MEMORANDUM

October 7th, 2019

TO:	Nicole Pesonen, Nyrstar Myra Falls
FROM:	Jeff Anderson
RE:	Post-closure ecosystem mapping: methodology and results
COPY:	Justin Straker, IEG

The Myra Falls mine on Vancouver Island, British Columbia, has completed a site-wide End Land Use and Post-closure Ecosystem Development Plan to inform site-specific reclamation prescriptions. This plan will be used to "cross-walk" projected post-closure ecosystems to capabilities for designated end land uses, primarily those of wildlife habitat and potentially of indigenous traditional land use.

This memo provides the post-closure ecosystem projections for disturbances within the permitted area of the mine site. These projections are based on our current understanding of the planned closure topography and reclamation materials available. The contents of this memo include the following:

- Methods - a description of the methods used to generate the post-closure ecosystem mapping;
- Limitations – knowledge gaps identified during the process and associated limitations;
- Results - a brief presentation and analysis of the mapped reclamation and end-land-use polygons;
- Fact sheets - fact sheets for the projected post-closure ecosystems, summarizing treatments for major reclamation units; and
- Model inputs - a list of references and sources for inputs to the model.

The resultant post-closure ecosystem map represents a first draft in what is expected to be an iterative process. As data gaps are filled, and closure planning gains greater detail, the post-closure projections will become more precise.

Methods

A post-closure ecosystem map was developed from 2019 closure topography and associated reclamation prescriptions (Nystar Myra Falls, 2016; Amec Foster Wheeler, 2016a.; Amec Foster Wheeler, 2016b.; Wood, 2018b.) . Ecological units (ecosites)[1] were assigned to distinct polygons according to

[1] The model utilizes BC's Biogeoclimatic Ecosystem Classification (BEC) system. This system classifies BC into topographic, climate and soil assemblages, and describes the ecosystems occurring said assemblage. The ecosites expressed in the model are at the site series level, as either a single site series or a range of several.

closure topography (e.g. slope angle, slope position, aspect), surface material properties (soil moisture and nutrient regimes) and depth of cover materials.[2]

Data analysis was conducted using IEG's Quantitative Ecohydrological Assessment (QEA) model (Straker et al., 2015a and 2015b)[3] as described in Figure 1:

1. AWSC model inputs - Data inputs to the model were sourced from the documents made available by Myra Falls; a detailed list of the documents used to source inputs to the model are included in the references section.
2. Use ruleset to classify SMR - The model uses soil particle-size distribution (PSD), organic-matter (OM) content, soil depth and layering, and topographical data to estimate plant-available water storage capacity (AWSC) of surficial materials using empirical (Saxton and Rawls, 2006) and mechanical (Clothier et al., 1977; Arya and Paris, 1981; Arya et al., 1999) models. Each site is then assigned a soil moisture regime (SMR) using model rules developed based on an analysis of data from more than 1,000 Terrestrial Ecosystem Mapping plots in BC (Baker and Straker, 2016).
3. Translate SMR to site series using edatopic grid - SMR classifications in combination with OM-based soil nutrient regime (SNR) assignments are then used to plot each site on appropriate edatopic grids (MoF, 1994) in order to predict each site's post-closure site series.

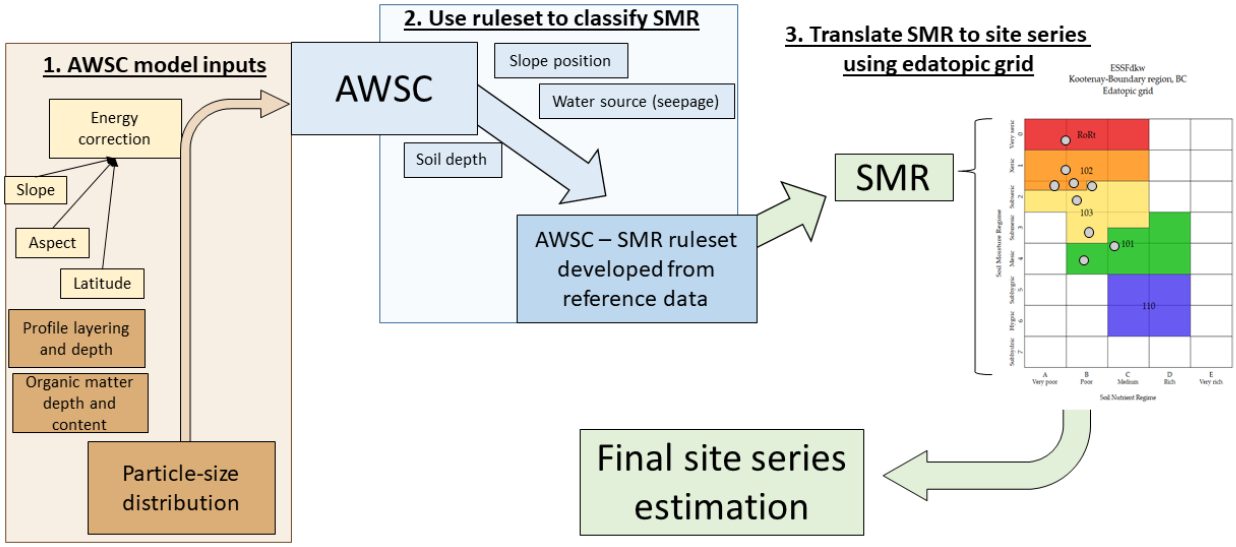

Figure 1. The structure of the Quantitative Ecohydrological Assessment (QEA) model used to estimate site characteristics.

In addition to being able to assess the SMR and site series of existing sites, the results of the QEA model can also be used to characterize waste and cover materials intended for planned reclamation sites to

[2] The top 100-cm of surficial-material properties and associated depths are analyzed as part of the model.

