Comparison between field surveyed and GIS derived descriptors of small streams within the west-central foothills of Alberta

Report prepared by Foothills Model Forest Employees:

Richard McCleary, Biologist

Christian Weik, GIS Coordinator

Jason Blackburn, Fish Technician

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Abstract

The primary objective of this study was to evaluate the accuracy of GIS derived values of slope and sinuosity for small streams in the west-central foothills of Alberta. A secondary objective of this study was to evaluate the measurements calculated by a GIS application developed by the Foothills Model Forest.

The study involved comparing GIS derived values of slope and sinuosity with field measures. The study included 29 sites representing the wide range of stream types encountered in the study area. Field measures were based on total station surveys over 100m of stream or more.

We found that sinuosity values for streams with a drainage area of less than 20 km^2 were underestimated by a value of 0.29. A sinuosity correction factor was developed to remove this bias. The bias in sinuosity effectively shortened stream length and resulted in over-estimates of stream slope. A slope correction factor was also developed. The application of the slope correction factor improved the accuracy of the GIS derived slope and also improved the accuracy of stream classification based on GIS derived slope.

We found that the GIS application developed by the Foothills Model Forest provided consistent measures of stream elevation regardless of the length of the stream that was studied. Although the DEM had a 25m resolution, the GIS application was capable of accurately determining elevations of points that were separated by only a few meters.

The scale of the initial aerial photography from which the stream information was derived has a very strong influence on the accuracy of GIS derived measures of slope and sinuosity. The sinuosity of small streams with a drainage area of less than 20 km^2 was poorly represented at most of our survey sites.

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The need for this research arose from a 1999 meeting attended by a number of different people interested in practical applications of a GIS tool developed by the Foothills Model Forest. At the meeting, the accuracy of GIS derived values of stream sinuosity and slope was called into question. Craig Johnson, Fish Biologist, Fish and Aquatics Research Program, Foothills Model Forest and George Sterling decided that the accuracy question held enough merit to warrant a comparison of field surveyed and GIS derived measures. In 1999, while serving on the project steering committee for the Fish and Aquatics Research Program at the Forest Model Forest, Craig Johnson and George Sterling provided the impetus for this work. Both biologists continued to provide input and direction during the development of the study plan, field surveys and data analysis.

Fieldwork was completed through the hard work and dedication of the Fish and Watershed Program staff including Barb Johnston, Tyler Muhly, Jason Blackburn, Mike Blackburn and Chantelle Bambrick. Julie Dugas of the Foothills Model Forest GIS Program completed a number of GIS procedures. Fran Hannington of the Foothills Model Forest, provided constructive criticism of a draft version of this manuscript.

Table of Contents

List of Figures

List of Tables

List of Equations

1. Introduction

Geo-spatial information and Geographic Information Systems (GIS) are powerful tools for describing characteristics of natural features across the landscape. In the practical application of geo-spatial information, it is important to understand the differences between interpreted datasets and that, which actually exist on the ground. This study focuses on two parameters frequently used by aquatic biologists and hydrologists to describe streams: slope and sinuosity. Stream slope is a relative measure of the change in elevation over a given distance. Sinuosity is a measurement of the degree to which a stream meanders down its valley. Resource managers commonly measure both slope and sinuosity when they conduct office-based stream assessments.

Due to cartographic processes, map-based measurements of stream slope are typically greater than true values (Isaak et. al. 1999). This overestimation results from the inability to capture the natural sinuosity of a stream, particularly for smaller water-bodies (Isaak et. al. 1999). This effectively shortens the length of a stream for a given reach and results in an exaggeration of slope (Isaak et al. 1999).

We hypothesized that within the study area, a number of factors including stream order, stream slope, presence of a forest canopy and upstream watershed area influenced the ability of the cartographer, who completed the initial mapping, to accurately capture the natural stream sinuosity. The findings from this hypothesis testing exercise were intended to guide us in the development of a calibration factor to improve the accuracy of map-based measurements.

In addition, we posed two additional hypotheses that relate to the GIS interpretation of stream slope. First, we hypothesized that the quality of digital elevation information influenced the accuracy and precision of GIS slope calculations. Second we hypothesized that due to the resolution of digital elevation information, accuracy of GIS slope measurements for small stream segments (<150m) would increase as the length of the stream segment in question increased.

The study area for this project was the west-central foothills of Alberta. Small streams are the most numerous water-bodies in the study area and foresters encounter them on a regular basis as they plan roads and timber harvest. The ability of foresters and fish biologists to understand these environments through the use of GIS interpreted information is important to their effective management. As a result, this study focused on small streams – generally 10m wide or less.

The core GIS tools used in this study were originally developed by The Forestry Corp in 1998 under contract to the Foothills Model Forest. These tools are comprised of a significant number of Arc Macro Language (AML) programs written to automate the data preparation, analyses, and data formatting processes (The Forestry Corp 1998). These tools were originally developed under the name Watershed Assessment Model (WAM). Between 1998 and 2002, the Foothills Model Forest GIS team made some improvements to the tools (Foothills Model Forest 2002a). Some concern arose with the fit between what the improved tools offered and their name and as a result, the staff of the Foothills Model Forest changed the name of the application to the Hydrologic Attributes Generated from GIS (HAGGIS).

1.1 The Stream Reach

A stream's physical characteristics change from source to mouth and the biotic communities establish accordingly along this continuum (Vannote et al. 1980). A common first step in the description of a stream along this continuum is to divide the stream network into a series of reaches. A reach is a length of stream with similar width, slope, vegetation and sinuosity. Reach breaks also occur wherever there is a change in stream order.

The exercise of dividing the stream network into reaches was previously completed for all streams within selected watersheds in the Weldwood Forest Management Agreement Area (Foothills Model Forest 2002) and we utilized the results from that exercise during site selection.

1.2 True Values of Slope and Sinuosity

In similar studies, slope measurements were taken with standard surveyor's instruments – the rod, level and tape (Isaak et al. 1999). In our study, we also used standard surveyor's instruments to collect true values of slope. However, rather than a rod, level and tape we used a total station and prism pole to measure slope. A total station consists of an instrument called a theodolite, in conjunction with an automatic distance meter (Zeiske 2000). The theodolite is a standard surveyor's instrument that is used to measure both horizontal and vertical angles (Merriam-Webster 1993). The software within the total station uses the angle and distance measurements to calculate the position and height of a surveyed point (x, y and z; or easting, northing and elevation). Measures of actual slope and sinuosity can then be derived from the line that connects the series of surveyed points along a stream.

1.3 Processing a Digital Elevation Model Prior to Hydrologic Analysis

The key geo-spatial layer employed in hydrologic analyses is the Digital Elevation Model or DEM. This layer is a representation of the Earth's surface, or of its topography. Hydrologic analyses typically involve modeling the movement of water across this surface. Therefore it is imperative that the DEM provides an accurate representation of reality.

Within Alberta, DEM data are made available through the provincial government. To receive these data, the user submits a request to the Resources Data Division of Alberta Sustainable Resource Development. These data are then extracted from the 1:20,000 base features dataset and provided at a resolution of 25 meters. These data, as they are delivered, are not hydrologically corrected. That is, the surface is not smoothed to force drainage of all cells to the edge of the surface. This issue prevents many analyses from being performed with realistic results. To rectify this problem, data users typically run several processes on the DEM to force drainage from the surface and enable better hydrologic analyses.

1.4 Resolution of the Geo-spatial Stream Layer

Within the province of Alberta, the geo-spatial stream layer was originally interpreted from 1:60,000 digital ortho-photographs (pers. comm. K. Tripp, Section Leader – Data Distribution, Resource Data – Data Management, Sustainable Resource Development, Alberta Government 2002). Although GIS software packages typically enable users to view the data at any scale, the accuracy of the data ultimately reflects the effective resolution of the original aerial photography. This study provided an opportunity to determine the effective resolution of the digital stream network for capturing stream sinuosity. We hypothesize that there is an average threshold along the stream continuum from mouth upstream towards the source at which the natural sinuosity of a stream is no longer effectively represented.

2. Methods

2.1 DEM Pre-Processing

In order to create a DEM that was hydrologically correct (i.e. drainage issues resolved), we completed a number of processes. The key process in forcing drainage was application of the Australia National University DEM (ANUDEM) algorithm. Several additional processes were run in order to ensure complete smoothing. These processes were built into the HAGGIS tool set (Foothills Model Forest 2002a) and were performed using tools available in ARC/INFO GIS software (Environmental Systems Research Institute 2001).

2.2 Single Line Network Pre-Processing

A single line stream network geo-spatial layer is required to measure slope and sinuosity of segments within the stream network. This layer provides a single line flow of water across the landscape, including areas where water flows through lakes and large rivers, which are typically represented by a line along each bank or shore.

An external consultant completed the creation of the single line network layer. The process involved acquiring base features single line hydrography from the Alberta government and enforcing true single line topology. This process included assigning a Strahler stream order value to every arc segment in the stream network. Strahler stream order was then used to coarsely stratify the stream network and to build the route or travel paths for the network analysis.

2.3 Parameters Influencing the Accuracy of GIS Sinuosity Measurements

A number of parameters including stream order, stream gradient, presence of a forest canopy and upstream drainage area may have influenced the ability of a cartographer to accurately capture the natural sinuosity of a stream during the mapping process. For site selection and analysis, geo-spatial information on these four parameters was readily available from two previously completed stream classification exercises (Foothills Model Forest 2002b and Golder Associates Ltd. 2002).

2.3.1 Stream Order

Stream order is a commonly used measure of relative stream size (Figure 1). Streams of interest for this study included first through fourth order. Stream order was used both during the site selection process and during the evaluation of GIS slope accuracy.

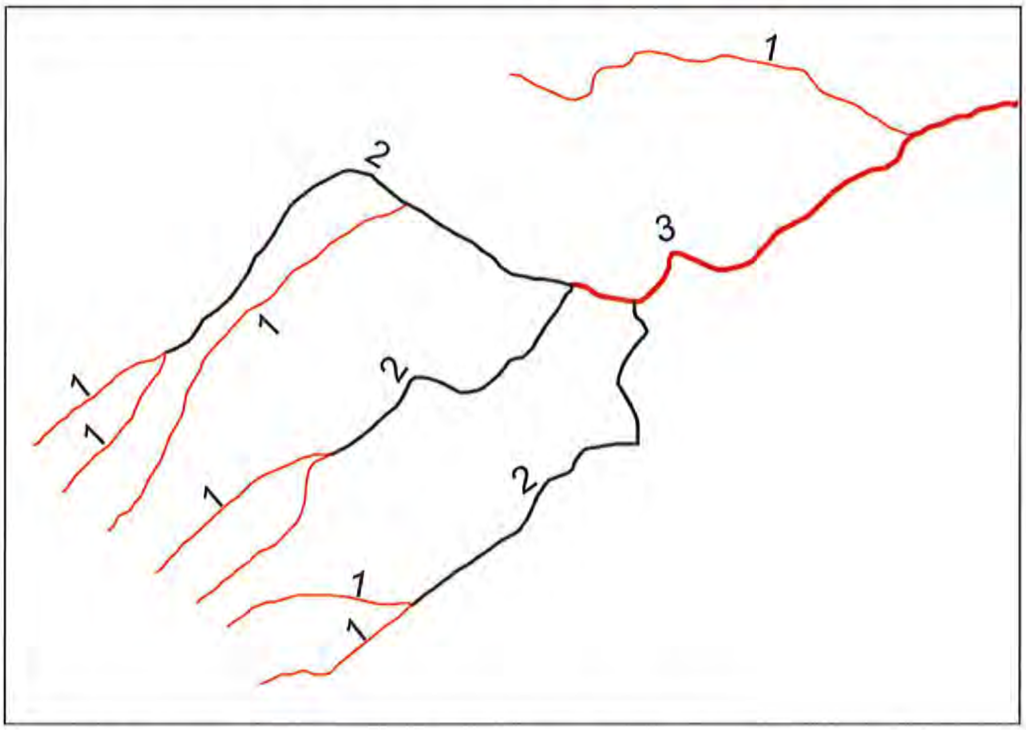

Figure 1. Map of ordered streams within a small watershed.

2.3.2 Stream Gradient

For site selection, reaches were stratified using the results of the Foothills Model Forest stream classification exercise for selected watersheds within the Weldwood FMA (Figure 2). The slope classes used in that classification were consistent with Rosgen (1994). These measures of stream gradient from the classification exercise were not used in the evaluation process.

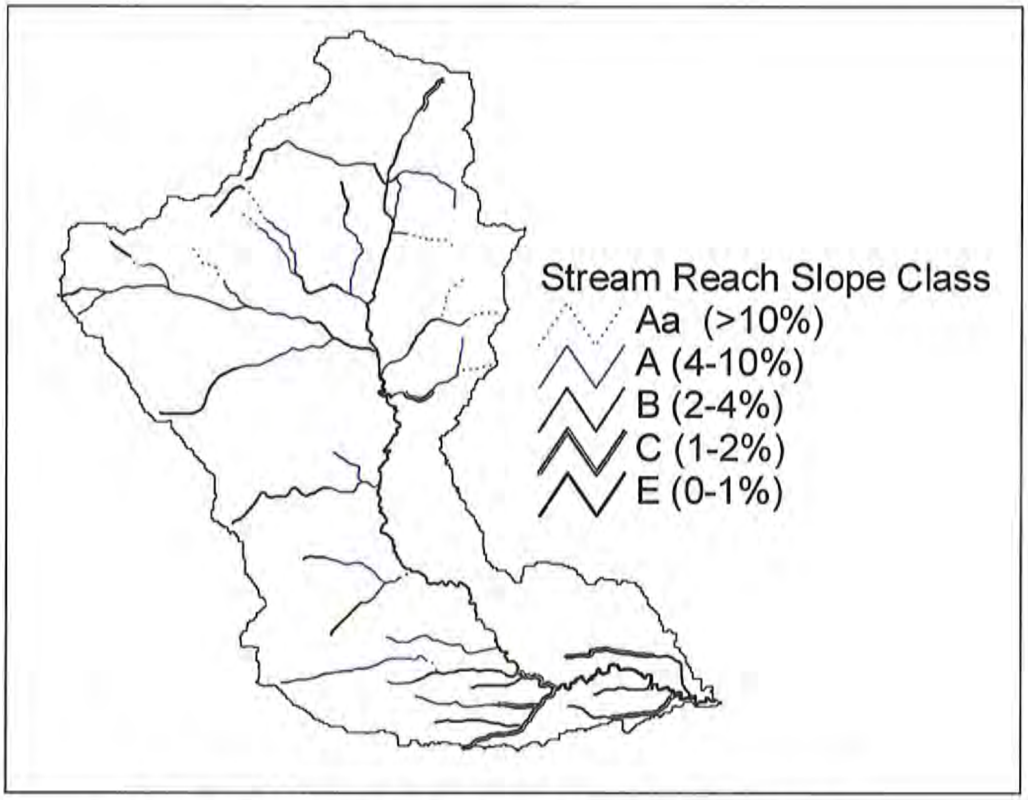

Figure 2. Map of stream reaches by slope class within a watershed.

