Report 2.2

Overview Assessment of Historic and Current Land-use Activities in Selected Foothills Model Forest Watersheds

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December 06, 2002

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Abstract

Land-use activities including timber harvest, road construction and oil and gas exploration may have direct or indirect effects on aquatic resources. As a result of a long-standing practice of maintaining streamside buffer strips during forest harvest, direct effects within the study area are mainly limited to road construction.

Indirect effects of land-use were thought to be mainly related to changes in peak flow associated with forest clearing. In other areas of western North America where watersheds are dominated by snowmelt run-off events, increases in peak flows have been associated with increased stream channel instability and subsequent loss of aquatic habitat quality. With the importance of summer-storm runoff events in the study area, this indirect relationship between forest clearing and increased channel instability cannot be inferred.

In order to provide an opportunity to determine if changes in aquatic resources were related to direct or indirect effects of land-use, we created a number of land-use indices including extent of harvest, road density, and seismic line density. The indices were calculated for current conditions as well as for a benchmark year that corresponded to the date of historical fish inventory studies. The levels of harvest and road development varied between the 15 watersheds both at the benchmark and current year.

Acknowledgements

In 2002, this project was funded through a partnership that included the Alberta Conservation Association (ACA), Weldwood of Canada Ltd. (Hinton Division), and the Canadian Forest Service. The funding from Weldwood was made available through the Forest Resources Improvement Program. Additional support for this Foothills Model Forest project was received through Alberta Sustainable Resource Development and Jasper National Park.

We would like to thank staff members from Weldwood of Canada Ltd. (Hinton Division), including Rick Bonar and Chris Spytz, for providing review of project design, and for their support. Foothills Model Forest employees who contributed to this project included Christian Weik, Julie Dugas, Chantelle Bambrick, Scott Wilson, and Fran Hanington. Keith Campbell of Campbell Forestry Consultants participated in the historical road analysis. Bill Tinge, Land Management Forester, Alberta Sustainable Resource Development, provided a review of the province's disposition data management process.

Table of Contents

List of Tables

List of Figures

1. Introduction

Understanding and evaluating the effects of land-use activities on aquatic resources is an important component of sustainable forest management. Aquatic resources, including fish habitat, fish populations, and clean water, are important resources in the forest management equation. Land-use activities within the Foothills Model Forest (FMF) include gravel extraction, road construction, mining, timber harvest, and oil and gas exploration. These land-use activities may have direct and indirect effects on aquatic resources.

Direct effects of land-use activities include sedimentation from road runoff and clearing of riparian areas. During rain events or spring run-off, sediments from road surfaces and ditches may enter a body of water causing sedimentation and eventually degrading the aquatic ecosystem. Sediments that deposit within gravel and cobble substrates, decrease salmonid spawning productivity and decrease the quality of habitat for macroinvertebrates, which serve as food for many fish species (McGurk and Fong 1995). Clearing riparian areas can cause direct impacts to streambanks and loss of long-term large woody debris supply, which can reduce fish habitat diversity and productivity. In the Weldwood FMA, ground rules in place since the 1950's when forest harvest began have required maintenance of streamside buffer strips (Bonar 2002). As a result, impacts associated with clearing riparian areas have generally been limited to road/stream crossings.

Indirect effects of land-use include changes in peak flows and subsequent channel instability. Timber harvesting can result in an increase in annual water yield as a result of the reduction in the uptake and transpiration of water from the soil (Klapproth and Johnson 2000). Trees intercept snow and allow for slowed snowmelt, evaporation, and sublimation in the canopy. The cutting and removal of trees disturbs soil and exposes it to the sun's radiation, ultimately increasing the rate of snowmelt and runoff potential into aquatic ecosystems (MacDonald et al. 1990). This increase in runoff may contribute to a resizing of the stream channel through bank erosion and scour (Hogan and Ward 1997). Recent research has confirmed that these riparian sediment sources are often the dominant sediment source within glaciated basins in Canada (Ashmore et. al. 2000).

Although forest harvest activities that occur in snow-melt dominated basins are known to impact peak flows and channel stability (Hogan and Ward 1997), hydrological studies within the FMF have suggested that harvest related changes to peak flow are not substantial because summer-storm runoff events dominate regional foothills hydrographs (Swanson 1997). Runoff events during these summer storm events are not influenced by the decreased evapotranspiration associated with forest clearing (Swanson 1997). However, this suggested lack of association between forest clearing, increased peak flows, increased channel stability and subsequent habitat impacts has yet to be substantiated in the region.

Strategies for evaluating the effects of forestry and other land-use activities include monitoring channel disturbance from increased peak flows, sediment loads and annual water yield. However, these factors are inherently expensive and difficult to quantify (MacDonald et al. 1990). Therefore we selected a number of indices, which could indicate potential effects of various activities on aquatic ecosystems. For this overview assessment, these indices were calculated using existing information. Collection of land-use data through remote sensing or other activities was beyond the scope of this study. These indices were used to describe both historic and current land-use conditions in each watershed. To enable a comparison between land-use and fish populations, the benchmark year for historic land-use description corresponds to the date of historic fisheries inventories (McCleary et al. 2002).

2. Methods

The study area is comprised of 15 monitoring watersheds within the FMF. All or part of each watershed is located within the Weldwood FMA (Figure 1). The Tri-creeks watershed includes adjacent watersheds of Eunice, Wampus, and Deerlick creeks, respectively. Watershed and stream characteristics within each basin are described in detail in Report 2.4, Watershed and Stream Classification.

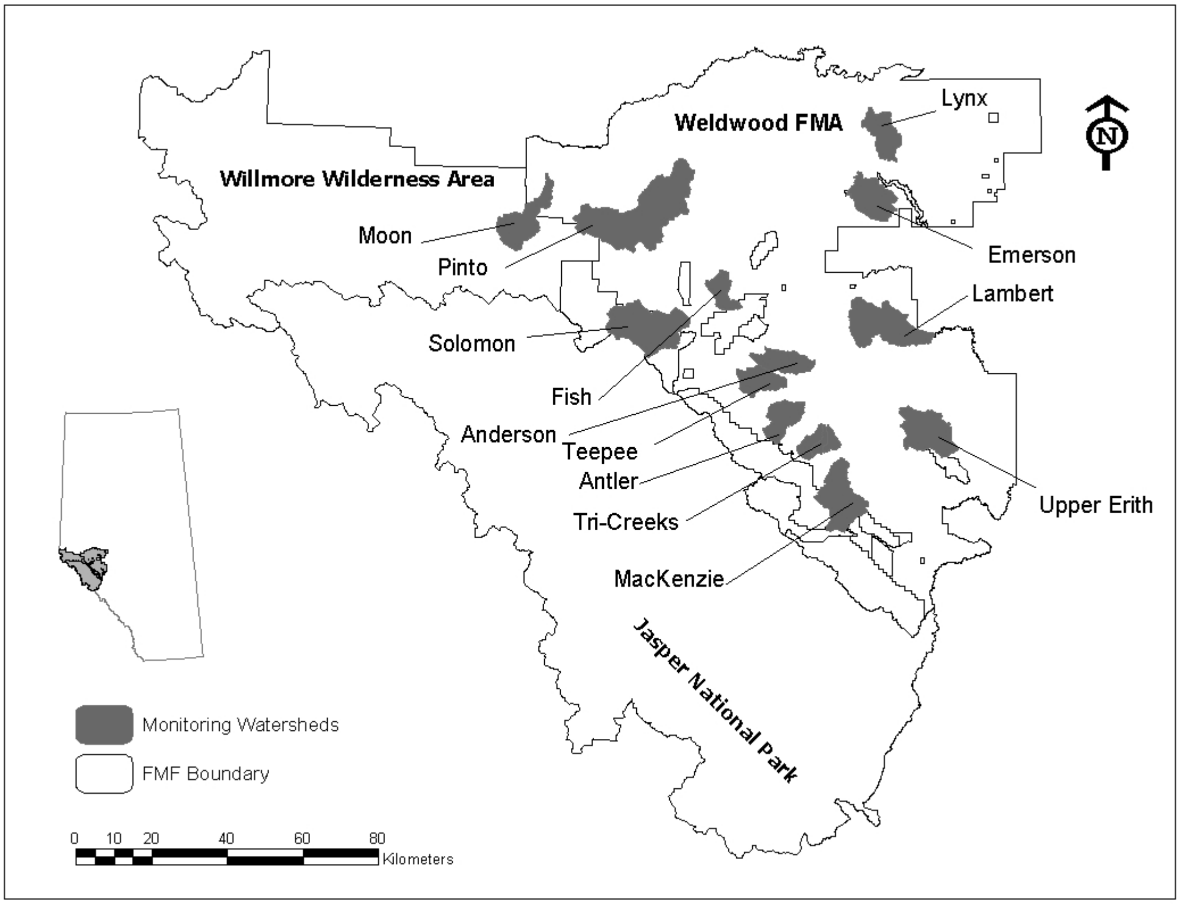

Figure 1. Monitoring watersheds within the Foothills Model Forest.

Using existing information, a number of indices were calculated to describe the current biophysical and land-use characteristics, and historic land-use conditions within each watershed. The indices and the methods used to calculate them are described below. Both tables and maps are provided to illustrate the biophysical and historic and current land-use conditions for each monitoring watershed within the Weldwood FMA.

The following are digital data sources, used in GIS to derive the historic and current indices:

1. Alberta Vegetation Inventory (AVI). AVI information was gathered through the Forest Cover Inventory Project (Weldwood 1999).
2. 2001 Orthographic Photos – Provided by Weldwood (2002).
3. Cut History - Weldwood provided road layers in two different data sets; all blocks up to and including 1999 and 2000 cut blocks.
4. Roads Layer – Provided by Weldwood (2001)

5. Seismic Line Layer – Provided by Weldwood (2001)
6. Lands and Provisional Layers – Dispositions and Reservations (Weldwood).
7. Ecoregion (Provincial data set - Alberta Government)
8. Land Status Automated System.

2.1 Background on Disposition Data Management within Provincial Lands within the Foothills Model Forest

Weldwood maintains records of historic harvesting activities, which were made available for this study. Historic road information was not as readily available. However, with an understanding of disposition data management, a methodology for extracting historic road information was developed.

Any agency interested in building a permanent road on Alberta public lands must first obtain a disposition called a License of Occupation (LOC), which is issued through Alberta Sustainable Resource Development (ASRD). Within their Forest Management Agreement (FMA), Weldwood is defined as an occupant of the public lands and therefore any agency interested in building a permanent road on those lands must first obtain Weldwood's permission. As a result of the dual management scenario within the Weldwood FMA, both ASRD and Weldwood maintain a record of all dispositions including permanent roads, pipelines and powerlines.

ASRD has developed the Land Status Automated System (LSAS), which maintains a record of all dispositions including permanent roads, well sites, pipelines, powerlines and other features. Although both energy sector companies and forestry sector companies must currently obtain an LOC for all permanent roads, historically many of the permanent roads built by the forest sector were approved as part of a company's annual operating plan. As a result, the LSAS contains accurate disposition information, including the date of application, for all energy sector permanent roads, however it may not contain the initial date of application for forest sector roads. One other limitation of the LSAS for determining history of road development is the method of storing disposition location data. This information is stored as the legal land description and there is no spatial information, such as a map, that is linked directly to the LSAS.

Weldwood has incorporated key information from the LSAS into their own roads database. Using GIS, this database was linked to a map of all road segments within the FMA. Weldwood titled this information as the Lands and Provisional Layer –Dispositions and

Reservations. With the extensive energy sector activities within the FMA, a certain road disposition may change hands between several companies over time. Therefore, Weldwood updates the information regularly and the records of all previous dispositions for any given road are maintained on file. Although the date of application for historic forest sector roads may not be contained within the Lands and Provisional Layer or the LSAS, permanent roads are typically constructed one to three years prior to logging. Therefore the approximate date of construction can be determined by referring to the year of harvest of the cut blocks that a particular permanent road was built to access. Harvest date information is contained in the Weldwood Cut History Layer.

In conclusion, historic and current permanent road information can be obtained by referring to the LSAS, the Weldwood Lands and Provisional Layer and the Weldwood Cut History Layer.

2.2 Biophysical Descriptors (Current)

2.2.1 Watershed Area (km^2)

Watershed boundaries were derived from DEM and stream network data using a GIS tool developed by the FMF (FMF 1998). Watershed area includes the total area of each monitoring watershed within and outside the Weldwood FMA. Watershed area within each boundary was calculated in Arcview 8.2 (ESRI 2002) and data was managed with Microsoft Access 2000.

2.2.2 Monitoring Watershed ID

Each monitoring watershed was given an arbitrary number for easy identification. Numbers were assigned to each watershed starting from the most northerly geographic location to the furthest southerly watershed within the Weldwood FMA (i.e. Lynx Creek watershed is the most northerly watershed, and thus given the ID # 1, and McKenzie watershed is geographically the most southern watershed within the FMA, and thus given the ID # 15, respectively).

2.2.3 AVI Area (km^2)

Defined as the area of each monitoring watershed that contains AVI data. AVI data covered those areas within the Weldwood FMA. GIS analysis was completed using ArcMap 8.2 (ESRI 2002) and data was managed with Microsoft Access 2000.

2.2.4 Percent Watershed with AVI

The area of each monitoring watershed that fell within the Weldwood FMA divided by the total watershed area, and then multiplied by one hundred.

2.2.5 Percent Watershed Outside FMA

Expressed as a percentage of the monitoring watershed area outside the Weldwood FMA. This is the area for which no AVI data was assigned.