[3] A full description of model parameters and routines is provided in Baker and Straker (2016).

inform cover placement depths and revegetation strategies. Both model applications are utilized in this report.

Development of cover scenarios

Cover prescriptions for constructed landforms are described in the 2016 Addendum Report to the 2014 IC&R Plan (Nystar Myra Falls, 2016), and associated documents (Figure 2). The following cover prescriptions are used in the post-closure ecosystem models:

- Lynx Tailings Disposal Facility (TDF) and associated facilities – 30 cm of growth material over a compacted till layer. The compacted till layer is expected to be low- to non-permeable and will not contribute to plant available water storage.
- Old TDF and associated facilities – 100 cm of growth material over a 30 cm drainage layer, which will cover an impermeable membrane.
- Waste-Rock Dumps (WRDs) – It is expected that WRDs 2, 3, 4 and 7 will be stripped to till, while WRDs 1 and 6 will receive a 100-cm growth material, as recommended in the 2018 Topsoil Management Plan (Wood, 2018b).

The total volume of growth medium required for implementation of the above treatments on the associated facilities at Myra Falls is approximately 550,720 m^3. Growth materials will be comprised of till/topsoil from local sources (Nyrstar Myra Falls, 2016)[4], such as those used on the seismic berm upgrade ("berm material") [5] (IEG, 2016), or stockpiled materials described in the 2018 Topsoil Management Plan ("stockpile material") (Wood, 2018b.). The limited available data on both materials suggests that they are different enough to support different projected post-closure ecosystems. The model was run using each of these growth materials to create the following scenarios:

- Scenario 1 – all growth materials are assumed to have the characteristics of stockpile material[6]; and
- Scenario 2 – all growth materials are assumed to have the average characteristics of the berm material.

[4] The 2018 Topsoil Management Plan states that, "in addition to salvaged and stockpiled materials described, soil materials can be developed on suitably textured substrates, such as fine-textured non-potential-acid-generating (PAG) material or native till". If characterizations are made of such materials at a future date, these materials or a mixture of materials could be included in future iterations of this exercise.

[5] These materials were sampled and characterised as part of the reclamation assessments on the Old TDF Seismic Berm Upgrade. They are referred to as "till" in several reports (IEG, 2013; Nystar Myra Falls, 2016), though they demonstrate some characteristics which may suggest they are not solely morainal material. For example, the coarse fragments are strongly angular and there is a low fine content. This project would benefit from confirmation of the source for these materials.

[6] The area along the Old TDF Seismic Berm is not expected to be recovered; Scenario 1 modelled berm materials as the cover.

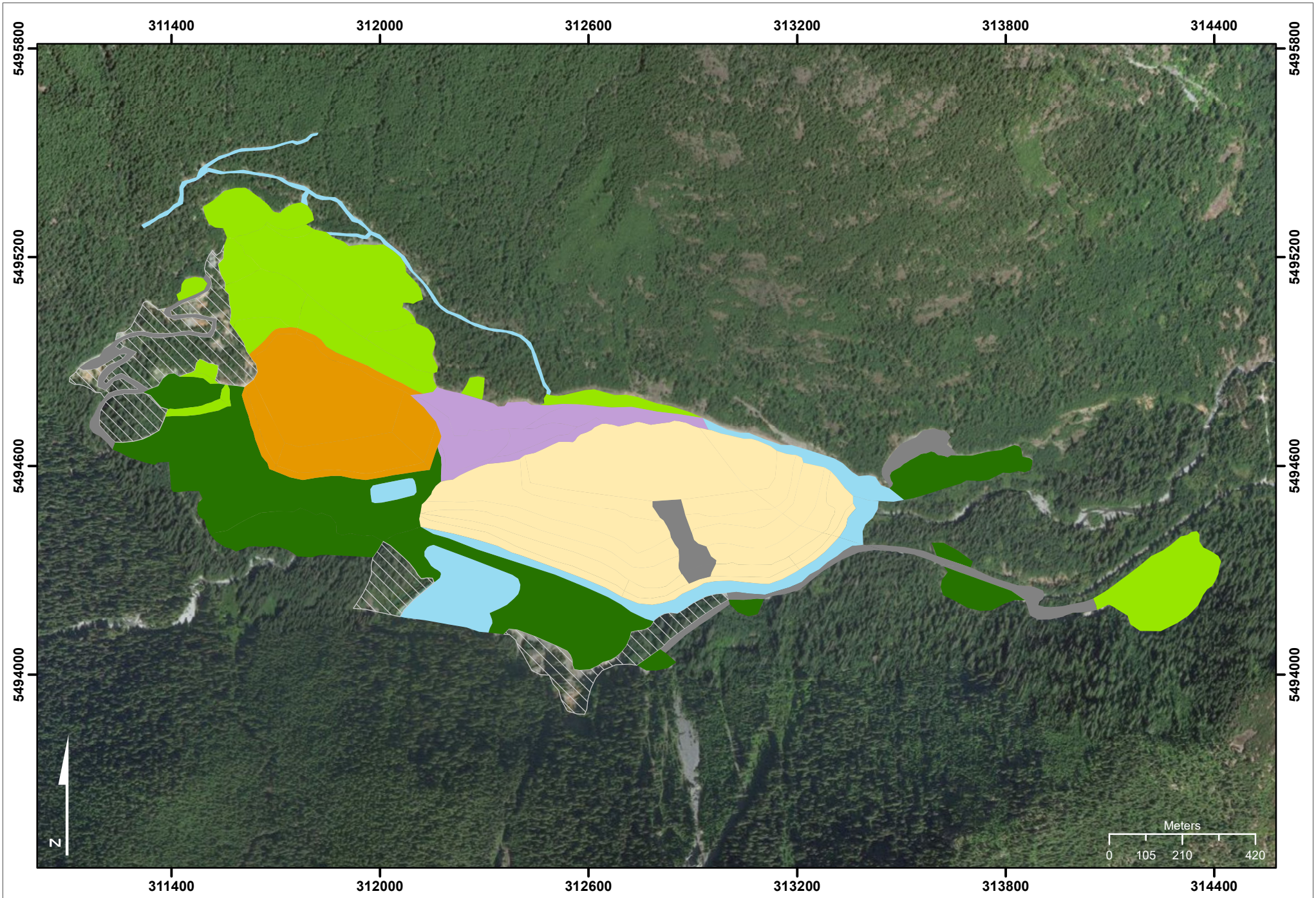

Figure 2. Modeled cover treatments and soil material areas at Myra Falls mine.

