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

LiDAR Surveys and Flood Mapping of Balamban River

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

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For questions/queries regarding this report, contact:

Dr. Roland Emerito S. Otadoy
Project Leader, Phil-LiDAR 1 Program
University of San Carlos
Cebu City, Philippines 6000
E-mail: rolandotadoy2012@gmail.com

Enrico C. Paringit, Dr. Eng.
Program Leader, Phil-LiDAR 1 Program
University of the Philippines Diliman
Quezon City, Philippines 1101
E-mail: ecparingit@up.edu.ph

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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 BALAMBAN RIVER

Enrico C. Paringit, Dr. Eng., Dr. Roland Emerito S. Otadoy, and Engr. Aure Flo Oraya

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) Grant-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 26 river basins in the Central Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Balamban River Basin

The Balamban River Basin covers three (3) Municipalities and two (2) cities in Cebu. The DENR River Basin Control Office (RCBO 2015) identified the basin to have a drainage area of 231 km2 and an estimated 139 million cubic meter annual run-off.

Its main stem, Balamban River, passes along Barangays Biasong, Nangka, and Cantuod, all within the Municipality of Balamban. It is part of the river systems in Central Visayas Region under the PHIL-LIDAR 1 partner HEI, University of San Carlos (USC). There is a total of 9,216 people residing within the immediate vicinity of the river which is distributed among three (3) barangays, namely: Biasong, Nangka, and Cantuod (NSO, 2010). Most of the livelihood of the population in Western Cebu are the extraction, consumption, and management of coastal and marine resources found in their province. Recently, Typhoon Seniang, brought about immense flooding and landslides to Municipalities such as Sibonga, Ronda, and Dumanjung in Cebu in December 2014.

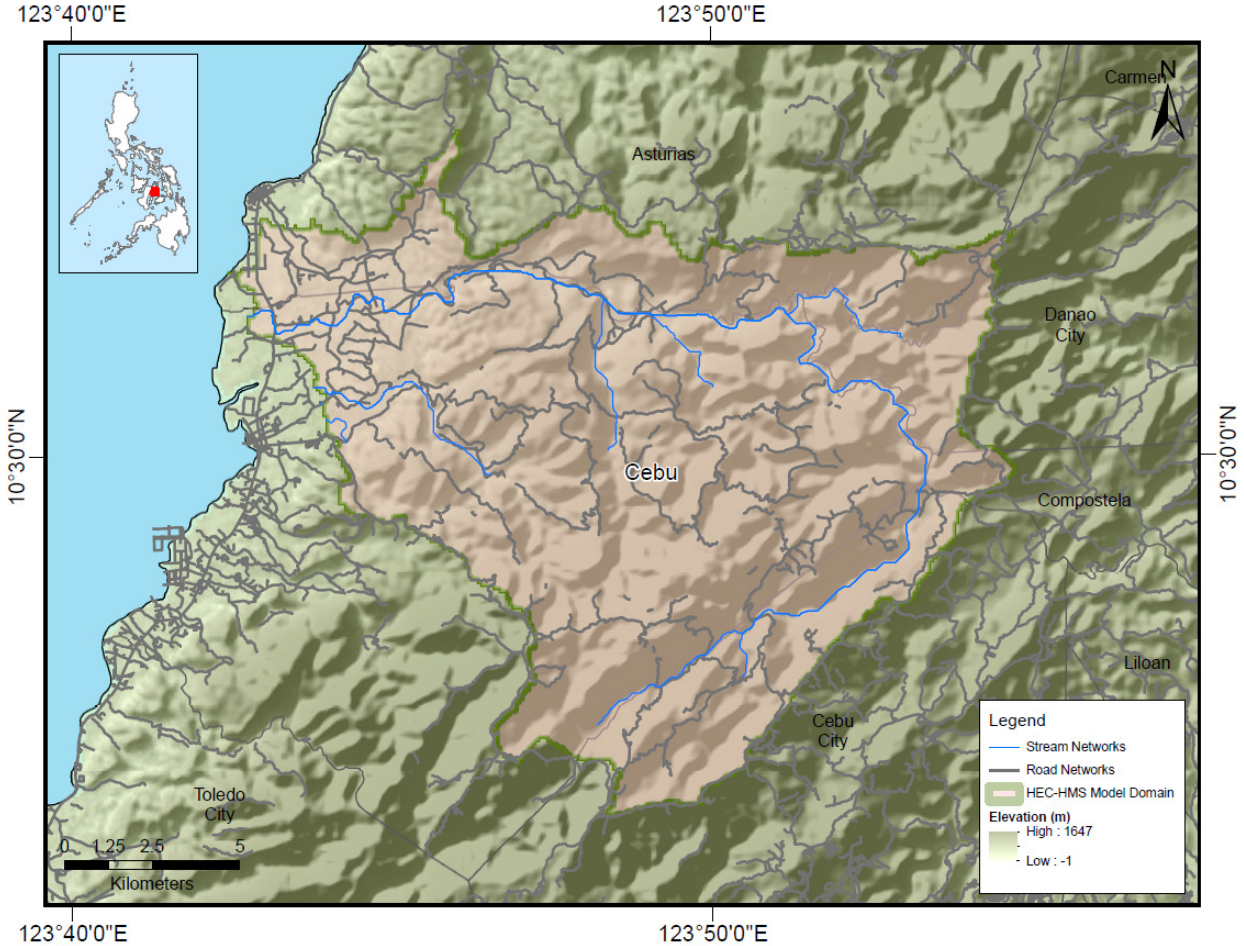

Figure 1. Map of Balamban River Basin (in brown)

CHAPTER 2: LIDAR DATA ACQUISITION OF THE BALAMBAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Acuna, Engr. Gerome Hipolito, Ms. Julie Pearl S. Mars, and Jeriel Paul A. Alamban, Geol.

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 Balamban 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 Balamban 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)
BLK36D	1000	30	50	200	30	130	5
BLK36E	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."

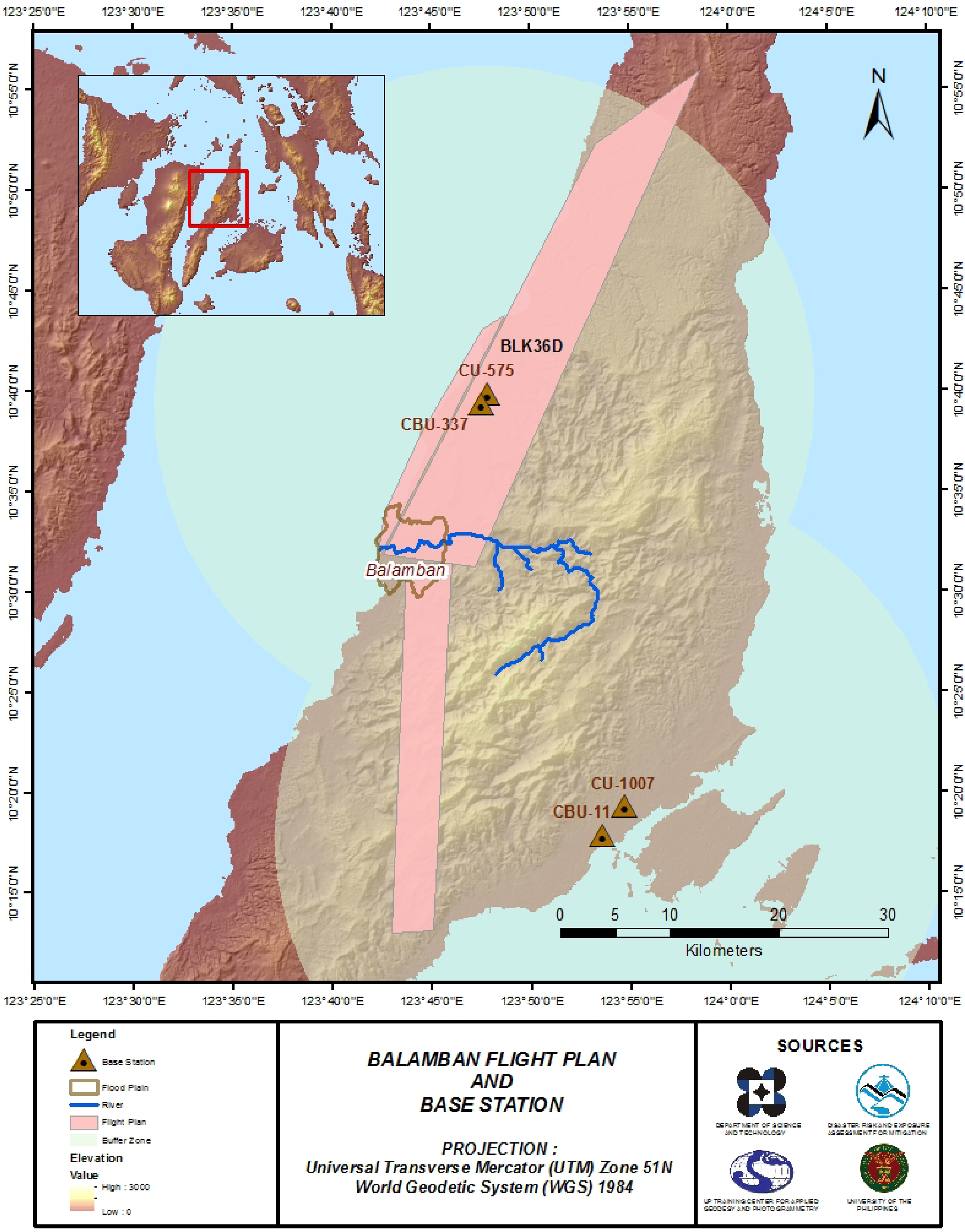

Figure 2. Flight Plan and base station used for the Balamban Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA ground control points: CBU-11 and CBU-337 which are of second (2nd) order accuracy. Two (2) NAMRIA benchmarks were also recovered: CU-1007 and CU-575 which are of first (1st) order accuracy. These benchmarks were used as vertical reference points and were also established as ground control points. The certifications for the NAMRIA reference points and benchmarks are found in Annex A-2 while the baseline processing reports for the established control points are found in Annex A-3. These were used as base stations during flight operations for the entire duration of the survey (August 6 and 12, 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 Balamban floodplain are shown in Figure 2.

Figure 3 to Figure 6 show the recovered NAMRIA control station within the area. In addition Table 2 to Table 5 show the details about the following NAMRIA control stations and established points, Table 6 shows the list of all ground control points occupied during the acquisition with the corresponding dates of utilization. The list of team members are found in Annex 4.

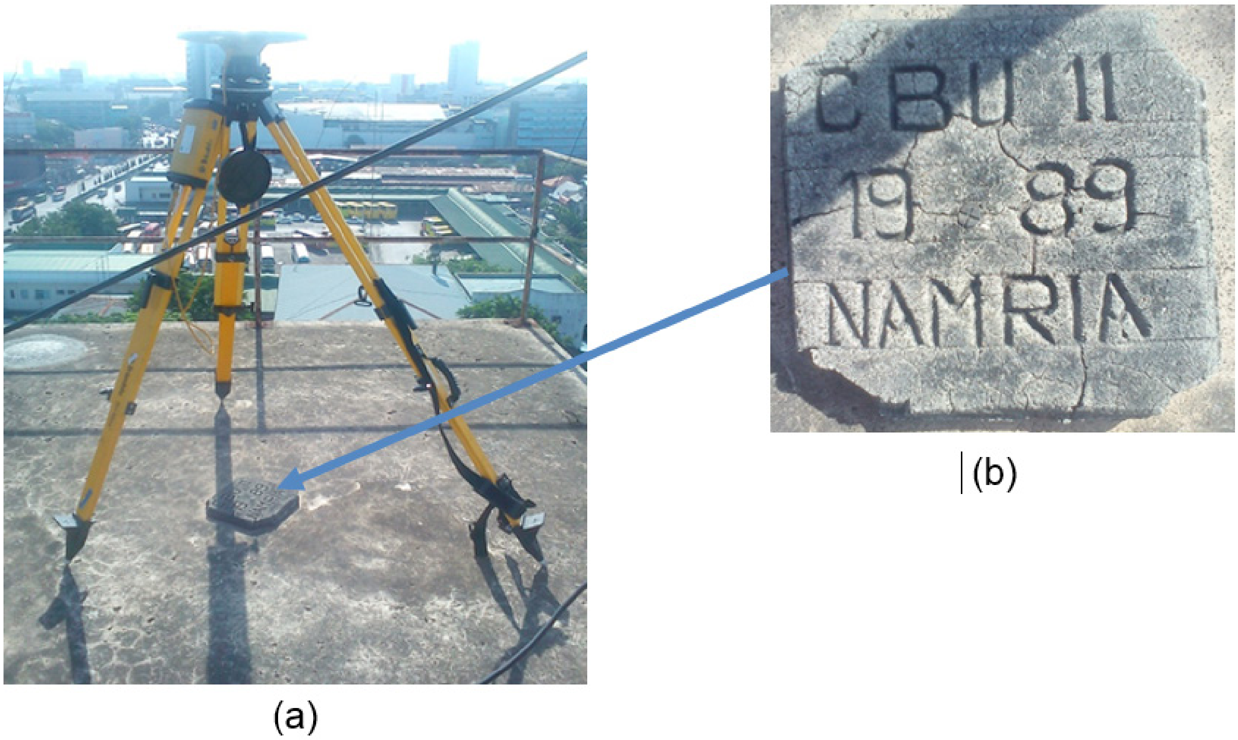

Figure 3. GPS set-up over CBU-11 on the roof top of the 75 feet concrete tower of Metro Cebu Fire Station, Cebu City Proper (a) and NAMRIA reference point CBU-11 (b) as recovered by the field team.

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 Of 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

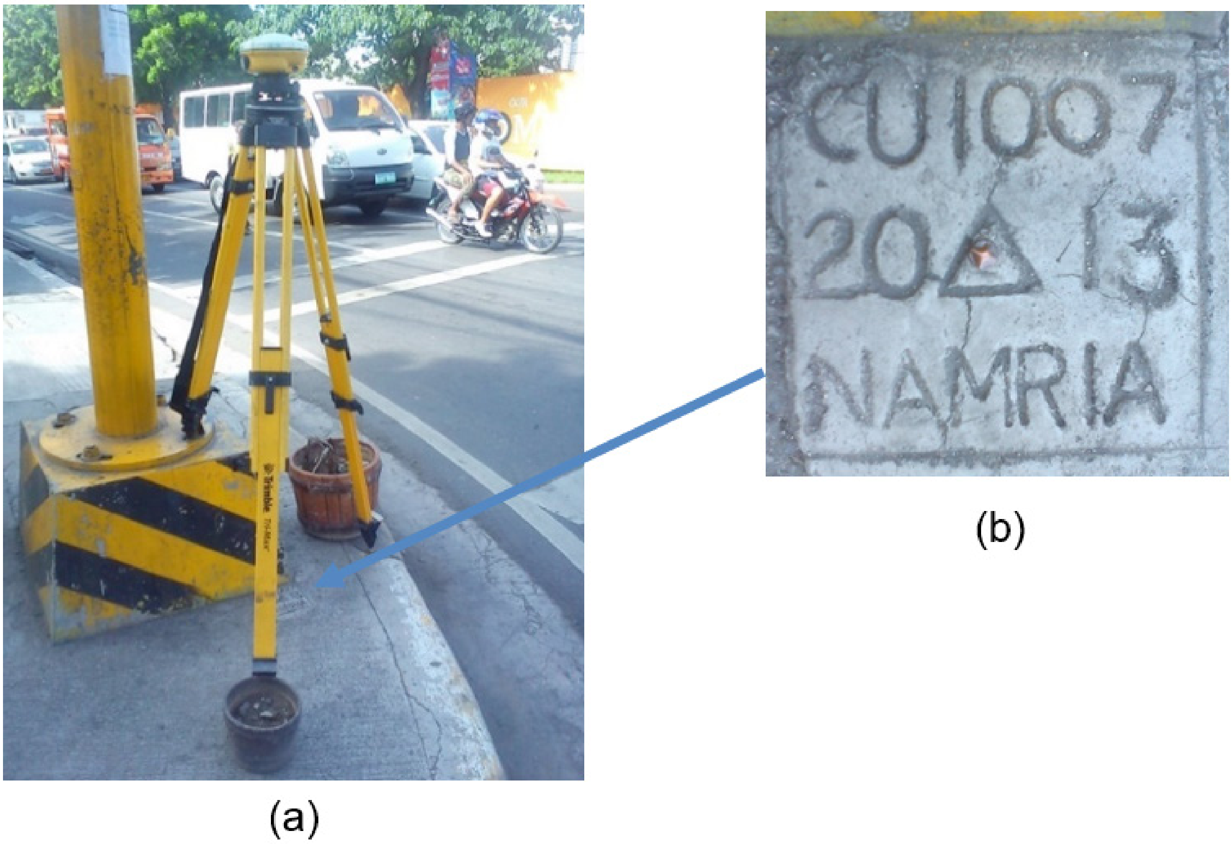

Figure 4. GPS set-up over CU-1007 along F. Cabang National Road and Juan Luna Avenue, in the base of the stop light NW of PLDT panel, Barangay Mabolo, Cebu City (a) and NAMRIA reference point CU-1007 (b) as recovered by the field team.

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

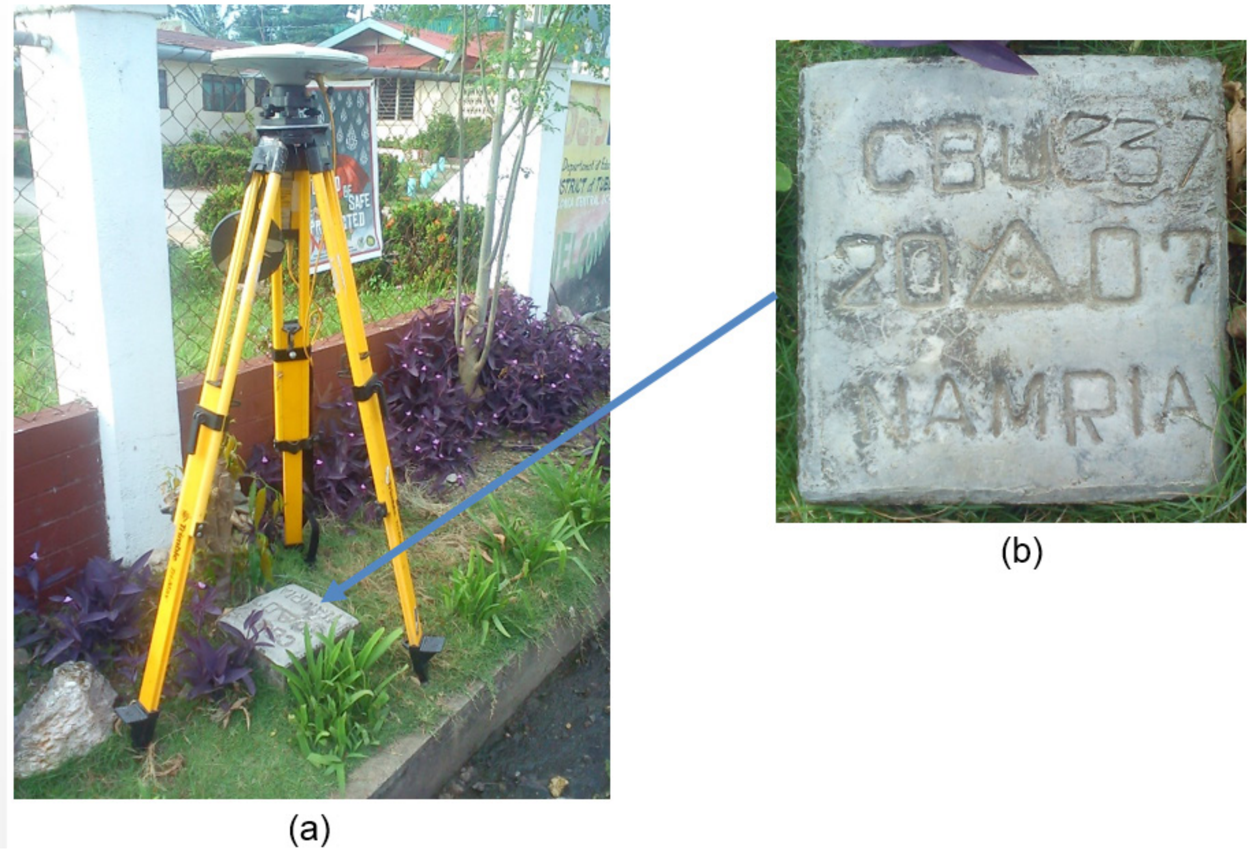

Figure 5. GPS set-up over CBU-337 outside Colonia Central School in Barangay Colonia, Tuburan, Cebu (a) and NAMRIA reference point CBU-337 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point CBU-337 used as base station for the LiDAR acquisition.

Station Name	**CBU-337**	
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° 39' 23.68236" 123° 47' 24.66142" 29.987 m
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	586,455.051 m 1,178,456.495 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 39' 19.45980" 123° 47' 29.88199" 90.660 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	586,424.79 m 1,178,044.01 m

(a)

Figure 6. GPS set-up over CU-575 at the right side of the National Road going to Tuburan Town Proper, near KM Post No. 87 in Barangay Colonia, Tuburan, Cebu (a) and NAMRIA reference point CU-575 (b) as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point CU-575 used as base station for the LiDAR acquisition.

Station Name	**CU-575**	
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° 39' 54.85976" 123° 47' 43.61537" 28.568 m
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	587,058.76 m 1,179,426.958 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 39' 50.63546" North 123° 47' 48.83243" East 89.233 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	586,498.1305 m 1,179,003.08 m

Table 6. Ground control points used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
August 6, 2014	1801P	1BLK36D218A	CBU-337 and CU-575
August 12, 2014	1827P	1BLK36ES224B	CBU-11 and CU-1007

2.3 Flight Missions

Two (2) missions were conducted to complete the LiDAR Data Acquisition in Balamban floodplain, for a total of seven hours and forty-one minutes (7+41) of flying time for RP-C9022. All missions were acquired using the Pegasus LiDAR system. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 8 shows the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for the LiDAR data acquisition of the Balamban 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
August 6, 2014	1801P	316.09	347.35	19.51	327.84	NA	4	18
August 12, 2014	1827P	134.55	145.54	5.93	139.61	NA	3	23
TOTAL		**450.64**	**492.89**	**25.44**	**467.45**	**NA**	**7**	**41**

Table 8. Actual parameters used during the LiDAR data acquisition of the Balamban Floodplain.

Flight Number	**Flying Height (m AGL)**	**Overlap (%)**	**FOV (θ)**	**PRF (khz)**	**Scan Frequency (Hz)**	**Average Speed (kts)**	**Average Turn Time (Minutes)**
BLK36D	1200	30	50	200	30	130	5
BLK36E	1000	30	50	200	30	130	5

2.4 Survey Coverage

Balamban floodplain is located in the province of Cebu with majority of the floodplain situated within the municipalities of Asturias and Tuburan. Municipality of Tabuelan is fully covered by the survey. The list of cities and municipalities surveyed, with at least one (1) square kilometer coverage, is shown in Table 9. The actual coverage of the LiDAR acquisition for Balamban floodplain is presented in Figure 7.

Table 9. List of municipalities and cities surveyed of the Balamban Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Cebu	Asturias	252.52	88.29	34.96%
	Balamban	236.29	62.96	26.65%
	Borbon	91.56	2.09	2.28%
	Minglanilla	58.44	8.3	14.20%
	Naga City	98.77	36.23	36.68%
	San Fernando	76.46	2.27	2.97%
	San Remigio	97.13	8.31	8.56%
	Tabogon	91.49	2.18	2.38%
	Tabuelan	85.94	63.98	74.45%
	Toledo City	214.07	40.88	19.10%
	Tuburan	242.78	129.4	53.30%
Total		**1545.45**	**444.89**	**28.79%**

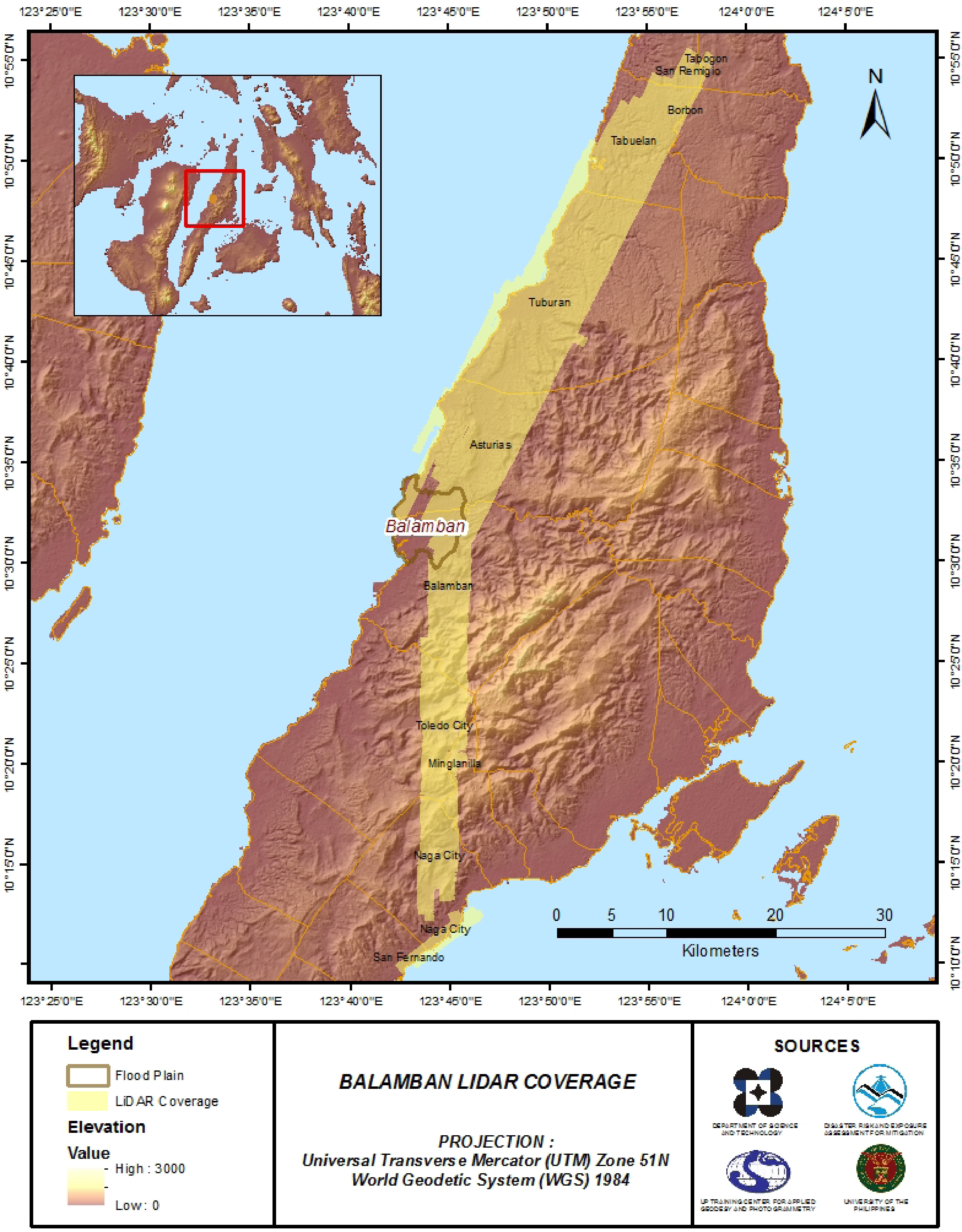

Figure 7. Actual LiDAR survey coverage of the Balamban Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE BALAMBAN FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo, Engr. Joida F. Prieto , Ailyn G. Biñas , Engr. Jennifer B. Saguran, Engr. Monalyne C. Rabino, Engr. Chelou P. Prado, Engr. Ma. Joanne I. Balaga, Engr. Erica Erin E. Elazegui

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 8.

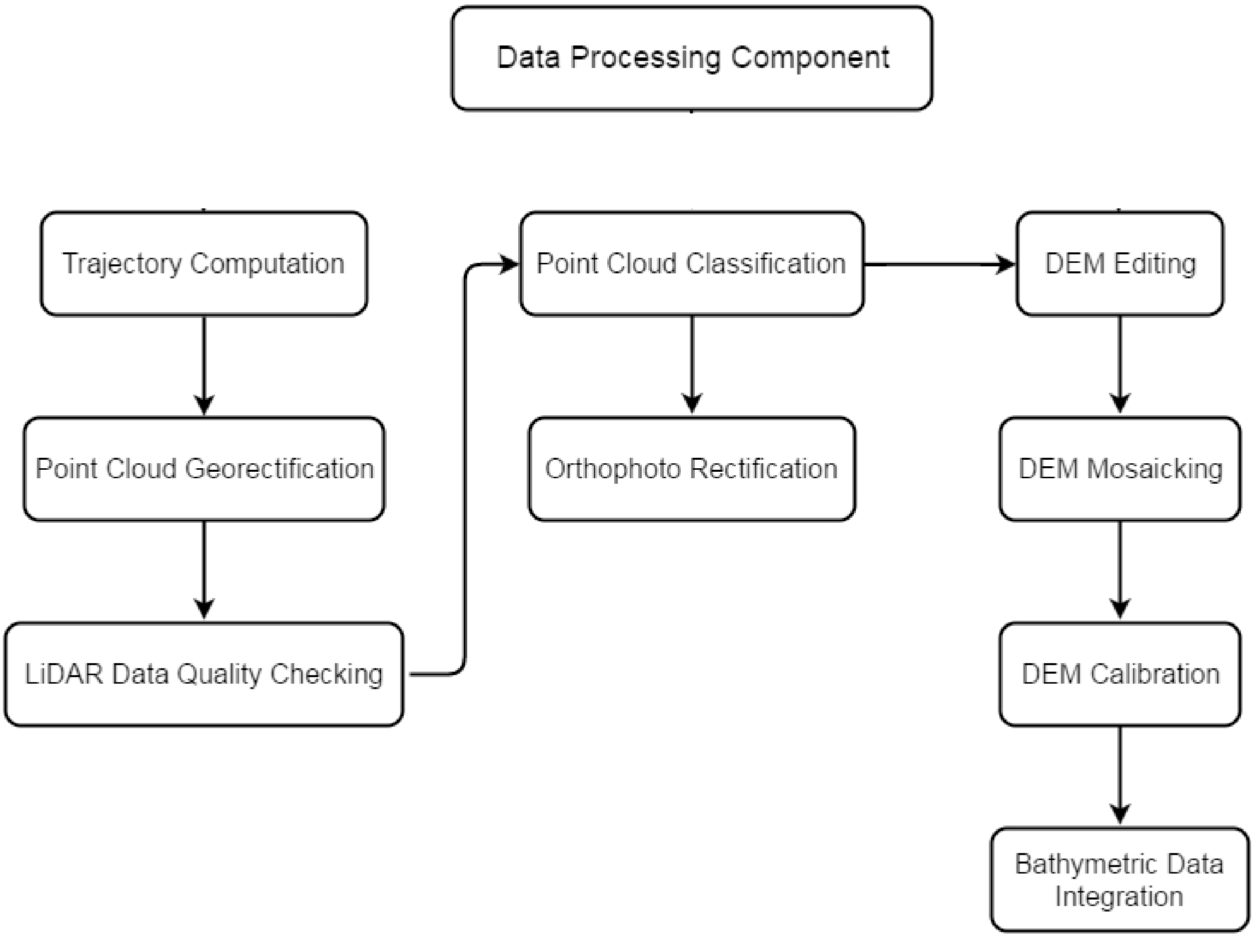

Figure 8. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Balamban floodplain can be found in Annex 5. All missions flown during the first and second survey conducted on July and August 2014 respectively used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Balamban, Cebu.

The Data Acquisition Component (DAC) transferred a total of 108.50 Gigabytes of Range data, 946 Megabytes of POS data, 33.63 Megabytes of GPS base station data, and 181.9 Gigabytes of raw image data to the data server on July 29, 2014 for the first survey and August 13, 2014 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Balamban was fully transferred on September 16, 2014, as indicated on the Data Transfer Sheets for Balamban floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 1801P, one of the Balamban flights, which is the North, East, and Down position RMSE values are shown in Figure 9. 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 August 6, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

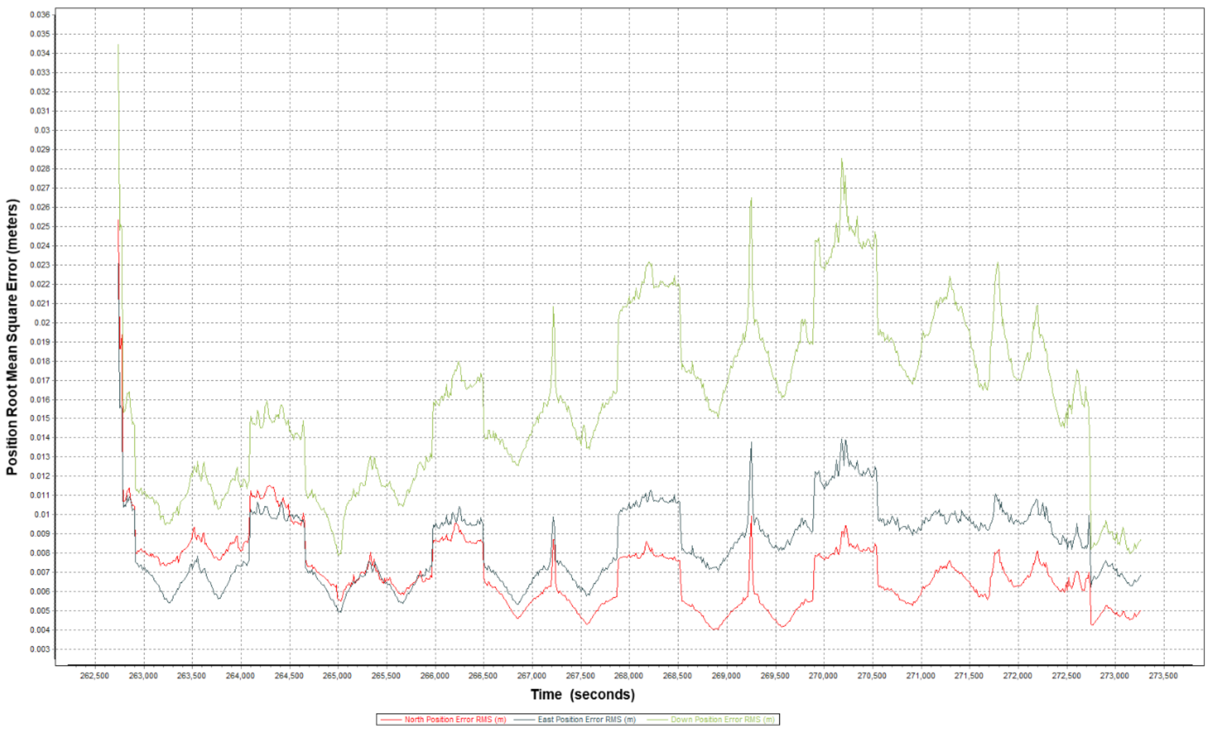

Figure 9. Smoothed Performance Metrics of Balamban Flight 1801P

The time of flight was from 262500 seconds to 273500 seconds, which corresponds to morning of August 6, 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 9 shows that the North position RMSE peaks at 1.20 centimeters, the East position RMSE peaks at 1.40 centimeters, and the Down position RMSE peaks at 2.90 centimeters, which are within the prescribed accuracies described in the methodology.

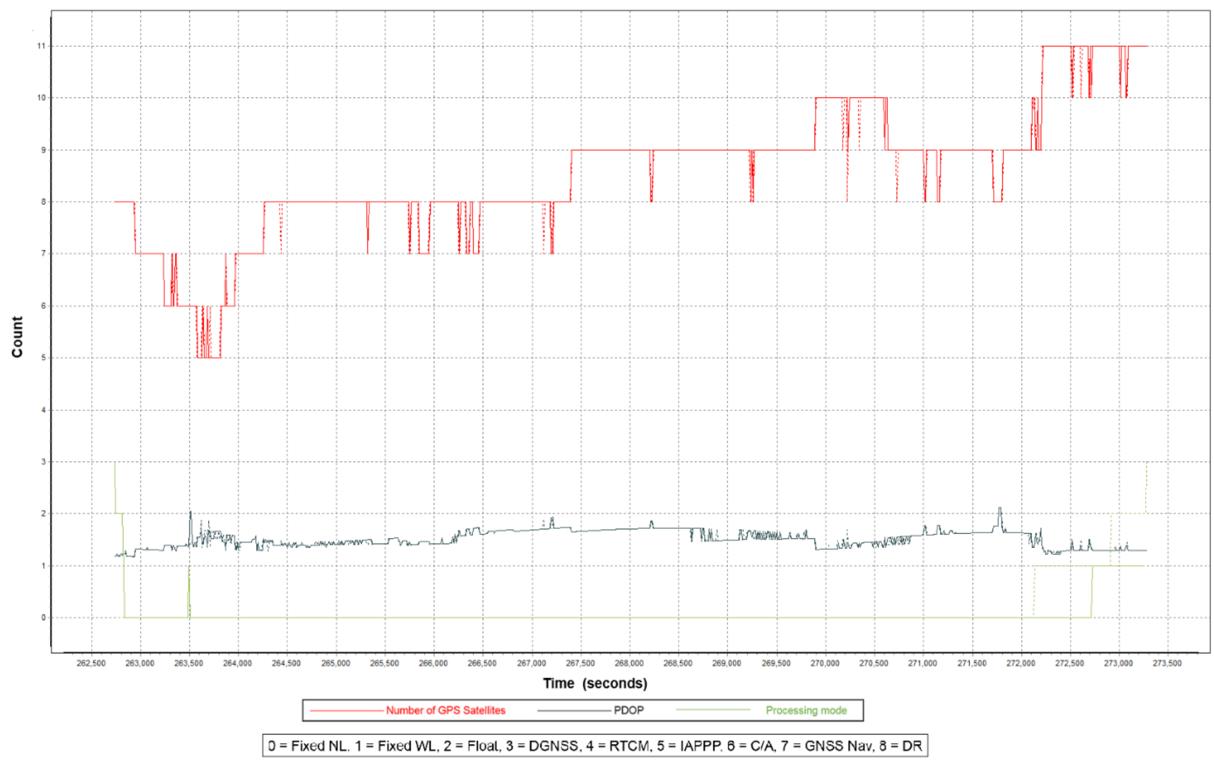

Figure 10. Solution Status Parameters of Balamban Flight 1801P

The Solution Status parameters of flight 1801P, one of the Balamban flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 10. The graphs indicate that the number of satellites during the acquisition go down to 6. Majority of the time, the number of satellites tracked was between 5 and 11. 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 Balamban flights is shown in Figure 11.

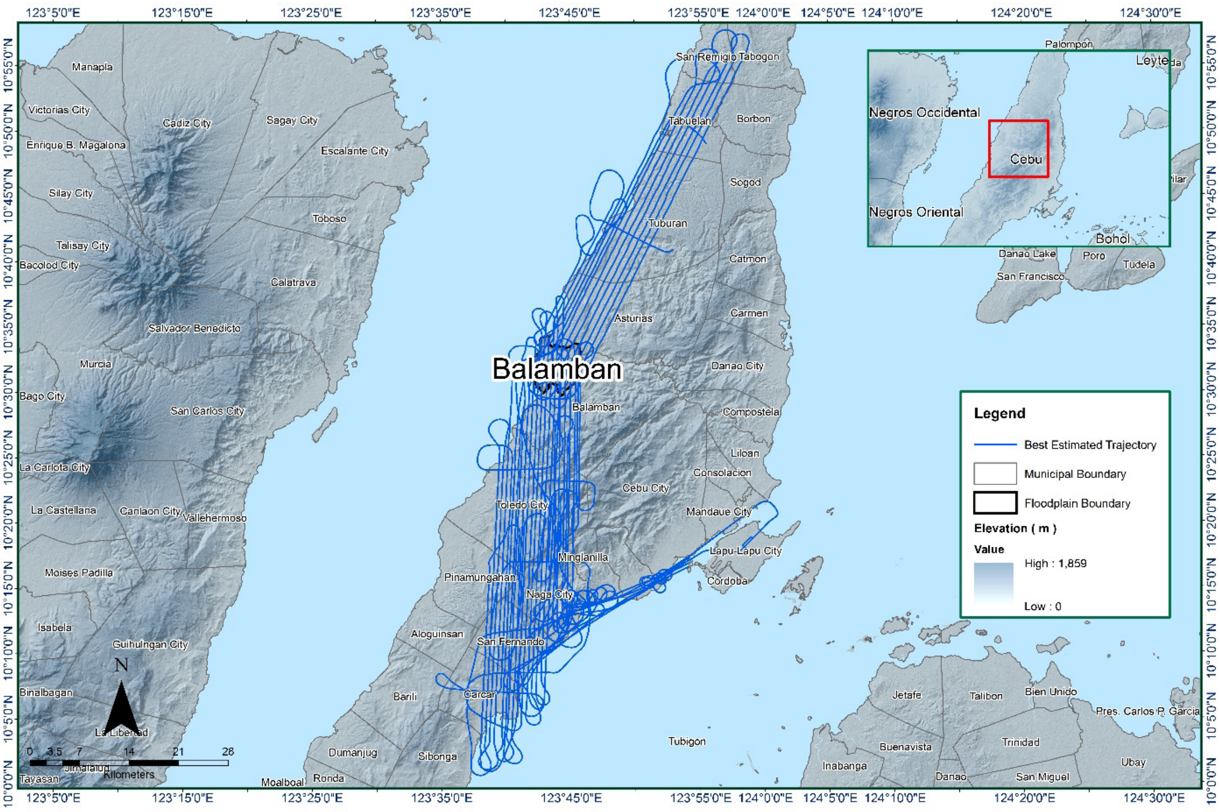

Figure 11. Best Estimated Trajectory of the LiDAR missions conducted over the Balamban Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 56 flight lines, with each flight line containing two channels, 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 Balamban floodplain are given in Table 10.

Table 10. Self-calibration Results values for Balamban flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000153
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000411
GPS Position Z-correction stdev	<0.01meters	0.0068

The optimum accuracy is obtained for all Balamban 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 Balamban Floodplain is shown in Figure 12. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

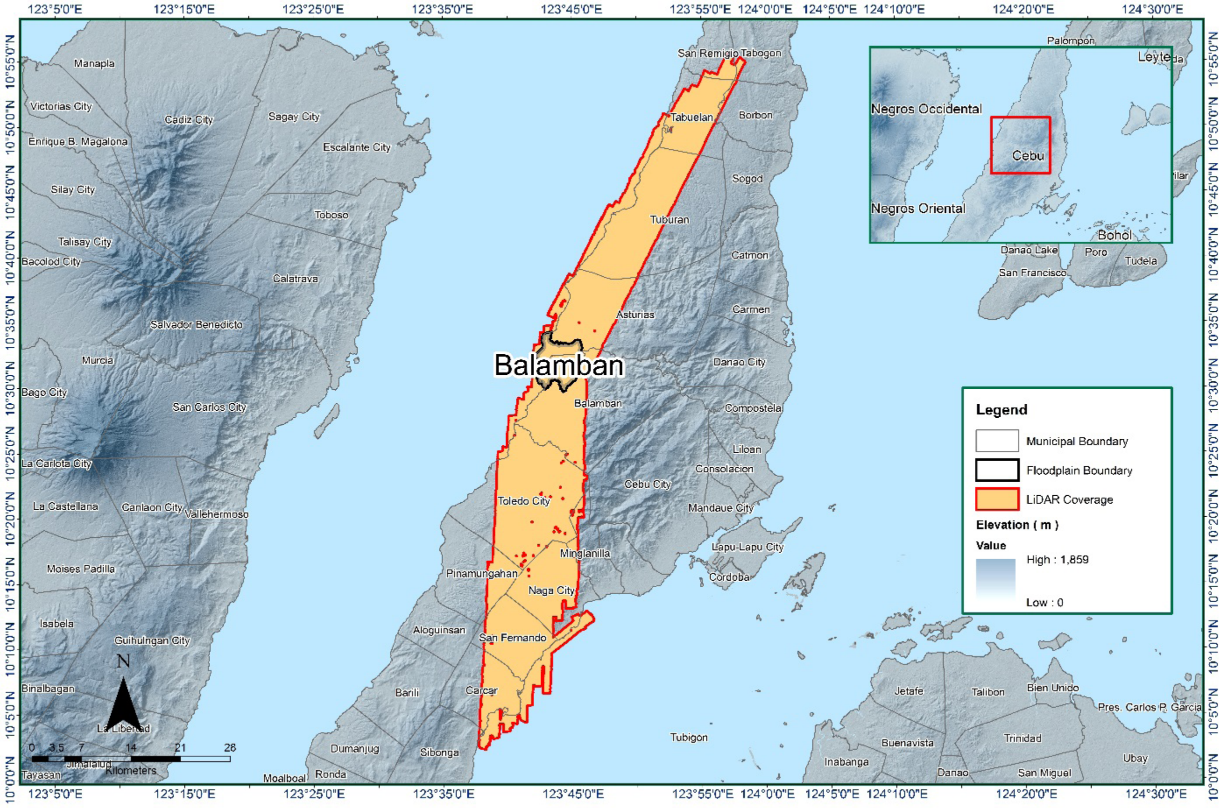

Figure 12. Boundary of the processed LiDAR data over Balamban Floodplain

The total area covered by the Balamban missions is 969.47 sq.km that is comprised of two (2) flight acquisitions grouped and merged into two (2) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Balamban Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Cebu_Blk36D	1801P	360.46
Cebu_Blk36E_supplement	1827P	147.20
Cebu_Blk36E	1777P	461.81
	1779P	
TOTAL		969.47 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 13. Since the Pegasus system both 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.

