ASSESSMENT OF LIDAR SURVEY IN THE PEACE-ATHABASCA DELTA

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LIST OF ACRONYMS

LiDAR	Airborne Light Detection and Ranging
UCL	Unclassified LiDAR
ACL	Automatically Classified LiDAR
MCL	Manually Classified LiDAR
GPS	Global Positioning System
LAI	Leaf Area Index
DCIS	Dog Camp Island
DCQU	Dog Camp Quarry benchmark
DL	Duck Lake
EL	Egg Lake
JBM	Jemis Lake Benchmark
JBIP	Jemis Lake Temporary Benchmark Iron Pin
CHIP	Radio Tower Hill (BM: 686004)
MDIP	Morphology-Dependent Interpolation Procedure
TIN	Triangulation Interpolation Algorithm

INTRODUCTION

A LiDAR (Airborne Light Detection and Ranging) survey was conducted at selected sites within the Peace-Athabasca Delta, Alberta, on June 16-18, 2000. An overview map of the Delta is illustrated in Figure 1. The LiDAR data were collected and processed by Optech Inc., while National Hydrology Research Centre (NHRC) and BC HYDRO provided ground support by operating GPS base stations for LiDAR aircraft corrections and by collecting ground survey data for LiDAR accuracy assessment. The ground survey data were processed and the LiDAR data were gridded by NHRC. This report evaluates the LiDAR data based on the collected ground survey data. It also describes the algorithm used to grid the LiDAR elevation points into manageable digital elevation models (DEMs). The produced LiDAR DEMs were also used to improve a 25m resolution DEM of the Peace-Athabasca Delta that was previously generated by NHRC based on 1:50,000 NTS contour lines, survey points and lake outlines.

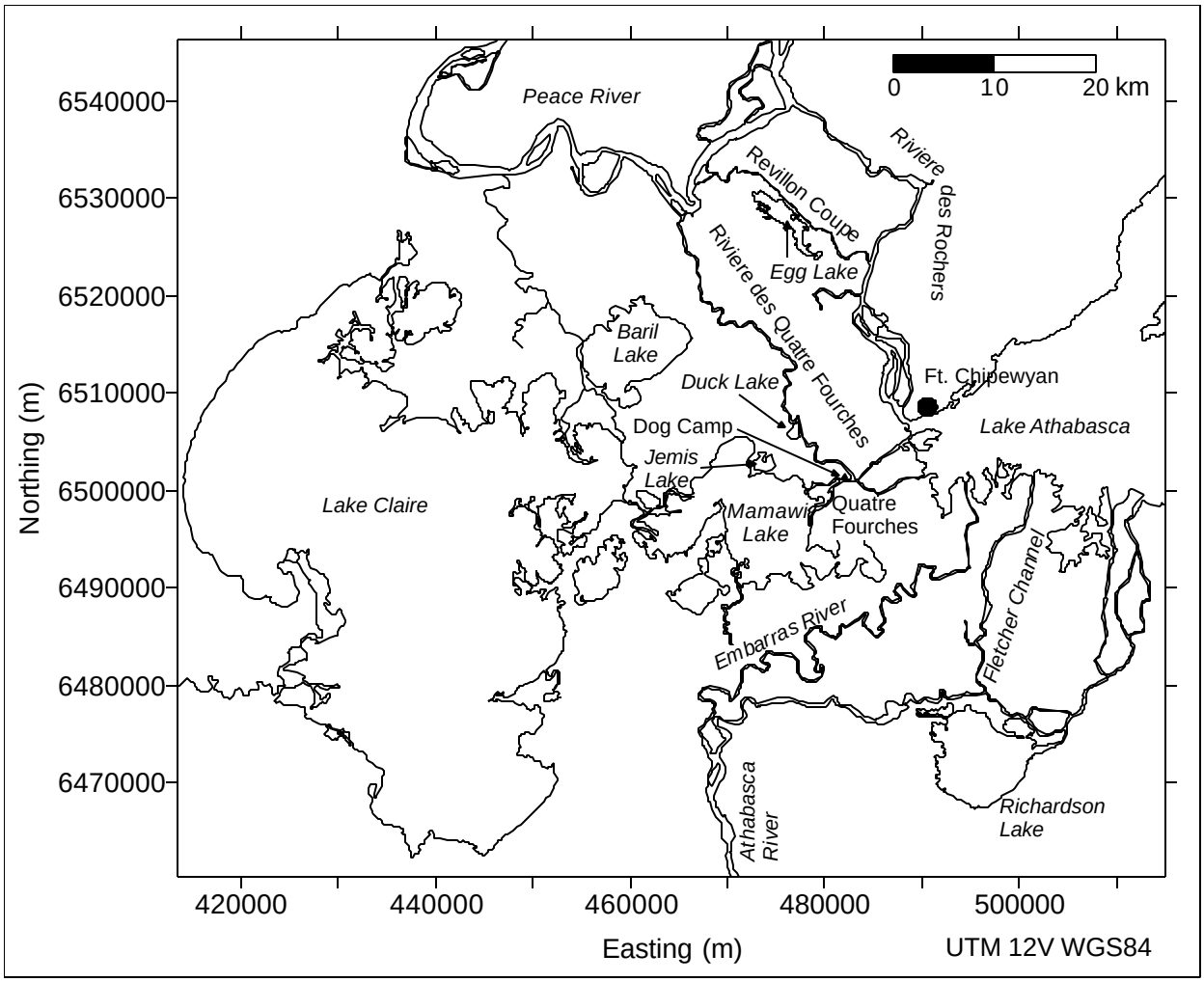

Figure 1. The Peace-Athabasca Delta, Alberta.

STUDY AREAS

Seven areas within the Peace-Athabasca Delta were surveyed with the LiDAR. These areas are illustrated in Figure 2 and listed in Table 1. The LiDAR surveys were conducted along the levees of river channels and within the Jemis Lake basin. LiDAR verification data were collected *in situ* in Jemis Lake (Area A) and Dog Camp (Area B) at the time of the LiDAR survey. The Jemis Lake basin includes areas that are covered by mud, thick grass and relatively dense willows. These vegetation types are characteristic of most areas within the delta, making it ideal for LiDAR accuracy assessment. The Dog Camp area was suited for accuracy assessment because it contains two benchmarks with known co-ordinates that can be used for a total station survey. The land covers of Dog Camp include grass, willow, and bedrock.

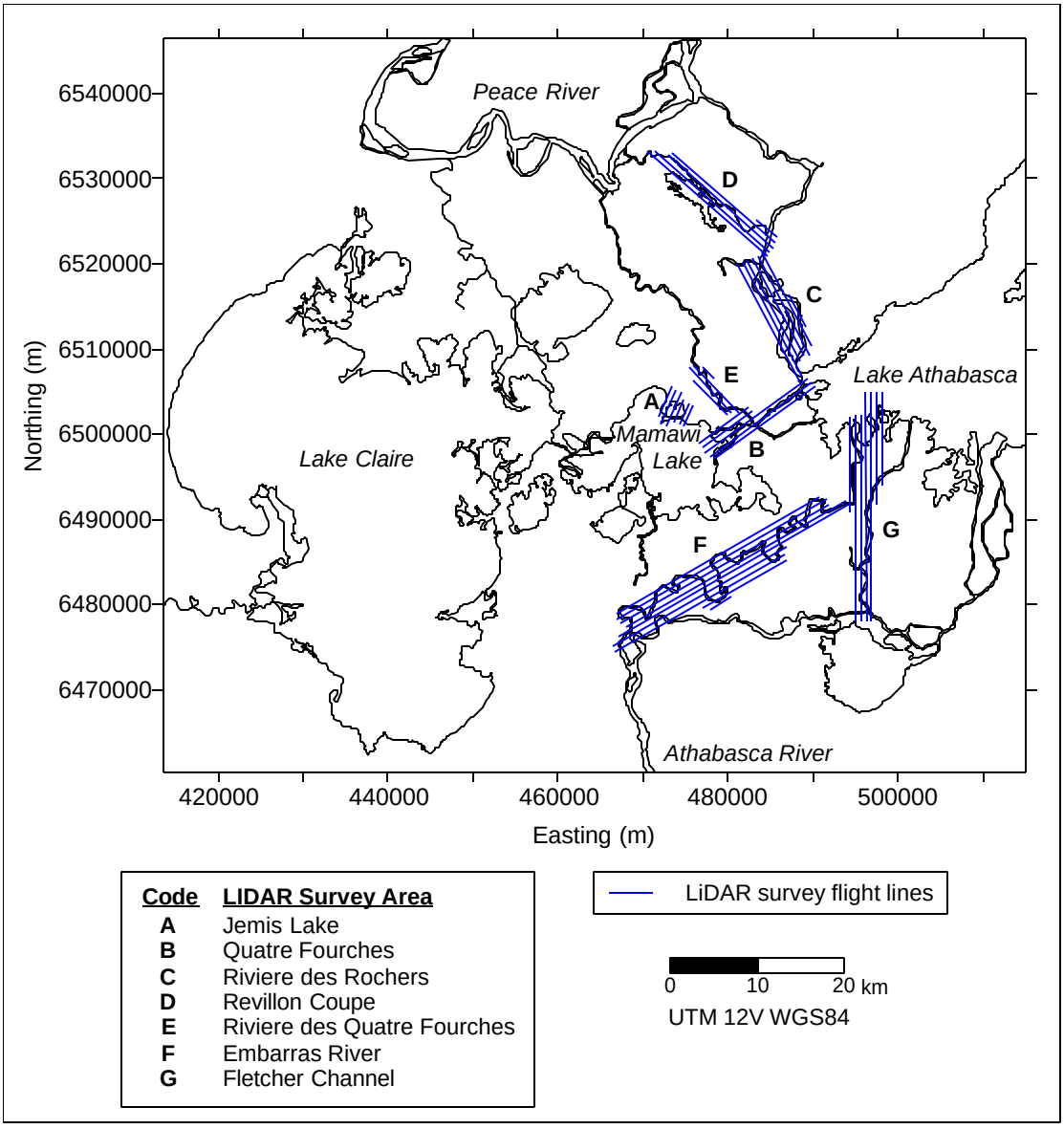

Figure 2. The LiDAR survey areas in the Peace-Athabasca Delta.

Table 1. The LiDAR survey areas.

Code	Area
A	Jemis Lake
B	Quatre Fourches between Mamawi Lake and Lake Athabasca (includes Dog Camp)
C	Rivière des Rochers between Lake Athabasca and Revillon Coupe
D	Revillon Coupé (includes east end of Egg Lake)
E	South portion of Chenal des Quatre Fourches (includes east part of Duck Lake)
F	Embarras River
G	Fletcher Channel

LIDAR SURVEY

The LiDAR survey was conducted on June 16-18, 2000, by Optech. Embarras River and Fletcher Channel (Area F and G) were surveyed on June 16. Geodetic grade Ashtech Z-surveyor GPS receivers were established as base stations on Dog Camp Island, the north shore of Embarras River, and the Radio Tower Hill in Fort Chipewyan. The GPS base stations were operated by NHRC and BC HYRDO and the data were used by Optech to correct the LiDAR aircraft position. The other areas (Area A-E) were surveyed on June 17, with the GPS base stations located on Dog Camp Island, an island in Egg Lake, and the Radio Tower Hill. Some problem areas were re-surveyed on June 18 and the GPS base stations were placed on the shore of Embarras River, on an island in Egg Lake, and on the Radio Tower Hill. All base stations were placed on benchmarks, except for the Embarras River station. A GPS receiver was set up on the Embarras River station on one additional day for approximately four hours to ensure that an accurate position could be obtained for that point. Ultimately, the Embarras River station was not used. Table 2 lists the GPS base stations that were eventually used by Optech to correct the aircraft position. The locations of the GPS base stations are illustrated in Figure 3.

Table 2. The GPS base stations that were used to correct each LiDAR survey area. The co-ordinates are given in UTM 12V projection using the WGS84 datum.

Area	GPS Base Station	Code	Easting (m)	Northing (m)	Elev. (m.a.s.l.)
A	Dog Camp Island	DCIS	481643.58	6501172.86	211.35
B	Dog Camp Island	DCIS	481643.58	6501172.86	211.35
C	Egg Lake	EL01	475896.53	6528648.42	211.82
D	Egg Lake	EL01	475896.53	6528648.42	211.82
E	Radio Tower Hill (BM: 686004)	CHIP	491011.80	6509197.28	276.72
F	Radio Tower Hill (BM: 686004)	CHIP	491011.80	6509197.28	276.72

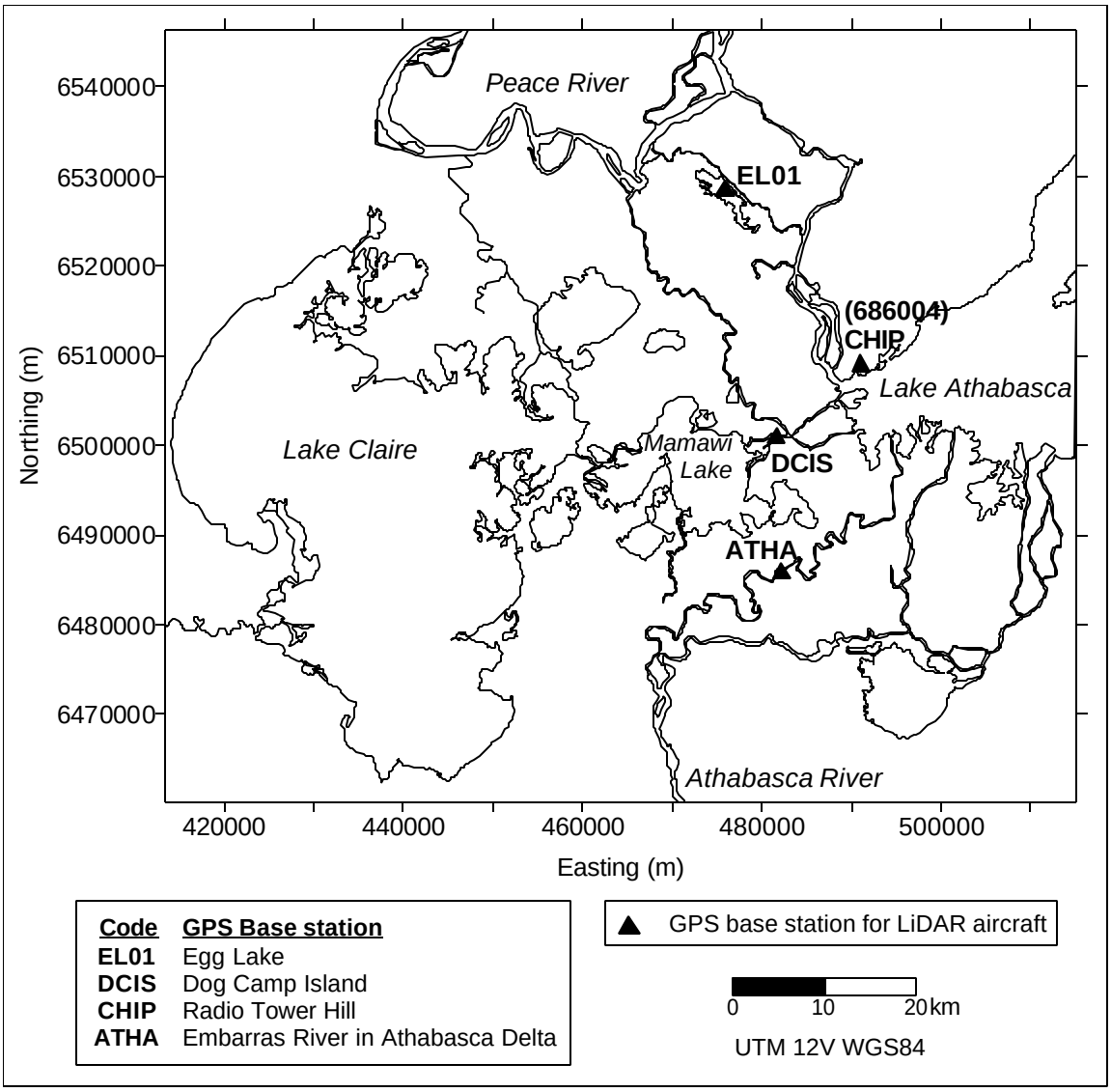

Figure 3. The locations of the GPS base stations.

GROUND VERIFICATION DATA

To enable accuracy assessment of LiDAR data, elevation surveys were conducted in Jemis Lake basin and Dog Camp area using a Sokkia SET4C total station instrument. The total station survey was conducted in areas covered by grass, willow, mud and bedrock to facilitate an assessment of LiDAR data in different land cover types. The height and LAI (Leaf Area Index) of the surveyed vegetation were recorded and photographs were taken.

The vegetation types described in this document are only general and were not identified by a Botanist. For example, grasses include all grass-like vegetation. See Timoney (1996) for a detailed description of vegetation types within the Peace-Athabasca Delta.

Jemis Lake

The total station survey was conducted on the west end of Jemis Lake on June 15 and 16, 2000. The JBM1 benchmark, which was established by NHRC in 1995 (Lavergne 1995; Carter 1996), was used as instrument site for the survey. The benchmark is marked with a rod in the ground and its co-ordinates were originally established using differential GPS. The rod was bent about 2 cm when found, but was straightened out. An Ashtech receiver was used to confirm the co-ordinates of JBM1 and to establish a back site for the survey. The back site (JBIP) was set about 30m south-southeast of JBM1 and was temporarily marked with an iron pin in the ground. GPS data were collected for approximately 20 minutes on each site with 1-second intervals. To enable differential post-processing of the GPS data, another Ashtech receiver was set up to simultaneously record data on the Radio Tower Hill benchmark (BM: 686004, Code: CHIP). The GPS data were later post-processed by Stephen Gibbard, PFRA, using Trimble Geomatics Office V.1.0 software. An elevation angle cut-off of 13°, a PDOP cut-off of 7, and an iono-free fixed solution were used for the differential post-processing. The geoid model for the elevation values was set to GSD95. The corrected GPS readings are listed in Table 3. The JBIP elevation refers to ground level, while the JBM1 elevation refers to the top of the rod.

Table 3. Corrected GPS data from Jemis Lake.

	UTM 12V NAD27		UTM 12V WGS84		Orthometric
Site	**Northing (m)**	**Easting (m)**	**Northing (m)**	**Easting (m)**	**Elevation (m)**
JBIP	6502745.89	471965.66	6502969.72	471910.48	209.86
JBM1 -00	6502780.89	471962.79	6503004.73	471907.61	210.03
JBM1 -95*	6502780.97	471962.78	6503004.80	471907.60	209.97

*GPS co-ordinates obtained by Lavergne (1995).

The survey was conducted with the total station set up on JBM1, using the JBIP site as the back site. Photographs of the two GPS sites are provided in Appendix 1. In the field, the JBM1 co-ordinates were set to 471962m east and 6502782m north (NAD27) with an elevation of 209.97m. This is not the exact easting and northing of JBM1 and all the surveyed points were corrected for the difference afterwards (see below). The entered elevation value of the JBM1 rod is the measured value from 1995, which is 6 cm lower than the value obtained in this study (see Table 3). The JBIP co-ordinates were unknown at the time of the survey. The azimuth from JBM1 to the JBIP back site was measured to 179° 30’ (true north) using a compass. The azimuth was entered into the total station and used to calculate the co-ordinates of JBIP.

During post-processing, the northing and easting of each survey point were corrected based on the differences between [1)] the entered co-ordinates and the “true” GPS co-ordinates of JBM1 and [2)] the calculated co-ordinates and the “true” GPS co-ordinates of JBIP. The co-ordinates were also converted from NAD27 datum to WGS84 datum.

An elevation of 209.81m was obtained for the JBIP back site using the total station, which, again, is 5 cm lower than the elevation acquired by the GPS. Since 0.05m is well within the error of the LiDAR instrumentation and it is not known which elevation value is correct (or if the rod

was simply pulled out by ice), the elevation values were left unchanged. The accuracy of the survey points is approximately 0.15m horizontal and 0.10m vertical.

Areas covered by grass, willow and mud were surveyed with the total station. Photographs of the grassed area around the two GPS sites (JBM1 and JBIP) and the mud flat are provided in Appendix 1. The uncorrected and corrected survey points are illustrated in Figure 4 and listed in Appendix 2. The fresh green grass in the area was about 30-40 cm high and the thatch layer was roughly 10-15 cm thick. The LAI (Leaf Area Index) of the fresh grass was measured to 1.3 about 5m southwest of JBIP, while the LAI of the fresh grass and thatch was 4.52. The willows in the area were 4-7 m tall and the leaves were partially or fully foliated on most shrubs. The LAI of the willows was measured to 2.22 about 3m in from the willow edge, between the survey targets 1013 and 1014 (see Figure 4). The willows were about 6m tall at the LAI site.

Dog Camp

The survey in Dog Camp was conducted on June 17, 2000. The total station was set up on the DCQU benchmark, which is located on the top of the hill (quarry). The DCQU co-ordinates were set to 481765.02m east and 650142.21m north (WGS84) with an elevation of 223.05m. These are the exact co-ordinates of the benchmark. The DCIS benchmark on Dog Camp Island was used as back site. Since a GPS receiver was stationed on DCIS, the back site was measured to a point 1m behind the benchmark. The difference between the measured and "true" co-ordinates of the survey points was less than 0.15m (horizontal). This is within the error of the instrument and, as a result, the survey points were not corrected. The elevation values are accurate within 0.05m.

Eight sites with different vegetation characteristics were selected and several points were surveyed within the sites. Photographs were taken and the LAI was measured for each site. Appendix 1 and 3 contain the photographs and the survey information, respectively. Figure 5 shows the eight survey sites superimposed on an IKONOS image.

LIDAR DATA

The LiDAR data were received from Optech in three different formats: unclassified, automatically classified and manually classified. The unclassified LiDAR (UCL) data set includes all first and second pulse laser data and laser intensity values (*.all). The automatically classified LiDAR (ACL) data set contains the same data as the UCL data set, except that the data have been classified into ground (*.grd) and vegetation (*.veg) using default parameter settings in the Realm software. The vegetation files represent the pulses that did not penetrate the vegetation layer. According to Optech, there are problems with this data set in areas of dense vegetation. The manually classified LiDAR (MCL) data set contains ground data points only (*.grd). These were classified using manual parameter settings to minimise the number of erroneously classified points in dense vegetation.

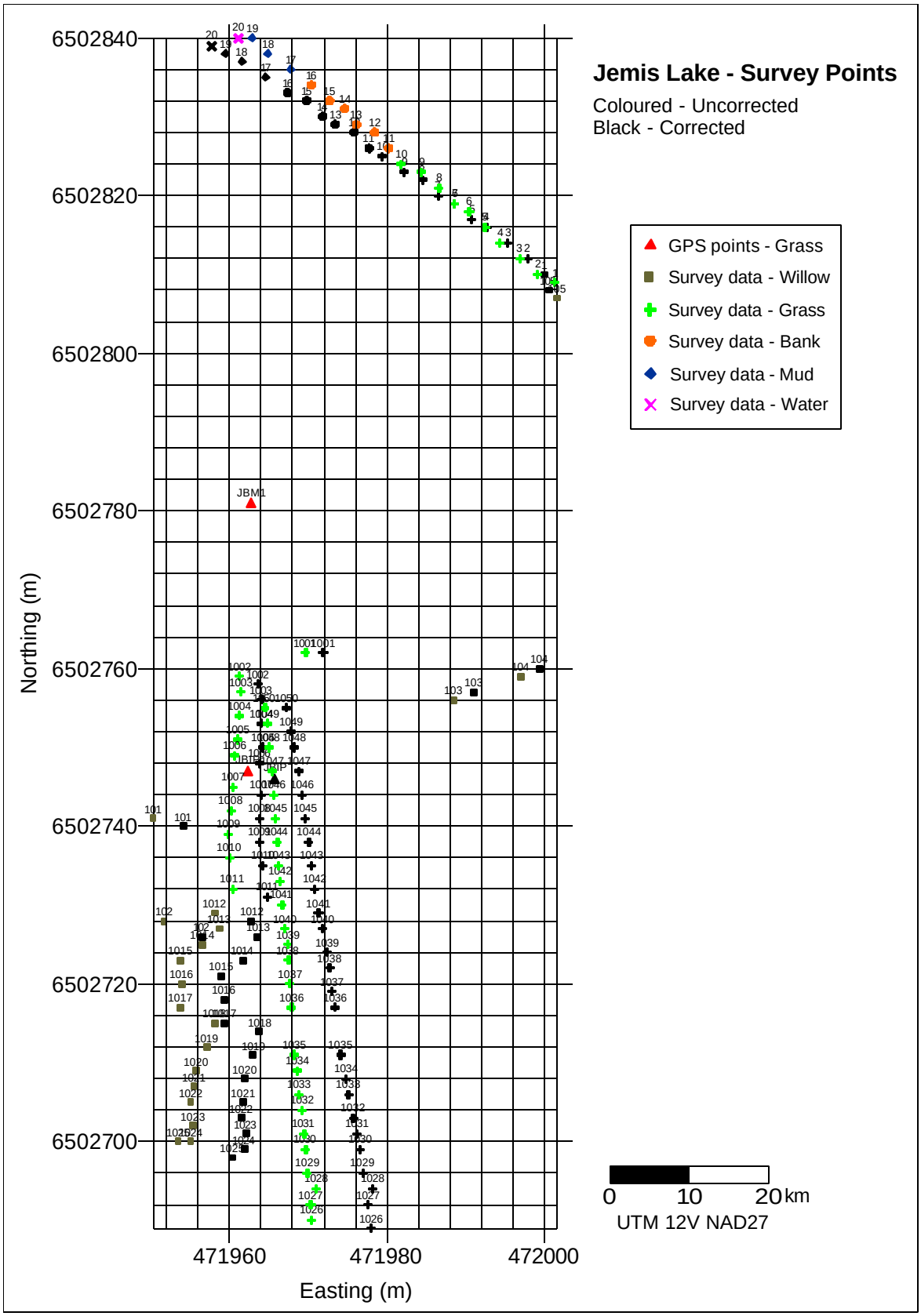

Figure 4. The uncorrected (coloured) and uncorrected (black) survey points in Jemis Lake.

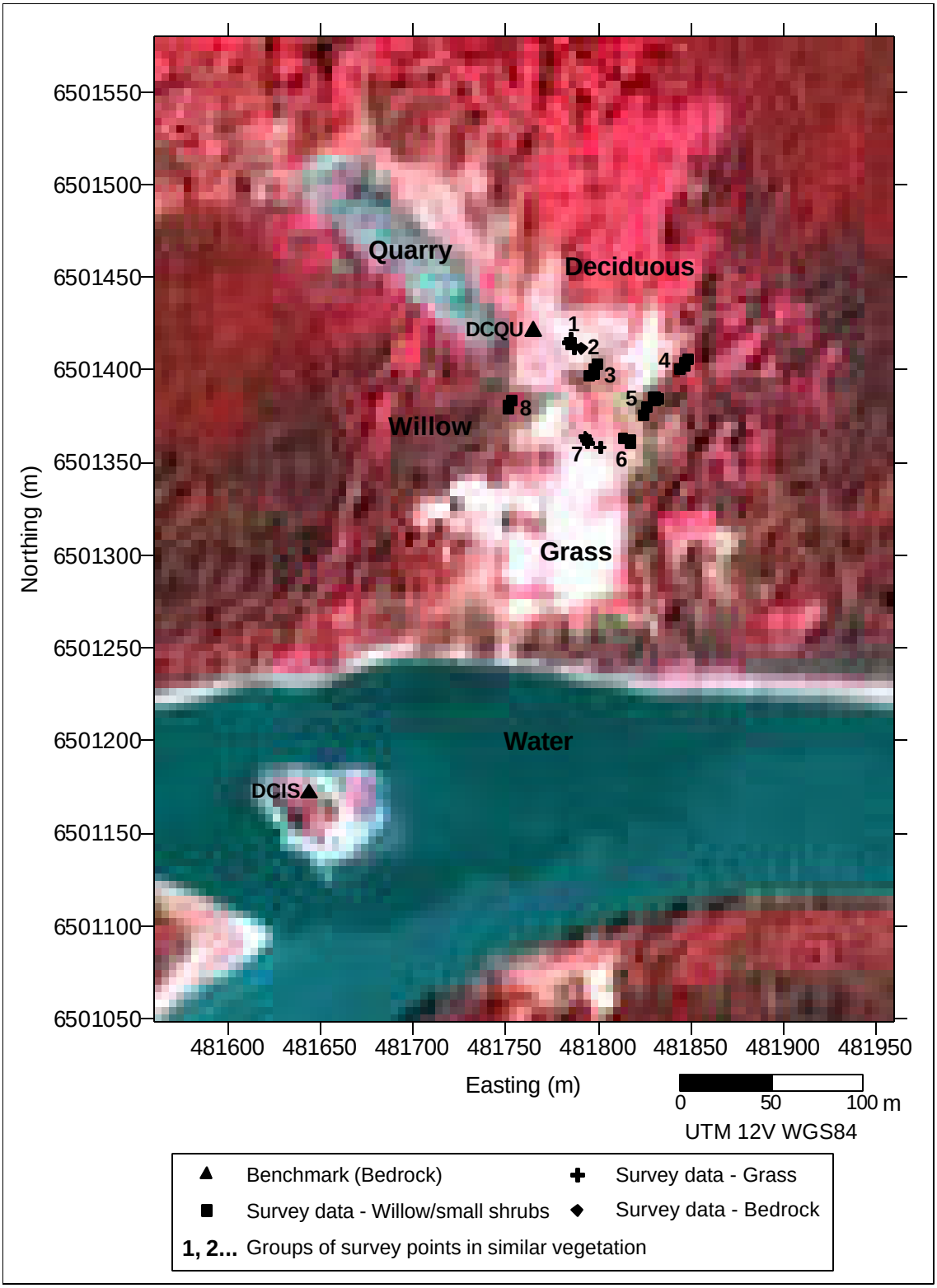

Figure 5. The eight survey sites in Dog Camp superimposed on an IKONOS image (acquired on May 31, 2000).

Each individual data file is a 2km by 2km patch, which is named according to the first three digits of the easting and first four digits of the northing on the bottom left corner of the patch. The data columns in the MCL files are organised as easting, northing, and LiDAR pulse (or elevation). In the UCL and the ACL data sets, the data columns are organised in the following order: easting, northing, LiDAR pulse (elevation 1), laser intensity, easting, northing, LiDAR pulse (elevation 2), and laser intensity. The LiDAR pulse in column 3 (elevation 1) should be used for analysis of ground data. This column represents the LiDAR pulse column in the MCL data set. The reported approximate LiDAR point density is 1.4m by 1.4m, but many points are as close as 0.25m.

COMPARISON OF LIDAR DATA AND SURVEY DATA

The LiDAR data were compared to surveyed data using PCI software version 7.0. The data were also imported to Surfer version 7.0 for visual display. Survey data collected in Jemis Lake (LiDAR Area A) and Dog Camp area (LiDAR Area B) were used for the LiDAR verification. NHRC survey points in Duck Lake (LiDAR Area E) (Carter 1996) as well as benchmarks located in Egg Lake (LiDAR Area D), Dog Camp Island (LiDAR Area B), and on an island in Rivière des Rochers (LiDAR Area C) were also compared with LiDAR data.

The elevations of the surveyed points were compared with the elevations of the closest LiDAR point in all three LiDAR data sets. Only the points that were classified as ground were analysed in this study (*.grd). No values were recorded if there were no LiDAR points close enough to the survey point. In a varying topography, the horizontal distance between compared points was kept below 0.5m, but if the area was flat and the surrounding points did not show much variation in elevation, a longer distance was accepted. Both elevations are reported for the UCL and the ACL data sets, but it is Elevation 1 that should be used. Appendix 4 lists all the LiDAR files that were used for the comparisons.

