a limited range from the road[2]
			• Subsequent re-application may be required
			• Grass seed has less root strength than woody vegetation
			• Prevents ingress and creates competition of native vegetation species
			• Grass and legumes attract wildlife

Method	Benefits	Requirements	Limitations
			• Grass not suitable as a treatment method in the boreal forest • Creates competition for shrubs and seedling growth
Straw bale barrier[1]	• Slows water velocity, promotes sediment deposition[2] • Economical • Biodegradable • Promotes plant growth • Easy installation	• Complete contact with surface (prevent undermining or “punching”) • Surface velocities > 0.3 m/s • Maintenance after high flow events • Single row often sufficient	• Availability of straw varies seasonally • Cannot be used on sandy soils • Short life span (~ 2 seasons) • Hand installation, may be labour intensive • May contain other plant material such as weeds[2] • Associated with limited success

Mulching/hydromulching[1]
 	
Hydromulching is a slurry of water, fibrous materials, and tackifier sprayed onto exposed soils
	• Immediate soil protection from surface runoff
	• Promotes seed growth
	• Economical
	• Limits weed growth[4]
	• Composed of various types of materials (wood chips, straw, recycled news paper etc.)
	• Hydro-mulching:
	  • Efficient application to large areas
	  • Wind/water erosion protection
	  • Suitable for application on slopes
		• Application to sloped surfaces may require added tackifier
		• Nitrogen fertilizer may be needed
		• Mechanical straw blowers for large areas
		• Hand installation of straw possible
		• Hydro-mulching requires specialized equipment, limiting distance from the road to ~ 150 m
			• May deplete available nitrogen
			• Application to slopes may require additional equipment
			• Straw cannot be used on sandy soils
			• May introduce invasive plants/weeds
			• Material availability varies
			• Limited application distance from the road when hydromulching[2]
			• Subsequent re-application may be required
			• Associated with limited success
			• Can prevent the establishment of vegetation if over applied

Compost application[1,2] *Compost applied as a blanket, berm or within a sock; use native leaf litter mulch* 	• Provides slope protection • Economical • Can be used on slopes • Promotes plant growth • Divert surface water	• Apply on slopes 27 degrees • Blankets and berms applied using specialized blower trucks • Socks must be staked into place	• Site must have access to blower trucks (within 90 m) for blanket application • Application to steep slopes may be difficult • Cannot be applied to areas with constant flow

[1] Government of Alberta. 2011. Alberta Transportation Erosion and Sediment Control Manual

[2] FPInnovations. 2007. Erosion and Sediment Control Practices for Forest Roads and Stream Crossings. Advantage Vol. 9 No. 5

[3] Charlie Lake Conservation Society. 2006. Oil and Gas Well/Facility Site Erosion Management

[4] COSIA. 2013. In-situ Oil Sands Extraction Reclamation and Restoration Practices and Opportunities Compilation

[5] Polster, D. 2017. Natural Processes: Restoration of Drastically Disturbed Sites

[6] Salix. 2017. Coir Rolls. Available at: https://www.salixrw.com/product/coir-rolls/ Accessed November 2017

[7] Schoonmaker. 2017. Summary Memo of Hardwood Cutting Research Conducted at Canadian Natural Resources Ltd. Peace River Complex and Cliffdale Facility (2012-2017)

Figure 2-1
Seeding the pioneering species Sitka Alder on a 50-degree rock cut in Roger's Pass resulted in the establishment of a forest of conifers following natural successional trajectories.

Bioengineering systems are tailored to mimic the recovery processes that have operated to restore disturbed sites in nature. Hence, treatments like dense live staking mimic the growth of pioneering species along the banks of large rivers that collect sediment and preventing erosion. They are designed to physically treat the problem site prior to the growth of the plants, therefore, there is the advantage that the structures get stronger over time as the plants grow.

Bioengineering systems can provide effective solutions for ESC, when coupled with techniques such as the rough and loose technique (Polster 2015). Erosion happens when rainfall hits the ground surface (raindrop erosion), or when water moves across the ground surface (sheet, rill and gully erosion). So, if the ground is rough and loose, and dense live staking (50 cm spacing) is used to provide a cover (like an umbrella) on the site, then the growth of the cuttings will protect the surface and the stems will slow any flow across the surface. The rough and loose ground will also slow the flow across the ground and allow the rainwater to soak into the near-surface groundwater system.

Making ground rough and loose and scattering 100 m^3/ha of coarse woody material on the surface will foster the establishment of pioneering species (Figure 2-2). This will then initiate the natural plant community successional trajectories and will ensure that the site maintains a healthy vegetation cover into the future. By encouraging the natural recovery processes to function on a disturbed site, the need to plant expensive native species is reduced or eliminated since the pioneering species are designed to initiate plant community development on the site.

Figure 2-2
Rough and loose ground surface with woody material can be used to control erosion and promote the recovery of large disturbed sites. None of the vegetation in this photo was planted on site; but established after 5 years from the treatment.

The key to the successful use of bioengineering systems for ESC is to keep in mind that the work is done with living plant materials so **keeping them alive is essential to success**. In addition, collecting the cuttings that are used in bioengineering systems during the dormant season will ensure that they have the highest level of stored carbohydrate reserves possible. This will increase the success rate of cuttings developing roots and shoots quickly on the treatment site.

There are a wide variety of bioengineering techniques that can be used to control erosion and encourage sediment deposition (Table 2-3). The key is to protect the soil surface from raindrop erosion and to slow the flow velocity of any water. Live silt fencing is a simple technique that can be used in ditches to slow the flow of water in the ditch and create a willowy wetland that serves to control erosion and allow sediment deposition (Figure 2-3). Live bank protection can be used on streams to protect streambanks from erosion (Figure 2-4; Polster 2006). Growth of the cuttings used in the live bank protection creates a willowy riparian zone that serves to slow the near surface flows of the stream, thus reducing risk of erosion.

Figure 2-3
Live silt fencing can be used to control sediment in flowing streams by slowing water flow velocity allowing sediment to drop out. Live silt fencing creates a willowy wetland that will continue to collect sediment for decades.

Figure 2-4
Live bank protection such as wattle fences prevent erosion by creating a willowy riparian zone.

The benefits, requirements for, and limitations to each of the bioengineering ESC technique have been summarized in Table 2-3. In general working with living plants means that considerations to maintain the life of the plant is essential for success of bioengineering projects. Moisture during the early weeks of vegetation establishment is critical for plant survival. The soils where these treatments are used must not be compacted or otherwise inhospitable to plant growth. Avoid sites where contamination (e.g., salts, hydrocarbons, and metals) may be preventing, or limiting plant growth. Use locally available plant materials to ensure genetic compatibility with the local vegetation and compatibility with the Alberta Forest Genetic Resource Management and Conservation Standards (Alberta Agriculture and Forestry 2016). The use of non-native species is not recommended.

2.3 CONVENTIONAL EROSION AND SEDIMENTATION CONTROL

For this document, conventional ESC techniques use concrete, riprap, aggregate, nylon, geotextiles (commonly polypropylene or polyester), and wire (i.e., baskets and/or cages). These materials can be used in various combinations together (i.e., gabion baskets consist of riprap encased in wire baskets) or with bioengineering techniques (i.e., vegetated riprap).

Table 2-4 lists a variety of different conventional techniques that are used or can be used at oil sands facilities during different phases of construction, along with comparable bioengineering techniques.

Table 2-4
Common Conventional and Bioengineering ESC Approaches During Construction

Conventional	Bioengineering (Live Plant Materials)	Reclamation and Non-plant Material
Stripping, Grading and Site Preparation		
• Preserve existing vegetation to existing possible • Surface grading, roughening and texturing • Topsoil salvage and placement (preserve natural seed banks)		
Erosion Control: Water Management		
• Temporary berms and diversion channels • Riprap-lined channels • Temporary slope drains • Energy dissipaters • Check dams • Gabion baskets • Concrete channels	• Live pole drains • Gravel bar staking • Live smiles • Vegetated channels	N/A
Erosion Control: Soil Management		
• Aggregate cover • Riprap • Concrete blankets • Concrete lock blocks • Geotextile mats • Gabion baskets • Gabion mattress	• Live staking • Wattle fences • Live smiles • Brush layering • Live silt fences • Live gully breaks • Live shade • Pocket planting and joint planting • Live fascines • Coir rolls • Live reinforced earth walls • Live siltation • Live bank protection • Rolled erosion control products (natural fibers) • Vegetated riprap • Gravel bar staking • Vegetated mechanical stabilized earth	• Rough and loose soil management • Seeding/ hydroseeding • Rolled erosion control products (nylon) • Mulching/hydro-mulching • Compost applications
Sediment Control		
• Sediment traps & basins • Silt fences • Gabions • Constructed Wetland	• Brush layering • Wattle fences • Live silt fences • Modified brush layering • Live fascines • Live gully breaks • Live bank protection • Gravel bar staking • Live reinforced earth walls • Pocket planting and joint planting • Constructed Wetland	• Compost socks • Straw bale barriers

3 Bioengineering and Conventional Erosion and Sedimentation Control

3.1 CURRENT EROSION AND SEDIMENTATION CONTROL TECHNIQUES USED

Table 3-1 summarizes the types of techniques that have been used to control erosion and sedimentation at several in-situ and mining oil sands operations in northern Alberta, and at some coal mines and forestry companies in Alberta or British Columbia and municipalities in Alberta. What is not apparent from the table is the frequency of use, or the purpose of the ESC applications which varied from operational, to use at problem sites, to experimental evaluation for future use. The ESC approaches used at these operations are outlined briefly in this section.

Because some statements in this section have been generalized and integrated from several operations, each statement may not apply to all in-situ or mine operations.

Table 3-1
Summary of Bioengineering and Conventional Techniques Used in Case Studies by Companies

	Bioengineering						Remediation & Non-living Plant Material										Conventional Techniques													
	Live Staking	Wattle Fence	Live Toe Staking	Live Pole Drain	Live Silt Fence	Brush Layer	Coconut Mat	Aspen Mat	Coarse Woody Debris	Rough and Loose	Mulching	Seeding	Vegetation Planting	Vegetated Channels	Coir Rolls (natural fibers)	Straw Bales	Riprap/Aggregate/Armoured Channels	Concrete Blanket	Concrete Lock Blocks	Silt Fence	Concrete Channels	Geotextile/Rubber Liners	Clay Liner	Gabion Basket	Berms	Geotextile Mat	Check Dams	Flocculants	Sediment Traps	Natural Revegetation
Oil Sands (In-situ)																														
Cenovus Energy		✓		✓	✓		✓		✓	✓				✓			✓													✓
ConocoPhilips	✓			✓					✓	✓		✓	✓				✓			✓		✓			✓	✓	✓			✓
Nexen							✓	✓	✓			✓	✓				✓			✓									✓	
Oil Sands (Mining)																														
Canadian Natural	✓	✓					✓					✓	✓																	
Imperial	✓	✓		✓			✓					✓					✓			✓							✓			✓
Suncor		✓					✓		✓			✓	✓		✓	✓	✓	✓				✓	✓	✓	✓					✓
Syncrude	✓			✓		✓	✓		✓	✓			✓	✓			✓		✓		✓	✓								✓
Coal																														
Teck Resources	✓	✓				✓	✓		✓	✓			✓		✓		✓										✓	✓		
TransAlta	✓				✓		✓				✓	✓				✓	✓							✓						✓
Municipalities																														
Various	✓	✓	✓		✓	✓	✓		✓			✓	✓		✓		✓				✓		✓				✓			

3.1.1 In-situ Oil Sands – Operations and Reclamation Planning

This section discusses the types of ESC practices that are currently used at three in-situ operations in northern Alberta.

- The in-situ facilities are young in their operations (less than 15 years), so permanent landscape closure and associated ESC applications have not been initiated, except on small scale areas such as borrow sites, remote sumps, or Oil Sands Exploration (OSE) sites.
- Due to the flat topography at some in-situ sites, such as Cenovus' Foster Creek and Christina Lake projects, limited ESC measures have been required.
- At in-situ operations on hilly terrain where more ESC is required, such as ConocoPhillips Canada's Surmont and Nexen's Long Lake projects, primarily conventional techniques have been used.
  - This has focused on the use of check dams, aggregate cover, riprap and/or liners on drainage ditches, spillways, pipeline corridors, roads, culverts, abutments and banks of bridges, and abutments of above-ground pipelines. The ESC also includes use of energy diffusers or rock covered spillways at water release points to the environment.
  - At Surmont's Central Processing Facility conventional ESC techniques have been primarily used. Woody material that is combustible, and shrubs such as saskatoon and blueberry that can attract bears and result in potential human-wildlife conflicts, have been avoided.
- Bioengineering has been used during the last few years at some in-situ operations.
  - These techniques have been installed for specific problem sites such as groundwater seeps and slope slumping at well pads. Wattle fences, live pole drains and/or live silt fences were used at Cenovus's Foster Creek, after conventional riprap, coconut matting and/or erosion control socks had failed. Live pole drains were installed at the ConocoPhillips Canada's Surmont site.
  - Pilot research to test the effectiveness of specific techniques such as live staking has been conducted at the Surmont and Nexen's Long-lake projects.
  - Rough and loose soil treatment, combined with the use of coarse woody material and seedling planting, have successfully controlled erosion issues and resulted in the establishment of a diversity of plant species on soil stockpiles and borrow pits at the Foster Creek and Surmont sites. A research program being conducted by the Northern Alberta Institute of Technology Boreal Research Institute's (NAIT-BRI) at Surmont is testing the effectiveness of different rough and loose treatments on various slopes, soil types and with variable vegetation densities.
  - Factors that improve the success of live staking are being researched at several oil sands operations, including Surmont and CNRL's Peace River and Cliffdale facilities, through NAIT-BRI's by Dr. Schoonmaker.
- Some ESC techniques have been eliminated or seen their use reduced at some in-situ operations because they have been relatively ineffective or required high maintenance or ultimate disposal. These techniques include:
  - Coconut matting that fails if improperly installed, and can reduce plant species diversity by promoting the growth of grasses,
  - Silt fences that fail if improperly installed or maintained,
  - Silt fencing and matting that contain plastic mesh that needs to be disposed at closure, and
  - Seeding due to its potential to introduce weeds.
- Some conventional ESC measures have failed due to high volumes and/or velocities of water such groundwater seepage (washed out riprap and coconut matting at well pads at Foster Creek) or stormwater flows (washed out geotextiles and rock from steep 18 degree spillways slopes at Surmont).

3.1.2 Oil Sands Mines – Operations and Closure Landscape

This section discusses the types of erosion and sedimentation practices that are currently used at seven mine operations in northern Alberta.

A major focus of ESC during the operation of oil sands mines is to manage water by diverting it away from the mining areas and plant sites through perimeter ditches, and by designing the working landscape with gentle slopes to minimize erosion potential. For example, most of the Syncrude Base Mine operation has shallow slopes, ranging from one to two degrees, with some steeper slopes associated with the overburden dumps (around four degrees) and tailings dams (seven degrees). Landforms with steeper slopes such as overburden dumps or tailing sand storage areas are revegetated as soon as possible to manage erosion and promote stability.

Water management drainage structures typically require ESC measures, such as check dams, gabion baskets, or natural revegetation to prevent erosion and scouring. Run-off diverted through these drainages and released to the natural environment is generally first passed through settling ponds.

Short-term landscape features within the mine (lasting approximately two to three years) are typically not actively managed with ESC measures.

The most common ESC techniques used at all the mines during operations have been conventional, although smaller site-specific bioengineering techniques have been implemented. Natural revegetation strategies have also been used at some sites.

Planning and designing closure landscapes to support maintenance-free, self-sustaining landforms, and ecosystems like natural ecosystems is very advanced at some of the more mature mines such as Syncrude's Mildred Lake, but is still in its infancy at other mines. Closure landscape planning will provide more opportunity to use bioengineering techniques to reduce erosion and establish vegetation. Some conventional ESC measures installed during operations will need to be removed upon closure.

3.1.2.1 Mine Operations and Erosion and Sedimentation Control

On most of **Syncrude's Mildred Lake and Aurora Mine** sites, reclamation through placement of mineral/peat mix and planting of trees and shrubs has led to rapid revegetation of sites reducing the need for implementation of further erosion control measures. Reclamation at Mildred Lake started in 1982, and several areas have reclamation/vegetation which is mature enough to achieve Reclamation Certification. To-date, only Gateway Hill has a Reclamation Certificate.

Proper risk management techniques are used to evaluate how erosion control will be executed and what controls should be used. Syncrude has successfully used bioengineering techniques to manage slumping slopes along pipeline rights-of-way near Beaver Creek and the Aurora T-pit Hill. Live pole drains were used to remove excess water from groundwater seeps and surface water, and brush layers with contour fascines or straw coirs were used to stabilize the slopes. Muskeg and native seed mixes were applied to these sites and has led to successful vegetation establishment. In addition, bioengineering is used in sensitive areas where there is an interest in returning land to a natural state and where stakeholder perception is important such as the outfall on the Athabasca River.

Bioengineering techniques are generally not used in areas where there is low tolerance for instability or failure. In these cases, conventional forms of erosion control such as concrete blocks and riprap are used, and two examples are presented here.

- Piperack's at Syncrude's Mildred Lake plant site are inspected regularly for deficiencies or leaks. Hence erosion issues on adjacent slopes are managed with concrete blocks and not bioengineering techniques. Vegetation cover would impede visual inspections.
- Wildlife such deer and bears can be attracted to vegetation during revegetation activities. On operational sites, this can result in an increase in wildlife-human conflicts increasing the risk for staff, wildlife and operation at the site. Therefore, bioengineering techniques and the establishment of vegetation is usually not allowed within plant sites, tailings ponds or mine areas.

Most ESC methods used at both **Suncor's Base and Fort Hills** mines during operations have been conventional approaches. The Fort Hills mine has very sandy soils, so erosion and sedimentation control is an important issue, and operations prefers to use an approach that provides immediate erosion control. Fort Hills has large amounts of peat available which has been used in reclamation to encourage rapid revegetation, such as along the slopes of the compensation lake.

Suncor has employed a five-step conventional ESC approach for their landforms at Fort Hills, including steep slopes along roadways, drainage ditches and outlet channels, sumps, and sediment ponds.

- On large slopes, filter cloth is used to create drains and move seepage from groundwater away from the slopes,
- Armouring, using riprap, concrete blankets, or gabion baskets, is placed on top of the filter cloth,
- For waterbodies:
    - Nylon-rolled erosion control mats are placed near the water's edge,
    - Coconut rolled erosion control products are placed higher on the slope than the nylon mats, away from the water's edge, and
    - Hydroseeding is used before placement of the rolled erosion control mats.

At the Base Mine during operations, most ESC measures used have been conventional techniques or natural revegetation, although there are some examples of small bioengineering projects.

- Conventional ESC measures, including heavy armoring (either riprap, or a specialized concrete blankets) along with erosion control products, are used to manage high velocity flow areas.
- Most perimeter ditches, used to keep water away from development areas, have been allowed to re-vegetate naturally with grasses and bulrushes. Some perimeter ditches were hydroseeded however, the technique was not typically effective due to thin topsoil or the lack of moisture.
- ESC planning for 2018 on firebreaks created to protect the Base Mine during the 2016 Fort McMurray fires includes both conventional and bioengineering approaches. Firebreaks will be regraded to promote positive drainage off site, top soil and seed mixes will be applied to promote

vegetation regrowth, and silt fences will be installed where appropriate to control sheet flow. Additionally, ESC techniques will include the use of coconut erosion control mats, coarse woody material and live willow staking, such as along steep slopes of the Athabasca River.

- Coconut erosion control mats and straw coirs have been used in swales to convey water off slopes by Clarke Creek. Slope regrading and silt fences have been used to manage erosion and sedimentation issues along the gravel access winter road.

Much of the ESC used during operations on **Imperial's Kearl Lake** mine has been focused on storm water management structures including drainways, culverts and bridges, and releasing water to naturally vegetated areas.