2.2.6 Dominant Ecoregion Outside FMA

Characterizes the area outside the AVI coverage within each monitoring watershed. The dominant ecoregion was assigned for the unclassified portion of each watershed with less than one hundred percent AVI coverage. Potential ecoregions include Subalpine, Upper Foothills, Lower Foothills, and Montane, respectively. The dominant ecoregion was determined from the Alberta Government ecoregion dataset for the province.

2.2.7 Area Natural Non-Forest (km^2)

Defined as natural cover types that have <6% vegetation cover or lands which have ≥6% vegetation cover but < 6% tree cover (Nesby 1996). Natural non-forest areas are defined as either non-forest vegetated, water bodies or mineral exposed lands. Non-forest vegetated lands consist of shrub and herbaceous dominated plant communities. Water bodies include permanent ice/snow, streams, rivers, and lakes. Mineral exposed lands are comprised of burn areas, barren rock, sand, cutbank, and exposed mineral or gravel layers (Nesby 1996).

Large portions of natural non-forest areas are non-forested wetlands. The extent of wetlands is important when considering basin wide hydrological impacts because non-forested wetland areas that border streams can have high sediment and peak flow attenuation capacities (Price and Waddington 2000). Therefore, these areas may potentially provide some buffering capacity for upstream forestry related impacts.

2.2.8 Percent Natural Non-Forest

Each area derived from the above criteria expressed as a percentage of the AVI area. Area naturally non-forest was divided by AVI area and multiplied by one hundred.

2.2.9 Area Commercial Forest (km^2)

Commercial forest was the area within each watershed that could potentially be utilized for timber harvest within the Weldwood FMA. Commercial forest does not contain natural non-forested areas, non-commercial forest areas (see 2.1.11 below), and total area anthropogenic (see 2.2.1 below). GIS analysis was completed using ArcMap 8.2 (ESRI 2002) and data was managed with Microsoft Access 2000.

It is important to note that this area does not necessarily mean it will be harvested. Several other factors work to reduce the contributing area of potential commercial forest harvest including excessively steep terrain, highly sensitive riparian areas and protected areas.

2.2.10 Percent Commercial Forest

The sum of area commercial forest divided by the AVI area and multiplied by one hundred. Analysis was accomplished using ArcMap 8.2 (ESRI 2002) and data was managed with Microsoft Access 2000.

2.2.11 Area Non-Commercial Forest (km^2)

Defined as the land area containing stands of black spruce/larch yield group and non-forest areas (Nesby 1996). GIS analysis was completed using ArcMap 8.2 (ESRI 2002) and data was managed with Microsoft Access 2000.

These areas are unable to support commercial forest typically because their wetland characteristics make them unsuitable for silviculture. As the extent of non-commercial forest within a basin increases, so does the importance of groundwater drainage over surface water drainage. Although channel instabilities resulting from increases in peak flow have been documented in surface water dominated drainages, this connection in groundwater dominated areas has not been established.

2.2.12 Percent Non-Commercial Forest

The sum of Non-Commercial Forest area divided by the AVI Area and multiplied by one hundred.

2.3 Historic Land-use Indices

2.3.1 Benchmark Year

For most of the monitoring watersheds, fish population information from historic inventory projects was available (McCleary and Nelin 2002). For simplicity, benchmark years all begin at the year 1950 and end at the year for which historical fish population data is known (Refer to chapter 1.1).

2.3.2 Harvested Area (km^2)

Historic harvest area includes blocks cut from 1950 to the corresponding benchmark year for each watershed. This information was provided in the Weldwood cut history dataset. According to Weldwood some blocks cut prior to 1994 were missing from the dataset. Therefore, 2001 orthographic photos were used to confirm the extent of historical harvest within each watershed. Cut blocks were displayed within each monitoring watershed and total harvest area was calculated using Arcview 8.2 (ESRI 2002) and managed with Microsoft Access 2000.

2.3.3 Percent Harvested

The total area of all cut blocks harvested (between the benchmark years) within each monitoring watershed divided by the AVI area and multiplied by one hundred.

2.3.4 Total Kilometers of Road

Defined as permanent roads of Class 1, 2, 3, and 4-A (Table 1) that were present during the benchmark year for each watershed. This recognizes that wide ranges of other roads existed in each monitoring watershed, but were temporary in nature (class 4-B and 5 roads).

Table 1. Summary of road guidelines (adapted from Weldwood 2002).

Road Class	Intended Term of Use	Max. Clearing Width (m)	Road Abandonment	Access Control
I	Permanent	40	Remove all crossing structures, additional erosion control measures implemented and active maintenance as required.	As Legislated
II	Permanent	40	See Class I	As Legislated
III	Permanent	35	See Class I	As Legislated
IV-A	Permanent	35	See Class I	Based on Wildlife Concerns
IV-B	Temporary	8 to 20	See Class I	Based on Wildlife Concerns
V	Temporary	8 to 20	See Class I	Based on Wildlife Concerns

Construction and deactivation of temporary roads is standard practice during timber harvest. Although temporary roads may have affected aquatic resources, they were not considered in this analysis. However the measurement of permanent roads provided a consistent index of road development between the different watersheds. The task of quantifying the level of road development for all current and historic roads of all classes was beyond the scope and resources available for this project.

Historic road data was obtained using five different sources of information including:

1. Weldwood 2001 Orthographic Photos.
2. Weldwood Cut History.
3. Weldwood 2001 Roads Layer.
4. Weldwood Lands and Provisional Layer – Dispositions and Reservations.
5. Land Status Automated System (LSAS).

First, using ArcGIS 8.0, we displayed all road information contained in the Weldwood 2001 Roads Layer along with the 2001 orthographic roads layer. For the purpose of this report, roads with a clearing width of less than 20m were considered temporary and were removed. Then we digitized any additional roads with a clearing width of greater than 20m.

To confirm which of the roads were present at the benchmark year for each watershed, we queried the Weldwood Lands and Provisional Layer for the year that the LOC was applied for. If a section of road with a known year of application was isolated by another section of road without a known year of application, the road with the unknown date was assigned an application date of the road with the known date. The LOC application date was generally available for energy sector roads and some forest sector roads. To determine the age of the remaining roads, we assumed the date of construction as one year before harvest was initiated in the portion of the watershed, which the road accessed. The year of application was two years before harvest.

2.3.5 Index of Road Density

Expressed as the total length of class 1, 2, 3, and 4-A roads divided by the AVI area of each monitoring watershed (km^2).

2.4 Current Land-use Indices (2000 - 2001)

2.4.1Total Area Anthropogenic (km^2)

Defined as lands that have been influenced or altered by human activity. Lands are typically separated into either anthropogenic vegetated or non-vegetated areas (Nesby 1996). Total area anthropogenic includes both vegetated and non-vegetated lands of the following criteria: Anthropogenic vegetated lands include agricultural areas or croplands and industrial lands include areas such as pipelines, well sites, and unknown clearings. Anthropogenic non-vegetated lands include cities, towns, or ribbon development, permanent highways, right-of-ways, railroads, gravel roads, gravel pits, farmsteads, mines, other industrial sites, and water reservoirs or lagoons (Nesby 1996).

It should be noted that total area anthropogenic is based solely on the AVI designation of anthropogenic areas, and does not include harvested areas. Permanent or temporary roads may have been included if AVI designated those roads as anthropogenic during the time of survey.

2.4.2 Percent Total Anthropogenic

Each area derived from the above criteria expressed as a percentage of the AVI area. Total area anthropogenic divided by the AVI area and multiplied by one hundred.

2.4.3 Harvest Area (km^2)

Weldwood provided historic cut block information in two different layers, one included cut history up to and including 1999, and the other was cut blocks for the year 2000. These two layers were appended to derive a total harvested area for each monitoring watershed. According to Weldwood some blocks cut prior to 1994 were missing from the dataset. Therefore, 2001 orthographic photos were used to confirm the extent of historical harvest within each watershed. Cut blocks were displayed within each monitoring watershed and total harvest area was calculated using Arcview 8.2 (ESRI 2002) and managed with Microsoft Access 2000.

2.4.4 Percent Harvest

The total area of all cut blocks within each monitoring watershed divided by the total watershed area and multiplied by one hundred.

2.4.5 Total Kilometers of Road

Total kilometers of road includes those roads under road class 1, 2, 3, and 4-A types (Table 1). Roads that are considered class 4 were included in analysis if the road clearing area was greater than 20 meters. To determine current roads, we followed the same procedure as historic roads, only we did not include roads with a clearing width of greater than 20m if they were classified as Class 4B or 5 in the Weldwood roads database (indicating that they had been deactivated). As with historic roads, we recognize that a wide range of other roads exist in each monitoring watershed, including temporary and deactivated roads. However, these criteria provide a consistent index of road development between the different monitoring watersheds. In addition, our target audience for this study includes the local resource managers from Weldwood and ASRD. By using the same system for describing roads that they use on a daily basis these parties may be able to make the best use of our findings.

2.4.6 Index of Road Density

Expressed as the total length of class 1, 2, 3, and 4-A roads divided by the AVI area of each monitoring watershed.

2.4.7 Kilometers of Seismic Line

Defined as the total length of seismic line in each monitoring watershed. This includes all seismic lines in the digital layer provided by Weldwood. It should be noted that this might include planned seismic lines, which may not exist, or seismic lines that have fully regenerated. It should also be noted that seismic lines are of variable widths, from eight meters to hand cut (Weldwood 2001). GIS analysis was performed in ArcMap 8.2 (ESRI 2002) and data was managed with Microsoft Access 2000.

2.4.8 Kilometers of Seismic Line / Square Kilometer of Watershed

Seismic line density calculated by dividing kilometers of seismic line by the AVI area in each monitoring watershed.

3. Results

The results are presented in three parts. First, maps are presented that illustrate the differences in levels of commercial timber harvest and road development between historic and current conditions. Second, the biophysical, historic and current land-use indices for all watersheds are presented in three individual tables. Third, a summary table is presented to illustrate the changes in levels of harvest and road density in each watershed. Historic information was not obtained for seismic lines. Therefore, seismic lines do not appear on the land-use maps provided, but were included in summary tables instead.

In the McKenzie Creek monitoring watershed, there has been no historic or present timber harvest or road construction/maintenance, thus no biophysical or land-use map was provided. However, some gravel roads do exist within the watershed but are now considered inactive for reclamation purposes. There was a lack of historic fisheries information in Emerson Creek watershed, therefore no benchmark year was identified and historic land-use conditions were not described.

3.1 Historic and Current Land-use Maps

3.1.1 Anderson Creek

By 1974, harvesting had occurred in the northern portion of the watershed and roads had been constructed to harvest the western portion (Figure 2). The current road density in the watershed was relatively higher in 2000 than 1974 (Figure 2 and 3). During the 1980's and 1990's several more square kilometers of commercial forest were harvested (Figure 3). By 2001, harvesting was completed in the western portion and roads in that area was either set as abandoned or deactivated (Figure 3). Road development and first pass harvest within the southern portion of the watershed had been completed.

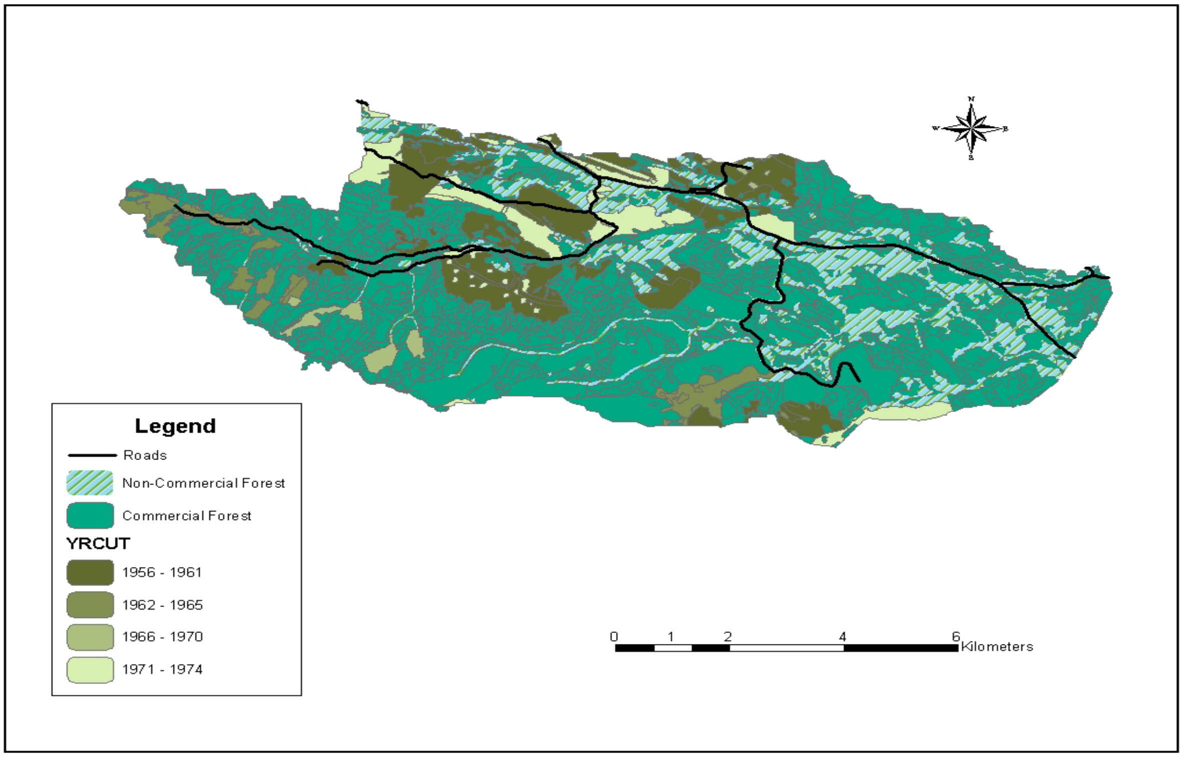

Figure 2. Map of Anderson Creek watershed, illustrating the cut blocks and road network present between the years 1950 – 1974.

