Trail Degradation on the Nine Mile Trail System, Nova Scotia: The Effects of Users on Trail Compaction and Rutting

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Abstract

Deterioration of back country trails is a major issue for trail builders, managers and users. Trail deterioration can be caused through overuse, by use for unintended purposes; or by improper construction techniques or maintenance. To adequately maintain a trail system, managers need to understand both the physical properties of soils and underlying geomorphology, as well as the impacts that various types of uses will have on the trail. The impacts can vary depending on the geological properties at the trail site. We seek to provide trail managers with essential data regarding the influence that both the trail substrate and users can have on a trail bed. To achieve this, we studied a section of trail on the new Nine Mile Trail system just north of Elmsdale N.S. At this site we analyzed the soil moisture and soil temperature, as well as examined the annual precipitation trends. We also conducted a controlled test consisting of 100 passes by mountain bike and 100 passes by hiker with the impact of these two activities on trail compaction and roughness recorded. The average compaction of trail cross-section was 2.2mm, with a greater impact where the trail had higher than average soil moisture (as much as 1 cm on wet transects to as little as 0.1 cm on dry transects). Both hiking and mountain biking showed a similar amount of compaction after the runs. However we also compared the impact on the roughness of the trail as measured by sinuosity (the width of the transect along the micro-topography over the straight line width). For roughness the variations were quite small, on the whole mountain biking showed a slightly higher rutting tendency than the hiking, with sinuosity ratios of ~1.034 for biking compaired to a ratio of ~1.031 for hiking. However both of these are smaller then the baseline average of 1.037. These results show that a large number of factors can influence trail degradation. While our findings are specific to this trail, the methods used for determining both the natural effects and the user-influenced trail degradation can be applied to any trail location.

Acknowledgments

This study was possible due to the efforts of many different people. Mostly my supervisor, Lawrence Plug who helped me with editing, acquiring references, and providing me with the office space to work. Also Thomas Duffett who helped in building and designing the LT-device and John Thibodeau for teaching me how to run the LiDAR. Thanks also to Christian Rafuse and Fergus Tweedale who assisted in data collection.

Table of Contents

Table of Contents (cont.)

Table of Tables

Table of Figures

CHAPTER 1 **Introduction**

1.1 Previous works

In recent decades there has been an increase in the usage of multi-use trails and trail systems, in regions including the United States (White et al. 2006), New Zealand (Cessford 2003) and Australia (Goeft & Alder 2001). Corresponding with the increase in general use there has been an increase in the different types of activities on the trails; riding ATV's, mountain biking, cross-country skiing, horseback riding, snowmobiling and hiking (Wilson & Seney 1994; Leung & Marion 1996). The increase in trail use, as well as in the types of users has led to concerns about the sustainability of trails in regards to soil erosion and compaction as well as disruption to the local environment (Marion & Wimpey 2007). In order to better equip and build their trails, managers and care takers need to have accurate and reliable information regarding the number of users of the trail and the impacts that the various types of uses can have on the trail bed, and on surrounding flora and fauna.

Previous studies on trail degradation have focused on many different aspects of trail degradation. Some examined the impact of trail use on the sediment load in runoff water (Wilson & Seney 1994), as well as comparing the effect of the various types of trail users (Weaver & Dale 1978). These studies conducted experimental trampling on a trail surface and found that there was a large variation in the impacts of the different uses for the trail and that these impacts also varied with the slope of the trail. Weaver and Dale (1978) determined that motorcycles have a greater effect on the trail depth while going uphill, but horses and hikers had a greater effect while going downhill. This is consistent with Goeft and Adler's (2001) findings on the physical effects of mountain biking for both recreational and racing conditions on old and new trails. They maintained a study area for a period of a year and found that older tracks had a greater tendency to be eroded on uphill slopes, while newer ones actually had slightly higher erosion rates on flat surfaces. These findings were repeated in other studies, which also showed that natural elements such as topography, soil moisture and type (Bryan 1977), and forest type (mature vs. new; hardwood vs. Softwood) (Bratton et al. 1979) have a larger effect on the degradation of a trail bed than the actual type of use. Other studies have focused on hiking and mountain biking specifically, and have examined the various perceptions that people have regarding the impacts of those two activities on trails or wilderness settings in general. Cessford (2003) looked at the perceptions of users, particularly hikers towards mountain bikers and found that most hikers perceive that mountain bikers pose a greater degradation impact to the trail, probably due to the fact that much of the deterioration caused by bikes is more visible than that caused by hikers (in particular rutting caused by bike tires, and the further "spray" of muddy water, compared to the compaction of hikers; see figure 3.3 for example). This view is not just limited to users, as 67% of US state park directors perceive mountain biking as a problem to their parks, but only 13% of state parks have actually conducted studies to assess the impact of mountain biking within their parks (White et al. 2006). In 1999 the Nova Scotia Department of Economic Development and Tourism commissioned a study of hiking and multi-use trail users (G.P. Consulting 1999) to find out the experience desired by the various trail users and devise strategies to improve experiences. The findings show that users in Nova Scotia are divided as to whether mountain biking and hiking should be permitted on the same trail, owing to perceptions on issues ranging from safety to trail deterioration. However in a similar study from New Zealand (Cessford 2003) where mountain bikers were allowed to ride on a long-used hiking trail, the majority of hikers said that mountain bikers had no effect on their experience, outnumbering those who expressed negative impressions of mountain bikers by a 2:1 ratio. Cessford (2003) also found that those hikers who had the fewest encounters with mountain bikers on the trail were the most likely to have a negative impression of mountain biking. These are issues that can be addressed by intelligent trail planning, careful maintenance and keeping the various users informed about the rules and status of the trail.

1.2 Purpose

This study will attempt to look at the absolute and relative trail degradation from the two main non-motorized users of trails in Nova Scotia, mountain biking and hiking. This will be done in order to give the trail managers a better idea of how to construct, maintain and choose appropriate users for the trail and provide advice on how to minimize the effect of human impact on the trail bed. The roughness of trails and changes in roughness will be quantified through sinuosity calculations of the micro-topography of the trail. Compaction will be measured in cross-track transects. Natural factors that also can play a role in trail degradation such as soil moisture and type, vegetation and trail surface topography will also be measured. To date, no such studies like this have been done in Atlantic Canada, and few of those done elsewhere have taken place in a humid maritime climate such as Nova Scotia's. In order to conduct this study we created a new robust, lightweight and portable apparatus (our Low-Tech device) for measuring trail degradation on remote trails. Using this we are able to quantify and accurately compare the effects of mountain biking and hiking on the surface of the trail bed. We also present historical temperature and precipitation patterns for the area so that the findings of this study can be understood within a broader context.

Another goal of this study is to compare the usefulness of the LT-device with measuring techniques employed by other studies, and see if it provides a useful alternative. Bayfield (1973) used a similar model to ours creating a frame from which they dropped 10 wooden pegs which were measured to gather the surface topographic variance. Bayfield claims this device worked well in gathering the general trend of the trail morphology, but was unsatisfactory when there were narrow rutting and boulders in the track. Bratton et al. (1979) examined trail effects in the Great Smoky Mountains National Park, and their approach was purely qualitative and based on visual estimations of the percentage of the trail that was rutted, and provided no methods for quantifying rutting or compaction. Their method has the benefit of being quick and easy to establish, but also variations between individuals researchers can make this type of assessment unreproducible. Goeft and Adler (2001) decided to use a more high tech approach to measuring compaction. They used a hand held penetrometer and took readings at 5 cm intervals across various transects of the trail. This approach gave accurate compaction values across the trail bed, but not trail micro-topography or the change through time to the trail's surface. White et al. (2006) used a very simple approach, stringing a taut nylon cord above the trail and measuring the maximum depth of the trail from the cord to the trail surface.

All of these approaches have their benefits and drawbacks. Compared to the earlier methods, ours is closest to Bayfield's (1973) frame and post system, but with a greater spatial resolution (2cm horizontal vs ~7 cm), speed of data acquisition and less uncertainty from instrument error (~2.5 mm for ours while Bayfield's (1973) is not assessed).

1.3 Geological and Geographical Setting

The location for this project is the Nine Mile River trail system in Nova Scotia, Canada (lat/long: 45° 0.594' N, 63° 33.327' W; UTM: 20T 456230m E 4984200m N). It lies approximately 80km North of Halifax Nova Scotia, and 10km North of Stanfield International Airport (Figures 1.1, 1.2). The surface geology of the area is typical of glacially deposited systems, and much of the soil is underlain by glacial till deposited during the last glaciation (Stea et al. 1992). The bedrock for the area is the Meguma Super-Group composed of metamorphic slates of the Halifax Group and metagreywacke of the Goldenville Group (Sangster and Smith 2007). The site also borders the Wolfville Formation, which is composed of massive evaporite deposits and limestone beds.

The soil of the area is classified according to a Nova Scotia Department of Natural Resources report on Nova Scotian soil classification (Keys 2007) as soil type 5 (Figure 1.3), which is a fresh-moist, fine to medium textured soil, relatively loamy with slightly higher levels of clay concentration, with moderate to high drainage depending on the grade of slope. However other soils in the area are classed as 2, 3, or 6 depending on the

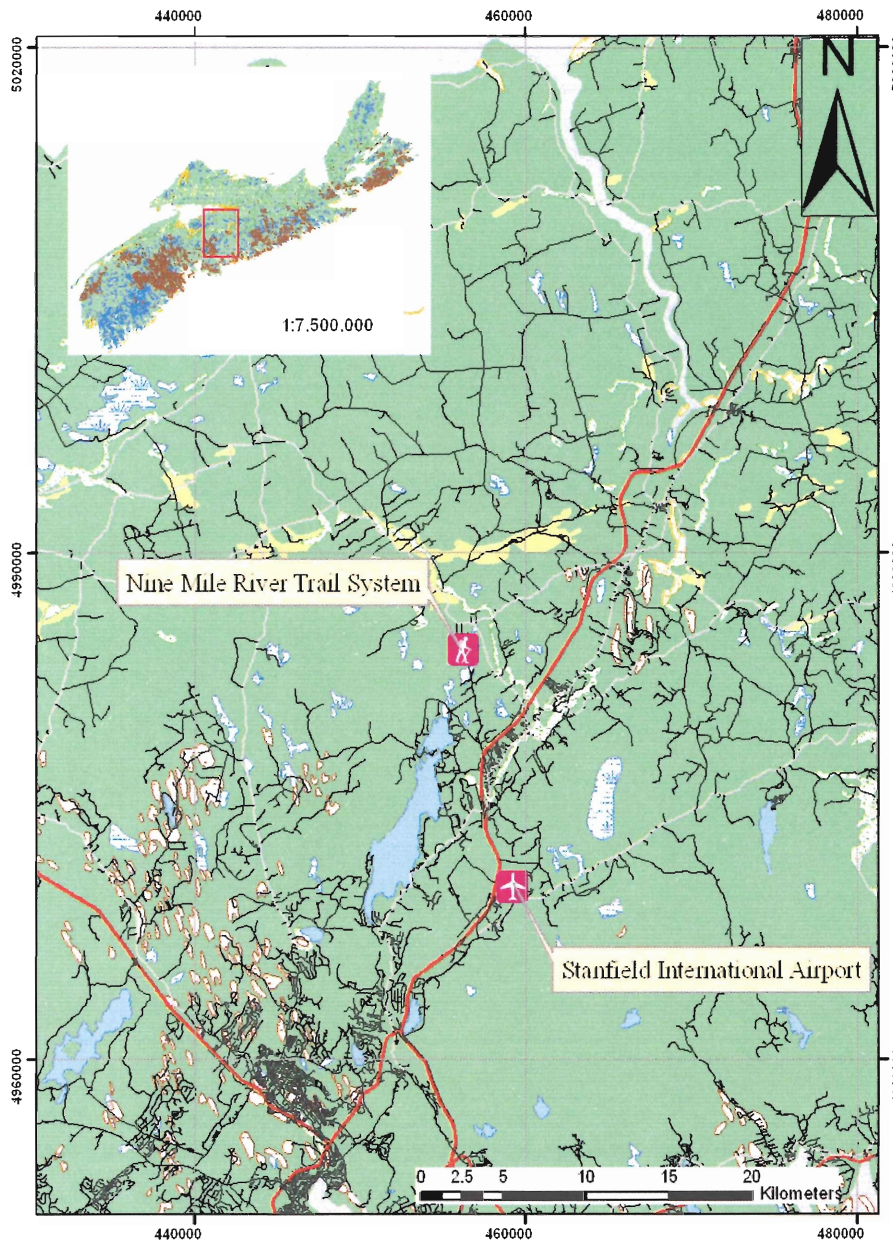

Figure 1.1. Map of the geographical area around the Nine Mile River trail system (Base-map: Stea et al. 1992)

moisture content and coarseness of texture, from this we are fairly confident that these four soil classes are likely to be observed along the course of the trail. This report also includes a hazard rating table (Table 1.1) that outlines the risk of compaction, rutting, erosion, frost heaves, wind-throw and organic layer loss. For all of these characteristics, soil type 5 is rated as moderate, except for erosion risk on slopes greater then 10% where the risk of erosion is high. A wetter soil type, such as 3 or 6 tends to have high levels for all of these risks, and very high on steep slopes. Knowledge of the soil type for the trail location is important when knowing how and where to construct and maintain a trail.

Figure 1.2. Map of the Nine Mile River Trail System. Star shows the location of our study on the trail.

Soil Type	Compaction	Rutting	Erosion (<10% slope)	Erosion (>10% slope)	Frost Heave	Wind-throw	Forest Floor Loss
Type 2	Low-Mod	Low	Low	Mod	Low	Low-Mod	High
Type 3	Mod-High	Mod	Mod	Mod-High	Low-Mod	Mod	Mod
Type 5	Mod	Mod	Mod	High	Mod	Low-Mod	Low-Mod
Type 6	High	High	Mod-High	Very High	High	High	Mod

Table 1.1. Hazard table for the various types of soils found near Nine Mile Trail. Shadowed columns show the factors that are user influenced. Adapted from Keys (2007)

Figure 1.3. Soil profile of a type 5 soil showing red coloured horizons which are high in clay. From Keys (2007)

CHAPTER 2 **Methods**

2.1 Data Collection

Field data for this study was collected at Nine Mile River trail system, Nova Scotia on November 14th 2010.

2.1.1. Low-Tech Device

A key part of this study was the development of our LT-Device (low-tech cross-beam and rod device) which enabled us to measure the cross sectional micro-topography of the trail bed. The concept for this this device was brought about by combining certain measuring devices found in literature and using that methodology as a basis to come up with the template for our device. These models for trail micro-topographic measuring include a point quadrant frame whereby ten wooden pegs were dropped through holes in a frame at 7.5 cm spacings (Bayfield 1973); another used a simple nylon cord or stick as a level line from which they measured the point of maximum incision (Weaver and Dale 1978; White et al. 2006). Our goal was to improve upon this and build a device that would give us a full micro-topographic profile of a transect. The device is simple to build, consisting of a square cross-beam (we used two, one metal, 2.5 m in length, and one wooden, 1.5 m in length), with holes drilled through at fixed intervals (2 cm in our case), which allows us to drop through marked threaded rod with a fixed thread count of 20 threads per inch, which gives us a quick and easy measurement of the distance between the bottom of the cross-beam and the ground (Figure 2.1). For this study we used two cross-beams in order to collect the data faster, as well as to accommodate wider sections of the trail. Full details on how to build and the LT-device used are given in appendix A.

