Road Rehabilitation Algorithm

MODELING UPDATE

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PROJECT [1273-3]

Prepared for:

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Acknowledgements

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- Chartwell Consultants – development of original algorithm
- Bill Chapman – Emeritus Research Scientist, FLNRORD – development of original algorithm
- West Fraser Ltd. – planning and algorithm development

Executive Summary

The Road Rehabilitation Algorithm Modeling Update project is one component of a larger, multi-phase process currently being developed and implemented by the Society for Ecosystem Restoration in Northern BC (SERN) to identify and reforest unused forest roads. A GIS algorithm was previously developed that classified existing access structures as temporary or permanent as defined in the Forest Planning and Practices Regulation (FPPR). This report describes modifications to this GIS algorithm focused on improvements to classification accuracy in the identification of road reforestation opportunities. The objective is to improve upon the classification algorithm for use in future road rehabilitation programs. The long-term vision is to develop an algorithm that can be adapted and applied to any land base in the province. To achieve this, a modified algorithm was developed and tested on a smaller land base, the Stuart Nechako District, with the intended application for any low relief terrain in the Interior of the Province.

Experience in developing the new algorithm showed an improvement in classification accuracy by defining a core road network as the first step. Classification accuracy was 89.6%, ranging from 65 to 100% on individual validation map tiles, and 90% in the Francois Lake area. The leading causes of misclassification where: internal roads in NFG cutblocks, roads that were not needed to maintain access for harvest opportunities, and in the Francois Lake area, reclassification to ensure NOE continuity. The largest single cause of misclassification were roads internal to NFG cutblocks. Overall, the classification accuracy achieved by the modified algorithm was considered acceptable as a starting point for road rehabilitation planning projects, large scale cumulative effects analysis, and access management planning. To further improvements on the algorithm and increase classification accuracy, it is recommended that further work be completed with the approach and assumptions applied to NFG cutblocks, harvest opportunity and intentional reserve areas, and adjacent stand age. The algorithm is optimized for use in low relief terrain; it is recommended that prior to its use in steeper terrain that modifications to algorithm assumptions be investigated.

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List of Acronyms

AOI	Area of Interest
BCGS	British Columbia Geographic System
DBH	Diameter Breast Height
FCI	Forest Carbon Initiative
FG	Free Growing
FPPR	Forest Planning and Practices Regulation
FSR	Forest Service Road
FTEN	Forest Tenure
FWA	Freshwater Atlas
GIS	Geographic Information System
IRDB	Integrated Roads Database
MPB	Mountain Pine Beetle
NOE	No Opportunity Expected
NFG	Not Free Growing
OGMA	Old Growth Management Area
RESULTS	Reporting Silviculture Updates and Land Status Tracking System
ROP	Reforestation Opportunity
SERN	Society for Ecosystem Restoration in North Central British Columbia
TRIM	Terrain Resource Information Management
TSA	Timber Supply Area
TSR	Timber Supply Review
VRI	Vegetation Resource Inventory

Introduction

The provincial government has initiated several road rehabilitation initiatives in the Stuart Nechako Resource District (the District) as a result of significant timber harvesting that occurred in response to Mountain Pine Beetle (MPB). This project is one component of a larger, multi-phase process currently being developed and implemented by the Society for Ecosystem Restoration in Northern BC (SERN) to identify and reforest unused forest roads. A GIS algorithm was previously developed that classified existing access structures as temporary or permanent as defined in the Forest Planning and Practices Regulation (FPPR). This report describes modifications to this GIS algorithm focused on improvements to classification accuracy in the identification of road reforestation opportunities.

PROJECT OBJECTIVES

The objective of this project is to improve upon the previously developed road classification algorithm to be used for future road rehabilitation planning and program implementation. The long-term vision is to develop an algorithm that can be adapted and applied to any land base in the province. To achieve this, a modified algorithm was developed and tested on a smaller land base, the Stuart Nechako District, with the intended application for any low relief terrain in the Interior of the Province. This project will assist in the delivery of the overall Road Rehabilitation Program currently underway in the District by improving the accuracy of road classification for the purpose of identifying reforestation opportunities in support of provincial forest carbon initiatives (i.e. FCI). Improvements to the algorithm will increase the effectiveness of the program and its ability to assist in meeting a number of other objectives, including improving timber supply, managing access, and improving wildlife forage availability.

STUDY AREA

Algorithm development and validation was focused on the Stuart Nechako Resource District (formally the Vanderhoof and Fort St. James Districts), as well as 3 nearby Resource Districts in Central and Northern B.C.: Nadina, Quesnel and Prince George (Figure 1). Initial development of the algorithm was based on a 37,000 ha project area south of Francois Lake Provincial Park. It was then validated on 19 map tiles distributed across the 4 Districts. The Francois Lake area was selected because of its size and recent experience gained from the road rehabilitation program currently being delivered by SERN.

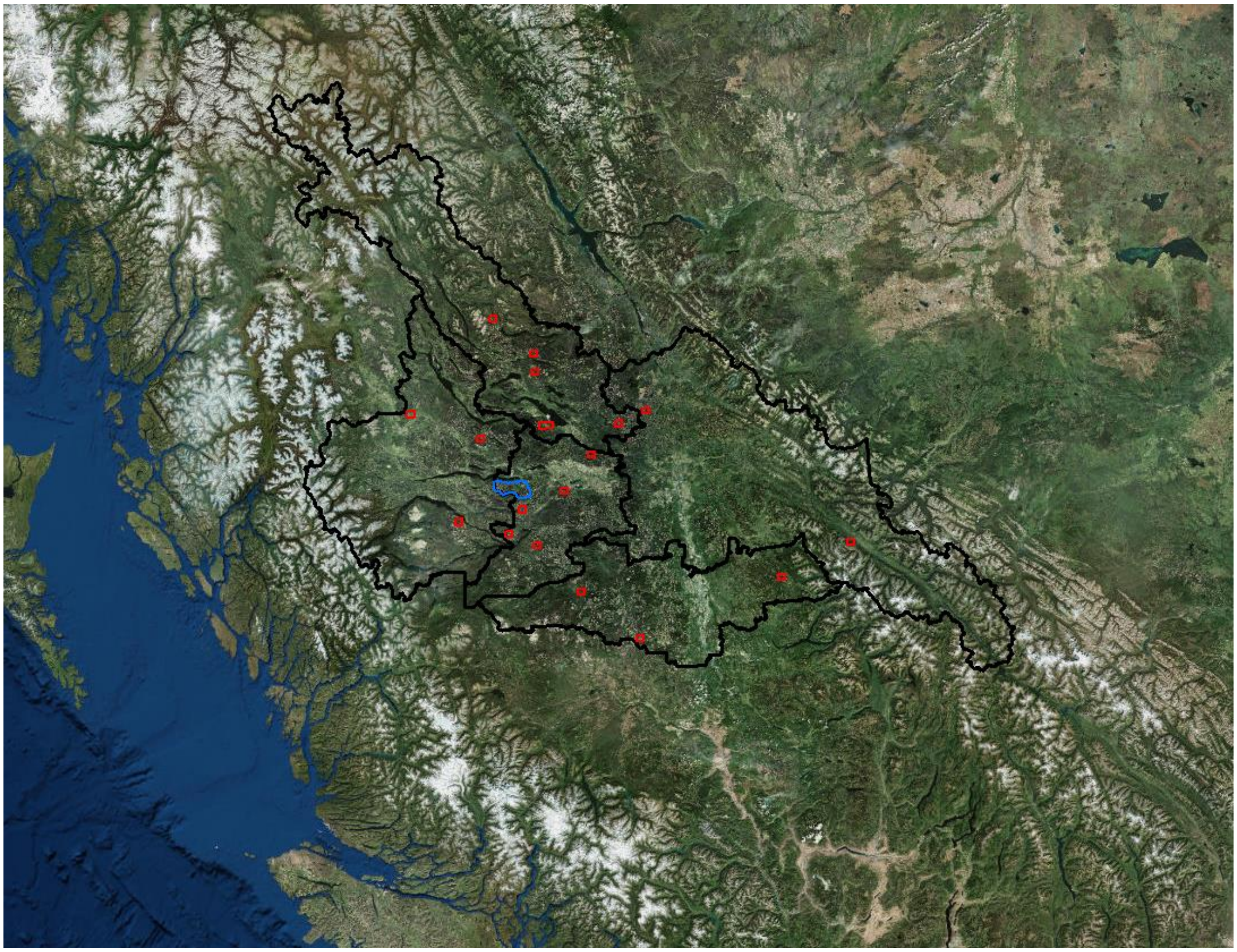

Figure 1 Location of the Francois Lake area (blue) and validation map tiles (red) across 4 Natural Resource Districts (black)

Approach

The following steps were undertaken in the implementation of the project. Additional details regarding final algorithm parameters and procedures applied in the GIS analysis can be found in Appendix 1 – GIS Analysis.

ALGORITHM DEVELOPMENT

Table 1 lists the databases available through GeoBC that were assembled for input data sources and organized in a geodatabase. A slope layer was manually generated using TRIM data to identify inoperable areas where slopes are greater than 40%. The original algorithm was reviewed and GIS modifications to address known issues were defined. Through an iterative process of refinement, specific sets of modifications were reviewed visually and redefined as needed.

The key factors driving road classification are: the definition of future harvest opportunity, the geographic location of roads relative to the opportunity, free growing status of a cutblock, and constraints limiting road construction and harvesting. Based on these assumptions, roads were classified as either a Reforestation Opportunity (ROP) or No Opportunity Expected (NOE). This classification differs from the original algorithm which used 'temporary' and 'permanent' as defined in the FPPR because not all temporary access will qualify as a reforestation opportunity, and in some cases permanent roads are no longer required for access.