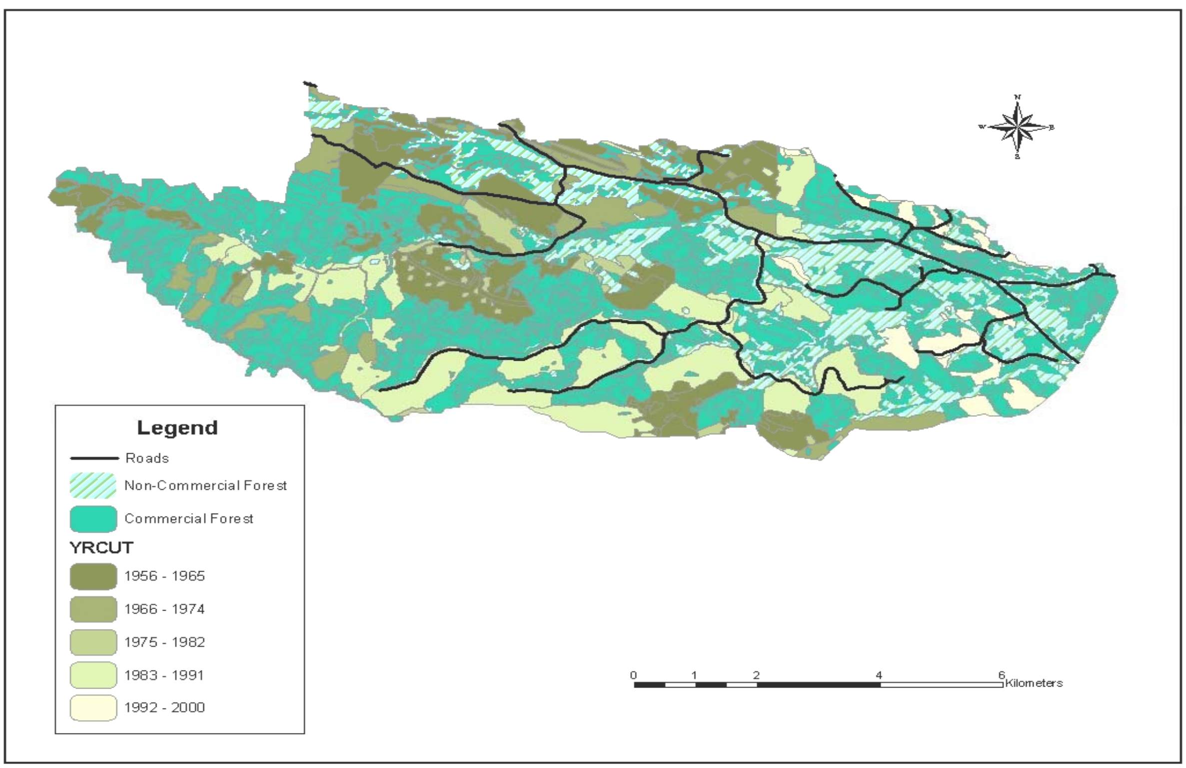

Figure 3. Map of Anderson Creek watershed, illustrating both recent and historic cut-blocks and the current road network between the years 1950 - 2000.

3.1.2 Antler Creek

By 1982, timber harvesting occurred in the western portion of the watershed (Figure 4). Most roads to access these areas were temporary, and information on their current status was unavailable. The road density in the Antler Creek watershed did not change between 1982 and 2000 (Figure 4 and 5). There was an increase in harvesting in the southern area of the watershed during the late 1980's and throughout the 1990's (Figure 5). The roads used to remove the timber were also temporary and no information on their status was available.

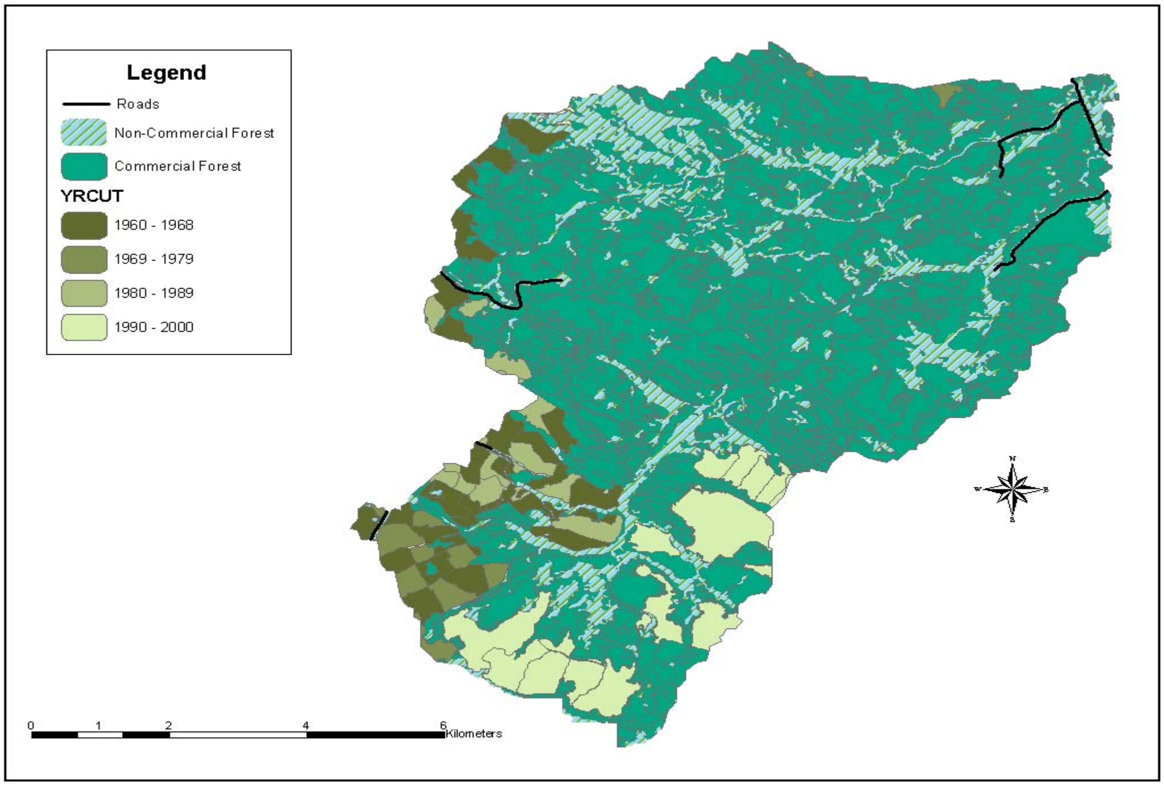

Figure 4 Map of Antler Creek watershed illustrating cut blocks and road network present between the years 1950 – 1982.

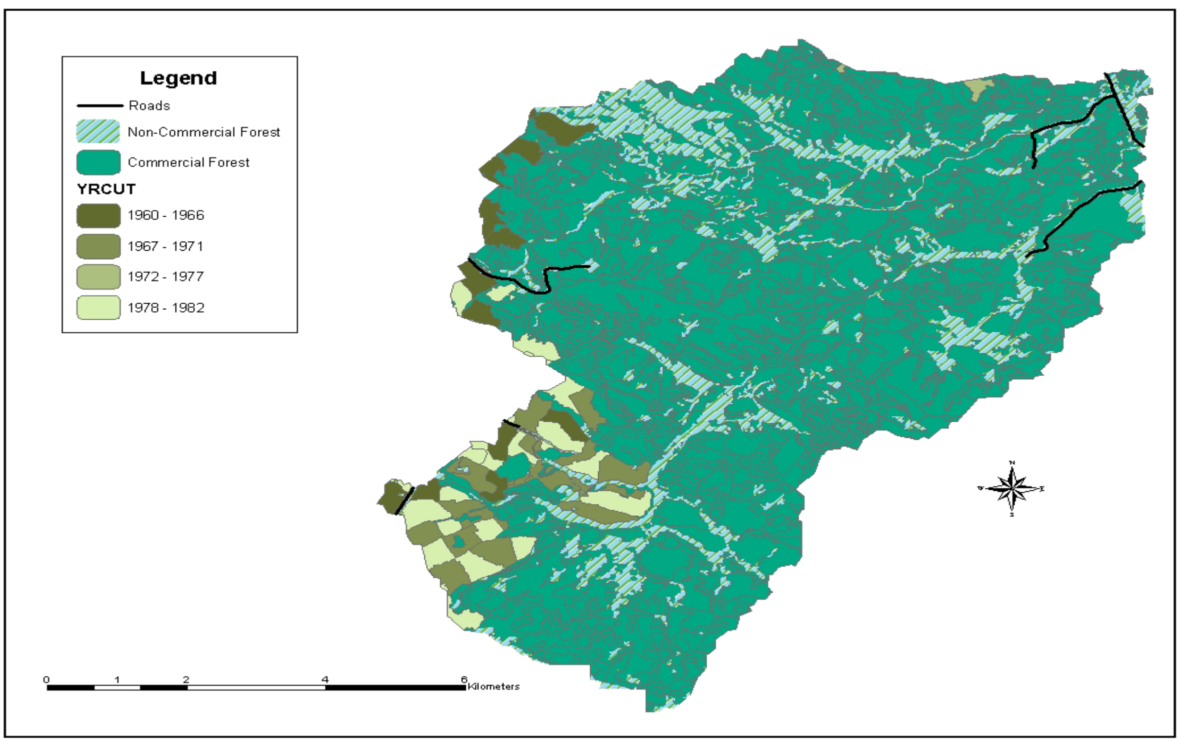

Figure 5. Map of Antler Creek watershed illustrating both historic and recent cut blocks and road network between the years 1950 - 2000.

3.1.3 Fish Creek

Fish Creek watershed provides a good example of the application of the two-pass harvest system. By the benchmark year of 1977, the first pass had been completed and the second pass was initiated (Figure 6). The road density in this watershed has had minimal change over the past 50 years and all of the original roads were still designated as permanent (Figure 7). Most of the commercial forest harvest occurred prior to 1975. However, several cut blocks were added to the watershed during the second pass in the 1980's (Figure 7).

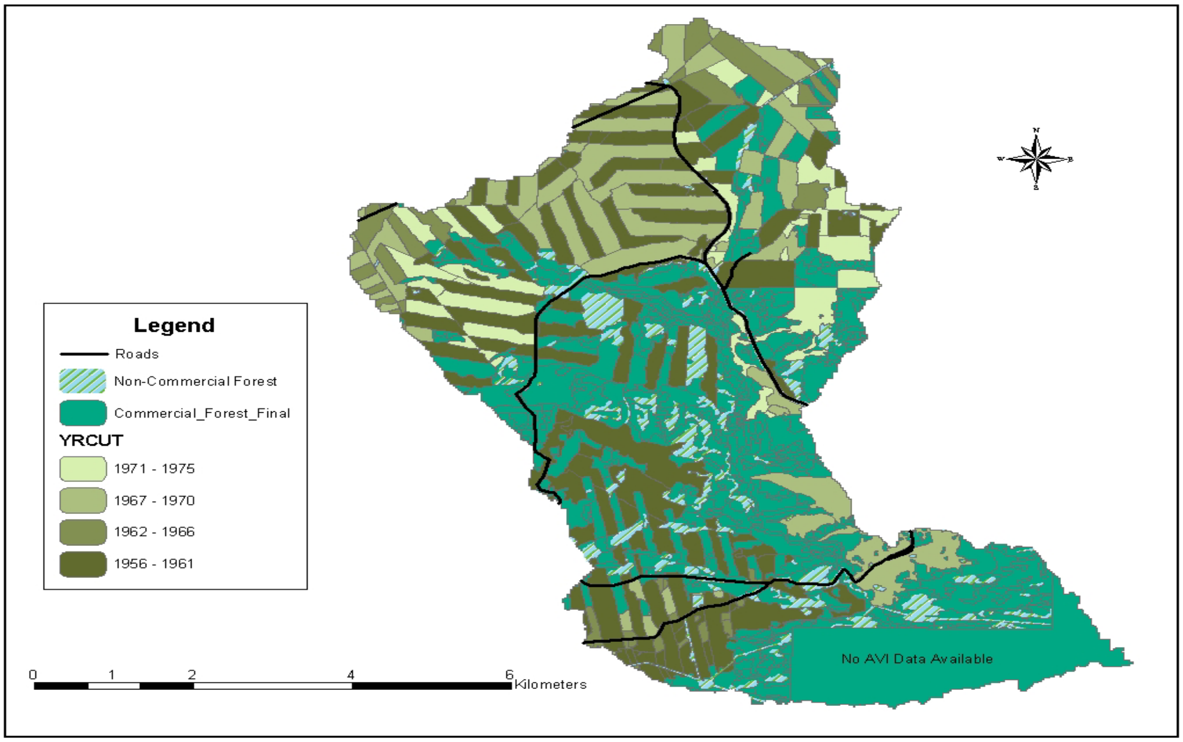

Figure 6. Map of Fish Creek watershed illustrating cut blocks and road network present between the years 1950 – 1977.