2.3.3 Presence / Absence of a Forest Canopy

Information on the presence / absence of a forest canopy was determined using the riparian vegetation class information from the Foothills Model Forest Level 1 Stream Classification (Figure 3). This riparian vegetation classification was determined from Alberta Vegetation Inventory (AVI) data, which was provided by Weldwood for the study area. The AVI is a provincial standard procedure that generates a digital geo-spatial layer and accompanying database to identify the type, extent and conditions of vegetation across a study area (Nesby 1996).

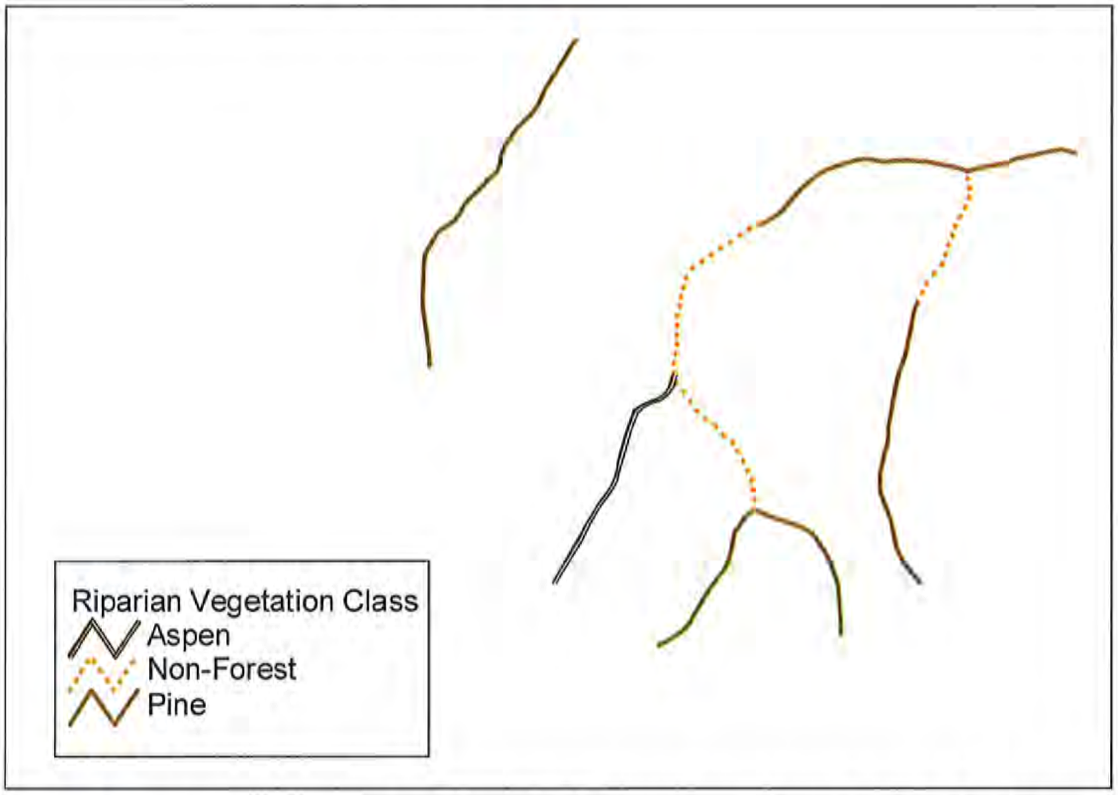

Figure 3. Dominant riparian vegetation class by stream reach from Foothills Model Forest Level 1 Stream Classification.

For the purposes of this study the six riparian vegetation classes were grouped into two classes (

Table 1). Non-forested wetland communities included shrub-dominated non-forest lands. Within the study area, black spruce / tamarack forests typically had limited canopy closure and were therefore included in the canopy absent category.

Table 1. Riparian vegetation classes and canopy status.

Riparian Vegetation Class	Canopy Status
Aspen	Present
Black spruce / larch	Absent
Fir	Present
Non-forested wetland	Absent
Pine	Present
Spruce	Present

2.3.4 Upstream Drainage Area

Upstream drainage area was not used for site selection, however this parameter was used in the evaluation process. Upstream drainage area at each study site was determined from the results of the Level 2 stream classification (Golder Associates Ltd. 2002). For the Level 2 classification, the stream network covering the Weldwood FMA was divided into reaches with similar slope. Reach length averaged 300 m. For each reach, the classification included several descriptive fields including the total drainage area. The total drainage area was defined as the area of the entire contributing watershed above the downstream end of a reach. The drainage area for each of our field survey sites was determined from the Level 2 classification by a common ArcView GIS function (Environmental Systems Research Institute 1998). For the purposes of analysis, drainage area was divided into several classes and used as an ordinal variable, rather than its initial continuous form.

2.4 Site Selection

In order to minimize travel time, candidate sites were identified as those in close proximity to roads. Of the candidate sites, 23 were chosen randomly to cover the range of different combinations of stream order and slope. Six additional sites from another study were also utilized. A total of 29 sites were identified for field surveys (Table 2). Due to the budget limitations, sample replication within the various combinations of slope and order was limited.

Table 2. Summary of survey sites by slope class and stream order.

Slope Class	Total Number of Sites	Stream Order			
		1	2	3	4
4-10 %	8	3	2	3	--
2-4 %	5	1	1	2	1
1-2 %	7	--	1	3	3
0-1 %	9	2	2	2	3
Total	29	6	6	10	7

In order to determine if the presence of a forest canopy influenced sinuosity, sites were also selected from both canopy types (Table 3).

Table 3. Summary of survey sites by canopy status and stream order.

Canopy Class	Total Number of Sites	Stream Order			
		1	2	3	4
Present	16	3	3	7	3
Absent	13	3	3	3	4
Total	29	6	6	10	7

2.5 Field Surveys

A total station was obtained on a rental agreement from a surveying company in Edmonton. The instrument is accurate to the nearest mm in all three dimensions. Prior to this project, we were familiar with the principles of surveying and the proper use of a rod, level and tape. At the start of the project, the company provided us with training on the use of a total station. This training session included field use and care of the equipment, data downloading and data processing. Our field surveys were based on the following procedure:

- We traveled to the pre-determined location on a stream.
- Determined the best location for the total station based on line of site in an upstream and downstream direction.
- Set up the total station and level the unit.
- Using a GPS unit, collected the easting, northing and elevation at the total station.
- Entered these values from the GPS unit into the total station to establish the location of the station.
- Recorded these values in the surveyor's notebook.
- Established a permanent benchmark within the line of site from the total station (nail in a tree with blaze or an iron post).
- Took a compass reading from the total station to the benchmark.
- Set the orientation of the total station by aiming the total station at the benchmark and entering the compass reading into the total station.
- Measured the height of the prism pole and entered the value into the total station.
- Began surveying at the benchmark.
- Recorded the benchmark location into the surveyor's notebook.

In order to allow other researchers to replicate the survey in the future, we established at least one additional benchmark before moving the total station. We then recorded the benchmark location data into the surveyor's notebook. The surveyor's assistant proceeded upstream, following the thalweg or deepest course of the stream channel. We captured all slope breaks in the channel bed that were associated with riffles, cascades, runs and pools. We surveyed at least one representative channel cross-section. During the course of the survey, we noted any errors such as incorrect prism pole height or incorrect point codes in the surveyor's notebook. When it was necessary to move the total station in order to complete the survey, we followed the procedures as outlined in the total station manual for establishing additional stations or hubs.

The total station could have operated without the use of real world (GPS) coordinates and compass-derived orientation. It is common practice for surveyors to enter 1000 m for the easting, 1000 m for the northing and 100 m elevation, and then choose an arbitrary orientation. This approach was used for the first five sites that were surveyed. However, we introduced the use of real world coordinates and compass orientation to enable a basic GIS overlay of the surveyed data on the provincial streams layer (Appendix 1, Site 18). The alignment of the overlay reflected the accuracy of the GPS unit and compass. Real world coordinates and a compass orientation were used for sites 6-29.

2.6 Field Data Management

At the end of each field day, all survey data were downloaded from the total station. In order to conduct error checking, the downloaded data were then converted so that the Point ID, easting, northing, elevation, point code, line code and prism pole height were organized into a table for each point (Table 4).

Table 4. Example of converted data output file used for error checking

Id	Easting	Northing	Elevation	Line Code	Point Code	Prism Height
9	953.434	997.376	99.6	CL[1]		1.55
10	1001.402	995.004	98.799	X1[2]	RB[3]	1.55
11	1000.722	992.327	98.468	X1		1.55

[1] CL = stream centerline, [2] X1 = cross-section #1, [3] RB = right bank

In order to ensure that the correct line code, point code and prism height were assigned to each surveyed point, the converted data were displayed using ArcView GIS (Environmental Systems Research Institute 1998). Any errors noted in the surveyor's notebook were also addressed at this time. Once the field survey component of the project was completed, the data from all site surveys were moved into an Access database.

2.7 Determining Sinuosity and Slope from Surveyed Data

Sinuosity is defined as the total stream length divided by its valley length. For the survey data, the total stream length was equal to the cumulative distance of the stream thalweg survey. The valley length was equivalent to the as-the-crow-flies distance from the first point in the survey to the last point (Figure 4). Stream length and valley lengths were determined from the survey data output file through the use of an ARC/INFO GIS procedure (Environmental Systems Research Institute 2001).

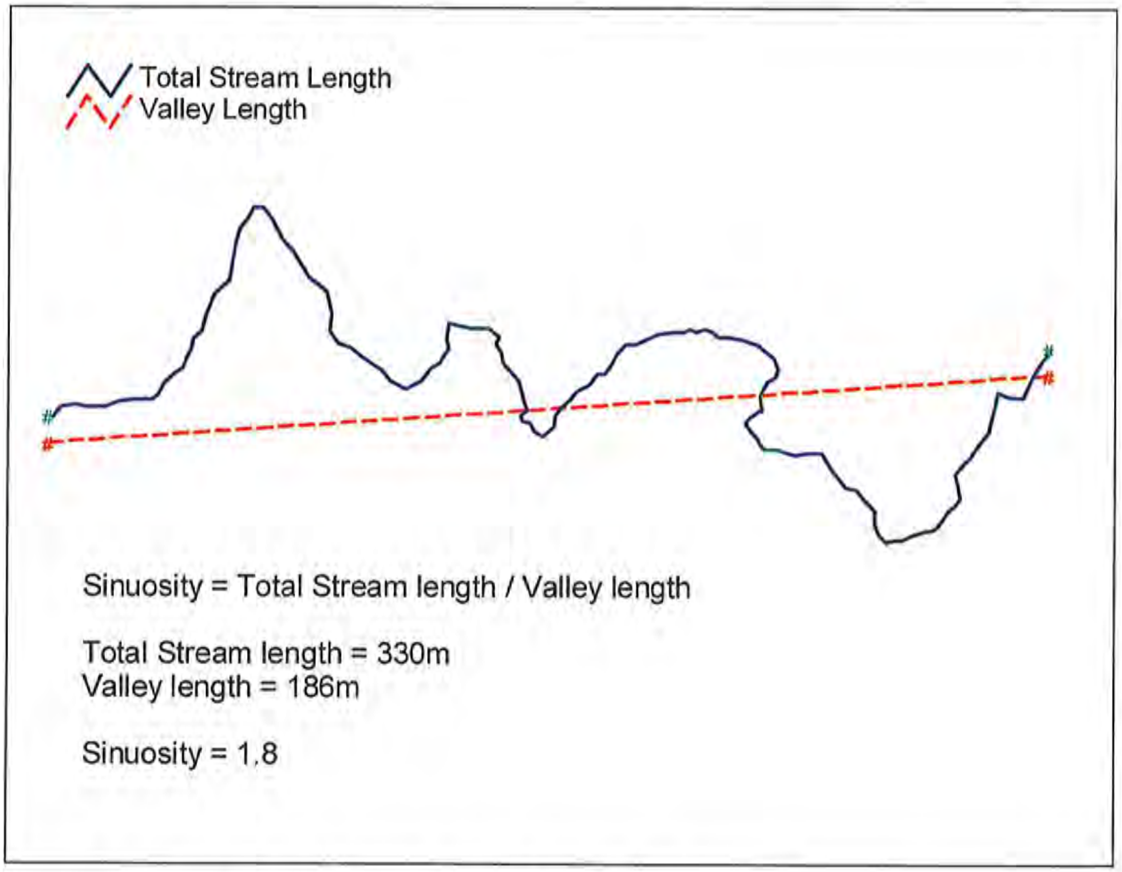

Figure 4. Determination of stream sinuosity using GIS.

Stream slope is a relative measure of the inclination of a streambed. It is expressed as a percentage and is obtained by dividing the change in elevation over a reach by the length of the reach and multiplying this value by 100. Determining the change in elevation over the course of a reach from the surveyed data presented a unique challenge. At the reach scale, the overall elevation of the streambed will increase as one proceeds upstream. However, at the habitat unit scale (riffle-run-pool) the bed-elevation of most streams will increase as one proceeds upstream through a riffle and then the elevation may decrease into the next pool. In order to ensure that this variation would not influence slope calculation for the shorter distance of many of our surveys, the slope measurement was based on the distance between the first riffle crest and the last riffle crest encountered along the stream profile (Figure 5). For each survey site, the points corresponding to the first and last riffle crests were determined (Appendix 1 – stream profiles).

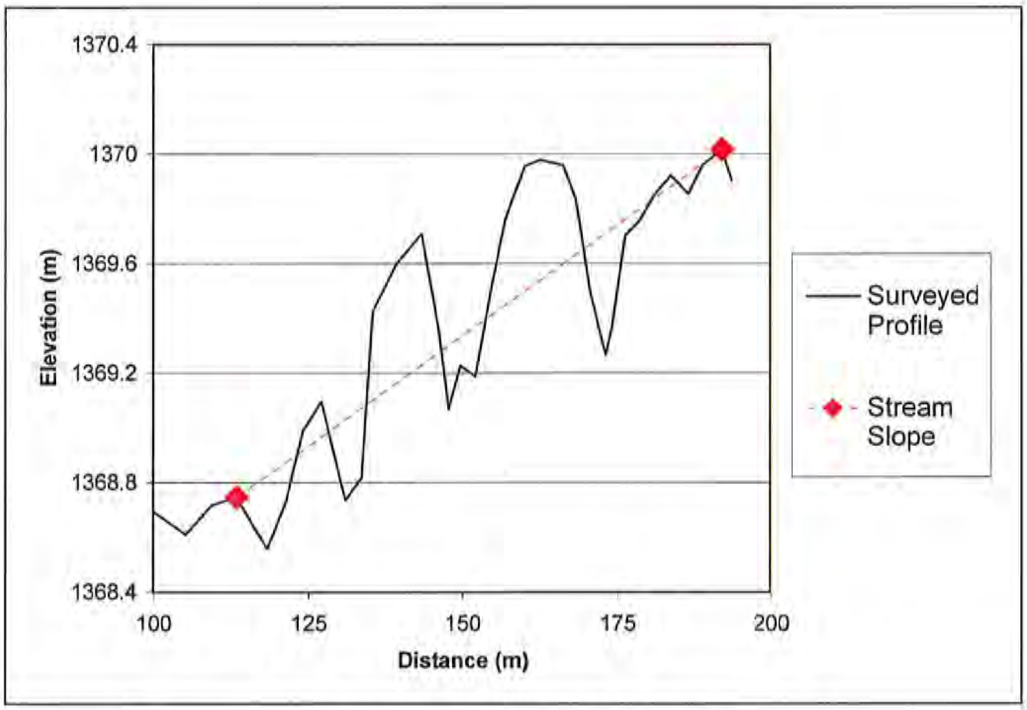

Figure 5. Determination of channel slope from stream profile survey.

