Report 2.4.1a

Level 1 Classification: Basin Characteristics

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Acknowledgements

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Abstract

This report describes one component of an ecosystem-based classification of watersheds and streams. Similar ecological frameworks have proven useful in modern forestry science, physical geography and aquatic biology. The classification has two purposes. Firstly, it is a key component in our multi-year study into the effects of human use activities on fish and fish habitat. Secondly, the system is also intended to facilitate the development of watershed based resource management plans.

The classification is hierarchical in nature and is divided into three parts: GIS–based watershed classification; GIS-based stream reach classification; and field-based stream reach classification. This report includes the methods and results of the GIS-based watershed classification. The other two components are presented in separate reports. Ecosystem structure and processes that occur at both the basin and reach scales influence the sensitivity and productive capacity of aquatic systems. Therefore, such a hierarchical classification was required to meet our purposes.

Our watershed classification utilized six basin descriptors including: basin size, mean basin slope, mean basin elevation, extent of wetlands, extent of lakes, and dominant natural subregion. These descriptors were selected because they are related to many important physical and biological processes including habitat selection, erosion, climate, biological productivity, hydrologic response to forest clearing, and sediment delivery.

Based on these six characteristics, we found that the degree of similarity between fifteen watersheds ranged widely. Only 19 of the 105 possible watershed pairs displayed medium or high similarity.

Our findings suggest the major ecological processes differ between the 15 watersheds and a s a result, response to land-use activities will also differ. Therefore, a multiple variable analysis that includes watershed characteristics and land-use measures could be used to attempt to explain fish distributions and abundance patters among the selected watersheds.

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1 Introduction

We have selected an ecosystem-based framework for this study. This is to ensure that both sustainable forest management and aquatic resource monitoring objectives are achieved. Modern forest management strategies use an ecosystem approach that considers biological, and physical components and the processes that connect them (Kimmins 1987). This ecosystem framework has proved useful in land-use related research in a number of disciplines, including physical geography and aquatic biology.

In the science of physical geography, this ecosystem approach has proven essential when evaluating effects of land-use on the environment. A hierarchical approach that describes landform processes at a variety of scales is recommended for assessing watershed response to both natural and anthropogenic environmental change (Montgomery and Buffington 1993, Rosgen and Silvey 1996). When evaluating the response of a drainage basin to timber harvest, several complex interactive variables that should be considered include biophysical conditions, climate and hydrologic variables and management activities themselves (Brardinoni et al. 2002). In riparian areas, ecological functions as well as human uses vary with landform, vegetation and position along the stream continuum and therefore a management framework that considers these factors is advised (Quinn et al. 2001). When considering the response of a particular stream reach to timber harvest, it is also important to consider the riparian vegetation type, channel slope and configuration (biophysical conditions) along with the type of management activity because these factors will affect the ecosystem response (Grant 1986).

An ecosystem approach applied at a variety of scales has also improved our understanding of the importance of natural versus human factors for influencing aquatic resources. Landscape-scale biophysical attributes and land-use patterns along with site characteristics including channel morphology and buffer attributes, were important for influencing aquatic invertebrate assemblages (Richards et al. 1996). Studies of aquatic communities that did not consider these large-scale patterns in geology and hydrology, as well as local landscape factors, were biased in terms of the relative importance of these factors (Wiley et al. 1977). In addition, Imhof et al. (1996) identified the importance of incorporating watershed scale ecosystem attributes into the study of impacts observed at the reach level and other authors suggested a hierarchal framework, which included climatic, geologic, physiologic, and land cover attributes, for effective stream habitat management. More recently, this view that large-scale physical characteristics influence reach scale habitats and the organism that they support was quantified through the use of a predictive model (Davies et al. 2000).

Recognizing the importance of biological, physical and climatic components, we developed a watershed and stream classification to describe fifteen different watersheds within the Foothills Model Forest. The purpose of this classification system was two-fold:

1) The system represents a key component of our multi-year study into the effects of human activities on aquatic resources; and
2) The system is also intended to facilitate the development of basin and stream reach specific resource management plans.

1.1 Organization of the FMF Watershed and Stream Classification System

For the purposes of this project, an office-based classification (Level 1) was conducted at two scales – the basin and the stream reach. The landform scale is an important intermediate scale for assessing watershed response and two studies have been previously completed in this area including Dumanski et al. (1972) and Bruha (1996). The results of these landform classification exercises were available in GIS format and were not presented in this study. A field based stream reach classification (Level 2) was also conducted and the results are presented in a separate report.

Findings from the Level 1 Assessment are presented in two different reports. This report, the first in the series, describes basin characteristics and processes, while the second describes reach characteristics and processes.

2 Methods

2.1 Basin Descriptors

2.2.1 Stream Order

The changes in aquatic habitat and fish community structure related to increasing stream size along the stream continuum are well described in aquatic ecology (Vannote et al. 1980). Therefore, measures of stream size were a primary component of this classification exercise. Stream order was the first indictor of watershed size that was selected for this study, and was previously assigned to all streams within the FMF using the standard Shrahler stream order methodology (Figure 1). For each monitoring watershed, stream order was established at the stream mouth.

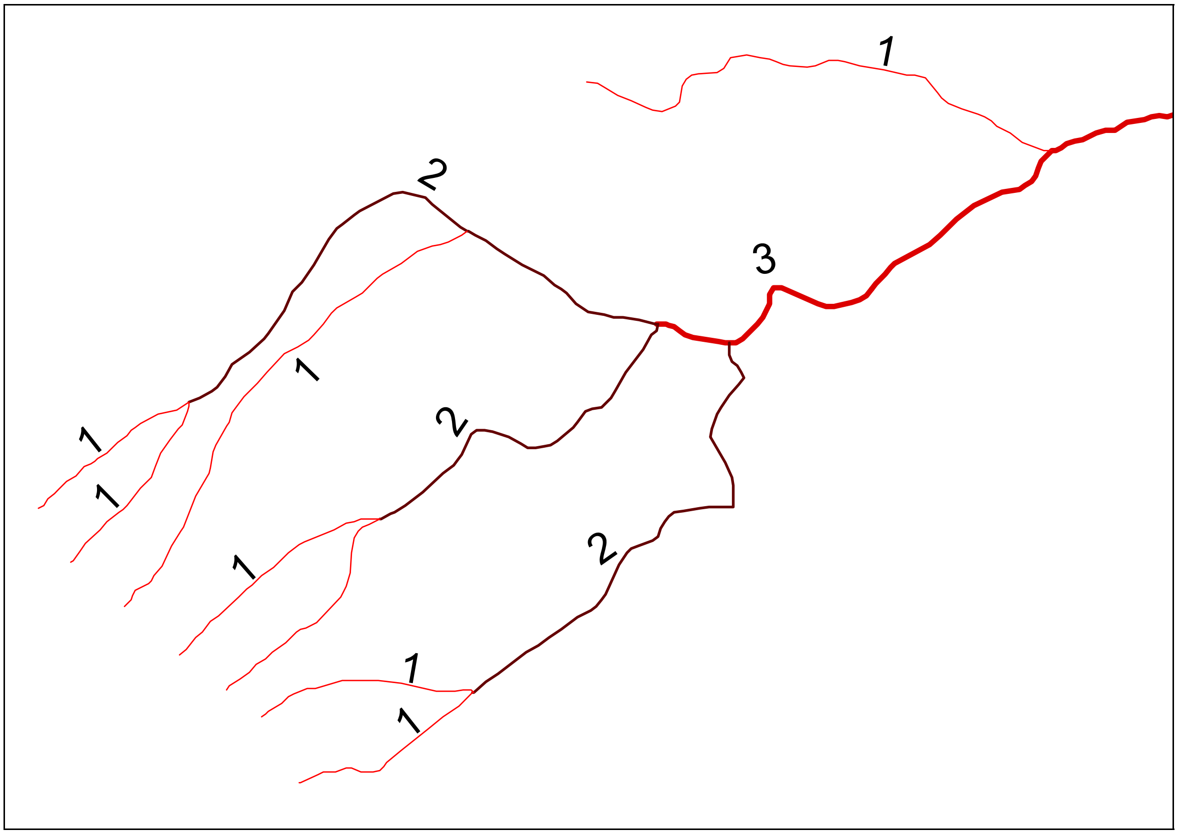

Figure 1. Determining stream order from mapped channel network.

2.2.2 Drainage Area

Stream order classifications have several limitations including: their dependence upon map scale, frequent modification based on terrain and failure to describe ecological processes and headwater streams (Gomi et al. 2002). Therefore, we also include drainage area as a measure of stream size. The total drainage area for each watershed, in square kilometers, was calculated in ArcView 3.2 (ESRI 1999).

2.2.3 Basin Slope

Terrain steepness or slope can influence the rates of chronic surface erosion, probability of mass-wasting events, as well as basin sediment yield. Slope is an important parameter in the equation for predicting soil loss due to surface erosion (Figure 2).

