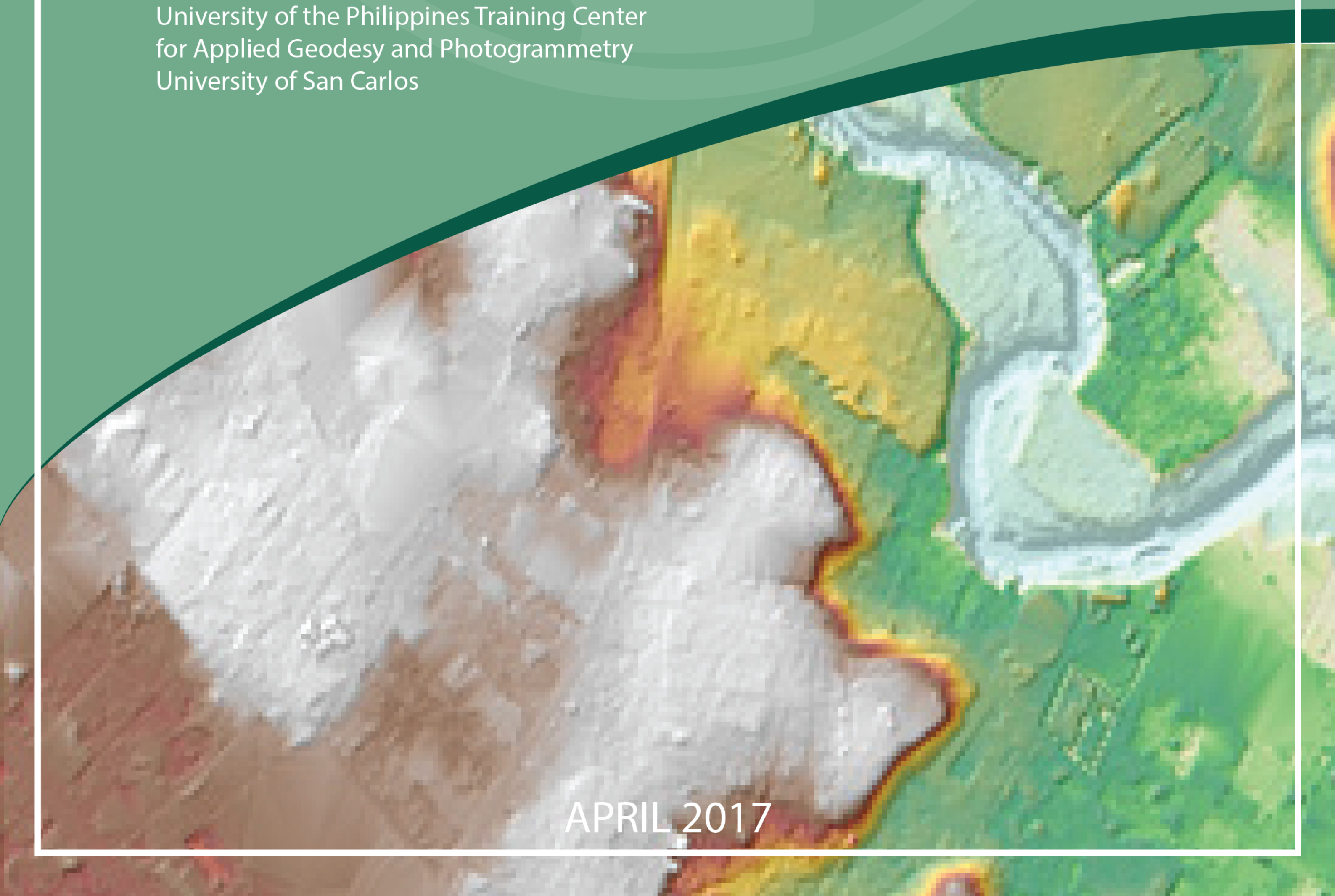
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Kotkot River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of San Carlos



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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DA-BSWM	Department of Agriculture - Bureau of Soil and Water Management
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]

IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
USC	University of San Carlos
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND KOTKOT RIVER

Enrico C. Paringit, Dr. Eng. and Dr. Roland Otadoy

1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program entitled “Nationwide Hazard Mapping using LiDAR” or Phil-LiDAR 1 in 2014, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods described in this report are thoroughly described in a separate publication entitled “Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods (Paringit, et. al., 2017) available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of San Carlos (USC). USC is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 18 river basins in the Central Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Kotkot River Basin

The Kotkot River Basin covers the Municipalities of Liloan and Compostela, and Cebu City, Province of Cebu. The DENR River Basin Control Office identified the basin to have a drainage area of 82 km2 and an estimate annual runoff of 49 million cubic meter (MCM) (RBCO, 2015).

Its main stem, Kotkot River, is part of the seventeen (17) river systems in Central Visayas Region under the PHIL-LIDAR 1 partner HEI, University of San Carlos Cebu (USC). According to the 2015 national census of NSO, a total of 8,778 persons are residing within the immediate vicinity of the river which is distributed among two barangays in the Municipality of Liloan namely: Cabadiangan and Kotkot. The Municipality of Liloan is locally known to be producers of ceramic items such as plant pots, bricks, jars, etc. Another is its producing and marketing local biscuits known as Ronquillos. The marketing of Ronquillos provides livelihood to the locals (Source: http://liloan.gov.ph/). Last December 2014, Typhoon Ruby, internationally known as Hagupit, devastated Southern Luzon and Visayas region; moreover, the province of Cebu was placed under storm signal number 2 by the National Disaster Risk Reduction Management Council. In the Municipality of Liloan, around 1,000 families were evacuated (Source: http://www.rappler.com/move-ph/issues/disasters/typhoon-ruby/77291-abandoned-baby-liloan-rubyph).

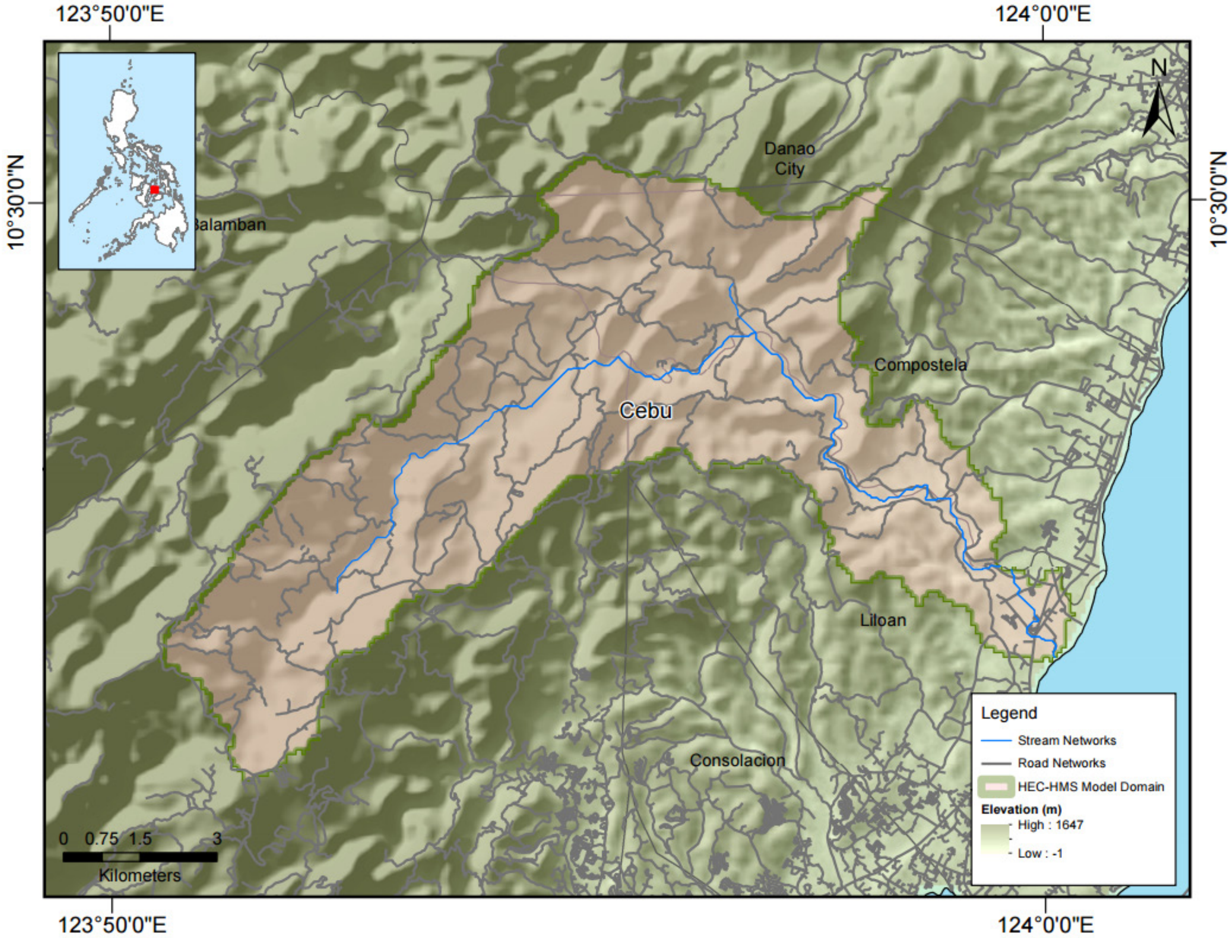

Figure 1. Map of Kotkot River Basin (in brown)

CHAPTER 2: LIDAR DATA ACQUISITION OF THE KOTKOT FLOODPLAIN

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The methods applied in this Chapter were based on the DREAM methods manual (Sarmiento, et al., 2014) and further enhanced and updated in Paringit, et al. (2017).

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Kotkot floodplain in Cebu. These missions were planned for 16 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 1 shows the flight plan for Kotkot floodplain.

Table 1. Flight planning parameters for the Pegasus LiDAR system.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK47A	1000	30	50	200	30	130	5
BLK47B	1000	30	50	200	30	130	5

[1] The explanation of the parameters used are in the volume “LiDAR Surveys and Flood Mapping in the Philippines: Methods.”

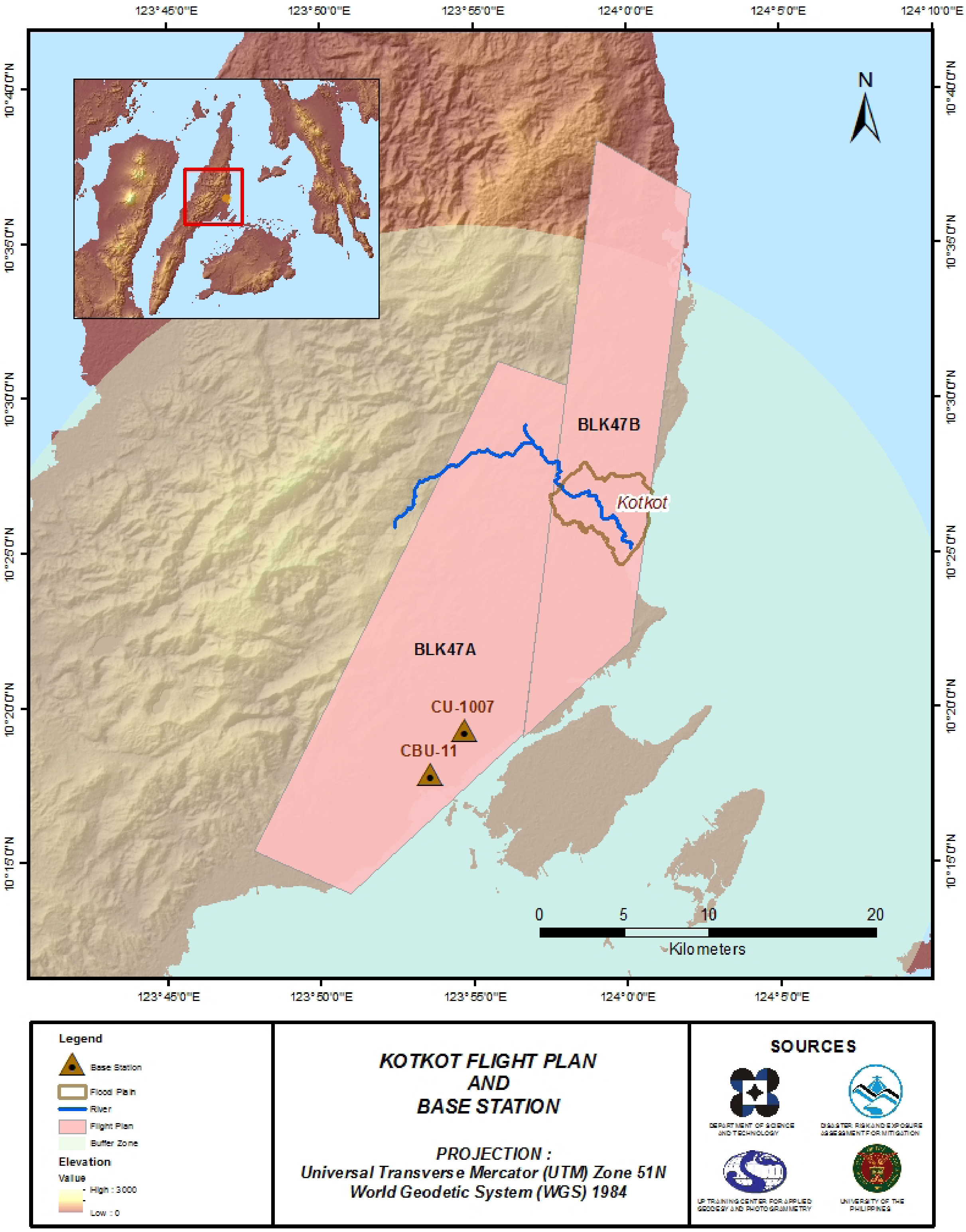
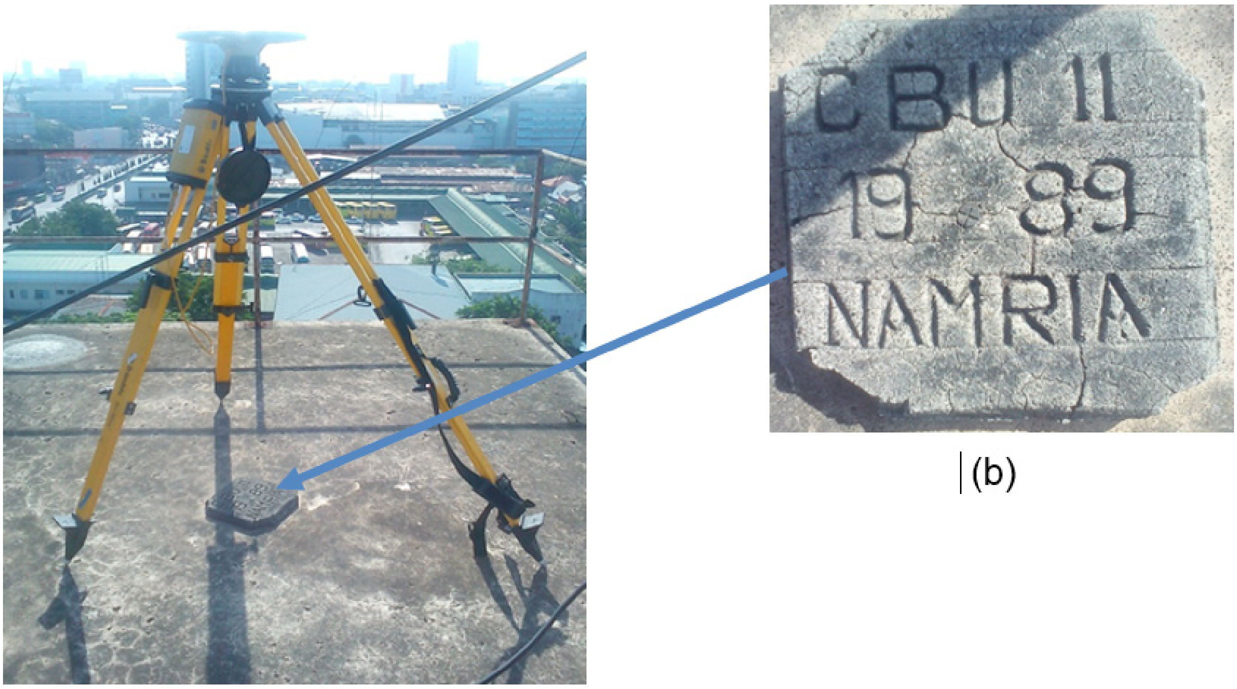


Figure 2. Flight Plan and base station used for the Kotkot Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover one (1) NAMRIA ground control point: CBU-11 which is of second (2nd) order accuracy. One (1) NAMRIA benchmark was also recovered: CU-1007 which is of second (2nd) order accuracy. This benchmark was used as vertical reference point and was also established as ground control point. The certifications for the NAMRIA reference point and benchmark are found in Annex A-2 while the baseline processing reports for the established control point is found in Annex A-3. These were used as base stations during flight operations for the entire duration of the survey (July 18, 28 and 30, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Kotkot floodplain are shown in Figure 2.

Figure 3 to Figure 4 show the recovered NAMRIA control station within the area, in addition Table 2 to Table 3 show the details about the following NAMRIA control stations and established points, Table 4 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey, and Figure 5 shows the location of base stations used for the survey of Kotkot floodplain.



(a) (b)

Figure 3. GPS set-up over CBU-11 on the roof top of the 75 feet concrete tower of Metro Cebu Fire Station, Cebu City Proper (a) and NAMRIA reference point CBU-11 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point CBU-11 used as base station for the LiDAR acquisition.

Station Name	**CBU-11**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10° 17' 56.00367" 123° 53' 26.63633" 44.27700 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	597,568.76 m 1,138,921.917 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 17' 51.88109" North 125° 53' 31.88503" East 106.03300 m
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	597,534.61 m 1,138,523.27 m

(a) (b)

Figure 4. GPS set-up over CU-1007 along F. Cabang National Road and Juan Luna Avenue, in the base of the stop light NW of PLDT panel, Barangay Mabolo, Cebu City (a) and NAMRIA reference point CU-1007 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point CU-1007 used as base station for the LiDAR acquisition.

Station Name	**CU-1007**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10° 19' 18.03224" 123° 54' 34.11152" 23.4975 m
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	599,647.206 m 1,141,459.818 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 19' 13.90544" North 123° 54' 39.35806" East 85.2465 m
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	599,579.97 m 1,141,048.504 m

Table 4. Ground control points used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
July 18, 2014	1725P	1BLK47B199A	CBU-11 and CU-1007
July 28, 2014	1765P	1BLK47B209A	CBU-11 and CU-1007
July 30, 2014	1773P	1BLK47A211A	CBU-11 and CU-1007

2.3 Flight Missions

Three (3) missions were conducted to complete the LiDAR Data Acquisition in Kotkot Floodplain, for a total of eleven hours and fifty-four minutes (11+54) of flying time for RP-C9022. All missions were acquired using the Pegasus LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 shows the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for the LiDAR data acquisition of the Kotkot Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
July 18, 2014	1725P	181.34	214.16	13.69	200.44	NA	4	6
July 28, 2014	1765P	181.34	150.21	18.94	129.31	NA	3	48
July 30, 2014	1773P	267.94	261.23	NA	261.23	NA	4	0
TOTAL		**630.62**	**625.60**	**32.63**	**590.98**	**NA**	**11**	**54**

Table 6. Actual parameters used during the LiDAR data acquisition of the Kotkot Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK47A	1000	30	50	125	30	130	5
BLK47B	1000	30	50	125	30	130	5

2.4 Survey Coverage

Kotkot floodplain is located in the province of Cebu with majority of the floodplain situated within the city of Cebu, and municipalities of Consolacion and Liloan. The list of cities and municipalities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Kotkot floodplain is presented in Figure 5.

Table 7. List of municipalities and cities surveyed of the Kotkot Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Cebu	Carmen	58.44	40.23	68.84%
	Catmon	92.99	15.33	16.49%
	Cebu City	290.59	135.38	46.59%
	Compostela	51.55	46.55	90.30%
	Consolacion	32.98	32.96	99.94%
	Danao City	137.12	84.3	61.48%
	Lapu-Lapu City	63.42	3	4.73%
	Liloan	54.98	54.95	99.95%
	Mandaue City	31	30.99	99.97%
	Minglanilla	51.76	5.21	10.07%
	Talisay City	48.61	23.86	49.08%
Total		**913.44**	**472.76**	**51.76%**

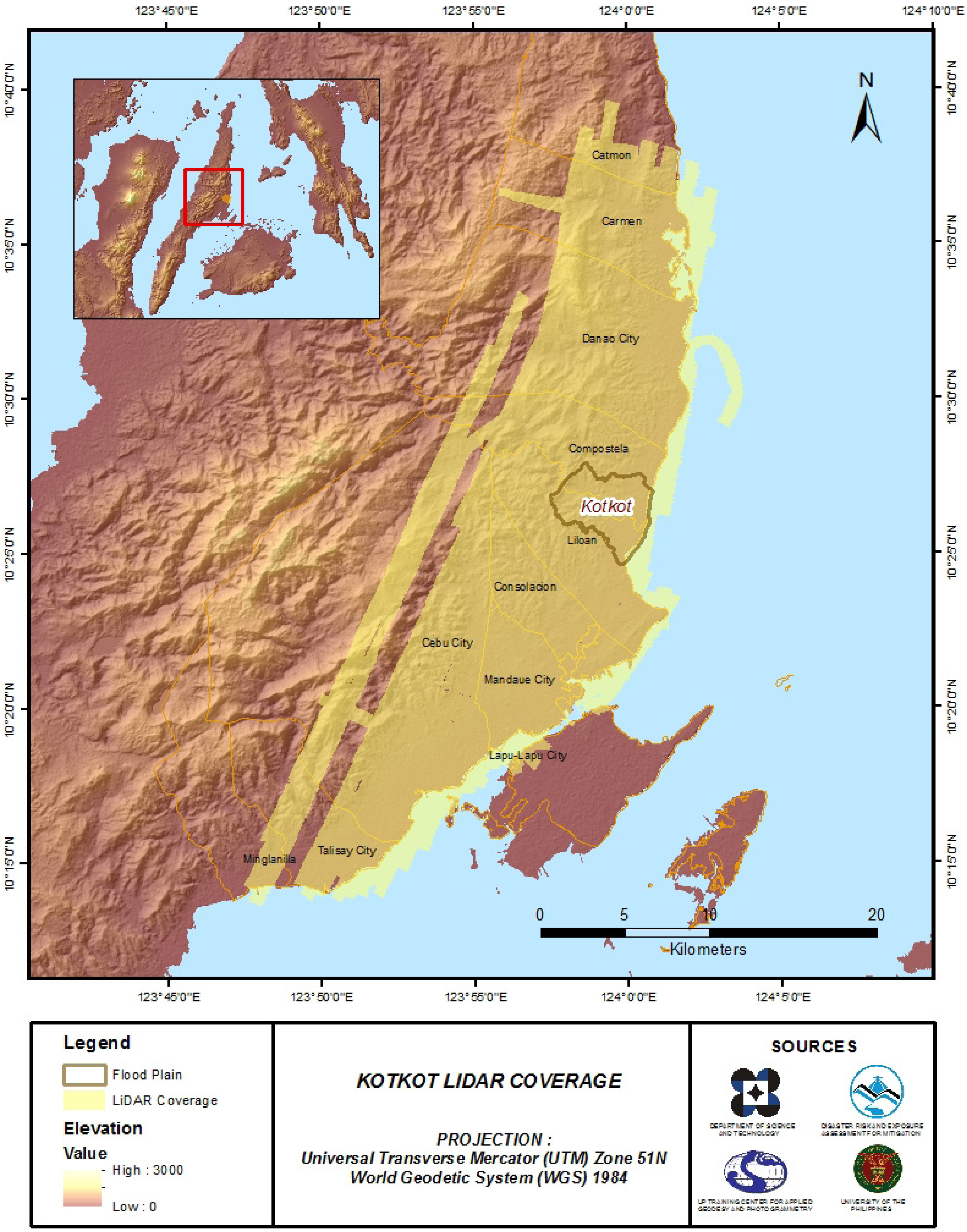


Figure 5. Actual LiDAR survey coverage of the Kotkot Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE KOTKOT FLOODPLAIN

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The methods applied in this Chapter were based on the DREAM methods manual (Ang, et al., 2014) and further enhanced and updated in Paringit, et al. (2017)

3.1 Overview of the LiDAR Data Pre-Processing

The data transmitted by the Data Acquisition Component are checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory is done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification is performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds are subject for quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, are met. The point clouds are then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model.

Using the elevation of points gathered in the field, the LiDAR-derived digital models are calibrated. Portions of the river that are barely penetrated by the LiDAR system are replaced by the actual river geometry measured from the field by the Data Validation and Bathymetry Component. LiDAR acquired temporally are then mosaicked to completely cover the target river systems in the Philippines. Orthorectification of images acquired simultaneously with the LiDAR data is done through the help of the georectified point clouds and the metadata containing the time the image was captured.

These processes are summarized in the flowchart shown in Figure 6.

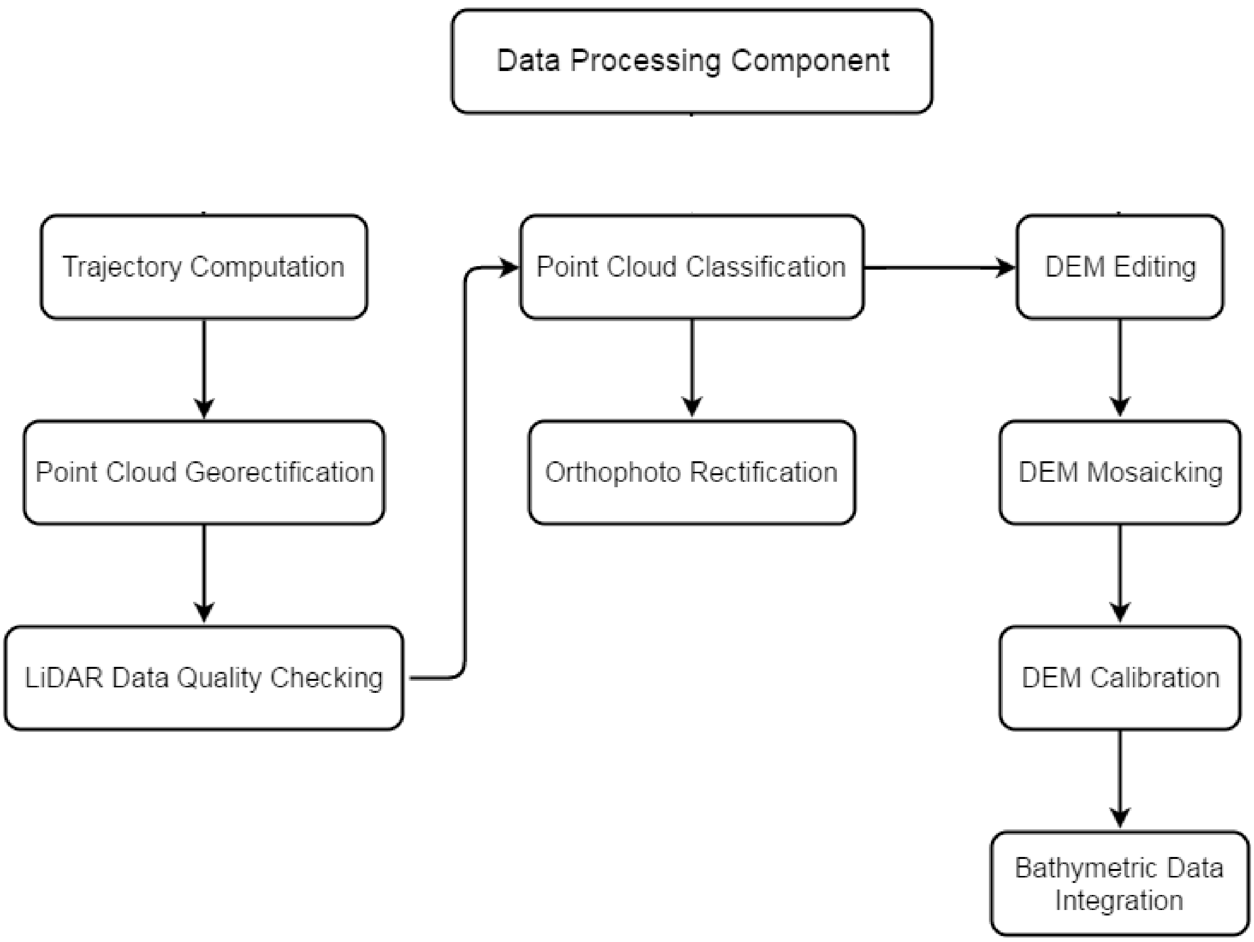


Figure 6. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Kotkot floodplain can be found in Annex 5: Data Transfer Sheets. Missions flown during the survey conducted on July 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Liloan, Cebu.

The Data Acquisition Component (DAC) transferred a total of 67.6 Gigabytes of Range data, 2.47 Gigabytes of POS data, 1.40 Gigabytes of GPS base station data, and 450.2 Gigabytes of raw image data to the data server on August 4, 2014 for the survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Kotkot was fully transferred on August 20, 2016, as indicated on the Data Transfer Sheets for Kotkot floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 1765P, one of the Kotkot flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on July 28, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

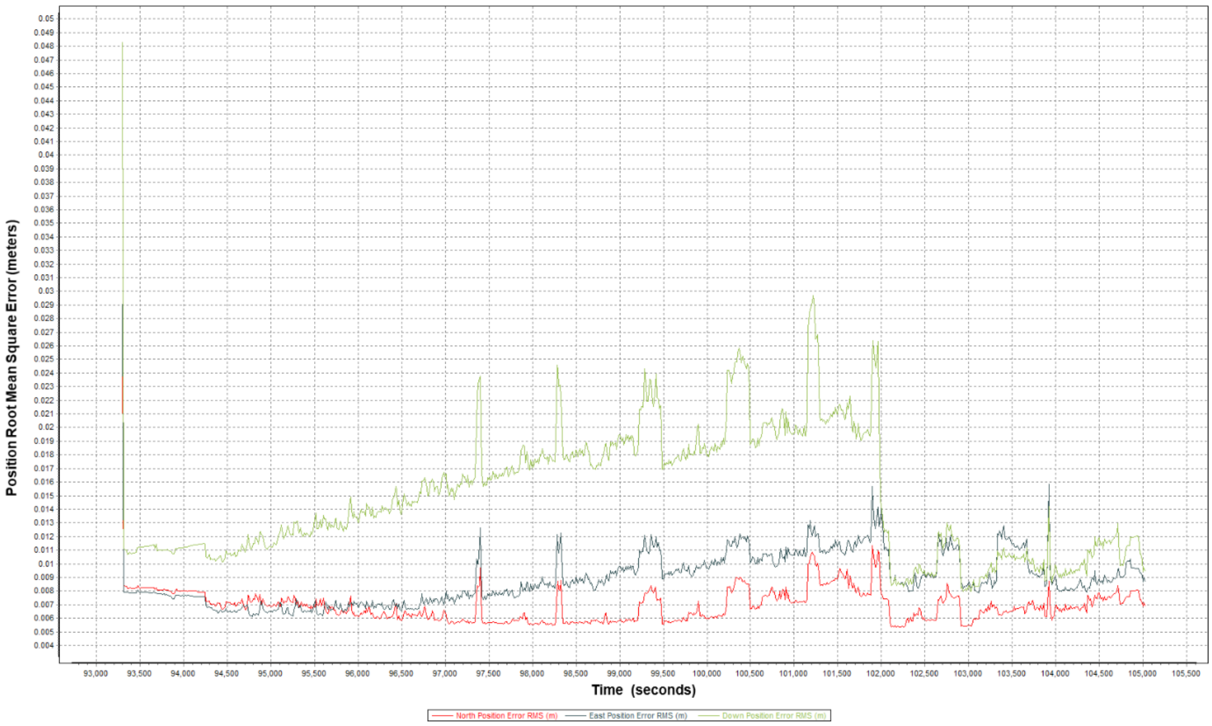


Figure 7. Smoothed Performance Metric Parameters of Kotkot Flight 1765P

The time of flight was from 93000 seconds to 105000 seconds, which corresponds to morning of July 28, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft.

Redundant measurements from the POS system quickly minimize the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 7 shows that the North position RMSE peaks at 1.10 centimeters, the East position RMSE peaks at 1. 60 centimeters, and the Down position RMSE peaks at 2.50 centimeters, which are within the prescribed accuracies described in the methodology.

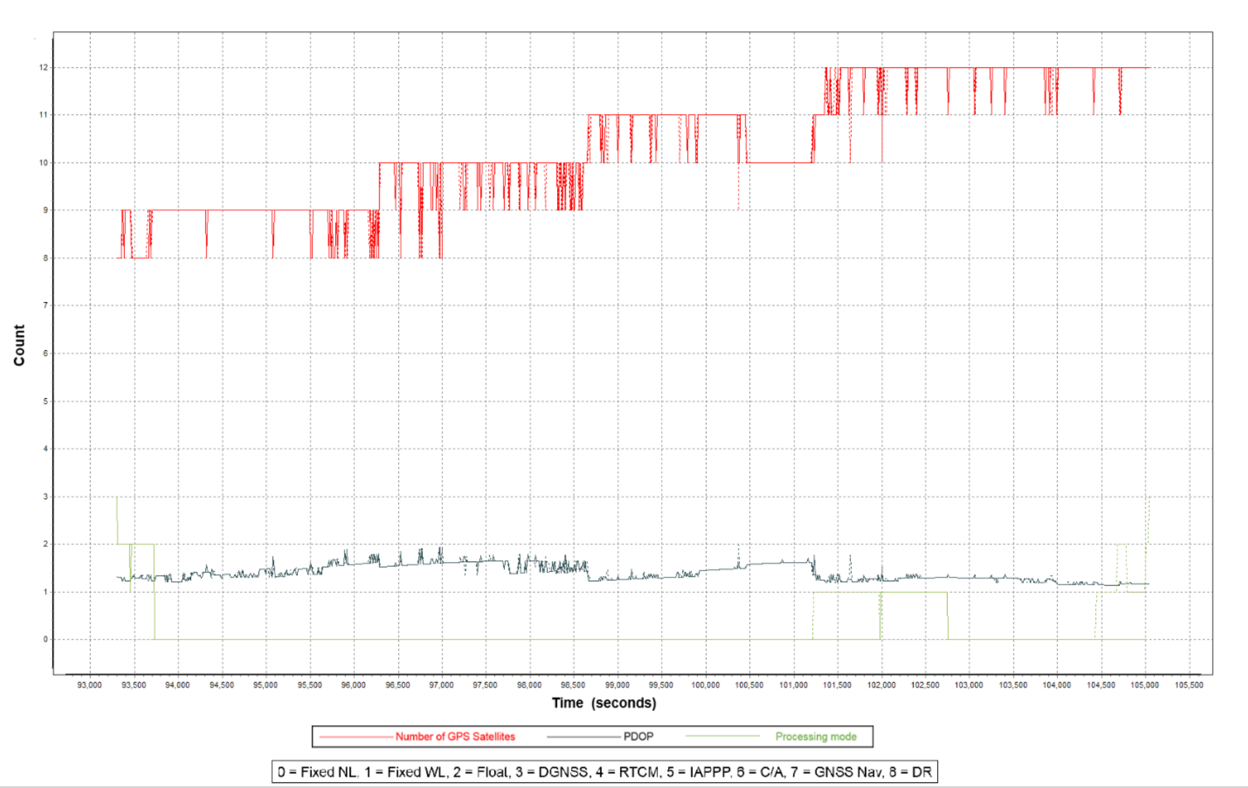


Figure 8. Solution Status Parameters of Kotkot Flight 1765P

The Solution Status parameters of flight 1765P, one of the Kotkot flights, which are the number of GPS satellites, Positional Dilution of Precision, and the GPS processing mode used are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 2 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Kotkot flights is shown in Figure 9.

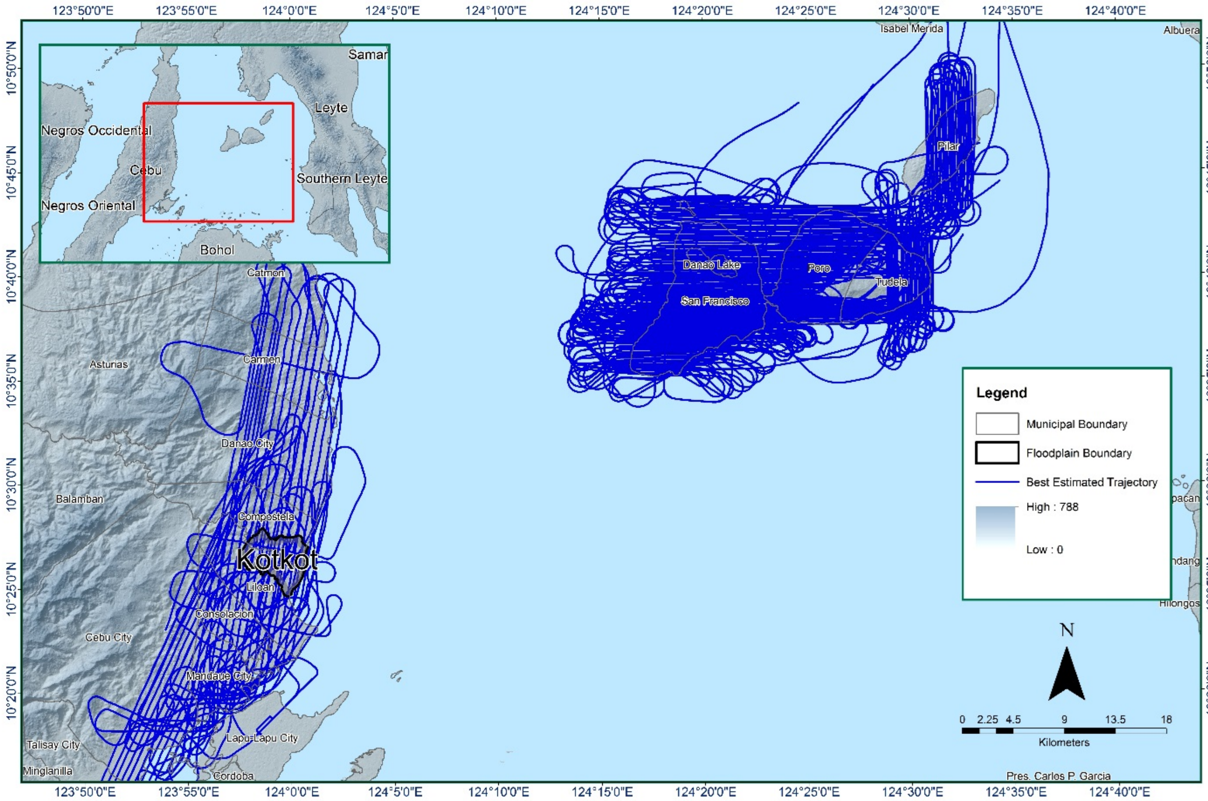


Figure 9. Best Estimated Trajectory of the LiDAR missions conducted over the Kotkot Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 267 flight lines, with each flight line containing one channel, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Kotkot floodplain are given in Table 8.

Table 8. Self-calibration Results values for Kotkot flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000197
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000872
GPS Position Z-correction stdev	<0.01meters	0.0046

The optimum accuracy is obtained for all Kotkot flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in Annex 8: Mission Summary Reports.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Kotkot Floodplain is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

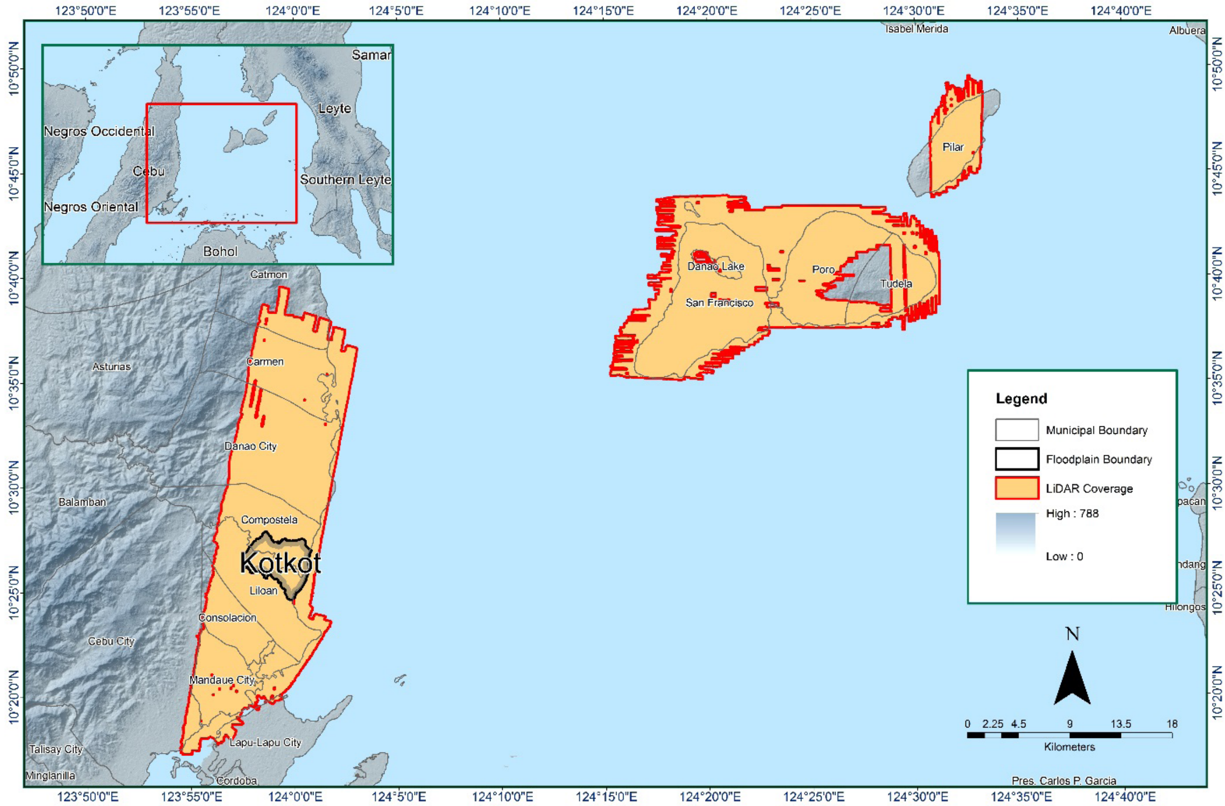


Figure 10. Boundary of the processed LiDAR data over Kotkot Floodplain

The total area covered by the Kotkot missions is 712.26 sq.km that is comprised of three (3) flight acquisitions grouped and merged into one (1) block as shown in Table 9.

Table 9. List of LiDAR blocks for Kotkot Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Cebu_Blk47B	1725P	330.68
	1765P	
	1773P	
Ormoc_Camotes_Blk48D	8403AC	32.03
	8406AC	
Ormoc_Camotes_Blk48D_supplement	8400AC	57.07
Ormoc_Camotes_Blk48F	8393AC	35.09
Ormoc_Camotes_Blk48A	8390AC	67.21
Ormoc_Camotes_Blk48A_additional	8405AC	4.65
Ormoc_Camotes_Blk48A_supplement	8406AC	11.27
	8407AC	
Ormoc_Camotes_Blk48B	8405AC	51.09
	8407AC	
Ormoc_Camotes_Blk48B_additional	8404AC	3.24
Ormoc_Camotes_Blk48B_supplement	8406AC	24.85
Ormoc_Camotes_Blk48C	8403AC	57.56
	8404AC	
	8406AC	
Ormoc_Camotes_Blk48C_supplement	8403AC	23.52
	8404AC	
	8406AC	
Ormoc_Camotes_Blk48C_supplement2	8400AC	5.88
TOTAL		**712.26 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 11. Since the Aquarius system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines. While for the Pegasus system which employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines..

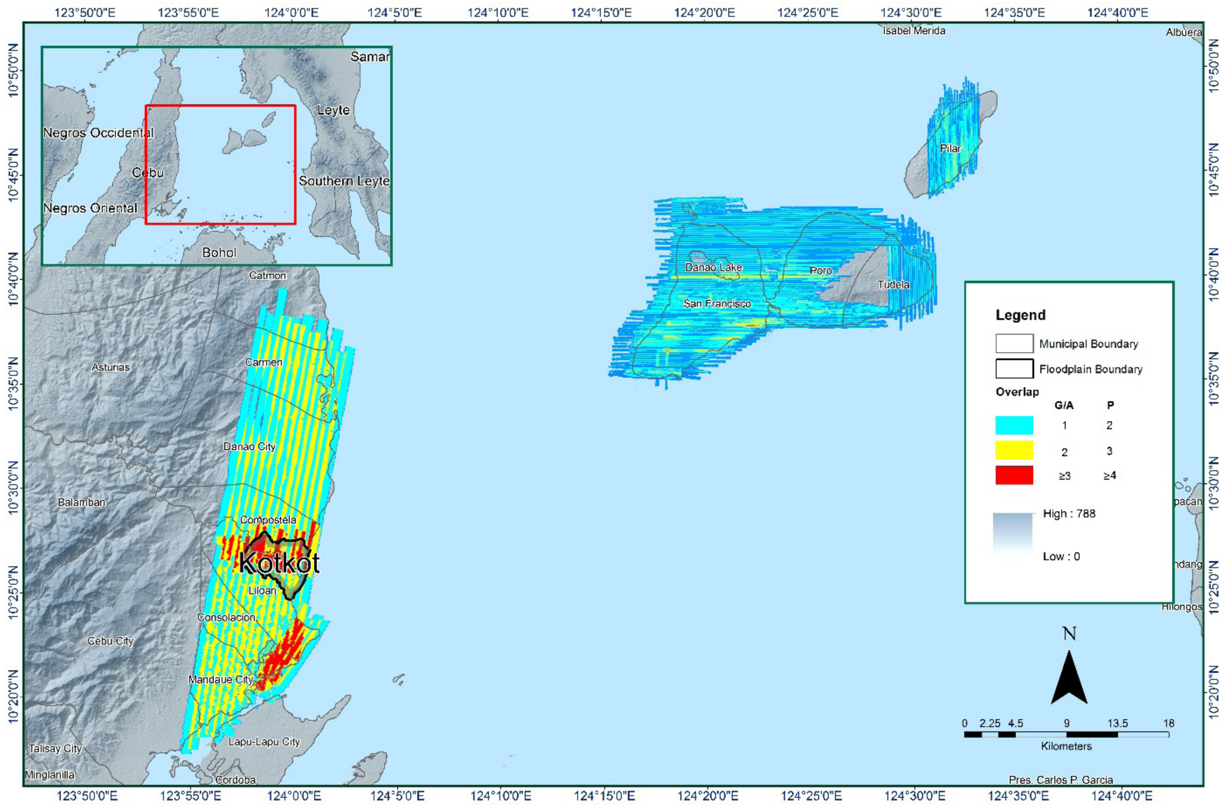


Figure 11. Image of data overlap for Kotkot Floodplain.

The overlap statistics per block for the Kotkot floodplain can be found in Annex 8: Mission Summary Reports. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the maximum percent overlap is 51.91%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 12. It was determined that all LiDAR data for Kotkot floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.32 points per square meter.

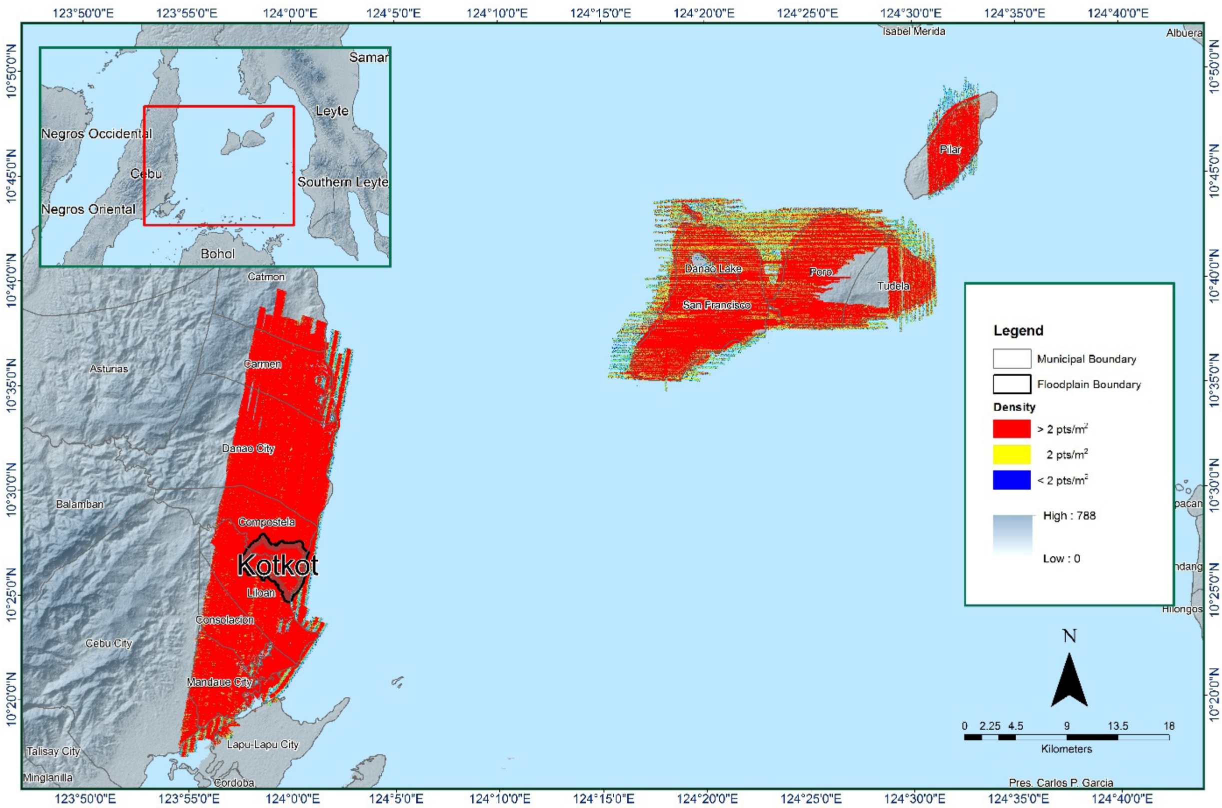


Figure 12. Pulse density map of merged LiDAR data for Kotkot Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

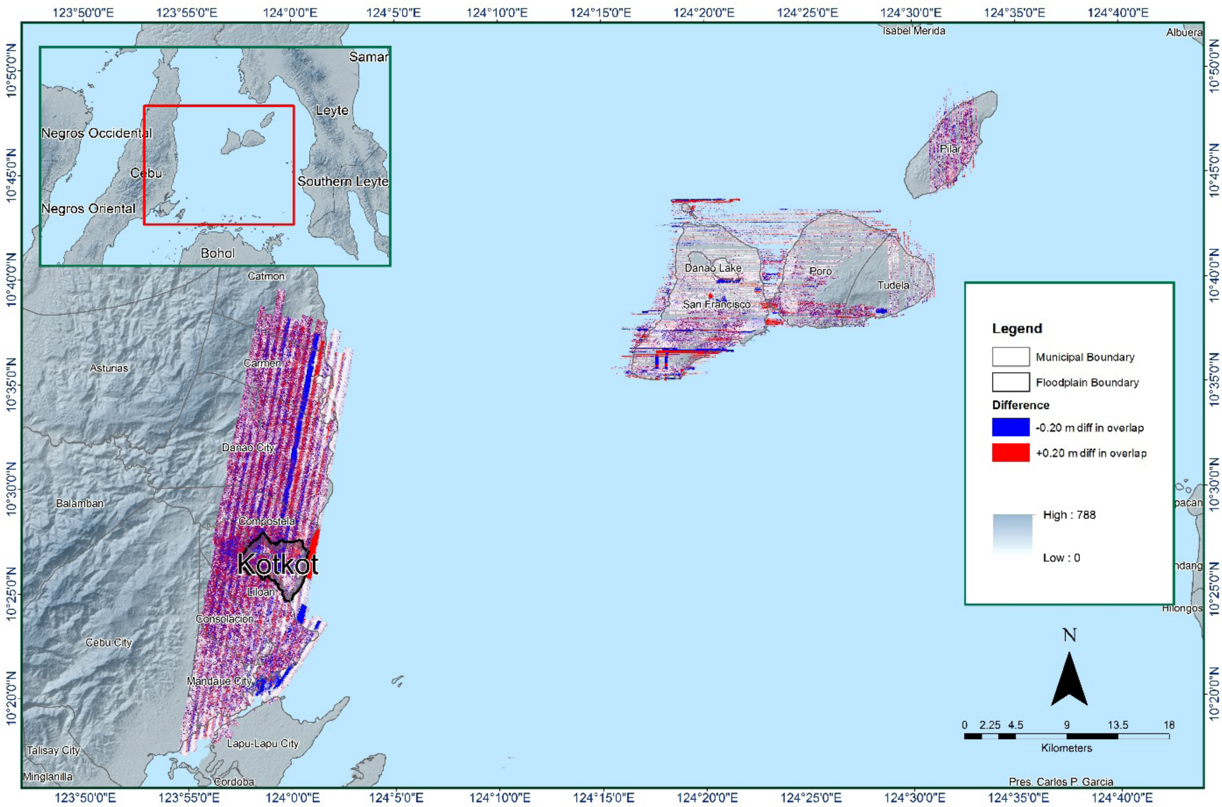


Figure 13. Elevation Difference Map between flight lines for Kotkot Floodplain Survey.

A screen capture of the processed LAS data from a Kotkot flight 1765P loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

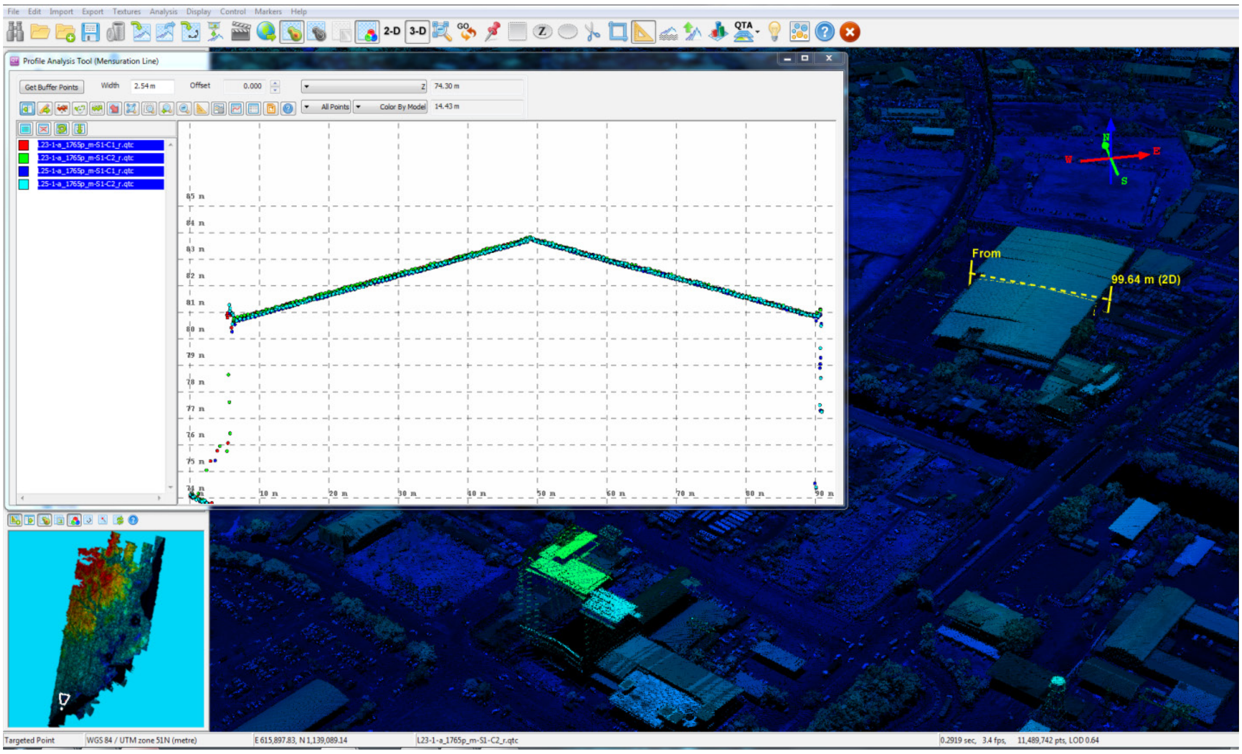


Figure 14. Quality checking for Kotkot Flight 1765P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Kotkot classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	550,288,762
Low Vegetation	432,557,372
Medium Vegetation	799,286,212
High Vegetation	741,050,725
Building	105,954,346

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Kotkot floodplain is shown in Figure 15. A total of 1,038 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 769.16 meters and 9.81 meters respectively.

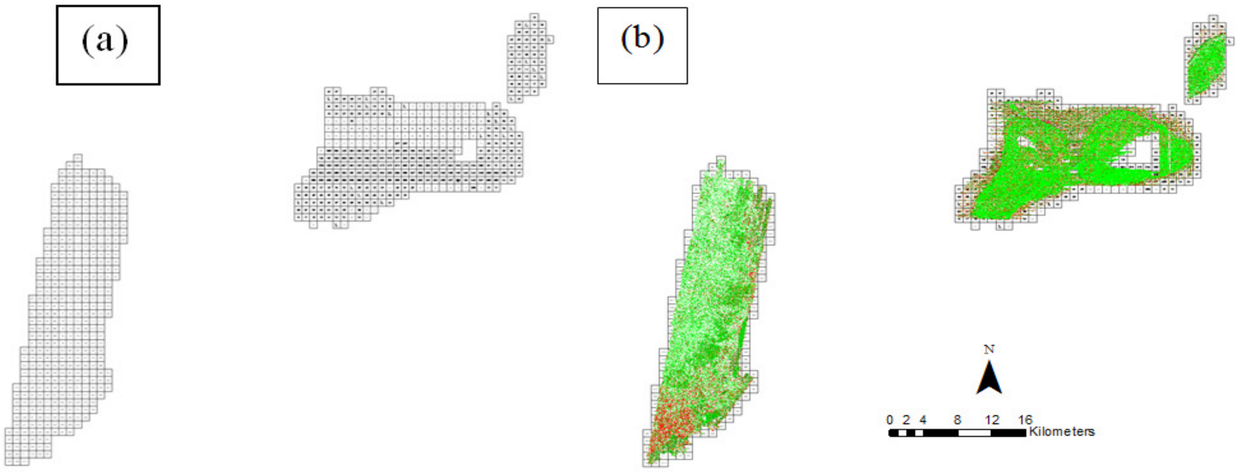


Figure 15. Tiles for Kotkot Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 16. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

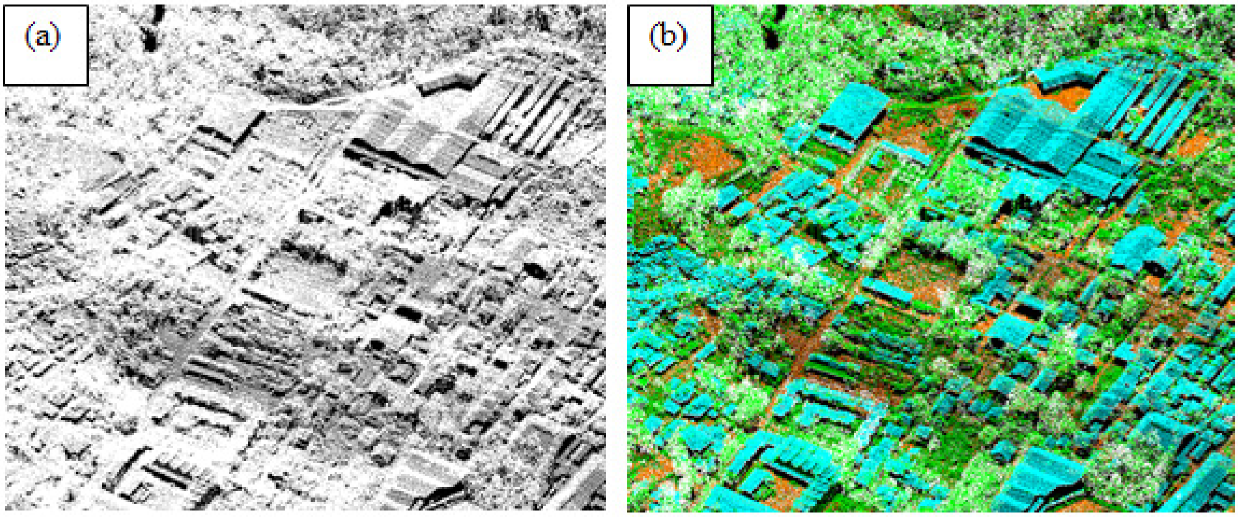


Figure 16. Point cloud before (a) and after (b) classification

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 17. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

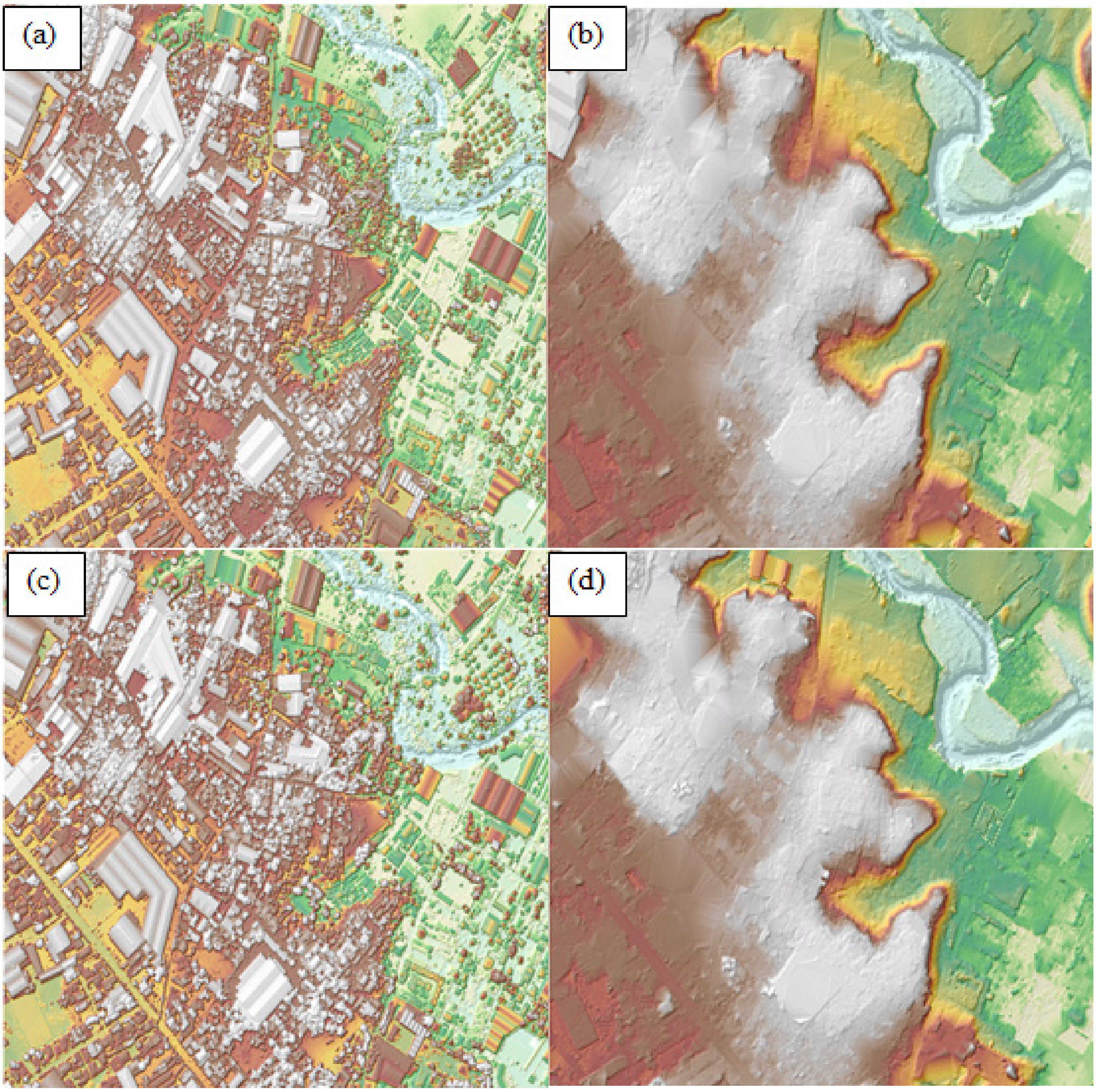


Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Kotkot Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 393 1km by 1km tiles area covered by Kotkot floodplain is shown in Figure 18. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Kotkot floodplain has a total of 332.55 sq.km orthophotogaph coverage comprised of 1212 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 19.

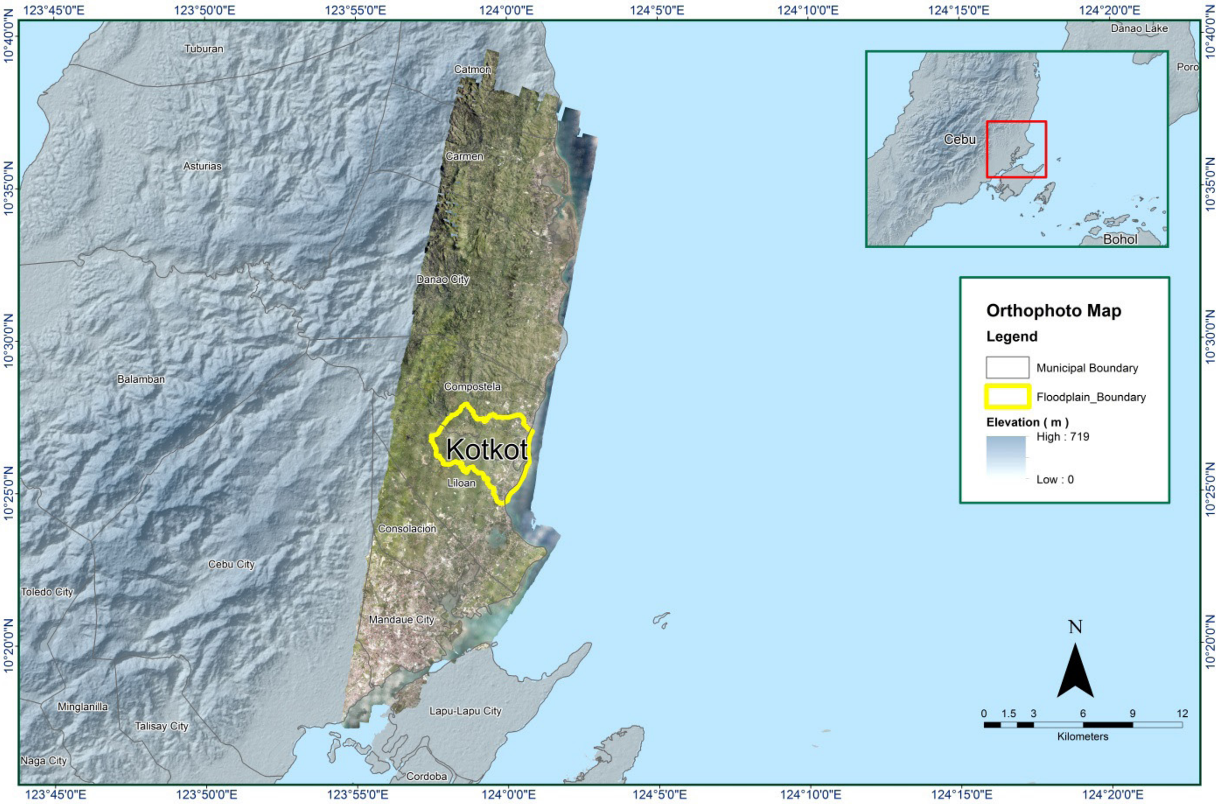


Figure 18. Kotkot Floodplain with available orthophotographs.

Figure 19. Sample orthophotograph tiles for Kotkot Floodplain.

3.8 DEM Editing and Hydro-Correction

One (1) mission block was processed for Kotkot flood plain. This block is composed of Cebu block with a total area of 330.68 square kilometers. Table 11shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Cebu_Blk47B	330.68
Ormoc_Camotes_Blk48D	32.03
Ormoc_Camotes_Blk48D_additional	8.11
Ormoc_Camotes_Blk48D_supplement	57.07
Ormoc_Camotes_Blk48F	35.09
Ormoc_Camotes_Blk48A	67.21
Ormoc_Camotes_Blk48A_additional	4.65
Ormoc_Camotes_Blk48A_supplement	11.27
Ormoc_Camotes_Blk48B	51.09
Ormoc_Camotes_Blk48B_additional	3.24
Ormoc_Camotes_Blk48B_supplement	24.85
Ormoc_Camotes_Blk48C	57.56
Ormoc_Camotes_Blk48C_supplement	23.52
Ormoc_Camotes_Blk48C_supplement2	5.88
TOTAL	**712.26 sq. km**

Portions of DTM before and after manual editing are shown in Figure 20. Portions of the DTM of Kotkot unfilled during processing (Figure 20a) were filled during further processing (Figure 20b). Another is the bridge (Figure 20c) is also considered to be an impedance to the flow of water and has to be removed (Figure 20d) in order to hydrologically correct the river. These are shown in the figure below.

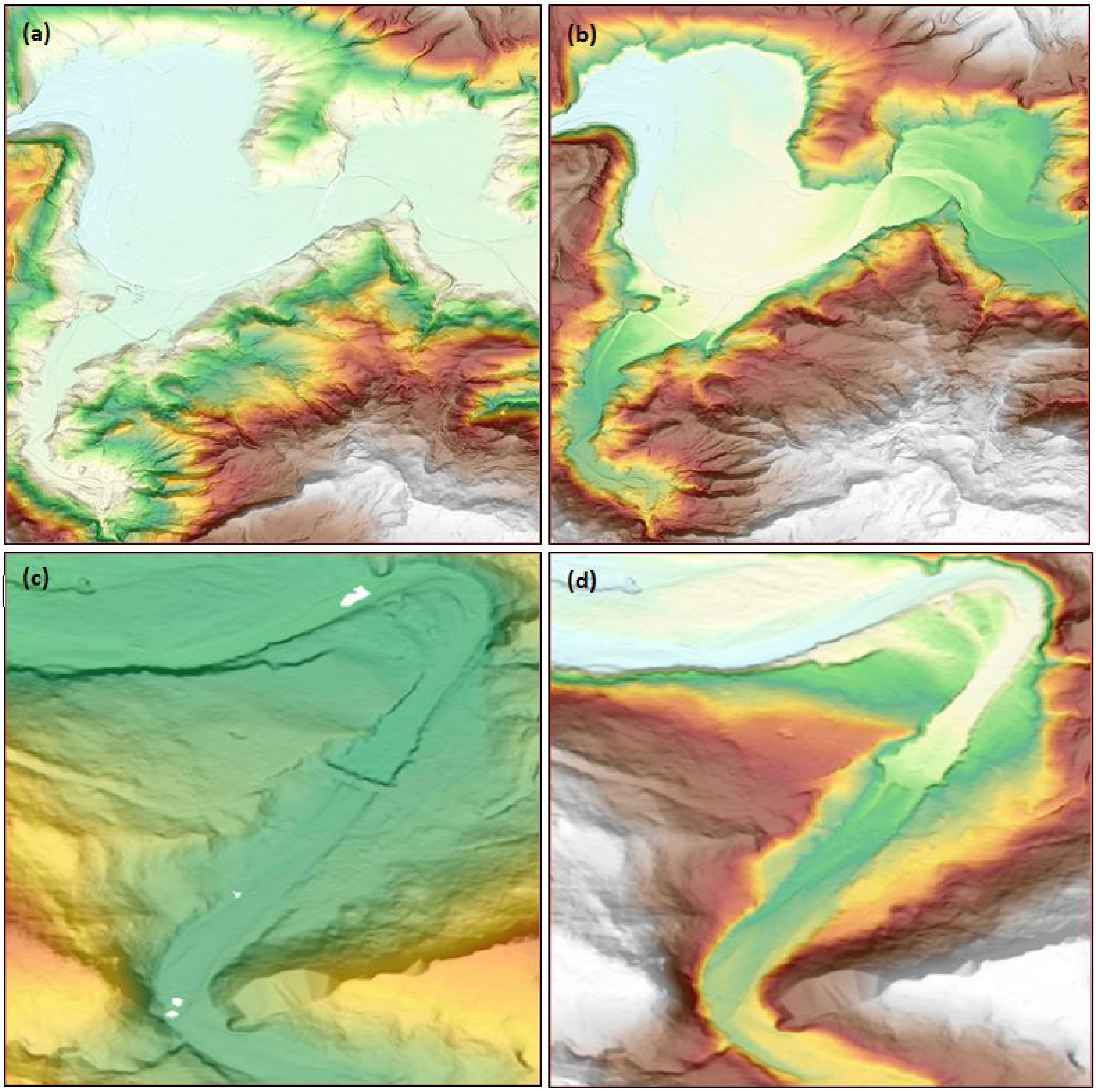


Figure 20. Portions in the DTM of Kotkot floodplain (a) before and (b) after filling data gaps; (c) before and (d) after removing the bridge in editing.

3.9 Mosaicking of Blocks

Cebu_Blk47B was mosaicked to Cebu_Blk47Aa which covers Kotkot. Cebu_Blk47A was used as reference and no shift values has been obtained. Table B-5 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Kotkot floodplain is shown in Figure 21. It can be seen that the entire Kotkot floodplain is 100% covered by LiDAR data.

Table 12. Shift values of each LiDAR block of Kotkot Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Cebu_Blk47B	0.00	0.00	-3.22
Ormoc_Camotes_Blk48D	0.00	0.00	-0.02
Ormoc_Camotes_Blk48D_additional	0.00	2.23	-0.48
Ormoc_Camotes_Blk48D_supplement	0.06	1.89	-0.47
Ormoc_Camotes_Blk48F	NA	NA	NA
Ormoc_Camotes_Blk48A	1.57	-1.97	0.30
Ormoc_Camotes_Blk48A_additional	0.00	0.00	-7.23
Ormoc_Camotes_Blk48A_supplement	0.00	0.00	-6.39
Ormoc_Camotes_Blk48B	0.00	0.00	-6.62
Ormoc_Camotes_Blk48B_additional	0.00	0.00	-0.09
Ormoc_Camotes_Blk48B_supplement	0.00	0.00	0.00
Ormoc_Camotes_Blk48C	0.00	0.00	-0.05
Ormoc_Camotes_Blk48C_supplement	0.00	0.00	0.01
Ormoc_Camotes_Blk48D_supplement2	0.00	0.00	-0.52

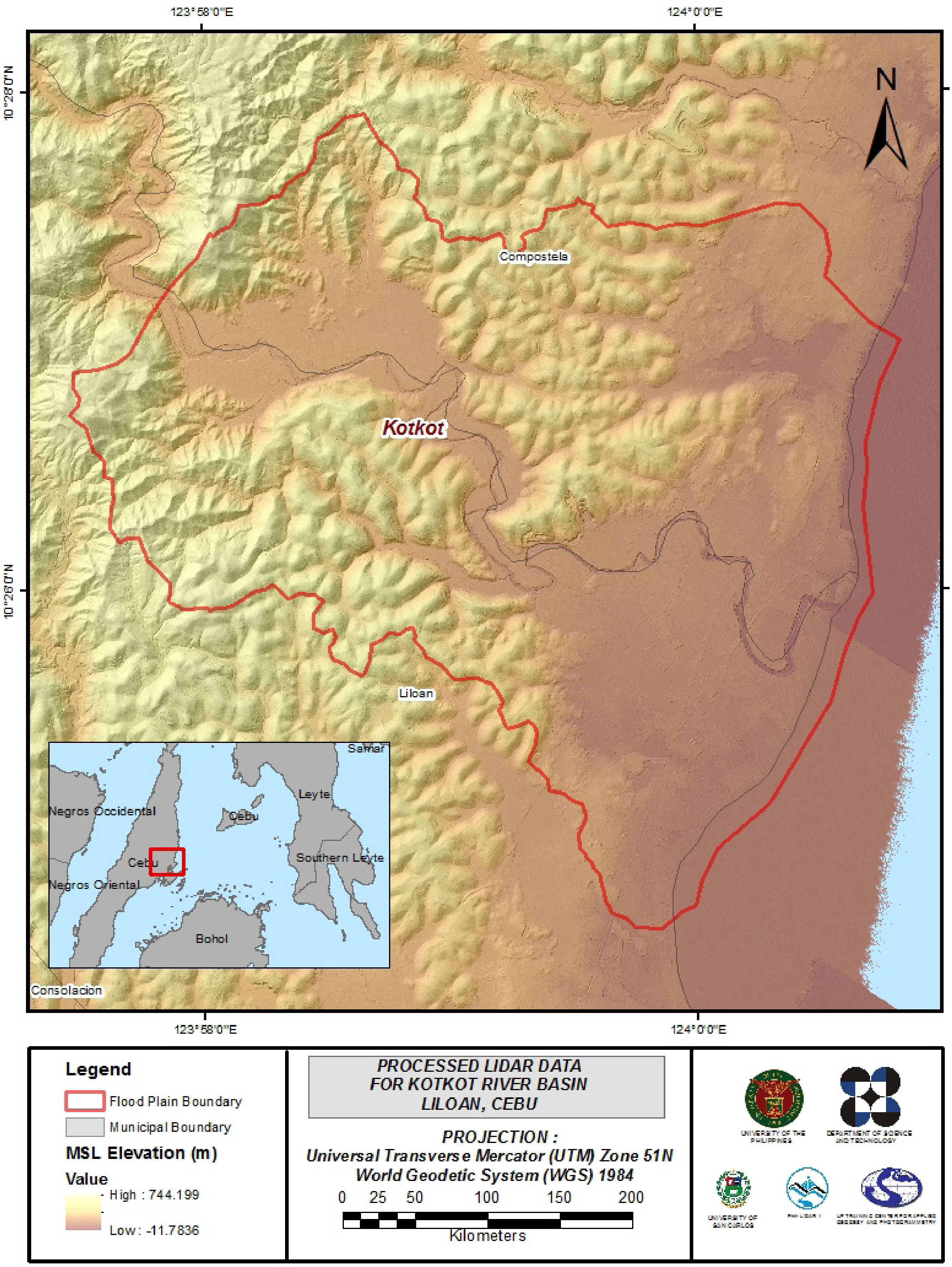


Figure 21. Map of Processed LiDAR Data for Kotkot Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model (DEM)

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Kotkot to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 22,471 survey points were gathered for all the flood plains within the province of Cebu wherein the Kotkot floodplain is located. Random selection of 80% of the survey points, resulting to 17,977 points, was used for calibration.