- Conventional use of riprap, aggregate check dams, and sediment control fences are used in and adjacent to these structures to reduce erosion.
- Techniques selected have focused on the rapid establishment of interim vegetation and extensive application of coconut erosion control mats to manage erosion and sedimentation along roads and around tailings ponds. Due to improper installation, coconut mats have presented challenges in controlling erosion.
- Small scale bioengineering techniques have been successfully tested for repairing and impeding erosion issues. These include fascines and live pole drains (to manage groundwater seeps on slopes along the plant access road), wattle fencing (to stabilize overburden slopes), and live staking.

Canadian Natural uses conventional ESC measures at the **Jackpine and Muskeg River mines** (previously owned by Shell Canada Ltd.), such as riprap and armoring, to manage erosion risk.

Small scale bioengineering projects, such as wattle fencing and live stakes, have been constructed at the top of gullies to prevent further erosion on the Shallow Stripping Study Area. Live staking has also been installed amongst the riprap used under the Muskeg River connector bridge.

3.1.2.2 Mine Closure Landscape and Erosion and Sedimentation Control

Landscape closure is still at the conceptual planning stage at most of the oil sands mines, except for: construction of compensation lakes (Suncor and Canadian Natural), the construction of ponds and creeks that mimic natural landforms and ecosystems (Syncrude), and fen construction (Suncor). Although these structure use of a mix of conventional and bioengineering ESC techniques, there will be more opportunities to use bioengineering methods to control erosion issues and as a revegetation strategy during closure reclamation at oil sands developments.

The closure landscape reclamation activities have been focused on three areas related to ESC.

1. Rapid, sustainable vegetation re-establishment. The oil sands mine operators are interested in the feasibility and opportunity to use bioengineering on reclaimed landscapes. Incorporating bioengineering techniques would help support rapid revegetation, slope and soil stabilization, and support reclamation principles of creating sustainable and maintenance-free landscapes.

Syncrude has been researching best management approaches to improve the propagation and survival of live plants, as the establishment of roots and growth of the vegetation is key to the success of bioengineering techniques. They have also been testing the efficiency of bioengineering applications for use during landscape closure, specifically testing for effectiveness in stabilizing slopes and vegetation regrowth. At the Alpha swale site on an overburden dump, fascines and seedlings had better survival and erosion control effectiveness than brush layers and live staking.

2. Water management, and designing the landscape to reduce the number of steep slopes and high-velocity water run-off sites. Syncrude is examining the feasibility of moving water from landform structures using different types of drainage channels, and incorporating various conventional ESC and bioengineering approaches (see Appendix A). The channels types included:
   - Vegetated channels,
   - Alluvial channels,
   - Steeper ephemeral channels on overburden dumps,
   - Steeper ephemeral channels from Mine to End Pit Lakes (EPLs), and
   - Permanent channels from EPLs to the natural waterbodies, or from the natural waterbodies to EPLs.

3. Creating landforms and ecosystems that mimic natural systems for the closure landscape:
   - Syncrude is researching the construction of streams in the closure landscapes that mimic natural streams with their meandering shape and ponding. Natural creeks can absorb extra water flow without experiencing incremental erosion. Constructed channels will be good candidates for incorporating bioengineering techniques and implementing revegetation strategies.
   - Syncrude successfully constructed two ponds with a connector channel in a backfilled pit area by covering the site with mineral/peat soil mix that has revegetated naturally. Coarse woody material was incorporated into the design to reduce water velocities and erosion potential. Beavers are now inhabiting the pond.

3.1.2.3 Compensation Lakes and Nikanotee Fen

ESC techniques used during construction for four landscape level closure structures, including three compensation lakes (two constructed at Suncor’s Fort Hills and Base mines, and one at CNRL’s Muskeg/Jackpine Mine), and Suncor’s Nikanotee fen were reviewed.

For the Fort Hills Compensation Lake, Suncor has used primarily conventional ESC approaches including riprap armouring along banks, channels, and at natural seeps, with cobble placement along the channel outlet to the Athabasca River. Steep slopes above the water edge were lined with coconut matting and coarse woody material was placed along the banks of the channels and lake shoreline. Native vegetation along the shoreline was quickly established by spreading recently stockpiled muskeg soils (stored for less than one season and hence maintained a natural seed bank).

The Compensation Lake at the Base Mine was constructed between 2007 and 2012, as part of the Steepbank Expansion. The lake was lined with a clay geosynthetic liner and the adjacent shoreline slopes gently graded. The shoreline was armoured with gravel to protect against wave action and the outlet channel was lined with riprap and cobbles. Coconut mats were placed on the exposed soils to prevent erosion. Trees, shrubs, and aquatic vegetation were planted along the shoreline. The biodegradable geosynthetic liners have not broken down as expected and are making the shorelines unstable.

The Compensation Lake at the Muskeg River/Jackpine Mine was constructed over a two-year period from 2009 to 2011. Unfortunately, due to rapid filling of the lake and the high flow velocity, much of the erosion control materials placed to reduce the erosion from wave action (e.g., coconut matting) and soil materials were washed away.

The Nikanotee Fen that covers 3 ha within a 32-ha watershed was constructed in 2013 at Suncor's Base Mine. A key finding in designing this larger swale is the need to manage the volumes, flow and velocity of water to reduce erosion and sedimentation. The fen was subjected too a large amount of runoff from the adjacent constructed slopes resulting in gully and rill erosions, and sediment deposition. To reduce water flow and velocity, berms with recharge basins were constructed upslope of the fen, and contoured furrows were plowed across the upland slopes. Straw bales were dug into sites where rills and gullies had started, and successfully stopped erosion. Staked bio-logs, however, failed due to poor installation.

3.1.3 Coal Mines – Operations and Closure Landscape

Operations personnel from five **Teck Resources** coal mines in British Columbia's Elk Valley (Fording River, Greenhills, Line Creek, Elkview and Coal Mountain Operation), two coal mines at the Cardinal River operation in central Alberta (Luscar and Cheviot River), and from a Bioengineering Project along a steep slope of the Columbia River near Trail, British Columbia were interviewed to understand the ESC approaches that have been implemented.

Similar to the oil sands mines, ESC measures used at the Teck coal mines start with controlling water runoff volumes to reduce the potential for erosion and sedimentation. This is done by regrading sites to gentle slopes and by directing potential runoff through ditches, and sumps and/or sedimentation ponds prior to release to the environment. Water structures are managed with conventional ESC measures: armouring with riprap, water is slowed by check dams and water quality is improved with the use of flocculants. The mines also design operational landforms, such as haul ramps and material dumps, considering the flow of runoff and preventing impoundments and these features become part of the closure landscape.

Bioengineering approaches using live plant materials are not currently incorporated into Teck's ESC management plans for mine operations. This is pursued due to the dynamic nature of the coal mine operations, and frequent changes in the landscape.

Bioengineering is typically used as part of the closure landscape at **Cardinal River coal mines**. During progressive reclamation, rough and loose soil placement, tree and shrub seedlings planting, and non-living plant materials (including straw logs, coconut/jute mats and coarse woody material) are used at the mine.

The rough and loose mounding of soil/woody material on reclaimed sites at the **Cheviot Mine** has been very successful at managing erosion and sediment issues and promoting native species establishment. A mix of salvaged soil, subsoil and coarse woody material is dumped in mounds, and tree and shrub seedlings are planted in micro-topographic sites.

Coconut mats have been used to manage erosion in some water channels, but they present maintenance challenges due to high winds in the region. Some hydroseeding and tackifiers are used on site, but they are limited to avoid the introduction of weeds.

A **steep 45-degree slope along the Columbia River** that was influenced by the Teck metallurgic smelter near Trail, British Columbia was treated using bioengineering techniques as it was experiencing slumping and erosion issues. The intent of the project was to re-establish vegetation and improve the visual aesthetics, and to improve slope stability and the functionality of the riparian zone along the river. After removing the existing riprap and excavating and terracing the slope, gullies and rills were backfilled and topsoil applied to the slope. Wattle fences were placed on the steeper slopes, brush layers were installed in the riparian areas, and live staking was added in small pockets across the site. After four years, the planted trees were 7 to 10 m tall and vegetation had established over most of the site. Wattle fences successfully acted as slope breaks and reduced erosion, brush layers produced a thick riparian zone along the river, and live staking had successful growth on all the but highest slopes.

Irrigation and fertilization were considered necessary to ensure successful rooting and long-term survival of the cuttings. The irrigation system was complex, had a high maintenance requirement and was expensive to operate.

Other bioengineering projects at the Teck mines have included:

- Creation of aquatic habitat in 2017 along the McLeod River in central Alberta at an historic coal mine site using wattle fencing, planting willow and dwarf birch, and using coconut mats to control erosion, and
- Live staking along the Fording River in Elk Valley to improve riparian vegetation and fish habitat.

TransAlta operates the **Whitewood** and **Highvale** coal mines in central Alberta that provide fuel for several power generation plants. TransAlta is interested in practical, low cost reclamation approaches that will create agricultural lands, and steeper rolling parklands with treed areas, wetlands, and end-pit lakes.

The mines are reclaimed progressively and ESC measures are only implemented during reclamation. Currently, ESC approaches used at the mines are 40% conventional (e.g., gabion baskets and riprap primarily in drainways) and 60% bioengineering techniques (e.g., hydroseeding and live staking).

Reclamation requires long-term planning with consideration of watershed development and management across the entire reclaimed landscape. At the coal mines, water is managed on-site to minimize erosion.

- Natural clean water is diverted around the mine through man-made ditches and natural creeks into Lake Wabamum. Gabion baskets are used to armour high velocity drainways.

- All secondary water is captured on-site and retained in sediment and retention ponds (designed for 1:100-year floods). It is then pumped and piped to the cooling pond at Sundance where it is treated at the water treatment plant. A portion of this treated water is returned to Lake Wabamum (variable each year to reflect natural amounts being removed from watershed by the mines) and the rest is treated and used in the power plants.

ESC approaches currently used at both the Whitewood and Highvale mines include: coconut matting, hydroseeding, mulching, live staking, compost application, riparian preservation, and straw-bale barriers.

TransAlta is considering using sod to re-establish vegetation in the future, like some of the mines in the United States. Bioengineering approaches also being considered for future reclamation at the mines include live pole drains, live gully breaks, live bank protection, and gravel bar staking

3.1.4 Municipalities and Forestry

Most municipal ESC projects use a combination of conventional and bioengineering techniques. The case studies reviewed focused on stream bank stabilization, dyke re-armouring, managing groundwater seeps, and bridge abutments. The case studies included:

- **John Mathews Creek stream bank stabilization**: used riprap with topsoil and seeding, covered with coconut mats, salvaged trees as coarse woody material, and planted native trees and shrubs.
- **Canmore Bow River dyke re-armouring**: used riprap and large boulders, live staking within the riprap, and planting conifers on the bank.
- **Cavell Tarn Creek streambank erosion and seeps exposed during flooding at the Edith Cavell in Jasper National Park**: used a combination of wattle fence, brush layer, and live stake bioengineering approaches and temporary conventional ESC approaches.
- **Kakisa River ESC for bridge abutment and bank stabilization**: used riprap, slope contouring, silt fencing, and rock and straw check dams. Bioengineering included willow stakes and hydroseeding covered with erosion control mats.
- **North Saskatchewan River bank stabilization**: near the Town of Devon a wattle fence was constructed.
- **Blackmud Creek streambank stabilization**: used wattle fencing, live pole drains and live siltation.

Guidelines on ESC prepared by the City of Calgary (2011) and Alberta Transportation (Government of Alberta 2011) discuss the integration of both conventional and bioengineering erosion controls into the planning and implementation of a single project.

Forestry companies were not able to provide case studies to illustrate ESC techniques for this report. However, they did provide three manuals that are used by several forestry companies to guide ESC planning and implementation on projects. The manuals discuss both conventional ESC and bioengineering approaches, and their contents are outlined in Appendix A. The three manuals referenced are:

- FPInnovations. 2016. Resource Roads and Wetlands: A Guide for Planning, Construction and Maintenance.

- Diashowa-Marubeni International Ltd (DMI). 2016. Watercourse Crossing Field Guide and Strategy Manual.
- FPInnovations. 2007. Erosion and Sediment Control Practices for Forest Roads and Stream Crossings.

3.2 BENEFITS AND LIMITATIONS OF CONVENTIONAL VERSUS BIOENGINEERING ESC IN OIL SANDS OPERATIONS

The most commonly cited benefits and limitations of conventional and bioengineering approaches for ESC identified by operations personnel are outlined in Sections 3.2.1 and 3.2.2.

3.2.1 Bioengineering Erosion and Sedimentation Control

The most common **advantages of bioengineering ESC** identified by operations personnel during interviews were.

- Rapid establishment of vegetation is one of the best, long-term ways to reduce erosion and control sediment, and bioengineering successfully revegetates areas. For example, erosion is currently less of an issue at the 12-year-old Surmont 1 site due to well established vegetation, than at the 2-year-old Surmont 2 site where vegetation is still being re-established.
- ESC using live plant material takes a longer time to establish (three to eight months), but once established it is permanent and self-healing, and has lower maintenance requirements compared to conventional ESC.
- Plant material for bioengineering projects can often be sourced locally from riparian areas, early successional ecosystems or “mine advance” areas on lands adjacent to the ESC site. There is a need to comply with the Government of Alberta Forest Genetic Resource Management and Conservation Standards (Alberta Agriculture and Forestry, 2016), and get permission to access and cut plant material from AER.
- Because locally available native plant materials (i.e., willow, aspen, dogwood) are used, the materials are typically less expensive than conventional ESC materials (e.g., aggregate, gabion baskets etc.).
- Vegetation regrowth resulting from bioengineering is natural in appearance, aesthetically pleasing and blends into the surrounding ecosystems. Using native species can increase habitat biodiversity compared to conventional techniques using riprap, gabion baskets and other measures. Bioengineering fits well into the objectives of closure landscapes as the resulting vegetation is low maintenance and self-healing, and mimicking natural analogues. It initiates ecological succession processes by accumulating leaf litter, conditioning the soils and building up a bank of seed and plant propagules.
- Techniques such as live pole drains can effectively remove excess water from problem sites, and allow other ESC measures to be effectively installed.

Some **challenges of bioengineering techniques** identified during interviews included:

- Lack of knowledge on the implementation and limitations for each technique, understanding Best Management Practices for installation, and a lack of professionals trained to design and install various applications was the most commonly identified challenge. Bioengineering has only recently been implemented at many oil sands operations, and further research is required to test functionality and effective establishment. Some research on different applications and on different landscapes, moisture and soil conditions, and installation approaches is being conducted. However, many bioengineering techniques are not yet considered field proven and the risks are not well understood, compared to those of conventional ESC approaches.

- The collection of plant materials and the installation of bioengineering applications is considered labour-intensive and time-consuming, and can present safety concerns:
  - Shrubs and tree materials are often cut by hand, requiring several people, and there are often challenges accessing collection sites,
  - Cut live stakes need to be soaked for several days before being used to construct structures, and
  - The installation of wattle fences, and brush fences requires several people and can occur on steeper slopes where proper safety precautions need to be followed.
- Bulk sourcing of shrub and tree plant materials (e.g., willow, aspen, dogwood) for bioengineering may become an issue as bioengineering projects are pursued on larger landscape levels or concurrently at several oil sands sites In the future, plant material collection may require applications for genetic variance to obtain material outside of current seed zones (Alberta Agriculture and Forestry 2016). This will result in more paper work with the Alberta Government, and will be more expensive due to transportation costs. Options such as growing seedlings in a nursery or cultivating them in fields (stooling beds) should be examined.
- Bioengineering applications can only be installed during short time windows (i.e., spring and fall) when willows are dormant, and these do not always match the windows when erosion control is required. Fall conditions can be cold and/or icy, presenting safety issues.
- Vegetation can attract wildlife and hence bioengineering approaches are not encouraged at plant sites, tailings pond and mines, or other areas where wildlife can cause human conflicts and safety issues.
- Vegetation can take three to eight months (or longer depending on the timing of installation related to growing seasons) to establish before soils are stabilized and the risk of erosion is managed. Also, it can take longer to source required volumes of plant materials (harvesting, or growing of live cuttings) than for conventional ESC.

3.2.2 Conventional Erosion and Sediment Control

The most common **advantages of conventional ESC** identified by operational personnel were:

- Conventional techniques can be installed year-round, and they provide immediate ESC upon installation, with predictable performances. With bioengineering techniques, vegetation can take several months to reach peak erosion control.
- Conventional techniques and their effectiveness for ESC are well understood with many field-proven case studies and there are many trained professionals available for planning, design, and installation.
- Conventional approaches such as armoring are more successful at preventing erosion under conditions of high water flow and velocities.

- Public awareness of ESC since the riprap and other structures are seen, while bioengineering is less visible.

Some of the **limitations of conventional ESC** identified during interviews with operational personnel were:

- Conventional ESC is very expensive compared to bioengineering and can be time-consuming to install.
- The structures are not natural-looking or aesthetically pleasing, and do not blend into the landscape.
- They may require high maintenance depending on the techniques (e.g., inspection of silt fences, and cleaning sediment from riprap and silt fences to ensure they are effective). Over time conventional structures can degrade.
- Some structures such as metal anchors, plastic mesh, concrete and underground drainage would need to be removed for closure.

There were conflicting opinions on the availability of materials for conventional ESC (e.g., aggregate, riprap), with some individuals noting materials are usually readily available and easily sourced, and other personnel stating materials cannot be sourced locally, require long haul distances, and there may be aggregate supply shortages in the future in the Fort McMurray area.

3.3 RECOMMENDATIONS FOR ESC FOR THE OIL SANDS OPERATIONS

There are 10 factors to be considered when determining the suitability of specific erosion control practices for a project.

1. **Risks or Consequences of Failure:** Projects with high risks to operations and personnel and/or areas with low tolerance of failure currently lead engineers to select conventional ESC. This selection is partially due to the lack of knowledge on and yet unproven track record of bioengineering techniques. Examples of higher risk situations include:
   - Where water could cause damage to critical operations, and risk must be reduced as much as possible, conventional ESC will be used despite higher costs. For example, pipe racks need regular integrity inspections and vegetation could hide leaks or deficiencies, hence only conventional solutions for erosion are used.
   - Wildlife can cause safety hazards for operations and personnel. Hence, vegetation (bioengineering) that could attract wildlife is discouraged within plant sites, tailings ponds and mines.
2. **Need for Immediacy:** For sensitive areas that require immediate erosion protection, conventional solutions are often used, as vegetation establishment (using bioengineering techniques) can take too long to be effective.
3. **Water Flow and Velocity:** Some ESC products, such as nylon matting or riprap, are better able to withstand the shear forces that accompany high flows and/or high velocities. Live poles drains have been effectively used to move water away from problem areas and allow other ESC measures to be installed.