2.8 Determining Slope and Sinuosity for geo-spatial layers

Slope and sinuosity analyses were performed on the stream network by applying the *dynamic segmentation* modeling tools available in ARC/INFO GIS (Environmental Systems Research Institute 2001). These tools enable the modeling of precise point and linear events along a stream section of common order. For example, one can determine the slope of a reach from the 1.5km to the 2.8km points along a given section of stream.

The process to perform these analyses was built into the HAGGIS tool set and is essentially comprised of a series of complex GIS calculations that perform all the tasks sequentially, in a single run. The input to HAGGIS to perform these analyses was simply a point layer representing the start location from a given field survey. Slope and sinuosity were calculated for the arc (stream segment) as defined by the length upstream of the actual field survey. The input table for HAGGIS included several fields (Table 5).

Table 5. Example HAGGIS input table for regular survey site.

Site_Id	Easting	Northing	Upstream Distance (m)	Downstream Distance (m)
5	495663	5885632	149	0
6	482550	5889804	127	0

The easting and northing were the coordinates for the downstream end of the stream survey (start point). The upstream distance represented the total length of the stream segment in an upstream direction to be included in the analysis. The downstream distance represented the length of stream in a downstream direction that should be included in the analysis. For the run of the original survey segment the total distance or arc length, was equal to the length of stream that was surveyed in the field (Table 5). For a second run to determine if slope and sinuosity were influenced by segment length, an additional 100 m were added to the segment in both an upstream and downstream direction (Table 6).

Table 6. Example HAGGIS input table for survey site with 200m length extension.

Site_Id	Easting	Northing	Upstream Distance (m)	Downstream Distance (m)
5	495663	5885632	249	100
6	482550	5889804	227	100

The outputs from HAGGIS included a summary table with slope and sinuosity values, as well as geo-spatial information that were used to display the plan view (Figure 6) and stream profile of the study reach (Figure 7). A stream profile and plan view was produced from these HAGGIS outputs for each survey site (Appendix 1).

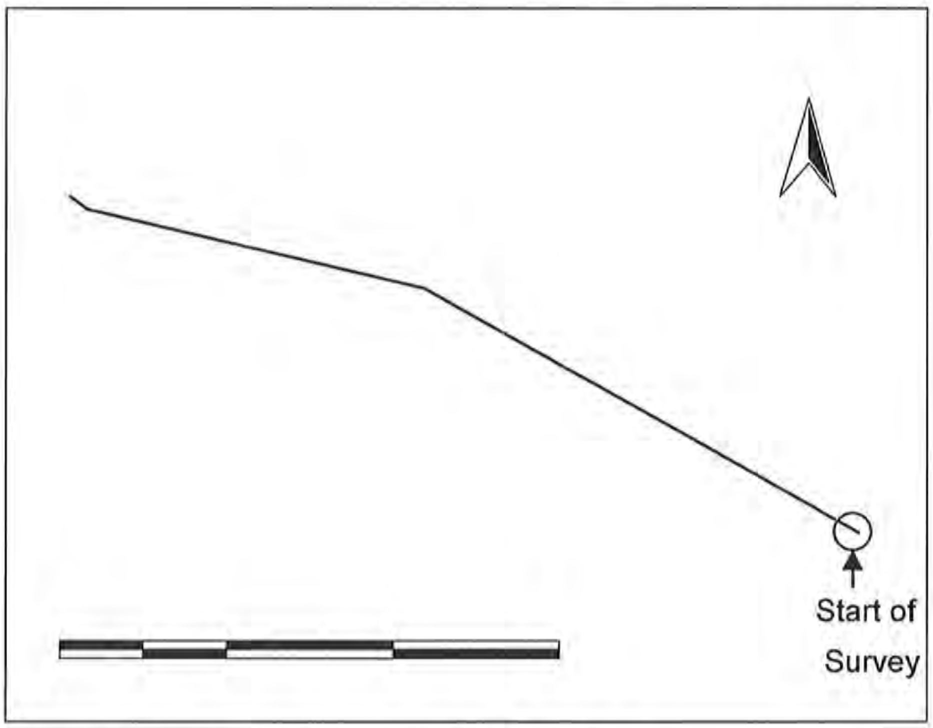

Figure 6. Plan view produced from HAGGIS output.

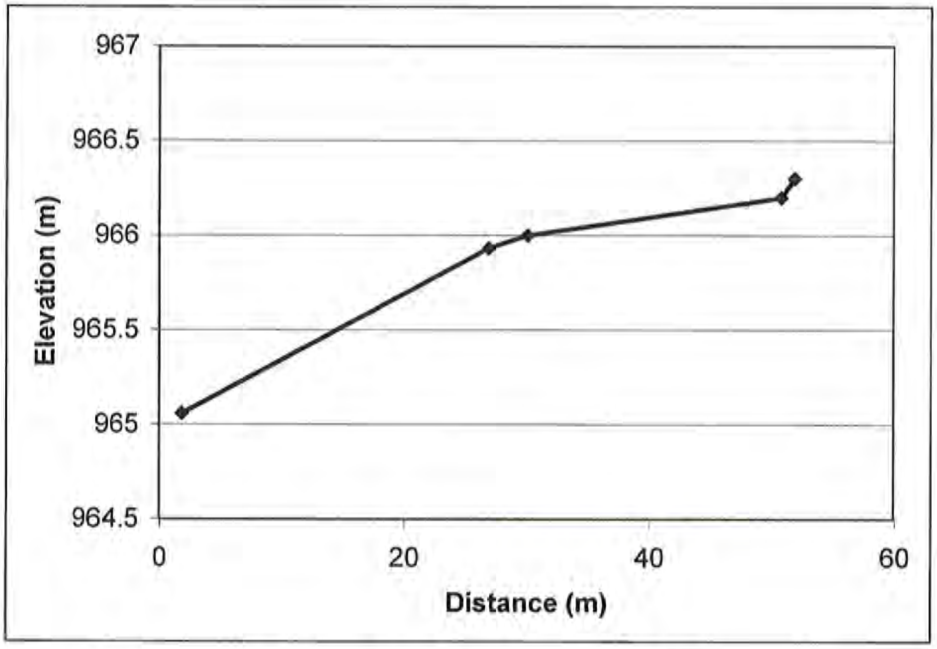

Figure 7. Channel profile produced from HAGGIS output.

2.9 Data Analyses

Data distributions were compared to the standard normal distribution. Out-liers were identified and examined.

Slope accuracy was a variable calculated to indicate whether the GIS derived slope was an overestimate or underestimate of the surveyed slope (Equation 1). Positive values of slope accuracy indicate the GIS slope was an overestimate, while negative values indicate that the GIS slope was an underestimate. Accuracy increases as the value approaches zero.

Equation 1. Slope accuracy equation.

Slope accuracy (%) = GIS derived slope (%) – surveyed slope (%)

This procedure to determine slope accuracy was based on the procedure to complete a paired-samples T Test which compares the means of two variables based on their differences and tests whether the average is different from 0 (SPSS Inc. 1999a). Using the SPSS statistical software (SPSS Inc. 1999b), a paired-samples T Test was completed with GIS derived slope values and surveyed slope values.

Sinuosity accuracy was a variable calculated to indicate whether the GIS derived sinuosity was an overestimate or underestimate of the surveyed sinuosity (Equation 2). Positive values of sinuosity accuracy indicate the GIS sinuosity was an overestimate, while negative values indicate that the GIS sinuosity was an underestimate. Accuracy increases as the value approaches zero.

Equation 2. Sinuosity accuracy equation.

Sinuosity accuracy* = GIS derived sinuosity* – surveyed sinuosity*

* Sinuosity is a unit-less measure.

This procedure to determine sinuosity accuracy was based on the procedure to complete a paired-samples T Test which compares the means of two variables based on their differences and tests whether the average is different from 0 (SPSS Inc. 1999). Using the SPSS statistical software (SPSS Inc. 1999b), a paired-samples T Test was completed with GIS derived sinuosity values and surveyed sinuosity values.

In order to ensure that correct values were reported, slope and sinuosity values were queried from the database and analyzed using statistical software. The entire query and analysis procedure was repeated a second time. Outputs from the first and second runs were compared to ensure that correct results were reported.

3. Results

Although a total of 29 sites were visited in the field, the statistical analysis was based on field surveys taken at 26 sites and three sites were excluded. Two sites did not have stream channels and the data from a third site was found to be an out-lier. Site 20 was located in a non-forested wetland area and no stream channel was present (Appendix 1). Site 22 was located in a forested draw and no stream channel was present (Appendix 1). Site 12 was a small permanent stream located in a draw that had been harvested (Appendix 1). The slope accuracy measure from this site was an out-lier in the distribution and was attributed to the unusual occurrence of a natural bench in steep terrain. As a result, the data from Site 12 was removed from the analysis.

3.1 Effects of HAGGIS DEM Processing and Stream Segment Length Extension on GIS Slope Accuracy

Both DEM sources yielded overestimates of stream slope (Table 7). Hydrologically corrected slope calculations were generally more accurate than the raw DEM calculations (i.e. closer to 0), however the differences were not statistically significant (Table 7). The use of the hydrologically corrected DEM resulted in improved precision of GIS derived slope (Table 7).

Table 7. Comparisons of GIS slope accuracy between two different DEMs.

Variable	N	Mean Difference	Std. Deviation	t value
RAW DEM slope accuracy	26	+0.78	1.24	--
Hydrologically corrected DEM slope accuracy	26	+0.64	0.79	--
Raw DEM – Hydrologically corrected accuracy	26	0.13	1.03	0.663[a]

[a] Indicates no difference in raw DEM and Hydrologically corrected DEM with 95 percent confidence using paired t test.

As a result of its higher performance, only the hydrologically corrected DEM was used for the analysis of stream segment length on slope accuracy. Increasing stream segment length by 200m did not result in a more accurate GIS measure of stream slope (Table 8).

Table 8. Comparisons of GIS slope accuracy between two different stream segment lengths.

Variable	N	Mean	Std. Deviation	t value
GIS slope accuracy (surveyed length)	26	+0.64	0.79	--
GIS slope accuracy (extended length)	26	+0.74	0.73	--
Surveyed length – extended length accuracy	26	-0.10	0.81	-0.640[a]

[a] Indicates no difference in GIS slope accuracy between surveyed length and extended length with 95 percent confidence using paired t test.

3.2 Comparison of Surveyed Sinuosity and GIS derived Sinuosity

GIS overestimated stream sinuosity by an average of 0.23 among the 26 sample sites and the GIS derived sinuosity and surveyed sinuosity was significantly different (Table 9).

Table 9. Comparison of GIS derived sinuosity and surveyed sinuosity.

Variable	Mean	Std. Deviation	t value
GIS derived sinuosity	1.13	0.17	--
Surveyed sinuosity	1.36	0.25	--
Sinuosity accuracy (GIS sinuosity – surveyed sinuosity)	+0.23	0.23	5.216 [b]

[b] Indicates GIS sinuosity different from surveyed sinuosity with 95 percent confidence using paired t test (n=26).

Stream order, stream slope class or presence of a canopy could not explain the differences between the true sinuosity and the GIS derived sinuosity. Differences in surveyed sinuosity and GIS derived sinuosity were apparent but not significant among five drainage area classes (Figure 8).

3.3 Comparison between Surveyed and GIS derived values of Slope

GIS overestimated stream slope by an average of 0.6% among the 26 sample sites and the GIS derived slope and surveyed slope were significantly different (Table 11).

Table 11. Comparisons of GIS derived slope and surveyed slope.

Variable	Mean	Std. Deviation	t value
GIS derived slope	2.54	2.06	--
Surveyed slope	1.90	1.85	--
Slope accuracy (GIS slope – surveyed slope)	+0.64	0.79	-4.149 [b]

[b] Indicates GIS slope different from surveyed slope with 95 percent confidence using paired t test (n=26).

The differences between the true slope and the GIS derived slope could not be explained by stream order, drainage area class, stream slope class or presence of a canopy.

3.4 Development and Evaluation of a Sinuosity Correction Formula

The systematic underestimation of stream sinuosity by a value of 0.29 for basins less than 20 km^2 effectively reduced stream length and thereby increased stream slope. Therefore, a formula was developed to correct the sinuosity according to this bias (Equation 3).

Equation 3. Sinuosity correction formula

Where basin slope $<20km^2$, corrected sinuosity = sinuosity + 0.29

The corrected GIS sinuosity was no longer significantly different from surveyed sinuosity (Table 12).

Table 12. Comparison of corrected GIS derived sinuosity and surveyed sinuosity.

Variable	Mean	Std. Deviation	t value
Corrected GIS sinuosity	1.36	0.17	--
Surveyed sinuosity	1.36	0.25	--
Corrected sinuosity accuracy	0.00	0.21	-0.081 [a]

[a] Indicates no difference in corrected GIS sinuosity accuracy and surveyed sinuosity with 95 percent confidence using paired t test (n=26).

3.5 Development and Evaluation of a Slope Correction Factor

In consideration of this known bias in sinuosity, a slope correction factor was developed (Equation 4). This formula was developed from the formulas for slope and sinuosity (Appendix 3).

Equation 4. Slope correction formula

$$\text{Corrected slope} = \frac{\text{slope} * \text{sinuosity}}{(\text{corrected sinuosity})}$$

3.6 Evaluation of Corrected GIS Slope Values

Although the corrected GIS slope overestimated surveyed slope by an average of 0.17%, the corrected slope and surveyed slope were no longer significantly different (Table 13).

Table 13. Comparisons of corrected GIS derived slope and surveyed slope.

Variable	Mean	Std. Deviation	t value
Corrected GIS derived slope	2.08	1.59	--
Surveyed slope	1.90	1.85	--
Slope accuracy (GIS slope – surveyed slope)	+0.17	0.77	1.147 [a]

[a] Indicates corrected GIS slope was not different from surveyed slope with 95 percent confidence using paired t test (n=26).

Channel classification schemes frequently use channel slope as one of the main criteria for grouping channels into similar types. Before calibration, only 35 percent of the sites were correctly classified, while after calibration, 58 percent of the sites were correctly classified (Table 14).

Table 14. Comparison of classification accuracy using original and adjusted GIS slope.

