GPS Validation of Lidar Elevation Models Report for Central and Eastern Prince Edward Island

Dr. Tim Webster and Candace MacDonald
with field support from
Kevin McGuigan, Charity Mouland, Nathan Crowell,
and Peter MacDermott

Applied Geomatics Research Group
NSCC, Middleton, NS

Executive Summary

The government of Prince Edward Island acquired light detection and ranging (LiDAR) data for the entire province in 2007. Lidar is a laser ranging system that fires laser pulses at the ground from an aircraft and deduces the elevation of the land based on the return time of the pulse to an expected vertical accuracy of 15 – 30 cm for every point measurement 1-2 metres on the ground. Lidar data should be validated against data with a known accuracy greater than that of the lidar. Real Time Kinematic (RTK) GPS has a horizontal and vertical precision of a few centimetres, and thus can be used to verify lidar products such as the digital elevation model (DEM) and digital surface model (DSM).

The lidar DEM was provided to the Applied Geomatics Research Group (AGRG) in Middleton, NS for validation. AGRG collected GPS validation data on July 26-29, 2010 using 13 of the high precision network (HPN) survey monuments located across PEI. The purpose of the validation analysis was to determine the quality of the lidar DEM and ensure that it accurately reflects heights within 0.30 m vertical.

Overall the lidar derived DEMs appear to be within the specifications outlined by the PEI government. Based on our analysis of the accuracy of the lidar DEMs, they can be used with confidence for many applications e.g. derivation of slope for example. Although our analysis has indicated that the derived elevations along roads are accurate to within 30 cm, we have identified and highlighted a potential problem that is not related to the operation and integration of the positioning errors of the lidar system. This error is related to ground classification of the original lidar point cloud. The classification of ground points has a direct impact on how the lidar DEM represents the true ground surface. The beach transect discussed in this report indicates a probable classification error of the points at the top of a steep mud bank along the coast. These types of classification errors are common in lidar and the data must be critically examined in order to identify them as they potentially impact subsequent analysis and interpretation of these data.

1.0 - Introduction

The government of Prince Edward Island acquired light detection and ranging (LiDAR) data for the entire province in 2007. Lidar is a laser ranging system that fires laser pulses at the ground from an aircraft and deduces the elevation of the land based on the return time of the pulse. The ground position of each laser pulse is known through the integrated navigation system on the aircraft (GPS & IMU), which allows for precise mapping of the topography to an expected vertical accuracy of 15 – 30 cm for every point measurement 1-2 metres on the ground.

Lidar data should be validated against data with a known accuracy greater than that of the lidar survey. Real Time Kinematic (RTK) GPS (Figure 1) has a horizontal and vertical precision of a few centimetres and greater than that of lidar, therefore can be used to verify lidar products such as the digital elevation model (DEM) and digital surface model (DSM).

The lidar DEM was provided to Applied Geomatics Research Group (AGRG) in Middleton, NS for validation. AGRG collected GPS validation data on July 26-29, 2010 using 13 of the high precision network (HPN) survey monuments located across PEI (Figure 2). The purpose of the validation analysis was to determine the quality of the lidar DEM and ensure that it accurately reflects heights within 0.30 m vertical.

RTK GPS data were collected along roads and highways, similar to the method TerraPoint used when validating the DEM of the westernmost portion of PEI (see Figure 1, Webster, 2010). This new set of validation data was collected to ensure coverage of the remainder of the province for increased independent validation, which was recommended in the Webster, 2010 report.

Figure 1. Equipment setup. (A) van RTK setup, (B) setting up a base station over HPN027, and (C) Collecting RTK GPS beach transect

2.0 – Methods

The general validation methods used in this report follow those outlined in Webster (2005) and involve comparing the GPS points to the interpolated raster DEM derived from the ground classified lidar points.

2.1 RTK Collection

Using the HPN monuments across the province, base stations were set up at pre-determined sites and RTK measurements were taken along highways and roads within the radio coverage radius (11 km typical - 20 km maximum) of the corresponding base station.

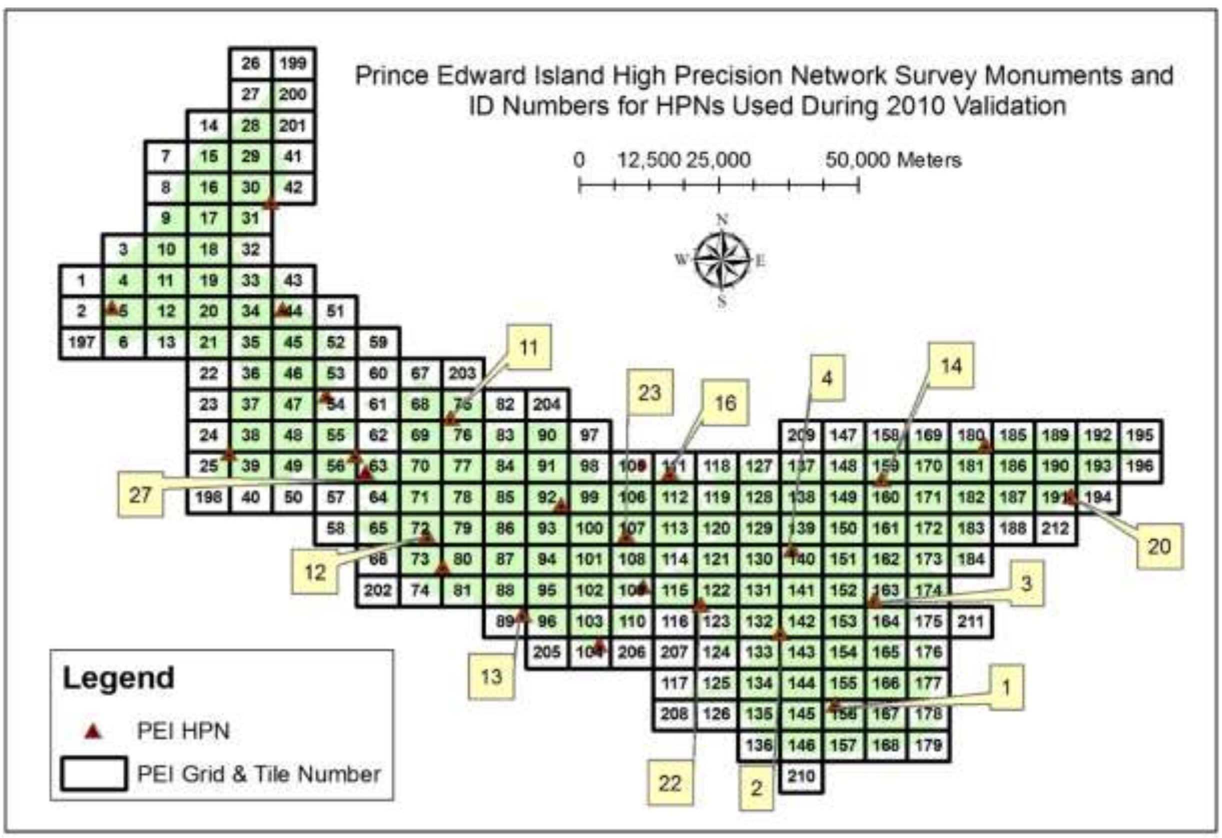


Figure 2. HPN monument locations across PEI, and ID numbers for ones used for RTK collection, July 26-29, 2010

There were two types of surveys completed for validation: RTK road traverses and a limited number of beach profile transects. To survey the elevation of the base of the road, the base station was set up over an HPN, and the radio and RTK GPS antenna were attached to the vehicle for data collection. The rover GPS unit on the vehicle was set to record every 2 seconds producing a large sample of validation points to compare to the DEM. Roads in PEI provided a good validation surface for a couple of reasons. First, their size and shape made them clearly visible on the lidar DEM. Also, the PEI road network is extensive and provides coverage across the entire province, both inland as well as along the coast. This enables validation data for a larger area to be collected than traverses on foot. However, this limits validation of natural features close to the water such as cliffs and dunes. So, to ensure validation of the coastline, two additional coastal transects were surveyed on foot using the pole and rover GPS. Elevations were collected beginning on the landward side of the coast and traversing seaward into the inter-tidal zone.

A total of 13 HPNs were used as base stations to collect the validation data. Only GPS rover points with a vertical precision better than 10 cm were used to compare with the lidar DEM. Analysis and post-processing of the GPS points was done in Leica Geo Office v.7.1. The heights were transformed from ellipsoidal heights (above GRS80) into orthometric heights above the geoid (MSL), using the HT2 geoid-ellipsoid separation model from Natural Resources Canada (Geodetic Survey Division). During analysis, it was discovered that GPS points associated with some HPNs contained vertical or horizontal offsets, such as HPN014 and HPN020, respectively (Figure 2). See Appendix B for the relationship between our HPN numbering scheme (ID field) and their official designation (HPN field). For example, the GPS points derived from HPN014 didn't line up with the roads in the DEM (Figure 2). The coordinates used during base station setup were the published coordinates provided by the government of PEI, but it was theorized that some of these coordinates may be incorrect. In discussions with one of the lidar data providers, PHB, it was mentioned that they used Precise Point Positioning to obtain the coordinates on some monuments used to control the lidar aircraft trajectory.

2.1 - Precise Point Positioning of Base Stations

During this project, reference RTK base station setup included logging GPS observations at all of the HPN sites used, which allows post processing of the base station position to compare against the published coordinates for each location. To test the theory that the published coordinates may have been incorrect, the logged observations from the base stations were post-processed using Natural Resource Canada's (NRCan) online Precise Point Positioning (PPP) GPS post-processing service. This service takes the observations for the stationary base station and uses refined ephemeris data to provide a better, more precise estimate for the location of that base. Appendix A contains published and PPP coordinates for each HPN visited during the survey. The results illustrated a large offset for both HPN014 and HPN020, with variable offsets for many other HPNs.

Having incorrect base station coordinates can have huge implications in lidar validation. Figure 3 shows GPS points processed with published and PPP coordinates for HPN014 as well as the measured offset of 336 m between identical points in both data sets. Research into the source of these discrepancies was beyond the scope of this project and was not further explored.

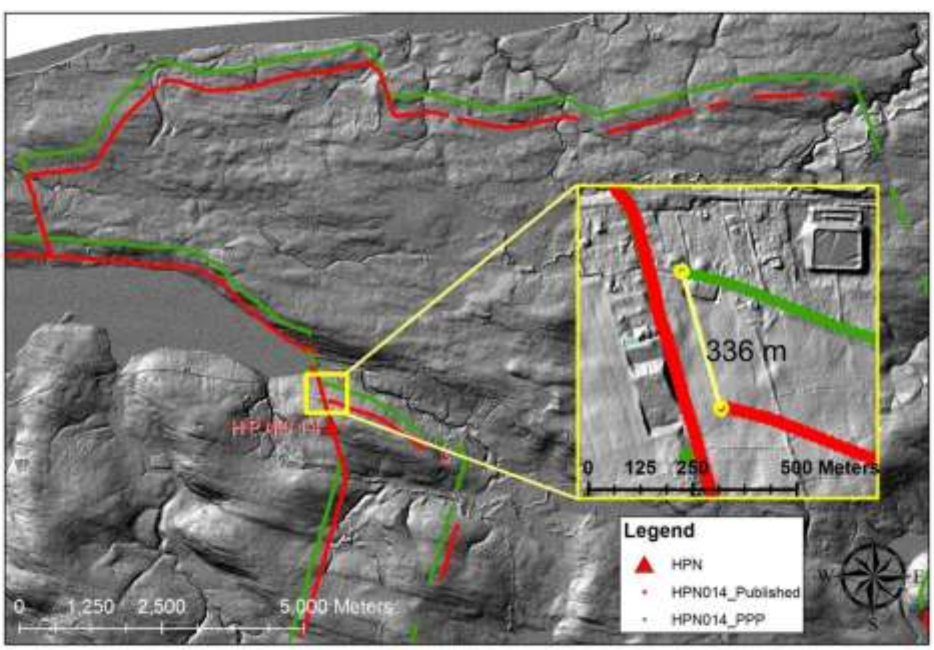


Figure 3. Lateral offset observed in published HPN 14 coordinate GPS (red) and post-processed HPN GPS (green)

2.2 – Lidar DEM Validation

The DEMs to validate were provided as individually tiled blocks corresponding to the 1:10,000 map sheet grid tile numbers on the grid provided by the PEI government (shown in Figure 2). To validate the vertical accuracy of each of these DEMs, the GPS points were tiled according to the same grid. The validation of each individual tile DEM was evaluated by comparing each GPS point with respect to the value of its corresponding cell on the lidar-derived DEM. Analysing the height difference (DZ = DEM – GPS) of all the measurements in a tile tells how far the lidar DEM is above (positive DZ values) or below (negative DZ values) the true ground elevation, assumed to correspond with the height derived from the GPS data. All GPS points within a lidar DEM tile were used to calculate the mean DZ value and the standard deviation of DZ.

As offsets were seen in some original base station data, the published coordinate validation for multiple tiles returned values too high to be acceptable. After reprocessing the GPS data and repeating the validation for those tiles using a select set PPP post-processed coordinates, a reduction in error was achieved and the validation for the DEM in those areas is now within the acceptable 0.30 m outlined by the government of PEI (Appendix A). Values n/a indicate that the pre-PPP GPS points were not reported for those tiles.

A complete list of DZ means and standard deviations for all tiles, including both published and PPP coordinate information is found in Appendix A.

2.3 - Transects

Multiple GPS points were taken along two coastal transects. Transects can provide useful information for ongoing coastline erosion studies, as well as shoreline classification of airborne lidar data and validation for coastal areas.

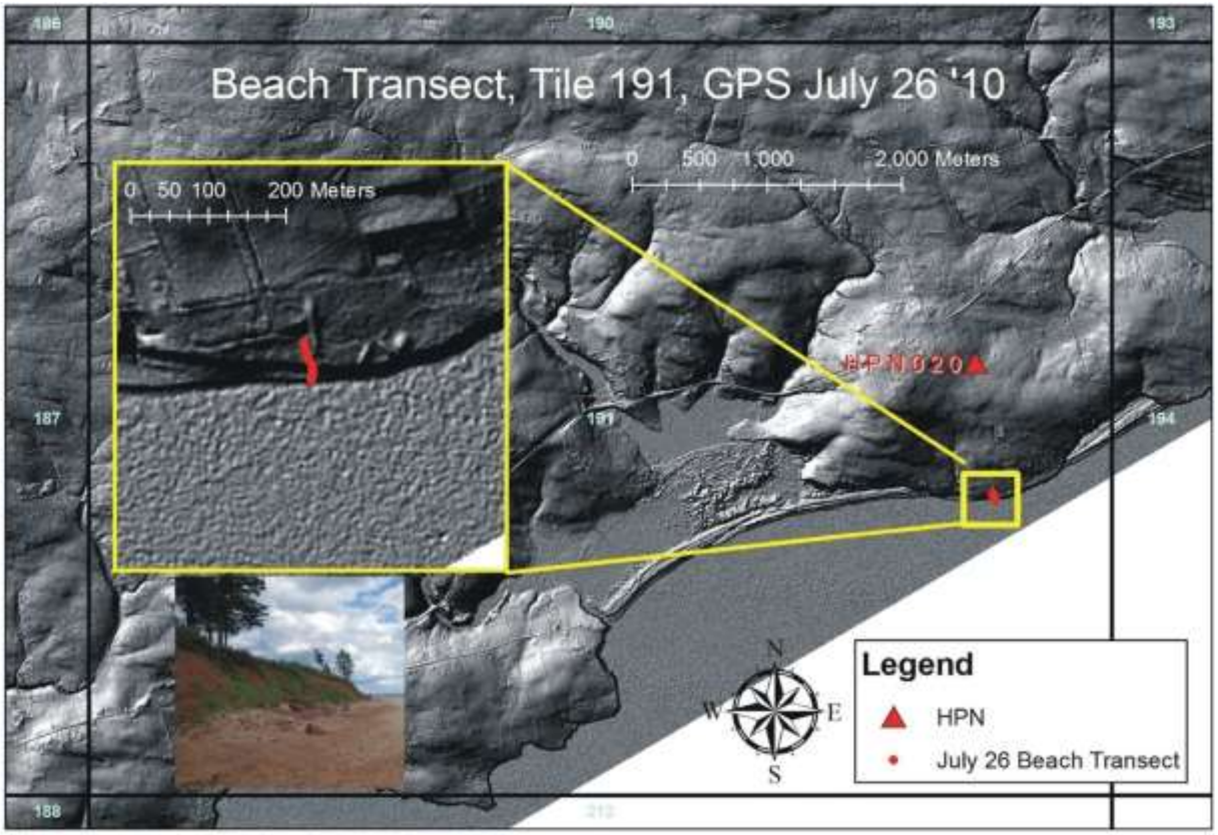


Figure 4. Tile 191 - Unconsolidated glacial till cliff transect on southeast coast and inset photo of transect location.

These transects were used to validate the coastlines in tiles 191 and 105. Tile 191 (Figure 4) was a transect over a steep unconsolidated glacial till bank (see Figure 4 inset photo). GPS points were taken approximately every 1-2 metres along the ground, with few being taken on the cliff face due to safety and damage concerns. The transect from tile 105 (Figure 5) was surveyed over a dune in the Cavendish Provincial Park, along the northern central coast.

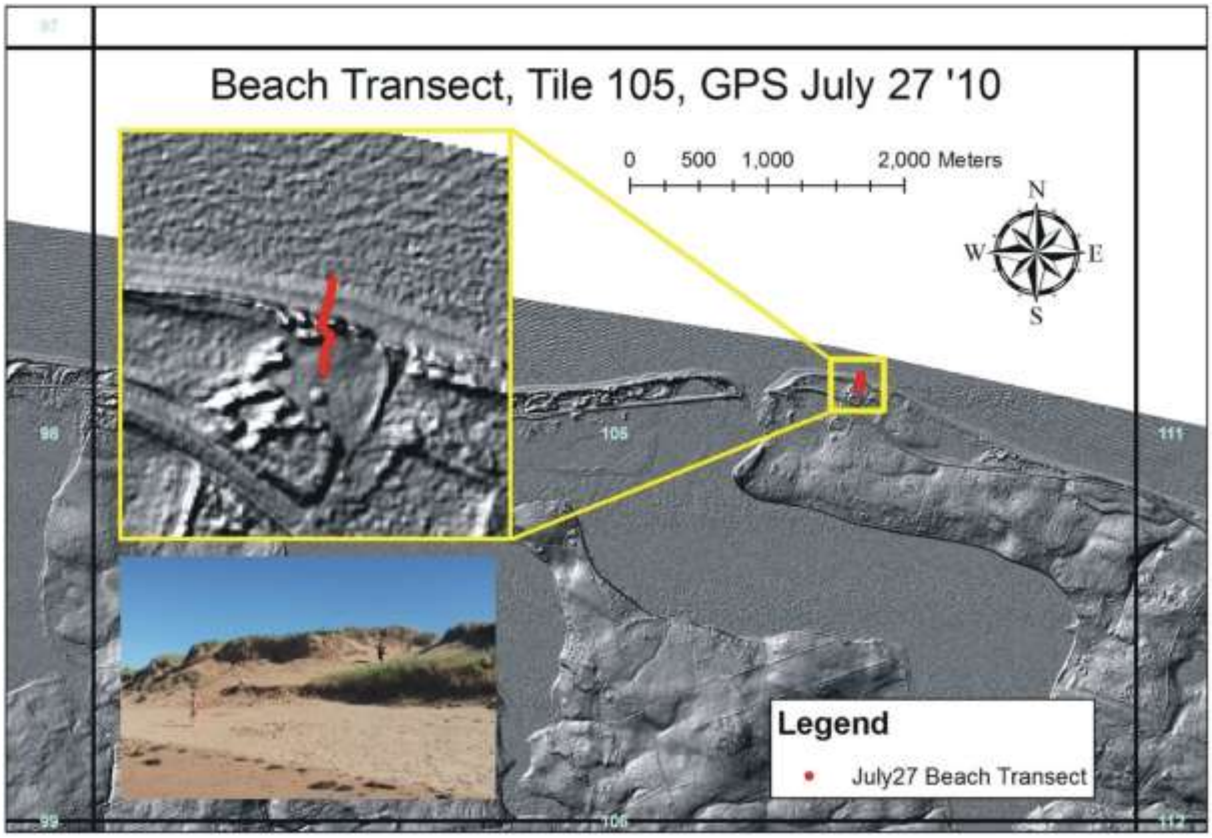


Figure 5. Tile 105 – Beach dune transect on central North coast (Cavendish Park) and inset photo of transect location.

3.0 – Results

3.1 – Lidar DEM Validation & PPP

It was determined that the published coordinates for HPN014 (2402) and HPN020 (5803) were incorrect, and should be reviewed. Figure 6 shows that a difference in height (DZ) of 0 to roughly 0.5 m between published and post-processed coordinates exists for most of the HPNs visited. HPN020 and 014 had much higher DZs than the others, at 1.6 and 11.3 m, respectively. Note that the height difference for HPN 014 was removed from Figure 6 to preserve the vertical scale of the chart. In addition, the published latitude and longitude for HPN014 put its location over 300 m away from where we thought it was, though this was the only one with a large lateral offset. HPN 15 and 19 were inaccessible and could not be found respectively and were thus not used in the field campaign and analysis.