Table 1 Datasets Assembled for Algorithm Development

Type	Name	Dataset	Download Date
Roads	Integrated Road Database		
Roads	FTEN Roads	FTEN_ROAD_SECTION_LINES	1/24/2018
Opportunity	VRI	VEG_COMP_LYR_R1_POLY	1/25/2018
Cutblock	VRI Cutblocks	VEG_CONSOLIDATED_CUT_BLOCKS	1/24/2018
Cutblock	RESULTS Openings	RSLT_OPENING	1/25/2018
Cutblock	Forest Cover Reserves	RSLT_FOREST_COVER_RESERVE	1/24/2018
Cutblock	FTEN Cutblocks	FTEN_CUT_BLOCK_POLY	1/24/2018
Hard Constraint	OGMA	OGMA_LEG	1/23/2018
Hard Constraint	Integrated Cadastral Fabric (Private Land)	pmbc_parcel_fabric_poly	1/23/2018
Hard Constraint	FTEN Recreation Polygons	FTEN_RECREATION_POLY	1/23/2018
Hard Constraint	Provincial Parks, Ecological Reserves, Protected Areas	TA_PARK_ECORES_PA	1/23/2018
Hard Constraint	National Parks	CLAB_NATIONAL_PARKS	1/23/2018
Hard Constraint	Slope greater than 40%	TRIM	
Hard Constraint	FWA Lakes	FWA_LAKES_POLY	1/23/2018
Hard Constraint	FWA Rivers	FWA_RIVERS_POLY	1/23/2018
Hard Constraint	FWA Streams (major)	FWA_STREAM_NETWORKS	1/23/2018
Soft Constraint	FWA Streams (minor)	FWA_STREAM_NETWORKS	1/23/2018
Soft Constraint	Wetlands	NRC_WATER_WETLAND_250K	1/24/2018

INTEGRATED ROADS DATABASE

The Integrated Roads Database (IRDB) provided the raw data for road classification and identification of reforestation opportunities. Roads in the IRDB are comprised of numerous small segments that are frequently duplicated. As an initial step in data preparation, all road segments were merged into a single segment that started and ended at a road junction. This process was expected to reduce classification errors experienced from short segments and provide a uniform classification over longer distances, which also reduces time spent re-classifying roads later in the planning process.

A second step in preparing the roads database was to define a core road network using all Forest Service Roads (FSR), named roads (residential roads, highways, etc.), and active FTEN permit roads longer than 5 km. Defining a core road network facilitated the use of path analysis which was a key method in accurately identifying access to harvest opportunities and avoiding multiple, redundant roads accessing a single opportunity.

HARVEST OPPORTUNITY

Harvest opportunity was defined as a function of three attributes: merchantable conifer volume, patch size, and distance between vegetation resource inventory (VRI) polygons that were combined into larger opportunity polygons. Quantitative limits for these grouping criteria were defined as:

1. Merchantable conifer volume – minimum volume of 140 m^3/ha in lodgepole pine leading stands at 12.5 cm dbh, and 182 m^3/ha in all other conifer leading stands at 17.5 cm dbh.
2. Minimum area of 20 ha obtained by grouping VRI polygons that met the above conifer volume thresholds.
3. Distance between grouped VRI polygons less than 50 meters.

Volume criteria correspond to the values used in the most recent Prince George TSA Timber Supply Review (TSR). A minimum area of 20 hectares was selected to avoid small isolated patches of timber that would be unlikely to be harvested. The separation distance of 50 meters was selected to include nearby patches of timber that were not contiguous, while avoiding patches at greater distances that may be on opposite sides of riparian or gully features.

CUTBLOCK FREE GROWING STATUS

To accommodate potential silvicultural activities, a requirement in the algorithm was to maintain access to not free growing (NFG) cutblocks and, in the case of large blocks, provide internal access to maintain safe walking distances. Safe walking distance was defined as 800 m from a driveable road based on consultation with licensees. Three different methods of classifying NFG roads were evaluated:

1. Classifying all internal cutblock roads longer than 800 meters as NOE
2. Classifying all internal roads of any length as a ROP
3. Classifying only "dead-end" roads that are less than 800 m as ROP and the other NFG-intersecting roads as NOE.

CONSTRAINTS

There were very few modifications to constraints from the original algorithm. The only significant change was in the approach to stream classification and wetlands. In the original algorithm all rivers and streams of order 2 or greater were considered 'hard' constraints, meaning roads could not cross them and harvest opportunities could not be joined across them. Order 1 streams were considered a 'soft' constraint, meaning there was an added cost to crossing them. Wetlands were not considered a constraint.

In consideration of the low relief terrain that the modified algorithm is focused on, streams of order 3 and greater were treated as 'hard' constraints, order 2 streams as 'soft' constraints, and order 1 streams were not considered a constraint. Wetlands were considered to be a 'hard' constraint with no buffer.

ALGORITHM VALIDATION

Initial development and testing of the algorithm was completed in the Francois Lake project area. The modified algorithm was then tested on randomly selected map tiles in the Stuart Nechako[1], Nadina, Quesnel and Prince George Resource Districts. The goal of the algorithm was to correctly identify roads as either Reforestation Opportunities (ROP) or No Opportunity Expected (NOE). Misclassification was defined simply as any incorrect identification of these two categories. The rate of road misclassification

[1] The Vanderhoof and Fort. St. James Districts have been recently merged to the Stuart Nechako Resource District

was quantified for each selected map tile by dividing the length of reclassified roads by total road length.

In each District, all map tiles were categorized by the percentage of available timber already harvested. Three map tiles were then randomly selected, one from each of the following classes of percent area harvested: 10-30%, 30-50%, and 50-90%. Six additional tiles, two in each of the area harvested categories, were randomly selected from the Stuart Nechako District. Map tiles clipped by District boundaries were excluded by only selecting tiles greater than 14,000 ha.

PLANNING PROCESS

The classified road dataset is designed to be the first step in a multi-phase operational planning process, which would generally be structured as:

1. Road classification produced by algorithm.
2. Manual review and modification of road classification using additional data sources and stakeholder consultation.
3. Licensee review considering future development plans and outstanding obligations.
4. Field assessments of identified opportunities in support of treatment prescriptions.
5. Final stakeholder and licensee consultation.
6. Implementation of reforestation plan.

In the case of the Francois Lake project area, the original algorithm was reviewed in conjunction with satellite imagery, known development planning, and local knowledge to further refine road classification to be reflective of current practices. In-block roads, spur roads, and general access roads that did not access future harvesting opportunities or ongoing silviculture obligations were identified as potential candidates for reforestation. Once this in-depth review was completed, a list of candidate roads for rehabilitation were developed and mapped. This established the referral package delivered to the major forest licensee operating in the area (West Fraser Ltd.) to further refine candidate roads selected for field assessments. This engagement allowed for integration of licensee plans, resulting in roads being identified for rehabilitation that better reflected operational realities.

Field assessments were then completed in the fall of 2017 to verify the road selection process for rehabilitation and reforestation opportunities. Data collected from these assessments were used to update the classified road dataset and analyze results to identify trends or issues that could be resolved through modifications to the algorithm. Insight gained from this experience was used in developing the modified algorithm assumptions and methods.

DELIVERABLES

In addition to this report, a geodatabase containing the classified road dataset and output data layers (e.g. opportunities, constraints) was produced for the Stuart Nechako Resource District. The GIS algorithm was also automated as part of this project, and the resulting collection of scripts with user defined inputs for land base specific assumptions was provided.

Results

INTEGRATED ROAD DATABASE

Experience in developing the new algorithm showed an improvement in classification accuracy by defining a core road network as the first step. Figure 2 shows the core network defined for the Francois Lake area using all Forest Service Roads (FSR), all named roads (residential roads, highways, etc.), and all active FTEN permit roads longer than 5 km. Defining a core road network facilitated the use of path analysis which was a key method in accurately identifying access to harvest opportunities and avoiding multiple, redundant roads accessing a single opportunity.