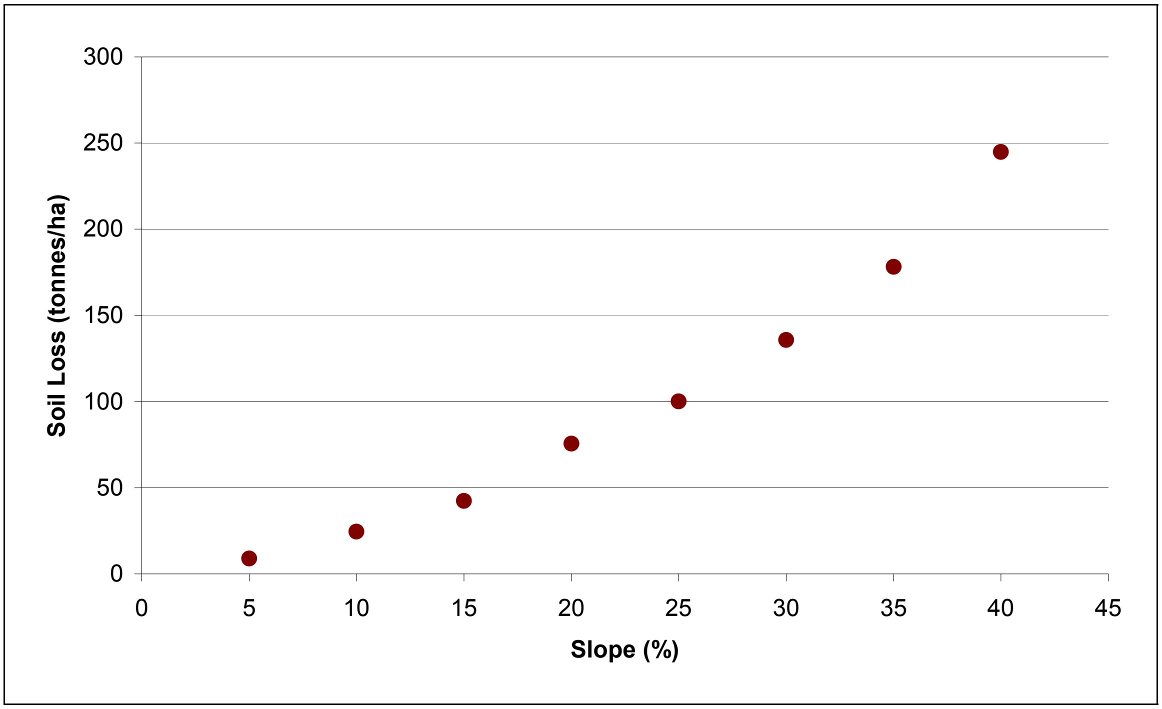

Figure 2. Predictions of soil loss for the most common soil group sub-group (Orthic Gray Luvisol) within the upper and lower foothills in the Hinton-Edson area on an unvegetated 20m long slope (calculated with information from Dumanski et al. 1972 and Tajek et al. 1985).

The probability of episodic soil movement events increases with slope. Slopes with gradients < 49% tend to be stable, given they are comprised of a shallow overburden with low particle cohesion (Chatwin et al. 1994). At the watershed scale, annual sediment yield has been found to increase exponentially with relief ratio, which is calculated by dividing basin relief by basin length (Gordon et al. 1992). Terrain steepness is also an important component of models that predict sediment yield to streams (Wilson et al. 2001).

Although many measures of basin slope are available, mean basin slope was selected because of the ease that it could be calculated using available GIS technology. A slope class for each watershed was assigned based on the mean slope value (Table 1).

Table 1. Slope classes

Mean Slope	Slope Class
< 10 %	Low
10 – 25 %	Medium
> 25 %	High

2.1.4 Basin Elevation

Climate is a primary factor driving landform and biological processes. Elevation was selected as an indicator of climate because higher elevations accumulate more moisture while lower elevations have warmer summer temperature and as a result may have higher overall biological productivity rates.

The elevation information for each watershed was obtained from the provincial 25-meter DEM within each basin's boundaries. The mean elevation in meters was calculated using ArcView 3.2 (ESRI 1999). Elevation range was calculated by subtracting the minimum elevation from the maximum.

An elevation class for each watershed was assigned based on the mean elevation value (Table 2).

Table 2. Elevation classes

Mean Elevation	Elevation Class
< 1300 m	Low
1300 – 1500 m	Medium
> 1500 m	High

2.1.5 Ecological Classification of Watersheds

An existing ecological classification provided information to the natural subregion level (biogeoclimatic zone) for all lands contained within the monitoring watersheds (Yellowhead Ecosystem Working Group 1998). The widespread occurrence of gleysolic and organic soils in the lower foothills (plateau benchlands) is indicative in the importance of groundwater versus surface flow pathways in this natural subregion (Dumanski et al. 1972).

In addition, the capacity of individual watersheds to buffer major flood events also varies between natural sub-regions. Watersheds, including Solomon Creek, that have extensive high relief areas above the tree line have very little water storage capacity and respond quickly to summer storms (Bender and Sawatsky 1998). Additionally, concerns over changes in channel stability resulting from harvest related increases in peak flow may not be translatable from forested watersheds in western North America to those in more boreal environments. Boreal regions often contain extensive muskegs, wet areas and beaver dams and little is known about the potential buffering capacity of these areas for influencing water storage (Swanson et al. 1998). In conclusion, the importance of peak flow related impacts likely varies between different natural subregions and this should be considered when evaluating the effects of land-use activities.

For each watershed, the total area for each of the natural subregions was calculated using ArcView 3.2 (ESRI 1999) and the dominant subregion was identified.

2.1.6 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). Using the Alberta Vegetation Inventory (AVI) for the study area, we identified vegetation-based indicators for two wetland types (Table 3). The total area for each wetland type and total wetland area was calculated for each watershed.

Table 3. Vegetation-based indicators used to identify wetlands within the study basins.

Wetland Type	Corresponding Wetland Class (NWWG 1997)	AVI Criteria
Black spruce / Larch	Bog	At least 6 % canopy cover of Black spruce or larch with < 2% canopy cover of other tree species (Weldwood 1999).
Non-Forested Wetlands	Fens, swamps, and marshes	Vegetated lands with <6% tree cover dominated by shrub, herbaceous or bryophyte species (Nesby 1996).

Although the AVI coverage was limited in the high relief basins (Moon, Mackenzie, and Solomon creeks), we assumed that the extent and importance of wetlands in steep terrain would be insignificant. Therefore, the percent of wetlands for these three basins was based on total basin area. Two low relief basins (Lambert and Pinto creeks) also did not contain full AVI coverage. However, due to the common occurrence of wetlands in low relief areas, the percent of wetlands was calculated using only portions of the watershed with AVI coverage. A wetland class for each watershed was assigned based on the total percent of vegetation-based wetlands (Table 4).

Table 4. Vegetation-based wetland classes.

Percent Total	Wetland Class
< 10	Low
10 - 20	Medium
> 20	High

2.1.7 Lakes

The location and extent of lakes within a watershed will influence physical processes and biota that a watershed supports. Watershed lake area has a direct influence on sediment delivery to the stream channel (Hogan et al. 1998). Species such as Burbot (*Lota lota*) and Finescale Dace (*Chrosomus neogaeus*) are well adapted to completing all life history stages in lakes while other native fish species, which are found in the study area, including Rainbow Trout (*Oncorhynchus mykiss*) and Bull Trout (*Salvelinus confluentus*) are best adapted to flowing water stream habitats to complete various life history stages (Scott and Crossman 1973). As a result, we included lake area, expressed as a percentage of the drainage basin area. Lake area included area of permanent and intermittent lakes, and oxbow lakes. This information was obtained from the Alberta Government data set coverage of Rivers and Lakes.

A lake class was assigned based on the total percent of lakes in each monitoring watershed (Table 5)

Table 5. Lake classes.

Percent Total	Lake Class
< 0.05	Low
0.05 – 0.10	Medium
> 0.10	High

2.1.8 Production of Topographical Maps

To summarize the physiographic characteristics for each watershed we produced topographical maps in ArcMap 8.2 (ESRI 2002) using Landsat TM imagery (1996 for northern FMA watersheds and 1999 for southern FMA watersheds). Draping the Landsat image over a shaded relief map derived from a 25 meter DEM created the background image. The Landsat TM was displayed with three colors: red, green, and blue. The red hues represented areas where there was a lack of vegetation, green hues represented vegetated areas, and bluish hues represented snow, ice, and water. The total effect was produced by using the transparency function on the Landsat images (70 % transparent), thus showing the shaded relief (which is gray) with some color provided by the imagery overlaid on top.

Ordered streams were drawn over the background image described above. Order 1 streams were left out to avoid unnecessary clutter. Lakes were added. Finally, the selected monitoring watershed boundaries were outlined in orange.

3 Results

3.1 Summary for all Selected Monitoring Watersheds

Slope and elevation characteristics for each watershed are presented in order from mean basin slope to lowest mean basin slope (Table 6).

Table 6. Drainage area and slope statistics for all selected monitoring watersheds.

Watershed Name	Drainage Area (km^2)	Stream Order	Max. Slope (%)	Mean Slope (%)	Slope Class	Elevation Range (m)	Mean Elevation (m)	Elevation Class
Moon	111	5	433	38	High	1216	1864	High
Solomon	192	6	578	35	High	1443	1500	High
MacKenzie	140	4	156	29	High	1004	1736	High
Deerlick	15	3	82	21	Medium	424	1463	Medium
Wampus	28	4	85	18	Medium	453	1454	Medium
Teepee	68	5	92	17	Medium	507	1451	Medium
Eunice	16	3	77	17	Medium	416	1446	Medium
Antler	73	5	82	15	Medium	504	1414	Medium
Anderson	74	4	79	15	Medium	553	1399	Medium
Upper Erith	129	4	80	13	Medium	400	1257	Low
Lynx	80	4	92	12	Medium	552	1122	Low
Fish	49	3	105	9	Low	574	1318	Medium
Pinto	337	5	93	9	Low	685	1360	Medium
Emerson	100	4	76	7	Low	302	1073	Low
Lambert	173	4	81	5	Low	233	1100	Low

Total area by natural subregion and dominant ecoregion for each watershed are presented in order from highest relief basin to lowest relief basin (Table 7).

Table 7. Summary of total area by natural sub-region and dominant ecoregion for each watershed.