4. **Topography/Slopes:** Different ESC methods are suited for different topographies and slopes. Bioengineering techniques such as wattle fencing can be used on slopes less than 70 degrees, fascines or fibre rolls on slopes less than 45 degrees, and brush layers on slopes up to 27 degrees. Conventional techniques are usually used on shallower slopes. For example riprap armouring is used on slopes up to 27 degrees and gabion baskets are used on slopes that range from 33 to 63 degrees. Erosion and control matting is used on slopes less than 21 degrees (Government of Alberta 2011).
5. **Soil Characteristics and Moisture:** Soil texture and chemistry can affect the performance of some erosion control methods. Good contact between ESC measure and the slope and soil is required for rolled erosion control products, straw bales etc. Sandy soils may allow water to run under these controls. Bioengineering requires suitable moisture to permit vegetation growth, especially in the first several months, to ensure vegetation establishment. For areas with non-soil or poor growing medium, conventional as opposed to bioengineering is the preferred method as the vegetation growth and erosion control will be poor in the short-term.
6. **Accessibility** (for collecting live plant materials and installations)**:** Some ESC methods require manual labour for the collection of live plant material and to install the application (e.g., live pole staking, wattle fence), and these sites must be safely accessed. Some ESC such as brush layers, wattle fences and rough and loose soil placement may require support from heavy machinery or spider excavators.
7. **Weather and Season:** Bioengineering approaches are very dependant on the weather and season. Live plant material can be harvested only when they are dormant (October to April), and planted from short periods in the fall (before freeze-up) or spring (after soil thaw and growth begins; mid-May to mid-June). Also, shorter growing seasons may slow plant growth, and adequate precipitation (or irrigation) is necessary for plant survival and viability. Conventional approaches can be used throughout the year.
8. **Permanency of Techniques:** Some ESC measures are intended to be temporary in nature (i.e., erosion and control matting, mulch, tackifiers, silt fencing), while others are considered permanent control measures. Bioengineering using shrubs or trees is considered a permanent form of ESC that can be incorporated into closure reclamation. Some components of conventional engineering such as wire, anchors etc. must be removed at reclamation closure.
9. **Availability of Materials:** Larger projects must manage sourcing and availability of materials for both bioengineering and conventional ESC; operators have sited shortages of materials for both types of ESC. For bioengineering, obtaining adequate harvestable materials (which requires Government approvals) and contractors with proper capacity (knowledge and skills) are required. Although much of the live plant materials are obtained from the wild, some companies such as Syncrude have established stooling beds to produce live plant cuttings (2 stooling beds with a capacity of over 30,000 stems for willow and poplar annually).
10. **Cost:** A balance between the cost (i.e., installation, materials, monitoring, maintenance and removal) and achieving the necessary level of control within the required time frame for the level of risk identified needs to be considered when selecting the ESC approach.

3.3.1.1 High Level Recommendations for ESC for Oil Sands Operations

Key high-level recommendations for ESC in the oil sands region that have been consolidated from across industrial sectors are summarized in Table 3-2.

- As illustrated in the case studies for municipalities and several oil sands projects, the **integration of both conventional and bioengineering techniques** within a single project has proven successful. This is supported by several ESC guidelines and manuals such as those prepared by Alberta Transportation, City of Calgary and Forestry companies.
- Natural re-vegetation using **rough and loose soil management** with **coarse woody material,** and the planting of shrub and tree seedlings is being used more commonly at some of the oil sands and coal mines for rapid revegetation. The rough and loose technique leaves many microsites that slow water, capture seeds and promote vegetation growth, whereas compacted, homogeneous slopes do not hold water or allow seeds to establish. Also, there is less preparation and maintenance costs associated with this technique (e.g., no bulldozers or ESC repairs required). Rough and loose soil management has been used at various application scales from large areas as illustrated at the Cardinal River coal mine, to smaller scales such as soil storage sites at Surmont and Foster Creek, drainage ditches at Foster Creek, and burrow pits at Long Lake and Foster Creek.
- The use of the rough and loose technique will allow oil sands operators to **move away from the practice of hydroseeding**, and grasses and legumes seeding for ESC in the boreal forest. Grasses and legumes reduce the survival of tree and shrub seedlings, and reduce the potential for ingress of native plant species from surrounding areas.
- **Bioengineering techniques** to establish vegetation is **discouraged at higher risk operational sites** where wildlife could increase human-wildlife conflicts, or where rapid or certain ESC is required to manage safety risks, or where vegetation would obscure visual integrity inspections.
- Bioengineering techniques using live plants are considered **permanent ESC methods** that require little maintenance once established. They are particularly successful along streambanks, drainways and near groundwater seeps where the vegetation helps manage the water sources that cause can erosion, and stabilize the slopes with their root masses. These techniques are particularly useful for **operational projects away from high ESC risk areas** such as at well pads, soil stock piles, bridges, roads and for the **closure landscape**.
  - Bioengineering using live plants require a moisture source during the early months of shrub and tree establishment. If shrubs and trees do not have access to water due to topography, depth to the water level, or soils types during this period, they will not survive. Irrigation has been used successfully in the establishment of wattle fences, brush layers and live stakes.
- Bioengineering techniques may be challenging to implement for larger-scale, landscape-level projects, due to the intense labour required for installation (e.g., brush layers or wattle fencing), and due to the limited availability of live cuttings. Live plant cuttings could be grown in stooling beds (cultivated in fields) or rooted in nurseries.
- Although erosion and control matting is used at several oil sands and coal operations, it can be challenging to install, maintain and remove at final reclamation. It can also inhibit plant species diversity by promoting grass growth, and has been shown to fail on steeper and larger-scale slopes.

Table 3-2
Summary of Key Learnings Related to Bioengineering ESC

Oil Sands Operations Phase: Successes and Lessons Learned
Successes: Cenovus used wattle fences and live staking to stabilize soils and live pole drains to reduce soil moisture (directed water to perimeter ditches and offsite) at well pads where grading had exposed groundwater seeps and caused slope slumping. Conventional ESC measures had previously failed, as water got underneath erosion control matting and riprap. ConocoPhillips used live staking and seedling planting, in combination with rough and loose soil placement, to successfully reclaim soil stockpiles at the Surmont in-situ operation. Green alder was the most successful species. The use of live fascines at reclamation research swale conducted by Syncrude, were more successful than brush layering for stabilizing soils and revegetating the site. Brush layers extended above the surface (approximately 1 m), captured surface debris and eventually failed, creating channels. Seedling planting was more successful at establishing vegetation and became the preferred approach over live staking that failed to achieve targeted 70% success rates.
Lessons Learned: Coconut matting, used in a variety of different settings (both in mining and in-situ), often failed to stabilize exposed soils, even if they had been keyed to the soil surface adequately. Failure occurred within the first few months after installation, as water could get underneath the matting. Harvesting live plant material required manual labour and access to harvesting sites could be challenging: • A team of six people harvested 150 willows at the Cenovus' Foster Creek site in four hours, • Harvesting plant material between October to April led to safety concerns for personnel in the field (i.e., cold and icy/muddy), and • Finding trained/experienced professionals in bioengineering to assist with design and installation was challenging. Hydroseeding was commonly used to stabilize exposed soils at oil sands facilities (both in mining and in-situ), however, it was prone to failure in areas where topsoil was thin or there was a lack of rain. Live staking was most successful when the cuttings were fully inserted into a moisture-rich soil layer. Live stakes inserted into 35 cm of peat/mineral mix survived better than those inserted deep into tailings sands or into the shallow LFH layer (Research slopes at Jackpine/Muskeg River mines). For the small-scale bioengineering projects at Imperial's Kearl Mine, certified professionals were hired to ensure proper installation of bioengineering applications. Poor installation of live material at some facilities leads to failure and additional costs.

Table 3-2 (cont'd)

Live Staking Research by NAIT-BRI
Results from five research programs led by Dr. Schoonmaker include: • Painting cut/exposed ends of live stakes with non-toxic latex reduced cutting desiccation, • Planting in areas with no competition (from grasses, legumes, and other cover crops) increased cutting survival rates, • Cuttings harvested from lowland settings have a higher survival rate than those harvested from upland environments, and • Cuttings which are long (30 to 100 cm) and have a diameter of 0.5 to 3 cm have higher chances of survival.
Unique Aspects Related to Balsam Poplar Live Staking: • Ripped furrowed soils improved poplar survival rates; 60% of the poplars planted on soils with a range of microsite conditions survived better than those planted on flat soils, compacted soil where only 20% survived. • Hot-planting hardwood (rooted nursey stock with leaves) was less successful when compared to non-rooted hardwood cuttings of poplar. Hot-planting carried the risk of high desiccation rates as exposed leaves lost water more rapidly. Rooted hardwood planted during the dormancy period (i.e., rooted with no leaves) resulted in higher survival rates (80%).
Unique Aspects Related to Willow Live Stakes: • Hot-planting was effective when using willow. Sixty percent of hot-planted willows survived their first year, while only 10% of unrooted willows survived.
Planting rooted vegetation is more expensive, as cuttings must be harvested on-site, taken to a nursey to establish the root system, and delivered back to site for planting. Under ideal conditions (good plant material, good soil moisture and limited plant competition), unrooted stakes have an approximate survival rate of 50%. In comparison, rooted poles have 80 to 100% survival rates under ideal conditions.

Table 3-2 (cont'd)

Syncrude Live Plant Research
For large projects, applying bioengineering techniques in the spring is more suitable than installation in the fall. • Plant material should be harvested when willows, poplar etc. are dormant (October to April). • There is a very narrow window between harvesting live plant material and installation prior to topsoil freezing in the fall. After October, soil begins to freeze, so installation of live plant material is not recommended. It is challenging to generate good contact between the wattle fascines, or live poles etc., and the soil, and peat needs to be added to fill the void spaces. • Harvested material must be kept frozen and stored to prevent desiccation (bagged or covered with blankets). • Natural features that are locally available can be used to store, freeze, and soak live plant material (i.e., cover with snow and placed on small frozen ponds) until they can be installed in the spring. • Planting must occur around mid-May when approximately the top 30 cm of topsoil has thawed. Planting beyond June 10 has a negative effect on survivorship, as live plant material loses vitality.
Duration of ESC techniques: • Erosion blankets are good from one season (straw) up to three or four seasons (coir or coconut). Long-term protection labels on blankets mean they are made of non-biodegradable material (plastic) and would have to be removed prior to closure. • Spray on mulch has a similar lifespan of one season to 18 months.
Source Materials: • Much of the live plant materials are obtained from the wild; Syncrude produces live plant cuttings at two stooling beds with a capacity of over 30,000 stems for willow and poplar annually.

Within the swales where bioengineering techniques were tested:
• Live fascines (using 2 to 3 m long willow and poplar cuttings) are installed perpendicular to water flow. They established within the first year of installation and provided good erosion control.
• Brush layers failed in their first year; the willows extended 1 m above the surface and collected debris during spring thaws or heavy rainfall events. Eventually the brush layers failed under the pressure of the debris and caused a hydrologic surge, creating channels along the swale.
• Currently seedlings (willow, poplar, dogwood, and river alder grown from cuttings) are used preferentially over willow staking for planting between wattles. Historically, willow stakes failed to achieve 70% success rates due to:
  • Spring droughts that are endemic to northern Alberta,
  • Delays in installation that compromised live stake vitality,
  • Poor handling and storage practices, and
  • Live poles were stored for too long, vitality suffered and survivorship was low.

Table 3-2 (cont'd)

Coal Mining and Municipalities: Successes and Lessons Learned
Live plant materials require good quality soil to provide a suitable growth medium. • Glacial fluvial soil materials do not retain moisture very well, so live plant material along a slope of the Columbia River near the Teck smelter, required irrigation. Live plant materials are vulnerable to failure if herbivory occurs during early establishment and the site may require fencing.
Live cuttings require good contact with earthen materials, if they are to successfully establish and stabilize soils. Cuttings placed in burlap bags filled with topsoil and placed within the riprap along the shoreline of the Bow River failed to establish, as the bags were easily ripped, exposed and dislodged.
At Teck's Cardinal River Operation, salvaged soil and subsoil are mixed with felled trees on-site to create reclamation material that was then placed in rough and loose mounds to promote revegetation. By sourcing woody material locally, Teck limited their use of straw bales and hydroseeding, and reduced their risk of introducing invasive species and weeds.
Coconut matting, hydroseeding, and mulch were applied to spoil pit slopes at a TransAlta mine; rills and gullies formed as the limited topsoil failed to support vegetation growth. Over the subsequent three years, ESC measures were re-application until 70% vegetation cover was achieved.

3.4 MOVING TOWARDS BIOENGINEERING TECHNIQUES, PRACTICES, AND RESEARCH

Three recommendations are proposed to develop bioengineering into a more common ESC practice in the oil sands region.

1. **Increase Training on Bioengineering Techniques and Installation**

   ESC requirements are often contracted to third-party consultants at oil sands operations. Many of the oil sands personnel who oversee the contractors do not have formal training in bioengineering techniques, although they are often knowledgeable about conventional techniques through their education. By providing training on bioengineering options, requirements and installation, operations personnel will understand all available options for ESC (bioengineering and conventional) and make informed decision on the Best Management Practices for the project site. They will also be able to recognize if bioengineering techniques have been installed correctly.

   Many of the operations personnel interviewed indicated they would welcome guidelines and information on bioengineering to better understand all options that are available for preventing and repairing erosion.

2. Coordinate Live Plant Production for Bioengineering Installations

As oil sands projects advance toward closure reclamation, a greater abundance of shrub and tree cuttings will be required for bioengineering ESC and may be restricted by the lack of available materials if only wild collections of cuttings are considered. Options to increase shrub and tree cuttings include:

- Consider bulk cutting production by growing cuttings in a nursery such as green houses, or in stooling beds (cultivated in fields). This could be pursued as part of an expanded Oil Sands Vegetation Cooperative, or the Alberta Tree Improvement and Seed Centre.
- Consider starting shrub and trees required for bioengineering from seed rather than field cuttings.

The use of a greenhouse or stooling bed to produce live cuttings would require longer and earlier planning.

3. Coordinate and Expand Research on Bioengineering Techniques

NAIT-BRI has conducted studies involving live staking and rough and loose soil management at several oil sands sites. Consequently, the key researcher could compile information on the best practices for the installation and survival of live staking as summarized in Table 3-2.

If research on other aspects of bioengineering practices was coordinated amongst oil sands operators, the science and effectiveness of best management practices could be advanced more rapidly.

It became apparent during the interviews that more field testing is needed as well as case studies on bioengineering techniques under different topographic, soil and weather conditions. This could increase our understanding of the limits, risks, and opportunities for their use, and increase confidence in the effectiveness and performance of bioengineering techniques.

3.4.1 Short-term Steps to Achieve Recommendations

Five short-term steps to achieve some of the recommendations identified above include:

1. Develop a guidebook for practical planning, installation and maintenance of bioengineering techniques that can be used in the field.
2. Develop training videos that illustrate the proper installation, monitoring and maintenance of bioengineering applications.
3. Design a workshop to train operational personnel on bioengineering techniques and a field excursion to install a wattle fence, or brush layer.
4. Convert the soil bioengineering application knowledge into civil engineering language, including structure strength, sediment filter capacity, water removal capacity of plants etc. that can be used to compare conventional to bioengineering ESC opportunities and limitations.

5. A cost comparison of bioengineering and conventional techniques from installation through maintenance.

Closure

This report was prepared for Canada's Oil Sands Innovation Alliance (COSIA) to document erosion and sediment control (ESC) approaches currently used by in-situ and mining companies in northern Alberta and by some other industry sectors including coal and forestry. Information was collected through interviews with, and reports acquired from operational personnel. Case studies were summarized, and successes and lessons learned from both conventional and bioengineering ESC identified, and recommendations related to ESC for the oil sands facilities presented.

Primary authors or contributors to this report, in alphabetical order, from Associated Environmental include: Kristen Anderson, Stephanie Findley, and Judith Smith, and from Polster Environmental Service Ltd., Dave Polster.

The services provided by Associated Environmental Consultants Inc. in the preparation of this report were conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions.

Respectfully submitted,
Associated Environmental Consultants Inc.

Judith Smith M. Sc., P. Biol.
Environmental Assessment Manager

May 23, 2018

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Appendix A - Annotated Key Reference Documents on Erosion and Sedimentation Control

Annotated information from key references used in this study for Bioengineering and Conventional Erosion and Sedimentation Control are outlined below.

1. Regional Drainage Sustainability Options, Mildred Lake Closure – 2014

<table>
<tr><td>Author</td><td colspan="3">Barr Engineering Company (Barr)</td></tr>
<tr><td rowspan="2">Document Type</td><td rowspan="2">Literature Review</td><td colspan="2">ESC Approach</td></tr>
<tr><td colspan="2">Soil Bioengineering Techniques</td></tr>
<tr><td>Industry</td><td colspan="3">Oil sands mining</td></tr>
<tr><td>Geography and Geology</td><td colspan="3">Soil: Mine tailings (non-cohesive sand and gravel and natural sub soils)
Climate: Northern climates
Vegetation: Spruce and Douglas Fir, willow (or similar)</td></tr>
<tr><td rowspan="2">Applicable Landforms</td><td>Vegetated channels</td><td>Alluvial channels</td><td>Permanent or ephemeral channels</td></tr>
<tr><td>Wetlands</td><td>Subsurface water management</td><td>Closure drainage channels</td></tr>
<tr><td>Current Practices</td><td colspan="3">Mild/steep sloped watercourses:
- Live timber crib wall
- Timber cribs
- Live timber frames
- Brush layering
Establish vegetated overbanks on connected floodplains.
Adding wetlands act as upland reservoirs and can reduce flow.</td></tr>
<tr><td>Other Comments</td><td colspan="3">This literature review was created to specifically address the riprap lined drainage channels as part of the mine closure plan for Syncrude’s Mildred Lake site.</td></tr>
</table>

2. Oil and Gas Well/Facility Site Erosion Management – 2006

Author	Charlie Lake Conservation Society		
Document Type	Case Study	**ESC Approach**	
		Conventional Management	
Industry	Oil and Gas Well/Facility Site		
Geography and Geology	**Location:** Charlie Lake watershed in northeastern British Columbia (~281 km^2)		
Applicable Landforms	Roads	Building sites	
	Culverts	Drainage ditches	
Current Practices	2-year review of erosion and sedimentation issues in Charlie Lake: - Rills - Gullies - Scour around culverts - Erosion outside dyke perimeter Underlying causes to erosion: - Lack of vegetation - Interruption of natural water drainage channels - Lack of ESC knowledge/planning Bioengineering recommendations: - Vegetation cover - Seeding/mulching - Rolled erosion control products - Live staking		
Other Comments	Erosion and sedimentation issues from well sites located in Charlie Lake watershed, lead to water quality issues in Charlie Lake. This report identified underlying causes to the erosion and suggested mitigation measures to limit sediment releases to Charlie Lake		

3. City of Calgary; Guidelines of Erosion and Sediment Control – 2011

Author	City of Calgary			
Document Type	Guidelines	**ESC Approach**		
		Conventional Management (primarily), with some Bioengineering		
Industry	Municipal Projects/Infrastructure			
Geography and Geology	Primarily disturbed soils within Grassland/Parkland natural regions and Foothills Fescue, Foothills Parkland, and Central Parkland natural sub-regions.			
Applicable Landforms	Roads	Culverts	Bridges	Watercourse Crossings
	Building Sites	Subsurface Water Management	Overburden Stockpiles	Borrow Sites
	Cut Slopes/Fill Slopes	Drainage Ditches	Permanent or Ephemeral Channels	Overburden Dumps
	Vegetated Channels	Alluvial Channels	Wetlands	Pipelines
Current Practices	Contains best practises for controlling erosion and sedimentation on urban construction sites.			

Stripping, Grading, and Site Preparation	**Erosion Control: Stormwater Management**	**Erosion Control: Soil Stabilization**	**Sediment Control**
Construction Scheduling and Phasing	Temporary Berms and Channels (Run-off Diversion and Storage)	**Seeding/Sod***	Dust Control
Preserving Existing Vegetation*	**Grass-lined Channels***	**Mulching***	Construction Dewatering Practices
Topsoil salvage and Placement*	Riprap-lined Channels	**Hydroseeding or Hydro-mulching***	Sediment Traps and Basins
Surface Grading, Roughening, and Slope Texturing*	Slope Drains	**Rolled Erosion Control Products***	**Compost Berms and Basins***

	Stabilized Construction Site Exits/Entrances	Energy Dissipaters/Outlet Control	**Compost Blankets***	Silt Fence
		Check Dams	**Straw/Fibre Wattles (Rolls)***	Storm Drain Inlet Protection
			Aggregate Cover	Flocculants and Coagulants
			Riprap	
			Cellular Confinement Systems	
			Live staking, wattles, and brush layering*	

*Indicates bioengineering approaches

Other Comments	Many of these approaches are the same as those found in the **Alberta Transportation Erosion and Sediment Control Manual (2011)**. This document adapts these approaches to apply to municipal projects.