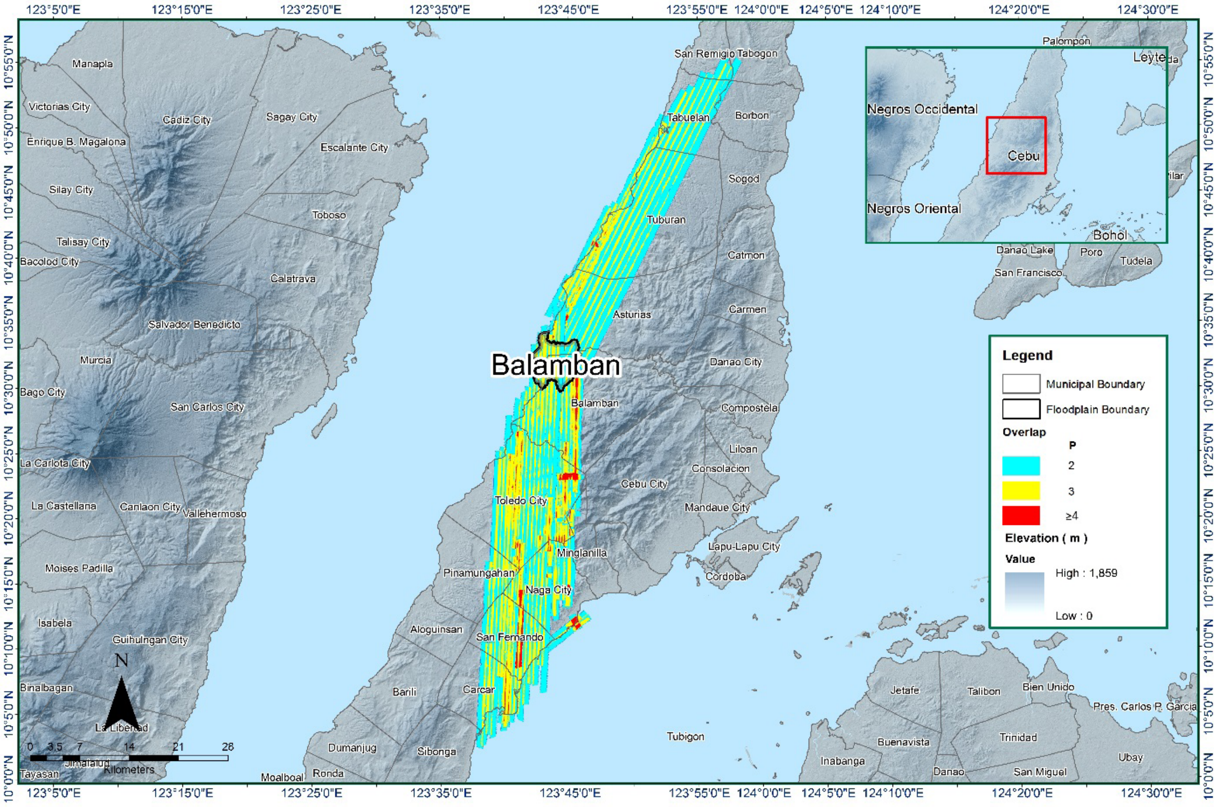

Figure 13. Image of data overlap for Balamban Floodplain.

The overlap statistics per block for the Balamban floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 32.62% and 50.75% respectively, 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 14. It was determined that all LiDAR data for Balamban floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.17 points per square meter.

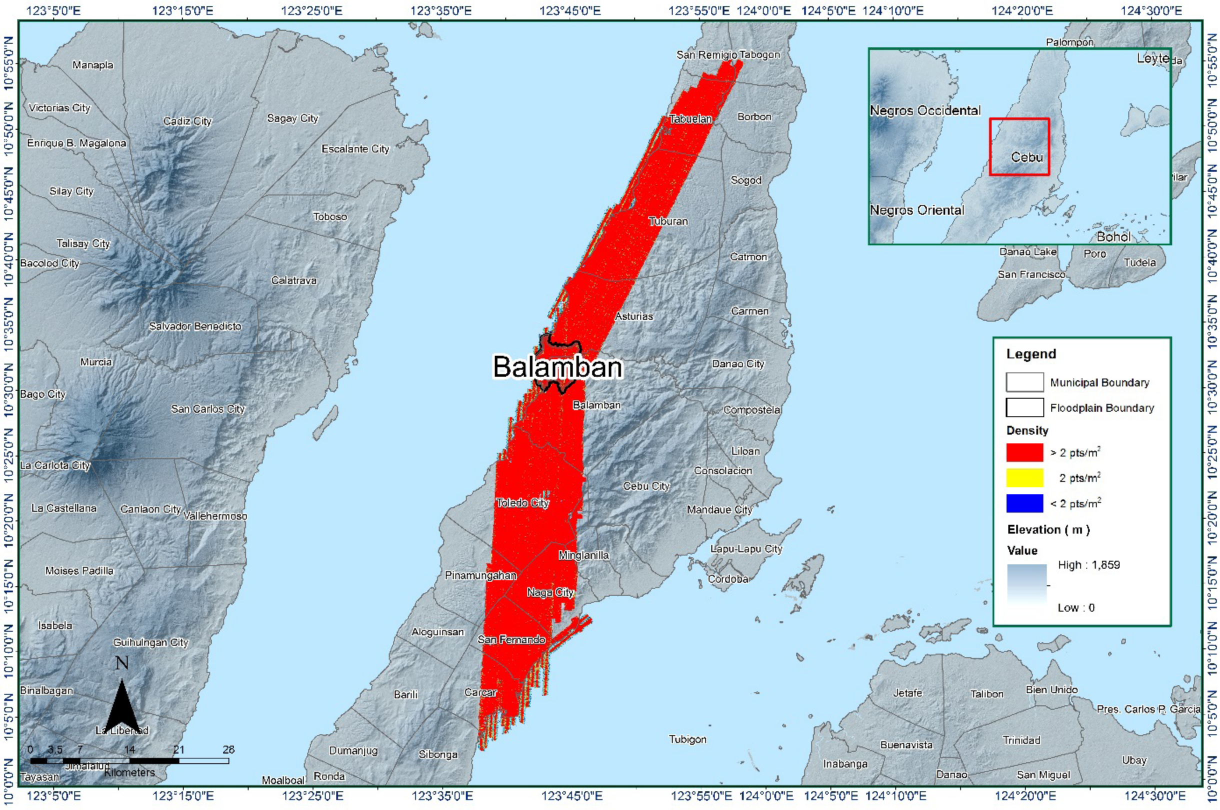

Figure 14. Pulse density map of merged LiDAR data for Balamban Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 15. 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.

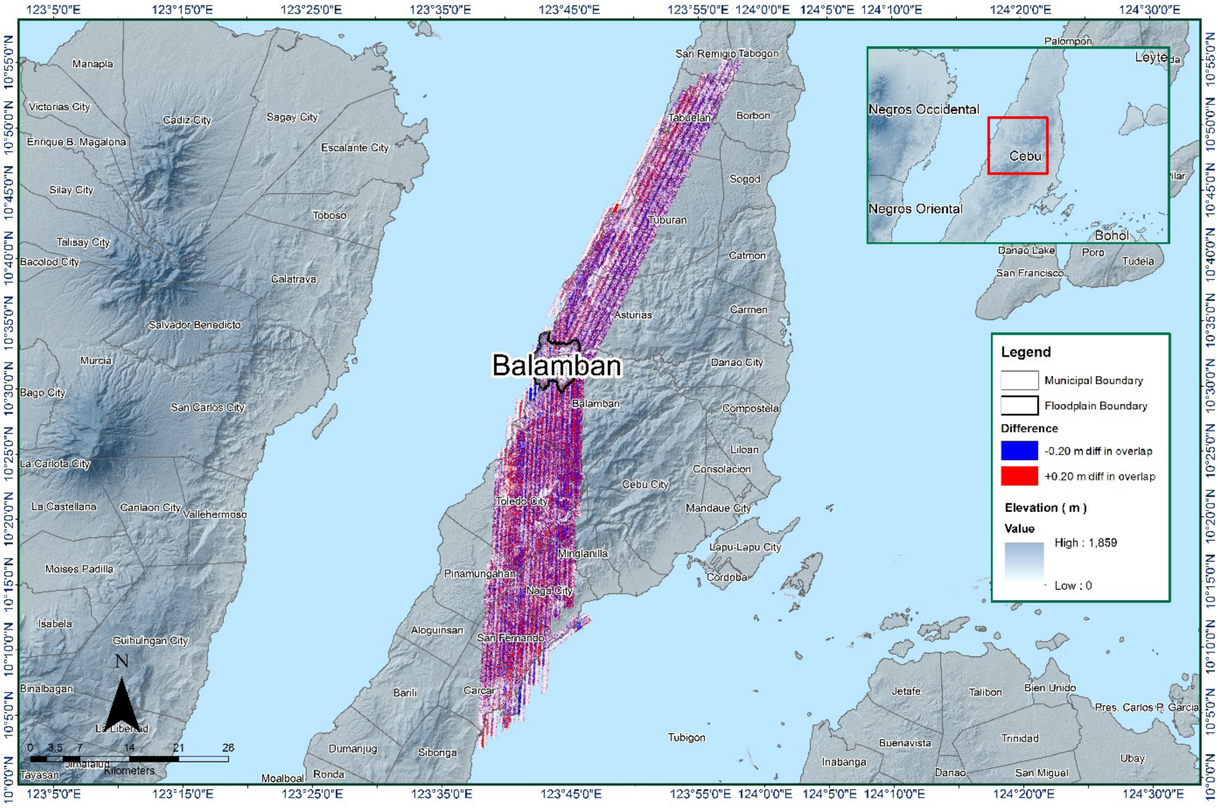

Figure 15. Elevation Difference Map between flight lines for Balamban Floodplain Survey.

A screen capture of the processed LAS data from a Balamban flight 1801P loaded in QT Modeler is shown in Figure 16. 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.

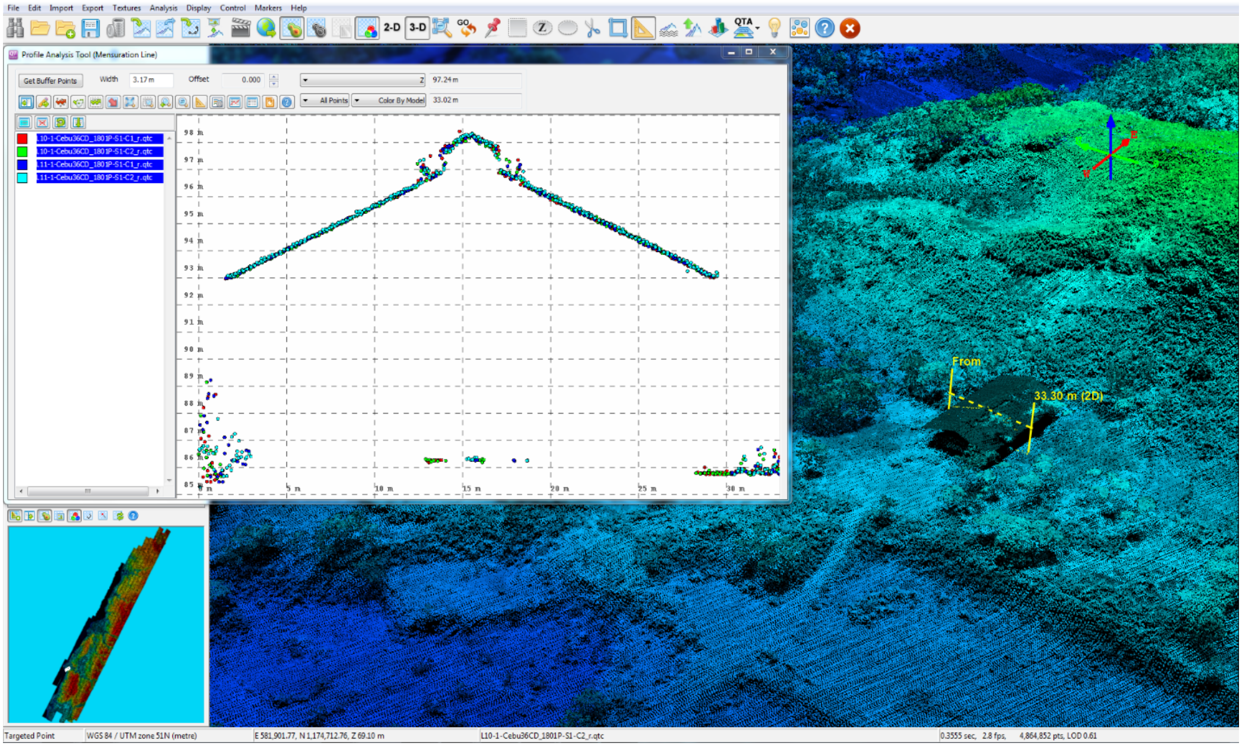

Figure 16. Quality checking for Balamban Flight 1801P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 12. Balamban classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	870,045,470
Low Vegetation	693,542,547
Medium Vegetation	1,661,610,389
High Vegetation	1,099,769,758
Building	52,914,299

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Balamban floodplain is shown in Figure 17. A total of 1,195 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 805.43 meters and 53.14 meters respectively.

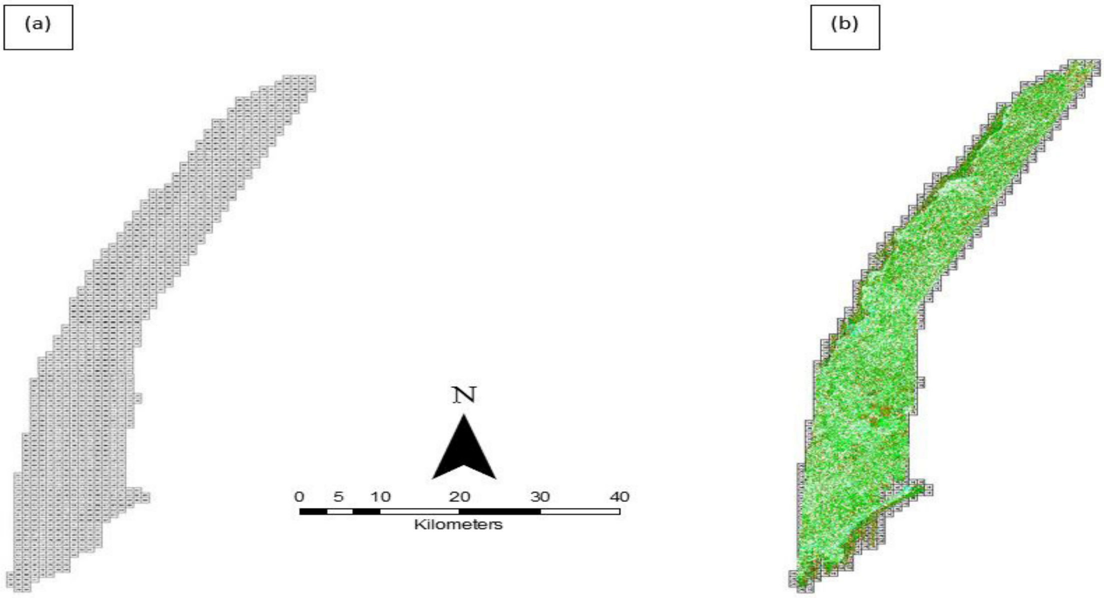

Figure 17. Tiles for Balamban Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 18. 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.

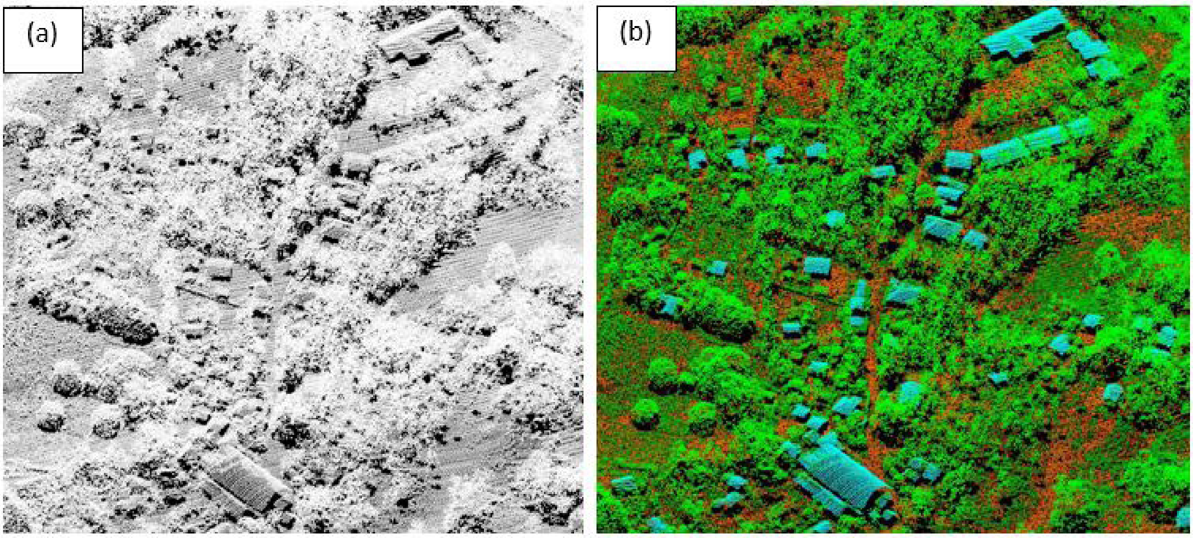

Figure 18. Point cloud before (a) and after (b) classification

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 19. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

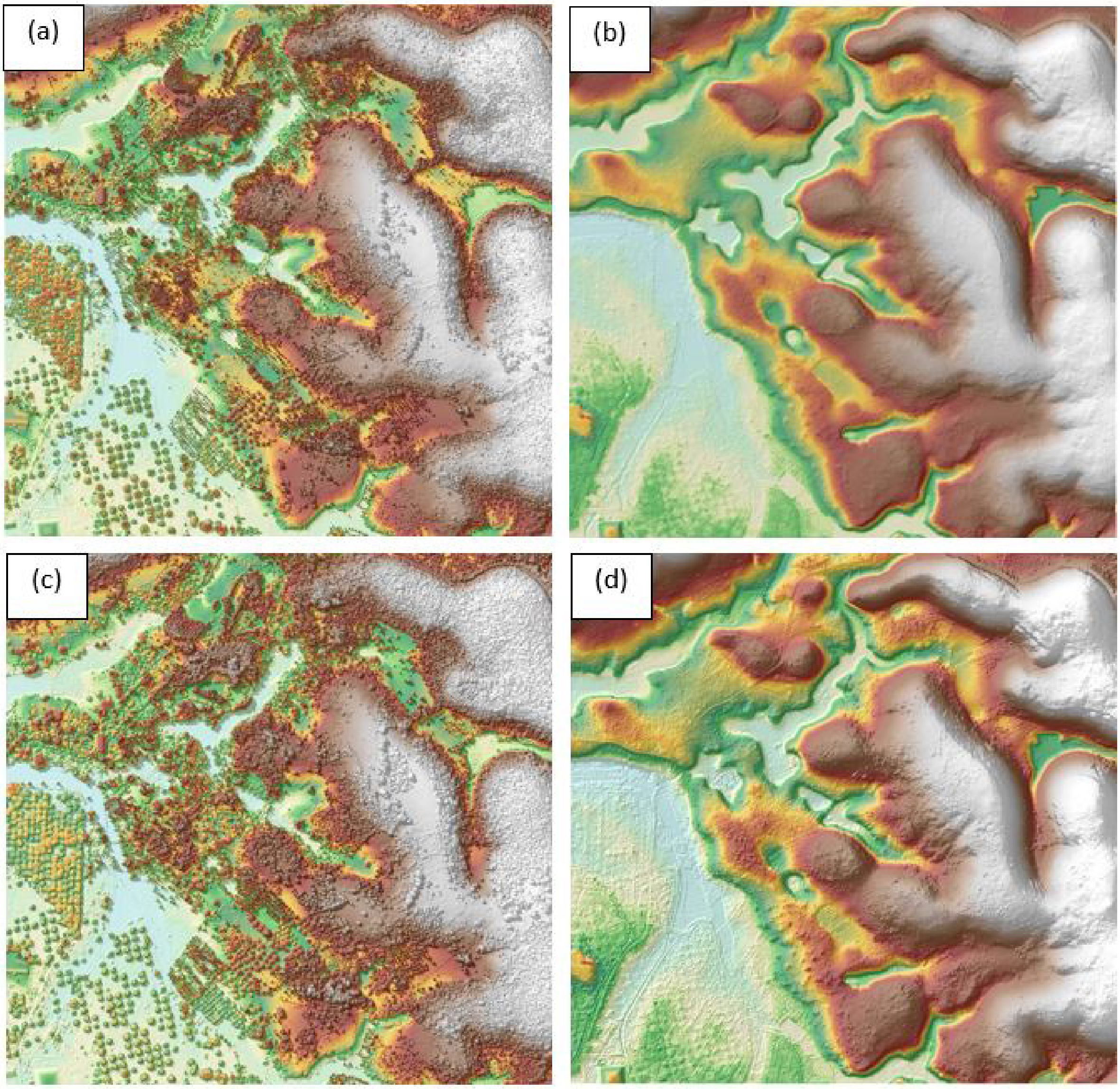

Figure 19. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Balamban Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 1154 1km by 1km tiles area covered by Balamban floodplain is shown in Figure 20. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Balamban floodplain has a total of 907.55 sq.km orthophotograph coverage comprised of 2,816 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 21.

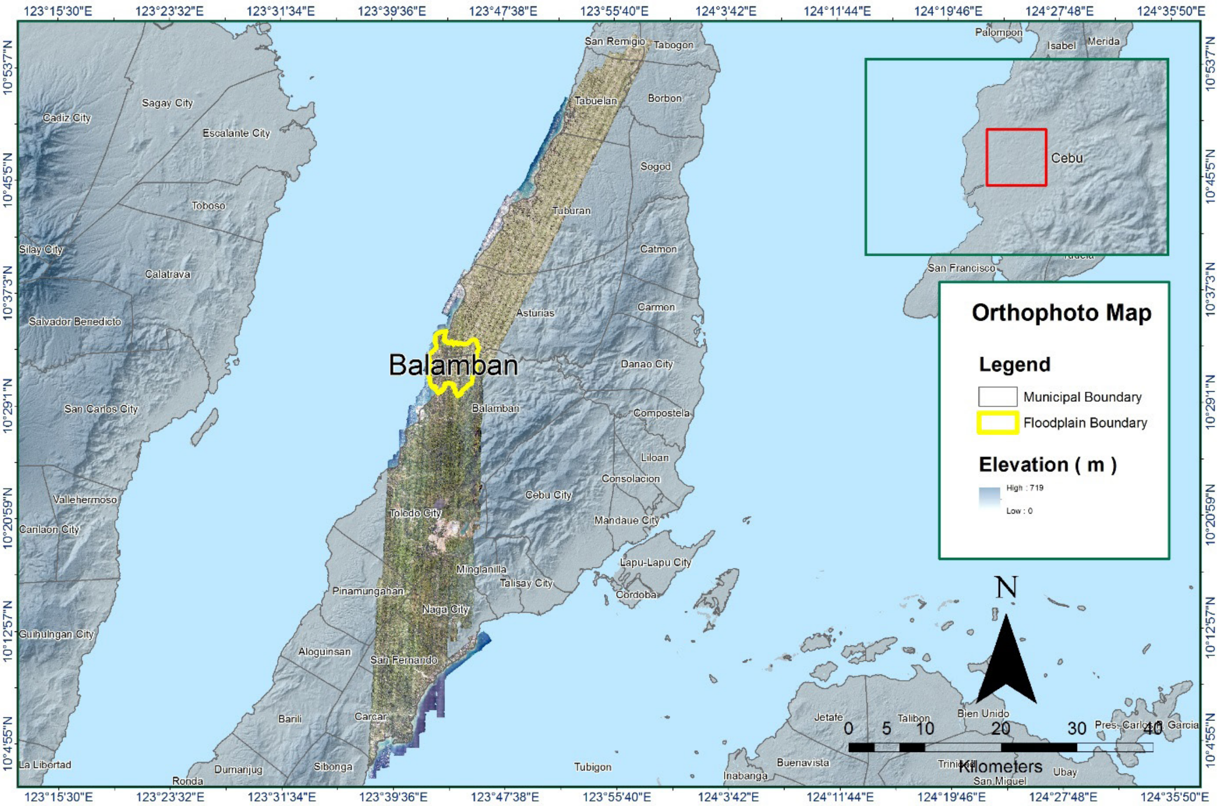

Figure 20. Balamban Floodplain with available orthophotographs.

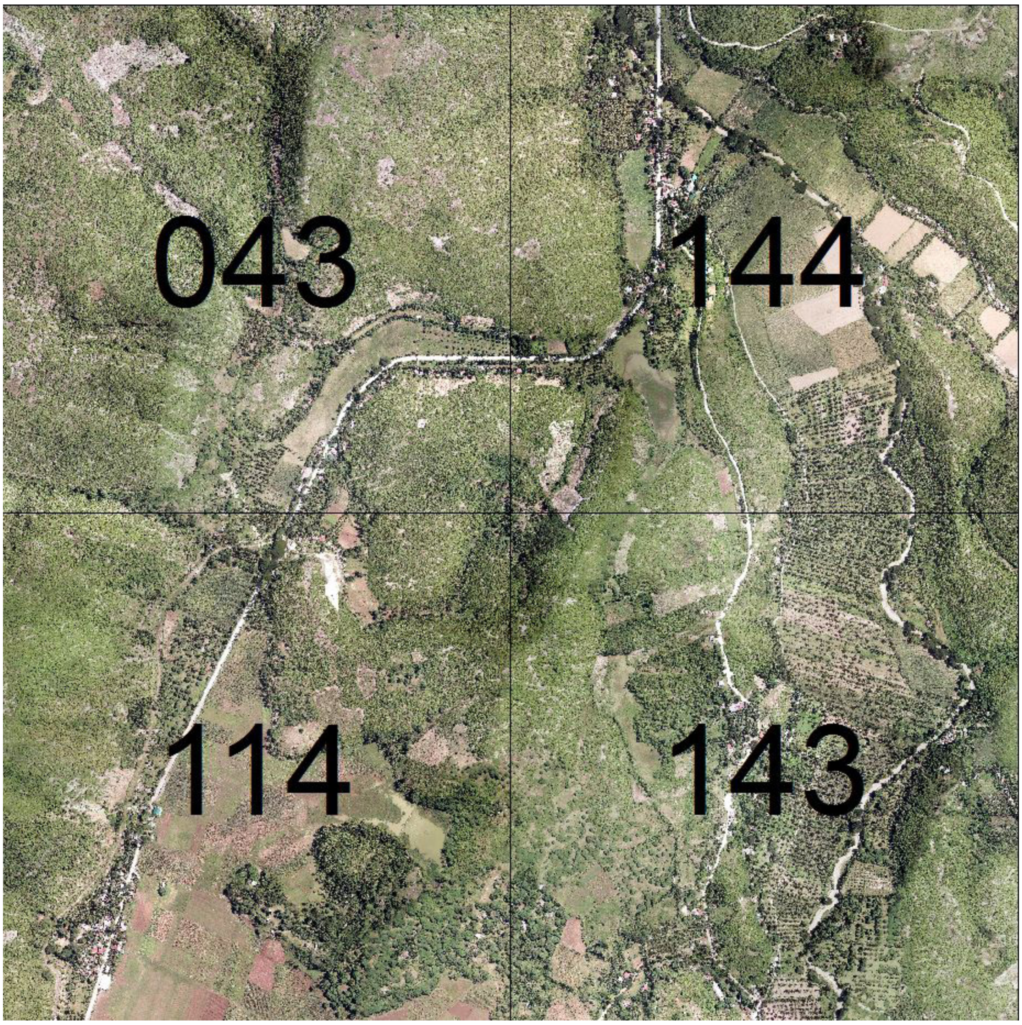

Figure 21. Sample orthophotograph tiles for Balamban Floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Balamban flood plain. These blocks are composed of Cebu block with a total area of 969.47 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Cebu_Blk36D	360.46
Cebu_Blk36E_supplement	147.20
Cebu_Blk36E	461.81
TOTAL	**969.47 sq.km**

Portions of DTM before and after manual editing are shown in Figure 21. A road (Figure 21a) has been misclassified and removed during classification process and has to be interpolated to complete the surface (Figure 21b) to allow the correct flow of water. Disconnected rivers (Figure 21c) are also edited (Figure 21d) in order to hydrologically correct the river. Another example is an interpolated river bank (Figure 21e) it has to be retrieved using object retrieval to achieve the actual surface (Figure 21f). A pit (Figure 21g) was removed through interpolation (Figure 21h).

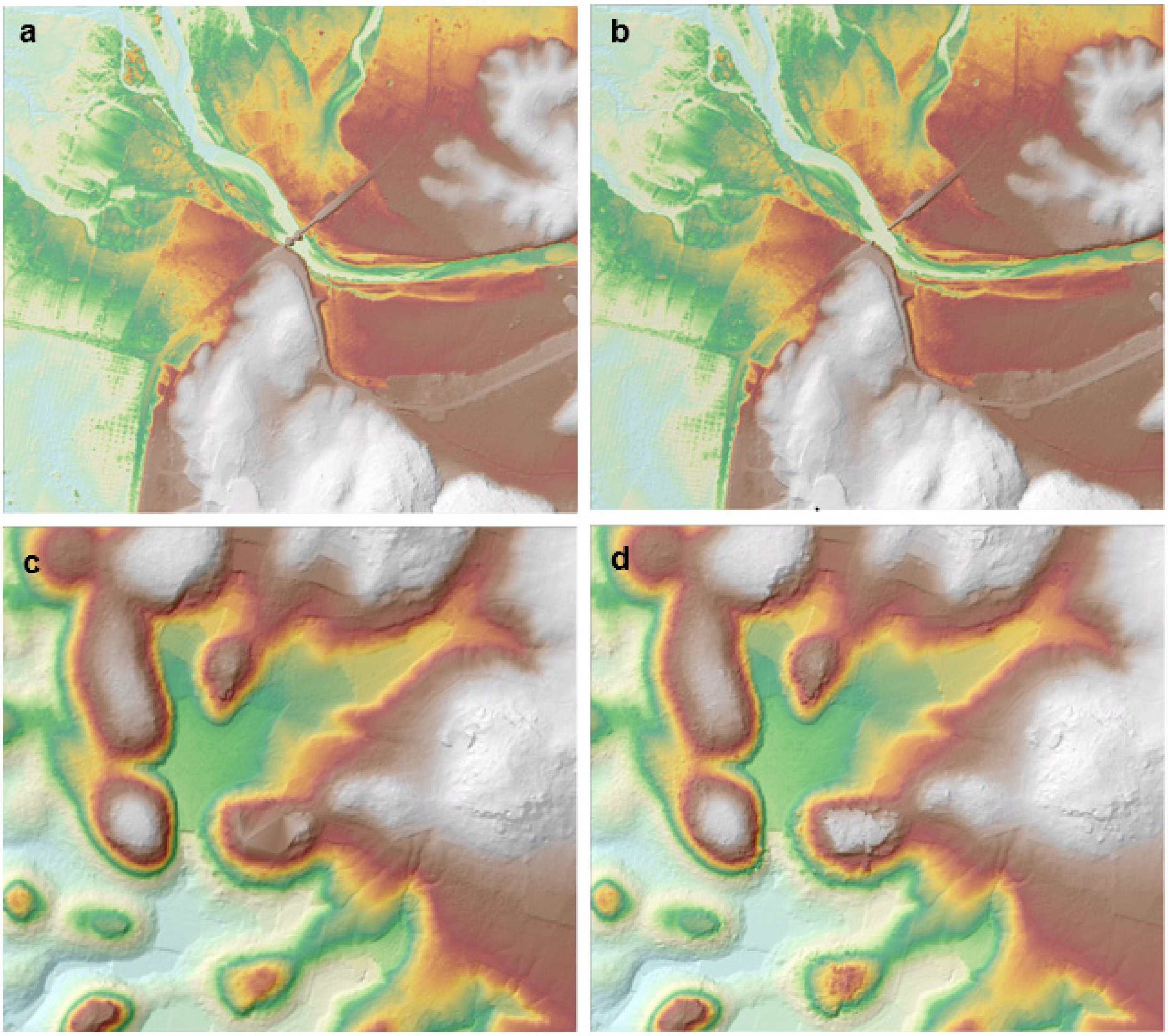

Figure 22. Portions in the DTM of Balamban floodplain – a bridge before (a) and after (b) manual editing; a mountainous area before (c) and after (d) data retrieval.

3.9 Mosaicking of Blocks

Cebu_Blk36G was used as the reference block at the start of mosaicking because of the presence of more fixed built-up structures. Cebu blocks 36E, 36F, 36G and 36H have already been mosaicked prior to mosaicking of blocks 36D and 36E_supplement. Table 14 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Balamban floodplain is shown in Figure 23. It can be seen that the entire Balamban floodplain is 100% covered by LiDAR data.

Table 14. Shift values of each LiDAR block of Balamban Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Cebu_Blk36D	0.00	0.00	-0.25
Cebu_Blk36E_supplement	0.00	0.00	-3.80
Cebu_Blk36E	0.00	0.00	-0.24

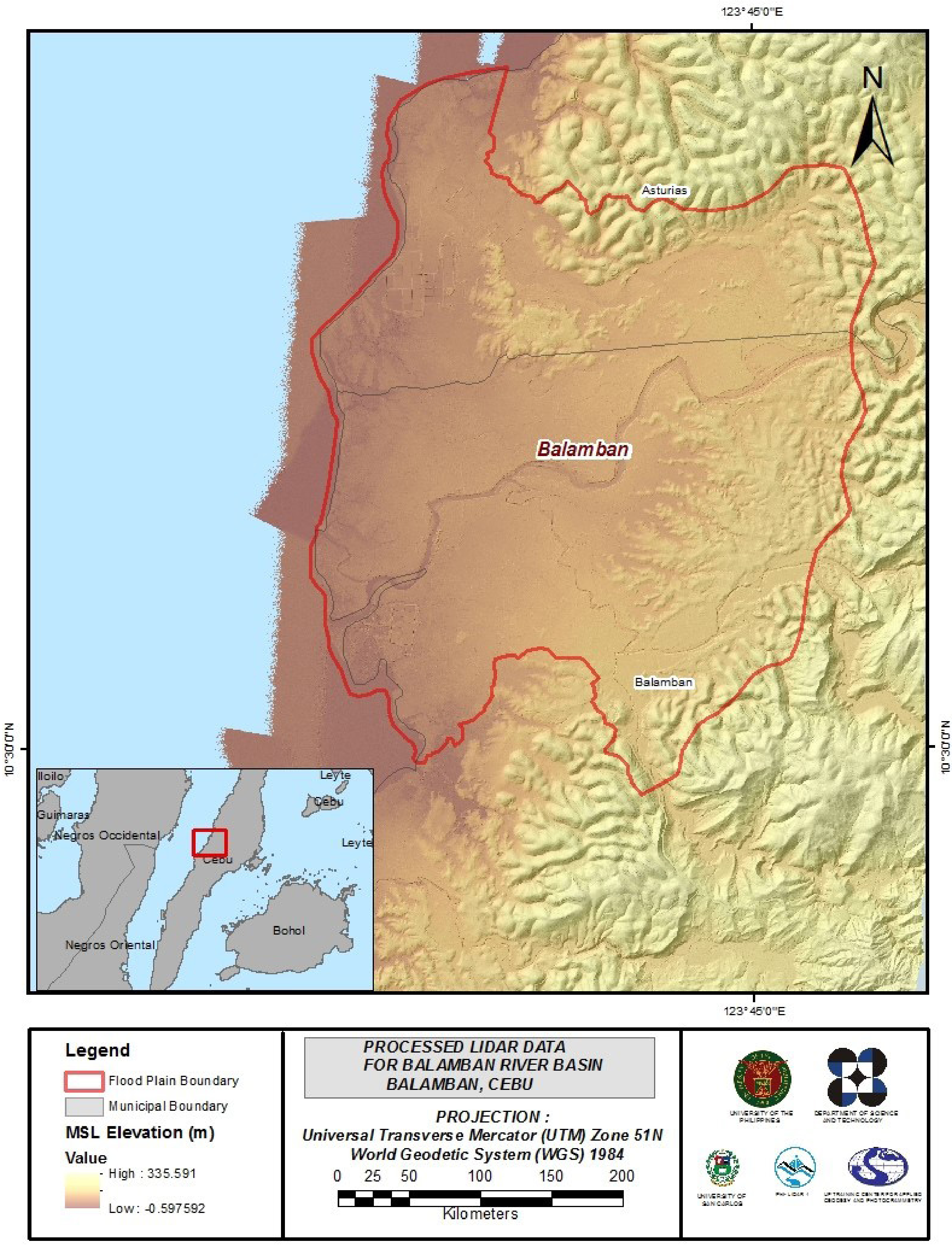

Figure 23. Map of Processed LiDAR Data for Balamban Floodplain

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 Balamban to collect points with which the LiDAR dataset is validated is shown in Figure 24. A total of 22,471 survey points were gathered for all the flood plains within the province of Cebu wherein the Balamban floodplain is located. Random selection of 80% of the survey points, resulting to 17,977 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 25. 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 15 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

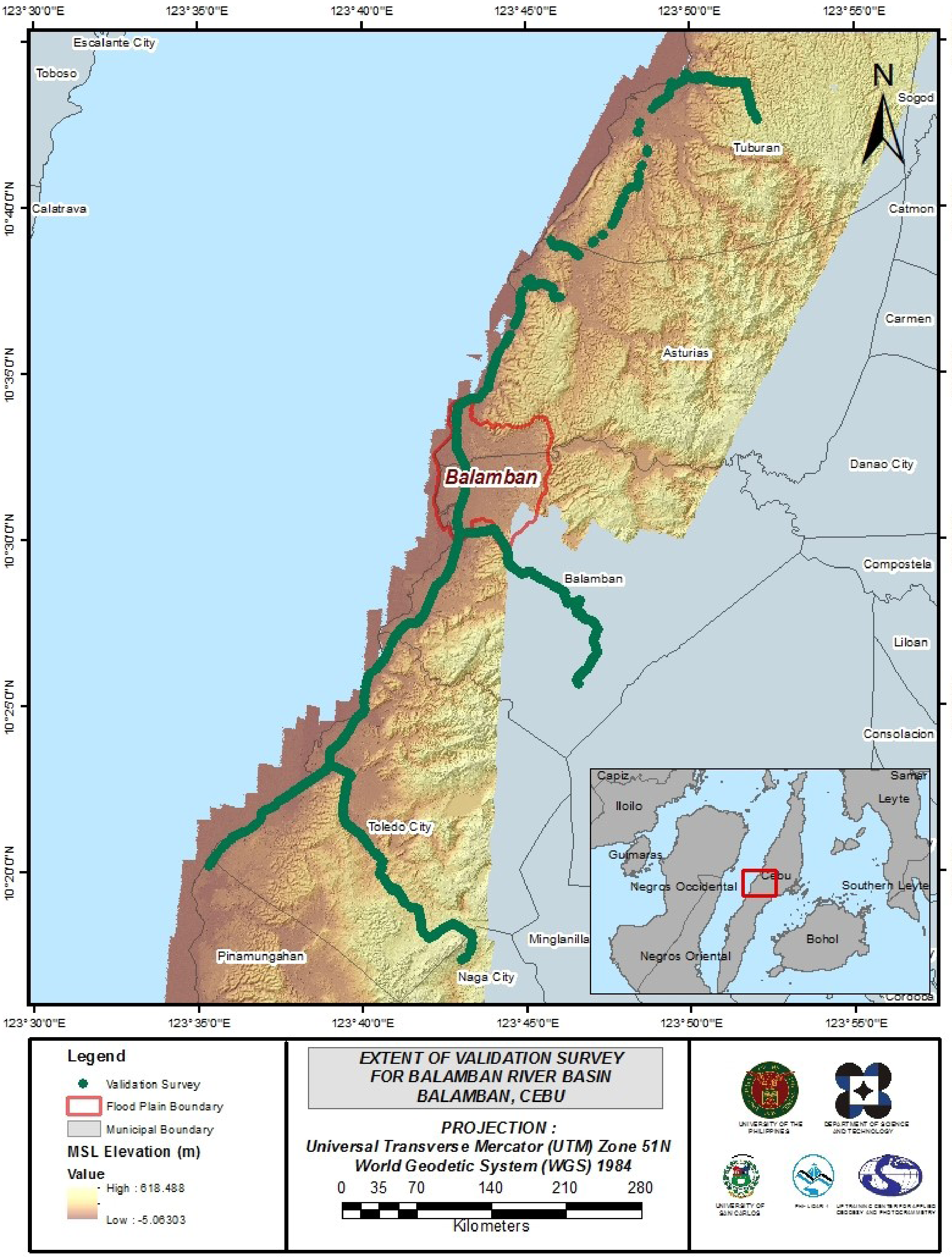

Figure 24. Map of Balamban Floodplain with validation survey points in green.

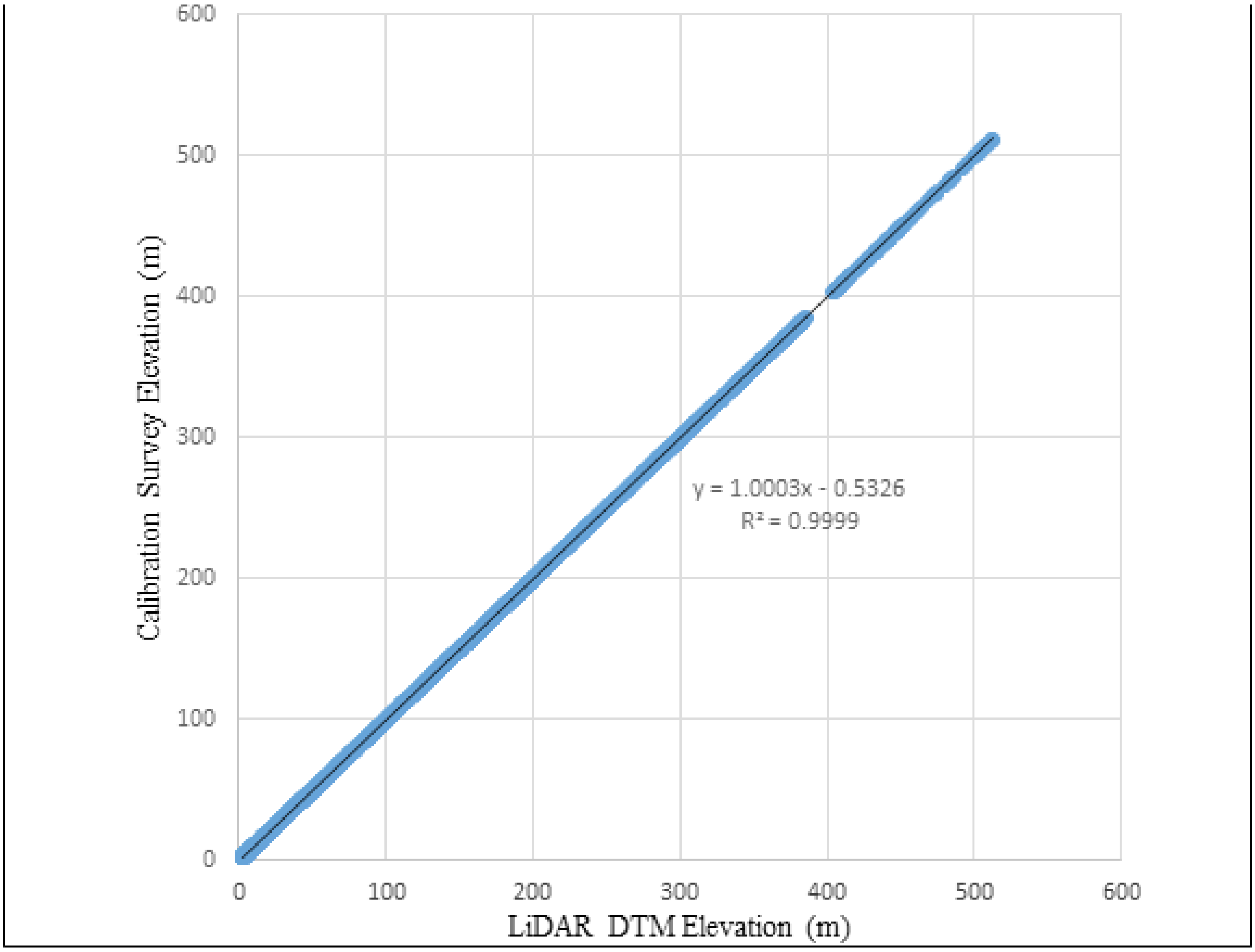

Figure 25. Correlation plot between calibration survey points and LiDAR data.

Table 15. 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 were intersected to the flood plain, resulting to 355 points, were used for the validation of calibrated Balamban 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 26. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.14 meters, as shown in Table 16.