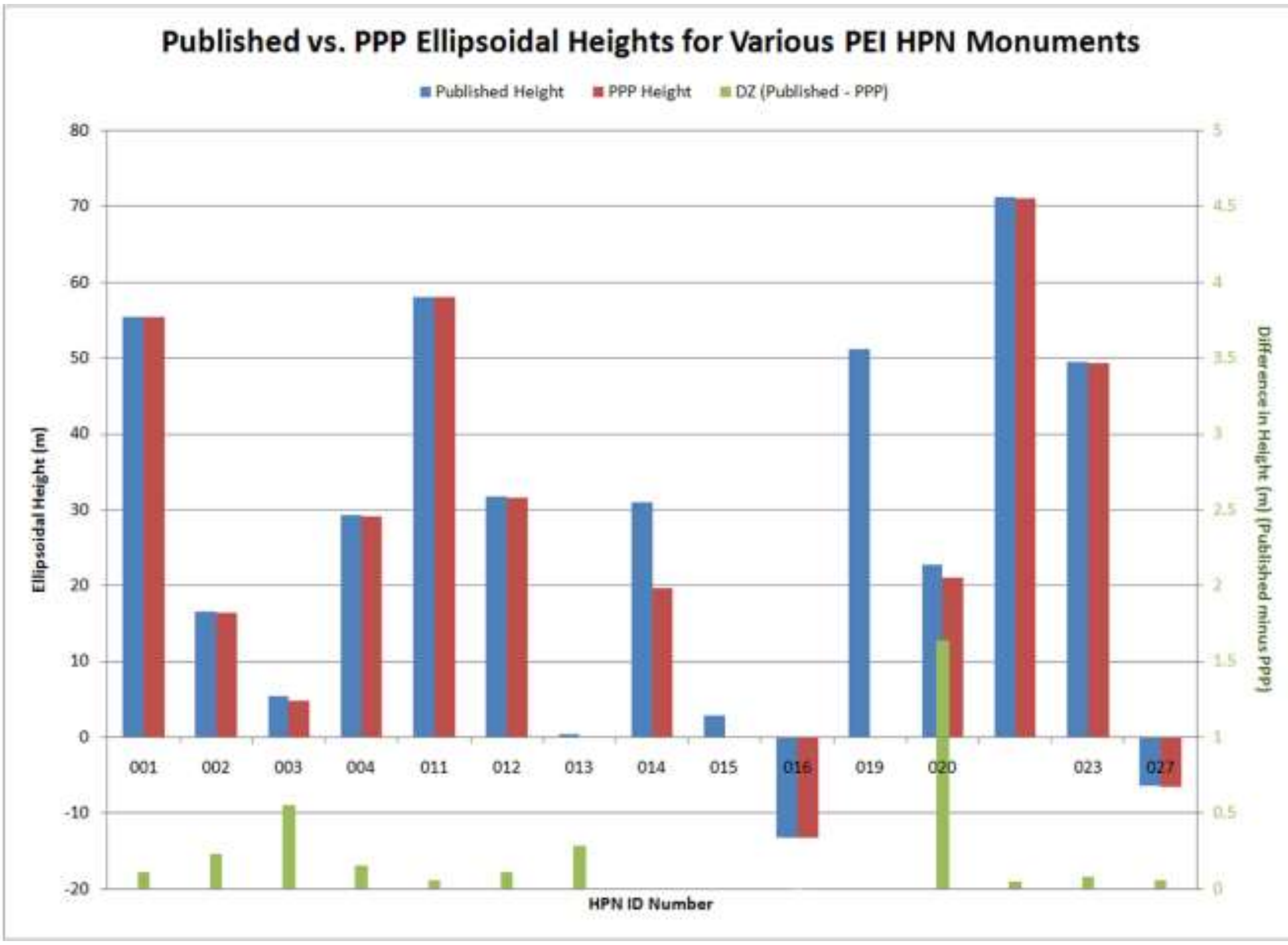


Figure 6. Published verses PPP heights for each HPN monument (HPN014 height difference excluded).

Overall, 5 of 13 HPNs were fully validated using post-processed coordinates (001, 003, 014, 016, and 020). The overall DZ mean and standard deviation (SD) for all validation data is summarized and outlined in Table 1 for the original HNP coordinates and those derived from PPP. The mean and SD DZ for published coordinates does not include HPN014 due to the lateral offset (realistic validation could not be done). The mean and SDs for PPP coordinates include post-processed validation information for HPN001, 003, 014, 016, and 020 while the mean and SDs for all other HPNs use published coordinate information.

In general, a lower mean DZ was observed for post-processed (PPP) coordinates than for the published coordinated for HPN base station locations. Considering only 4 of 13 HPNs were fully validated using these post-processed values, a further reduction in mean could be seen if validation was re-done using all precise point positioned coordinates. A full report of mean and standard deviations by tile is provided in Appendix A.

	Published Coordinates		PPP Coordinates	
	Mean DZ (DEM- GPS)	**SD of DZ (DEM - GPS)**	**Mean DZ (DEM- GPS)**	**SD of DZ (DEM - GPS)**
Total Overall:	-0.22	0.12	-0.10	0.10

Table 1. Total overall mean DZ (DEM – GPS) and standard deviation of DZ (SD of DZ) for published and post-processed coordinates

3.2 – Transects

Profile analysis for tile 191 (Figure 7) shows a potential error in the lidar ground classification, where the top edge of the cliff is classified as non-ground due to the steep angle and height of the cliff. These cliff edge lidar points were part of a non-ground class. Therefore, the edge of the cliff would have been excluded during the construction of the DEM, however they were included during the DSM construction (Figure 7). The bottom offset between GPS and lidar surfaces, where the foot of the cliff has receded landward may reflect active erosion of the cliff since the lidar survey in 2007. The pattern of erosion from the foot of the slope and building up of the material at the base is characteristic of the beach erosion process. The profile in Figure 7 of the Lidar DSM for the same transect shows the cliff edge exists and was in almost the same location in 2010 as it was in 2007. Cliff misclassification is a common problem when using lidar for coastal areas. It is important to understand and identify this problem if the lidar DEM is to be used for erosion and flood risk surveys.

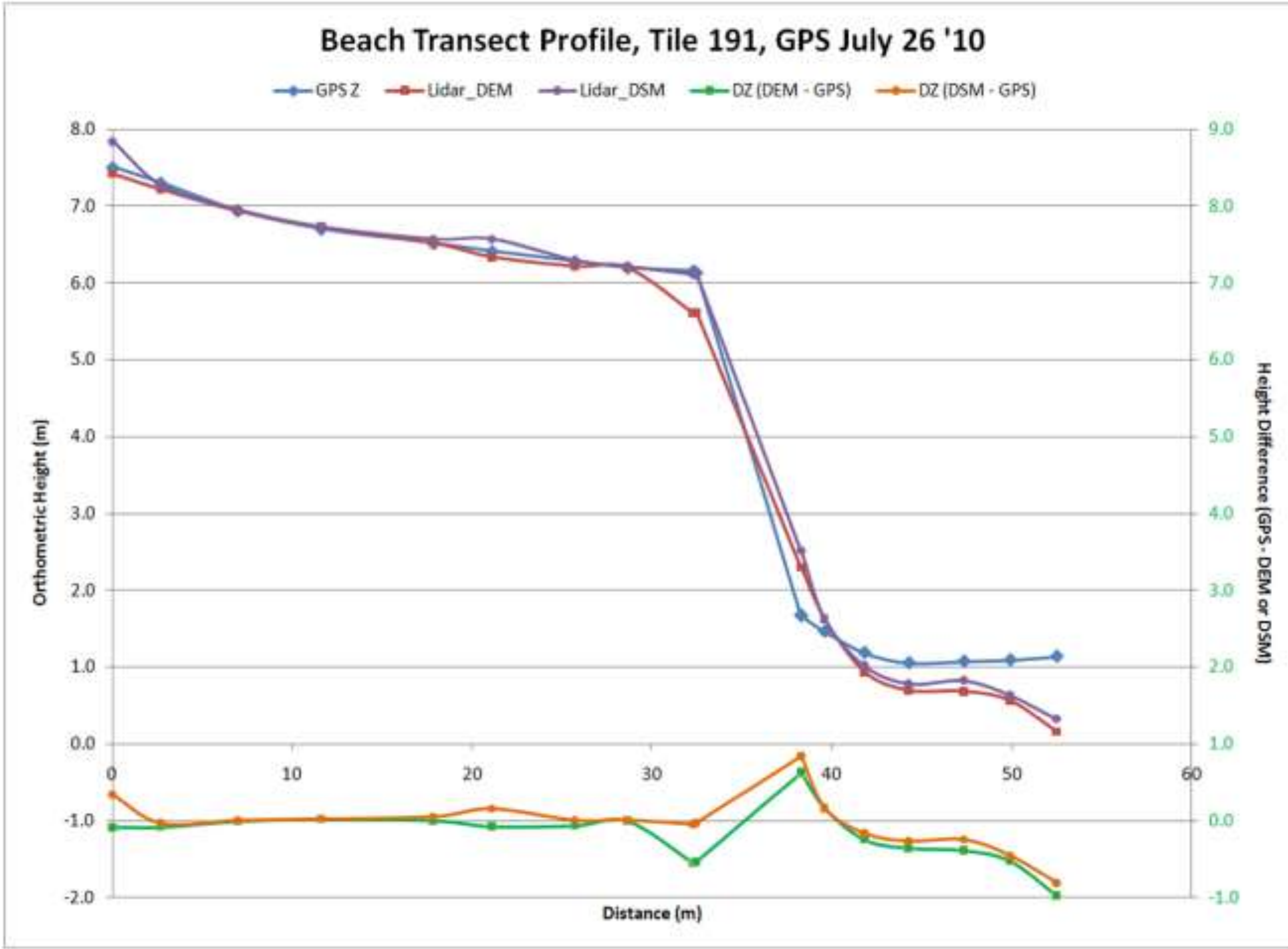


Figure 7. Transect GPS points (landward to seaward) compared with the lidar DEM and DSM along with the DZ of each surface (lower green & orange lines) showing a probable ground classification error at the cliff edge.

Profile analysis (Figure 8) of the transect in block 105 (Figure 5) shows a higher, and narrower dune in 2010 than in 2007. The DSM surface is higher than that of the DEM, possibly due to vegetation. Aside from one mound of sand that was present in 2007 but missing in 2010, the GPS closely aligns with DEM and DSM values for this transect.

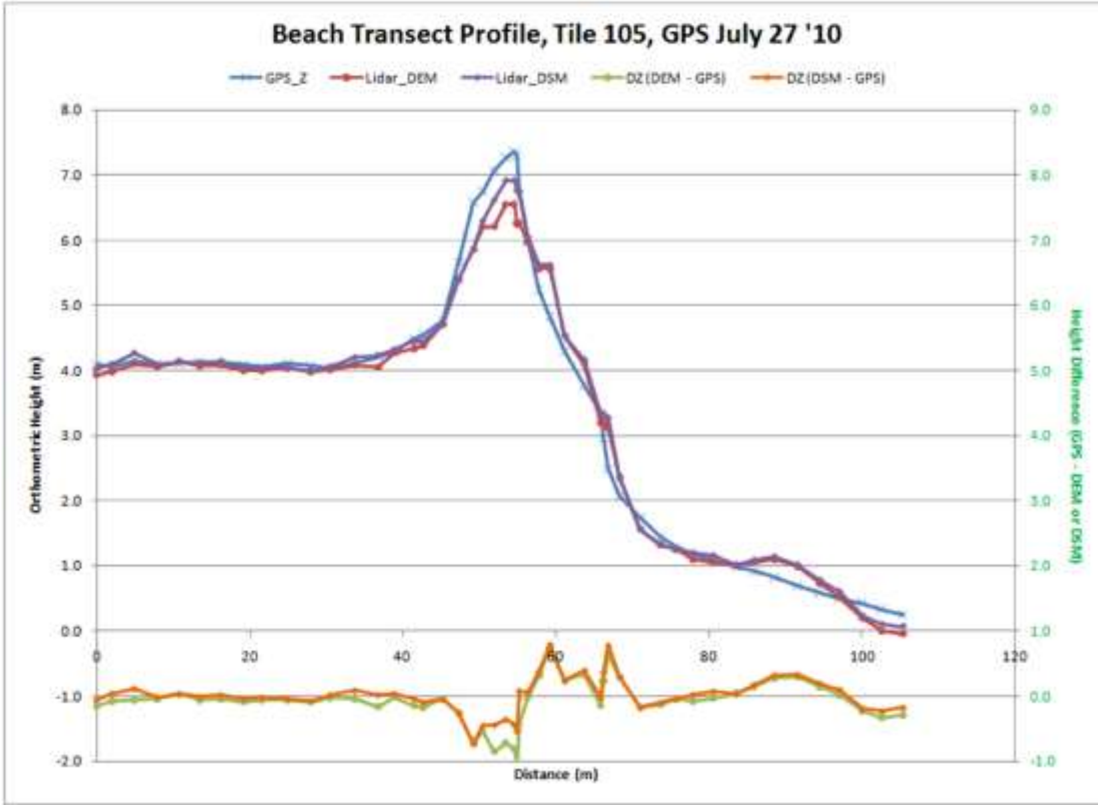


Figure 8. Transect GPS points (landward to seaward) compared with the lidar DEM and DSM along with the DZ of each surface (lower green & orange lines) of a dune at Cavendish Beach Provincial Park.

<u>3.3 - Problem Monuments</u>

During the course of GPS collection two HPN monuments were visited but were unable to be used. HPN015 from Clearspring, was surrounded by shoulder-high rose bushes which made it inaccessible under the tight time constraints of the project. The other monument, HPN019 in Hunter River, was not observed and would have required a metal detector and a shovel, neither of which were available at the time (Figure 9). In addition, the phone number on the monument survey marker said to call if there were any issues, however when the number was called, an elderly lady answered and has received many calls throughout the years regarding survey markers, but she knows nothing about them and requested the contact phone number be changed.

Figure 9. Inaccessible HPN015 (on left) and missing or buried HPN019 (on right)

Discussion

The quality of the HPN coordinates has complicated the interpretations of this report. However, after re-processing some of the GPS base positions utilizing the revised coordinates via PPP, the general observations of the lidar DEM data is that it meets the specifications of a vertical accuracy of 30 cm. Generally a mean offset near 15 cm was observed with a standard deviation of around 10 cm. The comparison of GPS and the DEM for each tile can be observed both spatially (Appendix C) and statistically (Appendix D). In the set of maps in Appendix C, the lidar DEM tile number is shown in green at the center of each tile and the HPN used for the survey is highlighted in red. The spatial distribution of DZ is depicted with maps that show the lidar shaded relief DEM where each GPS point is colour coded based on the DZ (DEM-GPS) value where red indicated the DZ is beyond 30 cm and shades of blue indicates the DEM is too high but within the 30 cm specification, or shades of green indicates the DEM is too low but within 30 cm. The statistical distribution of the DZ error is reported with histograms of the DZ, ideally the DZ error should be centered about 0 m and a tight standard deviation of less than 15 cm for each tile should be observed. The distribution should be normally distributed (ie. Gaussian) and if a bi-modal distribution is observed there may be issues of lidar flight line vertical offsets within the DEM and tile.

In cases where the GPS data were collected along bridges where the bridge may not be represented in the DEM (points on the bridge classified as non-ground, thus not used to derive the DEM), those GPS points were removed from the analysis.

Conclusions

Overall the lidar derived DEM appears to be within the specifications outlined by the PEI government. Based on our analysis of the accuracy of the lidar DEMs, they can be used with confidence for many applications e.g. derivation of slope for example. Although our analysis has indicated that the derived elevations along roads are accurate to within 30 cm, we have identified and highlighted a potential problem that is not related to the operation and integration of the positioning errors of the lidar system. This error is related to ground classification of the original lidar point cloud. The beach transect discussed in this report indicates a probable classification error of the points along the top of a steep bank along the coast. These types of classification errors are common in lidar and the data must be critically examined in order for these issues to be identified if they potentially impact subsequent analysis of the data.

In the case of using the lidar derived DEM as a bench mark for future or past erosions studies, this error could have significant potential implications when assessing things like change detection if it is not corrected or compensated for. We would recommend caution when using the lidar DEM for coastal areas that have elevated shorelines (typical of bedrock and glacial till bank cliffs) and to always examine the DSM to determine if a classification error has occurred.

References

Webster, T.L., 2005. LIDAR validation using GIS: A case study comparison between two LIDAR collection methods. *GeoCarto International, 20*, 11-19.

Webster, T., 2010. Assessment of Validation data for PEI Lidar Data. Report to PEI Government Climate Change.

Appendix A

Mean and Standard Deviations for each tile

			Published Coordinates		PPP Coordinates	
	HPN	Tile	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)
July 26 2010	014	147			0.062868	0.105372
		148			0.102911	0.112555
		158			0.051065	0.087376
		159	N/A	N/A	-0.015559	0.167650
		160			-0.025237	0.137353
		161			0.032155	0.078715
		169			-0.030329	0.078880
		170			-0.099166	0.089942
		171			-0.076256	0.080230
	020	185	n/a		-0.121953	0.089584
		186	n/a		-0.145943	0.114495
		187	-1.767929	0.26856	-0.112319	0.229458
		188	-1.772028	0.177421	-0.125495	0.084930
		189	-1.79963	0.078252	-0.014799	0.100659
		190	n/a		-0.147742	0.081156
		191	-1.802481	0.102596	-0.170910	0.100576
		192	-1.748446	0.095389	-0.112226	0.084962
		193	-1.826281	0.082062	-0.188346	0.080948
		194	-1.818496	0.069948	-0.181748	0.069055
		195	-1.73427	0.129551	-0.113656	0.107909
		196	-1.771521	0.095432	-0.152201	0.087554
	HPN	Tile	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)
July 27 2010	011	67	-0.032560	0.089044		
		68	-0.157719	0.109650		
		69	-0.172287	0.095015		
		70	-0.226115	0.095023		
		75	-0.097201	0.104521		
		76	-0.155336	0.103751		
		77	-0.183386	0.092350		
	016	105	-0.193329	0.105107	-0.195676	0.105292
		106	-0.152496	0.131908	-0.154716	0.132252
		107	-0.415891	0.966842	none??	
		111	-0.150023	0.098635	-0.152279	0.097583
		112	-0.138636	0.138513	-0.140530	0.149044
		113				

HPN	Tile	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)
	119	-0.170237	0.115237	-0.173079	0.115755
	120	-0.218658	0.095796	-0.226408	0.098667
023	93	-0.216767	0.222208		
	99	-0.184564	0.124436		
	100	-0.120545	0.099439		
	101	-0.102738	0.085641		
	106	-0.129016	0.087899		
	107	-0.094666	0.092755		
	108	-0.141832	0.092810		

HPN	Tile	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)
001	144	-0.344290	0.076534	-0.087645	0.087171
	145	-0.299575	0.076482	-0.055259	0.066637
	155	-0.292941	0.099614	-0.043275	0.107053
	156	-0.244102	0.132371	-0.020195	0.103845
	166	-0.209726	0.109072	0.011102	0.100777
	167				
002	131	-0.119431	0.085000		
	132	-0.155866	0.096895		
	133	-0.166807	0.101676		
	141	-0.106530	0.083755		
	142	-0.125315	0.091417		
	143	-0.149175	0.092149		
	144	-0.110390	0.074558		
003	163	-0.045426	0.110843	0.49292	0.101819
004	129	-0.070887	0.116361		
	130	-0.066205	0.079769		
	131	-0.201506	0.095449		
	139	-0.142546	0.106207		
	140	-0.127420	0.105897		
	141	-0.262969	0.103453		
	151	-0.177635	0.112460		

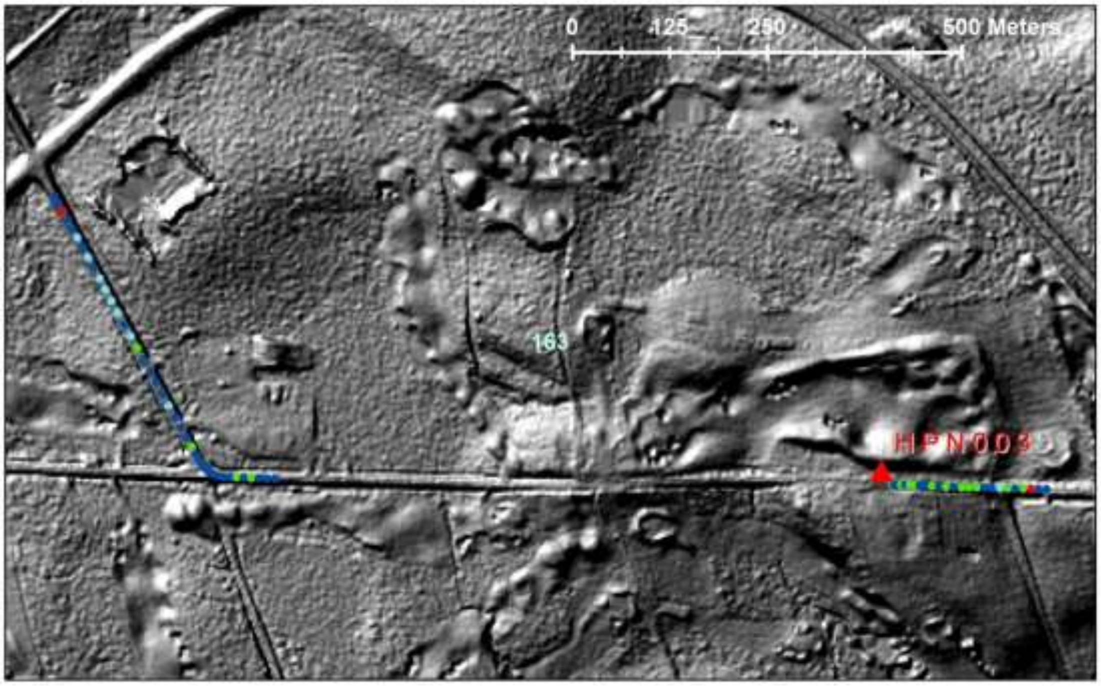
HPN	Tile	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)	Mean DZ (DEM-GPS)	SD of DZ (DEM - GPS)
012	58	-0.032473	0.087415		
	63	-0.195765	0.100858		
	64	-0.162819	0.118321		
	65	-0.028508	0.151464		
	66	-0.069360	0.104734		
	72	-0.117546	0.097407		
	73	-0.137319	0.108415		
	74	-0.176519	0.078615		
	79	-0.073972	0.074364		

013	202	-0.165649	0.069946		
	87	-0.108729	0.106504	0.189498	0.108687
	88	-0.134325	0.116317	0.155990	0.112792
	89	-0.171610	0.089610	0.098382	0.091067
	96	-0.138157	0.093495	0.145229	0.092980
	103	-0.203646	0.318249	0.096308	0.317681
022	114	-0.067867	0.095703		
	115	-0.101166	0.087658		
	116	-0.132040	0.070420		
	121	-0.107318	0.076516		
	122	-0.112510	0.098173		
	123	-0.127634	0.080839		
	131	-0.179872	0.093064		
	132	-0.212484	0.088259		
027	48	-0.074487	0.125174		
	49	-0.104388	0.022427		
	55	-0.187062	0.120535		
	56	-0.178370	0.103406		
	63	-0.173724	0.096787		
	64	-0.127352	0.117723		
	70	-0.192395	0.110901		
	71	-0.192419	0.085932		
	77	-0.146497	0.107263		

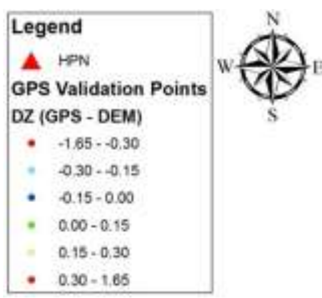
	Published Coordinates		**PPP Coordinates**	
	Mean DZ (DEM- GPS)	**SD of DZ (DEM - GPS)**	**Mean DZ (DEM- GPS)**	**SD of DZ (DEM - GPS)**
Total Overall:	-0.22	0.12	-0.10	0.10