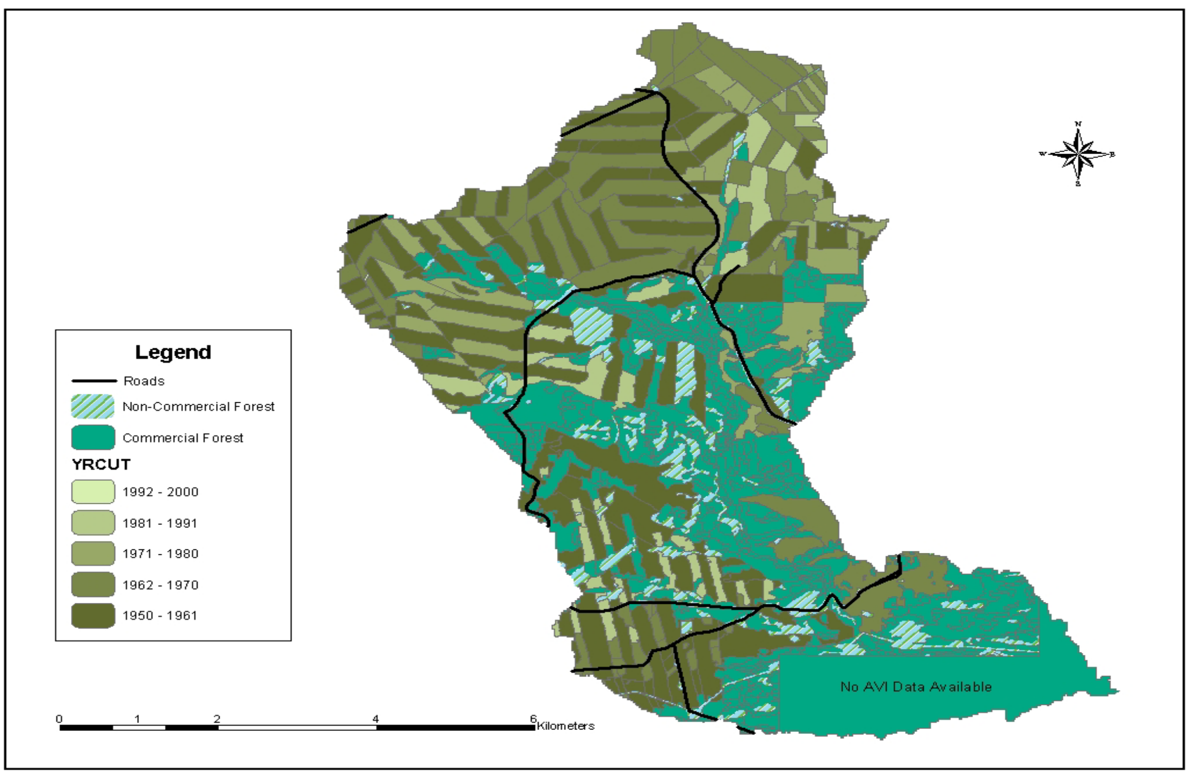

Figure 7. Map of Fish Creek watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 – 2000.

3.1.4 Lambert Creek

Lambert Creek contains widespread areas of non-commercial forest. Although no timber harvest had occurred, road development had been initiated (Figure 8). Timber harvest occurred after the benchmark year of 1979. All harvesting was completed either during the 1980's, 1990's, and year 2000 (Figure 9). After the benchmark year, several kilometers of road were constructed through the southern portion of the watershed.

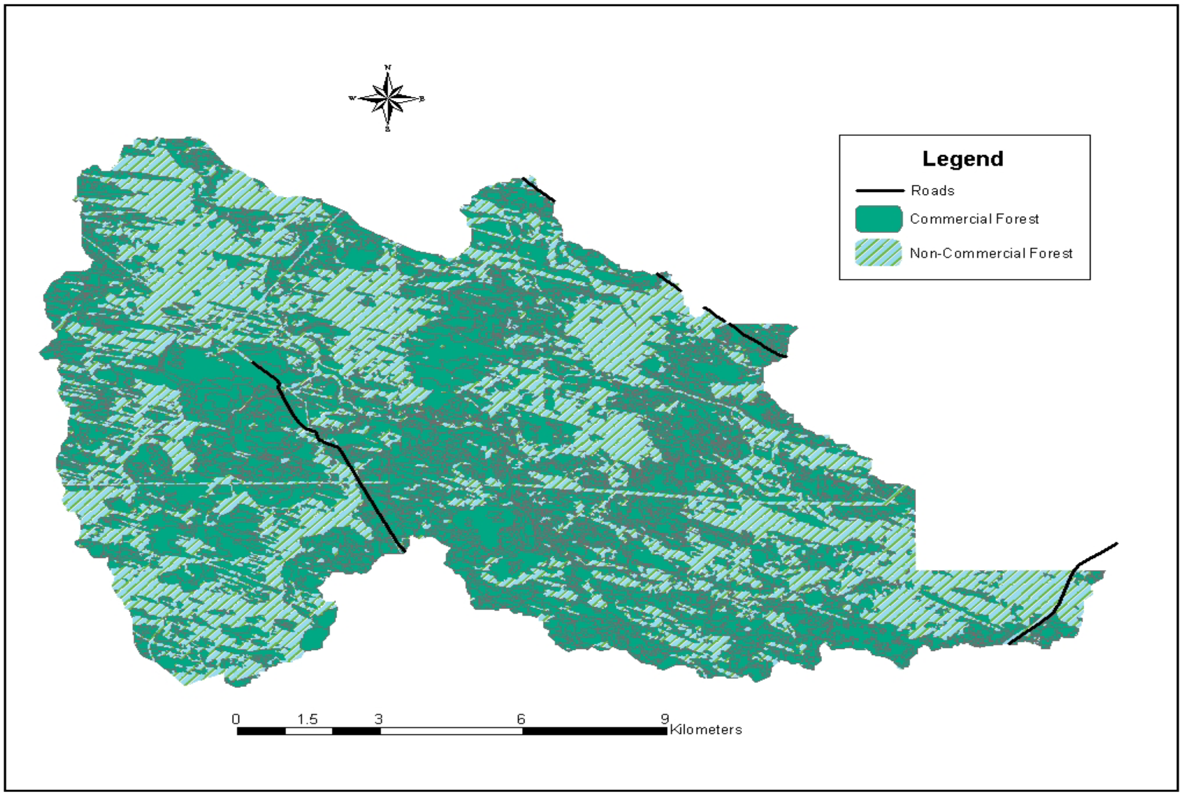

Figure 8. Map of Lambert Creek watershed illustrating cut blocks and road network between the years 1950 – 1979.

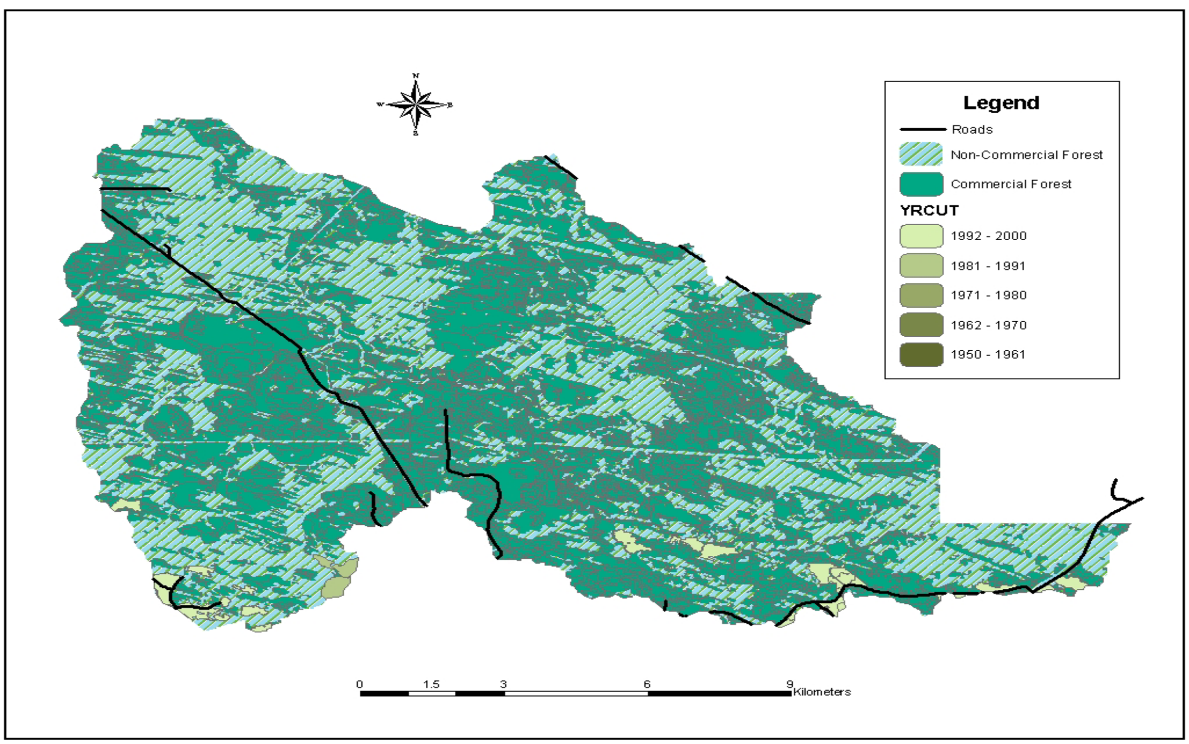

Figure 9. Map of Lambert Creek watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.1.5 Lynx Creek

Lynx Creek contains widespread areas of commercial forest. Prior to 1986 most of the commercial forest harvest was in the northwest section of this watershed (Figure 10). Roads were constructed to access these harvest areas as well as oil/gas well sites. The current road density is relatively higher than what it was between the years 1950 – 1986 (Figure 10 and 11). Several cut blocks were added in the central and southern areas during the 1980’s, 1990’s, and year 2000 (Figure 11). In addition to the roads built for forest harvest, several roads have been built to access well sites.

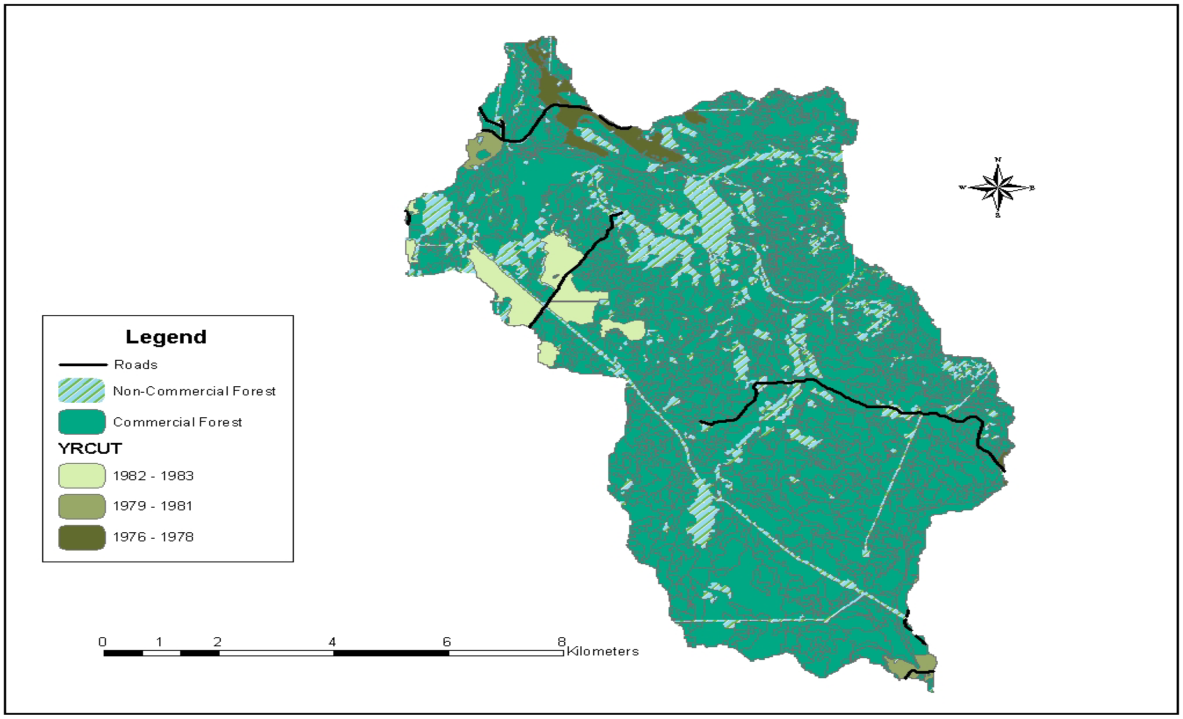

Figure 10. Map of Lynx Creek watershed illustrating cut blocks and road network between the years 1950 – 1986.