4. Watercourse Crossing Field Guide and Strategy Manual -2016

<table>
<tr><td>Author</td><td colspan="4">Daishowa-Marubeni International Ltd. (DMI)</td></tr>
<tr><td rowspan="2">Document Type</td><td rowspan="2">Manual</td><td colspan="3">ESC Approach</td></tr>
<tr><td colspan="3">Conventional and Bioengineering</td></tr>
<tr><td>Industry</td><td colspan="4">Forestry</td></tr>
<tr><td>Geography and Geology</td><td colspan="4">Various watercourse crossing types</td></tr>
<tr><td rowspan="2">Applicable Landforms</td><td>Roads</td><td>Bridges</td><td>Culverts</td><td>Drainage ditches</td></tr>
<tr><td>Watercourse crossings</td><td>Wetlands</td><td>Vegetated channels</td><td>Alluvial channels</td></tr>
<tr><td>Current Practices</td><td colspan="4">Watercourse crossing techniques outlined in this manual include:
Temporary
• Log fill
• Wood culvert style log fill
• Snow fills
• Ice bridges
• Portable single span bridges
Permanent
Single span structures with:
• Composite precast concrete
• Non-composite precast concrete
• Timber deck
• Precast reinforced concrete
• Driven steel piles
• Spread footings
• Precast concrete block footings
• Timber wingwall system
This DMI manual uses a Stream Crossing Assessment Ranking (SCAR); the assessment considers four input factors to determine the priority and monitoring requirements for water crossings. The SCAR is can be used to determine:
• Proportion of crossings monitored,
• Method of monitoring, and
• Monitoring frequency.
Monitoring can ensure compliance with regulatory standards and protect watercourses.</td></tr>
</table>

5. Erosion and Sediment Control Practices for Forest Roads and Stream Crossing – 2007

<table>
<tr><td>Author</td><td colspan="4">FPInnovations</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Operations Guide</td><td colspan="3">ESC Approach</td></tr>
<tr><td colspan="3">Conventional and Bioengineering</td></tr>
<tr><td>Industry</td><td colspan="4">Forestry</td></tr>
<tr><td>Geography and Geology</td><td colspan="4">Roadways in forested areas and occasionally in riparian areas. Disturbed soils from the road itself or surrounding cut slopes, fill slopes, ditches, and other features where the soils have been disturbed.</td></tr>
<tr><td rowspan="2">Applicable Landforms</td><td>Roads</td><td>Culverts</td><td>Bridges</td><td>Drainage ditches</td></tr>
<tr><td>Wetlands</td><td>Watercourse Crossing</td><td colspan="2">Cut Slopes/Fill Slopes</td></tr>
<tr><td>Current Practices</td><td colspan="4">Erosion prevention using:
• Tracking machines to create micro-terracing (i.e., rough and loose)
• Retain native vegetation; limit soil disturbance
• “lop-and-scatter” application of non-merchantable steams (i.e., coarse woody material)
• Dry seeding: using hand-held/ATV mounted/power seed spreaders
• Hydroseeding/hydromulching
• Compost application
    ◦ Blow dry compost
    ◦ Compost socks
• Live plant material
    ◦ Wattle fences
    ◦ Brush layers
• Rolled erosion control blankets/mat (inert plant materials)
• Straw and crop stalks
• Logging debris: create a rough and loose surface texture through the addition of coarse woody debris
• Aggregate cover (rocks, riprap, etc.)
• Chemical soil stabilization
Containing/collecting sediment:
• Geotextile fences (silt fences)
• Straw bales
• Sediment pond/basin
• Flocculants</td></tr>
</table>

Other Comments	A quick overview for this operation guide is also available in a presentation titled **Erosion and sediment control: Handbook introduction** by Clayton Gillies, available at FPInnovations.

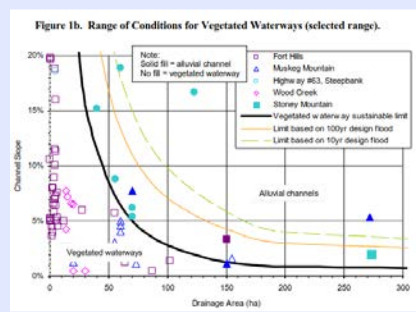
6. Resources Roads and Wetlands: A Guide for Planning, Construction and Maintenance – 2016

Author	FPInnovations		
Document Type	Guide	**ESC Approach**	
		Conventional Management Bioengineering (non-living plant material)	
Industry	Forestry		
Geography and Geology	Saturated, poor bearing capacity soils typical to wetland environments		
Applicable Landforms	Roads	Bridges	Watercourse crossing
	Wetlands	Culverts	Subsurface water management
Current Practices	Minimize disturbance of sediment during installation or decommissioning of roads/bridges in wetlands. Use of corduroy structures/techniques (logs) for: - Culverts - Roads - Winter watercourse crossings Corduroy materials can remain after decommissioning (biodegradable), limiting sediment disturbance. 		
Other Comments	Corduroy culverts are similar to Live Pole Drains, only constructed from non-living logs.		

7. Alluvial Channel Design Manual – 2008

<table>
<tr><td>Author</td><td colspan="4">Golder Associates</td></tr>
<tr><td rowspan="2">Document Type</td><td rowspan="2">Manual</td><td colspan="3">ESC Approach</td></tr>
<tr><td colspan="3">Conventional Management with Bioengineering support</td></tr>
<tr><td>Industry</td><td colspan="4">Canadian Oil Sands Network for Research and Development and Department of Fisheries and Oceans</td></tr>
<tr><td>Geography and Geology</td><td colspan="4">Several soil types considered: (1) undisturbed, (2) consolidated sand/silt/clay material, (3) sand cap over unconsolidated material, (4) silt/clay cap on unconsolidated thickened tailings, (5) sand material on steep slopes (high water table), (6) sand material on steep slopes (low water table), (7) overburden dumps, (8) coke material</td></tr>
<tr><td rowspan="2">Applicable Landforms</td><td>Overburden dumps</td><td>Vegetated channels</td><td>Alluvial channels</td><td>Tailings dyke</td></tr>
<tr><td>Ephemeral or permanent channels</td><td>End-pit lakes</td><td>Wetlands</td><td>Closure drainage channels</td></tr>
<tr><td>Current Practices</td><td colspan="4">Geomorphic approach to alluvial channel design on varies soils (bioengineering support Yes/No):
(1) Yes: supports natural vegetation
(2) Yes/No: results may vary depending on soil type
(3) No: soil salinity too high to support vegetation for > 30 years
(4) Yes: If moisture levels are suitable, vegetate swales and ridges
(5) No: high rates of surface runoff and erosion
(6) Yes: woody plants can be established along channel edges
(7) Maybe: potential for live pole drains, live staking to control soil moisture
(8) Yes: drain using vegetated channels</td></tr>
<tr><td>Other Comments</td><td colspan="4">This manual only uses bioengineering as support through soil/slope stabilization and soil moisture control.</td></tr>
</table>

8. Vegetated Waterway Design Guidelines – 2004

<table>
<tr><td>Author</td><td colspan="4">Golder Associates</td></tr>
<tr><td rowspan="2">Document Type</td><td rowspan="2">Guidelines</td><td colspan="3">ESC Approach</td></tr>
<tr><td colspan="3">Bioengineering</td></tr>
<tr><td>Industry</td><td colspan="4">Oil sands mining</td></tr>
<tr><td>Geography and Geology</td><td colspan="4">Soils within reclaimed or operation oil sands mines are combination of cohesive and non-cohesive soils. High percentage of non-cohesive sands and gravels. Saline and sodic soils were not represented in this report.</td></tr>
<tr><td rowspan="2">Applicable Landforms</td><td>Vegetated channels</td><td>Alluvial channels</td><td>Wetlands</td><td rowspan="2">Ephemeral or permanent channels</td></tr>
<tr><td>Closure drainage channels</td><td>Culverts</td><td>Drainage ditches</td></tr>
<tr><td>Current Practices</td><td colspan="4">Range of conditions for vegetated waterways:
- Channel slope vs drainage area
- E.g., drainage areas > 50 ha requires slopes <5 % if vegetated
Most suitable for:
- Ephemeral flows or continuous low velocity flows
- Mature vegetation communities
- ESC measures until maturity
Require:
- 0.8 m of reclamation depth
- Good soil moisture holding capacity

</td></tr>
</table>

9. Alberta Transportation: Erosion and Sediment Control Manual – 2011

Author	Government of Alberta: Alberta Transportation			
Document Type	Manual	**ESC Approach**		
		Conventional Management (primarily), with some Bioengineering		
Industry	Provincial Infrastructure			
Geography and Geology	Varies across Alberta			
Applicable Landforms	Roads	Culverts	Bridges	Watercourse Crossings
	Drainage Ditches	Cut Slopes/Fill Slopes	Overburden Stockpiles	Borrow Sites
	Subsurface Water Management	Overburden Dumps	Permanent or Ephemeral Channels	Building Sites
	Vegetated Channels	Alluvial Channels	Wetlands	Pipelines
Current Practices	Details various Erosion and Sediment Control Best Management Practices (BMPs)			

Erosion Control	Sediment Control	Erosion & Sediment Control	Streambank Stabilization
Rolled Erosion Control Products*	Silt Fence	Gabions	**Live Staking***
Riprap Armouring	Continuous Perimeter Control Structures	Rock Check Dam	**Brush layering***
Cellular Confinement System	Storm Drain Inlet Sediment Barrier	Synthetic Permeable Barrier	**Choir Rolls***
Offtake Ditch	**Straw Bale Barrier***	**Mulching***	**Brush Mattress***
Seeding*	Energy Dissipaters	**Hydroseeding***	**Live Siltation***
Topsoiling	Sediment Traps and Basins	**Hydromulching***	**Willow Post and Poles***

	Slope Texturing	Slope Drains	**Riparian Zone Preservation***	Rock Vanes
	Polyacrylamide (PAM)	Groundwater Control	Pumped Silt Control Systems	Longitudinal Stone Toe
	Compost Blanket*	**Choir Rolls***	Scheduling	**Vegetated Mechanical Stabilized Earth***
		Wattles (Live Fascine) *	Stabilized Worksite Entrances	**Vegetated Riprap**
			Straw Mulching & Crimping*	
	***Indicates bioengineering approach**			
Other Comments	Refer to the **Government of the Northwest Territories, Department of Transportation – Erosion and Sediment Control Manual (2013)** for erosion and sediment control approaches which are suitable for use in northern climatic and biophysical conditions.			

10. In-situ Oil Sands Extraction Reclamation and Restoration Practices and Opportunities Compilation – 2013

Author	Navus Environmental Inc.		
Document Type	Compilation	**ESC Approach**	
		Conventional Management Basic Bioengineering Techniques	
Industry	In-situ oil sands		
Geography and Geology	N/A		
Applicable Landforms	Overburden stockpiles	Building construction site	Drainage ditches
	Culverts	Cut slopes/Fill slopes	Borrow sites
Current Practices	Leaving native vegetation/root systems: - Riparian/vegetation zone preservation - Preserve organic material on soil - Loosening soil/ roughing the soil surface (encourage drainage). Preventative erosion control methods: - Live staking - Wattles - Rolled back organic material - Woody material cover - Mulch/straw cover - Drainage channel construction surrounding site Benefits: - Prevent sedimentation - Stabilizes soils - Maintain surface soils - Promote vegetation establishment		
Other Comments	Emphasizes the importance of including erosion control using bioengineering techniques in the planning phase of project development to limit the need for extensive, costly erosion control measures in the future.		

11. Natural Process: Restoration of Drastically Distributed Sites – 2017

Author	Polster, David			
Document Type	Guidelines	**ESC Approach**		
		Bioengineering Techniques		
Industry	Polster Environmental Services Ltd.			
Geography and Geology	Soils with acid generating rock, high metal levels, and saline soils were beyond the scope of these guidelines			
Applicable Landforms	Overburden stockpiles	Roads	Pipelines	Bridges
	Borrow sites	End-pit lakes	Wetlands	Watercourse crossings
	Building sites	Vegetated channels	Alluvial channels	Permanent or ephemeral channels
	Drainage ditches	Culverts	Cut slopes/Fill slopes	Subsurface water management
Current Practices	Wattle Fences: - Reduce slope angle - Stabilize soil - Establish vegetation growth Live Pole Drains: - Stabilize soil slumps - Drain excess moisture in soil - Establish hydrophytic vegetation communities Brush Layers: - Reduce surface erosion - Stabilizes slopes - Reduces water flow - Traps sediment - Promotes vegetation growth Modified Brush Layers: - Capture large falling debris Stabilize slopes Live gully breaks:		Live staking: - Stabilized soil - Increase channel roughness - Reduces flow velocity - Traps sediment - Successional vegetation growth - Variety of applications Gravel bar staking: - Tolerates high flow velocities - Quick slope stabilization - Captures sediment - Reduces water velocity Live smiles: - Slopes with silt flows - High tensile strength - Promote root development in weak soil	

	- Slow water velocity - Reduce potential for torrents Live bank protection: - Protects against scouring - Promote riparian vegetation growth - Stabilizes over-steepened slopes Live silt fences: - Slow water velocity - Promote sediment deposition - Trap debris	Live reinforced earth walls: - Stabilize undercut banks - Address piping failures - Provides shear resistance Live shade: - Create fish habitat Pocket and joint planting: - Prevent bank erosion
Other Comments	Information can also be found in **Soil Bioengineering for Site Restoration** by *Dave F. Polster*. Published by the NAIT-BIR in 2013	

12. A Visual Guide to Handling Woody Material for Forested Land Reclamation – 2012

Author	Pyper, M and T. Vinge		
Document Type	Guide	**ESC Approach**	
		Bioengineering	
Industry	Research on Industrial Sites: University of Alberta		
Geography and Geology	Various		
Applicable Landforms	Overburden Stockpiles	Borrow Sites	Closure Drainage
	Overburden Dumps	Cut Slopes/Fill Slopes	
Current Practices	Promote site reclamation and vegetation diversity using applying **coarse woody materials** creating a **rough and loose** approach to soil erosion. Recent changes to the 20120 Reclamation Criteria for Wellsites and Associated Facilities on Forested Lands permit now encourage the use od woody material application as a reclamation tool. This guide provides recommendations on volume thresholds and techniques to balance fire risk using: • Mulch, • Rough mulching, • Chunking, and • Whole logs.		
Other Comments	This is a quick guide; more detailed information can be found in **Managing Woody Material on Industrial Sites (2012)** by T. Vinge and M. Pyper.		

13. Summary Memo of Hardwood Cutting Research Conducted at Canadian Natural Resources Ltd. Peace River Complex and Cliffdale Facility – 2017

<table>
<tr><td>Author</td><td colspan="3">Schoonmaker, Amanda</td></tr>
<tr><td rowspan="2">Document Type</td><td rowspan="2">Research Memo</td><td colspan="2">ESC Approach</td></tr>
<tr><td colspan="2">Bioengineering Research</td></tr>
<tr><td>Industry</td><td colspan="3">Northern Alberta Institute of Technology Boreal Research Institute (NAIT-BIR)</td></tr>
<tr><td>Geography and Geology</td><td colspan="3">Treatment plot locations varied, test sites included:
• Oil sands exploration well sites,
• Compacted dump site,
• Reclaimed airstrip, and
• Borrow pits.</td></tr>
<tr><td rowspan="4">Applicable Landforms</td><td>Overburden stockpiles</td><td>Roads</td><td>Pipelines</td></tr>
<tr><td>Borrow sites</td><td>End-pit lakes</td><td>Wetlands</td></tr>
<tr><td>Building sites</td><td>Vegetated channels</td><td>Alluvial channels</td></tr>
<tr><td>Drainage ditches</td><td>Culverts</td><td>Cut slopes/Fill slopes</td></tr>
<tr><td>Current Practices</td><td colspan="3"><u>Balsam Poplar</u>
- Sites relatively free from competition (i.e., no grasses or sod present) during the first growing season, vegetation establishment was recorded at 50%-60%.
- Planting position along ripped furrows; a 20% increase in survivorship was observed when compared with conventional soil treatment.
<u>Hot-Planting (i.e., rooted nursey stock seedlings with leaves)</u>
- Planting in June as apposed to the dormancy period in spring/fall.
- Hot-planting less reliable than using unrooted hardwood cuttings.
- Hot-planting carries increased risk of desiccation through exposed leaves.
- May see greater improvement of establishment if hardwood cuttings are rooted but planted during dormancy period.
<u>Willows</u>
- Same experiment as hot-planting but using willow in place of hardwood.
- Willow survival rates of 60% for hot-planted willows (10% survival for unrooted).</td></tr>
</table>

	- Increase willow survivorship by: o Painting non-toxic latex on cut/exposed ends, o Use long cuttings, o Harvest willows from lowland areas, and o Diameters > 0.5 cm.
Other Comments	This is a summary document which includes the results from the following projects by Amanda Schoonmaker (some of the findings are in preliminary stages and have not been published): 1) Delineation wells final report, 2) Cliffdale Remote Sump Progress Report, 3) CNRL Airstrip Reclamation Research, and 4) Effect of Study Size and Source Location on Willow Cutting Survival in North America.

14. Bioengineering Case Studies: Sustainable Stream Bank and Slope Stabilization – 2014

Author	Wendi Goldsmith, Donald Gray, and John McCullah			
Document Type	Case Studies	**ESC Approach**		
		Bioengineering		
Industry	Research on Industrial Sites: University of Alberta			
Geography and Geology	Various			
Applicable Landforms	Overburden stockpiles	Roads	Pipelines	Bridges
	Borrow sites	End-pit lakes	Wetlands	Watercourse crossings
	Building sites	Vegetated channels	Alluvial channels	Permanent or ephemeral channels
	Drainage ditches	Culverts	Cut slopes/Fill slopes	Subsurface water management
Current Practices	This book covers 35 different bioengineering projects completed in both eastern and western USA, and within the Great Lakes Area. Types of projects include: • Stream bank repair • Stream bank protection • Erosion control • Runoff control • Slope failure • Highway cutslope repair • Slope stabilization • Riverbank restoration • Riverbank stabilization • Road stabilization • Gully repair • Watershed restoration • Landslide repair			

	Techniques employed include: • Live poles • Vegetated riprap • Riparian planting • Live staking • Coir logs • Coconuts mats • Revegetation • Live fascines • Seeding • Vegetated gabion baskets • Brushlayering • Wattle fences • Bioswales • Live boom • Live crib wall • Coarse woody material • Vegetated mechanically stabilized earth • Live siltation • Vegetated channels • Live brush mattress
Other Comments	Book focuses on environmentally sustainable erosion and sediment control practices and incorporates non-living plant material (i.e., conventional approaches) with some employed techniques.

Appendix B - Case Studies

B.1. Oil Sands: In-Situ

B.1.1. Case Study 1: Cenovus Foster Creek

Company:	Cenovus		
Development:	In-situ	**Phase:**	Operations
Location:	Foster Creek, AB	**ESC Approach:**	Conventional with small bioengineering projects
Geographical/ Geological Aspect of Site:	Located in a relatively flat topographic region; there are 38 well pads and only 2 pads (E15 and E20) have erosion control concerns. Soils are clay rich interspersed with sand lenses.		

ESC Approaches:
The topography in this region is relatively flat, therefore, limited ESC measures are required at the Foster Creek operation. Most ESC measures employed are conventional and primarily consist of installing riprap around bridges, and armouring culverts. Culverts have minimal erosion issues due to the flat nature of the topography, but they require occasional maintenance to remove sediment build-up. Some culverts have naturally regrown vegetation.

Coconut matting and silt fences are considered for temporary ESC measures only. Historically, silt fences have not functioned effectively as they have been installed incorrectly, and coconut matting can inhibit species diversity by promoting grass growth.