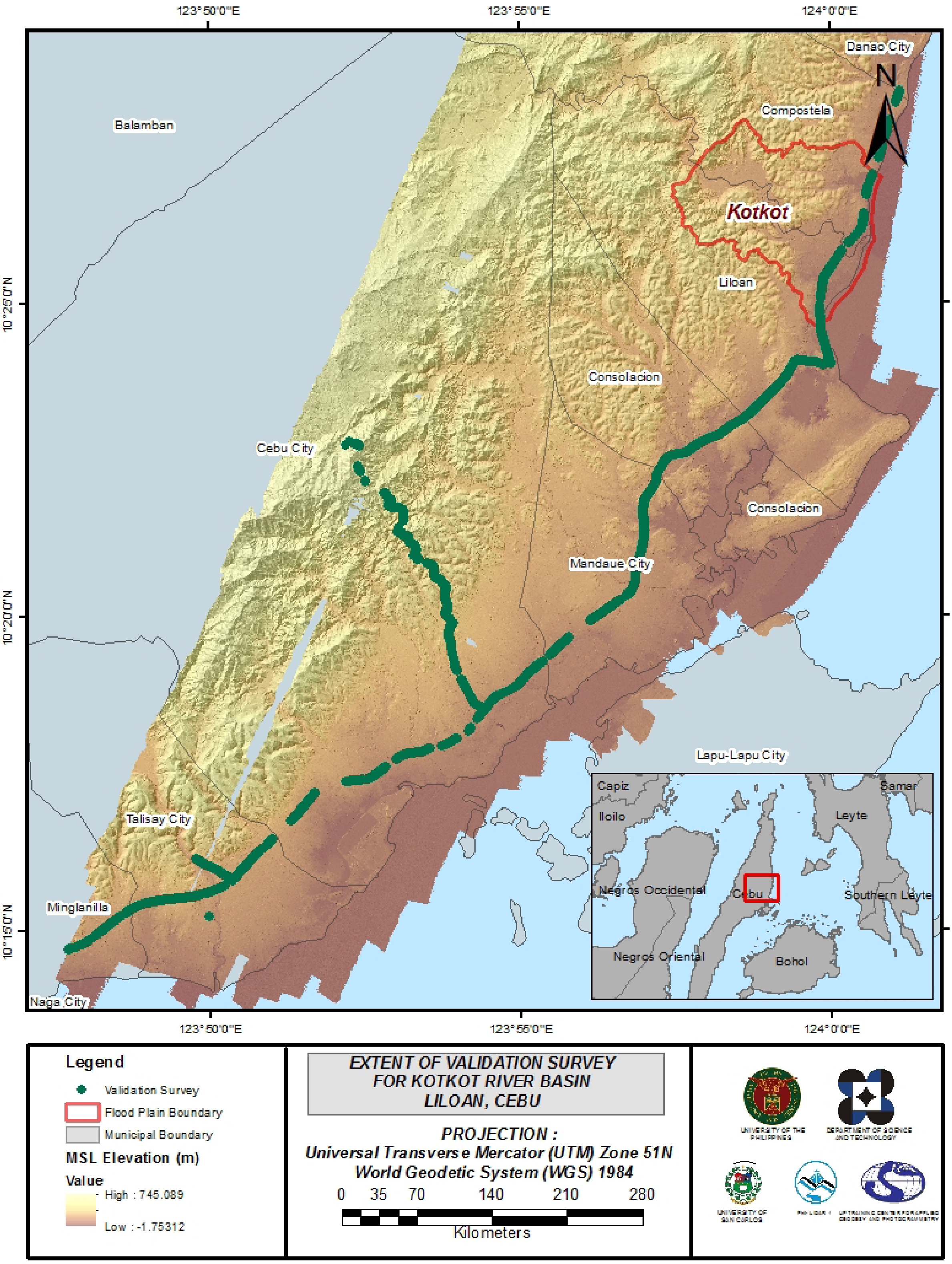


Figure 22. Map of Kotkot Floodplain with validation survey points in green.

A good correlation between the uncalibrated mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 0.55 meters with a standard deviation of 0.20 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 0.55 meters, to the mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

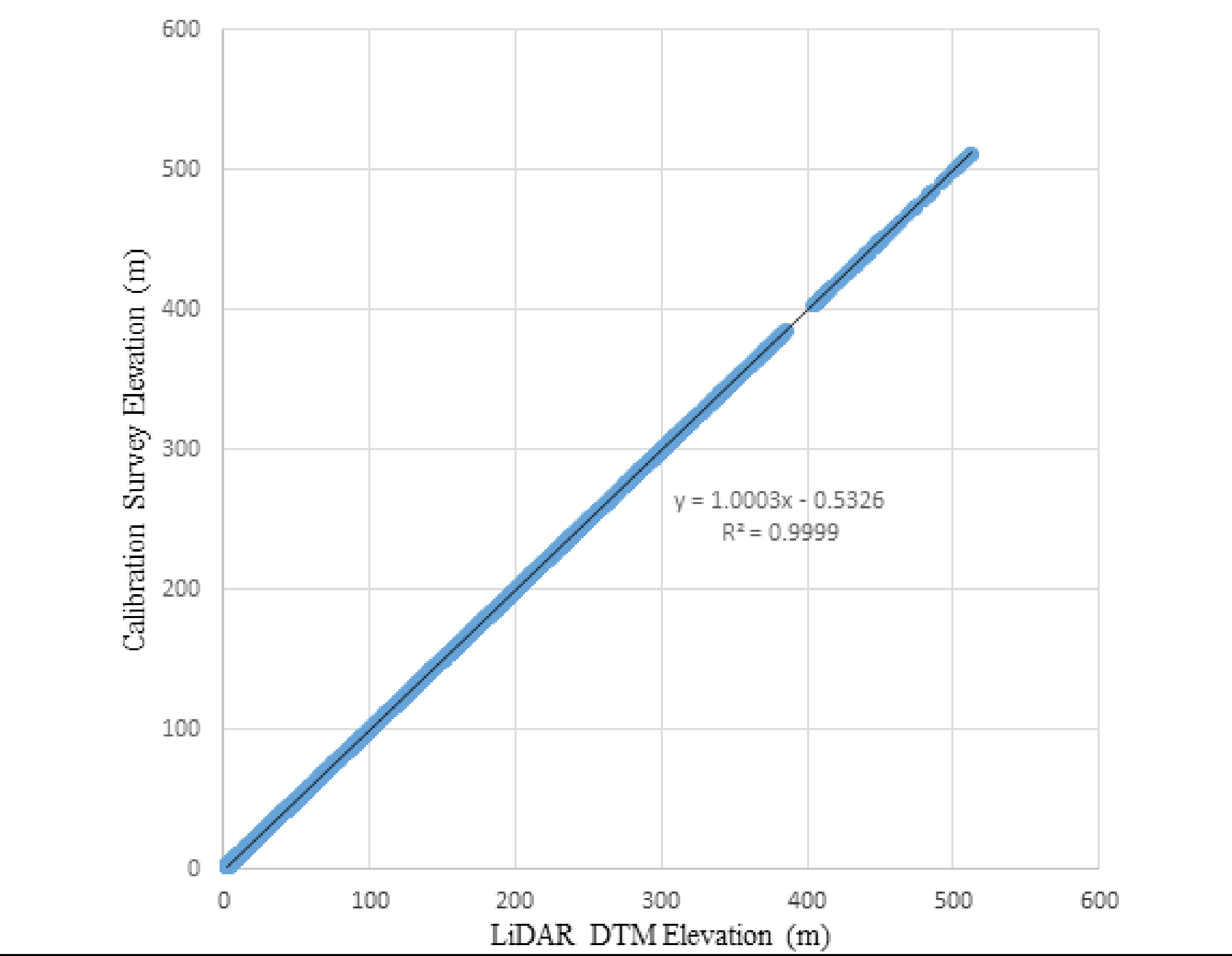


Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	0.55
Standard Deviation	0.20
Average	-0.51
Minimum	-1.01
Maximum	-0.00005

The remaining 20% of the total survey points that are near Kotkot flood plain, resulting to 314 points, were used for the validation of calibrated Kotkot DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM, is shown in Figure 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.11 meters, as shown in Table 14.

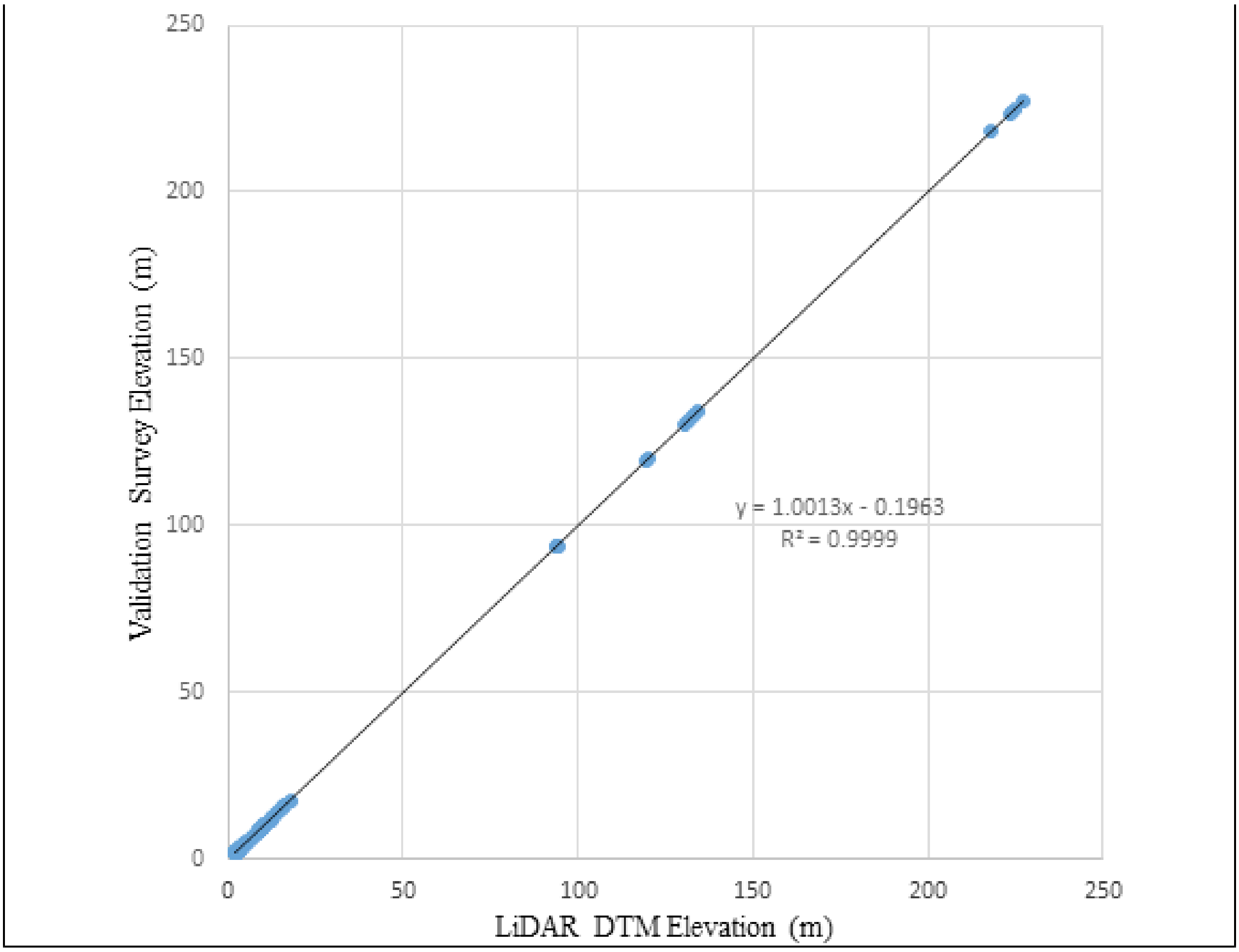


Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.11
Average	-0.17
Minimum	-0.26
Maximum	0.22

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Kotkot with 1,209 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.018 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Kotkot integrated with the processed LiDAR DEM is shown in Figure 25.

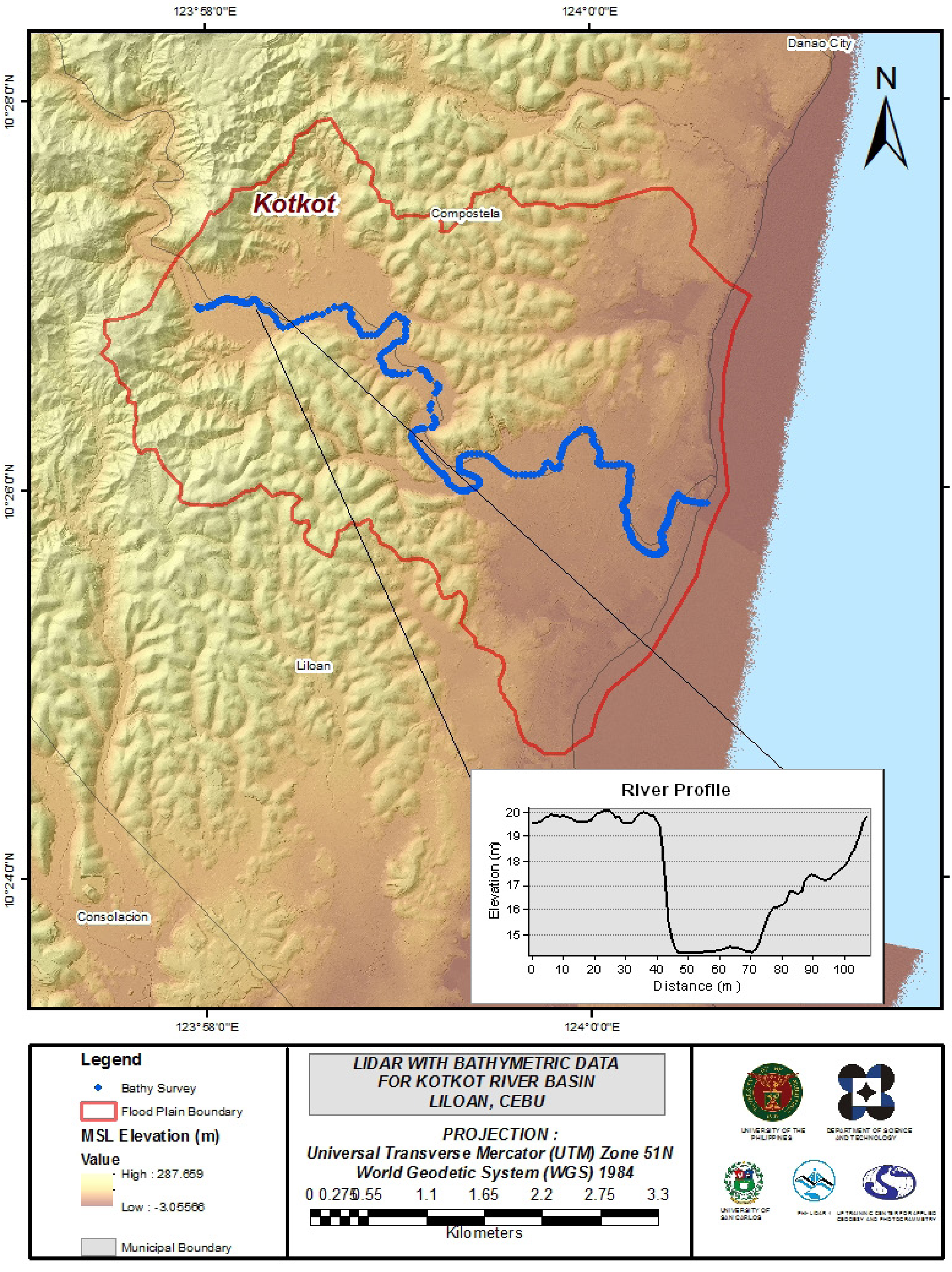


Figure 25. Map of Kotkot Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

The features salient in flood hazard exposure analysis include buildings, road networks, bridges and water bodies within the floodplain area with 200 m buffer zone. Mosaicked LiDAR DEM with 1 m resolution was used to delineate footprints of building features, which consist of residential buildings, government offices, medical facilities, religious institutions, and commercial establishments, among others. Road networks comprise of main thoroughfares such as highways and municipal and barangay roads essential for routing of disaster response efforts. These features are represented by a network of road centerlines.

3.12.1 Quality Checking of Digitized Features' Boundary

Kotkot floodplain, including its 200 m buffer, has a total area of 24.94 sq km. For this area, a total of 5.0 sq.km, corresponding to a total of 1,538 building features, were considered for QC. Figure 26 shows the QC blocks for Kotkot floodplain.

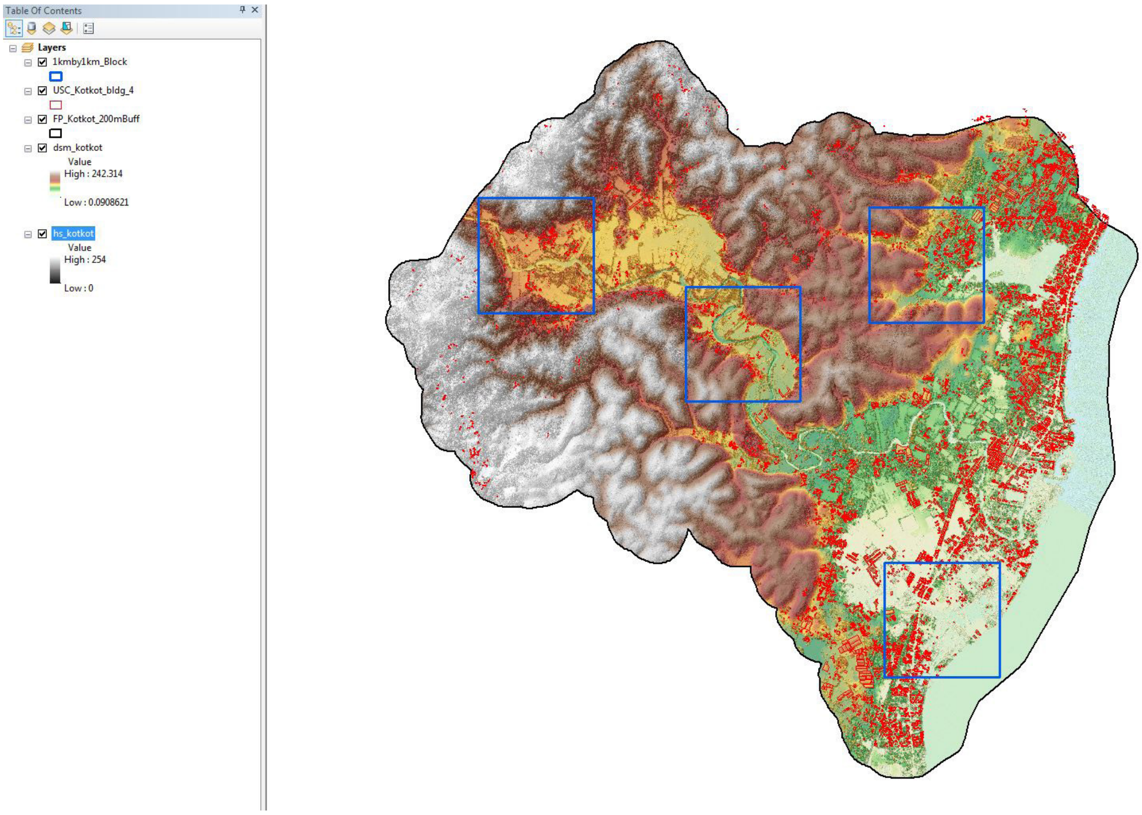


Figure26. Blocks (in blue) of Kotkot building features that were subjected to QC

Quality checking of Kotkot building features resulted in the ratings shown in Table 15.

Table 15. Quality Checking Ratings for Kotkot Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Kotkot	99.93	99.28	97.01	PASSED

3.12.2 Height Extraction

Height extraction was done for 9,584 building features in Kotkot floodplain. Of these building features, 974 were filtered out after height extraction, resulting to 8,610 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 8.70 m.

3.12.3 Feature Attribution

In attribution, combination of participatory mapping and actual field validation was done. Representatives from LGU were invited to assist in the determination of the features. The remaining unidentified features were then validated on the field.

Table 16 summarizes the number of building features per type. On the other hand, Table 17 shows the total length of each road type, while Table 18 shows the number of water features extracted per type.

Table 16. Building Features Extracted for Kotkot Floodplain.

Facility Type	No. of Features
Residential	8,011
School	91
Market	6
Agricultural/Agro-Industrial Facilities	8
Medical Institutions	4
Barangay Hall	7
Military Institution	0
Sports Center/Gymnasium/Covered Court	2
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	2
NGO/CSO Offices	13
Police Station	0
Water Supply/Sewerage	17
Religious Institutions	19
Bank	
Factory	143
Gas Station	1
Fire Station	0
Other Government Offices	1
Other Commercial Establishments	285
Total	**8,610**

Table 17. Total Length of Extracted Roads for Kotkot Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Kotkot	56.82	19.05	0	5.11	0	80.98

Table 18. Number of Extracted Water Bodies for Kotkot Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Kotkot	1	0	0	0	0	1

A total of 3 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

All extracted ground features were completely given the required attributes. All these output features comprise the flood hazard exposure database for the floodplain. This completes the feature extraction phase of the project.

Figure 27 shows the Digital Surface Model (DSM) of Kotkot floodplain overlaid with its ground features.

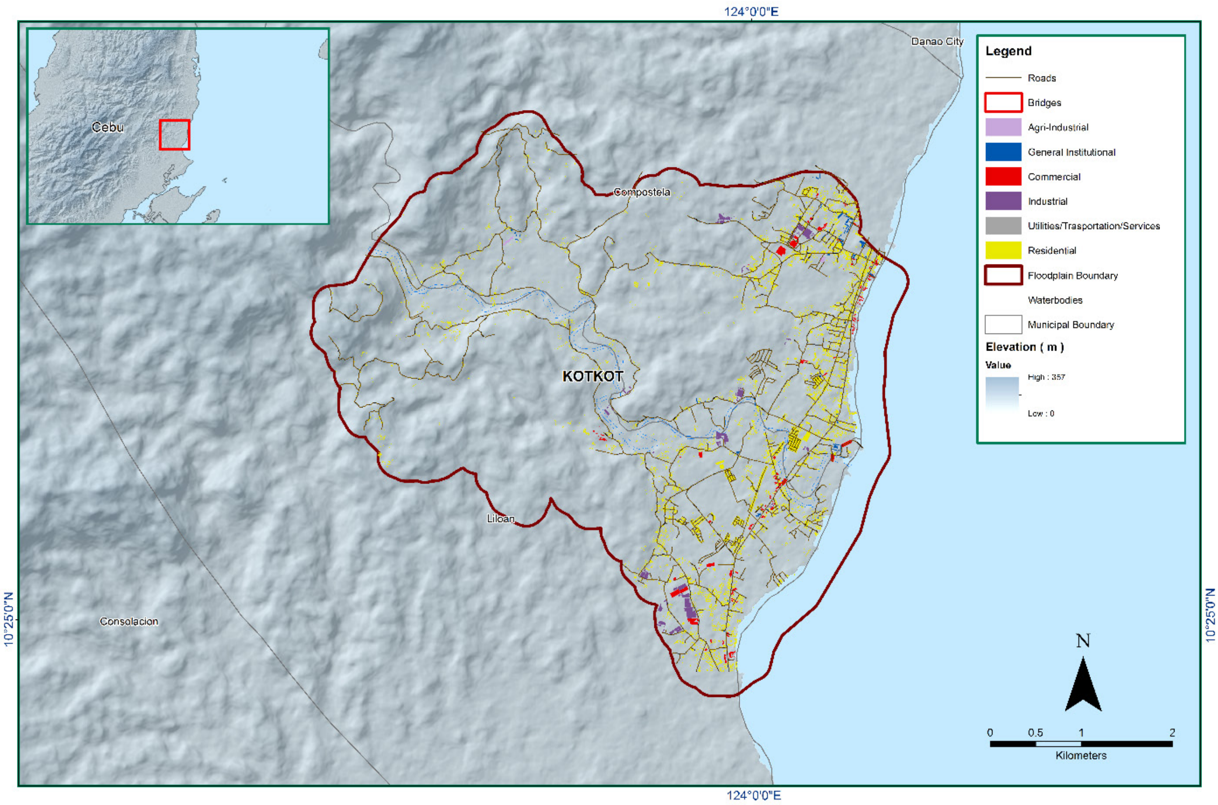


Figure 27. Extracted features for Kotkot Floodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE KOTKOT RIVER BASIN

Engr. Louie P. Balicanta, Engr. Joemarie Caballero, Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo, Ms. Jeline M. Amante, Marie Angelique R. Estipona, Charie Mae V. Manliguez, Engr. Janina Jupiter, and Vie Marie Paola M. Rivera

The methods applied in this Chapter were based on the DREAM methods manual (Balicanta, et al., 2014) and further enhanced and updated in Paringit, et al. (2017).

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Cotcot River on January 29 –February 7, 2015 with the following scope of work: reconnaissance; control survey; cross-section and as-built at Kotkot Bridge in Brgy. Kotkot, Municipality of Liloan; ground validation data acquisition of about 48.46 km covering the national highway from Municipality of Compostela up to the City of Talisay; and bathymetric survey from its upstream in Brgy. Cabadiangan, Municipality of Liloan, Cebu down to the mouth of the river in Brgy. San Estaca, Municipality of Compostela, Cebu with approximate length of 8.827 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique. The entire survey extent is illustrated in Figure 28.

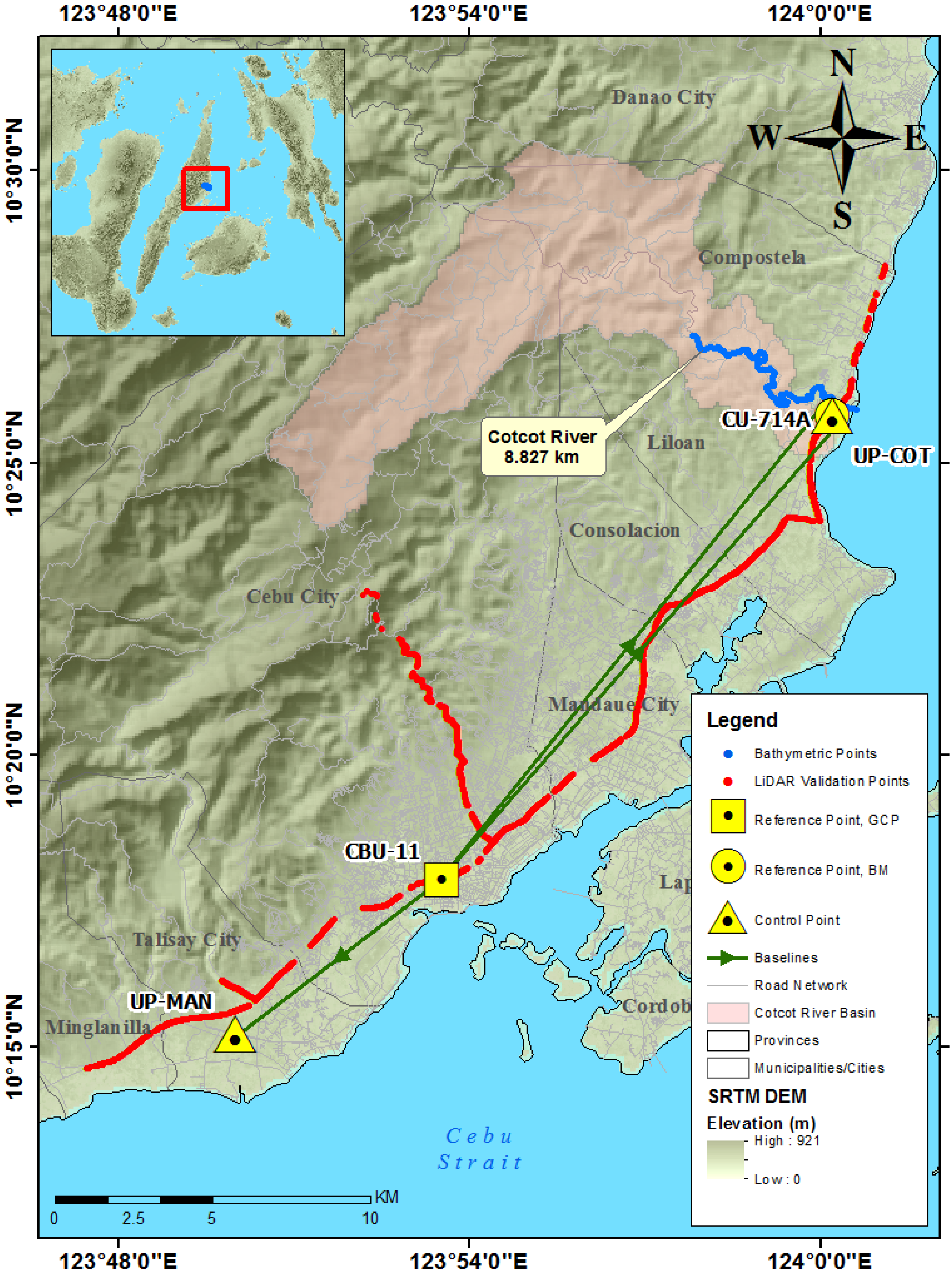


Figure 28. Extent of the bathymetric survey (in blue line) in Kotkot River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for Cotcot River Basin is composed of a signle loop and a baseline established on February 3, 2015 occupying the following reference points: CBU-11, a second order GCP in Town Proper, Cebu City; CU-714A, a first order BM in Brgy. Cotcot, Municipality of Liloan, Cebu.

UP established control points were established along the approach of bridges, namely: UP-COT, located at Cotcot Bridge, Brgy. Cotcot, Municipality of Liloan; and, UP-MAN, located at Mananga Bridge, Brgy. Lawaan II, Talisay City, all in Cebu.

The summary of references and control points and its location is summarized in Table 19 while the GNSS network established is illustrated in Figure 29.

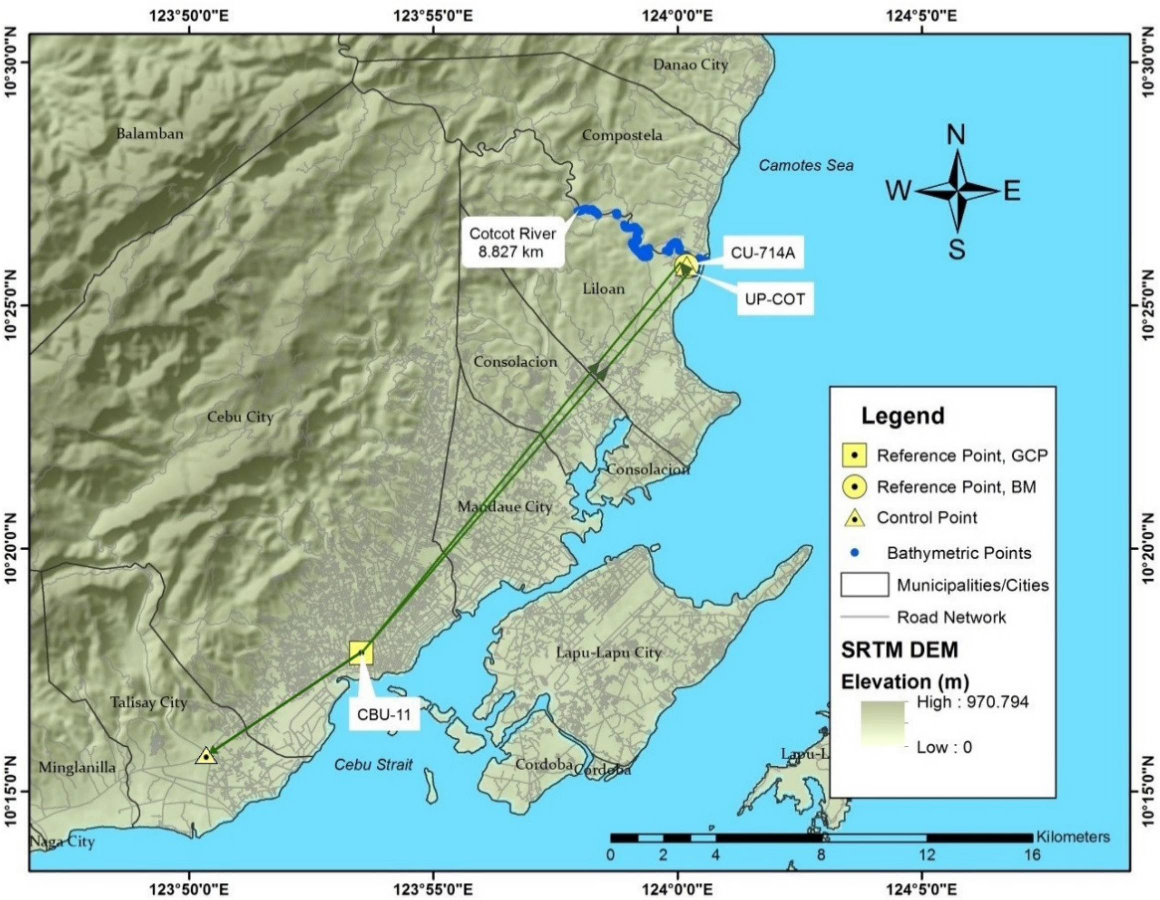


Figure 29. The GNSS Network established in the Kotkot River Survey.

Table 19. List of Reference and Control Points occupied for Kotkot River Survey (Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
CU-714A	1st order, BM	-	-	69.2	39.851	2014
CBU-11	2nd order, GCP	10°17'51.88109"	123°53'31.88503"	102.916	-	1989
UP-COT	UP Established	-	-	69.232	-	2015
UP-MAN	UP Established	-	-	77.561	-	2015

The GNSS set ups made in the location of the reference and control points in Cotcot River are shown in Figure 30 to Figure 33.

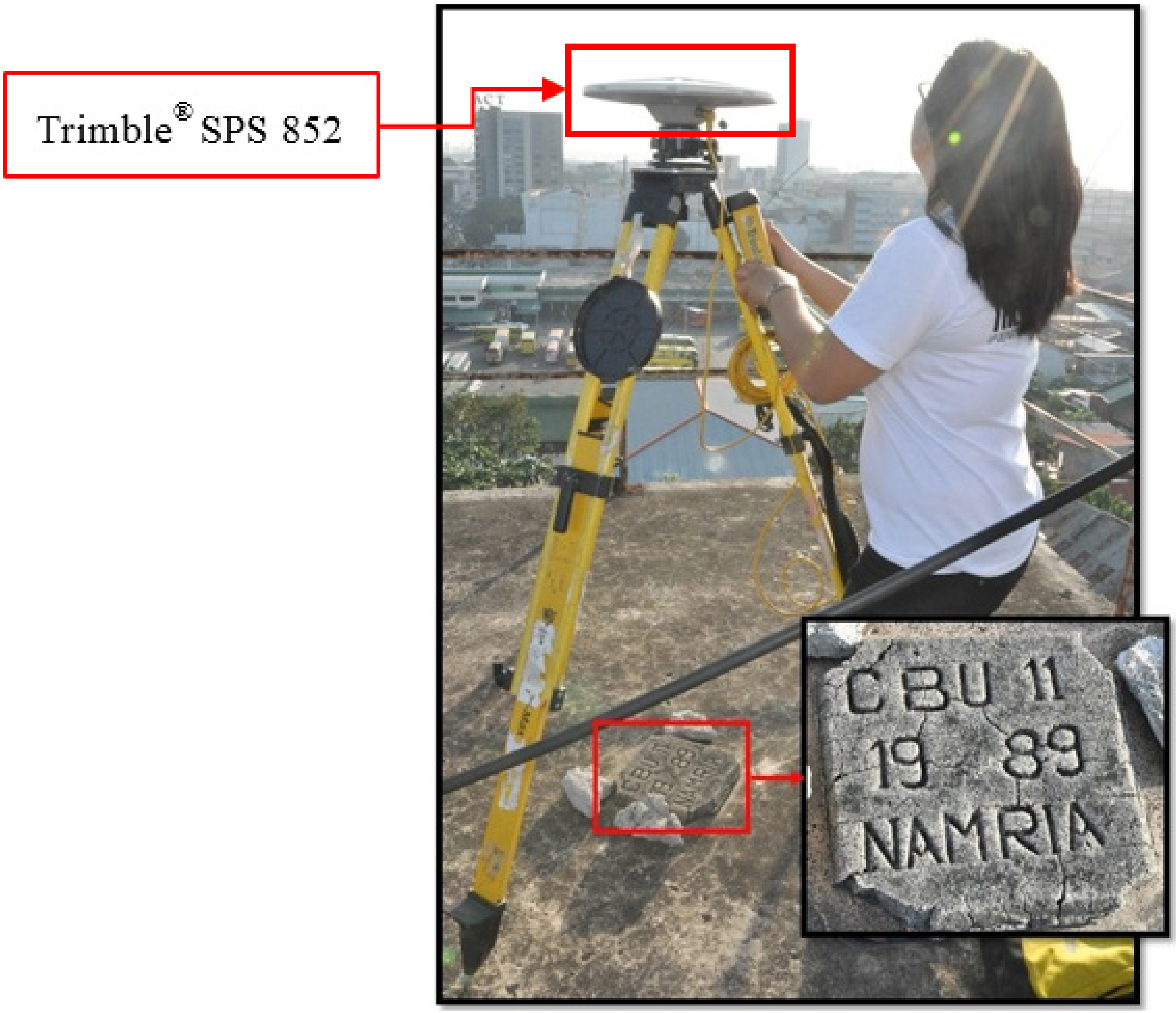


Figure 30. GNSS base receiver, Trimble® SPS 852, at CBU-11, located in Brgy. Sambag II, Cebu City

Figure 31. GNSS receiver setup, Trimble® SPS 882, at CU-714A, at the approach of Cotcot Bridge in Brgy. Cotcot, Municpality of Liloan, Cebu

Figure 32. GNSS base receiver, Trimble® SPS 852, at UP-COT, at the approach of Cotcot Bridge in Brgy. Cotcot, Municipality of Liloan, Cebu

Figure 33. GNSS base receiver, Trimble® SPS 852, at UP-MAN, at the approach of Mananga Bridge in Brgy. Lawaan II, Talisay City, Cebu

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/-20cm and +/-10cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Cotcot River Basin is summarized in Table 20 generated TBC software.

Table 20. Baseline Processing Summary Report for Kotkot River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
CBU-11 --- CU-714A	02-10-15	Fixed	0.004	0.024	39°41'13"	19038.24	-33.728
CBU-11 --- UP-COT	02-10-15	Fixed	0.004	0.02	39°41'14"	19036.53	-33.675
UP-COT --- CU-714A	02-10-15	Fixed	0.002	0.003	38°47'52"	1.709	-0.032
CBU-11 --- UP-MAN	02-10-15	Fixed	0.005	0.031	232°59'22"	8091.038	-25.356

As shown in Table 20, a total of four (4) baselines were processed and all of them passed the required accuracy set by the project.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is performed using TBC. Looking at the Adjusted Grid Coordinates table of the TBC generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 cm and z less than 10 cm or in equation from:

$$\sqrt{((x_e)^2 + (y_e)^2)} < 20cm \text{ and } z_e < 10\ cm$$

Where:

xe is the Easting Error,
ye is the Northing Error, and
ze is the Elevation Error

The three (3) control points, CBU-11, CU-714A and UP-COT were occupied and observed simultaneously to form a GNSS loop. Coordinates of CBU-11 and elevation values of CU-714A held fixed during the processing of the control points as presented in Table 21. Through these reference points, the coordinates and elevation of the unknown control points were computed.

Table 21. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
CBU-11	Global	Fixed	Fixed		
Local	Fixed	Fixed			Fixed
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22. All fixed control points have no values for grid and elevation errors.

Table 22. Adjusted grid coordinates for the control points used in the Kotkot River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Cons-traint
CBU-11	579101.757	?	1139552.798	?	287.891	0.028	LL
597693.442	?	1138468.476	?	39.851	0.018	LL	
CU-714A	578391.244	0.004	1162634.434	0.003	4.293	0.026	
609806.801	0.003	1153149.343	0.002	6.284	?	e	e
UP-COT	572351.798	0.004	1147658.769	0.003	13.024	0.029	
609805.735	0.003	1153148.008	0.002	6.316	0.003		

The network is fixed at reference points. The list of adjusted grid coordinates of the network is shown in Table C-4. Using the equation for horizontal and for the vertical; below is the computation for accuracy that passed the required precision:

a. CBU-11
Horizontal accuracy = Fixed
Vertical accuracy = 1.8 cm < 10 cm

b. CU-714A
Horizontal accuracy = √ ((0.3) ² + (0.2) ²
= √(0.90 + 0.40)
= 1.1 cm < 20 cm
Vertical accuracy = Fixed

c. UP-COT
Horizontal accuracy = √ ((0.3) ² + (0.2) ²
= √(0.90 + 0.40)
= 1.1 cm < 20 cm
Vertical accuracy = 0.3 cm < 10 cm

d. UP-COT
Horizontal accuracy = √ ((0.3) ² + (0.2) ²
= √(0.90 + 0.40)
= 1.1 cm < 20 cm
Vertical accuracy = 0.3 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the three occupied control points are within the required accuracy of the project.

Table 23. Adjusted geodetic coordinates for control points used in the Kotkot River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
CBU-11	N10°17'51.88109"	E123°53'31.88503"	102.916	0.018	LL
CU-714A	N10°25'48.64678"	E124°00'11.61859"	69.200	?	e
UP-COT	N10°25'48.60343"	E124°00'11.58340"	69.232	0.003	

The adjusted geodetic coordinates is presented in Table 23. The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 23. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 24.

Table 24. The reference and control points utilized in the Kotkot River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N			
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	EGM Ortho (m)	BM Ortho (m)
CU-714A	1st order, BM	10°17'51.88109"	123°53'31.88503"	102.916	1138468.476	597693.442	39.851	287.844
CBU-11	2nd order, GCP	10°25'48.64678"	124°00'11.61859"	69.2	1153149.343	609806.801	6.284	58.767
UP-COT	UP Estab-lished	10°25'48.60343"	124°00'11.58340"	69.232	1153148.008	609805.735	6.316	3.317
UP-MAN	UP Estab-lished	10°15'13.34202"	123°49'59.57490"	77.561	1133581.459	591247.957	14.47	4.332

4.5 Cross-section and Bridge As-Built survey and Water Level Marking

Cross-section survey was conducted on December 11, 2015 at the upstream portion of the Balamban River in Brgy. Biasong, Municipality of Balamban using GNSS receiver Trimble® SPS 882 in PPK survey technique. The area identified by USC for their flow data gathering site is a non-bridge location as shown in Figure 37.

Figure 34. Kotkot Bridge facing upstream

Figure 35. As-built survey of Kotkot Bridge

The cross-sectional line of Cotcot Bridge is about 44.5 m with thirty-two cross-sectional points using the control point UP-COT as the GNSS base station The location map of Kotkot Bridge cross-section survey, cross-section diagram, and the bridge data form are shown in Figure 36 to Figure 39.

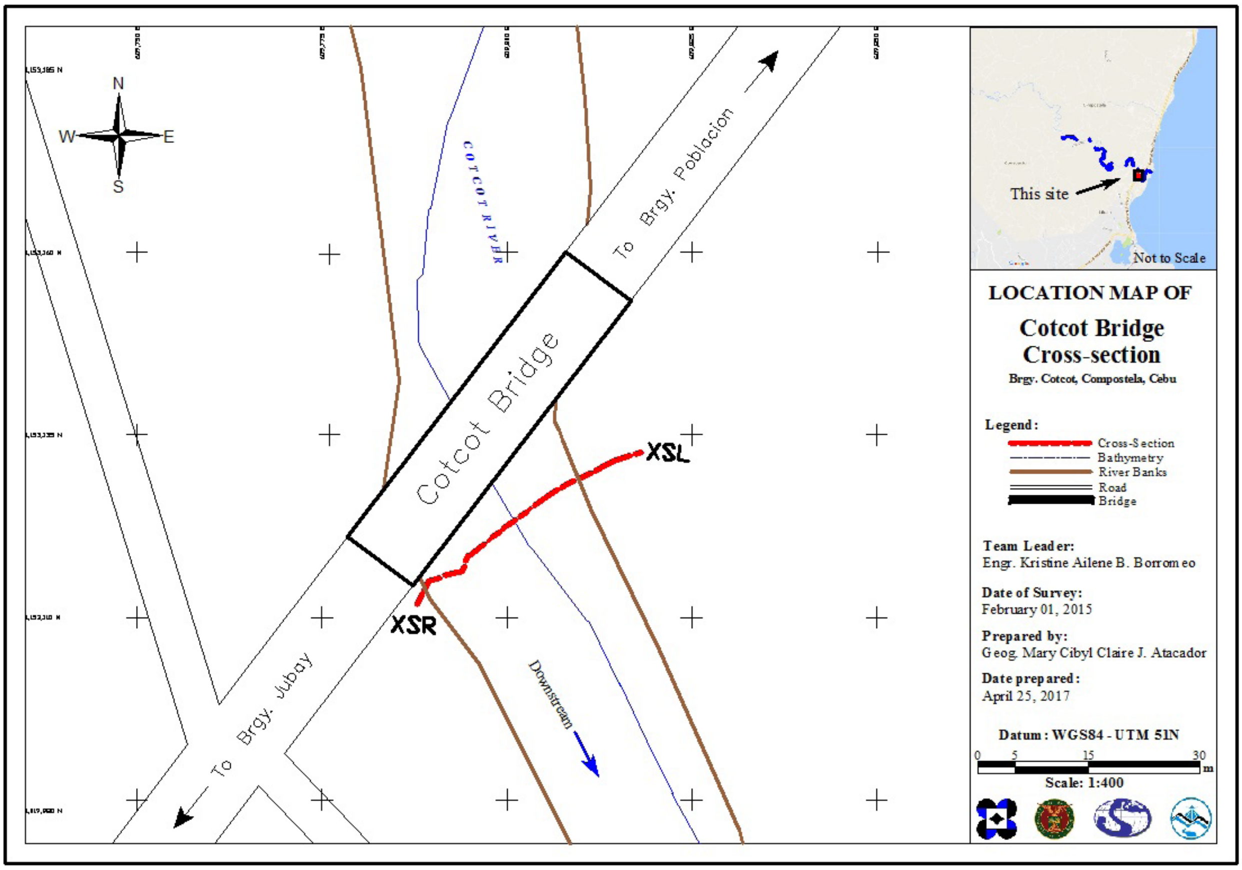


Figure 36. Location map of Kotkot River cross-section survey

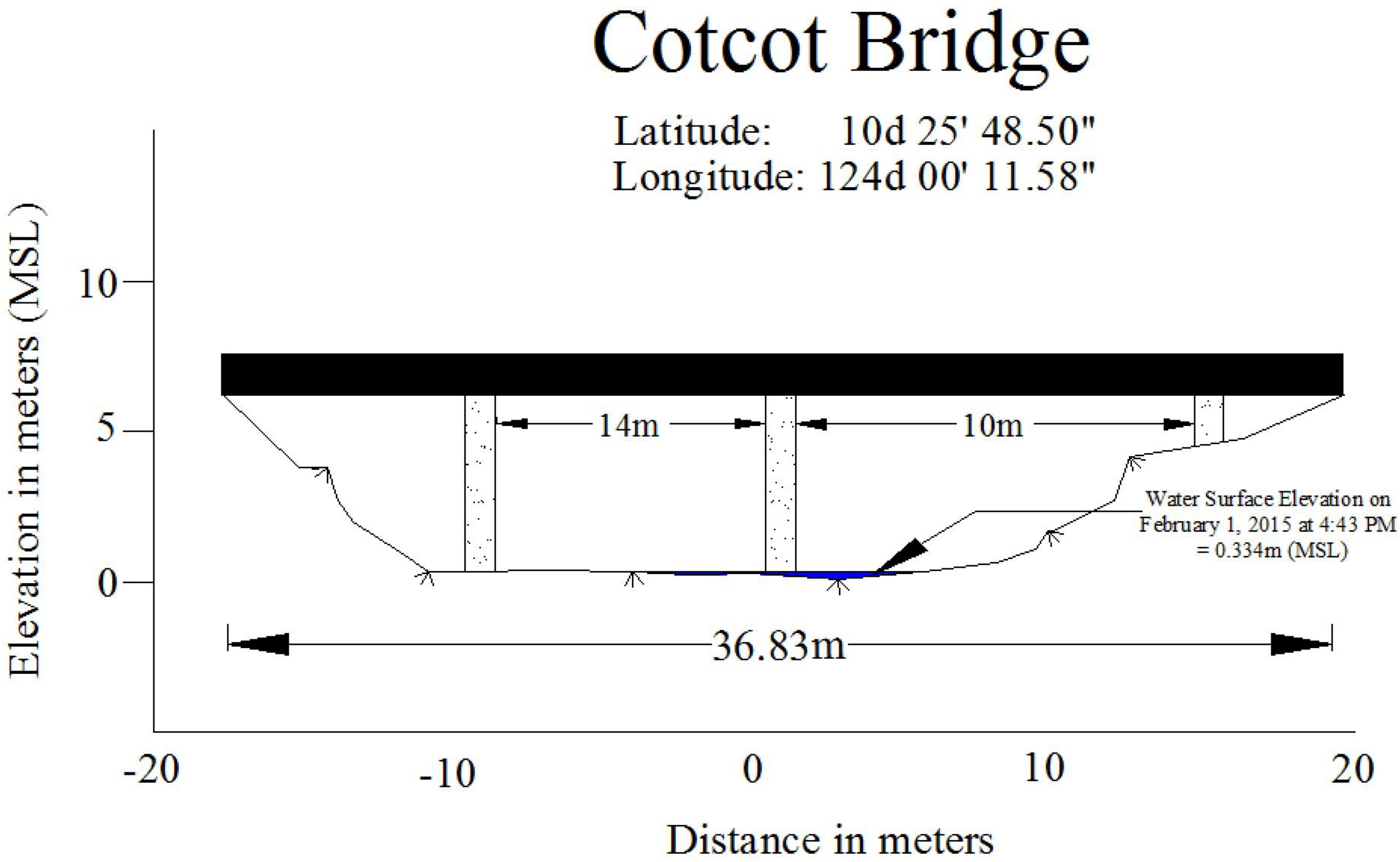


Figure 37. Kotkot Riverbed cross-section diagram

Bridge Data Form

Culvert Name: **Cotcot Bridge** **Date:** **February 1, 2015**

River Name: **Cotcot River** **Time:** **04:41PM**

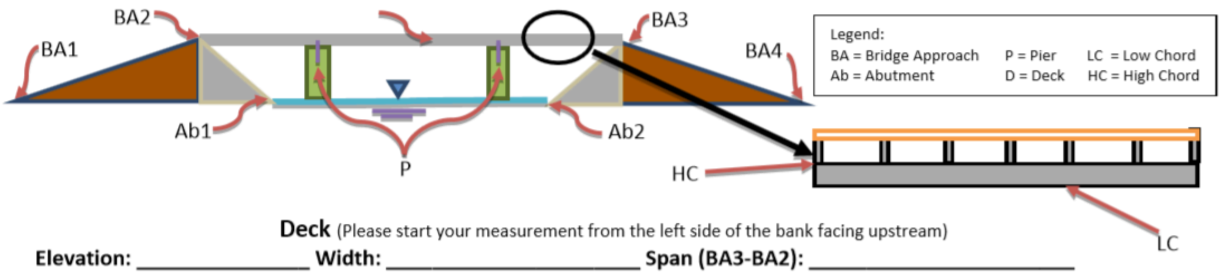
Location (Brgy, City,Region): **Municipality of Li-loan, Cebu Province**

Survey Team: **Cebu Survey Team**

Flow condition: low **normal** high

Weather Condition: **fair** raining

Latitude: **10d25'48.60"** **Longitude:** **124d00'11.58"**



Deck (Please start your measurement from the left side of the bank facing upstream)

Elevation: _______________ **Width:** ______________________ **Span (BA3-BA2):** ______________________

	Station	High Chord Elevation	Low Chord Elevation
1			
2			
3			
4			
5			

Bridge Approach (Please start your measurement from the left side of the bank facing upstream)

	Station(Distance from BA3)	Elevation (MSL)		Station(Distance from BA1)	Elevation (MSL)
BA1	52.29 m	6.214 m	BA3	52.29 m	6.095 m
BA2	49.81 m	6.11 m	BA4	55.46 m	6.124 m

Abutment: Is the abutment sloping? Yes No; If yes, fill in the following information:

	Station (Distance from BA1)	Elevation
Ab1	n/a	n/a
Ab2	n/a	n/a

Pier (Please start your measurement from the left side of the bank facing upstream)

Figure 38. Kotkot Bridge data form

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on February 1, 2, 4, 5, and 6, 2015 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached in front of the vehicle as shown in Figure 39. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was m and measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The survey was conducted using PPK technique on a continuous topography mode with UP-COT and UP-MAN occupied as the GNSS base stations.

On the first day, survey started from the Municipality of Compostela to the Municipality of Liloan. On the second day, the survey continued from the Municipality of Liloan going to Mandaue City. The remaining days covered the major roads from Mandaue City to Cebu and Talisay Cities. The reference point CBU-11 was occupied as the GNSS base station for the survey.

Figure 39. Validation points acquisition survey set up along Kotkot River Basin

The conducted survey on February 1, 2015 started from Brgy. Estaca, Municipality of Compostela, going west traversing the Municipalities Liloan, Consolacion, Manadue City, Talisay City, and Minglanilla; and ended in Brgy. Hippodromo, Cebu City. A total of 6,730 points were gathered with approximate length of 48.46 km using UP-MAN and UP-COT base stations for the entire extent validation points acquisition survey as illustrated in the map in Figure 40.

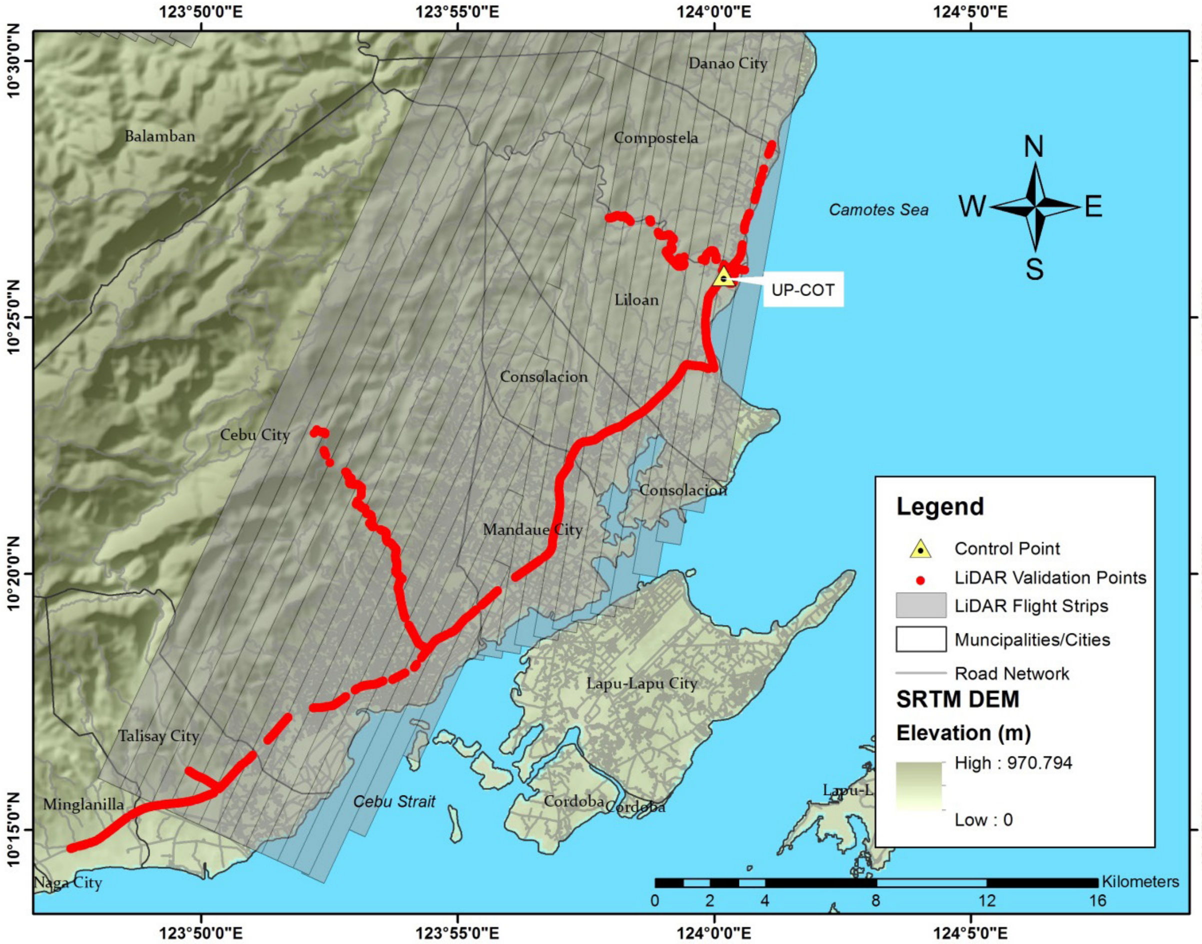


Figure 40. Validation point acquisition survey of Kotkot River basin

4.7 River Bathymetric Survey

Manual Bathymetric survey was executed on January 30, February 1 and 5, 2015 using Trimble® SPS 882 in GNSS PPK survey technique as illustrated in Figure C-14. The survey started in Brgy. Cabadiangan, Municipality of Liloan with coordinates 10°26'56.24470"N, 123°57'57.27338"E, traversing down the river and ended at Brgy. Cotcot, Municipality of Liloan with coordinates 10°25'55.40460"N, 124°00'36.05752"E. The control point UP-COT was used as GNSS base station all throughout the entire survey.

Figure 41. Bathymetric survey in Kotkot River

The bathymetric survey for Cotcot River gathered a total of 940 points covering 8.827 km of the river traversing Barangays Cabadiangan and Cotcot, in Municipality of Liloan. A CAD drawing was also produced to illustrate the riverbed profile of Cotcot River. As shown in Figure 43 and, the highest and lowest elevation has a 22.685-m difference. The highest elevation observed was 25.793 m above MSL located in the middle portion of the river in in Brgy. Cotcot, Municipality of Liloan; while the lowest was -3.108 m below MSL located near the mouth, in the same Barangay.

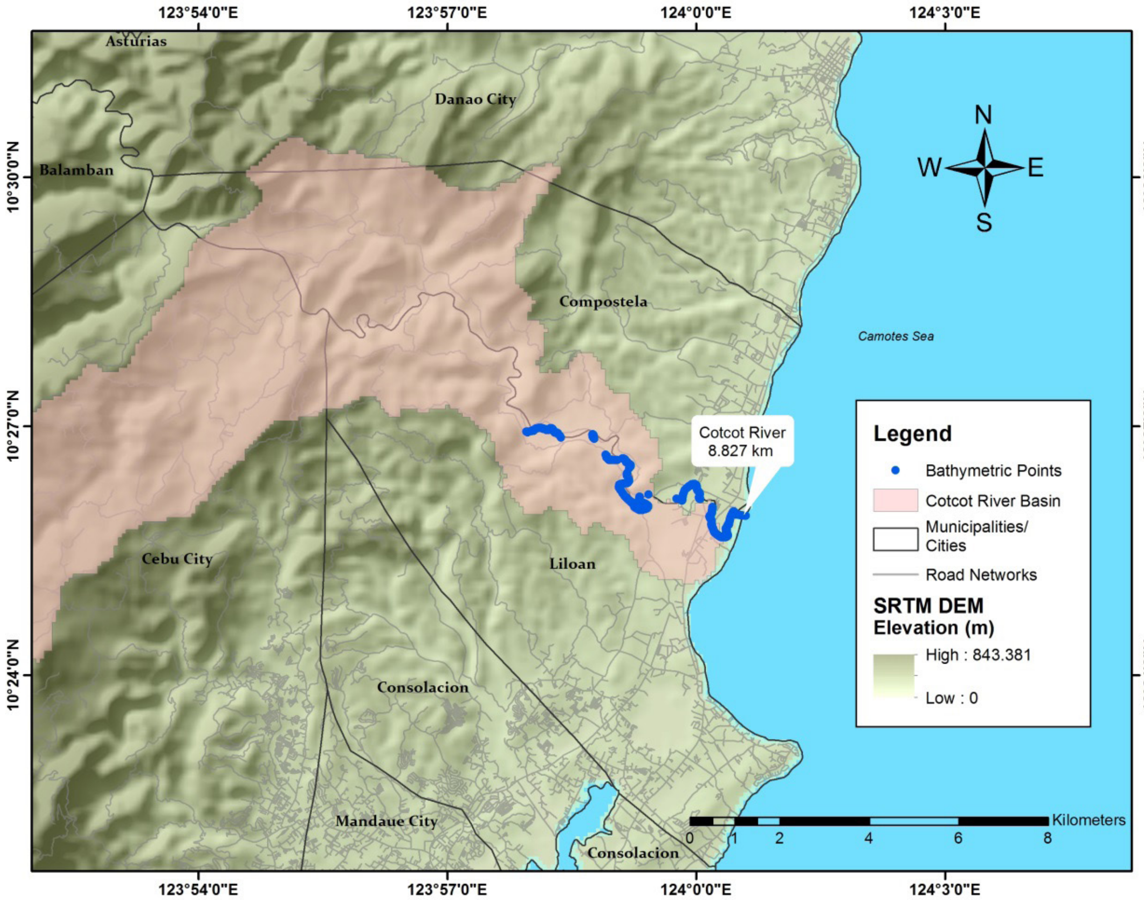


Figure 42. Extent of the Kotkot River Bathymetry Survey

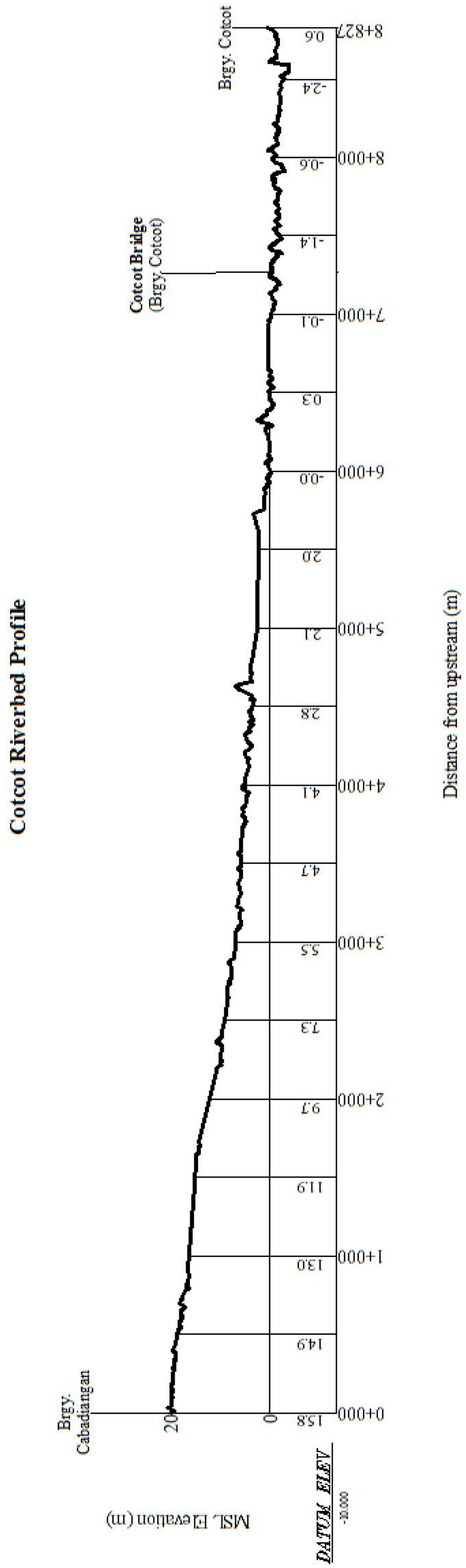


Figure 43. Kotkot riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

Alfredo Mahar Francisco A. Lagmay, Christopher Noel L. Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil R. Tingin, and Pauline Racoma

The methods applied in this Chapter were based on the DREAM methods manual (Lagmay, et al., 2014) and further enhanced and updated in Paringit, et al. (2017)

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All data that affect the hydrologic cycle of the Kotkot River Basin were monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Kotkot River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an installed rain gauge by the University of San Carlos Phil LiDAR 1 team. The station was installed in Brgy. Mulao. The location of this station in the watershed is presented in Figure 44.

The total precipitation in the Brgy. Mulao Station is 33.6 mm. The rainfall peaked to 7.8 mm on 15:10 on February 23, 2017.

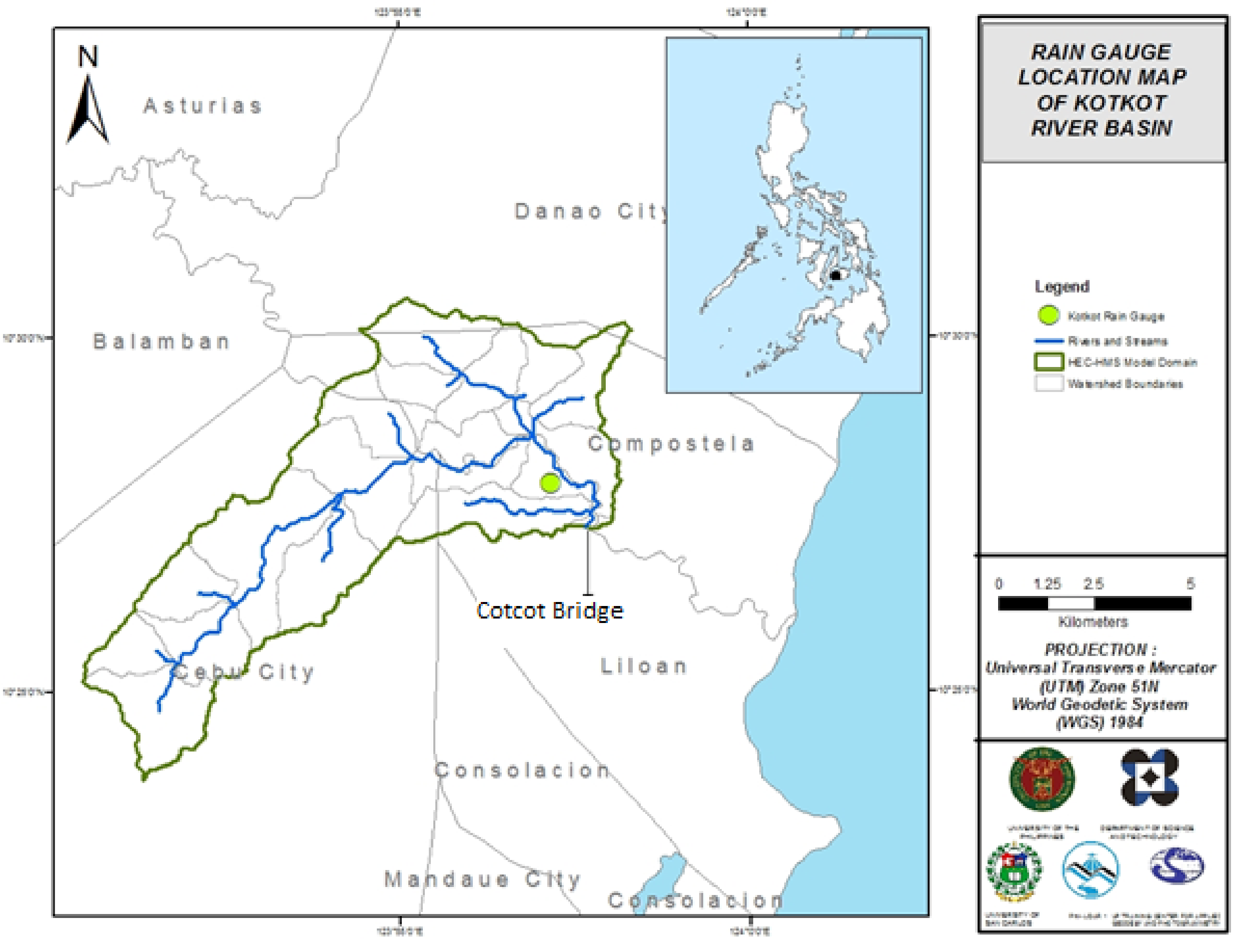


Figure 44. Location map of the Kotkot HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Kotkot Bridge (10°27'19.13"N and 123°57'40.89"E). It gives the relationship between the observed water levels and outflow of the watershed at this location.

For Kotkot Bridge, the rating curve is expressed as shown in Figure 45.

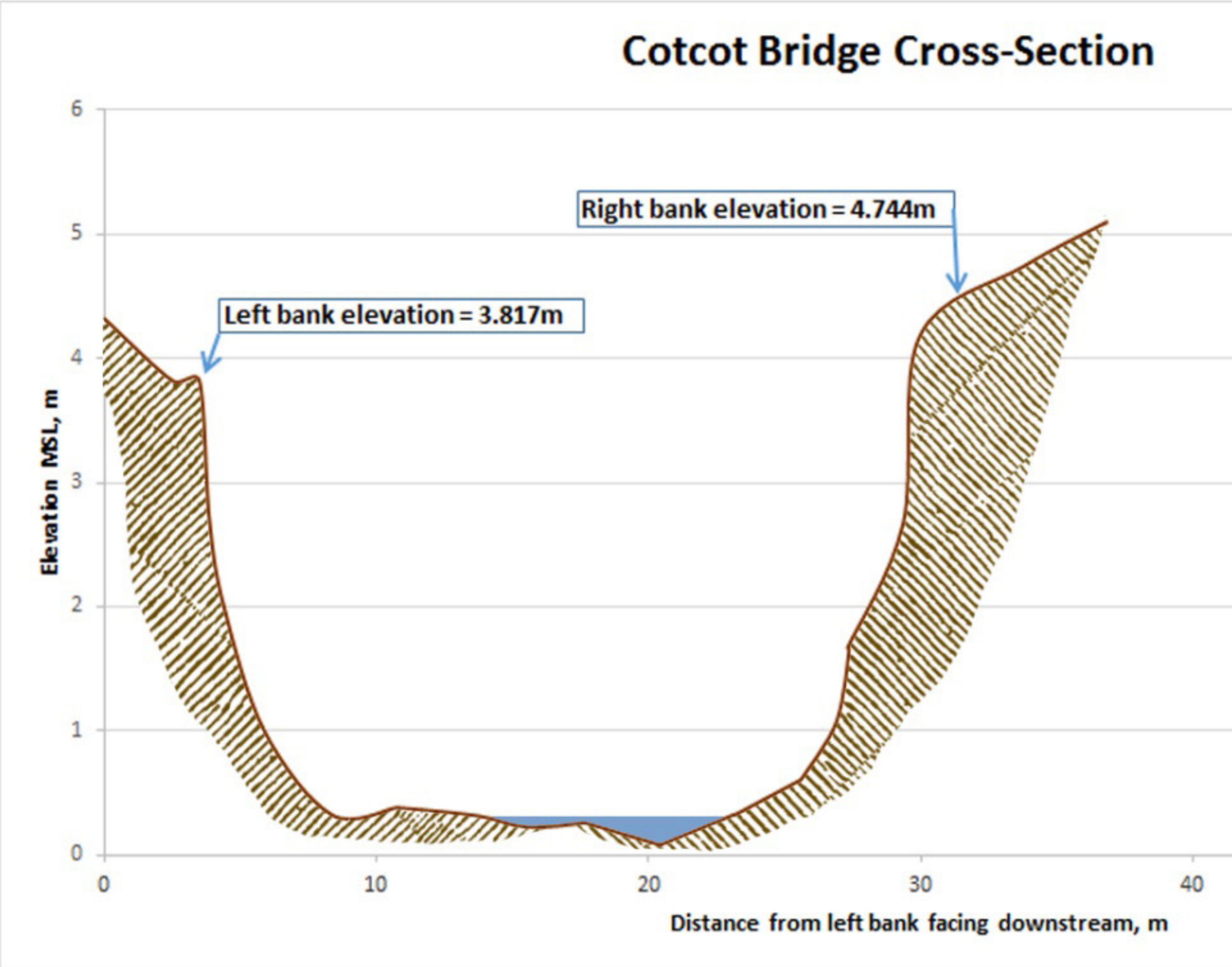


Figure 45. Cross-section plot of Kotkot Bridge (Date surveyed: 1 February 2015)

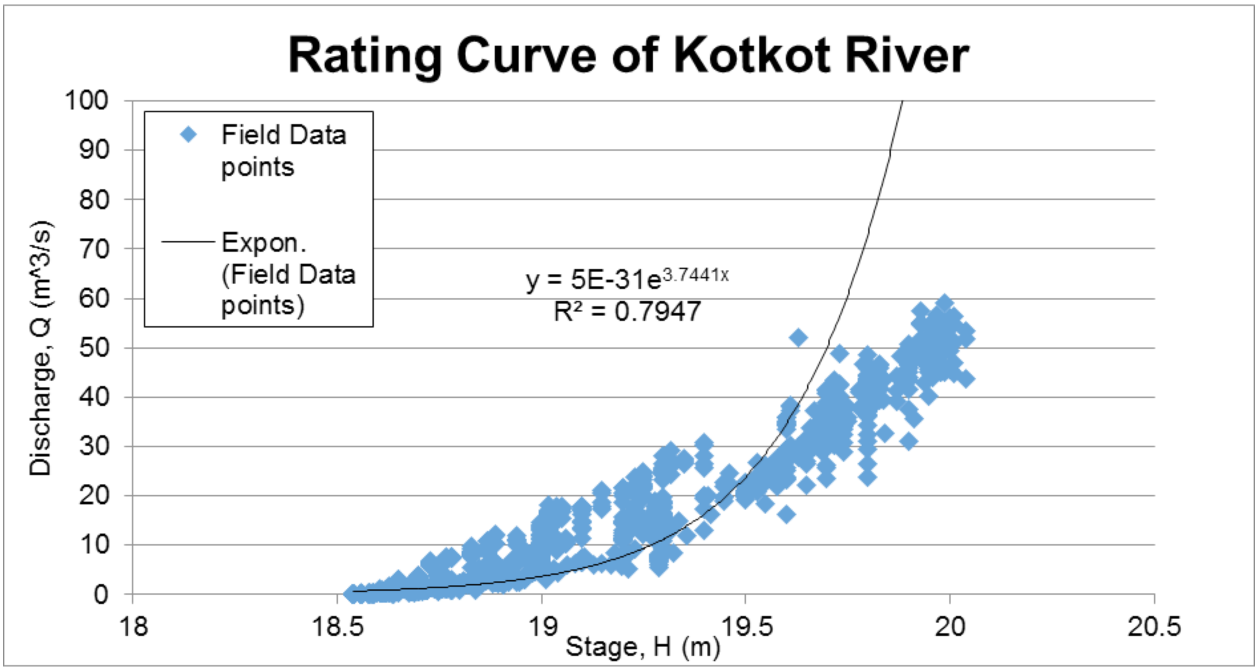


Figure 46. Rating curve at Kotkot Bridge in Kotkot River

This rating curve equation was used to compute the river outflow at Kotkot Bridge for the calibration of the HEC-HMS model shown in Figure 47. Peak discharge is 31.856 m3/s at 19:05, February 23, 2017.

