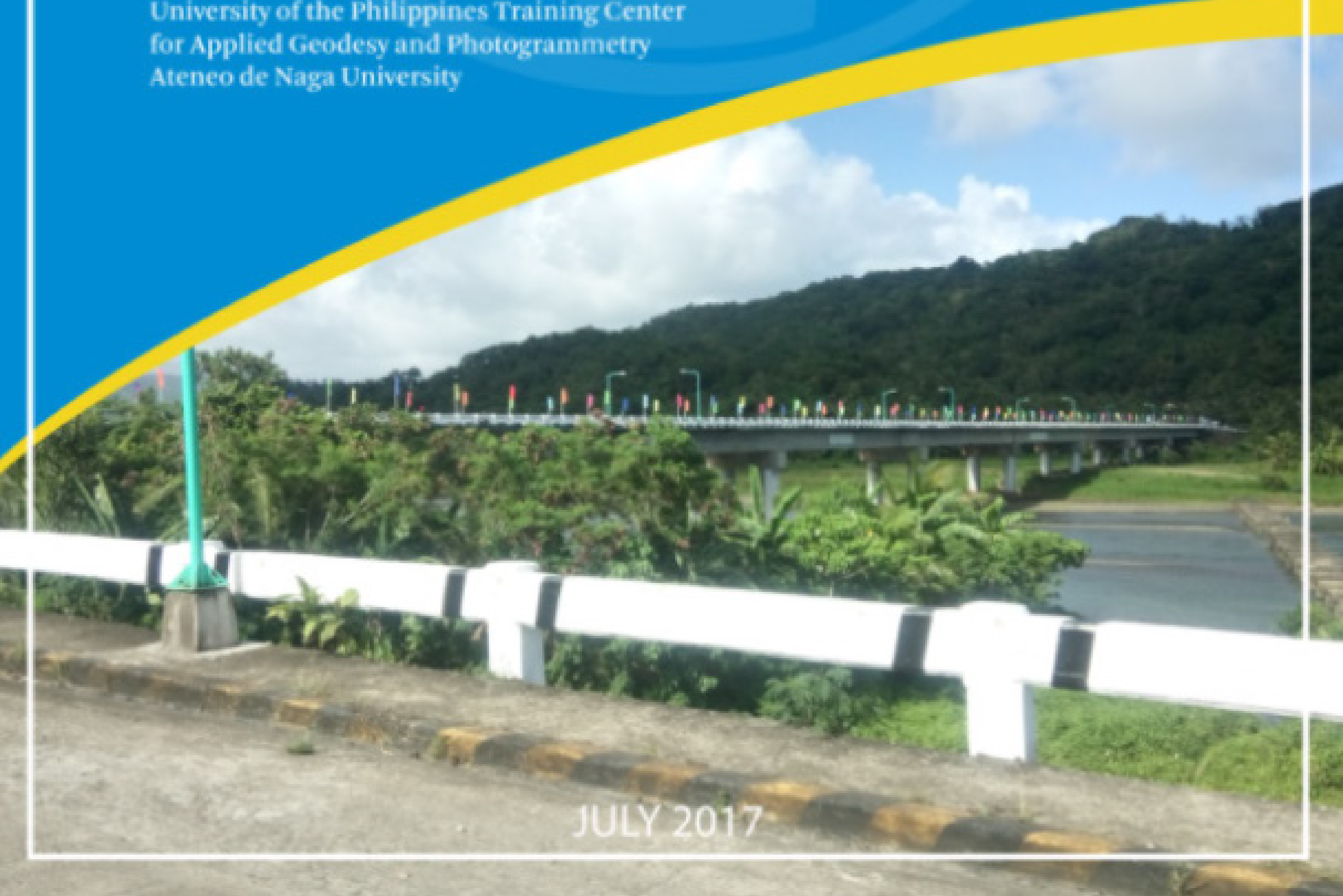
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

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

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the 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 Bato River Basin

This river basin is under six (6) different municipalities in Catanduanes, namely: Baras, Bato, Caramoran, Gigmoto, San Miguel, and Viga. Four (4) of these municipalities are fifth class: Gigmoto, Baras, Bato and San Miguel. Viga is a fourth class and Caramoran is a third-class municipality. Based on the 2015 census, the population of these municipalities are as follow: Bato – 21,279, San Miguel - 15,006, Gigmoto – 8,368, Baras – 12,848, Viga – 21,624 and Caramoran with 30,056. According to DENR River Basin Control Office, it has a drainage area of 305 km2 and an estimated annual run-off of 413 million cubic meter (MCM) (RBCO, 2015).

Bato River empties this basin out to Cabugao Bay the same as Pajo River. This basin is actually east of the Mts. Howayon, Pacogon and Lantad. This is a very extensive river basin as it extends well into the interior of the island of Catanduanes. The Catanduanes Watershed Forest Reserve is also in this area which includes the towns of Virac, Bato, San Miguel, Pandan, Calolbon and Baras.

As an area under Type II climate, this river basin experiences pronounced rains from November to April and wet the rest of the year.

Its main stem, Bato River is part of the 24 river systems under the PHIL-LiDAR 1 partner HEI, Ateneo de Naga University.

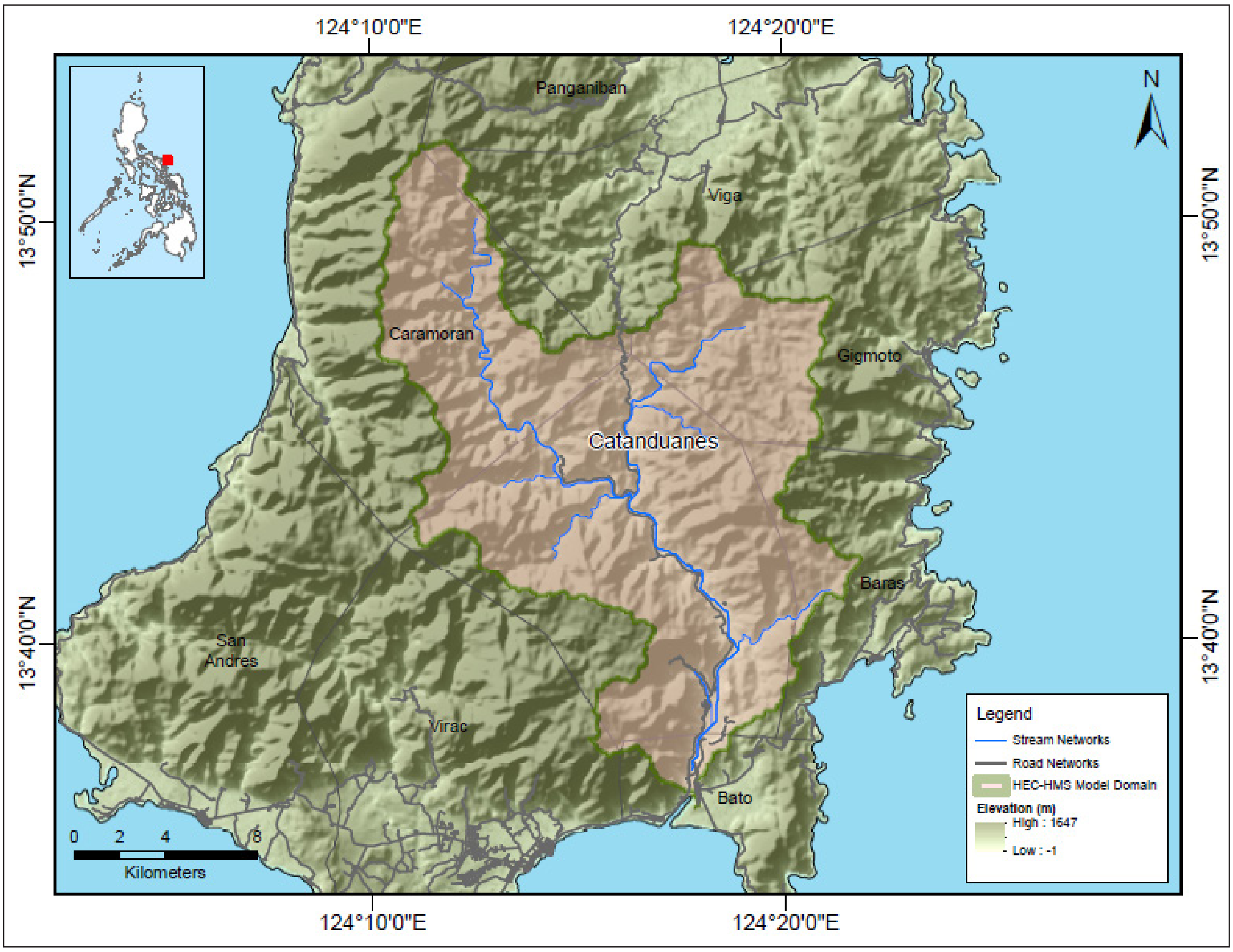

Figure 1. Map of the Bato River Basin (in brown)

Agriculture and fishing are the major industries in the area. Also, the best variety abaca fiber is produced in Bato. Tourism is also being pushed in the area. Binurong Point in Baras, Catanduanes is being touted as the Island's counterpart for Batanes or Ireland even. Some other tourist attraction includes Palumbanes islands in Caramoran at the northwestern part of Catanduanes.

The most recent and significant flooding in the area was on November 2006 cause by Typhoon Durian "Reming" (http://www.gmanetwork.com/news/story/22508/news/nation/typhoon-reming-moves-out-of-rp-55-killed-in-albay, 2006)

CHAPTER 2: LIDAR DATA ACQUISITION OF THE BATO FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Bato floodplain in Catanduanes. These missions were planned for 16 lines that run for at most four (4) 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 for Bato floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR System.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK25A	1000	20	50	200	30	130	5
BLK25B	1000	20	50	200	30	130	5
BLK25C	1000	20	50	200	30	130	5
BLK25D	1000	30	50	200	30	130	5
BLK25H	1000	20	50	200	30	130	5