Appendix B

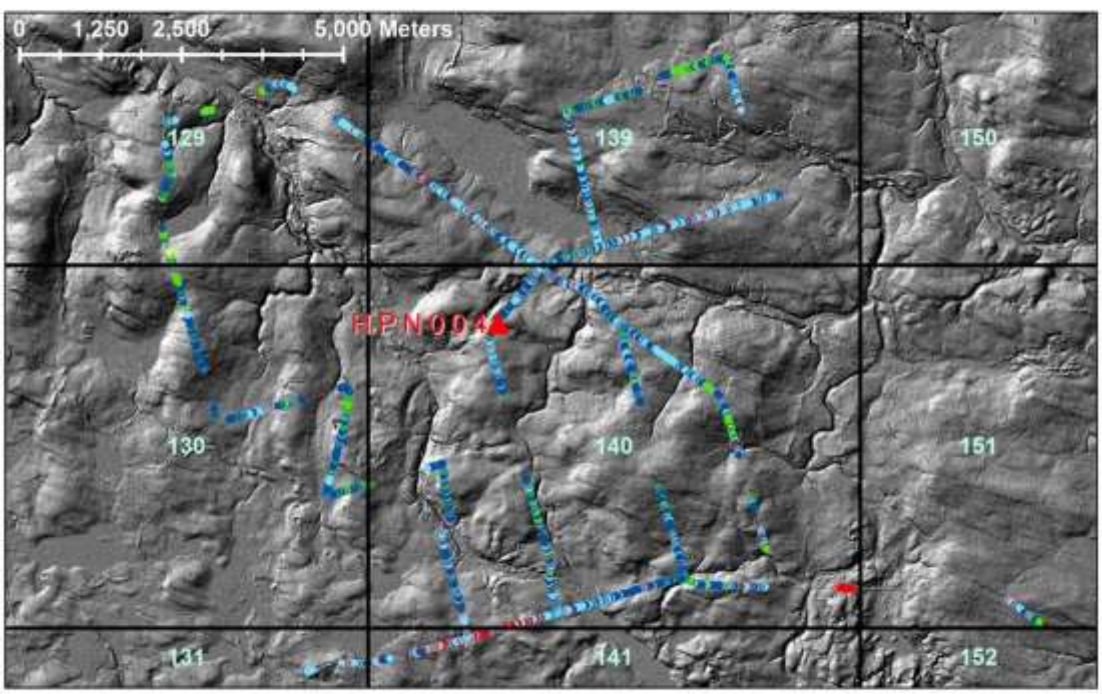
Height Difference between Published and Post-Processed PEI HPN Coordinates

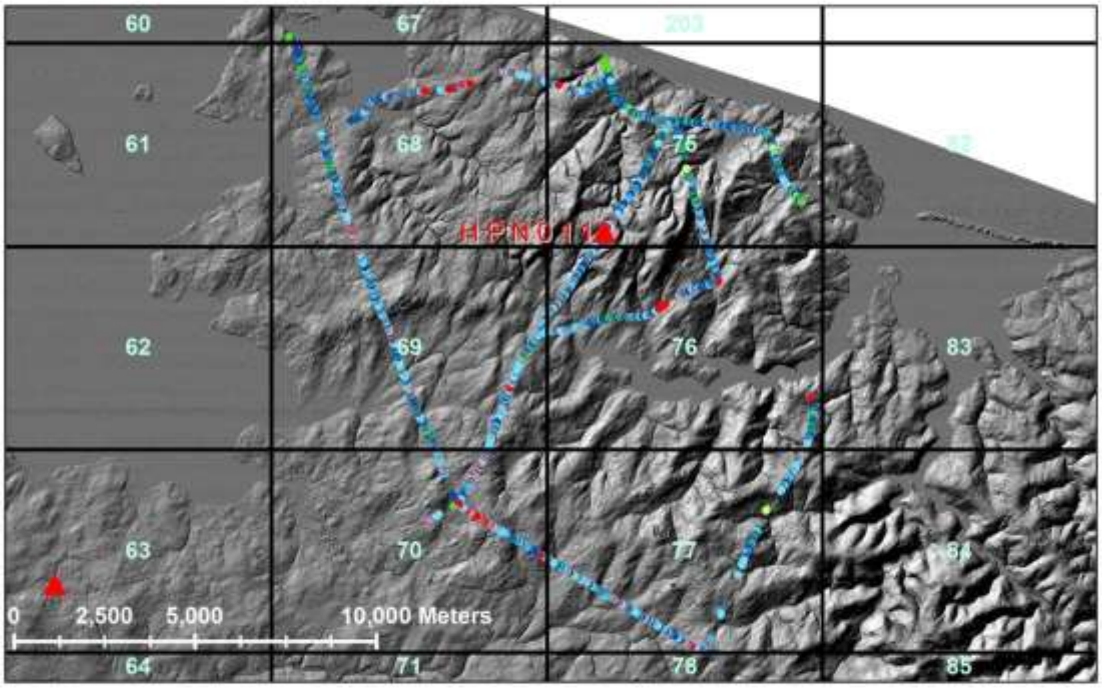


HPN003

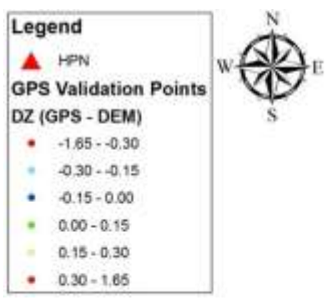


HPN004

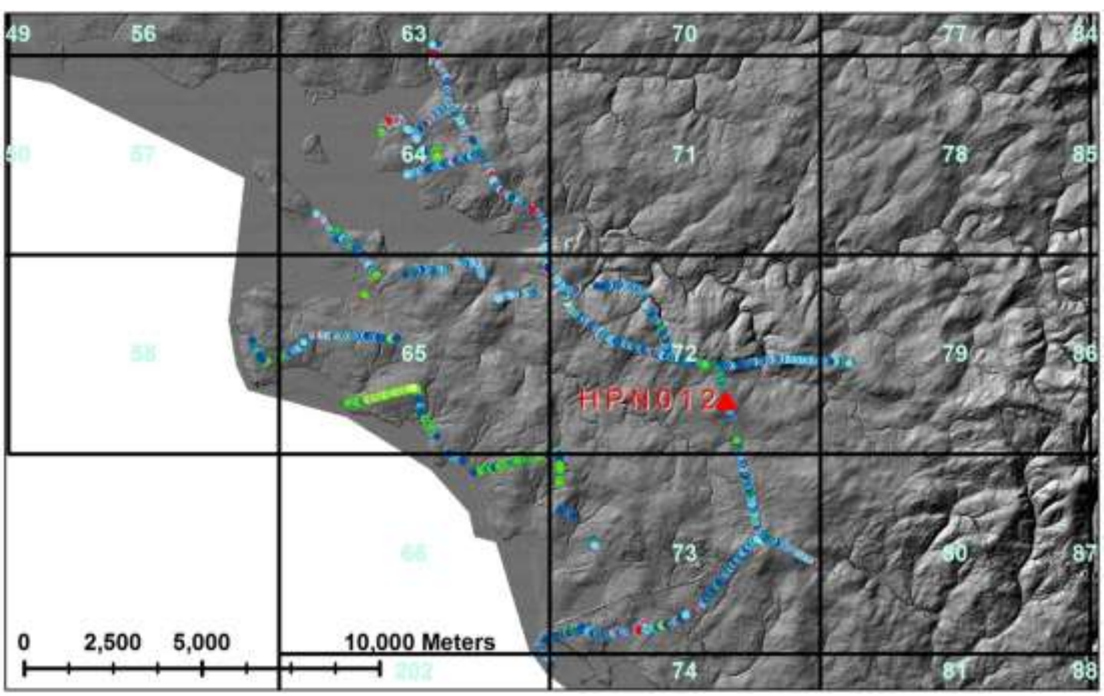


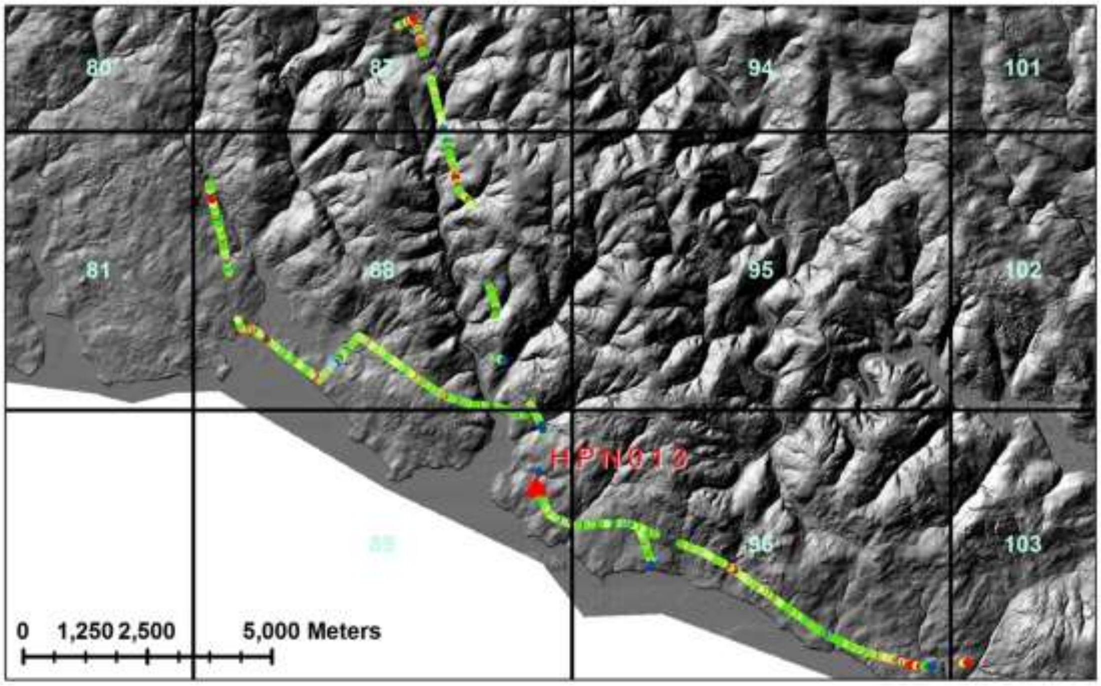


HPN011

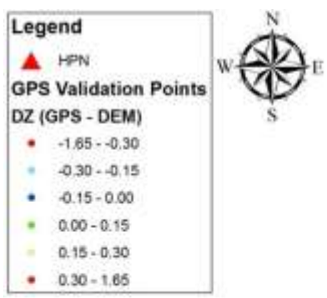


HPN012

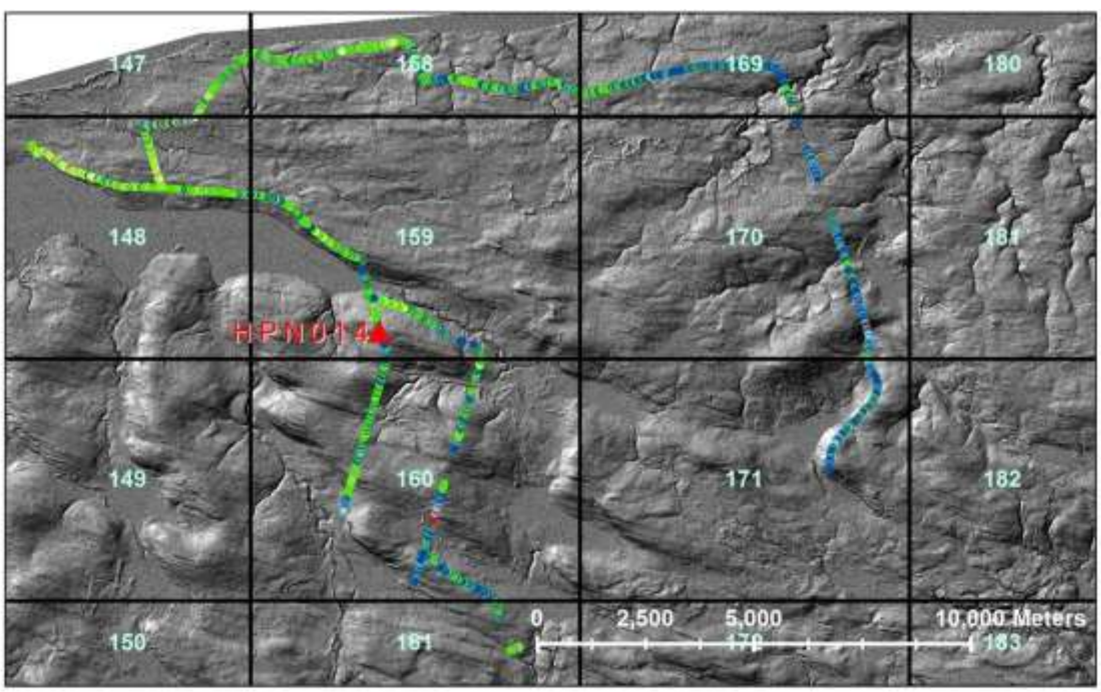


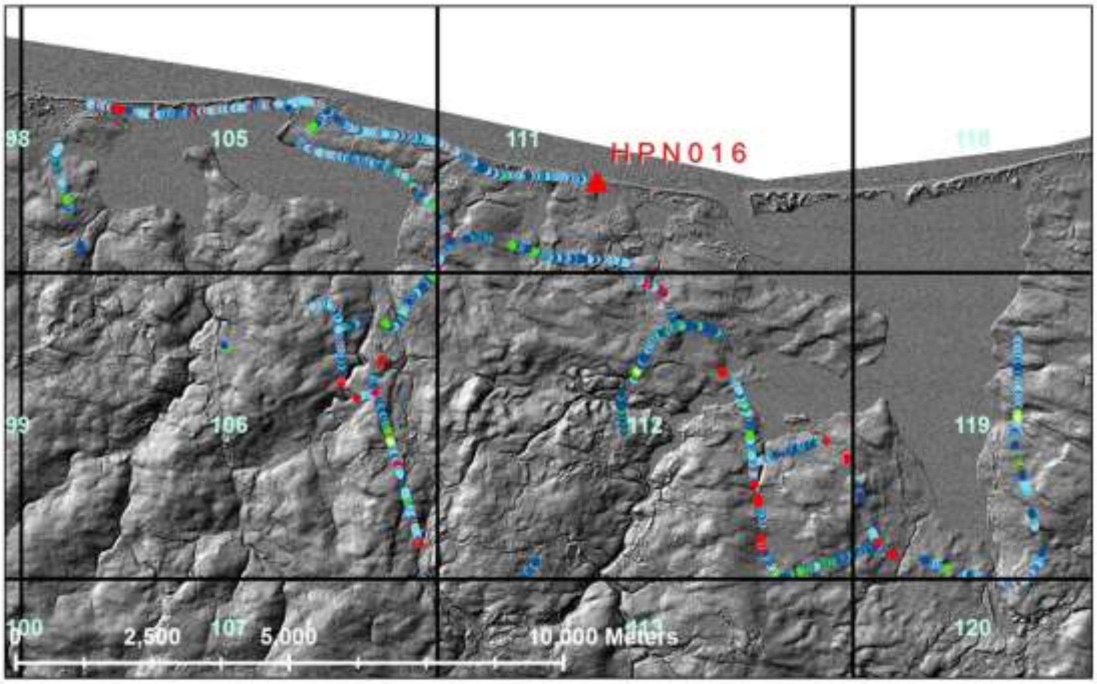


HPN013

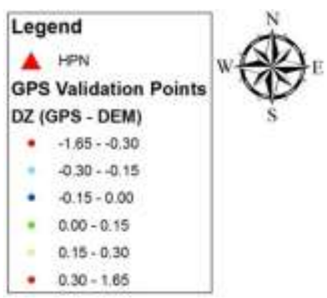


HPN014

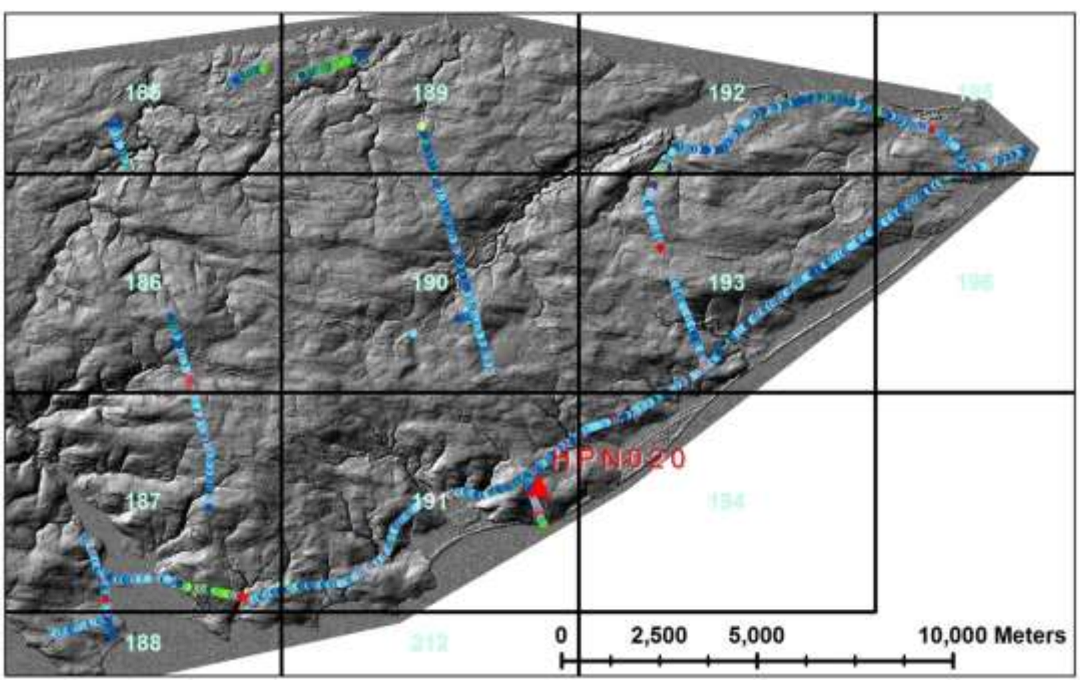


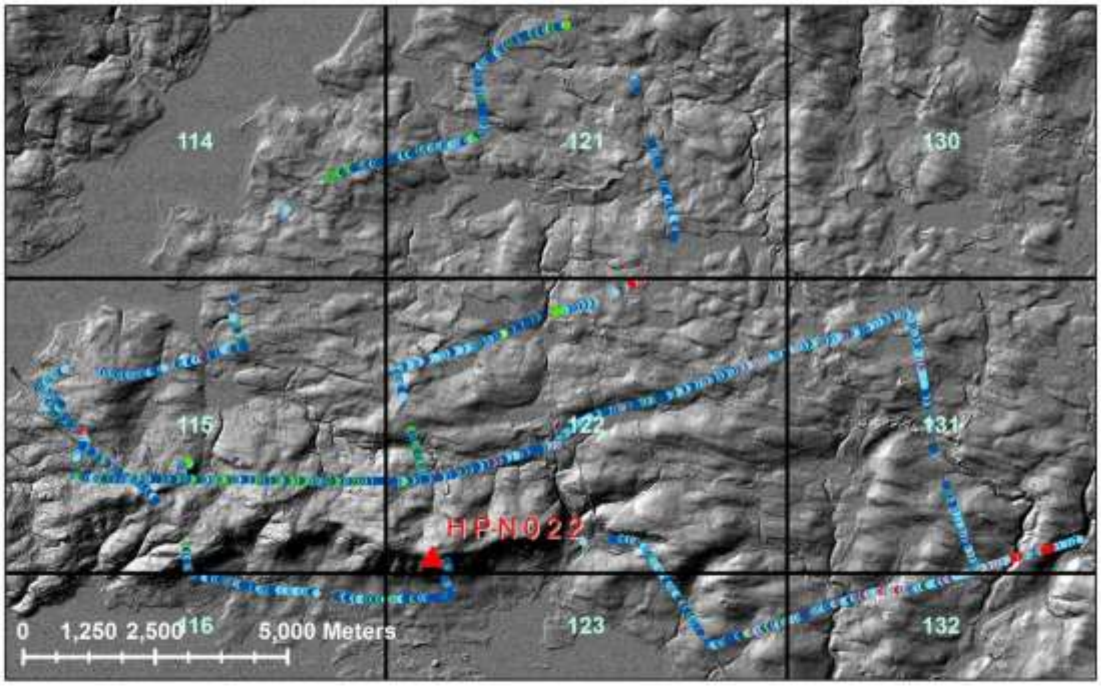


HPN016

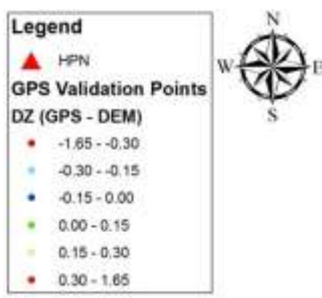


HPN020

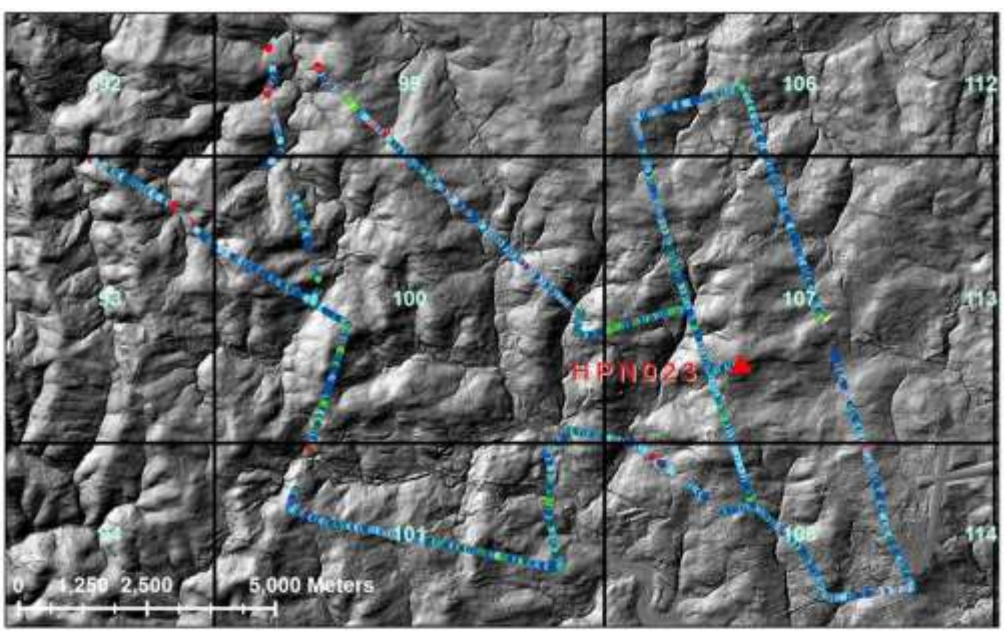


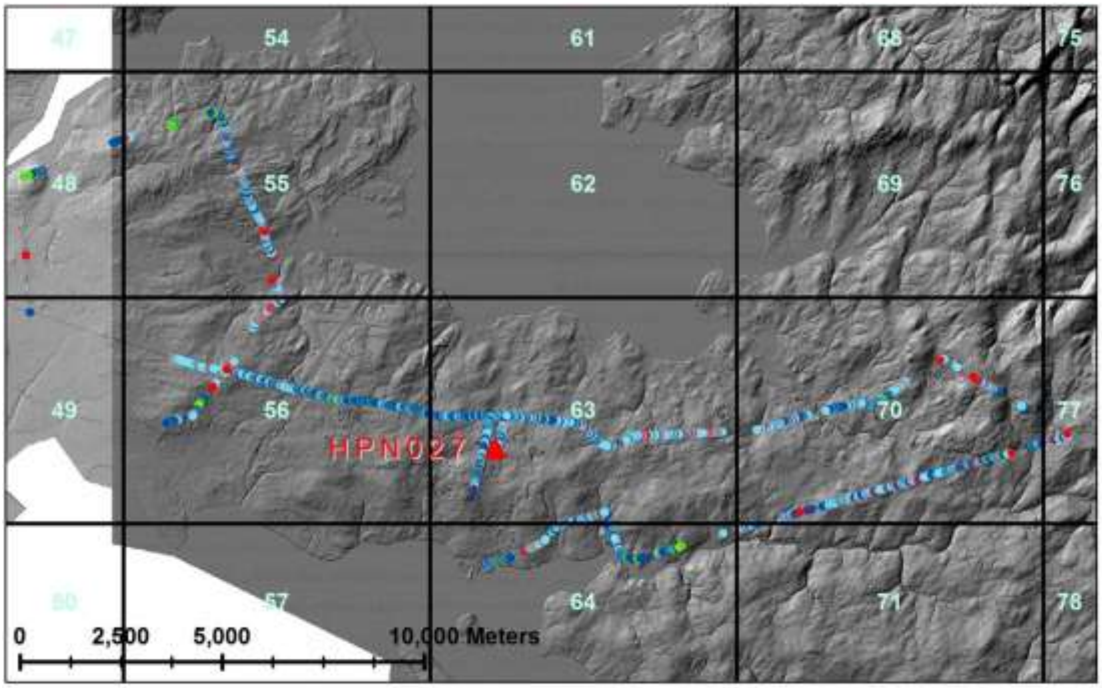


HPN022

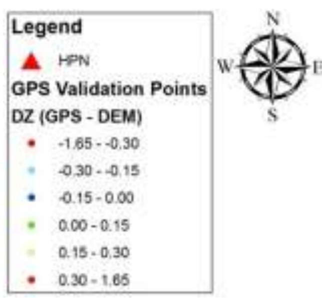


HPN023




54
61
68
75
48
55
62
69
76
49
56
63
70
77
57
64
71
78
HPN027
0
2,500
5,000
10,000 Meters