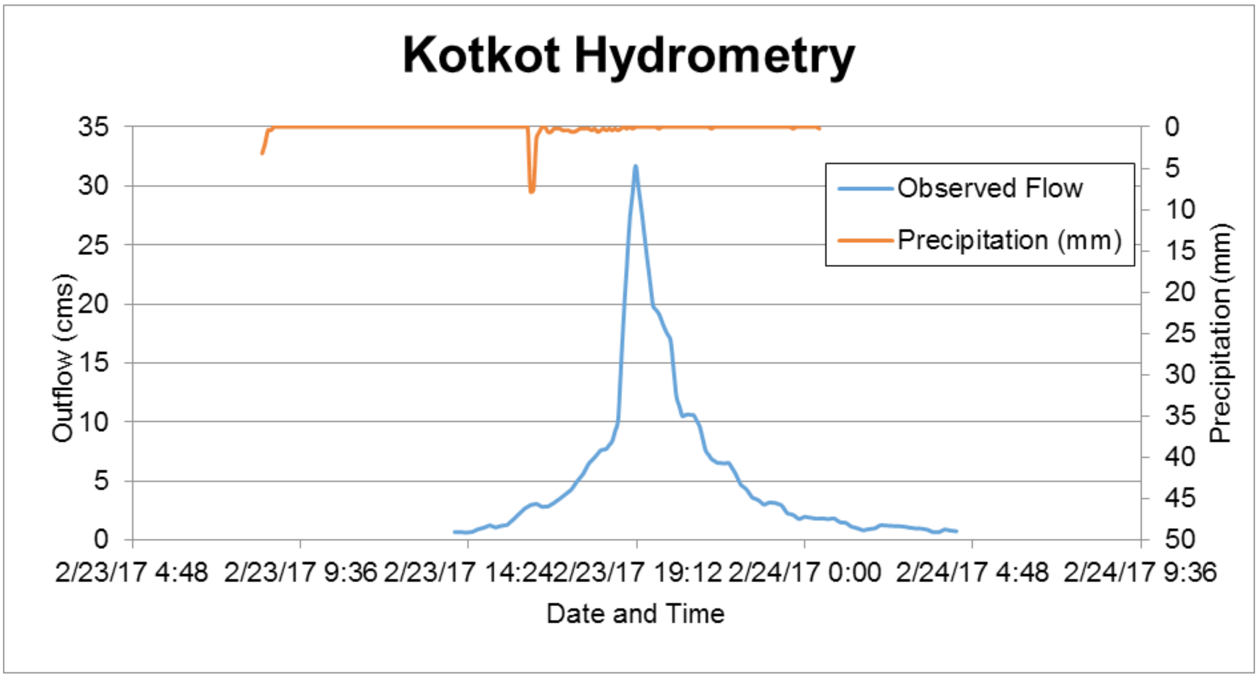


Figure 47. Rainfall and outflow data at Kotkot Bridge used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Mactan Point Gauge. This station chosen based on its proximity to the Kotkot watershed. The extreme values for this watershed were computed based on a 37-year record.

Table 25. RIDF values for Mactan Point Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	18.5	28.1	35.6	48.1	68	82.1	104.6	124.9	145
5	25.9	38.3	63.8	63.8	90.4	108.8	137.5	165.2	190.8
10	30.8	45	74.2	74.2	105.3	126.5	159.3	191.9	221.2
15	33.5	48.8	80.1	80.1	113.7	136.5	171.5	206.9	238.4
20	35.5	51.5	84.2	84.2	119.6	143.5	180.1	217.5	250.4
25	37	53.6	87.3	87.3	124.1	148.9	186.7	225.6	259.6
50	41.5	59.9	97.1	97.1	138.1	165.5	207.1	250.6	288.1
100	46.1	66.2	106.8	106.8	151.9	181.9	227.4	275.4	316.3

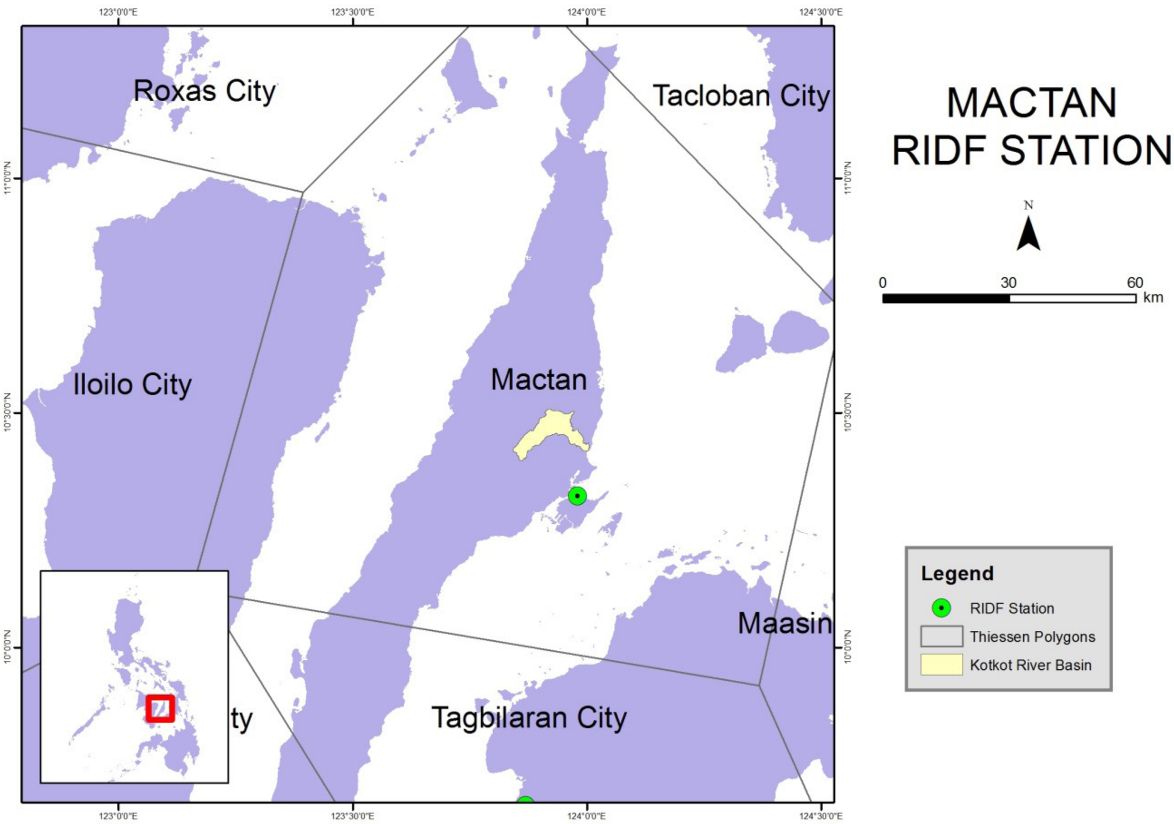


Figure 48. Location of Mactan RIDF Station relative to Kotkot River Basin

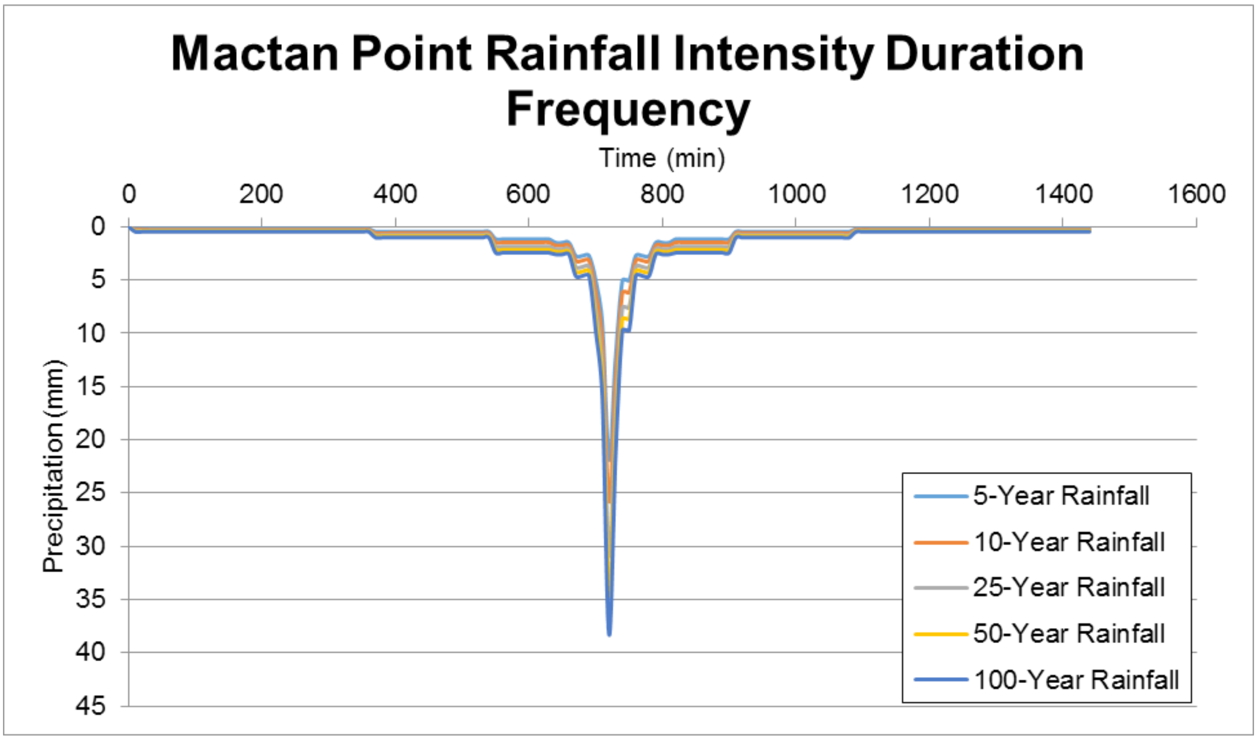


Figure 49. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management under the Department of Agriculture (DA-BSWM). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Kotkot River Basin are shown in Figure 50 and Figure 51, respectively.

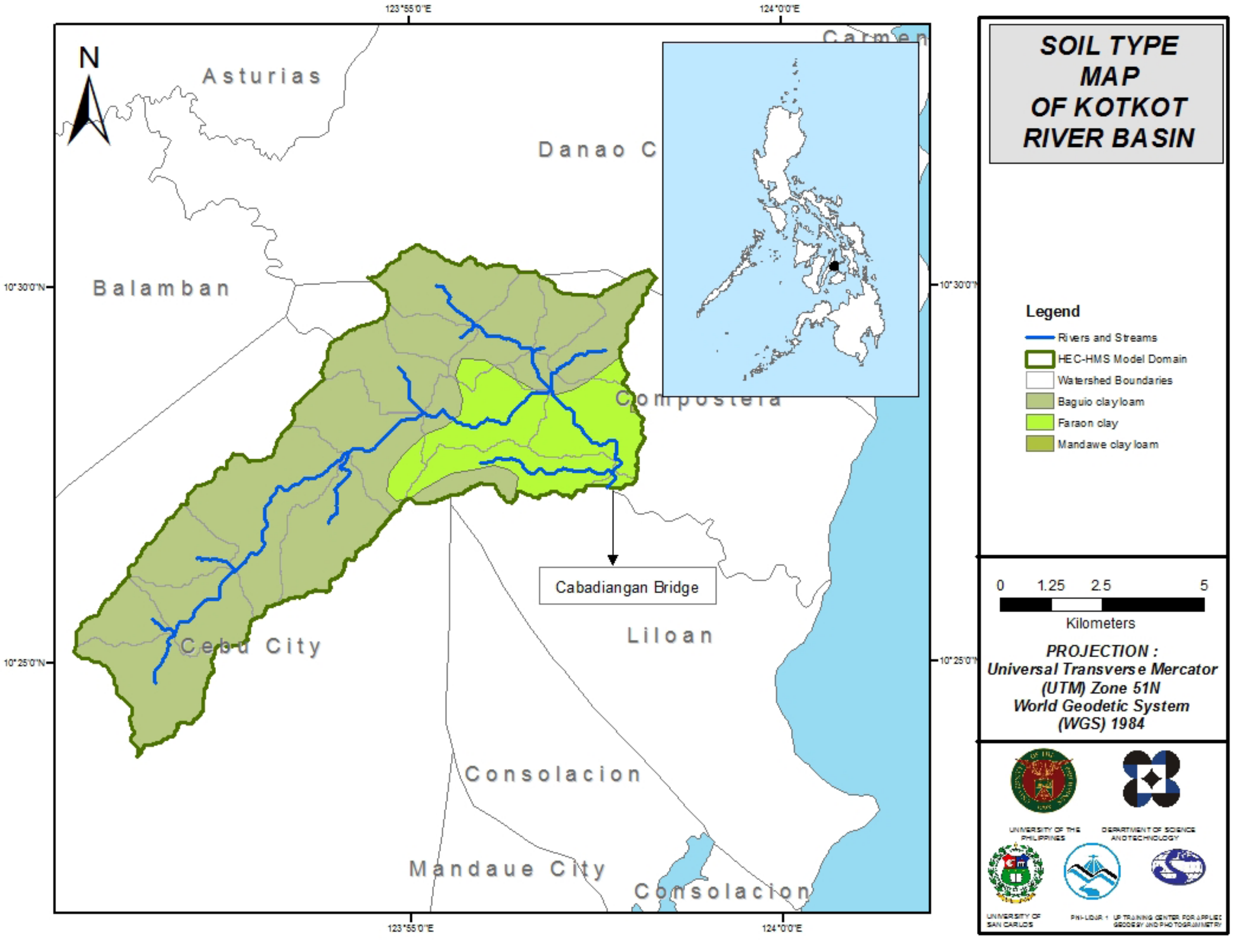


Figure 50. Soil Map of Kotkot River Basin used for the estimation of the CN parameter. (Source: DA)

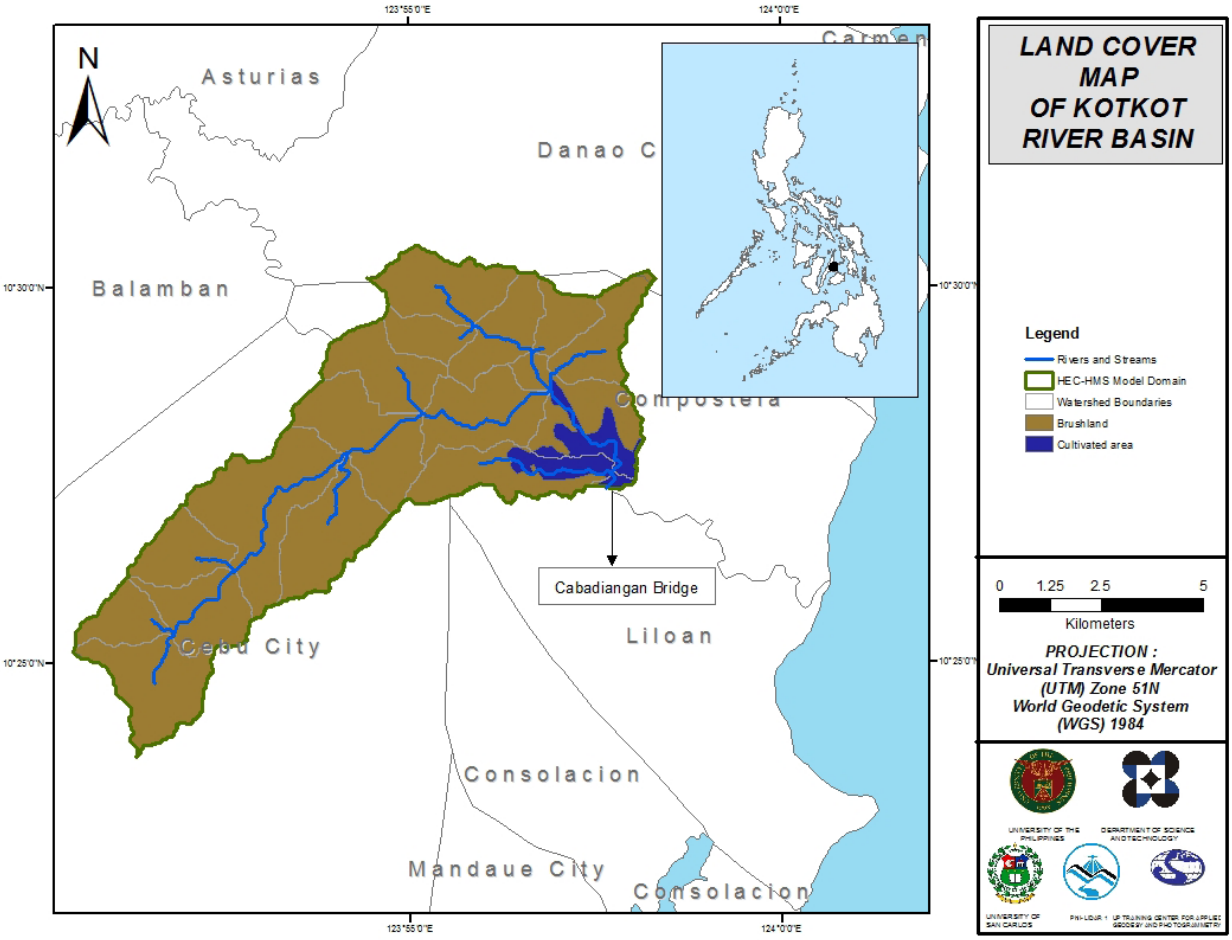


Figure 51. Land Cover Map of Kotkot River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For the Kotkot river basin, three (3) soil classes were identified. These are Baguio clay loam, Faraon clay, and Mandaue clay loam. Moreover, two (2) land cover classes were identified. Most of the Kotkot river basin is brushland, while a small portion is cultivated area.

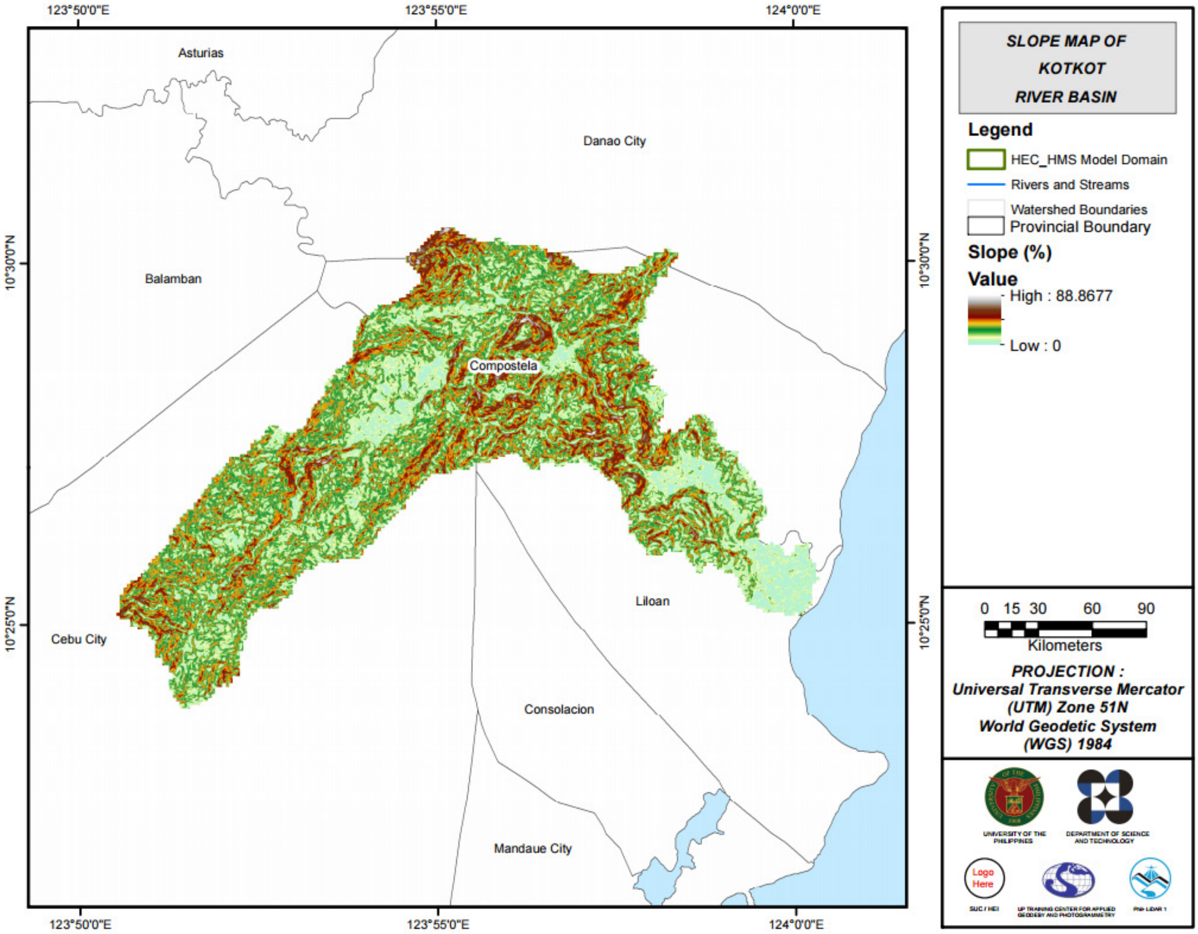


Figure 52. Slope Map of Kotkot River Basin

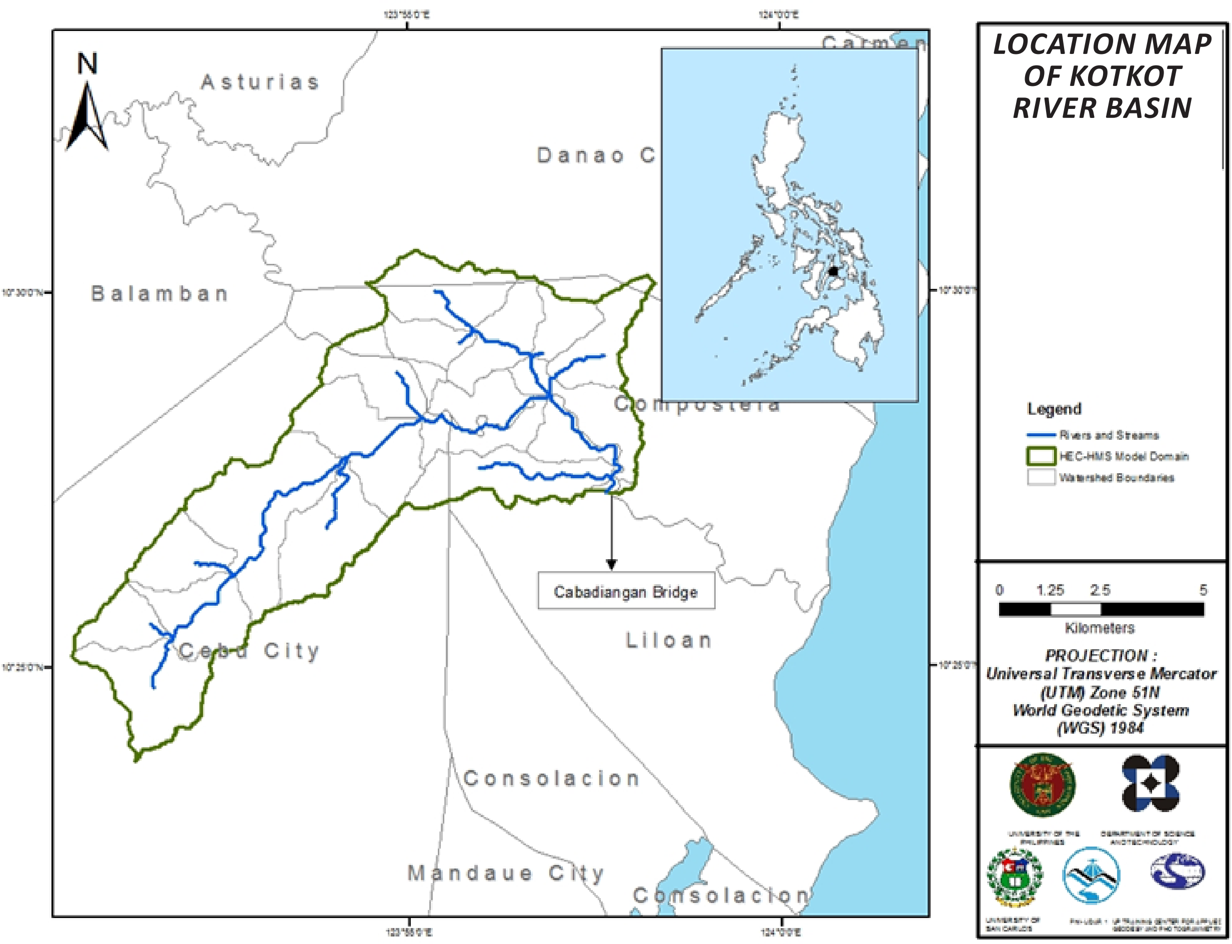


Figure 53. Stream Delineation Map of Kotkot River Basin

The Kotkot basin model comprises 19 sub basins, 9 reaches, and 9 junctions. The main outlet is outlet 1. This basin model is illustrated in Figure 54. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed rain gauge near and inside the river

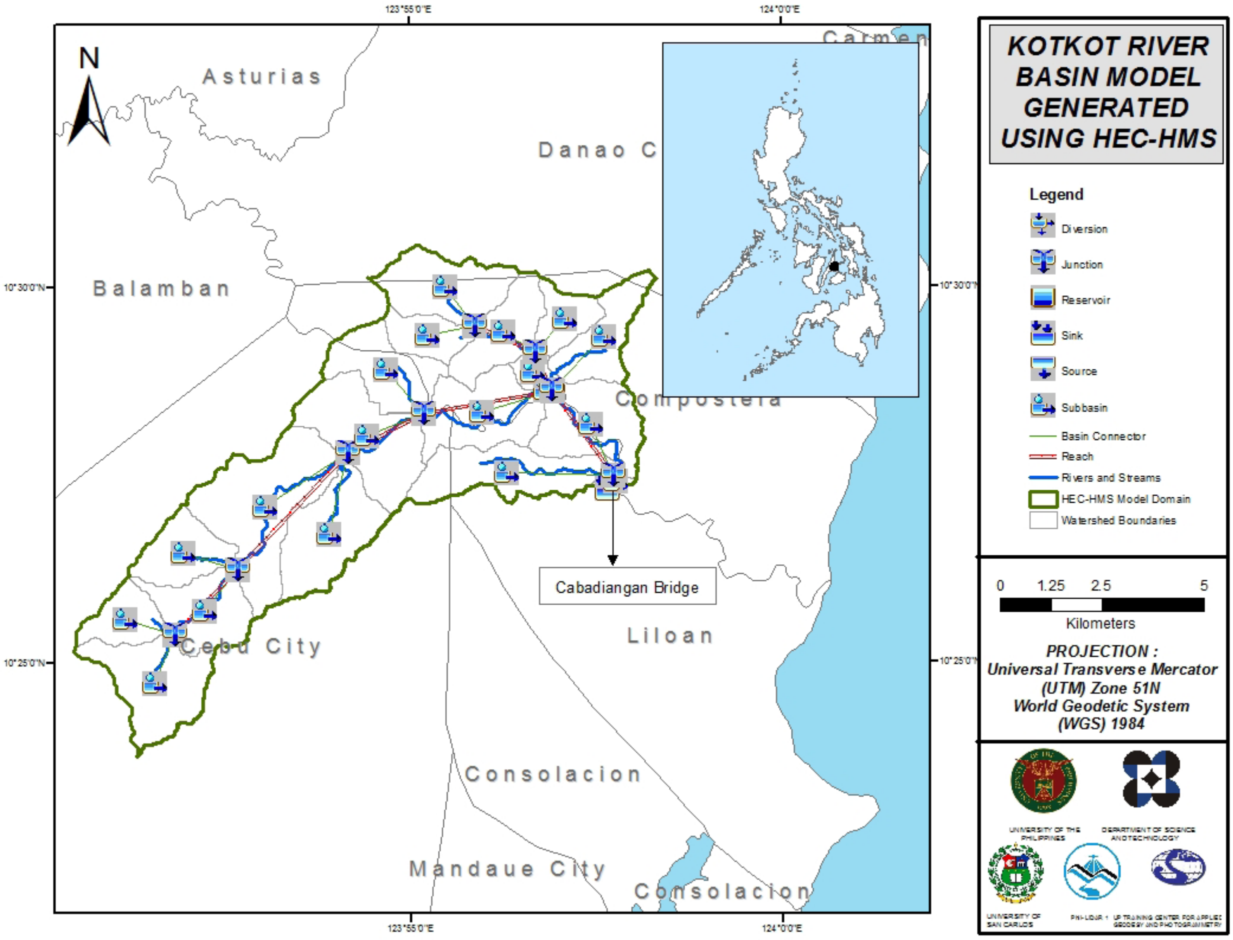


Figure 54. Kotkot River Basin model generated in HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS.

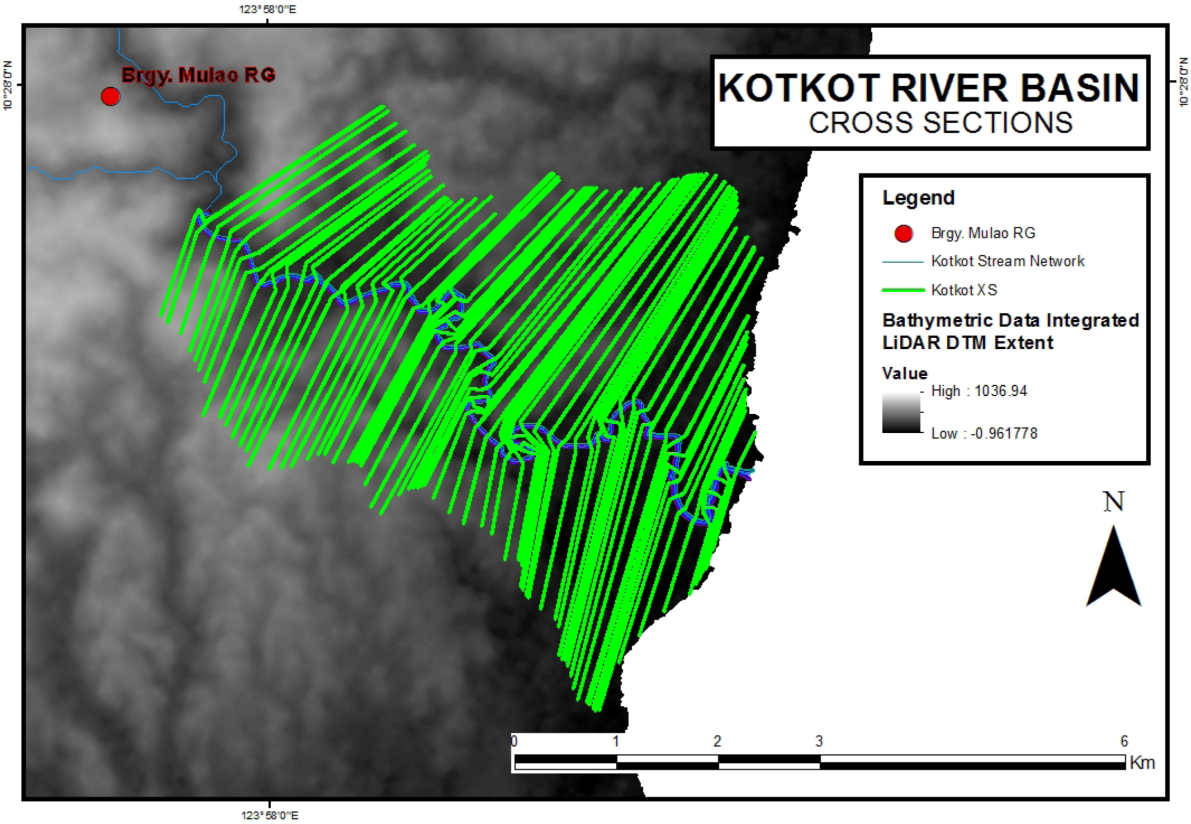


Figure 55. River cross-section of Kotkot River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modelling process allows for the creation of a model with boundaries that are almost exactly coincidental with that of the catchment area. As such, they have approximately the same land area and location. The entire area is divided into square grid elements, 10 meter by 10 meter in size. Each element is assigned a unique grid element number which serves as its identifier, then attributed with the parameters required for modelling such as x-and y-coordinate of centroid, names of adjacent grid elements, Manning coefficient of roughness, infiltration, and elevation value. The elements are arranged spatially to form the model, allowing the software to simulate the flow of water across the grid elements and in eight directions (north, south, east, west, northeast, northwest, southeast, southwest).

Based on the elevation and flow direction, it is seen that the water will generally flow from the northwest of the model to the eastsouth, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

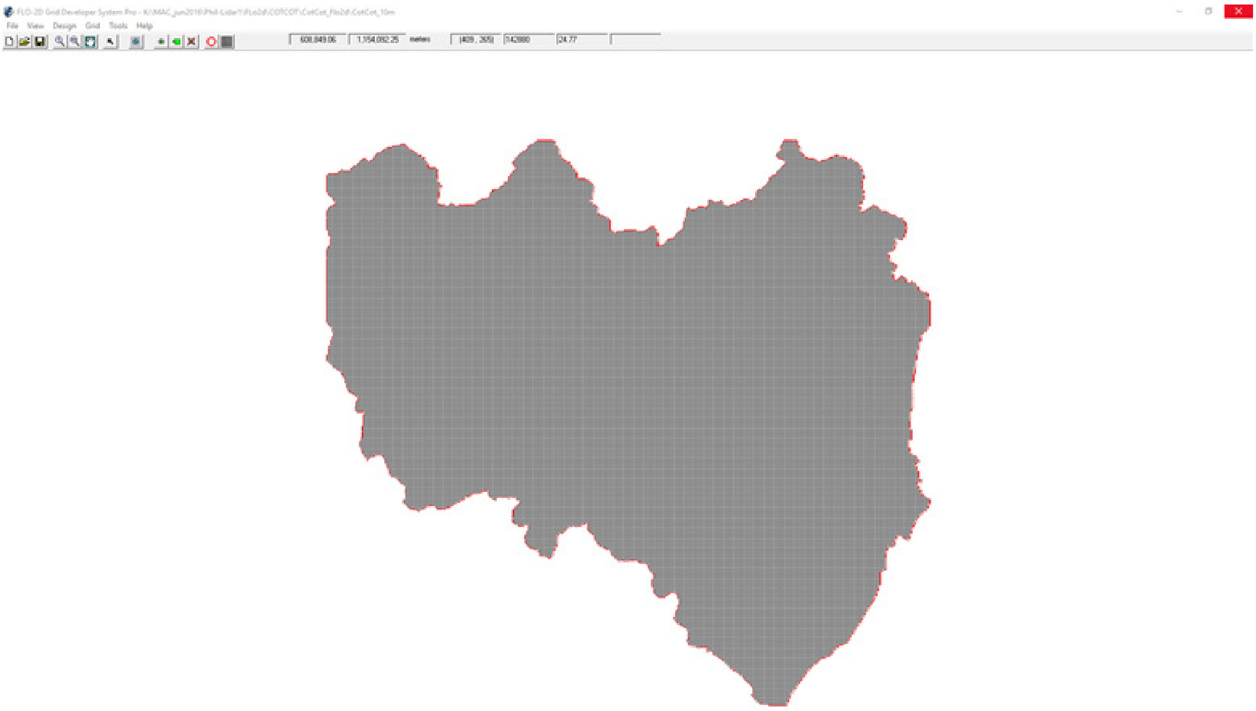


Figure 56. Screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 14.70435 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 sq.m./s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 21631400.00 sq.m.

There is a total of 14278952.38 m3 of water entering the model. Of this amount, 5733800.68 m3 is due to rainfall while 8545151.70 m3 is inflow from other areas outside the model. 3 960 626.75 m3 of this water is lost to infiltration and interception, while 2382241.25 m3 is stored by the flood plain. The rest, amounting up to 14278953.00 cu.m, is outflow.

5.5.1 Discharge data using Dr. Horritt's recommended hydrologic method

The river discharge values for the nine rivers entering the floodplain are shown in Figure 57 and the peak values are summarized in Table 26.

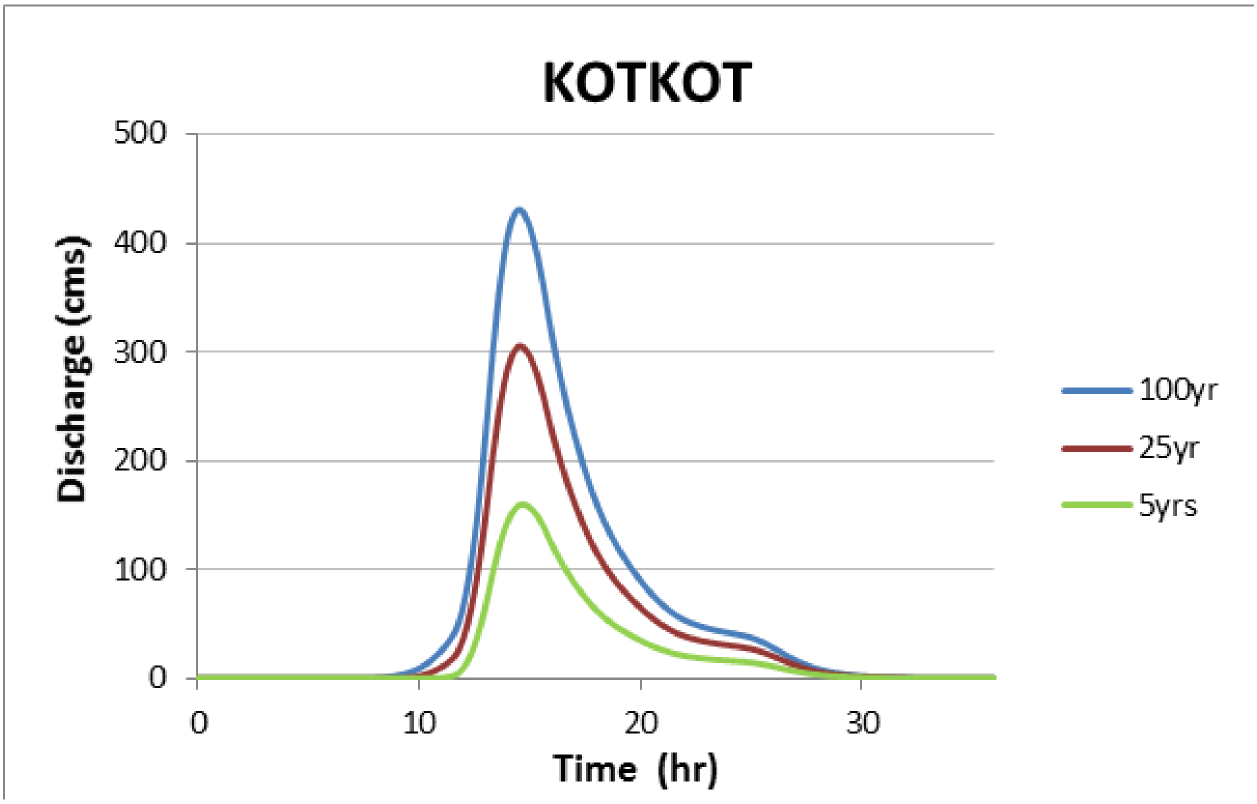


Figure 57. Kotkot river (1) generated discharge using 5-, 25-, and 100-year Iba rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 26. Summary of Kotkot river discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	430.9	14 hours, 50 minutes
25-Year	305.2	14 hours, 50 minutes
5-Year	159.9	14 hours, 50 minutes

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 27.

Table 27. Validation of river discharge estimates

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Kotkot (1)	140.712	100.600	157.989	Pass	Pass

Eight out of nine of the results from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful and specific discharge methods. One did not pass and will need further recalculation. The eight passing values are based on theory but are supported using other discharge computation methods so they were good to use flood modeling. These values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.6 Results of HMS Calibration

After calibrating the Kotkot HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 58 shows the comparison between the two discharge data.

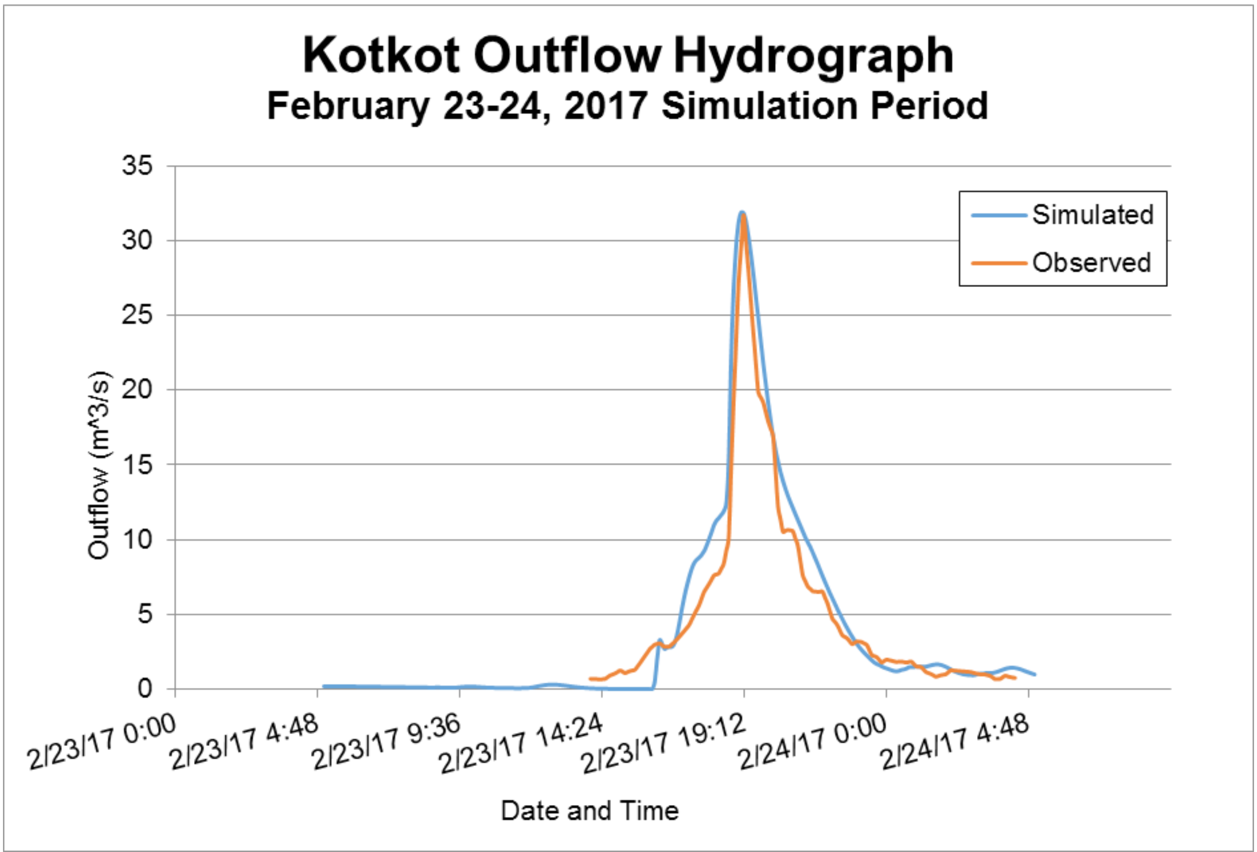


Figure 58. Outflow hydrograph of Kotkot produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 28 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 28. Range of calibrated values for the Kotkot River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.85-42.12
			Curve Number	35.20-99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0-1
			Storage Coefficient (hr)	0.19-16.33
	Baseflow	Recession	Recession Constant	0.02-1.31
			Ratio to Peak	0-0.01
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0-0.02

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.85 to 42.12 mm signifies that there is minimal to average amount of infiltration or rainfall interception by vegetation.

The curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 65 to 90 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Kotkot, the basin mostly consists of brushland and cultivated areas; and, the soil consists of clay and clay loam. The curve number is 35 to 99.

The time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.19 to 16.33 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events, while ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0 to 0.01indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0 to 0.02 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0 to 0.14 corresponds to the common roughness in Hinatuan watershed, which is determined to be brushland and cultivated areas (Brunner, 2010).

Table 29. Summary of the Efficiency Test of the Kotkot HMS Model

Accuracy measure	Value
RMSE	2.00
r2	0.98
NSE	0.91
PBIAS	-15.41
RSR	0.30

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 1.9989.

The Pearson correlation coefficient (assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9837

The Nash-Sutcliffe (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of 0.9103.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is -15.4146.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.2995.

5.7 Calculated outflow hydrographs and discharge values for different rainfall return periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph show the Kotkot outflow using the Mactan Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-, 10-, 25-, 50-, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a uniform duration of 24 hours and varying return periods.

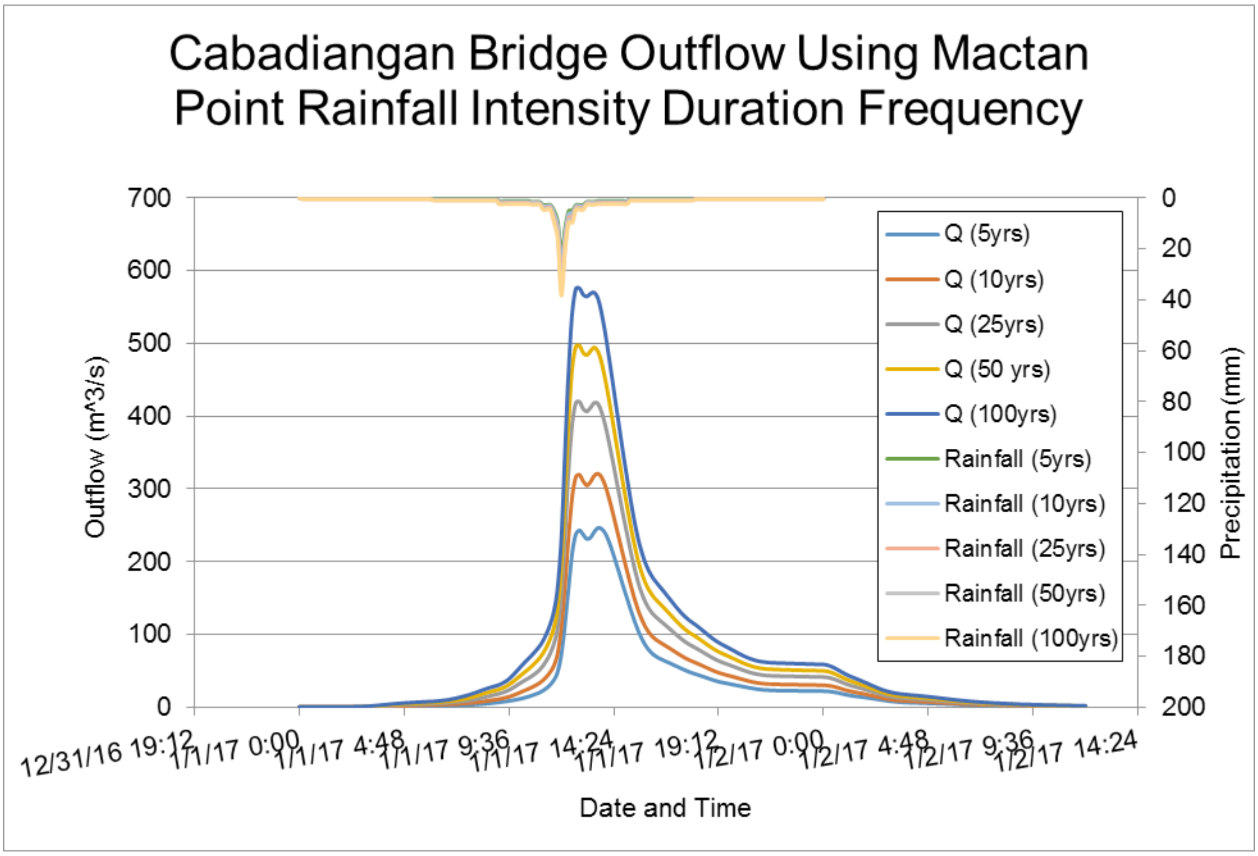


Figure 59. Outflow hydrograph at Cabadiangan Bridge, Liloan generated using Mactan Point RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Kotkot River discharge using the Mactan Point Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 30.

Table 30. Peak values of the Kotkot HEC-HMS Model outflow using the Mactan RIDF 24-hour values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	139.1	21.9	246.372	1 hour, 40 minutes
10-Year	169.7	25.8	321.188	1 hour, 40 minutes
25-Year	208.5	30.9	419.772	1 hour, 30 minutes
50-Year	237.2	34.6	496.696	1 hour, 30 minutes
100-Year	265.7	38.3	575.664	1 hour, 30 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown. The sample generated map of Kotkot River using the calibrated event flow is shown in Figure 60.

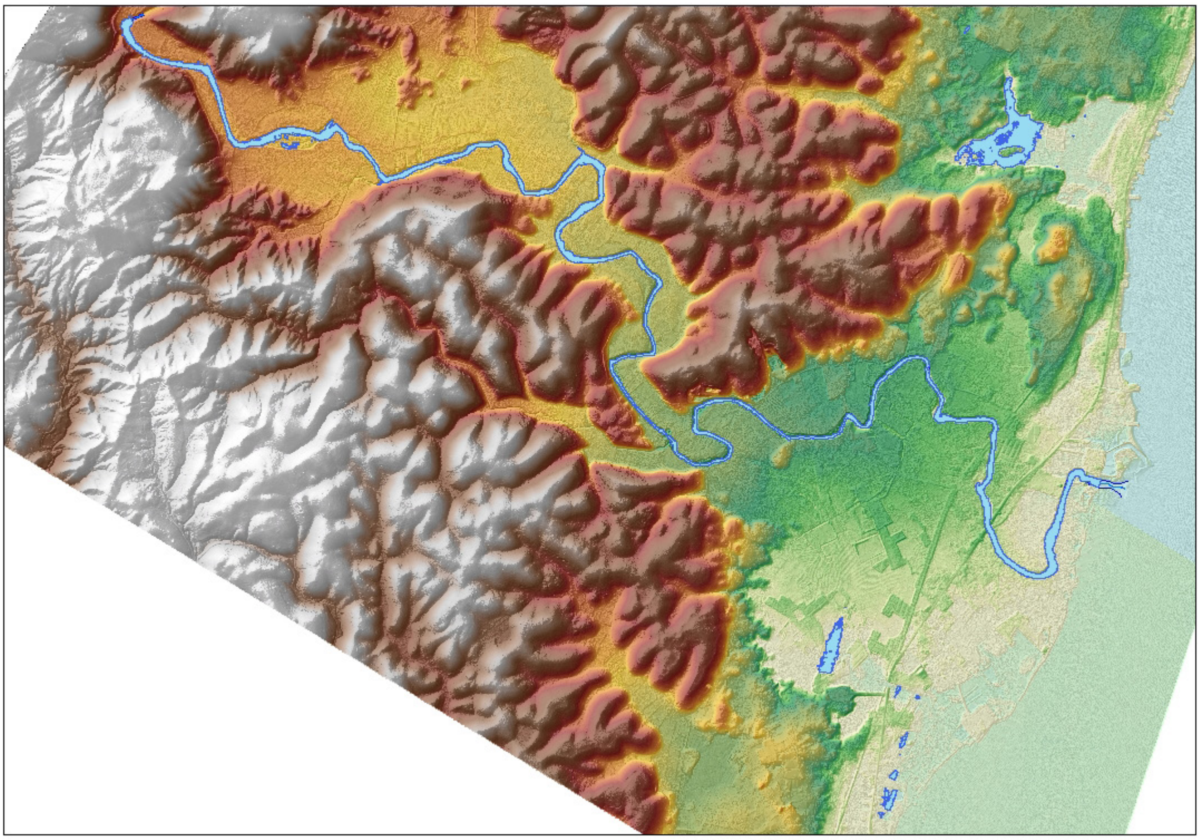


Figure 60. Sample output map of Kotkot RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 62 to Figure 67 shows the 5-, 25-, and 100-year rain return scenarios of the Kotkot floodplain.

The generated flood hazard maps for the Kotkot Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAGASA for hazard maps - “Low”, “Medium”, and “High” - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr). Figure 61 to Figure 66 shows the 5-, 25-, and 100-year rain return scenarios of the Kotkot floodplain.

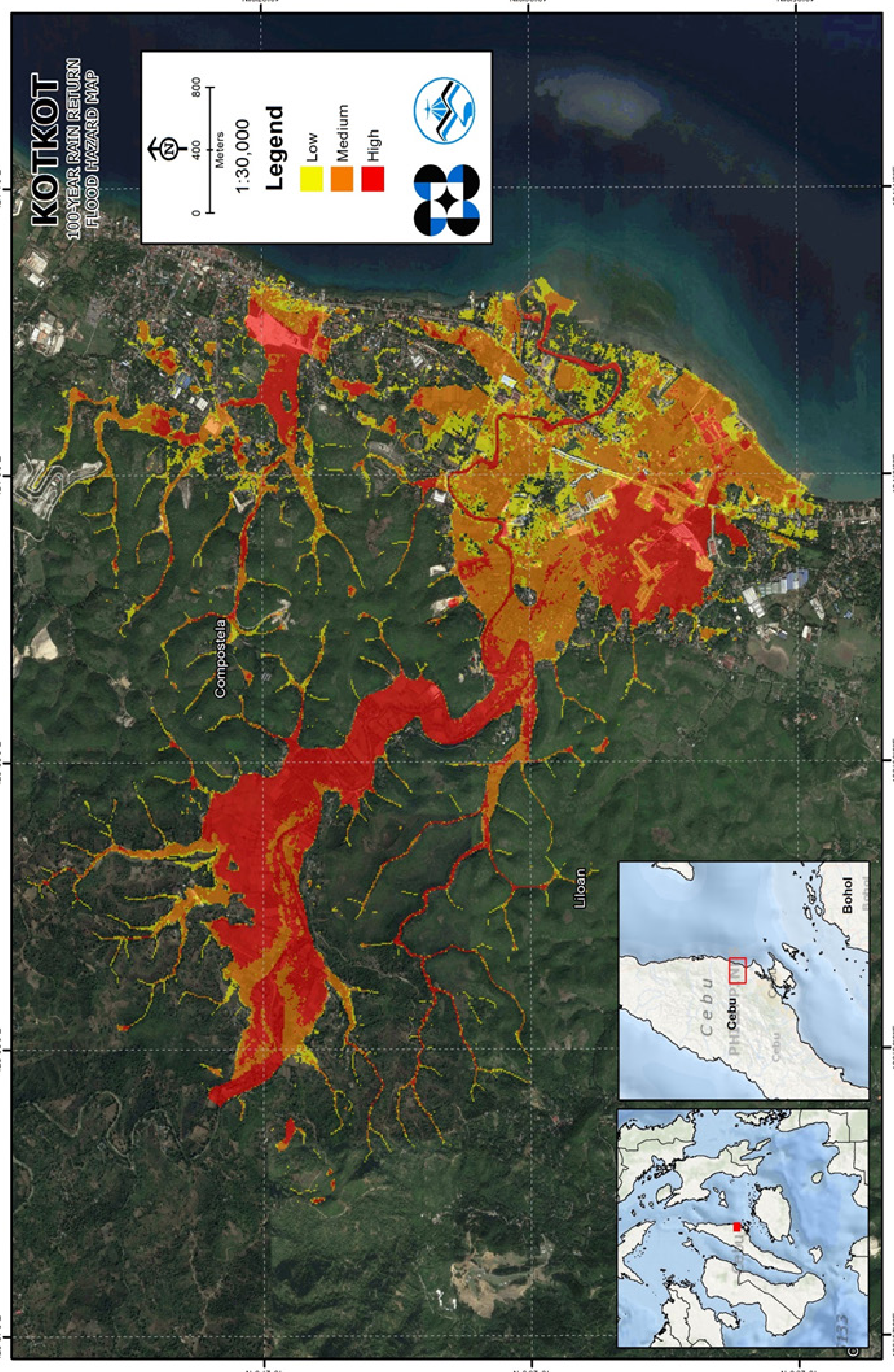


Figure 61. 100-year Flood Hazard Map for Kotkot Floodplain overlaid on Google Earth imagery

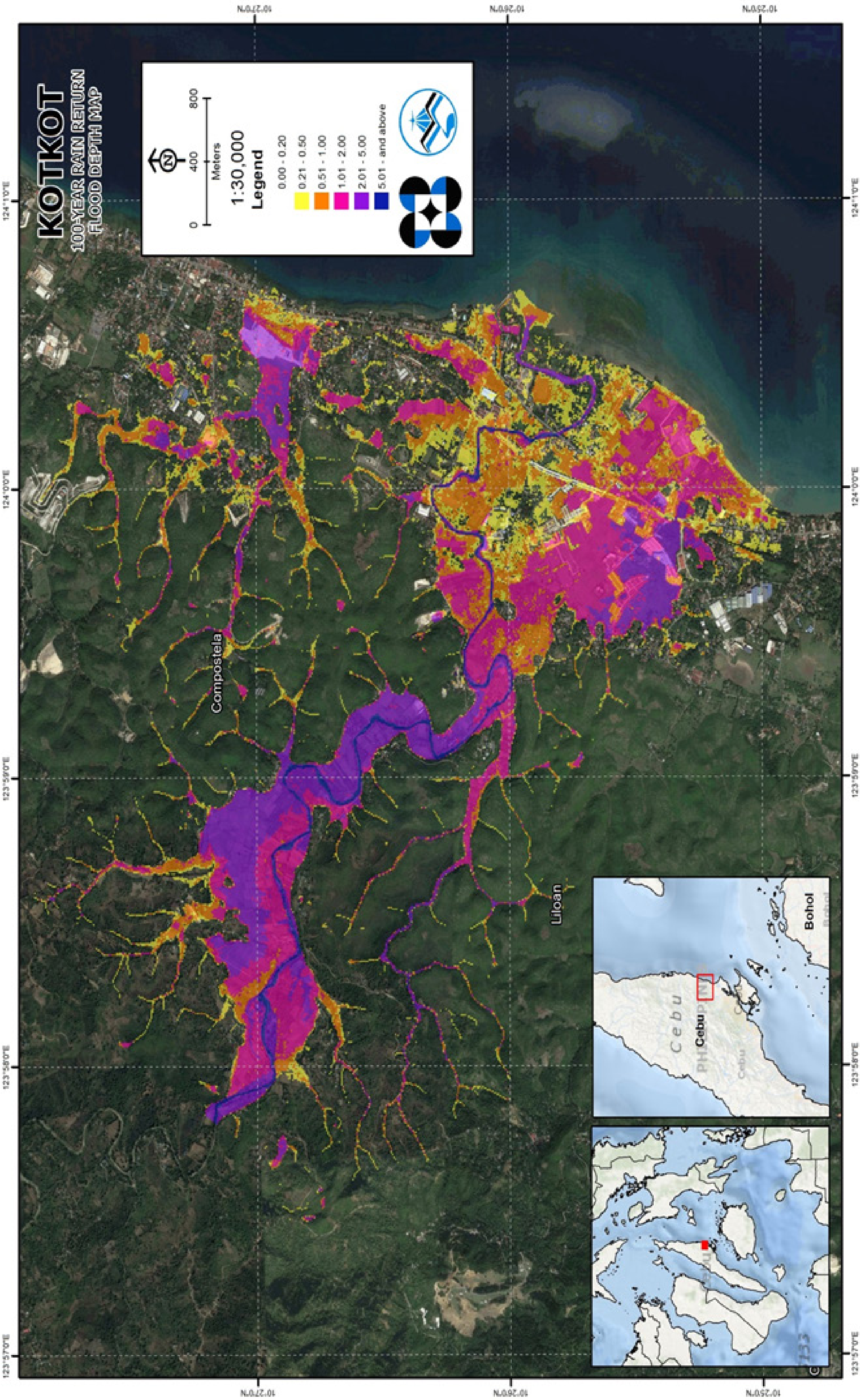


Figure 62. 100-year Flow Depth Map for Kotkot Floodplain overlaid on Google Earth imagery

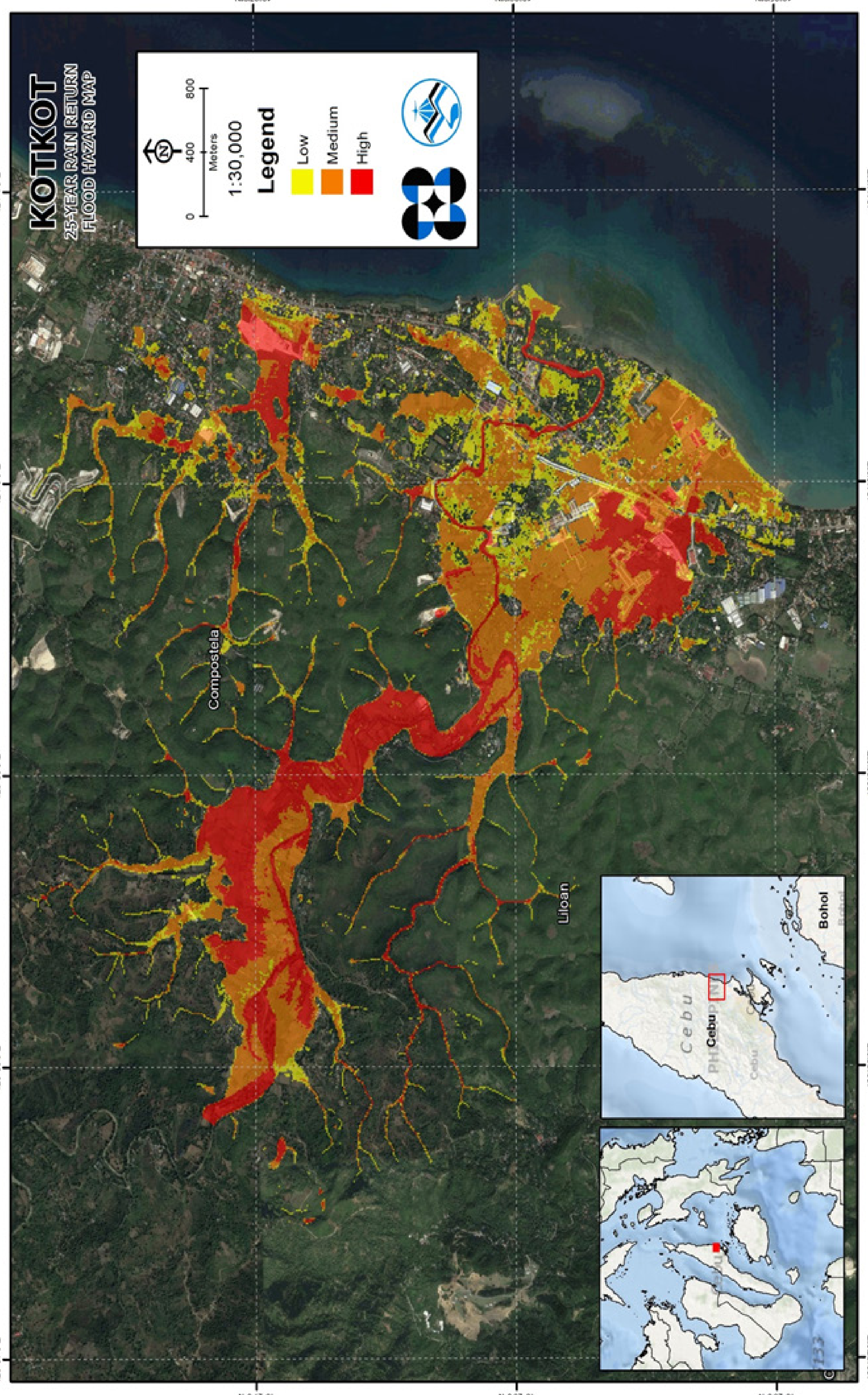


Figure 63. 25-year Flood Hazard Map for Kotkot Floodplain overlaid on Google Earth imagery

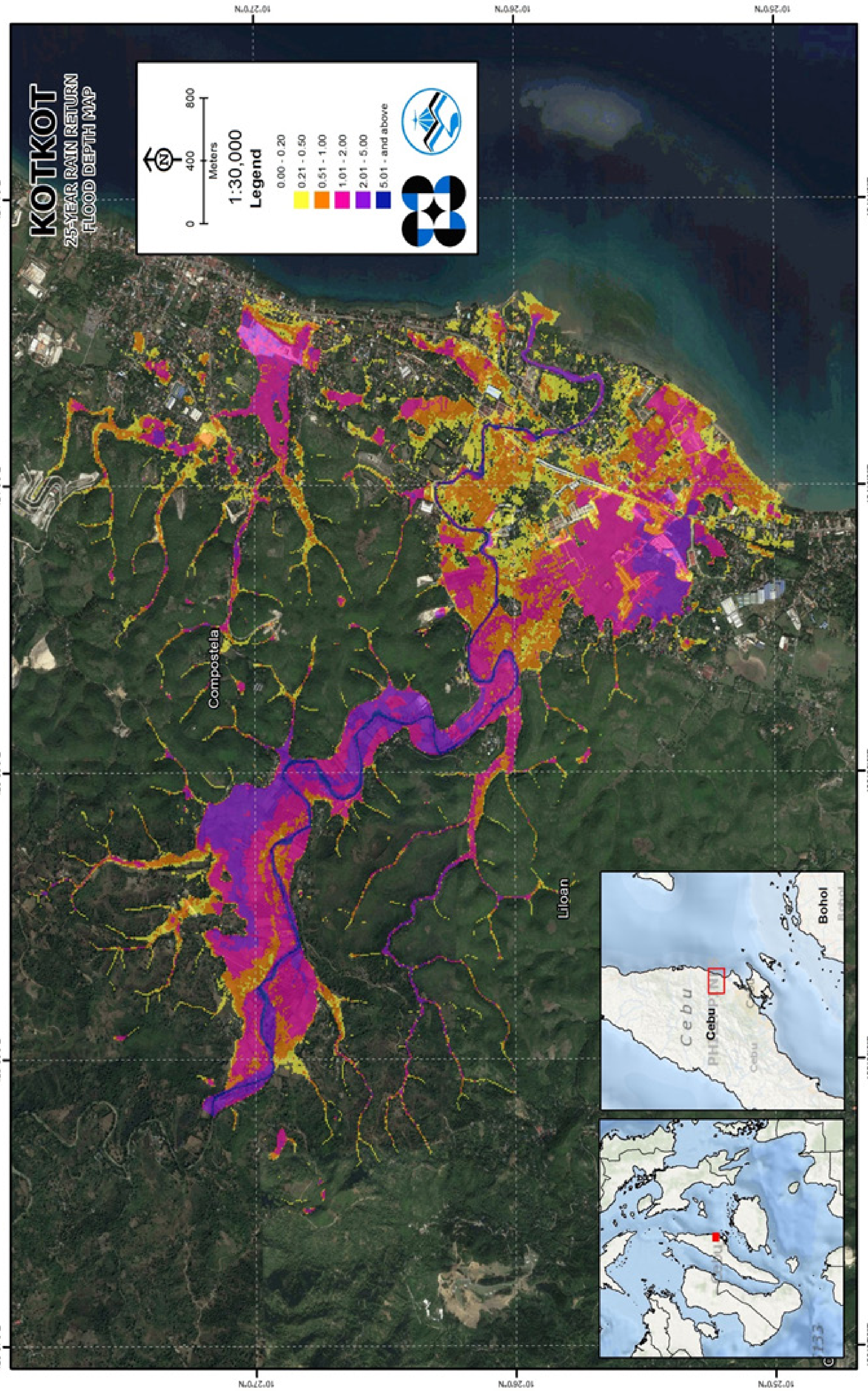


Figure 64. 25-year Flow Depth Map for Kotkot Floodplain overlaid on Google Earth imagery

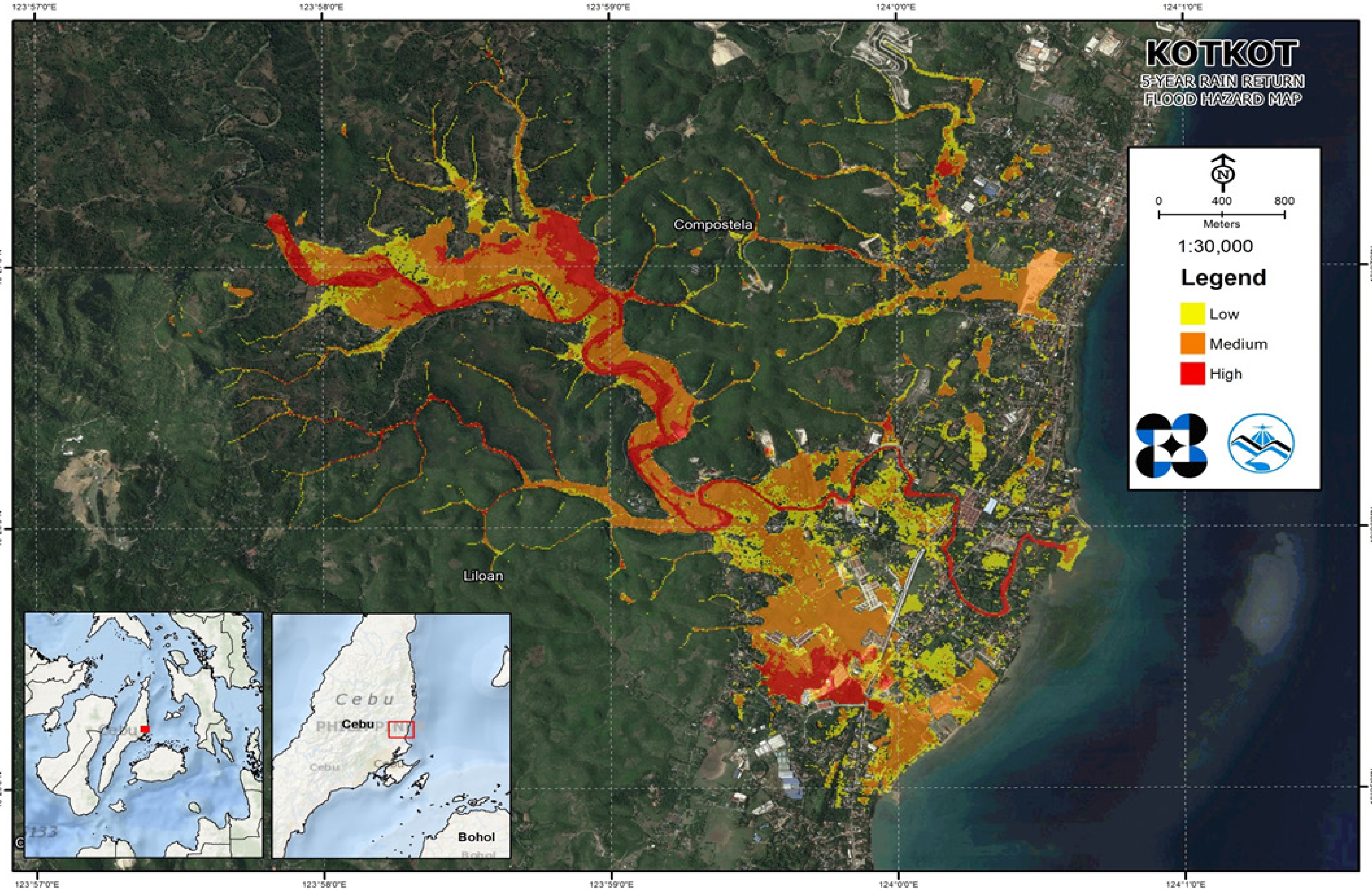


Figure 65. 5-year Flood Hazard Map for Kotkot Floodplain overlaid on Google Earth imagery

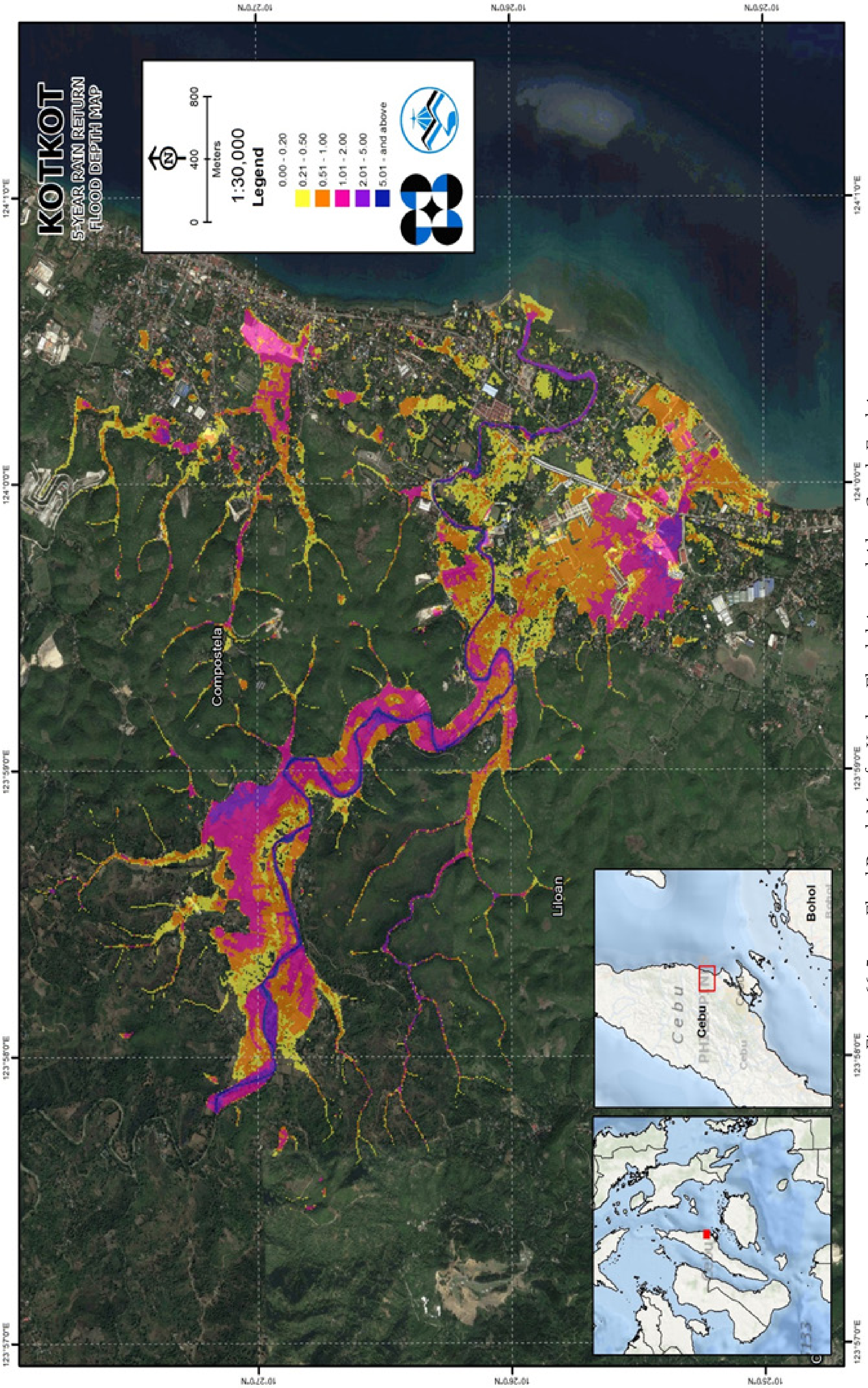


Figure 66. 5-year Flood Depth Map for Kotkot Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Kotkot river basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 10 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period for the municipality of Compostela, listed in Table 31 and shown in Figure 67 are the affected areas in square kilometres by flood depth per barangay.

Table 31. Affected areas in Compostela, Cebu during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Compostela (in sq. km.)					
	Cabadiangan	Cambayog	Cogon	Estaca	Poblacion	Tamiao
0.03-0.20	1.71	0.97	2.04	1.31	0.56	2.09
0.21-0.50	0.19	0.038	0.14	0.16	0.036	0.13
0.51-1.00	0.26	0.029	0.087	0.071	0.063	0.17
1.01-2.00	0.29	0.04	0.036	0.052	0.078	0.13
2.01-5.00	0.058	0.0084	0.0041	0.017	0.0006	0.018
> 5.00	0.01	0	0	0.0028	0	0.016

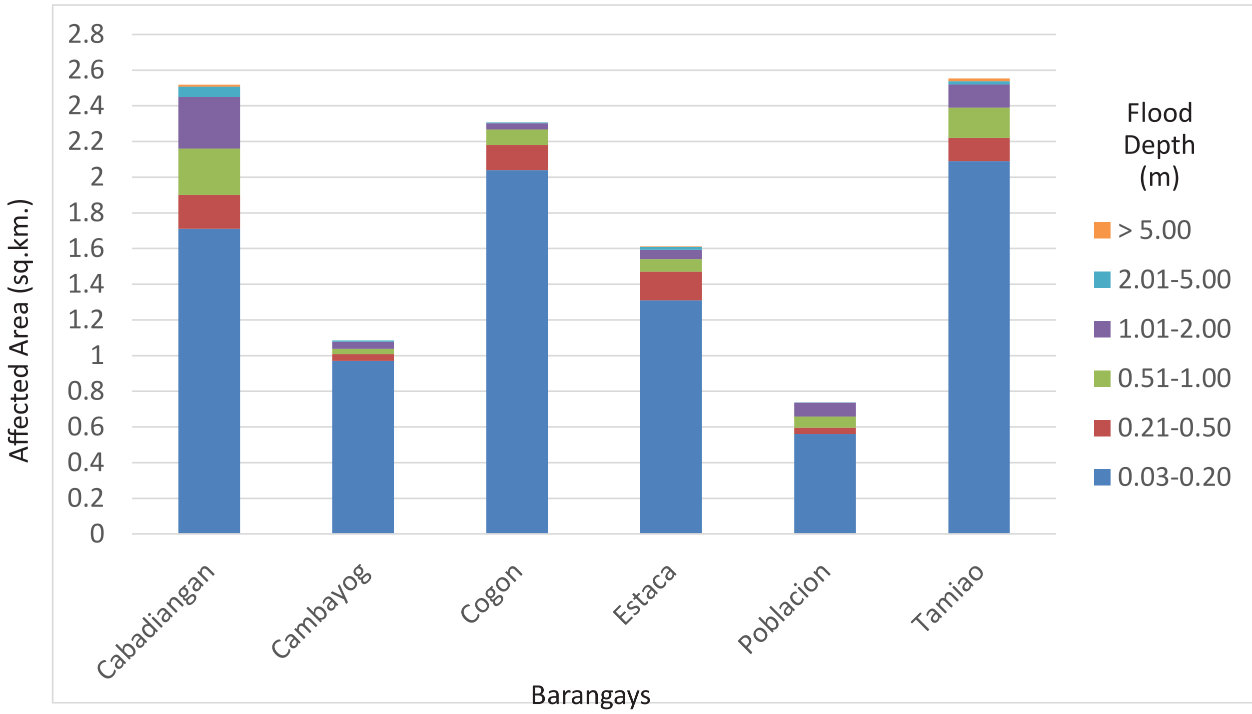


Figure 67. Affected Areas in Compostela, Cebu during 5-Year Rainfall Return Period

For the municipality of Liloan, listed in Table 32 and shown in Figure 68 are the affected areas in square kilometres by flood depth per barangay.