Jemis Lake

Due to the large number of LiDAR points, the surveyed area in Jemis Lake was divided into two smaller areas. Figures 6 and 7 show the spatial distribution of the LiDAR and survey points in Area 1 (north) and 2 (south), respectively. In Area 1, the survey points run from a grassed area in the southeast, down a relatively steep bank, and out on the mud flat in the northwest. The last point was surveyed on the water surface of Mamawi Lake. A photograph of the mudflat is shown in Appendix 1. Area 2 includes the two GPS points and that were used as instrument site (JBM1) and back site (JBIP) for the survey. The survey transects in Area 2 run through grassed areas and willow shrubs.

Figure 6 and 7 illustrate that there are more ACL points than MCL points. Since abrupt changes in the UCL data set commonly indicate that the laser beam could not penetrate the vegetation surface, the higher points were classified as vegetation during the LiDAR processing and thus removed. The manual classification was set to be more sensitive to elevation changes compared

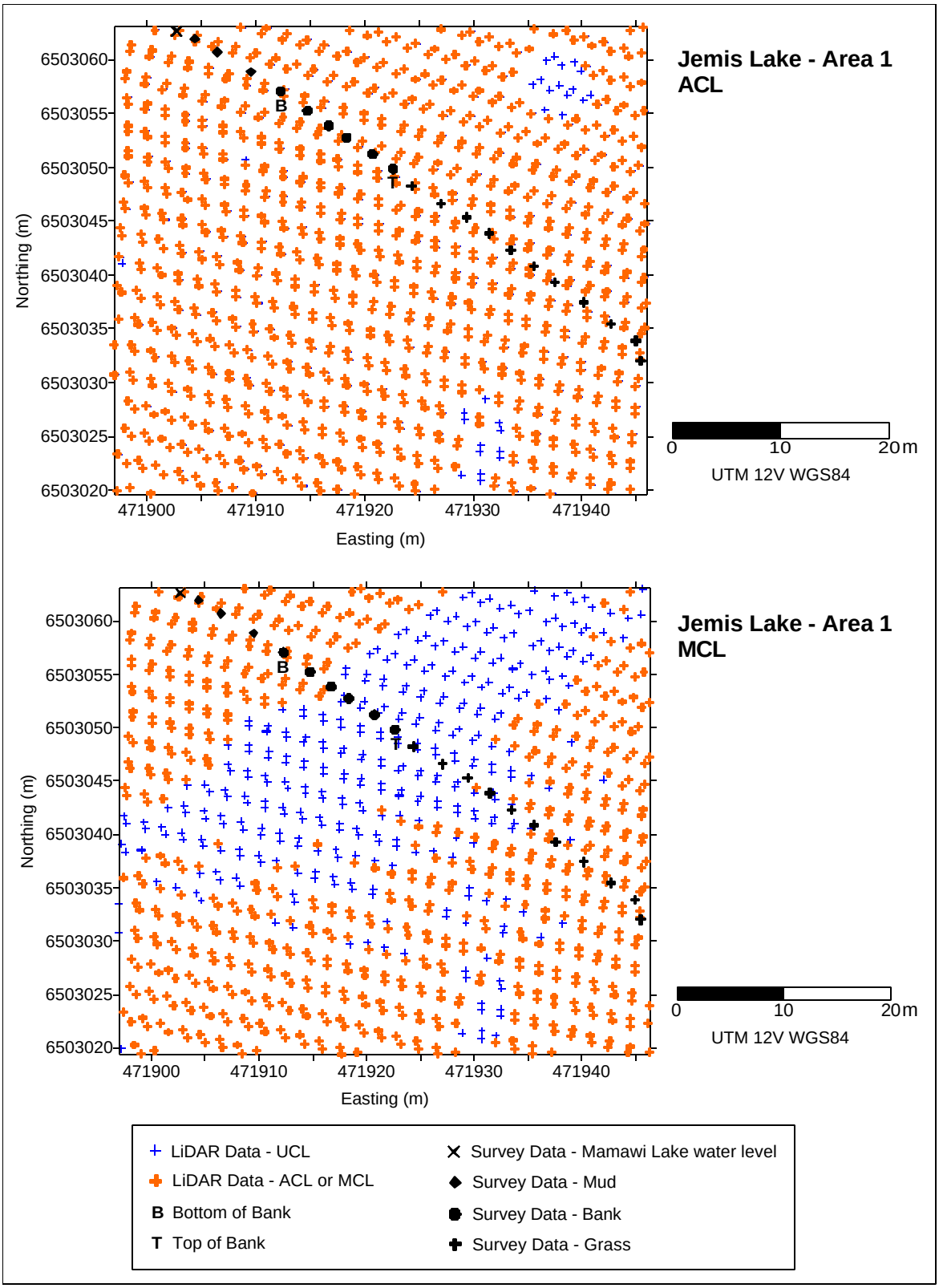

Figure 6. The spatial distribution of LiDAR points in Jemis Lake (Area 1).

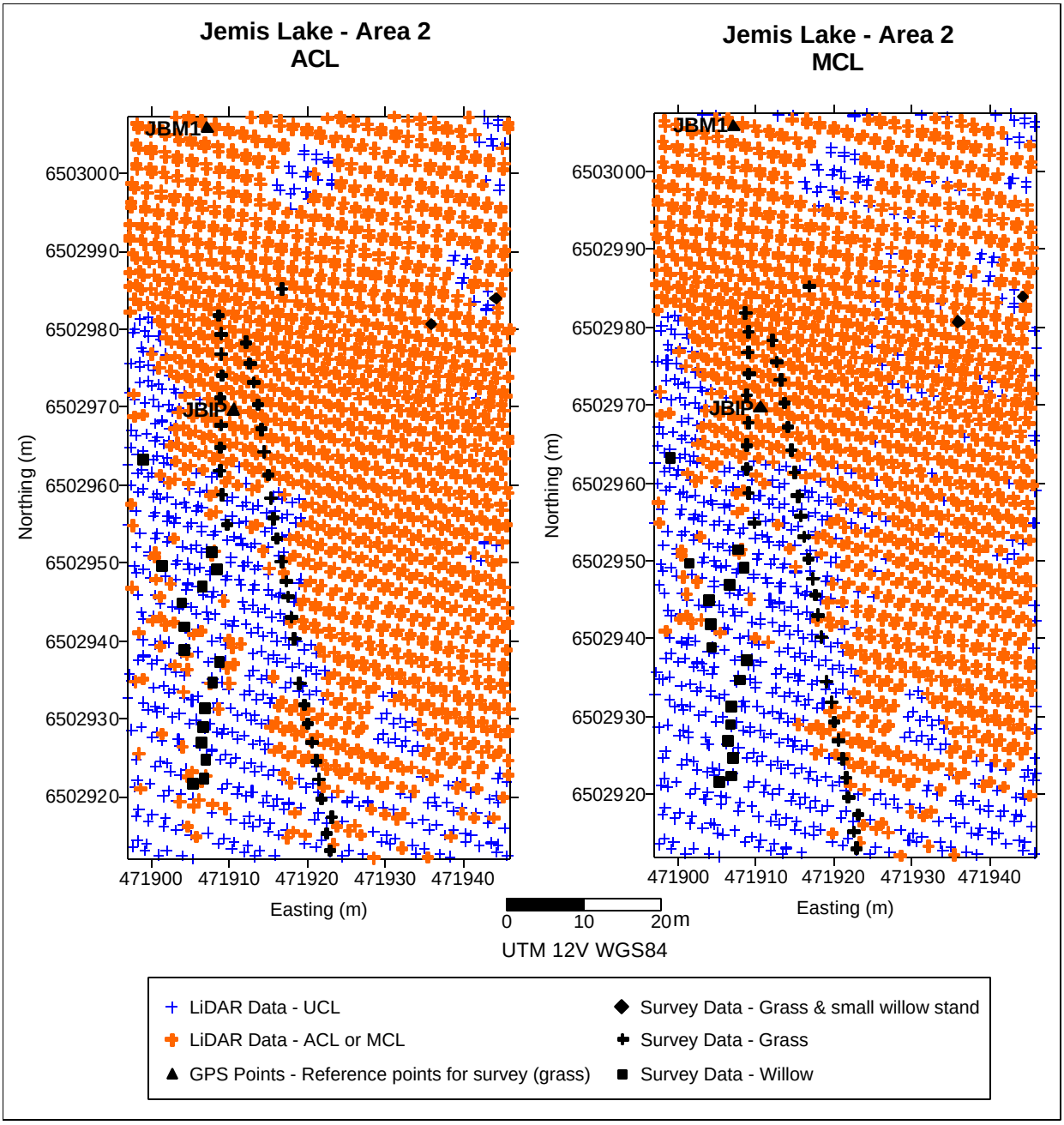

Figure 7. The spatial distribution of LiDAR points in Jemis Lake (Area 2).

to the automatic classification, resulting in fewer ground points. This means that the MCL data set may have excluded more points that did not completely penetrate dense vegetation, but at the same time, it also excluded points that represent natural variations in the topography. In Area 1, for example, the points along and on top of the steep bank were classified as vegetation by the manual classification. Figure 8 illustrates the ACL and MCL data gridded into 2m cells. The steep bank has been smoothed in the MCL grid, while it is preserved in the ACL grid. On the other hand, there is a 0.5m high peak on the northeast side of the ACL grid that probably should have been classified as vegetation.

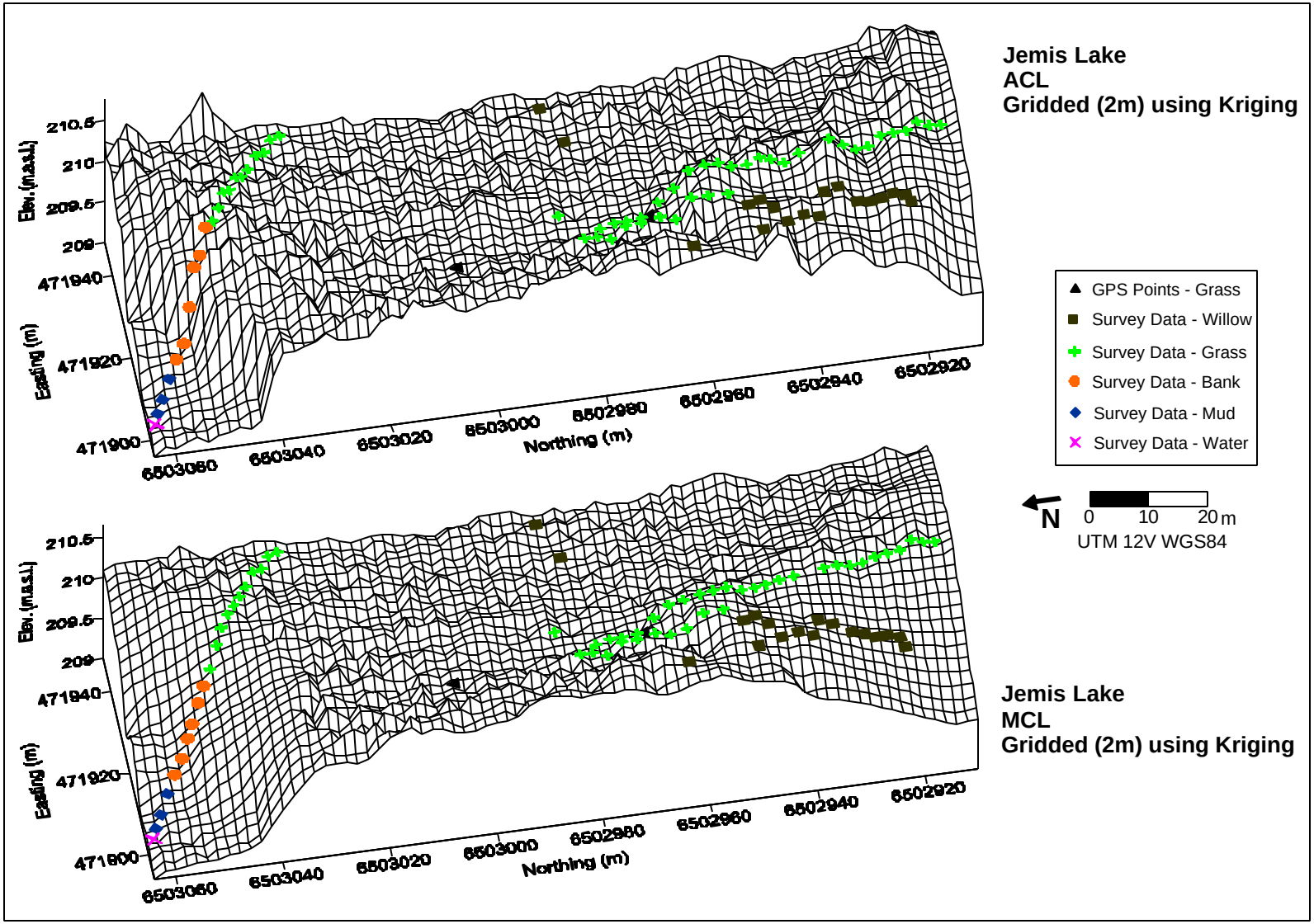

Figure 8. ACL and MCL data in the Jemis Lake (Area 1 and 2) gridded into 2m grid cells using Kriging. The survey points are superimposed on the grids.

All points that were compared are listed in Appendix 5 and the differences in elevation between the survey points and the LiDAR points are listed in Appendix 6. The minimum, maximum and average differences in elevation between survey data and LiDAR data are shown in Table 4.

The mean difference and the standard deviation of the difference between survey and LiDAR elevations are lower for the MCL data (see Table 4). Again, this indicates that the MCL data set is more conservative and contains less erroneously classified data points. The UCL data set contains all points (the vegetation points have not been removed), which is the reason why the elevation is several metres higher than the surveyed elevation in some cases.

The LiDAR elevations in Jemis Lake are consistently higher than the survey data. The average difference is about 0.5m. Figure 9 and 10 show the survey elevations plotted against the ACL elevations and the MCL elevations, respectively. Both figures show a strong positive bias in the LiDAR data.

Table 4. The minimum, maximum and mean difference between the elevation of LiDAR points (elev. 1) and survey points in Jemis Lake. The standard deviations of the differences and the number of points that were compared are also reported. Positive values indicate that the LiDAR elevations are higher.

	UCL - Survey Difference (m)	**ACL - Survey Difference (m)**	**MCL - Survey Difference (m)**
Min of All Points	0.24	0.24	0.24
Max of All Points	7.08	0.79	0.71
Mean of All Points	1.49	0.53	0.49
Stdv of All Points	1.90	0.14	0.12
# of Points Compared	49	36	28
Min of Mud Points	0.40	0.40	0.40
Max of Mud Points	0.42	0.42	0.42
Mean of Mud Points	0.41	0.41	0.41
Stdv of Mud Points	0.01	0.01	0.01
# of Points Compared	3	3	3
Min of Grass Points	0.24	0.24	0.24
Max of Grass Points	5.54	0.79	0.71
Mean of Grass Points	1.16	0.56	0.52
Stdv of Grass Points	1.27	0.14	0.13
# of Points Compared	33	25	19
Min of Willow Points	0.42	0.42	n/a
Max of Willow Points	7.08	0.65	n/a
Mean of Willow Points	4.45	0.53	n/a
Stdv of Willow Points	2.78	0.16	n/a
# of Points Compared	7	2	0

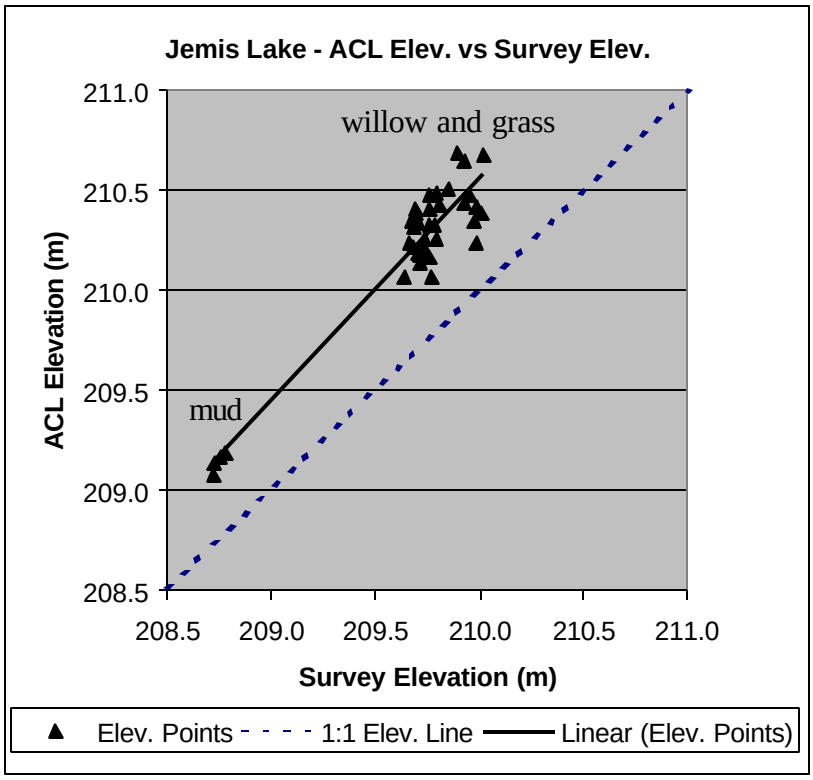

Figure 9. ACL elevations plotted against the survey elevations in Jemis Lake.

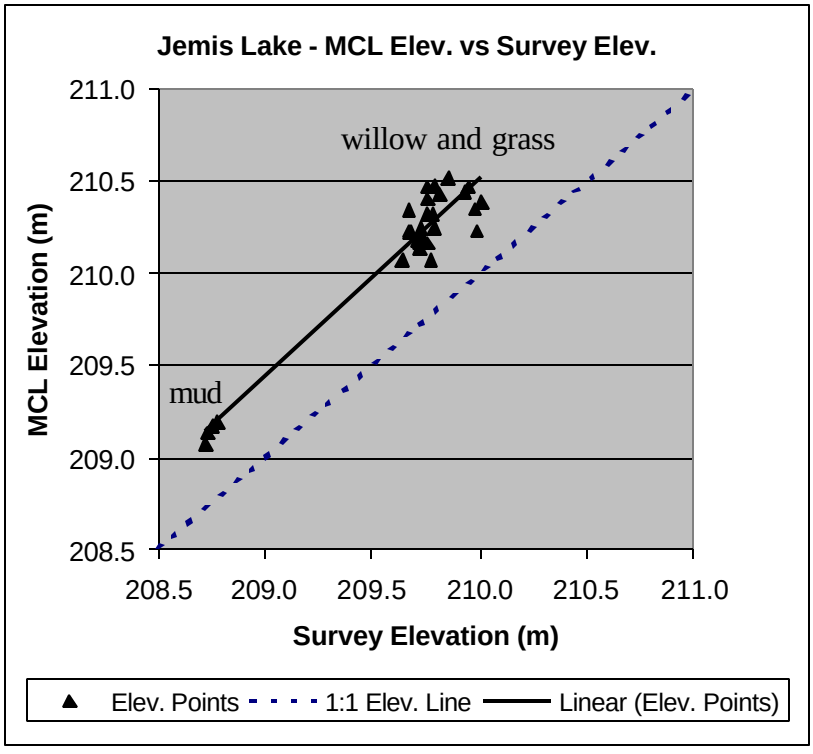

Figure 10. MCL elevations plotted against the survey elevations in Jemis Lake.

Three points were surveyed on bare mud and since there is no vegetation cover to obscure the laser pulse, the LiDAR elevation should be close to the surveyed elevation on these points. However, the LiDAR points on the mud are between 0.40m and 0.42m higher than the surveyed elevations. Therefore, it was assumed that the positive bias in the LiDAR data is about 0.4m.

If the LiDAR data were lowered by 0.4m, the average difference between all compared points would be about 0.10m. In areas covered by grass, the ACL elevations would be 0.16m higher than surveyed elevations, while the MCL elevations would be 0.12m higher. The layer of thatch in the grassed areas was between 0.10m and 0.15m thick with an LAI of 4.52. It is possible that the LiDAR signal could not completely penetrate the thick layer of thatch. Most of the LiDAR points did not penetrate the willows, resulting in very few ground points in the willow-covered areas (see southwest corner of Figure 7). Only two ACL points and no MCL points were close enough to be compared with survey data. After subtracting 0.4m from the original elevation values, the two ACL points would be 0.01m and 0.24m higher than the survey values.

The data in Jemis Lake suggest that the LiDAR elevations are, on average, 0.4m higher than surveyed elevations in non-vegetated areas and about 0.50m higher in vegetated areas. Figure 11 shows the original ACL elevations and the elevations lowered by both 0.4m and 0.5m plotted against survey elevations. Figure 12 shows a similar graph, but with MCL elevations.

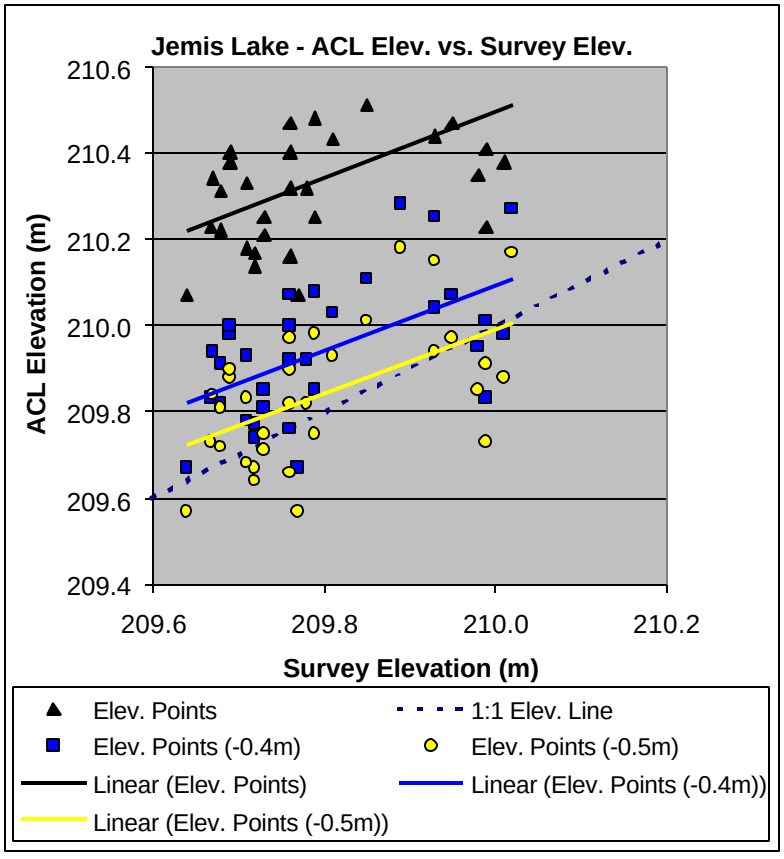

Figure 11. ACL elevations plotted against surveyed elevations in Jemis Lake. The original LiDAR elevations and the LiDAR elevations lowered by both 0.4m and 0.5m are plotted. Only points in vegetated areas are included.

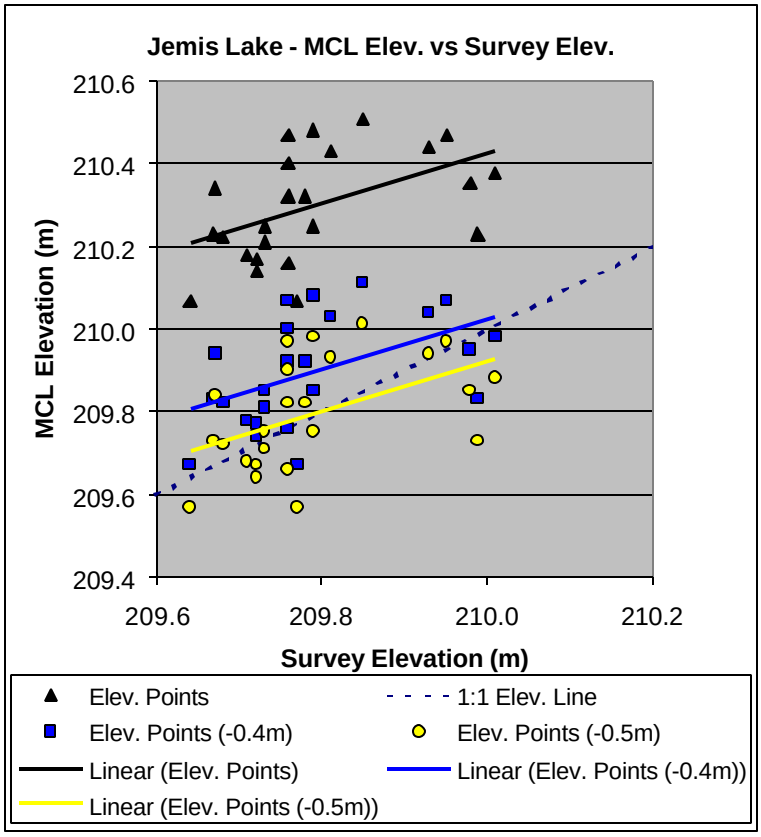

Figure 12. MCL elevations plotted against surveyed elevations in Jemis Lake. The original LiDAR elevations and the LiDAR elevations lowered by both 0.4m and 0.5m are plotted. Only points in vegetated areas are included.

Dog Camp

The Dog Camp Quarry benchmark (DCQU) is located on top of a bedrock outcrop (see photographs in Appendix 1). Many of the survey points are located on and around the hill. Figure 13 and 14 illustrate the distribution of the ACL and the MCL points, respectively. As in Jemis Lake, the MCL data set contains fewer ground points compared to the ACL data set. The elevation increases relatively rapidly up the hill, which may have caused many of the MCL points to be classified as vegetation.

The survey data and the three sets of LiDAR data were compared using PCI software. The compared points and their elevations are listed in Appendix 5. Appendix 6 shows the differences in elevation between the surveyed points and the LiDAR points. The maximum, minimum and average differences are listed in Table 5. Only one MCL point and 10 ACL points were close enough to a survey point to enable comparison. On average, the ACL elevations were 0.76m lower than surveyed elevations. The largest difference between survey data and LiDAR data is 11.5m on the DCQU point. If the points that are located on top of the hill are excluded (DCQU and Sites 1-3), the ACL points are, on average, 0.58m higher than the survey points.

Figure 15 and 16 illustrate the ACL and the MCL points gridded into 2m pixels. Figure 17 and 18 show the same grids but over a larger area. The survey points are superimposed on the grids. The ACL grid shows a hill, although it should be wider and higher. According to the gridded data, the DCQU point is on the bottom of the hill when it actually should be on top. In the MCL grid, the hill has been smoothened out considerably. Appendix 7 compares the survey point elevations with the gridded LiDAR elevations. The average difference between survey data and gridded LiDAR data is –1.48 and –2.79 for ACL data and MCL data, respectively. The negative values indicate that the LiDAR elevations are lower than the survey data. If the average difference is calculated for each survey site separately, it becomes clear that the sites on the more flat area on the bottom of the hill (Sites 4-8) have more accurate LiDAR elevations compared to the sites on the hill (Sites 1-3). Table 6 lists the average difference in elevation between survey data and gridded LiDAR data for each site. There are no MCL points in the vicinity of Sites 5 – 6 (see Figure 13), which explains the large differences in elevation between the gridded MCL data and the survey data.

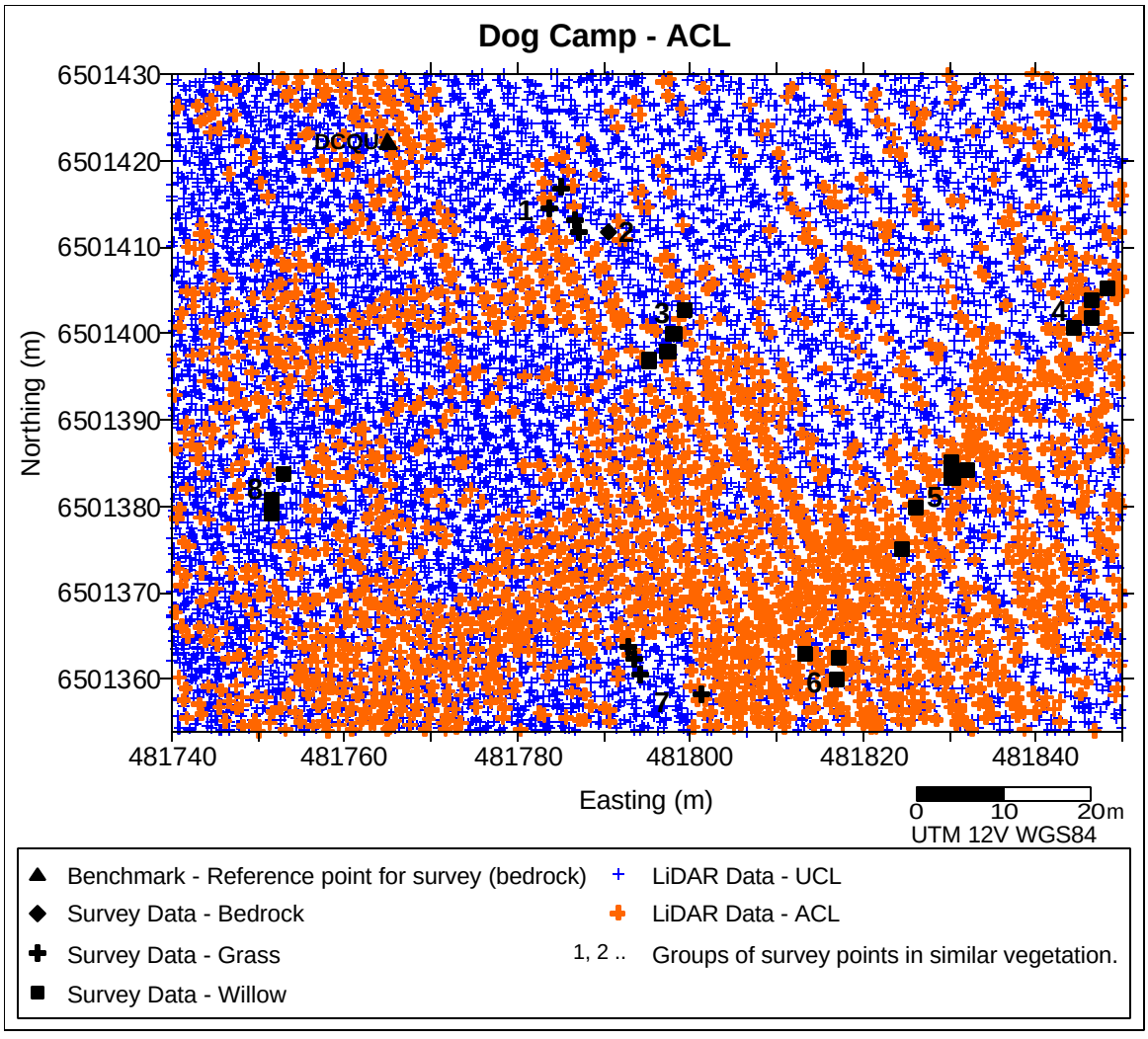

Figure 13. The spatial distribution of ACL data in Dog Camp. The survey points are also displayed.

