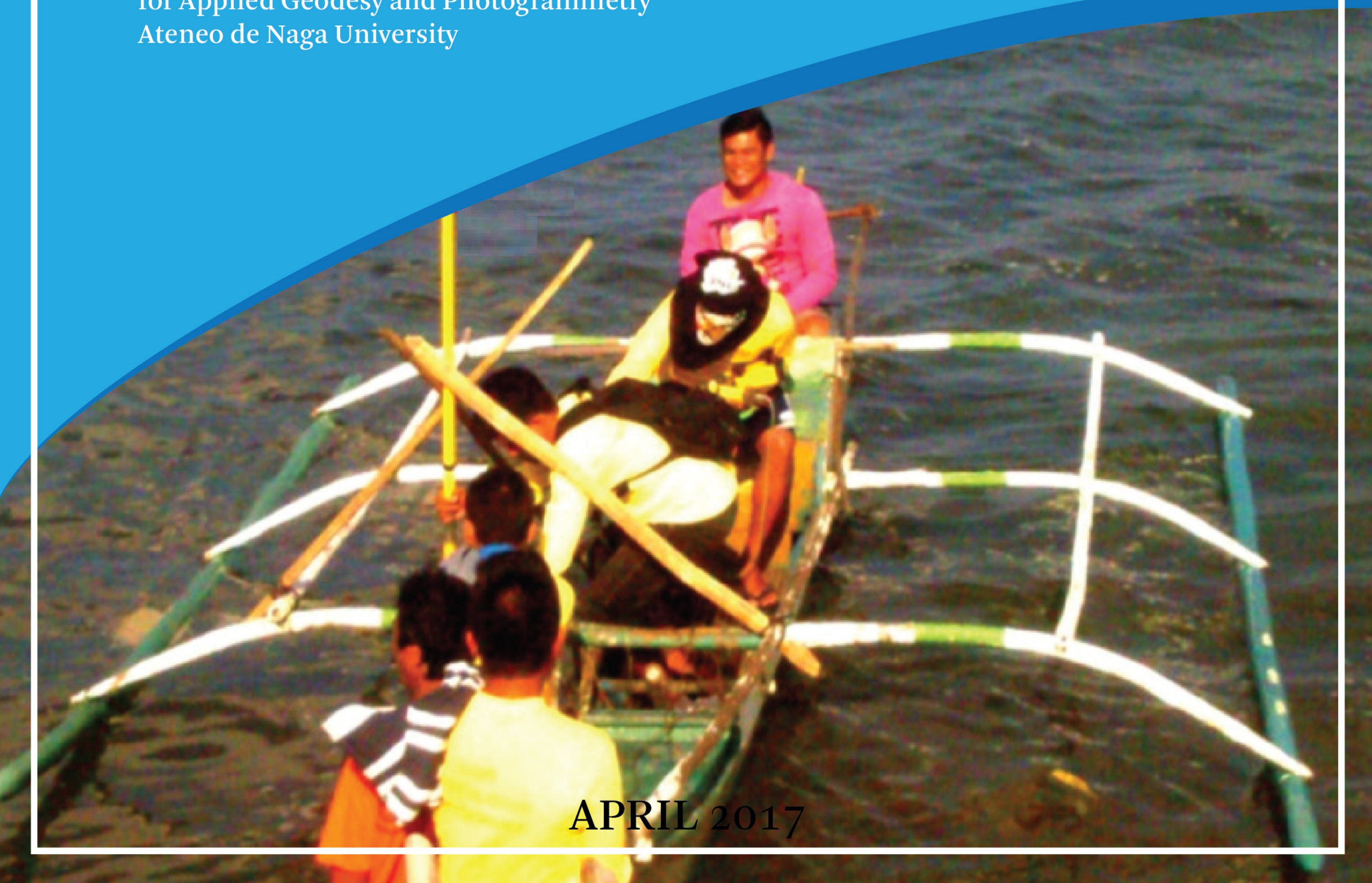
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR 1)

LiDAR Surveys and Flood Mapping of Napayawan River

University of the Philippines Training Center for Applied Geodesy and Photogrammetry
Ateneo de Naga University



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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ADNU	Ateneo de Naga University
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DA-BSWM	Department of Agriculture - Bureau of Soil and Water Management
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PSA	Philippine Statistics Authority
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND NAPAYAWAN RIVER

Enrico C. Paringit, Dr. Eng., Ms. Joanaviva C. Plopenio, and Engr. Ferdinand Bien

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Ateneo de Naga University (ADNU). (ADNU) 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 24 river basins in the Bicol Region. The university is located in Naga City in the province of Camarines Sur.

1.2 Overview of the Napayawan River Basin

The Napayawan River Basin covers the Municipalites of Aroroy, Milagros, and Mandaon in Masbate. Aroroy and Milagros are both first class municipalities, while Mandaon is a third class municipality. According to the 2015 national census of the Philippine Statistical Authority (PSA), a total of 3,554 persons are residing within the immediate vicinity of the river, which is distributed among Barangay Amutag in the Municipality of Aroroy and Barangay Bugtong in the Municipality of Mandaon. The town of Aroroy has a population of 86,168 distributed in its 41 barangays, Milagros has 57,473 in its 27 barangays and Mandaon with 41,262 residents in its 26 barangays based from the 2015 census.

The DENR River Basin Control Office (RBCO) states that the Napayawan Basin has a drainage are of 94 km^2 and an estimated 127 cubic meter (MCM) annual run-off (RBCO, 2015).

Its main stem, Napayawan River, is among the twenty-four (24) river systems in Bicol Region. The Napayawan River is about 15 km long and is the major stream that drains the basin out to the Sibuyan Sea in the west. An island near its mouth share the same name, Napayawan. It is bound to the north and south by low hills with poor vegetation cover. To the west where the headwaters are, the basin is also bound by a low mountain range of not more than 600 mASL.

As with the majority of Masbate Island, the area of Napayawan River Basin experiences a relatively dry season from November to April with rain distributed evenly during the rest of the year. This is classified as Type III of the modified Corona classification of climate in the Philippines.

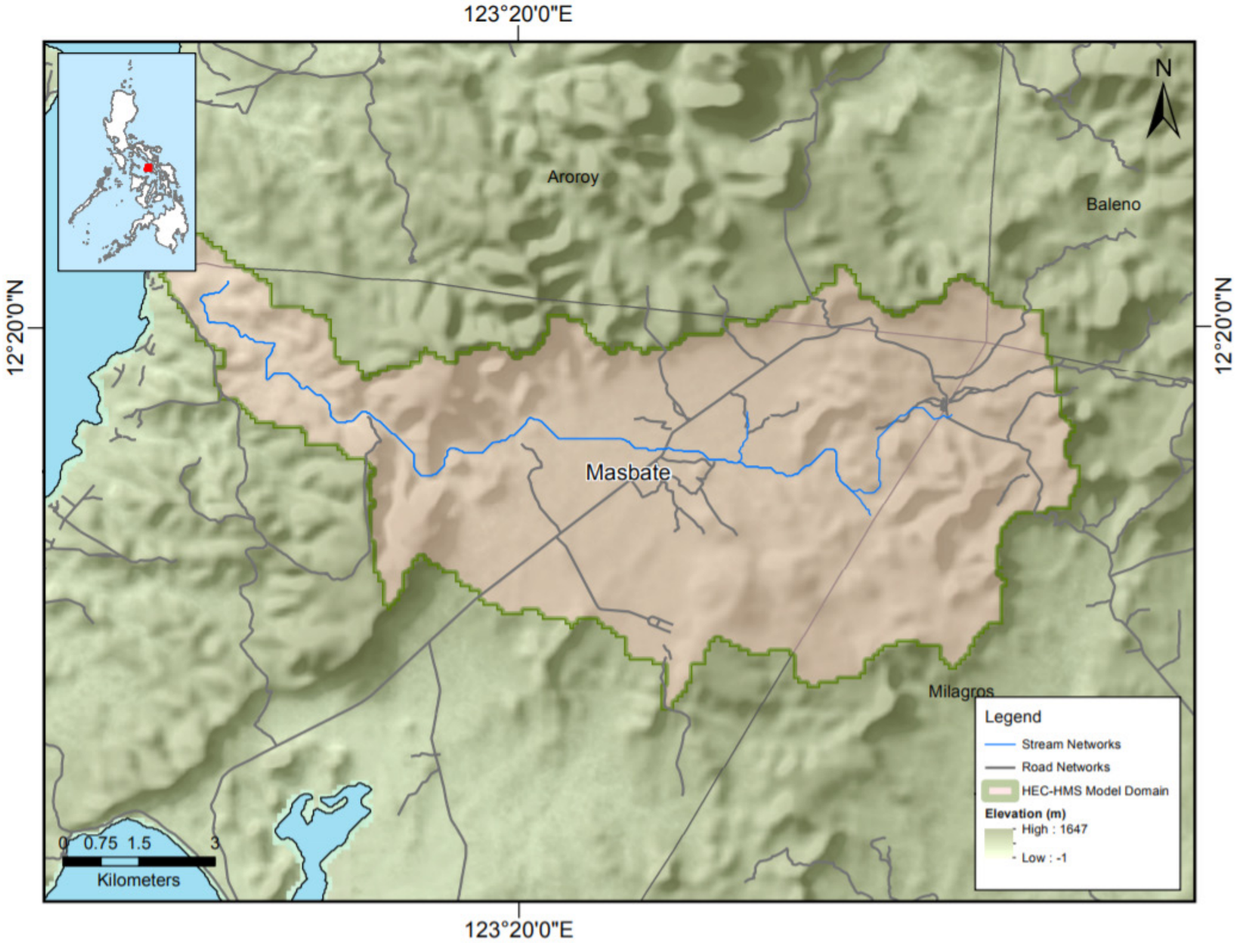

Figure 1. Map of Napayawan River Basin (in brown)

The economy of Masbate Province largely rests on livestock and agriculture with coconut, rice, and corn as main crops and top products (Philippine Statistics Authority, 2017). The area produces rice and precious metals such as gold particularly in Aroroy where mining industry thrives in both large scale and small scale levels.

Meanwhile, last December 7, 2014 Masbate City, was affected by Typhoon Ruby with 96 families evacuated, as per NDRRMC report (National Disaster Risk Reduction and Management Council, 2014).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE NAPAYAWAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Acuna, Engr. Gerome Hipolito, Ms. Pauline Joanne G. Arceo, and Engr. Kenneth A. Quisado.

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Napayawan floodplain in Masbate. These missions were planned for 12 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 shows the flight plans and base stations for Napayawan floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK32A	1000	30	50	200	30	130	5
	1200	30	50	200	30	130	5
	1000	25	50	200	30	130	5
BLK32B	800	35	50	200	30	130	5
	900	35	50	200	30	130	5
BLK32D	1000	30	50	200	30	130	5
	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."

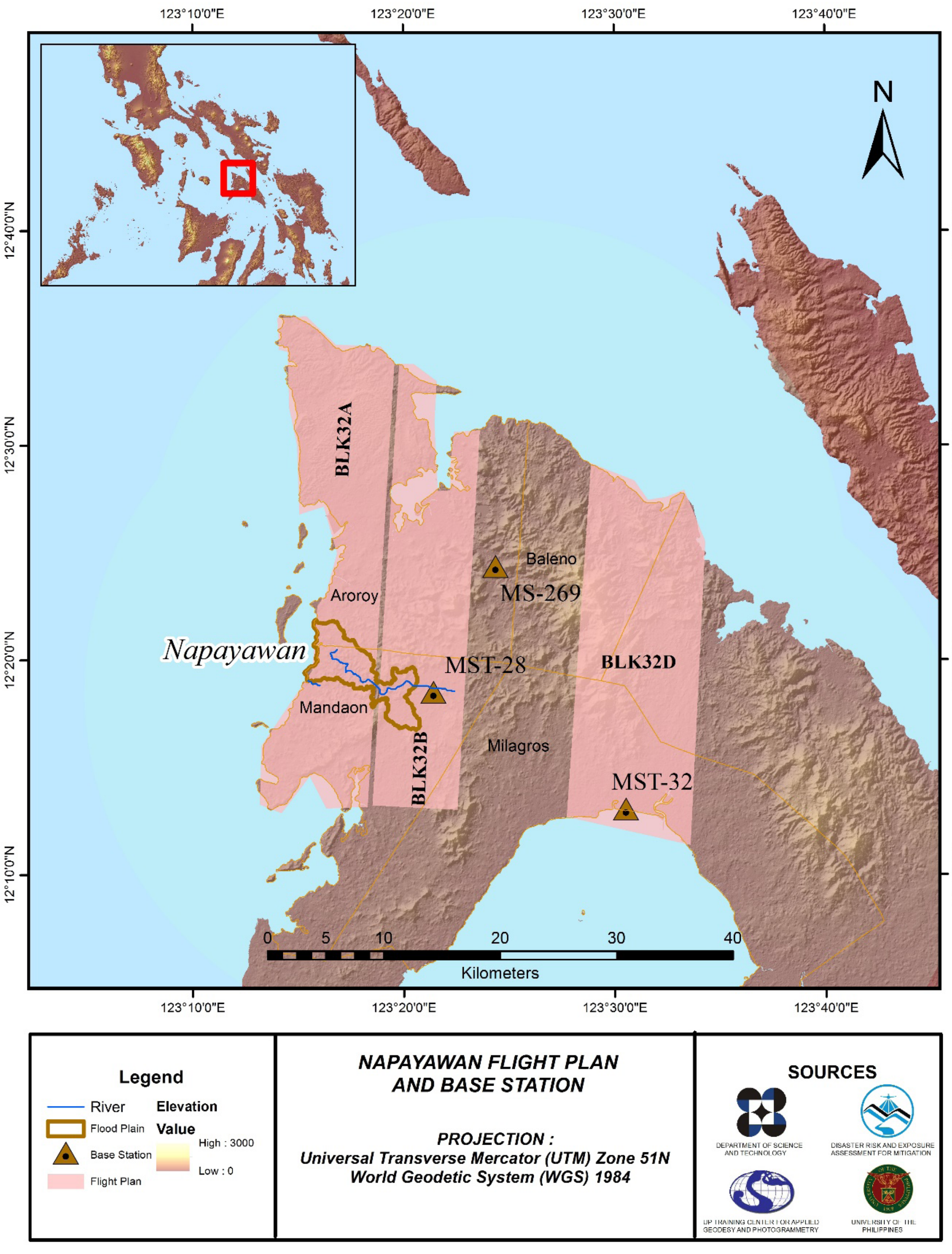

Figure 2. Flight Plan and base station used for the Napayawan Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover three (3) NAMRIA reference points: MST-28 and MST-32 which are of second (2nd) order accuracy and one (1) NAMRIA benchmark: MS-269 which is of first (1st) order accuracy. The benchmark was used as vertical reference point and was established as ground control point. The certifications for the NAMRIA reference points and benchmark are found in Annex 2 while the baseline processing report is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (April 4 - 11, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Napayawan floodplain are shown in Figure 2.

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

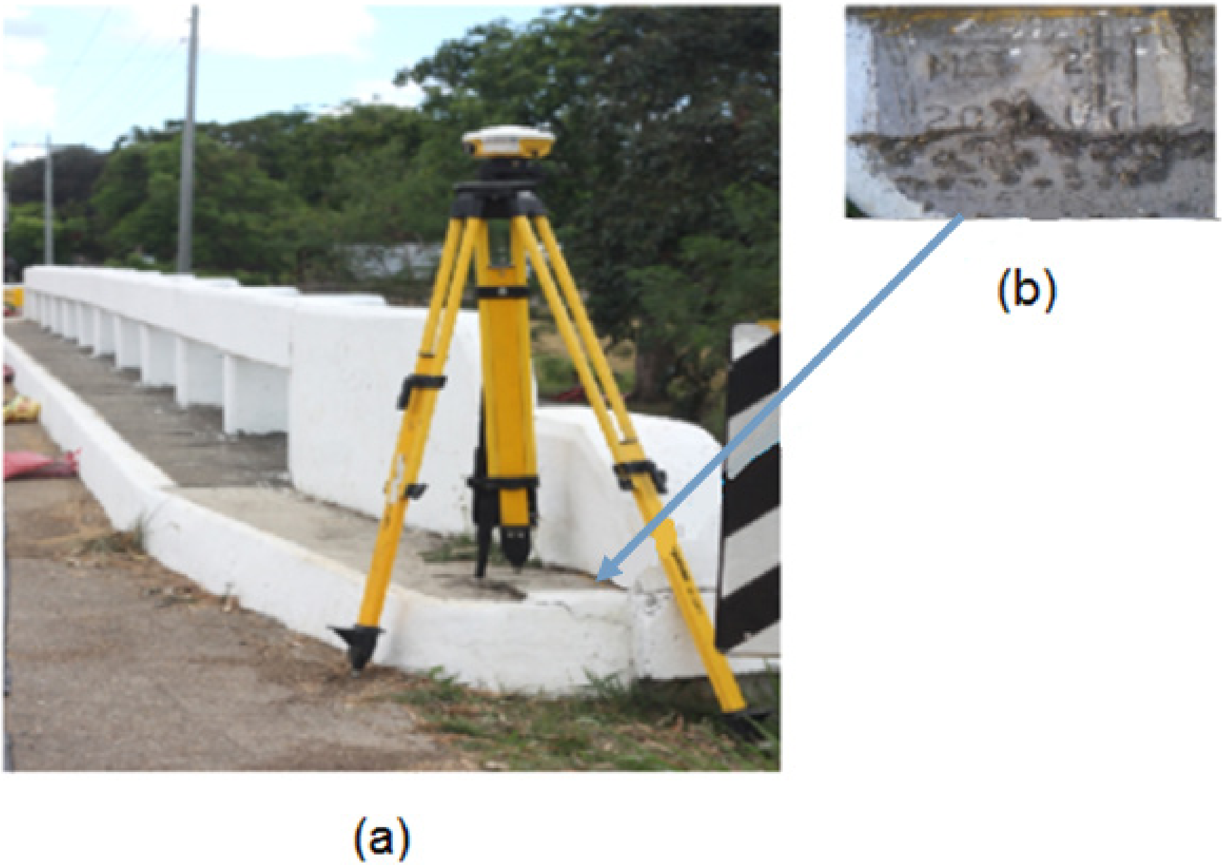

Figure 3. GPS set-up over MST-28 in Mambog Bridge, Barangay Bat-ongan, municipality of Napayawan, Masbate (a) and NAMRIA reference point MST-28 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point MST-28 used as base station for the LiDAR acquisition.

Station Name	**MST-28**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 18' 35.15371" North 123° 21' 19.21293" East 49.12800 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	538651.166 meters 1361224.57 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 18' 30.47973" North 123° 21' 24.28923" East 104.64900 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	538637.64 meters 1360748.12 meters

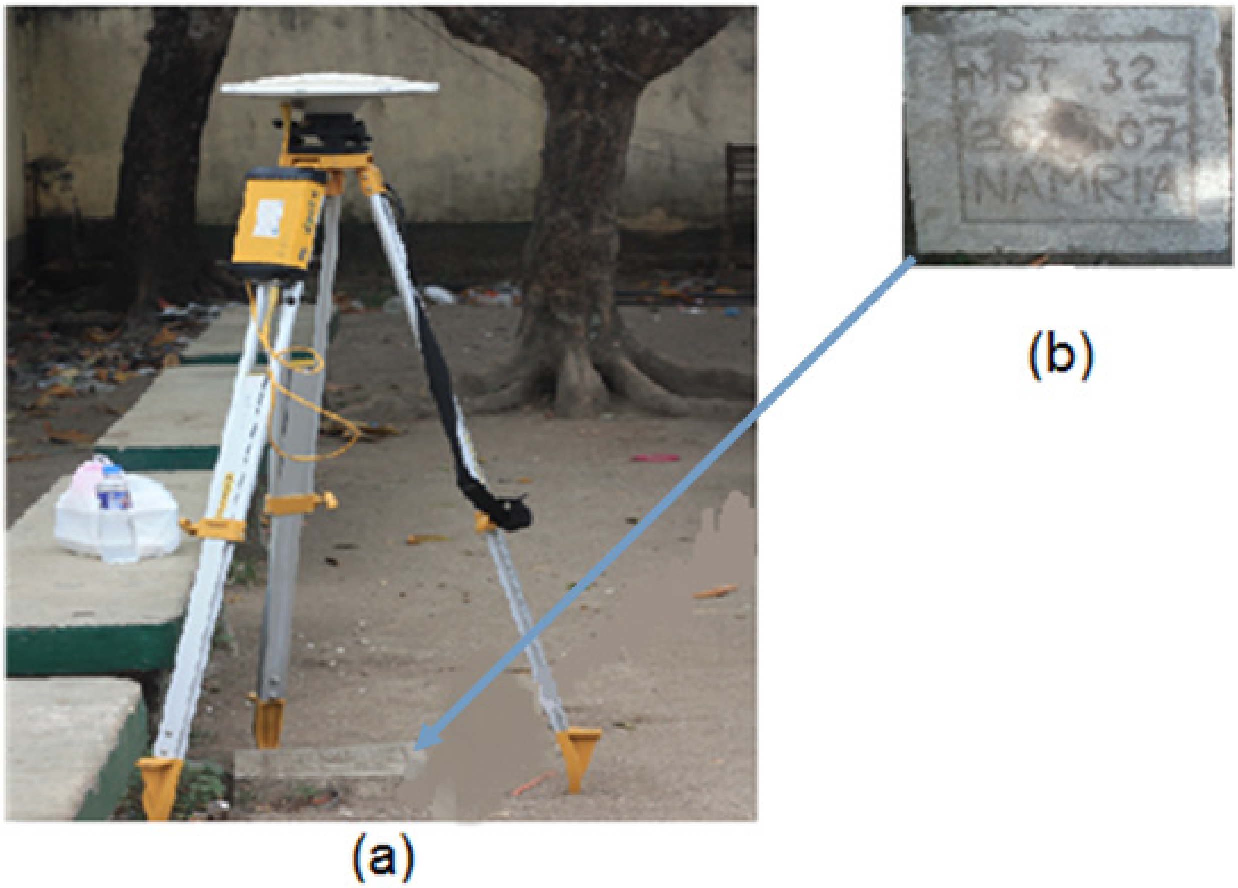

Figure 4. GPS set-up over MST-32 inside the compound of the Milagros Municipal Hall, Masbate (a) and NAMRIA reference point MST-32 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point MST-32 used as base station for the LiDAR acquisition.

Station Name	MST-32	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 13' 7.66936" North 123° 30' 26.72479" East 3.78300 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	555213.396 meters 1351188.593 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 13' 3.03064" North 123° 30' 31.80788" East 59.91100 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	555194.07 meters 1350715.65 meters

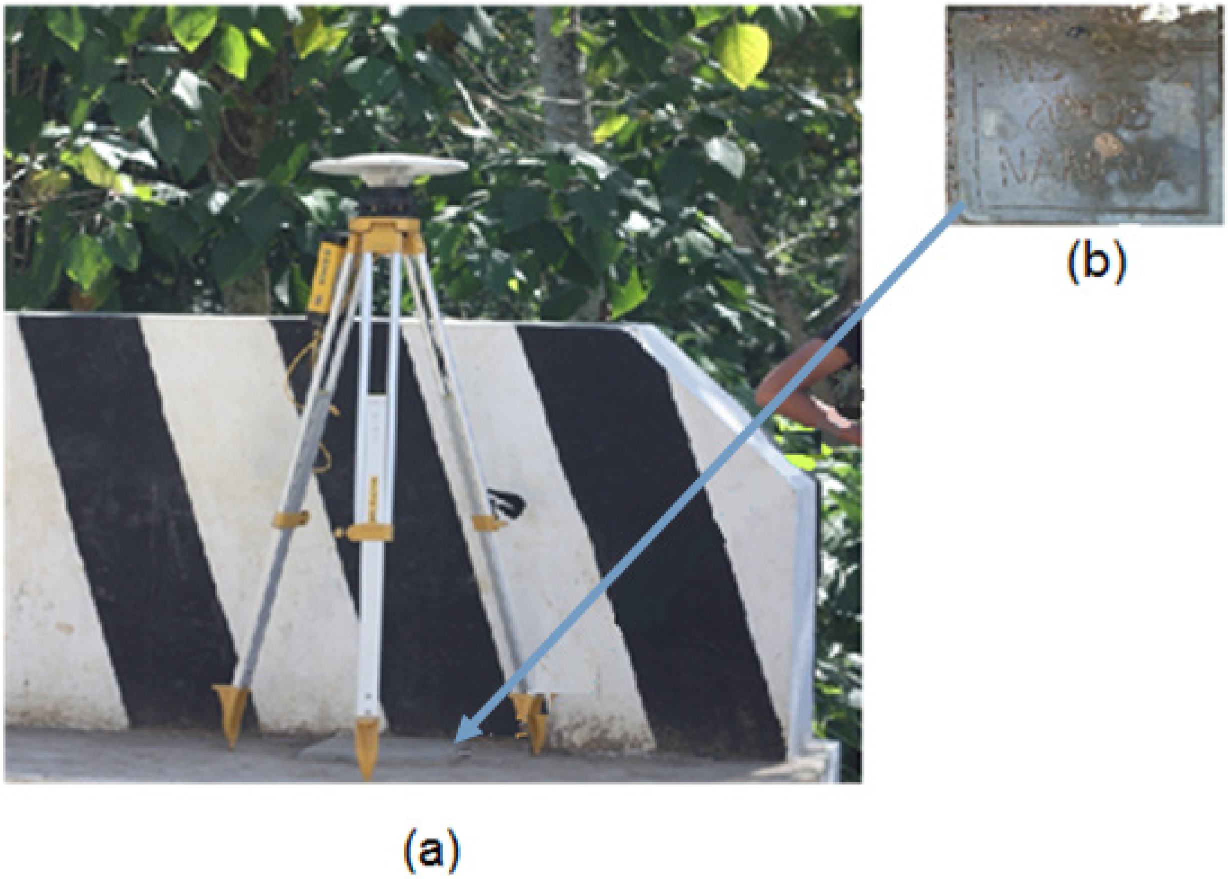

Figure 5. GPS set-up over MS-269 in Luy-a Bridge in Aroroy, Masbate (a) and NAMRIA benchmark MS-269 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA vertical control point MS-269 used as base station for the LiDAR acquisition with established coordinates.

Station Name	MS-269	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Elevation (mean sea level)	27.4076 meters	
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 24' 21.62786" North 123° 24' 21.40082" East 83.308 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 52N PRS 1992)	Easting Northing	544123.868 meters 1,902,971.42 meters

Table 5. Ground control points used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
April 4, 2014	1303P	1BLK32A094A	MS-269 & MST-28
April 4, 2014	1305P	1BLK32A094B	MS-269 & MST-28
April 8, 2014	1319P	1BLK32B098A	MST-28 & MST-32
April 11, 2014	1331P	1BLK32B101A	MST-28 & MST-32

2.3 Flight Missions

Four (4) missions were conducted to complete LiDAR data acquisition in Napayawan floodplain, for a total of twenty four hours and thirty five minutes (24+35) of flying time for RP-C9022. All missions were acquired using the Pegasus LiDAR systems. Table 6 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 7 presents the actual parameters used during the LiDAR data acquisition.

Table 6. Flight missions for the LiDAR data acquisition in Napayawan Floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)		Flying Hours	
							Hr	Min
April 4, 2014	1303P	287.82	301.88	11.90	289.98	800	3	41
April 4, 2014	1305P	287.82	239.52	14.15	225.37	326	2	59
April 8, 2014	1319P	247.35	254.69	12.44	242.25	294	4	17
April 11, 2014	1331P	247.35	127.61	0	127.61	460	2	35
TOTAL		**1070.34**	**923.71**	**38.49**	**885.21**	**885.21**	**13**	**32**

Table 7. Actual parameters used during the LiDAR data acquisition of the Napayawan Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1303P	1200, 1000	30	50	200	30	130	5
1305P	1000	25	50	200	30	130	5
1319P	900	35	50	200	30	130	5
1331P	800	35	50	200	30	130	5

2.4 Survey Coverage

Napayawan floodplain is located in the province of Masbate, with majority of the floodplain situated within the municipality of Mandaon. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 8. The actual coverage of the LiDAR acquisition for Napayawan floodplain is presented in Figure 6.

Table 8. List of municipalities and cities surveyed of the Napayawan Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Masbate	Aroroy	403.62	345.36	85.57%
	Mandaon	267.43	194.62	72.77%
	Baleno	200.24	28.01	13.99%
	Milagros	530.43	69.39	13.08%
	Masbate City	192.96	3.12	1.62%
Total		**1,594.68**	**640.5**	**40.16%**

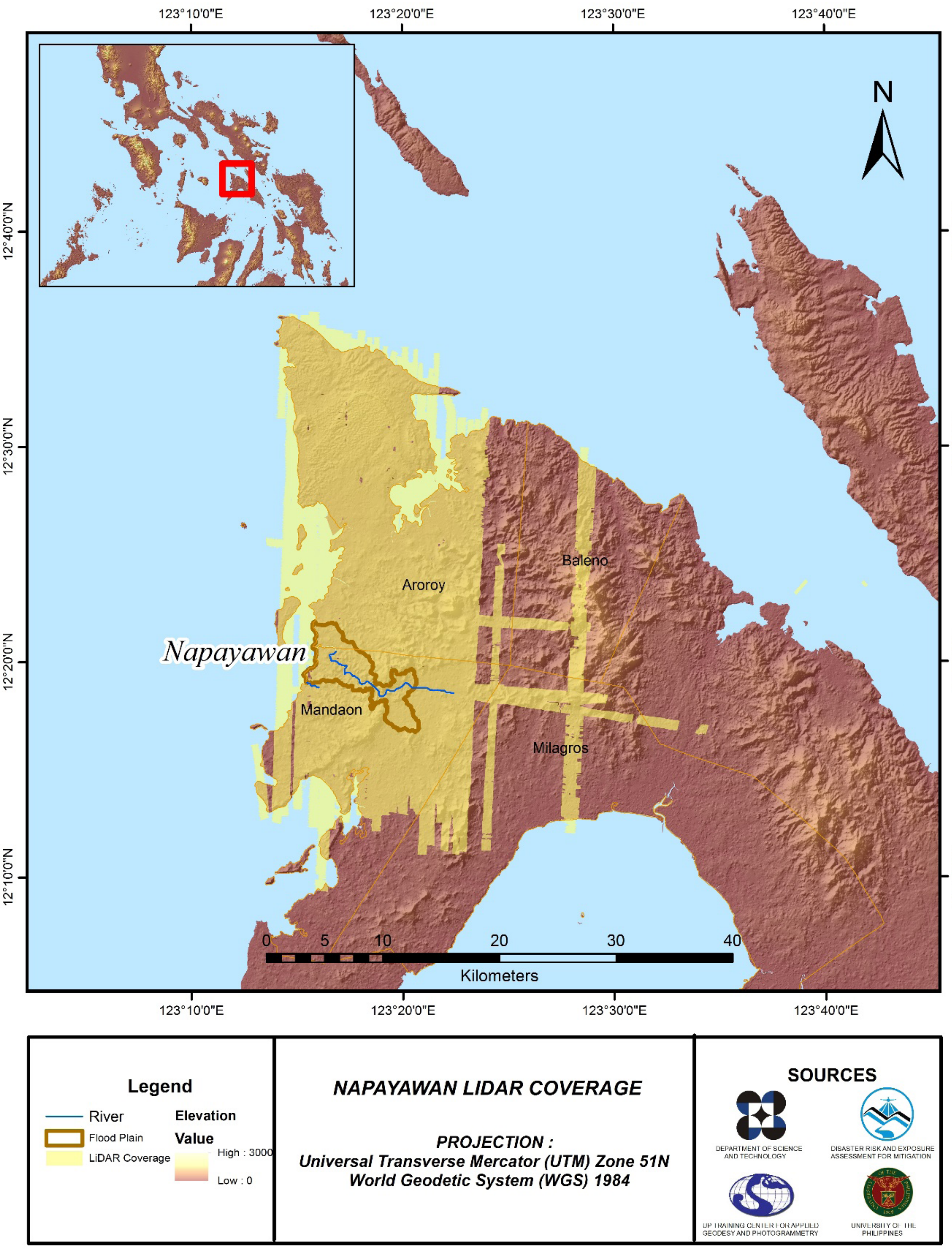

Figure 6. Actual LiDAR survey coverage of the Napayawan Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE NAPAYAWAN FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

These processes are summarized in the flowchart shown in Figure 7.

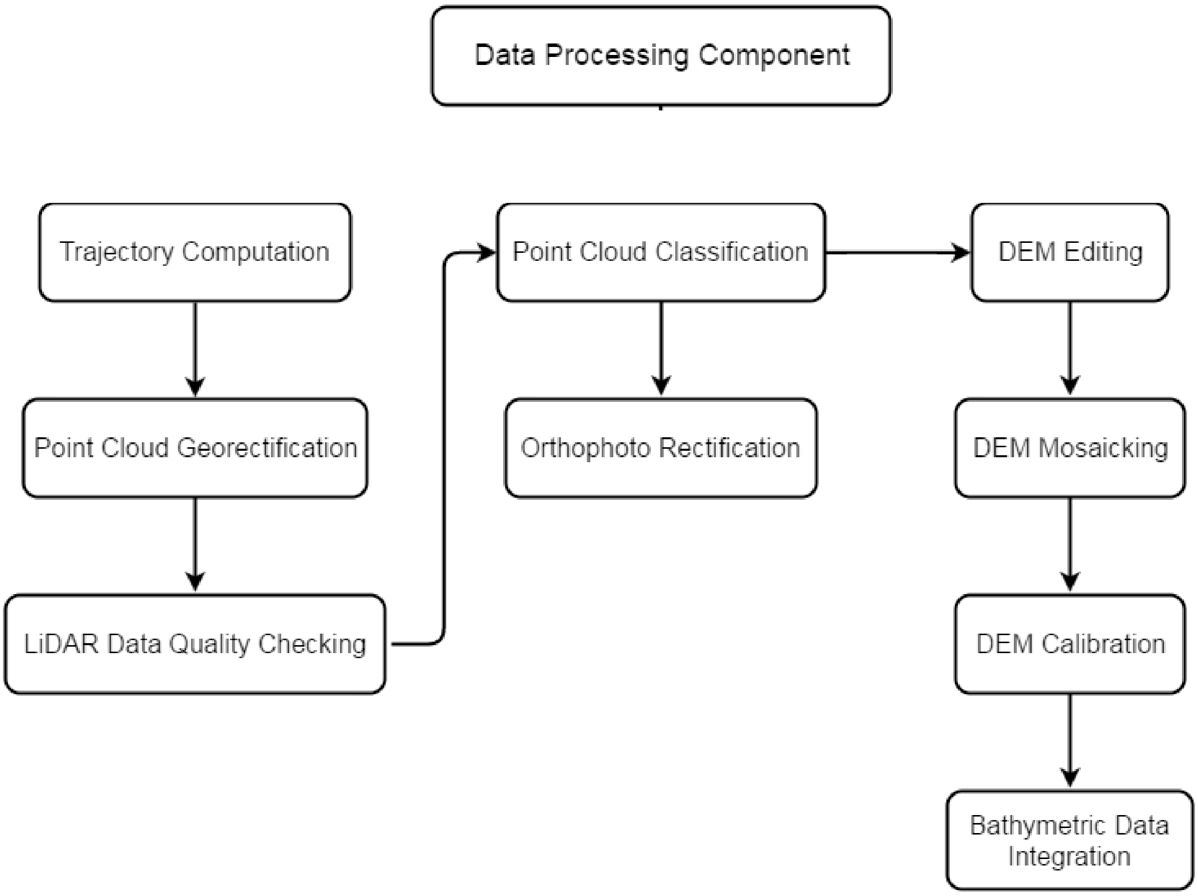

Figure 7. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Napayawan floodplain can be found in Annex 5. Missions flown during the first survey conducted on November 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Aquarius system were flown over Mandaon, Masbate.

The Data Acquisition Component (DAC) transferred a total of 106.7 Gigabytes of Range data, 767 Megabytes of POS data, 22.38 Megabytes of GPS base station data, and 144.30 Gigabytes of raw images to the data server on April 23, 2014. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Napayawan was fully transferred on April 23, 2014, as indicated on the Data Transfer Sheets for Napayawan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 1303P, one of the Napayawan flights, which is the North, East, and Down position RMSE values are shown in Figure 8. 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 April 4, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

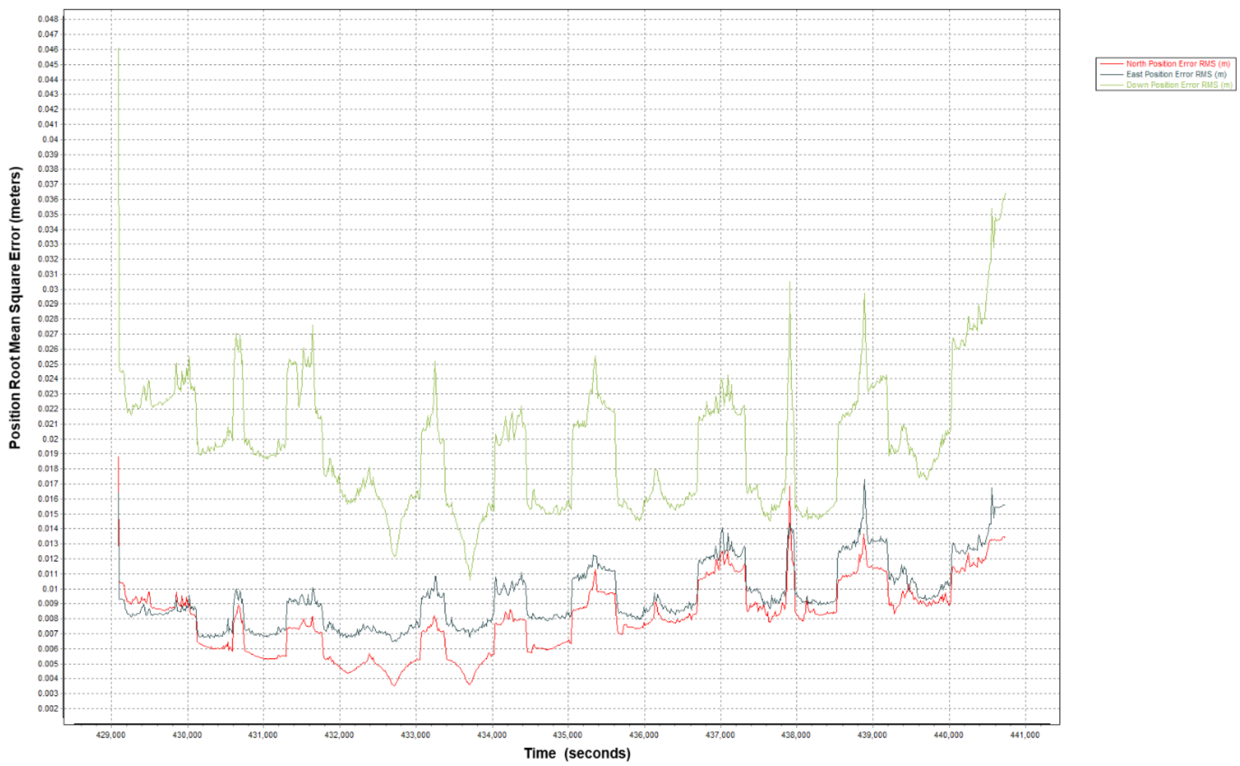

Figure 8. Smoothed Performance Metrics of Napayawan Flight 1303P

The time of flight was from 429000 seconds to 441000 seconds, which corresponds to afternoon of April 4, 2014 April 4. 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 turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8 shows that the North position RMSE peaks at 1.2 centimeters, the East position RMSE peaks at 1.4 centimeters, and the Down position RMSE peaks at 2.90 centimeters, which are within the prescribed accuracies described in the methodology.

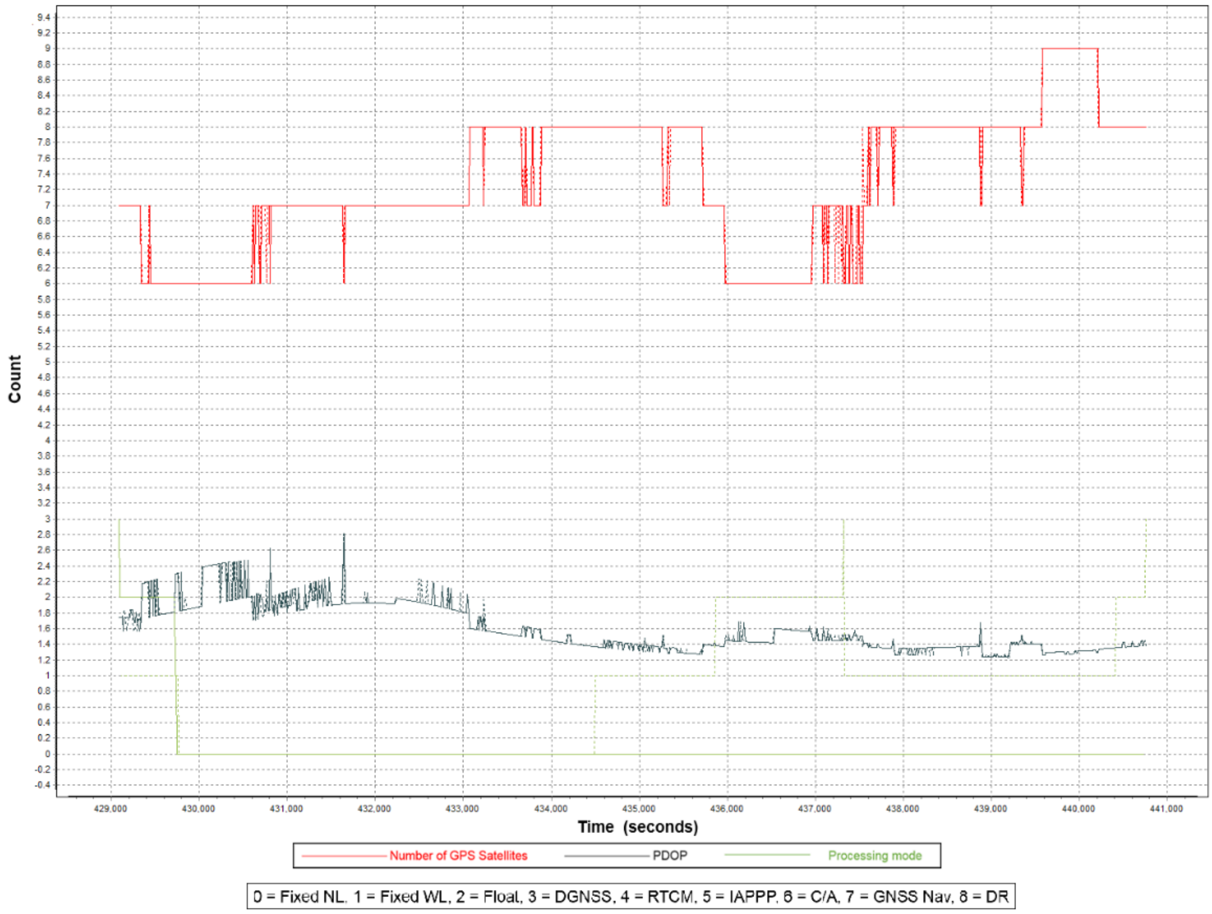

Figure 9. Solution Status Parameters of Napayawan Flight 1303P.

The Solution Status parameters of flight 1303P, one of the Napayawan flights, which indicate the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Most of the time, the number of satellites tracked was between 6 and 9. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 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 Napayawan flights is shown in Figure 10.

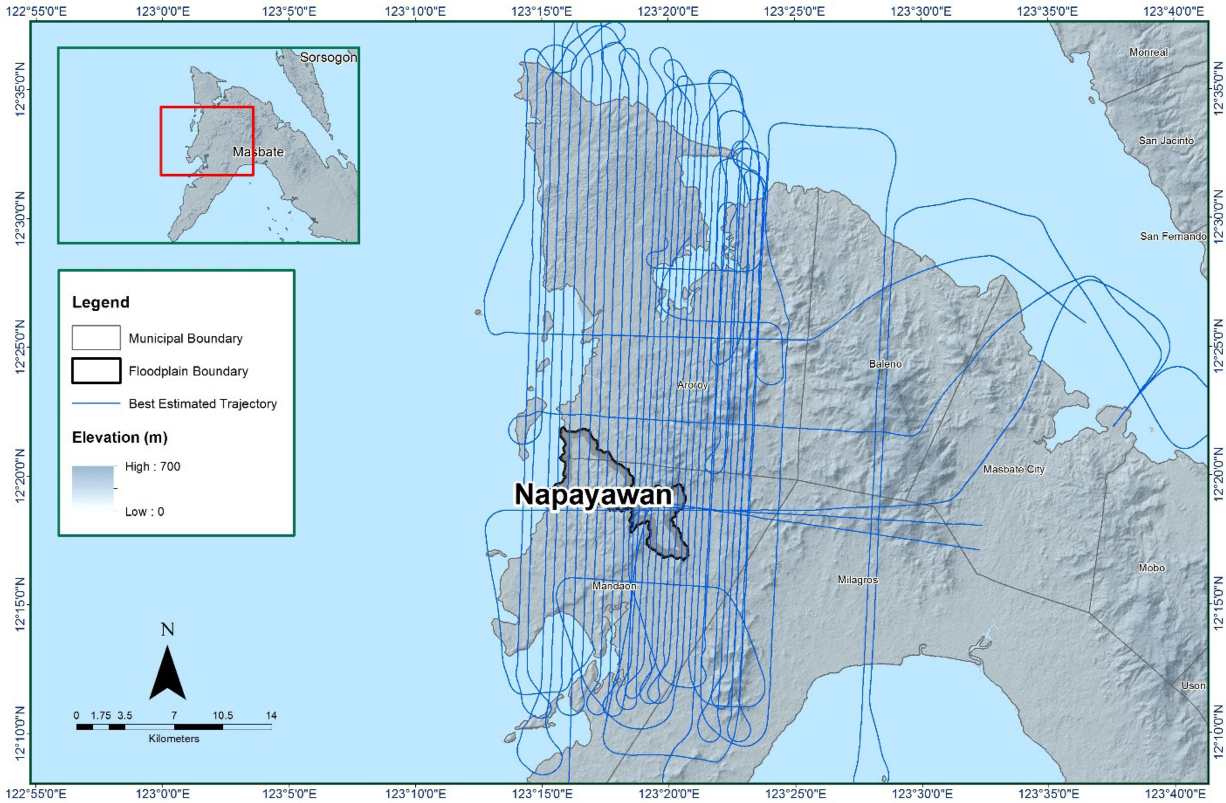

Figure 10. Best estimated trajectory of the LiDAR missions conducted over the Napayawan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 51 flight lines, with each flight line containing two channels, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Napayawan floodplain are given in Table 9.

