EFFECTS OF ROAD CONSTRUCTION COST IN DETERMINING WHETHER A BLOCK SHOULD BE HARVESTED IN THE SUMMER OR WINTER ON THE ROMEO MALETTE FOREST

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ABSTRACT

Svec, C. 2022. Effects of road construction cost in determining whether a block should be harvested in the summer or winter on the Romeo Malette Forest. Pp. 38

Keywords: bearing capacity, cost comparison, road construction, scenario, summer road, transportation, volume, winter road

Permanent and temporary forest roads are key infrastructures for the removal of raw forest products. Ensuring an efficient road network is laid out and proper construction methods are chosen will aid in reducing the total cost. Winter roads tend to be found on lower elevated blocks where there tends to be lower volumes. Summer roads are constructed on higher terrain or higher volume blocks. Green First and Debastos and Sons provided data and maps to undergo a cost comparison on three blocks. Three scenarios were used to determine the most optimal road network that will ensure the transportation costs will be economical. Summer roads were determined to be the more suitable construction method for blocks 417 and 449. Gravel aids in increasing the bearing capacity of the roads but can become costly if the haul is too far. Block 532 is located in lower terrain where a winter road network was recommended as the block contains low volume. We concluded that lower elevated blocks with summer road networks would cost too much. The low volume and wetlands increase the costs significantly as the construction process will require more work. This study determines an optimal road network for each block and provides cost comparison of each scenario.

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1. INTRODUCTION

This project examines different harvesting blocks in the 2019-2029 management plan on the Romeo Malette Forest (RMF) to see how the cost of road construction can affect the season of harvest. The Romeo Malette Forest is located in northeastern Ontario (Figure 1) and covers over 500,000 hectares of productive forest area (Woods et al. 2011). This report covers the planning and layout of road networks and the cost for constructing roads based on the road type. Determining the road type that provides the lowest cost per cubic meter is conducted. Analyzing the results will aid in the planning process of these blocks and will give the company and contractor a better perspective on costs and potential areas that require more attention.

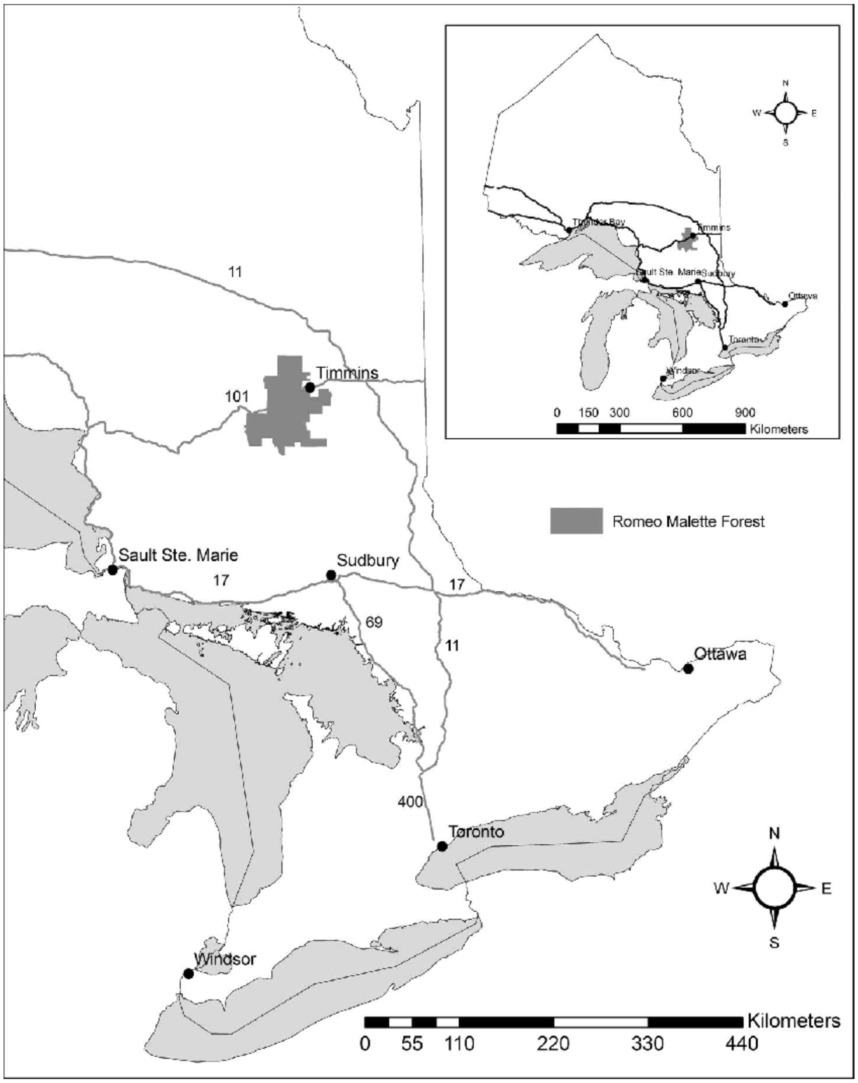

Figure 1. Map showing location of Romeo Malette Forest in Ontario

Being a part of the Debastos & Sons team for the past 10 summers has allowed me to gain experience and knowledge in the field. This team is one of the only contractors harvesting under Green First's license (Green First, 2022). Debastos & Sons harvests on average 400,000 m^3/year on the RMF and other forests surrounding Timmins. The company employs over 50 people from Timmins and surrounding communities and has over 20 contractors including mechanics, operators, drivers and others. The company is a stump-to-dump contractor where they do everything from planning and layout to harvesting and transporting logs to their desired mills.

1.1 Hypothesis

If a low elevated wetland area is harvested in the summertime, then it will increase the road construction cost. If a high elevated area is harvested in the summer, then road construction will cost less. A harvesting operation can become costly very quickly if the planning is not done correctly.

1.2 Objectives

The focus of this study was to examine future productive blocks and determine whether they should be harvested in the summer or winter months. This was determined by calculating the cost per cubic meter in three different road type scenarios. It is important to analyze different images and layers of the areas to determine the best road network for the different terrain types. A cost comparison was done on summer and winter roads on all blocks. Based on the cost per cubic meter, the most ideal road network for each block was determined. The results were compared and discussed to explain the reasoning for selecting a specific scenario for each block.

2. LITERATURE REVIEW

2.1 Planning

A forest/logging road can be defined as a method to provide entry to different areas for the numerous forestry-related practices and forest values (Pulkki, 2003). These primary, secondary, and tertiary roads are a necessity to the forest industry and provide access for other industries, essential, and recreational activities. These roads can be costly to construct if they are not laid out and planned properly. Some of the first steps of planning a harvest on a block are examining aerial images and locating the control points and potential issues that could occur (Pulkki, 2003). Points are then uploaded into the mapping system to be used as reference points while cruising. While laying out the road using ribbons, key features should be noted (Pulkki, 2003). Tree species can be used as key indicators to determine the soil type underneath the organic layer (Pulkki, 2003). Trembling aspen (*Populus tremuloides)* and white birch (*Betula papyrifera)* mixed in with pines are indicators of a well-drained site with potential gravel. This is important as it will decrease the distance for gravel procurement.

2.1.1 Aerial Imagery

A study was conducted to determine how precise aerial imagery measurements are on road lengths. The study was done on 6 different districts in West Virginia, and it analyzed how quantitative data on primary, secondary, and tertiary roads can be gathered from aerial images (Rowe et al, 1999). Logging roads used to be measured using steel tape and a staff compass (Kochenderfer, 1977). This study determined that using aerial images to measure distances can have an error from eight to fourteen percent depending on the clarity of the images captured (Rowe et al, 1999). This study was conducted over 20 years ago, meaning the development of using aerial images has come a long way, where we are now capable of identifying more than just measurements.

An unmanned aerial vehicle (UAV) is becoming an efficient tool in the forestry industry. Kameyama and Sugiura (2020) examined the accuracy of determining tree heights and stand volumes from images captured from their Phantom3 Advanced UAV. The drone could capture images at high and low speeds, as well as create 3-dimensional images (Kameyama and Sugiura, 2020). The results that were analyzed were not as accurate as they hoped for. The area that they used was a flat slope where there were images captured under 80 different forest conditions while also using different photography methods and weather conditions (Kameyama and Sugiura, 2020). The UAV Stand Inventory Manual states that there is still not enough knowledge to be able to analyze and interpret these images (MAFF, 2018). Drones are still in the beginner stages with the involvement in the forestry industry, but satellite imagery and aerial imagery are important. These two types of images are used when planning the layout of blocks and for many other forestry-related tasks.

Identifying key features from remote images such as roads have been analyzed for several decades, but recently LiDAR has provided some new approaches (White et al. 2010). LiDAR can create digital elevation models (DEM) which would produce an image where the different elevations are visible. These images are normally single band grayscale, where different shades of grey will represent the different elevations (White et al. 2010). While examining DEMs, the ability to view and locate different road networks was much better compared to other methods (White et al. 2010). The hill shade shapefile is one of the main methods of laying out roads using technology, while other layers such as LiDAR should be viewed to identify any potential issues. The accuracy of these DEMs is based on the different pixel resolutions, where a 2-meter pixel resolution will be more accurate than a 10-meter one.

2.1.2 Road layout

Optimizing a road network requires the road to be within the harvesting zone, away from rivers and buffers, caution towards erosion risks, and centering the road network on flat terrain (Safiah and Rodziah, 2010). Locating roads is important to ensure minimum problems as it provides an opportunity to see what the stands and terrain are like. Walking the potential road location to get an ideal view of the terrain, vegetation, and potential hazards are recommended (Pulkki, 2003). While locating roads it is important to identify indicative species such as birch and pine which indicate the availability of potential gravel (Pulkki, 2003). Ensuring there is material to construct a road with is important as it will aid to reduce costs. If material had to be hauled from another location, then that road cost will increase. Finally ribbon the final road network that will be most reliable and efficient and in case of doubts or uncertainties the supervisor should be consulted (Pulkki, 2003).

One of the main problems that could occur while planning access to a productive forested area is to ensure the spacing of the roads is providing efficient management (Yeap and Sessions, 1988). There are numerous objectives that must be considered when ensuring the spacing of the road network is appropriate for the area. When accessing a block with a primary road, the objective is to minimize the skidding distance and haul distances as well as keeping road construction costs down (Yeap and Sessions, 1988). The objective of primary roads on the Romeo Malette Forest is to maximize the speed of the log haul and tertiary roads are planned to minimize skidding distances. If skidding distances are too far, additional roads can be used, but the type of road construction will depend on the volume being brought to the roadside. This is an important task for the landowner or contractor trying to maximize their return from the resources on the land (Yeap and Sessions, 1988). Depending on where the harvesting area is located, the road construction type and material used will determine if the road will require the sub-grade to have a top layer of gravel.

2.2 Road Construction Techniques and Management

A cost comparison was done on non-frozen and frozen forest road construction where the road construction techniques used were like the ones in this report (Tevfik et al. 2021). Both summer and winter blocks aimed for 300 m skidding distances for treelength operations (Tevfik et al. 2021). The frozen forest road networks are normally the shortest and were found in the lower elevated areas (Tevfik et al. 2021). Higher elevated roads were regularly summer roads, where wetlands and stream crossings were avoided (Tevfik et al. 2021). These methods are used in regular operations schedules, where higher elevated blocks are harvested in summer and lower elevated in winter. During the winter season, there is more wood being hauled compared to summer (Pulkki, 2003). This is not the case for the Romeo Malette Forest as the haul is fairly even during summer and winter. Depending on the material being used, machinery access and the operational boundary will determine the most efficient construction methods and location (Pulkki, 2003).

2.2.1 Summer Road Construction

Excavators and bulldozers are the primary equipment used to build roads in elevated sandier areas (Pulkki, 2003). Excavators can be used for the construction of a brush matt in wetlands, grubbing, culvert installation, ditching where these tasks are more difficult with a bulldozer (Pulkki, 2003). When crossing wet areas, trees harvested from the road line can be used as the bottom layer of the road, this will allow the road to handle more weight (Pulkki, 2003). Bulldozers can be used in sandy grounds, where the removal of stumps and the organic layer is required (Pulkki, 2003). There is much more thinking involved in the planning and construction of summer roads, where winter roads can almost be built anywhere with cold temperatures.

The highest possibility of sediment falling into a river or stream is at the water crossings most often because the water must flow through a narrower culvert (Brown et al. 2015). Most of the sediment that falls into the water is during culvert and bridge installations and removals (Brown et al. 2015). When installing a crossing the guide supplied by the MNRF must be followed to limit disturbance to the ecosystem. The requirements of the MNRF and department of fisheries and oceans (DFO) are listed as required mitigation measurements to allow the crossing to be deemed harmless to fish (MNRF, 2021). The guide provides a list of requirements for the different types of crossings, whether a bridge or a culvert is needed. This is determined by analyzing and recording measurements of the stream or creek crossing.

2.2.2 Winter Road Construction

Wintertime is where companies make large pushes to haul as much wood as they can. With winters getting shorter due to increased temperatures, this is creating financial issues for forestry companies (Tevfik et al. 2019). Based on historical climate data, and predictions from studies, North America is expected to see warming temperatures in the upcoming years (Tevfik et al. 2019). This creates issues especially during spring break-up when winter roads begin to melt and their bearing capacity is limited. The amount of time the ground is frozen and the number of days with very low temperatures are important in this industry (Mokhirev and Petrova, 2020). The starting dates vary year to year when winter harvesting will begin as it all depends on the temperatures dropping below freezing point (Tevfik et al. 2019). When the primary roads are frozen enough to withstand the weight of a float truck, then this determines the beginning of the operation. Near the end of winter harvest, when temperatures are above zero during the day, hauling at night to stockpiles is a well-known haul method (Tevfik et al. 2019). Stockpiling wood is when trucks haul logs from the winter blocks during the night when it is below freezing point and bring them shorter distances where they can rehaul them during spring shut down (Pulkki, 2003). Stockpiling on the RMF can add an additional 10$/m^3 which could become costly, so planning the haul and maintaining mill inventory is critical to reduce costs. Climate change is predicted to increase logging costs by 11 percent and an additional 0.4 percent when stockpiling by the year 2080 (Tevfik et al. 2019).

Clay is a commonly used material to build winter logging roads on the RMF since it is located on the clay belt. The strength of frozen clay can withstand the weight of log trucks hauling when temperatures remain below freezing (Partington and Gillies, 2016). In areas where soil moisture levels are high, which is normally found in wetlands, winter roads are required (Partington and Gillies, 2016). Frozen soil and clay are normally stronger due to their particles freezing together than unfrozen terrain or ice (Czurda and Hohmann, 1997). Frozen roads can be stronger, but they rely on cold temperatures meaning the sun and warm temperatures can cause issues (Czurda and Hohmann, 1997).

2.3 Road Construction Costs

When calculating winter road cost, the construction of the road itself is the only expense, but for calculating summer roads, culvert installations, reactivation of old roads, and more time for constructing are all additional expenses (Tevfik et al. 2021). Operations during summer months on non-frozen roads are normally higher in cost because of the different elevations and crossings. (Tevfik et al. 2021). Four different blocks were looked at in northern Alberta, and it was determined that in the summer, higher elevated blocks cost more (Tevfik et al. 2021). These areas were more costly due to the removal of stumps, removal of organic layer to get road material, compacting and restoration, and water crossings (Tevfik et al. 2021)

Temperature records from previous years should be examined to estimate a time that hauling can begin in the winter, thus allowing a more accurate start day to begin road construction (Mokhirev and Petrova, 2020). Doing this creates an opportunity to increase the efficiency of logging and decrease costs of both construction and labor (Mokhirev and Petrova, 2020). The same study developed a methodology that creates a schedule to harvest and transport logs, improves the quality of roads, and decreases any additional expenses overall. This only applies during the winter harvest only, as the start day could be difficult to determine based on the weather.