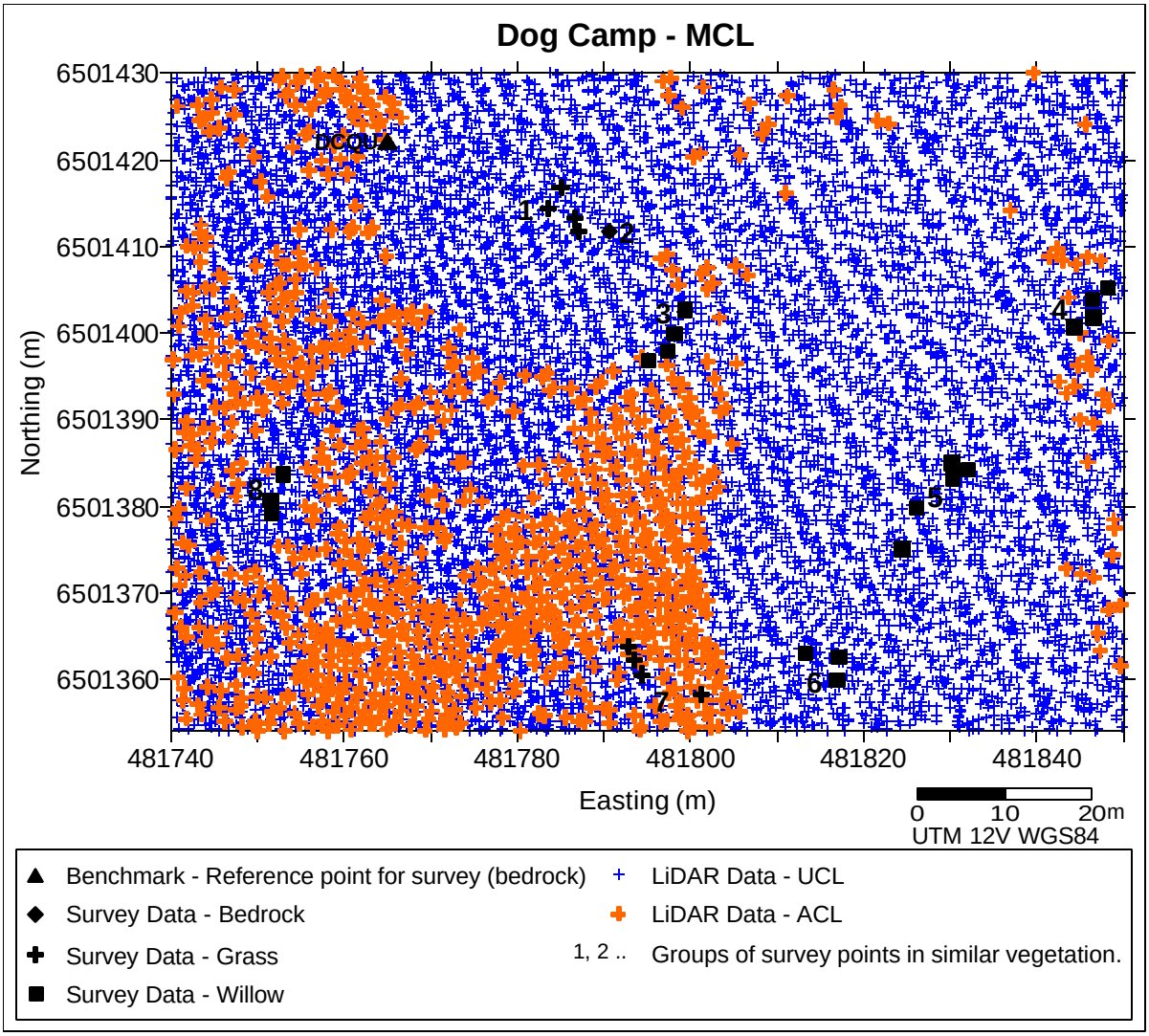

Figure 14. The spatial distribution of MCL data in Dog Camp. The survey points are also displayed.

The gridded ACL data are plotted against survey data in Figure 19. Only points from Sites 4-8 are included in the plot. Figure 19 also shows the gridded LiDAR data lowered by 0.4m and 0.5m (see Jemis Lake section). The average difference in elevation between gridded ACL data and survey data for Sites 4-8 changes from 0.26m to –0.14m when the LiDAR data are lowered by 0.4m. Lowering the LiDAR data by 0.5m changes the average difference to –0.24. A positive value indicates that the LiDAR elevations are higher than survey data.

Table 5. The minimum, maximum and mean difference between the elevation of LiDAR points (elev. 1) and survey points in Dog Camp. The standard deviations of the differences and the number of points that were compared are also reported. Positive values indicate that the LiDAR elevations are higher.

	UCL-Survey Difference (m)	**ACL-Survey Difference (m)**	**MCL-Survey Difference (m)**
Min of All Points	-11.53	-11.53	-11.53
Max of All Points	7.92	1.05	-11.53
Mean of All Points	0.71	-0.76	-11.53
Stdv of All Points	3.72	3.83	n/a
# of Points Compared	24	10	1
Min of Grass Points	-3.28	n/a	n/a
Max of Grass Points	7.80	n/a	n/a
Mean of Grass Points	1.62	n/a	n/a
Stdv of Grass Points	4.94	n/a	n/a
# of Points Compared	5	0	0
Min of Willow Points	-0.23	-0.23	n/a
Max of Willow Points	6.21	1.05	n/a
Mean of Willow Points	1.82	0.58	n/a
Stdv of Willow Points	1.92	0.46	n/a
# of Points Compared	16	8	0
Min of Bedrock Points	-11.53	-11.53	-11.53
Max of Bedrock Points	-0.68	-0.68	-11.53
Mean of Bedrock Points	-5.02	-6.11	-11.53
Stdv of Bedrock Points	5.74	7.67	n/a
# of Points Compared	3	2	1

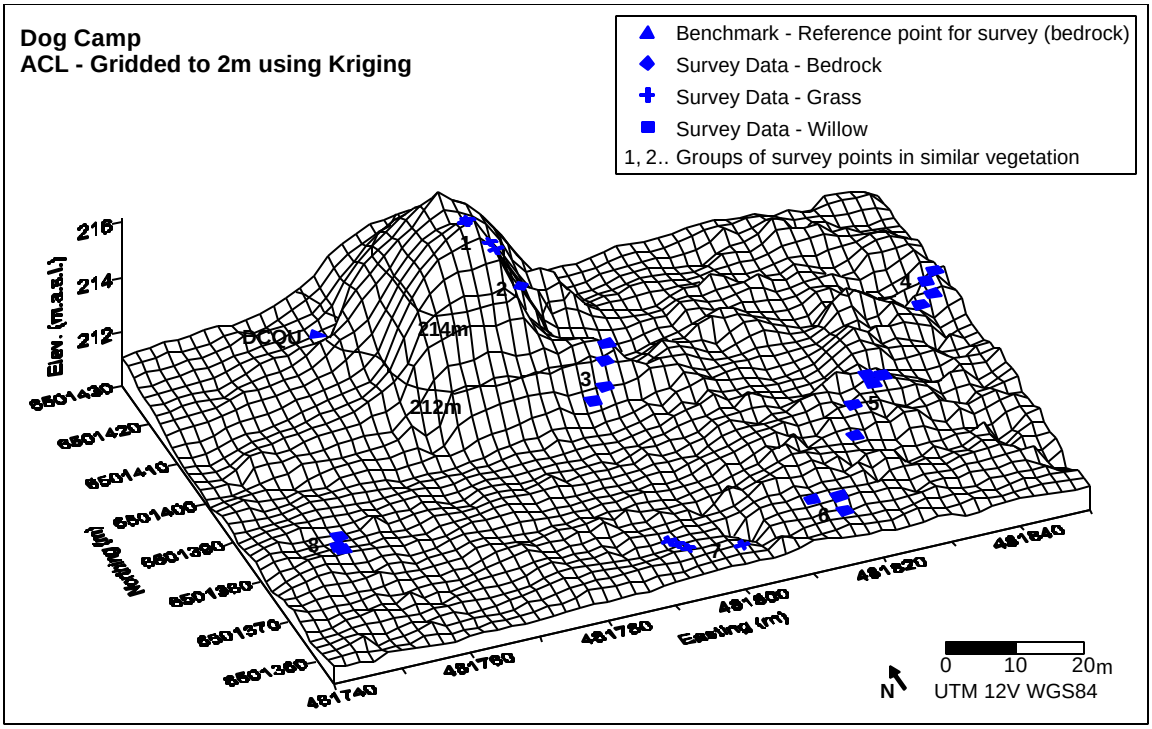

Figure 15. ACL data in Dog Camp gridded into 2m grid cells using Kriging. The survey points are superimposed on the grid.

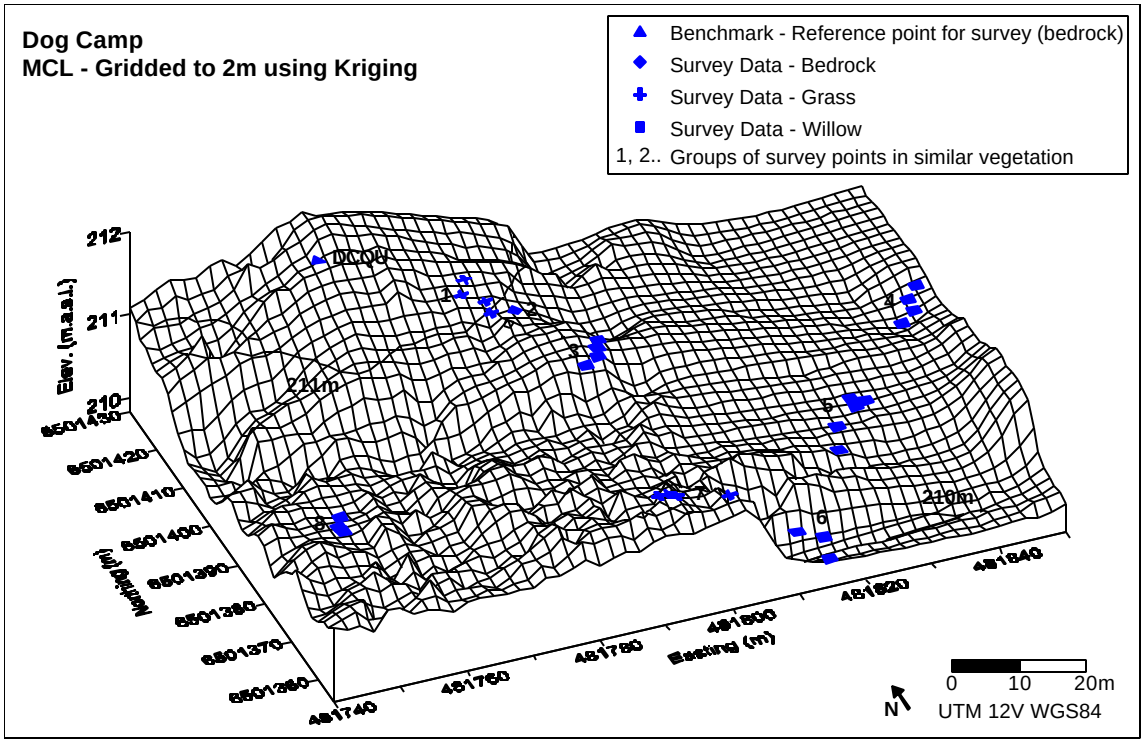

Figure 16. MCL data in Dog Camp gridded into 2m grid cells using Kriging. The survey points are superimposed on the grid.

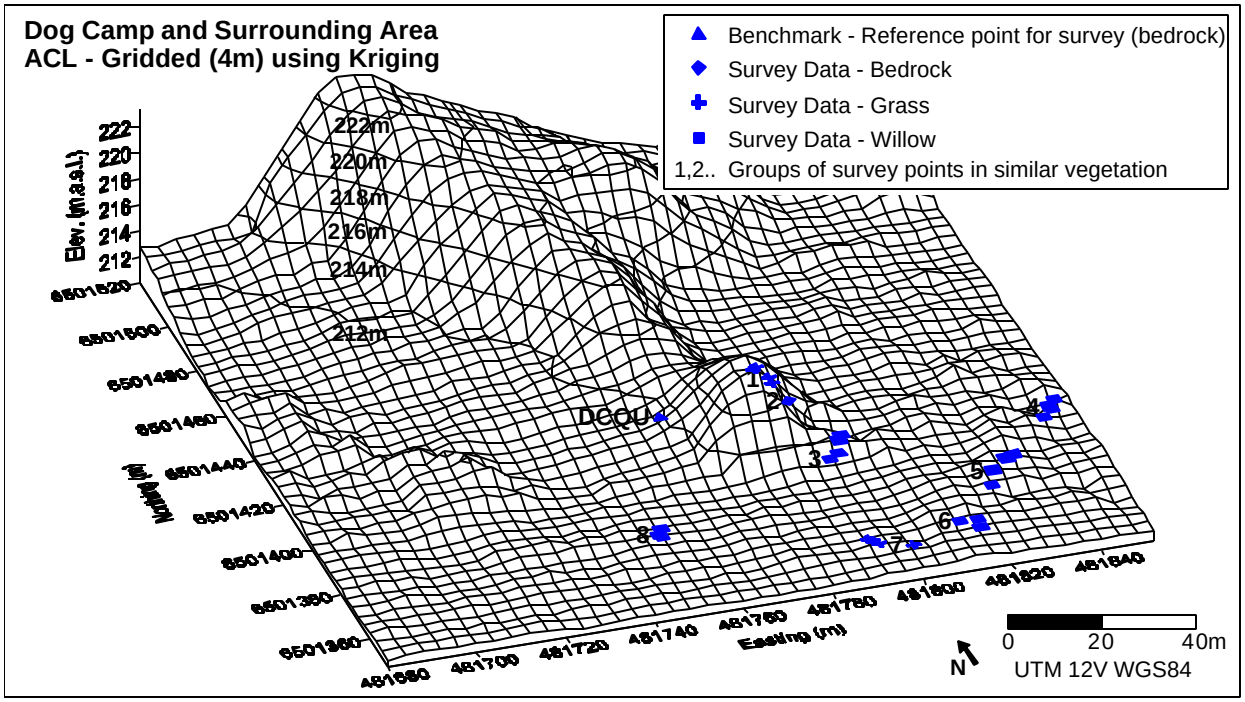

Figure 17. ACL data in Dog Camp and surrounding area gridded into 2m grid cells using Kriging. The survey points are superimposed on the grid.

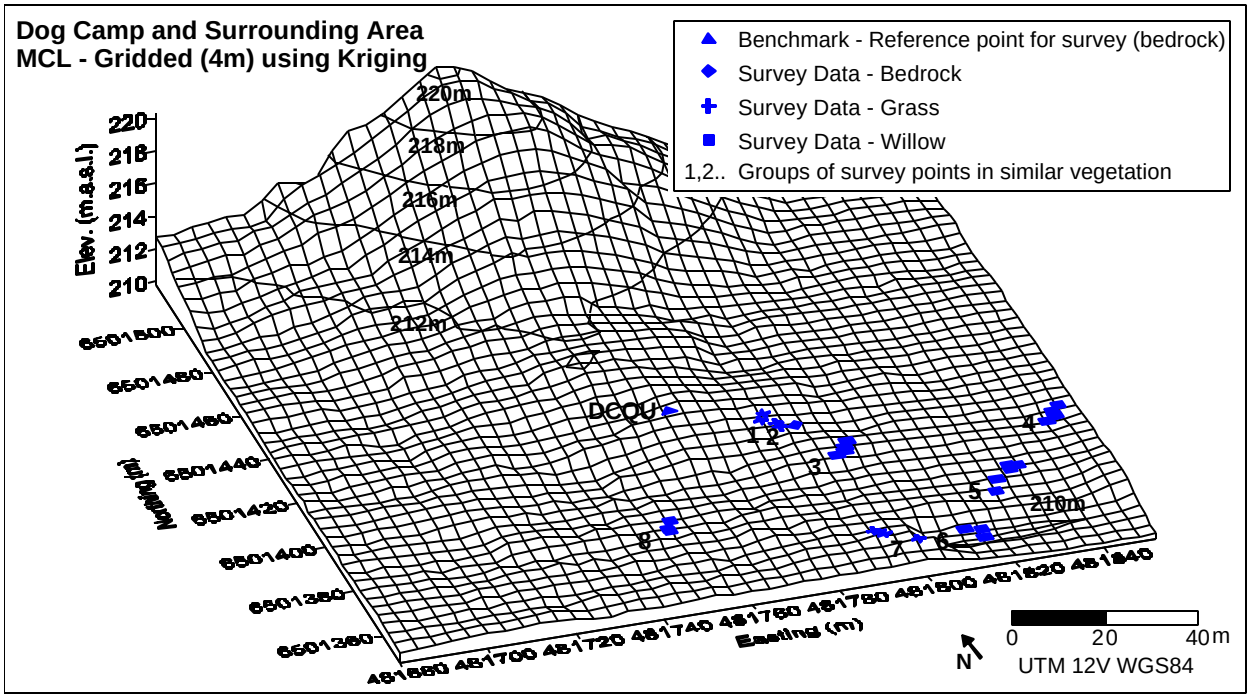

Figure 18. MCL data in Dog Camp and surrounding area gridded into 2m grid cells using Kriging. The survey points are superimposed on the grid.

Table 6. The average difference in elevation between gridded LiDAR data and survey data for each survey Site in Dog Camp. A positive value indicates that the LiDAR elevation is higher than the surveyed.

		Based on Gridded LiDAR Data	
		ACL-Survey	MCL-Survey
Survey Site	**Land Cover**	**Average Difference (m)**	**Average Difference (m)**
1	Grass/Low bush	-4.16	-8.56
2	Bedrock	-5.33	-8.04
3	Dead willow/bush	-3.62	-4.35
4	Edge of poplar	0.80	-0.47
5	Dead & live willow	0.56	-0.49
6	Willow/Grass	-0.19	-1.49
7	Grass	-0.42	-0.39
8	Tall & dense willow	0.40	0.27
DCQU	Bedrock	-11.53	-11.55

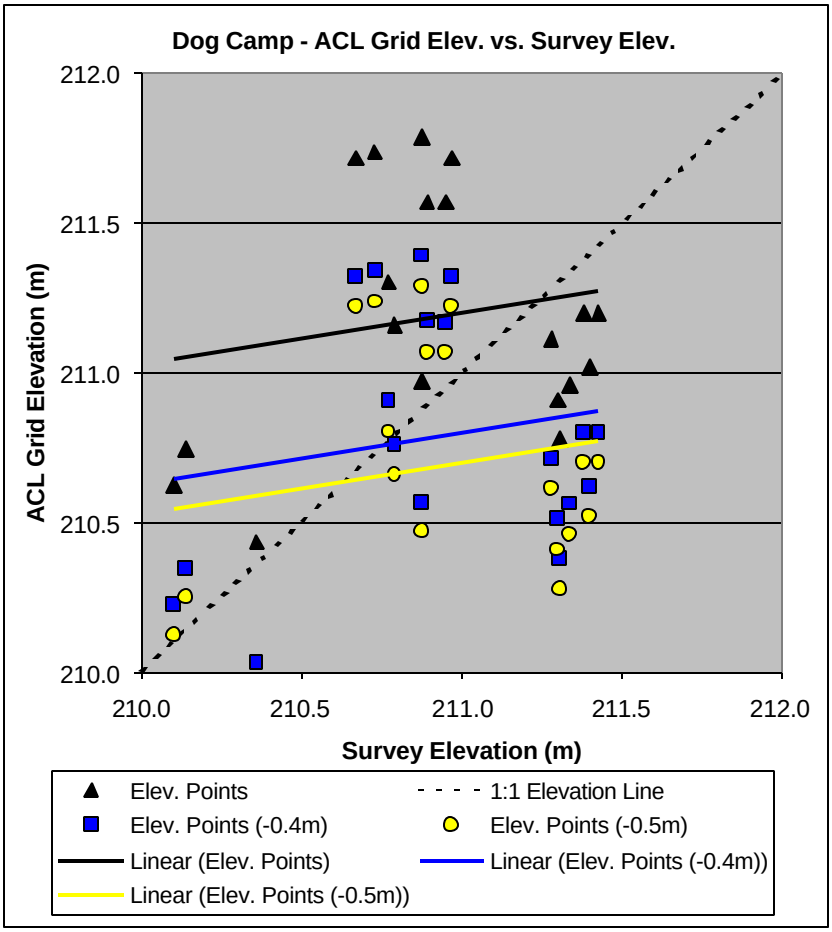

Figure 19. Gridded ACL elevations in Dog Camp plotted against surveyed elevations. The original gridded LiDAR elevations and the gridded LiDAR elevations lowered by both 0.4m and 0.5m are plotted. Only points from Sites 4-8 are included.

Duck Lake

Most of the survey points collected by NHRC in Duck Lake were located under water in June 2000. An IKONOS image, acquired on May 31, 2000, was used to identify four dry survey points located on the east levee. Figure 20 shows the survey points superimposed on the IKONOS image. Because of the wide distribution of the survey points and the large number of LiDAR points, the Duck Lake survey area was divided into three smaller areas. Figure 21, 22 and 23 illustrate the spatial distribution of the LiDAR points within the three areas. All the compared points are listed in Appendix 5 and the difference between the survey points and the LiDAR points are listed in Appendix 6. On average, the LiDAR data have about 0.5m higher elevation than the survey data. Figure 24 shows the ACL elevations plotted against the survey elevations. The MCL elevations are plotted against the survey elevations in Figure 25.

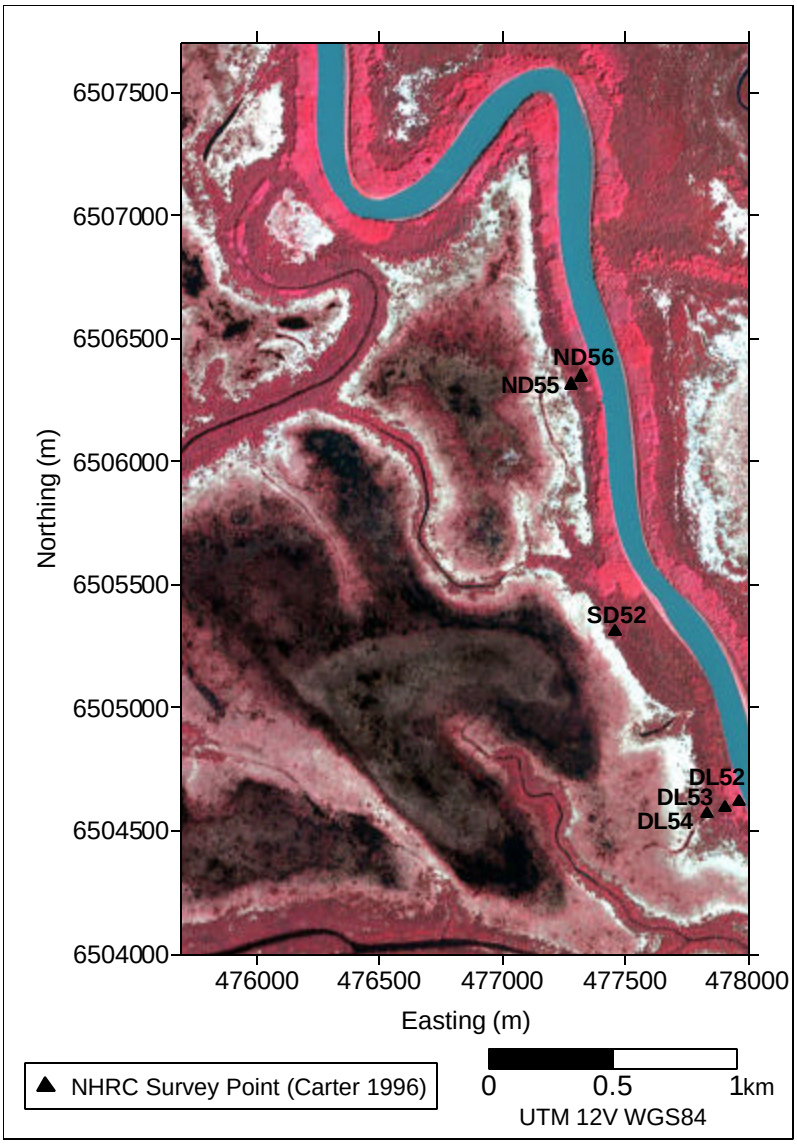

Figure 20. The NHRC survey points in Duck Lake superimposed on an IKONOS image (acquired on May 31, 2000).

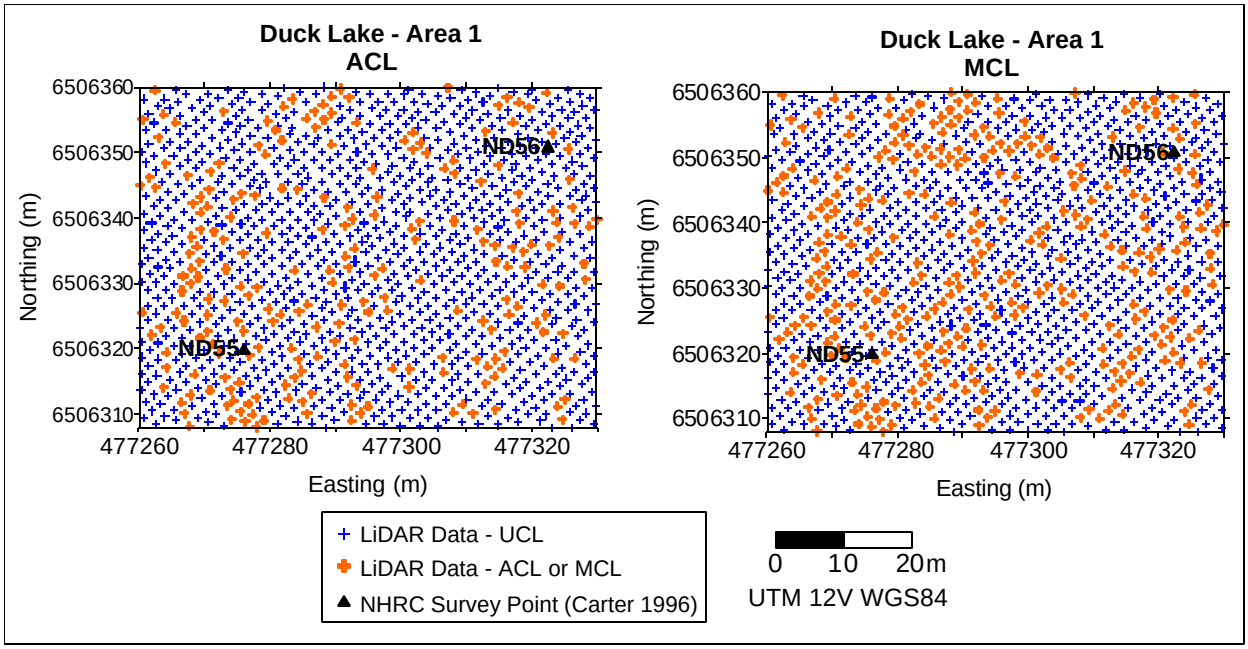

Figure 21. Spatial distribution of LiDAR points in Duck Lake (Area 1).

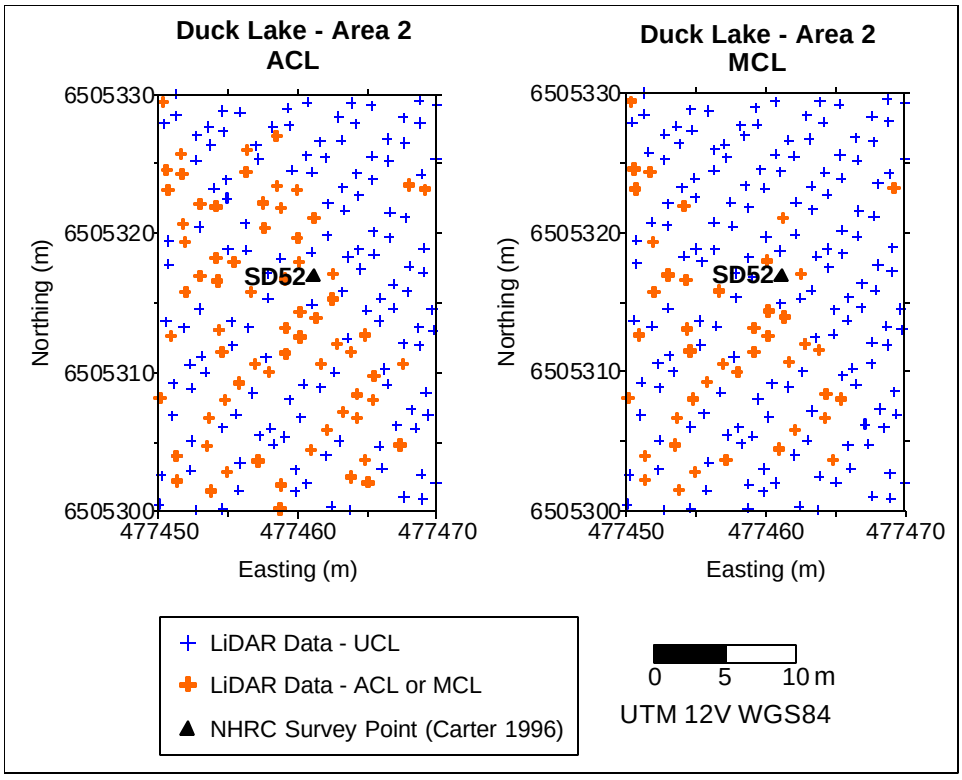

Figure 22. Spatial distribution of LiDAR points in Duck Lake (Area 2).

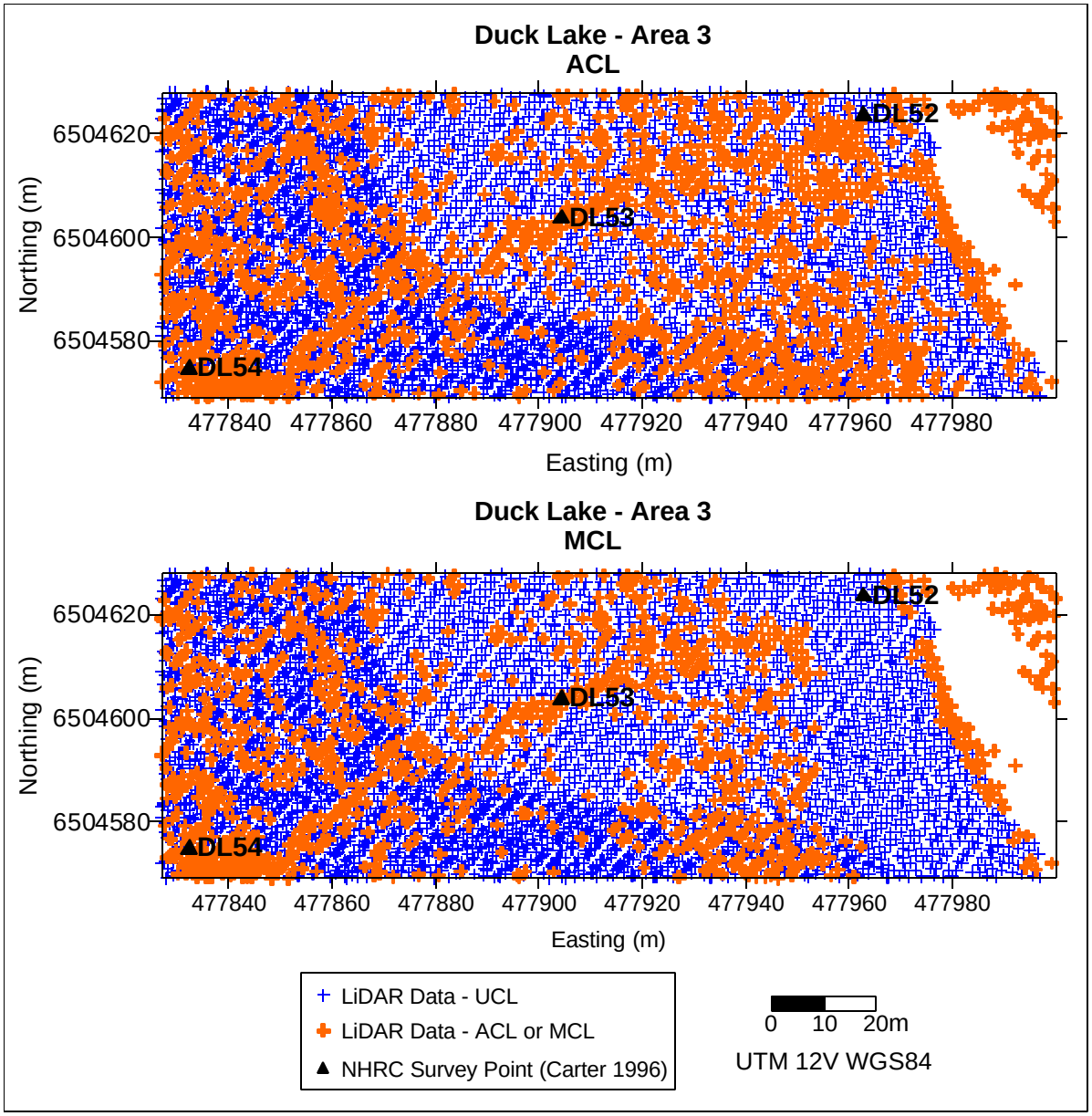

Figure 23. Spatial distribution of LiDAR points in Duck Lake (Area 3).