BASIN	Total Area (km^2)	Percent of Area by Natural Subregion (Biogeoclimatic Zone)							Dominant Ecoregion
		Alpine	Subalpine (Engelmann Spruce - Subalpine Fir)	Upper Foothills (Sub-Boreal Spruce)	Montane (Montane Spruce)	Boreal (White and Black Spruce)	Lower Foothills	Percent Total	
Moon	111	41	53	5				99	Subalpine
Solomon	192	13	60	55	1			129	Upper Foothills
MacKenzie	140	23	108	0				131	Subalpine
Deerlick	15		10	33				43	Subalpine
Wampus	28		11	64				75	Upper Foothills
Teepee	68		17	75				92	Upper Foothills
Eunice	16		3	81				84	Upper Foothills
Antler	73		21	71				92	Upper Foothills
Anderson	74		28	62				90	Subalpine
Upper Erith	129			100				100	Upper Foothills
Lynx	80			59			41	100	Upper Foothills
Fish	49			59			41	100	Upper Foothills
Pinto	337		7	88		3	2	100	Upper Foothills
Emerson	100			24			77	101	Lower Foothills
Lambert	173			43			57	100	Lower Foothills
Percent Total	1436	5	21	55	0.1	0.2	15	96	Upper Foothills

The percent of wetlands based on vegetation indicators and the percentage of lakes contained by each watershed are presented below (Table 8).

Table 8. The percentage of each wetland type within selected monitoring watersheds.

Watershed Name	% Black spruce / larch	% Non-Forested	% Total (Black spruce/larch + Non-forested wetland)	% Lakes
Moon	0.31	1.91	2.22	0.02
Solomon	1.17	2.61	3.78	0.02
MacKenzie	1.10	2.50	3.61	0.00
Deerlick	1.76	5.67	7.44	0.07
Wampus	2.24	3.89	6.13	0.00
Teepee	3.32	1.85	5.18	0.00
Eunice	4.37	1.32	5.69	0.04
Antler	8.19	3.77	11.97	0.01
Anderson	10.85	1.30	12.15	0.00
Upper Erith	4.75	7.97	12.73	0.05
Lynx	6.85	2.73	9.58	0.00
Fish	6.69	0.67	7.36	0.14
Pinto	23.92	7.63	31.55	0.04
Emerson	28.15	2.40	30.55	0.86
Lambert	30.83	3.95	34.79	0.80

3.2 Summary by Watershed

The maps for each watershed are displayed in order from the highest relief basin to lowest relief basin. Much of the western half of the Moon Creek watershed is located within sparsely vegetated or snow covered mountains (Figure 3).

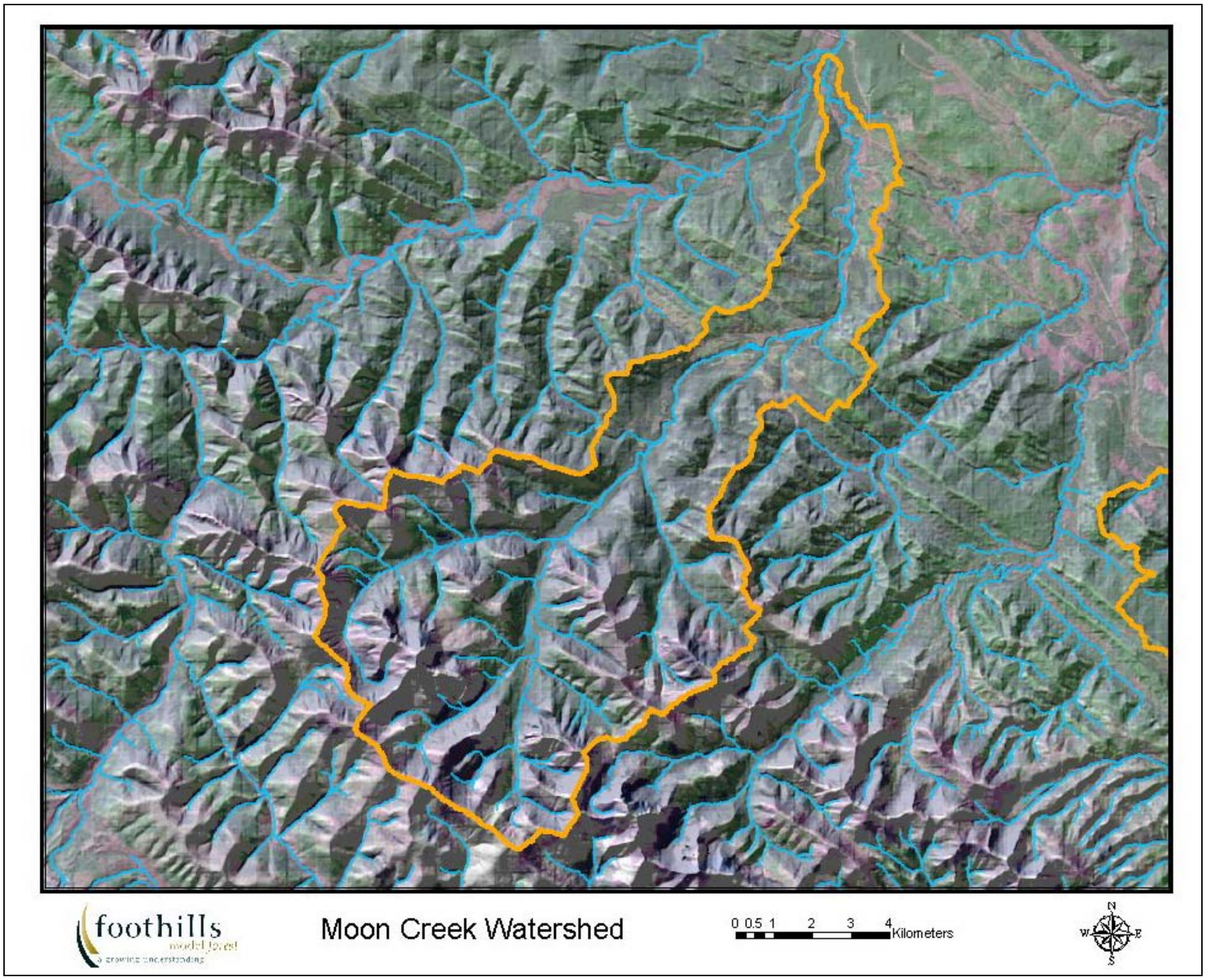

Figure 3. Landsat TM image of the Moon Creek watershed draped on a shaded relief map (based on a 25m DEM).

Most of the headwater streams within Solomon Creek watershed originate in the steep, sparsely vegetated mountains within the western portion of the basin. However, this watershed also supports continuously vegetated areas with much lower relief in the lower elevation eastern portion of the watershed (Figure 4).

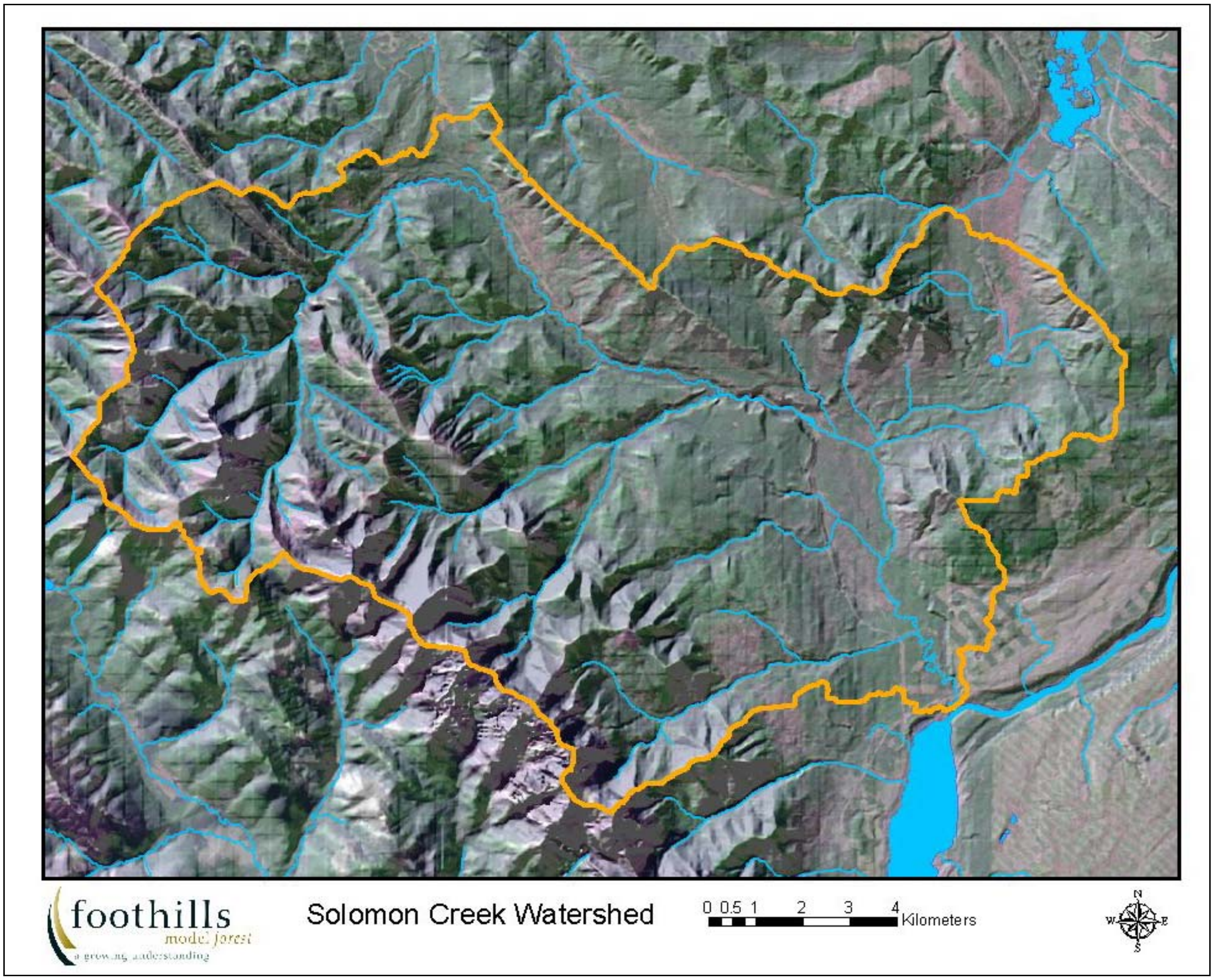

Figure 4. Landsat TM image of the Solomon Creek watershed draped on a shaded relief map (based on a 25m DEM).