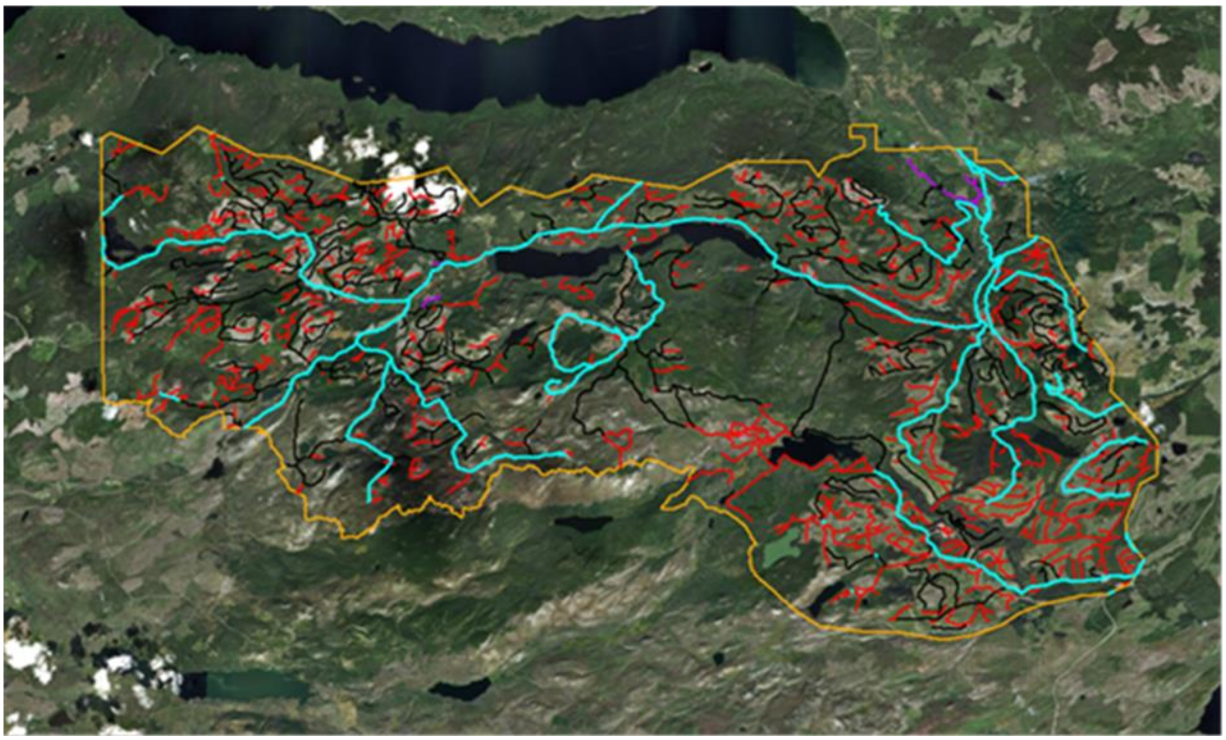

Figure 2 Core road network (highlighted blue) defined for Francois Lake area

MODIFIED ALGORITHM RESULTS

Road classification is a function of three key factors: cutblock free growing status, road location relative to a potential harvesting opportunity, and constraints due to a variety of factors such as private land, riparian areas, and mapped reserves. Appendix 1 describes in detail the parameters used to address each of these factors. This section provides a synopsis of the modified algorithm parameters and describes the outcomes of applying these in the road classification algorithm.

ROAD CLASSIFICATION ACCURACY

Results of algorithm road classification at Francois Lake and on 19 randomly selected map tiles are summarized in Table 2. A total of 2,098 km of road was classified by the algorithm and manually reviewed for accuracy. Overall, classification accuracy was 89.6%, ranging from 65 to 100% on individual validation map tiles, and 90% in the Francois Lake area.

As shown in Table 2, the leading causes of misclassification on the validation tiles and Francois Lake were internal roads in NFG cutblocks (58% and 41% respectively), NOE roads that were not needed to maintain access (16% and 13% respectively), and roads accessing harvest opportunities that were reclassified (13% validation tiles). Francois Lake also experienced a high rate of misclassification due to ROP to NOE continuity. This occurred in a few locations where longer road segments were classified as ROP however the adjoining road segments were NOE. In order to maintain access along that piece of the road network, the entire road needed to be classified as NOE.

Table 2 Road classification algorithm results

Map Tile	Total Misclass-ified (km)	Total Correct (km)	Total (km)	Accuracy (%)	Proportion misclassified by category: NFG in-block road, reclassified	NOE, not needed	NOE, duplicated	NOE, fragmentation	ROP to NOE continuity	Opportunity, reclassified	FTEN road, not needed
093B0641	3.1	54.0	57.1	**94.5%**	**92%**	8%	0%	0%	0%	0%	0%
093F0101	1.1	42.5	43.5	97.6%	**100%**	0%	0%	0%	0%	0%	0%
093F0471	0.0	7.5	7.5	100.0%	**0%**	0%	0%	0%	0%	0%	0%
093F0551	6.6	75.2	81.8	92.0%	**62%**	24%	0%	0%	15%	0%	0%
093F0612	0.4	44.7	45.1	99.1%	**100%**	0%	0%	0%	0%	0%	0%
093F0761	2.8	64.8	67.6	95.8%	**59%**	0%	0%	19%	0%	22%	0%
093F0893	10.0	66.9	76.9	**87.0%**	**86%**	1%	0%	9%	0%	4%	0%
093H0043	5.9	78.6	84.5	93.0%	**80%**	0%	0%	18%	0%	0%	2%
093H0391	24.5	45.3	69.8	**65.0%**	**30%**	34%	0%	9%	13%	15%	0%
093J0113	7.5	94.0	101.5	92.6%	**71%**	0%	0%	0%	3%	25%	0%
093J0431	10.1	88.2	98.3	89.8%	**100%**	0%	0%	0%	0%	0%	0%
093J0551	19.4	60.3	79.7	75.7%	**51%**	19%	0%	8%	0%	0%	22%
093K0331	7.3	67.3	74.6	90.2%	**92%**	5%	0%	0%	0%	3%	0%
093K0472	9.0	75.3	84.3	89.3%	**79%**	9%	0%	7%	6%	0%	0%
093K0481	9.3	53.3	62.6	85.1%	**22%**	56%	0%	0%	0%	21%	0%
093K0873	7.8	71.0	78.7	90.1%	**60%**	0%	0%	1%	0%	39%	0%
093L0581	2.4	70.1	72.5	96.7%	**0%**	0%	0%	0%	0%	100%	0%
093N0071	9.4	66.4	75.8	87.6%	**35%**	26%	0%	11%	0%	29%	0%
093N0341	2.2	41.0	43.2	95.0%	**35%**	0%	0%	0%	0%	65%	0%
Validation Sub-Total	**138.7**	**1166.5**	**1305.2**	**89.4%**	**58.2%**	**16.3%**	**0.0%**	**5.7%**	**3.4%**	**13.2%**	**3.2%**
Francois Lake	**79.3**	**713.2**	**792.5**	**90.0%**	**41.3%**	**13.1%**	**4.8%**	**0.7%**	**40.2%**	**0.0%**	**0.0%**
ALL	**218.0**	**1879.6**	**2097.7**	**89.6%**	**51.8%**	**15.1%**	**1.8%**	**3.8%**	**17.3%**	**8.2%**	**2.0%**

A cumulative frequency distribution showed that 89% of the 19 randomly selected validation tiles had a classification accuracy of 85% or better (Figure 3). The low classification accuracy of 65% on map tile 93H039.1 was an artifact of missing cutblock and VRI data. There was a large area (highlighted in Figure 4) with no denudation history recorded in the VRI database, despite evidence of old harvesting visible on Google Earth (Figure 5).

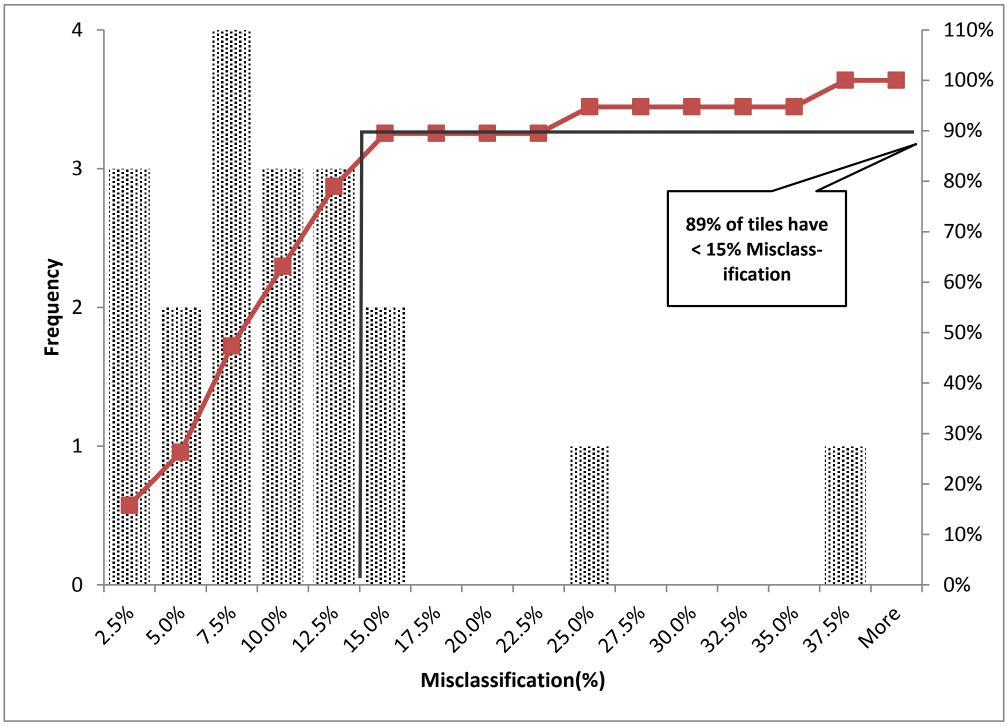

Figure 3 Cumulative frequency of misclassification error shown in red.