2.4 Stand Volumes

A study on the RMF was done examining the data collected from aerial images on the volume of different areas. Foresters were sent out to collect field data to compare the results (Woods et al. 2011). The cost of gathering LiDAR images has decreased over the past decade and the value of the images is increasing as we are analyzing them in greater depths (Woods et al. 2011). Using aerial images allows foresters to look at the type of wood and determine its value before entering the block. Woods (2011) determined that diameters, stand volume, and other measurements gathered from aerial images can be as accurate as field data on 400 m^3 areas. Completing these small plots provides an understanding of different parts of the area and allows different stands and costs to be determined.

Roads are required to access standing timber their construction and maintenance makes up almost 40% of the total cost (Mazo and Valeria, 2021). This is not the case for the Romeo Malette Forest as the roads make up about 15% of the total cost. From the data examined the road construction costs and the distance log trucks must travel to mills were one of the highest costs determined by Mazo and Valeria (2021). The total distance of roads required depends on the volume of the block and the location of the timber patches (Mazo and Valeria, 2021). The efficiency of the entire operation can be affected by the road construction where it directly affects the total cost (Mazo and Valeria, 2021). If the road network is not efficient, then operational costs and construction costs can increase. If the road network is designed where skidding distances exceed 300 meters, then the skidding productivity will be lower. Large harvest areas demonstrate positive effects on overall costs (Mazo and Valeria, 2021). The larger the volume is in the stand, then the lower overall costs would be because total costs are based on the volume being harvested. A main objective of forestry roads on the RMF is to ensure log trucks can travel at efficient speeds to decrease the transportation cost.

3. MATERIALS AND METHODS

Maps and shapefiles were received from Green First on blocks 417, 449, and 532 which are all located on the Romeo Mallette Forest (Figure 2). Hill shade layers, both two- and five-meter resolution, were supplied. LiDAR images are analyzed to predict the density of stands which helps estimate the volume of wood at roadside. All these shapefiles were imported into ArcMap where they can be edited and interpreted. Maps outlining the harvesting zones and stand types were used as well. Analyzing these different tools makes planning and laying out these blocks more efficient. An excel file containing the stand volumes was used to compare costs on three different scenarios to determine the best road network for each block.

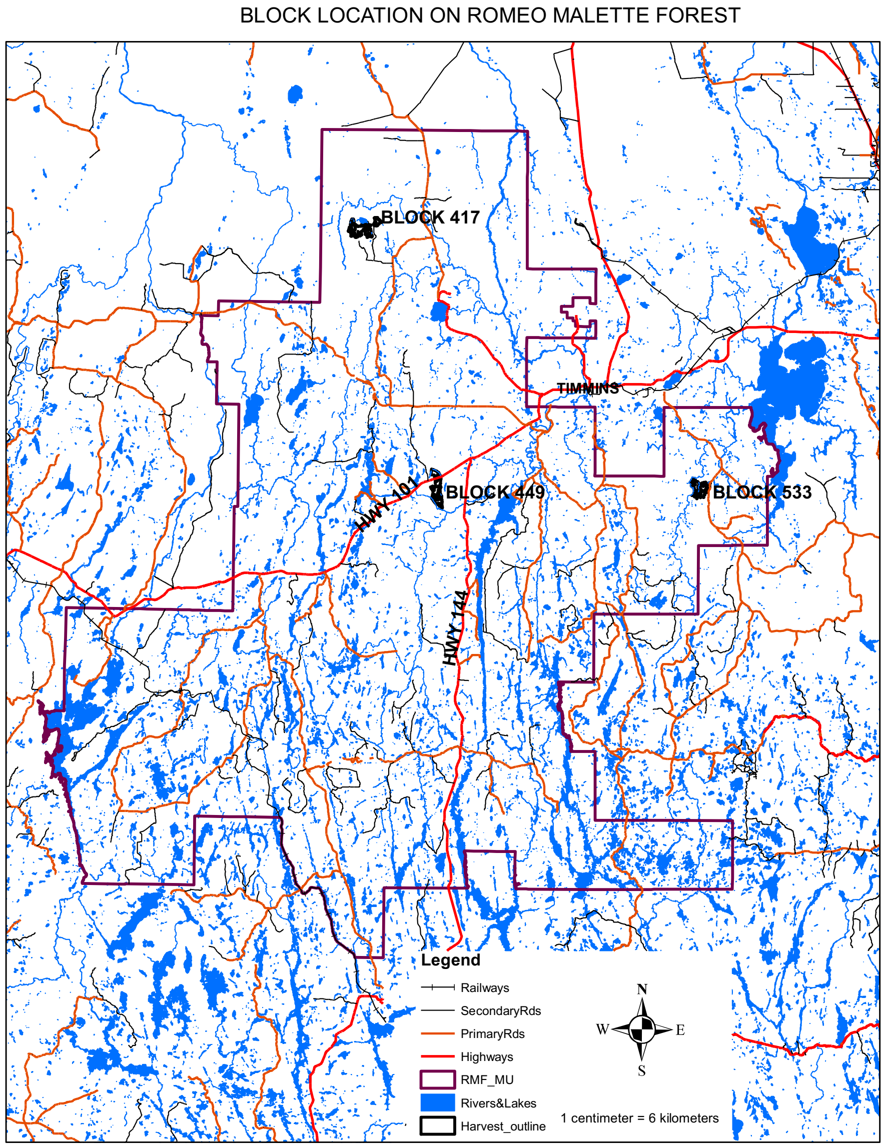

Figure 2. Block location map showing blocks 417, 449, and 532 on the RMF

All shapefiles and images were imported into ArcMap to compare the block location maps with the different layers. Looking at the digital elevation model (DEM) at two meters made identifying different terrain elevations easier. Before laying out the potential road network on ArcMap, analyzing the LiDAR images and comparing them to block location maps and DEM is important. This allows you to determine potential species on different elevations which can aid in identifying wetlands and swamps that may require more work. Figure 3 is showing a map of block 417 where the harvesting boundary, operational boundary, streams and buffers, the different stand types, road access points, and branch corridor are delineated**.** When examining this type of map, identification a potential gravel source would lead to lower costs.

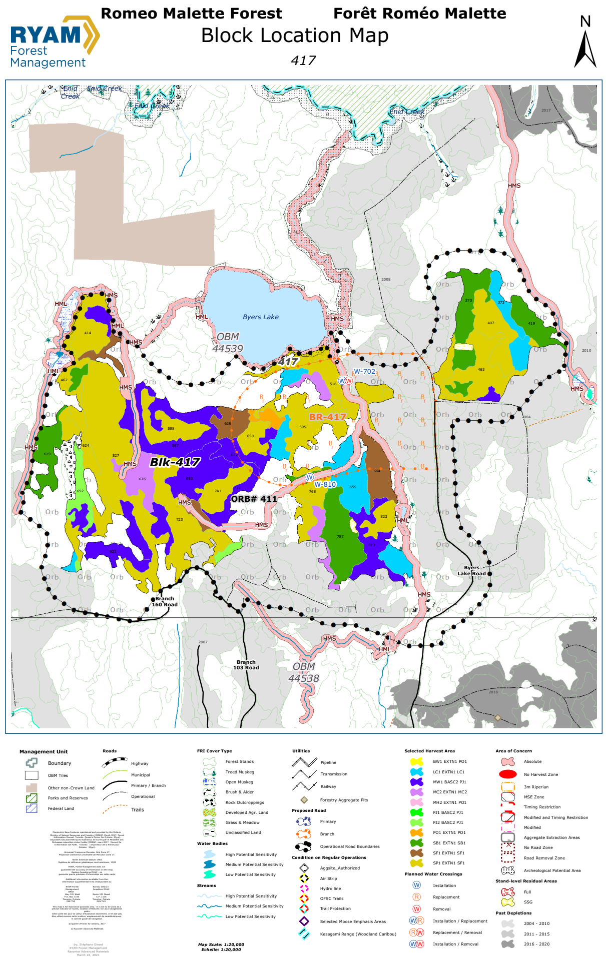

Figure 3. Block location map outlining harvesting boundary and access point for block 417

Comparing the aerial images and the DEMs allows for determining the best location for roads while predicting the ground material based on the stand types. The lime green areas tend to be jack pine (*Pinus banksiana)* stands, which are typically well-drained sites. Jack pine and trembling aspen mixed stands tend to contain a gravel material which is great for caping road surfaces, using the material for crossing installations or increasing the bearing capacity of a road. The foreman laying out the roads oversees the stands and determines whether the building material is suitable for construction. Foresters can move the centerline of the road to avoid bedrock, steep terrain, and other avoidable areas that may cause issues. Debastos and Sons have a subscription with Avenza, which is a mapping app for phones that tracks your location and contains different features for traversing roads.

When designing road networks in ArcMap, it is important to consider skidding distances. The most efficient distance for a skidder to operate at is around 300 meters, this is where the operator will be producing their maximum production if there no terrain obstacles. Examining the LiDAR images to estimate the amount of wood coming to the roadside is important to ensure there is enough room to store the logs. Short side roads can be built in areas that contain high volumes, to ensure there will be enough room at the roadside for the logs. Figure 4 is demonstrating an efficient road network with maximum 300-meter skidding distances.

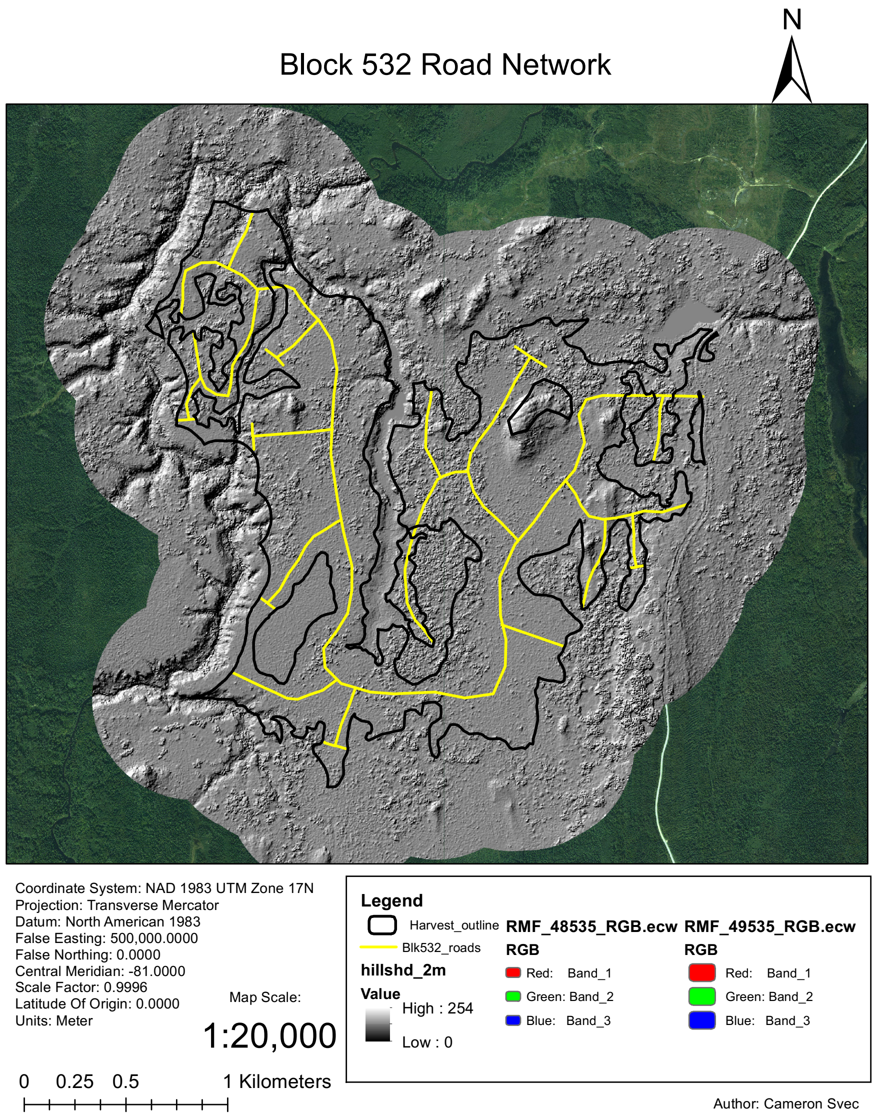

Figure 4. Block 532 road network with hill shade layer

The total distance of the entire road network must be measured to determine the total cost to build. Wetlands and higher elevated areas should be identified as they can alter the total cost. After the road construction costs were calculated for all blocks for all scenarios, a cost comparison was conducted on the scenarios to determine the most optimal construction technique.

An excel file has been supplied by Green First containing the volume of the stands within the blocks. The total volume of each block was supplied as well as the total area which was useful to compare costs. Using this information the cost of road construction per cubic meter was determined to select the most optimal road network with the most feasible road construction cost.

Debastos and Sons provided costs to construct each type of road. Elevated summer roads cost $10,500 per kilometer on average, elevated winter roads cost approximately $7,500 per kilometer, and stumped winter roads are around $6,000 per kilometer. These values assume that the ground material is ideal for building logging roads, therefore it could cost more if the wrong construction method is chosen. When determining the total cost to construct these road networks, the distances of each road must be measured and recorded. This will allow the determination of more precise costs if different road construction techniques are going to be used on the same block.

For each block, three scenarios were conducted demonstrating the costs of different road types. Scenario one had the main road as an elevated winter road and the tertiary winter roads stumped. Gravel is not typically required on winter roads since they are frozen. Scenario two is looking at the costs for an all-elevated summer road network with the main road graveled. Gravel costs must be analyzed closely as they can build up quickly if the gravel is being hauled long distances. If possible, finding gravel within the block boundary would keep the graveling costs down, but if you must haul it from another location the costs will increase quickly. Scenario three was another summer road network but included all the roads graveled.

Once the distances of each road are measured, adding up all the roads for each construction method was conducted to determine their cost. Taking the total distance of each construction method and multiplying them by the costs per kilometer was done. This was calculated for each scenario, where the total cost to build that distance of the road was given.

Following the construction cost, we must look at how much it will cost if gravel was required. The first step was locating gravel in the block - this was done by examining images and maps and traversing the area. By looking at the location block maps demonstrated in Figure 3 stand types were determined. Lime green is the most ideal color to examine for gravel as it is typically a jack pine and aspen mix. It is the forester's job to look for gravel sources while walking the centerline of the roads. When calculating the cost of graveling, every kilometer further you get from the gravel pit, it is an additional $1000 per kilometer.

Small culverts installed for draining so flooding doesn't occur were included in the building costs. If there are larger creeks or riparian zones that require larger culverts installed, then there will be additional costs. For a proper summer culvert installation, it will cost around $6,000 per installation. Temporary winter snow bridges cost about $1,000 and can only be accessed when frozen.

Once all the costs are calculated, combining all these expenses to determine the total cost was conducted. Dividing the total cost by the total volume of the block calculated the cost per cubic meter. Analyzing and comparing the cost per cubic meter for each scenario determined the most efficient construction method for each block. The lowest cost may not necessarily be the most efficient planning - ensuring winter blocks are harvested during the winter and summer blocks during the summer will maximize the summer grounds being harvested. It is important to prioritize summer harvests as the RMF contains lots of low ground. Harvesting winter blocks in the springtime is an option as well, as long as gravel is placed on the active roads.