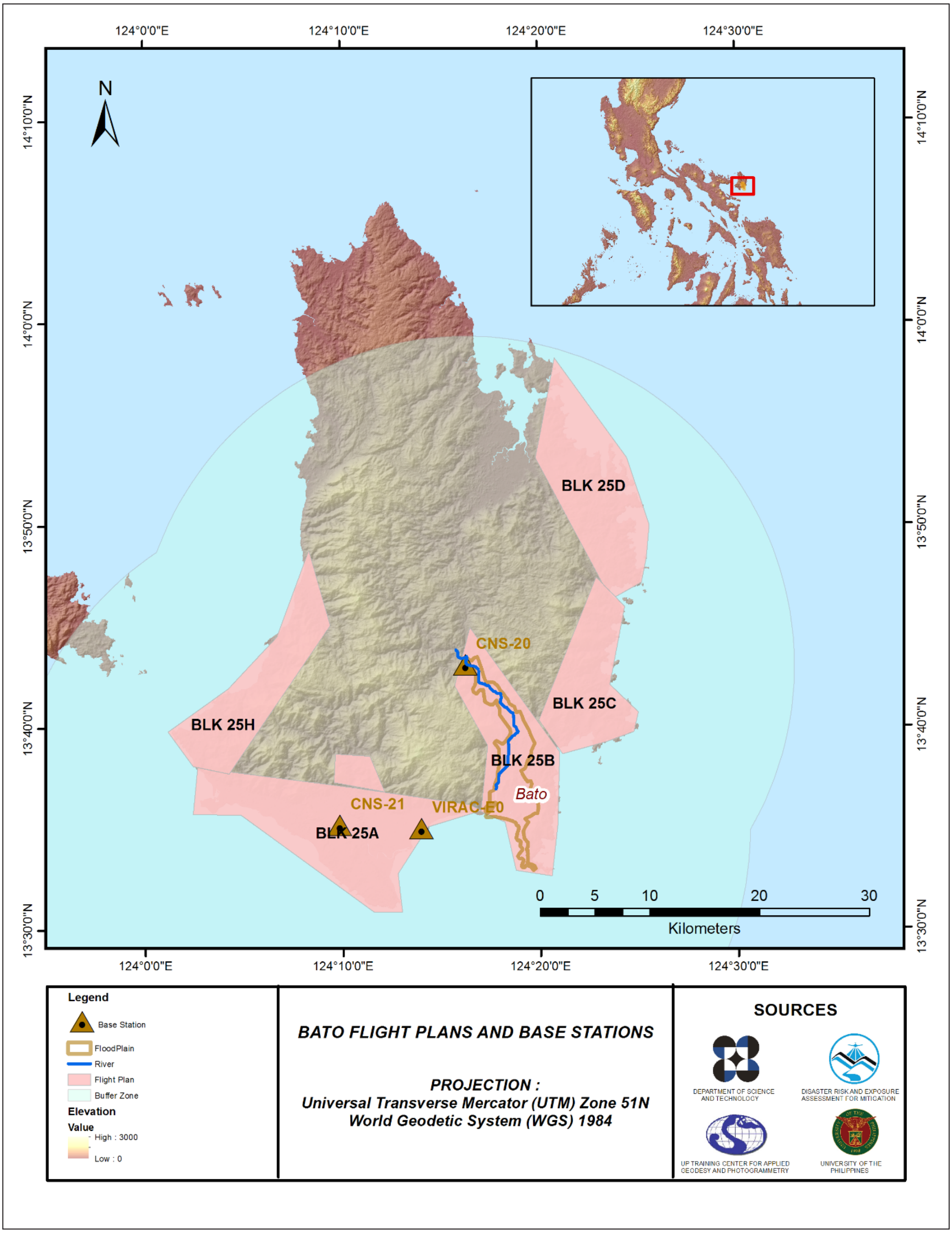

Figure 2. Flight plan and base stations used for Bato floodplain

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA horizontal ground control points: CNS-20 and CNS-21 which are of second (2nd) order accuracy. The team also established one (1) base station, VIRAC-E0. The certifications for the NAMRIA reference points are found in Annex 2, while the processing reports for the established ground control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (January 20 – February 4, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 985 and TOPCON GR5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Bato 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 NAMRIA reference points and established control point while Table 5 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization

(a) (b)

Figure 3. GPS set-up over CNS-21 at Palta Bridge, barangay Palta Small, Virac along Circumferential Road (a) and NAMRIA reference point CNS-21(b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point CNS-21 used as base station for the LiDAR acquisition.

Station Name	CNS-21	
Order of Accuracy	2^{nd}	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	13° 35' 14.37180" North
	Longitude	124° 9' 45.40531" East
	Ellipsoidal Height	83.10600 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting	625,825.638 m
	Northing	1,502,820.29m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	13° 35' 9.45275" North
	Longitude	124° 9' 50.36457" East
	Ellipsoidal Height	137.19500 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	625,781.60 m
	Northing	1,502,294.28 m

(a) (b)

Figure 4. GPS set-up over CNS-20 located at Malmag bridge along circumferential road at Barangay Pagsangahan (a) and NAMRIA reference point CNS-20 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point CNS-20 used as base station for the LiDAR acquisition.

Station Name	CNS-20	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	13° 43' 8.77572" North
	Longitude	124° 16' 9.57152" East
	Ellipsoidal Height	43.752 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting	637,300.168 meters
	Northing	1,517,459.029 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	13° 43' 3.83355" North
	Longitude	124° 16' 14.51857" East
	Ellipsoidal Height	97.736 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	637,252.11 meters
	Northing	1,516,927.89 meters

Figure 5. GPS set-up over established control point VIRAC-E0 at Barangay Palta Small, Virac Catanduanes.

Table 4. Table 4. Details of the established horizontal control point VIRAC-E0 used as base station for the LiDAR acquisition.

Station Name	VIRAC-E0	
Order of Accuracy	2^{nd}	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	13°35'03.52757" North
	Longitude	124°13'53.85198" East
	Ellipsoidal Height	4.565 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	13°34'58.61487" North
	Longitude	124°13'58.81098" East
	Ellipsoidal Height	58.830 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	633,250.707 meters
	Northing	1,501,997.753 meters

Table 5. Ground control points using LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
January 22, 2016	3010P	1BLK25A022A	CNS-21, VIRAC-E0
January 23, 2016	3012P	1BLK25B023A	CNS-20, CNS-21
January 23, 2016	3014P	1BLK25BC023B	CNS-20, CNS-21
January 24, 2016	3016P	1BLK25E024A	CNS-20, CNS-21

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Bato floodplain, for a total of thirteen hours and thirty-eight (13+38) minutes of flying time for RP-C9122. All missions were acquired using the Pegasus LiDAR system. 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 LiDAR data acquisition in Bato floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within Floodplain (km^2)	Area Surveyed Outside Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
January 22, 2016	3010P	256.29	167.89	37.91	129.98	NA	4	5
January 23, 2016	3012P	354.97	164.79	16.92	147.87	426	4	5
January 23, 2016	3014P	304.52	98.97	25.98	72.99	NA	2	47
January 24, 2016	3016P	352.55	123.14	11.43	111.71	NA	2	41
TOTAL		1268.33	554.79	92.24	462.55	426	13	38

Table 7. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (Hz)	Scan Frequency (kHz)	Average Speed (kts)	Average Turn Time (Minutes)
3010P	1000	20	50	200	30	110-130	5
3012P	1000	20	50	200	30	110-130	5
3014P	1000	20	50	200	30	110-130	5
3016P	1000	20	50	200	30	110-130	5

2.4 Survey Coverage

Bato floodplain is located in the province of Catanduanes and is situated within municipalities of Bato and San Miguel. Municipality of Bato is mostly covered by the survey. The list of municipalities surveyed, with at least one (1) square kilometer coverage, is shown in Table 8. In Figure 6, the actual coverage of the LiDAR acquisition for Bato floodplain is shown.

Table 8. List of municipalities and cities surveyed during Bato floodplain LiDAR survey.

Province	Municipality/ City	Area of Municipality/ City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Catanduanes	Bato	41.79	45.83	91%
	San Andres	111.97	172.88	65%
	Virac	110.76	175.30	63%
	Baras	33.28	75.39	44%
	San Miguel	58.90	174.25	34%
	Gigmoto	18.55	117.46	16%
	Viga	11.57	158.74	7%
	Caramoran	11.84	266.80	4%
TOTAL		398.66	1186.65	297.66%

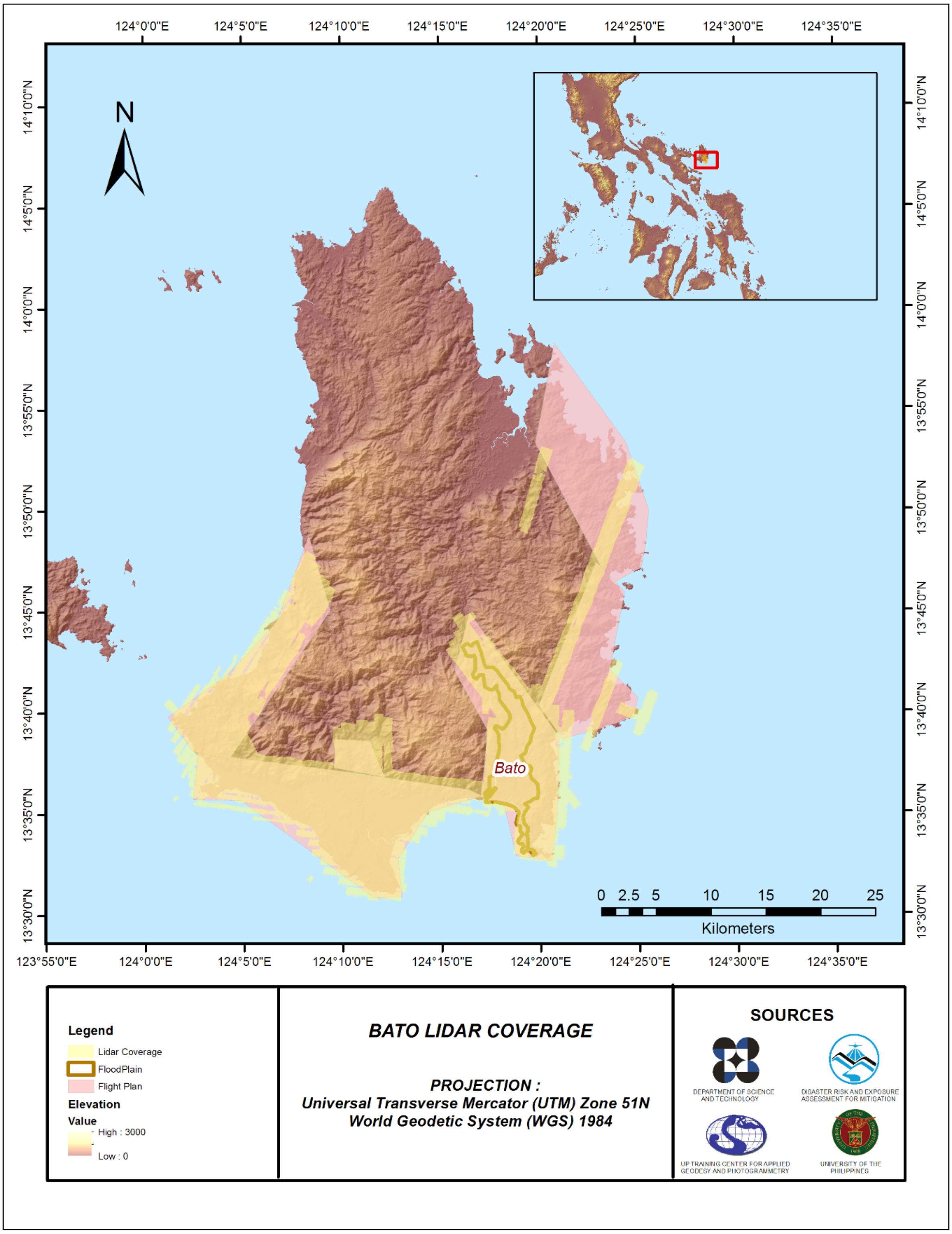

Figure 6. Actual LiDAR data acquisition for Bato floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE BATO 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.

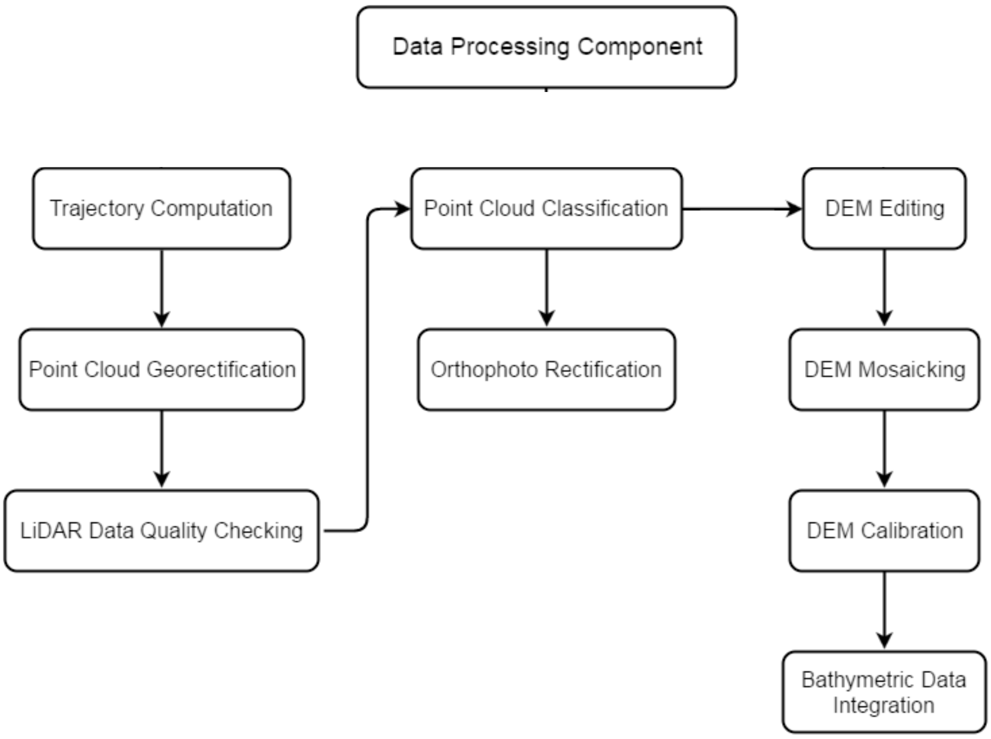


Figure 7. Schematic Diagram for Data Pre-Processing Component

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.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Bato floodplain can be found in Annex A-5. Data Transfer Sheets. Missions flown during the survey conducted on January 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Bato, Catanduanes. The Data Acquisition Component (DAC) transferred a total of 76.38 Gigabytes of Range data, 939 Megabytes of POS data, 407.6 Megabytes of GPS base station data, and 31.4 Gigabytes of raw image data to the data server on January 23, 2016 for the survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Bato was fully transferred on February 12, 2016, as indicated on the Data Transfer Sheets for Bato floodplain.