In the past, in high erosion areas, seed and coarse woody material have been applied to stabilize soils. Currently, however, Cenovus is seeding selectively as this approach can introduce weeds, and the AER is discouraging grass seeding as it can attract wildlife. Grasses also hinder the growth of lichen in the area.

Cenovus has used some bioengineering techniques on smaller projects, including coarse woody material, live pole drains, and live staking.

Case Studies:

Well Pad E15:

Site Conditions:	Water began to flow from a neighbouring fen after grading a 3:1 (18˚) slope at Well Pad E15. This saturated the surrounding soils and resulted in slumping along the graded slope adjacent to the pad.
Conventional Approaches:	Initially, conventional ESC approaches were used to treat the soil slump. Two drainage ditches were dug to direct the water flow into perimeter ditches. These ditches were lined with erosion control matting (coconut) and riprap (Figure B-1). ESC measures implemented failed and water continued to flow resulting in additional slope failure.
Bioengineering Approaches:	A wattle fence was then installed along a 3:1 (18˚) slope (Figure B-2). A 10 to 15-foot-long wattle fence was installed using 150 willows collected from nearby fens and bogs.
Successes:	Wattle fencing established successfully and reduced soil water content. The fence served as an economical, long-term solution and is still functioning 6 years later (Figure B-3).
Lessons Learned:	Erosion control mats failed after a few months (even though they had been keyed to the ground correctly), as water got underneath the geotextile cloth (Figure B-4 and B-5). Wattle fence construction was difficult and at the time, permission was needed from the AER to harvest willows from the lease. Willow harvesting was labour intensive; they were cut by hand using a team of 6 people over a one-half day. Accessing the willow harvesting site proved to be a challenge.

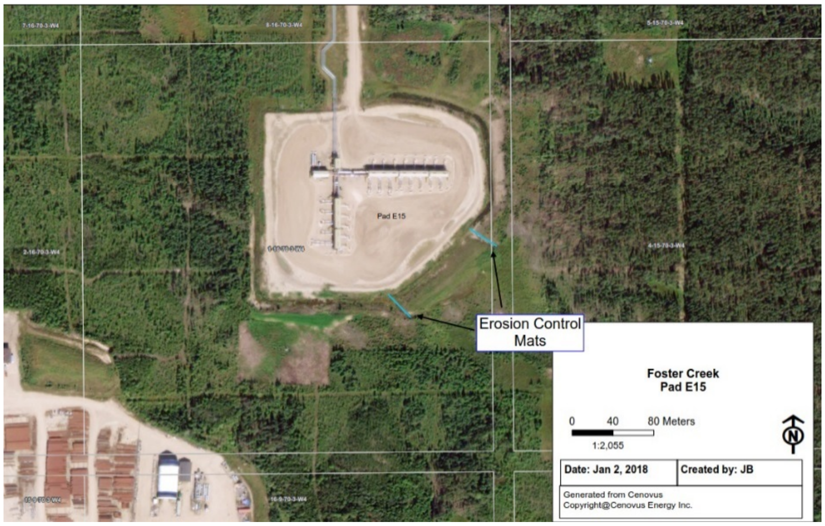


Figure B-1
Two drainage ditches lined with erosion control mats and riprap at Well Pad E15 at Foster Creek.

Figure B-2
Wattle fence installation after erosion control matting failed (June 27, 2012).

Figure B-3
Successful establishment of the wattle fence; growth two years after installation (September 10, 2014).

Figure B-4
Erosion control mat installed along southeast slope and water has begun eroding under the mats.

Figure B-5
Slump under erosion control matting.

Well Pad E20:

Site Conditions: An underground spring was encountered in a bank adjacent to Well Pad E20. As a result, the surrounding soils became saturated that led to slumping in the area.

Bioengineering Approaches: Initially, coconut matting was installed along with the geotextile cloth and erosion control socks to stabilize saturated soils (Figure B-6).

When the coconut matting failed, an additional drainage ditch was dug to support the bioengineering efforts after vegetation had established. A wattle fence, live pole drain, and live silt fence were installed (Figure B-7). The live pole drain treated an area of 30 m by 30 m, and between 40 to 50 willows were used over all three bioengineering approaches at E20.

Tree and shrub seedlings were also planted at the north end of Pad E20 (3,500 stems/ha).

Successes: The live pole drains successfully directed water into the perimeter ditches and reduced overall soil saturation (Figure B-8). It served as an economical, long-term solution to slumping, and is still functioning six years after installation (Figure B-9).

Lessons Learned: Erosion control mats failed after a few months (even though they had been keyed to the ground correctly) as water seeped from underneath the geotextile cloth and coconut matting.

The wattle fence failed to stabilize the slope; the fence was installed parallel to the flow of water and cut into a sand lens. It is unclear why the wattle fence failed, but high flow velocity and clay rich soils on site may have prevented willow establishment.

The willows used in the live silt fence never established and erosion continued around the willow poles.

Many of the seedling planted failed to establish at the top of the mound. The second year they were planted at the bottom which had a better success rate.

Figure B-6
Slumping and erosion control mat failure along the east side.

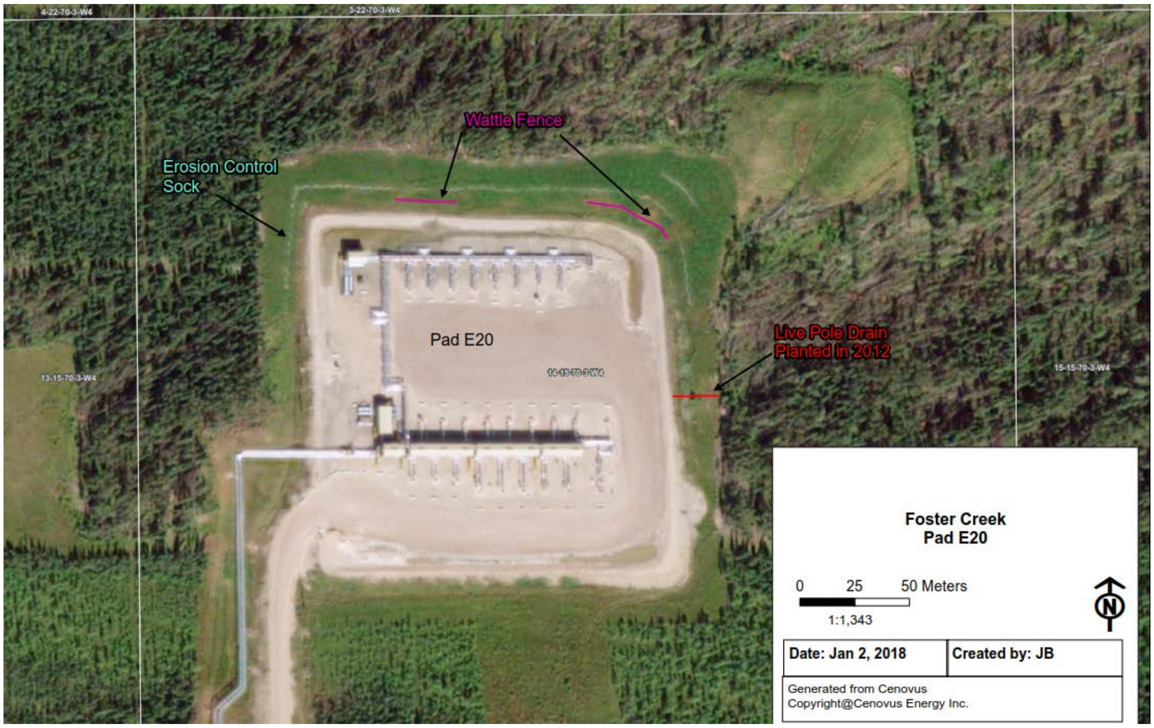


Figure B-7
Bioengineering approaches for Pad 20 (live silt fence not shown).

Figure B-8
Live pole drains used to reduce excess water that had lead to slope failure (August 27, 2012).

Figure B-9
Live pole drain establishment (September 10, 2014).

Soil Stockpiles

Site Conditions:	Two soil storage stockpiles (topsoil and subsoil) at Foster Creek were treated using two different techniques of ESC (Figure B-10).
Conventional Approaches:	N/A
Bioengineering Approaches:	The topsoil stockpile was left to revegetate naturally. The subsoil stockpile was treated using rough and loose soil placement and willow planting. A track hoe was used to create mounds and craters in a checkboard/diamond pattern to roughen the surface. Coarse woody material was added to both the topsoil and subsoil stockpiles at a density of 60m^3/ha.
Successes:	After five years, the subsoil stockpile established a variety of shrubs and trees (willows are six feet tall) that are still actively growing (Figure B-11).

Lessons Learned: After five years, the topsoil stockpile was 70% revegetated with grass and no trees or shrubs established.

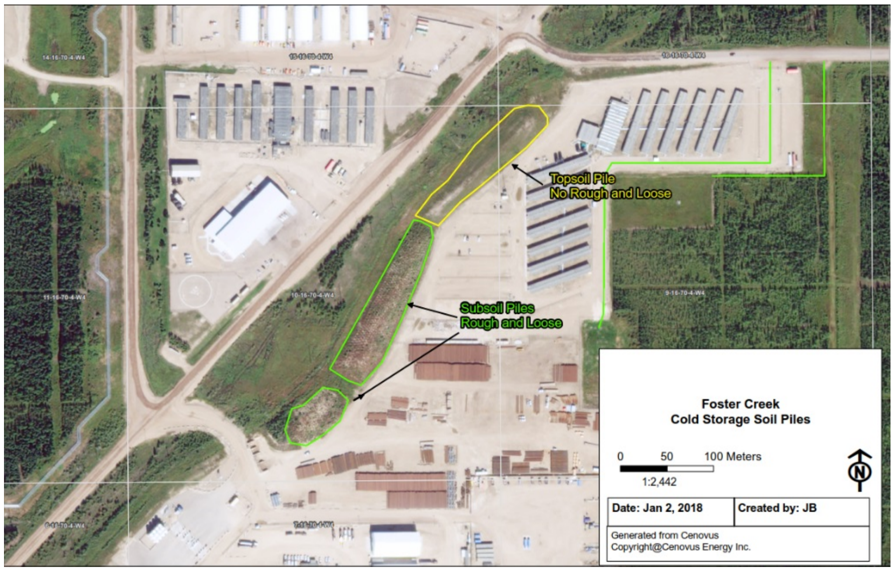


Figure B-10
Soil surface treatments for subsoil and topsoil stock piles at Foster Creek.

Figure B-11
Rough and loose topsoil stockpile supporting a healthy growth of willows and other plant species (September 10, 2014).

B.1.2. Case Study 2: ConocoPhillips Surmont

Company:	ConocoPhillips Canada Resources Corp.		
Development:	In-situ	**Phase:**	Operations
Location:	South of Fort McMurray, AB	**ESC Approach:**	Conventional; research bioengineering approaches
Geographical/ Geological Aspect of Site:	Surmont 1 was opened in 2007 and Surmont 2 was opened in 2015. Most of Surmont has primarily seasonal natural watercourses (seasonal water bodies are present) and has silty soils.		

ESC Approaches:

Erosion and sediment control at Surmont relies primarily on conventional techniques: drainage ditches with check dams of clay and aggregates, lined with riprap or geotextile/rubber mats; spillways lined with rocks around bends; culverts lined with geotextile cloth; check dams; and bermed pads (sump or culverts). Some conventional ESC measures (aggregate cover, silt fencing, and berms) are used around the above-ground pipeline corridors.

Any stormwater collected on-site is directed into stormwater ponds, tested for total suspended solids (TSS), and released onto rock stabilized spillways or sprayed through a diffuser to reduce the potential for erosion.

The NAIT-BIR is conducting a 10-year experiment on boreal forest reclamation techniques examining the effects of rough and loose site preparation, coarse woody material applications, planting densities, innovative plant delivery technologies (hitchhiker plugs) and herbicides. The trials also measure erosion and sedimentation data to understand the effectiveness of different techniques to hold soils in place. The effectiveness of smaller scale bioengineering techniques (i.e., live pole drain, live staking) are also being tested at Surmont.

Case Studies:

Soil Stockpiles

Site Conditions:	Topsoil and subsoil stockpiles, covering ~10 ha of land, are located at the northwest part of the camp. Subsoil piles have 3:1 (18˚) slopes, although some areas have been re-graded to reduce the slope to 2:1 (27˚).
Bioengineering Approaches:	To create a rough and loose surface, bulldozers corner bladed along the contours in most areas. Some steeper areas were mounded using a backhoe. (Figure B-12). Coarse woody material was applied to the slope and vegetation (jack pine, white spruce, aspen, paper birch, balsam poplar, willow, green alder, and fireweed) were planted. Some areas were left to revegetate naturally with no treatments applied.

Successes: Vegetation established one year after seeding. Green alder was very successful at establishing itself on the stockpiles (Figure B-13).

Breaking up and scattering large woody material on the stockpiles kept the soil in place on the stockpiles.

The recommended best management natural revegetation strategy for the stockpile slopes is that the soil should be un-compacted and the surface prepared using rough and loose with coarse woody material applied.

Less preparation and maintenance costs are associated with rough and loose techniques, but testing is still needed to determine applicability on various slopes and soil types.

Lessons Learned: During earlier erosion control trials, whole logs were placed along slopes instead of across slopes (to prevent the logs from rolling down the slope) which exacerbated erosion.

Aggressive weed management through herbicide application on the stockpiles killed the natural vegetation in the area, resulting in sparse grass and exposed soils prone to erosion.

Figure B-12
Rough and loose site preparation and coarse woody material application completed fall of 2015. Vegetation trials planted June 2016 (image taken July 17, 2016).

Figure B-13
Vegetation establishment one year after site preparation (image taken July 22, 2017).

Access Road

Conventional Approaches:	Soil check dams were created along a shallow ditch 10:1 (6°) every 150 m to reduce water flow and control erosion along a pipeline and road (Figure B-14). A mini-hoe and dump truck was used to create the check dams.
Bioengineering Approaches:	N/A
Successes:	As of 2017, the check dams have been functioning properly since their installation in 2016.
Lessons Learned:	Vegetating the check dams with shrubs could support their durability and greater longevity.

Figure B-14
Soil check dams adjacent to pipeline corridor and a road.

Central Processing Facility (CPF) South Drainage Ditch

Site Conditions:	One main drainway, lined with clay, takes runoff from the development site at Surmont 2 to the stormwater collection pond, and then to the stilling pond. Water is tested for TSS before being released into vegetated areas (Figure B-15).
Conventional Approaches:	Erosion at all corners of the drainage ditches, as well as at the spillways, is controlled using conventional ESC measures (i.e., geotextiles, riprap, and aggregate). The Stilling Pond has a steep (~ 2:1 or 27˚) 100 m long slope on the west side. Interwoven cinderblocks are placed at 45 degrees to reduce the velocity of water moving downslope. The drainway functions to reduce the TSS in the water flowing to the Stilling Pond.
Bioengineering Approaches:	The west side of the Stilling Pond is fully vegetated.
Successes:	N/A
Lessons Learned:	Drainways leading to the Stilling Pond require regular maintenance to remove sediment build-up.

Conventional approaches along the spillways have often failed, creating rilling and gullies. These spillways are steep with 3:1 (18˚) slopes, so geotextile and rocks wash-out with high runoff flows (Figures B-16 to B-18). A recommended improvement includes the addition of rock blankets or use of sticks to keep rocks in place along spillways.

Figure B-15
Spillway at CPF illustrating the various conventional ESC measures used to manage erosion.

Figure B-16
CPF South Ditch rills.

Figure B-17
CPF South Ditch rills.

Figure B-18
Water bypassing the rock guards along the South Ditch.

Live Pole Drains at Well Pad 104

Site Conditions:	Groundwater seeps were encountered 12-24-083-06 W4M.
Conventional Approaches:	N/A
Bioengineering Approaches:	In the summer of 2017, two live pole drains made of balsam poplar cuttings were installed on ~3:1 (18˚) slopes (Figure B-19).
Successes:	Unknown until Spring 2018.
Lessons Learned:	It was challenging to find qualified people to install the live pole drains. Original trenches dug in the winter were far too deep, and extra labour and expense were required to partly refill the trenches. The timing of the cutting collection in late August was sub-optimal.

Figure B-19
Trench and live pole drain prior to installation at 12-24-083-06 W4M.

Live Staking

Site Conditions	Roadside prone to sedimentation at base of stockpile.
Conventional Approaches:	N/A
Bioengineering Approaches:	The site was planted with rooted balsam poplar stakes (Figure B-20) and 150 – 200 live stakes were planted approximately 5 to 10 cm apart to catch sediment.
Successes:	Live silt fence grew successfully in the first year and is capturing sediment on-site.
Lessons Learned:	N/A

Figure B-20
Live staking survival and re-growth at Surmont.

Hydroseeding

Conventional Approaches:	N/A
Bioengineering Approaches:	Exposed soils were hydroseeded.
Successes:	Vegetation was established in several areas of the site including borrow pit (Figure B-21).
Lessons Learned:	Vegetation did not establish in multiple areas (Figure B-22).

Figure B-21
Successful hydroseeding on a borrow pit at Surmont.

Figure B-22
Unsuccessful hydroseeding on a subsoil stockpile at Surmont.

B.1.3. Case Study 3: Nexen Long Lake

Company:	Nexen		
Development:	In-situ/Gas Plant	**Phase:**	Operations and Closure
Location:	South of Fort McMurray, AB	**ESC Approach:**	Conventional with some basic bioengineering
Geographical/ Geological Aspect of Site:	The Long Lake in-situ facility opened in 2005, no closure ESC occurring with the exception of the Oil Sands Exploration sites (i.e., borrow pits and remote sumps).		

ESC Approaches:
Nexen considers ESC approaches on a case-by-case basis and the approach depends on what type of ESC is required and will provide the best results. ESC measures employed by Nexen tend to be primarily conventional. They are interested in additional information regarding alternative ESC techniques such as bioengineering. Some bioengineering techniques used previously include aspen matting, grass seed, and coarse woody material application. When clearing, 25% of the wood is salvaged, un-mulched, and used for roll-back.

Case Studies:
Kinosis Borrow Pit

Conventional Approaches:	Riprap was used to hold erosion control matting in place along low gradient ditches (96:1 or 0.6˚) at the Kinosis Borrow Pit (Figure B-23). Exposed soils along temporary roads and associated drainage ditches are treated with ditch blocks, sediment fencing, and sediment traps. The drainage ditches release water into vegetated areas (Figure B-24).
Bioengineering Approaches:	Erosion control matting (aspen) is used to line some low gradient ditches around the borrow pit. Soil mounds around the borrow pit were planted with seedlings on (2:1 or 27˚) slopes. Exposed soils adjacent to temporary roads and associated drainage ditches are covered with coconut matting. Coarse woody material is used to control erosion on reclaimed leases.
Successes:	N/A
Lessons Learned:	On Borrow Pit Slopes: Challenges related to planting seedlings on soil mounds. Many seedlings died in the first year as planted too close to the top of the mounds. The second year, seedlings were planted at the bottom of the mound with better success rates.

Figure B-23
Coconut matting with riprap armouring a drainway at the Kinosis Borrow Pit.

Figure B-24
An armoured drainway releasing into vegetated areas at Kinosis Borrow Pit.

B.2. Oil Sands: Mining

B.2.1. Case Study 4: Canadian Natural Resources Limited Muskeg River & Jackpine Mine

Company:	Canadian Natural Resources Limited (Canadian Natural)		
Development:	Mining	**Phase:**	Operations
Location:	Near Kearl Lake, Athabasca Oil Sands Region	**ESC Approach:**	Conventional ESC measures and some bioengineering methods
Geographical/ Geological Aspect of Site:	Boreal forest for northern Alberta.		

ESC Approaches:

The Muskeg River Mine opened in 2003, and the Jackpine Mine in 2010. Both mines cover over 21,000 ha.