		Original GIS Slope		Adjusted GIS Slope	
Slope Class	n	Sites correctly classified (n)	Sites correctly classified (%)	Sites correctly classified (n)	Sites correctly classified (%)
0-1%	9	5	56	5	56
1-2%	11	3	27	7	64
2-3%	2	0	0	1	50
3-4%	0	--	--	--	--
4-6%	3	1	33	1	33
6-10%	1	0	0	1	100
>10%	0	--	--	--	--
Total	26	9	35	15	58

4. Discussion:

4.1 Selection of a DEM for calculating slope

In our study, the use of a hydrologically corrected DEM resulted in improved precision and similar accuracy of GIS slope calculations. Another advantage of using the hydrologically corrected DEM was the removal of drainage sinks. This process ensured that all slope values were positive numbers (i.e. flowing downstream).

The accuracy of GIS slope calculations in this study did not improve when site length was increased from 100m to 300m. This indicates that these GIS applications provide an effective procedure, independent of scale, to extrapolate the elevation data from a DEM to a number of points that lie in close proximity.

4.2 Calibration of GIS generated Sinuosity to Reflect Actual Values

For stream reaches with upstream drainage areas of <20km^2, GIS generated sinuosity values were underestimated by 0.29. In contrast, the sinuosity accuracy measures from reaches with drainage areas >20km^2 were not significantly different from zero. This occurrence was likely a function of the resolution of the original 1:60,000 scale aerial photographs that were used to produce the stream information. At this scale, a stream 10m in width would appear as a line with a width of 0.167mm on the aerial photograph. Therefore, the interpreters likely had a difficult time discerning the small stream channels let alone their meander pattern. These findings suggest that the systematic bias in GIS calculations warrant application of a correction factor.

This bias in GIS sinuosity explained a portion of the over-estimation in GIS slope. Correcting slope based on the known bias in sinuosity resulted in improved overall accuracy.

5. Management Implications

Small streams within the west-central foothills are characterized by a well-developed meander pattern, regardless of gradient. This occurrence has implications for accurately interpreting two GIS based stream descriptors – slope and sinuosity. Calibration factors can be introduced if accurate values of these descriptors are important in the application of GIS derived stream descriptors.

This knowledge may have specific utility in stream classification initiatives that use channel slope as one of the classification criteria. By improving the accuracy of classification schemes that utilize channel slope, we may improve our ability to apply these stream classification systems. For example, by applying the correction factors, we increased the overall accuracy from 35 percent to 58 percent. As a result, the classification system may provide a reasonably accurate portrayal of the habitats selected by individual fish species.

This knowledge also has implications for those involved with forest hydrology and stream channel patterns. The high degree of sinuosity that was observed in all streams, regardless of channel gradient, indicates that floodplains along the small streams within the west-central foothills of Alberta are relatively well developed. In the classification of natural rivers (Rosgen 1999), the author described a total of 94 channel types along the stream continuum. In this classification system, the steeper streams tended to have low sinuosity values with poorly developed floodplains while low gradient streams tended to have high sinuosity values and well-developed floodplains (Rosgen 1999). In our study area, with the high sinuosity values, the well developed floodplains and the wide range of channel slope values, the majority of the streams that were surveyed fell with eight of the 94 channel types (E3b, E4b, E5b, E6b, E3, E4, E5, and E6). These results indicate that although the classification of natural rivers provides a robust system for naming the variety of stream channels across the North American landscape, it may have limited direct application for describing the range of stream types within the study area.

These well-developed floodplains along the small streams within the study area may deserve special management consideration. These areas contain recently deposited alluvial soils and support highly productive forest sites. These areas may be particularly vulnerable to soil compaction and erosion during timber harvest.

6. Literature Cited

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Appendix 1: Comparison of Surveyed and GIS Derived Stream Descriptors by Site

Appendix 2: Selected Statistical Outputs

Table 1. ANOVA for sinuosity accuracy (GIS sinuosity – surveyed sinuosity) grouped by drainage area class (<20km^2, >20km^2)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.363	1	.363	9.640	.005
Within Groups	.904	24	0.03765		
Total	1.267	25			

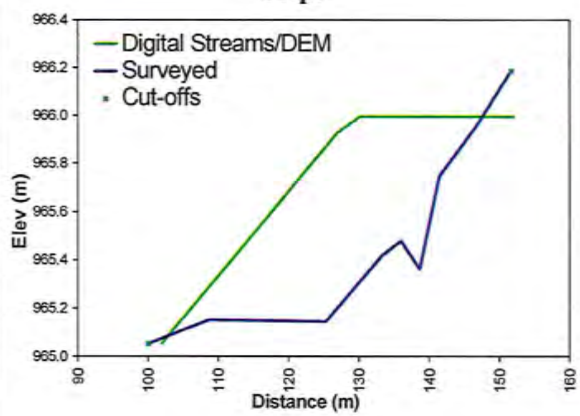
foothills model forest — a growing understanding

Site: 1

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Fish Creek **Watershed: Fish Creek**

Slope



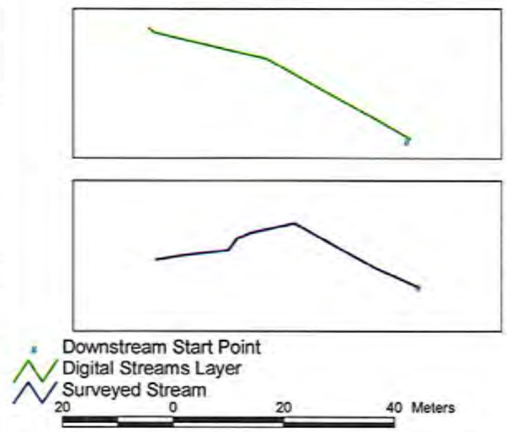
Source	Distance (m)	Slope (%)
Surveyed	51.6	2.2
GIS Digital Streams Layer/ DEM	51.6	1.9
Difference (Surveyed – GIS)		0.3

Survey Information	
FMF Site ID:	A201501
Survey Date:	8/1/01
Surveyor:	R. McCleary
Assistant:	Kinoshita

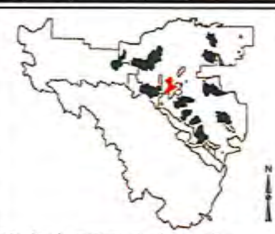
Watershed and Reach Characteristics	
Stream Order:	4
Drainage Area (km^2):	71.825
Dominant Riparian Vegetation:	Forested - White Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	51.6	1.1
GIS Digital Streams Layer	51.6	1.0
Difference (Surveyed – GIS)		0.1



Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

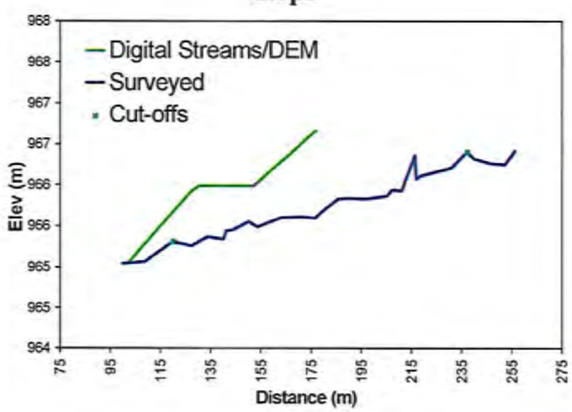
Comments: downstream view

foothills model forest — a growing understanding | Site: 2

Comparison of Surveyed and GIS Interpreted Stream Descriptors

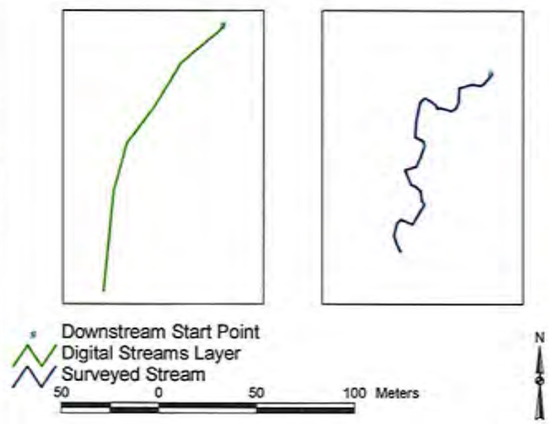
Stream: Erith Trib **Watershed: Upper Erith River**

Slope



Source	Distance (m)	Slope (%)
Surveyed	156.0	0.9
GIS Digital Streams Layer/ DEM	156.0	0.9
Difference (Surveyed – GIS)		0.1

Sinuosity



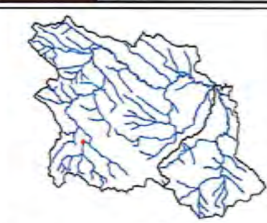
Source	Distance (m)	Sinuosity
Surveyed	156.0	1.6
GIS Digital Streams Layer	156.0	1.0
Difference (Surveyed – GIS)		0.5

Survey Information	
FMF Site ID:	A201502
Survey Date:	8/1/01
Surveyor:	R. McCleary
Assistant:	M. Blackburn

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	6.302
Dominant Riparian Vegetation:	Forested –Mixed Spruce

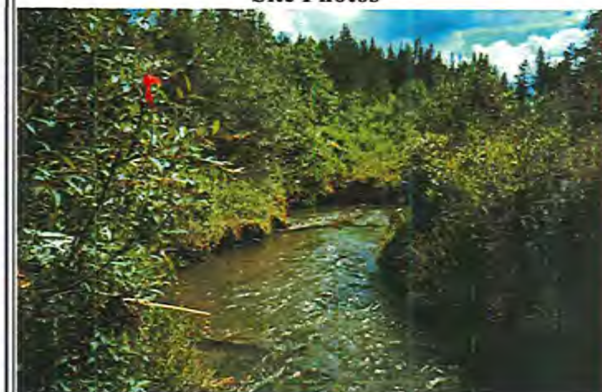
Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest



Location of Survey Site Within Monitoring Watershed

Site Photos



Comments: downstream view

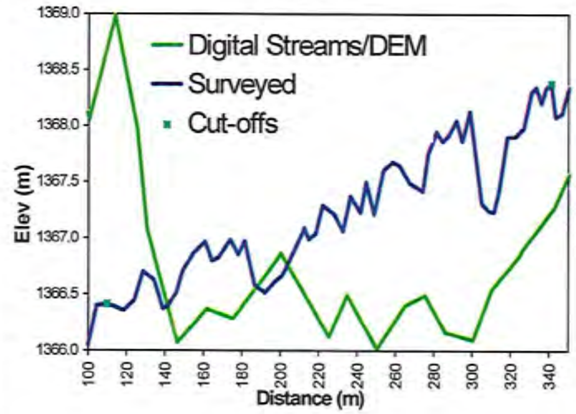
foothills model forest — a growing understanding

Site: 3

Comparison of Surveyed and GIS Interpreted Stream Descriptors

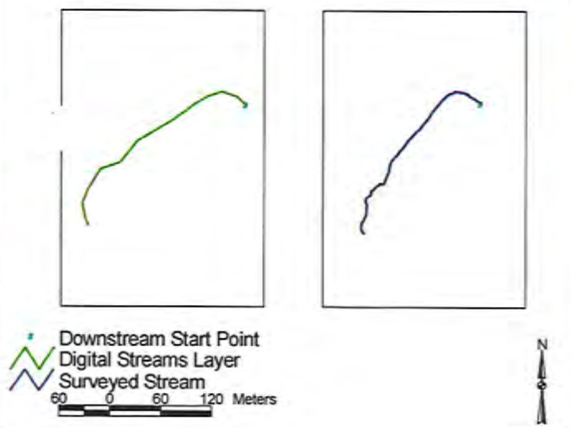
Stream: Pinto Creek **Watershed: Pinto Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	250.2	0.9
GIS Digital Streams Layer/ DEM	250.2	1.2
Difference (Surveyed – GIS)		-0.3

Sinuosity

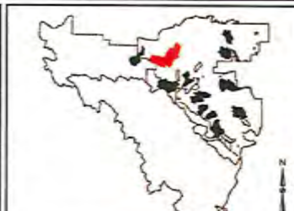


Source	Distance (m)	Sinuosity
Surveyed	250.2	1.1
GIS Digital Streams Layer	250.2	1.2
Difference (Surveyed – GIS)		0.0

Survey Information	
FMF Site ID:	A201503
Survey Date:	8/15/01
Surveyor:	R. McCleary
Assistant:	M. Blackburn

Watershed and Reach Characteristics	
Stream Order:	4
Drainage Area (km^2):	44.059
Dominant Riparian Vegetation:	Non-Forested Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002



Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

Comments: downstream view

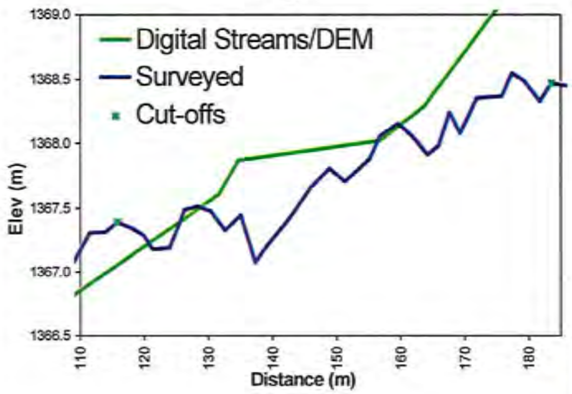
Comparison of Surveyed and GIS Interpreted Stream Descriptors

foothills model forest

Site: 4

Stream: trib to Pinto **Watershed: Pinto Creek**

Slope



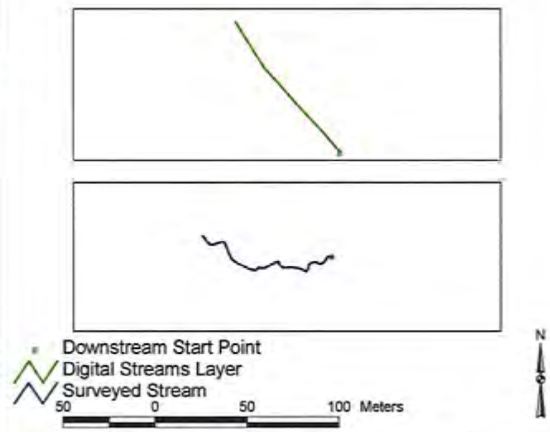
Source	Distance (m)	Slope (%)
Surveyed	89.6	1.6
GIS Digital Streams Layer/ DEM	89.6	3.2
Difference (Surveyed – GIS)		-1.6

Survey Information	
FMF Site ID:	A201504
Survey Date:	8/15/01
Surveyor:	R. McCleary
Assistant:	M. Blackburn

Watershed and Reach Characteristics	
Stream Order:	2
Drainage Area (km^2):	5.466
Dominant Riparian Vegetation:	Non-Forested Wetland

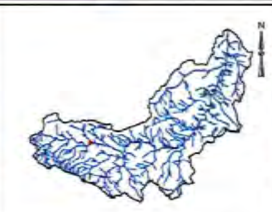
Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	89.6	1.2
GIS Digital Streams Layer	89.6	1.0
Difference (Surveyed – GIS)		0.2

