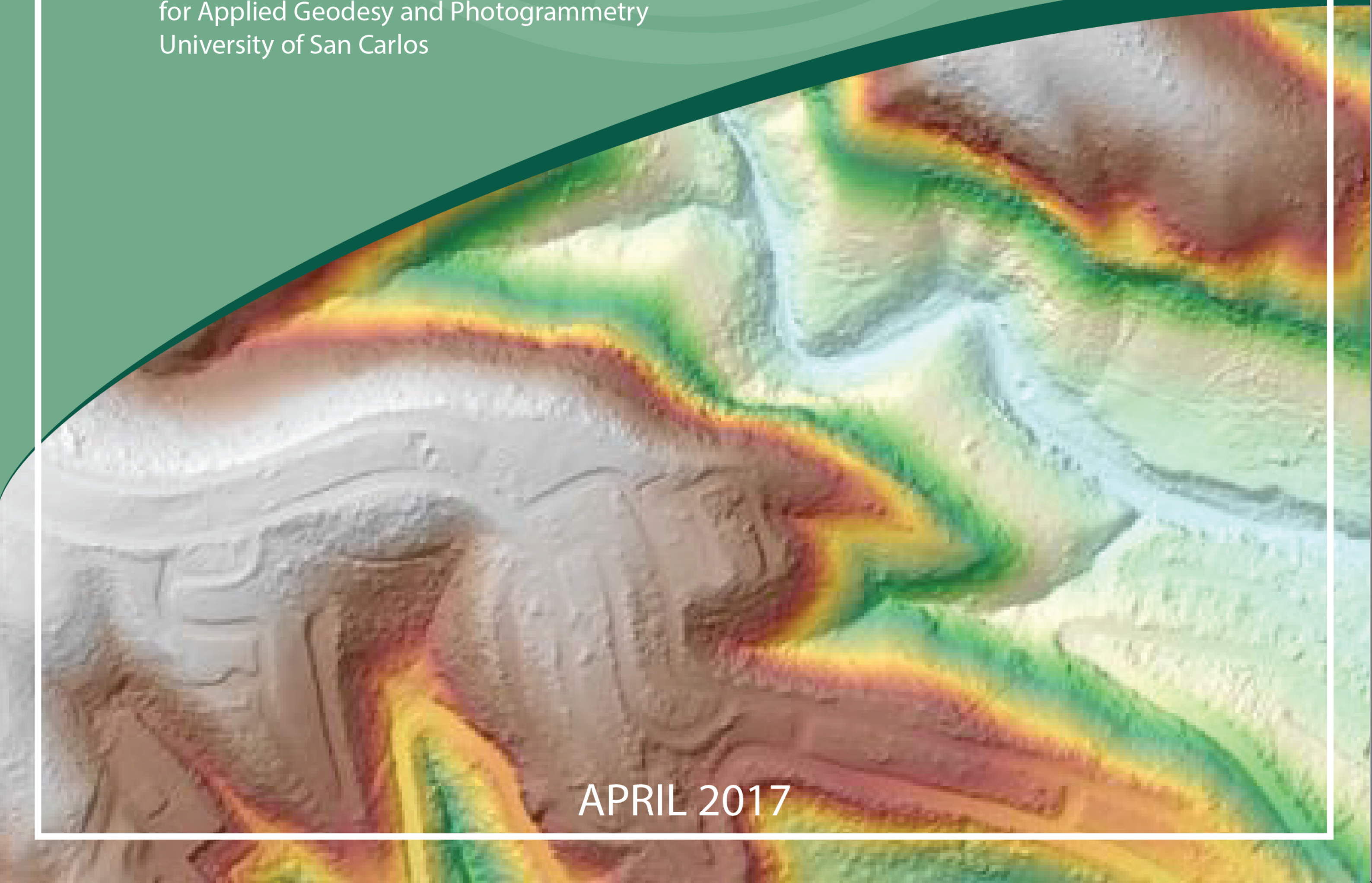
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Mananga 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
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
USC	University of San Carlos
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND MANANGA 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 in 2014” or Phil-LiDAR 1, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied 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 17 river basins in the Central Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Mananga River Basin

Mananga River has its head waters in Cebu City and drains to Talisay City. It is one of the three protected watersheds of Cebu. The catchment is located in the central part of the Province of Cebu and is classified under Type III weather in the Corona climate classification. It experiences dry season from November to April and wet season for the other months of the year.

Mananga River Basin covers the Cities of Cebu and Talisay, Province of Cebu. The DENR River Basin Control Office identified the basin to have a drainage area of 102 km2 and an estimated annual runoff of 61 million cubic meter (MCM) (RBCO, 2015).

Cebu City is the oldest city in the country. It is a 1st income class highly urbanized city and is a chartered city, independent of Cebu Province. It is where the oldest street – Colon Street and the oldest school – University of San Carlos is located. It has a population of 922,611. Industries in the city are widely varied and include shipbuilding, business processing outsourcing and real estate developments. Talisay City is located south of Cebu City. It is a 3rd income class component city with a population of 227,645. Fishing industry in the city is prominent as it is located near the coast.

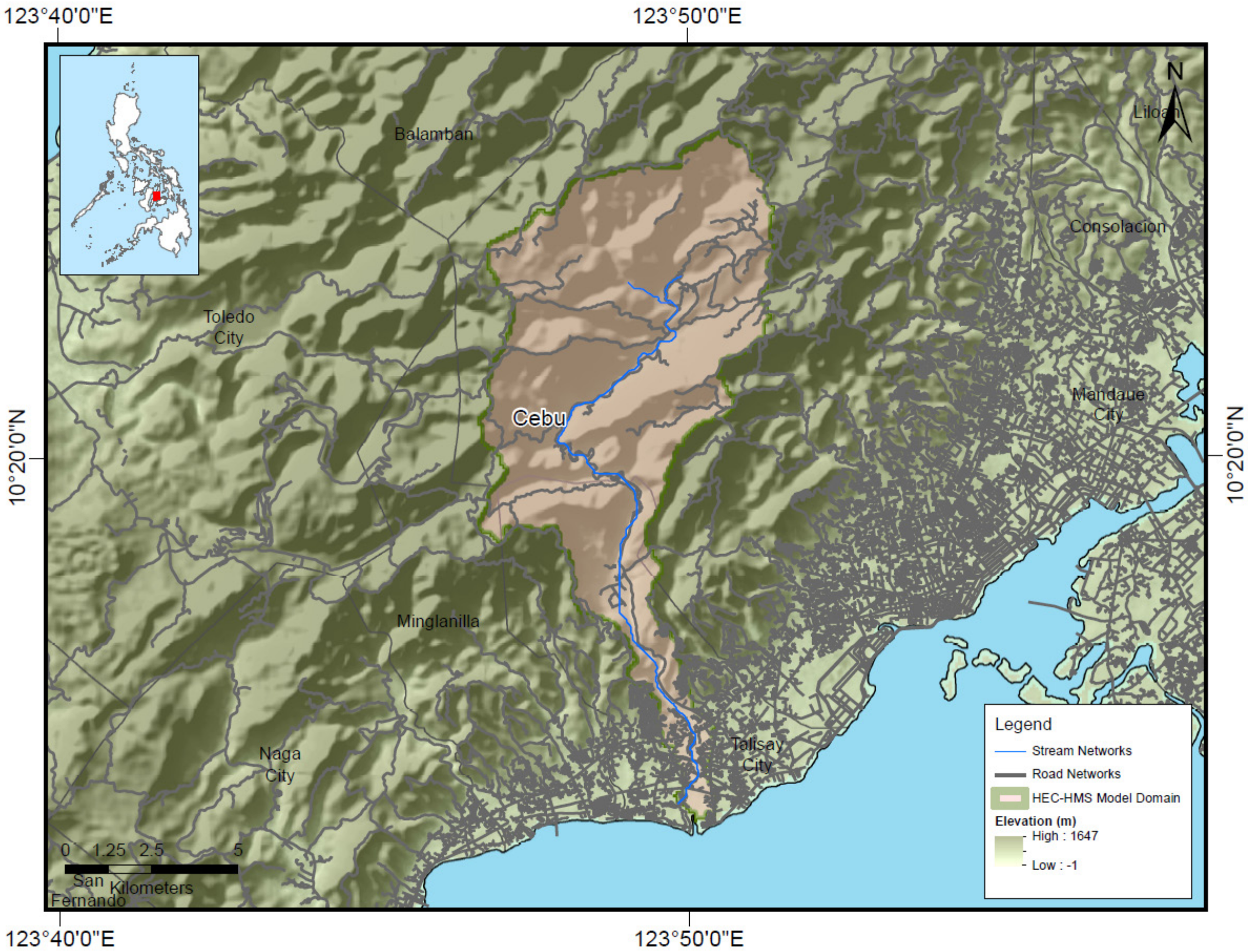

Figure 1. Map of the Mananga River Basin (in brown)

Its main stem, Mananga River, is part of the seventeen (17) river systems in Central Visayas Region. According to the 2015 national census of NSO, a total of 79,281 persons are residing within the immediate vicinity of the river which is distributed among eight barangays in Talisay City namely: Camp IV, Jaclupan, Maghaway, Lawaan III, Lawaan I, Lawaan II, Pooc, Dumlog, and Biasong. Talisay City is mostly commercialized, since it's part of Metro Cebu.

The busiest place of commerce is in Tabunok area where public markets and commercial establishments are found. Fishing is also a major source of economy in Talisay City since it has its own fish port. Aside from the previous economic activities, farming is another common livelihood for citizens who have land. Coconuts, Bananas, other crops, and livestock are usually the produce of local farmers (Source: http://www.cebu-bluewaters.com/talisay-city.html). In the upstream areas of Mananga River, quarrying activities are being implemented (Source: University of San Carlos, 2015). Last December 2014, Typhoon Ruby, internationally known as Hagupit, devastated Southern Luzon and Visayas region. In Talisay City, six (6) coastal barangays were evacuated; however, affected residents had a difficult time in finding shelter as most evacuation centers were full. Furthermore, all classes in Talisay City during the typhoon were suspended (Sources: http://www.gmanetwork.com/news/story/391307/news/regions/509-000-preemptively-evacuate-due-to-typhoon-ruby-ndrrmc; http://8list.ph/typhoon-ruby-ph-updates/).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE MANANGA FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Julie Pearl S. Mars, 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

To initiate the LiDAR acquisition survey of the Mananga floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Mananga Floodplain in Cebu. These flight missions were planned for 16 lines and ran for at most four and a half hours (4.5) including take-off, landing and turning time using one sensor – the Pegasus (see Annex 1 for sensor specifications). The flight planning parameters for the LiDAR system are outlined in Table 1. Figure 2, on the other hand, shows the flight plan for Mananga floodplain survey.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK47A	1200, 1000	30	50	200	30	130	5
Mactan Island	1200, 1000	30	50	200	30	130	5
Olango Island	1200	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.”

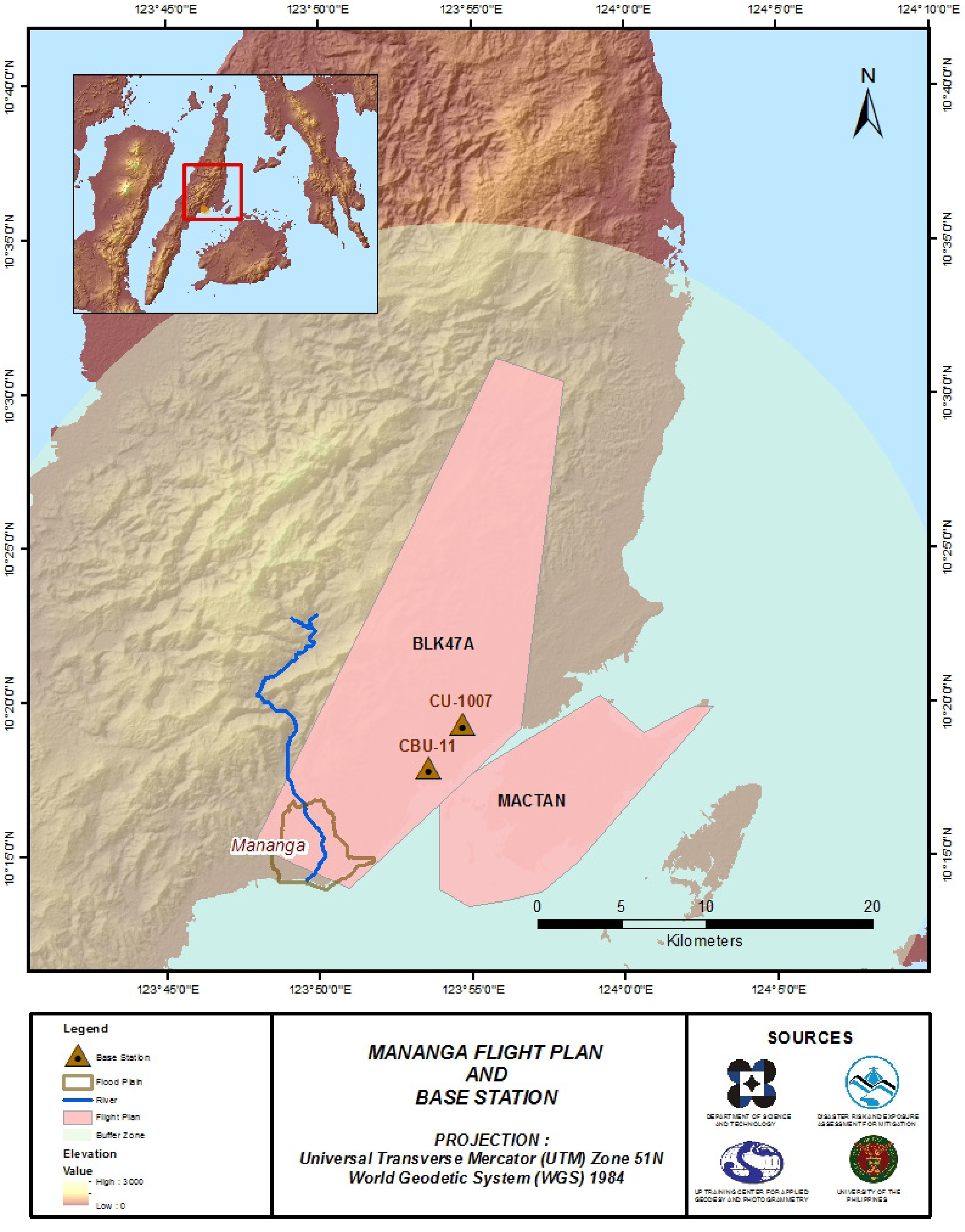

Figure 2. Flight plans and base stations used for Mananga Floodplain using the Pegasus sensor.

2.2 Ground Base Stations

The project team was able to recover one (1) NAMRIA ground control point: CBU-11 which is of second (2nd) order accuracy. One (1) NAMRIA benchmark was also recovered: CU-1007 which is of second (2nd) order accuracy.

The certification for the NAMRIA reference points and benchmarks are found in Annex 2 while the baseline processing reports for the established control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey from July 29-30, August 3, 9, and 12, 2014. Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852, and TRIMBLE SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Mananga floodplain are shown in Figure 2.

The succeeding sections depict the sets of reference points, control stations and established points, and the ground control points for the entire Mananga Floodplain LiDAR Survey. Figure 3

(a) (b)

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

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

Station Name	**CBU-11**	
Order of Accuracy	**2nd order**	
Relative Error (Horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10° 17’ 56.00367” 123° 53’ 26.63633” 44.27700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	597,568.76 meters 1,138,921.917 meters
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 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	597,534.61 meters 1,138,523.27 meters

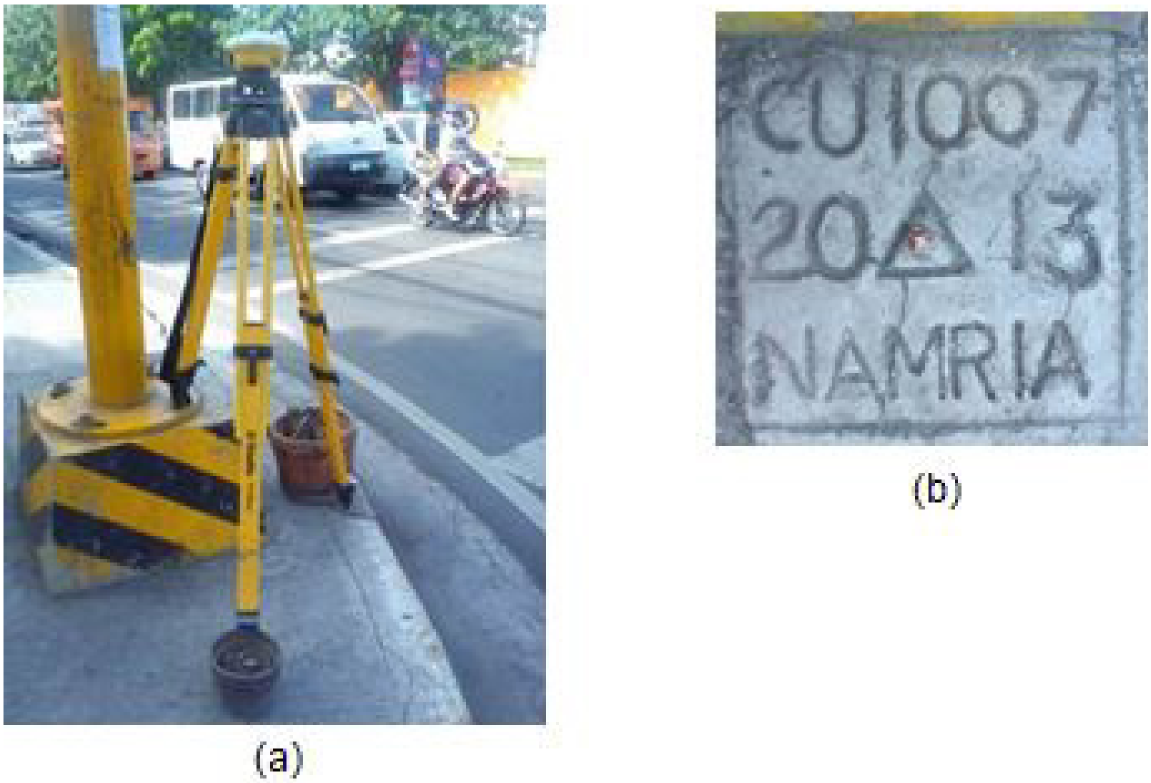

Figure 4. GPS set-up over CU-1007 along F. Cabang National Road and Juan Luna Avenue, in the base of the stop light NW of PLDT panel, Barangay Mabolo, Cebu City (a) and NAMRIA reference point CU-1007 (b) as recovered by the field team.

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 order	
Relative Error (Horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10° 19’ 18.03224” 123° 54’ 34.11152” 23.4975 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	599,647.206 meters 1,141,459.818 meters
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 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	599,579.97 meters 1,141,048.504 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
Date Surveyed	Flight Number	Mission Name	Ground Control Points
July 29, 2014	1769P	1BLK47A210A	CBU-11 and CU-1007
July 30, 2014	1773P	1BLK47A211A	CBU-11 and CU-1007
July 30, 2014	1775P	1BLK47A211B	CBU-11 and CU-1007
August 3, 2014	1789P	1MCTN215A	CBU-11 and CU-1007
August 3, 2014	1791P	1MCTN215B	CBU-11 and CU-1007
August 9, 2014	1813P	1MCTN221A	CBU-11 and CU-1007
August 12, 2014	1829P	1BLK36H47A225A	CBU-11
August 12, 2014	1831P	1OLNG225B	CBU-11

2.3 Flight Missions

A total of eight (8) missions were conducted to complete the LiDAR data acquisition in Mananga floodplain, for a total of twenty-four hours and thirty nine minutes (24+39) minutes of flying time for RP-C9022 (See Annex 6). All missions were acquired using the Pegasus LiDAR system. As shown below, the total area of actual coverage per mission and the corresponding flying hours are depicted in Table 5, while the actual parameters used during the LiDAR data acquisition are presented in Table 6.

Table 5. Flight missions for LiDAR data acquisition in Mananga floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
July 29, 2014	1769P	267.94	88.00	6.38	81.62	NA	2	18
July 30, 2014	1773P	267.94	261.63	12.81	248.82	NA	4	0
July 30, 2014	1775P	267.94	124.58	10.90	113.68	NA	1	54
August 3, 2014	1789P	105.49	84.53	NA	84.53	NA	4	5
August 3, 2014	1791P	373.43	79.89	NA	79.89	NA	2	42
August 9, 2014	1813P	373.43	129.04	10.09	118.95	NA	3	20
August 12, 2014	1829P	267.94	59.79	0.03	59.76	NA	2	57
August 12, 2014	1831P	373.43	93.13	NA	93.13	NA	3	23
TOTAL		2297.54	920.59	40.21	880.38	NA	24	39

Table 6. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1769P	1200	30	50	200	30	130	5
1773P	1000	30	50	200	30	130	5
1775P	1000	30	50	200	30	130	5
1789P	1200	30	50	200	30	130	5
1791P	1200	30	50	200	30	130	5
1813P	1000	30	50	200	30	130	5
1829P	1200	30	50	200	30	130	5
1831P	1200	30	50	200	30	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Mananga floodplain (See Annex 7). It is situated within the city of Talisay and municipality of Minglanilla. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage is shown in Table 7. Figure 5, on the other hand, shows the actual coverage of the LiDAR acquisition for the Mananga floodplain.

Table 7. List of municipalities and cities surveyed during Mananga floodplain LiDAR survey.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Cebu	Alegria	100.37	9.02	8.99%
	Badian	105.71	25.01	23.66%
	Cebu City	290.59	162.78	56.02%
	Compostela	51.55	18.72	36.31%
	Consolacion	32.98	15.2	46.09%
	Cordoba	9.83	9.72	98.88%
	Danao City	137.12	21.6	15.75%
	Lapu-Lapu City	63.42	63.15	99.57%
	Liloan	54.98	16.43	29.88%
	Mandaue City	31	8.53	27.52%
	Minglanilla	**51.76**	**15.36**	**29.68%**
	Naga City	**98.77**	**28.64**	**29.00%**
	San Fernando	**76.46**	**2.31**	**3.02%**
	Talisay City	**48.61**	**30.54**	**62.83%**
Total		**3,557.40**	**1,687.19**	**47.43%**

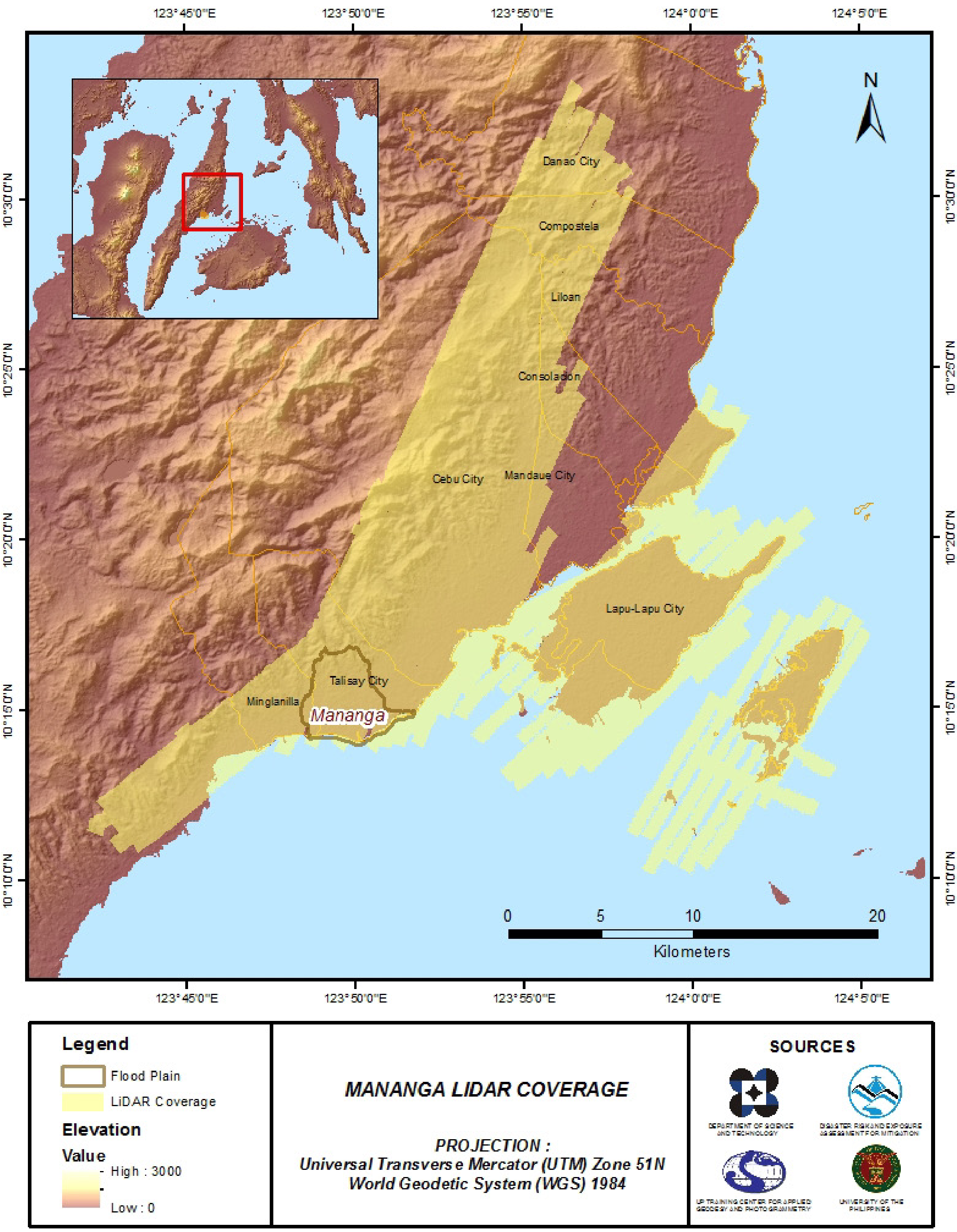

Figure 5. Actual LiDAR survey coverage for Mananga floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE MANANGA 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. Melanie C. Hingpit , Engr. Ma. Joanne I. Balaga, Engr. Erica Erin E. Elazegu

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

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

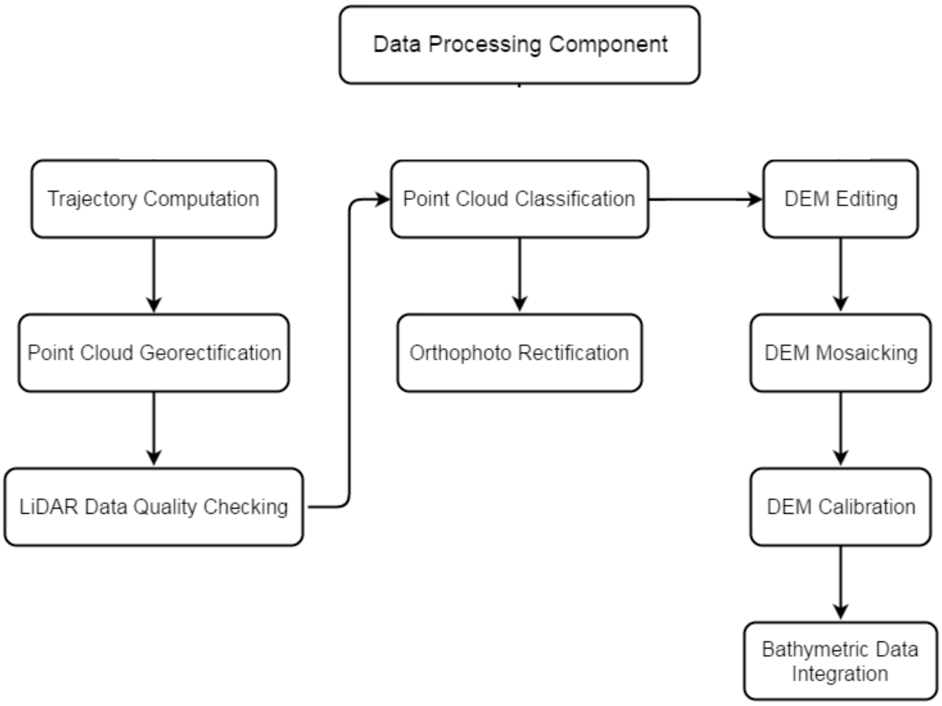

Figure 6. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

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

The Data Acquisition Component (DAC) transferred a total of 91.62 Gigabytes of Range data, 1.37 Gigabytes of POS data, 63.26 Megabytes of GPS base station data, and 128.87 Gigabytes of raw image data to the data server on August 20, 2014 for the first survey and September 16, 2014 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Mananga was fully transferred on September 16, 2014, as indicated on the Data Transfer Sheets for Mananga floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 1831P, one of the Mananga flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on August 13, 2014 00:00 AM. The y-axis is the RMSE value for that particular position.

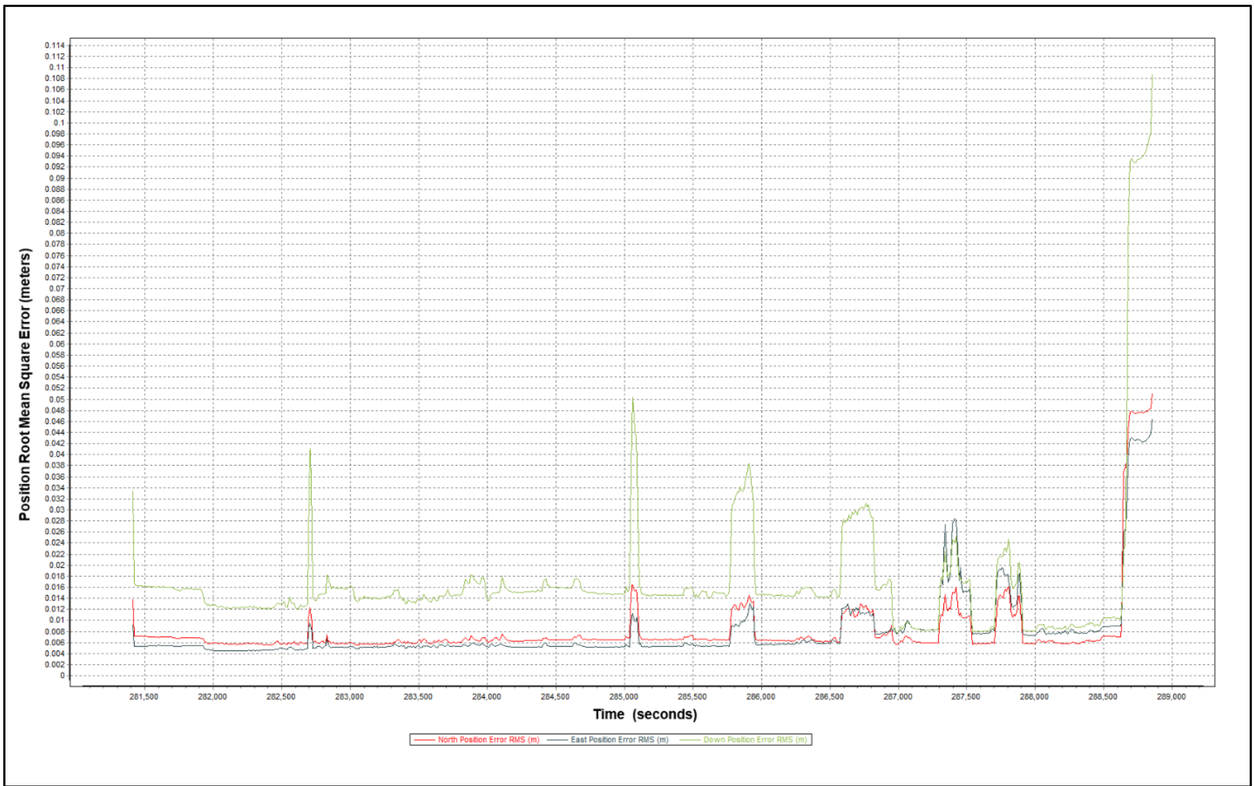

Figure 7. Smoothed Performance Metrics of Mananga Flight 1831P.

The time of flight was from 281400 seconds to 288600 seconds, which corresponds to afternoon of August 13, 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 minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turnaround period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 7 shows that the North position RMSE peaks at 1.60 centimeters, the East position RMSE peaks at 1.40 centimeters, and the Down position RMSE peaks at 5.00 centimeters, which are within the prescribed accuracies described in the methodology.

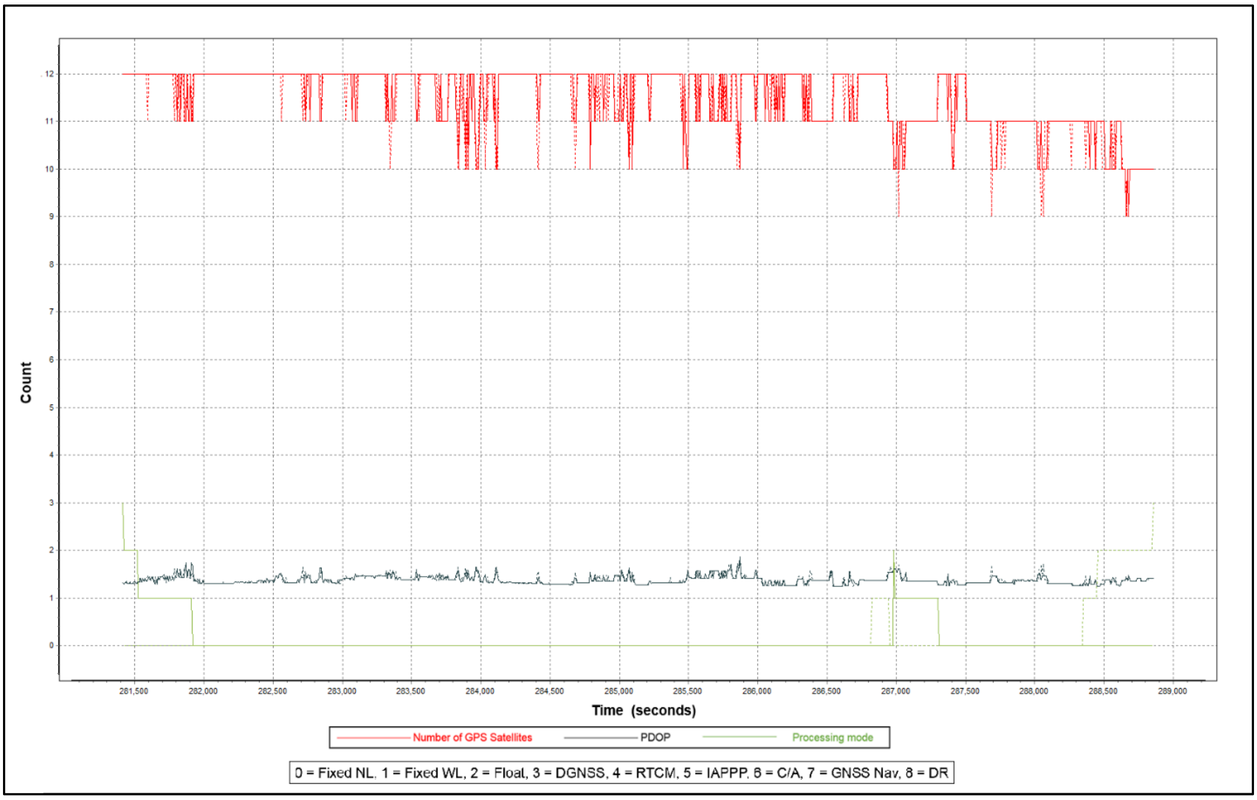

Figure 8. Solution Status Parameters of Mananga Flight 1831P.

The Solution Status parameters of flight 1831P one of the Mananga flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 10 and 12. 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 1 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 Mananga flights is shown in Figure 9.

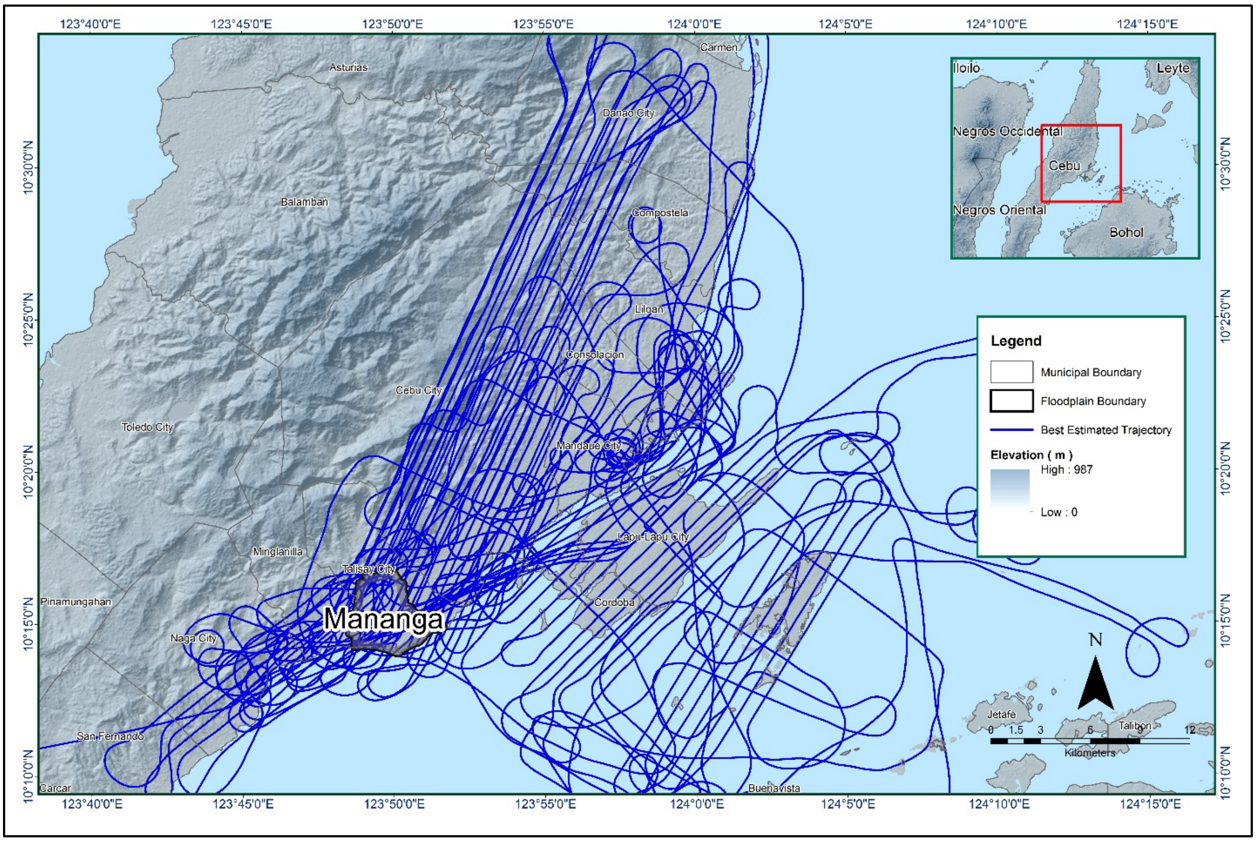

Figure 9. Best Estimated Trajectory of the LiDAR missions conducted over the Mananga Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 73 flight lines, with each flight line containing two channels, since the Pegasus system contain two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over the Mananga floodplain are given in Table 8.

Table 8. Self-calibration Results values for Mananga 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 were obtained for all Mananga flights based on the computed standard deviations of the corrections of the orientation parameters. The standard deviation values for individual blocks are available in the Mission Summary Reports in Annex 8.

3.5 LiDAR Data Quality Checking

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

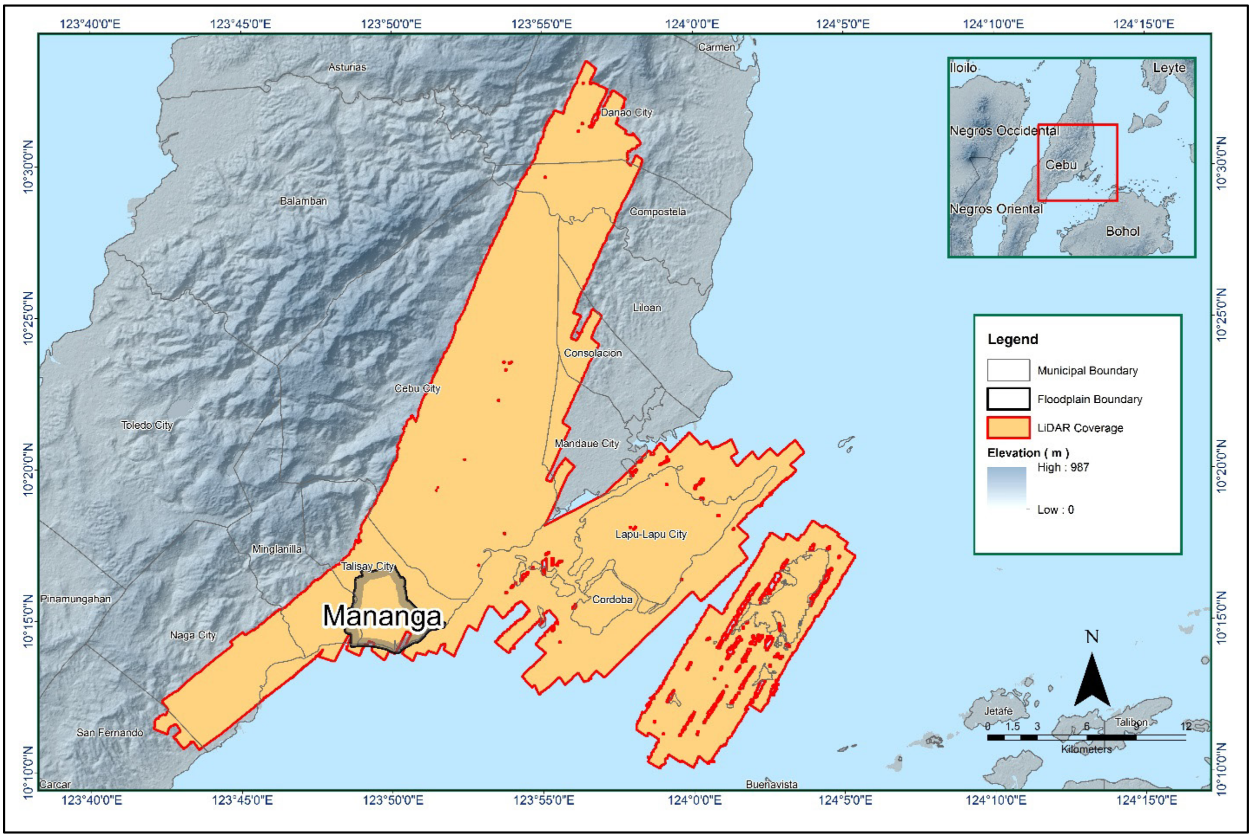

Figure 10. Boundary of the processed LiDAR data over Mananga Floodplain

The total area covered by the Mananga missions is 657.20 square kilometers (sq. kms.) that is comprised of eight (8) flight acquisitions grouped and merged into four (4) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Mananga Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Cebu_Blk47A	1769P	278.66
	1773P	169.74
	1775P	143.44
	1791P	202.76
Cebu_Blk47A_additional	1831P	16.57
MactanIsland	1789P	281.79
	1791P	169.39
	1813P	84.74
	1829P	
Olango_Island	1831P	80.18
TOTAL		657.20 sq.km

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

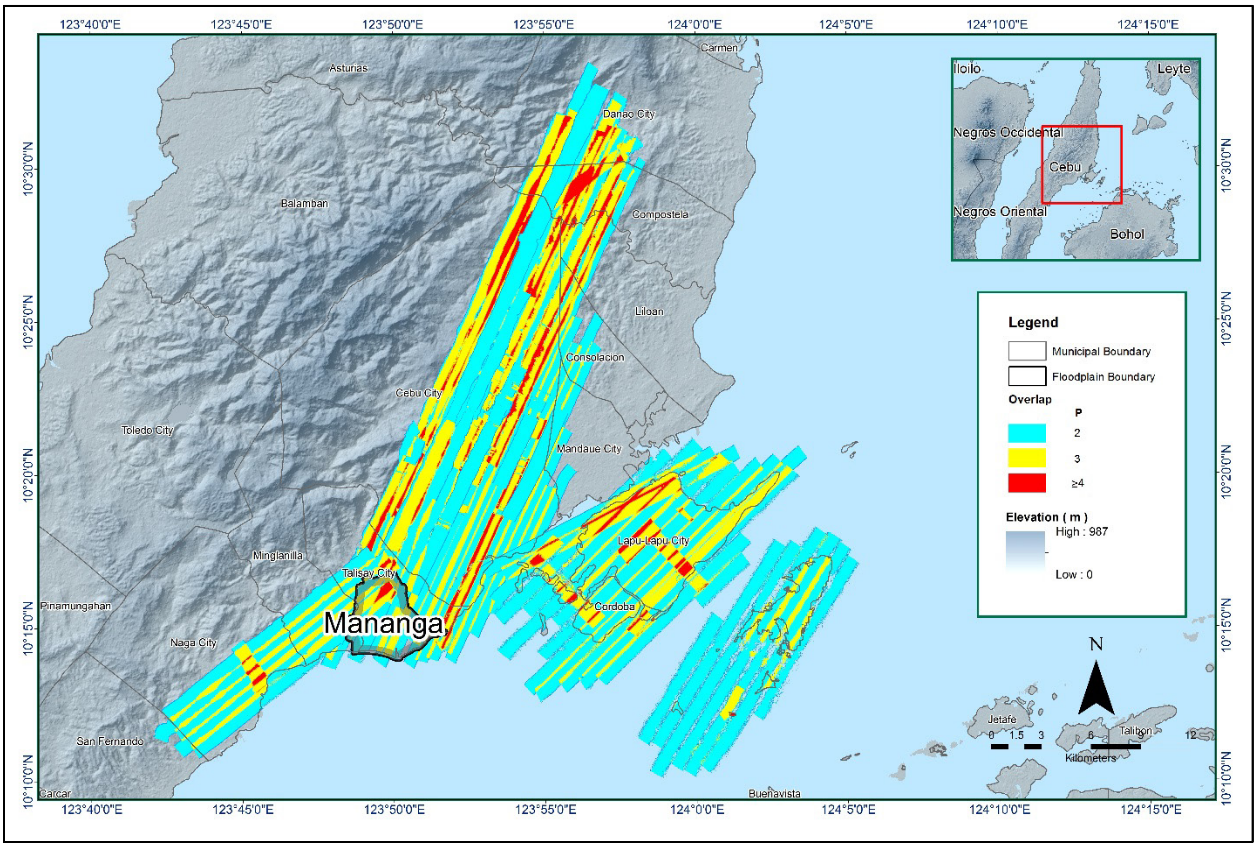

Figure 11. Image of data overlap for Mananga Floodplain.

The overlap statistics per block for the Mananga floodplain can be found in the Mission Summary Reports (Annex 8). One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 30.90% and 57.03% 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 two (2) points per square meter criterion is shown in Figure 12. It was determined that all LiDAR data for the Mananga floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.94 points per square meter.

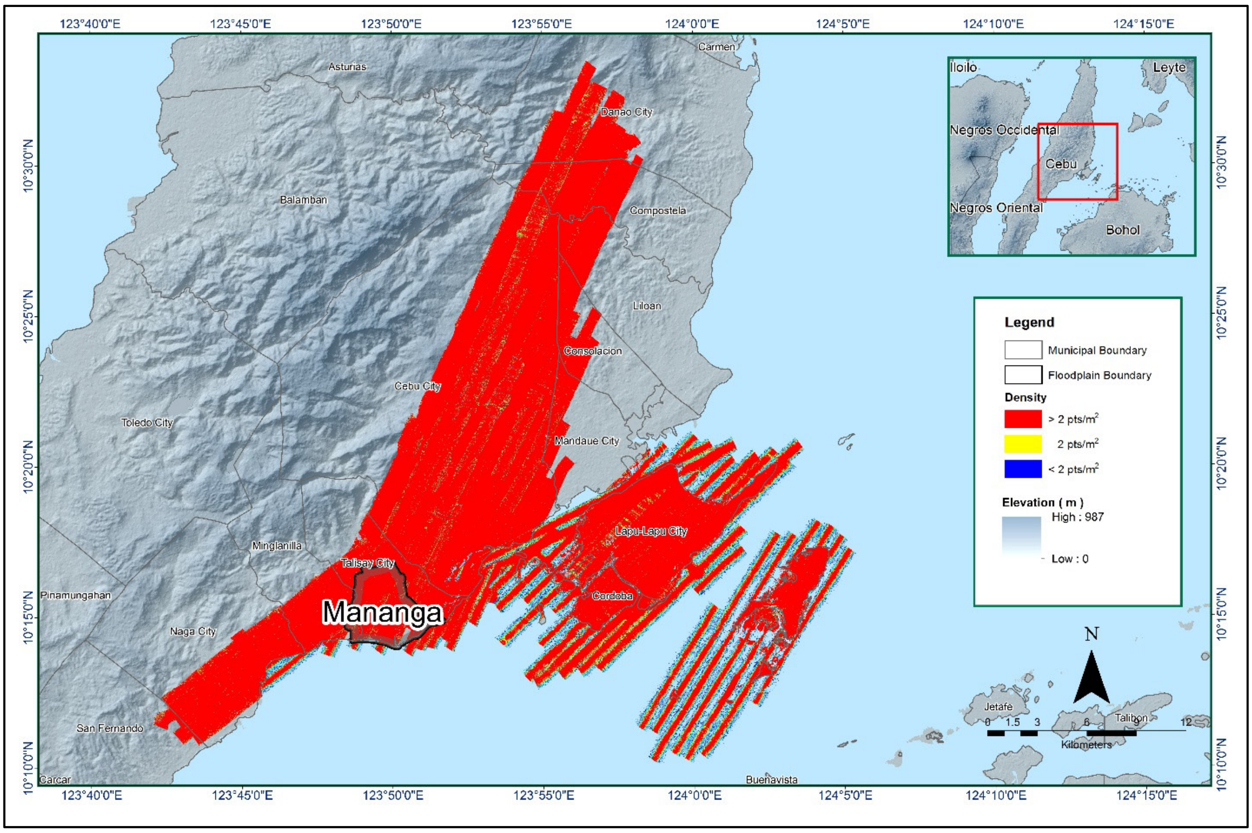

Figure 12. Pulse density map of merged LiDAR data for Mananga Floodplain.

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

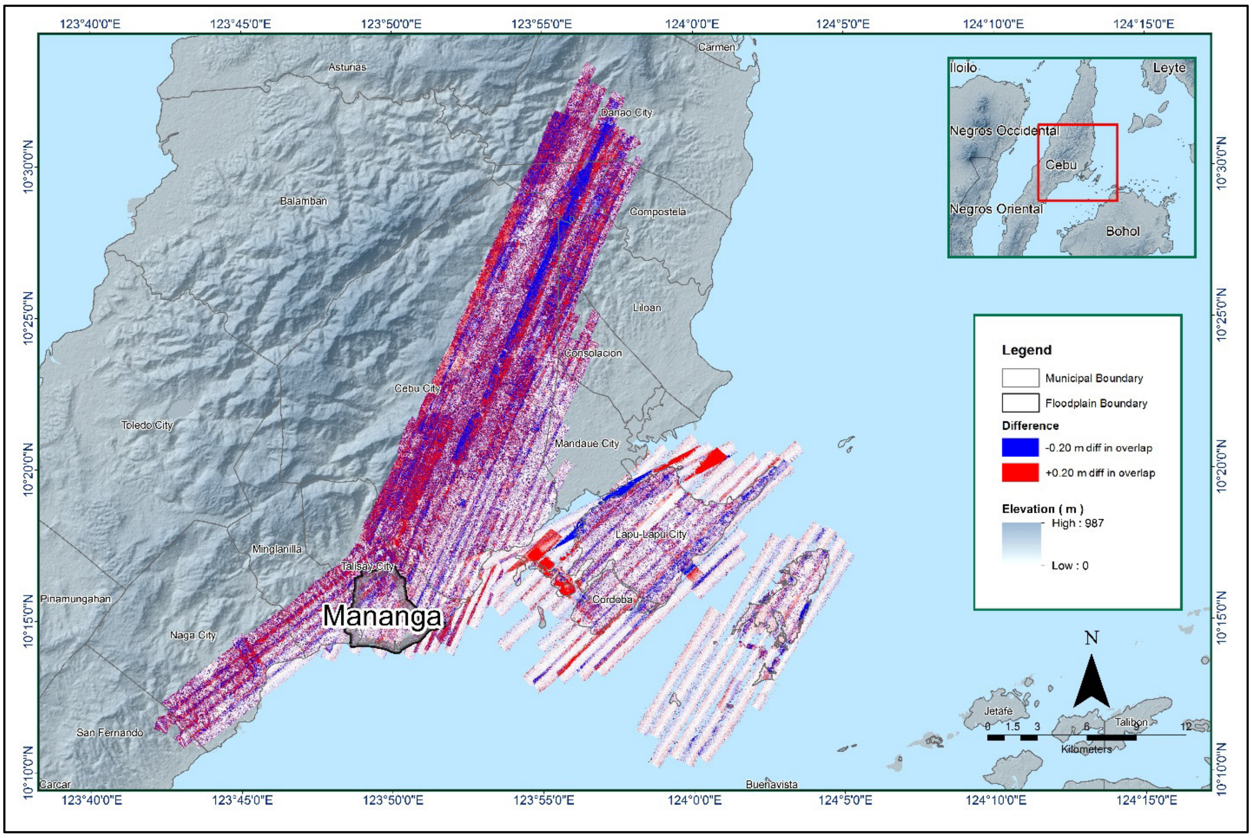

Figure 13. Elevation Difference Map between flight lines for Mananga Floodplain Survey.