Figure 2.1. Photograph of LT-Device being used on the trail (the long rods in the center are 30 cm in length, the shorter rods at the ends are 20 cm)

2.1.2 Transect Data Collection

The LT device was used to measure the micro-topography of all transects. This was done by mounting the LT-device on each end so that it was level, then dropping the rods through the cross-beam until they rest on the ground the ground. These rods are then photographed from a distance of approximately 50cm.The position of each rod is able to be measured at a later date using the photographs (Figure 2.2). That data is then entered into a spreadsheet program where exact distances from the trail bed to the base of the cross-beam were calculated and graphed (figure 3.2). Transect locations were spaced approximately every 10m for a total of twelve prospective sample transects, but only eight were actually measurable due to the location of some transects resting on wooden boardwalk and therefore unusable. The width of the transects ranged from 0.7 to 2 m; the width defined and measured as the non-vegetated surface of the trail. The same transects were used by both the hikers and the bikers in order to give a comparison between the effects of the two user groups. To avoid possible bias on account of precedence (e.g. hikers might compact the soil before the mountain bikers limiting their impact, or the mountain bikers might tear up the track causing an over estimation of the effect of hikers), the transects were split into two different sections of four transects each, with hikers going initially on the first set, while mountain bikers go first on the second set. Four different hikers participated, weighing 75kg, 79kg, 80kg, and 85kg respectively, wearing light hiking boots and travelling at a pace of ~4km/h. Two different mountain bikers, weighing 75kg and 85kg respectively, rode mountain bikes weighing 13kg with

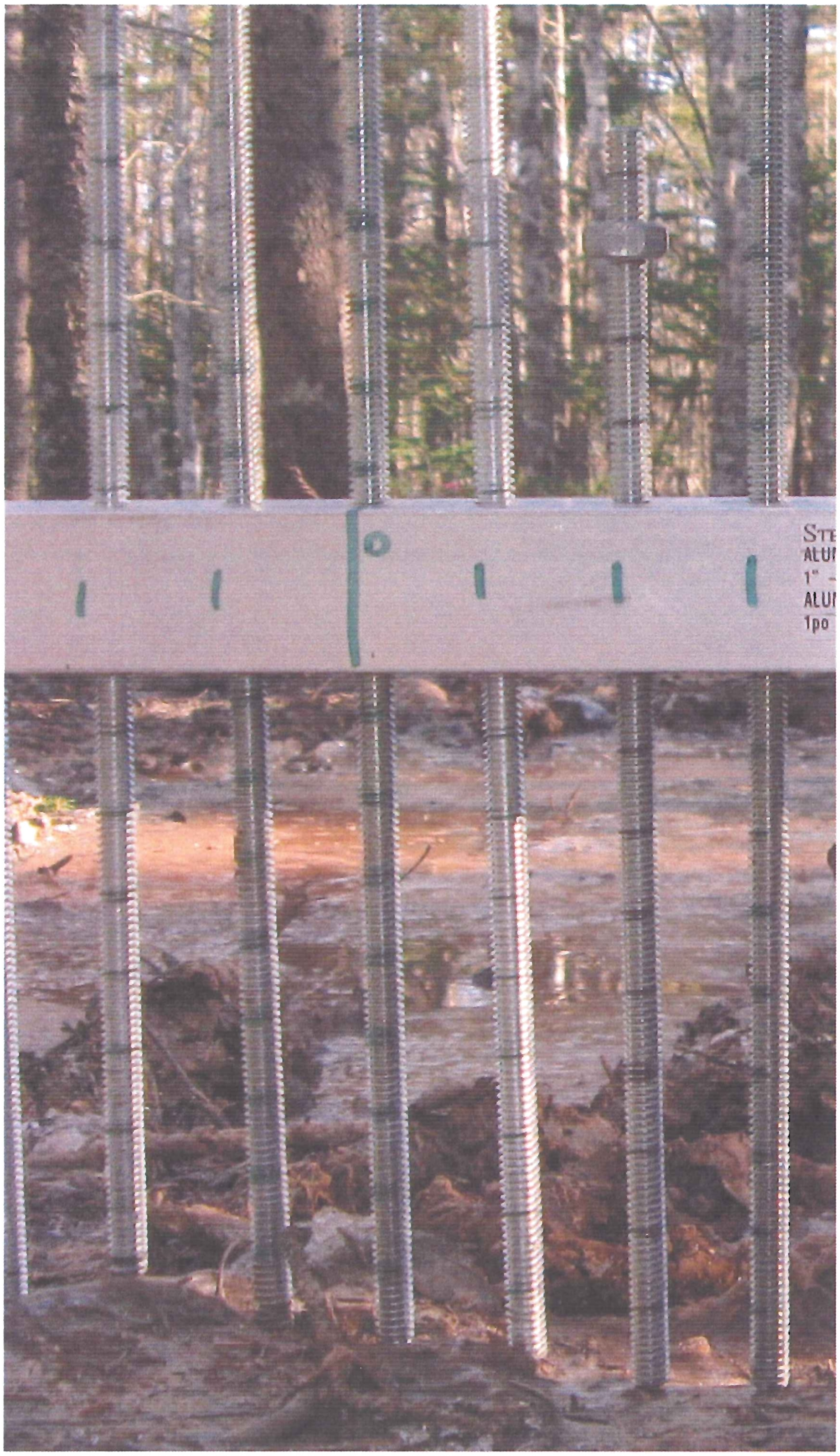

Figure 2.2. Example of actual photo used to count the threads to acquire the distance from the cross-beam base to the ground

2.1" wide knobby-treaded tires, travelling at an average speed of 13km/h (Figure 2.3). The micro-topographic data was acquired in three sets of transect measurements: the first measurement was acquired prior to any hikers or bikers took to the trail and provided the base line for this study, the second and third measurements provided data to assess change in the trail surface owing to use. On the first section, four different people walked a cumulative of 100 passes, crossing over the first set of transects . On the second section,

Figure 2.3. Mountain biker on the trail showing the equipment used and the visual impact on the trail

two people bicycled a total of 100 passes over the second set of transects. After the first pair of trial runs were completed, micro-topographic data was measured on all eight transects. A second trial run was then conducted. For the second trial run we switched the users; hikers walked the second section 100 times while the bikers rode 100 times over the first section. After this trial a third micro-topographic measurement was taken at each transect.

2.1.3 LiDAR Collection

We also used LiDAR (Light Detection And Ranging) on one of the transects in order to compare between two different methods of data collection, and to be able to digitally track the changes in physical disruption caused by the hikers and cyclists in 3-dimensions. The LiDAR system is an ILRIS-3D scanning device that scans a surface using a fine beam of light with 10kHz frequency, which is then reflected back to the sensor in the device which interprets it as a point with specific x,y and z coordinates (Optech 2009). This data is then used to create a point cloud to render a 3D image of the surface. The key feature that enabled us to use it was the pan-tilt feature which allows the LiDAR to tilt down at a maximum angle of 70°, allowing measurement of the trail surface. To image the trail surface we mounted the LiDAR on a fixed tripod (Figure 2.4) and angled it down so that the surface was approximately 2 m away from the device, we decided to only angle it at 45° so as to get a further distance from the ground. It was calibrated to record a point at every 1/1000th of a degree, giving an average resolution of 28 points per millimetre across the scanned section. Due to time and power constraints

Figure 2.4. ILRIS LiDAR scanner on tripod mount with pan-tilt base

the LIDAR was only used one transect (transect 8). Images were taken at the start and after each trial, for a total of three images.

2.1.4 Other Data

To add to this, *in situ* data for soil moisture content and soil temperature were also taken at each of the transect sites, using a soil temperature probe and a soil moisture meter. The historical weather data for the area was downloaded from Environment Canada's website (Environment Canada 2011). The Stanfield International Airport is the closest weather station to the trail site. Date ranges for the climate data extend from 1960 to 2010.

2.2 Calibration and Error

A series of reproducibility tests performed with the LT-Device were conducted in order to assess the instruments uncertainty in measuring micro-topography. These were all done at Dalhousie University in the month of October 2010. After running a six different calibrations on a controlled surface consisting of a dirt trail often used by students, which was done by setting the LT-device up, taking a measurement, taking it down, and then setting it up again in the same spot and retaking the measurements, and then keeping track of the differences between these two measurement. From this we calculated a measurement error of approximately 2.5mm (Table 2.1). There are three known causes for the error. 1) There is difficulty in knowing where one thread ended and the next started, particularly when looking at threads near the bottom of the cross-beam. This difficulty was unable to be mitigated. 2) The angle of the camera with respect to the base of the cross-beam: more threads are visible when looking up at the base then when looking down. We attempted to mitigate this by keeping the camera level with the base of the cross-beam, but this was not possible for all transects, depending on trail slope and morphology. 3) During take-down and set-up of the cross-beam it is not always possible to perfectly relocate the device.

Test 1	0.27				
	Run #1		Run #2		
	Height				Difference
Rod (cm)	Threads	cm	Threads	cm	#1-#2
0	100	12.7	97	12.32	0.381
2	97	12.32	96	12.19	0.127
4	96	12.19	97	12.32	-0.127
6	97	12.32	99	12.57	-0.254
8	96	12.19	97	12.32	-0.127
10	96	12.19	96	12.19	0.000
12	96	12.19	94	11.94	0.254
14	93	11.81	95	12.07	-0.254
16	90	11.43	96	12.19	-0.762
18	91	11.56	94	11.94	-0.381
20	92	11.68	93	11.81	-0.127
22	89	11.3	94	11.94	-0.635
24	88	11.18	91	11.56	-0.381
26	88	11.18	90	11.43	-0.254
28	89	11.3	92	11.68	-0.381
30	86	10.92	88	11.18	-0.254
32	85	10.8	88	11.18	-0.381
34	83	10.54	86	10.92	-0.381
36	83	10.54	83	10.54	0.000
38	82	10.41	83	10.54	-0.127
40	80	10.16	83	10.54	-0.381
				Standard Deviation (cm)	
					0.2704

Test 2	0.23				
	Run #1	Before	Run #2	After	
	Height				Difference
Rod (cm)	Threads	cm	Threads	cm	#1-#2
0	46	5.84	48.5	6.16	-0.318
2	48.5	6.16	50	6.35	-0.191
4	47.5	6.03	49	6.22	-0.191
6	50	6.35	53	6.73	-0.381
8	52	6.6	53	6.73	-0.127
10	53.5	6.79	54	6.86	-0.064
12	59.5	7.56	62.5	7.94	-0.381
14	64	8.13	61	7.75	0.381
16	63.5	8.06	59.5	7.56	0.508
18	60	7.62	60.5	7.68	-0.063
20	59	7.49	59	7.49	0.000
22	58	7.37	56.5	7.18	0.191
24	58	7.37	59	7.49	-0.127
26	58	7.37	57.5	7.3	0.063
28	73	9.27	72	9.14	0.127
30	75	9.53	75.5	9.59	-0.063
32	75.5	9.59	74.5	9.46	0.127
34	77	9.78	76	9.65	0.127
36	55.5	7.05	56.5	7.18	-0.127
38	52.5	6.67	54	6.86	-0.191
40	51	6.48	52.5	6.67	-0.191
				Standard Deviation (cm)	
					0.2292

Test 3	0.18				
	Run #1	Before	Run #2	After	
	Height				Difference
Rod (cm)	Threads	cm	Threads	cm	#1-#2
0	103.5	13.14	103	13.08	0.063
2	99.5	12.64	99.5	12.64	0.000
4	96.5	12.26	98	12.45	-0.191
6	97	12.32	96.5	12.26	0.063
8	96.5	12.26	98	12.45	-0.191
10	93	11.81	96	12.19	-0.381
12	94	11.94	94.5	12	-0.063
14	92	11.68	92	11.68	0.000
16	86.5	10.99	89	11.3	-0.318
18	84.5	10.73	87.5	11.11	-0.381
20	84.5	10.73	85	10.8	-0.064
22	87.5	11.11	86.5	10.99	0.127
24	87	11.05	85	10.8	0.254
26	84	10.67	84	10.67	0.000
28	84.5	10.73	83.5	10.6	0.127
30	85	10.8	87	11.05	-0.254
32	84	10.67	82	10.41	0.254
34	86	10.92	86	10.92	0.000
36	83.5	10.6	84.5	10.73	-0.127
38	84	10.67	84	10.67	0.000
40	84.5	10.73	86	10.92	-0.191
				Standard Deviation (cm)	
					0.1846

Test 4	0.08				
	Run #1	Before	Run #2	After	
	Height				Difference
Rod (cm)	Threads	cm	Threads	cm	#1-#2
0	87	11.05	86.5	10.99	0.063
2	86.5	10.99	87	11.05	-0.063
4	87.5	11.11	87.5	11.11	0.000
6	87.5	11.11	87.5	11.11	0.000
8	87.5	11.11	86.5	10.99	0.127
10	87	11.05	87.5	11.11	-0.064
12	86.5	10.99	85.5	10.86	0.127
14	86.5	10.99	86	10.92	0.064
16	87.5	11.11	87.5	11.11	0.000
18	89.5	11.37	88	11.18	0.190
20	90	11.43	89	11.3	0.127
22	89	11.3	89	11.3	0.000
24	89.5	11.37	88.5	11.24	0.127
26	87	11.05	88	11.18	-0.127
28	89.5	11.37	89.5	11.37	0.000
30	90	11.43	90	11.43	0.000
32	89	11.3	89	11.3	0.000
34	88.5	11.24	89	11.3	-0.064
36	91	11.56	91	11.56	0.000
38	90.5	11.49	91	11.56	-0.063
40	92	11.68	92	11.68	0.000
				Standard Deviation (cm)	
					0.081

Test 5	0.18				
	Run #1	After	Run #2	Test	
	Height				Difference
Rod (cm)	Threads	cm	Threads	cm	#1-#2
0	103	13.08	103	13.08	0.000
2	99.5	12.64	98.5	12.51	0.127
4	98	12.45	98	12.45	0.000
6	96.5	12.26	96.5	12.26	0.000
8	98	12.45	96.5	12.26	0.191
10	96	12.19	96	12.19	0.000
12	94.5	12	95	12.07	-0.063
14	92	11.68	93	11.81	-0.127
16	89	11.3	93	11.81	-0.508
18	87.5	11.11	88	11.18	-0.064
20	85	10.8	87	11.05	-0.254
22	86.5	10.99	89	11.3	-0.318
24	85	10.8	86	10.92	-0.127
26	84	10.67	84	10.67	0.000
28	83.5	10.6	85	10.8	-0.191
30	87	11.05	88	11.18	-0.127
32	82	10.41	84	10.67	-0.254
34	86	10.92	84	10.67	0.254
36	84.5	10.73	84	10.67	0.063
38	84	10.67	85.5	10.86	-0.191
40	86	10.92	85	10.8	0.127
				Standard Deviation	
					0.181

Test 6	0.53				
	Run #1	After	Run #2	Test	
	Height				Difference
Rod (cm)	Threads	cm	Threads	cm	#1-#2
0	48.5	6.16	45.5	5.78	0.381
2	50	6.35	49	6.22	0.127
4	49	6.22	49	6.22	0.000
6	53	6.73	51.5	6.54	0.191
8	53	6.73	53	6.73	0.000
10	54	6.86	54.5	6.92	-0.063
12	62.5	7.94	62	7.87	0.063
14	61	7.75	63	8	-0.254
16	59.5	7.56	62.5	7.94	-0.381
18	60.5	7.68	59.5	7.56	0.127
20	59	7.49	57.5	7.3	0.191
22	56.5	7.18	57	7.24	-0.064
24	59	7.49	59.5	7.56	-0.064
26	57.5	7.3	61.5	7.81	-0.508
28	72	9.14	59.5	7.56	1.588
30	75.5	9.59	74.5	9.46	0.127
32	74.5	9.46	74	9.4	0.063
34	76	9.65	63	8	1.651
36	56.5	7.18	57.5	7.3	-0.127
38	54	6.86	54.5	6.92	-0.063
40	52.5	6.67	54	6.86	-0.191
				Standard Deviation (cm)	
					0.533

Table 2.1. Data from 6 different LT-Device calibration tests showing standard deviation, average SD is .25 cm (2.5 mm)

CHAPTER 3 **Results**

3.1 LiDAR Data

The use of the LiDAR for measuring change in the trail bed was inconclusive. Due to errors in setting up the device too close to the trail surface, we were not able to gather sufficient data from the point clouds to assess deterioration of the trail. We were able to obtain one image (Figure 3.1) from the data where a few possible bike tracks may be picked out. This shows us the approximate roughness of the trail for the surface area that the LiDAR was shot at, but because there was only one image, at very poor quality, it was impossible to make any sort of quantitative assessment, and change analysis could not be performed.