Monitoring Watershed Locations Within the Foothills Model Forest



Location of Survey Site Within Monitoring Watershed

Site Photos

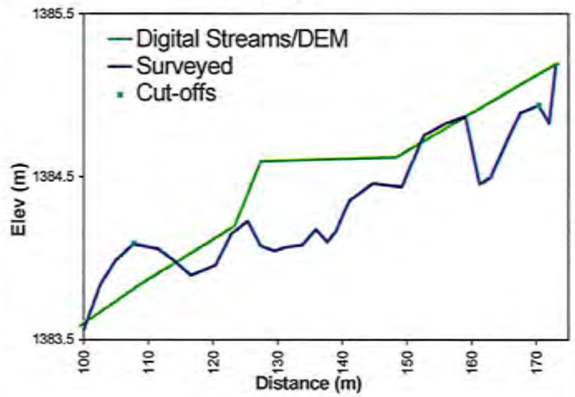
No photo Available

Site: 5

Comparison of Surveyed and GIS Interpreted Stream Descriptors

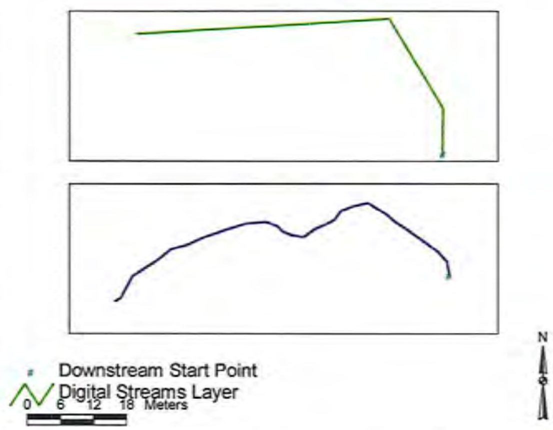
Stream: Anderson Creek   Watershed: Anderson Creek

Slope



Source	Distance (m)	Slope (%)
Surveyed	73.0	1.4
GIS Digital Streams Layer/ DEM	73.0	2.2
Difference (Surveyed – GIS)		-0.8

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	73.0	1.1
GIS Digital Streams Layer	73.0	1.2
Difference (Surveyed – GIS)		-0.1

Site Photos

Comments: downstream view

Survey Information	
FMF Site ID:	A201505
Survey Date:	8/16/01
Surveyor:	R. McCleary
Assistant:	M. Blackburn

Watershed and Reach Characteristics	
Stream Order:	4
Drainage Area (km^2):	17.688
Dominant Riparian Vegetation:	Forested - White Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest

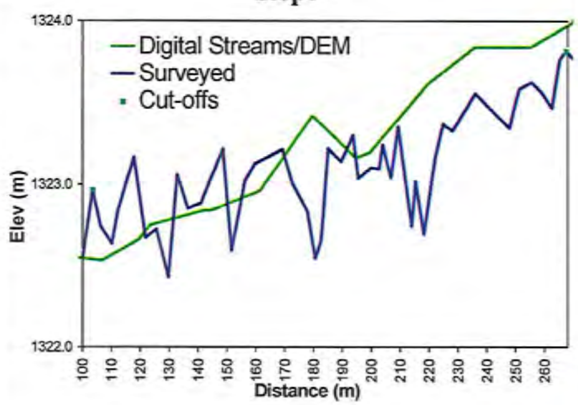
Location of Survey Site Within Monitoring Watershed

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Site: 6

Stream: Wigwam Creek **Watershed: Teepee Creek**

Slope



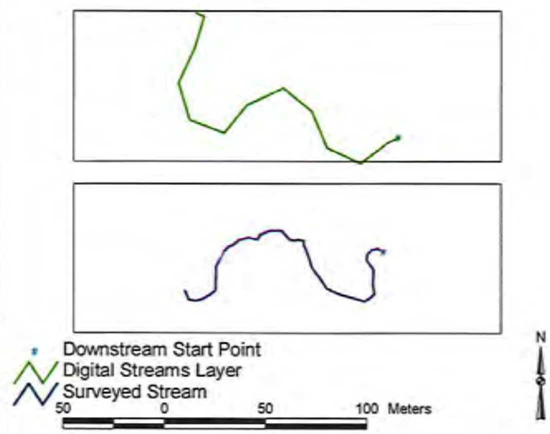
Source	Distance (m)	Slope (%)
Surveyed	194.2	0.5
GIS Digital Streams Layer/ DEM	194.2	1.2
Difference (Surveyed – GIS)		-0.7

Survey Information	
FMF Site ID:	A201506
Survey Date:	8/23/01
Surveyor:	R. McCleary
Assistant:	C. Weik

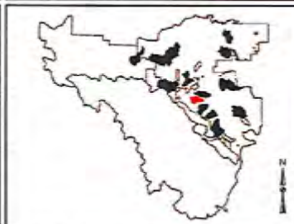
Watershed and Reach Characteristics	
Stream Order:	4
Drainage Area (km^2):	20.67
Dominant Riparian Vegetation:	Non-Forested Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

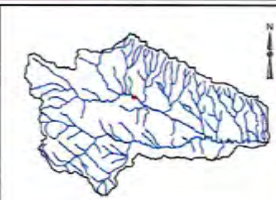
Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	194.2	1.6
GIS Digital Streams Layer	194.2	1.7
Difference (Surveyed – GIS)		-0.1



Monitoring Watershed Locations Within the Foothills Model Forest



Location of Survey Site Within Monitoring Watershed

Site Photos

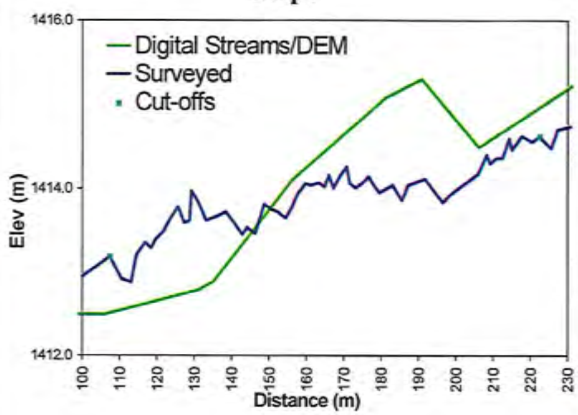
Comments: upstream view

Site: 7

Comparison of Surveyed and GIS Interpreted Stream Descriptors

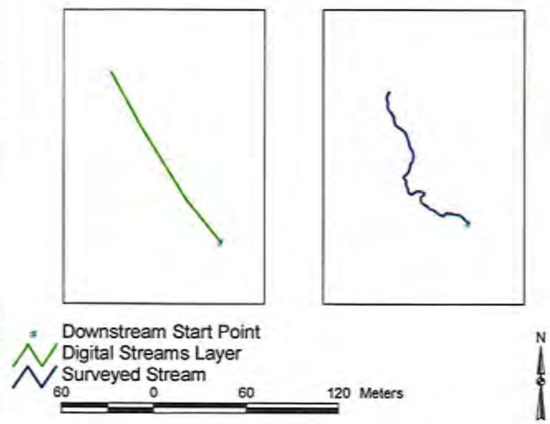
Stream: Wigwam Creek **Watershed: Teepee Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	130.6	1.2
GIS Digital Streams Layer/ DEM	130.6	2.1
Difference (Surveyed – GIS)		-0.9

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	130.6	1.3
GIS Digital Streams Layer	130.6	1.0
Difference (Surveyed – GIS)		0.3

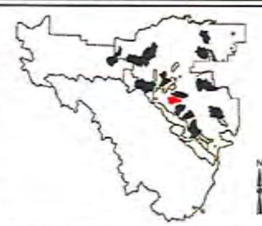
Site Photos

Comments: downstream side of culvert

Survey Information	
FMF Site ID:	A201507
Survey Date:	8/28/01
Surveyor:	R. McCleary
Assistant:	C. Weik

Watershed and Reach Characteristics	
Stream Order:	2
Drainage Area (km^2):	5.693
Dominant Riparian Vegetation:	Forested - White Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002



Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

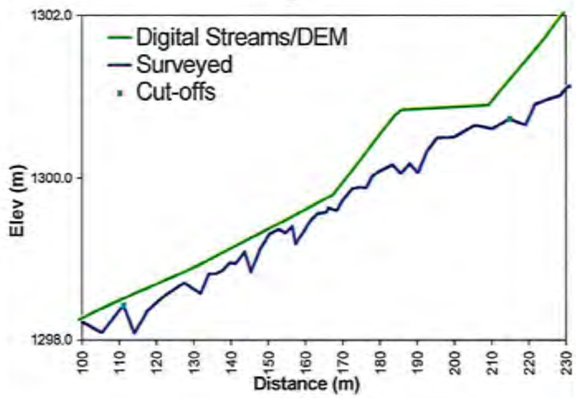
foothills model forest — a growing understanding

Site: 8

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Trib to Anderson Creek **Watershed: Anderson Creek**

Slope



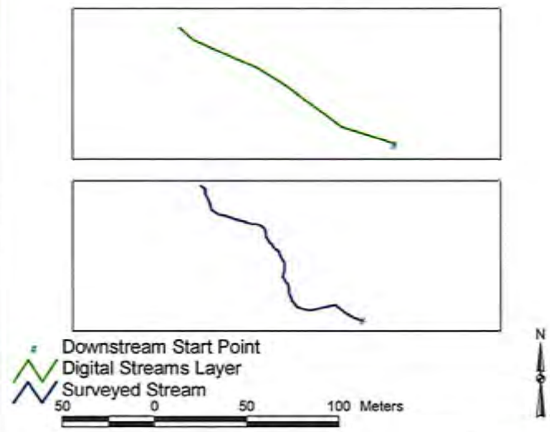
Source	Distance (m)	Slope (%)
Surveyed	133.5	2.2
GIS Digital Streams Layer/ DEM	133.5	3.2
Difference (Surveyed – GIS)		-1.0

Survey Information	
FMF Site ID:	A201508
Survey Date:	8/30/01
Surveyor:	R. McCleary
Assistant:	C. Johnson

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	9.374
Dominant Riparian Vegetation:	Forested - White Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity

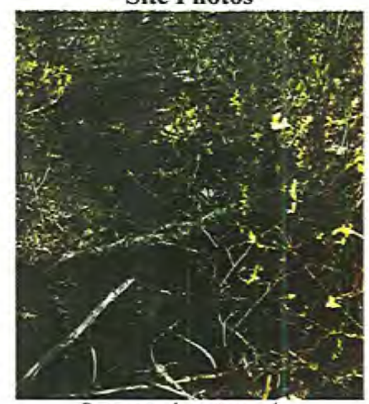


Source	Distance (m)	Sinuosity
Surveyed	133.5	1.2
GIS Digital Streams Layer	133.5	1.0
Difference (Surveyed – GIS)		0.2

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos



Comments: downstream view

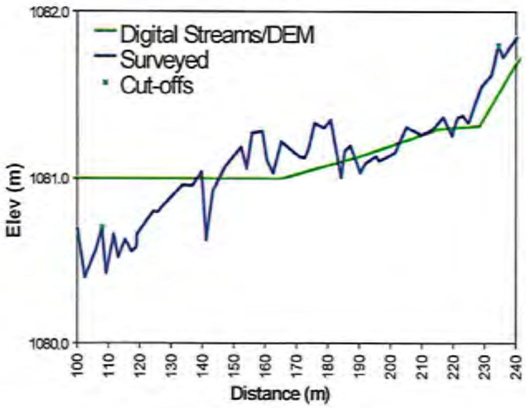
foothills model forest

Site: 9

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Trib to Lambert Creek **Watershed: Lambert Creek**

Slope



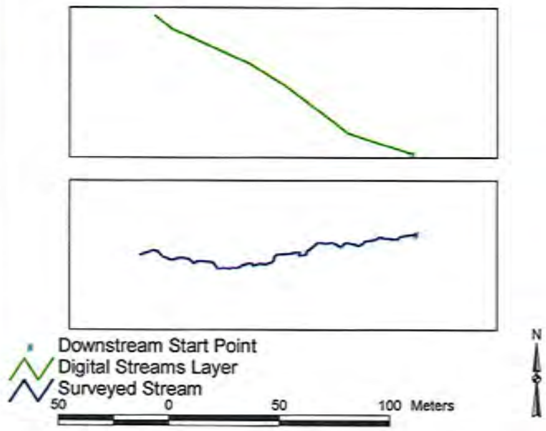
Source	Distance (m)	Slope (%)
Surveyed	140.2	0.9
GIS Digital Streams Layer/ DEM	140.2	0.5
Difference (Surveyed – GIS)		0.4

Survey Information	
FMF Site ID:	A201509
Survey Date:	9/10/01
Surveyor:	R. McCleary
Assistant:	J. Blackburn

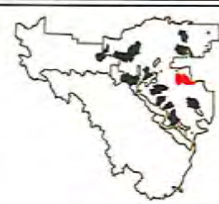
Watershed and Reach Characteristics	
Stream Order:	2
Drainage Area (km^2):	16.851
Dominant Riparian Vegetation:	Non-Forested Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	140.2	1.1
GIS Digital Streams Layer	140.2	1.0
Difference (Surveyed – GIS)		0.1



Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

Comments: bankfull width, downstream view

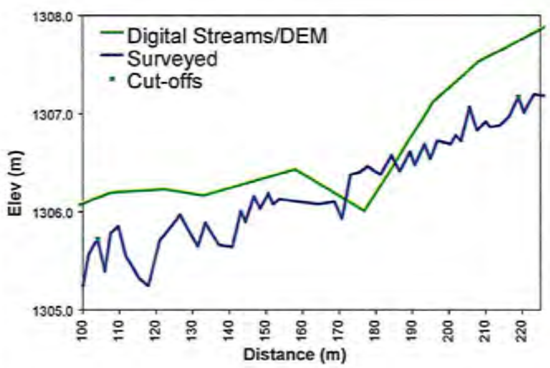
foothills model forest — a growing understanding

Site: 10

Comparison of Surveyed and GIS Interpreted Stream Descriptors

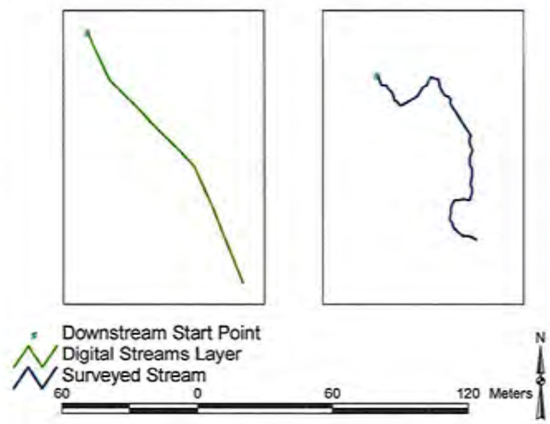
Stream: Eunice Creek **Watershed: Eunice Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	132.7	1.2
GIS Digital Streams Layer/ DEM	132.7	1.5
Difference (Surveyed – GIS)		-0.3

Sinuosity

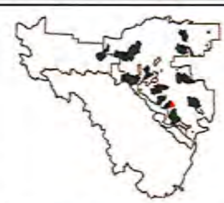


Source	Distance (m)	Sinuosity
Surveyed	132.7	1.6
GIS Digital Streams Layer	132.7	1.0
Difference (Surveyed – GIS)		0.6