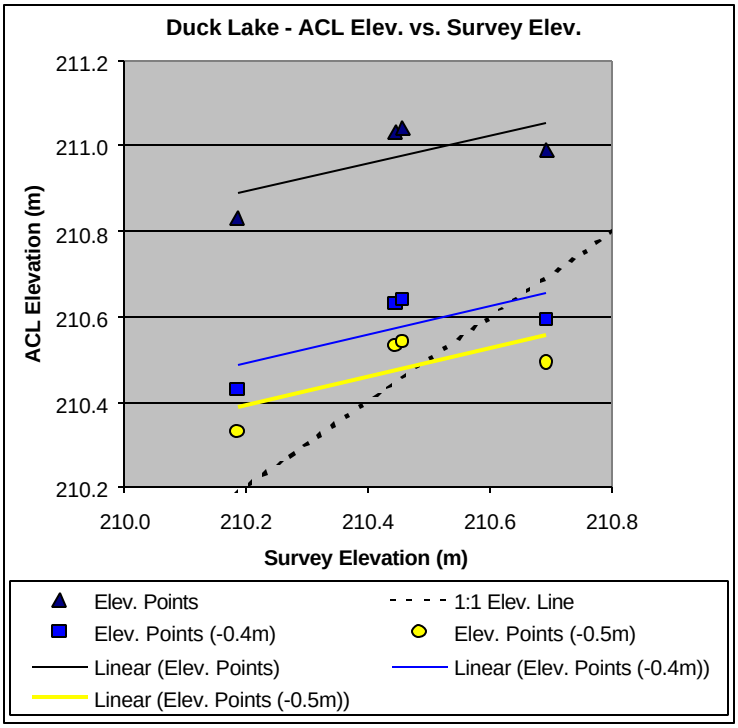

Figure 24. ACL elevations in Duck Lake plotted against surveyed elevations. The original LiDAR elevations and the LiDAR elevations lowered by both 0.4m and 0.5m are plotted.

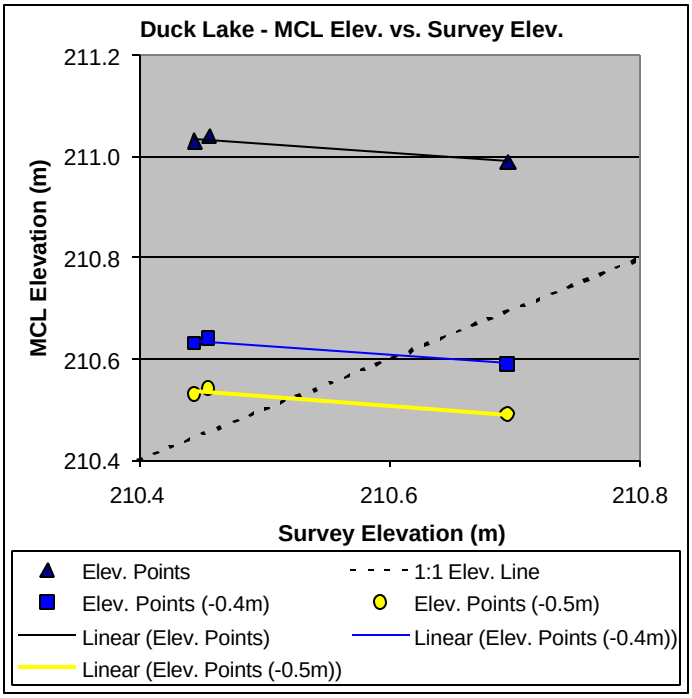

Figure 25. MCL elevations in Duck Lake plotted against surveyed elevations. The original LiDAR elevations and the LiDAR elevations lowered by both 0.4m and 0.5m are plotted.

Benchmarks

Benchmarks located in Egg Lake (EL01 and EL03), on Dog Camp Island (DCIS) and on an island in Rivière des Rochers (61A012) were compared with LiDAR data. Figure 26 shows the EL01 and EL03 benchmarks superimposed on an IKONOS image, while Figure 27 illustrates the 61A012 benchmark superimposed on a SPOT image. The location of the DCIS benchmark can be seen in Figure 5.

Figures 28 and 29 show the spatial distribution of LiDAR data around the EL01 point and the EL03 point, respectively. The spatial distribution of LiDAR data in the region of 61A012 and on Dog Camp Island is illustrated in Figure 30 and 31, respectively. All of the benchmarks are located on bedrock outcrops. The EL01, EL03 and DCIS outcrops were classified as vegetation by the manual classification and were, therefore, smoothened out considerably. However, the ACL and MCL data sets have the same number of ground points around the 61A012 benchmark even though it is located on an outcrop.

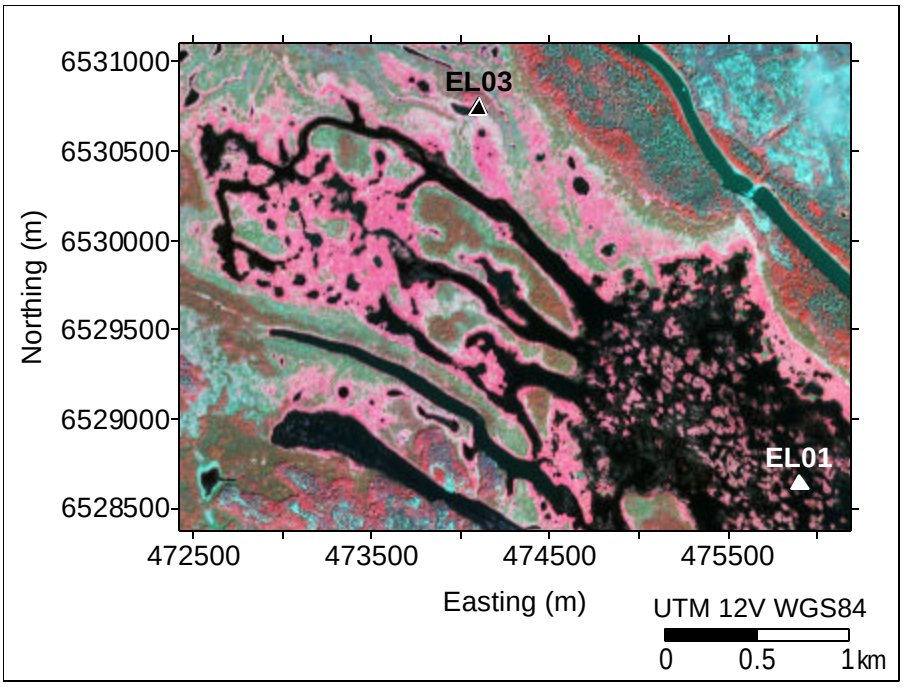

Figure 26. EL01 and EL03 benchmarks in northern Egg Lake superimposed on an IKONOS image (acquired on August 23, 2000).

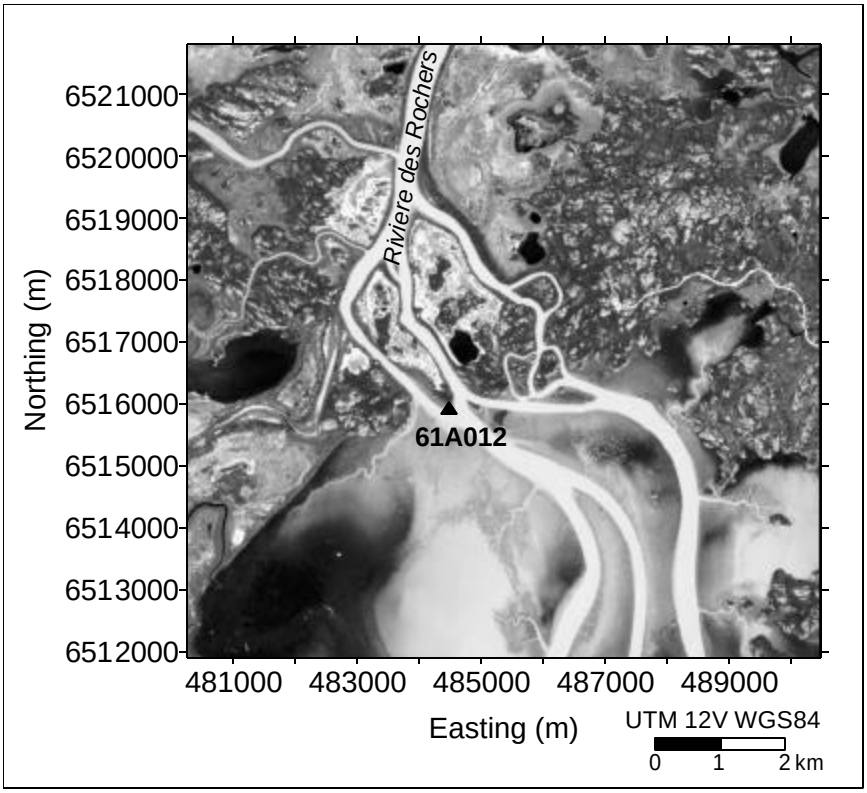

Figure 27. 61A012 benchmark on island in Rivière des Rochers superimposed on a SPOT image (acquired on June 22, 1990).

The co-ordinates and elevations of the benchmarks and LiDAR points are listed in Appendix 5. The differences in elevation between benchmarks and LiDAR data are shown in Appendix 6. In all cases, the LiDAR data had much lower elevations than the benchmarks. The LiDAR data were also lower than surveyed data over the two bedrock areas (DCQU and Site 2) in Dog Camp. There are not enough ground data to confirm if this is true for all bedrock areas or if the discrepancies related to the topography.

All Points

If all compared points are compiled, the average difference between LiDAR and survey elevations is 0.18m and 0.08m for ACL data and MCL data, respectively. The minimum, maximum and average differences between LiDAR data and all of the survey data are reported in Table 7. The data in Table 7 indicate that the LiDAR data are on average a few metres lower than survey data in bedrock areas, and about 0.5m higher than survey data in willow and grass covered areas.

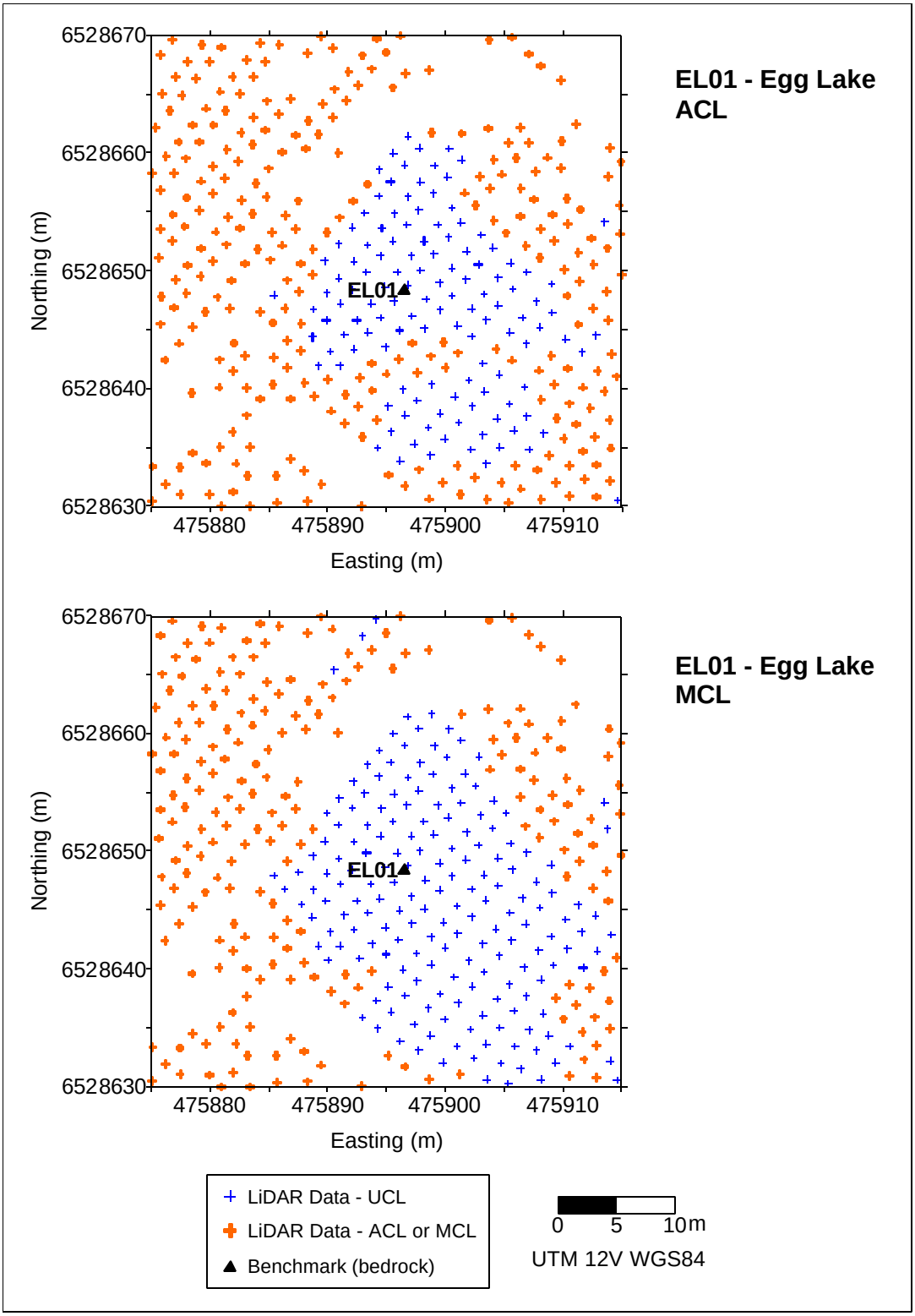

Figure 28. Spatial distribution of LiDAR points near the EL01 benchmark in Egg Lake.

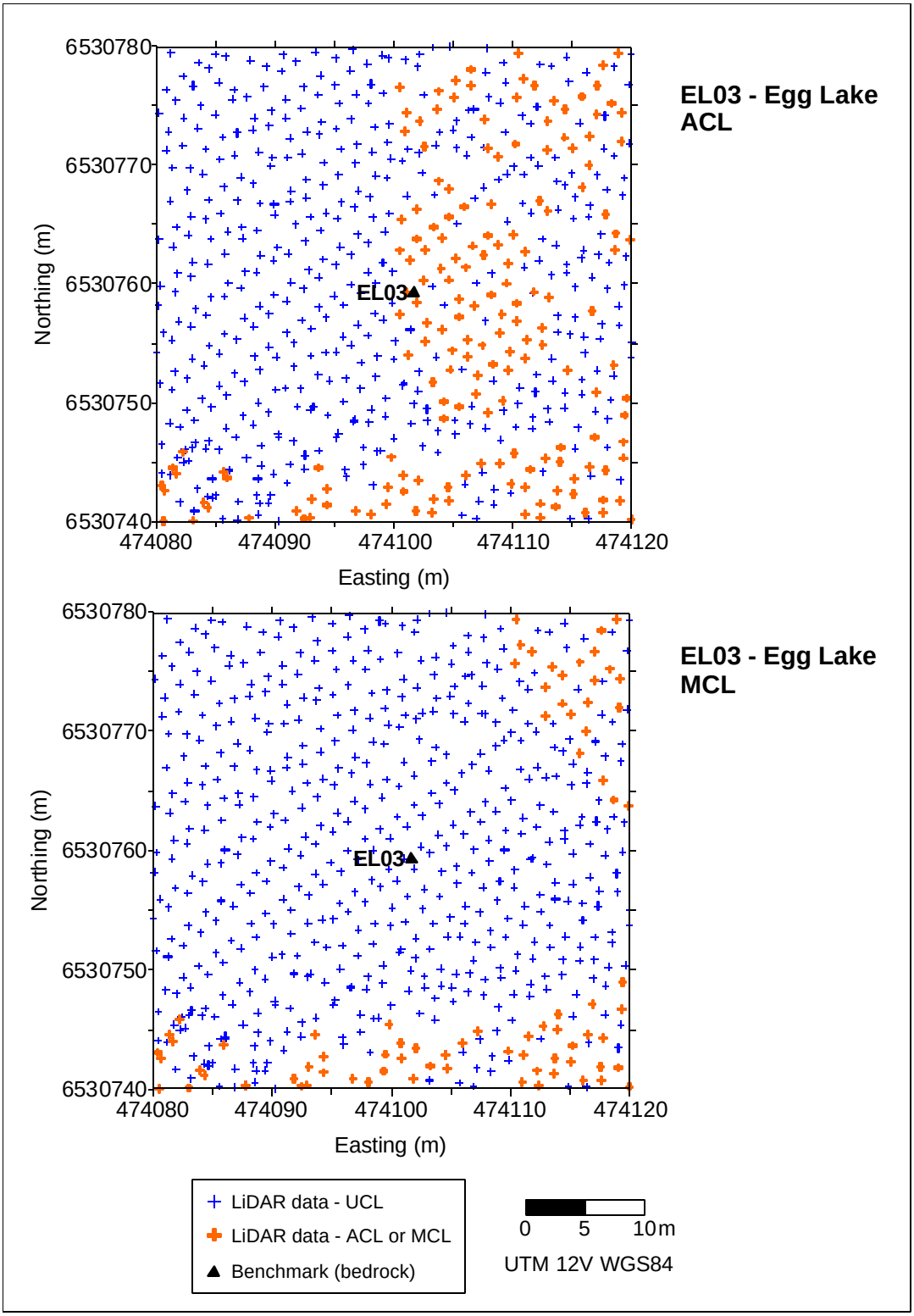

Figure 29. Spatial distribution of LiDAR points near the EL03 benchmark in Egg Lake.

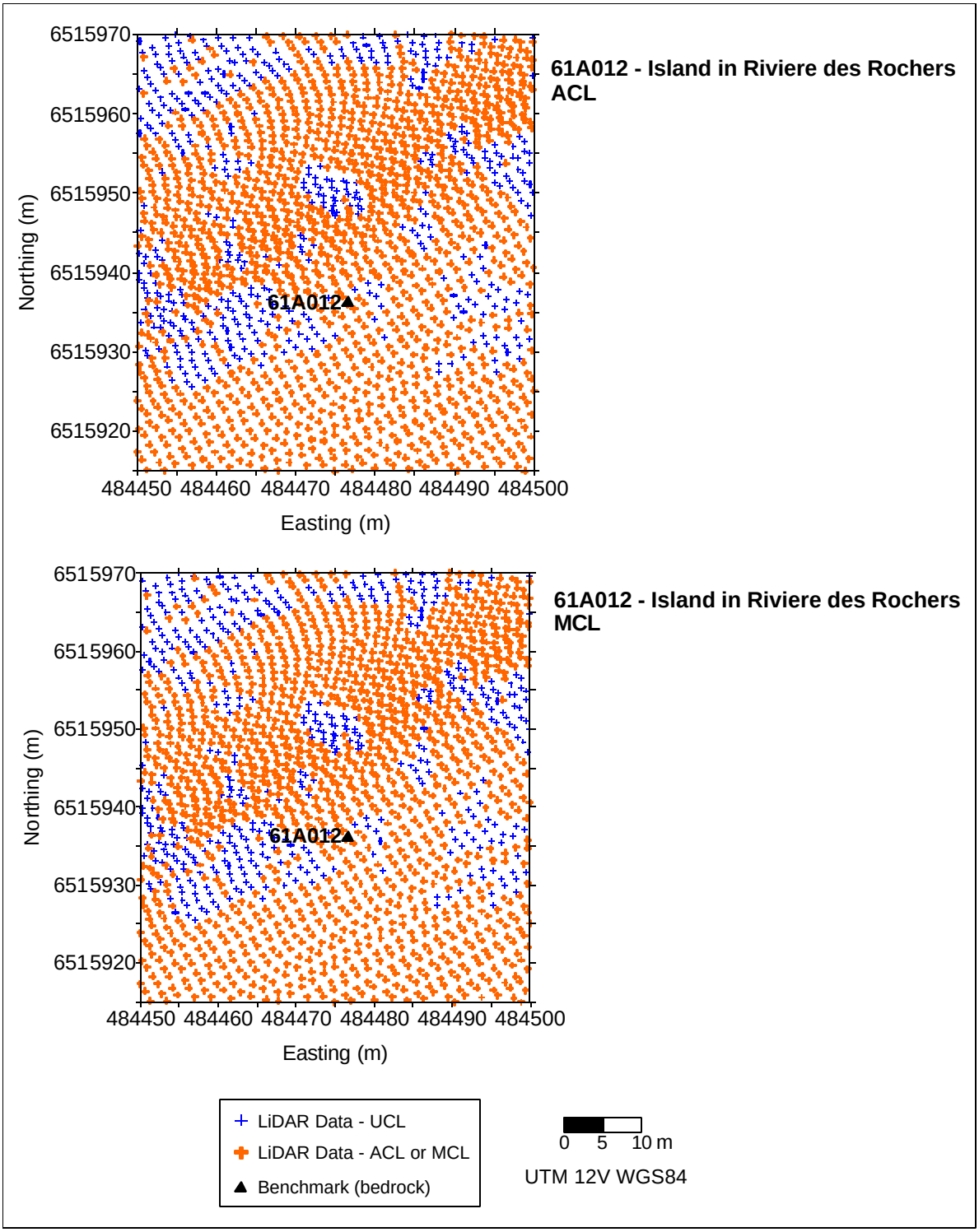

Figure 30. Spatial distribution of LiDAR points near the 61A012 benchmark on island in Rivière des Rochers.

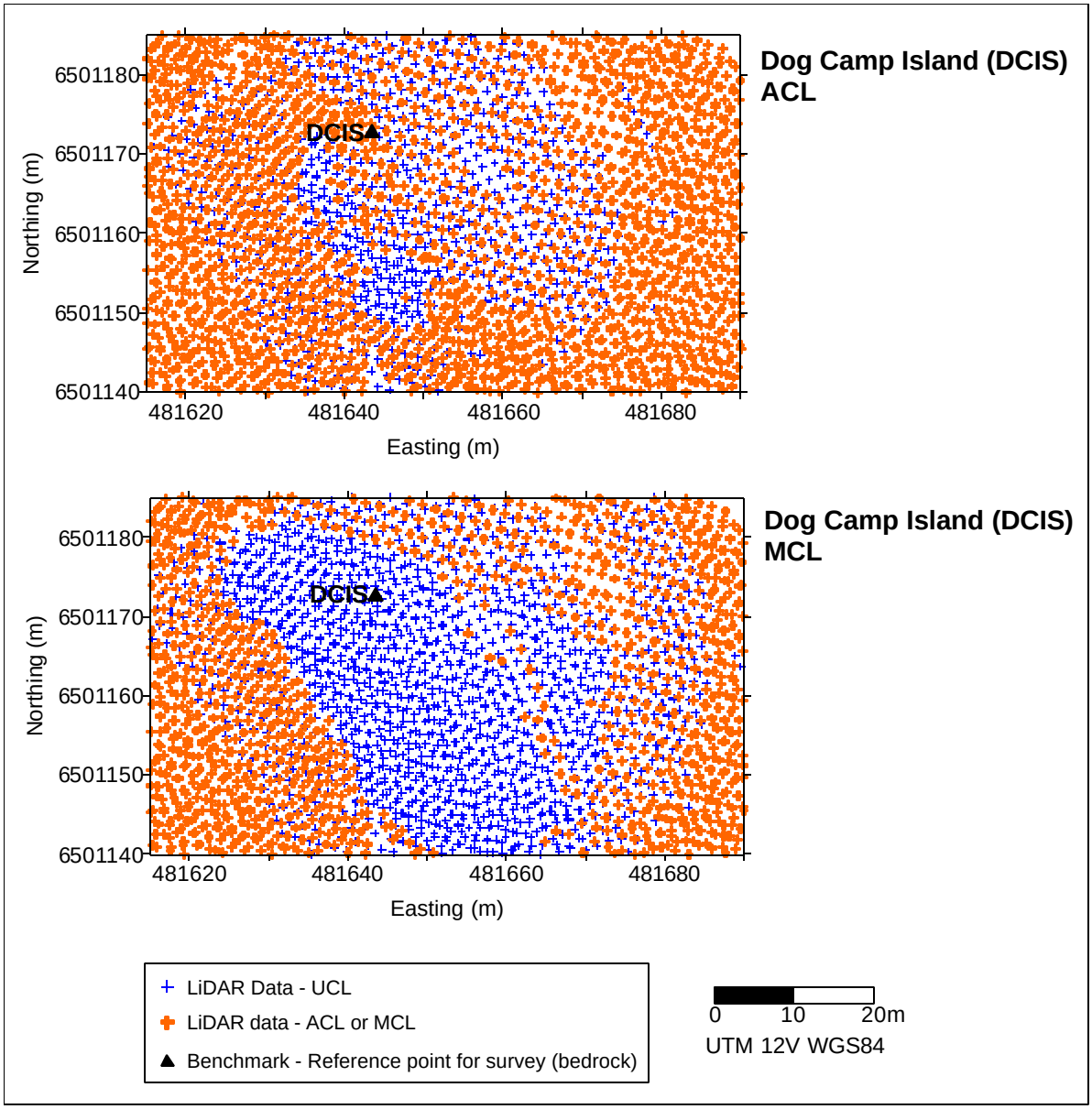

Figure 31. Spatial distribution of LiDAR points near the DCIS benchmark on Dog Camp Island in Quatre Fourches.

Table 7. The minimum, maximum and mean difference between the elevation of LiDAR points (elev. 1) and all survey points. The standard deviations of the differences and the number of points that were compared are also reported. Positive values indicate that the LiDAR elevations are higher.

	UCL-Survey Difference (m)	**ACL-Survey Difference (m)**	**MCL-Survey Difference (m)**
Min of All Points	-11.53	-11.53	-11.53
Max of All Points	7.92	1.05	0.71
Mean of All Points	1.13	0.18	0.08
Stdv of All Points	2.57	1.76	2.11
# of Points Compared	82	52	33
Min of Grass Points	-3.23	0.24	0.24
Max of Grass Points	7.92	0.79	0.71
Mean of Grass Points	1.07	0.56	0.52
Stdv of Grass Points	1.87	0.14	0.12
# of Points Compared	39	26	20
Min of Willow Points	-0.23	-0.23	0.30
Max of Willow Points	7.08	1.05	0.59
Mean of Willow Points	2.08	0.53	0.46
Stdv of Willow Points	2.29	0.31	0.13
# of Points Compared	33	18	7
Min of Bedrock Points	-11.53	-11.53	-11.53
Max of Bedrock Points	-0.26	-0.68	-1.09
Mean of Bedrock Points	-3.22	-4.09	-6.31
Stdv of Bedrock Points	4.22	5.07	7.38
# of Points Compared	6	4	2
Min of Mud Points	0.40	0.40	0.40
Max of Mud Points	0.42	0.42	0.42
Mean of Mud Points	0.41	0.41	0.41
Stdv of Mud Points	0.01	0.01	0.01
# of Points Compared	3	3	3
Min of Water Points	0.35	0.35	0.35
Max of Water Points	0.35	0.35	0.35
Mean of Water Points	0.35	0.35	0.35
Stdv of Water Points	n/a	n/a	n/a
# of Points Compared	1	1	1

LIDAR DATA GRIDDING

Evaluation of Gridding Algorithms

The spacing between LiDAR points vary from 0.25m to several metres. To retain the detailed topographical information, the cell size in a grid should be set to the smallest spacing of the data points. However, a cell size of 0.25m would produce very large gridded 2km by 2km patch files (8000 by 8000 grid cells) that are difficult to manage. Instead, a cell size of 4m was selected to reduce the grids to 500 by 500 cells for a 2km by 2km patch file. This enables gridded patch files to be merged together to a larger database that is still manageable.

Since the grid cell size is 4m and the spacing of data is anything between 0.25m and several metres, the interpolation process becomes difficult. Preferably, the values should be averaged when there are many data points within a grid cell, and interpolated from nearby points when there are no data points within a grid cell. However, none of the interpolation methods available in PCI or Surfer can do both averaging and interpolating. To find the interpolation method that is best suited for the LiDAR data sets, two databases, one with 0.25m grid cells and one with 4m grid cells, were created in PCI for the 224726502.grd patch file in the Jemis Lake area (Area A). Only the MCL data set was used for the evaluation.

In the 0.25m database, the LiDAR data were interpolated using a Kriging algorithm (Cressie 1993). The Kriging technique interpolates values by calculating the weighted sum of known points. The weights are determined by considering the co-variance between any two known points and between the unknown point and each of the known points. A spherical variogram with a nugget of 0 and a sill of 1 was used by the algorithm to determine the co-variances. The range was set (by the program) to the average distance between known points. An RTREE blocking method was used with a maximum number of 5 points in each block.

Another approach was to ”burn in” the elevation values of the LiDAR points into an empty raster channel, and then use an interpolator to fill in the empty grid cells. This method only works on the 0.25m data set, where there is maximum one LiDAR point per grid cell. A Morphology-Dependent Interpolation Procedure (MDIP) with a conic search algorithm was used to fill in the missing values. This method was very labour intensive since the 2km by 2km patch contained about 1,100,000 points and PCI could not manage to “burn in” all of the points at once. The patch file had to be divided into 11 smaller files that could be imported to PCI and burnt in separately.

The two elevation grids in the 0.25m database were aggregated (averaged) into 4m grid cells and transferred into the 4m database. The LiDAR points were also gridded directly into 4m grid cells using a Kriging algorithm, an inverse distance to power interpolation procedure, and a triangulation (TIN) interpolation method. The Kriging was conducted in PCI using the same settings as above. The Inverse Distance to Power grid was created using Surfer (since the PCI interpolator did not work correctly). The search radius was set to 2m and a value was only to be calculated if there was one or more points within the radius. This means that the points closest to the centre of a 4m-grid cell had more influence on the output value than those by the edge. The grid cell was assigned a value of zero if there were no points within the cell. The generated grid

was imported into PCI, where the grid cells with no elevation value were filled in using the MDIP interpolation method based on a conic search algorithm. The TIN grid was also created in Surfer, since PCI does not support the TIN algorithm. The data points were gridded into 4m grid cells and imported to PCI.

In PCI, the original MCL points were superimposed on each of the five 4m-grids. As a comparison of gridded data and actual LiDAR values, the gridded elevation at each LiDAR point was extracted from all five grids. The difference between actual LiDAR elevation and gridded elevation was calculated for each LiDAR point. The average, minimum and maximum absolute differences and the standard deviation of the differences are listed for all grids in Table 8. All grids are on average between 0.05m and 0.06m higher or lower than the original LiDAR values, except for the TIN grid, which is on average 0.18m off the original values. The original LiDAR values were best honoured by gridding the data into 0.25m cells using Kriging and, thereafter, averaging the 0.25m cells to 4m grid cells. The five grids are displayed in Appendix 8. An IKONOS image subset of the same area is also shown. Except for the TIN grid, which is very speckled, the grids are relatively similar and show the same trends. The two grids that were initially created in the 0.25m database are somewhat smoother and less speckled than the reminder of the grids. The striping and the brighter (higher) areas in the middle of Jemis Lake are reflected in the original LiDAR data and were not produced by the gridding process.

Table 8. The minimum, maximum and average absolute differences between original LiDAR point elevations and gridded LiDAR elevations. Manually classified LiDAR (MCL) data from Area A and patch file 24726502.grd were used for the comparison.

	Interpolated to 0.25m & averaged to 4m		**Interpolated to 4m**		
	Kriging	**Burn in values & MDIP interpolation**	**Kriging**	**Inverse Dis. to Power & MDIP interpolation**	**Triangulation (TIN)**
# Compared	1123867	1123867	1123867	1123867	1119315
Minimum	0	0	0	0	0
Maximum	0.91	0.88	1.02	1.01	14.42
Mean	0.05	0.06	0.06	0.06	0.18
Stdv	0.05	0.05	0.06	0.05	0.27

Methodology for LiDAR Data Gridding

The MCL data set contains fewer erroneously classified points (i.e. points that did not penetrate the vegetation layer completely) compared to the ACL data set, but it is also missing data points in areas with steep slopes. The MCL data set was preferred over the ACL data set since the relatively low relief and the vast areas with dense vegetation warrant a conservative data set.