3.3 Trajectory Computation

The *Smoothed Performance Metric* parameters of the computed trajectory for flight 3012P, one of the Bato 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 January 23, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

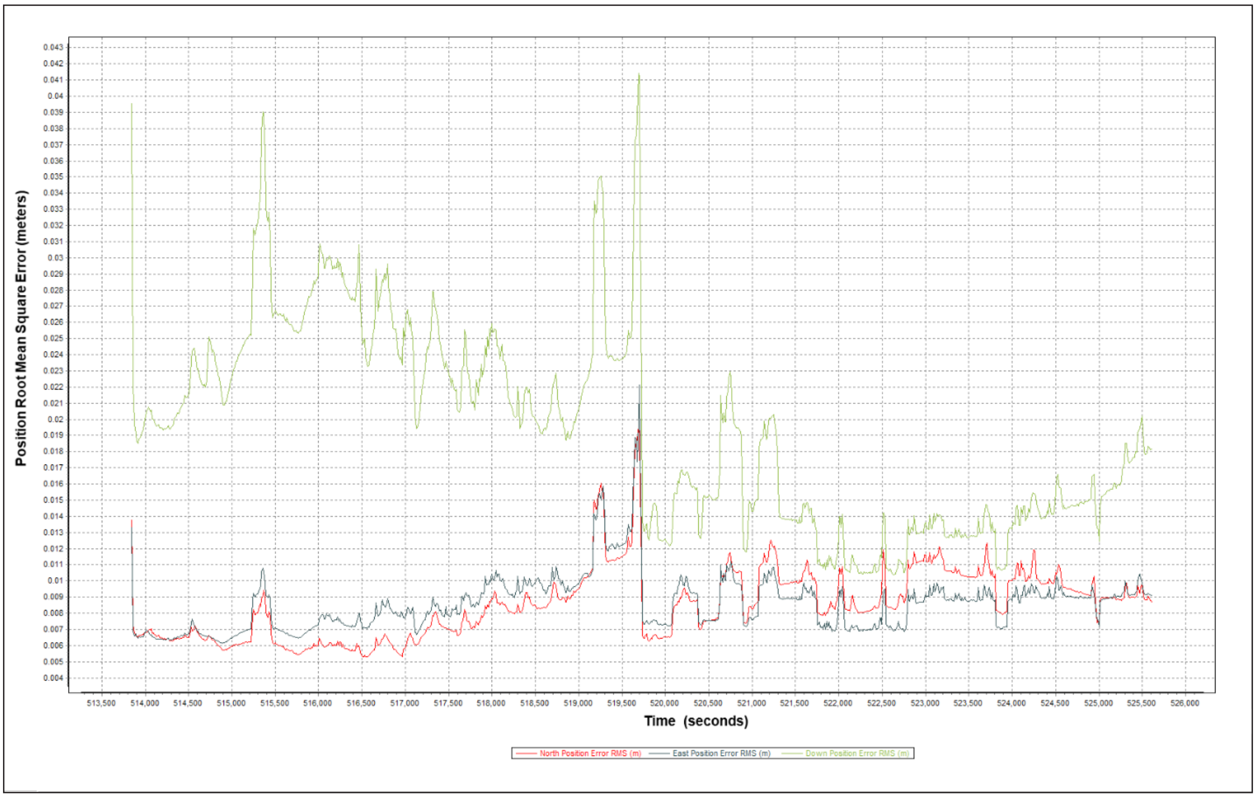


Figure 8. Smoothed Performance Metric Parameters of a Bato Flight 3012P.

The time of flight was from 513500 seconds to 525500 seconds, which corresponds to morning of January 23, 2016. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimize the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8 shows that the North position RMSE peaks at 2.0 centimeters, the East position RMSE peaks at 2.20 centimeters, and the Down position RMSE peaks at 4.10 centimeters, which are within the prescribed accuracies described in the methodology.

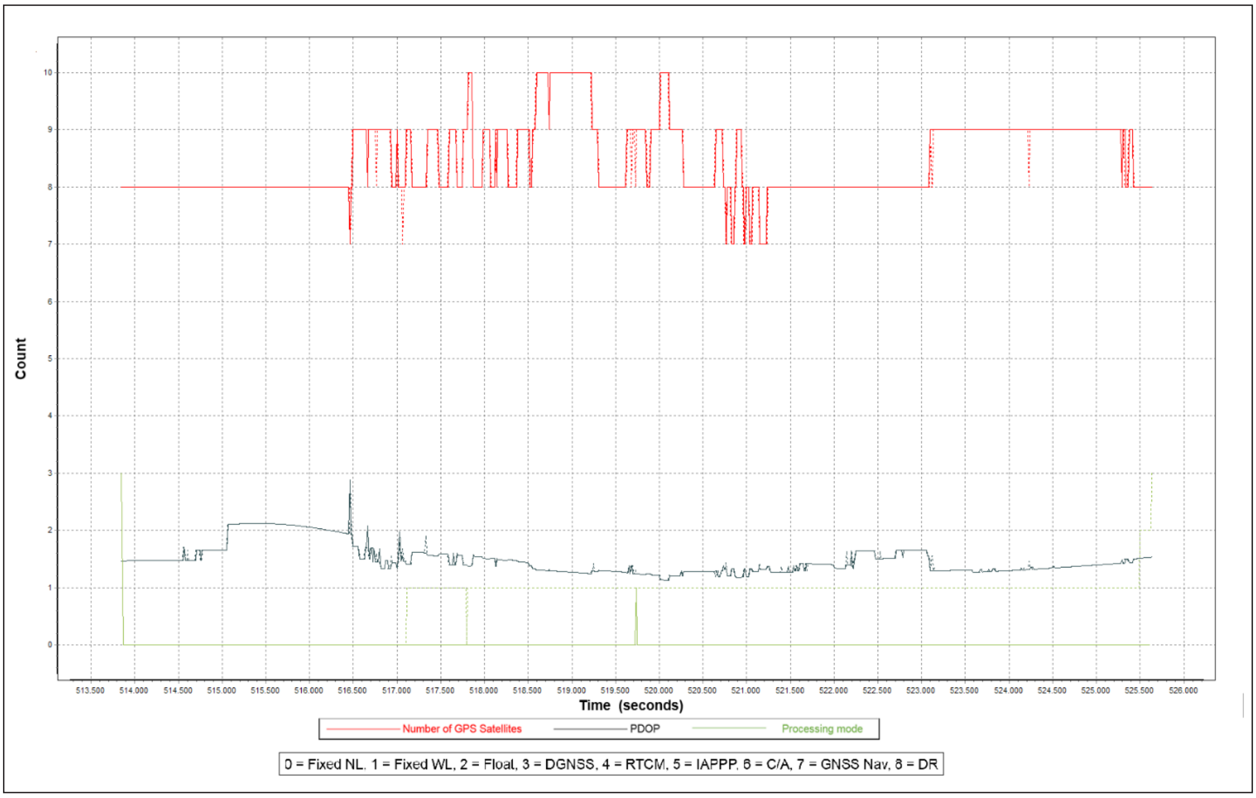


Figure 9. Solution Status Parameters of Bato Flight 3012P.

The *Solution Status* parameters of flight 3012P, one of the Bato flights, which are the number of GPS satellites, Positional Dilution of Precision, 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. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 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 Bato flights is shown in Figure 10.

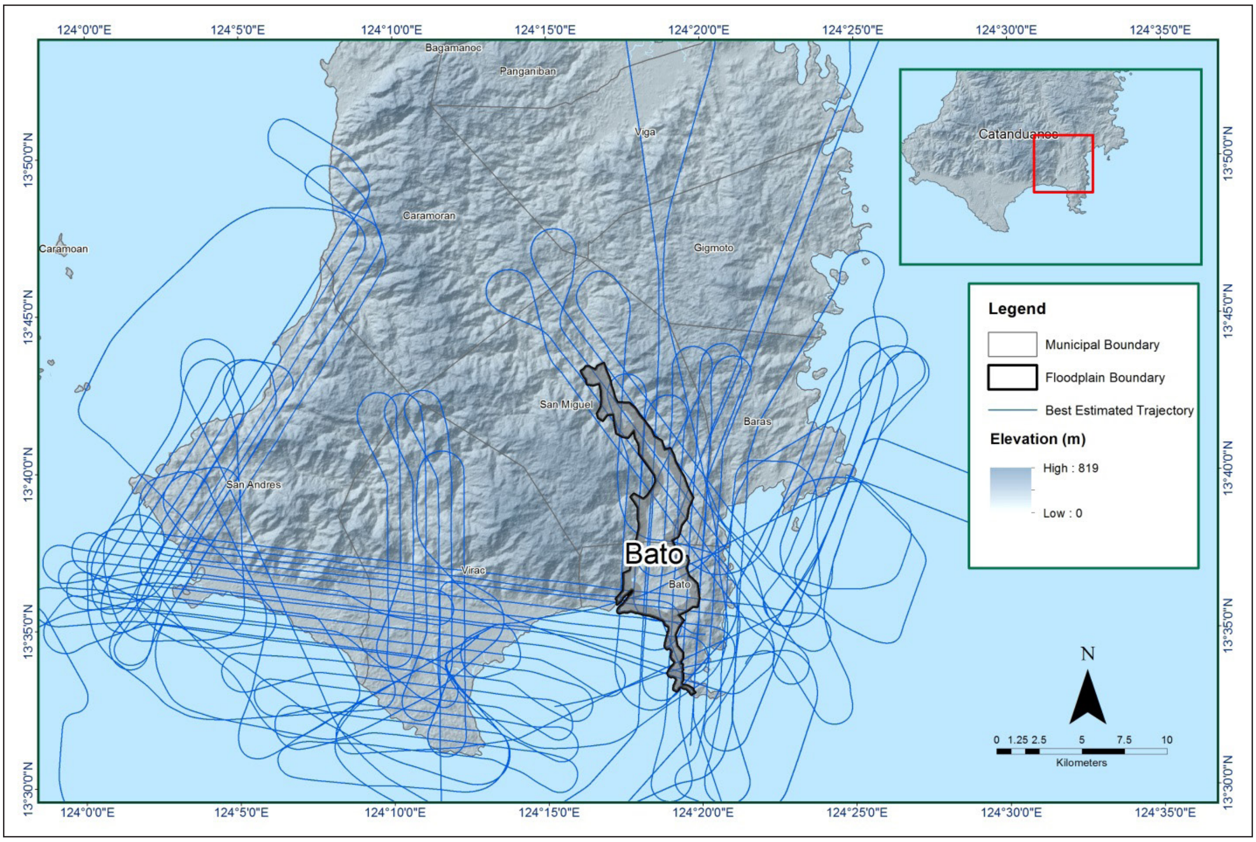


Figure 10. Best Estimated Trajectory for Bato floodplain.