4. RESULTS

Block location maps, DEM layers, and the canopy cover aerial images were all analyzed and considered to determine the best road network for each of the blocks. Over the three blocks, there was an average of 14 kilometers per block of roads required to access all standing timber. Based on the Forest Resource Inventory (FRI), block 417 covers 448 hectares and required 16 kilometers of road to harvest the stands efficiently. Block 449 covers just over 400 hectares and requires 12 kilometers of road to be built. Block 532 is smaller at 327 hectares which would require just over 14 kilometers of road to be built to access all areas of the block.

To determine the most ideal road network with proper road construction techniques, three scenarios were analyzed on all blocks while considering the cost per cubic meter. Scenario one consisted of all winter roads with no gravel, scenario two consisted of all summer roads with partial gravel, and scenario three was a full summer road network with all roads graveled.

4.1 Block 417 Road Network

Block 417 covers 448 hectares of productive forest area and contains a density of 70 m^3/ha. The block contains over 30,000 m^3 of softwoods and hardwoods with another 2,000 m^3 of eastern white cedar (*Thuja occidentalis*) and eastern larch (*Larix laricina*). The road network designed to access block 417 is shown in Figure 5. This block required more road building as there was a lot of bedrock to avoid. In the western section of the block the roads become more complex as avoiding bedrock was a priority. The forester walking the centerline may have to adjust the road depending on the accuracy of the aerial images.

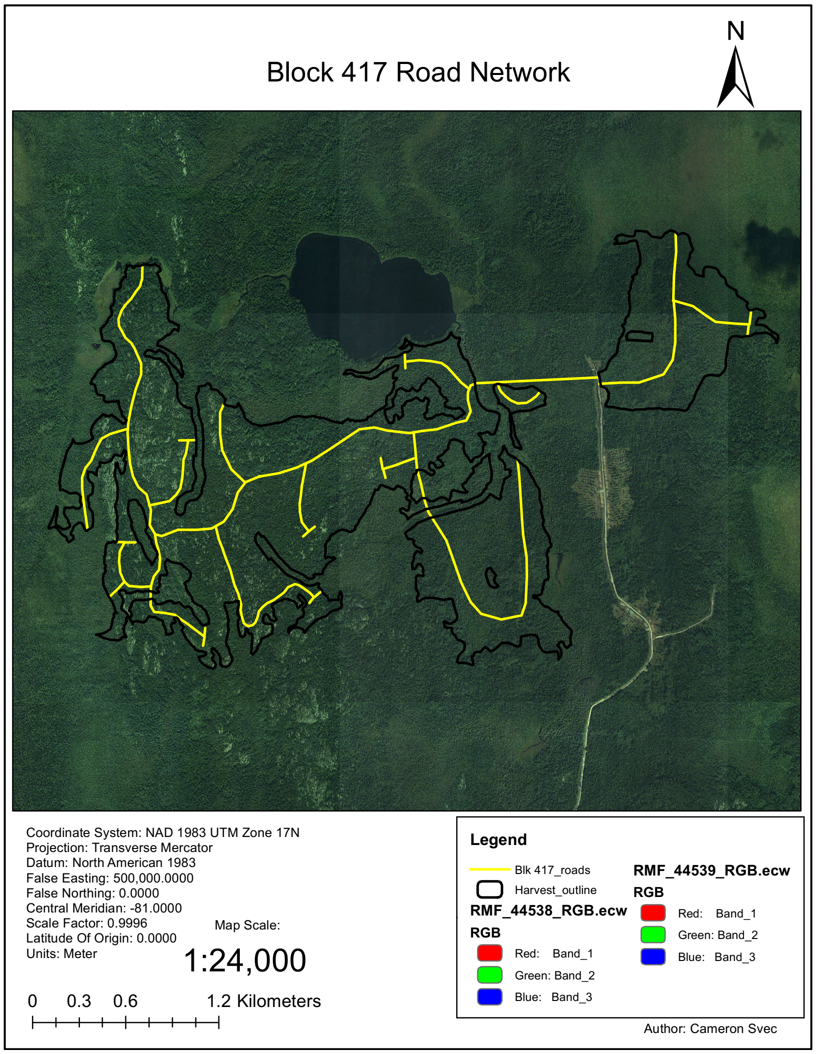

Figure 5. Road network for block 417 with canopy cover

Figure 6 shows the same block except with the hill shade layer. This layer is useful to determine the lower and higher elevated areas, which are beneficial when designing and building roads. The western part of the block contains large hills that could contain gravel-like material which could be used to cap the road surfaces. This will be determined when the road is being constructed and there is an excavator close by. The forester can go look at fallen over trees and stumps to gain a rough idea of what the ground material is like.

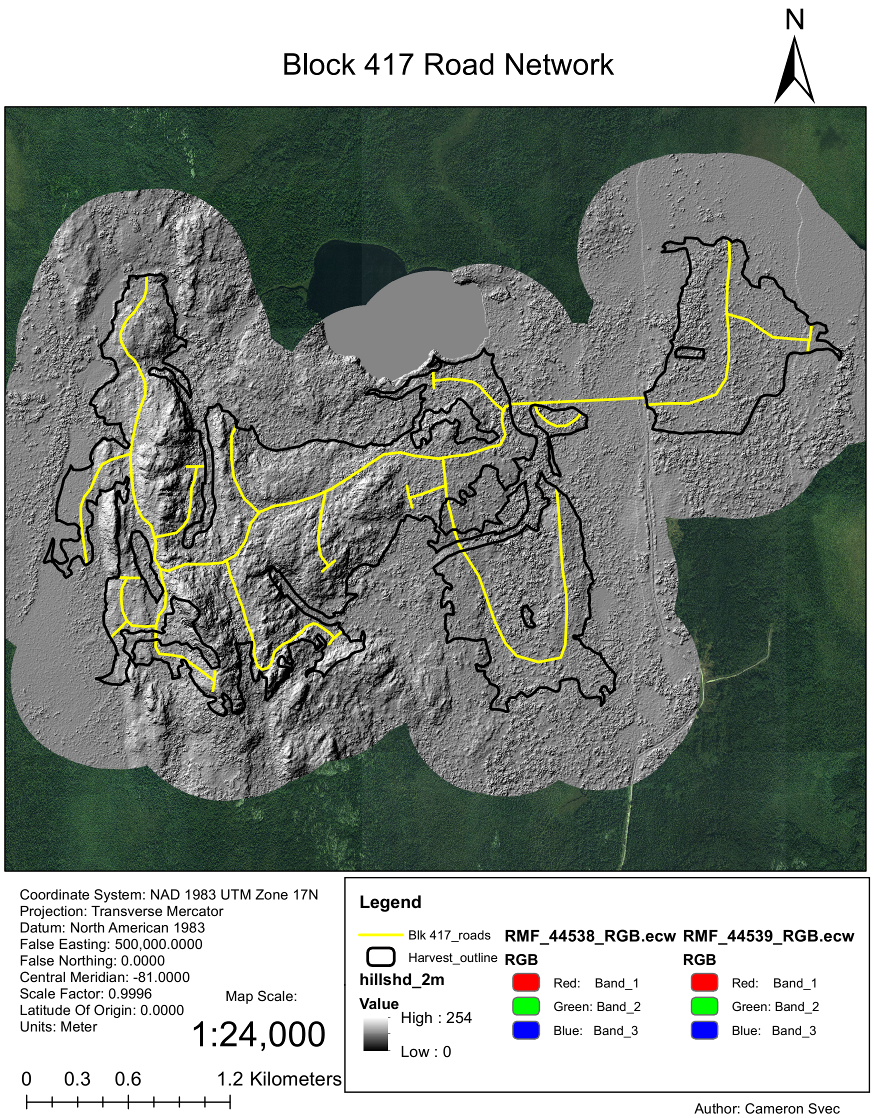

Figure 6. Road network for block 417 with hill shade

4.2 Block 417 Road Construction Costs

The cost per cubic meter for each block on three different scenarios was conducted. Table 1 shows the calculations made for the three scenarios where they were compared to determine the most optimal scenario.

Table 1. Costs for the three scenarios for block 417

	Scenario 1		Scenario 2		Scenario 3	
Road Type	Distance (km)	Cost ($)	Distance (km)	Cost ($)	Distance (km)	Cost ($)
Summer	0	0	16.3	171150	16.3	171150
Raised Winter	5.2	39000	0	0	0	0
Winter Stumped	11.1	66600	0	0	0	0
Total	16.3	105600	16.3	171150	16.3	171150
Gravel	0	0	5.2	27600	16.3	93250
Crossings	2	12000	2	12000	2	12000
Total Cost		117600		210750		276400
Total Volume ($/m^3)	33,437		33,437		33,437	
$/m^3		**3.5**		**6.3**		**8.3**

Scenario 2 would best suit this block, as it contains summer road construction with the main road graveled. The total cost to build the road network would be $171,150 and to gravel the main road would cost $27,600. The total cost for the road network would be around $210,750. The volume of the 448-hectare block is 33,437m^3 which brings the overall cost down. There are two crossings that must be installed in all scenarios, which adds additional costs up to $12,000. The cost per cubic meter was 6.3 which is within reason for a summer road network. The cost per cubic meter for scenario three is also within reason at 8.3, but since scenario two is lower and still constructs a suitable road network, it is the preferred one. Table 2 shows the cost per cubic meter for scenario 2 and tables used to determine these values can be found in the appendix IV. Appendix III includes the maps created identifying the different road construction types for block 417.

4.3 Block 449 Road Network

Block 449 is just over 400 hectares with a stand density of 97 m^3/ha. About 12 kilometers of road is required to access all standing timber. Figure 7 shows the road network on the north and south side of Highway 101 west. There is a source of gravel on the north side of the highway down the first side road to the right. This is where the gravel costs were calculated from.

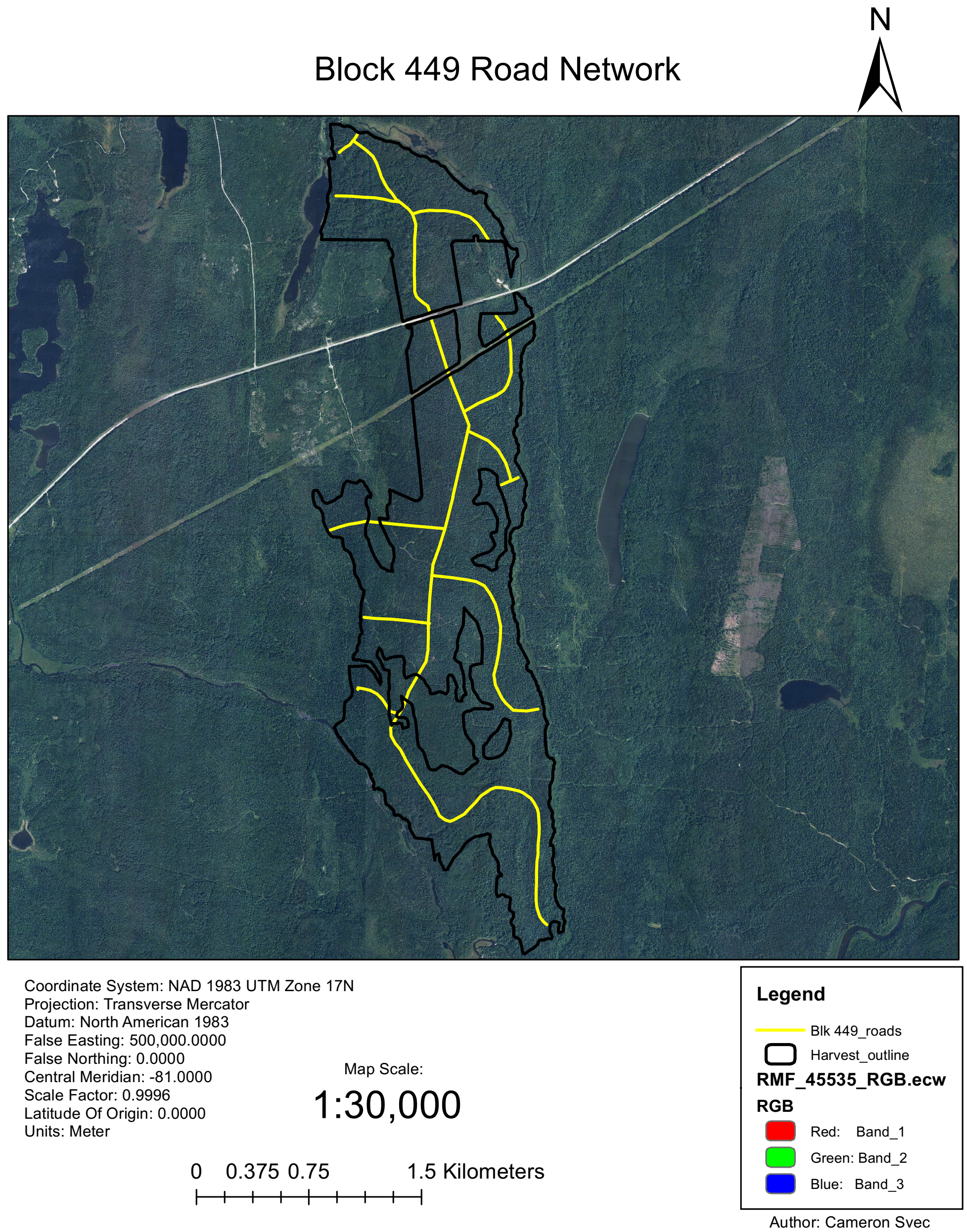

Figure 7. Road network for block 449 with canopy cover

Figure 8 shows the same block with the DEM layer to show that it is all on the same elevation. There aren't any large hills or objects visible from these layers, making the road network simple.