- Old Tailings Disposal Facility
- Lynx Tailing Disposal Facility
- Waste Rock Dumps 1 and 6
- Remaining disturbance
- Exposed till or colluvium
- Potential intact soil
- Potential intact ecosystem
- Water

Client: nyrstar

Created by: IEG Integral Ecology Group

Drawn by:	MI
Checked by:	JA
Date:	14-July-2019
Project:	NMFRS2-18
Datum/Coordinates:	NAD83/UTM Zone 10

Data gaps, limitations and assumptions

A core objective of this initial post-closure ecosystem-modelling exercise is to identify existing data gaps. A detailed accounting of such data gaps, the limitations they create, and the assumptions made for the purpose of this exercise is presented in Table 1.

In general, the data gaps are:

- Insufficient information regarding the characteristics of the following surficial materials:
    - Subsoils/parent materials within the permit boundary, such as till and soils which will be exposed through stripping of current waste rock dumps;
    - Stockpiled reclamation materials; and
    - Non-PAG waste rock which may be used as a component of growth materials.
- No material volume estimates for:
    - Stockpiled reclamation materials; and
    - Non-PAG waste rock which may be used as a component of growth materials.
- Lack of specificity in the current Closure Plan as it pertains to:
    - Reclamation of the areas around the plant site and administrative buildings
    - Decommissioning and revegetation of access roads
    - Restoration of waterways, including Myra Creek

These data gaps and our compensating assumptions decrease the accuracy of the QEA modeling process. Model accuracy will increase with additional sampling and lab analyses of the till, soil, reclamation material and non-PAG waste rock which will allow for a more representative characterization of site materials. Material volume estimates may constrain cover placement across the site resulting in modifications to post-closure ecosystem mapping.

Table 1. Data gaps, limitations, and resulting assumptions.

Data Gap	Limitation	Assumptions
Insufficient characterisation of stockpiled reclamation materials. The Topsoil Management Plan only provides the physical and chemical characteristics of a single sample.	One sample is not representative of all salvaged materials.	All growth materials in Scenario 1 are assumed in this model to have the qualities of a single sample from the stockpile material.
No estimate of site-wide material volumes	Plans may not be realistic if the material required in the closure plan is more than the volume of material available on site.	Material volumes are not limiting
No data on soil characteristics for the borrow area till, or till underlying the WRDs above the Lynx TDF	Cannot accurately model the post-closure ecosystems which will develop in these area	These areas were assumed to be comprised of one meter of the till material used in reclamation of the seismic berm.
There is no information available for the non-PAG waste rock referenced in the Topsoil Management Plan[7]	This material cannot be modelled without characterization	This material not used.
Lack of a detailed plan for reclamation and remediation of building facilities and surrounding area	Cannot accurately model the post-closure ecosystems which will develop in these area	It was assumed that these areas will be decompacted and covered using growth medium where necessary. Our model used application of 100 cm of stockpile material to represent these assumptions.

[7] As mentioned previously, the source of the seismic-berm material is uncertain, and it is possible that these materials are non-PAG waste rock.

Data Gap	Limitation	Assumptions
Lack of a detailed plan for reclamation of Myra Creek	The Topsoil Management Plan recommends placement of soil materials to create a riparian area. Without a more detail, such as the proposed cover material and depth, the recommendation cannot be modelled	The banks of the Myra Creek were not modelled differently from the remainder of the Old TDF
Lack of a detailed cover plan for WRDs 1 and 6	The treatment as modelled may not be accurate	WRD 1 and 6 were modelled as receiving 100 cm of growth material, as recommended in the Topsoil Management Plan (Wood, 2018b)
Lack of spatial data, or detailed diagrams of closure facilities	Uncertainty as to which areas will receive the prescribed soil treatment	Using the map from the Topsoil Management Plan and the 2019 Closure Topography, locations of closure facilities were roughly estimated.
Detailed microtopography and material data for the top of Lynx TDF	Uncertainty regarding if/where a perched water-table may develop	The model did not consider the formation of a perched water table on top of the Lynx-TDF.
Spatial closure mine topography does not extend to cover the dam access roads, nor is any treatment plan detailed for these areas	For these areas, slope and aspect could not be incorporated into the model. The actual material characteristics and depths are not known	These areas were modelled as flat (0 for slope), and as though the roads, once decompacted, will perform as though they are comprised of 100 cm of stockpile material.

Results

SMR can be translated into estimated site series using regional edatopic grids. Figure 3 depicts the CWHmm1 variant grid; site series from the CWHmm1 variant are projected to occur at most reclaimed sites in the post-closure landscape.