A northwest trending range bisects the MacKenzie Creek watershed. The lower elevation areas north of this range are characterized by moderate sloping, continuously vegetated terrain, while the higher elevation areas south of this range are characterized by sparsely vegetated terrain (Figure 5).

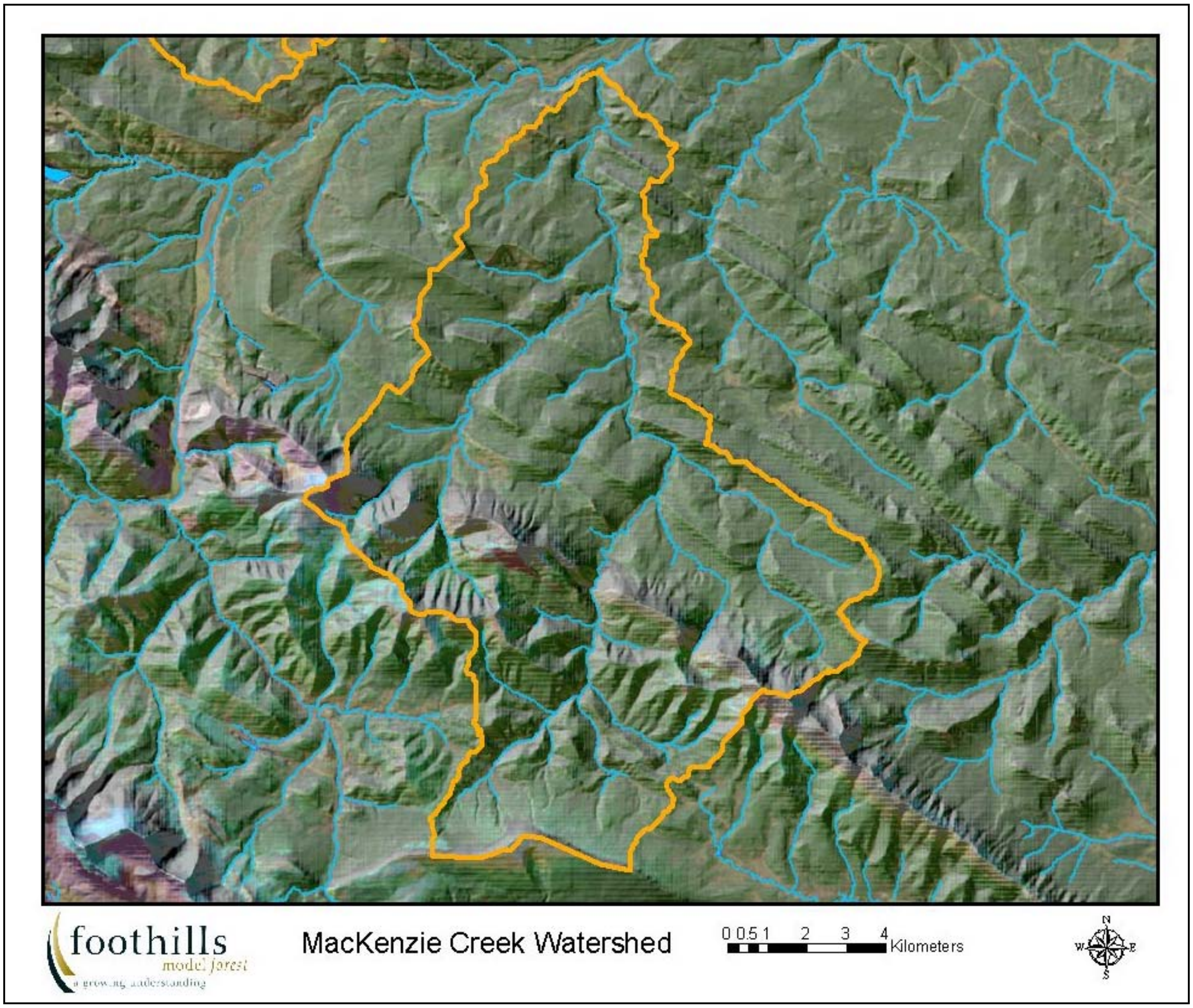

Figure 5. Landsat TM image of the MacKenzie Creek watershed draped on a shaded relief map (based on a 25m DEM).

All three watersheds that comprise the Tri-Creeks study area are characterized by moderately steep, heavily vegetated terrain. The lighter areas on the map indicate recent forest harvest (Figure 6).

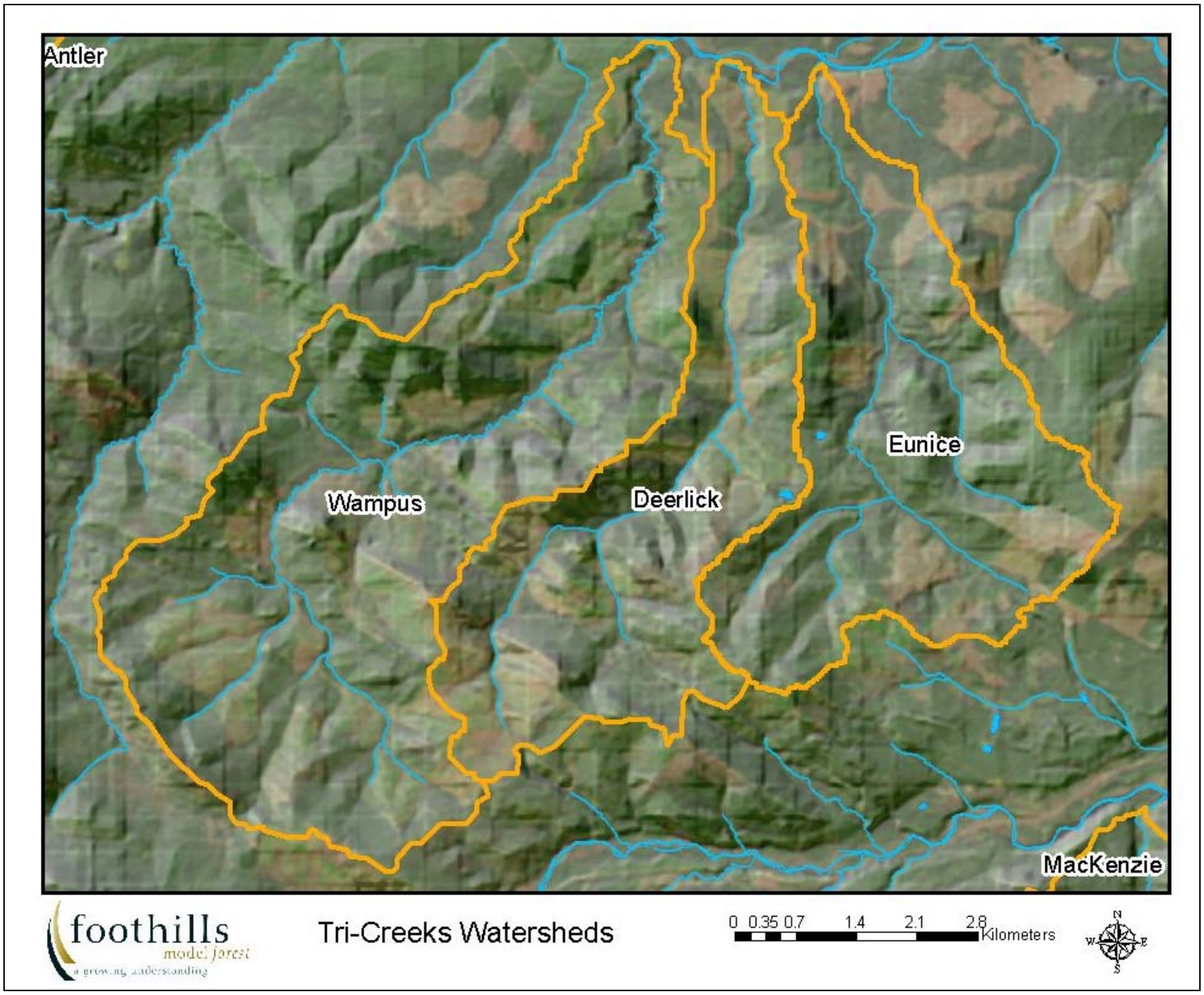

Figure 6. Landsat TM image of the Tri-Creeks watersheds draped on a shaded relief map (based on a 25m DEM).

The steepest terrain in the Teepee Creek watershed occurs along the northeastern boundary of the basin (Figure 7).