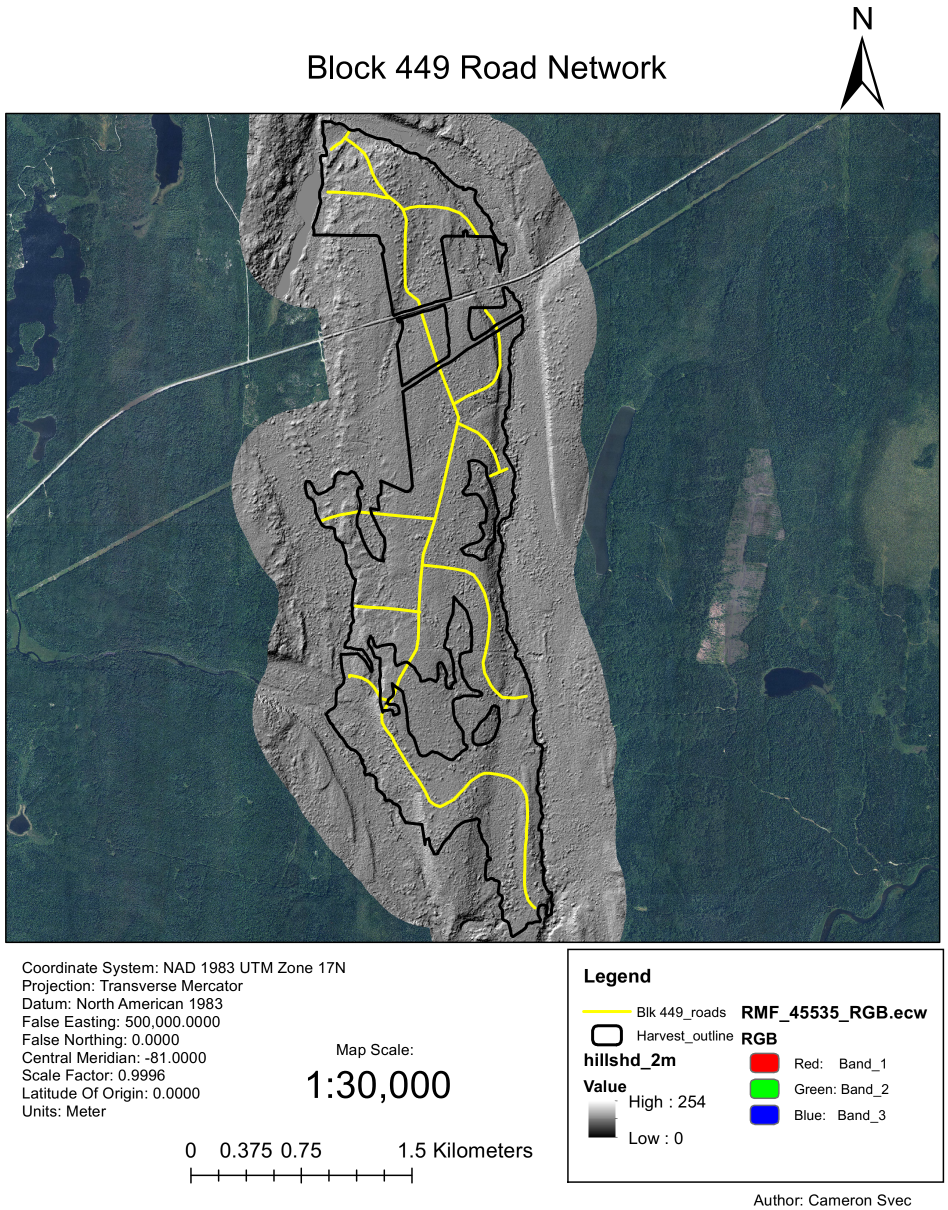

Figure 8. Road network with hill shade for block 449

4.4 Block 449 Road Construction Cost

Block 449 had the most volume at 47,284 m^3 which brought the cost per cubic meter down. Table 2 shows the costs for the three scenarios where they were compared to determine the most efficient construction method.

Table 2. Cost for all three scenarios for block 449

	Scenario 1		Scenario 2		Scenario 3	
Road Type	Distance (km)	Cost ($)	Distance (km)	Cost ($)	Distance (km)	Cost ($)
Summer	0	0	11.8	123900	11.8	123900
Winter Elevated	6.4	48000	0	0	0	0
Winter Stumped	5.4	32400	0	0	0	0
Total	11.8	80400	11.8	123900	11.8	123900
Gravel	0	0	6.4	54800	11.8	95300
Crossings	0	0	0	0	0	0
Total Cost		80400		178700		219200
Total Volume (m^3)	47,284		47,284		47,284	
$/m³		**1.7**		**3.8**		**4.6**

Scenario 2 was chosen for this block as it contains summer road construction. The total distance of the road network is 11.8 kilometers, which costs over $120,000 to construct summer roads. The total cost for scenario 2 was $178,700 with 6.4 kilometers of gravel done on the main road. When examining the terrain, the northeastern section of the block has some hills and the stand composition is favourable for gravel, therefore an assumption for a gravel pit in this location has been made for the calculation. The total cost to gravel the main road was $54,800allowing the log trucks to continue hauling during poor weather conditions. Since this block has a higher stand volume, the overall cost was 3.8 $\$/m^3$. Both scenario 2 and 3 show acceptable costs for summer road networks, but scenario two was selected due to the lower cost, but if required scenario 3 was also acceptable and would be favourable for a wet year.

4.5 Block 532 Road Network

Block 532 consisted of 14.5 kilometers of road to be built over the 327-hectare block. This block had the lowest volume of the three examined at 27,076 m^3 with a stand density of 72.3 m^3/ha. Due to the low volumes of this block, the cost of harvesting in the summer may be too expensive. Figure 9 shows the road network with the aerial imagery, where some lower-density areas can be seen.

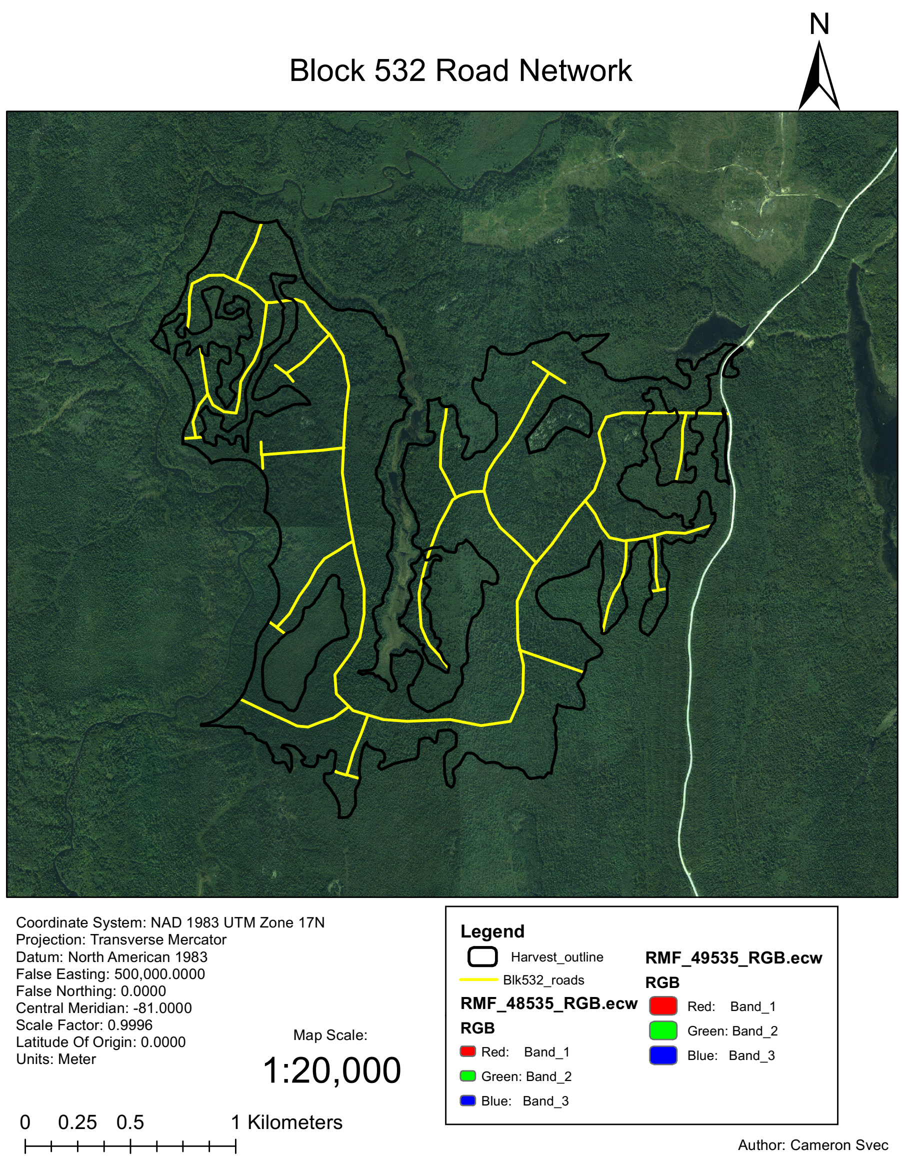

Figure 9. Road network with canopy cover for block 532

Figure 10 is showing block 532 road network with the 2 meter hill shade.

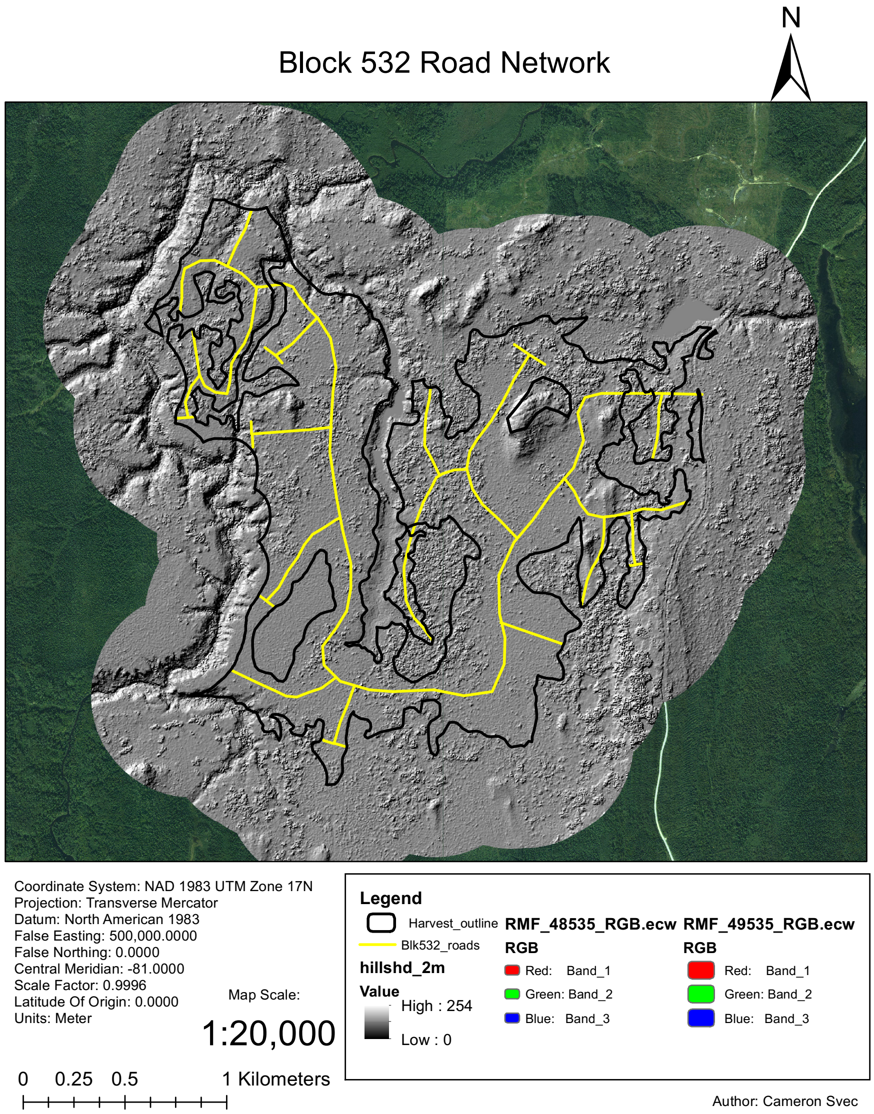

Figure 10. Hillshade layer showing road network for block 532

4.6 Block 532 Road Construction Cost

Looking at the maps, it was evident that the terrain was much lower than the other two blocks examined in this study. The total amount of road required to be constructed to access this block was 14.5 kilometers. Table 3 shows the costs calculated for block 532.

Table 3. Cost for the three scenarios for block 532

	Scenario 1		Scenario 2		Scenario 3	
Road Type	Distance (km)	Cost ($)	Distance (km)	Cost ($)	Distance (km)	Cost ($)
Summer	0	0	14.5	152250	14.5	152250
Winter Elevated	5.8	43500	0	0	0	0
Winter Stumped	8.7	52200	0	0	0	0
Total	14.5	95700	14.5	152250	14.5	152250
Gravel	0	0	5.8	74900	14.5	183550
Crossings	0	0	0	0	0	0
Total Cost		95700		227150		335800
Total Volume (m^3)	27,076		27,076		27,076	
$/m^3$		**3.5**		**8.4**		**12.4**

Scenario one shows the lowest cost per cubic meter making this scenario the most efficient for this block. It would cost about $95,700 to construct the road network, and no gravel was required. Scenario 1 costs 3.5 $/m^3$ which was the lowest out of the three scenarios. Scenario 2 costs 8.4 $/m^3$ which was within reason for a summer road network, but scenario 3 costs over 12 $/m^3$ which was too much. Since this block has a volume of 27,000 m^3 a winter road network would make the most sense as summer road can become costly in lower terrain.

5. DISCUSSION

Designing a proper road network can decrease the cost of road construction significantly if laid out efficiently. There are many factors that must be considered to design the most optimal road network. Terrain conditions, stand density, off-road transportation costs, construction and maintenance costs are a few factors that are important to analyze (Pulkki, 2003). Constructing a road on steep terrain can not only increase building costs, but it can also increase off-road transportation costs, road maintenance costs, log transportation costs and just makes it a more difficult operation. Analyzing the entire block and determining the most optimal road network is key to having a low cost and efficient operation. Pulkki (2003) discusses the demand of forest road networks on logging operations and how roads are designed to meet environmental protection and safety standards more than the needs of exporting natural resources. Ensuring there is little change to the environment is a main priority when designing road networks. The road network is designed in areas where there is enough material to construct a road with the least amount of alteration to ecosystems. Whether the road is temporary or permanent, it must be able to support the expected maximum weight at a reasonable speed throughout its entire activation.

If block 417 is harvested in the spring and summer, then the main road can be hauled on days where road conditions are wet and side roads during dry weather conditions. Leaving the main road for rainy days is important as it allows the haul to continue and keeps the total cost down. Scenario 1 shows how much the cost would go up if the entire block was graveled. It is not necessary to gravel all roads as higher elevation blocks tend to have a silty clay to gravel-like material that is good road building material. When this material is dry, it is very solid and has a much higher weight-bearing capacity than a wet road with this material. It is the supervisor’s job to monitor the road and determine if there is too much damage being done. This is important to consider as it is the main access point into the block, and operators must be able to access their machines to keep up with the log haul.

Block 417 has a lot of higher elevation in the western section of the block where a summer road network would best suit this terrain. Scenario 2 was chosen as the best construction method as it demonstrated an overall lower cost. To minimize building costs, it is important to use as much material as possible from the vicinity of the road right-of-way (Pullki, 2003). Gravel can become very costly fast if it is not planned and managed properly. Only graveling the main road of this block keeps the total cost down, while also being able to continue operations in various weather conditions. The closer the pit location is to the area being graveled, the cheaper it will cost (Pulkki, 2003). If trucks are capable of driving on the sub-grade, bottom-dumping trucks can be used to increase the production of graveling. End-dumping is another graveling method used when the sub-grade is too soft to drive on. For scenario 2, it would cost just over $27,000 to gravel the main road. This scenario allows for the operations to continue in all weather conditions. If the secondary roads cannot withstand the bearing capacity of the trucks, then the main road that contains a layer of gravel can be hauled on. The gravel increases the bearing capacity that the road can withstand, but the forester must monitor this road if the operation is undergoing during poor weather conditions. Scenario 3 demonstrated the cost of a summer road network with all the roads graveled. This would increase the bearing capacity and allow all roads to be hauled in poor weather conditions. The issue with this scenario is that it costs too much for the volume of the block. Scenario 1 demonstrated much lower building costs as it is a winter road network scenario. On average a winter road network should have a cost between 2 – 4 $/m^3, so this scenario would provide an optimal winter road network for the block. Due to the high elevations and high volume within the block, this would not be the most ideal construction method. There are many blocks on the Romeo Malette Forest that are located on a low elevation that will be harvested when it is frozen.

There are two crossings that must be installed in block 417. Small culverts installed for drainage are included in the construction cost, but the larger installations will cost more as there is a process that must be followed provided by the Ministry of Natural Resources. The installation will cost around $6,000 per culvert and take a shift to install, depending on the water flow and culvert size.