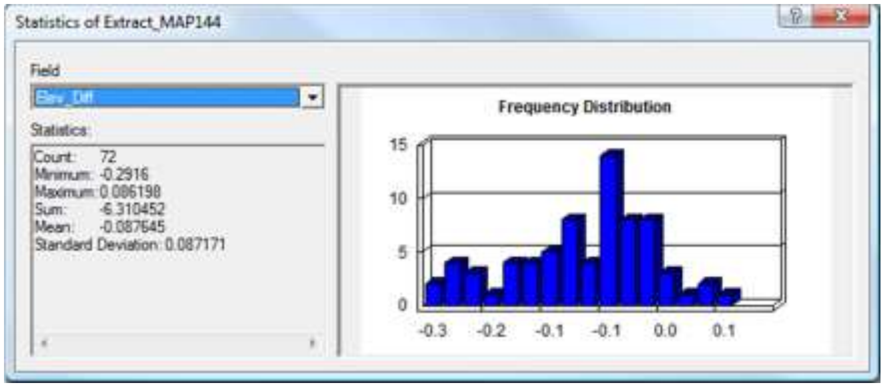
HPN027

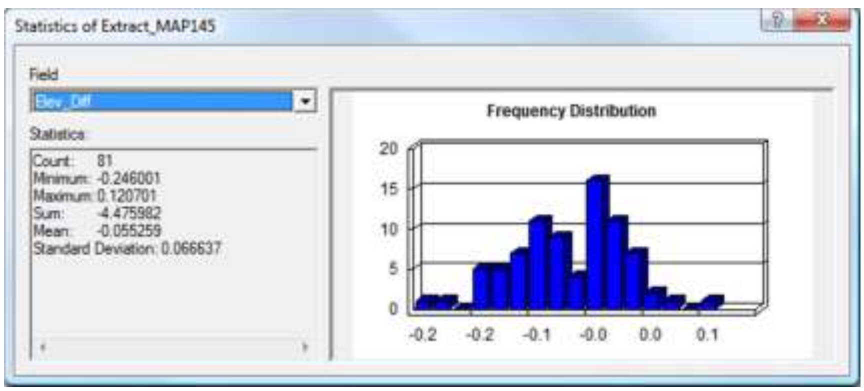

Legend
HPN
GPS Validation Points
DZ (GPS - DEM)
-1.65 - -0.30
-0.30 - -0.15
-0.15 - 0.00
0.00 - 0.15
0.15 - 0.30
0.30 - 1.65
N
W
E
S

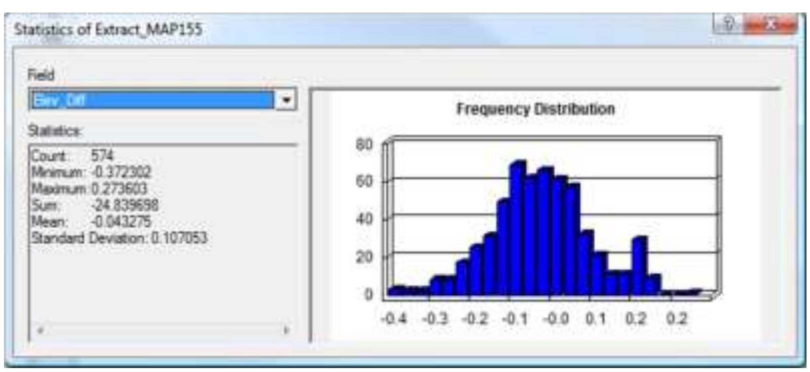
Appendix D

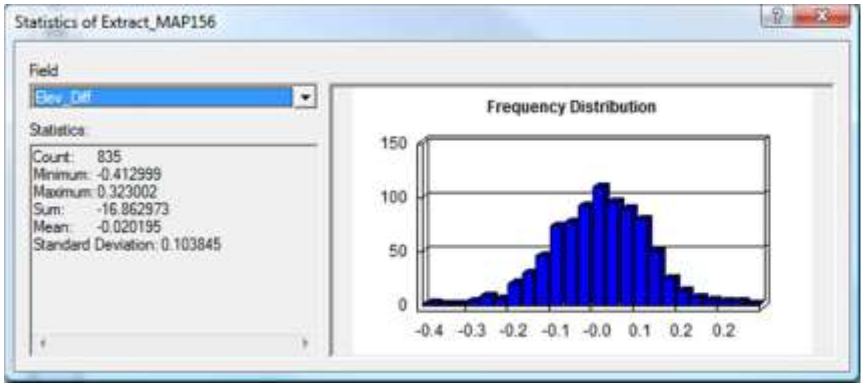
Histogram of Validation Error per Tile

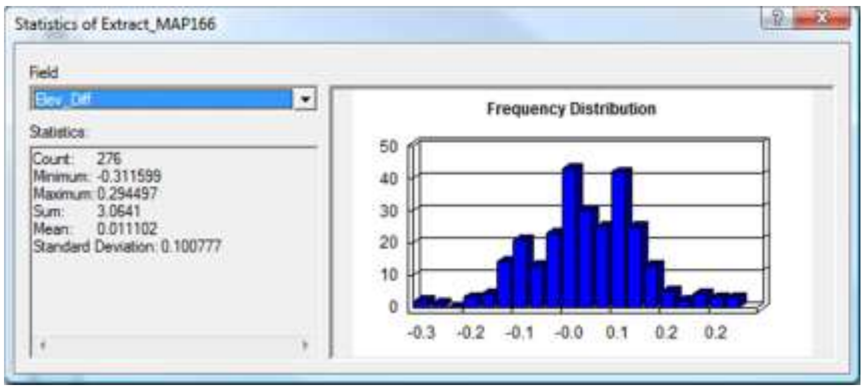
Reference HPN001



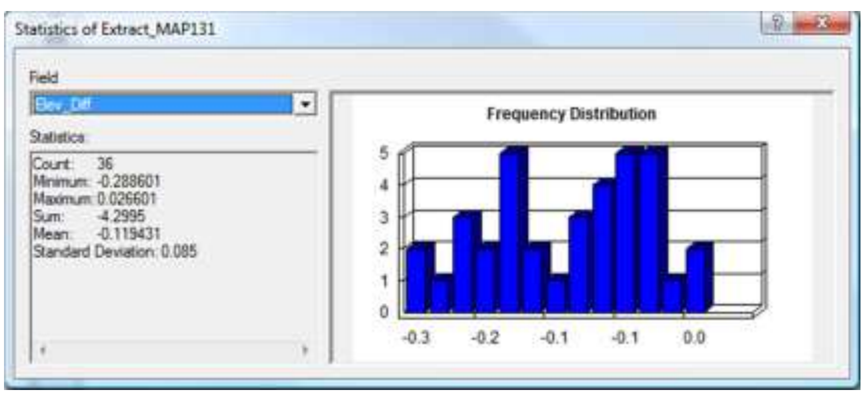


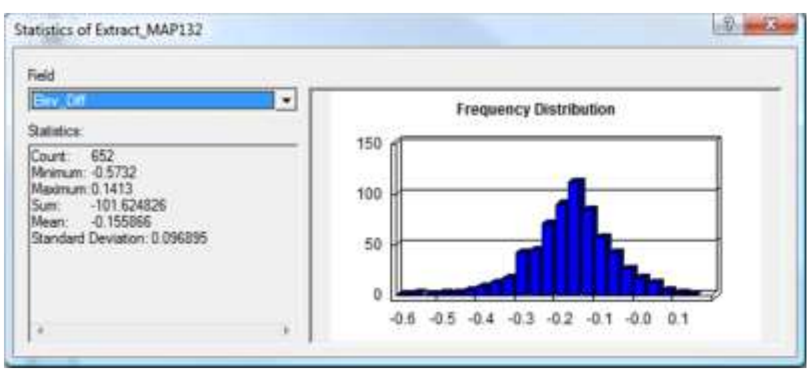


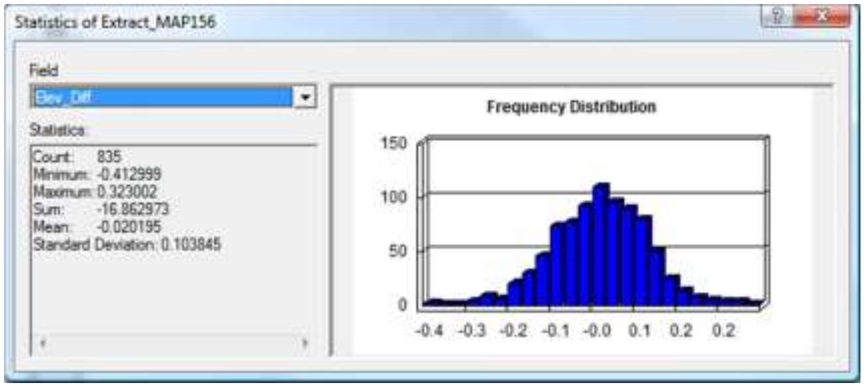


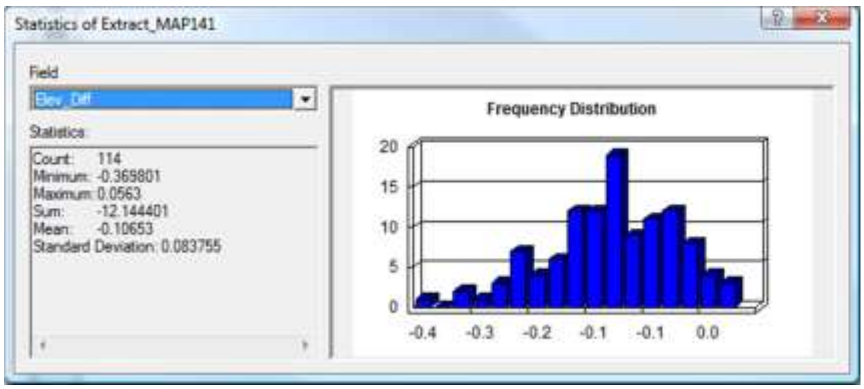


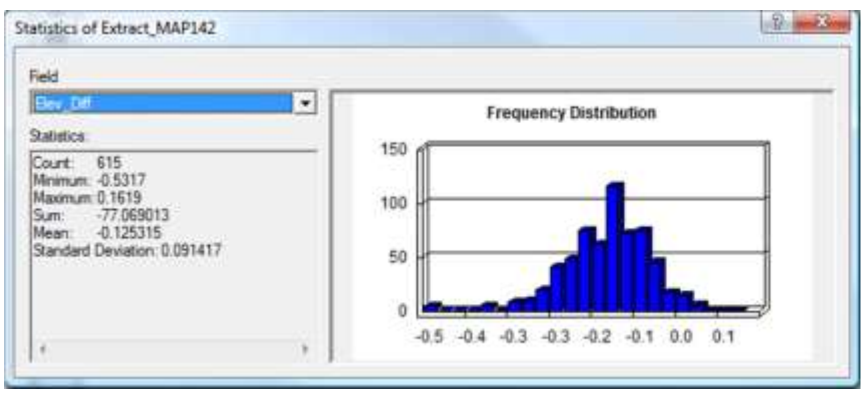
Reference HPN002

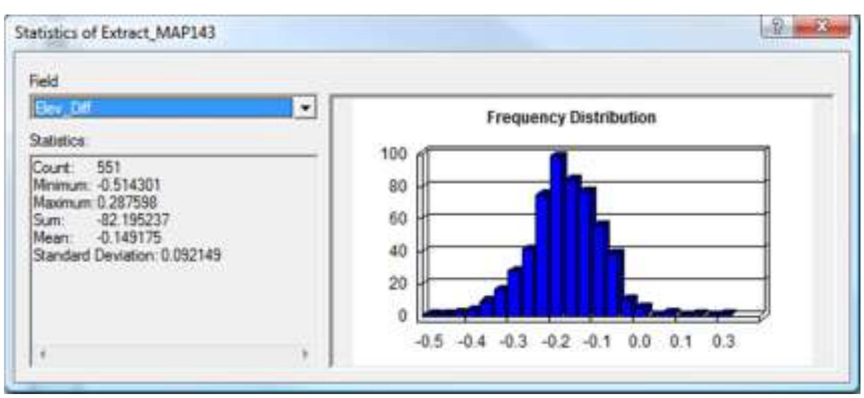


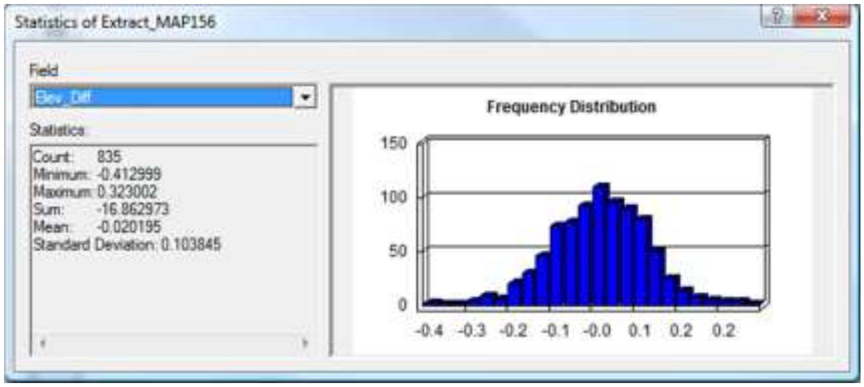



Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution

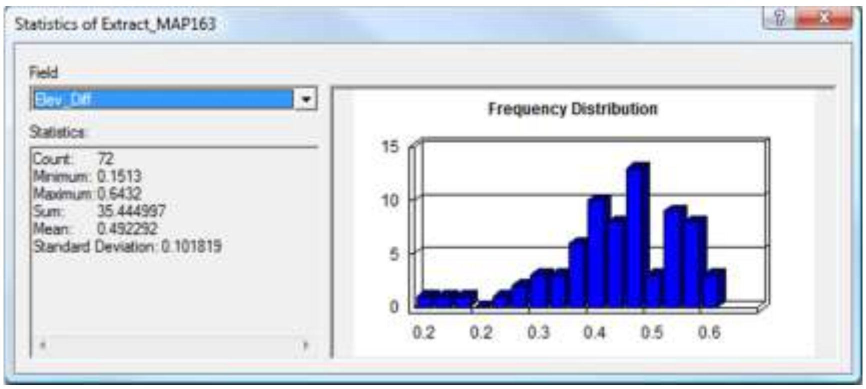

Statistics of Extract_MAP141
Field
Elev_Diff
Statistics
Count: 114
Minimum: -0.369801
Maximum: 0.0563
Sum: -12.144401
Mean: -0.10653
Standard Deviation: 0.083755
Frequency Distribution


Statistics of Extract_MAP142
Field
Elev_Diff
Statistics
Count: 615
Minimum: -0.5317
Maximum: 0.1619
Sum: -77.069013
Mean: -0.125315
Standard Deviation: 0.091417
Frequency Distribution

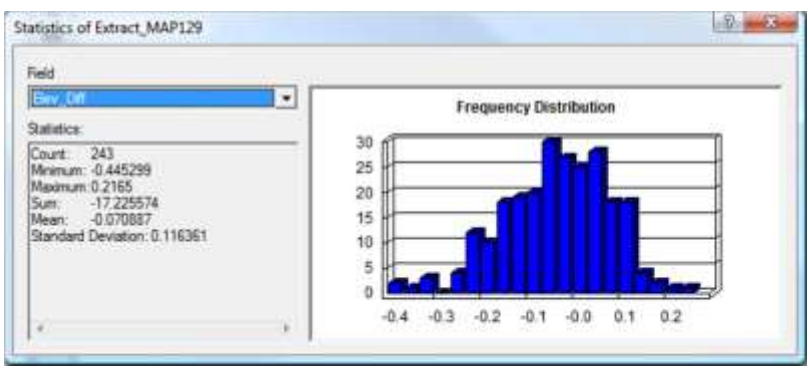

Statistics of Extract_MAP143
Field
Elev_Diff
Statistics
Count: 551
Minimum: -0.514301
Maximum: 0.287598
Sum: -82.195237
Mean: -0.149175
Standard Deviation: 0.092149
Frequency Distribution

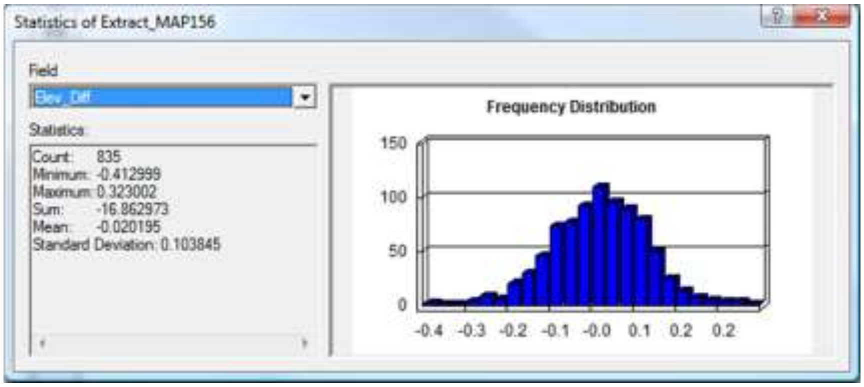


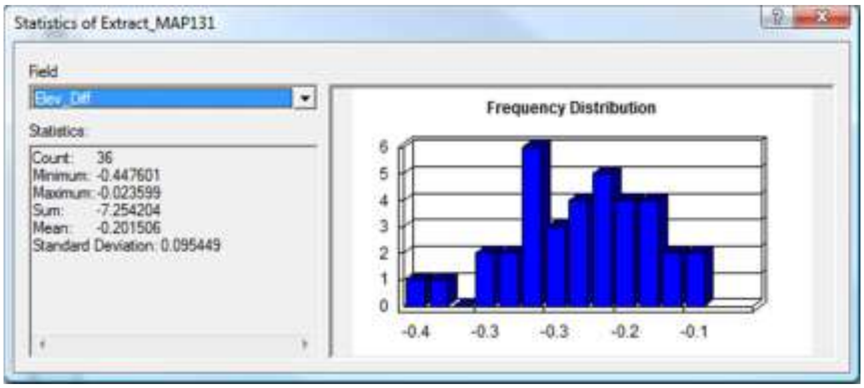
Reference HPN003

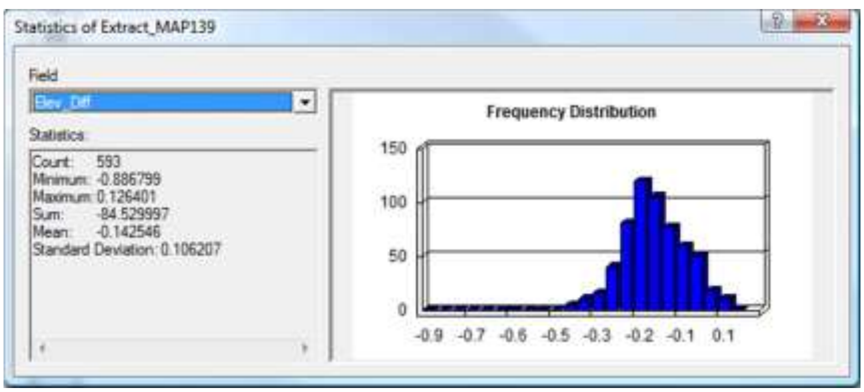


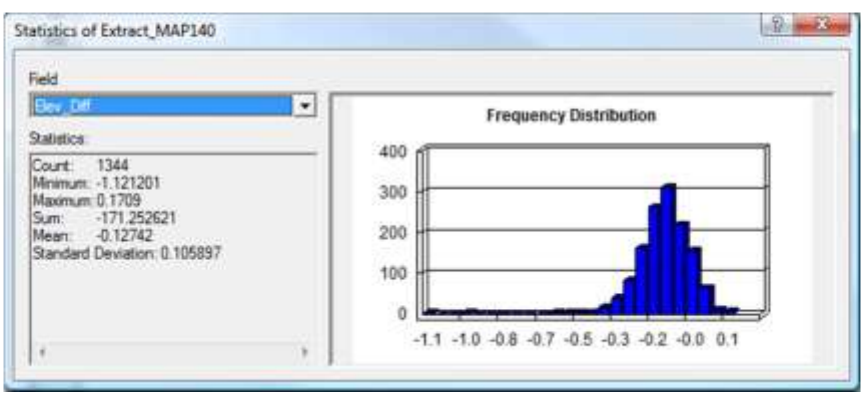
Reference HPN004

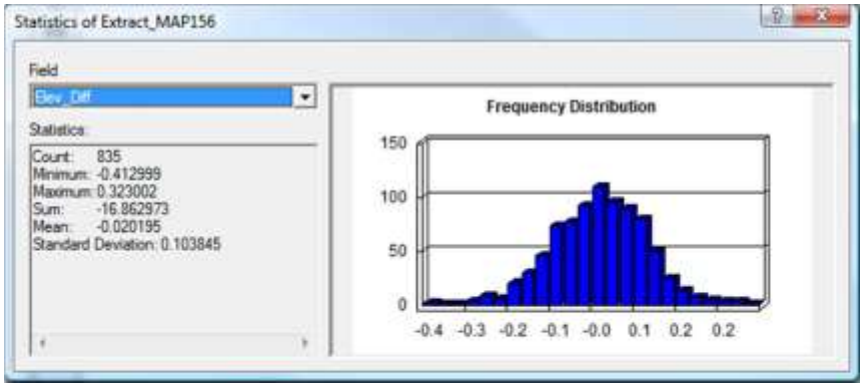


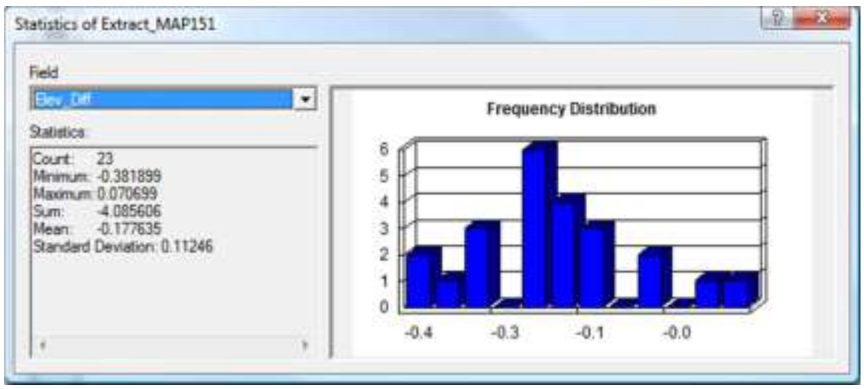

Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2


Statistics of Extract_MAP131
Field
Elev_Diff
Statistics
Count: 36
Minimum: -0.447601
Maximum: -0.023599
Sum: -7.254204
Mean: -0.201506
Standard Deviation: 0.095449
Frequency Distribution
6
5
4
3
2
1
0
-0.4 -0.3 -0.3 -0.2 -0.1