Table 9. Self-calibration Results values for Napayawan flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000416
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000422
GPS Position Z-correction stdev	<0.01meters	0.0061

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

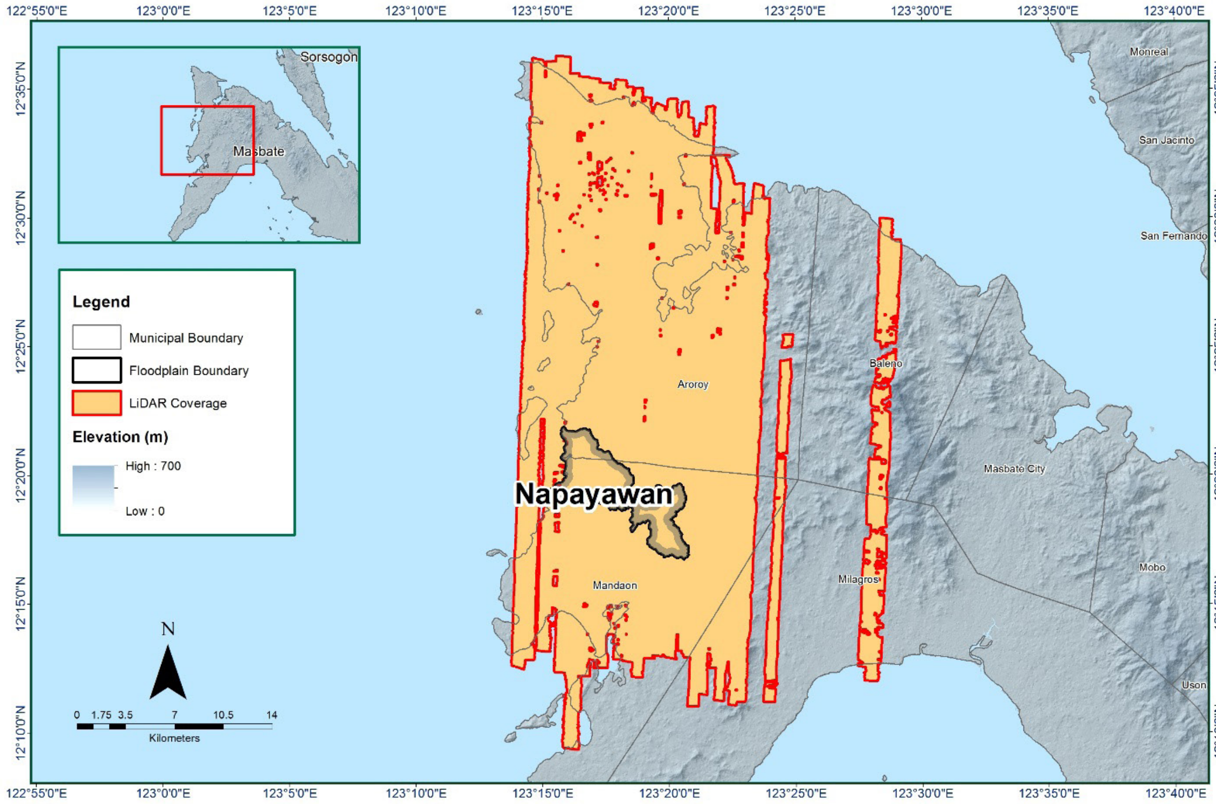

Figure 11. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Napayawan Floodplain.

The total area covered by the Napayawan missions is 790.77 sq.km that is comprised of four (4) flight acquisition grouped and merged into two (2) blocks as shown in Table 10.

Table 10. List of LiDAR blocks for Napayawan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Masbate Blk32A	1303P	324.74
	1305P	
Masbate Blk32B	1303P	466.03
	1319P	
	1331P	
TOTAL		**790.77 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 12. Since the Pegasus system employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

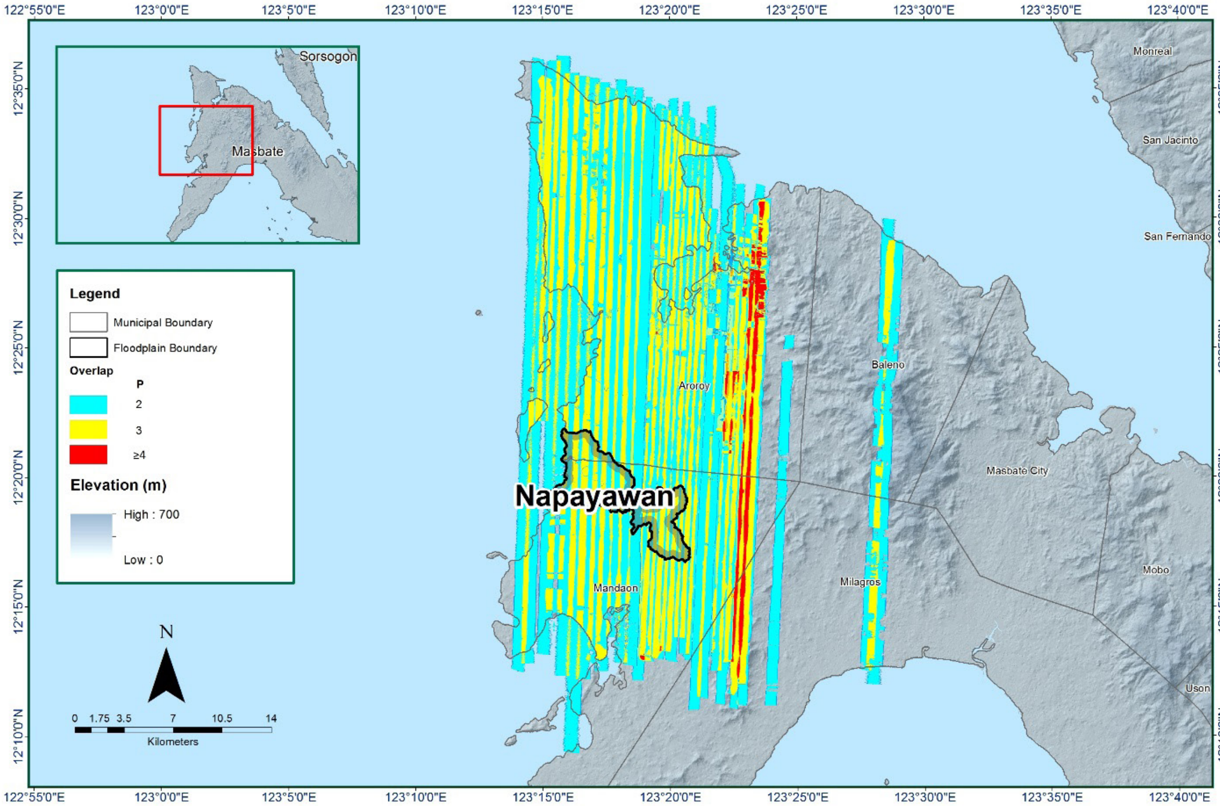

Figure 12. Image of data overlap for Napayawan Floodplain.

The overlap statistics per block for the Napayawan floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 32.14%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 13. It was determined that all LiDAR data for Napayawan floodplain satisfy the point density requirement, and the average density for the entire survey area is 6.35 points per square meter.

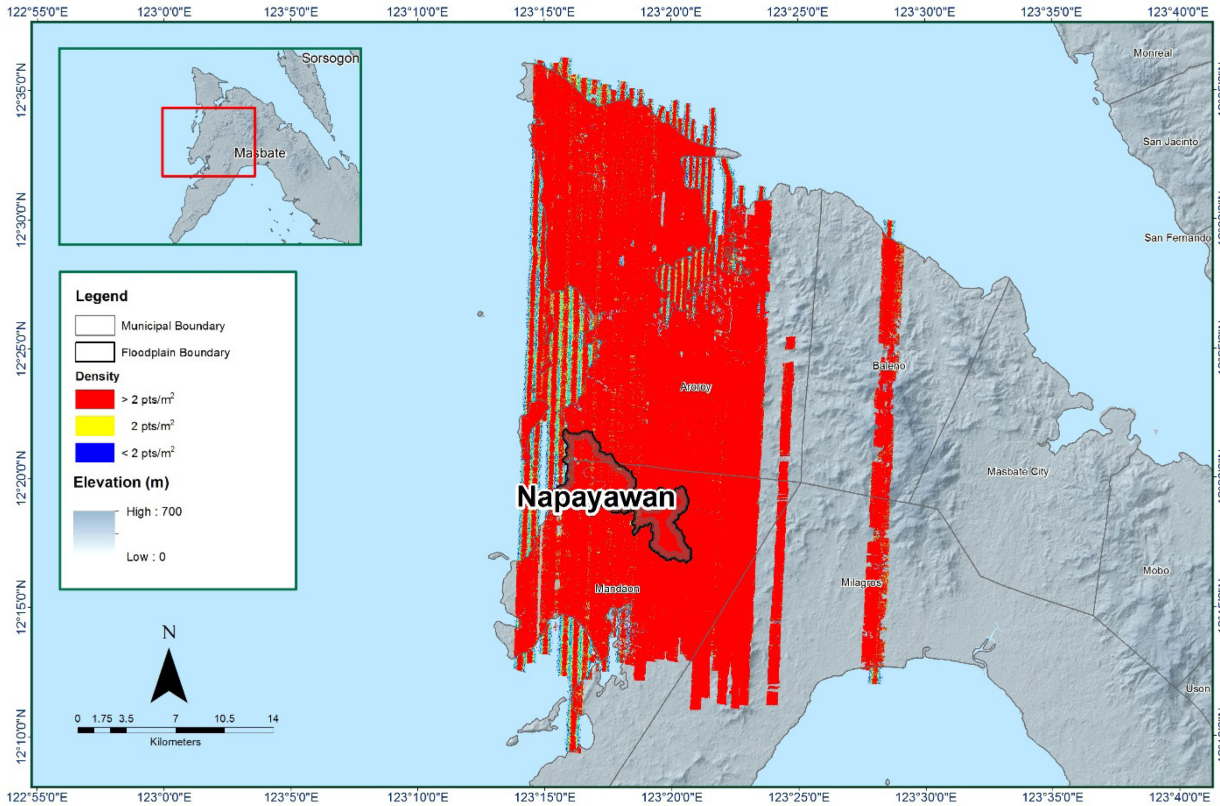

Figure 13. Pulse density map of merged LiDAR data for Napayawan Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 14. 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.

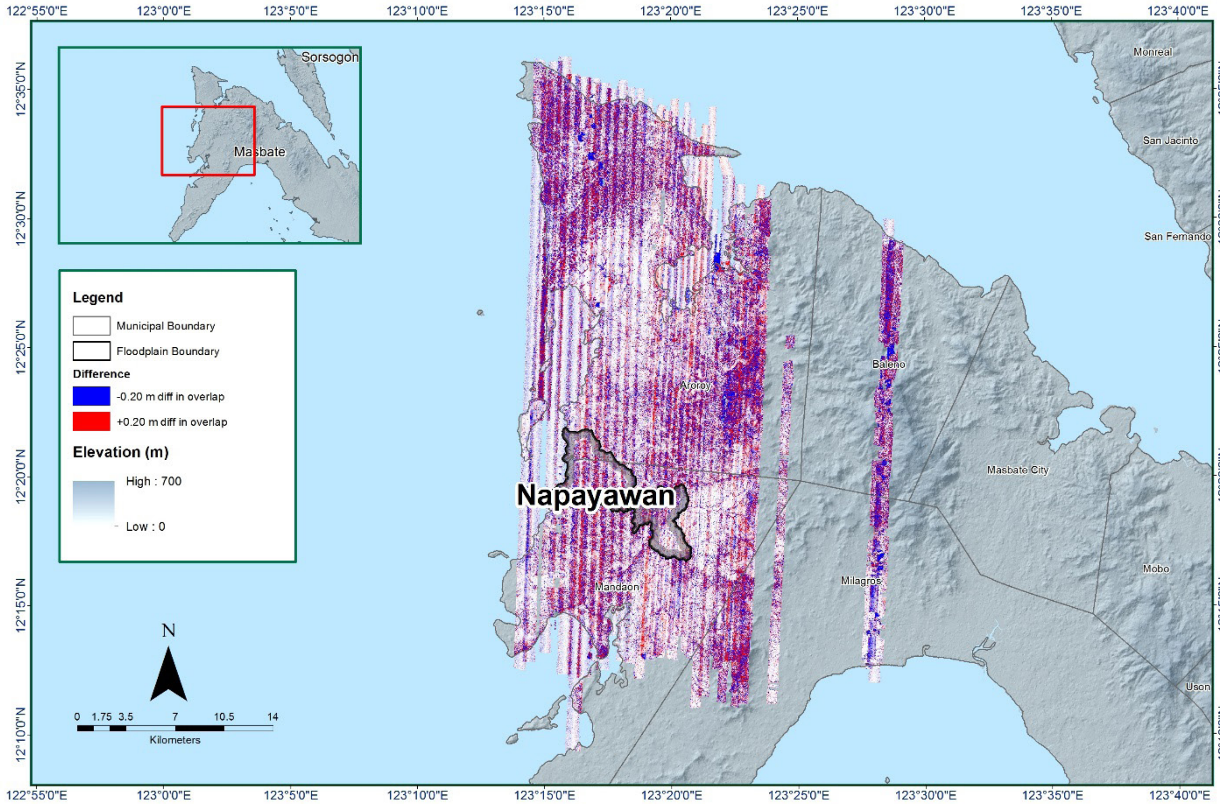

Figure 14. Elevation Difference Map between flight lines for Napayawan Floodplain Survey.

A screen capture of the processed LAS data from a Napayawan flight 1303P loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed blue 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.

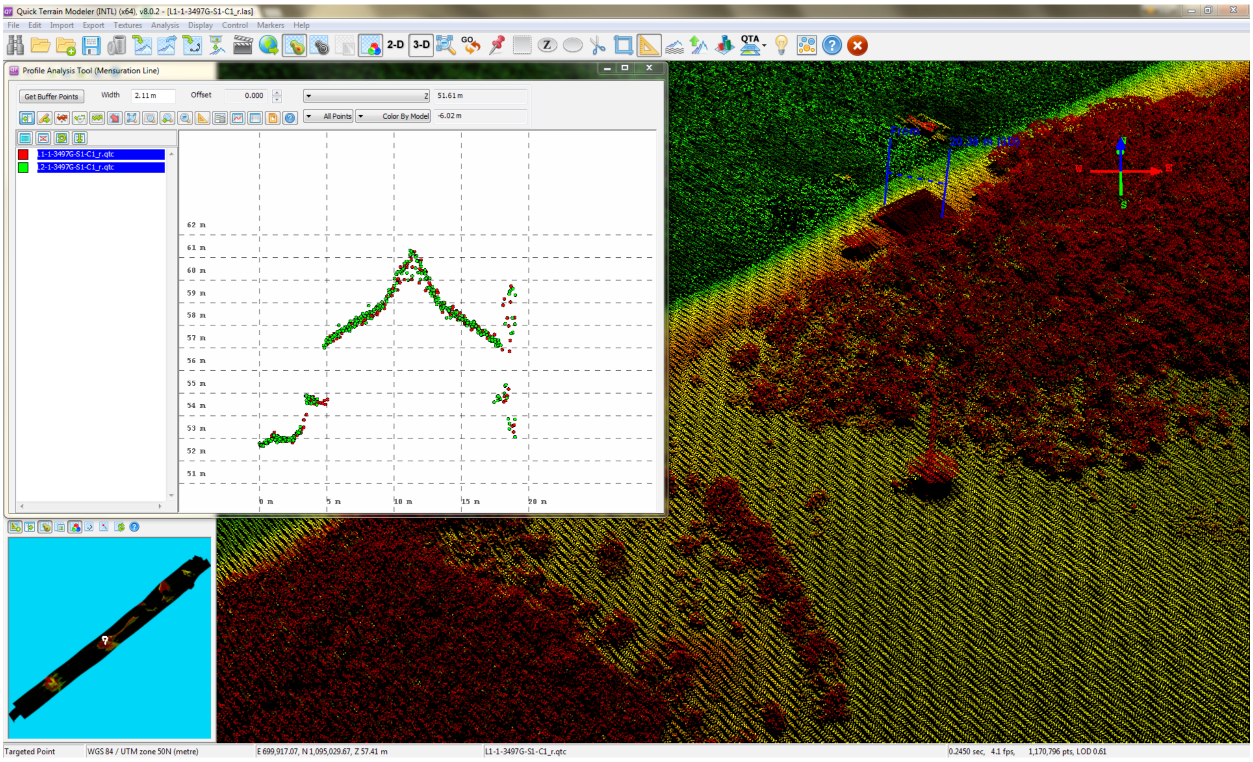

Figure 15. Quality checking for Napayawan Flight 1303P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Napayawan classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	1,161,348,178
Low Vegetation	949,928,136
Medium Vegetation	1,069,115,741
High Vegetation	531,567,484
Building	11,358,533

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Napayawan floodplain is shown in Figure 16. A total of 1,077 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 11. The point cloud has a maximum and minimum 766.45 meters and 55.95 meters respectively.

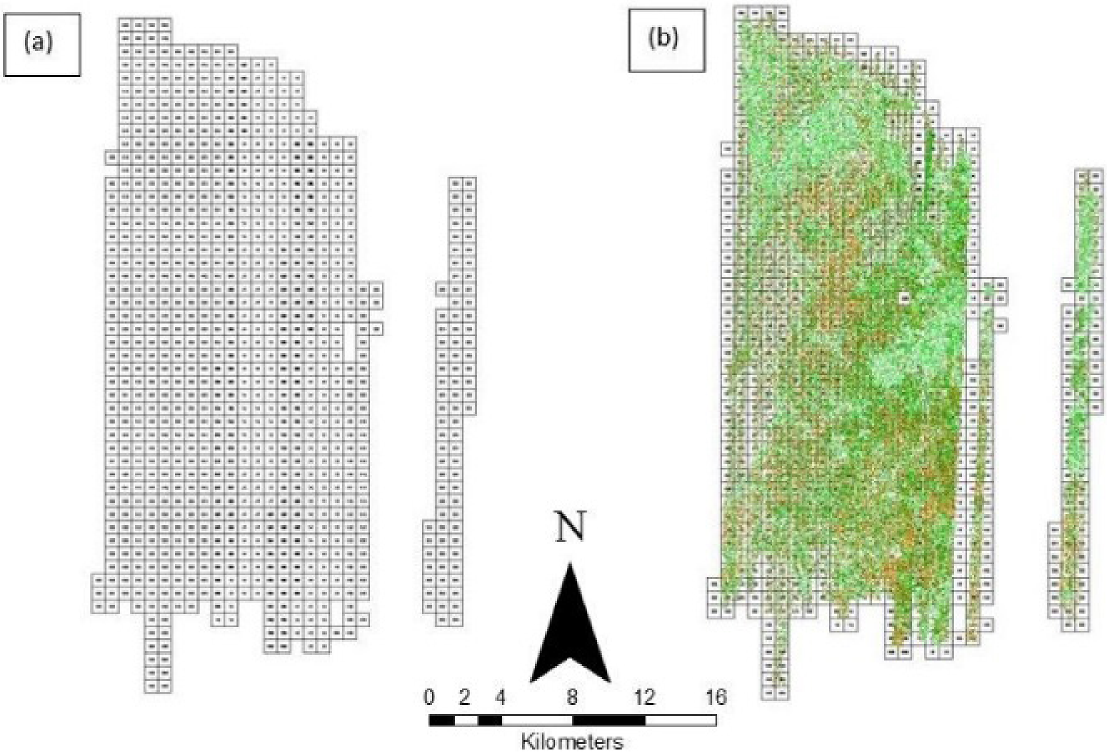

Figure 16. Tiles for Napayawan Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

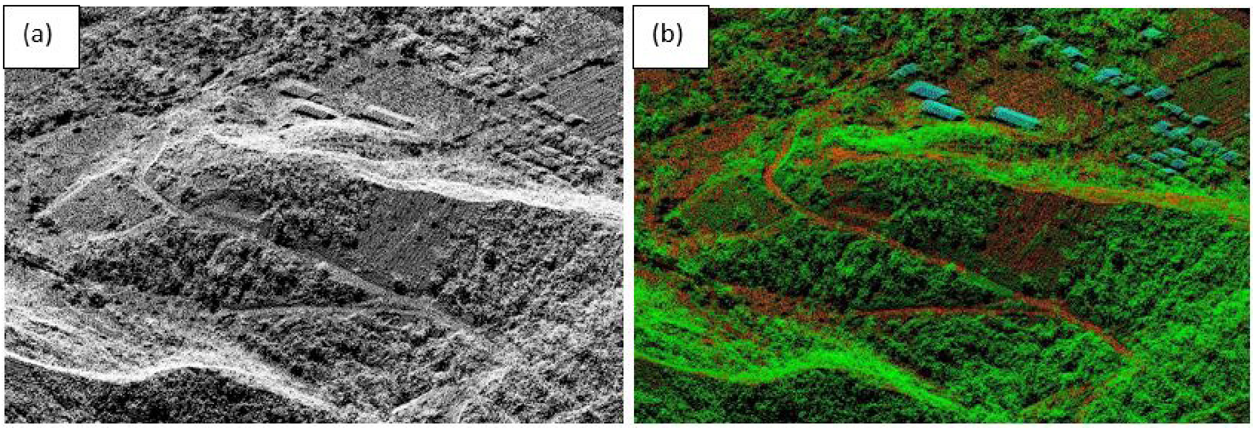

Figure 17. Point cloud before (a) and after (b) classification

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 18. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

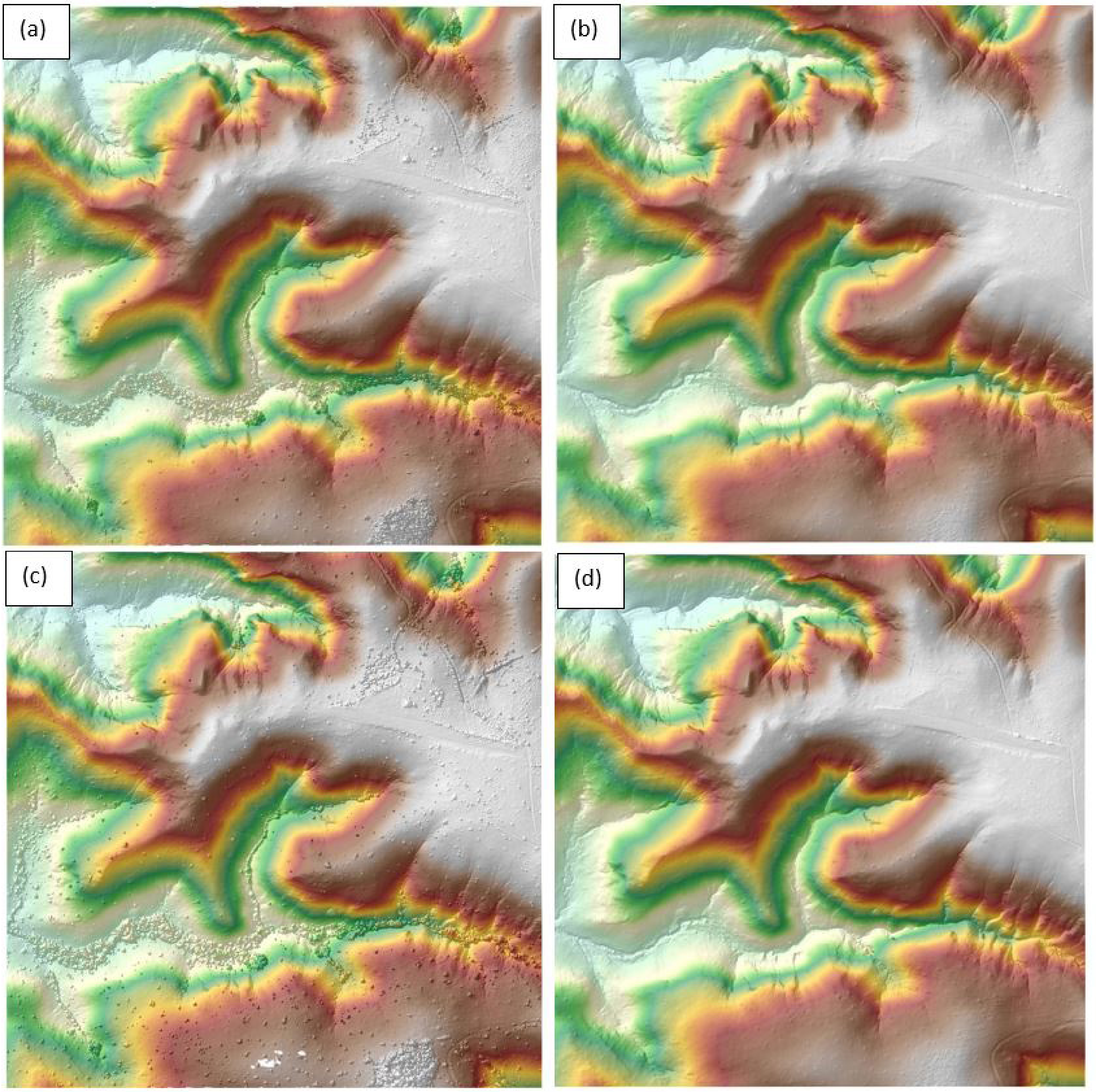

Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Napayawan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 661 1km by 1km tiles area covered by Napayawan floodplain is shown in Figure 19. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Napayawan floodplain has a total of 474.61 sq.km orthophotogaph coverage comprised of 1,338 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 20.

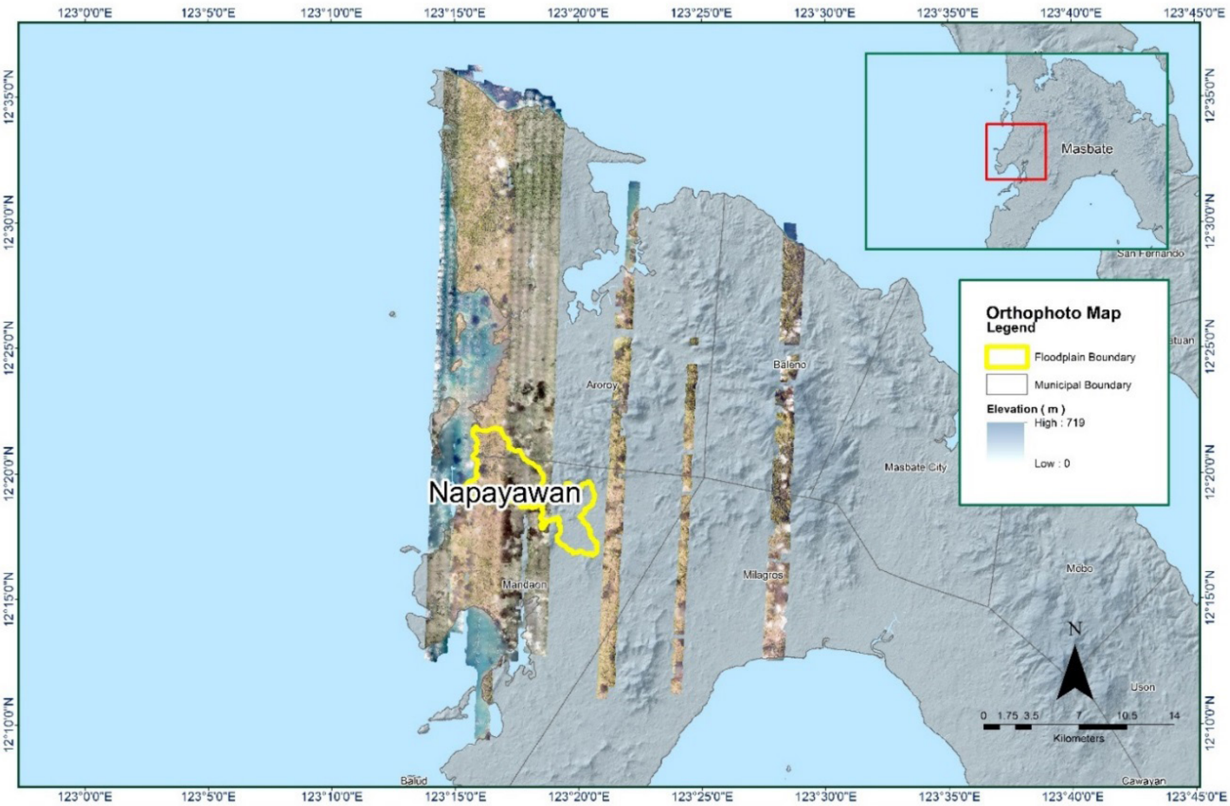

Figure 19. Napayawan floodplain with available orthophotographs

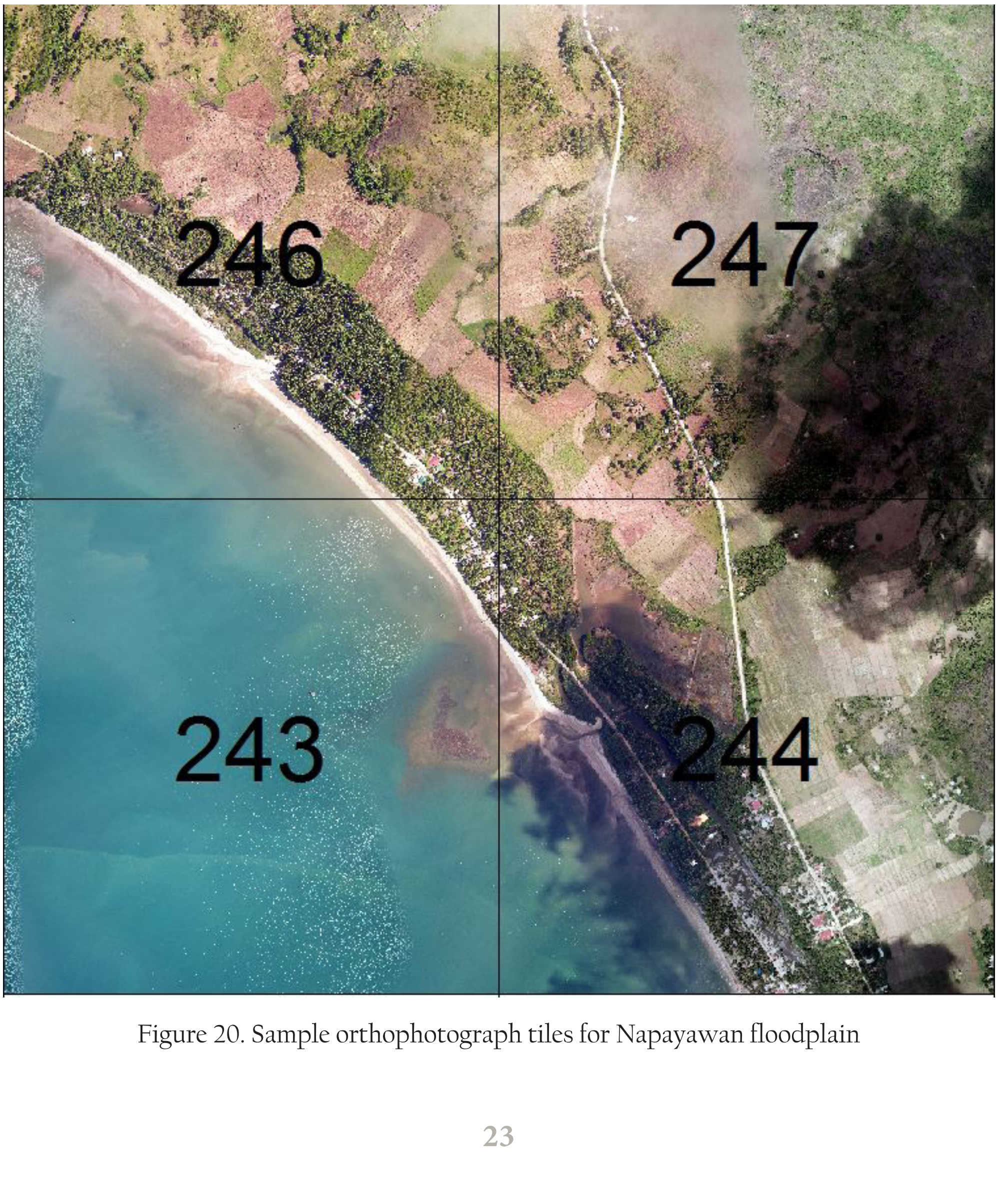

Figure 20. Sample orthophotograph tiles for Napayawan floodplain

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Napayawan flood plain. These blocks are composed of Masbate blocks with a total area of 790.77 square kilometers. Table 12 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Masbate Blk32B	324.74
Masbate Blk32A	466.03
TOTAL	**790.77 sq.km**

Portions of DTM before and after manual editing are shown in Figure 21. The bridge (Figure 21a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 21b) in order to hydrologically correct the river. The paddy field (Figure 21c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 21d) to allow the correct flow of water. Another example is a surface that has been misclassified due to thick vegetation, such as in this case, a highland. The surface appears to have been interpolated in the DTM after classification (Figure 21e) and has to be retrieved back from secondary DTM during manual editing (Figure 21f).

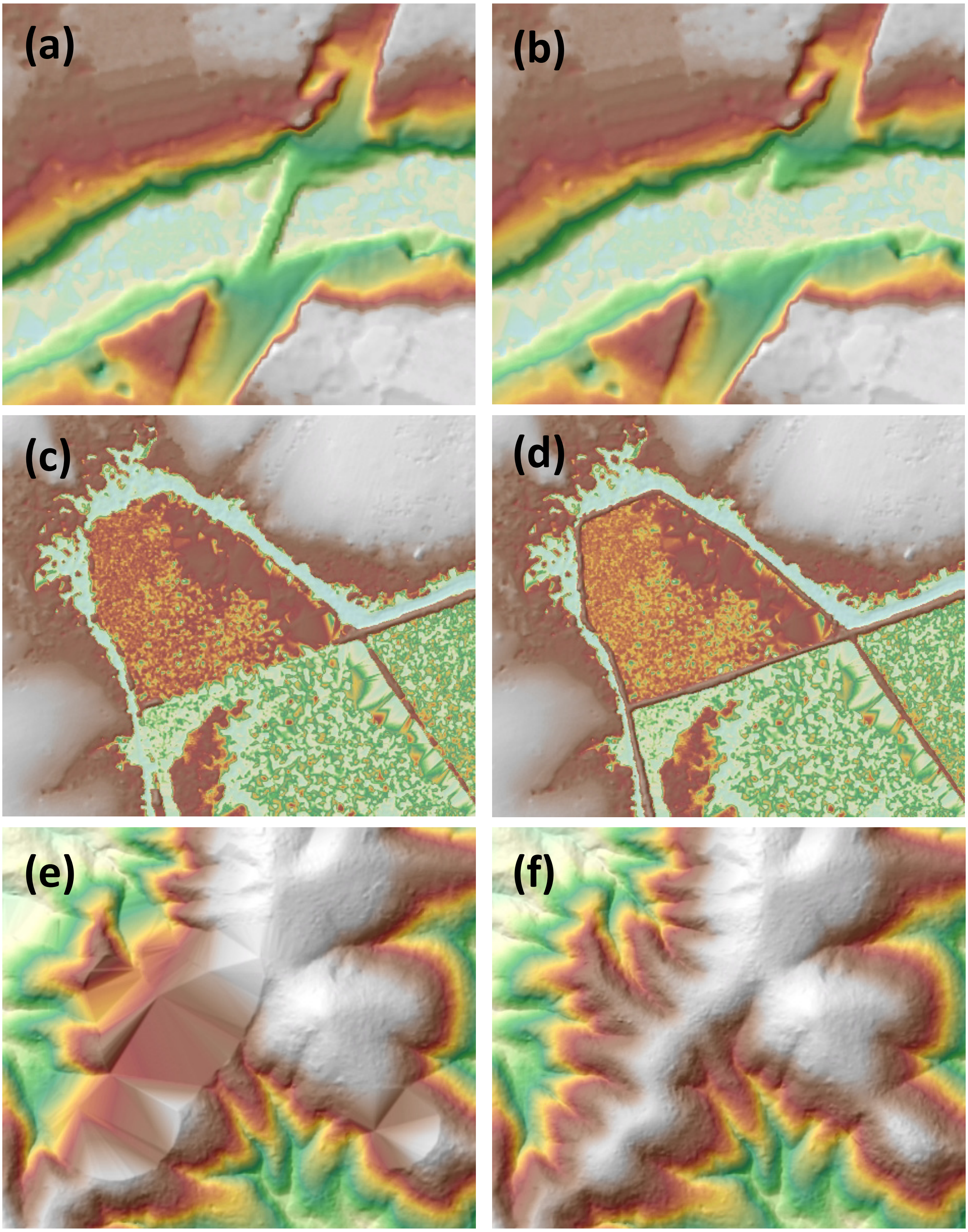

Figure 21. Portions in the DTM of Napayawan floodplain – a bridge before (a) and after (b) manual editing; a paddy field before (c) and after (d) data retrieval; and a highland before (e) and after (f) data retrieval.

3.9 Mosaicking of Blocks

Masbate_Blk32A was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 13 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Napayawan floodplain is shown in Figure 22. It can be seen that the entire Napayawan floodplain is 99.34% covered by LiDAR data.

Table 13. Shift values of each LiDAR block of Napayawan Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Masbate_Blk32B	0.00	0.00	0.00
Masbate_Blk32A	0.00	0.00	0.00

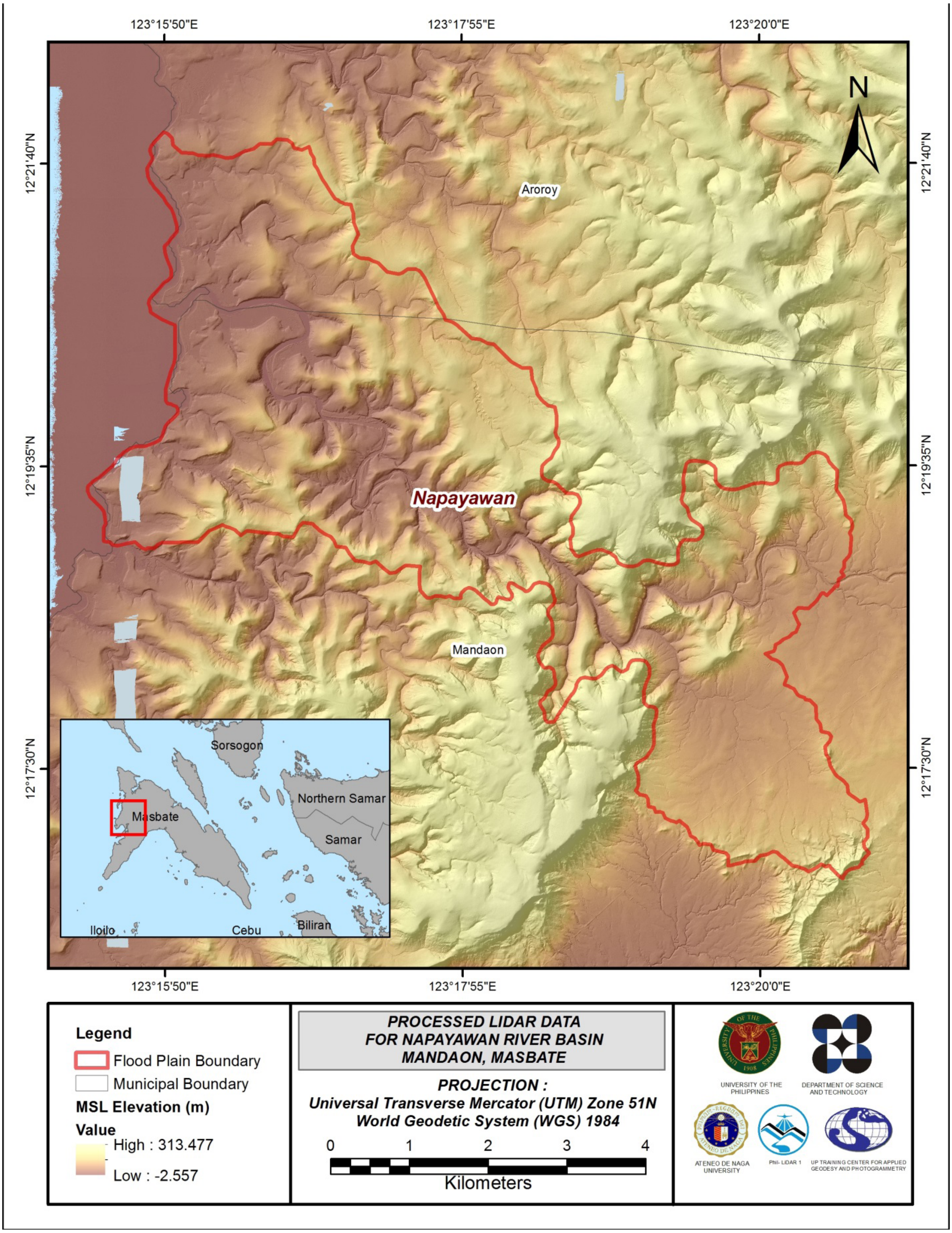

Figure 22. Map of Processed LiDAR Data for Napayawan Floodplain

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 Napayawan to collect points with which the LiDAR dataset is validated is shown in Figure 23. A total of 1135 survey points were used for calibration and validation of Napayawan LiDAR data. Random selection of 80% of the survey points, resulting to 1087 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 24. 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 elevation values is 5.331 meters with a standard deviation of 0.152 meters. Calibration of Napayawan LiDAR data was done by subtracting the height difference value, 5.331 meters, to Napayawan mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

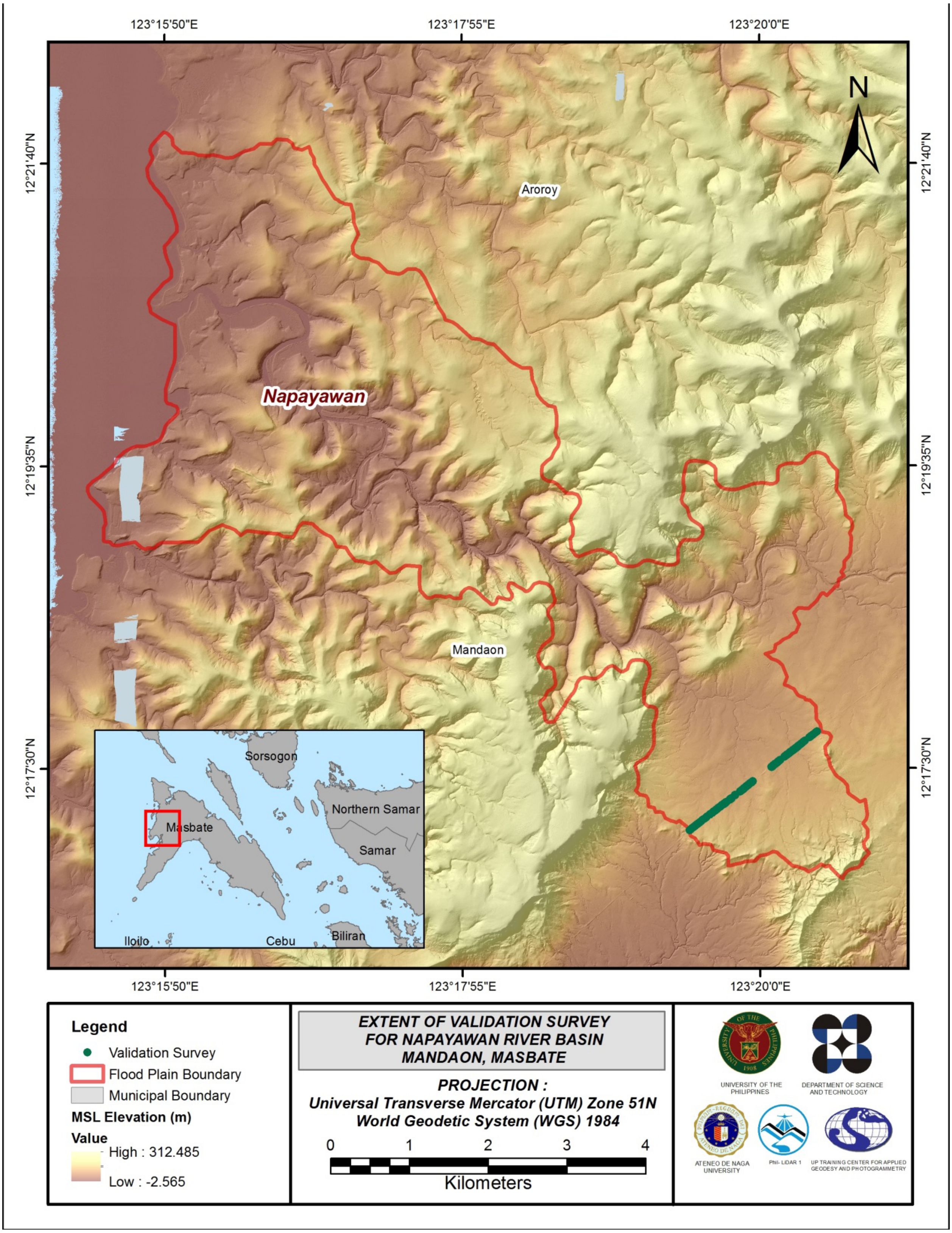

Figure 23. Map of Napayawan Floodplain with validation survey points in green.