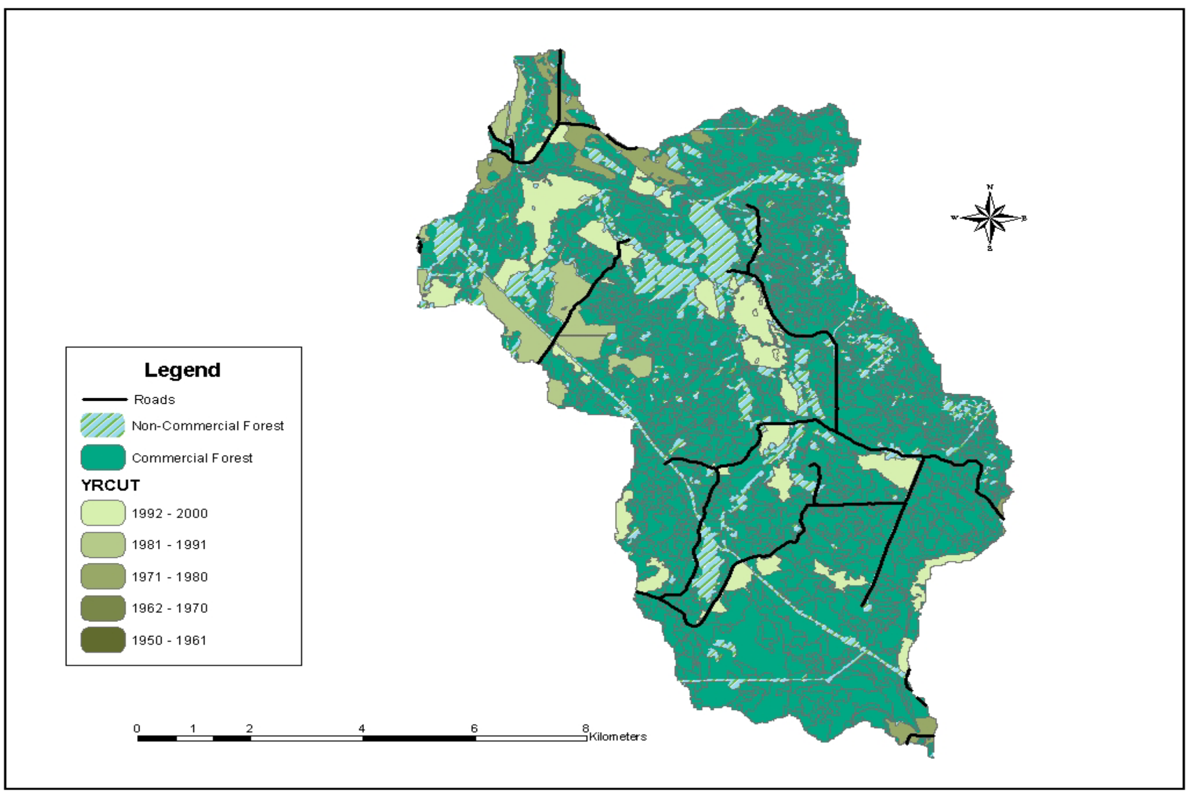

Figure 11. Map of Lynx Creek watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.1.6 Moon Creek

A high percentage of the commercial timber harvest commenced during the 1960's and early 1970's (Figure 12). Most of the roads in the central portion of the watershed were temporary. The road density before the benchmark year of 1985 is relatively higher than the current road system found in this watershed (Figure 12 and 13). There has been minimal commercial forest harvest since the benchmark year of 1985 (Figure 13). Several roads have become deactivated or set for reclamation purposes within this watershed.

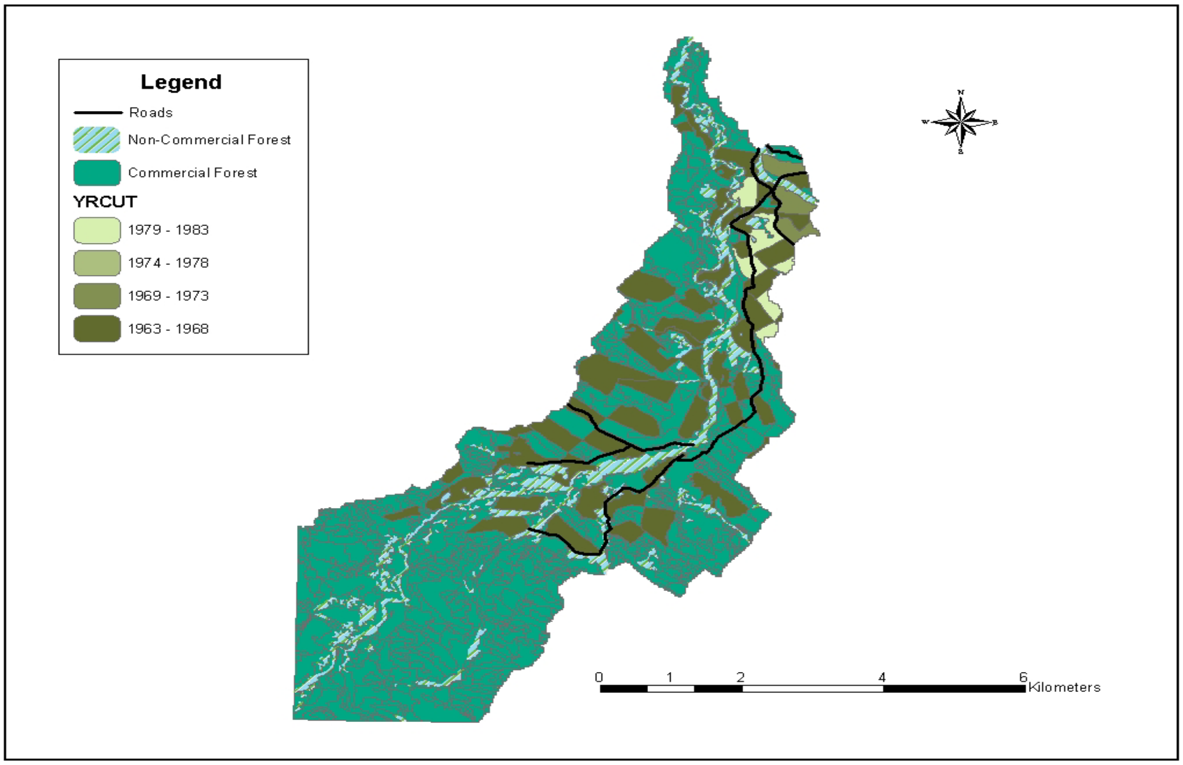

Figure 12. Map of Moon Creek watershed illustrating cut blocks and road network between the years 1950 – 1985.

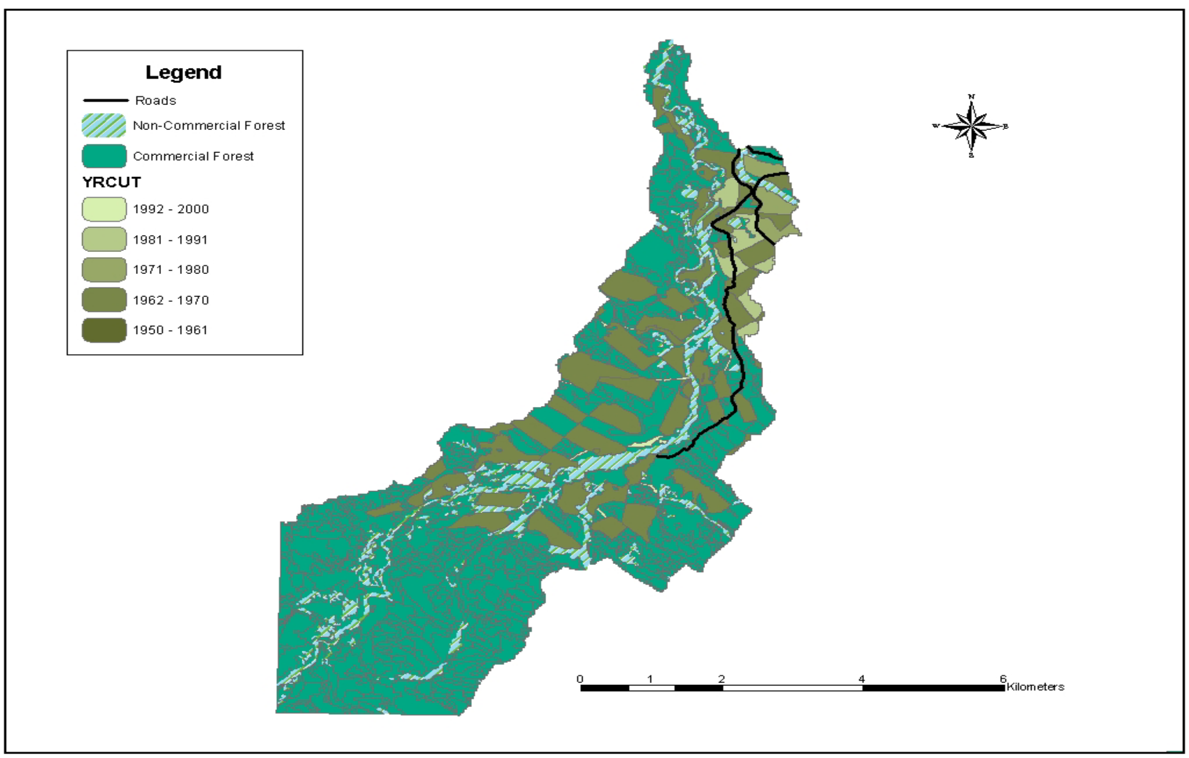

Figure 13. Map of Moon Creek watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.1.7 Pinto Creek

By 1982, commercial timber harvest was concentrated in the northern portion of this watershed (Figure 14). Roads were constructed and primarily used for timber hauling. The 2000 road density was considerably higher than what it was in 1982 (Figure 14 and 15). After 1982, harvesting was scattered across the Pinto Creek watershed. With the increase in harvest, road construction increased in the north and northeast sections (Figure 15).

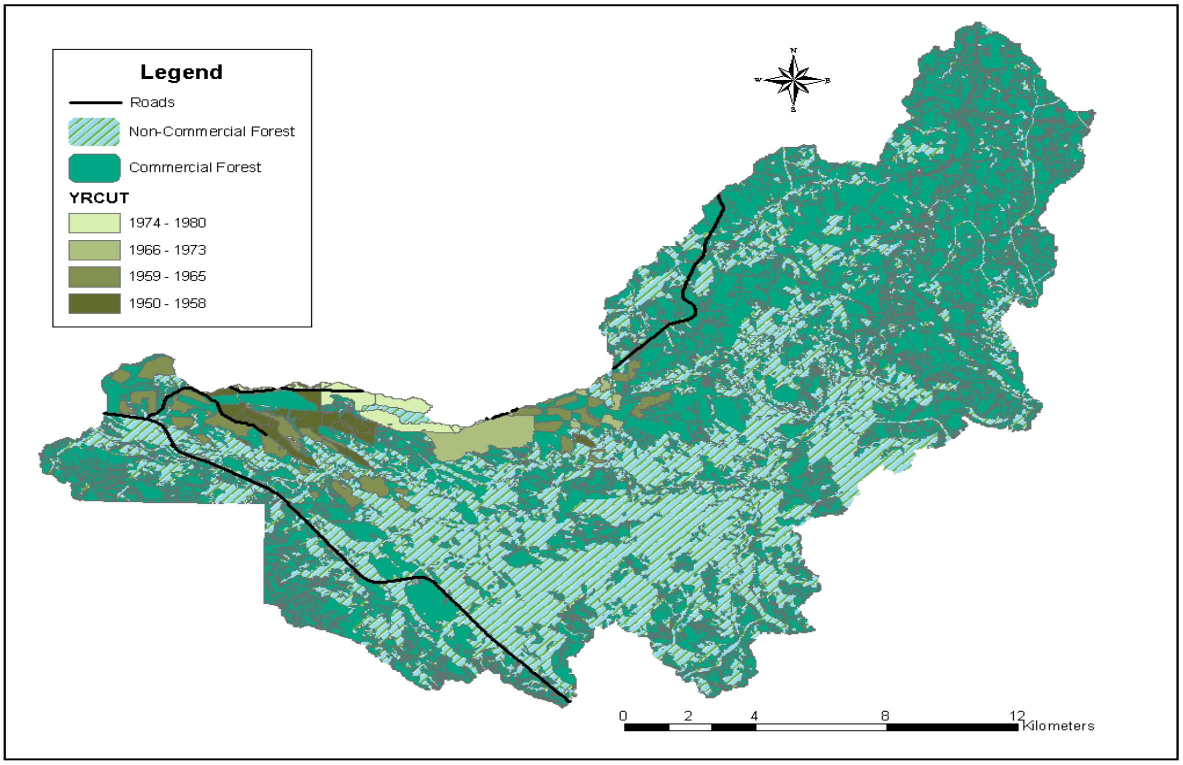

Figure 14. Map of Pinto Creek watershed illustrating cut blocks and road network between the years 1950 – 1982.