Survey Information	
FMF Site ID:	A201510
Survey Date:	9/15/01
Surveyor:	R. McCleary
Assistant:	T. Muhly

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	14.89
Dominant Riparian Vegetation:	Forested - Mixed Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002



Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

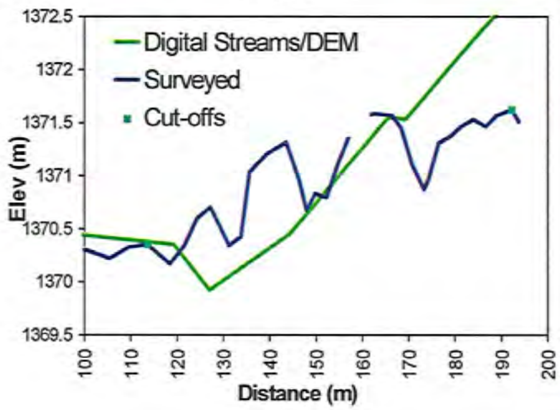
Comments: downstream view

foothills model forest — Site: 11

Comparison of Surveyed and GIS Interpreted Stream Descriptors

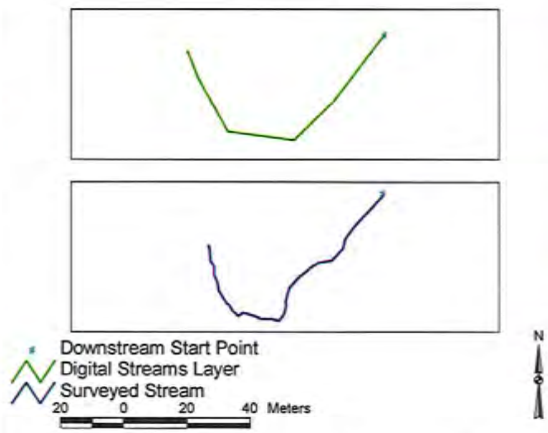
Stream: Wigwam Creek — **Watershed: Teepee Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	93.7	1.6
GIS Digital Streams Layer/ DEM	93.7	3.0
Difference (Surveyed – GIS)		-1.4

Sinuosity



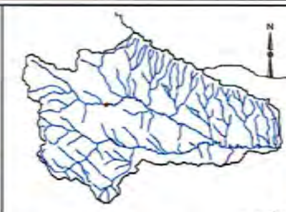
Source	Distance (m)	Sinuosity
Surveyed	93.7	1.7
GIS Digital Streams Layer	93.7	1.5
Difference (Surveyed – GIS)		0.2

Survey Information	
FMF Site ID:	A201511
Survey Date:	9/18/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	9.824
Dominant Riparian Vegetation:	Forested - Mixed Spruce

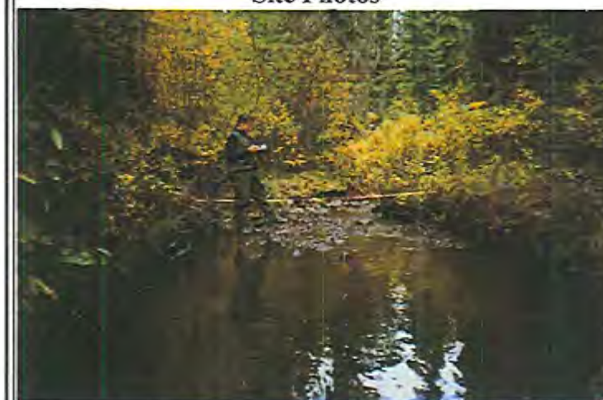
Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest



Location of Survey Site Within Monitoring Watershed

Site Photos



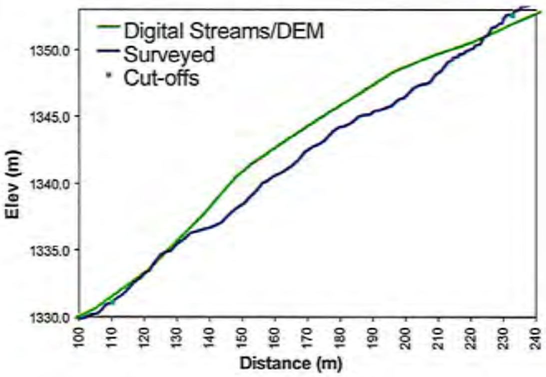
Comments: Bankfull width, downstream view

foothills model forest — a growing understanding | Site: 12

Comparison of Surveyed and GIS Interpreted Stream Descriptors

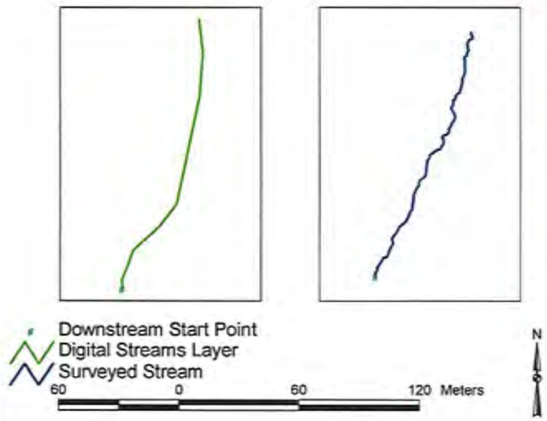
Stream: Trib to Wigwam Creek **Watershed: Teepee Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	146.1	17.5
GIS Digital Streams Layer/ DEM	146.1	16.0
Difference (Surveyed – GIS)		1.5

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	146.1	1.1
GIS Digital Streams Layer	146.1	1.0
Difference (Surveyed – GIS)		0.1

Site Photos

Comments: bankfull width

Survey Information	
FMF Site ID:	A201512
Survey Date:	9/19/01
Surveyor:	R. McCleary
Assistant:	T. Muhly

Watershed and Reach Characteristics	
Stream Order:	1
Drainage Area (km^2):	0.243
Dominant Riparian Vegetation:	Forested Pine (harvested)

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

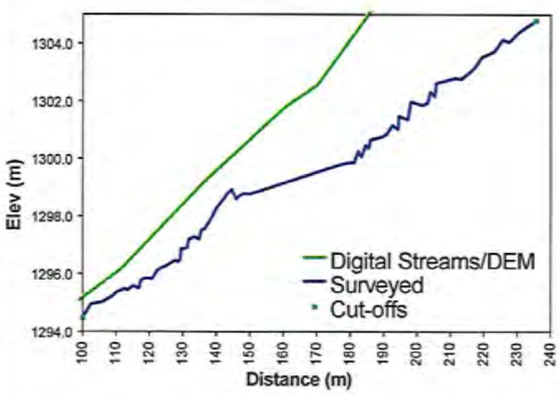
Comparison of Surveyed and GIS Interpreted Stream Descriptors

foothills model forest — a growing understanding

Site: 13

Stream: Trib to Fish Creek **Watershed: Fish Creek**

Slope



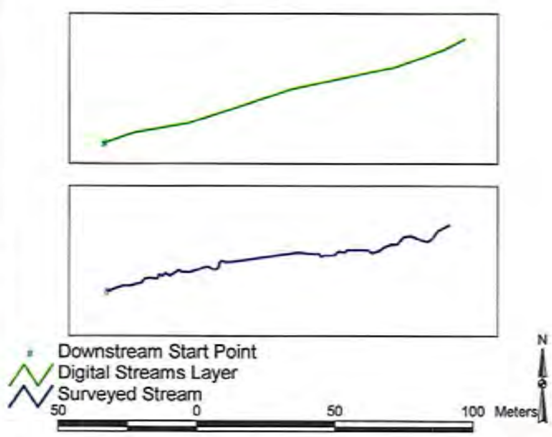
Source	Distance (m)	Slope (%)
Surveyed	135.5	8.5
GIS Digital Streams Layer/ DEM	135.5	10.6
Difference (Surveyed – GIS)		-2.1

Survey Information	
FMF Site ID:	A201513
Survey Date:	9/20/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

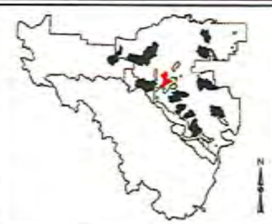
Watershed and Reach Characteristics	
Stream Order:	2
Drainage Area (km^2):	1.569
Dominant Riparian Vegetation:	Forested - White Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

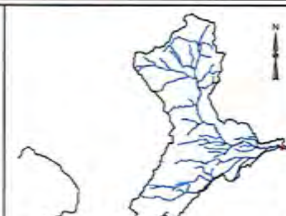
Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	135.5	1.1
GIS Digital Streams Layer	135.5	1.0
Difference (Surveyed – GIS)		0.1



Monitoring Watershed Locations Within the Foothills Model Forest



Location of Survey Site Within Monitoring Watershed

Site Photos

Comments: upstream view

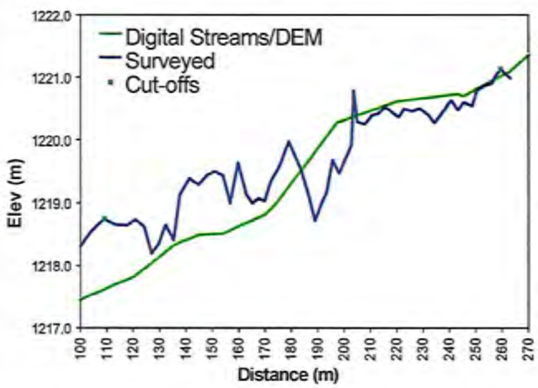
foothills model forest — a growing understanding

Site: 14

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Neat Creek **Watershed: Antler Creek**

Slope



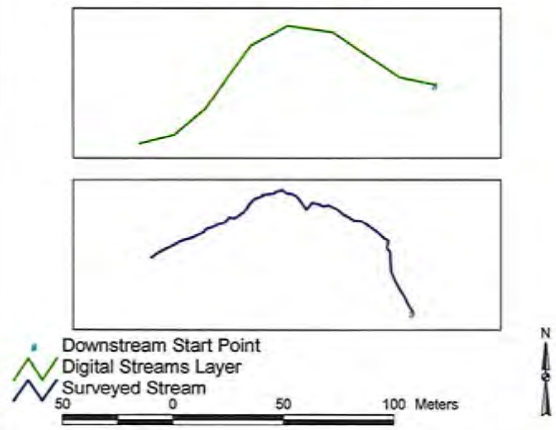
Source	Distance (m)	Slope (%)
Surveyed	162.9	1.6
GIS Digital Streams Layer/ DEM	162.9	1.8
Difference (Surveyed – GIS)		-02

Survey Information	
FMF Site ID:	A201514
Survey Date:	9/24/01
Surveyor:	B. Johnston
Assistant:	T. Muhly

Watershed and Reach Characteristics	
Stream Order:	4
Drainage Area (km^2):	24.96
Dominant Riparian Vegetation:	Forested - White Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity

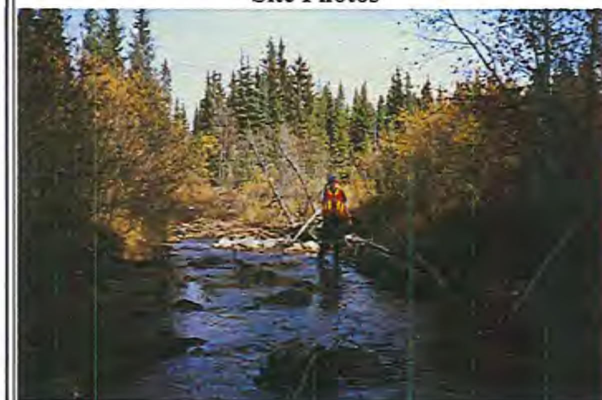


Source	Distance (m)	Sinuosity
Surveyed	162.9	1.3
GIS Digital Streams Layer	162.9	1.2
Difference (Surveyed – GIS)		0.1

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos



Comments: upstream view

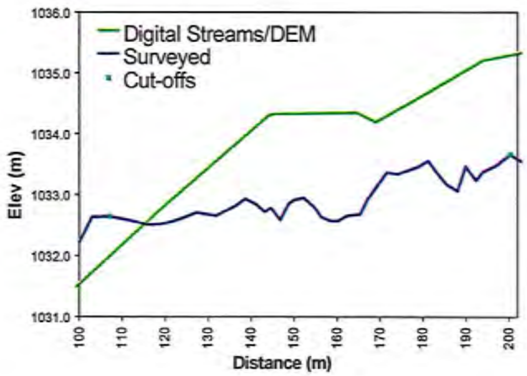
foothills model forest — a growing understanding

Site: 15

Comparison of Surveyed and GIS Interpreted Stream Descriptors

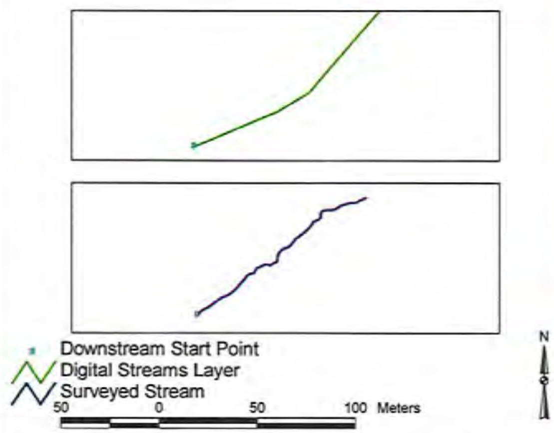
Stream: Trib to Emerson **Watershed: Emerson Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	119.2	1.1
GIS Digital Streams Layer/ DEM	119.2	3.1
Difference (Surveyed – GIS)		-2.0

Sinuosity

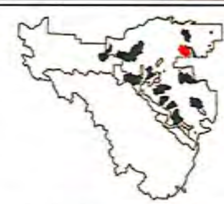


Source	Distance (m)	Sinuosity
Surveyed	119.2	1.1
GIS Digital Streams Layer	119.2	1.0
Difference (Surveyed – GIS)		0.1

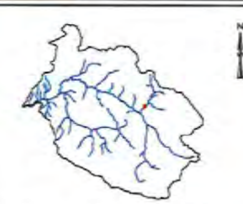
Survey Information	
FMF Site ID:	A201515
Survey Date:	9/25/01
Surveyor:	B. Johnston
Assistant:	T. Muhly

Watershed and Reach Characteristics	
Stream Order:	2
Drainage Area (km^2):	11.506
Dominant Riparian Vegetation:	Forested - Pine