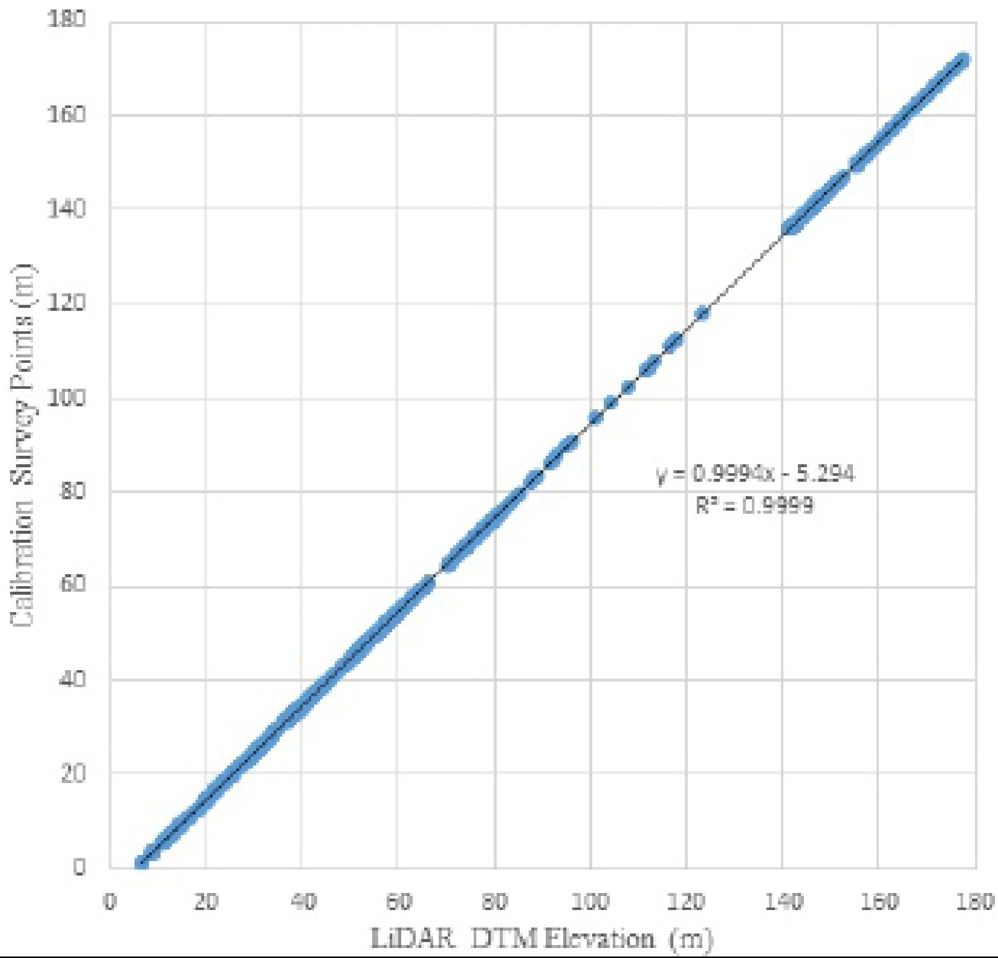

Figure 24. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	5.331
Standard Deviation	0.152
Average	-5.329
Minimum	-5.633
Maximum	-5.025

The remaining survey points that fall within the floodplain boundary, resulting to 114 points, were used for the validation of calibrated Napayawan 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 25. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.098 meters with a standard deviation of 0.062 meters, as shown in Table 15.

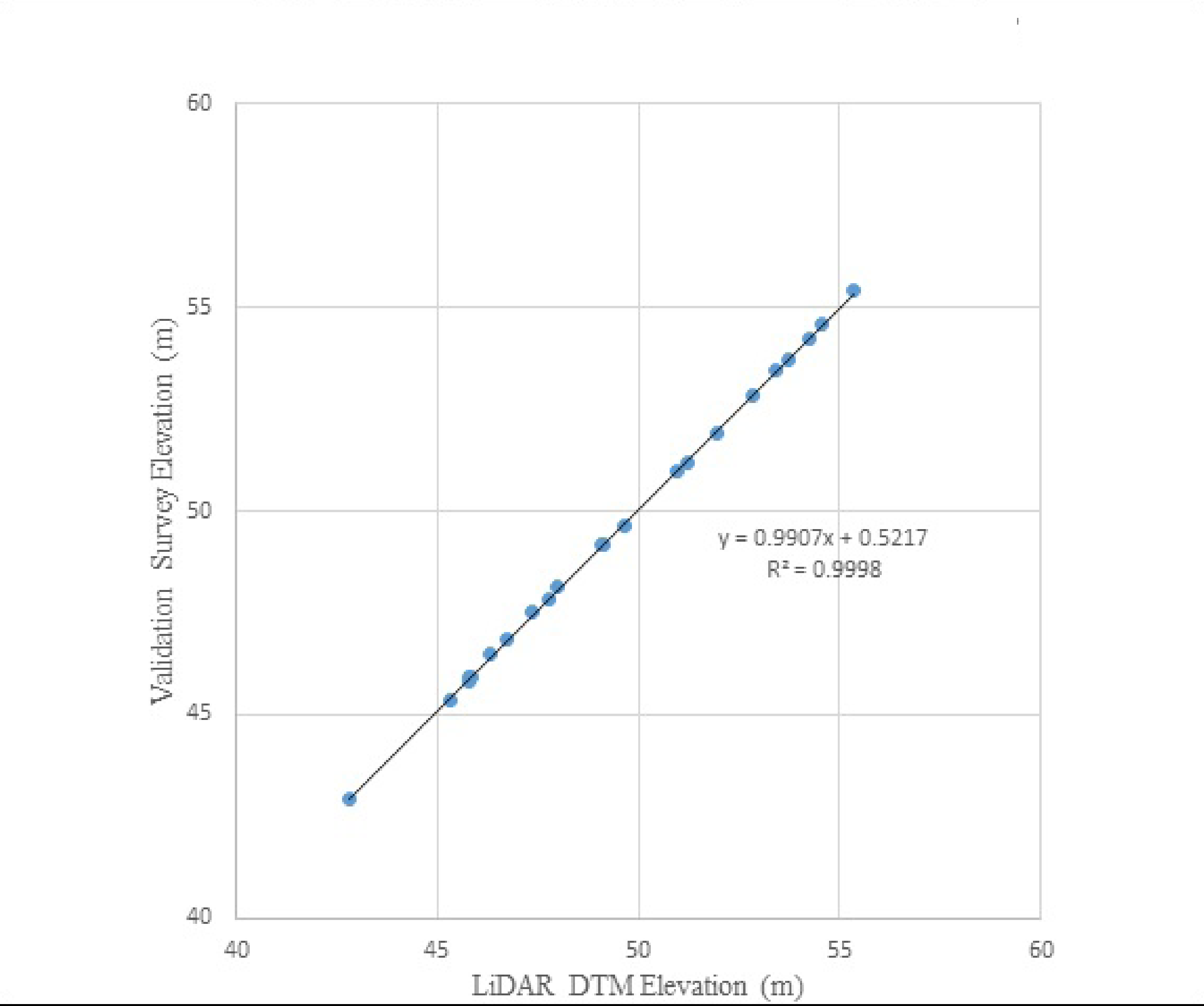

Figure 25. Correlation plot between validation survey points and LiDAR data.

Table 15. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.098
Standard Deviation	0.062
Average	0.076
Minimum	-0.041
Maximum	0.203

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline and zigzag data was available for Napayawan with 1737 bathymetric survey points. The resulting raster surface produced was done by Kernel interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.697 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Napayawan integrated with the processed LiDAR DEM is shown in Figure 26.

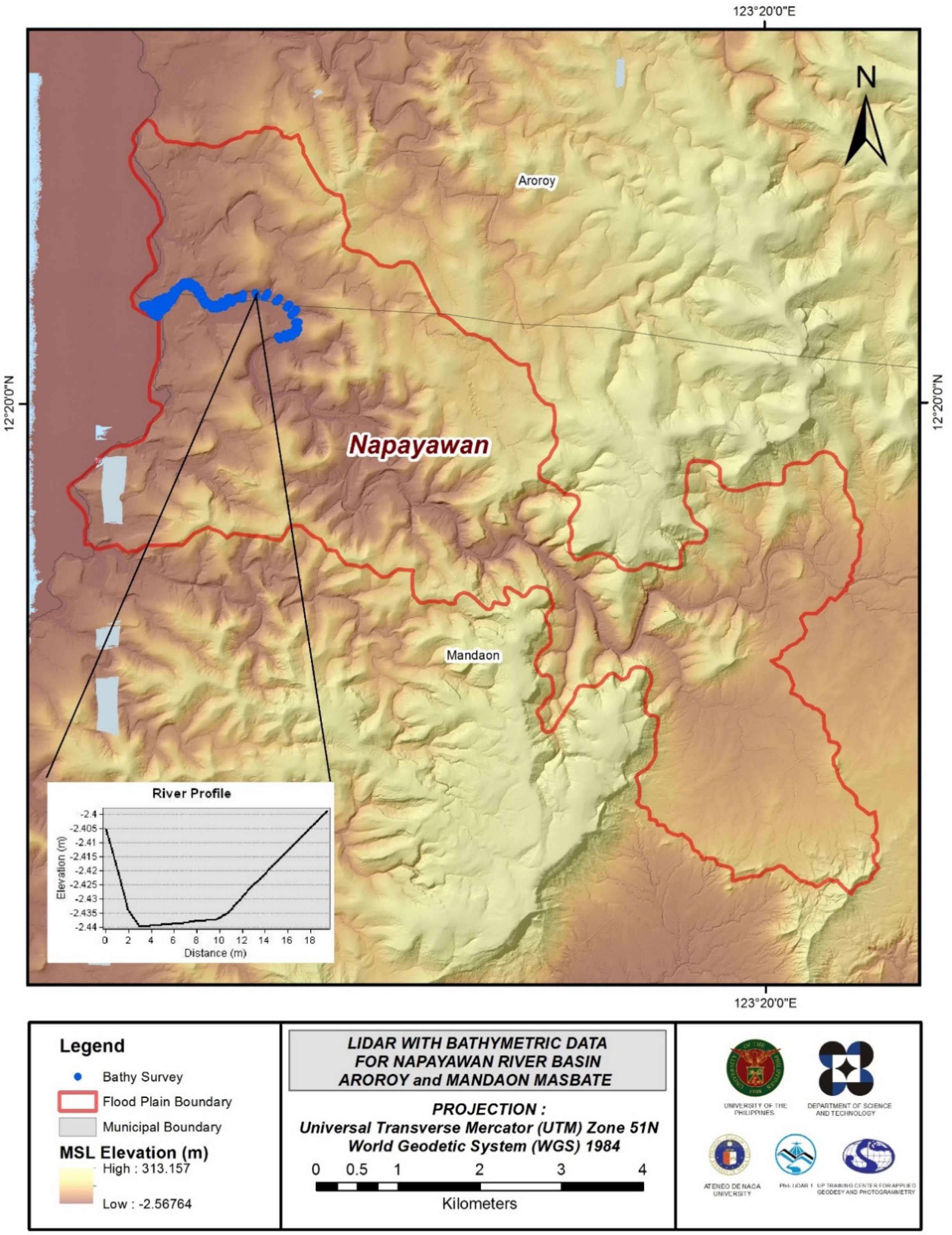

Figure 26. Map of Napayawan Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Napayawan floodplain, including its 200 m buffer, has a total area of 42.59 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 625 building features, are considered for QC. Figure 27 shows the QC blocks for Napayawan floodplain.

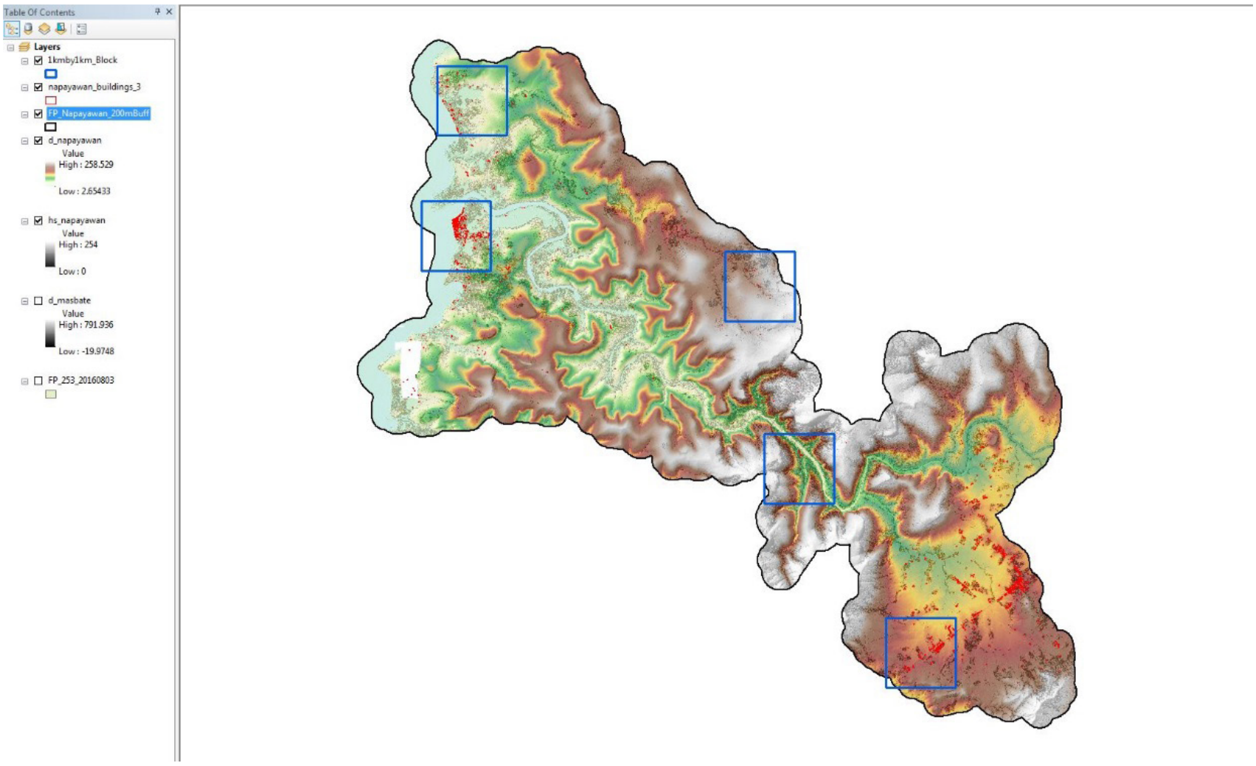

Figure 27. Blocks (in blue) of Napayawan building features subjected to QC

Quality checking of Napayawan building features resulted in the ratings shown in Table 16.

Table 16. Quality Checking Ratings for Napayawan Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Napayawan	100.00	100.00	99.68	PASSED

3.12.2 Height Extraction

Height extraction was done for 1,131 building features in Napayawan floodplain. Of these building features, 59 were filtered out after height extraction, resulting to 1,072 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 4.14 m.

3.12.3 Feature Attribution

The digitized features were marked and coded in the field using handheld GPS receivers. The attributes of non-residential buildings were first identified; all other buildings were then coded as residential. An nDSM was generated using the LiDAR DEMs to extract the heights of the buildings. A minimum height of 2 meters was used to filter out the terrain features that were digitized as buildings. Buildings that were not yet constructed during the time of LiDAR acquisition were noted as new buildings in the attribute table.

Feature Attribution was done for 1,072 building features in Napayawan Floodplain with the use of participatory mapping and innovations. The approach used in participatory mapping undergoes the creation of feature extracted maps in the area and presenting spatial knowledge to the community with the premise that the local community in the area are considered experts in determining the correct attributes of the building features in the area.

The innovation used in this process is the creation of an android application called reGIS. The Resource Extraction for Geographic Information System (reGIS)[1] app was developed to supplement and increase the field gathering procedures being done by the AdNU Phil-LiDAR 1. The Android application allows the user to automate some procedures in data gathering and feature attribution to further improve and accelerate the geotagging process. The app lets the user record the current GPS location together with its corresponding exposure features, code, timestamp, accuracy and additional remarks. This is all done by a few swipes with the help of the device's pre-defined list of exposure features. This effectively allows unified and standardized sets of data.

Table 17 summarizes the number of building features per type. On the other hand, Table 18 shows the total length of each road type, while Table 19 shows the number of water features extracted per type.

[1]Resource Extraction for Geographic Information System (reGIS), March 17,2015.

Table 17. Building Features Extracted for Napayawan Floodplain.

Facility Type	No. of Features
Residential	1,017
School	30
Market	1
Agricultural/Agro-Industrial Facili-ties	2
Medical Institutions	2
Barangay Hall	2
Military Institution	0
Sports Cen-ter/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	1
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	0
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	13
Total	**1,072**

Table 18. Total Length of Extracted Roads for Napayawan Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Napayawan	15.19926	0	0	2.55587	0.00	17.75513

Table 19. Number of Extracted Water Bodies for Napayawan Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Napayawan	1	13	1	0	0	15

A total of 2 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 28 shows the Digital Surface Model (DSM) of Napayawan floodplain overlaid with its ground features.

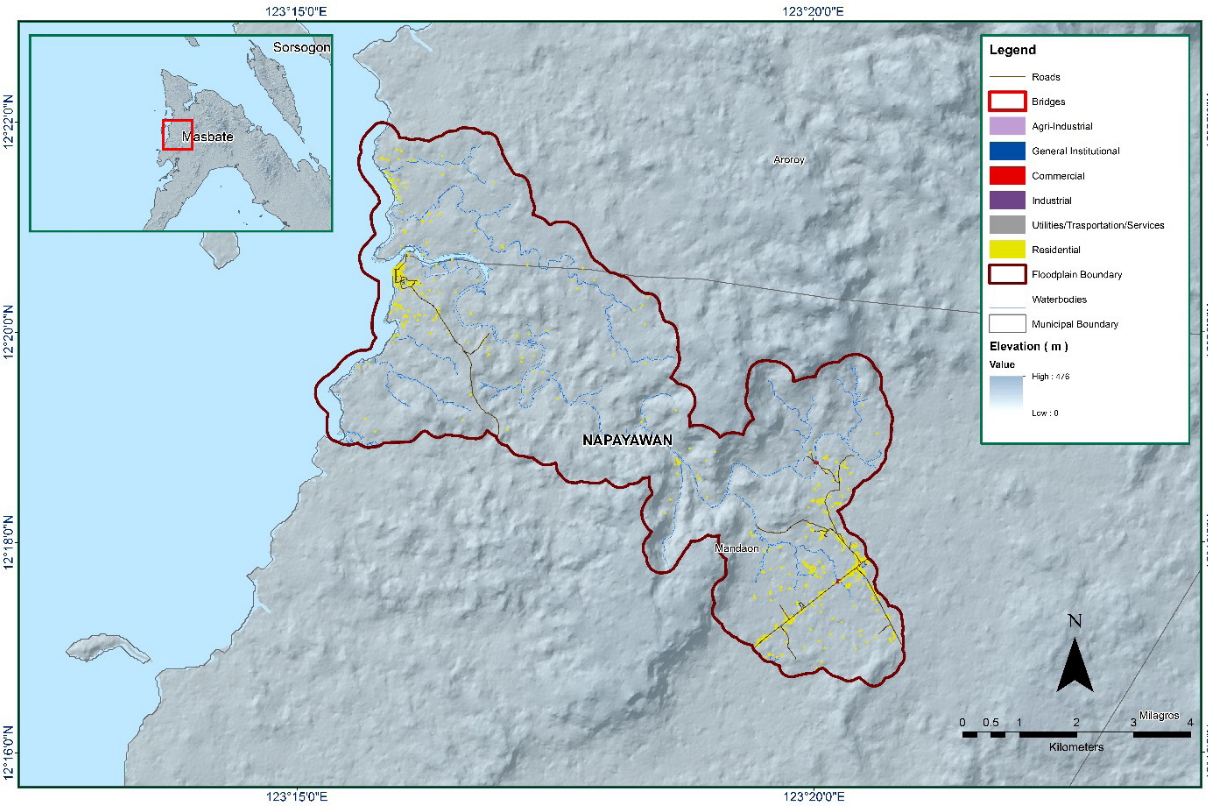

Figure 28. Extracted features for Napayawan Floodplain.

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

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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

H.O. Noveloso Surveying (HONS) conducted a field survey in Napayawan River on January 21, 2017, on March 11, 2017, and on March 13-14, 2017 with the following scope: reconnaissance; control survey for the establishment of a control point; and cross-section on the mouth of the river in Brgy. Amutag, Municipality of Mandaon, Masbate; and bathymetric survey from its upstream in Brgy. Bugtong, Municipality of Mandaon, Masbate to the mouth of the river located in Brgy. Amutag, Municipality of Aroroy, Masbate with an approximate length of 2.555 km using a dual frequency Topcon™ GR-5, a Hydrolite™ Single Beam Echo Sounder, and a Sokkia™ Set 3030 Total Station. The entire survey extent is illustrated in Figure 29..

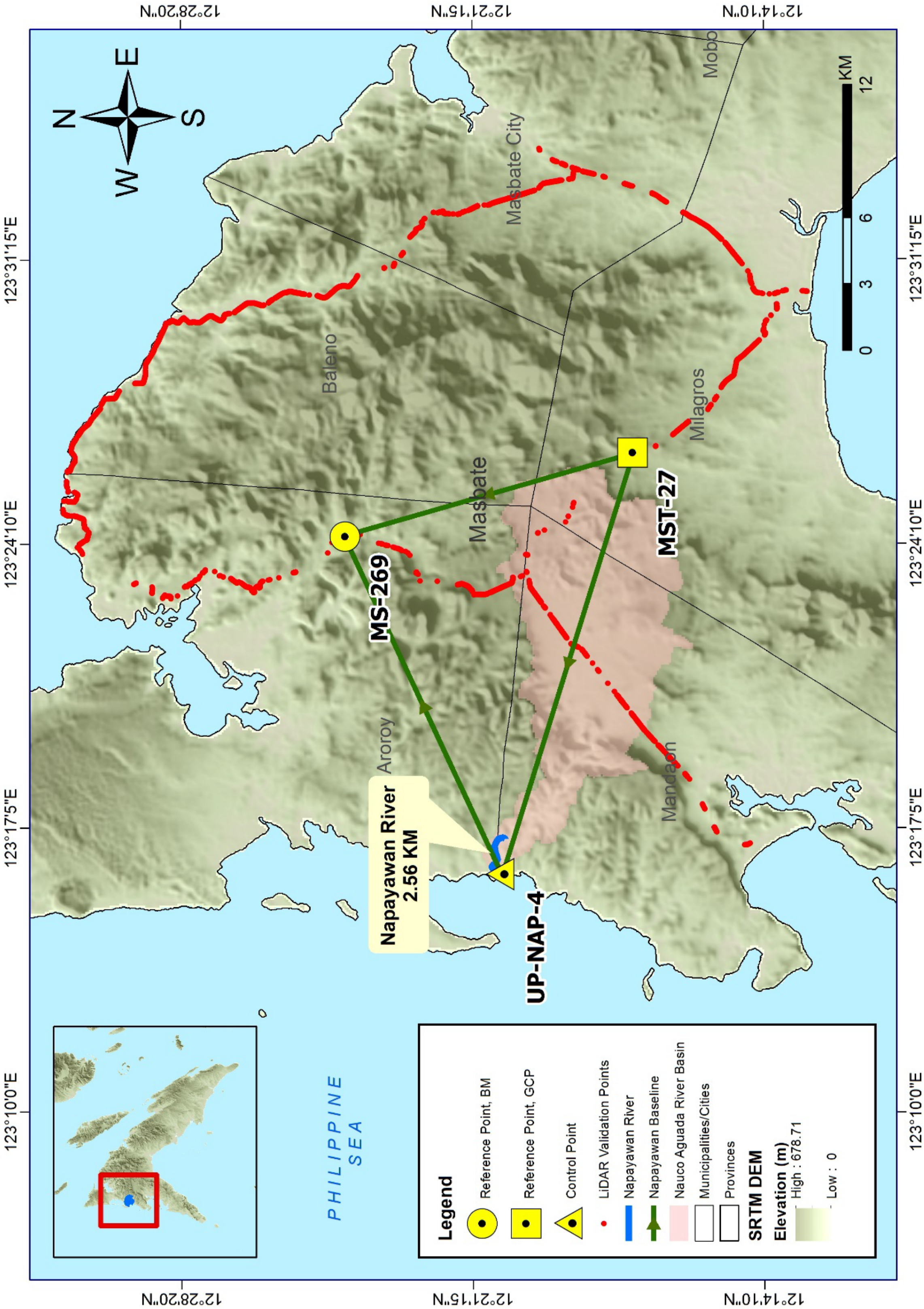


Figure 29. Extent of the bathymetric survey (in blue line) in Napayawan River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for Napayawan River is composed of one (1) network with one (1) loop. The network was established on February 2, 2017, occupying the following reference points: MST-27, a second-order GCP, in Brgy. Matiporon, Milagros, Masbate and MS-269, a first-order BM, in Brgy. Luy-A, Aroroy, Masbate.

One (1) established control point by the contractor, UP-TAN-4 located in Brgy. Bugtong, Mandaon, Masbate, was used as marker.

The GNSS network established is illustrated in Figure 30 while the summary of reference and control points and its location is summarized in Table 20.

Table 20. List of Reference and Control Points occupied for Napayawan 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
MST-27	2nd order, GCP	12°17'22.32360"N	123°26'26.50548"E	110.173	2007	2007
MS-269	1st order, BM	12°24'21.62832"N	123°24'21.39804"E	83.348	2008	2009
UP-NAP-4	Established	12°20'35.82837"N	123°15'55.68722"E	57.179	01-21-17	2-26-16

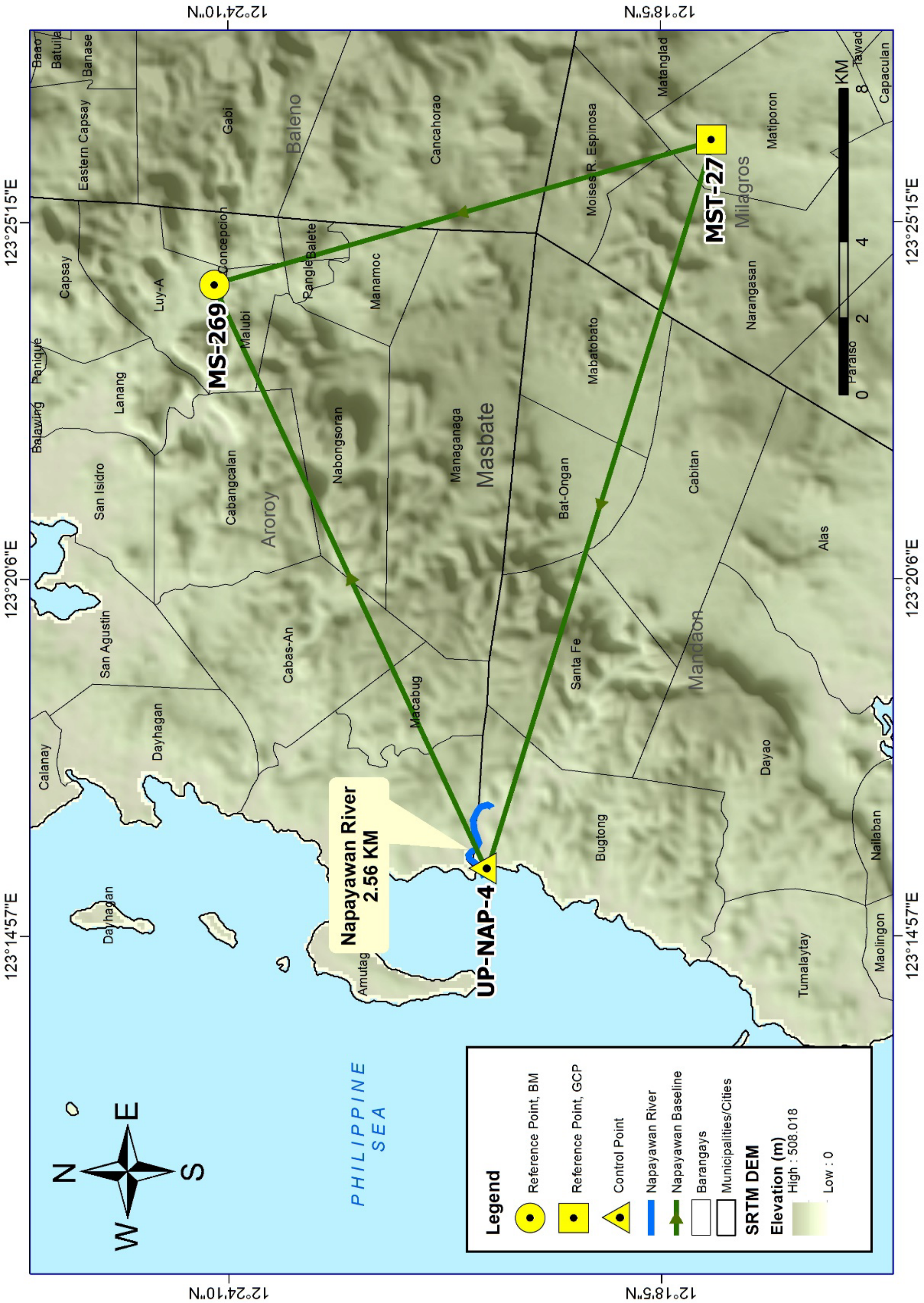


Figure 30. The GNSS Network established in the Napayawan River Survey.

The GNSS set-ups on recovered reference points and established control points in Napayawan River are shown from Figure 31 to Figure 33.

Figure 31. GNSS base set up, Trimble® SPS 882, at MST-27, located at the approach of Mabuaya Bridge in Brgy. Matiporon, Milagros, Masbate

Figure 32. GNSS receiver set up, Trimble® SPS 985, at MS-269, located at the approach of Luy-A bridge in Brgy. Luy-A, Aroroy, Masbate

Figure 33. GNSS receiver set up, Trimble® SPS 985, at UP-NAP-4, located at the port in Brgy. Bugtong, Mandaon, Masbate

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Napayawan River Basin is summarized in Table 21 generated by TBC software.

Table 21. Baseline Processing Summary Report for Napayawan River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
MST-27 ---UP-NAP-4	02-02-2017	Fixed	0.004	0.019	287°20'42"	19966.162	52.966
MST-27 --- MS-269	02-02-2017	Fixed	0.006	0.032	343°39'19"	13427.841	-26.951
UP-NAP-4--- MS-269	02-02-2017	Fixed	0.004	0.020	65°33'27"	16778.618	25.990

As shown Table 21, a total of three (3) baselines were processed. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

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

for each control point. See the Network Adjustment Report shown in Table 22 to Table 25 for complete details.

The three (3) control points, MST-27, MS-269 and UP-NAP-4, were occupied and observed simultaneously to form a GNSS loop. The elevation value of MS-269, and the coordinate values of MST-27 were held fixed as presented in Table 22. Through this reference point, the coordinates and elevations of the unknown control points will be computed.

Table 22. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
MS-269	Grid				Fixed
MST-27	Global	Fixed	Fixed		
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 23.

Table 23. Adjusted grid coordinates for the control points used in the Napayawan River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
MS-269	544123.787	0.003	1371483.455	0.002	27.408	?	e
MST-27	547922.386	?	1358609.337	?	53.580	0.016	LL
UP-NAP-4	528861.684	0.002	1364528.258	0.002	1.542	0.014	

With the mentioned equation, $\sqrt{((x_e)^2 + (y_e)^2)}$ <20cm and $z_e < 10\ cm$ for horizontal and $z_e < 10\ cm$ for the vertical;

the computation for the accuracy are as follows:

a. MS-269

horizontal accuracy	=	√((0.3)² + (0.2)²
	=	√ (0.9 + 0.4)
	=	0.13 < 20 cm
vertical accuracy	=	Fixed

b. MST-27

horizontal accuracy	=	Fixed
vertical accuracy	=	1.6 < 20 cm

c. UP-NAP-4

horizontal accuracy	=	√((0.2)² + (0.2)²
	=	√ (0.4 + 0.4)
	=	0.8 < 20 cm
vertical accuracy	=	1.4 < 20 cm

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

Table 24. Adjusted geodetic coordinates for control points used in the Napayawan River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoidal Height (Meter)	Height Error (Meter)	Constraint
MS-269	N12°17'22.32360"	E123°26'26.50548"	109.098	0.016	LL
MST-27	N12°24'21.62919"	E123°24'21.39813"	82.132	?	e
UP-NAP-4	N12°20'35.82854"	E123°15'55.68705"	56.137	0.014	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 23 and Table 24. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 25.

Table 25. Reference and control points utilized in the Napayawan River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N			
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	EGM Ortho (m)	BM Ortho (m)
MS-269	2nd Order, GCP	12°17'22.32360"N	123°26'26.50548"E	62.912	1371483.455	1358609.337	547922.4	287.844
MST-27	1st Order, BM	12°24'21.62832"N	123°24'21.39804"E	86.168	1371483.455	544123.787	27.408	58.767
UP-NAP-4	Established	12°20'35.82837"N	123°15'55.68722"E	46.732	1364528.258	528861.684	1.542	3.317

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

Cross-section survey was conducted on March 14, 2017 at the mouth of Napayawan River in Brgy. Amutag, Mandaon, Masbate. A Sokkia™ Set CX Total Station was utilized for this survey as shown in Figure 35.

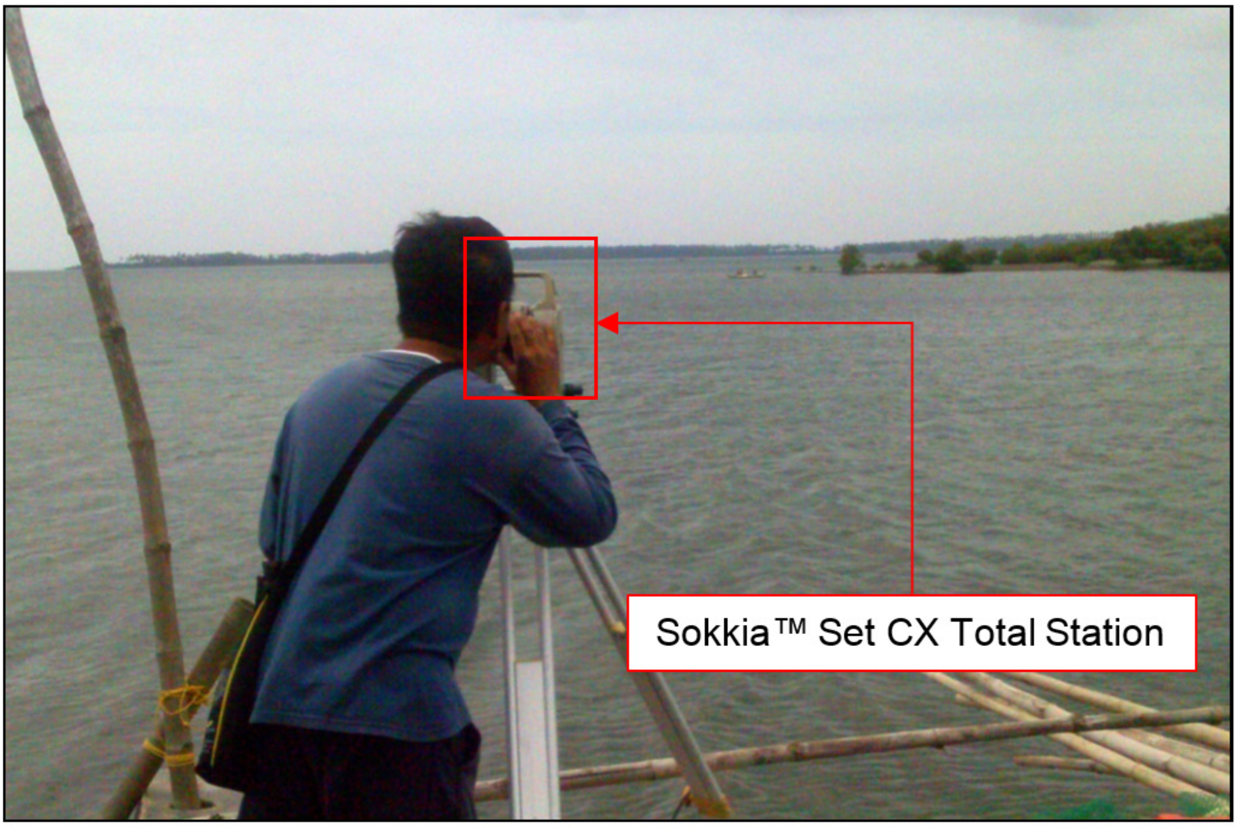


Figure 34. Cross-section survey at the mouth of Napayawan River

The cross-sectional line of Napayawan River is about 213 m with one hundred fifty-nine (159) cross-sectional points using the control point UP-NAP-3 as the GNSS base station. The location map of the cross-section is shown in Figure 36. The water level elevation for Napayawan River, as seen in the cross-section diagram in Figure 37, was determined on March 11, 2017 at 1:00 PM using a Sokkia™ Set 3030 Total Station.

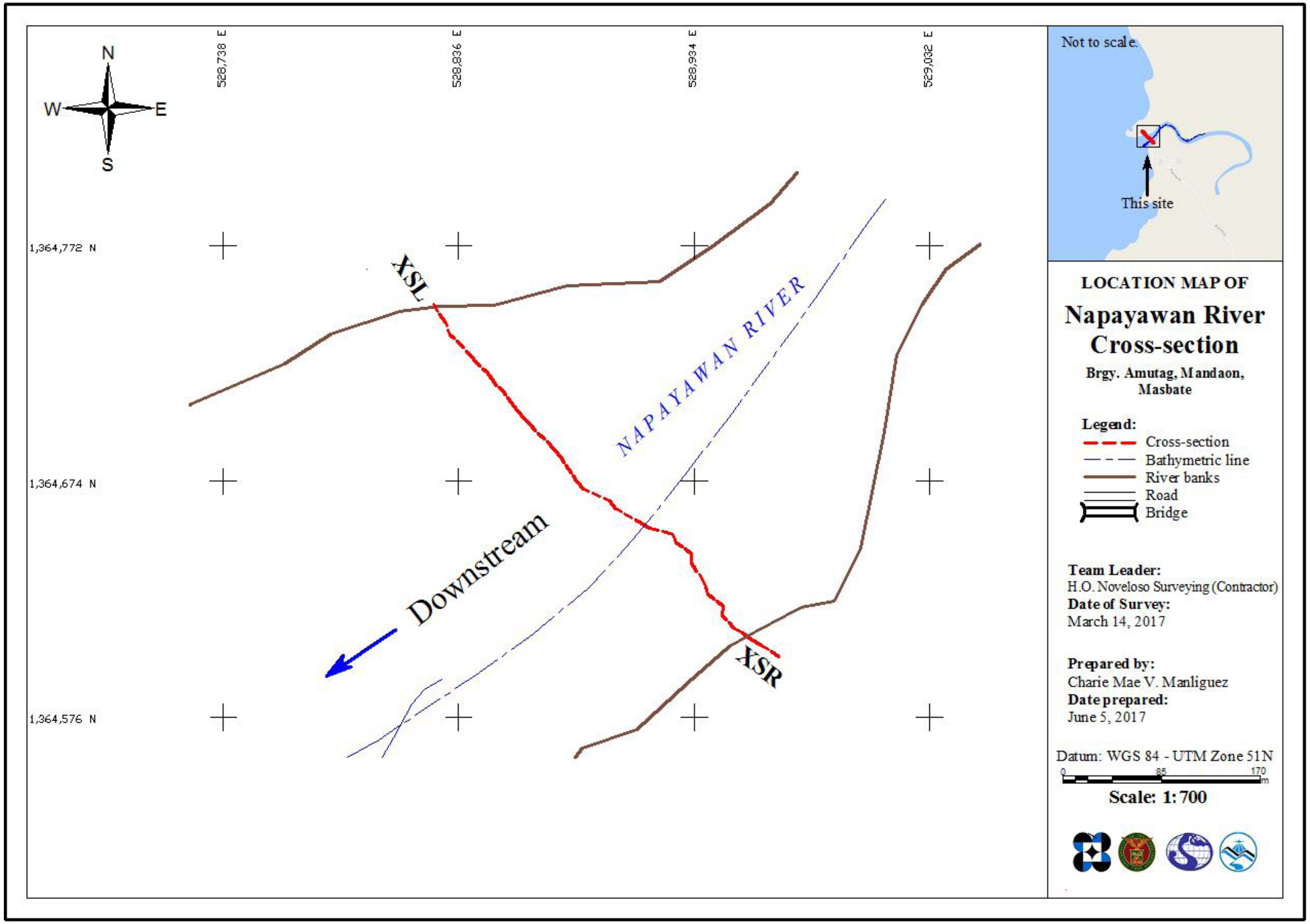


Figure 35. Location map of Napayawan River cross-section survey

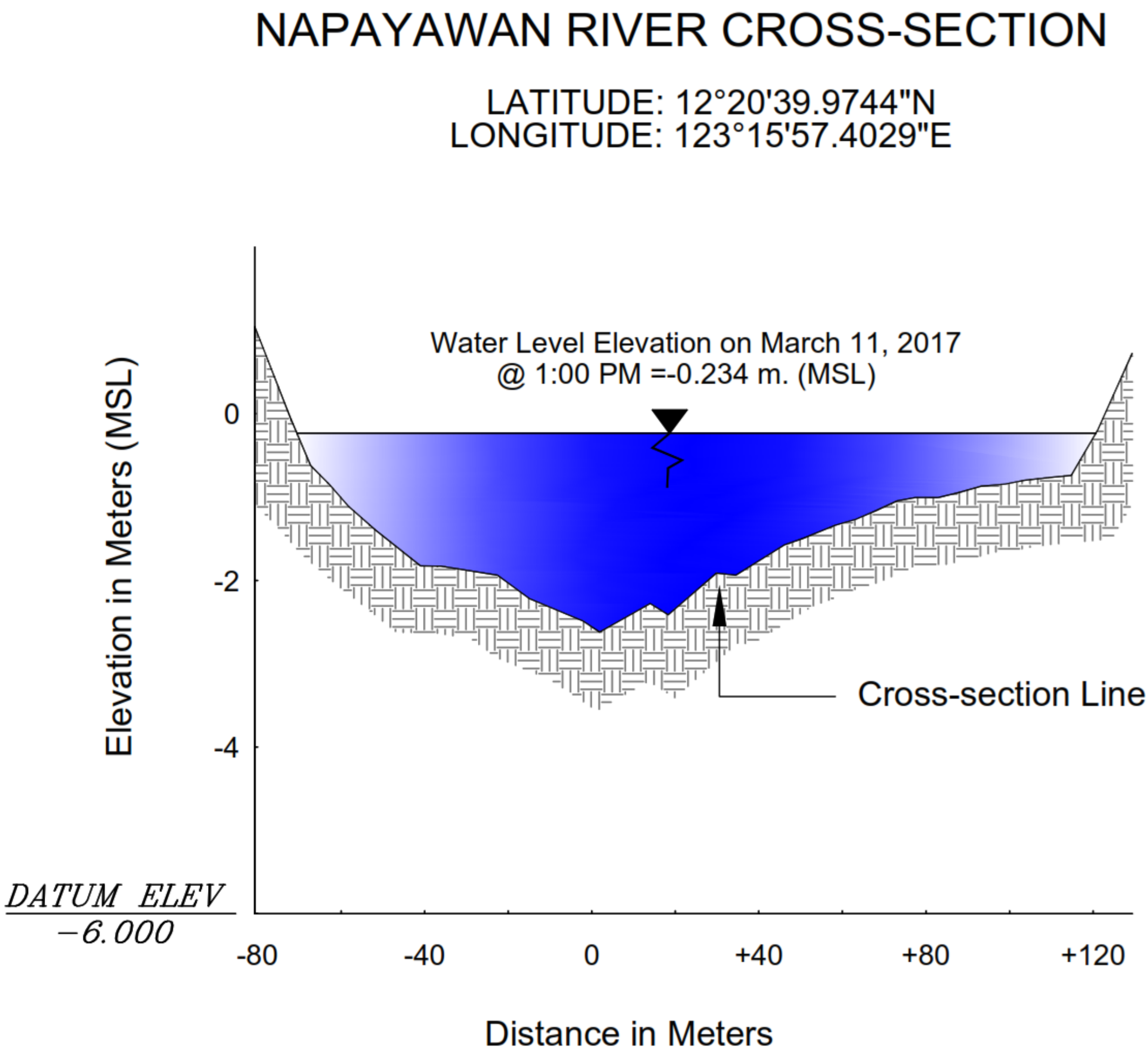


Figure 36. Napayawan River cross-section diagram

Water surface elevation of Napayawan River was determined by a Sokkia™ Set 3030 Total Station on March 14, 2017 at 1:00 PM at the pier in Brgy. Bugtong, Mandaon, Masbate with a value of 1.375 m in MSL. This was translated into marking at the edge of the port as shown in Figure 37. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Napayawan River, Ateneo de Naga University.

