2003 Comparison Testing of LTPP Profilers
Final Report

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1.0 INTRODUCTION

In the Long Term Pavement Performance (LTPP) Program, profile data at General Pavement Studies (GPS) and Specific Pavement Studies (SPS) sections are collected by four regional contractors. Each Regional Support Contractor (RSC) uses an International Cybernetics Corporation (ICC) MDR 4083 inertial profiler to collect profile data. These profilers are equipped with three laser sensors that collect data along the left and right wheel paths, and along the center of the lane. Profile data are collected at 25 mm intervals along each of these paths.

After completion of data collection, the ProQual software is used to compute profile data at 150 mm intervals along the left and right wheel paths. This computation is performed using a 300 mm moving average on the profile data collected at 25 mm intervals. After quality assurance checks, these data are uploaded to the LTPP database. The profile data collected at 25 mm intervals are stored at the regional offices.

A comparison test between the four ICC profilers used by the LTPP Regional Support Contractors was performed from July 14 to 17, 2003. The comparison test was performed at the Mn/Road facility in Albertville, Minnesota. This was the first comparison of the four LTPP ICC profilers since they went into operation in August 2002. The K. J. Law T-6600 profiler that is operated by the North Central RSC also took part in the comparison test. This profiler is equipped with three infrared sensors and collects data along the left and right wheel paths, and along the center of the lane.

The profiler comparison was carried out using the procedures described in LTPP Directive P-19, Annual Inter-Regional Profiler Comparison Tests. Five test sections were used for profile testing and one test section was used to evaluate the accuracy of the Distance Measuring Instrument (DMI).

The purpose of the profiler comparison test was to: (1) evaluate the static accuracy of the height sensors in the profilers, (2) evaluate the results from the bounce test, (3) evaluate the accuracy of the DMI, (4) compare International Roughness Index (IRI) values obtained by the LTPP profilers with those from the Dipstick, (5) compare the IRI values between the four profilers, and (6) compare the profiles obtained by the profilers. One test section was profiled at different speeds by an ICC profiler and the K. J. Law profiler to evaluate the effect of speed on the IRI and profile.

After completion of the comparison test, each RSC summarized the results obtained for their profiler during the comparison test, and forwarded the results to the Federal Highway Administration (FHWA) and its Technical Support Services Contractor (TSSC). This report summarizes the activities that were conducted during the comparison test and presents the results of the inter-regional comparison between the LTPP profilers.

2.0 TEST PLAN AND TEST SECTIONS

2.1 Test Plan

The following tests were carried out during the profiler comparison:

1. Static height sensor test: This test was performed to evaluate the precision and bias of the profiler height sensors in the static mode.

2. Bounce test: The static and dynamic bounce test IRI values of the profilers were compared using the results from this test.

3. DMI test: This test was performed to evaluate the precision and bias of the DMI.

4. Profiling of sections: Five test sections were profiled for the comparison test. Dipstick measurements were also obtained at those test sections. The IRI values obtained by the profilers were compared with the IRI values obtained from the Dipstick. The IRI values were also used to evaluate the repeatability of the profilers and to compare IRI values between the profilers. The profile data were used to evaluate the repeatability of the profilers, and to compare profiles obtained by the different profilers.

5. Evaluate effect of speed on profile and IRI: One test section was profiled with an ICC profiler and the K. J. Law profiler at different speeds to evaluate the effect of speed on profile and IRI.

2.2 Test Sections

One test section was established for DMI testing and five test sections were established for profile testing. The DMI section was established on the low volume loop at Mn/Road. Two of the profile test sections were surfaced with asphalt concrete (AC), while the other two sections were portland cement concrete (PCC) surfaced. The remaining profile test section had a chip seal. All profile test sections were 152.4 m long. Table 2.1 lists the test sections that were used as profile sections.

Table 2.1. Profile test sections.

Test Section	Surface Type	Location	Roughness
1	AC	Mn/Road Low Volume Loop	Smooth
2	AC	Mn/Road Mainline	Rough
3	PCC	Mn/Road Low Volume Loop	Smooth
4	PCC	Mn/Road Low Volume Loop	Medium Rough
5	Chip Seal	Access Road to Mn/Road Office	Rough

The following is a brief description of the characteristics of the test sections.

Section 1 (Smooth AC): The inside lane of cell 29 in the Mn/Road low volume loop was used as section 1. This section had several low to moderate severity transverse cracks. A few localized areas of low severity alligator cracking were also located within the section. In addition, this section had low severity rutting.

Section 2 (Rough AC): This test section encompassed a portion of cells 17 and 18 of the Mn/Road mainline. The test section was located in the outside lane. Transverse cracks were located throughout the test section. Most of these cracks had been repaired with a patching material.

Section 3 (Smooth PCC): This test section encompassed a portion of cells 36 and 37 in the Mn/Road low volume loop. The test section was located in the outside lane. There were no distresses within the test section.

Section 4 (Medium Rough PCC): This test section encompassed a portion of cells 38 and 39 in the Mn/Road low volume loop. The test section was located in the inside lane. There were no distresses within the test section except for a moderate severity transverse crack on one slab.

Section 5 (Chip Seal): This section was located on the road outside the entrance gate to the Mn/Road facility. A few low to medium severity transverse cracks were located within the test section.

3.0 STATIC HEIGHT SENSOR TEST

3.1 Overview

The purpose of performing the static height sensor test is to evaluate the precision and bias of the profiler height sensors in the static mode. The specified requirements are that the bias be within 0.25 mm and that precision be less than 0.125 mm (see Directive P-19).

3.2 Test Procedure

The static height sensor test was performed on each height sensor in the ICC profilers using the following procedure.

1. Measure distance from the ground to the glass face of the height sensor, and record the reading for each height sensor.

2. Drive the vehicle so that all four tires rest on support blocks. The height of each support block should be 76 mm.

3. Place a calibration base plate on the ground under each laser sensor. Place a calibration surface plate on top of each base plate. Let computer take at least 500 readings.

4. Place a block on each base plate such that the 25 mm side of the block is vertical. Place a calibration surface plate on top of each block. Let computer take at least 500 readings and then record value shown for ‘Dif Ht’ on the computer screen for each sensor.

5. Repeat steps 3 and 4 for block heights of 50 mm, 75 mm and 100 mm. For the 100 mm block height, place two blocks on top of each other such that the 50 mm sides are vertical to get a block height of 100 mm.

6. Repeat steps 3 through 5 four more times and record readings.

The sensors in the K. J. Law profiler were calibrated prior to performing the height sensor test. The laser sensors in the ICC profilers cannot be calibrated by the user. The height sensor test on the K. J. Law profiler was performed for three block heights (i.e., 25 mm, 50 mm and 75 mm). The height sensors in the K. J. Law profiler have a lower measuring range than the sensors in the ICC profilers, and hence the sensor test at 100 mm cannot be performed on the K. J. Law profiler.

3.3 Test Results

The data obtained from the static height sensor test are included in Appendix A. The bias and precision of each height sensor for heights corresponding to 25 mm, 50 mm, 75 mm and 100 mm were computed from the data included in Appendix A. (Results for the K. J. Law profiler show values for the three block positions of 25 mm, 50 mm and 75 mm). For example, at the 25 mm block position, the bias of the height sensor is the difference between the average of the five readings obtained from the five repeat tests and 25 mm, while the precision of the height sensor is the standard deviation of the heights obtained at this position for the five tests.

Tables 3.1 and 3.2, respectively, present the bias and precision values for the three height sensors in each profiler corresponding to the 25 mm, 50 mm, 75 mm and 100 mm heights. (Results for the K. J. Law profiler show values for the three block positions of 25 mm, 50 mm and 75 mm). These results are also presented in figures 3.1 and 3.2 for bias and precision, respectively.
The LTPP specified criteria are that the bias of the sensors be within 0.25-mm and that the precision (standard deviation) of the sensors be less than 0.125-mm (see Directive P-19).

The following sensors did not meet the specified bias criterion of $\pm$ 0.25 mm: (1) North Central center sensor at 25 mm, (2) North Central left sensor at 75 mm, (3) Southern left sensor at 100 mm, (4) Southern center sensor at 75 mm, (5) Southern right sensor at 75 mm, and (6) Western center sensor at 50 mm, 75 mm and 100 mm.

Table 3.1. Bias values from static height sensor test.

Position	Sensor	Region				
		North Atlantic	North Central	Southern	Western	K. J. Law
25 mm	Left	0.00	0.12	0.11	0.16	-0.01
	Center	-0.06	0.37	-0.14	-0.07	0.01
	Right	-0.08	0.14	0.08	0.07	-0.01
50 mm	Left	-0.04	0.14	0.03	0.09	0.01
	Center	-0.18	0.20	-0.01	-0.34	0.05
	Right	-0.12	0.07	0.03	-0.06	0.11
75 mm	Left	0.05	0.26	0.16	0.08	-0.12
	Center	-0.10	0.12	0.42	-0.48	0.11
	Right	0.05	0.06	0.26	0.00	0.12
100 mm	Left	0.06	0.24	0.28	0.13	N/A
	Center	0.18	0.18	0.12	-0.74	N/A
	Right	0.21	0.07	0.09	-0.11	N/A

Note: Measurements at 100 mm not performed for the K.J. Law profiler.

Table 3.2. Precision values from static height sensor test.

Position	Sensor	Region				
		North Atlantic	North Central	Southern	Western	K. J. Law
25 mm	Left	0.045	0.031	0.049	0.055	0.054
	Center	0.186	0.024	0.471	0.029	0.124
	Right	0.450	0.040	0.144	0.053	0.051
50 mm	Left	0.021	0.006	0.123	0.054	0.084
	Center	0.121	0.021	0.132	0.081	0.153
	Right	0.144	0.047	0.030	0.069	0.088
75 mm	Left	0.423	0.028	0.050	0.035	0.042
	Center	0.153	0.024	0.516	0.070	0.126
	Right	0.165	0.022	0.401	0.072	0.081
100 mm	Left	0.145	0.059	0.116	0.023	N/A
	Center	0.059	0.036	0.146	0.049	N/A
	Right	0.037	0.070	0.056	0.050	N/A

Note: Measurements at 100 mm not performed for the K.J. Law profiler.

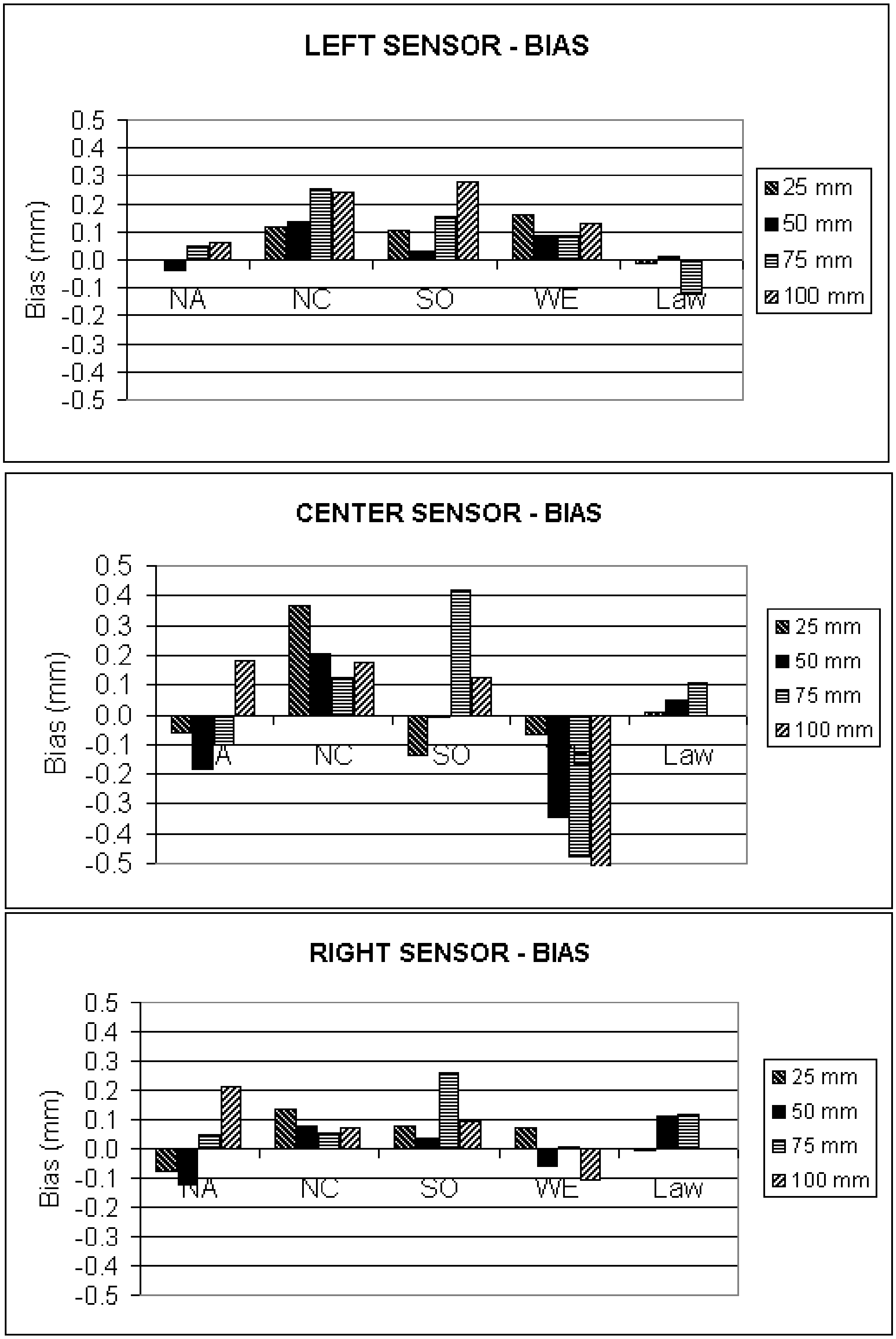


Figure 3.1. Bias values from static height sensor test (NA- North Atlantic, NC – North Central, SO – Southern, WE – Western).

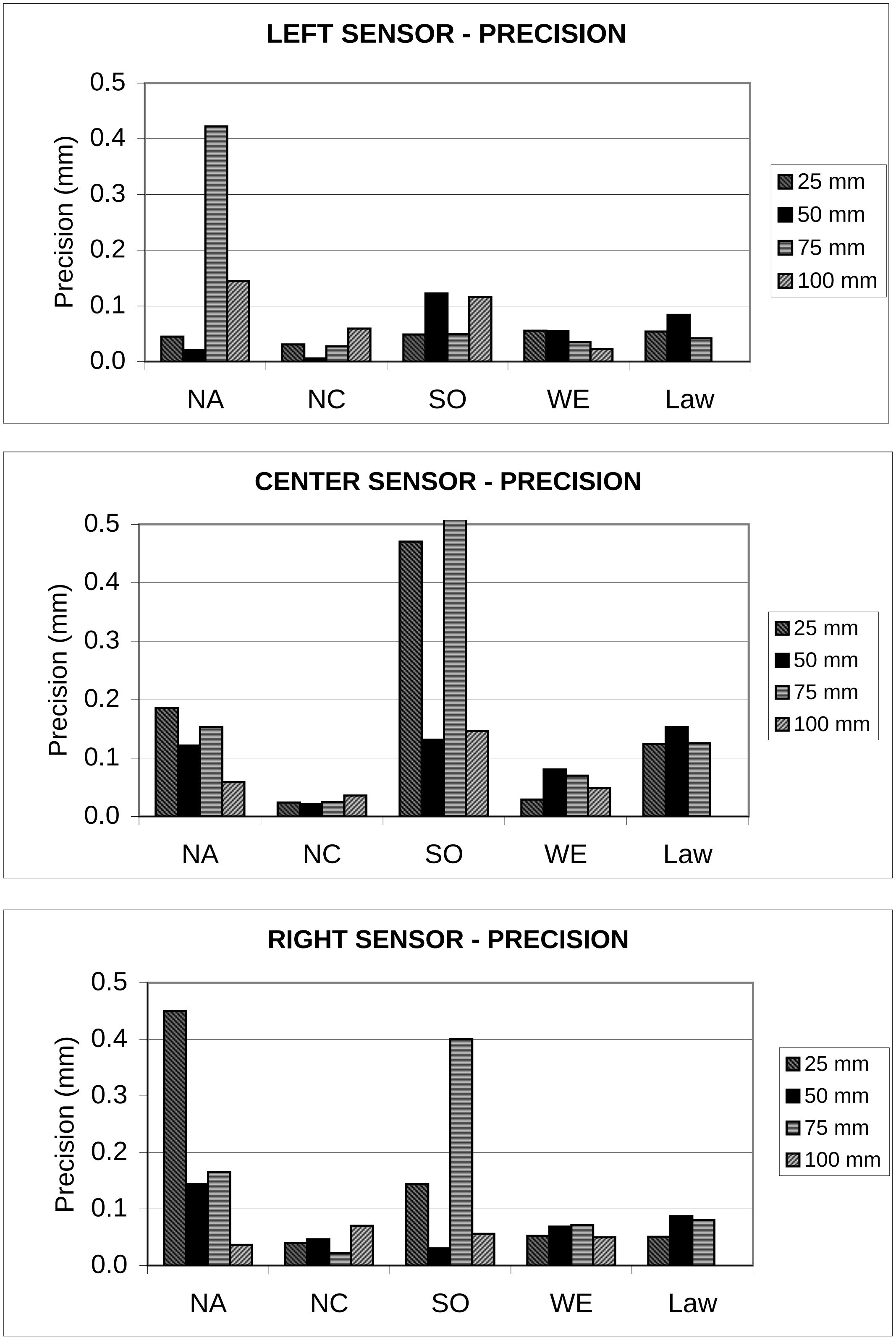


Figure 3.2. Precision values for height sensors from static height sensor test (NA- North Atlantic, NC – North Central, SO – Southern, WE – Western).

The following sensors did not meet the specified precision criterion of 0.125 mm: (1) North Atlantic center sensor at 25 mm and 75 mm, (2) North Atlantic right sensor at 25 mm, 50 mm, and 75 mm, (3) North Atlantic left sensor at 75 mm and 100 mm, (4) Southern center sensor at 25 mm, 50 mm, 75 mm, and 100 mm, (5) Southern right sensor at 25 mm and 75 mm, and (6) K.J. Law center sensor at 50 mm and 75 mm.

The Western RSC was aware that the center sensor in their profiler had a problem prior to performing the height sensor test. They had been in contact with ICC to obtain a replacement sensor for the center sensor. The blocks used for the test on the North Atlantic profiler had a mark made with a felt pen on the blocks so that the operator could center the blocks during testing. These marks may have affected the readings that were obtained.

Each RSC was also requested to measure the distance from the ground to the sensor glass of the height sensor (when the vehicle was off the blocks). These results are presented in table 3.3.

Table 3.3. Distance from ground to sensor glass.

Profiler	Distance From Ground to Sensor Glass (mm)		
	Left Sensor	Center Sensor	Right Sensor
North Atlantic - ICC	323	327	326
North Central - ICC	318	321	319
Southern - ICC	325	323	323
Western - ICC	321	326	330
K. J. Law	247	250	260

According to the LTPP Manual for Profile Measurements (hereafter referred to as the Profile Manual), the distance from the ground to the glass face of the height sensor should be 325 ± 5 mm for the ICC profilers. The value indicated in the Profile Manual was provided by ICC. All three sensors in the North Atlantic, Southern and Western profilers were within the specified limit. In the North Central profiler, the center sensor was within the limit, but the left and right sensors were below the manufacturer specified lower limit by 2 mm and 1 mm, respectively. These values are very small and are unlikely to have an impact on the quality of the data collected by the sensors.

3.4 Repeat Testing

Because several sensors failed the bias and precision criterion, the FHWA requested each RSC to repeat the height sensor test on their ICC profiler. Possible causes for the height sensor not passing the static test criteria could have been movements occurring in the vehicle when the test was been conducted, or marks on blocks that were used for testing.

Each RSC performed the repeat static height sensor test at their facility. In order to eliminate any effect of vehicle movement on the test results, the vehicle was placed on jacks before conducting the test. The blocks that were used for the test were cleaned prior to performing the test. The center sensor in the Western profiler had been replaced when the repeat test was performed. The data obtained from the repeat test are included in Appendix B.

Tables 3.4 and 3.5, respectively, present the bias and precision values for the three height sensors in each profiler corresponding to the 25 mm, 50 mm, 75 mm and 100 mm heights. These results are also presented in figures 3.3 and 3.4 for bias and precision, respectively. The LTPP specified criteria are that the bias of the sensors be within 0.25-mm and that the precision (standard deviation) of the sensors be less than 0.125-mm (see Directive P-19).

All sensors in all four profilers met the precision criterion. All sensors in all four profilers met the bias criterion except for the center sensor of the North Central profiler at the 25 mm position. At the 25 mm position the bias of the center sensor was 0.27 mm, which was 0.02 mm outside the tolerance.

3.5 Summary

Results from the static height sensor test that was performed on the profilers at Mn/Road indicated several cases where the sensors failed the bias and precision criteria. The cause for the failure of these criteria may have been movements that occurred in the vehicle when the test was performed, as well as marks that were present on the blocks that were used for the test. When performing the static height sensor test, the operator must make sure that no movements are induced on the vehicle as such movements will affect test results. The operator should be very careful when using the keyboard to not induce any movement in the vehicle, and also not lean on the vehicle during the test as such conditions can affect test results.

Each RSC repeated the height sensor test at their facility. The vehicle was placed on jacks when performing this test to eliminate any vehicle movement during the test. In addition, a clean set of blocks was used to perform the test. All sensors in all profilers passed the precision criterion when the test was repeated. All sensors in all profilers, except for the center sensor in the North Central profiler at the 25 mm position met the bias criterion when the test was repeated. At the 25 mm position, the North Central profiler had a bias value of 0.27 mm, which was 0.02 mm outside the specified tolerance.

4.0 COMPARISON OF BOUNCE TEST RESULTS

A bounce test was performed on all profilers prior to profile data collection. The bounce test consists of a static test and a dynamic bounce test. The static test is performed to evaluate the noise in the sensors. In this test, the bounce test procedures are followed, but no motion is induced on the vehicle. During the dynamic bounce test, a bouncing motion is induced on the profiler. The profile recorded during the static test and dynamic bounce test is used to compute

Table 3.4. Bias values from repeat static height sensor test.

Position	Sensor	Region			
		North Atlantic	North Central	Southern	Western
25 mm	Left	0.248	0.006	0.087	0.094
	Center	-0.020	0.270	-0.022	-0.034
	Right	0.120	0.079	0.150	0.000
50 mm	Left	0.094	-0.075	0.106	-0.003
	Center	-0.055	0.129	-0.024	-0.110
	Right	0.128	-0.066	0.059	-0.004
75 mm	Left	-0.020	-0.011	0.206	0.019
	Center	-0.116	0.056	-0.101	-0.138
	Right	0.137	-0.047	0.032	-0.089
100 mm	Left	-0.133	0.014	0.214	-0.030
	Center	-0.064	-0.004	-0.134	-0.139
	Right	0.163	-0.120	0.068	-0.121

Table 3.5. Precision values from repeat static height sensor test.

Position	Sensor	Region			
		North Atlantic	North Central	Southern	Western
25 mm	Left	0.032	0.016	0.036	0.062
	Center	0.050	0.018	0.094	0.055
	Right	0.029	0.025	0.041	0.024
50 mm	Left	0.051	0.043	0.006	0.039
	Center	0.031	0.032	0.072	0.058
	Right	0.025	0.044	0.032	0.047
75 mm	Left	0.017	0.084	0.028	0.019
	Center	0.034	0.007	0.050	0.021
	Right	0.021	0.019	0.044	0.026
100 mm	Left	0.029	0.040	0.030	0.054
	Center	0.032	0.032	0.049	0.022
	Right	0.021	0.027	0.064	0.048

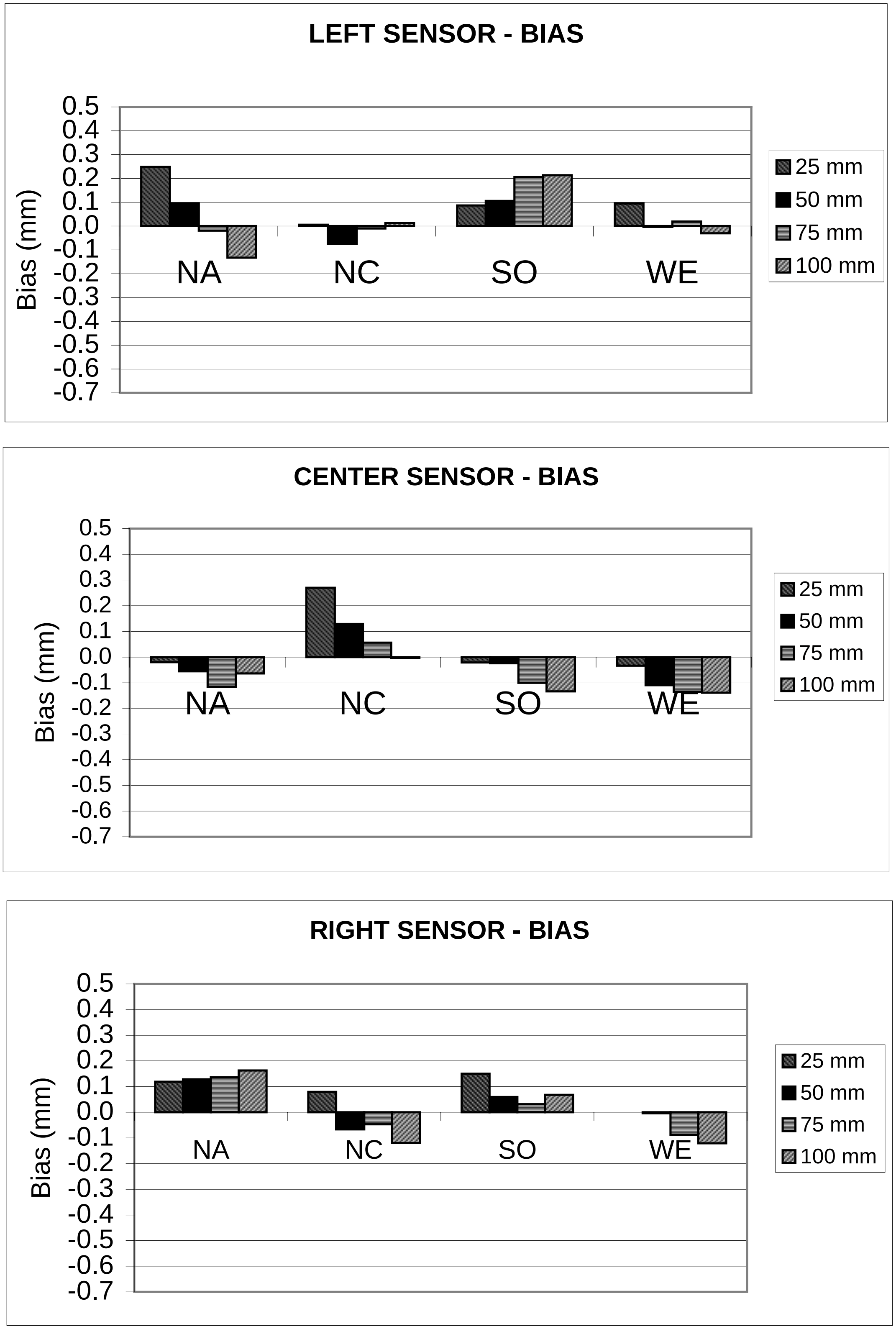


Figure 3.3. Bias values from repeat static height sensor test (NA – North Atlantic, NC – North Central, SO – Southern, WE – Western).

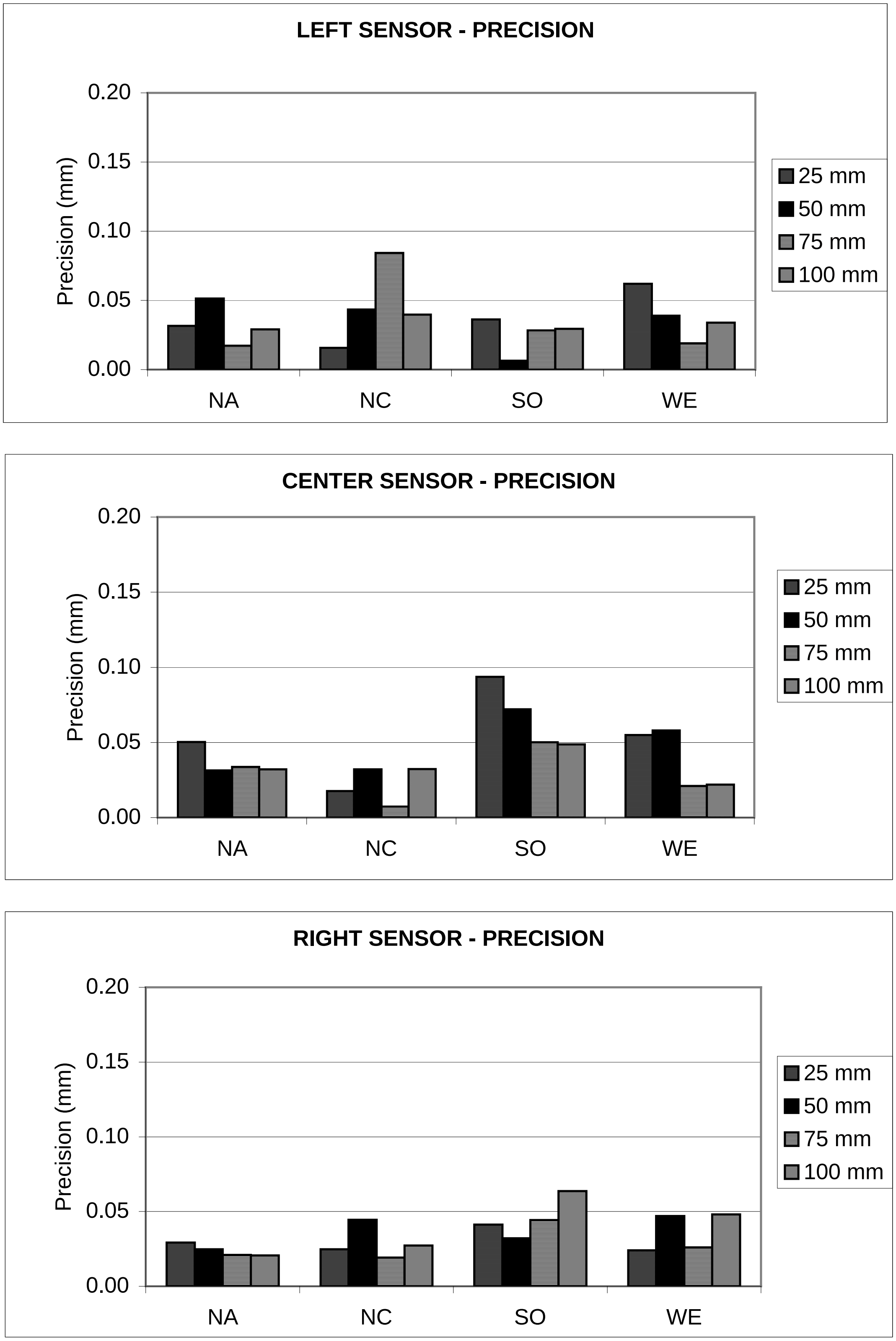


Figure 3.4. Precision values from repeat static height sensor test (NA- North Atlantic, NC – North Central, SO – Southern, WE – Western).

an IRI value for each test. Table 4.1 presents the IRI values from the static and dynamic bounce test as well as the difference in IRI value between the dynamic and static tests for the five profilers. If a region submitted IRI values from the bounce tests performed on more than one day, the averaged IRI values are presented in table 4.1. According to the criteria presented in the LTPP Profile Manual, the static test IRI value should be less than 0.08 m/km, while the difference in IRI value between the dynamic bounce and static test should be less than 0.10 m/km. None of the sensors for which bounce test values were submitted failed the bounce test criteria.

Table 4.1. IRI values from bounce test.

Profiler	IRI Value (m/km)								
	Static Test			Dynamic Test			Dynamic - Static		
	Left	Center	Right	Left	Center	Right	Left	Center	Right
North Atlantic	0.02	N/A	0.04	0.03	N/A	0.05	0.01	N/A	0.01
North Central	0.03	0.03	0.07	0.07	0.07	0.09	0.04	0.04	0.02
Southern	0.06	N/A	0.05	0.08	N/A	0.07	0.02	N/A	0.02
Western	0.05	0.05	0.05	0.10	0.10	0.11	0.05	0.05	0.06
K. J. Law	0.05	N/A	0.05	0.08	N/A	0.08	0.03	N/A	0.03
N/A: The center sensor IRI is not displayed for K. J. Law profiler. The center sensor IRI values were not submitted for North Atlantic and Southern profilers									

5.0 EVALUATION OF DMI TEST RESULTS

5.1 Overview

The purpose of the DMI test is to evaluate the bias and precision of the DMI in the profilers. The specified criteria are that the DMI bias be within 0.05% of the distance and that DMI precision be less than 0.025% of the distance (see Directive P19). A 304.8 m long section was laid out as the DMI section. For a 304.8 m long test section, the bias and precision values are 0.152 m and 0.076 m, respectively.

5.2 Test Procedure

All profilers calibrated their DMI at the DMI section prior to obtaining profile measurements. Immediately after the DMI was calibrated, each profiler performed six runs on the DMI section and recorded the distance measured between the start and the end of the section. The tire pressure during each DMI run was also recorded. After profiling all test sections, each profiler again performed six repeat runs on the DMI section and recorded the distance between the start and end of the section. The purpose of obtaining the second set of measurements was to evaluate the stability of the DMI over time. The K. J. Law profiler used a 305 m length for calibration and DMI testing, as a length of 304.8 m could not be entered into the software.

5.3 Test Results

Table 5.1 presents the results obtained from the DMI testing that was conducted immediately after calibrating the DMI. Table 5.1 presents the tire pressure before and after testing, the air temperature before and after testing, the DMI reading for each run, average of DMI readings, and the standard deviation of DMI readings. Table 5.1 also indicates whether or not the profiler met the bias and precision criterion.

Table 5.1. Results of DMI tests performed immediately after calibration.

Description	Region				
	North Atlantic	North Central	Southern	Western	K.J.Law
DMI Reading - Run 1 (m)	304.776	304.842	304.761	304.691	304.990
DMI Reading - Run 2 (m)	304.629	304.783	304.741	304.731	305.000
DMI Reading - Run 3 (m)	304.629	304.803	304.701	304.711	305.010
DMI Reading - Run 4 (m)	304.609	304.744	304.662	304.691	305.000
DMI Reading - Run 5 (m)	304.570	304.744	304.682	304.672	305.000
DMI Reading - Run 6 (m)	304.511	304.744	304.682	304.652	305.000
Average	**304.62**	**304.78**	**304.70**	**304.69**	**305.00**
Length of Section (m)	**304.80**	**304.80**	**304.80**	**304.80**	**305.00**
Bias (m)	**-0.18**	**-0.02**	**-0.10**	**-0.11**	**0.00**
Standard Deviation (m)	**0.09**	**0.04**	**0.04**	**0.03**	**0.01**
Bias Criterion Satisfied?	**No**	**Yes**	**Yes**	**Yes**	**Yes**
Precision Criterion Satisfied?	**No**	**Yes**	**Yes**	**Yes**	**Yes**
Left rear tire pressure before test (psi)	80	81	82.5	82	66
Left rear tire pressure after test (psi)	82	82	81.5	80	67
Right rear tire pressure before test (psi)	80	82	82	80	65
Right rear tire pressure after test (psi)	82	82	81.5	82	66
Before Measurements - Air Temp. (°C)	25.6	N/A	27.0	24.5	19.6
After Measurements - Air Temp. (°C)	25.1	N/A	26.3	24.5	19.4

All profilers except for the North Atlantic one passed both the bias and the precision criterion. The North Atlantic profiler failed both the bias and precision criterion. An evaluation of the DMI readings obtained by the North Atlantic profiler showed that they decreased as the testing progressed. The tire pressure of the rear tires in the North Atlantic profiler was 2 psi higher at the end of the test, which indicates the tires were probably not warmed-up sufficiently when the DMI was calibrated. The reason why the North Atlantic profiler failed both the bias and precision criterion is most likely because the tires of the profiler were not sufficiently warmed-up when the DMI was calibrated.

After completing the DMI test, the operator of the North Atlantic profiler realized that the DMI did not meet the bias and precision criterion and recalibrated the DMI. However, as the profiler was experiencing some problems with the battery charging system, the operator did not have sufficient time to perform the DMI test after the DMI was recalibrated.

The purpose of obtaining measurements at the DMI section after the test sections were profiled was to evaluate the stability of the DMI over time. Table 5.2 presents the results obtained from the DMI testing that was performed after the profilers completed data collection at the five profile test sections.

Table 5.2. Results of DMI tests performed after profiling the test sections.

Description	Region				
	North Atlantic	North Central	Southern	Western	K.J. Law
DMI Reading - Run 1 (m)	304.844	304.881	305.156	304.868	305.03
DMI Reading - Run 2 (m)	304.805	304.881	305.117	304.829	305.02
DMI Reading - Run 3 (m)	304.766	304.822	305.057	304.789	305.05
DMI Reading - Run 4 (m)	304.746	304.822	305.057	304.789	305.02
DMI Reading - Run 5 (m)	304.766	304.842	305.057	304.750	305.01
DMI Reading - Run 6 (m)	304.707	304.822	305.038	304.711	305.00
Average	**304.77**	**304.85**	**305.08**	**304.79**	**305.02**
Length of Section (m)	**304.80**	**304.80**	**304.80**	**304.80**	**305.00**
Bias (m)	**-0.03**	**0.05**	**0.28**	**-0.01**	**0.02**
Standard Deviation (m)	**0.05**	**0.03**	**0.05**	**0.06**	**0.02**
Bias Criterion Satisfied?	**Yes**	**Yes**	**No**	**Yes**	**Yes**
Precision Criterion Satisfied?	**Yes**	**Yes**	**No**	**Yes**	**Yes**
Left rear tire pressure before test (psi)	82	81	82	82	64.5
Left rear tire pressure after test (psi)	82	81	82	80	65
Right rear tire pressure before test (psi)	82	82	82	82	65
Right rear tire pressure after test (psi)	82	82	82	82	64
Before Measurements - Air Temp. (°C)	22.3	N/A	26.7	22.4	17.2
After Measurements - Air Temp. (°C)	22.2	N/A	26.4	22.3	17.1

All profilers except for the Southern one passed both the bias and precision criterion for the DMI. The Southern profiler failed both the bias and precision criterion. The DMI readings obtained by the Southern profiler showed that the DMI readings decreased as repeat runs were obtained. Again, the probable cause for this is that the tires in the profiler were not warmed-up sufficiently when testing was performed. As indicated previously, after the North Atlantic profiler failed the pre-testing DMI test, the operator recalibrated the DMI. Therefore, the North

Atlantic profiler was able to meet both the bias and the precision criterion when the DMI test was performed after the test sections were profiled.

In order to verify that the DMI in the North Atlantic profiler was functioning properly, the FHWA requested the North Atlantic RSC to repeat the DMI test. The North Atlantic profiler repeated the test at a test site in their region that was 300 m in length. The DMI readings obtained for the six runs after the DMI was calibrated were: 300.077, 299.960, 299.960, 299.979, 299.920 and 299.999 m. Based on these readings the bias and the precision of the DMI were 0.017 m and 0.053 m respectively. Both the bias and precision were within the specified criterion.

5.4 Summary

For the DMI test that was performed immediately after calibration, all four profilers met the specified bias and precision criterion, except for the North Atlantic profiler. The DMI readings obtained by the profiler decreased as repeat runs were obtained. This was probably caused by tires in the profiler not being sufficiently warmed-up when the DMI was calibrated.

All profilers met the specified DMI bias and precision criterion for post-profile DMI testing except for the Southern profiler. The DMI readings obtained by this profiler decreased as repeat runs were obtained. It appears that the tires in the Southern profiler were not sufficiently warmed-up when the post-profile DMI test was performed. The North Atlantic profiler recalibrated the DMI when the operator realized the profiler failed the pre-profiling DMI test. That is the reason why the profiler was able to pass the post-profile DMI test although it failed the pre-profile DMI test.

The North Atlantic profiler repeated the DMI test at a location in their region. The profiler was able to meet both the DMI bias and precision criterion during this test.

6.0 COMPARISON OF IRI VALUES AND PROFILES

6.1 Overview

This section describes the following: (1) data collection activities that were carried out at the test sections, (2) IRI values obtained from Dipstick measurements, (3) evaluation of repeatability of IRI values obtained by the profilers, (4) comparison of IRI obtained by the profilers with IRI obtained from Dipstick measurements, (5) evaluation of point-to-point repeatability of profile data, (6) evaluation of repeatability of profile data by a visual review of profile plots containing the repeat profile runs collected by a profiler at a test section, and (7) comparison of profile data collected by the different profilers. An overall discussion of the results obtained from the analyses that were carried out on the profile data are described at the end of the section. In the tables and graphs presented in this section, the following notations are used for the profilers: NA - North Atlantic, NC – North Central, SO – Southern, WE –Western, and Law – K. J. Law.

6.2 Data Collection

Five test sections were used for the profiler comparison. Dipstick measurements were obtained along both wheel paths at each test section following the procedures described in the Profile Manual. Dipstick measurements on PCC sections were obtained in the afternoon to eliminate the effect of temperature related curling on profile measurements. Table 6.1 presents the following information for each test section: regional contractor who performed Dipstick measurements, Dipstick model used for testing, date of testing, and start and end time for testing.

Table 6.1. Dipstick testing at test sections.

Section Number	Region Performing Measurements	Dipstick Used For Measurements	Date of Testing	Start Time	End Time
1	Southern	Southern – Model 2000	7/15/03	9:35	11:17
2	Northern	North Atlantic - Model 2000	7/15/03	16:25	18:05
3	Western	Western - Model 1500	7/15/03	14:24	15:35
4	Southern	Southern – Model 2000	7/15/03	14:31	15:31
5	Western	Western - Model 1500	7/15/03	11:30	12:51

All five test sections were profiled by the four LTPP ICC profilers and the LTPP K. J. Law profiler. The test sections were profiled using the procedures outlined in the Profile Manual. Profile measurements on PCC sections were obtained in the afternoon to eliminate the effect of temperature related curling on profile measurements. Data processing was performed using the current version of the ProQual software. Each region selected five profile runs for each test section for the IRI comparison, and submitted the IRI values to FHWA and the TSSC. Table 6.2 shows the profile runs that were selected by the regions for the IRI comparison.

Table 6.2. Profile runs selected for analysis.

Region	Runs Selected for Analysis				
	Test Section				
	1	2	3	4	5
North Atlantic	2, 3, 4, 5, 6	4, 5, 6, 7, 8	1, 2, 4, 5, 6	2, 3, 4, 5, 6	3, 4, 5, 6, 7
North Central	4, 5, 6, 7, 8	2, 5, 7, 8, 9	1, 4, 5, 6, 8	4, 6, 7, 8, 9	1, 5, 6, 7, 8
Southern	2, 4, 6, 8, 9	3, 6, 7, 8, 9	3, 4, 6, 7, 8	1, 3, 4, 5, 6	2, 3, 6, 7, 9
Western	3, 4, 6, 8, 9	2, 4, 5, 8, 9	3, 4, 5, 6, 9	3, 4, 5, 6, 8	5, 6, 7, 8, 9
K. J. Law	3, 4, 5, 6, 7	2, 3, 6, 7, 8	3, 4, 5, 6, 8	2, 3, 4, 8. 9	1, 4, 6, 7, 8

6.3 IRI From Dipstick Measurements

The RSC that collected the Dipstick data also entered them into ProQual and computed IRI values for the left and the right wheel paths. The Dipstick elevation data were also analyzed using the Roadruf program to compute IRI. A comparison of IRI values obtained from ProQual and Roadruf showed that there were some minor differences in the IRI values. Table 6.3 presents the IRI values computed from the Dipstick measurements.

Table 6.3. IRI values from Dipstick Measurements.

Section Number	Dipstick IRI (m/km)			
	Left Wheel Path		Right Wheel Path	
	ProQual	Roadruf	ProQual	Roadruf
1	N/A	1.170	N/A	1.811
2	2.876	2.797	2.867	2.791
3	0.898	0.880	0.995	0.991
4	1.351	1.320	1.675	1.644
5	2.292	2.235	2.695	2.628

The difference in IRI values between ProQual and Roadruf ranged from 0.004 to 0.079 m/km, with the IRI value from ProQual being greater than the one from Roadruf in all cases. A comparison of IRI values obtained using ProQual and Roadruf for profiler data showed the values were similar. When ProQual computes IRI for Dipstick data, it first applies a filter that has an upper wavelength cut-off of 100 m, and then it uses the filtered data to compute the IRI value. When Roadruf computes IRI for Dipstick data, the program uses the Dipstick elevation profile to compute IRI. The filtering of the Dipstick data that is performed by ProQual may be the cause for the difference in Dipstick IRI values between Roadruf and ProQual. The IRI values computed from Roadruf were used as the reference IRI in the data analysis.

6.4 Analysis of IRI Values

The IRI values computed from profile measurements were used to perform the following analyses.

1. Evaluate repeatability of IRI values obtained by the profilers.
2. Compare Dipstick IRI with profiler IRI.
3. Compare IRI values obtained by the four profilers at the five test sections.

6.4.1 Repeatability of IRI Values

The left and right wheel path IRI values obtained by the profilers for the profile runs selected at the test sections (see table 6.2) are presented in Appendix C. These five IRI values were used to compute the standard deviation of the IRI for the left and right wheel paths at each test section.

The computed standard deviations are shown in table 6.4. The IRI standard deviations for the left and right wheel paths are shown graphically in figures 6.1 and 6.2, respectively.

The precision criterion for IRI indicated in Directive P-19 is that the IRI standard deviation from multiple runs at a section should be less than 0.04 m/km. This criterion was not met for the following cases: (1) North Central – left wheel path of section 2 and 4, (2) K. J. Law – left wheel path of section 5, (3) all profilers except for North Central – right wheel path of section 1, and (4) all profilers – right wheel path of section 2.

At section 2, the North Central profiler had an IRI standard deviation of 0.042 m/km for the left wheel path. Two other ICC profilers, North Atlantic and Western, had IRI standard deviations of 0.034 m/km and 0.039 m/km, respectively. This indicates the left wheel path of site 2 has features that can cause an IRI standard deviation close to 0.40 m/km to occur. The IRI standard deviation of the North Central profiler was close to the values obtained by the North Atlantic and Western profilers, and was over the specified criterion by 0.02 m/km. The reason for this profiler to not meet the specified criterion is attributed to variations in the wheel paths followed by the profiler for the repeat runs.

At section 4, the North Central profiler had an IRI standard deviation of 0.042 m/km, which was 0.02 m/km above the specified criterion. At section 5, the K. J. Law profiler had an IRI standard deviation of 0.061 m/km, which was 0.021 m/km above the specified criterion. For both these cases, the cause for the IRI standard deviation being above the specified criterion is not clear, and needs further investigation.