ESC measures employed by Canadian Natural at the two mines primarily consists of conventional approaches. In areas with higher risks, conventional measures are used even if the expense is greater. Closure plans for the mine are focused on using conventional ESC measures. Bioengineering has been used only in smaller local or in low risk areas. Revegetation has been the most successful when peat materials have been dumped into stockpiles and left to revegetate naturally. Currently, NAIT-BRI has been conducting research on live staking at the Peace River area operations.

Case Studies:

Compensation Lake: Jackpine Mine

Site Conditions:	A compensation lake was constructed over two years (2009 to 2011)
Conventional Approaches:	N/A
Bioengineering Approaches:	Soil material (peat-mineral mix) was placed on the shorelines and covered with coconut matting to aid in revegetation and to control for erosion and sedimentation. Larger willows were transplanted along the shoreline and in upland areas. Rat-root was planted along the shoreline.
Successes:	N/A
Lessons Learned:	The rapid filling of the lake, which resulted in high water velocity that washed away much of the coconut matting and most of the soil materials. In the future, an energy model should be used to determine the optimum rate of filling of the lake to minimize erosion potential. The inlet should also be armoured to prevent channel erosion and scour.

Shallow West Stripping Area: Muskeg River Mine

Site Conditions:	Erosion issues on a 150 to 200 m long, 6:1 (10˚) slope in the stripping area were identified. Overland waterflow removed the LFH/peat mineral mix layers causing the creation of deep gullies in the tailings sand layer.
Conventional Approaches:	N/A
Bioengineering Approaches:	Several wattle fences and live staking (using willow) were constructed at the top of the gullies. Willows were locally sourced and cut during the dormancy period. They were soaked in the Muskeg River before use in wattle fences and live staking.
Successes:	Both the wattle fence and the live stakes installed were effective at reducing further erosion and stabilizing soils.

Lessons Learned: The ends of the live stakes needed to be placed into the moist soil layers (peat/mineral mix) if they were going to successfully establish. Cuttings placed too deep (into the tailings sand) or too shallow (LFH) and the cuttings did not survive. As a result, it was easier to ensure success if the peat/mineral mix layer is applied up to 35 cm.

In the future, a geohazard plan should be included in the planning phase to predict high energy impact areas from water flow.

Creation of Cover Crop for Erosion Control: Albian Sand Mines

Site Conditions: Over the last 30 years, seeding methods and mixtures to establish vegetation on reclaimed sites have varied from hydroseeding grasses and perennial legumes to using barley as a cover/nurse crop to initiate vegetation growth. Barely has been favoured over grass as it has proven to be less competitive to tree, shrub and forb vegetation. In 2016 and 2017, different plant species were assessed in relation to early establishment of cover crops and management of erosion. Cover crops also reduce the need for fertilizer which can lead to high weed growth.

Conventional Approaches: N/A

Bioengineering Approaches: Two research plots were established on organic soil horizon (LFH) material:

- Four cover crop types were tested (control, barley, pea, and barley/pea mix), and
- Two fertilizer treatments (control and fertilized with 100kg N, 40kg P, and 20kg K) were used.

Successes: Both the barley and the peas grew successfully without the need for fertilizer.

The barely/pea mix grew better with fertilizer.

Lessons Learned: Cover crop species density was not impacted by the application of fertilizer; however, the percent of the surface covered by crops was greater when fertilizer was applied (Figure B-25 and Figure B-26). Cover crops displaced native species in the fertilized plots

The cover crops attracted wildlife (geese) and subsequent herbivory decreased the cover value. This plant mix may not be suitable on operational sites where wildlife is not desired.

Figure B-25
Fertilized cover crops.

Figure B-26
Unfertilized cover crops.

B.2.2. Case Study 5: Imperial Oil Kearl Mine

Company:	Imperial Oil Resources Limited (Imperial)		
Development:	Mining	**Phase:**	Operations
Location:	Near Kearl Lake, Athabasca Oil Sands Region	**ESC Approach:**	Water management and landscape design over ESC
Geographical/ Geological Aspect of Site:	Boreal forest in northern Alberta		

ESC Approaches:
Imperial's Kearl mine's initial start-up was in 2013 with the expansion beginning in 2015.

New sites are designed with shallow slopes to reduce the potential for erosion. Silt fences are used at some sites to stop the release of sediment off lease. Storm water management on site uses the following conventional approaches:

- Aggregate check dams along perimeter ditches (requiring periodic cleaning),
- Riprap channels along slope leading towards drainways,
- Drainway outlets release into natural vegetated areas (i.e., bogs or fens), and
- Riprap and sediment fences are used for bridges and culverts.

Small scale bioengineering techniques have been applied at Kearl including live pole drains, wattle fencing, and live staking. Imperial established interim vegetation cover along the toe of tailings slopes using roughly placed 60% peat, 40% mineral soil mixes, and native seeds. Coconut matting is also used on occasion to help seeds establish, although proper installation of this measure has been an issue.

Case Studies:
Live Pole Drains: Main Plant Access Road (MPAR)

Site Conditions:	Along the main plant access road, a groundwater seep needed to be managed to maintain the integrity of a 3:1 (18˚) slope (Figure B-27).
Conventional Approaches:	N/A
Bioengineering Approaches:	Live pole drains or live fascines, were installed in groundwater seep; four were in 2016 and one in 2017 (Figure B-28).

Trenches were dug 30 cm deep along the entire extent the slope. Thumb-width willows were cut at 1.5 to 2 m lengths for construction of the live fascines, and additional 1 m length willows were cut as stakes. The live fascines were placed in the trenches, staked into place, and backfilled (treated over to reduce air pockets).

A perennial grass seed mix was broadcast over the disturbed areas.

Successes: The four poles installed in 2016 established successfully and are still effectively managing the groundwater seep drainage.

The taller, narrower drains, shaped like an arched "M", function better than the shorter and wider drains (Figure B-).

Lessons Learned: The willow's dormancy window is narrow, hence installation of the live poles occurred in cold, slippery conditions.

Figure B-27
A view of large boulders and saturated materials along the MPAR.

Figure B-28
Live fascines that have been placed in the 30 cm by 30 cm trench.

Figure B-29
The completed view of the arched “M” shaped live pole drain trench.

Noda Wattle Fence

Site Conditions:	An overburden stockpiles with 5:1 (11˚) slopes required stabilization.
Conventional Approaches:	N/A
Bioengineering Approaches:	Wattle fences were installed as part of a pilot project at two slope failure locations on the overburden stockpiles. One area was 4 m wide and a 4-tier wattle fence was installed, and the second area was 6 m wide and the wattle fence consisted of 6-tiers (Figure B-29). Wattle fences were constructed of willows cut roughly to 1.5 to 2 m lengths with diameters between 2 to 4 cm. Wattle fences were installed at the toe of the slope and backfilled using peat (Figure B-30).
Successes:	Fences were installed in October 2017 and the site will be evaluated in spring of 2018.
Lessons Learned:	Certified professionals were hired to design and install the fences.

Figure B-29
Four-tiered wattle fence constructed along a 5:1 (11˚) slope on overburden dump.

Figure B-30
The wattle fence backfilled with excess cuttings, live fascines, and peat.

B.2.3. Case Study 6: Suncor Energy Fort Hills & Base Mine

Company:	Suncor Energy		
Development:	Mining	**Phase:**	Operations and Reclamation
Location:	Near Kearl Lake Athabasca Oil Sands Region	**ESC Approach:**	Conventional ESC measures applied with minimal bioengineering techniques during operations. Closure ESC plans at two compensation lakes and Nikanotee Fen research site are discussed.
Geographical/ Geological Aspect of Site:	Boreal forest of northern Alberta		

ESC Approaches:

Fort Hills covers an area greater that 17,000 ha and began production in in early 2018 and has a production life of 50 years. Base Mine is an older mining operation, consisting of the Millennium and Steepbank mines, and covers a total area of over 19,000 ha.

Fort Hills is located on sandy soils that have a high erosion and sedimentation potential. Suncor typically applies a five-step ESC approach to their landforms:

- Placing filter cloth on large slopes is used below the riprap to create drains and move seepage from groundwater away from the slopes,
- Armouring using riprap, concrete blankets, and/or gabion baskets,
- Hydroseeding, using a tackifier if required, on exposed soils,
- Using nylon rolled erosion control product along pond waterlines, and
- Using coconut rolled erosion control mats above the nylon mats and the pond waterline.

Fort Hills has an abundance of peat available within their lease, hence peat is often used in combination with grass seed to promote faster vegetation growth. Excessive erosion and sedimentation issues require bi-annual dredging of ditches and sumps to remove excess sediment.

There are concerns using bioengineering for operational ESC methods at either Fort Hills or Base Mine due to the potential of attracting wildlife into the plants, mines or the tailings ponds.

Case Studies:

Mine Dump 9: Base Mine

Site Conditions:	Since 2013, several perimeter drainage ditches have collected water from Mine Dump 9 (MD9) and divert it to settling ponds prior to release into natural drainage channels and watercourses. The average grade of these ditches is approximately 96:1 (.6˚).
Conventional Approaches:	Drop structures are used to control erosion in approximately 13 ditches around MD9 (Figure B-31). All inlets and outlets of culverts are lined with riprap. A buildup of sediment does occur in these ditches overtime and needs to be removed.
Bioengineering Approaches:	Several ditches have revegetated through natural succession over a five to 10 year period. In some cases, ditches have been treated with hydroseeding, but grasses failed to establish using this approach due t o lack of rain or thin topsoil.
Successes:	Native grasses and cattails have established naturally in some ditches.
Lessons Learned:	In some cases, ditches were treated with hydroseeding, but grasses failed to establish using this approach due to lack of rain or thin topsoil.

Figure B-31
Drop structure installed along a perimeter ditch with riprap armouring at MD9.

2016 Wildfire Fire Breaks

Site Conditions: The 2016 wildfire in Fort McMurray necessitated the creation of 10 fire breaks to protect Base Mine from damage, some of which were cleared off-lease. Soils were exposed in these firebreaks and require measures to manage erosion and sedimentation issues. Different approaches have been proposed for on-lease and off-lease fire breaks.

Conventional Approaches: Conventional erosion and sedimentation control is being recommended for on lease fire breaks. Measures have included soil regrading to direct storm water towards natural vegetation (Figure B-32), applying topsoil to promote vegetation growth, and installing silt fences (Figure B-33). Silt fences along the fire breaks at Base Mine will require regular monitoring.

No conventional ESC approaches are being planned for off-lease reclamation.

Bioengineering Approaches: Bioengineering approaches being proposed for on-lease fire breaks include:

- The use of rolled erosion control matting (coconut mats),
- Application of coarse woody material, and
- Willow live staking along the steep slopes of the Athabasca River.

For fire breaks located off-lease, mulching, and application of woody material with aspen seedling plantings are being prescribed. Off-lease fire breaks will need to be monitored for noxious weeds and vegetation establishment.

Successes: Work will start spring 2018.

Lessons Learned: N/A

Figure B-32
Ponded water along fire breaks at Base Mine. Regrading to move water towards natural vegetation has been proposed.

Figure B-33
Silt fences used for on-lease fire breaks at Base Mine.

Fee Lot #6

Site Conditions: A temporary bridge crossing over Clarke Creek was required to access off-site gravel pits from Fee Lot #6. Trees were cleared during the winter (February to March in 2013), and mulch was applied to the pit after gravel salvaging to protect the soils. Temporary crossings were removed for the spring and summer months, and then re-installed over winter each year until project completion. Slopes along a creek crossing required subsequent remediation.

Conventional Approaches: Slope regrading and silt fences were used to manage ESC issues adjacent to Clarke Creek. This work was scheduled over winter to limit impacts to the creek bed and surrounding banks.

Bioengineering Approaches: Areas along the gravel bars in the creek, were also mulched, covered with coconut matting, and straw coir rolls and extra plants add to the sites to stop erosion and encourage vegetation regrowth (Figure B-34).

Successes: Natural revegetation within 25 to 30 m of Clarke Creek is thick and well developed with no signs of erosion occurring (Figure B-35).

Lessons Learned: Continuous monitoring is recommended to evaluate the performance of conventional ESC measures, and determine if repairs or replacements are required, as well as to monitor revegetation in the area.

Mulch is preventing vegetation from establishing and requires thinning out, and revegetation has been less successful on the upper slopes of the road and is sparse at the top of the slopes.

The 2016 Fort McMurray fire damaged or destroyed some of the ESC measures (Figure B-36), and herbivory has occurred on some of the straw coirs (Figure B-37).

Figure B-34
A swale lined with erosion control matting and straw coirs that convey water off-site.

Figure B-35
Silt fence and revegetation near Clarke Creek.

Figure B-36
A silt fence burnt by 2016 fire. Remaining soils have poor vegetation cover.

Figure B-37
Evidence of herbivory on straw coir rolls.

Closure – Nikanotee Fen

Site Conditions: As part of a joint industry partnership with Imperial and Shell Canada, a three-hectare fen was constructed in 2013 based on research from the University of Waterloo. The fen experienced high run-on flows from upland slopes resulting in the creation of erosion gullies and rills, and sediment deposition within the fen (Figure B-38).

Conventional Approaches: Conventional approaches were used to address larger landscape issues at the fen and included contouring, and berms.

Contours were plowed across the upland slopes to reduce water flow and velocity.

Berms (hummocks) were constructed on the upland behind recharge basins to reduced water velocity and increase groundwater recharge to the fen. Berms were typically 2 to 30 m long, with one berm a longer 100 m.

Both methods proved to be successful, although some of the recharge sites are getting filled with sediment.

Bioengineering Approaches: Smaller, local issues, were managed using bioengineering techniques and included bio-logs and straw bales.

Bio-logs were staked and consisted of mesh with straw (10 to 100 m in length and 10 to 15 cm in diameter). These were not successful.

Where rills and gullies had formed, a hole was dug and straw bales were place into the hole to prevent further erosion. This technique was successful.

Successes: Straw bales were successfully installed to prevent further erosion of rills and gullies.

Contours and berms were plowed into the upland slopes and successfully reduced water flow.

Lessons Learned: Bio-logs were not properly installed and failed to limit sediment deposition in the fen (Figure B-39).

A key lesson learned in designing the landscape for larger swales, like the fen, is the need to manage the volumes, flow, and velocity of water to reduce erosion and sedimentation, especially during periods of snow melt.

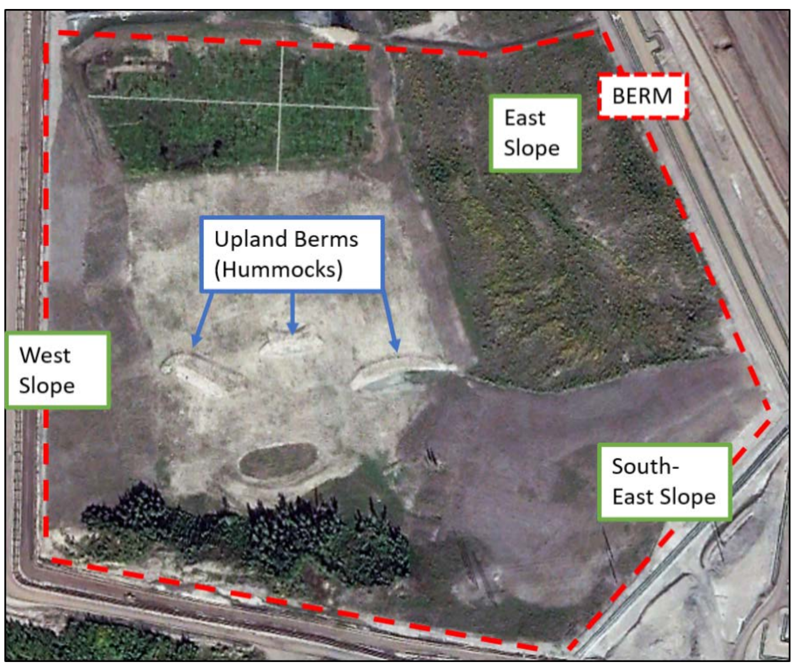


Figure B-38
Plan view of Nikanotee Fen including hillslopes and perimeter berm.

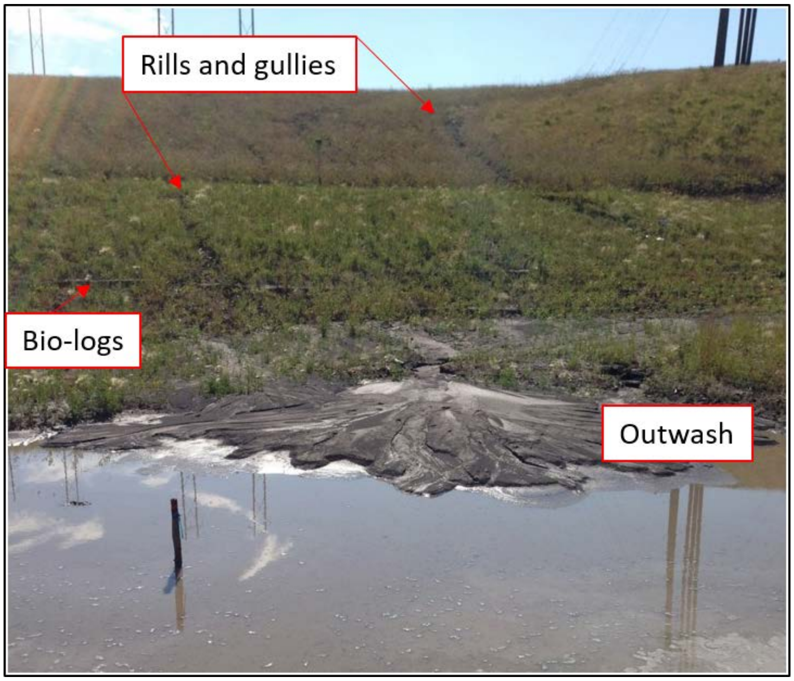


Figure B-39
Rills and gullies which formed at the Nikanotee Fen.

Closure – Compensation Lake Fort Hills

Site Conditions:	A compensation lake at the Fort Hills Mine has been constructed to compensate for the loss of fish habitat.
Conventional Approaches:	Construction of the compensation lake involved digging down to the mineral layer (limestone/shale) and lining the area surrounding the lake with peat, riprap, and subsoils and topsoil (Figure B-40 and Figure B-41). Channels were defined using riprap, and large boulders were used to create fish habitat. Outlet channels were lined with various sized cobbles, while the banks were armoured with riprap.
Bioengineering Approaches:	The topsoil used around the lake was only stored for one season, as a result the areas revegetated naturally using the natural seed bank stored in the soils. Steep slopes were lined with coconut matting above the waterline. Coarse woody material was placed along channel banks of the Athabasca River and along the lake shoreline (Figure B-42).
Successes:	Revegetation using natural seed banks allowed rapid re-establishment (within one growing season) of a diverse vegetation community (Figure B-43).

Lessons Learned: N/A

Figure B-40
Riprap armouring and soil placement along the outlet channel leading from the compensation lake.

Figure B-41
Riprap armouring along the shoreline of the compensation lake.

Figure B-42
Coarse woody material placed along the outlet channel at the compensation lake.

Figure B-43
Vegetation re-established at compensation lake.

Closure – Compensation Lake Base Mine

Site Conditions:	A compensation lake was constructed at the Base Mine as part of the Steepbank Expansion. Construction began in 2007 and was completed in 2012. The lake was lined with a clay liner and the shorelines graded to gentle slopes (3-5:1 or 18˚-11˚). The outfall of the lake leads towards a natural creek, Unnamed Creek.
Conventional Approaches:	The lake was lined using a geosynthetic liner made of granular sodium bentonite clay, sandwiched between two geotextiles, and held together by needle punching (Figure B-44). The liner was covered using soils deemed suitable for aquatic life (Figure B-45). Shorelines were armoured with gravel to protect against wave-action erosion, and the outlet channel was lined with riprap and cobbles (Figure B-46).
Bioengineering Approaches:	Coconut matting was used on exposed soils around the lake and along the outlet channel leading to Unnamed Creek. Large woody materials were placed in the lake to provide potential fish habitat (Figure B-47). Trees, shrubs and aquatic plants were planted around the shoreline of the compensation lake.
Successes:	Vegetation is growing through the coconut matting around the lake.
Lessons Learned:	The biodegradable geosynthetic liner used around the lake did not break down after two years (still intact seven years after installation) and as a result, the surface has become unstable and slippery, and is separating from the soil. Establishment of the planted vegetation has been slow around the lake.