A screen capture of the processed LAS data from a Mananga flight 1831P loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

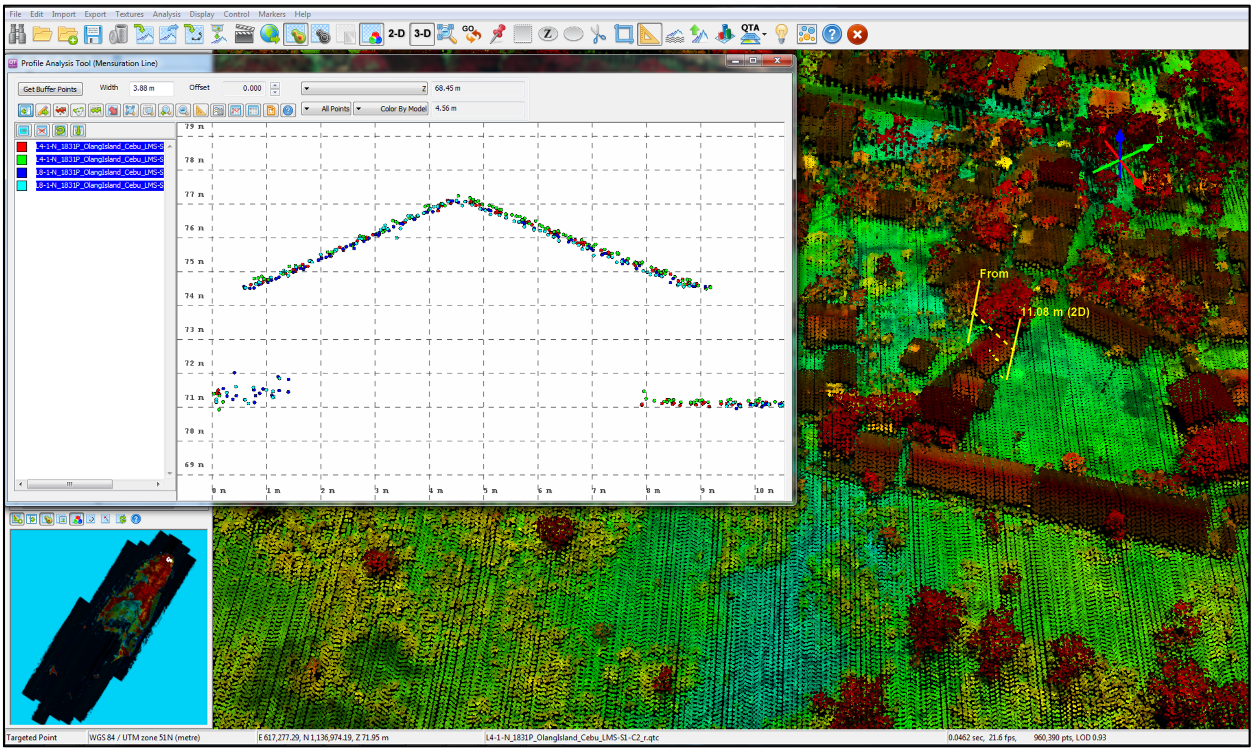

Figure 14. Quality checking for a Mananga flight 2842P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Mananga classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	231,645,241
Low Vegetation	197,658,802
Medium Vegetation	542,123,812
High Vegetation	610,620,811
Building	48,798,021

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Mananga floodplain is shown in Figure 15. A total of 943 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 15. The point cloud has a maximum and minimum height of 906.41 meters and 67.02 meters, respectively.

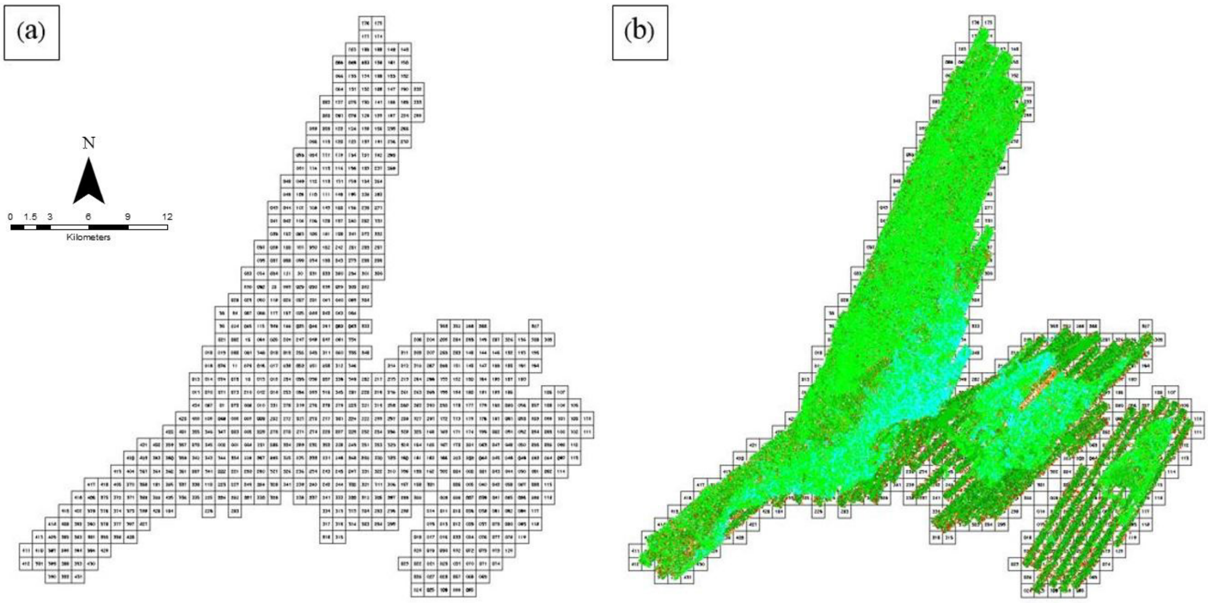

Figure 15. Tiles for Mananga Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 16. The ground points are in orange, while 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 the canopy are classified correctly, due to the density of the LiDAR data.

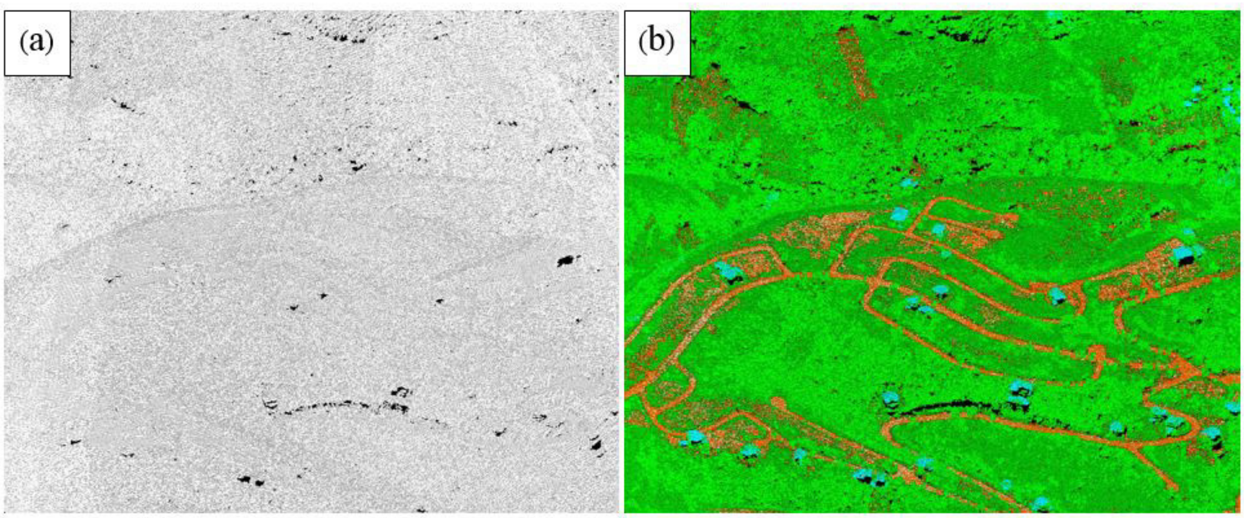

Figure 16. Point cloud before (a) and after (b) classification

The production of the 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 show in Figure 17

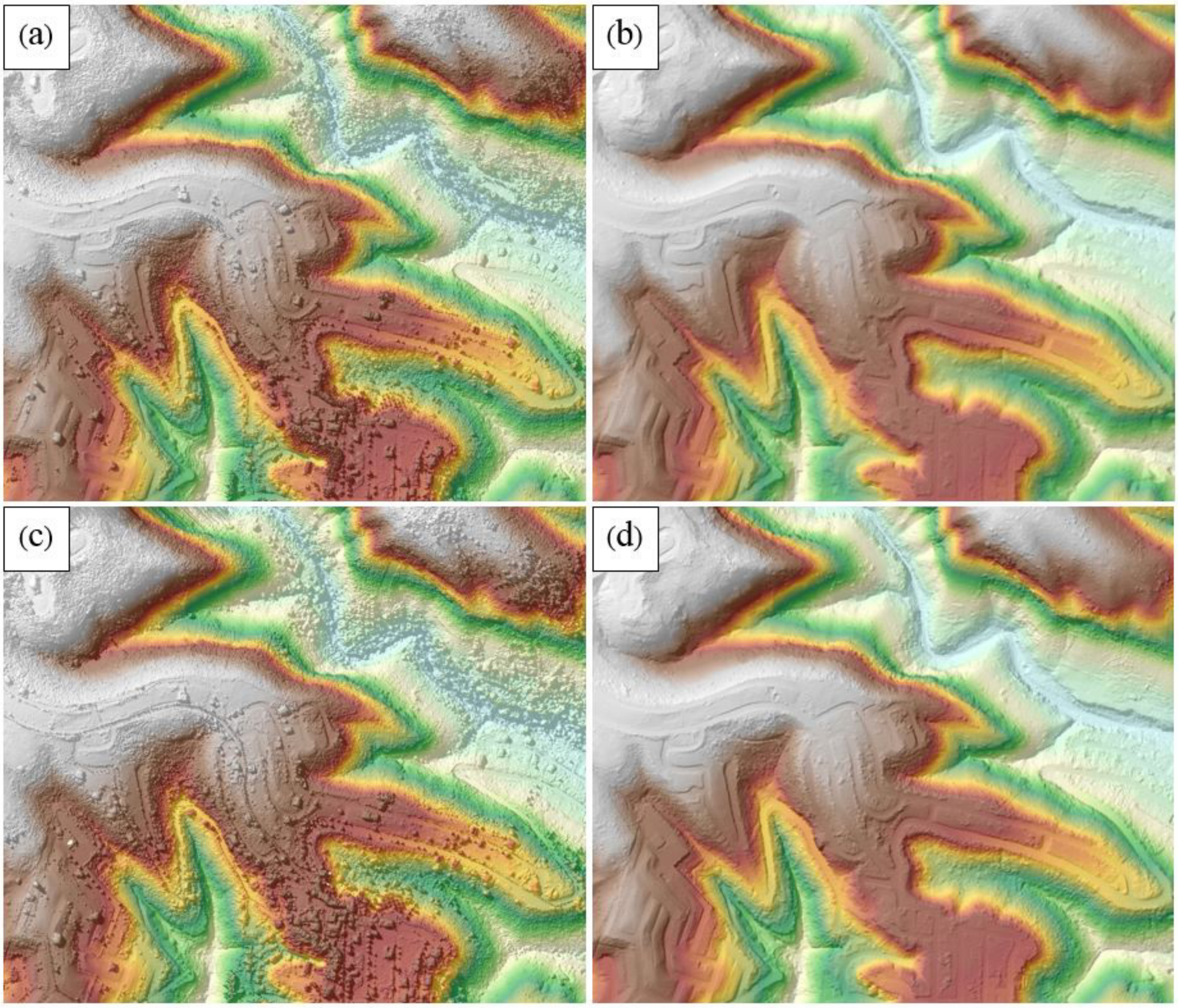

Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Mananga Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 834 1km by 1km tiles area covered by Mananga floodplain is shown in Figure 18. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Mananga floodplain has a total of 629.41 sq.km orthophotogaph coverage comprised of 1,959 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 19.

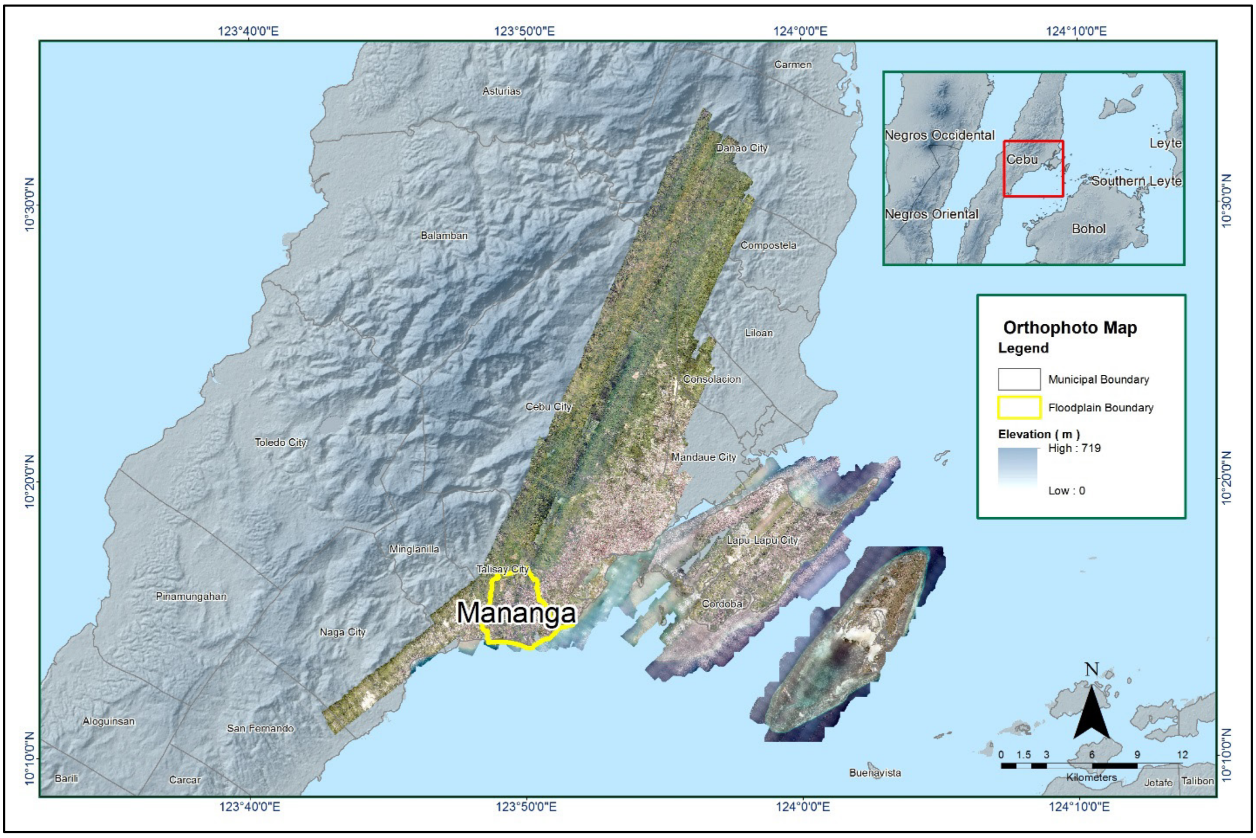

Figure 18. Mananga Floodplain with available orthophotographs.

Figure 19. Sample orthophotograph tiles for Mananga Floodplain.

3.8 DEM Editing and Hydro-Correction

Four (4) mission blocks were processed for Mananga flood plain. These blocks are composed of Cebu, Mactan, and Olango blocks with a total area of 657.20 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Cebu_Blk47A	278.66
Cebu_Blk47A_additional	16.57
MactanIsland	281.79
Olango_Island	80.18
TOTAL	657.20 sq.km

Figure 20 shows portions of a DTM before and after manual editing. As evident in the figure, the interpolated area (Figure 20a) has been misclassified during classification process and has to be retrieved to complete the surface (Figure 20b). Another is the bridge (Figure 20c) is also considered to be an impedance to the flow of water and has to be removed (Figure 20d) in order to hydrologically correct the river.

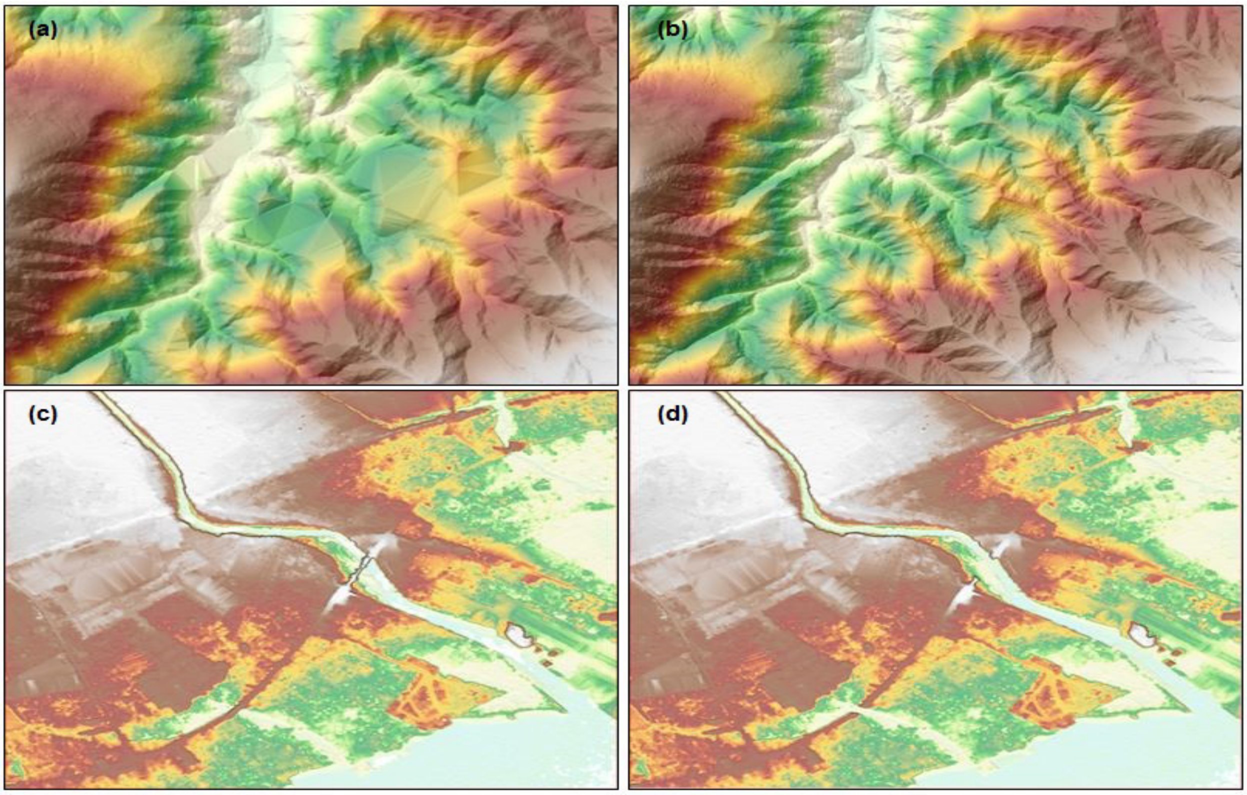

Figure 20. Portions in the DTM of the Mananga Floodplain – (a) before and (b) after filling data gaps; a bridge before (c) and after (d) manual editing.

3.9 Mosaicking of Blocks

Cebu_Blk47A was used as the reference block at the start of mosaicking because this block was referred to a base with an acceptable order of accuracy. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

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

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Cebu_Blk47A	0.00	0.00	-3.22
Cebu_Blk47A_additional	0.00	0.00	-3.65
MactanIsland	0.00	0.00	-3.18
Olango_Island	0.00	0.00	-3.22

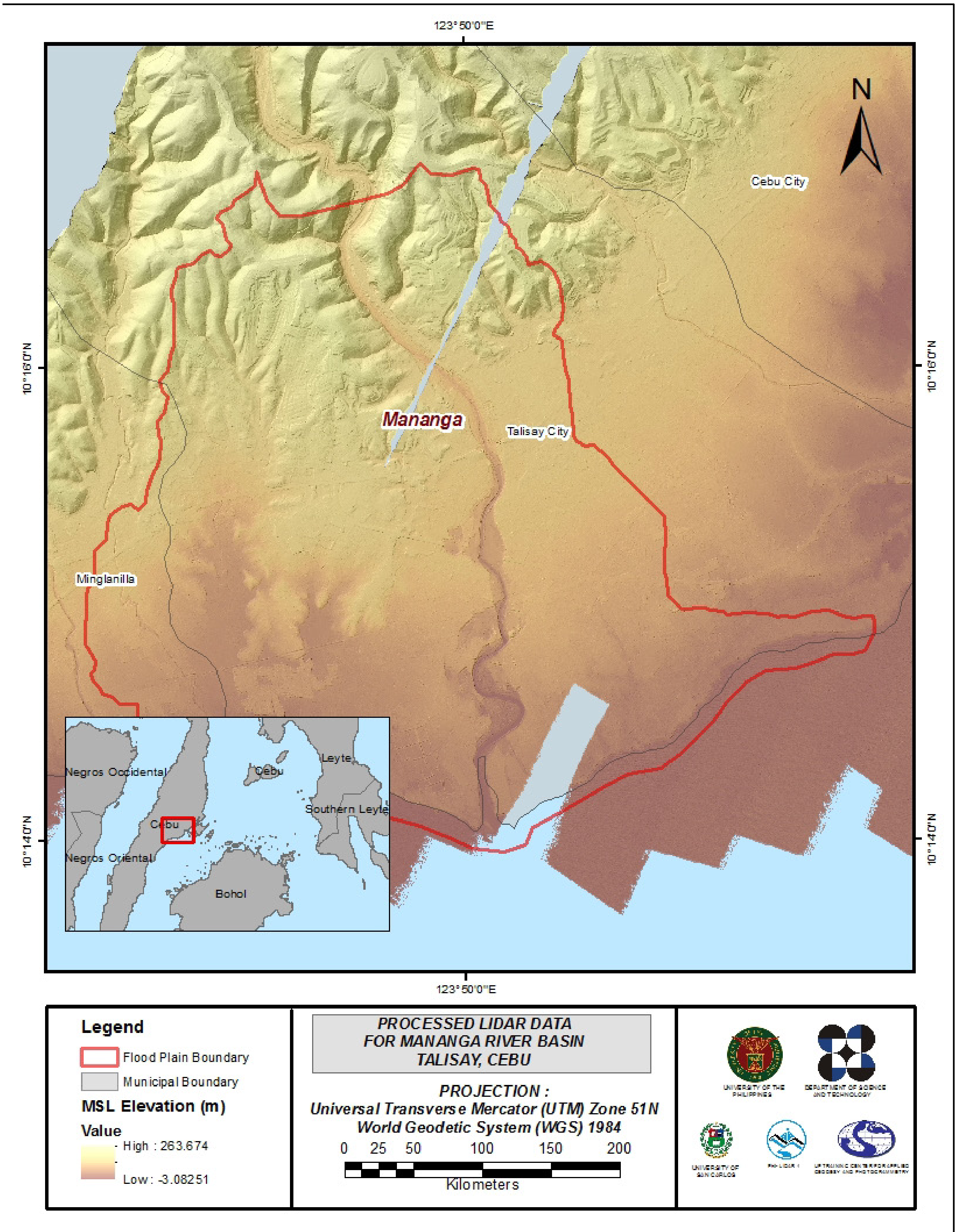


Figure 21 . Map of Processed LiDAR Data for Mananga Floodplain.

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 Mananga to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 22,471 survey points were gathered for all the flood plains within the province of Cebu wherein the Mananga 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 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 0.55 meters with a standard deviation of 0.20 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 0.55 meters, to the mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

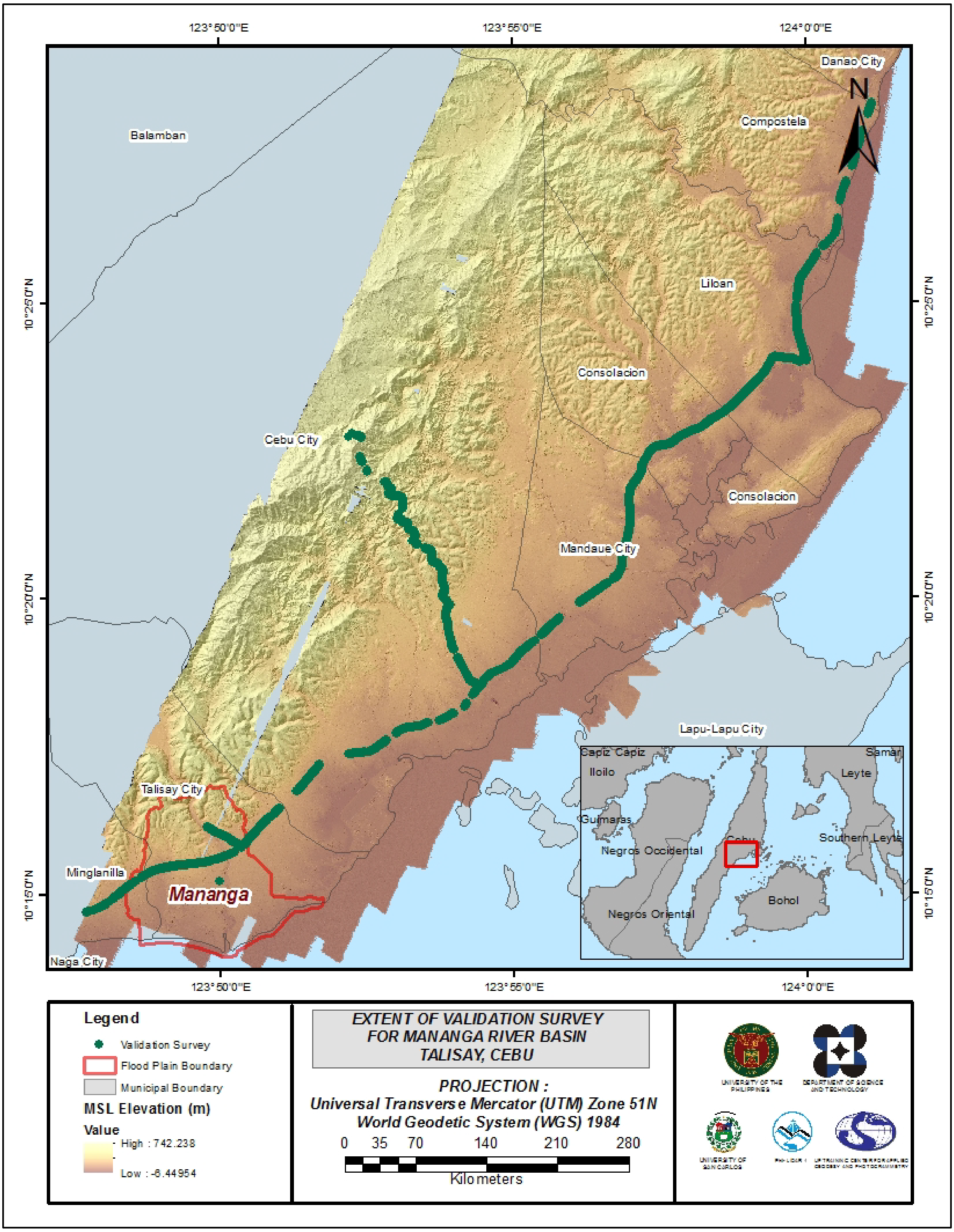


Figure 22. Map of Mananga Floodplain with validation survey points in green.

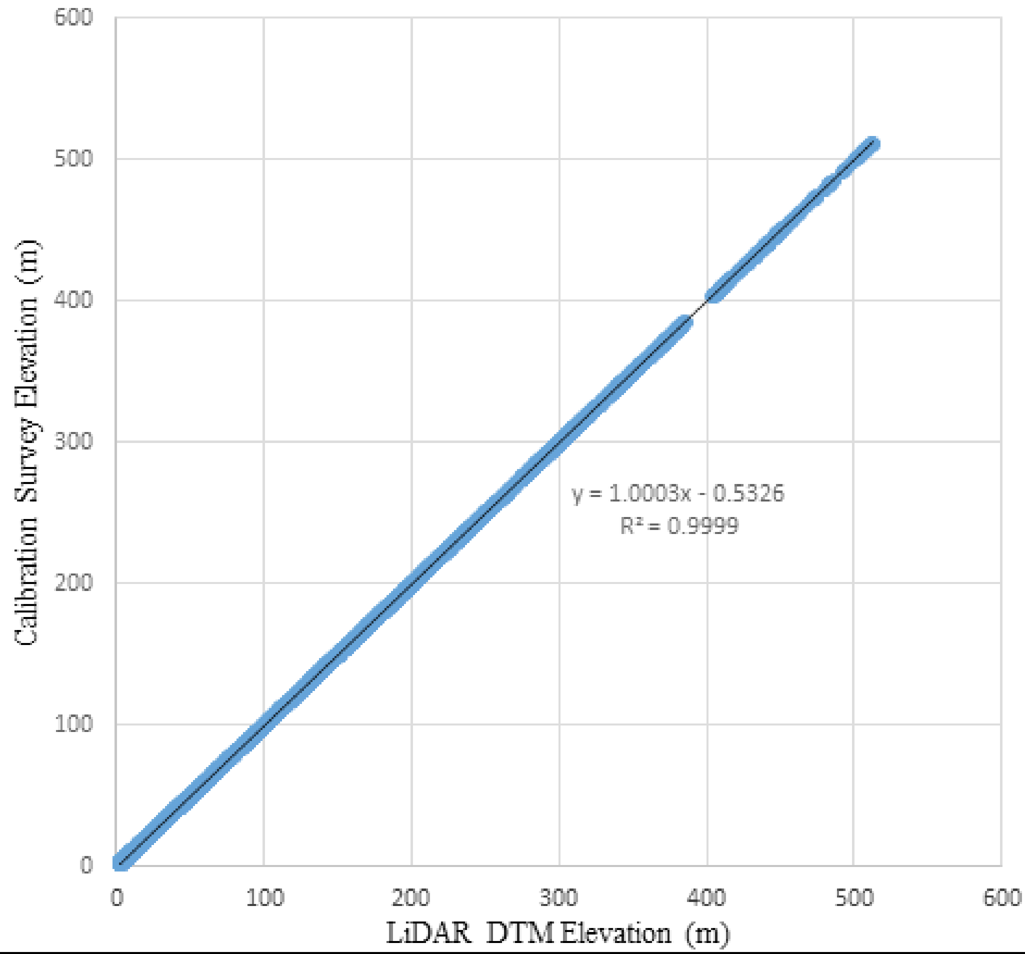


Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures

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

The remaining 20% of the total survey points that are near Mananga flood plain, resulting to 681 points, were used for the validation of calibrated Mananga DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM, is shown in Figure 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.18 meters, as shown in Table 14.

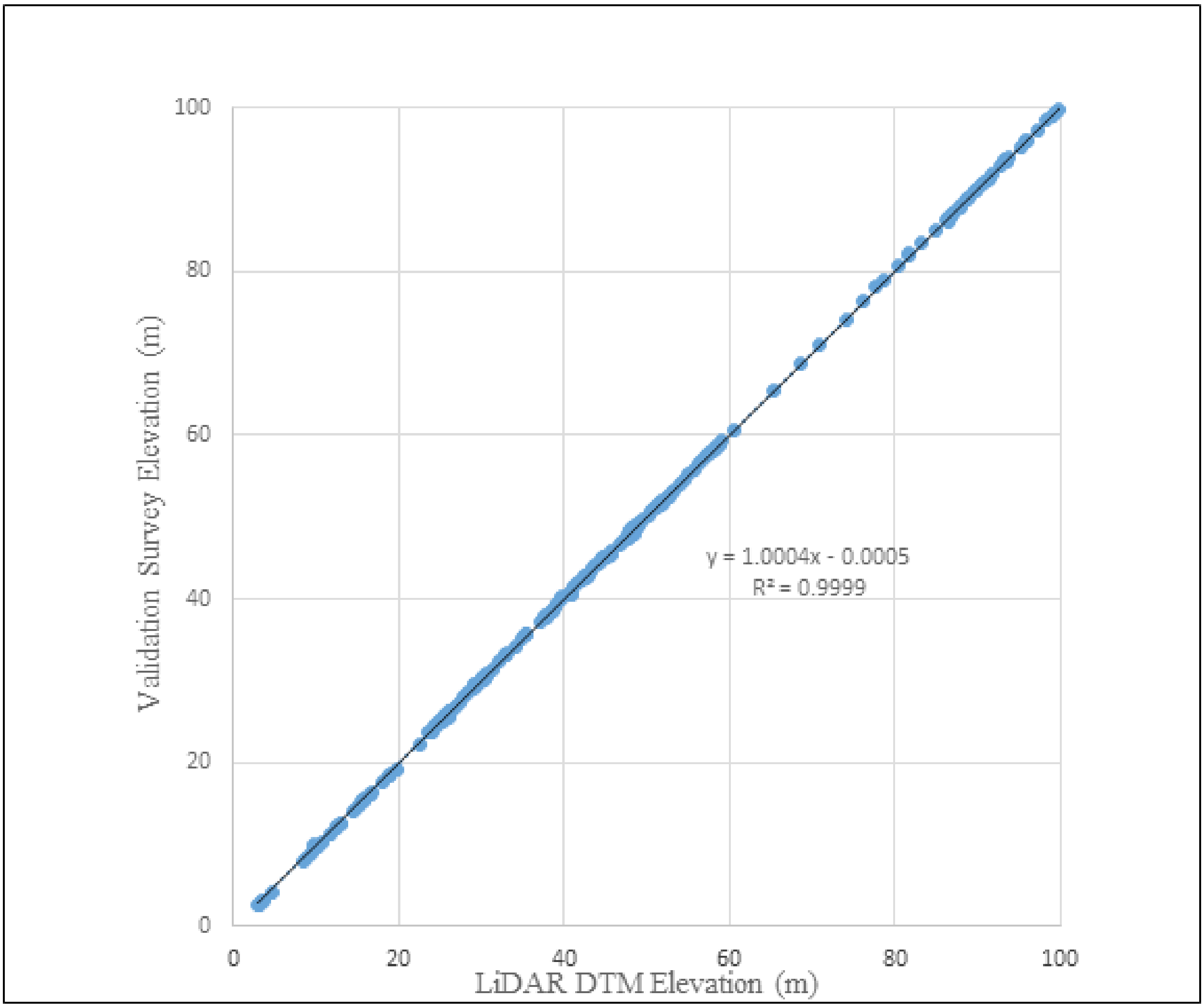


Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.18
Average	0.08
Minimum	-0.46
Maximum	0.52

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and cross-section data were available for Mananga with 1,570 bathymetric survey points. The resulting raster surface produced was done by Local Polynomial interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.09 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Mananga integrated with the processed LiDAR DEM is shown in Figure 25.

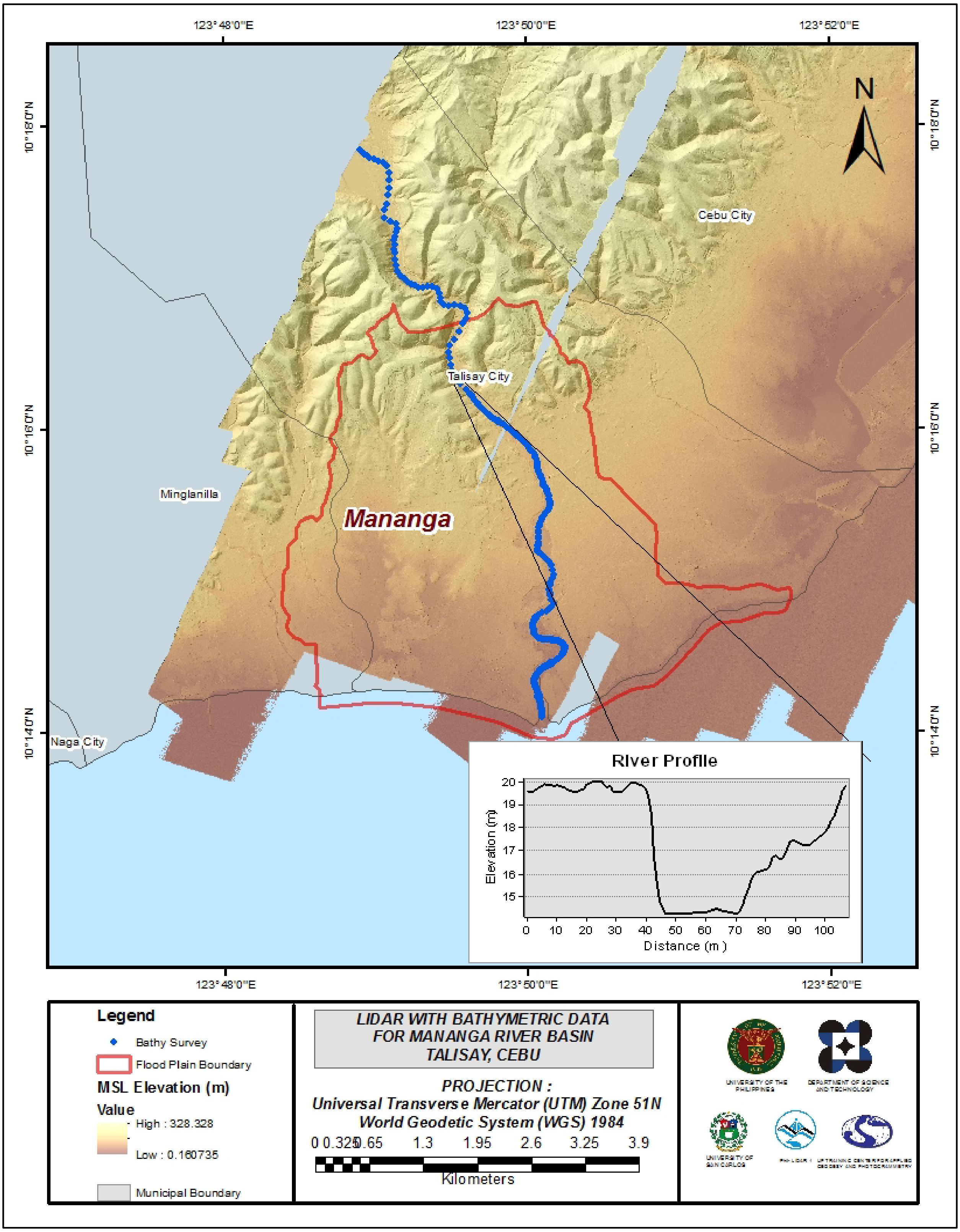


Figure 25. Map of Mananga Floodplain with bathymetric survey points in blue.

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 a 200-meter buffer zone. Mosaicked LiDAR DEMs with a 1-m resolution were used to delineate footprints of building features, which comprised 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 the routing of disaster response efforts. These features are represented by network of road centerlines.

3.12.1 Quality Checking of Digitized Features' Boundary

Mananga floodplain, including its 200 m buffer, has a total area of 22.55 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 4,863 building features, are considered for QC. Figure 26 shows the QC blocks for Mananga floodplain.

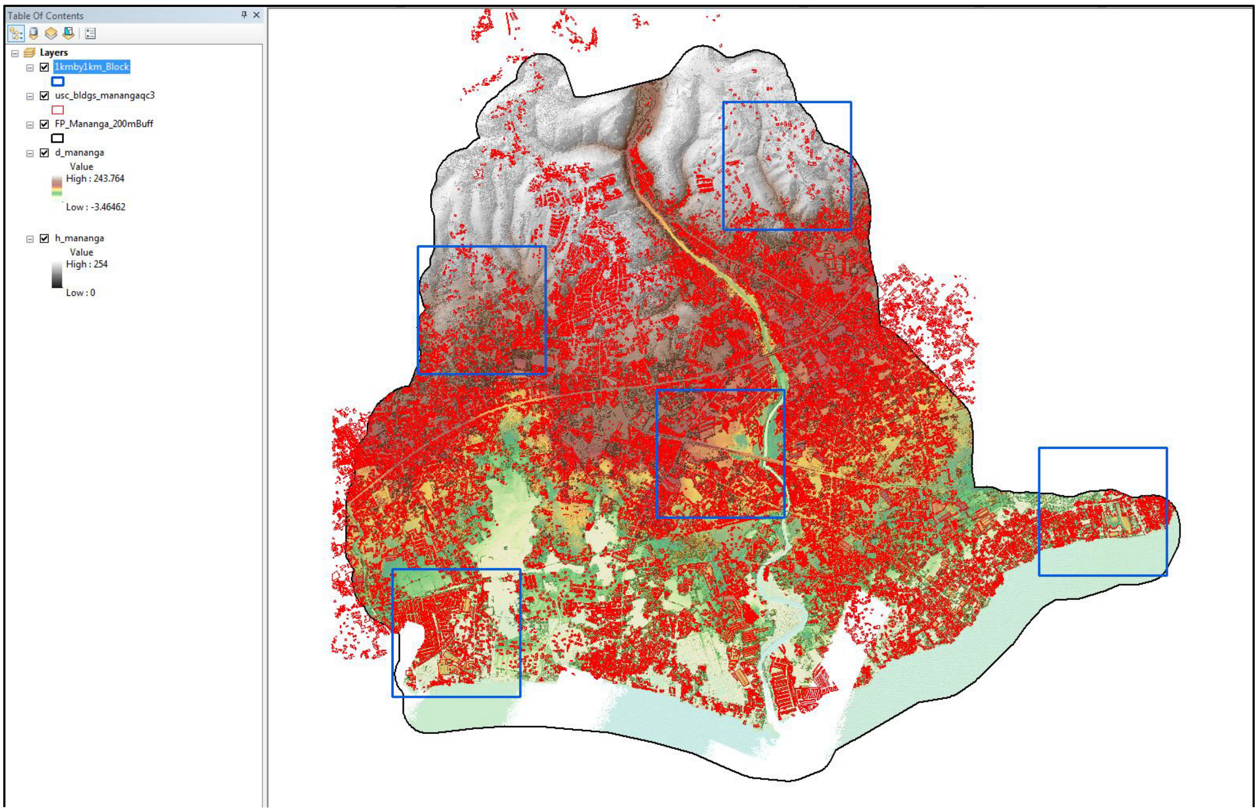


Figure 26. Blocks (in blue) of Mananga building features that was subjected to QC.

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

Table 15. Details of the quality checking ratings for the building features extracted for the Mananga River Basin

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Mananga	99.79	100.00	97.99	PASSED

3.12.2 Height Extraction

Height extraction was done for 32,691 building features in Mananga floodplain. Of these building features, 2,778 were filtered out after height extraction, resulting to 29,913 buildings with height attributes. The lowest building height is at 2.00 meters, while the highest building is at 10.88 meters.

3.12.3 Feature Attribution

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

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

Table 16. Building Features Extracted for Mananga Floodplain.

Facility Type	No. of Features
Residential	28,860
School	176
Market	29
Agricultural/Agro-Industrial Facilities	46
Medical Institutions	6
Barangay Hall	12
Military Institution	0
Sports Center/Gymnasium/Covered Court	4
Telecommunication Facilities	
Transport Terminal	21
Warehouse	288
Power Plant/Substation	0
NGO/CSO Offices	2
Police Station	1
Water Supply/Sewerage	0
Religious Institutions	47
Bank	3
Factory	15
Gas Station	8
Fire Station	0
Other Government Offices	3
Other Commercial Establishments	392
Total	**29,913**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Mananga	117	24	7.9	5.3	0	154.18

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

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Mananga	32	2	0	0	20	2

A total of 8 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

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

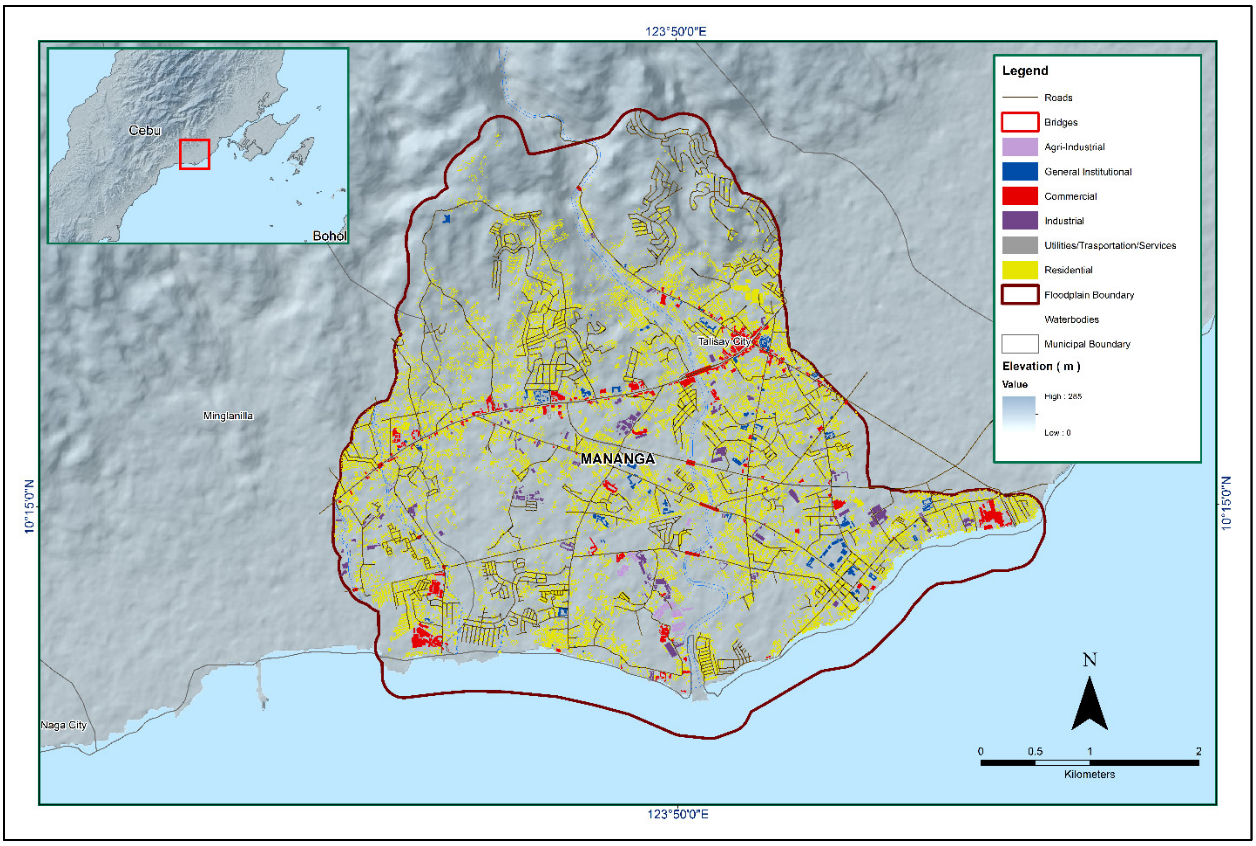


Figure 27. Extracted features for Mananga Floodplain.

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

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

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Mananga River on January 29 to February 7, 2015. Generally, the scope of work was comprised of (i) initial reconnaissance; (ii) control point survey for the establishment of a control point; (iii) ground validation data acquisition of about 48.46 km covering the national highway from Municipality of Compostela up to the City of Talisay; and (iv) bathymetric survey from its upstream in Brgy. Camp IV, Talisay City, Cebu down to the mouth of the river in Brgy. Biasong, Talisay City, Cebu with an approximate length of 11.026 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique. Figure 28 illustrates the extent of the entire survey in Mananga River.

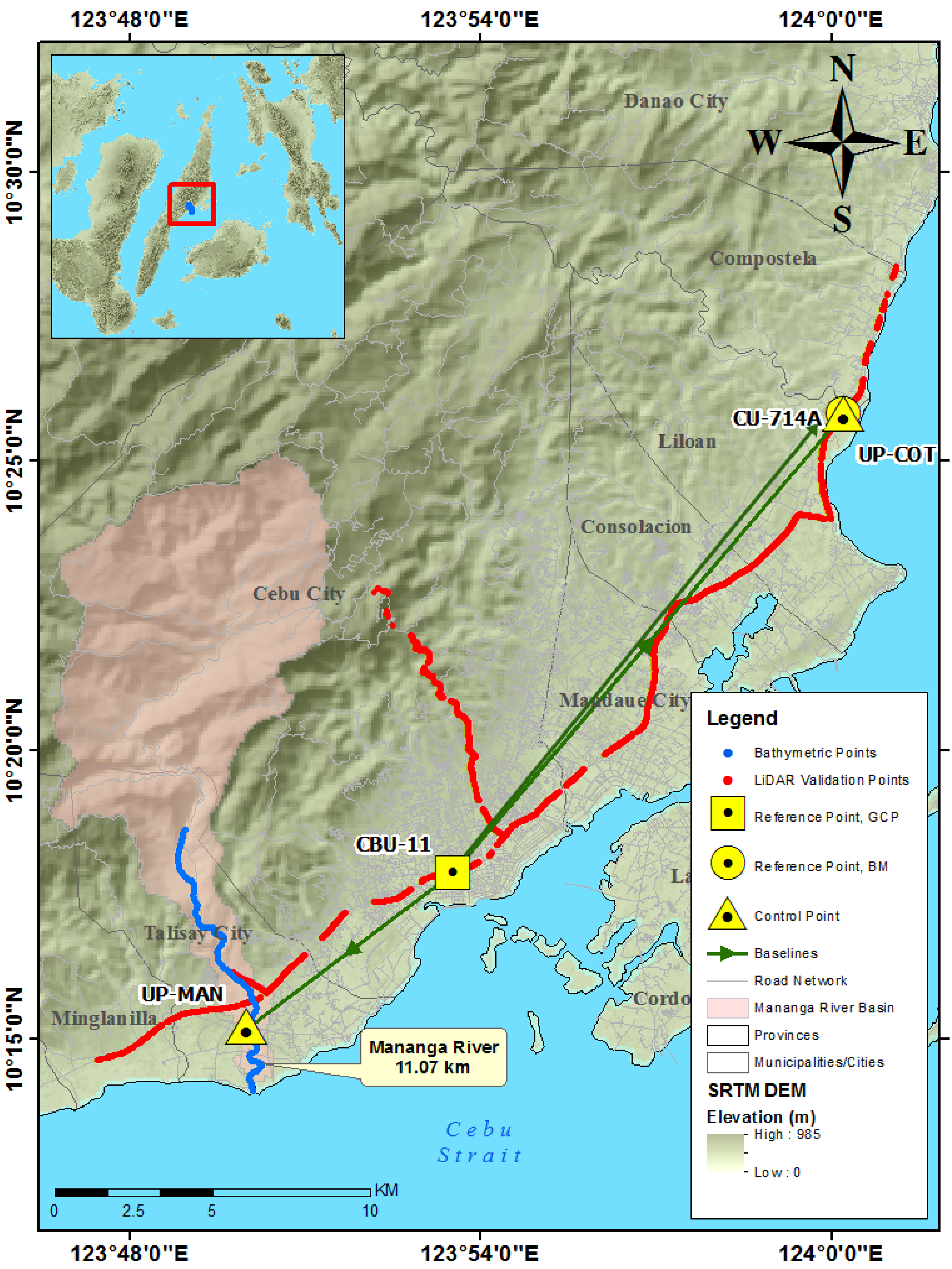


Figure 28 . Extent of the bathymetric survey (in blue line) in Mananga River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network utilized for the Mananga River Basin is composed of one (1) loop and a baseline that was established on February 3, 2016, which occupied the following reference points: CBU-11, a second-order GCP in Town Proper, Cebu City; CU-714A, a first order BM in Brgy. Cotcot, Municipality of Liloan, Cebu.

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

Table 19 depicts the summary of reference and control points utilized, with their corresponding locations, while Figure 29 shows the GNSS network established in the Mananga River Survey.