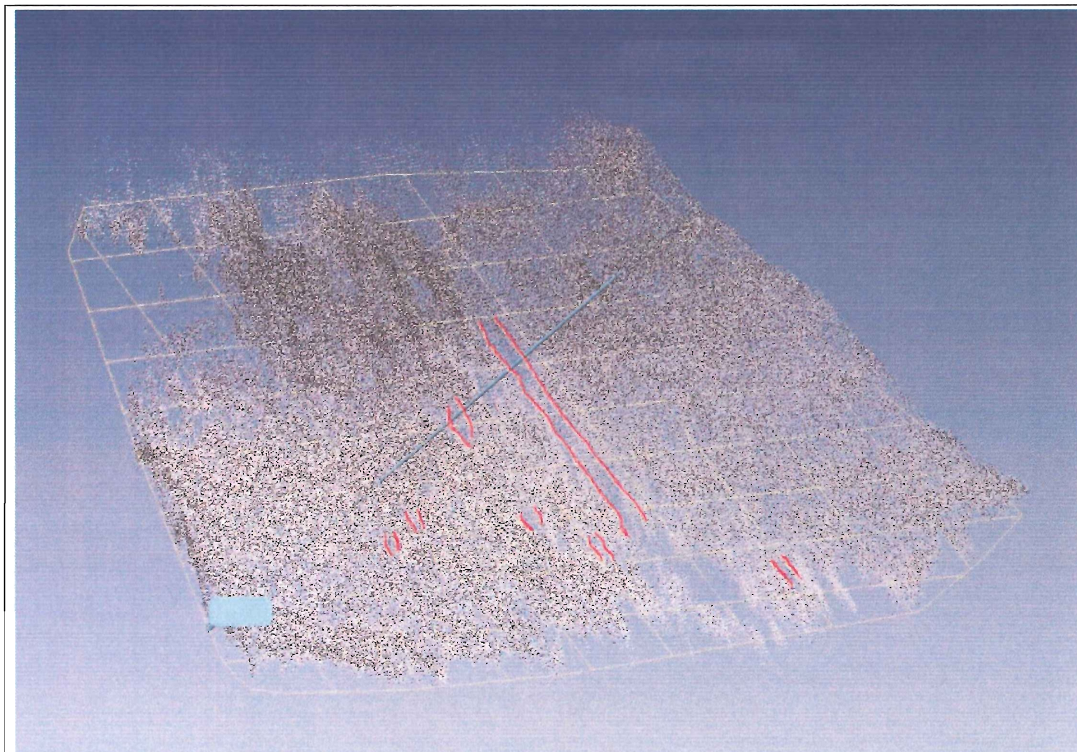

Figure 3.1. Point cloud image of LiDAR output, approximate ruts are outlined in red

3.2 LT Data

Complete tables of the transect data can be found in Appendix A2.2.

3.2.1 *Trail Compaction and Material Loss*

The first step in looking at the data was to see if there was an overall trend showing a net change in the distance from the cross-beam to the trail surface. One drawback to the LT-device is it is unable to differentiate between compaction and material loss, meaning that we are uncertain if such changes in distance from cross-beam to trail surface are as a result of compression on the trail or by the movement of material caused by the trials. We tested for the changes in track distance by looking at the differences (measured as the baseline minus the test, so a positive number means a loss of distance (or gain of material) , while a negative number means a gain of distance(or a loss of material)) between the three runs, using the first measurement as a baseline for the other two runs, the differences at each point along the transect were then averaged out and used to determine if the trail showed an overall loss of material, a summary of such

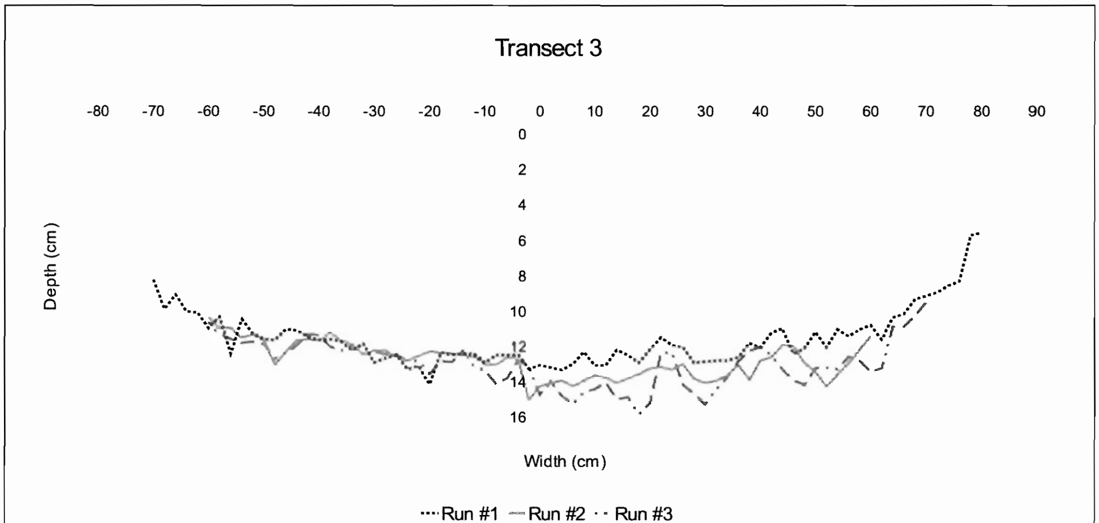

Figure 3.2. Sample plot of transect 3 showing the differences between the various tests

values is displayed in table 3.1. From this analysis we were able to determine a source of error as the numbers in table 3.1 show an increase in material or trail uplift, which is not to be expected given the results from previous studies. The source of error is interpreted as the change in relative height from the bottom of the cross-beam to the ground due to a change in the depth of the devices mounting pegs. To correct for this we determined that the smallest difference between runs should exist along the edges where the users have not passed, so the average of the difference at the two end pegs was then added to the original results for both run 2 and 3, this added number is to be taken as the approximate compression of the mounting pegs between the various runs (Table 3.2). Analysis of this data shows a minor compression factor on most transects between the various runs as a result of the tests, with the first runs having a more significant impact then the second.

	Transect # (Walk Then Bike)			Transect # (Bike Then Walk)				
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Baseline – Test 1	-0.09	0.50	0.52	0.48	0.67	0.69	2.55	0.00
Test 1 – Test 2	1.90	-0.11	0.15	0.19	0.27	2.46	-0.17	1.87
Baseline – Test 2	1.81	0.40	0.67	0.67	0.94	3.15	2.38	1.87

Table 3.1. Uncorrected compaction data

	Transect # (Walk Then Bike)			Transect # (Bike Then Walk)				
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Baseline – Test 1	-0.63	-0.64	-1.26	-0.95	-0.44	-0.43	-0.59	0.57
Test 1 – Test 2	-0.42	0.52	-0.20	0.45	0.40	0.53	0.27	-0.07
Baseline – Test 2	-1.05	-0.11	-1.46	-0.50	-0.04	0.10	-0.32	0.50

Table 3.2. Corrected compaction data

3.2.2 *Trail roughness*

As well as looking at the overall compression and material loss at the transect point we also analyzed the effect that the test runs had on the profile of the transect. This effect can be seen on the plots like figure 3.2 or in photos like figure 3.3, however while qualitatively the effect is evident, a more quantitative assessment was required. This was performed by producing a sinuosity analysis of each run, in which we compared the cross-track straight length with the length calculated from the cross-beam data (i.e. a straight path vs. a curved path), summarized in Table 3.3. Due to the small vertical variations compared to the horizontal our sinuosity values are quite low, close to 1, meaning that any absolute variation in the roughness will be quite small. The results of the sinuosity calculations show that when bikers go first there is a greater roughening of the trail bed then if the hikers go first.

Figure 3.3. Visual effect on the trail-bed from biking and walking. Bike ruts a generated along and near to the trail axis. Trail widening by boot prints are also visible at the edges of this wet depression. This photograph, because it is at a wet transect, shows the greatest effects of both users.

	Transect # (Walk Then Bike)				Transect # (Bike Then Walk)			
	1	2	3	4	5	6	7	8
Baseline	1.037	1.022	1.065	1.064	1.032	1.020	1.023	1.032
Test 1	1.006	1.015	1.020	1.048	1.078	1.018	1.021	1.038
Test 2	1.034	1.013	1.017	1.054	1.055	1.010	1.040	1.050
Change (B-1)	0.031	0.007	0.045	0.016	-0.046	0.002	0.002	-0.006
Change (1-2)	-0.028	0.002	0.003	-0.006	0.023	0.008	-0.019	-0.012
Change (B-2)	0.003	0.009	0.048	0.010	-0.023	0.010	-0.017	-0.018

Table 3.3. Sinuosity calculations from each transect

3.3 Soil Moisture and Temperature

Table 3.4 shows the soil temperature and moisture content data which was collected and analyzed at each transect. The soil-moisture values correspond to the transects that had visible standing water on or near them, however even transects without standing water have high levels of soil-moisture (>70%).

	Transect # (Walk Then Bike)				Transect # (Bike Then Walk)			
	1	2	3	4	5	6	7	8
Soil Moisture (%)	70	56	88	80	82	78	75	86
Temperature (°C)	2	1	1	1	1	2	1	1

Table 3.4. Soil moisture and temperature for each of the 8 transects

3.4 Comparison Between Hikers and Bikers

In order to properly assess the data, the fundamental difference in the way that mountain bikes and hikers interact with the trail surface must be taken into account. For hikers, the contact with the trail bed is made only in certain small condensed areas of pressure (i.e. where they place their foot), with some possible dragging or scuffing depending on the hiker. This means that the expected impact to the trail surface from hikers is more likely to be compactional than ruts or material movement. A mountain bike on the other hand makes contact with the trail surface by means of a tire that in continuously resting on a narrow section of the trail, and the damage to the trail is due to the rotational aspect of the tires. This means that the expected impact to the trail from mountain bikes is more likely to be a rutting feature or material loss due to the tires throwing dirt and/or tires due to the rotational force.

CHAPTER 4 **Analysis and Interpretation**

4.1 LiDAR

We were unable to use LiDAR data for change analysis, owing to successfully acquiring only one image that has ruts that can be picked out.

4.2 Compaction

The compaction data was quite variable, more so than would be expected, our values show that five of the transects (#'s 1, 3, 4, 7 and 8) show a statistically significant change in compaction, and one of those (transect 8) actually shows a relative rebound (Table 3.2). Separating out the first and the second passes over the trail there is statistical difference between the two, with the first pass showing high levels of compaction with an average of 0.55cm among all of the transects. However this was not mirrored in the second pass as that had an overall rebounding effect, raising up and average value of 0.19cm. This trend shows that the first users of the trail weather hikers or bikers, have a greater effect on the compaction than subsequent users. This agrees with the findings of Weaver and Dale (1978) who conducted a trampling study using 1000 passes and found that the first 100 had a greater effect then the subsequent 900, especially in forested areas such as our trail section. This trend was not dependent of the nature of the user on the trail as all of the transects except transect # 8 showed a greater compaction rate after the first pass then the second (Table 3.2). When comparing walking to biking on the trail there was a minor trend showing that hiking (at 0.29 cm) had a greater compaction impact then mountain biking (at 0.07 cm). However the impact of order seems to be more important then the type of user on the trail, as the first trials show that hiking had a larger

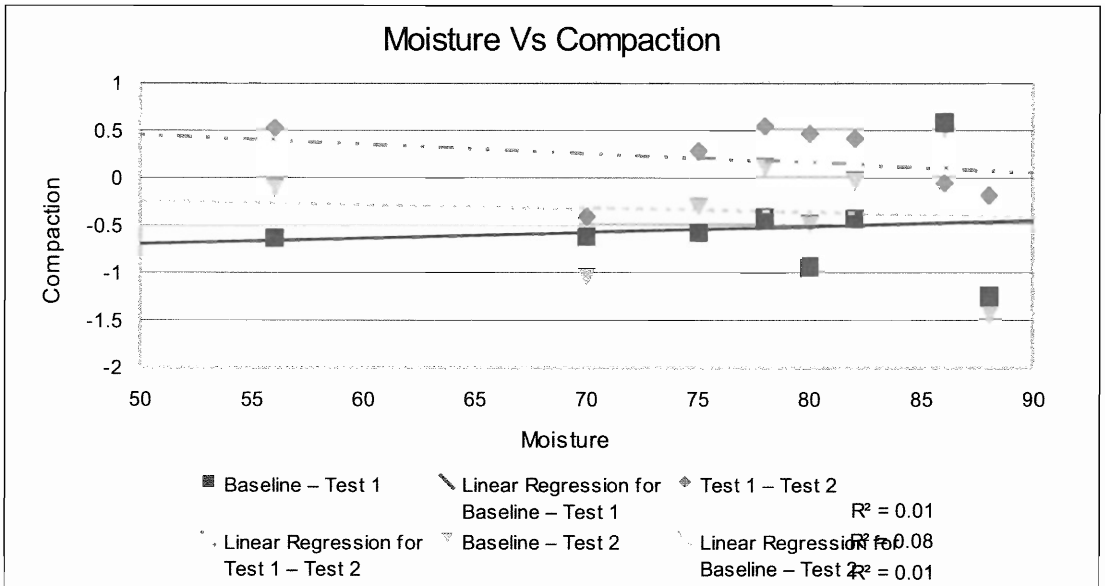

Figure 4.1. Plot of soil moisture vs. mean compaction for the various transects. All of the trend-lines show a lack of correlation between soil moisture and compaction

compaction impact ((h)0.87 cm to (b)0.22 cm) but the second trials show that biking had a larger impact ((b)0.09 cm rebound to (h)0.28 cm rebound). Another important analysis that we conducted was the potential correlation between moisture and compaction, a correlation that was found in many of the previous studies. For our test, we were able to find no statistical correlation between the amount of compaction and the moisture content in the soil, which is problematic as it differs greatly from the results found in previous studies (Figure 4.1). This maybe due to fact that all of the transects had a high soil moisture content.