At section 2, all profilers failed to meet the IRI standard deviation criterion along the right wheel path, while at section 1 all profilers except for the North Central profiler failed the criterion along the right wheel path. Distresses were present along the right wheel path at sections 1 and 4, and variability in the paths profiled by the profilers was the likely cause for the profilers to fail the specified criterion. When distresses are present on the wheel path, variations in the path followed by the profiler during different runs can result in variations in the features that are recorded in the profile. This in turn will result in variations in IRI values between the runs, and contribute to a higher standard deviation of IRI.

6.4.2 Comparison of IRI Values

The left and right wheel path IRI values of the five runs that were used for analysis for the test sections for all profilers are presented in Appendix C. The average IRI value for each profiler at each test section computed from the IRI values of the five runs is shown in table 6.5. This table also includes the Dipstick IRI at each section. The IRI values are shown graphically for the left and right wheel paths in figures 6.3 and 6.4, respectively.

Table 6.4. Standard deviation of IRI.

Wheel Path	Profiler	Standard Deviation of IRI (m/km) Test Section 1	2	3	4	5
Left	NA - ICC	0.02	0.03	0.01	0.03	0.02
	NC - ICC	0.01	0.04	0.01	0.04	0.02
	SO - ICC	0.02	0.02	0.01	0.03	0.03
	WE - ICC	0.01	0.04	0.01	0.01	0.04
	K.J. Law	0.02	0.03	0.01	0.01	0.06
Right	NA - ICC	0.07	0.11	0.02	0.02	0.02
	NC - ICC	0.01	0.13	0.01	0.01	0.03
	SO - ICC	0.07	0.08	0.02	0.03	0.04
	WE - ICC	0.08	0.09	0.01	0.01	0.03
	K.J. Law	0.04	0.08	0.02	0.02	0.03

Note: NA - North Atlantic, NC - North Central, SO - Southern, WE - Western

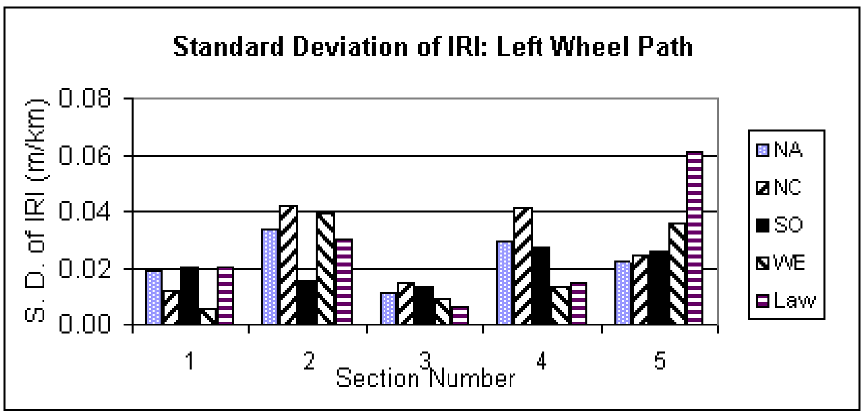


Figure 6.1. Standard deviation of IRI – left wheel path.

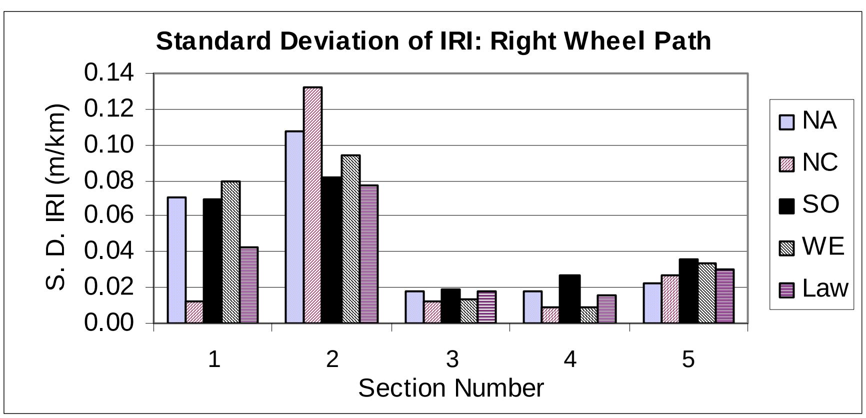


Figure 6.2 Standard deviation of IRI – right wheel path.

Table 6.5. Average IRI values.

Wheel Path	Profiler	Average IRI (m/km)				
		Test Section				
		1	2	3	4	5
Left	Dipstick	1.170	2.797	0.880	1.320	2.235
	NA - ICC	1.269	2.762	0.925	1.451	2.249
	NC – ICC	1.256	2.753	0.925	1.569	2.149
	SO – ICC	1.286	2.780	0.926	1.452	2.147
	WE - ICC	1.283	2.751	0.907	1.431	2.201
	K.J. Law	1.307	2.749	0.943	1.471	2.248
Right	Dipstick	1.811	2.791	0.991	1.644	2.628
	NA - ICC	1.682	2.814	0.982	1.699	2.540
	NC – ICC	1.734	3.013	1.024	1.723	2.540
	SO – ICC	1.688	2.616	0.964	1.671	2.544
	WE - ICC	1.656	2.539	0.973	1.712	2.500
	K.J. Law	1.636	2.462	0.958	1.698	2.437

Note: Dipstick IRI obtained from a single run, NA - North Atlantic, NC - North Central, SO - Southern, WE - Western

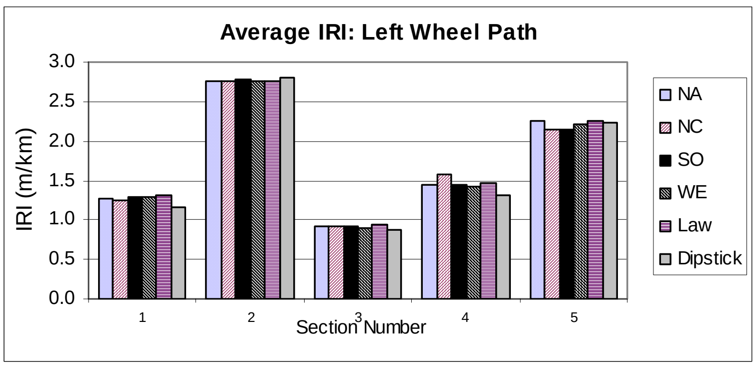


Figure 6.3. IRI values left wheel path.

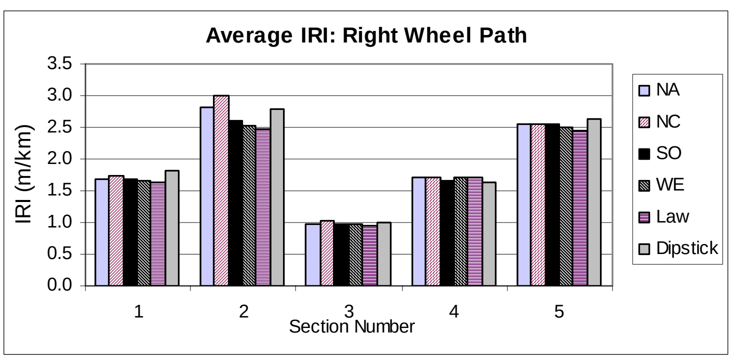


Figure 6.4. IRI values right wheel path.

The difference between the average profiler IRI value and the reference IRI value obtained from the Dipstick (i.e., average profiler IRI – Dipstick IRI) at each test section for each wheel path are shown in table 6.6. These values for the left and right wheel paths are presented graphically in figures 6.5 and 6.6, respectively.

Directive P-19 indicates the difference between the Dipstick IRI and profiler IRI should be within ± 0.16 m/km. This criterion was not met for the following cases: (1) section 1 and section 5 – K. J. Law, right wheel path, (2) section 4 – North Central, left wheel path. (3) section 2 – right wheel path, all profilers except for North Atlantic.

At sections 1 and 5, along the right wheel path, the K. J. Law profiler obtained IRI values that were less than the Dipstick IRI by 0.18 m/km and 0.19 m/km, respectively. The cause for the discrepancy is not apparent and needs further investigation. At section 4, along the left wheel path, the North Central profiler obtained an IRI that was 0.25 m/km greater than the IRI from the Dipstick. There are differences in magnitudes of profile features present on the profiles obtained by the Dipstick and the North Central profiler along the left wheel path at section 4 that is likely to be the cause for the difference in IRI. The probable cause is that the North Central profiler followed a path that was different than the path that was measured by the Dipstick. Further investigation is needed to look into this issue.

At section 2, along the right wheel path, all profilers except for the North Atlantic profiler failed the specified criterion for difference in IRI with the Dipstick IRI. The Southern, Western, and K. J. Law profiler obtained IRI values that were lower than the Dipstick IRI by 0.18 m/km, 0.25 m/km, and 0.33 m/km, respectively. However, the North Central profiler obtained an IRI that was 0.22 m/km higher than the Dipstick IRI. Comparison of profiles from the Dipstick and the profilers indicated the same features were present in all profiles, but the magnitudes of the features were different, which resulted in differences in IRI. Further investigation is needed to look into this issue.

At some sections, all five profilers showed a positive bias in IRI when compared to the Dipstick IRI, while at other sections all five profilers showed a negative bias. Further investigation is needed to identify the reason for this behavior.

6.5 Evaluation of Profiles

6.5.1 Overview

Three types of analyses were performed to evaluate the profile data collected by the profilers. In the first analysis, the point-to-point repeatability of each profiler along the left and right wheel path at each section was evaluated. In the second analysis, a visual review was performed on overlaid profile plots that showed the replicate profile runs collected by a profiler at each section to evaluate the repeatability of the profilers. In the third analysis, one profile was selected from each profiler at each test section, and the profiles for the left and right wheel paths were compared between the profilers.

Table 6.6. Difference between profiler and Dipstick IRI.

Wheel Path	Profiler	Avg. Profiler IRI - Dipstick IRI (m/km)				
		Site				
		1	2	3	4	5
Left	NA – ICC	0.10	-0.03	0.04	0.13	0.01
	NC – ICC	0.09	-0.04	0.05	0.25	-0.09
	SO – ICC	0.12	-0.02	0.05	0.13	-0.09
	WE – ICC	0.11	-0.05	0.03	0.11	-0.03
	K.J. Law	0.14	-0.05	0.06	0.15	0.01
Right	NA – ICC	-0.13	0.02	-0.01	0.05	-0.09
	NC – ICC	-0.08	0.22	0.03	0.08	-0.09
	SO – ICC	-0.12	-0.18	-0.03	0.03	-0.08
	WE – ICC	-0.15	-0.25	-0.02	0.07	-0.13
	K.J. Law	-0.18	-0.33	-0.03	0.05	-0.19

NA - North Atlantic, NC - North Central, SO - Southern, WE – Western

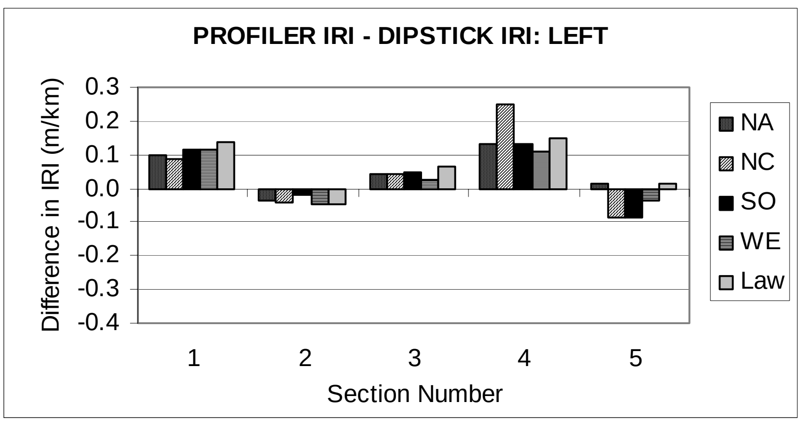


Figure 6.5. Difference between profiler and Dipstick IRI, left wheel path.

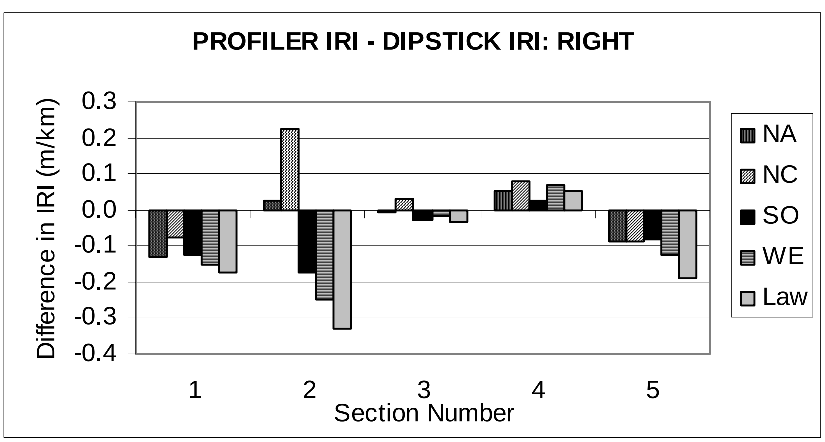


Figure 6.6. Difference between profiler and Dipstick IRI, right wheel path.

6.5.2 Point to Point Repeatability of Profile Data

The point-to-point repeatability of profile data collected by each profiler along the left and right wheel paths was performed using the averaged data files generated by ProQual. ProQual processes the 25 mm data collected by the profilers by applying a 300 mm moving average on the data, and saving the data at 150 mm intervals. Files for upload to the LTPP database that contain the 150 mm data are generated by ProQual. These files do not contain the center path profile, hence the point-to-point repeatability was not computed for the center path. For a specific section, the five profiler runs whose IRI values were used in the IRI comparison study (see table 6.2) were used in the point-to-point repeatability analysis. The following procedure was used to compute the point-to-point repeatability of a profiler for a specific path (i.e., left and right wheel paths) at each section.

1. At each longitudinal interval, compute the standard deviation of the elevation values using the data from the five runs. For example, the first data point corresponds to data collected at station 0. The elevation values recorded for the five runs at this station are used to compute the standard deviation. The next data point is recorded at 150 mm. The elevations recorded at a distance of 150 mm are then used to compute the standard deviation. This process is repeated for all data recording intervals.

2. Compute the average of the standard deviation values. This average value is referred to as the point-to-point repeatability of the profile.

Table 6.7 presents the point-to-point repeatability values for the profilers along the left and right wheel paths at each test section. A lower profile repeatability is indicated with higher point-to-point repeatability values. These values are shown graphically in figure 6.7 and 6.8 for the left and right wheel paths, respectively. The point-to-point repeatability values do not necessarily reflect the ability of the profiler to obtain repeatable profiles. The point-to-point repeatability is also affected by the ability of the profiler driver to follow a consistent path during the repeat runs that are performed at a section.

Along the left wheel path, the Southern ICC profiler and the K. J. Law profiler showed the highest point-to-point repeatability values (i.e., poorest repeatability). When the four ICC profilers were considered, the Southern profiler had the highest point-to-point repeatability at all five sections along the left wheel path. Along the right wheel path, the K. J. Law profiler had the highest point-to-point repeatability value at all sections except for section 5. When the ICC profilers were compared along the right wheel path, the Southern profiler had the highest value at three out of the five sections.

Past studies with LTPP data have indicated that the point-to-point repeatability on a test section with an IRI of less than 1.4 m/km is usually less than 0.5 mm, while on test sections with an IRI greater than 2.4 m/km, the point-to-point repeatability can be as high as 0.80 mm. The point-to-point repeatability value obtained at a pavement section will also depend on the distresses present along the wheel paths of the pavement section. When the North Atlantic, North Central and Western ICC profilers were considered, point-to-point repeatability values higher than 0.50 mm

Table 6.7. Point-to-point repeatability values.

Wheel Path	Profiler	Point-To-Point Repeatability (mm)				
		Test Section				
		1	2	3	4	5
Left	NA - ICC	0.51	0.34	0.15	0.20	0.25
	NC - ICC	0.22	0.26	0.17	0.22	0.36
	SO - ICC	0.85	0.88	0.52	0.75	1.44
	WE - ICC	0.36	0.53	0.21	0.38	0.80
	K.J. Law	1.20	1.21	0.48	0.94	1.06
Right	NA - ICC	0.56	0.44	0.15	0.18	0.26
	NC - ICC	0.28	0.30	0.18	0.30	0.46
	SO - ICC	0.73	0.28	0.40	0.24	2.08
	WE - ICC	0.45	0.34	0.21	0.44	0.43
	K.J. Law	0.95	1.37	0.51	0.77	1.03

NA - North Atlantic, NC - North Central, WE - Western, SO - Southern

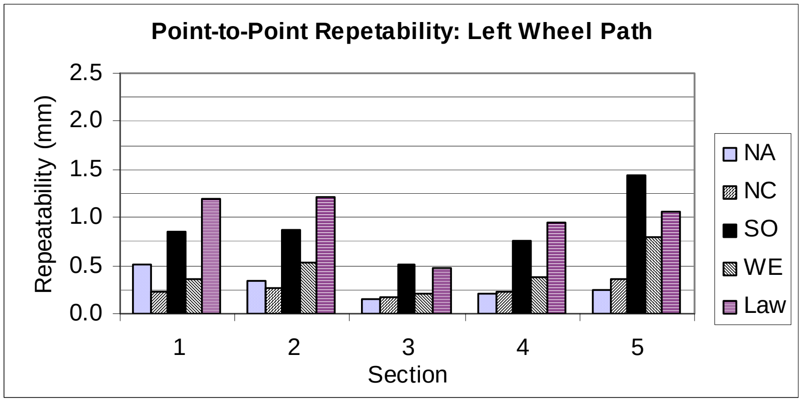


Figure 6.7. Point-to-point repeatability – left wheel path.

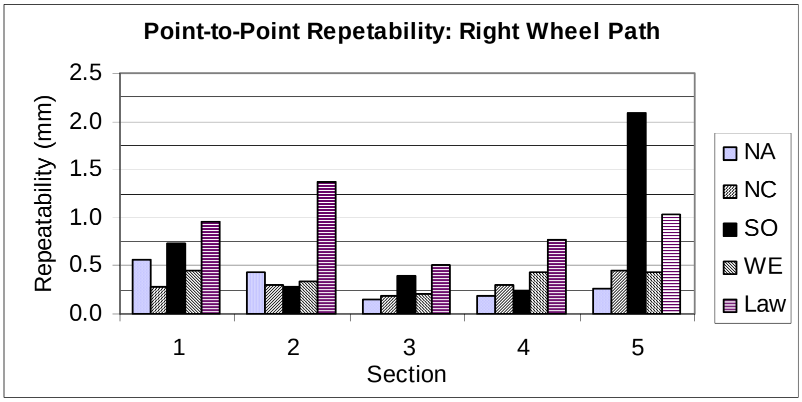


Figure 6.8 Point-to-point repeatability – right wheel path.

were noted for the following cases: (1) North Atlantic profiler, section 1 – left wheel path (value of 0.51) and section 1 – right wheel path (value of 0.56), and (2) Western Profiler: section 2 – left wheel path (value of 0.53) and section 5 – left wheel path (value of 0.80). The Southern profiler had values in excess of 0.50 along left wheel path at all sections, and had the highest value along the left wheel path at all five test sections. The Southern profiler also had point-to-point repeatability values in excess of 0.50 mm along the right wheel path at two sections (section 1 a value of 0.73 and section 5 a value of 2.08). The K. J. Law profiler had values in excess of 0.50 along the left and right wheel paths at all sections except for the left wheel path of section 3.

This analysis clearly indicates the Southern ICC profiler was showing lower profile repeatability when compared to the other three ICC profilers along the left wheel path.

6.5.3 Comparison of Replicate Profile Runs Collected by Each Profiler

A visual observation of the multiple profile run plots at each section for each profiler was performed to evaluate the repeatability of profile data. This evaluation was performed separately for the left, right and center sensor data. Appendix D contains the overlaid profile plots for all profilers along the left and right wheel paths at all test sections. Separate plots are presented for each profiler. The five profile runs shown on each plot are the profile runs that were used in the IRI evaluation. A review of these plots indicate the following: (1) generally the North Atlantic, North Central and Western ICC profilers are showing good profile repeatability along both wheel paths, (2) repeatability of the K. J. Law profile runs is much less than the repeatability of the North Atlantic, North Central and Western ICC profilers along both wheel paths, (3) repeatability of the Southern profiler runs along the left wheel path is much less than the repeatability of the other three ICC profilers, (4) the Southern profiler exhibits lower profile repeatability when compared to the other ICC profilers at sections 1 and 5 along the right wheel path.

Although the Southern ICC profiler showed poor profile repeatability when compared to the other three ICC profilers, the IRI values obtained by the Southern profiler were comparable to the IRI values obtained by the other three profilers. This indicates the differences in the profiles between the replicate runs for the Southern profiler are occurring for longer wavelengths, which are outside the range of wavelengths that influence the IRI.

Appendix E contains the overlaid profile plots for the center path at all sections. Separate plots are presented for each profiler. A review of these plots indicated the center sensors in all profilers showed good repeatability at all test sections except for the center sensor in the Southern profiler at sections 1 and 3.

6.5.4 Comparison of Profiles Between Profilers

A representative profile for each ICC profiler was selected for each section by evaluating the five replicate profile runs available at a test section. Thereafter, these profiles were overlaid separately for the left and the right wheel paths to compare the profile plots of the four ICC profilers. The profiles from the K. J. Law profiler were not used in this evaluation as a previous study indicated there were differences between profiles collected by the ICC and K. J. Law profilers. The differences in the profiles between the two profilers were caused because of differences in the long wavelengths. Appendix F contains the overlaid profile plots from the four ICC profilers as well as offset profile plots for these profilers. The overlaid profile plots indicate reasonable agreement in profiles between the four ICC profilers, with no profiler showing a profile shape that is not in agreement with the rest of the profilers. The offset plots show that all four profilers appear to be capturing similar profile features present on the pavement.

6.5.5 Profile Repeatability of Southern Profiler

The profiles collected by the Southern ICC profiler during the profiler comparison test were less repeatable than the profiles collected by the other three ICC profilers. This may have been caused by incorrect operation of the profiler by the profiler operator or it may be related to a problem with the profiler. The Southern RSC hired a new profiler operator shortly after the Mn/Road test was conducted. A set of profile data collected by the new profiler operator at GPS sections in the Southern Region was evaluated to determine if the poor repeatability of the Southern profiler at the Mn/Road test was caused by the way the profiler was operated. Table 6.8 shows the GPS sections that were used in this evaluation.

Table 6.8. GPS Sites in Southern region used to evaluate profile repeatability.

GPS Site Number	Description	IRI (m/km)		
		Left Wheel Path	Right Wheel Path	Average
404154	Smooth AC	1.07	1.21	1.08
404165	Rough AC	2.37	2.71	2.36
404155	Smooth PCC	1.00	0.90	1.01
133020	Medium Rough PCC	1.41	1.39	1.46
486179	Chip Seal	1.79	1.61	1.76

The procedure described in section 6.5.2 was followed to compute the point-to-point repeatability of the profile data for the sections shown in table 6.8. Table 6.9 presents the computed point-to-point repeatability values for the GPS sections.

The point-to-point repeatability values shown in table 6.9 are comparable with the values obtained by the other three ICC profilers at Mn/Road test sections that had similar IRI values. Appendix G presents the overlaid profile plots for the five sites shown in table 6.9. For each site separate plots are shown for the left, center and right paths. A visual review of the profile plots indicated that the Southern ICC profiler was exhibiting good repeatability of profiles along all three paths at all five sites. The level of repeatability observed in these plots appears to be similar to that exhibited by the other three ICC profilers at Mn/Road.

Table 6.9. Point to point repeatability values for GPS sections.

GPS Site Number	Description	IRI (m/km)		Point to Point Repeatability (mm)	
		Left Wheel Path	Right Wheel Path	Left Wheel Path	Right Wheel Path
404154	Smooth AC	1.07	1.21	0.17	0.12
404165	Rough AC	2.37	2.71	0.38	0.55
404155	Smooth PCC	1.00	0.90	0.18	0.12
133020	Medium Rough PCC	1.41	1.39	0.25	0.22
486179	Chip Seal	1.79	1.61	0.68	0.19

This investigation indicated that the lower profile repeatability of the Southern RSC profiler at the Mn Road test was likely due to problems with operational procedures (e.g., insufficient lead in) that were followed by the profiler operator.

6.6 Summary

Repeatability of IRI Values

The precision criterion for IRI indicated in Directive P-19 is that the IRI standard deviation from multiple runs at a section should be less than 0.04 m/km. This criterion was met for all cases except for the following: (1) all profilers except for North Central – right wheel path of section 1, (2) all profilers – right wheel path of section 2, (3) North Central – left wheel path of section 2 and 4, (4) K. J. Law – left wheel path of section 5,

Distresses were present along the right wheel path at sections 1 and 4, and variability in the paths profiled by the profilers was the likely cause for the profilers to fail the specified criterion at these two sites. At section 2, the North Central profiler had an IRI standard deviation of 0.042 m/km for the left wheel path, which was just above the specified criterion. The cause for the profiler not being able to meet the specified criterion is attributed to variations in the profile path.

At section 4, the North Central profiler had an IRI standard deviation of 0.042 m/km, which was 0.02 m/km above the specified criterion, while at section 5, the K. J. Law profiler had an IRI standard deviation of 0.061 m/km, which was 0.021 m/km above the specified criterion. For both these cases, the cause for the IRI standard deviation being above the specified criterion is not clear, and needs further investigation.

Comparison of IRI Values

Good agreement between profiler IRI and Dipstick IRI was obtained for the majority of the cases. Directive P-19 indicates the difference between the Dipstick IRI and profiler IRI should be within ± 0.16 m/km. This criterion was met for all cases except for the following: (1) section 1 and section 5 – K. J. Law, right wheel path, (2) section 4 – North Central, left wheel path. (3) section 2 – right wheel path, all profilers except for North Atlantic.

At sections 1 and 5, along the right wheel path, the K. J. Law profiler obtained IRI values that were less than the Dipstick IRI by 0.18 m/km and 0.19 m/km, respectively. These values are just above the specified criterion.

At section 4, along the left wheel path, the North Central profiler obtained an IRI that was 0.25 m/km greater than the IRI from the Dipstick. There are differences in magnitudes of profile features present on the profiles obtained by the Dipstick and the North Central profiler that is likely to be the cause for the difference in IRI. Further investigation is needed to look into this issue.

At section 2, along the right wheel path, all profilers except for the North Atlantic profiler failed the specified criterion for difference in IRI with the Dipstick IRI. Pavement distresses were present along the right wheel path at section 2. Comparison of profiles from the Dipstick and the profilers indicated the generally the same features were present in all profiles, but the magnitudes of some features were different, which resulted in differences in IRI. Further investigation is needed to look into this issue.

Comparison of Profiles

The K. J. Law profiler and the Southern ICC profiler showed much higher variability in replicate profiles collected along the left wheel path at all sections when compared to the data collected by the other three ICC profilers. Along the right wheel path, the K. J. Law profiler showed much higher variability in replicate profiles when compared to the ICC profilers. Comparison of right wheel path data for the ICC profilers indicated that the Southern ICC profiler showed the highest variability at three sections. A visual examination of the profile data plots along the center path indicated that all profilers seemed to be showing similar repeatability, except that at sections 1 and 3 the Southern profiler showed poor repeatability when compared to the other profilers.

A comparison of profiles obtained by the four ICC profilers at the five test sections indicated all four profilers are capturing similar profile features. A profile feature that appeared in any ICC profiler was also present on the profiles collected by the other ICC profilers.

The Southern RSC hired a new profiler operator shortly after the Mn/Road tests were completed. The data collected by that operator at five GPS sections were evaluated to investigate the repeatability of the Southern profiler. This investigation indicated that the Southern profiler was obtaining repeatable data that were comparable to the data obtained by the other three ICC profilers at the Mn/Road test sections. The poor repeatability of the Southern profiler at the

Mn/Road test sections is attributed to incorrect operational procedures that were followed by the profiler operator.

7.0 EFFECT OF TEST SPEED ON IRI AND PROFILE

An experiment was performed using the Southern ICC profiler and the K. J. Law profiler to investigate the effect of test speed on IRI and profile. This experiment was performed at test section 1. Each profiler obtained profile measurements at this test section at test speeds of 35 km/h, 50 km/h, 65 km/h, 80 km/h, 95 km/h and 110 km/h, with two runs being performed at each test speed. Tables 7.1 and 7.2 show the IRI values that were obtained for the Southern ICC profiler and the K. J. Law profilers, respectively.

A t-test was performed to investigate if the mean IRI value obtained from profiles collected at test speeds of 35 km/h, 50 km/h, 65 km/h, 95 km/h and 110 km/h for each profiler was different from the mean IRI value obtained by that profiler when the section was tested at a speed of 80 km/h. The mean IRI value for the test speed of 80 km/h was obtained from the five profiler runs that were conducted at this section during the comparison test (see Table 6.5). The t-test was conducted separately for the left and right wheel path IRI for the Southern ICC profiler as well as the K. J. Law profiler using the first set of data collected for the speed test. The t-test indicated there was no difference in the IRI values for both profilers along both wheel paths (at $\alpha = 0.05$).

8.0 CONCLUSIONS

The results from the profiler comparison study and subsequent testing indicated that the four ICC profilers that are currently collecting data for the LTPP program are performing satisfactorily.

A discussion of the results obtained form each of the analysis performed on the data are presented next.

Static Height Sensor Test Results:

Results from the static height sensor test conducted during the profiler comparison indicated there were several cases where the sensors in the profilers failed to meet the specified bias criterion (bias within ± 0.25 mm) and the precision criterion (precision < 0.125 mm). The cause for the failure of these criteria may have been due to movements that occurred in the vehicle when the test was performed, as well as marks that were present on the blocks that were used for the testing of one profiler.

Table 7.1. IRI values for Southern ICC profiler from speed test.

Profiler Speed (km/h)	IRI (m/km)			
	First Set of Runs		Second Set of Runs	
	Left Wheel Path	Right Wheel Path	Left Wheel Path	Right Wheel Path
35	1.34	1.53	1.32	1.72
50	1.29	1.73	1.27	1.75
65	1.30	1.71	1.29	1.75
80	1.30	1.64	1.29	1.74
95	1.28	1.59	1.29	1.63
110	1.33	1.58	1.29	1.69
Average	1.30	1.63	1.29	1.71
Std. Dev.	0.024	0.078	0.018	0.046

Table 7.2. IRI values for K. J. Law profiler from speed test.

Profiler Speed (km/h)	IRI (m/km)			
	First Set of Runs		Second Set of Runs	
	Left Wheel Path	Right Wheel Path	Left Wheel Path	Right Wheel Path
35	1.27	1.69	1.29	1.72
50	1.25	1.74	1.24	1.76
65	1.29	1.69	1.31	1.70
80	1.30	1.72	1.27	1.72
95	1.34	1.58	1.32	1.64
110	1.30	1.66	1.28	1.70
Average	1.29	1.68	1.28	1.71
Std. Dev.	0.031	0.056	0.034	0.040

After the Mn/Road test, each RSC repeated the height sensor test on their profiler at their facility. The vehicle was placed on jacks when performing this test to eliminate any vehicle movement during the test. In addition, a clean set of blocks was used to perform the test. All sensors in all profilers passed the precision criterion when the test was repeated. All sensors in all profilers, except for the center sensor in the North Central profiler at the 25 mm position met the bias criterion when the test was repeated. At the 25 mm position, the center sensor in the North Central profiler had a bias value of 0.27 mm, which was 0.02 mm outside the specified tolerance. As the data from the center sensor are not stored in the LTPP database, and as the sensor was out of the specified tolerance at only one position by 0.02 mm, it does not raise any serous concerns about the data collected by this profiler. However, the North Central RSC should keep track of the performance of this sensor during the monthly sensor calibration check, and if further deterioration in the sensor is noted ICC should be contacted to resolve this issue.

Bounce Test Results

The left and right sensors of the four ICC profilers as well as the K. J. Law profiler met the bounce test criteria that are specified in the Profile Manual. These criteria are that the IRI from the static test be less than 0.08 m/km, and the difference between the dynamic bounce test and the static test be less than 0.10 m/km.

DMI Test Results

Results from the DMI test that was performed immediately after calibration of the DMI indicated that the ICC profilers from the North Central, Southern and Western regions, and the K. J. Law profiler passed the DMI bias and precision criterion. The North Atlantic profiler failed both the bias and the precision criterion because the tires in the profiler were not sufficiently warmed up when the test was conducted. The North Atlantic profiler subsequently conducted another DMI test, and met both the DMI bias and precision criterion.

Precision of IRI

Overall, all profilers appear to be obtaining repeatable IRI values. The data did not indicate that a particular profiler was behaving differently than the other profilers as far as IRI repeatability is concerned. The precision criterion for IRI indicated in Directive P-19 is that the IRI standard deviation from multiple runs at a section should be less than 0.04 m/km. However, if distresses are present along the wheel path, sometimes this criterion cannot be met because even a slight shift in the path profiled can have a significant impact on the IRI.

The IRI precision criterion was met for all cases except for the following few cases: (1) all profilers except for North Central – right wheel path of section 1, (2) all profilers – right wheel path of section 2, (3) North Central – left wheel path of section 2 and 4, (4) K. J. Law – left wheel path of section 5.

Distresses were present along the right wheel path at sections 1 and 4, and variability in the paths profiled by the profilers was the likely cause for the profilers to fail the specified criterion at these two sites. At section 2, the North Central profiler had an IRI standard deviation of 0.04 m/km for the left wheel path, which was just above the specified criterion, and the cause for the profiler not being able to meet the specified criterion is attributed to variations in the profile path.

At section 4, the North Central profiler had an IRI standard deviation of 0.04 m/km, which was 0.02 m/km above the specified criterion, while at section 5, the K. J. Law profiler had an IRI standard deviation of 0.06 m/km, which was 0.02 m/km above the specified criterion. In both cases, the cause for the IRI standard deviation being above the specified criterion is not clear, and needs further investigation.

Comparison Profiler and Dipstick IRI Values

Good agreement between profiler IRI and Dipstick IRI was obtained for the majority of the cases. Directive P-19 indicates the difference between the Dipstick IRI and profiler IRI should be within ± 0.16 m/km. This criterion was met for all cases except for the following: (1) section 1 and section 5 – K. J. Law, right wheel path, (2) section 4 – North Central, left wheel path. (3) section 2 – right wheel path, all profilers except for North Atlantic.

At section 2, along the right wheel path, all profilers except for the North Atlantic profiler failed the specified criterion for difference in IRI with the Dipstick IRI. Pavement distresses were present along the right wheel path at section 2. The cause for the failure of the specified criterion may be because of the differences in the way downward features on the pavement are measured by the Dipstick and the laser sensors. The dipstick has a footpad of 32 mm that can bridge over distresses, while the 1 mm diameter laser sensor will record such features. In addition the Dipstick has a sampling interval of 304.8 mm when compared to 25 mm for profilers, which can also have an impact on the IRI.

At section 4, along the left wheel path, the North Central profiler obtained an IRI that was 0.25 m/km greater than the IRI from the Dipstick. There are differences in magnitudes of profile features present on the profiles obtained by the Dipstick and the North Central profiler that is likely to be the cause for the difference in IRI. This may have been caused because the profiler followed a path different from the path that was measured with the Dipstick.

At sections 1 and 5, along the right wheel path, the K. J. Law profiler obtained IRI values that were less than the Dipstick IRI by 0.18 m/km and 0.19 m/km, respectively. The cause for the discrepancy is not apparent and needs further investigation.

Profile Repeatability and Comparison of Profiles

An evaluation of the profile data collected by the North Central, North Atlantic and Western ICC profilers indicated profile data collected by these profilers generally have a similar repeatability. The K. J. Law profiler as well as the Southern ICC profiler showed much higher variability in profile data along the two wheel paths when compared to the other three ICC profilers.

A comparison of profiles obtained by the four ICC profilers at the five test sections indicated all four profilers are capturing similar profile features. A profile feature that appeared in any ICC profiler was also present on the profiles collected by the other ICC profilers.

The Southern RSC hired a new profiler operator shortly after the Mn/Road tests were completed. The data collected by the new operator at five GPS sections were evaluated to investigate the repeatability of the Southern profiler. This investigation indicated that the Southern profiler was obtaining repeatable data that was comparable to the data obtained by the other three ICC profilers at the Mn/Road test sections. The poor profile repeatability obtained by the Southern profiler at the Mn/Road test sections may have been caused by problems with operational procedures (e.g., insufficient lead in, not maintaining a constant speed) that were followed by the profiler operator.

Collection of Data at Different Speeds

Collection of profiles at different speeds (35 km/h, 50 km/h, 65 km/h, 80 km/h, 95 km/h and 110 km/h) was performed by the K. J. Law and Southern ICC profilers. The analysis of the data indicated the IRI value did not appear to be influenced by the speed of testing over the tested speed range.

9.0 RECOMMENDATIONS FOR FURTHER STUDIES

These recommendations are presented for investigating some of the observations that were noted during this data analysis.

1. At some sections the difference between profiler and Dipstick IRI was greater than the 0.16 m/km criterion that is specified in LTPP Directive P-19. Usually, such cases occurred on sections that had pavement distresses along the wheel paths. These differences may be related to differences in the way downward features on a pavement are captured by the profiler and the Dipstick. The Dipstick has a footpad diameter of 32 mm that can bridge over cracks, while the laser sensors in the profiler can measure the depth of a crack. In addition, there are differences in the sampling interval between the profiler and the Dipstick that can also contribute to differences in IRI. Further study is needed to investigate the cause of the difference in IRI between the profiler and the Dipstick at sections that had an IRI difference that was greeter than the 0.16 m/km tolerance specified in Directive P-19.

2. At some sections, all five profilers showed a positive bias in IRI when compared to the Dipstick IRI, while at other sections all five profilers showed a negative bias. Further investigation is needed to identify the reason for this behavior.

APPENDIX A

STATIC HEIGHT SENSOR TEST RESULTS: MN/ROAD TEST

STATIC HEIGHT SENSOR MEASUREMENTS

RSC : North Atlantic ICC

DATE : July 17/2003

DISTANCE FROM GROUND TO SENSOR GLASS (mm): **LEFT :** 323 **CENTER :** 327 **RIGHT :** 326

LEFT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	134.640	134.310	134.090	133.920	133.710	134.134	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.081	25.072	25.015	25.010	24.975	25.031	25.03	0.001	0.045
BASE PLATE + 50 mm BLK + CAL PLATE	49.960	49.988	49.958	49.990	49.941	49.967	50.007	-0.040	0.021
BASE PLATE + 75 mm BLK + CAL PLATE	74.762	74.831	74.991	75.793	74.883	75.052	75.001	0.051	**0.423**
BASE PLATE + 100 mm BLK + CAL PLATE	100.041	100.196	100.251	99.891	100.020	100.080	100.021	0.059	**0.145**

CENTER SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	142.250	141.950	141.680	141.630	141.410	141.784	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.136	25.188	24.770	24.916	24.828	24.968	25.027	-0.059	**0.186**
BASE PLATE + 50 mm BLK + CAL PLATE	49.696	50.010	49.801	49.870	49.752	49.826	50.005	-0.179	0.121
BASE PLATE + 75 mm BLK + CAL PLATE	75.130	74.800	74.775	74.797	74.970	74.894	74.998	-0.104	**0.153**
BASE PLATE + 100 mm BLK + CAL PLATE	100.231	100.258	100.107	100.197	100.231	100.205	100.025	0.180	0.059

RIGHT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	140.070	145.800	145.630	145.500	145.310	144.462	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	24.913	25.198	24.177	25.229	25.215	24.946	25.024	-0.078	**0.450**
BASE PLATE + 50 mm BLK + CAL PLATE	49.805	49.990	49.813	49.731	50.076	49.883	50.005	-0.122	**0.144**
BASE PLATE + 75 mm BLK + CAL PLATE	74.903	75.331	75.001	74.991	74.996	75.044	74.998	0.046	**0.165**
BASE PLATE + 100 mm BLK + CAL PLATE	100.203	100.251	100.279	100.202	100.271	100.241	100.028	0.213	0.037

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC : North Central ICC

DATE : July 15/2003

DISTANCE FROM GROUND TO SENSOR GLASS (mm): **LEFT :** 318 **CENTER :** 321 **RIGHT :** 319

LEFT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	150.780	150.590	150.540	150.500	150.310	150.544	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.143	25.119	25.183	25.127	25.184	25.151	25.031	0.120	0.031
BASE PLATE + 50 mm BLK + CAL PLATE	50.158	50.148	50.155	50.150	50.162	50.155	50.017	0.138	0.006
BASE PLATE + 75 mm BLK + CAL PLATE	75.264	75.224	75.265	75.295	75.287	75.267	75.011	**0.256**	0.028
BASE PLATE + 100 mm BLK + CAL PLATE	100.364	100.244	100.205	100.278	100.294	100.277	100.037	0.240	0.059

CENTER SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	148.570	148.450	148.450	148.420	148.290	148.436	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.354	25.405	25.408	25.392	25.412	25.394	25.028	**0.366**	0.024
BASE PLATE + 50 mm BLK + CAL PLATE	50.220	50.175	50.209	50.222	50.228	50.211	50.007	0.204	0.021
BASE PLATE + 75 mm BLK + CAL PLATE	75.125	75.099	75.151	75.150	75.158	75.137	75.014	0.123	0.024
BASE PLATE + 100 mm BLK + CAL PLATE	100.209	100.121	100.139	100.187	100.155	100.162	99.986	0.176	0.036

RIGHT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	148.100	147.950	147.960	147.910	147.850	147.954	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.130	25.125	25.191	25.212	25.137	25.159	25.022	0.137	0.040
BASE PLATE + 50 mm BLK + CAL PLATE	50.085	50.096	50.105	50.010	50.136	50.086	50.012	0.074	0.047
BASE PLATE + 75 mm BLK + CAL PLATE	75.061	75.031	75.029	75.076	75.070	75.053	74.998	0.055	0.022
BASE PLATE + 100 mm BLK + CAL PLATE	100.192	100.108	99.996	100.075	100.104	100.095	100.027	0.068	0.070

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: Southern ICC

Date: 16-Jul-03

Distance from Ground to Sensor Glass (mm): Left: 325 Center 323 Right 323

Left Sensor	Measured Height of Block (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown for Height 1)	148.790	148.700	148.850	148.980	148.900	148.844	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.172	25.104	25.177	25.145	25.062	25.132	25.024	0.108	0.049
Base Plate + 50 mm Block + Calibration Plate	49.901	50.089	50.197	50.099	49.938	50.045	50.012	0.033	0.123
Base Plate + 75 mm Block + Calibration Plate	75.133	75.190	75.216	75.091	75.177	75.161	75.006	0.155	0.050
Base Plate + 100 mm Block + Calibration Plate	100.283	100.122	100.339	100.411	100.393	100.310	100.031	**0.279**	0.116

Center Sensor	Measured Height of Block (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown in Height 1)	148.430	148.450	148.510	148.060	148.050	148.300	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	24.062	25.073	25.175	25.178	24.948	24.887	25.025	-0.138	**0.471**
Base Plate + 50 mm Block + Calibration Plate	49.988	50.122	50.148	49.836	49.925	50.004	50.012	-0.008	**0.132**
Base Plate + 75 mm Block + Calibration Plate	75.128	75.085	75.996	74.963	75.993	75.433	75.013	**0.420**	**0.516**
Base Plate + 100 mm Block + Calibration Plate	100.257	100.376	100.110	100.076	100.017	100.167	100.043	0.124	**0.146**

Right Sensor	Measured Height of Block (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown in Height 1)	146.610	146.430	146.360	145.560	148.500	146.692	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	24.862	25.089	25.126	25.223	25.200	25.100	25.024	0.076	**0.144**
Base Plate + 50 mm Block + Calibration Plate	50.045	50.024	50.092	50.014	50.055	50.046	50.012	0.034	0.030
Base Plate + 75 mm Block + Calibration Plate	75.013	75.018	75.963	75.240	75.093	75.265	75.006	**0.259**	**0.401**
Base Plate + 100 mm Block + Calibration Plate	100.099	100.053	100.195	100.108	100.163	100.124	100.030	0.094	0.056

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: Western ICC
Date: 15-Jul-03

Distance from Ground to Sensor Glass (mm): Left: 321 Center: 326 Right: 330

Left Sensor	Measured Height of Block (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown for Height 1)	162.93	162.86	163.00	162.91	162.94	162.928	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.223	25.118	25.242	25.128	25.173	25.1768	25.017	0.160	0.055
Base Plate + 50 mm Block + Calibration Plate	50.162	50.156	50.082	50.078	50.036	50.1028	50.015	0.088	0.054
Base Plate + 75 mm Block + Calibration Plate	75.066	75.117	75.109	75.039	75.051	75.0764	74.993	0.083	0.035
Base Plate + 100 mm Block + Calibration Plate	100.178	100.143	100.134	100.140	100.182	100.1554	100.025	0.130	0.023

Center Sensor	Measured Height of Block (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown in Height 1)	153.64	153.63	153.64	153.63	153.63	153.634	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	24.963	24.916	24.954	24.992	24.935	24.952	25.019	-0.067	0.029
Base Plate + 50 mm Block + Calibration Plate	49.589	49.691	49.793	49.635	49.617	49.665	50.007	**-0.342**	0.081
Base Plate + 75 mm Block + Calibration Plate	74.529	74.541	74.400	74.589	74.514	74.5146	74.991	**-0.476**	0.070
Base Plate + 100 mm Block + Calibration Plate	99.312	99.246	99.332	99.298	99.214	99.2804	100.017	**-0.737**	0.049

Right Sensor	Measured Height of Block (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown in Height 1)	157.69	157.78	157.72	157.72	157.69	157.72	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.043	25.167	25.114	25.098	25.042	25.0928	25.023	0.070	0.053
Base Plate + 50 mm Block + Calibration Plate	49.893	49.943	49.995	49.894	50.053	49.9556	50.015	-0.059	0.069
Base Plate + 75 mm Block + Calibration Plate	75.004	75.079	74.922	74.940	75.069	75.0028	74.998	0.005	0.072
Base Plate + 100 mm Block + Calibration Plate	99.873	99.916	99.881	99.961	99.988	99.9238	100.030	-0.106	0.050

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC : North Central KJ Law
DATE : July 15/2003

DISTANCE FROM GROUND TO SENSOR GLASS (mm): **LEFT :** 295.3 **CENTER :** 269.1 **RIGHT :** 272

LEFT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					Average (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Deviation of Heights (mm)
	TEST 1*	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	280.382	280.209	279.809	279.999	280.134	280.038	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.095	24.915	24.984	24.996	25.047	24.986	25	-0.015	0.054
BASE PLATE + 50 mm BLK + CAL PLATE	50.128	49.904	50.043	49.997	50.102	50.012	50	0.012	0.084
BASE PLATE + 75 mm BLK + CAL PLATE	74.967	74.827	74.859	74.895	74.922	74.876	75	-0.124	0.042