Figure 37. Water level markings at the side of the pier in Brgy. Bugtong, Mandaon, Masbate

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC on December 5-6, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 882, which was attached on top of the vehicle as shown in Figure 38. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 1.902 m and measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with MST-4549 and MST-27 occupied as the GNSS base stations in the conduct of the survey.

The first day of the validation points acquisition survey ran from Mabuaya Bridge in Brgy. Matiporon, Milagros to Brgy. Poblacion, Aroroy via Baleno in an almost semi-circumferential route. The reference point MST-4549 was utilized during this survey. The second day of this survey also started in Mabuaya Bridge going to Brgy. Poblacion in Aroroy via Mandaon, the other half of the circumferential road. This survey also covered Mandaon Road which started from Brgy. Mabatobato going southwest towards Brgy. Nailaban, both in the Municipality of Mandaon. The reference point MST-27 was used as base station for the last route.

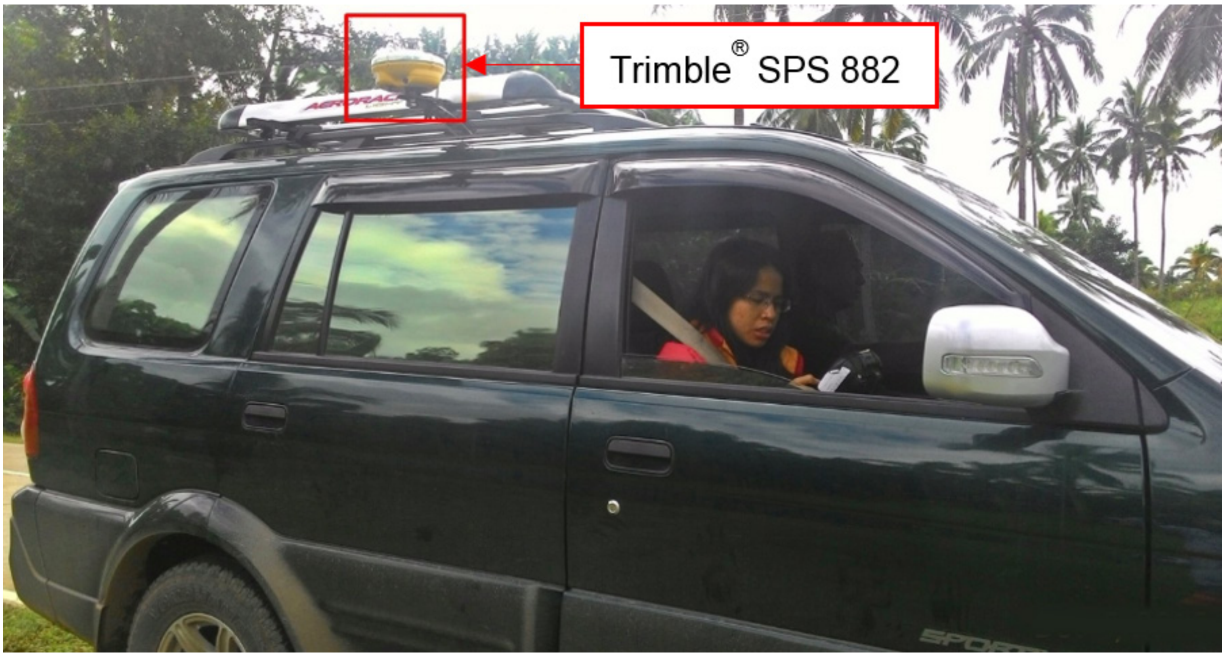


Figure 38. Validation points acquisition survey set-up for Napayawan River

The survey gathered a total of 4,709 points with approximate length of 112 km using MST-27 and MST-4549 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 39.

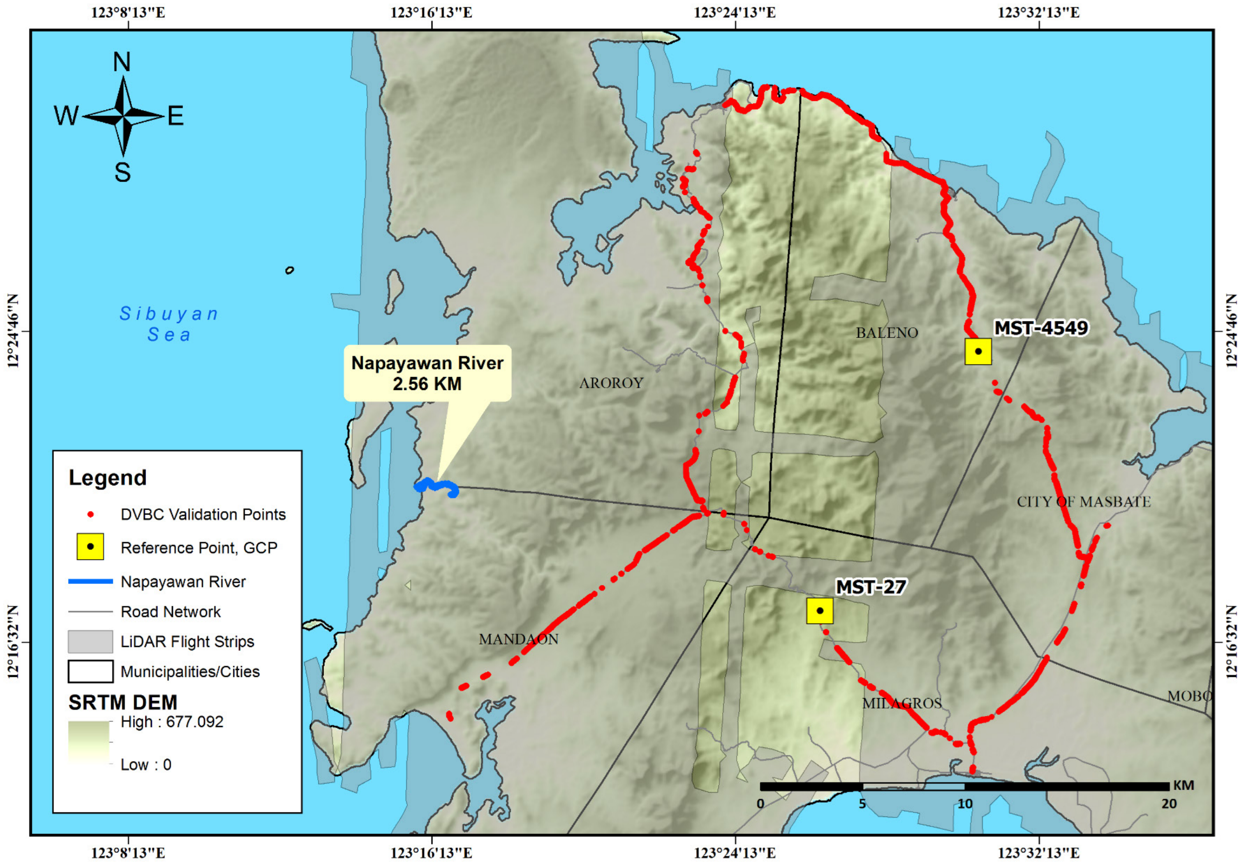


Figure 39. Validation point acquisition survey of Napayawan River basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on March 10, 2017 using a dual frequency Topcon™ GR-5 GPS and a Hydrolite™ Single Beam Echo Sounder mounted on a motor boat, as illustrated in Figure 40.

The survey started in Brgy. Amutag, Aroroy, Masbate, with coordinates 12°20'39.7384"N, 123°16'19.1784"E and ended at the mouth of the river in Brgy. Amutag, Aroroy, Masbate as well with coordinates 12°20'36.6532"N, 123°15'51.0820"E.

Figure 40. Bathymetric survey of HONS along Napayawan River

Manual bathymetric survey was executed on March 11 and 13, 2017 using a Sokkia™ Set 3030 Total Station as illustrated in Figure C-13. The manual bathymetric survey started in Brgy. Bugtong, Mandaon, Masbate with coordinates 12°20'27.1958"N, 123°16'42.3617"E, traversing down the river and ended at the starting point of the bathymetric survey using a boat in Brgy. Amutag, Aroroy, Masbate. The control points UP-NAP-1, UP-NAP-2, UP-NAP-3, and UP-NAP-4 were used as GNSS base stations all throughout the entire survey.

Figure 41. Manual bathymetric survey of HONS along Napayawan River

Gathering of random points for the checking of HONS's bathymetric data was performed by DVBC on February 1, 2017 using a survey grade GNSS Rover receiver attached to a boat as seen in Figure 42. A map showing the DVBC bathymetric checking points is shown in Figure 43.

Figure 42. Gathering of random bathymetric points along Napayawan River

Linear square correlation (R2) and RMSE analysis were also performed on the two (2) datasets and a computed R2 value of 0.876 for the bathymetric data is within the required range for R2, which is 0.85 to 1. Additionally, an RMSE value of 0.247 for the bathymetric data was obtained. Both the computed R2 and RMSE values are within the accuracy required by the program.

The bathymetric survey for Napayawan River gathered a total of 1,116 points covering 2.560 km of the river traversing Brgy. Bugtong in the Municipality of Mandaon and Brgy. Amutag, in the Municipality of Aroroy. A CAD drawing was also produced to illustrate the riverbed profile of Napayawan River. As shown in Figure C- 17, the highest and lowest elevation has a 6.023 m difference. The highest elevation observed was -1.481 m below MSL located in Brgy. Bugtong, Mandaon, Masbate, while the lowest was -7.504 m below MSL located in Brgy. Amutag, Aroroy, Masbate.

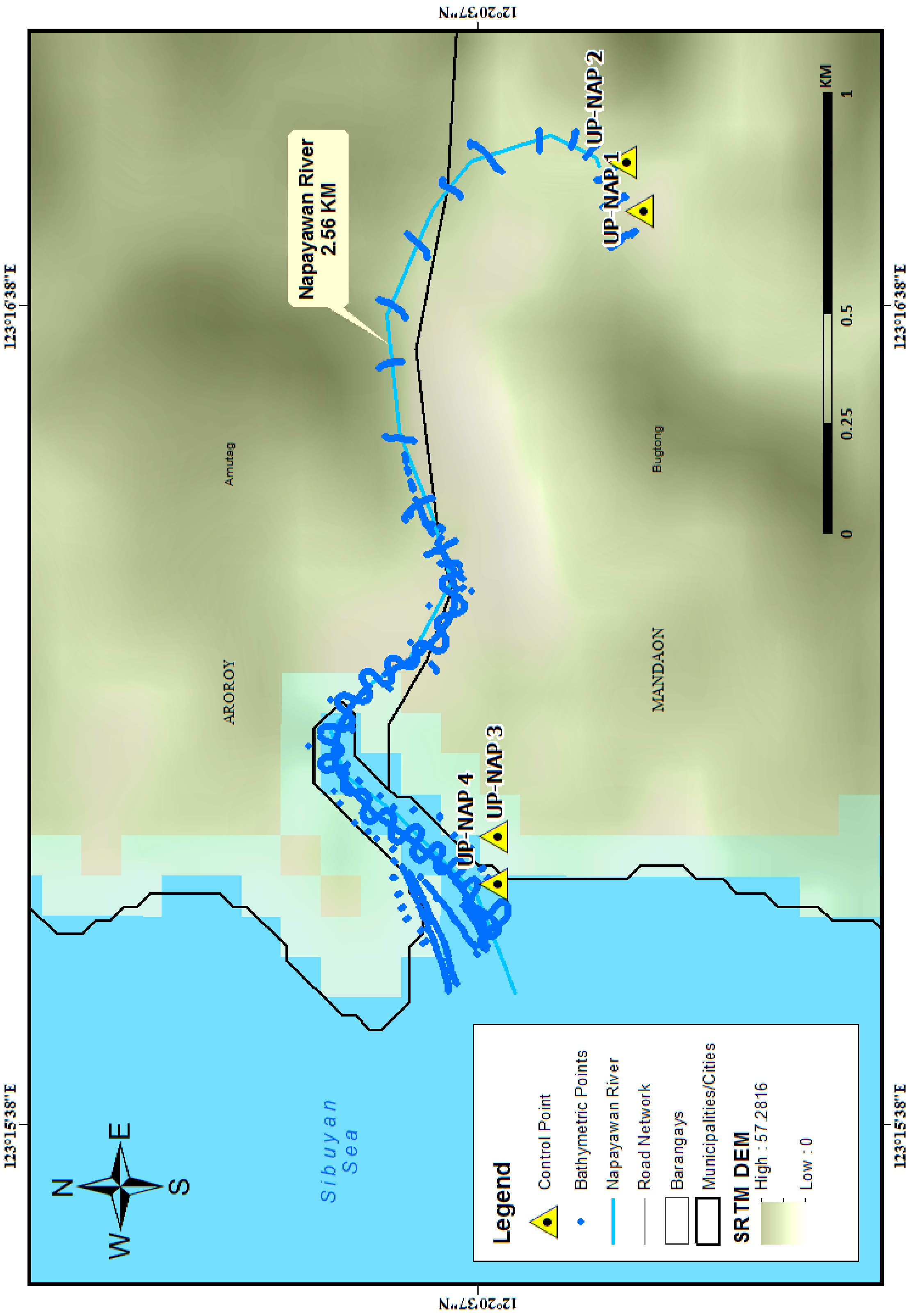


Figure 43. Bathymetric survey of Napayawan River

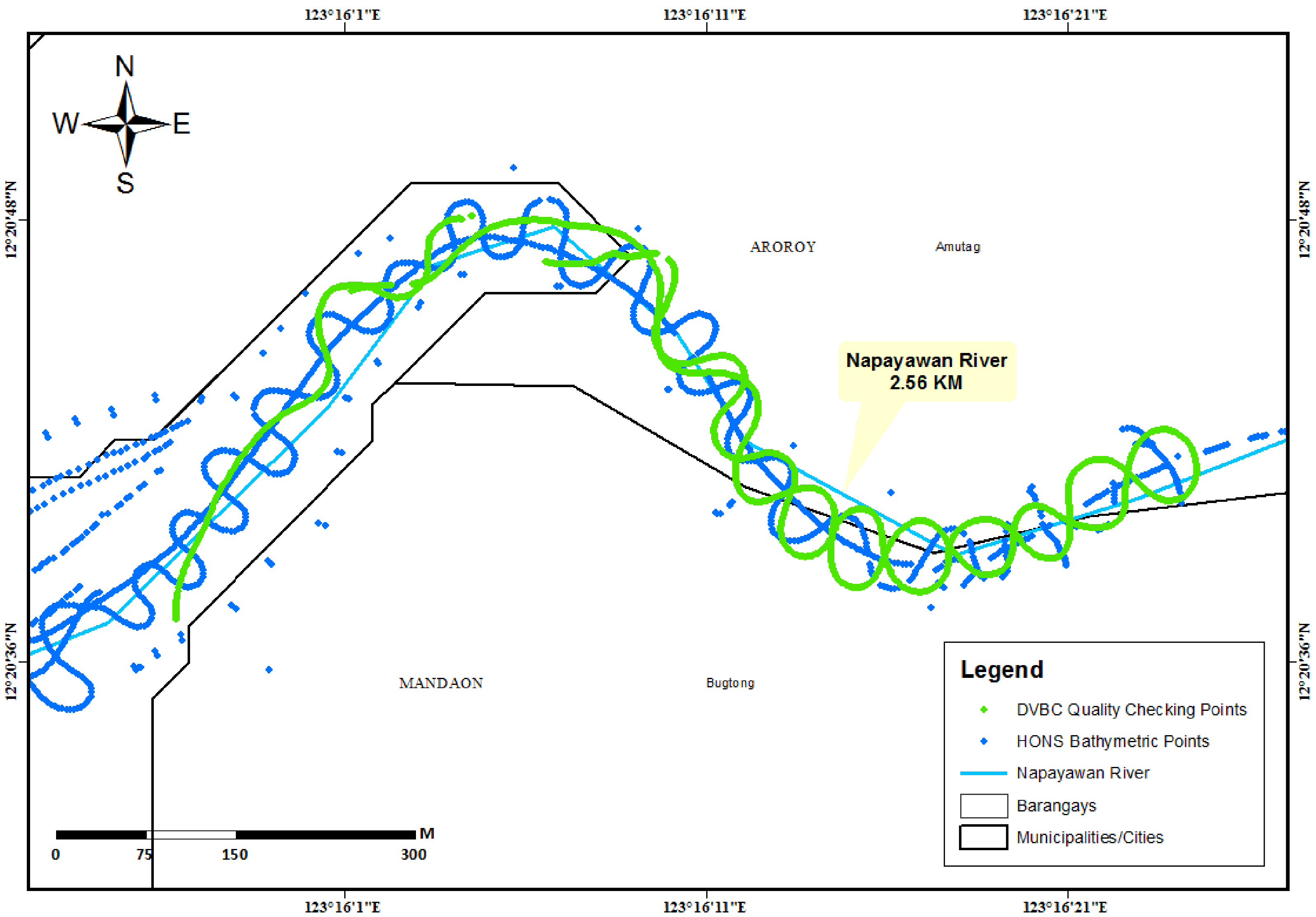


Figure 44. Quality checking points gathered along Napayawan River by DVBC

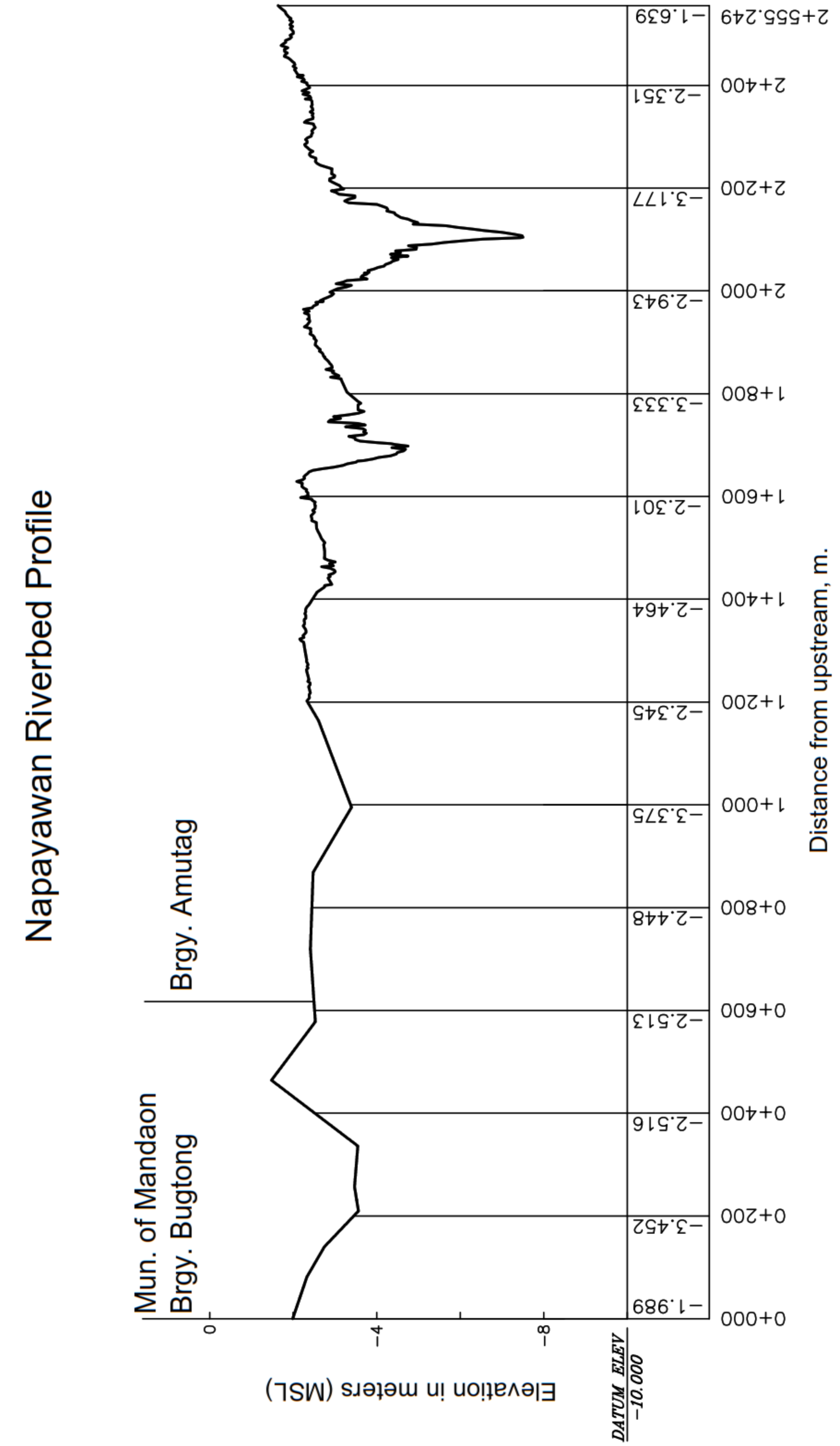


Figure 45. Napayawan Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Alfredo Mahar Francisco A. Lagmay, Christopher Noel L. Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil R. Tingin, Gianni Sumajit, Engr. Ferdinand E. Bien, Daniel S. Baer, Jr., Engr. Mary Ruth A. Bongon, Mark D. Delloro, Sarah Mae F. Fulleros, Engr. Julius Hector S. Manchete, Ernesto F. Razal, Jr., Aaron P. San Andres, Engr. Lech Fidel C. Pante, Engr. Juan Paulo B. Besa, Engr. Mark A. Sta. Isabel, and John Paul B. Obina

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All data that affect the hydrologic cycle of the Napayawan 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 Napayawan River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from one automatic rain gauge (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The rain gauge was installed at Tagaytay Bridge ARG (Figure 46). The precipitation data collection started from December 06, 2014 at 12:00 AM to December 09, 2014 at 4:00 PM with a 10-minute recording interval.

The total precipitation for this event in Tagaytay Bridge ARG is 26.6mm. It has a peak rainfall of 5mm on December 08, 2014 at 11:30 AM. The lag time between the peak rainfall and discharge is 14 hours.

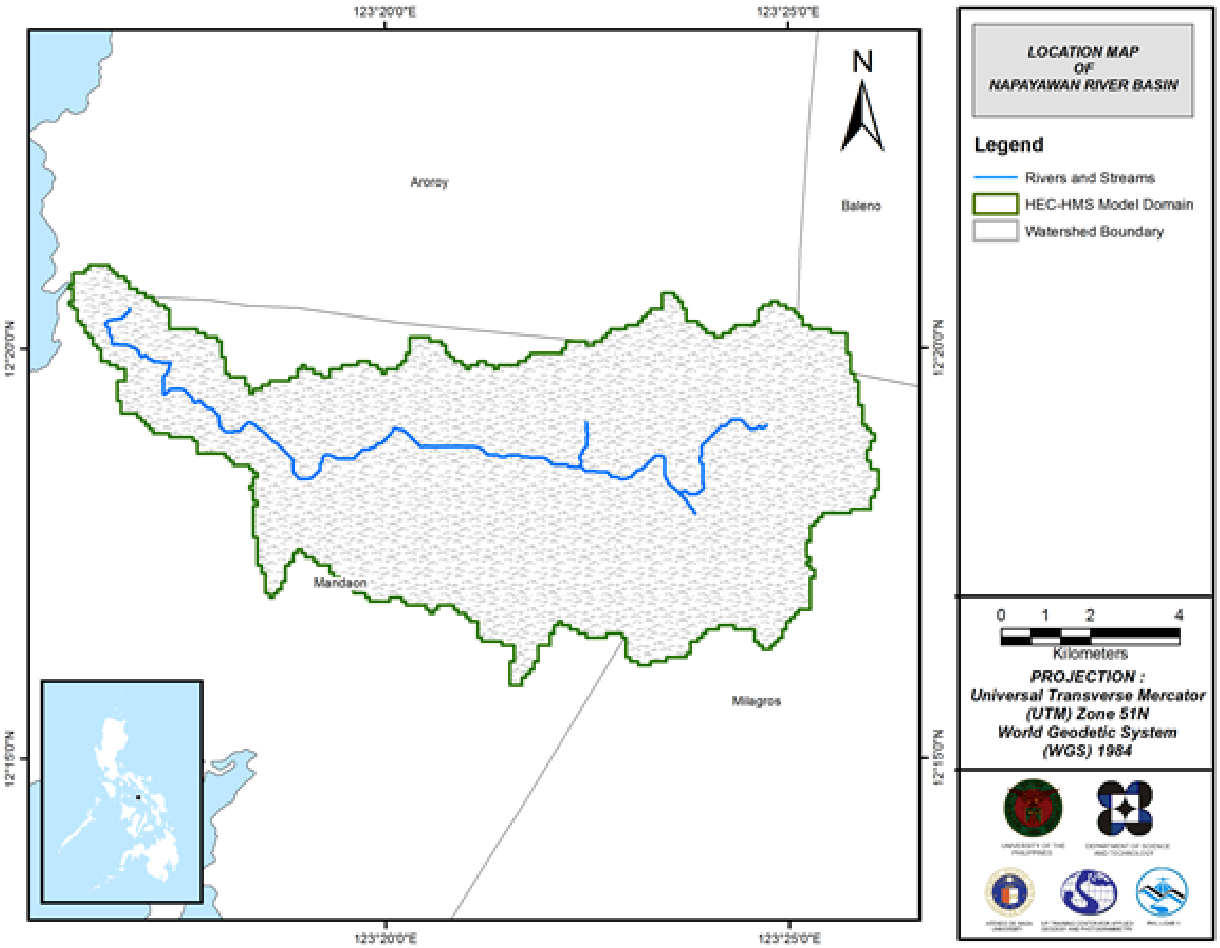


Figure 46. Location map of the Napayawan HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Ilog Bridge, Brgy. Sta. Fe, Pilar, Sorsogon (12°55’1.31”N, 123°38’33.21”E). It gives the relationship between the observed water levels at Ilog Bridge and outflow of the watershed at this location.

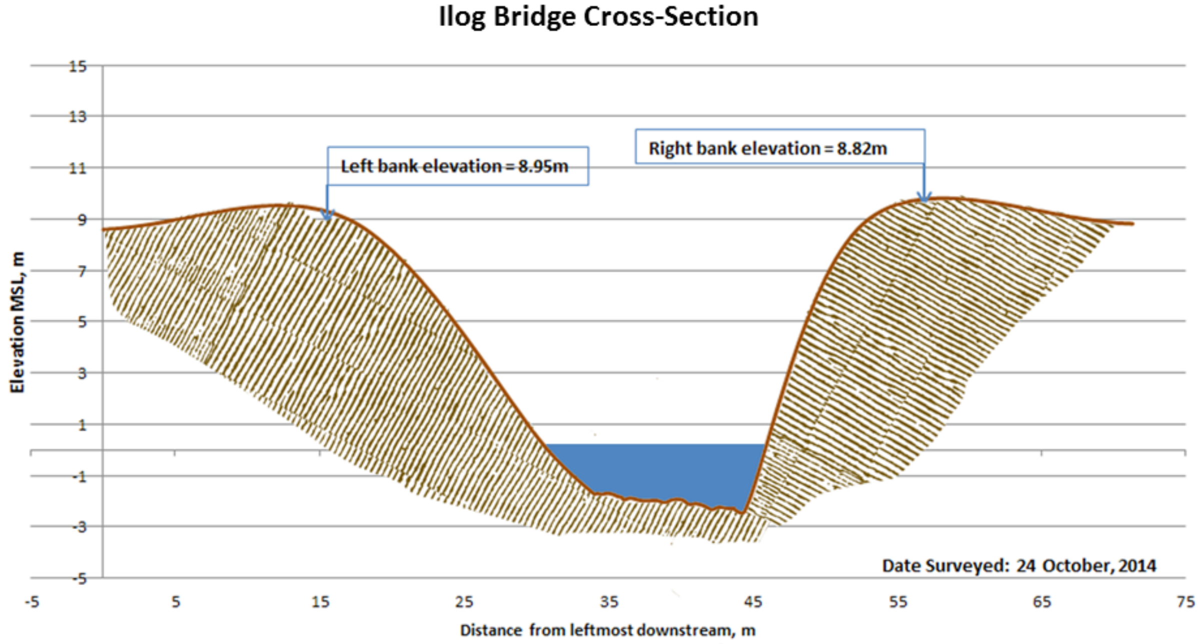


Figure 47. Cross-section plot of Napayawan (also known as Ilog) Bridge

For Ilog Bridge, the rating curve is expressed as Q = 17.933e0.6765h as shown in Figure 47.

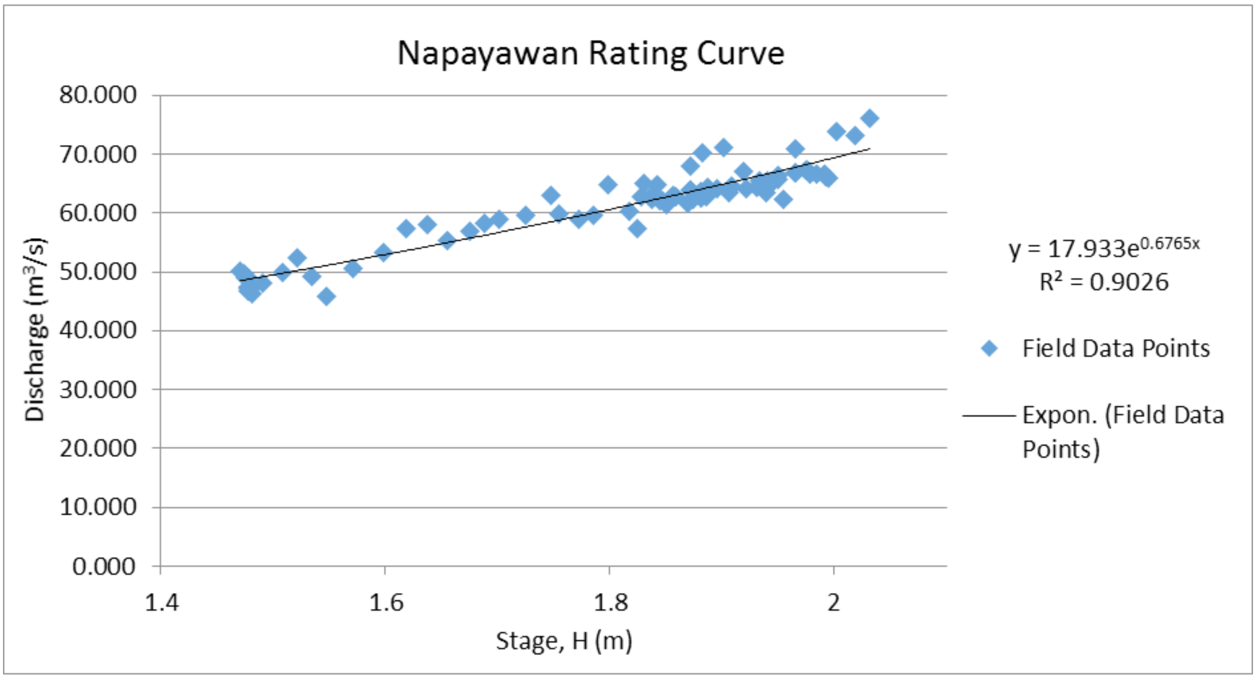


Figure 48. Rating curve of Napayawan (also known as Ilog) Bridge in Pilar, Sorsogon

This rating curve equation was used to compute the river outflow at Ilog Bridge for the calibration of the HEC-HMS model shown in Figure 49. The total rainfall for this event is 26.6mm and the peak discharge is 82.843m3/s at 1:30 AM, December 09, 2014.

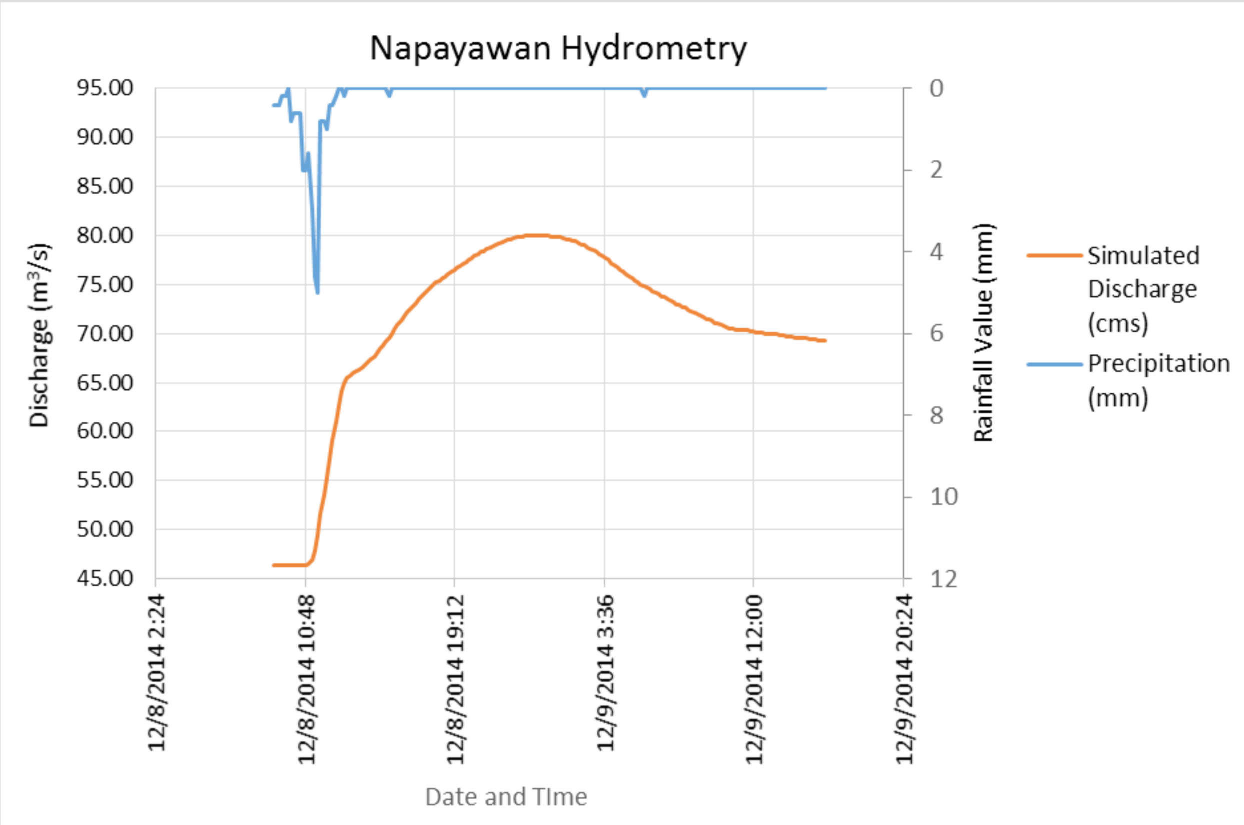


Figure 49. Rainfall and outflow data of the Napayawan River Basin used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Legazpi RIDF. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time. This station was chosen based on its proximity to the Napayawan watershed. The extreme values for this watershed were computed based on a 26-year record. with the computed extreme values shown in Table 26.

Table 26. RIDF values for Napayawan Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	**10 mins**	**20 mins**	**30 mins**	**1 hr**	**2 hrs**	**3 hrs**	**6 hrs**	**12 hrs**	**24 hrs**
2	21	31.9	39.6	53.4	74.5	89.3	119.2	145.5	176.4
5	29.1	43.8	54.5	76.7	113.4	138.5	189.8	228.7	260.5
10	34.5	51.6	64.3	92.2	139.1	171.1	236.6	283.8	316.1
15	37.5	56	69.8	100.9	153.6	189.4	263	314.8	347.5
20	39.6	59.1	73.7	107	163.7	202.3	281.5	336.6	369.5
25	41.3	61.5	76.7	111.7	171.6	212.2	295.7	353.4	386.4
50	46.3	68.9	85.9	126.2	195.7	242.7	339.6	405	438.6
100	51.3	76.2	95.1	140.5	219.6	273.1	383.1	456.2	490.3

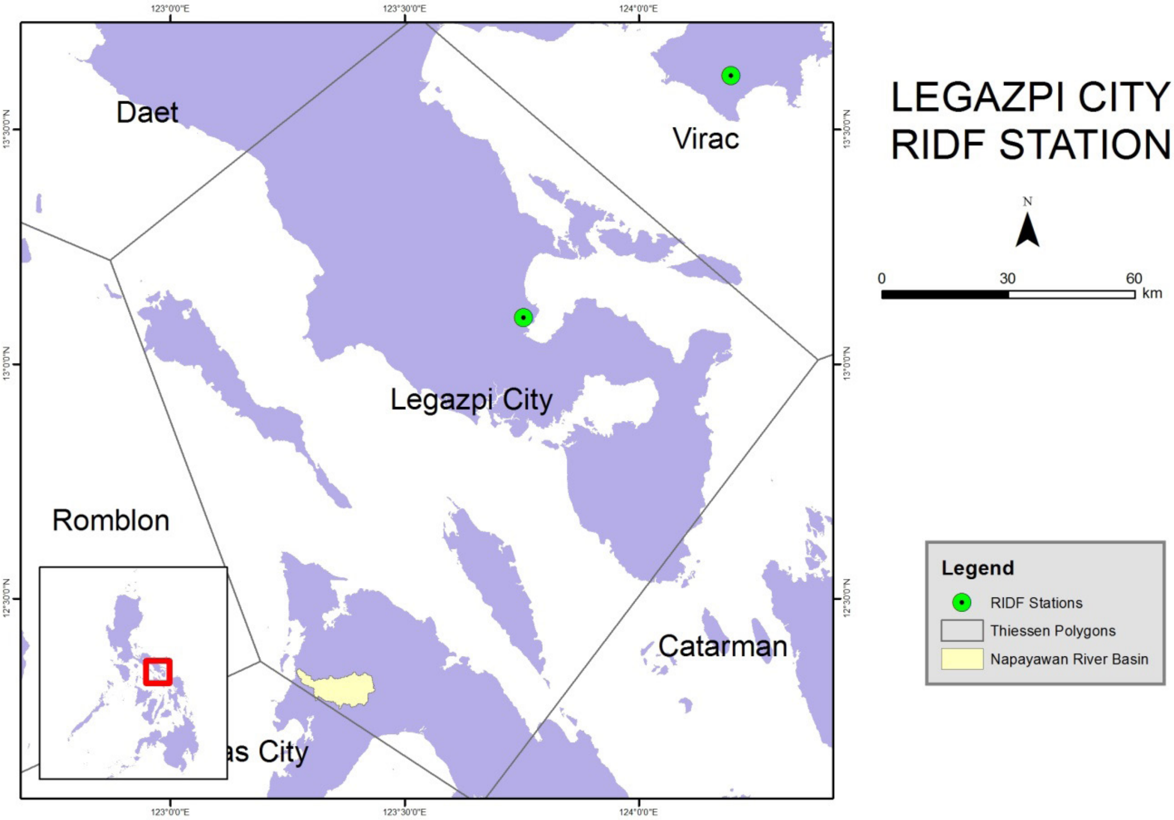


Figure 50. Location of Legazpi RIDF Station relative to Napayawan River Basin

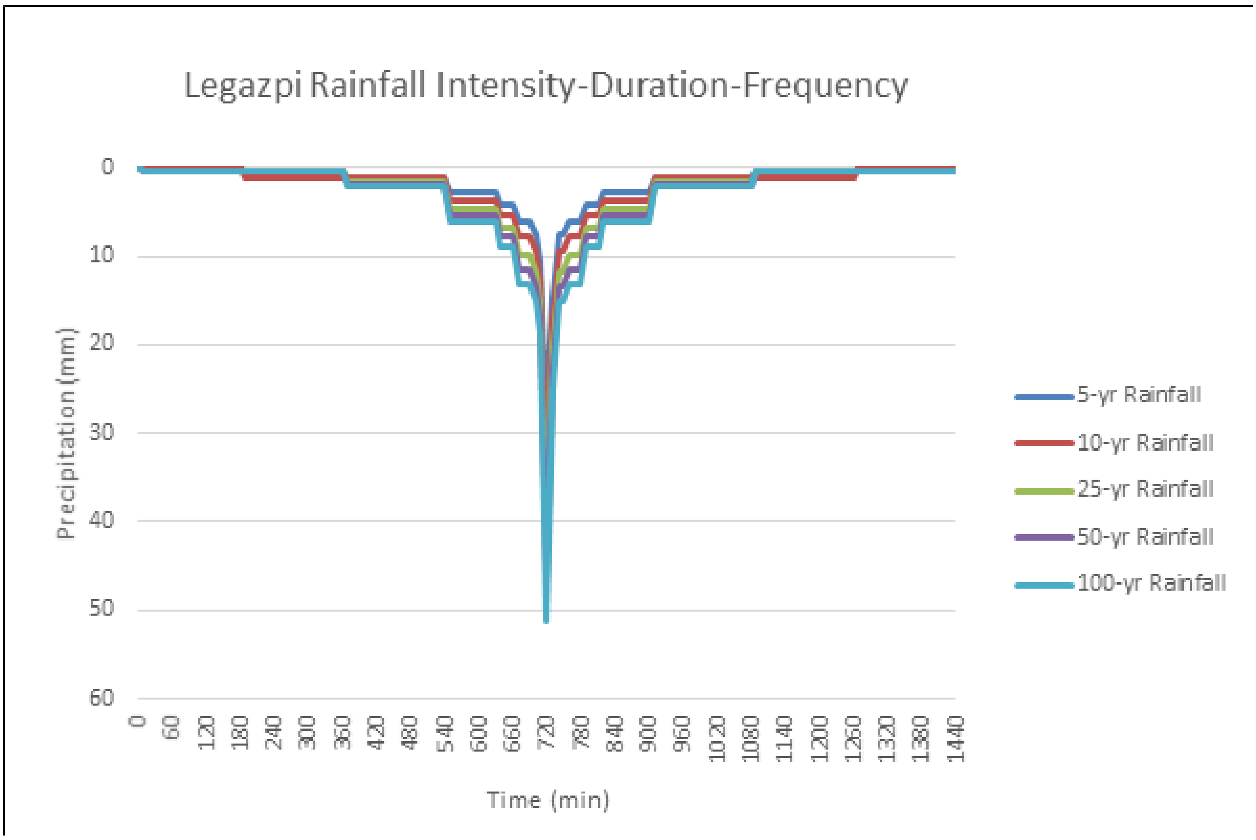


Figure 51. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management under the Department of Agriculture (DA-BSWM). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Napayawan River Basin are shown in Figure 52 and Figure 53, respectively.

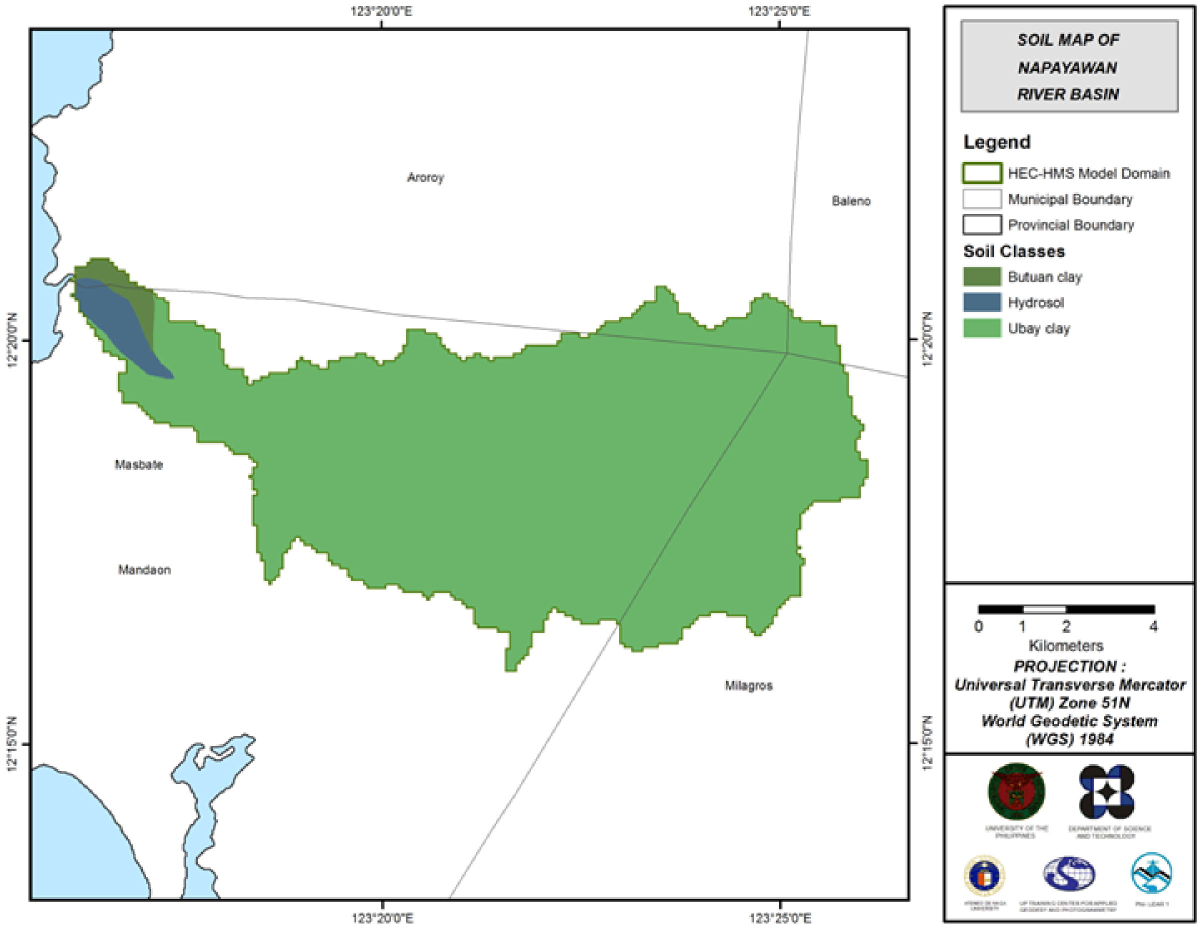


Figure 52. Soil Map of Napayawan River Basin used for the estimation of the CN parameter.