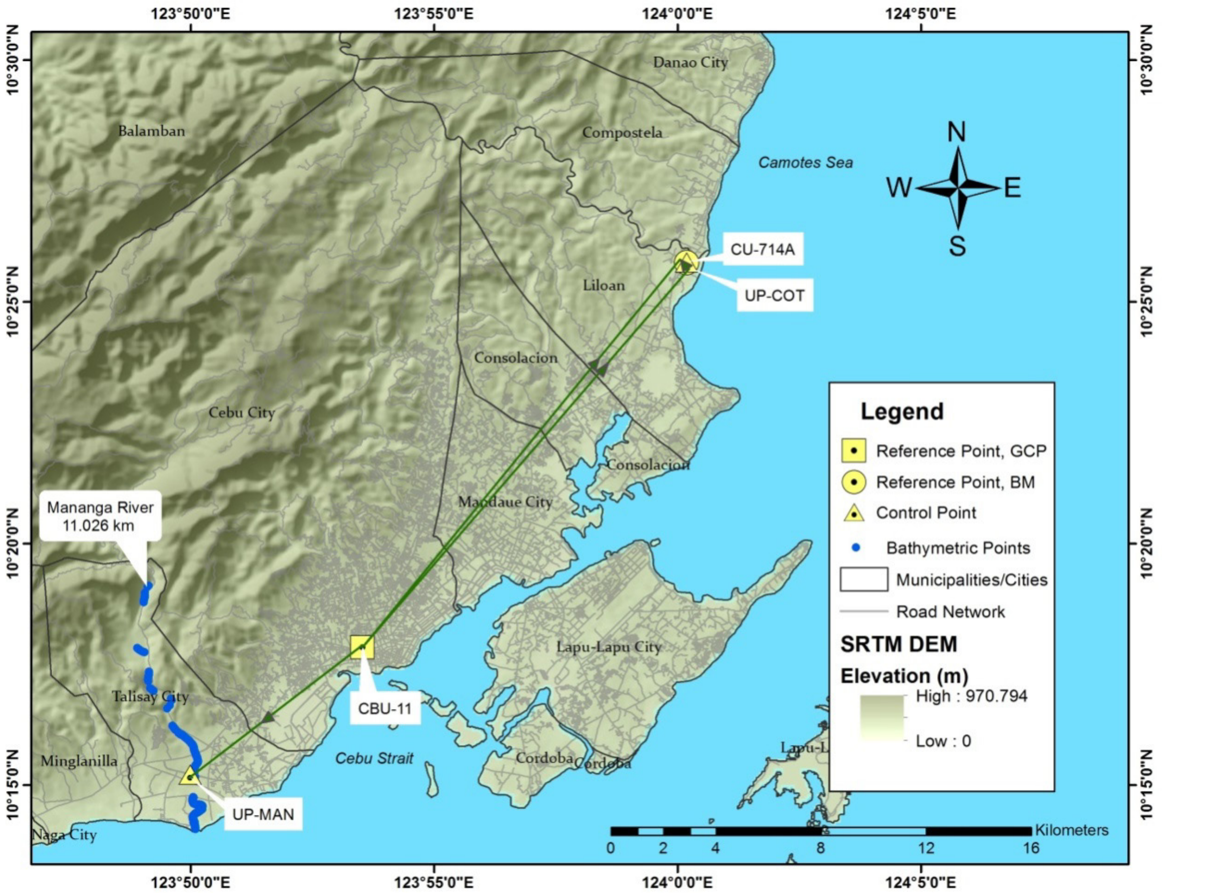


Figure 29. Mananga River Basin Control Survey Extent.

Table 19. List of Reference and Control Points occupied for Mananga River Survey

(Source: NAMRIA; UP-TCAGP)

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

Figure 30 to Figure 35 depict the setup of the GNSS on recovered reference points and established control points in the Mananga River.

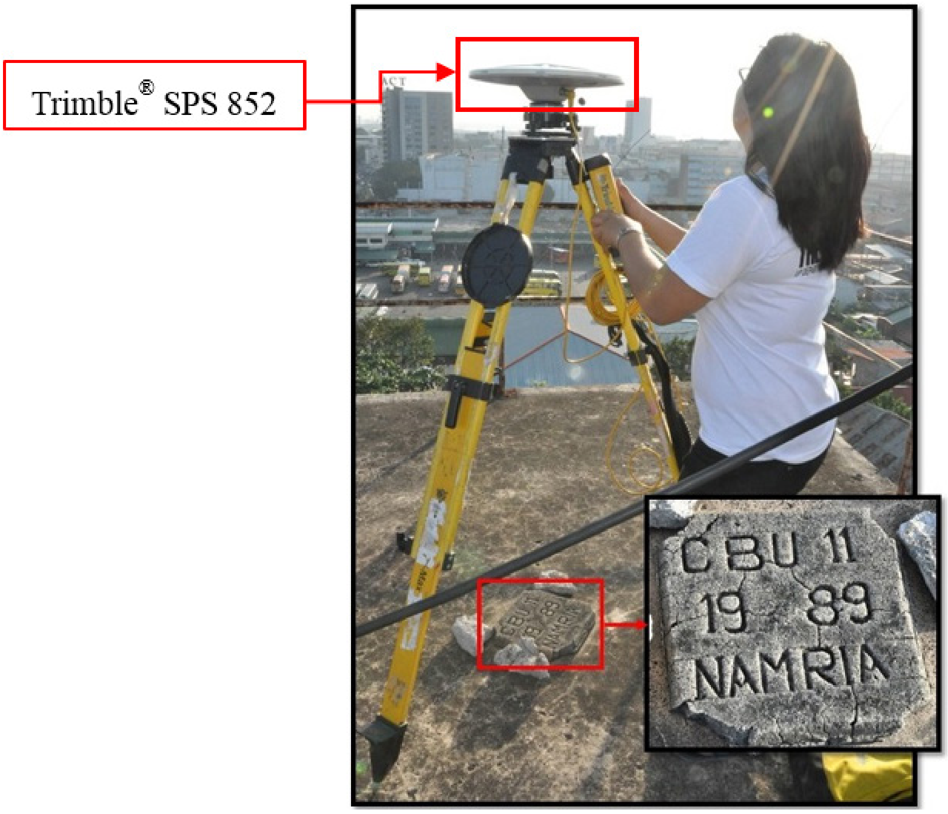


Figure 30. GNSS base receiver, Trimble® SPS 852, at CBU-11, located in Brgy. Sambag II, Cebu City

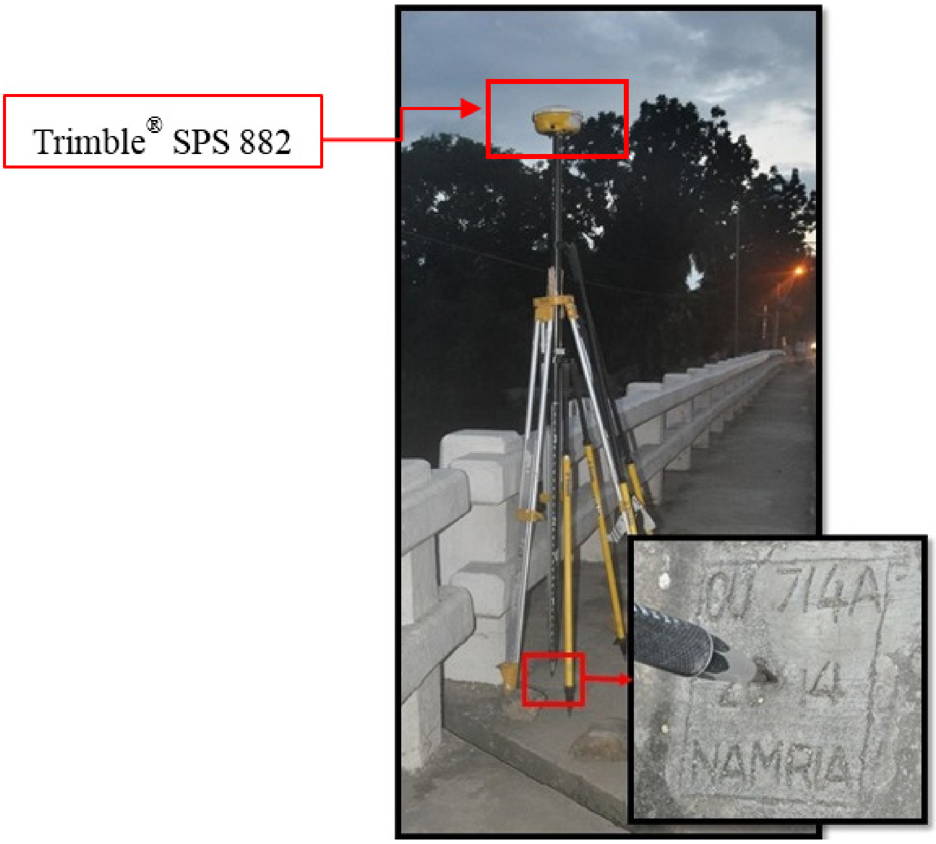


Figure 31. GNSS receiver setup, Trimble® SPS 882, at CU-714A, at the approach of Cotcot Bridge in Brgy. Cotcot, Municpality of Liloan, Cebu

Figure 32. GNSS receiver setup, Trimble® SPS 882, at CG-373, located at the approach of Bangan Bridge in Brgy. Bangan, Municipality of Sanchez Mira, Cagayan

Figure 33. GNSS receiver setup, Trimble® SPS 852, at UP-CLA, located at the approach of Cabicungan Bridge in Brgy. Dibalio, Municipality of Claveria, Cagayan

Figure 34. GNSS base receiver, Trimble® SPS 852, at UP-COT, at the approach of Cotcot Bridge in Brgy. Cotcot, Municipality of Liloan, Cebu

Figure 35. GNSS base receiver, Trimble® SPS 852, at UP-MAN, at the approach of Mananga Bridge in Brgy. Lawaan II, Talisay City, Cebu

4.3 Baseline Processing

The 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 cases where one or more baselines did not meet all of these criteria, masking was performed. Masking is the removal or covering of portions of the baseline data using the same processing software. The data is then repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, a resurvey is initiated. Table 20 presents the baseline processing results of control points in the Mananga River Basin, as generated by the TBC software.

Table 20. The Baseline processing report for the Pambujan River GNSS static observation survey.

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

As shown in Table 20, a total of four (4) baselines were processed with the coordinates of CBU-11 held fixed for coordinate value; and CU-714A fixed for elevation values; it is apparent that all baselines passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

x_e is the Easting Error,

y_e is the Northing Error, and

z_e is the Elevation Error

For complete details, see the Network Adjustment Report shown in Table 21 to Table 24

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

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

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
CBU-11	Local	Fixed	Fixed		
CU-714A	Grid				Fixed
Fixed = 0.000001(Meter)					

Likewise, the list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22

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

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CBU-11	597693.442	?	1138468.476	?	39.851	0.018	LL
CU-714A	609806.801	0.003	1153149.343	0.002	6.284	?	e
UP-COT	609805.735	0.003	1153148.008	0.002	6.316	0.003	

The results of the computation for accuracy are as follows:

a.CBU-11

Horizontal accuracy = Fixed
Vertical accuracy = 1.8 cm < 10 cm

b.CU-714A

Horizontal accuracy = $\surd\,((0.3)^2 + (0.2)^2$
= $\surd(0.90 + 0.40)$
= 1.1 cm < 20 cm
Vertical accuracy = Fixed

c.UP-COT

Horizontal accuracy = $\surd\,((0.3)^2 + (0.2)^2$
= $\surd(0.90 + 0.40)$
= 1.1 cm < 20 cm
Vertical accuracy = 0.3 cm < 10 cm

d.UP-COT

Horizontal accuracy = $\surd\,((0.3)^2 + (0.2)^2$
= $\surd(0.90 + 0.40)$
= 1.1 cm < 20 cm
Vertical accuracy = 0.3 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the three (3) occupied control points are within the required precision.

Table 23. Adjusted geodetic coordinates for control points used in the Mananga River Flood Plain validation.

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

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 23. Based on the results of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met. The computed coordinates of the reference and control points utilized in the Mananga River GNSS Static Survey are seen in Table 24.

Table 24. The reference and control points utilized in the Silaga 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)	BM Ortho (m)
CU-714A	1st order, BM	10°17'51.88109"	123°53'31.88503"	102.916	1138468.476	597693.442	39.851
CBU-11	2nd order, GCP	10°25'48.64678"	124°00'11.61859"	69.2	1153149.343	609806.801	6.284
UP-COT	UP Established	10°25'48.60343"	124°00'11.58340"	69.232	1153148.008	609805.735	6.316
UP-MAN	UP Established	10°15'13.34202"	123°49'59.57490"	77.561	1133581.459	591247.957	14.47

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

The bridge cross-section and as-built survey were conducted on December 16, 2015 at the upstream side Mananga bridge (Figure 36) in Brgy. Camp IV, Talisay City, Province of Cebu using GNSS receiver Trimble® SPS 882 in PPK survey technique.

Figure 36. Mananga Bridge facing upstream.

The length of the cross-sectional line surveyed at Mananga Bridge is about 73.89 m with sixty-nine (69) cross-sectional points using the control point. The location map, cross-section diagram, and the accomplished bridge data form are shown in Figure 37 and Figure 39.

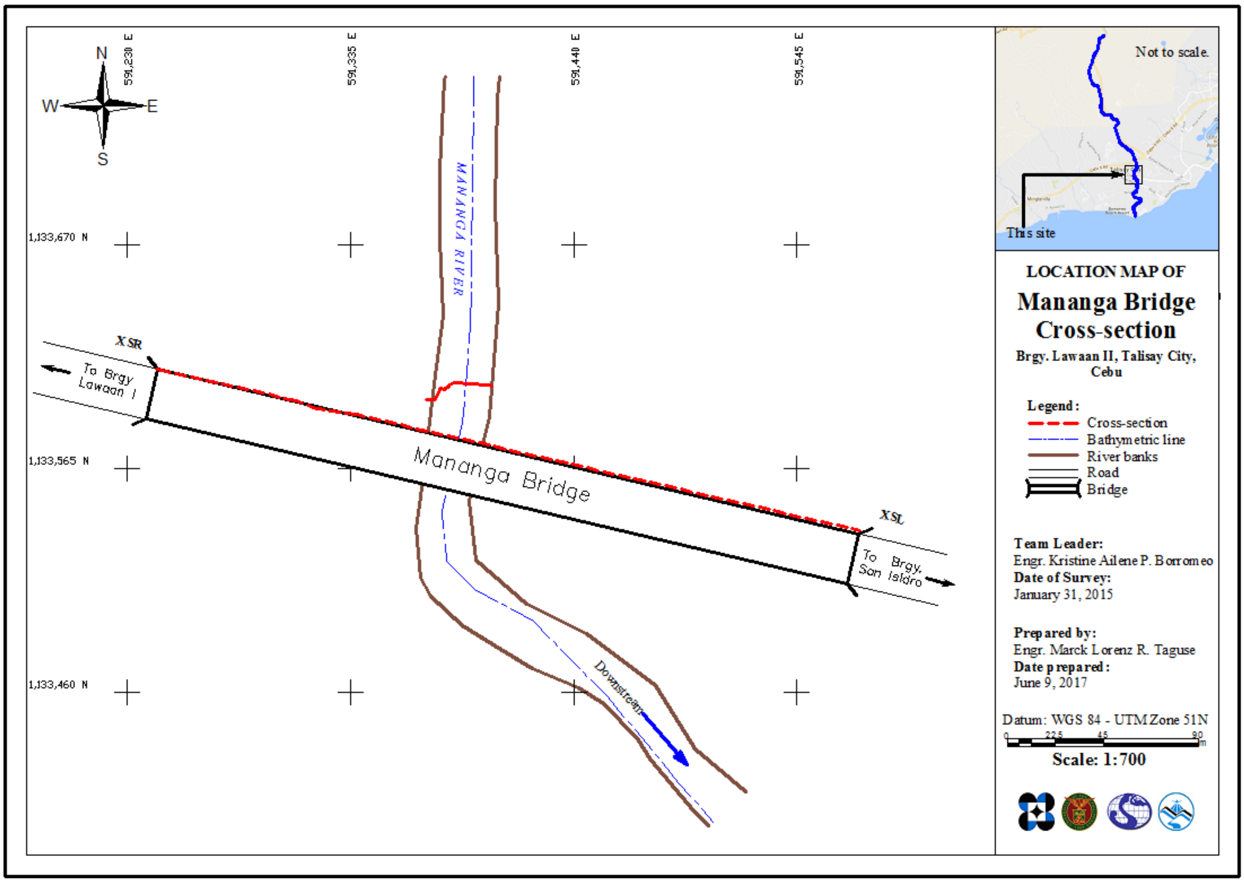


Figure 37. Location map of the San Juan Bridge Cross Section.

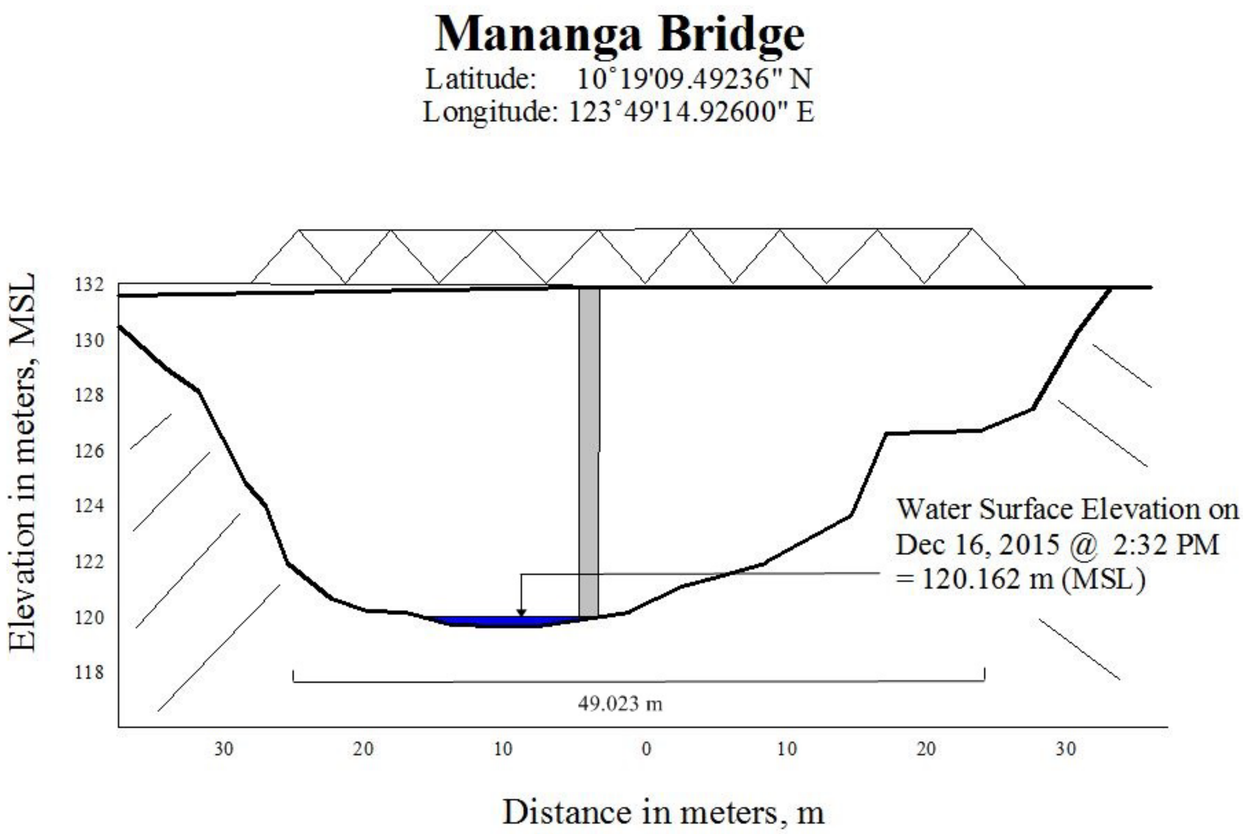
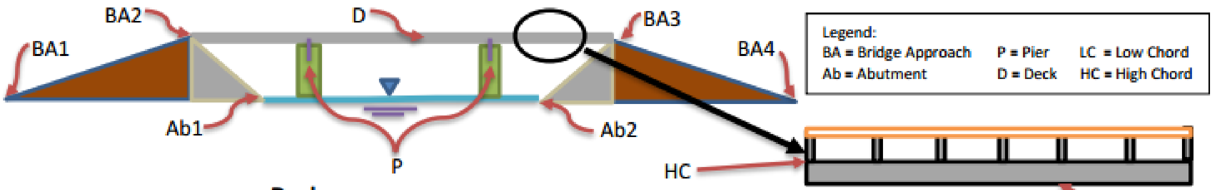


Figure 38. The Mananga Bridge cross-section survey drawn to scale.

Bridge Data Form

Bridge Name: Mananga Bridge	**Date:** December 16, 2015
River Name: Mananga River	**Time:** 2:15 PM
Location (Brgy, City,Region): Brgy. Camp IV, Talisay City, Cebu	
Survey Team: Jeline Amante, Rodel Alberto, Bennet Salvador, Kim Tort	
Flow condition: normal	**Weather Condition:** fair
Latitude: 10°19'09.49236" N	**Longitude:** 123°49'14.92600" E



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

Elevation: 131.852 m **Width:** Not available **Span (BA3-BA2):** 73.898 m

	Station	High Chord Elevation	Low Chord Elevation
1	Not available	Not available	Not available

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

	Station(Distance from BA2)	Elevation		Station(Distance from BA2)	Elevation
BA1	Not available	Not available	BA3	73.898 m	131.851
BA2	0 m	130.402 m	BA4	Not available	Not available

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

	Station (Distance from BA1)	Elevation
Ab1	Not available	Not available

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

Shape: Not available Number of Piers: 1 Height of column footing: Not available

	Station (Distance from BA2)	Elevation	Pier Diameter
Pier	33.549	131.852	Not available

NOTE: Use the center of the pier as reference to its station

Figure 39. The Mananga Bridge as-built survey data.

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on February 1, 2015 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted at the side of a vehicle as shown in Figure 40. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-MAN and UP-COT occupied as the GNSS base stations in the conduct of the survey.

Figure 40. GNSS Receiver Trimble® SPS 882 installed on a vehicle for Ground Validation Survey.

The survey started from Brgy. Estaca, Municipality of Compostela, going west traversing the Municipalities Liloan, Consolacion, Manadue City, Talisay City, and Minglanilla; and ended in Brgy. Hippodromo, Cebu City. The survey gathered a total of 6,730 points with approximate length of 48.46 km using UP-MAN and UP-COT as GNSS base stations for the entire extent validation points acquisition survey as illustrated in the map in Figure 41.

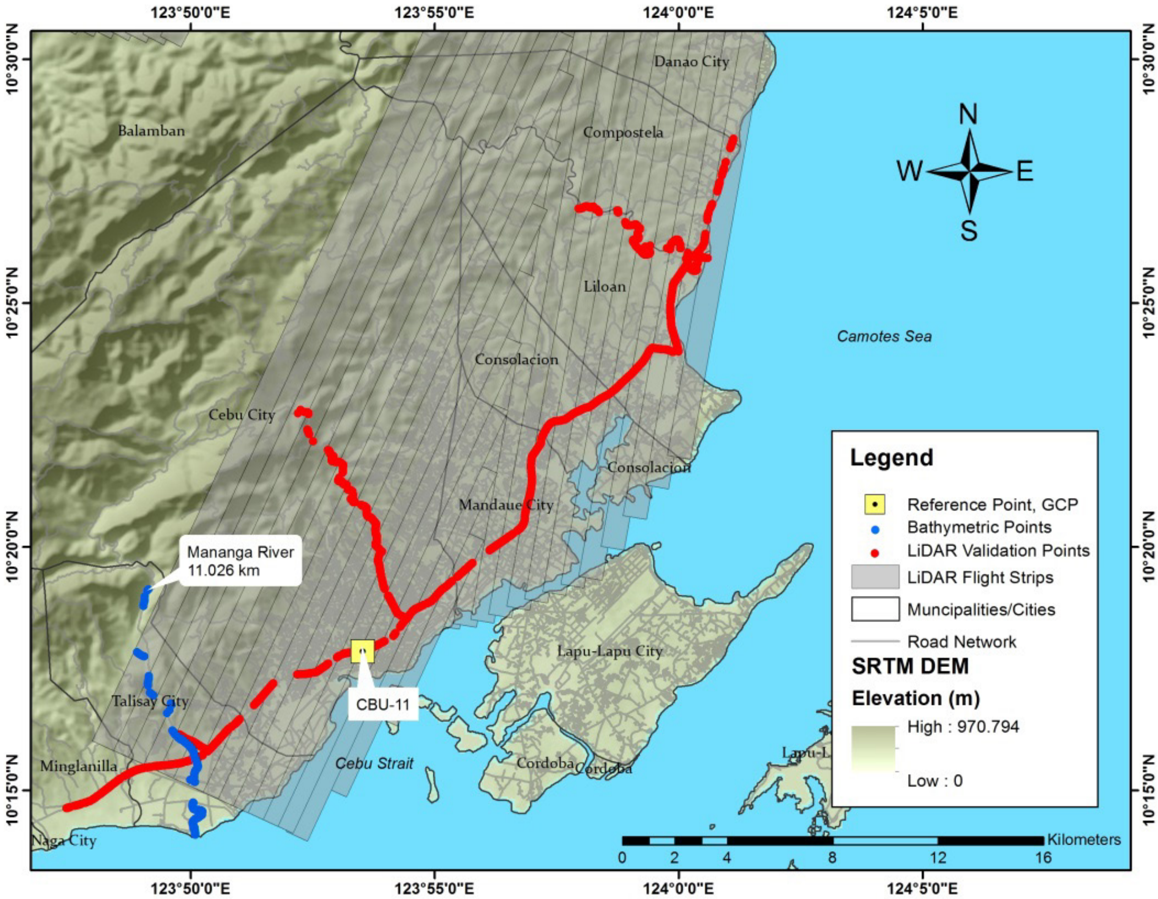


Figure 41. The extent of the LiDAR ground validation survey (in red) for Mananga River Basin.

4.7 River Bathymetric Survey

A bathymetric survey was performed on February 4, 2015 using a Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode and Ohmex™ single beam echo sounder, as illustrated in Figure 42. The extent of the survey started in Brgy. Dumlog, Talisay City, Cebu with coordinates 10°14'35.41063"N, 123°50'13.03585"E, and ended at the mouth of the river in Brgy. Biasong, also in Talisay City, with coordinates 10°14'05.67101"N, 123°50'05.77997"E, as shown in the map in Figure 44.

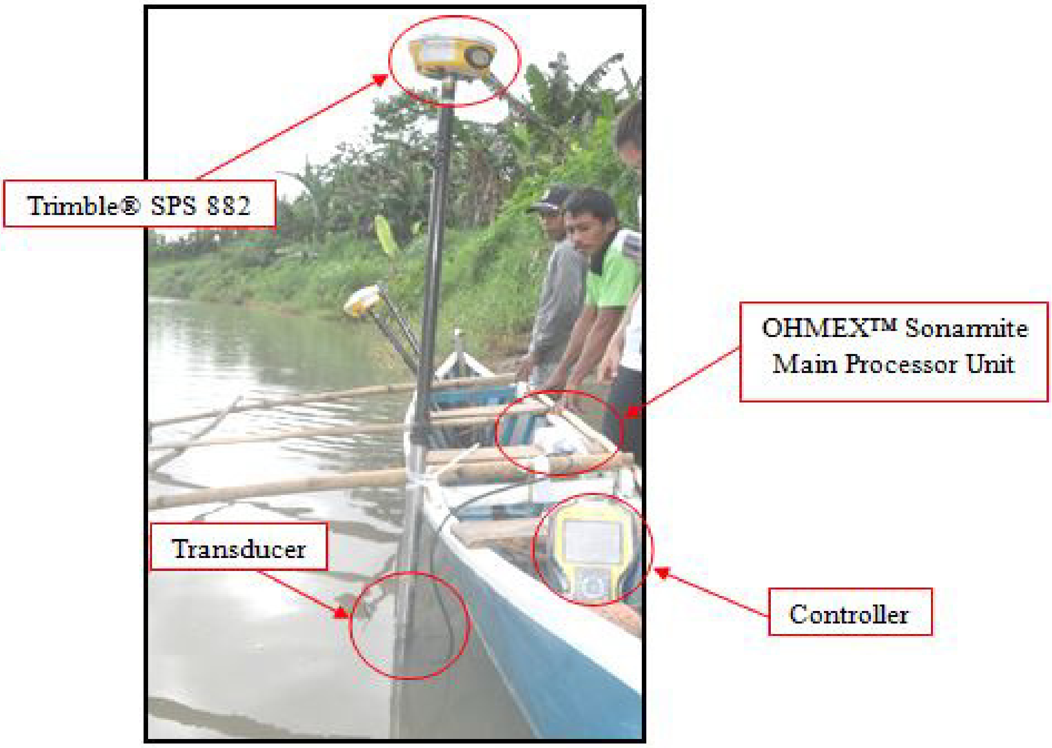


Figure 42. Set up of the bathymetric survey at Mananga River using Ohmex™ single beam echo sounder.

Manual bathymetric survey was done in two tributaries on February 2, 2015 using a Trimble® SPS 882 GNSS PPK survey technique in continuous topo mode as shown in Figure 43. The survey started in Brgy. Camp IV, Talisay City with coordinates 10°19'07.63097"N, 123°49'08.14545"E, traversing down the river and ended at the starting point of bathymetric survey using boat in Brgy. Dumlog, Talisay City. The control point UP-MAN was occupied as the GNSS base station all throughout the surveys.

Figure 43. Set-up for the manual bathymetric survey.

Overall, the bathymetric survey for Mananga River gathered a total of 1,519 points covering 11.026 km of the river traversing Barangays Camp IV, Jaclupan, Maghaway, Lawaan III, Lawaan II, Lawaan I, Pooc, Dumlog, and Biasong, in Talisay City. A CAD drawing was also produced to illustrate the riverbed profile of Mananga River. As shown in Figure 45 and, the highest and lowest elevation has a 50.674-m difference. The highest elevation observed was 53.378 m above MSL located in Brgy. Camp IV, Talisay City; while the lowest was -2.704 m below MSL located in Brgy. Biasong, also in Talisay City

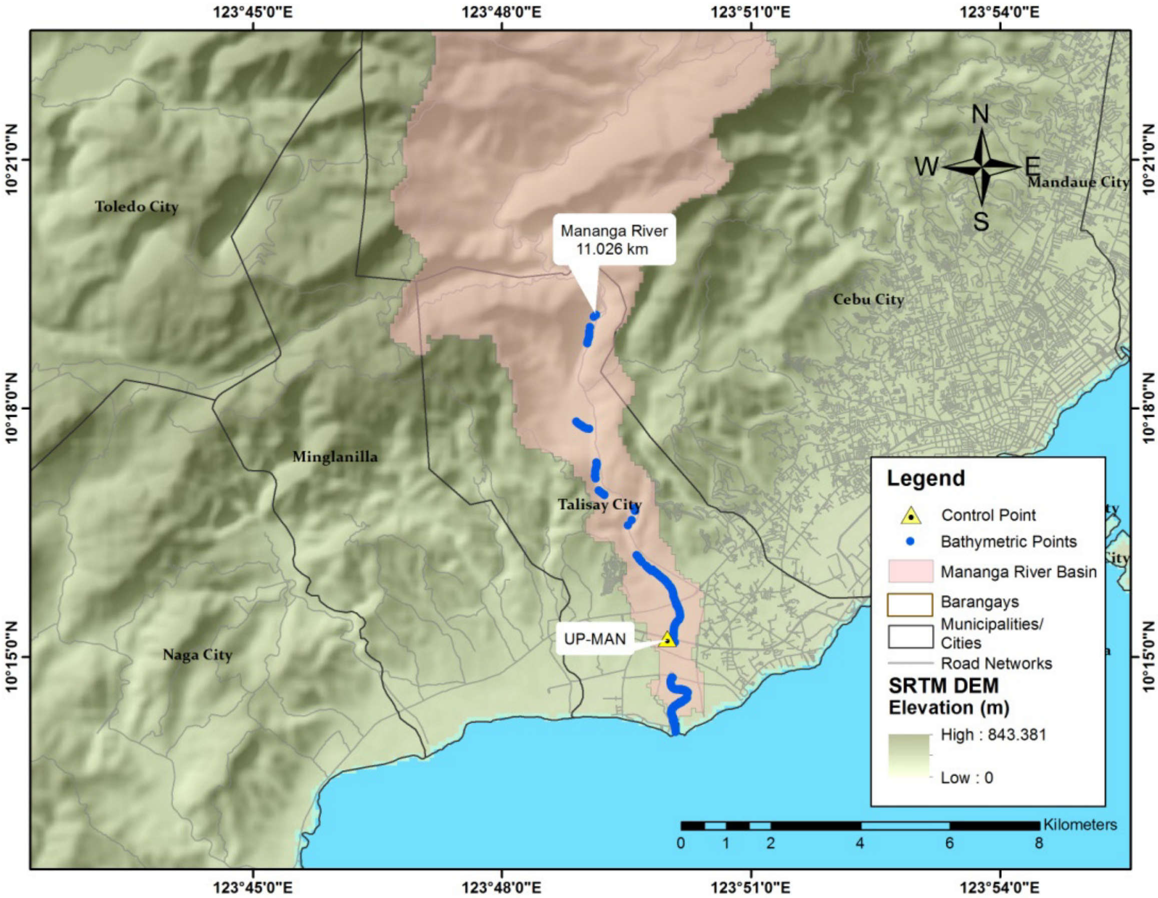


Figure 44. The extent of the Mananga River Bathymetry Survey.

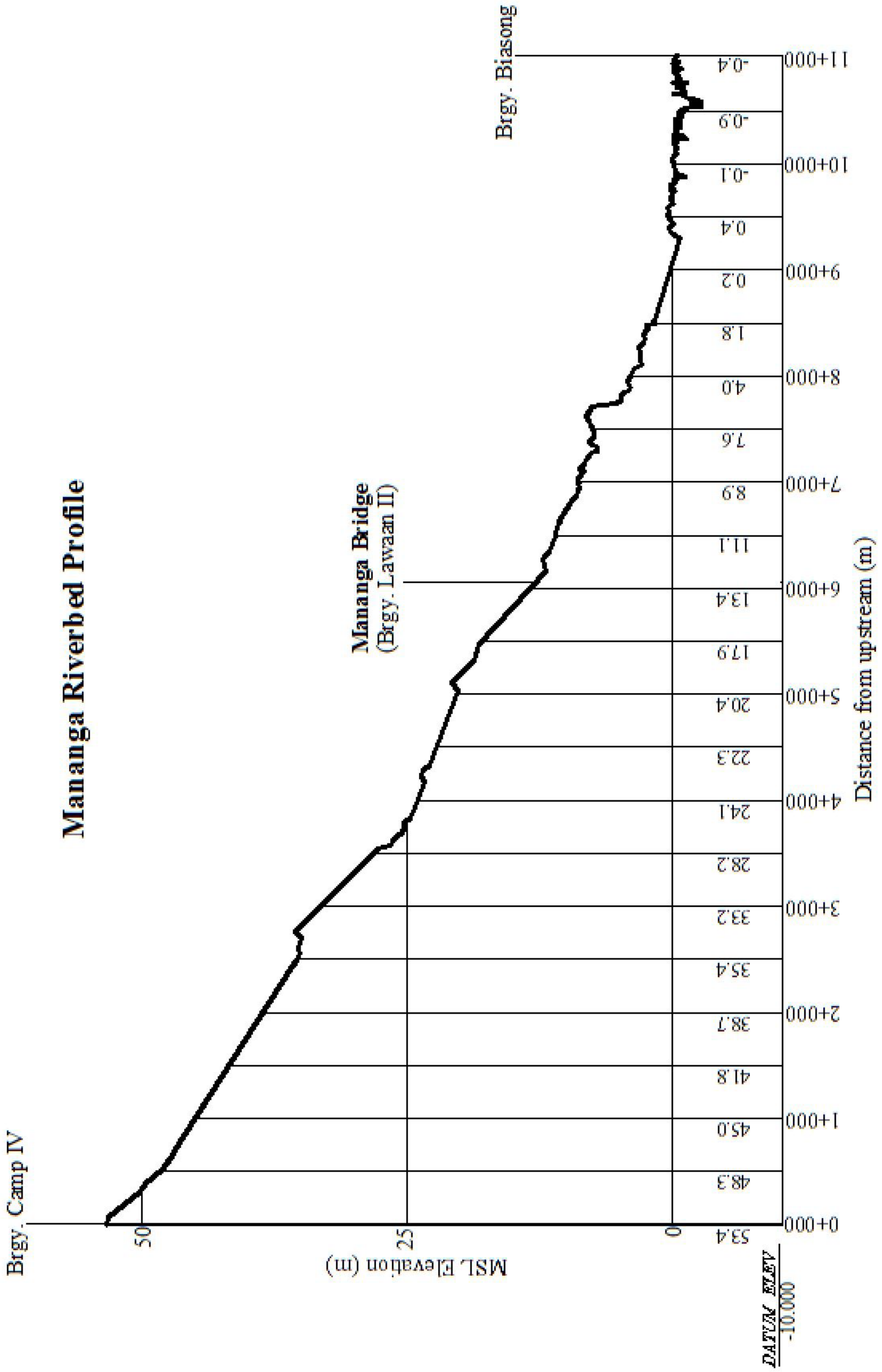


Figure 45. The Mananga Riverbed Profile from first Cabcaborao upstream.

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, 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 components and data that affect the hydrologic cycle of the Ibod 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 Ibod River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an installed rain gauge by the University of San Carlos Phil LiDAR 1 team. The station was installed in Brgy. Manipis. The location of this station in the watershed is presented in Figure 46.

The total precipitation for this event in San Juan ARG was 16.5 mm. It has a peak rainfall of 5.5 mm. on March 15, 2017 at 07:15 PM.

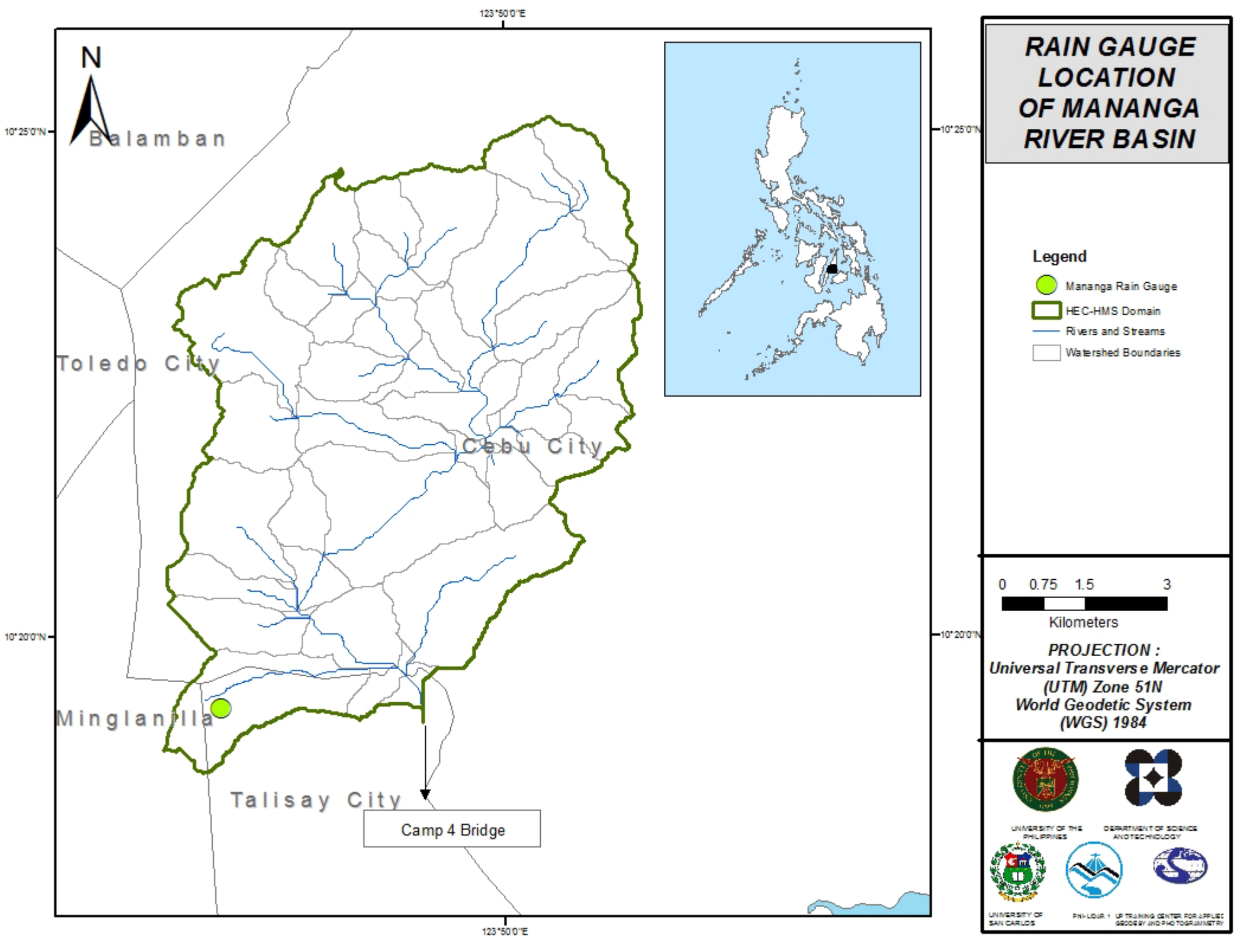


Figure 46. Location Map of the Mananga HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Camp 4 Bridge (123°49'15.6"N and 10°19'9.48"E). It gives the relationship between the observed water levels and outflow of the watershed at this location.

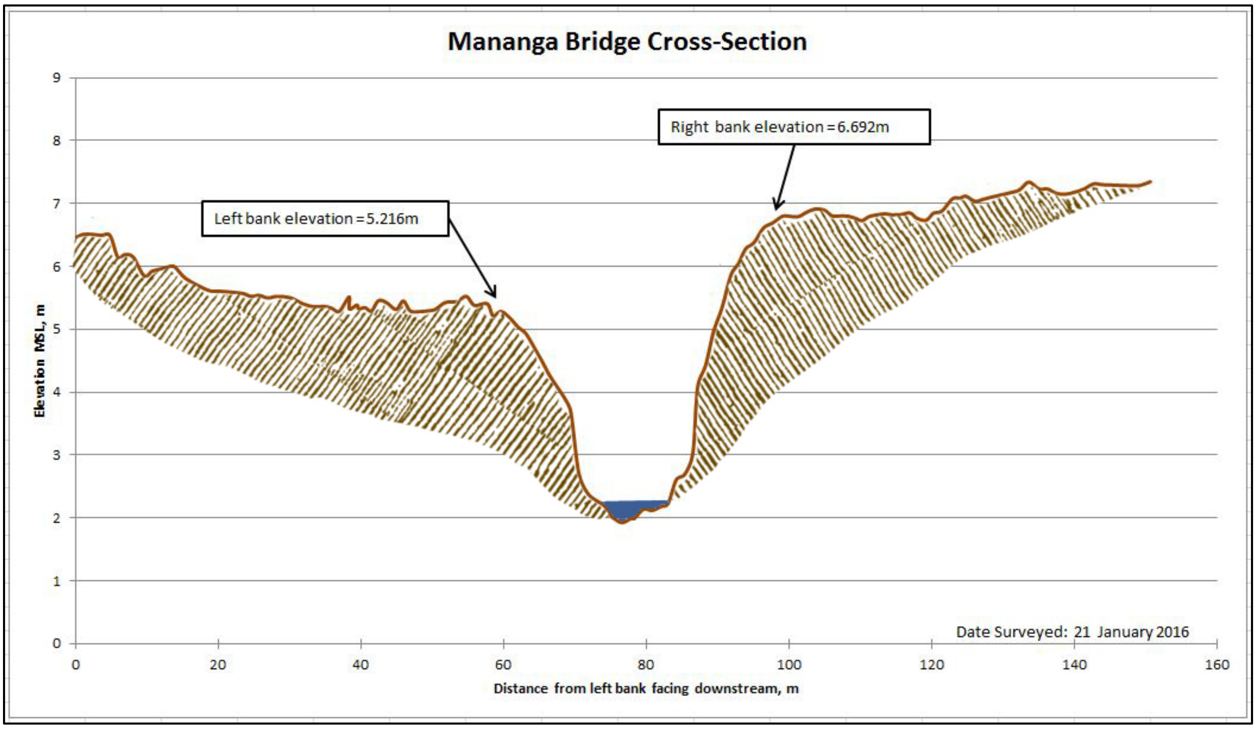


Figure 47. Cross-section plot of Mananga Bridge

For Mananga Bridge, the rating curve is expressed as Q = 4E-23e4.4666h as shown in Figure 48.

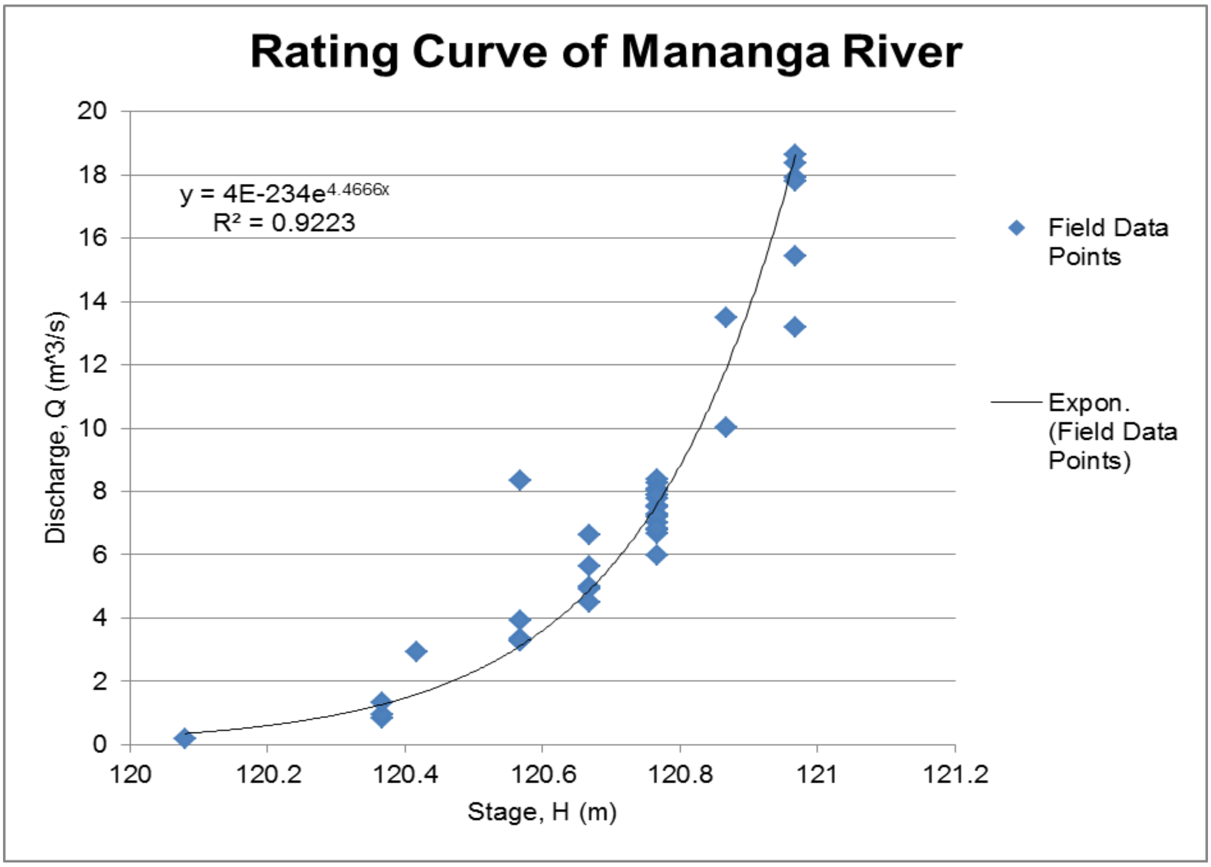


Figure 48. The rating curve at Camp 4 Bridge, Talisay City.

This rating curve equation was used to compute the river outflow at Mananga Bridge for the calibration of the HEC-HMS model shown in Figure 49. The total rainfall for this event is 34.29 mm and the peak discharge is 17.71 m3/s at 7:415 PM of March 15, 2017.

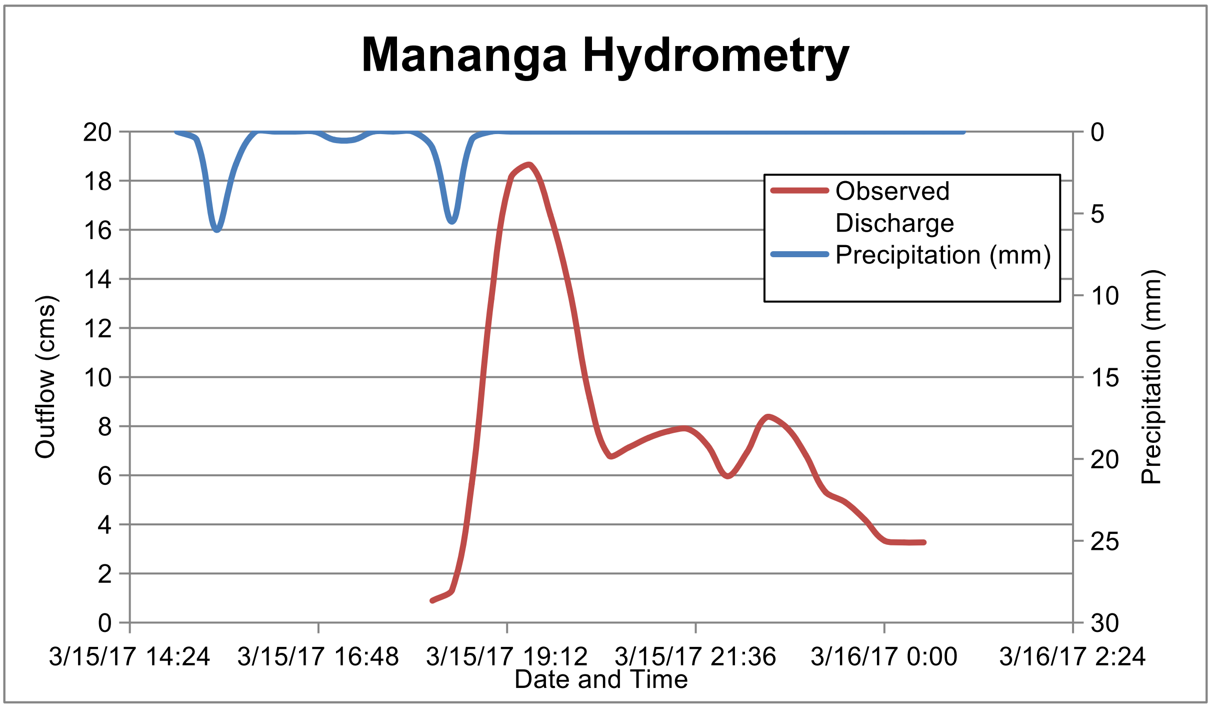


Figure 49. Rainfall and outflow data at Camp 4 Bridge, which was used for modeling.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Mactan Rain Gauge (Table 25). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values in such a way that certain peak values will be attained at a certain time (Figure 48). This station was selected based on its proximity to the Mananga watershed. The extreme values for this watershed were computed based on a 37-year record.

Table 25. RIDF values for the Laoag Rain Gauge, as 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

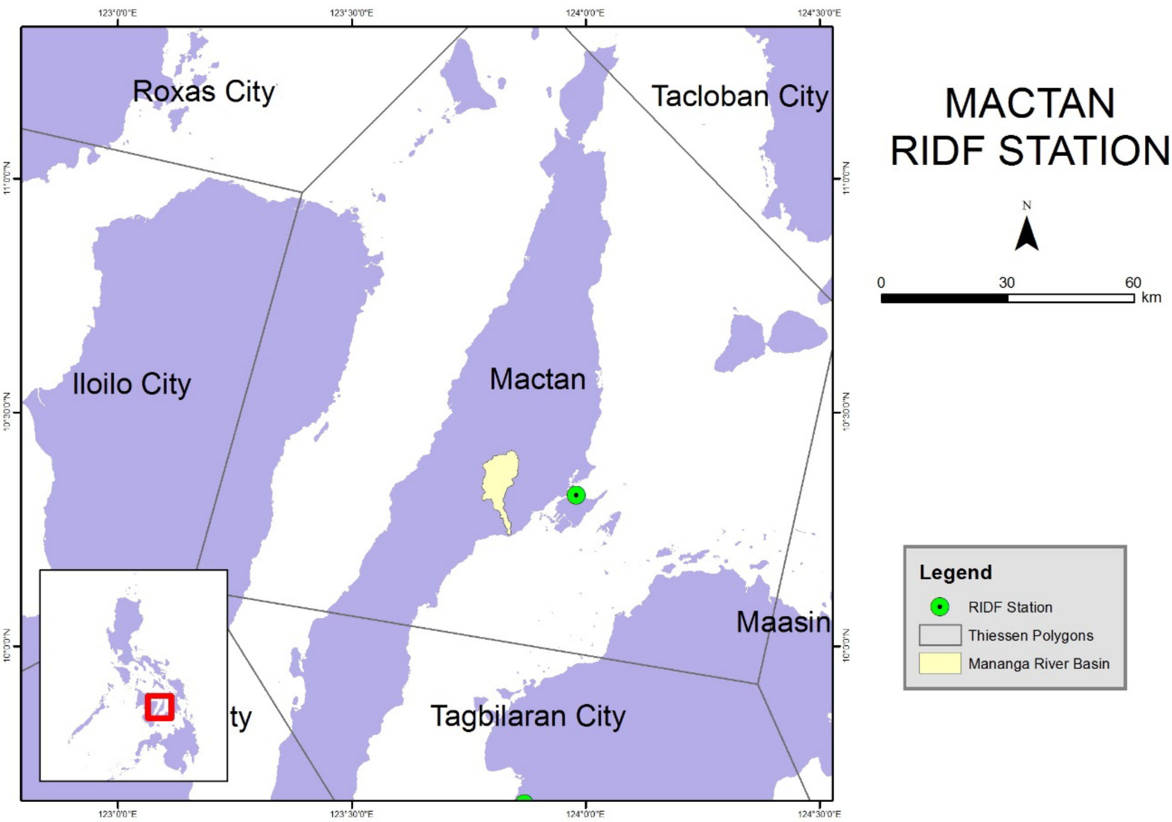


Figure 50. Location of Mactan RIDF Station relative to Mananga River Basin.