Table 32. Affected areas in Liloan, Cebu during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Liloan (in sq. km.)			
	Cabadiangan	Cotcot	Jubay	Lataban
0.03-0.20	3.88	2.22	0.5	0.038
0.21-0.50	0.17	0.53	0.075	0.00036
0.51-1.00	0.27	0.63	0.078	0.0002
1.01-2.00	0.28	0.35	0.012	0.000084
2.01-5.00	0.13	0.096	0.00099	0
> 5.00	0.055	0.018	0	0

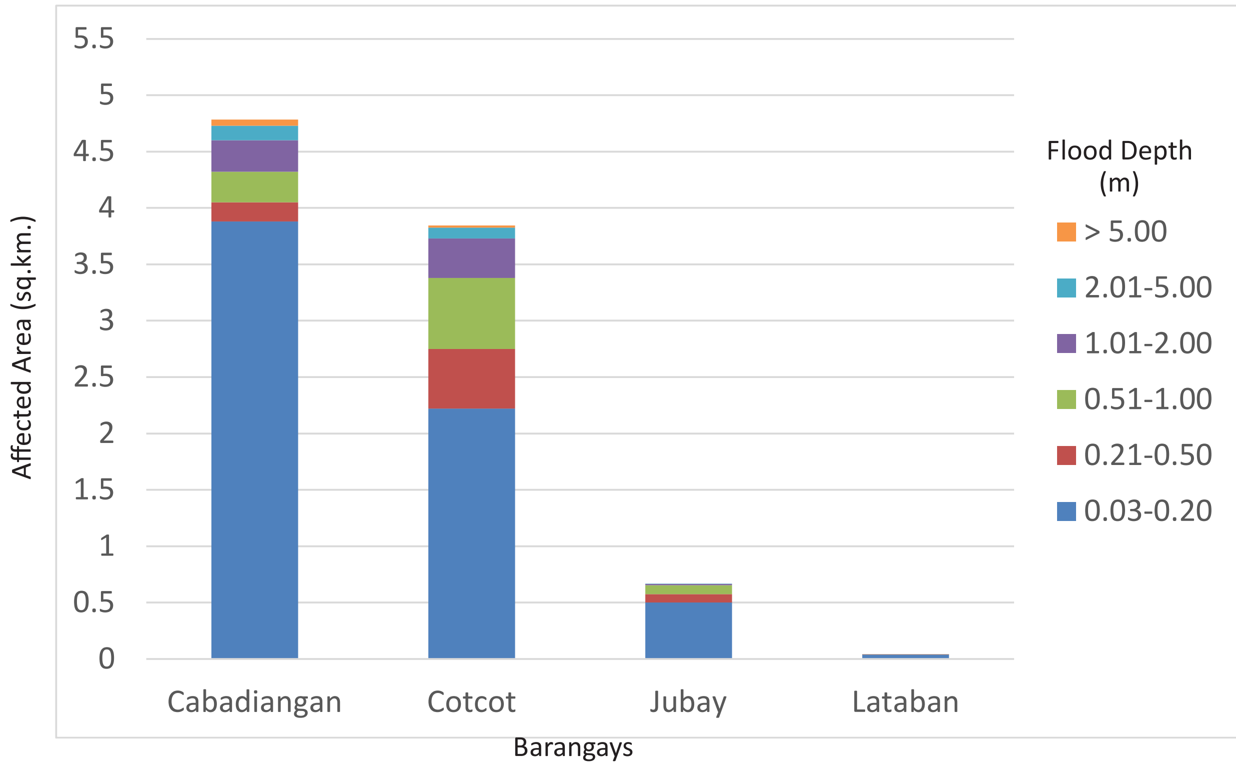


Figure 68. Affected Areas in Liloan, Cebu during 5-Year Rainfall Return Period

For the 25-year return period for the municipality of Compostela, listed in Table 33 and shown in Figure 69 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected areas in Compostela, Cebu during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Compostela (in sq. km.)					
	Cabadiangan	Cambayog	Cogon	Estaca	Poblacion	Tamiao
0.03-0.20	1.63	0.94	1.97	1.03	0.51	2.02
0.21-0.50	0.11	0.038	0.14	0.25	0.047	0.11
0.51-1.00	0.16	0.04	0.12	0.18	0.041	0.16
1.01-2.00	0.37	0.019	0.061	0.13	0.11	0.16
2.01-5.00	0.23	0.042	0.0099	0.027	0.032	0.08
> 5.00	0.012	0	0	0.005	0	0.019

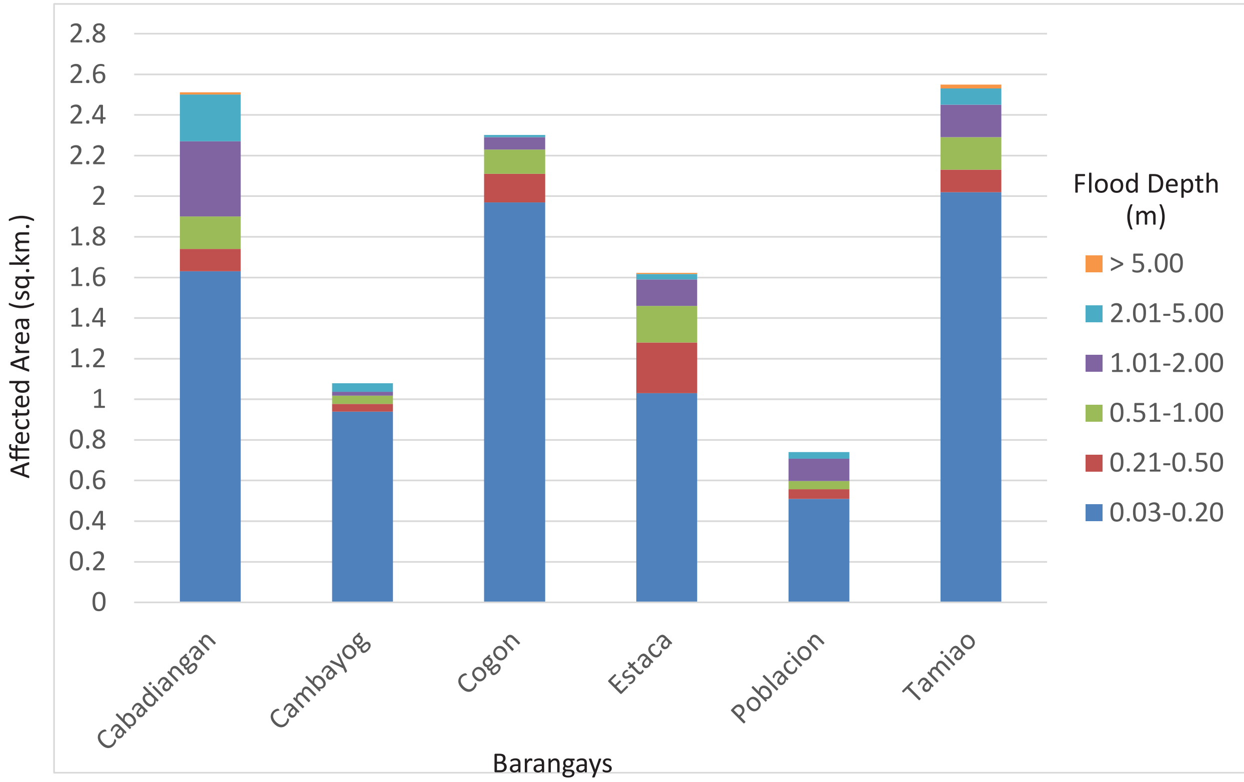


Figure 69. Affected Areas in Compostela, Cebu during 25-Year Rainfall Return Period

For the municipality of Liloan, listed in Table 34 and shown in Figure 70 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected areas in Liloan, Cebu during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Liloan (in sq. km.)			
	Cabadiangan	Cotcot	Jubay	Lataban
0.03-0.20	3.79	1.69	0.44	0.038
0.21-0.50	0.11	0.46	0.091	0.00066
0.51-1.00	0.18	0.67	0.079	0.0002
1.01-2.00	0.36	0.78	0.049	0.000084
2.01-5.00	0.27	0.21	0.01	0
> 5.00	0.068	0.025	0	0

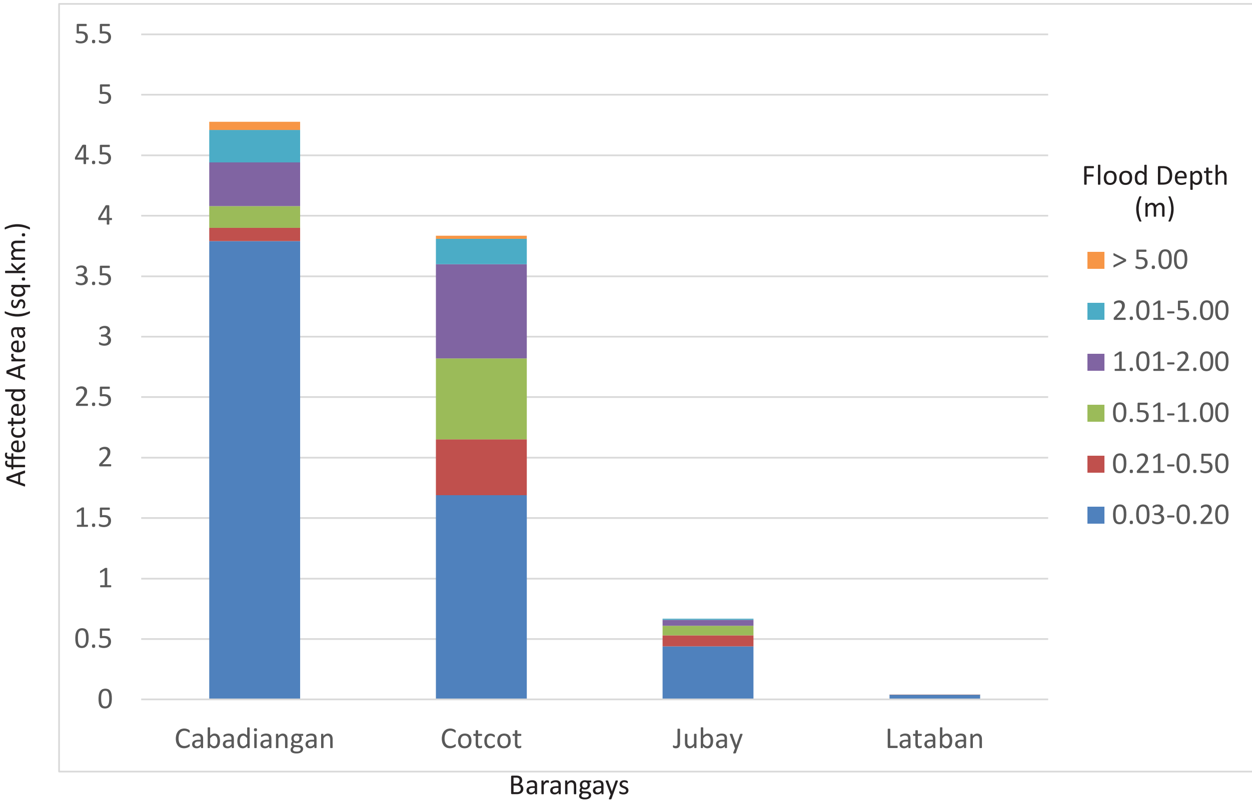


Figure 70. Affected Areas in Liloan, Cebu during 25-Year Rainfall Return Period

For the 100-year return period for the municipality of Compostela, listed in Table 35 and shown in Figure 71 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected areas in Compostela, Cebu during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Compostela (in sq. km.)					
	Cabadiangan	Cambayog	Cogon	Estaca	Poblacion	Tamiao
0.03-0.20	1.6	0.93	1.92	0.9	0.48	1.99
0.21-0.50	0.09	0.039	0.14	0.26	0.057	0.11
0.51-1.00	0.12	0.041	0.14	0.23	0.044	0.15
1.01-2.00	0.28	0.027	0.08	0.15	0.073	0.16
2.01-5.00	0.41	0.046	0.015	0.065	0.088	0.12
> 5.00	0.014	0	0	0.0053	0	0.02

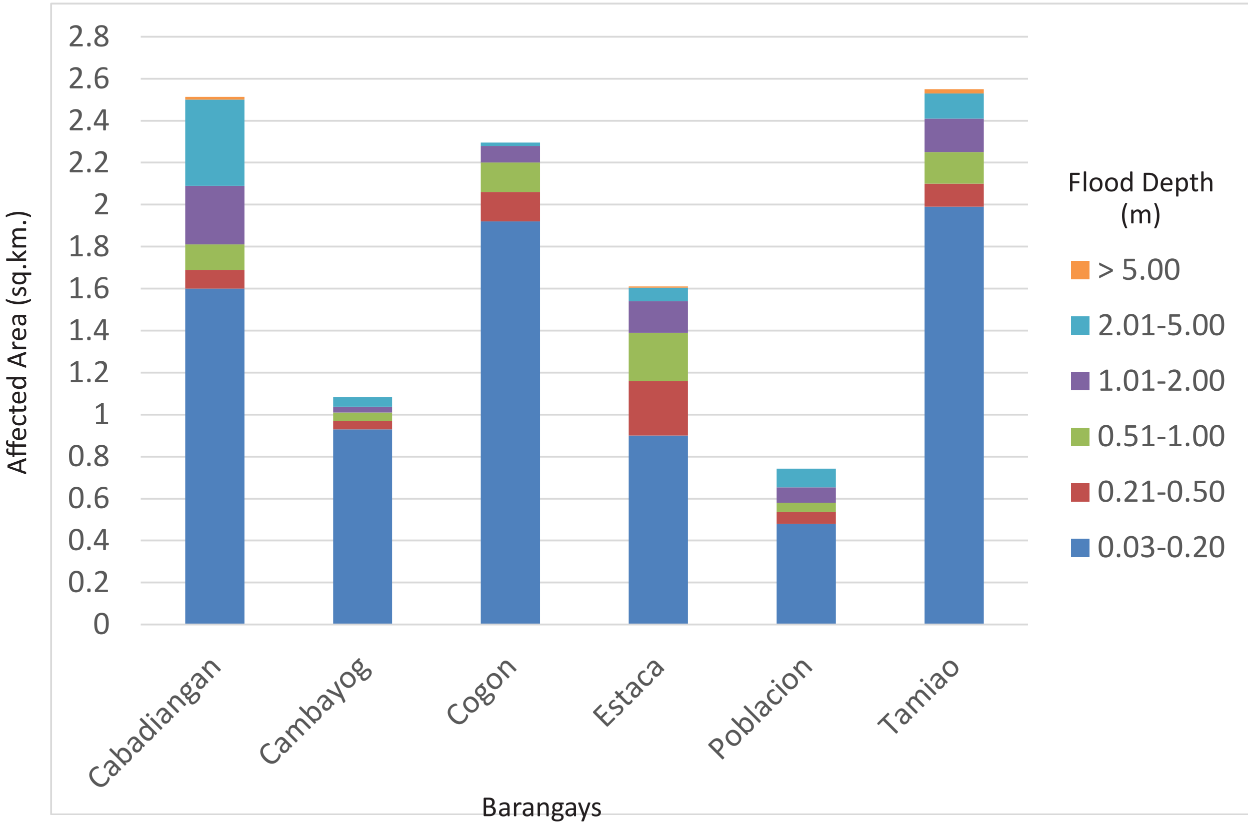


Figure 71. Affected Areas in Compostela, Cebu during 100-Year Rainfall Return Period

For the municipality of Liloan, listed in Table 36 and shown in Figure 72 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected areas in Liloan, Cebu during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Liloan (in sq. km.)			
	Cabadiangan	Cotcot	Jubay	Lataban
0.03-0.20	3.76	1.49	0.41	0.038
0.21-0.50	0.098	0.42	0.098	0.00076
0.51-1.00	0.11	0.68	0.077	0.0002
1.01-2.00	0.35	0.94	0.065	0.00018
2.01-5.00	0.38	0.29	0.016	0
> 5.00	0.078	0.028	0	0

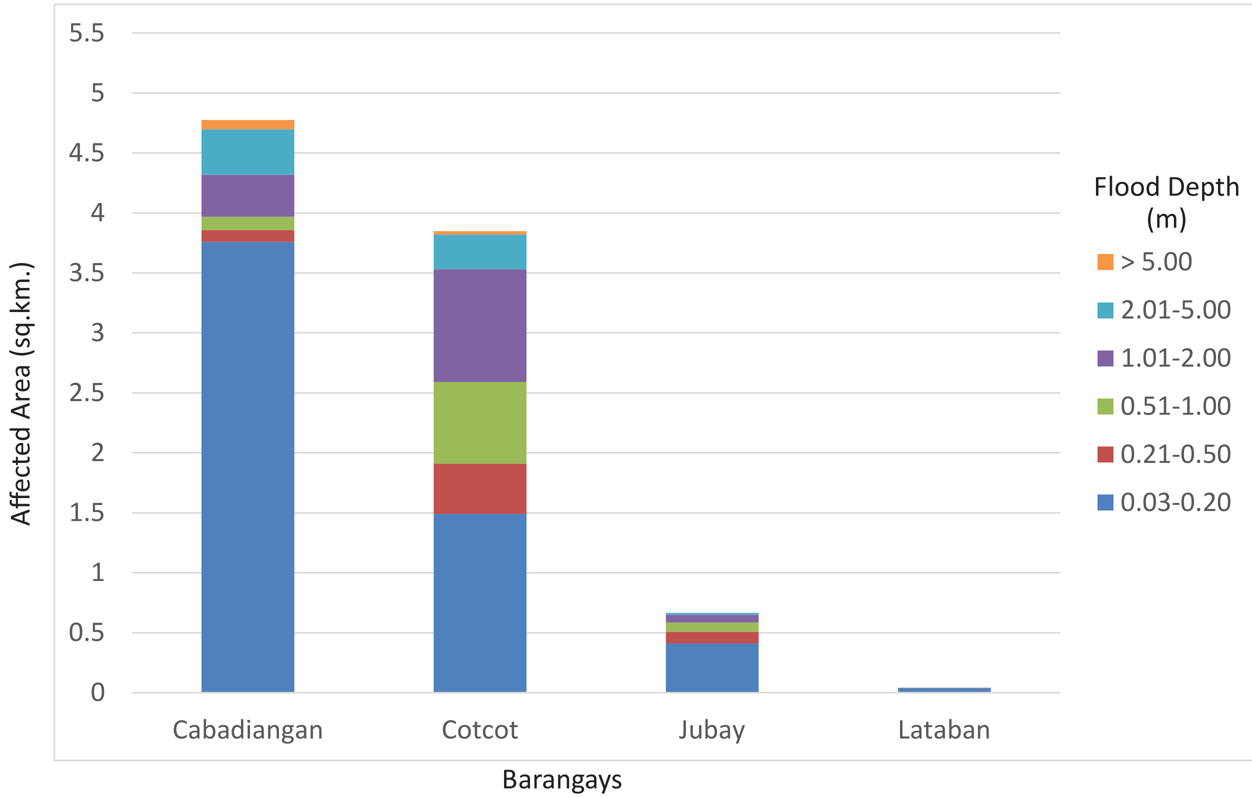


Figure 72. Affected Areas in Liloan, Cebu during 100-Year Rainfall Return Period

5.11 Flood Validation

Survey was done along the floodplain of Kotkot River to validate the generated flood maps. The team gathered secondary data regarding flood occurrence in the area. Ground validation points were acquired as well as the other necessary details like date of occurrence, name of typhoon and actual flood depth.

During validation, the team was assisted by the local Disaster Risk Reduction and Management representative. Residents along the floodplain were interviewed of the historical flood events they experiences.

The flood validation data were obtained on January 11-12, 2016. Actual flood depth acquired from the ground validation were then computed and compared to the flood depth simulated by the model. An RMSE value of 1.38 was obtained.

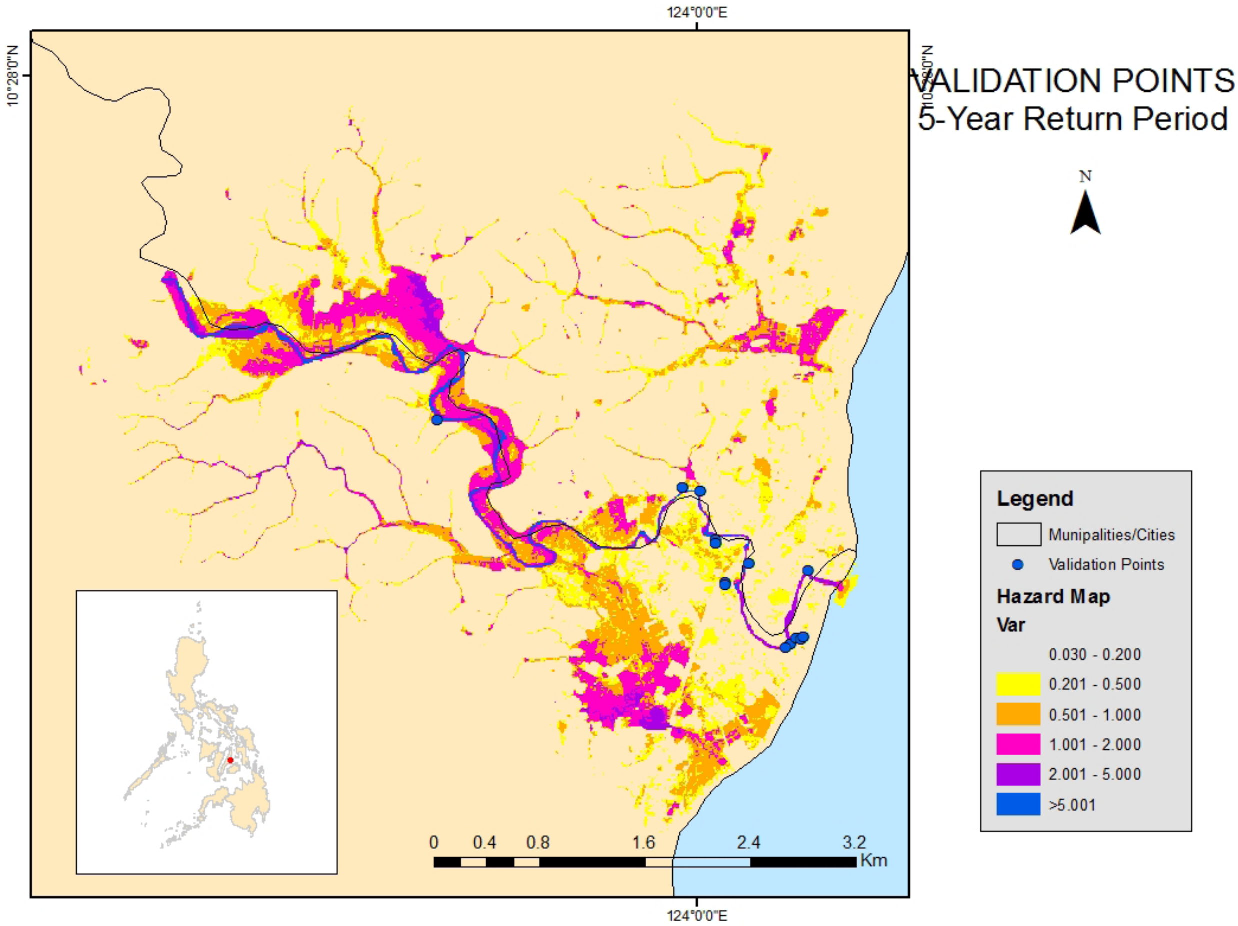


Figure 74. Kotkot Flood Validation Points

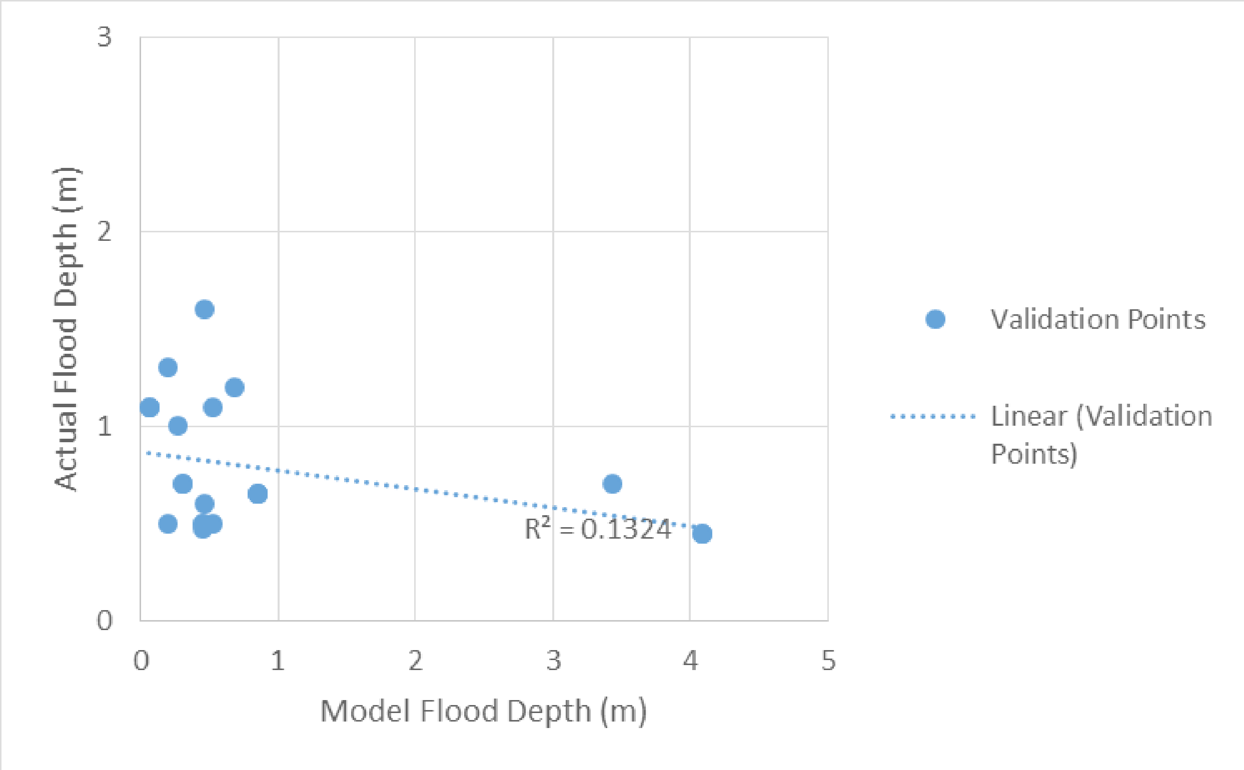


Figure 75. Flood map depth vs. actual flood depth

Table 37. Actual flood vs simulated flood depth at different levels in the Kotkot River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	0	0	0	0	0	0	0
0.21-0.50	1	3	1	0	2	0	7
0.51-1.00	0	4	3	0	1	0	8
1.01-2.00	3	1	2	0	0	0	6
2.01-5.00	0	0	0	0	0	0	0
> 5.00	0	0	0	0	0	0	0
Total	4	8	6	6	3	0	21

The overall accuracy generated by the flood model is estimated at 28.57% with 6 points correctly matching the actual flood depths. In addition, there were 4 points estimated one level above and below the correct flood depths while there were 2 points and 5 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 11 points were underestimated in the modelled flood depths of Kotkot. The summary of the accuracy assessment is presented in Table 38.

Table 38. Summary of the Accuracy Assessment in the Kotkot River Basin Survey

	No. of Points	%
Correct	6	28.57
Overestimated	4	19.05
Underestimated	11	52.38
Total	21	100.00

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ANNEXES

Annex 1. Optech Technical Specification of the Pegasus Sensor

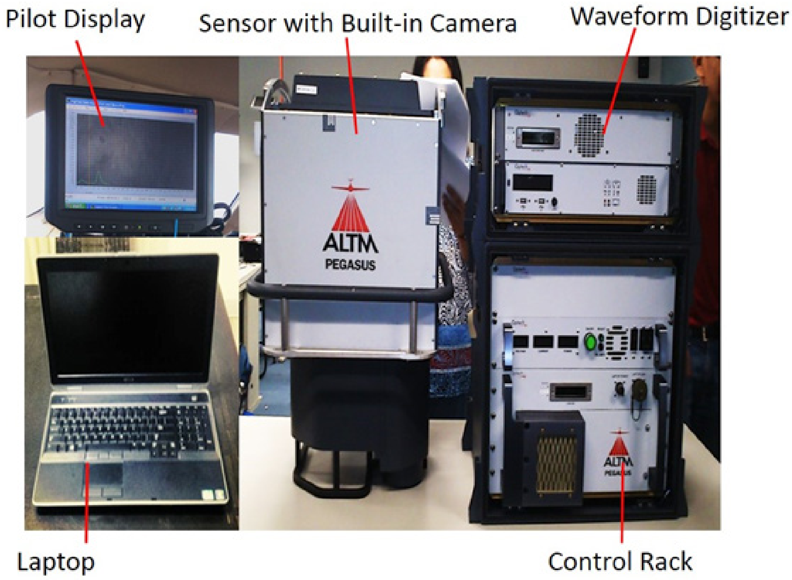

Figure A-1.1. Pegasus Sensor

Table A-1.1. Parameters and Specification of Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-5000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, 1σ
Elevation accuracy (2)	< 5-20 cm, 1σ
Effective laser repetition rate	Programmable, 100-500 kHz
Position and orientation system	POS AV ™AP50 (OEM)
Scan width (FOV)	Programmable, 0-75 ˚
Scan frequency (5)	Programmable, 0-140 Hz (effective)
Sensor scan product	800 maximum
Beam divergence	0.25 mrad (1/e)
Roll compensation	Programmable, ±37˚ (FOV dependent)
Vertical target separation distance	<0.7 m
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V, 800 W, 30 A
Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

1 Target reflectivity ≥20%
2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility
3 Angle of incidence ≤20˚
4 Target size ≥ laser footprint5 Dependent on system configuration

Annex 2. NAMRIA Certification of Reference Points Used in the LIDAR Survey

1. CBU-11

Republic of the Philippines
Department of Environment and Natural Resources
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

July 25, 2014

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **CEBU**
Station Name: **CBU-11**
Order: **2nd**

Island: **VISAYAS**
Municipality: **CEBU CITY (CAPITAL)**
Barangay: **TOWN PROPER**
MSL Elevation:

PRS92 Coordinates

Latitude: **10° 17' 56.00367"**	Longitude: **123° 53' 26.63633"**	Ellipsoidal Hgt: **44.27700 m.**

WGS84 Coordinates

Latitude: **10° 17' 51.88109"**	Longitude: **123° 53' 31.88503"**	Ellipsoidal Hgt: **106.03300 m.**

PTM / PRS92 Coordinates

Northing: **1138921.917 m.**	Easting: **597568.76 m.**	Zone: **4**

UTM / PRS92 Coordinates

Northing: **1,138,523.27**	Easting: **597,534.61**	Zone: **51**

Location Description

CBU-11 , "FIRE TOWER""

From the intersection of Jonas Avenue and Cebu South Expressway drive 600 meters going West to Metro Cebu Fire Department station. The staion is located on the roof top of 75 feet concrete tower of Metro Cebu Fire Department at the left side of the road.

Staion mark is a cross cut on top of 0.15 m x 0.01 min diameter brass rod, set in drill hole; centered in 0.25 m c 0.25 m cement patty; 0.03 m protruding above roof top of the 75 feet concrete tower of Metro Cebu Fire department station. Inacribed with station name.

recomputed 3/19/2014

Requesting Party: **UP-TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8799582 A**
T.N.: **2014-1728**

RUEL DM. BELEN, MNSA
Director, Mapping And Geodesy Branch

9907252014131741

CIP/4701/12/09/814

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. CBU-11

3. CU-1007

Republic of the Philippines
Department of Environment and Natural Resources
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

August 08, 2014

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **CEBU**
Station Name: **CU-1007**

Island: **Visayas**	Municipality: **CEBU CITY (CAPITAL)**	Barangay: **MABOLO**
Elevation: **18.4803 m.**	Order: **2nd Order**	Datum: **Mean Sea Level**

Location Description

CU-1007

Station is located along F. Cabang National Road and Juan Luna Avenue, Mabolo, Cebu City. It is in the base of the stop light NW of PLDT panel near Cantomeza Sports Bar south of police outpost.

Mark is the head of a 4" copper nail, set flushed on a drilled hole, centered on a 15cm x 15cm cement putty flushed on a concrete pavement with inscription "CU-1007, 2013, NAMRIA".

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Pupose: **Reference**
OR Number: **8799670 A**
T.N.: **2014-1780**

RUEL DM. BELEN, MNSA
Director, Mapping And Geodesy Branch

9 9 0 8 0 8 2 0 1 4 1 4 0 5 3 2

CERTIFICATION INTERNATIONAL ISO 9001:2008 CIP/4701/12/09/814

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. CU-1007

Annex 3. Baseline Processing Reports of Control Points used in the LIDAR Survey

1. CU-1007

Table A-3.1. CU-1007

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
CBU-11 --- CU-1007 (B1)	CBU-11	CU-1007	Fixed	0.011	0.024	39°09'57"	3250.555	-20.791
CBU-11 --- CU-1007 (B2)	CBU-11	CU-1007	Fixed	0.007	0.020	39°09'57"	3250.580	-20.768

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

From:	CBU-11				
Grid		Local		Global	
Easting	597534.610 m	Latitude	N10°17'56.00367"	Latitude	N10°17'51.88109"
Northing	1138523.275 m	Longitude	E123°53'26.63633"	Longitude	E123°53'31.88503"
Elevation	42.967 m	Height	44.277 m	Height	106.032 m

To:	CU-1007				
Grid		Local		Global	
Easting	599579.964 m	Latitude	N10°19'18.03187"	Latitude	N10°19'13.90507"
Northing	1141048.492 m	Longitude	E123°54'34.11133"	Longitude	E123°54'39.35787"
Elevation	22.185 m	Height	23.486 m	Height	85.235 m

Vector					
ΔEasting	2045.355 m	NS Fwd Azimuth	39°09'57"	ΔX	-1440.983 m
ΔNorthing	2525.217 m	Ellipsoid Dist.	3250.555 m	ΔY	-1536.406 m
ΔElevation	-20.783 m	ΔHeight	-20.791 m	ΔZ	2475.814 m

Standard Errors

Vector errors:					
σ ΔEasting	0.004 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.008 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.003 m	σ ΔY	0.010 m
σ ΔElevation	0.012 m	σ ΔHeight	0.012 m	σ ΔZ	0.003 m

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, DR.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader - I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	ENGR. GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	GRACE SINADJAN ENGR. IRO NIEL ROXAS	UP-TCAGP
	RA	JERIEL PAUL ALAMBAN, GEOL.	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	KENNETH QUISADO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. RAYMUND DOMINE	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. FERDINAND DE OCAMPO	AAC

Annex 5. Data Transfer Sheet for Kotkot Floodplain

DATA TRANSFER SHEET
07/31/2014(CEBU ready)

ATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
, 2014	1765	1BLK47B209A	Pegasus	1.89	1.22	9.62	219	29.4	238	18.7	NA	~~9.70~~ 6.6	1KB	1KB	39/57	NA	Z:\Airborne_Raw

Received from

Name TIN ANONYA
Position RA
Signature

Received by

Name JOIDA PRIETO
Position SSRS
Signature 8/5/14

Figure A-5.1. Transfer Sheet for Kotkot Floodplain - A

DATA TRANSFER SHEET
08/01/2014(CEBU ready)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
7/18/2014	1725P	1BLK47B199A	Pegasus	2.62	1.67	13.8	232	45.1	315	26	117	5.03	1KB	1KB	51	NA	Z:\Airborne_Raw
7/22/2014	1741P	1BLK36H203A	Pegasus	2.24	1.5	12.1	250	40.4	288	23.3	69.3	10.4	1KB	1KB	55/53	NA	Z:\Airborne_Raw
7/22/2014	1743P	1BLK36H203B	Pegasus	1.93	1.15	7.95	170	29.6	243	18.5	124	10.4	1KB	1KB	55	NA	Z:\Airborne_Raw
7/23/2014	1747P	1BLK36A204B	Pegasus	NA	1.82	12.8	227	48.4	385	27.5	NA	9.78	1KB	1KB	38/30	NA	Z:\Airborne_Raw
7/24/2014	1749P	1BLK36AS205A	Pegasus	NA	708	7.24	192	13.8	114	10.9	NA	3.45	1KB	1KB	37	NA	Z:\Airborne_Raw

Received from

Name TIN ANDAYA
Position RA
Signature

Received by

Name JOIDA F. PRIETO
Position SSRS
Signature 8/4/2014

Figure A-5.2. Transfer Sheet for Kotkot Floodplain - B

DATA TRANSFER SHEET
08/15/2014(CEBU ready)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
7/29/2014	1769P	1BLK47A210A	Pegasus	931	0.99	3.45	95.7	10.5	85	9.18	NA	6.47	1KB	1KB	495	NA	Z:\DAC\RAWDATA
730/2014	1773P	1BLK47A211A	Pegasus	2.31	2.06	8.4	238	38.5	318	22.9	NA	8.16	1KB	1KB	97.7	NA	Z:\DAC\RAWDATA
7/30/2014	1775P	1BLK47A211B	Pegasus	1.61	1.67	7.96	141	22.5	200	15.1	NA	8.16	1KB	1KB	1	NA	Z:\DAC\RAWDATA
7/31/2014	1777P	1BLK36E212A	Pegasus	3.37	3.82	9.71	262	59.6	442	32.4	NA	9.13	1KB	1KB	45	NA	Z:\DAC\RAWDATA
7/31/2014	1779P	1BLK36EF212B	Pegasus	2.64	3.04	8.87	239	41.3	359	25.8	NA	9.13	1KB	1KB	96.4	NA	Z:\DAC\RAWDATA
8/01/2014	1781P	1BLK36F213A	Pegasus	2.57	2.94	9.09	215	41.7	340	25.5	NA	6.61	1KB	1KB	33	NA	Z:\DAC\RAWDATA
8/02/2014	1785P	1BLK36GF214A	Pegasus	3.36	3.78	9.87	250	46.2	335	32.7	NA	10.9	1KB	1KB	163	NA	Z:\DAC\RAWDATA
8/02/2014	1787P	1BLK36G214B	Pegasus	3.07	3.41	9.24	250	48.3	45/57/270	29.5	NA	10.9	1KB	1KB	40	NA	Z:\DAC\RAWDATA
8/03/2014	1789P	1MCTN215A	Pegasus	732	1.02	7.16	250	13.4	105	9.33	NA	8.84	1KB	1KB	612	NA	Z:\DAC\RAWDATA
8/03/2014	1791P	1MCTN215B	Pegasus	517	736	5.44	167	7.61	69	6.52	NA	8.84	1KB	1KB	624	NA	Z:\DAC\RAWDATA
8/04/2014	1793P	1BLK36EFGS216A	Pegasus	NA	746	5.12	144	11	77	6.7	NA	2.11	1KB	1KB	189	NA	Z:\DAC\RAWDATA
8/06/2014	1801P	1BLK36D218A	Pegasus	NA	3.6	9.62	258	54	384	32.1	NA	8.9	1KB	1KB	59.3	NA	Z:\DAC\RAWDATA
8/06/2014	1803P	1BLK36C218B	Pegasus	3.58	3.83	12.1	224	22.7/37.1	153/1/275	33	NA	8.9	1KB	1KB	93.8	NA	Z:\DAC\RAWDATA
8/07/2014	1805P	1BLK36B219A	Pegasus	3.41	3.91	10,945	280	60.4	441	34.5	NA	7.01	1KB	1KB	121	NA	Z:\DAC\RAWDATA

Received from
Name TIN ANDAYA
Position RA
Signature

Received by
Name JOIDA PRIETO
Position SSRS
Signature 8/20/14

Figure A-5.3. Transfer Sheet for Kotkot Floodplain - C

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 1725P

DREAM Data Acquisition Flight Log — Flight Log No.: 1725P

Lidar Operator: G. Sinadjan	ALTM Model: Peg	Type: VFR	Mission Name: 1DLK47B199A	Aircraft Type: CesnnaT206H	Aircraft Identification: RP-C9022
Pilot: C. Alfonso	Co-Pilot: F. Deocampo	Route: Cebu		Airport of Departure: Cebu	Airport of Arrival: Cebu
Date: July 18, 2014	PRF: kHz	Scan Freq : Hz	1/2 Scan Angle: °	Approx. Swath:	Eyesafe: m
Set of Hard Drive	A	B	Mission Folder Name:	Camera Mission Folder Name	
Weather:			Ground Base Station	Ground Surveyor	

LINE #:	Speed Kts	Rng/Ht m AGL	GPS Status SVS	GPS Status PDOP	Comments
Primary POS					
					Mission successful at 1000m flying height; cut lines due to aerial survey restrictions within 10 miles of Mactan International Airport please refer to electronic op log

Problems and Solutions

RECEIVED FROM:
NAME:
POSITION:
SIGNATURE:
DATE TRANSFERRED:

RECEIVED BY:
NAME:
POSITION:
SIGNATURE:
DATE TRANSFERRED:

Figure A-6.1. Flight Log for Mission 1725P

2. Flight Log for 1765P Mission

DREAM Data Acquisition Flight Log

Lidar Operator: I. Roxas | ALTM Model: Peg | Type: VFR | Mission Name: 1BLK47B209A | Flight Log No.: 176

Pilot: C. Alfonso | Co-Pilot: F. Deocampo | Route: Cebu | Aircraft Type: CesnnaT206H | Aircraft Identification: RP-C9022

Airport of Departure: Cebu | Airport of Arrival: Cebu

Date: July 28, 2014 | PRF: kHz | Scan Freq: Hz | 1/2 Scan Angle: • | Approx. Swath: | Eyesafe: m

Set of Hard Drive: A B | Mission Folder Name: | Camera Mission Folder Name

Weather: | Ground Base Station | Ground Surveyor

LINE #:	Speed Kts	Rng/Ht m AGL	GPS Status SVS	GPS Status PDOP	Comments
Primary POS					
					Mission successful at 1000 m flying height. Completed remaining portion of BLK47B. Completed LMS Calibration. Please refer to electronic oplog.

Problems and Solutions

RECEIVED FROM:
NAME:
POSITION:
SIGNATURE:
DATE TRANSFERRED:

RECEIVED BY:
NAME:
POSITION:
SIGNATURE:
DATE TRANSFERRED:

DREAM Disaster Risk Exposure and Assessment for Mitigation

Figure A-6.2. Flight Log for Mission 1765P

3. Flight Log for 1773P Mission

DREAM Data Acquisition Flight Log

Lidar Operator: I. Roxas | ALTM Model: Peg | Type: VFR | Mission Name: 1BLK47A211A | Flight Log No.: 17

Pilot: C. Alfonso | Co-Pilot: F. Deocampo | Route: Cebu | Aircraft Type: CesnnaT206H | Aircraft Identification: RP-C902

Airport of Departure: Cebu | Airport of Arrival: Cebu

Date: July 30, 2014 | PRF: kHz | Scan Freq : Hz | 1/2 Scan Angle: ° | Approx. Swath: | Eyesafe: m

Set of Hard Drive: A | B | Mission Folder Name: | Camera Mission Folder Name

Weather: | Ground Base Station | Ground Surveyor

LINE #:	Speed Kts	Rng/Ht m AGL	GPS Status SVS	GPS Status PDOP	Comments
Primary POS					
					Data acquired in BLK 47A at 1000 m flying height; some lines were cut due to airport restrictions. Please refer to electronic oplog

Problems and Solutions

RECEIVED FROM:
NAME:
POSITION:

SIGNATURE:
DATE TRANSFERRED:

RECEIVED BY:
NAME:
POSITION:

SIGNATURE:
DATE TRANSFERRED:

DREAM Disaster Risk Exposure and Assessment for Mitigation

Figure A-6.3. Flight Log for Mission 1773P

Annex 7. Flight Status Reports

Cebu Mission
July 18, 28 & 30, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1725P	BLK47B	1BLK47B199A	G. Sinadjan	July 18	Mission successful at 1000m flying height; Cut lines due to aerial survey restrictions within 10 miles of Mactan International Airport; 214.16 sq. km
1765P	BLK47B	1BLK47B209A	I. Roxas	July 28	LMS Calibration then surveyed lines in BLK47B; 150.21 sq. km
1773P	BLK47A, BLK47B	1BLK47A211A	I. Roxas	July 30	Data acquired in BLK 47A at 100m flying height; some lines were cut due to airport restriction; 261.23 sq.km

LAS BOUNDARIED PER FLIGHT

Flight No. :	1725P			
Area:	BLK47B			
Mission Name:	1BLK47B199A			
Parameters:	Altitude:	1000m; Scan Frequency:		30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.1. Swath for Flight No. 1725P

Flight No. :	1765P			
Area:	BLK47B			
Mission Name:	1BLK47B209A			
Parameters:	Altitude:	1000m; Scan Frequency:		30Hz;
	Scan Angle:	25deg;	Overlap:	30%

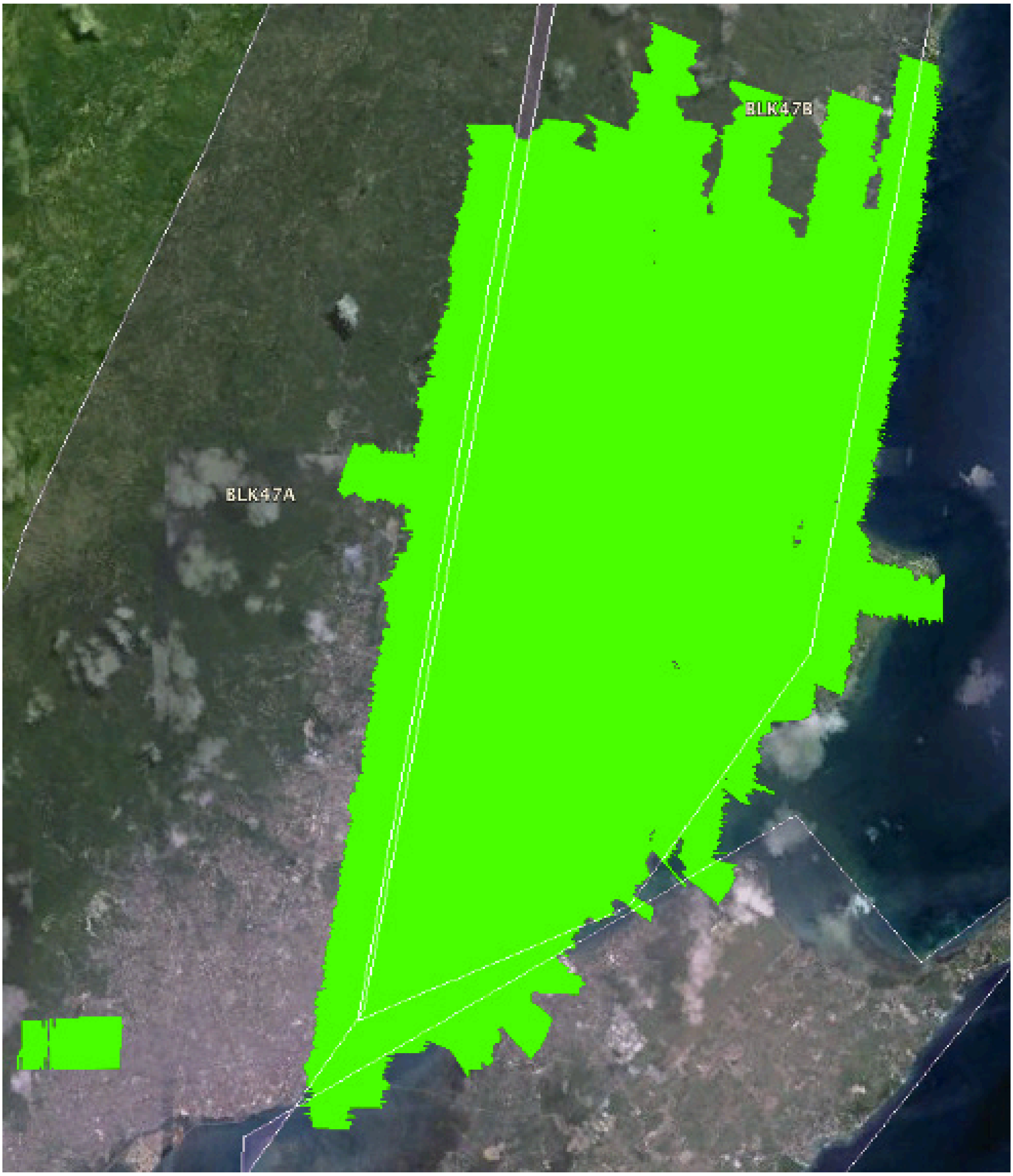

Figure A-7.2. Swath for Flight No. 1765P

Flight No. :	1773P			
Area:	BLK47A, BLK47B			
Mission Name:	1BLK47A211A			
Parameters:	Altitude:	1000m; Scan Frequency:		30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.3. Swath for Flight No. 1773P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk47B

Flight Area	Cebu
Mission Name	Blk47B
Inclusive Flights	1725P, 1765P, 1773P
Mission Name	1BLK47B209A
Range data size	67.6 GB
Base data size	19.79 MB
POS	689 MB
Image	113 GB
Transfer date	August 5, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.05
RMSE for East Position (<4.0 cm)	1.6
RMSE for Down Position (<8.0 cm)	3.0
Boresight correction stdev (<0.001deg)	0.000197
IMU attitude correction stdev (<0.001deg)	0.000872
GPS position stdev (<0.01m)	0.0046
Minimum % overlap (>25)	51.91%
Ave point cloud density per sq.m. (>2.0)	6.64
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	396
Maximum Height	769.16 m
Minimum Height	54.01 m
Classification (# of points)	
Ground	271,851,635
Low vegetation	224,945,412
Medium vegetation	576,905,882
High vegetation	379,458,758
Building	94,537,324
Orthophoto	Yes
Processed by	Engr. Carlyn Ann Ibañez, Engr. Antonio Chua, Jr., Engr. Roa Shelmar Redo

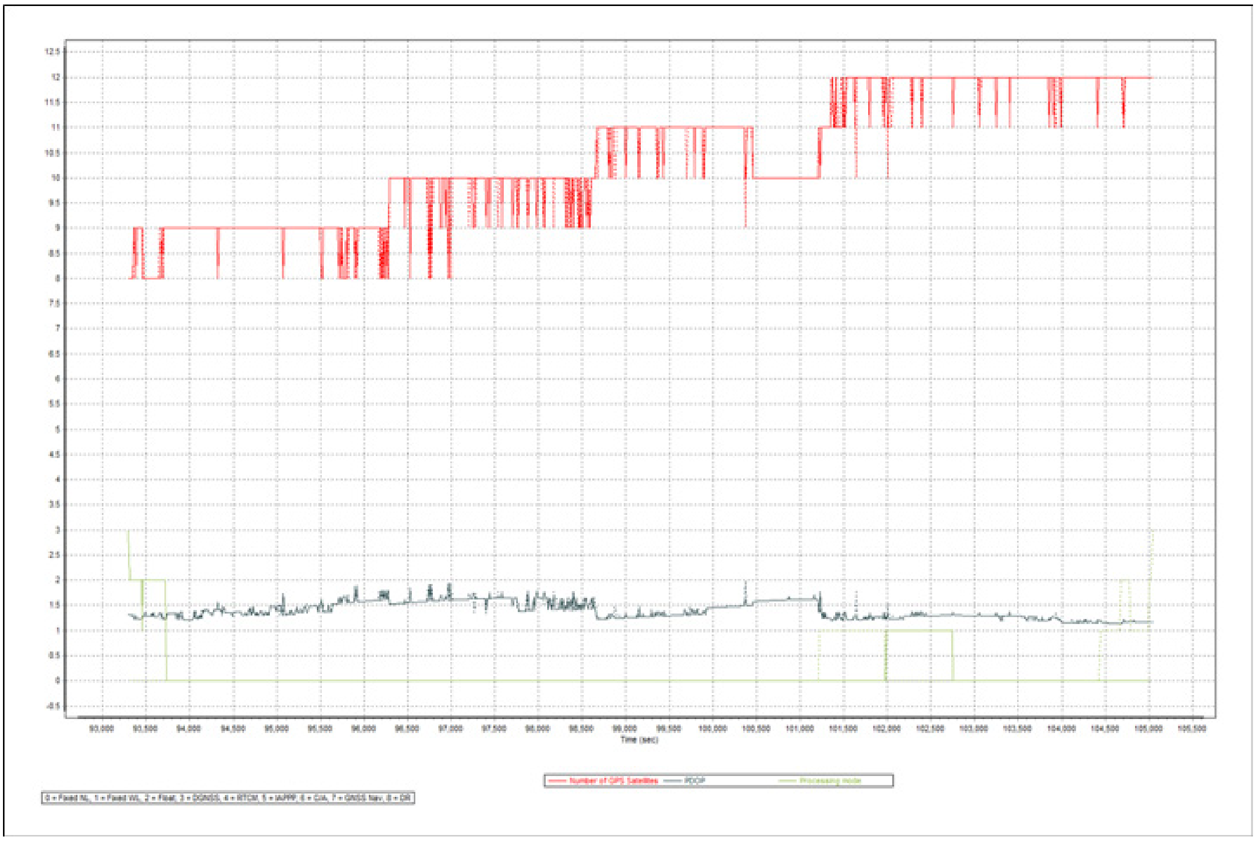

Figure A-8.1. Solution Status

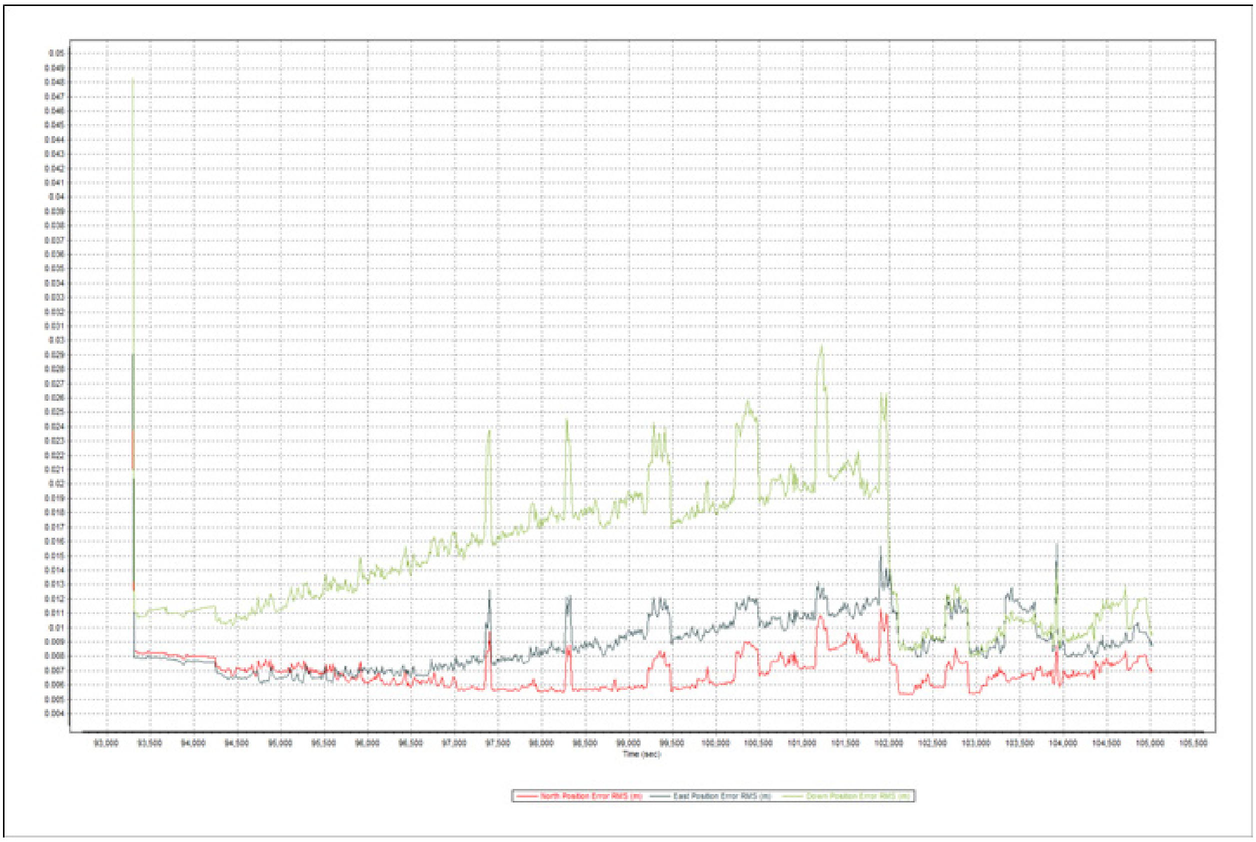

Figure A-8.2. Smoothed Performance Metrics Parameters

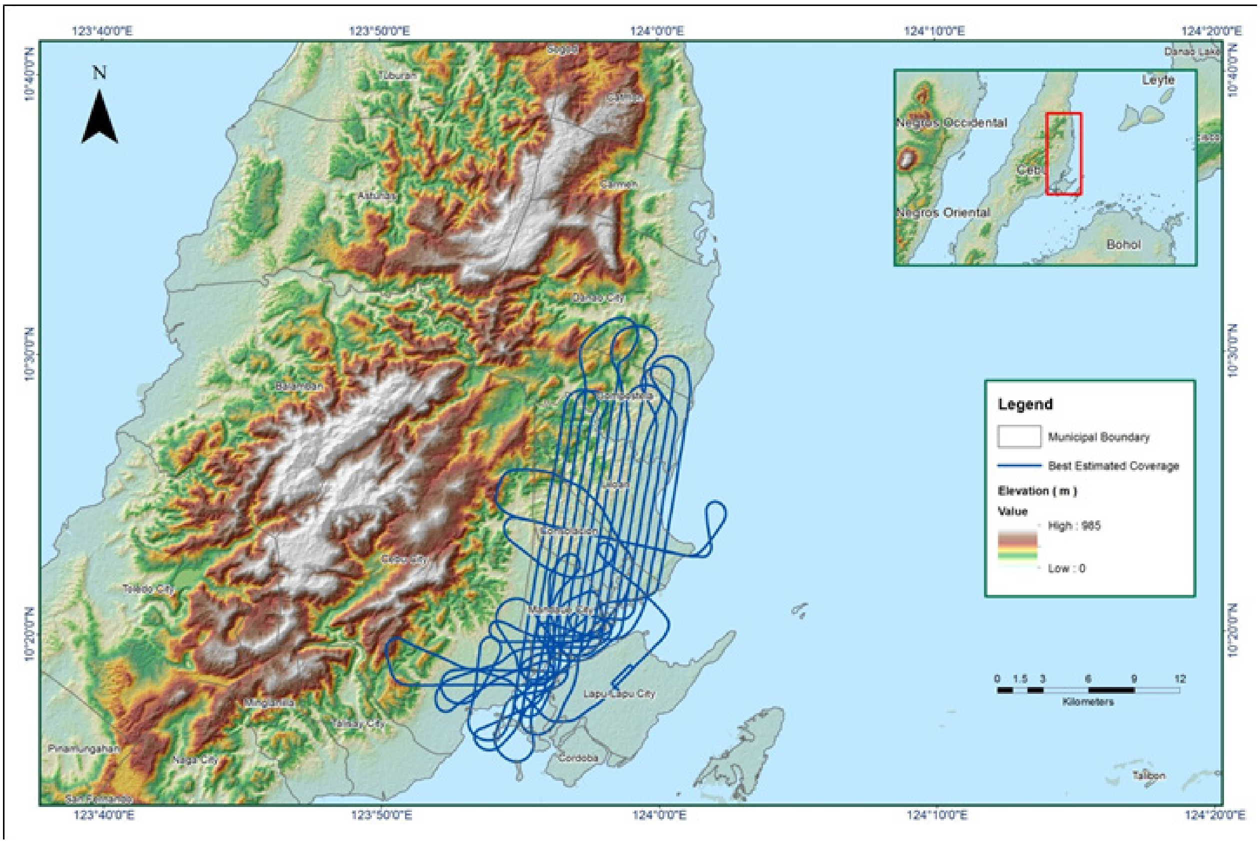

Figure A-8.3. Best Estimated Trajectory

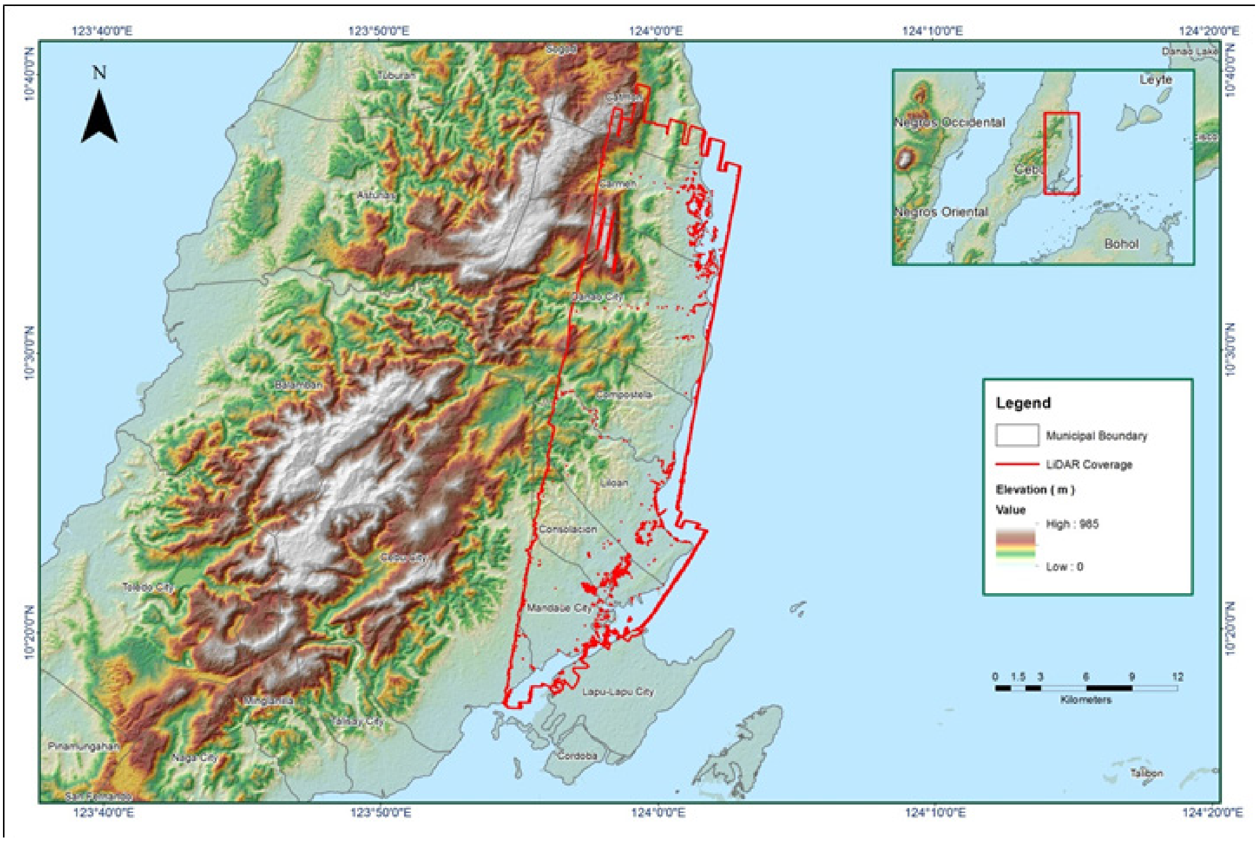

Figure A-8.4. Coverage of LiDAR data

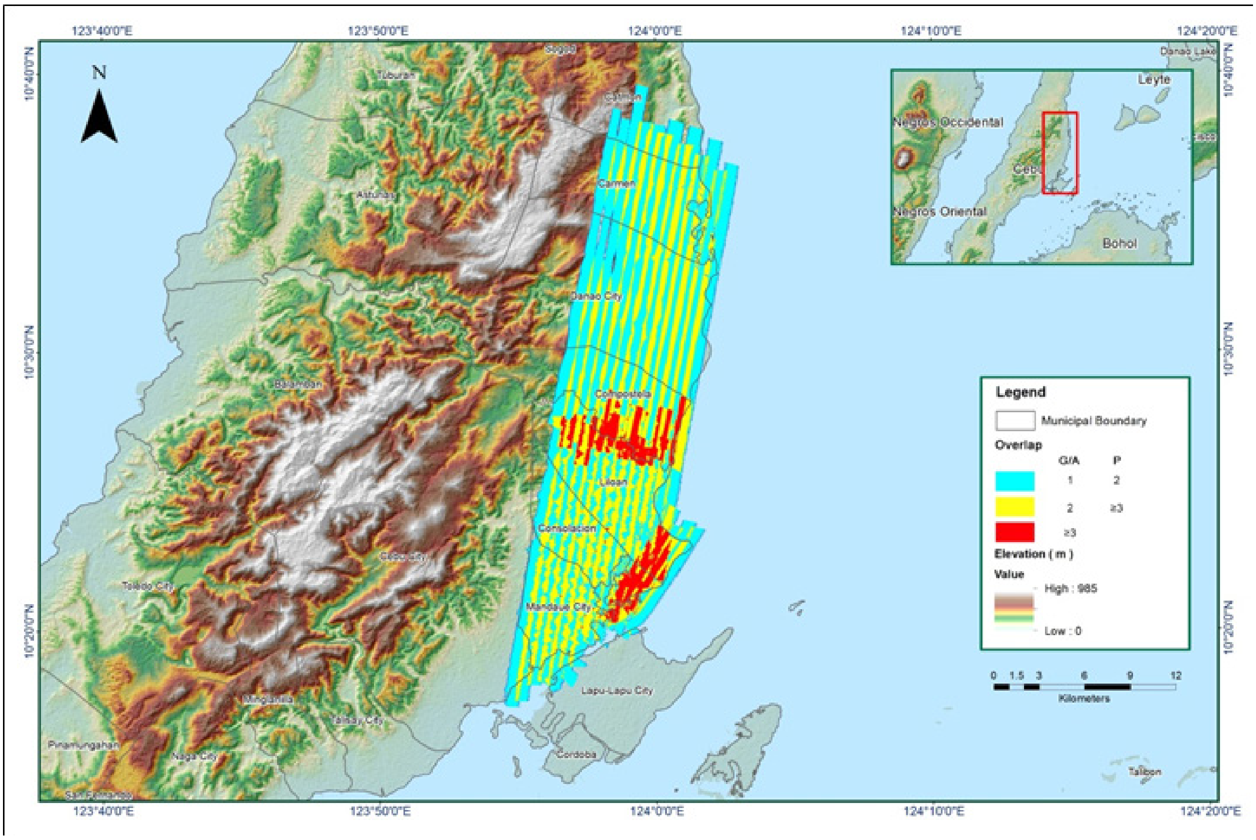

Figure A-8.5. Image of Data Overlap

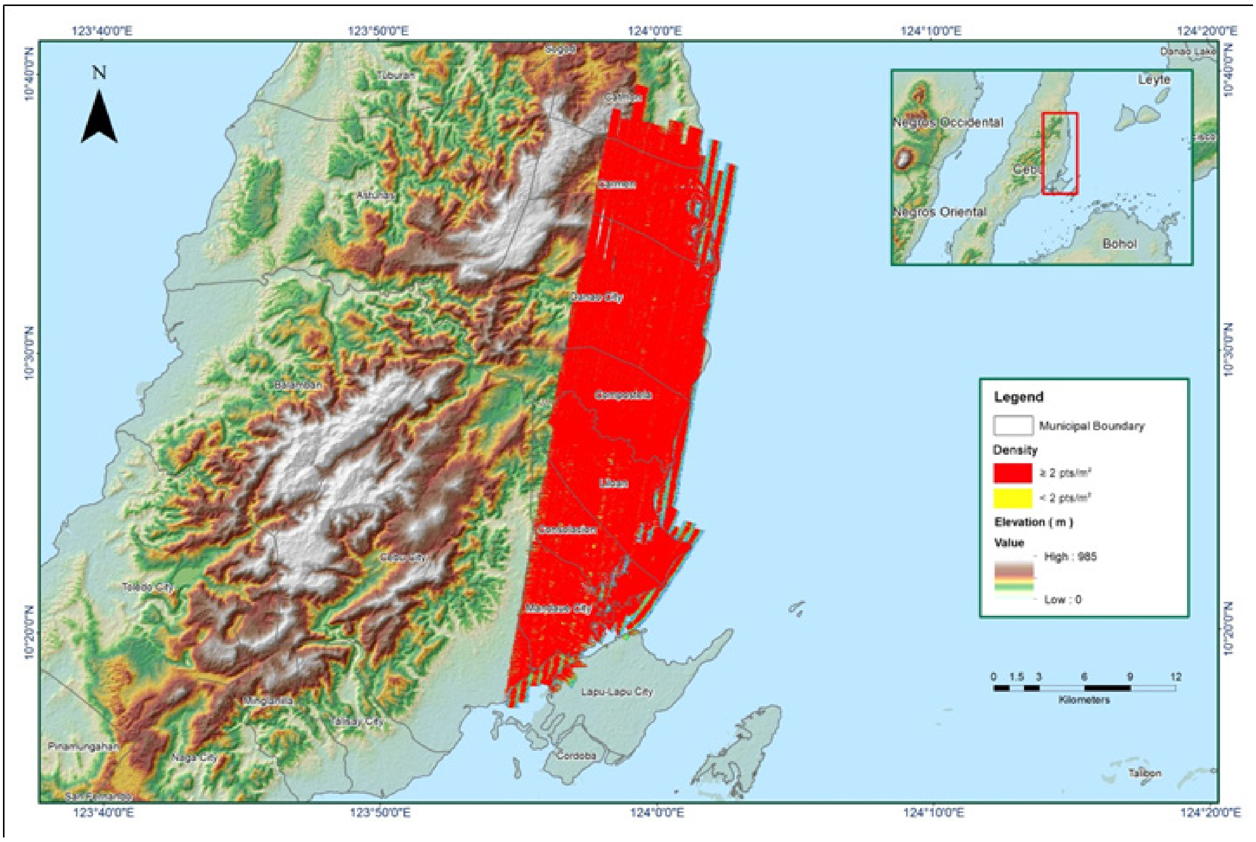

Figure A-8.6. Density map of merged LiDAR data

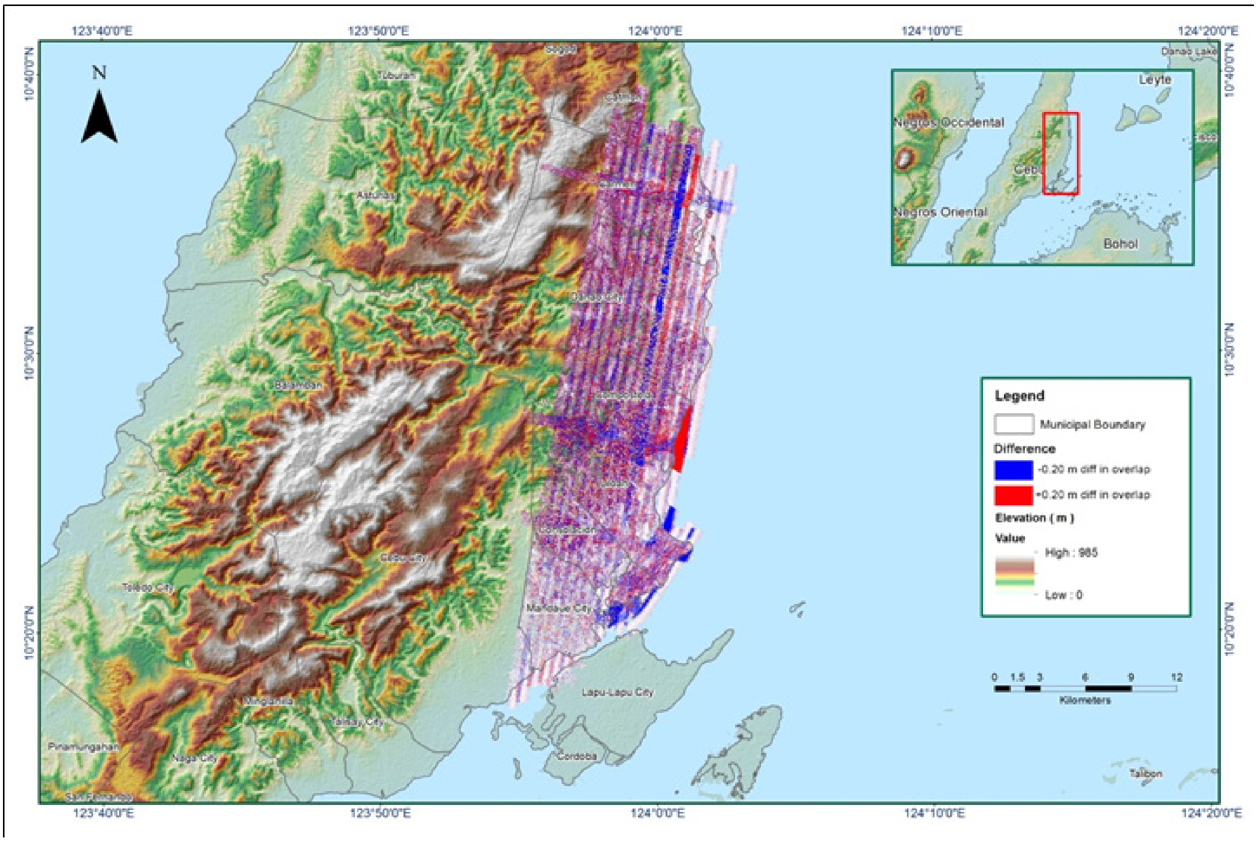

Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk48D

Flight Area	Ormoc_Camotes
Mission Name	Blk48D
Inclusive Flights	8403AC
Range data size	9.82 GB
POS	282 MB
Image	59.1 MB
Base Station	144 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	33.08
RMSE for East Position (<4.0 cm)	34.50
RMSE for Down Position (<8.0 cm)	40.08
Boresight correction stdev (<0.001deg)	0.000231
IMU attitude correction stdev (<0.001deg)	0.019286
GPS position stdev (<0.01m)	0.0196
Minimum % overlap (>25)	59.21
Ave point cloud density per sq.m. (>2.0)	4.84
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	51
Maximum Height	368.52
Minimum Height	44.54
Classification (# of points)	
Ground	30,266,189
Low vegetation	23,814,799
Medium vegetation	31,421,991
High vegetation	25,383,767
Building	565,457
Orthophoto	None
Processed by	Engr. Irish Cortez, Engr. Jennifer Saguran, Aljon Rei Araneta, Alex Escobido, Engr. Czarina Añonuevo