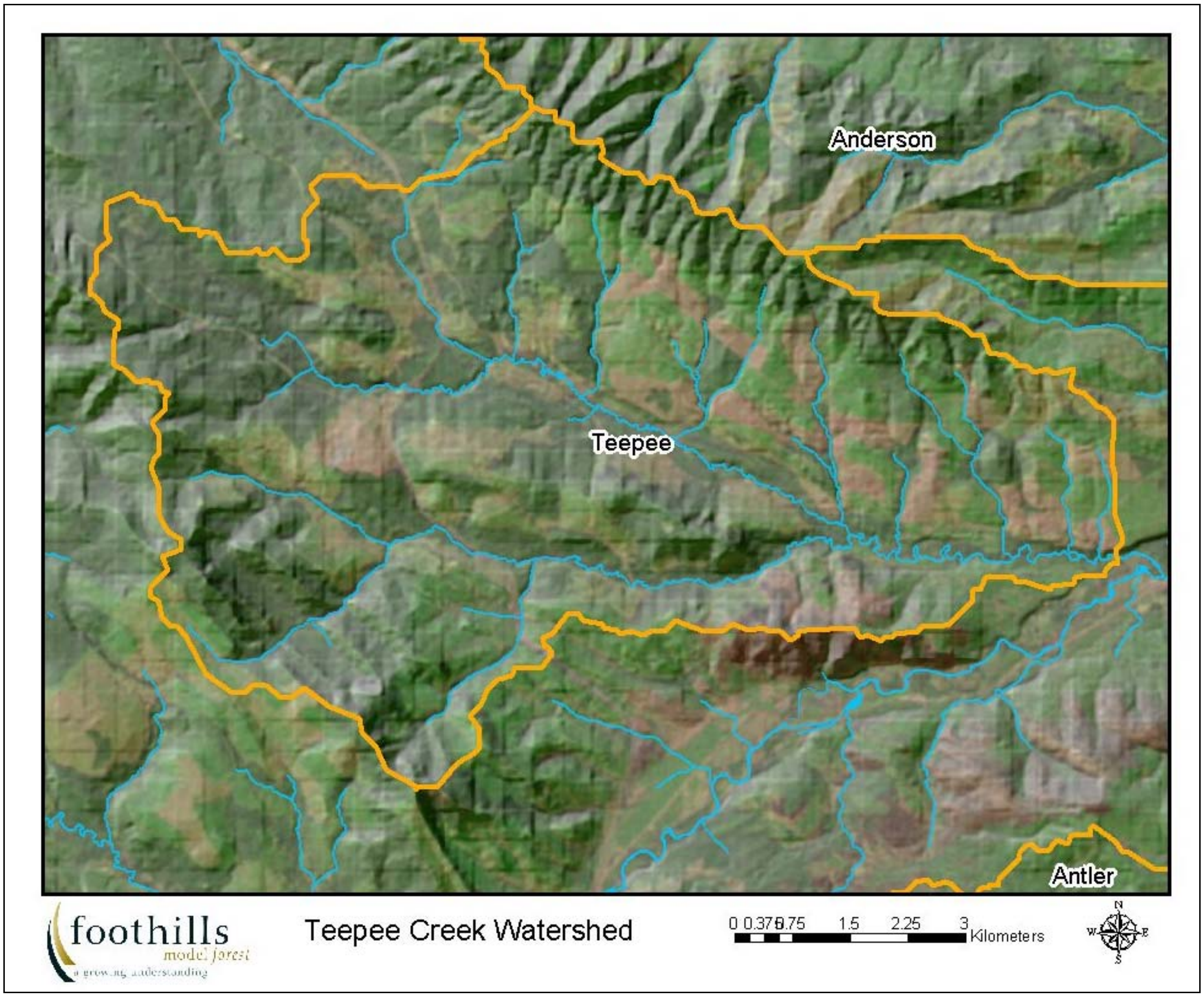

Figure 7. Landsat TM image of the Tri-Creeks watersheds draped on a shaded relief map (based on a 25m DEM).

There is a low relief sub-basin in the northern part of the Antler Creek watershed. The remainder of this watershed is characterized by moderately sloping terrain (Figure 8).

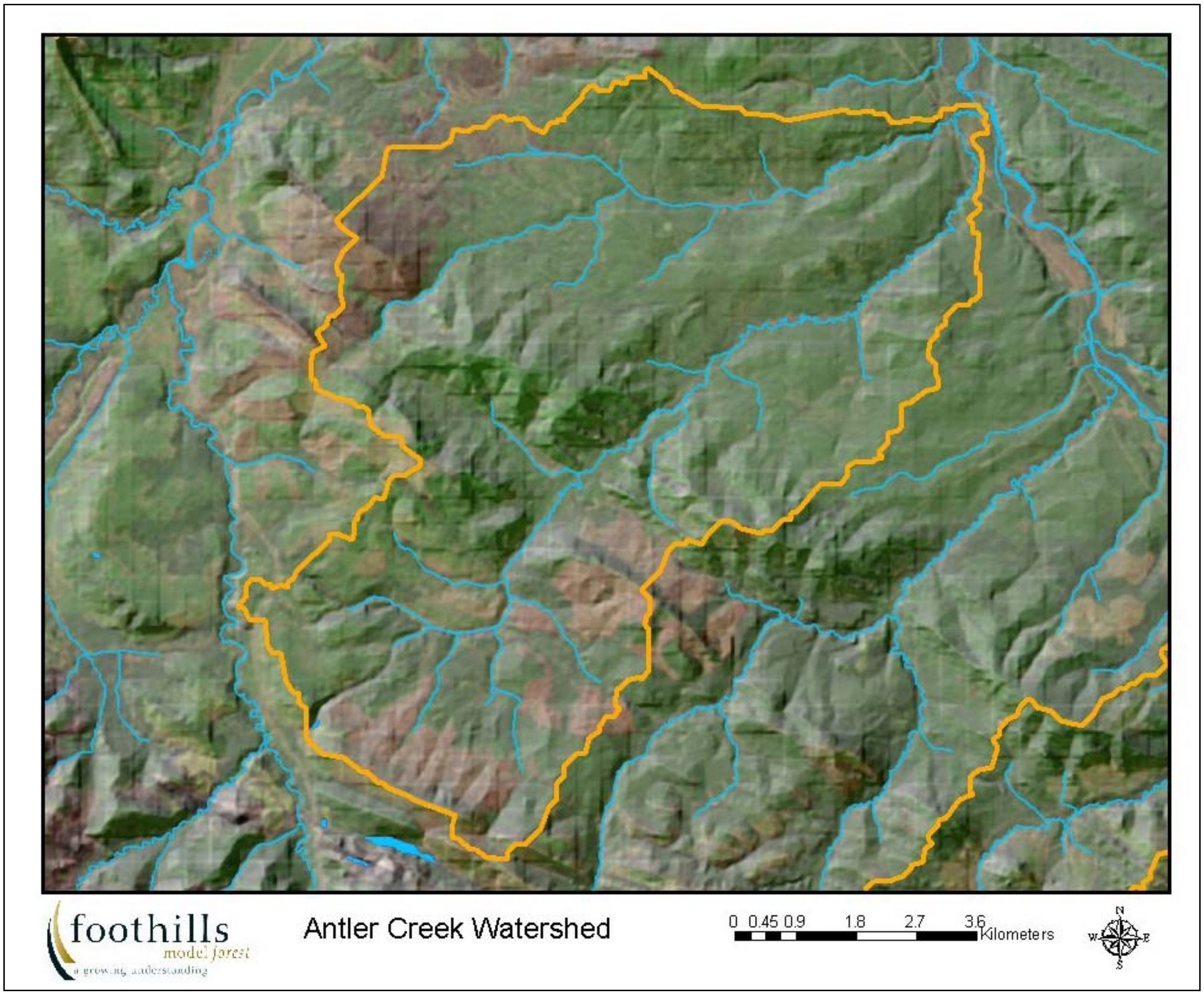

Figure 8. Landsat TM image of the Antler Creek watershed draped on a shaded relief map (based on a 25m DEM).

There are high relief ridges that surround the western most headwaters of the Anderson Creek mainstem. In the north and east portions of this watershed, however, are low relief terrain indicative of the lower foothills plateau bench lands (Figure 9).

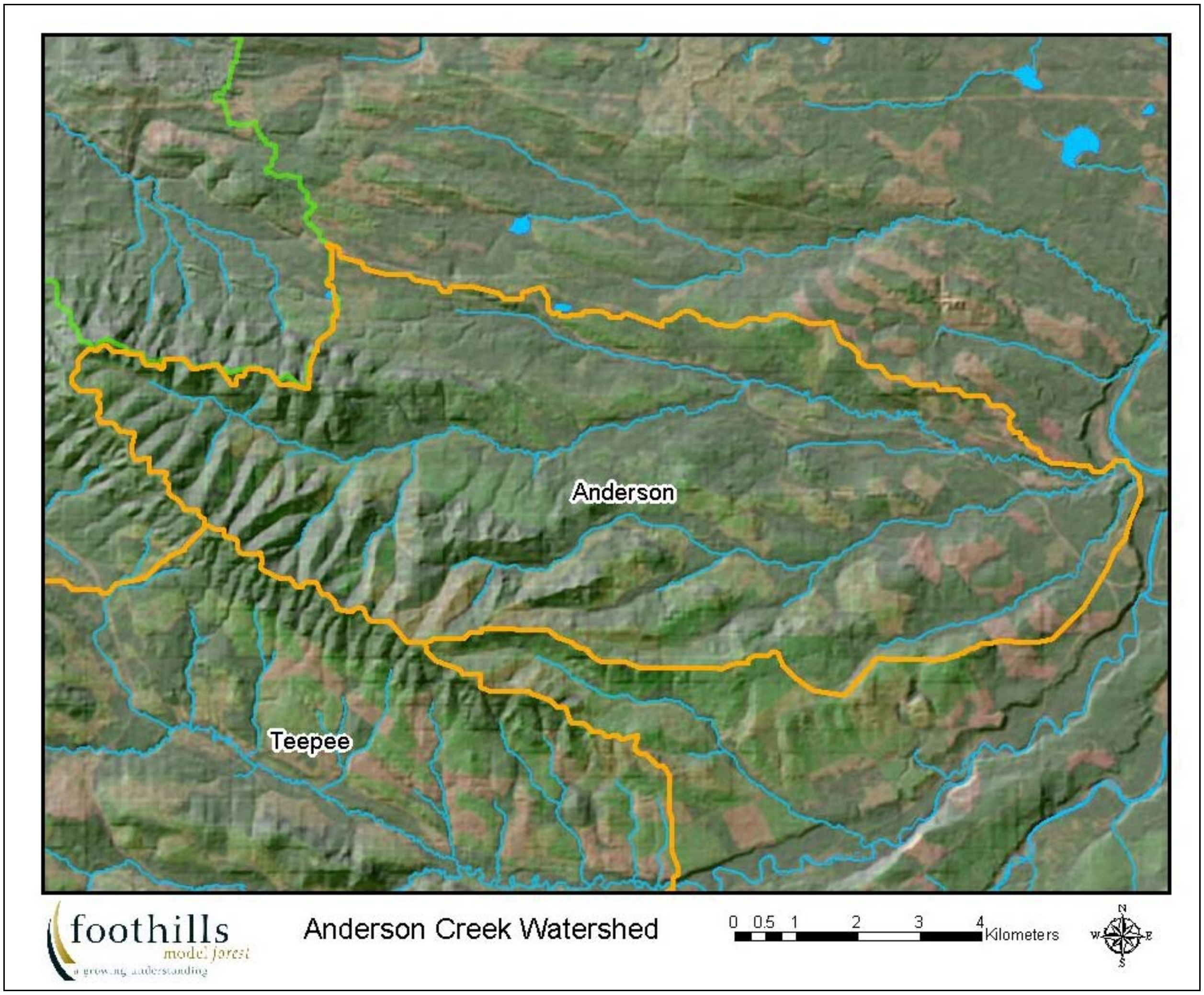

Figure 9. Landsat TM image of the Anderson Creek watershed draped on a shaded relief map (based on a 25m DEM).