The comparison of LiDAR data with survey data indicated that the MCL elevations are, on average, 0.4m higher in mud, 0.48m higher in willows and grass, and several metres lower in bedrock areas (the bedrock areas need to be confirmed). Therefore, the LiDAR elevations were

lowered by 0.45m (the average between vegetated and non-vegetated areas). To reduce the file size of the gridded data, the LiDAR elevations were converted from metres to centimetres. This enabled a 16-bit unsigned data channel to be used for the grids instead of a 32-bit real channel. The elevation values were lowered by the set amount at the same time as the units were changed.

A 0.25m and 4m database were created for each 2km by 2km patch file. The MCL data points were first gridded to 0.25m grid cells using Kriging and then averaged to 4m grid cells. Areas A-E were gridded using maximum 5 points in each block. Area F was gridded using maximum 7-9 points per block and Area G using maximum 7 points per block. The grid files were named according to the original patch files, that is, the first three numbers of the easting and the first four numbers of the northing of the lower left corner. The 0.25m grid files and the 4m grid files were given *_s.pix and *.pix extensions, respectively. A mosaic of the 4m grids was created for each LiDAR area (Area A-G). The mosaics were named according to the LiDAR survey area that they cover. For example, the 4m grid mosaic of Area A (Jemis Lake) was named Area_A.pix. The 0.25m grids, the 4m grids and the 4m grid mosaic for each LiDAR survey area were zipped together. Examples of the zip-file naming convention are: A_grid_25cm.zip (for the 0.25m grids in Area A), A_grid_4m.zip (for the 4m grids in Area A), and A_mosaic_4m.zip (for the 4m grid mosaic of Area A). Each zip-file contains a read-me file with meta-data.

Gridding Results

The overall gridding results were good, especially in areas with many LiDAR points. Areas with no LiDAR points resulted in a "blocky" appearance due to the block Kriging algorithm. Some of the patch files only contained data in a small portion of the 2km by 2km area. The areas that were not covered by the LiDAR survey were masked out in the mosaics (a value of 20000cm was applied to all "no data" grid cells). The seven mosaics are shown in Appendix 9.

During the gridding process, it was also observed that a few areas experienced shifting in X and Y direction. In these areas, some channels were represented twice or were disconnected. Figure 32 illustrates a few examples of this problem. The disconnected channels are especially noticeable in Area B (Quatre Fourches), although a few channels are disconnected or shifted in most other survey areas as well. The problem may be a result of surveying certain areas twice (problem areas were re-surveyed on June 18, 2000) or mis-alignment between adjacent scan lines.

After creating the mosaics, it was noted that Area E (Chenal des Quatre Fourches) also included the Dog Camp area. The "shifts" that were seen in the Area B grid are not present in the Area E grid. The two grids also show differences in elevation values. The Area E grid is generally between 0.2m and 10m higher than the Area B grid. The river elevations differ with about 0.2m, while the largest differences occur over the bedrock outcrops.

To assess the accuracy of the grids, the surveyed elevations were compared to the gridded elevations. The benchmark points were not included in the comparison. The results are listed in Appendix 10 and summarised in Table 9. The results indicate that the Area E grid over Dog

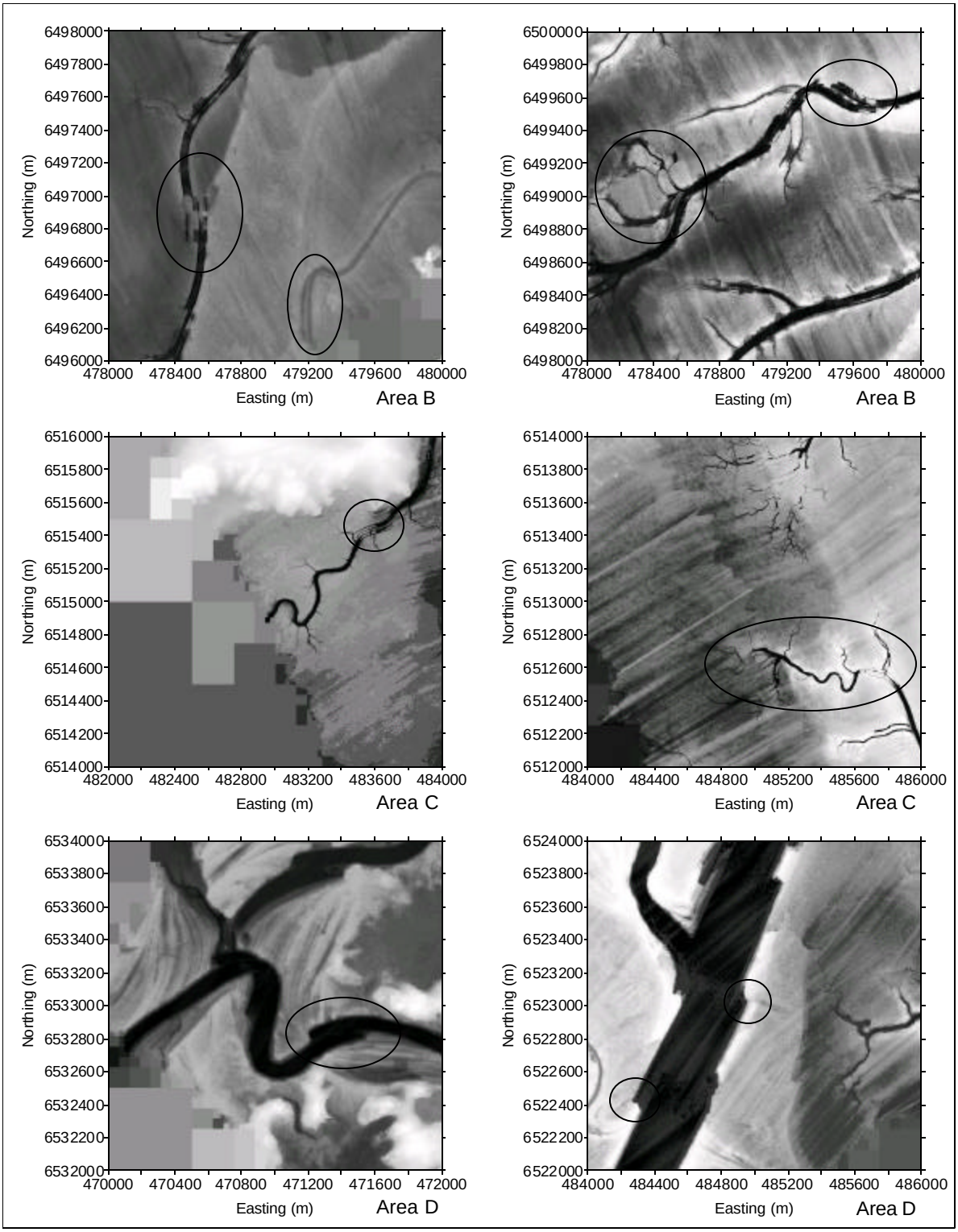

Figure 32. A few examples of gridded patch files from Area B, C and D with X-Y shifting problems (encircled). The figures are digital elevation models where high elevations are represented by light colours and vice versa. The areas with no input LiDAR points have a blocky appearance (see west part of the middle left grid for an example).

Camp has a higher accuracy compared to the Area B grid. However, the points on top of the Dog Camp hill are still several metres off. If all points are compared (using Area E grid for Dog Camp), the gridded LiDAR elevations are on average 0.67m lower than the surveyed elevations (standard deviation is 1.90m). However, if the DCQU benchmark and the points on top of the Dog Camp hill (Sites 1-3) are excluded from the comparison, the gridded elevations are on average 0.035m higher than surveyed elevations (standard deviation is 0.22m).

Table 9. The minimum, maximum and average differences between 4m LiDAR grid elevations and surveyed elevations. The standard deviations are also reported. Positive values indicate that the LiDAR grid elevations are higher.

	Jemis Grid-Survey	**Duck Grid-Survey**	**Dog Camp (B) Grid-Survey**	**Dog Camp (E) Grid-Survey**
	Difference (m)	**Difference (m)**	**Difference (m)**	**Difference (m)**
Min	-0.49	-1.12	-11.89	-8.96
Max	0.26	0.54	-0.07	0.21
Mean	-0.02	0.03	-3.20	-1.90
Stdv	0.16	0.58	3.61	2.86

INSERTING LIDAR GRID MOSAICS INTO A 25M DEM

The generated LiDAR mosaics of Area A-G were used to enhance a 25m resolution DEM (pad-dem.pix) of the Peace-Athabasca Delta. The 25m DEM was previously produced by NHRC using a TIN algorithm based on 1:50,000 NTS contour lines, survey points and lake outlines (see Zhao 1997 for details). To facilitate a merger, the LiDAR mosaics were aggregated into 25m grid cells and the 25m DEM was re-projected from a NAD27 datum to a WGS84 datum. The two data sets were merged using the IMERGE command in PCI.

Figure 33 illustrates how the Jemis Lake LiDAR mosaic is inserted into the 25m DEM. As shown in Figure 33, the original 25m DEM lacks the detail that can be seen in the LiDAR mosaic. The same procedure was repeated with the other LiDAR mosaics. Appendix 11 shows the original 25m DEM of the Peace-Athabasca Delta and the resulting DEM/LiDAR combination.

DATA COMPACT DISCS

The original LiDAR data points, the gridded LiDAR data, the grid mosaics, the grid mosaics combined with the original 25m DEM and a digital version of this report are provided on compact discs (CDs). All the data CDs are listed in Appendix 12. All data files are stored in PCI format (*.pix) and the report is stored in Adobe Acrobat PDF format.

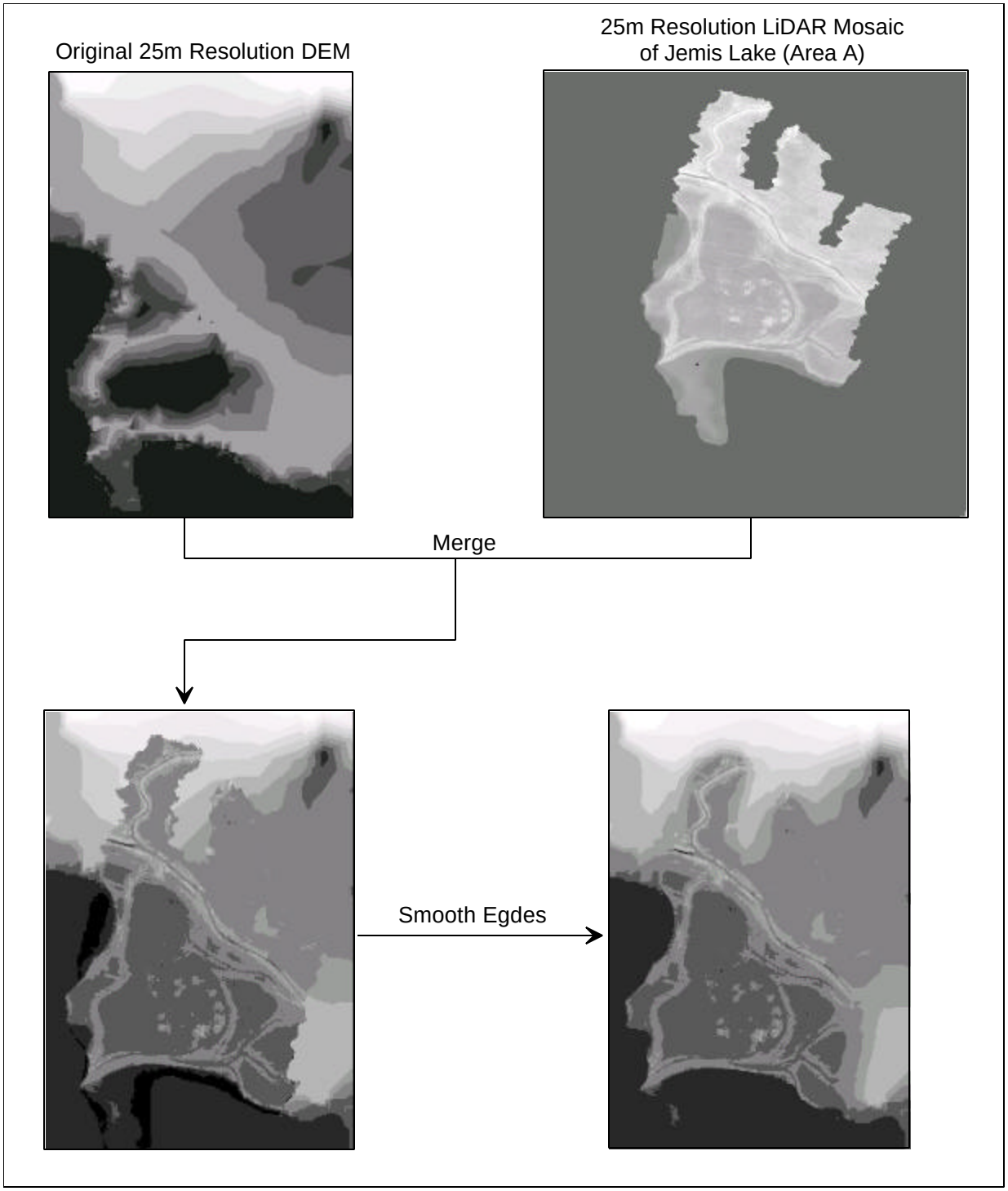

Figure 33. Merging the LiDAR grid mosaic of Jemis Lake (Area A) with the original 25m DEM of the Peace-Athabasca Delta.

SUMMARY AND CONCLUSIONS

The MCL data set is more conservative and contains less ground data points compared to the ACL data set. Many of the vegetation points that were erroneously classified as ground in the ACL data set were classified correctly in the MCL data set. On the other hand, ground points in rapidly changing terrain were erroneously classified as vegetation in the MCL data set. The more conservative MCL data set was preferred for this study because of the relatively low relief within the Peace-Athabasca Delta.

The comparison of LiDAR data with survey data indicated that the MCL elevations are, on average, 0.4m higher than survey data in mud covered areas and about 0.48m higher in willows and grass. In bedrock areas, the LiDAR data had much lower elevations compared to survey data. All of the bedrock points that were used for the comparison were located on outcrops with higher relief, which may have affected the LiDAR values. The reason for the discrepancies on the bedrock outcrops needs further investigation.

After lowering the MCL elevations by 0.45m to compensate for the positive bias, the MCL data has on average 0.04m higher elevation values compared to survey data in relatively flat areas covered by mud, grass or willow (the survey points high relief bedrock areas are excluded). The standard deviation of the differences between MCL data and survey data is 0.12m.

The lowered MCL data were first gridded into 0.25m grid cells using Kriging and then aggregated into 4m grid cells. The gridded elevations are, on average, 0.67m lower than the surveyed elevations. The standard deviation is 1.90m. In relatively flat areas that are covered by mud, grass or willow, the gridded elevations are on average only about 0.035m lower than survey elevations. The standard deviation is only 0.22m in the low relief areas.

Some areas also experienced shifting in X and Y direction, resulting in disconnected channels or channels that are represented twice (in different locations). The shifting is especially noticeable in Area B.

The mosaics of the LiDAR grids were aggregated into 25m grid cells and merged with a 25m resolution DEM that was generated in a previous study based on 1:50,000 contour lines. The merged data set shows that, even at 25m resolution, the LiDAR data add a lot of detail to the DEM.

In conclusion, the LiDAR grids give very useful details of the topography of basins and levees. After removing the positive bias, the relative accuracy is comparatively good in low relief areas. The accuracy of high relief/bedrock areas needs confirmation. In addition, the X-Y shifting may cause problems for applications like flow direction analysis.

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APPENDIX 1

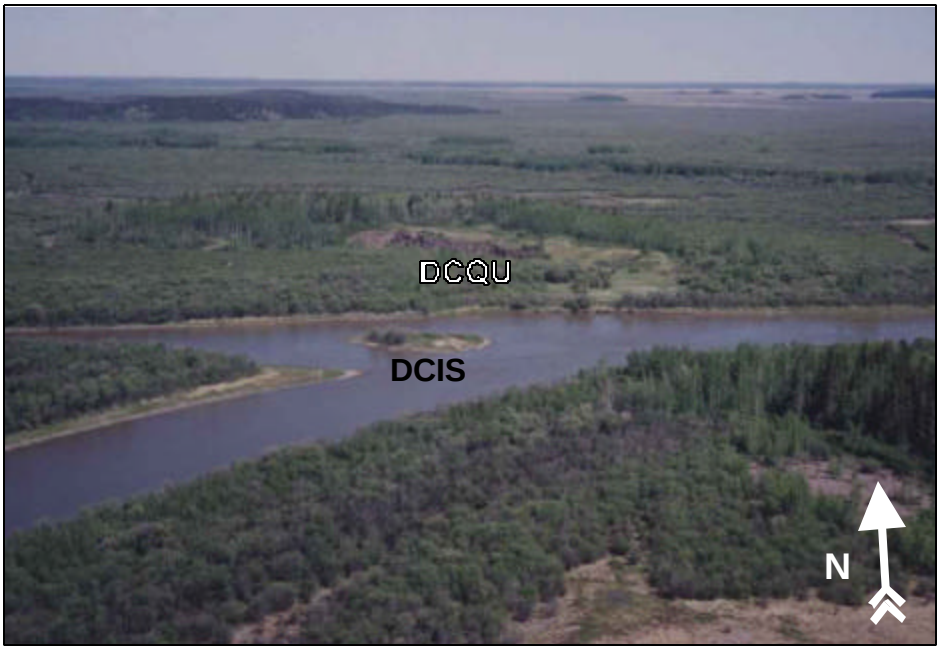
- PHOTOGRAPHS –

Jemis Lake - JBIP GPS Point

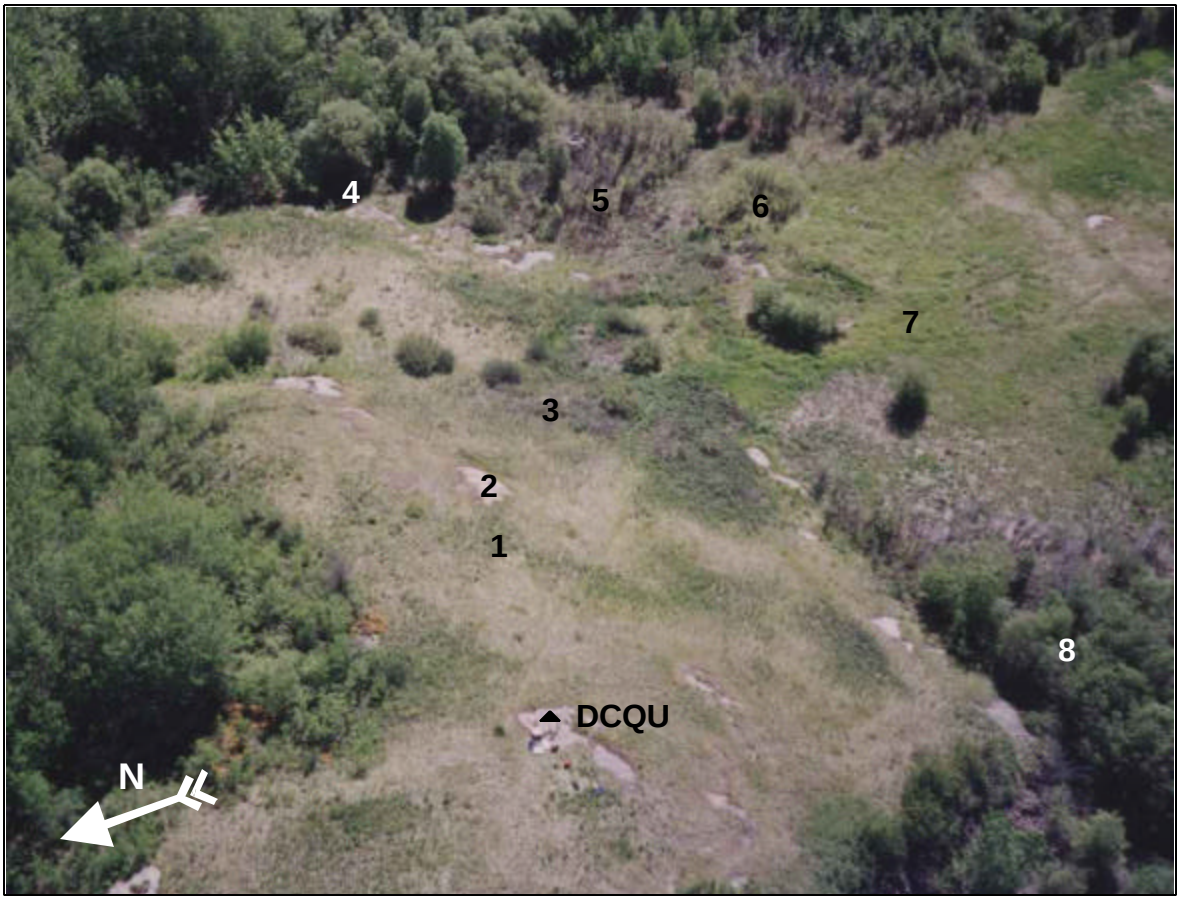
Jemis Lake - JBM1 GPS Point (JBIP in background)

Jemis Lake - Mud Flat

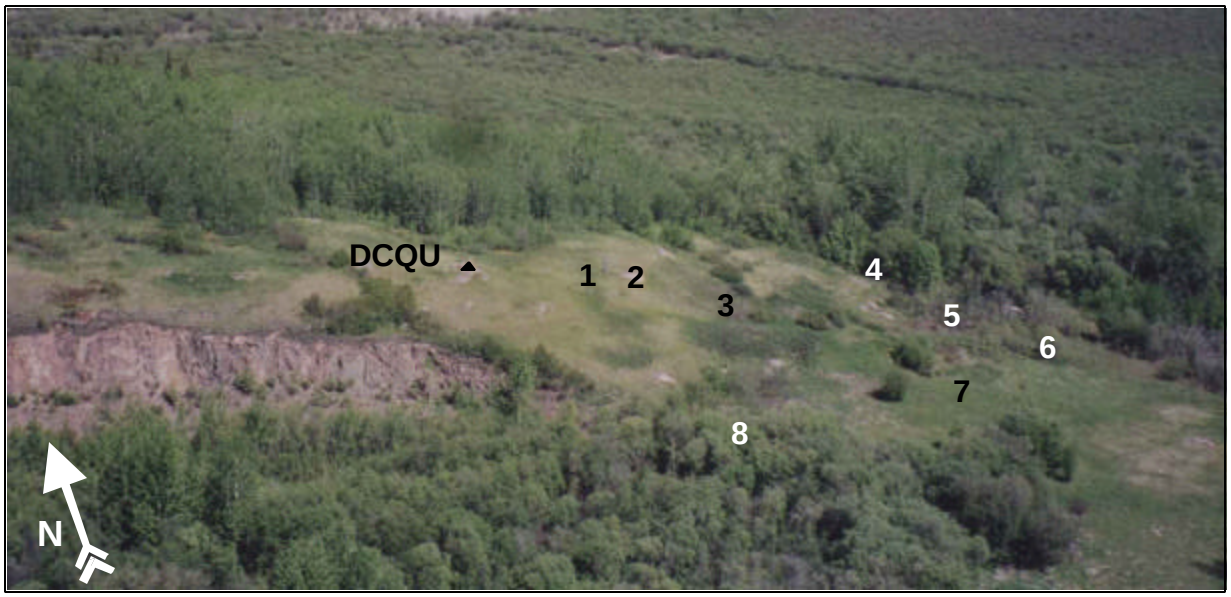
Dog Camp Quarry (DCQU) and Dog Camp Island (DCIS)

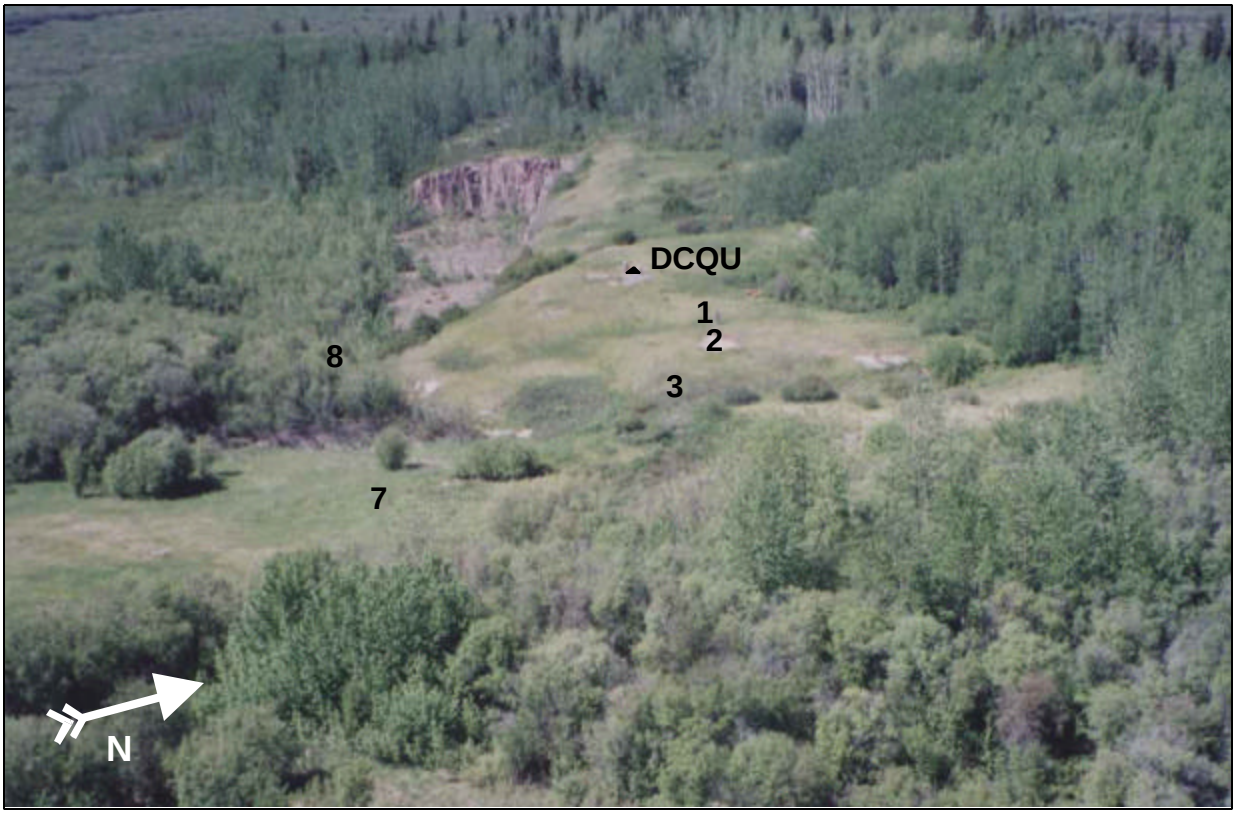


Dog Camp Quarry (DCQU) and the Survey Sites



Dog Camp Quarry (DCQU) and the Survey Sites





Dog Camp Island (DCIS)

Dog Camp Quarry (DCQU) Survey Sites

Photo 1 - Site 1

Photo 2 - Site 1

Photo 3 - Site 2

Photo 4 - Site 3

Photo 5 - Site 4

Photo 6 - Site 5

Dog Camp Quarry (DCQU) Survey Sites

Photo 7 - Site 5

Photo 8 - Site 6

Photo 9 - Site 6

Photo 10 - Site 7

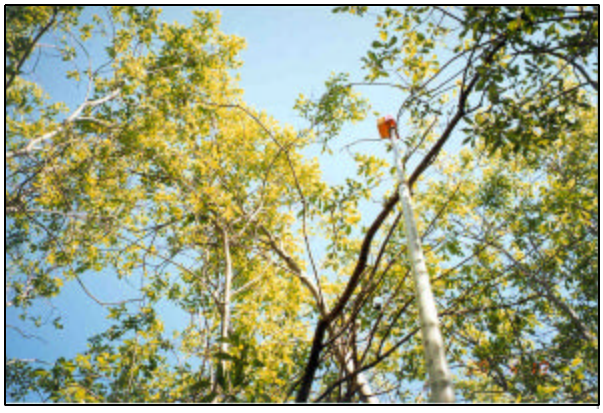


Photo 11 - Site 8

Photo 12 - Site 8

APPENDIX 2

JEMIS LAKE - UNCORRECTED AND CORRECTED SURVEY POINTS

Jemis Lake - Uncorrected and Corrected Survey Points

All values are in metres.