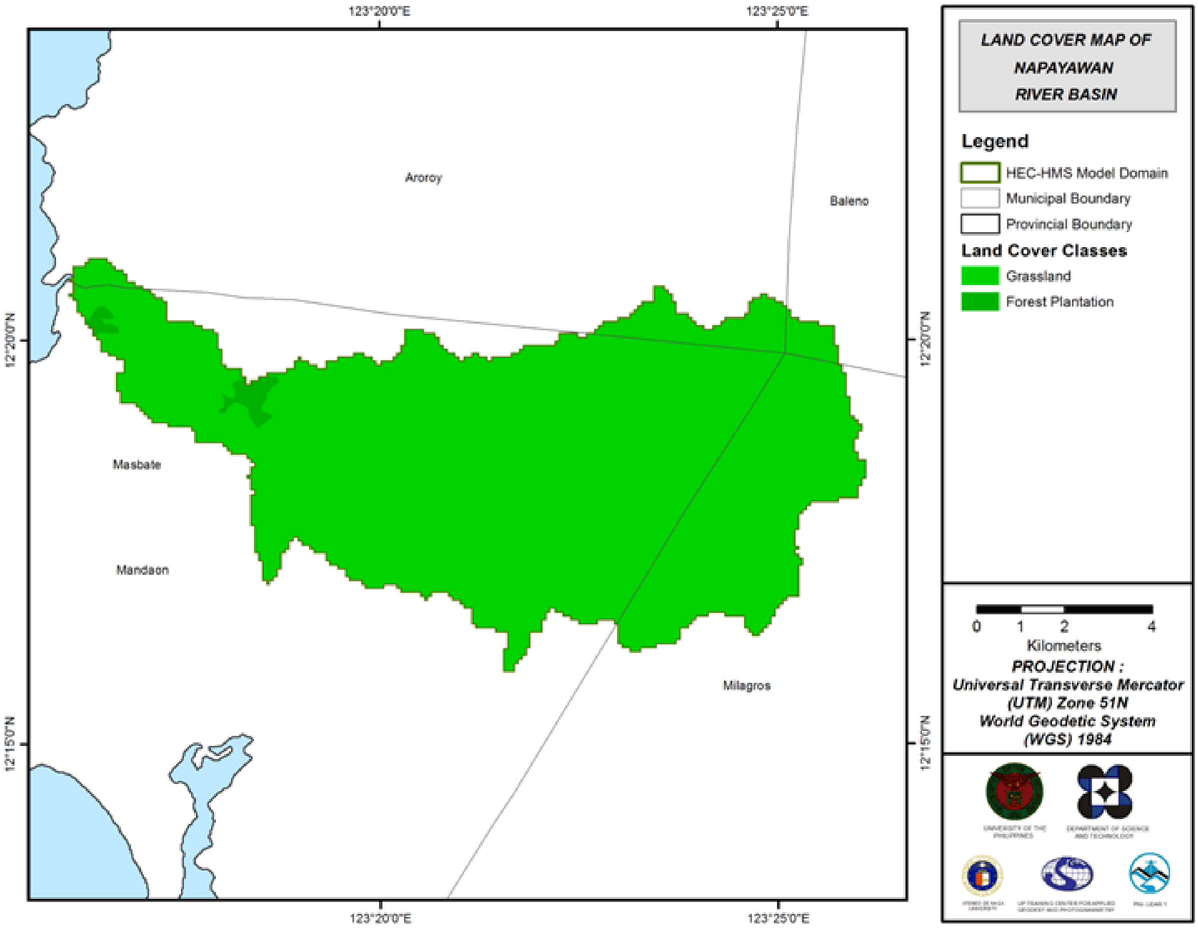


Figure 53. Land Cover Map of Napayawan River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model.

For Napayawan, three (3) soil classes were identified. These are Butuan Clay, Hydrosol, and Ubay clay. Moreover, two (2) land cover classes were identified. These are grassland and forest plantation.

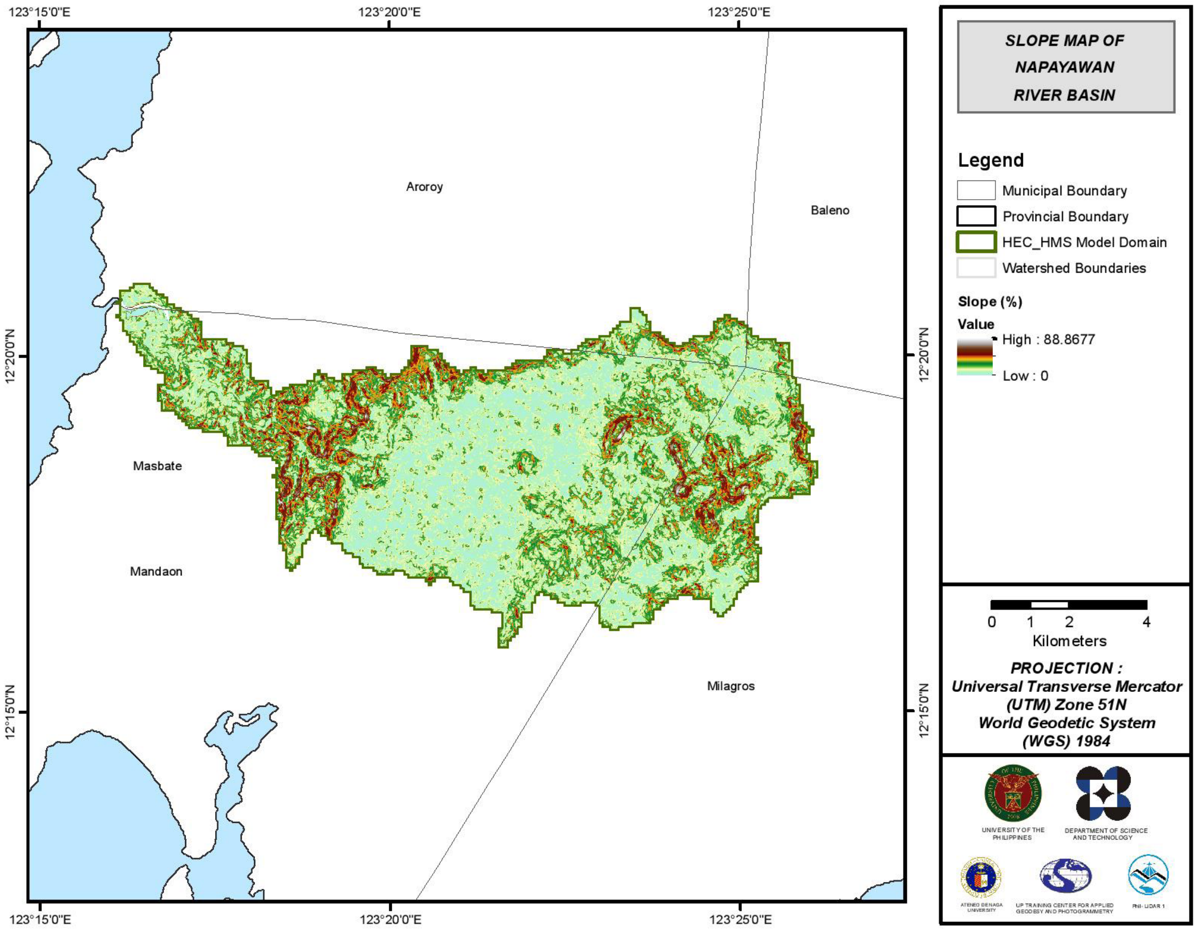


Figure 54. Slope Map of Napayawan River Basin

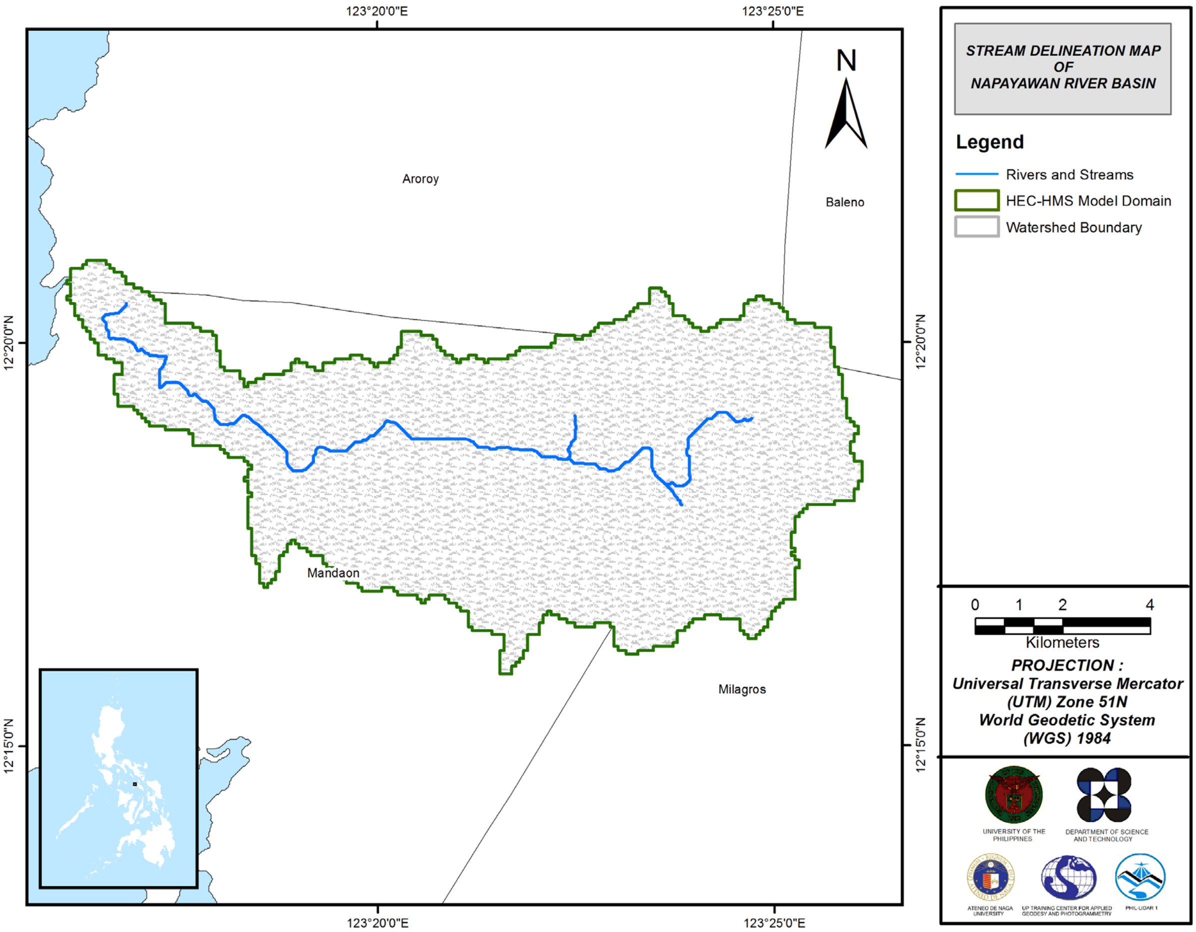


Figure 55. Stream Delineation Map of Napayawan River Basin

Using the SAR-based DEM, the Napayawan basin was delineated and further divided into subbasins. The model consists of 19 sub basins, 9 reaches, and 9 junctions, as shown in Figure 56. The main outlet is Ilog Bridge.

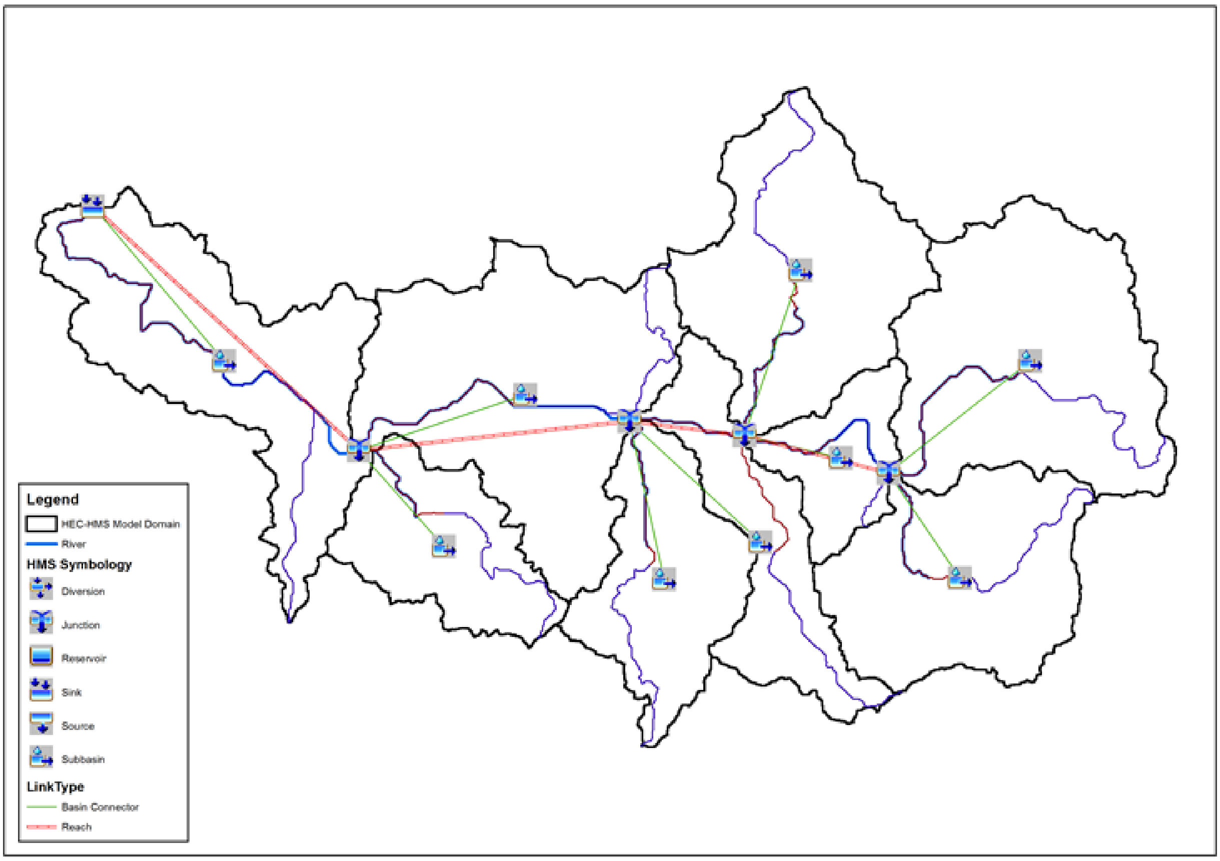


Figure 56. Napayawan River Basin model generated in HEC-HMS

5.4 Cross-section Data

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

Figure 57. River cross-section of Napayawan River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

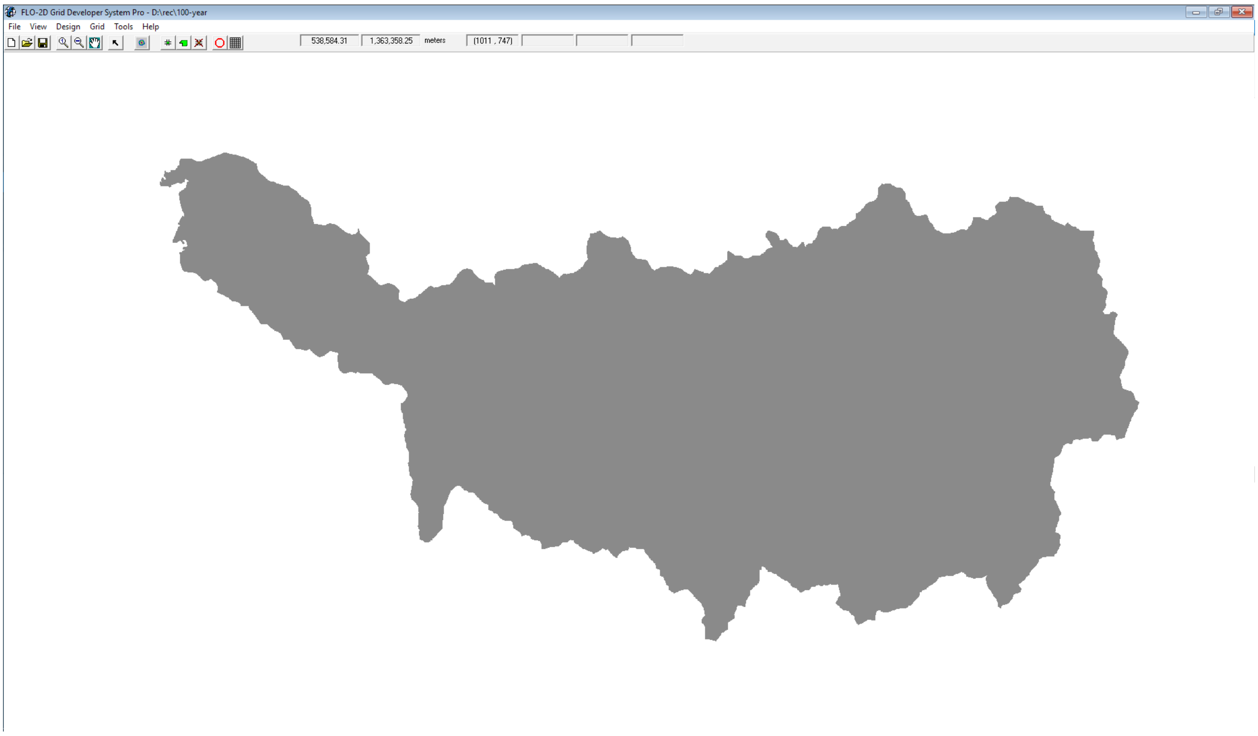


Figure 58. Screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 64.34 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0m2/s. The generated hazard maps for Napayawan are in Figure 62, Figure 64, and Figure 66.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 92,986,848.00 m2. The generated flood depth maps for Napayawan are in Figure 63, Figure 65, and Figure 67.

There is a total of 26,488,002.31m3 of water entering the model, the entirety of which is due to rainfall. 6,013,650.50 m3 of this water is lost to infiltration and interception, while 7,905,485.42 m3 is stored by the flood plain. The rest, amounting up to 12,568,859.88 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Napayawan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 59 shows the comparison between the two discharge data.

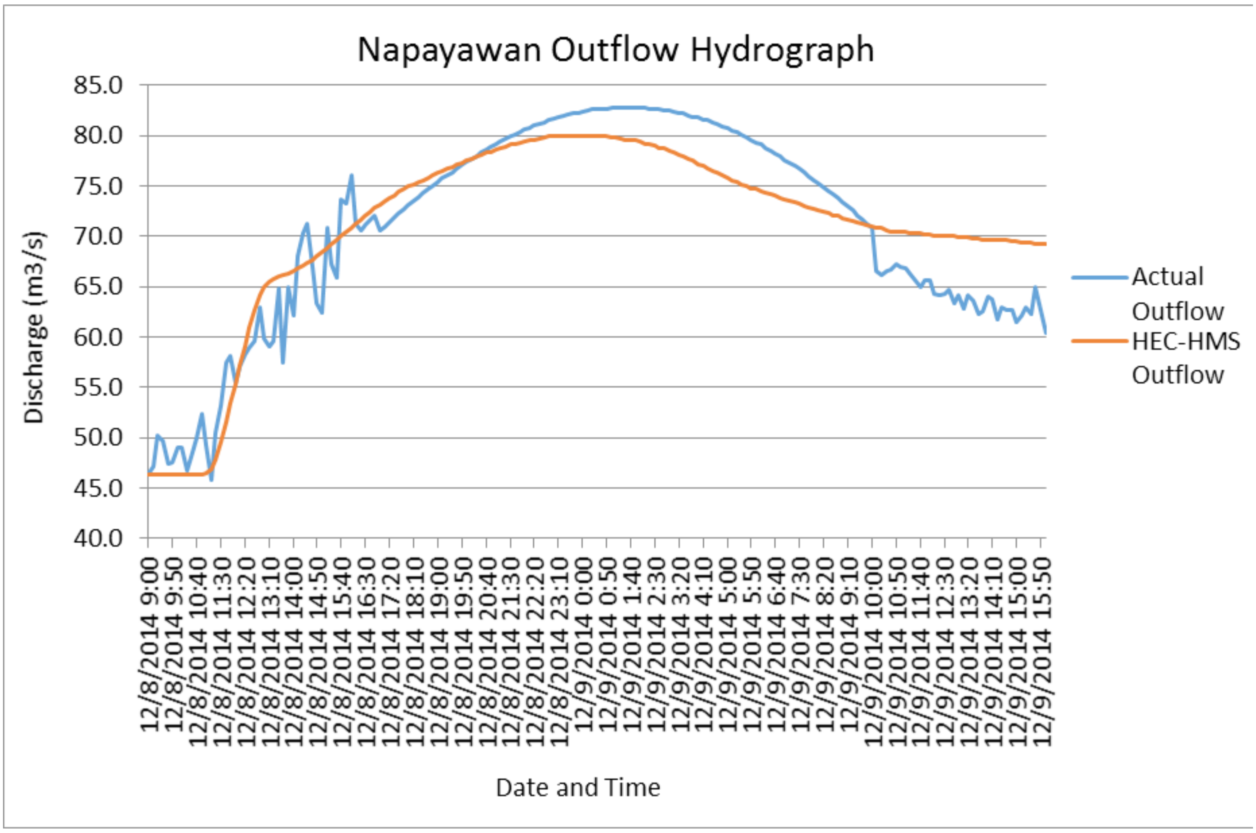


Figure 59. Outflow hydrograph of Napayawan produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 27 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 27. Range of calibrated values for the Napayawan River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	1 - 6
			Curve Number	64 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.02 - 17
			Storage Coefficient (hr)	0.07 - 10
	Baseflow	Recession	Recession Constant	0.6 - 1
			Ratio to Peak	0.3 - 1
Reach	Routing	Muskingum-Cunge	Slope	0.0001 - 0.4
			Manning's Coefficient	0.0001 - 1

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 1 mm to 6 mm means that there is average amount of infiltration or rainfall interception by vegetation.

The curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 64 to 99 for curve number is wider than the advisable for Philippine watersheds (70-80), depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Napayawan, the basin mostly consists of grassland and the soil consists of Sevilla clay, Annam clay loam, and Panganiran clay.

The time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.02 hours to 17 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. For Napayawan, it will take at least 17 hours from the peak discharge to go back to the initial discharge.

Manning's roughness coefficient of 1 corresponds to the common roughness in Napayawan watershed, which is determined to be a mangrove forest with trees with heavy stand that flow into branches (Brunner, 2010).

Table 28. Summary of the Efficiency Test of the Napayawan HMS Model

Accuracy measure	Value
RMSE	3.812
r2	0.8607
NSE	0.8593
PBIAS	0.0377
RSR	0.3752

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 3.812 (m3/s).

The Pearson correlation coefficient (r2) 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 0.8607.

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 0.8593.

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 0.0377.

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 0.3752.

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 15) shows the Napayawan outflow using the synthetic storm events using the Legazpi 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 reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods from 554m3/s in a 5-year return period to 1111.8m3/s in a 100-year return period.

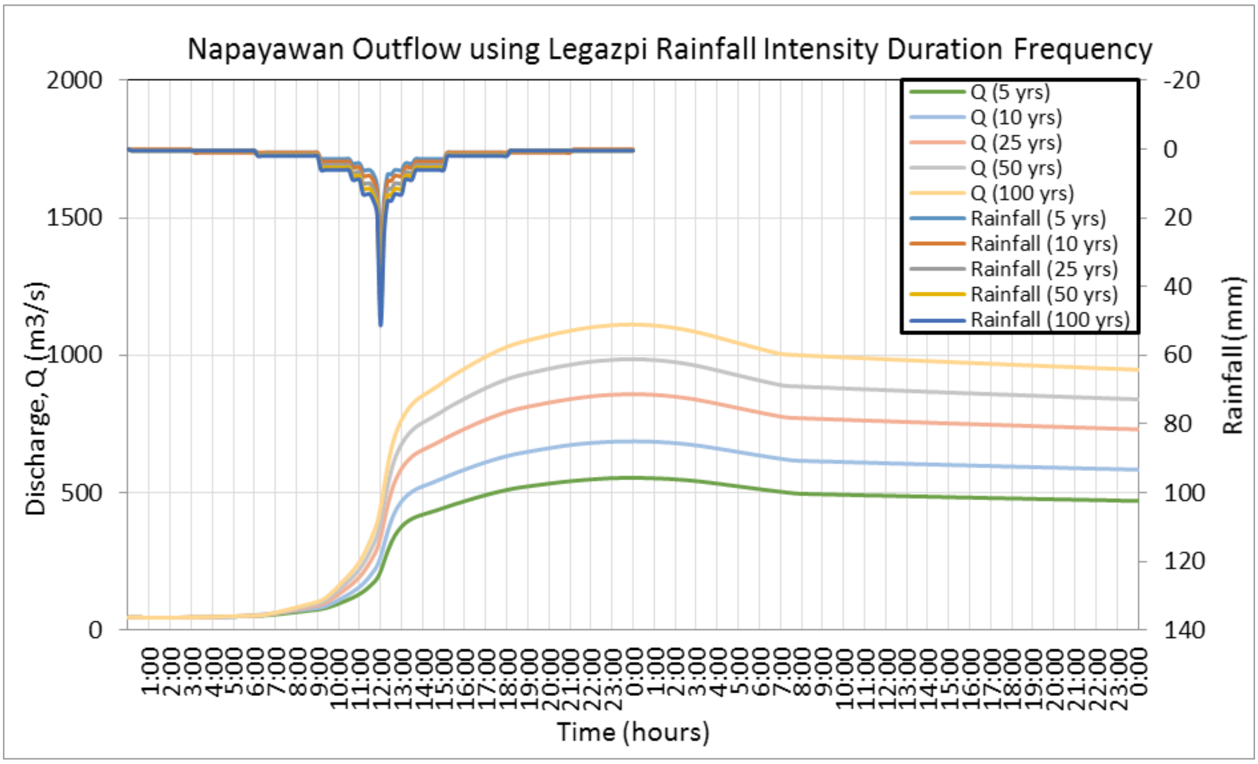


Figure 60. Outflow hydrograph at the Napayawan Basin generated using the simulated rain events for 24-hour period for Legazpi station

A summary of the total precipitation, peak rainfall, peak outflow, and time to peak of the Napayawan discharge using the Legazpi Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 29.

Table 29. Peak values of the Napayawan HECHMS Model outflow using the Legazpi RIDF 24-hour values

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	260.5	29.1	554	11 hour, 40 minutes
10-Year	316.1	34.5	686.8	12 hours
25-Year	386.4	41.3	858.4	11 hour, 50 minutes
50-Year	438.4	46.3	985.7	11 hour, 50 minutes
100-Year	490.3	51.3	1111.8	11 hour, 50 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM/ Phil-LiDAR 1 website. For this publication, only a sample output map river was to be shown, since only the ADNU-DVC base flow was calibrated. Figure 61 shows a generated sample map of the Napayawan River using the calibrated HMS base flow.

Figure 61. Sample output map of Napayawan RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. The generated flood hazard maps for the Tambang Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAGASA for hazard maps - "Low", "Medium", and "High" - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr). Figure 62 to Figure 67 shows the 5-, 25-, and 100-year rain return scenarios of the Napayawan floodplain. The flood plain, with an area of 47.08km2, covers two (2) municipalities, namely Aroroy and Mandaon. Table 30 shows the percentage of area affected by flooding per municipality.

Table 30. Municipalities affected in Napayawan Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Aroroy	403.62	0.9	0.22
Mandaon	267.43	46.14	17.25

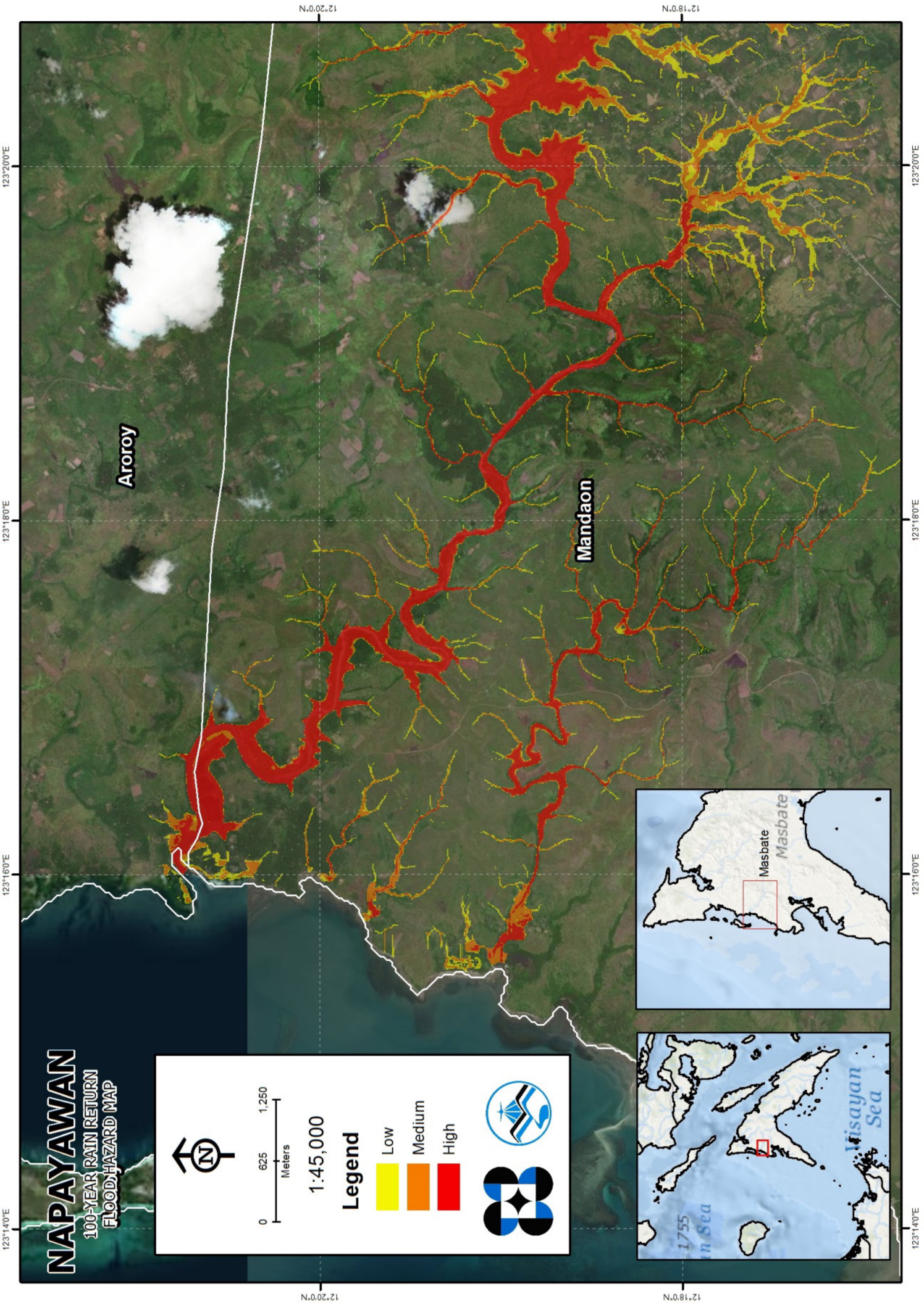


Figure 62. 100-year Flood Hazard Map for Napayawan Floodplain overlaid on Google Earth imagery

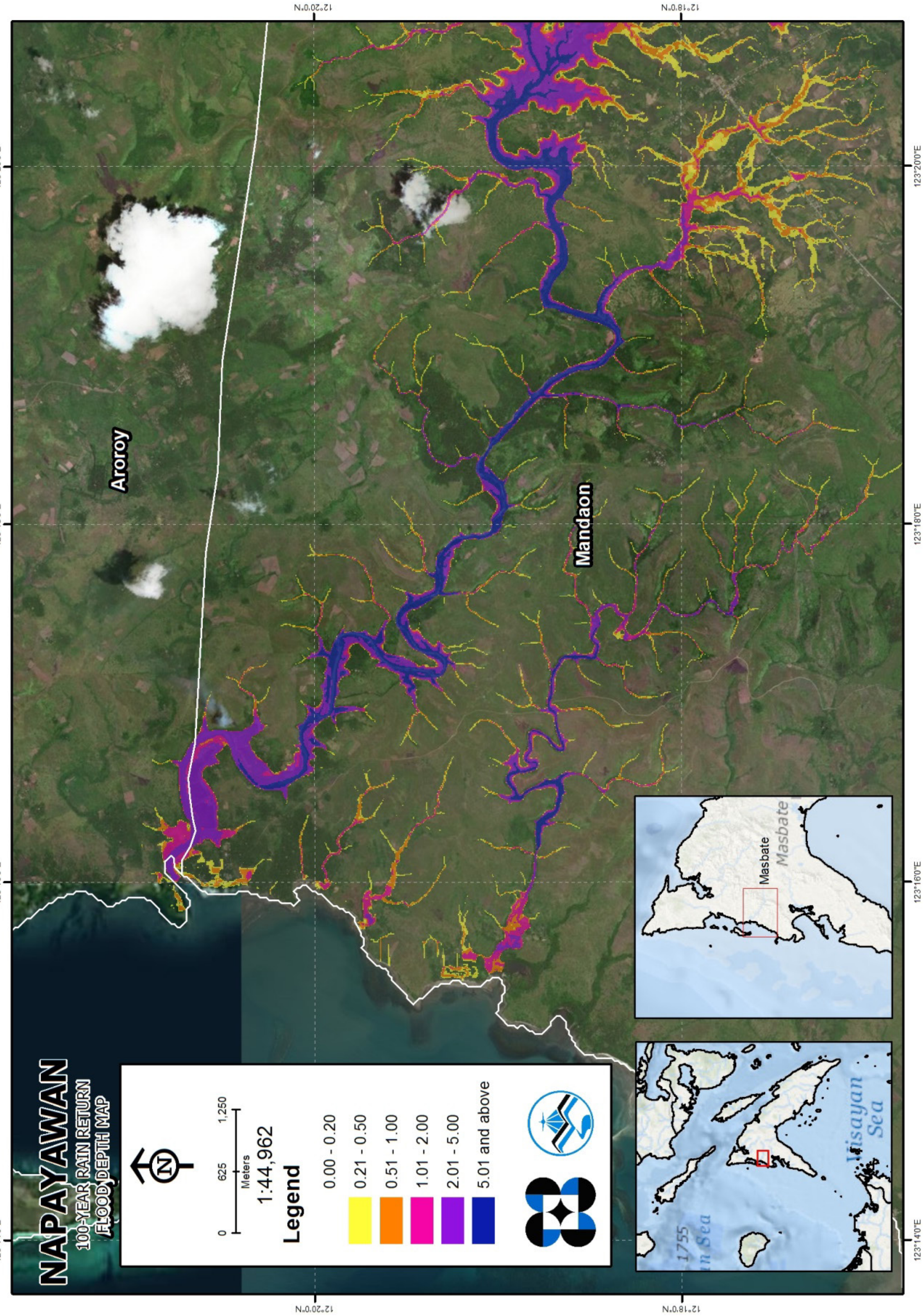


Figure 63. 100-year Flow Depth Map for Napayawan Floodplain overlaid on Google Earth imagery

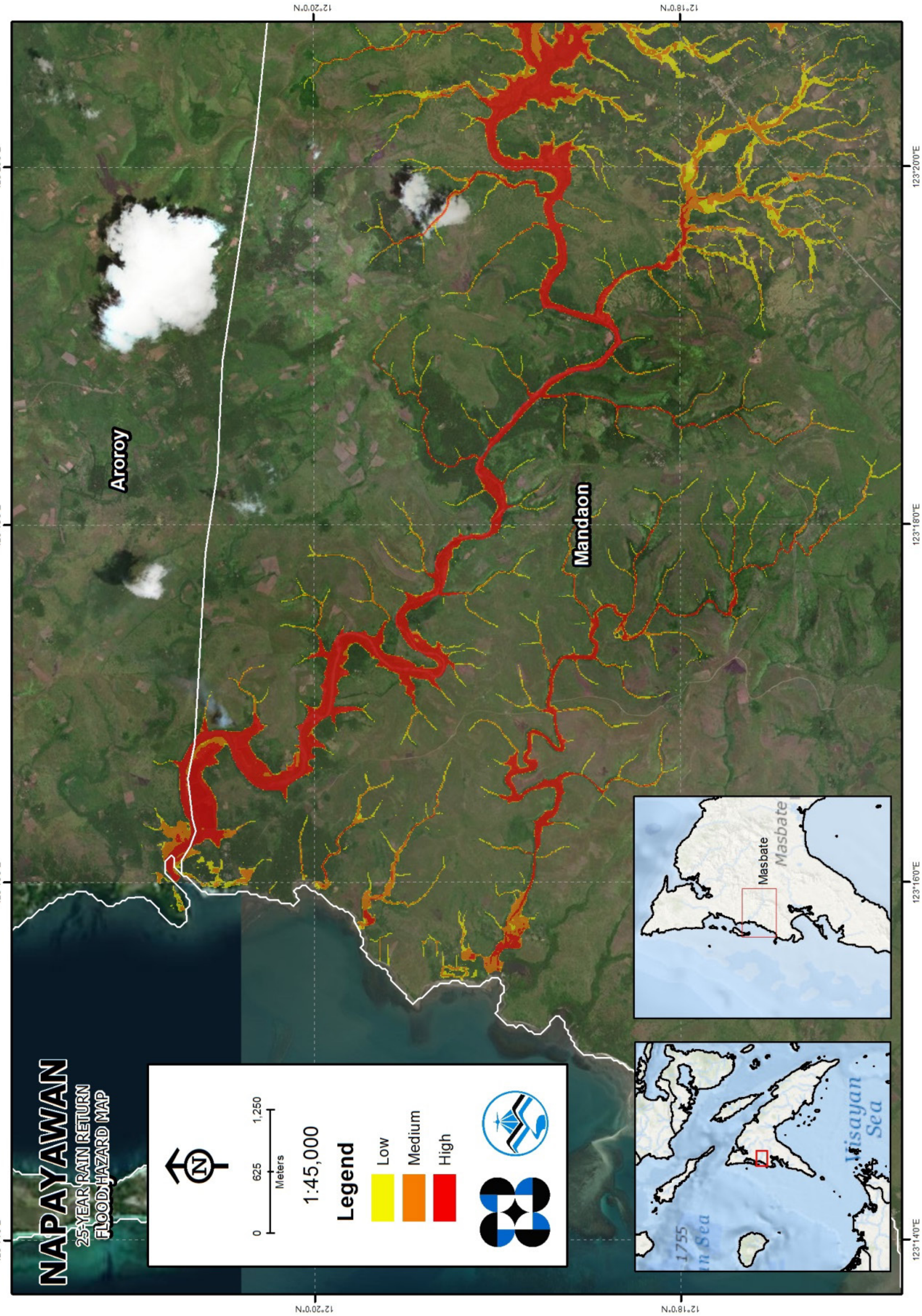


Figure 64. 25-year Flood Hazard Map for Napayawan Floodplain overlaid on Google Earth imagery

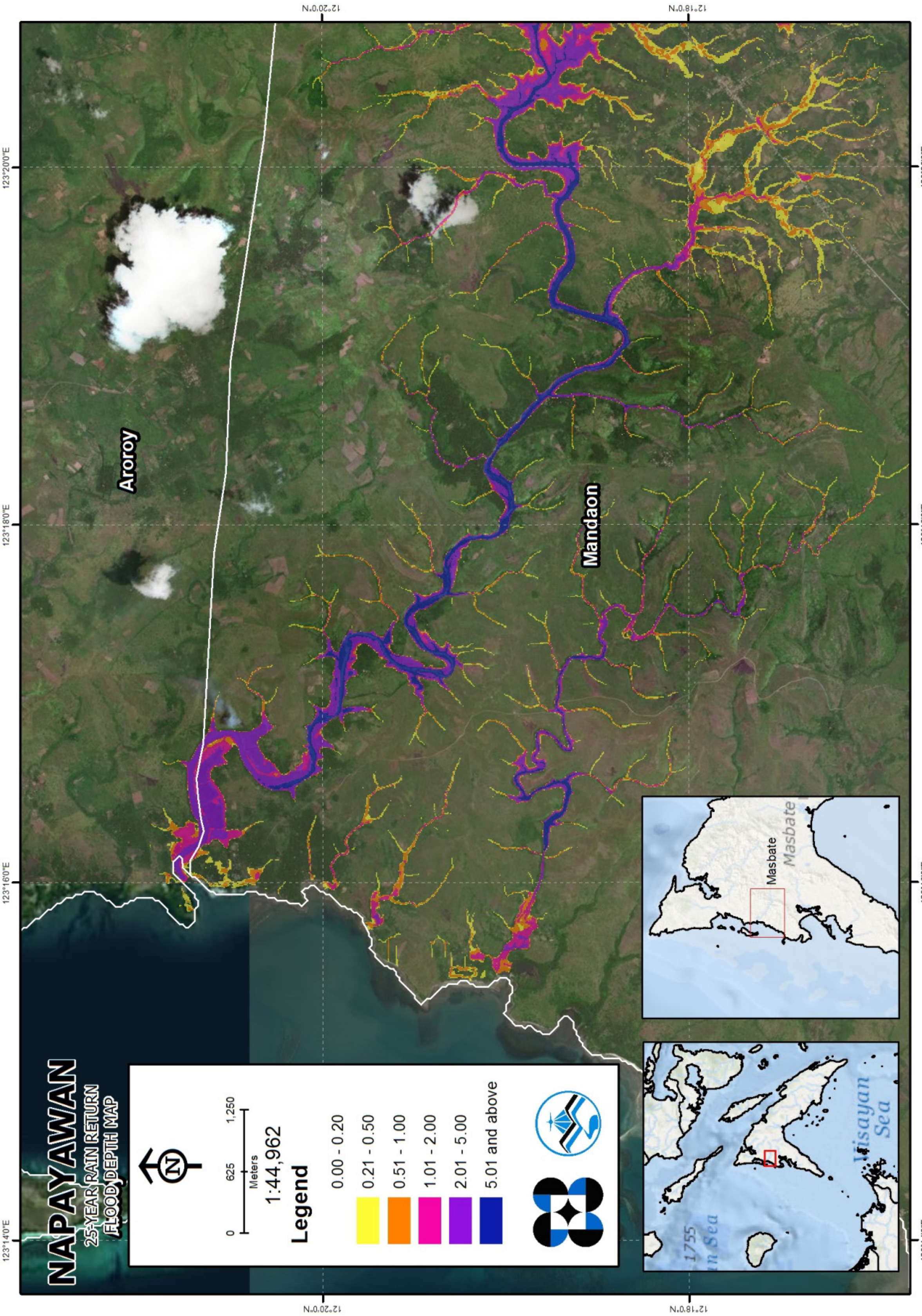


Figure 65. 25-year Flow Depth Map for Napayawan Floodplain overlaid on Google Earth imagery

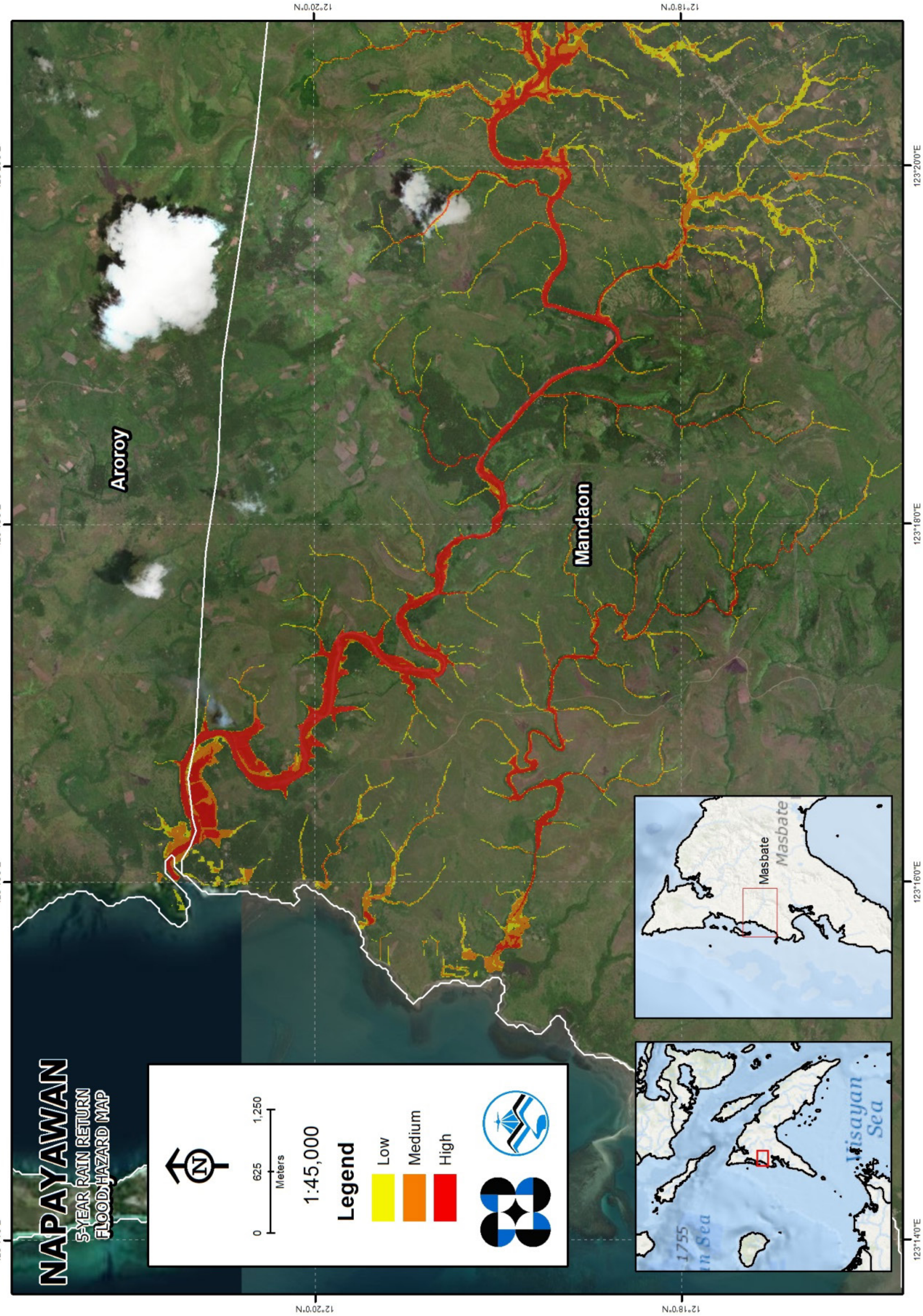


Figure 66. 5-year Flood Hazard Map for Napayawan Floodplain overlaid on Google Earth imagery

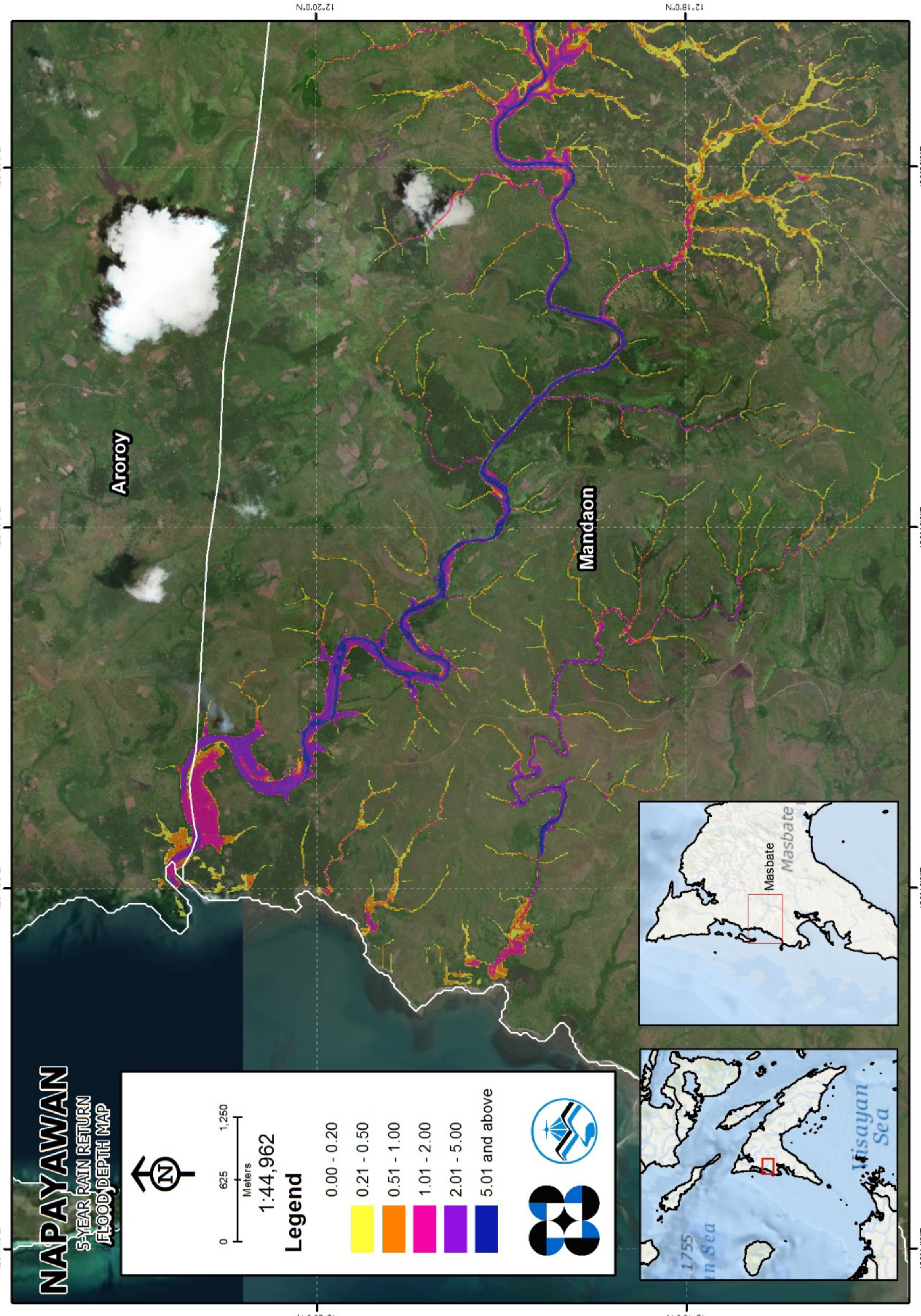


Figure 67. 5-year Flood Depth Map for Napayawan Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Napayawan River Basin, grouped accordingly by municipality. For the said basin, two (2) municipalities consisting of 7 barangays are expected to experience flooding when subjected to the three rainfall return period scenarios.