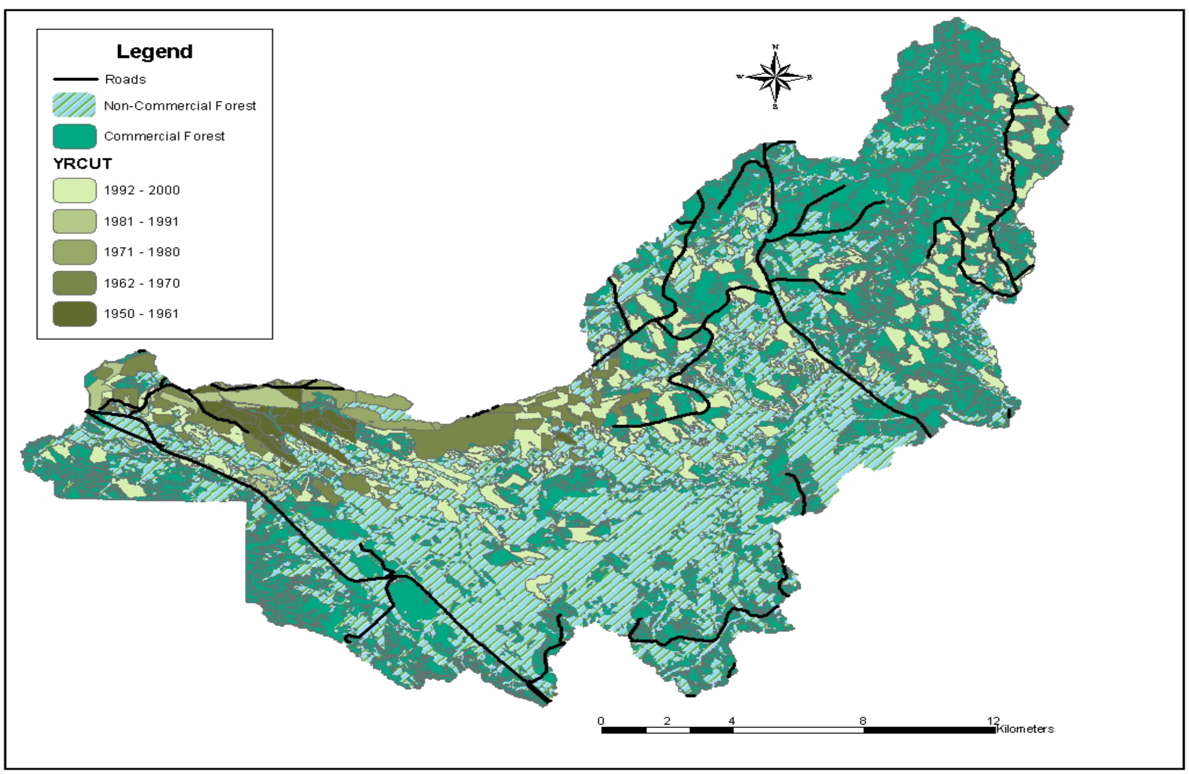

Figure 15. Map of Pinto Creek watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.1.7 Solomon Creek

There was only one section of road added to this watershed prior to the benchmark year of 1974 (Figure 16). Additionally, there was no commercial timber harvest prior to the benchmark year. Solomon Creek watershed has widespread commercial forest throughout. However, there has been no commercial forest harvest in this watershed prior to the year 2000 (Figure 17). There has been one section of permanent road constructed in this watershed since the benchmark year of 1974.

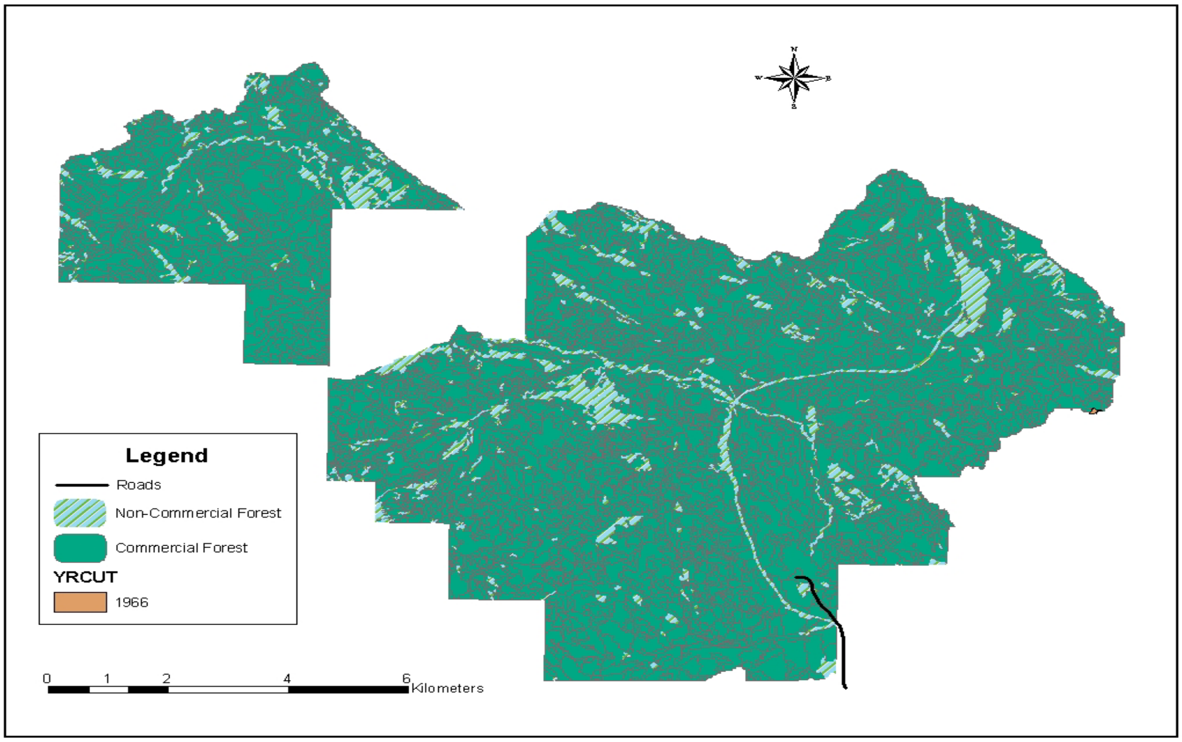

Figure 16. Map of Solomon Creek watershed illustrating cut blocks and road network between the years 1950 – 1974.

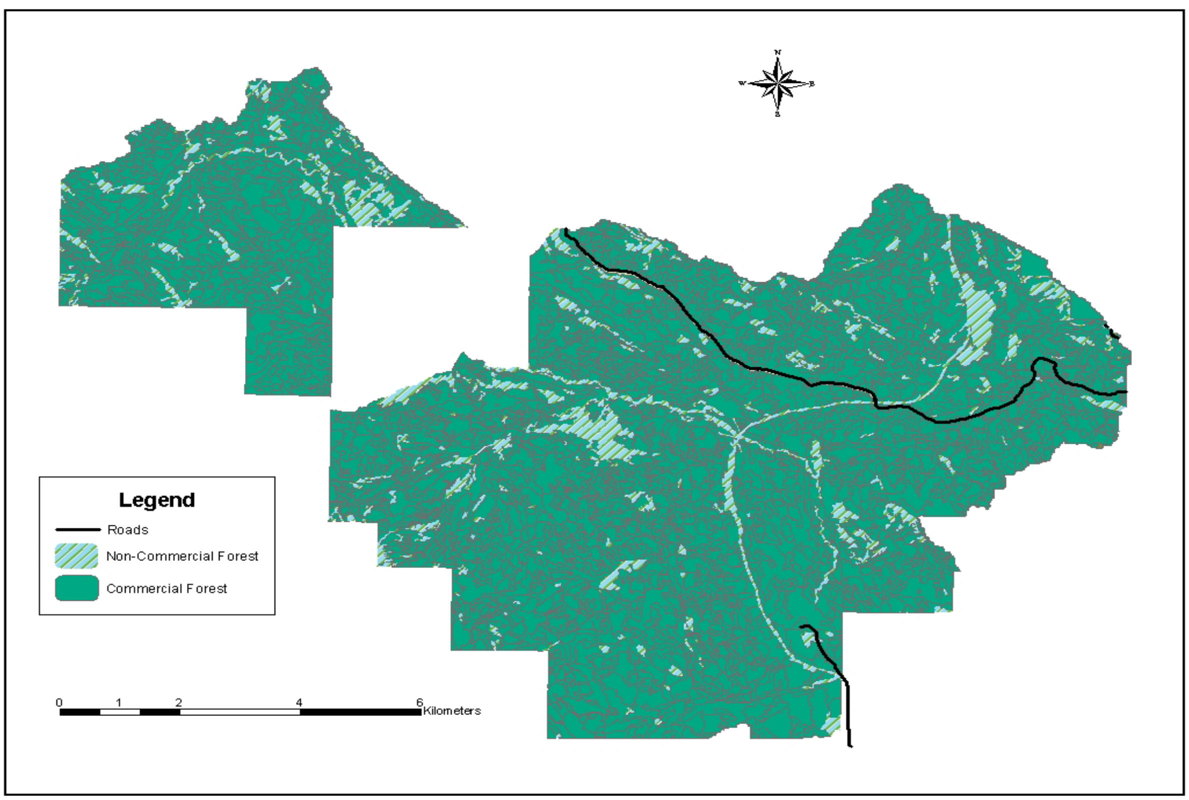

Figure 17. Map of Solomon Creek watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.1.9 Teepee Creek

By 1982, several kilometers of road were constructed and the first pass was harvested throughout the eastern two thirds of the watershed (Figure 18). The 2000 road density was relatively higher than prior to the benchmark year of 1982 (Figure 18 and 19). Commercial timber harvest has steadily taken place prior to and after the benchmark year. The current road density and commercial harvest is relatively high compared to other monitoring watersheds (Figure 19).

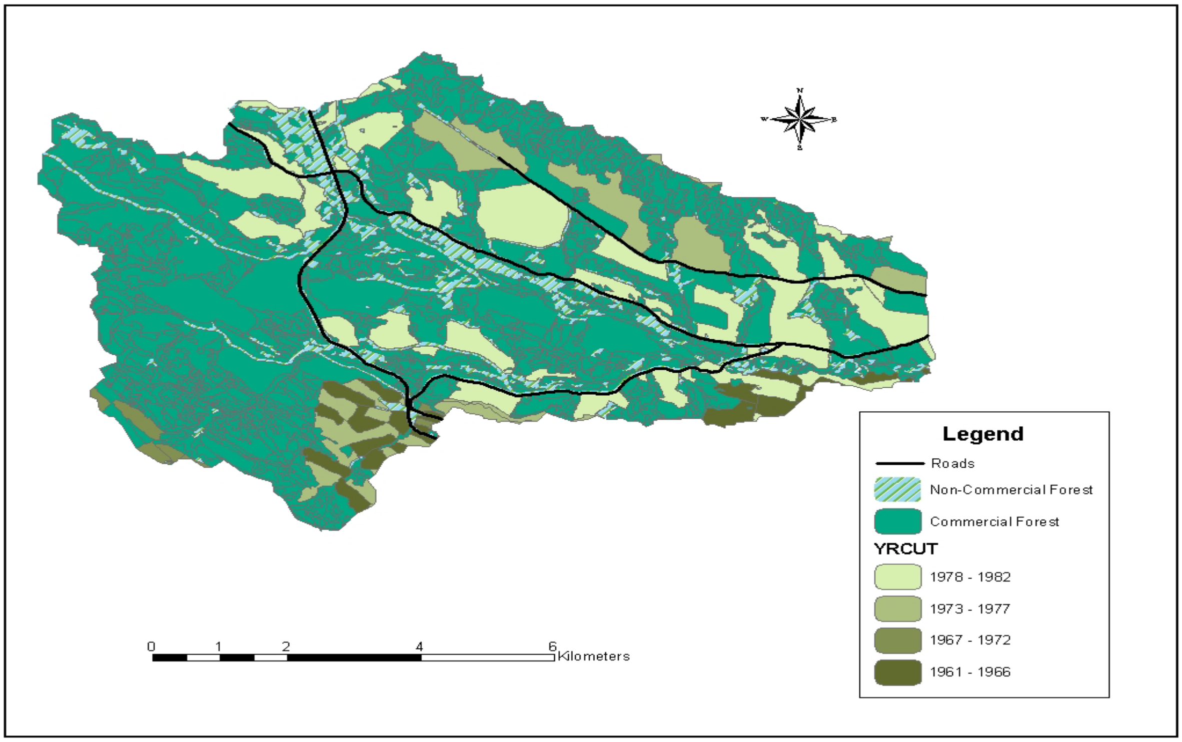

Figure 18. Map of Teepee Creek watershed illustrating cut blocks and road network between the years 1950 – 1982.