Due to the lower cost per cubic meter and higher volume of timber, block 449 will contain a summer road network. Scenario 1 has a lower overall summer road network cost, making it the construction method of choice. Having access to gravel within the harvesting boundary decreases costs significantly. This scenario provided a good road network with low costs because of the close access to gravel and high timber volume. If there is a lot of precipitation during the hauling of this block, this scenario would allow the main road to continue to be hauled. Scenario 3 would allow for hauling to occur during poor weather conditions throughout the entire block, but the forester must monitor the roads to ensure there is minimal damage. Scenario 3 demonstrated the costs if all the roads were graveled, showing higher costs than scenario 2. The decision would ultimately come down to Green First to determine the amount of money they are willing to spend on graveling. Scenario 1 has the lowest cost per cubic meter because of the winter road construction. Since this block is on higher terrain, a summer scenario was recommended as it contains high volume which brings the overall cost for a summer road network down.

Based on the DEM layers, block 532 is on much lower terrain than the other two blocks examined in this study. Due to the low elevation and low volume, it was evident that this would be a winter harvest with a winter road network. Scenario 1 shows the lowest cost and due to the low volume on this block, summer roads would cost too much. As demonstrated in scenarios 2 and 3, the cost per cubic meter is too much to harvest 27,000m^3. This lowland block would have the most optimal road network with winter road construction and no graveling. No gravel is required as the roads are built with a clay-like material which is very solid when frozen. These frozen roads can withstand the weight of loaded log trucks, therefore the only required maintenance would be grading and sanding. Scenarios 2 and 3 demonstrate summer road networks for block 532, which not only cost more but would require more work to maintain and gravel. This block will most likely have a higher water table level than the other two blocks, limiting material if gravel is located as digging below the water table in aggregated pits is limited. When building roads, operators are allowed to dig below the water table to gather material for the road sub-grade. Elevated summer roads would take a long time to dry the road sub-grade on this terrain and would require more gravel to ensure the bearing capacity of the road is strong enough. A brush matt would help increase the weight bearing if summer road construction was conducted. Building summer roads in winter blocks increase cost and can cause more problems throughout the operations.

An important factor to consider when planning a winter harvest is to ensure that winter ground in being harvested in the winter and summer terrain is harvested in the summertime. An option could be to harvest a winter terrain when it is frozen and plan that log haul to remove the wood during the spring. The roads being hauled in the springtime would require gravel as the ground is beginning to thaw. This would provide more work for contractors, allow monitoring of mill inventory, avoid stockpiling and ensure summer harvests begin in the summertime. For example, in block 532 a winter road network was recommended. Even though the cost for a full summer road network with gravel exceeds the recommended costs, it could potentially be worth it as you could save money from stockpiling. Stockpiling could add up to an additional 10 $\$/m^3$ to the transportation cost so if this block contained a more expensive summer road network, then there would be no stockpiling required. It is known that there is an aggregated pit eight kilometers away from the block, so there will be gravel available, but it may cost more if gravel is not located in the block. There is a spruce swamp that must be crossed as shown in Appendix II Figure 16 that would increase the cost of summer road construction. Even though the cost could exceed 12 $\$/m^3$ it may be worth harvesting in the winter when the ground is frozen and haul it in the spring. This would ensure contractors not have to shut down for spring break-up, aid in monitoring wood inventory at the desired mills and ensure summer ground is being harvested during the summertime, so no summer ground is wasted.

Tevfik (et al. 2021) study demonstrated that the cost of a nonfrozen road in a wetland block increases from 0.30 $\$/m^3$ to 2.14 $\$/m^3$. Road construction cost over 4 harvesting units was done where they determined that building summer roads in wetlands cost 6.7 times more than constructed winter roads. This study was done in northern Alberta where the harvesting and construction methods could be different. The Romeo Malette Forest is located on the clay belt creating lower elevated blocks, and more wetlands to build roads through. The difference between the summer and winter road costs in this study was much greater, which made it easier to determine the most optimal scenario. The average of scenario 1 for the three blocks covered in this study was 2.9 $\$/m^3$. Scenario 2 had an average of 6.1 $\$/m^3$ and scenario 3 - 8.4 $\$/m^3$. It would cost 2.1 times more to construct scenario 2 compared to scenario 1. This was determined by dividing the average cost of scenario 2 by the average cost of scenario 1. The same calculation was done comparing scenario 3 to scenario 1 where it was determined to cost 2.9 times more. These values are much lower compared to the study examined. This could be because the terrain is different, they use different road construction methods, or they have lower block volumes.

From multiple summer job experiences running the gravel crew I was able to view different types of road construction and have a better understanding of the whole process. This study allowed me to argue my personal knowledge as well as expand it through other studies. The results produced from this project will allow me to suggest possible road networks and provide efficient cost comparisons to Green First and Debastos and Sons when these blocks become active.

6. CONCLUSION

After multiple scenarios were conducted, the three scenarios presented in the results were the most optimal construction methods for these three blocks. It was determined that building elevated summer roads in lower terrain significantly increases the costs, especially if gravel is not present in the block. This confirms the hypothesis that the construction cost is significantly affected by the terrain and volume. The planning phase of harvesting blocks is by far one of the most important aspects of the operation. If poor road networks and construction methods are used, then the cost of the entire project will be expensive. With the Romeo Malette Forest being located on the clay belt, there are many blocks that are classified as winter harvests, therefore if there is an opportunity where summer road networks can be constructed efficiently, contractors should take advantage. Blocks 417 and 449 were determined to have a fair cost per cubic meter to construct elevated summer road networks. This is because they are found on higher terrain and contain higher volumes then block 532. Block 532 was found on a lower elevated area, where building a winter road network was found to be the most optimal solution. With lower terrain and gravel access an additional eight kilometers, a frozen road network would be the best choice.