4.3 Roughness

Roughness analysis of the trail surface was assessed using sinuosity measurements of transect topography. These values showed a stronger correlation with the moisture content of the soil than compaction, but no statistically significant difference

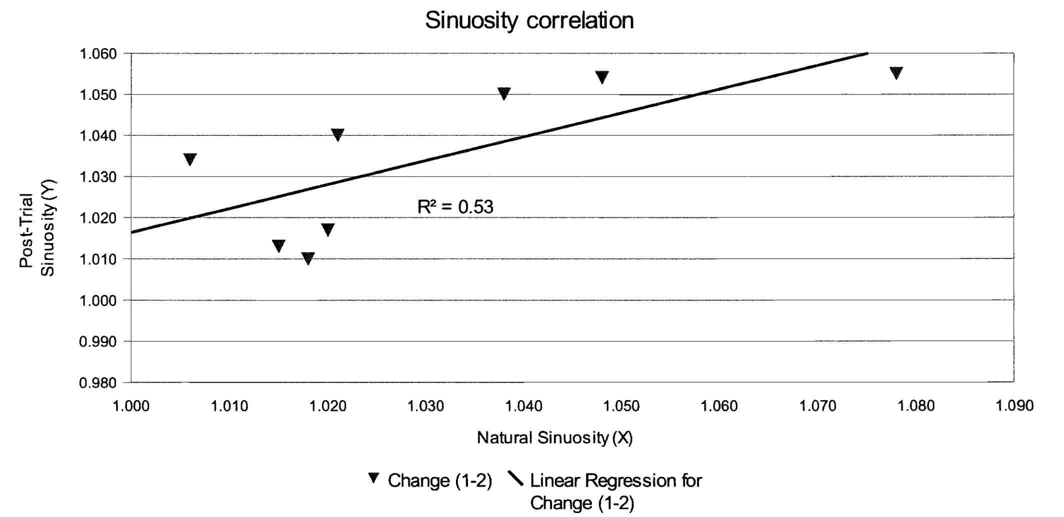

Figure 4.2. Sinuosity correlation between the two trials

when comparing hiking to mountain biking. The results show that the average sinuosity of walking was only fractionally lower then the sinuosity of mountain biking (1.031 and 1.034 respectively), even on the small scale differences that we were looking at in general (see Table 3.3) where the maximum change from baseline for any transect was -0.046. The average change from base line was actually a general flattening trend (1.037 baseline to 1.034 after the second run), however due to the small values of the changes statistically we saw no measurable change in the roughness of the trail between the natural state and the altered state after the trials. There were minor correlations when we compared the change in sinuosity from the baseline to the first trials (hiking and biking) and those to the second trials (biking and hiking). In this we saw in overall roughening effect after the first trial, and then a smoothing effect after the second trial, but these values were also quite small (changes from baseline of +.006 and -.004 respectively). One feature of note its that there is no correlation between the sinuosity baseline test (the undisturbed trail) and the two trials, however there was a strong correlation be between the sinuosity levels

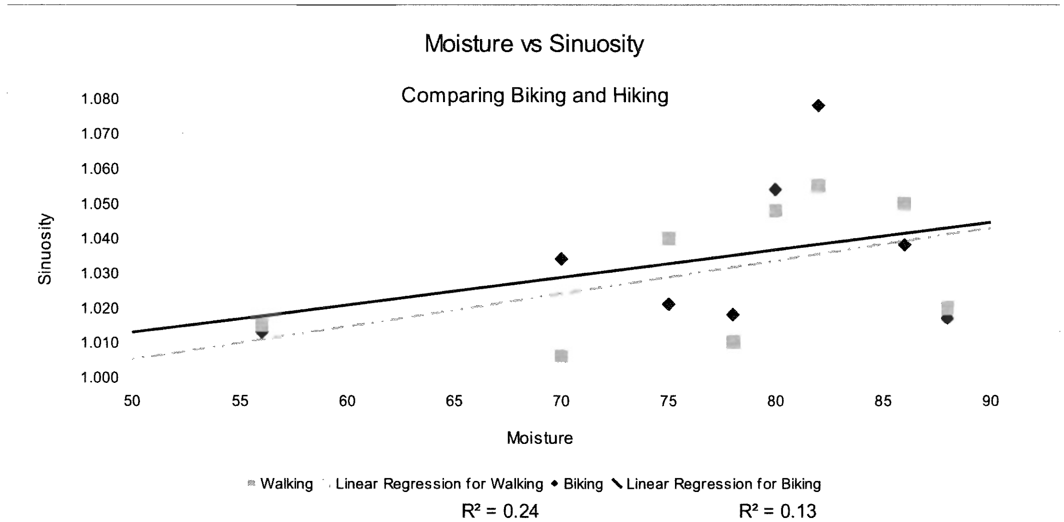

Figure 4.3. Moisture vs Sinuosity correlation graph showing that walking is more impacted by moisture then biking

of the two trials(figure 4.2). This can mean that natural roughness of the various transects is at distinctly different locations than the roughness that the users imposed upon the trail. This would imply a greater influence on the damage that users cause, because instead of simply amplifying the natural deterioration they tend to create deterioration in new areas on the trail bed that did not show it prior to the users influence.

We started to see a bit more correlation with sinuosity when we factored in the soil moisture (figure 4.3) which shows a positive correlation with soil moisture and sinuosity levels, although the R^2 values are still very weak, the reason for which is just as likely due to the small number of samples rather then a weaker correlation. One feature we also see in figure 4.3 is that there is a slightly stronger correlation between moisture content and roughness for hiking then mountain biking. This feature may be due to hikers tending to go around standing water, while bikers tend to go through the water, which means that the effect on the trail centre is greater for bikers then for hikers, but the impact to the area on the borders of the trail is greater for hikers. One feature that we did see is that when we plot the roughness values against the compaction (Figure 4.4) there is a weak to moderately negative correlation, meaning that the transects with the greatest roughness values are also the transects that have the greatest amount of compaction. This also means that when combined with the moisture graph (Figure 4.3) the same transects that are wetter that plot in the far right of the compaction-sinuosity graph.

4.4 LT-Device Comparison

The LT-device worked quite well for the purposes that we designed it for, it was compact and light-weight enough to easily bring it into our test site as well as easy to set up and take down. It produced all of the data that we required of it, providing a simple way to create a micro-topographic cross-section of the trail surface as well as giving us an idea of the amount of compaction that was done to the trail. Much of the downsides of the device have already been discussed, such as the mounting and the inability to distinguish material loss from compaction. Unlike most of the existing techniques (described in Chapter 1) ours is able to gather a full cross-section of the trail and determine micro-scale changes at any point along the transect as well as give a quantitative value on the compaction of the trail bed.

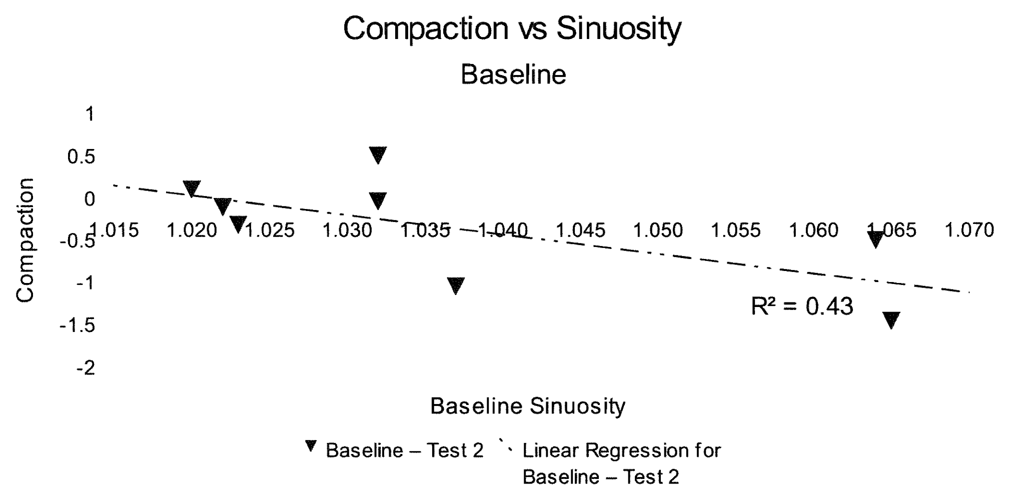

Figure 4.4. Showing the negative correlation between the sinuosity and the compaction of the trail

CHAPTER 5 **Discussion**

5.1 Implications

The purpose of this study was to quantify and characterize changes in micro-topography of a trail in Nova Scotia and compare the influence of mountain bikers and hikers. This was done in an effort to provide trail designers and managers with information needed to build and maintain a multi-use trail system in Nova Scotia. The data that we have appears for the most part to correspond with much of the findings from previous studies, and shows that moisture content of the soil and the presence of standing water has an degrading effect on the substrate. This is an important factor to consider, because when looking at the weather data for the area, the majority of the precipitation for the area comes in the fall to late spring(Figure 5.1), during this time some of the precipitation falls as snow which can dissuade use of a trail. Temperature during this time of year can also play a factor, not only in keeping people indoors, but also in freezing the ground which in turn can limit the impact that users have by holding the soil in place. With less precipitation during the summer when the user demand is highest, there is less impact from users compared to other areas of the world that may have peak rainfall during the summer.

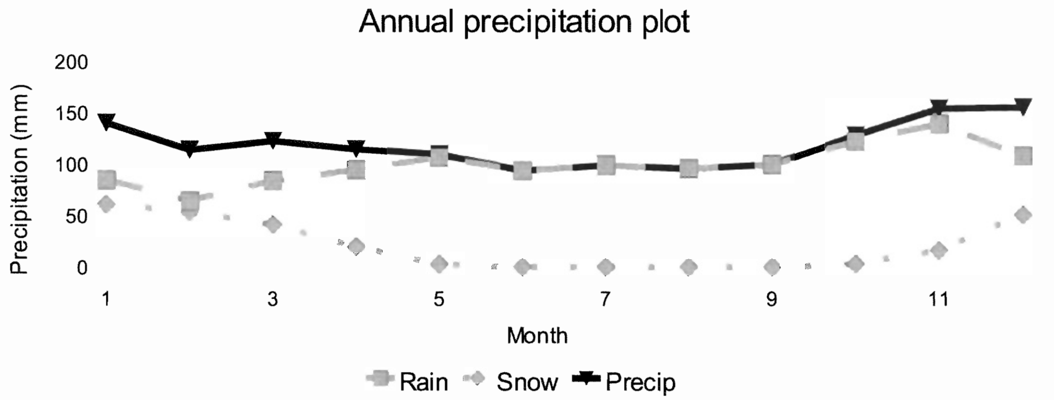

Figure 5.1. Annual precipitation monthly averages

5.2 Recommendations

One of the key purposes of this study was to provide recommendations so that builders and managers of trails would have a better understanding of how to build and maintain a trail in the Nova Scotian climate. We have come up with a couple of recommendations to be able to build better trails in Nova Scotia. One of the ways that managers of trails can better protect their surfaces is to plan ahead, and try to build their trails on sites that have relatively few bodies of standing water, or in areas where the potential for water draining onto the trail bed is low so as to not facilitate the destruction of the trail. Managers should also try to determine the locations on the trail where deterioration is likely to occur and potentially build walkways over them, or attempt to armour them using crushed gravel.

5.3 Future work

The shortcomings of this study leave a few areas where further work can be done to give a better understanding for the effects of various users on trail beds. One of the major things that need to be achieved is be a larger sample size that encompasses a larger trail section or small sections of multiple trails. This would be important as it might strengthen correlations, as much of the information that we have comes from quite a small data set. Along with a larger sample size, a longer time frame might also be a potential for improvement. Our study was conducted in one day we were limited in what impacts we could see. If this study was to be conducted over a whole season there may be a difference in the measurable impacts to the trail surface. A source of potential error in this study was the change in mounting height from the ground of the LT-device; this could be fixed if perhaps a more permanent structure for mounting the cross-beams was constructed, but the more pieces to the apparatus, the less mobile it becomes and you lose some of the ability to access remote trails. We were unable to use LiDAR to image the trail surface properly. However, if a future study mounted the device on the top of some sort of arch that the trail users could pass beneath, it would make quantitative analysis of trail degradation in 3-dimensions much easier and give a clearer picture on the effects that users have on the trail surface. Difficulties caused by LiDAR power demands, weight and sensitivity to rain would persist however.

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APPENDICES

A1 Building and Design of an LT-Device

A1.1 LT-Device specifications

We conducted this study with two LT-device cross-beams. The first that we built (Figure A1.1) was constructed out of a pine beam, 5 cm x 5 cm x 1.5 m, and the second (Figure A1.2) out of a hollow aluminium beam, 2.5 cm x 2.5 cm x 2.5 m. For each device we determined the centre, and then from that point measured holes at 2 cm intervals on either side for a total of 61 holes on the 1.5 m long pine cross-beam and 121 holes on the 2.5 m aluminium cross-beam. After measuring out the points the holes were then drilled through the cross-beam with a ¼" drill-bit to allow for the threaded rods to drop through. At points roughly 3 cm in from each end of the cross-beams we drilled another, larger hole to allow for easy mounting using rods that serve as feet.

A1.2 Threaded rods

The second main feature of this device were the threaded rods (Figure A1.3). For this we used ~30 m of ¼" 20 count threaded rod, cut into ~200 rods of three different lengths (20 cm, 30 cm and 40 cm) so that both cross-beams could be used at the same time. Each rod was then marked at 10 thread intervals to make counting easier when analyzing photographs.

A1.3 Mounting

The cross-beams were mounted in the ground from the holes drilled on the ends. We first drove a pair of the longer rods into the ground at the appropriate distance apart for the rod used. The depth at which they were driven was variable, but appropriate for the transect so as the whole width of the trail could be accurately measured.