Survey Points			Uncorrected UTM 12V NAD27		Corrected UTM 12V NAD27		Corrected UTM 12V WGS84	
Cover Type	**ID**	**Elev.**	**Easting**	**Northing**	**Easting**	**Northing**	**Easting**	**Northing**
JBIP	1000	209.81	471962.30	6502746.85	471965.66	6502745.86	471907.12	6503005.89
grass	1001	209.72	471969.65	6502761.79	471971.90	6502761.30	471916.82	6502985.19
grass	1002	209.76	471961.26	6502759.01	471963.73	6502757.91	471908.65	6502981.80
grass	1003	209.76	471961.41	6502756.59	471964.06	6502755.51	471908.98	6502979.40
grass	1004	209.79	471961.20	6502753.98	471964.04	6502752.89	471908.96	6502976.78
grass	1005	209.78	471961.12	6502751.23	471964.16	6502750.14	471909.08	6502974.03
grass	1006	209.74	471960.69	6502748.45	471963.94	6502747.34	471908.86	6502971.23
grass	1007	209.76	471960.54	6502744.92	471964.05	6502743.81	471908.97	6502967.70
grass	1008	209.75	471960.22	6502742.07	471963.93	6502740.94	471908.85	6502964.83
grass	1009	209.85	471959.94	6502739.07	471963.87	6502737.93	471908.79	6502961.82
grass	1010	209.86	471959.99	6502735.95	471964.15	6502734.82	471909.07	6502958.71
grass	1011	209.97	471960.43	6502732.08	471964.87	6502730.99	471909.79	6502954.88
edge of willow	1012	209.95	471958.10	6502728.80	471962.79	6502727.55	471907.71	6502951.44
willow	1013	210.05	471958.71	6502726.47	471963.57	6502725.27	471908.49	6502949.16
willow	1014	209.99	471956.63	6502724.40	471961.65	6502723.05	471906.57	6502946.94
willow	1015	209.96	471953.83	6502722.55	471958.99	6502721.00	471903.91	6502944.89
willow	1016	209.97	471953.90	6502719.42	471959.29	6502717.89	471904.30	6502938.90
willow	1017	209.99	471953.78	6502716.54	471959.38	6502715.01	471904.30	6502938.90
willow	1018	209.96	471958.09	6502714.57	471963.82	6502713.36	471908.74	6502937.25
willow	1019	210.02	471957.05	6502712.11	471962.96	6502710.83	471907.88	6502934.72
willow	1020	210.00	471955.82	6502708.78	471961.98	6502707.42	471906.90	6502931.31
willow	1021	210.00	471955.47	6502706.47	471961.80	6502705.09	471906.72	6502928.98
willow	1022	209.98	471955.06	6502704.42	471961.54	6502703.01	471906.46	6502926.90
willow	1023	210.01	471955.41	6502702.17	471962.05	6502700.79	471906.97	6502924.68
willow	1024	209.99	471955.05	6502699.90	471961.86	6502698.50	471906.78	6502922.39
willow	1025	209.99	471953.51	6502699.29	471960.37	6502697.78	471905.29	6502921.67
grass	1026	209.98	471970.44	6502689.43	471977.97	6502689.19	471922.89	6502913.08
grass	1027	209.97	471970.24	6502691.60	471977.62	6502691.34	471922.54	6502915.23
grass	1028	209.99	471970.96	6502693.73	471978.18	6502693.51	471923.10	6502917.40
grass	1029	209.99	471969.89	6502696.07	471976.94	6502695.77	471921.86	6502919.66
grass	1030	209.99	471969.72	6502698.60	471976.59	6502698.28	471921.51	6502922.17
grass	1031	209.98	471969.52	6502701.03	471976.21	6502700.69	471921.13	6502924.58
grass	1032	209.99	471969.16	6502703.43	471975.67	6502703.06	471920.59	6502926.95
grass	1033	210.00	471968.79	6502705.85	471975.13	6502705.44	471920.05	6502929.33
grass	1034	210.01	471968.59	6502708.36	471974.75	6502707.93	471919.67	6502931.82
grass	1035	209.96	471968.16	6502711.07	471974.12	6502710.60	471919.04	6502934.49
grass	1036	209.93	471967.91	6502716.86	471973.45	6502716.36	471918.37	6502940.25
grass	1037	209.93	471967.70	6502719.65	471973.03	6502719.13	471917.95	6502943.02
grass	1038	209.91	471967.50	6502722.27	471972.64	6502721.72	471917.56	6502945.61
grass	1039	209.89	471967.38	6502724.34	471972.37	6502723.78	471917.29	6502947.67
grass	1040	209.93	471966.99	6502726.91	471971.79	6502726.31	471916.71	6502950.20
grass	1041	209.84	471966.65	6502729.87	471971.24	6502729.24	471916.16	6502953.13
grass	1042	209.74	471966.39	6502732.47	471970.79	6502731.82	471915.71	6502955.71

Jemis Lake - Continued…

Survey Points			Uncorrected UTM 12V NAD27		Corrected UTM 12V NAD27		Corrected UTM 12V WGS84	
Cover Type	**ID**	**Elev.**	**Easting**	**Northing**	**Easting**	**Northing**	**Easting**	**Northing**
grass	1043	209.82	471966.21	6502735.10	471970.42	6502734.43	471915.34	6502958.32
grass	1044	209.85	471966.08	6502738.13	471970.07	6502737.44	471914.99	6502961.33
grass	1045	209.76	471965.81	6502741.06	471969.58	6502740.34	471914.50	6502964.23
grass	1046	209.79	471965.60	6502744.02	471969.16	6502743.28	471914.08	6502967.17
grass	1047	209.76	471965.42	6502747.18	471968.75	6502746.42	471913.67	6502970.31
grass	1048	209.73	471965.10	6502750.11	471968.21	6502749.31	471913.13	6502973.20
grass	1049	209.73	471964.80	6502752.52	471967.74	6502751.70	471912.66	6502975.59
grass	1050	209.73	471964.47	6502755.24	471967.21	6502754.39	471912.13	6502978.28
JBIP	1051	209.81	471962.32	6502746.82	471965.68	6502745.83	471910.60	6502969.72
edge of willow	1	209.71	472001.27	6502808.28	472000.04	6502809.97	471944.96	6503033.86
grass	2	209.64	471999.11	6502810.00	471997.76	6502811.53	471942.68	6503035.42
grass	3	209.71	471996.79	6502812.20	471995.28	6502813.55	471940.20	6503037.44
grass	4	209.61	471994.27	6502814.24	471992.62	6502815.40	471937.54	6503039.29
grass	5	209.67	471992.42	6502815.92	471990.65	6502816.95	471935.57	6503040.84
grass	6	209.69	471990.40	6502817.56	471988.52	6502818.43	471933.44	6503042.32
grass	7	209.68	471988.52	6502819.23	471986.52	6502819.96	471931.44	6503043.85
grass	8	209.75	471986.59	6502820.84	471984.48	6502821.43	471929.40	6503045.32
grass	9	209.71	471984.36	6502822.30	471982.15	6502822.72	471927.07	6503046.61
grass	10	209.69	471981.76	6502824.14	471979.42	6502824.36	471924.34	6503048.25
top of bank	11	209.71	471980.18	6502825.85	471977.72	6502825.95	471922.64	6503049.84
bank	12	209.09	471978.39	6502827.35	471975.82	6502827.32	471920.74	6503051.21
bank	13	208.99	471976.12	6502829.06	471973.44	6502828.86	471918.36	6503052.75
bank	14	208.96	471974.56	6502830.28	471971.79	6502829.96	471916.71	6503053.85
bank	15	208.93	471972.71	6502831.80	471969.83	6502831.34	471914.75	6503055.23
bottom of bank: mud	16	208.79	471970.38	6502833.81	471967.36	6502833.18	471912.28	6503057.07
mud	17	208.78	471967.75	6502835.80	471964.60	6502834.97	471909.52	6503058.86
mud	18	208.75	471964.87	6502837.85	471961.57	6502836.80	471906.49	6503060.69
mud	19	208.73	471962.87	6502839.27	471959.48	6502838.07	471904.40	6503061.96
WL - Mamawi (17:07)	20	208.72	471961.23	6502840.07	471957.78	6502838.75	471902.70	6503062.64
tree height: 5.89	101	210.02	471950.27	6502741.16	471954.08	6502739.31	471899.00	6502963.20
tree height: 7.03	102	209.97	471951.72	6502727.50	471956.52	6502725.79	471901.44	6502949.68
tree height: 3.80	103	209.77	471988.40	6502755.92	471991.03	6502756.81	471935.95	6502980.70
tree height: 4.08	104	209.72	471996.88	6502758.52	471999.29	6502760.02	471944.21	6502983.91
tree height: 4.46	105	209.68	472001.60	6502806.41	472000.50	6502808.13	471945.42	6503032.02

APPENDIX 3

DOG CAMP – SURVEY INFORMATION

Dog Camp - Survey Information

All values are in metres and in UTM 12V WGS84 projection.

ID	Site	Easting	Northing	Elev.	Photo	Description	~Veg. Height	LAI	Comment
1	1	481785.03	6501416.90	220.10	1,2	Grass & Low brush	<50 cm		
2	1	481786.71	6501413.23	219.55	1,2	Grass & Low brush	<50 cm		
3	1	481787.05	6501411.81	219.24	1,2	Grass & Low brush	<50 cm		
4	1	481783.62	6501414.46	219.70	1,2	Grass & Low brush	<50 cm		
5	2	481790.65	6501411.76	219.00	3	Bedrock			
6	3	481799.49	6501402.68	215.82	4	Dead willow, Rose bushes, Fireweed	1m, <50cm	0.98	
7	3	481798.19	6501399.92	215.39	4	Dead willow, Rose bushes, Fireweed	1m, <50cm		
8	3	481797.42	6501397.93	214.99	4	Dead willow, Rose bushes, Fireweed	1m, <50cm		
9	3	481795.22	6501396.90	214.86	4	Dead willow, Rose bushes, Fireweed	1m, <50cm		
10	4	481846.47	6501403.90	210.97	5	Edge of tall poplar (aspen), Rose bushes	<19m, 1m	1.25	LAI
11	4	481848.25	6501405.27	210.73	5	Edge of tall poplar (aspen), Rose bushes	<19m, 1m		at ID 10
12	4	481846.55	6501401.80	210.77	5	Edge of tall poplar (aspen), Rose bushes	<19m, 1m		
13	4	481844.36	6501400.69	210.88	5	Edge of tall poplar (aspen), Rose bushes	<19m, 1m		
14	5	481830.25	6501385.00	210.79	7	Dead & live willows, Rose bushes, Thatch, Bedrock east of willow stand	<4.5m, <50cm	1.97	LAI
15	5	481832.10	6501384.22	210.67	7	Dead & live willows, Rose bushes, Thatch, Bedrock east of willow stand	<4.5m, <50cm		at ID 14
16	5	481830.34	6501383.26	210.89	7	Dead & live willows, Rose bushes, Thatch, Bedrock east of willow stand	<4.5m, <50cm		
17	5	481826.14	6501379.82	210.95	6	Dead & live willows, Rose bushes, Thatch, Bedrock east of willow stand	<4.5m, <50cm	0.86	at ID 17
18	5	481824.45	6501375.05	210.88	6	Dead & live willows, Rose bushes, Thatch, Bedrock east of willow stand	<4.5m, <50cm		
19	6	481813.34	6501363.02	211.38	8,9	Sparse Willows, Grass & Fireweed	<4m, <20cm	0.76	LAI incl.
20	6	481817.13	6501362.53	211.43	8,9	Sparse Willows, Grass & Fireweed	<4m, <20cm		grass &
21	6	481816.91	6501359.96	211.28	8,9	Sparse Willows, Grass & Fireweed	<4m, <20cm		willow
22	7	481801.23	6501358.23	211.40	10	Grass, Some thatch beneath	<40cm	1.61	LAI
23	7	481794.33	6501360.58	211.34	10	Grass, Some thatch beneath	<40cm		doesn't
24	7	481793.56	6501362.31	211.30	10	Grass, Some thatch beneath	<40cm		incl.
25	7	481792.89	6501363.84	211.31	10	Grass, Some thatch beneath	<40cm		thatch
26	8	481752.90	6501383.73	210.36	11,12	Tall and dense Willow, Branches & leaves on the ground, Horsetail	<10m	1.93	
27	8	481751.52	6501380.66	210.10	11,12	Tall and dense Willow, Branches & leaves on the ground, Horsetail	<10m		
28	8	481751.64	6501379.28	210.14	11,12	Tall and dense Willow, Branches & leaves on the ground, Horsetail	<10m		

APPENDIX 4

THE LIDAR FILES USED FOR COMPARISON WITH SURVEY DATA

The LiDAR Patch Files used for Comparison with Survey Data

		LiDAR Files used for Comparison		
Survey Area	**LiDAR Area ID**	**UCL**	**ACL**	**MCL**
Jemis Lake	A	24706502.all	24706502.grd	24706502.grd
Dog Camp	B	24806500.all	24806500.grd	24806500.grd
Duck Lake	E	24766504.all	24766504.grd	24766504.grd
		24766506.all	24766506.grd	24766506.grd
61A012	C	24846514.all	24846514.grd	24846514.grd
EL01	D	24746528.all	24746528.grd	24746528.grd
EL03	D	24746530.all	24746530.grd	24746530.grd
DCIS	B	24806500.all	24806500.grd	24806500.grd

APPENDIX 5

COMPARISON OF SURVEY POINTS WITH LIDAR POINTS

Jemis Lake – Comparison of Survey Points with LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

Survey Points					LiDAR Points						
							UCL		ACL		MCL
Cover Type	ID	Easting	Northing	Elev	Easting	Northing	Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
grass	JBM1	471907.12	6503005.89	209.67	471906.62	6503006.15	210.23	210.14	210.23	210.14	210.23
grass	1001	471916.82	6502985.19	209.72	471916.57	6502985.85	210.17	210.07	210.17	210.07	210.17
grass	1002	471908.65	6502981.80	209.76	471909.28	6502981.97	210.32	210.17	210.32	210.17	210.32
grass	1004	471908.96	6502976.78	209.79	471909.02	6502976.84	210.25	210.16	210.25	210.16	210.25
grass	1005	471909.08	6502974.03	209.78	471908.96	6502974.19	210.32	210.26	210.32	210.26	210.32
grass	1007	471908.97	6502967.70	209.76	471908.76	6502967.72	210.47	210.39	210.47	210.39	210.47
grass	1009	471908.79	6502961.82	209.85	471908.46	6502961.42	210.87	210.75			
willow_edge	1012	471907.71	6502951.44	209.95	471908.09	6502951.48	210.47	210.38	210.47	210.38	210.47
willow	1015	471903.91	6502944.89	209.96	471904.09	6502944.69	216.29	216.17			
willow	1017	471904.30	6502938.90	209.99	471904.50	6502938.98	214.80	214.76			
willow	1018	471908.74	6502937.25	209.96	471908.93	6502936.74	215.26	215.19			
willow	1019	471907.88	6502934.72	210.02	471907.53	6502934.53	210.67	217.00	210.67	217.00	
willow	1021	471906.72	6502928.98	210.00	471906.82	6502928.76	216.54	216.54			
willow	1022	471906.46	6502926.90	209.98	471906.12	6502926.49	217.06	216.98			
willow	1024	471906.78	6502922.39	209.99	471906.99	6502922.64	210.41	215.18	210.41	215.18	
grass	1026	471922.89	6502913.08	209.98	471922.92	6502912.89	212.34	212.28			
grass	1028	471923.10	6502917.40	209.99	471923.08	6502917.31	213.51	213.39			
grass	1031	471921.13	6502924.58	209.98	471921.77	6502924.60	210.35	210.25	210.35	210.25	210.35
grass	1032	471920.59	6502926.95	209.99	471920.56	6502927.26	210.23	210.16	210.23	210.16	210.23
grass	1034	471919.67	6502931.82	210.01	471920.13	6502931.16	210.38	210.26	210.38	210.26	210.38
grass	1035	471919.04	6502934.49	209.96	471919.40	6502934.14	211.57	211.47			
grass	1036	471918.37	6502940.25	209.93	471918.71	6502939.99	212.63	212.49			
grass	1037	471917.95	6502943.02	209.93	471917.85	6502942.31	210.44	210.36	210.44	210.36	210.44
grass	1038	471917.56	6502945.61	209.91	471918.25	6502944.97	213.57	213.50			
grass	1039	471917.29	6502947.67	209.89	471916.98	6502948.66	210.68	215.40	210.68	215.40	
grass	1040	471916.71	6502950.20	209.93	471917.73	6502950.45	210.65	210.55	210.65	210.55	
grass	1041	471916.16	6502953.13	209.84	471916.79	6502953.31	213.62	213.58			
grass	1043	471915.34	6502958.32	209.82	471915.63	6502958.49	215.36	215.29			
grass	1044	471914.99	6502961.33	209.85	471914.83	6502961.20	210.51	210.44	210.51	210.44	210.51
grass	1045	471914.50	6502964.23	209.76	471914.61	6502964.23	210.40	210.31	210.40	210.31	210.40
grass	1046	471914.08	6502967.17	209.79	471913.50	6502966.95	210.48	210.37	210.48	210.37	210.48
grass	1047	471913.67	6502970.31	209.76	471913.76	6502970.73	210.16	210.09	210.16	210.09	210.16
grass	1048	471913.13	6502973.20	209.73	471913.51	6502973.34	210.25	210.12	210.25	210.12	210.25
grass	1049	471912.66	6502975.59	209.73	471912.45	6502975.84	210.21	210.10	210.21	210.10	210.21
JBIP	1051	471910.60	6502969.72	209.81	471910.73	6502970.01	210.43	210.29	210.43	210.29	210.43
willow_edge	1	471944.96	6503033.86	209.71	471945.43	6503034.59	210.18	210.13	210.18	210.13	210.18
grass	2	471942.68	6503035.42	209.64	471942.22	6503035.55	210.07	209.97	210.07	209.97	210.07
grass	5	471935.57	6503040.84	209.67	471935.29	6503040.59	210.34	210.19	210.34	210.19	210.34
grass	6	471933.44	6503042.32	209.69	471933.48	6503042.86	210.38	210.30	210.38	210.30	
grass	7	471931.44	6503043.85	209.68	471931.82	6503043.91	210.31	210.19	210.31	210.19	
grass	10	471924.34	6503048.25	209.69	471924.73	6503048.59	210.40	210.31	210.40	210.31	

Jemis Lake – Continued…

Survey Points					LiDAR Points						
							UCL		ACL		MCL
Cover Type	**ID**	**Easting**	**Northing**	**Elev**	**Easting**	**Northing**	**Elev 1**	**Elev 2**	**Elev 1**	**Elev 2**	**Elev 1**
top_of_bank	11	471922.64	6503049.84	209.71	471922.89	6503049.14	210.33	210.23	210.33	210.23	
mud	17	471909.52	6503058.86	208.78	471909.21	6503058.24	209.19	209.08	209.19	209.08	209.19
mud	18	471906.49	6503060.69	208.75	471906.05	6503061.17	209.17	209.16	209.17	209.16	209.17
mud	19	471904.40	6503061.96	208.73	471904.42	6503061.66	209.13	209.07	209.13	209.07	209.13
Mamawi_WL	20	471902.70	6503062.64	208.72	471903.04	6503062.74	209.07	208.94	209.07	208.94	209.07
tree_height:3.80	103	471935.95	6502980.70	209.77	471935.72	6502980.32	210.07	209.97	210.07	209.97	210.07
tree_height:4.08	104	471944.21	6502983.91	209.72	471944.68	6502984.44	210.14	210.07	210.14	210.07	210.14
tree_height:4.46	105	471945.42	6503032.02	209.68	471945.36	6503032.15	210.22	210.16	210.22	210.16	210.22

Dog Camp – Comparison of Survey Points with LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

Survey Points						LiDAR Points						
								UCL		ACL		MCL
Cover Type	Site	ID	Easting	Northing	Elev	Easting	Northing	Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
Grass/Low_brush	1	1	481785.03	6501416.90	220.10	481784.92	6501416.60	217.40	217.28			
Grass/Low_brush	1	3	481787.05	6501411.81	219.24	481787.13	6501412.09	216.01	215.96			
Grass/Low_brush	1	4	481783.62	6501414.46	219.70	481783.49	6501414.71	220.68	220.58			
Bedrock	2	5	481790.65	6501411.76	219.00	481790.23	6501412.20	216.29	216.15			
Dead_willow,bush	3	6	481799.49	6501402.68	215.82	481799.67	6501402.64	218.10	217.95			
Dead_willow,bush	3	7	481798.19	6501399.92	215.39	481798.10	6501399.61	217.36	217.26			
Dead_willow,bush	3	9	481795.22	6501396.90	214.86	481794.94	6501397.22	217.22	217.09			
Poplar_edge,bush	4	10	481846.47	6501403.90	210.97	481846.33	6501403.90	211.72	211.64	211.72	211.64	
Poplar_edge,bush	4	11	481848.25	6501405.27	210.73	481848.47	6501405.50	211.74	211.60	211.74	211.60	
Poplar_edge,bush	4	13	481844.36	6501400.69	210.88	481844.53	6501401.15	211.79	211.65	211.79	211.65	
Dead&live_willow	5	14	481830.25	6501385.00	210.79	481829.53	6501385.15	211.16	223.24	211.16	223.24	
Dead&live_willow	5	15	481832.10	6501384.22	210.67	481831.81	6501384.15	211.72	211.58	211.72	211.58	
Dead&live_willow	5	16	481830.34	6501383.26	210.89	481830.58	6501383.06	211.57	211.43	211.57	211.43	
Dead&live_willow	5	17	481826.14	6501379.82	210.95	481826.03	6501379.34	211.86	219.69			
Dead&live_willow	5	18	481824.45	6501375.05	210.88	481824.51	6501375.32	210.97	210.87	210.97	210.87	
Sparse_Willow	6	20	481817.13	6501362.53	211.43	481817.22	6501362.13	211.20	211.11	211.20	211.11	
Sparse_Willow	6	21	481816.91	6501359.96	211.28	481817.32	6501360.07	212.90	212.85			
Grass	7	22	481801.23	6501358.23	211.40	481801.03	6501358.16	211.32	216.93			
Grass	7	23	481794.33	6501360.58	211.34	481794.15	6501360.41	219.26	219.14			
Tall_Willow	8	26	481752.90	6501383.73	210.36	481753.18	6501383.93	216.57	216.46			
Tall_Willow	8	27	481751.52	6501380.66	210.10	481751.60	6501381.21	216.30	216.19			
Tall_Willow	8	28	481751.64	6501379.28	210.14	481751.57	6501379.77	213.13	213.09			
Bedrock	BM	DCQU	481765.00	6501422.21	223.05	481764.65	6501422.33	211.52	211.41	211.52	211.41	211.52

Duck Lake – Comparison of NHRC Survey Points with LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

NHRC Survey Points				LiDAR Points						
						UCL		ACL		MCL
ID	Easting	Northing	Elev	Easting	Northing	Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
ND55	477276.13	6506319.79	210.45	477276.90	6506318.98	211.03	217.71	211.03	217.71	211.03
ND56	477322.43	6506350.79	210.75	477325.55	6506350.52	214.78	214.72			
SD52	477461.13	6505316.79	210.46	477462.49	6505317.07	211.04	218.59	211.04	218.59	211.04
DL52	477962.85	6504623.79	211.70	477963.41	6504623.55	212.20	230.95			
DL53	477904.35	6504603.79	210.69	477904.40	6504604.34	210.99	218.82	210.99	218.82	210.99
DL54	477832.44	6504574.79	210.19	477833.13	6504573.81	210.83	210.70	210.83	210.74	

Comparison of Benchmarks with LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

Survey Points				LiDAR Points						
						UCL		ACL		MCL
ID	Easting	Northing	Elev	Easting	Northing	Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
EL01	475896.53	6528648.42	211.82	475896.83	6528648.77	211.56	211.53			
EL03	474101.67	6530759.37	217.82	474101.06	6530759.30	214.78	214.69	214.78	214.69	
61A012	484476.57	6515936.30	211.16	484476.41	6515935.89	210.07	209.91	210.07	209.91	210.07
DCIS	481643.50	6501172.86	211.35	481643.81	6501173.30	210.67	210.59	210.67	210.59	

APPENDIX 6

DIFFERENCE BETWEEN SURVEY AND LIDAR POINTS

Jemis Lake – Difference between Survey and LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

A positive difference value indicates that the LiDAR elevation is higher than the surveyed.

		Horizontal Distance Between Points	Difference in Elevation…				
			UCL-Survey		ACL-Survey		MCL-Survey
Cover Type	ID		Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
grass	JBM1	0.56	0.56	0.47	0.56	0.47	0.56
grass	1001	0.70	0.45	0.35	0.45	0.35	0.45
grass	1002	0.66	0.56	0.41	0.56	0.41	0.56
grass	1004	0.09	0.46	0.37	0.46	0.37	0.46
grass	1005	0.19	0.54	0.48	0.54	0.48	0.54
grass	1007	0.21	0.71	0.63	0.71	0.63	0.71
grass	1009	0.52	1.02	0.90			
willow_edge	1012	0.39	0.52	0.43	0.52	0.43	0.52
willow	1015	0.28	6.33	6.21			
willow	1017	0.22	4.81	4.77			
willow	1018	0.55	5.30	5.23			
willow	1019	0.40	0.65	6.98	0.65	6.98	
willow	1021	0.25	6.54	6.54			
willow	1022	0.53	7.08	7.00			
willow	1024	0.33	0.42	5.19	0.42	5.19	
grass	1026	0.20	2.36	2.30			
grass	1028	0.10	3.52	3.40			
grass	1031	0.64	0.37	0.27	0.37	0.27	0.37
grass	1032	0.31	0.24	0.17	0.24	0.17	0.24
grass	1034	0.81	0.37	0.25	0.37	0.25	0.37
grass	1035	0.51	1.61	1.51			
grass	1036	0.43	2.70	2.56			
grass	1037	0.72	0.51	0.43	0.51	0.43	0.51
grass	1038	0.95	3.66	3.59			
grass	1039	1.03	0.79	5.51	0.79	5.51	
grass	1040	1.05	0.72	0.62	0.72	0.62	
grass	1041	0.66	3.78	3.74			
grass	1043	0.34	5.54	5.47			
grass	1044	0.21	0.66	0.59	0.66	0.59	0.66
grass	1045	0.11	0.64	0.55	0.64	0.55	0.64
grass	1046	0.62	0.69	0.58	0.69	0.58	0.69
grass	1047	0.43	0.40	0.33	0.40	0.33	0.40
grass	1048	0.41	0.52	0.39	0.52	0.39	0.52
grass	1049	0.32	0.48	0.37	0.48	0.37	0.48
JBIP	1051	0.32	0.62	0.48	0.62	0.48	0.62
willow_edge	1	0.87	0.47	0.42	0.47	0.42	0.47
grass	2	0.47	0.43	0.33	0.43	0.33	0.43
grass	5	0.37	0.67	0.52	0.67	0.52	0.67
grass	6	0.54	0.69	0.61	0.69	0.61	
grass	7	0.39	0.63	0.51	0.63	0.51	
grass	10	0.52	0.71	0.62	0.71	0.62	

Jemis Lake - Continued…

		Horizontal Distance Between Points	Difference in Elevation…				
			UCL-Survey		ACL-Survey		MCL-Survey
Cover Type	ID		Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
top_of_bank	11	0.75	0.62	0.52	0.62	0.52	
mud	17	0.69	0.41	0.30	0.41	0.30	0.41
mud	18	0.65	0.42	0.41	0.42	0.41	0.42
mud	19	0.30	0.40	0.34	0.40	0.34	0.40
Mamawi_WL	20	0.36	0.35	0.22	0.35	0.22	0.35
tree_height:3.80	103	0.44	0.30	0.20	0.30	0.20	0.30
tree_height:4.08	104	0.71	0.42	0.35	0.42	0.35	0.42
tree_height:4.46	105	0.14	0.54	0.48	0.54	0.48	0.54

Dog Camp – Difference between Survey and LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

A positive difference value indicates that the LiDAR elevation is higher than the surveyed.

			Horizontal Distance Between Points	Difference in Elevation…				
				UCL-Survey		ACL-Survey		MCL-Survey
Cover Type	Site	ID		Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
Grass/Low_brush	1	1	0.32	-2.70	-2.82			
Grass/Low_brush	1	3	0.29	-3.23	-3.28			
Grass/Low_brush	1	4	0.28	0.98	0.88			
Bedrock	2	5	0.61	-2.71	-2.85			
Dead_willow,bush	3	6	0.18	2.28	2.13			
Dead_willow,bush	3	7	0.32	1.97	1.87			
Dead_willow,bush	3	9	0.43	2.36	2.23			
Poplar_edge,bush	4	10	0.14	0.75	0.67	0.75	0.67	
Poplar_edge,bush	4	11	0.32	1.01	0.87	1.01	0.87	
Poplar_edge,bush	4	13	0.49	0.91	0.77	0.91	0.77	
Dead&live_willow	5	14	0.74	0.37	12.45	0.37	12.45	
Dead&live_willow	5	15	0.30	1.05	0.91	1.05	0.91	
Dead&live_willow	5	16	0.31	0.68	0.54	0.68	0.54	
Dead&live_willow	5	17	0.49	0.91	8.74			
Dead&live_willow	5	18	0.28	0.09	-0.01	0.09	-0.01	
Sparse_Willow	6	20	0.41	-0.23	-0.32	-0.23	-0.32	
Sparse_Willow	6	21	0.42	1.62	1.57			
Grass	7	22	0.21	-0.08	5.53			
Grass	7	23	0.25	7.92	7.8			
Tall_Willow	8	26	0.34	6.21	6.1			
Tall_Willow	8	27	0.56	6.20	6.09			
Tall_Willow	8	28	0.49	2.99	2.95			
Bedrock	BM	DCQU	0.37	-11.53	-11.64	-11.53	-11.64	-11.53

Duck Lake – Difference between NHRC Survey and LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

A positive difference value indicates that the LiDAR elevation is higher than the surveyed.

NHRC Survey Point ID	Horizontal Distance Between Points	Difference in Elevation…				
		UCL-Survey		ACL-Survey		MCL-Survey
		Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
ND55	1.12	0.59	7.27	0.59	7.27	0.59
ND56	3.13	4.03	3.97			
SD52	1.38	0.58	8.13	0.58	8.13	0.58
DL52	0.61	0.50	19.25			
DL53	0.55	0.30	8.13	0.30	8.13	0.30
DL54	1.20	0.65	0.51	0.65	0.56	

	Difference in Elevation…				
	UCL-Survey		ACL-Survey		MCL-Survey
	Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
Minimum	0.30	0.51	0.30	0.56	0.30
Maximum	4.03	19.25	0.65	8.13	0.59
Mean	1.11	7.88	0.53	6.02	0.49
Stdv	1.44	6.31	0.16	3.67	0.17

Difference between Benchmarks and LiDAR Points

All values are in metres and in UTM 12V WGS84 projection.

Elev 1 values represent ground elevation.

A positive difference value indicates that the LiDAR elevation is higher than the benchmark elevation. All benchmarks are located on bedrock outcrops.

	Horizontal Distance Between Points	Difference in Elevation…				
		UCL-Survey		ACL-Survey		MCL-Survey
ID		Elev 1	Elev 2	Elev 1	Elev 2	Elev 1
EL01	0.46	-0.26	-0.29			
EL03	0.61	-3.04	-3.13	-3.04	-3.13	
61A012	0.44	-1.09	-1.25	-1.09	-1.25	-1.09
DCIS	0.54	-0.68	-0.76	-0.68	-0.76	

APPENDIX 7

DOG CAMP – DIFFERENCE BETWEEN SURVEY ELEVATIONS AND GRIDDED LIDAR ELEVATIONS

Dog Camp – The Difference between Survey Elevations and Gridded LiDAR Elevations

The LiDAR data were gridded to 2m grid cells using Kriging (in Surfer).

All values are in metres. A positive difference value indicates that the gridded LiDAR elevation is higher than the surveyed elevation.