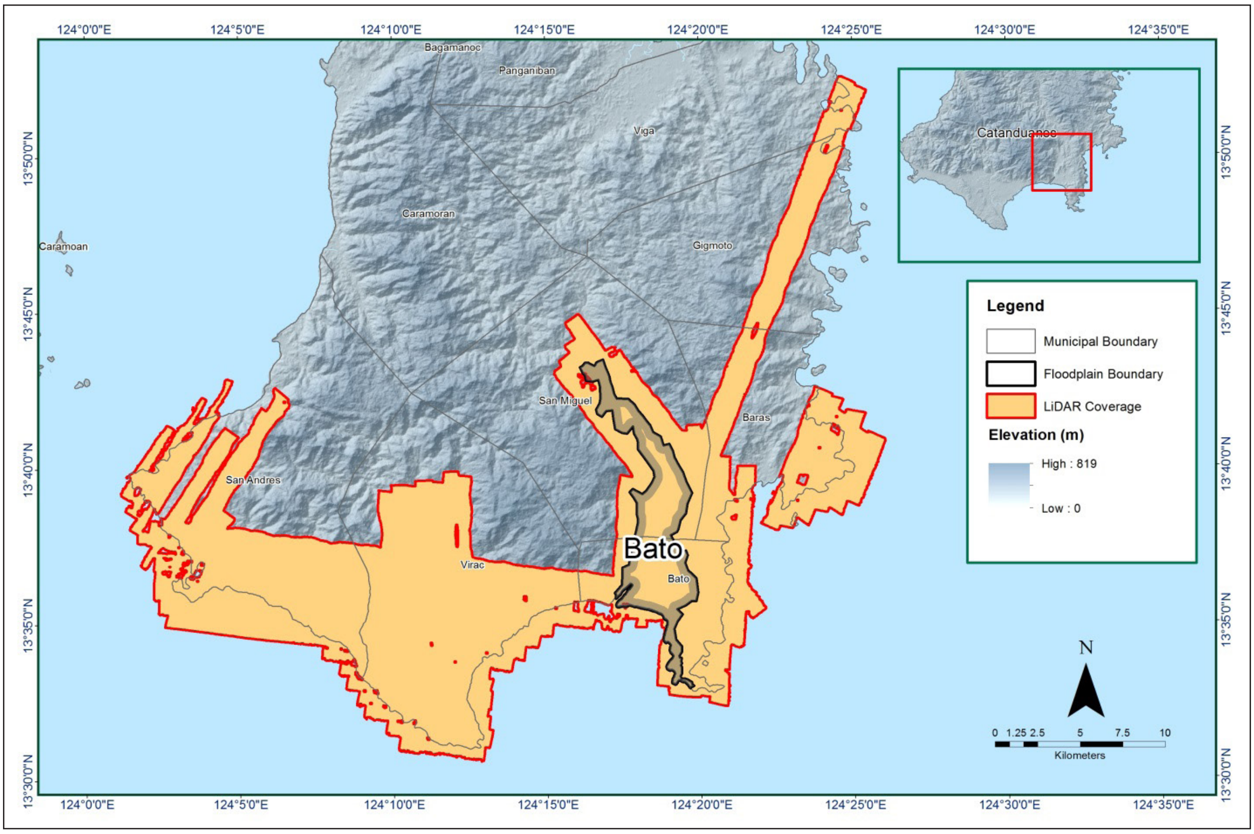


Figure 11. Boundary of the processed LiDAR data over Bato Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 70 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 Bato floodplain are given in Table 9.

Table 9. Self-Calibration Results values for Bato flights.

Parameter	Value
Boresight Correction stdev (<0.001degrees)	0.000504
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.001092
GPS Position Z-correction stdev (<0.01meters)	0.0023

The optimum accuracy is obtained for all Bato flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex B-1. Mission Summary Reports.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Bato Floodplain is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

The total area covered by the Bato missions is 576.03 sq.km that is comprised of five (5) flight acquisitions grouped and merged into six (6) blocks as shown in Table 10.

Table 10. List of LiDAR blocks for Bato floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Catanduanes_Blk25C	3012P	72.07
	3014P	
	3028P	
Catanduanes_Blk25B	3014P	74.04
	3016P	
Catanduanes_Blk25B_supplement	3012P	83.46
Catanduanes_Blk25A	3012P	148.23
	3028P	
Catanduanes_Blk25A_supplement	3012P	97.62
Catanduanes_Blk25H_additional	3016P	100.62
TOTAL		576.03 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.

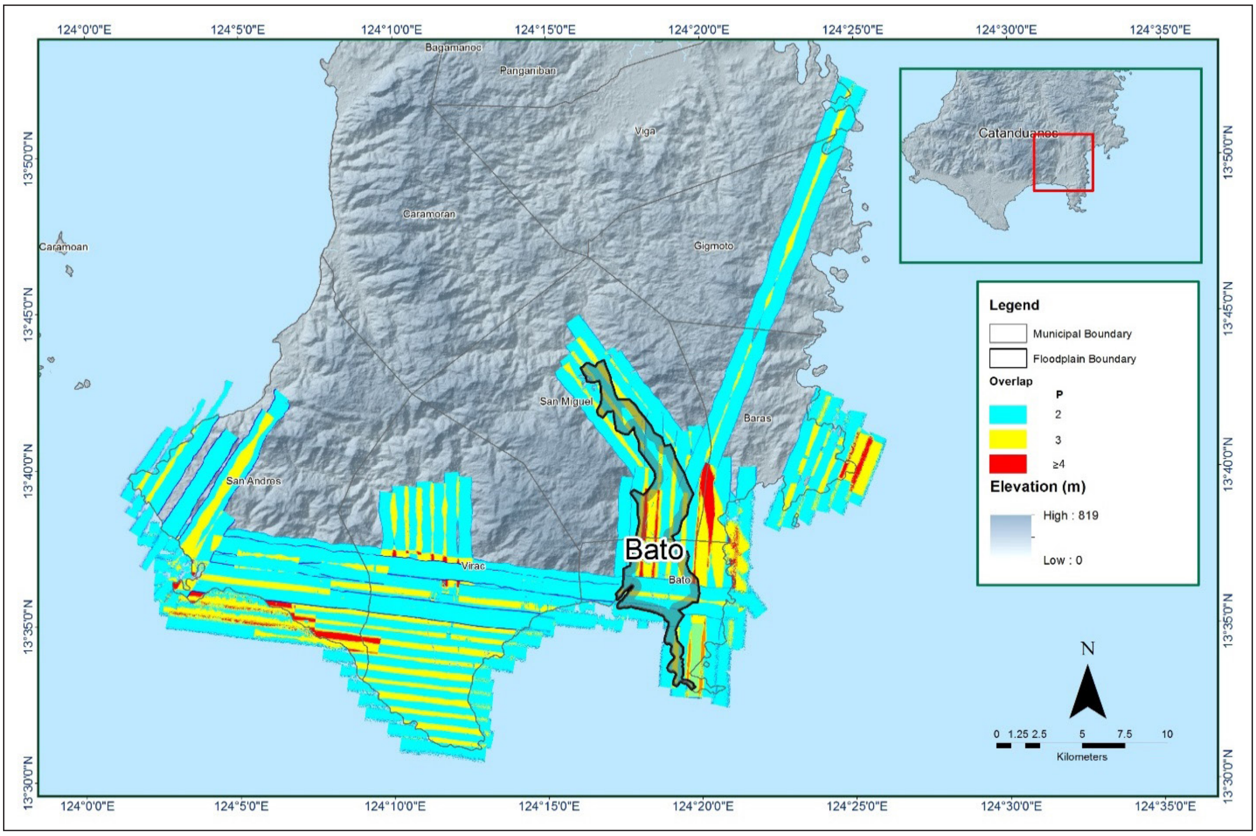


Figure 12. Image of data overlap for Bato floodplain.

The overlap statistics per block for the Bato floodplain can be found in Annex B-1. Mission Summary Reports. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 25.58% and 45.24% respectively, which passed the 25% requirement.

The 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 Bato floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.20 points per square meter.

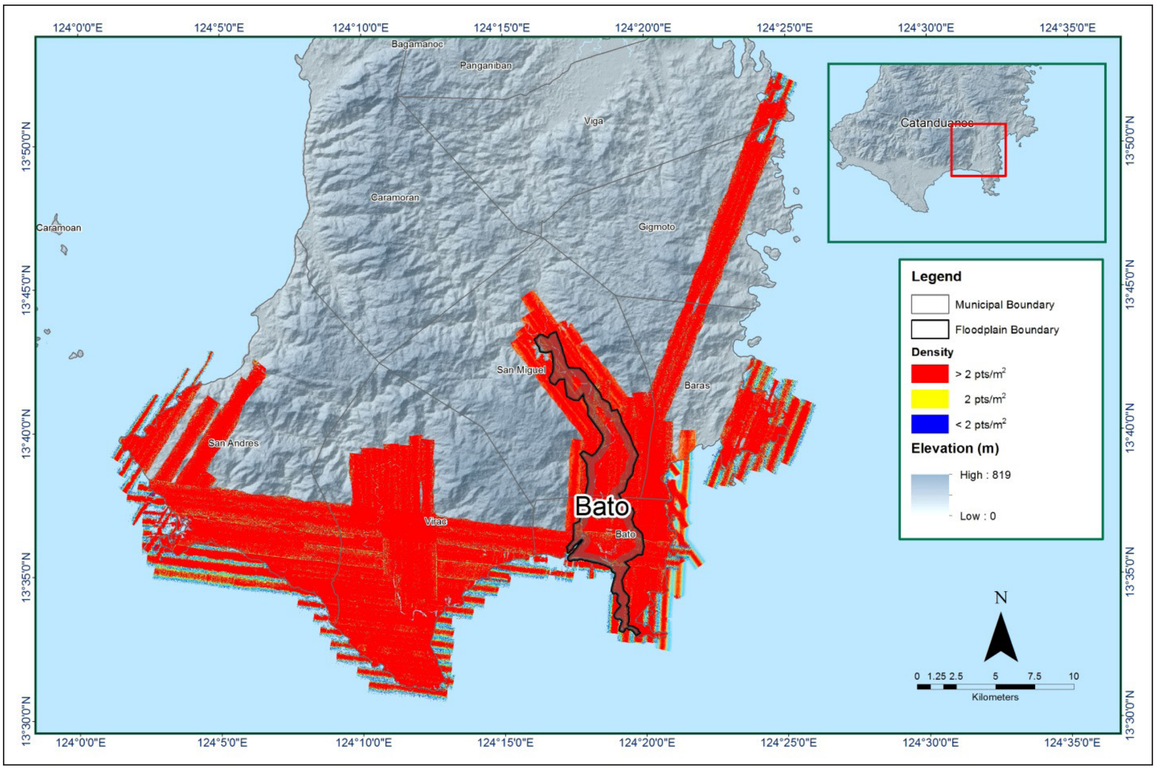


Figure 13. Density map of merged LiDAR data for Bato floodplain.

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.