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8. APPENDICIES

8.1 Appendix I

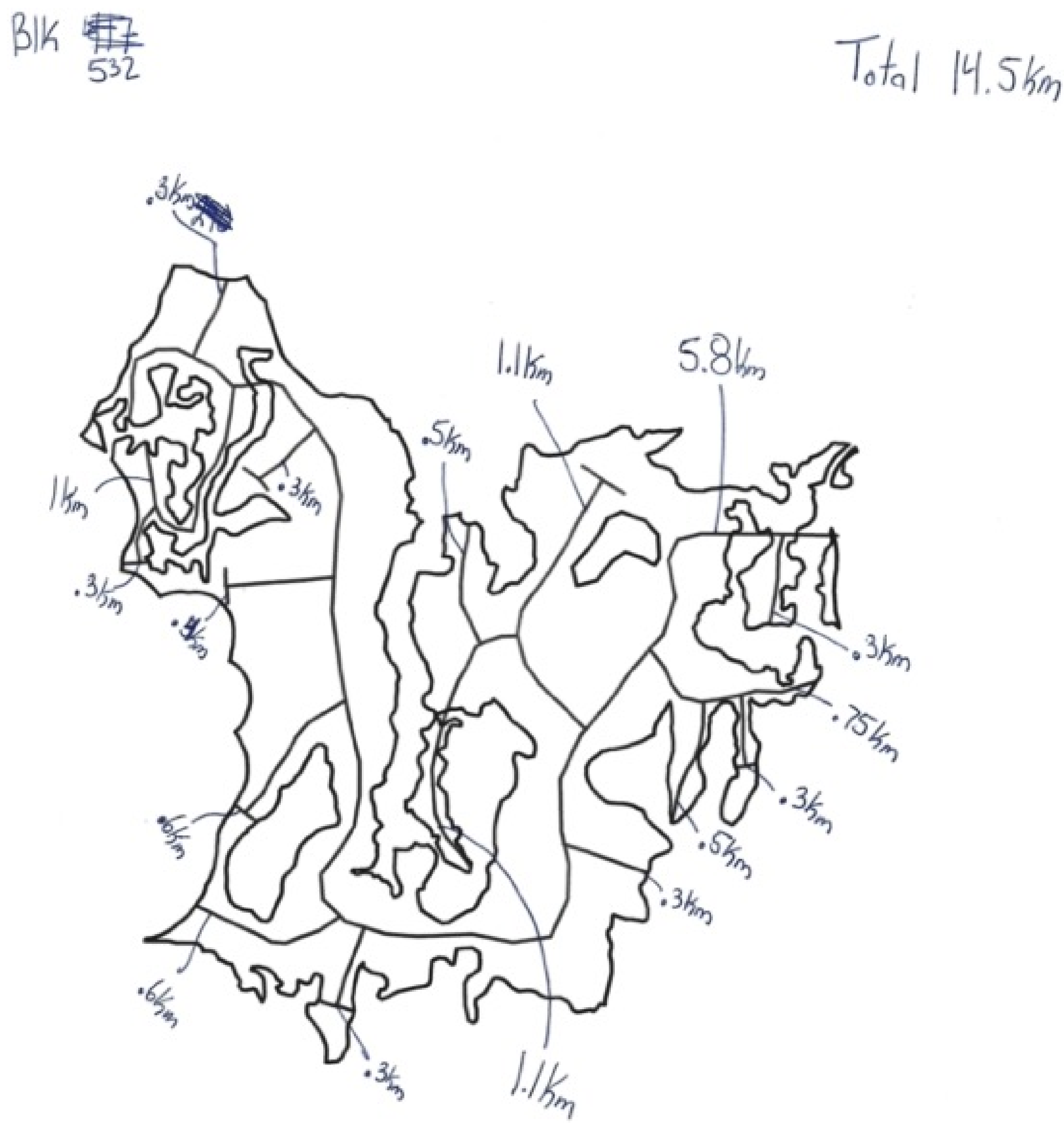

Figure 11. Map with distances of each road for block 532

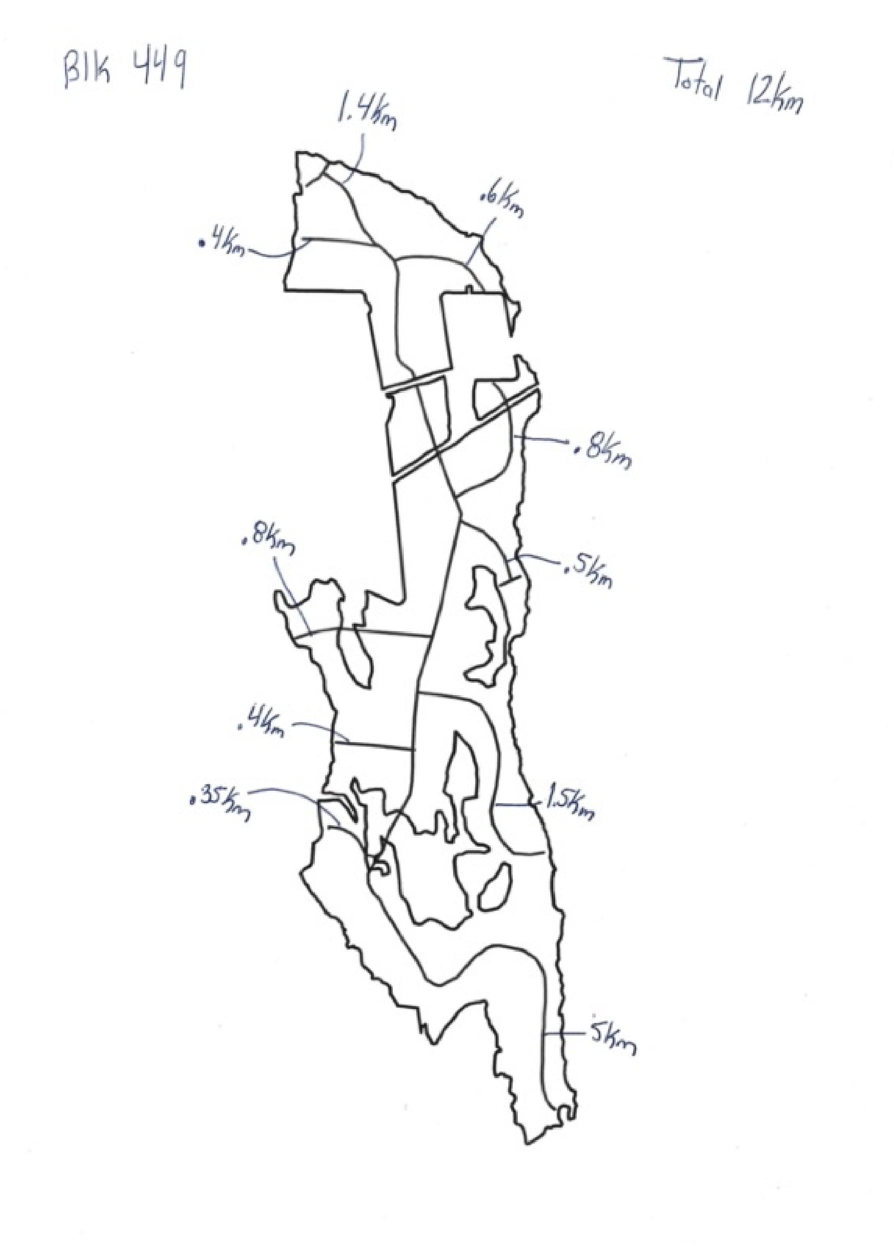

Figure 12. Road distances for block 449

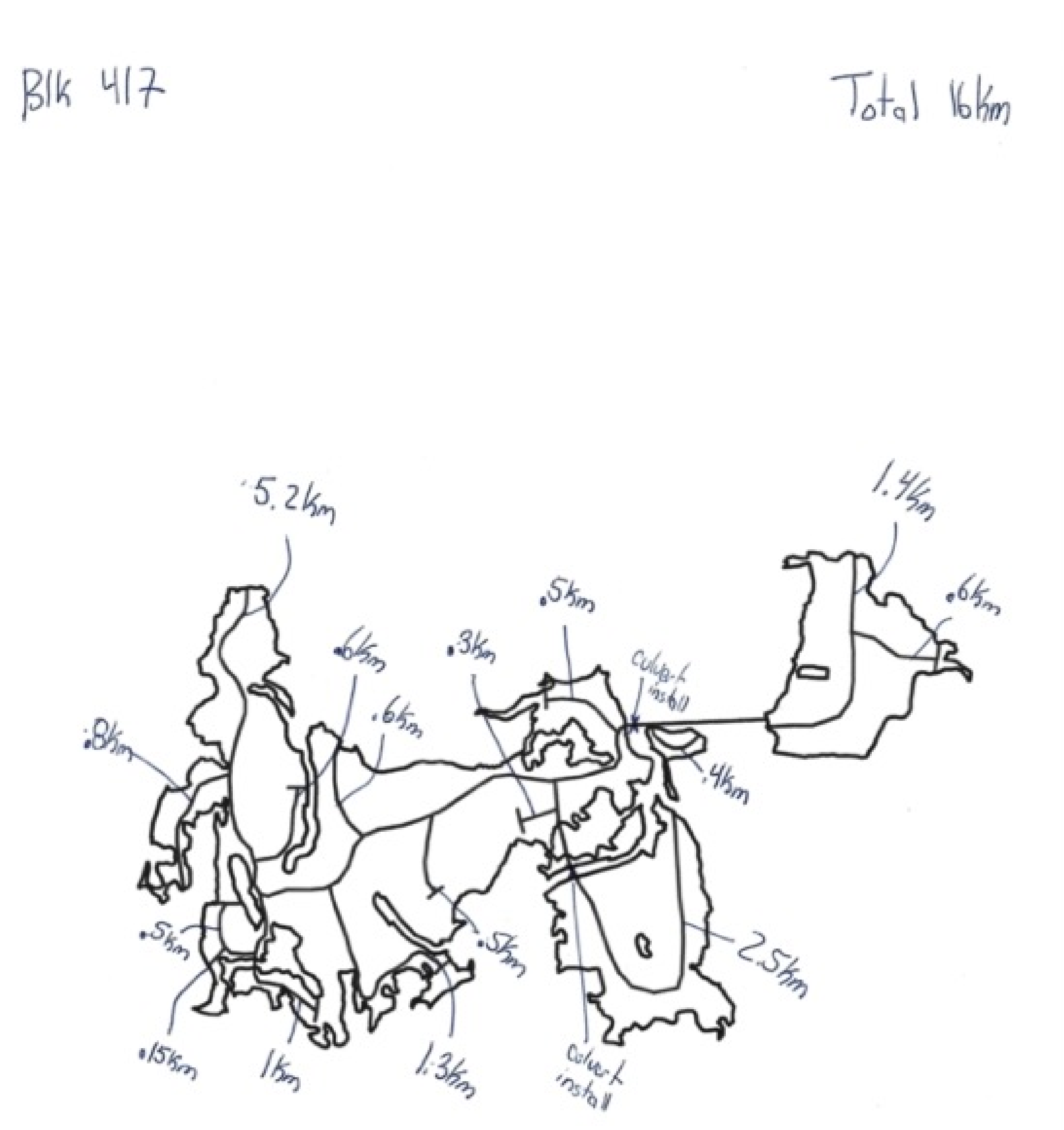

Figure 13. Road distances for block 417

8.2 Appendix II

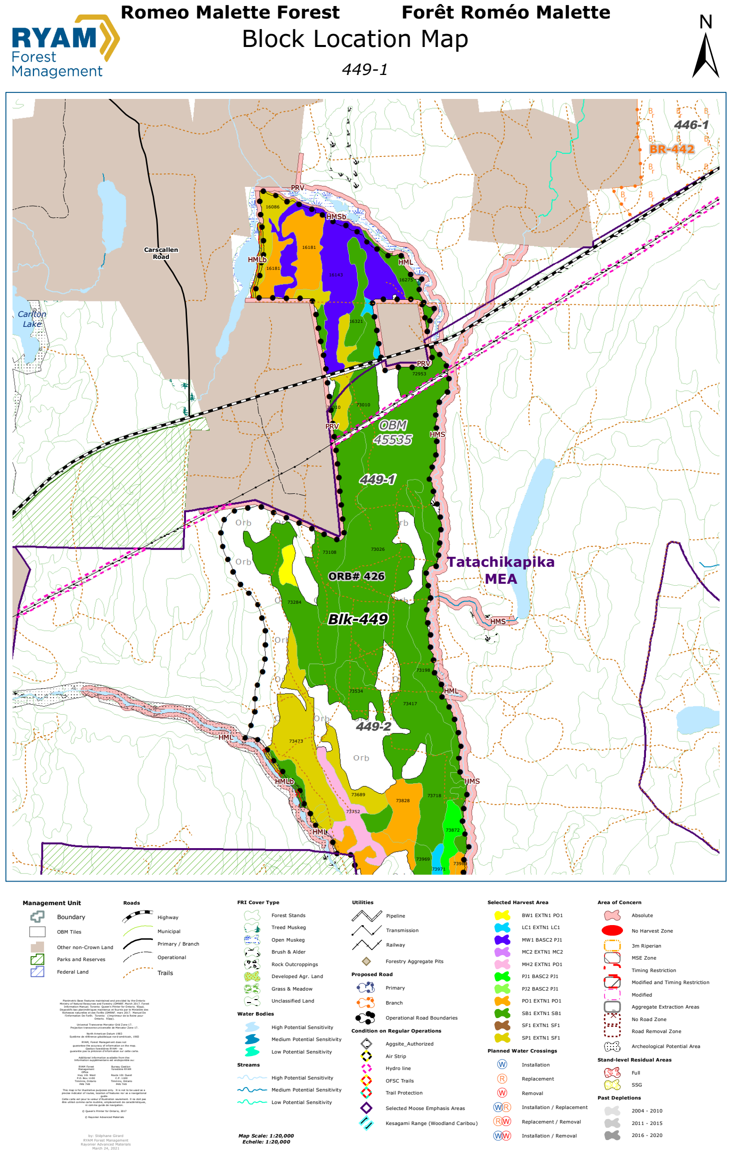

Figure 14. North map of block 449 on Romeo Mallette Forest

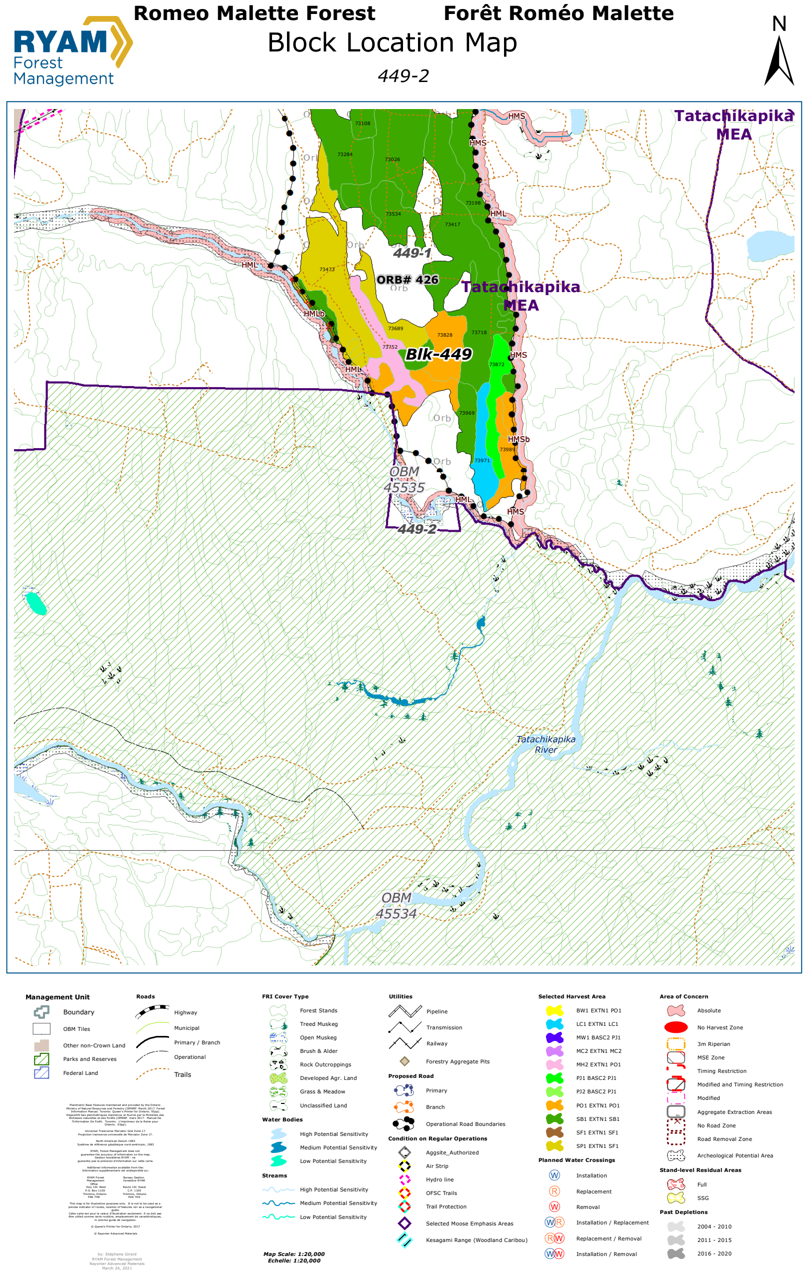

Figure 15. South block map location of 449 on Romeo Mallette Forest

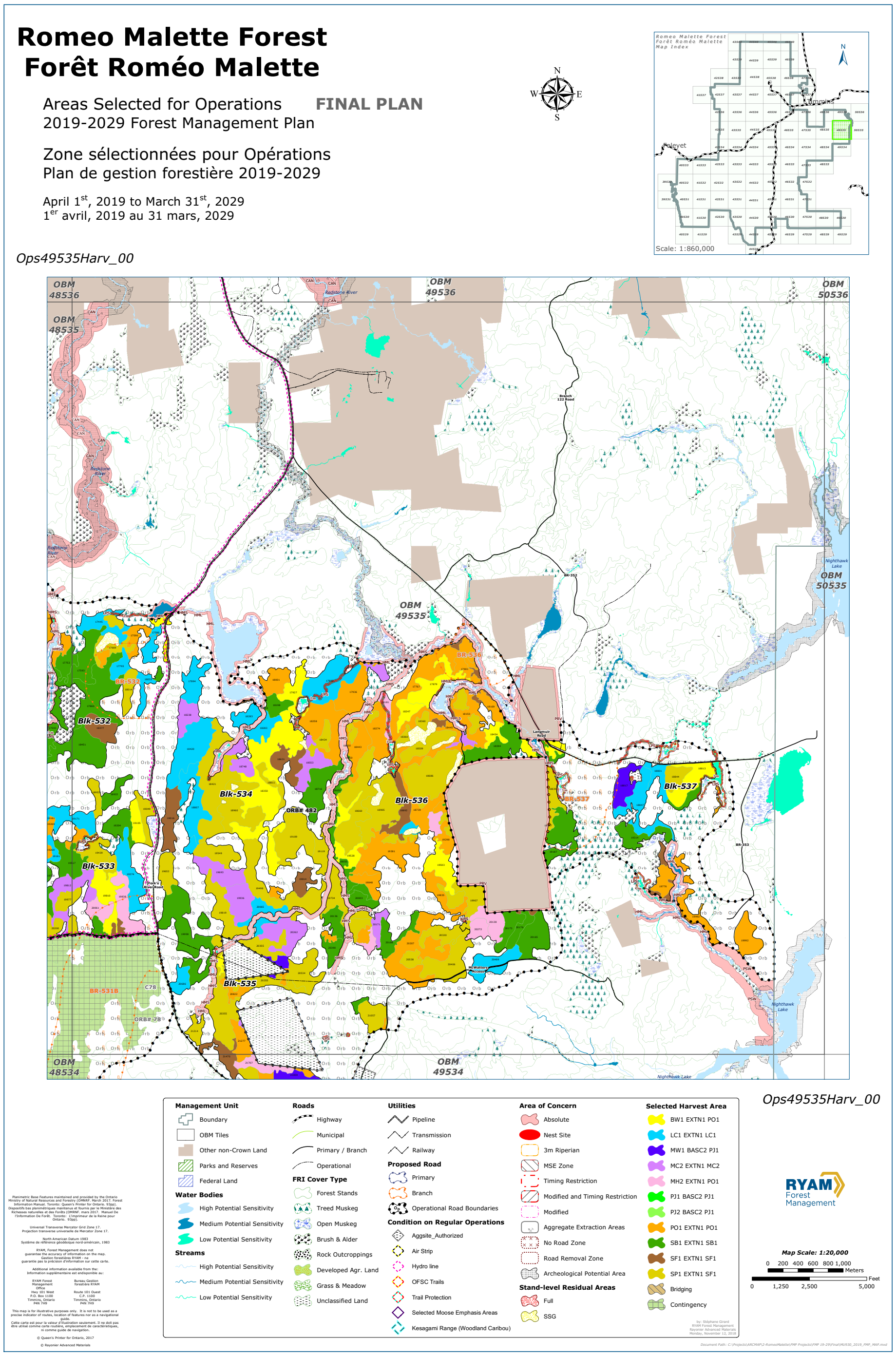

Figure 16. Block 532 map 1 on Romeo Mallette Forest

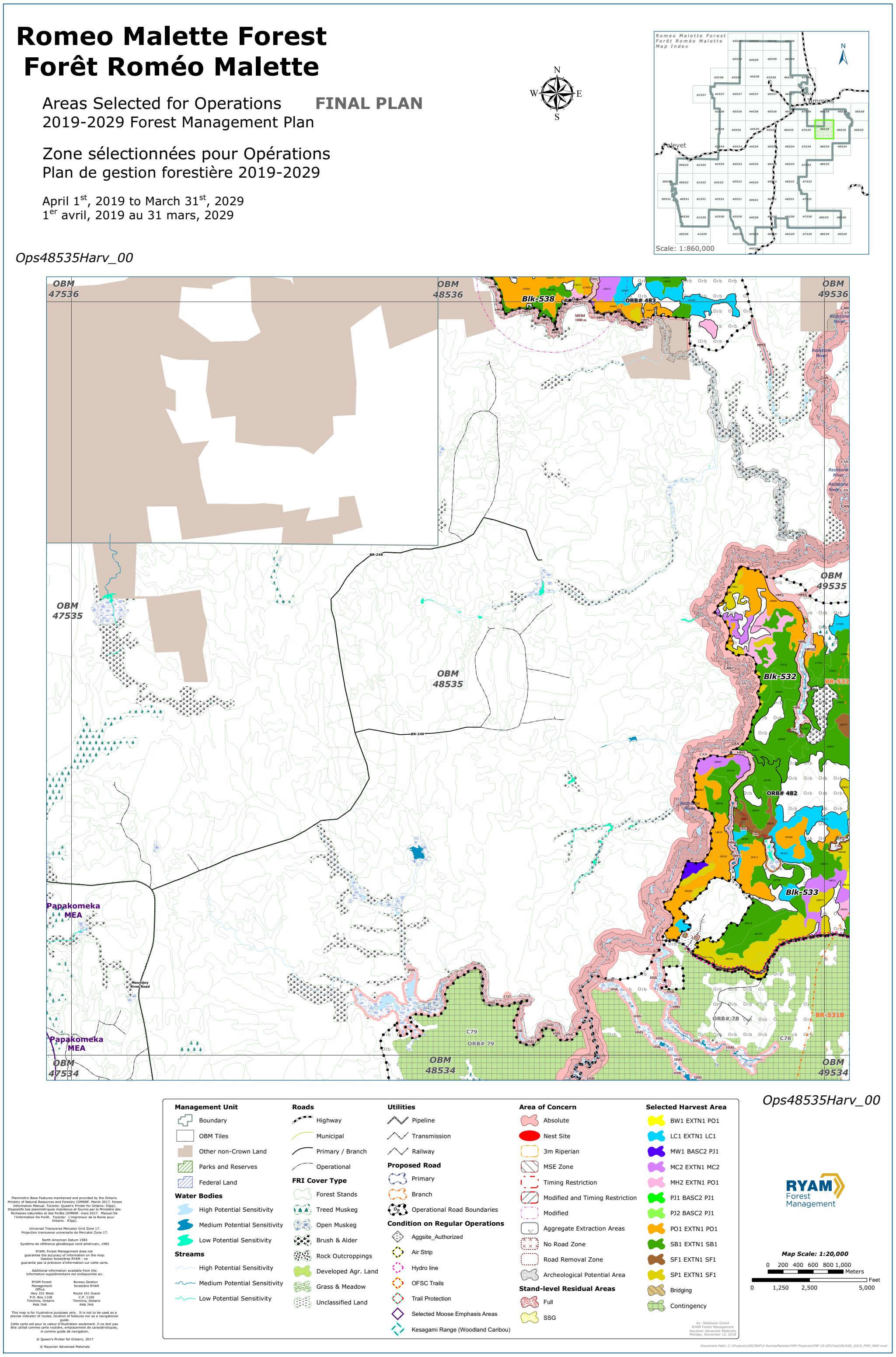

Figure 17. Block 532 map 2 on Romeo Mallette Forest