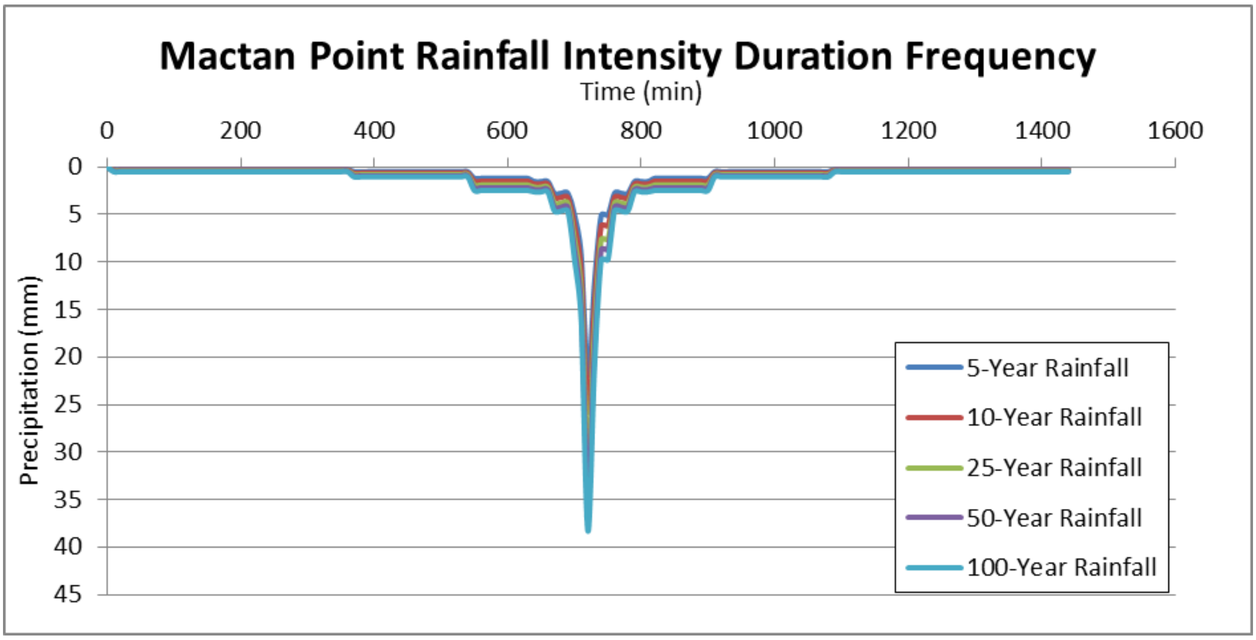


Figure 51. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 from the Bureau of Soils under the Department of Environment and Natural Resources Management. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Mananga River Basin are shown in Figure 52 and Figure 53, respectively.

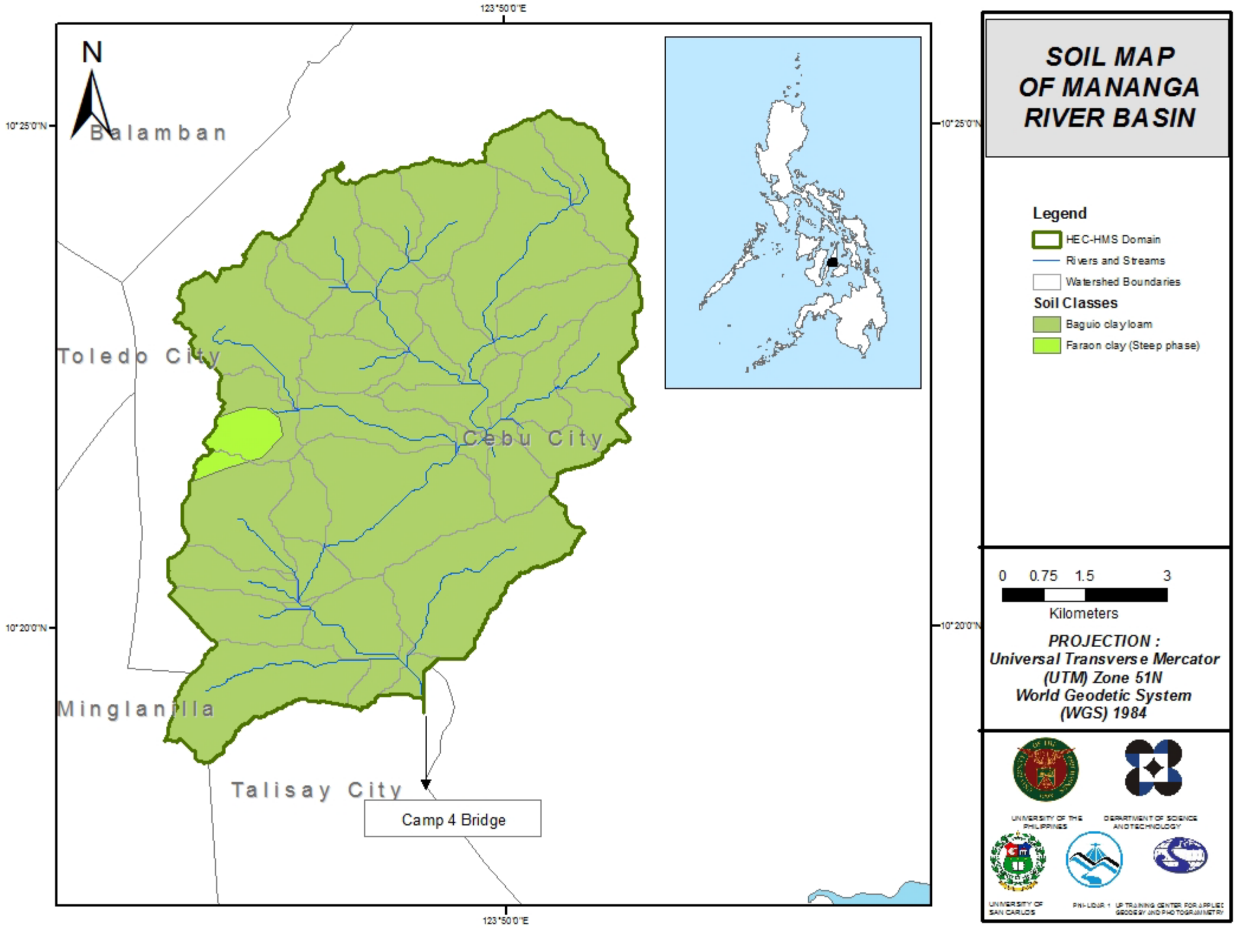


Figure 52. Soil Map of Mananga River Basin

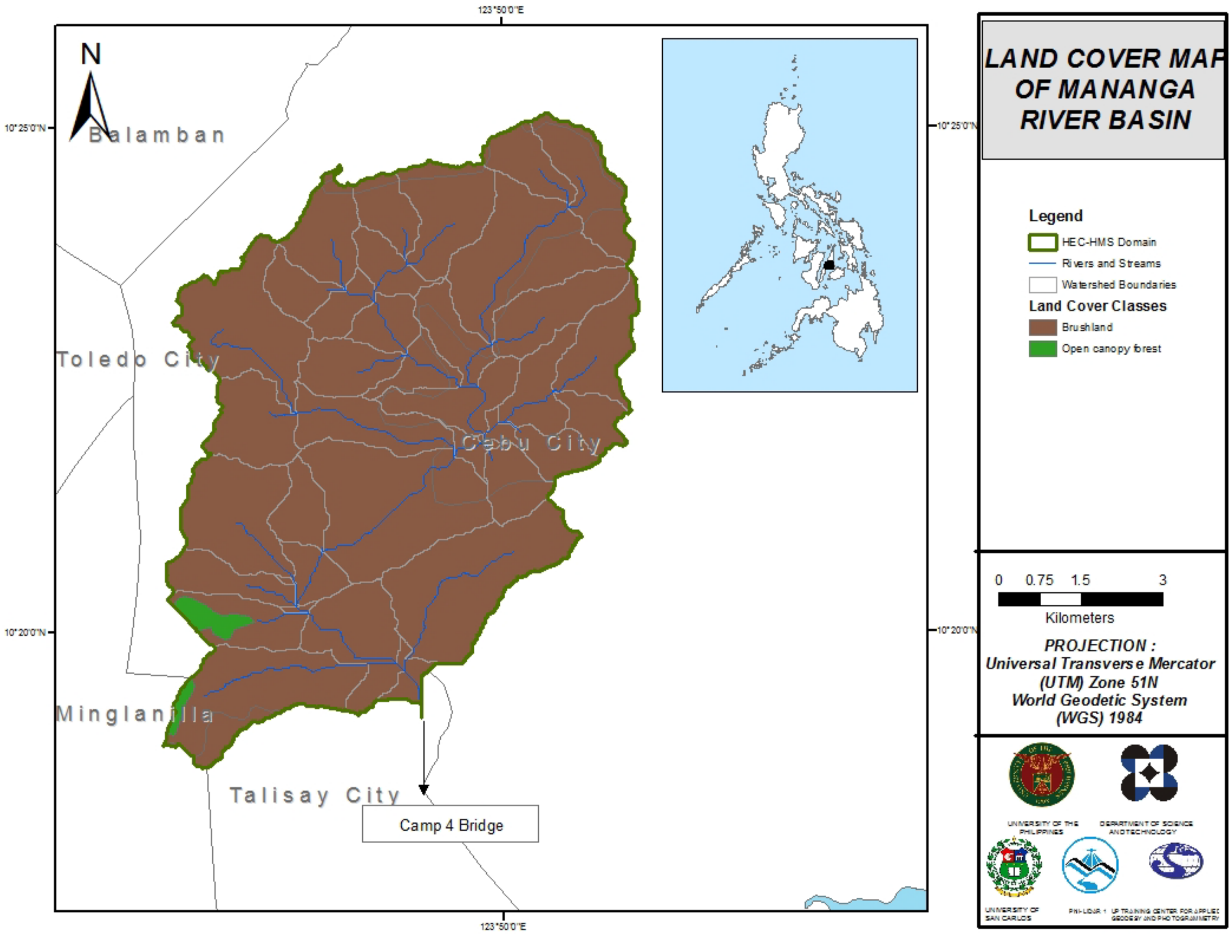


Figure 53. Land Cover Map of Mananga River Basin

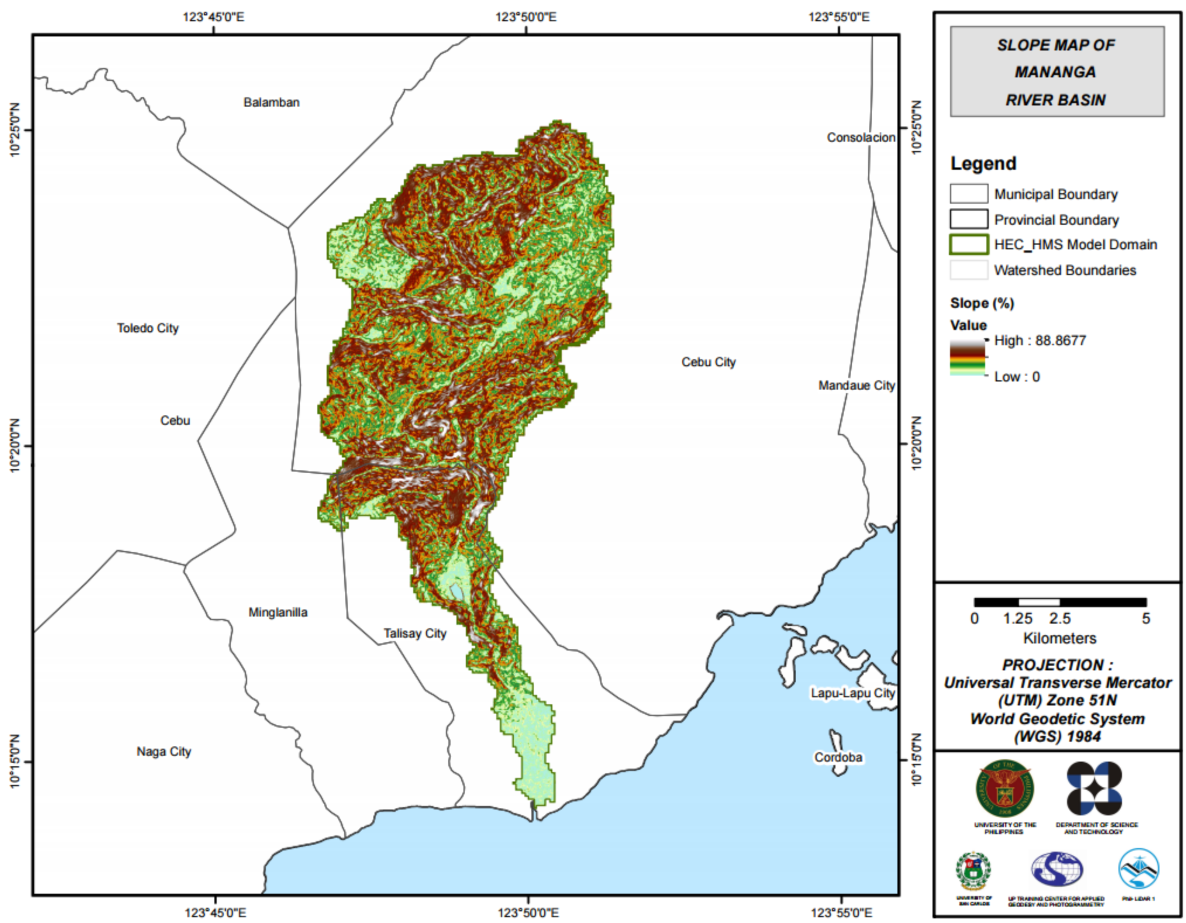


Figure 54. Slope Map of Mananga River Basin

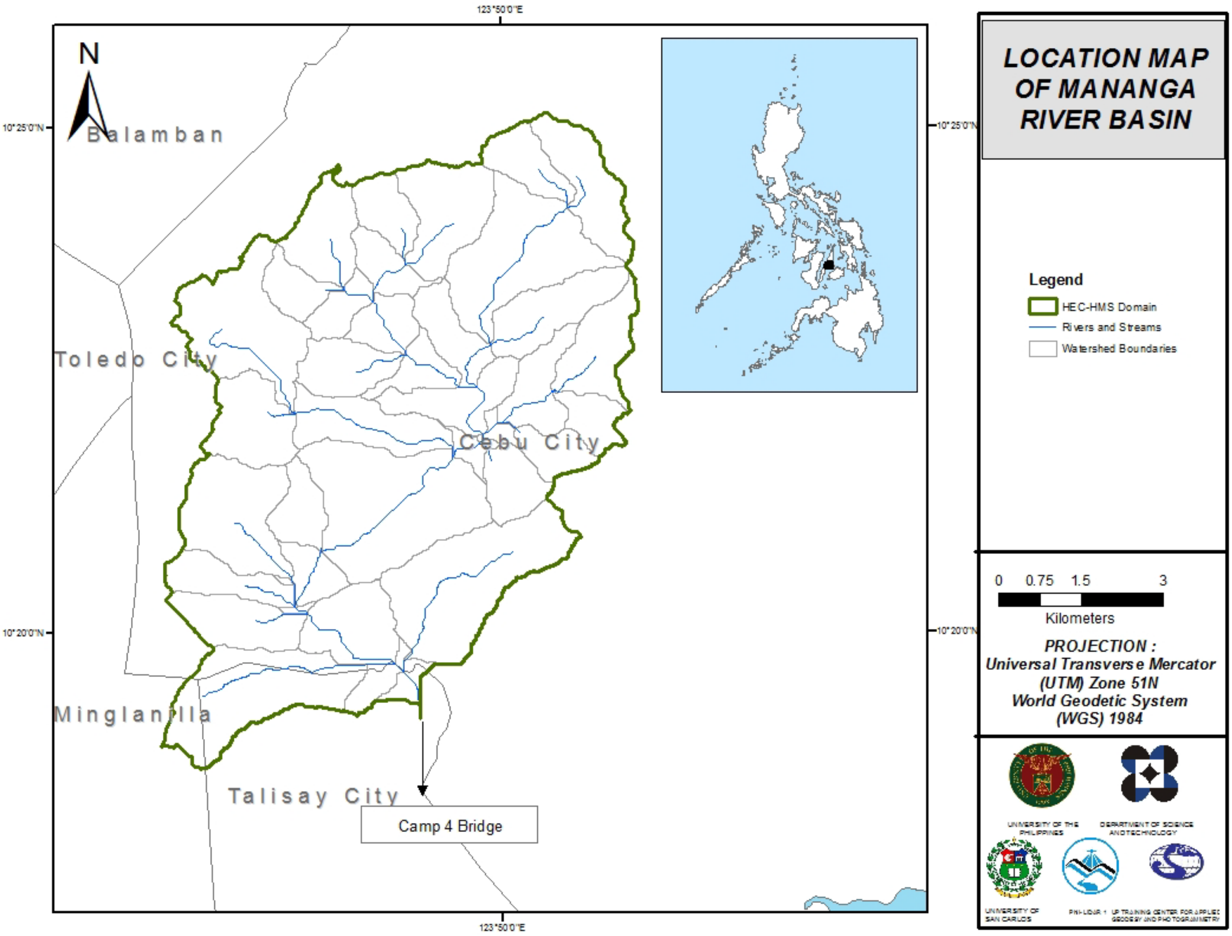


Figure 55. Stream Delineation Map of Mananga River Basin

Using the SAR-based DEM, the Mananga basin was delineated and further subdivided into subbasins. The model consists of 39 sub basins, 19 reaches, and 19 junctions as shown in Figure 56 (See Annex 10).

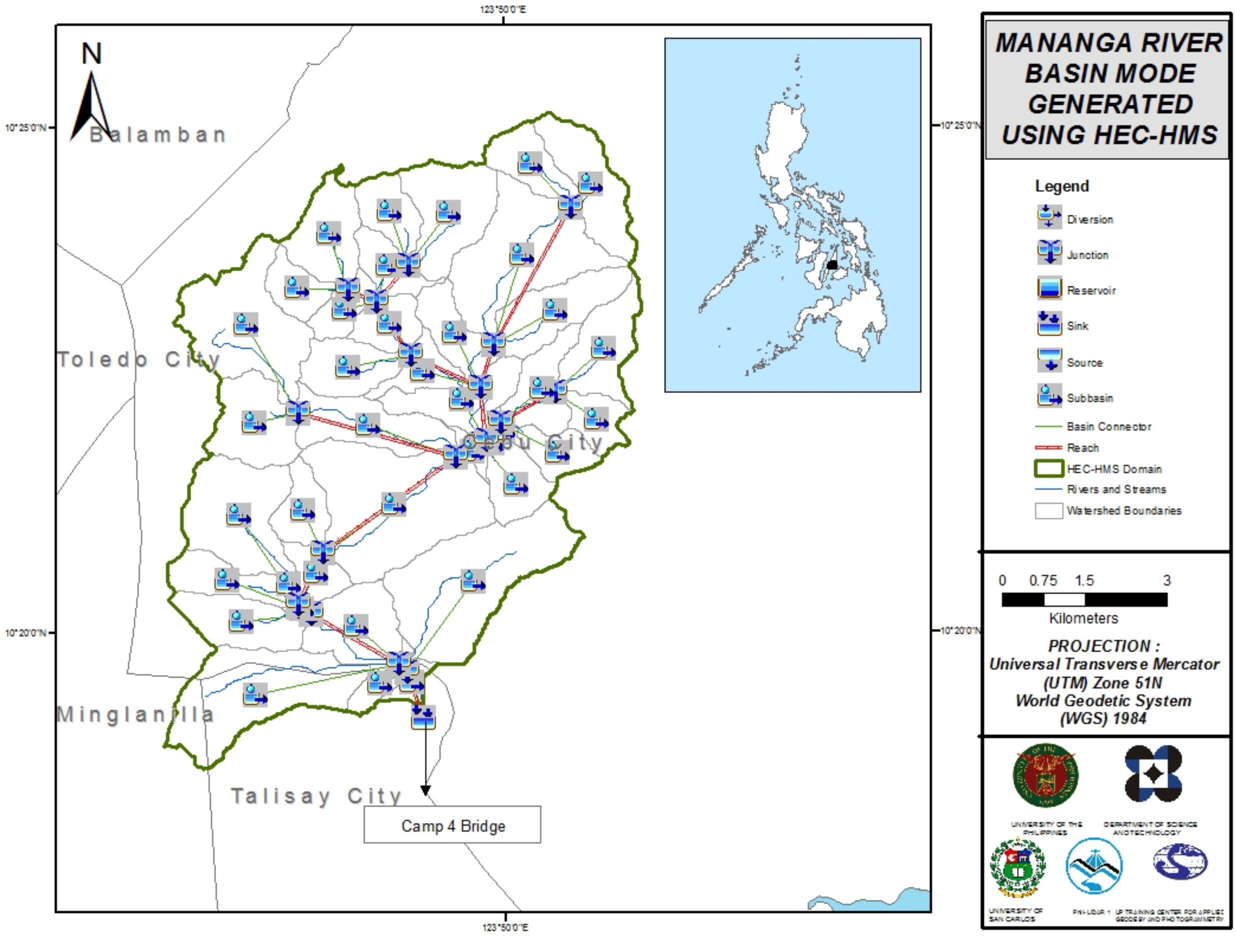


Figure 56. Mananga river basin model generated in HEC-HMS.

5.4 Cross-section Data

The riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data, which was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 57).

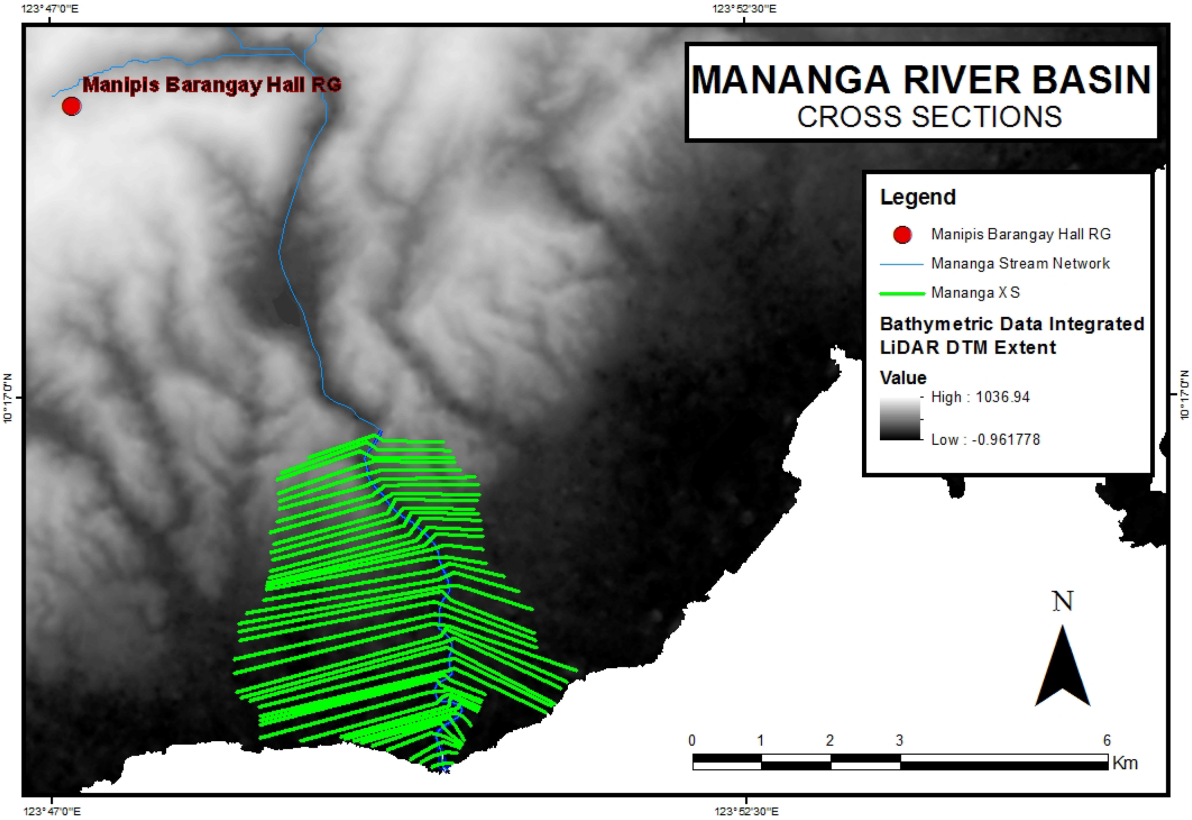


Figure 57. River cross-section of the Mananga River through the ArcMap HEC GeoRas tool.

5.5 Flo 2D Model

After running the flood map simulation in FLO-2D GDS Pro, FLO-2D Mapper Pro was used to read the resulting hazard and flow depth maps. The standard input values for reading the simulation results are shown on Figure 58.

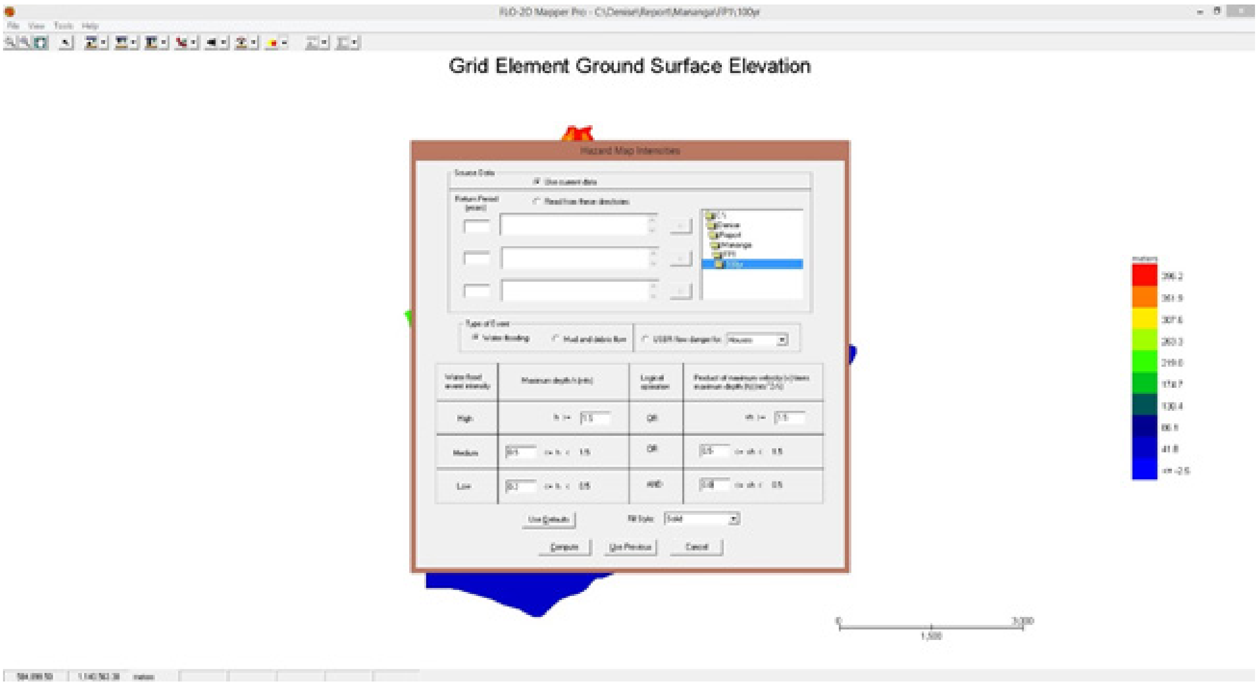


Figure 58. FLO-2D Mapper Pro General Procedure

In order to produce the hazard maps, set input for low maximum depth as 0.2 m, and vh, product of maximum velocity and maximum depth (m^2/s), as greater than or equal to zero. The program will then compute for the flood inundation and will generate shapefiles for the hazard and flow depth scenario.

The final procedure in creating the maps is to prepare them with the aid of ArcMap. The generated shapefiles from FLO-2D Mapper Pro were processed and in ArcMap.

5.6 Results of HMS Calibration

After calibrating the Mananga HEC-HMS river basin model (See Annex 9), its accuracy was measured against the observed values.

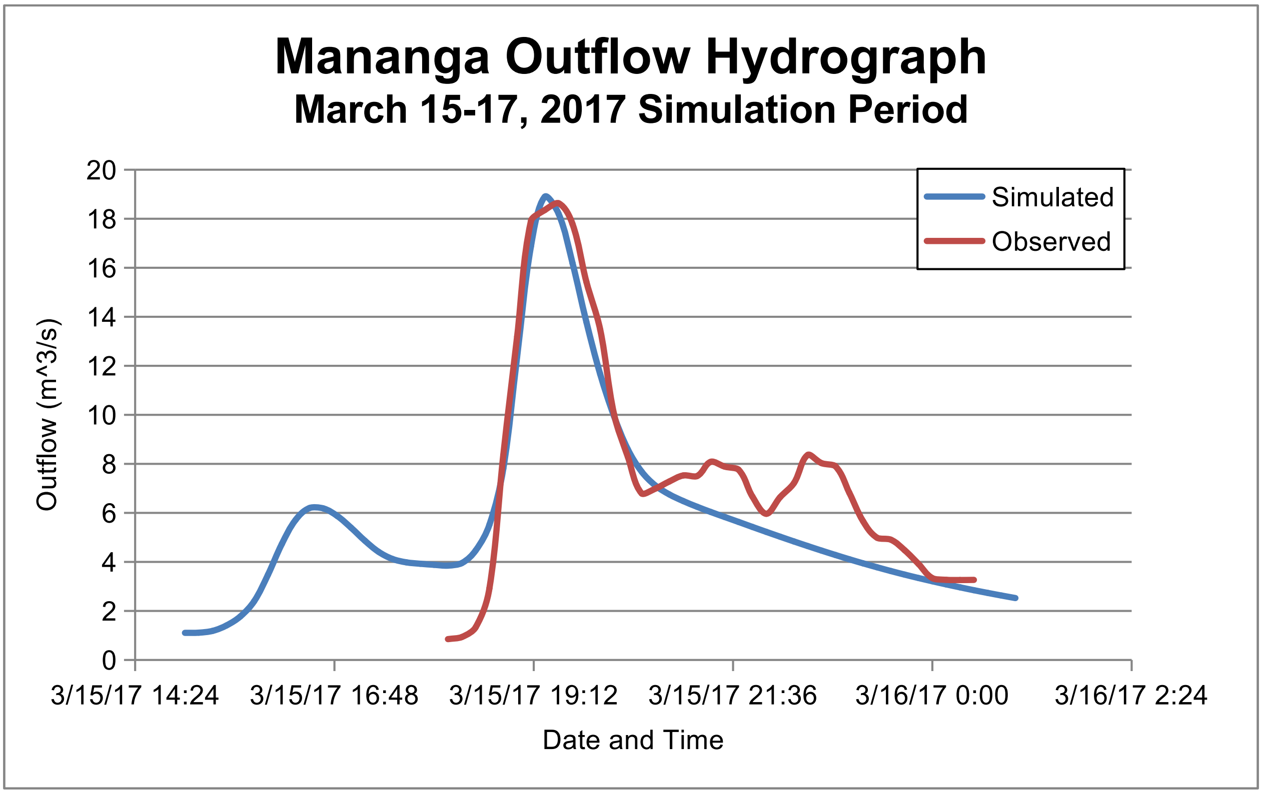


Figure 59. Outflow Hydrograph of Mananga produced by the HEC-HMS model compared with observed outflow.

Table 26 shows the adjusted ranges of values of the parameters used in calibrating the model.

Table 26. Range of calibrated values for the Mananga River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.3 - 7
			Curve Number	35 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.03 - 1
			Storage Coefficient (hr)	0.4 - 19
	Baseflow	Recession	Recession Constant	0.7 - 1
			Ratio to Peak	0.1
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0002 – 0.017

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.3mm to 7mm means that there is minimal to average amount of infiltration of rainfall intercepted by vegetation.

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 Mananga, the basin consists mainly of brushlands and the soil consists of mostly undifferentiated land and clay.

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 0.03 hours to 1 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 and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant values within the range of 0.7 - 1 indicate that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.1 indicates a much steeper receding limb of the outflow hydrograph.

Manning's roughness coefficients correspond to the common roughness of Philippine watersheds. Mananga river basin reaches' Manning's coefficients that range from 0.0002 to 0.017 showing that there is variety in surface roughness all over the catchment (Brunner, 2010).

Table 27. Summary of the Efficiency Test of the Mananga HMS Model

Accuracy measure	Value
RMSE	1.8083
r2	0.9368
NSE	0.8509
PBIAS	9.8716
RSR	0.3862

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 1.8083.
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 0.9368.

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 0.8509.

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 9.8716.

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 0.3862..

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 (Figure 60) shows the Mananga outflow using the Laoag Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results show increasing outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

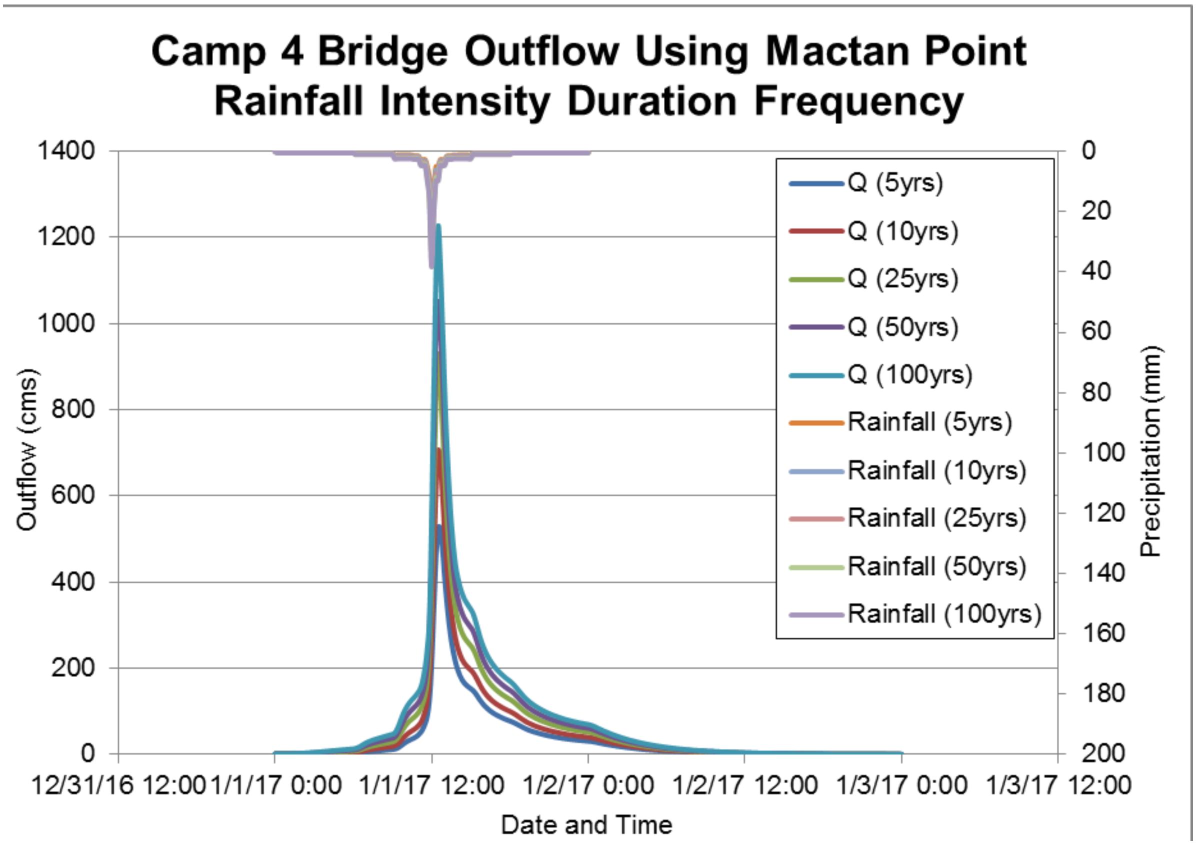


Figure 60. The Outflow hydrograph at the Mananga Station, generated using the Mactan RIDF simulated in HEC-HMS.

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Mananga discharge using the Laoag Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 28.

Table 28. The peak values of the Mananga HEC-HMS Model outflow using the Maasin RIDF.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	139.1	21.900	528.197	30 minutes
10-Year	169.7	25.800	705.740	30 minutes
25-Year	208.5	30.900	929.521	30 minutes
50-Year	237.2	34.600	1,051.181	30 minutes
100-Year	265.7	38.300	1,227.257	30 minutes

5.7.2. Discharge data using Dr. Horritts's recommended hydrologic method

The river discharges for the three rivers entering the floodplain are shown in Figures 61 to 62, and the peak values are summarized in Tables 32 to 36.

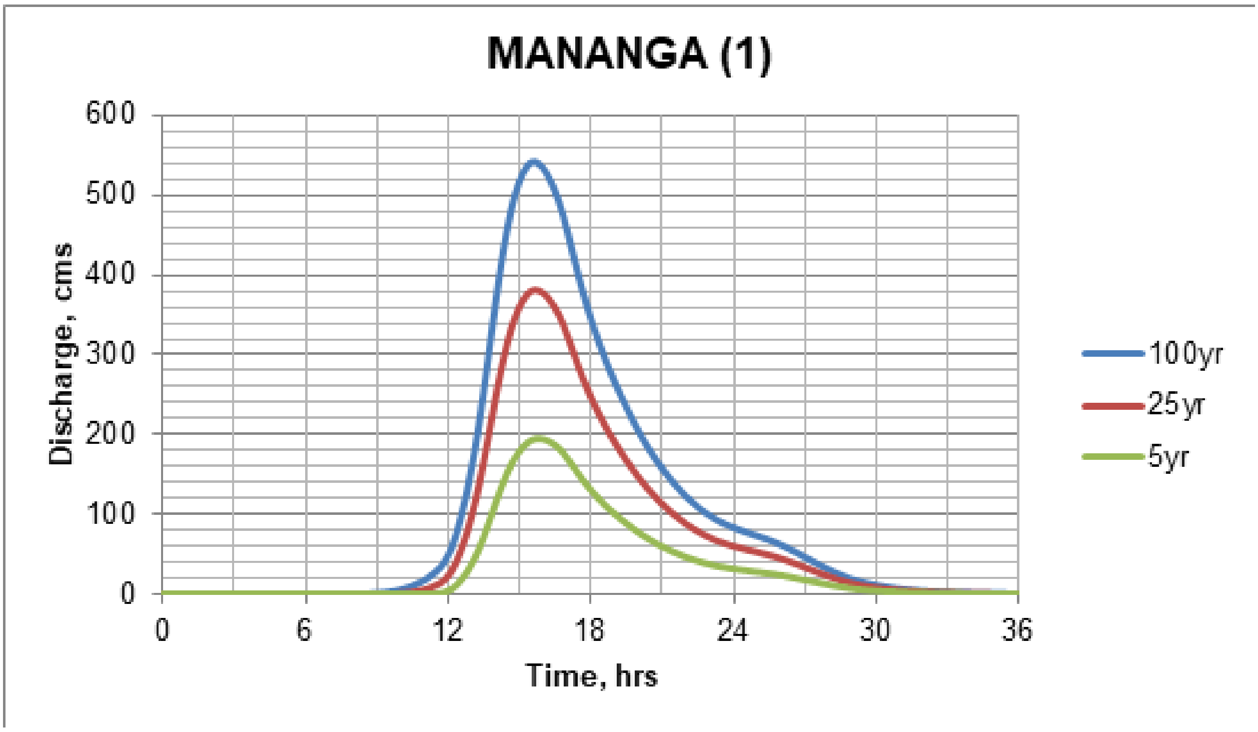


Figure 61. Mananga river (1) generated discharge using 5-, 25-, and 100-year Mactan rainfall intensity-duration-frequency (RIDF) in HEC-HMS.

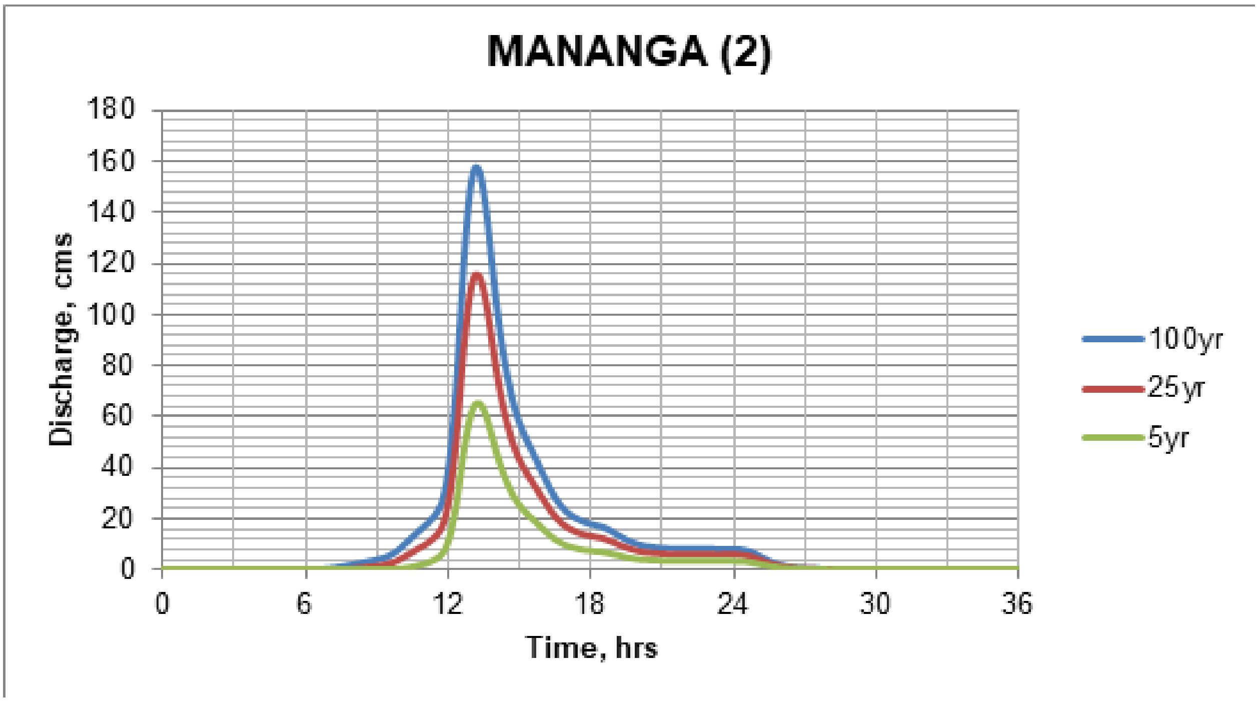


Figure 62. Mananga river (2) generated discharge using 5-, 25-, and 100-year Mactan rainfall intensity-duration-frequency (RIDF) in HEC-HMS.

Table 29. Summary of Mananga river (1) discharge generated in HEC-HMS.

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	541.6	15 hours, 40 minutes
25-Year	380.3	15 hours, 40 minutes
5-Year	195.2	15 hours, 50 minutes

Table 30. Summary of Mananga river (2) discharge generated in HEC-HMS.

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	157.7	13 hours, 10 minutes
25-Year	115.6	13 hours, 10 minutes
5-Year	65.1	13 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 31.

Table 31. Validation of river discharge estimates.

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Mananga (1)	171.776	321.240	212.517	Pass	Pass
Mananga (2)	57.288	85.860	48.802	Pass	Pass

The two 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. For this publication, only a sample output map river was to be shown. Figure 63 shows a generated sample map of the Mananga River using the calibrated HMS base flow.

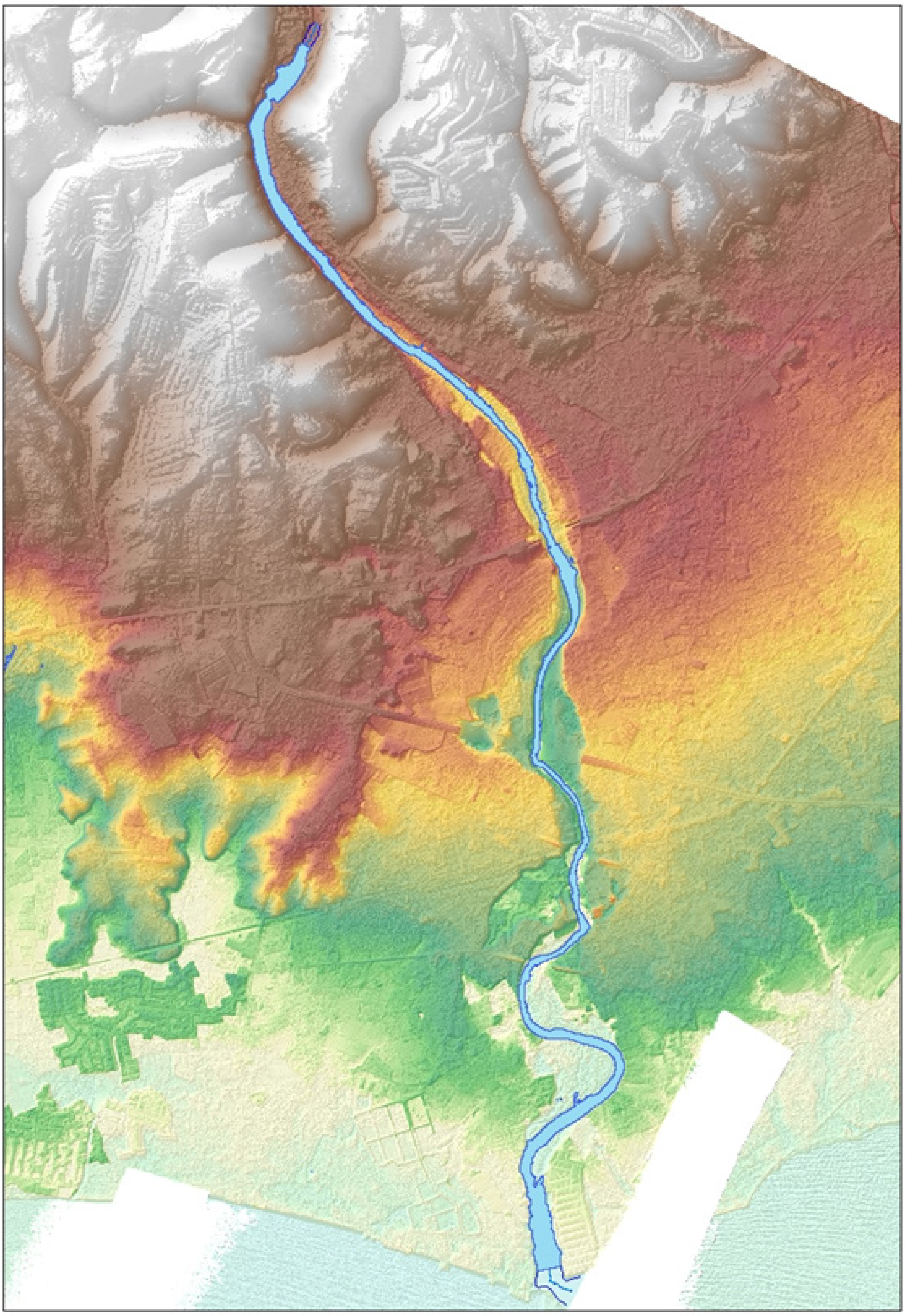


Figure 63. Sample output map of Mananga RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 64 to Figure 69 show the 5-, 25-, and 100-year rain return scenarios of the Mananga floodplain. The floodplain covers two (2) municipalities from one (1) province. Table 32 shows the percentage of area affected by flooding per municipality.

Table 32. Municipalities affected in Mananga Floodplain.

Province	Municipality	Total Area (sq.km.)	Area Flooded (sq. km.)	% Flooded
Cebu	Minglanilla	51.1		
Cebu	Talisay	42.09		

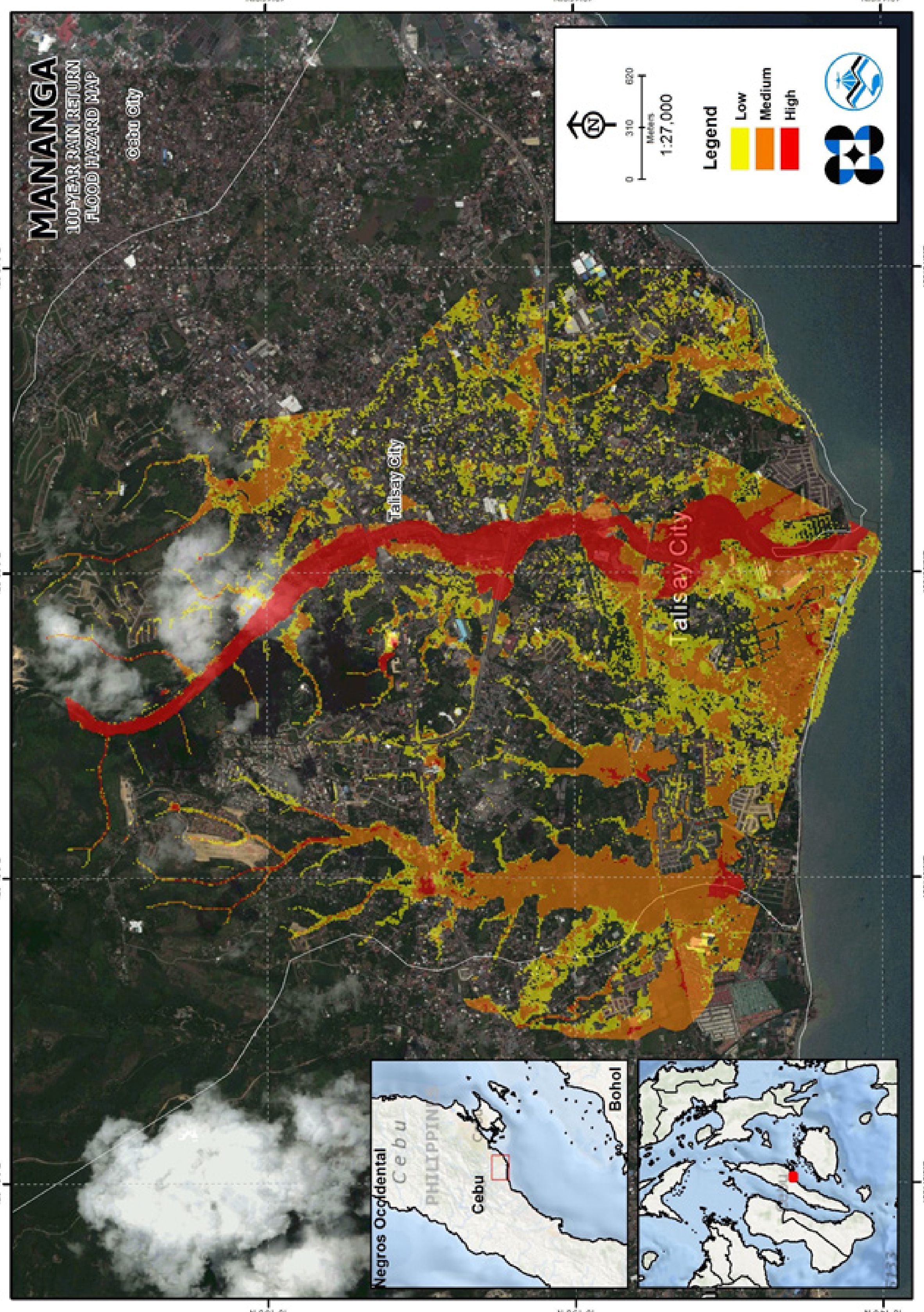


Figure 64. A 100-year Flood Hazard Map for Mananga Floodplain overlaid on Google Earth imagery.