CENTER SENSOR	MEASURED HEIGHT OF BLOCK (mm)					Average (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Deviation of Heights (mm)
	TEST 1*	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	263.122	263.183	262.963	262.892	262.891	262.982	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.155	25.176	25.025	24.911	24.917	25.007	25	0.007	0.124
BASE PLATE + 50 mm BLK + CAL PLATE	50.439	50.245	50.094	49.906	49.952	50.049	50	0.049	**0.153**
BASE PLATE + 75 mm BLK + CAL PLATE	75.600	75.281	75.120	74.991	75.047	75.110	75	0.110	**0.126**

RIGHT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					Average (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Deviation of Heights (mm)
	TEST 1*	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	331.650	332.546	332.343	332.528	332.576	332.498	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	24.963	24.938	24.969	25.057	25.003	24.992	25	-0.008	0.051
BASE PLATE + 50 mm BLK + CAL PLATE	49.993	50.008	50.068	50.157	50.203	50.109	50	0.109	0.088
BASE PLATE + 75 mm BLK + CAL PLATE	74.773	75.052	75.044	75.180	75.195	75.118	75	0.118	0.081

* Test 1 was used to calibrate sensors, therefore average and standard deviation was calculated using results from tests 2 to 5

Note: Values outside tolerance are shown in bold

APPENDIX B

RESULTS OBTAINED BY REPEATING STATIC HEIGHT SENSOR TEST

STATIC HEIGHT SENSOR MEASUREMENTS

RSC : North Atlantic Region
DATE : 14-Oct-03

LEFT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	146.270	146.290	146.300	146.310	146.030	146.240	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.267	25.314	25.281	25.226	25.273	25.272	25.024	0.248	0.032
BASE PLATE + 50 mm BLK + CAL PLATE	50.137	50.069	50.025	50.148	50.117	50.099	50.005	0.094	0.051
BASE PLATE + 75 mm BLK + CAL PLATE	74.957	74.986	74.991	74.963	74.995	74.978	74.998	-0.020	0.017
BASE PLATE + 100 mm BLK + CAL PLATE	99.867	99.900	99.863	99.881	99.934	99.889	100.022	-0.133	0.029

CENTER SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	151.550	151.660	151.700	151.810	151.810	151.706	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	24.914	25.008	25.010	25.034	25.038	25.001	25.021	-0.020	0.050
BASE PLATE + 50 mm BLK + CAL PLATE	49.990	49.956	49.954	49.947	49.902	49.950	50.005	-0.055	0.031
BASE PLATE + 75 mm BLK + CAL PLATE	74.869	74.908	74.871	74.941	74.861	74.890	75.006	-0.116	0.034
BASE PLATE + 100 mm BLK + CAL PLATE	99.923	99.944	99.961	99.931	100.004	99.953	100.017	-0.064	0.032

RIGHT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	151.100	151.030	151.120	151.210	151.250	151.142	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.184	25.131	25.172	25.121	25.125	25.147	25.027	0.120	0.029
BASE PLATE + 50 mm BLK + CAL PLATE	50.112	50.127	50.139	50.176	50.123	50.135	50.007	0.128	0.025
BASE PLATE + 75 mm BLK + CAL PLATE	75.132	75.101	75.156	75.147	75.139	75.135	74.998	0.137	0.021
BASE PLATE + 100 mm BLK + CAL PLATE	100.168	100.166	100.216	100.194	100.182	100.185	100.022	0.163	0.021

STATIC HEIGHT SENSOR MEASUREMENTS

RSC : North Central Region
DATE : 2-Oct-03

LEFT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	143.060	143.090	143.100	143.120	143.170	143.108	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.049	25.030	25.033	25.010	25.047	25.034	25.028	0.006	0.016
BASE PLATE + 50 mm BLK + CAL PLATE	49.969	49.968	49.917	49.989	49.884	49.945	50.02	-0.075	0.043
BASE PLATE + 75 mm BLK + CAL PLATE	74.980	74.893	75.030	75.013	75.126	75.008	75.019	-0.011	0.084
BASE PLATE + 100 mm BLK + CAL PLATE	99.948	100.024	100.005	100.042	100.046	100.013	99.999	0.014	0.040

CENTER SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	141.980	141.980	141.990	141.990	142.000	141.988	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.275	25.287	25.321	25.298	25.307	25.298	25.028	**0.270**	0.018
BASE PLATE + 50 mm BLK + CAL PLATE	50.118	50.137	50.131	50.200	50.134	50.144	50.015	0.129	0.032
BASE PLATE + 75 mm BLK + CAL PLATE	75.066	75.060	75.074	75.079	75.072	75.070	75.014	0.056	0.007
BASE PLATE + 100 mm BLK + CAL PLATE	100.070	100.032	100.027	99.988	99.998	100.023	100.027	-0.004	0.032

RIGHT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	141.930	141.920	141.870	141.920	141.910	141.910	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.141	25.116	25.073	25.100	25.105	25.107	25.028	0.079	0.025
BASE PLATE + 50 mm BLK + CAL PLATE	50.000	49.968	49.909	49.899	49.978	49.951	50.017	-0.066	0.044
BASE PLATE + 75 mm BLK + CAL PLATE	74.988	74.981	74.969	74.940	74.957	74.967	75.014	-0.047	0.019
BASE PLATE + 100 mm BLK + CAL PLATE	99.900	99.950	99.904	99.883	99.884	99.904	100.024	-0.120	0.027

STATIC HEIGHT SENSOR MEASUREMENTS

RSC : Southern Region
DATE : 16-Oct-03

LEFT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	154.210	154.320	154.220	154.190	154.250	154.238	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.059	25.158	25.098	25.106	25.123	25.109	25.022	0.087	0.036
BASE PLATE + 50 mm BLK + CAL PLATE	50.124	50.122	50.112	50.122	50.110	50.118	50.012	0.106	0.006
BASE PLATE + 75 mm BLK + CAL PLATE	75.165	75.236	75.216	75.232	75.210	75.212	75.006	0.206	0.028
BASE PLATE + 100 mm BLK + CAL PLATE	100.198	100.260	100.245	100.228	100.274	100.241	100.027	0.214	0.030

CENTER SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	158.715	158.750	158.720	158.700	158.720	158.721	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.097	25.081	24.966	25.007	24.866	25.003	25.025	-0.022	0.094
BASE PLATE + 50 mm BLK + CAL PLATE	50.085	50.024	49.910	49.925	49.995	49.988	50.012	-0.024	0.072
BASE PLATE + 75 mm BLK + CAL PLATE	74.829	74.942	74.941	74.949	74.906	74.913	75.014	-0.101	0.050
BASE PLATE + 100 mm BLK + CAL PLATE	99.853	99.979	99.889	99.881	99.874	99.895	100.029	-0.134	0.049

RIGHT SENSOR	MEASURED HEIGHT OF BLOCK (mm)					AVG. OF HEIGHTS (mm)	ACTUAL BLOCK HEIGHT (mm)	AVERAGE MINUS ACTUAL (mm)	STD. DEV. OF HEIGHTS (mm)
	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	153.550	153.550	153.610	153.510	153.570	153.558	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.171	25.194	25.242	25.161	25.132	25.180	25.030	0.150	0.041
BASE PLATE + 50 mm BLK + CAL PLATE	50.100	50.045	50.026	50.091	50.085	50.069	50.010	0.059	0.032
BASE PLATE + 75 mm BLK + CAL PLATE	75.116	75.044	75.068	75.027	74.999	75.051	75.019	0.032	0.044
BASE PLATE + 100 mm BLK + CAL PLATE	100.016	100.104	100.068	100.073	100.189	100.090	100.022	0.068	0.064

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: WRSC
Date: 26-Feb-04

Distance from Ground to Sensor Glass (mm): Left: 329 Center: 329 Right: 330

Left Sensor

Position	Height of Block (Note 1)					Avg. of Heights (mm)	Actual Block Height (mm)	Actual Minus Average (mm)	Std Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	169.26	169.19	169.19	169.20	169.14	169.196	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.185	25.126	25.095	25.148	25.022	25.1152	25.021	0.094	0.062
BASE PLATE + 50 mm BLK + CAL PLATE	49.964	49.998	50.002	50.001	50.072	50.0074	50.010	-0.003	0.039
BASE PLATE + 75 mm BLK + CAL PLATE	75.033	75.005	74.986	75.029	75.006	75.0118	74.993	0.019	0.019
BASE PLATE + 100 mm BLK + CAL PLATE	99.983	100.081	99.939	99.971	99.975	99.9898	100.020	-0.030	0.054

Center Sensor

Position	Height of Block (Note 1)					Avg. of Heights (mm)	Actual Block Height (mm)	Actual Minus Average (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	165.47	165.47	165.50	165.49	165.52	165.49	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	24.914	24.949	24.993	25.032	25.046	24.9868	25.021	-0.034	0.055
BASE PLATE + 50 mm BLK + CAL PLATE	49.899	49.802	49.925	49.953	49.919	49.8996	50.010	-0.110	0.058
BASE PLATE + 75 mm BLK + CAL PLATE	74.832	74.878	74.835	74.862	74.869	74.8552	74.993	-0.138	0.021
BASE PLATE + 100 mm BLK + CAL PLATE	99.845	99.880	99.888	99.896	99.898	99.8814	100.020	-0.139	0.022

Right Sensor

Position	Height of Block (Note 1)					Avg. of Heights (mm)	Actual Block Height (mm)	Actual Minus Average (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
BASE + CAL PLATE (VALUE FOR HGT 1)	170.20	170.16	170.17	170.20	170.14	170.174	N/A	N/A	N/A
BASE PLATE + 25 mm BLK + CAL PLATE	25.048	25.031	25.036	24.999	24.992	25.0212	25.021	0.000	0.024
BASE PLATE + 50 mm BLK + CAL PLATE	50.051	49.951	50.034	49.959	50.033	50.0056	50.010	-0.004	0.047
BASE PLATE + 75 mm BLK + CAL PLATE	74.948	74.882	74.894	74.893	74.904	74.9042	74.993	-0.089	0.026
BASE PLATE + 100 mm BLK + CAL PLATE	99.952	99.939	99.903	99.855	99.847	99.8992	100.020	-0.121	0.048

APPENDIX C

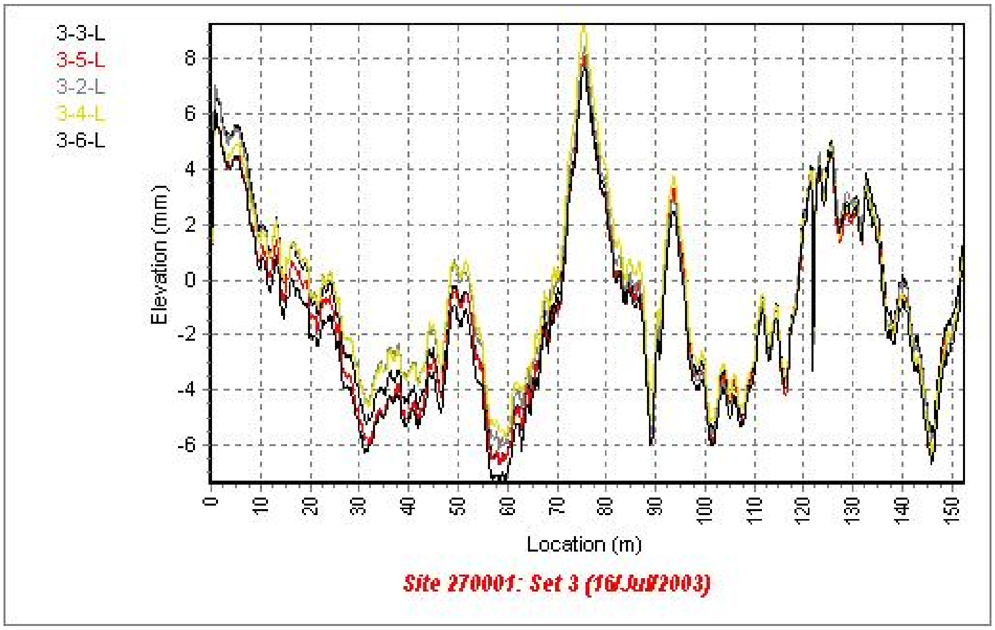
IRI VALUES OF PROFILE RUNS

Test Section	Profiler	Left Wheel Path IRI (m/km)							Right Wheel Path IRI (m/km)						
		Run Number							Run Number						
		1	2	3	4	5	Avg	S.D	1	2	3	4	5	Avg	S.D.
1	NA - ICC	1.246	1.274	1.278	1.292	1.253	1.269	0.019	1.754	1.689	1.596	1.626	1.747	1.682	0.071
1	NC - ICC	1.260	1.258	1.238	1.271	1.251	1.256	0.012	1.746	1.733	1.744	1.716	1.733	1.734	0.012
1	SO - ICC	1.319	1.265	1.276	1.282	1.288	1.286	0.020	1.599	1.749	1.736	1.729	1.627	1.688	0.070
1	WE - ICC	1.291	1.275	1.283	1.286	1.282	1.283	0.006	1.591	1.566	1.654	1.752	1.719	1.656	0.080
1	K.J. Law	1.302	1.288	1.317	1.338	1.291	1.307	0.021	1.653	1.66	1.638	1.563	1.666	1.636	0.042
2	NA - ICC	2.728	2.723	2.788	2.788	2.784	2.762	0.034	3.001	2.810	2.745	2.759	2.756	2.814	0.107
2	NC - ICC	2.700	2.751	2.815	2.765	2.736	2.753	0.042	2.927	2.861	3.044	3.209	3.024	3.013	0.132
2	SO - ICC	2.779	2.790	2.779	2.797	2.756	2.780	0.016	2.683	2.505	2.584	2.596	2.710	2.616	0.082
2	WE - ICC	2.758	2.760	2.758	2.686	2.792	2.751	0.039	2.646	2.457	2.638	2.467	2.489	2.539	0.094
2	K.J. Law	2.732	2.754	2.788	2.708	2.762	2.749	0.030	2.391	2.505	2.576	2.424	2.414	2.462	0.077
3	NA - ICC	0.913	0.936	0.937	0.921	0.917	0.925	0.011	0.982	0.955	0.975	0.995	1.001	0.982	0.018
3	NC - ICC	0.910	0.946	0.929	0.911	0.929	0.925	0.015	1.037	1.017	1.016	1.012	1.036	1.024	0.012
3	SO - ICC	0.920	0.932	0.946	0.919	0.912	0.926	0.013	0.958	0.944	0.954	0.969	0.994	0.964	0.019
3	WE - ICC	0.914	0.901	0.894	0.913	0.914	0.907	0.009	0.968	0.973	0.992	0.979	0.955	0.973	0.014
3	K.J. Law	0.951	0.947	0.934	0.943	0.941	0.943	0.006	0.967	0.959	0.929	0.957	0.977	0.958	0.018
4	NA - ICC	1.484	1.435	1.434	1.482	1.422	1.451	0.029	1.692	1.681	1.692	1.727	1.701	1.699	0.017
4	NC - ICC	1.611	1.512	1.539	1.592	1.592	1.569	0.042	1.713	1.718	1.726	1.737	1.720	1.723	0.009
4	SO - ICC	1.461	1.430	1.436	1.439	1.496	1.452	0.027	1.680	1.667	1.686	1.695	1.627	1.671	0.027
4	WE - ICC	1.448	1.416	1.442	1.421	1.428	1.431	0.014	1.705	1.722	1.716	1.716	1.699	1.712	0.009
4	K.J. Law	1.491	1.468	1.469	1.477	1.450	1.471	0.015	1.704	1.686	1.718	1.703	1.677	1.698	0.016
5	NA - ICC	2.267	2.210	2.258	2.259	2.249	2.249	0.023	2.535	2.505	2.541	2.554	2.564	2.540	0.022
5	NC - ICC	2.166	2.164	2.119	2.170	2.124	2.149	0.025	2.529	2.546	2.515	2.583	2.526	2.540	0.027
5	SO - ICC	2.166	2.181	2.141	2.121	2.127	2.147	0.026	2.554	2.539	2.490	2.589	2.548	2.544	0.036
5	WE - ICC	2.209	2.246	2.219	2.156	2.175	2.201	0.036	2.556	2.492	2.505	2.477	2.470	2.500	0.034
5	K.J. Law	2.304	2.298	2.170	2.270	2.197	2.248	0.061	2.393	2.475	2.438	2.425	2.452	2.437	0.031

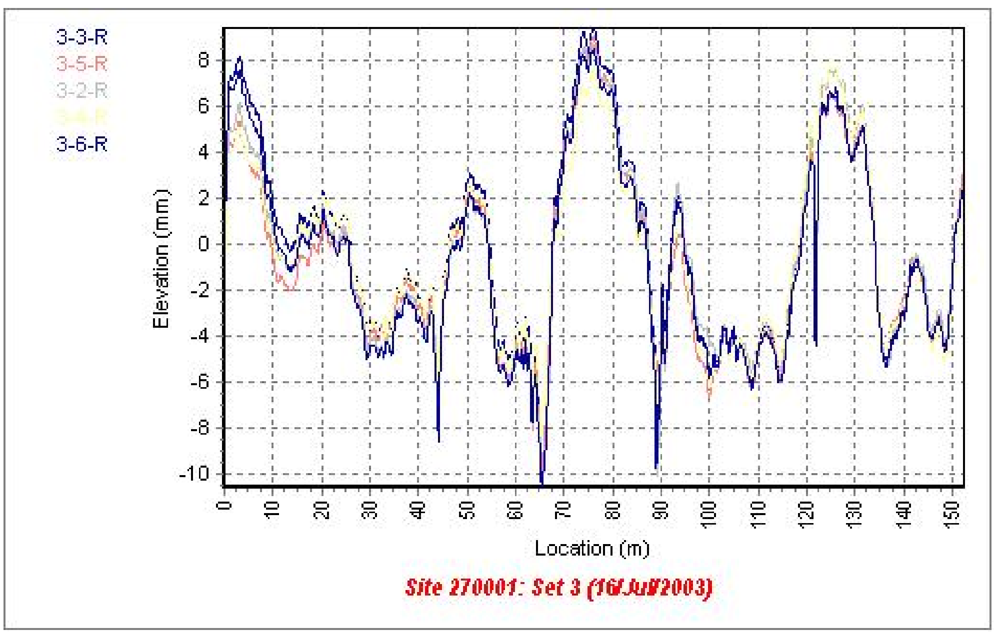
Note: SD - Standard Deviation, Avg - Average, NA - North Atlantic, NC - North Central, SO - Southern, WE - Western

APPENDIX D

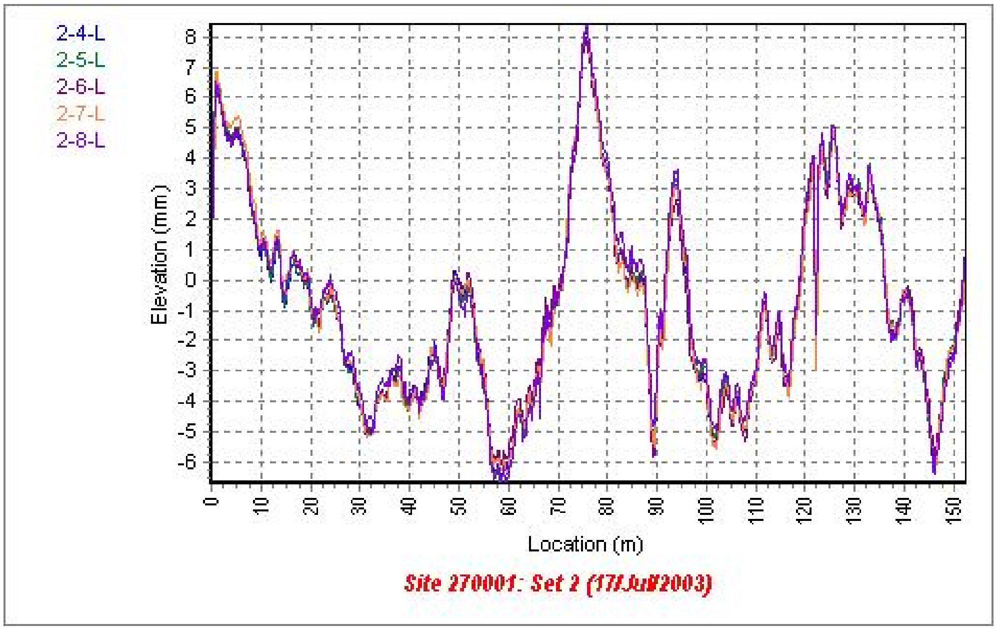
REPLICATE PROFILE RUNS OBTAINED BY THE PROFILERS



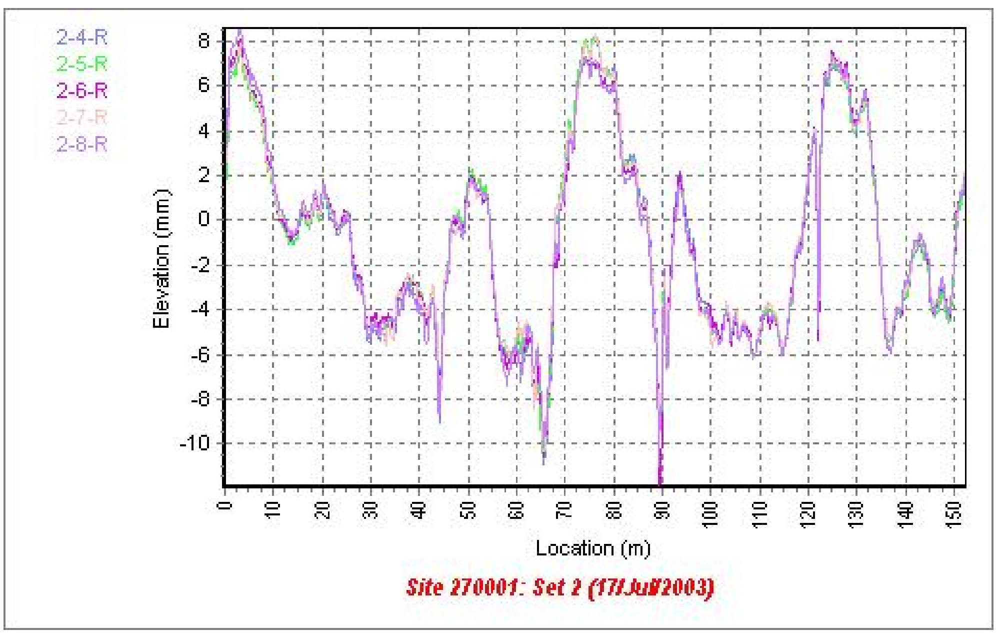
Site 1 – North Atlantic – Left Wheel Path.



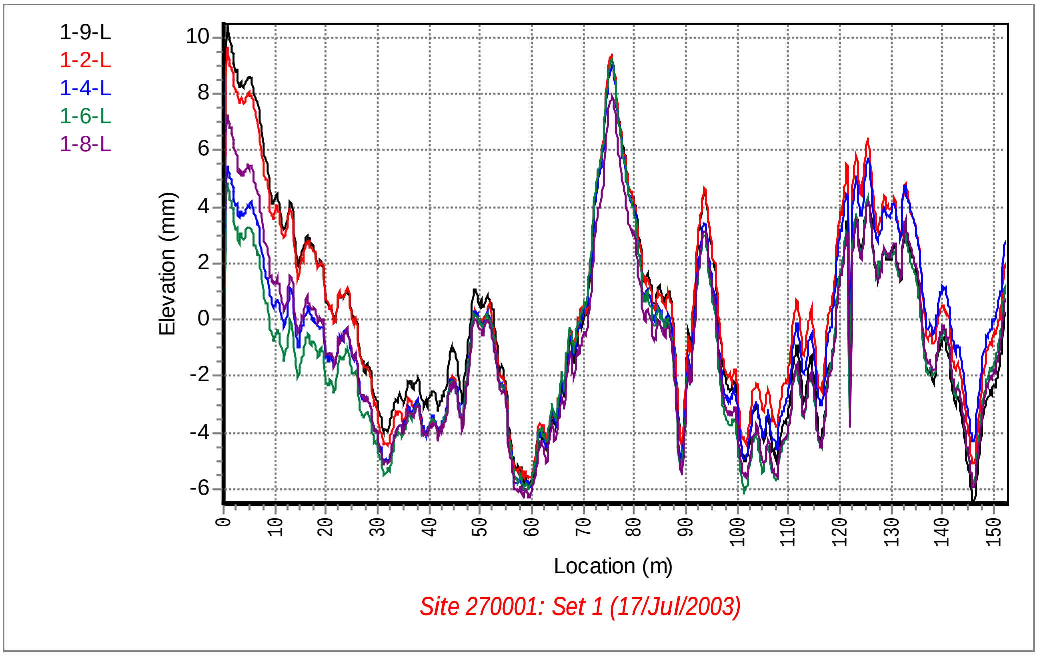
Site 1 - North Atlantic – Right Wheel Path.



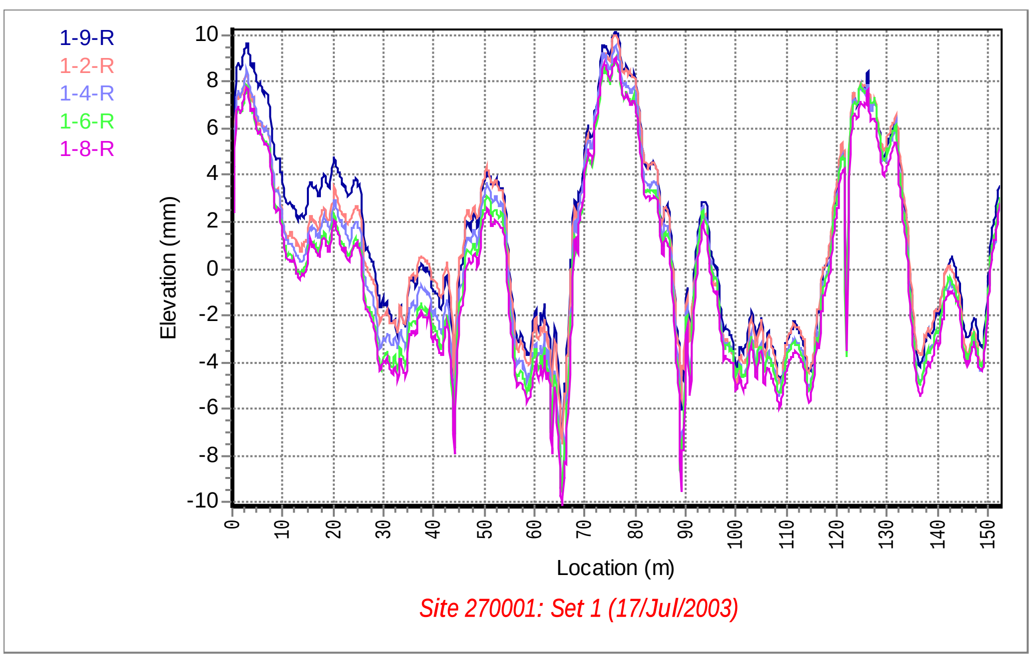
Site 1 – North Central – Left Wheel Path.



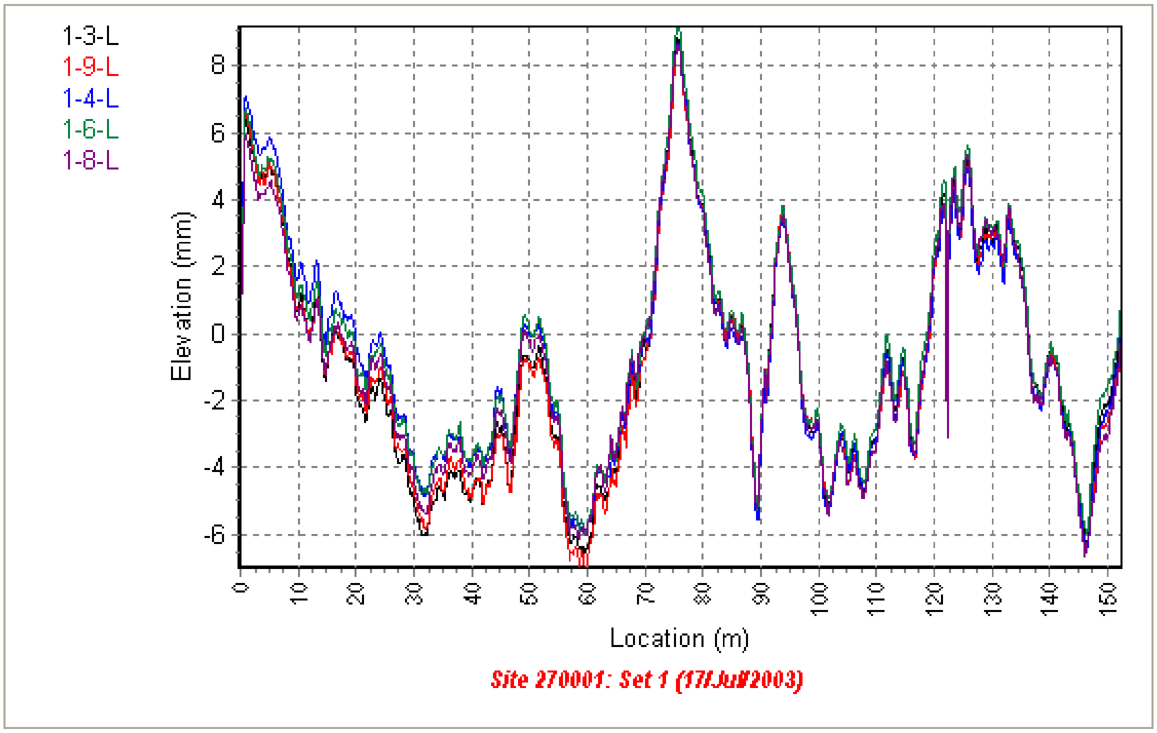
Site 1 – North Central – Right Wheel Path.



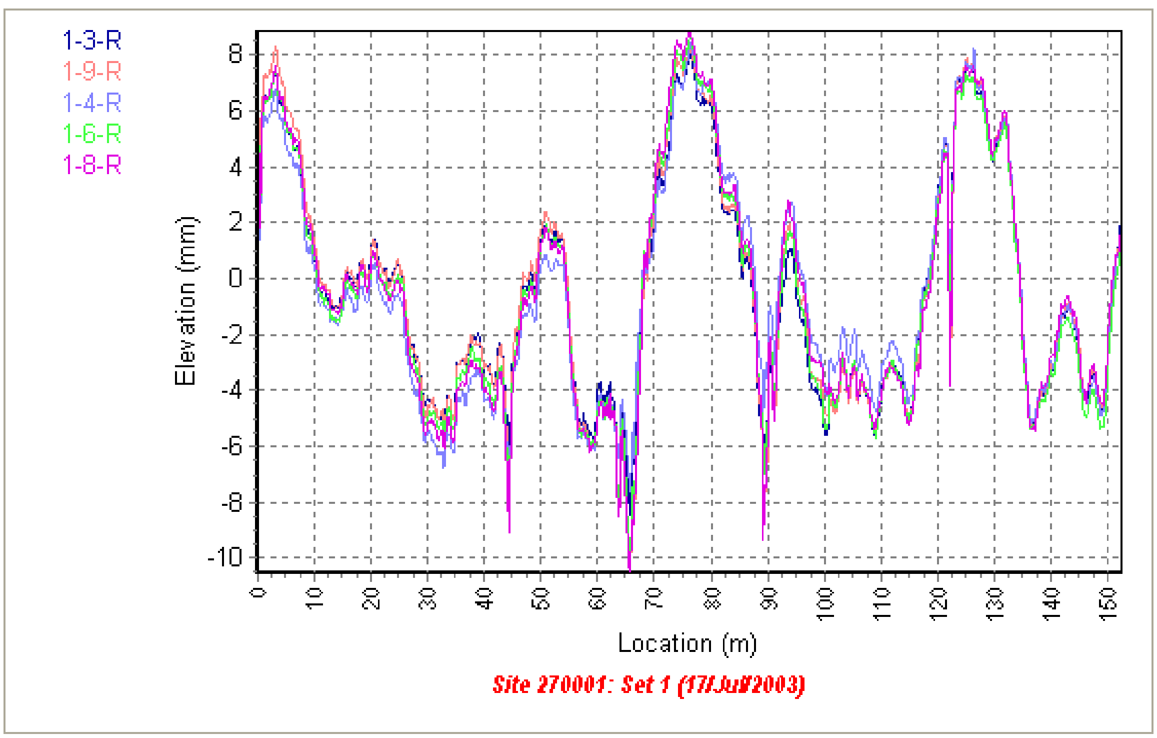
Site 1 – Southern – Left Wheel Path



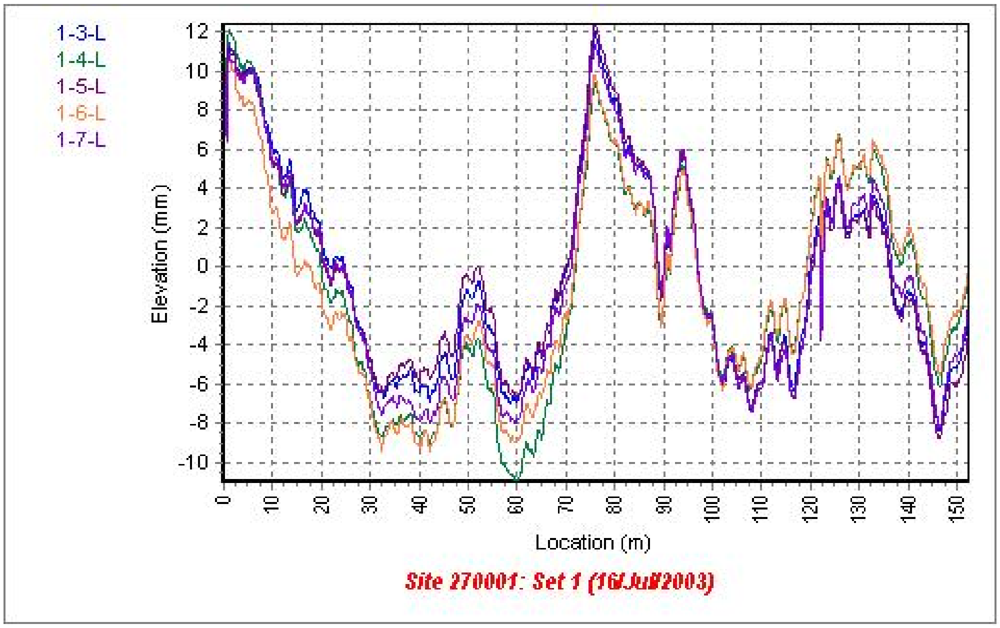
Site 1 – Southern – Right Wheel Path



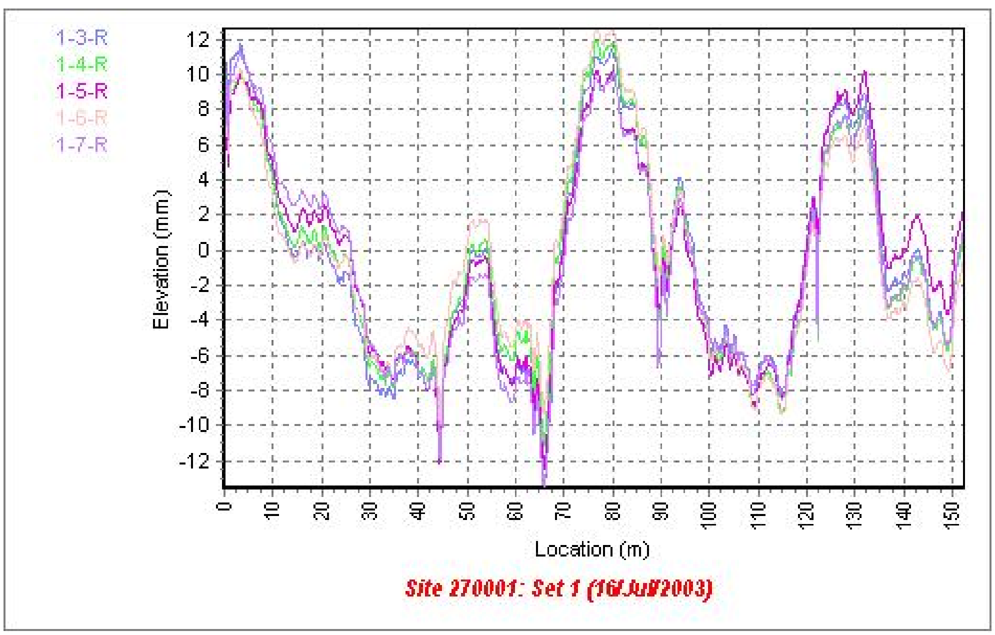
Site 1 – Western – Left Wheel Path



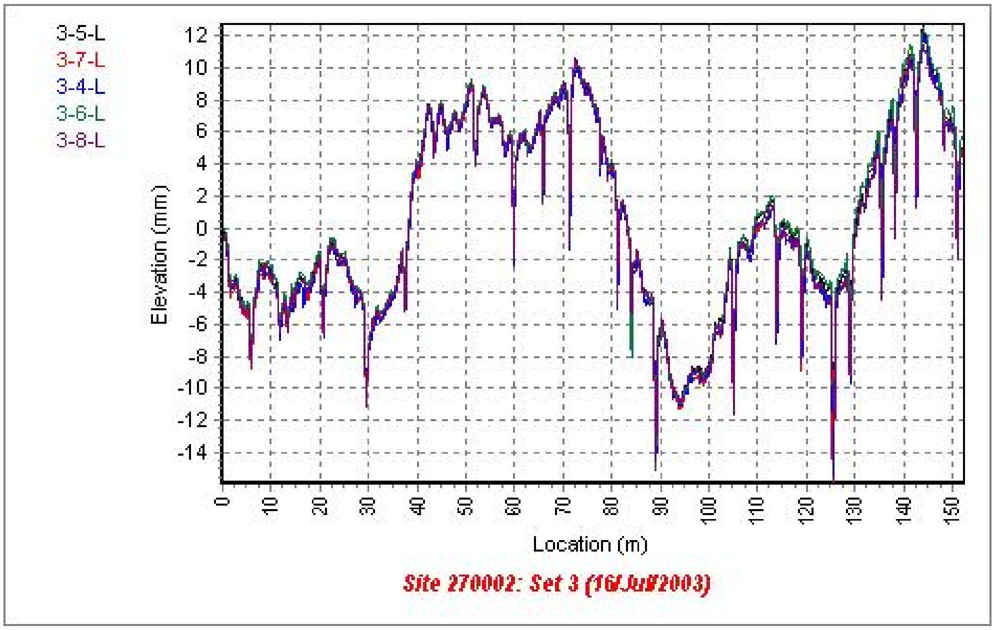
Site 1 – Western - Right Wheel Path.



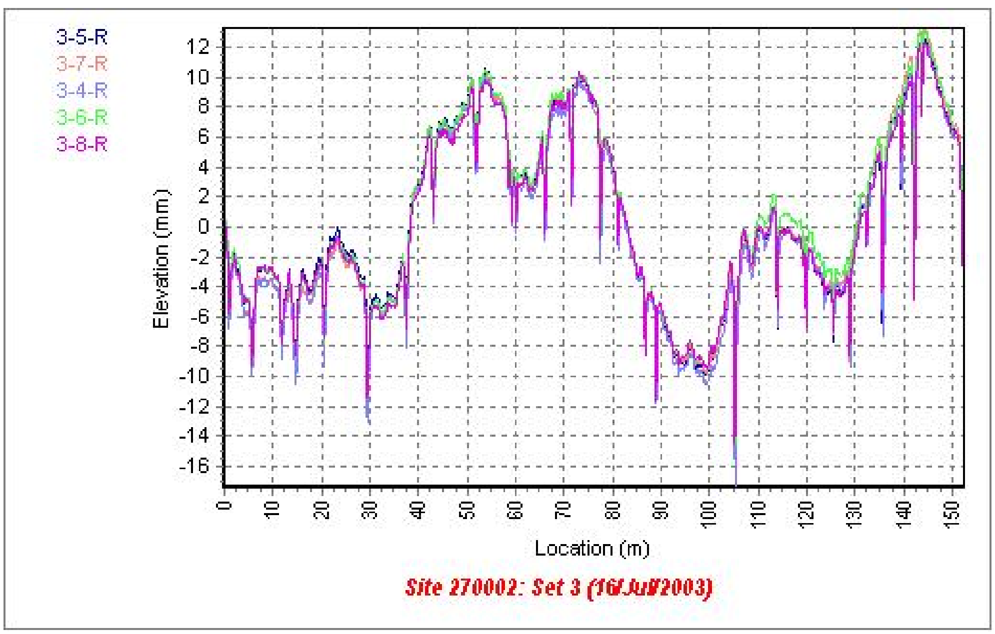
Site 1 - K.J. Law – Left Wheel Path.



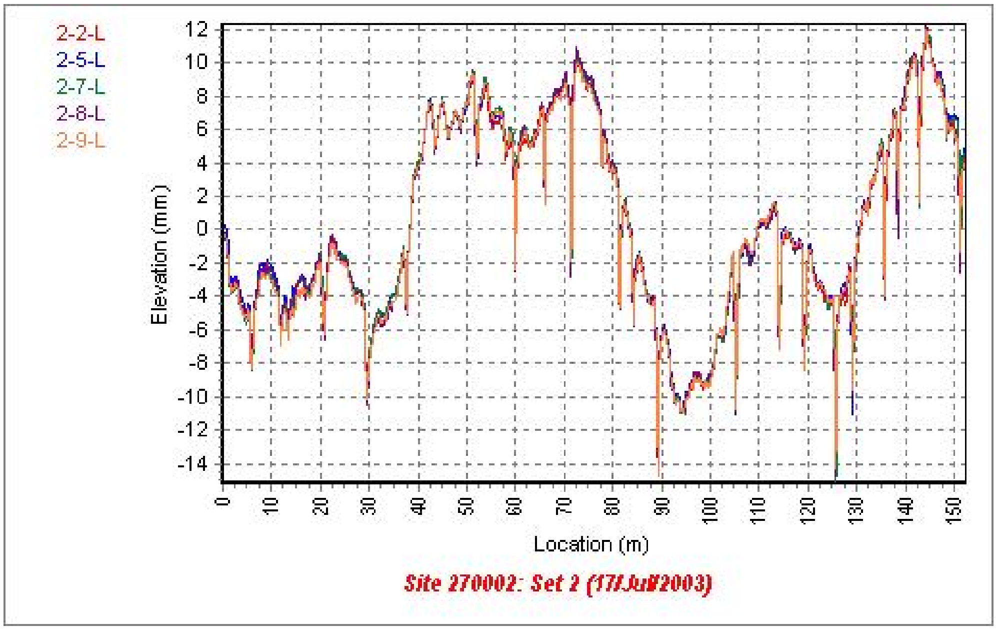
Site 1 – K.J. Law – Right Wheel Path.



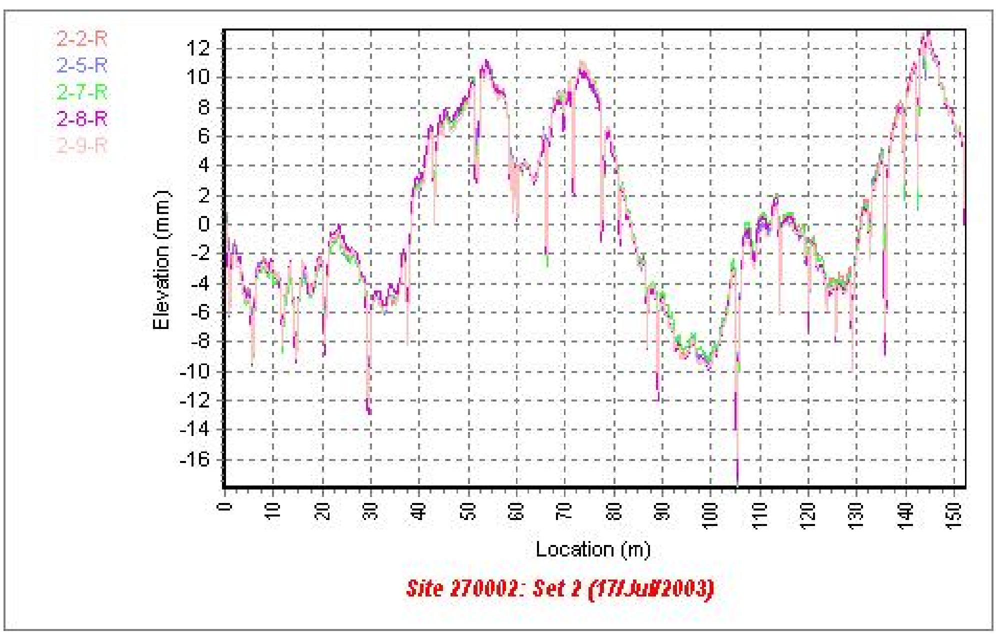
Site 2 – North Atlantic – Left Wheel Path.



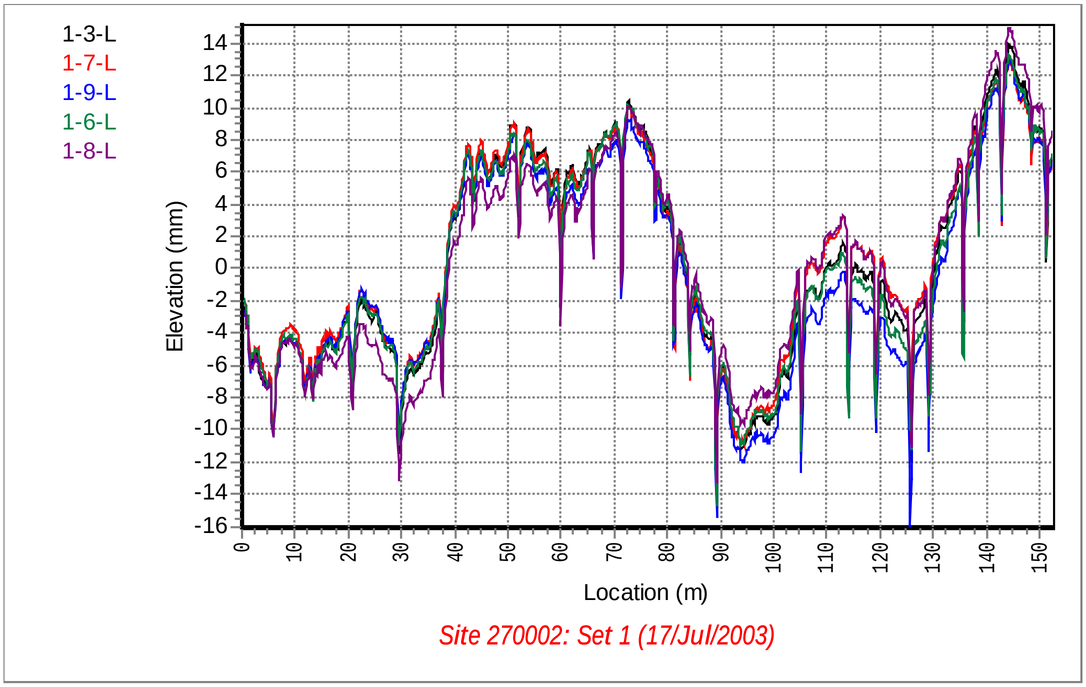
Site 2 – North Atlantic – Right Wheel Path.