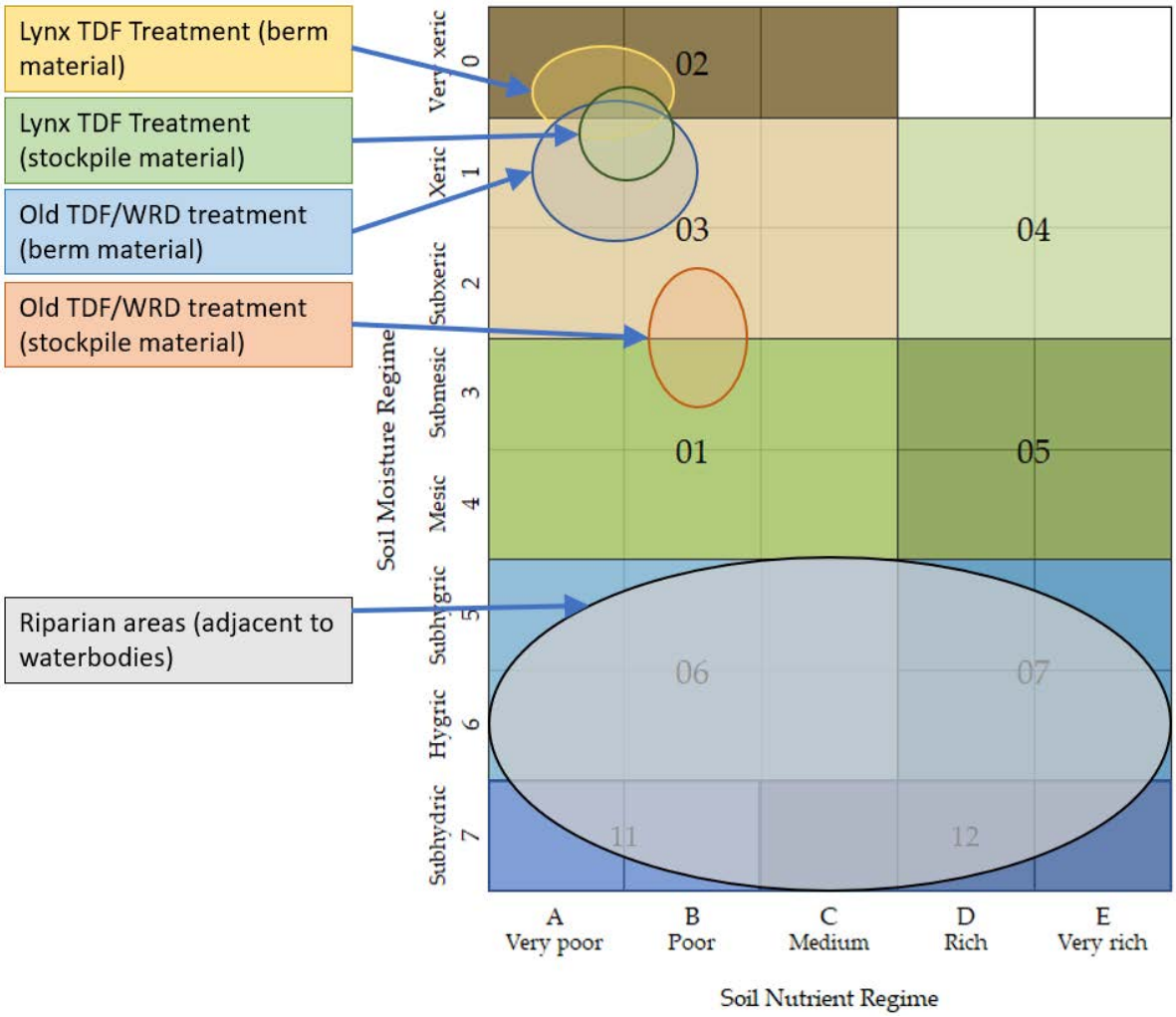

Figure 3. CWHmm1 edatopic grid positions indicating estimated site series of cover treatment/material combinations.

The berm material can hold less plant-available water because it contains fewer fine-fraction particles than the stockpile materials; it can support very xeric or xeric ecosystems in the post-closure environment, regardless of material depth. The stockpile materials contain more fine-fractions particles, so are capable of supporting subxeric to submesic ecosystems, but only where a 100-cm cover depth is placed. A 30-cm cover depth of stockpile material supports ecosystems in a similar SMR range to the berm materials.

The resulting post-closure ecosystem projections are presented for scenarios 1 and 2 in Figures 4 and 5, respectively. 01/03 ecosystems are projected on landforms receiving a 100-cm cover of the stockpile material (WRD 1, 6 and the Old TDF). In both scenarios, the Lynx tailings dam is uniformly the drier 02/03 ecosystems, though this may change if enough data is provided to model perched water tables in future iterations.

In both scenarios 1 and 2, 01 ecosystems occur in the relatively flat areas along the valley-bottom which appear to have relatively natural soils intact. As noted in the assumptions, due to the lack of data for these areas, it was assumed that these areas would perform as though they are constructed from 100 cm of stockpile material. These areas may vary from this assumption, and thus be less uniform.