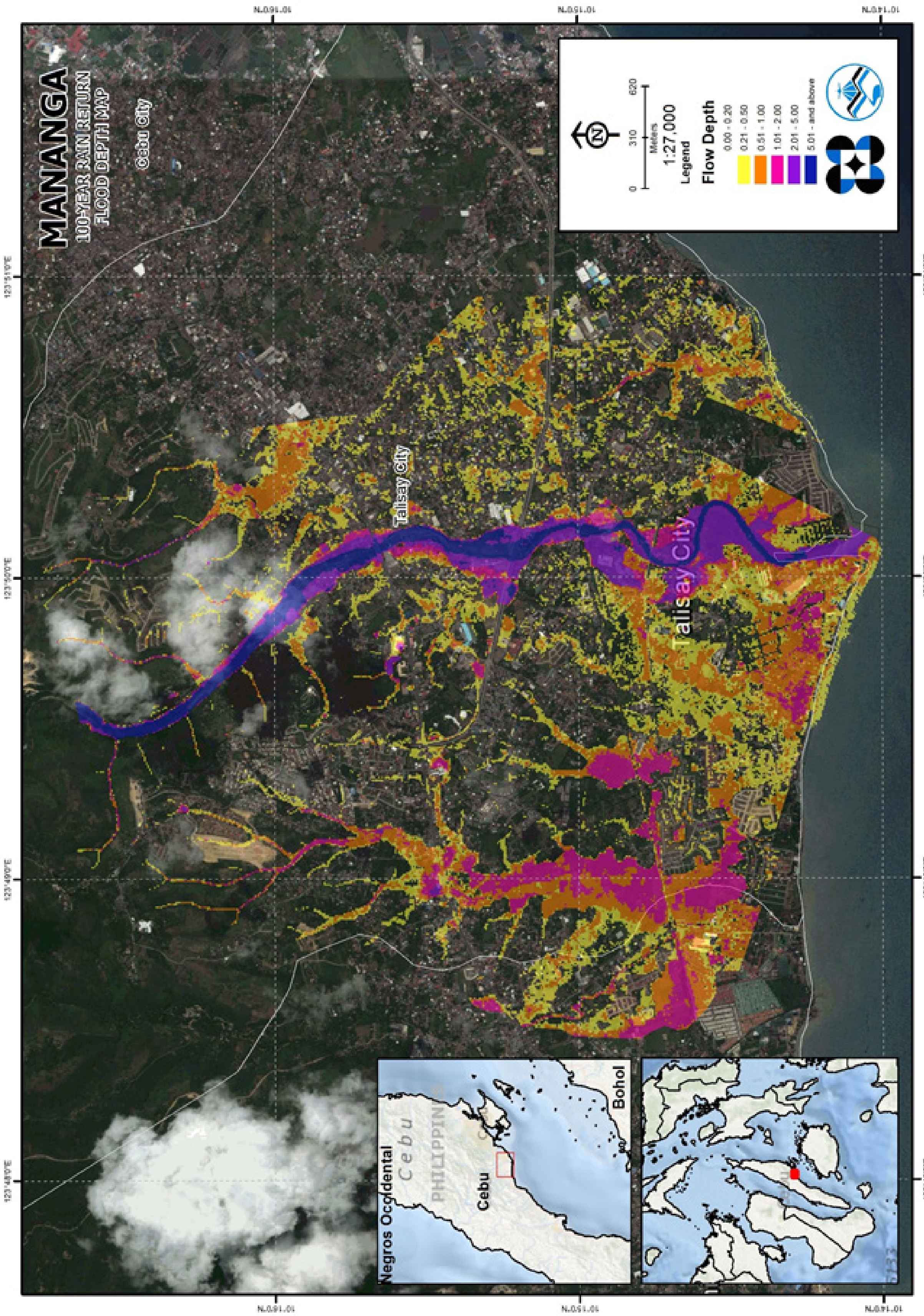


Figure 65. A 100-year Flow Depth Map for Mananga Floodplain overlaid on Google Earth imagery.

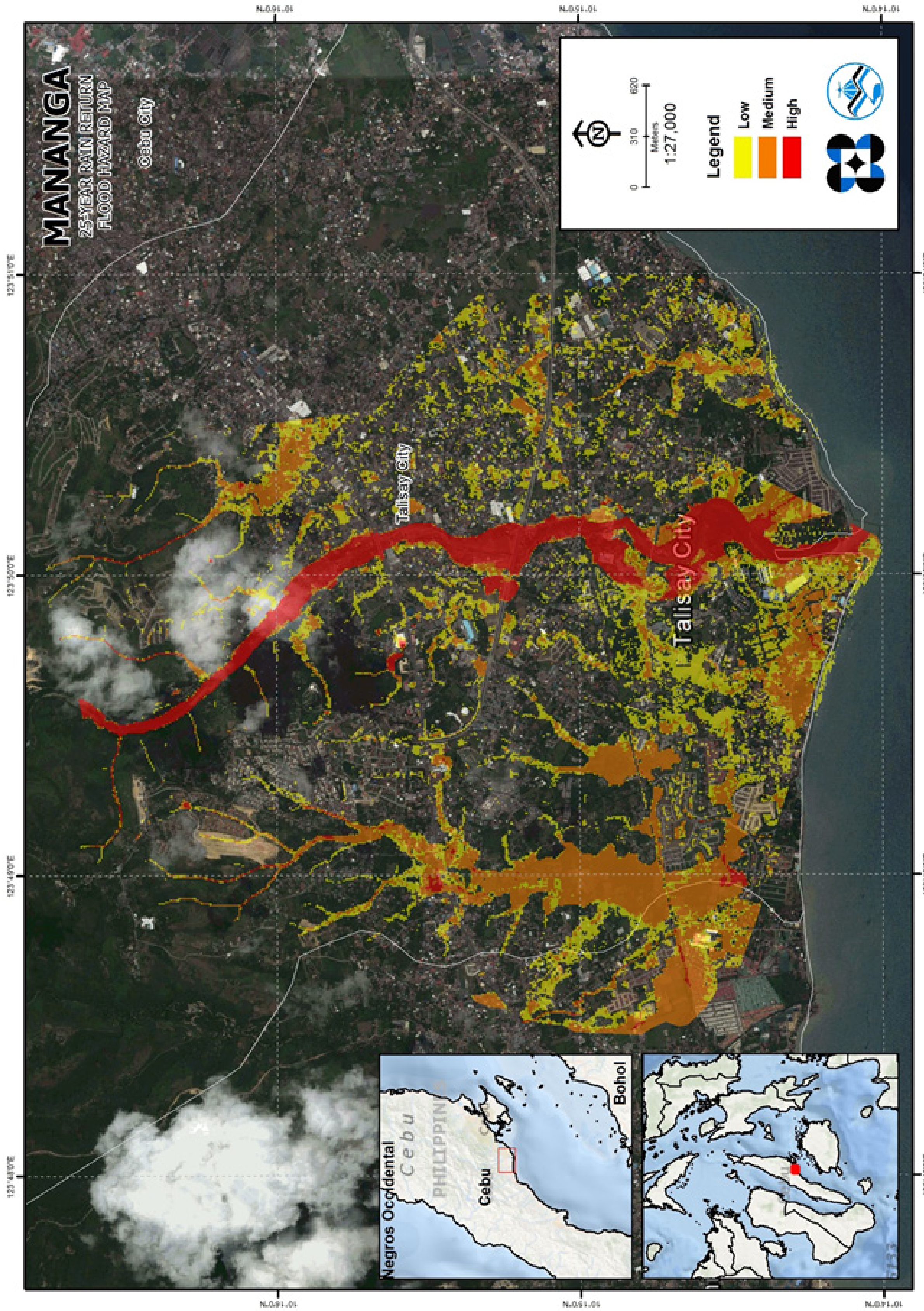


Figure 66. A 25-year Flood Hazard Map for Mananga Floodplain overlaid on Google Earth imagery.

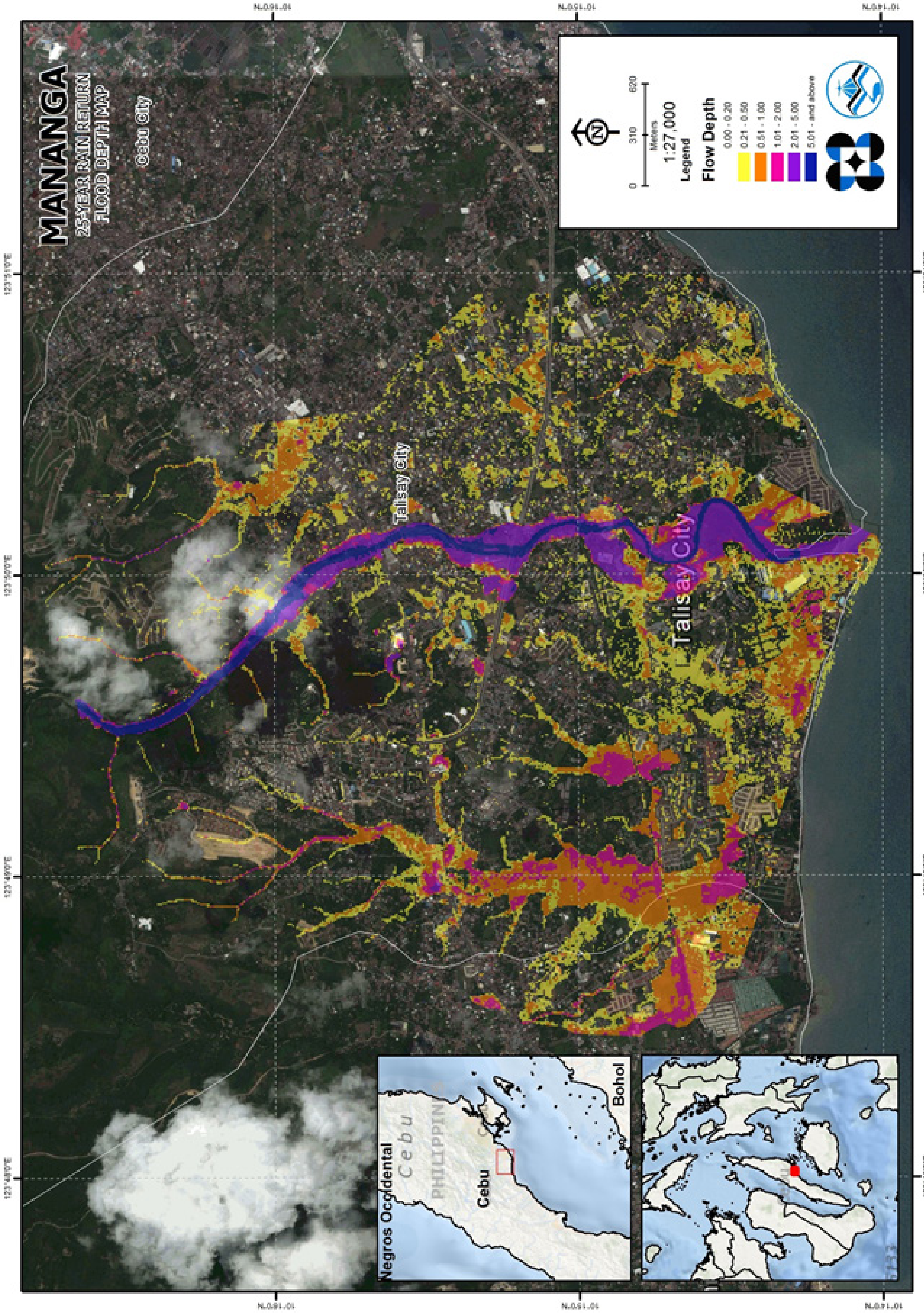


Figure 67. A 25-year Flow Depth Map for Mananga Floodplain overlaid on Google Earth imagery.

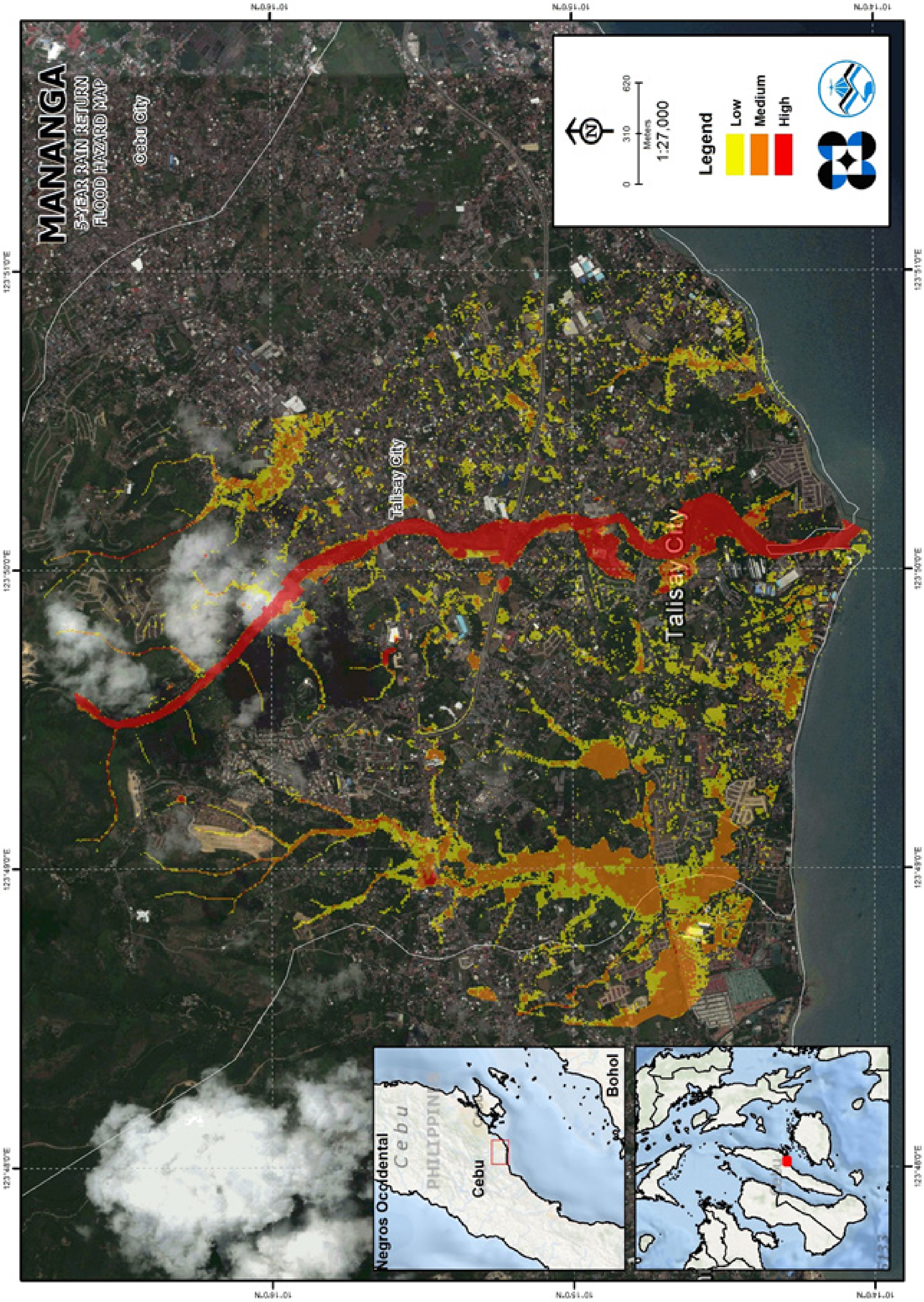


Figure 68. A 5-year Flood Hazard Map for Mananga Floodplain overlaid on Google Earth imagery.

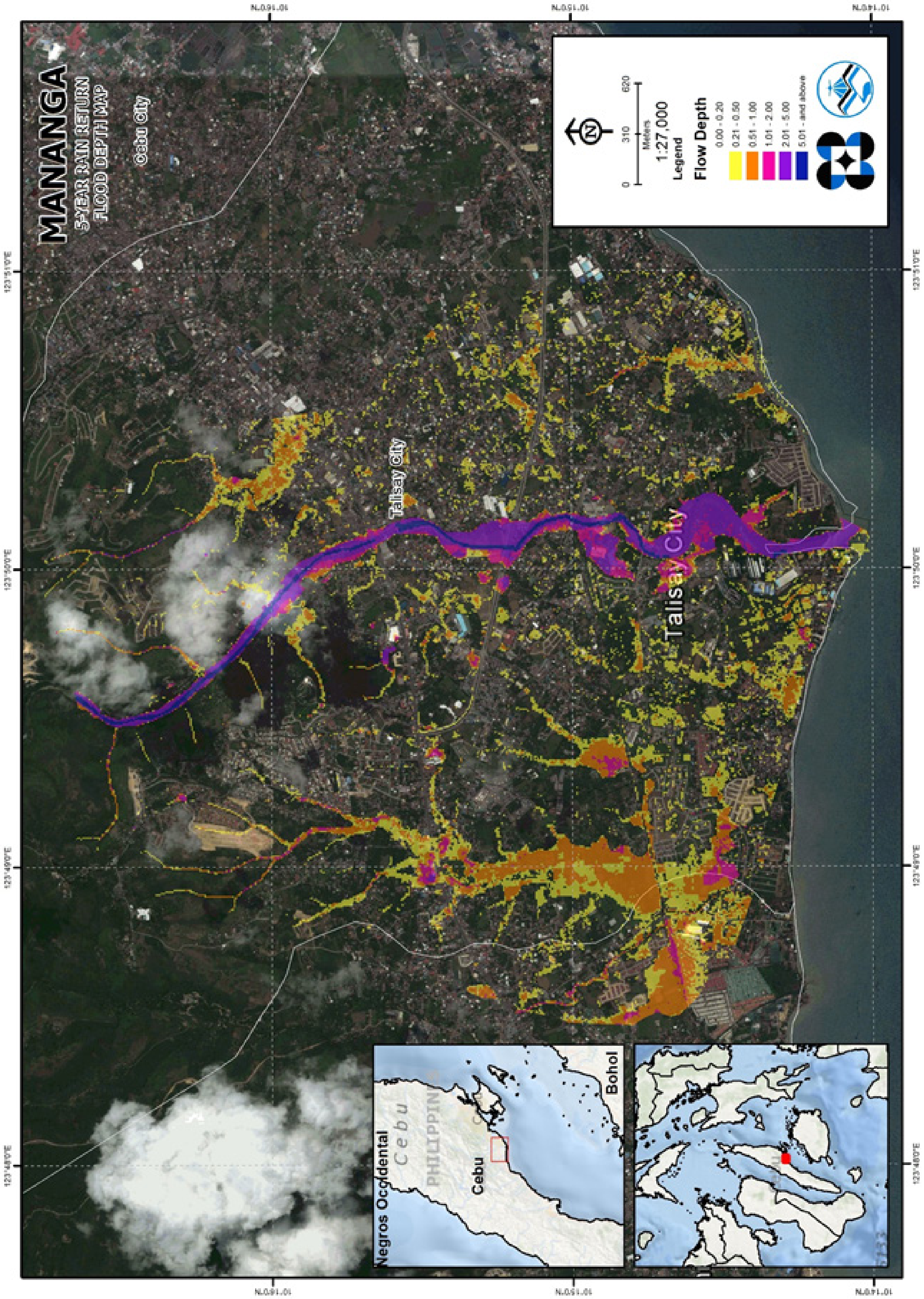


Figure 69. A 5-year Flood Depth Map for Mananga Floodplain overlaid on Google Earth imagery.

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Mananga river basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 20 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 0.36% of the municipality of Minglanilla with an area of 51.1 sq. km. will experience flood levels of less 0.20 meters. 0.136% of the area will experience flood levels of 0.21 to 0.50 meters while 0.15%, and 0.022% of the area will experience flood depths of 0.51 to 1 meter, and 1.01 to 2 meters, respectively. Listed in Table 33 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected Areas in Minglanilla, Cebu during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Minglanilla (in sq. km.)		
	Linao	Pakigne	Tungkil
0.03-0.20	0.25	0.0094	0.24
0.21-0.50	0.035	0.00058	0.16
0.51-1.00	0.018	0.0001	0.19
1.01-2.00	0.0046	0	0.026
2.01-5.00	0	0	0
> 5.00	0	0	0

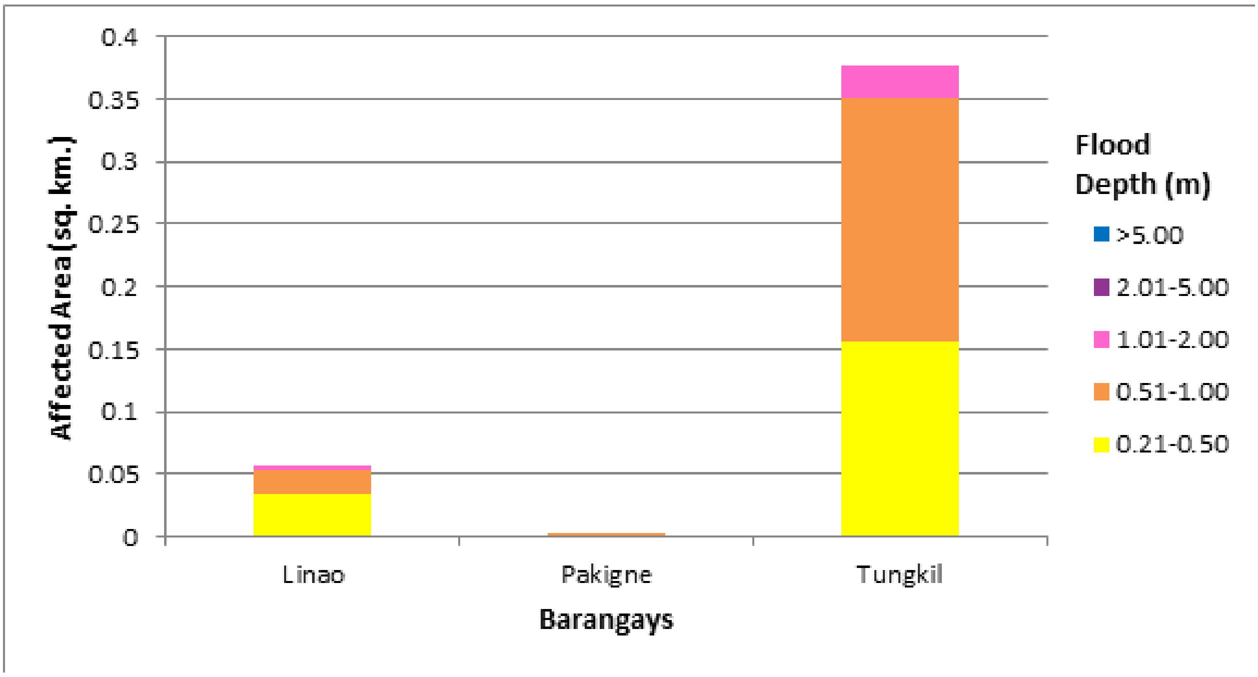


Figure 70. Affected Areas in Minglanilla, Cebu during 5-Year Rainfall Return Period

For the city of Talisay, with an area of 42.09 sq. km., 28.93% will experience flood levels of less 0.20 meters. 3.45% of the area will experience flood levels of 0.21 to 0.50 meters while 1.59%, 0.58%, 0.91%, and 0.23% 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 Table 35 are the affected areas in square kilometres by flood depth per barangay.

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

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Talisay City (in sq. km.)								
	Biasong	Bulacao	Cadulawan	Cansojong	Dumlog	Jaclupan	Lagtang	Lawaan I	Lawaan II
0.03-0.20	0.59	0.0078	0.079	0.12	0.54	0.052	1.21	0.99	0.35
0.21-0.50	0.12	0.00031	0.00034	0.0086	0.064	0.0013	0.094	0.082	0.035
0.51-1.00	0.041	0	0	0.0005	0.015	0.0001	0.058	0.024	0.008
1.01-2.00	0.036	0	0	0	0.02	0.0001	0.0055	0.019	0.022
2.01-5.00	0.077	0	0	0	0.061	0	0.0028	0.027	0.064
> 5.00	0.0073	0	0	0	0.00014	0	0	0.012	0.015

Table 35. Affected Areas in Talisay City, Cebu during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Talisay City (in sq. km.)							
	Lawaan III	Linao	Maghaway	Mohon	Poblacion	Pooc	San Isidro	Tabunoc
0.03-0.20	0.35	0.69	1.34	2.02	1.57	0.44	1.05	0.9
0.21-0.50	0.035	0.08	0.16	0.049	0.24	0.091	0.23	0.15
0.51-1.00	0.008	0.03	0.085	0.032	0.25	0.024	0.066	0.024
1.01-2.00	0.022	0.026	0.026	0.017	0.035	0.00036	0.038	0.00064
2.01-5.00	0.064	0.061	0.0021	0.041	0.026	0	0.019	0
> 5.00	0.015	0.02	0	0.03	0.006	0	0.0039	0

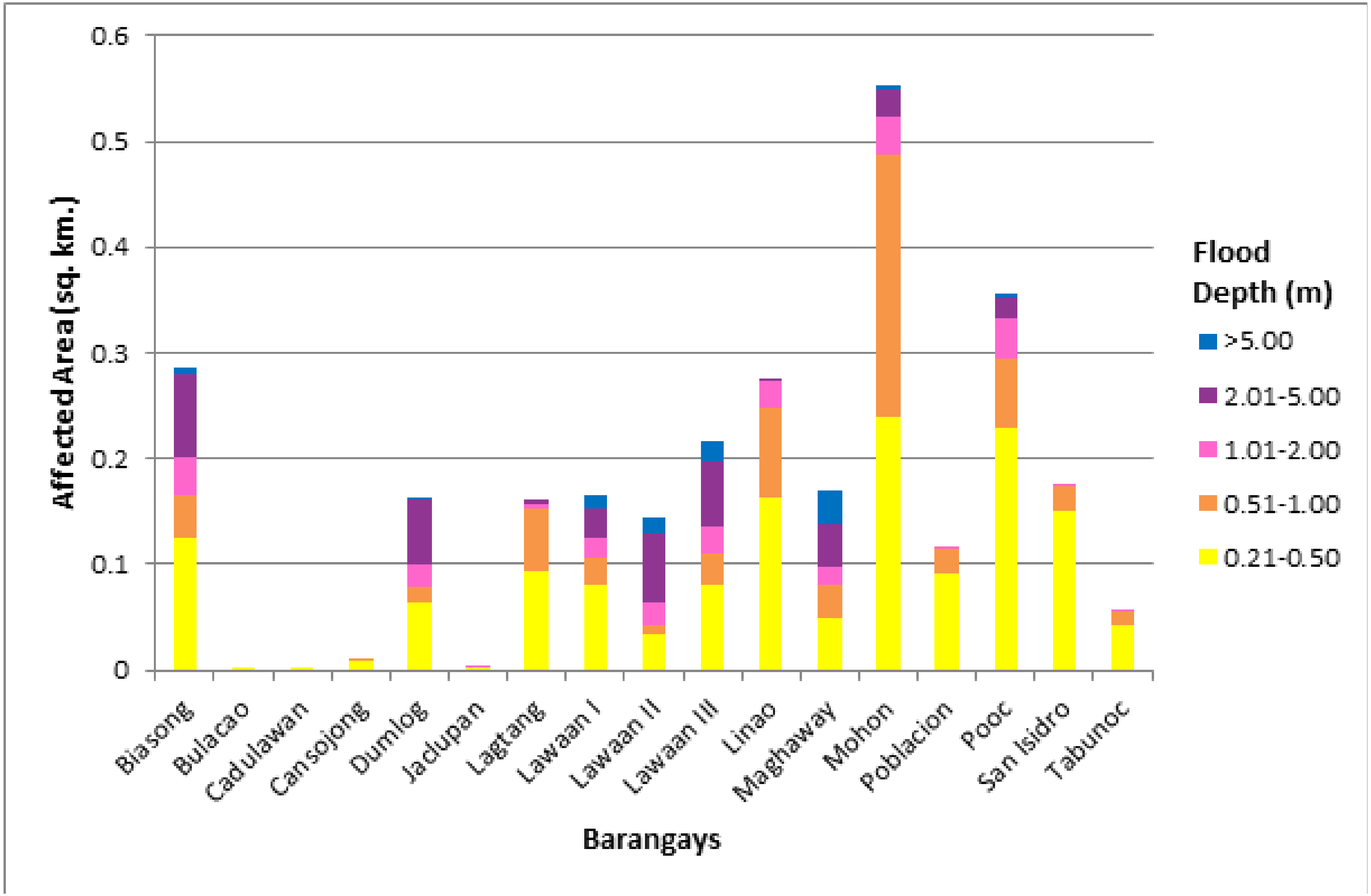


Figure 71. Affected Areas in Talisay City, Cebu during 5-Year Rainfall Return Period

For the 25-year return period, 0.36% of the municipality of Asturias with an area of 51.1 sq. km. will experience flood levels of less 0.20 meters. 0.136% of the area will experience flood levels of 0.21 to 0.50 meters while 0.15%, and 0.022% of the area will experience flood depths of 0.51 to 1 meter, and 1.01 to 2 meters, respectively. Listed in Table 36 are the affected areas in square kilometres by flood depth per barangay.

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

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Minglanilla (in sq. km.)		
	Linao	Pakigne	Tungkil
0.03-0.20	0.21	0.009	0.19
0.21-0.50	0.06	0.00084	0.12
0.51-1.00	0.026	0.0002	0.22
1.01-2.00	0.011	0	0.087
2.01-5.00	0	0	0
> 5.00	0	0	0

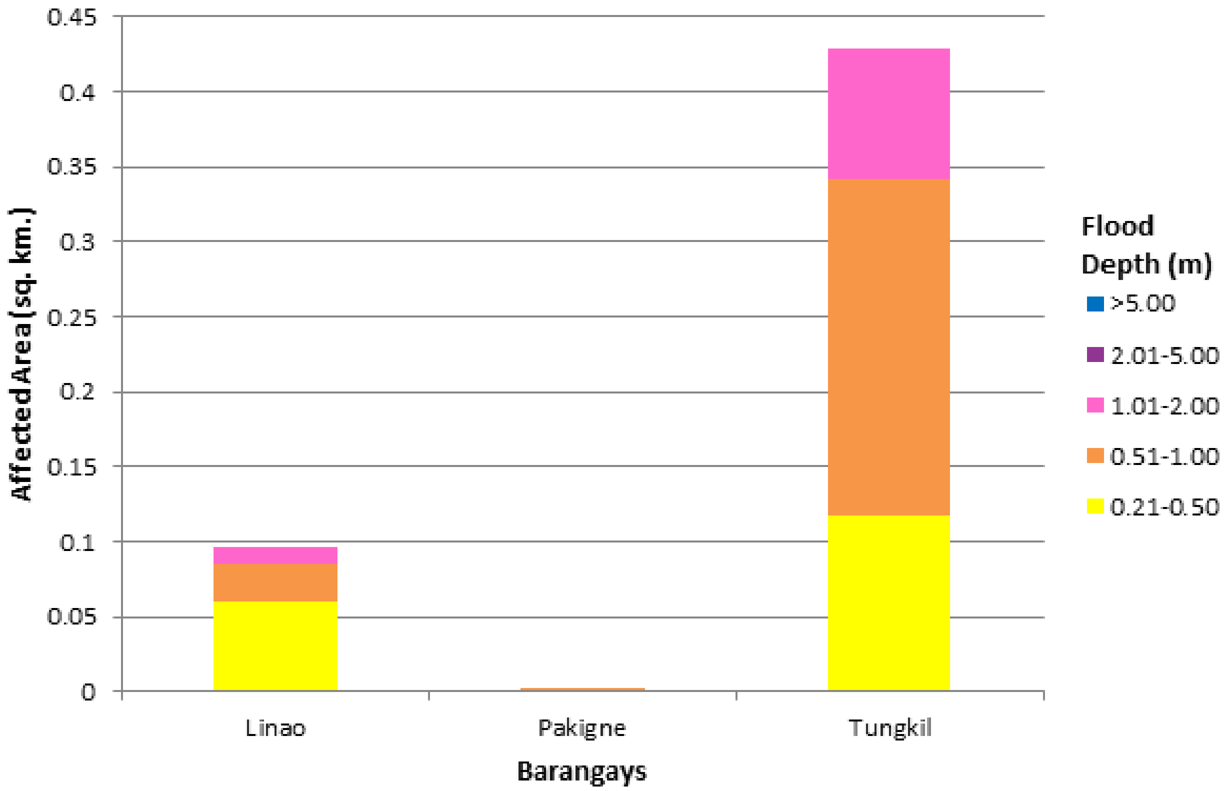


Figure 72. Affected Areas in Minglanilla, Cebu during 25-Year Rainfall Return Period

For the city of Talisay, with an area of 42.09 sq. km., 25.81% will experience flood levels of less 0.20 meters. 4.6% of the area will experience flood levels of 0.21 to 0.50 meters while 2.65%, 0.97%, 1.07%, and 0.59% 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 Table 38 are the affected areas in square kilometres by flood depth per barangay.

Table 37. Affected Areas in Talisay City, Cebu during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Talisay City (in sq. km.)								
	Biasong	Bulacao	Cadulawan	Cansojong	Dumlog	Jaclupan	Lagtang	Lawaan I	Lawaan II
0.03-0.20	0.35	0.0077	0.079	0.11	0.41	0.052	1.17	0.9	0.31
0.21-0.50	0.19	0.00039	0.00063	0.017	0.13	0.0014	0.098	0.12	0.054
0.51-1.00	0.16	0	0	0.0016	0.068	0.0002	0.09	0.041	0.0098
1.01-2.00	0.065	0	0	0	0.017	0.0002	0.0079	0.022	0.0083
2.01-5.00	0.094	0	0	0	0.057	0	0.0039	0.045	0.073
> 5.00	0.023	0	0	0	0.019	0	0	0.026	0.036

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

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Talisay City (in sq. km.)							
	Lawaan III	Linao	Maghaway	Mohon	Poblacion	Pooc	San Isidro	Tabunoc
0.03-0.20	0.31	0.61	1.27	1.98	1.43	0.38	0.79	0.79
0.21-0.50	0.054	0.11	0.17	0.057	0.22	0.13	0.35	0.23
0.51-1.00	0.0098	0.039	0.12	0.034	0.28	0.047	0.16	0.052
1.01-2.00	0.0083	0.02	0.048	0.023	0.13	0.0015	0.062	0.0017
2.01-5.00	0.073	0.068	0.0031	0.025	0.046	0	0.037	0
> 5.00	0.015	0.02	0	0.03	0.006	0	0.0039	0

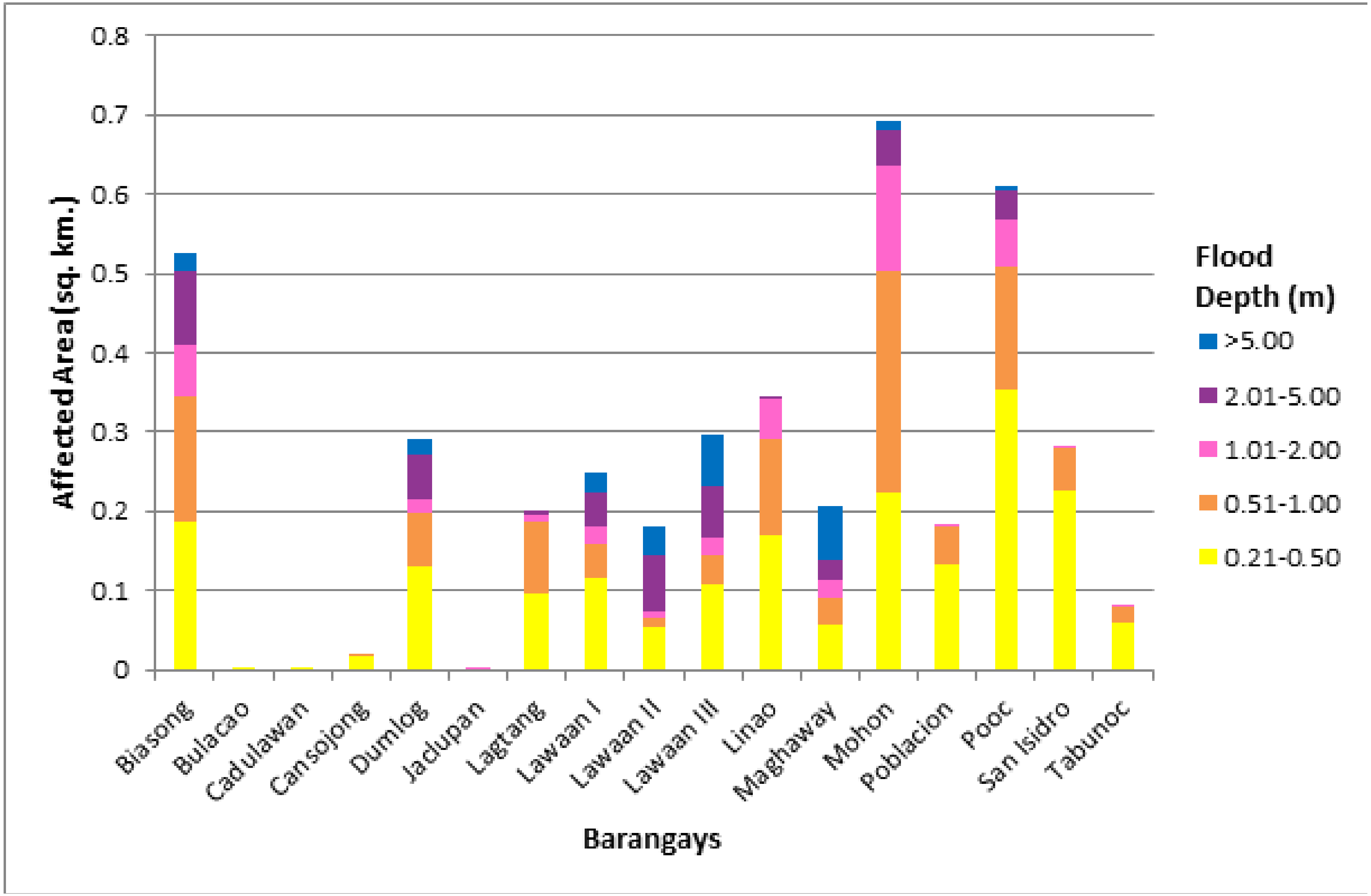


Figure 73. Affected Areas in Talisay City, Cebu during 25-Year Rainfall Return Period

For the 100-year return period, 0.36% of the municipality of Asturias with an area of 51.1 sq. km. will experience flood levels of less 0.20 meters. 0.136% of the area will experience flood levels of 0.21 to 0.50 meters while 0.15%, and 0.022% of the area will experience flood depths of 0.51 to 1 meter, and 1.01 to 2 meters, respectively. Listed in Table 39 are the affected areas in square kilometres by flood depth per barangay.

Table 39. Affected Areas in Minglanilla, Cebu during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Minglanilla (in sq. km.)		
	Linao	Pakigne	Tungkil
0.03-0.20	0.18	0.0089	0.15
0.21-0.50	0.079	0.00098	0.11
0.51-1.00	0.037	0.0002	0.2
1.01-2.00	0.016	0	0.16
2.01-5.00	0.0003	0	0
> 5.00	0	0	0

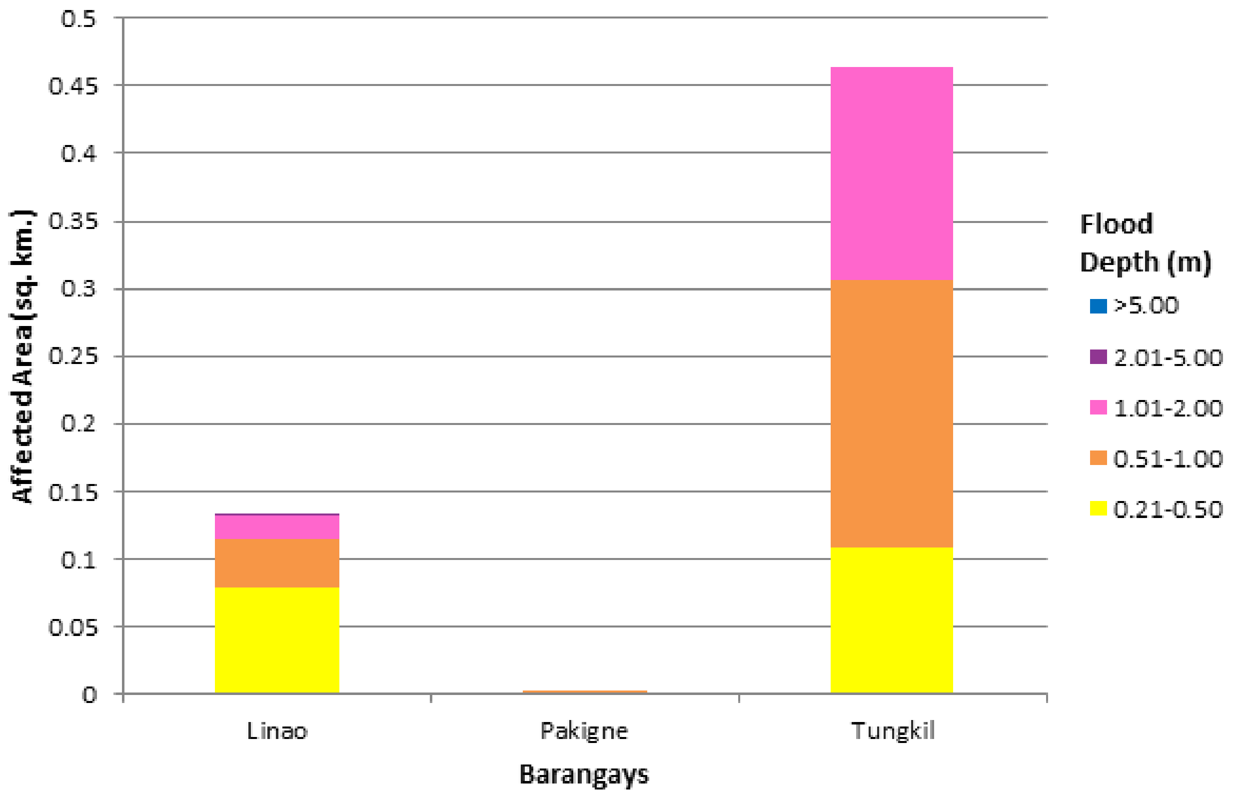


Figure 74. Affected Areas in Minglanilla, Cebu during -Year Rainfall Return Period

For the city of Talisay, with an area of 42.09 sq. km., 23.64% will experience flood levels of less 0.20 meters. 5.08% of the area will experience flood levels of 0.21 to 0.50 meters while 3.5%, 1.61%, 1.07%, and 0.8% 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 40 and Table 41 are the affected areas in square kilometres by flood depth per barangay.

Table 40. Affected Areas in Talisay City, Cebu during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Talisay City (in sq. km.)								
	Biasong	Bulacao	Cadulawan	Cansojong	Dumlog	Jaclupan	Lagtang	Lawaan I	Lawaan II
0.03-0.20	0.21	0.0076	0.079	0.11	0.33	0.051	1.14	0.83	0.29
0.21-0.50	0.16	0.00046	0.00063	0.022	0.15	0.0017	0.1	0.14	0.068
0.51-1.00	0.27	0.000047	0	0.0022	0.12	0.00044	0.11	0.059	0.014
1.01-2.00	0.11	0	0	0	0.025	0.0002	0.013	0.038	0.0094
2.01-5.00	0.1	0	0	0	0.059	0	0.0047	0.049	0.055
> 5.00	0.026	0	0	0	0.021	0	0	0.034	0.06

Table 41. Affected Areas in Talisay City, Cebu during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Talisay City (in sq. km.)							
	Lawaan III	Linao	Maghaway	Mohon	Poblacion	Pooc	San Isidro	Tabunoc
0.03-0.20	0.29	0.55	1.23	1.95	1.34	0.34	0.57	0.72
0.21-0.50	0.068	0.12	0.17	0.061	0.25	0.15	0.39	0.28
0.51-1.00	0.014	0.054	0.13	0.037	0.22	0.068	0.3	0.075
1.01-2.00	0.0094	0.023	0.074	0.029	0.25	0.005	0.1	0.0025
2.01-5.00	0.055	0.065	0.0041	0.023	0.046	0	0.041	0
> 5.00	0.06	0.09	0	0.086	0.012	0	0.0083	0

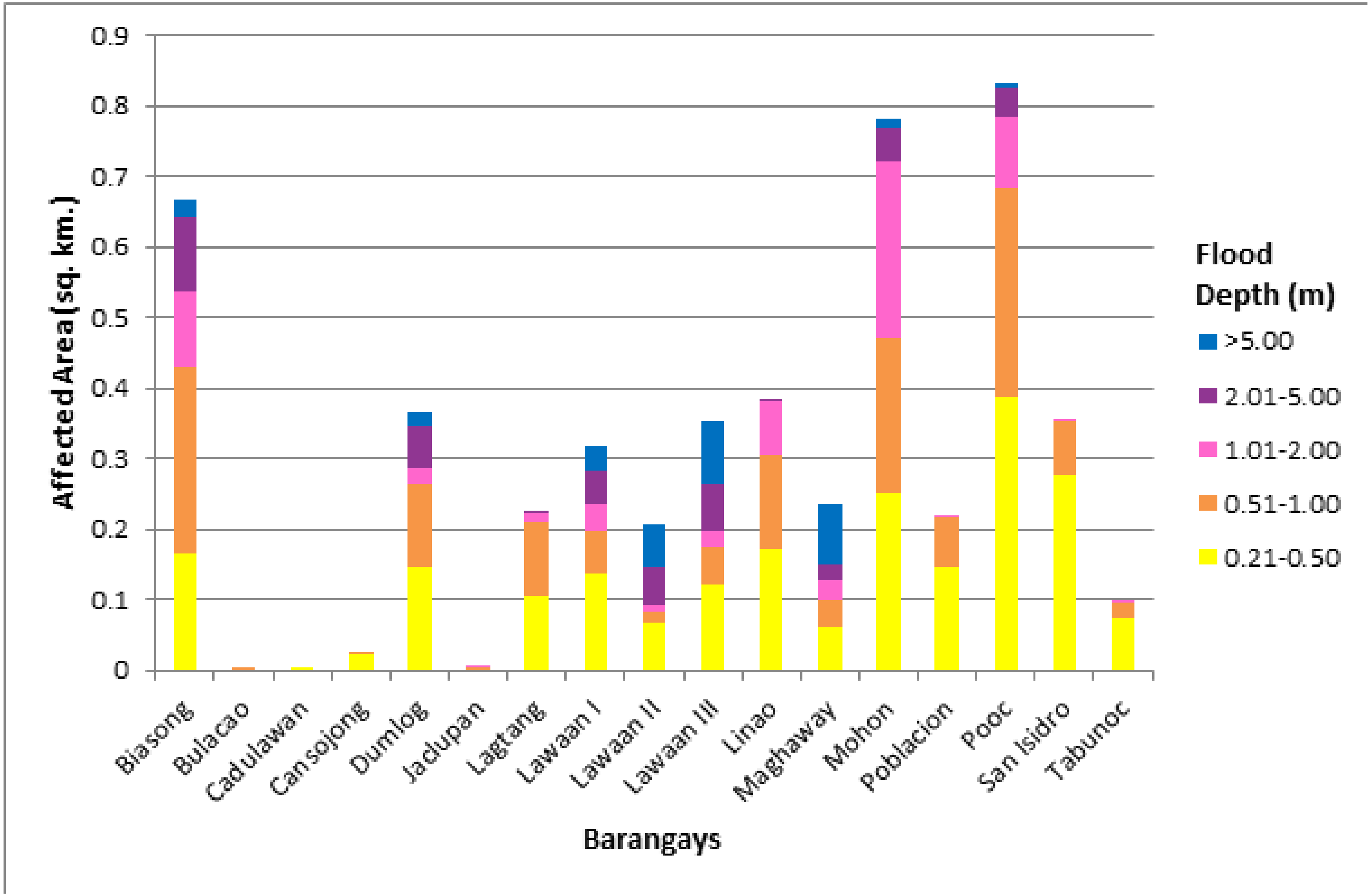


Figure 75. Affected Areas in Talisay City, Cebu during 100-Year Rainfall Return Period

Among the barangays in the municipality of Minglanilla, Tungkil is projected to have the highest percentage of area that will experience flood levels at 1.21%. Meanwhile, Linao posted the second highest percentage of area that may be affected by flood depths at 0.61%.

Among the barangays in the city of Talisay, Maghaway is projected to have the highest percentage of area that will experience flood levels at 5.2%. Meanwhile, Mohon posted the second highest percentage of area that may be affected by flood depths at 5.05%.

Moreover, the generated flood hazard maps for the Mananga 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 42. 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	1.72	2.21	2.44
Medium	1.09	1.82	2.56
High	0.63	0.86	1.01
TOTAL	**3.44**	**4.89**	**6.01**

Of the 23 identified Education Institutions in the Mananga Floodplain, 4 schools were assessed to be exposed to Low level flooding during a 5 year scenario. In the 25 year scenario, 6 schools were assessed to be exposed to low level flooding, while 1 school was assessed to be exposed to medium level flooding in the same scenario. In the 100 year scenario, 8 schools were assessed to be exposed to low level flooding, while 1 school was assessed to be exposed to medium level flooding in the same scenario. See Annex 12 for a detailed enumeration of schools in the Mananga floodplain.

Of the 5 identified Medical Institutions in the Mananga Floodplain, 1 medical institution was assessed to be exposed to Low level flooding during a 5 year scenario, while 1 medical institution was assessed to be exposed to medium level flooding in the same scenario. In the 25 year scenario, 2 medical institutions were assessed to be exposed to low level flooding, while 1 medical institution was assessed to be exposed to medium level flooding in the same scenario. In the 100 year scenario, 2 medical institutions were assessed to be exposed to low level flooding, while 1 medical institution was assessed to be exposed to medium level flooding in the same scenario. See Annex 13 for a detailed enumeration of hospitals and clinics in the Mananga floodplain.

5.11 Flood Validation

Survey was done along the floodplain of Mananga 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.

The validation points were obtained on January 11-12, 2016. During validation, the team was assisted by the local representative from the City of Talisay. 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 1.95 was obtained. The validation points are found in Annex 11.

Figure 76. Validation Points for a 5-year Flood Depth Map of the Mananga Floodplain.

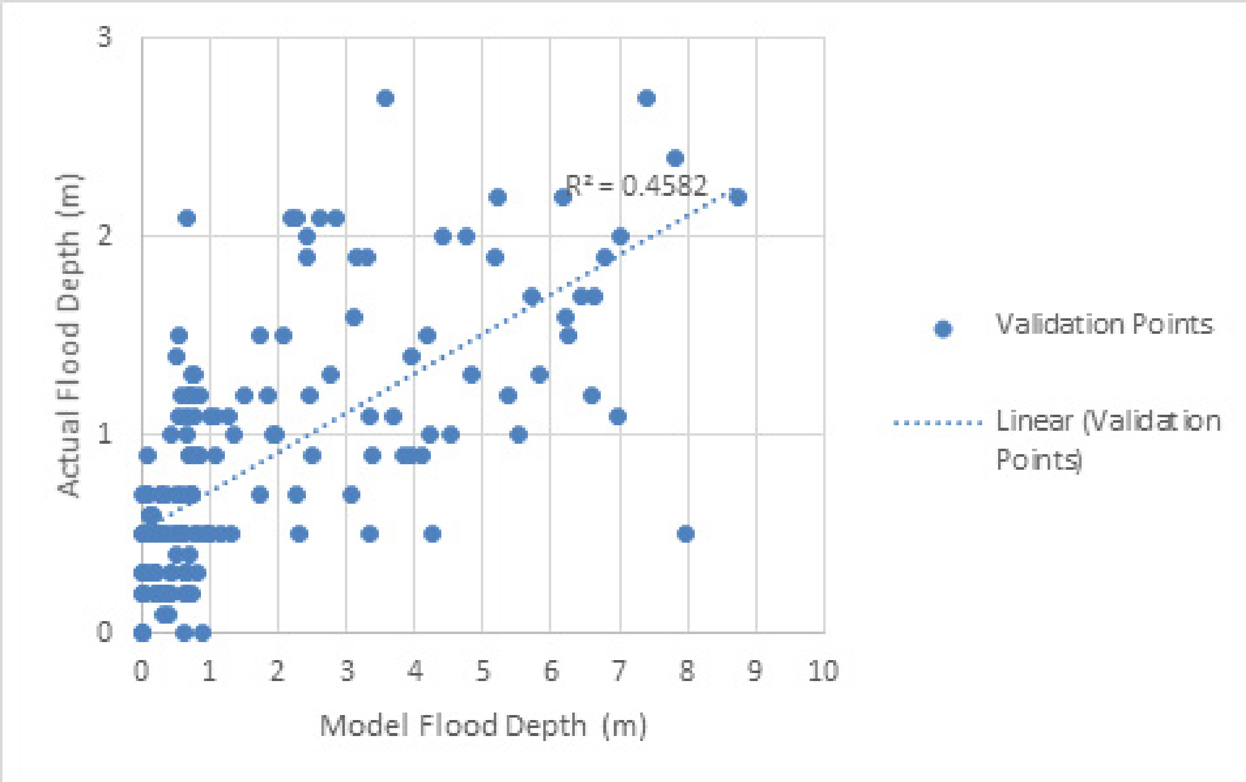


Figure 77. Flood depth map vs actual flood depth.