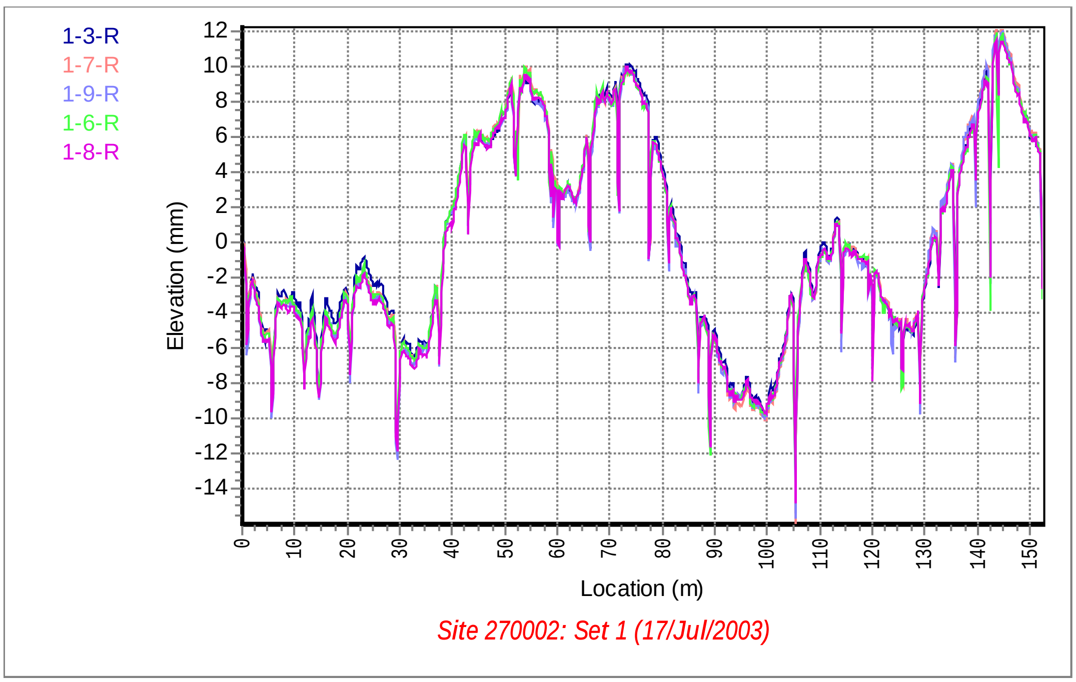
Site 2 – North Central – Left Wheel Path.



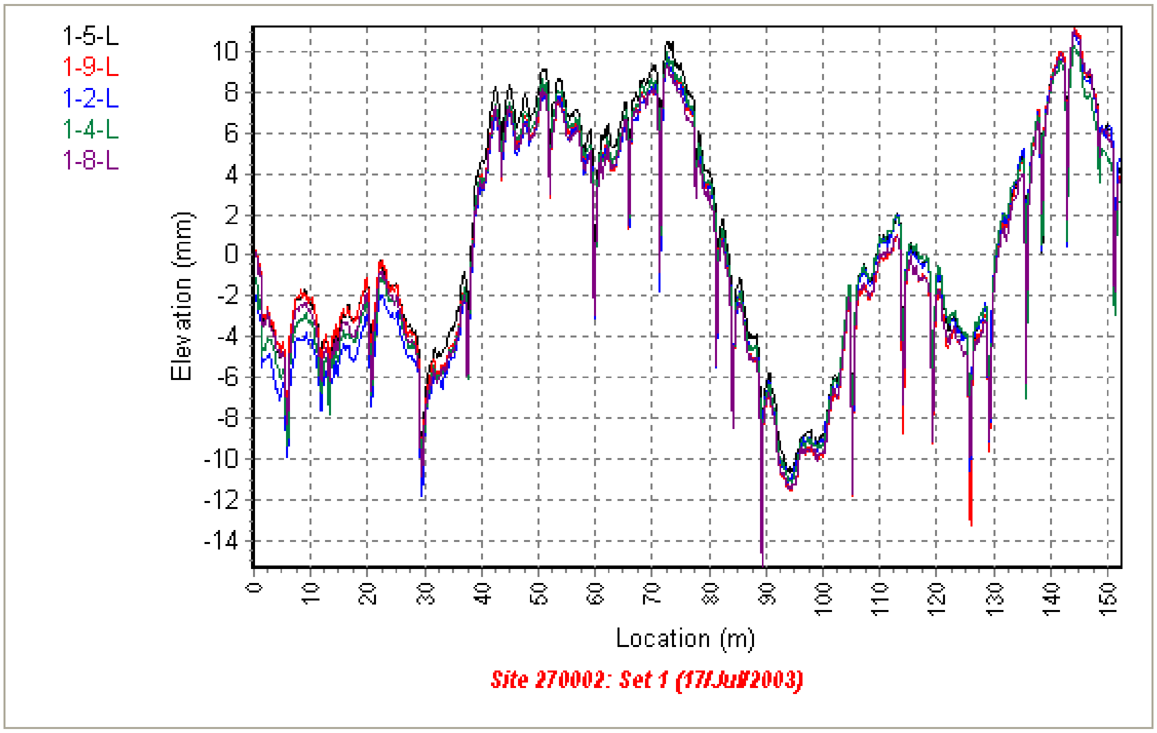
Site 2 – North Central – Right Wheel Path.



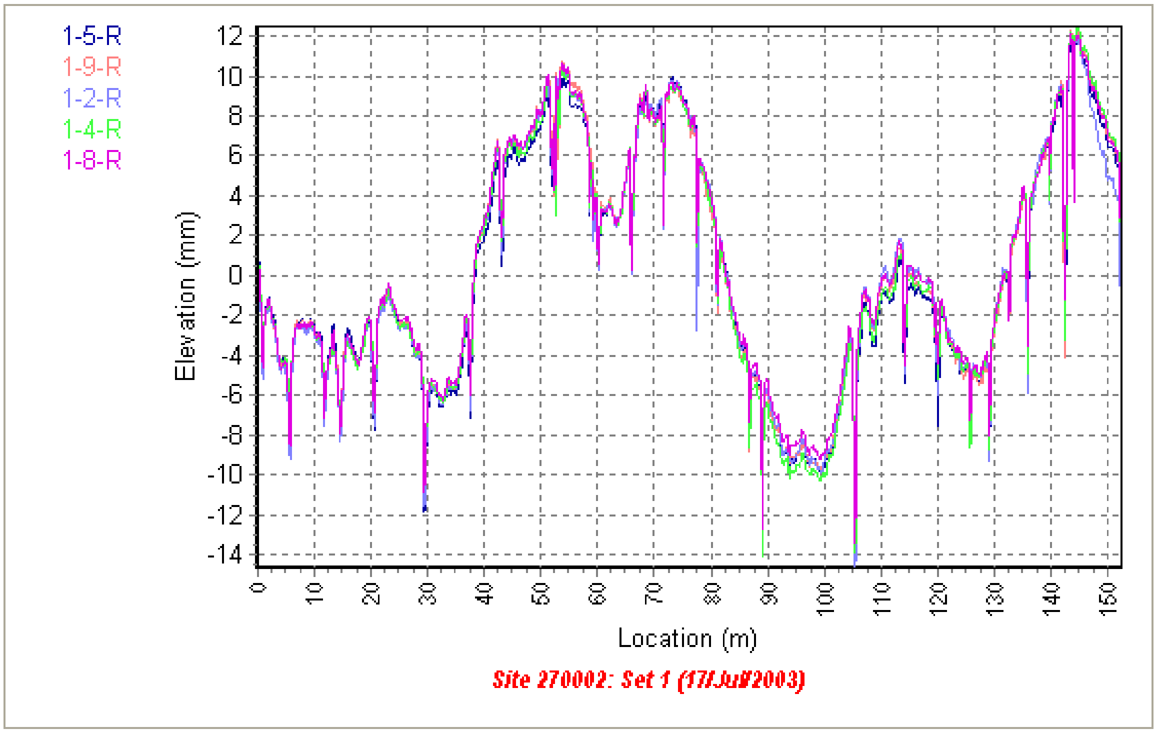
Site 2 – Southern – Left Wheel Path.



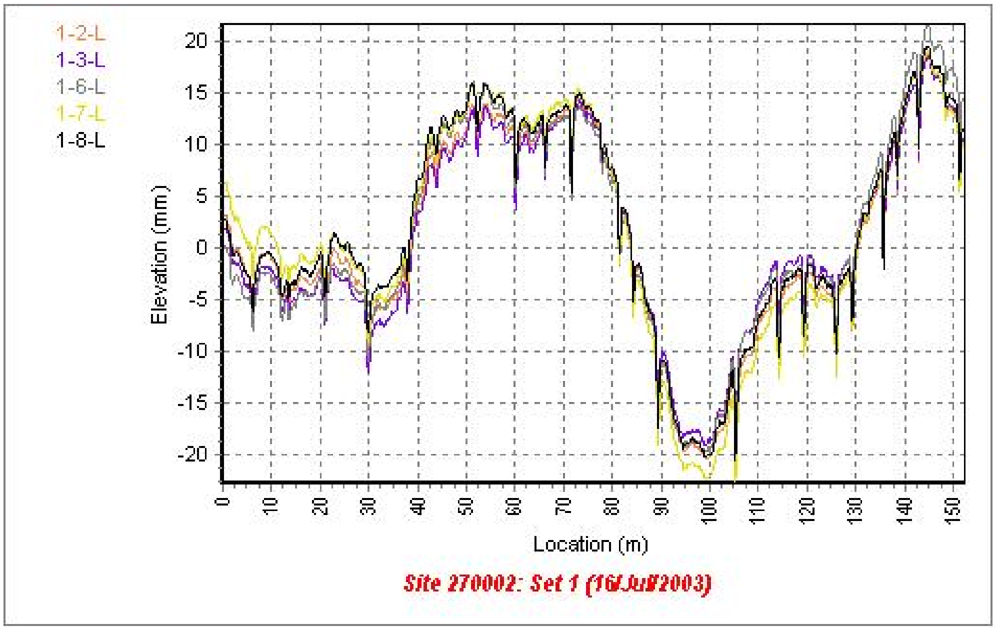
Site 2 – Southern – Right Wheel Path.



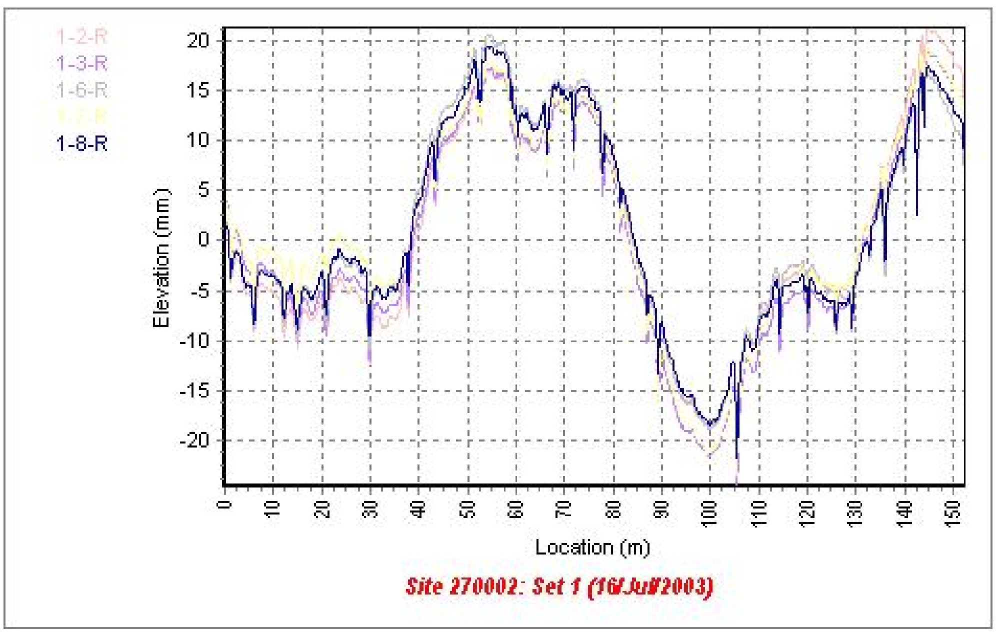
Site 2 – Western – Left Wheel Path.



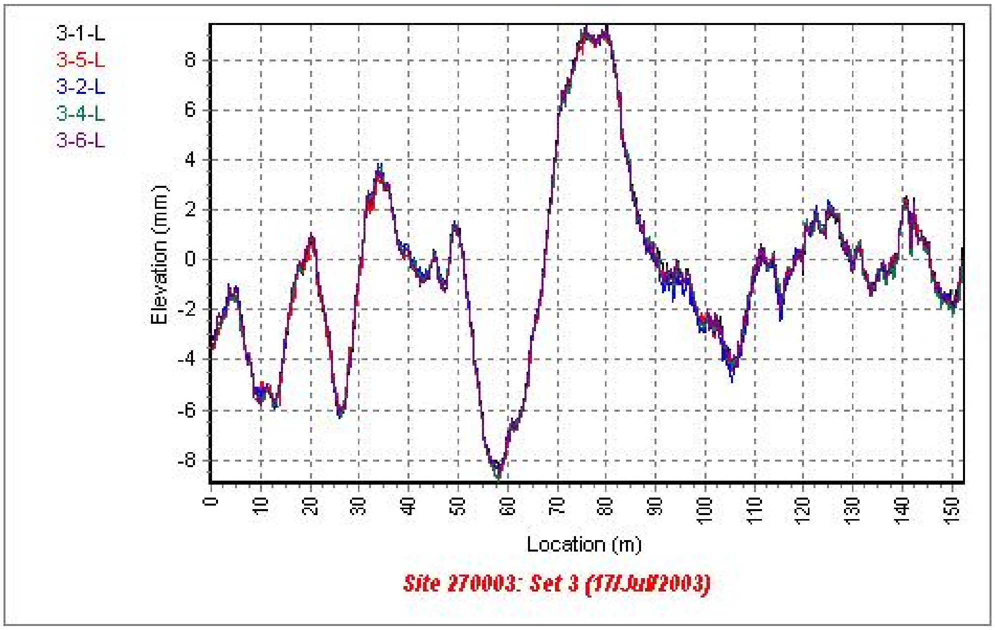
Site 2 – Western – Right Wheel Path.



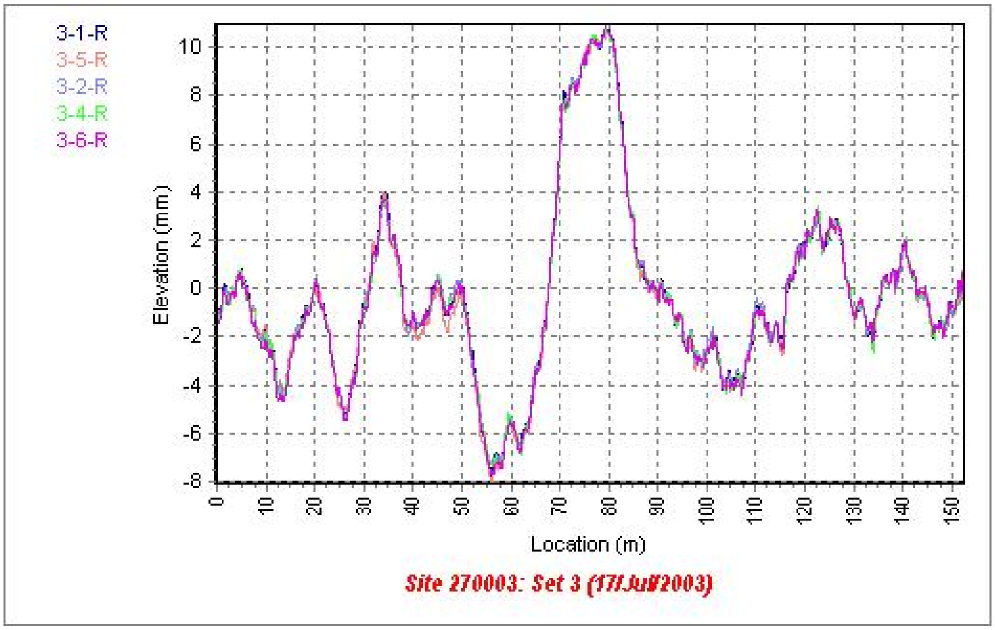
Site 2 – K.J. Law – Left Wheel Path.



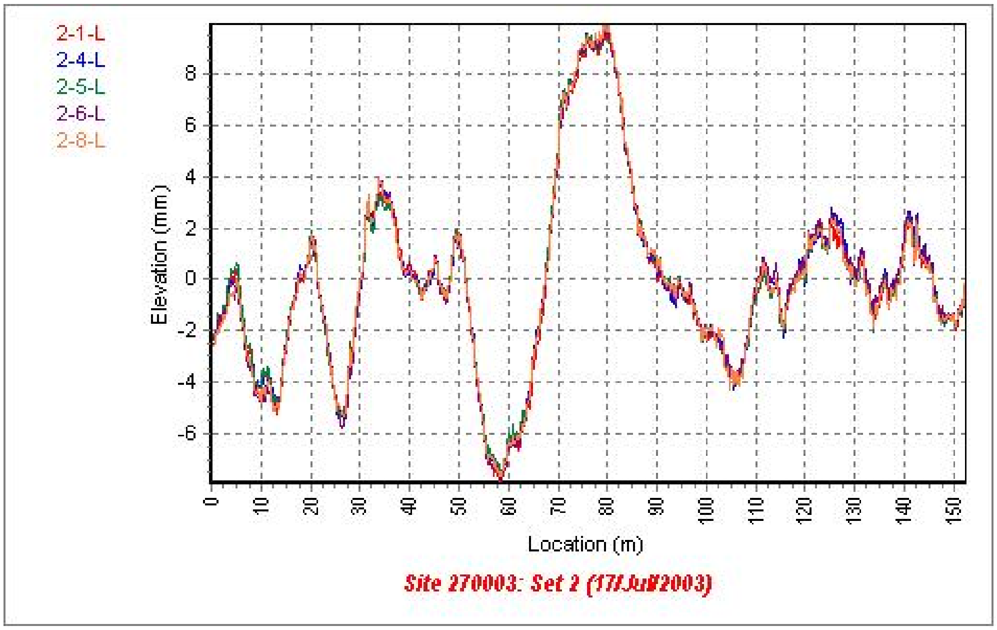
Site 2 – K.J. Law – Right Wheel Path.



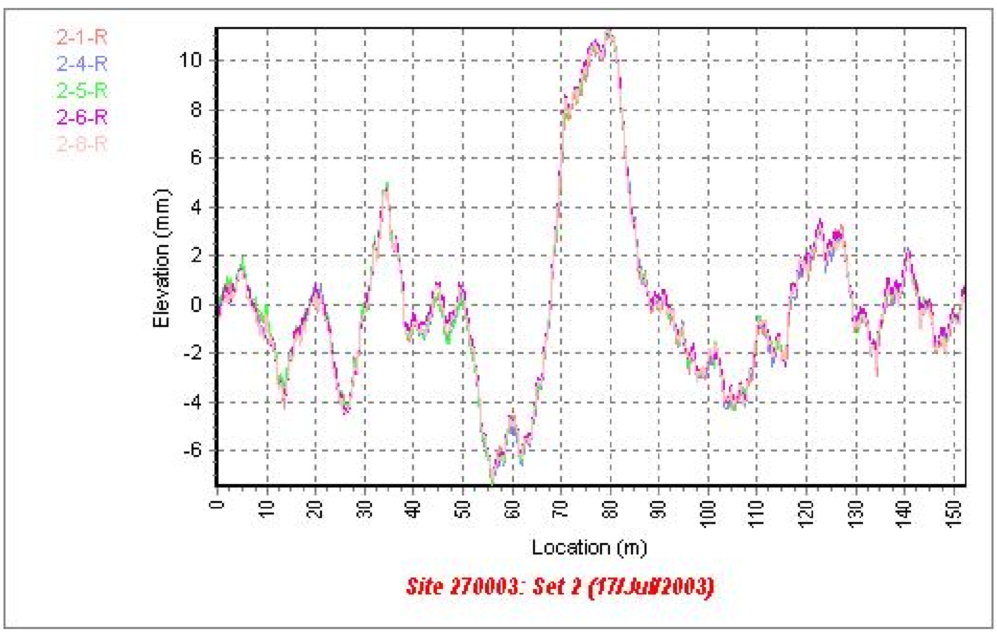
Site 3 – North Atlantic – Left Wheel Path.



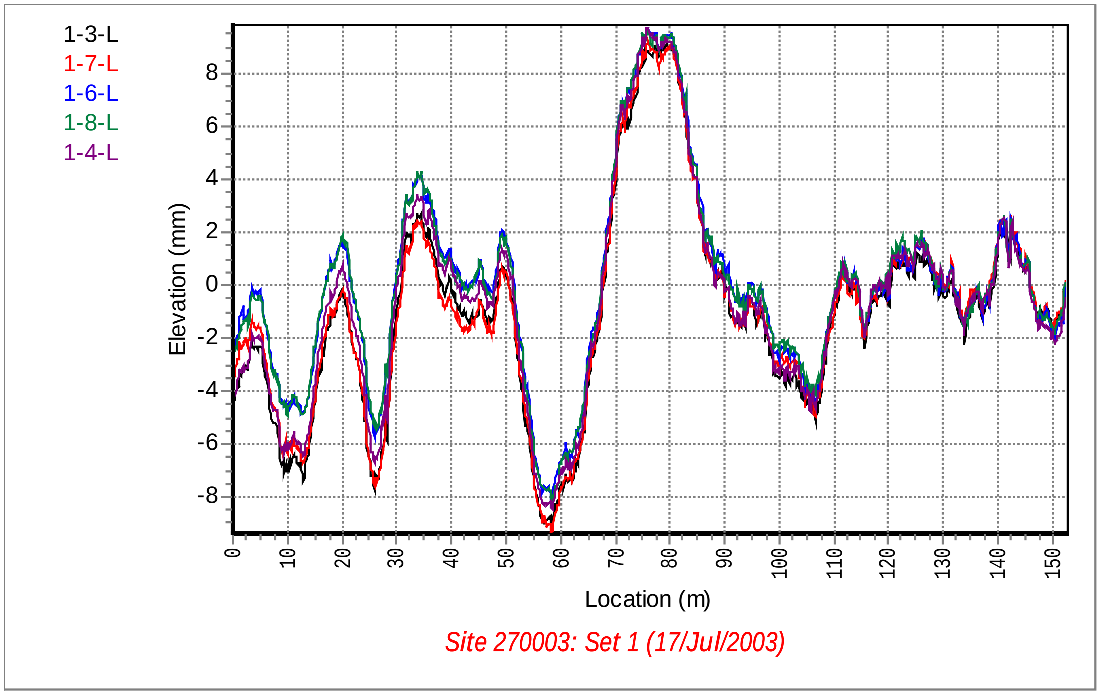
Site 3 – North Atlantic – Right Wheel Path.



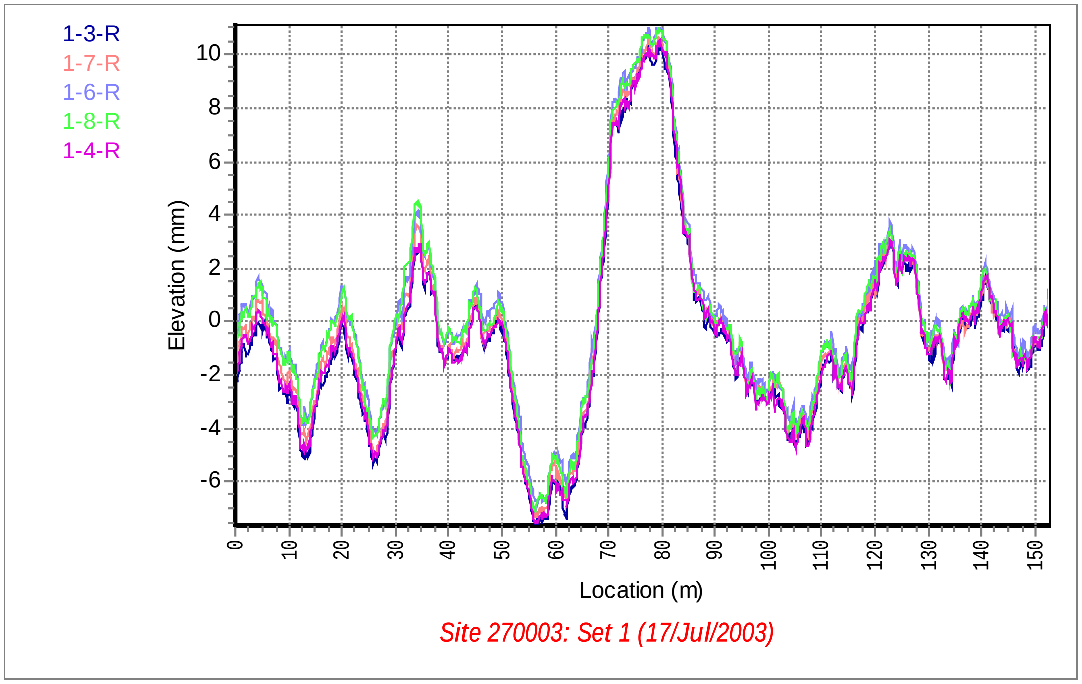
Site 3 – North Central – Left Wheel Path.



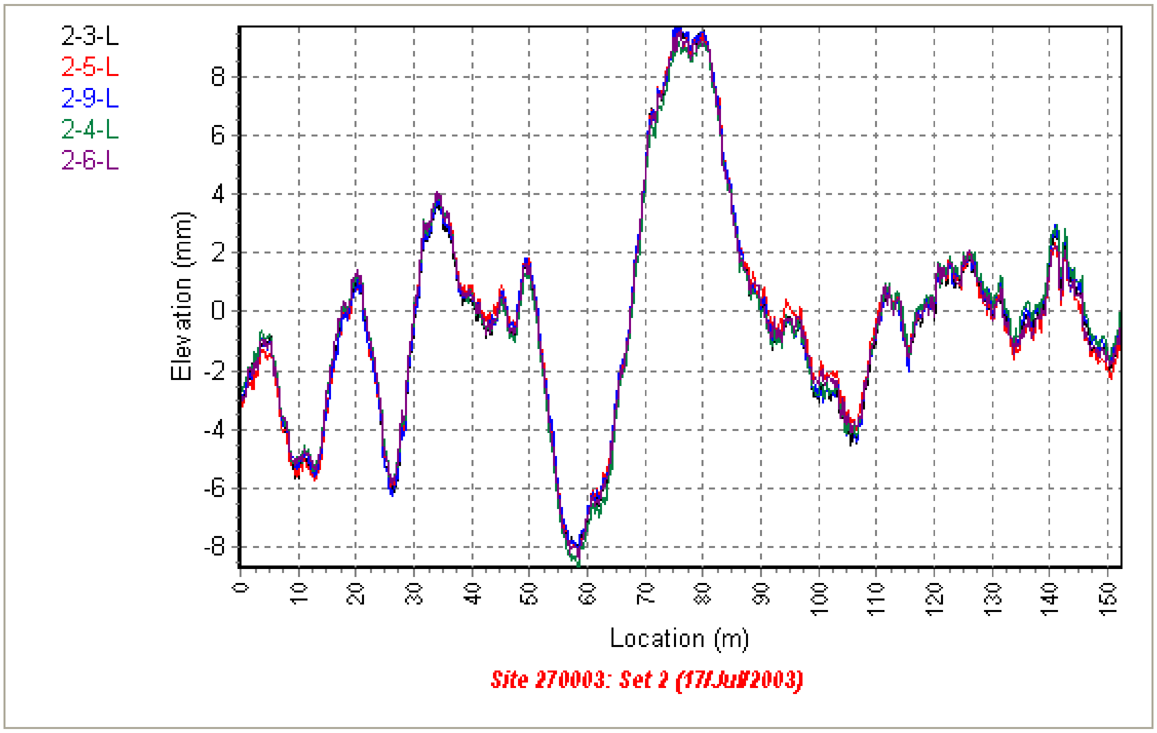
Site 3 – North Central – Right Wheel Path.



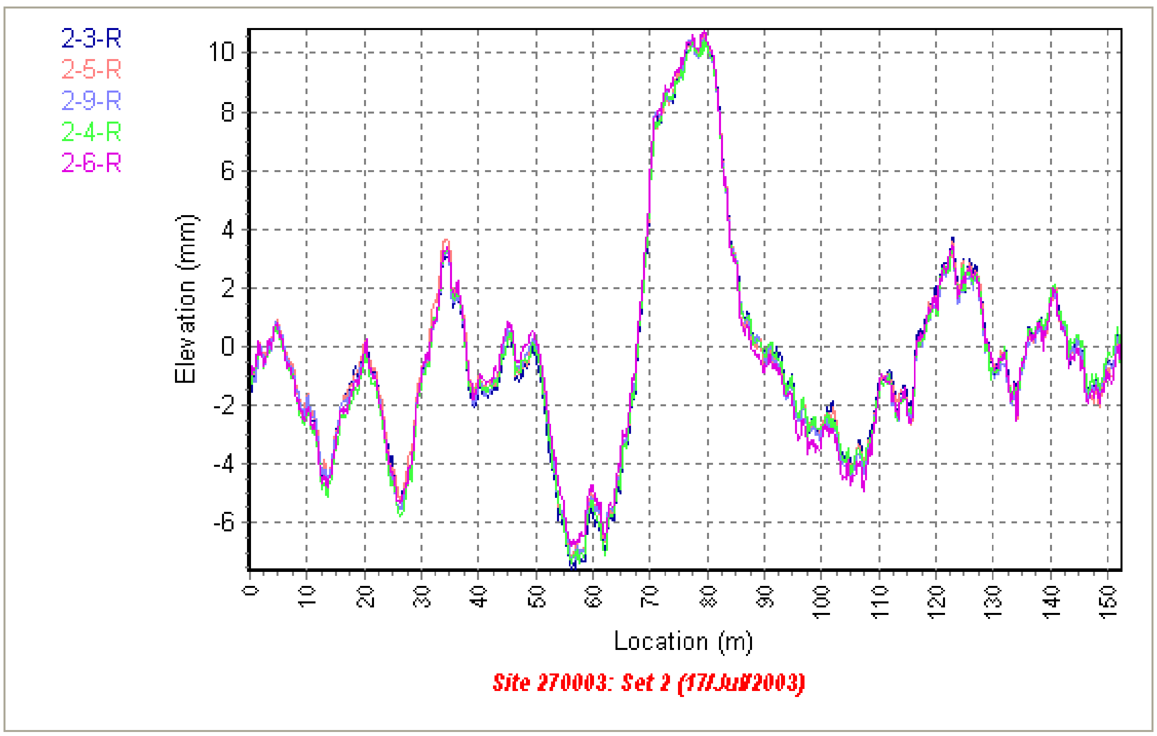
Site 3 – Southern – Left Wheel Path.



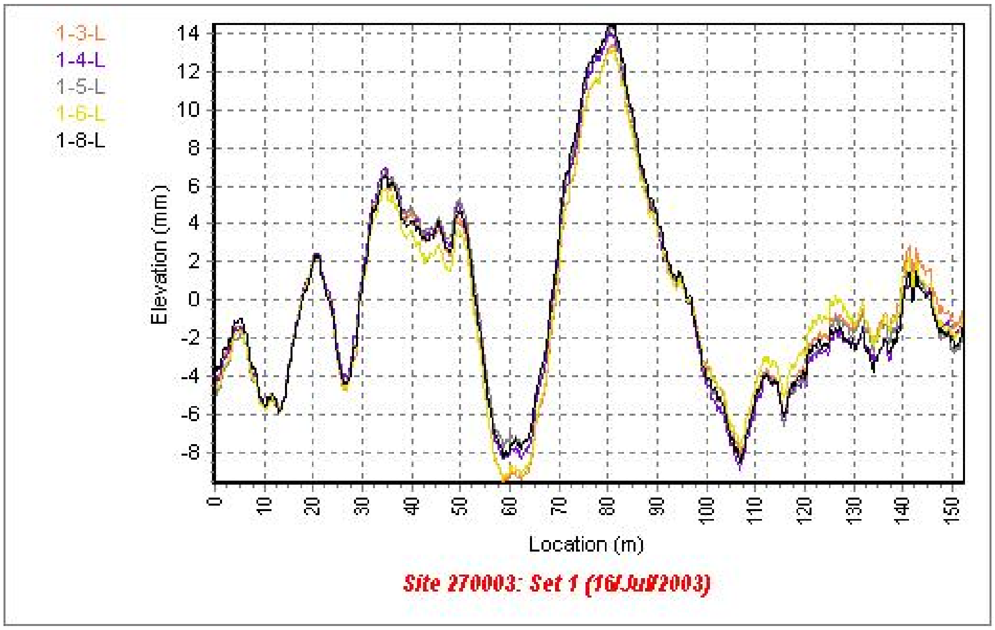
Site 3 – Southern – Right Wheel Path.



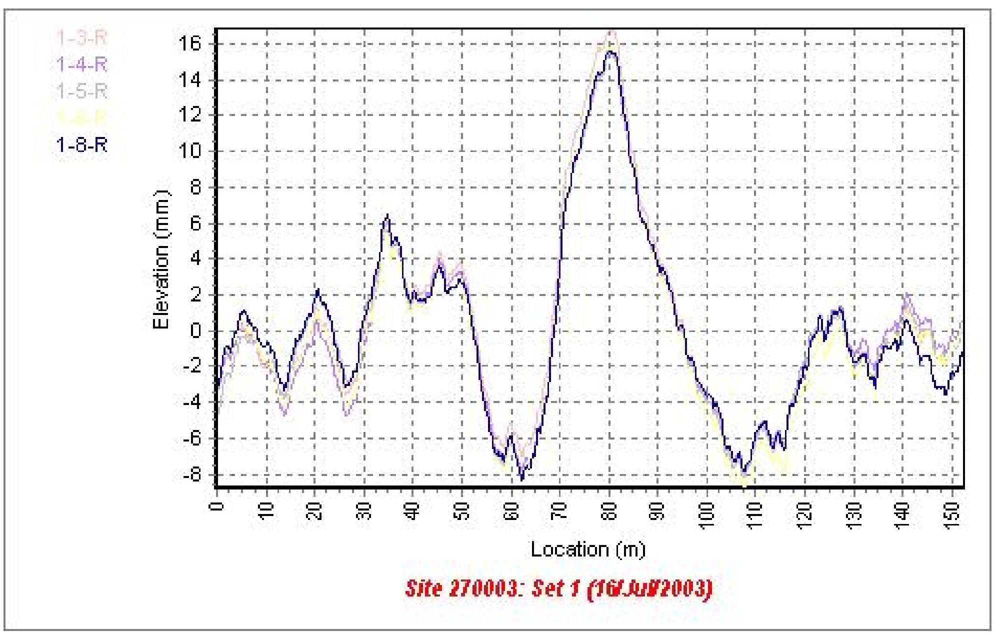
Site 3 – Western – Left Wheel Path.



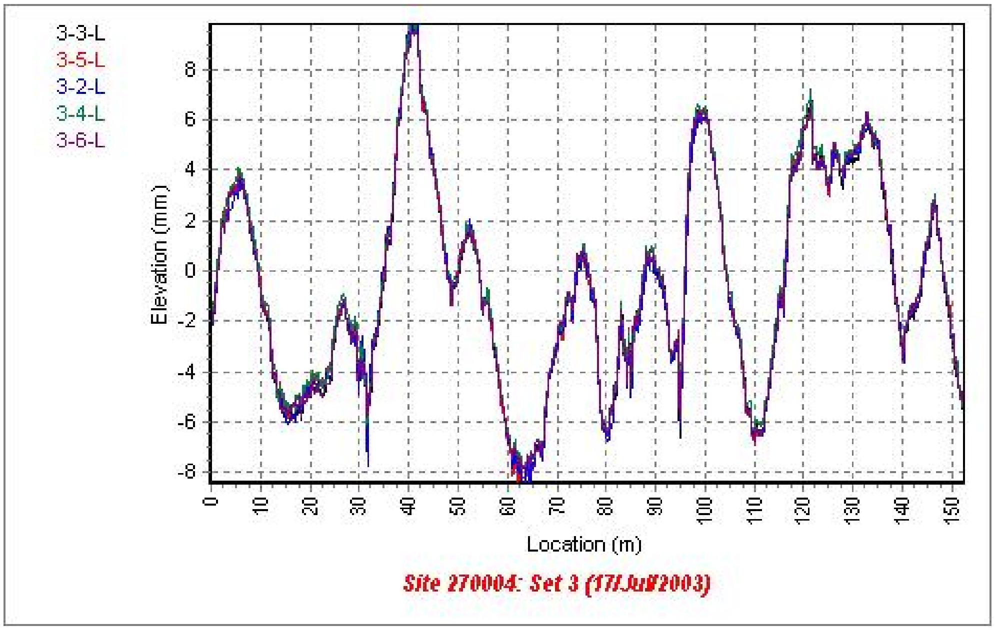
Site 3 – Western – Right Wheel Path.



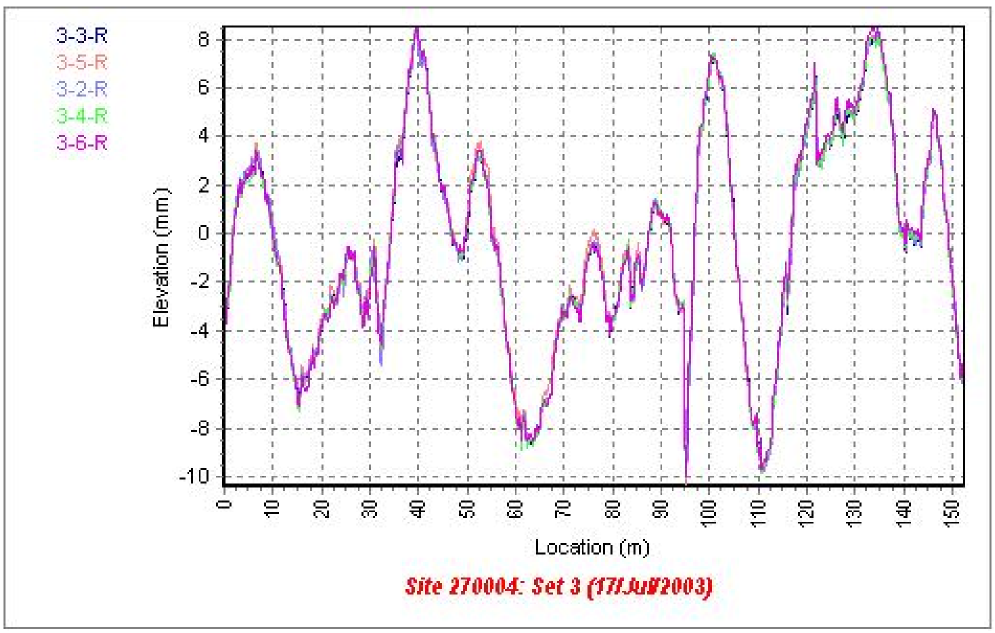
Site 3 – K.J. Law – Left Wheel Path.



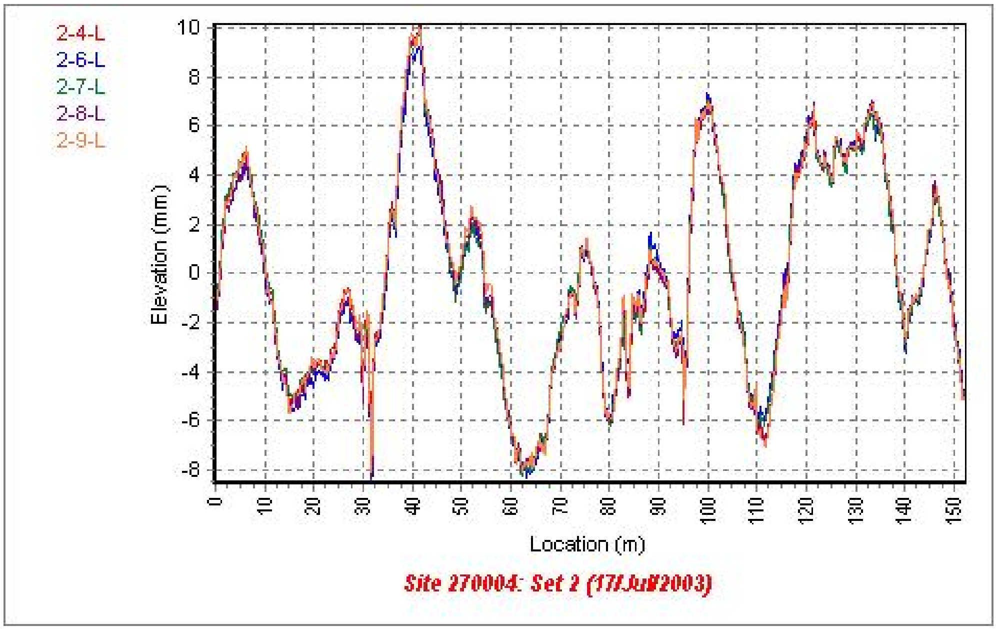
Site 3 – K.J. Law – Right Wheel Path.



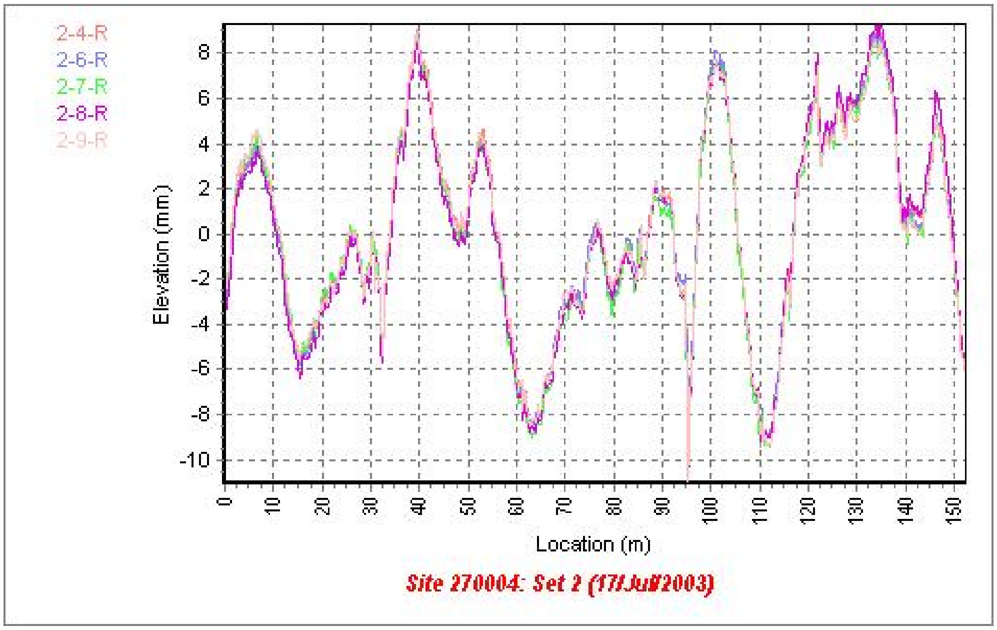
Site 4 - North Atlantic – Left Wheel Path..



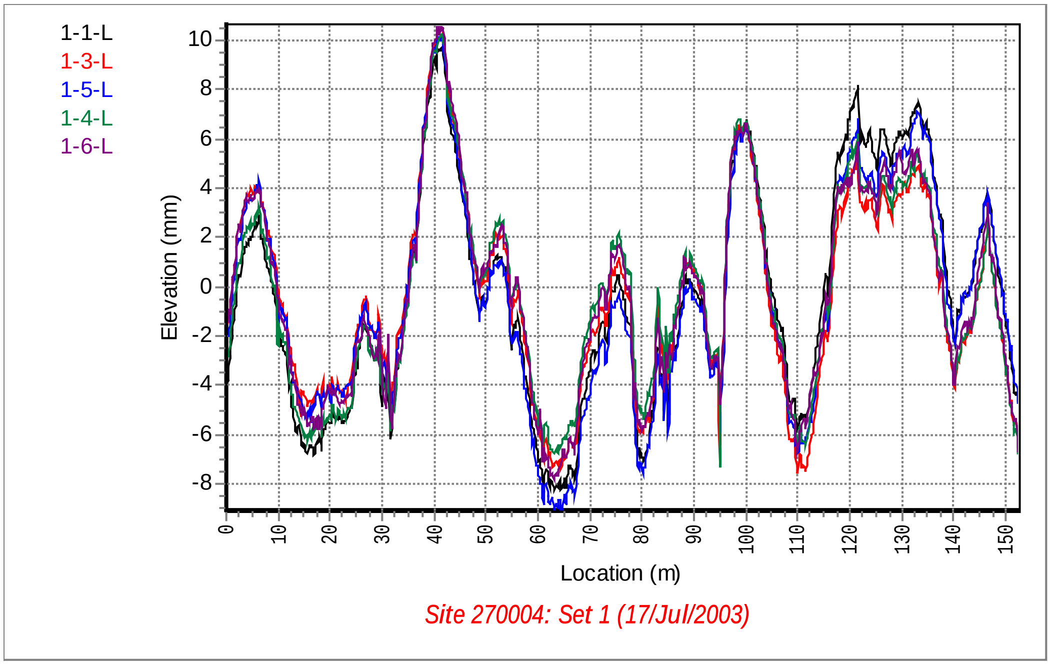
Site 4 – North Atlantic – Right Wheel Path.