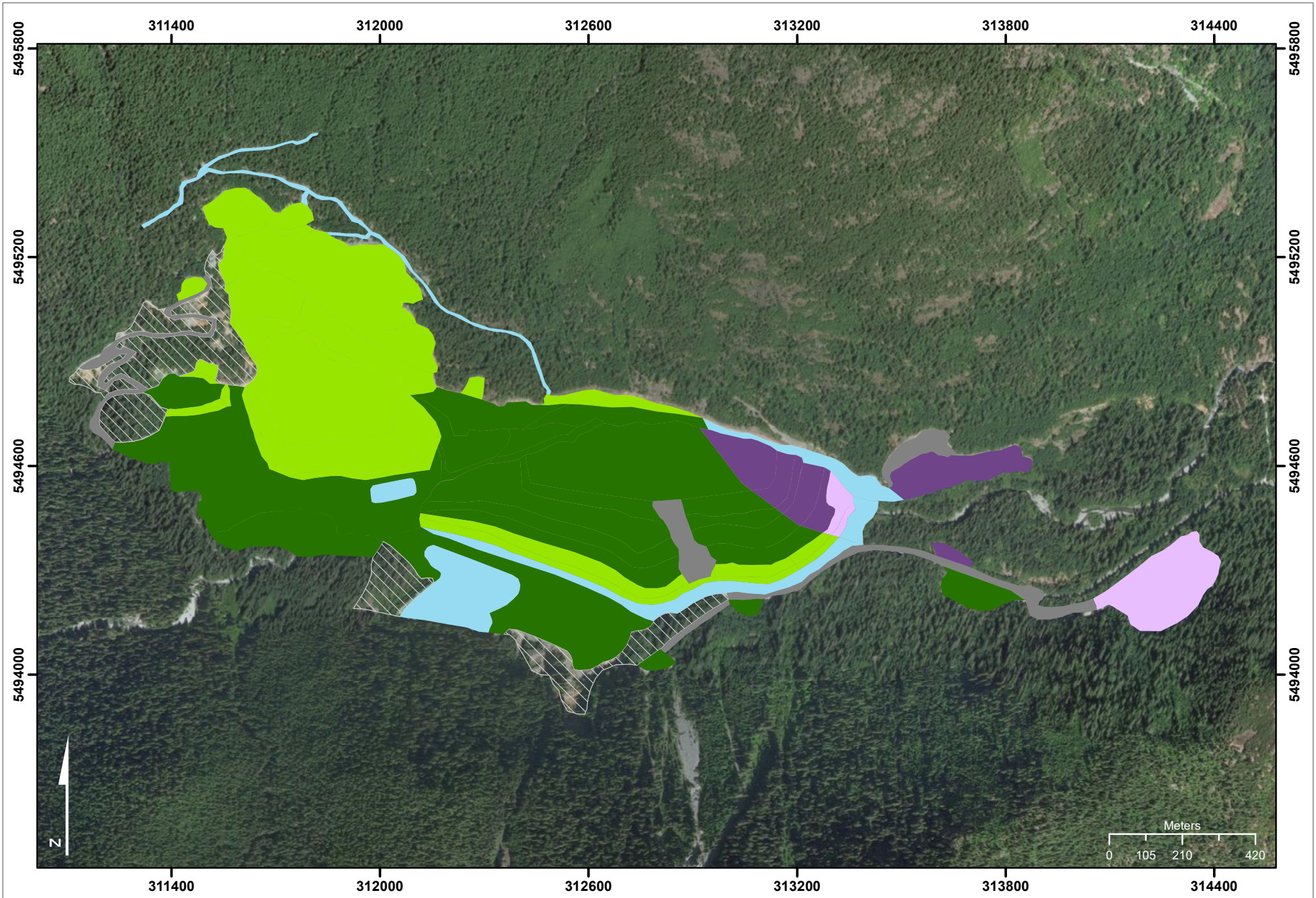

Figure 4. Scenario One predicted post-closure biogeoclimatic site series.

- CWHmm1-01/03
- CWHmm1-02/03
- CWHxm2-01/03
- CWHxm2-02/03
- Remaining disturbance
- Potential intact ecosystem
- Water

Client: nyrstar

Created by: IEG Integral Ecology Group

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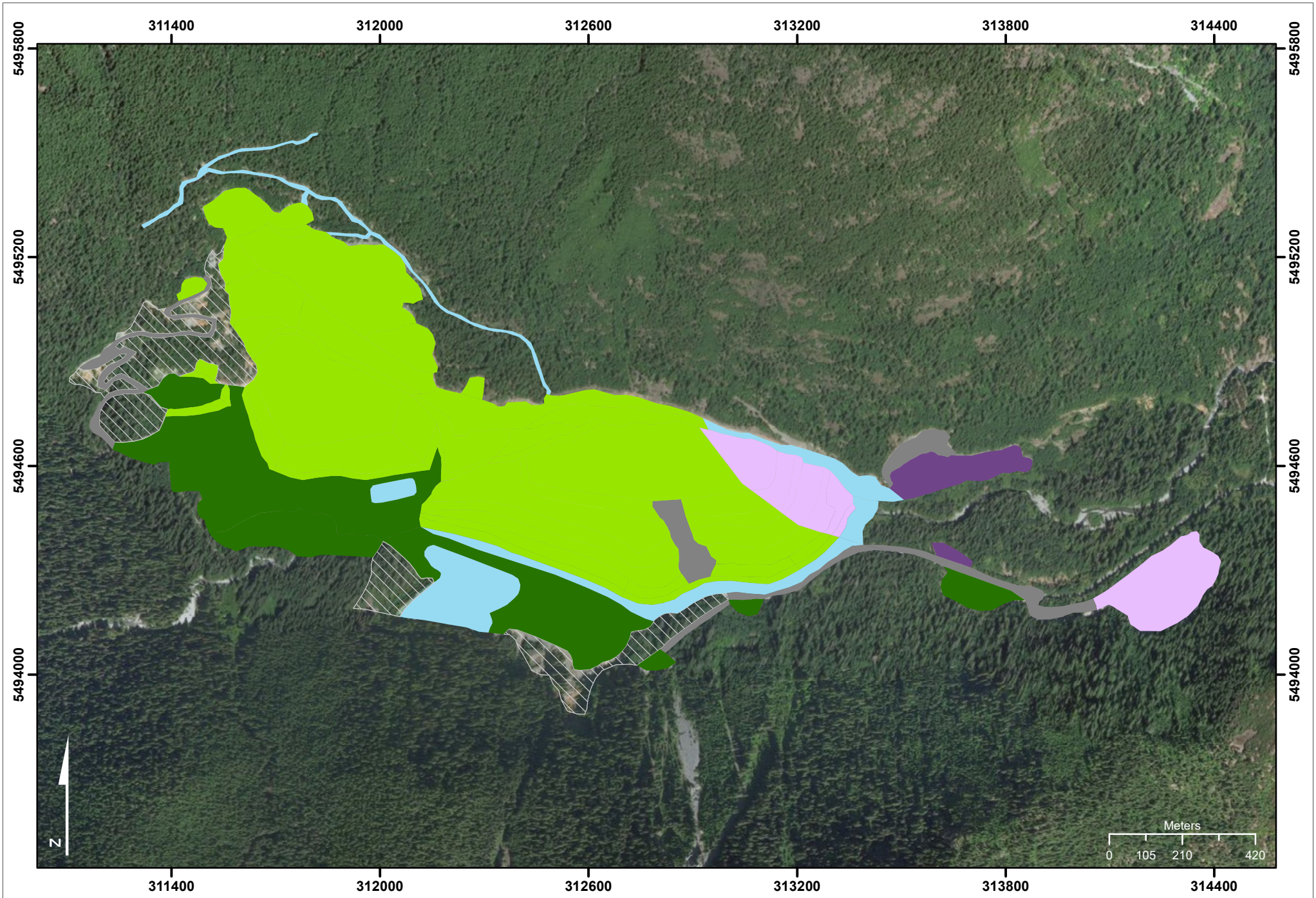