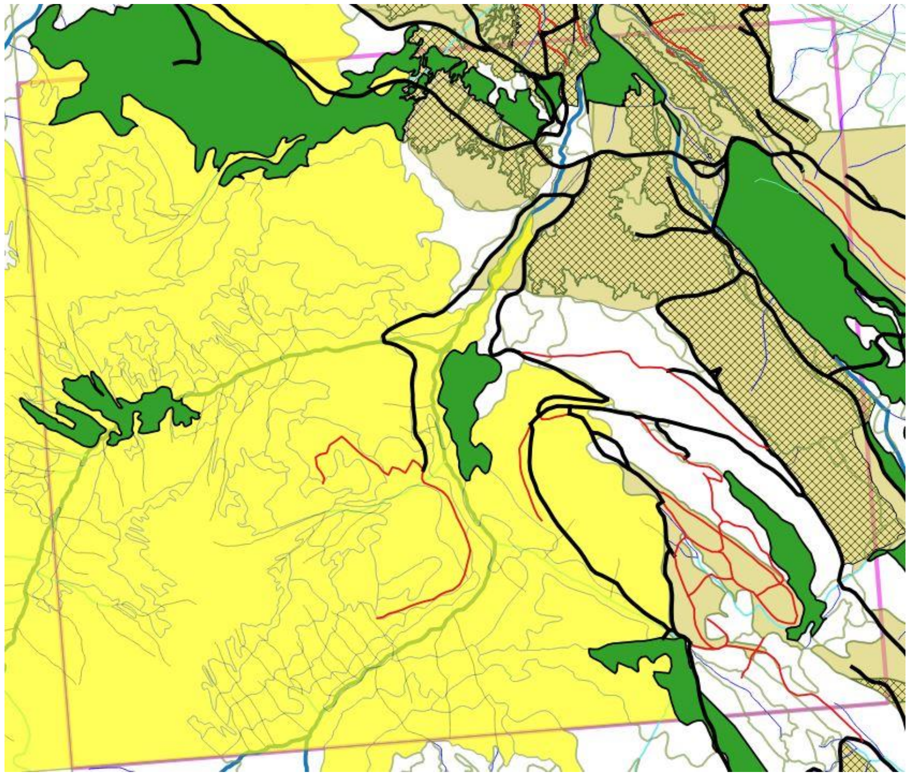

Figure 4 Example map tile with low classification accuracy. Areas in yellow are VRI Polygons with missing information on disturbance and denudation history.

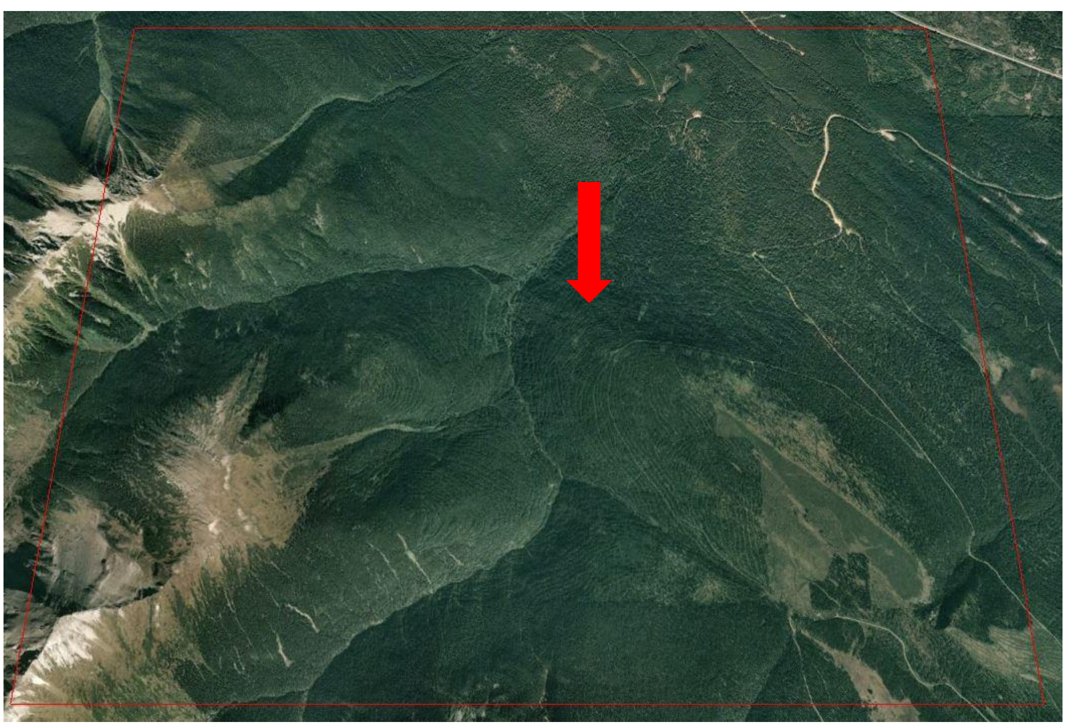

Figure 5 Google Earth image of example map tile with low classification accuracy. Red arrow shows large area of old harvesting with missing information in VRI.

There was a weak but statistically significant linear trend of increasing misclassification error with increased road construction (Figure 6).

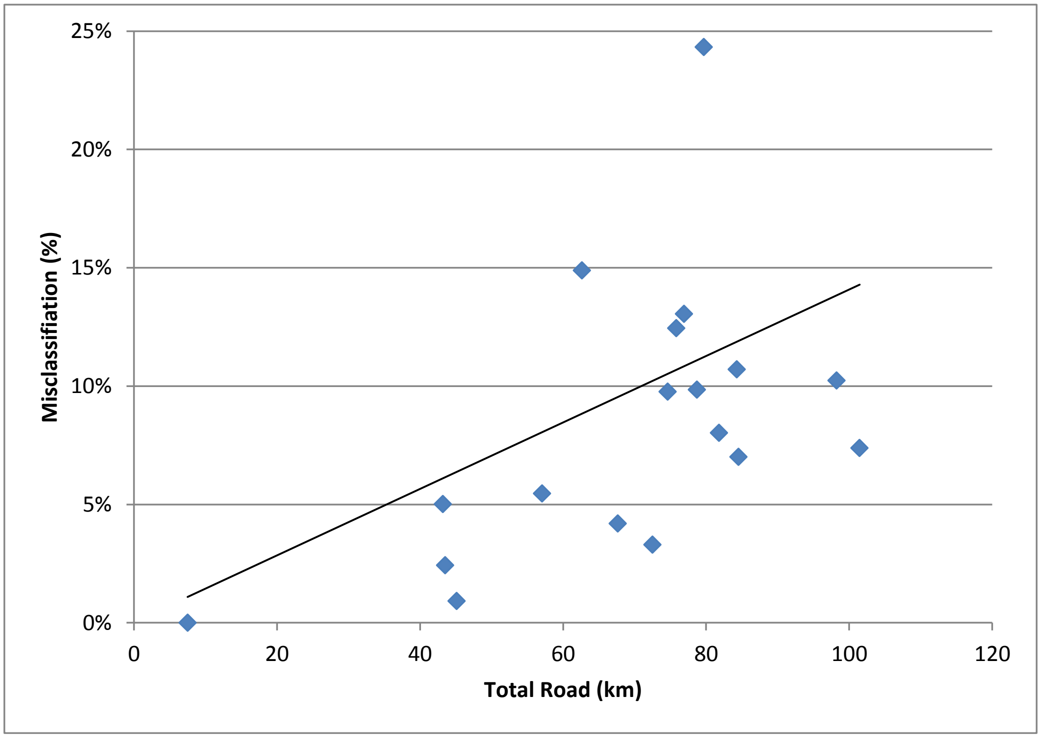

Figure 6 Misclassification error as a function of total road length

HARVEST OPPORTUNITY

The definition of harvest opportunity was modified to better reflect current timber supply modeling and operational practice in the Central and North Interior. The threshold volume for a merchantable opportunity was increased from 100 m^3/ha to 140 m^3/ha in lodgepole pine leading stands, and 182 m^3/ha in all other stands, to align with the utilization thresholds currently used in the Prince George TSR.

Other changes included increasing the minimum area from 10 ha to 20 ha, and grouping polygons less than 20 ha that were separated by a distance of less than 50 meters. In the original algorithm, polygons were grouped only if they were contiguous. It also classified all roads within 400 m of an opportunity as NOE, which frequently resulted in multiple roads accessing a single opportunity. This was resolved in the modified algorithm using a path analysis which selected the single road that provided the most efficient route to the core road network.

The algorithm was not capable of identifying obvious leave areas associated with gullies or riparian features which resulted in over classification of NOE roads to provide access. Figure 7 shows an example of an obvious, isolated riparian leave area. The narrow shape and presence of a low order stream is an indicator of a leave area with no future harvesting opportunity.