Table 43. Actual Flood Depth versus Simulated Flood Depth at different levels in the Mananga 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	8	11	6	0	0	0	25
0.21-0.50	15	10	19	2	3	1	50
0.51-1.00	8	5	10	5	9	1	38
1.01-2.00	0	0	13	5	15	12	45
2.01-5.00	0	0	1	0	5	5	11
> 5.00	0	0	0	0	0	0	0
Total	31	26	49	12	32	19	169

On the whole, the overall accuracy generated by the flood model is estimated at 22.49% with 38 points correctly matching the actual flood depths. In addition, there were 83 points estimated one level above and below the correct flood depths while there were 38 points and 5 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 42 points were underestimated in the modelled flood depths of Mananga.

Table 44. Summary of the Accuracy Assessment in the Mananga River Basin Survey.

	No. of Points	%
Correct	38	22.49
Overestimated	89	52.66
Underestimated	42	24.85
Total	169	100.00

REFERENCES

Ang M.O., 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.O., 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., Paringit E.C., et al. 2014. DREAM Data Acquisition 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. Technical Specifications of the LIDAR Sensors used in the Mananga Floodplain Survey

1. PEGASUS SENSOR

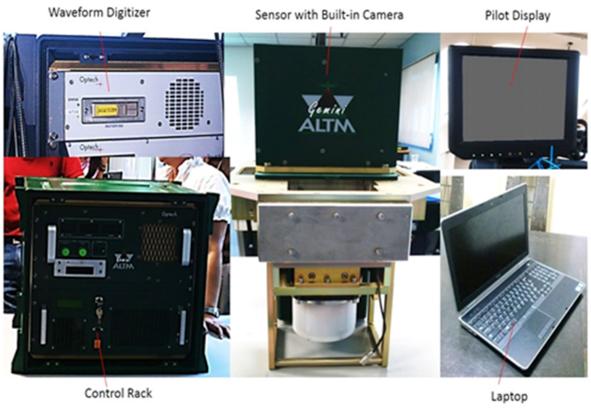

Figure A-1.1. Pegasus Sensor

Table A-1.1. Parameters and Specifications of Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM); 220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
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)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

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**		Barangay: **TOWN PROPER**
Municipality: **CEBU CITY (CAPITAL)**		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. 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

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Figure A-2.2. CU-1007

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

1. CU-1007

Table A-3.1. CU-1007

Processing Summary

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

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

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

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

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

Standard Errors

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

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.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	UP-TCAGP
	RA	ENGR. IRO NIEL ROXAS	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JERIEL PAUL ALAMBAN, GEOL.	UP-TCAGP
	RA	KENNETH QUISADO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG RANDY SISON	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. FERDINAND DE OCAMPO	AAC

Annex 5. Data Transfer Sheet for Mananga 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 Mananga 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

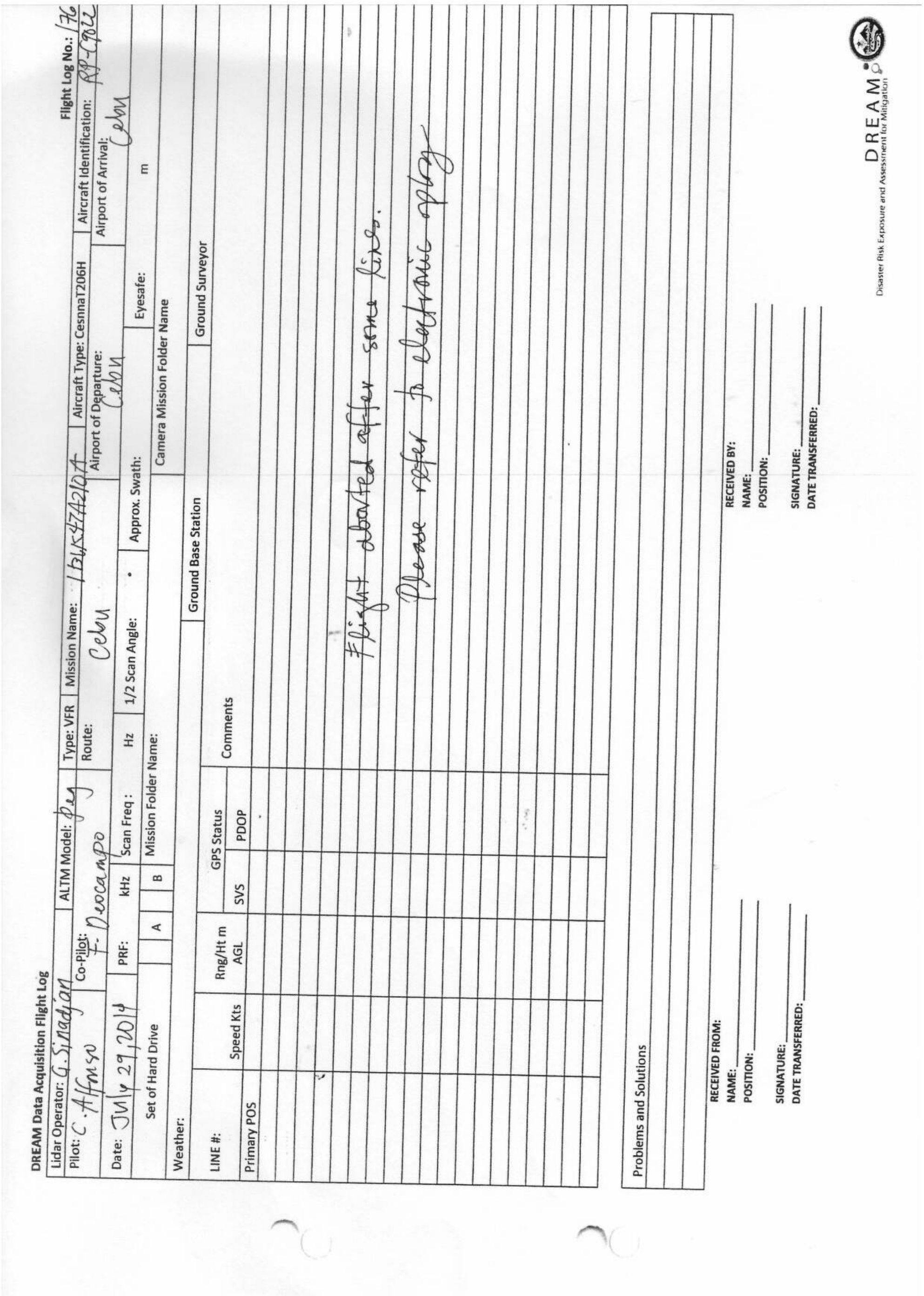
Received by

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

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

Annex 6. Flight logs for the flight missions

1. Flight Log for 1769P Mission


DREAM Data Acquisition Flight Log

Flight Log No.: 176

Lidar Operator: G. Sinadjan | ALTM Model: Peg | Type: VFR | Mission Name: 1BLK47A210A | Aircraft Type: CesnnaT206H | Aircraft Identification: RP-C9022

Pilot: C. Alfonso | Co-Pilot: F. Deocampo | Route: Cebu | Airport of Departure: Cebu | Airport of Arrival: Cebu

Date: July 29, 2014 | PRF: kHz | Scan Freq: Hz | 1/2 Scan Angle: | Approx. Swath: | Eyesafe: m

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

Weather: | Ground Base Station | Ground Surveyor

LINE #:	Speed Kts	Rng/Ht m AGL	GPS Status SVS	GPS Status PDOP	Comments
Primary POS					Flight aborted after some lines. Please refer to electronic flog.

Problems and Solutions

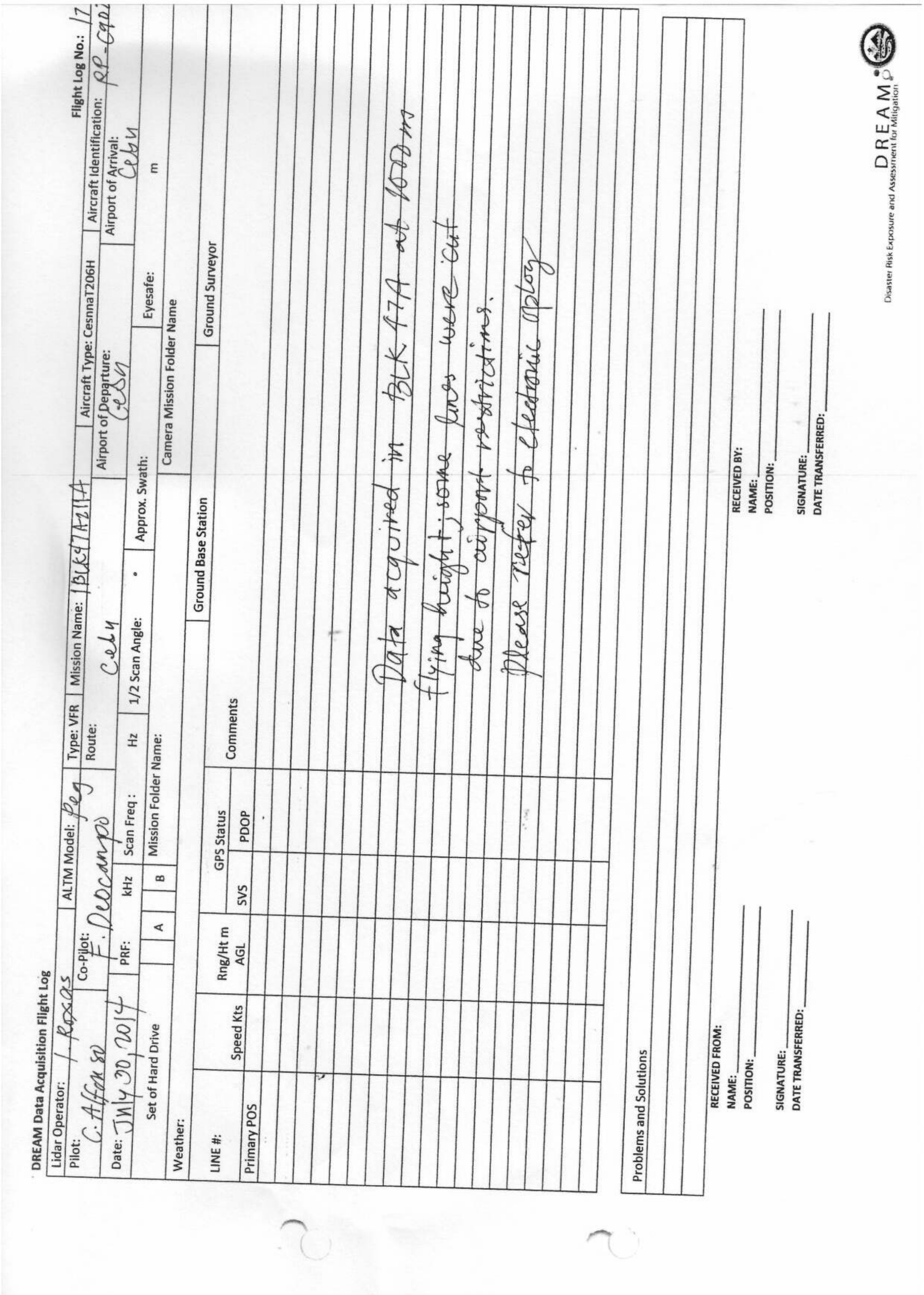
RECEIVED FROM:
NAME:
POSITION:
SIGNATURE:
DATE TRANSFERRED:

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

DREAM Disaster Risk Exposure and Assessment for Mitigation

Figure A-6.1. Flight Log for Mission 1769P

2. Flight Log for 1773P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 17

Lidar Operator: I. Roxas		ALTM Model: Peg	Type: VFR	Mission Name: 1BLK47A211A	Aircraft Type: CesnnaT206H	Aircraft Identification: RP-C9022
Pilot: C. Alfonso	Co-Pilot: F. Deocampo		Route: Cebu		Airport of Departure: Cebu	Airport of Arrival: Cebu
Date: July 30, 2014	PRF: kHz	Scan Freq: Hz	1/2 Scan Angle:	Approx. Swath:	Eyesafe: m	
Set of Hard Drive: A B	Mission Folder Name:			Camera Mission Folder Name		
Weather:			Ground Base Station		Ground Surveyor	

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

Problems and Solutions

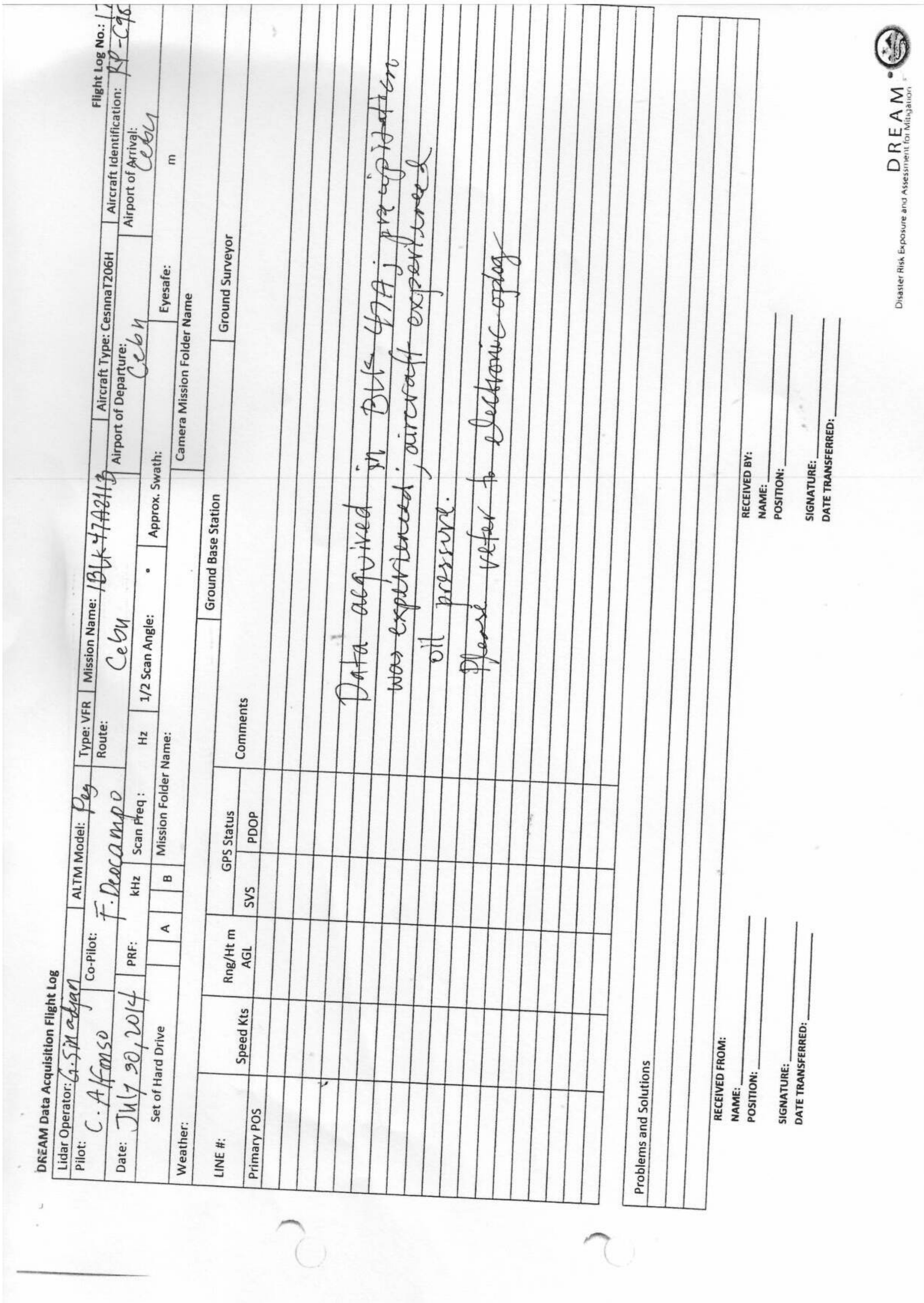
RECEIVED FROM:
NAME:
POSITION:
SIGNATURE:
DATE TRANSFERRED:

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

DREAM Disaster Risk Exposure and Assessment for Mitigation

Figure A-6.2. Flight Log for Mission 1773P

3. Flight Log for 1775P Mission


DREAM Data Acquisition Flight Log

Flight Log No.:

Lidar Operator: G. Sinadjan	ALTM Model: Peg	Type: VFR	Mission Name: 1BLK47A213	Aircraft Type: CesnnaT206H	Aircraft Identification: RP-C9
Pilot: C. Alfonso	Co-Pilot: F. Deocampo	Route: Cebu		Airport of Departure: Cebu	Airport of Arrival: Cebu
Date: July 30, 2014	PRF: kHz	Scan Freq: Hz	1/2 Scan Angle: °	Approx. Swath:	Eyesafe: m
Set of Hard Drive	A	B	Mission Folder Name:	Camera Mission Folder Name	
Weather:			Ground Base Station	Ground Surveyor	

LINE #:	Speed Kts	Rng/Ht m AGL	GPS Status SVS	GPS Status PDOP	Comments
Primary POS					Data acquired in BLK 47A; precipitation was experienced; aircraft experienced oil pressure. Please refer to electronic oplog

Problems and Solutions

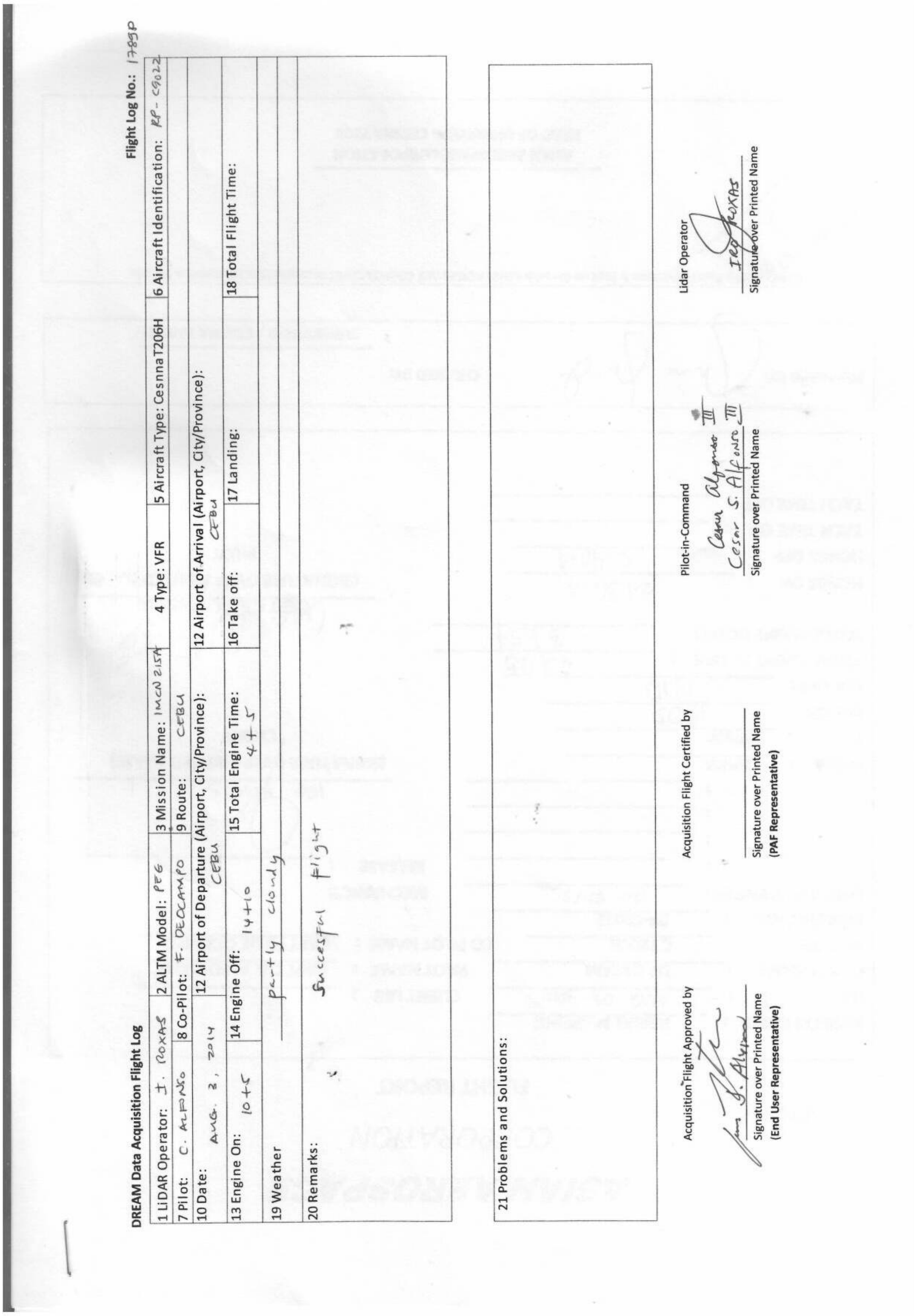
RECEIVED FROM:
NAME:
POSITION:
SIGNATURE:
DATE TRANSFERRED:

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

DREAM Disaster Risk Exposure and Assessment for Mitigation

Figure A-6.3. Flight Log for Mission 1775P

4. Flight Log for 1789P Mission



DREAM Data Acquisition Flight Log — Flight Log No.: 1789P

1 LIDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name: 1MCN215A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: F. Delcampo	9 Route: CEBU			
10 Date: Aug. 2, 2014	12 Airport of Departure (Airport, City/Province): CEBU		12 Airport of Arrival (Airport, City/Province): CEBU		
13 Engine On: 10+5	14 Engine Off: 14+10	15 Total Engine Time: 4+5	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	partly cloudy				
20 Remarks:	successful flight				

21 Problems and Solutions:

Acquisition Flight Approved by — J. S. Alfonso — Signature over Printed Name (End User Representative)

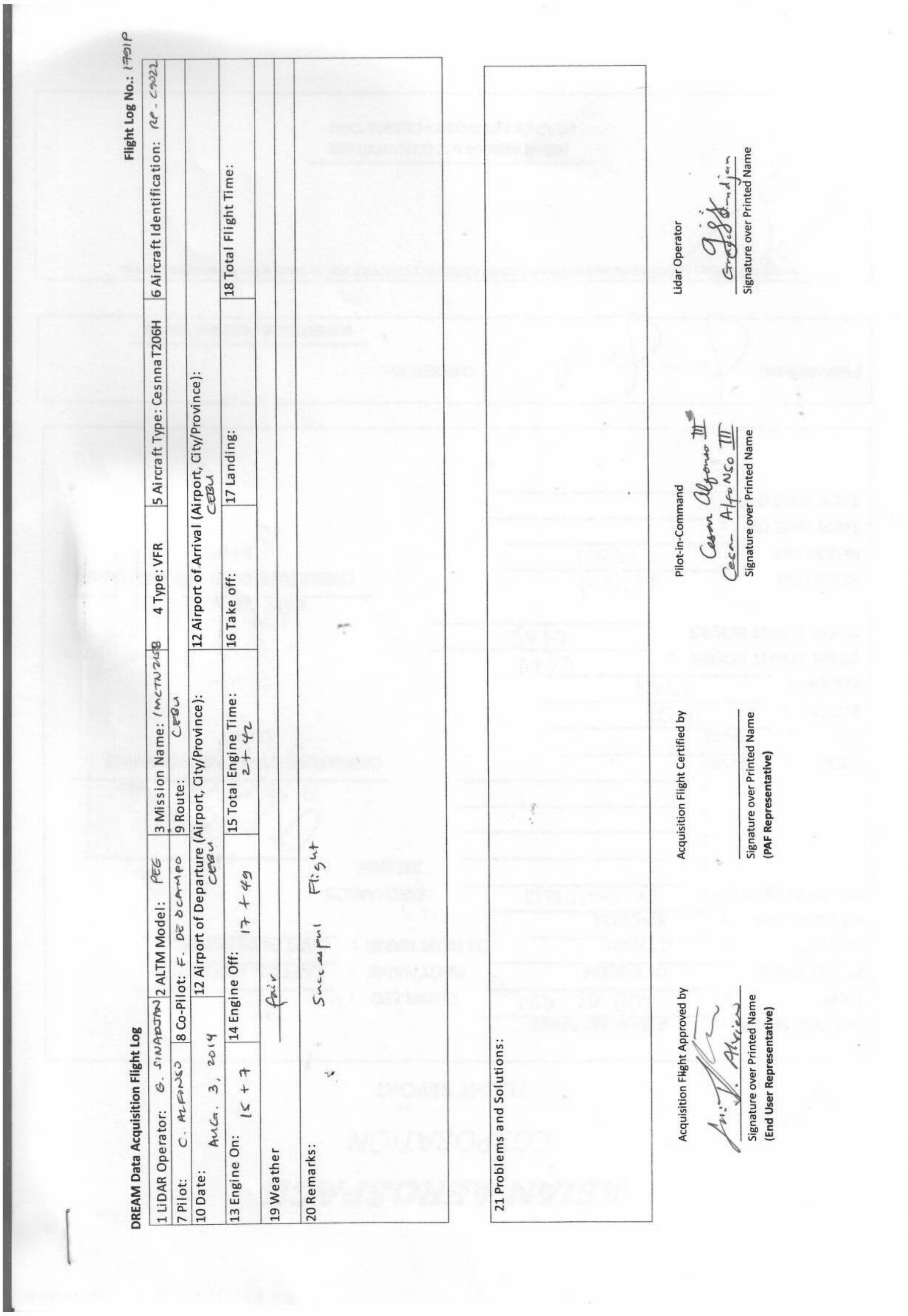
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Cesar S. Alfonso III — Signature over Printed Name

Lidar Operator — I. Roxas — Signature over Printed Name

Figure A-6.4. Flight Log for Mission 1789P

5. Flight Log for 1791P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1791P

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: PEG	3 Mission Name: 1MCTN245B	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: F. De Ocampo	9 Route: Cebu			
10 Date: Aug. 3, 2014	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 15+7	14 Engine Off: 17+49	15 Total Engine Time: 2+42	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Fair					
20 Remarks: Successful Flight					

21 Problems and Solutions:

Acquisition Flight Approved by — J. Alviar — Signature over Printed Name (End User Representative)

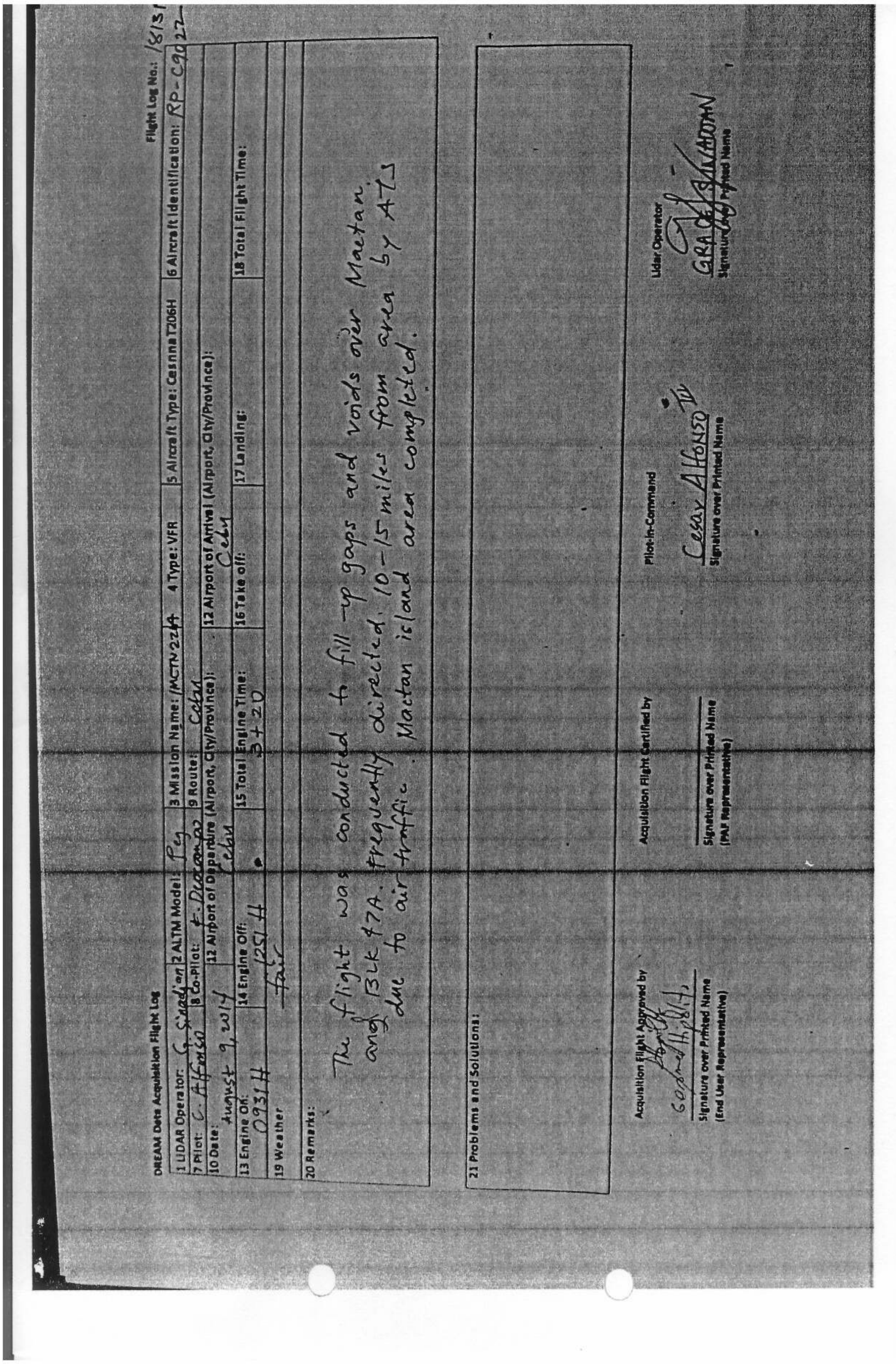
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Cesar Alfonso III — Signature over Printed Name

Lidar Operator — G. Sinadjan — Signature over Printed Name

Figure A-6.5. Flight Log for Mission 1791P

6. Flight Log for 1813P Mission



DREAM Data Acquisition Flight Log — Flight Log No.: 1813P

1 LIDAR Operator: G. Sinadjan	2 ALTM Model: Peg	3 Mission Name: 1MCTN224A	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: E. Dacanay	9 Route: Cebu			
10 Date: August 9, 2014	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 0931H	14 Engine Off: 1251H	15 Total Engine Time: 3+20	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: fair					

20 Remarks:

The flight was conducted to fill-up gaps and voids over Mactan and BLK 47A. frequently directed 10-15 miles from area by ATC [?] due to air traffic. Mactan island area completed.

21 Problems and Solutions:

Acquisition Flight Approved by: Godofredo H. Bel [?] — Signature over Printed Name (End User Representative)

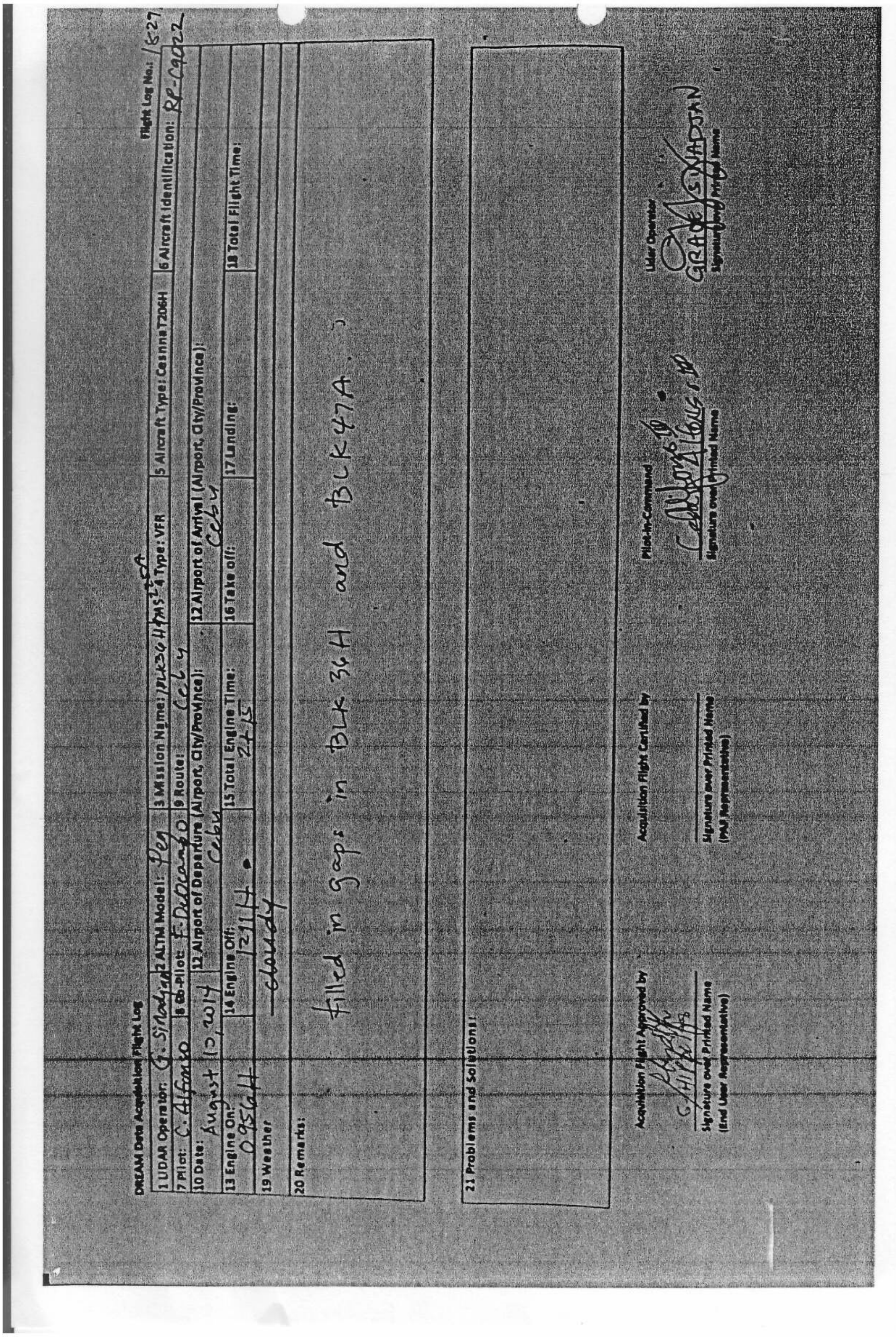
Acquisition Flight Certified by: Signature over Printed Name (PAF Representative)

Pilot-in-Command: Cesar Alfonso IV — Signature over Printed Name

Lidar Operator: Grace Sinadjan — Signature over Printed Name

Figure A-6.6. Flight Log for Mission 1813P

7. Flight Log for 1829P Mission



DREAM Data Acquisition Flight Log — Flight Log No.: 1827

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Peg	3 Mission Name: 1BLK36H47AS222A	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: E. DeGuzman	9 Route: Cebu			
10 Date: August 10, 2014	12 Airport of Departure (Airport, City/Province): Cebu	12 Airport of Arrival (Airport, City/Province): Cebu			
13 Engine On: 0956H	14 Engine Off: 1211H	15 Total Engine Time: 2+15	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Filled in gaps in BLK 36H and BLK47A.

21 Problems and Solutions:

Acquisition Flight Approved by — Signature over Printed Name (End User Representative)

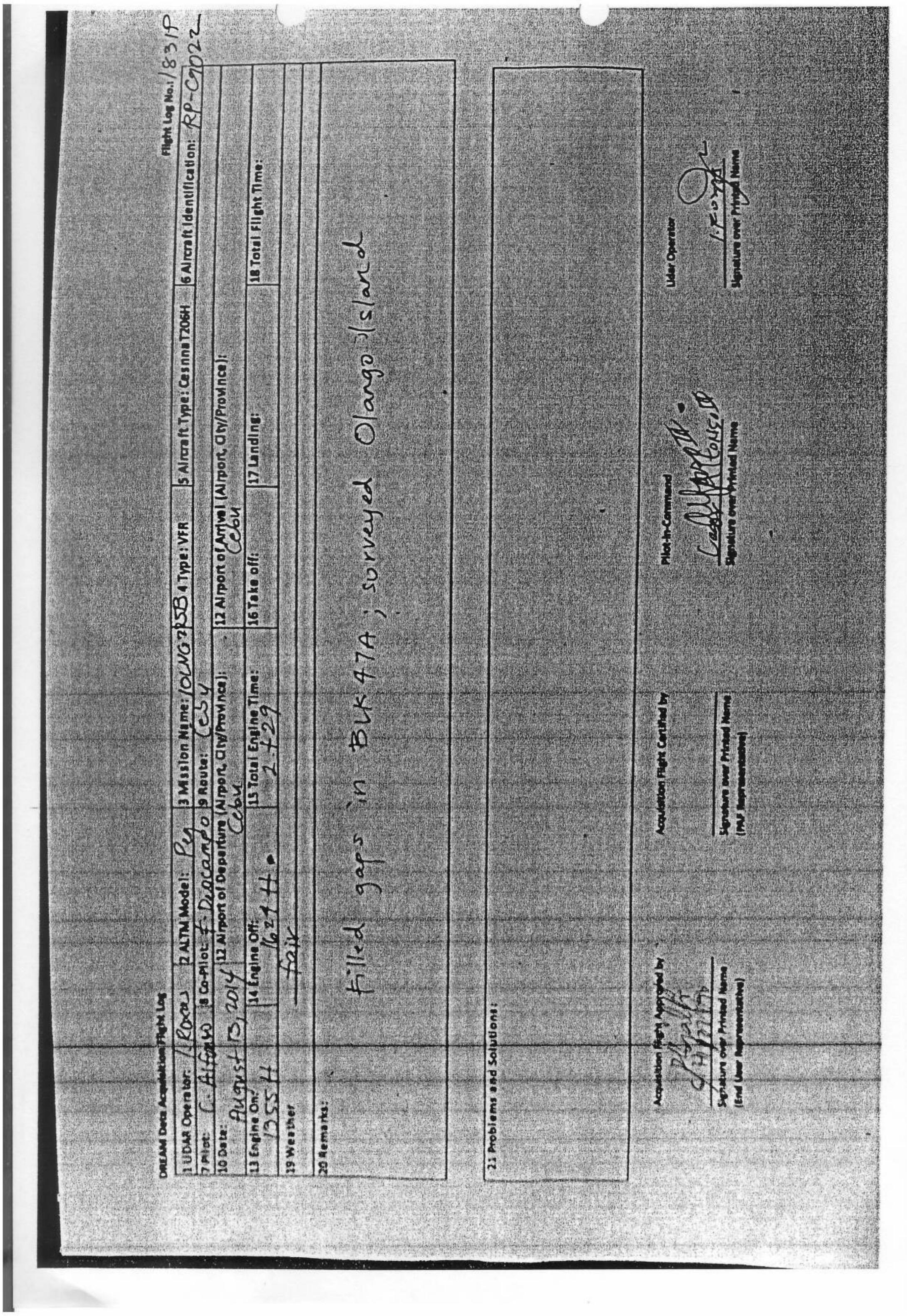
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator: GRACE SINADJAN — Signature over Printed Name

Figure A-6.7. Flight Log for Mission 1829P

8. Flight Log for 1831P Mission



DREAM Data Acquisition Flight Log — Flight Log No.: 1831P

1 LIDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name: 10LNG7?5B	4 Type: VFR	5 Aircraft Type: Cessnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: F. Dulocampo	9 Route: Cebu			
10 Date: August 13, 2014	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 1355H	14 Engine Off: 1624 H	15 Total Engine Time: 2+29	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: fair					

20 Remarks:

Filled gaps in BLK 47A; surveyed Olango Island

21 Problems and Solutions:

Acquisition Flight Approved by — Signature over Printed Name (End User Representative)

Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — I. Roxas — Signature over Printed Name

Figure A-6.8. Flight Log for Mission 1831P

Annex 7. Flight status reports

Cebu
July 20 & 30, August 3, 9 & 13, 2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1769P	BLK47A	1BLK47A210A	G. Sinadjan	July 23	Flight aborted after a few lines due to cloud build up;
1773P	BLK47A	1BLK47A211A	I. Roxas	July 30	Data acquired in BLK 47A at 100m flying height; some lines were cut due to airport restriction; 261.23 sq.km
1775P	BLK47A	1BLK47A211B	G. Sinadjan	July 30	Data acquired in BLK 47A; precipitation was experienced;
1789P	MACTAN ISLAND	1MCTN215A	I. Roxas	August 3	Surveyed lines over Mactan Island; frequently directed 10-15 miles from area by ATS due to air traffic;
1791P	MACTAN ISLAND; BLK47A	1MCTN215B	G. Sinadjan	August 3	Surveyed lines over Mactan Island; frequently directed 10-15 miles from area by ATS due to air traffic;
1813P	MACTAN ISLAND; BLK47A	1MCTN221A	G. Sinadjan	August 9	The flight was conducted to fill-up gaps and voids over Mactan and BLK47A; frequently directed 10-15 miles from area by ATS due to air traffic; Mactan Island area completed;
1829P	BLK47A	1BLK36H47A225A	G. Sinadjan	August 13	Filled in gaps in BLK36H and BLK47A;
1831P	BLK47A; OLANGO ISLAND	1OLNG225B	I. Roxas	August 13	Filled in gaps in BLK47A; surveyed Olango Island;

SWATH PER FLIGHT MISSION

Flight No. :	1769P			
Area:	BLK47A			
Mission Name:	1BLK47A210A			
Parameters:	Altitude: 1200m;		Scan Frequency: 30Hz;	
	Scan Angle: 25deg;		Overlap: 30%	

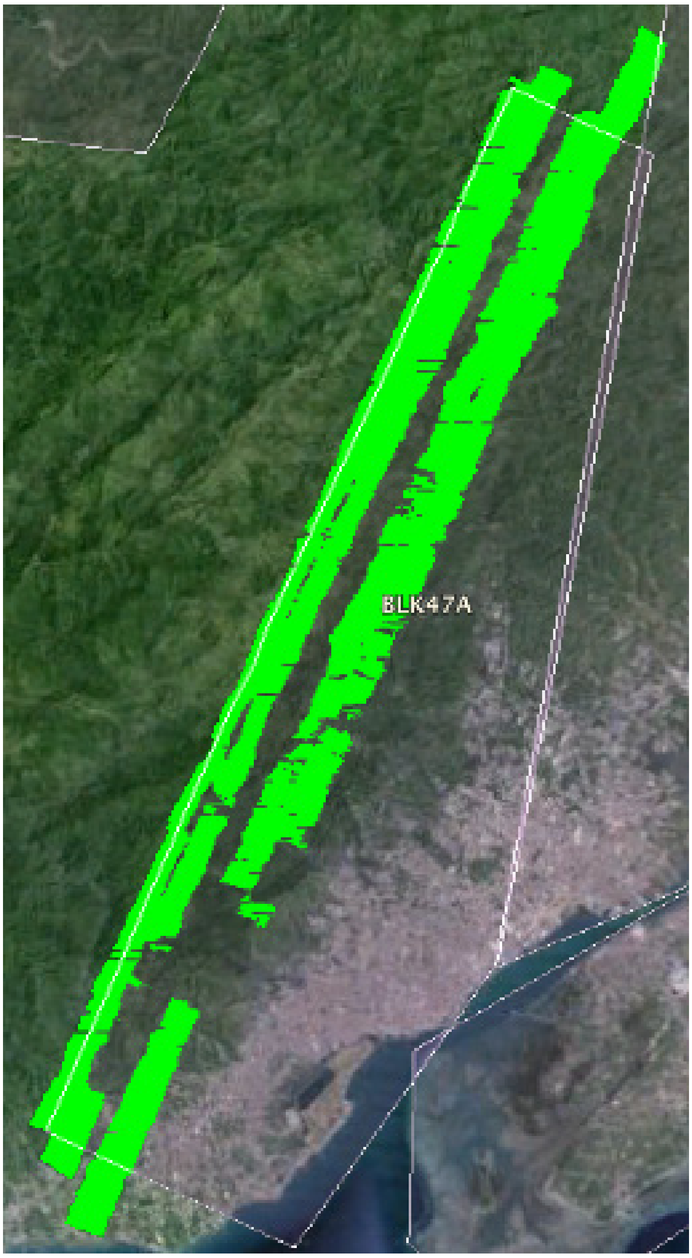


Figure A-7.1. Swath for Flight No. 1769P

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

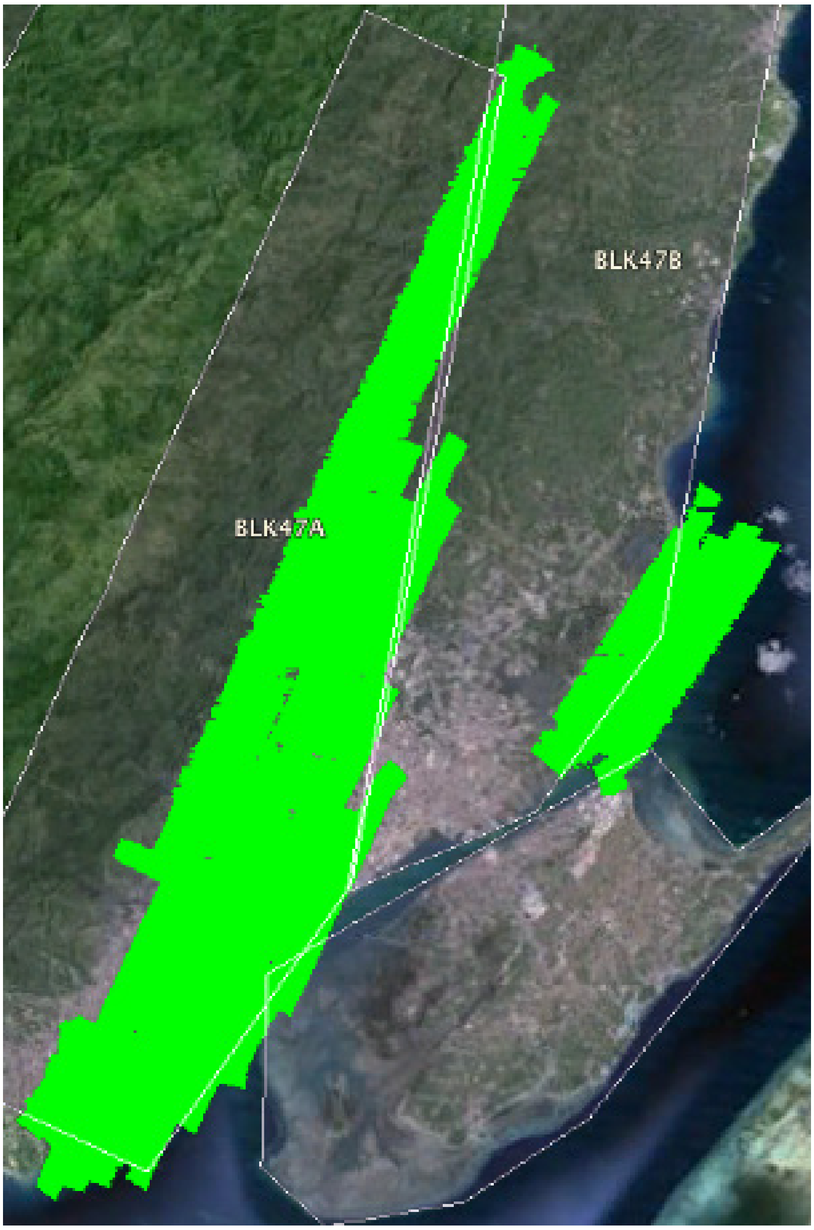


Figure A-7.2. Swath for Flight No. 1773P

Flight No. :	1775P			
Area:	BLK47A			
Mission Name:	1BLK47A211B			
Parameters:	Altitude:	1000m;	Scan Frequency:	30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.3. Swath for Flight No. 1775P

Flight No. :	1789P			
Area:	MACTAN ISLAND			
Mission Name:	1MCTN215A			
Parameters:	Altitude:	1200m;	Scan Frequency:	30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.4. Swath for Flight No. 1789P

Flight No. :	1791P			
Area:	MACTAN ISLAND, BLK47A			
Mission Name:	1MCTN215B			
Parameters:	Altitude:	1200m;	Scan Frequency:	30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.5. Swath for Flight No. 1791P

Flight No. :	1813P				
Area:	MACTAN ISLAND, BLK47A				
Mission Name:	1MCTN221A				
Parameters:	Altitude:	1000m;	Scan Frequency:	30Hz;	
	Scan Angle:	25deg;	Overlap:	30%	

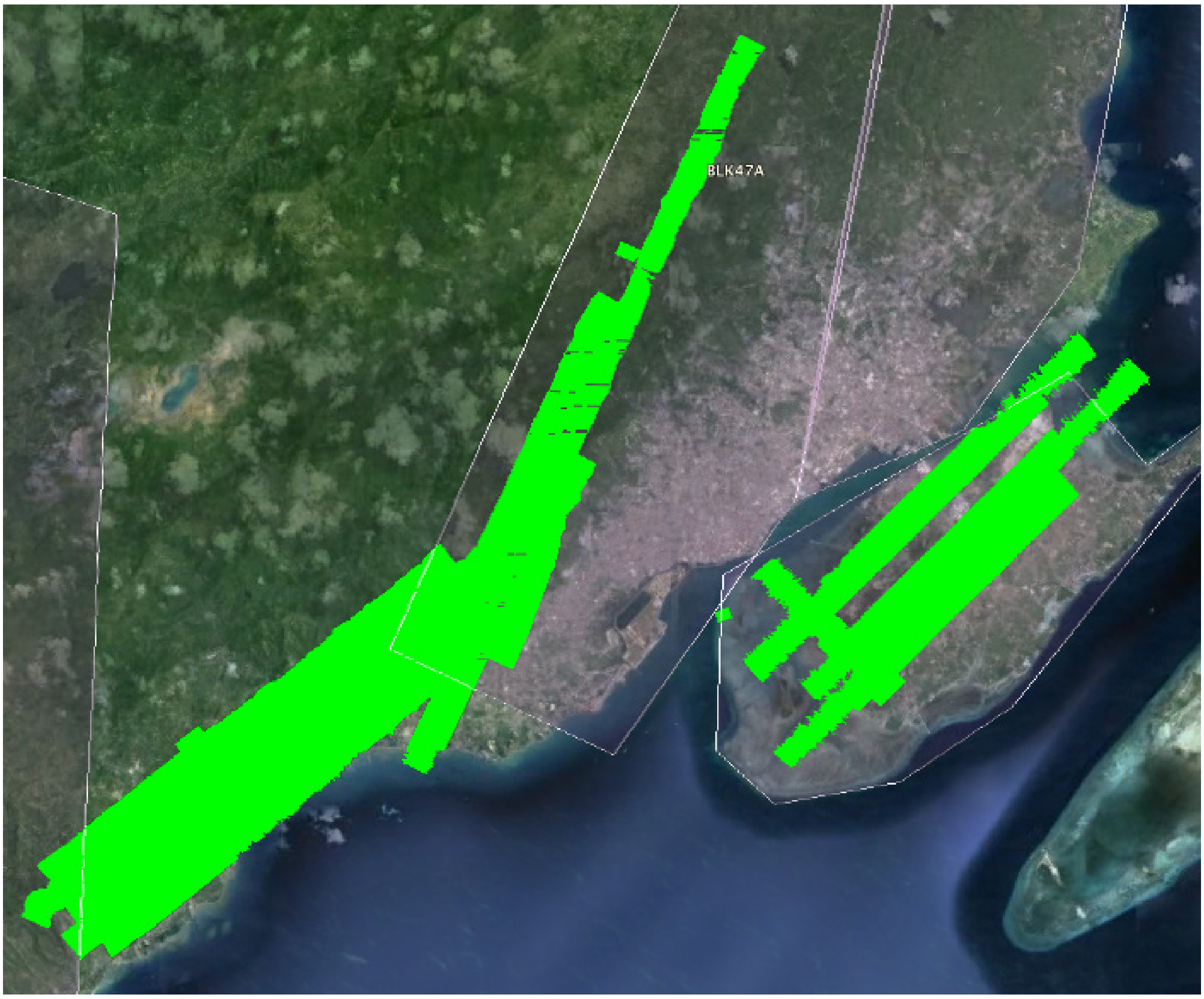


Figure A-7.6. Swath for Flight No. 1813P

Flight No. :	1829P			
Area:	BLK47A			
Mission Name:	1BLK36H47A225A			
Parameters:	Altitude:	1200m;	Scan Frequency:	30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.7. Swath for Flight No. 1829P