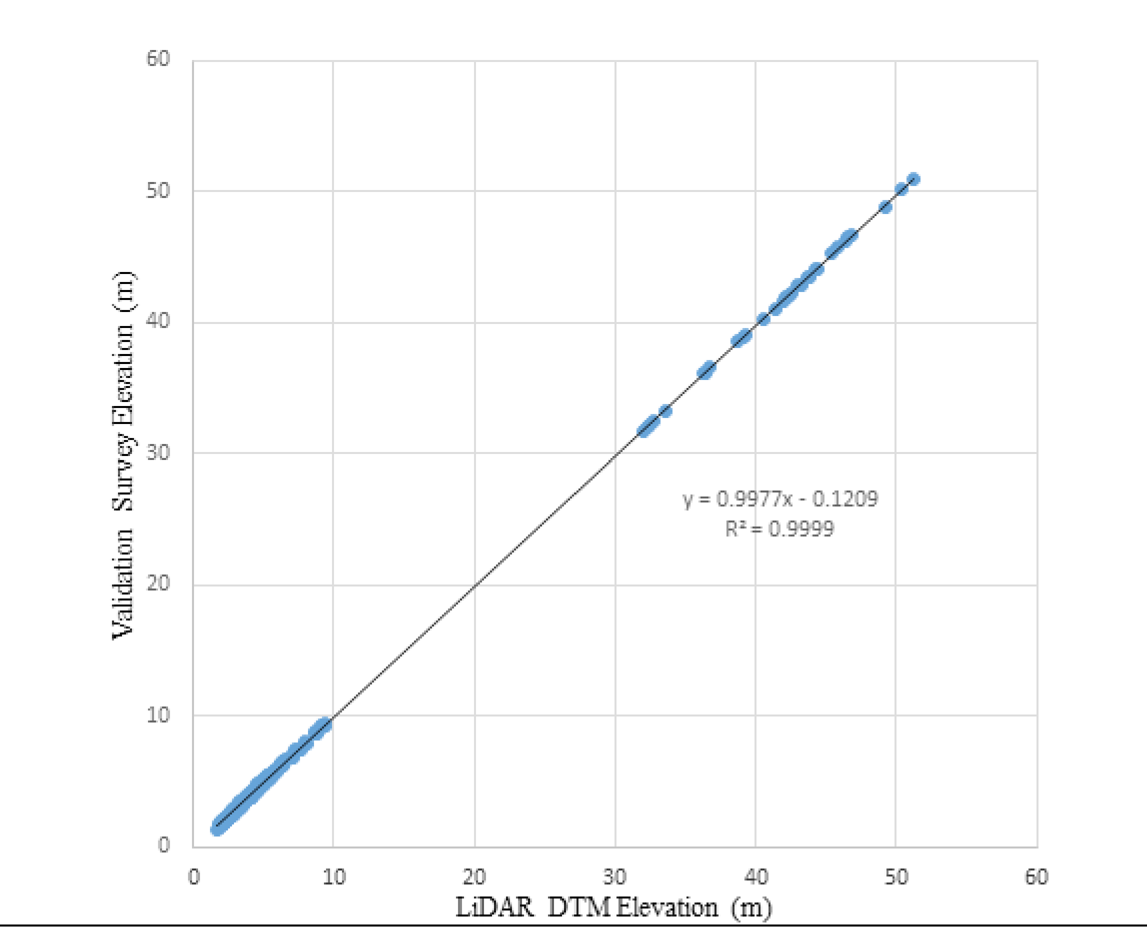

Figure 26. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.14
Average	0.14
Minimum	-0.20
Maximum	0.38

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, both centerline and zigzag data points were acquired for Balamban with 17,461 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 0.004 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Balamban integrated with the processed LiDAR DEM is shown in Figure 27.

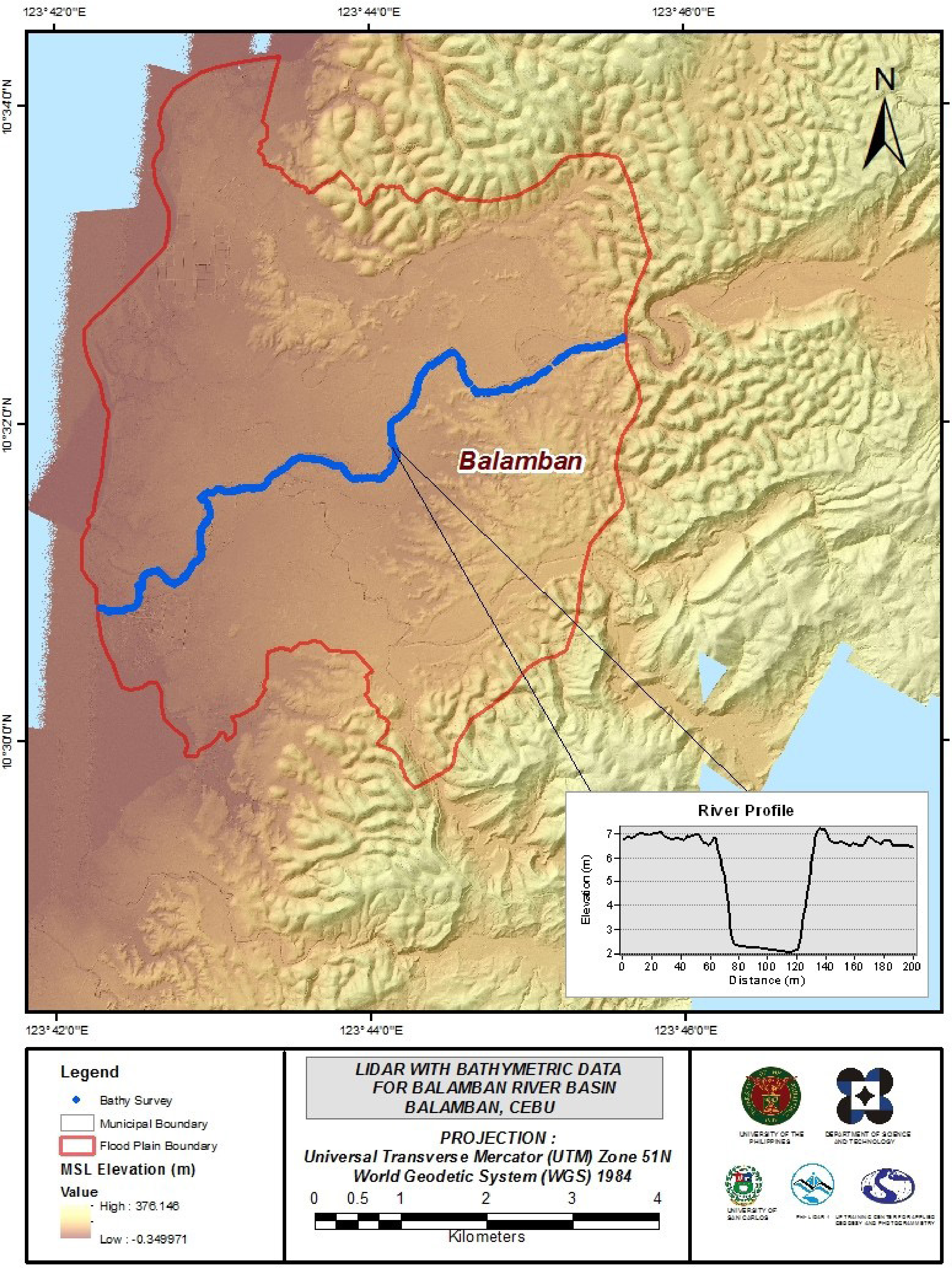

Figure 27. Map of Balamban Floodplain with bathymetric survey points shown in blue.

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

Balamban floodplain, including its 200 m buffer, has a total area of 42.83 sq km. For this area, a total of 5.0 sq.km, corresponding to a total of 1,510 building features, are considered for QC. Figure 28 shows the QC blocks for Balamban floodplain.

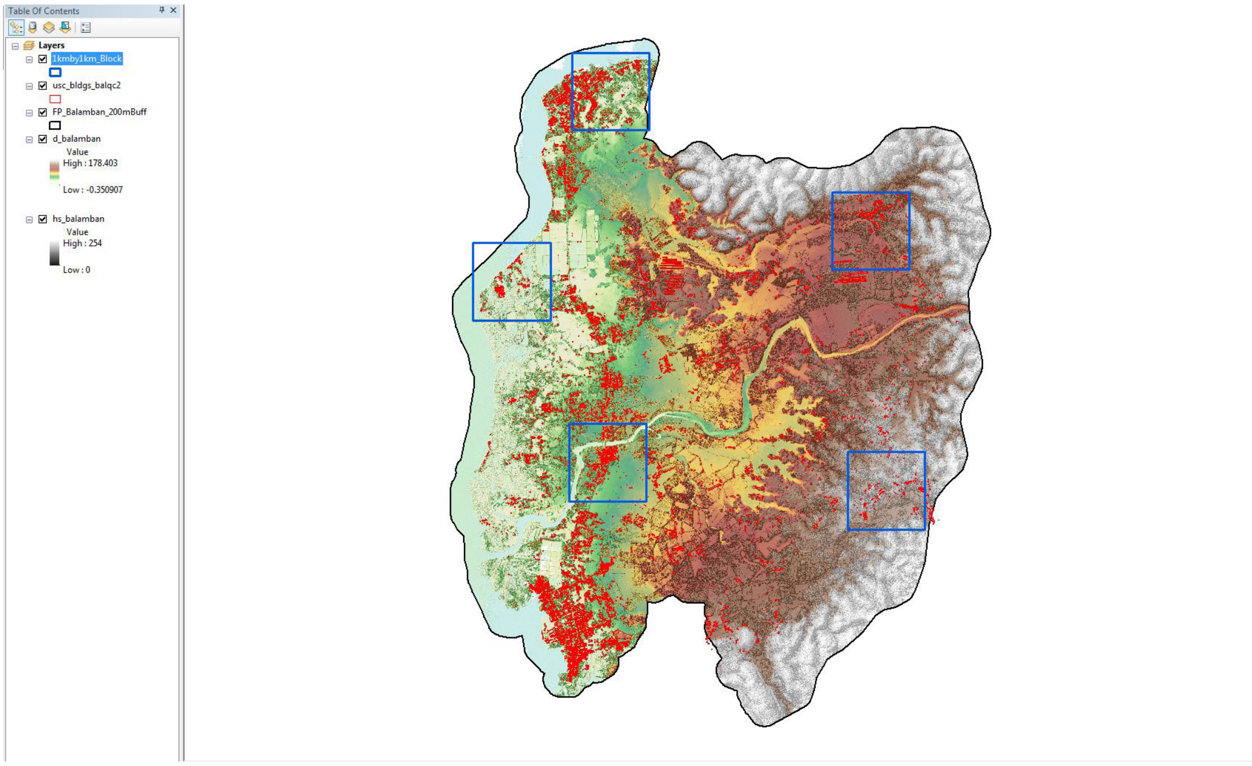

Figure28. Blocks (in blue) of Balamban building features that were subjected to QC

Quality checking of Balamban building features resulted in the ratings shown in Table 17.

Table 17. Quality Checking Ratings for Balamban Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Balamban	100.00	100.00	99.21	PASSED

3.12.2 Height Extraction

Height extraction was done for 11,002 building features in Balamban floodplain. Of these building features, 2,578 were filtered out after height extraction, resulting to 8,424 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 6.13 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 18 summarizes the number of building features per type. On the other hand, Table 19 shows the total length of each road type, while Table 20 shows the number of water features extracted per type.

Table 18. Building Features Extracted for Balamban Floodplain.

Facility Type	No. of Features
Residential	8,023
School	73
Market	14
Agricultural/Agro-Industrial Facilities	89
Medical Institutions	6
Barangay Hall	7
Military Institution	0
Sports Center/Gymnasium/Covered Court	8
Telecommunication Facilities	0
Transport Terminal	1
Warehouse	17
Power Plant/Substation	0
NGO/CSO Offices	1
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	13
Bank	3
Factory	0
Gas Station	6
Fire Station	0
Other Government Offices	10
Other Commercial Establishments	148
Total	**8,424**

Table 19. Total Length of Extracted Roads for Balamban Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Balamban	38.99	18.66	0	10.716	0	68.36

Table 20. Number of Extracted Water Bodies for Balamban Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Balamban	2	1	0	0	69	72

A total of 2 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 29 shows the Digital Surface Model (DSM) of Balamban floodplain overlaid with its ground features.

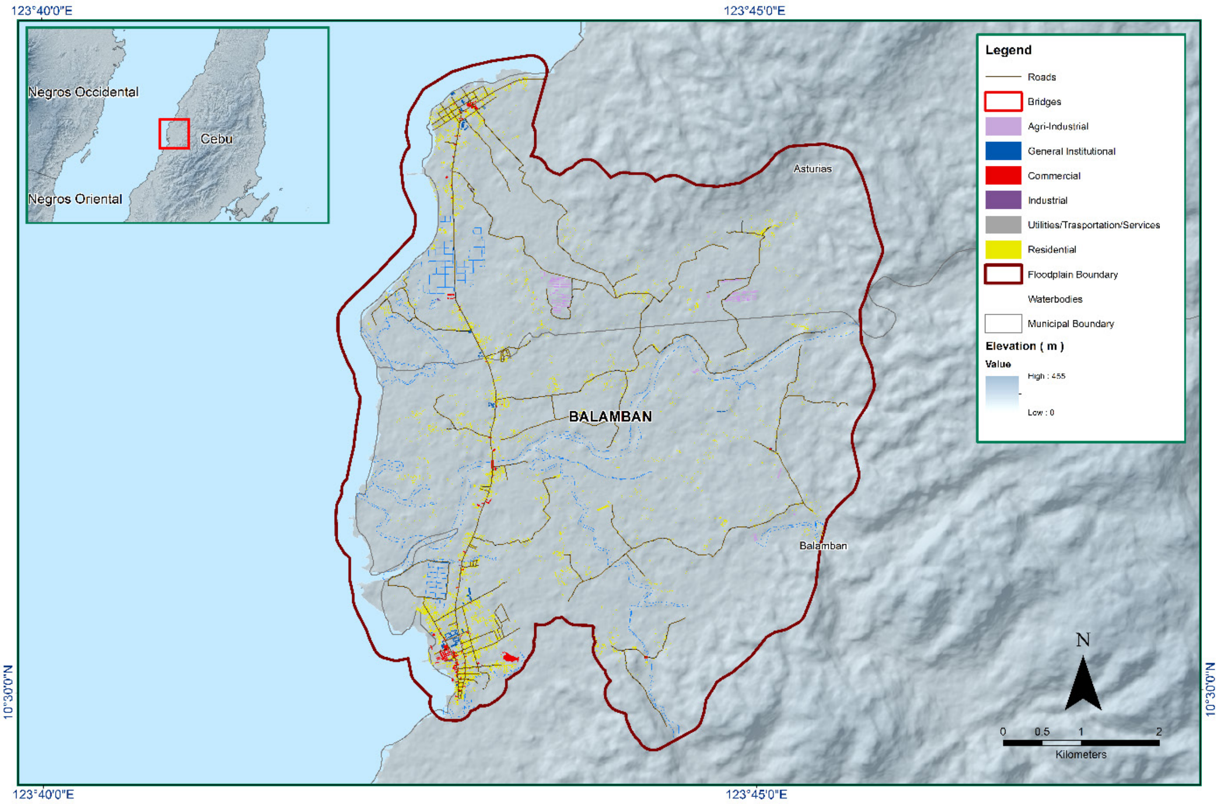

Figure 29. Extracted features for Balamban Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie Caballero, Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, For. Rodel C. Alberto, Cybil Claire Atacador, Engr. Lorenz R. Taguse

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 Balamban River on December 5 – 17, 2015 with the following scope of work: reconnaissance; control survey; cross-section survey; validation points data acquisition of about 97.43 km for the areas traversing the Municipalities of Asturias and Balamban, and Toledo City; and bathymetric survey from Brgy. Biasong down to Brgy. Cantuod, Municipality of Balamban, with an estimated length of 9.31 km using Trimble® SPS 882 GNSS PPK survey technique. The entire survey extent is illustrated in Figure 30.

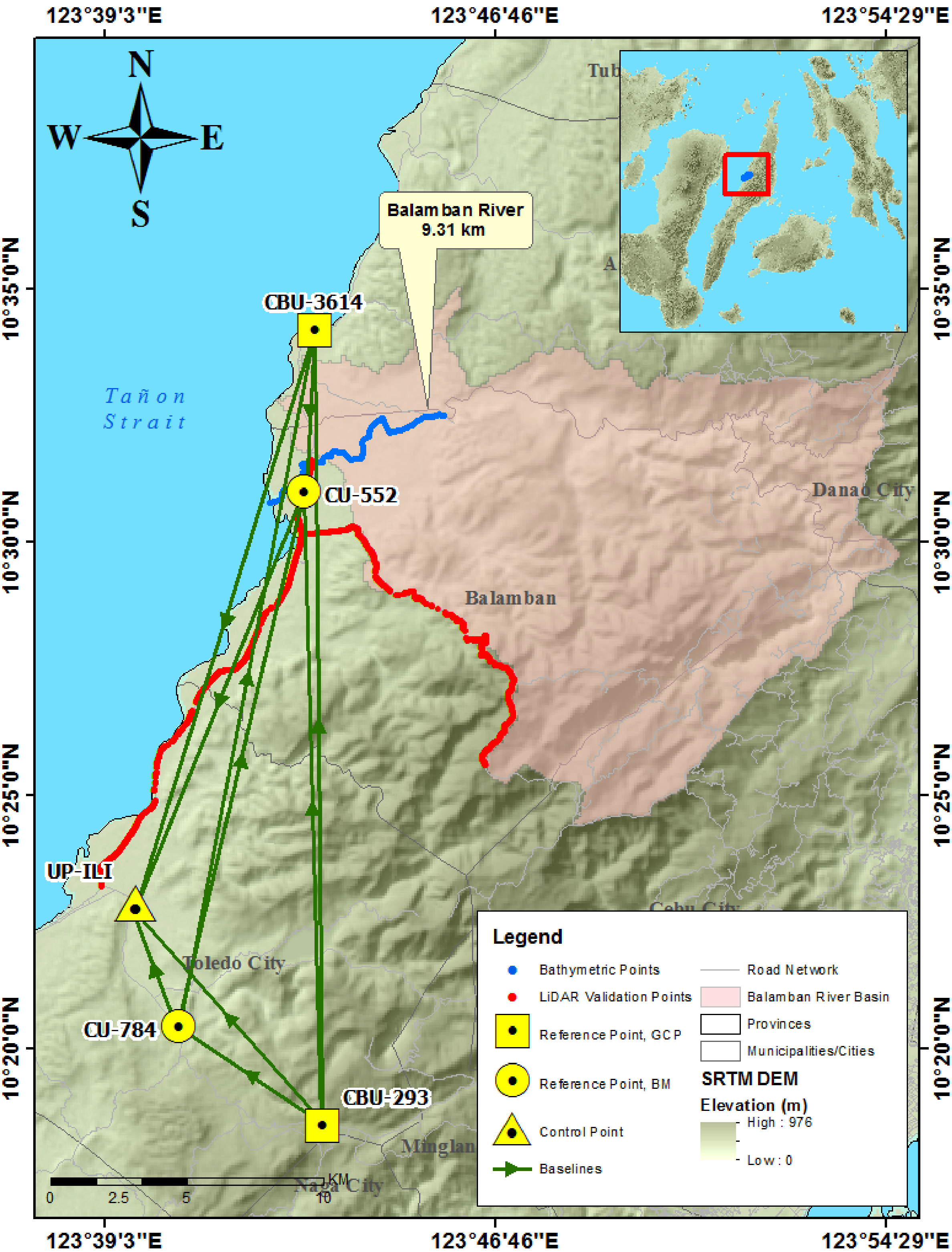

Figure 30. Extent of the bathymetric survey (in blue line) in Balamban River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network for this survey is composed of five (5) loops established on December 7, 2015 occupying the following reference points: CBU-293, a second order GCP located inside Cantabaco National High School in Brgy. Cantabaco, Toledo City; and, CU-784, a first order BM in Brgy. Balud, Toledo City.

One (1) control point was established along the approach of a bridge namely UP-ILI at Ilihan Bridge in Brgy. Ilihan, Toledo City. The control points CBU-3614, in Brgy. Poblacion, Municipality of Asturias; and, CU-552 in Brgy. Cantuod, Municipality of Balamban both established by NAMRIA, were also occupied to use as markers for the network.

The summary of reference and control points and its location is summarized in Table 21 while the GNSS network established is illustrated in Figure 31.

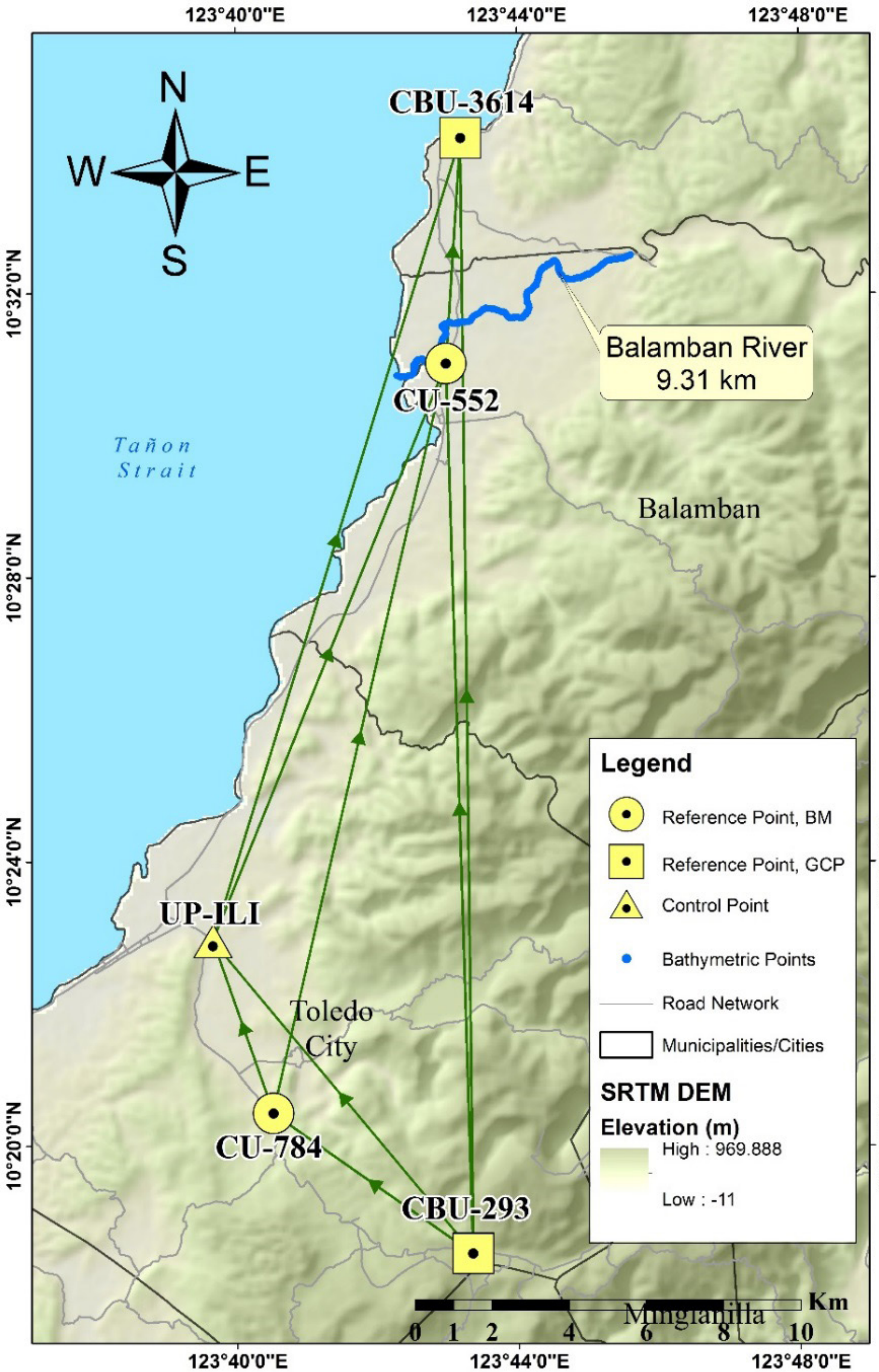

Figure 31. The GNSS Network established in the Balamban River Survey.

Table 21. List of Reference and Control Points occupied for Balamban River Survey

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
CBU-293	2nd order, GCP	10°18'28.70835"	123°43'20.76082"	350.838	-	2007
CU-784	1st order, BM	-	-	121.354	58.767	2014
CBU-3614	Used as marker	-	-	-	-	2007
CU-552	used as marker	-	-	-	-	2003
UP-ILI	UP Established	-	-	-	-	12-7-2015

The GNSS set-ups on recovered reference points and established control points in Balamban River are shown in Figure 32 to Figure 36.

Figure 32. GNSS receiver set-up, Trimble® SPS 852, at CBU-293 in front of Cantabaco National High School in Brgy. Cantabaco, Toledo City, Cebu

Figure 33. GNSS receiver setup, Trimble® Zephyr™ Model 2, at CU-784 Balud Bridge approach in Brgy. Balud, Toledo City, Cebu

Figure 34. GNSS receiver set-up, Trimble® Zephyr ™ Model 2, at CBU-3614, Lapu-lapu Bridge approach in Brgy. Poblacion, Municipality of Asturias, Cebu

Figure 35. GNSS receiver set-up, Trimble® Zephyr ™ Model 2, at CU-552 along the national highway in Brgy. Cantuod, Balamban, Cebu

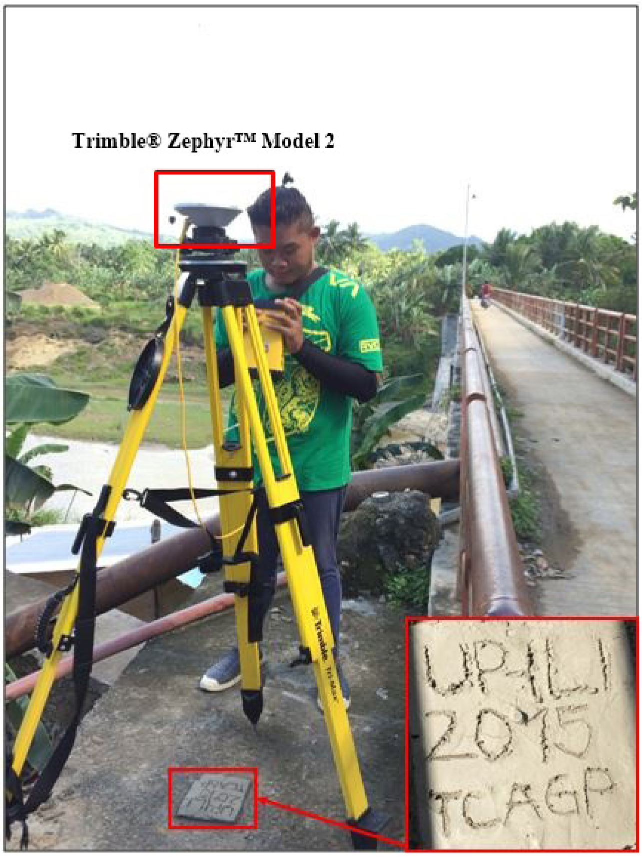

Figure 36. GNSS receiver set-up, Trimble® Zephyr ™ Model 2, at control point UP-ILI in the approach of Ilihan Foot Bridge in Brgy. Ilihan, Toledo City, Cebu

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm 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 Balamban River Basin is summarized in Table 22 generated by TBC software.

Table 22. Baseline Processing Summary Report for Balamban River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
CU-784 --- UP-ILI (B1)	12-7-2015	Fixed	0.006	0.034	340°45'16"	4741.533	-45.998
CU-552 --- UP-ILI (B9)	12-7-2015	Fixed	0.004	0.022	202°05'36"	16152.939	9.102
CBU-293 --- CU-784 (B3)	12-7-2015	Fixed	0.006	0.028	305°11'33"	6328.249	-229.449
CU-784 --- CBU--3614 (B6)	12-7-2015	Fixed	0.006	0.042	10°56'41"	25772.836	-56.329
CU784 --- CU-552 (B10)	12-7-2015	Fixed	0.004	0.021	13°03'37"	19960.518	-55.135
CBU-3614 --- CU-552 (B7)	12-7-2015	Fixed	0.005	0.026	183°44'41"	5872.324	1.233
CBU-293 --- CBU-3614 (B4)	12-7-2015	Fixed	0.008	0.035	359°27'24"	28951.752	-285.917
CBU-293 --- CU-552 (B8)	12-7-2015	Fixed	0.006	0.022	358°22'03"	23100.039	-284.613
CBU-293 --- UP-ILI (B2)	12-7-2015	Fixed	0.004	0.019	320°20'42"	10551.869	-275.506
CBU-3614 --- UP-ILI (B5)	12-7-2015	Fixed	0.004	0.027	197°13'50"	21805.194	10.384

As shown in Table 22, a total of ten (10) baselines were processed with reference point CBU-293 and CU-784 held fixed for coordinate and elevation values. All of them passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is performed using TBC. Looking at the Adjusted Grid Coordinates Table C-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 form:

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

Where:

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

for each control point. See the Network Adjustment Report shown in Table 23 to Table 26 for the complete details.

The five (5) control points, CBU-293, CU-784, CBU-3614, CU-552 and UP-ILI were occupied and observed simultaneously to form a GNSS loop. Coordinates of CBU-293 and elevation value of CU-784 were held fixed during the processing of the control points as presented in Table 23. Through these reference points, the coordinates of the unknown control points will be computed.

Table 23. 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-293	Global	Fixed	Fixed		
CU-784	Grid				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 24. The fixed control point CBU-293 has no values for standard errors.

Table 24. Adjusted grid coordinates for the control points used in the Balamban River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CBU-293	579101.757	?	1139552.798	?	287.891	0.028	LL
CBU-3614	578761.189	0.004	1168493.192	0.004	3.267	0.033	
CU-552	578391.244	0.004	1162634.434	0.003	4.293	0.026	
CU-784	573923.645	0.004	1143187.034	0.004	58.767	?	e
UP-ILI	572351.798	0.004	1147658.769	0.003	13.024	0.029	

The network is fixed at reference point CBU-293 with known coordinates, and CU-784 with known elevation. With the mentioned equation, for horizontal and for the vertical; the computation for the accuracy are as follows:

a.	CBU-293	=	fixed
		=	2.8 < 10 cm
b.	CU-784		
	horizontal accuracy	=	√((0.4)² + (0.3)²
		=	√(0.16 + 0.9)
		=	1.03 cm < 20 cm
	vertical accuracy	=	fixed
c.	CBU-3614		
	horizontal accuracy	=	√((0.4)² + (0.4)²
		=	√(0.16 + 0.16)
		=	0.57 cm < 20 cm
	vertical accuracy	=	3.3 < 10 cm
d.	CU-552		
	horizontal accuracy	=	√((0.4)² + (0.3)²
		=	√(0.16 +0.9)
		=	1.03 cm < 20 cm
	vertical accuracy	=	2.6 < 10 cm
e.	UP-ILI		
	horizontal accuracy	=	√((0.4)² + (0.3)²
		=	√(0.16 + 0.9)
		=	1.03 cm < 20 cm
	vertical accuracy	=	2.9 < 10 cm

Table 25. Adjusted geodetic coordinates for control points used in the Balamban River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
CBU-293	N10°18'28.70835"	E123°43'20.76082"	350.838	0.028	LL
CBU-3614	N10°34'10.94597"	E123°43'11.73023"	64.969	0.033	
CU-552	N10°31'00.23116"	E123°42'59.11634"	66.222	0.026	
CU-784	N10°20'27.39811"	E123°40'30.77220"	121.354	?	e
UP-ILI	N10°22'53.09406"	E123°39'39.39389"	75.336	0.029	

The adjusted geodetic coordinates is presented in Table 25. The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 25. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 26.

Table 26. The reference and control points utilized in the Balamban 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)
CBU-293	2nd order GCP	10°18'28.70835"	123°43'20.76082"	350.838	1139553	579101.8	287.992	287.844
CU-784	1st order BM	10°20'27.39811"	123°40'30.77220"	121.354	1143187	573923.6	58.915	58.767
CBU-3614	Used as Marker	10°34'10.94597"	123°43'11.73023"	64.969	1168493	578761.2	3.465	3.317
CU-552	Used as Marker	10°31'00.23116"	123°42'59.11634"	66.222	1162634	578391.2	4.480	4.332
UP-ILI	UP Established	10°22'53.09406"	123°39'39.39389"	75.336	1147659	572351.8	13.149	13.001

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 37. Cross-section survey conducted on Balamban river in Brgy. Biasong, Municipality of Balamban

The cross-sectional line for the upstream portion of Balamban Riverbed is about 23 m with thirty-nine (39) cross-sectional points acquired using CU-552 as the GNSS base station. The location map of the Balamban River cross-section and cross-section diagram are shown in Figure 38 and Figure 39.

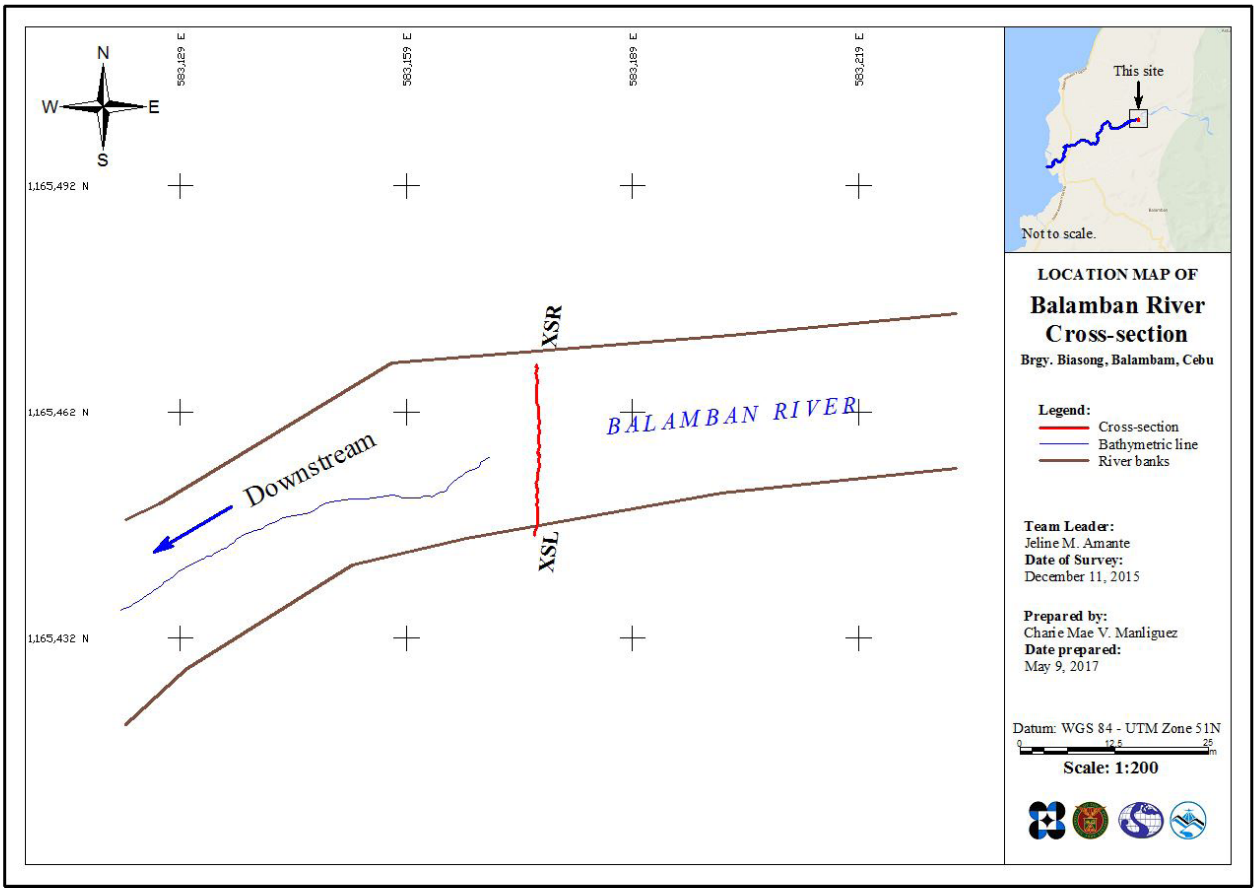

Figure 38. Location map of Balamban River cross-section survey

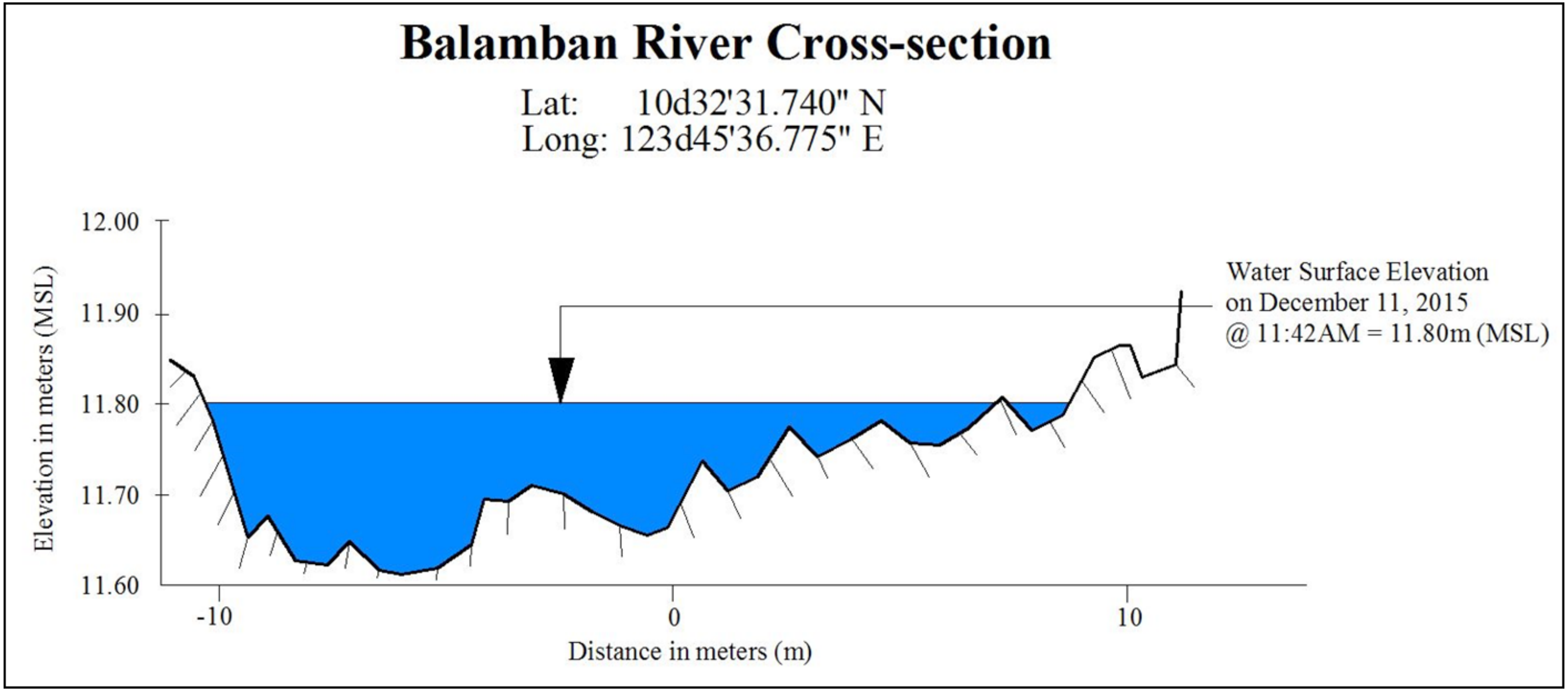

Figure 39. Balamban Riverbed cross-section diagram

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on December 12 and 4, 2015 using a survey-grade GNSS rover receiver, Trimble® SPS 882, mounted on a pole which was attached to the side of the vehicle as shown in Figure 40 (A). It was secured with cable ties to ensure that it was horizontally and vertically balanced. The antenna height was 2.170 m measured from the ground up to the bottom of notch of the GNSS rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with CBU-3015, CBU-3614, CU-552, DPWHECS, UP-ILI occupied as the GNSS base stations all throughout the conduct of the survey.

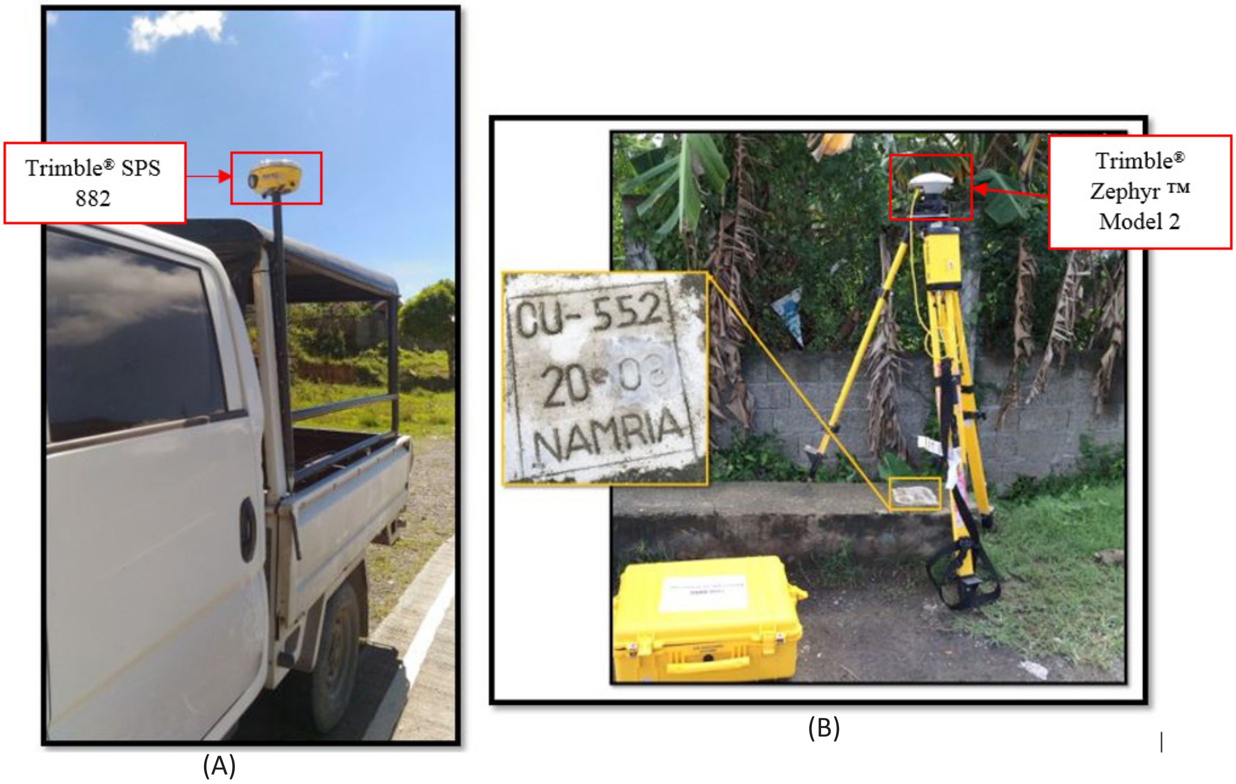

Figure 40. (A) Setup of Trimble® SPS 882 attached to a vehicle and (B) Setting up of GNSS base station at CU-522

The validation points acquisition survey for the Balamban River Basin traversed the Municipalities of Balamban, and Toledo City. The route of the survey aims to traverse LiDAR flight strips perpendicularly for the basin. A total of 12,473 points with an approximate length of 97.43 km was acquired for the validation point acquisition survey as shown in the map in Figure 41.

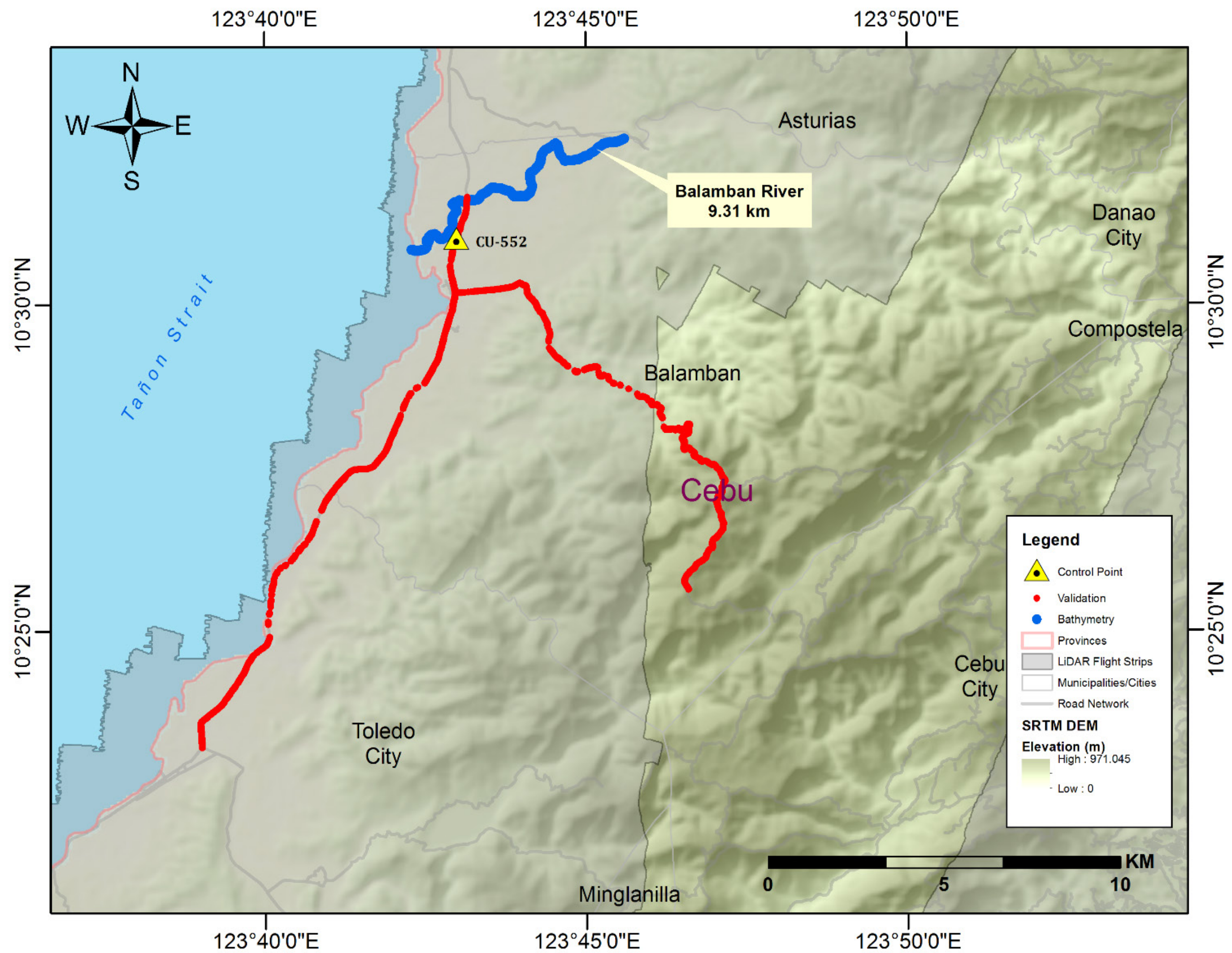

Figure 41. Validation point acquisition survey of Balamban River basin

4.7 River Bathymetric Survey

Manual bathymetric survey was executed on December 11 and 15, 2015 using a Trimble® SPS 882 GNSS PPK technique as shown in Figure 42. The survey began by dividing the team into two – the first group began from the upstream in Brgy. Biasong, Municipality of Balamban, with coordinates 10°32’31.72051”N 123°45’36.56535”E, until the boundary of Brgy. Cantuod, Municipality of Balamban. Meanwhile the second group started from Brgy. Cantuod, Municipality of Balamban, with coordinates 10°30’50.14355”N 123°42’17.07862”E, going to the mouth of the river within the same barangay. The survey was conducted with the assistance of personnel from the University of San Carlos. Portions of the river with data gaps were resurveyed on December 15, 2015. The control point CU-552 was used as base station for the whole conduct of the survey.