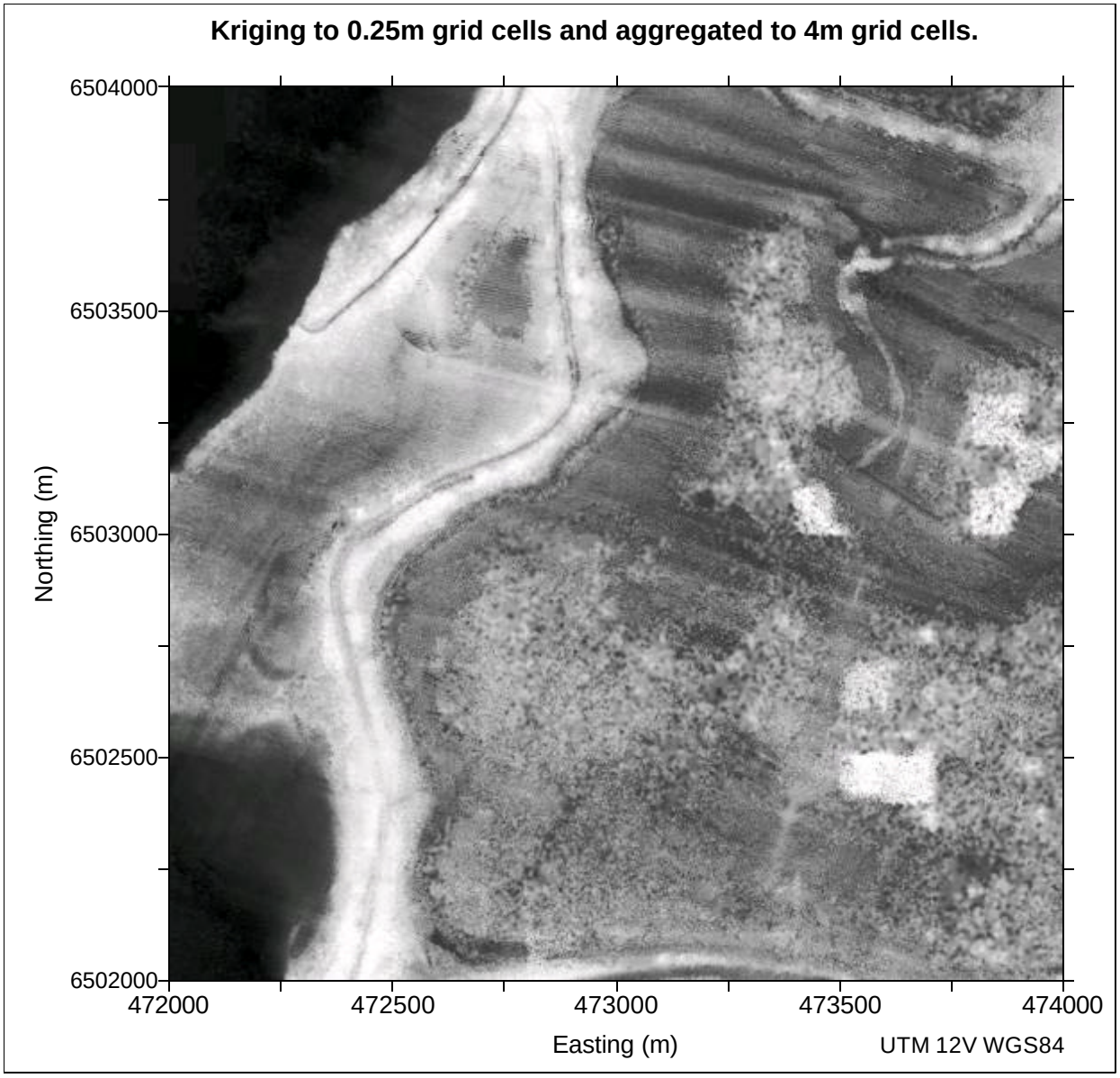
				Gridded LiDAR Data		Difference in Elevation…	
Survey Points				ACL	MCL	ACL-Survey	MCL-Survey
Cover Type	Site	ID	Elev	Elev	Elev	Difference	Difference
Grass/Low_brush	1	1	220.10	215.45	211.17	-4.65	-8.93
Grass/Low_brush	1	2	219.55	215.35	211.04	-4.20	-8.51
Grass/Low_brush	1	3	219.24	215.35	211.04	-3.89	-8.20
Grass/Low_brush	1	4	219.70	215.82	211.11	-3.88	-8.59
Bedrock	2	5	219.00	213.67	210.96	-5.33	-8.04
Dead_willow,bush	3	6	215.82	212.56	210.98	-3.26	-4.84
Dead_willow,bush	3	7	215.39	211.94	210.90	-3.45	-4.49
Dead_willow,bush	3	8	214.99	211.33	210.93	-3.66	-4.06
Dead_willow,bush	3	9	214.86	210.77	210.84	-4.09	-4.02
Poplar_edge,bush	4	10	210.97	211.72	210.40	0.75	-0.57
Poplar_edge,bush	4	11	210.73	211.74	210.44	1.01	-0.29
Poplar_edge,bush	4	12	210.77	211.31	210.35	0.54	-0.42
Poplar_edge,bush	4	13	210.88	211.79	210.29	0.91	-0.59
Dead&live_willow	5	14	210.79	211.16	210.36	0.37	-0.43
Dead&live_willow	5	15	210.67	211.72	210.36	1.05	-0.31
Dead&live_willow	5	16	210.89	211.57	210.35	0.68	-0.54
Dead&live_willow	5	17	210.95	211.57	210.35	0.62	-0.60
Dead&live_willow	5	18	210.88	210.97	210.30	0.09	-0.58
Sparse_Willow	6	19	211.38	211.20	209.88	-0.18	-1.50
Sparse_Willow	6	20	211.43	211.20	209.90	-0.23	-1.53
Sparse_Willow	6	21	211.28	211.12	209.84	-0.16	-1.44
Grass	7	22	211.40	211.02	211.01	-0.38	-0.39
Grass	7	23	211.34	210.96	211.01	-0.38	-0.33
Grass	7	24	211.30	210.91	210.99	-0.39	-0.31
Grass	7	25	211.31	210.78	210.77	-0.53	-0.54
Tall_Willow	8	26	210.36	210.43	210.43	0.07	0.07
Tall_Willow	8	27	210.10	210.62	210.49	0.52	0.39
Tall_Willow	8	28	210.14	210.75	210.49	0.61	0.35
Bedrock	9	DCQU	223.05	211.52	211.50	-11.53	-11.55

	ACL-Survey	MCL-Survey
	Difference	Difference
Minimum	-11.53	-11.55
Maximum	1.05	0.39
Mean	-1.48	-2.79
Stdv	2.84	3.55

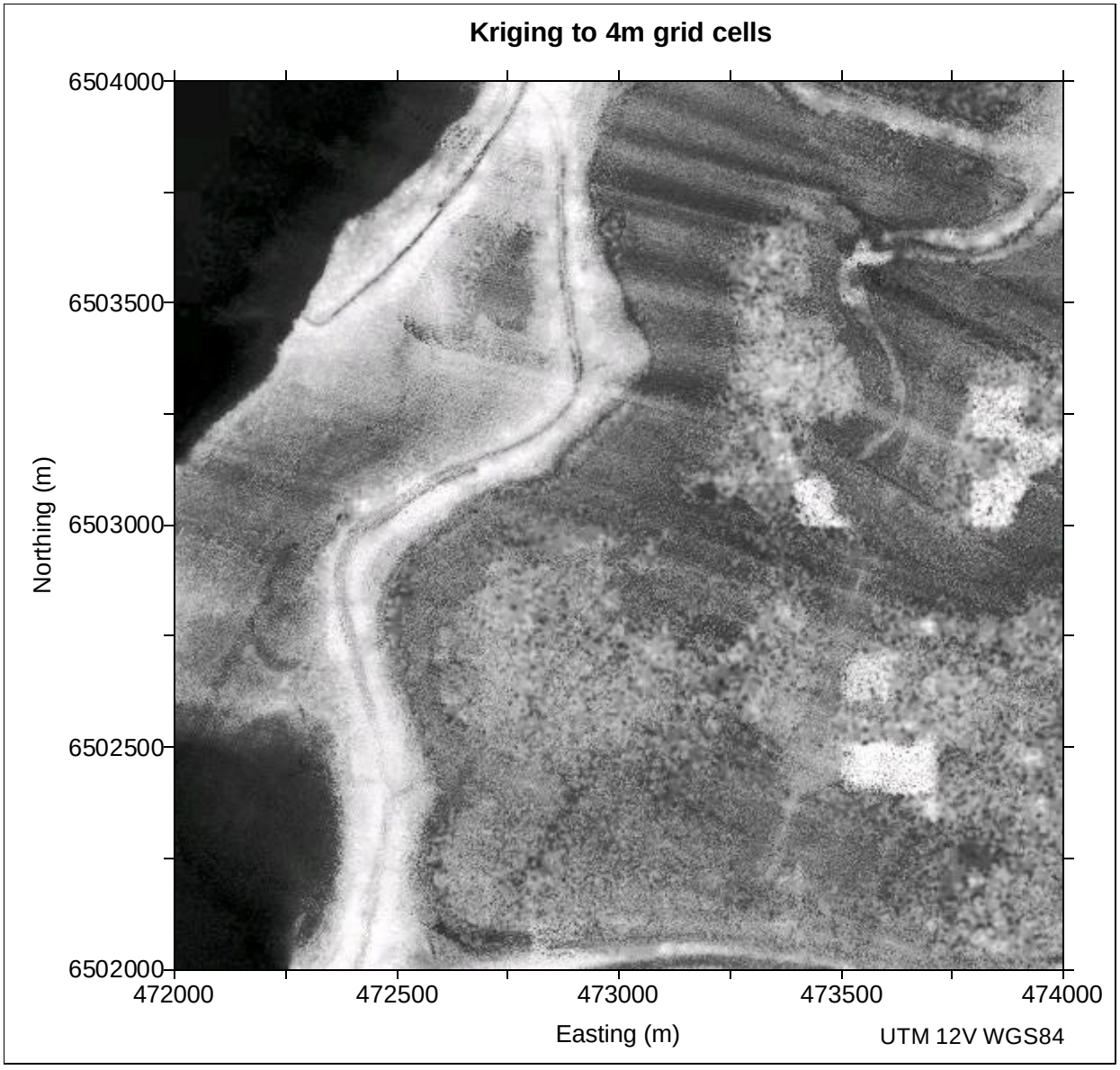
APPENDIX 8

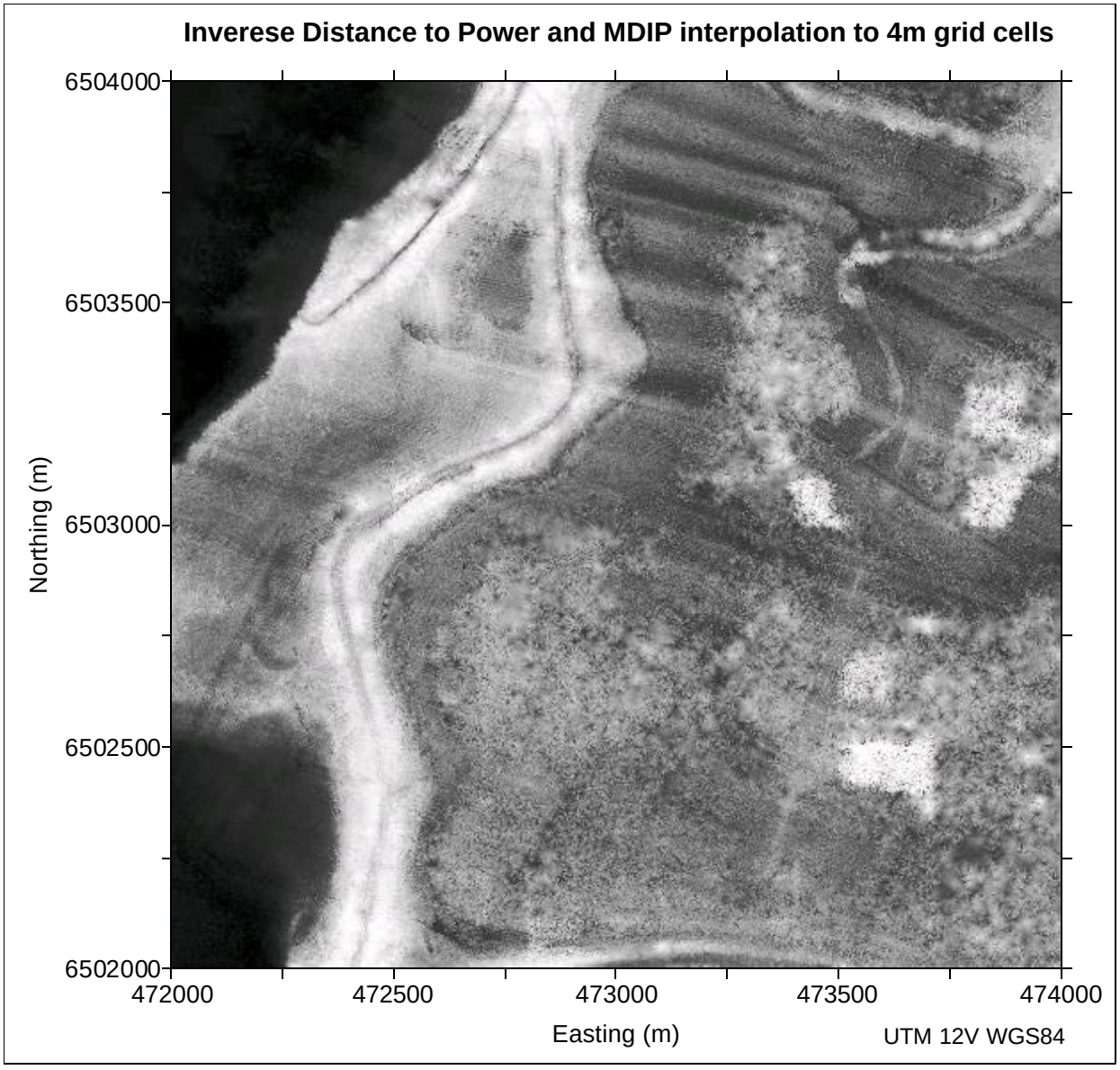
MCL DATA IN PATCH FILE 224726502.GRD (JEMIS LAKE) INTERPOLATED INTO 4M GRIDS BY FIVE DIFFERENT ALGORITHMS

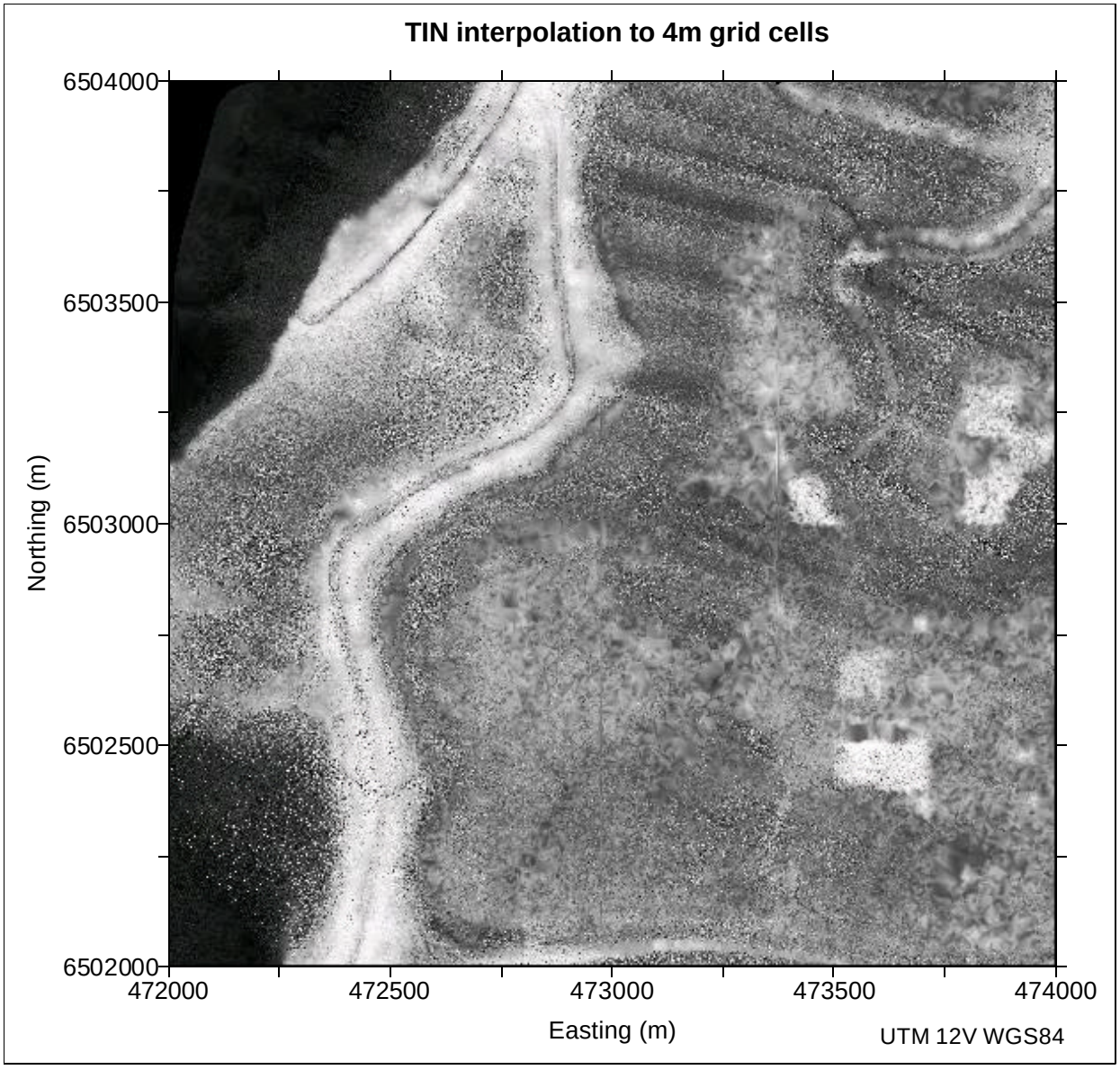
(IKONOS IMAGE OF AREA IS ALSO SHOWN)


Kriging to 0.25m grid cells and aggregated to 4m grid cells.
6504000
6503500
6503000
6502500
6502000
Northing (m)
472000
472500
473000
473500
474000
Easting (m)
UTM 12V WGS84


Values burnt in to 0.25m grid cells, interpolated using MDIP
and aggregated to 4m grid cells.
6504000
6503500
6503000
6502500
6502000
Northing (m)
472000
472500
473000
473500
474000
Easting (m)
UTM 12V WGS84

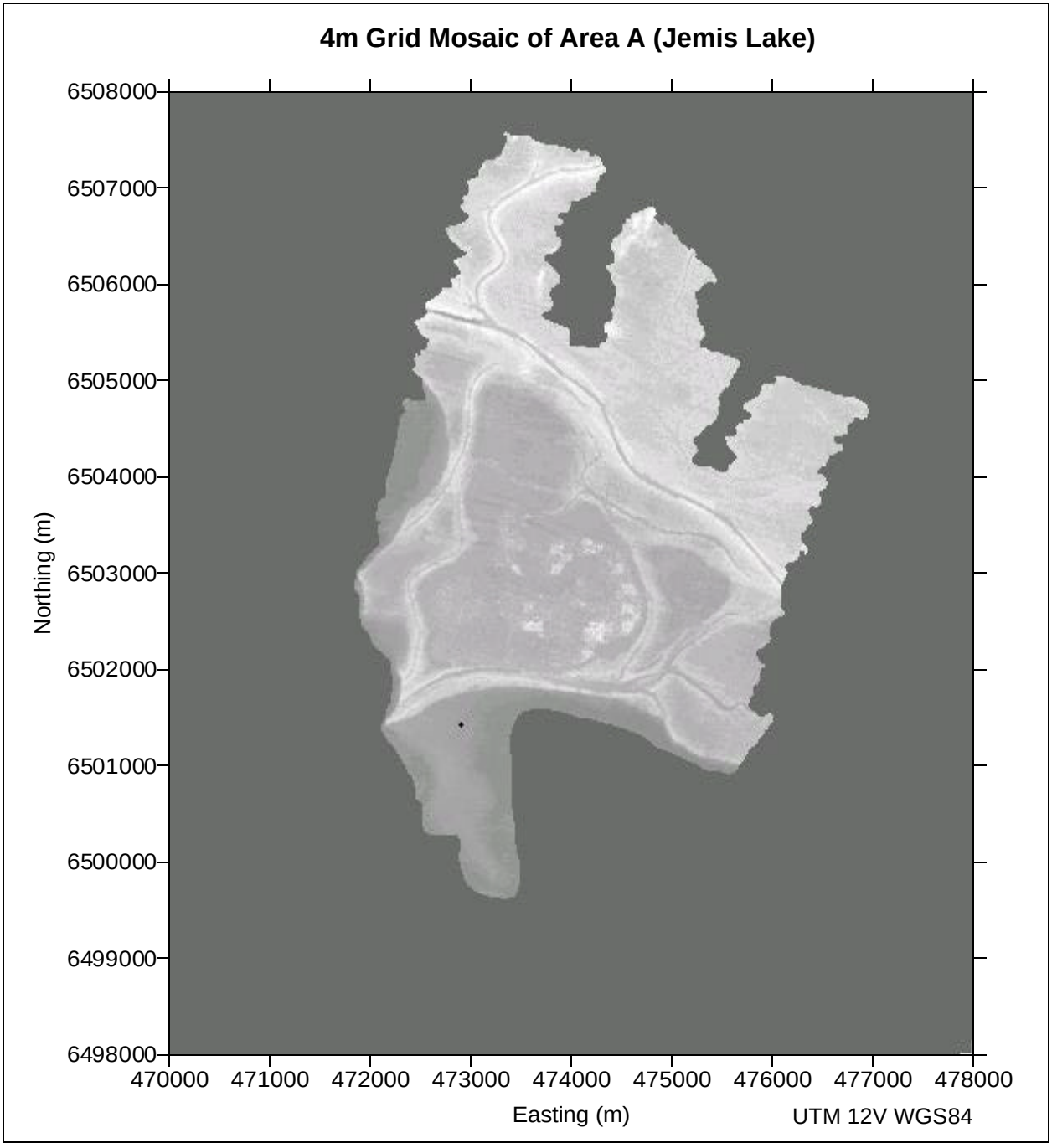

Kriging to 4m grid cells
6504000
6503500
6503000
6502500
6502000
Northing (m)
472000
472500
473000
473500
474000
Easting (m)
UTM 12V WGS84

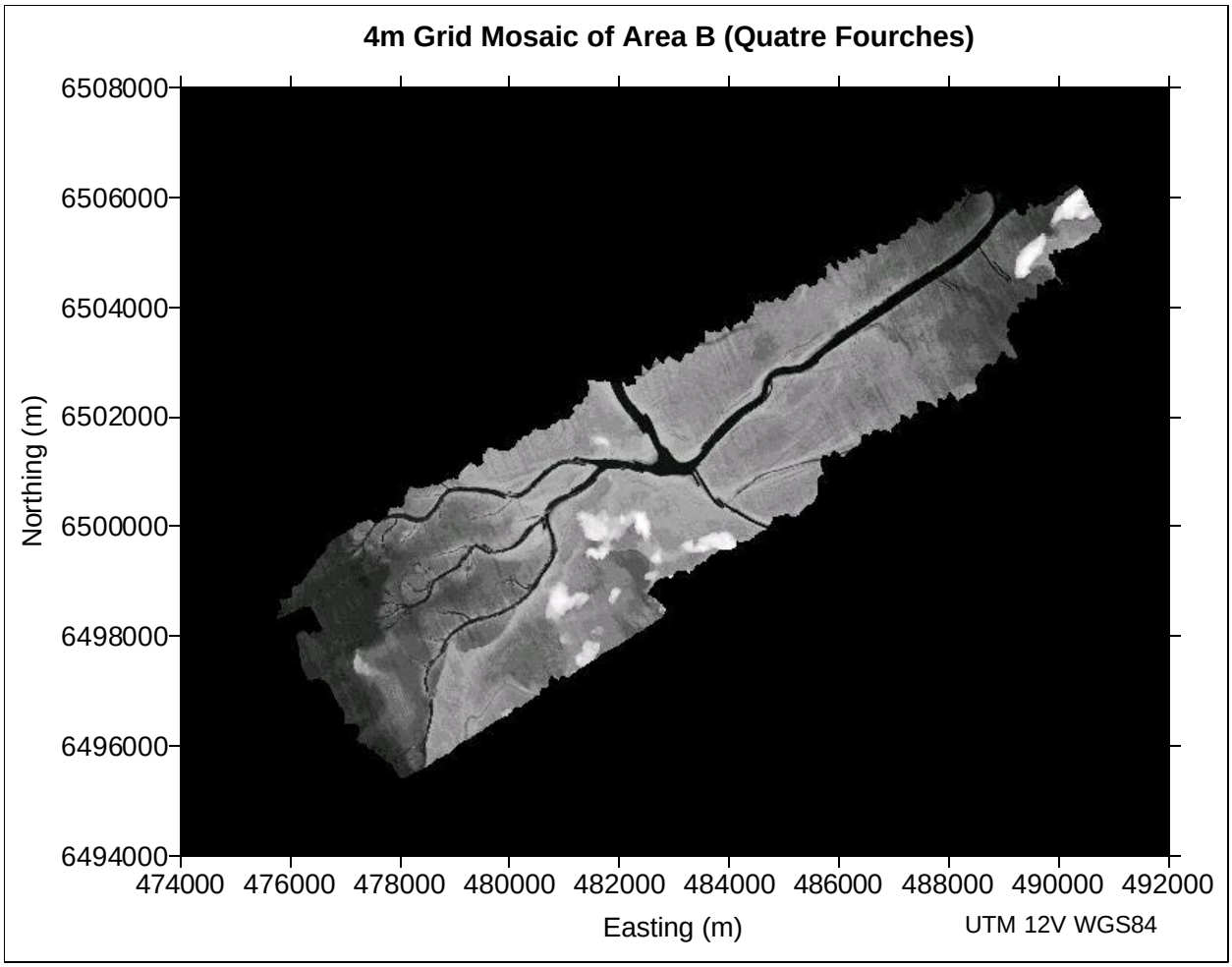

Inverese Distance to Power and MDIP interpolation to 4m grid cells
6504000
6503500
6503000
6502500
6502000
Northing (m)
472000
472500
473000
473500
474000
Easting (m)
UTM 12V WGS84

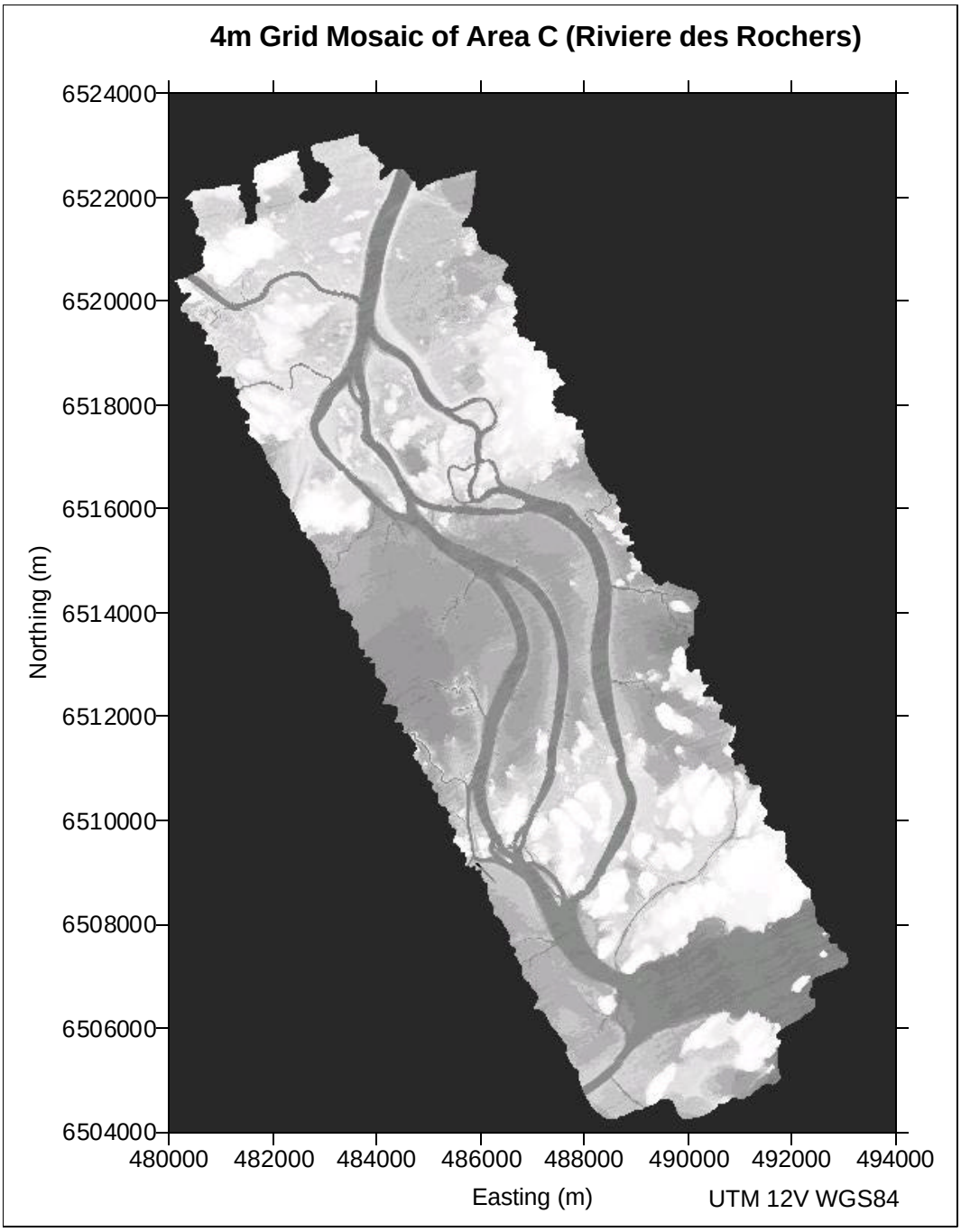

TIN interpolation to 4m grid cells
6504000
6503500
6503000
6502500
6502000
Northing (m)
472000
472500
473000
473500
474000
Easting (m)
UTM 12V WGS84