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002



Monitoring Watershed Locations Within the Foothills Model Forest



Location of Survey Site Within Monitoring Watershed

Site Photos

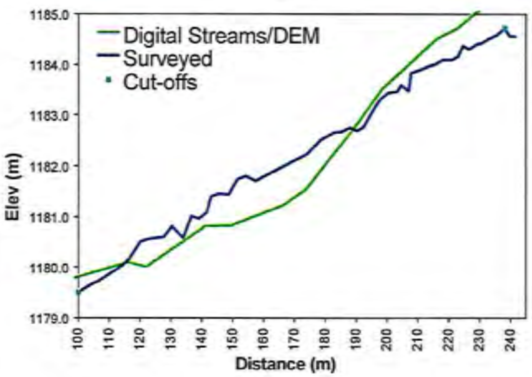
Comments: downstream view

foothills model forest — a growing understanding | Site: 16

Comparison of Surveyed and GIS Interpreted Stream Descriptors

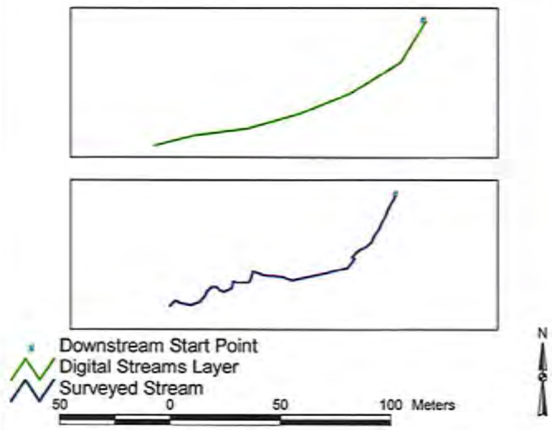
Stream: Trib to Erith **Watershed: Upper Erith River**

Slope



Source	Distance (m)	Slope (%)
Surveyed	141.4	4.0
GIS Digital Streams Layer/ DEM	141.4	4.1
Difference (Surveyed – GIS)		-0.1

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	141.4	1.2
GIS Digital Streams Layer	141.4	1.0
Difference (Surveyed – GIS)		0.2

Site Photos

Comments: downstream view

Survey Information	
FMF Site ID:	A201516
Survey Date:	10/10/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	2.619
Dominant Riparian Vegetation:	Forested – Mixed Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

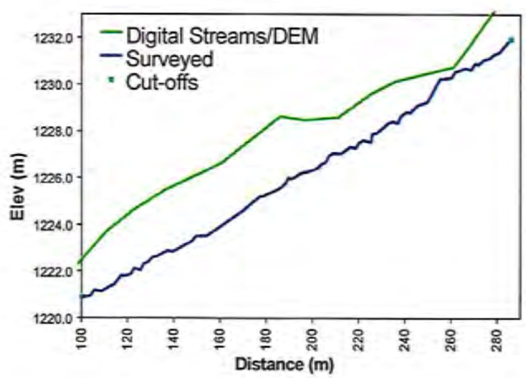
foothills model forest — a growing understanding

Site: 17

Comparison of Surveyed and GIS Interpreted Stream Descriptors

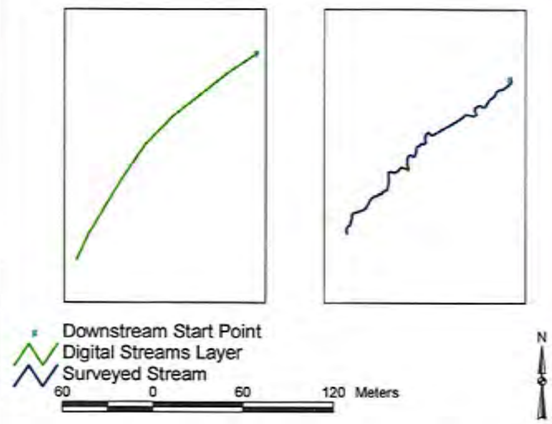
Stream: Trib to Erith **Watershed: Upper Erith River**

Slope



Source	Distance (m)	Slope (%)
Surveyed	185.7	5.9
GIS Digital Streams Layer/ DEM	185.7	6.2
Difference (Surveyed – GIS)		-0.3

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	185.7	1.2
GIS Digital Streams Layer	185.7	1.0
Difference (Surveyed – GIS)		0.2

Survey Information	
FMF Site ID:	A201517
Survey Date:	10/10/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	2
Drainage Area (km^2):	1.041
Dominant Riparian Vegetation:	Forested - Pine

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

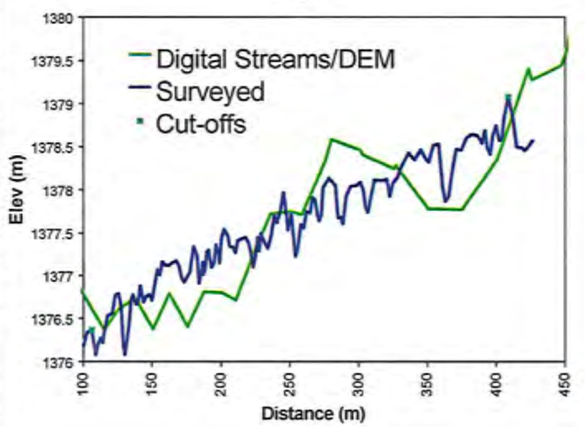
Comments: downstream view

Site: 18

Comparison of Surveyed and GIS Interpreted Stream Descriptors

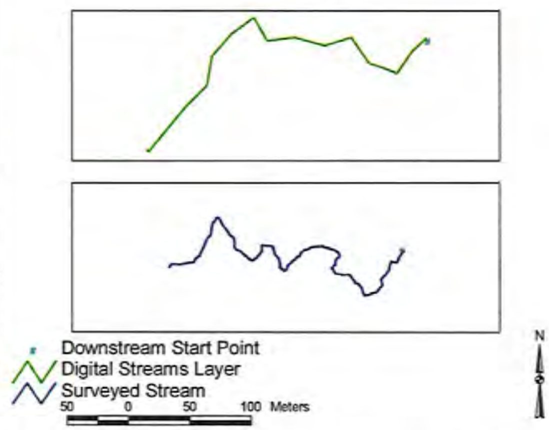
Stream: Wampus Creek **Watershed: Wampus Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	326.0	0.9
GIS Digital Streams Layer/ DEM	326.0	0.9
Difference (Surveyed – GIS)		0.0

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	326.0	1.8
GIS Digital Streams Layer	326.0	1.3
Difference (Surveyed – GIS)		0.4

Site Photos

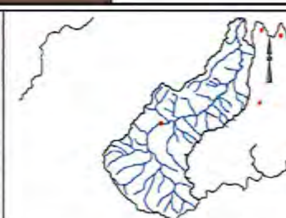
Comments: downstream view

Survey Information	
FMF Site ID:	A201518
Survey Date:	10/11/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	4
Drainage Area (km^2):	12.782
Dominant Riparian Vegetation:	Non-Forested Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest



Location of Survey Site Within Monitoring Watershed

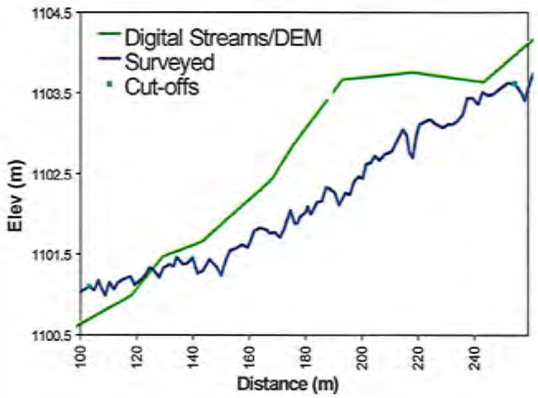
foothills model forest — a growing understanding

Site: 19

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Trib to Erith **Watershed: Upper Erith River**

Slope



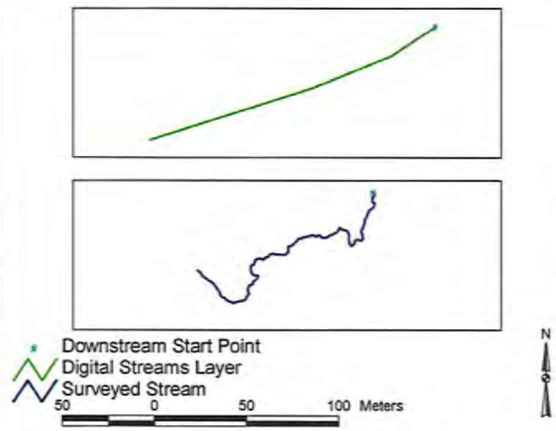
Source	Distance (m)	Slope (%)
Surveyed	168.0	1.7
GIS Digital Streams Layer/ DEM	168.0	2.3
Difference (Surveyed – GIS)		-0.6

Survey Information	
FMF Site ID:	A201519
Survey Date:	10/12/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	1
Drainage Area (km^2):	1.72
Dominant Riparian Vegetation:	Black Spruce / Larch Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	168.0	1.6
GIS Digital Streams Layer	168.0	1.0
Difference (Surveyed – GIS)		0.5

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

Comments: bankfull width, downstream view

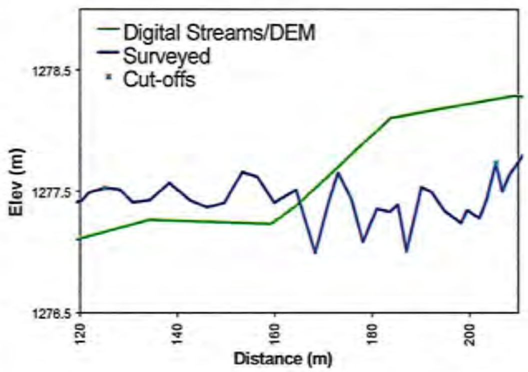
foothills model forest — a growing understanding

Site: 21

Comparison of Surveyed and GIS Interpreted Stream Descriptors

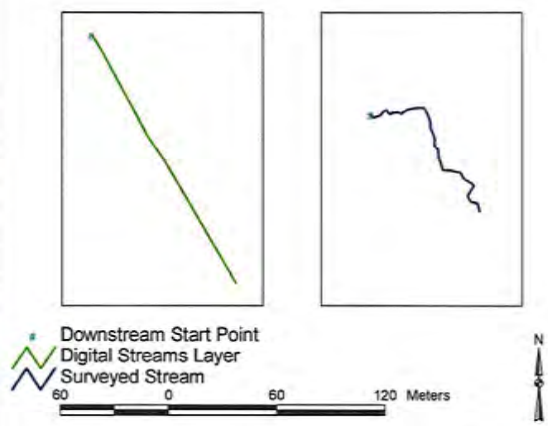
Stream: Trib to Pinto **Watershed: Pinto Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	158.9	0.3
GIS Digital Streams Layer/ DEM	158.9	0.8
Difference (Surveyed – GIS)		-0.6

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	158.9	1.2
GIS Digital Streams Layer	158.9	1.0
Difference (Surveyed – GIS)		0.2

Site Photos

Comments: upstream view

Survey Information	
FMF Site ID:	A201521
Survey Date:	10/15/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	8.345
Dominant Riparian Vegetation:	Non-Forested Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

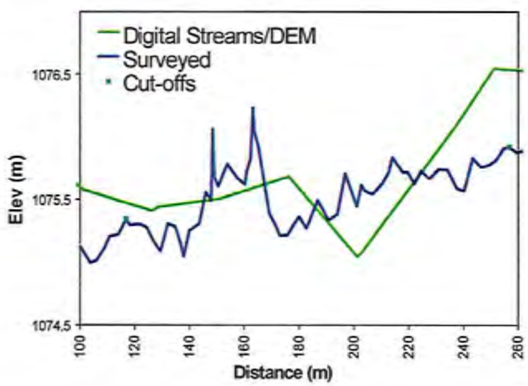
foothills model forest — a growing understanding

Site: 23

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Trib to Emerson **Watershed: Emerson Creek**

Slope



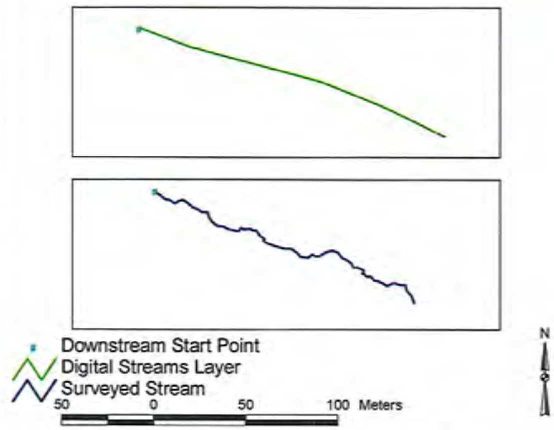
Source	Distance (m)	Slope (%)
Surveyed	176.1	0.4
GIS Digital Streams Layer/ DEM	176.1	0.9
Difference (Surveyed – GIS)		-0.4

Survey Information	
FMF Site ID:	A201523
Survey Date:	10/16/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	1
Drainage Area (km^2):	5.316
Dominant Riparian Vegetation:	Black Spruce / Larch Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity

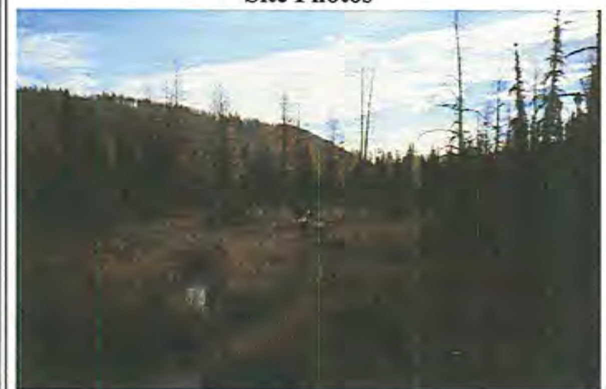


Source	Distance (m)	Sinuosity
Surveyed	176.1	1.2
GIS Digital Streams Layer	176.1	1.0
Difference (Surveyed – GIS)		0.2

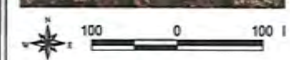
Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos



Comments: downstream view



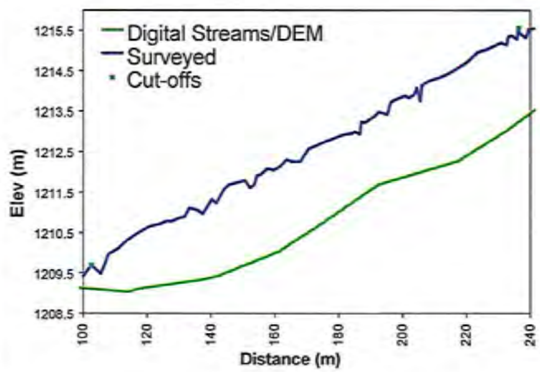
foothills model forest — a growing understanding

Site: 24

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Trib to Erith **Watershed: Upper Erith River**

Slope



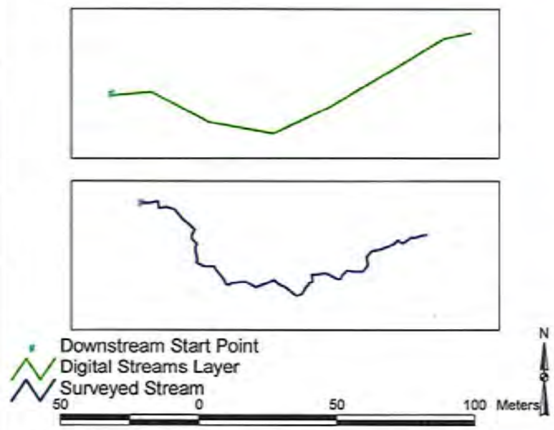
Source	Distance (m)	Slope (%)
Surveyed	141.9	4.4
GIS Digital Streams Layer/ DEM	141.9	3.2
Difference (Surveyed – GIS)		1.2