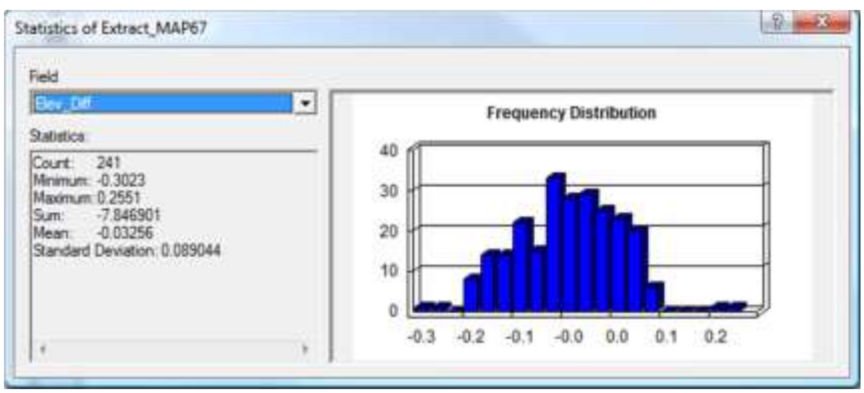

Statistics of Extract_MAP139
Field
Elev_Diff
Statistics
Count: 593
Minimum: -0.886799
Maximum: 0.126401
Sum: -84.529997
Mean: -0.142546
Standard Deviation: 0.106207
Frequency Distribution
150
100
50
0
-0.9 -0.7 -0.6 -0.5 -0.3 -0.2 -0.1 0.1

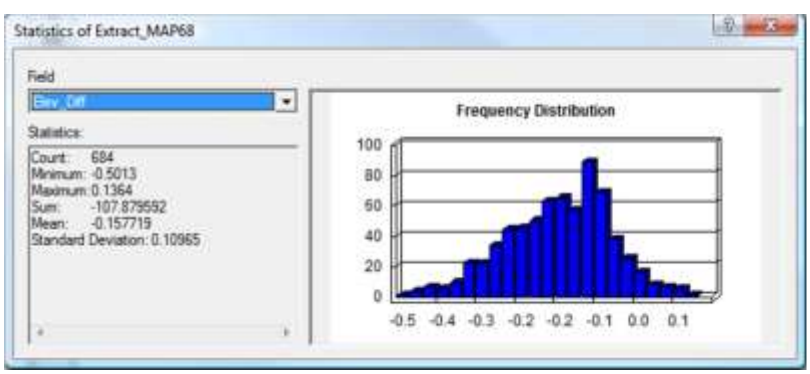

Statistics of Extract_MAP140
Field
Elev_Diff
Statistics
Count: 1344
Minimum: -1.121201
Maximum: 0.1709
Sum: -171.252621
Mean: -0.12742
Standard Deviation: 0.105897
Frequency Distribution
400
300
200
100
0
-1.1 -1.0 -0.8 -0.7 -0.5 -0.3 -0.2 -0.0 0.1

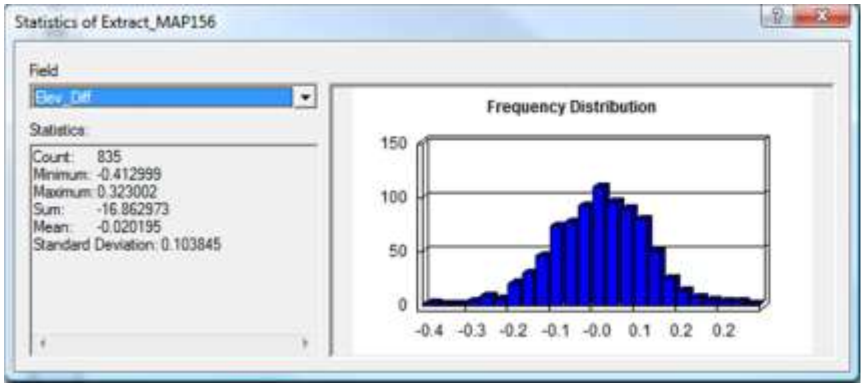


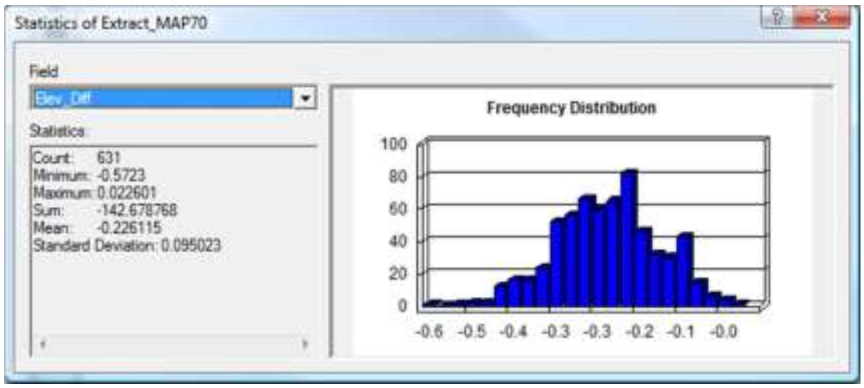


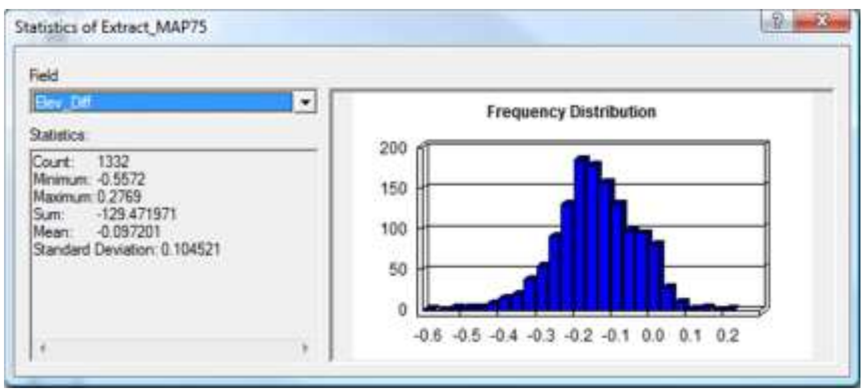
Reference HPN011

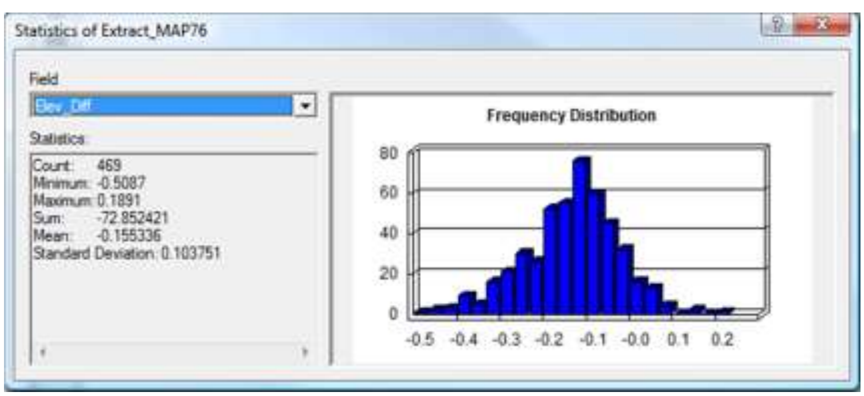


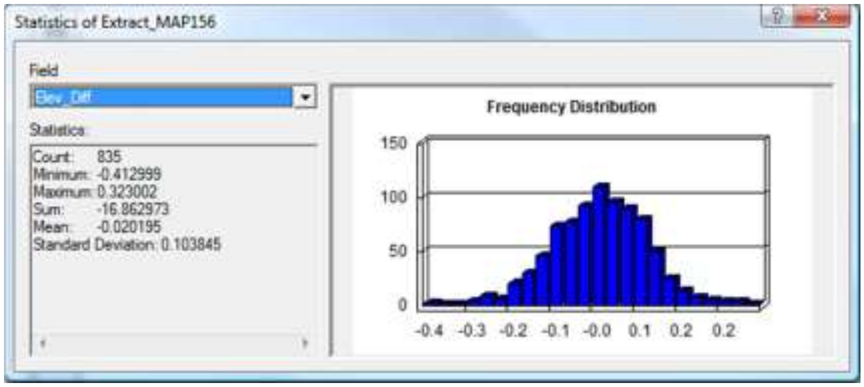



Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2

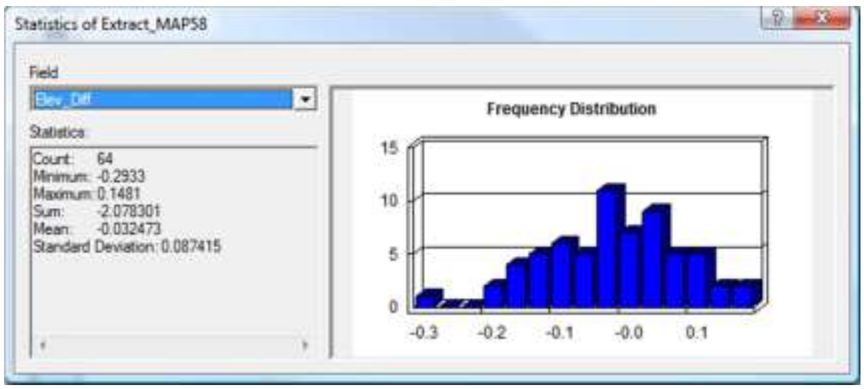

Statistics of Extract_MAP70
Field
Elev_Diff
Statistics
Count: 631
Minimum: -0.5723
Maximum: 0.022601
Sum: -142.678768
Mean: -0.226115
Standard Deviation: 0.095023
Frequency Distribution
100
80
60
40
20
0
-0.6 -0.5 -0.4 -0.3 -0.3 -0.2 -0.1 -0.0

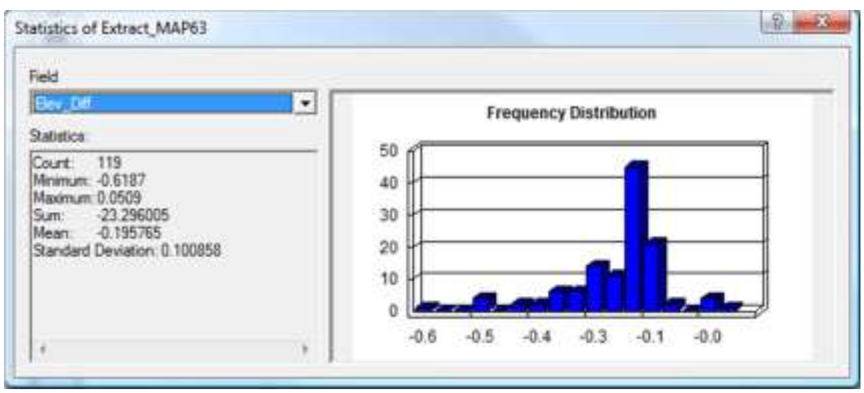

Statistics of Extract_MAP75
Field
Elev_Diff
Statistics
Count: 1332
Minimum: -0.5572
Maximum: 0.2769
Sum: -129.471971
Mean: -0.097201
Standard Deviation: 0.104521
Frequency Distribution
200
150
100
50
0
-0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2

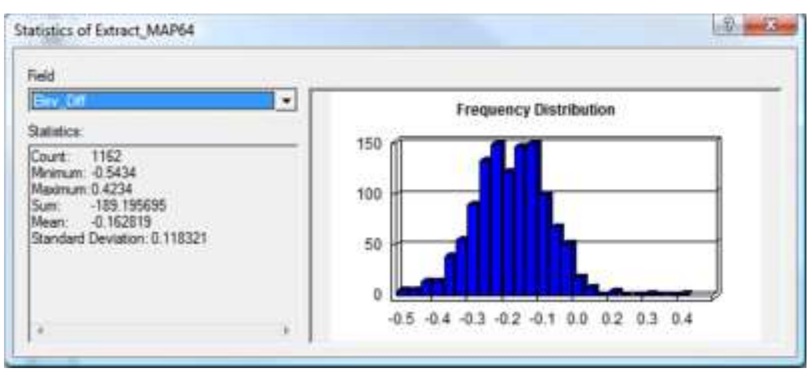

Statistics of Extract_MAP76
Field
Elev_Diff
Statistics
Count: 469
Minimum: -0.5087
Maximum: 0.1891
Sum: -72.852421
Mean: -0.155336
Standard Deviation: 0.103751
Frequency Distribution
80
60
40
20
0
-0.5 -0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2

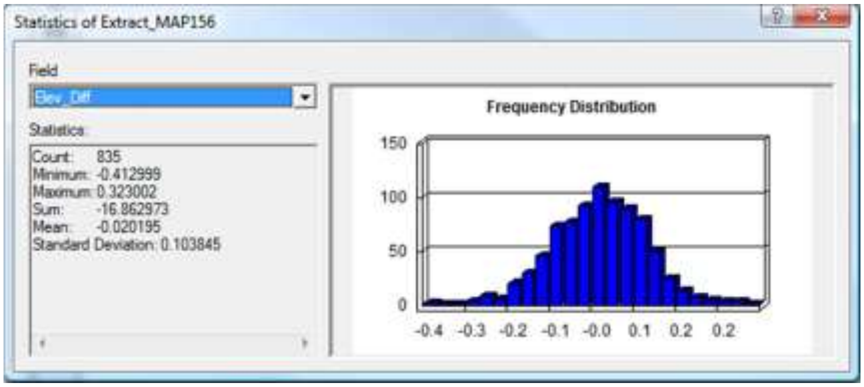


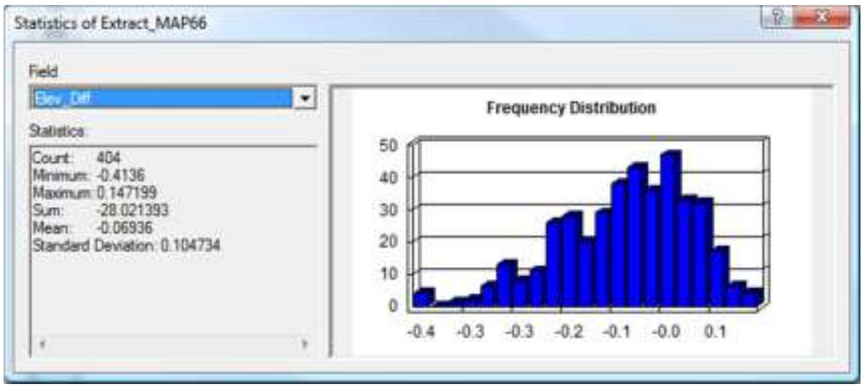
Reference HPN012

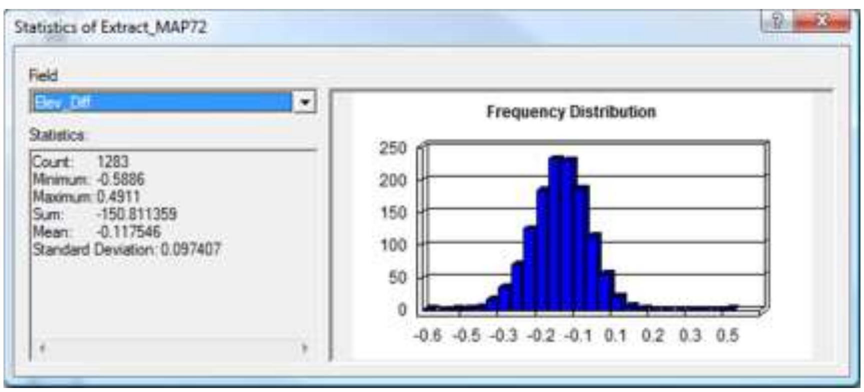


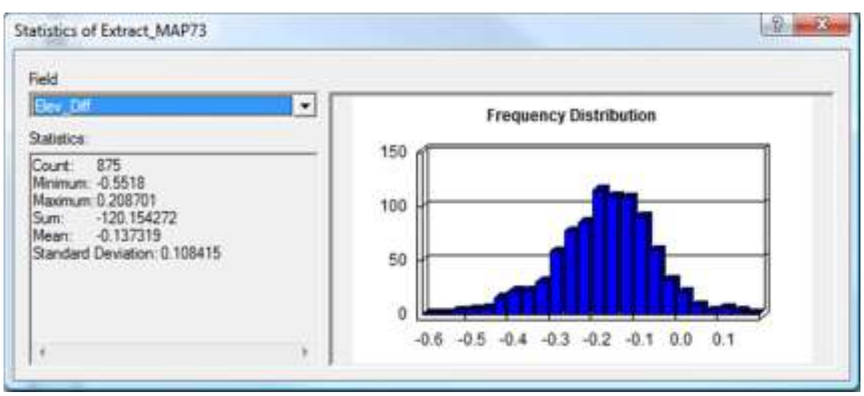


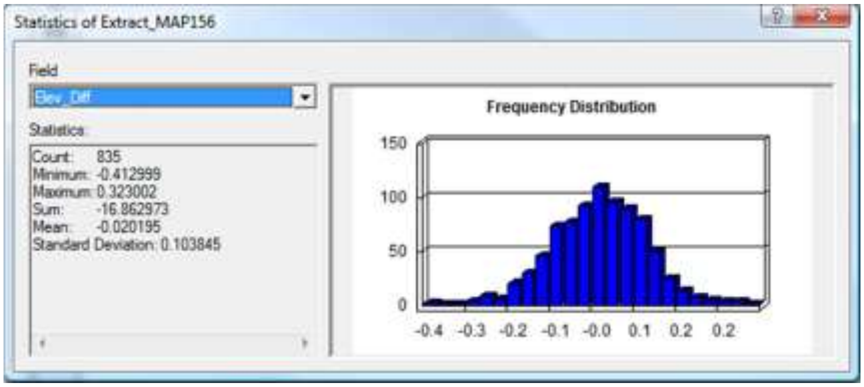


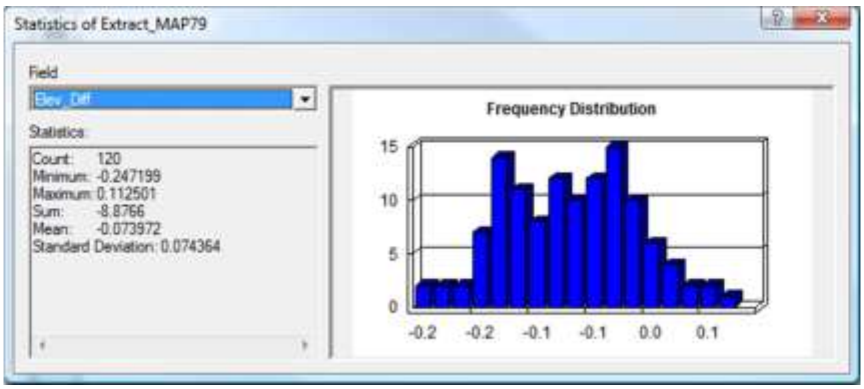

Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution

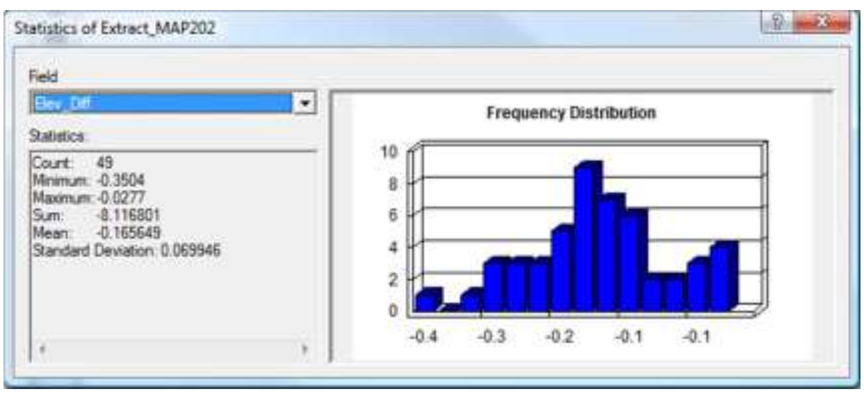

Statistics of Extract_MAP66
Field
Elev_Diff
Statistics
Count: 404
Minimum: -0.4136
Maximum: 0.147199
Sum: -28.021393
Mean: -0.06936
Standard Deviation: 0.104734
Frequency Distribution


Statistics of Extract_MAP72
Field
Elev_Diff
Statistics
Count: 1283
Minimum: -0.5886
Maximum: 0.4911
Sum: -150.811359
Mean: -0.117546
Standard Deviation: 0.097407
Frequency Distribution