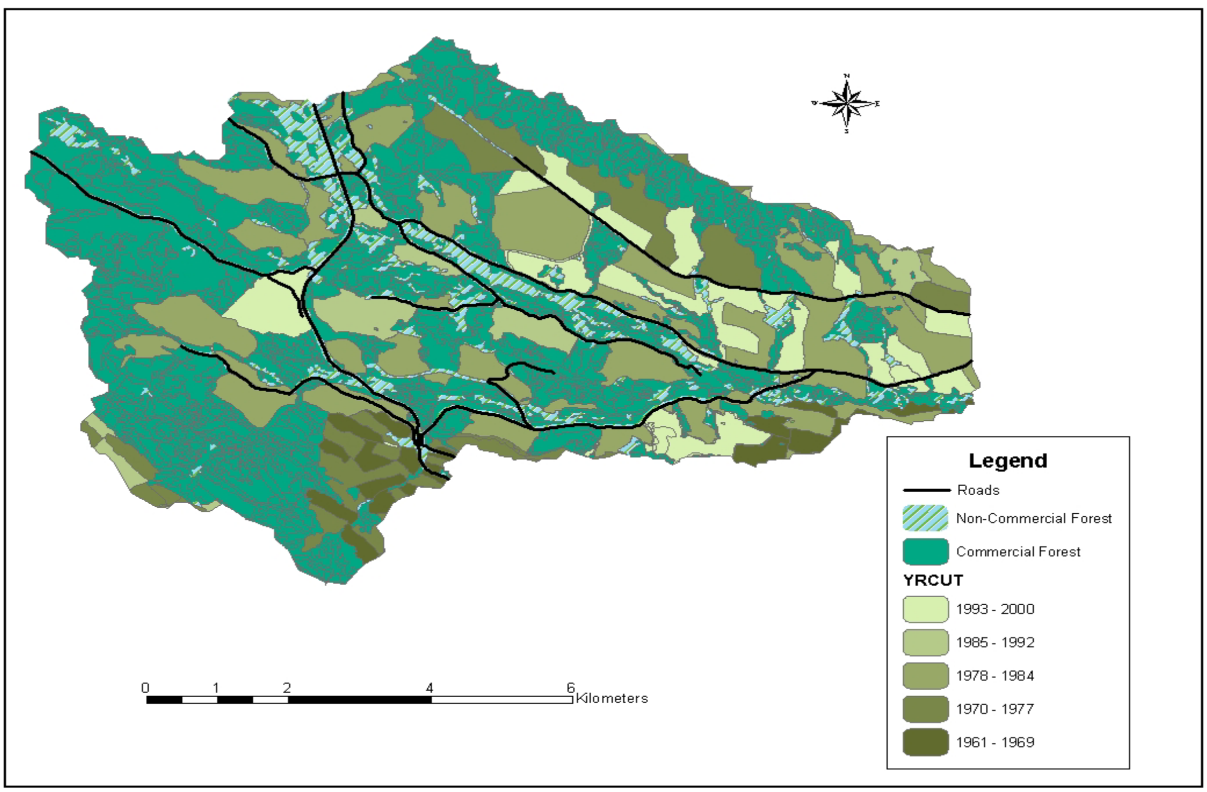

Figure 19. Map of Teepee Creek watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.1.10 Upper Erith Creek

There was no commercial timber harvest prior to the benchmark year of 1979 (Figure 20). Roads that were constructed were primarily used to access oil/gas well sites. The road density and harvest area in 2000 was much higher than before the benchmark year of 1979 (Figure 20 and 21). A majority of the road construction and timber harvest took place in the late 1990's and year 2000 (Figure 21).

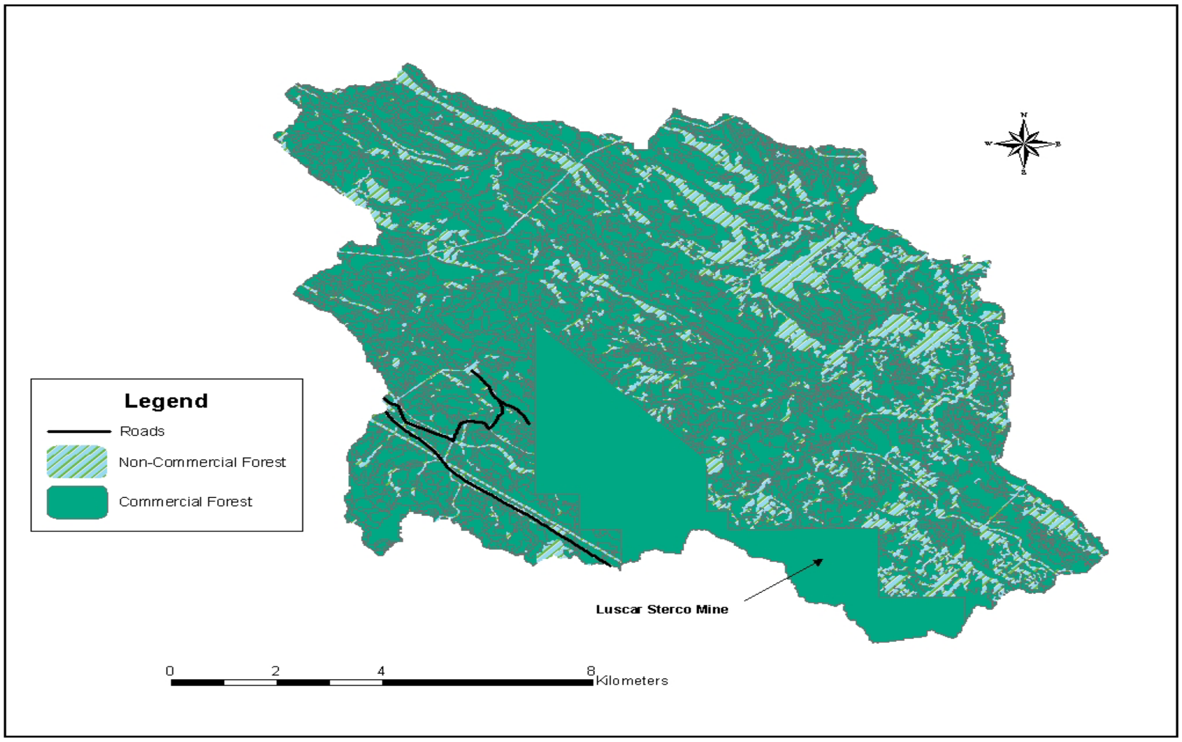

Figure 20. Map of Upper Erith River watershed illustrating cut blocks and road network between the years 1950 – 1979.

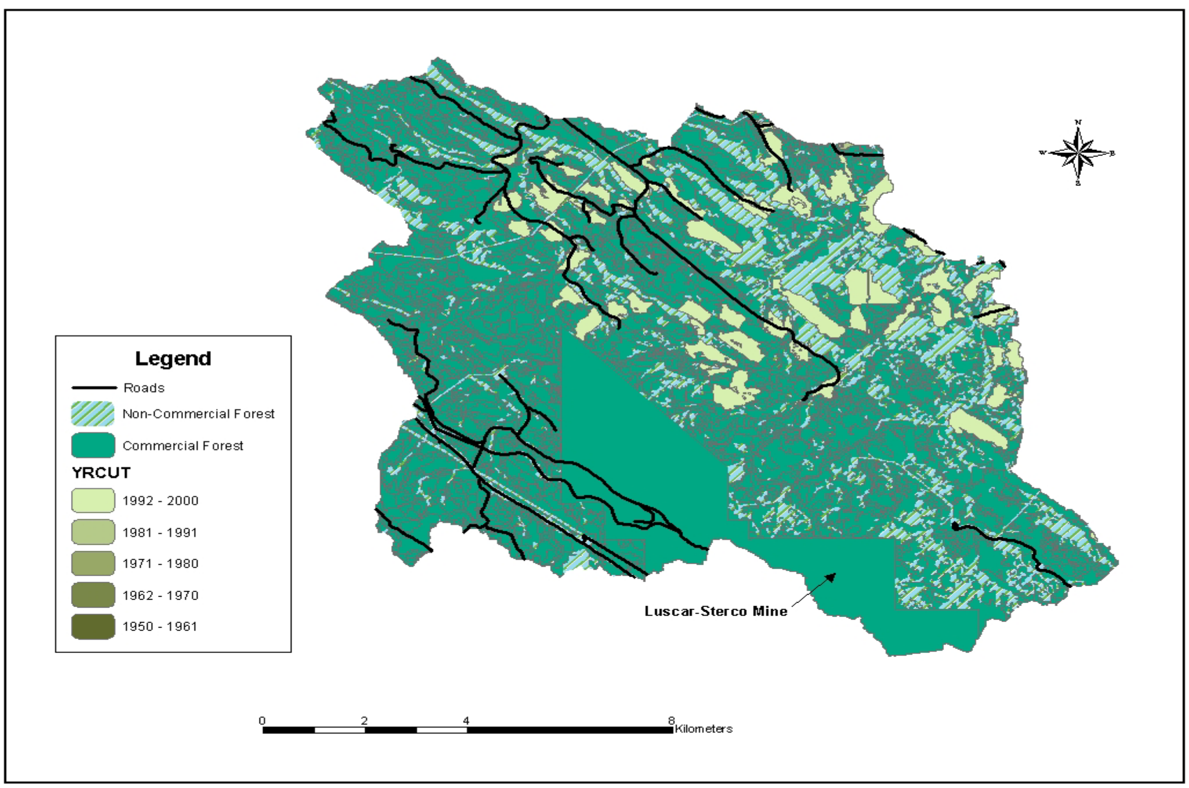

Figure 21. Map of Upper Erith River watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.1.11 Tri-Creeks

By 1985, roads were constructed and commercial timber harvest primarily occurred within the Deerlick and Wampus Creek watersheds. The road density prior to the benchmark year of 1985 is slightly higher than the current road density (Figure 22 and 23). It is evident that roads have become deactivated and set for reclamation purposes. A majority of the timber harvest occurred prior to the benchmark year, however some harvest and road construction took place in the southern and northern portions of Eunice Creek watershed (Figure 23).

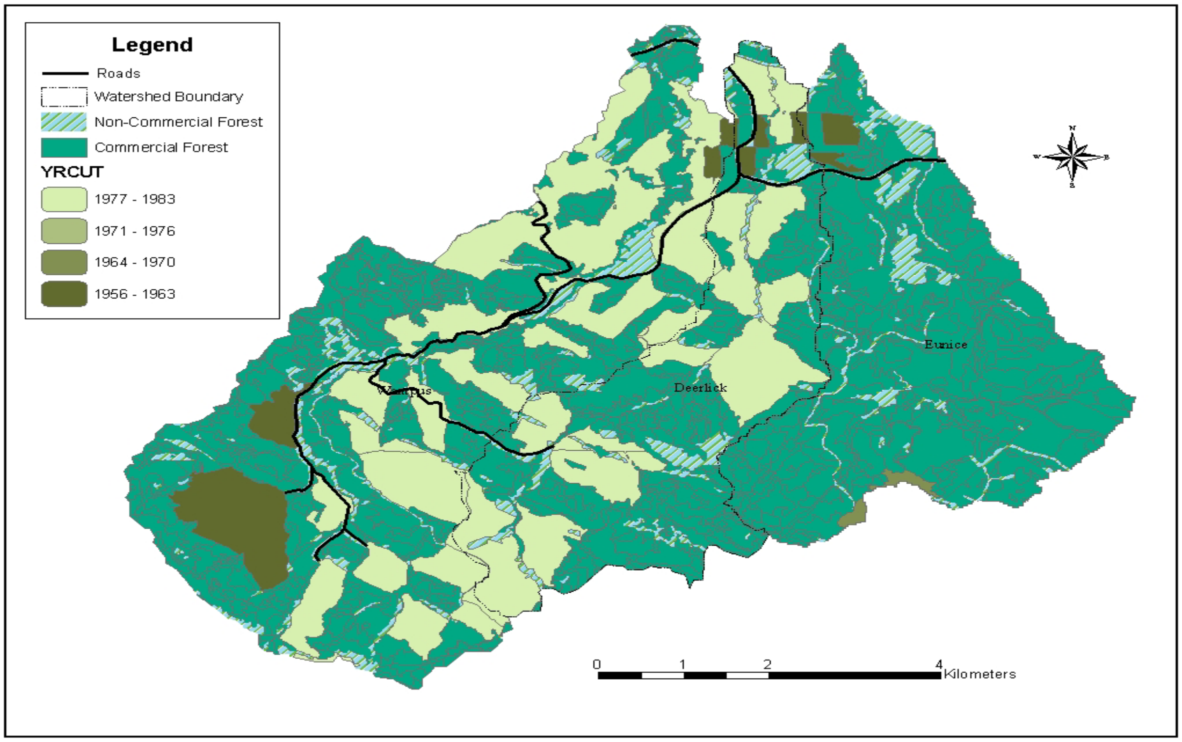

Figure 22. Map of Tri-Creeks watershed illustrating cut blocks and road network between the years 1950 – 1985.

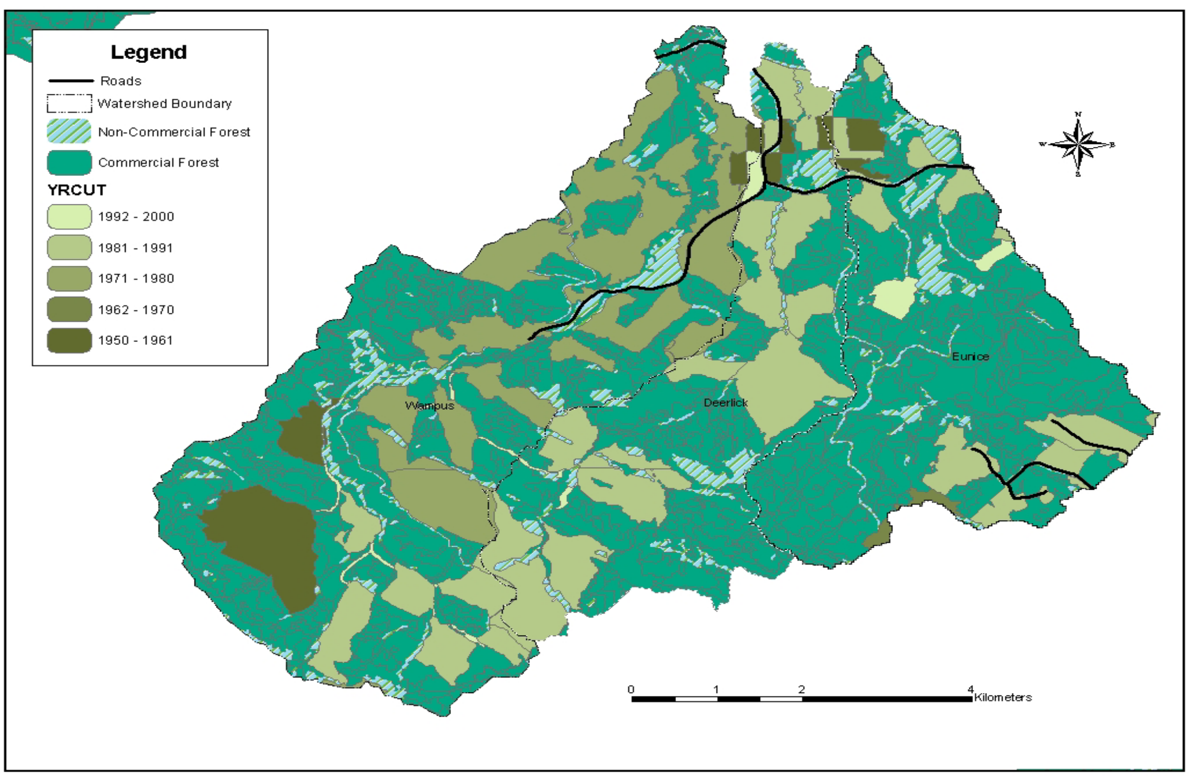

Figure 23. Map of Tri-Creeks watershed illustrating both recent and historic cut-blocks and the current road network in the years 1950 - 2000.