Survey Information	
FMF Site ID:	A201524
Survey Date:	10/16/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

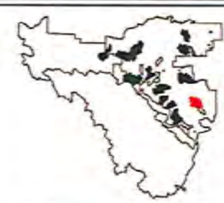
Watershed and Reach Characteristics	
Stream Order:	1
Drainage Area (km^2):	1.234
Dominant Riparian Vegetation:	Forested - Pine

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	141.9	1.4
GIS Digital Streams Layer	141.9	1.1
Difference (Surveyed – GIS)		0.3



Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

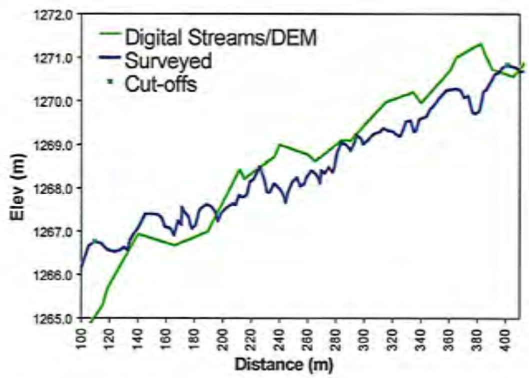
Comments: bankfull width, upstream view

Site: 25

Comparison of Surveyed and GIS Interpreted Stream Descriptors

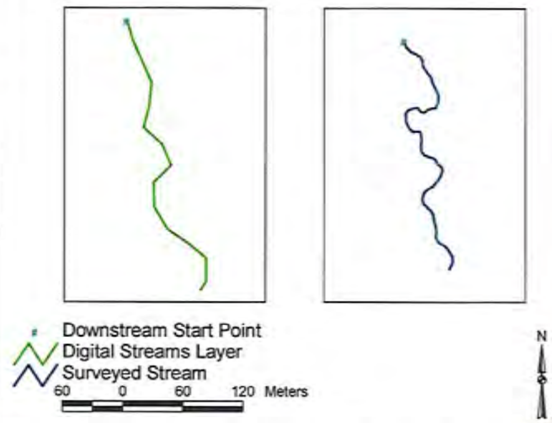
Stream: Deerlick Creek **Watershed: Deerlick Creek**

Slope



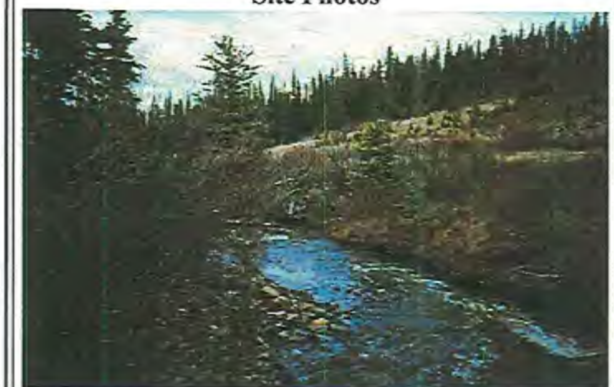
Source	Distance (m)	Slope (%)
Surveyed	314.8	1.4
GIS Digital Streams Layer/ DEM	314.8	2.3
Difference (Surveyed – GIS)		-0.9

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	314.8	1.4
GIS Digital Streams Layer	314.8	1.1
Difference (Surveyed – GIS)		0.2

Site Photos



Comments: upstream view

Survey Information	
FMF Site ID:	A201525
Survey Date:	10/17/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	14.864
Dominant Riparian Vegetation:	Non-Forested Wetland

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

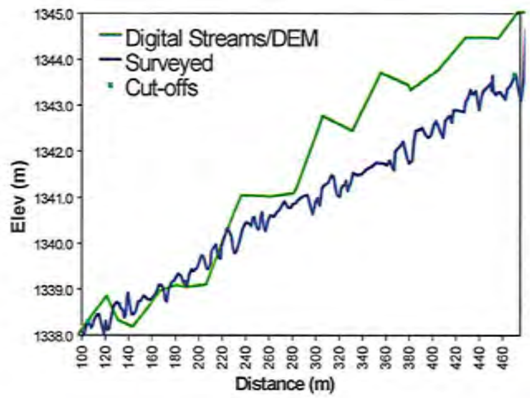
Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Site: 26

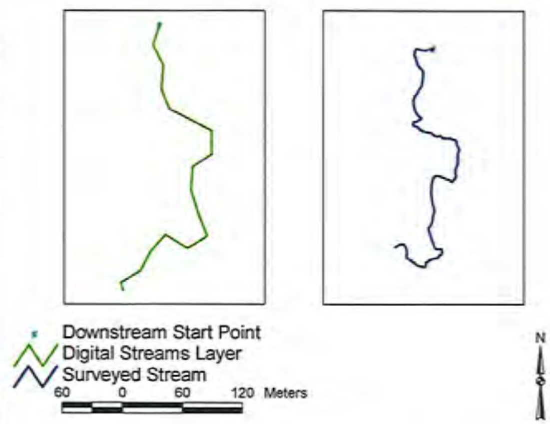
Stream: Deerlick Creek **Watershed: Deerlick Creek**

Slope



Source	Distance (m)	Slope (%)
Surveyed	380.0	1.5
GIS Digital Streams Layer/ DEM	380.0	1.8
Difference (Surveyed – GIS)		-0.3

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	380.0	1.8
GIS Digital Streams Layer	380.0	1.4
Difference (Surveyed – GIS)		0.4

Survey Information	
FMF Site ID:	A201526
Survey Date:	10/22/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

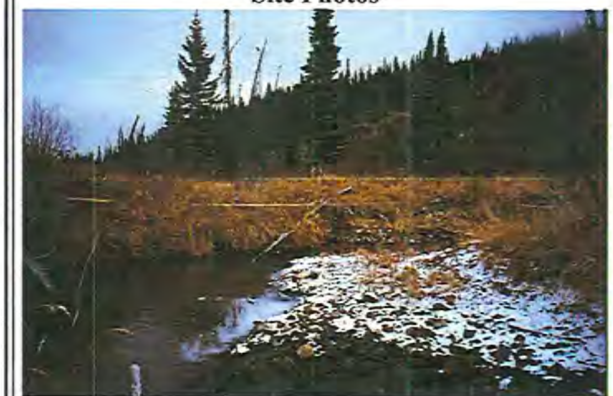
Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	10.961
Dominant Riparian Vegetation:	Non-Forested Wetland

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos



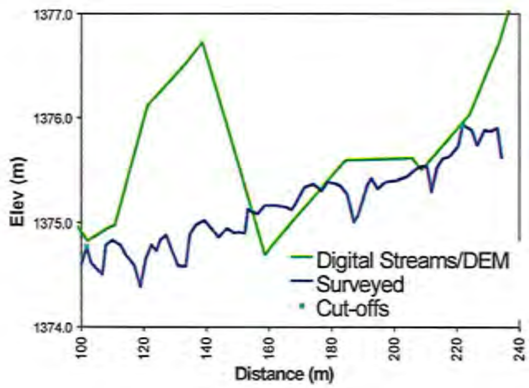
Comments: downstream view

Site: 27

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Eunice Creek **Watershed: Eunice Creek**

Slope



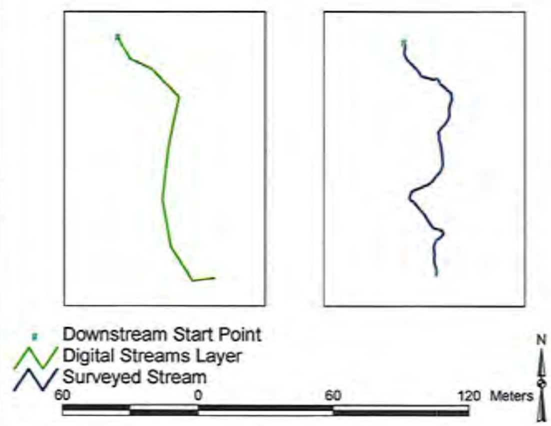
Source	Distance (m)	Slope (%)
Surveyed	134.2	1.0
GIS Digital Streams Layer/ DEM	134.2	1.5
Difference (Surveyed – GIS)		-0.6

Survey Information	
FMF Site ID:	A201527
Survey Date:	10/23/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	7.044
Dominant Riparian Vegetation:	Forested - Pine

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	134.2	1.3
GIS Digital Streams Layer	134.2	1.2
Difference (Surveyed – GIS)		0.2

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

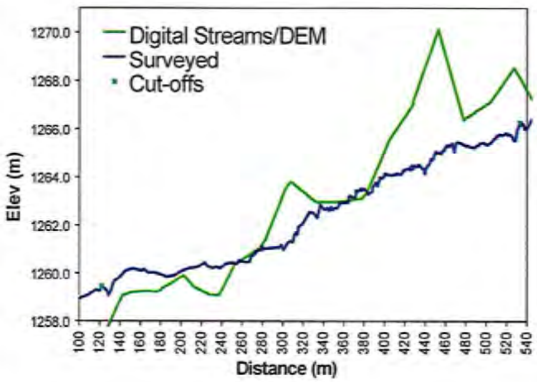
Comments: bankfull width, downstream view

Site: 28

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Wampus Creek **Watershed: Wampus Creek**

Slope



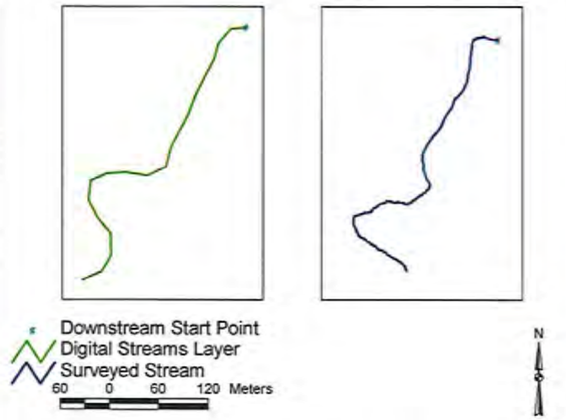
Source	Distance (m)	Slope (%)
Surveyed	452.0	1.0
GIS Digital Streams Layer/ DEM	452.0	3.1
Difference (Surveyed – GIS)		-2.1

Survey Information	
FMF Site ID:	A201528
Survey Date:	10/24/01
Surveyor:	R. McCleary
Assistant:	B. Johnston

Watershed and Reach Characteristics	
Stream Order:	4
Drainage Area (km^2):	28.93
Dominant Riparian Vegetation:	Forested - White Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity

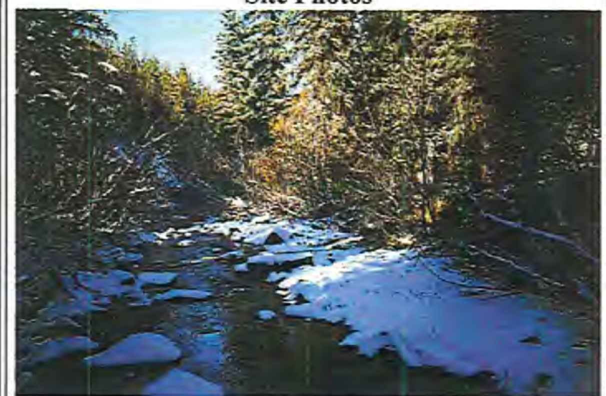


Source	Distance (m)	Sinuosity
Surveyed	452.0	1.1
GIS Digital Streams Layer	452.0	1.2
Difference (Surveyed – GIS)		-0.2

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos



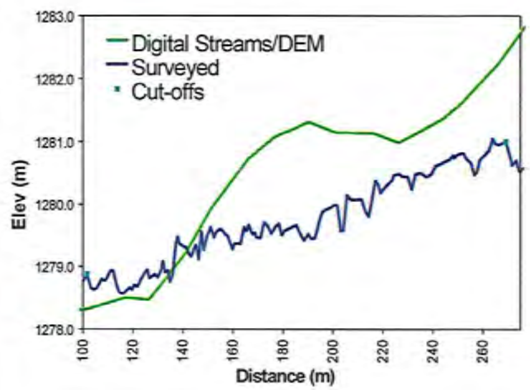
Comments: bankfull width, downstream view

Site: 29

Comparison of Surveyed and GIS Interpreted Stream Descriptors

Stream: Eunice Creek **Watershed: Eunice Creek**

Slope



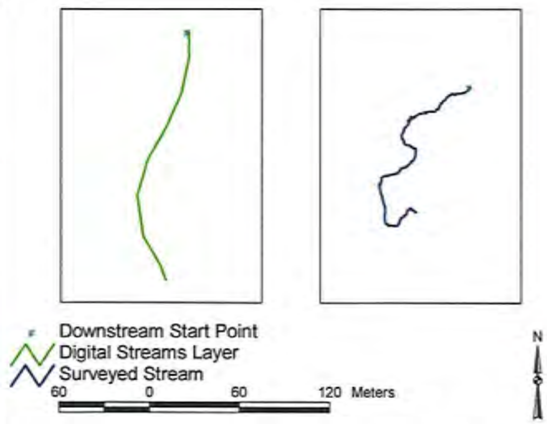
Source	Distance (m)	Slope (%)
Surveyed	176.0	1.3
GIS Digital Streams Layer/ DEM	176.0	2.6
Difference (Surveyed – GIS)		-1.3

Survey Information	
FMF Site ID:	A201529
Survey Date:	10/25/01
Surveyor:	R. McCleary
Assistant:	T. Muhly

Watershed and Reach Characteristics	
Stream Order:	3
Drainage Area (km^2):	17.029
Dominant Riparian Vegetation:	Forested - Mixed Spruce

Figure created by: R.McCleary, J.Blackburn, and S. Wilson
Date: 4 February 2002

Sinuosity



Source	Distance (m)	Sinuosity
Surveyed	176.0	1.8
GIS Digital Streams Layer	176.0	1.1
Difference (Surveyed – GIS)		0.8

Monitoring Watershed Locations Within the Foothills Model Forest

Location of Survey Site Within Monitoring Watershed

Site Photos

Comments: downstream view

Appendix 3: Procedure to Slope Correction Formula

Step	Equation
1. Corrected slope equation	$corrected\_slope = \frac{rise * 100}{corrected\_stream\_length}$
2. Solve for rise	$rise = \frac{slope * stream\_length}{100}$
3. Solve for corrected stream length	$corrected\_stream\_length = corrected\_sinuosity * valley\_length$
4. Solve for valley length	$valley\_length = \frac{stream\_length}{sinuosity}$
5. Substitute into corrected slope equation	$corrected\_slope = \frac{slope * stream\_length * 100 * 100^{-1}}{corrected\_sinuosity * stream\_length * sinuosity^{-1}}$
6. Simplify equation	$corrected\_slope = \frac{slope * sinuosity}{corrected\_sinuosity}$