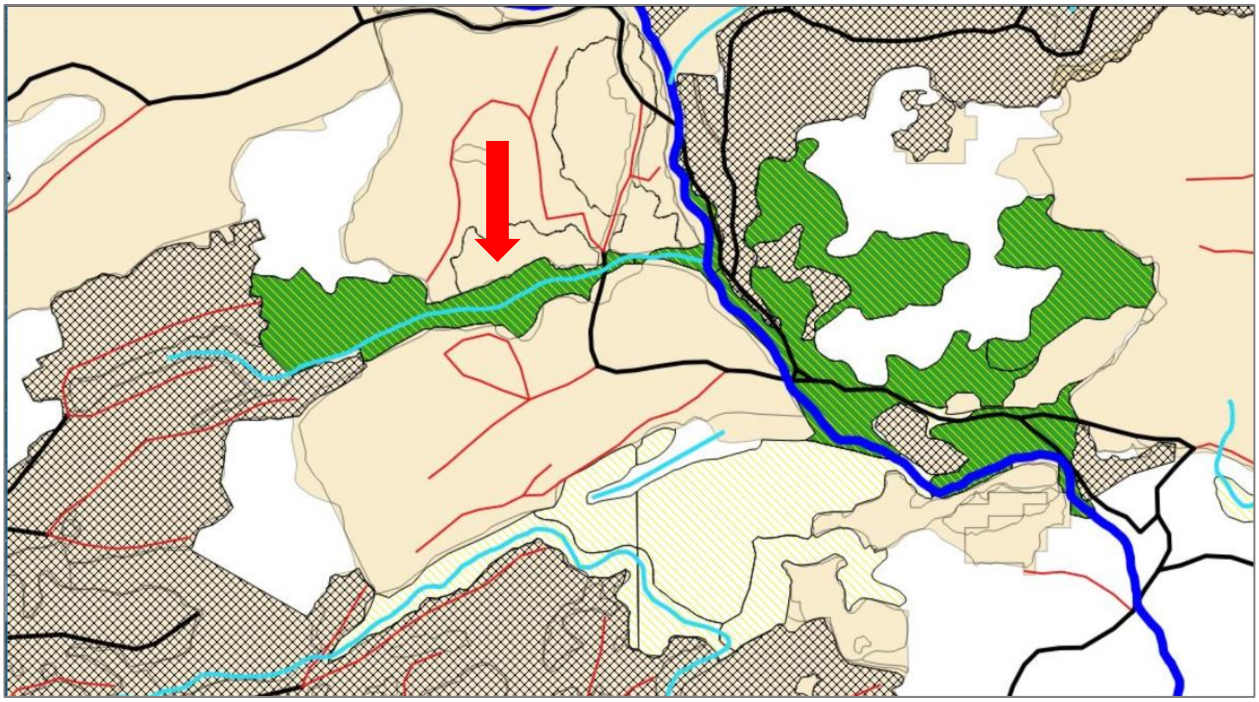

Figure 7 Example of an isolated riparian leave area classified as a harvest opportunity. The elongated shape with the presence of a low order stream is an indicator of a leave area with no future harvesting opportunity

Overall, reclassification of roads providing access to a harvesting opportunity on the validation tiles and at Francois Lake accounted for 8% of misclassification error (Table 2). In many cases, misclassification resulted from the algorithm selecting a road that upon review was determined to be unsuitable operationally.

CUTBLOCK FREE GROWING STATUS

Cutblock free growing status was not considered in the earlier version of the algorithm. Accurately determining road access for NFG cutblocks was a complex programming challenge that could not be fully addressed with the resources available in this project. In the interim, the best approximation was to classify all internal roads in NFG blocks longer than 800 meters as NOE. This approach led to over classification of NOE roads where there were multiple roads greater than 800 meters (

Figure 8), and where 800 meter walking access could be provided from alternative locations other than internal cutblock roads.

The biggest single cause of misclassification was internal roads in NFG cutblocks. The proportion of misclassification attributable to NFG roads was 71% or greater on 8 of the 19 validation tiles (Table 2). Misclassification was lowest using the criteria that all internal roads longer than 800 m were classified as NOE. This resulted in misclassification of 139 km of road in 219 road segments (Table 3). The other two methods had greater road length, and therefore a greater number of misclassified road segments.

Table 3 Cutblock free growing status misclassification

Method	Road Segments to Reclassify	Length of Reclassified Segments (km)	Change Length to Reclassify (km)
1	219	138.7	N/A
2	317	196.8	+ 58.1
3	257	148.5	+ 9.8

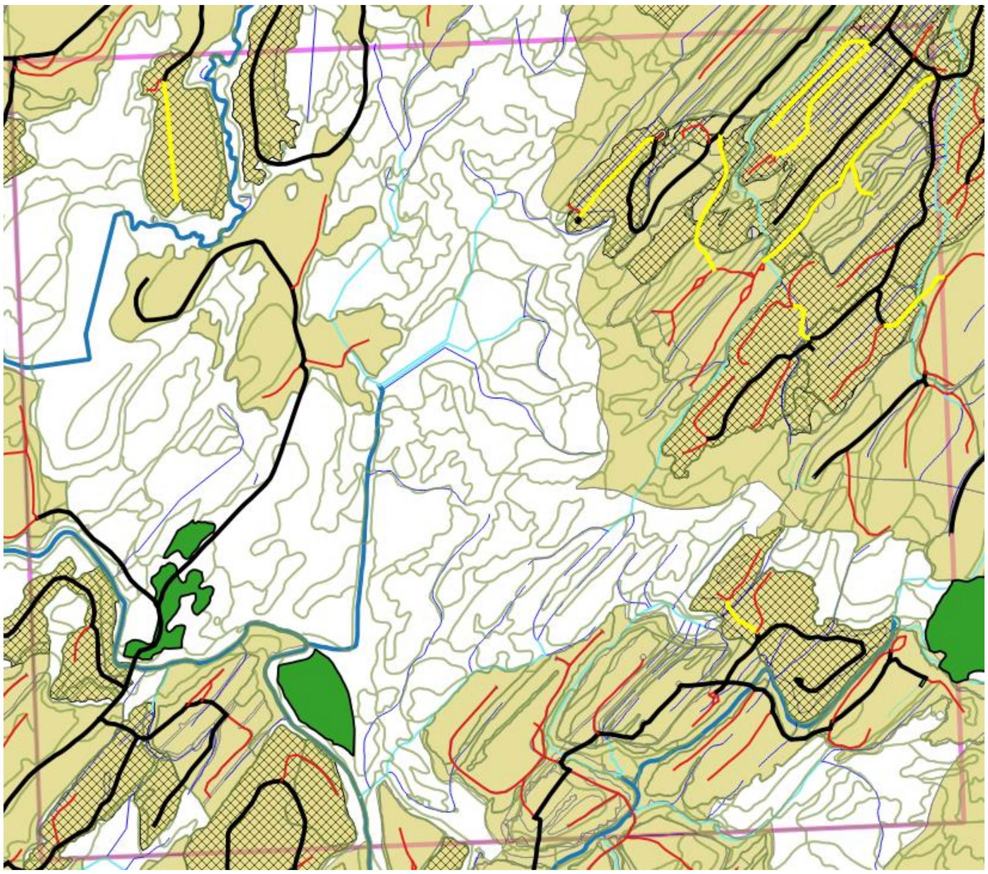

Figure 8 Example map tile with multiple redundant NOE roads (yellow) in NFG cutblocks (tan polygons with hatching). Classified roads shown as ROP (red) and NOE (black).

Discussion

The algorithm was developed to classify roads in low relief terrain where slope gradients are less than 40% and the dominant harvesting system is skidding to roadside work areas. Road layout in steep terrain, where harvesting systems commonly include cable yarding or purpose built skid trails with skidding to a central landing, was not evaluated in this project. The following discussion assumes that the algorithm is applied to a land base with the low relief terrain commonly found in the BC Interior.

An overall classification accuracy of 89.6% was considered acceptable as a starting point for road rehabilitation planning projects, large scale cumulative effects analysis, and access management planning. However, accuracy on individual map tiles ranged as low as 65%. Analysis of the 19 randomly selected validation tiles identified three factors accounting for 88% of misclassification error: multiple unneeded roads in NFG cutblocks (58%), NOE roads that were not needed for access (16%), and incorrect classification of roads accessing harvest opportunities (13%). Similar results were obtained from the Francois Lake area. These problems can be resolved through modifications to the current algorithm that were beyond the scope of this project.

Some residual error was anticipated due to the fact that the IRDB is not a networked dataset and represents roads as short, sometimes duplicated, segments. This fundamental limitation was approached using two methods: 1) merging short and duplicated segments to longer segments that extended between road junctions, and 2) defining a core network of NOE roads using named roads such as FSR's and active FTEN roads longer than 5 km. This type of modification by GeoBC that considers how roads are represented in the IRDB would facilitate more accurate analyses of roads for reforestation opportunities and would achieve other objectives such as access management and cumulative impacts analyses. Without the initial step of merging road segments, results of these types of analyses will be comprised.

The requirement of maintaining access to all NFG cutblocks, and internal access on large cutblocks to maintain safe walking distances (800 m), raises a new planning opportunity anticipating changes in free growing status in the short term (e.g. 8-12 years) depending on the ecosystem, planted species, and silvicultural treatment. A desirable modification of the current algorithm would be to create a third category of road, "Future Reforestation Opportunity", that would identify roads whose classification will change in the short term in conjunction with a change in free growing status of adjacent and nearby cutblocks.

The age of regenerating cutblocks adjacent to roads was not addressed in this algorithm; however, adjacent stand age is a significant consideration in prioritizing roads for reforestation. If the objective of road reforestation is production of a commercial crop, the delay in crop establishment on the road relative to the adjacent stand may reduce or eliminate the value of the road planted crop at time of harvest of the adjacent stand. Roads that are partially or fully occupied by non-crop vegetation will also likely require additional site preparation and follow-up treatment to establish a commercial crop. If the objective of road reforestation is establishment of carbon sinking vegetation, including shrubs or non-commercial deciduous species, this may have already been achieved on older roads. In general, partially or fully greened up roads are less suitable for crop establishment due to additional silvicultural effort, and the risk of not producing or producing a very low value crop at time of harvest for adjacent stands.

The threshold age at which roads become unsuitable for reforestation is a function of the goal of reforestation (e.g. crop production or carbon sequestration), the ecosystem, and the species planned for reforestation. These factors could be added to the algorithm as user defined inputs to be implemented on a site or region specific basis.

In operational planning, the definition of a harvest opportunity considers additional factors than were not used in the algorithm, such as distance to mill, species type and volume, and the exact location within an operating area. Additional cost factors can be defined on a case specific basis but cannot be included in the base algorithm if it is intended to be available for all users. For example, a marginal volume stand located close to a mill would represent a better potential opportunity than the same stand further away. For specific areas of interest, the definition of harvest opportunity can be changed by recoding that portion of the algorithm.