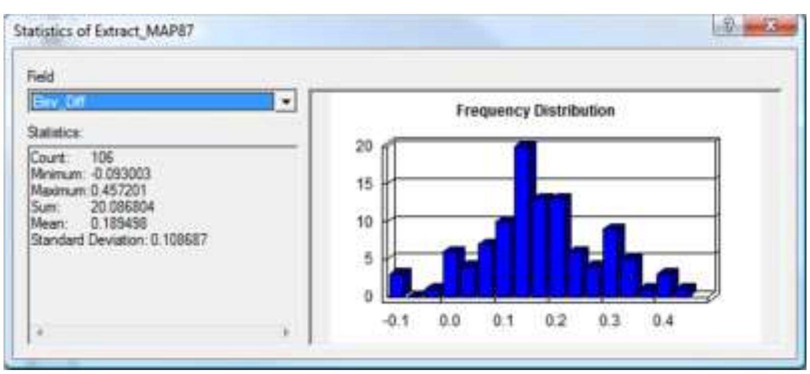

Statistics of Extract_MAP73
Field
Elev_Diff
Statistics
Count: 875
Minimum: -0.5518
Maximum: 0.208701
Sum: -120.154272
Mean: -0.137319
Standard Deviation: 0.108415
Frequency Distribution

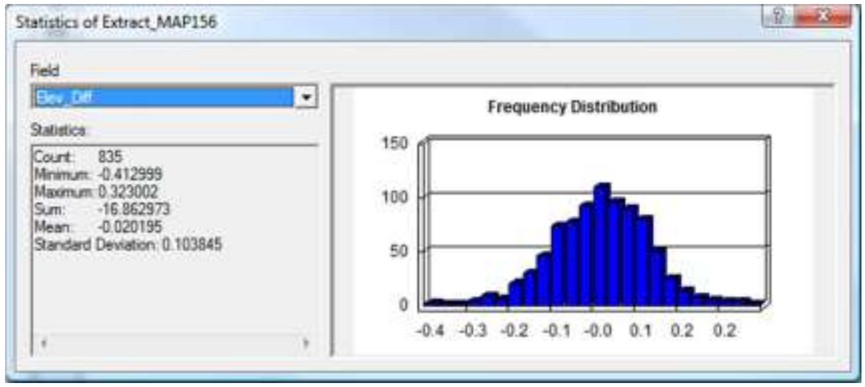


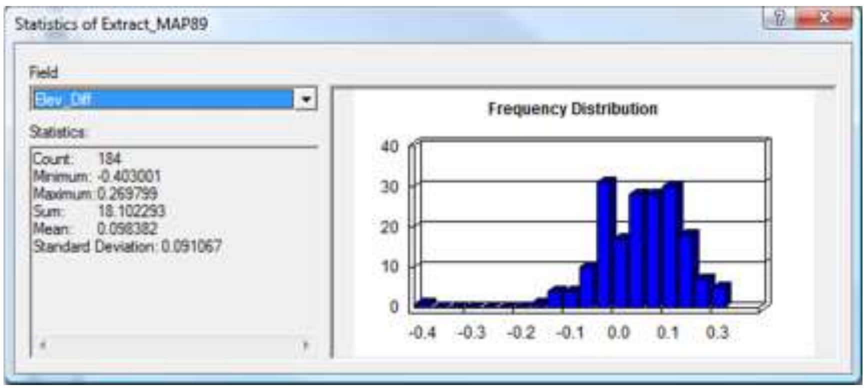


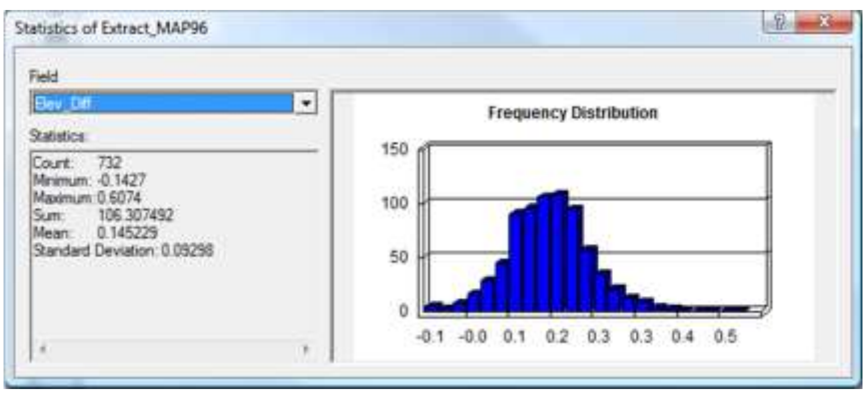


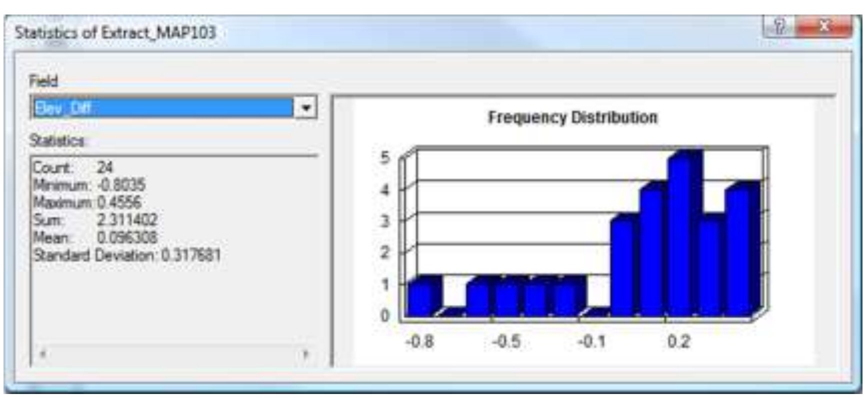
Reference HPN013



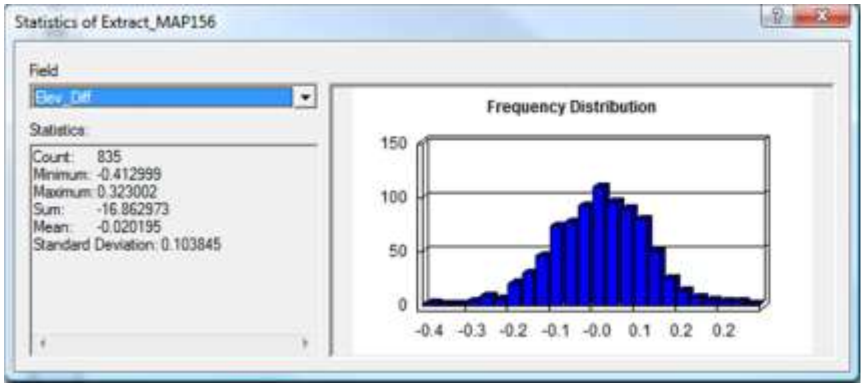


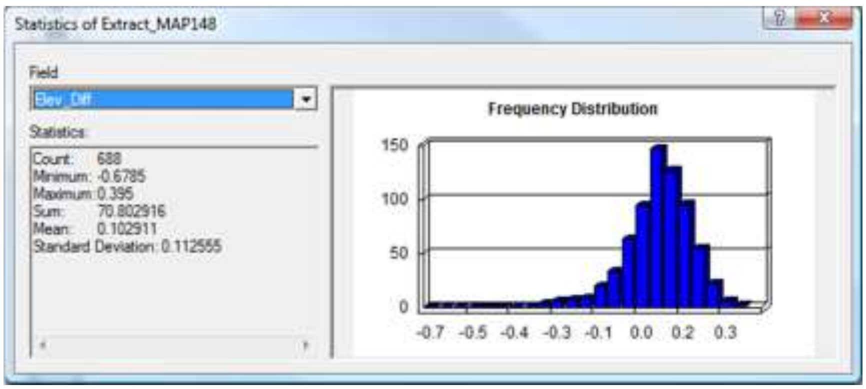


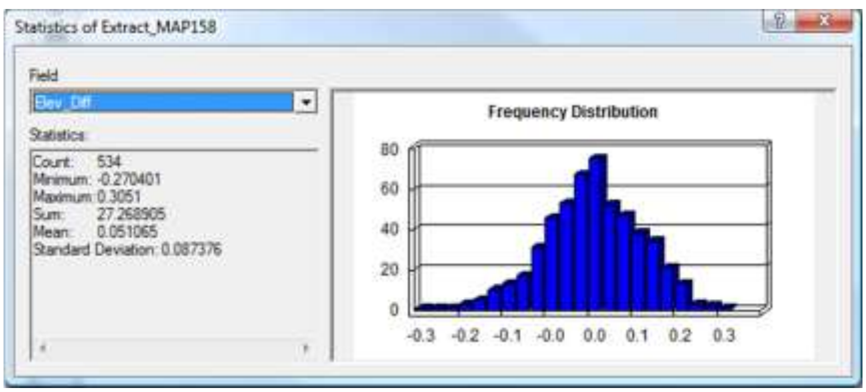


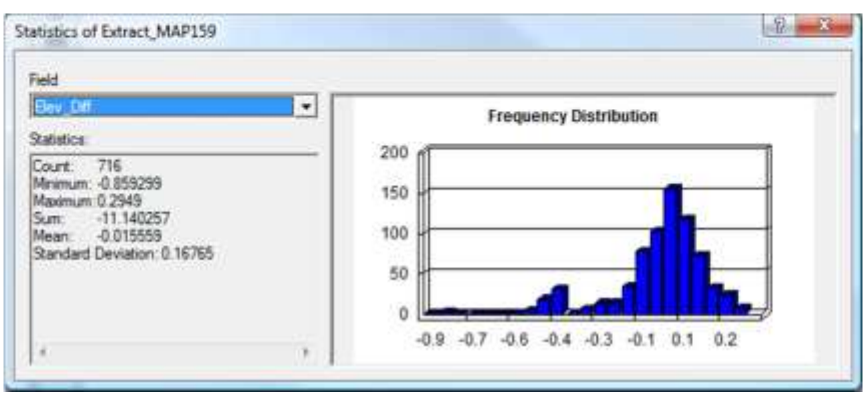


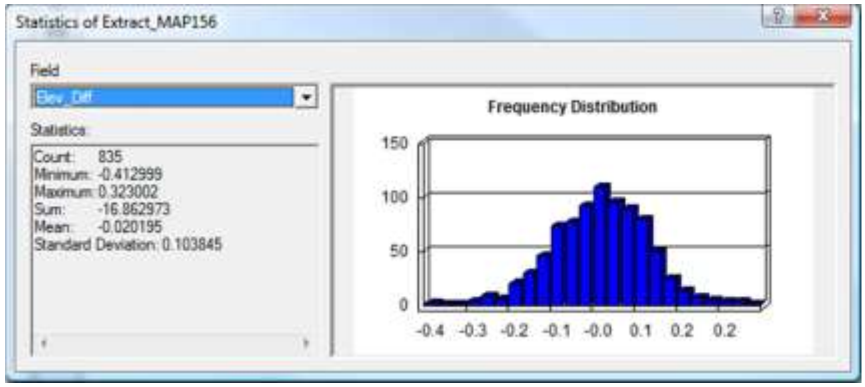
Reference HPN014


Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2

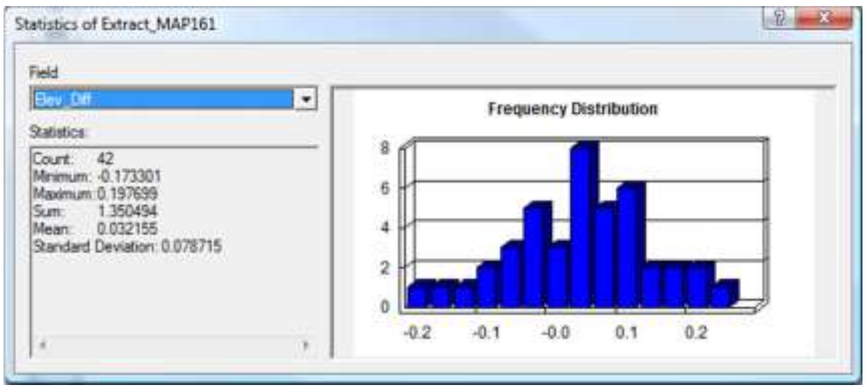

Statistics of Extract_MAP148
Field
Elev_Diff
Statistics
Count: 688
Minimum: -0.6785
Maximum: 0.395
Sum: 70.802916
Mean: 0.102911
Standard Deviation: 0.112555
Frequency Distribution
150
100
50
0
-0.7 -0.5 -0.4 -0.3 -0.1 0.0 0.2 0.3


Statistics of Extract_MAP158
Field
Elev_Diff
Statistics
Count: 534
Minimum: -0.270401
Maximum: 0.3051
Sum: 27.268905
Mean: 0.051065
Standard Deviation: 0.087376
Frequency Distribution
80
60
40
20
0
-0.3 -0.2 -0.1 -0.0 0.0 0.1 0.2 0.3

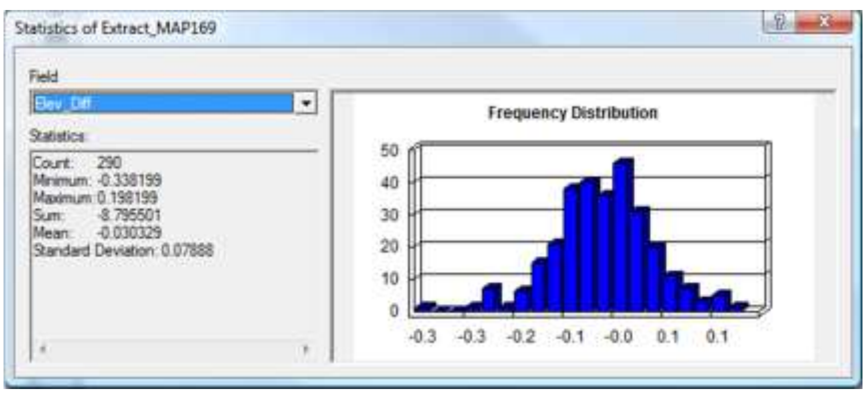

Statistics of Extract_MAP159
Field
Elev_Diff
Statistics
Count: 716
Minimum: -0.859299
Maximum: 0.2949
Sum: -11.140257
Mean: -0.015559
Standard Deviation: 0.16765
Frequency Distribution
200
150
100
50
0
-0.9 -0.7 -0.6 -0.4 -0.3 -0.1 0.1 0.2



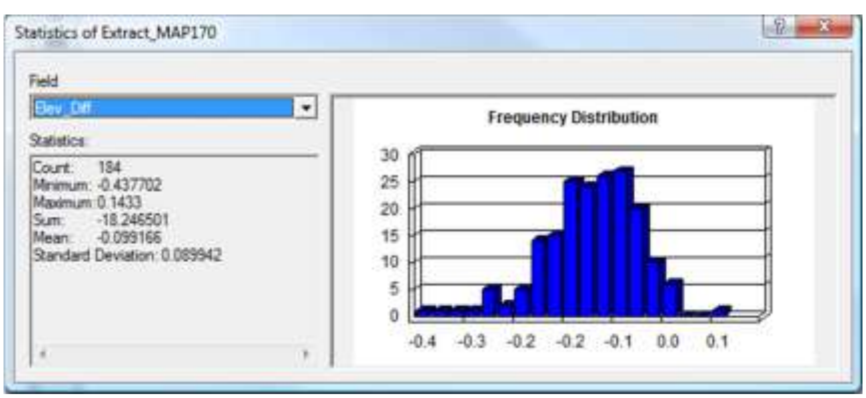
Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2



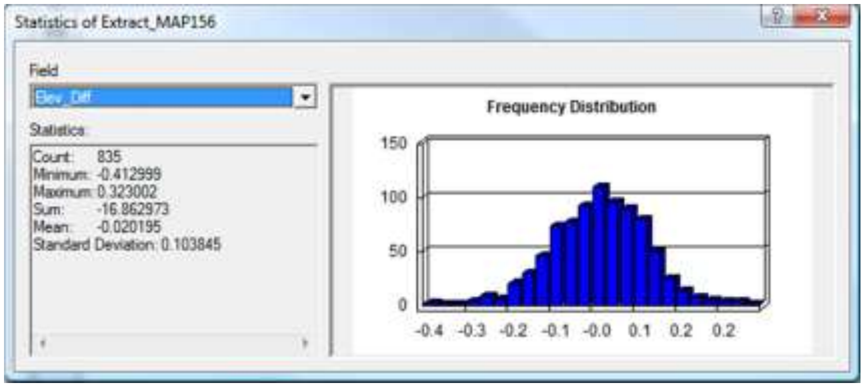
Statistics of Extract_MAP161
Field
Elev_Diff
Statistics
Count: 42
Minimum: -0.173301
Maximum: 0.197699
Sum: 1.350494
Mean: 0.032155
Standard Deviation: 0.078715
Frequency Distribution
8
6
4
2
0
-0.2 -0.1 -0.0 0.1 0.2



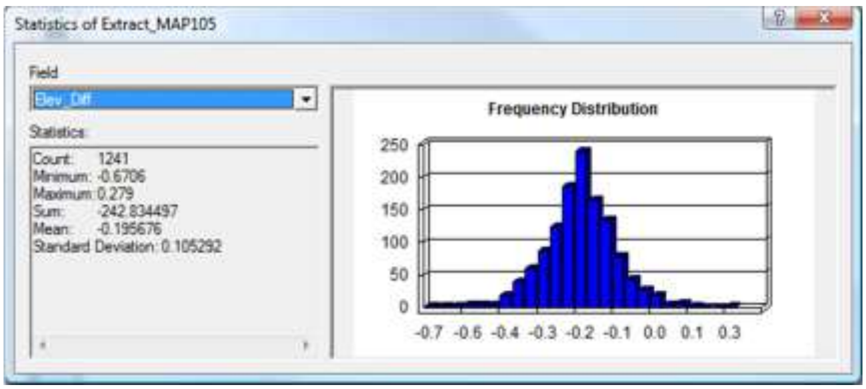
Statistics of Extract_MAP169
Field
Elev_Diff
Statistics
Count: 290
Minimum: -0.338199
Maximum: 0.198199
Sum: -8.795501
Mean: -0.030329
Standard Deviation: 0.07888
Frequency Distribution
50
40
30
20
10
0
-0.3 -0.3 -0.2 -0.1 -0.0 0.1 0.1

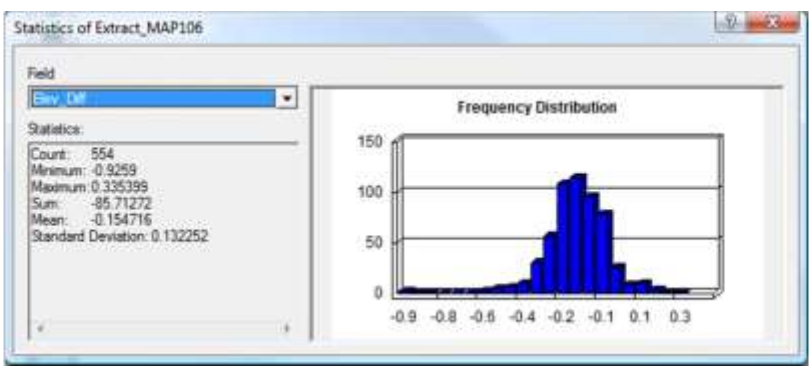


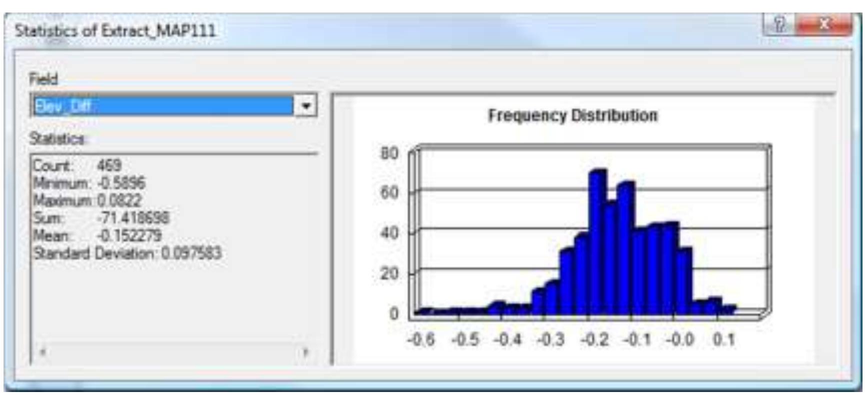
Statistics of Extract_MAP170
Field
Elev_Diff
Statistics
Count: 184
Minimum: -0.437702
Maximum: 0.1433
Sum: -18.246501
Mean: -0.099166
Standard Deviation: 0.089942
Frequency Distribution
30
25
20
15
10
5
0
-0.4 -0.3 -0.2 -0.2 -0.1 0.0 0.1