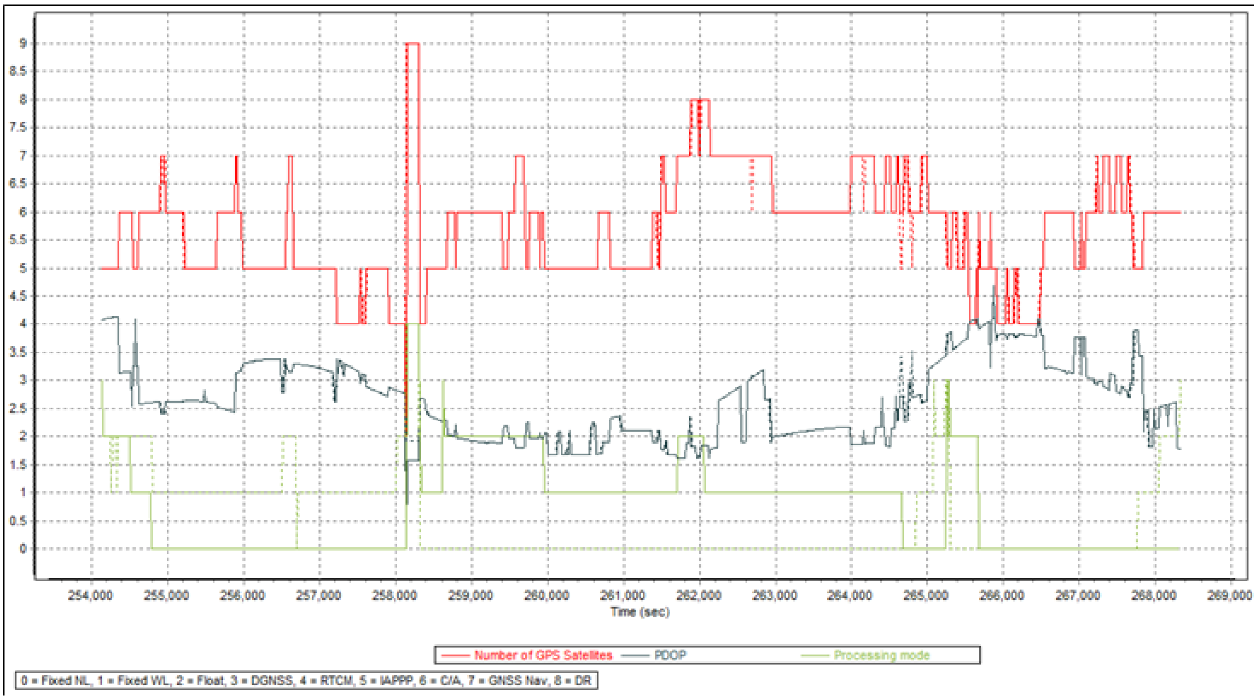

Figure A-8.8. Solution Status Parameters

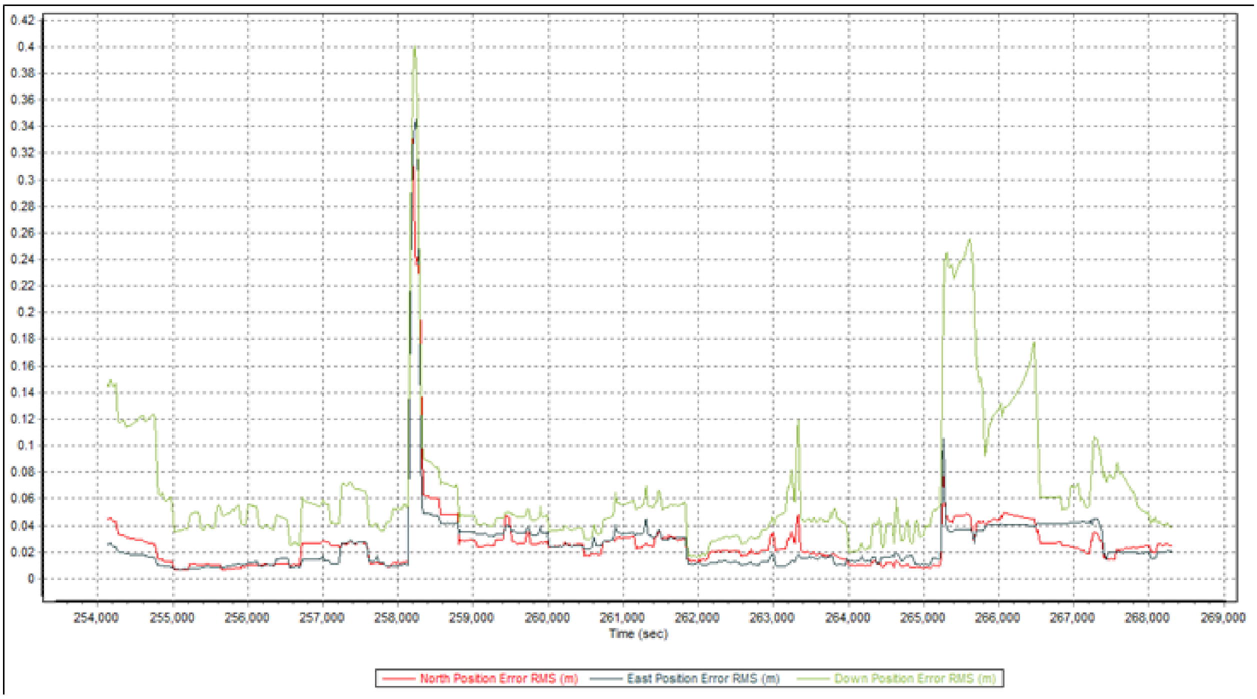

Figure A-8.9. Smoothed Performance Metrics Parameters

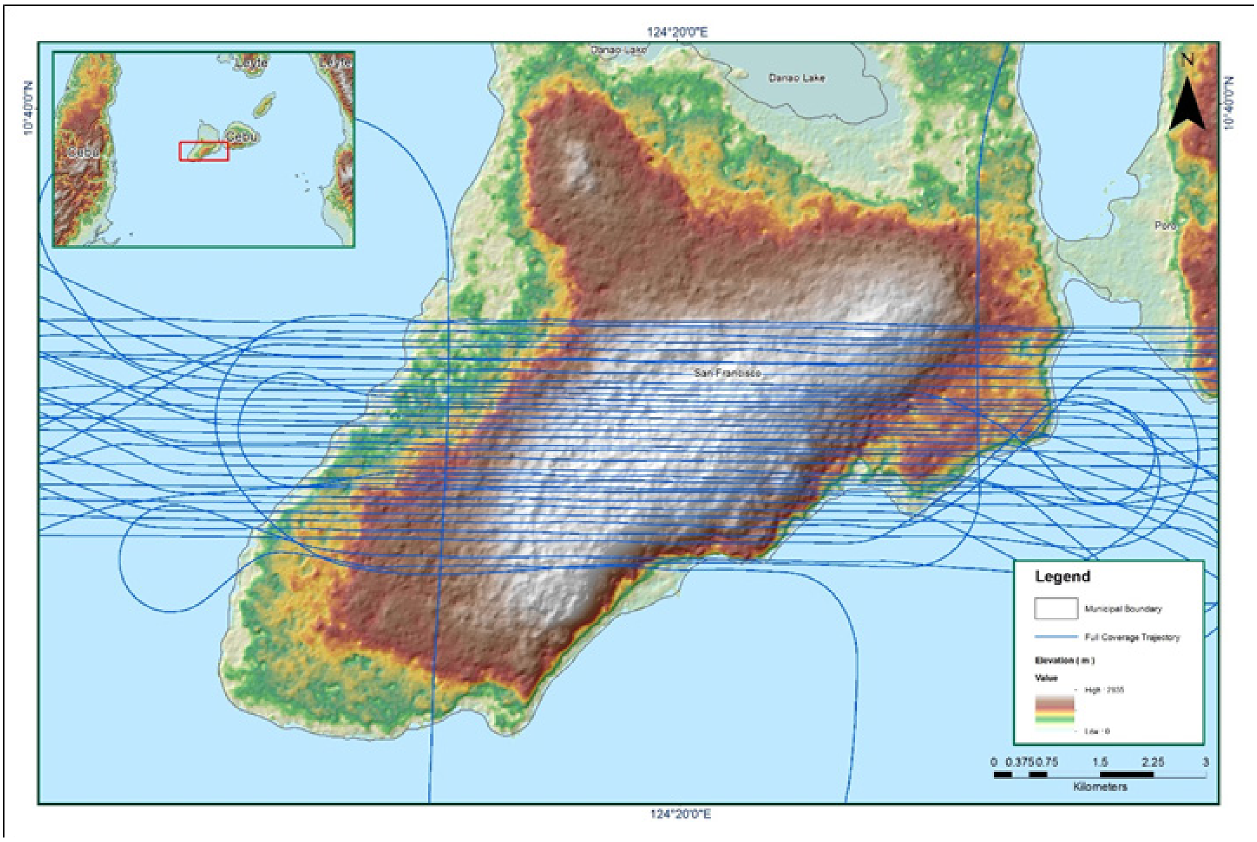

Figure A-8.10. Best Estimated Trajectory

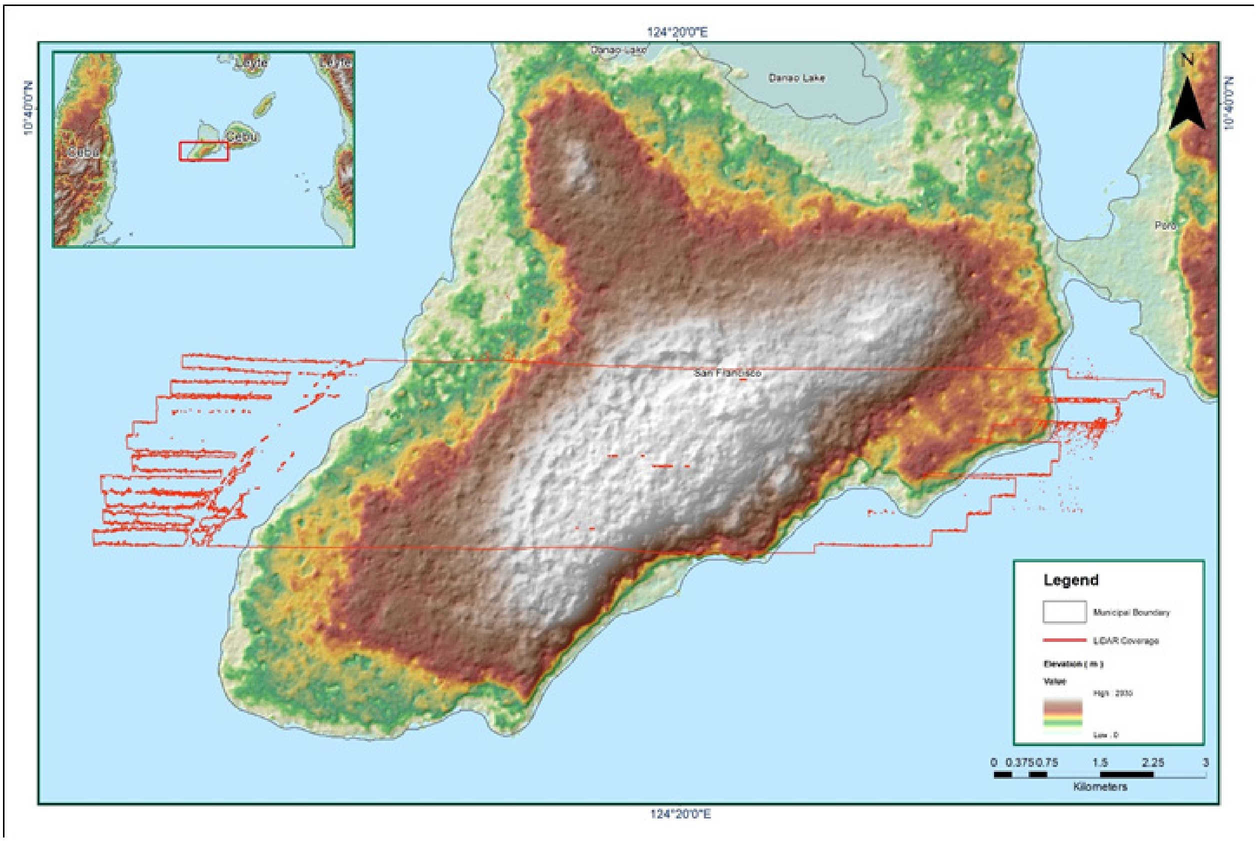

Figure A-8.11. Coverage of LiDAR data

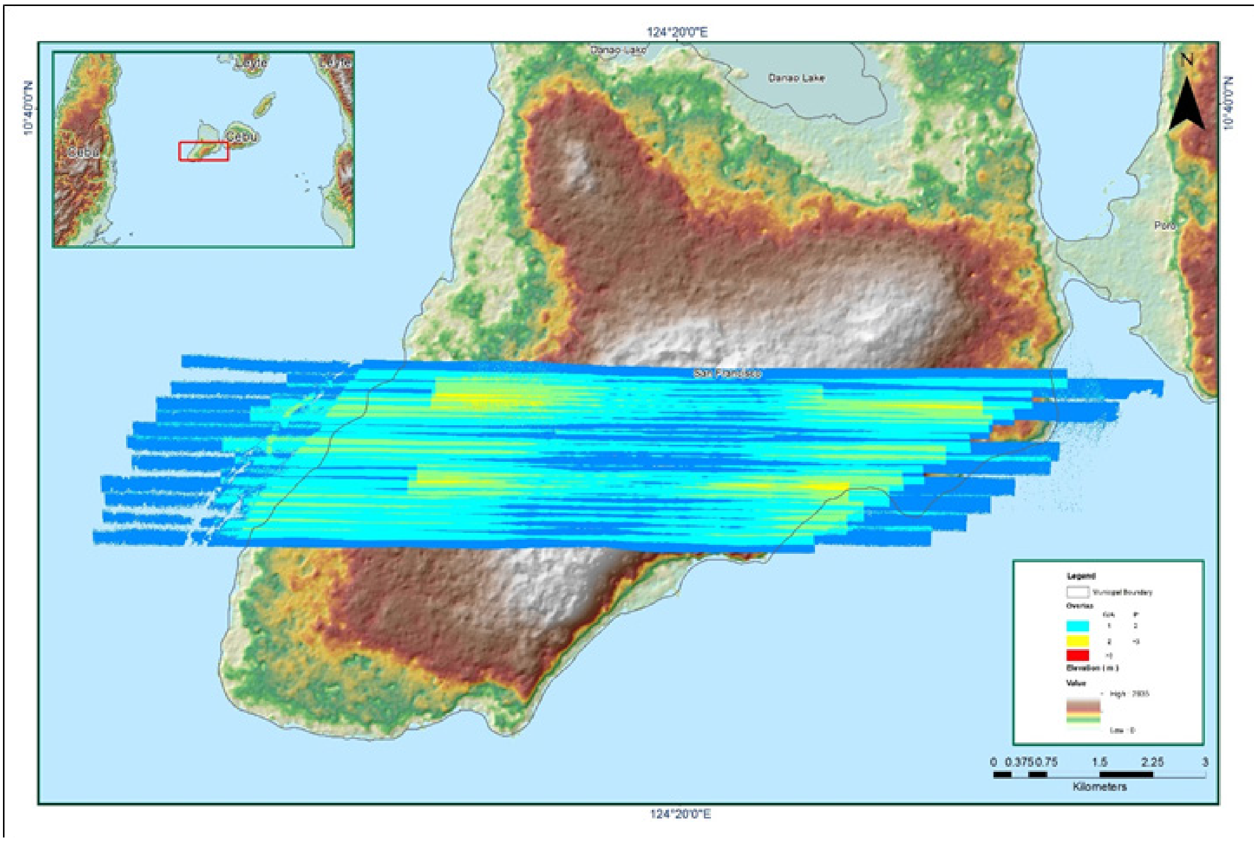

Figure A-8.12. Image of Data Overlap

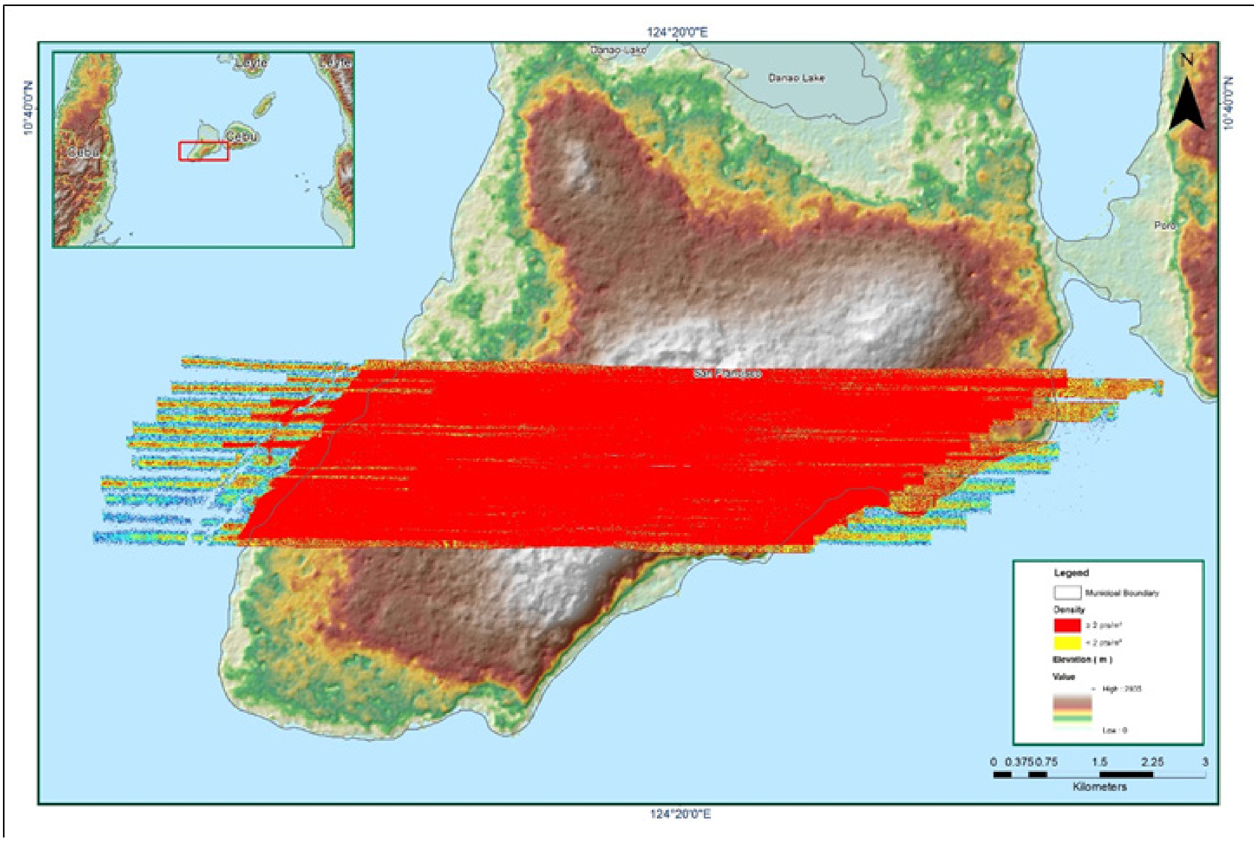

Figure A-8.13. Density map of merged LiDAR data

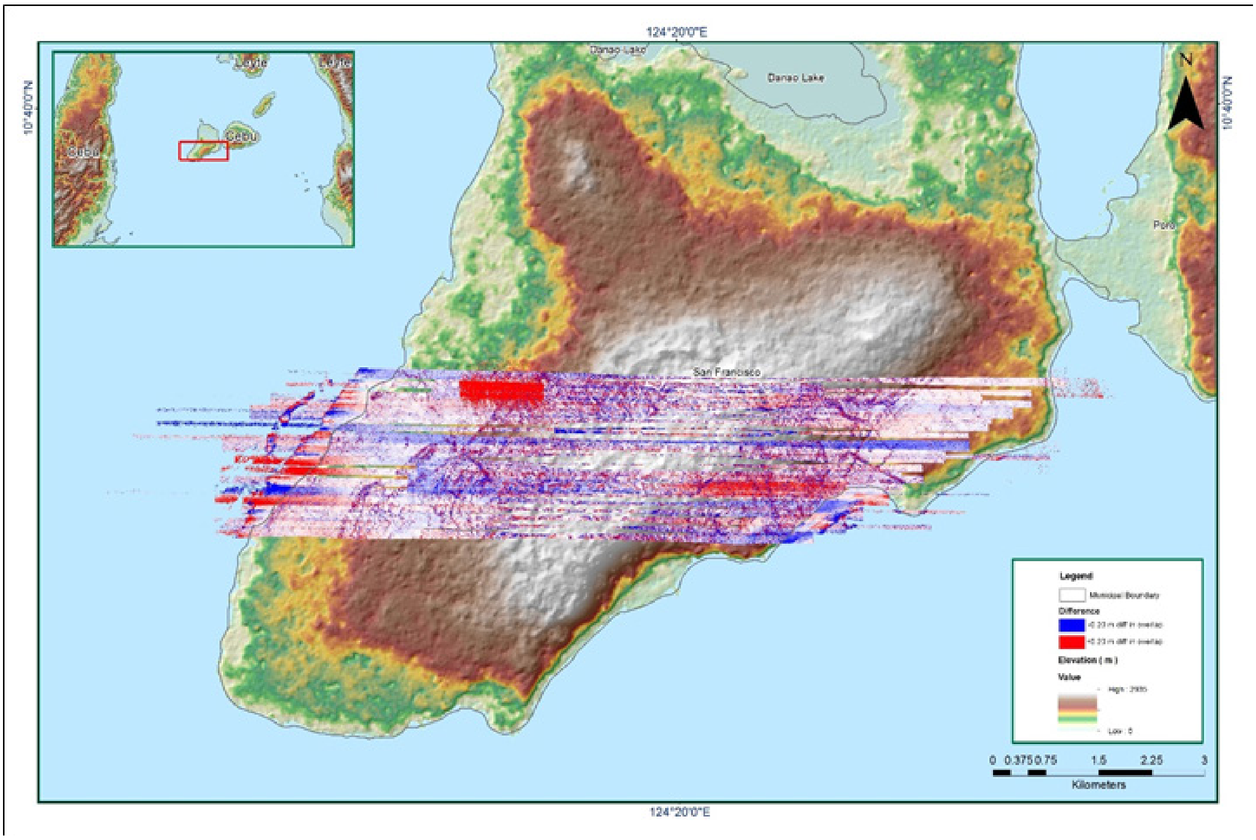

Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk48D_Additional

Flight Area	Ormoc_Camotes
Mission Name	Blk48D_Additional
Inclusive Flights	8406AC
Range data size	7.67 GB
POS	257 MB
Image	40.3 MB
Base Station	218 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	28.49
RMSE for East Position (<4.0 cm)	15.07
RMSE for Down Position (<8.0 cm)	38.87
Boresight correction stdev (<0.001deg)	0.000661
IMU attitude correction stdev (<0.001deg)	0.003780
GPS position stdev (<0.01m)	0.0136
Minimum % overlap (>25)	40.85
Ave point cloud density per sq.m. (>2.0)	3.29
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	18
Maximum Height	138.27
Minimum Height	47.68
Classification (# of points)	
Ground	5,769,644
Low vegetation	4,149,641
Medium vegetation	5,175,882
High vegetation	7,962,639
Building	398,700
Orthophoto	None
Processed by	Engr. Jennifer Saguran, Aljon Rei Araneta, Alex Escobido

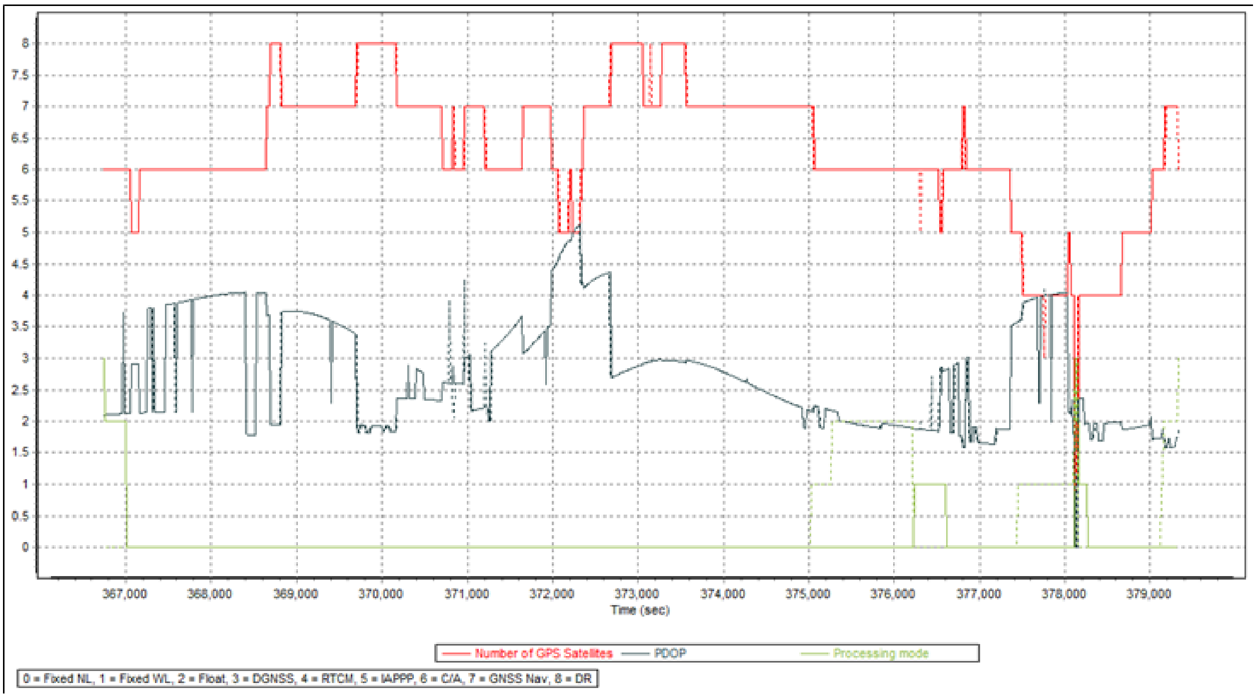

Figure A-8.15. Solution Status

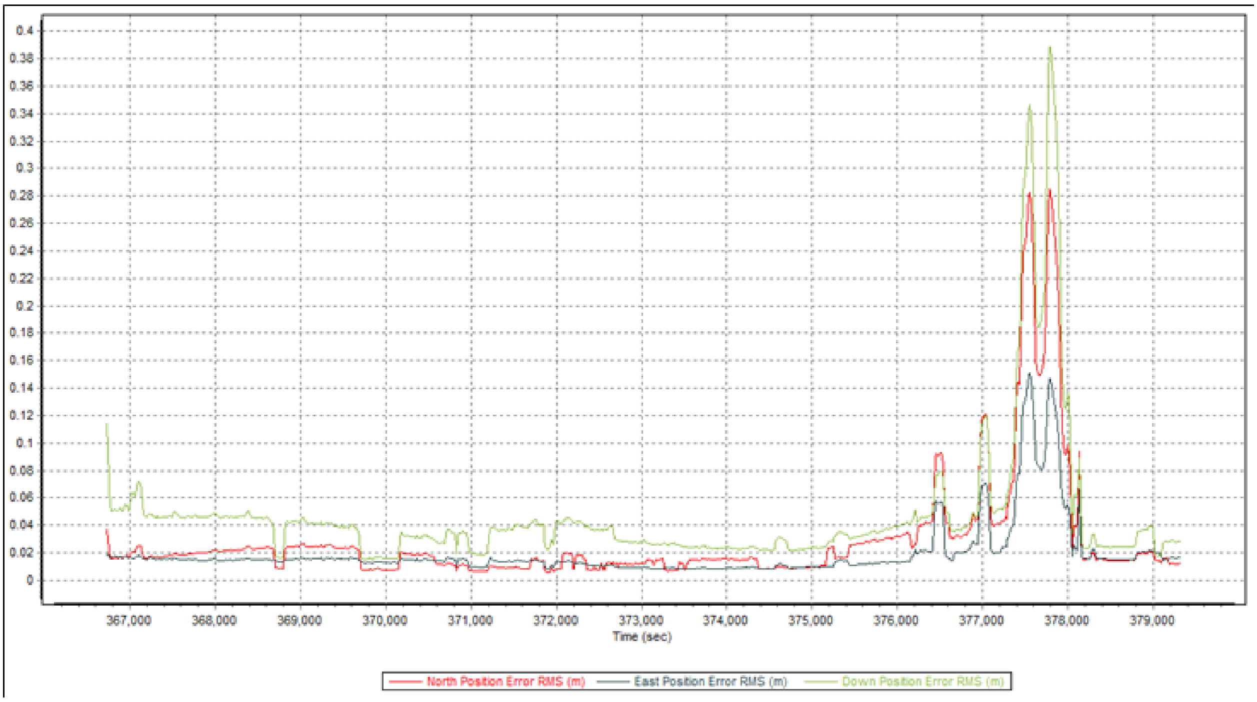

Figure A-8.16. Smoothed Performance Metric Parameters

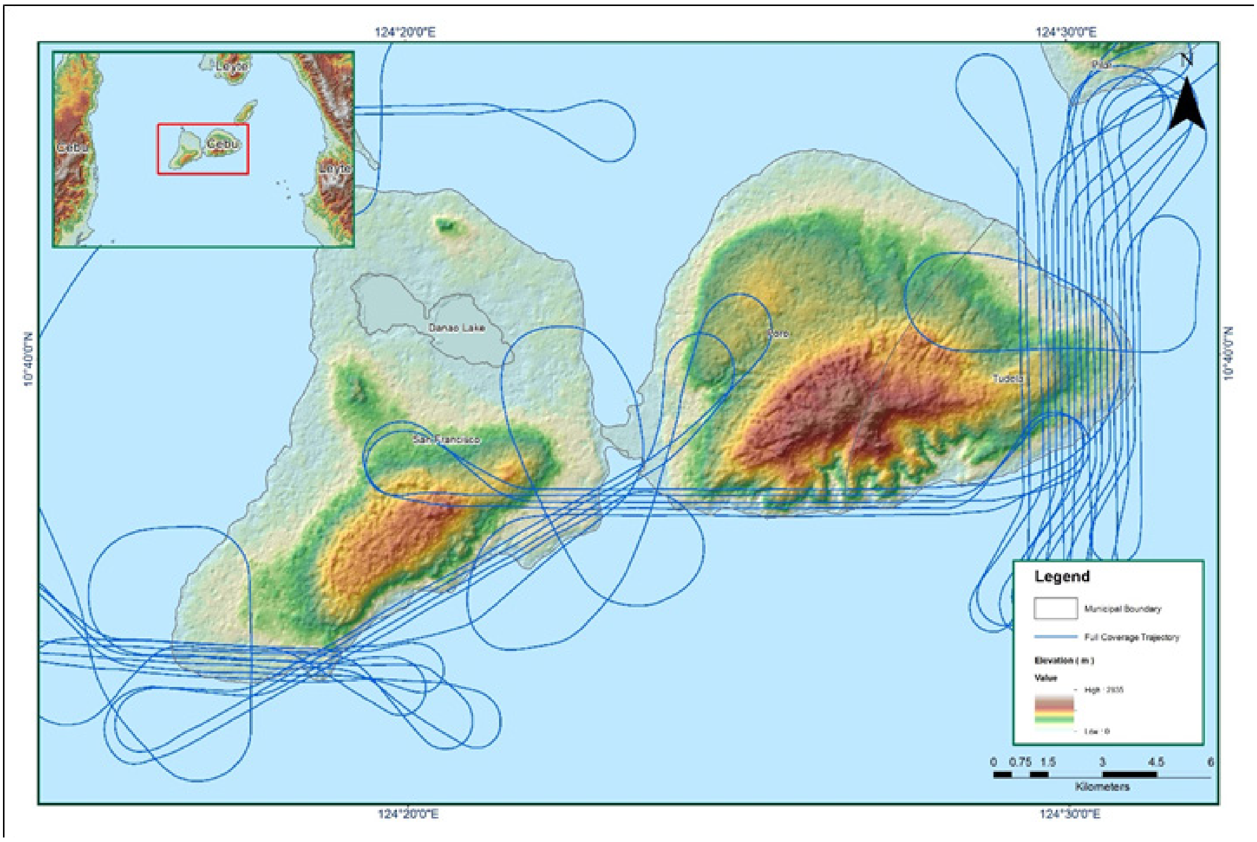

Figure A-8.17. Best Estimated Trajectory

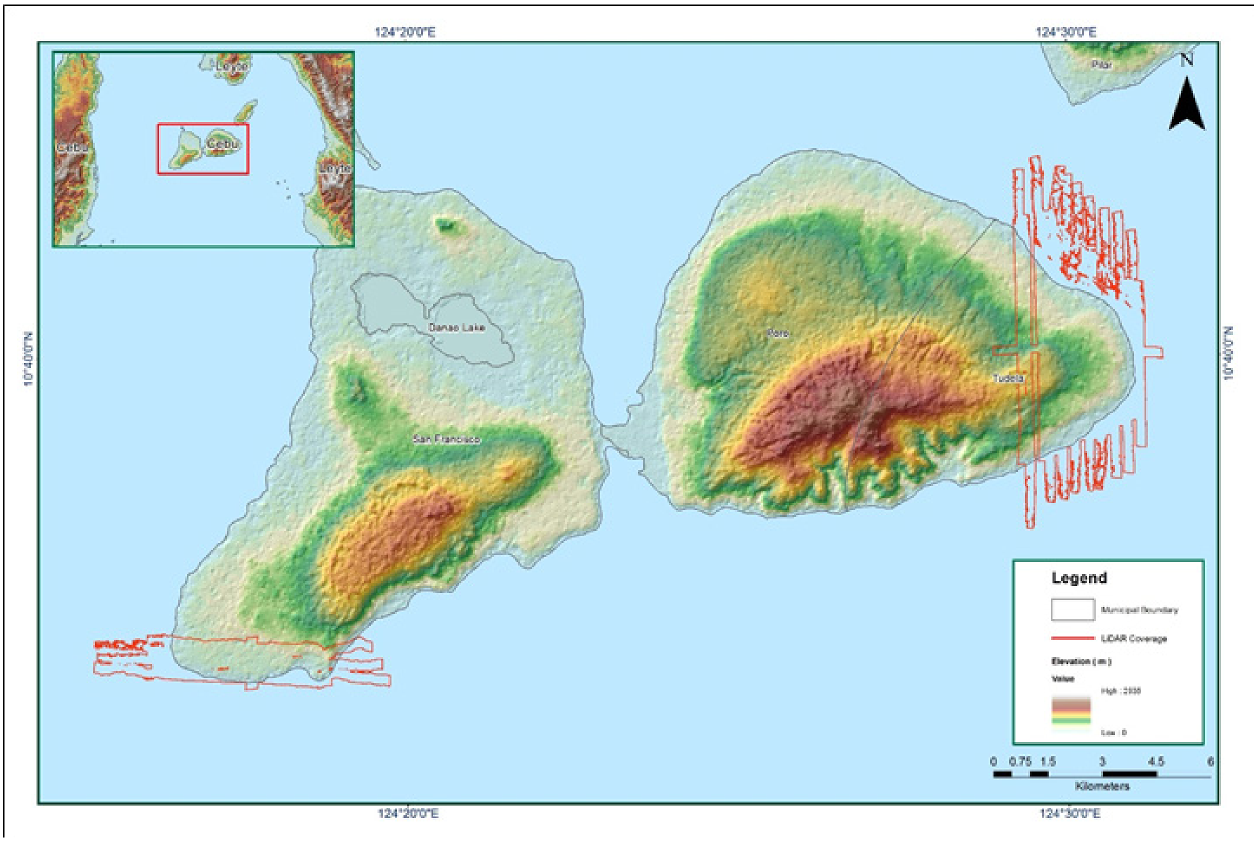

Figure A-8.18. Coverage of LiDAR data

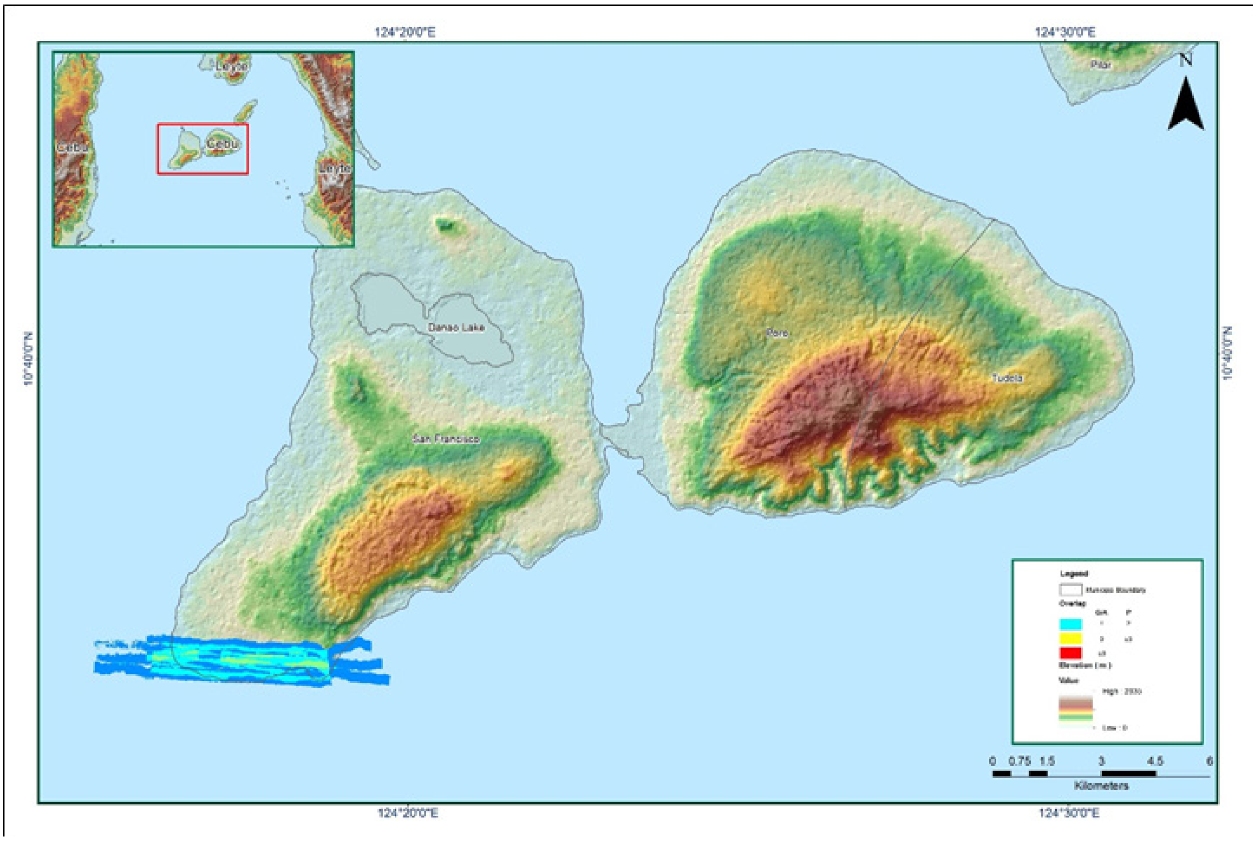

Figure A-8.19. Image of Data Overlap

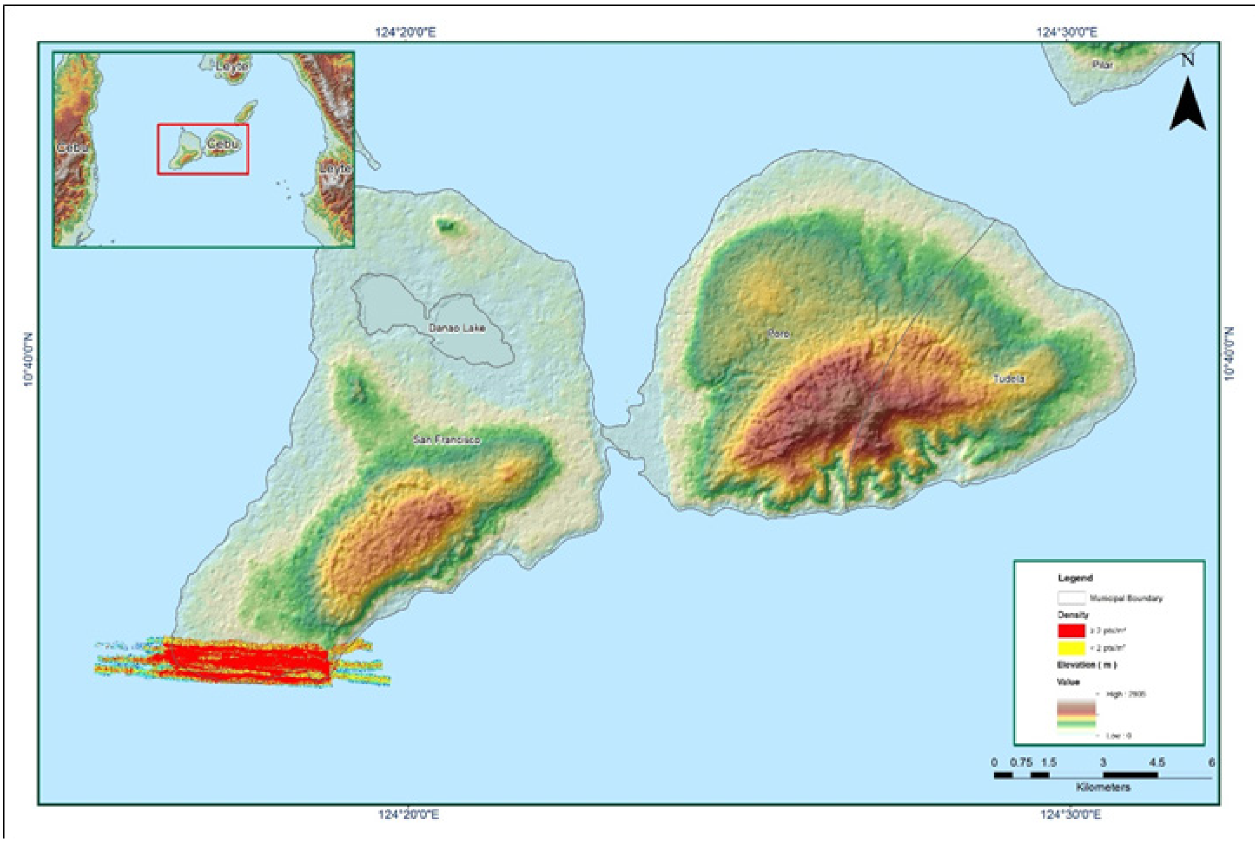

Figure A-8.20. Density map of merged LiDAR data

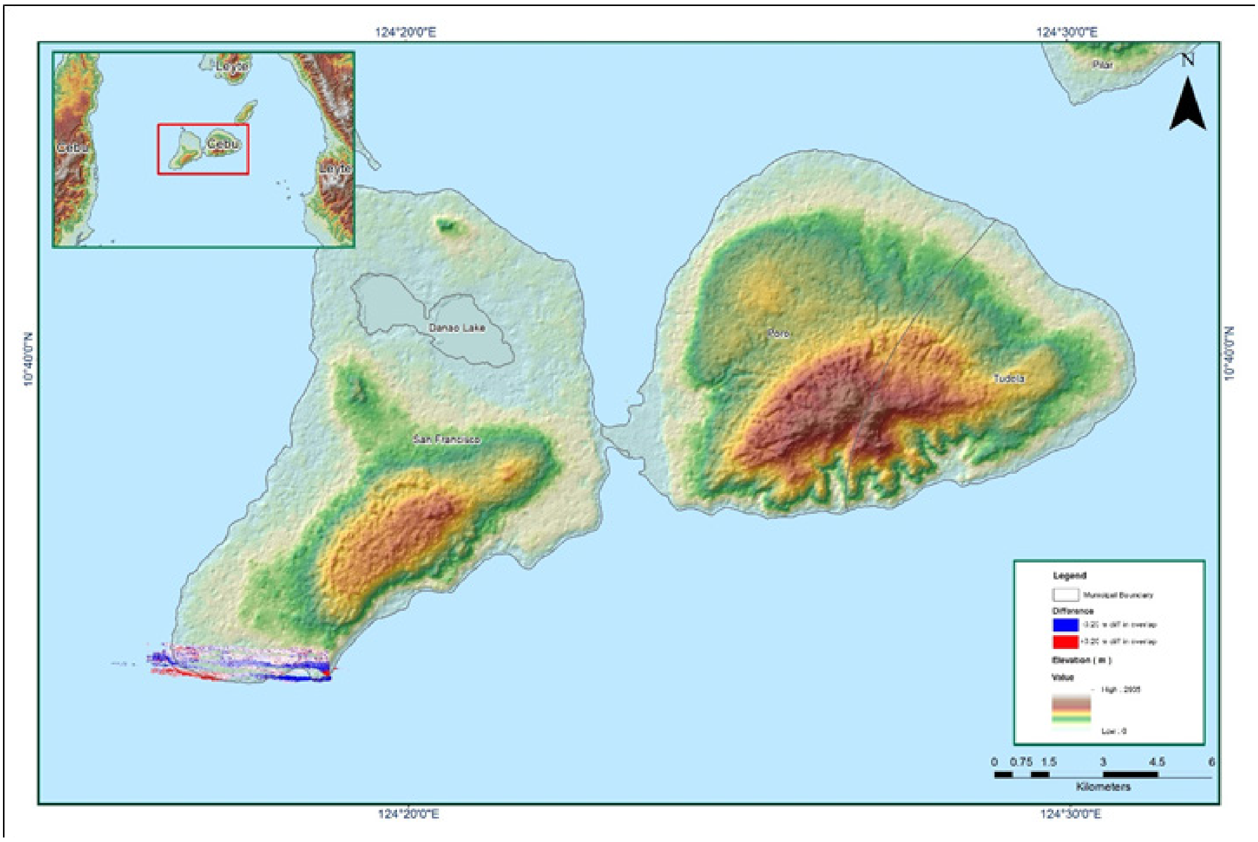

Figure A-8.21. Elevation difference between flight lines

Table A-8.4. Mission Summary Report for Mission Blk48D_Supplement

Flight Area	Ormoc_Camotes
Mission Name	Blk48D_Supplement
Inclusive Flights	8400AC/8403AC/8406AC
Range data size	20.6 GB
POS	657 MB
Image	115.4 MB
Base Station	411.4 MB
Transfer date	April 27, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	30.00
RMSE for East Position (<4.0 cm)	25.96
RMSE for Down Position (<8.0 cm)	33.97
Boresight correction stdev (<0.001deg)	0.000661
IMU attitude correction stdev (<0.001deg)	0.003780
GPS position stdev (<0.01m)	0.0136
Minimum % overlap (>25)	30.73
Ave point cloud density per sq.m. (>2.0)	2.89
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	34
Maximum Height	237.21
Minimum Height	51.45
Classification (# of points)	
Ground	11,785,110
Low vegetation	5,357,352
Medium vegetation	5,644,212
High vegetation	12,178,721
Building	406,904
Orthophoto	None
Processed by	Engr. Jennifer Saguran, Aljn Rei Araneta, Engr. Vincent Louise Azucena

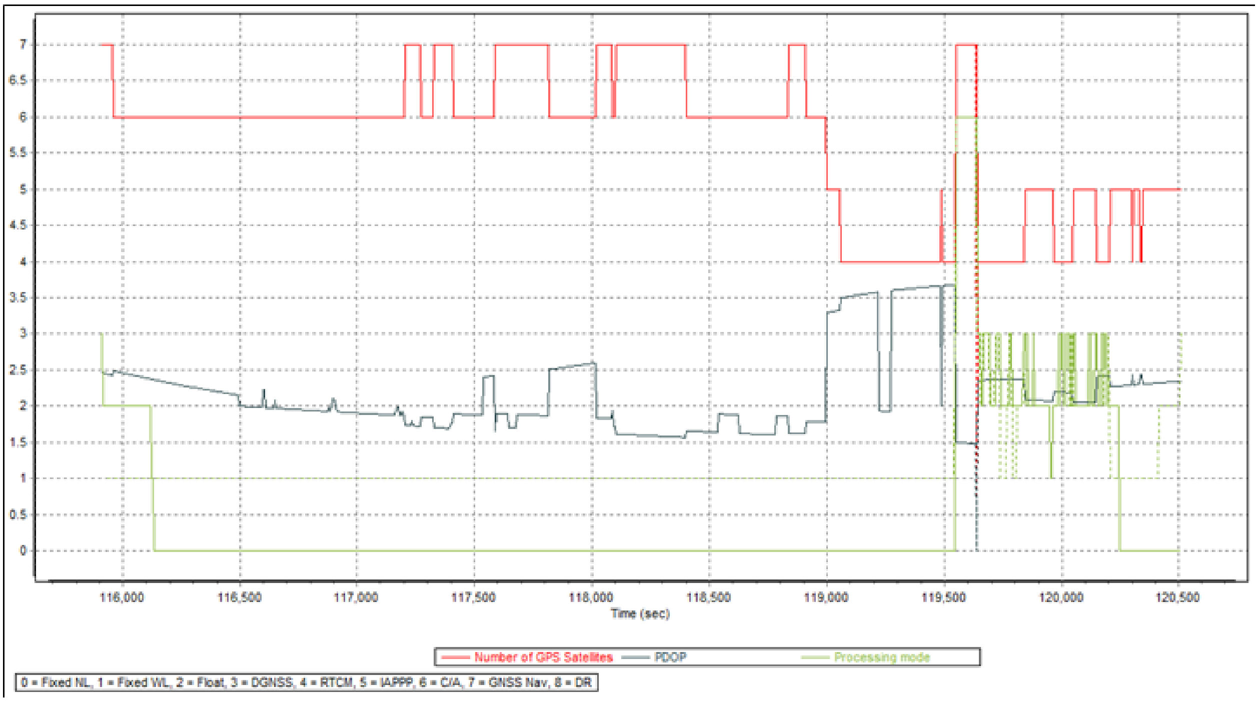

Figure A-8.22. Solution Status

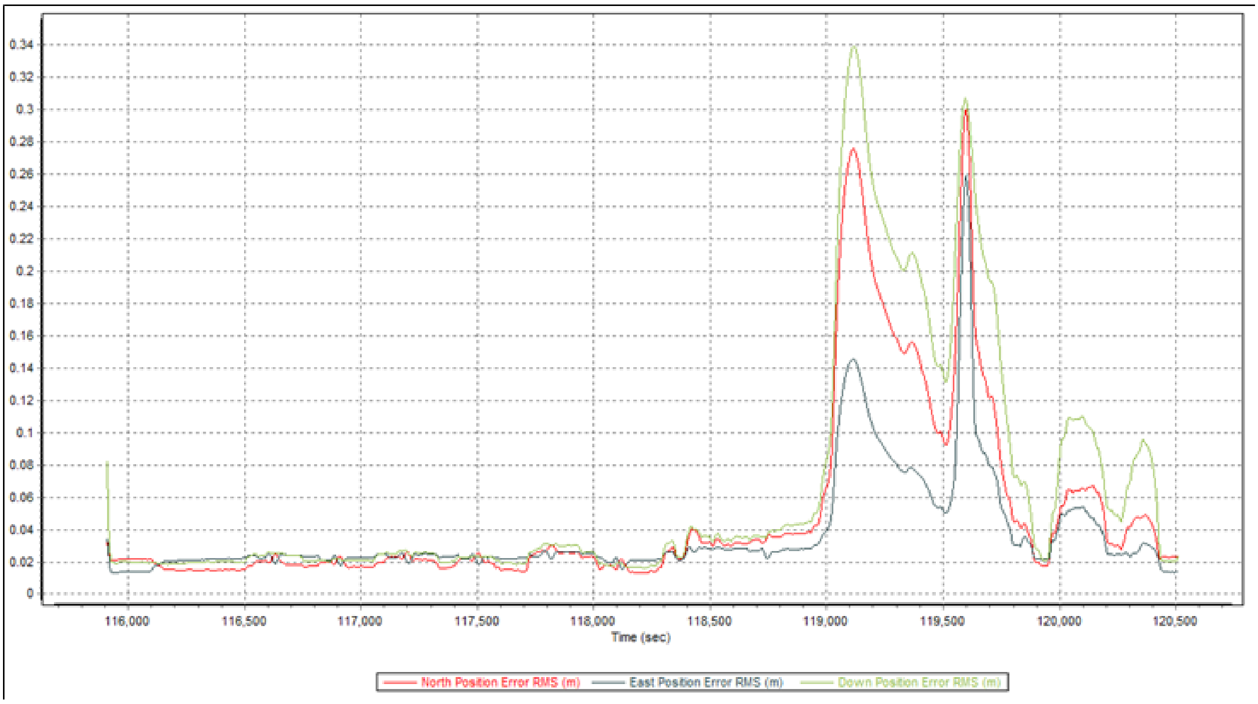

Figure A-8.23. Smoothed Performance Metric Parameters

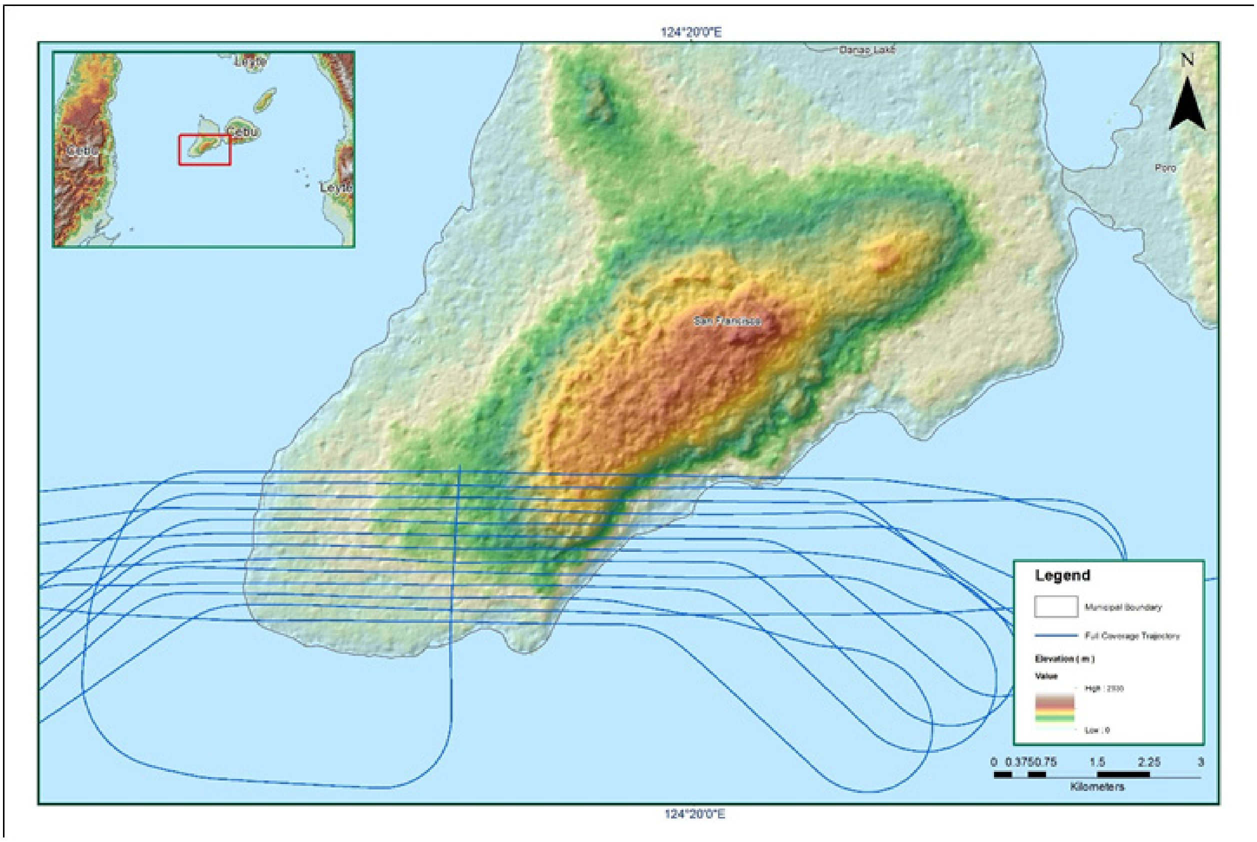

Figure A-8.24. Best Estimated Trajectory

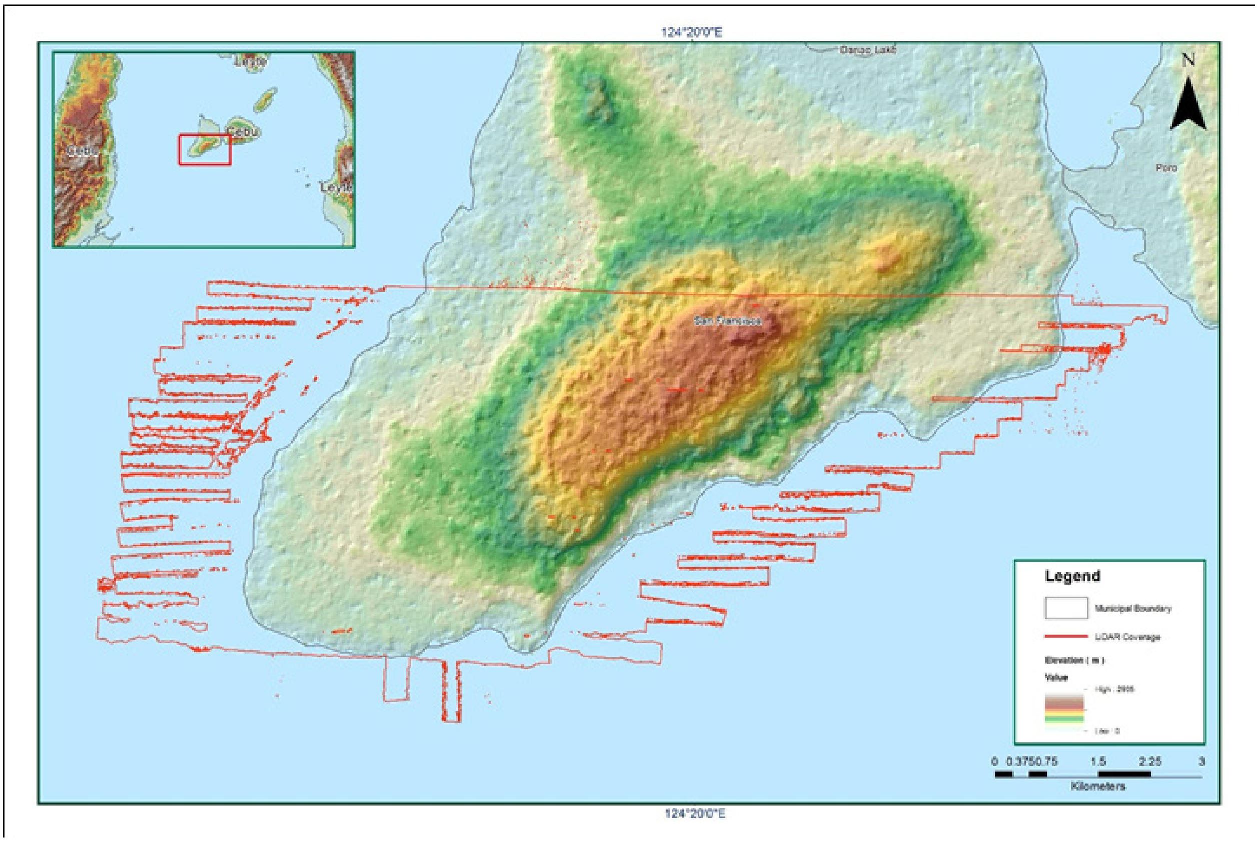

Figure A-8.25. Coverage of LiDAR data

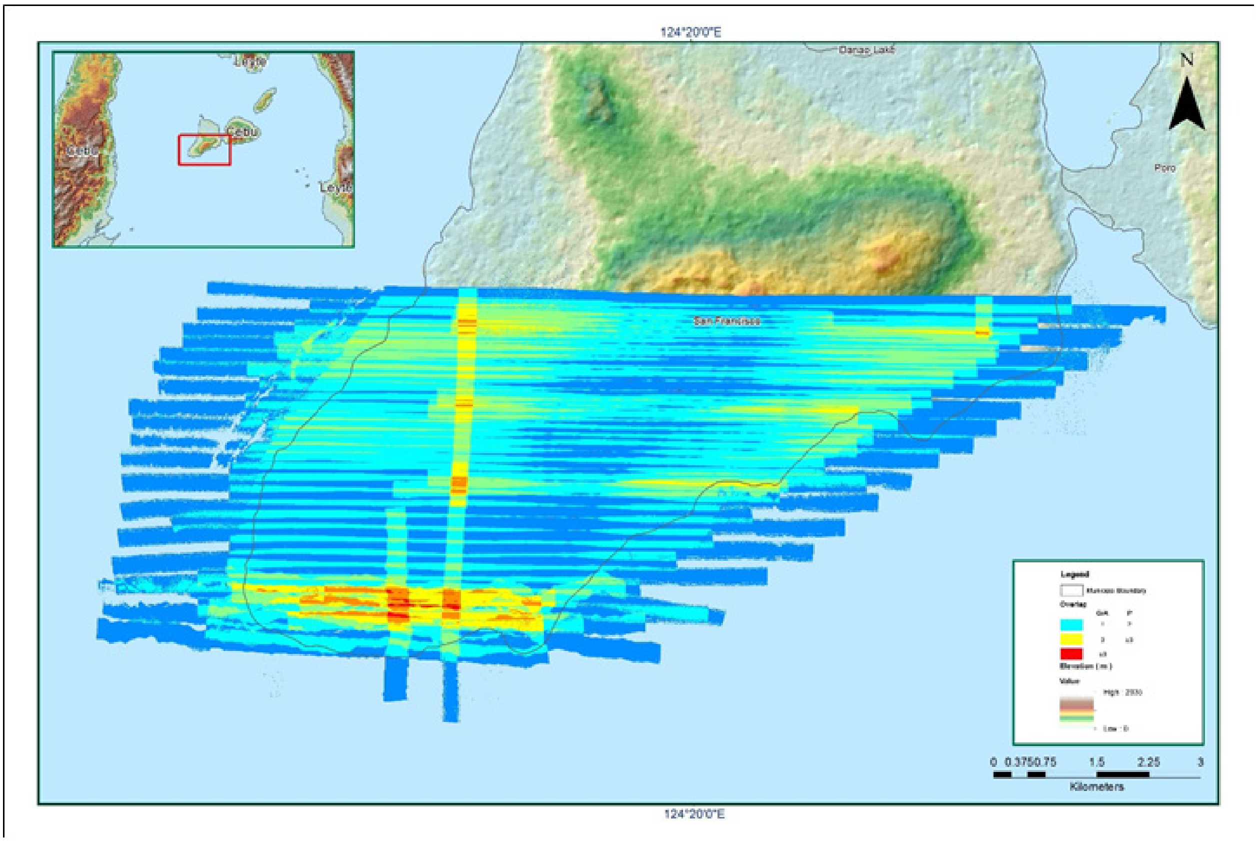

Figure A-8.26. Image of Data Overlap

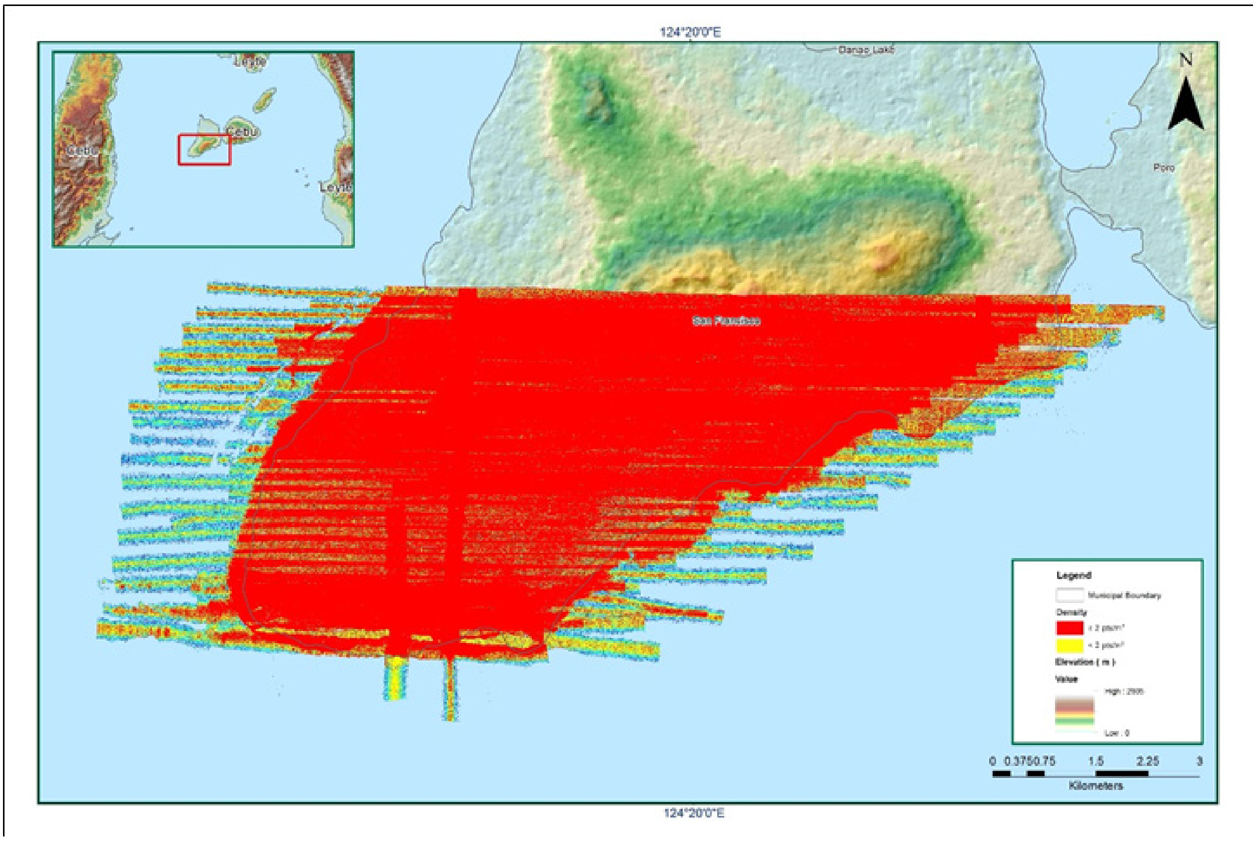

Figure A-8.27. Density map of merged LiDAR data

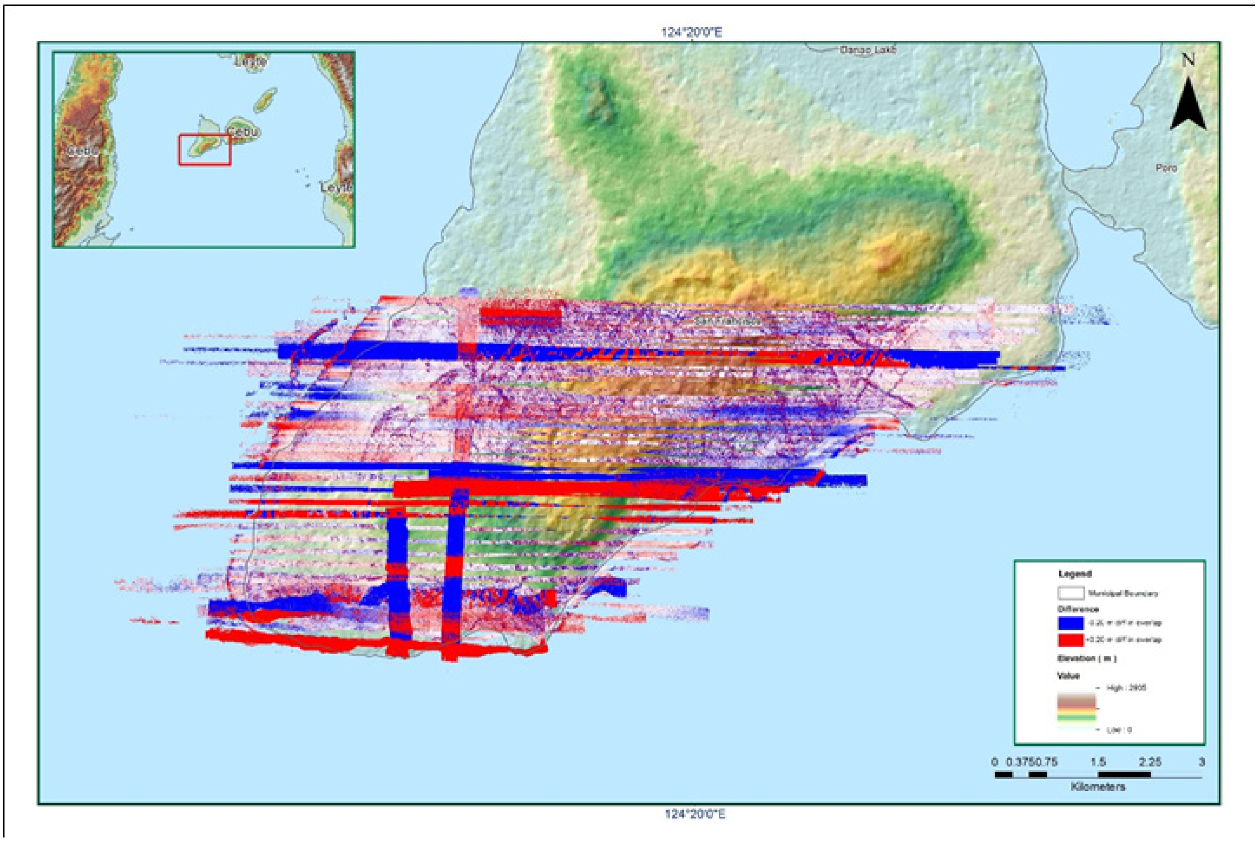

Figure A-8.28. Elevation difference between flight lines

Table A-8.5. Mission Summary Report for Mission Blk48F

Flight Area	Ormoc_Camotes
Mission Name	Blk48F
Inclusive Flights	8393AC
Range data size	7.71 GB
POS	164 MB
Image	29.1 GB
Base Station	167 MB
Transfer date	April 27, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.44
RMSE for East Position (<4.0 cm)	5.26
RMSE for Down Position (<8.0 cm)	18.04
Boresight correction stdev (<0.001deg)	0.000319
IMU attitude correction stdev (<0.001deg)	0.002247
GPS position stdev (<0.01m)	0.0020
Minimum % overlap (>25)	53.78
Ave point cloud density per sq.m. (>2.0)	4.3
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	51
Maximum Height	285.87
Minimum Height	47.03
Classification (# of points)	
Ground	20,189,536
Low vegetation	24,937,493
Medium vegetation	31,794,041
High vegetation	40,498,956
Building	1,450,685
Orthophoto	None
Processed by	Engr. Jennifer Saguran, Aljon Rie Araneta, Alex John Escobido