8.3 Appendix III

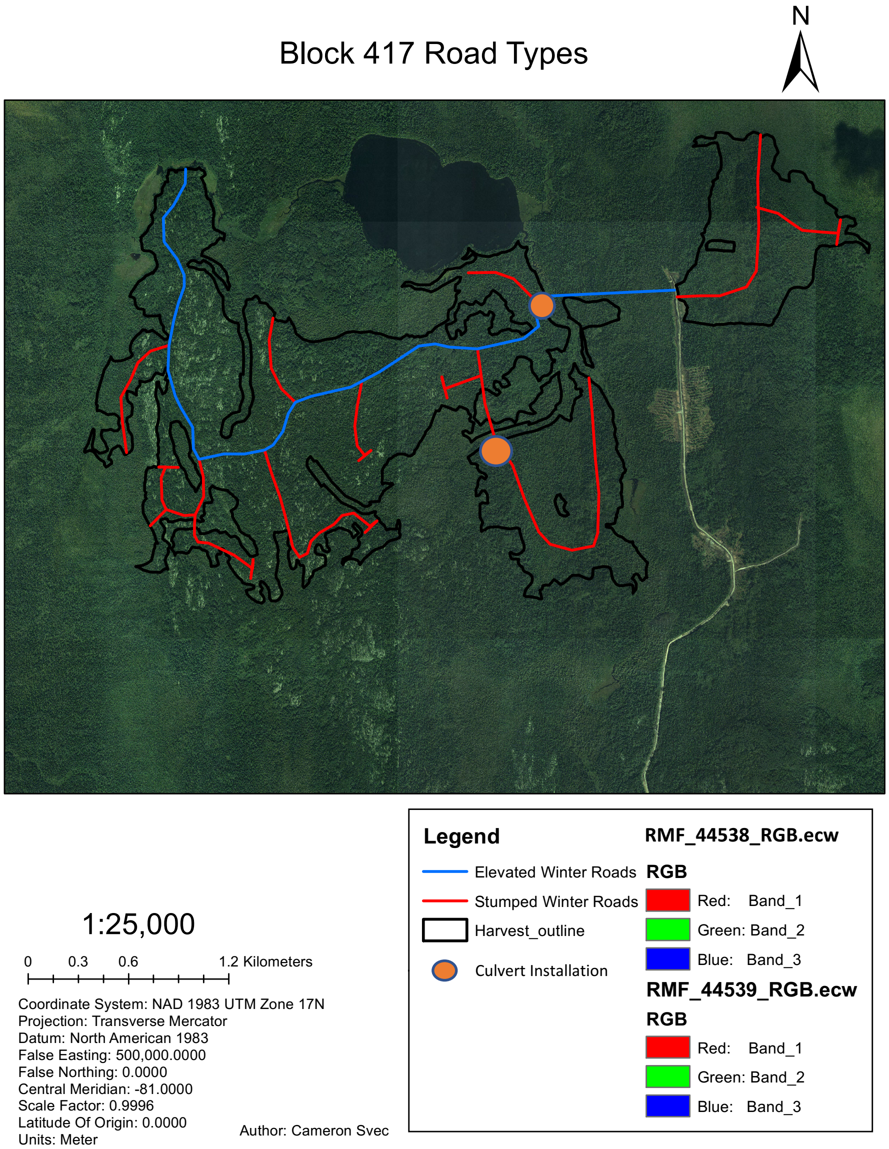

Figure 18. Road network construction method for scenario one on block 417

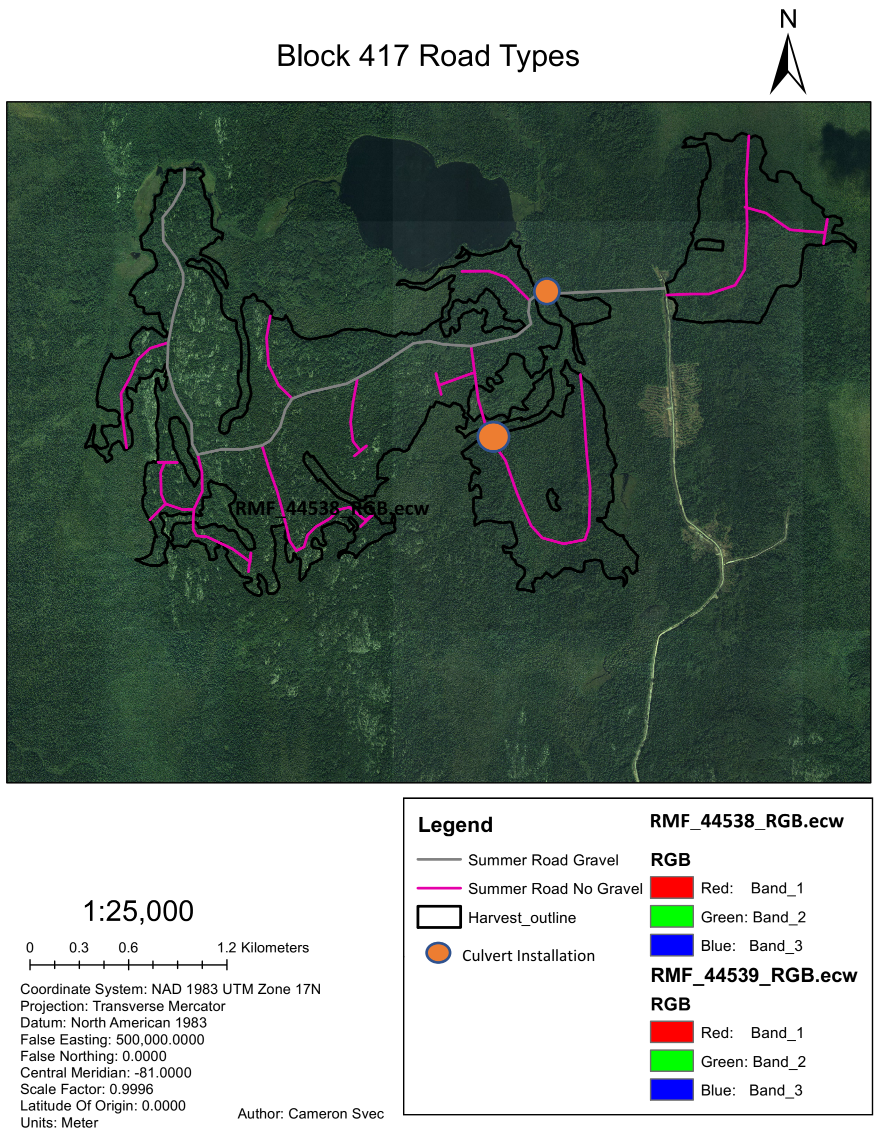

Figure 19. Road network construction methods for scenario two on block 417

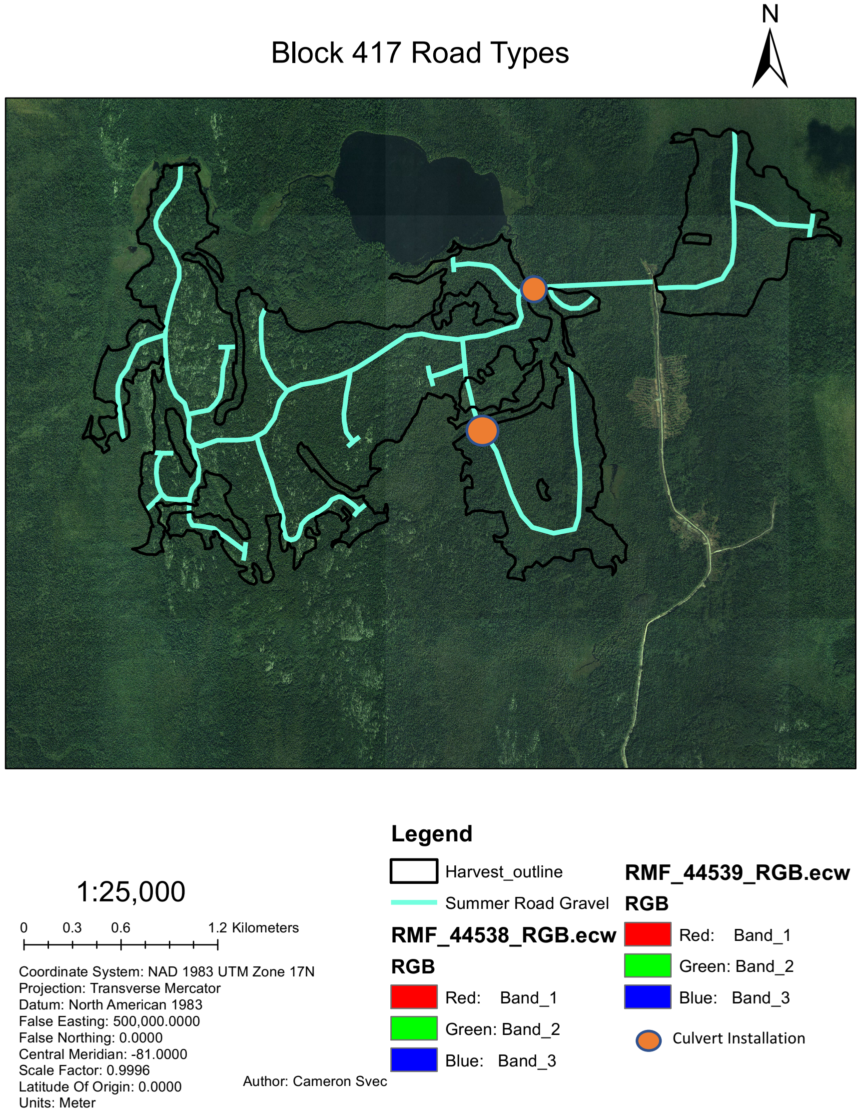

Figure 20. Road construction method for scenario three on block 417

8.4 Appendix IV

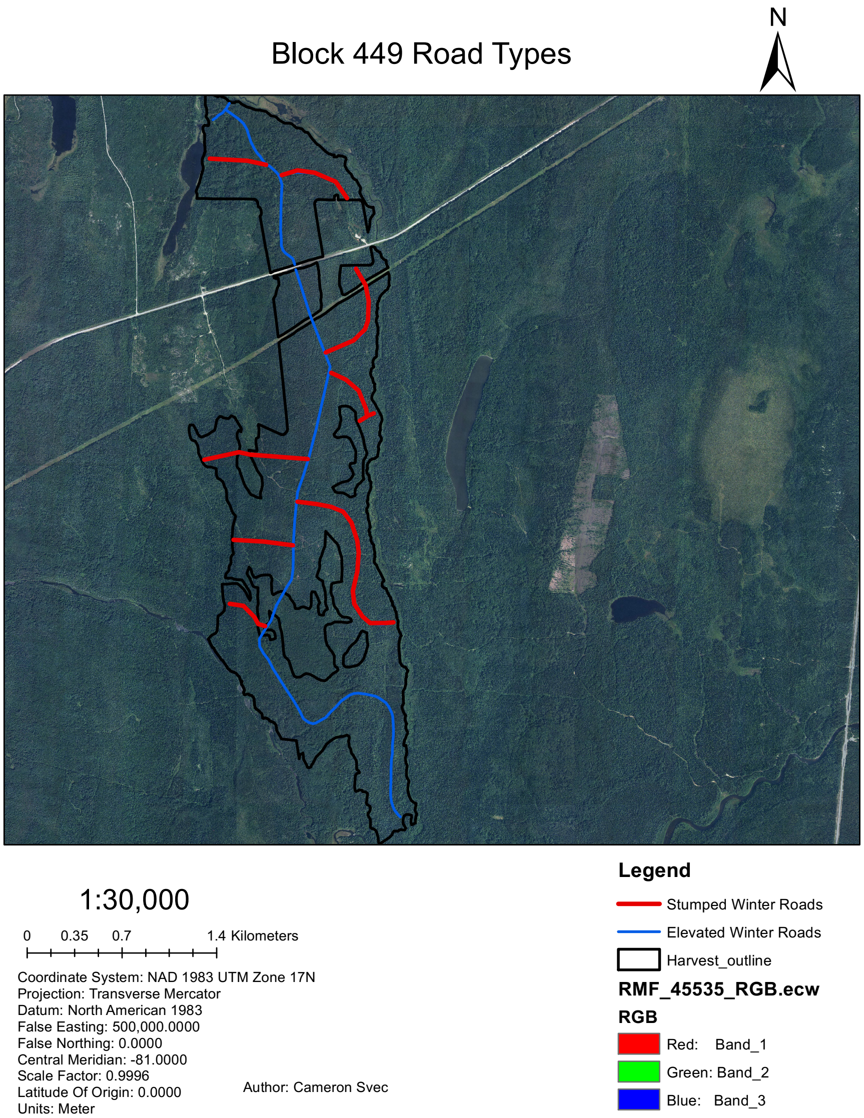

Figure 21. Road network construction method for scenario one on block 449

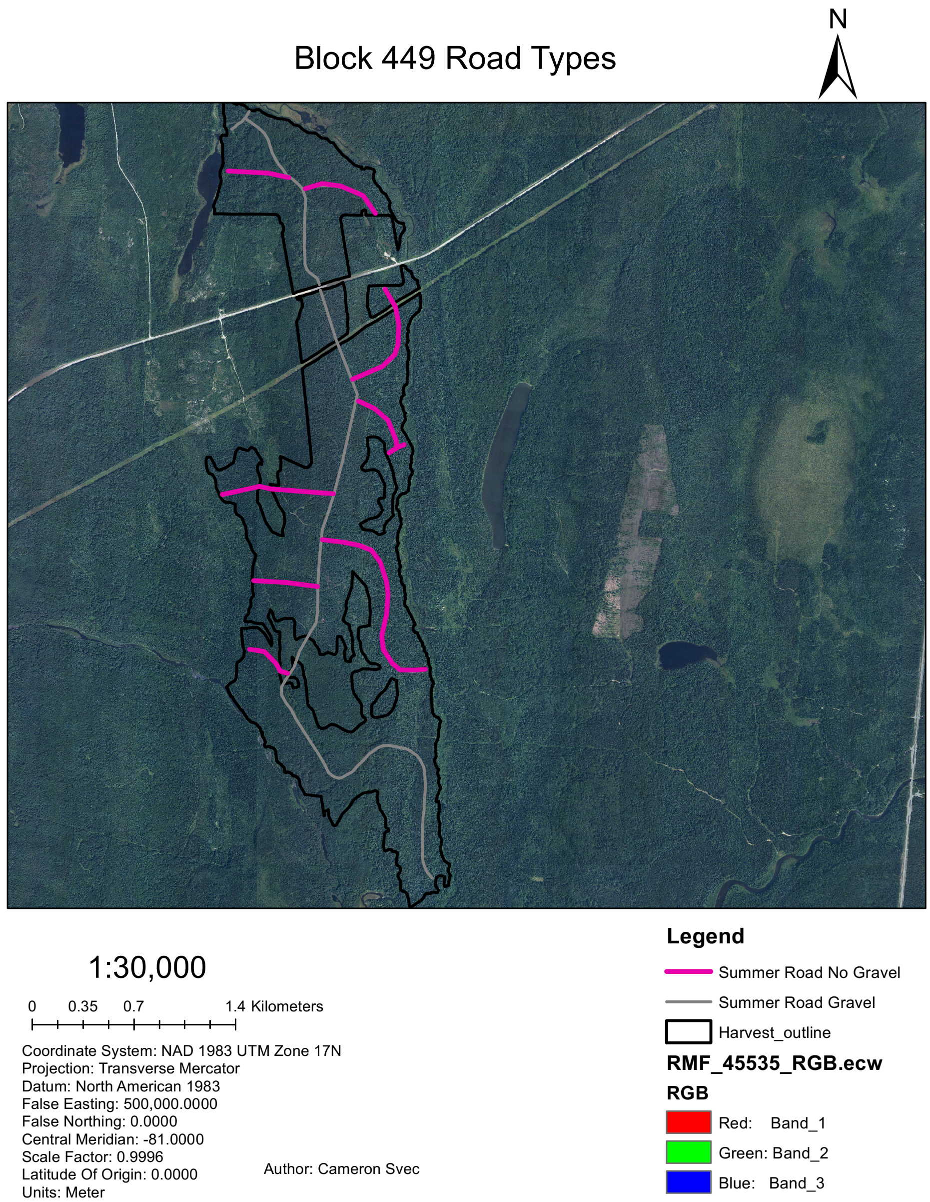

Figure 22. Road construction method for scenario two on block 449

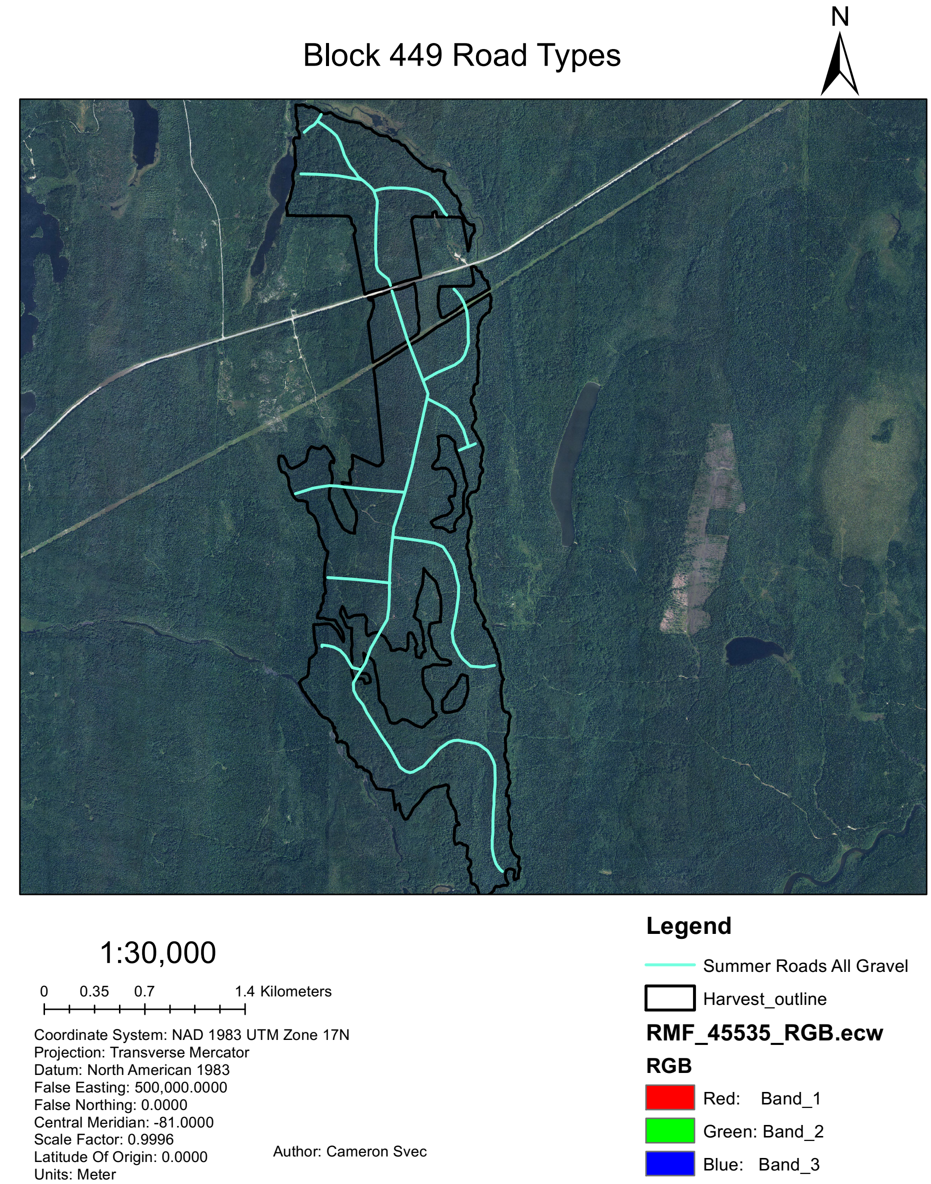

Figure 23. Road construction method for scenario three on block 449

8.5 Appendix V

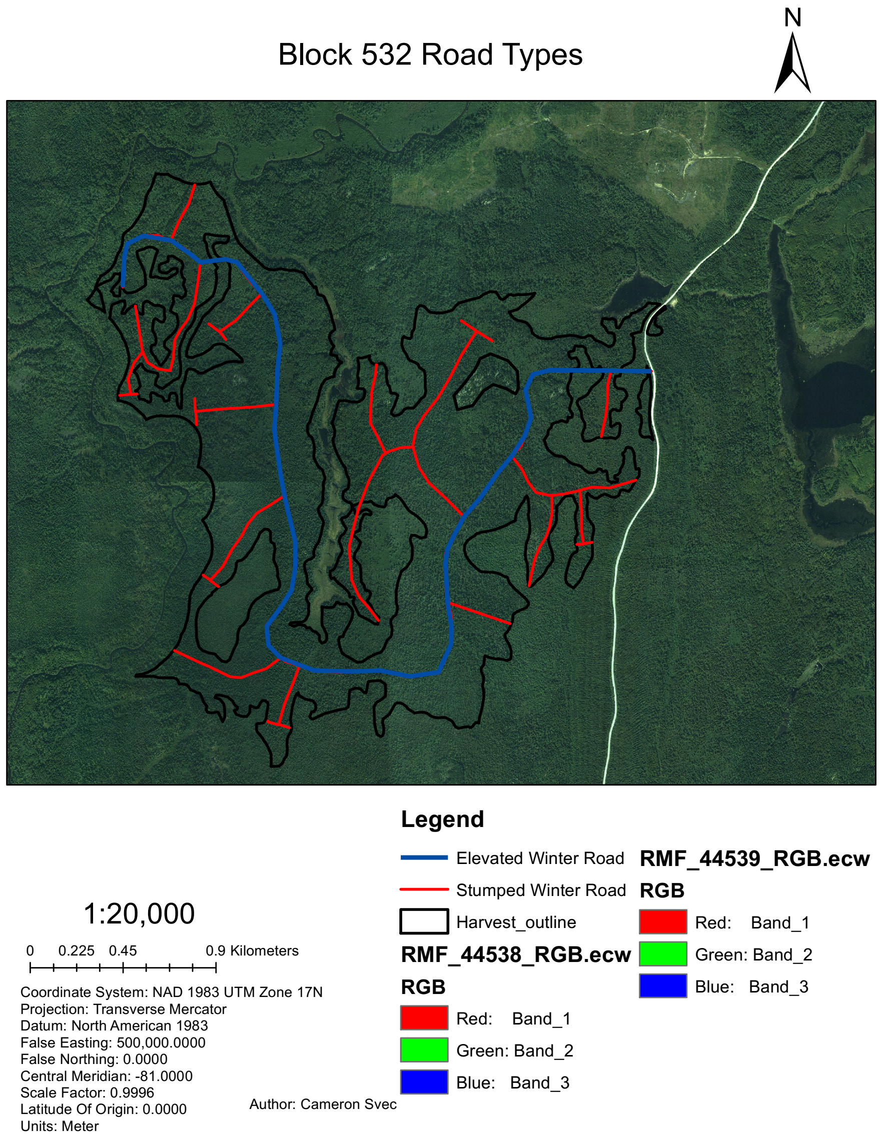