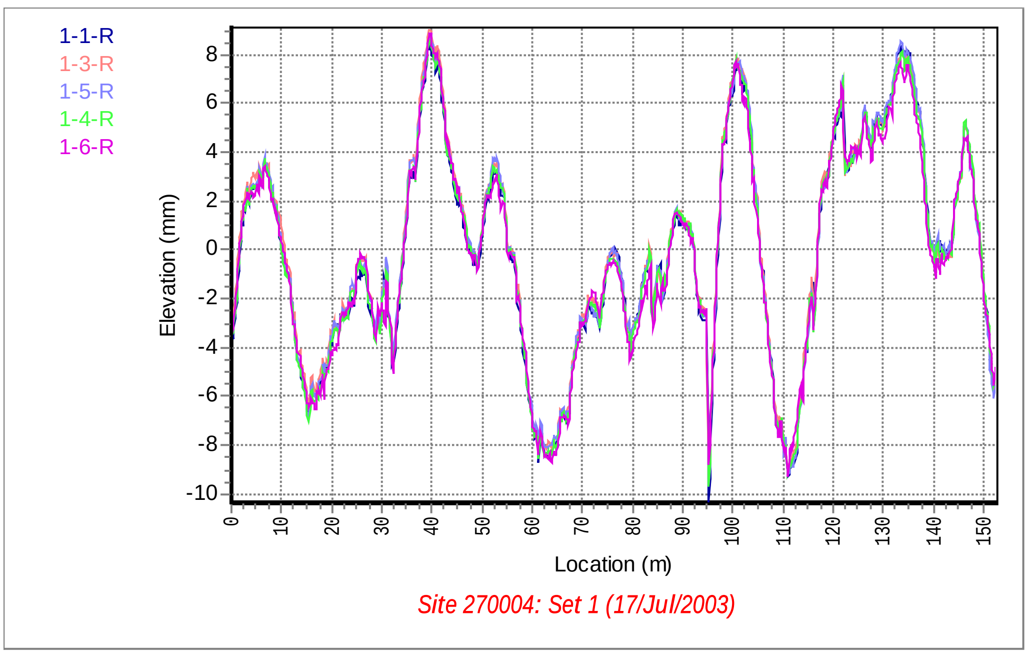
Site 4 – North Central – Left Wheel Path.



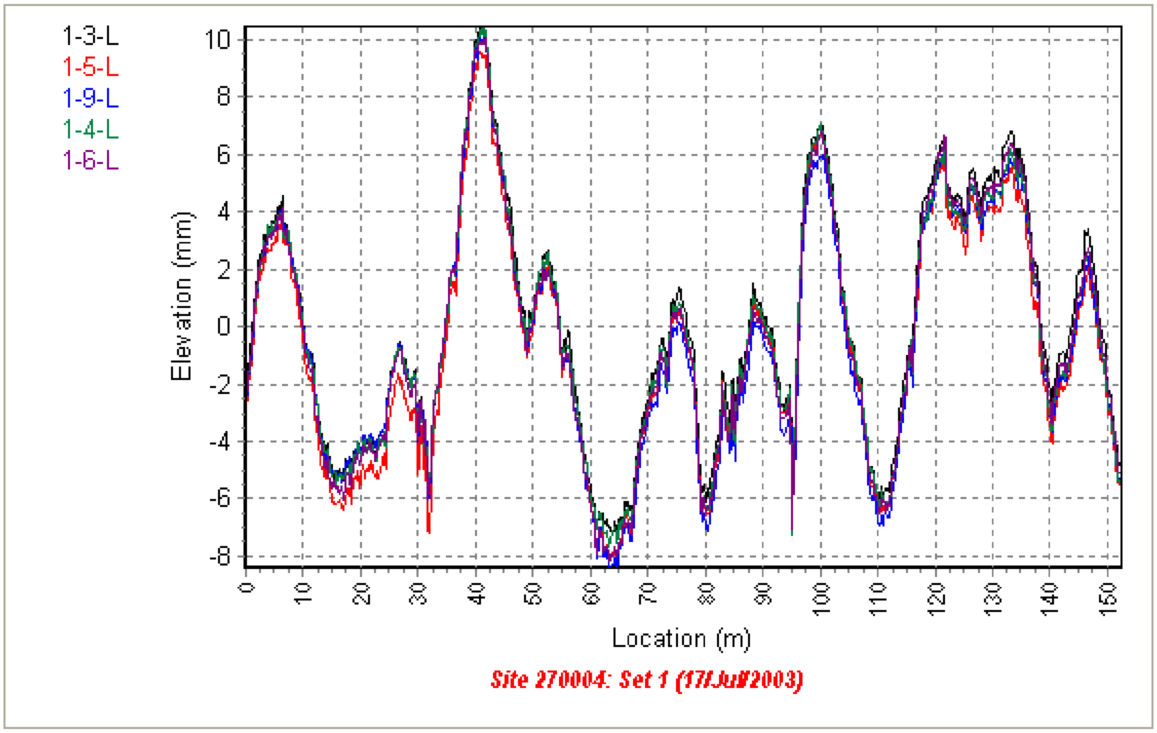
Site 4 – North Central – Right Wheel Path.



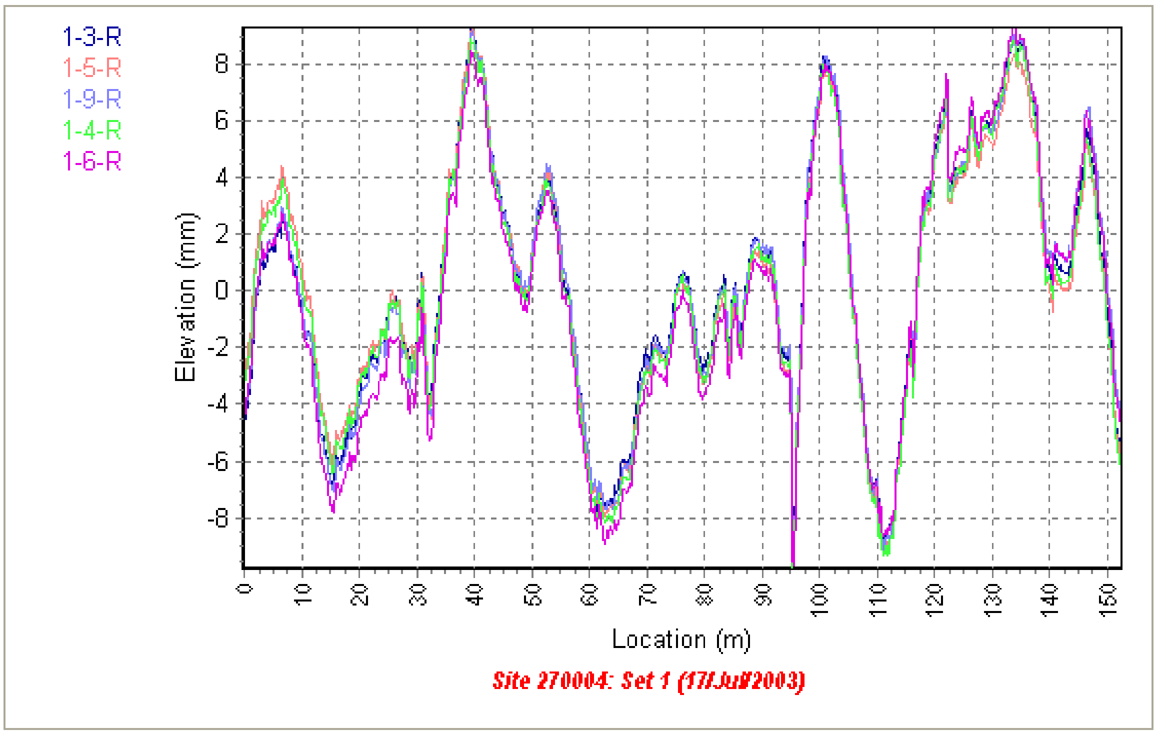
Site 4 – Southern – Left Wheel Path.



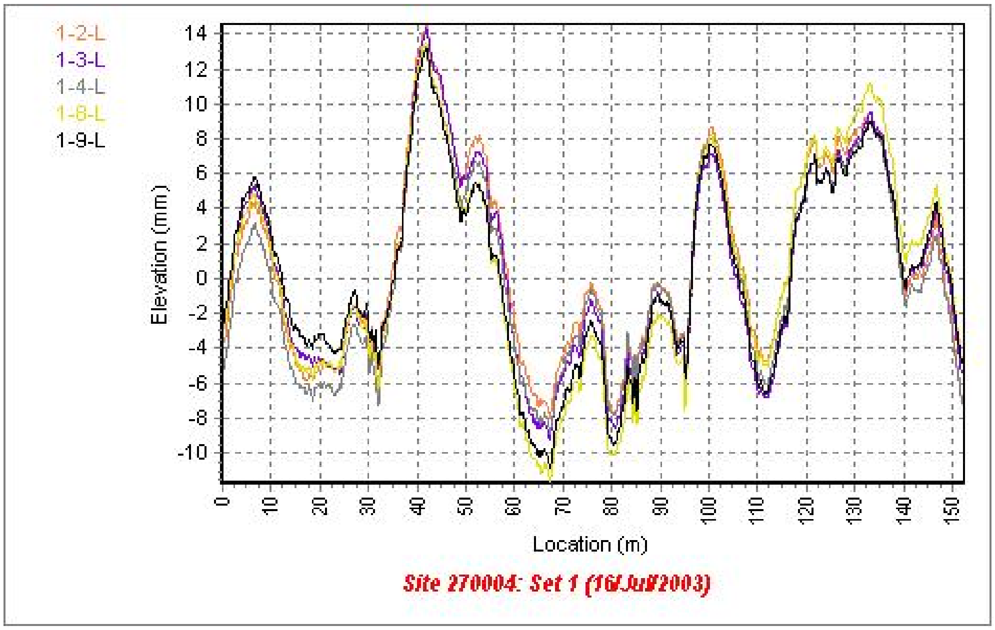
Site 4 – Southern – Right Wheel Path.



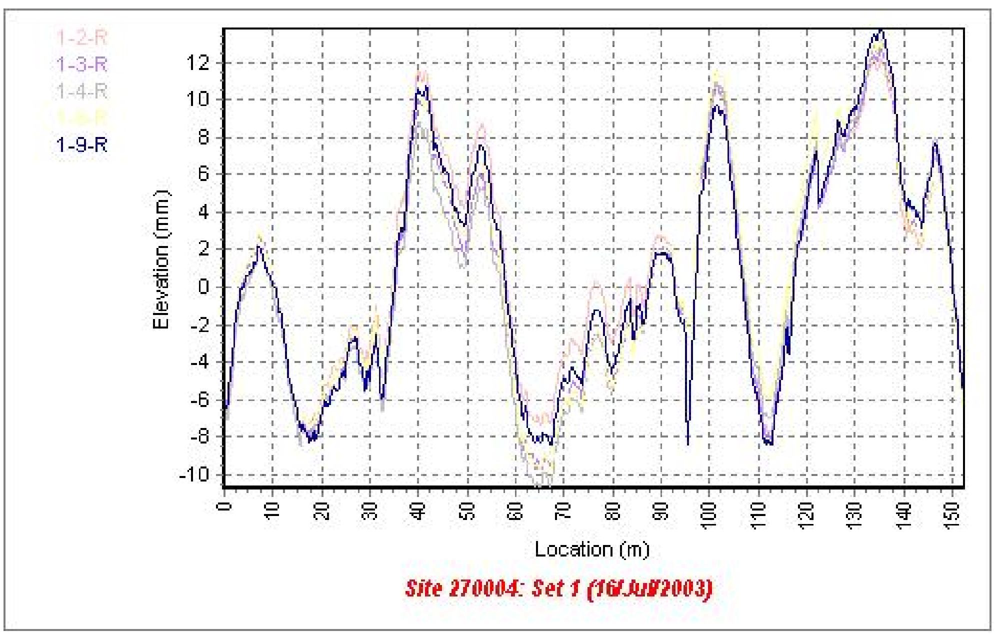
Site 4 – Western – Left Wheel Path.



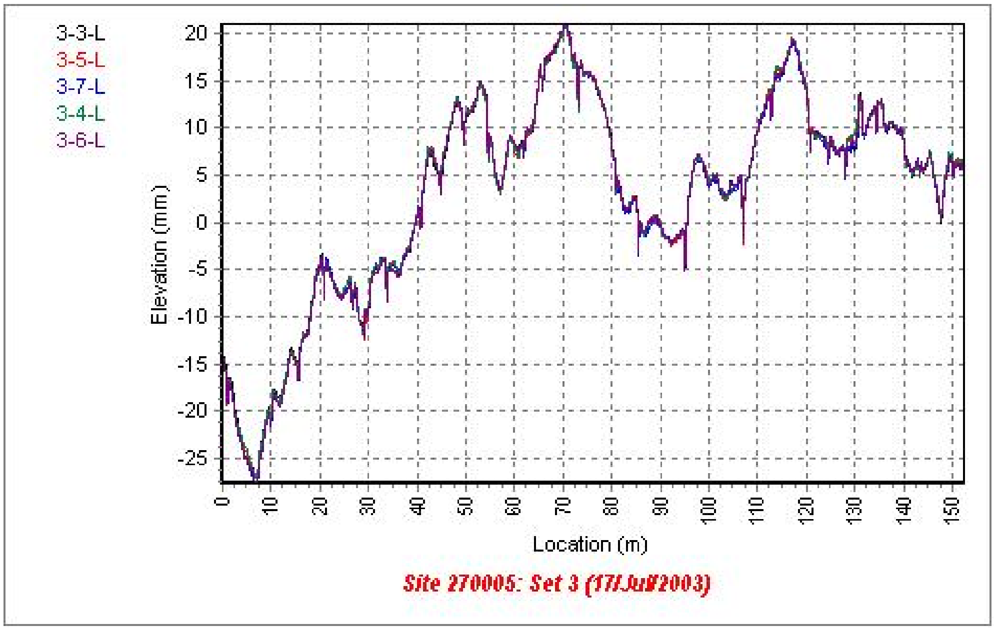
Site 4 – Western – Right Wheel Path.



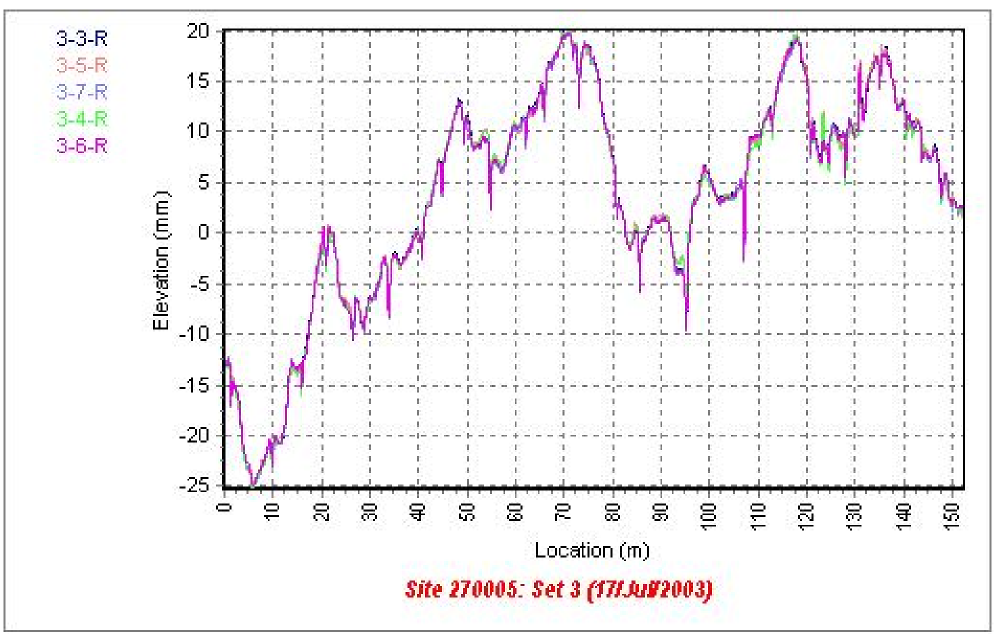
Site 4 – K.J. Law – Left Wheel Path.



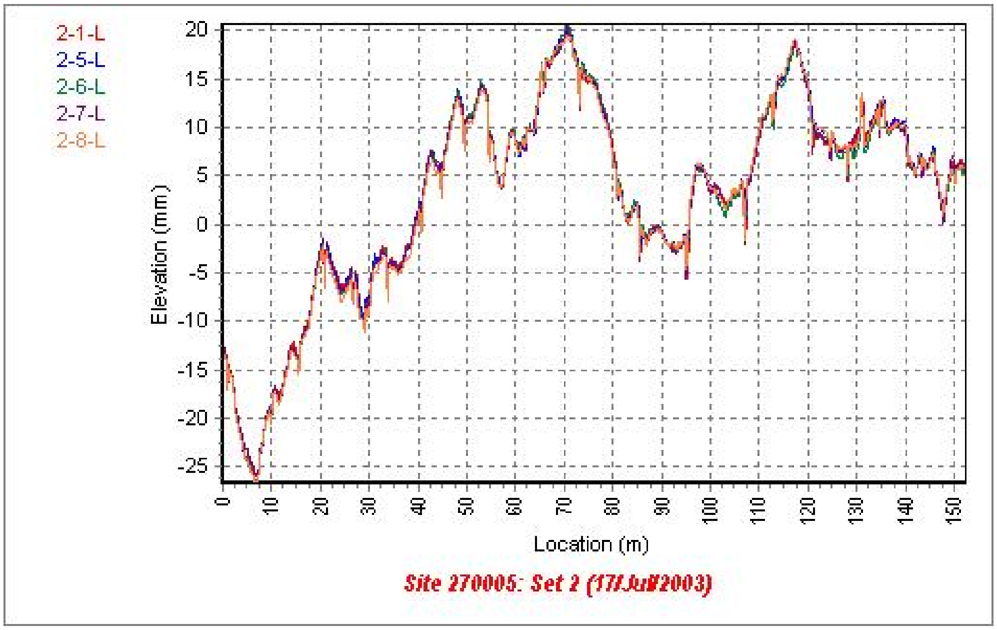
Site 4 – K.J. Law – Right Wheel Path.



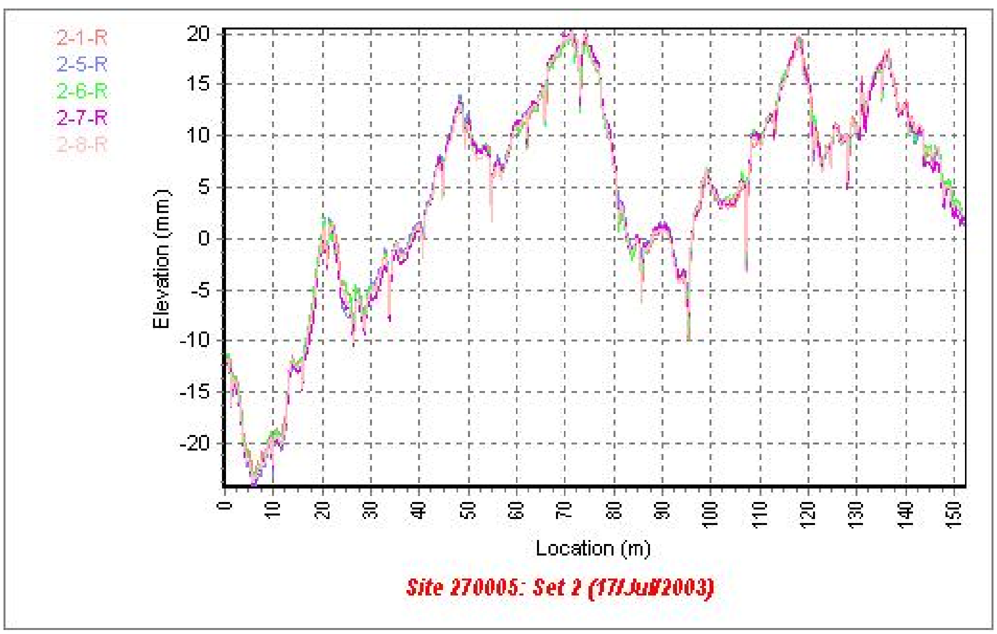
Site 5 – North Atlantic – Left Wheel Path.



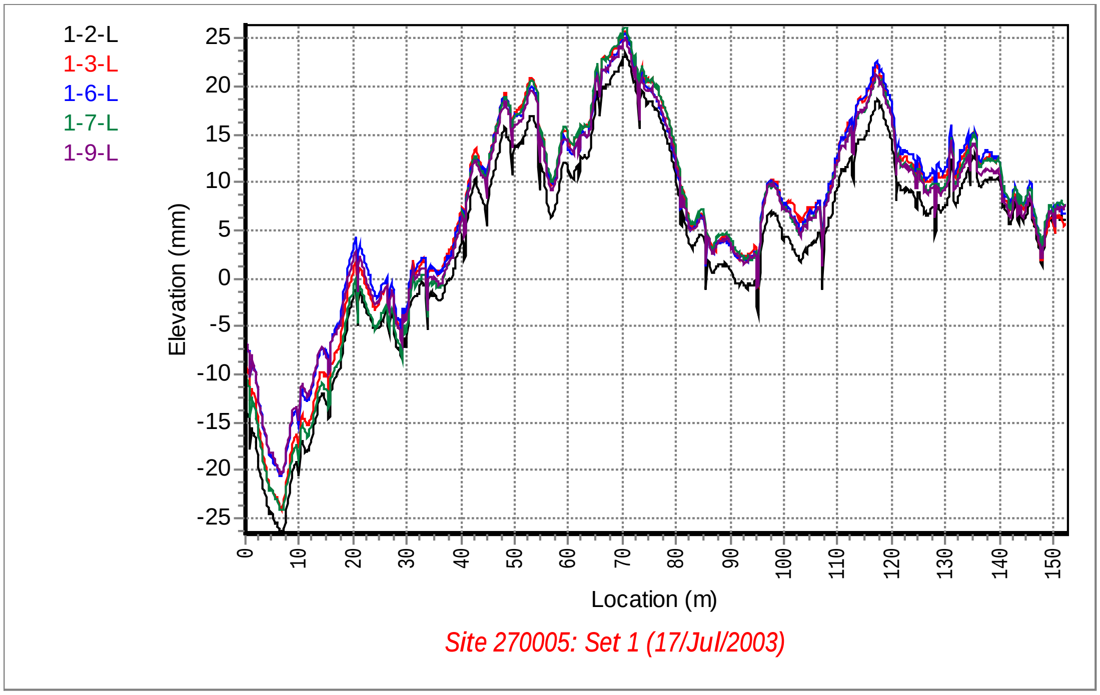
Site 5 – North Atlantic – Right Wheel Path.



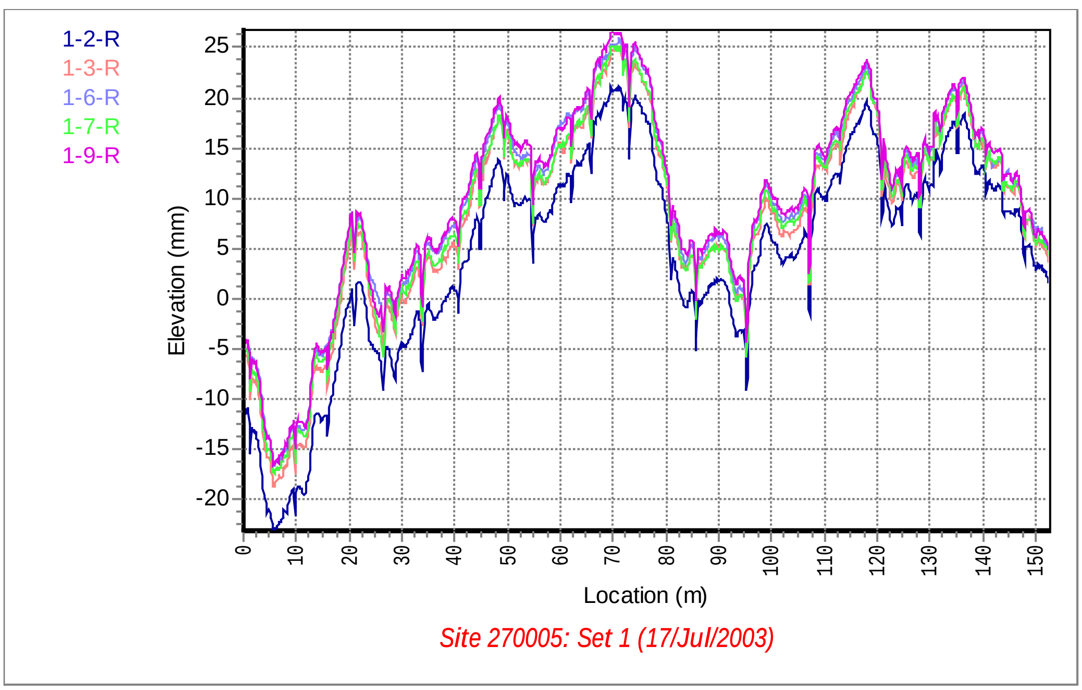
Site 5 – North Central – Left Wheel Path.



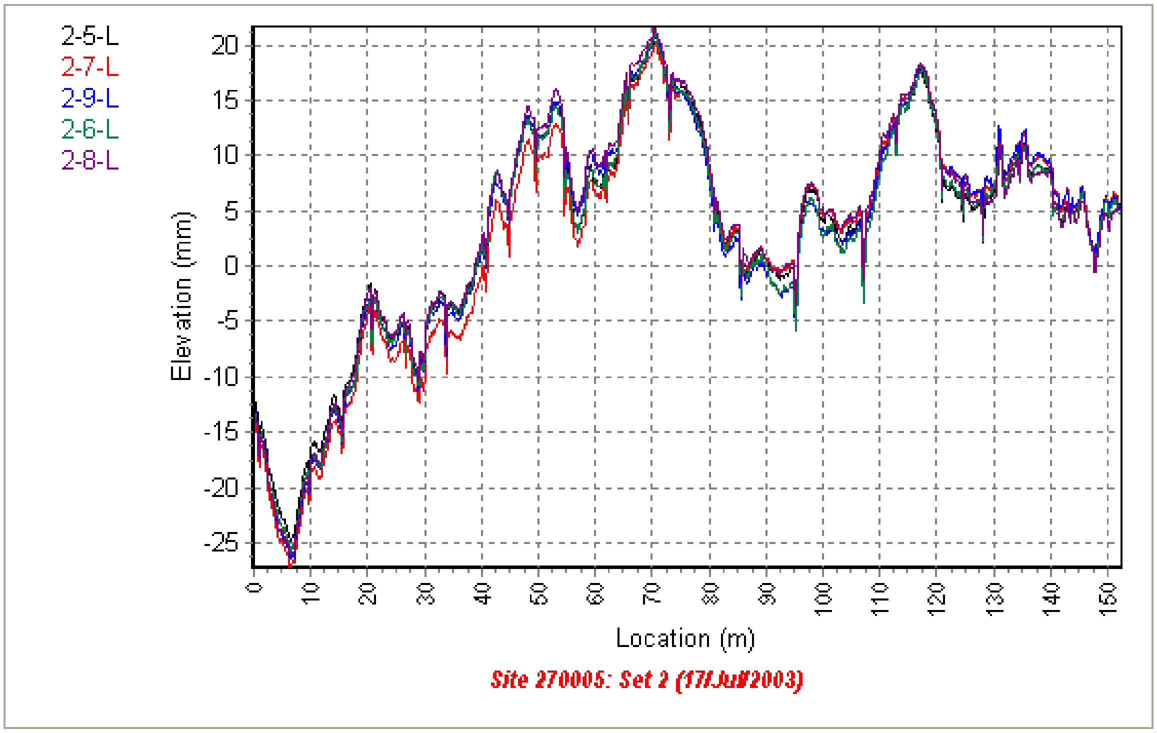
Site 5 – North Central – Right Wheel Path.



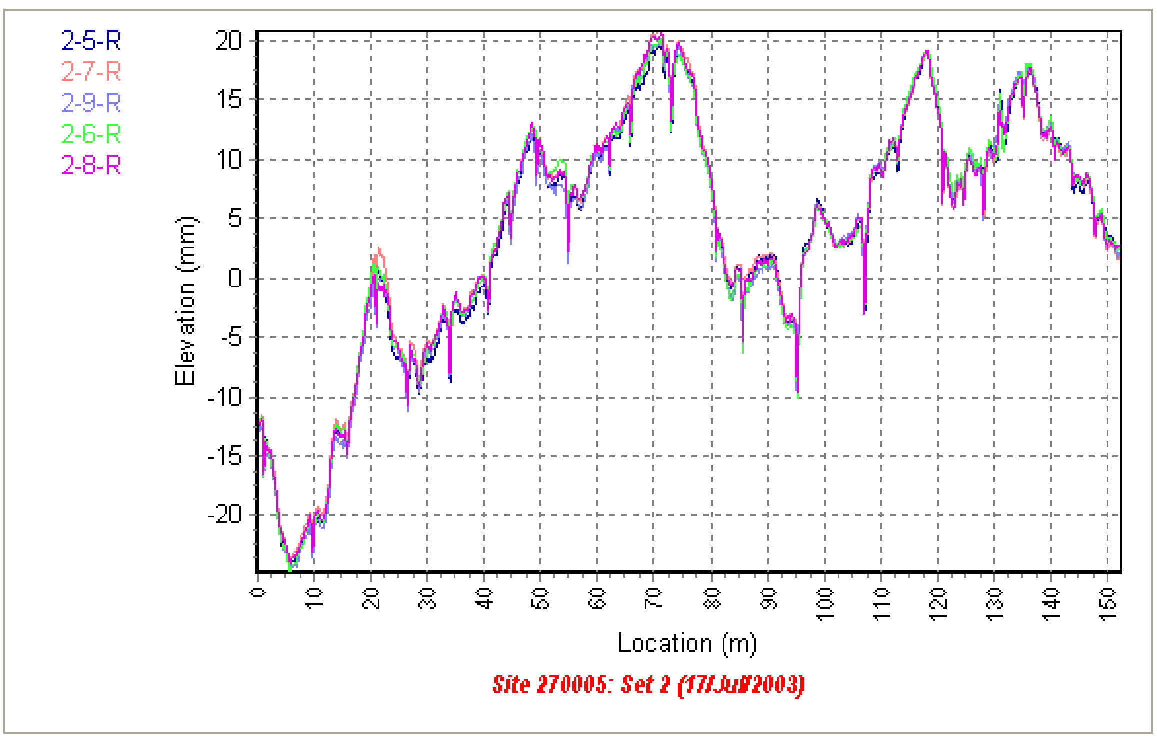
Site 5 – Southern – Left Wheel Path.



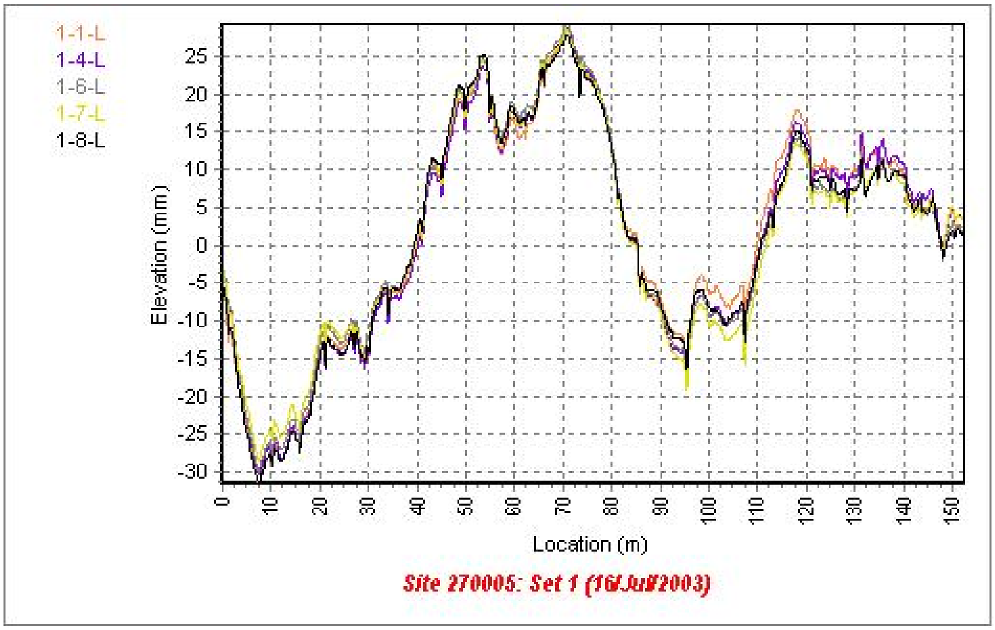
Site 5 – Southern – Right Wheel Path.



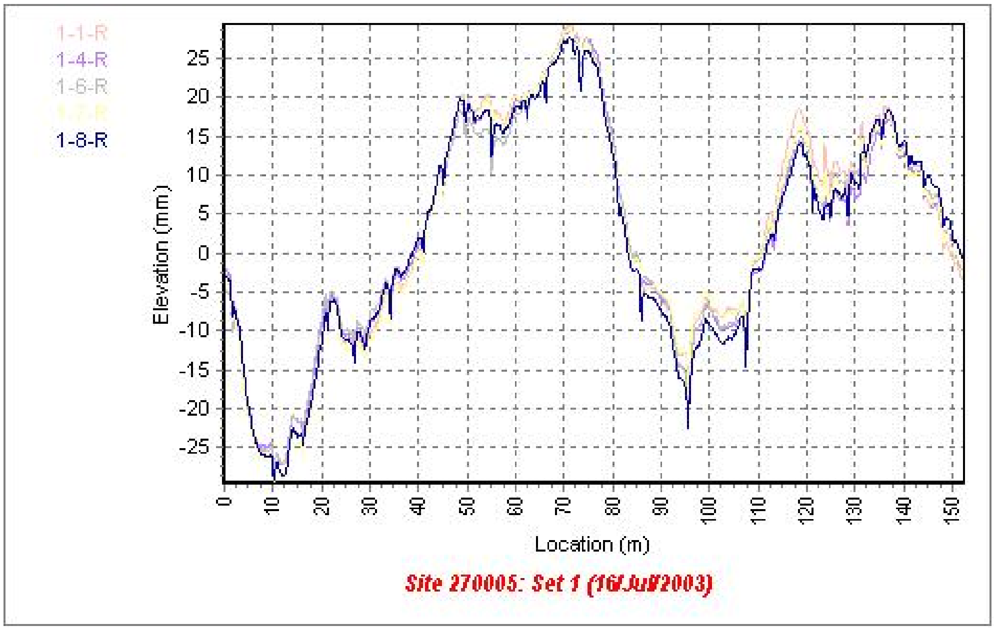
Site 5 – Western – Left Wheel Path.



Site 5 – Western – Right Wheel Path.



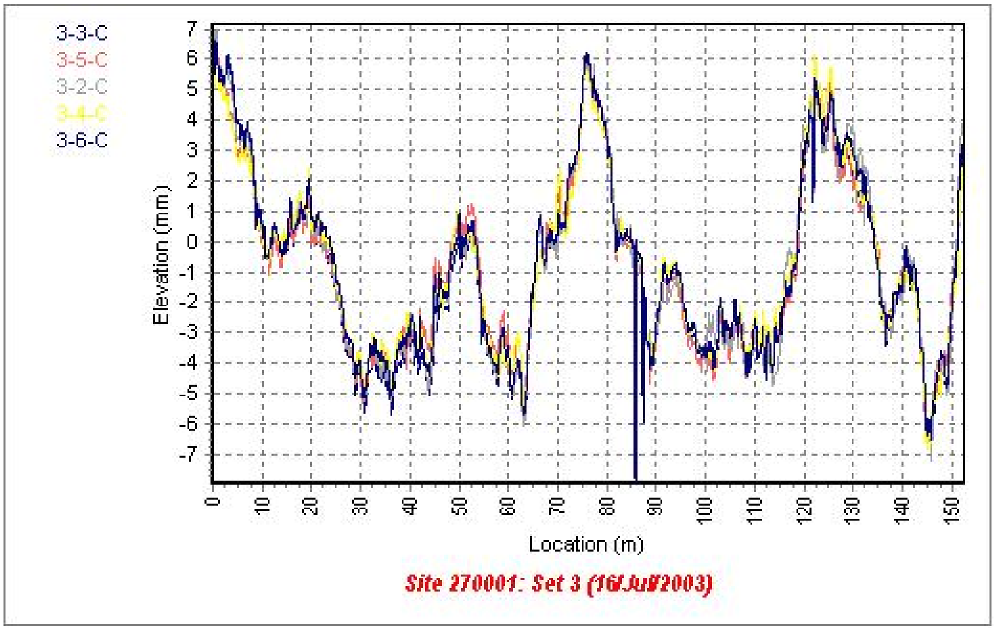
Site 5 – K.J. Law – Left Wheel Path.



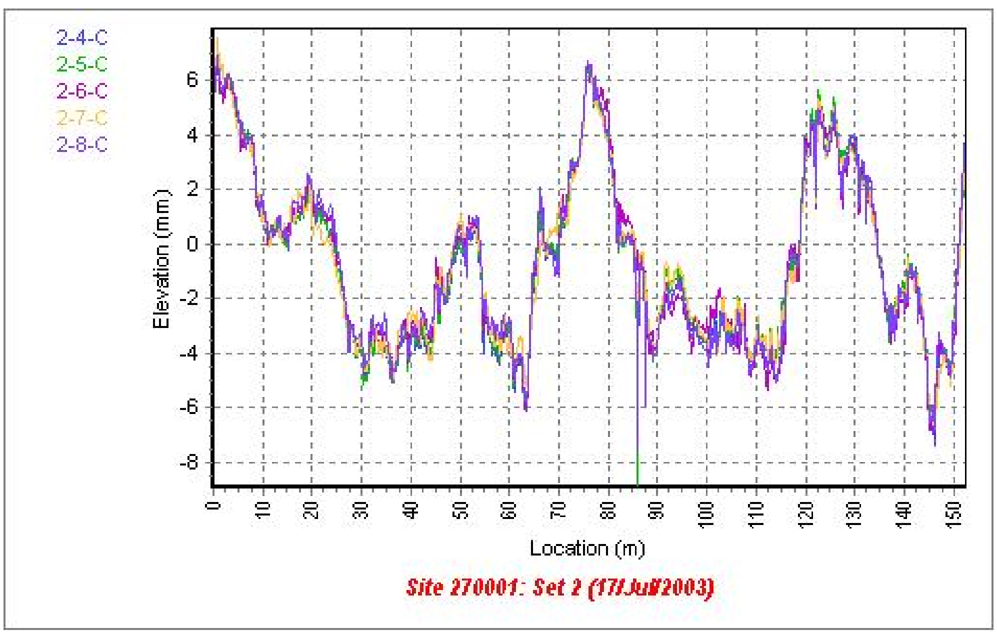
Site 5 – K.J. Law – Right Wheel Path.

APPENDIX E

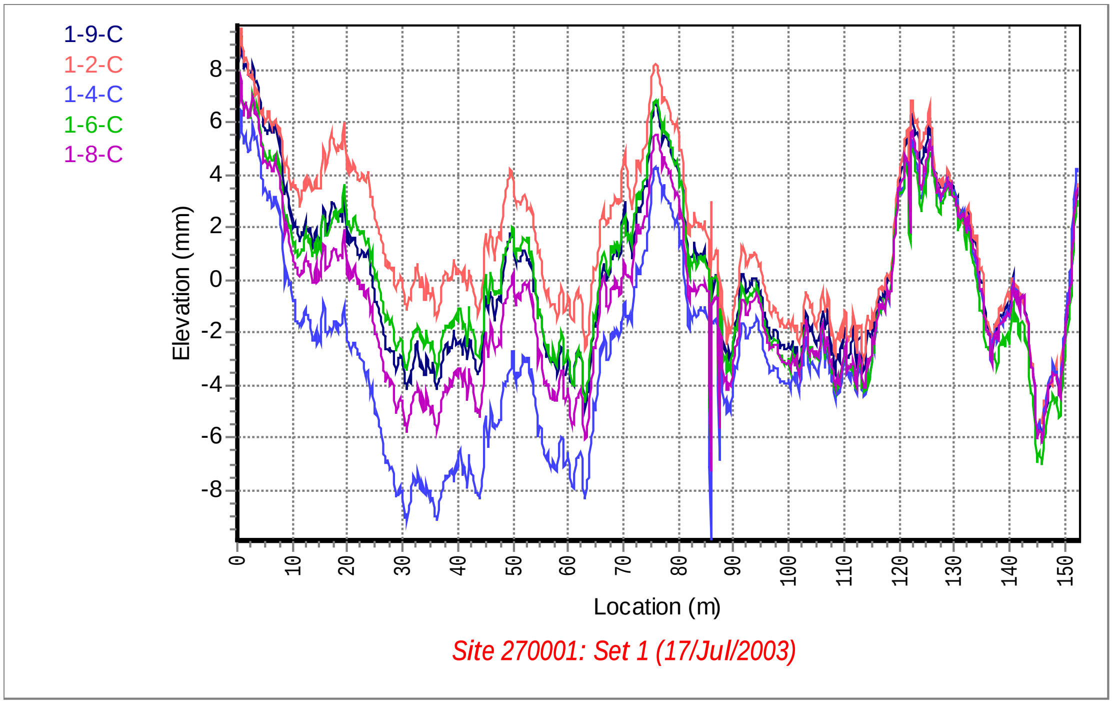
PLOTS OF REPLICATE CENTER PATH PROFILES OBTAINED BY PROFILERS



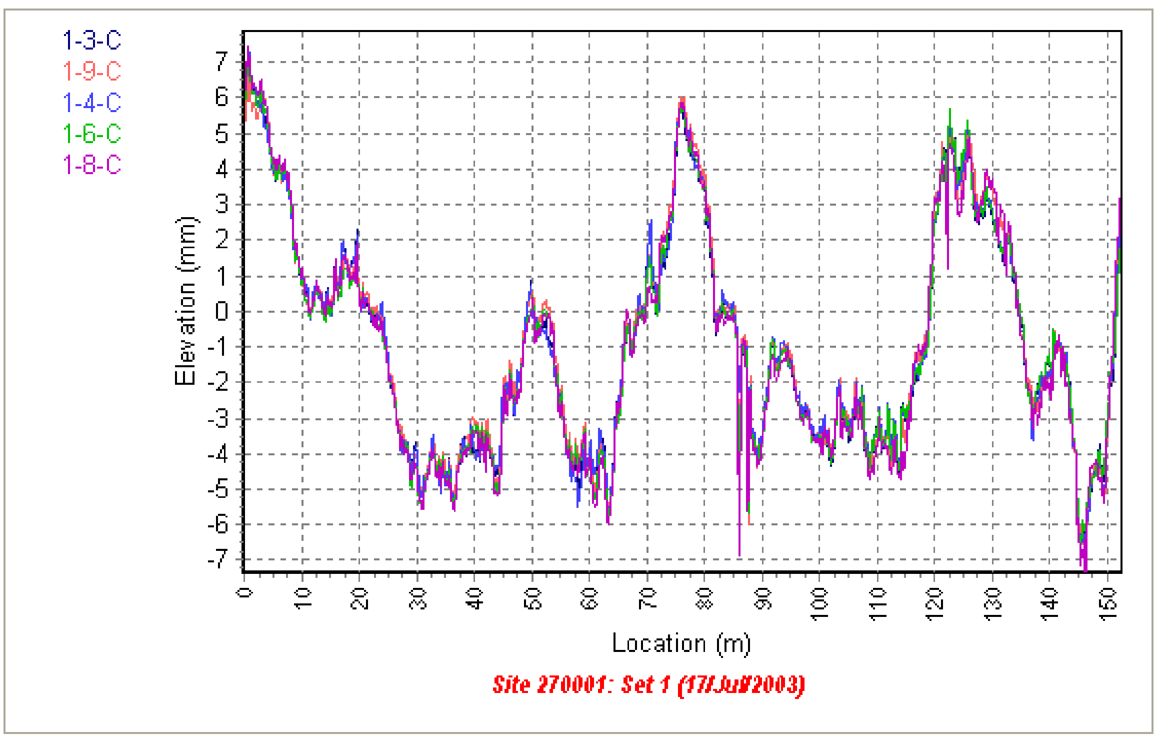
Site 1 – North Atlantic.



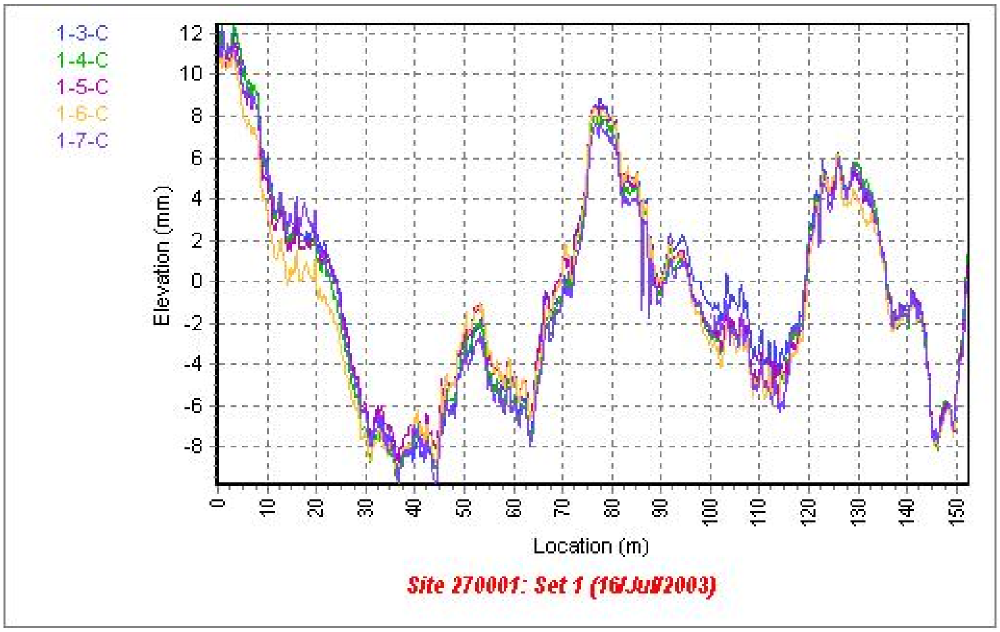
Site 1 – North Central.



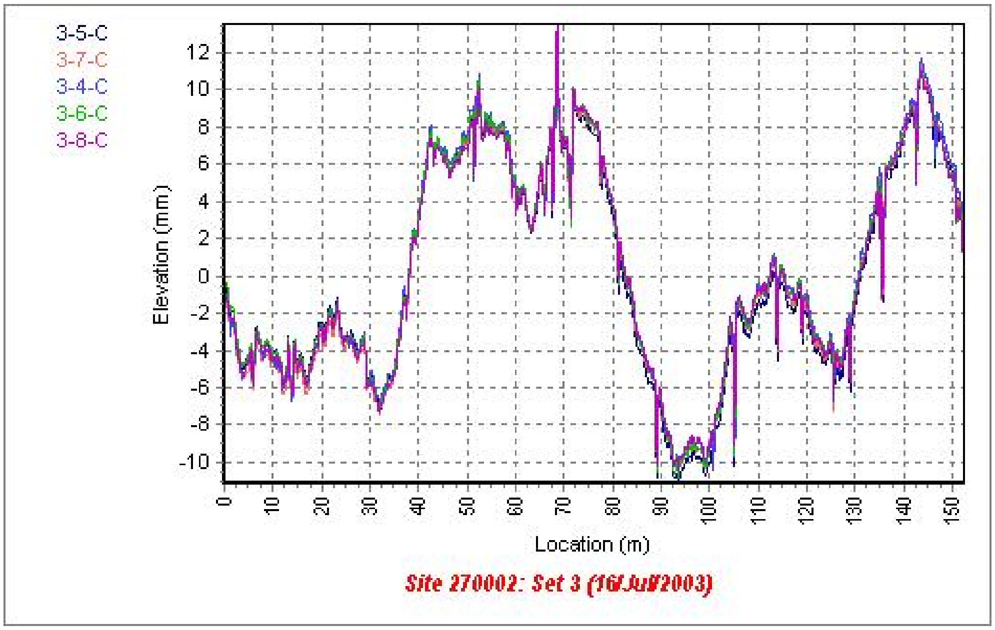
Site 1 – Southern.