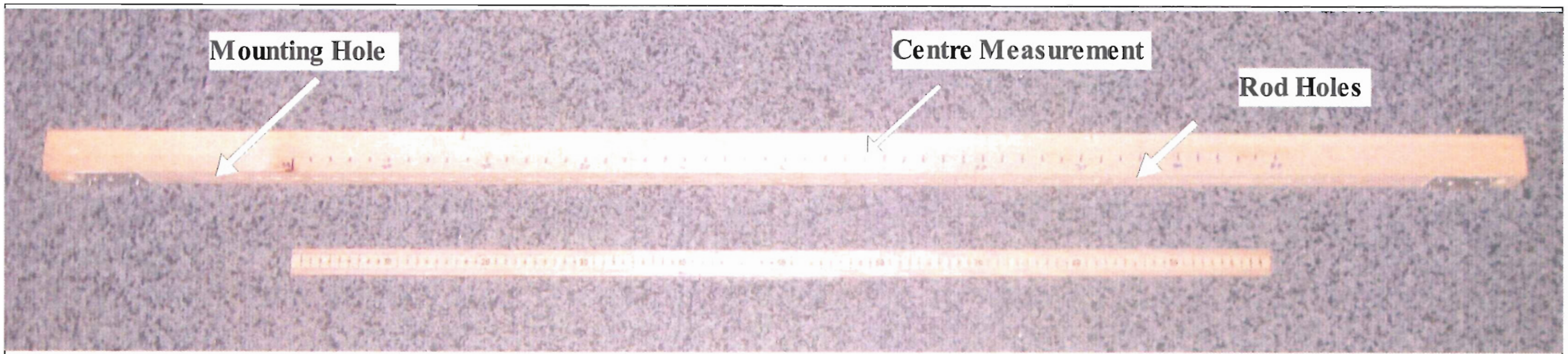

Figure A1.1 - Pine cross-beam of LT-Device, total length of cross-beam is 1.5 m (units in cm)

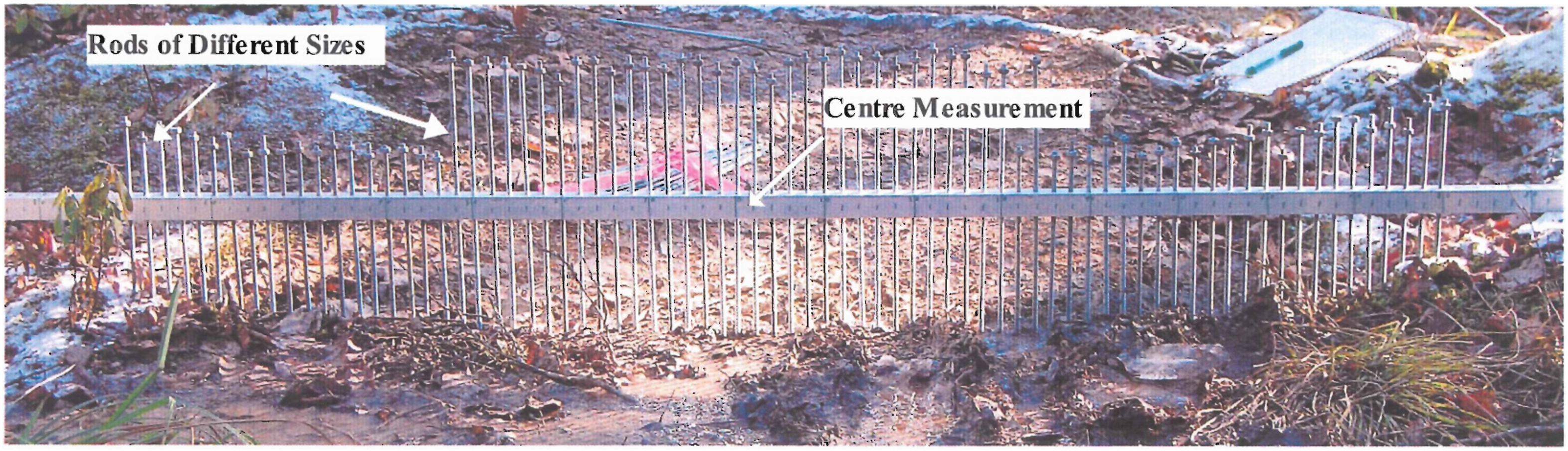

Figure A1.2: Field use of the metal cross-beam. Small rods are 20 cm in length, longer rods are 30 cm in length.

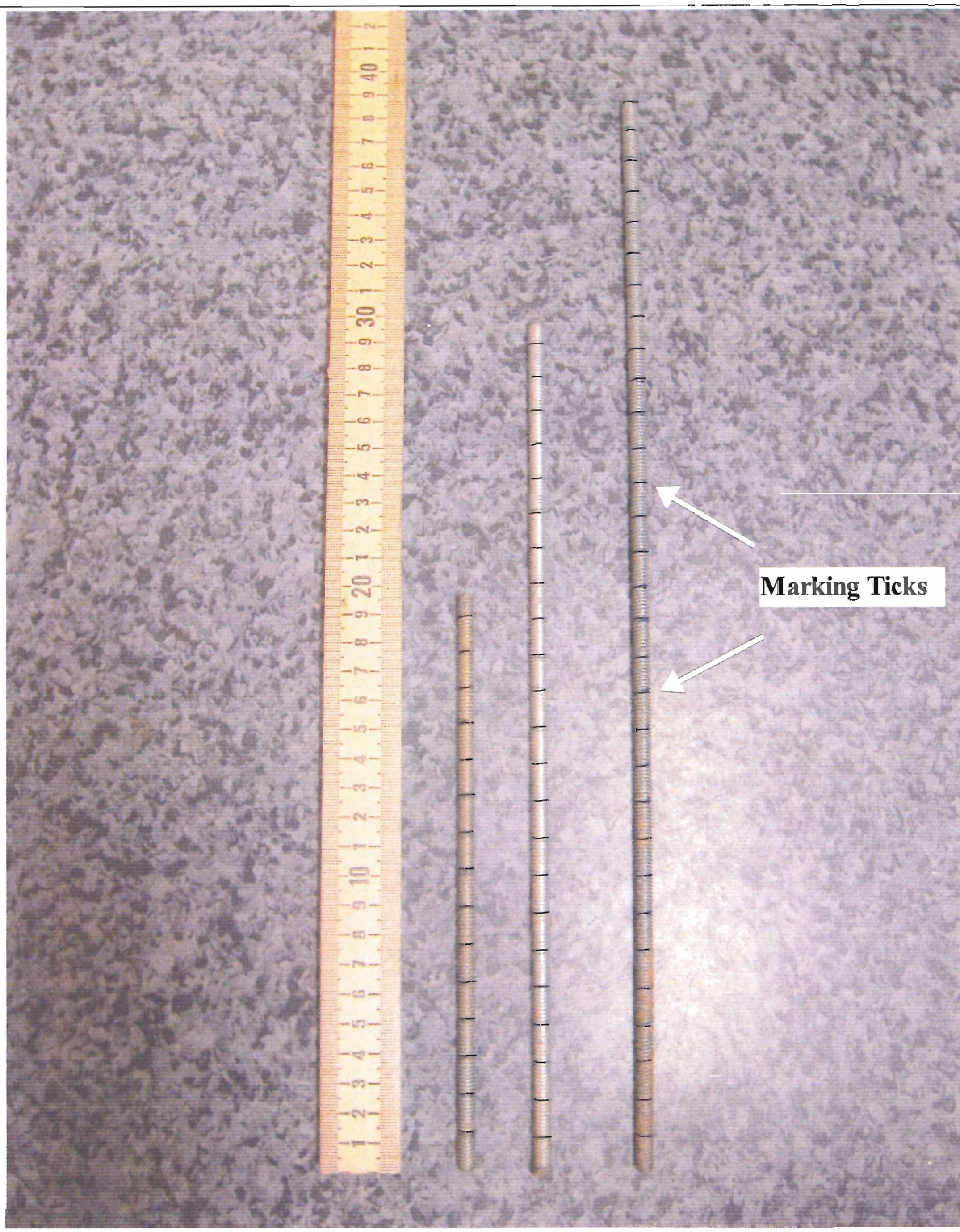

Figure A1.3: Image of the three different lengths of rods used in this study (units in cm)

A2 <u>Field Data</u>

A2.1 Weather Data

Weather data acquired from Environment Canada's (2011) website for the Stanfield International Airport, which is the closest weather station to the field site.

	Temp (°C)	Rain (mm)	Snow (cm)	Precip (mm)
Jan	-5.9	84.61	60.86	140.4
Feb	-5.71	64.31	53.42	114.12
Mar	-1.47	84.09	41.33	122.93
Apr	3.9	94.25	19.74	114.84
May	9.77	106.54	2.61	109.27
Jun	15.08	93.38	0	93.38
Jul	18.52	98.68	0	98.68
Aug	18.24	95.47	0	95.47
Sep	13.95	99.47	0	99.47
Oct	8.49	121.94	2.99	127.48
Nov	3.13	138.56	15.93	153.45

Table A2.1 - Monthly averages for Stanfield International Airport, Nova Scotia (1960-2010)

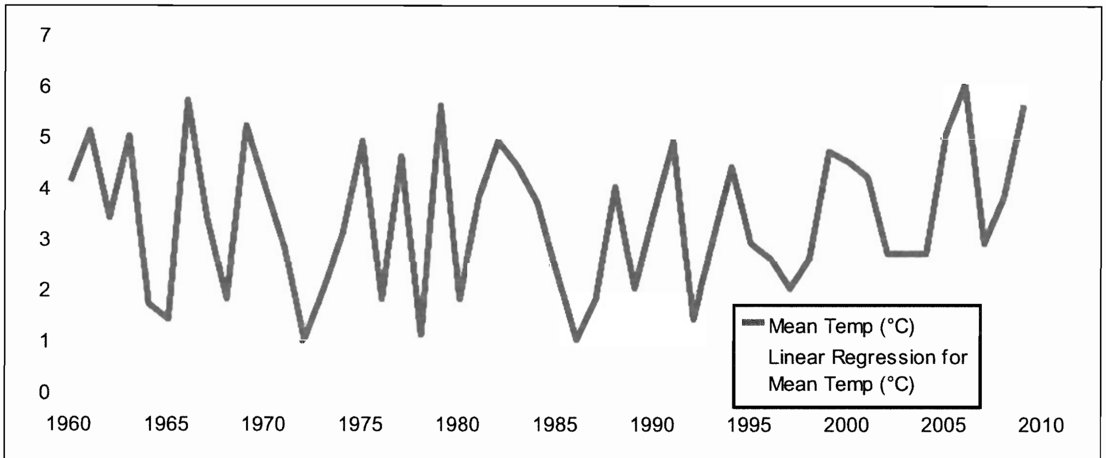

Figure A2.1: Mean monthly temperatures for the month of November, Stanfield International Airport (1960-2009)

A2.2 Transect Data

The following tables are the raw cross-track data. Column # 1 (Rod) gives the horizontal distance, positive or negative based from the approximate centre of the trail. Column # 2 (Threads) gives the distance in threads from the underside of the cross-beam of the LT-Device to the ground. Column # 3 (Depth) gives the uncorrected distance from the underside of the cross-beam to the ground in centimetres. The sinuosity column (#4 in Baseline, #5 in the tests) is the individual numerator value (actual distance, at the ground, from rod A to rod B) of the sinuosity equation. These values are added up and then divided by the total distance of the cross-beam. The correction column is the corrected distance from the underside of the cross-beam, the number is the value added to the value in column # 3.

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	Depth (cm)	Sinuosity	Rod (cm)	Threads	Depth (cm)	0.41	Sinuosity	Rod (cm)	Threads	Depth (cm)	2.86	Sinuosity
-30	64.5	8.19	2	-30	61.5	7.81	8.22	2.19	-30	63	8	10.86	2
-28	64.5	8.19	2.19	-28	68.5	8.7	9.11	2.02	-28	63	8	10.86	2.19
-26	71.5	9.08	2.01	-26	66.5	8.45	8.86	2.02	-26	70	8.89	11.75	2.06
-24	70	8.89	2.01	-24	68.5	8.7	9.11	2.05	-24	66	8.38	11.24	2.03
-22	71.5	9.08	2.06	-22	72	9.14	9.55	2.08	-22	68.5	8.7	11.56	2.16
-20	75.5	9.59	2	-20	76.5	9.72	10.13	2	-20	75	9.53	12.39	2.06
-18	75.5	9.59	2.03	-18	77	9.78	10.19	2.03	-18	79	10.03	12.89	2.01
-16	78	9.91	2.04	-16	79.5	10.1	10.51	2.04	-16	77.5	9.84	12.7	2.08
-14	75	9.53	2.22	-14	82.5	10.48	10.89	2	-14	73	9.27	12.13	2.02
-12	82.5	10.48	2.04	-12	83	10.54	10.95	2.27	-12	75	9.53	12.39	2
-10	79.5	10.1	2.68	-10	91.5	11.62	12.03	2.02	-10	75.5	9.59	12.45	2.03
-8	93.5	11.87	2.06	-8	93.5	11.87	12.28	2	-8	78	9.91	12.77	2
-6	97.5	12.38	2.02	-6	94.5	12	12.41	2.08	-6	79	10.03	12.89	2.03
-4	95.5	12.13	2.03	-4	99	12.57	12.98	2	-4	81.5	10.35	13.21	2.1
-2	98	12.45	2	-2	100	12.7	13.11	2	-2	76.5	9.72	12.58	2
0	99	12.57	2	0	99	12.57	12.98	2.24	0	75.5	9.59	12.45	2.1
2	99	12.57	2.02	2	91	11.56	11.97	2	2	80.5	10.22	13.08	2.01
4	97	12.32	2.14	4	91.5	11.62	12.03	2	4	82	10.41	13.27	2.06
6	91	11.56	2.14	6	92	11.68	12.09	2	6	78	9.91	12.77	2.1
8	85	10.8	2.16	8	91.5	11.62	12.03	2.03	8	73	9.27	12.13	2.02
10	91.5	11.62	2.68	10	94	11.94	12.35	2.34	10	71	9.02	11.88	2.3
12	105.5	13.4	2.16	12	103.5	13.14	13.55	2.06	12	62	7.87	10.73	2.02
14	99	12.57	2.3	14	107.5	13.65	14.06	2	14	64	8.13	10.99	2.05
16	108	13.72	2.06	16	106.5	13.53	13.94	2.24	16	67.5	8.57	11.43	2.19
18	104	13.21	2.04	18	98.5	12.51	12.92	2.19	18	60.5	7.68	10.54	
20	107	13.59	2.01	20	91.5	11.62	12.03	2.08	20				
22	105.5	13.4	3.18	22	96	12.19	12.6	2	22				
24	86	10.92	2.16	24	96	12.19	12.6	2.19	24				
26	92.5	11.75	2.04	26	89	11.3	11.71	2	26				
28	95.5	12.13	2	28	89.5	11.37	11.78	2.03	28				
30	96.5	12.26	2.01	30	92	11.68	12.09	2.01	30				
32	95	12.07	2.06	32	93.5	11.87	12.28	2.01	32				
34	91	11.56	2	34	92	11.68	12.09	2	34				
36	92	11.68	2.01	36	92	11.68	12.09	2.12	36				
38	90.5	11.49	2.12	38	86.5	10.99	11.4	2.1	38				
40	85	10.8		40	81.5	10.35	10.76		40				