Recommendations

Based on the results from the modified GIS algorithm, the following is recommended to further the road rehabilitation program initiative and continue improvements to the road classification algorithm:

1. Cutblocks that are not free growing are the largest single cause of misclassification error. The current algorithm is not capable of accurately classifying internal roads within a NFG cutblock. Further work to improve the accuracy of NFG road classification will significantly improve the overall results.
2. Misclassification caused by NFG status opens a larger discussion regarding the planning implications of anticipating a change in NFG to FG status. Currently many reforestation opportunities are lost by maintaining access to NFG. These roads are not NOE and should be viewed as a future reforestation opportunity. This could be addressed with a third road classification: Future ROP. Success is dependent on licensee involvement and commitment to reforestation post-harvest.
3. The definition of harvest opportunity is a key determinant of final road classification. The current algorithm is not capable of determining whether a leave area is associated with a gully or riparian feature that is inoperable. Further work to identify these features is recommended to improve the identification of harvest opportunity. One option could include exploring internal buffers and polygon grouping definitions to better identify intentional leave areas.
4. The algorithm is optimized for use in low relief terrain (less than 40% slope) where skidding to roadside and clearcutting is the dominant harvesting system. It is anticipated that modifications will be required for use in steeper terrain, and for other harvesting systems such as cable yarding and purposely built trails with skidding to a central landing. Prior to use in these circumstances, modifications to algorithm assumptions should be investigated.
5. Adjacent stand age can be a significant factor in determining the suitability and priority of roads for reforestation efforts. Addition of a component to filter or prioritize roads on the basis of adjacent stand age is recommended. This would be a final step in the algorithm, and allows for user input to reflect local conditions.

Appendix 1 – GIS Analysis

OVERVIEW

The purpose of this project is to develop an algorithm that automates road classification based on a set of assumptions. The three resulting road classifications are Reforestation Opportunity (ROP), No Opportunity Expected (NOE), and Other (permanent non-forestry roads). To classify roads, the algorithm takes into consideration the road type based on its attributes (e.g. FSR, FTEN, and named roads), access to future opportunity, access to non-free growing areas, and its location within a cutblock.

HARVEST OPPORTUNITY

The vegetation resource inventory (VRI) was used as the primary data source for identifying future harvest opportunities. The VEG_COMP_LRY_R1_POLY dataset was downloaded from the GeoBC database for use in this analysis.

For coniferous species other than pine, net live volume per hectare (m^3/ha) was determined using percent basal area of the tree layer at the 17.5 cm dbh utilization. Net live volume per hectare for pine species (PLI and PL) were determined using percent basal area of the tree layer at the 12.5 cm dbh utilization. The volumes were then summed for all species present in the VRI (e.g. species 1 through 6). For pine-leading stands (greater than 50% pine), 140 m^3/ha was used as the volume threshold. For all other conifer-leading stands (less than 50% pine, including balsam), 182 m^3/ha was used as the volume threshold. Areas that met these threshold requirements were then considered as a harvesting opportunity. Deciduous species were not included in this definition.

Hard constraints, wetlands and cutblock areas were removed from the opportunity layer as they were assumed to not be available for harvest. Next, slivers less than 0.5 ha were deleted from the dataset. The remaining opportunity polygons were aggregating based on a 50 m separation distance, and groupings greater than or equal to 20 ha were selected as the final opportunity layer.

Roads intersecting this opportunity layer were classified as NOE based on the assumption that the road would be used to access the harvest opportunity. For opportunities that did not have intersecting roads, a cost surface raster and a cost path were applied to identify the most efficient path from each opportunity cluster to the nearest FSR, named road or active FTEN road greater than 5 km which are assumed to be the longer, continuous permanent road networks.

Table 4 Data and Assumptions to Define Harvest Opportunity

Name	Dataset	Query	Download Date
VRI Opportunity	VEG_COMP_LYR_R1_POLY		1/25/2018

CUTBLOCKS

The four datasets downloaded from GeoBC and merged into a single integrated cutblocks layer include: VRI Cutblocks, RESULTS Openings, Forest Cover Reserves, and FTEN Cutblocks (Table 5). The area occupied by this integrated cutblock layer was removed from the opportunity layer.

Active FTEN roads greater than 5 km accessing multiple cutblocks were classified as NOE. Shorter roads within cutblocks that do not access an opportunity or a non-free growing area were classified as ROP.

Table 5 Data and Assumptions to Define Integrated Cutblocks

Name	Dataset	Query	Download Date
VRI Cutblocks	VEG_CONSOLIDATED_CUT_BLOCKS		1/24/2018
RESULTS Openings	RSLT_OPENING	"DN1_DIS_CD" <> 'B' and "DN2_DIS_CD" <> 'B'	1/25/2018
Forest Cover Reserves	RSLT_FOREST_COVER_RESERVE		1/24/2018
FTEN Cutblocks	FTEN_CUT_BLOCK_POLY		1/24/2018

FREE GROWING STATUS

The RESULTS Openings dataset was used to identify areas with outstanding silviculture obligations. Non-free growing (NFG) areas requiring future access were identified in the dataset and classified as NOE. Roads completely within a NFG block that were longer than 800 m were classified as ROP.

Table 6 Data and Assumptions to Define Silviculture Obligations

Name	Dataset	Query	Download Date
RESULTS Openings (Not Free Growing)	RSLT_OPENING	"OPEN_ST_CD" <> 'FG' and "DN1_DIS_CD" <> 'B' and "DN2_DIS_CD" <> 'B'	1/24/2018

HARD CONSTRAINTS

Hard constraints are areas where roads are unable to cross, which results in a separation between potential harvesting opportunities. The areas considered hard constraints in the algorithm are listed in Table 7. Roads within private lands are not considered in this project and were classified as Other. Hard constraints were given a value of "NULL" in the cost distance/path analysis, meaning that they cannot be used for travel.

Table 7 Data and Assumptions to Define Hard Constraints

Name	Dataset	Buffer (m)	Query	Download Date
OGMA	OGMA_LEG			1/23/2018
Integrated Cadastral Fabric (Private Land)	pmbc_parcel_fabric_poly		OWNER_TYPE in ('Private', 'First Nation', 'Unknown')	1/23/2018
FTEN Recreation Polygons	FTEN_RECREATION_POLY			1/23/2018
Provincial Parks, Ecological Reserves, Protected Areas	TA_PARK_ECORES_PA			1/23/2018
National Parks	CLAB_NATIONAL_PARKS			1/23/2018
Slope greater than 40%	TRIM			
FWA Lakes	FWA_LAKES_POLY	100		1/23/2018
FWA Rivers	FWA_RIVERS_POLY	50		1/23/2018
FWA Streams (major)	FWA_STREAM_NETWORKS	50	STRMRDR >= 3	1/23/2018

SOFT CONSTRAINTS

Soft constraints are areas passable by roads with an additional cost to operations (e.g. building stream crossings). The areas considered soft constraints in the algorithm are listed in Table 8. Soft constraints were used in the cost distance and path analysis to indicate undesirable travel path. In addition, wetlands were removed from the harvest opportunity layer.

Table 8 Data and Assumptions to Define Soft Constraints

Name	Dataset	Buffer (m)	Query	Download Date
FWA Streams (minor)	FWA_STREAM_NETWORKS	50	STRMRDR = 2	1/23/2018
Wetlands	NRC_WATER_WETLAND_250K			1/24/2018

ROADS

The IRDB was accompanied by the FTEN roads dataset. The IRDB classified FSRs as NOE and named roads as Other. The additional FTEN dataset was used to identify active FTEN roads greater than 5 km and classified these as NOE.

Table 9 Road Data and Assumptions

Name	Dataset	Query	Download Date
Roads	Integrated Road Database		
FTEN Roads	FTEN_ROAD_SECTION_LINES	"LIFE_ST_CD" = 'ACTIVE'	1/24/2018

SCRIPT DESCRIPTION

SCRIPT 1: DATASET INTEGRATION

The purpose of Script 1 is to integrate the harvest opportunity, cutblock, silviculture obligations (NFG), hard constraints and soft constraints datasets described above. The input is a CSV file that indicates the individual layer location, name, type, buffer distances, and query (Figure 9). An additional data input is the 'Area of Interest' (AOI) which is used to clip the data to the specific land base which the algorithm will be performed on.