Figure 24. Road construction method for scenario one on block 532

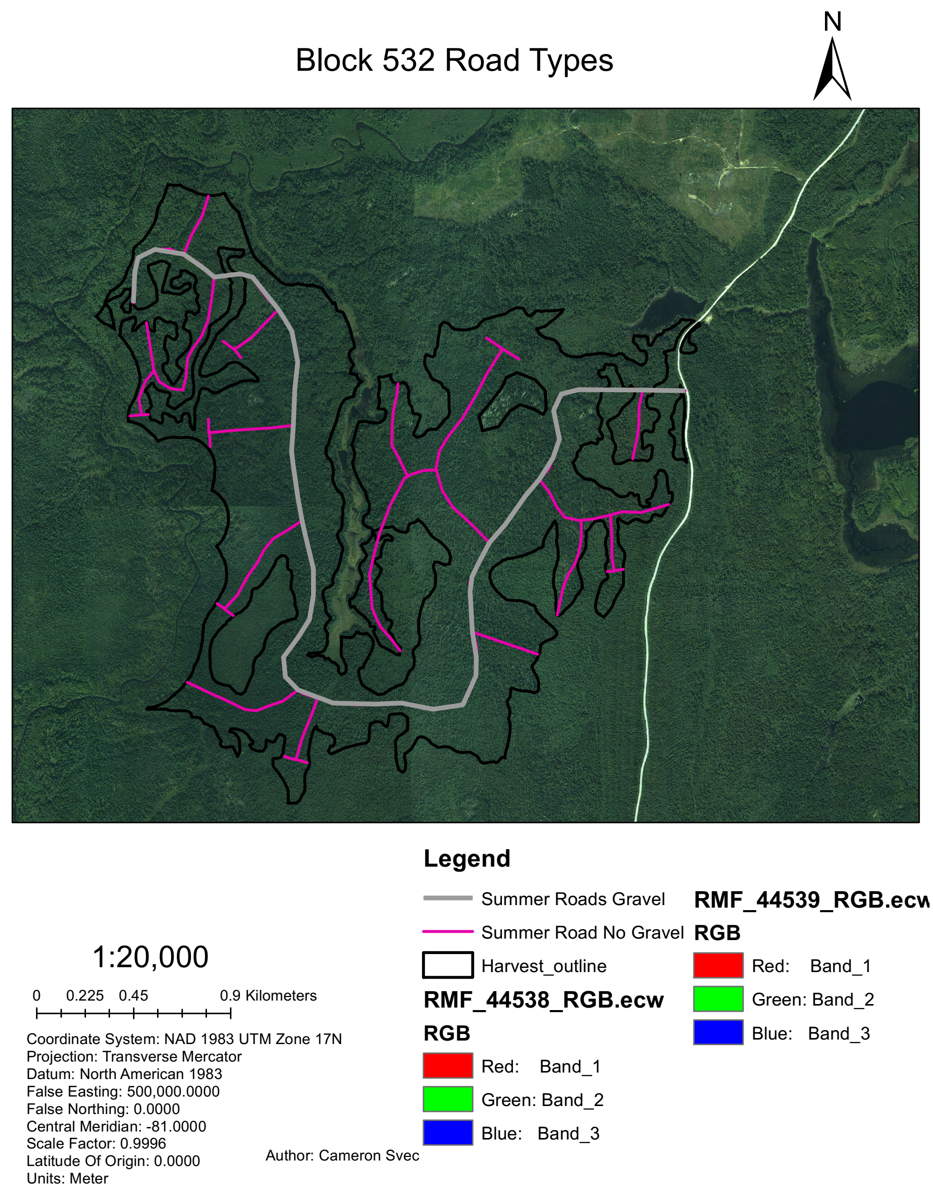

Figure 25. Road construction methods for scenario two on block 532

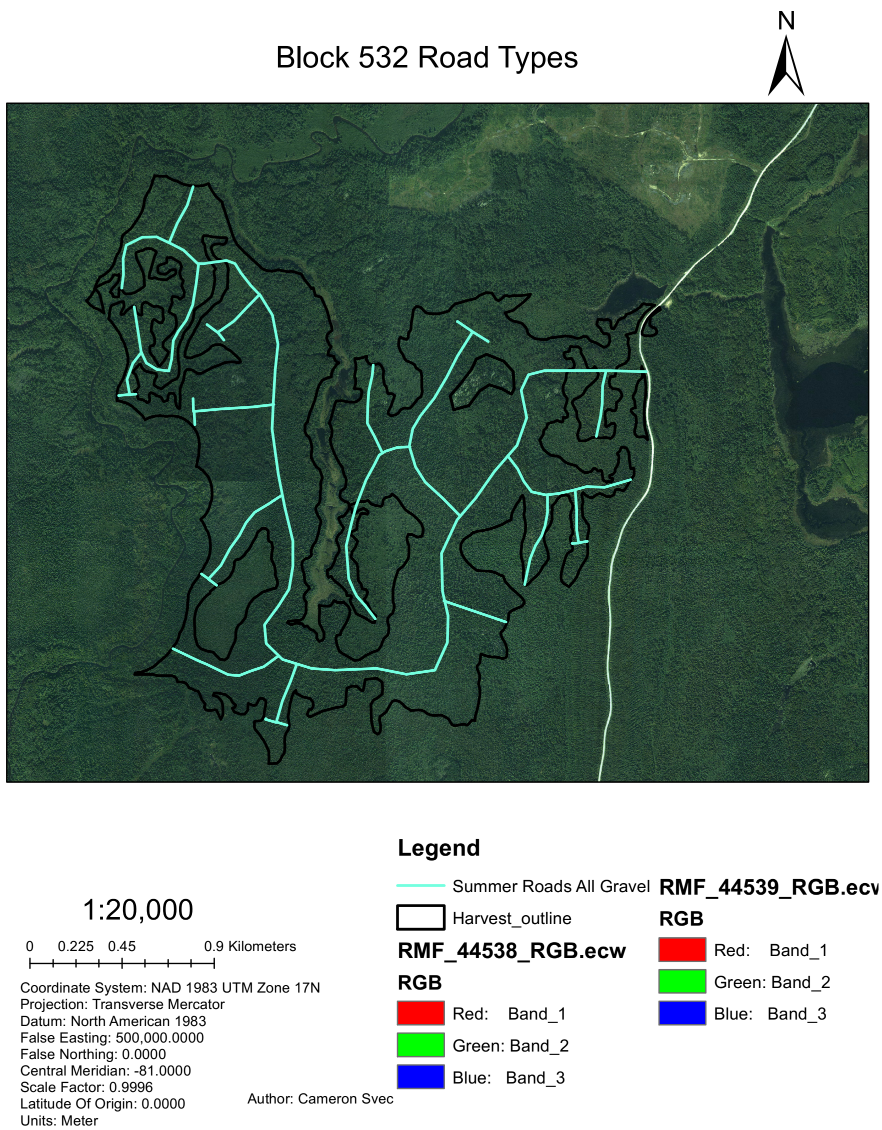

Figure 26. Road construction method for scenario three on block 532

8.6 Appendix VI

Table 4. Costs used when calculating construction costs

Road Type	$/km	$/100m
Summer Road	10,500	1,050
Raised Winter Road	7500	750
Stumped Winter Road	6000	600

Gravel	$/km	$/100m
1 km from pit	6500	650
2 km from pit	7500	750
3 km from pit	8500	850
4 km from pit	9500	950
5 km from pit	10500	1050
6 km from pit	11500	1150
7 km from pit	12500	1250
8 km from pit	13500	1350
9 km from pit	14500	1450
10 km from pit	15500	1550

Crossings	$/crossing
Summer	6000
Winter Snow Xing	1000