3.2 Summary of Biophysical Characteristics

The watersheds selected for this study differed in terms of the biophysical descriptors. Lambert, Pinto, and Upper Erith are the three largest watersheds within the study area (Table 2). Three watersheds bordering the western boundary of the Weldwood FMA, including McKenzie, Moon, and Solomon, had significant portions of the basin outside of the FMA. McKenzie and Moon watersheds are characterized by the subalpine natural subregion, and Solomon Creek was characterized by the upper foothills subregion. Moon, Pinto, and Upper Erith had the greatest percentage of the AVI area as natural non-forest areas. Of the basins with 100% AVI coverage, Eunice, McKenzie, Solomon, and Wampus had the greatest extent of the commercial forest. Emerson, Lambert, and Pinto had approximately one third of their total AVI area as non-commercial forest.

Table 2. Summary table illustrating the Biophysical characteristics for each monitoring watershed within the FMA.

Biophysical Descriptors												
Monitoring Watershed	Watershed Area (km^2)	Monitoring Watershed ID	AVI Area (km^2)	% With AVI	% Outside FMA	Dominant Ecoregion Outside FMA *	Area Natural Non-Forest (km^2)	% Natural Non-Forest	Area Commercial Forest (km^2)	% Commercial Forest	Area Non-Commercial Forest (km^2)	% Non-Commercial Forest
Anderson	73.8	8	73.8	100	0		1	1.4	63.3	85.8	10.4	14.2
Antler	73.3	10	72.9	99	1	UF	2.8	3.8	63.6	87.3	9.3	12.7
Deerlick	15.1	13	15.1	100	0		0.9	5.8	13.8	91.3	1.3	8.7
Emerson	100.3	3	100.3	100	0		3.3	3.3	66.6	66.4	33.7	33.6
Eunice	16.4	14	16.4	100	0		0.2	1.3	15.1	92.3	1.3	7.7
Fish	48.6	5	48.6	100	0		0.4	0.8	40.1	82.5	4.4	9
Lambert	173.3	6	167.5	97	3	LF	7.9	4.7	105.6	63.1	61.9	36.9
Lynx	80.1	1	80.1	100	0		2.2	2.8	70.7	88.2	9.5	11.8
McKenzie	139.8	15	70.5	50	50	SA	4.1	5.8	64.7	91.8	5.8	8.2
Moon	110.8	4	33.8	31	69	SA	2.8	8.2	30.6	90.4	3.2	9.6
Pinto	337.2	2	321.5	95	5	UF	24.9	7.7	211.5	65.8	106.5	33.1
Solomon	192.5	7	105.9	55	45	UF	5.4	5.1	97.2	91.8	8.4	7.9
Teepee	68.5	9	68.5	100	0		1.3	1.9	62.5	91.2	6	8.8
Upper Erith	128.8	11	128.8	100	0		10.3	8	94.1	73	18.3	14.2
Wampus	28.4	12	28.4	100	0		1.1	3.9	26.4	92.7	2.1	7.3

* UF = Upper Foothills, LF= Lower Foothills, SA= Subalpine

3.3 Historic Land-use Indices

At the benchmark year, the individual watersheds had a variety of levels of harvest and road development. Five watersheds had less than 3% of the total AVI area harvested, including Eunice, Lambert, McKenzie, Solomon, and Upper Erith (Table 2). Three of the watersheds had 40% or more of their total AVI area harvested including Deerlick, Fish, and Wampus. Anderson, Fish, Moon, Teepee, and Wampus Creeks had a road density of 0.5 km/km^2 or greater. Antler, Eunice, Lambert, McKenzie, Pinto, Solomon, and Upper Erith had relatively low historic road densities. Anderson, Deerlick, Fish, Moon, Teepee, and Wampus Creek watersheds had relatively high percentages of harvested area and high road density.

Table 3. Summary table illustrating the historic land-use activities in each monitoring watershed.

Monitoring Watershed	Benchmark Years	Harvested Area (km^2)	% Harvested	Total km of Road	Index of Road Density (Km of Road / km^2 of Watershed)
	Land-Use Descriptor				
Anderson	1950-1974	16.4	22.2	39.1	0.5
Antler	1950-1982	7	9.5	8.9	0.1
Deerlick	1950-1985	6.1	40.4	4.1	0.3
Emerson	No data	No data	0	No data	No data
Eunice	1950-1985	0.5	3.0	1.5	0.1
Fish	1950-1977	24.2	49.8	22.5	0.5
Lambert	1950-1979	0	0	12.4	0.1
Lynx	1950-1986	4.5	5.6	16.8	0.2
McKenzie	1950-1983	0	0	0	0
Moon	1950-1985	8	7.2	16.2	0.5
Pinto	1950-1982	19.3	5.7	36.1	0.1
Solomon	1950-1974	0.3	0.2	2.6	0
Teepee	1950-1982	17.4	25.4	33.6	0.5
Upper Erith	1950-1979	0	0	10.9	0.1
Wampus	1950-1985	11.4	40.1	16	0.6

3.4 Current Land-use Indices

At the year 2000, the study watersheds had a wide range of values for the land-use indices. Emerson, Lynx, and Teepee Creeks had the highest percentage of anthropogenic areas (pipelines and permanent roads) within the watershed boundaries (Table 4). Anderson, Deerlick, Fish, Teepee, and Wampus Creeks had approximately 40% of the AVI area harvested since 1950. By 2000, little or no harvest had occurred in Lambert, McKenzie, and Solomon watersheds. Antler, McKenzie, Solomon, and Wampus had the lowest index of road density. Emerson, Fish, Lambert, and Lynx watersheds had the highest density of seismic line development.

Table 4. Summary table illustrating the Land-use characteristics for each monitoring watershed within the FMA.

Land-use Indices								
Monitoring Watershed	**Total Area Anthropogenic (km^2)**	**% Total Anthropogenic**	**Harvested Area (km^2)**	**% Harvested (1950-2000)**	**Total Kilometers of Road**	**Index of Road Density** (Kilometers of Road/km2 of Watershed)	**Total Kilometers of Seismic Line**	**Kilometers of Seismic Line / km^2**
Anderson	1.4	1.9	29.1	39.4	52.4	0.7	140.9	1.9
Antler	0.5	0.7	12.5	17.1	8.9	0.1	160.1	2.2
Deerlick	0.2	1.1	6.3	41.7	3.3	0.2	20.8	1.4
Emerson	2.2	2.2	12.1	12.1	42.6	0.4	465.5	4.6
Eunice	0.3	2	3	18.3	5.6	0.3	30.2	1.8
Fish	0.7	1.5	27.1	55.8	24.1	0.5	176.1	3.6
Lambert	2.4	1.4	3	1.7	34.3	0.2	681.4	4.1
Lynx	1.7	2.2	11.3	14.1	38.7	0.5	373.2	4.7
McKenzie	0.2	0.2	0	0	0	0	194.5	2.8
Moon	0.1	0.4	8.1	7.3	9.1	0.3	53.7	1.6
Pinto	4.7	1.5	62	18.4	116.6	0.4	665.3	2.1
Solomon	0.7	0.6	0.3	0.2	14.4	0.1	166.5	1.6
Teepee	2.4	3.5	29.2	42.6	54.3	0.8	119.5	1.7
Upper Erith	1.9	1.4	11	8.5	78.6	0.6	188.9	1.5
Wampus	0.3	1.1	11.6	40.8	4.3	0.1	45.9	1.6

3.5 Extent of Changes in Harvest and Road Development

Total changes in land-use between the historic and current indices varied considerably between the watersheds (Table 5). Timber harvesting had not occurred evenly throughout each watershed after each benchmark year. Anderson, Eunice, and Teepee Creeks had the highest percentage of timber harvest following their benchmark years. McKenzie, Moon, Solomon, and Wampus Creeks have had the lowest area since their respective benchmark years.

Change in road density refers to the difference in road densities between the respective benchmark year and the roads found in 2001 (Table 5). Lynx, Pinto, Teepee, and Upper Erith watersheds had the greatest increase in road density following their respective benchmark years. Antler, Fish, Lambert, McKenzie, and Solomon Creeks had minimal change in road density following the benchmark year. Due to deactivation, Deerlick, Moon, and Wampus Creeks had fewer roads in 2001 than at the benchmark year.

Table 5. Summary table illustrating the changes in extent of harvest and road development from the benchmark year to present.

Monitoring Watershed	Historic		Current % Harvested	Change In % Harvested	Index of Road Density		Change In Road Density
	Year	% Harvested			Historic	Current	
Anderson Creek	1950-1974	22.2	39.4	17.2	0.5	0.7	0.2
Antler Creek	1950-1982	9.5	17.1	7.5	0.1	0.1	0
Deerlick Creek	1950-1985	40.4	41.7	1.3	0.3	0.2	-0.1
Emerson Creek	No data	No data	12.1	No data	No data	0.4	No data
Eunice Creek	1950-1985	3.0	18.3	15.2	0.1	0.3	0.2
Fish Creek	1950-1977	49.8	55.8	6.0	0.5	0.5	0
Lambert Creek	1950-1979	0	1.7	1.7	0.1	0.2	0.1
Lynx Creek	1950-1986	5.6	14.1	8.5	0.2	0.5	0.3
McKenzie Creek	1950-1983	0	0	0	0	0	0
Moon Creek	1950-1985	7.2	7.3	0.1	0.5	0.3	-0.2
Pinto Creek	1950-1982	5.7	18.4	12.7	0.1	0.4	0.3
Solomon Creek	1950-1974	0.2	0.2	0.0	0	0.1	0.1
Teepee Creek	1950-1982	25.4	42.6	17.2	0.5	0.8	0.3
Upper Erith River	1950-1979	0	8.5	8.5	0.1	0.6	0.5
Wampus Creek	1950-1985	40.1	40.8	0.7	0.6	0.1	-0.5

4. Discussion

Our literature review of potential forestry related impacts to fish habitat revealed that the strong connection between forest harvest, increased peak flows and subsequent stream channel changes, which has been documented in other areas of North America, can not be assumed to exist within the study area. This is due to the occurrence of summer storms rather than snowmelt runoff as the major channel forming runoff events. Therefore, this project has the potential to provide some information that may be useful to substantiate such a relationship.

Unlike many areas managed for forest harvest in western North America, the Weldwood FMA ground rules, in place since harvest was initiated in the 1950's, have required maintenance of stream-side buffer strips.

Since the creation of the Weldwood FMA, significant resources were invested to ensure that the timber supply was managed at a sustainable level. As a result, a detailed harvest history was available and was provided by Weldwood for the watersheds in digital format. The historical information was found to be 100% accurate when compared to current orthophotos. Accurate permanent road information was derived from a variety of sources. Because of the quality of information available, neither a sampling procedure nor statistics were required to provide an overview of land use.

Timber harvest was very unevenly distributed through time and space in the study watersheds. Levels of harvest ranged between 0 and 56% on the inventoried forest landbase. The change in the extent of harvest between the benchmark year and 2000 ranged between 0 and 17%. Density of permanent roads ranged from 0 to 0.8 km/km^2 and the change in density of permanent roads between the benchmark year and 2001 ranged between a decrease of 0.4 km/km^2 to an increase by 0.5 km/km^2.

Extent of harvest and density of permanent roads were not correlated for all watersheds and should therefore be considered separately in a comparison to any observed changes in aquatic resources.

5. Glossary of Terms

Annual Water Yield – Total outflow from all or part of a drainage basin through surface runoff or subsurface aquifers within a one-year period (Armantrout 1998).

Low Flow – The lowest discharge (water level) recorded over a specific period of time (Armantrout 1998).

Peak Flow – Highest discharge recorded within a specific period of time that is often related to spring snowmelt, summer, fall, or winter flows (Armantrout 1998).

Sedimentation – Action or process of forming and depositing sediments. Deposition of suspended matter by gravity when water velocity cannot transport the bed load (Armantrout 1998).

Sediment Load – General term that refers to sediment moved by a stream in suspension or at the bottom. Sediment load is not synonymous with either discharge or concentration (Armantrout 1998).

Water Quality – Term used to describe biological, chemical, and physical characteristics of an aquatic environment, usually in relation to the uses of water (Armantrout 1998).

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