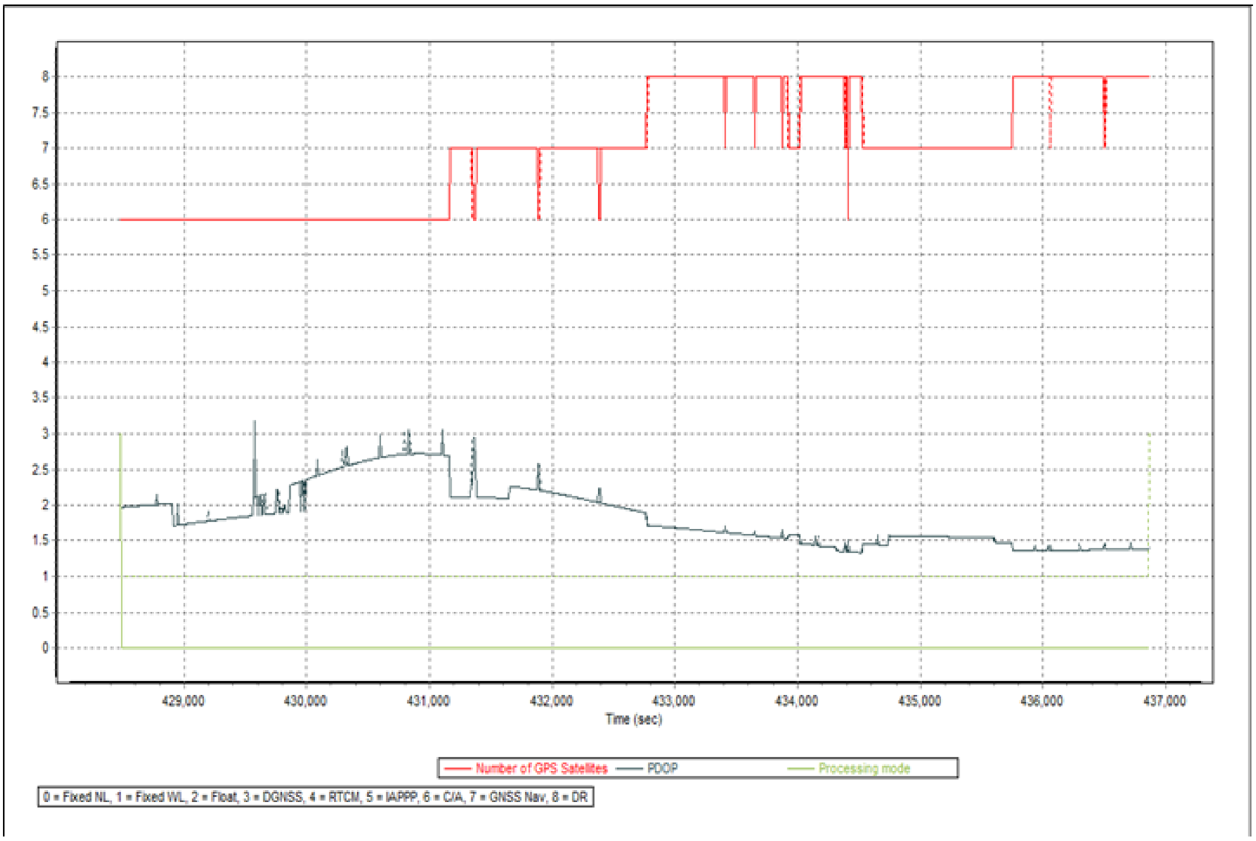

Figure A-8.29. Solution Status

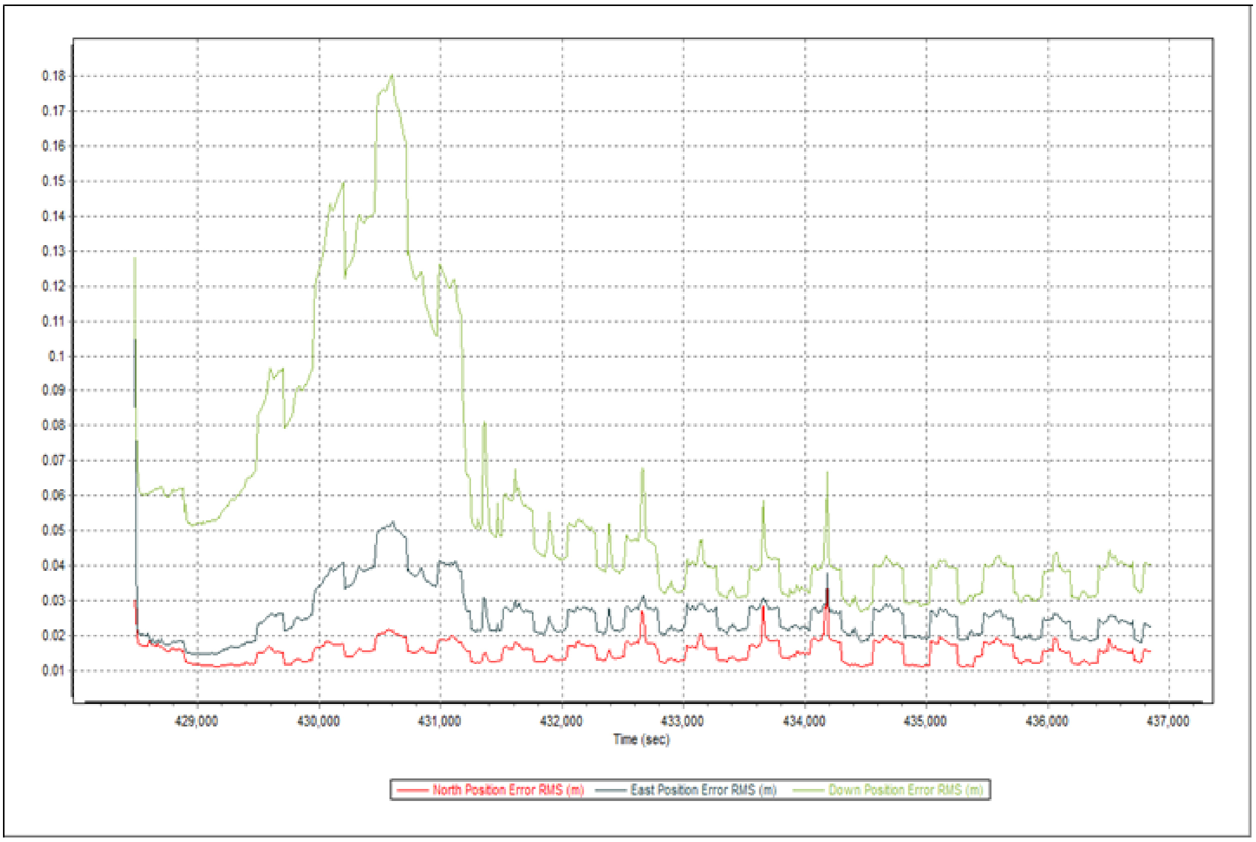

Figure A-8.30. Smoothed Performance Metric Parameters

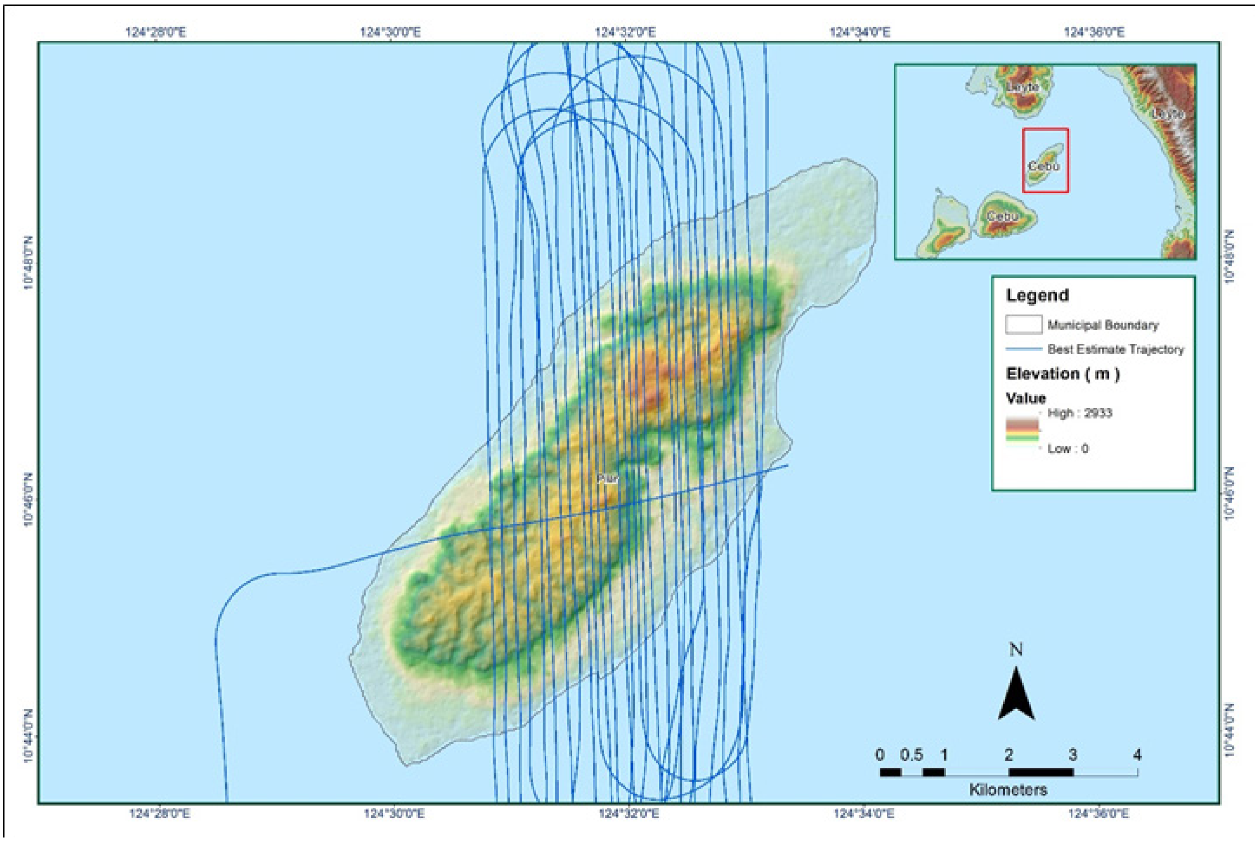

Figure A-8.31. Best Estimated Trajectory

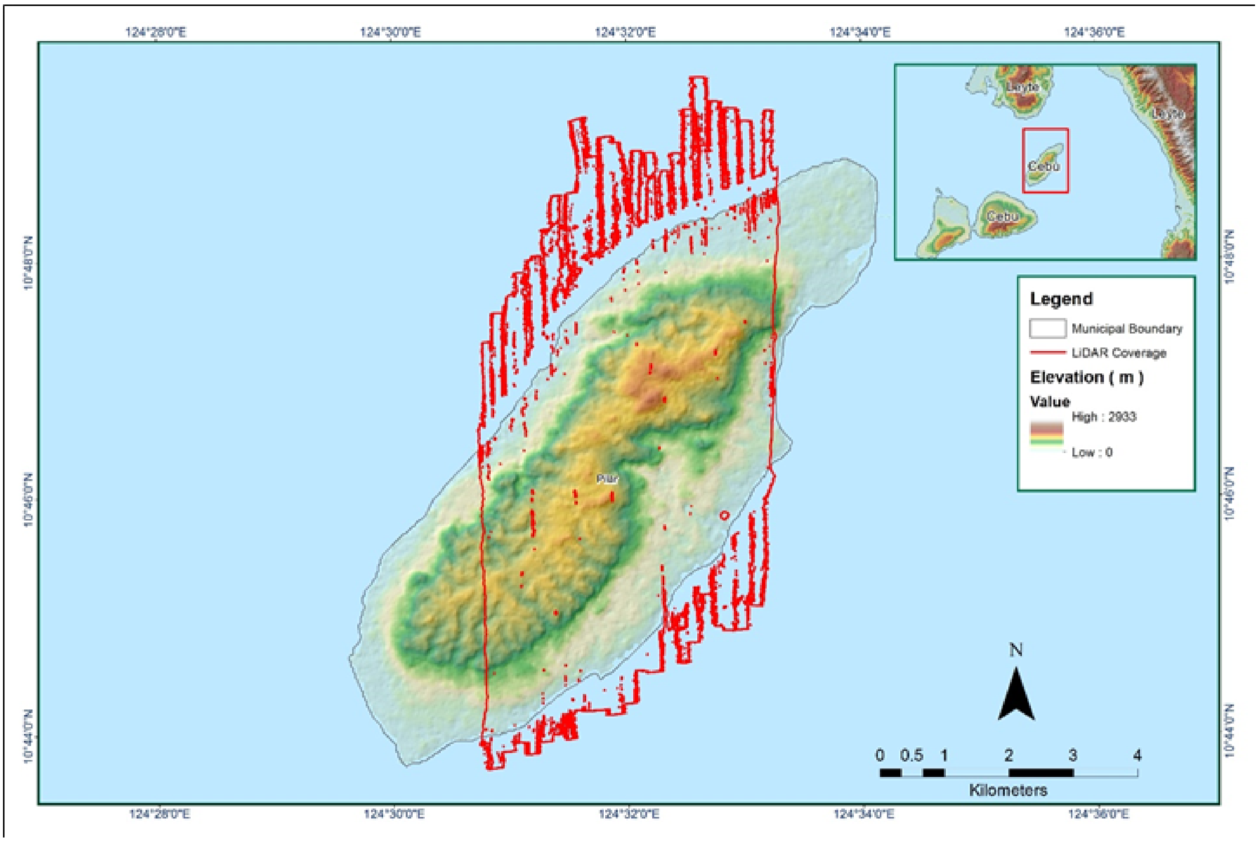

Figure A-8.32. Coverage of LiDAR data

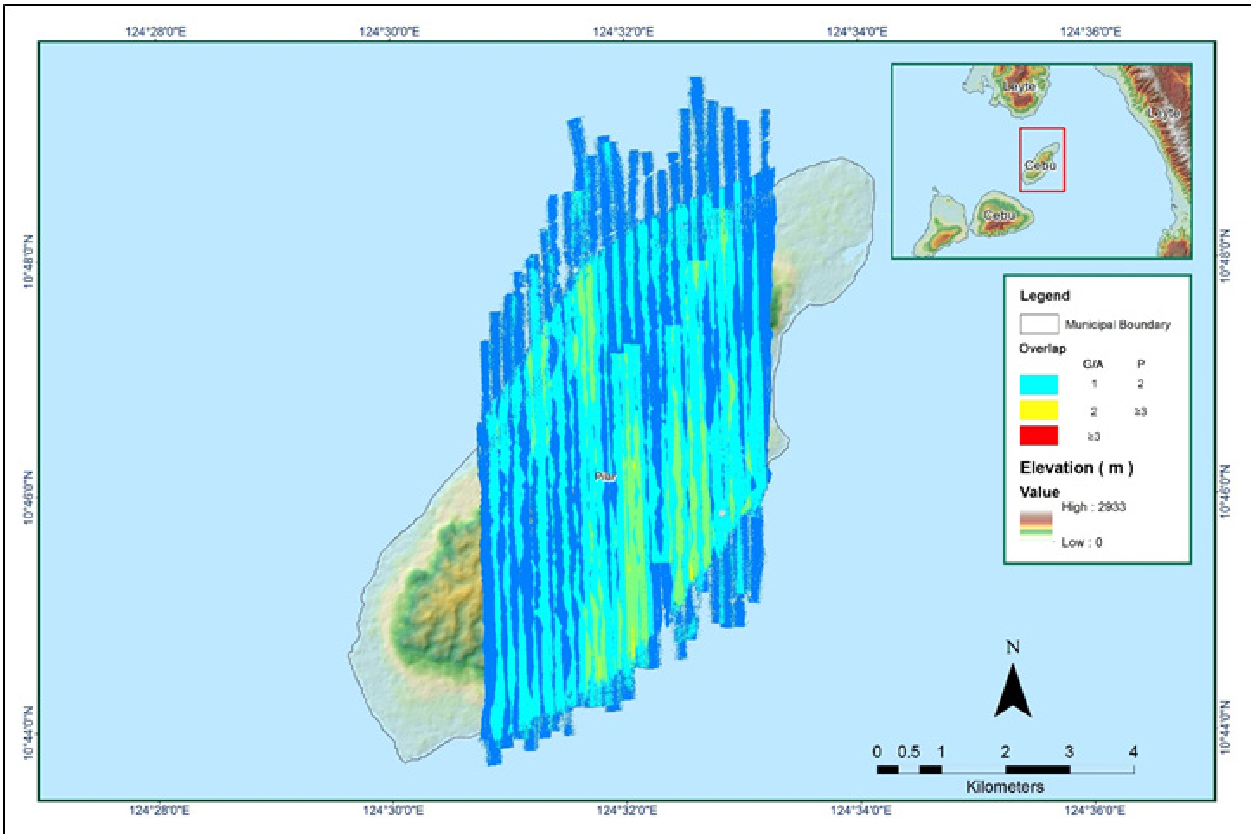

Figure A-8.33. Image of Data Overlap

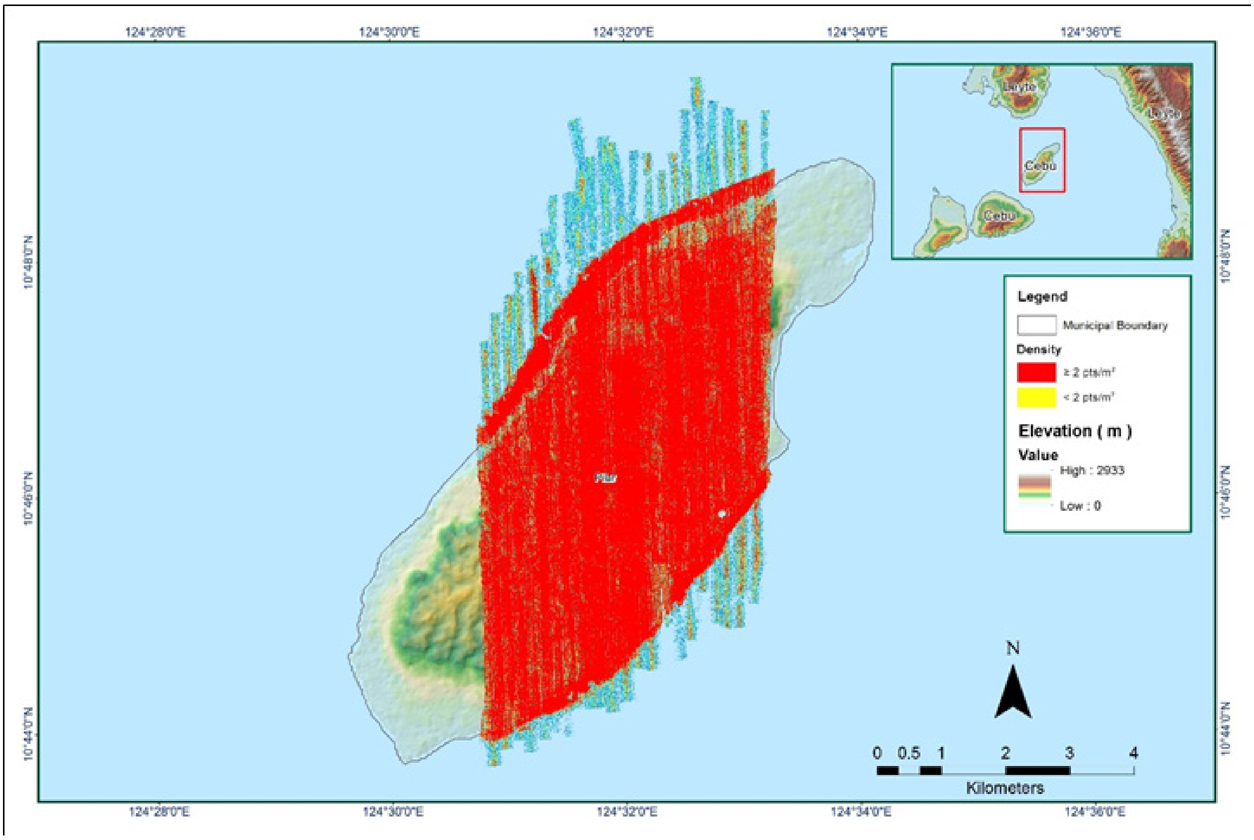

Figure A-8.34. Density map of merged LiDAR data

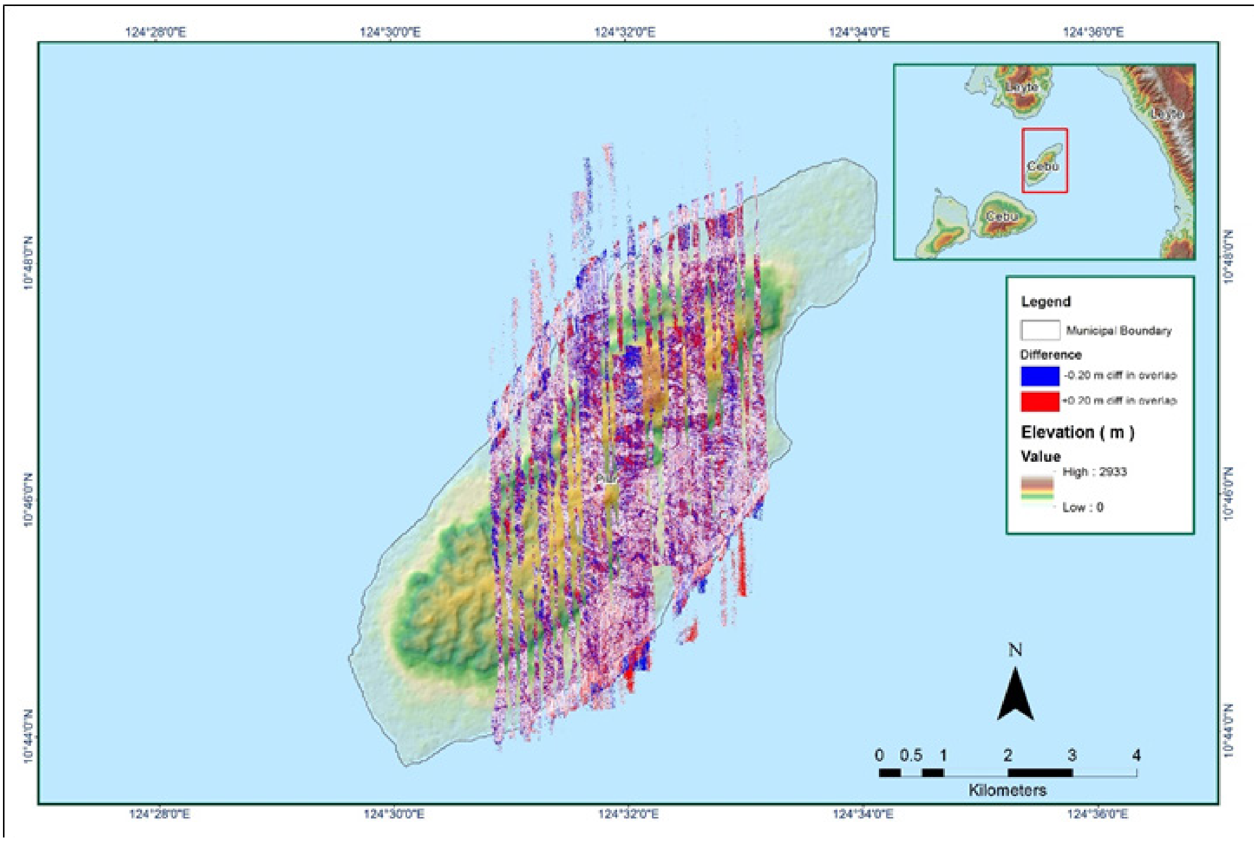

Figure A-8.35. Elevation difference between flight lines

Table A-8.6. Mission Summary Report for Mission Blk48A

Flight Area	Ormoc_Camotes
Mission Name	Blk48A
Inclusive Flights	8390AC/8405AC
Range data size	16.91 GB
POS	454 MB
Image	99.1 MB
Base Station	372 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.64
RMSE for East Position (<4.0 cm)	1.88
RMSE for Down Position (<8.0 cm)	4.44
Boresight correction stdev (<0.001deg)	0.000671
IMU attitude correction stdev (<0.001deg)	0.002979
GPS position stdev (<0.01m)	0.0032
Minimum % overlap (>25)	36.11
Ave point cloud density per sq.m. (>2.0)	2.54
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	94
Maximum Height	190.08
Minimum Height	45.03
Classification (# of points)	
Ground	50,986,969
Low vegetation	38,173,873
Medium vegetation	27,442,869
High vegetation	32,893,859
Building	2,299,645
Orthophoto	None
Processed by	Engr. Sheila Maye Santillan, Engr. Velina Angela Bemida, Engr. Czarina Añonuevo

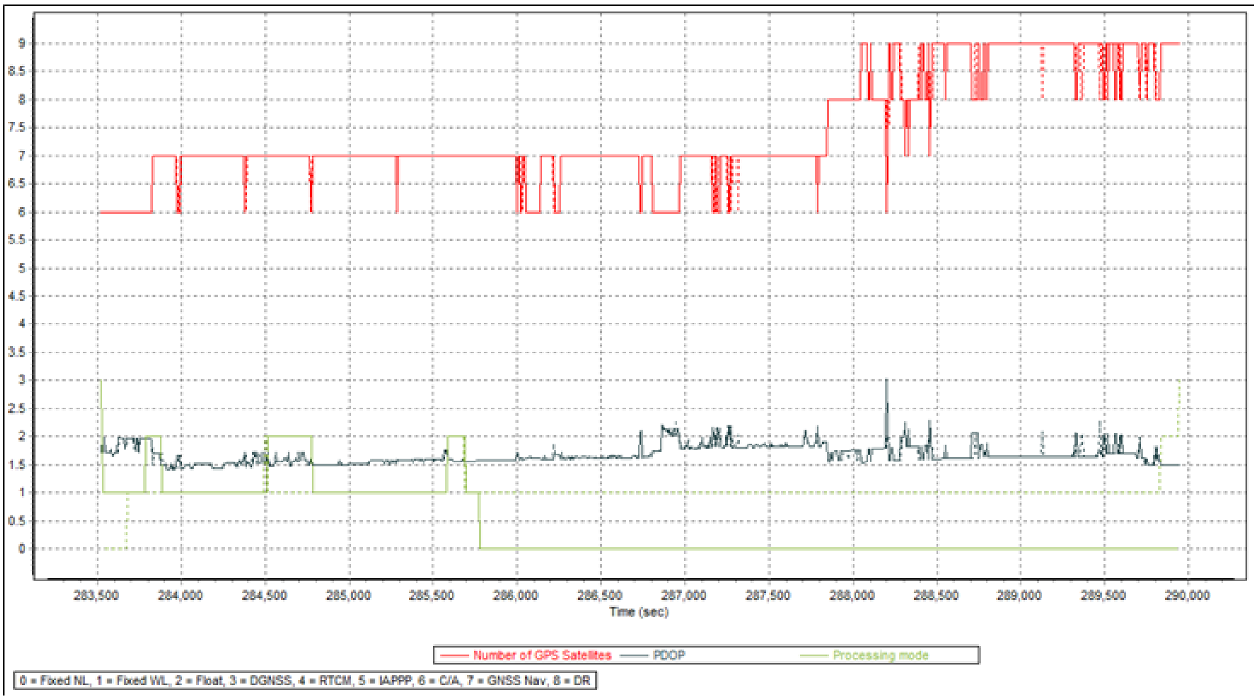

Figure A-8.36. Solution Status

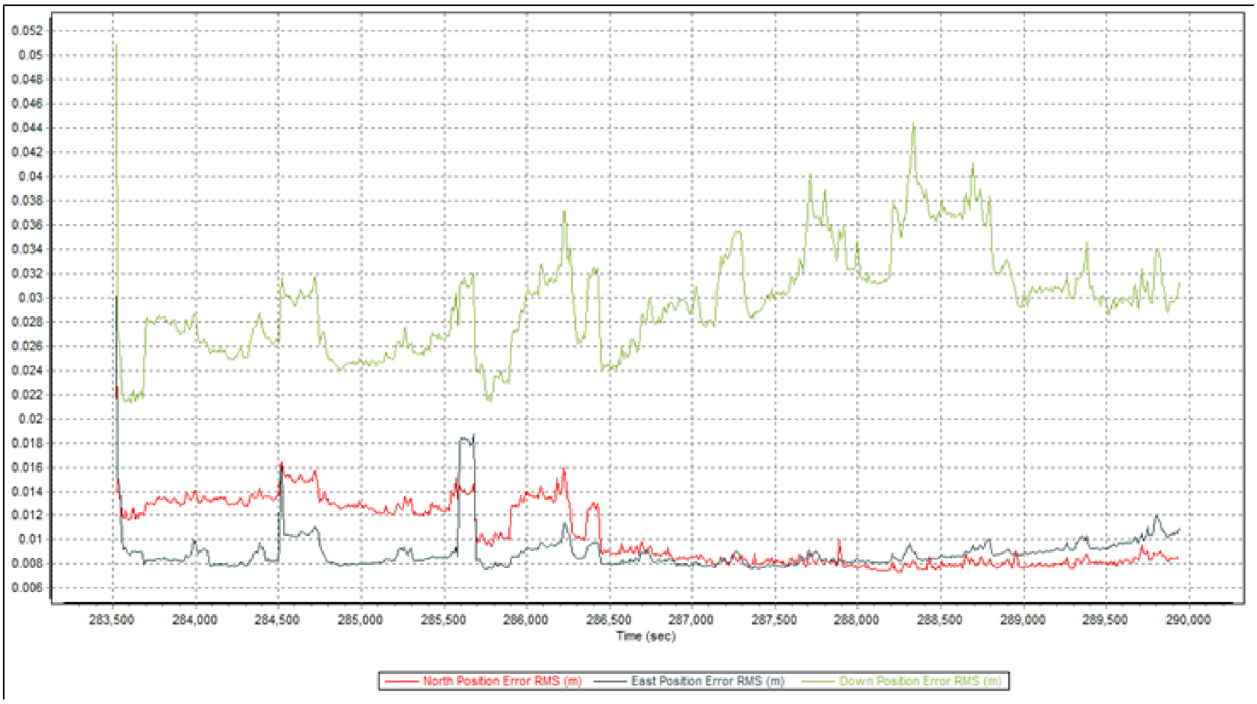

Figure A-8.37. Smoothed Performance Metric Parameters

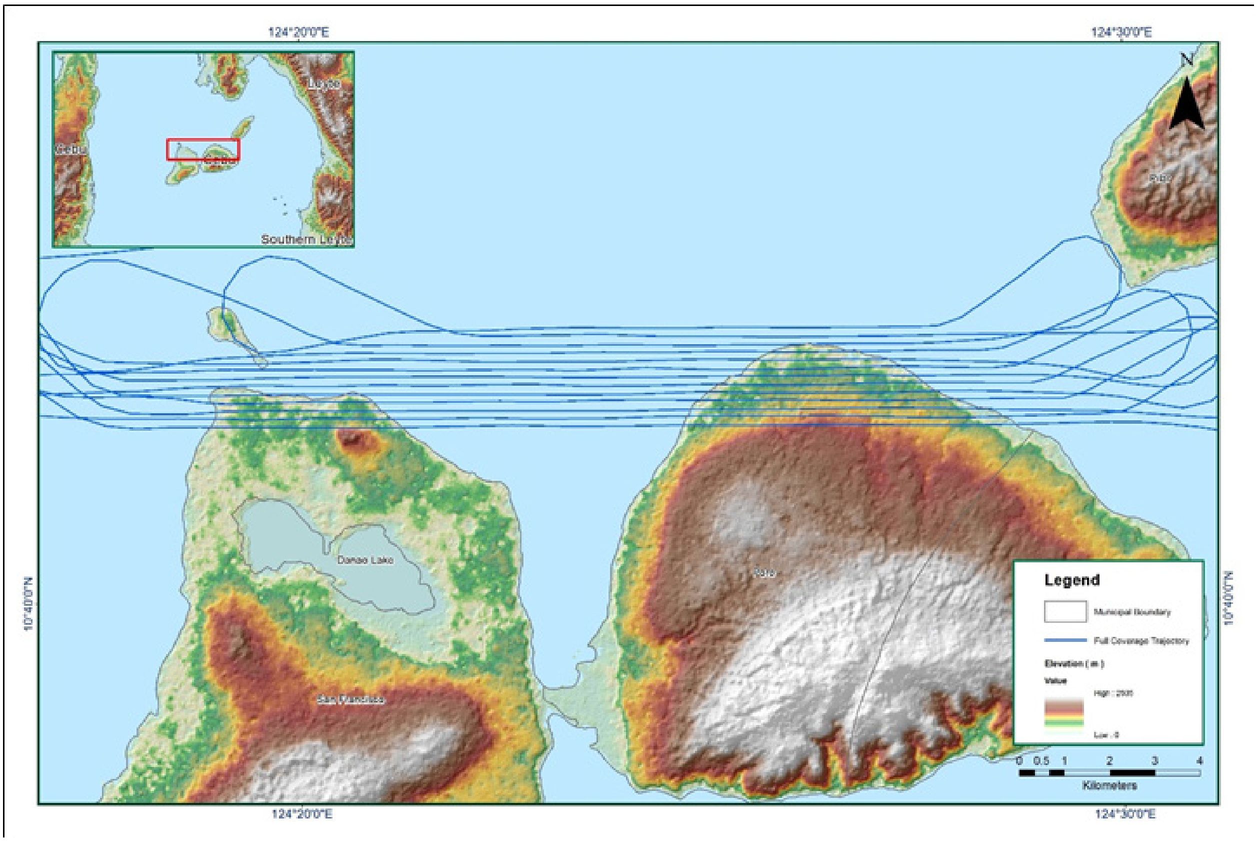

Figure A-8.38. Best Estimated Trajectory

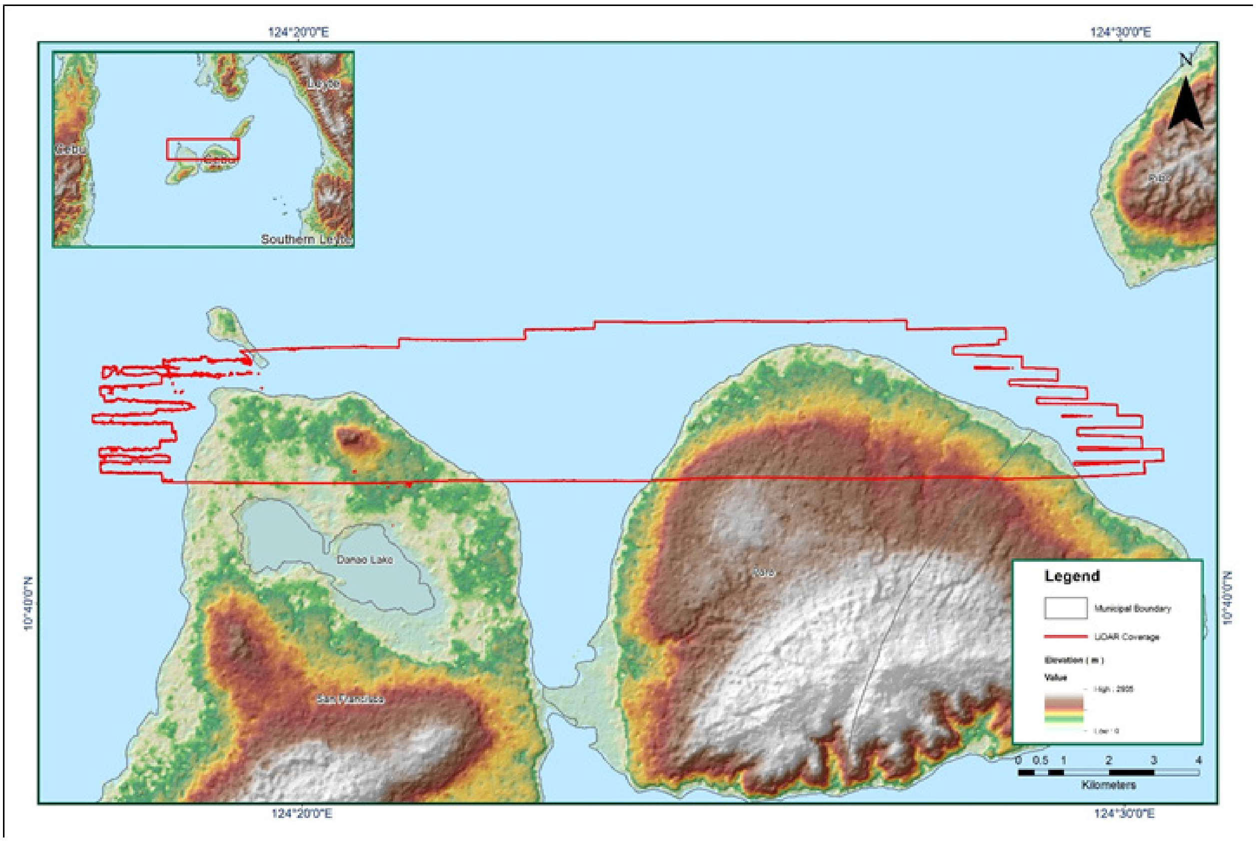

Figure A-8.39. Coverage of LiDAR data

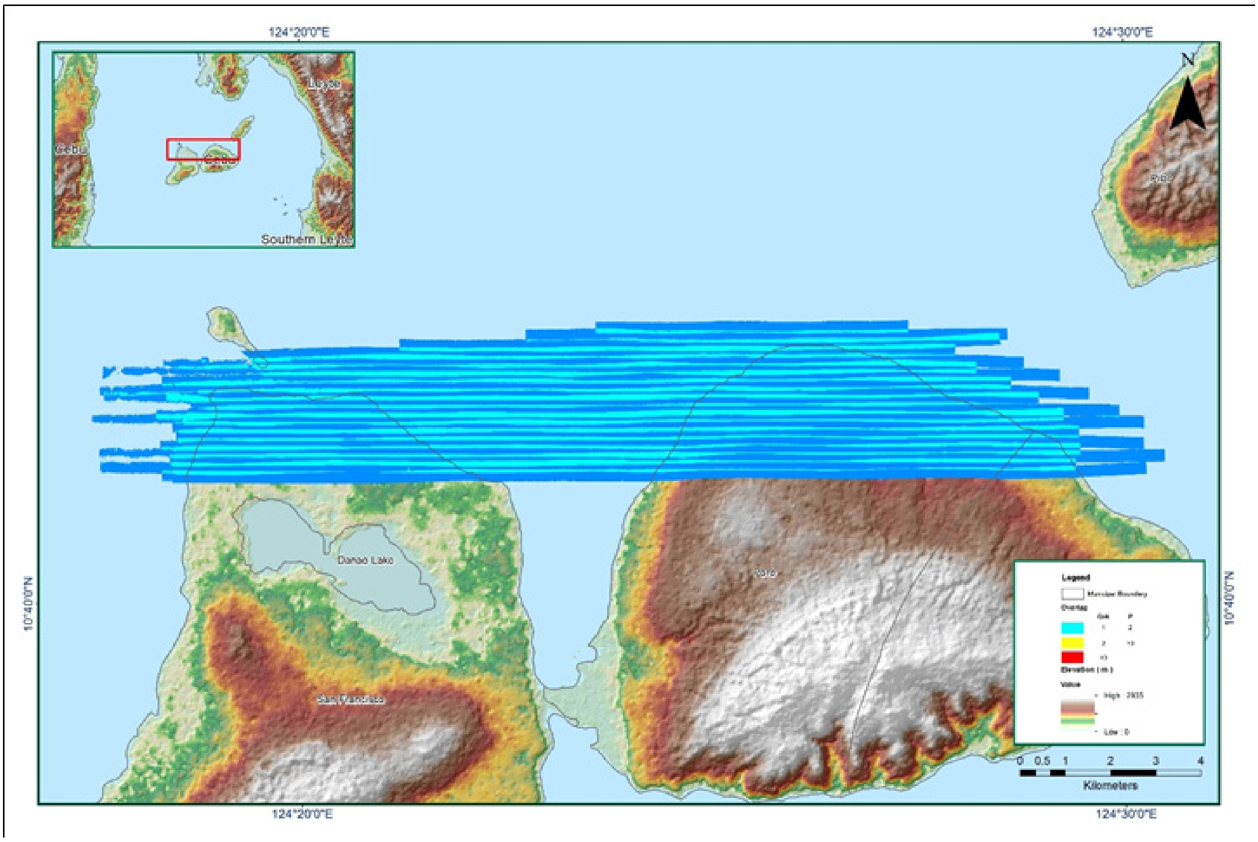

Figure A-8.40. Image of Data Overlap

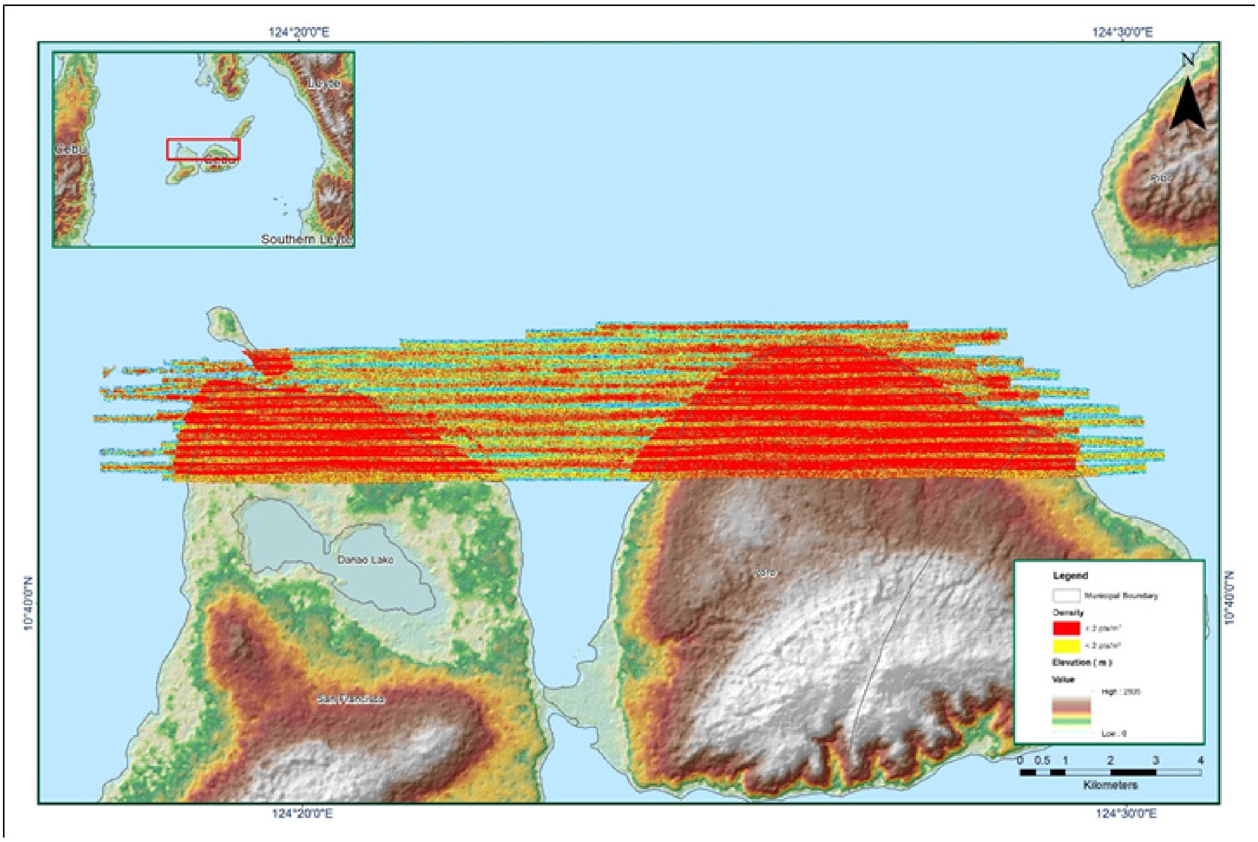

Figure A-8.41. Density map of merged LiDAR data

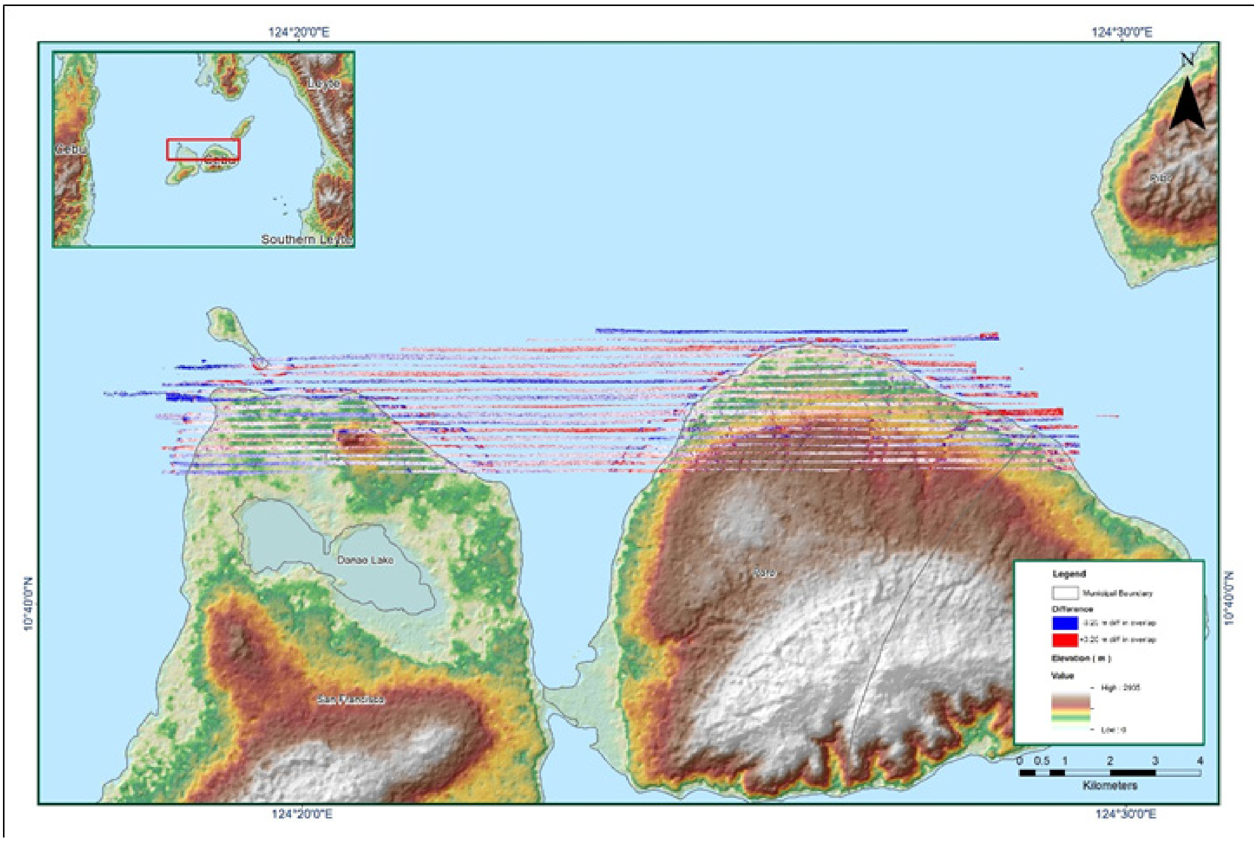

Figure A-8.42. Elevation difference between flight lines

Table A-8.7. Mission Summary Report for Mission Blk48A_additional

Flight Area	**Ormoc Camotes**
Mission Name	Blk48A_additional
Inclusive Flights	8405AC
Range data size	8.62 GB
POS data size	251 MB
Base data size	218 MB
Image	55.1 GB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.088
RMSE for East Position (<4.0 cm)	1.592
RMSE for Down Position (<8.0 cm)	4.825
Boresight correction stdev (<0.001deg)	0.001231
IMU attitude correction stdev (<0.001deg)	0.000954
GPS position stdev (<0.01m)	0.0023
Minimum % overlap (>25)	33.85
Ave point cloud density per sq.m. (>2.0)	4.31
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	13
Maximum Height	252.51
Minimum Height	53.29
Classification (# of points)	
Ground	4,333,619
Low vegetation	2,534,529
Medium vegetation	3,198,080
High vegetation	3,053,213
Building	81,556
Orthophoto	None
Processed by	Engr. Don Matthew Banatin, Engr. Harmond Santos, Engr. Monalyne Rabino

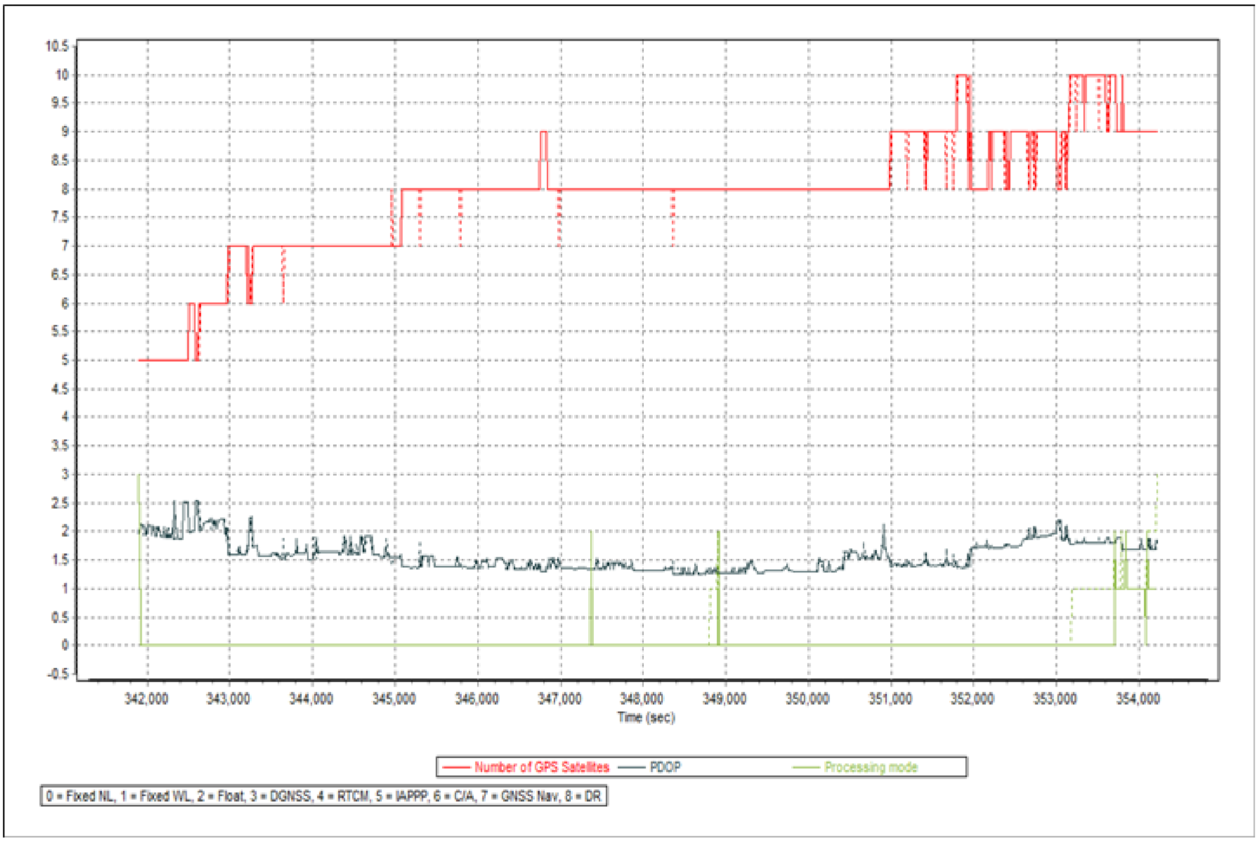

Figure A-8.43. Solution Status

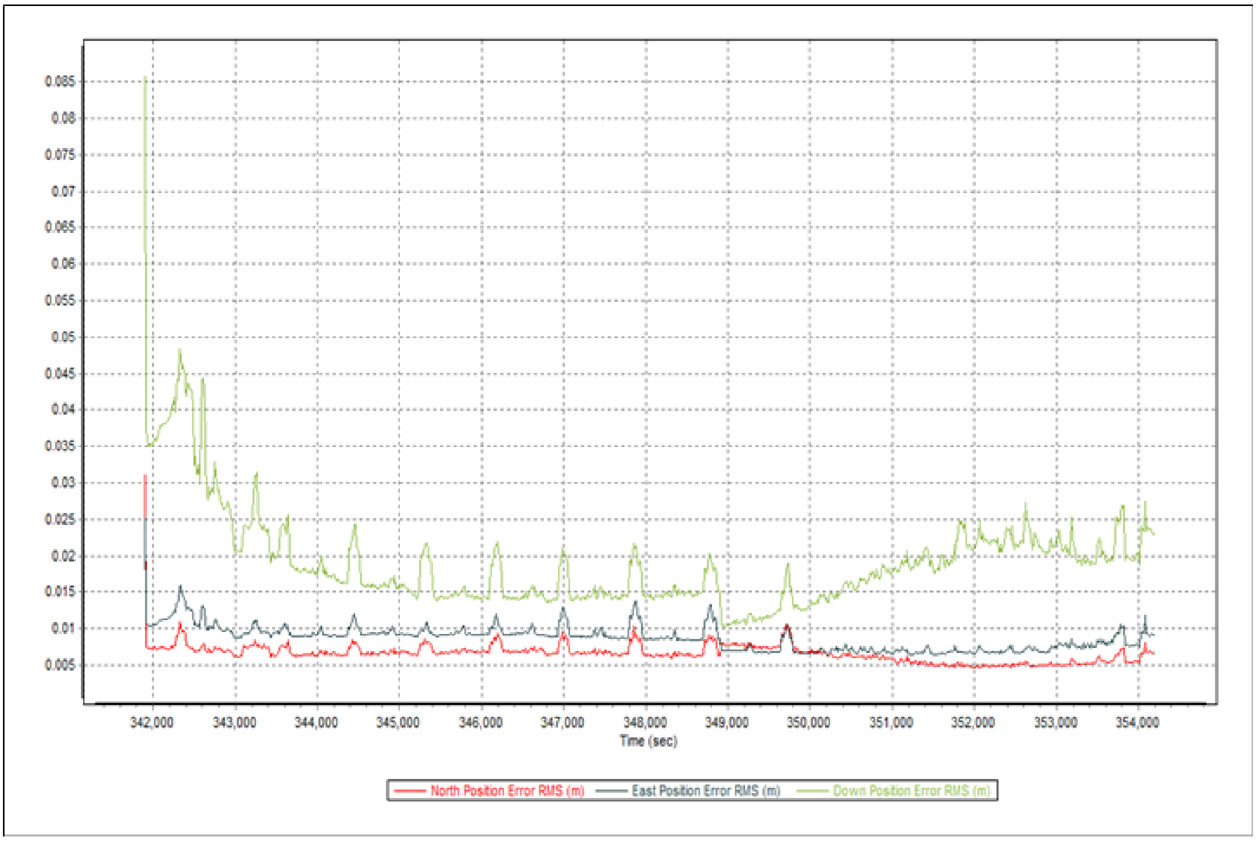

Figure A-8.44. Smoothed Performance Metric Parameters

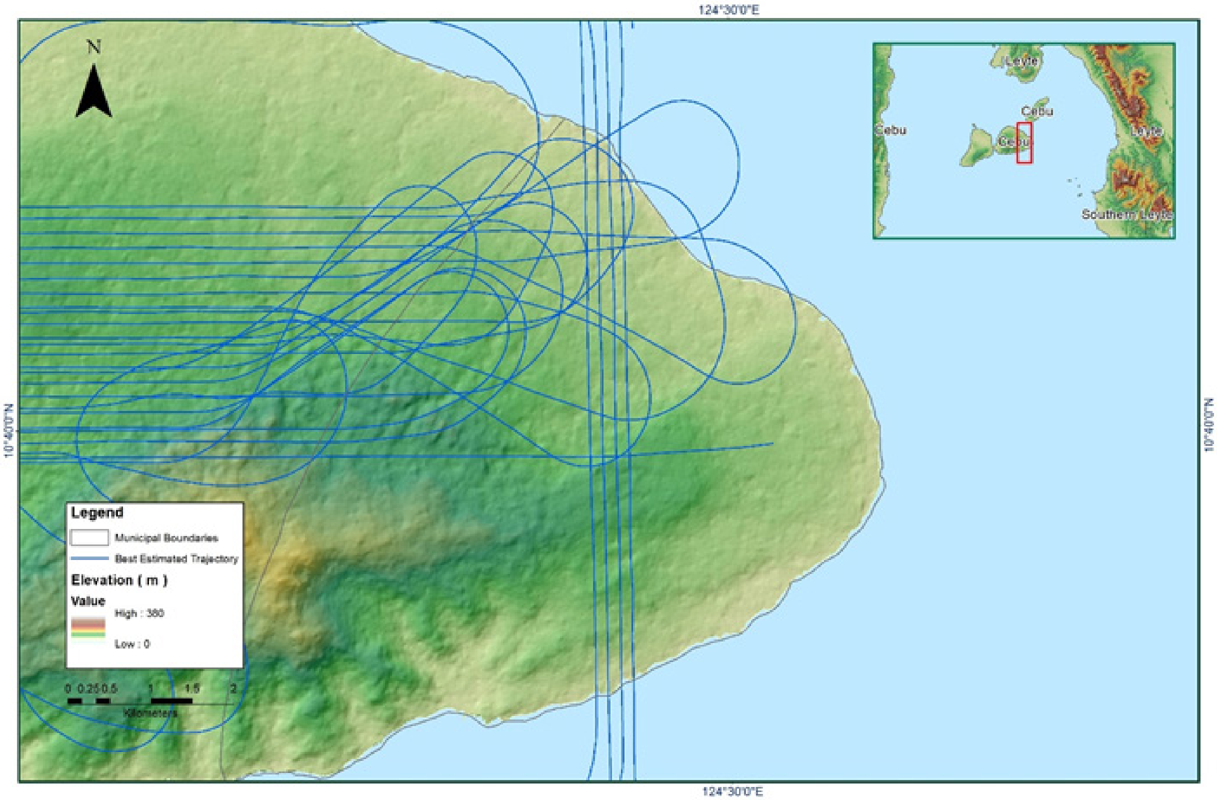

Figure A-8.45. Best Estimated Trajectory

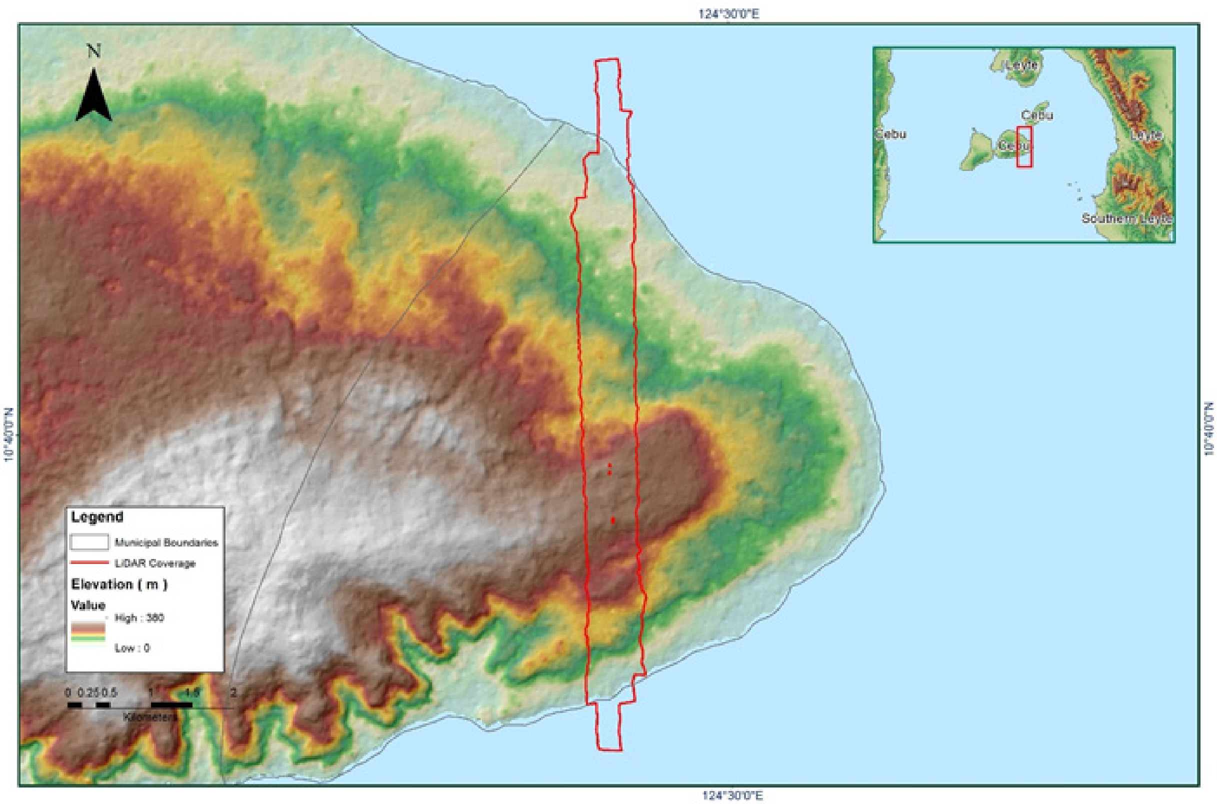

Figure A-8.46. Coverage of LiDAR data

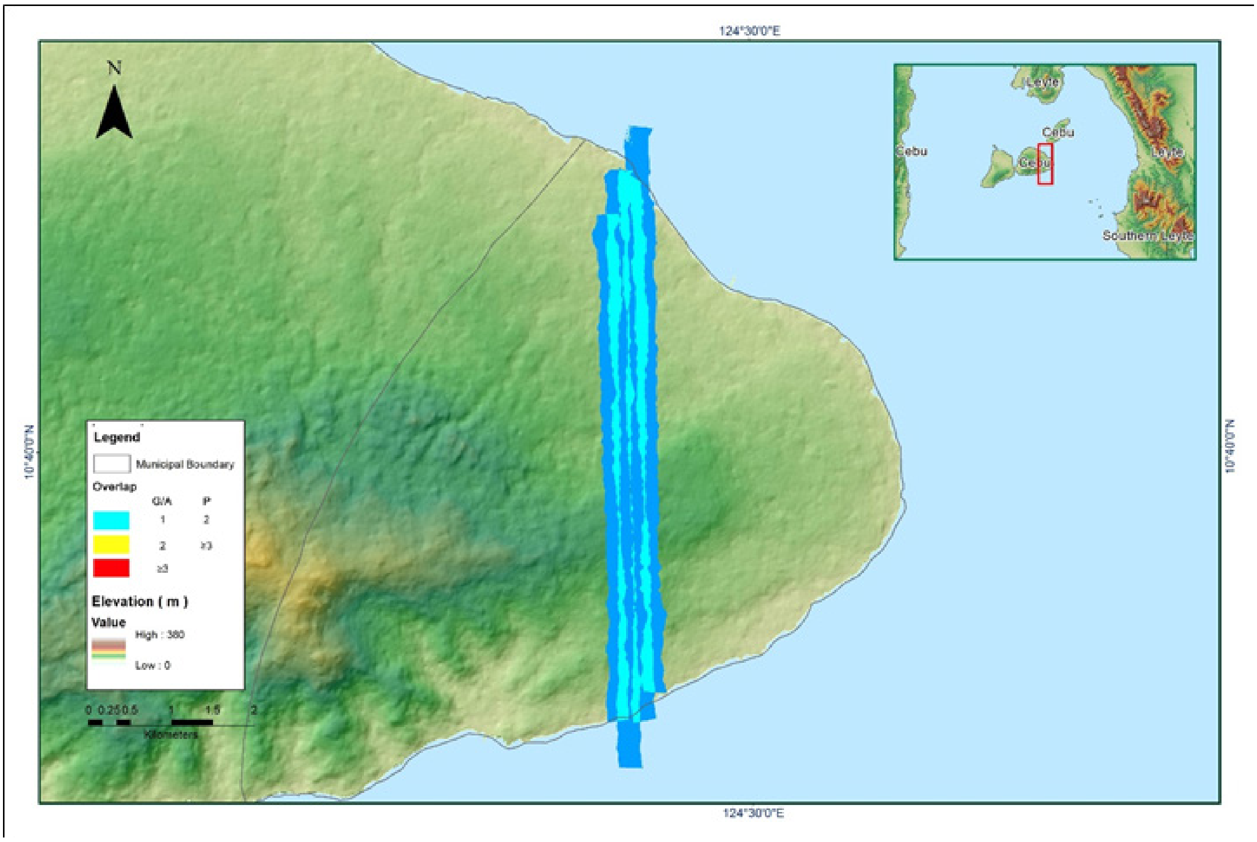

Figure A-8.47. Image of Data Overlap

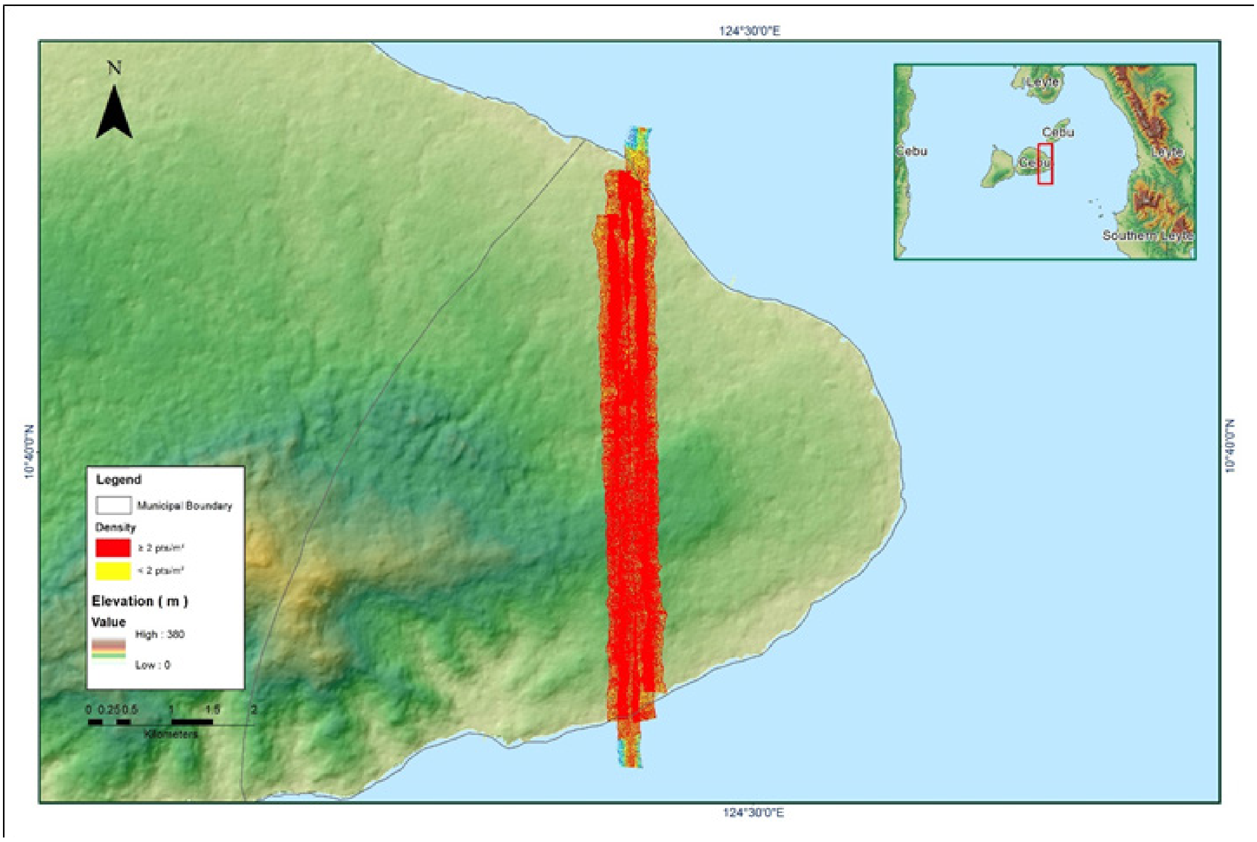

Figure A-8.48. Density map of merged LiDAR data

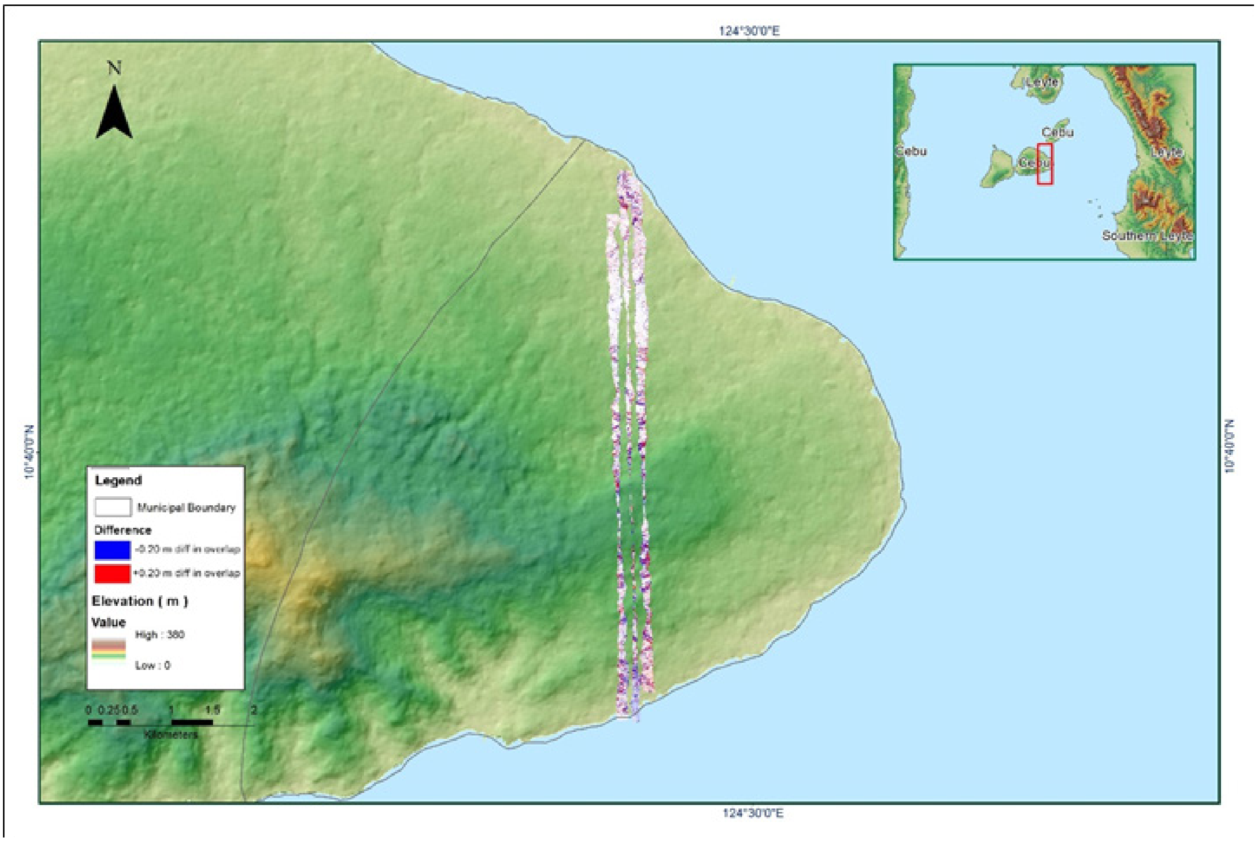

Figure A-8.49. Elevation difference between flight lines

Table A-8.8. Mission Summary Report for Mission Blk48A_Supplement

Flight Area	Ormoc_Camotes
Mission Name	Blk48A_Supplement
Inclusive Flights	8406AC/8407AC
Range data size	14.57 GB
POS	492 MB
Image	78.1 MB
Base Station	427 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.92
RMSE for East Position (<4.0 cm)	1.22
RMSE for Down Position (<8.0 cm)	1.94
Boresight correction stdev (<0.001deg)	N/A
IMU attitude correction stdev (<0.001deg)	N/A
GPS position stdev (<0.01m)	N/A
Minimum % overlap (>25)	27.35
Ave point cloud density per sq.m. (>2.0)	1.65
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	32
Maximum Height	108.04
Minimum Height	52.5
Classification (# of points)	
Ground	6,320,732
Low vegetation	4,815,354
Medium vegetation	2,599,141
High vegetation	1,137,452
Building	114,304
Orthophoto	None
Processed by	Engr. Don Matthew Bantin, Aljon Rie Araneta, Jovy Narisma

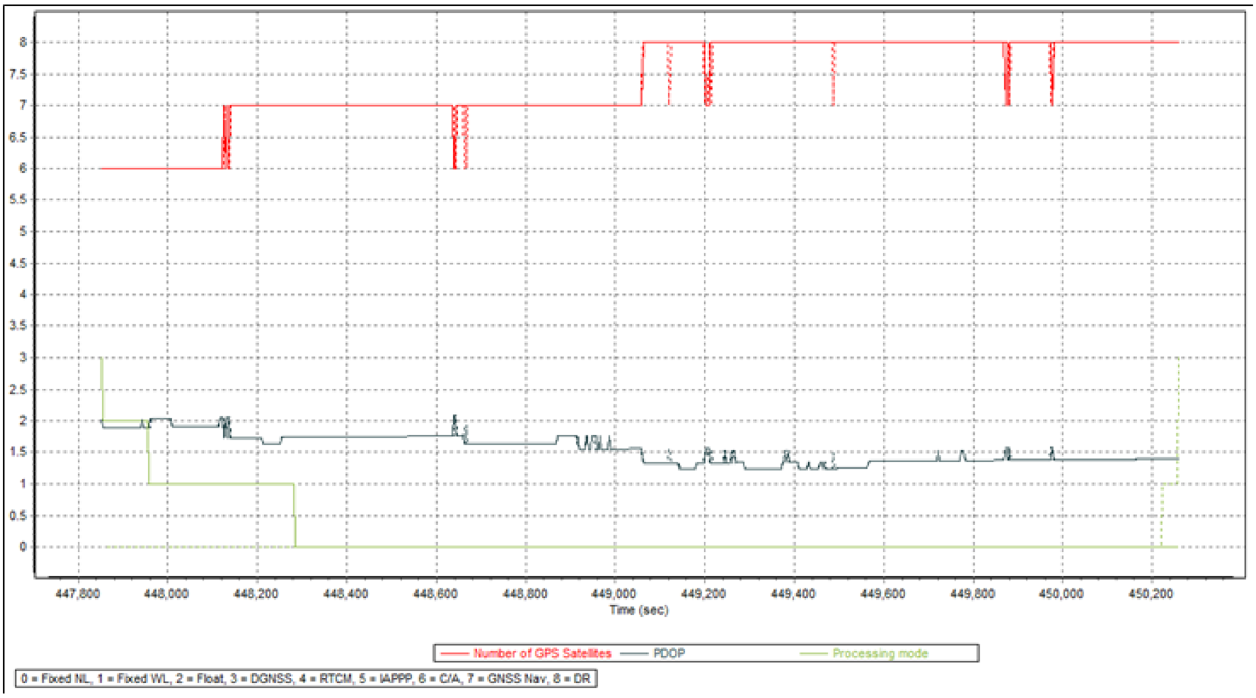

Figure A-8.50. Solution Status

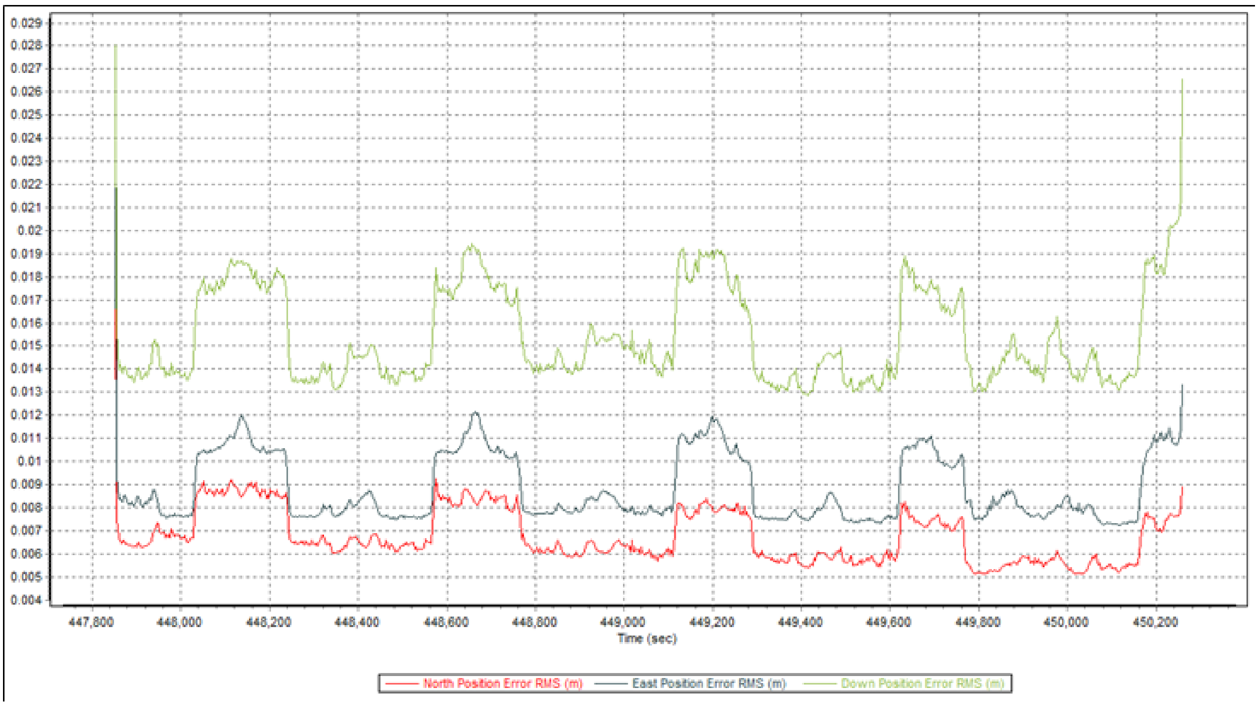

Figure A-8.51. Smoothed Performance Metric Parameters

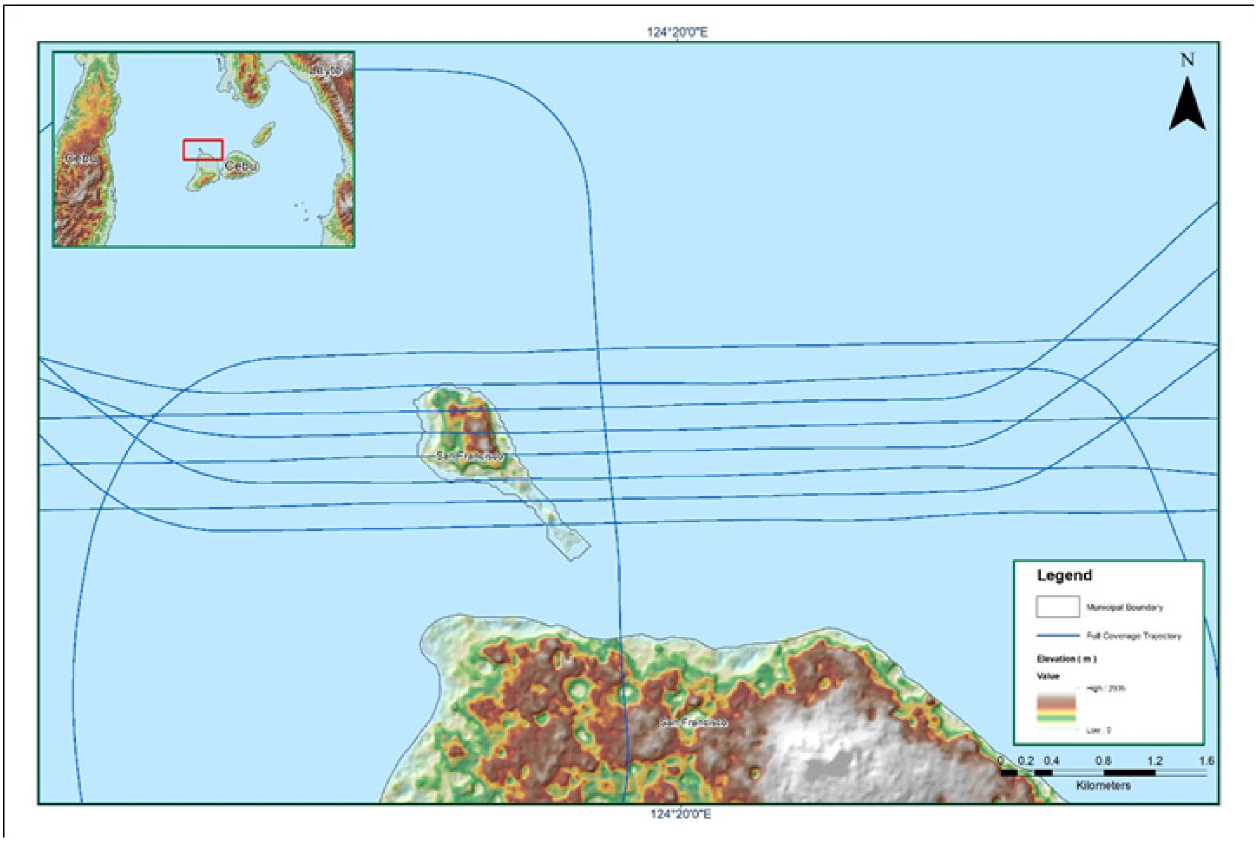

Figure A-8.52. Best Estimated Trajectory

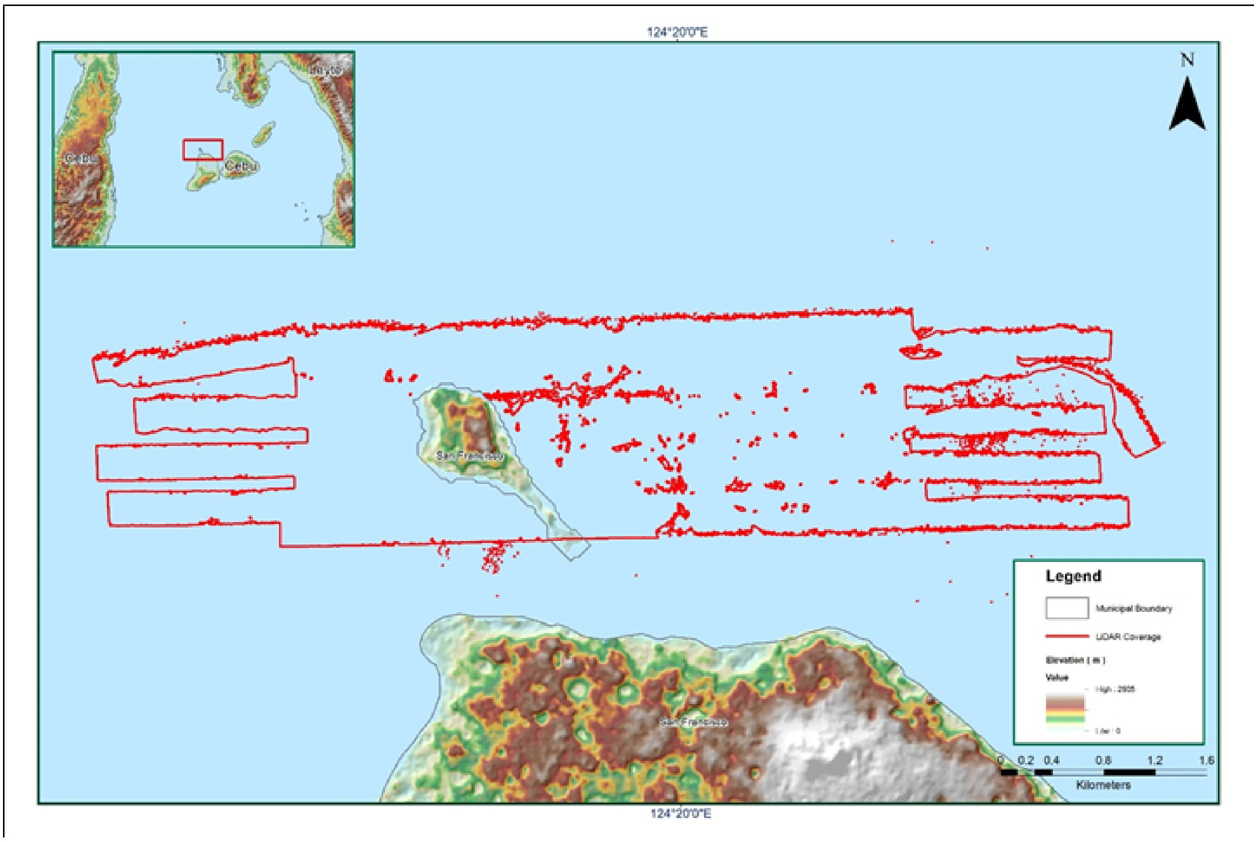

Figure A-8.53. Coverage of LiDAR data

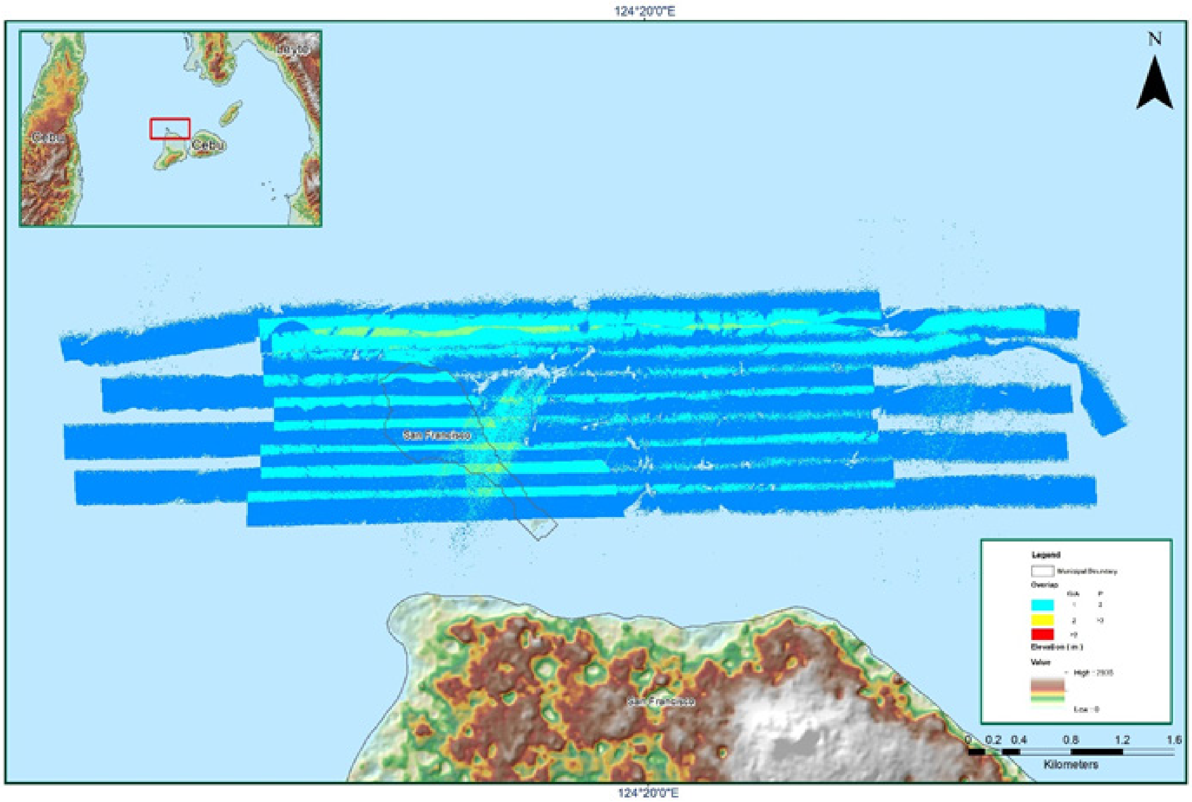

Figure A-8.54. Image of Data Overlap

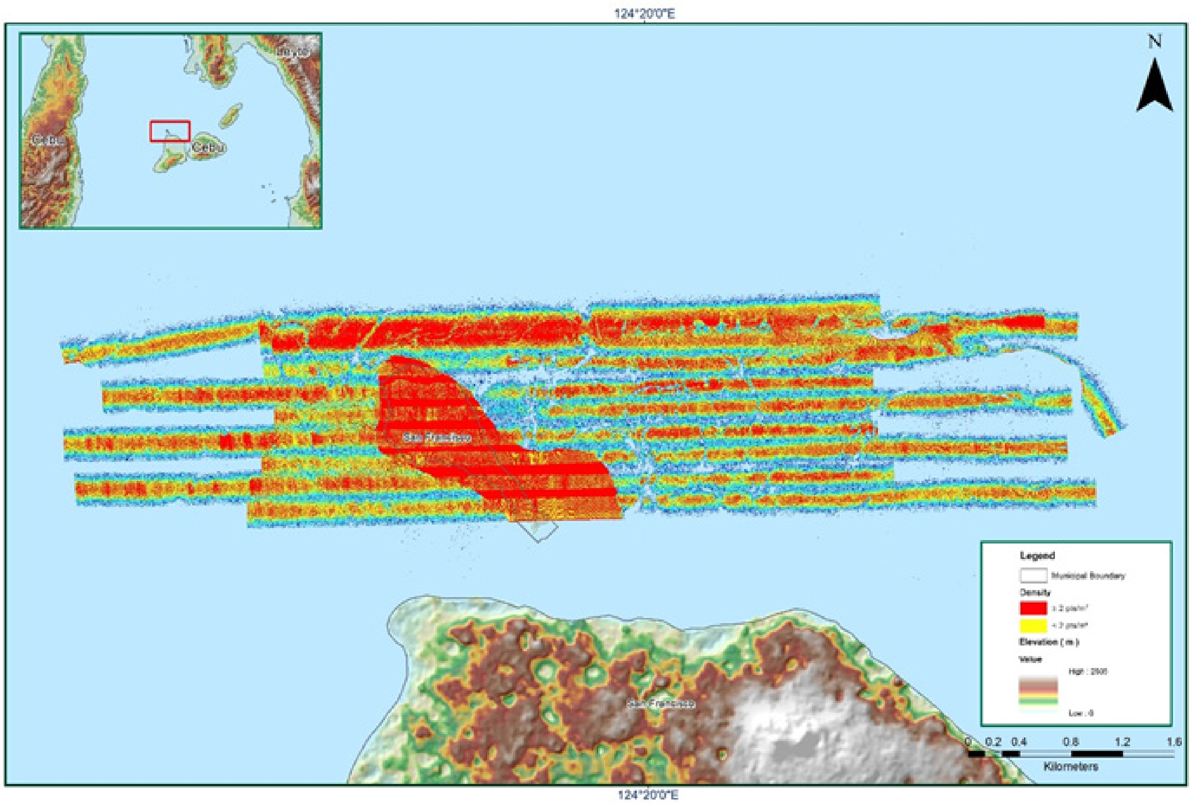

Figure A-8.55. Density map of merged LiDAR data

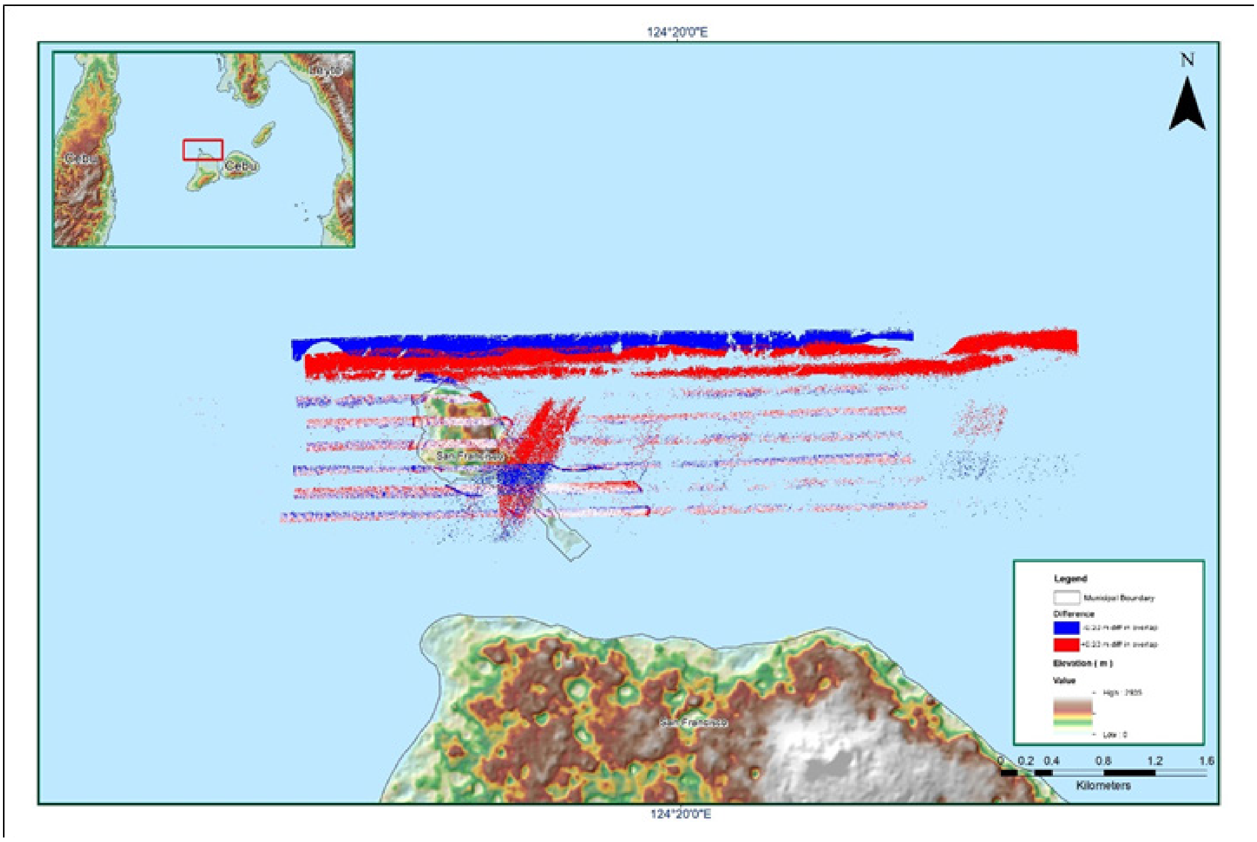

Figure A-8.56. Elevation difference between flight lines

Table A-8.9. Mission Summary Report for Mission Blk48B

Flight Area	Ormoc_Camotes
Mission Name	Blk48B
Inclusive Flights	8405AC/8407AC
Range data size	15.52 GB
POS	486 MB
Image	92.9 MB
Base Station	427 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.78
RMSE for East Position (<4.0 cm)	1.05
RMSE for Down Position (<8.0 cm)	1.37
Boresight correction stdev (<0.001deg)	N/A
IMU attitude correction stdev (<0.001deg)	N/A
GPS position stdev (<0.01m)	N/A
Minimum % overlap (>25)	48.19
Ave point cloud density per sq.m. (>2.0)	3.99
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	92
Maximum Height	344.6
Minimum Height	50.12
Classification (# of points)	
Ground	54,463,477
Low vegetation	38,014,766
Medium vegetation	35,147,634
High vegetation	51,984,004
Building	1,526,042
Orthophoto	None
Processed by	Engr. Don Matthew Banatin, Engr. Abigail Ching, Engr. Velina Angela Bemida, Marie Denise Bueno