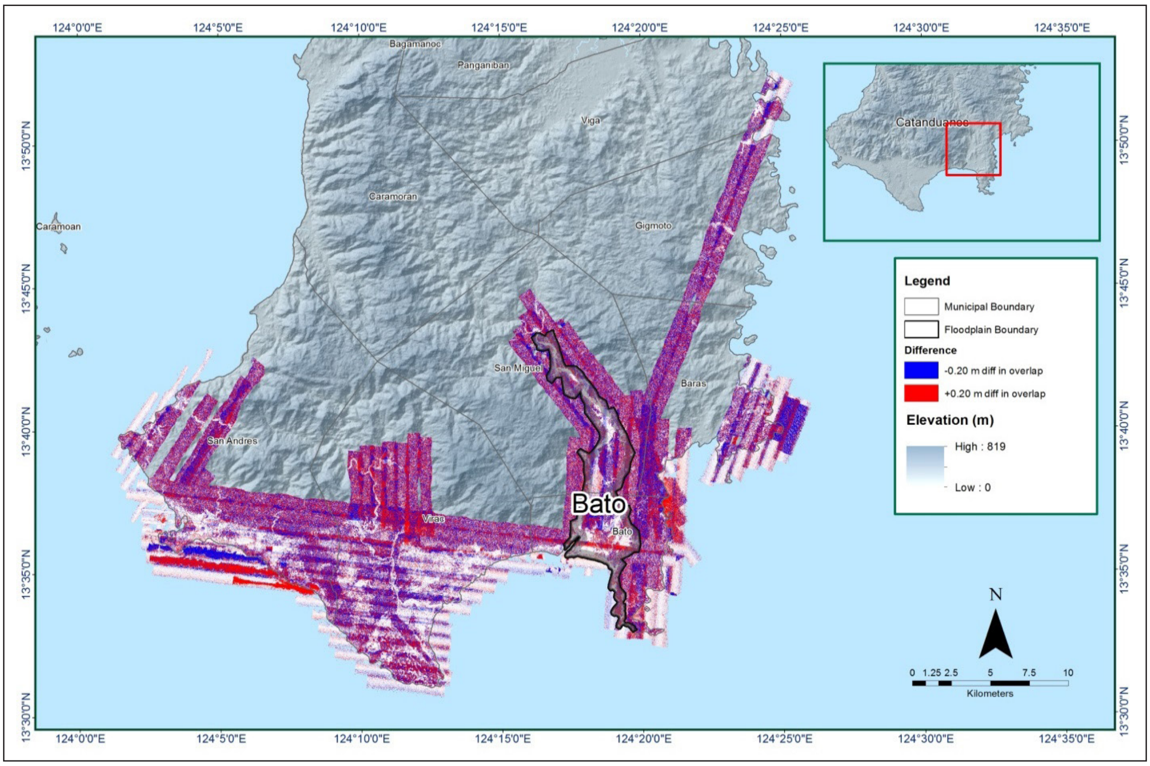


Figure 14. Elevation difference map between flight lines for Bato floodplain.

A screen capture of the processed LAS data from a Bato flight 3012P 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 red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

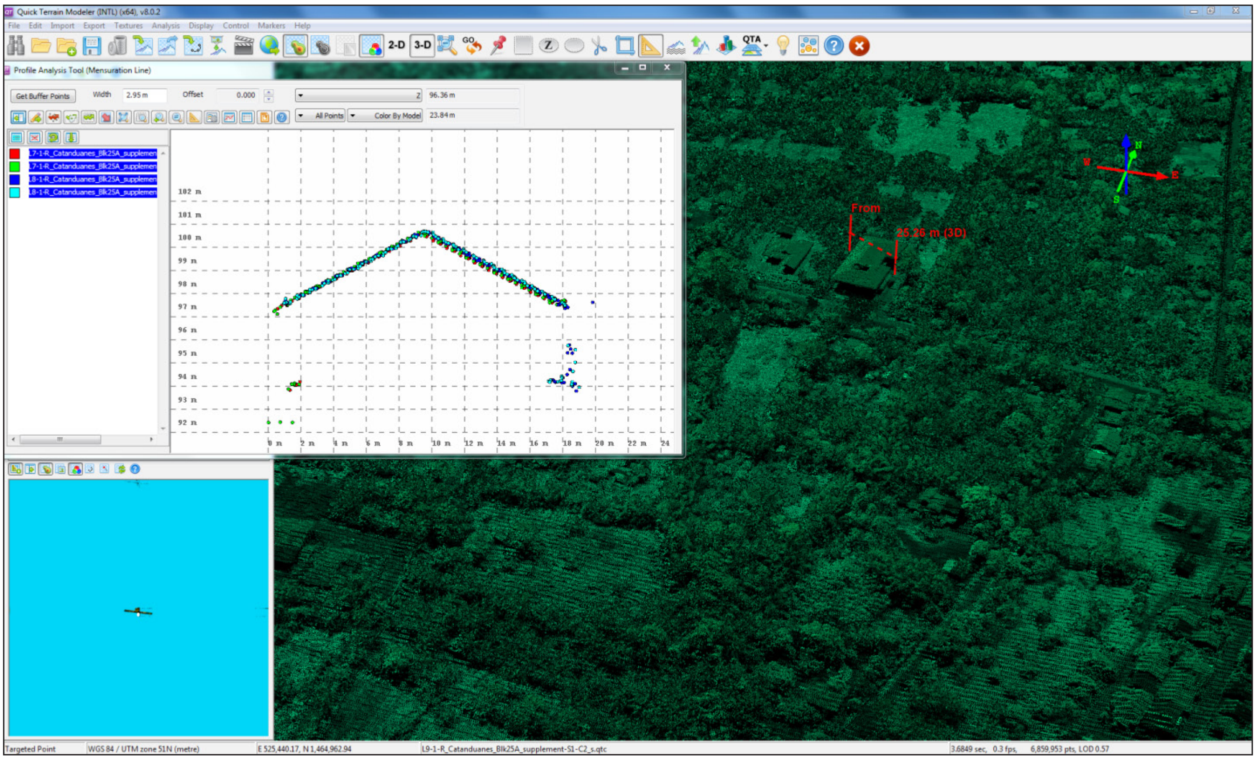


Figure 15. Quality checking for a Bato flight 3012P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Bato classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	405,563,214
Low Vegetation	202,861,051
Medium Vegetation	512,033,705
High Vegetation	2,163,524,038
Building	40,835,231

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Bato floodplain is shown in Figure 16. A total of 919 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 height of 767.53 meters and 47.95 meters respectively.

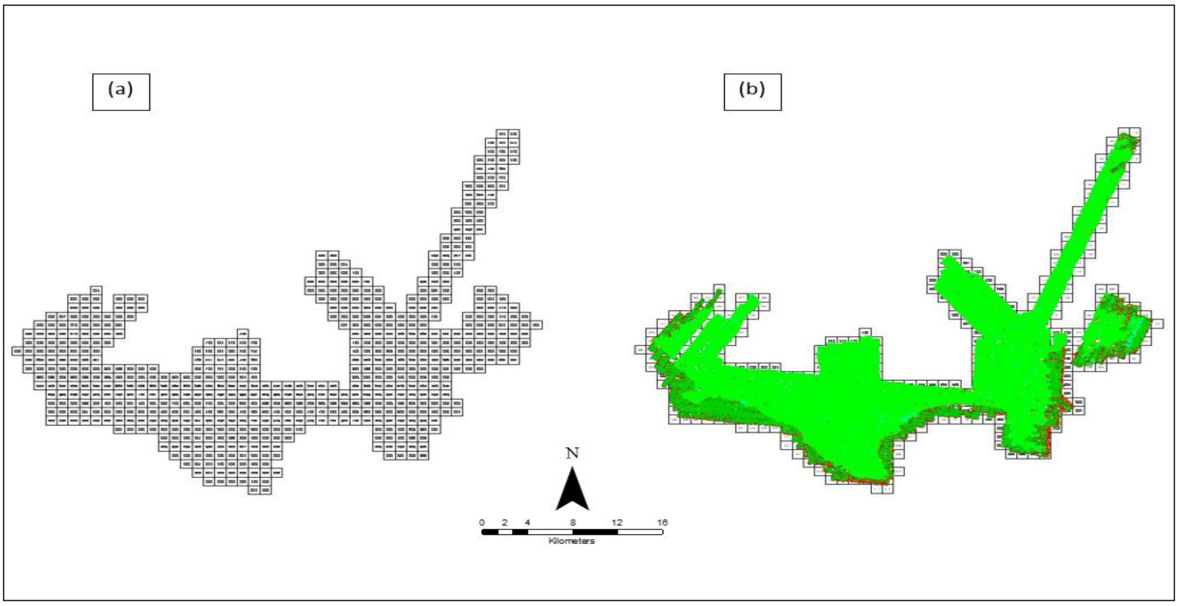


Figure 16. Tiles for Bato floodplain (a) and classification results (b) in TerraScan.

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.

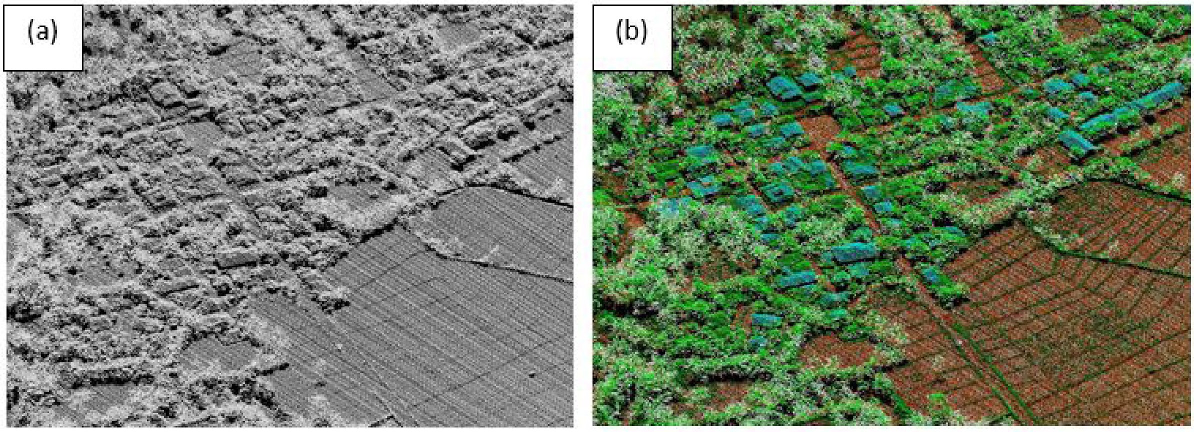


Figure 17. Point cloud before (a) and after (b) classification.

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.