Flight No. :	1831P			
Area:	BLK47A, OLANGO ISLAND			
Mission Name:	1OLNG225B			
Parameters:	Altitude:	1200m;	Scan Frequency:	30Hz;
	Scan Angle:	25deg;	Overlap:	30%

Figure A-7.8. Swath for Flight No. 1831P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk47A

Flight Area	Cebu
Mission Name	Blk47A
Inclusive Flights	1769P, 1773P, 1775P, 1791P
Mission Name	1BLK47A211A
Range data size	53.7 GB
Base data size	31.63 MB
POS	641.7 MB
Image	79.11 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)	1.0
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	2.5
Boresight correction stdev (<0.001deg)	0.000183
IMU attitude correction stdev (<0.001deg)	0.001034
GPS position stdev (<0.01m)	0.0057
Minimum % overlap (>25)	57.03%
Ave point cloud density per sq.m. (>2.0)	9.90
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	352
Maximum Height	906.41 m
Minimum Height	66.55 m
Classification (# of points)	
Ground	
Low vegetation	132,668,433
Medium vegetation	422,894,636
High vegetation	470,694,437
Building	31,684,469
Orthophoto	Yes
Processed by	Engr. Carlyn Ann Ibañez, Engr. Christy Lubiano, Marie Joyce Ilagan

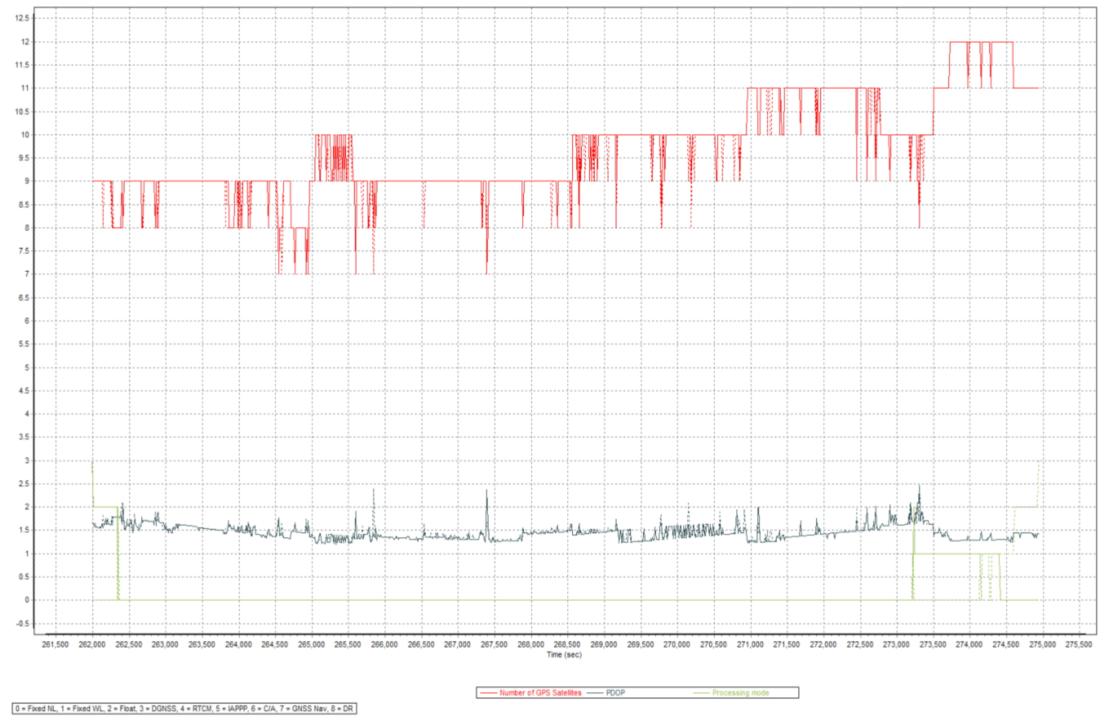


Figure A-8.1. Solution Status

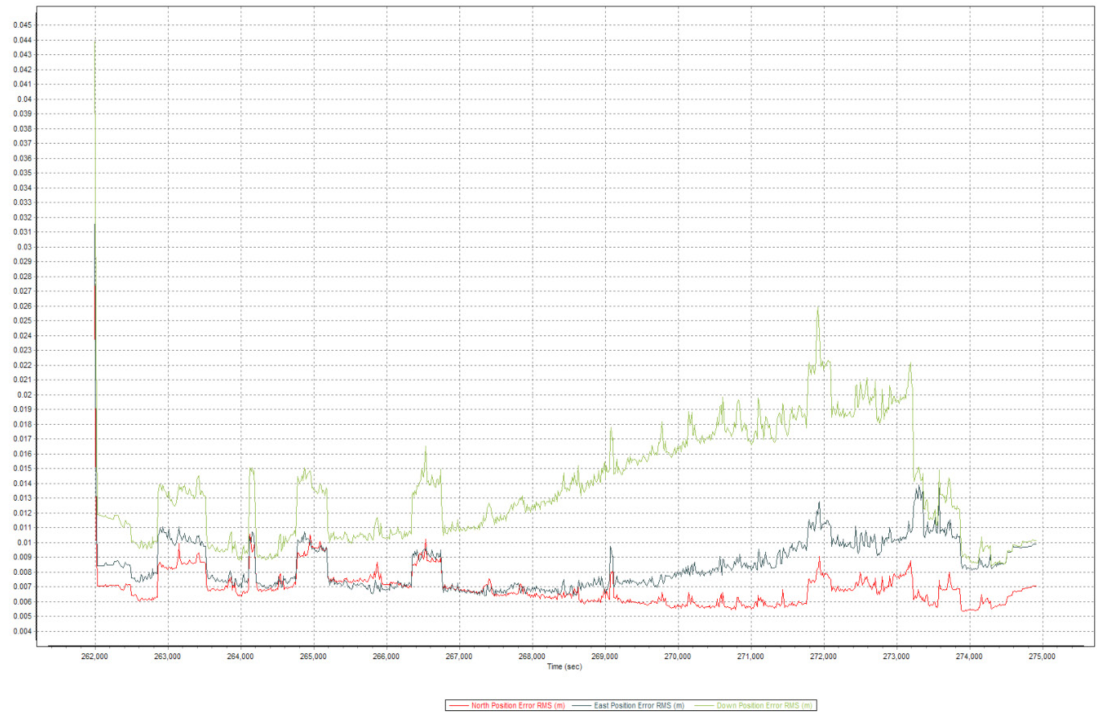


Figure A-8.2. Smoothed Performance Metrics Parameters

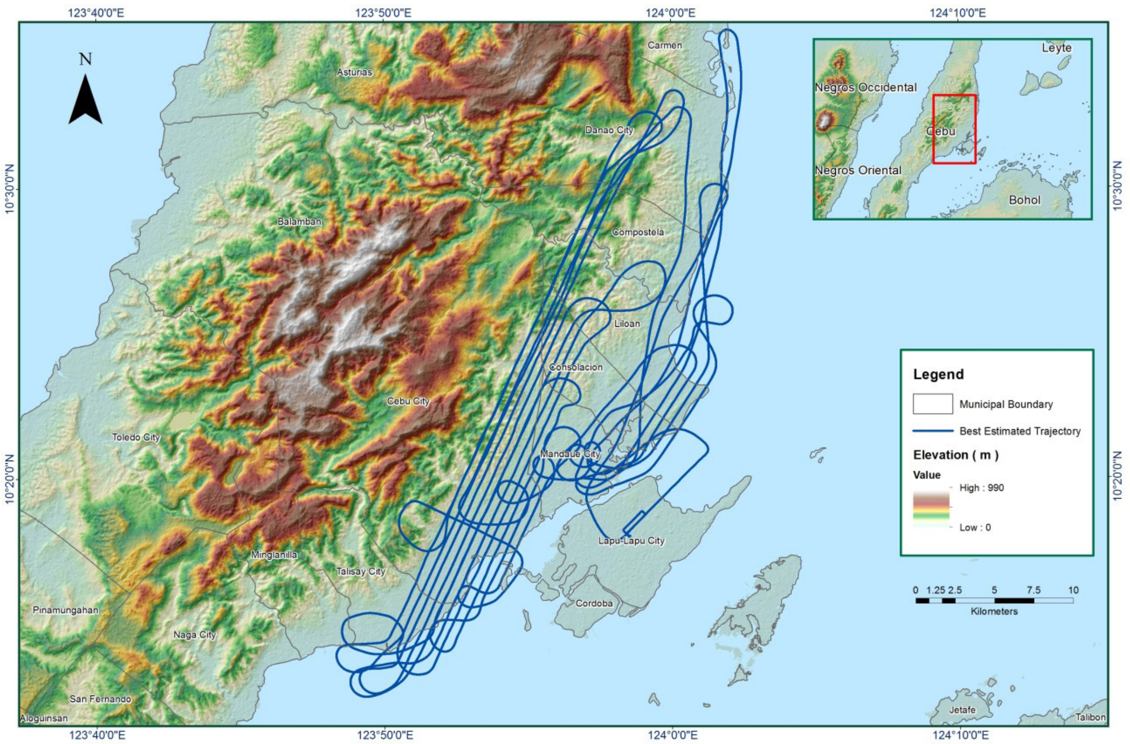


Figure A-8.3. Best Estimated Trajectory

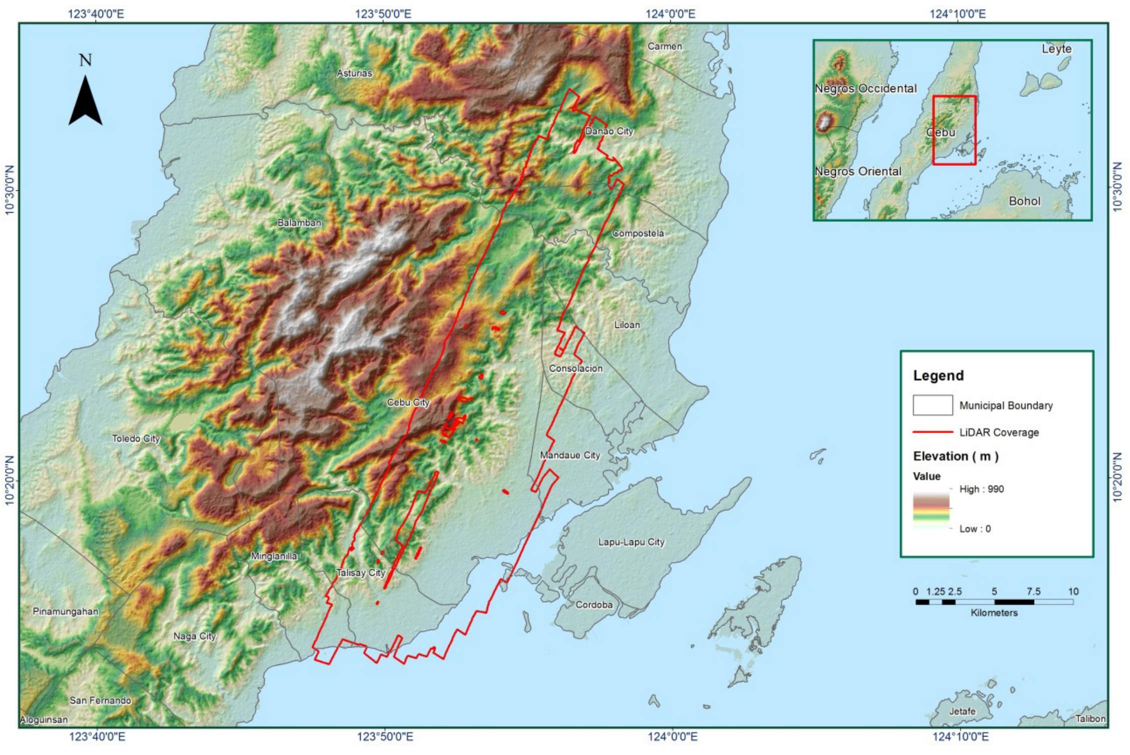


Figure A-8.4 Coverage of LiDAR data

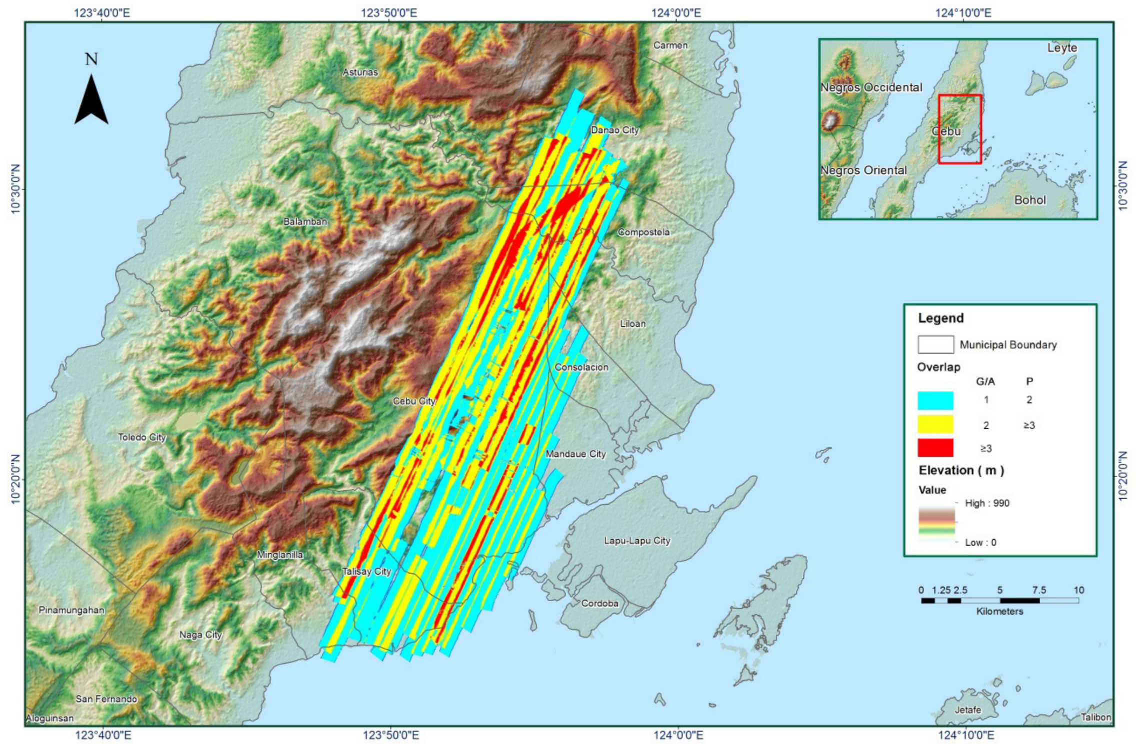


Figure A-8.5. Image of data overlap

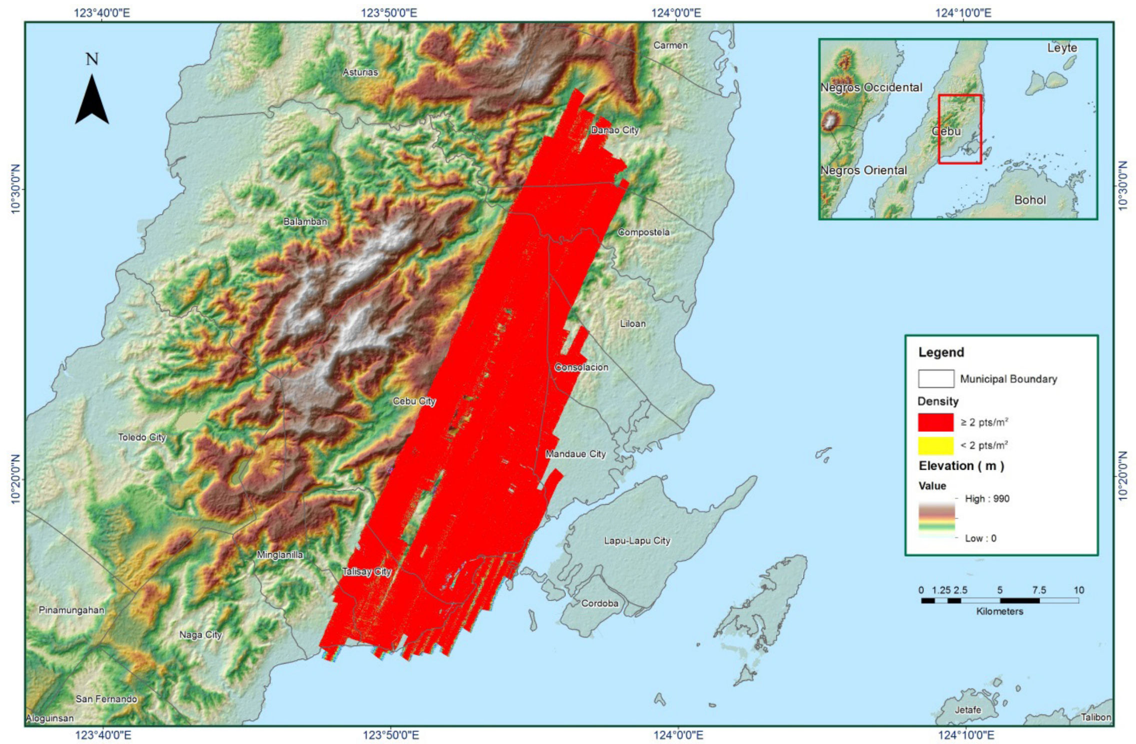


Figure A-8.6. Density map of merged LiDAR data

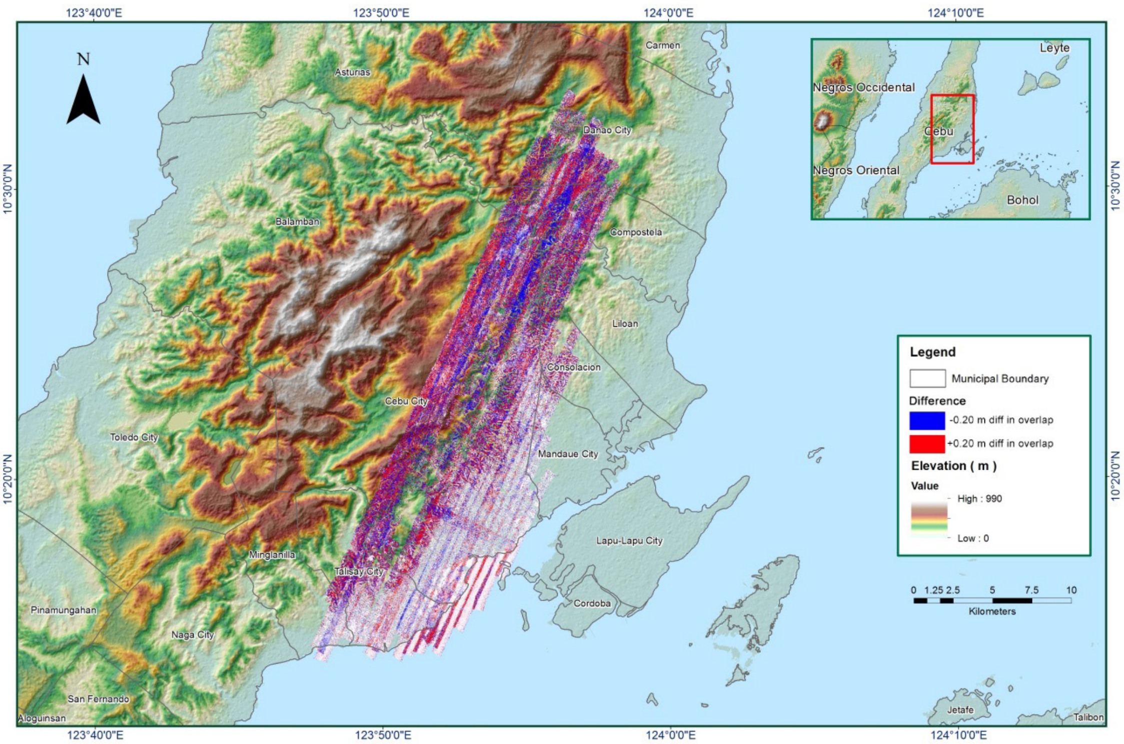


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk47A_additiona

Flight Area	Cebu
Mission Name	Blk47A_additional
Inclusive Flights	1831P
Mission Name	1OLNG225B
Range data size	9.04 GB
Base data size	8.78 MB
POS	143 MB
Image	13.7 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)	1.5
RMSE for East Position (<4.0 cm)	2.55
RMSE for Down Position (<8.0 cm)	5.0
Boresight correction stdev (<0.001deg)	0.001177
IMU attitude correction stdev (<0.001deg)	0.001467
GPS position stdev (<0.01m)	0.0248
Minimum % overlap (>25)	4.24%
Ave point cloud density per sq.m. (>2.0)	6.01
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	42
Maximum Height	811.03 m
Minimum Height	125.77 m
Classification (# of points)	
Ground	6,398,994
Low vegetation	3,584,009
Medium vegetation	17,116,374
High vegetation	35,360,993
Building	891,045
Orthophoto	Yes
Processed by	Engr. Analyn Naldo, Engr. Christy Lu-biano, Engr. Ma. Ailyn Olanda

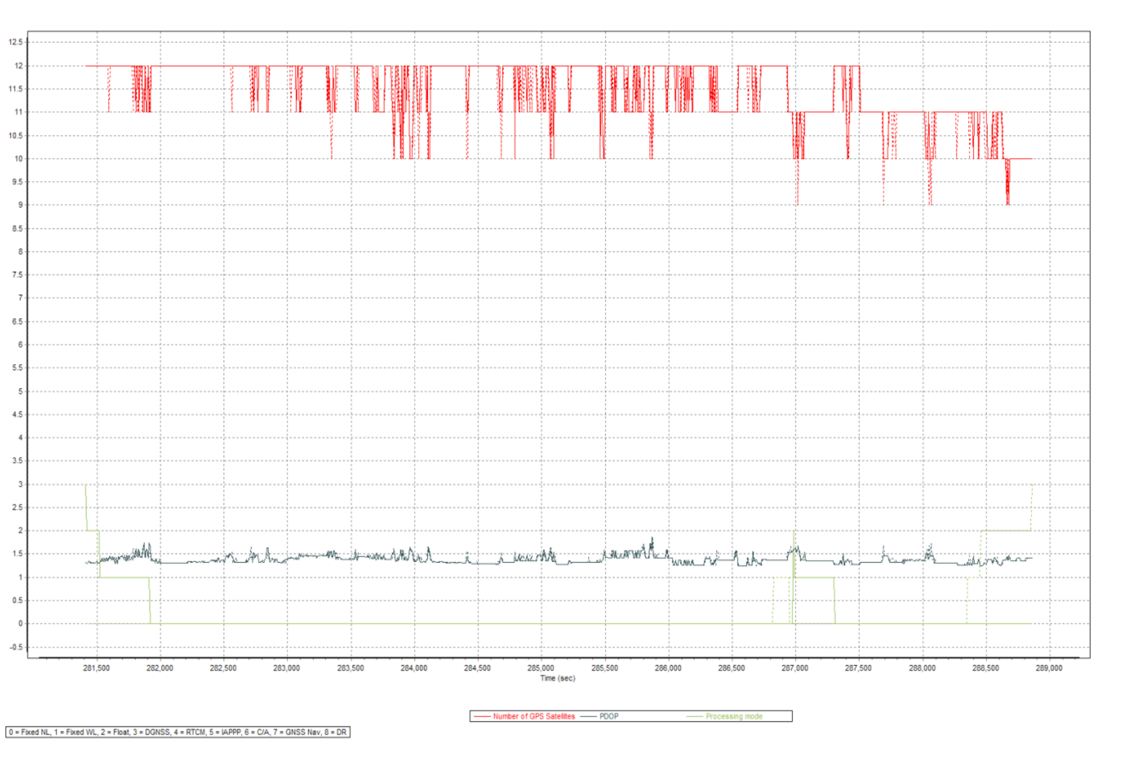


Figure A-8.8. Solution Status

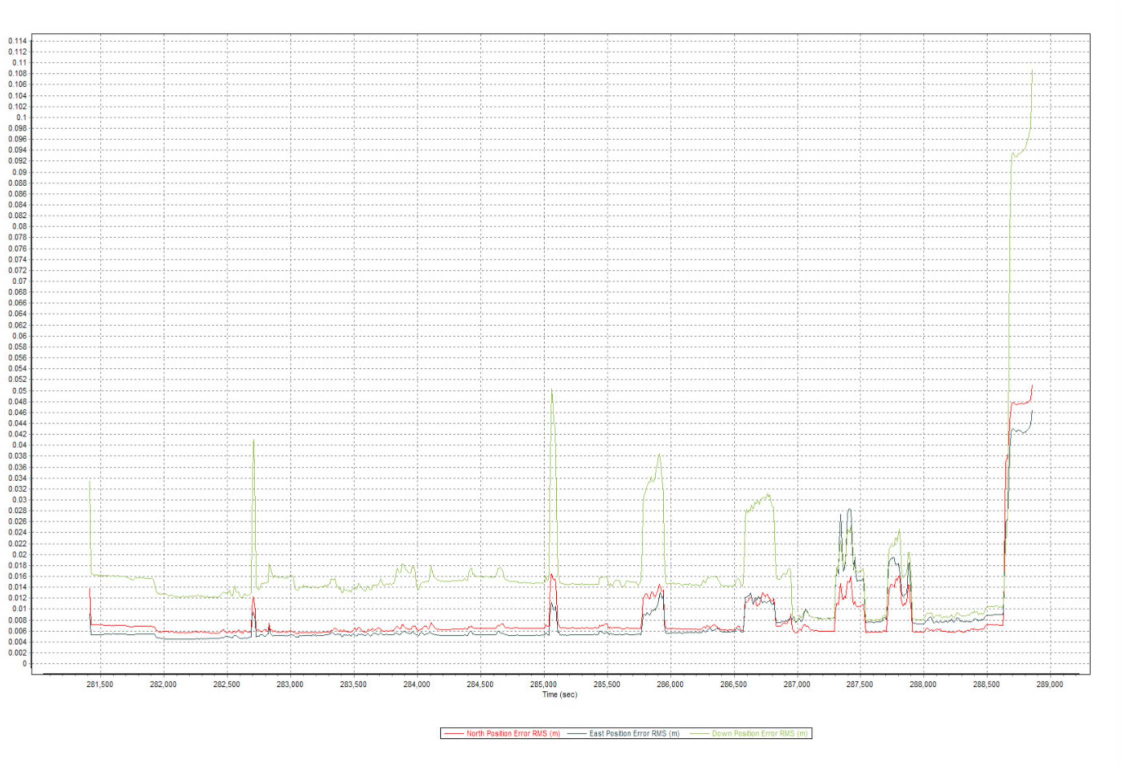


Figure A-8.9. Smoothed Performance Metrics Parameters

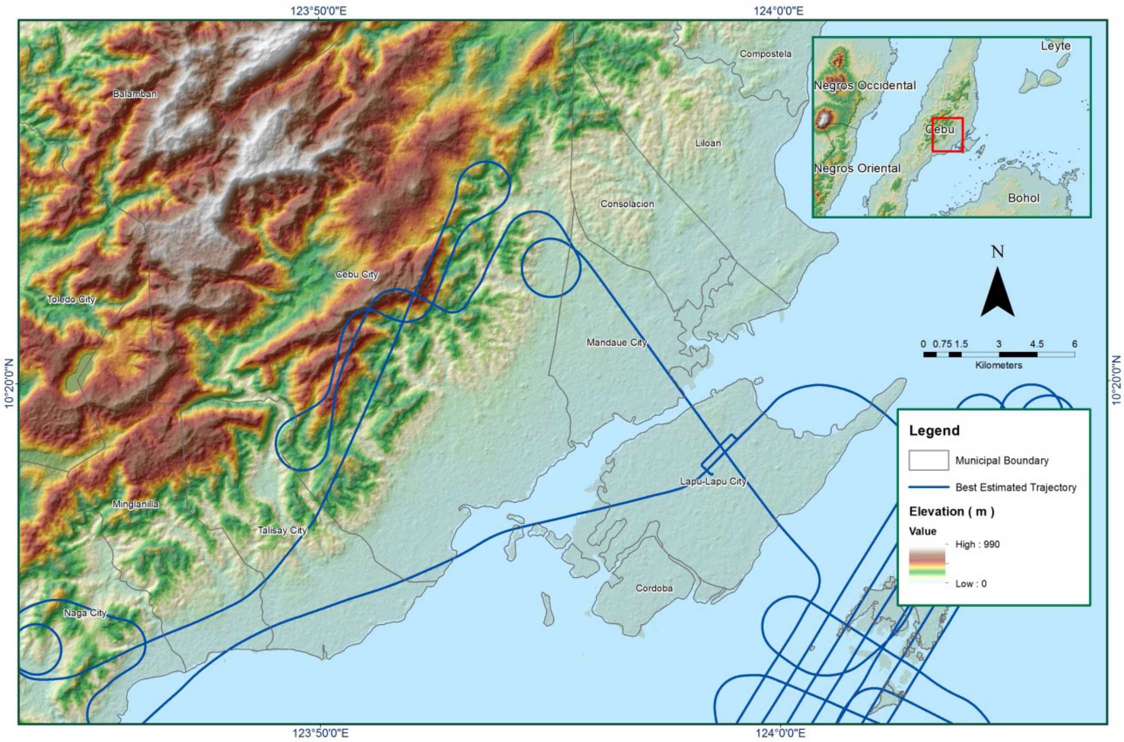


Figure A-8.10. Best Estimated Trajectory

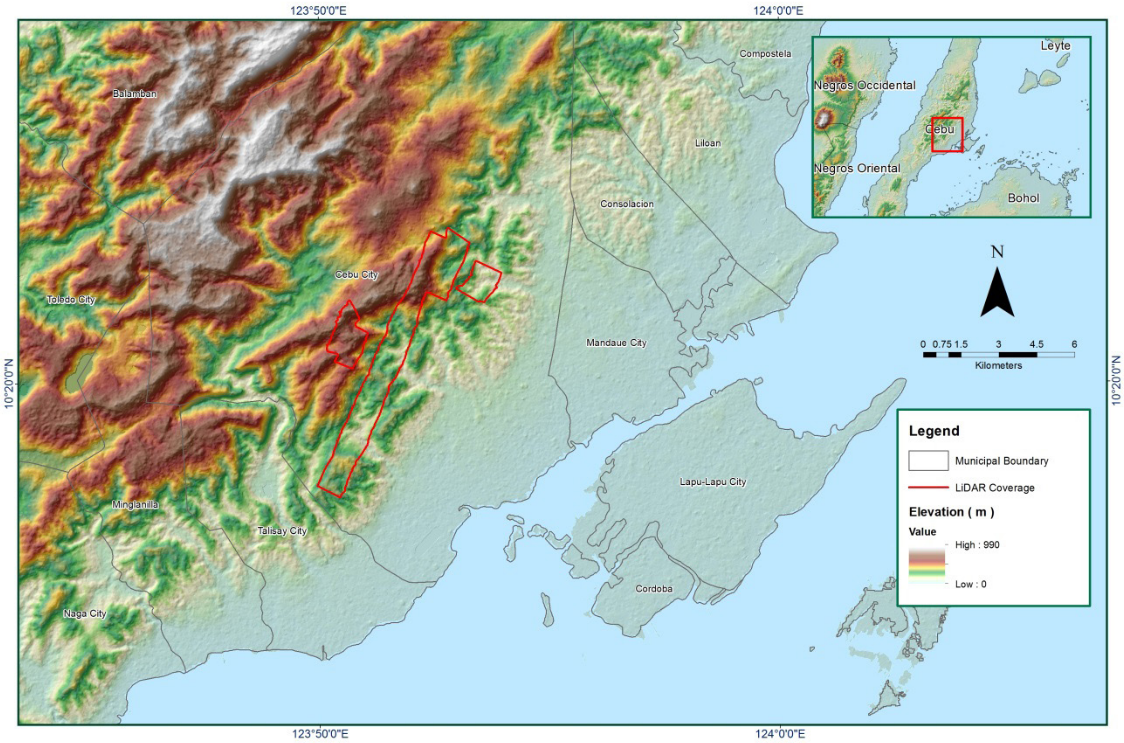


Figure A-8.11. Coverage of LiDAR data

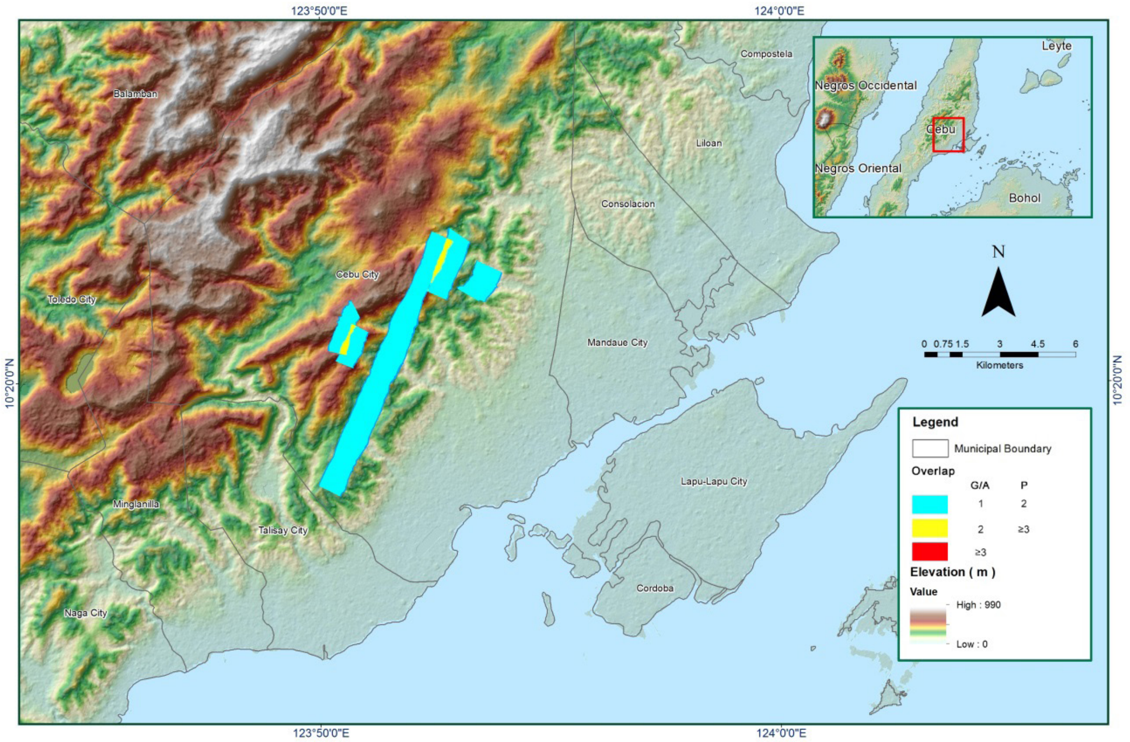


Figure A-8.12. Image of data overlap

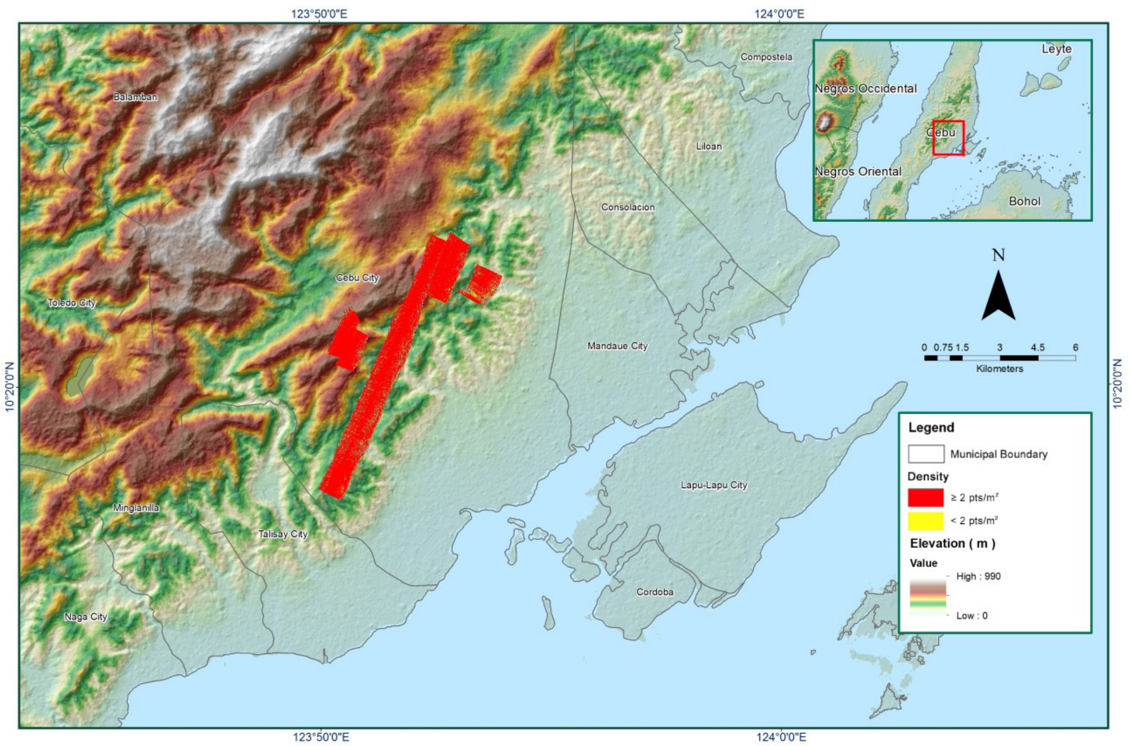


Figure A-8.13. Density map of merged LiDAR data

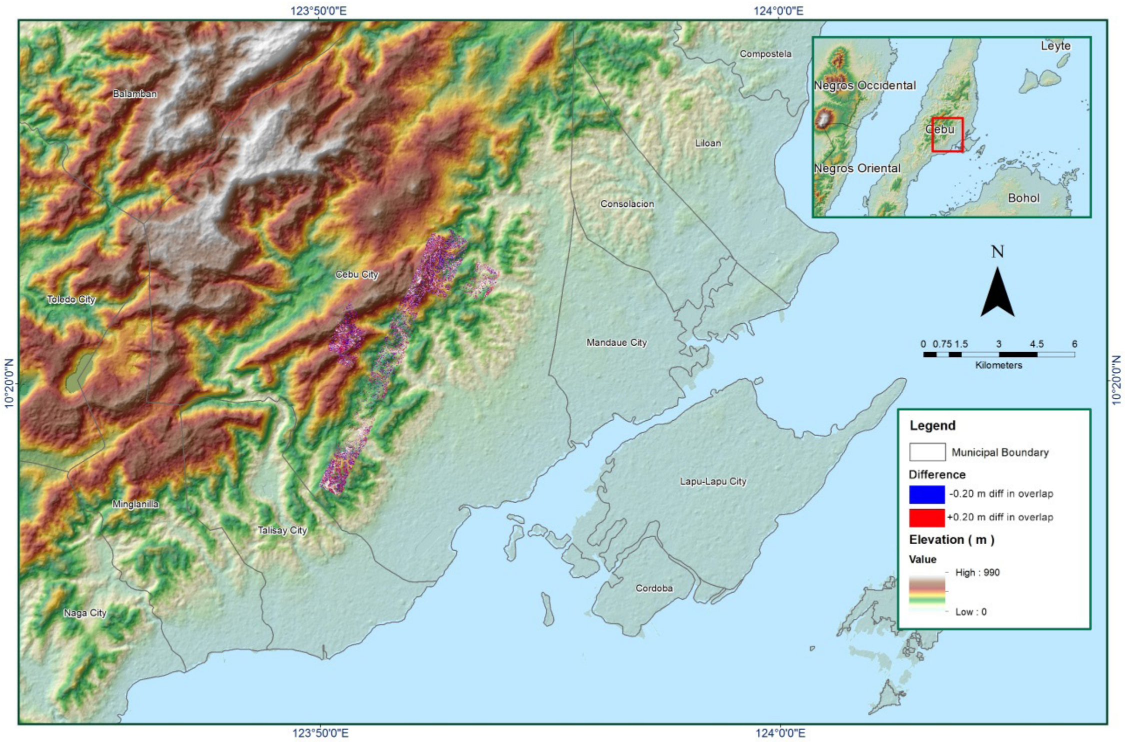


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Mactan Island

Flight Area	Cebu
Mission Name	Mactan Island
Inclusive Flights	1789P, 1791P, 1813P, 1829P
Mission Name	1MCTN221A
Range data size	35.4 GB
Base data size	31.69 MB
POS	752 MB
Image	43.67 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)	1.8
RMSE for East Position (<4.0 cm)	2.8
RMSE for Down Position (<8.0 cm)	4.5
Boresight correction stdev (<0.001deg)	0.001177
IMU attitude correction stdev (<0.001deg)	0.001467
GPS position stdev (<0.01m)	0.0248
Minimum % overlap (>25)	30.90%
Ave point cloud density per sq.m. (>2.0)	5.22
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	429
Maximum Height	810.97 m
Minimum Height	67.02 m
Classification (# of points)	
Ground	36870851
Low vegetation	19024257
Medium vegetation	72670579
High vegetation	97693379
Building	14902433
Orthophoto	Yes
Processed by	Engr. Jennifer Saguran, Engr. Christy Lubiano, Jovy Narisma