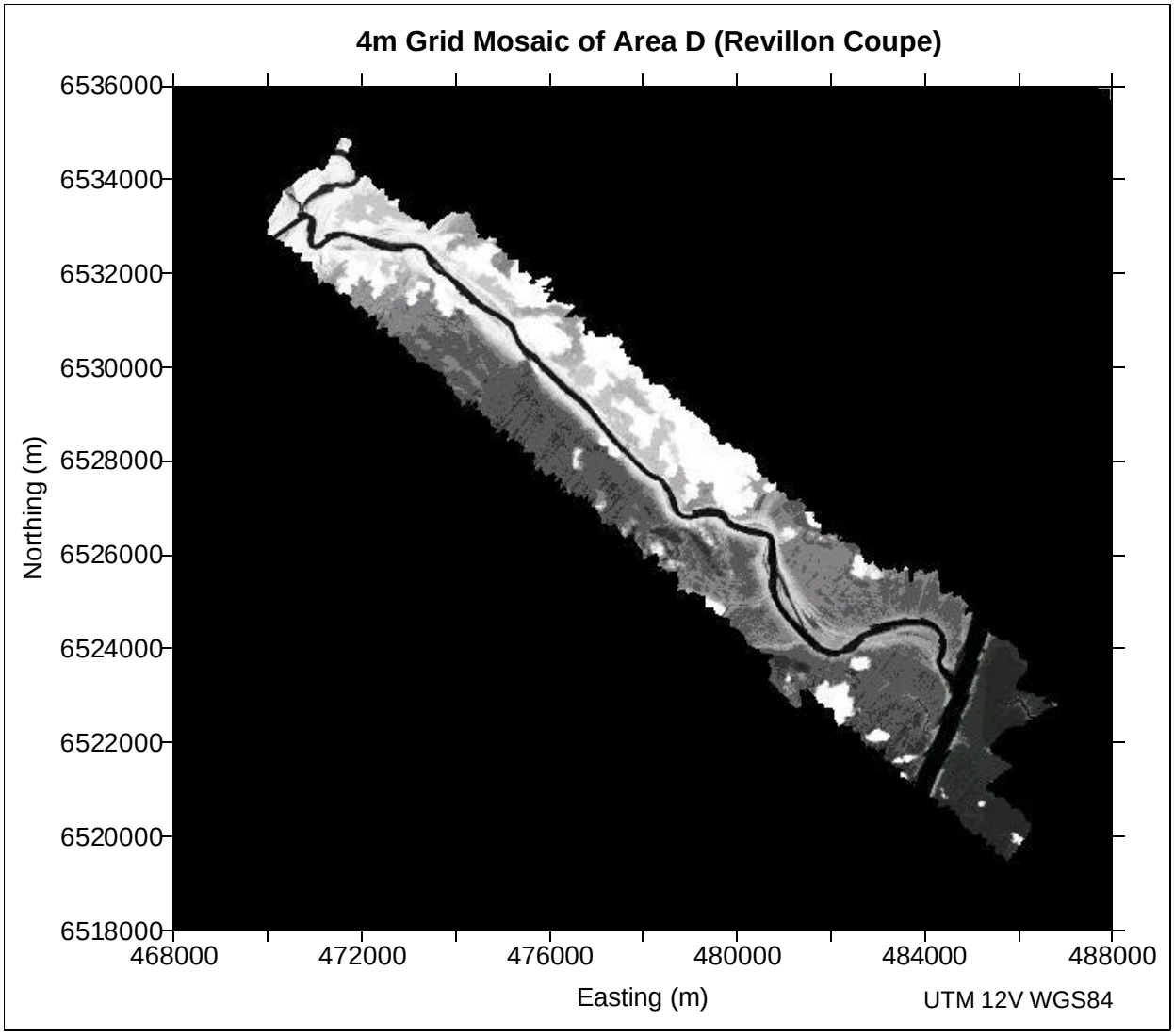
APPENDIX 9

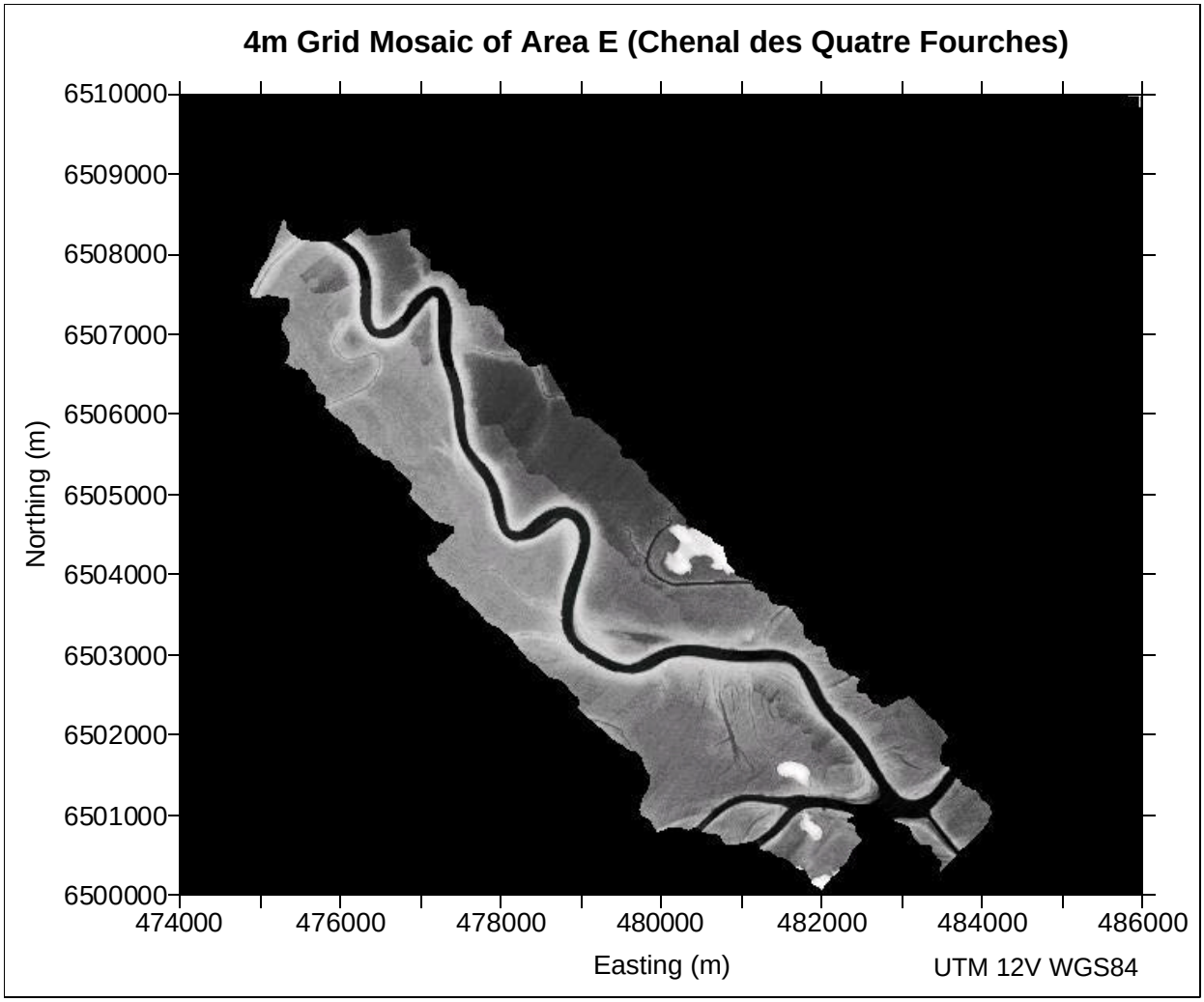
GRID MOSAICS

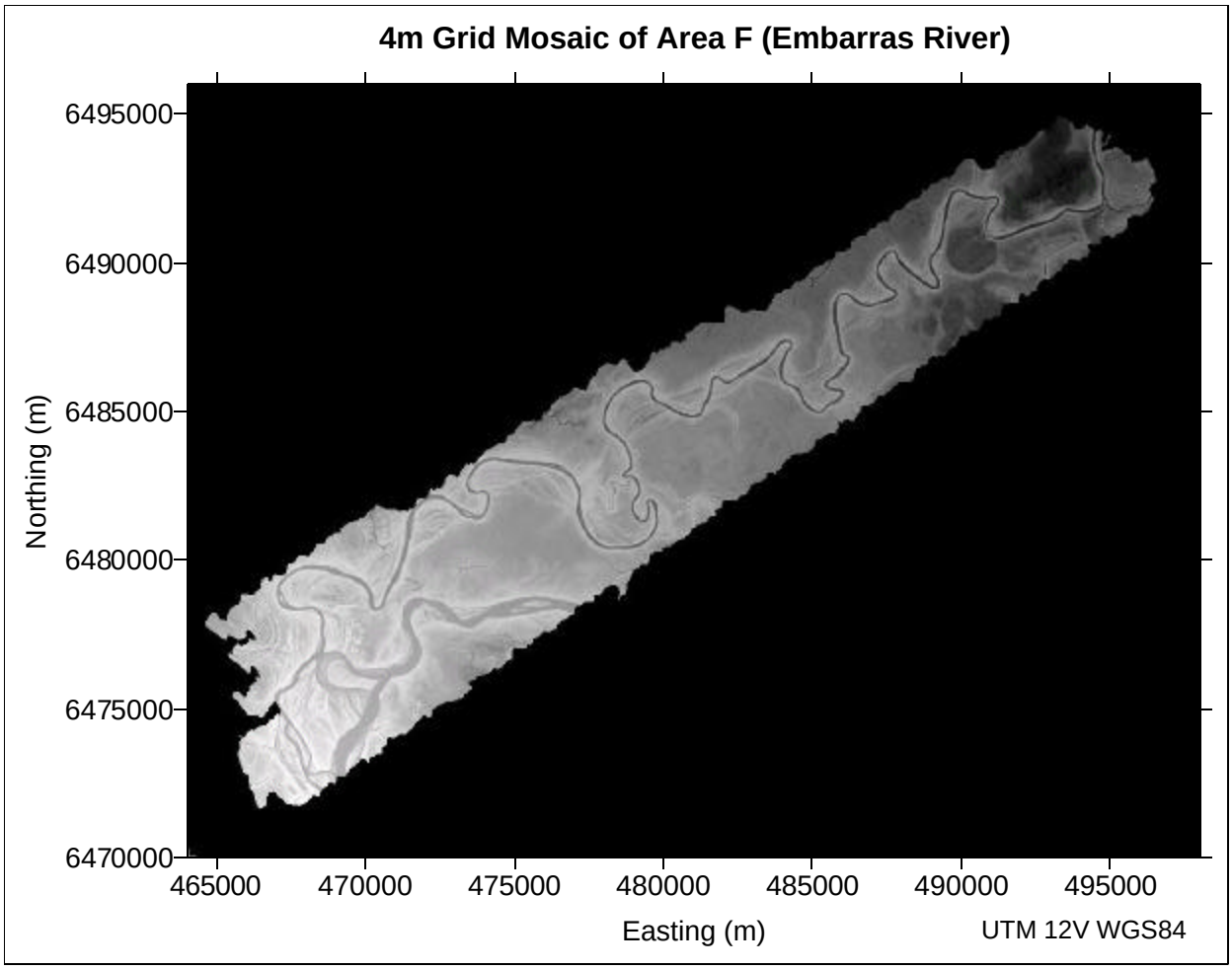

4m Grid Mosaic of Area A (Jemis Lake)
6508000
6507000
6506000
6505000
6504000
6503000
6502000
6501000
6500000
6499000
6498000
Northing (m)
470000
471000
472000
473000
474000
475000
476000
477000
478000
Easting (m)
UTM 12V WGS84

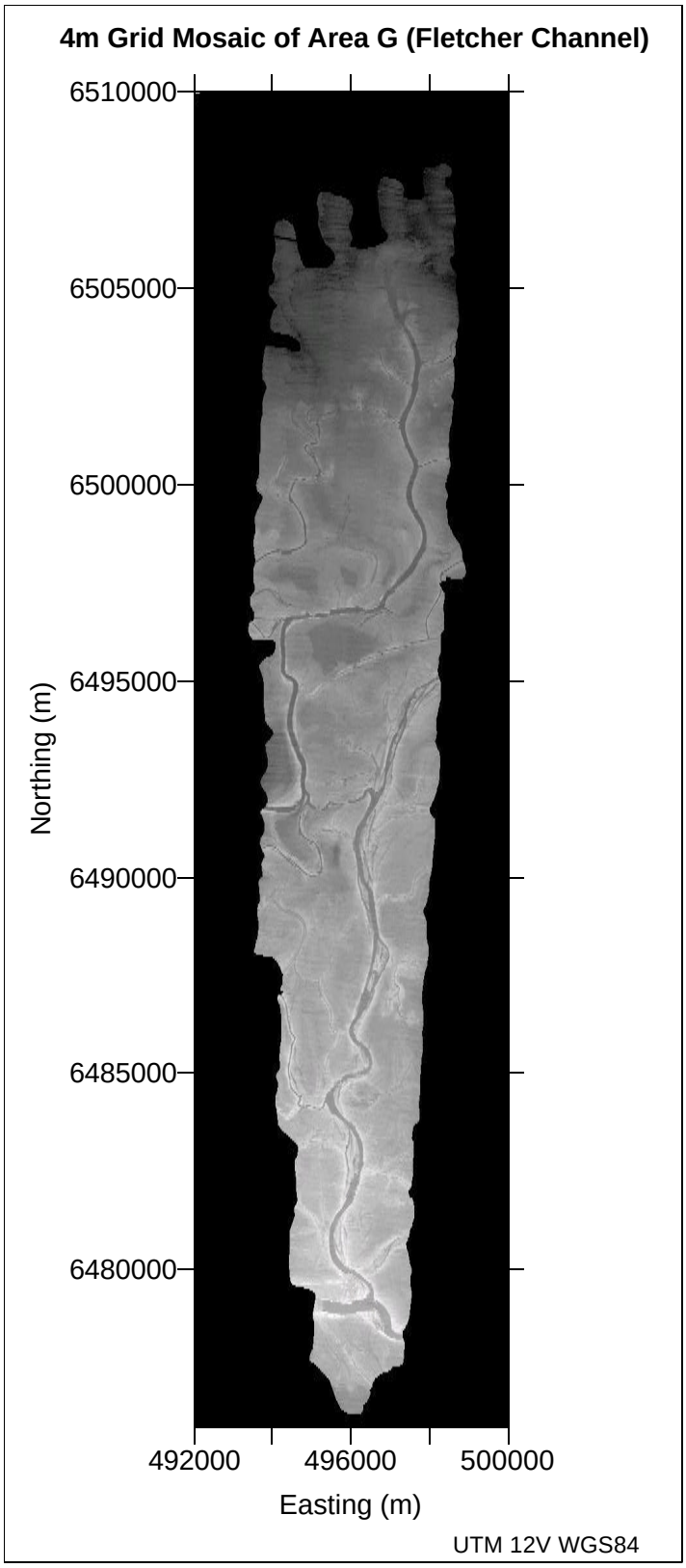

4m Grid Mosaic of Area B (Quatre Fourches)
6508000
6506000
6504000
6502000
6500000
6498000
6496000
6494000
Northing (m)
474000
476000
478000
480000
482000
484000
486000
488000
490000
492000
Easting (m)
UTM 12V WGS84


4m Grid Mosaic of Area C (Riviere des Rochers)
6524000
6522000
6520000
6518000
6516000
6514000
6512000
6510000
6508000
6506000
6504000
Northing (m)
480000
482000
484000
486000
488000
490000
492000
494000
Easting (m)
UTM 12V WGS84


4m Grid Mosaic of Area D (Revillon Coupe)
6536000
6534000
6532000
6530000
6528000
6526000
6524000
6522000
6520000
6518000
Northing (m)
468000
472000
476000
480000
484000
488000
Easting (m)
UTM 12V WGS84


4m Grid Mosaic of Area E (Chenal des Quatre Fourches)
6510000
6509000
6508000
6507000
6506000
6505000
6504000
6503000
6502000
6501000
6500000
Northing (m)
474000
476000
478000
480000
482000
484000
486000
Easting (m)
UTM 12V WGS84


4m Grid Mosaic of Area F (Embarras River)
6495000
6490000
6485000
6480000
6475000
6470000
Northing (m)
465000
470000
475000
480000
485000
490000
495000
Easting (m)
UTM 12V WGS84


4m Grid Mosaic of Area G (Fletcher Channel)
6510000
6505000
6500000
6495000
6490000
6485000
6480000
Northing (m)
492000
496000
500000
Easting (m)
UTM 12V WGS84

APPENDIX 10

COMPARISON OF SURVEY POINTS WITH 4M LIDAR GRIDS

Comparison of Survey Points with 4m LiDAR Grids

All values are in metres and in UTM 12V WGS84 projection.

A positive difference value indicates that the gridded LiDAR elevation is higher than the surveyed elevation.

		Survey Points				4m Grid	Difference in Elev.
Area	LiDAR Area	ID	Site	Cover Type	Elevation	Elevation	4m Grid-Survey
Dog Camp	B	1	1	GRASS/LOW_BRUSH	220.10	210.48	-9.62
Dog Camp	B	2	1	GRASS/LOW_BRUSH	219.55	210.41	-9.14
Dog Camp	B	3	1	GRASS/LOW_BRUSH	219.24	210.38	-8.86
Dog Camp	B	4	1	GRASS/LOW_BRUSH	219.70	210.77	-8.93
Dog Camp	B	5	2	BEDROCK	219.00	210.38	-8.62
Dog Camp	B	6	3	DEAD_WILLOW	215.82	210.44	-5.38
Dog Camp	B	7	3	DEAD_WILLOW	215.39	210.41	-4.98
Dog Camp	B	8	3	DEAD_WILLOW	214.99	210.41	-4.58
Dog Camp	B	9	3	DEAD_WILLOW	214.86	210.49	-4.37
Dog Camp	B	10	4	POPLAR_EDGE	210.97	209.93	-1.04
Dog Camp	B	11	4	POPLAR_EDGE	210.73	210.14	-0.59
Dog Camp	B	12	4	POPLAR_EDGE	210.77	209.93	-0.84
Dog Camp	B	13	4	POPLAR_EDGE	210.88	209.93	-0.95
Dog Camp	B	14	5	DEAD&LIVE_WILLOW	210.79	210.01	-0.78
Dog Camp	B	15	5	DEAD&LIVE_WILLOW	210.67	210.01	-0.66
Dog Camp	B	16	5	DEAD&LIVE_WILLOW	210.89	209.99	-0.90
Dog Camp	B	17	5	DEAD&LIVE_WILLOW	210.95	210.00	-0.95
Dog Camp	B	18	5	DEAD&LIVE_WILLOW	210.88	209.89	-0.99
Dog Camp	B	19	6	SPARSE_WILLOW	211.38	209.75	-1.63
Dog Camp	B	20	6	SPARSE_WILLOW	211.43	209.81	-1.62
Dog Camp	B	21	6	SPARSE_WILLOW	211.28	209.82	-1.46
Dog Camp	B	22	7	GRASS	211.40	210.45	-0.95
Dog Camp	B	23	7	GRASS	211.34	210.50	-0.84
Dog Camp	B	24	7	GRASS	211.30	210.50	-0.80
Dog Camp	B	25	7	GRASS	211.31	210.50	-0.81
Dog Camp	B	26	8	TALL_WILLOW	210.36	210.01	-0.35
Dog Camp	B	27	8	TALL_WILLOW	210.10	210.03	-0.07
Dog Camp	B	28	8	TALL_WILLOW	210.14	210.06	-0.08
Dog Camp	B	0	0	BEDROCK	223.05	211.16	-11.89
Dog Camp	E	1	1	GRASS/LOW_BRUSH	220.10	212.80	-7.30
Dog Camp	E	2	1	GRASS/LOW_BRUSH	219.55	212.80	-6.75
Dog Camp	E	3	1	GRASS/LOW_BRUSH	219.24	212.80	-6.44
Dog Camp	E	4	1	GRASS/LOW_BRUSH	219.70	213.20	-6.50
Dog Camp	E	5	2	BEDROCK	219.00	212.80	-6.20
Dog Camp	E	6	3	DEAD_WILLOW	215.82	212.40	-3.42
Dog Camp	E	7	3	DEAD_WILLOW	215.39	212.37	-3.02
Dog Camp	E	8	3	DEAD_WILLOW	214.99	212.37	-2.62
Dog Camp	E	9	3	DEAD_WILLOW	214.86	212.80	-2.06
Dog Camp	E	10	4	POPLAR_EDGE	210.97	210.62	-0.35
Dog Camp	E	11	4	POPLAR_EDGE	210.73	210.47	-0.26
Dog Camp	E	12	4	POPLAR_EDGE	210.77	210.62	-0.15

Continued…

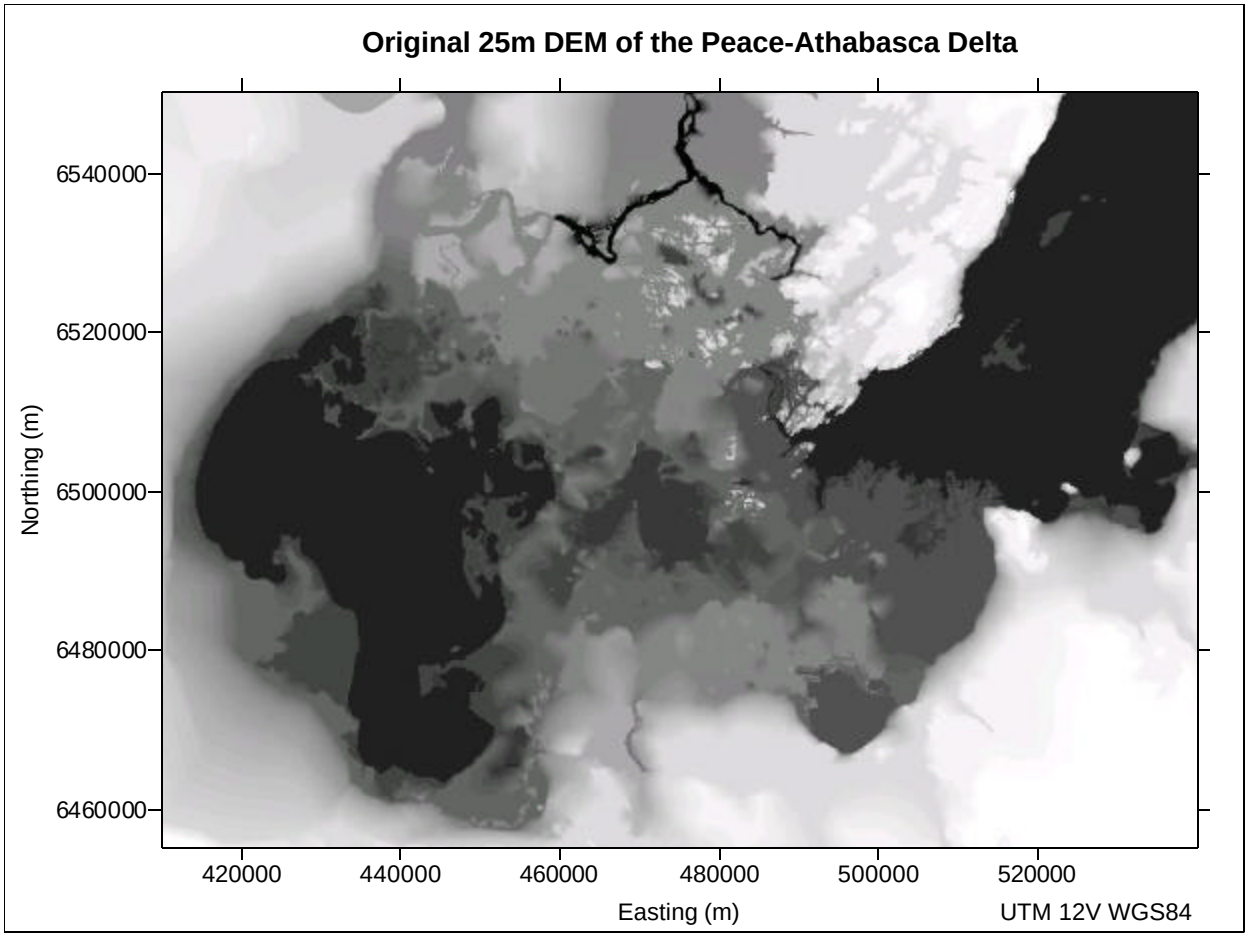
		Survey Points				4m Grid	Difference in Elev.
Area	LiDAR Area	ID	Site	Cover Type	Elevation	Elevation	4m Grid-Survey
Dog Camp	E	13	4	POPLAR_EDGE	210.88	210.62	-0.26
Dog Camp	E	14	5	DEAD&LIVE_WILLOW	210.79	210.92	0.13
Dog Camp	E	15	5	DEAD&LIVE_WILLOW	210.67	210.69	0.02
Dog Camp	E	16	5	DEAD&LIVE_WILLOW	210.89	211.05	0.16
Dog Camp	E	17	5	DEAD&LIVE_WILLOW	210.95	211.00	0.05
Dog Camp	E	18	5	DEAD&LIVE_WILLOW	210.88	211.03	0.15
Dog Camp	E	19	6	SPARSE_WILLOW	211.38	211.19	-0.19
Dog Camp	E	20	6	SPARSE_WILLOW	211.43	211.02	-0.41
Dog Camp	E	21	6	SPARSE_WILLOW	211.28	210.88	-0.40
Dog Camp	E	22	7	GRASS	211.40	211.21	-0.19
Dog Camp	E	23	7	GRASS	211.34	211.17	-0.17
Dog Camp	E	24	7	GRASS	211.30	211.17	-0.13
Dog Camp	E	25	7	GRASS	211.31	211.17	-0.14
Dog Camp	E	26	8	TALL_WILLOW	210.36	210.42	0.06
Dog Camp	E	27	8	TALL_WILLOW	210.10	210.31	0.21
Dog Camp	E	28	8	TALL_WILLOW	210.14	210.17	0.03
Dog Camp	E	0	0	BEDROCK	223.05	214.09	-8.96
Duck	E	DL52		WILLOW	211.70	210.58	-1.12
Duck	E	DL53		WILLOW	210.69	210.98	0.29
Duck	E	DL54		WILLOW	210.19	210.29	0.10
Duck	E	SD52		WILLOW	210.46	210.62	0.16
Duck	E	ND55		WILLOW	210.45	210.63	0.19
Duck	E	ND56		WILLOW	210.75	211.29	0.54
Jemis	A	JBM1		GRASS	209.67	209.78	0.11
Jemis	A	1001		GRASS	209.72	209.72	0.00
Jemis	A	1002		GRASS	209.76	209.78	0.02
Jemis	A	1004		GRASS	209.79	209.79	0.00
Jemis	A	1005		GRASS	209.78	209.85	0.07
Jemis	A	1007		GRASS	209.76	209.95	0.19
Jemis	A	1009		GRASS	209.85	210.01	0.16
Jemis	A	1012		WILLOW_EDGE	209.95	210.08	0.13
Jemis	A	1015		WILLOW	209.96	209.96	0.00
Jemis	A	1017		WILLOW	209.99	209.88	-0.11
Jemis	A	1018		WILLOW	209.96	209.89	-0.07
Jemis	A	1019		WILLOW	210.02	209.77	-0.25
Jemis	A	1021		WILLOW	210.00	209.65	-0.35
Jemis	A	1022		WILLOW	209.98	209.54	-0.44
Jemis	A	1024		WILLOW	209.99	209.50	-0.49
Jemis	A	1026		GRASS	209.98	209.91	-0.07
Jemis	A	1028		GRASS	209.99	209.94	-0.05
Jemis	A	1031		GRASS	209.98	209.95	-0.03
Jemis	A	1032		GRASS	209.99	209.95	-0.04
Jemis	A	1034		GRASS	210.01	209.89	-0.12
Jemis	A	1035		GRASS	209.96	209.96	0.00
Jemis	A	1036		GRASS	209.93	209.96	0.03

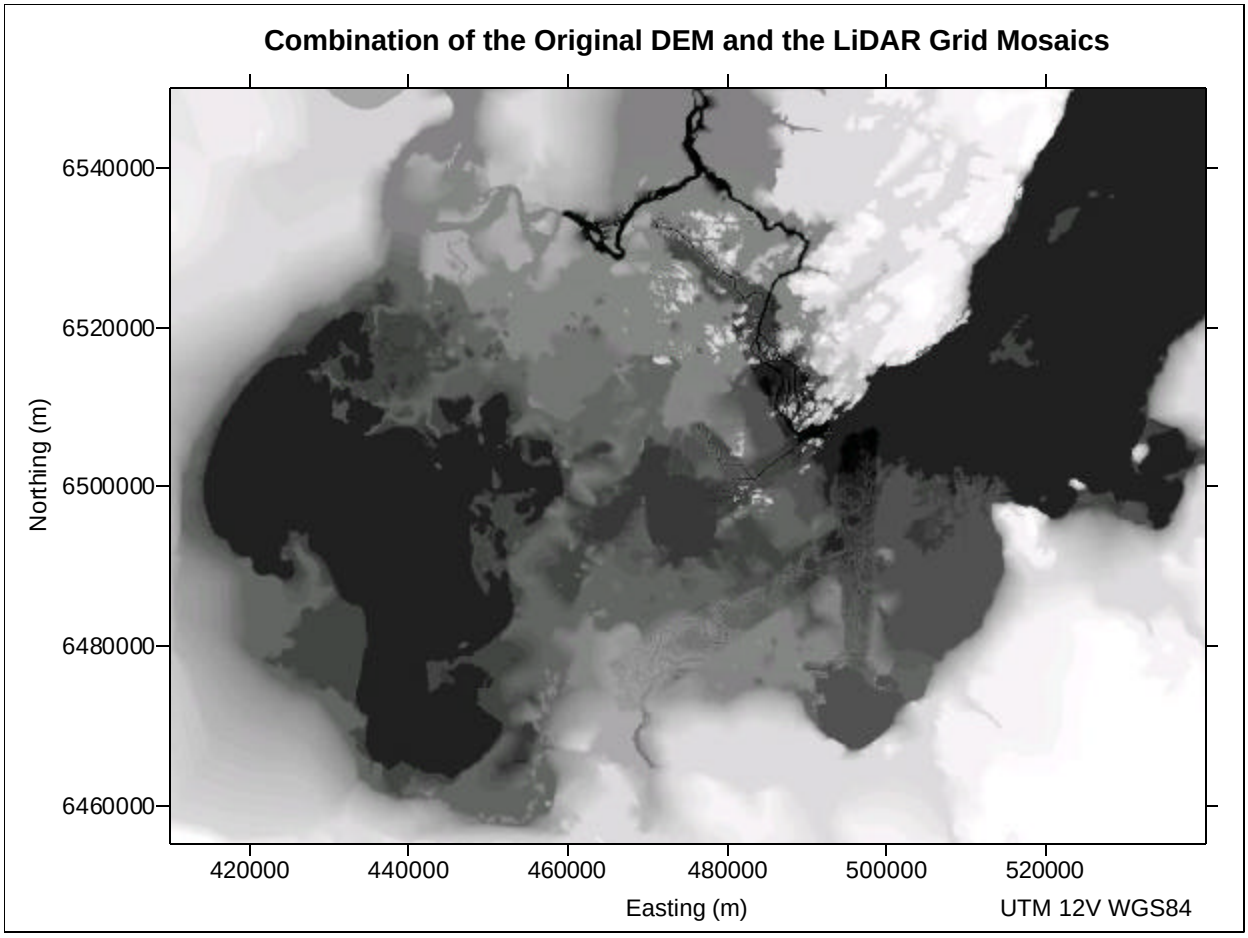
Continued…

		Survey Points				4m Grid	Difference in Elev.
Area	LiDAR Area	ID	Site	Cover Type	Elevation	Elevation	4m Grid-Survey
Jemis	A	1037		GRASS	209.93	209.96	0.03
Jemis	A	1038		GRASS	209.91	209.95	0.04
Jemis	A	1039		GRASS	209.89	209.95	0.06
Jemis	A	1040		GRASS	209.93	209.97	0.04
Jemis	A	1041		GRASS	209.84	209.99	0.15
Jemis	A	1043		GRASS	209.82	210.08	0.26
Jemis	A	1044		GRASS	209.85	210.02	0.17
Jemis	A	1045		GRASS	209.76	209.95	0.19
Jemis	A	1046		GRASS	209.79	209.95	0.16
Jemis	A	1047		GRASS	209.76	209.79	0.03
Jemis	A	1048		GRASS	209.73	209.77	0.04
Jemis	A	1049		GRASS	209.73	209.77	0.04
Jemis	A	1051		JBIP	209.81	209.91	0.10
Jemis	A	1		WILLOW_EDGE	209.71	209.70	-0.01
Jemis	A	2		GRASS	209.64	209.64	0.00
Jemis	A	5		GRASS	209.67	209.74	0.07
Jemis	A	6		GRASS	209.69	209.74	0.05
Jemis	A	7		GRASS	209.68	209.70	0.02
Jemis	A	10		GRASS	209.69	209.50	-0.19
Jemis	A	11		TOP_OF_BANK	209.71	209.38	-0.33
Jemis	A	17		MUD	208.78	208.78	0.00
Jemis	A	18		MUD	208.75	208.64	-0.11
Jemis	A	19		MUD	208.73	208.64	-0.09
Jemis	A	20		MAMAWI_WL	208.72	208.61	-0.11
Jemis	A	103		TREE_HEIGHT:_3.80	209.77	209.64	-0.13
Jemis	A	104		TREE_HEIGHT:_4.08	209.72	209.62	-0.10
Jemis	A	105		TREE_HEIGHT:_4.46	209.68	209.70	0.02

APPENDIX 11

ORIGINAL 25M DEM OF THE PEACE-ATHABASCA DELTA AND A COMBINATION OF THE ORIGINAL DEM AND THE LIDAR GRID MOSAICS


Original 25m DEM of the Peace-Athabasca Delta
6540000
6520000
6500000
6480000
6460000
Northing (m)
420000
440000
460000
480000
500000
520000
Easting (m)
UTM 12V WGS84


Combination of the Original DEM and the LiDAR Grid Mosaics
6540000
6520000
6500000
6480000
6460000
Northing (m)
420000
440000
460000
480000
500000
520000
Easting (m)
UTM 12V WGS84

APPENDIX 12

LIST OF DATA COMPACT DISCS

Data Compact Discs

Original LiDAR Data

Unclassifed LiDAR Data (UCL)	# of CD:s
Area A (Jemis Lake)	1
Area B (Quatre Fourches)	1
Area C (Riviere des Rochers)	2
Area D (Revillon Coupe)	1
Area E (Chenal des Quatre Fourches)	1
Area F (Embarras River)	4
Area G (Fletcher Channel)	2

Automatically Classified LiDAR Data (ACL)	# of CD:s
Area A (Jemis Lake)	1
Area B (Quatre Fourches)	1
Area C (Riviere des Rochers)	2
Area D (Revillon Coupe)	1
Area E (Chenal des Quatre Fourches)	1
Area F (Embarras River)	2
Area G (Fletcher Channel)	2

Manually Classified LiDAR Data (MCL)	# of CD:s
Area A, B, C, D, E	1
Area F, G	1

Gridded LiDAR Data

Area A (Jemis Lake)
CD 1 – 0.25m Grids, 4m Grids, Mosaic of 4m Grids

Area B (Quatre Fourches)
CD 1 – 0.25m Grids, 4m Grids, Mosaic of 4m Grids

Area C (Riviere des Rochers)
CD 1 – 0.25m Grids (17 of 43 Files)
CD 2 – 0.25m Grids (14 of 43 Files)
CD 3 – 0.25m Grids (12 of 43 Files), 4m Grids, Mosaic of 4m Grids

Area D (Revillon Coupe)
CD 1 – 0.25m Grids (30 of 34 Files)
CD 2 – 0.25m Grids (4 of 34 Files), 4m Grids, Mosaic of 4m Grids

Area E (Chenal des Quatre Fourches)
CD 1 – 0.25m Grids, 4m Grids, Mosaic of 4m Grids

Area F (Embarras River)
CD 1 – 0.25m Grids (25 of 79 Files)
CD 2 – 0.25m Grids (23 of 79 Files)
CD 3 – 0.25m Grids (21 of 79 Files)
CD 4 – 0.25m Grids (10 of 79 Files), 4m Grids, Mosaic of 4m Grids

Area G (Fletcher Channel)
CD 1 – 0.25m Grids (25 of 56 Files)
CD 2 – 0.25m Grids (17 of 56 Files)
CD 3 – 0.25m Grids (14 of 56 Files), 4m Grids, Mosaic of 4m Grids

Original 25m DEM and LiDAR Grid Mosaics

CD 1 - Original 25m DEM, LiDAR Grid Mosaics (25m Res.), and Original DEM merged with LiDAR mosaics.