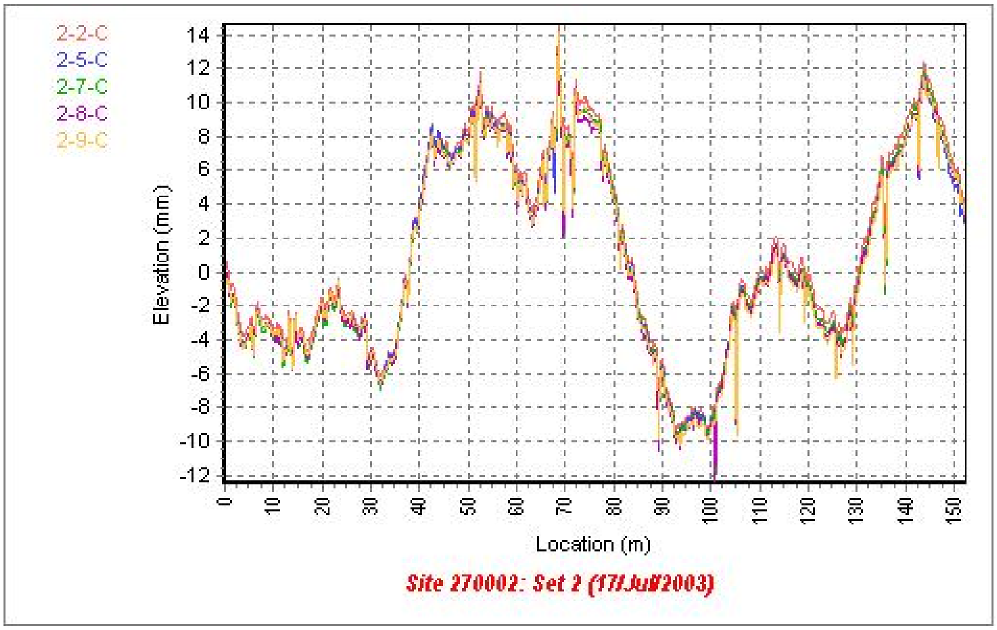
Site 1 – Western.


1-3-C
1-4-C
1-5-C
1-6-C
1-7-C
Elevation (mm)
Location (m)
Site 270001: Set 1 (16/Jul/2003)

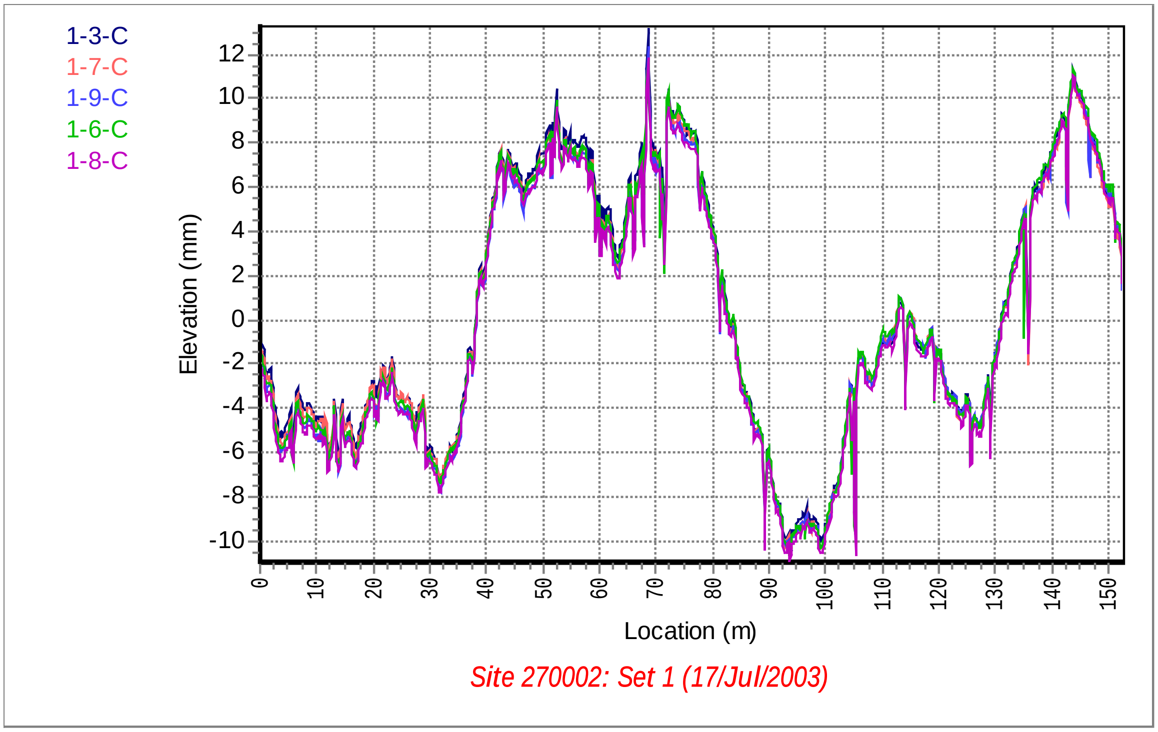
Site 1 – K.J. Law.



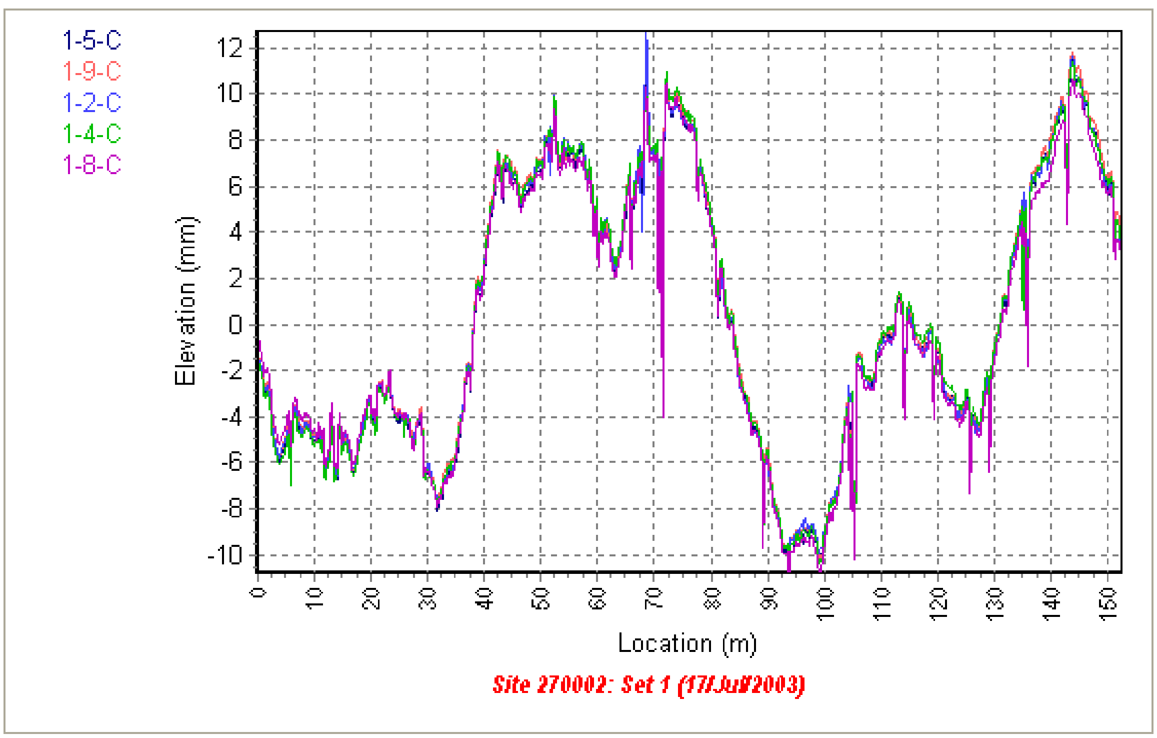
Site 2 – North Atlantic.



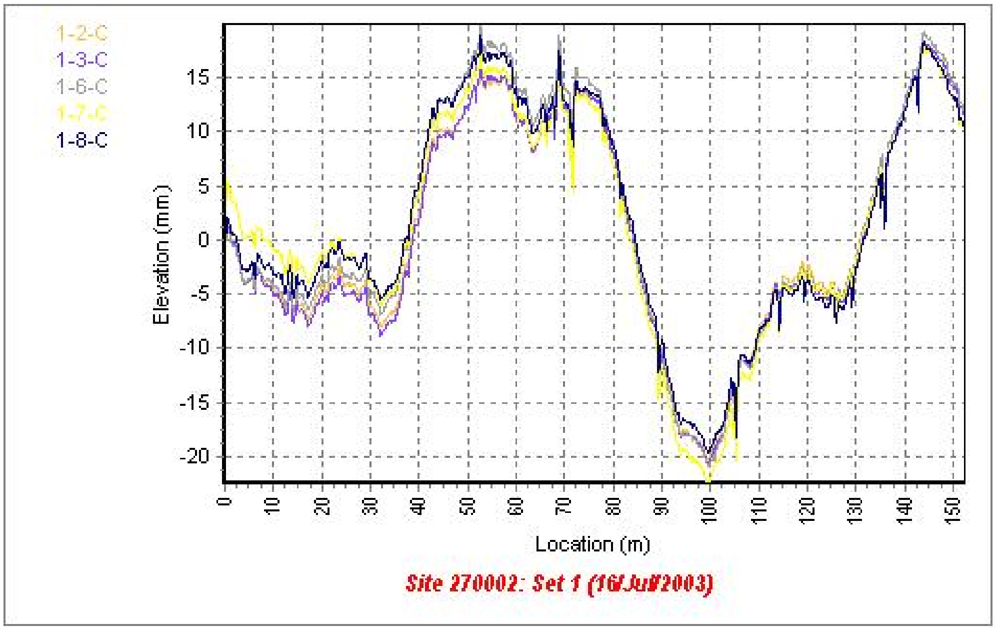
Site 2 – North Central.



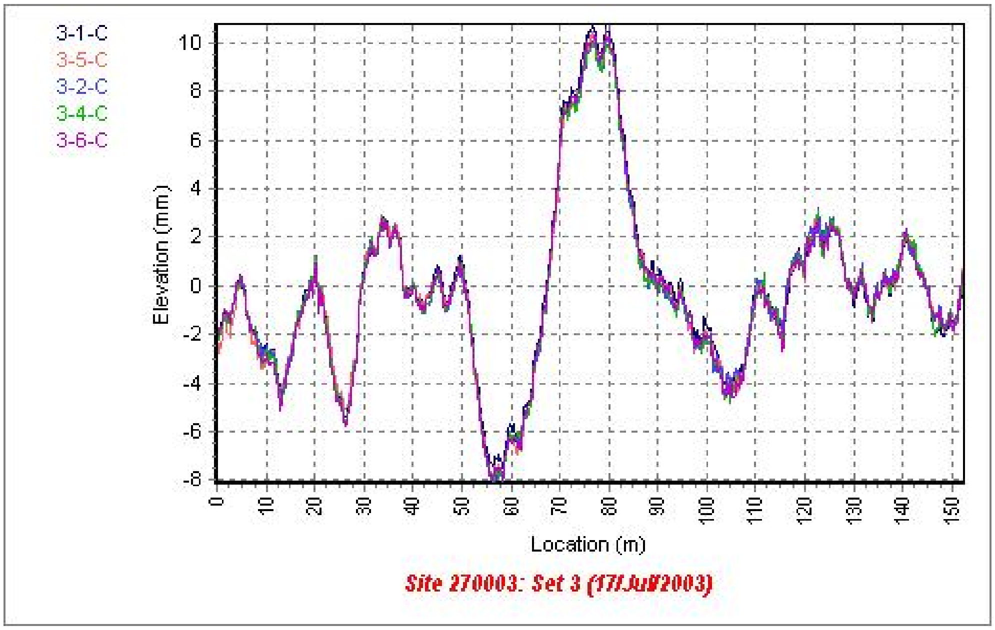
Site 2 – Southern.



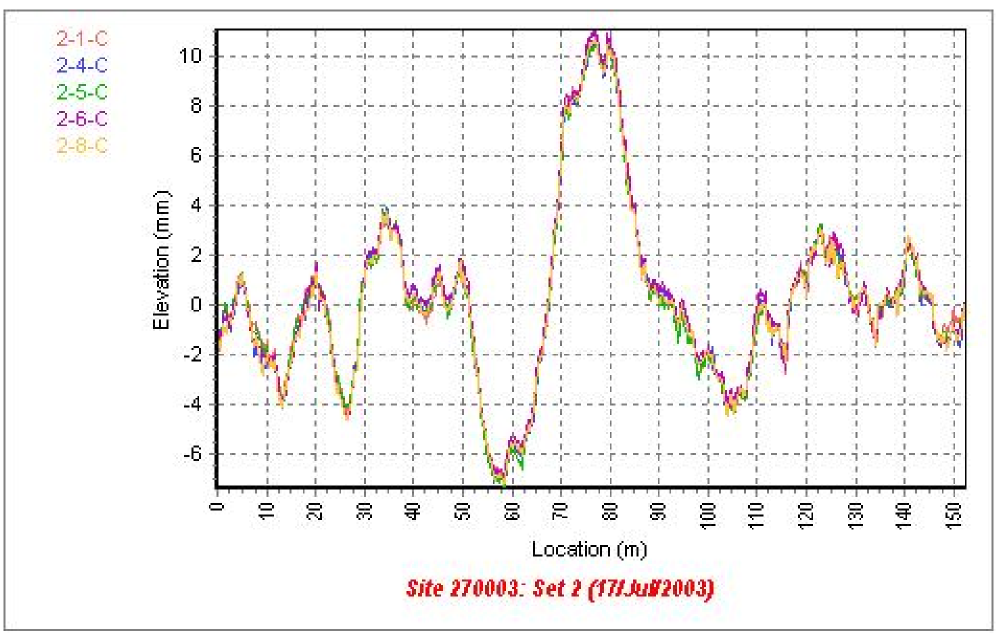
Site 2 – Western.


1-2-C
1-3-C
1-6-C
1-7-C
1-8-C
Elevation (mm)
Location (m)
Site 270002: Set 1 (16/Jul/2003)

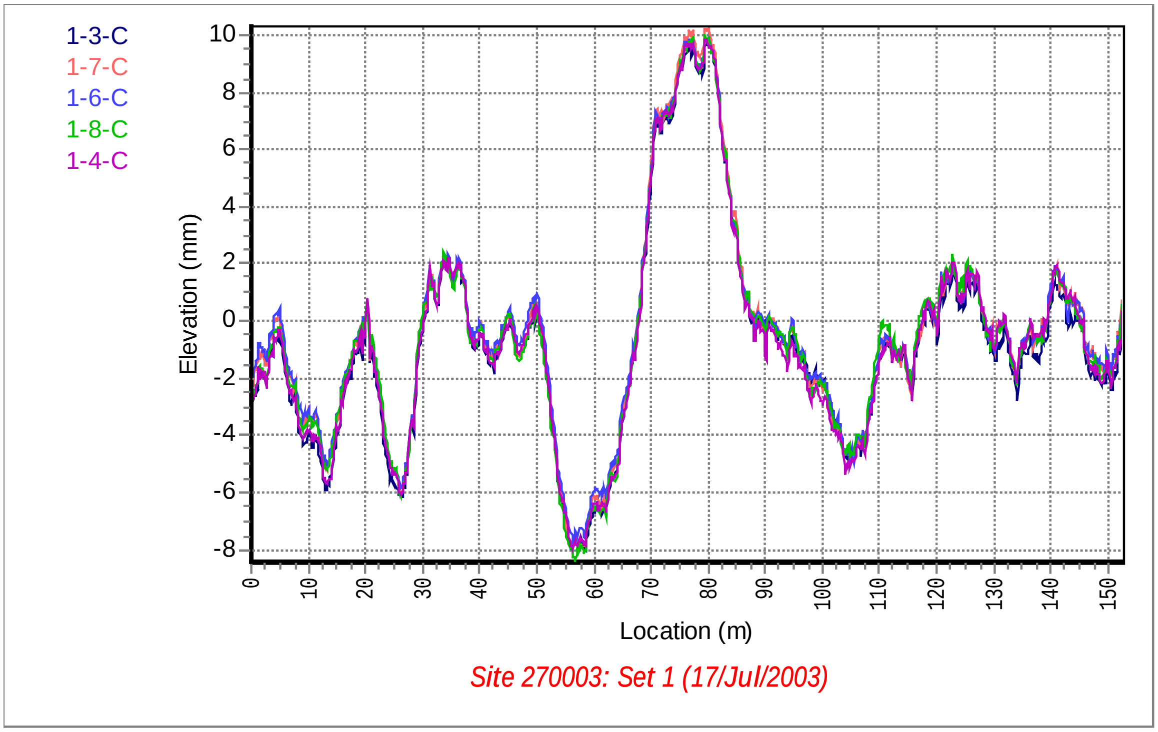
Site 2 – K.J. Law.



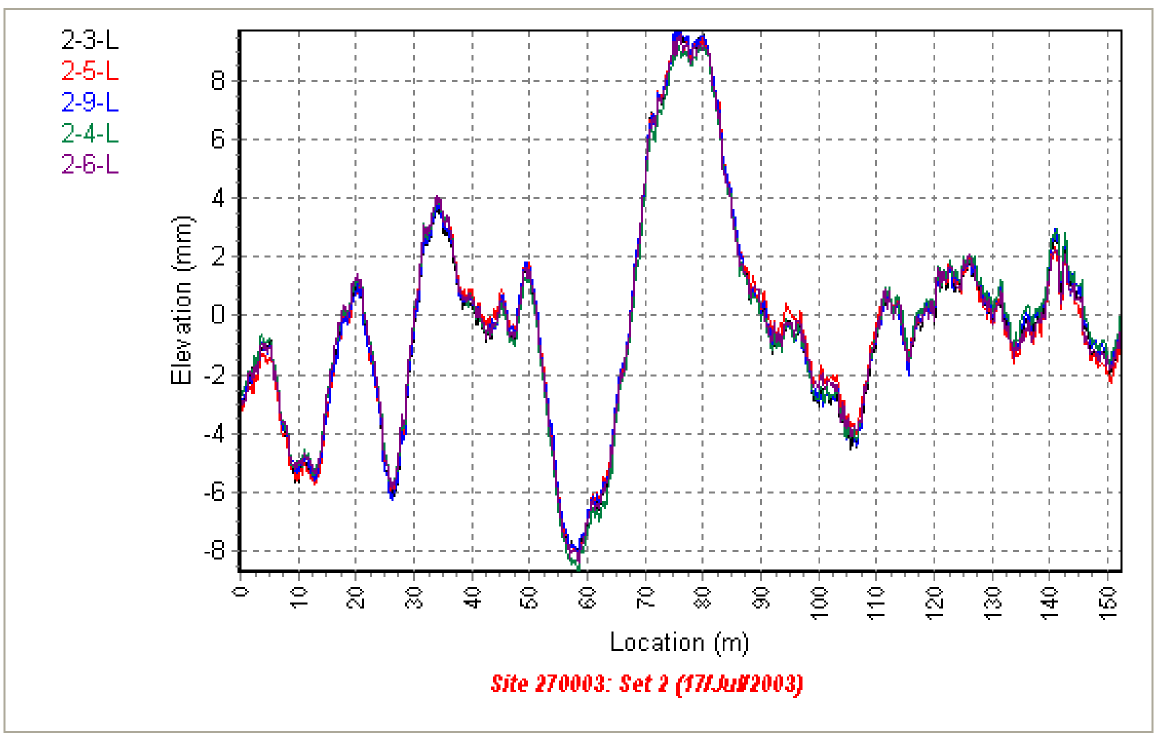
Site 3 – North Atlantic.



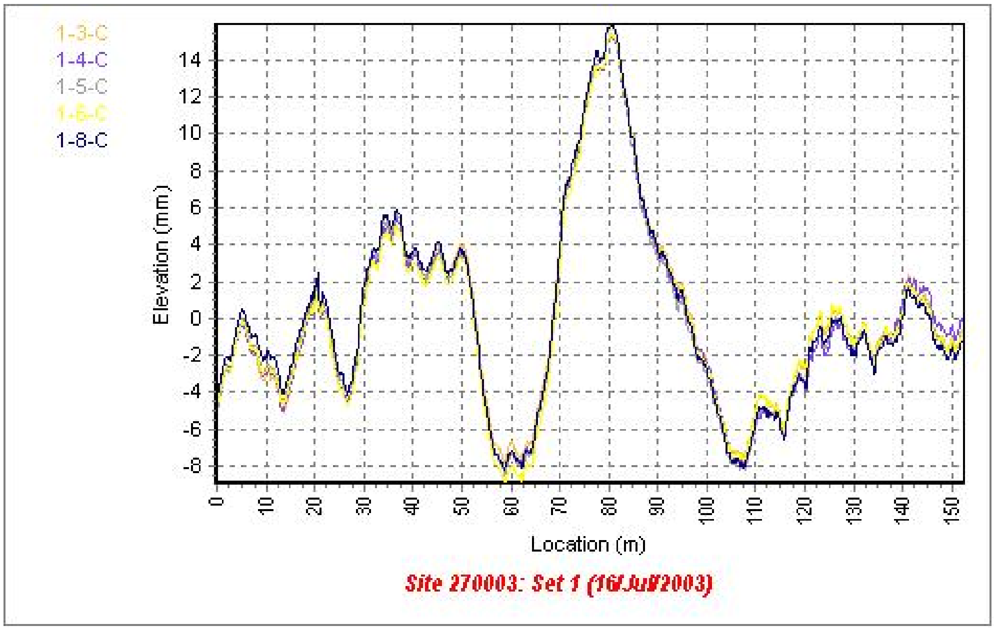
Site 3 – North Central.



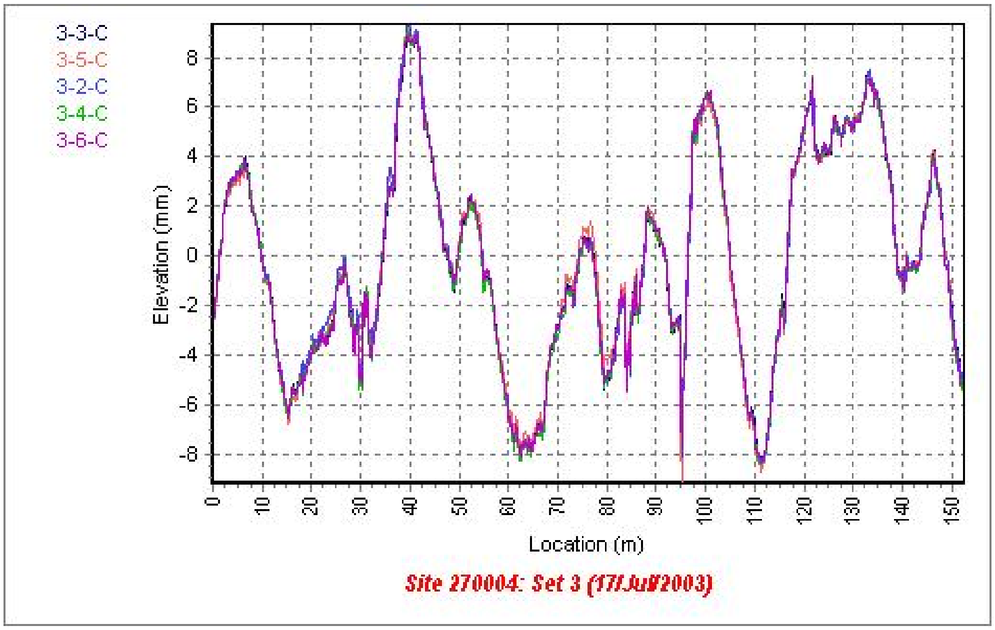
Site 3 – Southern.



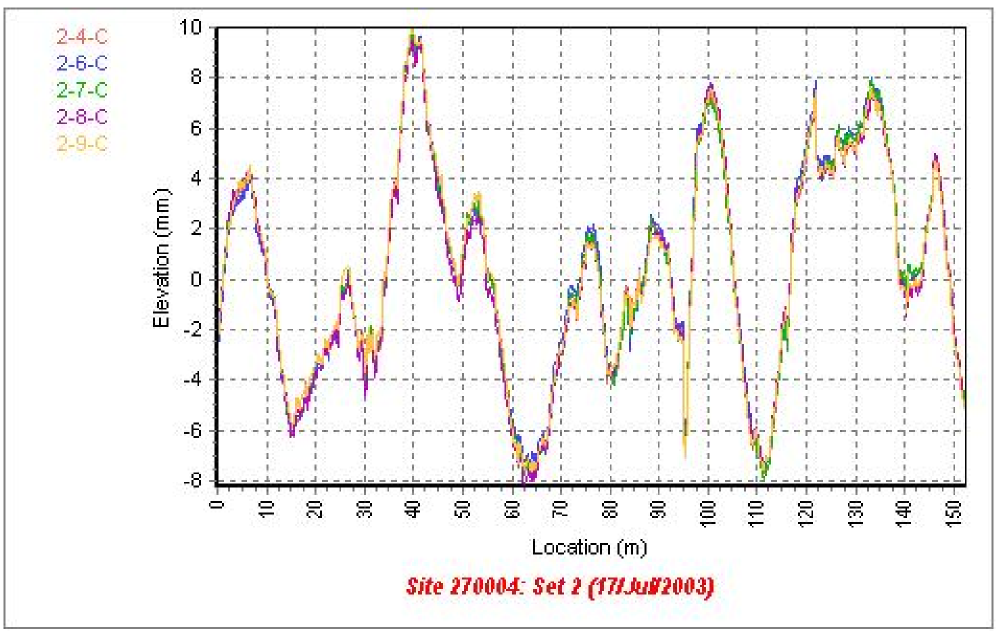
Site 3 – Western.


1-3-C
1-4-C
1-5-C
1-6-C
1-8-C
Elevation (mm)
Location (m)
Site 270003: Set 1 (16/Jul/2003)

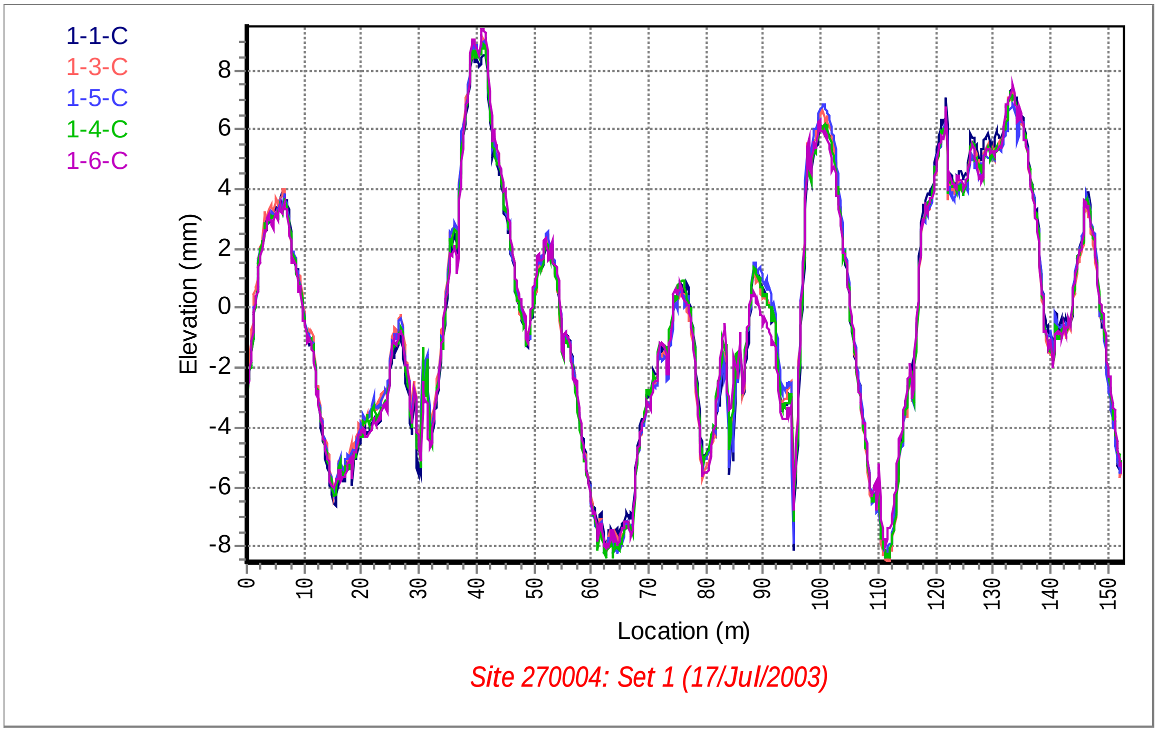
Site 3 – K.J. Law.



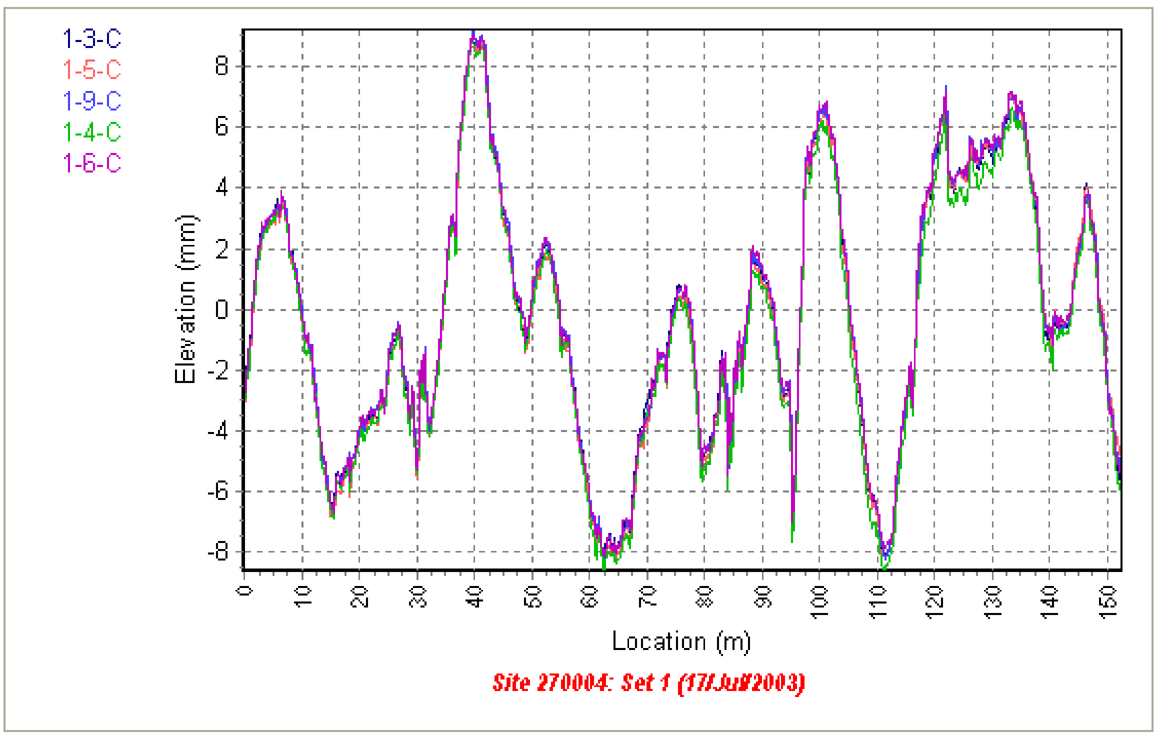
Site 4 – North Atlantic.



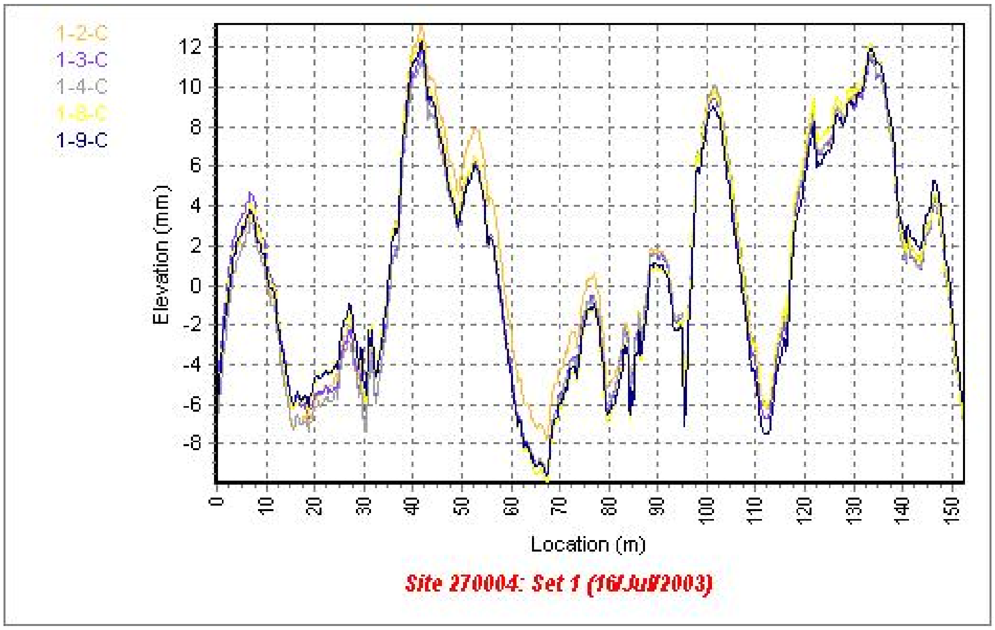
Site 4 – North Central.



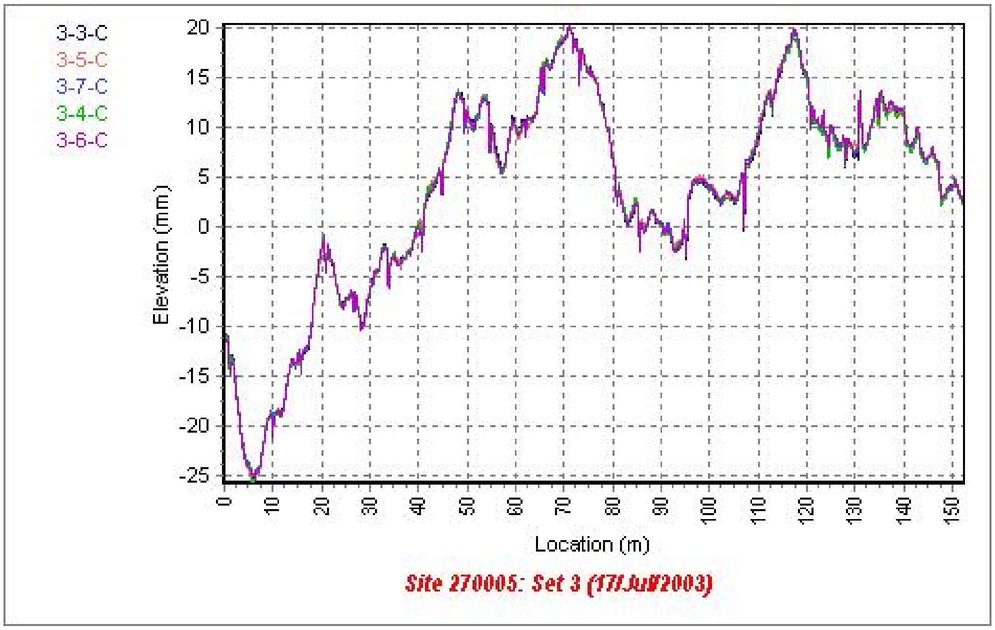
Site 4 – Southern.



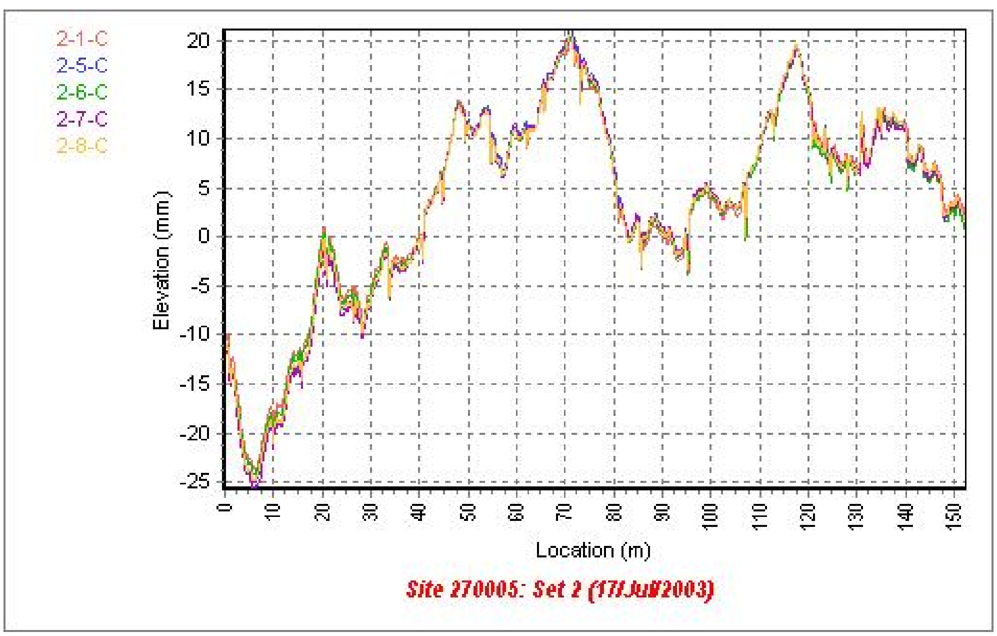
Site 4 – Western.


1-2-C
1-3-C
1-4-C
1-8-C
1-9-C
Elevation (mm)
Location (m)
Site 270004: Set 1 (16/Jul/2003)

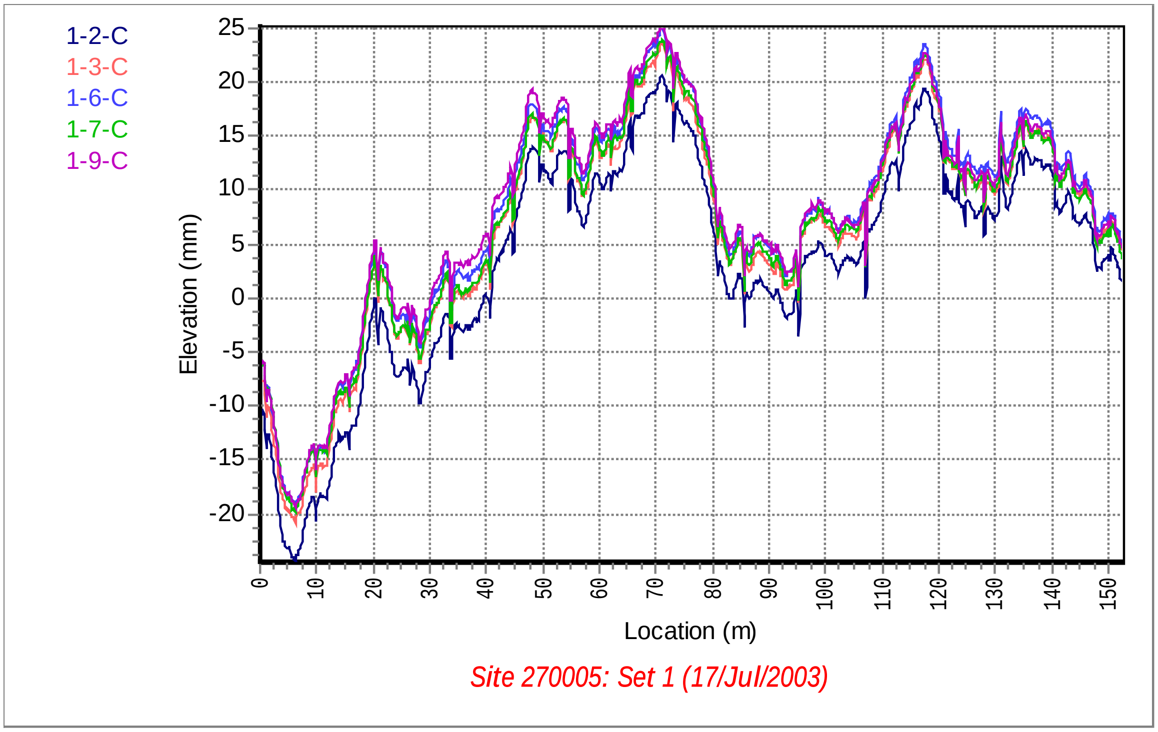
Site 4 – K.J. Law.



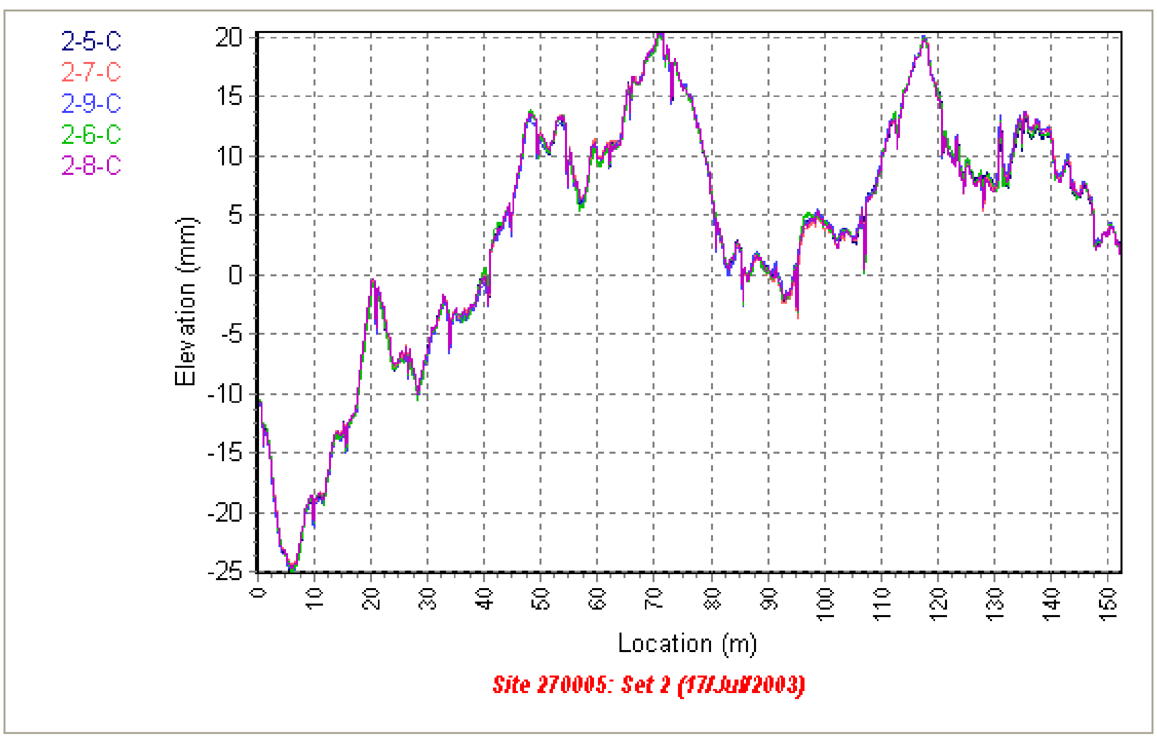
Site 5 – North Atlantic.



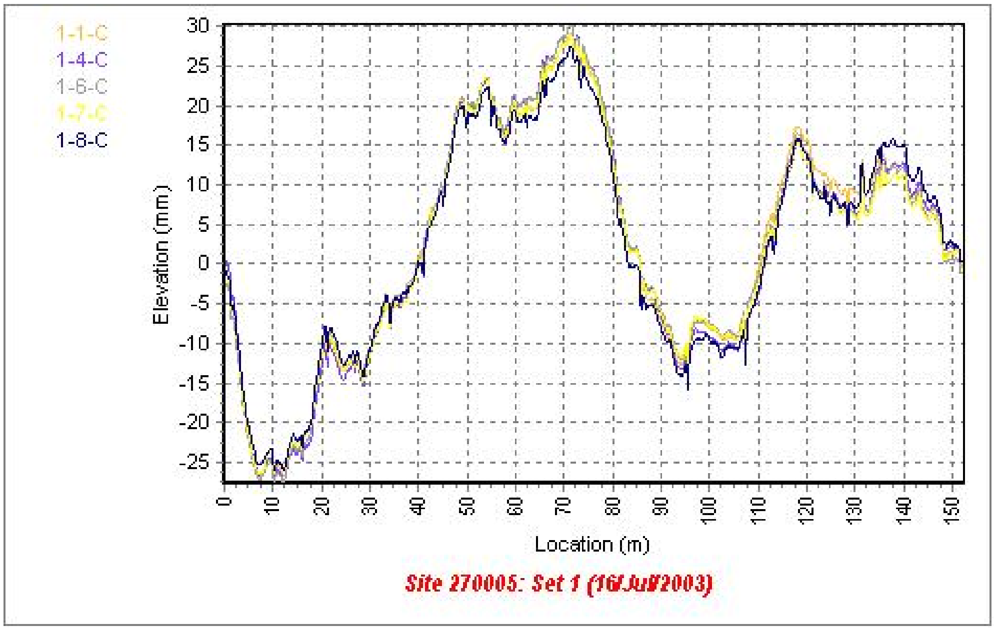
Site 5 – North Central.



Site 5 – Southern.



Site 5 – Western.