For the 5-year rainfall return period, 0.18% of the municipality of Aroroy with an area of 403.62 sq. km. will experience flood levels of less than 0.20 meters. 0.01% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.01%, 0.01%, and 0.01% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in Table 31 and shown in Figure 68 are the affected areas in Aroroy in square kilometres by flood depth per barangay.

Table 31. Affected areas in Aroroy, Masbate during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Aroroy (in sq. km.)
	Amutag
0.03-0.20	0.71
0.21-0.50	0.041
0.51-1.00	0.054
1.01-2.00	0.046
2.01-5.00	0.04
> 5.00	0

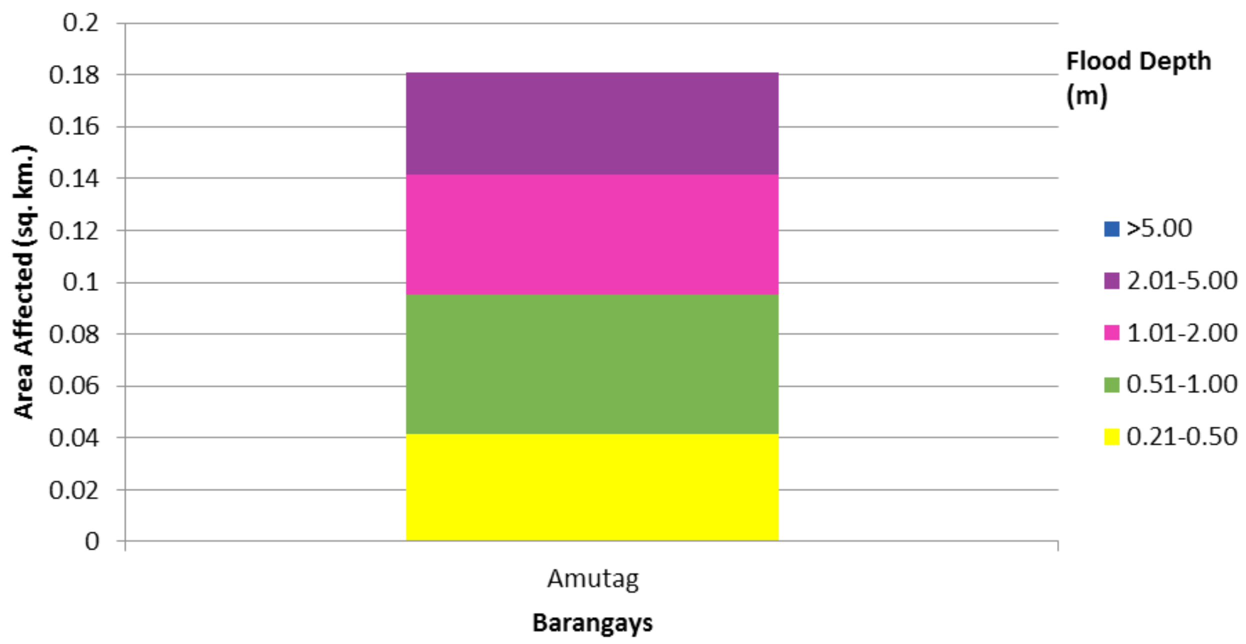


Figure 68. Affected Areas in Aroroy, Masbate during 5-Year Rainfall Return Period

For the municipality of Mandaon with an area of 267.43 sq. km., 15.47% will experience flood levels of less than 0.20 meters. 0.55% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.37%, 0.34%, 0.36%, and 0.16% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Listed in Table 32 and shown in Figure 68 are the affected areas in square kilometres by flood depth per barangay.

Table 32. Affected areas in Mandaon, Masbate during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Mandaon (in sq. km.)					
	Alas	Bat-Ongan	Bugtong	Cabitan	Dayao	Santa Fe
0.03-0.20	0.65	1.83	11.86	6.42	7.15	13.47
0.21-0.50	0.031	0.056	0.33	0.58	0.23	0.23
0.51-1.00	0.0071	0.046	0.33	0.31	0.11	0.18
1.01-2.00	0.00075	0.039	0.44	0.2	0.062	0.18
2.01-5.00	0	0.012	0.55	0.12	0.026	0.24
> 5.00	0	0.0077	0.15	0.038	0.0001	0.24

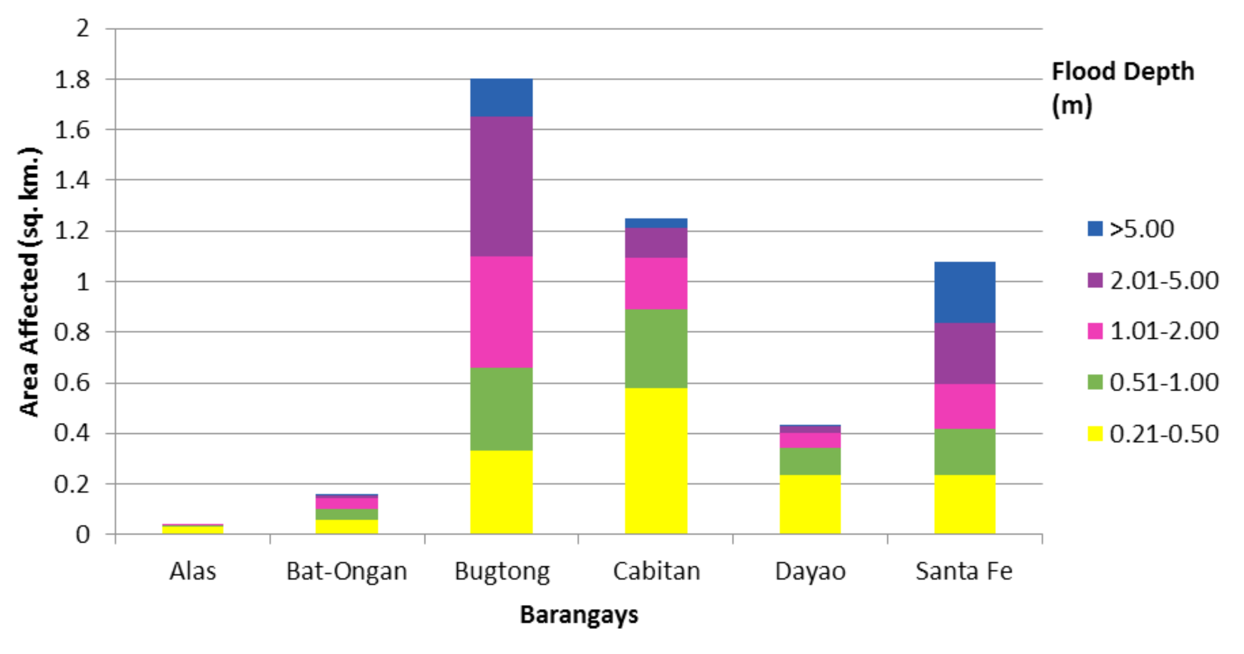


Figure 69. Affected Areas in Mandaon, Masbate during 5-Year Rainfall Return Period

For the 25-year rainfall return period, 0.17% of the municipality of Aroroy with an area of 403.62 sq. km. will experience flood levels of less than 0.20 meters. 0.007% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.008%, 0.02%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in Table 33 and shown in Figure 70 are the areas affected in Aroroy in square kilometers by flood depth per barangay.

Table 33. Affected areas in Aroroy, Masbate during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Aroroy (in sq. km.)
	Amutag
0.03-0.20	0.69
0.21-0.50	0.027
0.51-1.00	0.031
1.01-2.00	0.069
2.01-5.00	0.076
> 5.00	0

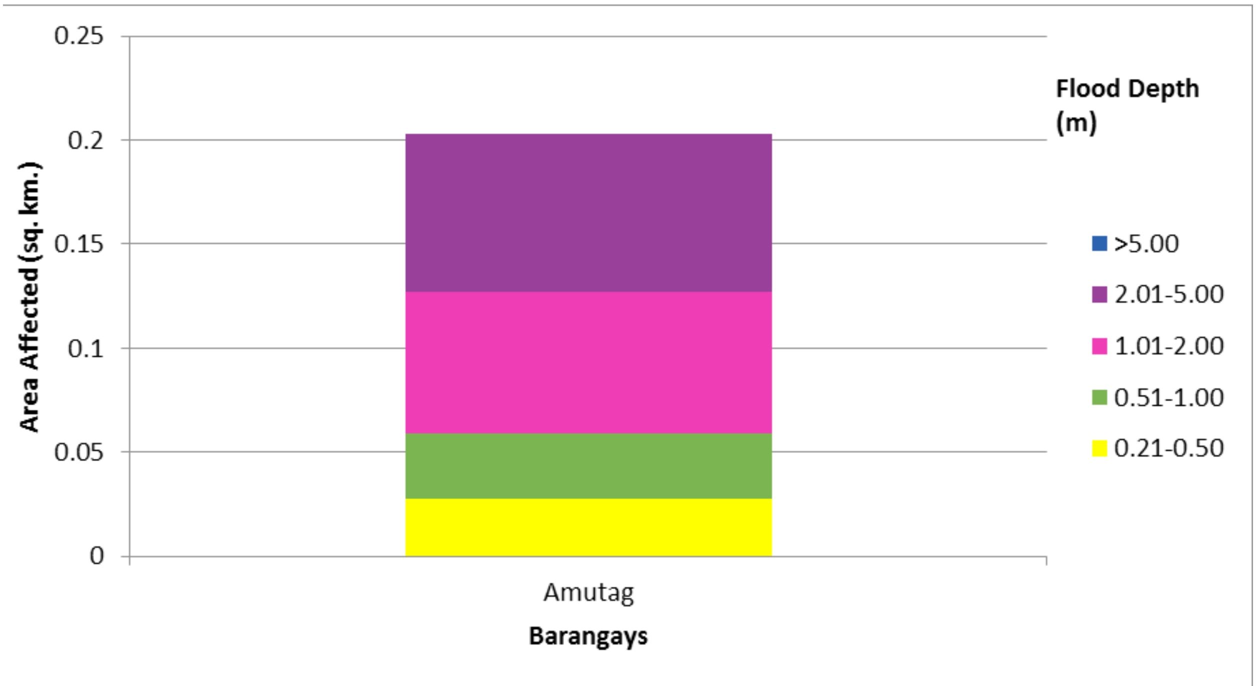


Figure 70. Affected Areas in Aroroy, Masbate during 25-Year Rainfall Return Period

For the municipality of Mandaon with an area of 267.43 sq. km., 15.02% will experience flood levels of less than 0.20 meters. 0.59% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.41%, 0.37%, 0.56%, and 0.3% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Listed in Table 34 and shown in Figure 71 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected areas in Mandaon, Masbate during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Mandaon (in sq. km.)					
	Alas	Bat-Ongan	Bugtong	Cabitan	Dayao	Santa Fe
0.03-0.20	0.64	1.78	11.62	5.9	7.04	13.19
0.21-0.50	0.039	0.062	0.31	0.65	0.27	0.24
0.51-1.00	0.011	0.051	0.32	0.38	0.14	0.2
1.01-2.00	0.0014	0.054	0.37	0.3	0.077	0.18
2.01-5.00	0	0.028	0.75	0.35	0.047	0.33
> 5.00	0	0.0086	0.29	0.081	0.0019	0.41

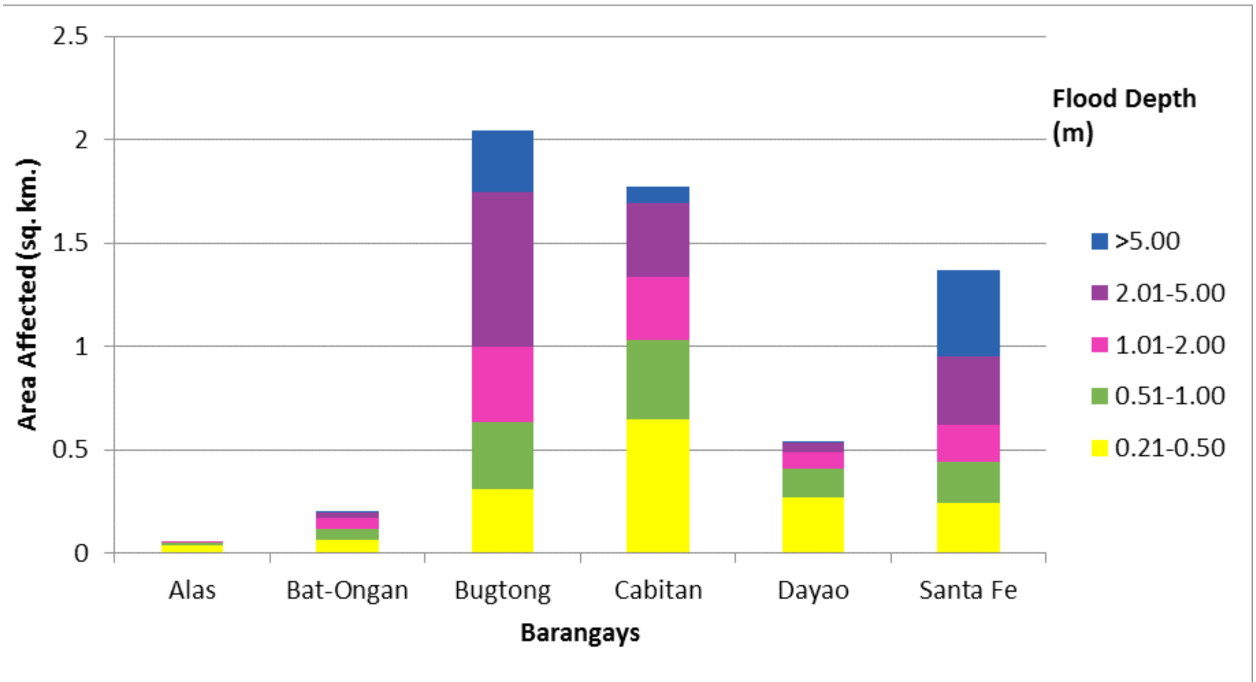


Figure 71. Affected Areas in Mandaon, Masbate during 25-Year Rainfall Return Period

For the 100-year rainfall return period, 0.17% of the municipality of Aroroy with an area of 403.62 sq. km. will experience flood levels of less than 0.20 meters. 0.007% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.007%, 0.02%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and 2.01 to 5 meters, respectively. Listed in Table 35 and shown in Figure 72 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected areas in Aroroy, Masbate during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Aroroy (in sq. km.)
	Amutag
0.03-0.20	0.68
0.21-0.50	0.026
0.51-1.00	0.028
1.01-2.00	0.076
2.01-5.00	0.083
> 5.00	0

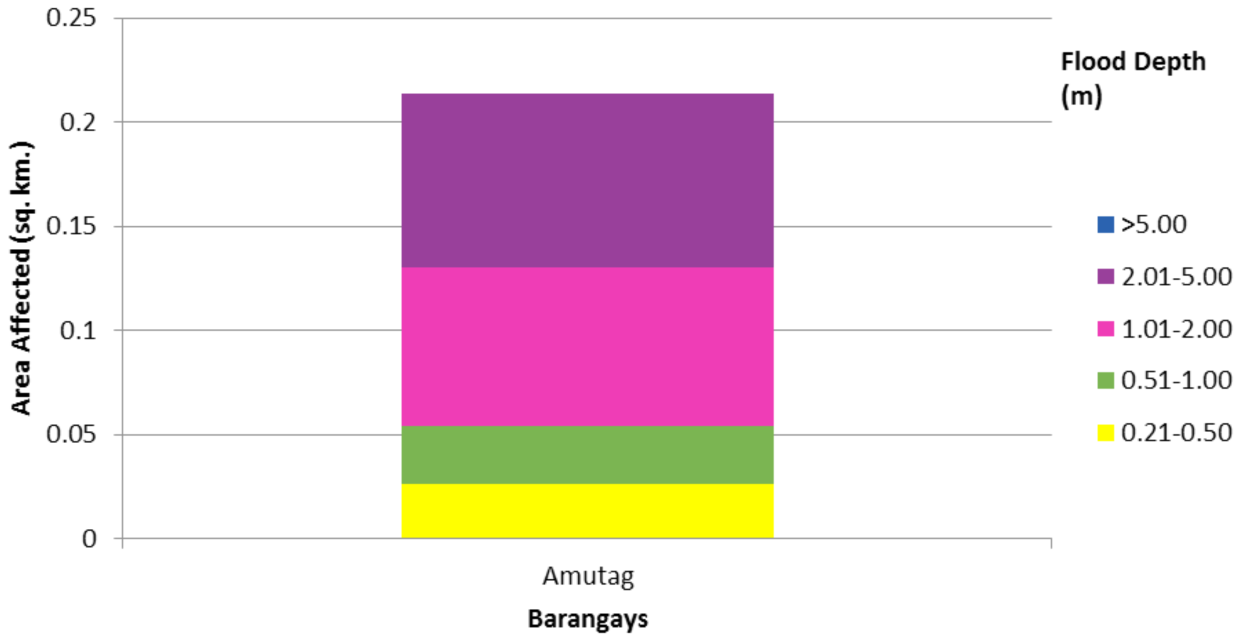


Figure 72. Affected Areas in Aroroy, Masbate during 100-Year Rainfall Return Period

For the municipality of Mandaon with an area of 267.43 sq. km., 14.67% will experience flood levels of less than 0.20 meters. 0.62% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.45%, 0.41%, 0.67%, and 0.43% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Listed in Table 36 and shown in Figure 73 are the areas affected in Mandaon in square kilometers by flood depth per barangay.

Table 36. Affected areas in Mandaon, Masbate during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Mandaon (in sq. km.)					
	Alas	Bat-Ongan	Bugtong	Cabitan	Dayao	Santa Fe
0.03-0.20	0.63	1.75	11.49	5.39	6.97	13
0.21-0.50	0.041	0.072	0.32	0.69	0.29	0.25
0.51-1.00	0.013	0.048	0.31	0.47	0.16	0.2
1.01-2.00	0.0026	0.059	0.37	0.37	0.087	0.2
2.01-5.00	0	0.05	0.78	0.54	0.061	0.35
> 5.00	0	0.011	0.38	0.21	0.0036	0.54

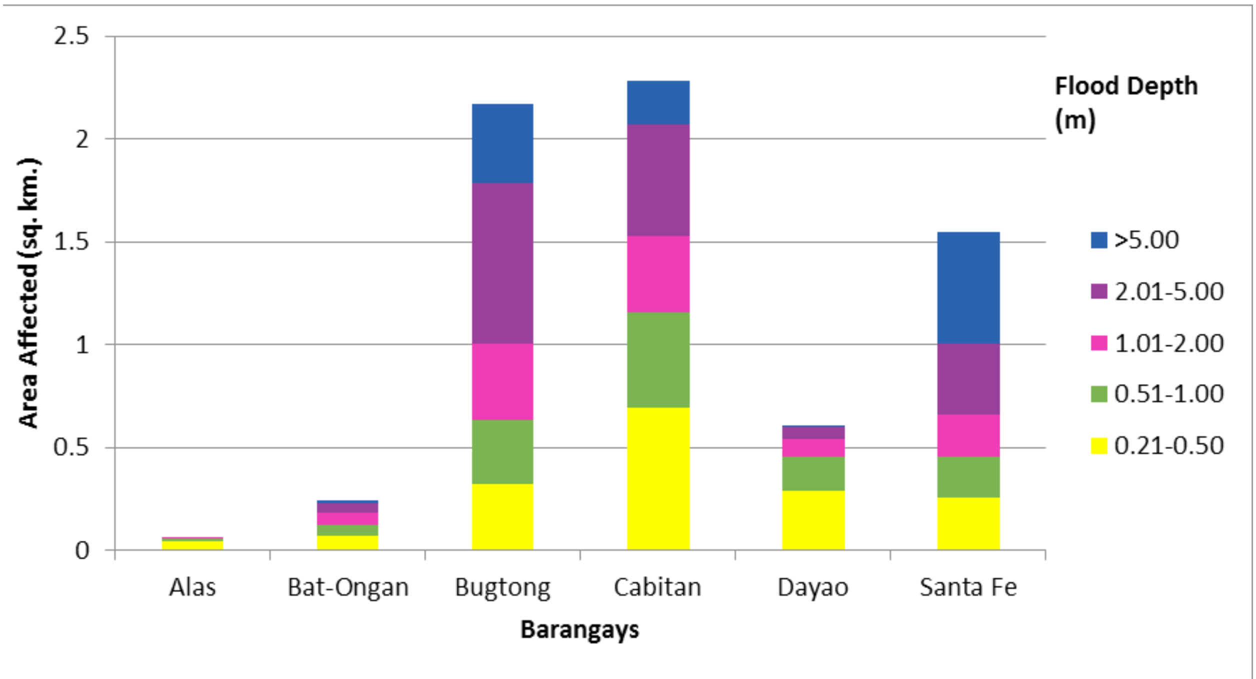


Figure 73. Affected Areas in Mandaon, Masbate during 100-Year Rainfall Return Period

Among the barangays in the municipality of Aroroy, only Amutag will experience flood levels at 0.22%.

Among the barangays in the municipality of Mandaon, Santa Fe is projected to have the highest percentage of area that will experience flood levels of at 5.44%. Meanwhile, Bugtong posted the second highest percentage of area that may be affected by flood depths at 5.11%.

Moreover, the generated flood hazard maps for the Napayawan flood plain 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 37. 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	1.52	1.62	1.71
Medium	1.52	1.71	1.86
High	2	2.95	3.65
TOTAL	**5.04**	**6.28**	**7.22**

Of the 4 identified Educational Institutions in Napayawan floodplain, none was assessed to be exposed to any flood level in all the rainfall scenarios, as shown in Annex 12.

Of the 2 identified Medical Institutions in Napayawan flood plain, 1 was assessed to be exposed to low, while none was assessed to be exposed to both medium and high level flooding in the 5-year scenario. In the 25-year scenario, none was assessed to be exposed to both low and high, while 1 was assessed to be exposed to medium level flooding. In the 100-year scenario, none was assessed to be exposed to both low and high, while 1 was assessed to be exposed to high level flooding. The medical institutions exposed to flooding are shown in Annex 13.

5.11 Flood Validation

In order to check and validate the extent of flooding in different river systems, there is a need to perform validation survey work. Field personnel gathered secondary data regarding flood occurrence in the area within the major river system in the Philippines.

From the Flood Depth Maps produced by Phil-LiDAR 1 Program, multiple points representing the different flood depths for different scenarios were identified for validation.

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood level in each location. Data gathering was done through a local DRRM office to obtain maps or situation reports about the past flooding events or interview some residents with knowledge of or have had experienced flooding in a particular area.

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed.

The flood validation consisted of 201 points randomly selected all over the Napayawan flood plain. It has an RMSE value of 0.493956.

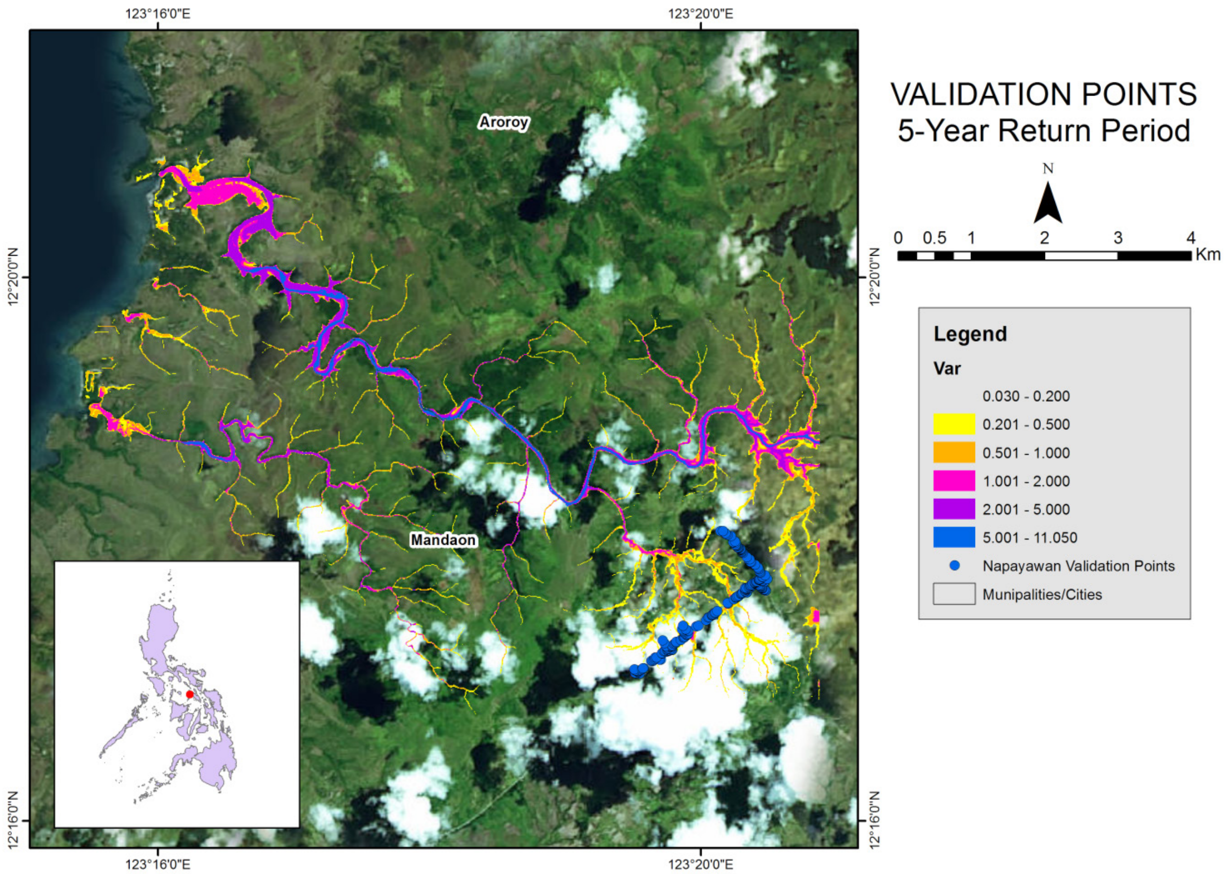


Figure 74. Validation points for the 5-Year flood depth map of the Napayawan Floodplain

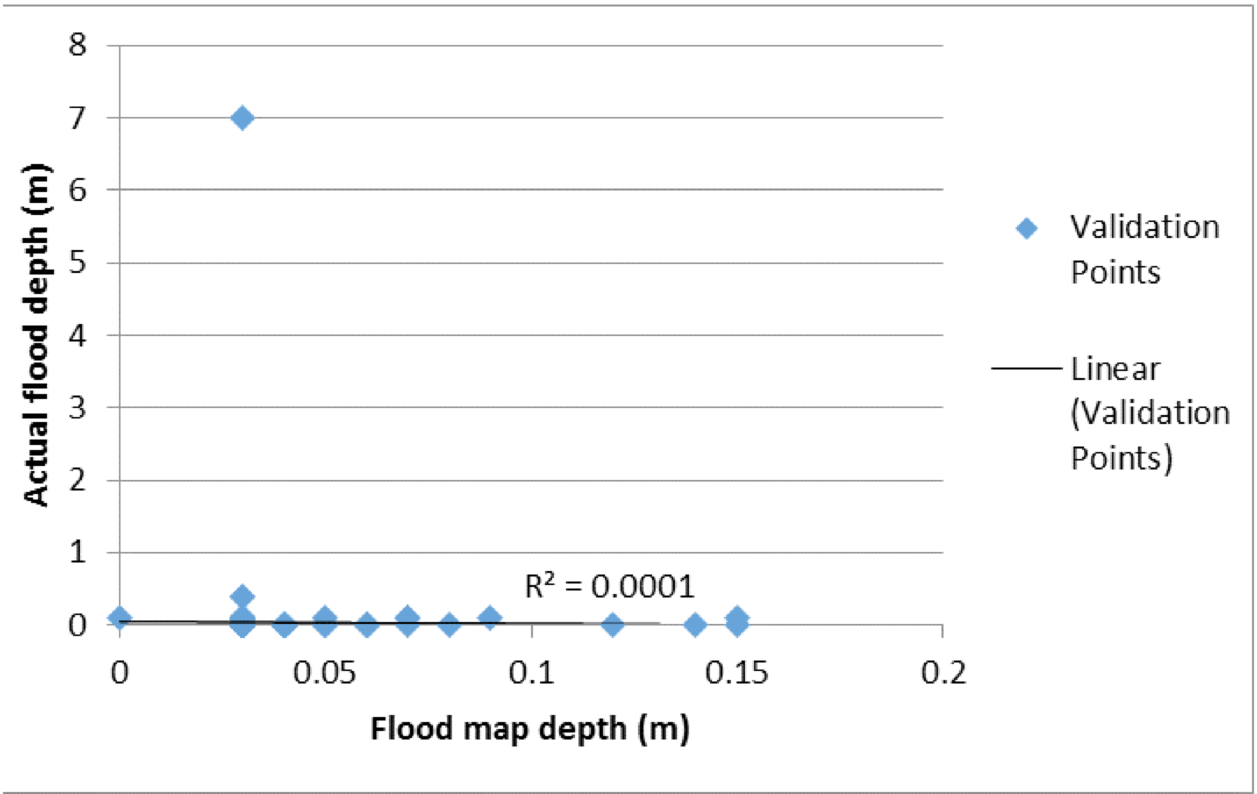


Figure 75. Flood map depth vs. actual flood depth

Table 38. Actual flood vs simulated flood depth at different levels in the Napayawan 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	52	37	59	1	0	0	149
0.21-0.50	0	2	23	0	0	0	25
0.51-1.00	0	0	0	0	0	0	0
1.01-2.00	0	0	0	0	0	0	0
2.01-5.00	0	0	0	0	0	0	0
> 5.00	0	0	0	0	0	0	0
Total	52	39	82	1	0	0	174

On the whole, the overall accuracy generated by the flood model is estimated at 99%, with 199 points correctly matching the actual flood depths. In addition, there was 1 point estimated one level above and below the correct flood depths, none estimated two levels above and below, and 1 point estimated three or more levels above and below the correct flood depths. No points were overestimated while a total of 2 were underestimated in the modelled flood depths of Napayawan. Table 39 depicts the summary of the accuracy assessment in the Napayawan River Basin survey.

Table 39. Summary of the Accuracy Assessment in the Napayawan River Basin Survey

	No. of Points	%
Correct	199	99.00
Overestimated	0	0.00
Underestimated	2	1.00
Total	201	100.00

REFERENCES

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

Balicanta L.P, Paringit E.C., et al. 2014. DREAM Data Validation Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

Brunner, G. H. 2010a. HEC-RAS River Analysis System Hydraulic Reference Manual. Davis, CA: U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center.

Lagmay A.F., Paringit E.C., et al. 2014. DREAM Flood Modeling Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

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

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

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

ANNEXES

Annex 1. Optech Technical Specification of the Pegasus Sensor

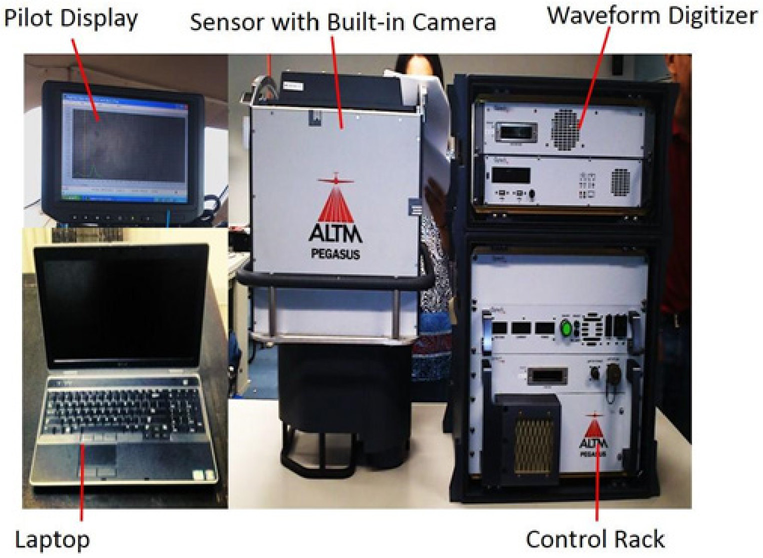


Figure A-1.1. Parameters and Specification of the Pegasus Sensor

Table A-1.1. Parameters and Specification of the Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-5000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, 1σ
Elevation accuracy (2)	< 5-20 cm, 1σ
Effective laser repetition rate	Programmable, 100-500 kHz
Position and orientation system	POS AV ™AP50 (OEM)
Scan width (FOV)	Programmable, 0-75 ˚
Scan frequency (5)	Programmable, 0-140 Hz (effective)
Sensor scan product	800 maximum
Beam divergence	0.25 mrad (1/e)
Roll compensation	Programmable, ±37˚ (FOV dependent)
Vertical target separation dis-tance	<0.7 m
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V, 800 W, 30 A
Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing
Relative humidity	0-95% no-condensing

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

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

1. MST-28

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

April 10, 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: **MASBATE**
Station Name: **MST-28**
Order: **2nd**

Island: **LUZON**
Municipality: **MANDAON**
Barangay: **BAT-ONGAN**

		PRS92 Coordinates			
Latitude:	**12° 18' 35.15371"**	Longitude:	**123° 21' 19.21293"**	Ellipsoidal Hgt:	**49.12800 m.**
		WGS84 Coordinates			
Latitude:	**12° 18' 30.47973"**	Longitude:	**123° 21' 24.28923"**	Ellipsoidal Hgt:	**104.64900 m.**
		PTM Coordinates			
Northing:	**1361224.57 m.**	Easting:	**538651.166 m.**	Zone:	**4**
		UTM Coordinates			
Northing:	**1,360,748.12**	Easting:	**538,637.64**	Zone:	**51**

Location Description

MST-28
From Masbate City Proper, travel for about 50.6 km. along the Nat'l. Highway going to Mambog Bridge at Brgy. Bat-ongan, Mandaon Town. Station is located at the right side wing of the said bridge. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete block protruding 0.05 m. above the ground surface, with inscriptions "MST-28 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-829**

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

9904102014140223

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. MST-28

2. MST-32

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

April 10, 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: **MASBATE**
Station Name: **MST-32**
Order: **2nd**

Island: **LUZON**
Municipality: **MILAGROS**
Barangay:

PRS92 Coordinates

Latitude: **12º 13' 7.66936"**	Longitude: **123º 30' 26.72479"**	Ellipsoidal Hgt: **3.78300 m.**

WGS84 Coordinates

Latitude: **12º 13' 3.03064"**	Longitude: **123º 30' 31.80788"**	Ellipsoidal Hgt: **59.91100 m.**

PTM Coordinates

Northing: **1351188.593 m.**	Easting: **555213.396 m.**	Zone: **4**

UTM Coordinates

Northing: **1,350,715.65**	Easting: **555,194.07**	Zone: **51**

Location Description

MST-32
From Masbate City Proper, travel for about 26 km. along the Nat'l. Highway going to Pob. Milagros. Station is located at the compound of the Milagros Mun. Hall, 30 m. NW, 2 m. E of the concrete fence, 5 m. SW of the basketball court and 10 m. W of the volleyball court. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete, with inscriptions "MST-32 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-838**

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

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

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. MST-32

3. MS-269

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

April 10, 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: **MASBATE** Station Name: **MS-269**	
Island: **LUZON**	Municipality: **AROROY**	Barangay: **LUY-A**
Elevation: **27.4076 m.**	Order: **1st Order**	Datum: **Mean Sea Level**

Location Description

MS-269

Station is in the Island / Province of Masbate, Municipality of Aroroy, along the road linking Aroroy with the town of Milagros, Barangay Luy-a, at the top of a concrete bridge. A diesel station is located nearby. Mark is the head of a 3" copper nail embedded into the bridge walkway / pavement with cement putty and inscription "MS-269; 2008; NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-841**

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

9 9 0 4 1 0 2 0 1 4 1 4 0 6 3 8

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.3. MS-269

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

1. MS-269

MS-269 - MST-28 (6:36:44 AM-10:31:44 AM) (S1)

Baseline observation:	MS-269 --- MST-28 (B1)
Processed:	5/13/2014 3:15:01 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.009 m
Vertical precision:	0.024 m
RMS:	0.004 m
Maximum PDOP:	2.923
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	4/4/2014 6:37:04 AM (Local: UTC+8hr)
Processing stop time:	4/4/2014 10:31:44 AM (Local: UTC+8hr)
Processing duration:	03:54:40
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	MST-28				
Grid		Local		Global	
Easting	538790.668 m	Latitude	N12°18'30.47973"	Latitude	N12°18'30.47973"
Northing	1360689.389 m	Longitude	E123°21'24.28923"	Longitude	E123°21'24.28923"
Elevation	49.498 m	Height	104.649 m	Height	104.649 m

To:	MS-269				
Grid		Local		Global	
Easting	544123.868 m	Latitude	N12°24'21.62786"	Latitude	N12°24'21.62786"
Northing	1371483.415 m	Longitude	E123°24'21.40082"	Longitude	E123°24'21.40082"
Elevation	28.584 m	Height	83.308 m	Height	83.308 m

Vector					
ΔEasting	5333.200 m	NS Fwd Azimuth	26°22'11"	ΔX	-3185.907 m
ΔNorthing	10794.025 m	Ellipsoid Dist.	12044.246 m	ΔY	-4889.699 m
ΔElevation	-20.914 m	ΔHeight	-21.341 m	ΔZ	10536.100 m

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

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

FIELD TEAM

LiDAR Operation	Supervising Science Research Specialist (SSRS)	ENGR. GEROME B. HIPOLITO	UP-TCAGP
	Research Associate (RA)	MARY CATHERINE ELIZABETH BALIGUAS	UP-TCAGP
	RA	ENGR. IRO NIEL ROXAS	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	ENGR. GRACE SINADJAN	UP-TCAGP
LiDAR Operation	Airborne Security	SSG MARLON TORRE	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. JEFFREY JEREMY ALAJAR	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. BRYAN DONGUINES	AAC

Annex 5. Data Transfer Sheet for Napayawan Floodplain

DATA TRANSFER SHEET
4/22/2014(MASBATE)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS (mb)	POS (mb)	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
4/1/2014	1291P	1BLK32KL091A	PEGASUS	2.91	3.36	9.99	256	43.6	332	29.8	NA	7.81	1KB	602	376	NA	Z:\Airborne_Raw\1291P
4/1/2014	1293P	1BLK32H091B	PEGASUS	1.75	1.46	3.85	115	24.7	213	15.6	NA	7.81	1KB	221	68.5	NA	Z:\Airborne_Raw\1293P
4/2/2014	1295P	1BLK32E092A	PEGASUS	2.93	3.42	8.9	225	54.2	404	29.2	NA	867KB	1KB	512	137	NA	Z:\Airborne_Raw\1295P
4/3/2014	1299P	1BLK32FG093A	PEGASUS	2.68	3.23	8.65	232	33.4	267	26.8	NA	7.59	1KB	358	113	NA	Z:\Airborne_Raw\1299P
4/3/2014	1301P	1BLK32F093B	PEGASUS	1.95	2.42	5.95	149	44.6	352	19.6	NA	7.59	1KB	538	201	NA	Z:\Airborne_Raw\1301P
4/4/2014	1303P	1BLK32A094A	PEGASUS	2.77	3.48	2.99	218	52.5	404	29.4	NA	6.67	1KB	694	186	NA	Z:\Airborne_Raw\1303P
4/4/2014	1305P	1BLK32A094B	PEGASUS	2.41	2.85	6.88	161	44.3	324	23.3	NA	6.67	1KB	400	2.41	NA	Z:\Airborne_Raw\1305P
4/5/2014	1307P	1BLK32DG095A	PEGASUS	3.84	4.48	4.12	271	67.2	514	37.7	NA	6.49	1KB	523	270	NA	Z:\Airborne_Raw\1307P
4/8/2014	1319P	1BLK32B098A	PEGASUS	3.66	4.32	9.93	254	17.7	526	36.2	NA	4.95	1KB	731	382	NA	Z:\Airborne_Raw\1319P
4/10/2014	1327P	1BLK32D100A	PEGASUS	2.16	2.47	6.99	175	37	277	21.7	NA	5.27	1KB	747	243	NA	Z:\Airborne_Raw\1327P
4/11/2014	1331P	1BLK32B101A	PEGASUS	1.76	1.9	5.09	134	29.8	232	17.8	NA	4.09	1KB	574	316	NA	Z:\Airborne_Raw\1331P