In the headwater areas of the Upper Erith River watershed, there is moderately sloping terrain broken by northwest to southeast trending ridges typical of the upper foothills. Plateau bench lands, a characteristic of the lower foothills, occur in the lower reaches of this basin (Figure 10).

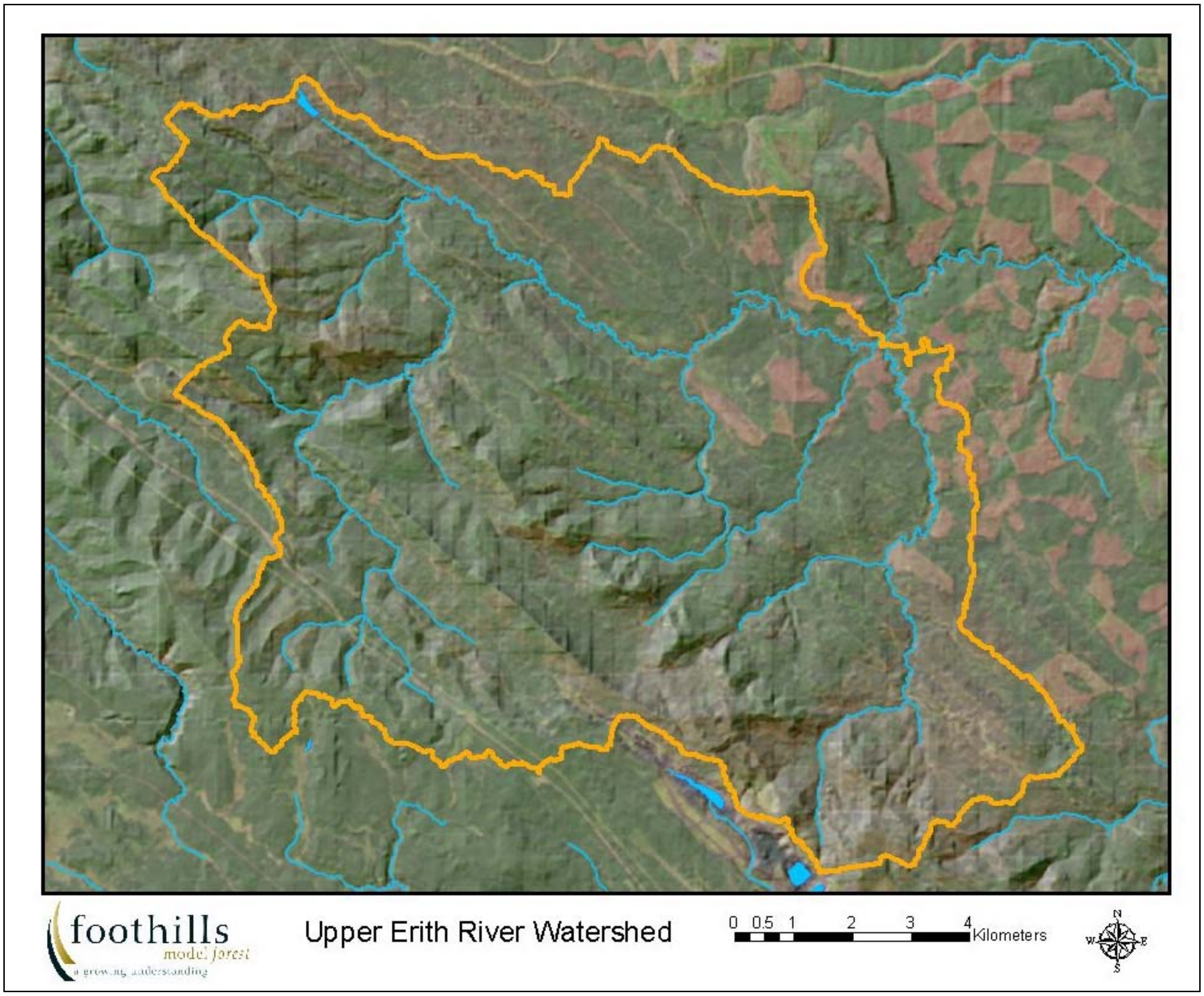

Figure 10. Landsat TM image of the Upper Erith River watershed draped on a shaded relief map (based on a 25m DEM).

The Lynx Creek watershed is a mixture of the moderately steep terrain of the upper foothills and the plateau bench lands of the lower foothills (Figure 11).

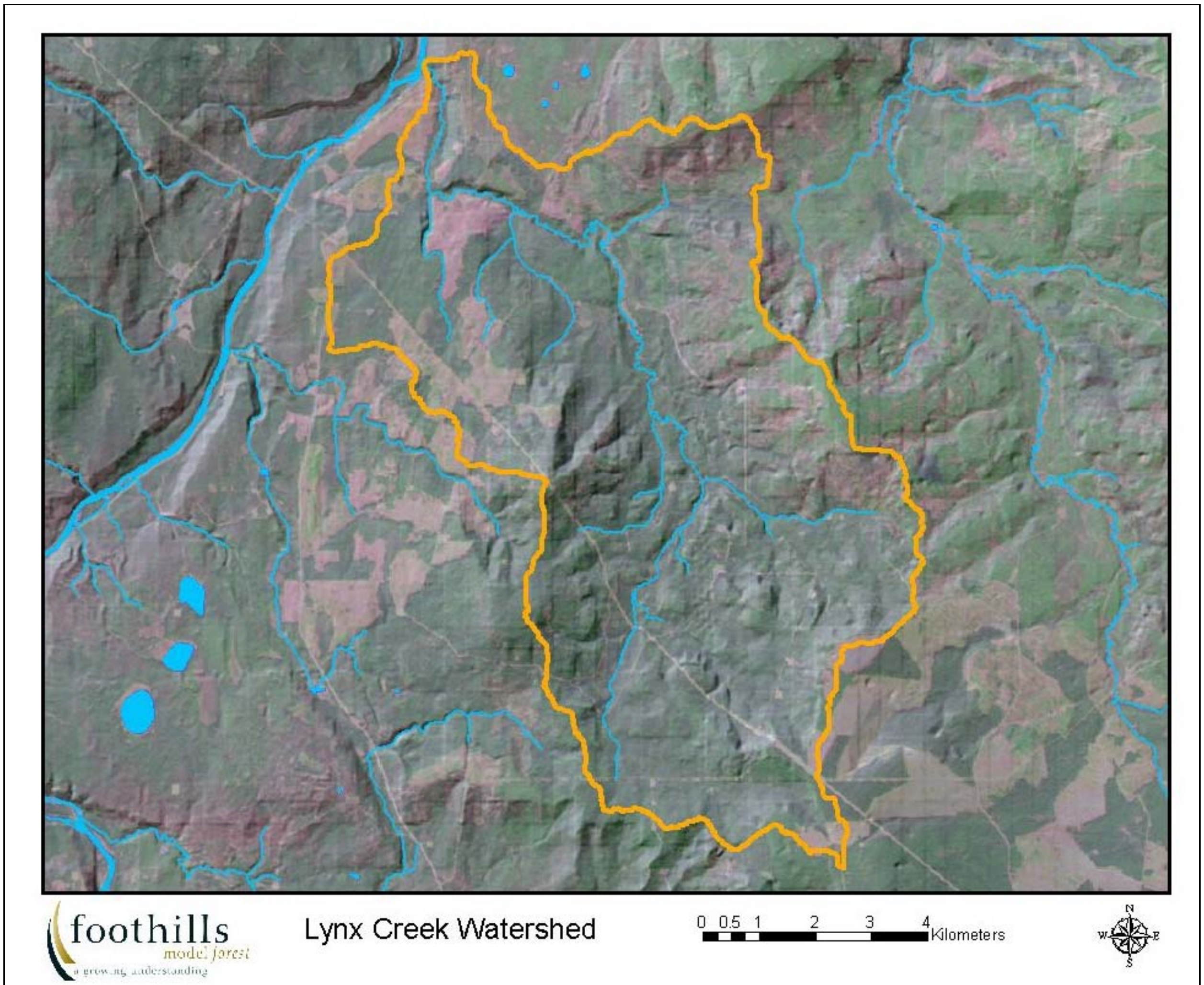

Figure 11. Landsat TM image of the Lynx Creek watershed draped on a shaded relief map (based on a 25m DEM).

In the Fish Creek watershed plateau bench lands occur in the northern-most headwaters with low to moderately steep areas further south. The mainstem flows through an incised valley in the middle portion of the basin (Figure 12).