Figure 5. Scenario Two predicted post-closure biogeoclimatic site series.

- CWHmm1-01/03
- CWHmm1-02/03
- CWHxm2-01/03
- CWHxm2-02/03
- Remaining disturbance
- Potential intact ecosystem
- Water

Client: nyrstar

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Closure Ecosystem Fact Sheets

The following fact sheets provide a brief description and characteristics of the site series expected to be present in the post-closure landscape at Myra Falls.

The species provided are a combination of characteristic species of the site series, as well as species which are recommended for use in reclamation (IEG, 2018; MoF, 1994; Robertson Geoconsultants Inc., 2014; Wood Environment and Infrastructure Solutions, 2019). Non-vascular species are included on the list, despite the limited body of knowledge for their use in reclamation.

Detailed reclamation prescriptions should be developed in consultation with First Nations. As Myra Falls completes construction of closure landforms, progressive reclamation should include vegetation trials and/or monitoring of reclaimed areas to consistently improve reclamation prescriptions.

Biogeoclimatic subzone	Ecosite group
Submontane Moist Maritime Coastal Western Hemlock Variant (CWHmm1)	02/03
Vegetation associations:	Douglas-fir/Western hemlock – Salal (02) Western hemlock/Western redcedar – Salal (03)

Reclamation summary

Occurs in the CWHmm1 portion of the mine, which makes up much of the site, on the western side. This ecosite group is expected on constructed landforms using the coarser "berm" material as cover and exposed till areas. These ecosites will be more abundant on constructed landforms in scenario 2 than in scenario 1.
These ecosystems are expected to develop into forested ecosystems and will gradually push toward the subxeric range in the long term as organic matter slowly builds up in the developing soil.

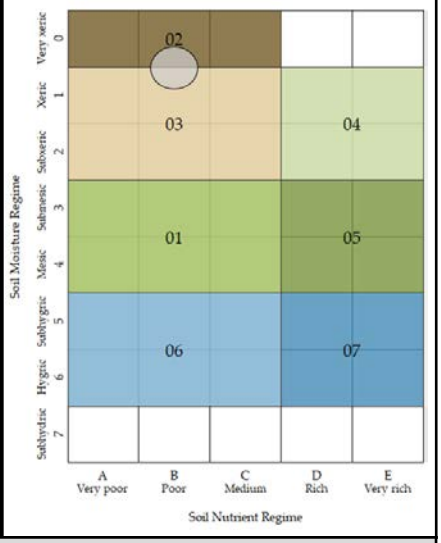
Site information

Soil materials:	Thin (30 cm) covers using "stockpile" materials; deeper covers using "berm" materials; exposed till
Landscape position:	Present on all landscape positions
Slope angle and aspect:	Present on all slopes and aspects. Tend toward drier on warm aspected slopes (SE-SW)
SMR:	Very xeric to Submesic
Elevation:	450-700 masl

Initial candidate revegetation species

Trees	Shrubs	Herbs	Non-vascular
Red alder	Alaskan blueberry	Five-leaved bramble	Pipecleaner moss
Lodgepole pine	Red huckleberry	Sword fern	Step moss
Douglas-fir	Salal	Pearly everlasting	Red-stemmed feathermoss
Western redcedar	Oval-leaved blueberry		*Cladina spp.*
	Black huckleberry		

Edatopic grid



Wildlife associations

Habitat Subtype: Conifer Forest – Dry

Associated species identified in *Mines Act* Permit M-26 Amendment: black bear, marten, Columbian black-tailed deer, cougar, wolf, deer mouse, red squirrel, Roosevelt elk

Other associated species: mammals – wolverine, ermine, beaver, bats (little brown myotis, Townsend's big-eared bat, big brown bat, California myotis, long-legged myotis, silver-haired bat, western long-eared myotis, Yuma myotis); birds – barn swallow, common nighthawk, bald eagle, northern goshawk, northern pygmy-owl, western screech-owl, trumpeter swan; amphibians – western toad

Biogeoclimatic subzone	Ecosite group
Submontane Moist Maritime Coastal Western Hemlock Variant (CWHmm1)	01/03
Vegetation associations:	Western hemlock/Balsam Fir – Pipecleaner moss (01)

Reclamation summary

Occurs in the CWHmm1 portion of the mine, which makes up much of the site, on the western side. This ecosite group is only expected on treatments with a full 100 cm of "stockpile" materials.
These ecosystems are expected to develop into forested ecosystems and will allow vegetation to establish quickly. Care will need to be taken in these areas to prevent the establishment of invasive species and aggressive agronomics. For this reason, aggressive grasses should only be used on these areas only where necessary to prevent erosion.