Received from

Name CARLOS JOAQUIN

Position RA

Signature 4/23/14

Received by

Name JOIDA F. PRIETO

Position SSRS

Signature 4/23/14

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

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 1303P

DREAM Data Acquisition Flight Log — **Flight Log No.:** 1303P

1 LiDAR Operator: I. Roxas	2 ALTM Model: PEG	3 Mission Name: 1BLK32A094A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: JJ Alajar	8 Co-Pilot: BJ Dongumes	9 Route:			
10 Date: 04 April 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 0456	14 Engine Off: 1037	15 Total Engine Time: 3+41	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: partly cloudy					

20 Remarks:

Surveyed 7 lines at BLK 32A, 2 lines at BLK 32C and 2 lines BLK 32B

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Hiroi H	Marlon Turang	JJ Alajar	I Roxas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.1. Flight Log for Mission 1303P

2. Flight Log for 1305P Mission

DREAM Data Acquisition Flight Log — **Flight Log No.:** 1305P

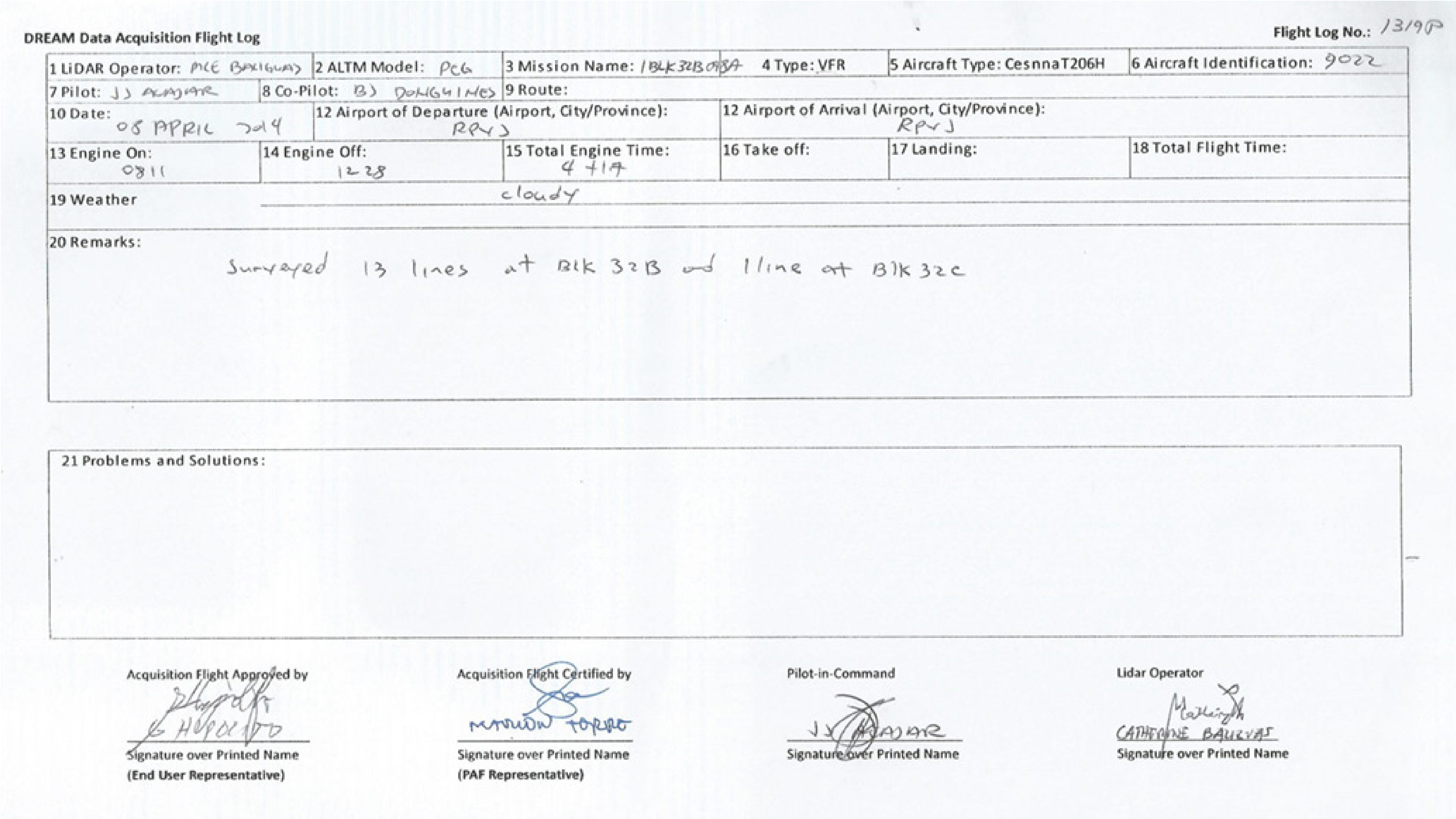
1 LiDAR Operator: ACE BALIGUAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32A094B	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: JJ ALVADAR	8 Co-Pilot: BJ DONGUINES	9 Route:			
10 Date: 04 APRIL 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 1122	14 Engine Off: 1421	15 Total Engine Time: 2+59	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Partly cloudy					
20 Remarks: completed BLK 32A					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
G HILARIO, PhD	MARLON TORRE	JJ ALVADAR	CATHERINE BALIGUAS
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.2. Flight Log for Mission 1305P

3. Flight Log for 1319P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1319P

1 LiDAR Operator: MCE BALIGUAS	2 ALTM Model: PEG	3 Mission Name: 1BLK32BO98A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: JJ ALAJAR	8 Co-Pilot: BJ DONGUINES	9 Route:			
10 Date: 08 APRIL 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 0811	14 Engine Off: 1228	15 Total Engine Time: 4+17	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	cloudy				
20 Remarks:	Surveyed 13 lines at BLK 32B and 1 line at BLK 32C				

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
G HIPOLITO	MARLON TORRE	JJ ALAJAR	CATHERINE BALIGUAS
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 1319P

4. Flight Log for 1331P Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1331P

1 LiDAR Operator: MCE BALIGUAS	2 ALTM Model: PEG	3 Mission Name: 1BlK32B,idA	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: JJ ALABAR	8 Co-Pilot: BJ DONGUINES	9 Route:			
10 Date: 11 April 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 0701	14 Engine Off: 0936	15 Total Engine Time: 2+35	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Cloudy					

20 Remarks:

Surveyed 5 lines at BlK 32B and covered voids within the area

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
C. Hipolito	Marlyn Pardo	JJ Alabar	Catherine Baliguas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.4. Flight Log for Mission 1331P

Annex 7. Flight Status Report

MASBATE
MARCH 18, 2014-APRIL 14,2014

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1303P	BLK32A	1BLK32A094A	I. ROXAS	04 APR 14	SURVEYED 7 LINES AT BLK32A, 2 LINES AT BLK32C AND 2 LINES BLK32B
1305P	BLK32A	1BLK32A094B	MCE. BALIGUAS	04 APR 14	COMPLETED BLK32A
1319P	BLK32B	1BLK32B098A	MCE. BALIGUAS	08 APR 14	SURVEYED 5 LINES AT BLK32B AND COVERED VOIDS WITHIN THE AREA
1331P	BLK32B	1BLK32B101A	MCE. BALIGUAS	11 APR 14	SURVEYED 5 LINES AT BLK32B AND COVERED VOIDS WITHIN THE AREA

SWATH BOUNDARIES PER MISSION FLIGHT

Flight No. :	1303P		
Area:	BLK32A		
Mission Name:	1BLK32A094A		
Parameters:	Altitude:	1200m and 1000m;	Scan Frequency: 30Hz;
Scan Angle:	25deg;	Overlap: 30%	

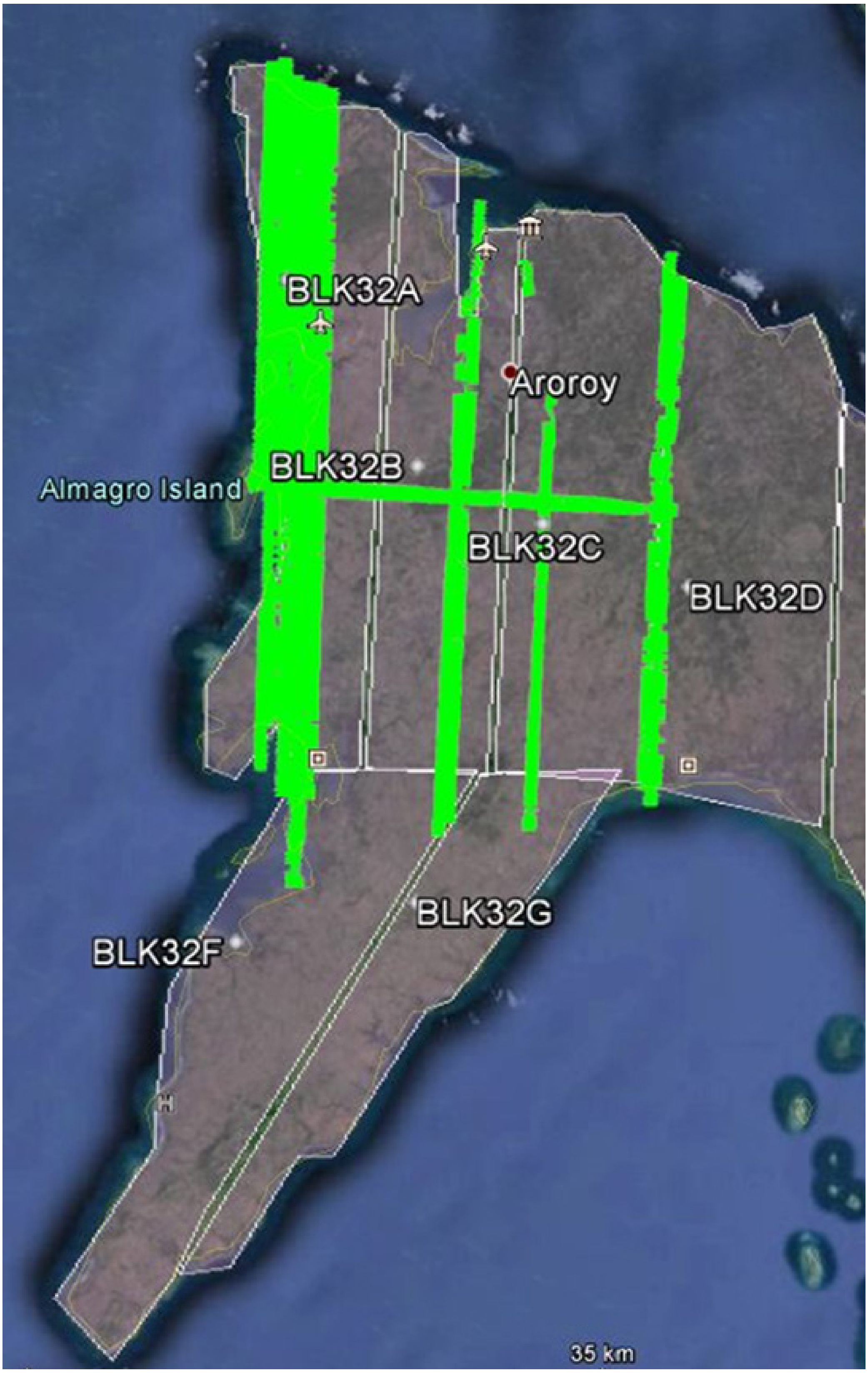


Figure A-7.1. Swath for Flight No. 1303P

Flight No. :	1305P		
Area:	BLK32A		
Mission Name:	1BLK32A094B		
Parameters:	Altitude:	1000m;	Scan Frequency: 30Hz;
Scan Angle:	25deg;	Overlap: 25%	

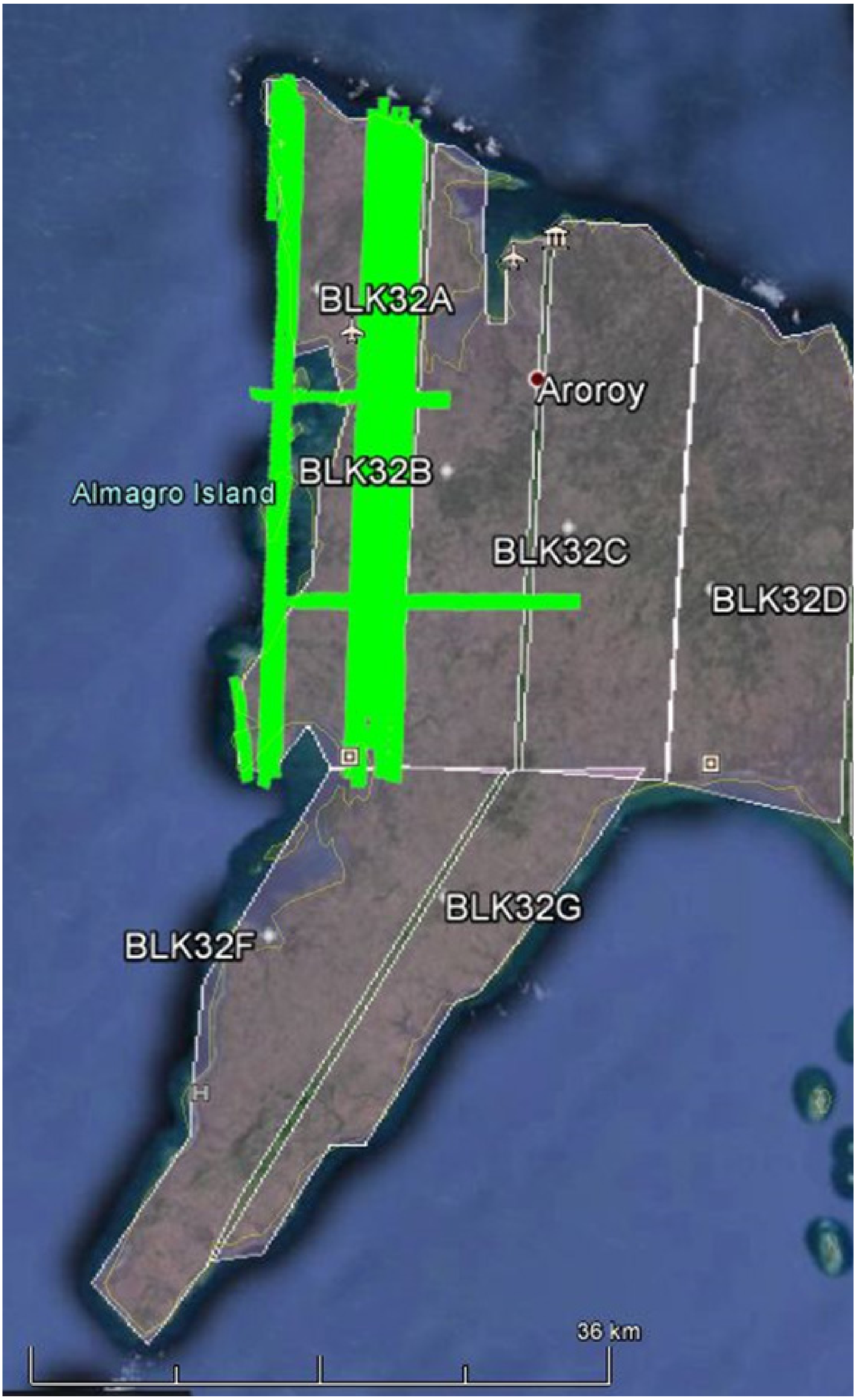


Figure A-7.2. Swath for Flight No. 1305P

Flight No. :	1319P		
Area:	BLK32B		
Mission Name:	1BLK32B098A		
Parameters:	Altitude:	900m;	Scan Frequency: 30Hz;
Scan Angle:	25deg;	Overlap: 35%	

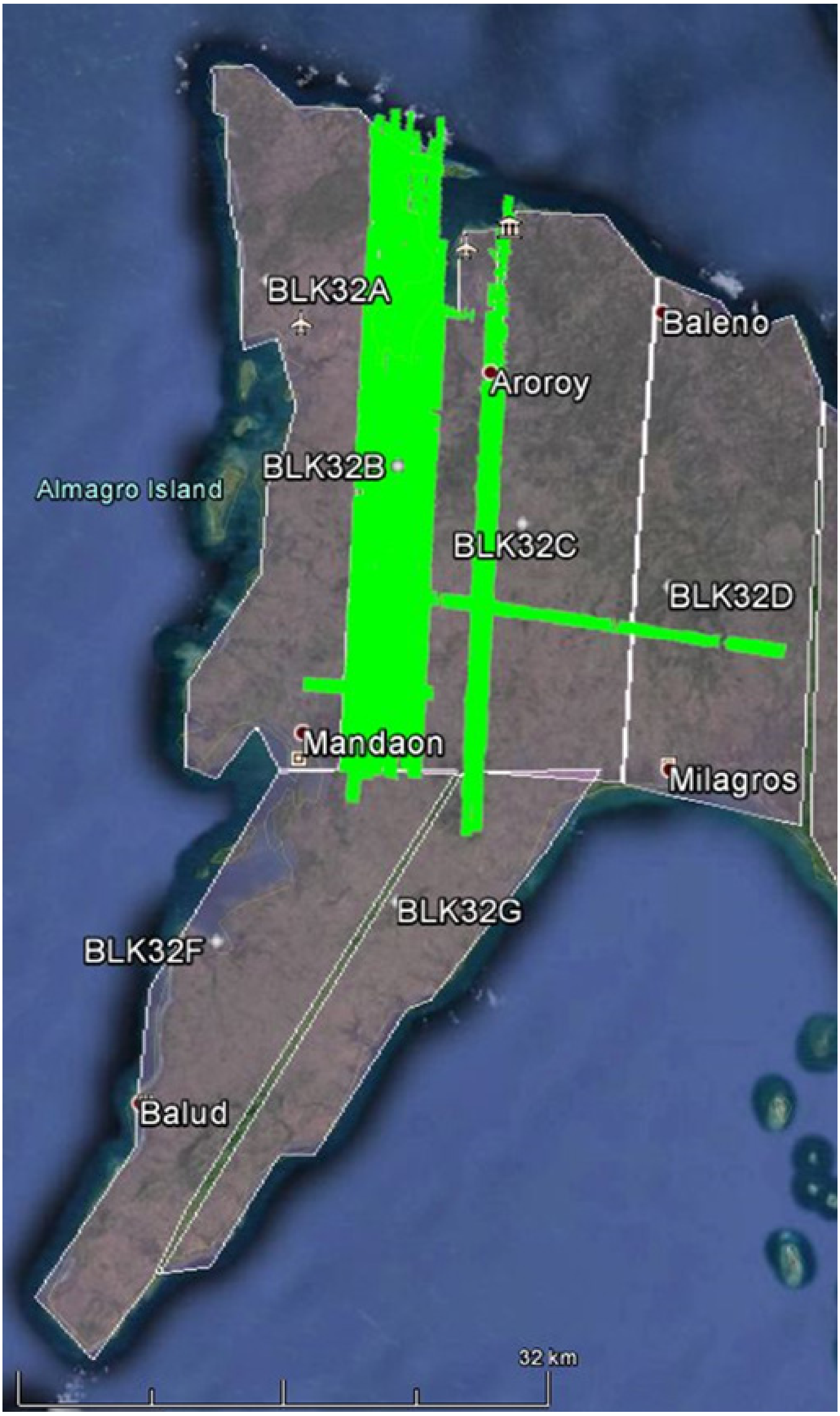


Figure A-7.3. Swath for Flight No. 23282P

Flight No. :	1331P
Area:	BLK32B
Mission Name:	1BLK32B101A
Parameters:	Altitude: 800m; Scan Frequency: 30Hz;
Scan Angle:	25deg; Overlap: 35%

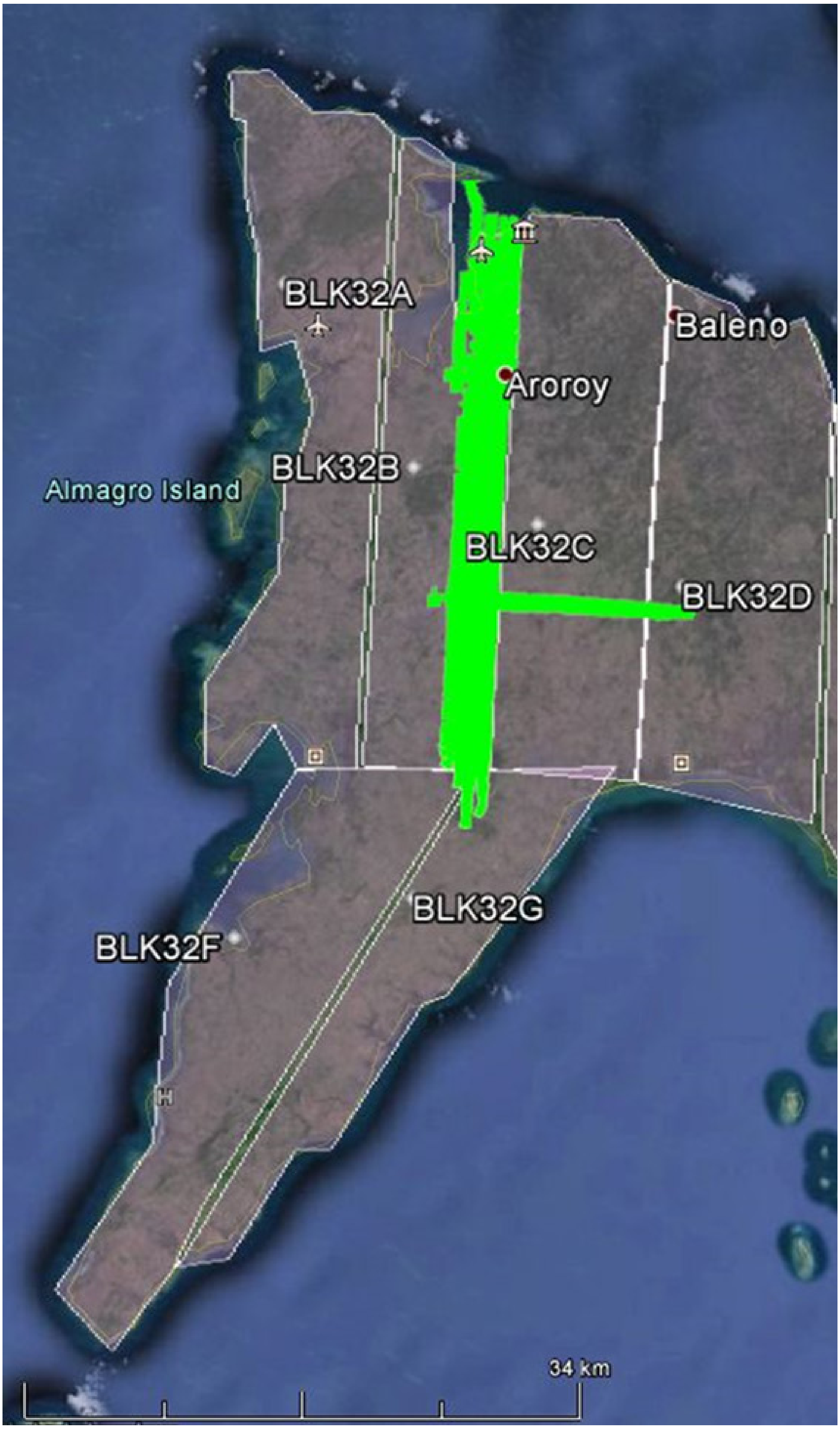


Figure A-7.4. Swath for Flight No. 23290P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk 32B

Flight Area	MASBATE
Mission Name	Blk 32B
Inclusive Flights	1319P, 1331P
Mission Name	1BLK32B098A, 1BLK32B101A
Range data size	54.0 GB
POS	388 MB
Base data size	9.04
Image	47.5 GB
Transfer date	April 22, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	2.9
Boresight correction stdev (<0.001deg)	N/A
IMU attitude correction stdev (<0.001deg)	N/A
GPS position stdev (<0.01m)	N/A
Minimum % overlap (>25)	61.52%
Ave point cloud density per sq.m. (>2.0)	4.66
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	394
Maximum Height	146.13m
Minimum Height	57.15m
Classification (# of points)	
Ground	1,946,372
Low vegetation	504,134
Medium vegetation	342,053
High vegetation	127,814
Building	7,547
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Jennifer Saguran, Engr. Mark Joshua Salvacion, Engr. Merven Natino, Ryan Dizon

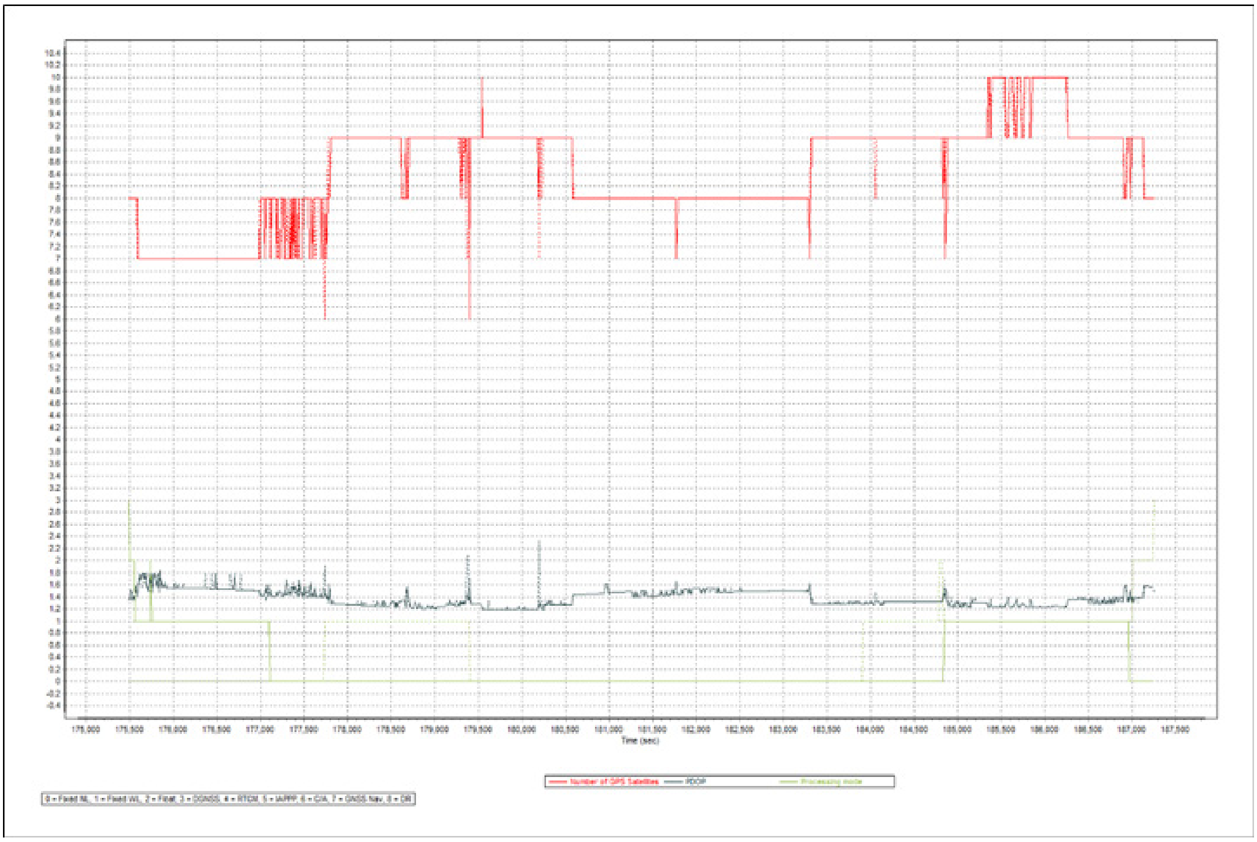


Figure A-8.1. Solution Status

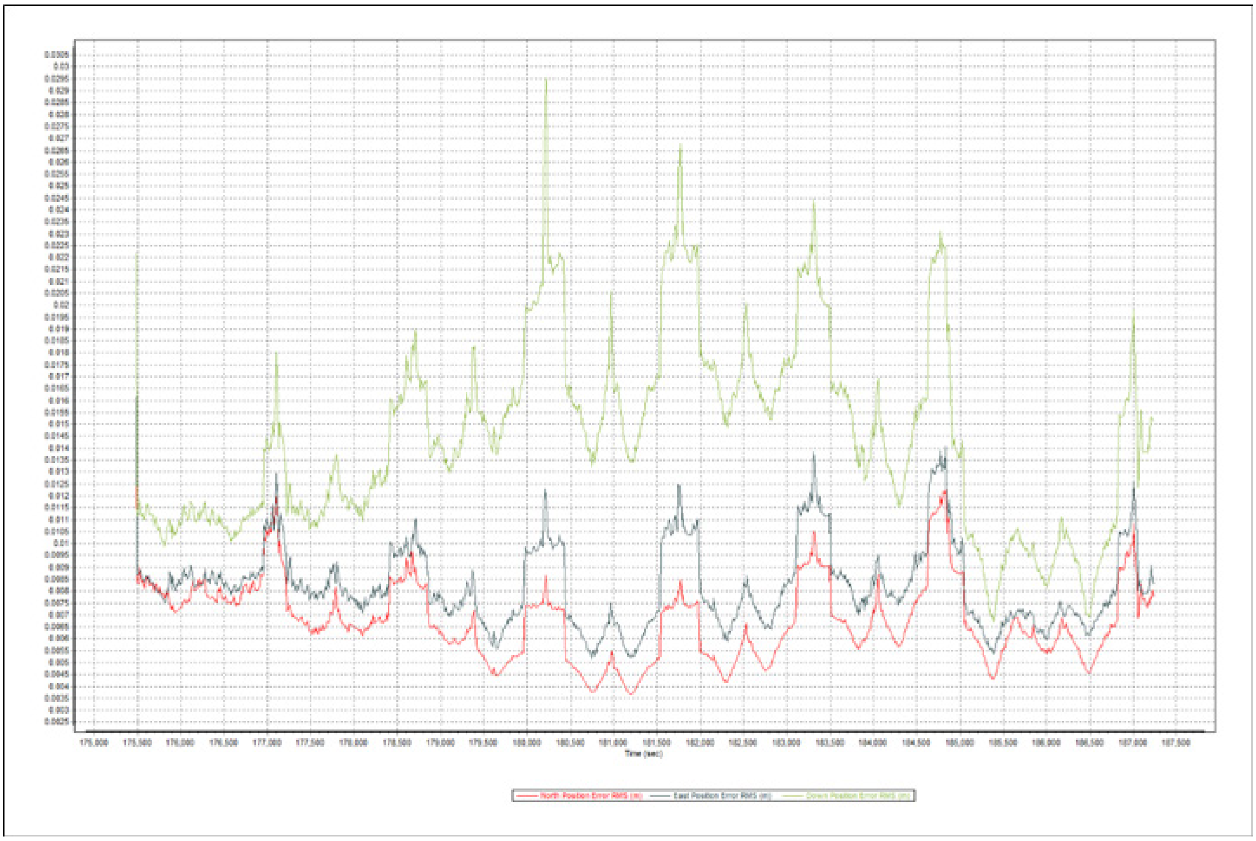


Figure A-8.2. Smoothed Performance Metrics Parameters

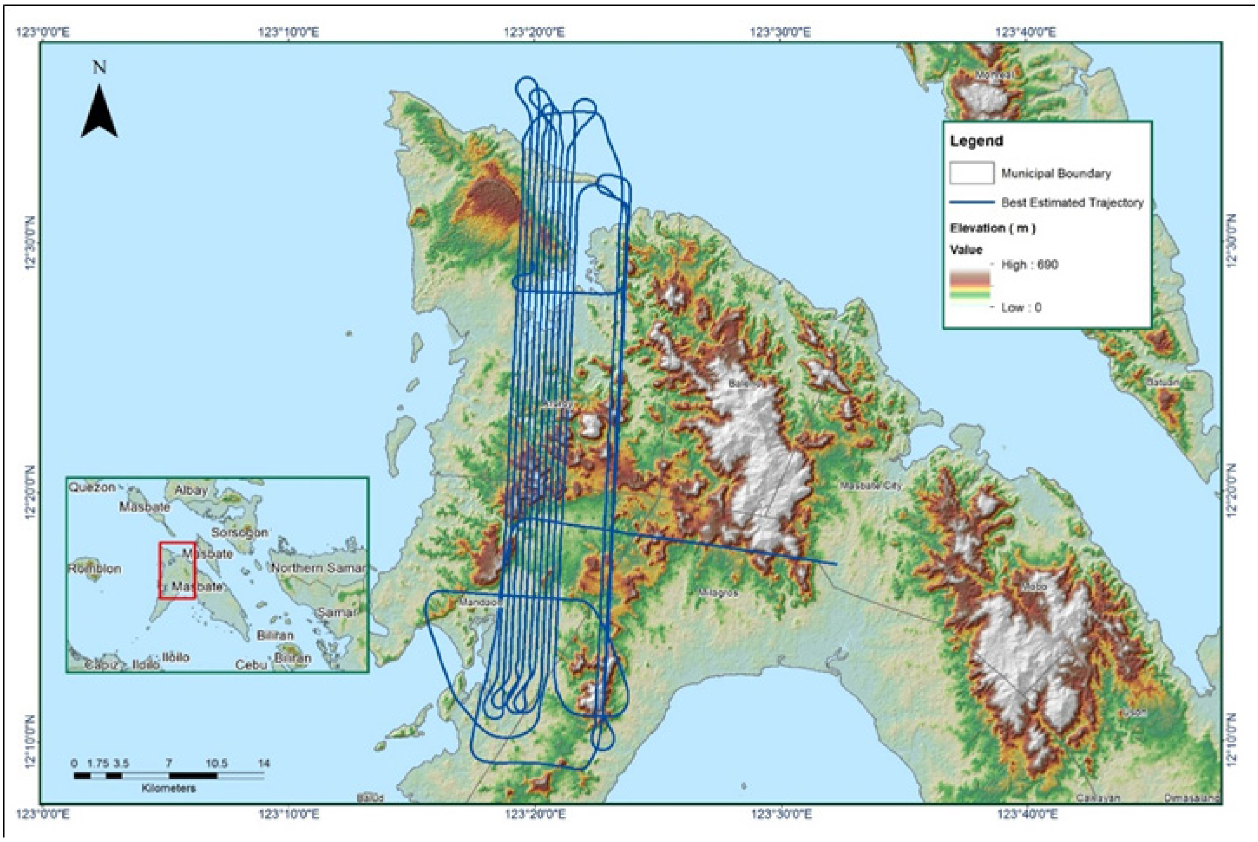


Figure A-8.3. Best Estimated Trajectory

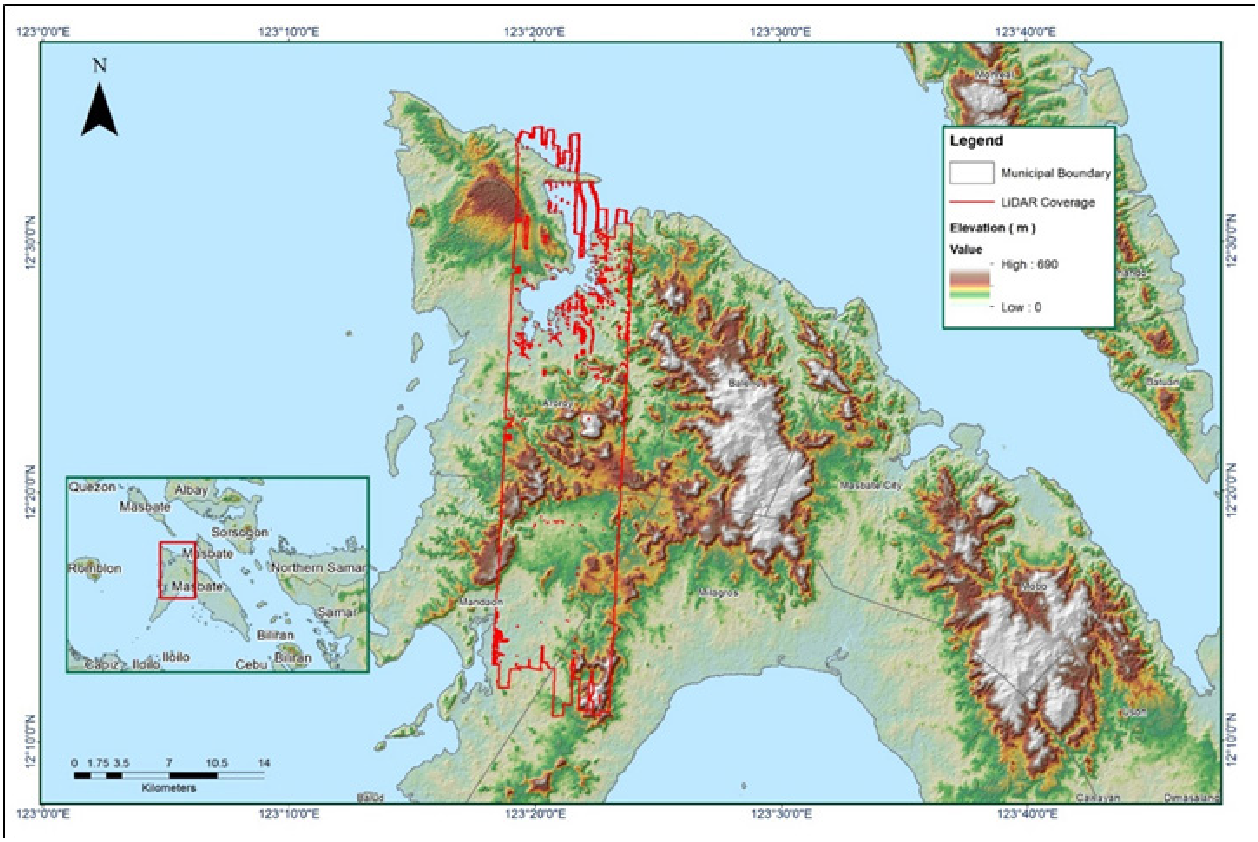


Figure A-8.4. Coverage of LiDAR data

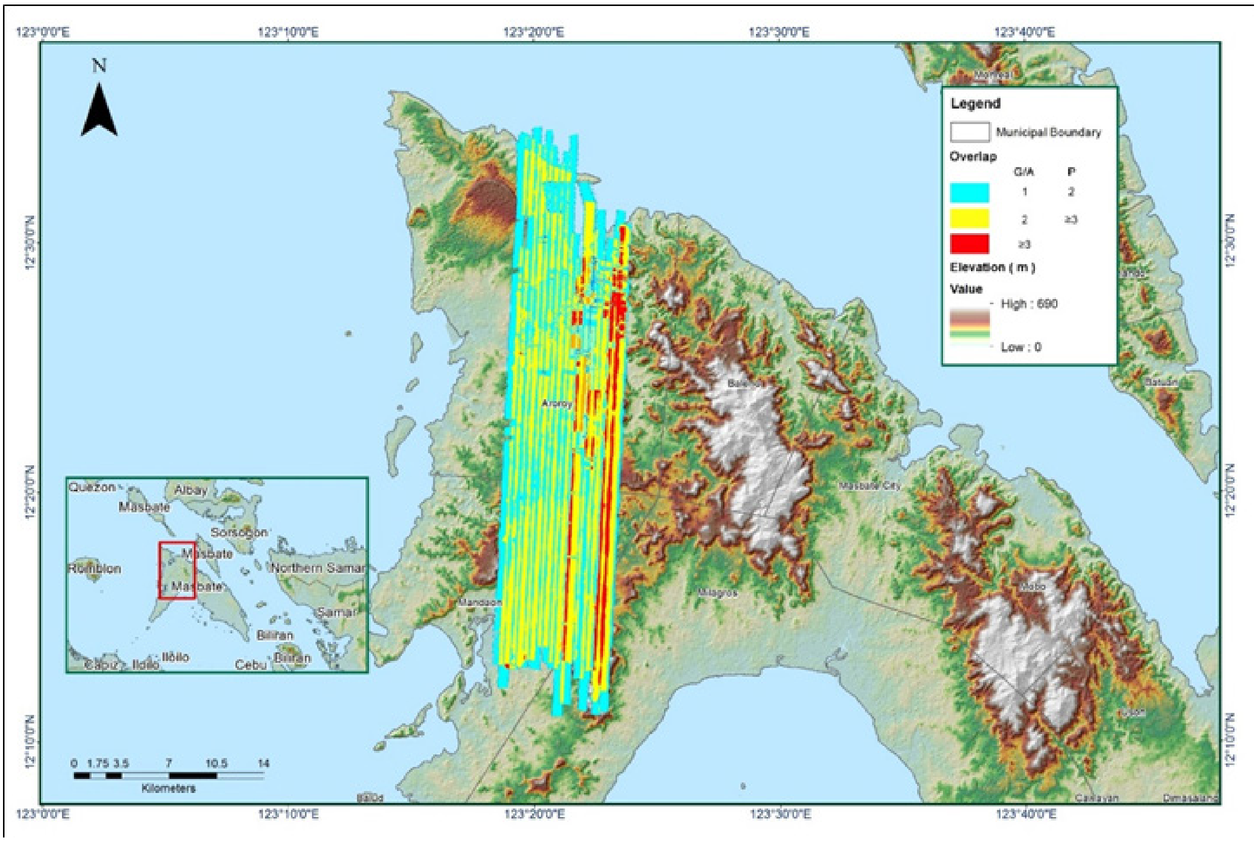


Figure A-8.5. Image of Data Overlap

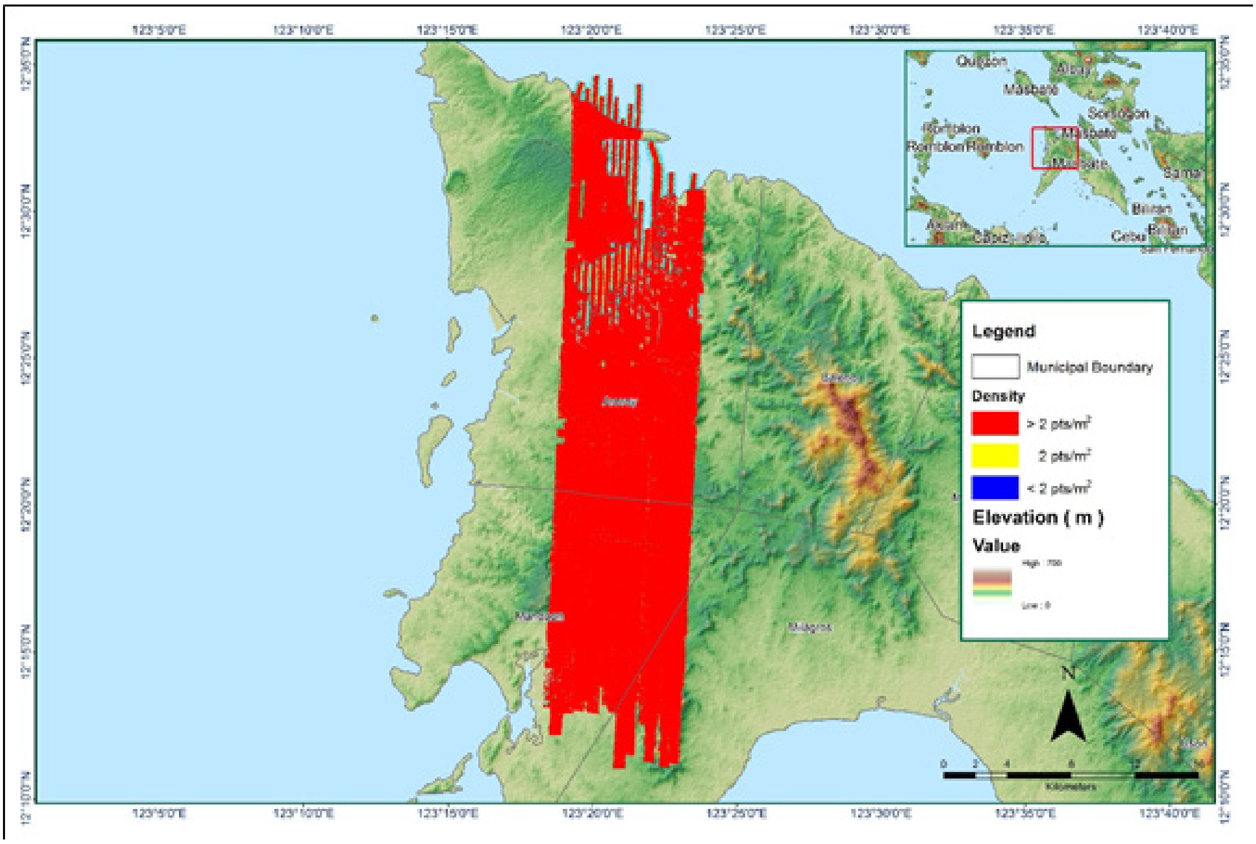


Figure A-8.6. Density map of merged LiDAR data

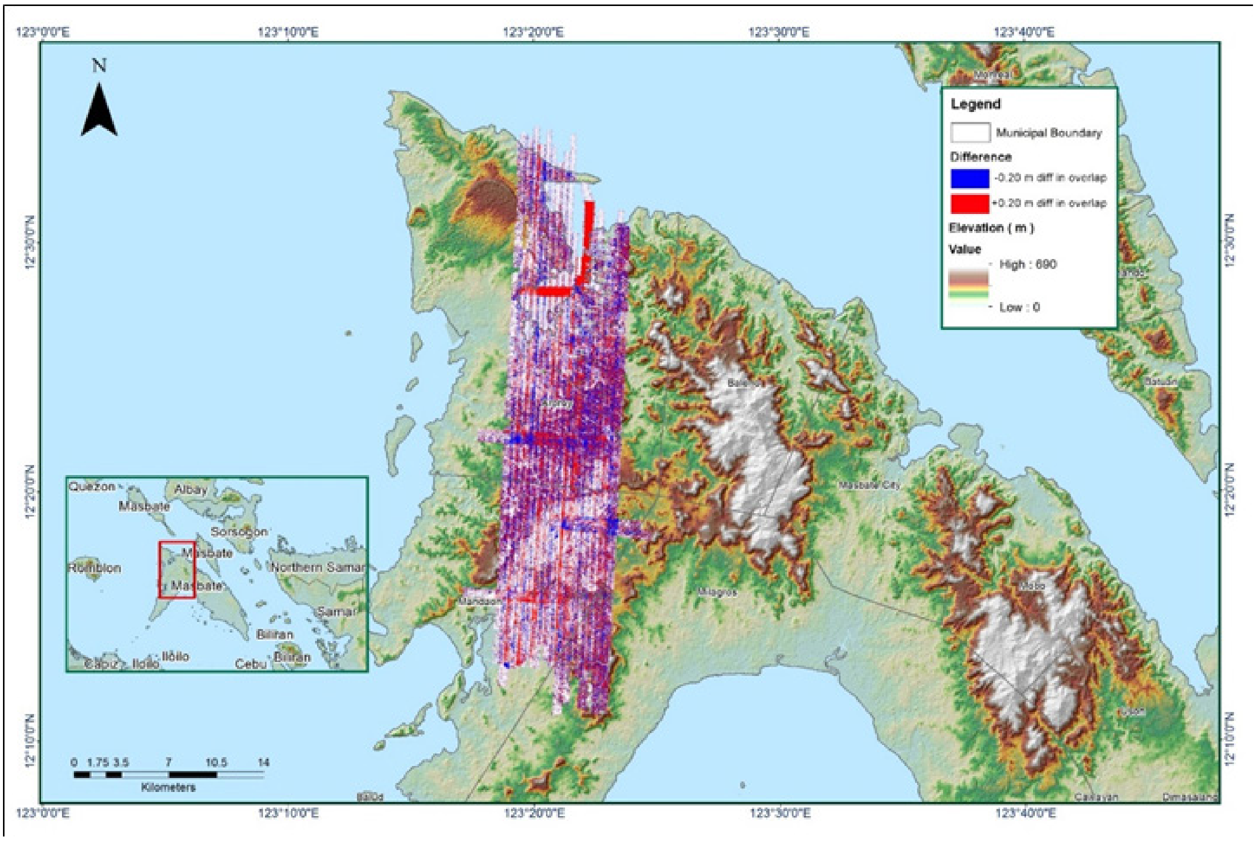


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk 32A

Flight Area	MASBATE
Mission Name	Blk 32A
Inclusive Flights	1303P, 1305P
Mission Name	1BLK32A094A, 1BLK32A094B
Range data size	52.7 GB
POS	379 MB
Base data size	13.34
Image	96.8 GB
Transfer date	April 22, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.7
RMSE for East Position (<4.0 cm)	1.7
RMSE for Down Position (<8.0 cm)	3.0
Boresight correction stdev (<0.001deg)	N/A
IMU attitude correction stdev (<0.001deg)	N/A
GPS position stdev (<0.01m)	N/A
Minimum % overlap (>25)	35.60%
Ave point cloud density per sq.m. (>2.0)	2.78
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	671
Maximum Height	710.95m
Minimum Height	55.95m
Classification (# of points)	
Ground	556,276,310
Low vegetation	419,293,403
Medium vegetation	439,040,885
High vegetation	260,239,514
Building	4,857,880
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Merven Natino, Engr. Jeffrey Delica