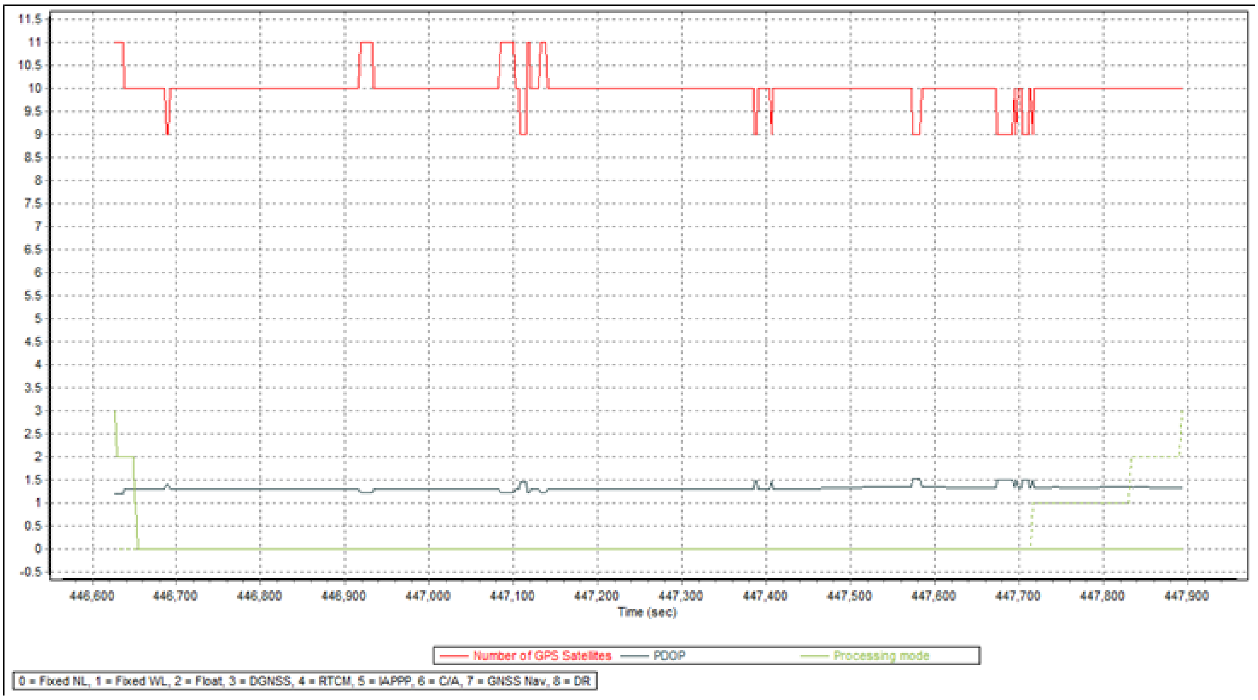

Figure A-8.57. Solution Status

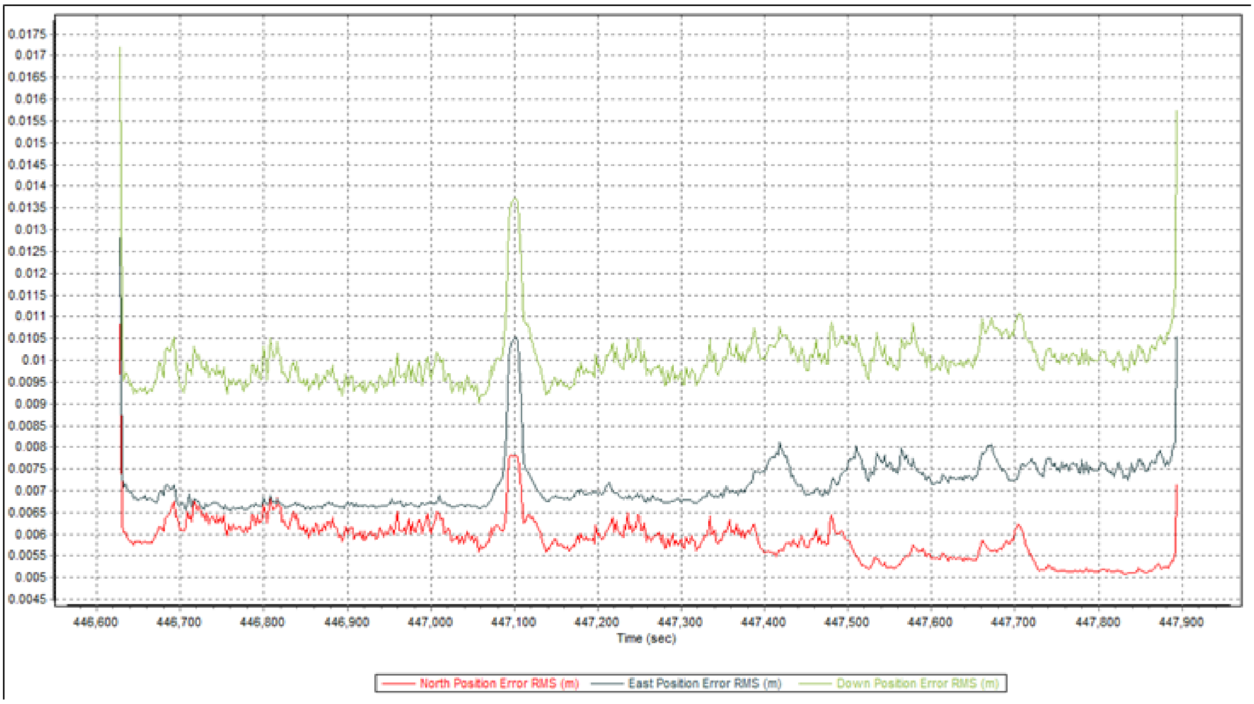

Figure A-8.58. Smoothed Performance Metric Parameters

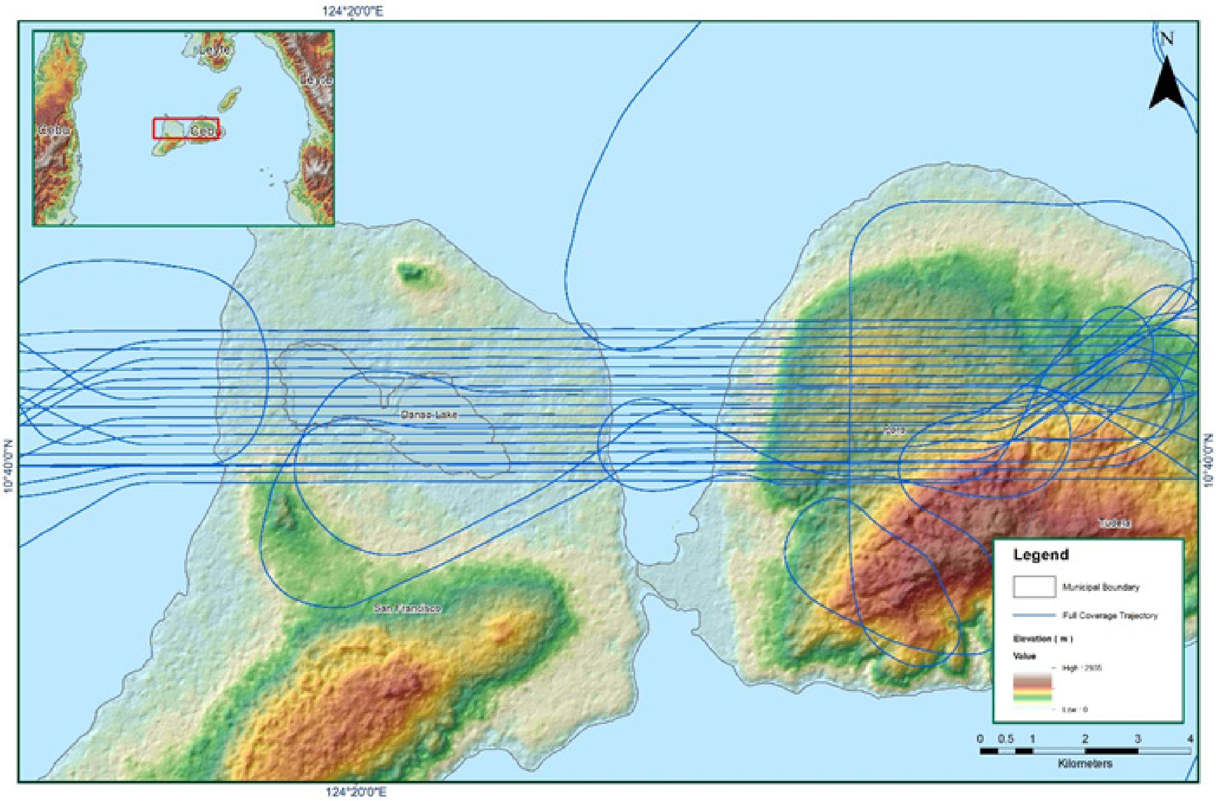

Figure A-8.59. Best Estimated Trajectory

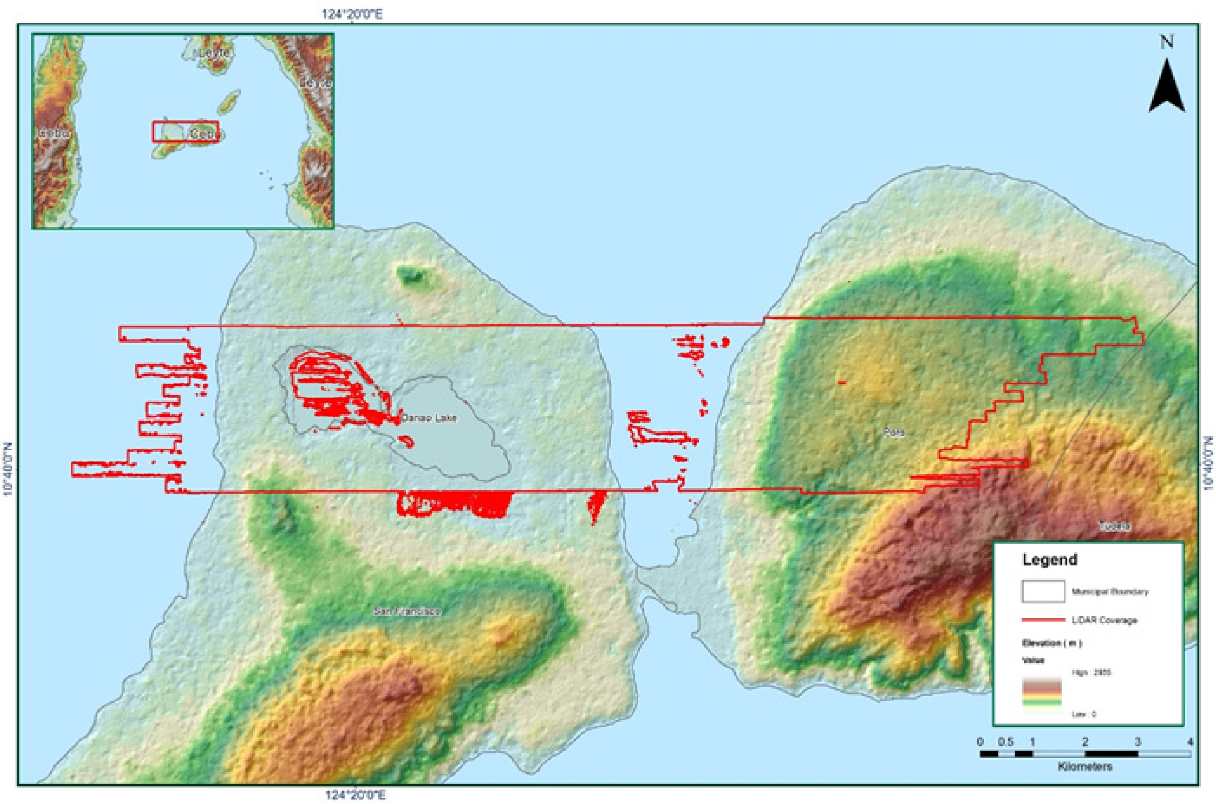

Figure A-8.60. Coverage of LiDAR data

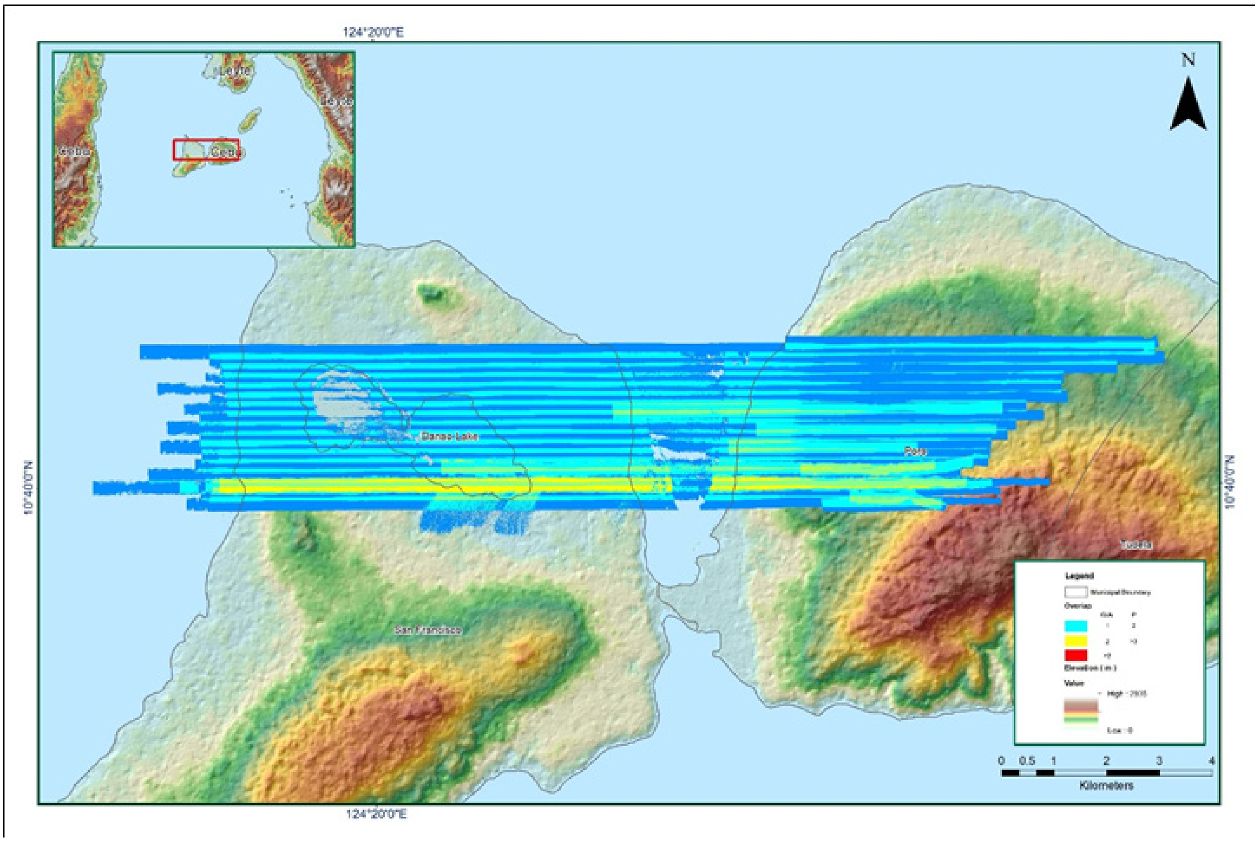

Figure A-8.61. Image of Data Overlap

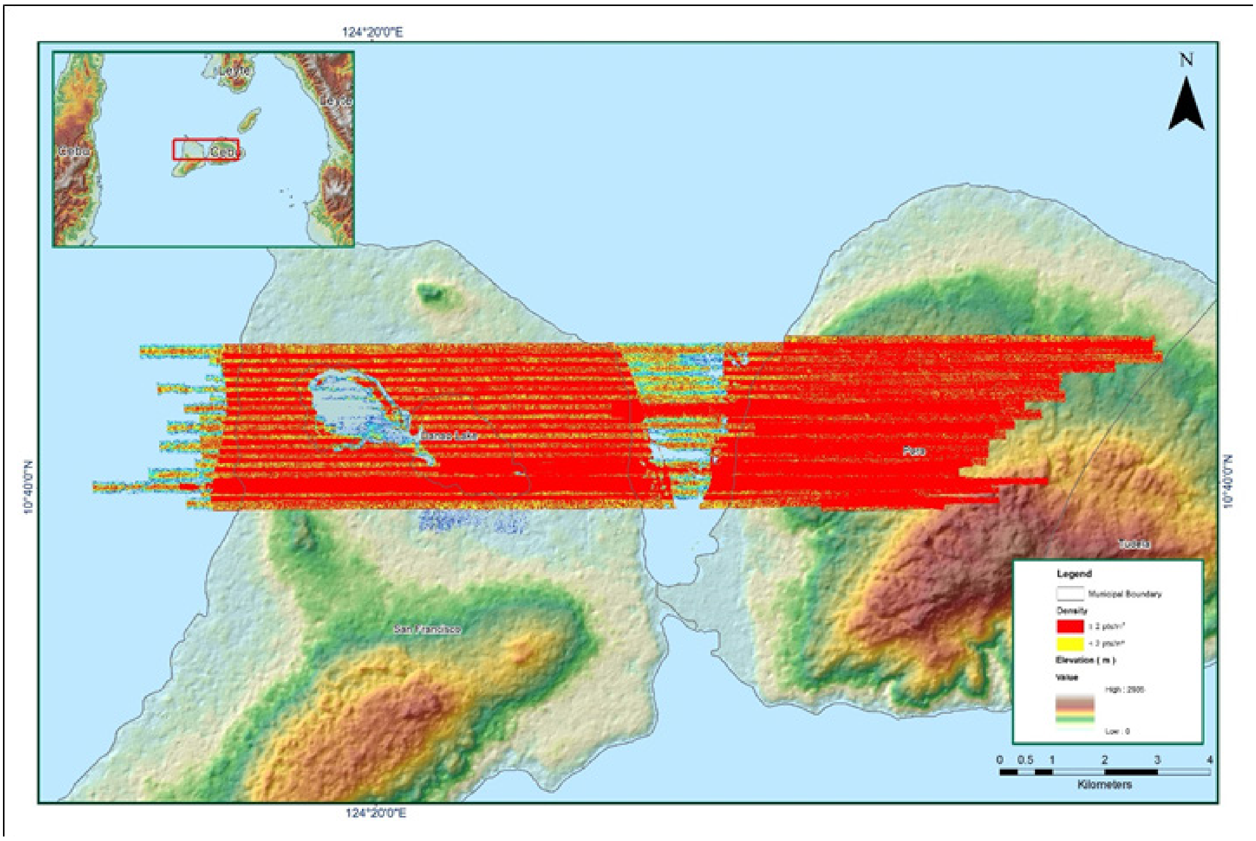

Figure A-8.62. Density map of merged LiDAR data

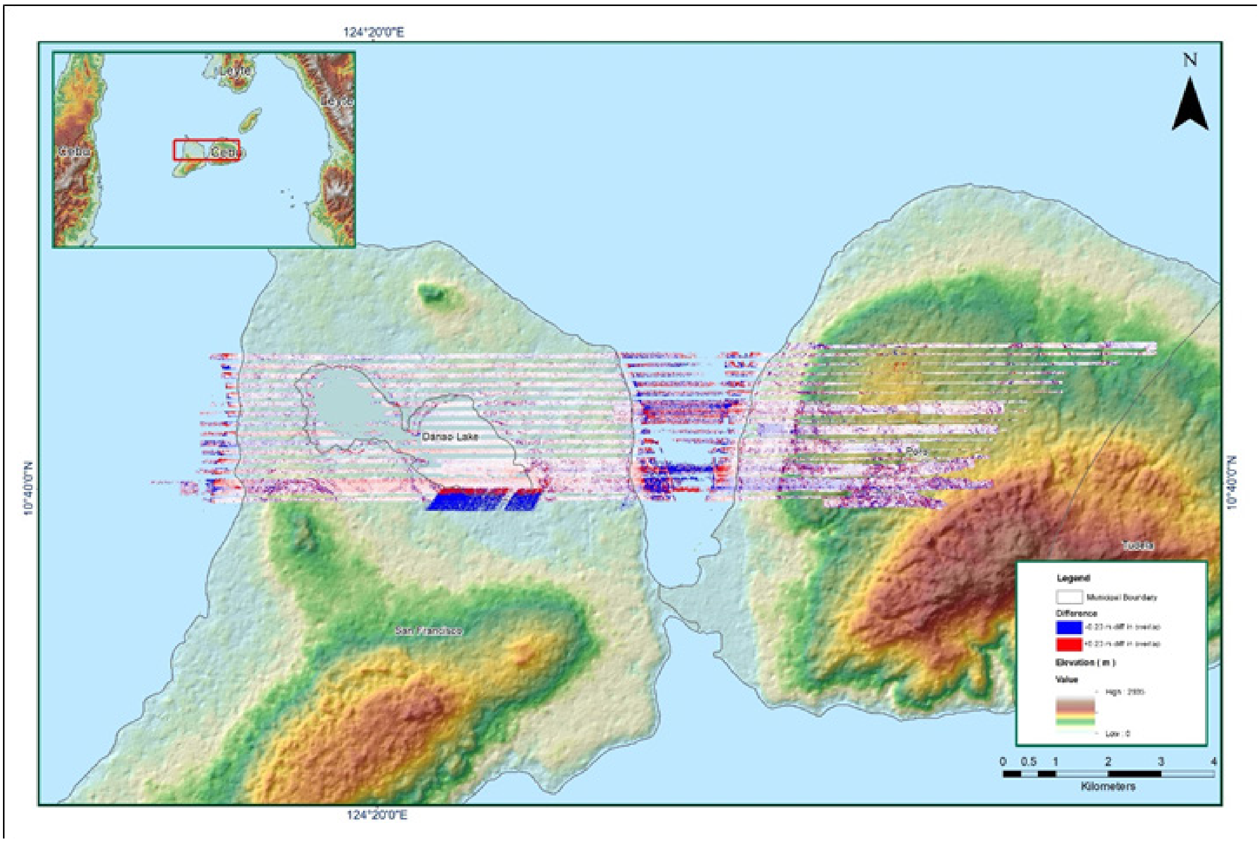

Figure A-8.63. Elevation difference between flight lines

Table A-8.10. Mission Summary Report for Mission Blk48B_additional

Flight Area	Ormoc Camotes
Mission Name	Blk48B_additional
Inclusive Flights	8404AC
Range data size	9.16 GB
POS data size	267 MB
Base data size	144 MB
Image	55.8 GB
Transfer date	April, 22, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.972
RMSE for East Position (<4.0 cm)	2.435
RMSE for Down Position (<8.0 cm)	7.121
Boresight correction stdev (<0.001deg)	0.000401
IMU attitude correction stdev (<0.001deg)	1.251499
GPS position stdev (<0.01m)	0.0255
Minimum % overlap (>25)	44.91
Ave point cloud density per sq.m. (>2.0)	4.55
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	16
Maximum Height	251.34
Minimum Height	59.18
Classification (# of points)	
Ground	3,290,193
Low vegetation	1,865,157
Medium vegetation	2,509,738
High vegetation	6,031,468
Building	71,038
Orthophoto	None
Processed by	Engr. Angelo Carlo Bongat, Engr. Harmond Santos, Wilbert Ian San Juan

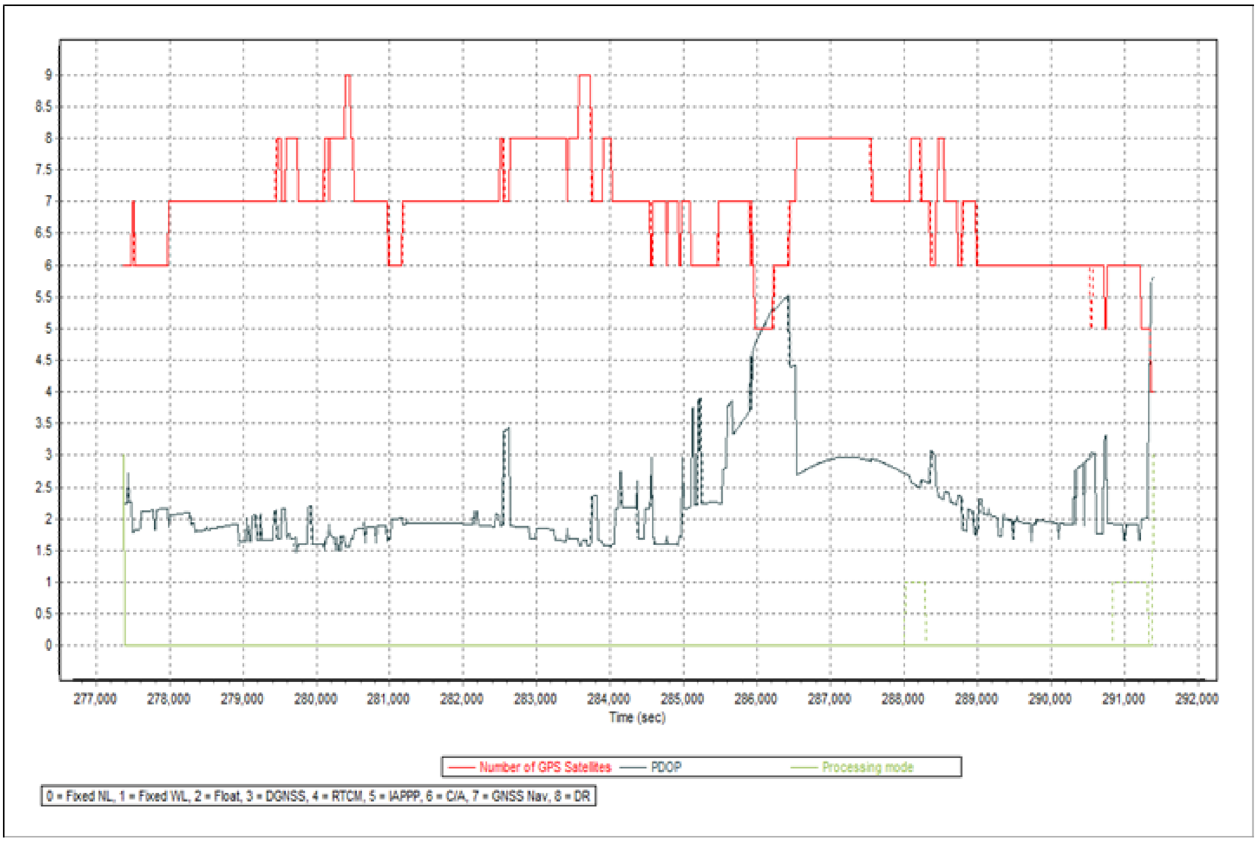

Figure A-8.64. Solution Status

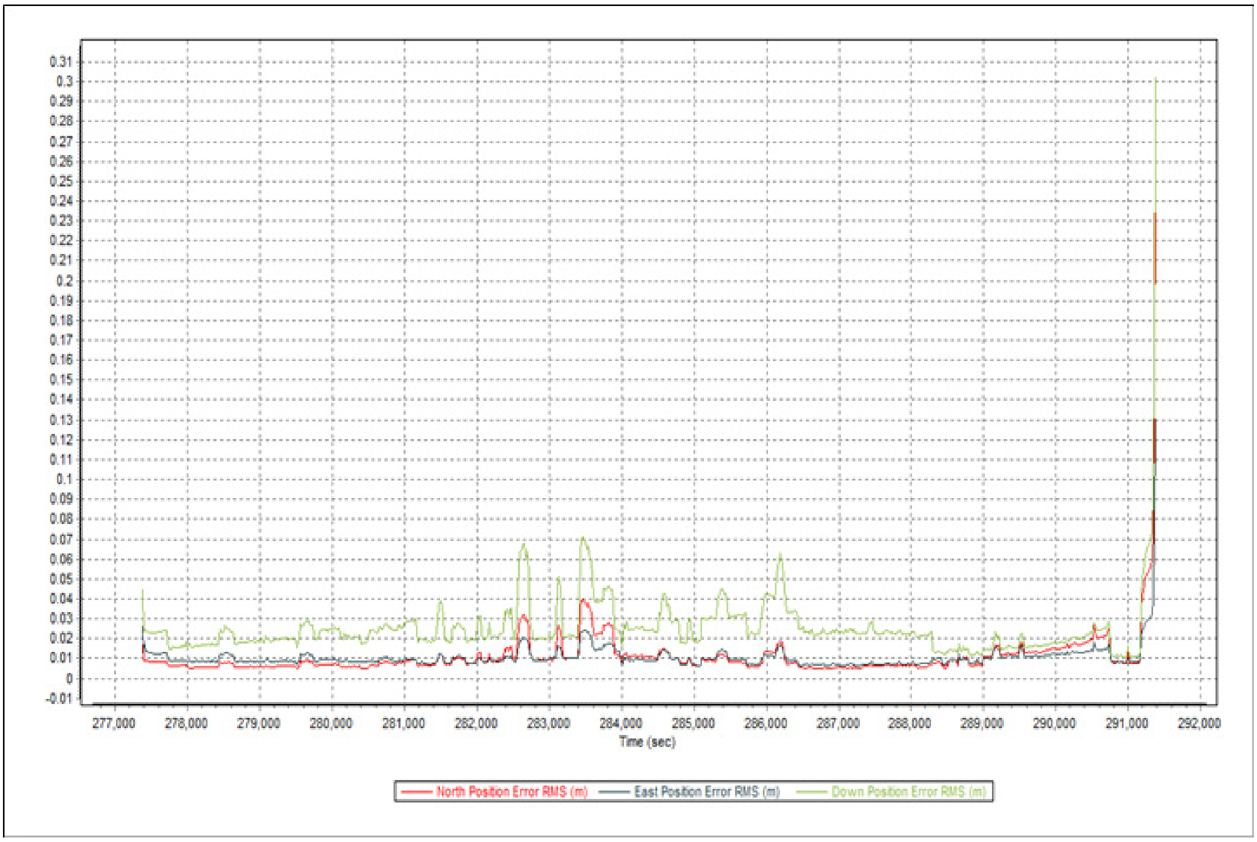

Figure A-8.65. Smoothed Performance Metric Parameters

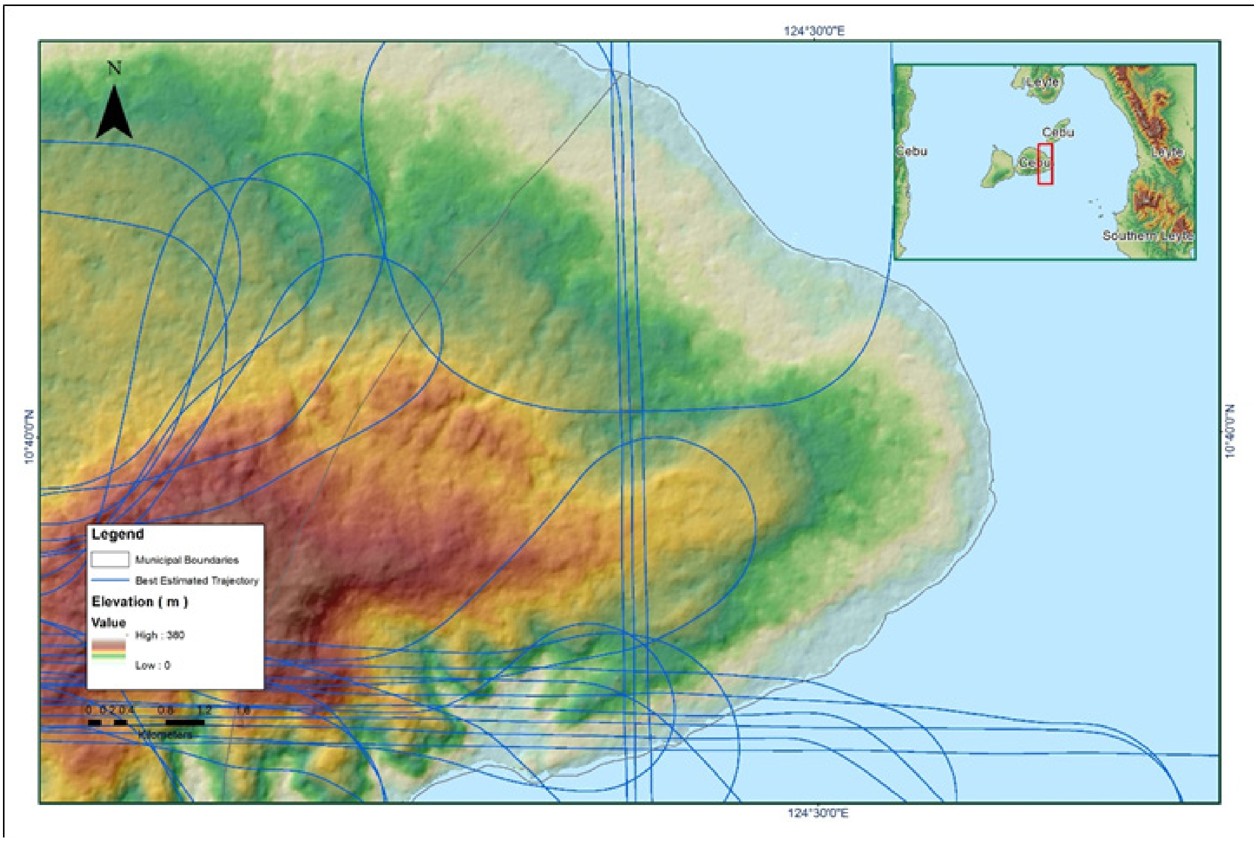

Figure A-8.66. Best Estimated Trajectory

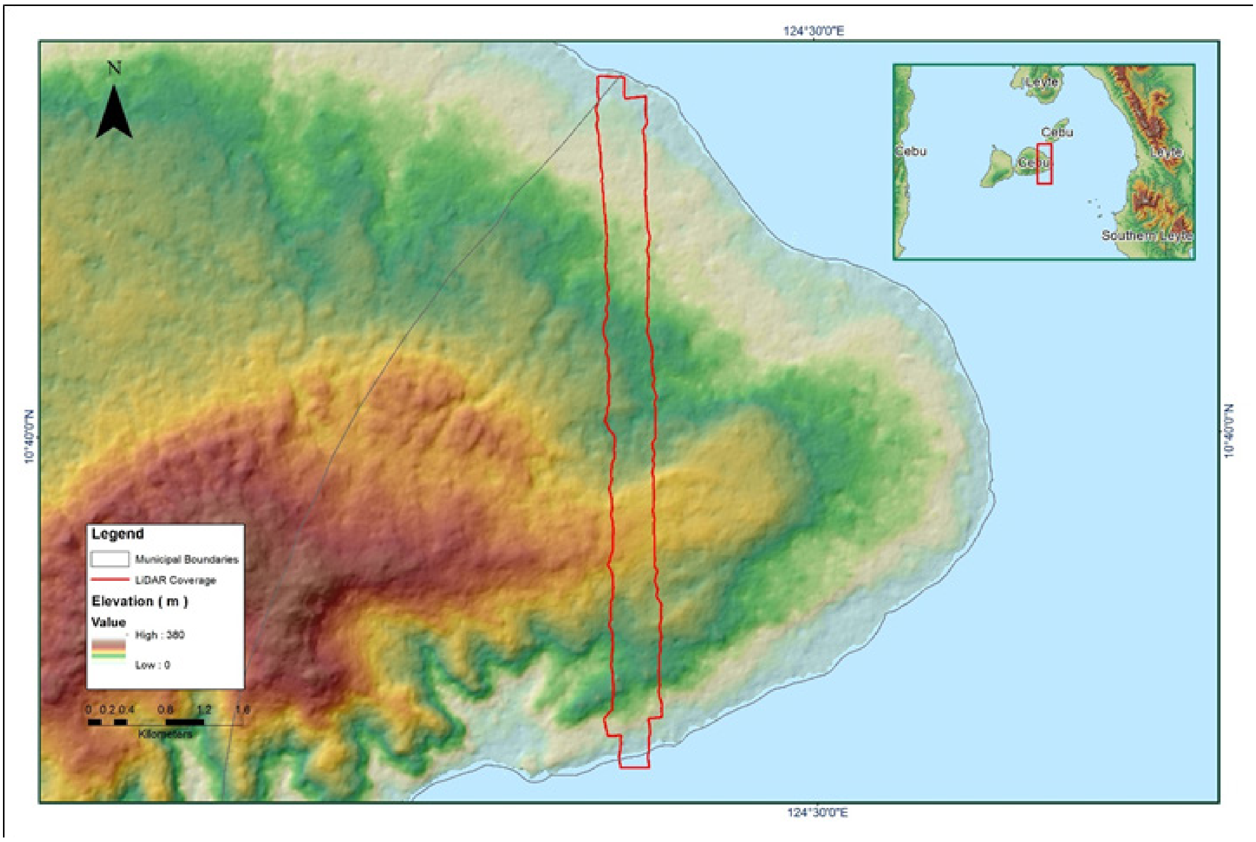

Figure A-8.67. Coverage of LiDAR data

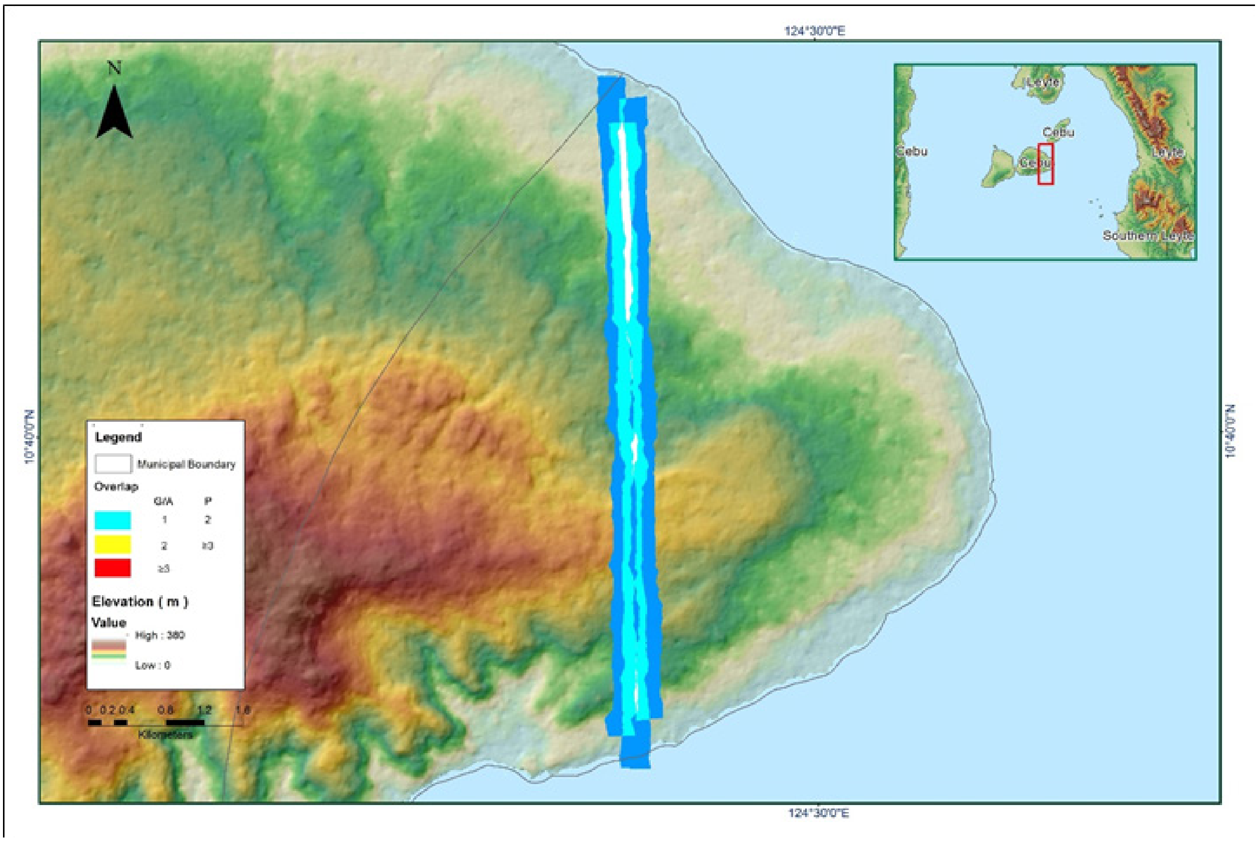

Figure A-8.68. Image of Data Overlap

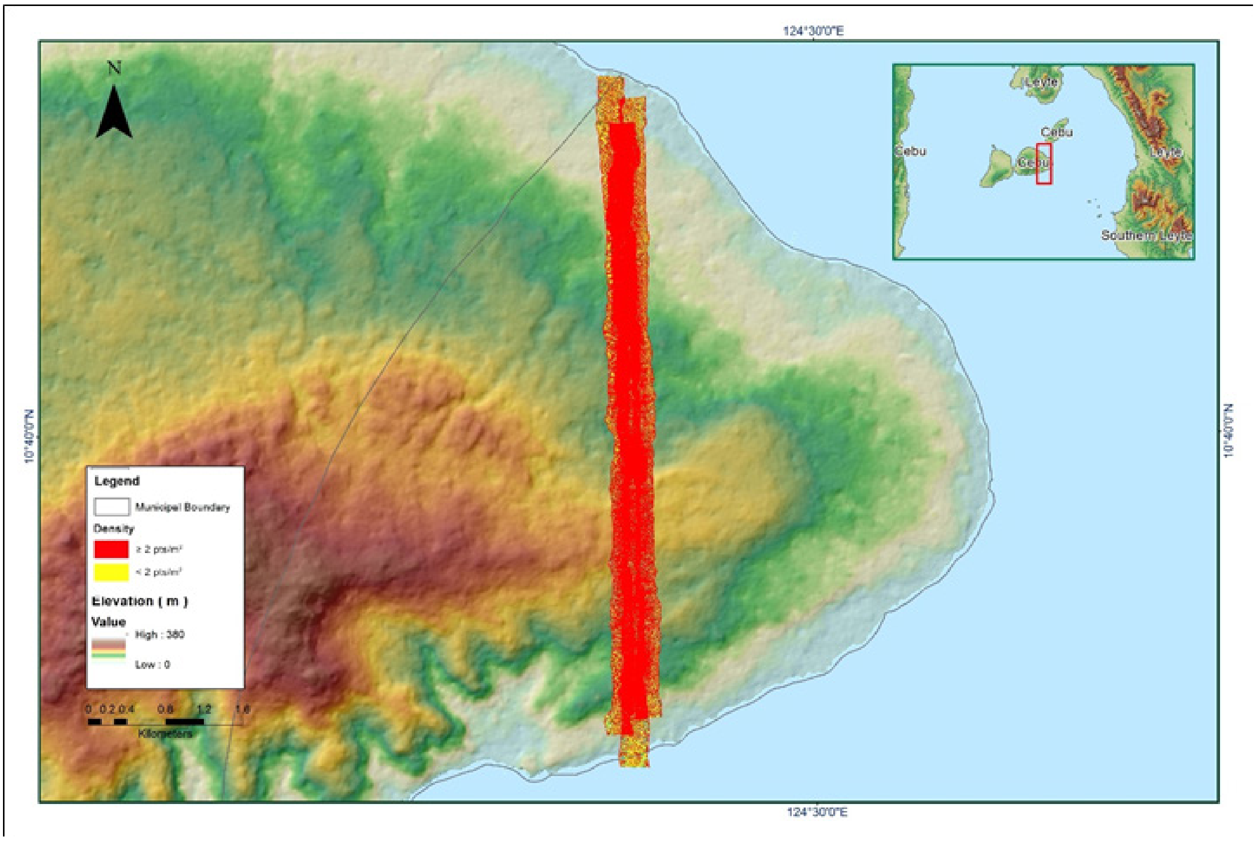

Figure A-8.69. Density map of merged LiDAR data

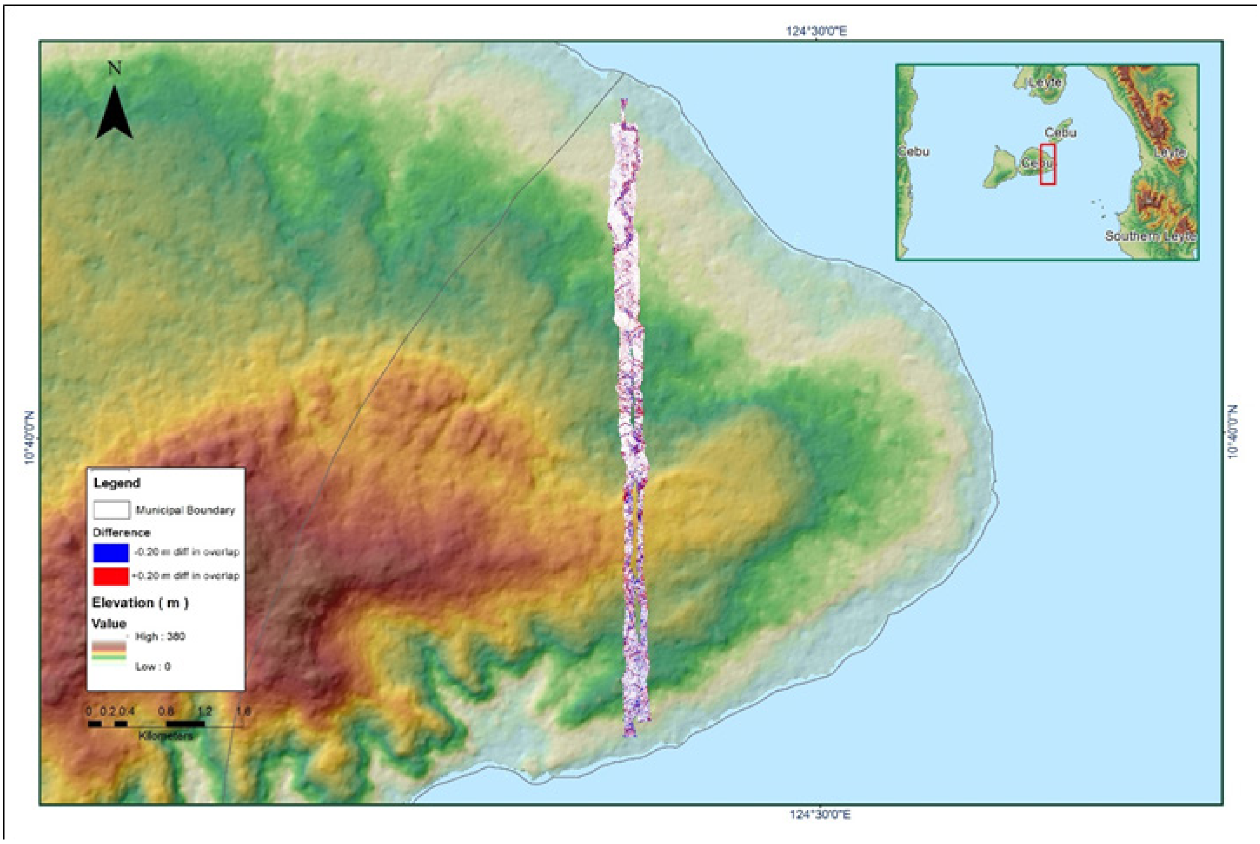

Figure A-8.70. Elevation difference between flight lines

Table A-8.11. Mission Summary Report for Mission Blk48B_Supplement

Flight Area	Ormoc_Camotes
Mission Name	Blk48B_Supplement
Inclusive Flights	8406AC
Range data size	7.67 GB
POS	257 MB
Image	40.3 MB
Base Station	218 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	28.49
RMSE for East Position (<4.0 cm)	15.08
RMSE for Down Position (<8.0 cm)	38.87
Boresight correction stdev (<0.001deg)	0.000661
IMU attitude correction stdev (<0.001deg)	0.003780
GPS position stdev (<0.01m)	0.0136
Minimum % overlap (>25)	26.59
Ave point cloud density per sq.m. (>2.0)	3.05
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	48
Maximum Height	232.09
Minimum Height	46.32
Classification (# of points)	
Ground	16,543,787
Low vegetation	11,721,982
Medium vegetation	10,747,768
High vegetation	24,200,357
Building	641,731
Orthophoto	None
Processed by	Engr. Jennifer Saguran, Engr. Ma. Joanne Balaga, Engr. Melissa Fernandez

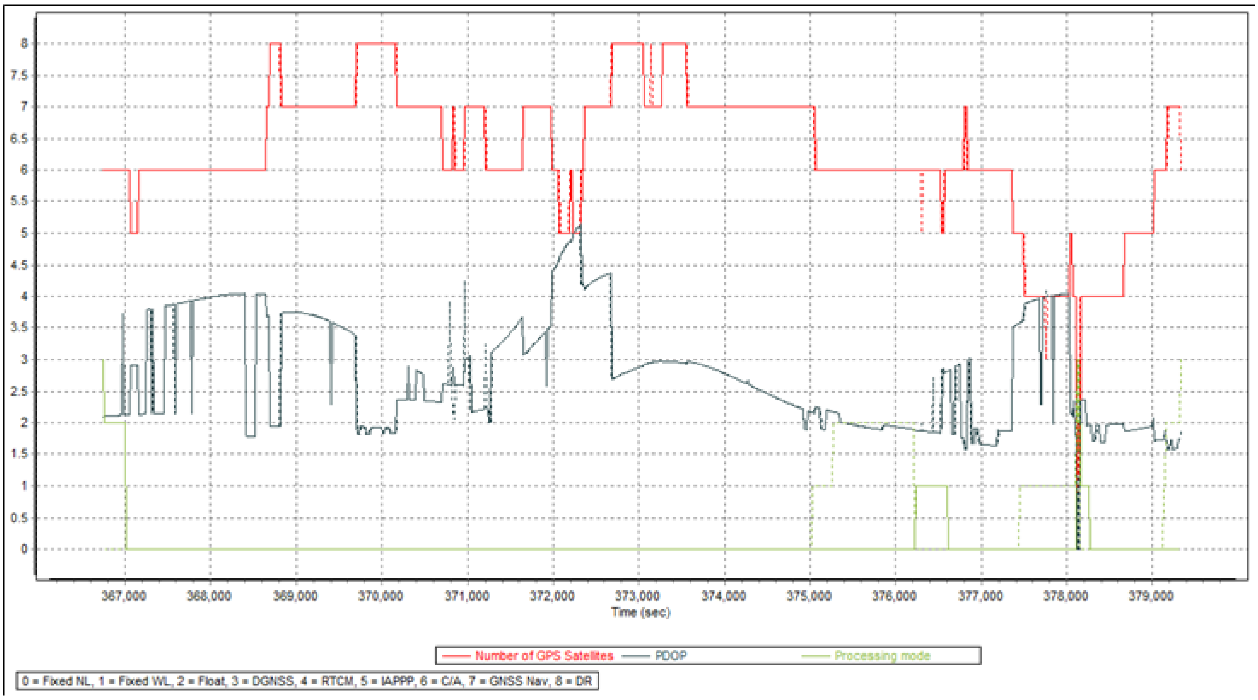

Figure A-8.71. Solution Status

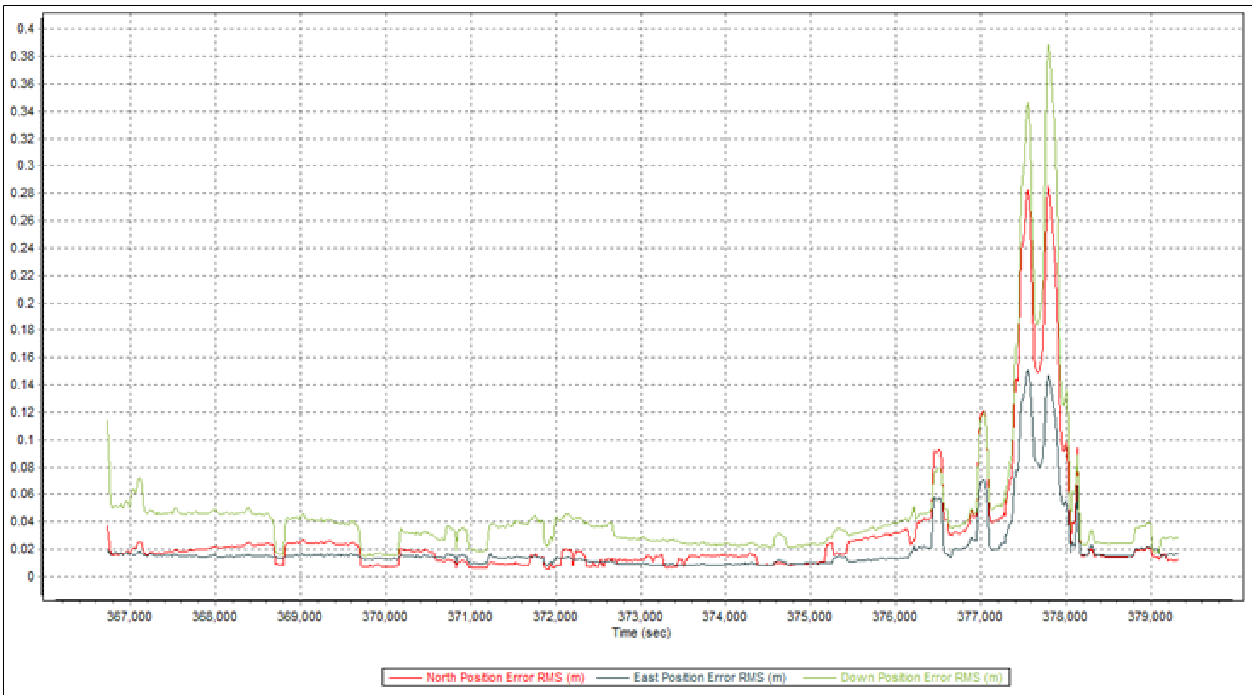

Figure A-8.72. Smoothed Performance Metric Parameters

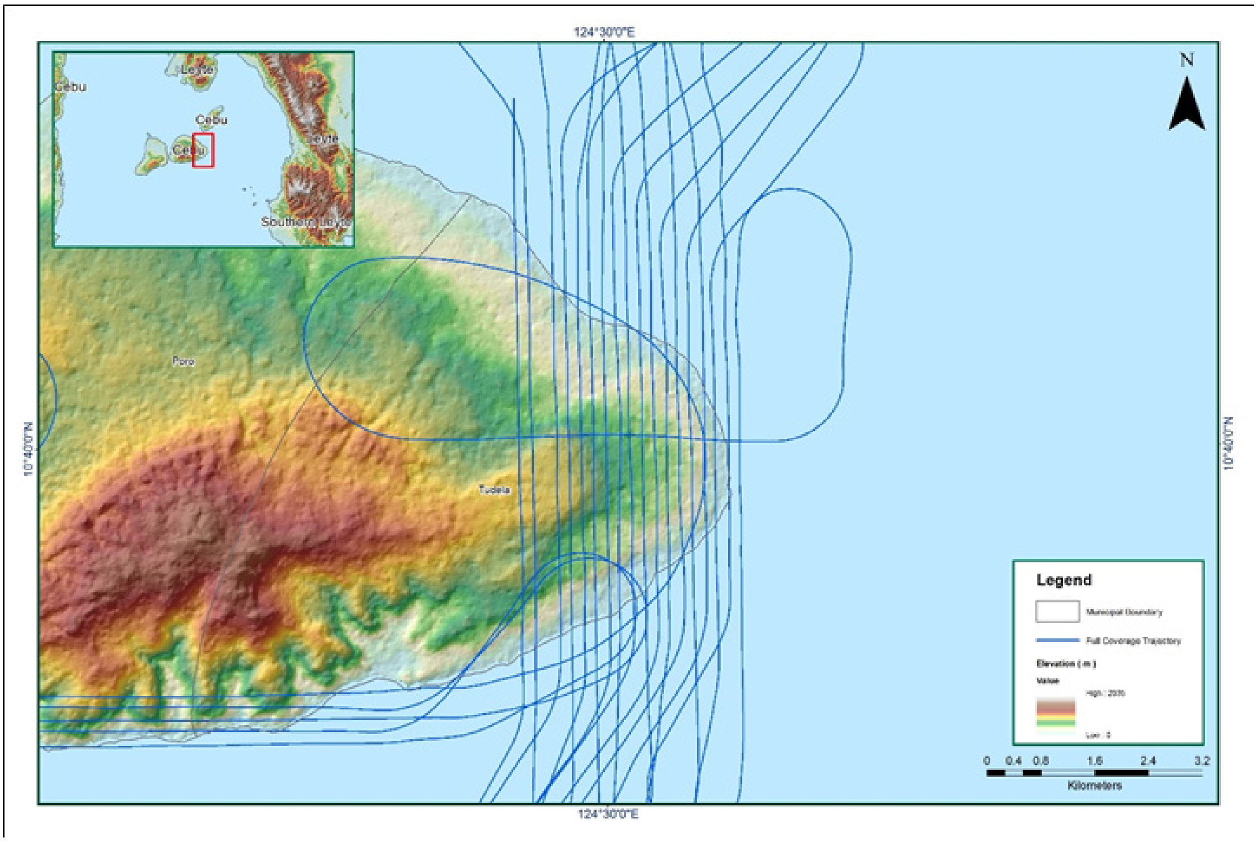

Figure A-8.73. Best Estimated Trajectory

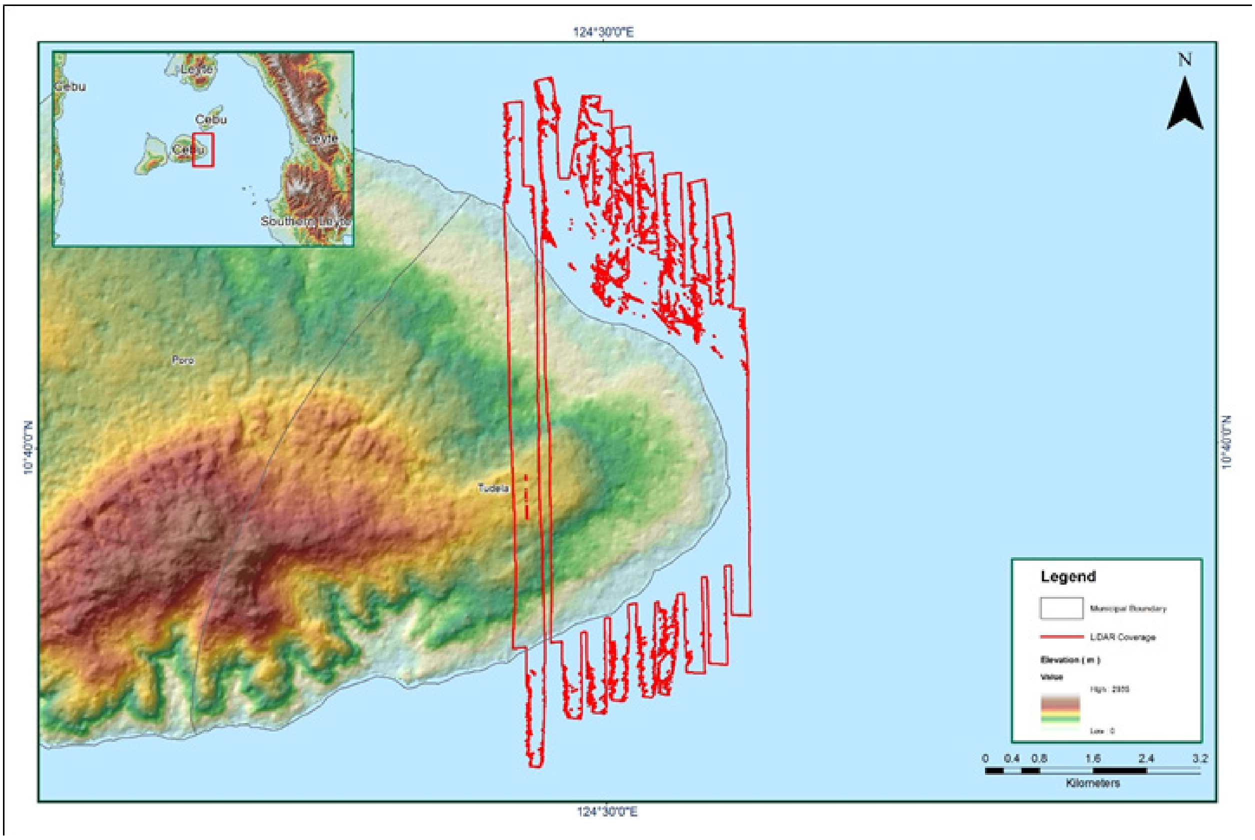

Figure A-8.74. Coverage of LiDAR data

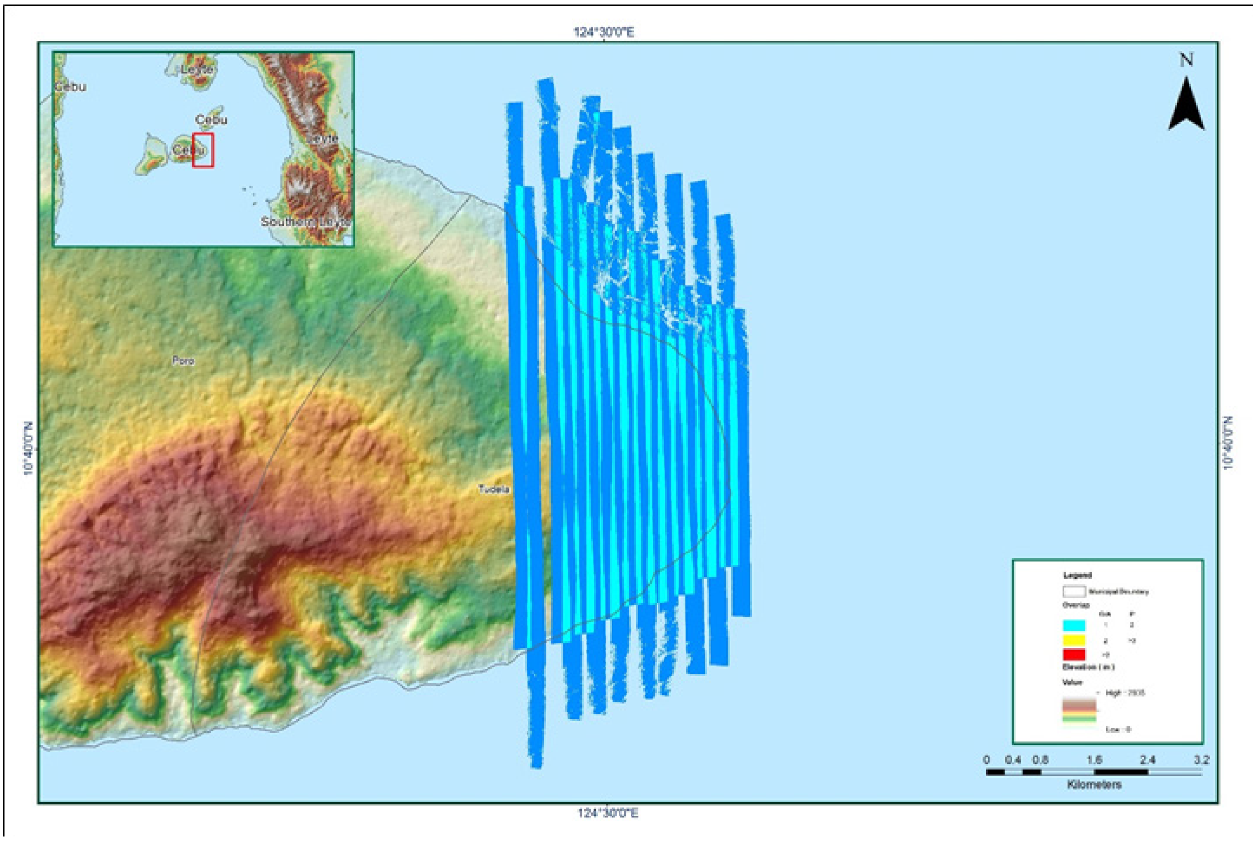

Figure A-8.75. Image of Data Overlap

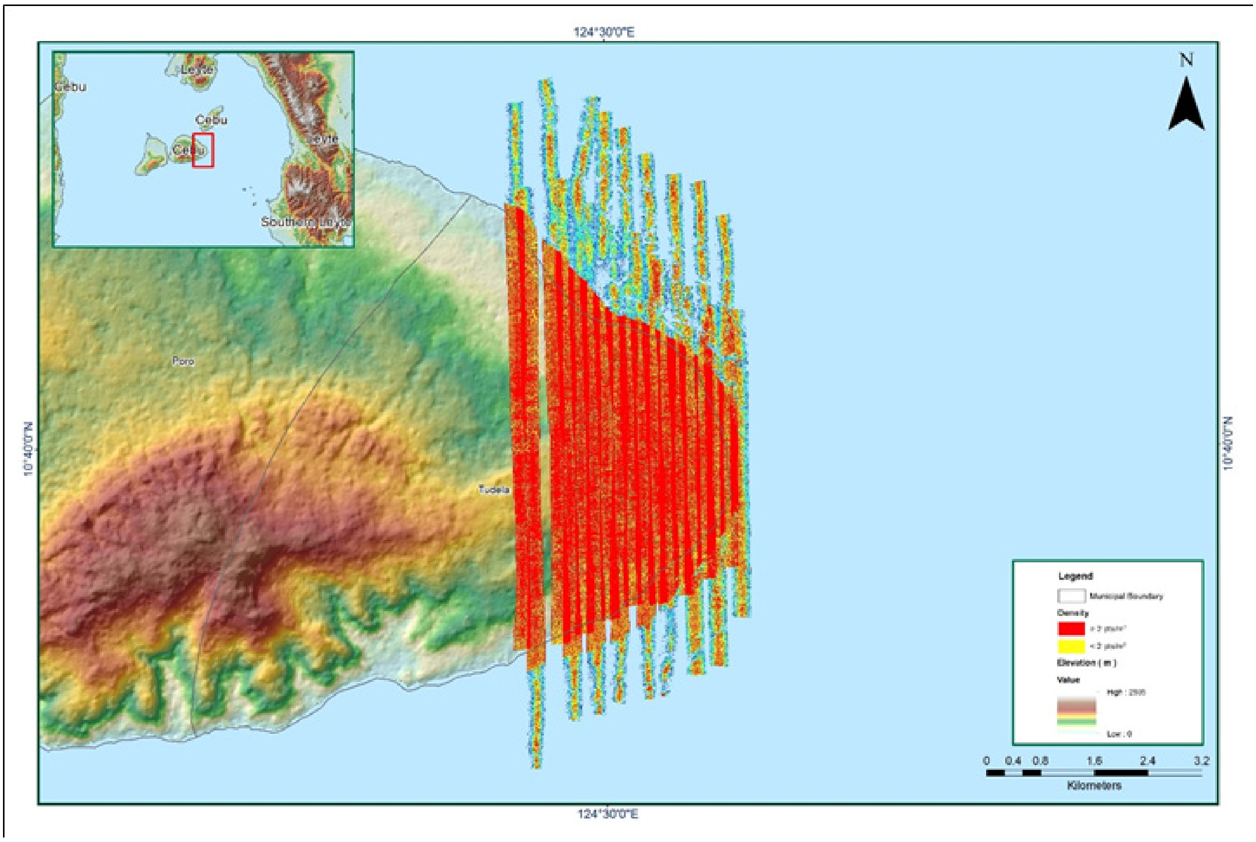

Figure A-8.76. Density map of merged LiDAR data

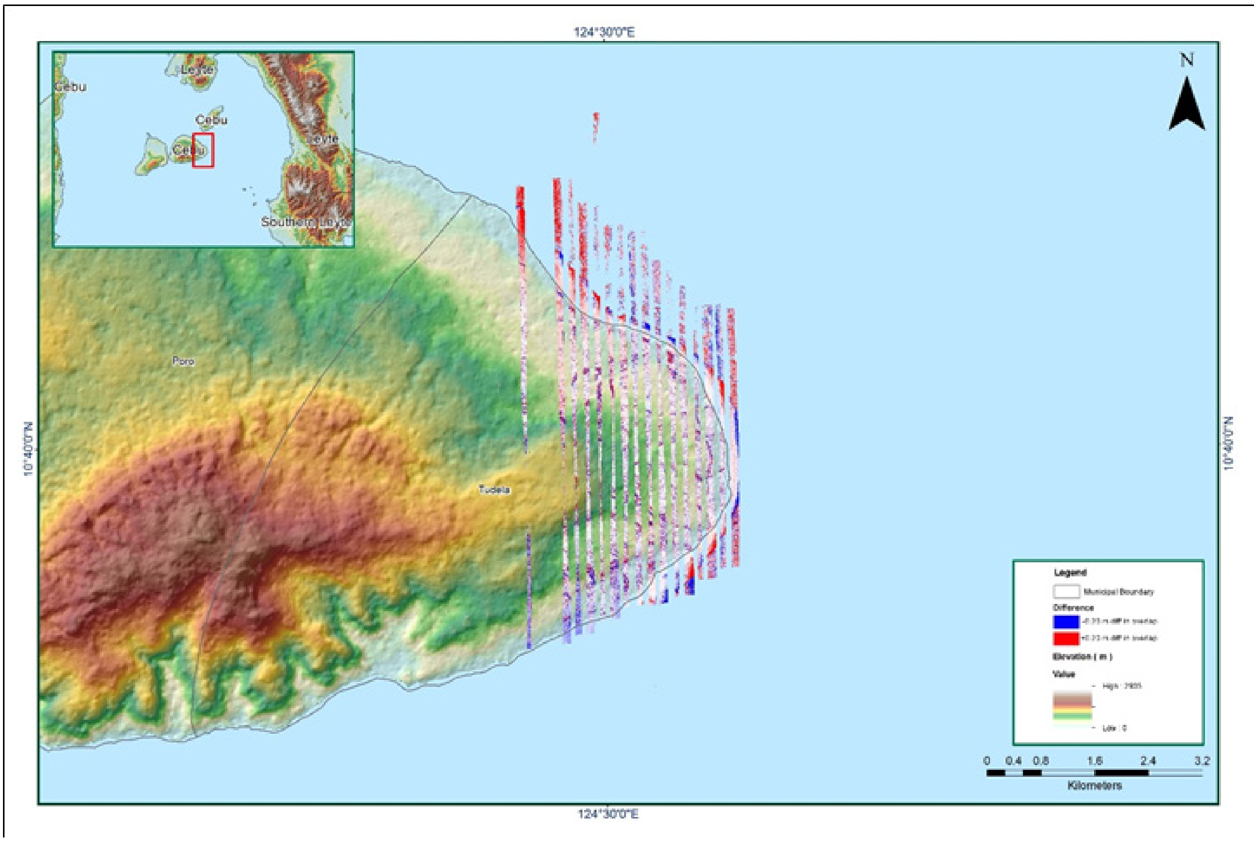

Figure A-8.77. Elevation difference between flight lines

Table A-8.12. Mission Summary Report for Mission Blk48C

Flight Area	Ormoc_Camotes
Mission Name	Blk48C
Inclusive Flights	8403AC/8404AC
Range data size	18.98 GB
POS	549 MB
Image	114.9 MB
Base Station	288 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.97
RMSE for East Position (<4.0 cm)	2.43
RMSE for Down Position (<8.0 cm)	7.12
Boresight correction stdev (<0.001deg)	0.000401
IMU attitude correction stdev (<0.001deg)	1.251499
GPS position stdev (<0.01m)	0.0255
Minimum % overlap (>25)	58.42
Ave point cloud density per sq.m. (>2.0)	4.62
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	112
Maximum Height	232.09
Minimum Height	46.32
Classification (# of points)	
Ground	49,846,498
Low vegetation	36,448,282
Medium vegetation	46,092,816
High vegetation	113,186,235
Building	2,578,267
Orthophoto	None
Processed by	Engr. Irish Cortez, Engr. Merven Matthew Natino, Engr. Monalyne Rabino