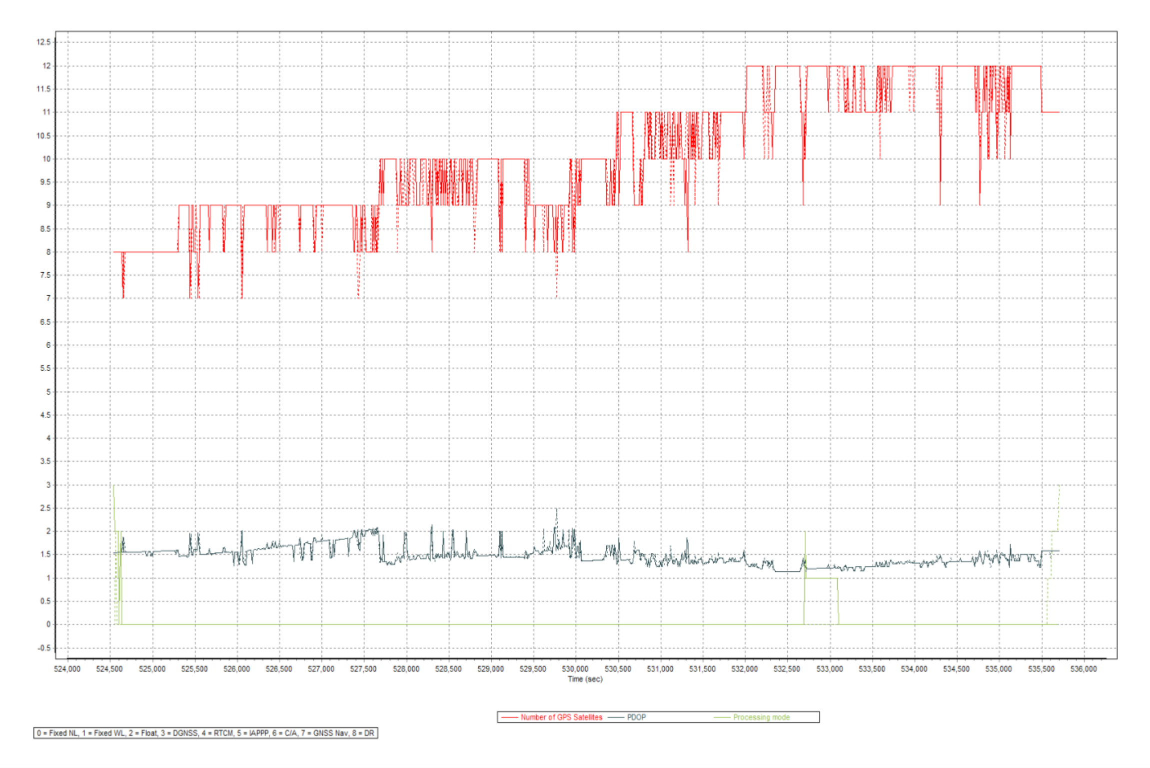


Figure A-8.15. Solution Status

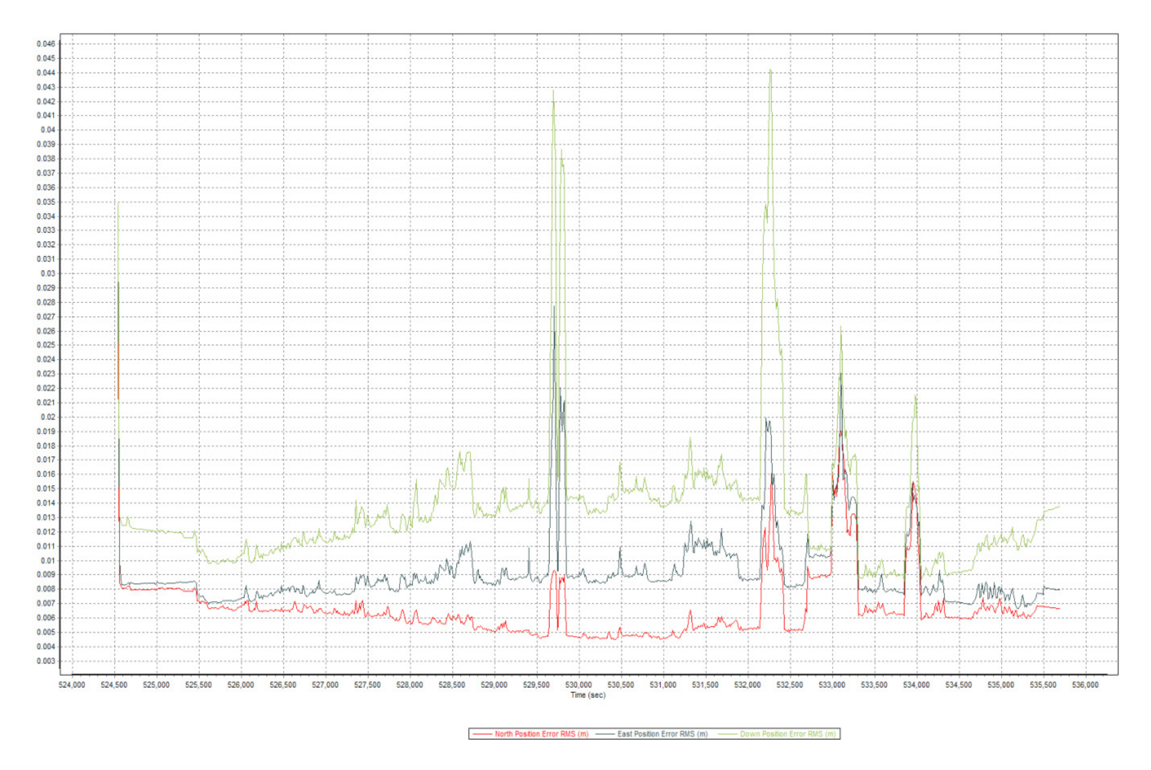


Figure A-8.16. Smoothed Performance Metrics Parameters

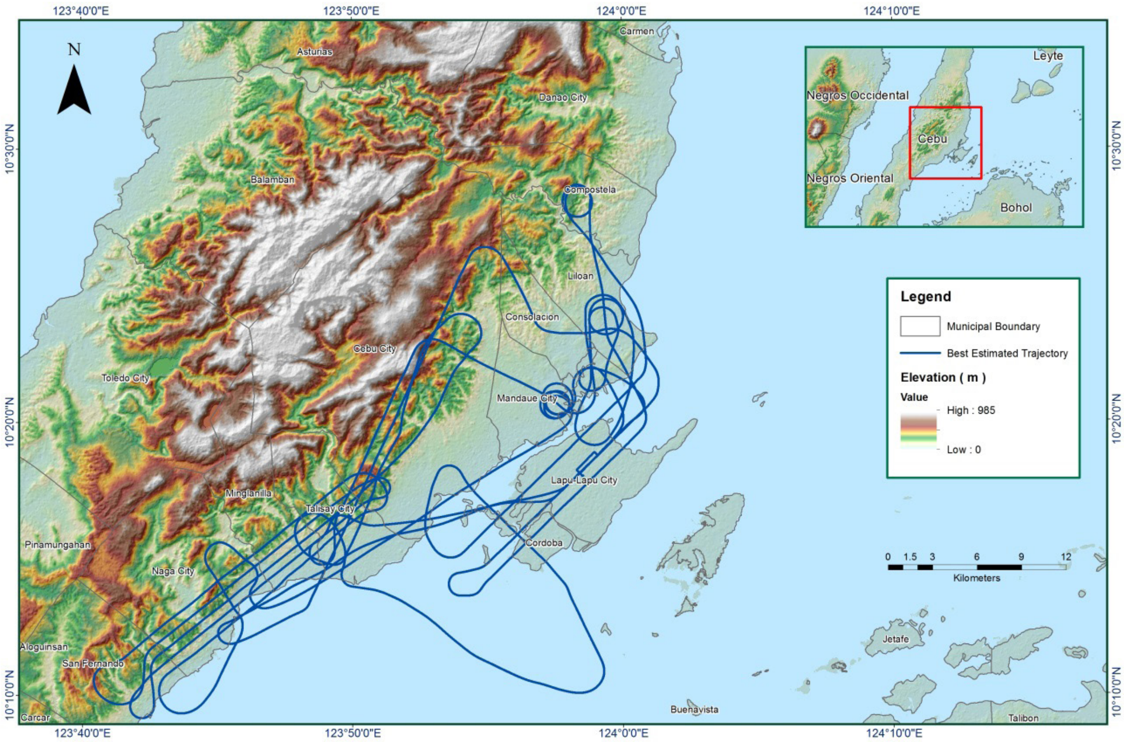


Figure A-8.17. Best Estimated Trajectory

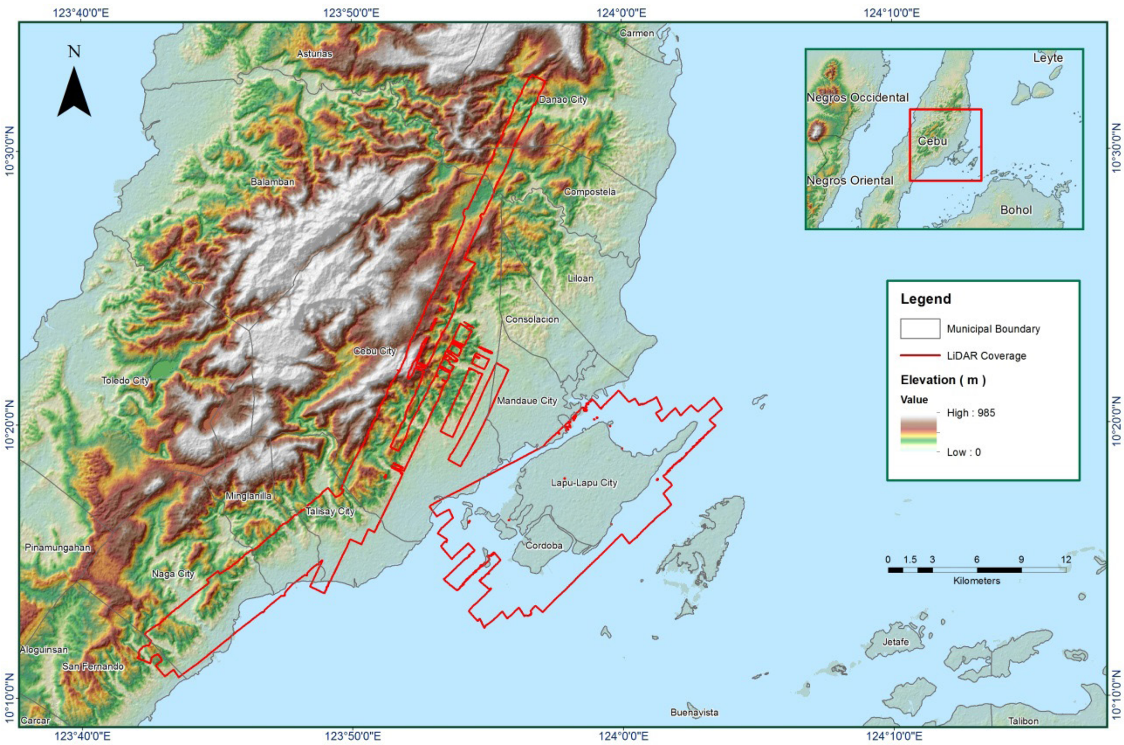


Figure A-8.18. Coverage of LiDAR data

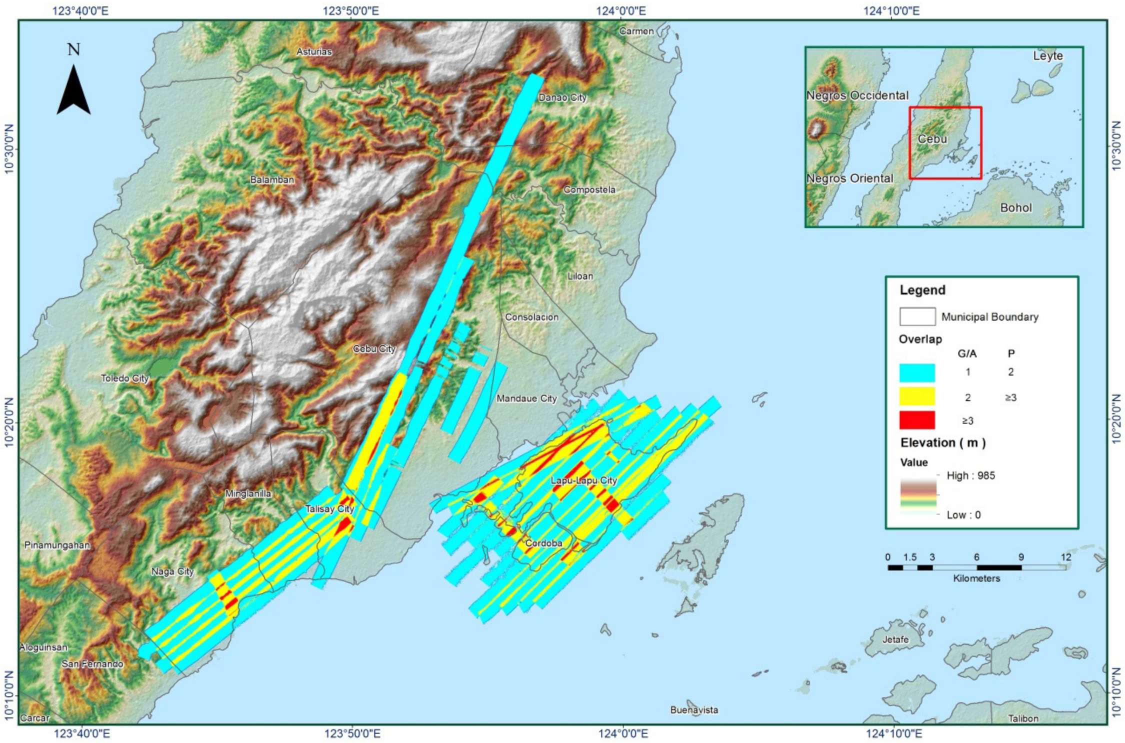


Figure A-8.19. Image of data overlap

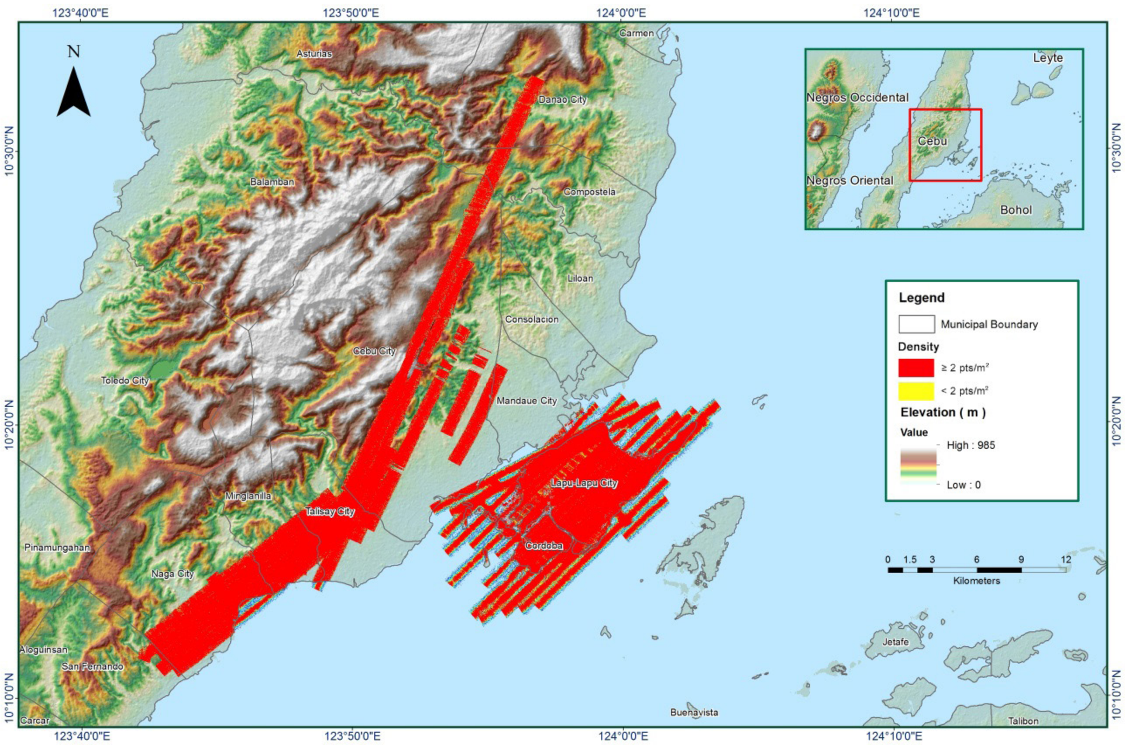


Figure A-8.20. Density map of merged LiDAR data

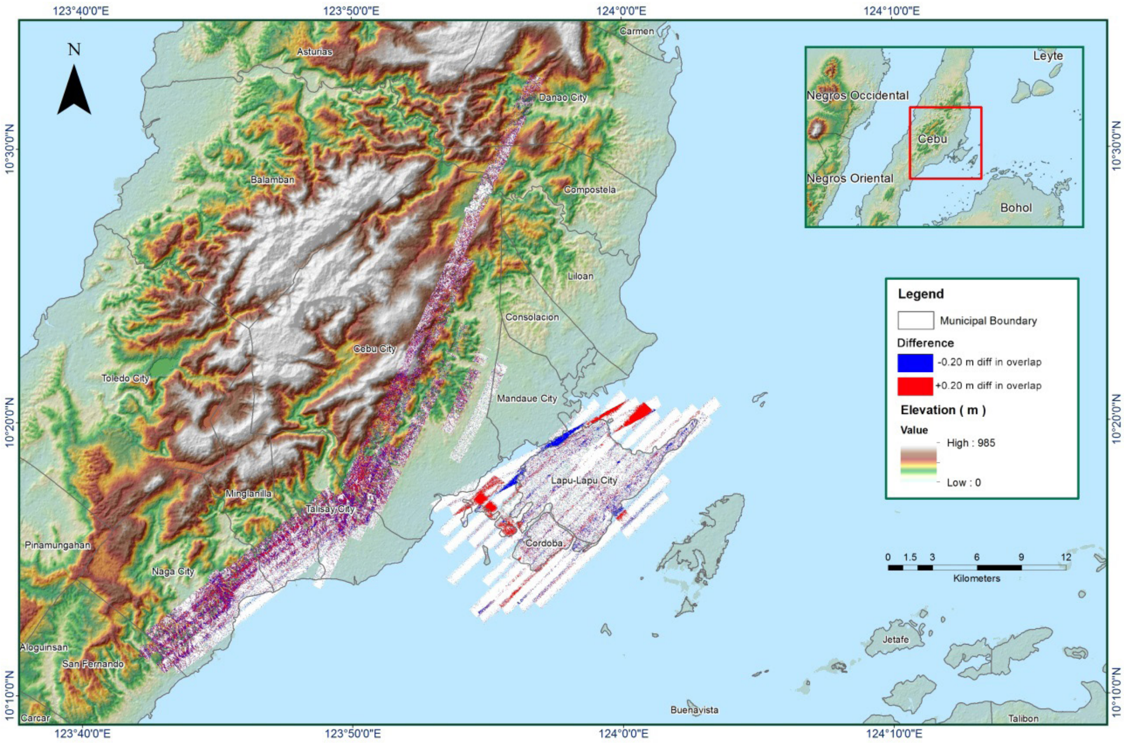


Figure A-8.21. Elevation difference between flight lines

Table A-8.4. Mission Summary Report for Mission Olango Island

Flight Area	Cebu
Mission Name	Olango Island
Inclusive Flights	1831P
Mission Name	1OLNG225B
Range data size	9.04 GB
Base data size	8.78 MB
POS	143 MB
Image	13.7 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)	1.5
RMSE for East Position (<4.0 cm)	2.55
RMSE for Down Position (<8.0 cm)	5.0
Boresight correction stdev (<0.001deg)	0.001177
IMU attitude correction stdev (<0.001deg)	0.001467
GPS position stdev (<0.01m)	0.0248
Minimum % overlap (>25)	12.45%
Ave point cloud density per sq.m. (>2.0)	2.38
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	120
Maximum Height	120.79 m
Minimum Height	67.31 m
Classification (# of points)	
Ground	48501321
Low vegetation	42382103
Medium vegetation	29442223
High vegetation	6872002
Building	1320074
Orthophoto	Yes
Processed by	Engr. Analyn Naldo, Engr. Harmond Santos, Engr. Elainne Lopez

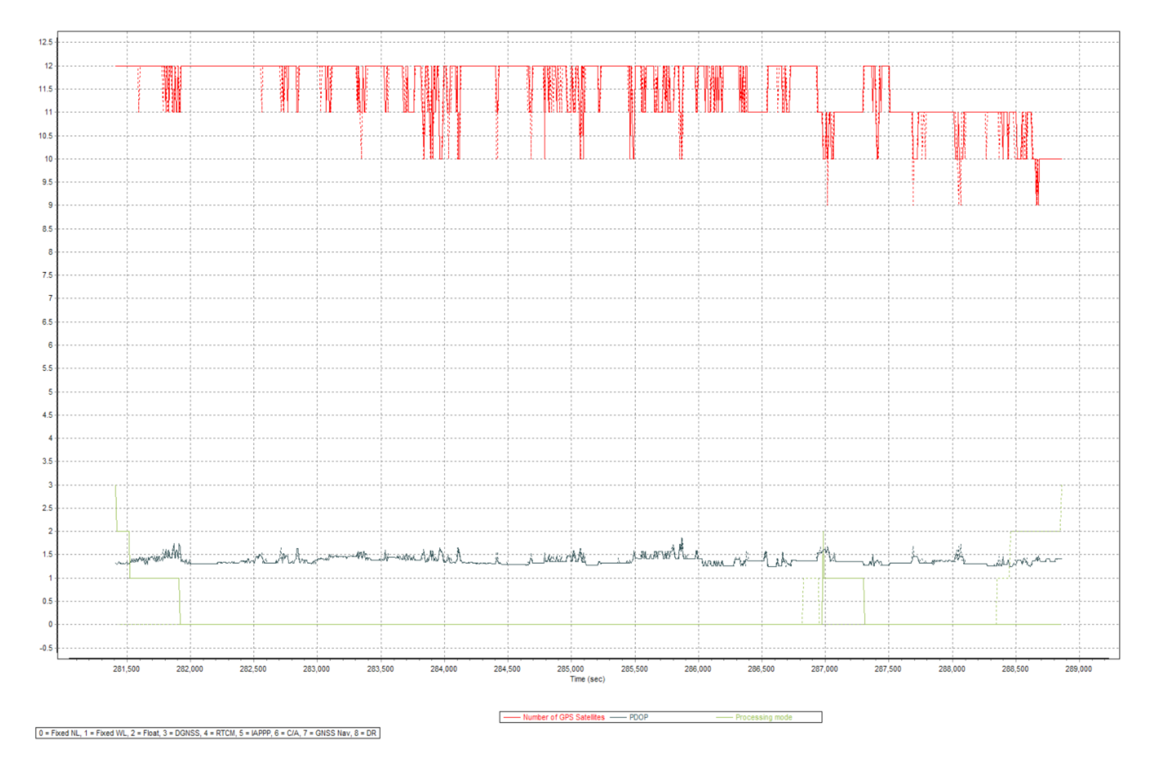


Figure A-8.22. Solution Status

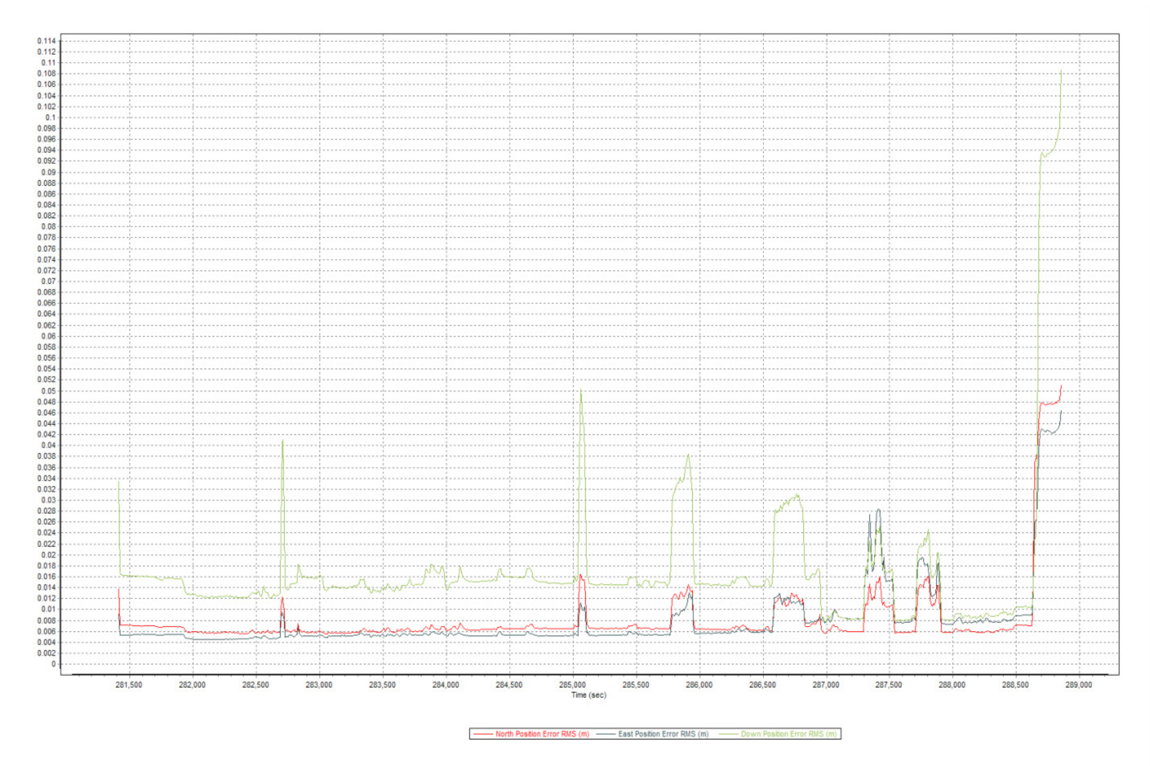


Figure A-8.23. Smoothed Performance Metrics Parameters

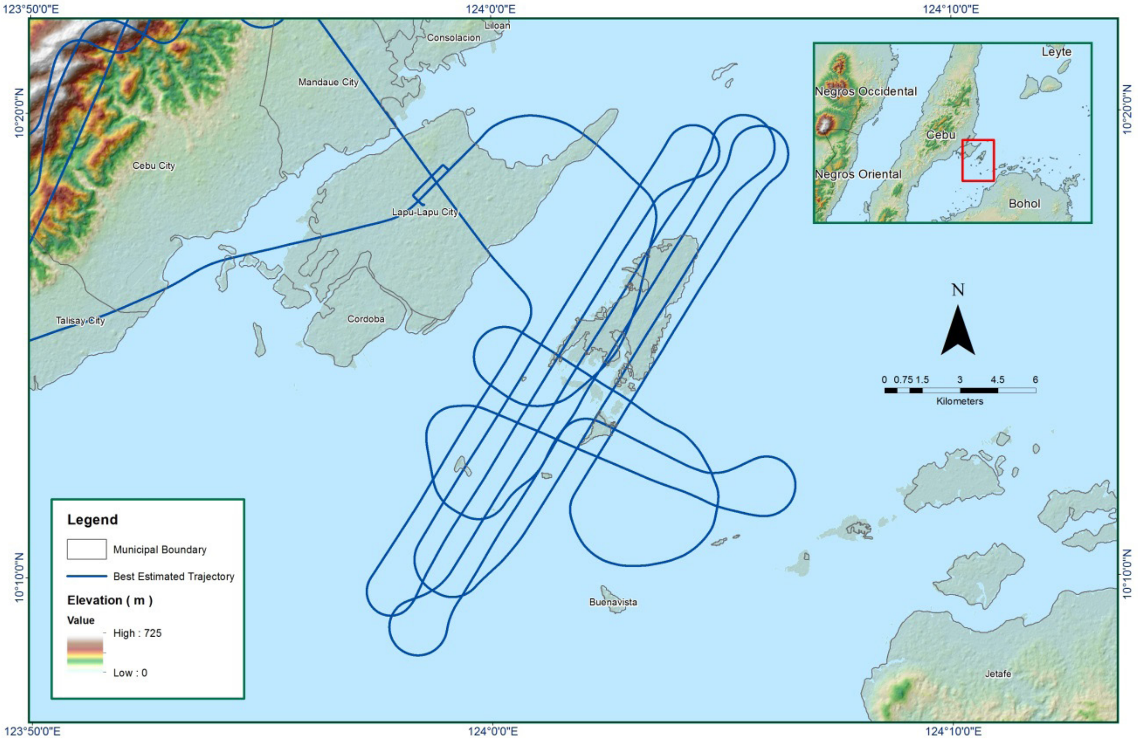


Figure A-8.24. Best Estimated Trajectory

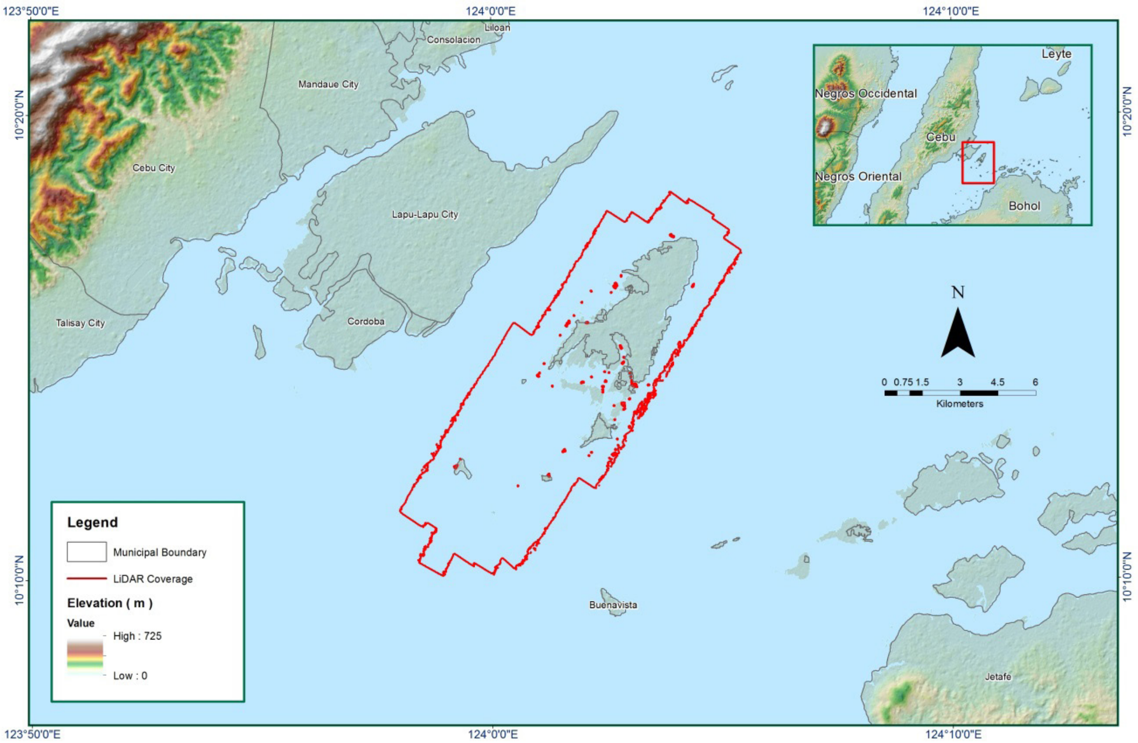


Figure A-8.25. Coverage of LiDAR data

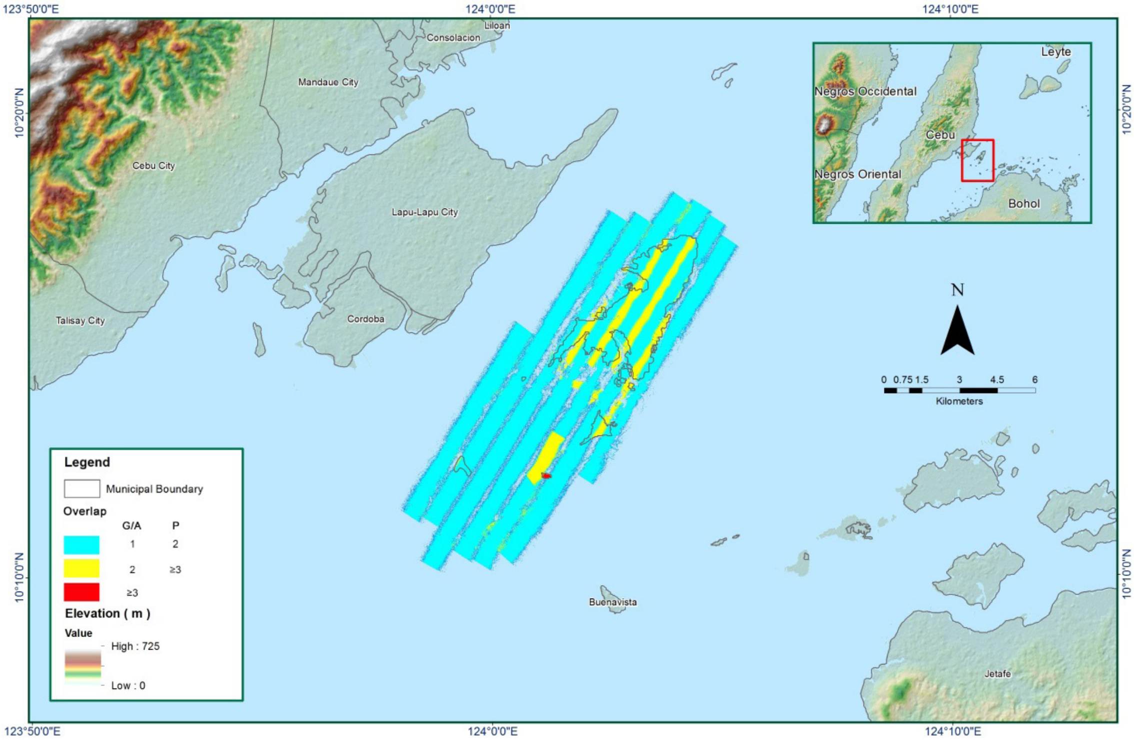


Figure A-8.26. Image of data overlap

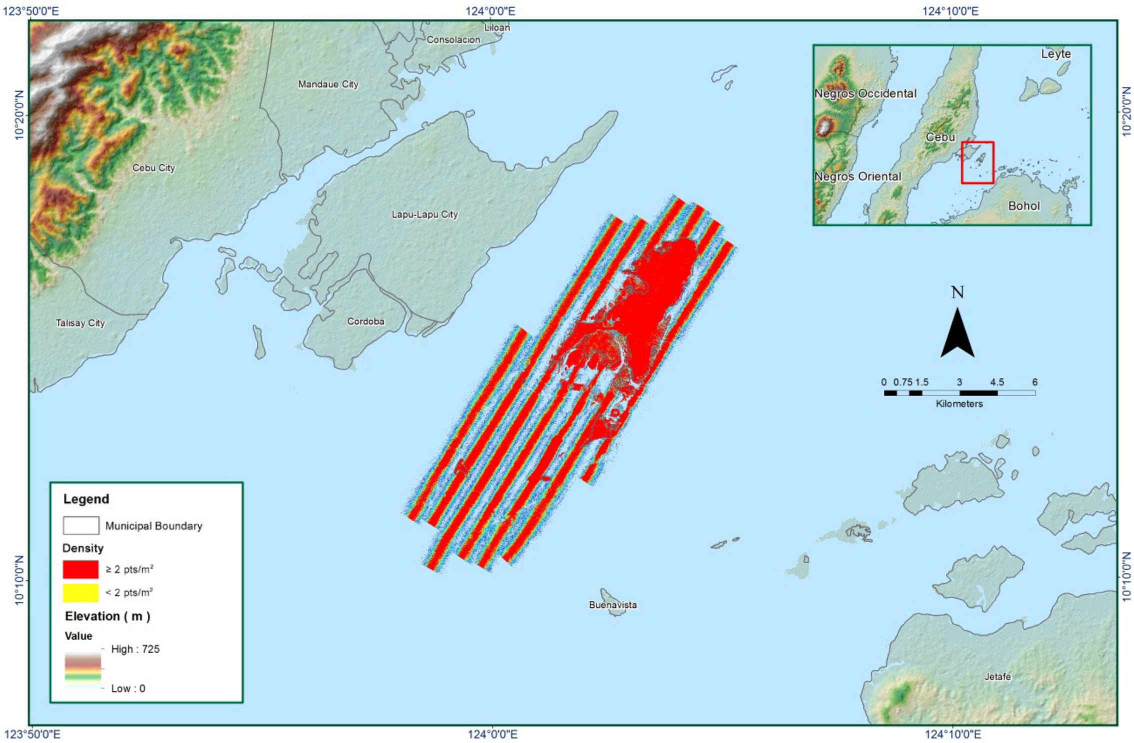


Figure A-8.27. Density map of merged LiDAR data

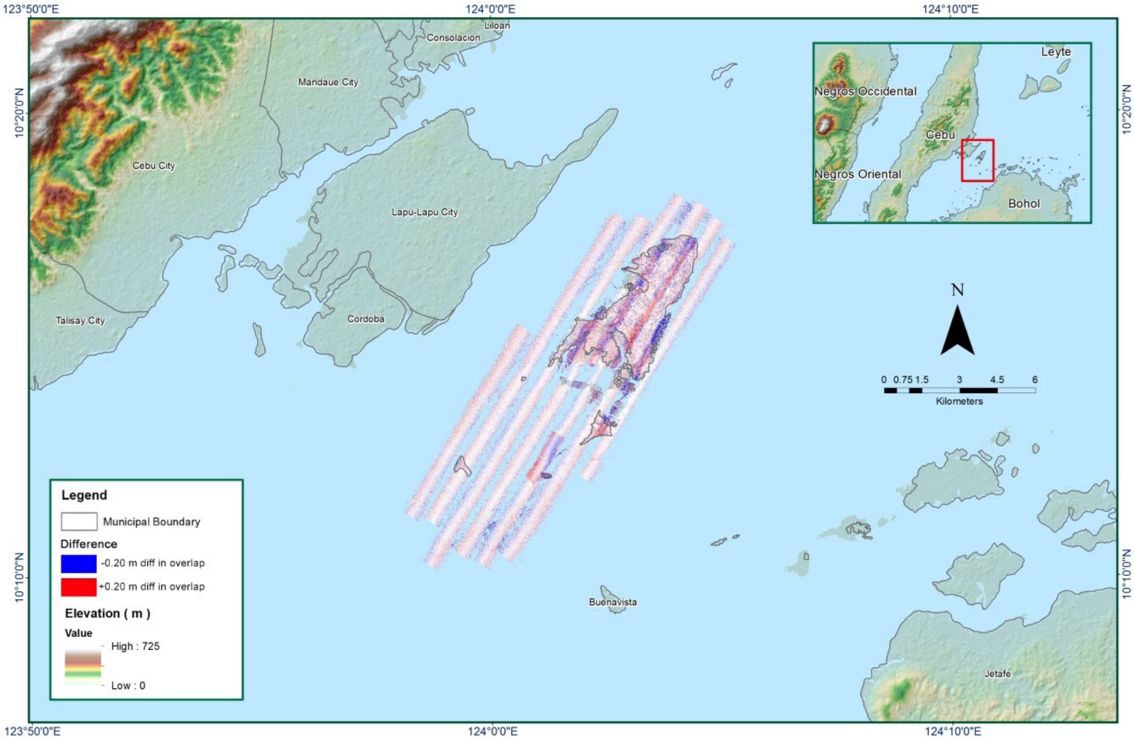


Figure A-8.28. Elevation difference between flight lines

Annex 9. Mananga Model Basin Parameters

Table A-9.1. Mananga Model Basin Parameters

Basin Number	SCS Curve Number Loss Model			Clark Transform Model		Recession Constant Baseflow Model				
	Initial Abstraction	Curve Number	Impervious	Time of Concentration	Storage Coefficient	Initial Type	Initial Discharge	Recession Constant	Threshold Type	Ratio to Peak
W400	2.8280455	83.8461	0	0.2152	0.2121602	Discharge	0.0209124	0.0008051	Ratio to Peak	0.13618
W410	2.2897328	52.2187	0	0.31314	0.2372482	Discharge	0.0365634	0.000781	Ratio to Peak	0.13296
W420	4.0428342	86.6951	0	2.2288	2.0106	Discharge	0.0725076	0.0017024	Ratio to Peak	0.09
W430	2.4806098	78.328	0	0.2725	0.265825	Discharge	0.041922	0.0012058	Ratio to Peak	0.18016
W440	2.2639199	78.3359	0	0.22415	0.129948	Discharge	0.0190008	0.0007812	Ratio to Peak	0.05993
W450	2.5606199	71.9336	0	0.24489	0.1599948	Discharge	0.0311814	0.001242	Ratio to Peak	0.1343
W460	2.5194775	78.7091	0	0.4264	0.128919	Discharge	0.0160558	0.0013141	Ratio to Peak	0.09041
W470	2.3026887	54.372	0	0.15943	0.1041642	Discharge	0.0156645	0.0017725	Ratio to Peak	0.09004
W480	2.6565529	81.7827	0	0.26302	0.1731562	Discharge	0.0135002	0.0015797	Ratio to Peak	0.09034
W490	2.6656517	54.6358	0	0.31178	0.1862196	Discharge	0.0170722	0.002646	Ratio to Peak	0.09045
W500	2.7182665	53.5728	0	0.41595	0.74709	Discharge	0.0343206	0.0017283	Ratio to Peak	0.09
W510	2.7297389	82.8877	0	3.0006	2.8733	Discharge	0.0651996	0.0009018	Ratio to Peak	0.09
W520	2.4087095	54.372	0	0.16552	0.258524	Discharge	0.0218556	0.0019303	Ratio to Peak	0.09
W530	2.6786076	79.9264	0	0.43227	0.162974	Discharge	0.0248724	0.0020098	Ratio to Peak	0.13457
W540	2.2926009	54.372	0	0.20492	1.0856	Discharge	0.031689	0.0019697	Ratio to Peak	0.09
W550	2.5327301	86.4547	0	0.17572	0.274449	Discharge	0.0151807	0.0011879	Ratio to Peak	0.09041
W560	2.6138281	86.5778	0	0.3811	0.385532	Discharge	0.0271044	0.0012	Ratio to Peak	0.0927
W570	2.5297631	80.8282	0	0.51437	0.2312016	Discharge	0.0240624	0.0020198	Ratio to Peak	0.09045
W580	2.6525969	81.558	0	0.27938	0.19662	Discharge	0.015054	0.0018088	Ratio to Peak	0.20675
W590	2.2612496	80.9337	0	0.33729	0.395724	Discharge	0.0360036	0.0013399	Ratio to Peak	0.0908
W600	3.8750009	73.4118	0	0.25336	0.27606	Discharge	0.0351162	0.0023113	Ratio to Peak	0.09

W610	2.5629935	86.954	0	0.19961	0.20444	Discharge	0.0153982	0.001353	Ratio to Peak	0.09071
W620	2.3979294	90.2865	0	0.2091	0.1429624	Discharge	0.0040233	0.0017902	Ratio to Peak	0.13095
W630	2.3032821	95.0211	0	0.11793	0.1137976	Discharge	0.0008865	0.0017811	Ratio to Peak	0.05371
W640	1.6645859	86.8553	10	0.16391	0.23941	Discharge	0.0055268	0.0005227	Ratio to Peak	0.06151
W650	2.4591485	82.2556	10	0.24559	0.25277	Discharge	0.0202662	0.0012806	Ratio to Peak	0.09039
W660	2.902715	76.6613	10	0.67846	0.70337	Discharge	0.0969102	0.0005836	Ratio to Peak	0.09
W670	2.9263521	80.1374	10	0.57127	0.32497	Discharge	0.0540108	0.0005836	Ratio to Peak	0.08993
W680	2.5587408	79.0442	10	0.26709	0.2599	Discharge	0.018396	0.0005955	Ratio to Peak	0.06
W690	2.7694967	75.2251	10	0.93693	1.7689	Discharge	0.0856134	0.0001176	Ratio to Peak	0.09
W700	2.7604968	78.7306	10	0.28765	0.28004	Discharge	0.0140019	0.0005955	Ratio to Peak	0.06
W710	2.7560463	82.1413	10	0.40714	0.38649	Discharge	0.0220428	0.0005252	Ratio to Peak	0.13294
W720	7.0605699	83.7572	10	0.29523	0.19195	Discharge	0.0006494	0.0001176	Ratio to Peak	0.06
W730	9.1346018	96.723	10	0.2727	0.17729	Discharge	0.0013102	0.0008754	Ratio to Peak	0.0402
W740	2.3470948	83.5442	10	0.40789	0.38387	Discharge	0.0300816	0.0005926	Ratio to Peak	0.09103
W750	2.7606946	51.1733	10	0.42369	0.6117	Discharge	0.0339678	0.0005955	Ratio to Peak	0.09
W760	2.702937	77.5337	10	0.92286	2.9678	Discharge	0.0714132	0.0008753	Ratio to Peak	0.09
W770	9.2140185	75.2251	10	0.23527	0.22823	Discharge	0.0097919	0.0005955	Ratio to Peak	0.0588
W780	9.2138207	75.2251	10	0.25775	0.25017	Discharge	0.0067964	0.0005956	Ratio to Peak	0.06

Annex 10. Mananga Model Reach Parameters

Table A-10.1. Mananga Model Reach Parameters

Reach Number	Muskingum Cunge Routing Model						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R110	Automatic Fixed Interval	1240.2	0.04793	0.010757	Trapezoid	20	1
R130	Automatic Fixed Interval	1635.4	0.03168	0.023258	Trapezoid	20	1
R140	Automatic Fixed Interval	1214.7	0.00937	0.010331	Trapezoid	20	1
R190	Automatic Fixed Interval	1313	0.05773	0.008174	Trapezoid	20	1
R210	Automatic Fixed Interval	1356.8	0.01359	0.007218	Trapezoid	20	1
R220	Automatic Fixed Interval	441.13	0.02858	0.016282	Trapezoid	20	1
R230	Automatic Fixed Interval	98.995	0.0001	0.062534	Trapezoid	20	1
R240	Automatic Fixed Interval	3490.1	0.07776	0.022345	Trapezoid	20	1
R250	Automatic Fixed Interval	616.27	0.00486	0.014818	Trapezoid	20	1
R280	Automatic Fixed Interval	3366.9	0.01539	0.012622	Trapezoid	20	1
R300	Automatic Fixed Interval	1142.3	0.00444	0.016437	Trapezoid	20	1
R320	Automatic Fixed Interval	54.142	0.0001	0.034749	Trapezoid	20	1
R330	Automatic Fixed Interval	299.71	0.0001	0.055899	Trapezoid	20	1
R350	Automatic Fixed Interval	2136.8	0.01076	0.04764	Trapezoid	20	1
R360	Automatic Fixed Interval	212.13	0.0001	0.083753	Trapezoid	20	1
R390	Automatic Fixed Interval	953.41	0.0001	0.026125	Trapezoid	20	1
R70	Automatic Fixed Interval	612.84	0.06455	0.007391	Trapezoid	20	1
R80	Automatic Fixed Interval	1071.5	0.04857	0.023616	Trapezoid	20	1
R90	Automatic Fixed Interval	3497.5	0.04031	0.00979	Trapezoid	20	1

Annex 11. Mananga Field Validation Points

Table A-11.1. Mananga Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event / Date	Return Period of Event
	Longitude	Latitude					
1	10.23583619	123.8315539	0.21	0.3	0.0081	Seniang	100-Year
2	10.23583619	123.8315539	0.71	1.2	0.2401	Ruping	100-Year
3	10.23597929	123.8314407	0.61	0.5	0.0121	Ruby	100-Year
4	10.23632834	123.830787	0.5	0.4	0.01	Ruby	100-Year
5	10.23637261	123.8307833	0.5	0.7	0.04	Ruby	100-Year
6	10.23640536	123.8340724	0.74	1.2	0.2116	Seniang	100-Year
7	10.23646265	123.8332613	0.65	1	0.1225	Basyang	100-Year
8	10.23663368	123.8333076	0.65	2.1	2.1025	Ruping	100-Year
9	10.2367502	123.8335549	0.51	1.4	0.7921	Seniang	100-Year
10	10.23708132	123.8290362	0.72	1.2	0.2304	Seniang	100-Year
11	10.23708132	123.8290362	0.96	0.5	0.2116	Ruby	100-Year
12	10.23716066	123.8288879	0.7	0.7	0	Ruby	100-Year
13	10.23792322	123.8288029	0.75	0.2	0.3025	Ruby	100-Year
14	10.23792322	123.8288029	0.9	0	0.81	Ruby	100-Year
15	10.23801388	123.8287138	0.78	0.5	0.0784	Ruby	100-Year
16	10.23801388	123.8287138	0.83	0.3	0.2809	Ruby	100-Year
17	10.23826964	123.8245655	0.68	0.3	0.1444	Ruby	100-Year
18	10.23826964	123.8245655	0.72	0.9	0.0324	Ruby	100-Year
19	10.23829526	123.8247481	0.54	1.5	0.9216	Ruping	100-Year
20	10.23829526	123.8247481	0.61	0.2	0.1681	Ruby	100-Year
21	10.23829526	123.8247481	0.67	0.2	0.2209	Seniang	100-Year

22	10.23829526	123.8247481	0.71	0.4	0.0961	Ruby	100-Year
23	10.23834017	123.8254366	0.61	0.3	0.0961	Ruby	100-Year
24	10.23838459	123.8251855	0.57	1.2	0.3969	Ruby	100-Year
25	10.23838459	123.8251855	0.62	0	0.3844	Ruby	100-Year
26	10.23872162	123.8259864	0.77	1.3	0.2809	Ruping	100-Year
27	10.23907701	123.8239775	0.03	0	0.0009	Basyang	100-Year
28	10.23908572	123.8243176	0.08	0.9	0.6724	Ruby	100-Year
29	10.23952436	123.8226954	0.41	0.2	0.0441	Ruby	100-Year
30	10.24004025	123.8223121	0.32	0.2	0.0144	Ruby	100-Year
31	10.2405632	123.8219617	0.42	1	0.3364	Seniang	100-Year
32	10.2405632	123.8219617	0.43	0.3	0.0169	Seniang	100-Year
33	10.24073814	123.8369867	0.86	1.2	0.1156	Ruping	100-Year
34	10.24126581	123.8221317	0.62	0.5	0.0144	Seniang	100-Year
35	10.24135748	123.8370406	5.73	1.7	16.2409	Ruping	100-Year
36	10.24175089	123.8335577	0.65	0.2	0.2025	Seniang	100-Year
37	10.24188562	123.8222922	0.19	0.3	0.0121	Seniang	100-Year
38	10.24188562	123.8222922	0.44	0.3	0.0196	Seniang	100-Year
39	10.24205888	123.8219018	0.34	0.7	0.1296	Seniang	100-Year
40	10.24225813	123.8218366	0.19	0.5	0.0961	Seniang	100-Year
41	10.24225813	123.8218366	0.32	0.5	0.0324	Seniang	100-Year
42	10.24238742	123.8331	0.31	0.2	0.0121	Seniang	100-Year
43	10.24249989	123.8334329	0.51	0.5	0.0001	Seniang	100-Year
44	10.24249989	123.8334329	0.6	0.5	0.01	Seniang	100-Year
45	10.24258207	123.8330355	0.3	0.7	0.16	Seniang	100-Year
46	10.2426773	123.8335247	0.58	0.7	0.0144	Seniang	100-Year
47	10.2426773	123.8335247	0.7	0.9	0.04	Seniang	100-Year
48	10.24276505	123.8333423	0.79	1.1	0.0961	Ruping	100-Year
49	10.24276505	123.8333423	0.83	0.5	0.1089	Seniang	100-Year

50	10.24291447	123.8219848	0.06	0.5	0.1936	Seniang	100-Year
51	10.24291447	123.8219848	0.2	0.2	0	Seniang	100-Year
52	10.24293821	123.8221486	0.08	0.7	0.3844	Seniang	100-Year
53	10.2429533	123.8223156	0.06	0.3	0.0576	Seniang	100-Year
54	10.24307377	123.8209117	0.2	0.3	0.01	Seniang	100-Year
55	10.24308125	123.8209465	0.16	0.6	0.1936	Seniang	100-Year
56	10.24321751	123.8219779	0.03	0.7	0.4489	Seniang	100-Year
57	10.24327664	123.8218167	0.03	0.5	0.2209	Seniang	100-Year
58	10.24327664	123.8218167	0.05	0.5	0.2025	Seniang	100-Year
59	10.24458477	123.8205168	0.03	0.2	0.0289	Seniang	100-Year
60	10.24495243	123.8384611	0.06	0.5	0.1936	Seniang	100-Year
61	10.24495243	123.8384611	0.1	0.7	0.36	Seniang	100-Year
62	10.24495243	123.8384611	0.13	0.6	0.2209	Seniang	100-Year
63	10.24495243	123.8384611	0.14	0.6	0.2116	Seniang	100-Year
64	10.24522666	123.8373252	0.13	0.6	0.2209	Seniang	100-Year
65	10.24522666	123.8373252	0.28	0.5	0.0484	Seniang	100-Year
66	10.24540708	123.8375035	0.2	0.2	0	Seniang	100-Year
67	10.24540708	123.8375035	0.23	0.2	0.0009	Seniang	100-Year
68	10.24570459	123.83399	3.56	2.7	0.7396	Seniang	100-Year
69	10.24591996	123.8332848	0.45	0.2	0.0625	Seniang	100-Year
70	10.24594076	123.8335332	0.33	0.2	0.0169	Ruby	100-Year
71	10.24594076	123.8335332	0.36	0.2	0.0256	Seniang	100-Year
72	10.24641218	123.8334902	0.93	0.5	0.1849	Ruby	100-Year
73	10.24641218	123.8334902	1.15	0.5	0.4225	Ruby	100-Year
74	10.24722421	123.8342248	1.08	0.9	0.0324	Seniang	100-Year
75	10.24722421	123.8342248	1.1	1.1	0	Seniang	100-Year
76	10.24726895	123.8346868	0.87	0.9	0.0009	Seniang	100-Year
77	10.24753708	123.834633	2.09	1.5	0.3481	Seniang	100-Year

78	10.24753708	123.834633	3.12	1.6	2.3104	Seniang	100-Year
79	10.24806396	123.8344518	3.35	1.1	5.0625	Queenie	100-Year
80	10.24806396	123.8344518	3.67	1.1	6.6049	Queenie	100-Year
81	10.24993597	123.8347306	0.05	0.2	0.0225	Queenie	100-Year
82	10.24993597	123.8347306	0.08	0.5	0.1764	Queenie	100-Year
83	10.24993597	123.8347306	0.12	0.3	0.0324	Queenie	100-Year
84	10.24996551	123.8349122	0.03	0.3	0.0729	Queenie	100-Year
85	10.24996883	123.8350718	0.03	0.3	0.0729	Queenie	100-Year
86	10.25023039	123.8353785	1.96	1	0.9216	Queenie	100-Year
87	10.25049696	123.8365251	2.42	2	0.1764	Seniang	100-Year
88	10.25068229	123.8365109	1.33	0.5	0.6889	Seniang	100-Year
89	10.25131504	123.8363981	3.08	0.7	5.6644	Seniang	100-Year
90	10.25156014	123.8361576	3.4	0.9	6.25	Seniang	100-Year
91	10.25156014	123.8361576	3.96	0.9	9.3636	Seniang	100-Year
92	10.25208069	123.836041	3.86	0.9	8.7616	Seniang	100-Year
93	10.25221446	123.8361264	1.87	1.2	0.4489	Ruping	100-Year
94	10.2522541	123.8359719	4.21	1	10.3041	Ruby	100-Year
95	10.25230432	123.8357991	5.21	2.2	9.0601	Ruping	100-Year
96	10.25238585	123.8360855	1.94	1	0.8836	Seniang	100-Year
97	10.25241828	123.8357742	5.18	1.9	10.7584	Ruping	100-Year
98	10.25248424	123.8361745	0.68	1.1	0.1764	Ruping	100-Year
99	10.25258879	123.8357167	4.82	1.3	12.3904	Seniang	100-Year
100	10.25263187	123.8360831	1.37	1	0.1369	Quennie	100-Year
101	10.25267787	123.8360619	1.72	1.5	0.0484	Seniang	100-Year
102	10.2557966	123.8340155	2.41	1.9	0.2601	Ruping	100-Year
103	10.2557966	123.8340155	2.85	2.1	0.5625	Ruping	100-Year
104	10.25613521	123.8336511	0.74	0.7	0.0016	Queenie	100-Year
105	10.25613521	123.8336511	0.99	1.1	0.0121	Ruby	100-Year

106	10.25701927	123.834216	2.29	2.1	0.0361	Ruping	100-Year
107	10.257535	123.8337709	0.04	0.5	0.2116	Queenie	100-Year
108	10.257535	123.8337709	0.24	0.5	0.0676	Queenie	100-Year
109	10.25753425	123.8340647	0.24	0.5	0.0676	Seniang	100-Year
110	10.25753425	123.8340647	0.3	0.7	0.16	Queenie	100-Year
111	10.25762723	123.8330739	0.32	0.1	0.0484	Queenie	100-Year
112	10.25762723	123.8330739	0.4	0.1	0.09	Queenie	100-Year
113	10.25762409	123.8342942	0.55	0.5	0.0025	Queenie	100-Year
114	10.25762409	123.8342942	0.68	0.3	0.1444	Seniang	100-Year
115	10.25762409	123.8342942	0.75	1.3	0.3025	Ruby	100-Year
116	10.25762409	123.8342942	0.78	0.9	0.0144	Ruby	100-Year
117	10.25850621	123.8345264	0.55	1.1	0.3025	Seniang	100-Year
118	10.25874263	123.8342971	0.03	0	0.0009	Seniang	100-Year
119	10.25874263	123.8342971	0.31	0.5	0.0361	Seniang	100-Year
120	10.25894108	123.8345389	0.51	0.5	0.0001	Queenie	100-Year
121	10.25894392	123.8346265	0.58	0.5	0.0064	Queenie	100-Year
122	10.25896223	123.836315	0.03	0.2	0.0289	Seniang	100-Year
123	10.25907074	123.8344181	0.3	0.2	0.01	Queenie	100-Year
124	10.25907074	123.8344181	0.33	0.2	0.0169	Queenie	100-Year
125	10.25919513	123.8346009	0.82	0.9	0.0064	Seniang	100-Year
126	10.25939192	123.8348467	0.99	0.5	0.2401	Seniang	100-Year
127	10.25939192	123.8348467	1.27	1.1	0.0289	Seniang	100-Year
128	10.26072247	123.8348544	7.39	2.7	21.9961	Ruping	100-Year
129	10.26079091	123.8348837	7.81	2.4	29.2681	Ruping	100-Year
130	10.26085052	123.8348033	6.19	2.2	15.9201	Seniang	100-Year
131	10.26404777	123.8332153	3.94	1.4	6.4516	Ruby	100-Year
132	10.26404777	123.8332153	4.1	0.9	10.24	Yolanda	100-Year
133	10.26404777	123.8332153	4.2	1.5	7.29	Ruby	100-Year

134	10.26404777	123.8332153	4.42	2	5.8564	Seniang	100-Year
135	10.2640986	123.8327589	3.3	1.9	1.96	Ruping	100-Year
136	10.2640986	123.8327589	3.35	0.5	8.1225	Yolanda	100-Year
137	10.26426369	123.8325767	1.49	1.2	0.0841	Yolanda	100-Year
138	10.26426369	123.8325767	2.78	1.3	2.1904	Yolanda	100-Year
139	10.26447003	123.8327288	3.14	1.9	1.5376	Ruping	100-Year
140	10.26457171	123.8326401	2.61	2.1	0.2601	Ruping	100-Year
141	10.26528437	123.8298018	0.4	0.5	0.01	Ruby	100-Year
142	10.26529016	123.8294105	0.51	0.5	0.0001	Seniang	100-Year
143	10.26559369	123.8298896	0.58	0.5	0.0064	Seniang	100-Year
144	10.26559369	123.8298896	0.74	0.7	0.0016	Seniang	100-Year
145	10.26585797	123.8315412	4.77	2	7.6729	Seniang	100-Year
146	10.26586599	123.8294989	0.03	0.5	0.2209	Seniang	100-Year
147	10.26586599	123.8294989	0.04	0.5	0.2116	Ruby	100-Year
148	10.26589104	123.8316873	6.97	1.1	34.4569	Ruby	100-Year
149	10.26609195	123.829328	0.03	0	0.0009	Ruby	100-Year
150	10.26640492	123.8309387	5.39	1.2	17.5561	Seniang	100-Year
151	10.26640492	123.8309387	5.52	1	20.4304	Ruby	100-Year
152	10.26640492	123.8309387	6.22	1.6	21.3444	Yolanda	100-Year
153	10.26640492	123.8309387	6.79	1.9	23.9121	Seniang	100-Year
154	10.26643595	123.8304822	1.74	0.7	1.0816	Seniang	100-Year
155	10.26643595	123.8304822	2.31	0.5	3.2761	Seniang	100-Year
156	10.26665013	123.8309393	7.96	0.5	55.6516	Seniang	100-Year
157	10.26665013	123.8309393	8.76	2.2	43.0336	Ruping	100-Year
158	10.26667693	123.8306655	4.27	0.5	14.2129	Seniang	100-Year
159	10.26667693	123.8306655	5.85	1.3	20.7025	Seniang	100-Year
160	10.26667693	123.8306655	6.43	1.7	22.3729	Seniang	100-Year
161	10.26667693	123.8306655	6.6	1.2	29.16	Ruby	100-Year

162	10.26676853	123.8302092	2.21	2.1	0.0121	Ruping	100-Year
163	10.26676853	123.8302092	2.29	0.7	2.5281	Yolanda	100-Year
164	10.26676853	123.8302092	2.45	1.2	1.5625	Yolanda	100-Year
165	10.26676853	123.8302092	2.52	0.9	2.6244	Yolanda	100-Year
166	10.26685826	123.8304833	4.53	1	12.4609	Yolanda	100-Year
167	10.26685826	123.8304833	6.26	1.5	22.6576	Ruby	100-Year
168	10.26685826	123.8304833	6.64	1.7	24.4036	Ruping	100-Year
169	10.26685826	123.8304833	7.01	2	25.1001	Ruping	100-Year

Annex 12. Educational Institutions affected by flooding Mananga Floodplain

Table A-12.1. Educational Institutions in Cebu affected by flooding in Mananga Flood Plain

Cebu				
Talisay City				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
TCG Center	Cansojong			
First Chinese Royal Academy	Dumlog		Low	Low
Cebu Sacred Heart College	Lawaan I			
San Isidro Elementary School	Lawaan II	Low	Low	Low
Lawaan III National Highschool	Lawaan III			
St. Scholastica's Academy	Lawaan III			Low
Cebu Sacred Heart College	Linao			
Lawaan Elementary School	Linao			
St. Thomas Aquinas Montessori	Linao			
Lagtang SDA Multigrade School	Maghaway			
Divino Amore Academy	Mohon	Low	Medium	Medium
Mohon Elementary School	Mohon			
Visayas Wesleyan Christian School Inc	Mohon			
Maghaway Elementary School	Poblacion	Low	Low	Low
Sisters of Mary Girls Town School	Poblacion			
Talisay City College	Poblacion			Low
Talisay City Elementary School	Poblacion			
Talisay Malayan Academy	Poblacion	Low	Low	Low
Pooc National High School	Pooc		Low	Low
Cebu Globalization ESL Center Inc	San Isidro			
Monterey School	San Isidro			
TCG Center	San Isidro			
Tabunok Elementary School	Tabunoc		Low	Low

Annex 13. Medical Institutions affected by flooding in Mananga Floodplain

Table A-13.1. Medical Institutions in Cebu affected by flooding in Mananga Flood Plain

Cebu				
Minglanilla				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Baking Medical Center	Linao			
Tungkil Health Center	Tungkil	Medium	Medium	Medium
Talisay City				
Talisay District Hospital	Lawaan II		Low	Low
Lagtang Health Center	Lawaan III			
Talisay District Hospital	San Isidro	Low	Low	Low