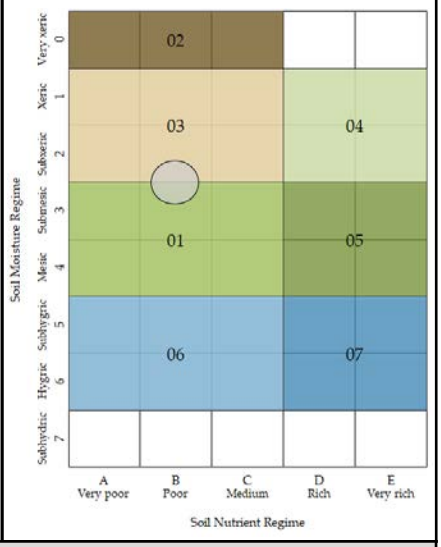
Site information

Soil materials:	Covers utilizing 100 cm of stockpile material
Landscape position:	Present on all level, tow and mid-slopes
Slope angle and aspect:	Present in flat or mildly sloped areas and on cooler aspected slopes (NE-NW)
SMR:	Submesic to Mesic
Elevation:	450-700 masl

Initial candidate revegetation species

Trees	Shrubs	Herbs	Non-vascular
Red alder	Salal	Bunchberry	Lanky moss
Douglas-fir	Dull Oregon-grape	Vanilla-leaf	Step moss
Western hemlock		Five-leaved bramble	Pipecleaner moss
Western redcedar		Deer fern	Oregon beaked moss
		Pearly everlasting	Flat moss

Edatopic grid



Wildlife associations

Habitat Subtype: Conifer Forest – Mesic/Conifer Forest – Dry

Associated species identified in *Mines Act* Permit M-26 Amendment: black bear, marten, Columbian black-tailed deer, cougar, wolf, deer mouse, red squirrel, Roosevelt elk

Other associated species: mammals – wolverine, ermine, beaver, bats (little brown myotis, Townsend's big-eared bat, big brown bat, California myotis, Keen's long-eared myotis, long-legged myotis, silver-haired bat, western long-eared myotis, Yuma myotis); birds – olive-sided flycatcher, band-tailed pigeon, barn swallow, common nighthawk, bald eagle, northern goshawk, northern pygmy-owl, western screech-owl, marbled murrelet, trumpeter swan; amphibians – western toad

Biogeoclimatic subzone	Ecosite group
Submontane Very Dry Maritime Coastal Western Hemlock Variant (CWHxm2)	02/03
Vegetation associations:	Douglas-fir/Lodgepole pine – Cladina (02) Douglas-fir/Western hemlock – Salal (03)

Reclamation summary

Occurs in the CWHxm2 portion of the mine, which occurs in the north-eastern portion of the mine site. This ecosite group is expected on constructed landforms using the coarser "berm" material as cover and exposed till areas. These ecosites will be more abundant on constructed landforms in scenario 2 than in scenario 1. These ecosystems are expected to develop into forested ecosystems and will gradually push toward the subxeric range in the long term as organic matter slowly builds up in the developing soil.

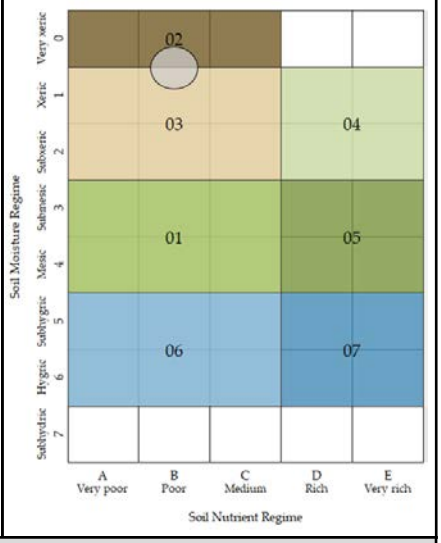
Site information

Soil materials:	Thin (30 cm) covers using "stockpile" materials; deeper covers using "berm" materials; exposed till
Landscape position:	Present on all landscape positions
Slope angle and aspect:	Present on all slopes and aspects. Tend toward drier on warm aspected slopes (SE-SW)
SMR:	Very xeric to Submesic
Elevation:	0-700 masl

Initial candidate revegetation species

Trees	Shrubs	Herbs	Non-vascular
Red alder	Common juniper	Vanilla-leaf	Step moss
Lodgepole pine	Red huckleberry	Sword fern	Oregon beaked moss
Douglas-fir	Salal	Pearly everlasting	
Western redcedar	Dull Oregon-grape		

Edatopic grid



Wildlife associations

Habitat Subtype: Conifer Forest – Dry

Associated species identified in *Mines Act* Permit M-26 Amendment: black bear, marten, Columbian black-tailed deer, cougar, wolf, deer mouse, red squirrel, Roosevelt elk

Other associated species: mammals – wolverine, ermine, beaver, bats (little brown myotis, Townsend's big-eared bat, big brown bat, California myotis, long-legged myotis, silver-haired bat, western long-eared myotis, Yuma myotis); birds – barn swallow, common nighthawk, bald eagle, northern goshawk, northern pygmy-owl, western screech-owl, trumpeter swan; amphibians – western toad

Biogeoclimatic subzone	Ecosite group
Submontane Very Dry Maritime Coastal Western Hemlock Variant (CWHxm2)	01/03
Vegetation associations:	Western hemlock/Douglas-fir – Kindbergia (01) Douglas-fir/Western hemlock – Salal (03)

Reclamation summary

Occurs in the CWHxm2 portion of the mine, which occurs in the north-eastern portion of the mine site. This ecosite group is only expected on treatments with a full 100 cm of stockpile materials.
These ecosystems are expected to develop into forested ecosystems and will allow vegetation to establish quickly. Care will need to be taken in these areas to prevent the establishment of invasive species and aggressive agronomics. For this reason, aggressive grasses should only be used on these areas only where necessary to prevent erosion.