Figure 42. Bathymetric survey in Balamban River

The bathymetric survey coverage for Balamban river is illustrated in Figure 43. Approximately 265 m of the delineated target bathymetric line was not covered due to quarrying activities found upstream. A CAD drawing was also produced to illustrate the Balamban riverbed centerline profile as shown in Figure 44. There is about a 10.83-m change in elevation observed within the 9 km of the 9.31 km bathymetric data from its upstream in Brgy. Biasong down to the mouth of the river in Brgy. Cantuod in Municipality of Balamban.

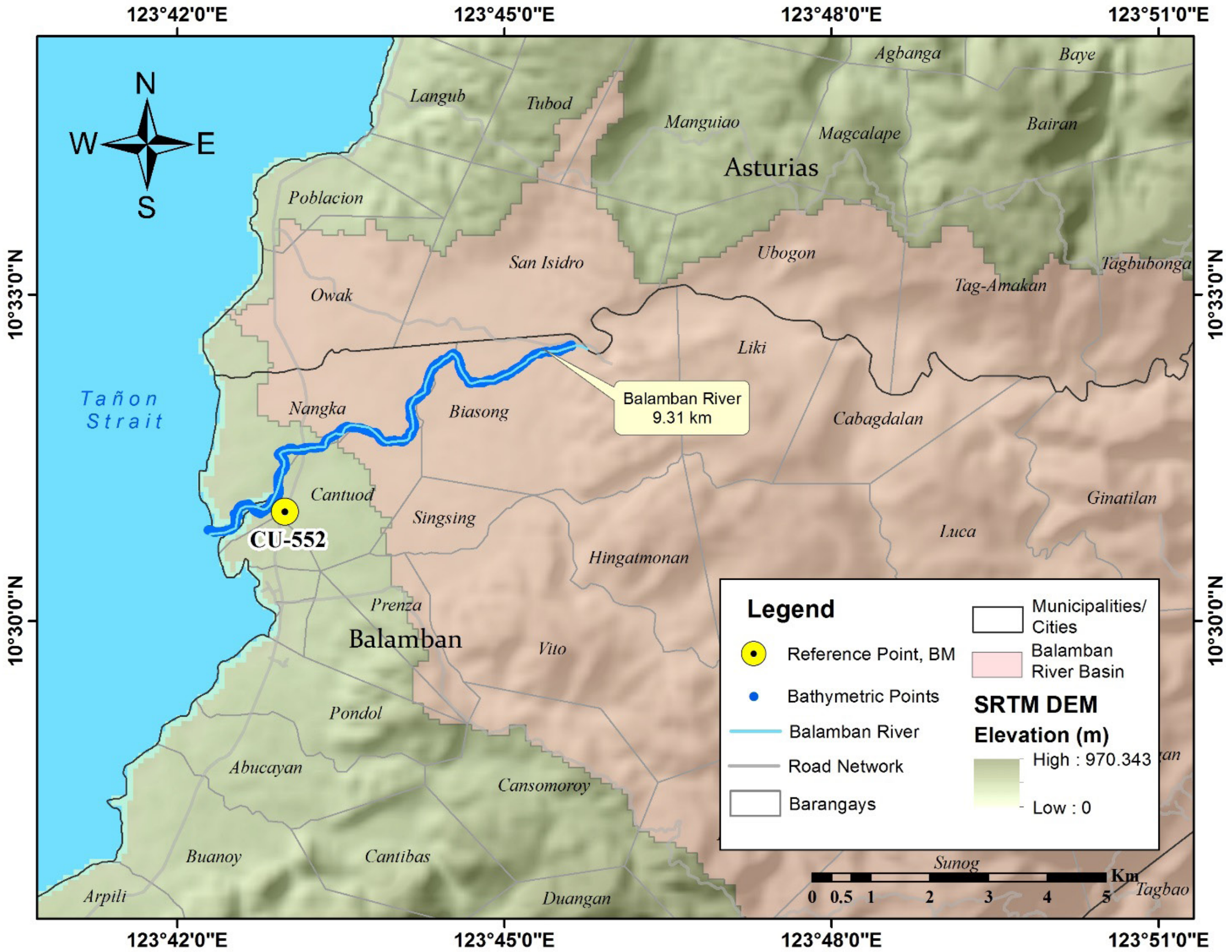

Figure 43. Extent of the Balamban River Bathymetry Survey

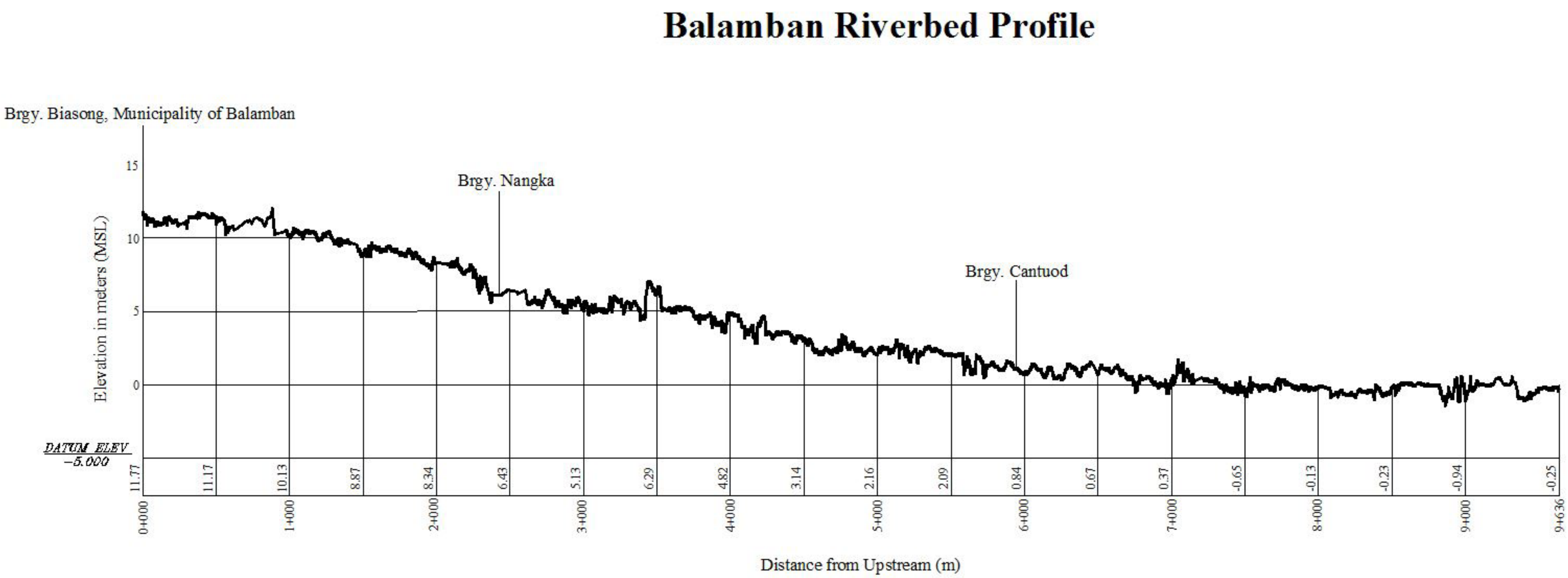

Figure 44. Balamban riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

Alfredo Mahar Francisco A. Lagmay, Enrico C. Paringit, Dr. Eng., 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 Silaga 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 Silaga River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from a data logging rain gauge installed by the USC Phil LIDAR 1. The rain gauge was installed in Brgy. Agbanga, Asturias with geographic coordinates of 10.5911 N and 123.803 E. Aside from this station, data from the rain gauge installed by DOST ASTI in Balamban Municipal Hall was also used. The location of the rain gages used in calibration in the watershed in presented in Figure 45.

The station in Brgy. Agbanga Asturias has a total precipitation of 125mm while that in Balamban Municipal hall has a total precipitation of 0.2mm. The peak rainfall of the station in Brgy. Agbanga is 7.8mm at 20:25 of November 5, 2016. The peak rainfall of the station in Balamban Municipal Hall is 0.2mm at 4:45 of November 4, 2016.

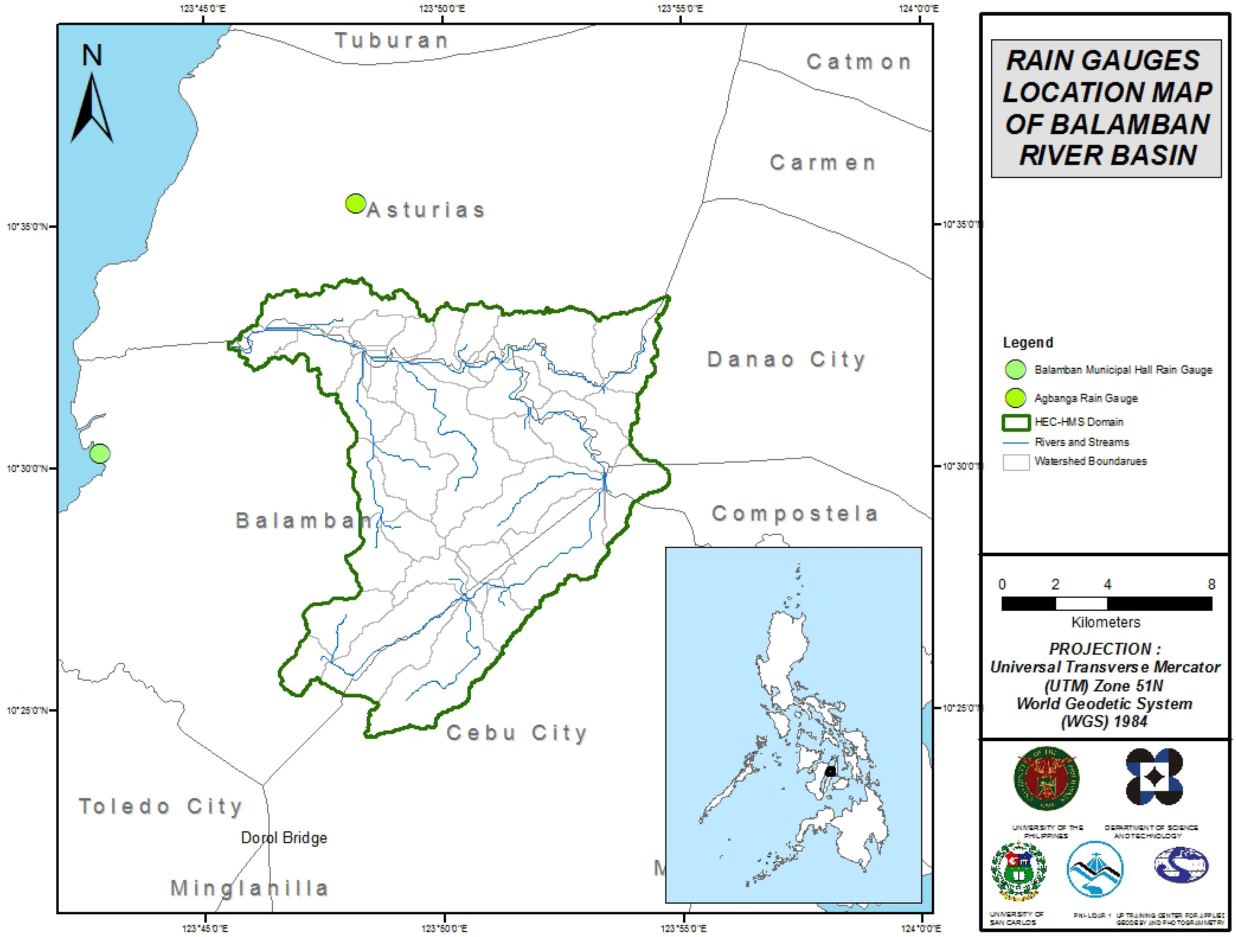

Figure 45. Location map of the Balamban HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Brgy. Biasong, Balamban (10°32’29.76”N, 123°45’32.40”E) with no bridge and water level monitoring sensor. It gives the relationship between the observed water levels and outflow of the watershed at this location.

For Brgy. Biasong, the rating curve is expressed as shown in Figure 47.

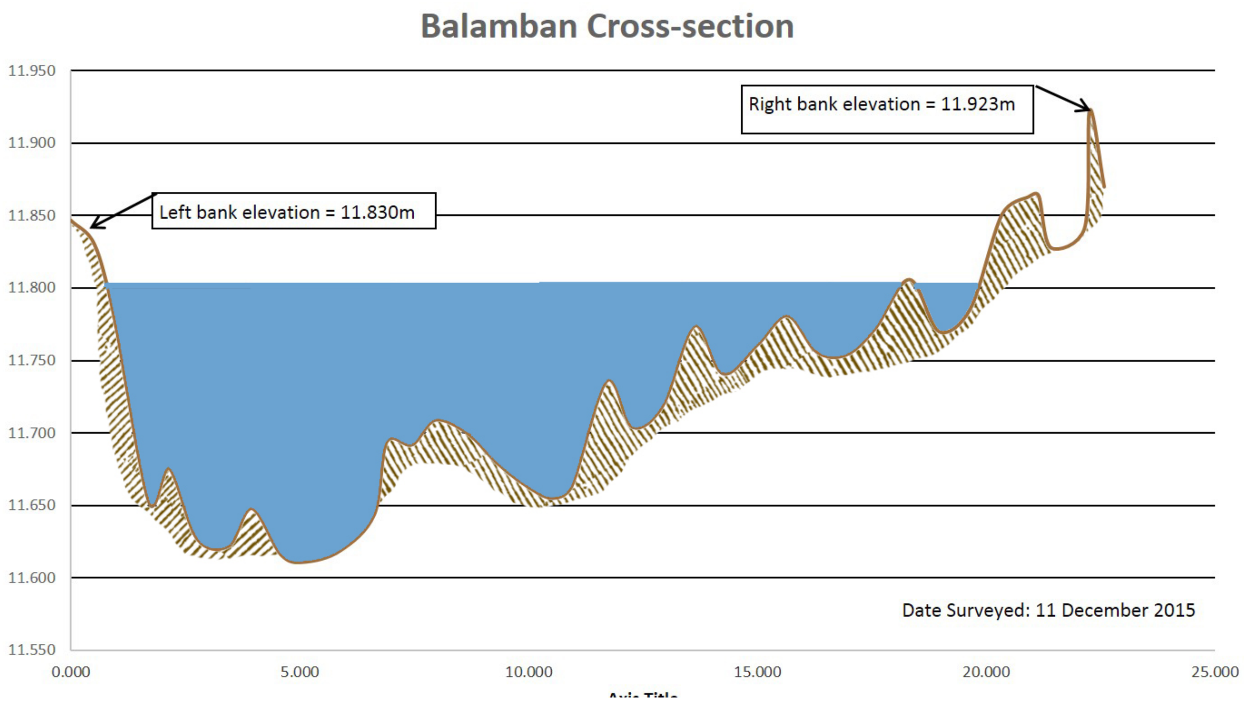

Figure 46. Cross-section plot of Balamban Bridge

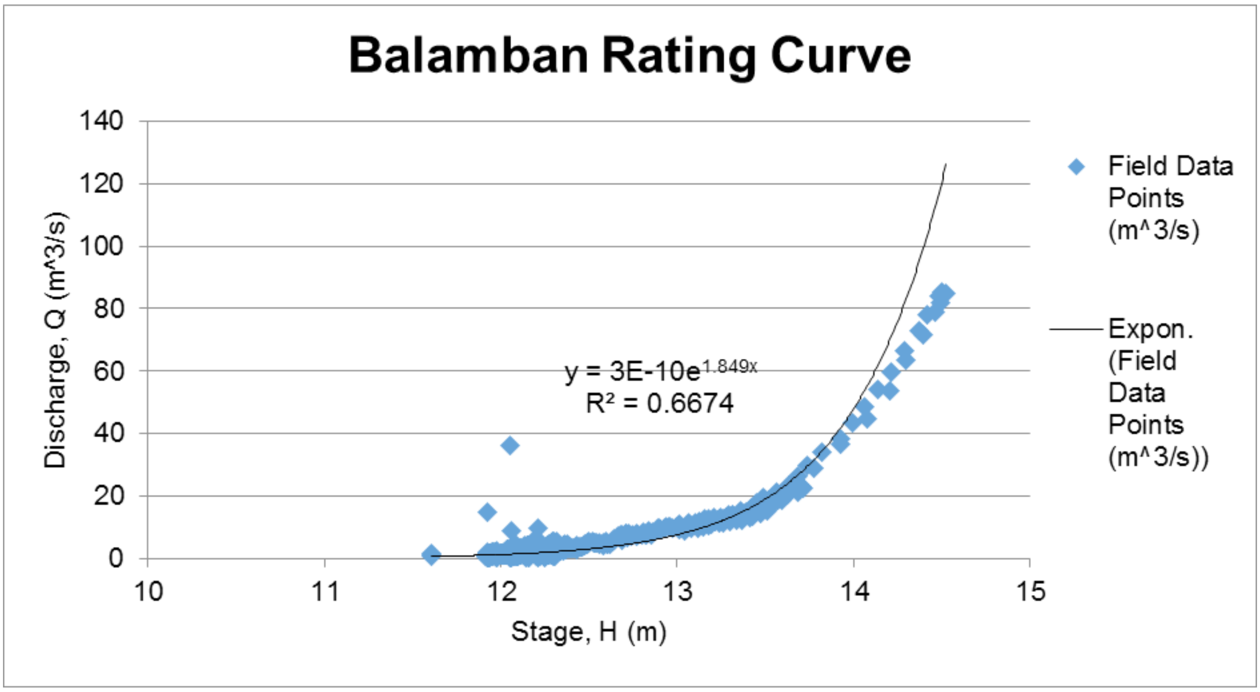

Figure 47. Rating curve at Brgy. Biasong, Balamban, Cebu

This rating curve equation was used to compute the river outflow at Brgy. Biasong (no bridge) for the calibration of the HEC-HMS model shown in Figure 48. Peak discharge is 84.689 m3/s at 22:20, November 5, 2016.

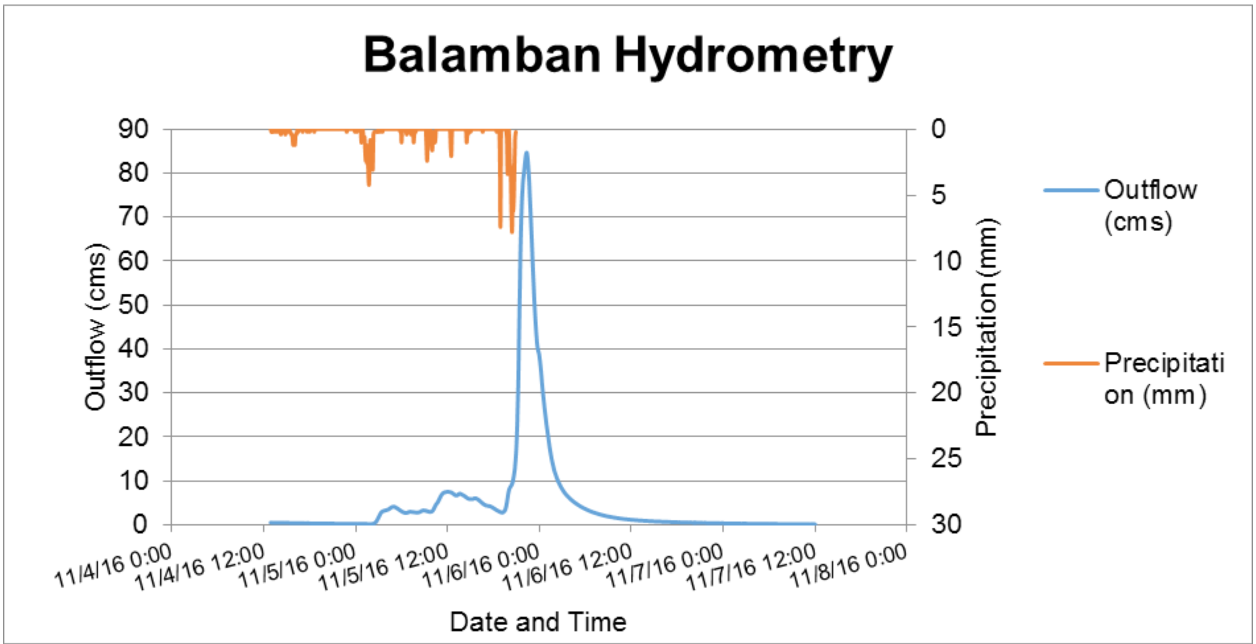

Figure 48. Rainfall and outflow data at Balamban used for modeling

5.2 RIDF Station

The Philippine 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 Balamban watershed. The extreme values for this watershed were computed based on a 37-year record.

Table 27. 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	15.9	24.7	31.4	41.4	53.7	60.5	73.1	83.4	92.8
5	21.9	34	43.2	58.4	74.9	84	105.2	122.6	139.1
10	25.8	40.2	51.1	69.7	88.9	99.6	126.3	148.6	169.7
15	28.1	43.6	55.5	76	96.8	108.4	138.3	163.3	187
20	29.6	46.1	58.6	80.5	102.3	114.5	146.7	173.5	199.1
25	30.9	48	61	83.9	106.6	119.3	153.1	181.4	208.5
50	34.6	53.8	68.3	94.4	119.7	133.9	173	205.8	237.2
100	38.3	59.5	75.6	104.9	132.7	148.4	192.7	230	265.7

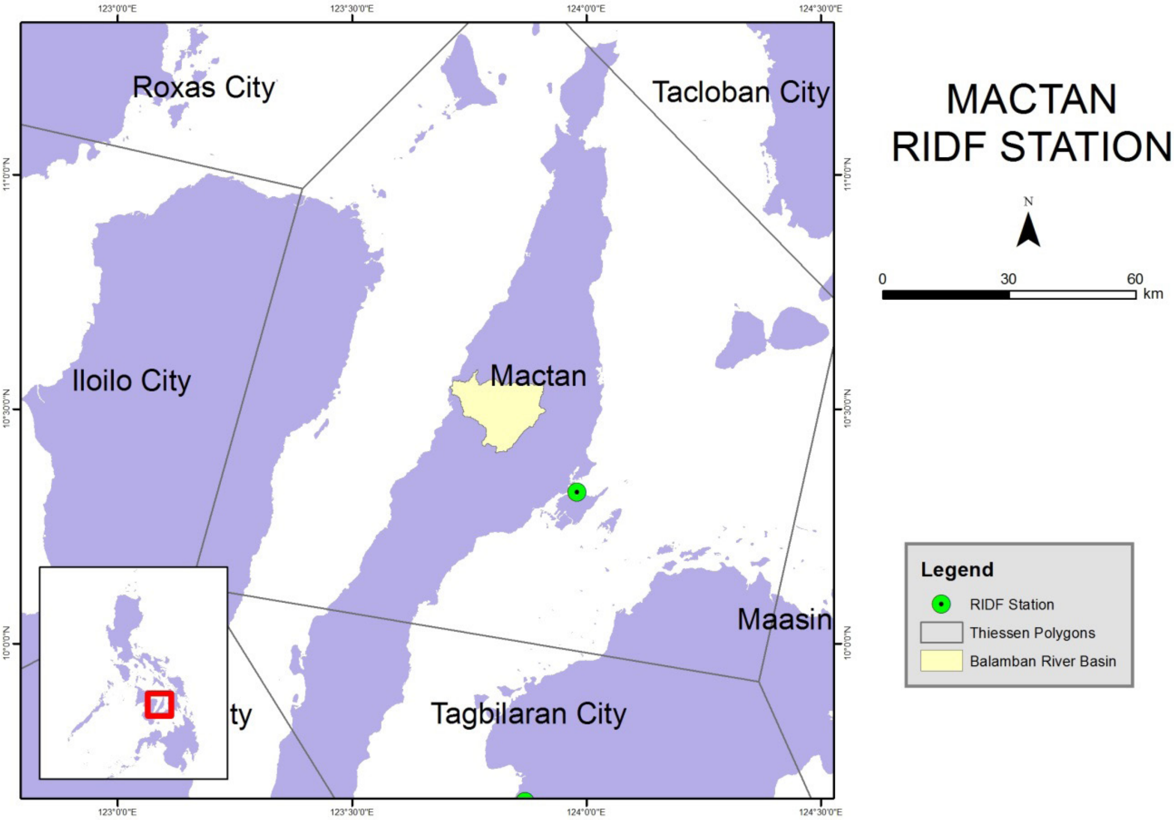

Figure 49. Location of Aparri RIDF Station relative to Balamban River Basin

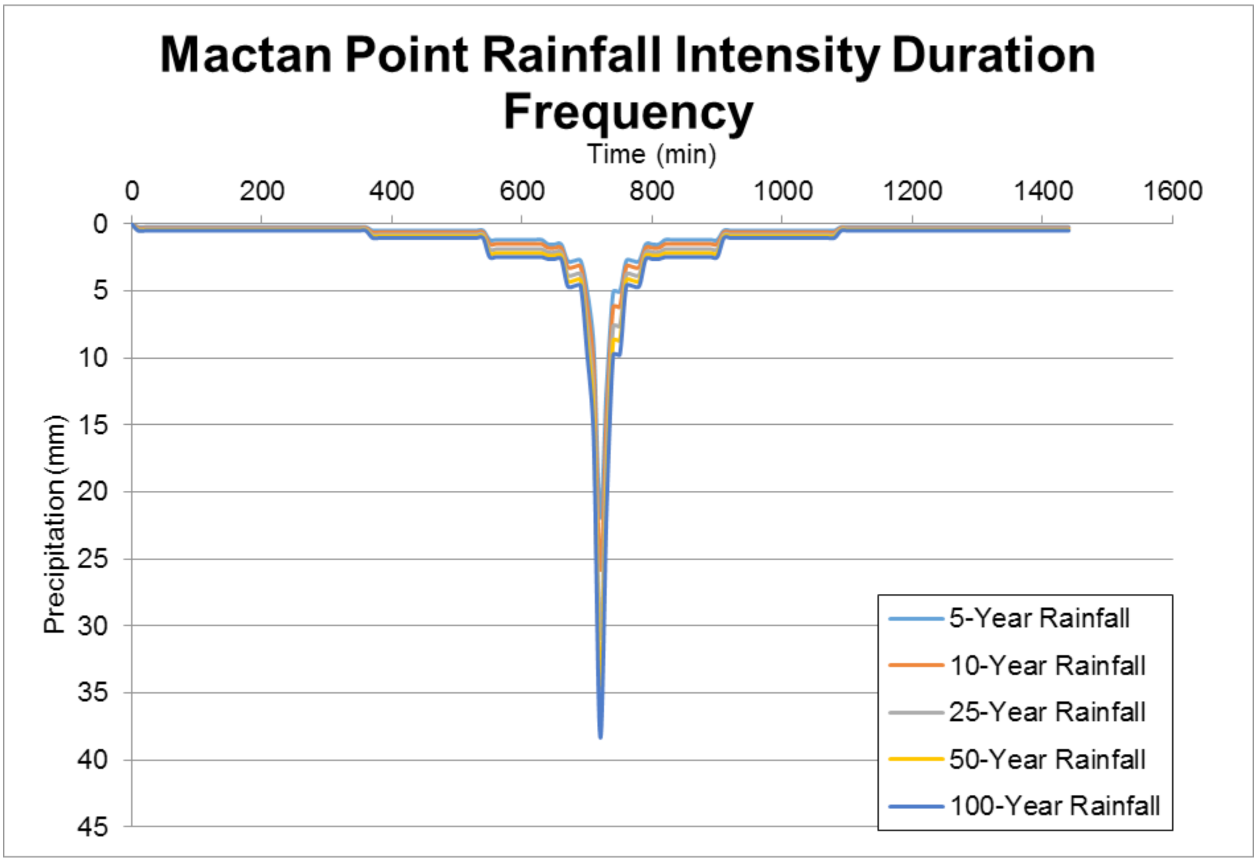

Figure 50. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was taken before 2004 from 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 Balamban River Basin are shown in Figure 51 and Figure 52, respectively.

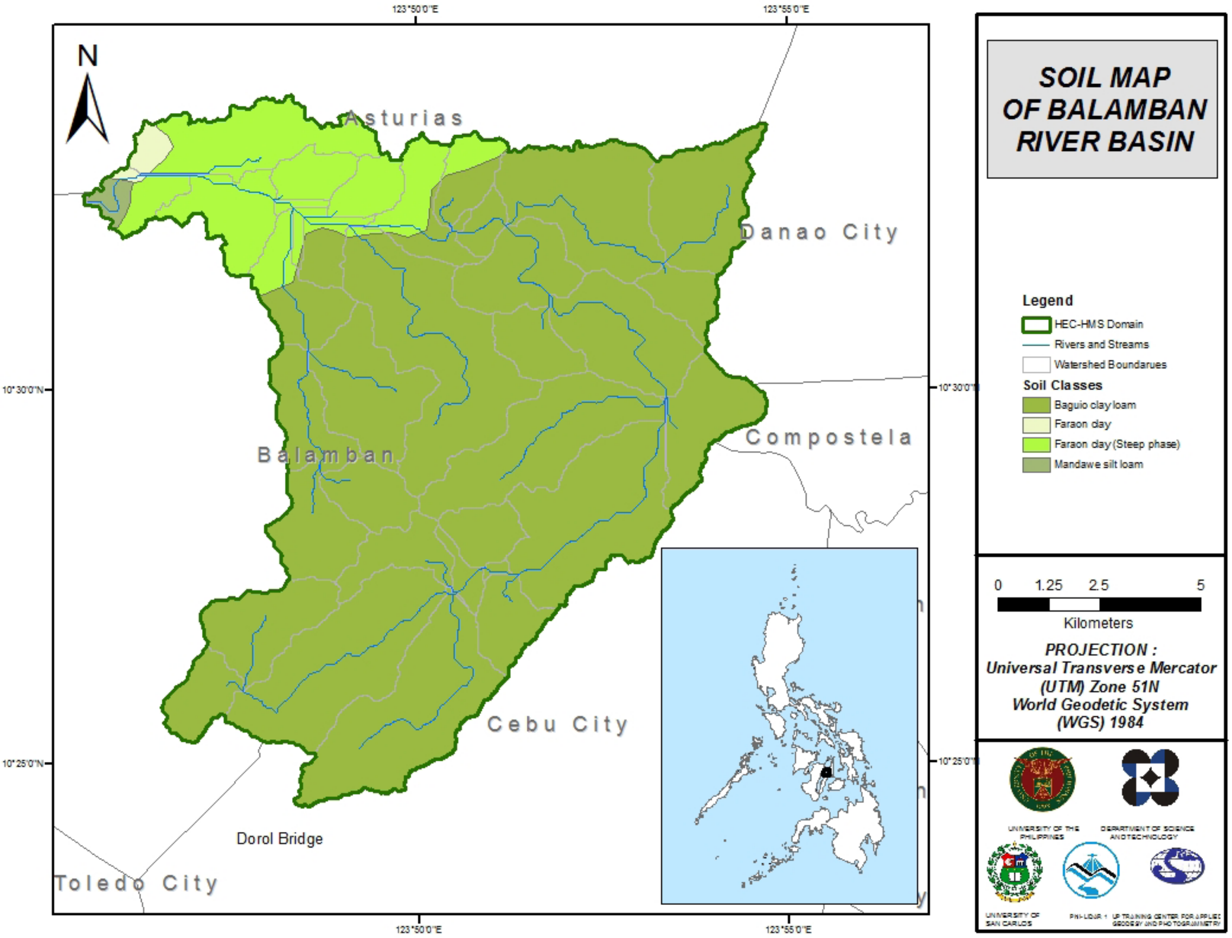

Figure 51. Soil Map of Balamban River Basin used for the estimation of the CN parameter.

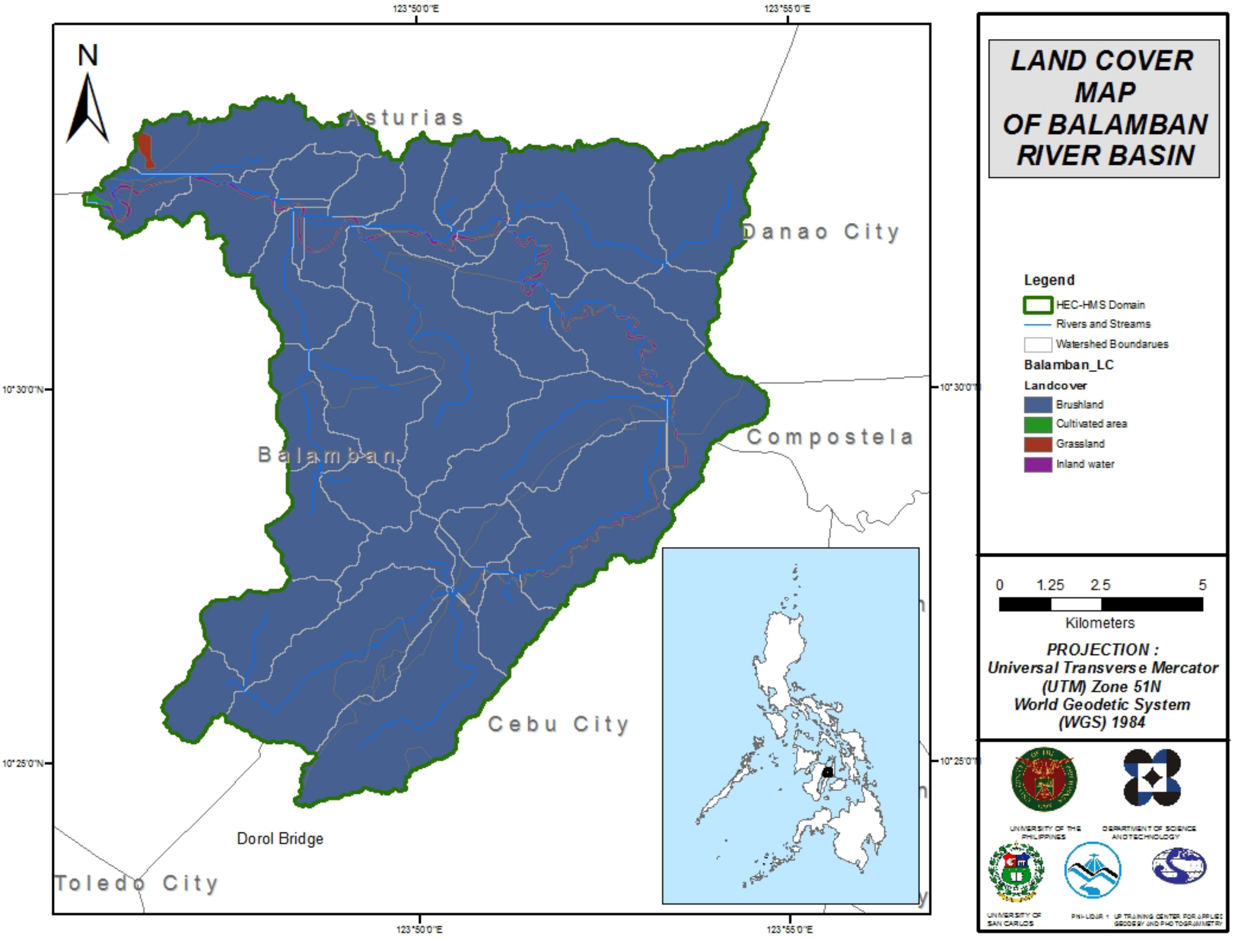

Figure 52. Land Cover Map of Balamban River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model.

For Balamban, four (4) soil classes were identified. These are Baguio clay loam, Faraon clay, Faraon clay (steep phase), and Mandaue silt loam. Moreover, three (3) land cover classes were identified. Most of the Balamban river basin is brushland, while some small portions of land are cultivated areas and grasslands.

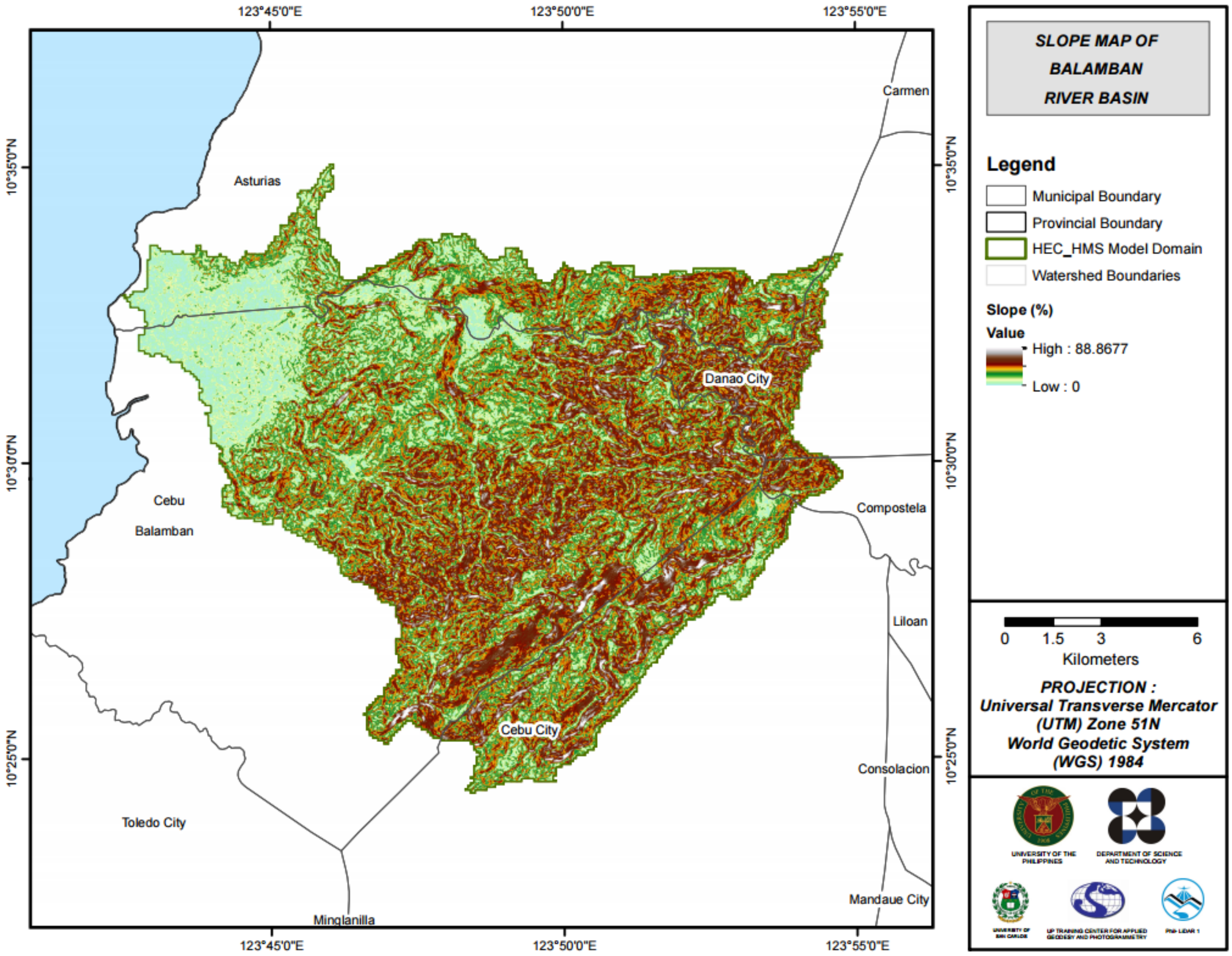

Figure 53. Slope Map of Balamban River Basin

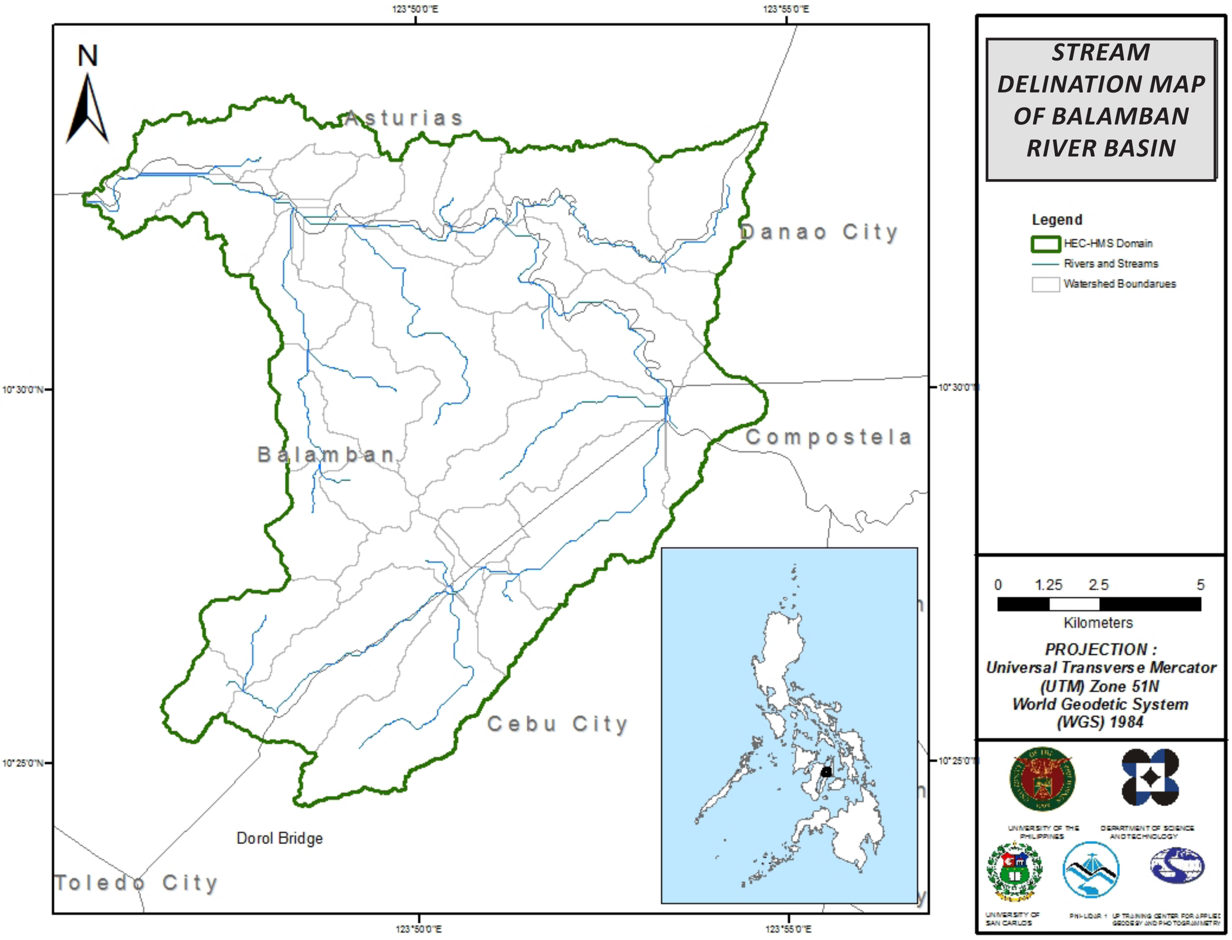

Figure 54. Stream Delineation Map of Balamban River Basin

After preprocessing of the watershed's hydrologic properties, the basin model of the watershed is then processed in HEC-HMS 3.5. HEC-HMS aims to generate the rainfall-runoff relationship in the watershed. Figure 55 shows basin model in HEC-HMS of Balamban River. It is composed of 34 subbasins and 18 reaches.