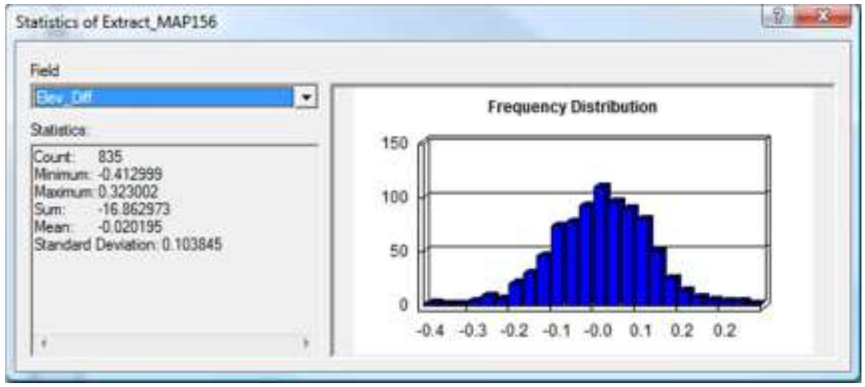


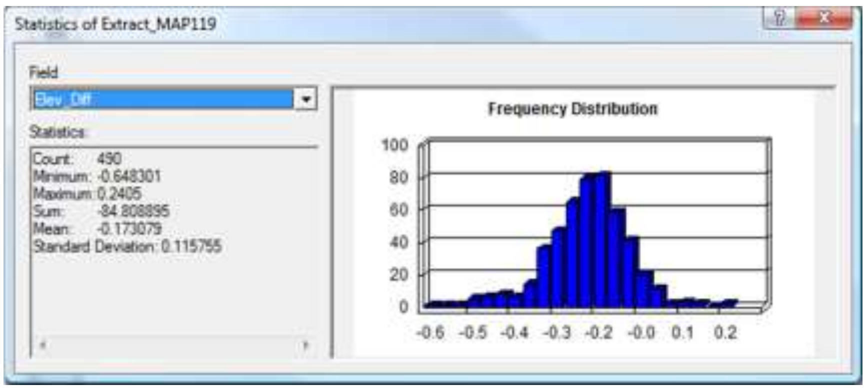
Reference HPN016

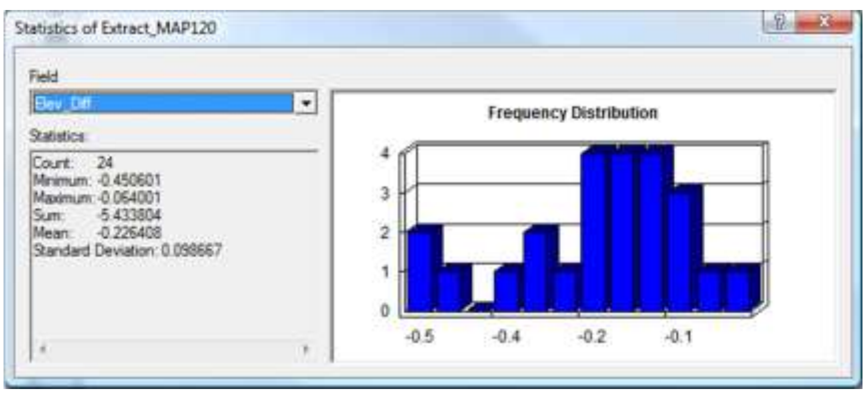




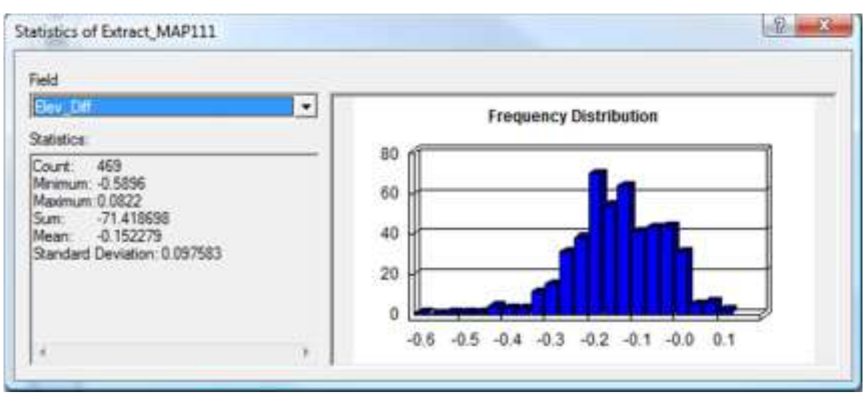


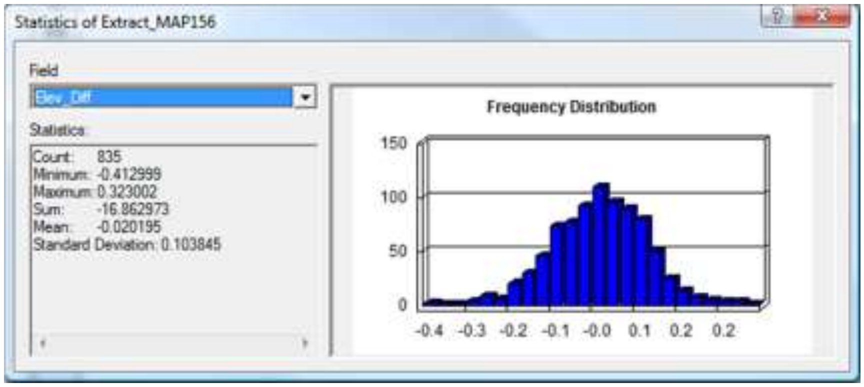


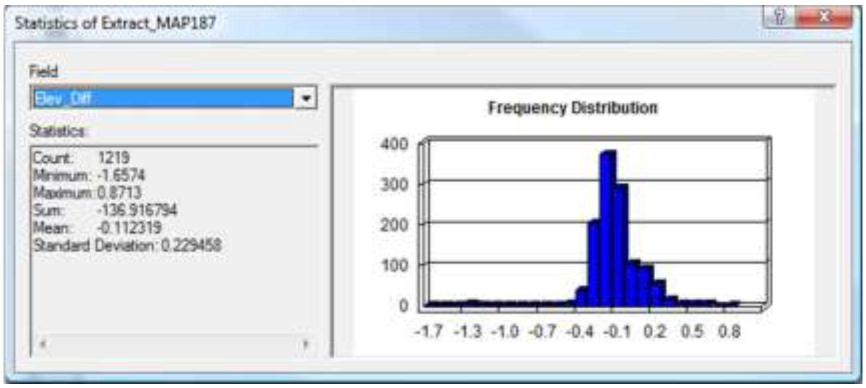


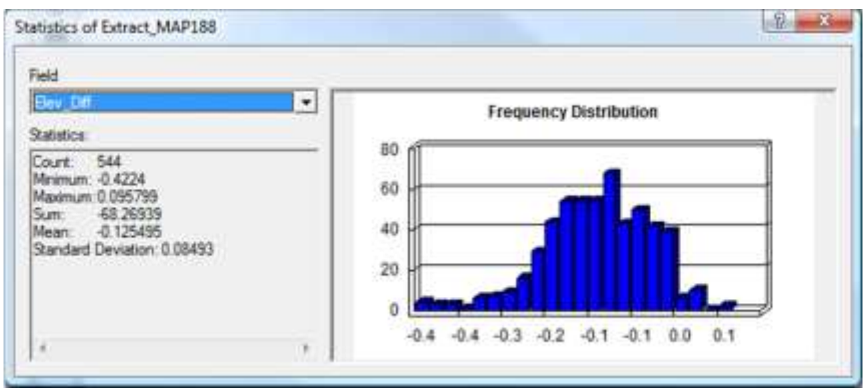


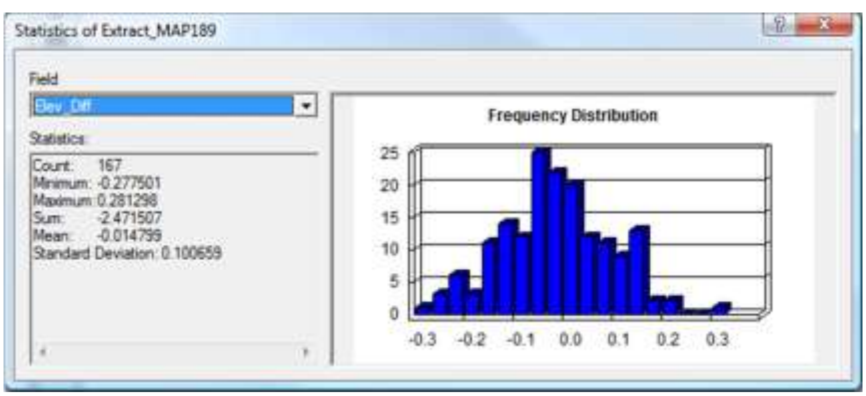
Reference HPN020

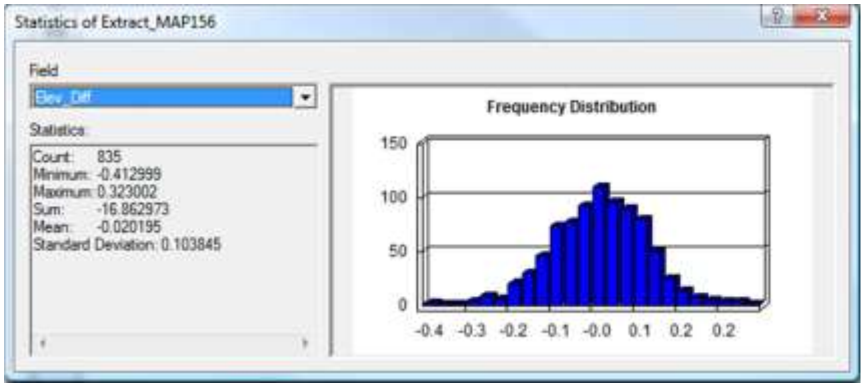


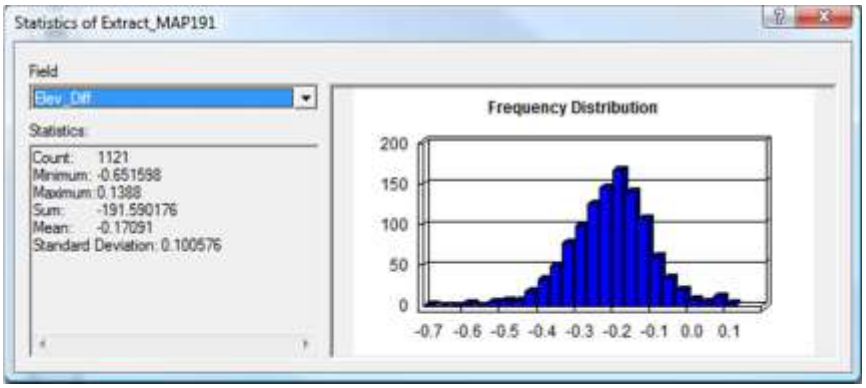

Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2

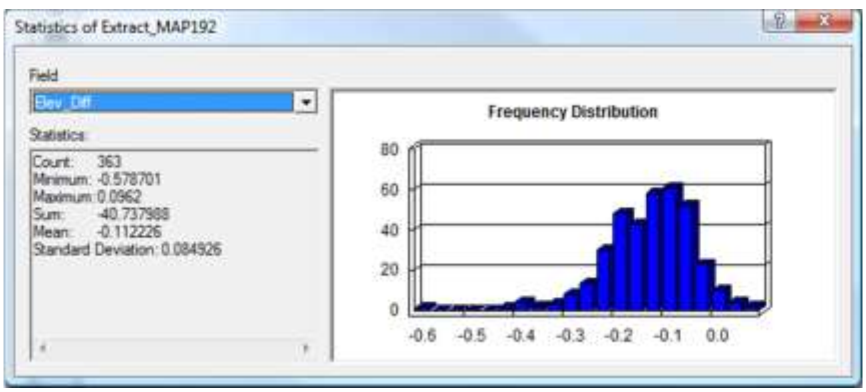

Statistics of Extract_MAP187
Field
Elev_Diff
Statistics
Count: 1219
Minimum: -1.6574
Maximum: 0.8713
Sum: -136.916794
Mean: -0.112319
Standard Deviation: 0.229458
Frequency Distribution
400
300
200
100
0
-1.7 -1.3 -1.0 -0.7 -0.4 -0.1 0.2 0.5 0.8

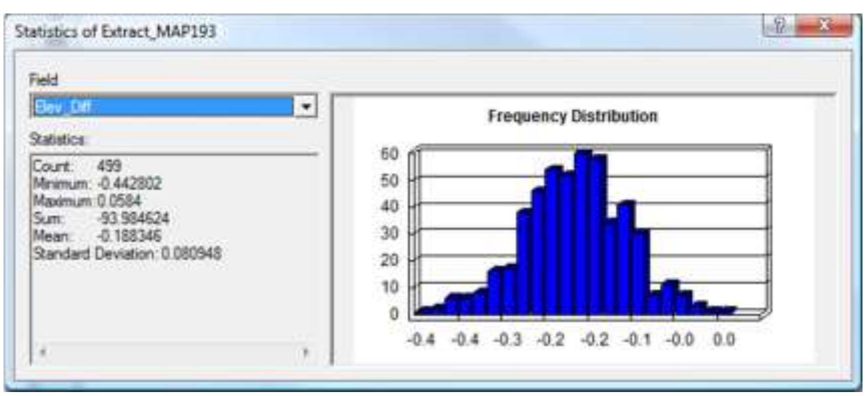

Statistics of Extract_MAP188
Field
Elev_Diff
Statistics
Count: 544
Minimum: -0.4224
Maximum: 0.095799
Sum: -68.26939
Mean: -0.125495
Standard Deviation: 0.08493
Frequency Distribution
80
60
40
20
0
-0.4 -0.4 -0.3 -0.2 -0.1 -0.1 0.0 0.1

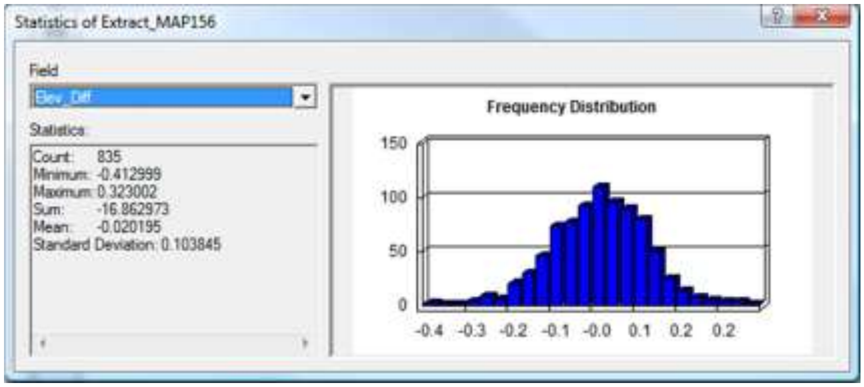

Statistics of Extract_MAP189
Field
Elev_Diff
Statistics
Count: 167
Minimum: -0.277501
Maximum: 0.281298
Sum: -2.471507
Mean: -0.014799
Standard Deviation: 0.100659
Frequency Distribution
25
20
15
10
5
0
-0.3 -0.2 -0.1 0.0 0.1 0.2 0.3

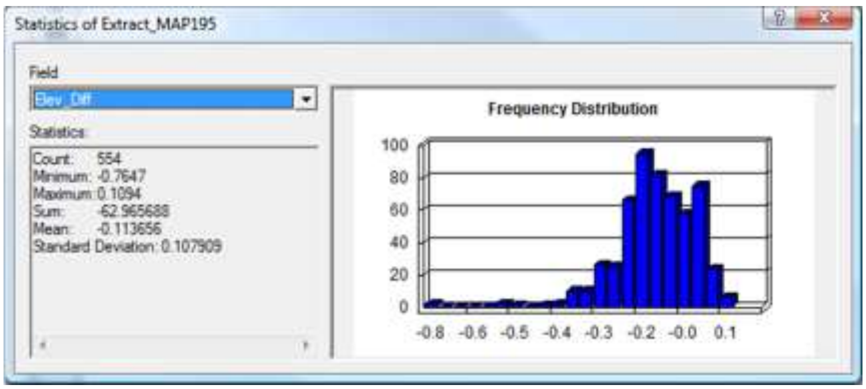

Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2

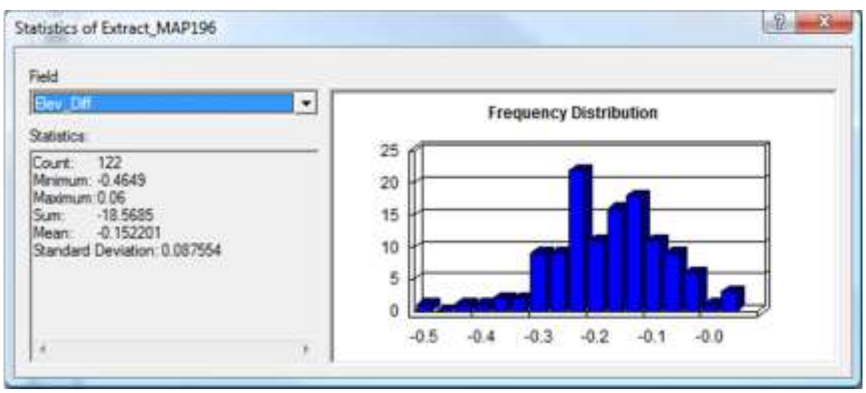

Statistics of Extract_MAP191
Field
Elev_Diff
Statistics
Count: 1121
Minimum: -0.651598
Maximum: 0.1388
Sum: -191.590176
Mean: -0.17091
Standard Deviation: 0.100576
Frequency Distribution
200
150
100
50
0
-0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1


Statistics of Extract_MAP192
Field
Elev_Diff
Statistics
Count: 363
Minimum: -0.578701
Maximum: 0.0962
Sum: -40.737988
Mean: -0.112226
Standard Deviation: 0.084926
Frequency Distribution
80
60
40
20
0
-0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0.0

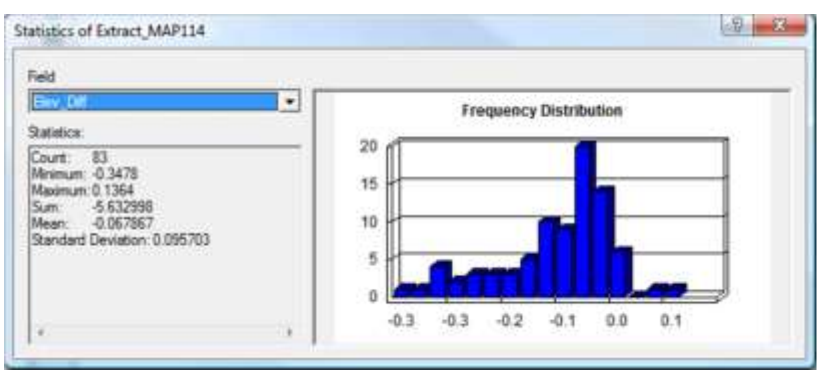

Statistics of Extract_MAP193
Field
Elev_Diff
Statistics
Count: 499
Minimum: -0.442802
Maximum: 0.0584
Sum: -93.984624
Mean: -0.188346
Standard Deviation: 0.080948
Frequency Distribution
60
50
40
30
20
10
0
-0.4 -0.4 -0.3 -0.2 -0.2 -0.1 -0.0 0.0

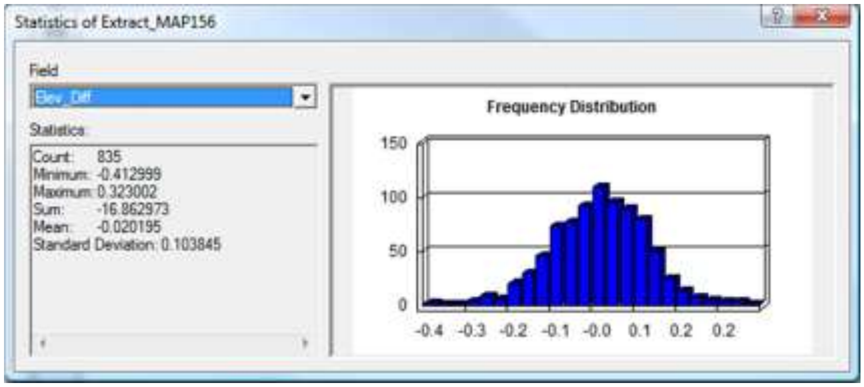


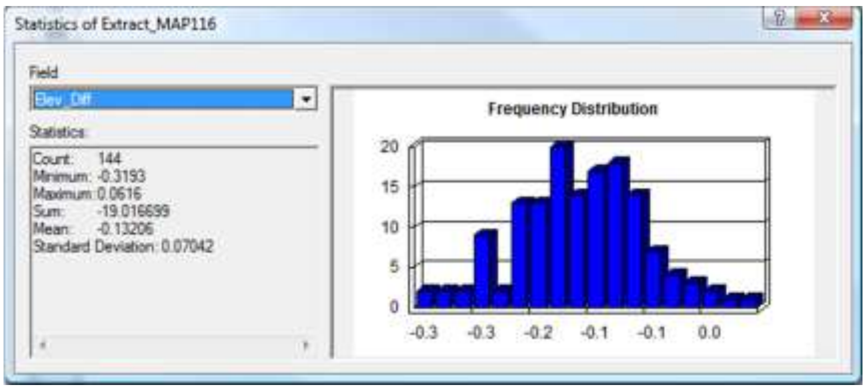


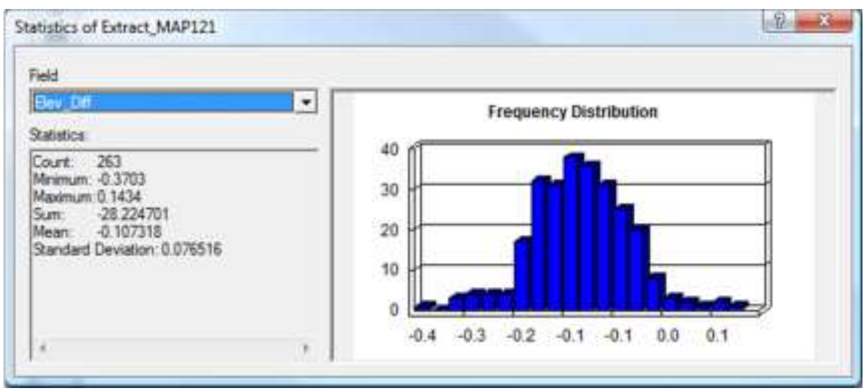


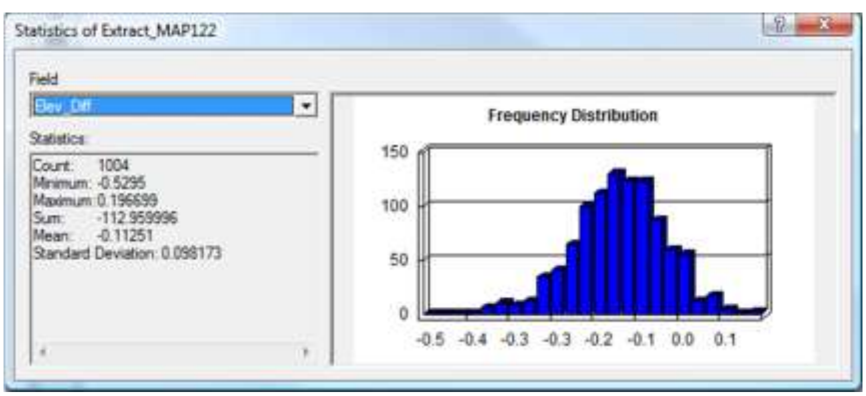
Reference HPN022

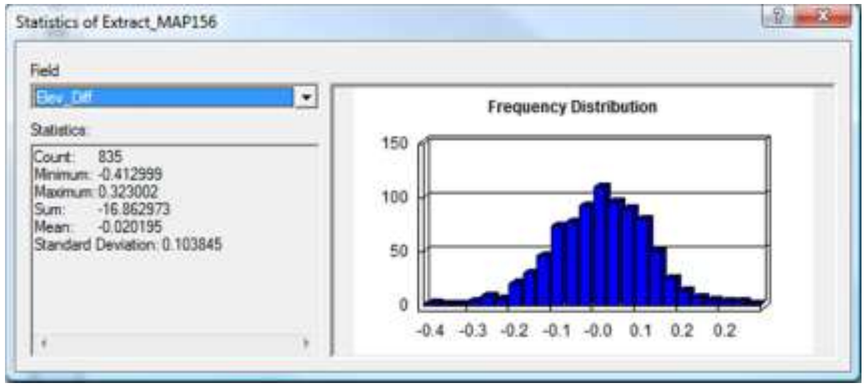


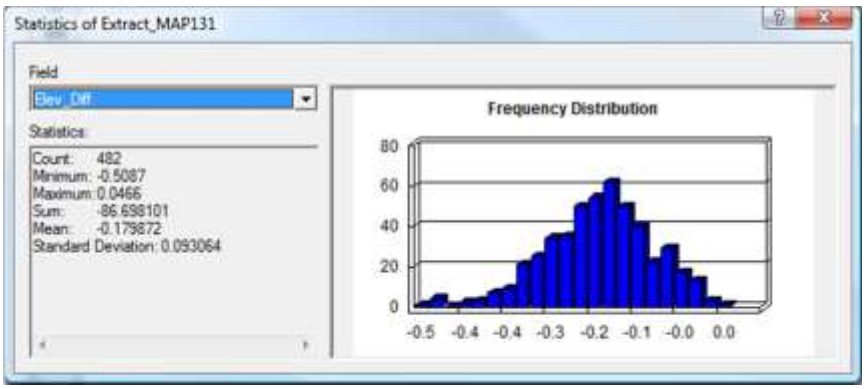

Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2

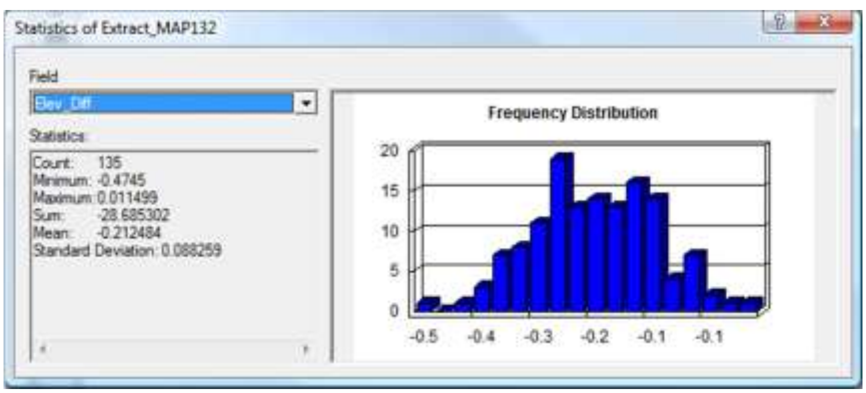

Statistics of Extract_MAP116
Field
Elev_Diff
Statistics
Count: 144
Minimum: -0.3193
Maximum: 0.0616
Sum: -19.016699
Mean: -0.13206
Standard Deviation: 0.07042
Frequency Distribution
20
15
10
5
0
-0.3 -0.3 -0.2 -0.1 -0.1 0.0