1	type	location	name	buffer	query
2	cutblock	C:\DataBC_download\VEG_CONSOLIDATED_CUT_BLOCKS_SP\CNS_CUT_BL_polygon.shp	VRI_cblk		
3	cutblock	C:\DataBC_download_20180123\RSLT_OPENING_SVW_full\RSLT_OPNGS_polygon.shp	RSLT_OPNG_cblk		"DN1_DIS_CD" <> 'B' and "DN2_DIS_CD" <> 'B'
4	cutblock	C:\DataBC_download_20180123\RSLT_FOREST_COVER_RESERVE_SVW\RSLT_FCRES_polygon.shp	RSLT_FCRES_cblk		
5	cutblock	C:\DataBC_download_20180123\FTEN_CUT_BLOCK_POLY_SVW\FTN_C_B_PL_polygon.shp	FTN_cblk		
6	opportunity	C:\DataBC_download\VEG_R1_PLY_polygon.shp	VRI_opp		
7	nfg_silv	C:\DataBC_download_20180123\RSLT_OPENING_SVW_full\RSLT_OPNGS_polygon.shp	RSLT_OPNG_NFG		"OPEN_ST_CD" <> 'FG' and "DN1_DIS_CD" <> 'B' and "DN2_DIS_CD" <> 'B'
8	hard_constraint	C:\DataBC_download_20180123\OGMA_LEG\OGMA_LEG\OGMA_LEG_C_polygon.shp	OGMA		
9	hard_constraint	C:\DataBC_download_20180123\pmbc_parcel_fabric_poly_svw.gdb\pmbc_parcel_fabric_poly_svw	private_land		OWNER_TYPE in ('Private', 'First Nation', 'Unknown')
10	hard_constraint	C:\DataBC_download_20180123\FTEN_RECREATION_POLY_SVW\FTN_REC_PL_polygon.shp	recreation		
11	hard_constraint	C:\DataBC_download_20180123\TA_PARK_ECORES_PA_SVW\TA_PEP_SVW_polygon.shp	parks_eco_res		
12	hard_constraint	C:\DataBC_download_20180123\CLAB_NATIONAL_PARKS\CLAB_NATPK_polygon.shp	national_park		
13	hard_constraint	C:\slope.gdb\slope_greater40	slope_greater_40		
14	hard_constraint	C:\DataBC_download_20180123\FWA_LAKES_POLY\FWLKSPL_polygon.shp	lake	100	
15	hard_constraint	C:\DataBC_download_20180123\Rivers\FWA_RIVERS_POLY\FWRVRSPL_polygon.shp	river	50	
16	hard_constraint	C:\DataBC_download_20180123\Rivers\FWA_STREAM_NETWORKS_SP\FWSTRMNTWR_line.shp	major_rivers	50	"STRMRDR" >= 3
17	soft_constraint	C:\DataBC_download_20180123\Rivers\FWA_STREAM_NETWORKS_SP\FWSTRMNTWR_line.shp	minor_rivers	50	"STRMRDR" = 2
18	soft_constraint	C:\DataBC_download_20180123\NRC_WATER_WETLAND_250K_SP\NRCWTRWTLN_polygon.shp	wetlands		
19	detailed_rds	C:\BC_CE_IntegratedRoads_2017_v1_20170214_no_TRIM.gdb\integrated_roads_no_TRIM	rds		
20	rds_ften	C:\DataBC_download_20180123\FTEN_ROAD_SECTION_LINES_SVW_fullBC\FTEN_RS_LN_line.shp	rds_ften		"LIFE_ST_CD" = 'ACTIVE'

Figure 9 CSV Input File for Script 1

First, all layers are queried or buffered as described above, then clipped to the AOI. Next, the layers with the same 'type' are integrated into a single output data layer. Types include cutblocks, opportunities, NFG, hard constraints, and soft constraints. It is important that the 'type' in the CSV matches the 'type' in the script. The list of outputs layers generated by Script 1 are shown in Figure 10. The "integrated_9hard_cost" layers means that 9 individual layers where 'type' was equal to 'hard_constraint' were used in the development of that integrated hard constraint layer.

Figure 10 Output Layers Generated by Script 1

SCRIPT 2: DEFINING OPPORTUNITY

The purpose of Script 2 is for further processing of the opportunity layers based on the conifer species content (species and percent) and volume (net live). Cutblocks, hard constraints and wetlands are removed from the opportunities. The remaining opportunity polygons are then grouped based on a 50 m separation distance. The grouped polygons greater than or equal to 20 ha are selected as the final opportunity layer.

Input data for this script includes wetlands and the VRI Opportunity (VRI_opp_clip), integrated cutblocks and hard constraints layers all created in Script 1. The resulting output layer is a processed opportunities layer (opp_20ha_50m) (Figure 11).

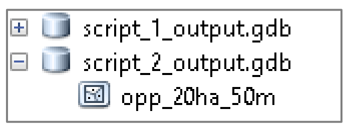

Figure 11 Output Layers Generated by Script 2

SCRIPT 3: ROAD CLASSIFICATION

The purpose of Script 3 is to produce a classified road dataset based on the data and assumptions used in development of Script 1 and 2. The following is the process within Script 3.

STEP 1 –CLASSIFICATION BASED ON ATTRIBUTES

- The road network is integrated using a 15 m tolerance distance. This is done to ensure that split and duplicated road segments become coincident. This was accomplished using the Integrate tool in ArcGIS.
- Roads are classified based on the attribute table:
    - FSR roads are classified as NOE
    - Named roads are classified as Other
    - Active FTEN roads greater than 5 km are classified as NOE. These include longer roads that access multiple cutblocks.

- All road segments are then dissolved into a single polyline network (preserving the classifications above) and re-fragmented at road intersections or junctions. This was completed using the Feature to Line tool in ArcGIS.

STEP 2 – HARVEST OPPORTUNITY

Roads are classified based on their relationship to opportunity using the cost distance and cost path Spatial Analyst tools in ArcGIS. These roads are classified as NOE and are assumed to provide future access to harvest opportunities. Inputs for this script are the layers generated by Script 1 and the opportunity layer generated by Script 2.

- Opportunity layer generated by Script 2 is buffered by 500 m and assigned a cost of 100.
- Roads are buffered by 25 m and assigned a cost of 1.
- Soft constraints are assigned a cost of 1,000.
- Hard constraint are assigned a cost of NULL (not allowed to travel on).
- These four layers are combined and converted into a raster using their cost value. The raster is then converted into a cost distance surface using NOE and Other roads from Step 1 as the input. These are the longer and more continuous permanent road networks.
- Next, the Cost Path tool is applied. This tool finds the path of least resistance, where traveling on the roads is a cost of 1 and is 100 times more preferred than traveling on the ground where the cost is 100. The input for the Cost Path tool is the grouped opportunity layer produced in Script 2. The goal of this tool is to find the most efficient path (preferably traveling on roads) from a grouped opportunity cluster to a continuous NOE road network.
- The resulting path is converted into a vector polyline and buffered by 70 m. Roads within this buffer are classified as NOE and assigned the rationale “access to opportunity”.
- Roads that intersect an opportunity are additionally classified as NOE and assigned the rationale “intersect opportunity”.

STEP 3 – FREE GROWING STATUS

Next, roads are classified based on their relationship to NFG blocks.

- Roads that intersect NFG within 10 m are classified as NOE.
- “Dead-end roads” that are completely within the NFG 20 m buffer and are less than 800 m are classified as NOE.

STEP 4 - FRAGMENTATION

The classification in Steps 2 and 3 creates a fragmented NOE and ROP network. To fix this fragmentation, another cost surface raster is applied.

- The entire road network is buffered by 25 m, assigned a cost of 1 and converted to a raster using the cost value.
- This raster is converted to a cost surface using NOE and Other roads from Step 1 as the input.

- Next, the Cost Path tool is applied with the fragmented NOE roads generated in Step 2 and 3 as the input. This allows the NOE fragments to connect back to the more continuous NOE and Other networks.

STEP 5 – FINAL CLASSIFICATION

Finally, the classification and rationale described in Steps 1 through 4 are summarized into the "type_all" and "ration_all" fields, respectively. These two fields are to be used for final road mapping and visualization. The final output is a classified roads layer (Figure 12). Table 10 provides a detailed explanation of the attribute fields utilized in this analysis.

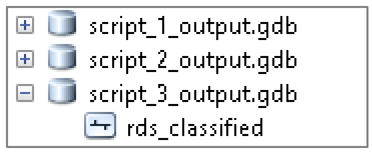

Figure 12 Final Classified Road Layer Generated by Script 3

Table 10 Data Dictionary for the Resultant Classified Roads Layer (rds_classified)

Field Name	Comments
type	Road type based on the original attribute table of the Integrated Roads Dataset. The type is either "other" or "NOE".
rationale	Provides the rationale for the above "type" field and is populated with either "named road" or "FSR".
type_FTEN	Active FTEN roads >5km are buffered and intersected with the roads layer. Any road that falls within the buffer is labeled with "FTEN"
type_LHF	This field summarizes "type and "type FTEN" categories. "FSR" and "other" roads take priority over the FTEN classification.
ration_LHF	This field provides the rationale for the above classification, includes "FSR", "named road" and "FTEN_greater_5km".
type_NFG	Roads that are classified during the NFG process are identified in this field. "ROP" category indicates that the road is a "dead-end" road that's within NFG and less than 800m in length. "NOE" category indicates that the road is longer than 800m, not dead-end roads, or that the road is not completely within the NFG block.
length_m	Length of the road segment in meters.
type_hard_const	Roads within Private Land are classified as "other" and identified in this field.
type_opp	Roads within harvest opportunities or roads that provide the most efficient access to the grouped opportunity area are identified in this field as "NOE".
ration_opp	Opportunity rationale includes "intersect opp", meaning that the road directly intersects an opportunity, and "cost distance" meaning that this is the most efficient access to the grouped opportunity as defined by the cost distance and cost path analysis.
cost	Cost value used in the fragmentation cost distance and cost path analysis. This is populated with 1.
type_frag	Roads fragments that are identified in the previous steps as "NOE", but do not connect to the main road network become connected through a cost surface and cost path analysis. The roads that are used to connect fragmented "NOE" to the main network are identified in this field as "NOE".
ration_frag	Rationale for fragmentation is populated with "frag".
type_all	This is the summarized classification category that should be used for viewing the layer. The final types include "NOE", "ROP", and "other".
ration_all	This field provides the summarized rationale used in the final road classification. The categories include "named road", "FSR", "FTEN greater 5km", "hard const", "opp access", "NFG access" and "fragmentation".

Appendix 2 – Sensitivity Analysis of Harvest Opportunity Criteria

METHODS

Sensitivity analysis was completed on 21 randomly selected map tiles in the Stuart Nechako, Nadina, Quesnel, and Prince George Resource Districts. All map tiles in each District were categorized by the percentage of available timber already harvested. Twelve map tiles in the Stuart Nechako and three map tiles in other Districts were randomly selected from each of the following classes of percent area harvested: 10-30%, 30-50%, and 50-90%. Map tiles clipped by District boundaries were excluded by restricting selection to tiles greater than 14,000 ha.