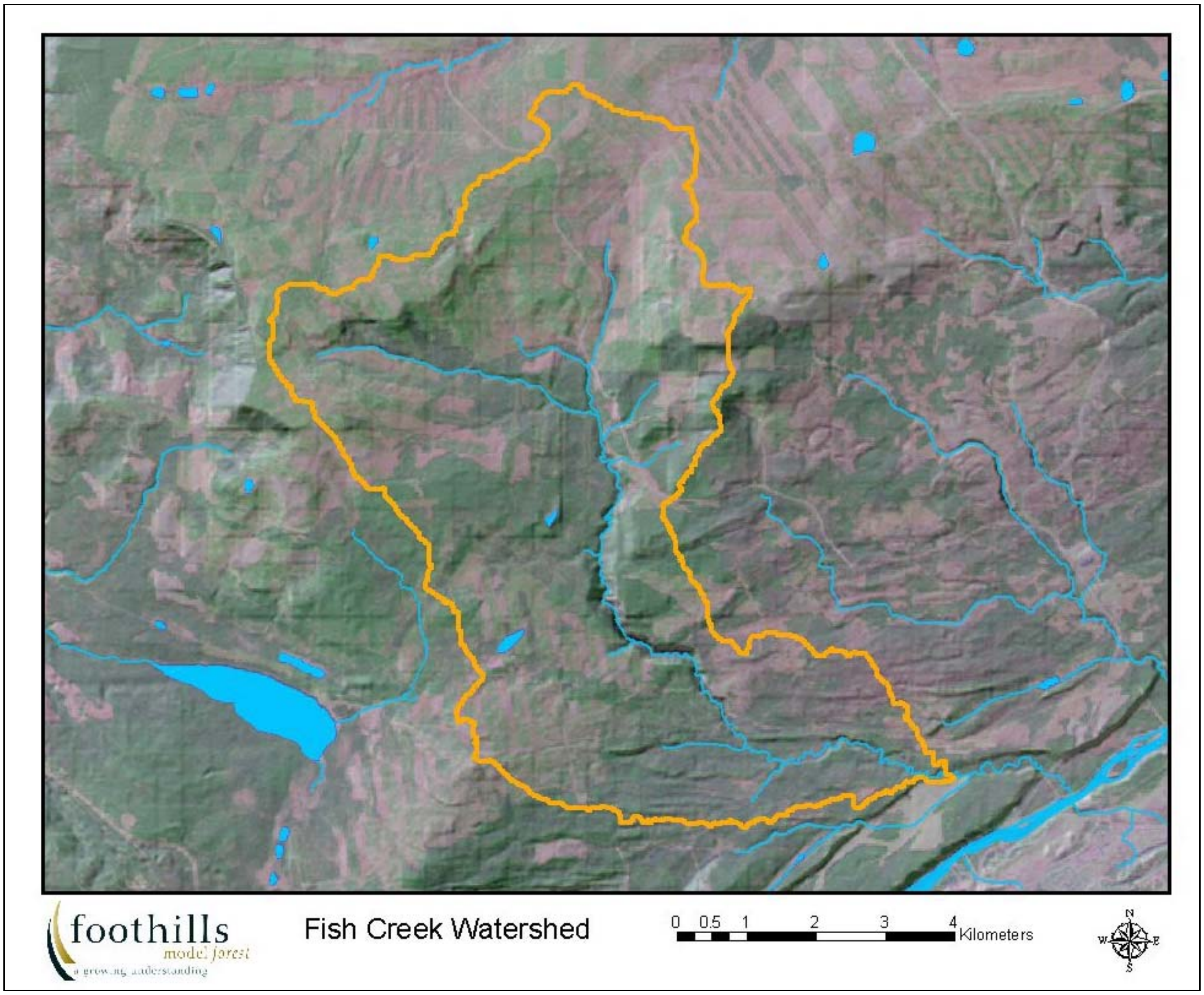

Figure 12. Landsat TM image of the Fish Creek watershed draped on a shaded relief map (based on a 25m DEM).

The Pinto Creek watershed is the largest of all the selected monitoring watersheds and therefore has a variety of characteristics. In the western headwaters, there is moderately steep terrain. In the central portion of the watershed are medium elevation plateau bench lands. In the lower portion of the watershed, Pinto Creek flows through an incised (Figure 13).

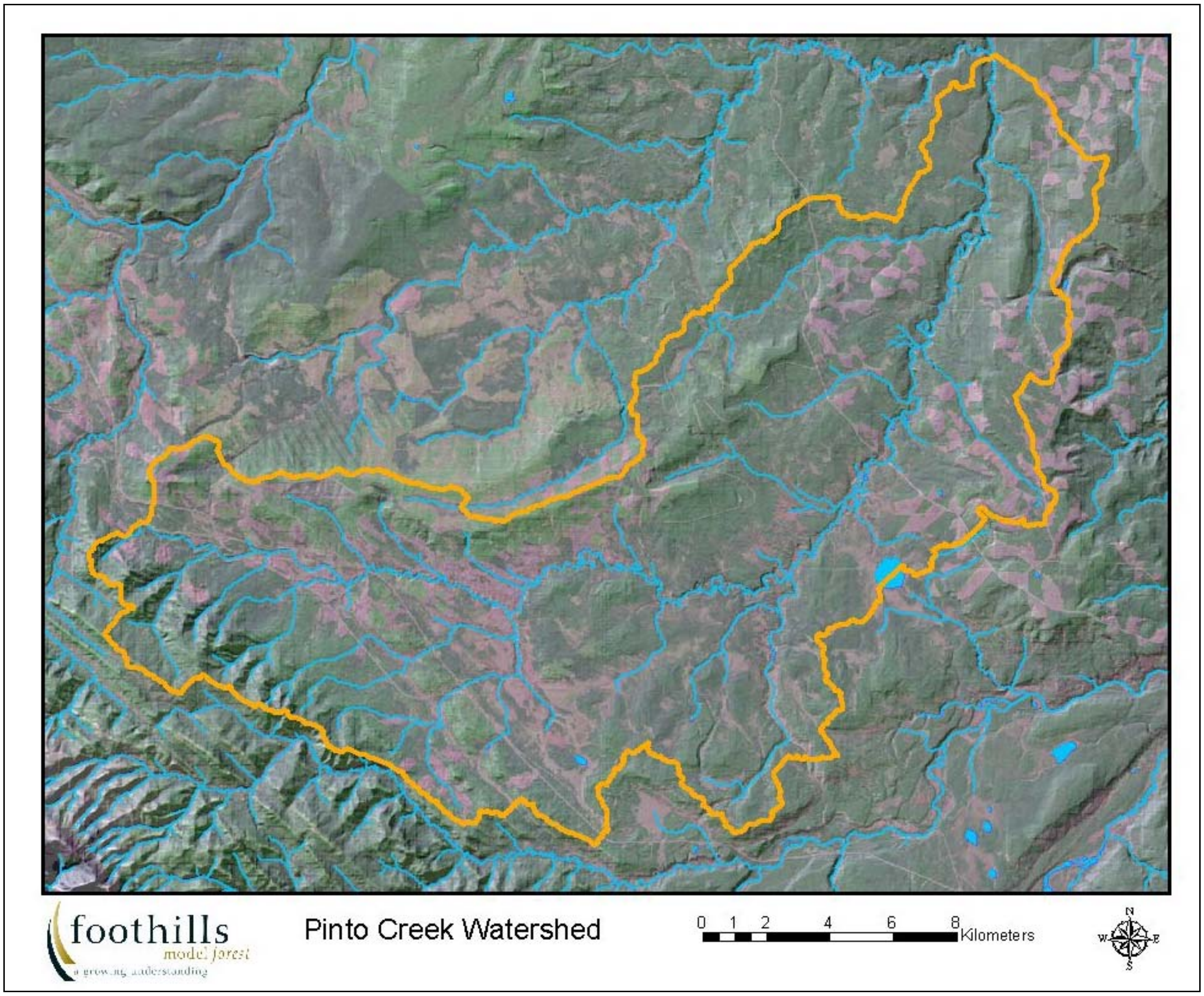

Figure 13. Landsat TM image of the Pinto Creek watershed draped on a shaded relief map (based on a 25m DEM).

The Emerson Creek watershed contains plateau bench lands that drop into an incised valley as the stream approaches the Athabasca River (Figure 14).