Figure B-44
Installation of the geosynthetic liner in compensation lake with a 12-inch overlap between sheets.

Figure B-45
Cover material application over the geosynthetic clay liner in compensation lake.

Figure B-46
Outlet channel at compensation lake lined with cobbles and coconut matting.

Figure B-47
Coarse woody material used to provide fish habitat in compensation lake.

B.2.4. Case Study 7: Syncrude Canada Ltd. Base Mine

Company:	Syncrude Canada Ltd.		
Development:	Mining	**Phase:**	Operations and Closure
Location:	Athabasca Oil Sands Region	**ESC Approach:**	Conventional (Operations) and Bioengineering
Geographical/ Geological Aspect of Site:	Boreal forest of northern Alberta		

ESC Approaches:

The Mildred Lake Mine began production in 1978 and reclamation began in 1982. Areas are progressively reclaimed as portions of the mine are closed. The overburden dumps, coke cells, and parts of southwest sand storage areas have been reclaimed and certified. Average slope on site ranges between < 10:1 (6˚), and approximately 2:1 (27˚).

Risk and safety to facilities is a factor in the selection of ESC techniques at the Syncrude oils sands mine. Bioengineering methods are not used on high risk structures or areas were there is a zero tolerance for failure of erosion techniques. In these cases, conventional approaches of erosion control are used. Syncrude has successfully used bioengineering methods to manage slumping slopes along pipeline rights-of-ways along Beaver Creek, and Aurora T-pit Hill. On most of their reclamation sites, placement of mineral/peat mix and planting of trees has proven to revegetate sites rapidly so no further erosion control is necessary.

Case Studies:

Beaver Creek Pipeline Right-of-Way

Site Conditions: A pipeline right-of-way on a slope of Beaver Creek was slumping due to groundwater seeps and excess surface water run-off (Figure B-48).

Conventional Approaches: N/A

Bioengineering Approaches: Brush layers and live fascines were installed where the slope in the pipeline right-of-way had failed. Live pole drains were installed along the slope failure to direct water away from the site. Muskeg and native grass seed were applied to revegetate the site (Figure B-49).

Successes: Within two years, vegetation within the treatment site is well established and has reduced erosion (Figure B-50). The live poles drains were successful at removing water from the pipeline right of way, but the excess water caused slope failure in the area adjacent to the Beaver Creek treatment area (Figure

B-51). Live pole drains were installed to remove excessive soil moisture in this newly failed site (Figure B-52). They were successful and the area revegetated within one year after remediation (Figure B-53).

Lessons Learned: N/A

Figure B-48
Slope failure at Beaver Creek within the pipeline right-of way.

Figure B-49
Brush layers and live fascines installed on pipeline right-of-way, October 2004.

Figure B-50
Vegetation growth on pipeline right-of-way, June 2006.

Figure B-51
Slope failure adjacent to Beaver Creek treatment area.

Figure B-52
Live pole drain installation at failure site, October 2005.

Figure B-53
Vegetation growth on slope failure adjacent to Beaver Creek treatment area in June 2006.

Aurora T-Pit Hill

Site Conditions:	A 120-meter section of a pipeline right-of-way was heavily rilled and gullied on T-Pit Hill (Figure B-54). The soil texture is fine to medium grained sands on slopes ranging from 10:1 (6˚) to 2:1 (27˚). The slope needed to be re-contoured to fill the deep rills and gullies before treatments were applied.
Conventional Approaches:	N/A
Bioengineering Approaches:	Brush layers and straw coir rolls were installed along the slope (Figure B-55 and Figure B-56). Local muskeg was added to the soil to help reduce rill erosion, the site was planted with native shrubs, seeded with native grasses, and fertilized.
Successes:	After four weeks, 60% of the willow cuttings had shoot growth (Figure B-57). In ten weeks, vegetation regrowth in-filled the exposed soils (Figure B-58).
Lessons Learned:	Rills were still forming on the surface four weeks after treatment installation. These areas required additional treatment with new brush layers and straw coir rolls.

Figure B-54
Gully formation at T-Pit Hill in June 2006.

Figure B-55
Brush layers and straw coir rolls installed along slope in June 2006.

Figure B-56
T-Pit Hill site after treatment in June 2006.

Figure B-57
Vegetation growth after four weeks, July 18, 2006.

Figure B-58
Vegetation growth after 10 weeks, September 1, 2006.

Pipe Rack Erosion and Safety Risk

Site Conditions: Slopes adjacent to some of the pipe racks onsite had begun to erode resulting in sediment being deposited onto the pipe racks, inhibiting visual inspections of these structures.

Conventional Approaches: Sediment was cleared away from the pipes leaving steep slopes. These slopes were re-graded to 3:1(18˚), covered in geotextiles and soil, and concrete lock blocks installed to prevent further erosion.

Bioengineering Approaches: N/A

Successes: N/A

Lessons Learned: Pipes run hot and require regular visual inspection to ensure there are no leaks or structural deficiencies. Therefore, bioengineering methods and vegetation are near pipe racks.

Coke Cell 5 (CC5) Decommissioning Excavation

Site Conditions and ESC Approaches:	The first coke cell was decommissioned at Base Mine in 2013. The internal topography was re-shaped into a valley with several vegetated channels constructed in a dendritic pattern to collect surface water from the outer edges of CC5, draining into one larger collector channel lined with riprap. Islands of undisturbed vegetation (from a previous reclamation program) were maintained beyond the edges of the drainage channels. Coarse woody material was placed within the valley.
Conventional Approaches	A D50 graded design approach was used for channel lining using progressively larger granular material (Coke /clay, sand, gravel, cobble, and then to riprap). This approach was designed to minimize surficial drainage down the sides of the reclaimed exterior slopes via sheet flow (Figure B-59).
Successes:	CC5 was successfully decommissioned with no significant erosion observed in the valley, outlet channel, or exterior slopes.
Lessons Learned:	This was a pilot excavation to facilitate risk reduction of a previously fluid-retaining structure to a non-fluid retaining structure (i.e., an inactive overburden dump). The design required the proven performance of granitic riprap as channel lining material allowed the structure to be delicensed as a dam. These measures are also expected to have created the geotechnical integrity necessary for eventual Reclamation Certification and Custodial Transfer. Bioengineering will be considered for similar cases in the future as more knowledge is gained.

Figure B-59
Aerial view of Coke Cell 5 looking east at Base Mine.

Closure – Golden Ponds

Site Conditions:	Two ponds connected by a small channel were created on a shallow slope north of Base Mine when a pit area had been backfilled and graded. The area was covered with a mineral/peat soil mix.
Conventional Approaches:	N/A
Bioengineering Approaches:	Coarse woody material was placed into the drainway to slow water velocity and reduce the potential for erosion. The site revegetated naturally via native seed banks in the soil and seeds blown in from neighbouring vegetation communities.
Successes:	This site revegetated quickly and no further erosion control is necessary at this site. A beaver has moved into the ponds and has constructed two lodges in the area.
Lessons Learned:	N/A

W1 Overburden Dump – Closure Surface Water Management

Site Conditions:	Seven swales were created between 2004 to 2017 using low berms to separate sub-watersheds. Each swale was designed to drain an area of approximately 30 to 50 ha, 500 to 700 m long, and 2 to 3 m deep. Gentle slopes greater than 10:1 (6˚) with 1.2 m of subsoil (primarily Pleistocene clay) and 30 cm of reclamation soil (peat) were created. Rills began forming on Alpha Swale in spring of 2004 (Figure B-60). This site was used as a test site to evaluate the effectiveness of bioengineering techniques.
Conventional Approaches:	Subdivision of watershed areas on crest of dump using horseshoe berms, minimizing watershed areas where surficial drainage down reclaimed dump slopes is via sheet-flow.
Bioengineering Approaches:	Four bioengineering techniques were tested including: • Brush layers, • Live fascines, • Live staking, and • Seedling planting. Brush layer rows were interspersed with live fascines rows and live staking along the swale (Figure B-61).
Successes:	Revegetation of the swale was successful; and vegetation communities have created strong root systems (Figure B-62 to Figure B-64). Currently only the live fascines and seedlings are used to revegetate the swales, as brush layering and live staking were not as successful at establishing vegetation and preventing erosion.
Lessons Learned:	Brush layers failed in their first year; the willows extended 1 m above the surface and collected debris during spring thaws or heavy rainfall events. Eventually the brush layers failed under the pressure of the debris and caused a hydrologic surge, creating channels along the swale. Live fascines did not catch debris, as they did not extend as far from the surface as the brush layers did, and vegetation regrowth established within the first year. Seedlings survivorship is higher than live staking and is now used in place of live staking.

Figure B-60
Alpha swale prior to treatment, spring 2004.

Figure B-61
Brush layering installation (left); live fascines used in combination with brush layering (right).

Figure B-62
Alpha swale growth after two years, June 2006.

Figure B-63
Alpha swale growth after five years, July 2009.

Figure B-64
Alpha swale growth after nine years June 2013.

B.4. Coal Mining

B.4.1. Case Study 8: Teck Resources Limited Elk River Valley, Central Alberta Coal Mines, and Bioengineering of Columbia River Bank

Company:	Teck Resources Ltd.		
Development:	Coal mining Smelter adjacent to Columbia River	**Project Phase:**	Operation and closure of coal mines, and Bioengineering ESC of Columbia River slopes
Locations:	Cardinal River Mines and McLeod River coal mines in Central Alberta (AB) Elk Valley Mines in southern British Columbia (BC) Columbia River, near Trail BC	**ESC Approach:**	Conventional and/or Bioengineering techniques

Geographical/ Geological Aspect of Site:	The Cardinal River operation in central Alberta, consists of the Cheviot and Luscar coal mines. Cheviot is actively mined while several areas of Luscar have been reclaimed and certified. Aquatic habitat enhancement was pursued at the McLeod River coal mine in central Alberta. The Elk Valley operations in southern BC consists of five mines; Coal Mountain Operations, Fording River, Greenhills, Line Creek, and Elkview mines. Coal Mine is about to enter the care and maintenance phase of operations, while the other four mines are actively mined and progressively reclaimed. A steep bank of the Columbia River near Trail BC had has been affected by the deposit of industrial material and the effects of SO_2 from the Smelter. This location was reclaimed to improve aesthetics using bioengineering approaches.

ESC Approaches:
ESC practices at the Teck Resources coal mines start with controlling sources of water to reduce the potential for erosion and sedimentation. This is done by diverting water from potential plant and mining areas, regrading the sites to gentle slopes, and by directing storm-water through ditches and sumps to sedimentation ponds. After settlement and once the water quality requirements are met, the water is released back into the environment. Water management structures are maintained with conventional ESC measures: riprap armouring, check dams, and the use of flocculants to promote water quality improvement.

Bioengineering approaches using live plant materials are not currently incorporated in Teck’s ESC Management Plans that outline the strategy for ESC implementation during mine operations. Little bioengineering is pursued on-site at Elk Valley mines do to the dynamic nature of these operations, as the landscape changes frequently.

Bioengineering is more typically used as part of the mine closure plans. During progressive reclamation, bioengineering techniques typically applied include rough and loose soil bioengineering, and planting of tree and shrub seedlings. Non-living plant materials used in the various mines including straw logs, coconut/jute matting, and the application of coarse woody material.

A steep slope along the Columbia River was reclaimed using wattle fences on the steeper slopes, brush layers in the riparian zone, and live stake installation in localized islands and pockets along the slope. The slope was irrigated to ensure survival of the bioengineering applications.

Case Studies:

Cardinal River Cheviot and Luscar Mines, Central Alberta:

Site Conditions: Cardinal River consists of two mining sites, Luscar and Cheviot located within subalpine ecoregions near Jasper National Park. These areas are characterised by moderate to extreme relief to rocky outcrops, fast flowing ephemeral streams, and high elevations. The Cheviot mine is being actively mined, while several areas of the Luscar mine have been reclaimed and certified. The mines are below tree line and ecosites share some structural similarities in vegetation to Fort Hills in the oil sands region such as mesic pine or spruce assemblages.

Conventional Approaches: The most frequently used ESC measures have been conventional, armouring and riprap are designed to attenuate and withstand natural fast flowing waters and/or to support fisheries habitat enhancement in either natural or reclaimed aquatics stream systems.

Bioengineering Approaches: The key approach to controlling ESC at Teck Coal's mine sites is managing surface water drainage at the landform scale. Current operations, such as locating and designing haulage ramps and dump locations, are designed considering landforms and water drainage. Considerations include the attenuation of surface flows, and preventing opportunistic impoundments within the anticipated mine closure landscape.

The rough and loose mounding of soil/woody material implemented on reclaimed sites at Teck's Cheviot Mine have been very successful at managing ESC issues and promoting native species re-establishment. The approach to reclaiming sites includes depositing a mix of salvaged soil, subsoil and coarse woody material in rough and loose mounds, planting of tree and shrub seedlings in micro-topographic sites, and leaving areas open to allow for the natural ingress of seeds. Reclamation material is dumped into piles or along slopes as windrows following the rough and loose treatment method (Figure B-65), and then covering soils applied at depth varying from 0 to 1 m, with a target depth of 30 cm. Direct salvage and placement of materials are completed wherever possible, but some materials need to be stockpiled.

Coconut matting has been used to help manage ESC issues in some drainage channels. This has successfully reduced some ESC issues; however, the coconut mats present installation and maintenance challenges as they move in the wind.

Teck has some limited hydroseeding, and square straw bales for ESC control.

Successes: Vegetation establishes well but can take up to three years. Vegetation cover is good, with a diversity of grasses, forbs, and shrubs (Figure B-66).

Rough mounding holds moisture and prevents winter desiccation/freezing of tree seedlings.

Lessons Learned: N/A

Figure B-65
Rough and loose placement of soils mixed with coarse woody material at Cheviot Mine.

Figure B-66
Vegetation coverage from rough and loose is good but re-establishment can take up to three years.

Upper McLeod River Aquatic Habitat Enhancement Project, Central Alberta

Site Conditions: Reclamation of the historic McLeod River coal mines in the early 1900's, resulted in low value riparian habitat and sites with active erosion and sedimentation issues (Figure B-67). Bioengineering techniques were used to remediate some sites along the McLeod River with the intent of enhancing aquatic habitat for waterfowl and fish.

Conventional Approaches: Earthworks at an overwintering pond along the McLeod River included (Figure B-68):

- Removal of coal stockpiles and replacing and recontouring soil,
- Realigning the Inlet channel and removing sediment, and
- Installing riprap for armoring.

Bioengineering Approaches: To establish vegetation in the area:

- Willow and dwarf birch were salvaged and re-planted and areas were seeded,
- Coconut matting and straw logs were installed to protect soils from erosion (Figure B-69), and
- Wattle fencing was constructed of willow along the stream channel to manage erosion, trap sediment in runoff and improve water quality (Figure B-70).

Successes: The success of vegetation establishment is unknown as project was completed in 2017.

Lessons Learned: N/A

Figure B-67
Historic mining operations in the early 1900s have resulted in poor riparian habitat.

Figure B-68
Earthwork progress for the Upper McLeod River Habitat Enhancement project.

Figure B-69
Coconut matting and straw logs installed to protect exposed soils along the McLeod River.

Figure B-70
Wattle fencing installed along a stream bank along the McLeod River.

Live Staking along Fording River, Elk Valley Mine:

Site Conditions:	Little bioengineering is pursued on-site at the mine due to the dynamic nature of these operations and frequent landscape alterations. Bioengineering is more typically used as part of the mine closure landscape.
Conventional Approaches:	N/A
Bioengineering Approaches:	In October 2017, 75 cottonwoods, 24 red osier dogwood, and 942 mixed species of willow were installed below boulders in the low lying areas along the Fording River (Figure B-71 to Figure B-73). The live staking was intended to add more vegetation along the stream margin to improve and provide additional fish habitat. This project serves as a good example for future bioengineering possibilities to establish and enhance riparian vegetation along banks of water bodies.
Successes:	Live staking reduces water velocity and encourages sediment deposition.
Lessons Learned:	Live staking was not originally incorporated as part of the ESC design and may have been installed too far upstream to be effective. It may have been better if brush layering had also been installed along with the live staking.

Figure B-71
Fording River prior to live staking.

Figure B-72
Live cuttings were planted below the boulders.

Figure B-73
Fording River after the live cuttings were planted in October 2017.

Bioengineering of River Slope of the Columbia River:

Site Conditions: A steep slope along the Columbia River, near Trail, British Columbia, had been influenced by a metallurgic smelter through deposition of industrial material and air emissions (SO_2) effecting vegetation. The reclaimed bank has a steep 1:1 (45˚) slope and is 60 m high and 600 m wide, covering six acres. The slope also supports active pipeline infrastructure for the smelter.

Conventional Approaches: Historically, riprap has been used to stabilize the lower slopes along the river, but the edges were unnaturally square and visually unappealing.

Bioengineering Approaches: Hence, over a two-year period starting in 2009, bioengineering techniques were used to reclaim the slope to stop slumping and erosion, improve the visual aesthetics, and to improve the functionality of the riparian vegetation along the river. Reclamation activities completed include the following:

- Excavated and terraced the slope using a spider backhoe,
- Removed existing riprap,
- Backfilled deep erosion gullies and covered the slope with topsoil,
- Established three zones that had different nutrient and moisture retention capacities (crest, middle, and toe of the slope),
- Planted vegetation using bioengineering techniques:
  - Wattle fences on steeper slopes (cottonwood and/or dogwood),
  - Brush layering in the riparian areas (willow), and
  - Live staking in localized islands or pockets throughout the site (cottonwood and/or dogwood).
- Irrigation and fertilization was required to promote rooting of the cuttings.

The irrigation system was necessary to establish vegetation and attain soil stabilization on the slope. The system was complex with high maintenance requirements (shower heads popping off) and was expensive to operate. However, once vegetation was established, a simpler, less expensive system was installed.

Successes: The site was monitored each year from 2010 to 2014.

- The planted trees were 7 to 10 feet tall by 2014 and vegetation had established over most of the slope.
- Most wattle fences established and successfully acted as slope breaks and have reduced erosion issues.
- The brush layers were extremely successful and heavy brush has developed along the river.

- The live staking had good regrowth success on the lower slopes, moderate success on the middle slope, and no success on the higher slopes.

Lessons Learned:

Irrigation:

- The nature of the soils on the slope (poor moisture retaining properties) required the site to be irrigated during the growing season - from May to September.

Vegetation establishment:

- The middle slope generally had moderate to low vegetation regrowth with both live staking and the wattle fencing methods. Shallow soil placement and erosion from the sudden effluent bursts from the pipeline has disturbed the site.
- There were challenges in completing the proper sequence of soil placement and wattle fence construction.
- Brush layering has attracted beaver activity and will require management to limit herbivory.

Soil placement, excavation and resources:

- Specialized equipment, a spider back-hoe, was required to excavate and terrace the slope. This piece of equipment is rare and was expensive for the company to use.
- Soil placement along the slope was uneven, ranging from 60 cm (in the gullies) to only 15 cm. This resulted in poor vegetation establishment in areas with 15 cm of soil.
- Sourcing high-quality soil was a challenge and soil of poorer quality was used in some areas.
- Collecting cuttings without damaging the surrounding ecology was a challenge.

Safety:

- Due to the steepness of the slope, workers had to be tied off for safety purposes.
- An irrigation system was installed (PVC pipe with sprinkler heads) and nutrients were added to the water (tea compost and protozoa) to fertilize the soil.
- Irrigation was expensive and required regular maintenance as sprinkle heads repeatedly came off.