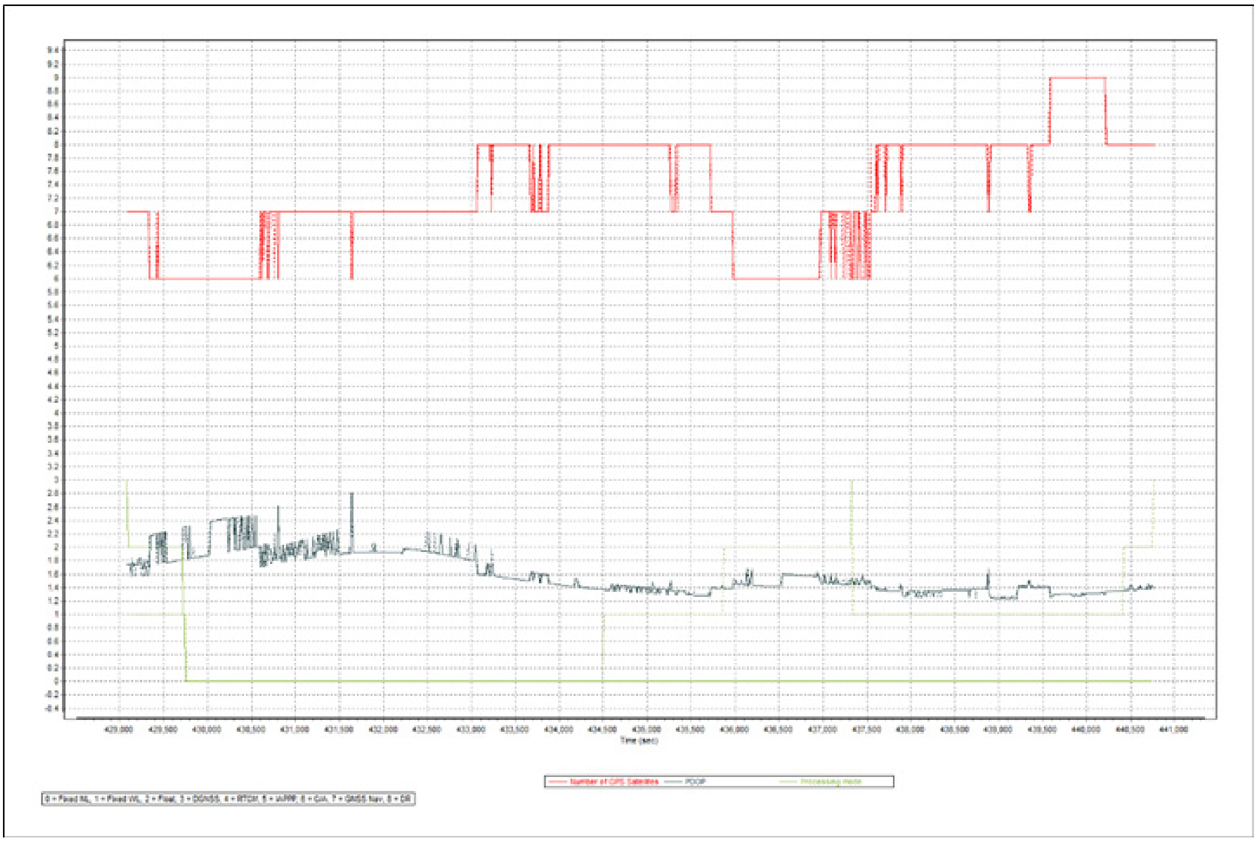


Figure A-8.8. Solution Status Parameters

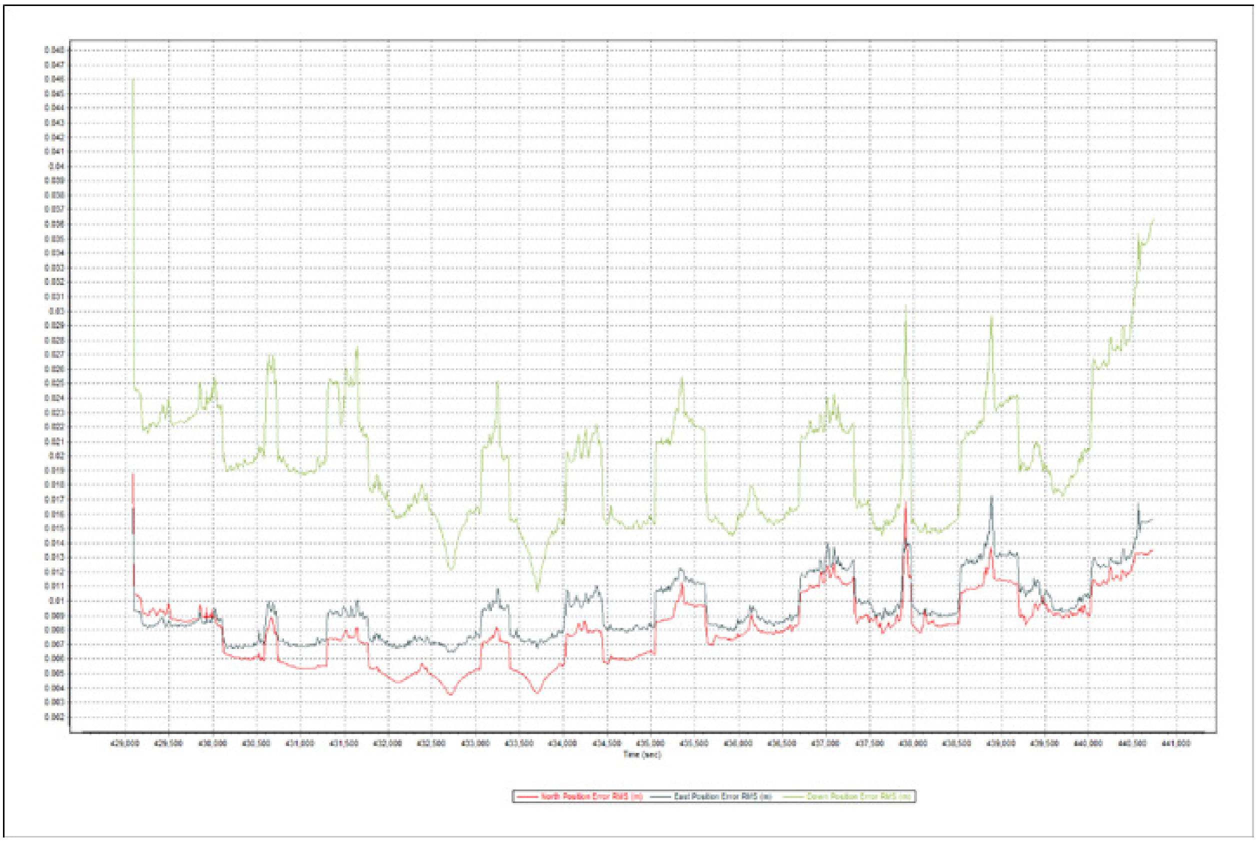


Figure A-8.9. Smoothed Performance Metrics Parameters

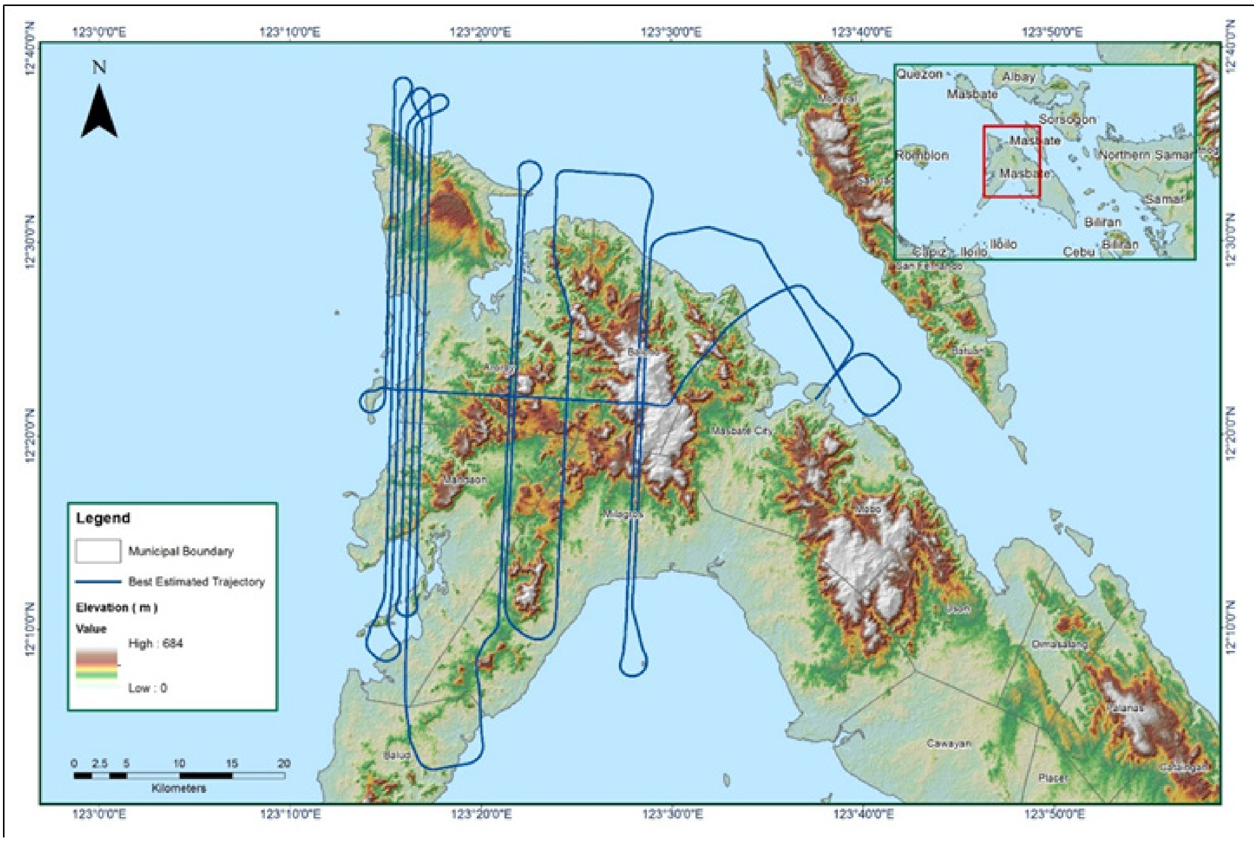


Figure A-8.10. Best Estimated Trajectory

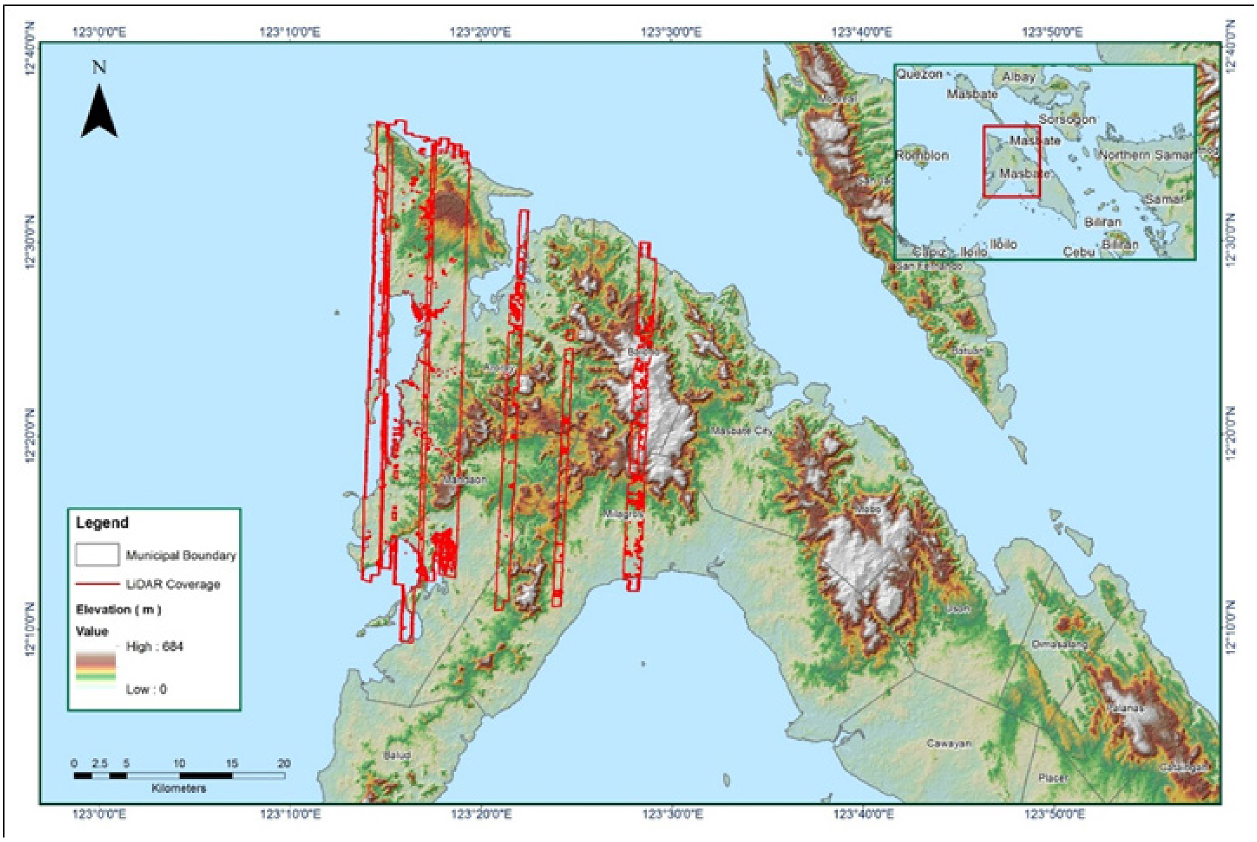


Figure A-8.11. Coverage of LiDAR data

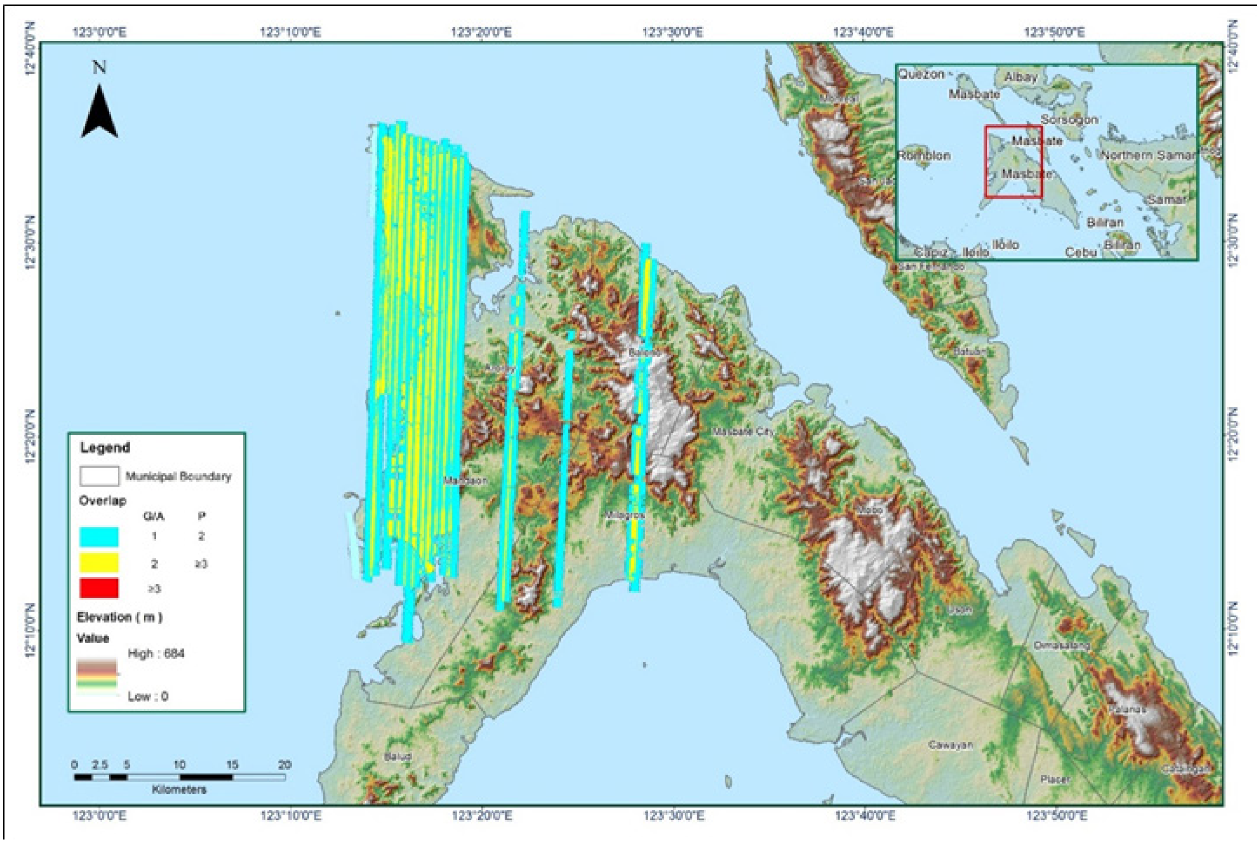


Figure A-8.12. Image of Data Overlap

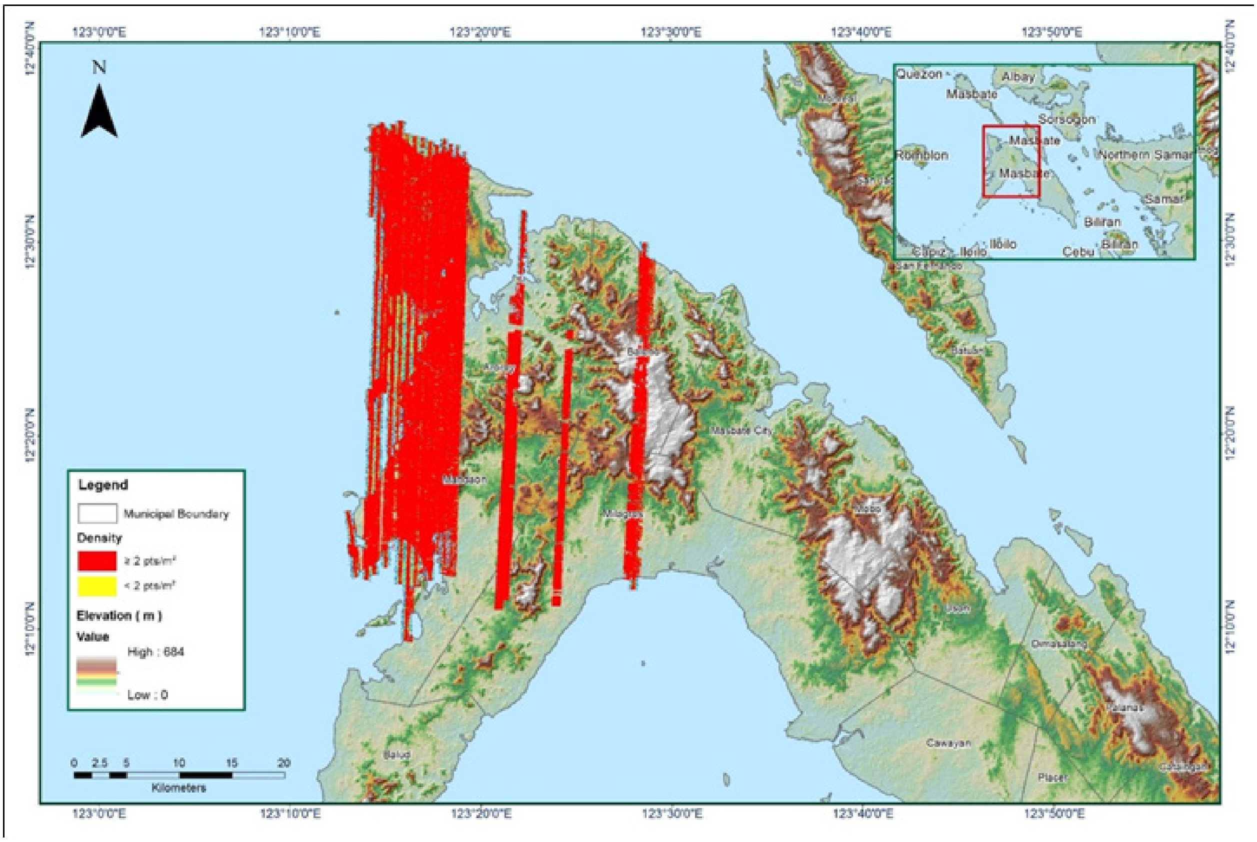


Figure A-8.13. Density map of merged LiDAR data

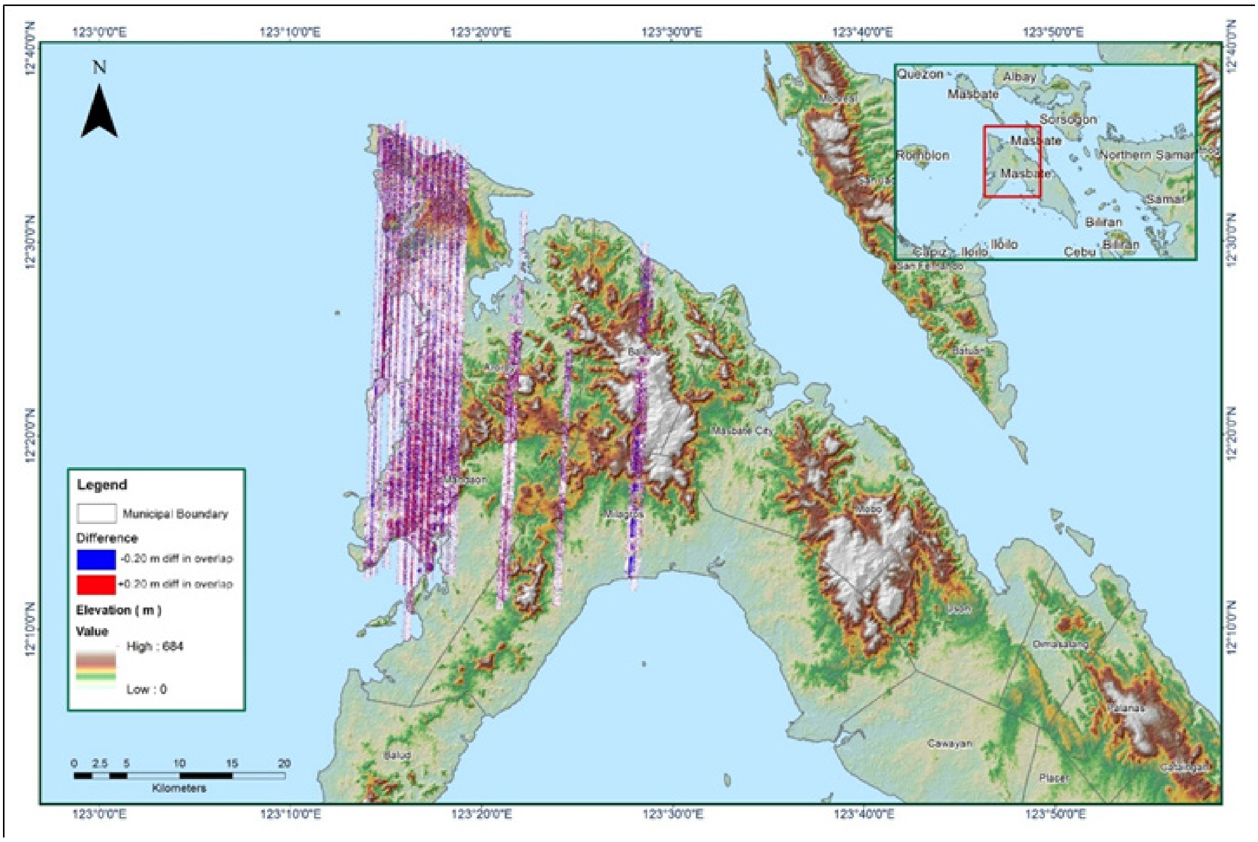


Figure A-8.14. Elevation difference between flight lines

Annex 9. Napayawan Model Basin Parameters

Table A-9.1. Napayawan Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow		
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Recession Constant	Threshold Type	Ratio to Peak
W100	3.30312282		0	3.617249	5.90335	0.5	Ratio to Peak	1
W110	1.89770115	87	0	2.395887	3.910087	0.5	Ratio to Peak	1
W120	1.89770115	87	0	2.716089	4.432658	0.5	Ratio to Peak	1
W130	1.89770115	87	0	3.021932	4.931793	0.5	Ratio to Peak	1
W140	1.89770115	87	0	3.00091	4.897485	0.5	Ratio to Peak	1
W150	1.89770115	87	0	1.893015	3.0894	0.5	Ratio to Peak	1
W160	1.89770115	87	0	2.954856	4.822325	0.5	Ratio to Peak	1
W170	1.89770115	87	0	2.437399	3.977836	0.5	Ratio to Peak	1
W180	1.89770115	87	0	2.469579	4.030353	0.5	Ratio to Peak	1

Annex 10. Napayawan Model Reach Parameters

Table A-10.1. Napayawan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R10	Automatic Fixed Interval	32260	19.90944	0.04	2760.57	30.03	0.005557
R20	Automatic Fixed Interval	22520	11.03197	0.04	1929.12	30.03	0.001926
R30	Automatic Fixed Interval	24420	15.87655	0.04	5159.31	30.03	0.002132
R40	Automatic Fixed Interval	29140	13.40003	0.04	8400.84	30.03	0
R50	Automatic Fixed Interval	25840	9.542285	0.04	3213.92	30.03	0.004441
R60	Automatic Fixed Interval	13340	13.97003	0.04	3747.68	30.03	0.007471
R70	Automatic Fixed Interval	19660	8.947136	0.04	1646.31	30.03	0.006009
R80	Automatic Fixed Interval	17980	10.62159	0.04	2303.17	30.03	0.0046
R90	Automatic Fixed Interval	20200	16.48138	0.04	2214.3	30.03	0.008944

Annex 11. Napayawan Field Validation Points

Table A-11.1. Napayawan Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	12.284805	123.325455	0.03	0	0.03		5-Year
2	12.285025	123.3256367	0.03	0	0.03		5-Year
3	12.284925	123.3256567	0.03	0	0.03		5-Year
4	12.28475333	123.325855	0.03	0	0.03		5-Year
5	12.285145	123.3258083	0.03	0	0.03		5-Year
6	12.28516	123.3258567	0.03	0	0.03		5-Year
7	12.28522333	123.326005	0.06	0	0.06		5-Year
8	12.28531167	123.3261467	0.03	0	0.03		5-Year
9	12.285415	123.32626	0.03	0	0.03		5-Year
10	12.28541167	123.3263417	0.03	0	0.03		5-Year
11	12.28627	123.3274283	0.03	0	0.03		5-Year
12	12.28640333	123.3275483	0.03	0	0.03		5-Year
13	12.28654333	123.3276867	0.03	0	0.03		5-Year
14	12.28672167	123.32775	0.15	0	0.15		5-Year
15	12.28645167	123.32827	0.03	0	0.03		5-Year
16	12.28644333	123.3284483	0.03	0	0.03		5-Year
17	12.287435	123.3290733	0.03	0	0.03		5-Year
18	12.28753833	123.3292783	0.03	0	0.03		5-Year
19	12.287525	123.3293333	0.03	0	0.03		5-Year
20	12.28756667	123.3292833	0.03	0	0.03		5-Year
21	12.28760167	123.3294733	0.04	0	0.04		5-Year
22	12.28753833	123.3294567	0.04	0	0.04		5-Year
23	12.28759167	123.329455	0.04	0	0.04		5-Year
24	12.2878	123.3296917	0.04	0	0.04		5-Year
25	12.28769833	123.3297717	0.03	0	0.03		5-Year
26	12.28766167	123.3298333	0.03	0	0.03		5-Year
27	12.28808667	123.3296383	0.03	0	0.03		5-Year
28	12.28807167	123.3298467	0.03	0	0.03		5-Year
29	12.288175	123.3298917	0.03	0	0.03		5-Year
30	12.288375	123.3300617	0.03	7	-6.97		5-Year
31	12.28854167	123.33033	0.03	0	0.03		5-Year
32	12.28863333	123.33031	0.04	0	0.04		5-Year
33	12.28888	123.3308833	0.07	0	0.07		5-Year
34	12.289155	123.3312183	0.03	0	0.03		5-Year
35	12.28917333	123.331295	0.03	0	0.03		5-Year
36	12.28928333	123.33138	0.03	0	0.03		5-Year
37	12.28953	123.3316267	0.03	0	0.03		5-Year
38	12.289495	123.3316367	0.03	0	0.03		5-Year
39	12.28959667	123.331755	0.03	0	0.03		5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
40	12.29002167	123.3318083	0.03	0	0.03		5-Year
41	12.29020333	123.3315167	0.03	0	0.03		5-Year
42	12.29011667	123.3313867	0.03	0	0.03		5-Year
43	12.29063	123.3311233	0.03	0	0.03		5-Year
44	12.29018333	123.331015	0.03	0	0.03		5-Year
45	12.29002333	123.3311917	0.03	0	0.03		5-Year
46	12.289885	123.3312367	0.03	0	0.03		5-Year
47	12.28988833	123.331245	0.03	0	0.03		5-Year
48	12.28975333	123.33131	0.03	0	0.03		5-Year
49	12.29335167	123.3366783	0.06	0	0.06		5-Year
50	12.293875	123.3374067	0.14	0	0.14		5-Year
51	12.294075	123.3376117	0.03	0	0.03		5-Year
52	12.29410667	123.3376917	0.03	0	0.03		5-Year
53	12.29408833	123.3377117	0.03	0	0.03		5-Year
54	12.29419833	123.3378183	0.03	0	0.03		5-Year
55	12.294195	123.33794	0.03	0	0.03		5-Year
56	12.29430833	123.3379833	0.03	0	0.03		5-Year
57	12.29487	123.338785	0.03	0	0.03		5-Year
58	12.29483	123.3388083	0.03	0	0.03		5-Year
59	12.29470333	123.338945	0.05	0	0.05		5-Year
60	12.29469833	123.3389733	0.05	0	0.05		5-Year
61	12.295025	123.3389533	0.03	0	0.03		5-Year
62	12.29511667	123.339	0.03	0	0.03		5-Year
63	12.295205	123.338935	0.03	0	0.03		5-Year
64	12.29527333	123.3393367	0.03	0.1	-0.07		5-Year
65	12.29543833	123.3394	0.03	0.1	-0.07		5-Year
66	12.29550667	123.33943	0.07	0.1	-0.03		5-Year
67	12.29543667	123.3395533	0.07	0.1	-0.03		5-Year
68	12.29577	123.33975	0.05	0.1	-0.05		5-Year
69	12.295865	123.33996	0.09	0.1	-0.01		5-Year
70	12.29576167	123.3401517	0.15	0.1	0.05		5-Year
71	12.29561167	123.3403667	0.03	0.1	-0.07		5-Year
72	12.295445	123.3405883	0.03	0	0.03		5-Year
73	12.29536333	123.3406783	0.03	0	0.03		5-Year
74	12.29527	123.3407733	0.03	0	0.03		5-Year
75	12.29518167	123.340865	0.03	0	0.03		5-Year
76	12.29521	123.340875	0.03	0	0.03		5-Year
77	12.295025	123.3410883	0.03	0	0.03		5-Year
78	12.29499833	123.3410617	0.03	0	0.03		5-Year
79	12.27884	123.3608433	0	0.1	-0.1		5-Year
80	12.29613333	123.3409783	0.03	0.1	-0.07		5-Year
81	12.29607833	123.3409	0.03	0.1	-0.07		5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
82	12.29613667	123.34095	0.03	0.1	-0.07		5-Year
83	12.29599167	123.3411317	0.03	0.1	-0.07		5-Year
84	12.29631167	123.3411717	0.03	0.1	-0.07		5-Year
85	12.296345	123.3414783	0.03	0.1	-0.07		5-Year
86	12.29660833	123.34094	0.03	0	0.03		5-Year
87	12.29658333	123.340865	0.03	0	0.03		5-Year
88	12.30220667	123.335805	0.03	0	0.03		5-Year
89	12.30087333	123.337325	0.03	0	0.03		5-Year
90	12.30083	123.337615	0.03	0	0.03		5-Year
91	12.30097167	123.3375583	0.03	0	0.03		5-Year
92	12.30083	123.33739	0.03	0	0.03		5-Year
93	12.3006	123.3376133	0.03	0	0.03		5-Year
94	12.300465	123.3376417	0.03	0	0.03		5-Year
95	12.30045167	123.33766	0.03	0	0.03		5-Year
96	12.30042167	123.3377433	0.03	0	0.03		5-Year
97	12.30034667	123.3377917	0.03	0	0.03		5-Year
98	12.30023167	123.3378617	0.03	0	0.03		5-Year
99	12.30022667	123.3379233	0.03	0	0.03		5-Year
100	12.30018667	123.3379867	0.03	0	0.03		5-Year
101	12.29902333	123.3390083	0.03	0	0.03		5-Year
102	12.29874667	123.3391767	0.03	0	0.03		5-Year
103	12.29875667	123.33932	0.03	0	0.03		5-Year
104	12.298475	123.3394183	0.03	0	0.03		5-Year
105	12.29839833	123.3395333	0.03	0	0.03		5-Year
106	12.2981	123.3400117	0.03	0	0.03		5-Year
107	12.29773833	123.3403333	0.03	0	0.03		5-Year
108	12.29764333	123.3403767	0.03	0	0.03		5-Year
109	12.29755	123.34046	0.03	0	0.03		5-Year
110	12.29734167	123.3405017	0.03	0	0.03		5-Year
111	12.297195	123.3406067	0.03	0	0.03		5-Year
112	12.29709833	123.3406367	0.04	0	0.04		5-Year
113	12.28526391	123.3251865	0.04	0	0.04		5-Year
114	12.28512287	123.3252378	0.03	0.4	-0.37		5-Year
115	12.28516122	123.3253651	0.03	0.02	0.01		5-Year
116	12.2848471	123.325258	0.03	0	0.03		5-Year
117	12.28512622	123.3255802	0.04	0	0.04		5-Year
118	12.28501349	123.3255811	0.03	0	0.03		5-Year
119	12.28506318	123.3256622	0.03	0	0.03		5-Year
120	12.28513926	123.3257916	0.03	0	0.03		5-Year
121	12.28627587	123.3272537	0.03	0	0.03		5-Year
122	12.28634908	123.3273511	0.03	0	0.03		5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
123	12.28673924	123.3278983	0.08	0	0.08		5-Year
124	12.28720791	123.3286063	0.03	0	0.03		5-Year
125	12.28722969	123.3285683	0.05	0	0.05		5-Year
126	12.28749591	123.3288097	0.03	0	0.03		5-Year
127	12.28749354	123.3288079	0.03	0	0.03		5-Year
128	12.28754973	123.3289623	0.03	0	0.03		5-Year
129	12.28772677	123.3291639	0.03	0	0.03		5-Year
130	12.28881841	123.3286428	0.03	0	0.03		5-Year
131	12.28848446	123.3288563	0.03	0	0.03		5-Year
132	12.28814058	123.3290952	0.03	0	0.03		5-Year
133	12.28796847	123.3292136	0.03	0	0.03		5-Year
134	12.28783131	123.3292761	0.03	0	0.03		5-Year
135	12.28802658	123.3296177	0.03	0	0.03		5-Year
136	12.2881424	123.329766	0.03	0	0.03		5-Year
137	12.28845156	123.3301719	0.03	0	0.03		5-Year
138	12.29051826	123.3327583	0.03	0	0.03		5-Year
139	12.29061299	123.33302	0.03	0	0.03		5-Year
140	12.29129617	123.3339962	0.03	0	0.03		5-Year
141	12.29163646	123.3342412	0.03	0	0.03		5-Year
142	12.29166298	123.3343815	0.03	0	0.03		5-Year
143	12.29190077	123.3347126	0.03	0	0.03		5-Year
144	12.29194575	123.3347563	0.03	0	0.03		5-Year
145	12.29197753	123.3347904	0.03	0	0.03		5-Year
146	12.29207604	123.3349247	0.03	0	0.03		5-Year
147	12.29219354	123.3350461	0.03	0	0.03		5-Year
148	12.2922069	123.3350619	0.03	0	0.03		5-Year
149	12.29224294	123.3351453	0.03	0	0.03		5-Year
150	12.2924374	123.335332	0.03	0	0.03		5-Year
151	12.29195837	123.3349391	0.03	0	0.03		5-Year
152	12.29342638	123.3366332	0.05	0	0.05		5-Year
153	12.29456006	123.3383187	0.03	0	0.03		5-Year
154	12.29451414	123.3382902	0.03	0	0.03		5-Year
155	12.29462412	123.3384276	0.03	0	0.03		5-Year
156	12.29469854	123.33852	0.03	0	0.03		5-Year
157	12.29498909	123.3388242	0.03	0	0.03		5-Year
158	12.29517434	123.3387667	0.03	0	0.03		5-Year
159	12.29519808	123.3387618	0.03	0	0.03		5-Year
160	12.29516518	123.3390146	0.03	0.1	-0.07		5-Year
161	12.2953334	123.33925	0.03	0.1	-0.07		5-Year
162	12.29554902	123.3395336	0.04	0	0.04		5-Year
163	12.29562018	123.3396584	0.03	0	0.03		5-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
164	12.29576916	123.3398328	0.06	0	0.06		5-Year
165	12.29576695	123.3398354	0.06	0	0.06		5-Year
166	12.2958271	123.3400028	0.12	0	0.12		5-Year
167	12.29592797	123.3400137	0.04	0	0.04		5-Year
168	12.29596715	123.3401261	0.04	0	0.04		5-Year
169	12.29600704	123.340173	0.03	0	0.03		5-Year
170	12.29556684	123.3405194	0.06	0	0.06		5-Year
171	12.29551086	123.340621	0.03	0	0.03		5-Year
172	12.2954285	123.3407232	0.03	0	0.03		5-Year
173	12.29531714	123.3408341	0.03	0	0.03		5-Year
174	12.29498664	123.3412046	0.03	0	0.03		5-Year
175	12.2948978	123.3412951	0.03	0	0.03		5-Year
176	12.29603019	123.3402549	0.03	0	0.03		5-Year
177	12.29623749	123.3404365	0.03	0	0.03		5-Year
178	12.29625204	123.3404772	0.03	0	0.03		5-Year
179	12.29626078	123.3405149	0.03	0	0.03		5-Year
180	12.29632713	123.3405489	0.03	0	0.03		5-Year
181	12.29632703	123.3405571	0.03	0	0.03		5-Year
182	12.29632113	123.3406229	0.03	0	0.03		5-Year
183	12.29642334	123.3406792	0.03	0	0.03		5-Year
184	12.30221672	123.3357428	0.03	0	0.03		5-Year
185	12.30221755	123.3357435	0.03	0	0.03		5-Year
186	12.30222517	123.3360392	0.03	0	0.03		5-Year
187	12.30222	123.3360386	0.03	0	0.03		5-Year
188	12.30195276	123.3363643	0.03	0	0.03		5-Year
189	12.3018551	123.3364292	0.03	0	0.03		5-Year
190	12.30173592	123.3366321	0.03	0	0.03		5-Year
191	12.30163102	123.3370625	0.03	0	0.03		5-Year
192	12.30014492	123.3380373	0.03	0	0.03		5-Year
193	12.29999306	123.3381499	0.03	0	0.03		5-Year
194	12.30005337	123.3381938	0.03	0	0.03		5-Year
195	12.29993438	123.3382424	0.03	0	0.03		5-Year
196	12.29988608	123.3382414	0.03	0	0.03		5-Year
197	12.29980721	123.3382864	0.03	0	0.03		5-Year
198	12.29973413	123.3383672	0.03	0	0.03		5-Year
199	12.2996416	123.3383742	0.03	0	0.03		5-Year
200	12.29955929	123.3385161	0.03	0	0.03		5-Year
201	12.29681089	123.3412033	0.03	0	0.03		5-Year

Annex 12. Educational Institutions affected by flooding in Napayawan Floodplain

Table A-12.1. Educational Institutions in Mandaon, Masbate affected by flooding in Napayawan Floodplain

Masbate				
Mandaon				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Bugtong Elementary School Mandaon	Bugtong			
Bugtong High School Mandaon	Bugtong			
Cabitan Elementary School Mandaon	Cabitan			
Cabitan National High School Mandaon	Dayao			

Annex 13. Health Institutions affected by flooding in Napayawan Floodplain

Table A-13.1. Health Institutions in Mandaon, Masbate affected by flooding in Napayawan Floodplain

Masbate				
Mandaon				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Bugtong Health Center Mandaon	Bugtong	Low	Medium	Medium
Cabitan Health Center Mandaon	Cabitan			