Statistics of Extract_MAP121
Field
Elev_Diff
Statistics
Count: 263
Minimum: -0.3703
Maximum: 0.1434
Sum: -28.224701
Mean: -0.107318
Standard Deviation: 0.076516
Frequency Distribution
40
30
20
10
0
-0.4 -0.3 -0.2 -0.1 -0.1 0.0 0.1

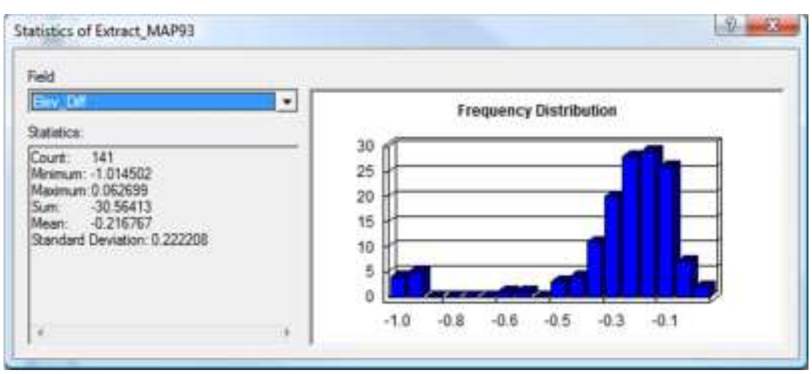

Statistics of Extract_MAP122
Field
Elev_Diff
Statistics
Count: 1004
Minimum: -0.5295
Maximum: 0.196699
Sum: -112.959996
Mean: -0.11251
Standard Deviation: 0.098173
Frequency Distribution
150
100
50
0
-0.5 -0.4 -0.3 -0.3 -0.2 -0.1 0.0 0.1

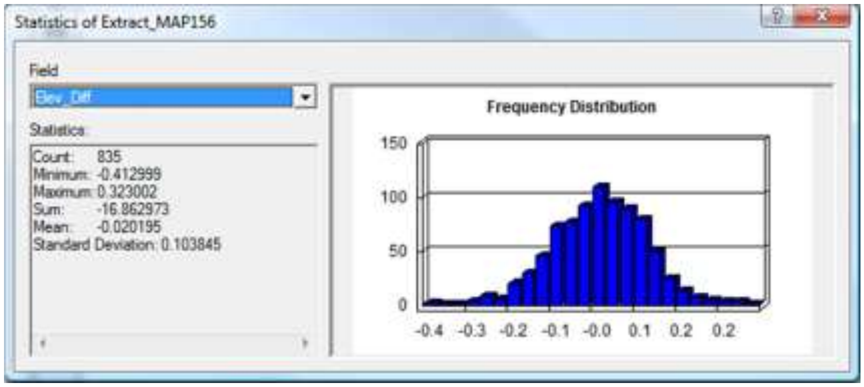


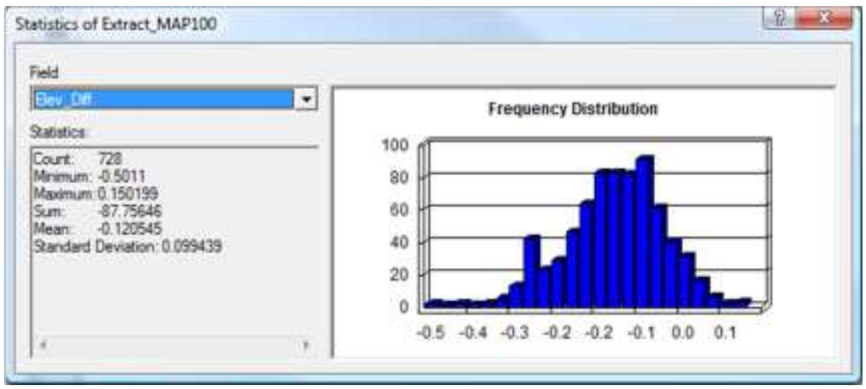


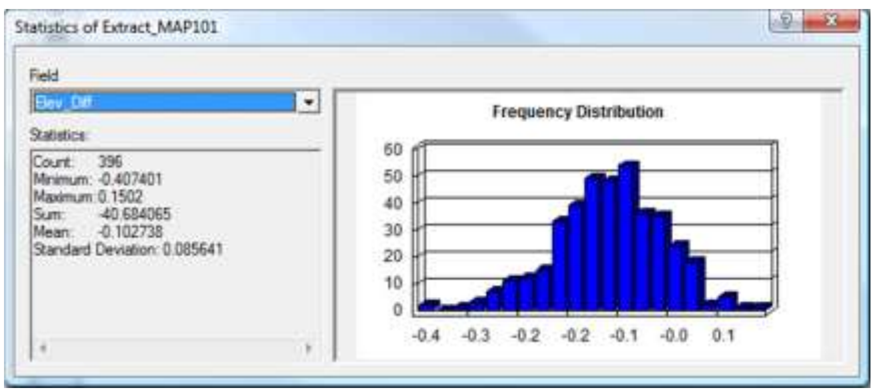


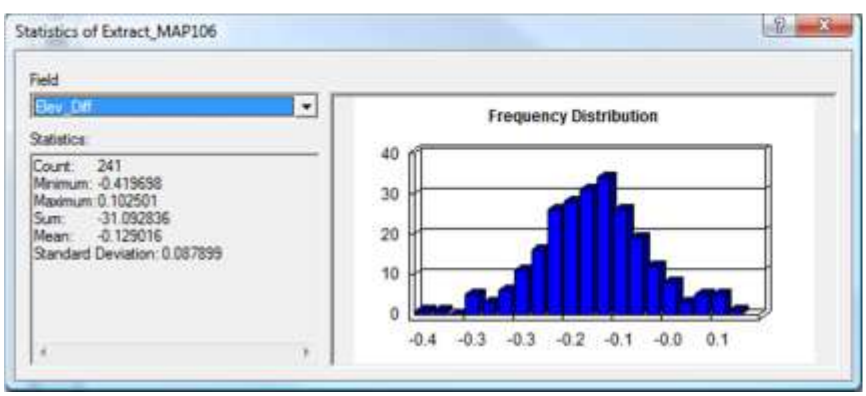
Reference HPN023

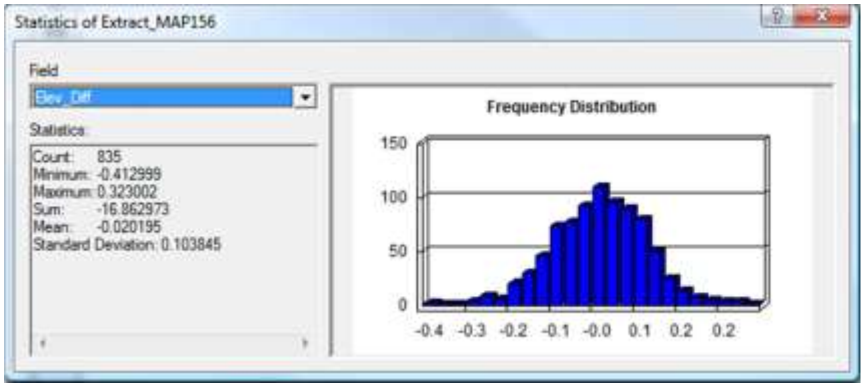


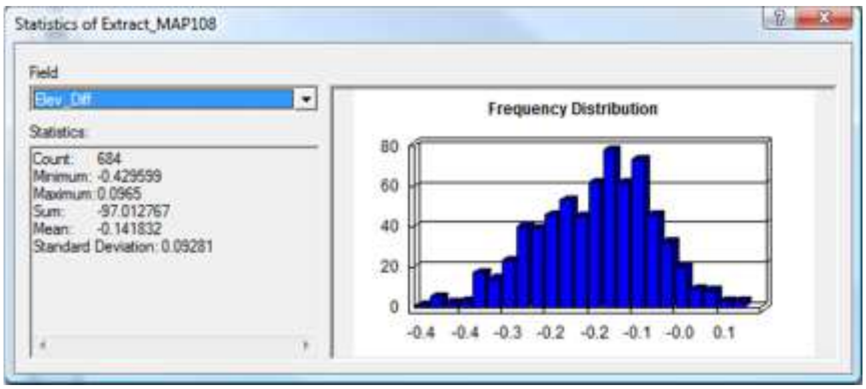

Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2


Statistics of Extract_MAP100
Field
Elev_Diff
Statistics
Count: 728
Minimum: -0.5011
Maximum: 0.150199
Sum: -87.75646
Mean: -0.120545
Standard Deviation: 0.099439
Frequency Distribution
100
80
60
40
20
0
-0.5 -0.4 -0.3 -0.2 -0.2 -0.1 0.0 0.1

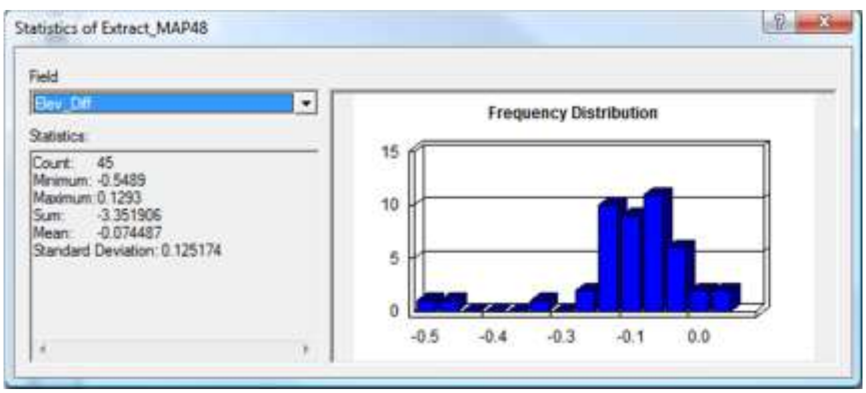

Statistics of Extract_MAP101
Field
Elev_Diff
Statistics
Count: 396
Minimum: -0.407401
Maximum: 0.1502
Sum: -40.684065
Mean: -0.102738
Standard Deviation: 0.085641
Frequency Distribution
60
50
40
30
20
10
0
-0.4 -0.3 -0.2 -0.2 -0.1 -0.0 0.1

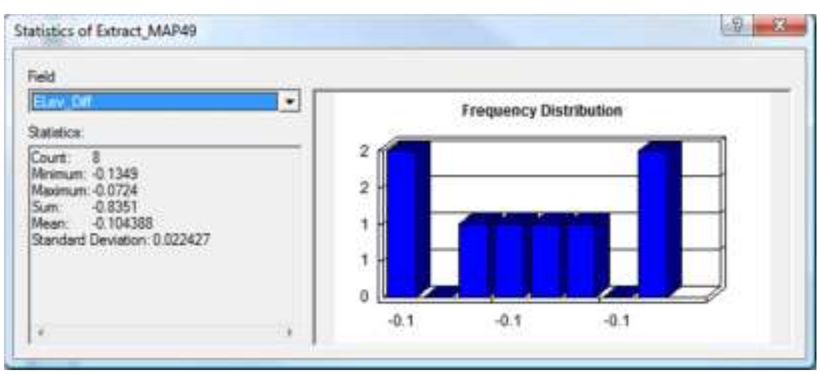

Statistics of Extract_MAP106
Field
Elev_Diff
Statistics
Count: 241
Minimum: -0.419698
Maximum: 0.102501
Sum: -31.092836
Mean: -0.129016
Standard Deviation: 0.087899
Frequency Distribution
40
30
20
10
0
-0.4 -0.3 -0.3 -0.2 -0.1 -0.0 0.1

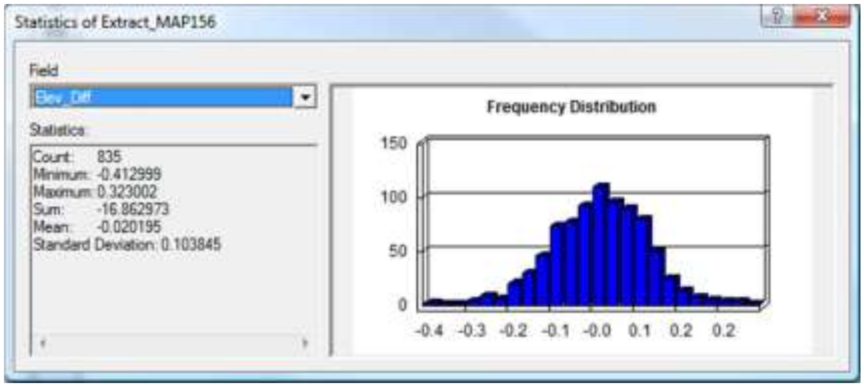


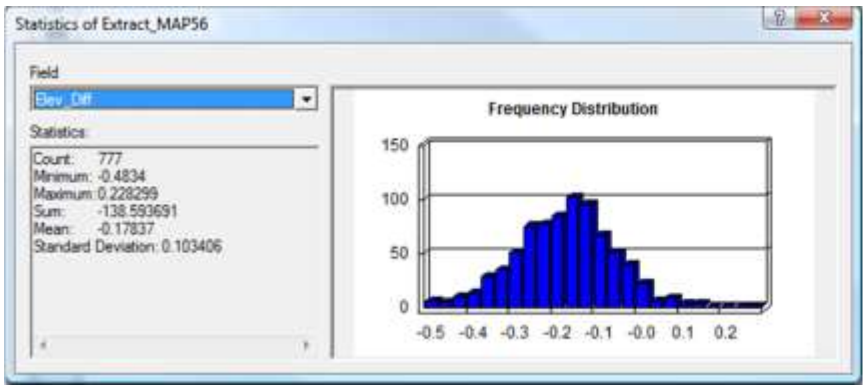


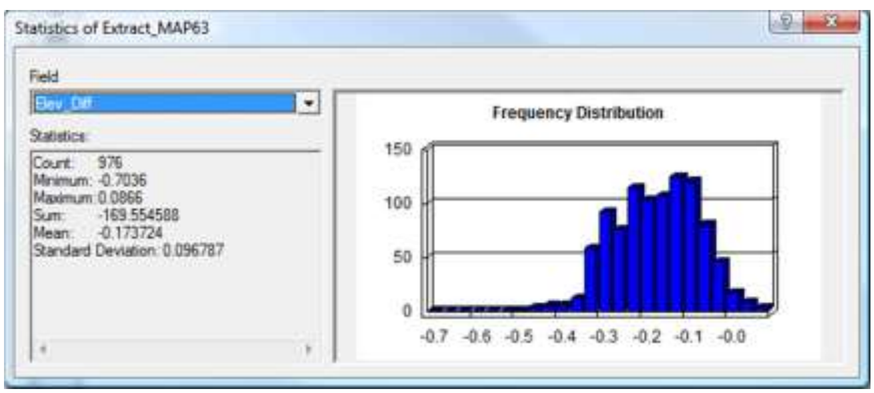
Reference HPN027

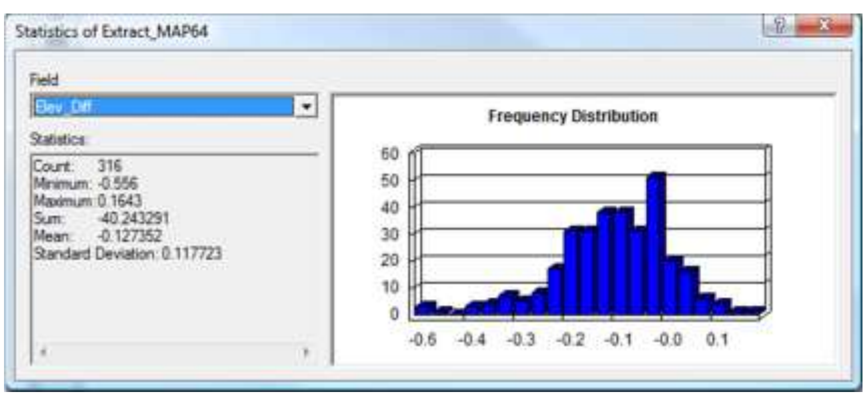


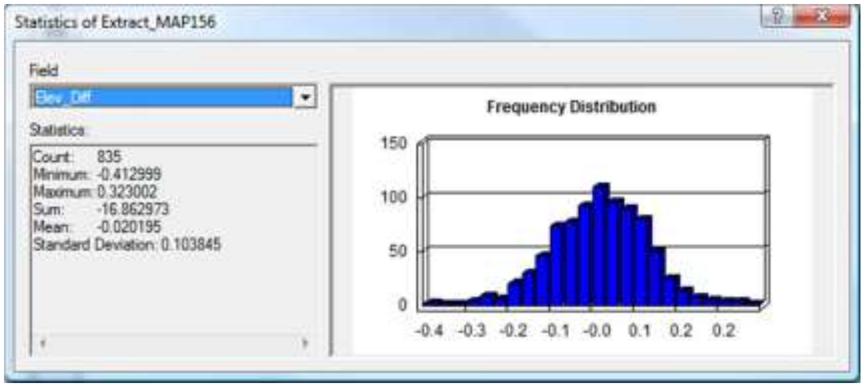


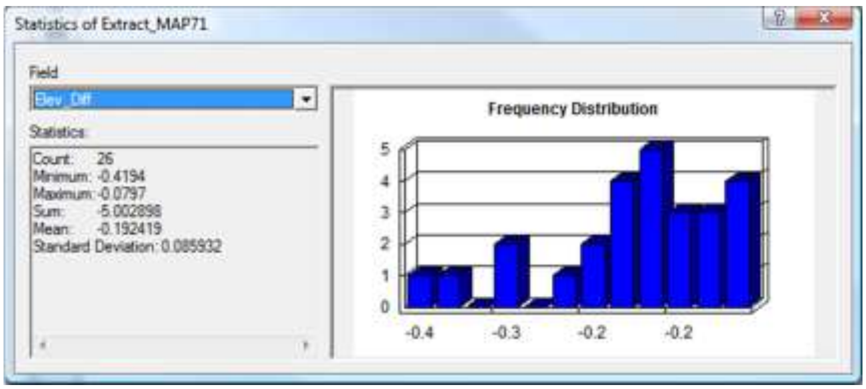

Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2

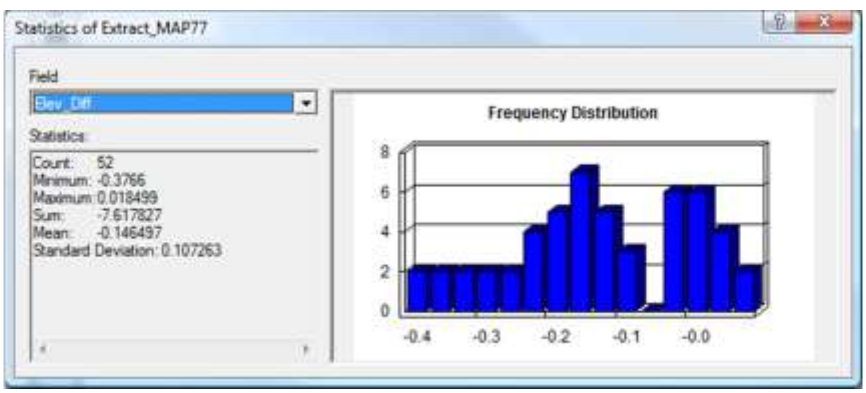

Statistics of Extract_MAP56
Field
Elev_Diff
Statistics
Count: 777
Minimum: -0.4834
Maximum: 0.228299
Sum: -138.593691
Mean: -0.17837
Standard Deviation: 0.103406
Frequency Distribution
150
100
50
0
-0.5 -0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2


Statistics of Extract_MAP63
Field
Elev_Diff
Statistics
Count: 976
Minimum: -0.7036
Maximum: 0.0866
Sum: -169.554588
Mean: -0.173724
Standard Deviation: 0.096787
Frequency Distribution
150
100
50
0
-0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 -0.0


Statistics of Extract_MAP64
Field
Elev_Diff
Statistics
Count: 316
Minimum: -0.556
Maximum: 0.1643
Sum: -40.243291
Mean: -0.127352
Standard Deviation: 0.117723
Frequency Distribution
60
50
40
30
20
10
0
-0.6 -0.4 -0.3 -0.2 -0.1 -0.0 0.1


Statistics of Extract_MAP156
Field
Elev_Diff
Statistics
Count: 835
Minimum: -0.412999
Maximum: 0.323002
Sum: -16.862973
Mean: -0.020195
Standard Deviation: 0.103845
Frequency Distribution
150
100
50
0
-0.4 -0.3 -0.2 -0.1 -0.0 0.1 0.2 0.2


Statistics of Extract_MAP71
Field
Elev_Diff
Statistics
Count: 26
Minimum: -0.4194
Maximum: -0.0797
Sum: -5.002898
Mean: -0.192419
Standard Deviation: 0.085932
Frequency Distribution
5
4
3
2
1
0
-0.4 -0.3 -0.2 -0.2


Statistics of Extract_MAP77
Field
Elev_Diff
Statistics
Count: 52
Minimum: -0.3766
Maximum: 0.018499
Sum: -7.617827
Mean: -0.146497
Standard Deviation: 0.107263
Frequency Distribution
8
6
4
2
0
-0.4 -0.3 -0.2 -0.1 -0.0