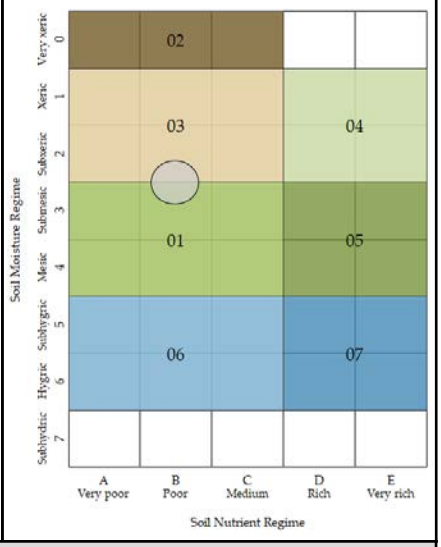
Site information

Soil materials:	Covers utilizing 100 cm of stockpile material
Landscape position:	Present on all level, tow and mid-slopes
Slope angle and aspect:	Present in flat or mildly sloped areas and on cooler aspected slopes (NE-NW)
SMR:	Submesic to Mesic
Elevation:	0-700 masl

Initial candidate revegetation species

Trees	Shrubs	Herbs	Non-vascular
Red alder	Salal	Sword fern	Lanky moss
Douglas-fir	Dull Oregon-grape	Vanilla-leaf	Step moss
Western hemlock	Red huckleberry	Twinflower	Oregon beaked moss
Western redcedar	Ocean-spray	Pearly everlasting	
Lodgepole pine			

Edatopic grid



Wildlife associations

Habitat Subtype: Conifer Forest – Mesic/Conifer Forest – Dry

Associated species identified in *Mines Act* Permit M-26 Amendment: black bear, marten, Columbian black-tailed deer, cougar, wolf, deer mouse, red squirrel, Roosevelt elk

Other associated species: mammals – wolverine, ermine, beaver, bats (little brown myotis, Townsend's big-eared bat, big brown bat, California myotis, Keen's long-eared myotis, long-legged myotis, silver-haired bat, western long-eared myotis, Yuma myotis); birds – olive-sided flycatcher, band-tailed pigeon, barn swallow, common nighthawk, bald eagle, northern goshawk, northern pygmy-owl, western screech-owl, marbled murrelet, trumpeter swan; amphibians – western toad

Bioclimatic subzone	Ecosite group
Submontane Very Dry Maritime Coastal Western Hemlock Variant (CWHxm2); and, Submontane Moist Maritime Coastal Western Hemlock Variant (CWHmm1)	Riparian (06/07/11/12)

Reclamation summary

Riparian areas are typified by highly productive vegetation, and occur adjacent to rivers, lakes, ponds, streams and wetlands, where water availability is less limiting of vegetation growth than other positions on the landscape. We expect narrow bands of these ecosystem types to form along waterbodies regardless of the material used in reclamation, but the thickness of these bands, and the moisture and nutrient regimes will shift based primarily on the qualities of the substrate. Riparian areas play a vital role in supporting vegetation, fish and wildlife habitats, and play a role in maintaining water quality.

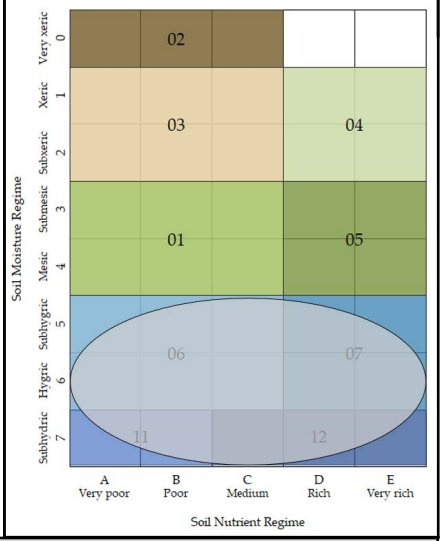
Site information

Soil materials:	It has not yet been determined what materials will be in place in these areas at the time of revegetation.
Landscape position:	Directly adjacent to waterbodies
Slope angle and aspect:	Present on slopes and flat benches directly adjacent to waterbodies
SMR:	Subhygric to Subhydric
Elevation:	0-700 masl

Initial candidate revegetation species

Trees	Shrubs	Herbs	Non-vascular
Red alder	Salal	Deer fern	Lanky moss
Black Cottonwood	Devil's club	Bunchberry	Step moss
Western hemlock	Red huckleberry	Skunk cabbage	Shiny liverwort
Western redcedar	Alaskan blueberry	sedge species	
		wildrye species	

Edatopic grid



Wildlife associations

Habitat Subtype: Riparian Forest

Associated species identified in *Mines Act* Permit M-26 Amendment: black bear, marten, Columbian black-tailed deer, cougar, wolf, deer mouse, red squirrel, Roosevelt elk

Other associated species: mammals – ermine, American water shrew, beaver, bats (little brown myotis, Townsend's big-eared bat, big brown bat, California myotis, hoary bat, Keen's long-eared myotis, silver-haired bat, western long-eared myotis, Yuma myotis); birds – olive-sided flycatcher, band-tailed pigeon, barn swallow, bald eagle, northern goshawk, northern pygmy-owl, western screech-owl, marbled murrelet; amphibians – western toad, northern red-legged frog, wandering salamander

References and model input sources

Table 2. Model input sources for Myra Falls post-closure mapping.

Model inputs	**Source**
Climate data	ClimateBC (2019)
“berm” materials characterization	Integral Ecology Group, 2013
“stockpile” materials characterization	Wood, 2018b.
“Drainage layer” materials characterization (underlying growth material for Old TDF cover treatment)	Generated from a description in Amec Foster Wheeler. 2016b
“Compacted till” materials characterization (underlying growth material for Lynx TDF cover treatment)	Generated from a description in Amec Foster Wheeler. 2016a

Amec Foster Wheeler. 2016a. Nyrstar Myra Falls Mine, Lynx TDF Dam Face Closure Cover Permit Level Design. December 16, 2016.

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