B.3.2. Case Study 9: TransAlta Whitewood and Highvale Mines

Company:	TransAlta		
Development:	Coal mines	**Project Phase:**	Closure Reclamation
Location:	Whitewood and Highvale coal mines in central Alberta	**ESC Approach:**	60% Bioengineering and 40% Conventional ESC
Geographical/ Geological Aspect of Site:	The Whitewood Mine provided coal for the Wabamun Power Generating plant and the Highvale Mine for the Sundance and Keephills Power Generating plants. Both mines are in central Alberta adjacent to Wabamun Lake in the Parkland region. This location is the transition zone between the White and Green zones of Alberta. Whitewood mine covers 1,900 ha and was opened in 1956 and closed in 2010; Highvale mine covers 6,500 ha and was opened in 1970, the mine is expected to cover 7,500 ha by end of life.		

ESC Approaches:
One of the biggest issues in the reclamation of coal mines is erosion and sedimentation control. Both TransAlta mines follow phased reclamation plans. All erosion and sedimentation control occurs during the reclamation phase. Currently, ESC approaches at the mines are 40% conventional (e.g., gabion baskets and riprap primarily in drain ways) and 60% bioengineering techniques (e.g., coconut matting on steeper slopes, hydro-seeding slopes, and live staking).

Reclamation requires long-term planning with consideration for future watershed developments and water management across the entire reclaimed landscape. Final reclaimed areas at the mines will be a diverse landscape dominated by leveled agricultural lands, steeper, rolling sloped parkland with treed areas, wetlands, and end-pit lakes. There are three end-pit lakes at Whitewood and five at Highvale. Water retention ponds will be re-engineered and reclaimed to open water wetlands with gradual shorelines and littoral zones (Figure B-74). Haul roads will be converted to drainways with riparian vegetation. Soil will need to be reconstructed and replaced. Topsoil salvage was not regulated during the mines construction and therefore, there is insufficient soil available for use in reclamation. Lands reconstructed for agricultural use require 35 cm to 1 m of subsoil and 20 cm of topsoil, and will be revegetated with cereal or forage crops to establish root mass.

Water is managed at the coal mines to minimize erosion. Management methods include:

- Diversion of natural clean water around the mine through a series of man-made ditches and natural creeks into Lake Wabamum; and

- All secondary water is captured on site and retained in sediment and retention ponds (designed for 1:100-year flood). Ponded water is pumped and piped to the cooling pond at Sundance where the water is treated at the water treatment plant. A portion of this treated water is returned to Lake Wabamum (variable each year to reflect natural amounts being removed from the watershed by the mines) and the rest is treated and used in the power plants.

Bioengineering approaches currently used at both Whitewood and Highvale mines include:

- Coconut matting,
- Hydroseeding,
- Mulching,
- Live staking,
- Compost application,
- Riparian preservation, and
- Straw-bale barriers.

TransAlta is also considering using sod to re-establish vegetation at some locations. Other mining companies in the United States use this method and have their own sod farms to provide the live material required. Other bioengineering approaches that are being considered for future use at the mine are live pole drains, live gully breaks, live bank protection, and gravel bar staking.

Gravel and riprap (six to 12 inch) used in conjunction with gabion baskets are used to armour high velocity drainways to reduce erosion and sedimentation issues. Gabion baskets are used in the stream that was built at Highvale Mine in 1985 to divert clean water around the mine. For the final reclamation landscape, the gabion baskets will be dismantled, wire removed, and the stones re-used for armouring, where necessary.

Figure B-74
Highvale Pit 3 Settling Pond reclaimed into a wetland (area certified and donated back to the Crown).

Case Studies:

Spoil Piles and Composting above the End-Pit Lake: Whitewood Mine:

Site Conditions:	Spoil piles have a 3:1 (18˚) slope and rills and gullies have formed. There was inadequate topsoil for reclamation at the Whitewood mine. Soil conservation regulations were not in place for the mines in the 1960s so topsoil was not salvaged. As a result, there is no topsoil available on-site to reclaim the spoil piles. Therefore, vegetation is being grown on suitable spoil (not sodic or saline) only.
Conventional Approaches:	NA
Bioengineering Approaches:	In 2014, coconut mats were installed along several erosion rills to reduce the high velocity flows. The coconut mats were hydro-seeded and then mulched. The mats biodegrade, and provide a thatch through which the seedling roots extend to the soil below. The land around the erosion rills were also hydro-seeded and mulched. A 50% success rate in stopping erosion was observed using this method. In each following year, up to 2017, areas where coconut matting failed was replaced. Now 70% of the slopes are vegetated and appear to be stabilized.

	Rocks exposed from surface erosion have been left in place to stabilize the slopes. Compost is being purchased from municipalities to create topsoil. In late 2017, 29,000 tonnes of compost were purchased and will be applied to stiff clays in the spring of 2018. Results of composting is not yet known.
Successes:	Coconut matting used resulted in 50% of the locations being successfully revegetated. This has increased to approximately 70% following repairs and replacement of failed matting.
Lessons Learned:	Topsoil will be salvaged from newer mining areas for re-use during reclamation at the Highvale mine. Reduce the areas of concentrated flows on spoil pile slopes by reducing number of drainage channels. Improve armouring and erosion protection through use of additional coconut matting. Coconut mats must be properly installed using staples or stakes, and in continuous contact with soils to prevent water moving beneath the mats and erosion and slope failure.

Live Staking at Whitewood and Highvale Mines:

Site Conditions:	TransAlta works with Paul Band First Nation school children to help harvest and plant live stakes at reclamation sites.
Conventional Approaches:	N/A
Bioengineering Approaches:	Live willow and balsam poplar are harvested during the dormancy period and planted in May around wetlands to supplement natural plant growth.
Successes:	Live staking installed in 2015 around step ponds had successfully established by 2017.
Lessons Learned:	Live stakes failed in areas that were too dry (i.e., ephemeral areas), hence, future live staking will focus on planting in wetter areas.

Natural Revegetation at Step Pond: Whitewood Mine:

Site Conditions:	Natural revegetation of a large haul road ramp used to access the mine.
Conventional Approaches:	The haul road was re-graded to create a series of ponds that flow into the reclaimed end-pit lake.
Bioengineering Approaches:	Areas adjacent to the ponds were seeded with grass, but most of the area was left to revegetate naturally. Live staking was completed in 2015 to further stabilize soils and establish vegetation (Figure B-75).
Successes:	Vegetation has stabilized the soils and live stakes have had a reasonable survival rate. Cattails have established in the pond naturally and ducks have begun using the end-pit lake.
Lessons Learned:	NA

Figure B-75
Haul road ramp at Whitewood Mine after reclamation.

B.4. Municipality and Other Projects

B.4.1. Case Study 10: John Matthews Creek Stream Bank Stabilization (2012)

Client	The City of Burnaby		
Development:	Ravine Stabilization	**Project Phase:**	Reclamation
Location:	Burnaby, BC	**Primary ESC Approach:**	Conventional and Bioengineering

Site Conditions: John Mathews Creek is a natural stream fed by municipal storm sewers in Burnaby, BC. The development of adjacent areas and a flood event in 2011 that breached the armoured section of the channel resulted in a channel incision 8 m deep. The incised channel caused the deposition of 400 cubic meters of sediment downstream (Figure B-76).

Bioengineering Approaches: The banks of the incised channel were armoured using riprap and topsoil was placed overtop the riprap. The banks were seeded, and covered with coconut matting to provide temporary erosion protection and promote vegetation growth (Figure B-77). Existing trees compromised along the ravine from excessive undercutting were salvaged and placed as coarse woody material along the riparian areas and surrounding natural areas to further stabilize soils, provide wildlife habitat, and create micro-climates to improve plant species diversity. Over 2,500 native trees and shrubs were planted along and adjacent to the ravine.

Conventional Approaches: A high flow diversion system was installed using high-density polyethylene pipes (Figure B-78). The stream bed was armoured using a geosynthetic clay liner, riprap, and large boulders (Figure B-79). The boulders created large step-down grade control. The banks of the ravine were also stabilized using riprap.

Successes: Nearly all-natural materials located on the site were re-used and over 2,500 native trees and shrubs were planted along, and adjacent to the ravine. One year after reclamation activities, the re-vegetated areas and plantings continue to grow and the site appears to be successfully revegetated (Figure B-80). Associated Engineering won the Award of Excellence for the reclamation of John Matthews Ravine from the Engineering Excellence held by the Association of Consulting Engineering Companies, British Columbia in 2014.

Lessons Learned: N/A

Figure B-76
John Matthews Ravine erosion prior to reclamation activities (2012).

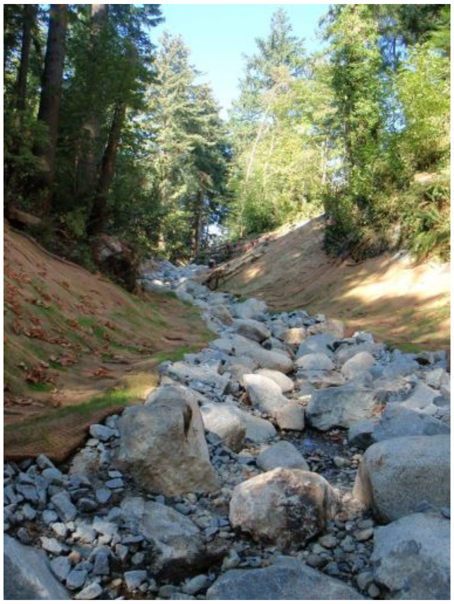


Figure B-77
Riprap was partially covered in soil, seeded with grass, and stabilized using coconut matting (2012).

Figure B-78
Diversion pipe installation (2012).

Figure B-79
Conventional techniques for ravine bed: geosynthetic liner, riprap, and large boulders (2012).

Figure B-80
Successful revegetation one year after reclamation activities (2013).

B.4.2. Case Study 11: Canmore Bow River Dyke Erosion Armouring (2013-2016)

Client	Alberta Transportation		
Development:	Bow River Rehabilitation	**Project Phase:**	Armouring Dyke to protect from erosion during flooding
Location:	Canmore, AB	**ESC Approach:**	Conventional and Bioengineering

Site Conditions: Dyke armouring was required along the Bow River to protect the dyke from further erosion during flood events. Armouring impacted fish habitat therefore compensation was required to replace lost/damaged habitat. Monitoring occurred for three years from 2013 to 2015.

Bioengineering Approaches: Live staking within the riprap was used to further protect against erosion and to improve fish habitat quality. Conifers were also planted on top of the river bank to stabilize soils and increase wildlife habitat. Willow cuttings were placed in burlap bags, filled with topsoil, and placed within the riprap along the shoreline.

Conventional Approaches: Riprap and large boulders were used to armour the dyke against continued erosion on the dyke revetments. Large boulder clusters were installed instream to improve fish habitat potential and quality adjacent to the bank armouring.

Successes: 93.3% of the conifers planted on top of the banks successfully established after two years, satisfying the 85% survival rate required under the *Fisheries Act.*

Lessons Learned: Willow cuttings experienced low survival rates (28.6% and 64.4% at two sites). 1035 willows were installed across both locations, 533 failed to establish by 2015 (Figure B-81). Low success rate of the willow cuttings was attributed to the improper installation techniques. Live stakes where encased in burlap bags filled with topsoil then placed within the riprap and not installed within earthen bank material beneath the riprap. Burlap bags were prone to tearing, desiccation or were displaced during high flow events (Figure B-82).

Figure B-81
Willow cutting were placed in burlap bags filled with soil, bags were ripped or dislodged exposing the cuttings.

Figure B-82
Failed willow establishment within riprap along the Bow River.

B.4.3. Case Study 12: Edith Cavell Stream Bank and Seep Stabilization (2017)

Client	Parks Canada, Jasper National Park		
Development:	Restoration and Rehabilitation	**Project Phase:**	Project Design Only
Location:	Mount Edith Cavell, Jasper, AB	**Primary ESC Approach:**	Bioengineering with few Conventional approaches

Site Conditions: A water surge in 2012 eroded the Cavell Tarn Creek banks and parking area infrastructure, and exposed two groundwater seeps in the area around Edith Cavell. Associated designed a restoration and rehabilitation plan for the area and outlined the ESC measures to be used during and after construction activities.

Bioengineering Approaches: Bioengineering approaches suggested for site erosion control and rehabilitation include:

- Live staking
- Brush layering
- Wattle fencing
- Fibre rolls
- Coarse woody material
- Log pond installation
- Live silt fences
- Rolled erosion control matting

The use of straw or hay is not permitted to prevent the spread of non-native plants and to avoid attracting wildlife in Jasper Nation Park.

Conventional Approaches: Most conventional ESC approaches were temporary, only used during the construction phase, and removed upon completion. Any permanent structures that remained in the project area after construction were built using natural and biodegradable materials. Conventional approaches suggested for this site include silt fences, rock check dams, and riprap.

Successes: This project is in the design phase, however both the reclamation and erosion and sediment control plan has been accepted by Parks Canada.

Lessons Learned: N/A

B.4.4. Case Study 13: Kakisa River ESC for Bridge Abutments and Bank Slopes (2010-2012)

Client	Government of Northwest Territories, Department of Transportation		
Development:	Bridge Construction	**Project Phase:**	Project design, construction, and monitoring
Location:	Kakisa River Bridge, NWT	**Primary ESC Approach:**	Conventional and Bioengineering

Site Conditions: Bridge replacement over Kakisa River was required as part of the Mackenzie Highway improvements. Associated designed the bridge, created the erosion and sediment control plan with both bioengineering and conventional approaches for bridge abutments and stream banks, and conducted a follow-up assessment.

Bioengineering Approaches: Exposed soils were seeded (hydroseeding) and covered with rolled erosion control mats. The mats were secured using rebar and wooden stakes. Live staking (willow) was also used to stabilize slopes. Straw bales were used to create check dams.

Conventional Approaches: Conventional approaches used in conjunction with bioengineering included riprap ditches, rock check-dams, and slope contouring and silt fences.

Successes: Grass and live stakes survived the first winter and were sprouting one year after seeding/planting. Straw check-dams were also still functioning normally (Figure B-83).

Lessons Learned: Erosion control matting not in contact with soils resulted in slope failures within the first year after installation (Figure B-84). Vegetation growth was either slow or negligible in these areas.

Live stakes were beginning to establish; however, soil saturation was still an issue on site.

Figure B-83
Straw check-dams one year after installation.

Figure B-84
Failing erosion control matting with minimal or no vegetation growth one year after installation.

B.4.5. Case Study 14: Devon Bioengineering Workshop (2017)

Client	Town of Devon		
Development:	Slope Stabilization	**Project Phase:**	Pilot Project Design and Construction
Location:	Devon, AB	**Primary ESC Approach:**	Bioengineering

Site Conditions: This pilot project stabilized an eroded bank along the North Saskatchewan River in the Town of Devon (Figure B-85). A steep escarpment < 1:1 (+/- 70˚) resulted from ongoing erosion at the site, which was likely related to removal of woody riparian vegetation along the bank in this location. The overly steep conditions create a challenge for native woody vegetation to naturally recover.

Bioengineering Approaches: In April 2017, a wattle fence was installed to create conditions for woody vegetation to become established (Figure B-86). A total of 8 rows of wattle fence were installed. The vertical stakes were approximately 90 cm long with 30 cm above ground. Horizontal stakes were stacked behind each row of vertical stakes. All stakes were at least 25 mm in diameter at the tip and included a mix of willow, poplar and red-osier dogwood.

Dense live staking was installed at the toe in a 1 to 2 m wide band. Stakes were approximately 70 cm long were and installed with 80% of its length in the ground. Often stakes 1 m long are used but stakes were made shorter due to frost that was present 50-60 cm below ground surface at the toe. The base of stakes was sharpened using an axe to make installation easier. All stakes were at least 25 mm in diameter at the tip and included a mix of willow species.

Watering was completed once a week until late September. A fence to control beaver was also installed using stucco wire-type fence. Weeds were hand pulled where species listed under the *Noxious Weed Control Act* were observed.

Conventional Approaches: N/A

Successes: Vegetation quickly grew along the slope (Figure B-87 to Figure B-90). Woody vegetation was over a metre tall by July, approximately three months following installation. The adjacent slopes, which did not receive any treatment, also grew some vegetation but large areas of exposed soil were still present.

Lessons Learned: The test site needed to be fenced off to prevent site disturbance and herbivory from deer or beaver.

Figure B-85
Minimal vegetation growth along river prior to bioengineering treatment.

Figure B-86
The upper 75% of the slope was stabilized using wattle fences, the lower 25% using live staking (April 19th, 2017).

Figure B-87
Plant regrowth May 28th, 2017.

Figure B-88
Plant regrowth June 18th, 2017.

Figure B-89
Plant regrowth July 11th, 2017.

Figure B-90
Plant regrowth August 3rd, 2017.

B.4.6. Case Study 15: Blackmud Creek Stream Bank Stabilization (2017)

Client	The City of Edmonton		
Development:	Creek Slope Stabilization	**Project Phase:**	Project Design Only
Location:	Blackmud Creek, AB	**Primary ESC Approach:**	Bioengineering

Site Conditions: At Blackmud Creek, peak flow event frequency has increased, invasive species have replaced riparian vegetation, and erosion issues/soil moisture has increased. Associated designed a slope stabilization plan to restore the affected areas and reduce erosion potential at four sites along the creek.

Bioengineering Approaches: Wattle fencing and live siltation were prescribed at four sites, live staking (poplar) at three of the sites and live pole drains were installed at one of the sites to further reduce soil moisture.

- 1 linear metre of wattle fence required approximately 15 m of willow stakes,
- Dense live siltation was installed with 10 cm spacing and each stake was at least 1 m long. Approximately 100 willow stakes were required for a square metre of staking.
- Over 700 live poplar cuttings and 30 metres of live pole drains were also recommended for further overbank stabilization and soil moisture reduction.

Conventional Approaches: N/A

Successes: N/A

Lessons Learned: All four sites will need to be fenced off to prevent herbivory. During the first year, cuttings should be watered to provide enough moisture to promote rooting.

B.4.7. Case Study 16: Battle Lake Gas Plant (2010-2017)

Company:	Imperial Oil Ltd.		
Development:	Former gas plant	**Phase:**	Closure Reclamation
Location:	Battle Lake, AB	**Primary ESC Approach:**	Bioengineering
Geographical/ Geological Aspect of Site:	Located in Battle Lake, AB on rolling hills. The site is generally west facing and is in the Aspen Parkland zone.		

Site Conditions: A gas plant site was decontaminated and regraded. Due to the smooth surface and compaction during grading so there were concerns about erosion and the whether vegetation would successfully re-establish on the site (Figure B-91).

Bioengineering Approaches: Traditionally sites such as the former gas plant site would be seeded with a mix of agronomic grasses and legumes. This is done to control erosion and to provide a foundation for subsequent vegetation growth. However, seeded sites preclude the development of woody vegetation so the site was treated with a rough and loose technique (Figure B-92).

Live staking was used to help establish pioneering vegetation (Balsam poplar, Willow, and Red-osier Dogwood):

- Cuttings were 2 m in length,
- Cuttings were inserted a minimum of 1 m into the soil, and
- Uneven, 1 to 2 m, spacing between cuttings (Figure B-93).

Conventional Approaches: N/A

Successes: Moderate growth was observed on the cuttings installed. Within seven years, healthy vegetation cover of pioneering species had established with later successional conifers coming in around the edges of the site (Figure B-94).

Lessons Learned: Fencing was installed around the reclaimed site to protect the cuttings from herbivory.

Figure B-91
Exposed soil at the gas plant was decontaminated and regraded (compacted and smooth.

Figure B-92
Rough and loose soil treatment.

Figure B-93
Live staking used to promote vegetation establishment after rough and loose treatment.

Figure B-94
Reclaimed gas plant seven years after rough and loose and live staking bioengineering techniques were applied.