A matrix of 18 combinations of 3 parameters defining harvest opportunity was analyzed to determine the effect of each parameter. Multiple regression and graphical analysis was used to determine parameter leverage. The following parameter levels were modeled:

- Volume (m^3): 100, 150
- Minimum Opportunity Area (ha.): 10, 20, 40
- Separation of Polygons (m): 50, 100, 150

For comparison among scenarios, a base case was defined with a minimum volume of 150 m^3, a maximum polygon separation of 50 m, and a minimum area of 20 ha. This was based on the merchantable volume criteria in the Prince George TSR (140 m^3 for lodgepole pine and 182 m^3 for other conifer species), and a 50 m separation distance that would exclude individual polygons on opposite sides of riparian or gully features that were potential obstacles.

RESULTS AND DISCUSSION

The trend of median opportunity area shown in Figure 13 conformed to expectations: opportunity area was lower with a higher volume threshold, increased slightly with increased separation distance, and decreased slightly with an increase in the minimum area for grouped polygons.

In comparison with the base case, there were small differences in median values for each scenario (Table 121). For volume of 150 m3, and a maximum separation of 50 meters, the difference in the minimum area of grouped polygons ranged from -8.9% for 10 hectares, and +4.5% for 40 hectares.

Multiple regression analysis showed that the volume threshold and the percentage of opportunity previously harvested in the map tile were statistically significant, but separation width and minimum area were not (Table 12). The linear trend was weak, with an R^2 of 0.16. A boxplot of all 18 parameter categories showed highly skewed distributions and a small difference in medians within each volume category (Figure 14).

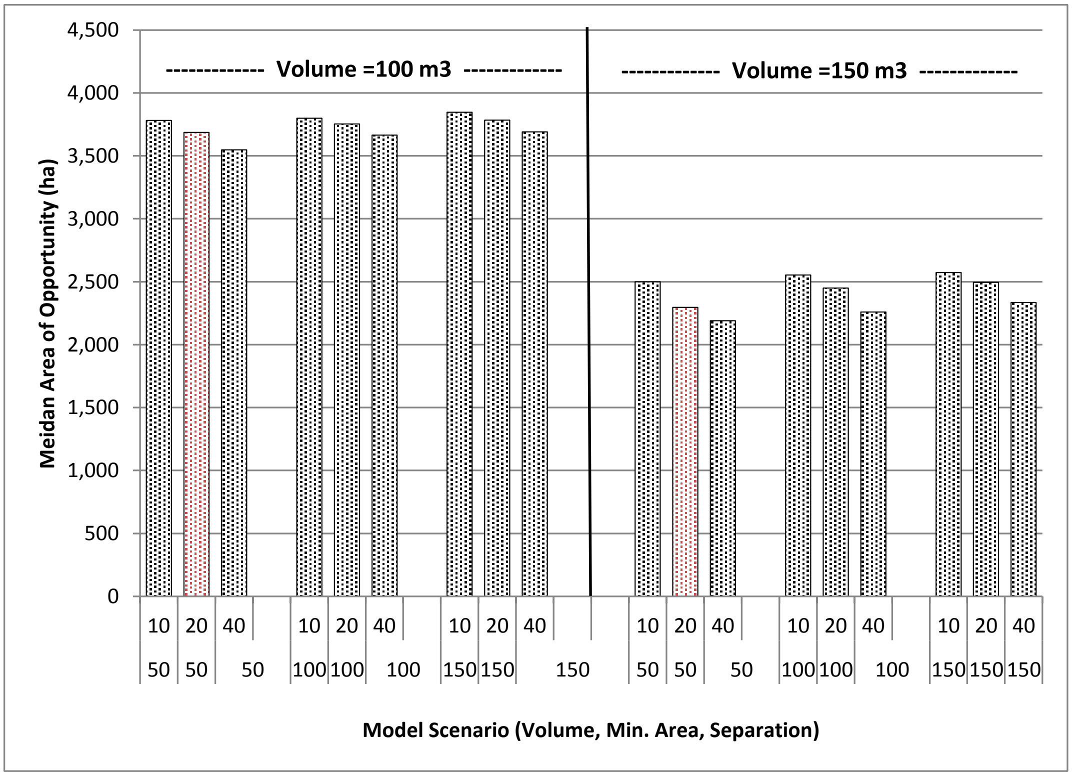

Figure 13 Comparison of median opportunity area by map tile for each of 18 modeled scenarios.

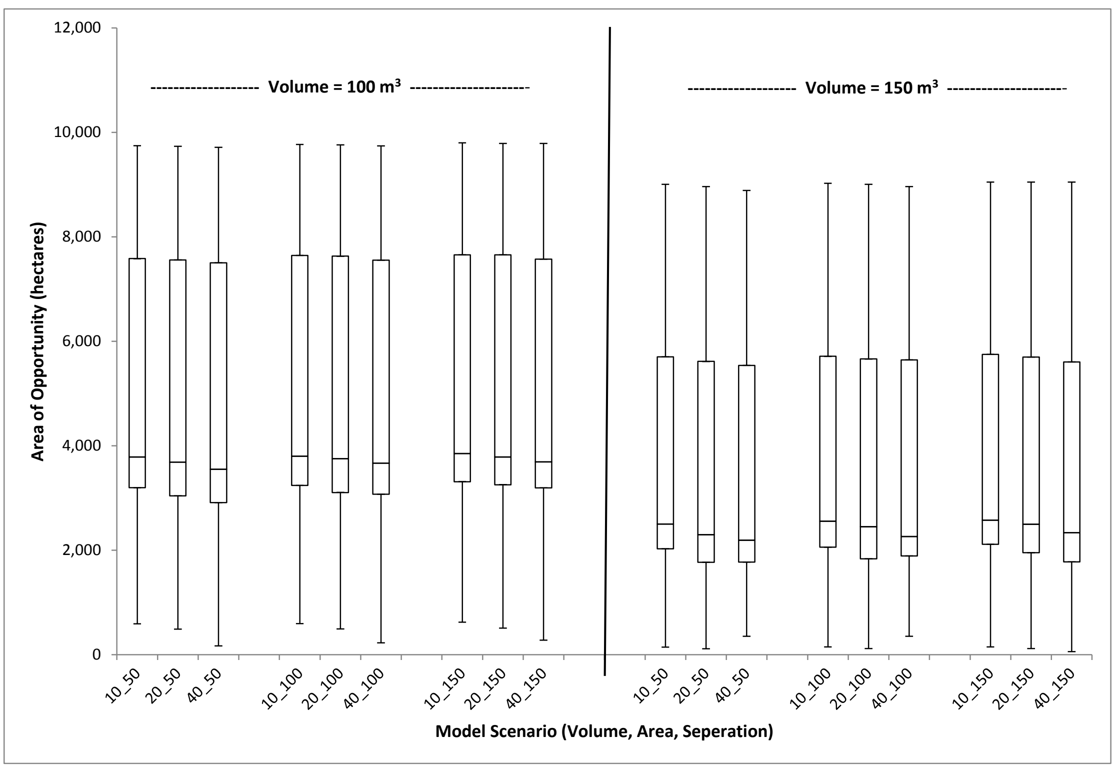

Figure 14 Boxplot of opportunity area by map tile for each of 18 modeled scenarios.

Table 11 Comparison of median opportunity on 21 map tiles from 18 modeled scenarios

		Volume = 100m^3			Volume = 150m^3		
Separation (m)	**Minimum Area (ha)**	**Opportunity Area (ha)**	**Difference from Base Case (ha)**	**Difference from Base Case (%)**	**Opportunity Area (ha)**	**Difference from Base Case (ha)**	**Difference from Base Case (%)**
50	10	3,782	-95	-2.6%	2,500	-205	-8.9%
50	**20**	**3,687**	**-0**	**-0.0%**	**2,296**	**-0**	**-0.0%**
50	40	3,549	+137	+3.7%	2,192	+104	+4.5%
100	10	3,800	-114	-3.1%	2,555	-259	-11.3%
100	20	3,754	-67	-1.8%	2,450	-154	-6.7%
100	40	3,665	+22	+0.6%	2,261	+35	+1.5%
150	10	3,848	-162	-4.4%	2,573	-277	-12.1%
150	20	3,784	-98	-2.7%	2,497	-201	-8.8%
150	40	3,691	-5	-0.1%	2,336	-41	-1.8%

Table 12 Regression of Harvest Opportunity Area by Map Tile vs. Percentage of Map Tile Harvested, Volume, Separation, and Minimum Area

Regression Statistics	
Multiple R	0.413529
R Square	0.171006
Adjusted R Squ	0.1576
Standard Error	2510.161
Observations	378

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	4.82E+08	80368773	12.75511	4.19251E-13
Residual	371	2.34E+09	6300909		
Total	377	2.82E+09			

	Coefficients	***Standard Error***	***t Stat***	***P-value***
Intercept	6703.236	414.5557	16.16969	6.83E-45
Harvested %	-45.2086	6.762255	-6.68543	8.48E-11
Volume	-1444.18	258.2175	-5.5929	4.34E-08
Separation 1	121.1716	316.2506	0.383151	0.701827
Separation 2	71.3001	316.2506	0.225454	0.82175
Area1	83.5625	316.2506	0.264229	0.79175
Area2	-117.235	316.2506	-0.3707	0.71107