Table A2.2. Raw data from transect # 1 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads cm		Sinuosit	Rod (cm)	Threads cm		1.14	Sinuosit	Rod (cm)	Threads cm		0.51	Sinuosit
-50	46	5.84	2.03	-50	40.5	5.14	6.28	4.05	-50				
-48	43.5	5.52	2.05	-48					-48				
-46	40	5.08	2.06	-46	35.5	4.51	5.65	2	-46				
-44	36	4.57	2.3	-44	36	4.57	5.71	4.06	-44				
-42	45	5.72	2	-42					-42	40.5	5.14	5.65	2
-40	45.5	5.78	2	-40	41.5	5.27	6.41	2.03	-40	39.5	5.02	5.53	2
-38	44.5	5.65	2.03	-38	39	4.95	6.09	4	-38	39.5	5.02	5.53	2.04
-36	42	5.33	2	-36					-36	36.5	4.64	5.15	2
-34	42.5	5.4	2	-34	37.5	4.76	5.9	2	-34	37.5	4.76	5.27	2.1
-32	41.5	5.27	2	-32	37.5	4.76	5.9	2	-32	32.5	4.13	4.64	2.05
-30	40.5	5.14	2	-30	36.5	4.64	5.78	2.06	-30	36	4.57	5.08	2.1
-28	40	5.08	2.01	-28	32.5	4.13	5.27	2.08	-28	31	3.94	4.45	2.06
-26	42	5.33	2	-26	37	4.7	5.84	2	-26	35	4.45	4.96	2.01
-24	41	5.21	2	-24	37.5	4.76	5.9	2.06	-24	36.5	4.64	5.15	2.01
-22	40	5.08	2	-22	33.5	4.25	5.39	2	-22	38.5	4.89	5.4	2.05
-20	41	5.21	2.01	-20	34.5	4.38	5.52	2.03	-20	35	4.45	4.96	2.03
-18	42.5	5.4	2	-18	37	4.7	5.84	2	-18	37.5	4.76	5.27	2.01
-16	42	5.33	2.01	-16	37.5	4.76	5.9	2	-16	39.5	5.02	5.53	2
-14	40.5	5.14	2.06	-14	37.5	4.76	5.9	2.03	-14	39	4.95	5.46	2
-12	44.5	5.65	2	-12	40	5.08	6.22	2	-12	40	5.08	5.59	2.0
-10	45	5.72	2	-10	39.5	5.02	6.16	2	-10	41.5	5.27	5.78	2.01
-8	45	5.72	2	-8	40.5	5.14	6.28	2	-8	43	5.46	5.97	2
-6	45	5.72	2	-6	40.5	5.14	6.28	2.01	-6	42.5	5.4	5.91	2
-4	44.5	5.65	2	-4	39	4.95	6.09	2	-4	42.5	5.4	5.91	4
-2	45	5.72	2	-2	39.5	5.02	6.16	2.08	-2				
0	45	5.72	2	0	35	4.45	5.59	2.06	0	41.5	5.27	5.78	2
2	45.5	5.78	2	2	39	4.95	6.09	2	2	42	5.33	5.84	2
4	45.5	5.78	2.04	4	38.5	4.89	6.03	2.01	4	42	5.33	5.84	2.05
6	42.5	5.4	2.14	6	37	4.7	5.84	2.06	6	38.5	4.89	5.4	2.01
8	36.5	4.64	2	8	33	4.19	5.33	2	8	36	4.57	5.08	2
10	36	4.57	2.01	10	34	4.32	5.46	2.01	10	36.5	4.64	5.15	2
12	34	4.32	2.06	12	32	4.06	5.2	2.04	12	37	4.7	5.21	2.01
14	38	4.83	2.24	14	35	4.45	5.59	2.1	14	35	4.45	4.96	2.05
16	46	5.84	2.05	16	40	5.08	6.22	2.08	16	38.5	4.89	5.4	2.04
18	42.5	5.4	2.14	18	35.5	4.51	5.65	2.06	18	35.5	4.51	5.02	2.06
20	36.5	4.64	2	20	31.5	4	5.14	2	20	31.5	4	4.51	2
22	37	4.7	2.08	22	32.5	4.13	5.27	2.04	22	30.5	3.87	4.38	2
24	32.5	4.13	2.03	24	29.5	3.75	4.89	2.01	24	30	3.81	4.32	2.11
26	30	3.81	2.04	26	27.5	3.49	4.63	2.01	26	24.5	3.11	3.62	2.01
28	33	4.19	2.01	28	29.5	3.75	4.89	2.21	28	26.5	3.37	3.88	2.08
30	34.5	4.38	2	30	22	2.79	3.93		30	31	3.94	4.45	
32	35.5	4.51	2.48	32					32				
34	24	3.05	2	34					34				
36	24	3.05	2.04	36					36				
38	27	3.43		38					38				

Table A2.3. Raw data from transect # 2 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	cm	Sinuosity	Rod (cm)	Threads	cm	1.78	Sinuosity	Rod (cm)	Threads	cm	1.78	Sinuosity
-70	65	8.26	2.59	-70		0			-70		0		
-68	78	9.91	2.16	-68		0			-68		0		
-66	71.5	9.08	2.22	-66		0			-66		0		
-64	79	10.03	2	-64		0			-64		0		
-62	79.5	10.1	2.19	-62		0			-62		0		
-60	86.5	10.99	2.1	-60	67.5	8.57	10.35	2.1	-60	67	8.51	10.64	2.12
-58	81.5	10.35	2.9	-58	72.5	9.21	10.99	2	-58	72.5	9.21	11.34	
-56	98	12.45	2.81	-56	72.5	9.21	10.99	2.08	-56				
-54	82.5	10.48	2.16	-54	77	9.78	11.56	2.01	-54	76.5	9.72	11.85	2
-52	89	11.3	2.03	-52	75.5	9.59	11.37	2.03	-52	76	9.65	11.78	2
-50	91.5	11.62	2	-50	78	9.91	11.69	2.44	-50	77	9.78	11.91	2.16
-48	92	11.68	2.1	-48	89	11.3	13.08	2.14	-48	83.5	10.6	12.73	2.03
-46	87	11.05	2	-46	83	10.54	12.32	2.1	-46	81	10.29	12.42	2.05
-44	87.5	11.11	2.04	-44	78	9.91	11.69	2	-44	77.5	9.84	11.97	2.1
-42	90.5	11.49	2.01	-42	77.5	9.84	11.62	2	-42	72.5	9.21	11.34	2
-40	92	11.68	2	-40	78	9.91	11.69	2.05	-40	73	9.27	11.4	2.1
-38	91.5	11.62	2	-38	74.5	9.46	11.24	2.05	-38	78	9.91	12.04	2.02
-36	92.5	11.75	2.06	-36	78	9.91	11.69	2.01	-36	80	10.16	12.29	2.03
-34	96.5	12.26	2.04	-34	79.5	10.1	11.88	2.1	-34	77.5	9.84	11.97	2.06
-32	93.5	11.87	2.27	-32	84.5	10.73	12.51	2.02	-32	81.5	10.35	12.48	2.01
-30	102	12.95	2.02	-30	82.5	10.48	12.26	2	-30	80	10.16	12.29	2.01
-28	100	12.7	2.01	-28	82.5	10.48	12.26	2.04	-28	81.5	10.35	12.48	2
-26	98.5	12.51	2.16	-26	85.5	10.86	12.64	2.01	-26	81.5	10.35	12.48	2.04
-24	105	13.34	2.01	-24	87	11.05	12.83	2.02	-24	84.5	10.73	12.86	2
-22	103.5	13.14	2.24	-22	85	10.8	12.58	2.02	-22	84.5	10.73	12.86	2.12
-20	111.5	14.16	2.68	-20	83	10.54	12.32	2	-20	90	11.43	13.56	2.12
-18	97.5	12.38	2	-18	83.5	10.6	12.38	2	-18	84.5	10.73	12.86	2
-16	98.5	12.51	2	-16	84	10.67	12.45	2	-16	85	10.8	12.93	2.1
-14	98	12.45	2	-14	84.5	10.73	12.51	2	-14	80	10.16	12.29	2.19
-12	98	12.45	2.06	-12	85.5	10.86	12.64	2.05	-12	87	11.05	13.18	2.01
-10	102	12.95	2.05	-10	89	11.3	13.08	2	-10	88.5	11.24	13.37	2.14
-8	98.5	12.51	2	-8	89	11.3	13.08	2.05	-8	94.5	12	14.13	2.03
-6	98.5	12.51	2	-6	85.5	10.86	12.64	2	-6	92	11.68	13.81	2.24
-4	98.5	12.51	2.14	-4	86.5	10.99	12.77	3.04	-4	84	10.67	12.8	2.04
-2	104.5	13.27	2.01	-2	104.5	13.27	15.05	2.14	-2	87	11.05	13.18	2.55
0	103	13.08	2	0	98.5	12.51	14.29	2.01	0	99.5	12.64	14.77	2.14
2	104	13.21	2	2	97	12.32	14.1	2	2	93.5	11.87	14	2.16
4	105	13.34	2.03	4	96	12.19	13.97	2.03	4	100	12.7	14.83	2.05
6	102.5	13.02	2.12	6	98.5	12.51	14.29	2.03	6	103.5	13.14	15.27	2.1
8	97	12.32	2.14	8	96	12.19	13.97	2.03	8	98.5	12.51	14.64	2.01
10	103	13.08	2	10	93.5	11.87	13.65	2	10	97	12.32	14.45	2.04
12	103	13.08	2.19	12	94.5	12	13.78	2.03	12	94	11.94	14.07	2.22
14	96	12.19	2.03	14	97	12.32	14.1	2.02	14	101.5	12.89	15.02	2
16	98.5	12.51	2.05	16	95	12.07	13.85	2.02	16	100.5	12.76	14.89	2.22
18	102	12.95	2.14	18	93	11.81	13.59	2.03	18	108	13.72	15.85	2.1
20	96	12.19	2.12	20	90.5	11.49	13.27	2	20	103	13.08	15.21	3.44
22	90.5	11.49	2.05	22	90	11.43	13.21	2	22	81	10.29	12.42	2
24	94	11.94	2	24	91	11.56	13.34	2.03	24	80.5	10.22	12.35	2.72
26	95	12.07	2.19	26	88.5	11.24	13.02	2.16	26	95	12.07	14.2	2.06
28	102	12.95	2	28	95	12.07	13.85	2.02	28	99	12.57	14.7	2.08
30	101.5	12.89	2	30	97	12.32	14.1	2	30	103.5	13.14	15.27	2.16
32	101	12.83	2	32	96	12.19	13.97	2.03	32	97	12.32	14.45	2.12
34	101	12.83	2.01	34	93.5	11.87	13.65	2.08	34	91.5	11.62	13.75	2.19
36	99.5	12.64	2.16	36	89	11.3	13.08	2.16	36	84.5	10.73	12.86	2.08
38	93	11.81	2.02	38	95.5	12.13	13.91	2.27	38	80	10.16	12.29	2.02
40	95	12.07	2.16	40	87	11.05	12.83	2.01	40	78	9.91	12.04	2.06
42	88.5	11.24	2.02	42	85.5	10.86	12.64	2.12	42	82	10.41	12.54	2.14
44	86.5	10.99	2.48	44	80	10.16	11.94	2	44	88	11.18	13.31	2.1
46	98	12.45	2.03	46	80.5	10.22	12	2.22	46	93	11.81	13.94	2.02
48	95.5	12.13	2.22	48	88	11.18	12.96	2.06	48	95	12.07	14.2	2.22
50	88	11.18	2.19	50	92	11.68	13.46	2.16	50	87.5	11.11	13.24	2
52	95	12.07	2.24	52	98.5	12.51	14.29	2.12	52	87.5	11.11	13.24	2
54	87	11.05	2.04	54	93	11.81	13.59	2.1	54	88	11.18	13.31	2.12
56	90	11.43	2.04	56	88	11.18	12.96	2.14	56	82.5	10.48	12.61	2.01
58	87	11.05	2.02	58	82	10.41	12.19	2.14	58	84	10.67	12.8	2.1
60	85	10.8	2.16	60	76	9.65	11.43		60	89	11.3	13.43	2.01
62	91.5	11.62	2.37	62		0			62	87.5	11.11	13.24	3.09
64	81.5	10.35	2.01	64		0			64	69	8.76	10.89	2
66	80	10.16	2.16	66		0			66	69	8.76	10.89	2.1
68	73.5	9.33	2.01	68		0			68	64	8.13	10.26	2.14
70	72	9.14	2.01	70		0			70	58	7.37	9.5	
72	70.5	8.95	2.04	72		0			72		0		
74	67.5	8.57	2.02	74		0			74		0		
76	65.5	8.32	3.28	76		0			76		0		
78	45	5.72	2	78		0			78		0		
80	44	5.59		80		0			80		0		