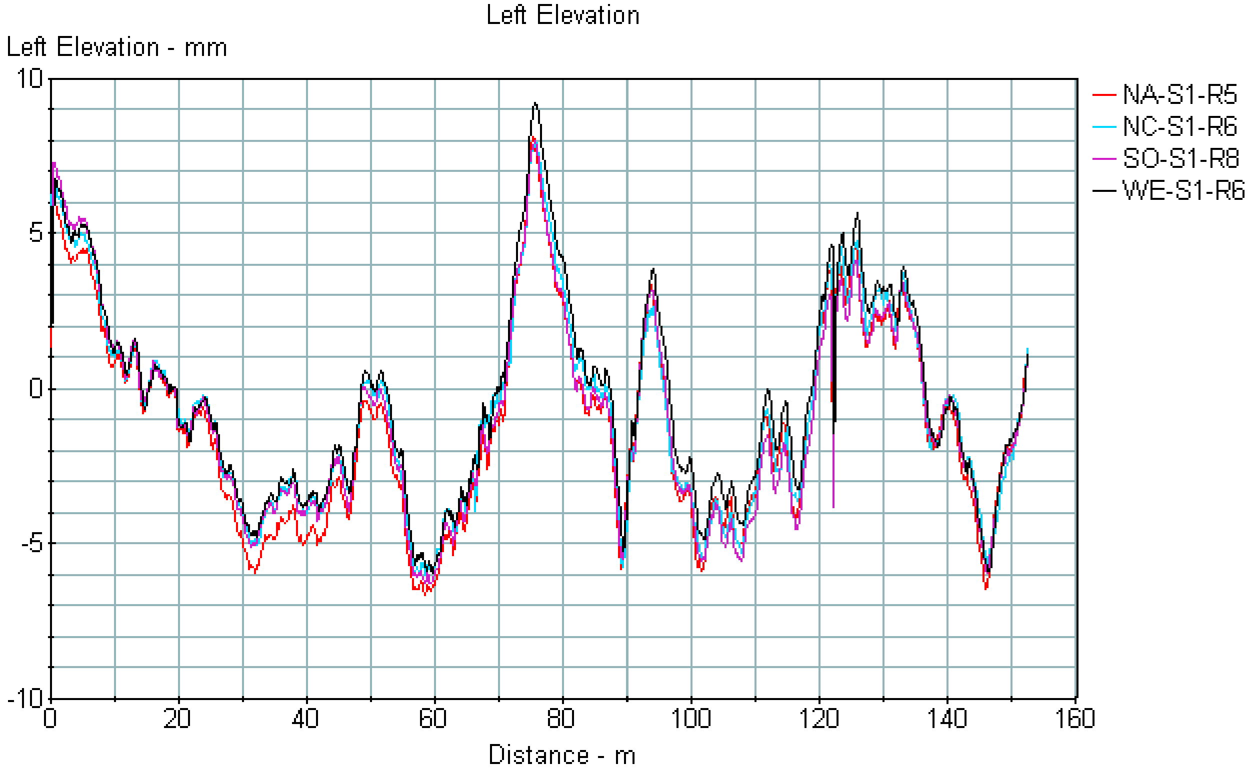

1-1-C
1-4-C
1-6-C
1-7-C
1-8-C
Elevation (mm)
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Location (m)
Site 270005: Set 1 (16/Jul/2003)

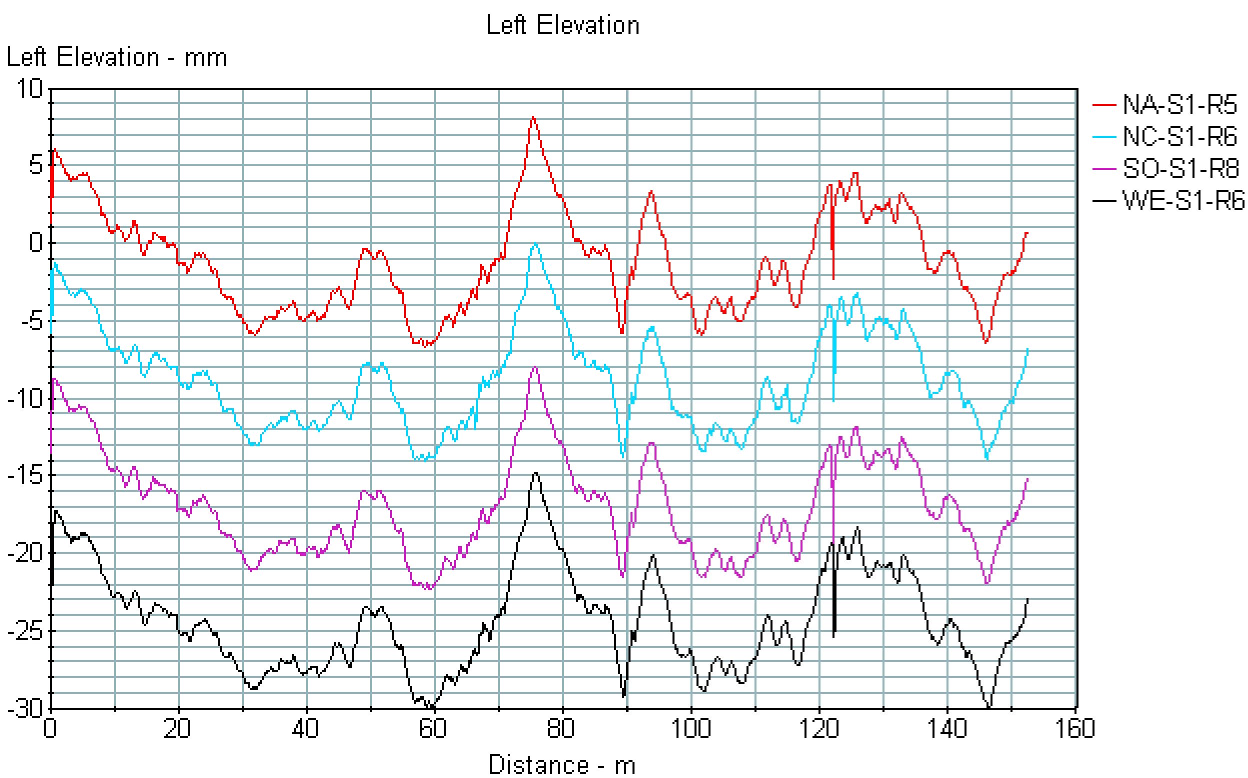
Site 5 – K.J. Law.