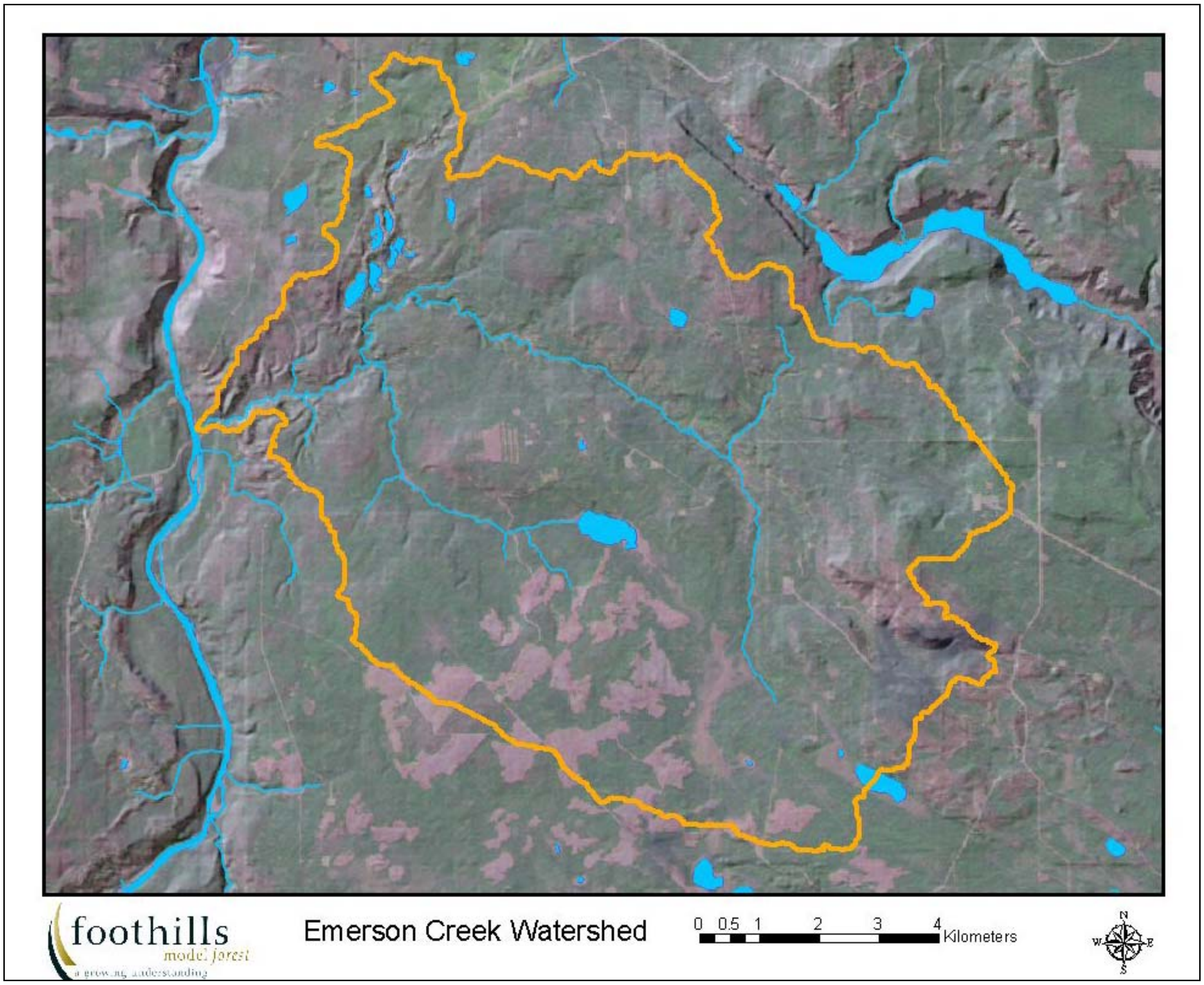

Figure 14. Landsat TM image of the Emerson Creek watershed draped on a shaded relief map (based on a 25m DEM).

The Lambert Creek watershed contains low elevation plateau bench lands with an incised valley in the middle portion of the watershed (Figure 15).

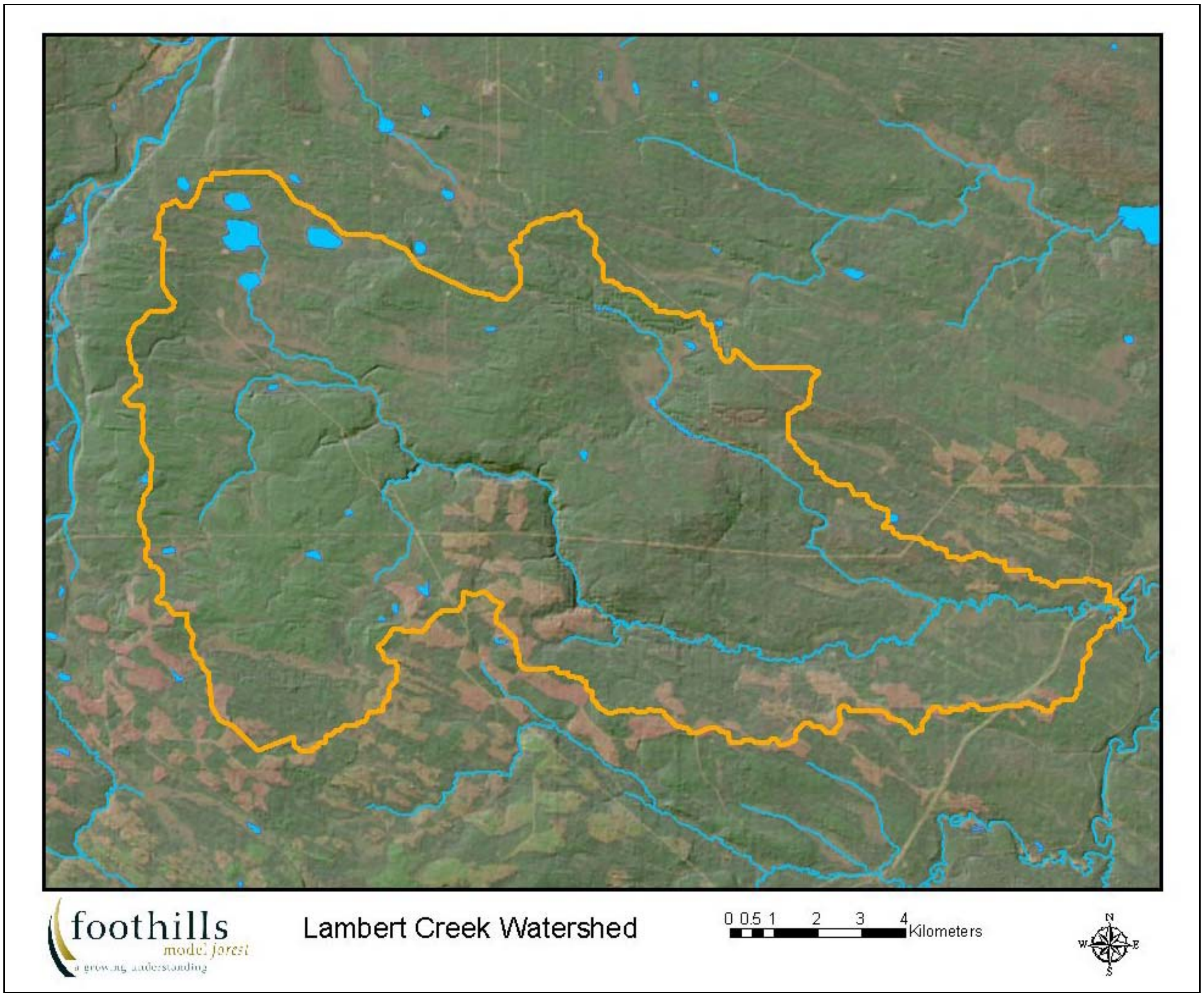

Figure 15. Landsat TM image of the Lambert Creek watershed draped on a shaded relief map (based on a 25m DEM).

4. Discussion

Watershed physiography for each basin was described using six descriptors including watershed size, steepness of terrain, mean basin elevation, wetland extent, lake extent and dominant natural subregion (Table 9).

Table 9. Summary of basin characteristics.

Watershed Name	Stream Order	Slope Class	Elevation Class	Wetland Class	Lake Class	Dominant Ecoregion	Potential Watershed Pairs
Moon	5	High	High	Low	Low	Subalpine	None
Solomon	6	High	High	Low	Low	Upper Foothills	None
MacKenzie	4	High	High	Low	Low	Subalpine	None
Deerlick	3	Medium	Medium	Low	Medium	Subalpine	1
Wampus	4	Medium	Medium	Low	Low	Upper Foothills	None
Teepee	5	Medium	Medium	Low	Low	Upper Foothills	2
Eunice	3	Medium	Medium	Low	Low	Upper Foothills	1
Antler	5	Medium	Medium	Medium	Low	Upper Foothills	2
Anderson	4	Medium	Medium	Medium	Low	Subalpine	None
Upper Erith	4	Medium	Low	Medium	Medium	Upper Foothills	3
Lynx	4	Medium	Low	Low	Low	Upper Foothills	3
Fish	3	Low	Medium	Low	High	Upper Foothills	None
Pinto	5	Low	Medium	High	Low	Upper Foothills	None
Emerson	4	Low	Low	High	High	Lower Foothills	4
Lambert	4	Low	Low	High	High	Lower Foothills	4

Based on the six watershed characteristics, the degree of similarity between the 15 basins ranged widely (Table 10). Only two watersheds shared identical values for all six characteristics (Lambert and Emerson). Five pairs of watersheds had identical values for five characteristics and 13 pairs of watersheds had identical values for four characteristics. The remaining 86 watershed combinations shared less than four identical characteristics.

Table 10. Similarity of watersheds based on number of shared characteristics.

	Moon	Solomon	MacKenzie	Deerlick	Wampus	Teepee	Eunice	Antler	Anderson	Upper Erith	Lynx	Fish	Pinto	Emerson
Solomon	4													
MacKenzie	5	4												
Deerlick	2	1	2											
Wampus	2	3	3	3										
Teepee	3	3	2	3	5									
Eunice	2	3	2	4	5	5								
Antler	2	2	1	2	4	4	4							
Anderson	2	1	3	3	4	3	3	4						
Upper Erith	2	1	1	2	3	2	2	3	3					
Lynx	2	3	3	2	5	4	4	3	3	4				
Fish	1	2	1	3	3	3	4	2	1	1	2			
Pinto	2	1	1	1	3	4	3	3	2	1	3	3		
Emerson	0	0	1	0	0	0	0	0	2	2	3	2	2	
Lambert	0	0	1	0	0	0	0	0	1	2	2	1	2	6

Each physiographic characteristic will influence both the response of the stream channels to human activities, as well as the types and productivity of aquatic organisms that inhabit the watershed. This has implications for both land-use planning and measuring changes in aquatic resources.

Based on these characteristics, watersheds may have a different sensitivities to changes in peak flow, water yield or sediment transport rates. Potentially, thresholds could be identified for the individual basin, based on its physiographic characteristics.

The basin classification system described in this report is also an important component of the larger multi-year study that is attempting to determine the effects of human-use activities on fish and fish habitat. The findings from this classification exercise have confirmed that a large amount of variation exists in physiographic characteristics between the 15 monitoring watersheds. These physiographic characteristics will influence both the fish community assemblages and the biological productivity and as a result, we would expect a high natural variability in these parameters between the watersheds. Levels of land-use were also variable among watersheds (Sherburne and McCleary 2003). Therefore, a multiple variable analysis that includes physical watershed characteristics and levels of land-use could be utilized to attempt to explain fish distribution and abundance patterns among the various watersheds.

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