Table A2.4. Raw data from transect # 3 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	cm	Sinuosity	Rod (cm)	Threads	cm	1.43	Sinuosity	Rod (cm)	Threads	cm	1.17	Sinuosity
-60	52	6.6	2.06	-60	46.5	5.91	7.34	2.24	-60	49.5	6.29	7.46	2.14
-58	56	7.11	2.19	-58	54.5	6.92	8.35	2.14	-58	55.5	7.05	8.22	4.4
-56	63	8	2.3	-56	60.5	7.68	9.11	2.34	-56				
-54	72	9.14	2.08	-54	70	8.89	10.32	2.4	-54	70	8.89	10.06	2.08
-52	76.5	9.72	2.37	-52	80.5	10.22	11.65	2	-52	74.5	9.46	10.63	4.01
-50	86.5	10.99	2.76	-50	80	10.16	11.59	2.05	-50				
-48	71.5	9.08	2.04	-48	83.5	10.6	12.03	2	-48	72.5	9.21	10.38	2
-46	68.5	8.7	2	-46	84	10.67	12.1	2.16	-46	72	9.14	10.31	2.16
-44	69.5	8.83	2.63	-44	77.5	9.84	11.27	2.02	-44	78.5	9.97	11.14	2.05
-42	83	10.54	2.03	-42	79.5	10.1	11.53	2.04	-42	75	9.53	10.7	2.37
-40	85.5	10.86	2.16	-40	76.5	9.72	11.15	2.06	-40	85	10.8	11.97	2.04
-38	92	11.68	2	-38	72.5	9.21	10.64	2.48	-38	88	11.18	12.35	2.06
-36	92	11.68	2	-36	84	10.67	12.1	2.16	-36	92	11.68	12.85	2
-34	93	11.81	2.14	-34	90.5	11.49	12.92	2	-34	93	11.81	12.98	2.04
-32	99	12.57	2.05	-32	89.5	11.37	12.8	2.02	-32	96	12.19	13.36	2.03
-30	95.5	12.13	2.03	-30	91.5	11.62	13.05	2.02	-30	93.5	11.87	13.04	2
-28	93	11.81	2.01	-28	93.5	11.87	13.3	2	-28	94	11.94	13.11	2.34
-26	94.5	12	2.02	-26	93	11.81	13.24	2.01	-26	84.5	10.73	11.9	2
-24	92.5	11.75	2.04	-24	91.5	11.62	13.05	2.04	-24	84.5	10.73	11.9	2.02
-22	89.5	11.37	2.04	-22	88.5	11.24	12.67	2.01	-22	82.5	10.48	11.65	2.04
-20	86.5	10.99	2.02	-20	90	11.43	12.86	2.12	-20	79.5	10.1	11.27	2.04
-18	88.5	11.24	2	-18	84.5	10.73	12.16	2.04	-18	76.5	9.72	10.89	2
-16	89.5	11.37	2.03	-16	87.5	11.11	12.54	2	-16	76.5	9.72	10.89	2.02
-14	92	11.68	2.03	-14	87.5	11.11	12.54	2	-14	78.5	9.97	11.14	2.08
-12	89.5	11.37	2.16	-12	87.5	11.11	12.54	2.08	-12	83	10.54	11.71	2.03
-10	83	10.54	2.02	-10	83	10.54	11.97	2	-10	80.5	10.22	11.39	2.05
-8	85	10.8	2	-8	83	10.54	11.97	2	-8	84	10.67	11.84	2.44
-6	85.5	10.86	2.27	-6	82.5	10.48	11.91	2.34	-6	73	9.27	10.44	2
-4	77	9.78	2.12	-4	73	9.27	10.7	4.18	-4	73.5	9.33	10.5	2.14
-2	82.5	10.48	2.03	-2					-2	79.5	10.1	11.27	2
0	85	10.8	2.04	0	82.5	10.48	11.91	2	0	80.5	10.22	11.39	2.08
2	88	11.18	2.01	2	83	10.54	11.97	2.05	2	85	10.8	11.97	2.03
4	89.5	11.37	2	4	86.5	10.99	12.42	2.02	4	87.5	11.11	12.28	2
6	90	11.43	2.01	6	88.5	11.24	12.67	2.1	6	87.5	11.11	12.28	2.16
8	88.5	11.24	2.02	8	83.5	10.6	12.03	2	8	81	10.29	11.46	2.03
10	86.5	10.99	2.19	10	84	10.67	12.1	2.06	10	83.5	10.6	11.77	2.06
12	93.5	11.87	2.37	12	80	10.16	11.59	2.01	12	79.5	10.1	11.27	2.03
14	83.5	10.6	2.04	14	78.5	9.97	11.4	2	14	77	9.78	10.95	2
16	80.5	10.22	2.01	16	78	9.91	11.34	2	16	77	9.78	10.95	2.02
18	82	10.41	2.03	18	78.5	9.97	11.4	2.03	18	75	9.53	10.7	2
20	79.5	10.1	2.01	20	76	9.65	11.08	2.06	20	76	9.65	10.82	2.03
22	78	9.91	2.27	22	72	9.14	10.57	4.1	22	73.5	9.33	10.5	2
24	86.5	10.99	2.03	24					24	74	9.4	10.57	2.12
26	84	10.67	2.01	26	79	10.03	11.46	2.04	26	79.5	10.1	11.27	2
28	82.5	10.48	2.04	28	82	10.41	11.84	2.06	28	80.5	10.22	11.39	2.02
30	85.5	10.86	2.02	30	86	10.92	12.35	2	30	82.5	10.48	11.65	2.14
32	87.5	11.11	2	32	86	10.92	12.35	2.02	32	88.5	11.24	12.41	2.01
34	87	11.05	2.22	34	88	11.18	12.61	2.1	34	87	11.05	12.22	2
36	79.5	10.1	2	36	83	10.54	11.97	2.14	36	86	10.92	12.09	2.05
38	78.5	9.97	2.04	38	89	11.3	12.73	2.02	38	82.5	10.48	11.65	2.37
40	81.5	10.35	2.14	40	87	11.05	12.48	2.22	40	72.5	9.21	10.38	2.24
42	87.5	11.11	2.02	42	79.5	10.1	11.53	2.16	42	80.5	10.22	11.39	2.1
44	89.5	11.37	2.37	44	86	10.92	12.35	2.12	44	85.5	10.86	12.03	2.12
46	99.5	12.64	2.4	46	91.5	11.62	13.05	2.24	46	80	10.16	11.33	2.37
48	110	13.97	2.24	48	83.5	10.6	12.03	2.19	48	90	11.43	12.6	2.22
50	102	12.95	2	50	90.5	11.49	12.92	2.22	50	82.5	10.48	11.65	2.19
52	101	12.83	2	52	83	10.54	11.97	2.04	52	89.5	11.37	12.54	2.12
54	101.5	12.89	3.44	54	80	10.16	11.59	2.48	54	84	10.67	11.84	2.03
56	79.5	10.1	2.05	56	68.5	8.7	10.13	2.34	56	81.5	10.35	11.52	3.38
58	76	9.65		58	59	7.49	8.92		58	60	7.62	8.79	2.06
60				60		0			60	56	7.11	8.28	

Table A2.5. Raw data from transect # 4 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	cm	Sinuosity	Rod (cm)	Threads	cm	1.11	Sinuosity	Rod (cm)	Threads	cm	0.98	Sinuosity
-102	54	6.86	2.85	-102									
-100	70	8.89	2.1	-100	62.5	7.94	9.05	2	-100				
-98	65	8.26	2	-98	62.5	7.94	9.05	2.12	-98				
-96	65	8.26	2.55	-96	57	7.24	8.35	2	-96				
-94	77.5	9.84	2.37	-94	57	7.24	8.35	2	-94				
-92	67.5	8.57	2.24	-92	56.5	7.18	8.29	2.08	-92				
-90	75.5	9.59	2.34	-90	61	7.75	8.86	2.34	-90				
-88	85	10.8	2.12	-88	70.5	8.95	10.06	2.59	-88				
-86	90.5	11.49	2	-86	83.5	10.6	11.71	2.01	-86				
-84	91.5	11.62	2.14	-84	85	10.8	11.91	2.04	-84				
-82	85.5	10.86	2.1	-82	82	10.41	11.52	2.05	-82				
-80	90.5	11.49	2	-80	85.5	10.86	11.97	2.01	-80	86	10.92	11.9	2.94
-78	90.5	11.49	2.03	-78	84	10.67	11.78	2	-78	69	8.76	9.74	2
-76	93	11.81	2.05	-76	83.5	10.6	11.71	2.01	-76	69.5	8.83	9.81	2
-74	96.5	12.26	2.14	-74	82	10.41	11.52	2.01	-74	69	8.76	9.74	2.24
-72	90.5	11.49	2.44	-72	83.5	10.6	11.71	2	-72	77	9.78	10.76	2.1
-70	101.5	12.89	2.4	-70	84.5	10.73	11.84	2.12	-70	82	10.41	11.39	2.19
-68	112	14.22	3.18	-68	90	11.43	12.54	2.1	-68	89	11.3	12.28	2.03
-66	92.5	11.75	2.01	-66	85	10.8	11.91	2.34	-66	91.5	11.62	12.6	2.01
-64	91	11.56	2	-64	94.5	12	13.11	2	-64	90	11.43	12.41	2.3
-62	91	11.56	2	-62	95	12.07	13.18	2.34	-62	99	12.57	13.55	2
-60	90.5	11.49	2.04	-60	85.5	10.86	11.97	2.02	-60	98	12.45	13.43	2.76
-58	87.5	11.11	2.04	-58	83.5	10.6	11.71	2.27	-58	83	10.54	11.52	2.19
-56	84.5	10.73	2.01	-56	75	9.53	10.64	2.1	-56	76	9.65	10.63	2
-54	83	10.54	2	-54	80	10.16	11.27	2.02	-54	75	9.53	10.51	2
-52	84	10.67	2	-52	82	10.41	11.52	2.3	-52	74	9.4	10.38	2.16
-50	85	10.8	2	-50	91	11.56	12.67	2.19	-50	80.5	10.22	11.2	2.76
-48	84	10.67	2.3	-48	84	10.67	11.78	2.05	-48	65.5	8.32	9.3	2
-46	75	9.53	2.04	-46	80.5	10.22	11.33	2	-46	66	8.38	9.36	2.68
-44	78	9.91	2	-44	81	10.29	11.4	2.01	-44	80	10.16	11.14	2.27
-42	79	10.03	2	-42	82.5	10.48	11.59	2.22	-42	88.5	11.24	12.22	2.12
-40	80	10.16	2.81	-40	75	9.53	10.64	2.1	-40	83	10.54	11.52	2.06
-38	95.5	12.13	2.05	-38	80	10.16	11.27	2	-38	79	10.03	11.01	2.06
-36	99	12.57	2.06	-36	80.5	10.22	11.33	2.27	-36	83	10.54	11.52	2.02
-34	95	12.07	2	-34	89	11.3	12.41	2.12	-34	81	10.29	11.27	2.08
-32	95	12.07	2.03	-32	83.5	10.6	11.71	2.22	-32	76.5	9.72	10.7	2.12
-30	92.5	11.75	2.03	-30	76	9.65	10.76	2.04	-30	71	9.02	10	2.37
-28	95	12.07	2.06	-28	73	9.27	10.38	2.08	-28	81	10.29	11.27	2.59
-26	99	12.57	2.44	-26	77.5	9.84	10.95	2.99	-26	94	11.94	12.92	2.06
-24	110	13.97	2.24	-24	60	7.62	8.73	2.12	-24	90	11.43	12.41	2.06
-22	102	12.95	2.22	-22	65.5	8.32	9.43	2.85	-22	94	11.94	12.92	2.02
-20	94.5	12	2.04	-20	81.5	10.35	11.46	2.19	-20	92	11.68	12.66	2.04
-18	97.5	12.38	2	-18	88.5	11.24	12.35	2	-18	89	11.3	12.28	2.19
-16	98.5	12.51	2.19	-16	89	11.3	12.41	2	-16	82	10.41	11.39	2.06
-14	105.5	13.4	2.02	-14	88	11.18	12.29	2.04	-14	86	10.92	11.9	2.06
-12	107.5	13.65	2.04	-12	85	10.8	11.91	2.3	-12	82	10.41	11.39	2.51
-10	104.5	13.27	2.06	-10	94	11.94	13.05	2.14	-10	70	8.89	9.87	2.06
-8	100.5	12.76	2.06	-8	100	12.7	13.81	2.85	-8	74	9.4	10.38	2.4
-6	104.5	13.27	2.19	-6	116	14.73	15.84	2.06	-6	84.5	10.73	11.71	2.12
-4	97.5	12.38	2.08	-4	120	15.24	16.35	2.02	-4	90	11.43	12.41	2.06
-2	102	12.95	2.04	-2	122	15.49	16.6	2.19	-2	94	11.94	12.92	2.14
0	105	13.34	2.04	0	115	14.61	15.72	2.14	0	100	12.7	13.68	2.44

Table A2.6. Raw data from transect # 5 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	cm	Sinuosity	Rod (cm)	Threads	cm	1.11	Sinuosity	Rod (cm)	Threads	cm	0.98	Sinuosity
2	108	13.72	4	*2*	109	13.84	14.95	2	*2*	111	14.1	15.08	2.24
4				*4*	110	13.97	15.08	2.37	*4*	103	13.08	14.06	2
6	106.5	13.53	2.04	*6*	120	15.24	16.35	4	*6*	104	13.21	14.19	2.37
8	109.5	13.91	2.1	*8*					*8*	114	14.48	15.46	2.06
10	104.5	13.27	2.08	*10*	119	15.11	16.22	2.14	*10*	118	14.99	15.97	2.34
12	100	12.7	2.1	*12*	125	15.88	16.99	2	*12*	127.5	16.19	17.17	4.14
14	95	12.07	2	*14*	124	15.75	16.86	2.12	*14*	99	12.57	13.55	2.19
16	95.5	12.13	2	*16*	118.5	15.05	16.16	2.06	*16*	92	11.68	12.66	2.44
18	95	12.07	2.1	*18*	114.5	14.54	15.65	2.48	*18*	103	13.08	14.06	3.54
20	100	12.7	2.03	*20*	103	13.08	14.19	2	*20*	126	16	16.98	2.19
22	102.5	13.02	2	*22*	103	13.08	14.19	2.06	*22*	119	15.11	16.09	2
24	102	12.95	2.08	*24*	99	12.57	13.68	2	*24*	118	14.99	15.97	3.13
26	97.5	12.38	2.24	*26*	98.5	12.51	13.62	2.05	*26*	99	12.57	13.55	2.24
28	105.5	13.4	4.1	*28*	95	12.07	13.18	2.44	*28*	91	11.56	12.54	2.72
30				*30*	84	10.67	11.78	2.24	*30*	76.5	9.72	10.7	2.72
32	112.5	14.29	2	*32*	92	11.68	12.79	2.76	*32*	62	7.87	8.85	2
34	112	14.22	2.44	*34*	107	13.59	14.7	2.03	*34*	61	7.75	8.73	2.14
36	123	15.62	3.33	*36*	104.5	13.27	14.38	2.19	*36*	67	8.51	9.49	2.3
38	102	12.95	2.01	*38*	97.5	12.38	13.49	2	*38*	76	9.65	10.63	2.06
40	100.5	12.76	3.86	*40*	98	12.45	13.56	2.06	*40*	80	10.16	11.14	2.37
42	74.5	9.46	2.19	*42*	94	11.94	13.05	2.04	*42*	90	11.43	12.41	2.02
44	67.5	8.57	2.19	*44*	91	11.56	12.67	2.03	*44*	92	11.68	12.66	2.04
46	74.5	9.46	3.18	*46*	88.5	11.24	12.35	2.55	*46*	89	11.3	12.28	3.97
48	55	6.99	2.22	*48*	76	9.65	10.76	2	*48*	62	7.87	8.85	2.02
50	62.5	7.94	2.16	*50*	76	9.65	10.76	5.34	*50*	60	7.62	8.6	2.1
52	56	7.11	2.51	*52*	37	4.7	5.81	2.51	*52*	55	6.99	7.97	2.3
54	68	8.64	2.22	*54*	49	6.22	7.33	4.1	*54*	64	8.13	9.11	2.1
56	75.5	9.59	2.06	*56*					*56*	69	8.76	9.74	2.12
58	79.5	10.1	2.72	*58*	56	7.11	8.22	2.02	*58*	63.5	8.06	9.04	2
60	65	8.26	2.05	*60*	54	6.86	7.97	2.06	*60*	64	8.13	9.11	2.1
62	61.5	7.81	2.14	*62*	50	6.35	7.46	2.08	*62*	59	7.49	8.47	2.1
64	67.5	8.57	2.9	*64*	54.5	6.92	8.03	2.12	*64*	54	6.86	7.84	2
66	84	10.67	2.72	*66*	49	6.22	7.33	2.16	*66*	55	6.99	7.97	2
68	69.5	8.83	2.1	*68*	55.5	7.05	8.16	2.1	*68*	54.5	6.92	7.9	2.3
70	64.5	8.19	2	*70*	50.5	6.41	7.52	2.19	*70*	45.5	5.78	6.76	2.05
72	63.5	8.06	2.01	*72*	43.5	5.52	6.63	2.08	*72*	49	6.22	7.2	2
74	62	7.87	2.02	*74*	39	4.95	6.06	2	*74*	48.5	6.16	7.14	2.14
76	60	7.62	2.12	*76*	39.5	5.02	6.13	2.34	*76*	54.5	6.92	7.9	2
78	65.5	8.32	2.1	*78*	49	6.22	7.33	2.24	*78*	54	6.86	7.84	2
80	60.5	7.68	2.06	*80*	57	7.24	8.35	2.19	*80*	55	6.99	7.97	2
82	64.5	8.19	2.19	*82*	64	8.13	9.24	2	*82*	54	6.86	7.84	2.19
84	71.5	9.08	2.08	*84*	65	8.26	9.37	4.01	*84*	61	7.75	8.73	2.04
86	76	9.65	2	*86*					*86*	64	8.13	9.11	2
88	76.5	9.72	2.03	*88*	67	8.51	9.62	2.1	*88*	63	8	8.98	2.02
90	74	9.4	2.02	*90*	62	7.87	8.98	2.01	*90*	61	7.75	8.73	2.04
92	76	9.65	2.01	*92*	63.5	8.06	9.17	2.01	*92*	64	8.13	9.11	2.02
94	74.5	9.46	2.08	*94*	65	8.26	9.37	2.1	*94*	66	8.38	9.36	2.06
96	79	10.03	2.14	*96*	60	7.62	8.73	2.27	*96*	70	8.89	9.87	2
98	85	10.8	2.14	*98*	68.5	8.7	9.81	2	*98*	70	8.89	9.87	2.68
100	79	10.03	2	*100*	69	8.76	9.87		*100*	84	10.67	11.65	2.76
102	79	10.03	2.02	*102*					*102*	69	8.76	9.74	2.04
104	81	10.29	2.05	*104*					*104*	66	8.38	9.36	2.02
106	84.5	10.73	2	*106*					*106*	64	8.13	9.11	2.3
108	84	10.67		*108*					*108*	73	9.27	10.25	
110				*110*					*110*				