APPENDIX F

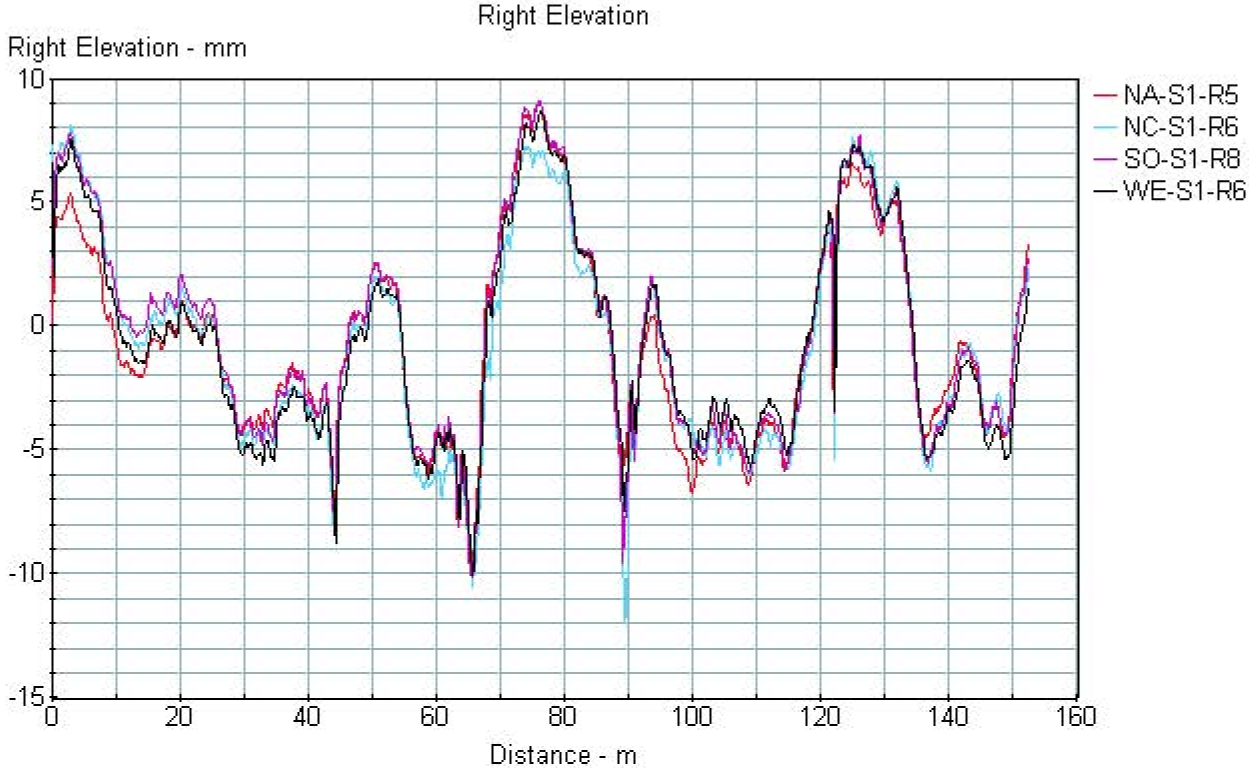
COMPARISON OF PROFILE PLOTS BETWEEN THE FOUR ICC PROFILERS

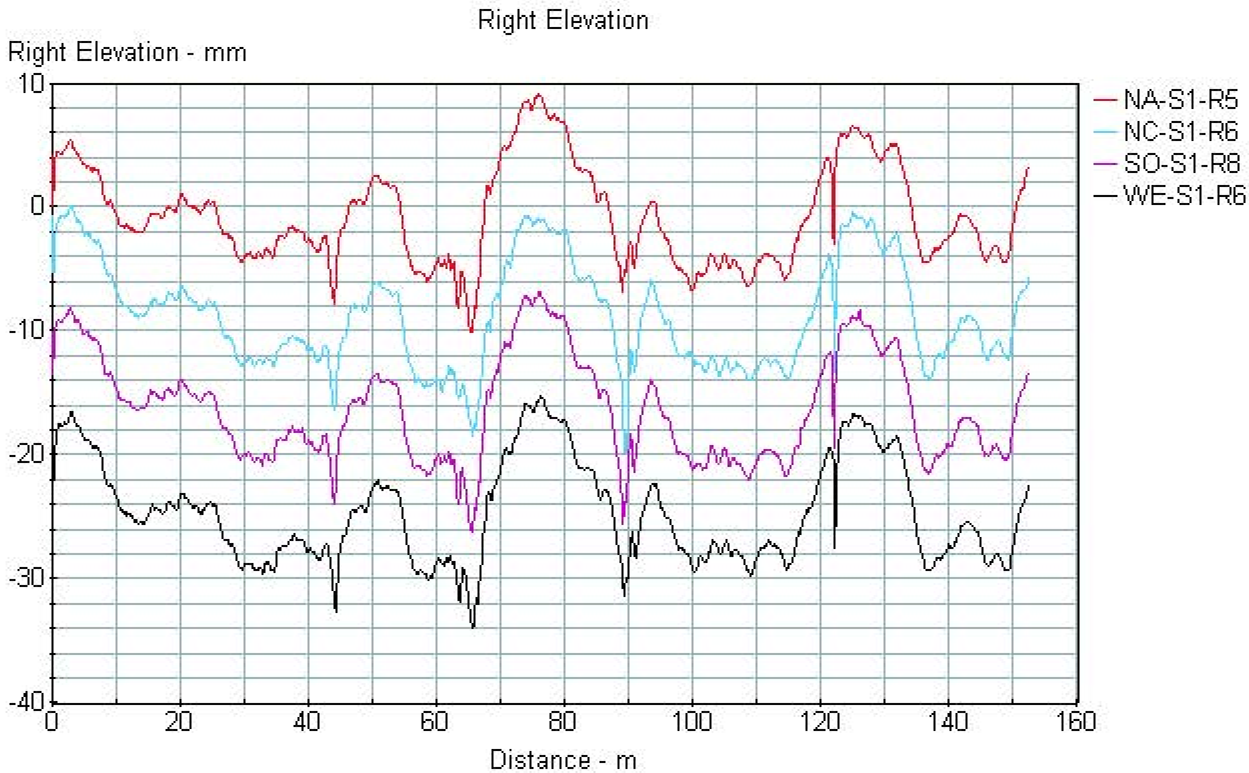
SITE 1 – LEFT WHEEL PATH



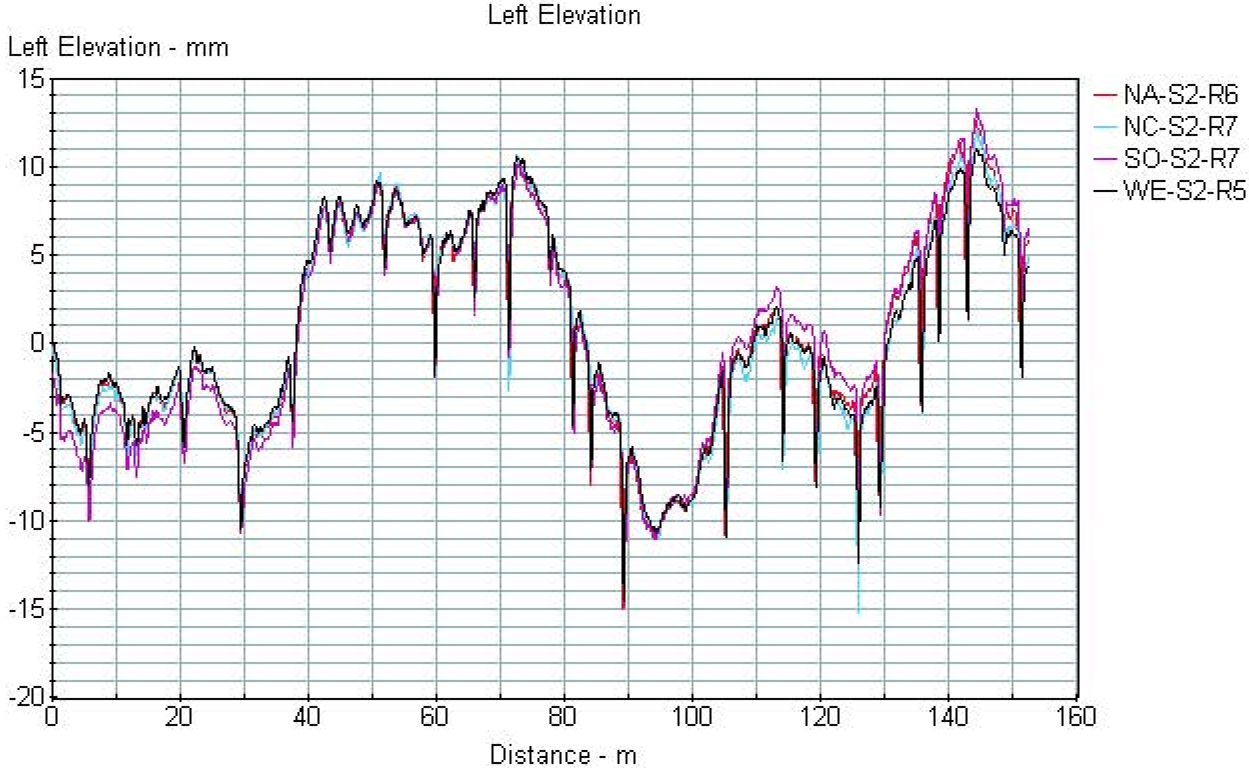


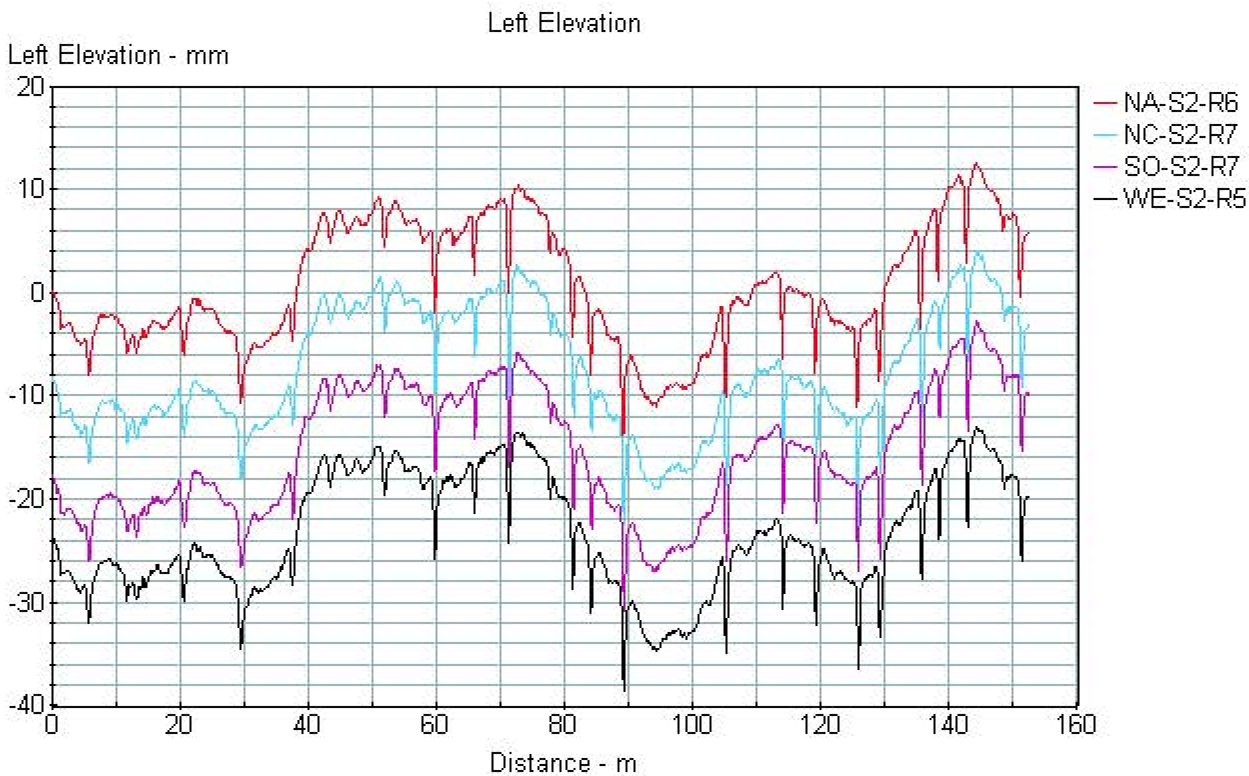
SITE 1 – RIGHT WHEEL PATH



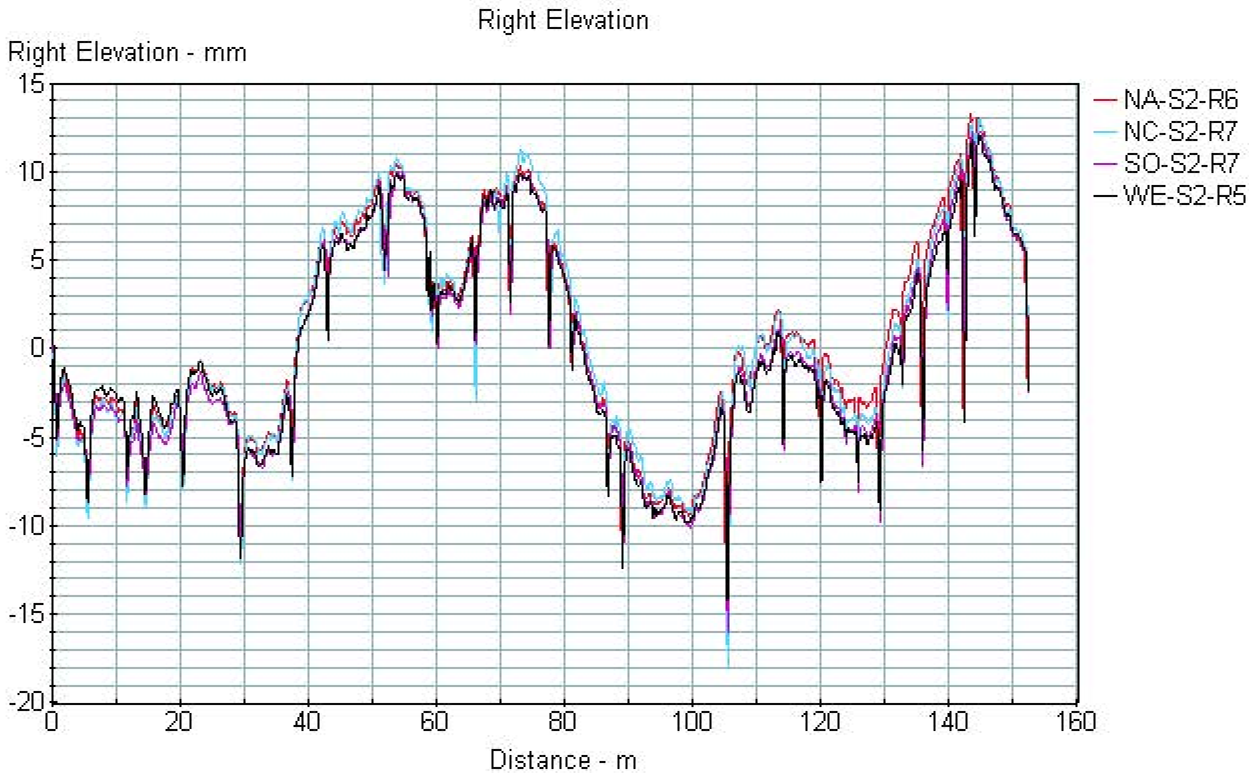


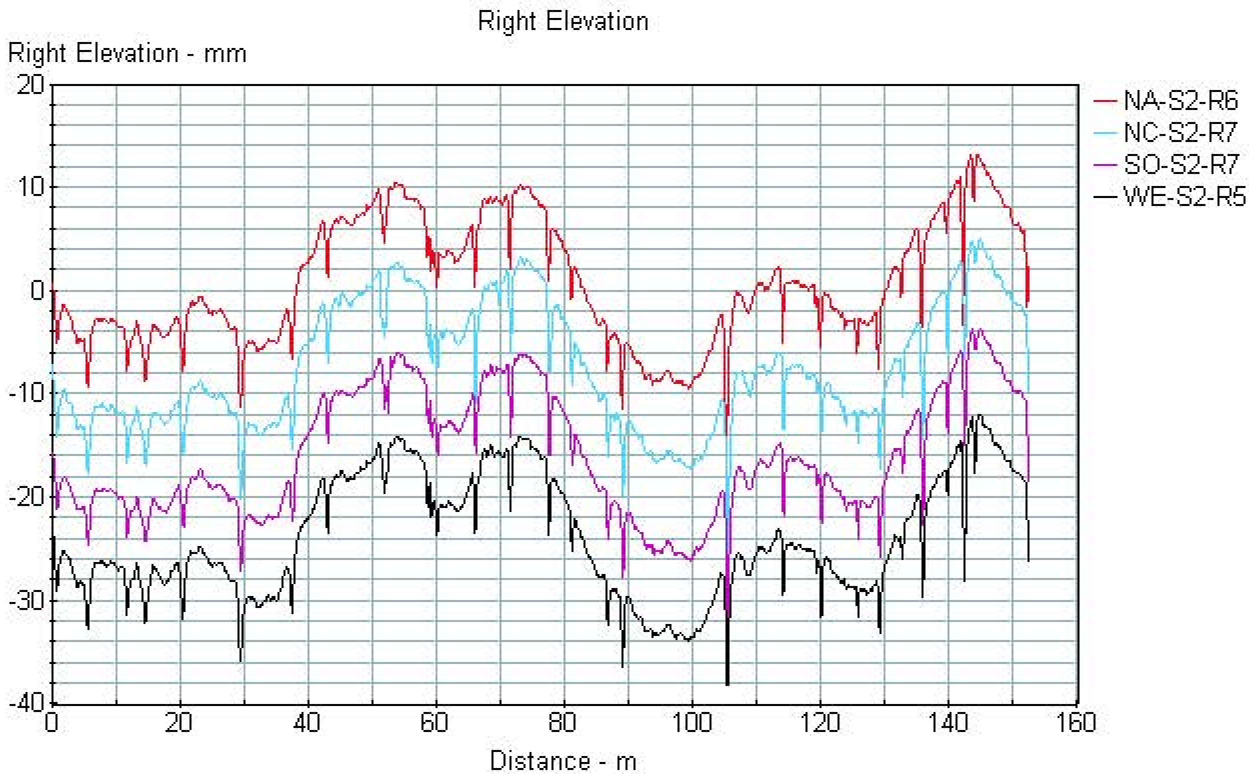
SITE 2 – LEFT WHEEL PATH



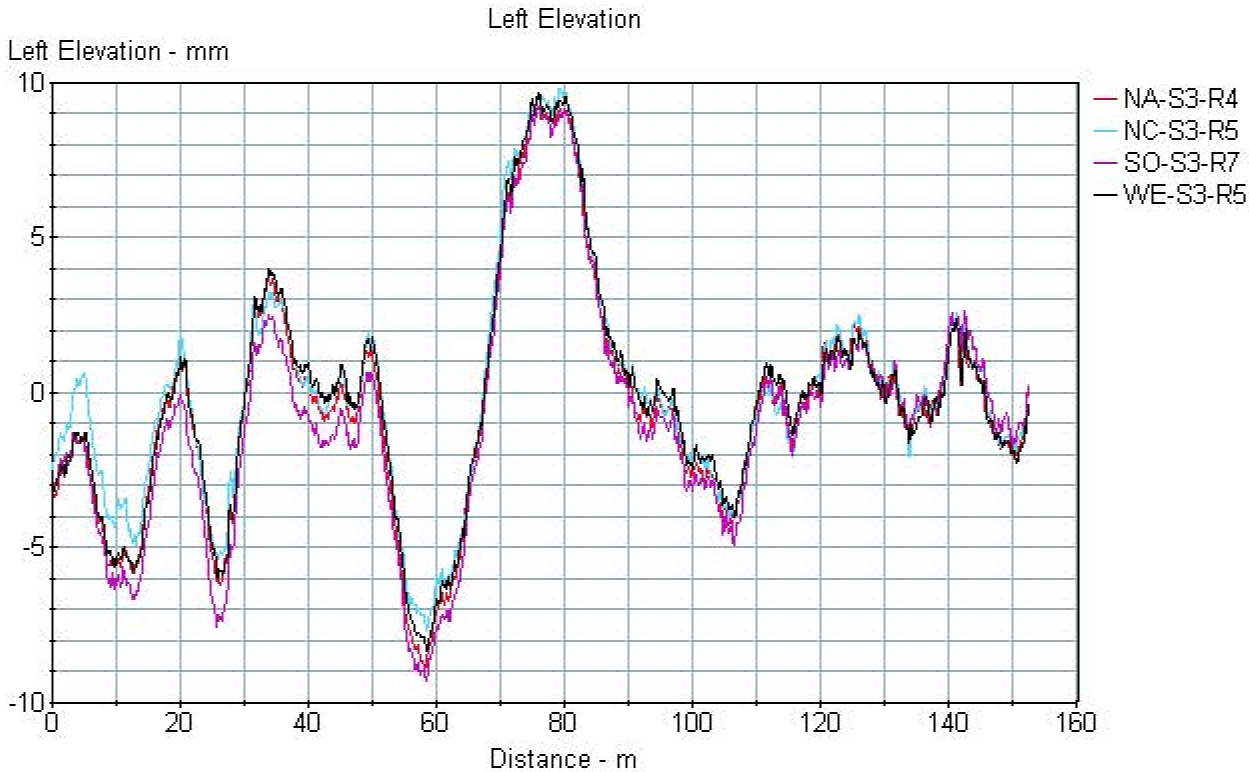


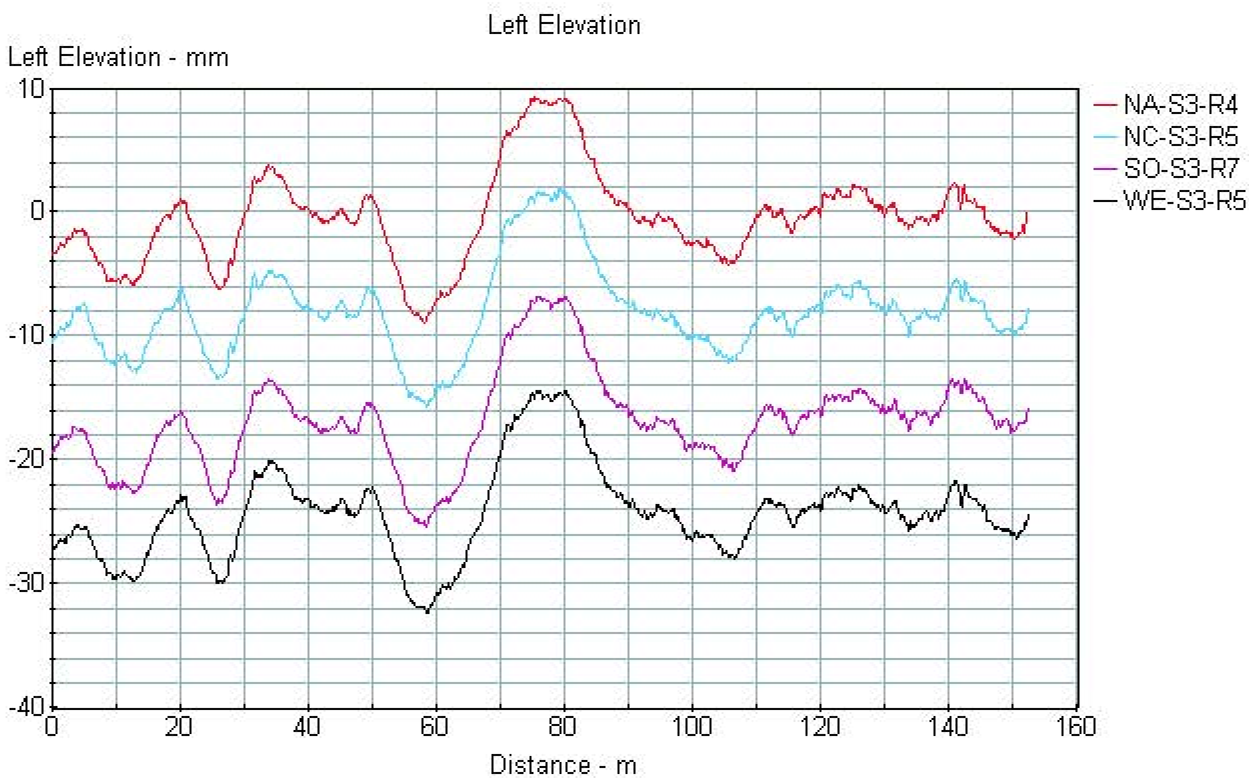
SITE 2 – RIGHT WHEEL PATH



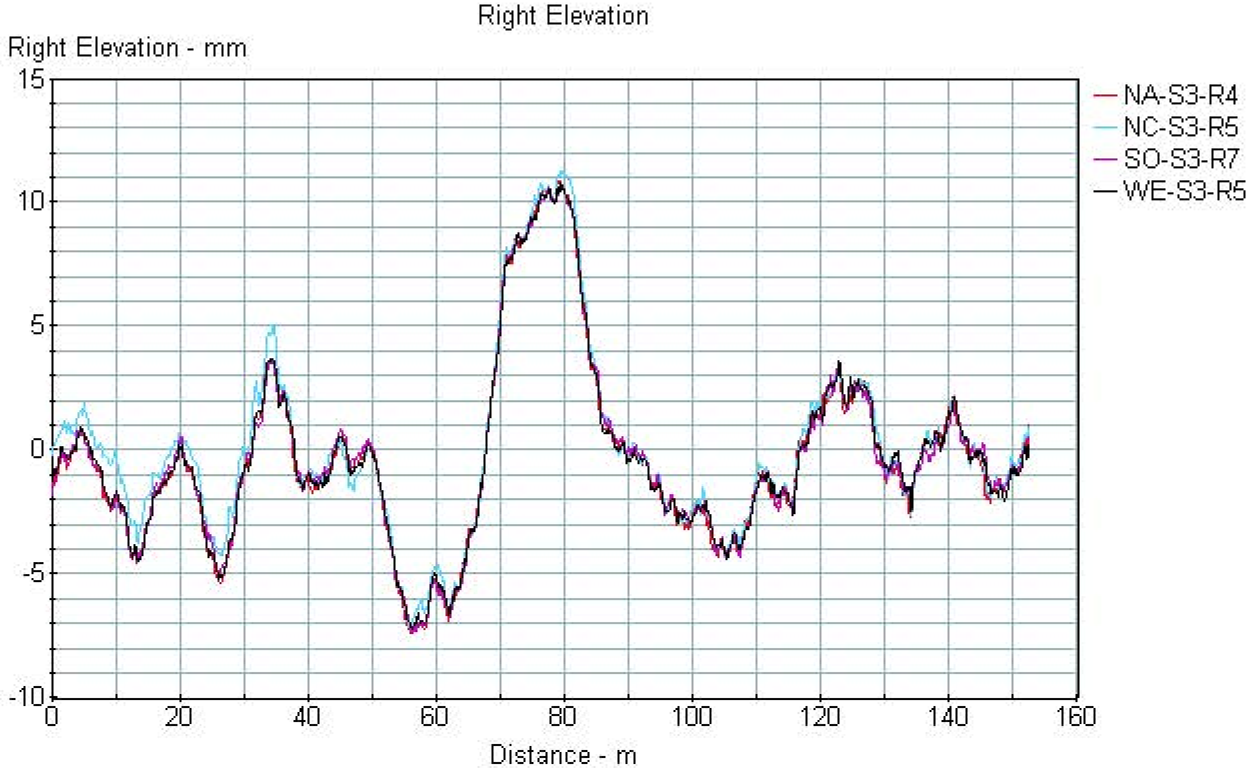


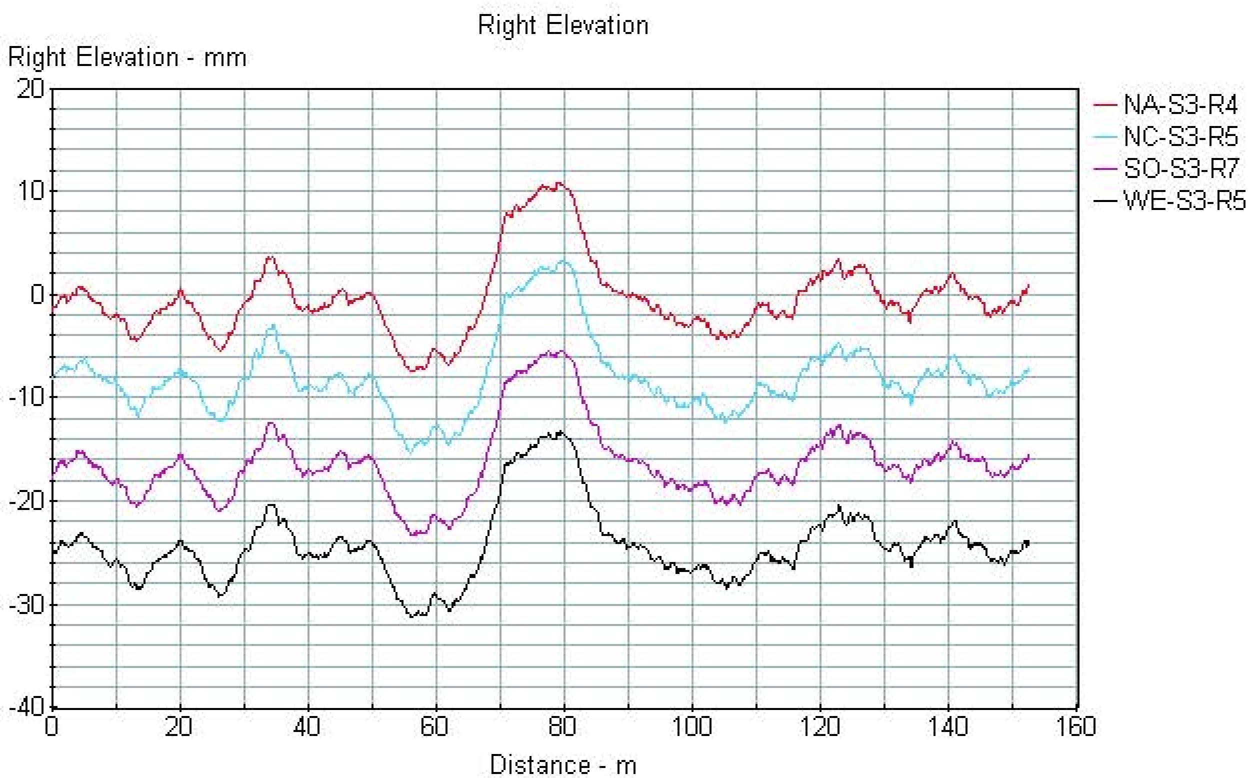
SITE 3 – LEFT WHEEL PATH



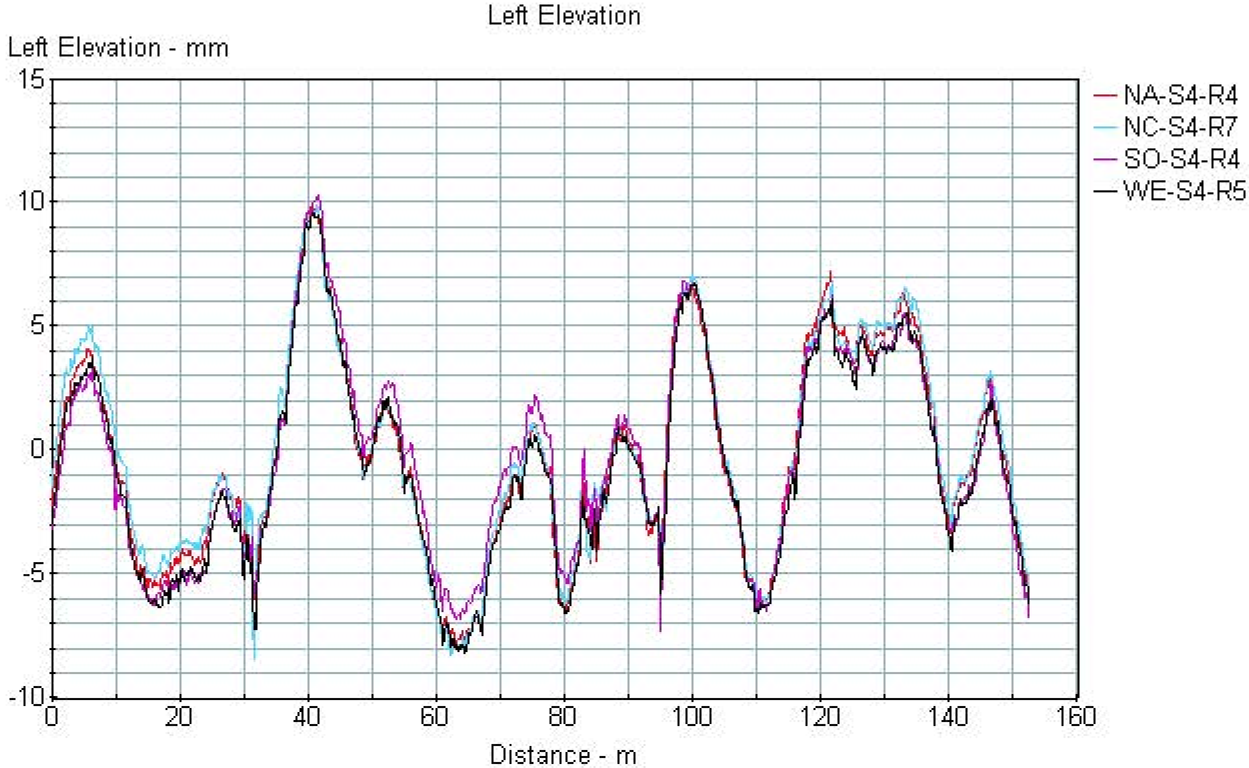


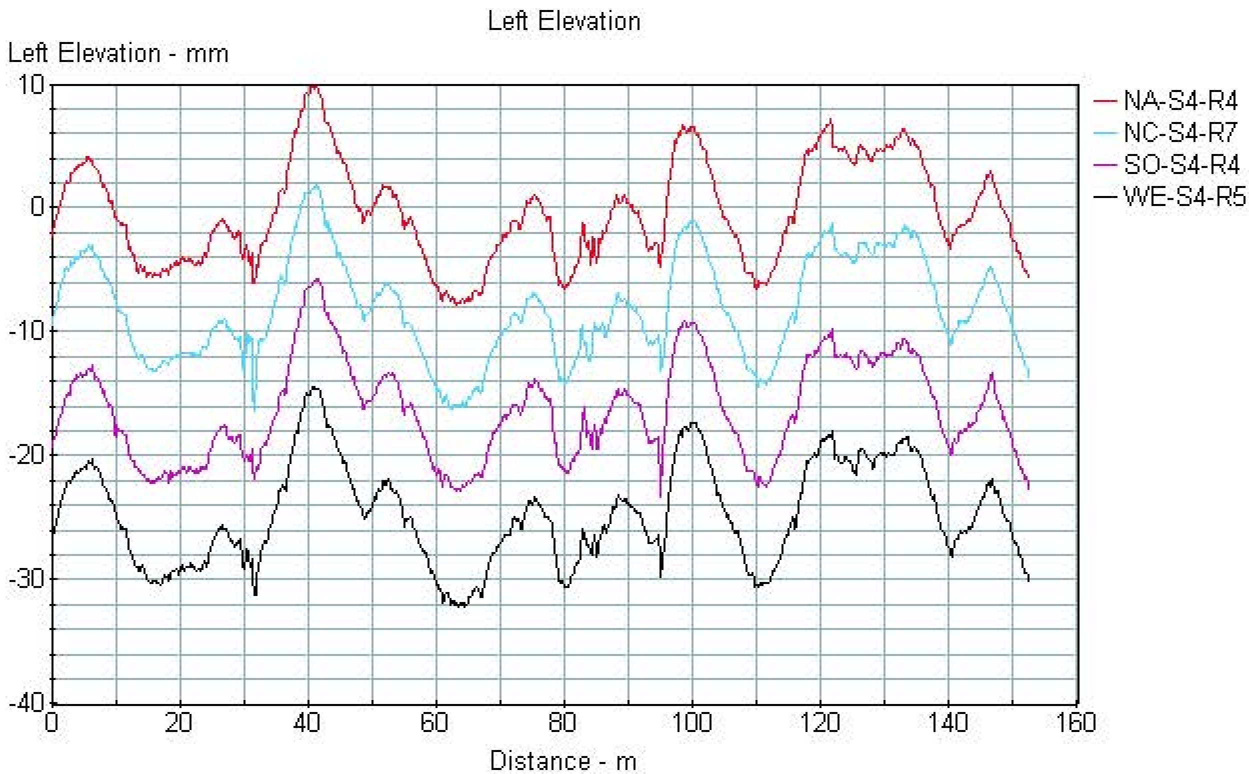
SITE 3 – RIGHT WHEEL PATH



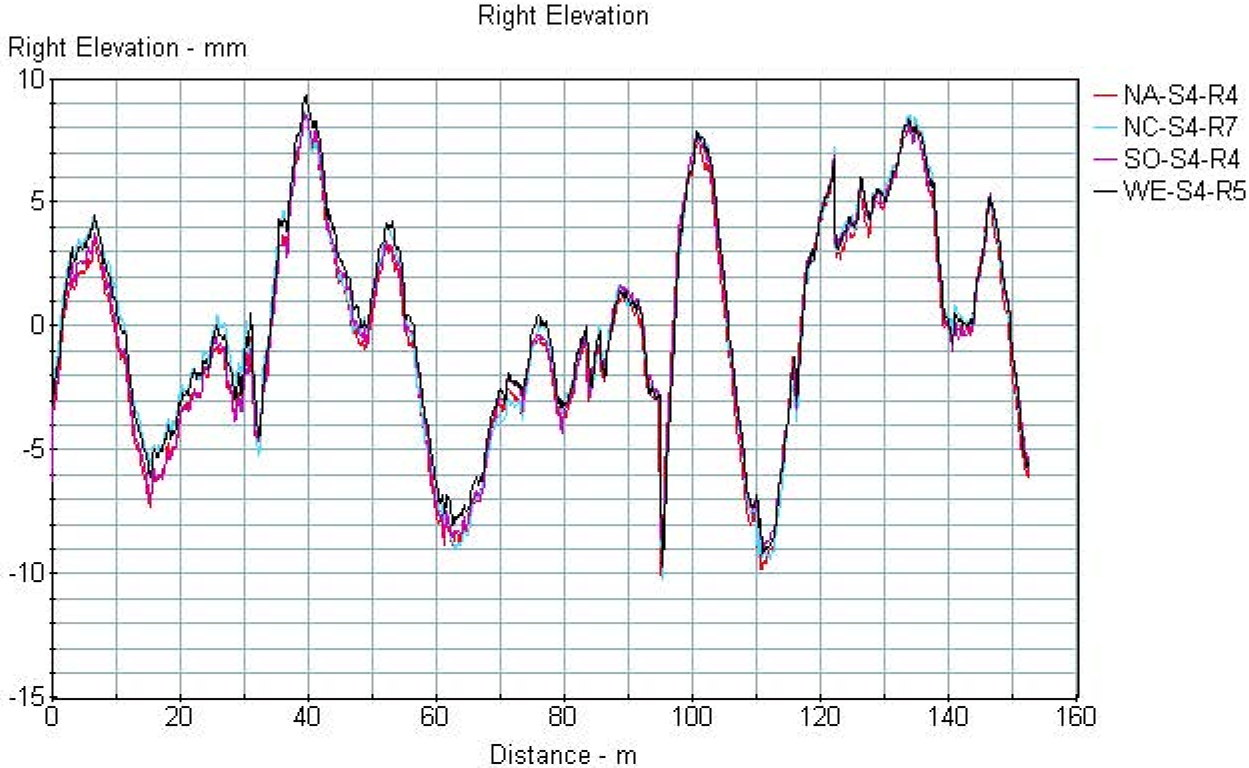


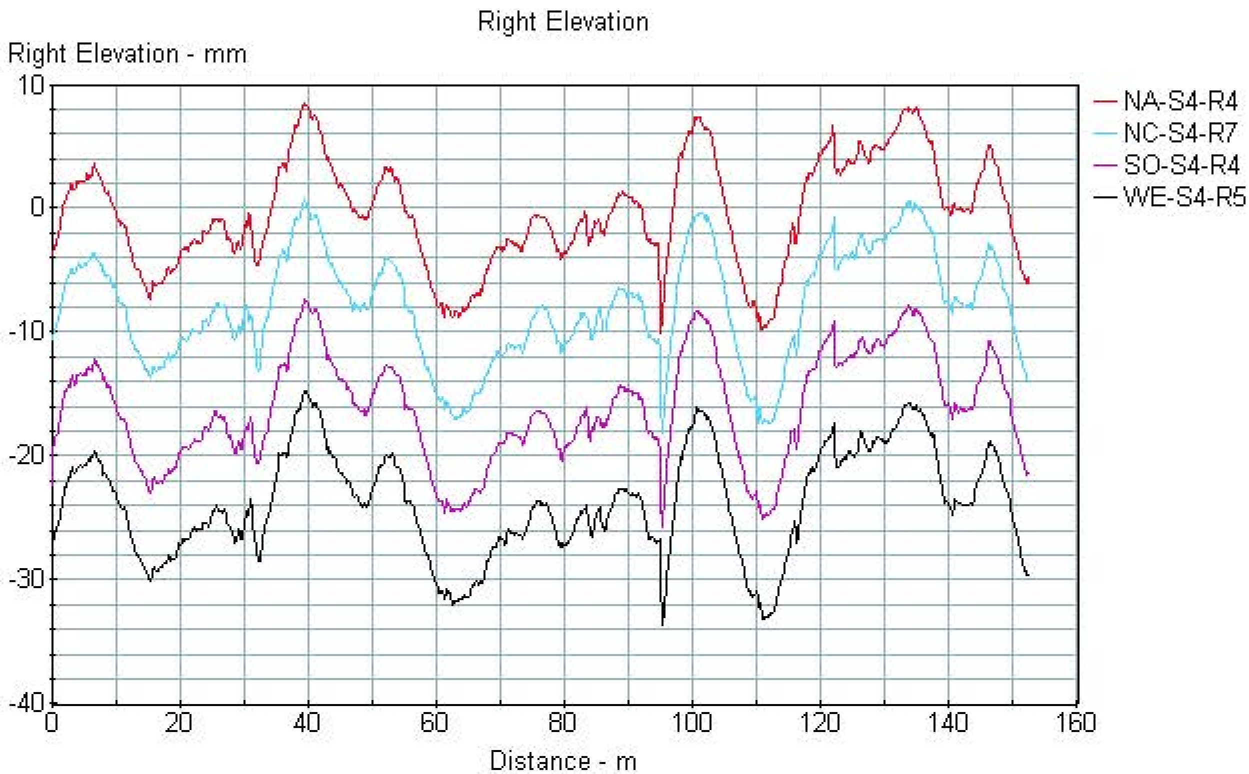
SITE 4 – LEFT WHEEL PATH



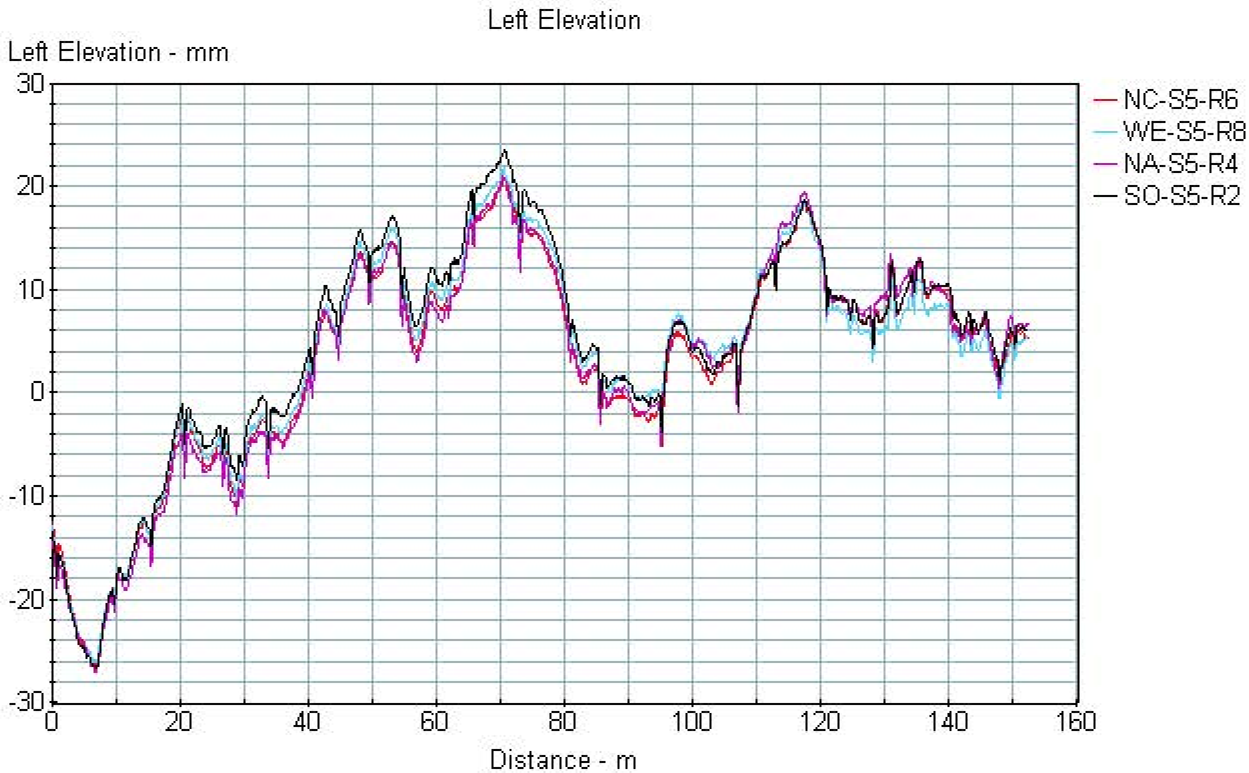


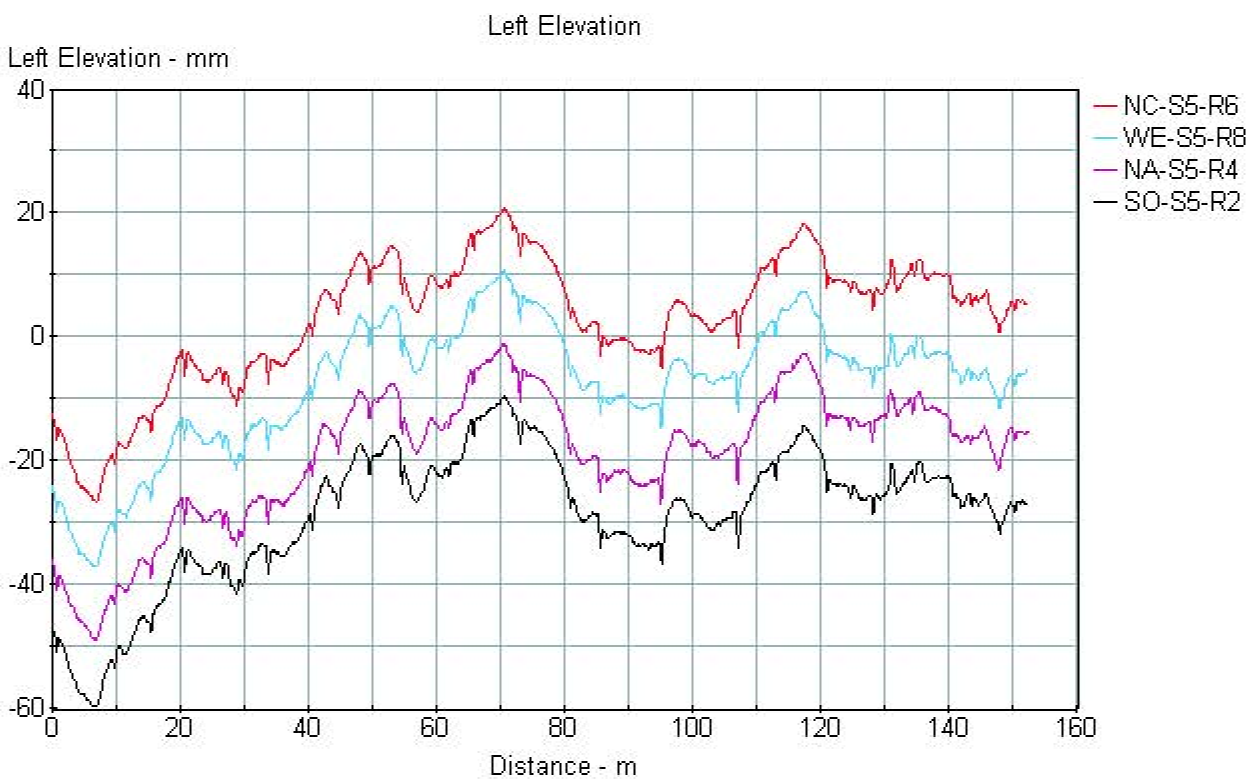
SITE 4 – RIGHT WHEEL PATH



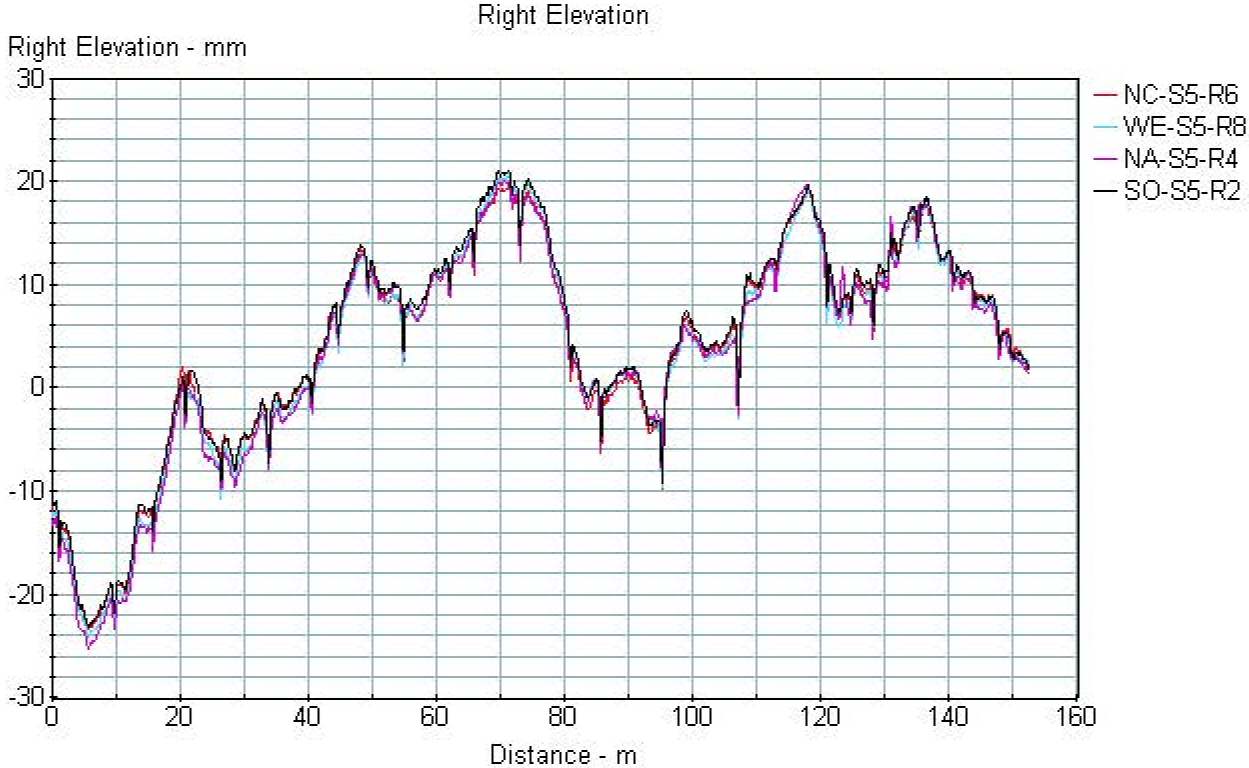


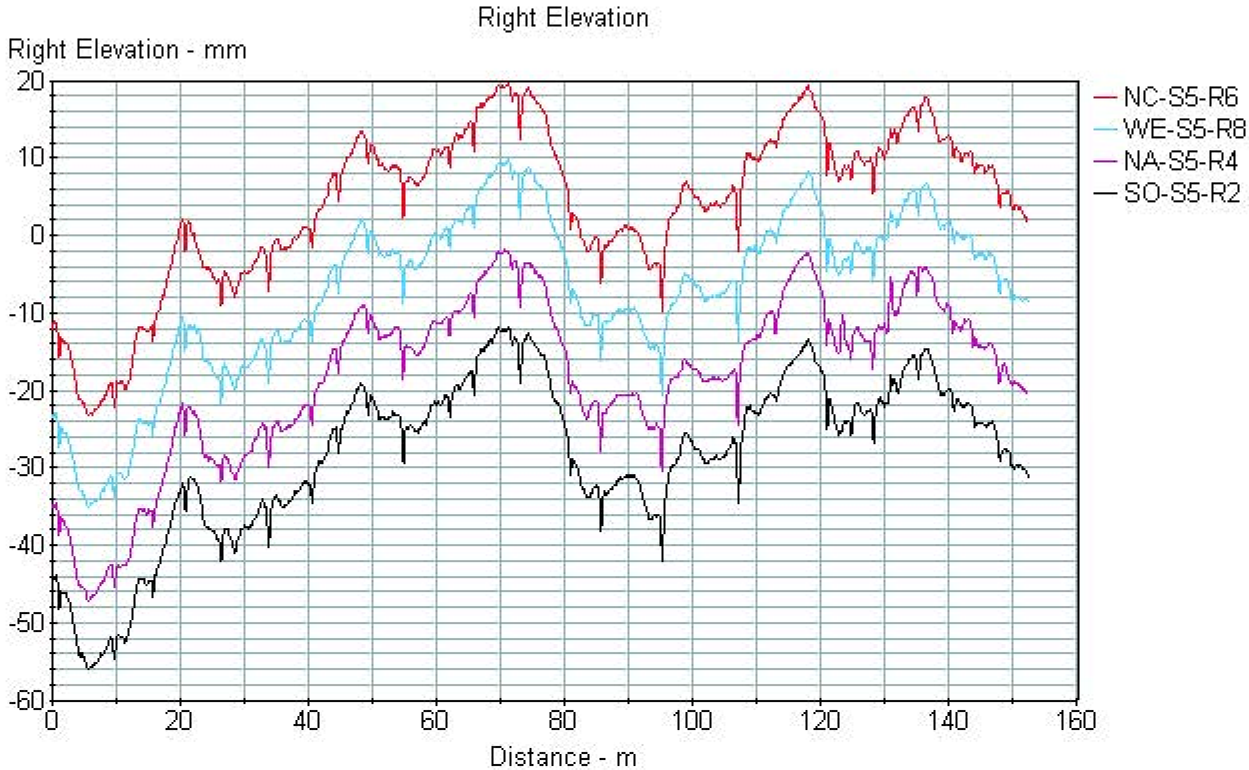
SITE 5 – LEFT WHEEL PATH





SITE 5 – RIGHT WHEEL PATH

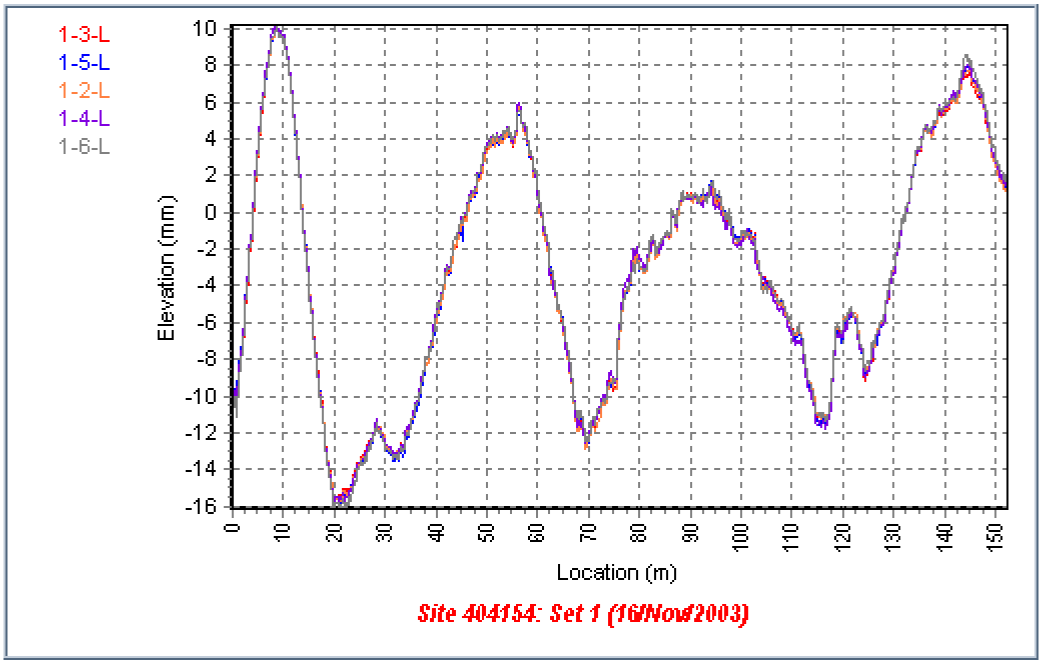




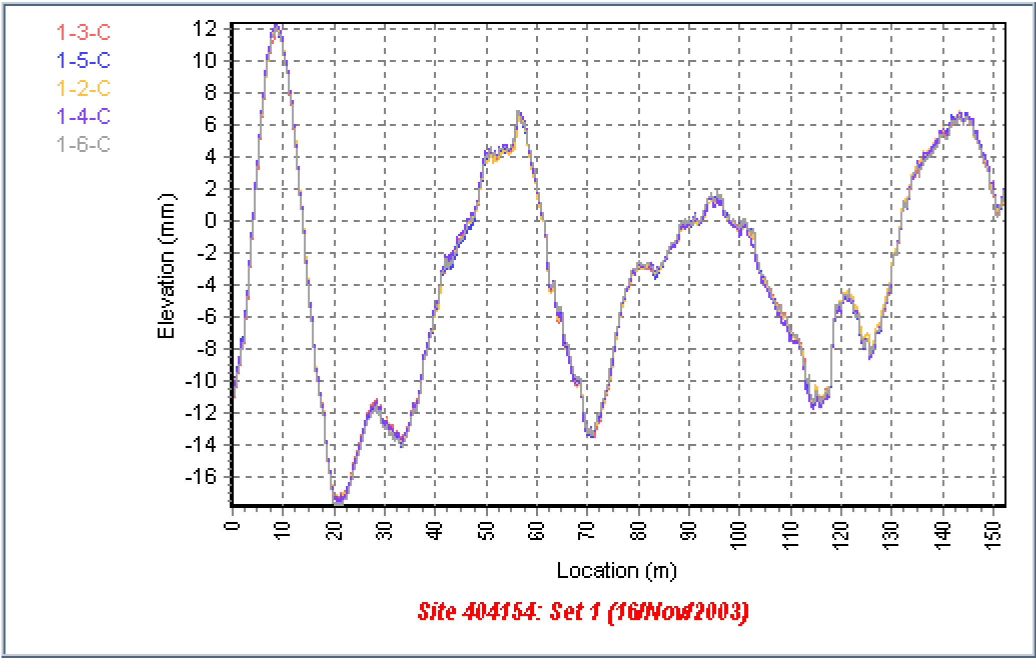
APPENDIX G

SOUTHERN RSC PROFILES FROM TESTING AT GPS SECTIONS

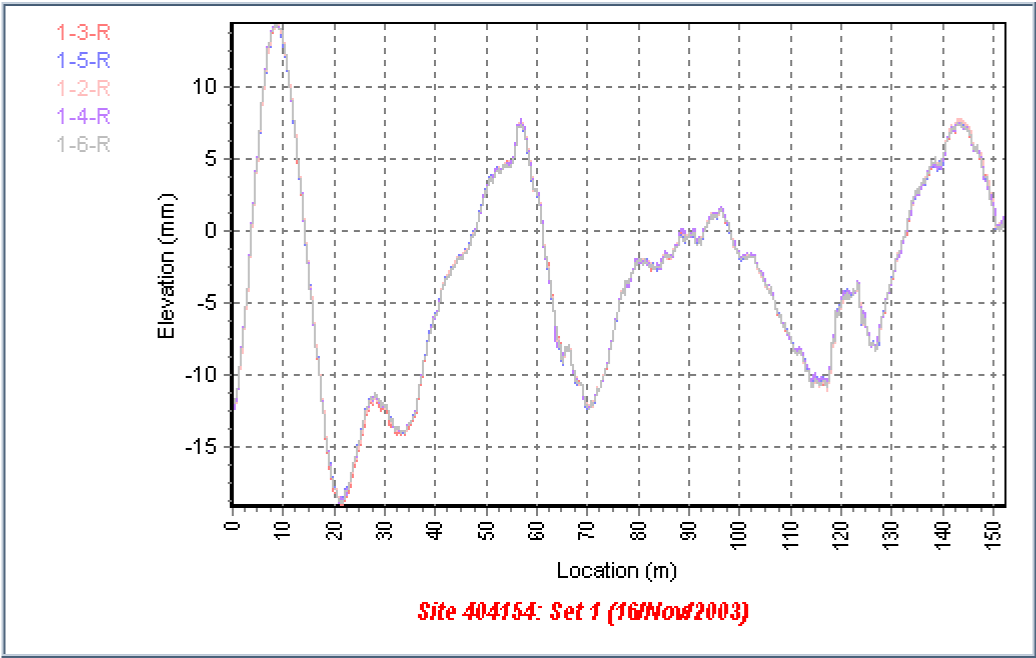
GPS 404154 (Smooth AC)



Left

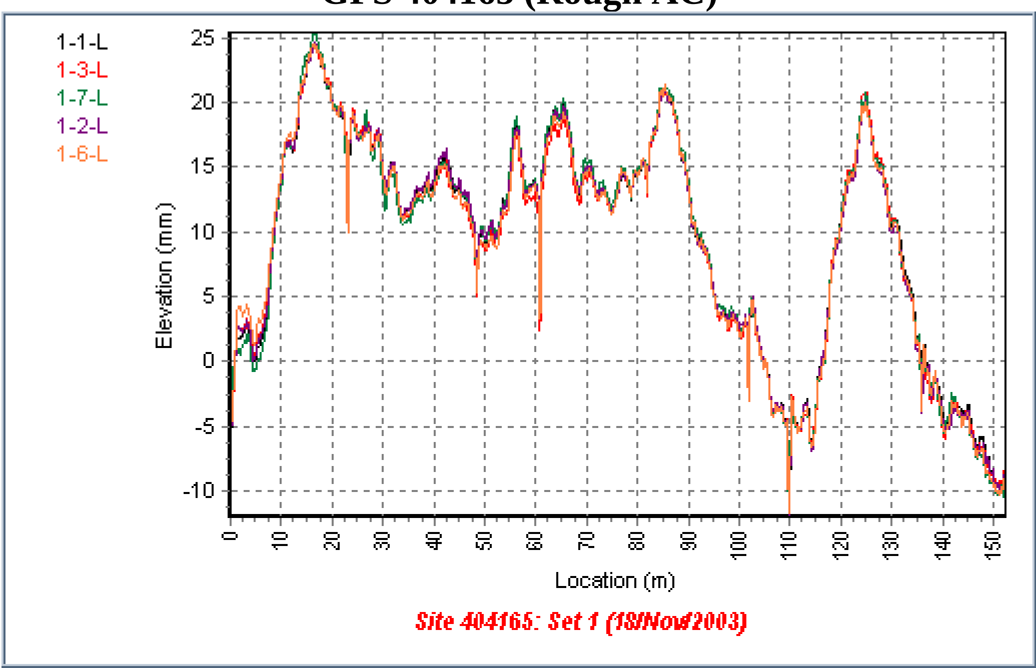


Center

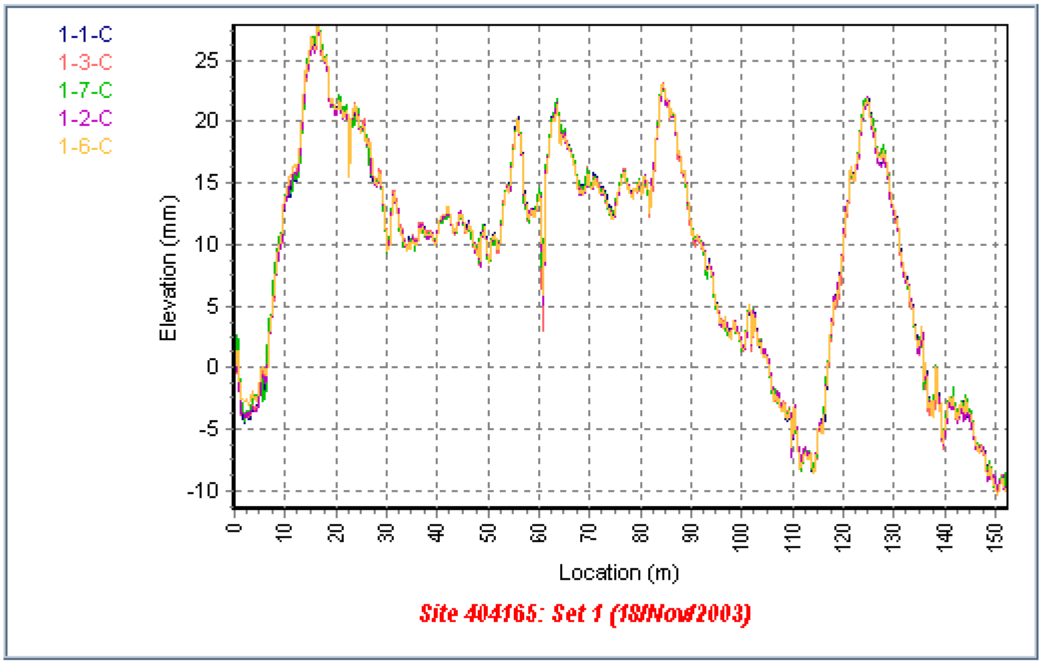


Right

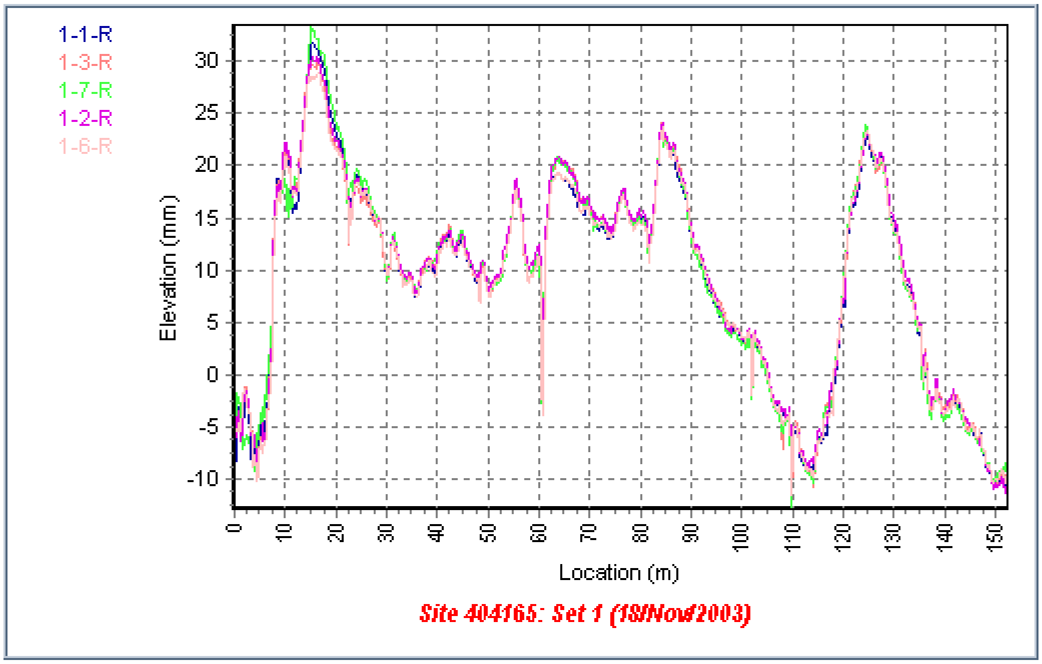
GPS 404165 (Rough AC)



Left

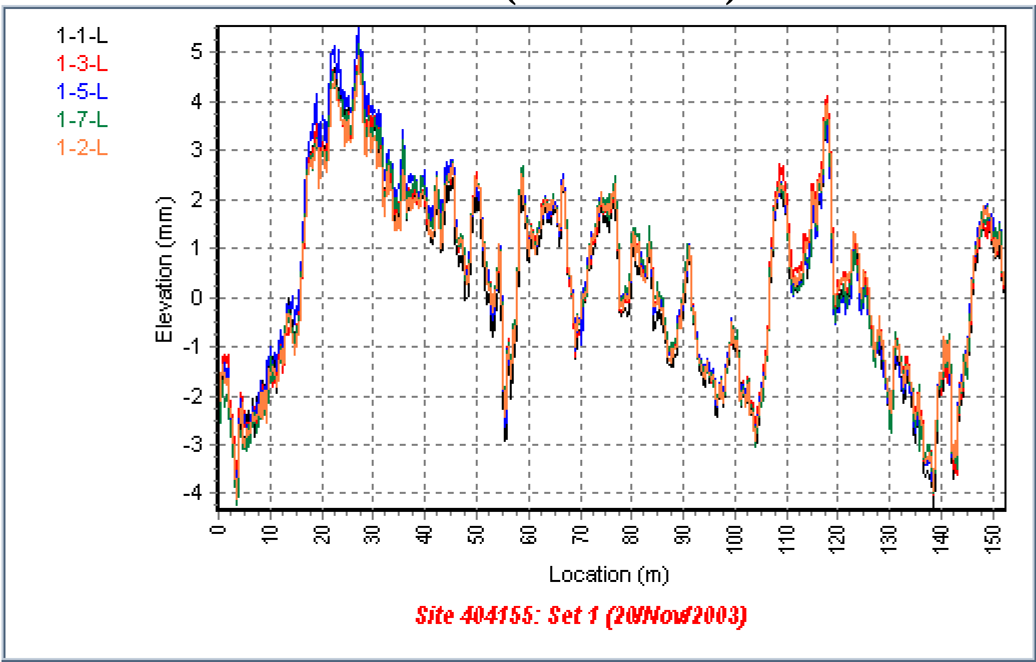


Center

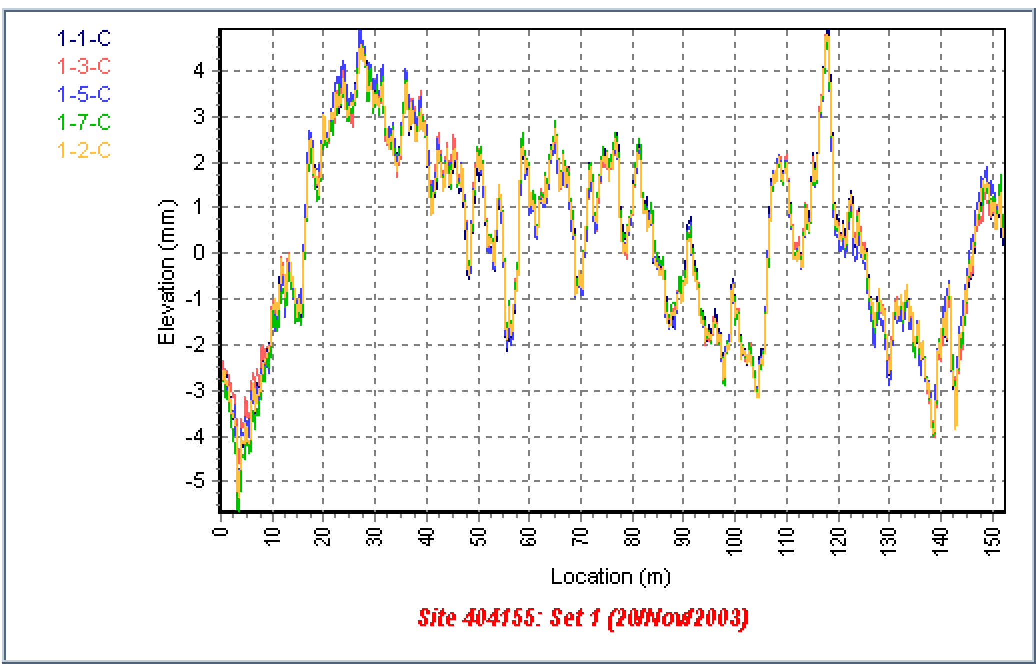


Right

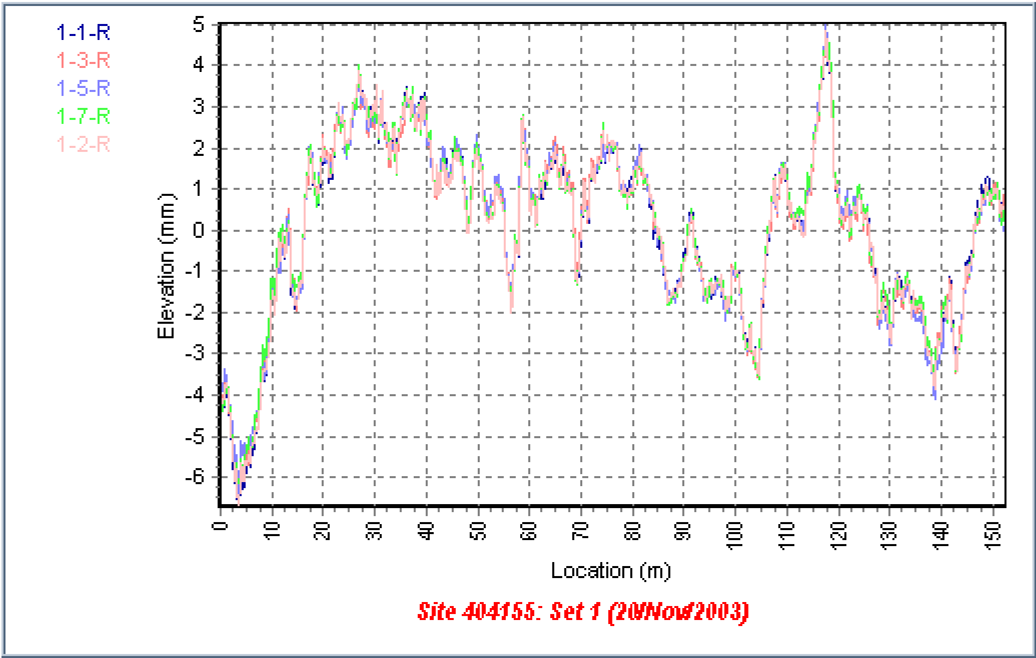
GPS 404155 (Smooth PCC)



Left

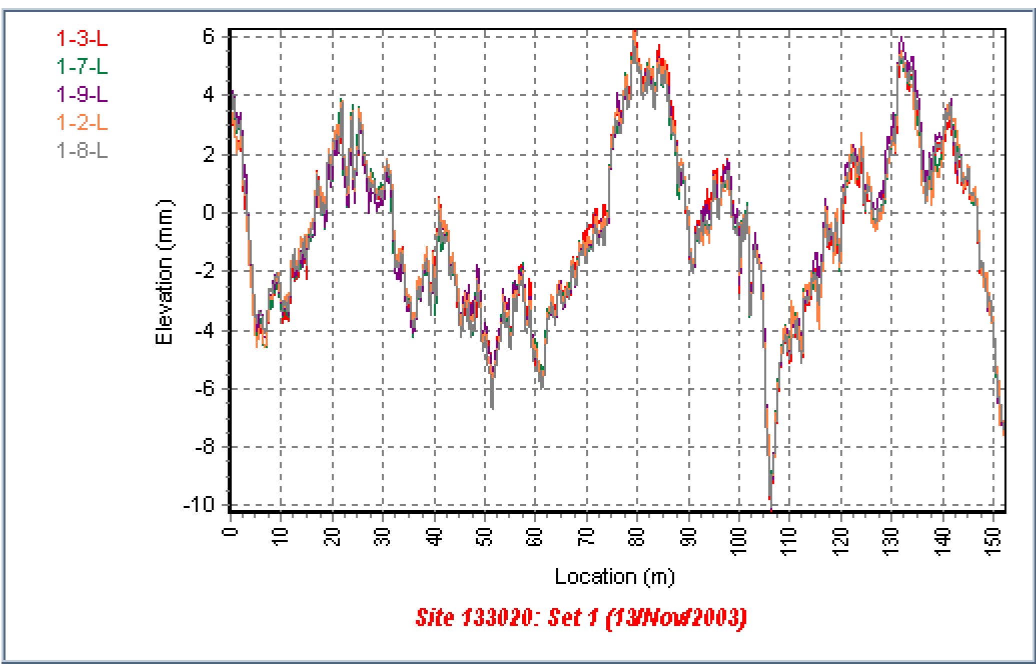


Center

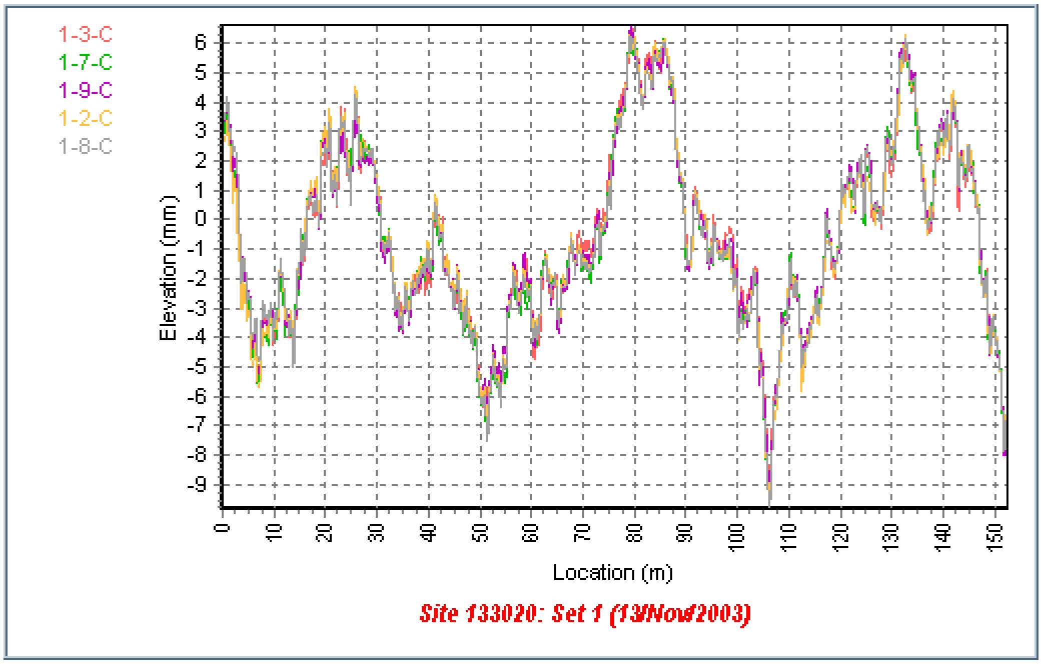


Right

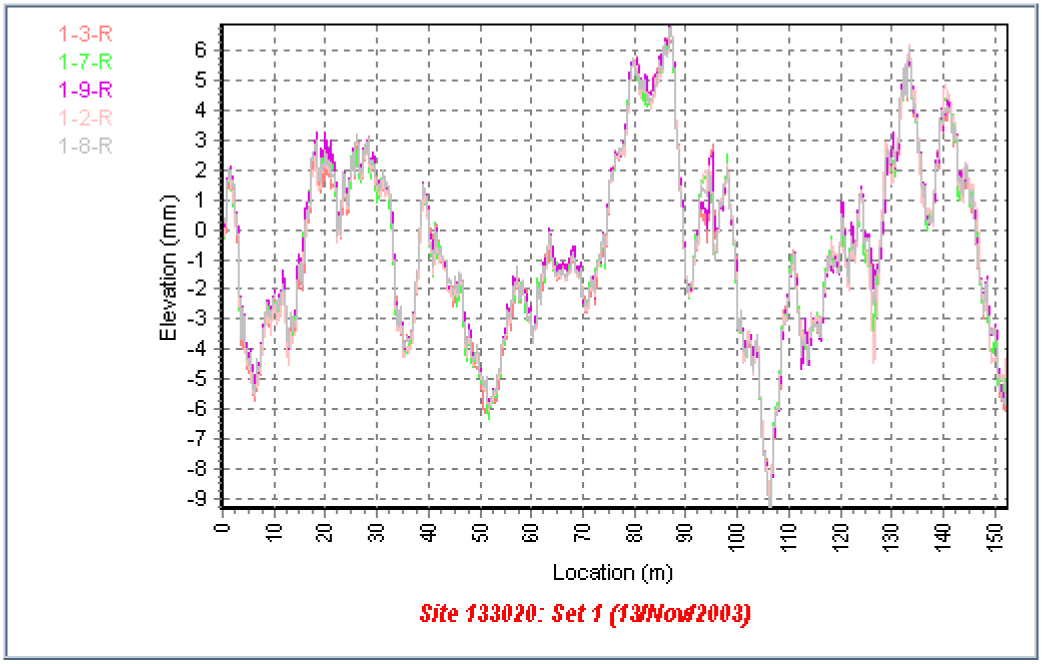
433020 (Medium Rough PCC)



Left

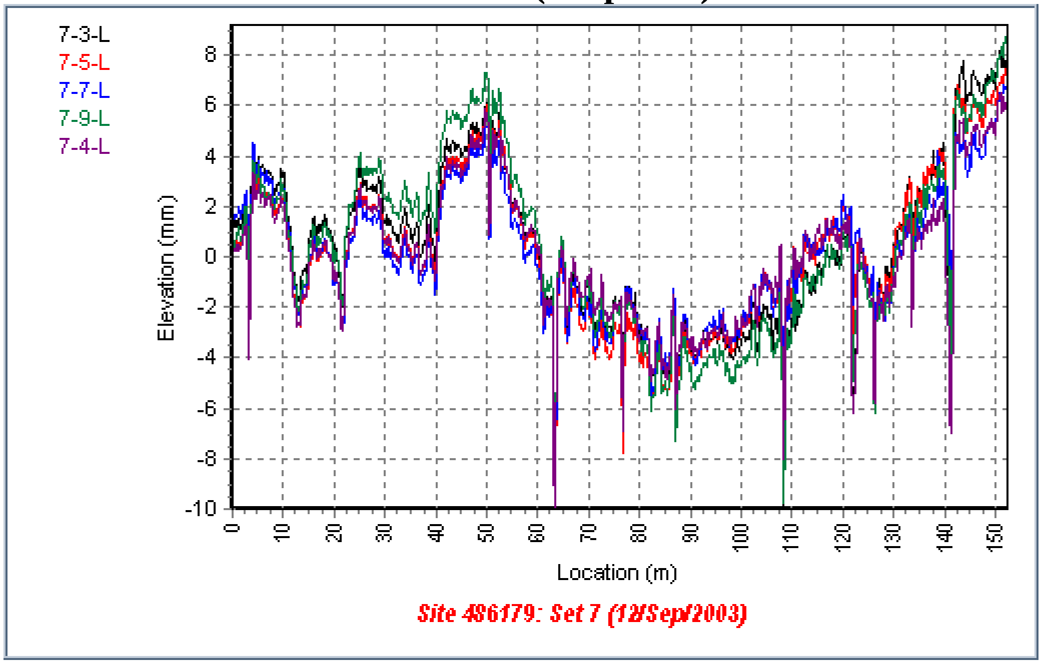


Center

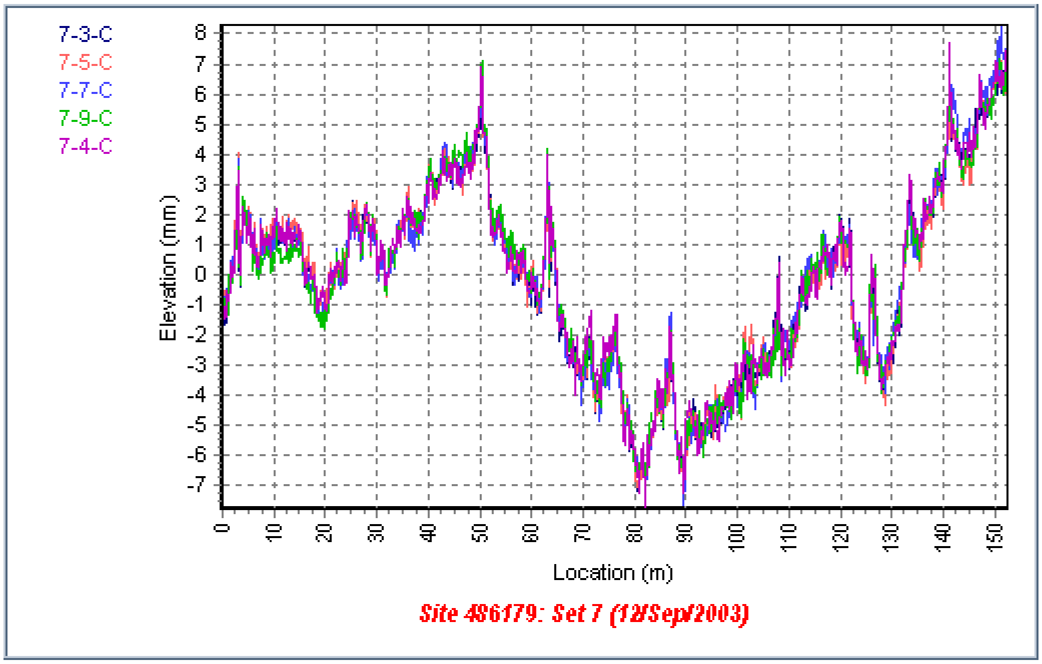


Right

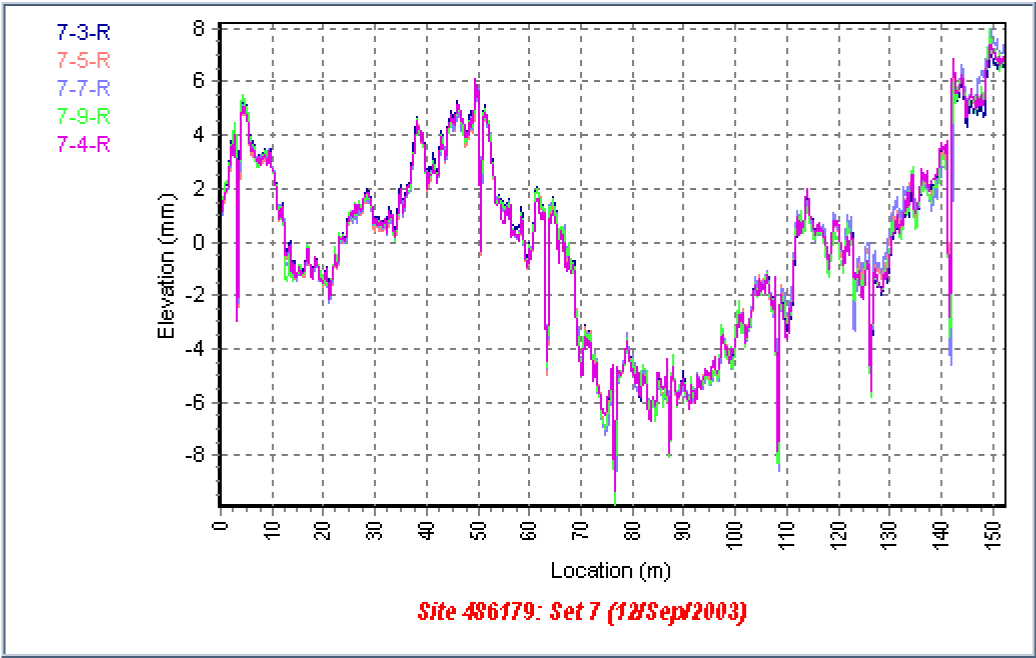
GPS 486174 (Chip Seal)



Left



Center


7-3-R
7-5-R
7-7-R
7-9-R
7-4-R
Elevation (mm)
Location (m)
Site 486179: Set 7 (12/Sep/2003)

Right