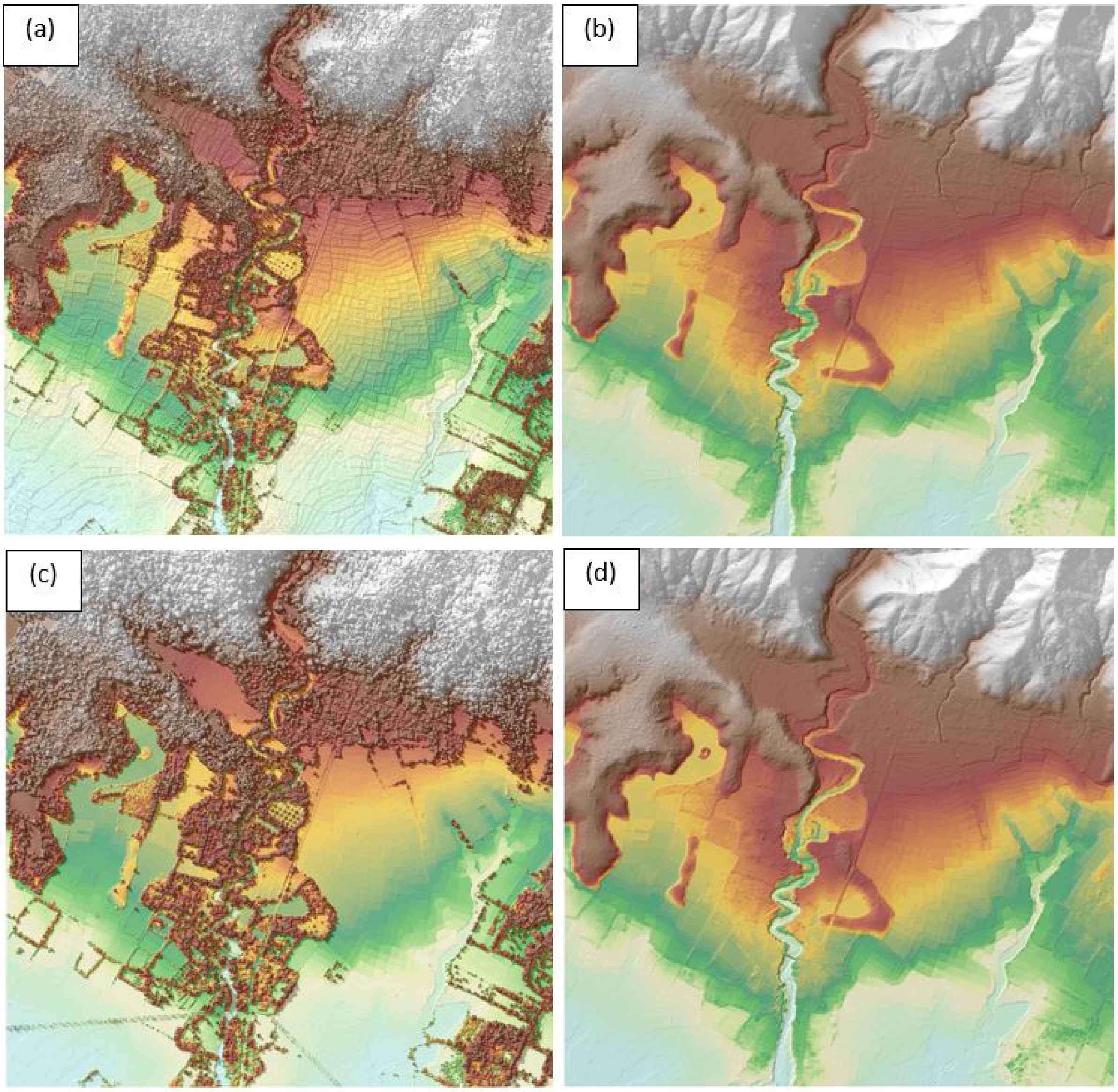


Figure 18. The Production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Bato floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 355 1km by 1km tiles area covered by Bato 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 Bato floodplain has a total of 200.78 sq.km orthophotogaph coverage comprised of 545 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 20.

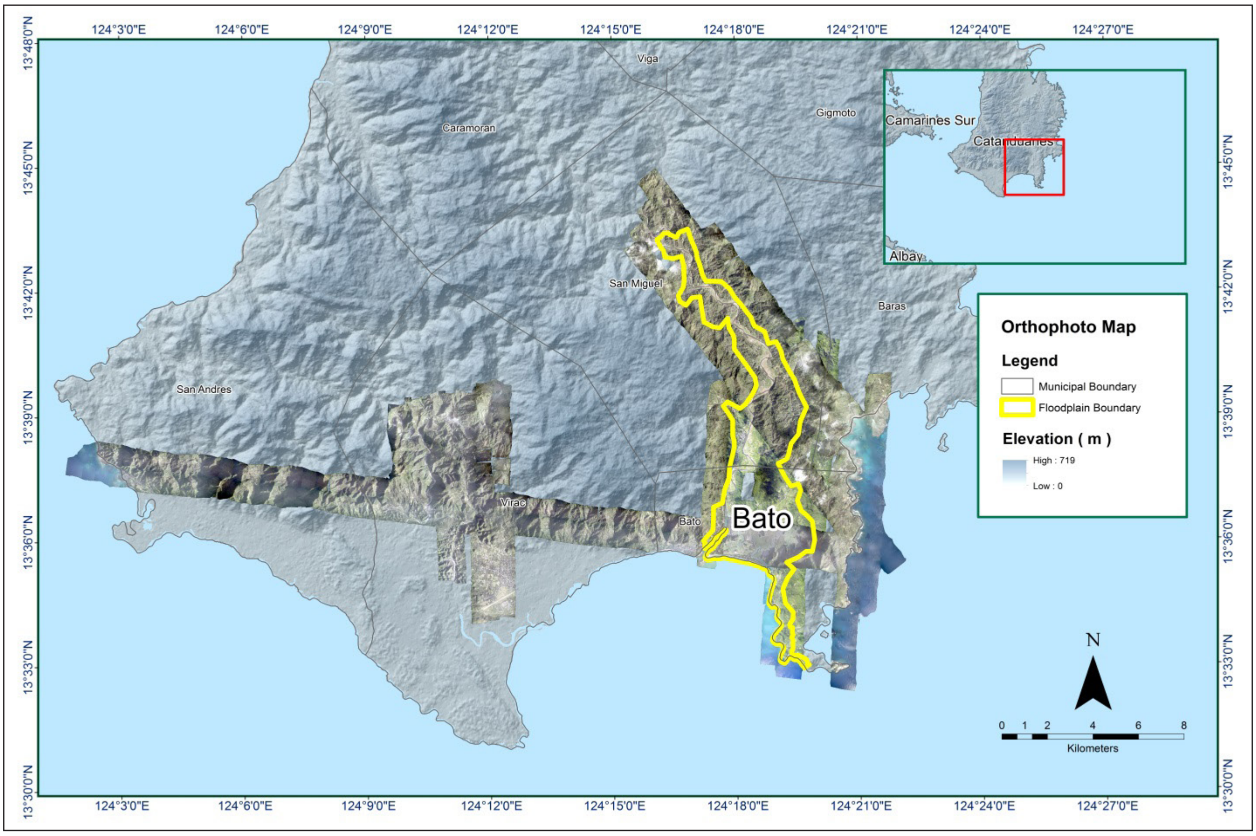


Figure 19. Bato floodplain with available orthophotographs.

Figure 20. Sample orthophotograph tiles for Bato floodplain.

3.8 DEM Editing and Hydro-Correction

Six (6) mission blocks were processed for Bato flood plain. These blocks are composed of Catanduanes blocks with a total area of 576.03 square kilometers. Table 12 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Catanduanes_Blk25C	72.07
Catanduanes_Blk25B	74.04
Catanduanes_Blk25B_supplement	83.46
Catanduanes_Blk25A	148.23
Catanduanes_Blk25A_supplemnt	97.62
Catanduanes_Blk25H_additional	100.61
TOTAL	**576.03 sq.km**

Portions of DTM before and after manual editing are shown in Figure 21. The mountain ridge (Figure 21a) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 21b) to allow the correct flow of water. The bridge (Figure 21c) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 21d) in order to hydrologically correct the river. Another example is a building that is still present in the DTM after classification (Figure 21e) and has to be removed through manual editing (Figure 21f).

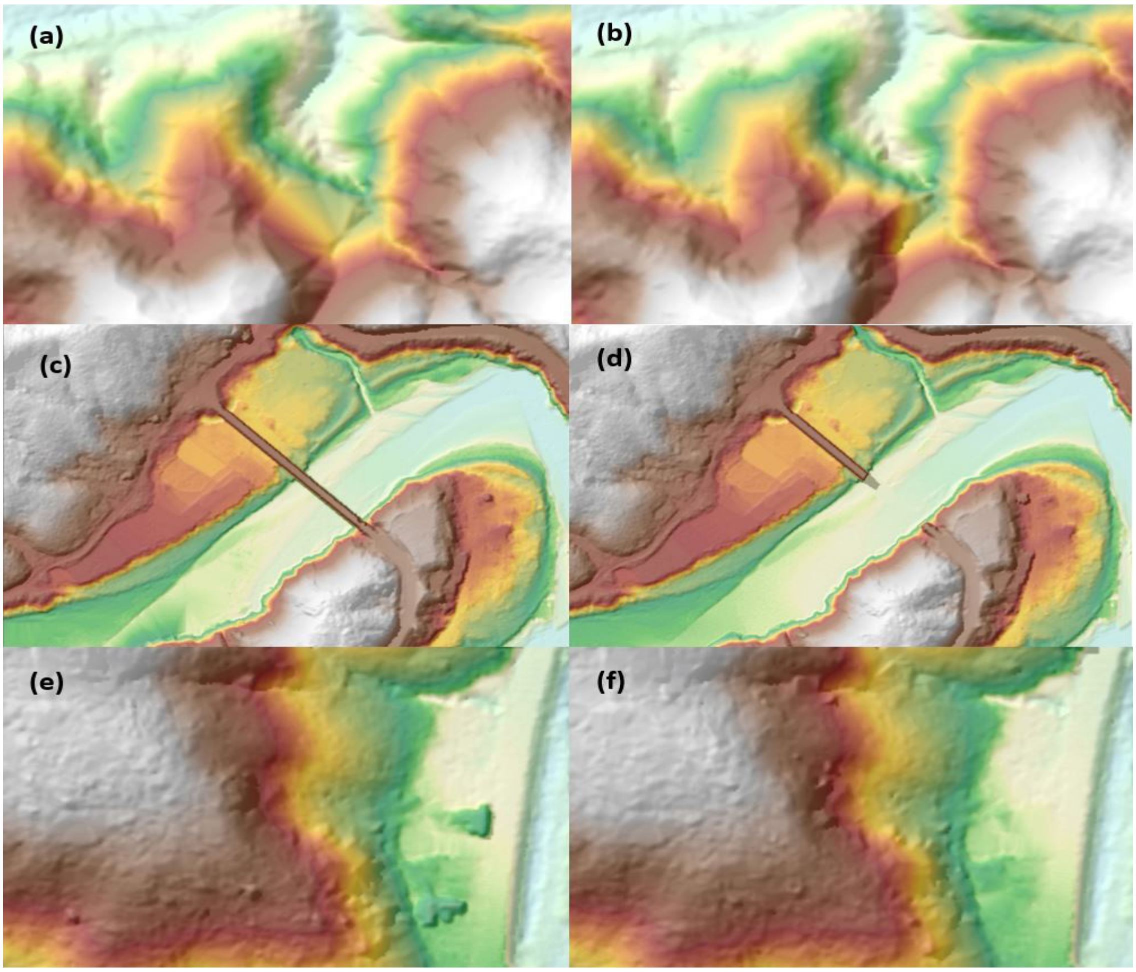


Figure 21. Portions in the DTM of Bato floodplain – a mountain ridge before (a) and after (b) data retrieval; a bridge before (c) and after (d) manual editing; and buildings before (e) and after (f) manual editing.

3.9 Mosaicking of Blocks

Catanduanes_Blk25B was used as the reference block at the start of mosaicking because it is located in the estuary of the river.

Mosaicked LiDAR DTM for Bato floodplain is shown in Figure 22. It can be seen that the entire Bato floodplain is 100% covered by LiDAR data.