Table A2.6(cont.). Raw data from transect # 5 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	cm	Sinuosity	Rod (cm)	Threads	cm	1.37	Sinuosity	Rod (cm)	Threads	cm	3.33	Sinuosity
-50	74	9.4	2.1	-50	54.5	6.92	8.29	2.22	-50	45	5.72	9.05	2.06
-48	69	8.76	2.04	-48	62	7.87	9.24	2.06	-48	41	5.21	8.54	2
-46	66	8.38	2.03	-46	58	7.37	8.74	2.44	-46	40	5.08	8.41	2.06
-44	68.5	8.7	2	-44	69	8.76	10.13	2.34	-44	44	5.59	8.92	2
-42	69	8.76	2	-42	59.5	7.56	8.93	2.03	-42	44.5	5.65	8.98	2
-40	69.5	8.83	2.01	-40	62	7.87	9.24	2	-40	44.5	5.65	8.98	2
-38	71	9.02	2.37	-38	62.5	7.94	9.31	2.01	-38	44.5	5.65	8.98	2.01
-36	81	10.29	2.19	-36	64	8.13	9.5	2.01	-36	46	5.84	9.17	2.02
-34	74	9.4	2	-34	62.5	7.94	9.31	2	-34	44	5.59	8.92	2
-32	73	9.27	2.04	-32	62	7.87	9.24	2.01	-32	45	5.72	9.05	2
-30	70	8.89	2	-30	63.5	8.06	9.43	2	-30	45	5.72	9.05	2.05
-28	69	8.76	2	-28	64	8.13	9.5	2.04	-28	41.5	5.27	8.6	2
-26	69	8.76	2.02	-26	61	7.75	9.12	2	-26	42	5.33	8.66	2
-24	67	8.51	2.02	-24	62	7.87	9.24	2.01	-24	42	5.33	8.66	2
-22	69	8.76	2	-22	63.5	8.06	9.43	2.01	-22	41.5	5.27	8.6	2
-20	68	8.64	2.05	-20	62	7.87	9.24	2.01	-20	42	5.33	8.66	2.03
-18	71.5	9.08	2	-18	63.5	8.06	9.43	2.01	-18	44.5	5.65	8.98	2
-16	72	9.14	2	-16	65	8.26	9.63	2	-16	45	5.72	9.05	2.03
-14	72.5	9.21	2.01	-14	66	8.38	9.75	2	-14	47.5	6.03	9.36	2
-12	74	9.4	2.03	-12	66.5	8.45	9.82	2.04	-12	46.5	5.91	9.24	2.06
-10	76.5	9.72	2.48	-10	69.5	8.83	10.2	2.06	-10	50.5	6.41	9.74	2.04
-8	88	11.18	2.06	-8	73.5	9.33	10.7	2.02	-8	53.5	6.79	10.12	2.01
-6	84	10.67	2	-6	75.5	9.59	10.96	2.04	-6	55	6.99	10.32	2.06
-4	85	10.8	2	-4	78.5	9.97	11.34	2.03	-4	59	7.49	10.82	2
-2	84	10.67	2.14	-2	76	9.65	11.02	2.06	-2	58.5	7.43	10.76	2.05
0	90	11.43	2.03	0	80	10.16	11.53	2.06	0	62	7.87	11.2	2.01
2	92.5	11.75	2	2	84	10.67	12.04	2.02	2	63.5	8.06	11.39	2
4	93	11.81	2	4	86	10.92	12.29	2	4	63.5	8.06	11.39	2.04
6	94	11.94	2.01	6	86	10.92	12.29	4.02	6	66.5	8.45	11.78	2.03
8	95.5	12.13	2	8					8	69	8.76	12.09	2
10	96	12.19	2	10	89	11.3	12.67	2	10	70	8.89	12.22	2.01
12	97	12.32	2	12	89.5	11.37	12.74	2	12	68.5	8.7	12.03	2.01
14	97	12.32	2.04	14	90	11.43	12.8	2	14	70	8.89	12.22	2
16	100	12.7	2	16	91	11.56	12.93	2	16	71	9.02	12.35	2
18	99	12.57	2.02	18	91	11.56	12.93	2	18	71	9.02	12.35	2.03
20	101	12.83	2	20	91	11.56	12.93	2.1	20	73.5	9.33	12.66	2.01
22	101.5	12.89	2	22	96	12.19	13.56	2.01	22	75	9.53	12.86	2
24	102	12.95	2	24	97.5	12.38	13.75	2.04	24	74.5	9.46	12.79	2
26	102.5	13.02	2	26	94.5	12	13.37	2.03	26	74	9.4	12.73	2
28	103	13.08	2	28	97	12.32	13.69	2	28	74.5	9.46	12.79	2.04
30	103	13.08	2.01	30	98	12.45	13.82	2.02	30	77.5	9.84	13.17	2
32	104.5	13.27	2.01	32	100	12.7	14.07	2.03	32	77.5	9.84	13.17	2
34	106	13.46	2.04	34	97.5	12.38	13.75	2	34	76.5	9.72	13.05	2
36	103	13.08	2	36	97.5	12.38	13.75	2.02	36	75.5	9.59	12.92	2.01
38	103	13.08	2.06	38	99.5	12.64	14.01	2	38	77	9.78	13.11	2.04
40	99	12.57	2.06	40	100	12.7	14.07	2.02	40	80	10.16	13.49	2
42	103	13.08	2.02	42	102	12.95	14.32	2	42	81	10.29	13.62	2
44	105	13.34	2	44	102.5	13.02	14.39	2.01	44	80	10.16	13.49	2.03
46	106	13.46		46	104	13.21	14.58	2.02	46	82.5	10.48	13.81	2.03
48		0		48	106	13.46	14.83	2	48	85	10.8	14.13	2.02
50		0		50	107	13.59	14.96	2.03	50	83	10.54	13.87	2.04
52		0		52	104.5	13.27	14.64	2.05	52	80	10.16	13.49	2.02
54		0		54	101	12.83	14.2		54	82	10.41	13.74	2.24
56		0		56		0			56	74	9.4	12.73	2.02
58		0		58		0			58	76	9.65	12.98	
60		0		60		0			60		0		

Table A2.7. Raw data from transect # 6 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	cm	Sinuosity	Rod (cm)	Threads	cm	3.14	Sinuosity	Rod (cm)	Threads	cm	2.7	Sinuosity
				-52	23	2.92	6.06	2.03					
-50		0		-50	25.5	3.24	6.38	2.06	-50		0		
-48		0		-48	29.5	3.75	6.89	2.02	-48		0		
-46		0		-46	27.5	3.49	6.63	2.14	-46		0		
-44		0		-44	21.5	2.73	5.87	2.03	-44		0		
-42	52	6.6	2.02	-42	24	3.05	6.19	2.02	-42		0		
-40	50	6.35	2	-40	26	3.3	6.44	2.22	-40	29	3.68	6.38	2.19
-38	49.5	6.29	2.34	-38	33.5	4.25	7.39	2.12	-38	36	4.57	7.27	2.06
-36	59	7.49	2.02	-36	39	4.95	8.09	2.04	-36	40	5.08	7.78	2.04
-34	61	7.75	2	-34	42	5.33	8.47	2	-34	43	5.46	8.16	2.85
-32	62	7.87	2.04	-32	42	5.33	8.47	2.06	-32	27	3.43	6.13	2.72
-30	65	8.26	2	-30	38	4.83	7.97	2.01	-30	41.5	5.27	7.97	2.14
-28	64	8.13	2.19	-28	36.5	4.64	7.78	2	-28	35.5	4.51	7.21	2
-26	57	7.24	2	-26	37	4.7	7.84	2.1	-26	36	4.57	7.27	2.02
-24	58	7.37	2.02	-24	32	4.06	7.2	2.02	-24	34	4.32	7.02	2.03
-22	60	7.62	2.01	-22	34	4.32	7.46	2	-22	36.5	4.64	7.34	2
-20	58.5	7.43	2	-20	34.5	4.38	7.52	2.01	-20	36.5	4.64	7.34	2
-18	57.5	7.3	2.12	-18	33	4.19	7.33	2.08	-18	35.5	4.51	7.21	2
-16	52	6.6	2.12	-16	37.5	4.76	7.9	2.01	-16	36.5	4.64	7.34	2
-14	57.5	7.3	2	-14	36	4.57	7.71	2	-14	36	4.57	7.27	2
-12	57.5	7.3	2.01	-12	36	4.57	7.71	2.01	-12	35.5	4.51	7.21	2.04
-10	59	7.49	2.06	-10	34.5	4.38	7.52	2.05	-10	38.5	4.89	7.59	2.02
-8	55	6.99	2.03	-8	38	4.83	7.97	2.05	-8	36.5	4.64	7.34	2.02
-6	52.5	6.67	2.14	-6	34.5	4.38	7.52	2	-6	34.5	4.38	7.08	2.01
-4	46.5	5.91	2.08	-4	33.5	4.25	7.39	2.08	-4	36	4.57	7.27	2
-2	51	6.48	2.14	-2	29	3.68	6.82	2.19	-2	36.5	4.64	7.34	2.04
0	57	7.24	2.06	0	36	4.57	7.71	4	0	33.5	4.25	6.95	2
2	53	6.73	2.01	2					2	34	4.32	7.02	2.01
4	51.5	6.54	2	4	35	4.45	7.59	2.08	4	35.5	4.51	7.21	2
6	50.5	6.41	2	6	30.5	3.87	7.01	2	6	35	4.45	7.15	2.1
8	51.5	6.54	2	8	31	3.94	7.08	2.02	8	30	3.81	6.51	2
10	52	6.6	2.02	10	29	3.68	6.82	2.01	10	30	3.81	6.51	2.06
12	50	6.35	2	12	27.5	3.49	6.63	2	12	26	3.3	6	2
14	50	6.35	2.04	14	27.5	3.49	6.63	2.02	14	27	3.43	6.13	2
16	47	5.97	2.02	16	25.5	3.24	6.38		16	27	3.43	6.13	2.04
18	45	5.72	2.01	18		0			18	24	3.05	5.75	2.02
20	43.5	5.52	2	20		0			20	22	2.79	5.49	
22	43	5.46	2.06	22		0			22		0		
24	39	4.95	2.01	24		0			24		0		
26	37.5	4.76	2.08	26		0			26		0		
28	33	4.19		28		0			28		0		
30		0		30		0			30		0		

Table A2.8: Raw data from transect # 7 including sinuosity

Baseline				Test # 1			Corrected		Test # 2			Corrected	
Rod (cm)	Threads	cm	Sinuosit	Rod (cm)	Threads	cm	0.57	Sinuosit	Rod (cm)	Threads	cm	1.37	Sinuosit
-30				-30					-30				
-28				-28					-28				
-26	28	3.56	2.06	-26	31	3.94	3.37	2.06	-26				
-24	32	4.06	4.04	-24	27	3.43	2.86	2	-24				
-22				-22	26	3.3	2.73	2.08	-22				
-20	27.5	3.49	2.08	-20	30.5	3.87	3.3	2	-20	24	3.05	4.42	2.37
-18	32	4.06	2.14	-18	31	3.94	3.37	2	-18	34	4.32	5.69	2.9
-16	38	4.83	2	-16	30	3.81	3.24	2.06	-16	17.5	2.22	3.59	2.27
-14	37	4.7	2.11	-14	34	4.32	3.75	2.01	-14	26	3.3	4.67	2.14
-12	42.5	5.4	4.01	-12	36	4.57	4	2	-12	32	4.06	5.43	2.19
-10				-10	35	4.45	3.88	2.3	-10	25	3.18	4.55	2.04
-8	45	5.72	2	-8	44	5.59	5.02	2.01	-8	22	2.79	4.16	2.37
-6	46	5.84	2	-6	42	5.33	4.76	2.1	-6	32	4.06	5.43	2.01
-4	47	5.97	2.27	-4	47	5.97	5.4	2.16	-4	34	4.32	5.69	2.01
-2	38.5	4.89	2.08	-2	40.5	5.14	4.57	2.21	-2	35.5	4.51	5.88	2.08
0	34	4.32	2.68	0	33	4.19	3.62	2.21	0	31	3.94	5.31	2.04
2	48	6.1	2.19	2	40.5	5.14	4.57	2	2	28	3.56	4.93	2
4	41	5.21	2.06	4	41	5.21	4.64	2.03	4	29	3.68	5.05	2
6	45	5.72	2	6	43.5	5.52	4.95	2.01	6	29	3.68	5.05	2.01
8	44.5	5.65	2	8	45.5	5.78	5.21	2.03	8	31	3.94	5.31	2.01
10	44	5.59	2.05	10	43	5.46	4.89	2.05	10	29.5	3.75	5.12	2.05
12	47.5	6.03	2.01	12	46.5	5.91	5.34	2.05	12	33	4.19	5.56	2
14	49	6.22	2.08	14	50	6.35	5.78	2.01	14	32	4.06	5.43	2
16	44.5	5.65	2	16	48.5	6.16	5.59	2	16	33	4.19	5.56	2.06
18	44	5.59	2.01	18	49	6.22	5.65	2.05	18	29	3.68	5.05	2.01
20	41.5	5.27	2	20	52.5	6.67	6.1	2.03	20	26.5	3.37	4.74	2
22	42	5.33	2	22	50	6.35	5.78	2	22	27	3.43	4.8	2.01
24	42.5	5.4	2.06	24	50	6.35	5.78	2.16	24	25.5	3.24	4.61	2.21
26	38.5	4.89	2.05	26	43.5	5.52	4.95	2.4	26	33	4.19	5.56	2.19
28	42	5.33	2	28	33	4.19	3.62	2.3	28	26	3.3	4.67	2
30	42.5	5.4	2	30	42	5.33	4.76	2	30	25	3.18	4.55	2
32	42	5.33	2.01	32	42	5.33	4.76	2.01	32	25	3.18	4.55	2
34	43.5	5.52	2	34	44	5.59	5.02	2	34	25	3.18	4.55	2.04
36	44	5.59	2.06	36	44	5.59	5.02	2.03	36	22	2.79	4.16	2.04
38	48	6.1	2.01	38	46.5	5.91	5.34	2.11	38	25	3.18	4.55	2.19
40	46.5	5.91	2	40	52	6.6	6.03	2.16	40	18	2.29	3.66	2.01
42	47.5	6.03	2.27	42	45.5	5.78	5.21	2.01	42	20	2.54	3.91	2.04
44	39	4.95	2.01	44	44	5.59	5.02	2	44	17	2.16	3.53	2.06
46	37.5	4.76	2	46	43.5	5.52	4.95		46	21	2.67	4.04	2.1
48	38.5	4.89	2.03	48					48	16	2.03	3.4	2.01
50	36	4.57		50					50	18	2.29	3.66	

Table A2.9. Raw data from transect # 8 including sinuosity