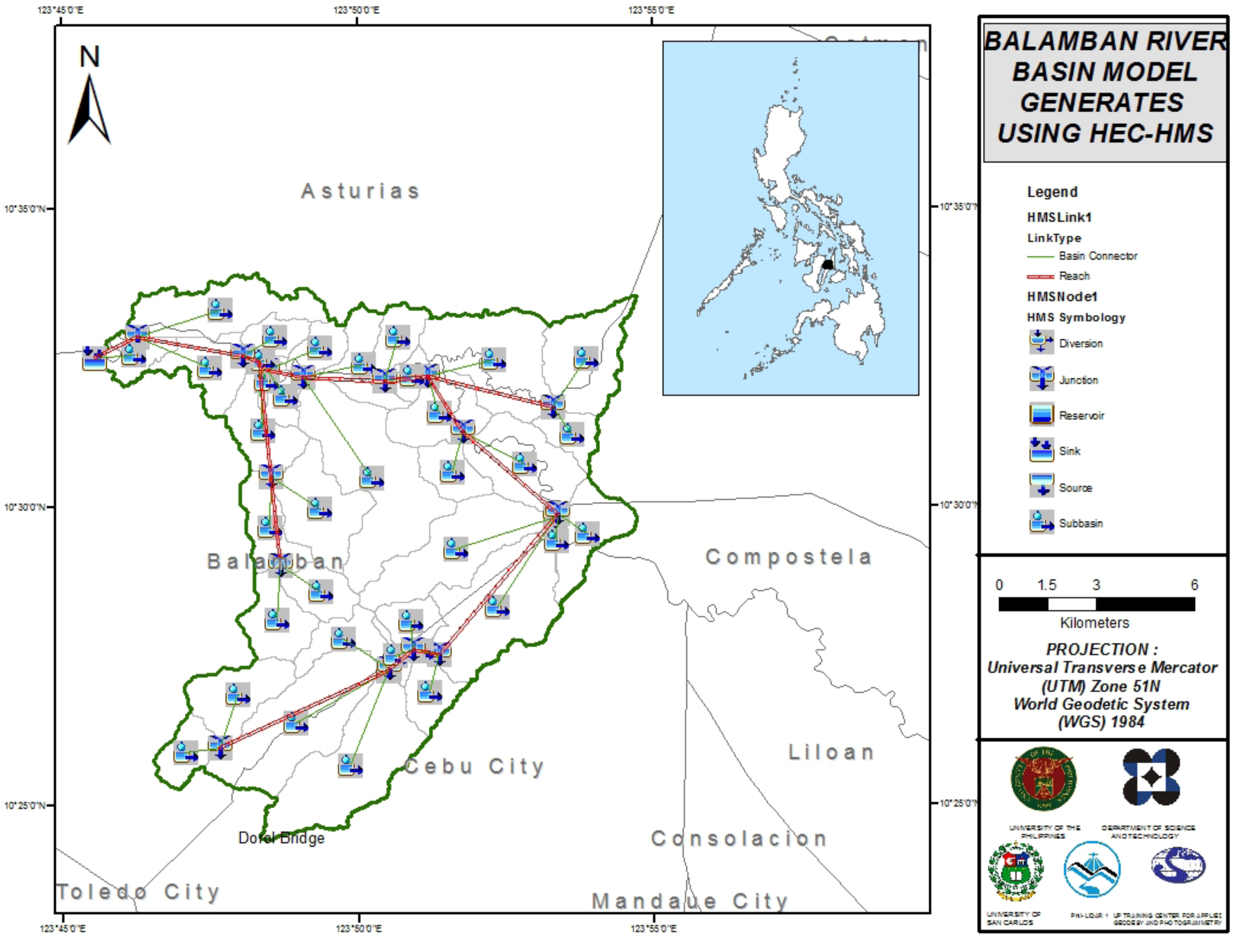

Figure 55. Balamban River Basin model generated in HEC-HMS

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.

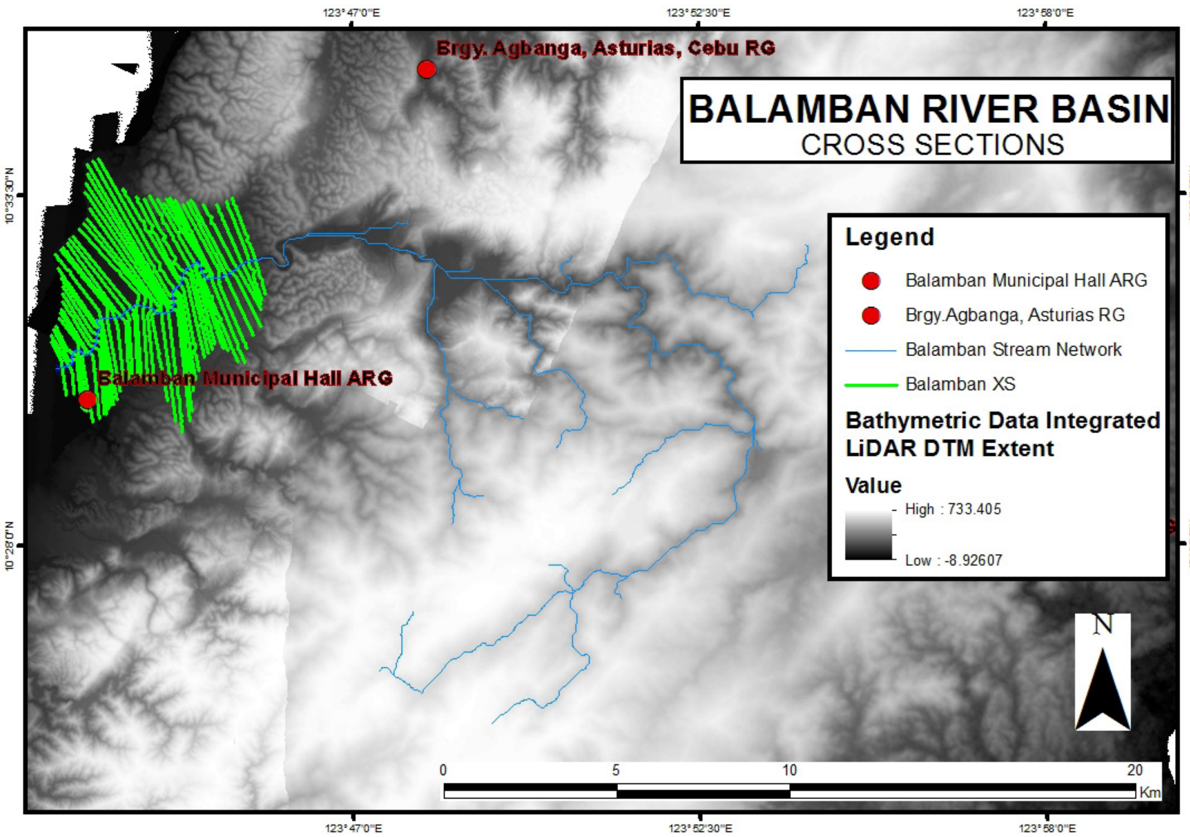

Figure 56. River cross-section of Balamban River generated through Arcmap HEC GeoRAS tool

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 south of the model to the northeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

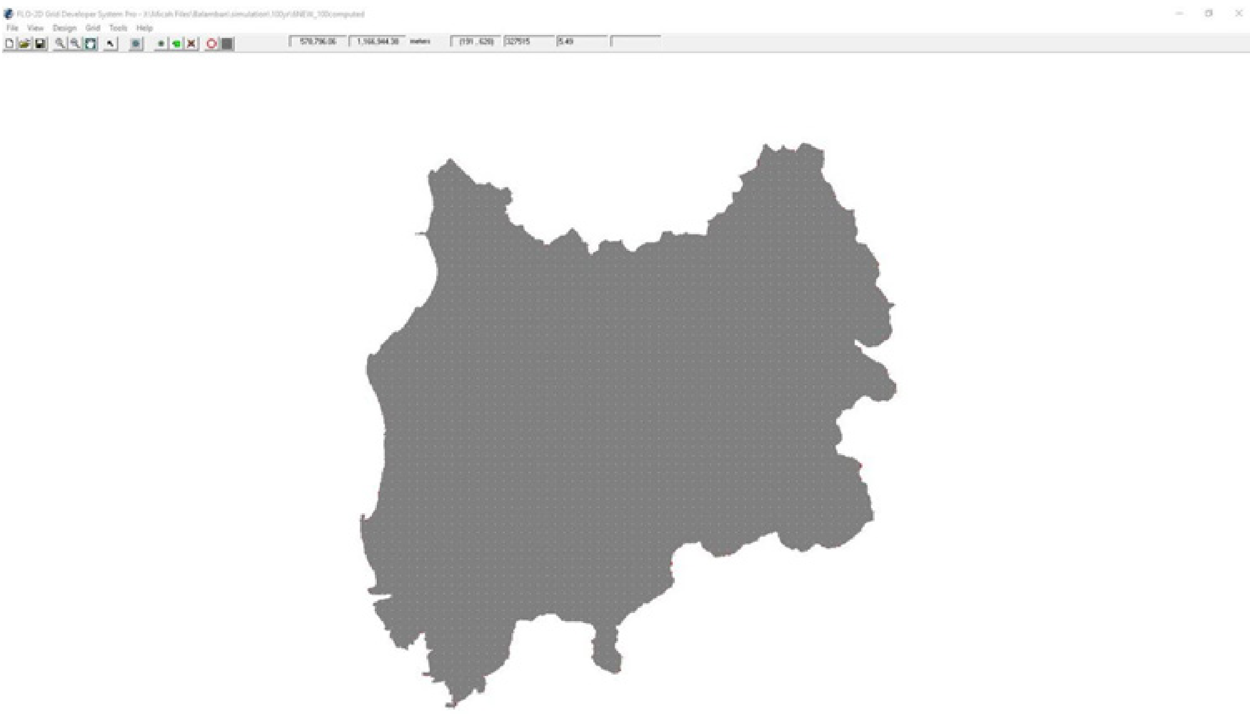

Figure 57. Screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 39.11060 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 m2/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 38050400.00 m2.

There is a total of 41994139.91 m3 of water entering the model. Of this amount, 9738413.73 m3 is due to rainfall while 32255726.18 m3 is inflow from other areas outside the model. 5526406.00 m3 of this water is lost to infiltration and interception, while 12030237.07 m3 is stored by the flood plain. The rest, amounting up to 24437500.93 m3, is outflow.

5.6 Results of HMS Calibration

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

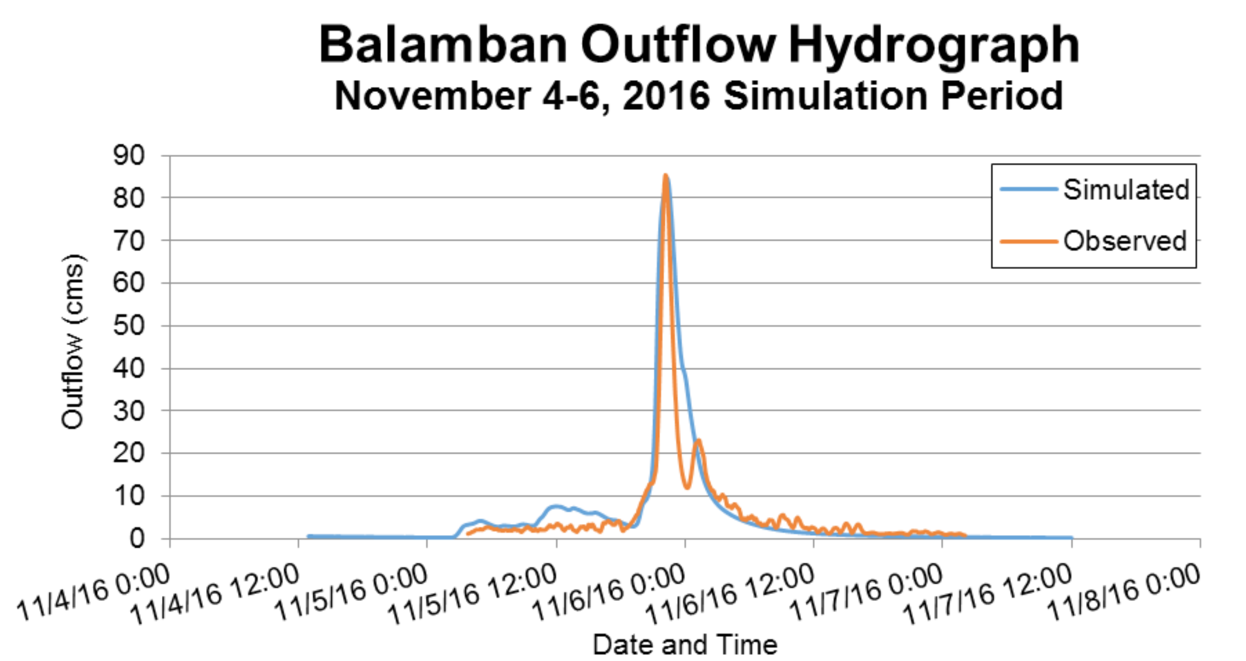

Figure 58. Outflow hydrograph of Balamban produced by the HEC-HMS model compared with observed outflow

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 Balamban River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	19.84-27.89
			Curve Number	41.34-45.34
			Impervious (%)	0
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.11-1.92
			Storage Coefficient (hr)	0.08-1.37
	Baseflow	Recession	Recession Constant	0.1
			Ratio to Peak	0.01
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.04

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 19.84 to 27.89mm 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 Balamba, the basin mostly brushland and the soil consists of clay, clay loam, and silt loam. The curve number is 41.34 to 45.34.

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 0.11 to 1.92 of an hour 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 0.1 indicates that the basin will quickly go back to its original discharge. Ratio to peak of 0.01 indicates a steep receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.04 corresponds to the common roughness in Hinatuan watershed, which is determined to be mostly brushland (Brunner, 2010).

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

Accuracy measure	Value
RMSE	6.2461
r2	0.8723
NSE	0.7284
PBIAS	23.09
RSR	0.5206

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 6.2461.

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 0.8723.

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 0.7284.
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 23.09.

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 0.5206

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 Balamban 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.

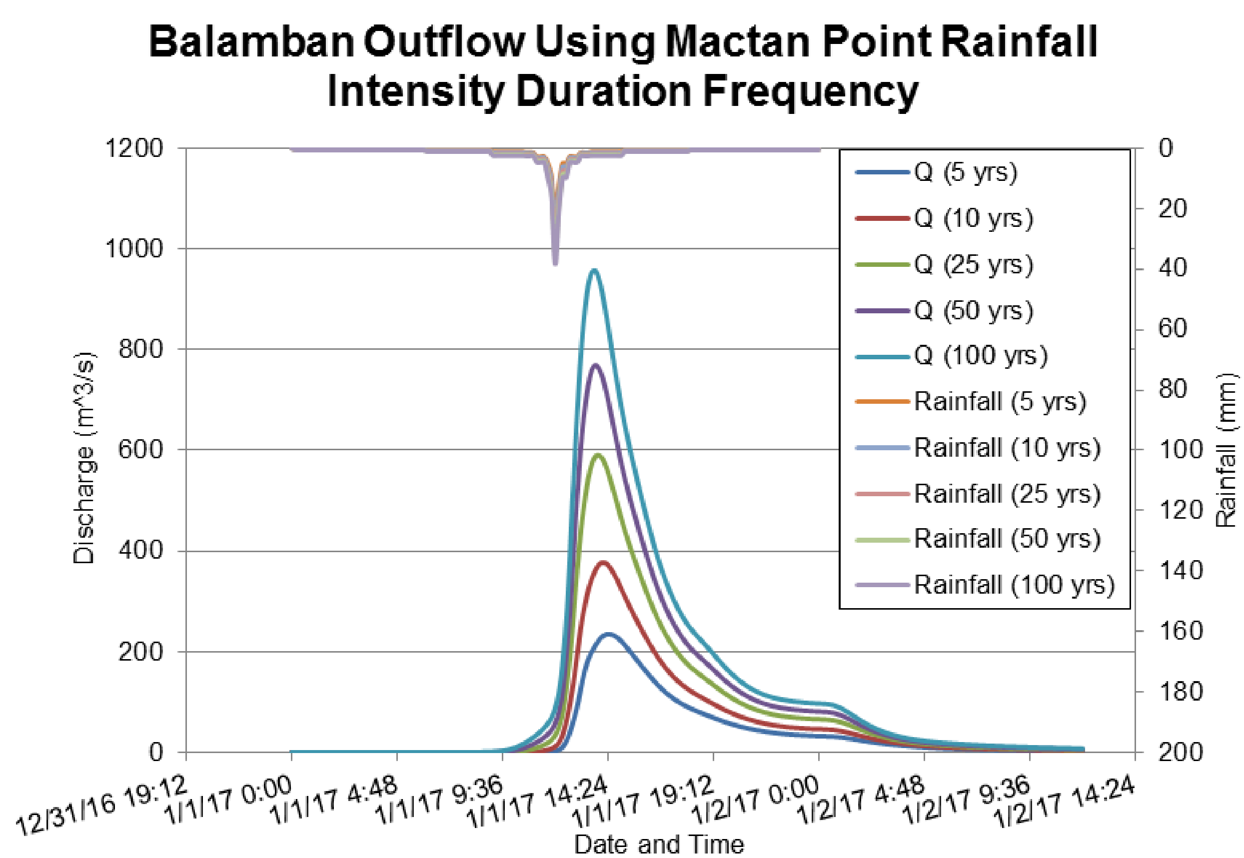

Figure 59. Outflow hydrograph at Brgy. Biasong, Balamban generated using Mactan Point RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Balamban 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 Balamban 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	235.189	2 hours, 30 minutes
10-Year	169.7	25.8	377.271	2 hours, 10 minutes
25-Year	208.5	30.9	590.225	2 hours
50-Year	237.2	34.6	769.239	1 hour, 50 minutes
100-Year	265.7	38.3	956.470	1 hour, 50 minutes

5.7.2 Discharge values using Dr. Horritt's recommended hydrologic method

The river discharge for the river entering the floodplain (Figure 9) are shown in Figure 60 and the peak values are summarized in Table 31.

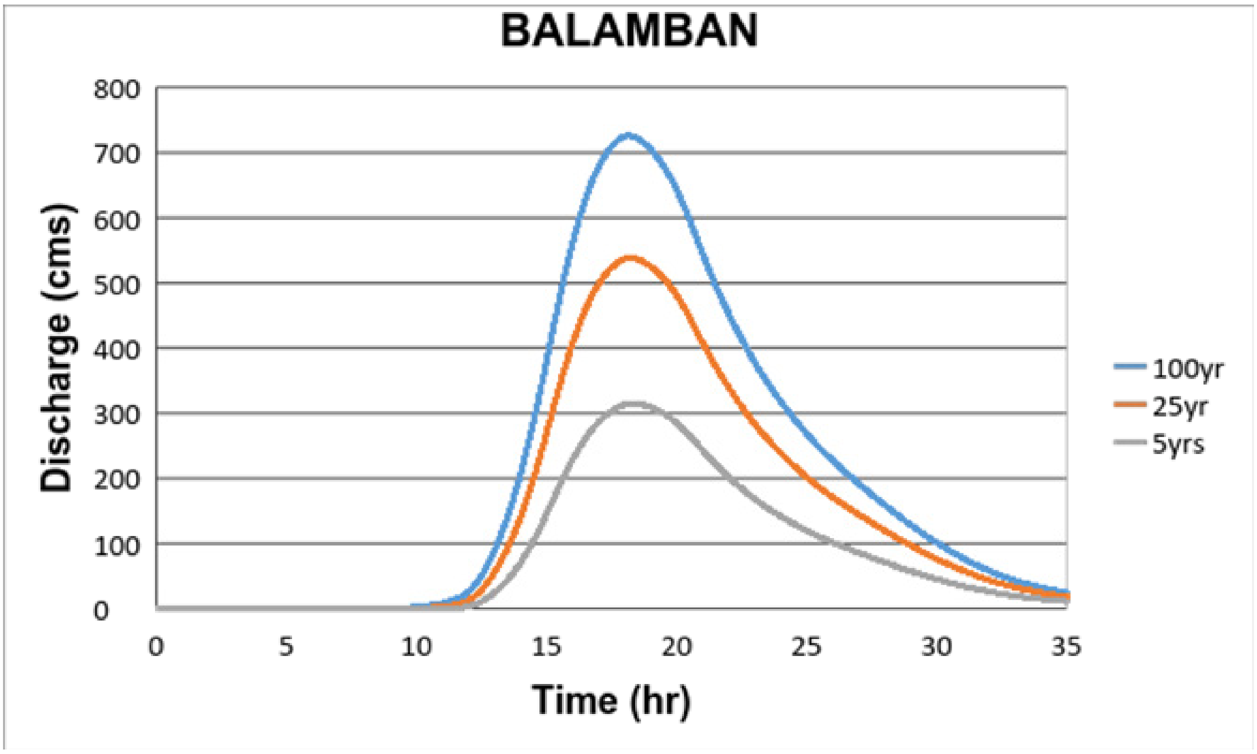

Figure 60. . Balamban river (1) generated discharge using 5-, 25-, and 100-year Mactan rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 31. Summary of Balamban river (1) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	725.9	18 hours, 10 minutes
25-Year	538.2	18 hours, 10 minutes
5-Year	314.6	18 hours, 20 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 32.

Table 32. Validation of river discharge estimates

Discharge Point	$Q_{MED(SCS)}$, cms	$Q_{BANKFUL}$, cms	$Q_{MED(SPEC)}$, cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Balamban	276.848	203.394	332.645	TRUE	TRUE

All values from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful and specific discharge methods. The calculated values are based on theory but are supported using other discharge computation methods so they were good to use flood modeling. However, 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.

5.8 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.

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 61 to Figure 66 shows the 5-, 25-, and 100-year rain return scenarios of the Balamban floodplain.

The generated flood hazard maps for the Balamban 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 60 to Figure 65 shows the 5-, 25-, and 100-year rain return scenarios of the Balamban floodplain. The floodplain covers two municipalites namely Asturias and Balamban.

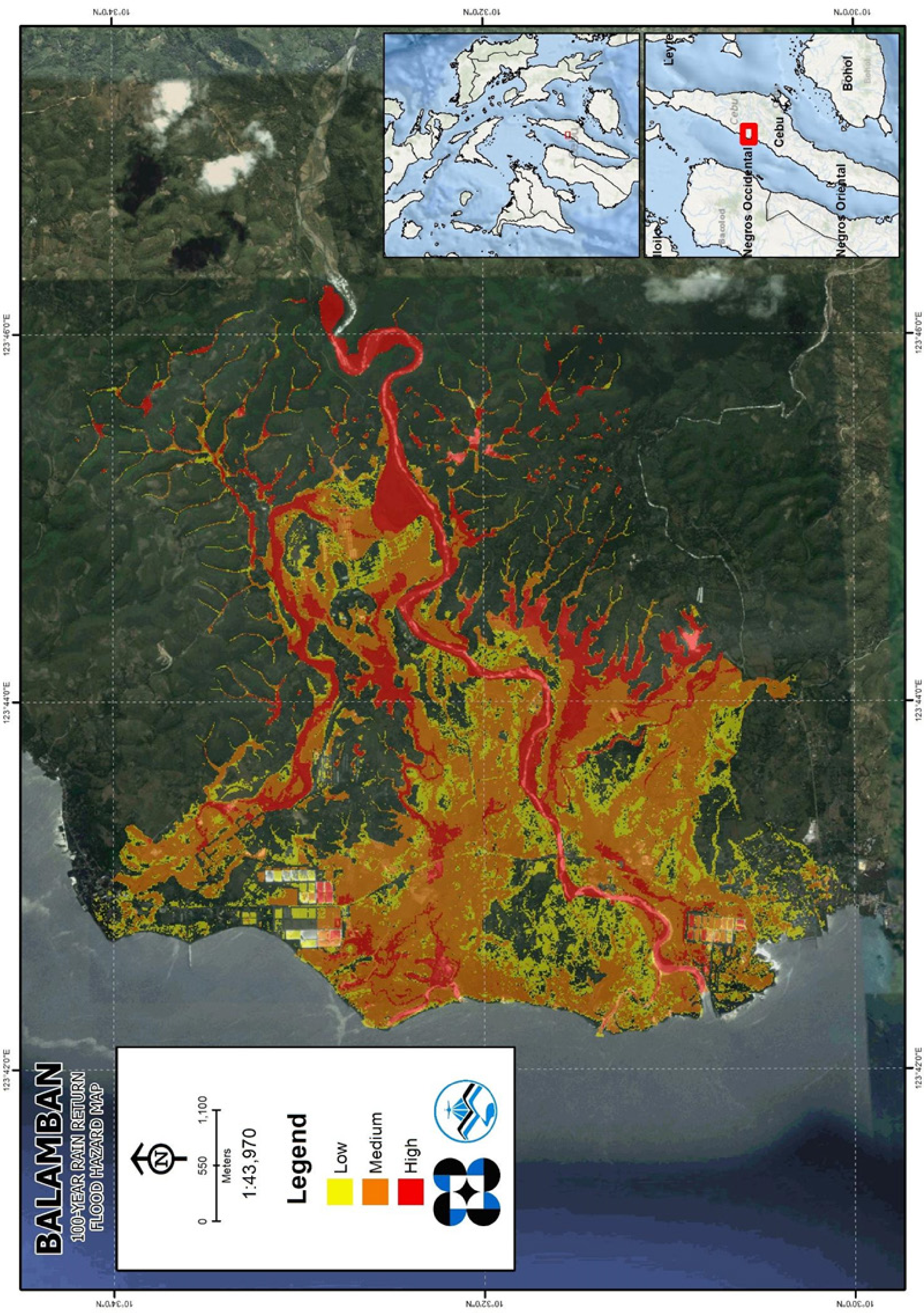

Figure 61. 100-year Flood Hazard Map for Balamban Floodplain overlaid on Google Earth imagery

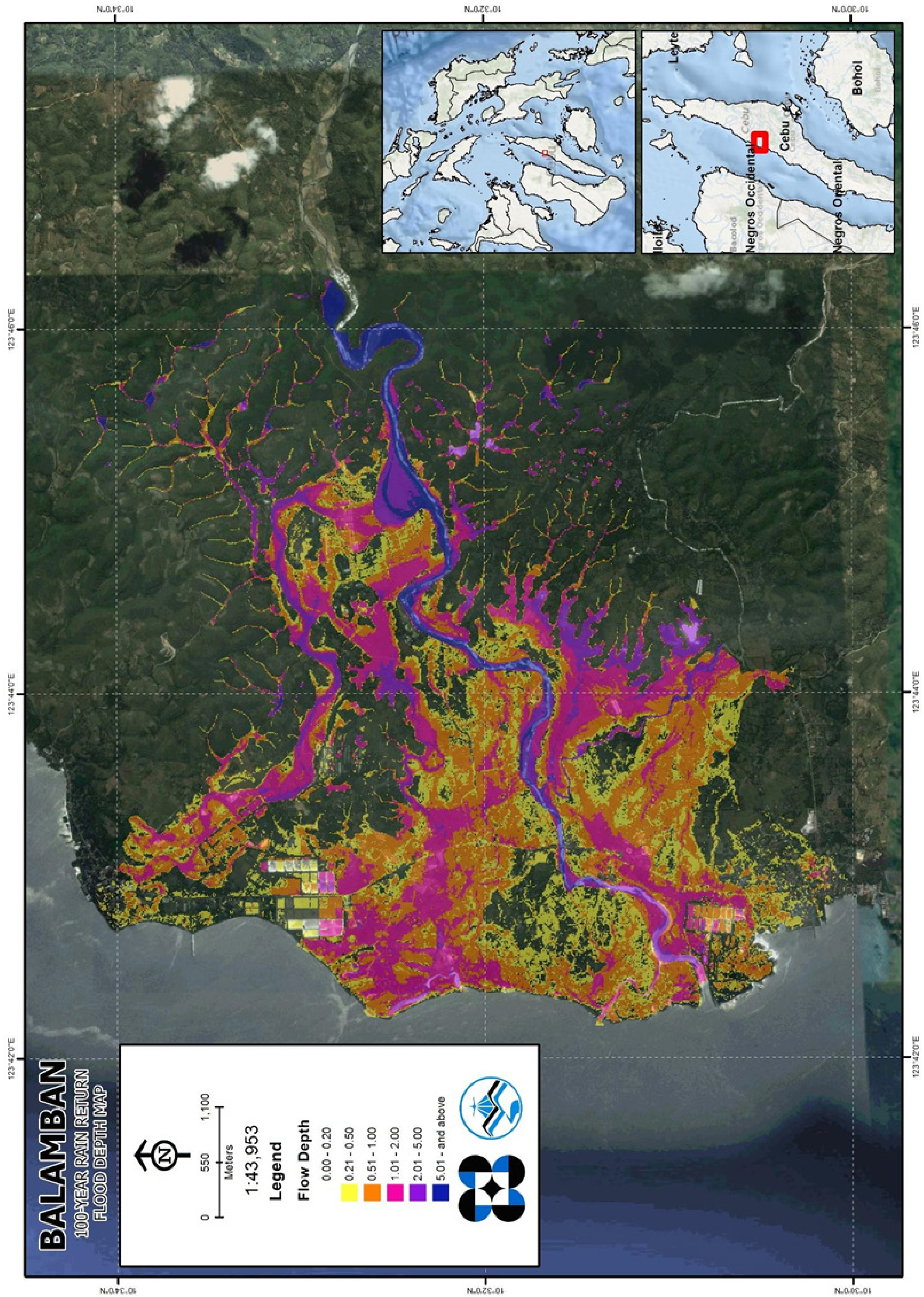

Figure 62. 100-year Flow Depth Map for Balamban Floodplain overlaid on Google Earth imagery

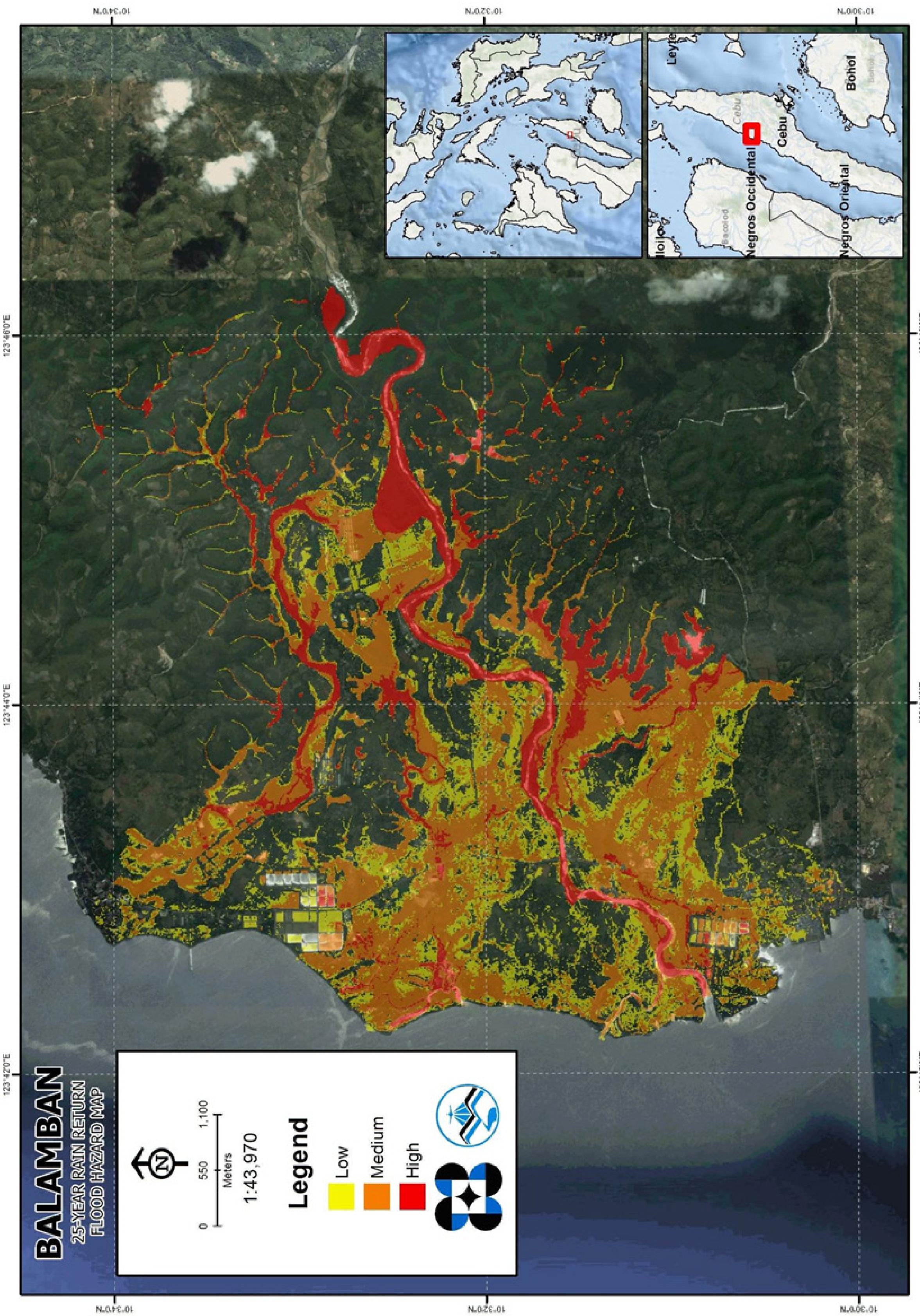

Figure 63. 25-year Flood Hazard Map for Balamban Floodplain overlaid on Google Earth imagery

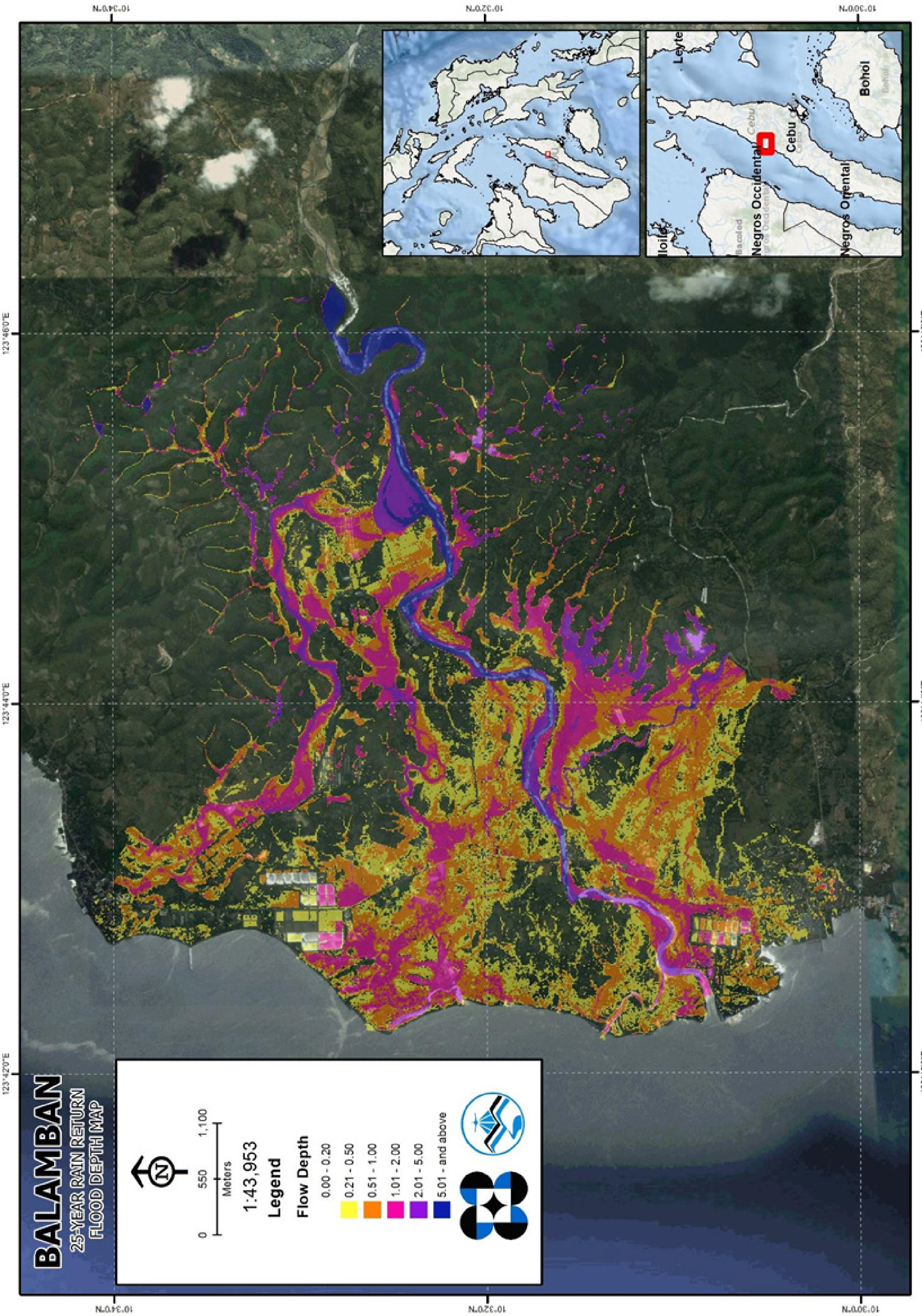

Figure 64. 25-year Flow Depth Map for Balamban Floodplain overlaid on Google Earth imagery

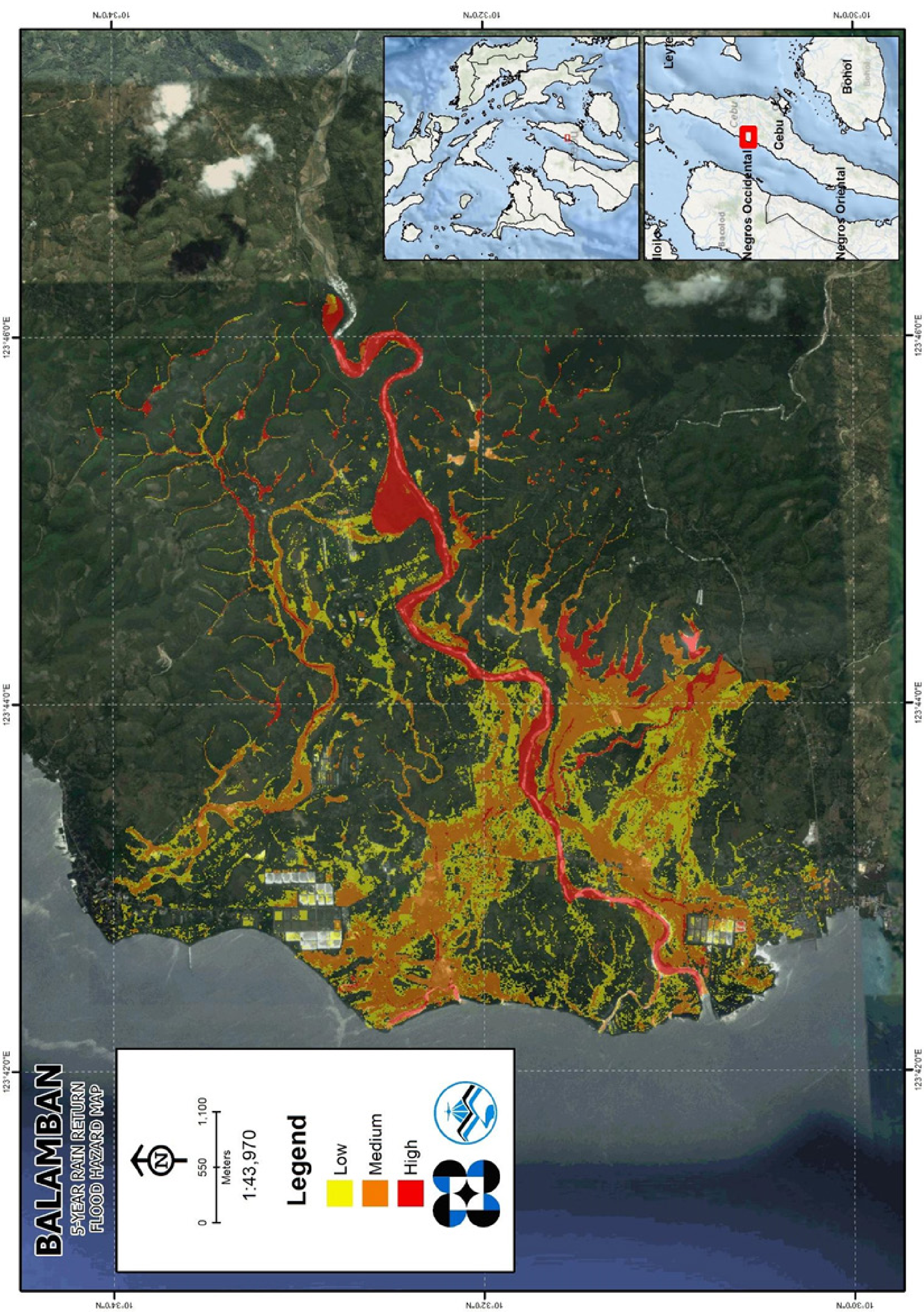

Figure 65. 5-year Flood Hazard Map for Balamban Floodplain overlaid on Google Earth imagery

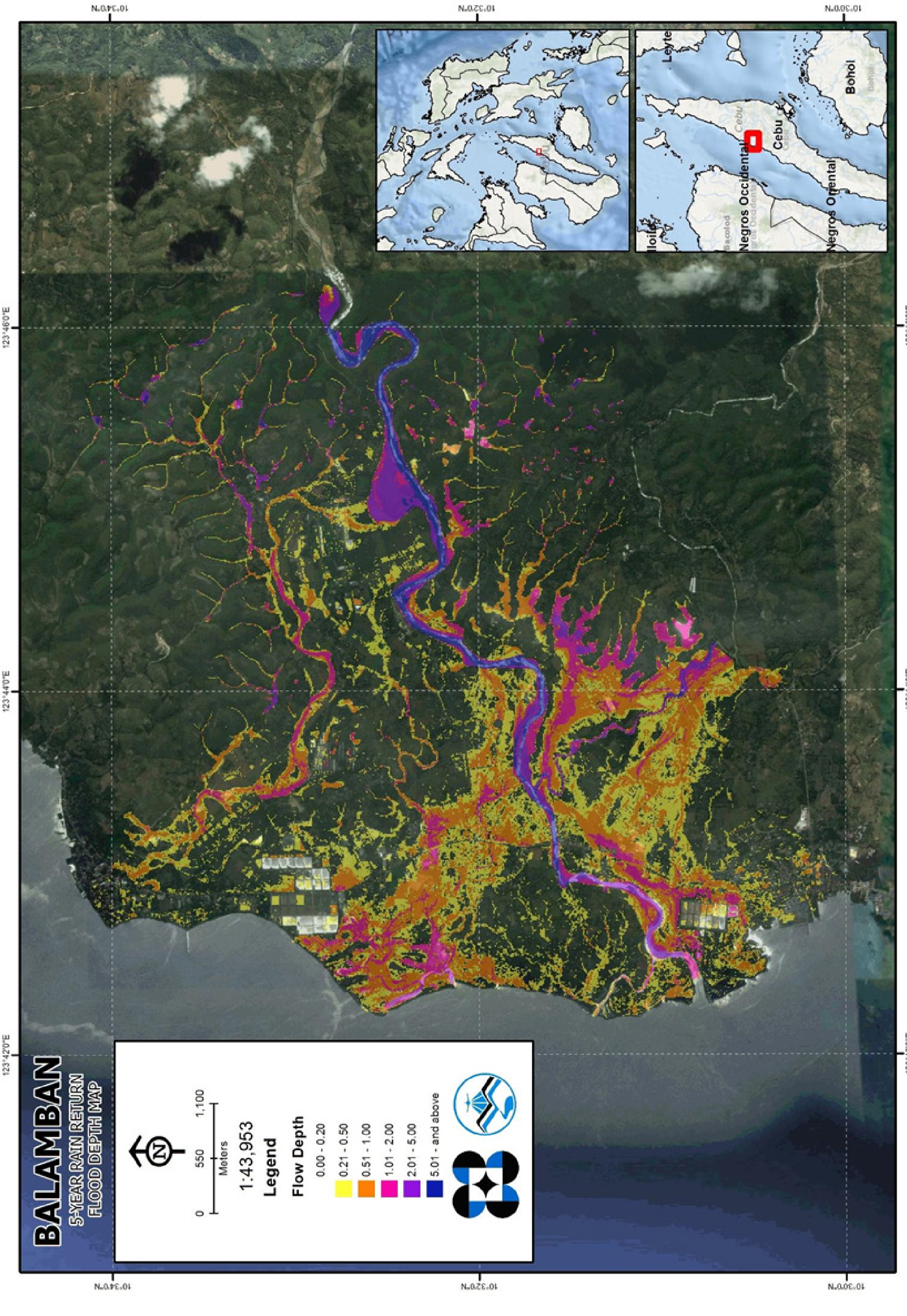

Figure 66. 5-year Flood Depth Map for Balamban Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Balamban river basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 16 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 8.73% of the municipality of Asturias with an area of 140.45 sq. km. will experience flood levels of less 0.20 meters. 1.115% of the area will experience flood levels of 0.21 to 0.50 meters while 0.77%, 0.34%, 0.07, and 0.04% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 33 and shown in Figure 67 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected areas in Asturias, Cebu during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Asturias (in sq. km.)				
	Manguiao	Owak	Poblacion	San Isidro	Tubod
0.03-0.20	0.19	4.34	0.79	6.76	0.19
0.21-0.50	0.0035	0.89	0.18	0.49	0.0035
0.51-1.00	0.0026	0.75	0.079	0.24	0.0014
1.01-2.00	0.00064	0.32	0.0015	0.16	0.0019
2.01-5.00	0	0.023	0	0.078	0.0025
> 5.00	0	0	0	0.061	0.0017