Table 13. Shift Values of each LiDAR Block of Bato floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Catanduanes_Blk25C	2.00	0.00	-1.165
Catanduanes_Blk25B	Reference Block		
Catanduanes_Blk25B_supplement	1.00	1.00	-1.075
Catanduanes_Blk25A	0.00	-1.00	-0.006
Catanduanes_Blk25A_supplemnt	0.00	0.00	-0.107
Catanduanes_Blk25H_additional	0.00	-1.00	-1.588

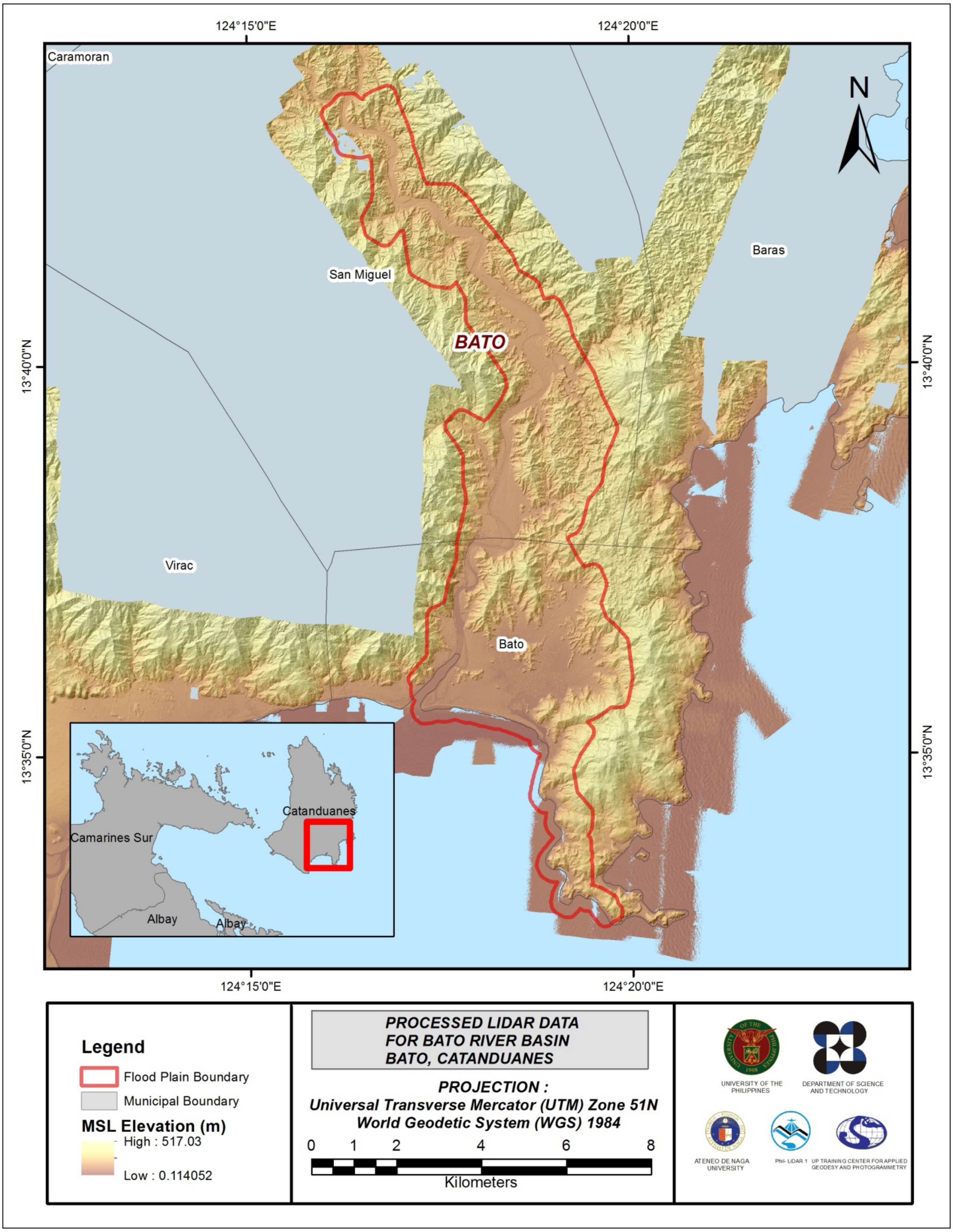


Figure 22. Figure 22. Map of Processed LiDAR Data for Bato Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Bato to collect points with which the LiDAR dataset is validated is shown in Figure 23 A total of 5,196 survey points were used for calibration and validation of Bato LiDAR data. Random selection of 80% of the survey points, resulting to 4782 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 1.42 meters with a standard deviation of 0.10 meters. Calibration of Bato LiDAR data was done by subtracting the height difference value, 1.42 meters, to Bato mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

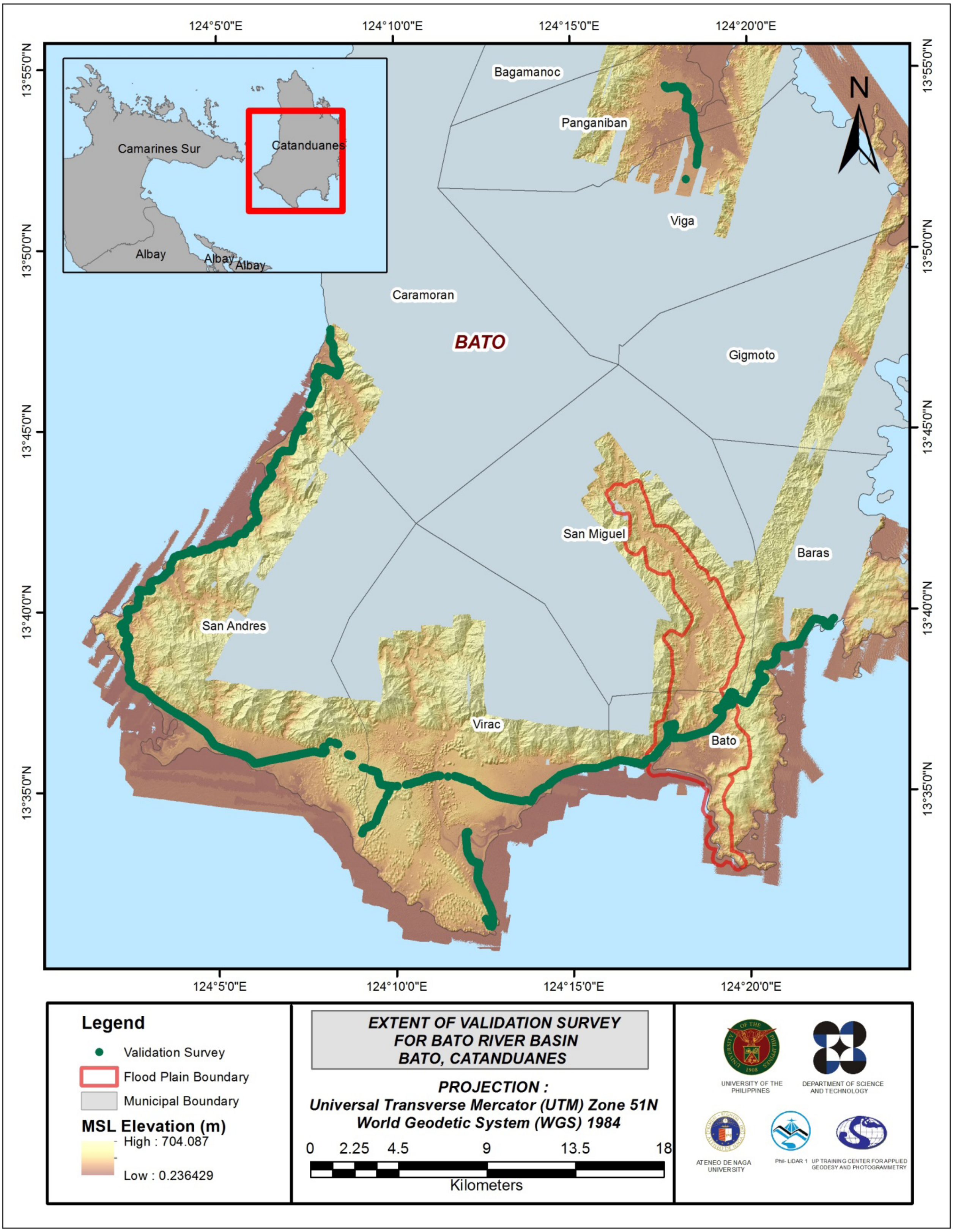


Figure 23. Map of Bato Flood Plain with validation survey points in green.

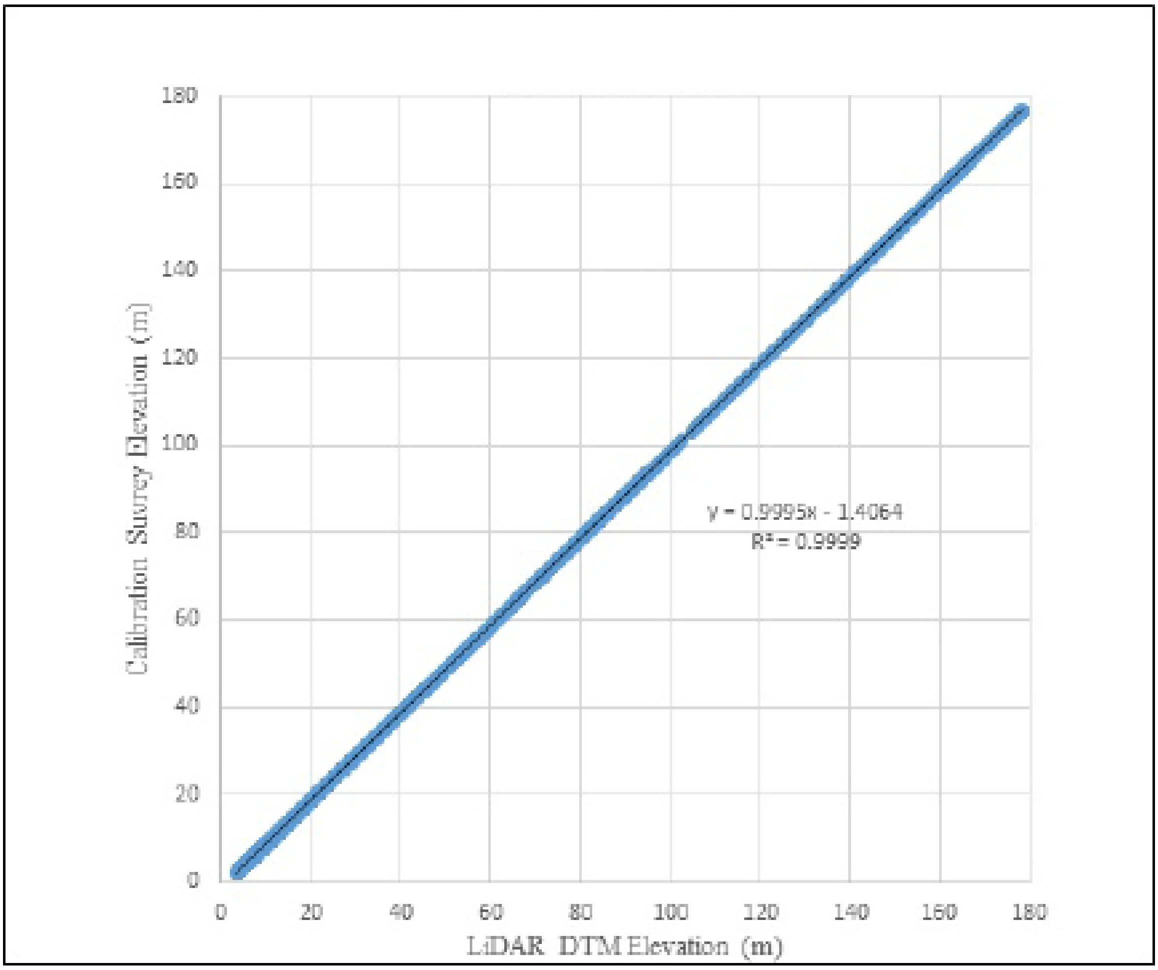


Figure 24. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	1.42
Standard Deviation	0.10
Average	-1.42
Minimum	-1.63
Maximum	-1.21

The remaining 20% of the total survey points, resulting to 206 points, were used for the validation of calibrated Bato 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 0.06 meters with a standard deviation of 0.05 meters, as shown in Table 15.