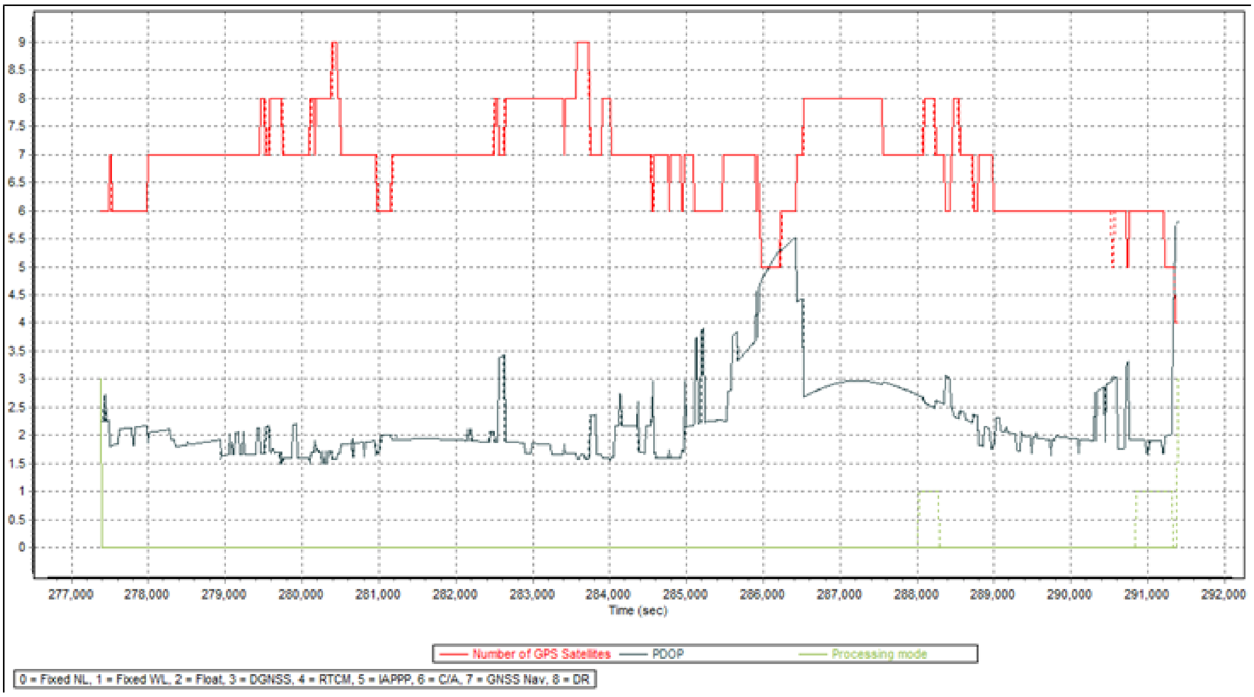

Figure A-8.78. Solution Status

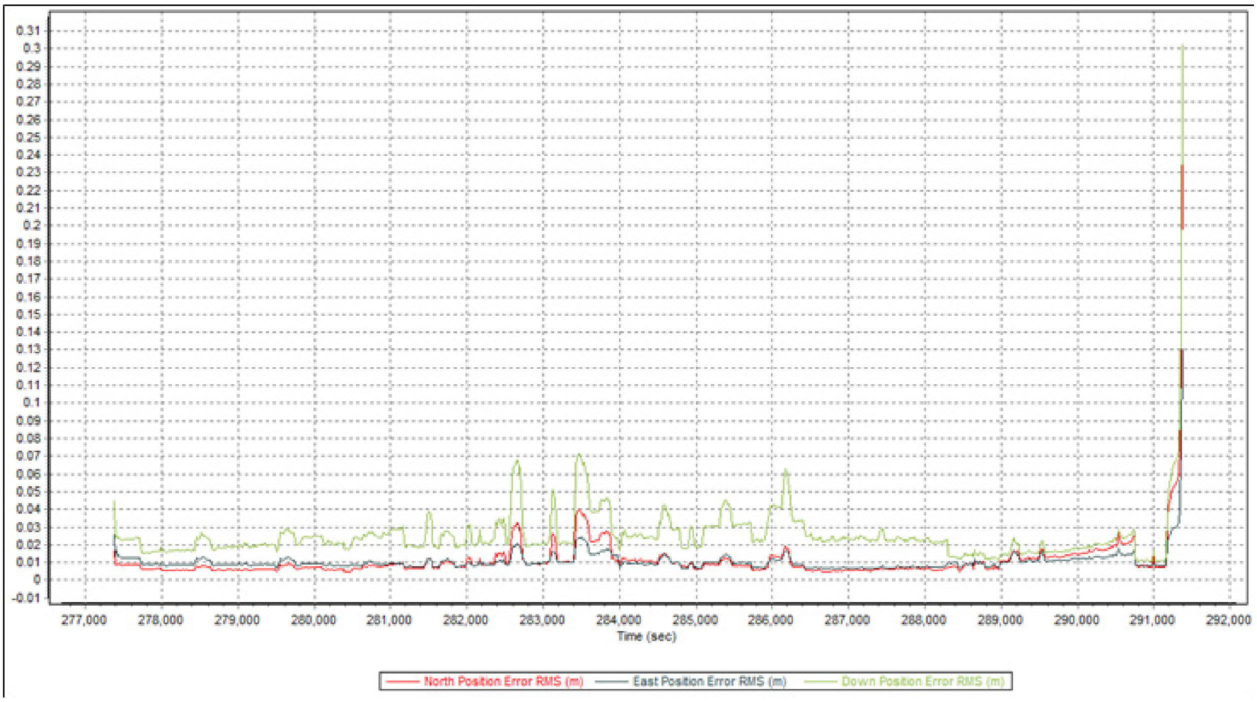

Figure A-8.79. Smoothed Performance Metric Parameters

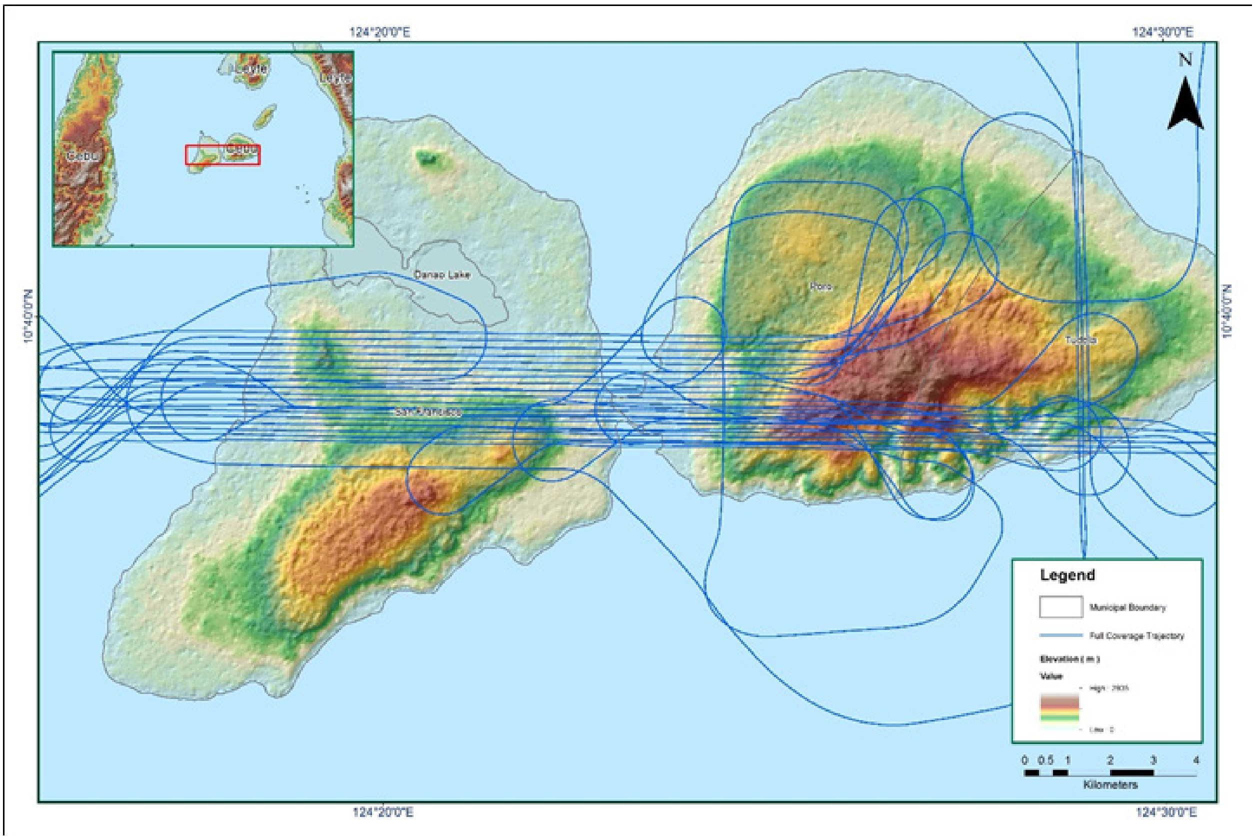

Figure A-8.80. Best Estimated Trajectory

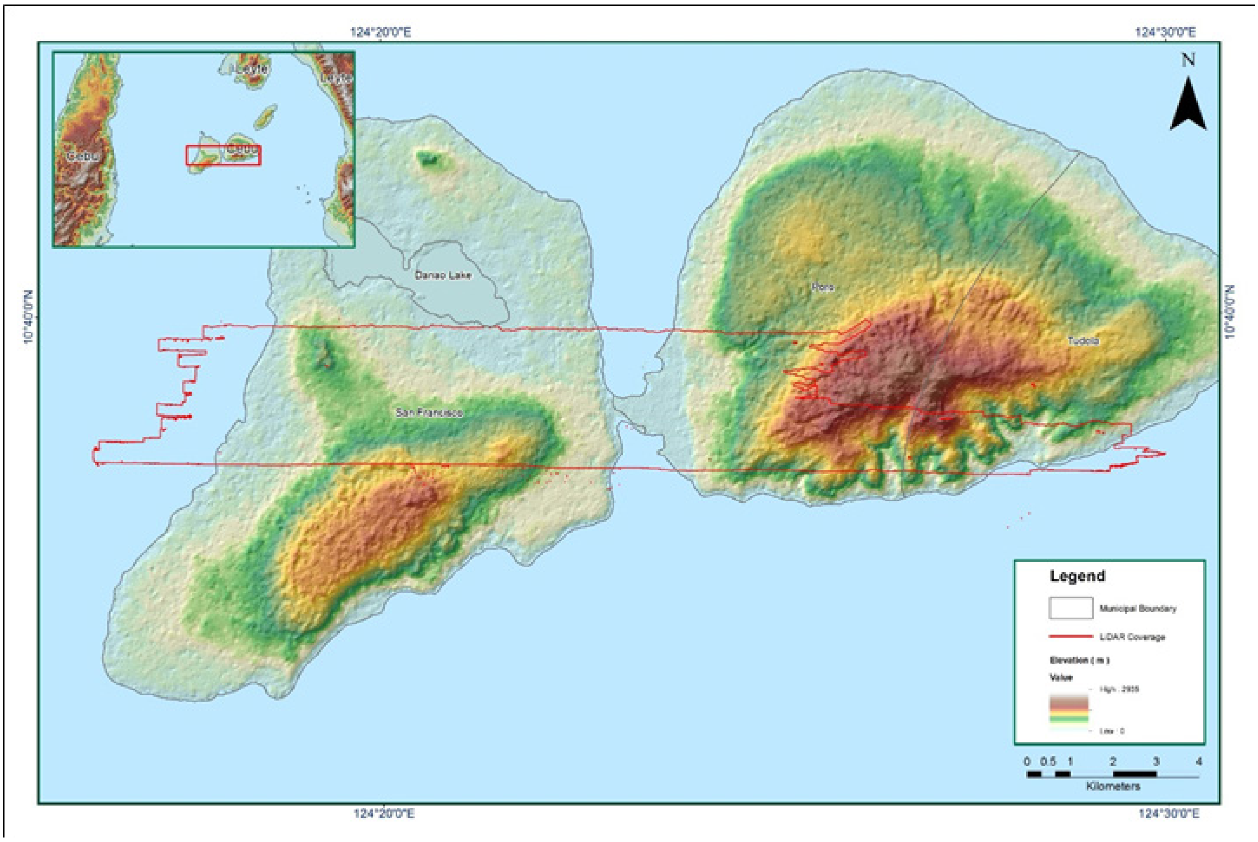

Figure A-8.81. Coverage of LiDAR data

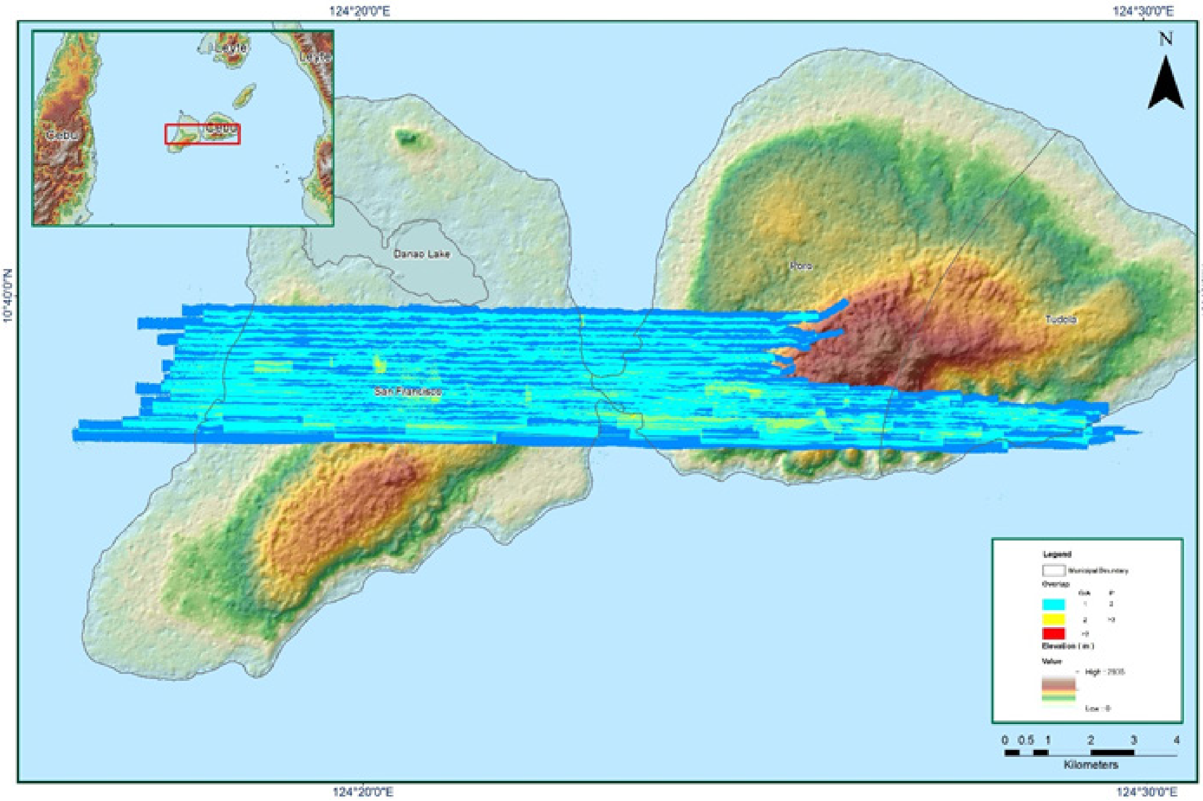

Figure A-8.82. Image of Data Overlap

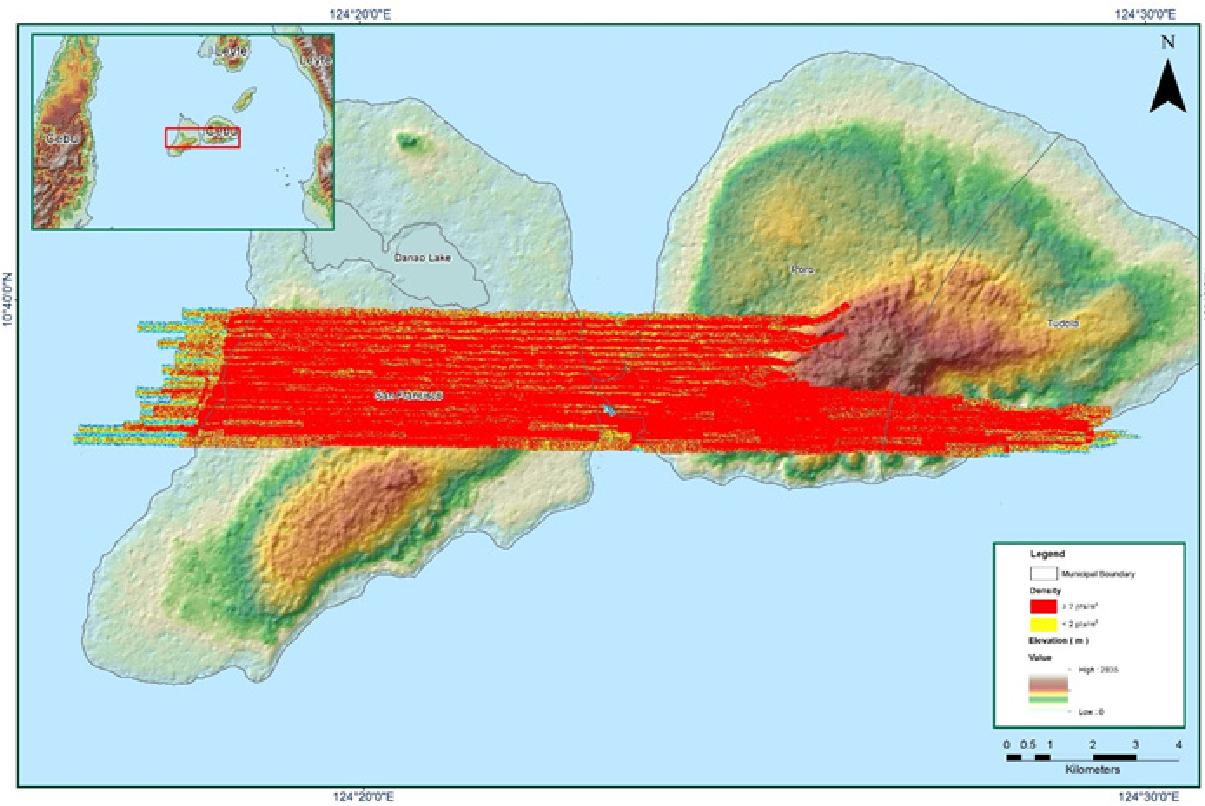

Figure A-8.83. Density map of merged LiDAR data

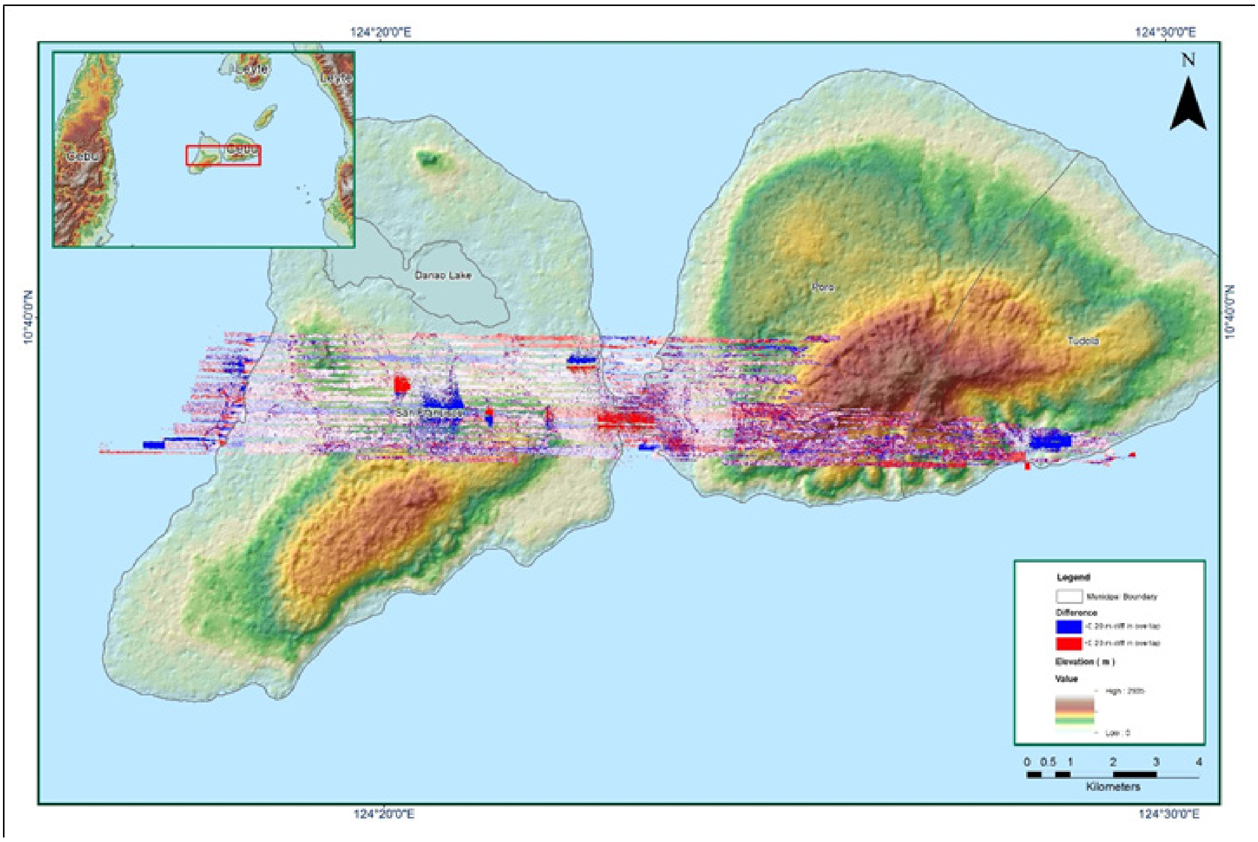

Figure A-8.84. Elevation difference between flight lines

Table A-8.13. Mission Summary Report for Mission Blk48C_Supplement

Flight Area	Ormoc_Camotes
Mission Name	Blk48C_Supplement
Inclusive Flights	8403AC/8404AC/8406AC
Range data size	26.65 GB
POS	806 MB
Image	155.2 MB
Base Station	506 MB
Transfer date	April 22, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	33.85
RMSE for East Position (<4.0 cm)	34.53
RMSE for Down Position (<8.0 cm)	39.33
Boresight correction stdev (<0.001deg)	N/A
IMU attitude correction stdev (<0.001deg)	N/A
GPS position stdev (<0.01m)	N/A
Minimum % overlap (>25)	37.32
Ave point cloud density per sq.m. (>2.0)	4.68
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	55
Maximum Height	368.57
Minimum Height	45.06
Classification (# of points)	
Ground	21,097,707
Low vegetation	13,806,902
Medium vegetation	18,111,519
High vegetation	37,279,663
Building	1,182,887
Orthophoto	None
Processed by	Engr. Irish Cortez, Engr. Jovelle Anjeanette Canlas, Alex Escobido, Marie Denise Bueno

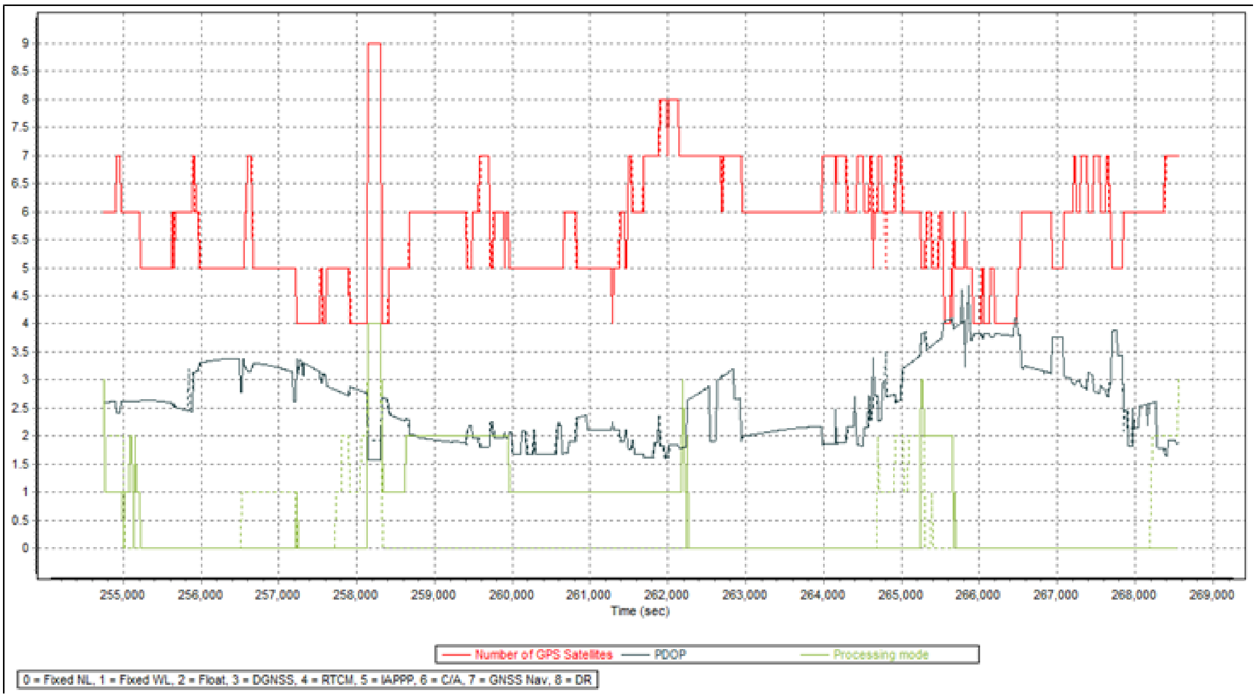

Figure A-8.85. Solution Status

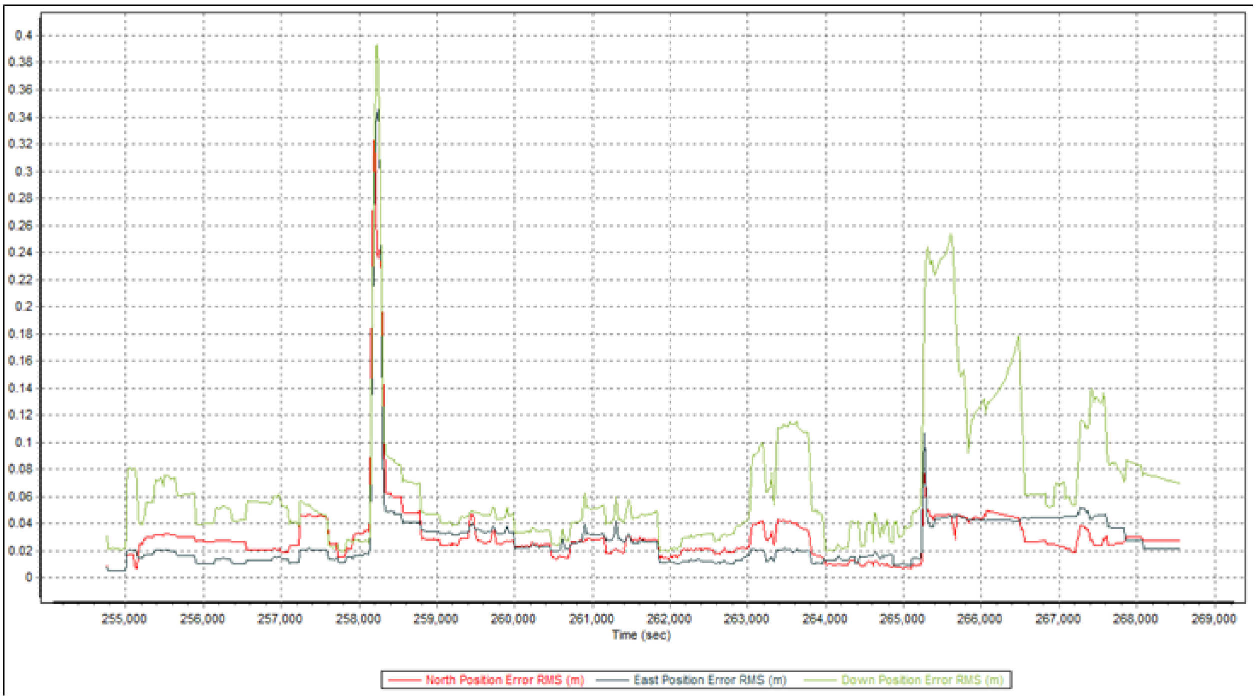

Figure A-8.86. Smoothed Performance Metric Parameters

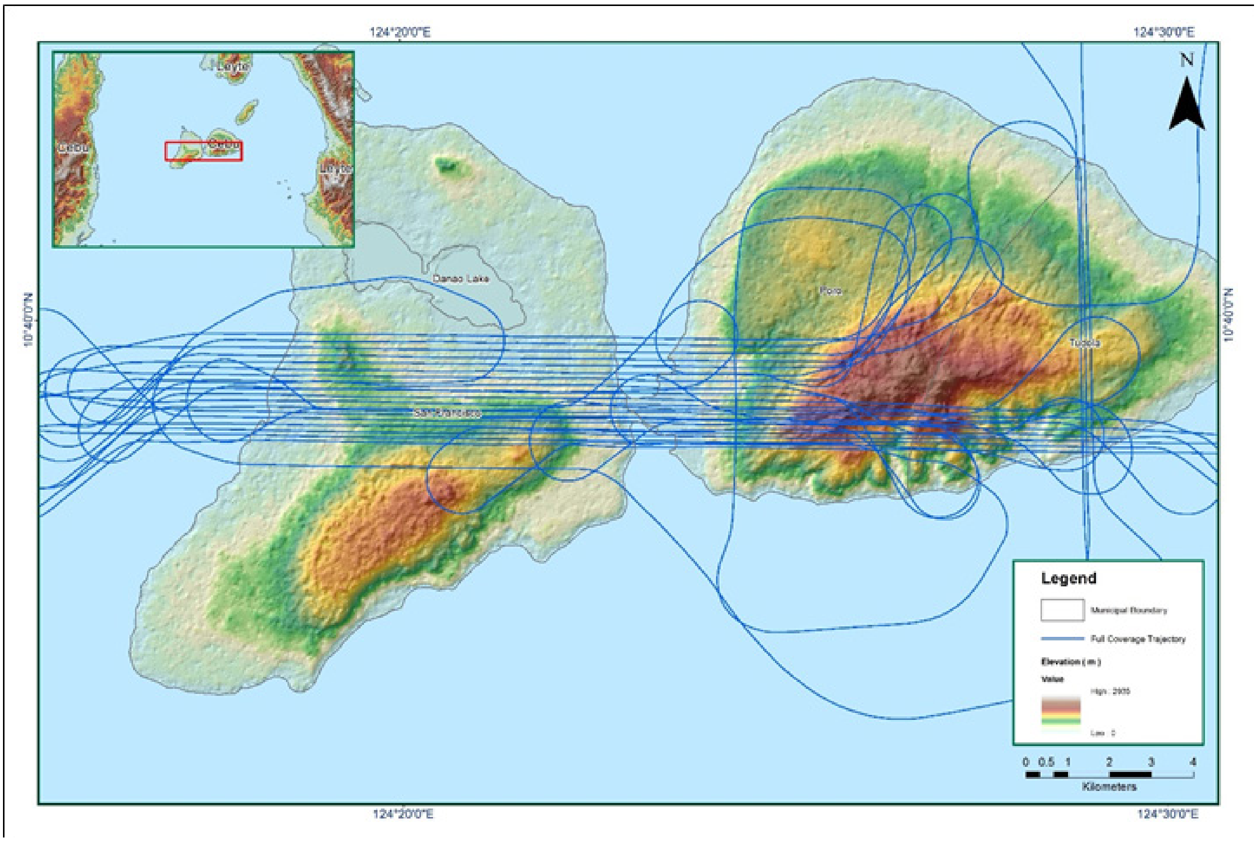

Figure A-8.87. Best Estimated Trajectory

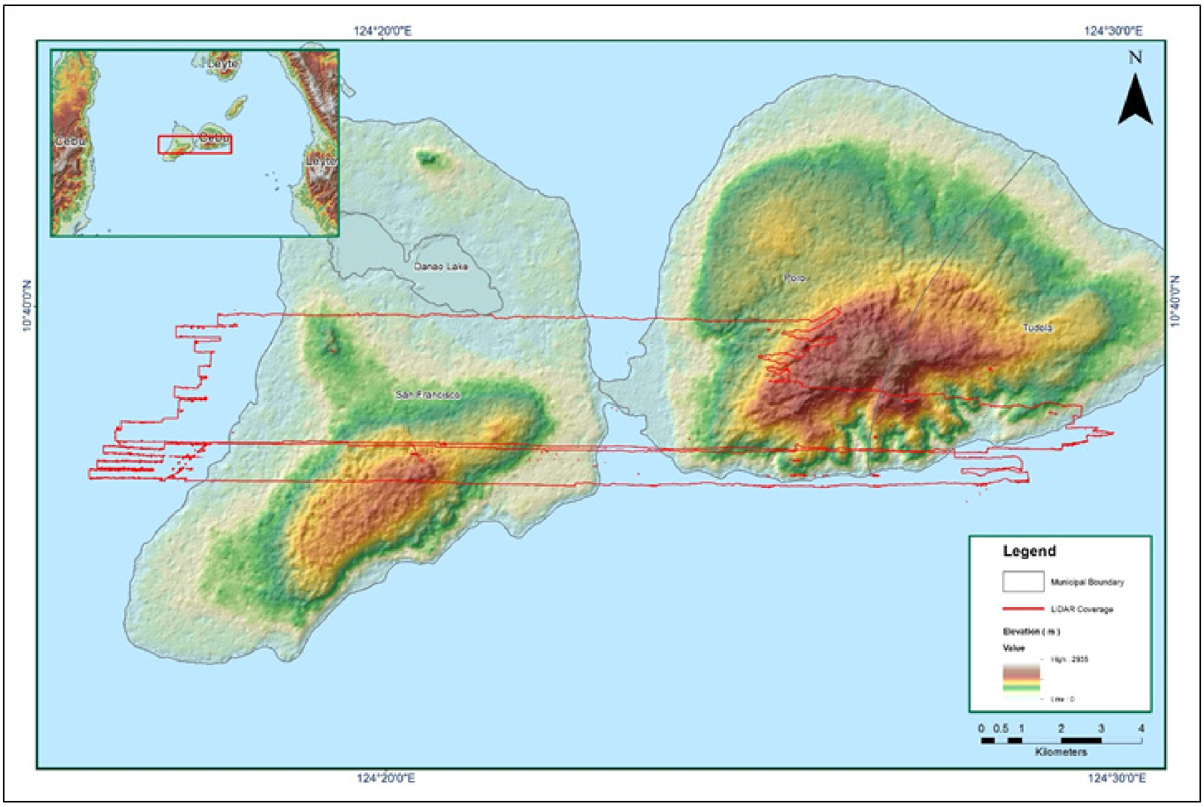

Figure A-8.88. Coverage of LiDAR data

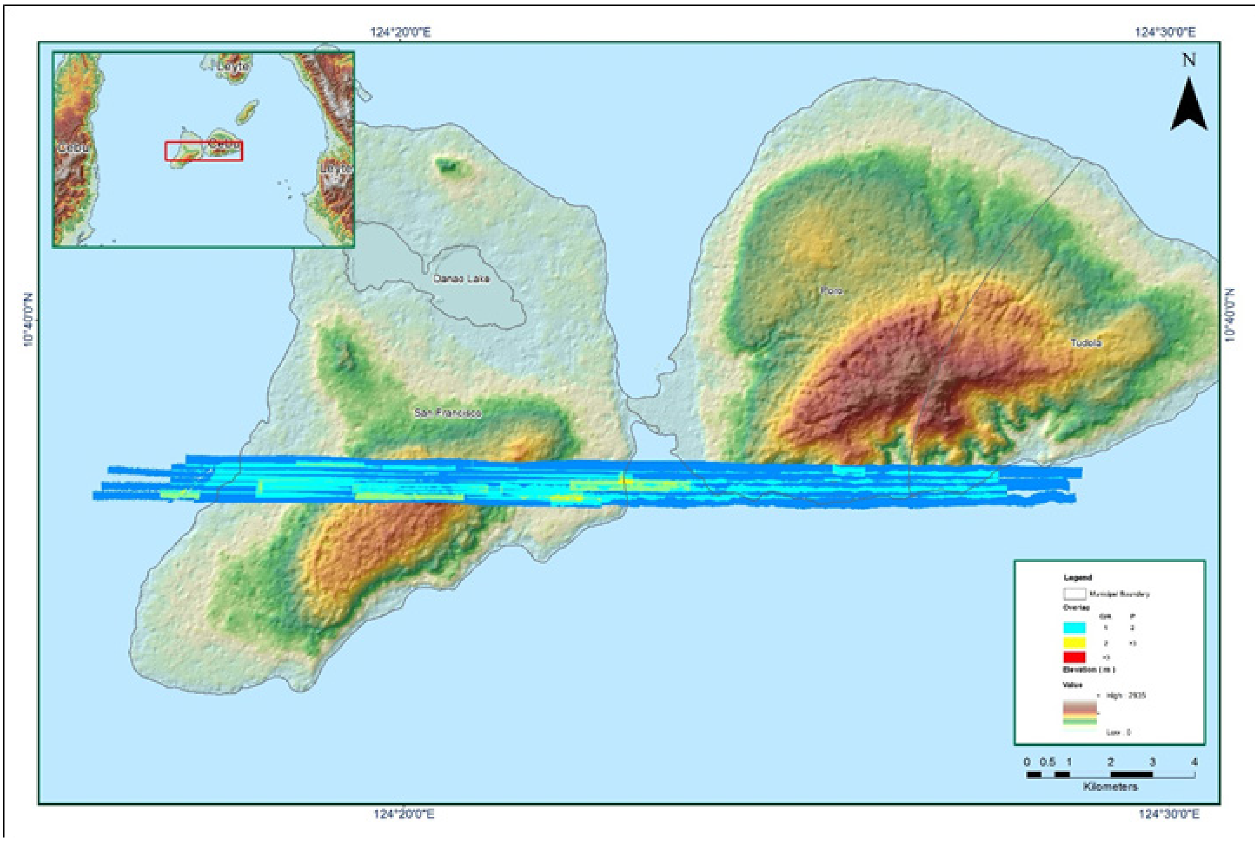

Figure A-8.89. Image of Data Overlap

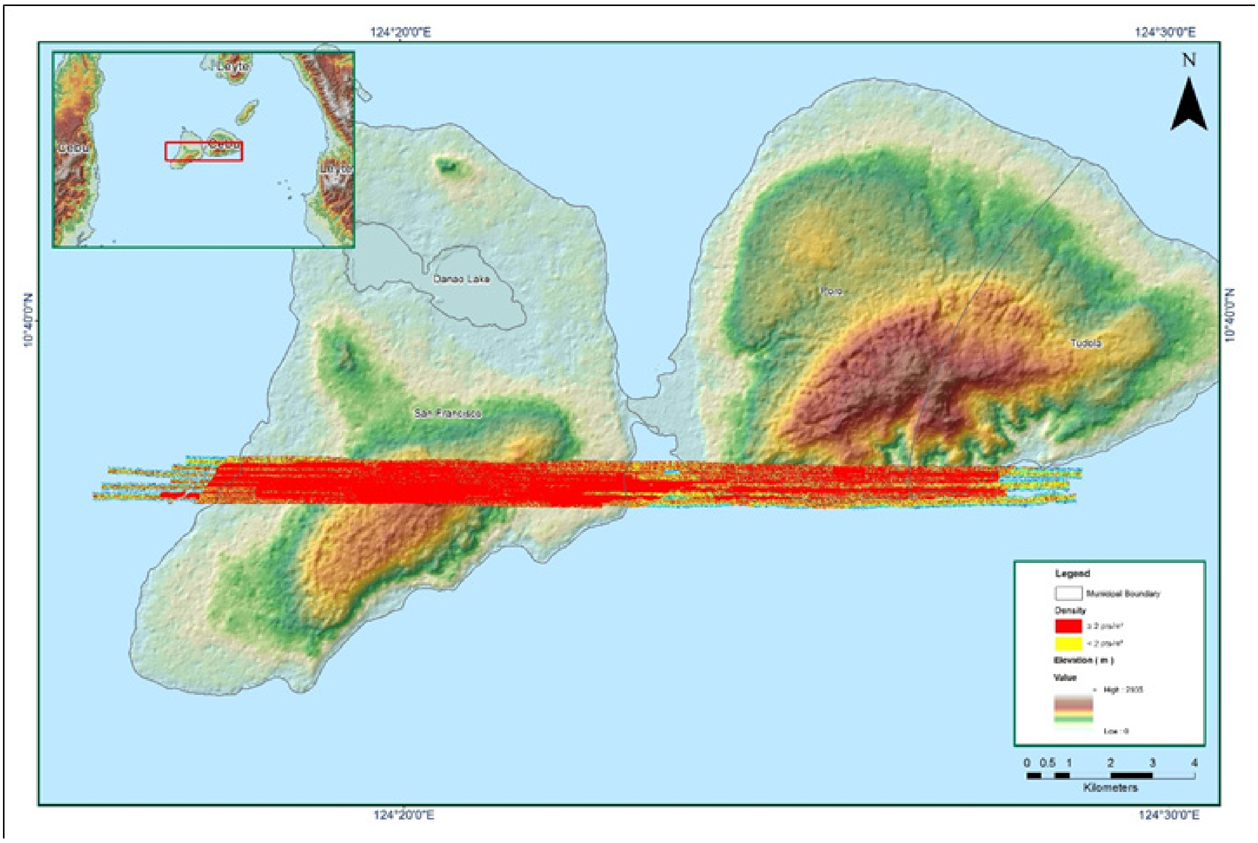

Figure A-8.90. Density map of merged LiDAR data

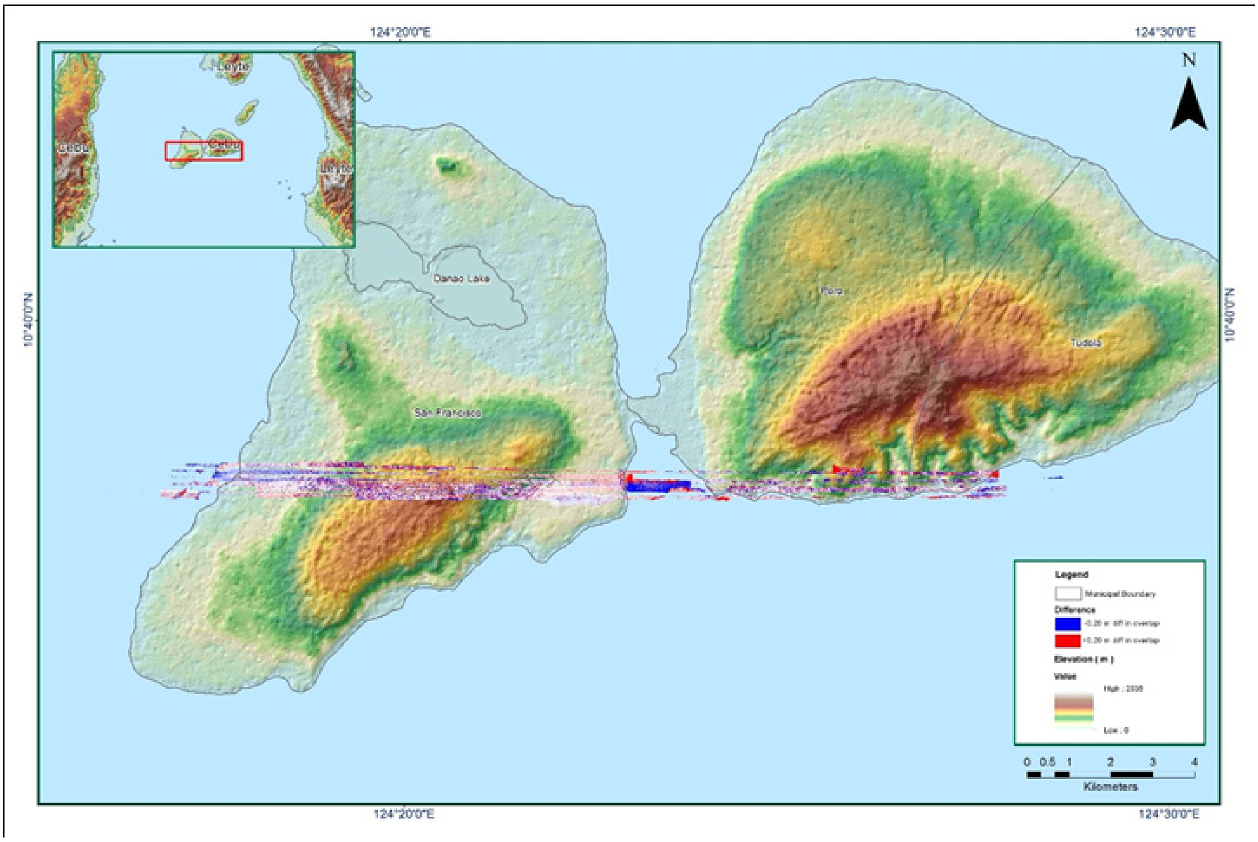

Figure A-8.91. Elevation difference between flight lines

Table A-8.14. Mission Summary Report for Mission Blk48D_supplement2

Flight Area	Ormoc_Camotes
Mission Name	Blk48D_supplement2
Inclusive Flights	8400AC
Range data size	3.11 GB
POS	118 MB
Image	16 MB
Base Station	49.4 MB
Transfer date	April 27, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	30.00
RMSE for East Position (<4.0 cm)	25.96
RMSE for Down Position (<8.0 cm)	33.97
Boresight correction stdev (<0.001deg)	0.000661
IMU attitude correction stdev (<0.001deg)	0.003780
GPS position stdev (<0.01m)	0.0136
Minimum % overlap (>25)	16.71
Ave point cloud density per sq.m. (>2.0)	2.76
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	26
Maximum Height	261.07 m
Minimum Height	53.89 m
Classification (# of points)	
Ground	3,543,666
Low vegetation	1,971,830
Medium vegetation	2,494,639
High vegetation	5,801,633
Building	99,806
Orthophoto	No
Processed by	Engr. Jennifer Saguran, Engr. Harmond Santos, Engr. Gladys Mae Apat

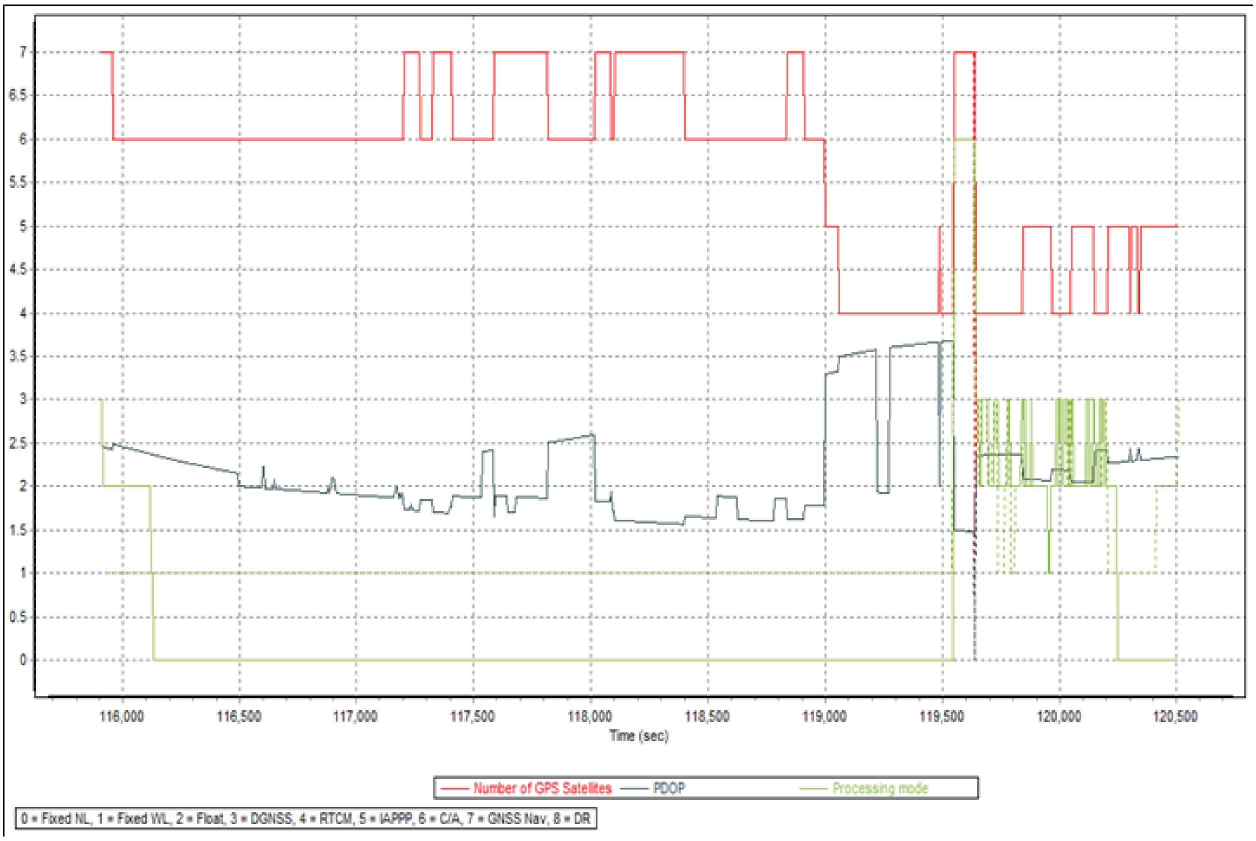

Figure A-8.43. Solution Status

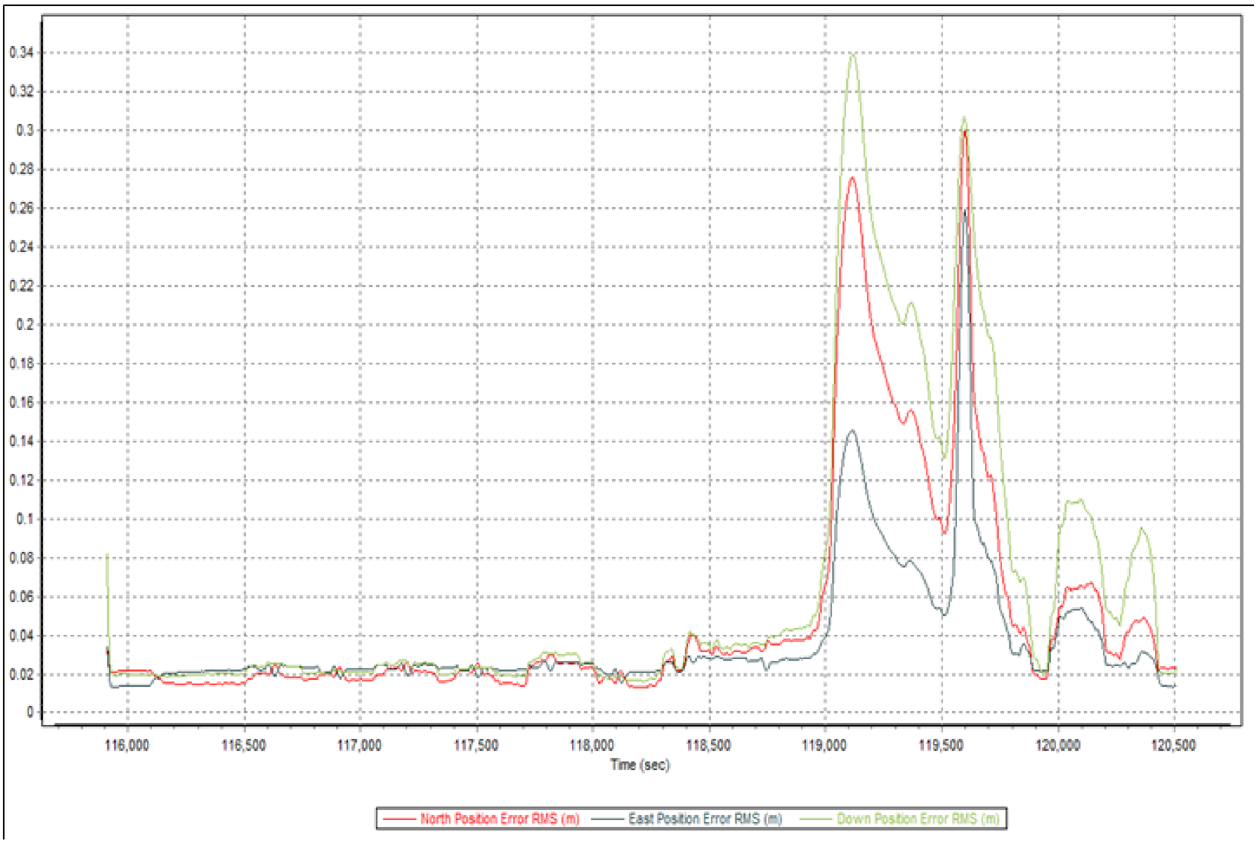

Figure A-8.44. Smoothed Performance Metric Parameters

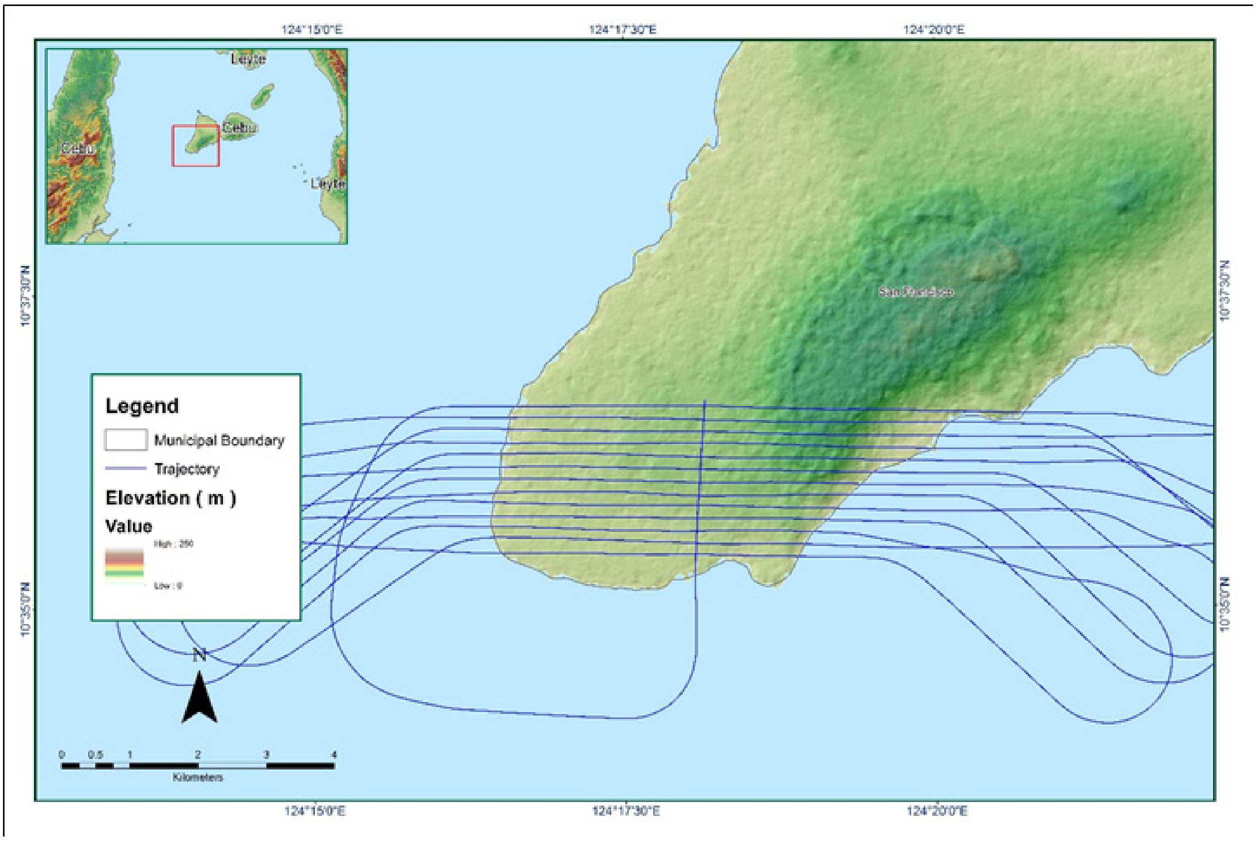

Figure A-8.45. Best Estimated Trajectory

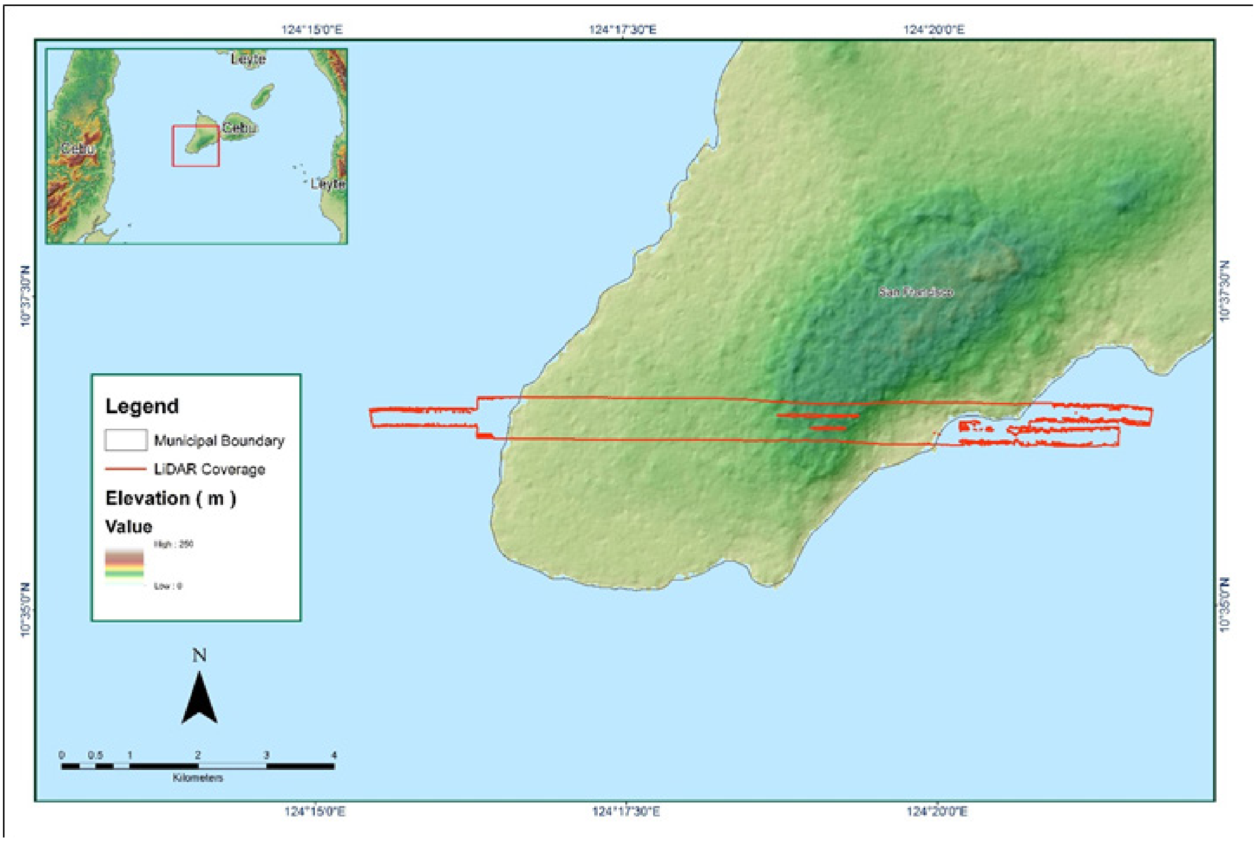

Figure A-8.46. Coverage of LiDAR data

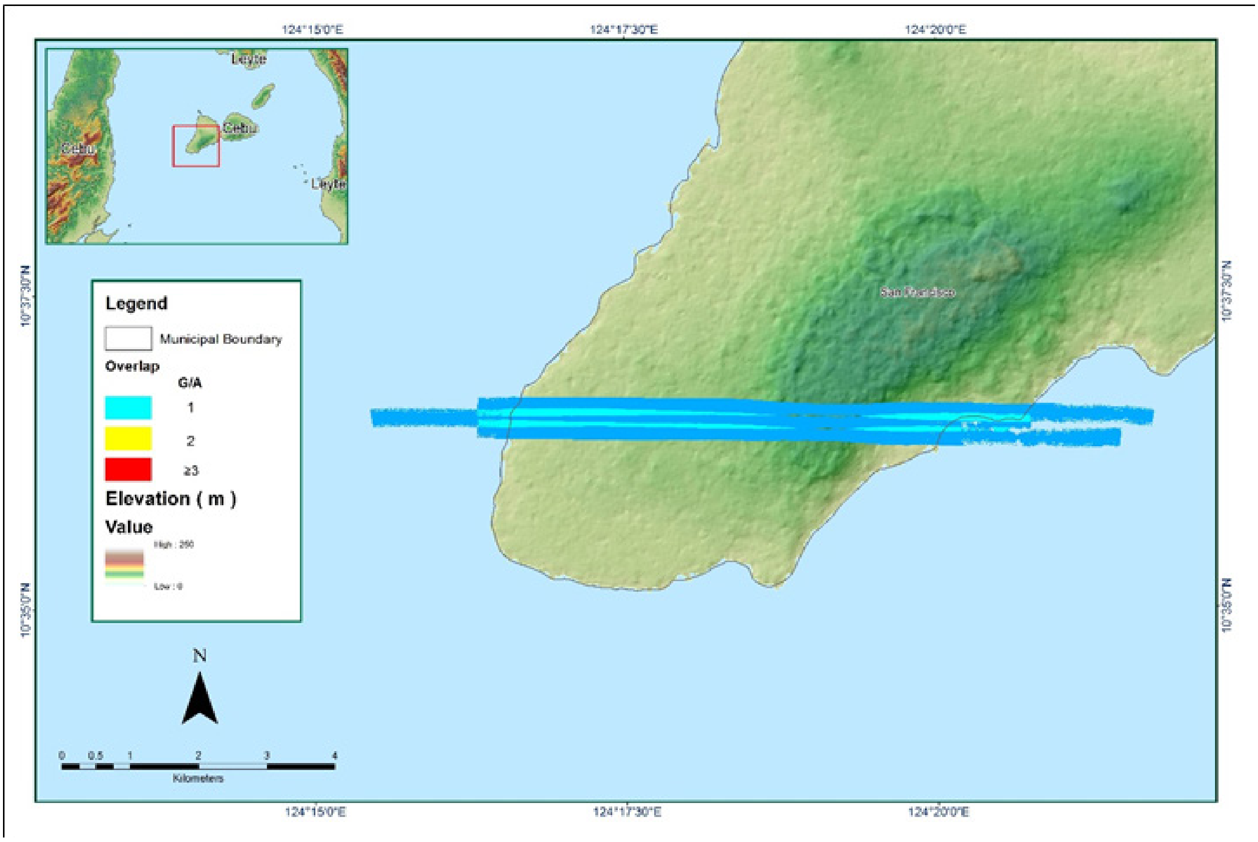

Figure A-8.47. Image of Data Overlap

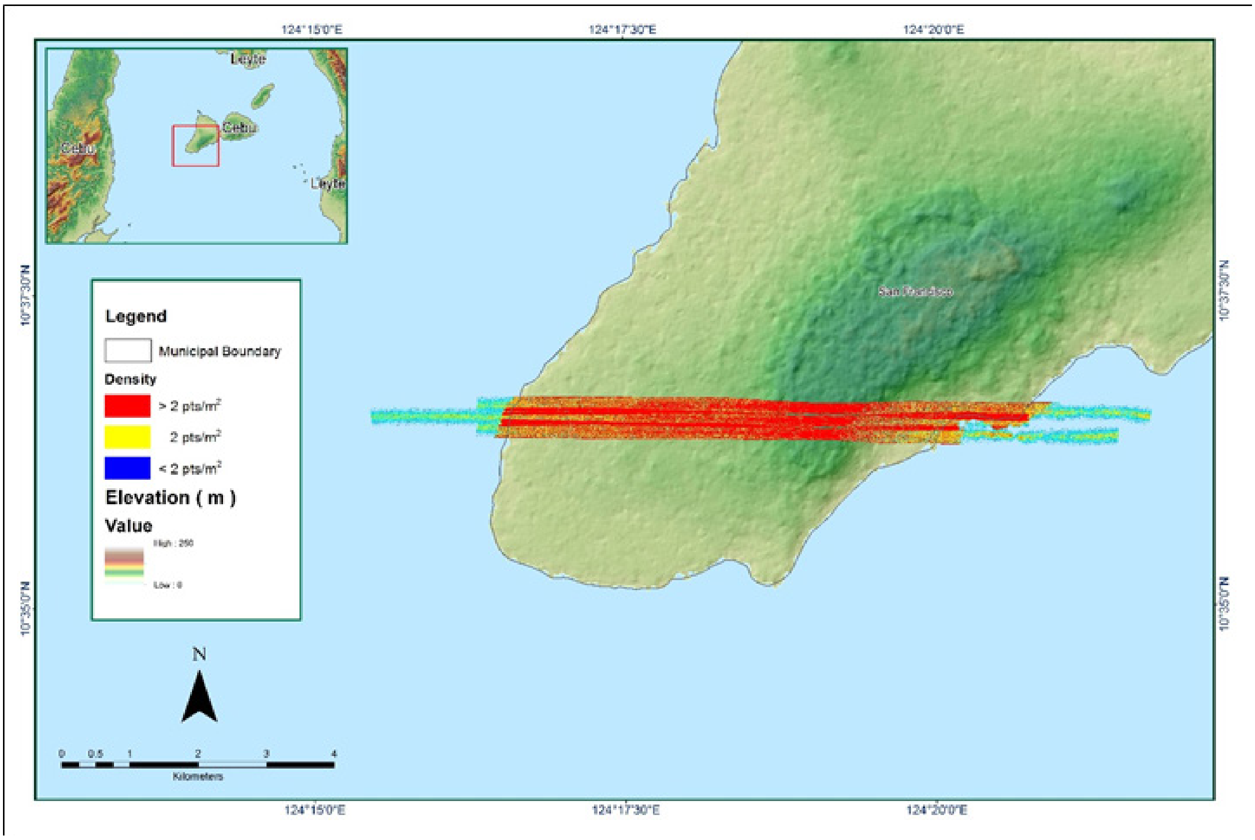

Figure A-8.48. Density map of merged LiDAR data

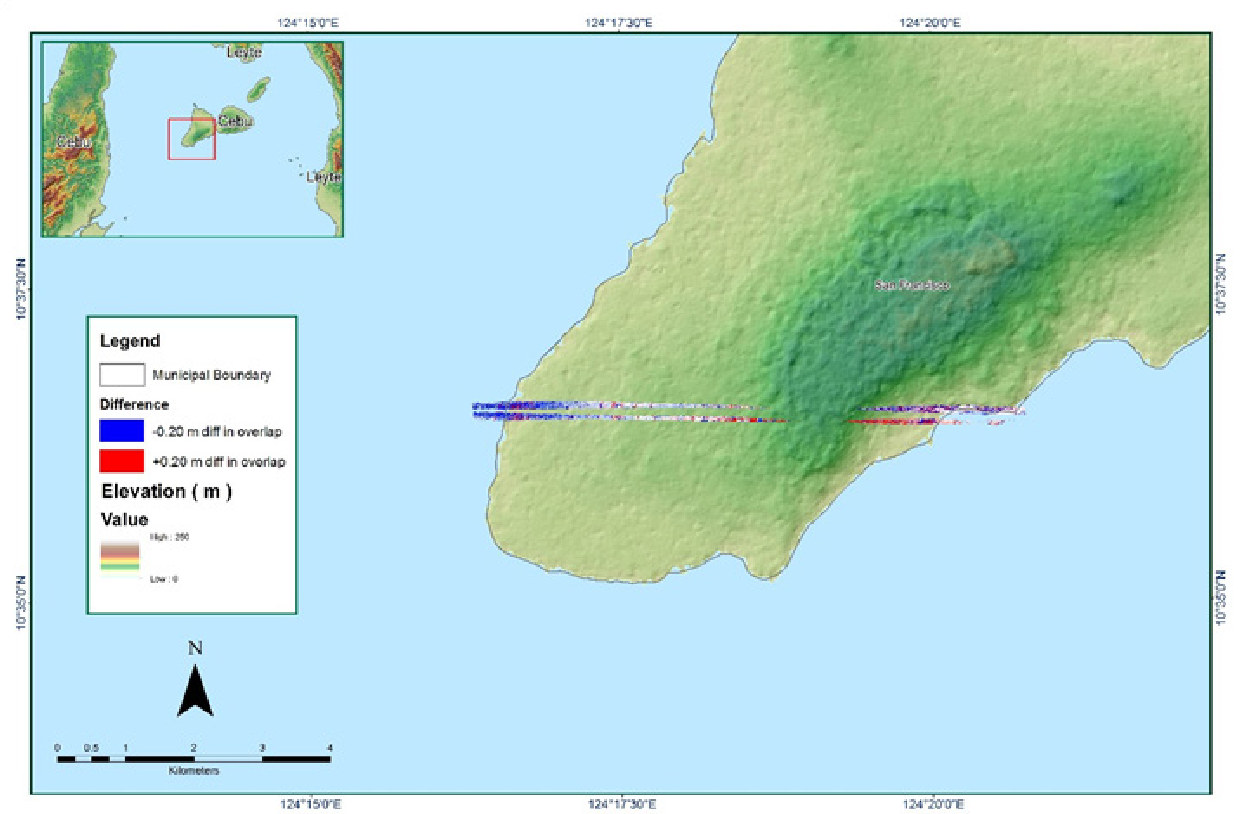

Figure A-8.49. Elevation difference between flight lines

Annex 9. Kotkot Model Basin Parameters

Table A-9.1. Kotkot Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threschold Type	Ratio to Peak
W200	4.3625	70.55136	1	2.6870336	0.1548282	Discharge	0.0130508	0.001038	Ratio to Peak	0.00049
W210	24.083	70.36858	1	0.71725	0.0339702	Discharge	0.0057814	0.001007	Ratio to Peak	0.00066
W220	19.037	93.83674	1	0.88621	0.0267519	Discharge	0.0096991	0.000323	Ratio to Peak	0.0005
W230	42.115	92.361	1	0.48953	0.0526265	Discharge	0.00558	0.000236	Ratio to Peak	0.00243
W240	5.804	80.31181	1	1.5863	0.0621633	Discharge	0.0095097	0.000168	Ratio to Peak	0.00069
W250	6.3586	82.17773	1	0.84942	0.021787	Discharge	0.0022221	0.000346	Ratio to Peak	0.00051
W260	2.3964	62.77978	0	2.7999	0.0901629	Discharge	0.0114167	0.000364	Ratio to Peak	0.00076
W270	14.023	99	0	0.80292	0.0271345	Discharge	1.05E-05	0.000109	Ratio to Peak	0.0033
W280	3.6637	78.08467	0	3.2082	0.1395728	Discharge	0.014291	0.000167	Ratio to Peak	0.00032
W290	5.2076	35.328	0	2.7514	0.0257521	Discharge	0.0174292	0.000243	Ratio to Peak	0.00088
W300	2.0593	35.195	0	0.38638	0.0195817	Discharge	0.0138717	0.000169	Ratio to Peak	0.00072
W310	6.2314	42.391	0	16.33088	1.312728	Discharge	0.0240979	0.00257	Ratio to Peak	0.02
W320	2.706	36.809	0	2.0077952	0.1819941	Discharge	0.0153836	0.001125	Ratio to Peak	0.00075
W330	4.6345	62.13133	0	1.1405	0.2012584	Discharge	0.0146731	0.000169	Ratio to Peak	0.00022
W340	1.9776	93.607	0	0.19083	0.0178313	Discharge	0.0007285	0.000169	Ratio to Peak	0.00034
W350	1.5482	48.176	0	1.563	0.088146	Discharge	0.0089067	0.001562	Ratio to Peak	0.00051
W360	0.85447	96.35959	0	1.2329	0.2021797	Discharge	0.0112672	0.002461	Ratio to Peak	0.00018
W370	2.521	99	0	1.0336	0.0731282	Discharge	0.0066213	0.005279	Ratio to Peak	0.00014
W380	11.329	53.66669	0	4.0481216	1.042397	Discharge	0.0154593	0.004915	Ratio to Peak	0.00841

Annex 10. Kotkot Model Reach Parameters

Table A-10.1. Kotkot Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	2323.2	0.0024	0.09185	Trapezoid	10	0.5
R120	Automatic Fixed Interval	3415.8	0.01385	0.05487	Trapezoid	15	0.5
R130	Automatic Fixed Interval	424.41	0.001	0.0477	Trapezoid	15	0.5
R160	Automatic Fixed Interval	4890.9	0.02245	0.08526	Trapezoid	10	0.5
R180	Automatic Fixed Interval	2601.8	0.03084	0.14061	Trapezoid	10	0.5
R30	Automatic Fixed Interval	1798.5	0.03536	0.01435	Trapezoid	15	0.5
R50	Automatic Fixed Interval	1167.8	0.01386	0.01624	Trapezoid	15	0.5
R70	Automatic Fixed Interval	14.142	0.11621	0.00011	Trapezoid	10	0.5
R90	Automatic Fixed Interval	4035.9	0.02134	0.06388	Trapezoid	10	0.5

Annex 11. Kotkot Field Validation Points

Table A-11.1. Kotkot Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	124.006391	10.427983	4.09	0.45	13.2496	Yolanda	100-Year
2	124.006391	10.427983	4.09	0.45	13.2496	Ruping	100-Year
3	124.006059	10.427686	3.43	0.7	7.4529	Ruping	100-Year
4	124.006783	10.428369	0.45	0.5	0.0025	Seniang	100-Year
5	124.007078	10.428256	0.45	0.47	0.0004	Yolanda	100-Year
6	124.007289	10.428409	0.31	0.7	0.1521	Yolanda	100-Year
7	124.007289	10.428409	0.31	0.7	0.1521	Bashang	100-Year
8	124.007587	10.432995	0.27	1	0.5329	Ruping	100-Year
9	124.003593	10.433477	0.2	1.3	1.21	Ruping	100-Year
10	124.003593	10.433477	0.2	0.5	0.09	Yolanda	100-Year
11	123.999059	10.438618	0.85	0.65	0.04	Quennie	100-Year
12	123.999059	10.438618	0.85	0.65	0.04	Ruby	100-Year
13	123.999059	10.438618	0.85	0.65	0.04	Seniang	100-Year
14	124.000231	10.438404	0.06	1.1	1.0816	Ruping	100-Year
15	124.000231	10.438404	0.06	1.1	1.0816	Puring	100-Year
16	124.001267	10.435118	0.45	0.5	0.0025	Yolanda	100-Year
17	124.001283	10.434806	0.47	0.6	0.0169	Yolanda	100-Year
18	124.001283	10.434806	0.47	1.6	1.2769	Ruping	100-Year
19	124.001942	10.432205	0.53	0.5	0.0009	Ruping	100-Year
20	124.001972	10.432026	0.52	1.1	0.3364	Ruping	100-Year
21	123.982256	10.443231	0.68	1.2	0.2704	Ruping	100-Year