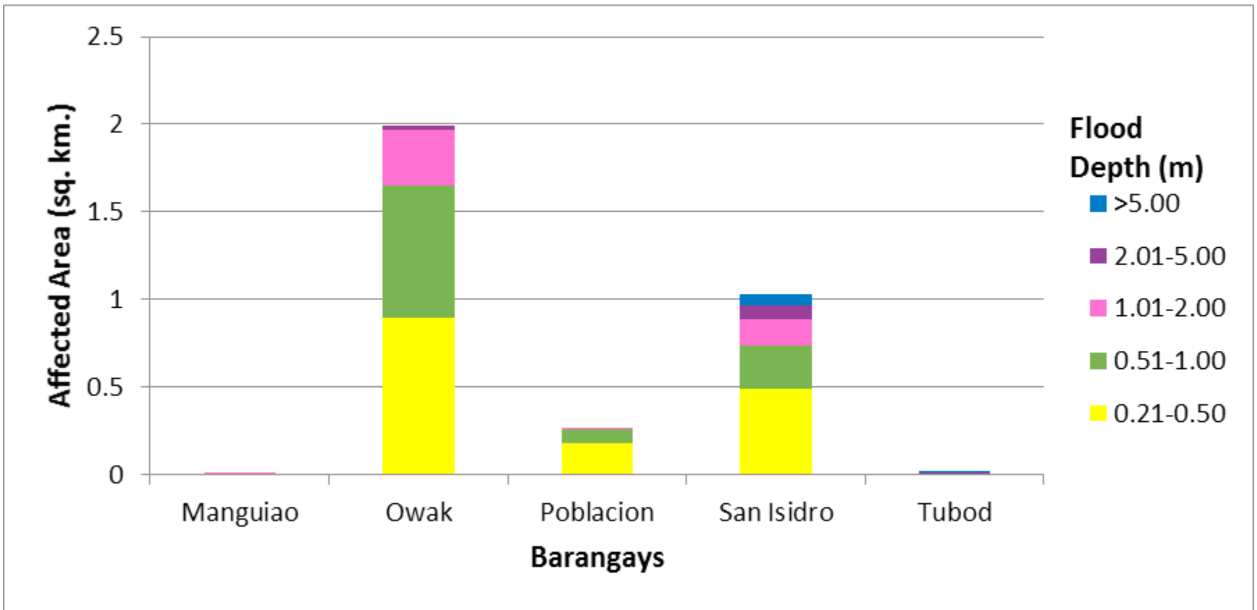

Figure 67. Affected Areas in Asturias, Cebu during 5-Year Rainfall Return Period

For the municipality of Balamban, with an area of 221.33 sq. km., 5.83% will experience flood levels of less 0.20 meters. 1.49% of the area will experience flood levels of 0.21 to 0.50 meters while 1.2%, 0.53%, 0.34%, and 0.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 34 and shown in Figure 68 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected Areas in Balamban, Cebu during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Balamban (in sq. km.)										
	Aliwanay	Baliwagan	Biasong	Cambuhawe	Cantuod	Hingatmonan	Nangka	Prenza	Santa Cruz-Santo Niño	Singsing	Vito
0.03-0.20	0.081	0.55	6.16	0.011	1.38	0.0017	3.46	0.096	0.49	0.67	0.00055
0.21-0.50	0.0083	0.21	0.34	0.0011	1.09	0	1.41	0.027	0.092	0.11	0.003
0.51-1.00	0.0052	0.16	0.32	0.0002	0.99	0	0.93	0.039	0.021	0.19	0.0016
1.01-2.00	0.0001	0.054	0.32	0	0.39	0	0.26	0.0045	0.0006	0.15	0.00015
2.01-5.00	0	0	0.39	0	0.11	0	0.22	0.0006	0	0.043	0
> 5.00	0	0	0.28	0	0.031	0	0.16	0	0	0.0071	0

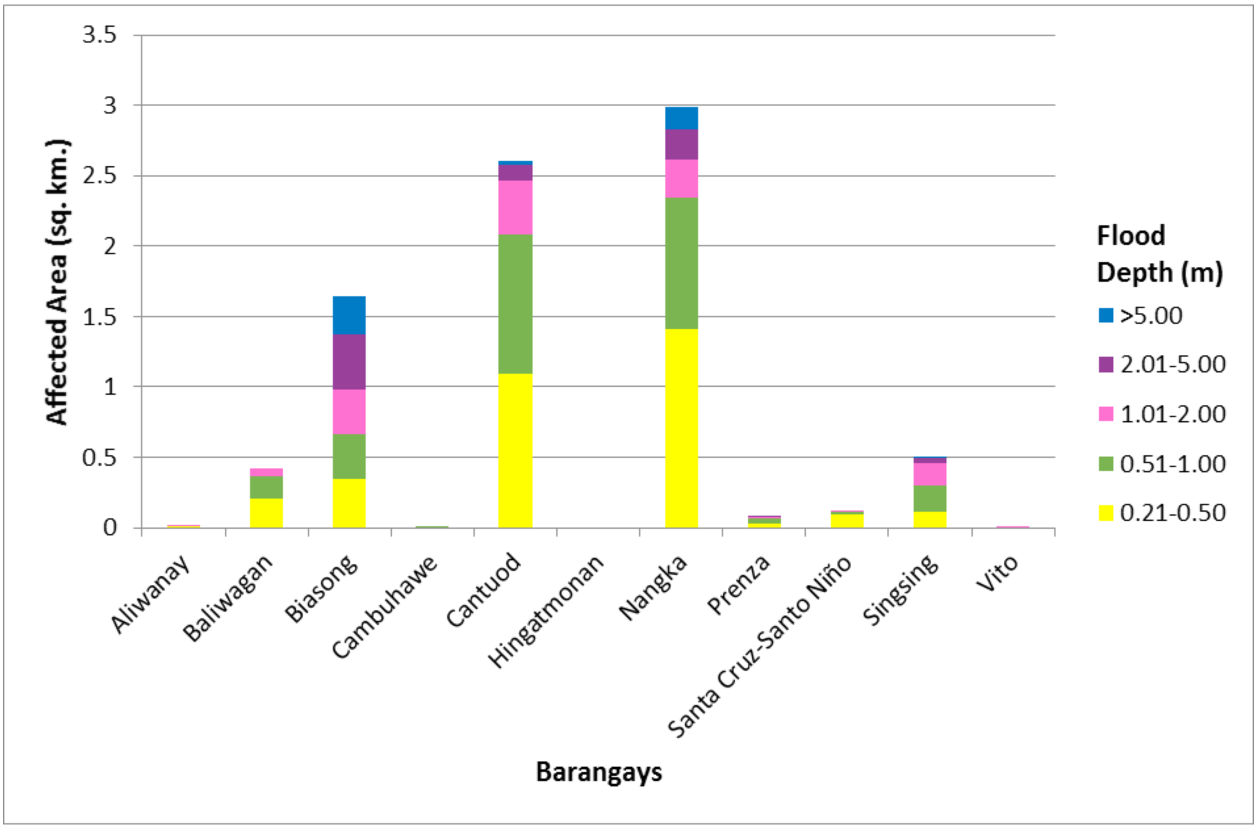

Figure 68. Affected Areas in Balamban, Cebu during 5-Year Rainfall Return Period

For the 25-year return period, 7.34% of the municipality of Asturias with an area of 140.45 sq. km. will experience flood levels of less 0.20 meters. 1.116% of the area will experience flood levels of 0.21 to 0.50 meters while 1.24%, 1.05%, 0.2, and 0.09% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 35 and shown in Figure 69 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected areas in Asturias, Cebu during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Asturias (in sq. km.)				
	Manguiao	Owak	Poblacion	San Isidro	Tubod
0.03-0.20	0.19	3.4	0.57	5.96	0.18
0.21-0.50	0.0051	0.92	0.21	0.49	0.0041
0.51-1.00	0.0023	1.05	0.2	0.48	0.002
1.01-2.00	0.0018	0.89	0.061	0.52	0.0023
2.01-5.00	0	0.068	0	0.21	0.0028
> 5.00	0	0.001	0	0.12	0.0034

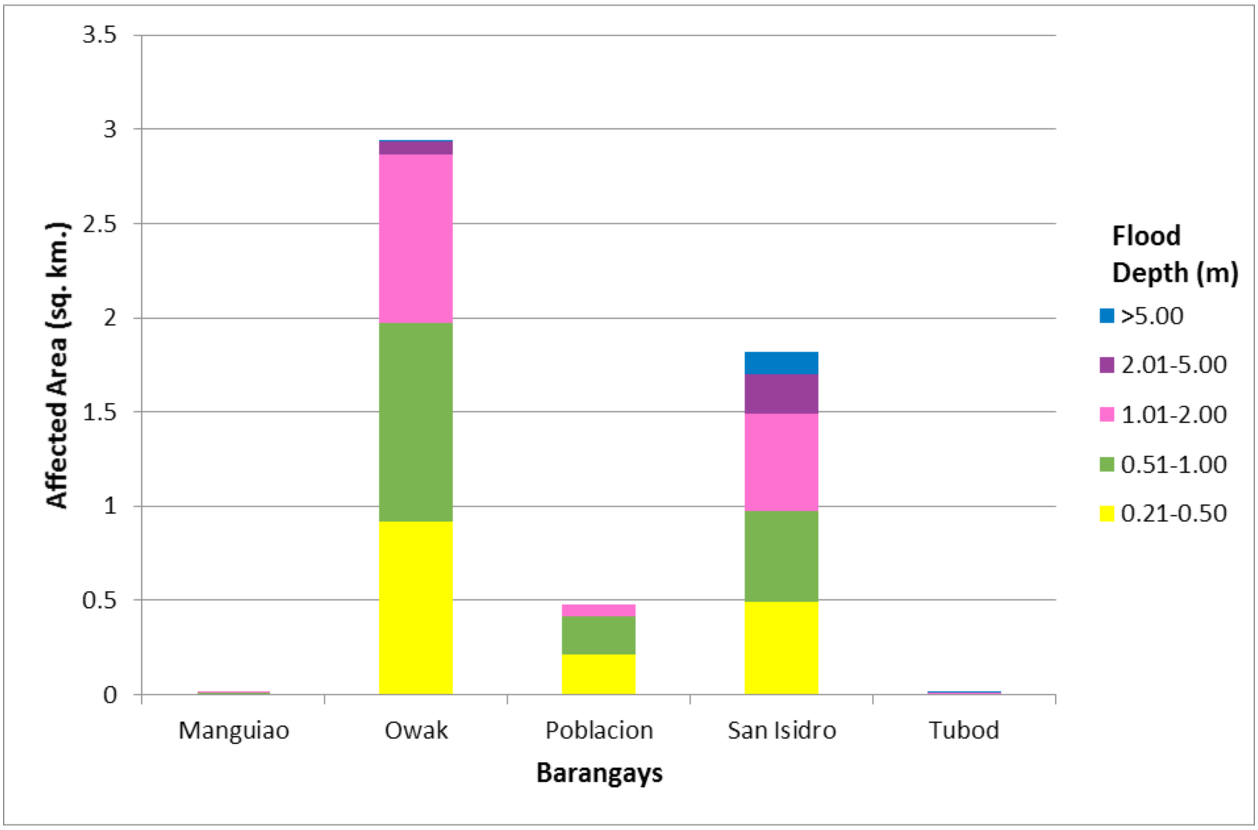

Figure 69. Affected Areas in Asturias, Cebu during 25-Year Rainfall Return Period

For the municipality of Balamban, with an area of 221.33 sq. km., 4.72% will experience flood levels of less 0.20 meters. 1.58% of the area will experience flood levels of 0.21 to 0.50 meters while 1.63%, 0.93%, 0.47%, and 0.29% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 36 and shown in Figure 70 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected Areas in Balamban, Cebu during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Balamban (in sq. km.)										
	Aliwanay	Baliwagan	Biasong	Cambuhawe	Cantuod	Hingatmonan	Nangka	Prenza	Santa Cruz-Santo Niño	Singsing	Vito
0.03-0.20	0.075	0.42	5.6	0.011	0.96	0.0017	2.27	0.087	0.43	0.59	0
0.21-0.50	0.013	0.22	0.41	0.0012	0.87	0	1.72	0.017	0.13	0.11	0.003
0.51-1.00	0.0057	0.23	0.45	0.0002	1.24	0	1.41	0.046	0.037	0.19	0.0017
1.01-2.00	0.0011	0.095	0.46	0	0.74	0	0.61	0.016	0.0032	0.14	0.00051
2.01-5.00	0	0.0013	0.45	0	0.16	0	0.27	0.0009	0	0.15	0
> 5.00	0	0	0.44	0	0.031	0	0.17	0	0	0.0047	0

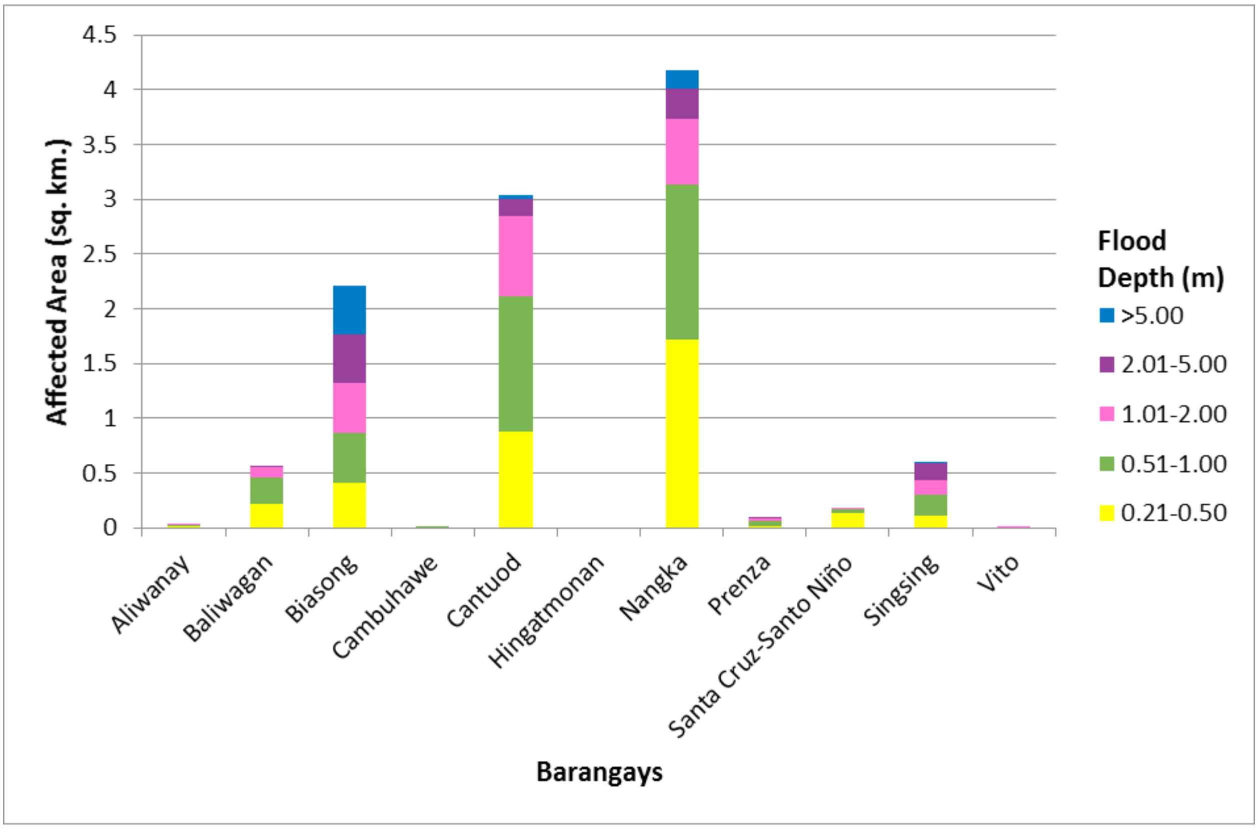

Figure 70. Affected Areas in Balamban, Cebu during 25-Year Rainfall Return Period

For the 100-year return period, 4.02% of the municipality of Asturias with an area of 140.45 sq. km. will experience flood levels of less 0.20 meters. 1.45% of the area will experience flood levels of 0.21 to 0.50 meters while 1.98%, 1.3%, 0.57, and 0.31% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 37 and shown in Figure 71 are the affected areas in square kilometres by flood depth per barangay.

Table 37. Affected areas in Asturias, Cebu during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Asturias (in sq. km.)				
	Manguiao	Owak	Poblacion	San Isidro	Tubod
0.03-0.20	0.19	3.07	0.51	5.72	0.18
0.21-0.50	0.0052	0.75	0.22	0.48	0.0047
0.51-1.00	0.0024	1.16	0.23	0.52	0.002
1.01-2.00	0.0023	1.21	0.096	0.64	0.0017
2.01-5.00	0	0.14	0	0.3	0.0038
> 5.00	0	0.0051	0	0.13	0.0042

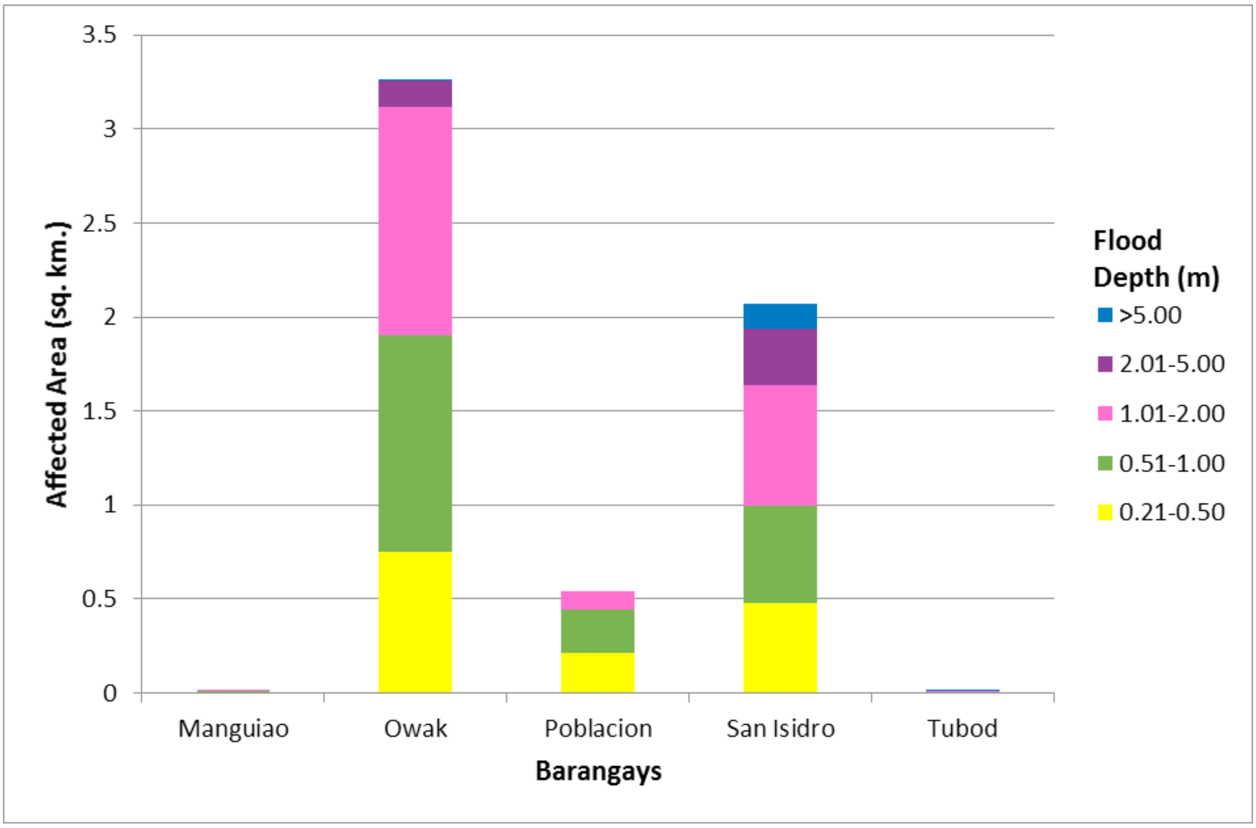

Figure 71. Affected Areas in Asturias, Cebu during 100-Year Rainfall Return Period

For the municipality of Balamban, with an area of 221.33 sq. km., 4.02% will experience flood levels of less 0.20 meters. 1.45% of the area will experience flood levels of 0.21 to 0.50 meters while 1.98%, 1.3%, 0.57%, and 0.31% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 38 and shown in Figure 72 are the affected areas in square kilometres by flood depth per barangay.

Table 38. Affected Areas in Balamban, Cebu during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Balamban (in sq. km.)										
	Aliwanay	Baliwagan	Biasong	Cambuhawe	Cantuod	Hingatmonan	Nangka	Prenza	Santa Cruz-Santo Niño	Singsing	Vito
0.03-0.20	0.072	0.36	5.37	0.011	0.75	0.0017	1.3	0.085	0.39	0.55	0
0.21-0.50	0.016	0.21	0.37	0.0014	0.75	0	1.57	0.014	0.15	0.11	0.0014
0.51-1.00	0.0054	0.27	0.5	0.0002	1.31	0	2.03	0.045	0.054	0.16	0.0031
1.01-2.00	0.0023	0.13	0.57	0	0.93	0	1.04	0.023	0.0051	0.18	0.00076
2.01-5.00	0	0.0062	0.54	0	0.21	0	0.33	0.0009	0	0.17	0
> 5.00	0	0	0.46	0	0.032	0	0.18	0	0	0.0055	0

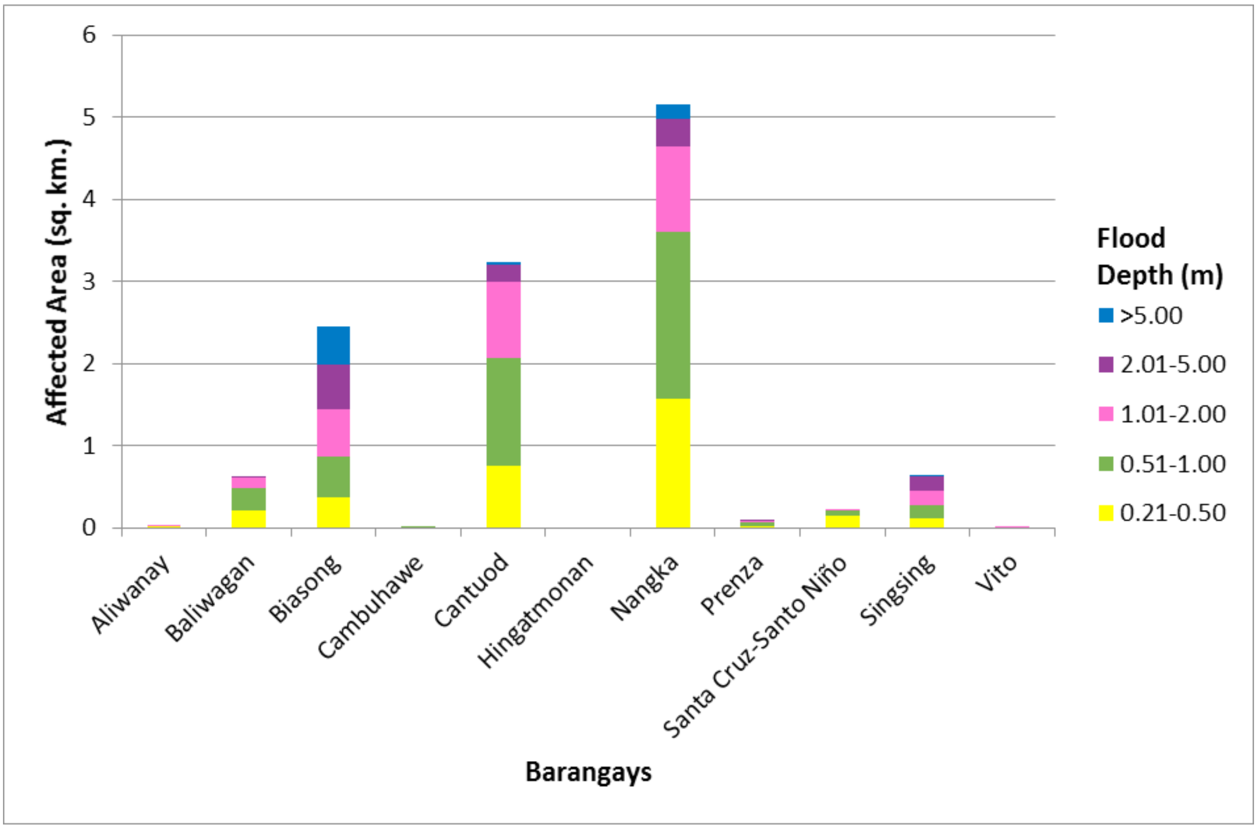

Figure 72. Affected Areas Balamban, Cebu during 100-Year Rainfall Return Period

Among the barangays in the municipality of Asturias, San Isidro is projected to have the highest percentage of area that will experience flood levels at 5.54%. Meanwhile, Owak posted the second highest percentage of area that may be affected by flood depths at 4.51%.

Among the barangays in the municipality of Balamban, Biasong is projected to have the highest percentage of area that will experience flood levels at 3.53%. Meanwhile, Nangka posted the second highest percentage of area that may be affected by flood depths at 2.92%.

Moreover, the generated flood hazard maps for the Balamban Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA 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).

Table 39. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	4.97	5.15	4.68
Medium	5.09	7.91	9.53
High	1.94	3.16	4.22
TOTAL	**12**	**16.22**	**18.43**

Of the 8 identified Education Institutions in the Balamban Flood plain, 4 schools were assessed to be exposed to Low level flooding during a 5 year scenario. In the 25 year scenario, 3 schools were assessed to be exposed to low level flooding, while 3 schools were assessed to be exposed to medium level flooding in the same scenario. In the 100 year scenario, 2 schools were assessed to be exposed to low level flooding, while 4 schools were assessed to be exposed to medium level flooding in the same scenario. The educational institutions exposed to flooding are shown in Annex 12.

Of the 4 identified Medical Institutions in the Balamban Flood Plain, 1 medical institution was assessed to be exposed to Low level flooding during a 5 year scenario. In the 100 year scenario, 2 medical institutions were assessed to be exposed to low level flooding. The medical institutions exposed to flooding are found in Annex 13.

5.11 Flood Validation

Survey was done along the floodplain of Balamban 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 representatives from the Municipality of Balamban. Residents along the floodplain were interviewed of the historical flood events they experiences.

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 0.7532 was obtained.

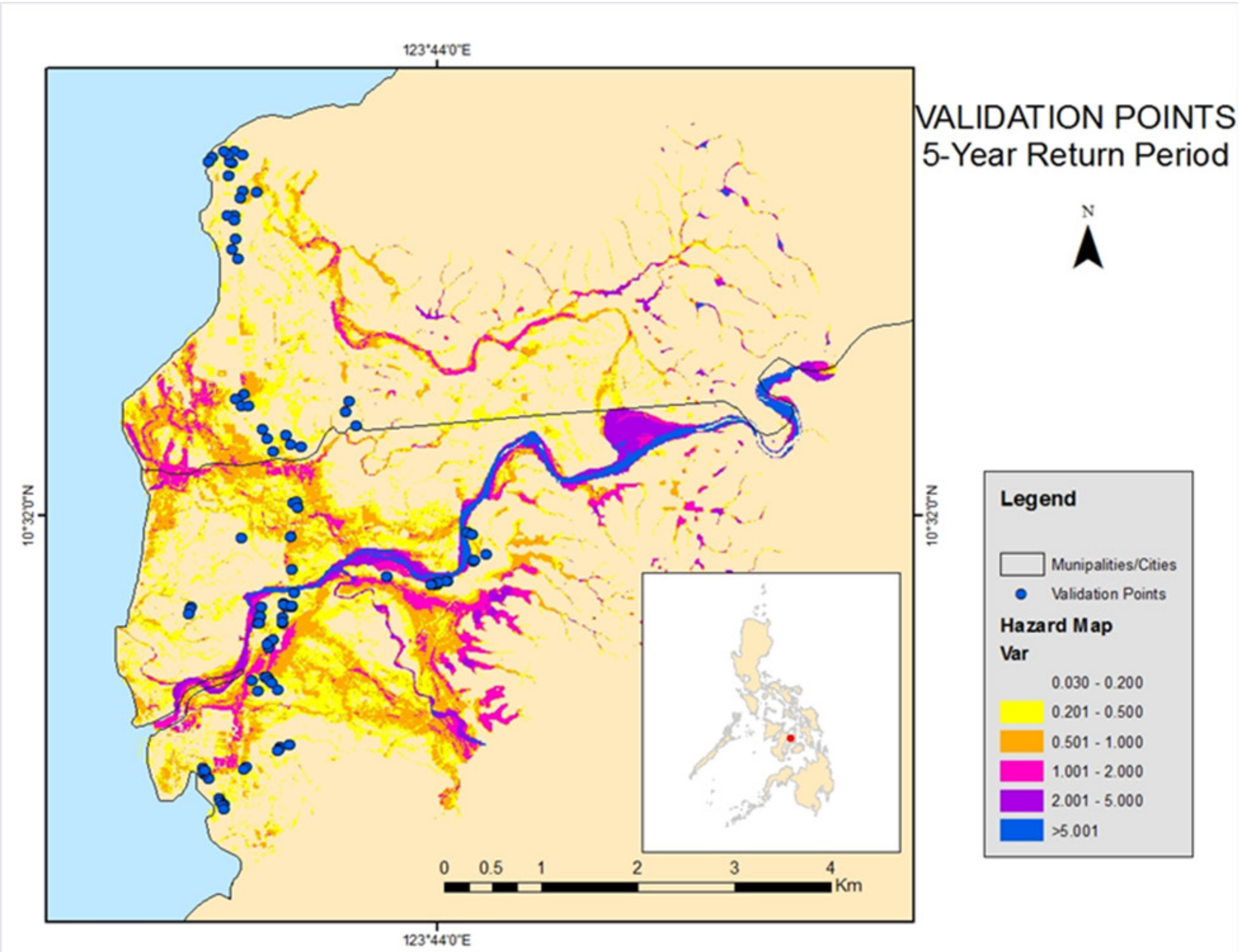

Figure 73. Balamban Flood Validation Points

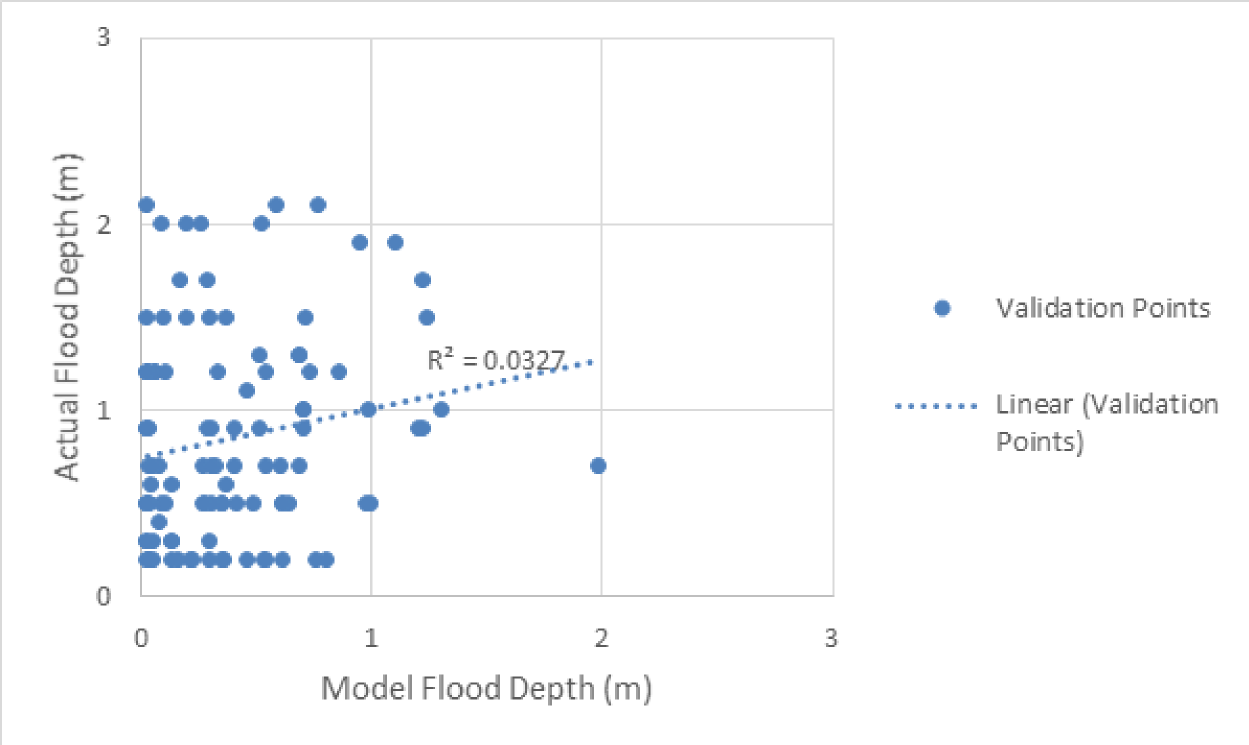

Figure 74. Flood map depth vs. actual flood depth

Table 40. Actual flood vs simulated flood depth at different levels in the Balamban 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	6	6	5	0	0	0	17
0.21-0.50	12	8	5	0	0	0	25
0.51-1.00	8	8	8	4	0	0	28
1.01-2.00	12	6	9	3	0	0	30
2.01-5.00	1	0	2	0	0	0	3
> 5.00		0	0	0	0	0	0
Total	39	28	29	7	0	0	103

The overall accuracy generated by the flood model is estimated at 25.74% with 156 points correctly matching the actual flood depths. In addition, there were 129 points estimated one level above and below the correct flood depths while there were 145 points and 164 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 364 points were underestimated in the modelled flood depths of Balamban. The summary of the accuracy assessment is presented in Table 40.

Table 41. Summary of the Accuracy Assessment in the Balamban River Basin Survey

	No. of Points	%
Correct	25	24.27
Overestimated	20	19.42
Underestimated	58	56.31
Total	103	100.00

REFERENCES

Ang M.C., Paringit E.C., et al. 2014. DREAM Data Processing Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

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Paringit, E.C., Balicanta, L.P., Ang, M.C., Lagmay, A.F., Sarmiento, C. 2017, Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

Sarmiento C.J.S., Paringit E.C., et al. 2014. DREAM Data Aquisition Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

UP TCAGP 2016. Acceptance and Evaluation of Synthetic Aperture Radar Digital Surface Model (SAR DSM) and Ground Control Points (GCP). Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

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

9 9 0 7 2 5 2 0 1 4 1 3 1 7 4 1

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

2. CBU-337

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-337**
Order: **2nd**

Island: **VISAYAS**		Barangay: **COLONIA**
Municipality: **TUBURAN**		MSL Elevation:
	PRS92 Coordinates	
Latitude: **10° 39' 23.68236"**	Longitude: **123° 47' 24.66412"**	Ellipsoidal Hgt: **29.98700 m.**
	WGS84 Coordinates	
Latitude: **10° 39' 19.45980"**	Longitude: **123° 47' 29.88199"**	Ellipsoidal Hgt: **90.66000 m.**
	PTM / PRS92 Coordinates	
Northing: **1178456.495 m.**	Easting: **586455.051 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **1,178,044.01**	Easting: **586,424.79**	Zone: **51**

Location Description

CBU-337

To reach the station, travel along S road to Naga City then turn W to the junction road leading to Toledo City and travel for one and a half hrs., after you reach Toledo City, turn N to Sangi junction leading to the Mun. of Tuburan and travel again for one and a half hrs. to reach the station. You will pass the Municipalities of Balamban and Asturias. After reaching Asturias Proper, continue travelling to Sta. Lucia Junction. When you reach the junction, turn right going to a concrete road and continue travelling to another junction leading to Brgy. Colonia and Brgy. Manguiao. After you reach the other junction, turn left to the road to reach Brgy. Colonia. The station is located aoutside the Colonia Central School compound near the concrete fence infront of the school.

Mark is the head of a 3 in. copper nail embedded and centered on a 30 cm x 30 cm x 1.20 m concrete monument, protruding about 20 cm above the ground with inscriptions, "CBU-337, 2007, NAMRIA".

Requesting Party: **UP-TCAGP / Engr. Christopher Cruz**
Pupose: **Reference**
OR Number: **8799582 A**
T.N.: **2014-1731**

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

9907252014131832

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. CBU-337

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-2.3. CU-1007

4. CU-575

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

August 29, 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-575**

Island: **CEBU**	Municipality: **TUBURAN**	Barangay: **FORTALIZA**
Elevation: **28.7137 +/- 0.00 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

BM CU-575 is located along the national highway of barangay Fortaliza, Tuburan 13 m NE of deep well, 20 m SE of Jessie Quer Residence, 25 m SE of Renante Quer residence, 0.20 m NW of km post 87. It is set on a drilled hole centered with a copper nail on a 0.20 m x 0.20 m cement putty, 0.02 m above a concrete surface of a riprap wall with inscription of CU-575.

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Purpose: **Reference**
OR Number: **8799780 A**
T.N.: **2014-1903**

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

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

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
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CIP/4701/12/09/814

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.4. CU-575

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

2. CU-575

Table A-3.2. CU-575

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
CBU-337 --- CU-575 (B1)	CBU-337	CU-575	Fixed	0.003	0.004	31°01'03"	1117.714	-1.414
CBU-337 --- CU-575 (B2)	CBU-337	CU-575	Fixed	0.002	0.003	31°01'04"	1117.719	-1.424

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

From:	CBU-337				
Grid		Local		Global	
Easting	586424.790 m	Latitude	N10°39'23.68236"	Latitude	N10°39'19.45981"
Northing	1178044.015 m	Longitude	E123°47'24.66412"	Longitude	E123°47'29.88199"
Elevation	28.962 m	Height	29.987 m	Height	90.659 m

To:	CU-575				
Grid		Local		Global	
Easting	586998.127 m	Latitude	N10°39'54.85973"	Latitude	N10°39'50.63543"
Northing	1179003.079 m	Longitude	E123°47'43.61525"	Longitude	E123°47'48.83231"
Elevation	27.560 m	Height	28.573 m	Height	89.238 m

Vector					
ΔEasting	573.336 m	NS Fwd Azimuth	31°01'03"	ΔX	-379.302 m
ΔNorthing	959.064 m	Ellipsoid Dist.	1117.714 m	ΔY	-468.760 m
ΔElevation	-1.402 m	ΔHeight	-1.414 m	ΔZ	941.111 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.001 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.002 m
σ ΔElevation	0.002 m	σ ΔHeight	0.002 m	σ ΔZ	0.001 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 Balamban Floodplain

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
Signature

Received by

Name JOIDA PRIETO
Position SSRS
Signature 8/20/14

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

DATA TRANSFER SHEET
09/05/2014(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	
8/9/2014	1813P	1MCTN221A	Pegasus	1.28	1.52	6.95	204	13.7	98	13.3	NA	5.23	1KB	1KB	222	NA	Z:\DAC\RAW DATA
8/11/2014	1821P	1BLK36AS223A	Pegasus	1.99	1.99	2.38	225	30.2	234	20.2	NA	4.45	1KB	1KB	314	NA	Z:\DAC\RAW DATA
8/12/2014	1825P	1BLK36ABC224A	Pegasus	1.31	1.36	5.78	164	20.8	159	12.5	NA	6.47	1KB	1KB	209	NA	Z:\DAC\RAW DATA
8/12/2014	1827P	1BLK36ES224B	Pegasus	1.88	2.02	6.41	187	27	245	18.2	NA	6.47	1KB	1KB	56.9	NA	Z:\DAC\RAW DATA
8/13/2014	1829P	1BLK36H47A225A	Pegasus	602	661	4.46	131	8.96	67	6.25	NA	8.78	1KB	1KB	265	NA	Z:\DAC\RAW DATA
8/13/2014	1831P	1OLNG225B	Pegasus	556	1.12	4.25	143	13.7	113	9.04	NA	8.78	1KB	1KB	29.8	NA	Z:\DAC\RAW DATA

Received from

Name TIN ANDAYA
Position RA
Signature

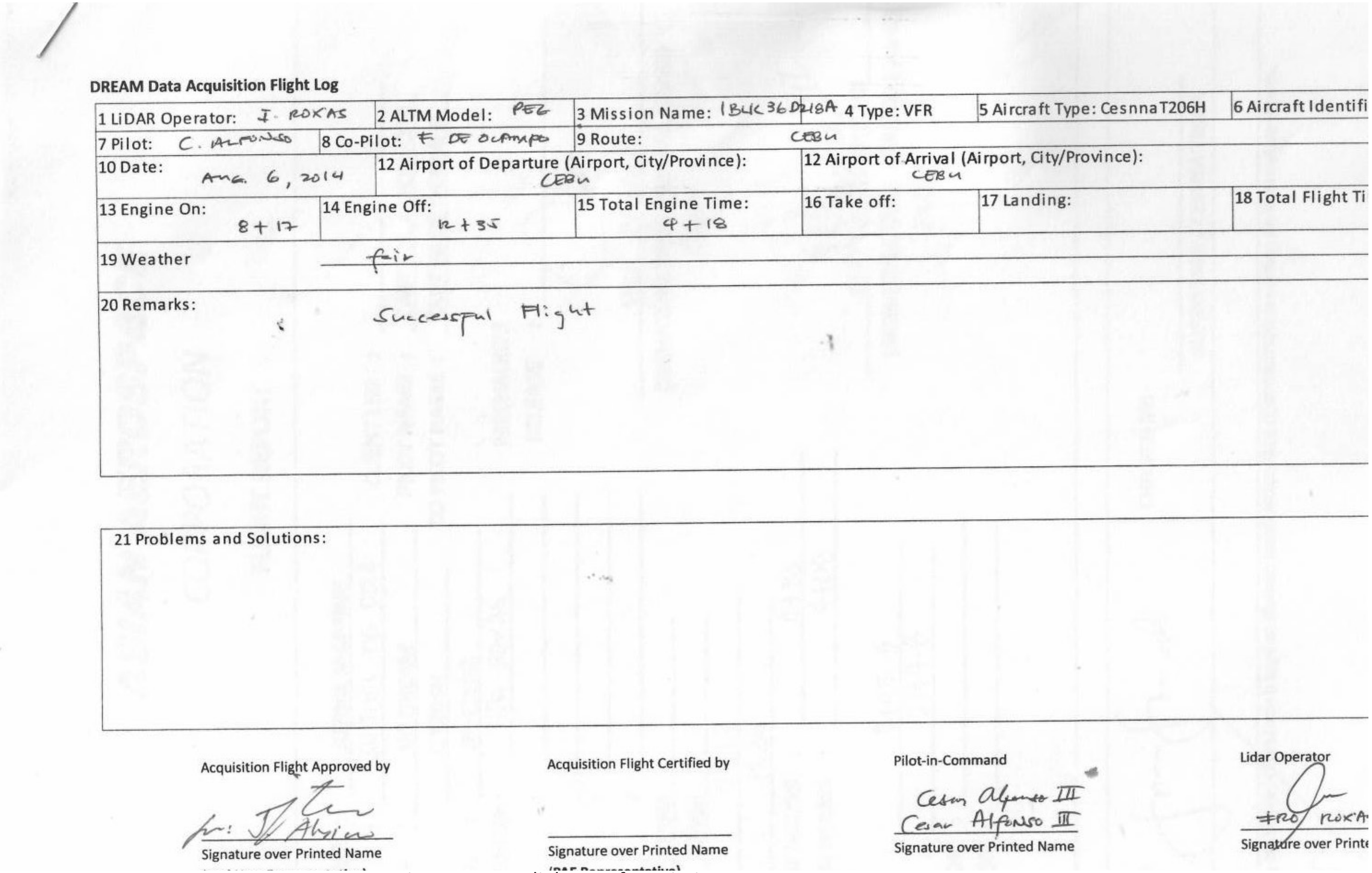
Received by

Name JOIDA F. PRIETO
Position SSRS 9/16/14
Signature

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

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 1801P



DREAM Data Acquisition Flight Log

1 LiDAR Operator: I. ROXAS	2 ALTM Model: PEG	3 Mission Name: 1BLK36D218A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identifi
7 Pilot: C. ALFONSO	8 Co-Pilot: F DE OCAMPO	9 Route: CEBU			
10 Date: Aug. 6, 2014	12 Airport of Departure (Airport, City/Province): CEBU		12 Airport of Arrival (Airport, City/Province): CEBU		
13 Engine On: 8+17	14 Engine Off: 12+35	15 Total Engine Time: 4+18	16 Take off:	17 Landing:	18 Total Flight Ti
19 Weather	fair				
20 Remarks:	Successful Flight				
21 Problems and Solutions:					

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar		Cesar Alfonso III	IRO ROXAS
Signature over Printed Name	Signature over Printed Name	Signature over Printed Name	Signature over Printe

Figure A-6.1. Flight Log for Mission 1801P

2. Flight Log for 1827P Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1827P

1 LIDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name: 1BLK36ES224B	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: F. Deocampo	9 Route: Cebu			
10 Date: August 12, 2014	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 1446 H	14 Engine Off: 1809 H	15 Total Engine Time: 3+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Filled in gaps in BLK 36E completed.

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Gerome Hipolito		C. Alfonso III	I. Roxas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.2. Flight Log for Mission 1827P

Annex 7. Flight Status Reports

Cebu Mission
August 6 and 12, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1801P	BLK36D	1BLK36D218A	I. Roxas	August 6	Completed BLK36D.
1827P	BLK36E	1BLK36ES224B	I. Roxas	August 12	Filled in gaps in BLK 36A, 36B and 36 C; Some coastal areas added.

LAS BOUNDARIED PER FLIGHT

Flight No. :	1801P			
Area:	BLK36D			
Mission Name:	1BLK47A211A			
Parameters:	Altitude:	1200m;	Scan Frequency:	30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.1. Swath for Flight No. 1801P

Flight No. :	1827P			
Area:	BLK36E			
Mission Name:	1BLK36ES224B			
Parameters:	Altitude:	1000m;	Scan Frequency:	30Hz;
	Scan Angle:	25deg;	Overlap:	30%

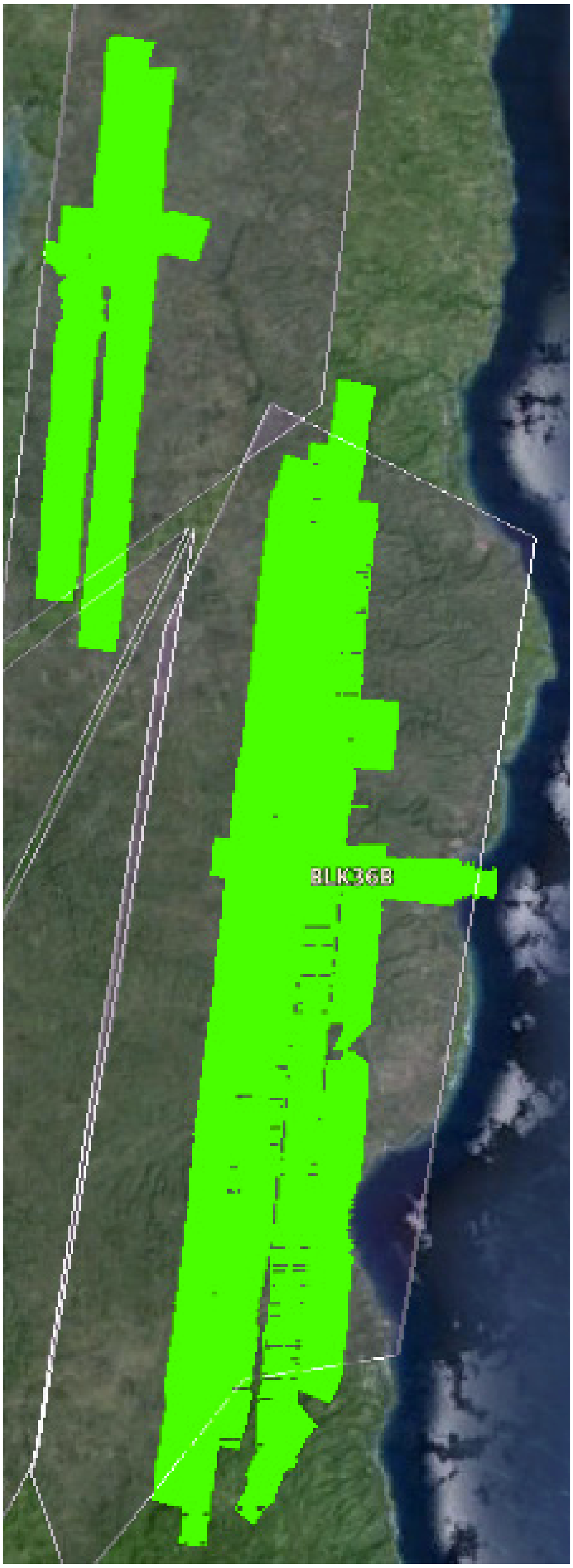


Figure A-7.2. Swath for Flight No. 1827P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk36D

Flight Area	Cebu
Mission Name	Blk36D
Inclusive Flights	1801P
Mission Name	1BLK36D218A
Range data size	32.1 GB
Base data size	8.9 MB
POS	258 MB
Image	54.0 GB
Transfer date	August 20, 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)	1.2
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	2.8
Boresight correction stdev (<0.001deg)	0.000153
IMU attitude correction stdev (<0.001deg)	0.000411
GPS position stdev (<0.01m)	0.0068
Minimum % overlap (>25)	32.62%
Ave point cloud density per sq.m. (>2.0)	5.31
Elevation difference between strips (<0.20m)	Yes
Number of 1km x 1km blocks	451
Maximum Height	358.11 m
Minimum Height	60.66 m
Classification (# of points)	
Ground	287,792,916
Low vegetation	214,914,170
Medium vegetation	546,398,318
High vegetation	258,444,081
Building	5,935,580
Orthophoto	Yes
Processed by	Engr. Jommer Medina, Aljon Rie Araneta, Jovy Narisma

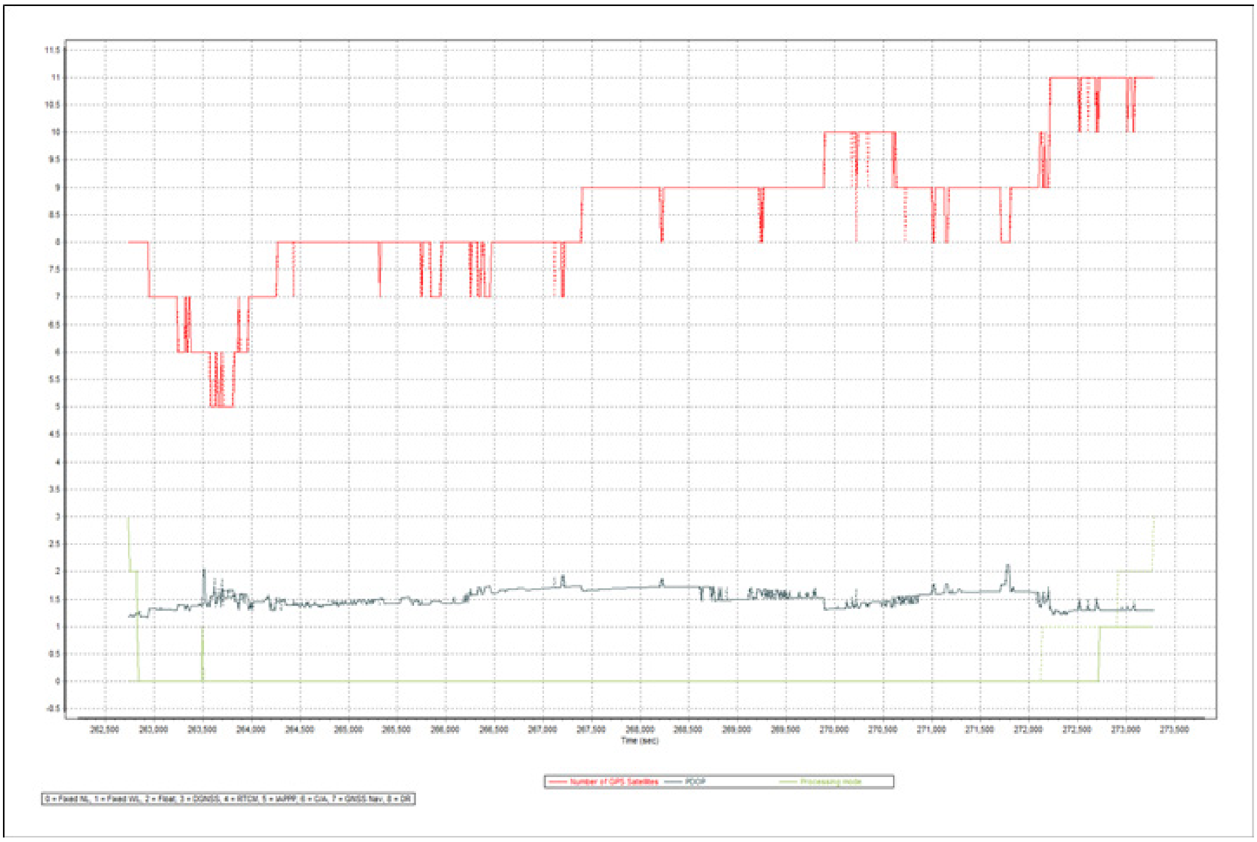


Figure A-8.1. Solution Status

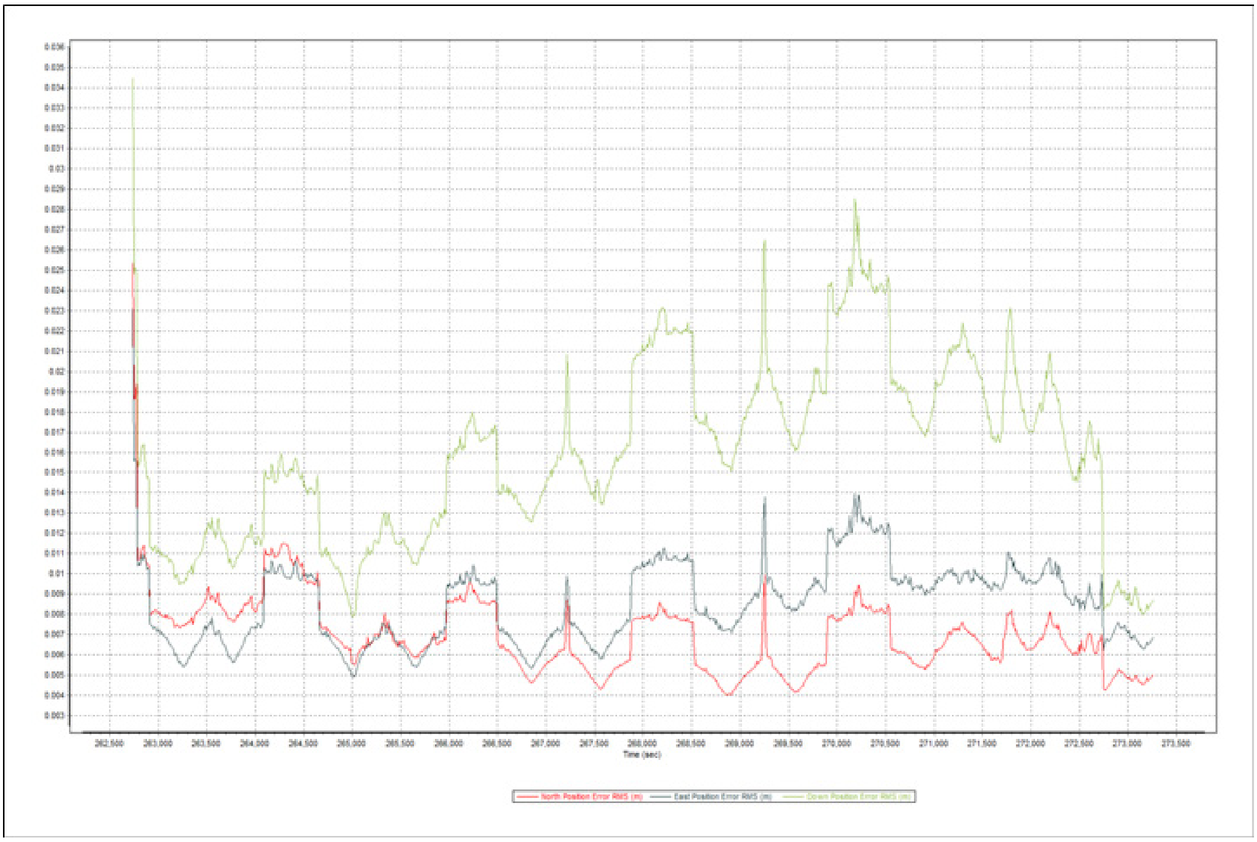


Figure A-8.2. Smoothed Performance Metrics Parameters

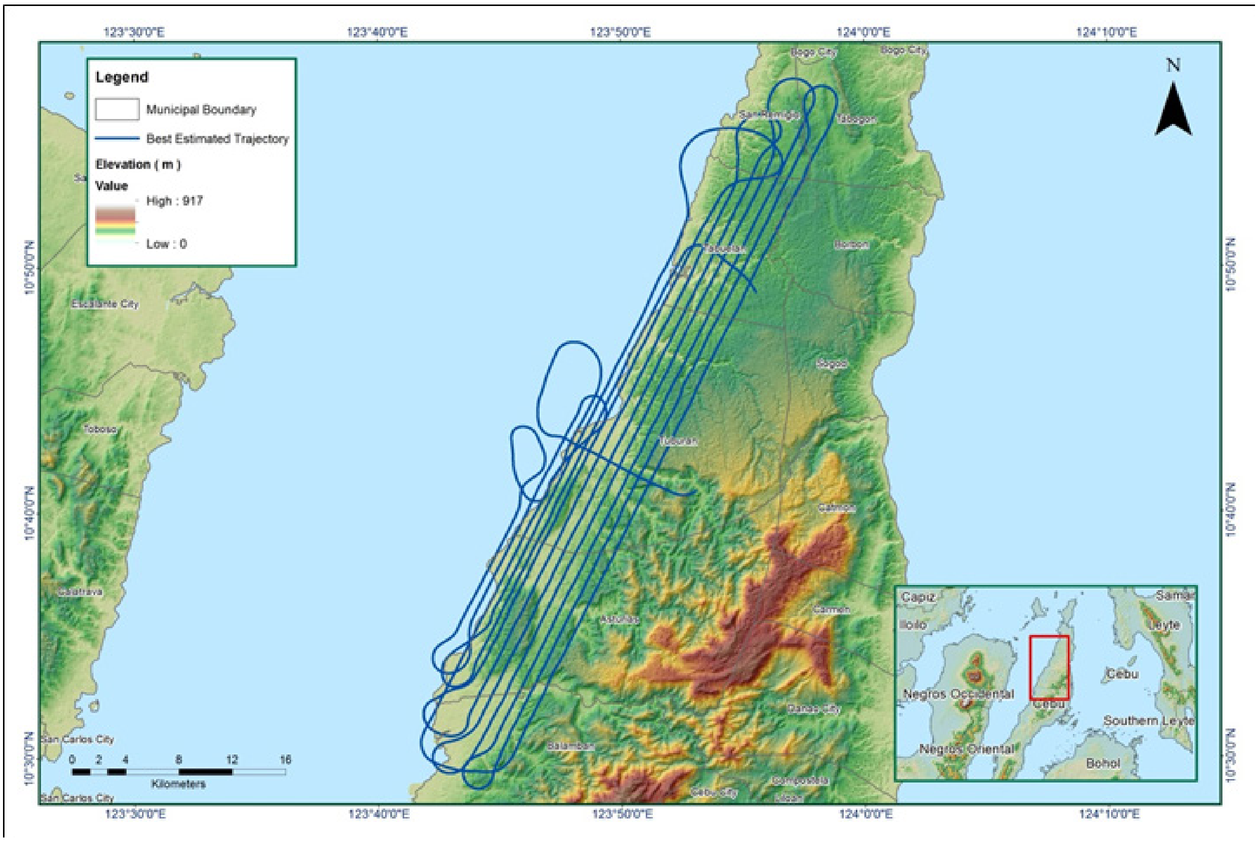


Figure A-8.3. Best Estimated Trajectory

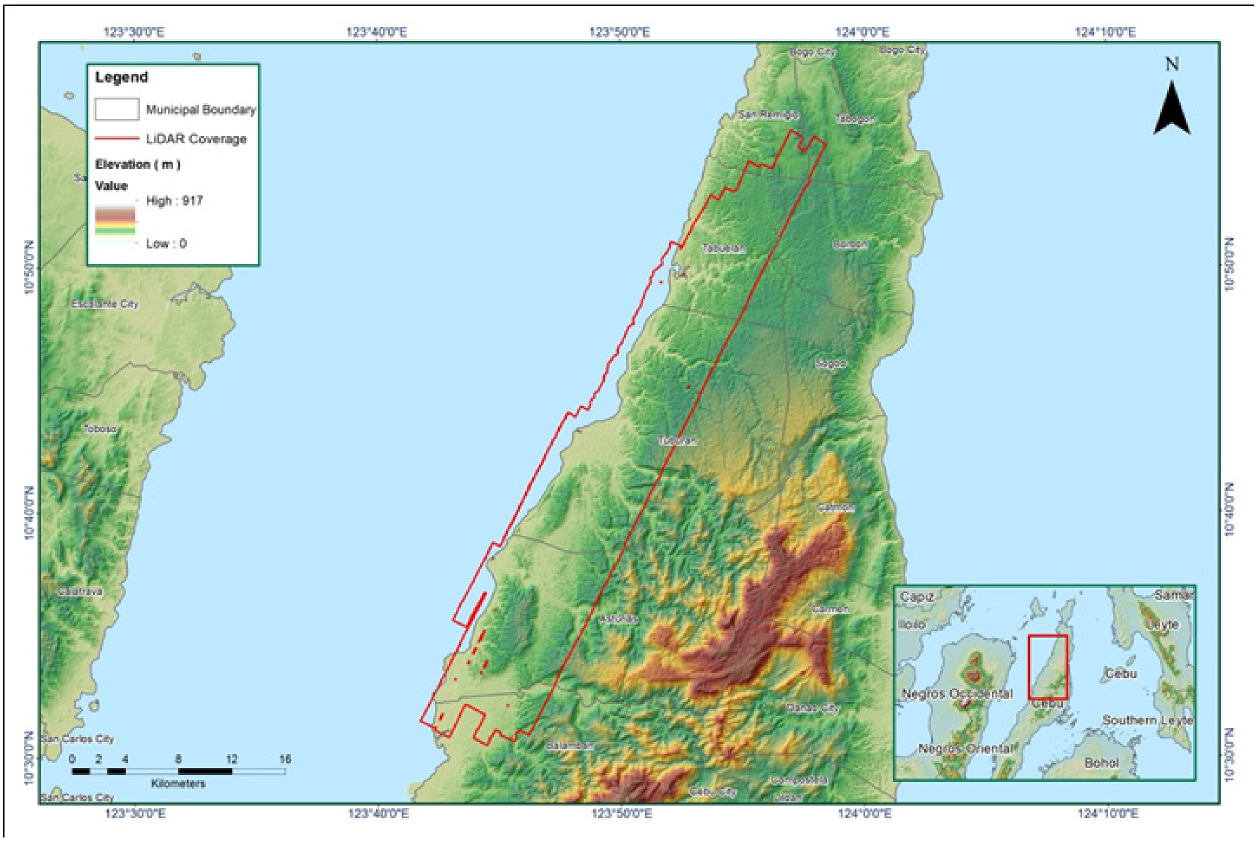


Figure A-8.4. Coverage of LiDAR data

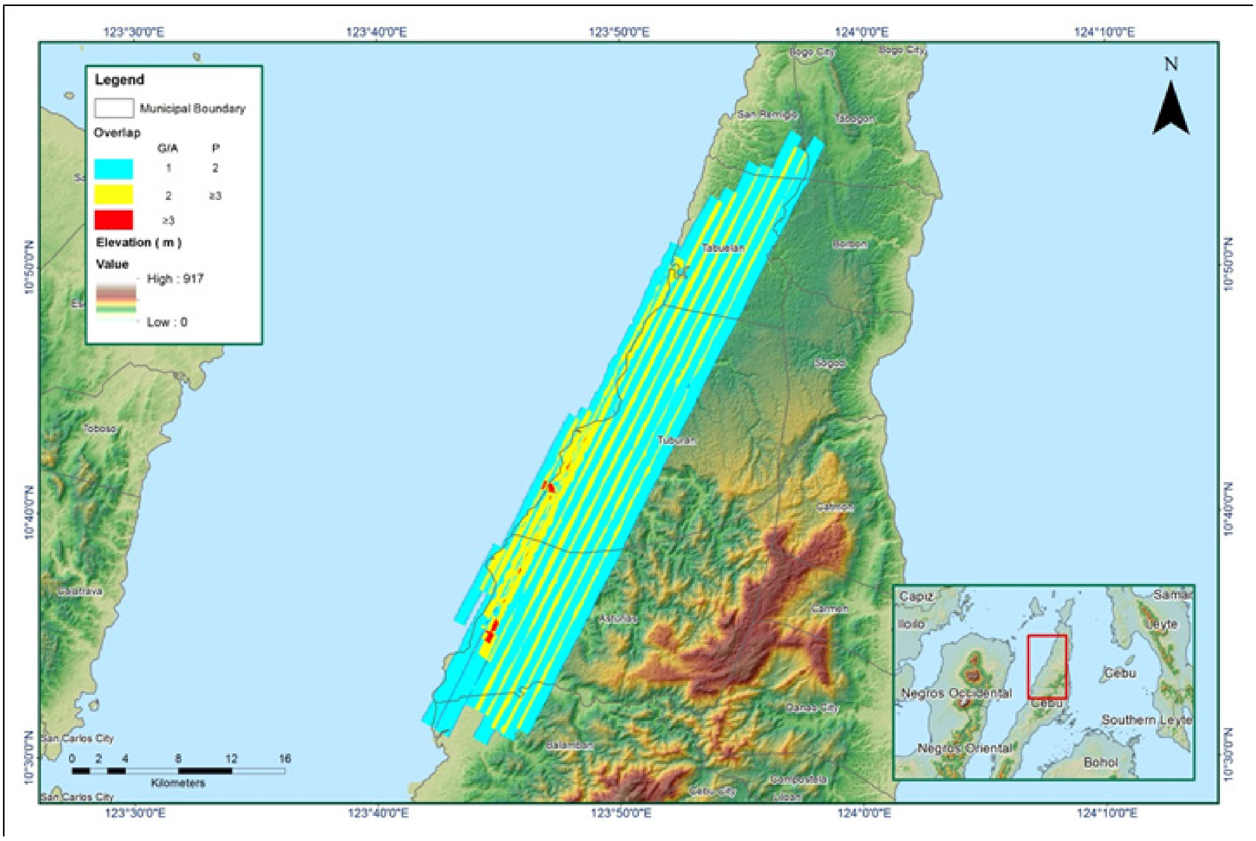


Figure A-8.5. Image of Data Overlap

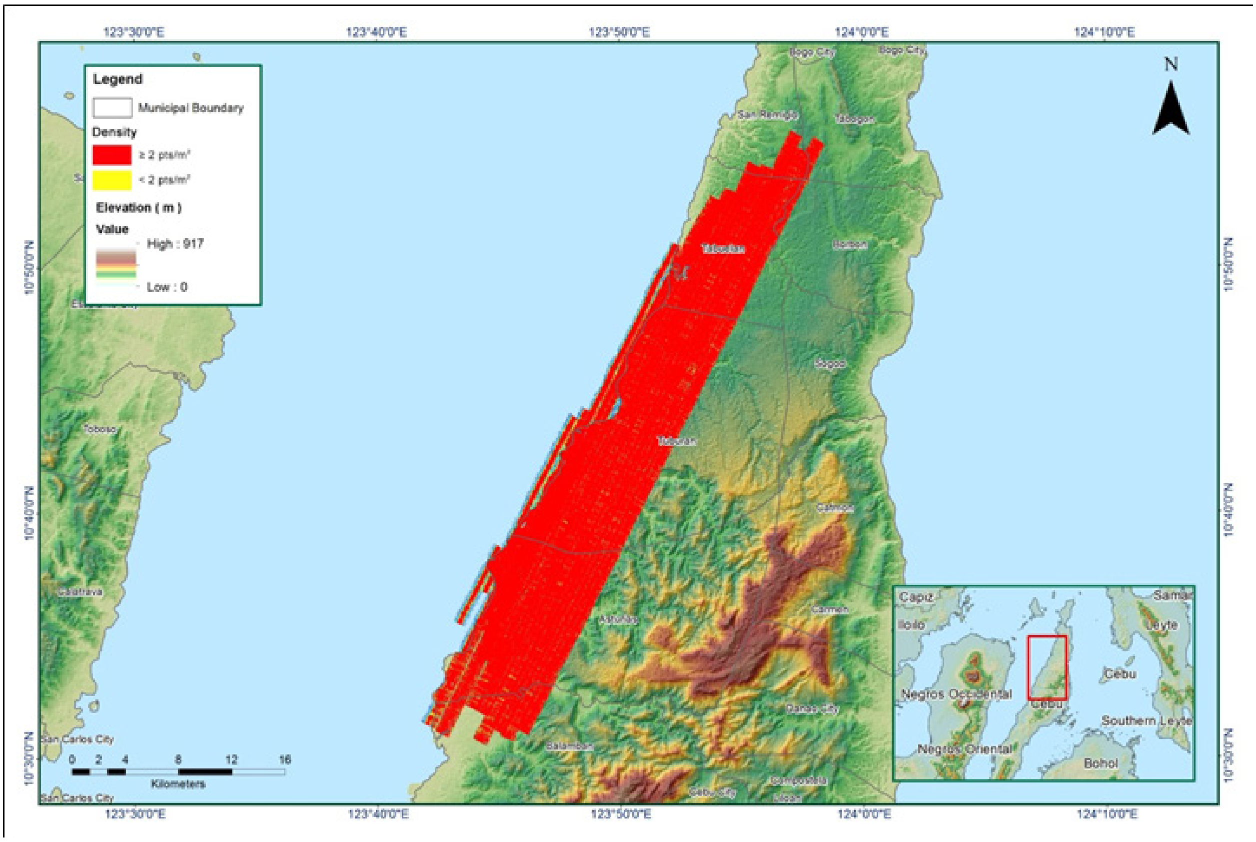


Figure A-8.6. Density map of merged LiDAR data

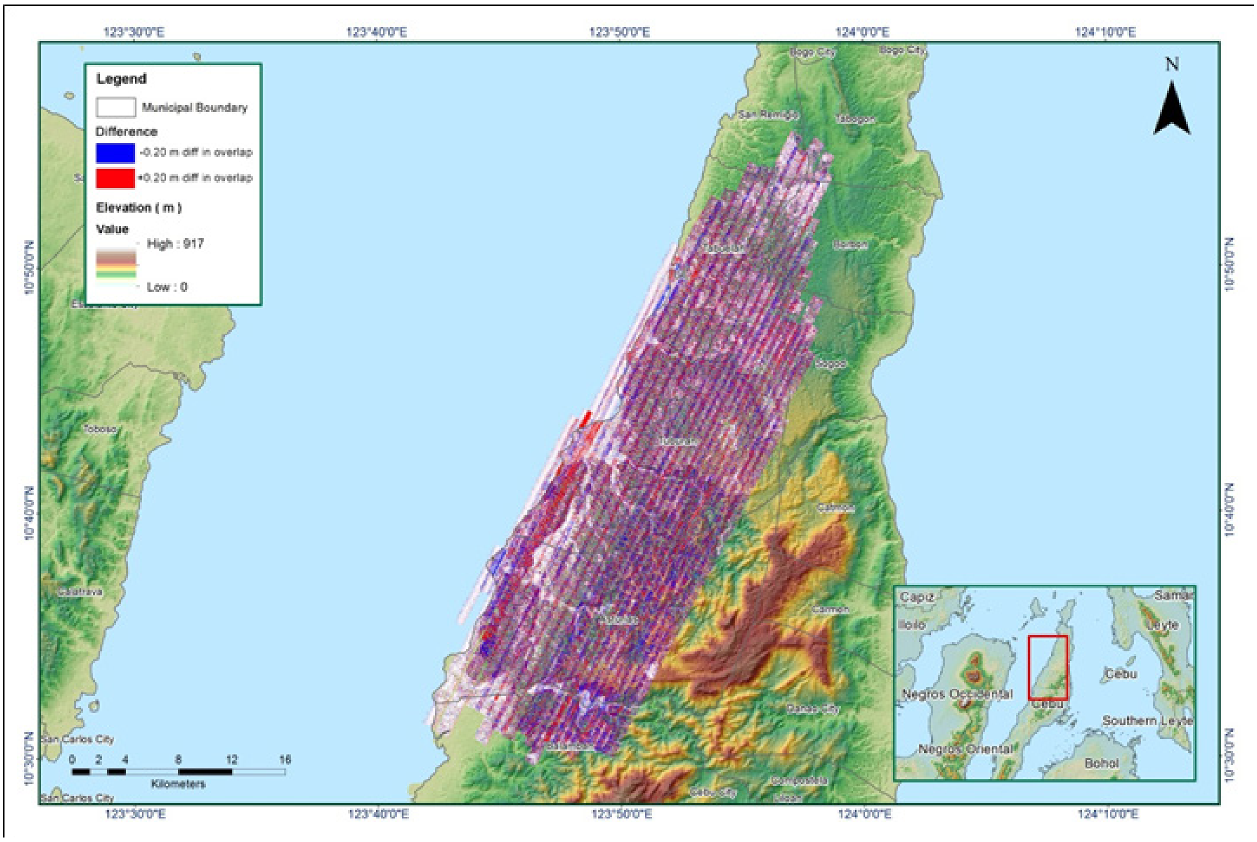


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk36E_supplement

Flight Area	Cebu
Mission Name	Blk36E_supplement
Inclusive Flights	1827P
Mission Name	1BLK36ES224B
Range data size	18.2 GB
Base data size	6.47 MB
POS	187 MB
Image	27.0 GB
Transfer date	September 16, 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)	1.2
RMSE for East Position (<4.0 cm)	1.6
RMSE for Down Position (<8.0 cm)	2.6
Boresight correction stdev (<0.001deg)	0.000297
IMU attitude correction stdev (<0.001deg)	0.002948
GPS position stdev (<0.01m)	0.0021
Minimum % overlap (>25)	50.75%
Ave point cloud density per sq.m. (>2.0)	7.35
Elevation difference between strips (<0.20m)	Yes
Number of 1km x 1km blocks	197
Maximum Height	805.43 m
Minimum Height	63.83 m
Classification (# of points)	
Ground	131,590,624
Low vegetation	97,532,716
Medium vegetation	284,834,002
High vegetation	235,682,817
Building	10,312,687
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Chelou Prado, Jovy Narisma

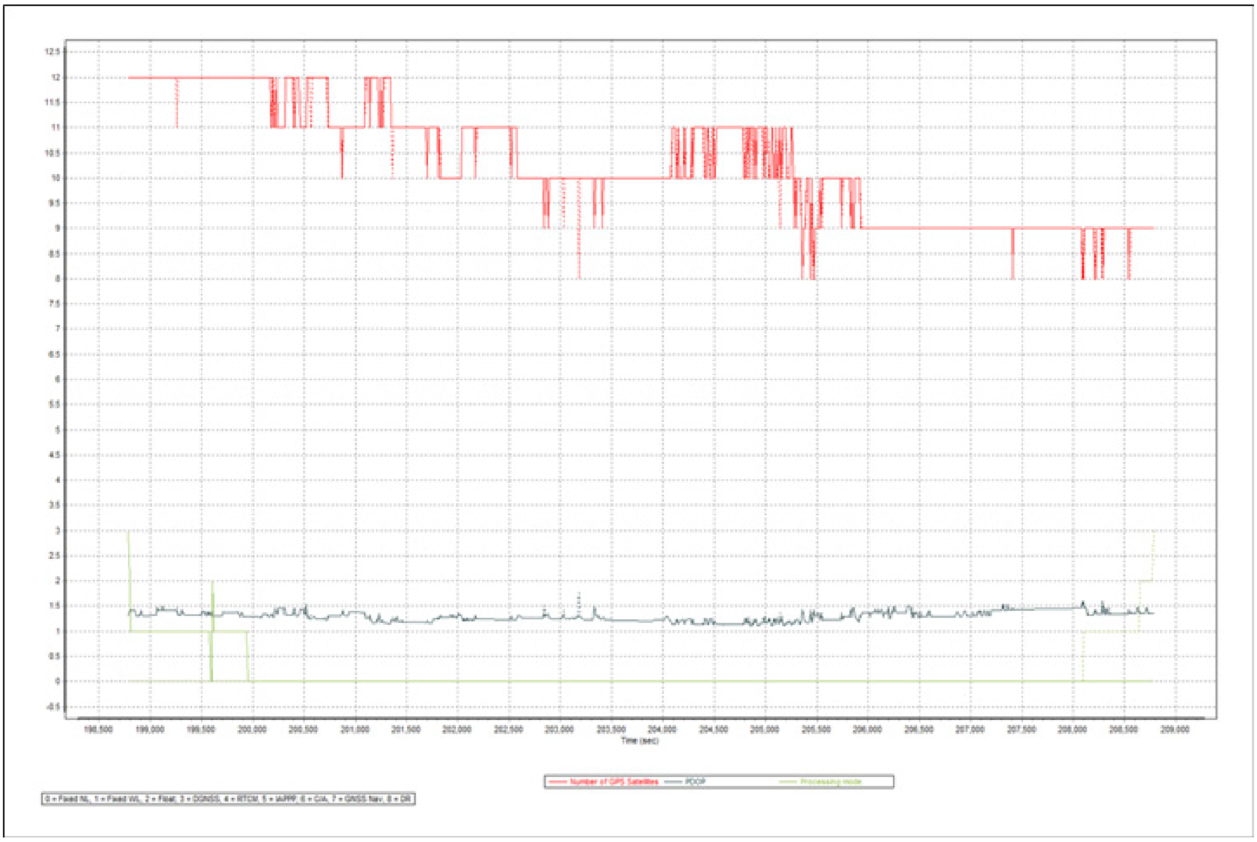


Figure A-8.8. Solution Status Parameters

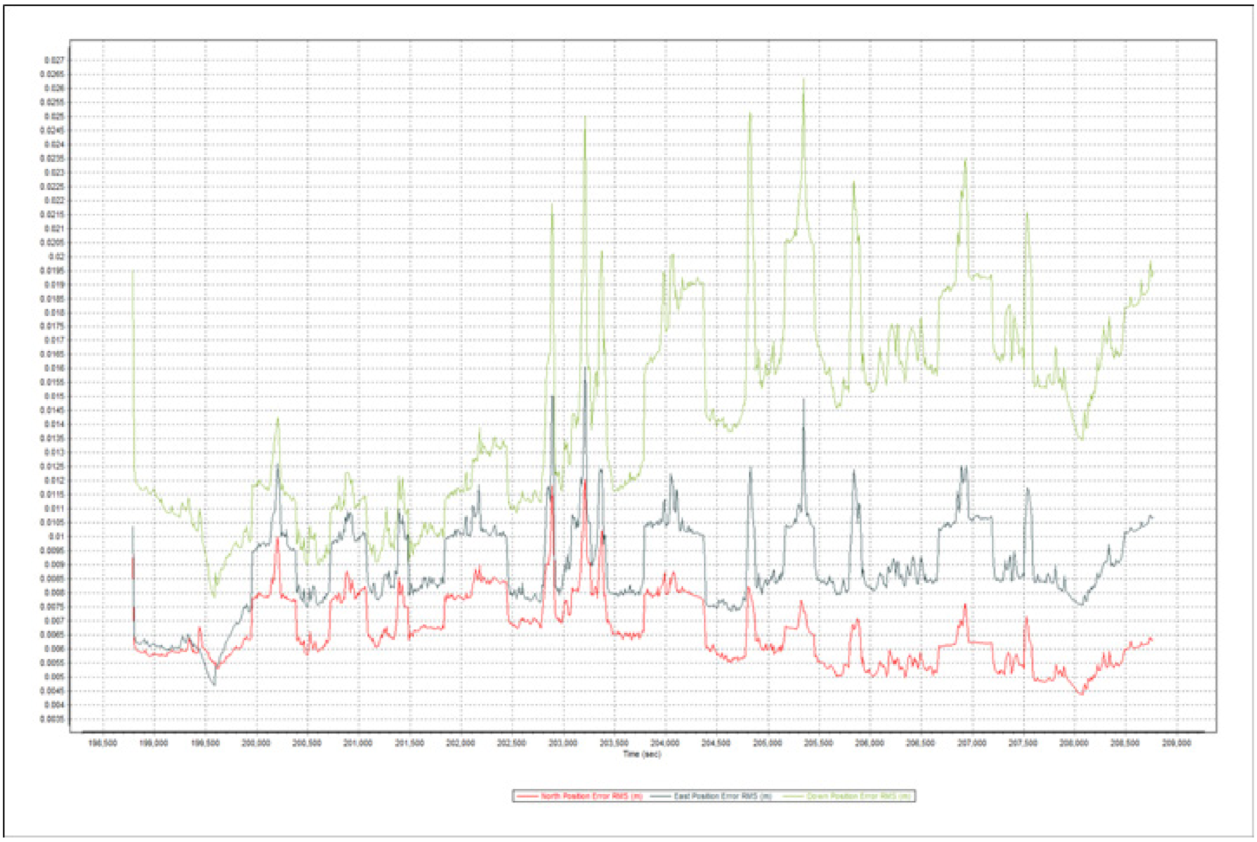


Figure A-8.9. Smoothed Performance Metrics Parameters

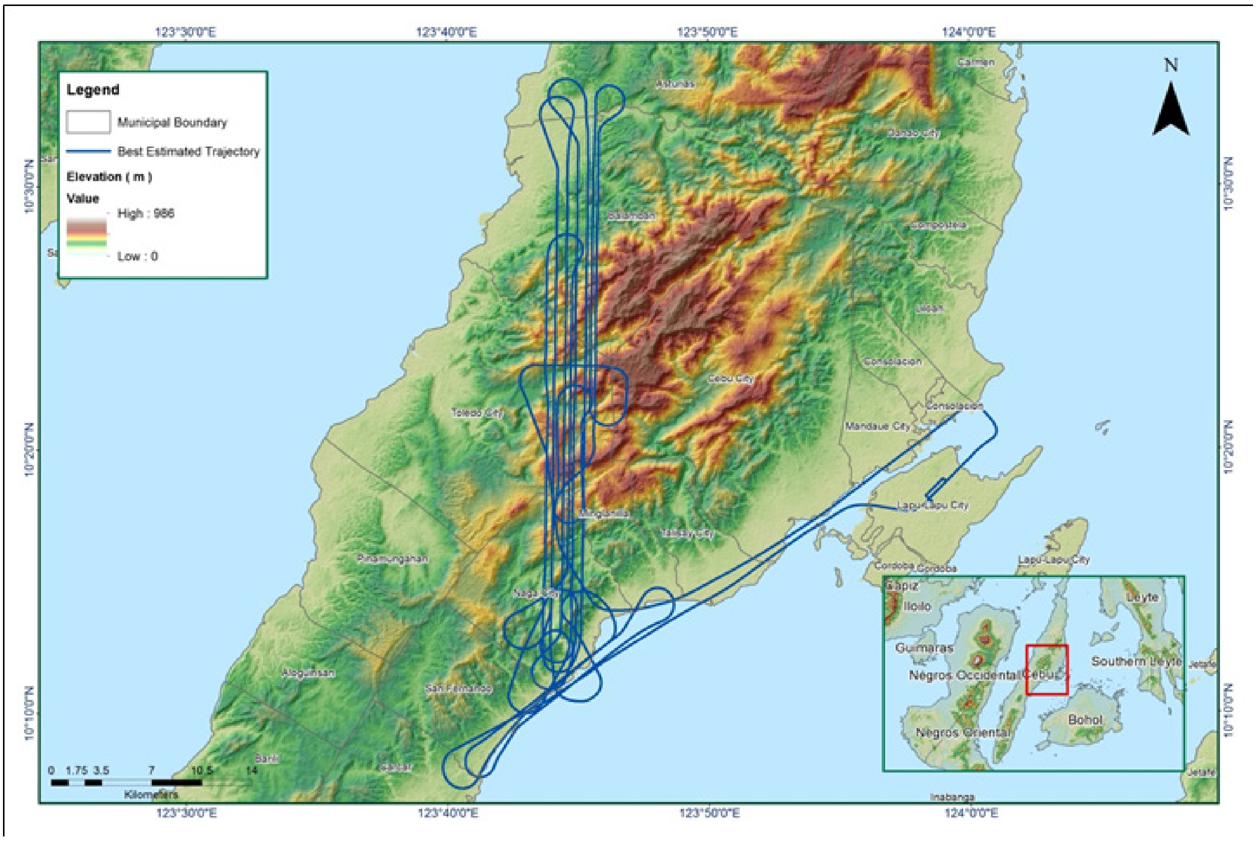


Figure A-8.10. Best Estimated Trajectory

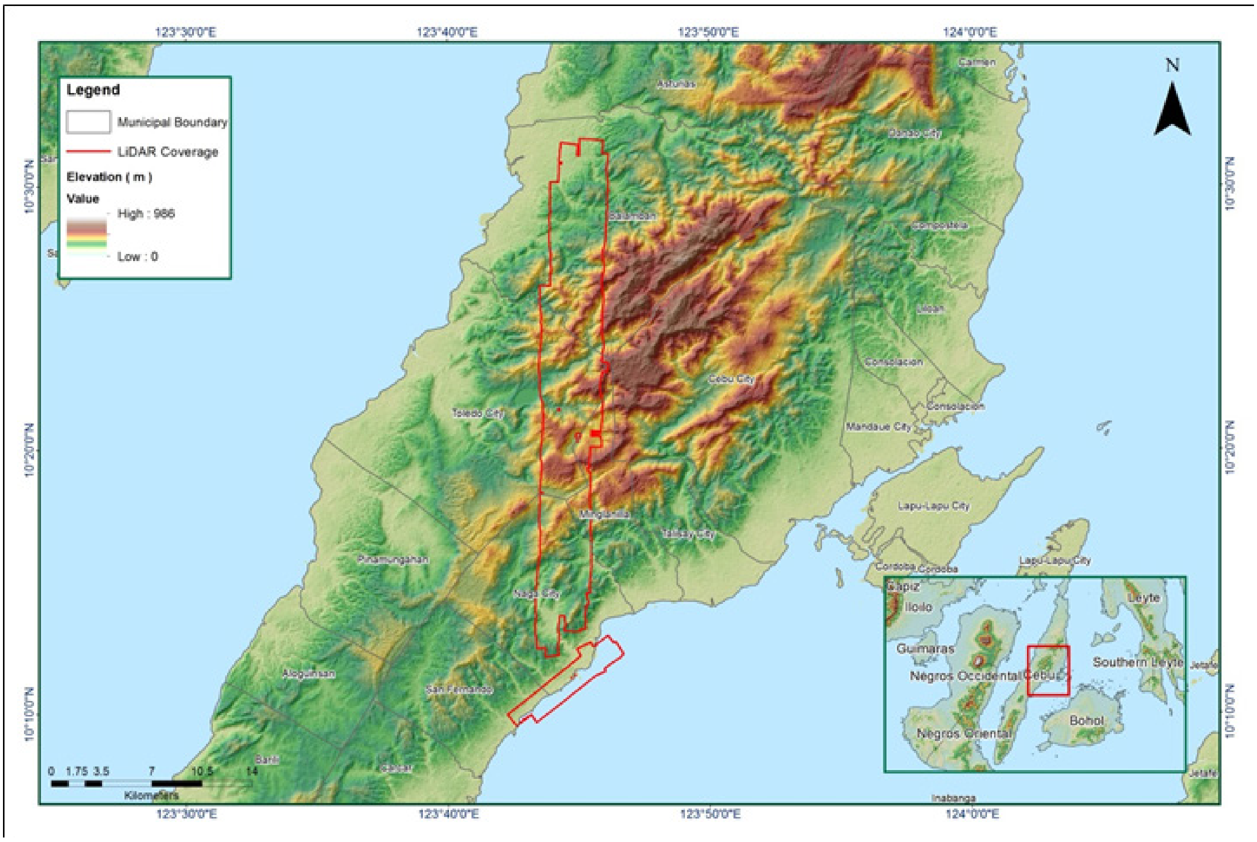


Figure A-8.11. Coverage of LiDAR data

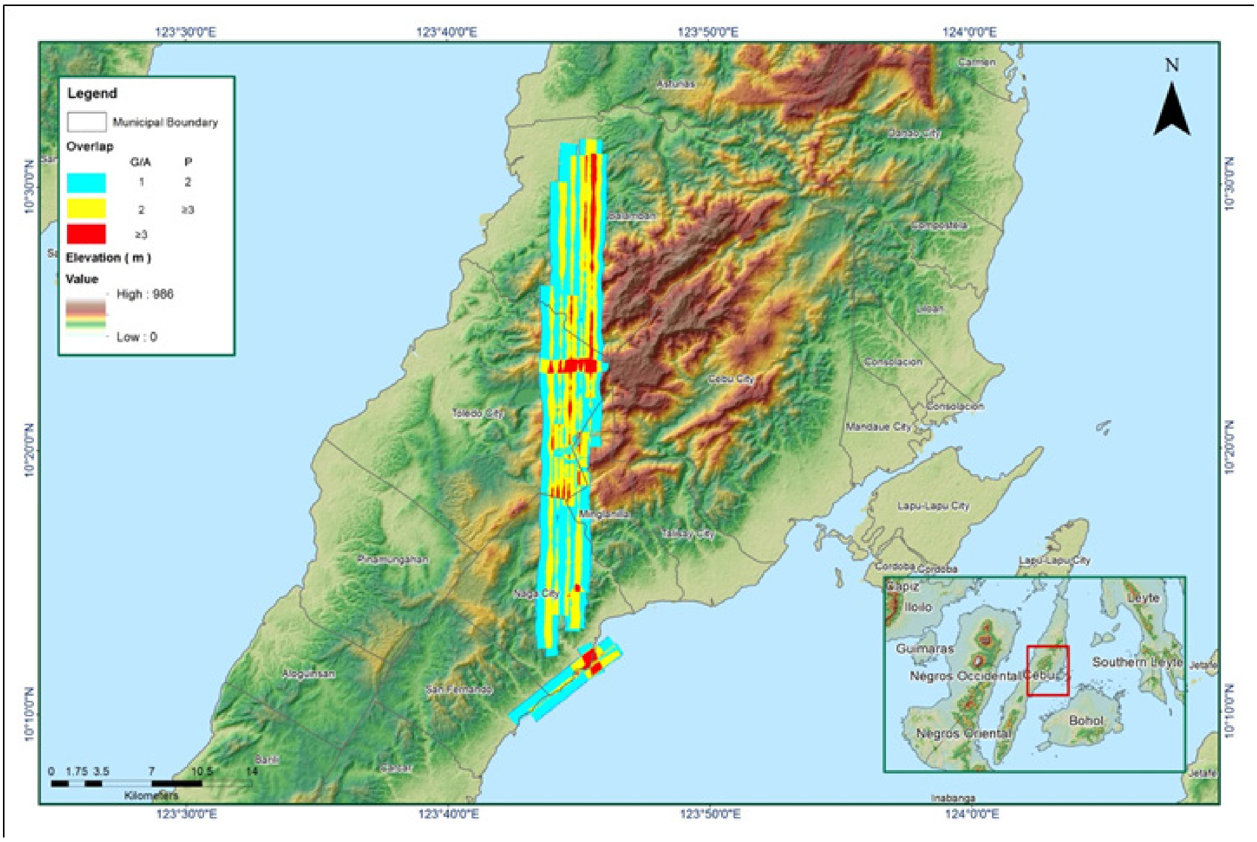


Figure A-8.12. Image of Data Overlap

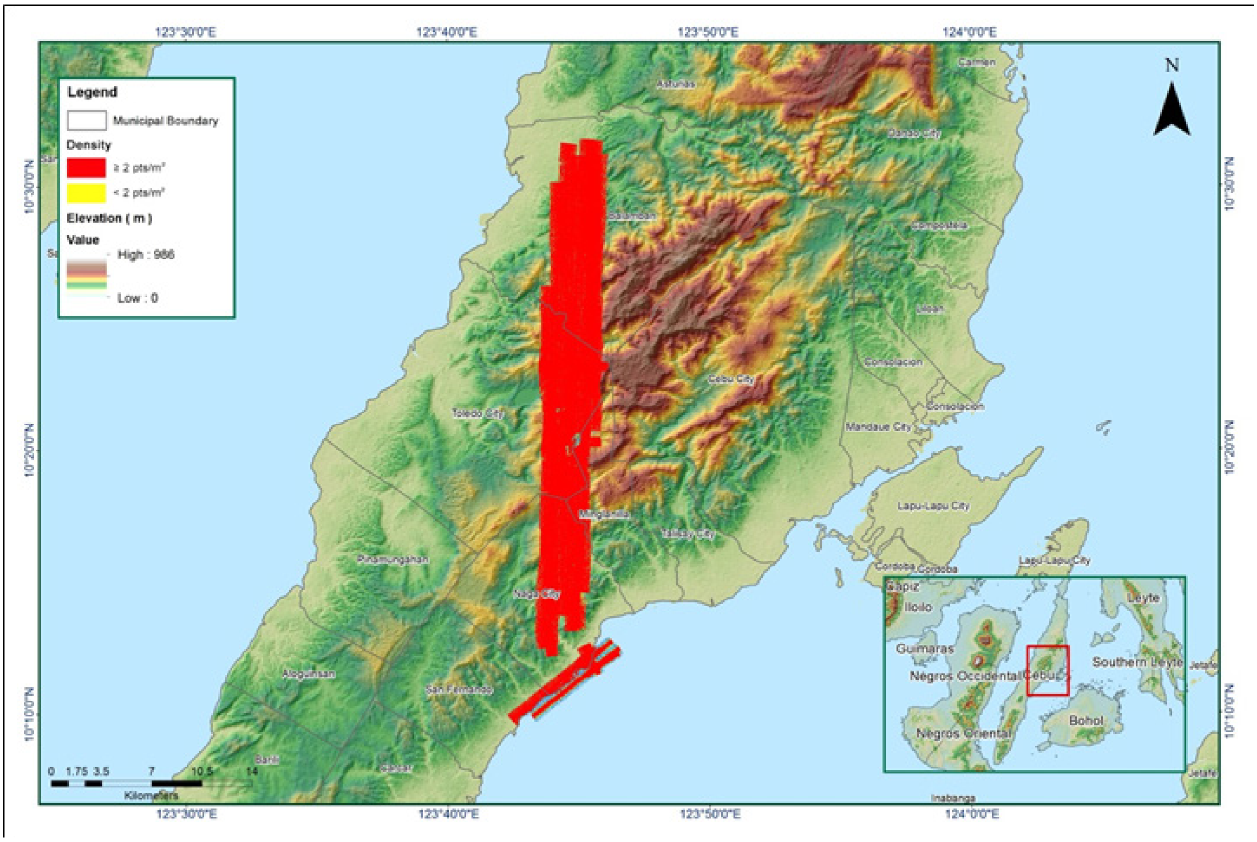


Figure A-8.13. Density map of merged LiDAR data

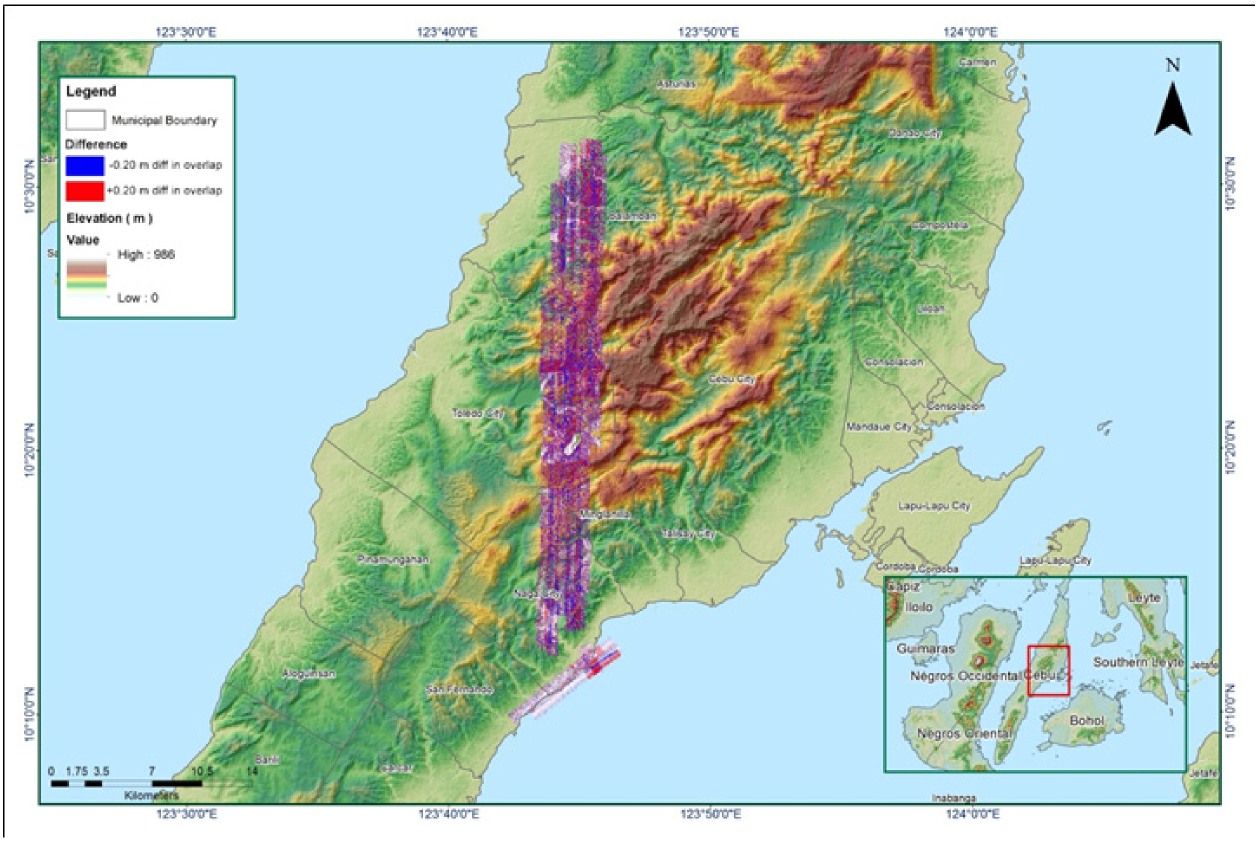


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk36E

Flight Area	Cebu
Mission Name	Blk36E
Inclusive Flights	1777P, 1779P
Mission Name	1BLK36E212A
Range data size	58.2 GB
POS	501 MB
Image	100.9 GB
Transfer date	August 20, 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)	1.5
RMSE for East Position (<4.0 cm)	2.4
RMSE for Down Position (<8.0 cm)	4.2
Boresight correction stdev (<0.001deg)	0.000297
IMU attitude correction stdev (<0.001deg)	0.002948
GPS position stdev (<0.01m)	0.0021
Minimum % overlap (>25)	51.18%
Ave point cloud density per sq.m. (>2.0)	7.19
Elevation difference between strips (<0.20m)	Yes
Number of 1km x 1km blocks	547
Maximum Height	707.71 m
Minimum Height	53.14 m
Classification (# of points)	
Ground	450,661,930
Low vegetation	381,095,661
Medium vegetation	830,378,069
High vegetation	60,5642,860
Building	36,666,032
Orthophoto	Yes
Processed by	Engr. Angelo Carlo Bongat, Engr. Harmond Santos, Engr. Gladys Mae Apat

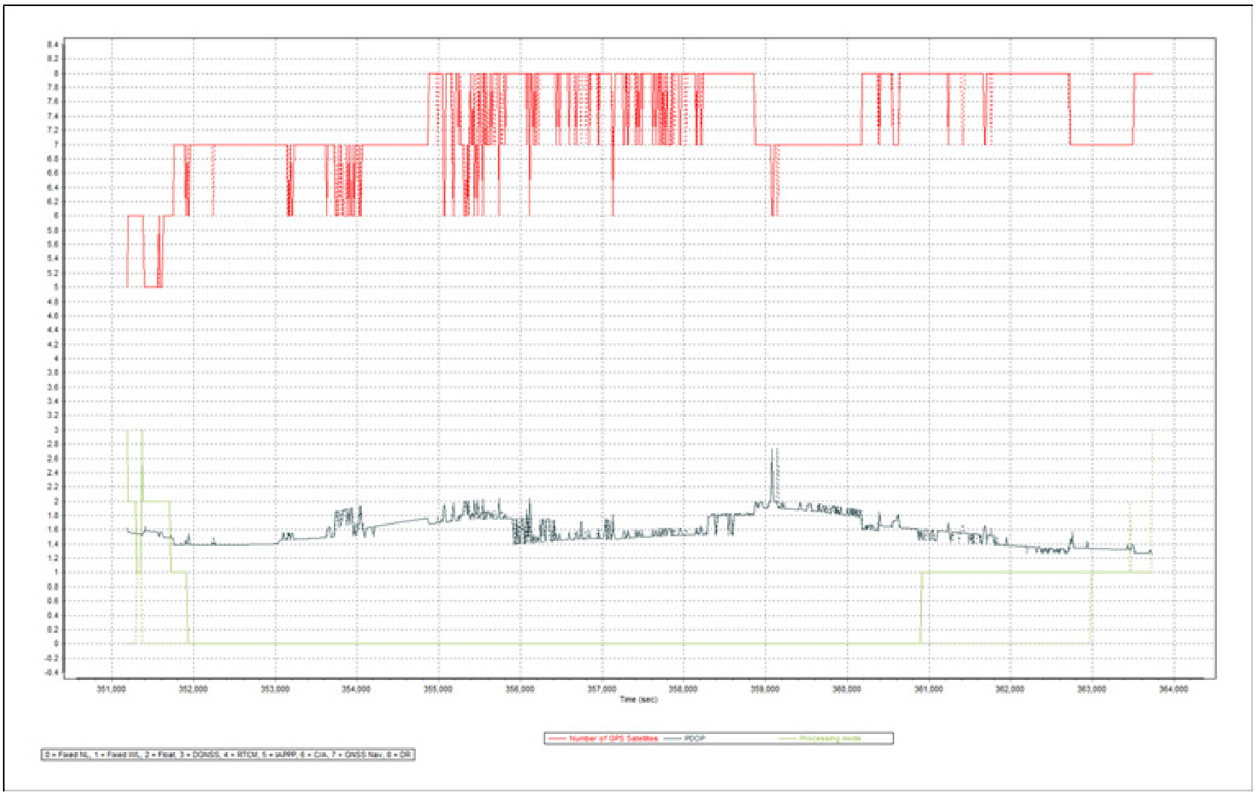


Figure A-8.15. Solution Status

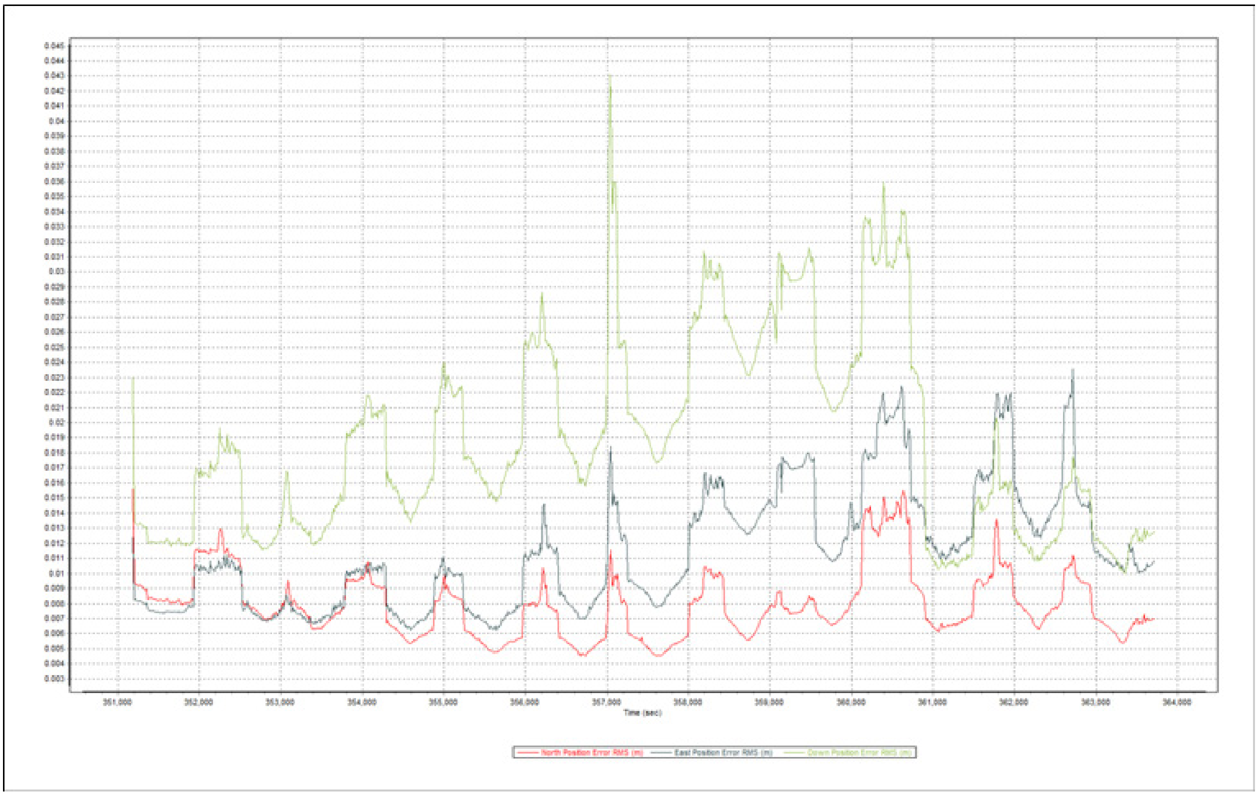


Figure A-8.16. Smoothed Performance Metric Parameters

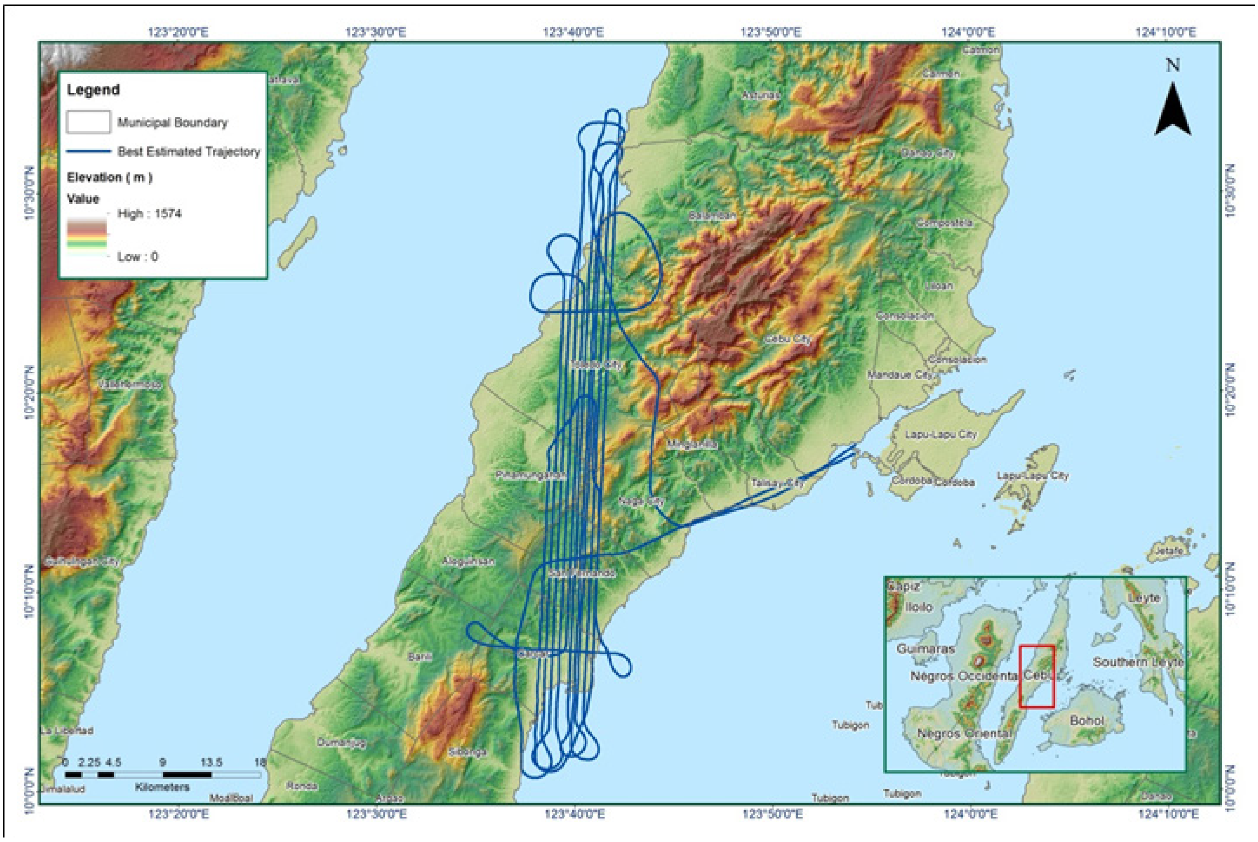


Figure A-8.17. Best Estimated Trajectory

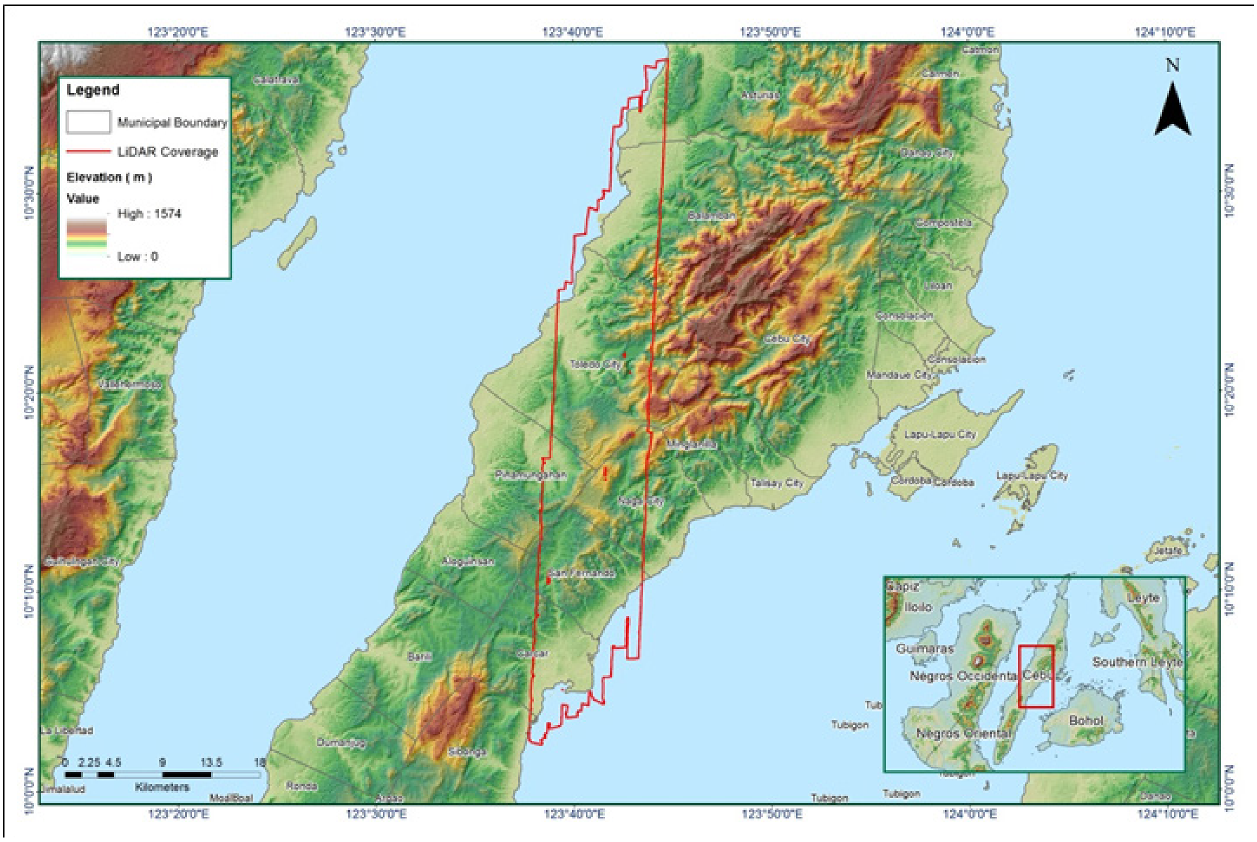


Figure A-8.18. Coverage of LiDAR data

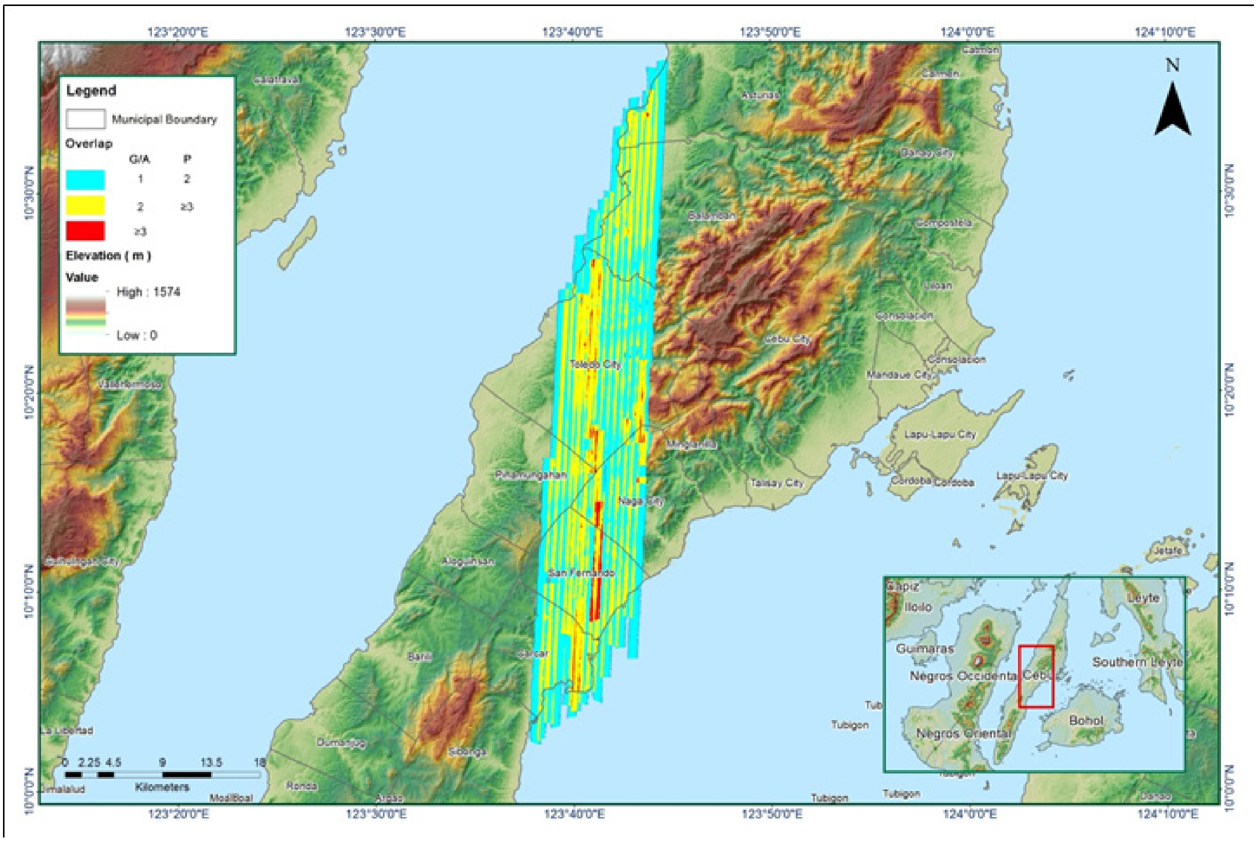


Figure A-8.19. Image of Data Overlap

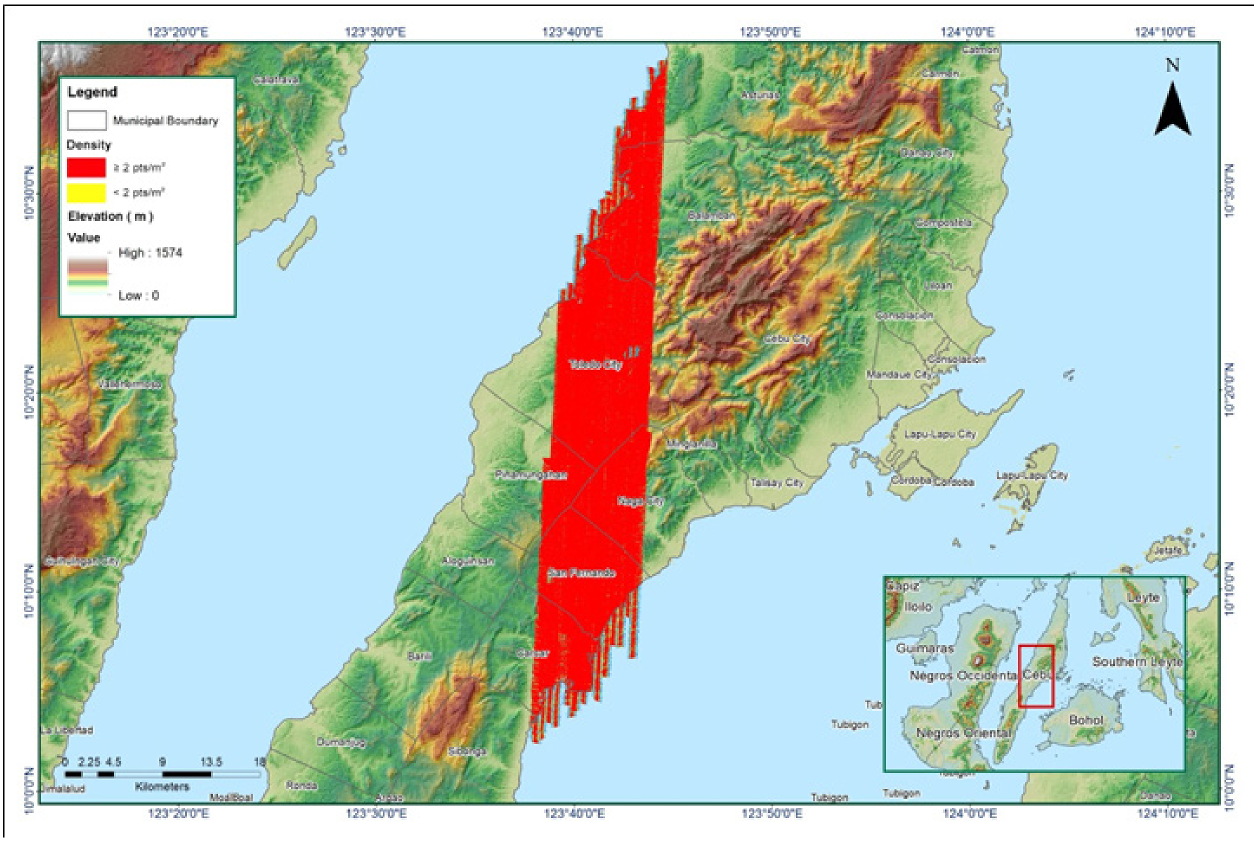


Figure A-8.20. Density map of merged LiDAR data

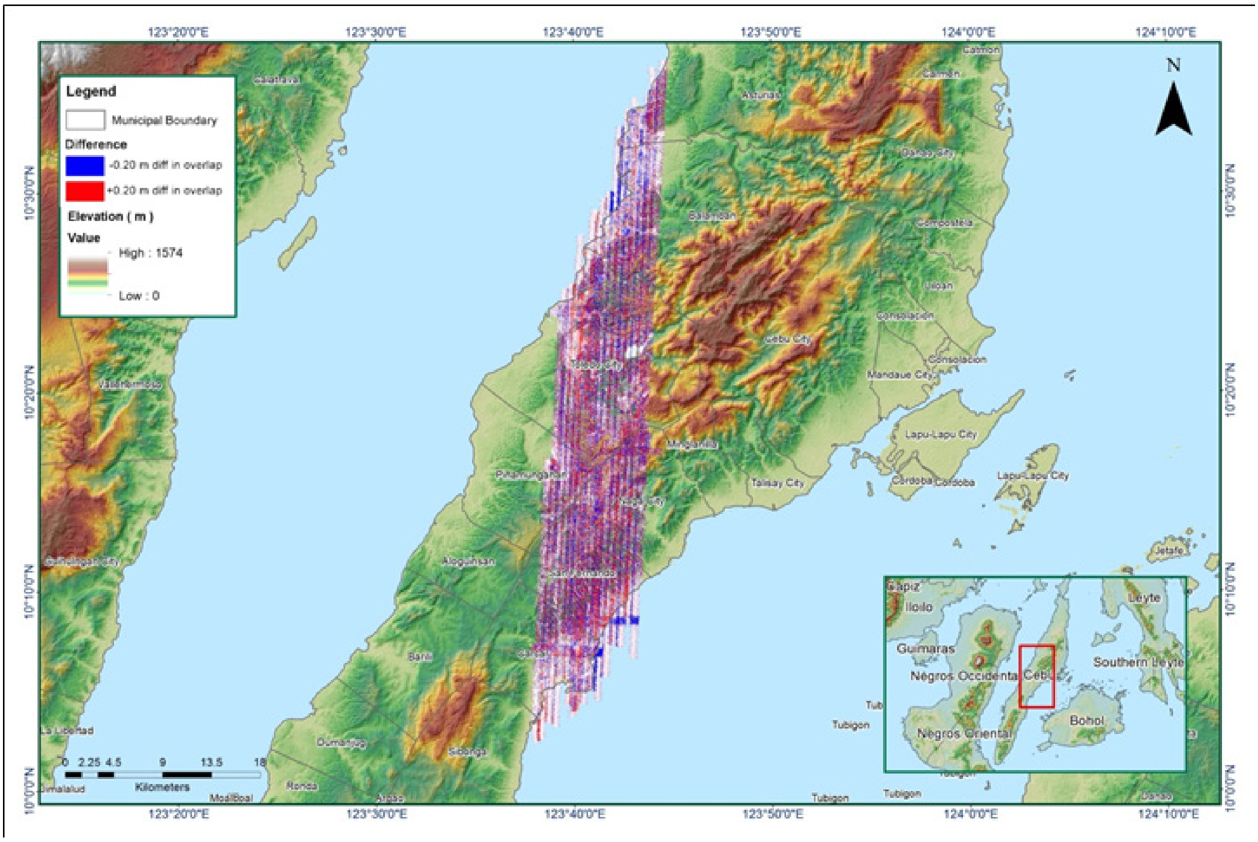


Figure A-8.21. Elevation difference between flight lines

Annex 9. Balamban Model Basin Parameters

Table A-9.1. Balamban 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	Ratio to Peak
W400	23.2995	43.5285	0	1.62176	1.1584	Discharge	0.0478628	0.1	0.01
W410	27.8875	41.34315	0	1.35933	0.97095	Discharge	0.0155812	0.1	0.01
W420	22.515	43.9263	0	1.24488	0.8892	Discharge	0.0271221	0.1	0.01
W430	23.4865	43.435	0	1.10033	0.78595	Discharge	0.0425753	0.1	0.01
W440	23.469	43.4435	0	1.27729	0.91235	Discharge	0.0131261	0.1	0.01
W450	23.4865	43.435	0	0.562492	0.40178	Discharge	0.0109891	0.1	0.01
W460	23.4865	43.435	0	0.664076	0.47434	Discharge	0.0020038	0.1	0.01
W470	19.839	45.3356	0	0.516383	0.368845	Discharge	0.0180612	0.1	0.01
W480	23.4865	43.435	0	1.22108	0.8722	Discharge	0.002263	0.1	0.01
W490	20.02	45.23785	0	0.61579	0.5222	Discharge	0.0091121	0.1	0.01
W500	23.39	43.48345	0	0.73108	0.5222	Discharge	0.0081081	0.1	0.01
W510	21.921	44.23145	0	0.493465	0.352475	Discharge	0.0054659	0.1	0.01
W520	21.7325	44.32835	0	0.46333	0.33095	Discharge	0.0168757	0.1	0.01
W530	22.4825	43.9416	0	0.86275	0.61625	Discharge	0.0217294	0.1	0.01
W540	22.179	44.098	0	0.86639	0.61885	Discharge	0.0097716	0.1	0.01
W550	23.4865	43.435	0	0.659694	0.47121	Discharge	0.0177668	0.1	0.01
W560	23.4865	43.435	0	0.49945	0.35675	Discharge	0.0314323	0.1	0.01
W570	22.1475	44.11415	0	1.37704	0.9836	Discharge	0.0913275	0.1	0.01
W580	23.3855	43.486	0	1.91961	1.37115	Discharge	0.0240281	0.1	0.01
W590	23.4865	43.435	0	0.8344	0.596	Discharge	0.0435647	0.1	0.01
W600	23.4865	43.435	0	1.02263	0.73045	Discharge	0.0591883	0.1	0.01
W610	23.4865	43.435	0	1.50647	1.07605	Discharge	0.0008019	0.1	0.01
W620	23.07	43.6441	0	0.90706	0.6479	Discharge	0.0211294	0.1	0.01

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	Ratio to Peak
W630	22.9905	43.68405	0	0.77308	0.5522	Discharge	0.05053	0.1	0.01
W640	22.982	43.6883	0	1.85598	1.3257	Discharge	0.0185855	0.1	0.01
W650	23.4865	43.435	0	0.73269	0.52335	Discharge	0.0186038	0.1	0.01
W660	23.4865	43.435	0	0.537068	0.38362	Discharge	0.0126644	0.1	0.01
W670	23.4865	43.435	0	0.81298	0.5807	Discharge	0.0101258	0.1	0.01
W680	23.4865	43.435	0	0.409213	0.292295	Discharge	0.0040783	0.1	0.01
W690	22.6215	43.87105	0	0.299299	0.213785	Discharge	0.00094328	0.1	0.01
W700	22.5205	43.9229	0	0.3451	0.2465	Discharge	0.012392	0.1	0.01
W710	23.265	43.5455	0	0.664608	0.47472	Discharge	0.050565	0.1	0.01
W720	23.4865	43.435	0	1.52306	1.0879	Discharge	0.00048213	0.1	0.01
W730	22.8585	43.7512	0	0.111748	0.07982	Discharge	0.0324962	0.1	0.01
W740	23.4865	43.435	0	1.00457	0.71755	Discharge	0.07521	0.1	0.01
W750	23.4755	43.4401	0	1.89896	1.3564	Discharge	0.0114325	0.1	0.01
W760	23.4865	43.435	0	0.632296	0.45164	Discharge	0.0152433	0.1	0.01

Annex 10. Balamban Model Reach Parameters

Table A-10.1. Balamban Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R40	Automatic Fixed Interval	3534	0.0063629	0.04	Trapezoid	25	1
R60	Automatic Fixed Interval	568.7	0.0001	0.04	Trapezoid	25	1
R70	Automatic Fixed Interval	2323	0.0096816	0.04	Trapezoid	25	1
R80	Automatic Fixed Interval	353.6	0.0001	0.04	Trapezoid	30	1
R100	Automatic Fixed Interval	1187	0.0001	0.04	Trapezoid	30	1
R120	Automatic Fixed Interval	1609	0.0114767	0.04	Trapezoid	30	1
R130	Automatic Fixed Interval	2901	0.0034006	0.04	Trapezoid	30	1
R140	Automatic Fixed Interval	5689	0.0190045	0.04	Trapezoid	30	1
R170	Automatic Fixed Interval	3141	0.0071778	0.04	Trapezoid	30	1
R190	Automatic Fixed Interval	3912	0.0226039	0.04	Trapezoid	30	1
R210	Automatic Fixed Interval	5285	0.0140137	0.04	Trapezoid	30	1
R220	Automatic Fixed Interval	130.7	0.0001	0.04	Trapezoid	30	1
R250	Automatic Fixed Interval	3297	0.0323351	0.04	Trapezoid	30	1
R300	Automatic Fixed Interval	878	0.0032265	0.04	Trapezoid	30	1
R310	Automatic Fixed Interval	6534	0.011901	0.04	Trapezoid	30	1
R330	Automatic Fixed Interval	1017	0.0383863	0.04	Trapezoid	30	1
R340	Automatic Fixed Interval	84.85	0.0001	0.04	Trapezoid	30	1
R380	Automatic Fixed Interval	6966	0.039832	0.04	Trapezoid	30	1

Annex 11. Balamban Field Validation Points

Table A-11.1. Balamban 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	10.53182	123.73613	0.735	1.2	0.216225	Yolanda	100-Year
2	10.53154	123.73662	0.543	0.7	0.024649	Puring	100-Year
3	10.53156	123.73659	0.543	0.2	0.117649	Ruping	100-Year
4	10.52964	123.73791	0.299	0.3	0.000001	Ruping	100-Year
5	10.52909	123.73672	0.034	0.7	0.443556	Ruping	100-Year
6	10.52911	123.73675	0.034	0.5	0.217156	Wilpring	100-Year
7	10.52714	123.73424	0.512	1.3	0.620944	Wilpring	100-Year
8	10.52715	123.73419	0.337	1.2	0.744769	Ruping	100-Year
9	10.52687	123.73327	0.349	0.2	0.022201	Ruping	100-Year
10	10.52690	123.73330	0.349	0.5	0.022801	Wilpring	100-Year
11	10.52705	123.73345	0.349	0.5	0.022801	Basyang	100-Year
12	10.52682	123.73284	0.686	0.7	0.000196	Yolanda	100-Year
13	10.52682	123.73280	0.686	1.3	0.376996	Ruping	100-Year
14	10.52684	123.73279	0.686	1.3	0.376996	Wilpring	100-Year
15	10.52766	123.72862	0.619	0.2	0.175561	Wilpring	100-Year
16	10.52763	123.72862	0.619	0.5	0.014161	Ruping	100-Year
17	10.52614	123.72004	0.283	0.5	0.047089	Yolanda	100-Year
18	10.52479	123.71698	0.325	0.7	0.140625	Yolanda	100-Year
19	10.52376	123.71681	0.545	1.2	0.429025	Yolanda	100-Year
20	10.52389	123.71680	0.372	0.6	0.051984	Ruping	100-Year
21	10.52389	123.71680	0.372	1.5	1.272384	Welpring	100-Year
22	10.52324	123.71664	0.704	1	0.087616	Basyang	100-Year
23	10.52323	123.71668	0.704	1	0.087616	Senyang	100-Year
24	10.52324	123.71667	0.704	0.9	0.038416	Yolanda	100-Year
25	10.51690	123.71661	0.164	0.2	0.001296	Welpring	100-Year
26	10.51706	123.71841	0.417	0.5	0.006889	Senyang	100-Year
27	10.52829	123.71978	0.268	0.7	0.186624	Basyang	100-Year
28	10.53121	123.71509	0.292	0.9	0.369664	Basyang	100-Year
29	10.53138	123.71967	1.239	1.5	0.068121	Senyang	100-Year
30	10.53450	123.71985	0.997	0.5	0.247009	Yolanda	100-Year
31	10.53459	123.72024	0.362	0.2	0.026244	Basyang	100-Year
32	10.53403	123.72028	0.459	0.2	0.067081	Basyang	100-Year
33	10.54141	123.71709	0.095	1.5	1.974025	Basyang	100-Year
34	10.54050	123.71752	0.137	0.2	0.003969	Welpring	100-Year
35	10.53925	123.71799	1.205	0.9	0.093025	Welpring	100-Year
36	10.53971	123.72066	0.489	0.5	0.000121	Senyang	100-Year
37	10.53991	123.71968	0.603	0.7	0.009409	Ruping	100-Year
38	10.54080	123.71919	0.301	0.2	0.010201	Yolanda	100-Year
39	10.54300	123.72478	0.03	0.2	0.0289	Basyang	100-Year
40	10.54399	123.72514	0.042	0.6	0.311364	Welpring	100-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
41	10.54173	123.72578	0.032	1.2	1.364224	Senyang	100-Year
42	10.55730	123.71475	0.03	0.9	0.7569	Senyang	100-Year
43	10.55915	123.71456	0.076	0.7	0.389376	Senyang	100-Year
44	10.55814	123.71418	0.082	0.4	0.101124	Ruping	100-Year
45	10.56129	123.71442	0.06	1.2	1.2996	Yolanda	100-Year
46	10.56134	123.71373	0.091	2	3.644281	Ruping	100-Year
47	10.56088	123.71447	0.03	1.2	1.3689	Basyang	100-Year
48	10.56361	123.71518	0.03	1.5	2.1609	Ruping	100-Year
49	10.56297	123.71492	0.038	0.9	0.743044	Ruping	100-Year
50	10.56728	123.71444	0.199	1.5	1.692601	Yolanda	100-Year
51	10.56626	123.71419	0.093	0.5	0.165649	Senyang	100-Year
52	10.56636	123.71396	0.222	0.2	0.000484	Welpring	100-Year
53	10.56703	123.71383	0.056	0.2	0.020736	Welpring	100-Year
54	10.56695	123.71514	0.137	0.6	0.214369	Basyang	100-Year
55	10.56499	123.71385	0.515	0.9	0.148225	Ruping	100-Year
56	10.56682	123.71237	0.065	1.2	1.288225	Ruping	100-Year
57	10.56637	123.71206	0.03	0.5	0.2209	Senyang	100-Year
58	10.56736	123.71342	0.174	1.7	2.328676	Yolanda	100-Year
59	10.56350	123.71648	0.951	1.9	0.900601	Yolanda	100-Year
60	10.54462	123.71528	1.306	1	0.093636	Yolanda	100-Year
61	10.54417	123.71472	0.639	0.5	0.019321	Ruping	100-Year
62	10.54420	123.71450	0.527	2	2.169729	Ruping	100-Year
63	10.54353	123.71504	0.461	1.1	0.408321	Senyang	100-Year
64	10.54356	123.71571	0.214	0.2	0.000196	Basyang	100-Year
65	10.52509	123.71898	0.031	0.2	0.028561	Yolanda	100-Year
66	10.52479	123.71924	0.03	0.3	0.0729	Yolanda	100-Year
67	10.52501	123.71900	0.031	0.5	0.219961	Yolanda	100-Year
68	10.52384	123.71886	0.111	1.2	1.185921	Yolanda	100-Year
69	10.52330	123.71891	0.133	0.3	0.027889	Basyang	100-Year
70	10.52333	123.71893	0.133	0.3	0.027889	Welpring	100-Year
71	10.52475	123.71979	0.31	0.5	0.0361	Senyang	100-Year
72	10.52485	123.71975	0.31	0.9	0.3481	Senyang	100-Year
73	10.52489	123.71974	0.31	0.7	0.1521	Welpring	100-Year
74	10.52153	123.71773	0.865	1.2	0.112225	Senyang	100-Year
75	10.52176	123.71803	1.102	1.9	0.636804	Senyang	100-Year
76	10.52101	123.71755	0.771	2.1	1.766241	Senyang	100-Year
77	10.52127	123.71753	0.99	1	0.0001	Yolanda	100-Year
78	10.51788	123.71610	0.716	1.5	0.614656	Yolanda	100-Year
79	10.51819	123.71722	0.808	0.2	0.369664	Senyang	100-Year
80	10.51823	123.71751	0.979	0.5	0.229441	Senyang	100-Year
81	10.51790	123.71766	1.99	0.7	1.6641	Ruping	100-Year
82	10.51771	123.71789	0.199	2	3.243601	Senyang	100-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
83	10.52483	123.71038	0.592	2.1	2.274064	Senyang	100-Year
84	10.52455	123.71027	0.274	0.5	0.051076	Senyang	100-Year
85	10.52414	123.71020	0.106	0.5	0.155236	Senyang	100-Year
86	10.50687	123.71301	0.763	0.2	0.316969	Senyang	100-Year
87	10.50661	123.71310	0.409	0.7	0.084681	Senyang	100-Year
88	10.50658	123.71311	0.409	0.9	0.241081	Senyang	100-Year
89	10.50640	123.71349	0.03	1.2	1.3689	Yolanda	100-Year
90	10.50625	123.71336	0.301	1.5	1.437601	Senyang	100-Year
91	10.50595	123.71347	0.291	1.7	1.985281	Senyang	100-Year
92	10.50876	123.71205	0.261	2	3.024121	Senyang	100-Year
93	10.50917	123.71162	0.03	2.1	4.2849	Senyang	100-Year
94	10.50968	123.71147	0.615	0.5	0.013225	Yolanda	100-Year
95	10.50945	123.71148	0.05	0.7	0.4225	Senyang	100-Year
96	10.50949	123.71165	1.221	0.9	0.103041	Senyang	100-Year
97	10.50980	123.71556	1.221	1.7	0.229441	Senyang	100-Year
98	10.50959	123.71532	0.03	0.5	0.2209	Senyang	100-Year
99	10.51171	123.71870	0.537	0.2	0.113569	Yolanda	100-Year
100	10.51152	123.71856	0.036	0.2	0.026896	Yolanda	100-Year
101	10.51138	123.71844	0.049	0.3	0.063001	Yolanda	100-Year
102	10.51192	123.71954	0.03	0.3	0.0729	Senyang	100-Year
103	10.51191	123.71951	0.03	0.9	0.7569	Senyang	100-Year

Annex 12. Educational Institutions affected by flooding in Balamban Floodplain

Table A-12.1. Educational Institutions in Asturias, Cebu affected by flooding in Balamban Floodplain

Cebu				
Asturias				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Anabelle Store	Owak		Medium	Medium
Owak Elementary School	Owak	Low	Medium	Medium
Asturias Central Eleemetary School	Poblacion		Low	Low

Table A-12.2. Educational Institutions Balamban, Cebu affected by flooding in Balamban Floodplain

Cebu				
Balamban				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Biasong Elementary School	Biasong			
Nangka Elementary School	Nangka	Low	Medium	Medium
School (Under Construction)	Nangka			
Balamban Central Elementary School	Santa Cruz-Santo Niño	Low	Low	Medium
Saint Francis Academy	Santa Cruz-Santo Niño	Low	Low	Low

Annex 13. Health Institutions affected by flooding in Balamban Floodplain

Table A-13.1. Health Institutions in Asturias, Cebu affected by flooding in Balamban Floodplain

Cebu				
Asturias				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Asturias Birthing and Health Center	Poblacion			

Table A-13.2. Health Institutions in Balamban, Cebu affected by flooding in Balamban Floodplain

Cebu				
Balamban				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Balamban District Hospital	Baliwagan			Low
Dental Clinic	Santa Cruz-Santo Niño			
Dumdum Medical Clinic	Santa Cruz-Santo Niño	Low		Low