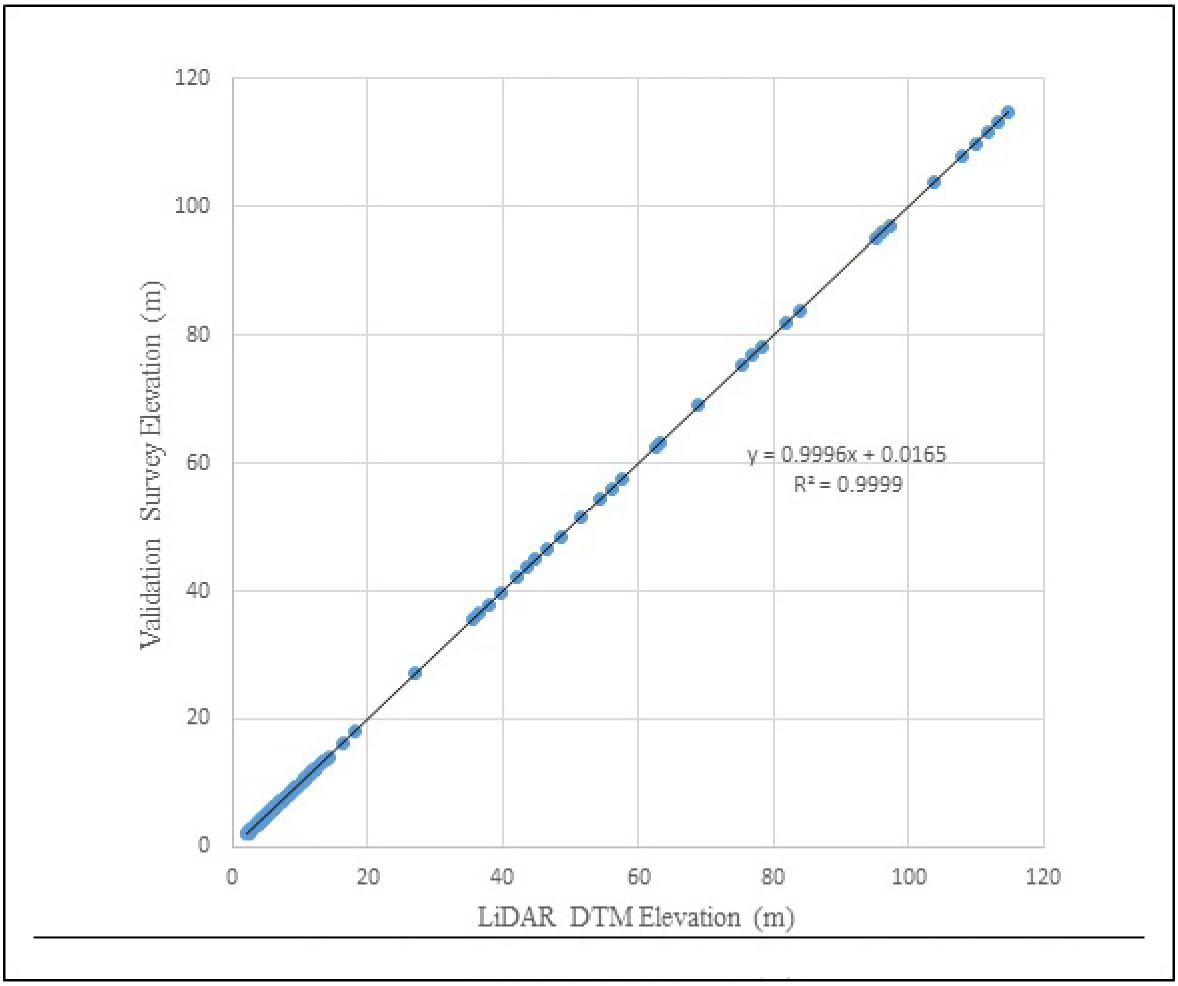


Figure 25. Correlation plot between validation survey points and LiDAR data.

Table 15. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.06
Standard Deviation	0.05
Average	0.01
Minimum	-0.10
Maximum	0.12

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data was available for Bato with 10,768 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.16 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Bato integrated with the processed LiDAR DEM is shown in Figure 26.

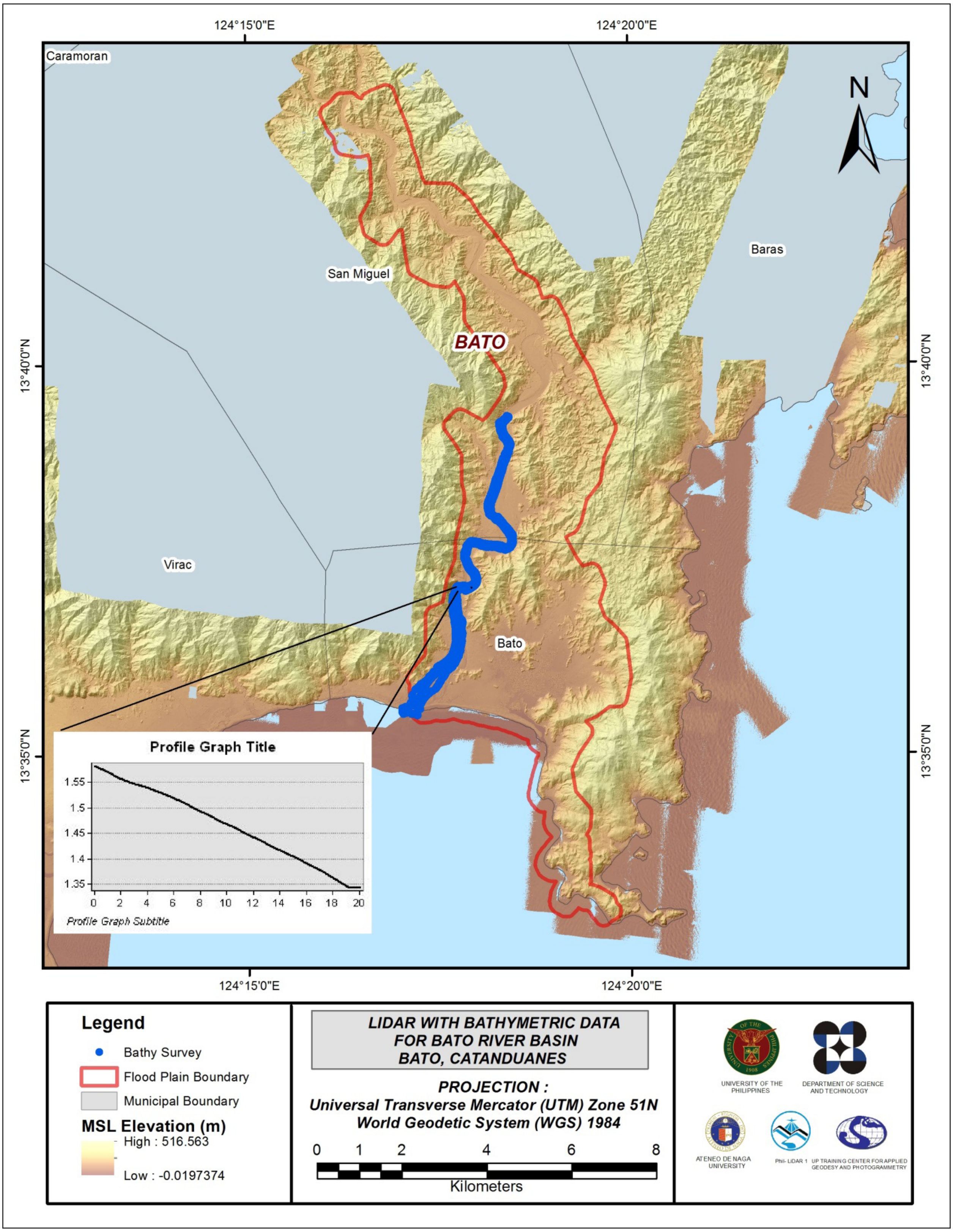


Figure 26. Map of Bato Flood Plain with bathymetric survey points shown in blue.

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

Bato floodplain, including its 200-m buffer, has a total area of 50.45 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 794 building features, are considered for QC. Figure 27 shows the QC blocks for Bato floodplain.

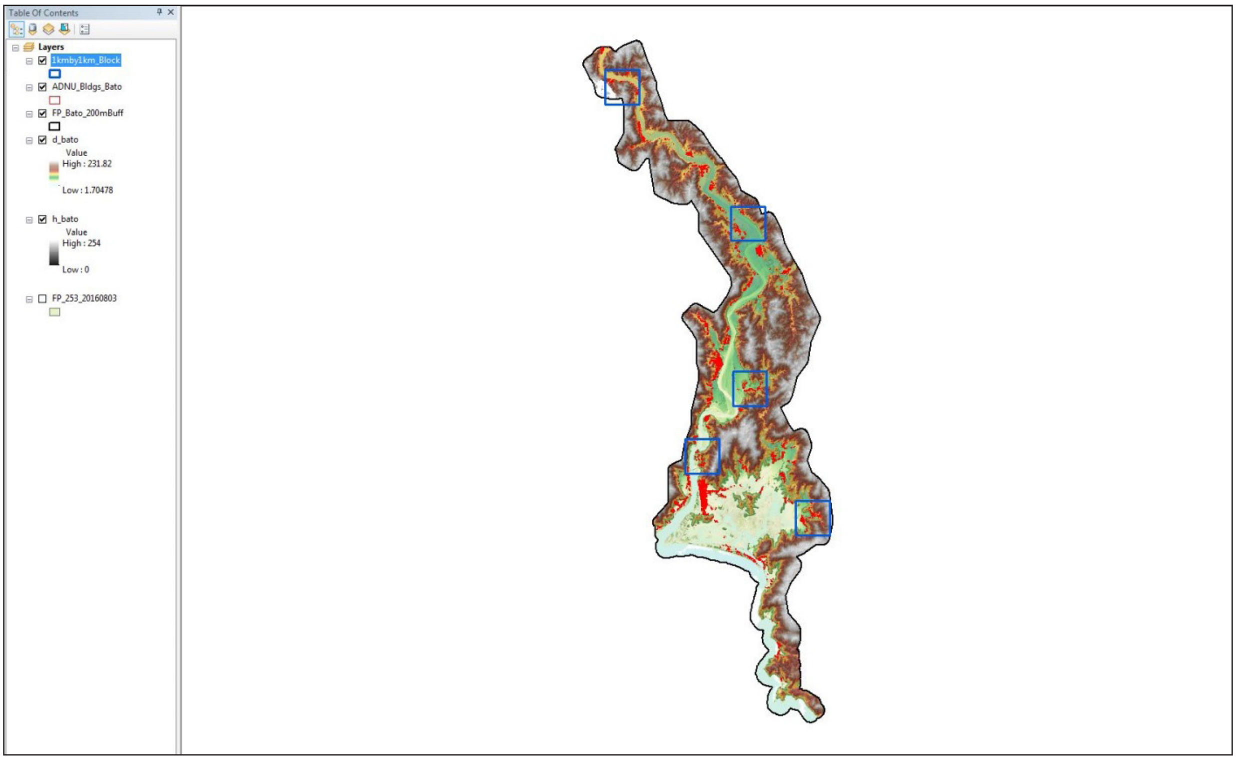


Figure 27. QC blocks for Bato building features.

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

Table 16. Quality Checking Ratings for Bato Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Bato	99.87	98.99	81.99	PASSED

3.12.2 Height Extraction

Height extraction was done for 5,225 building features in Bato floodplain. Of these building features, 11 were filtered out after height extraction, resulting to 5,214 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 7.39 m.

3.12.3 Feature Attribution

Feature Attribution was done for 5,214 building features in Bato 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[1]. 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

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

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.

Table 17. Number of Building Features Extracted for Bato Floodplain.

Facility Type	No. of Features
Residential	4863
School	171
Market	0
Agricultural/Agro-Industrial Facilities	1
Medical Institutions	18
Barangay Hall	32
Military Institution	0
Sports Center/Gymnasium/ Covered Court	4
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	13
NGO/CSO Offices	0
Police Station	3
Water Supply/Sewerage	1
Religious Institutions	58
Bank	0
Factory	0
Gas Station	0
Fire Station	1
Other Government Offices	15
Other Commercial Establishments	31
New Building*	3
Total	5214

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Bato	58.52643	4.52529	0	25.2783	0.00	**88.32992**

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

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Bato	2	16	0	0	0	18

A total of 24 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 Bato floodplain overlaid with its ground features.

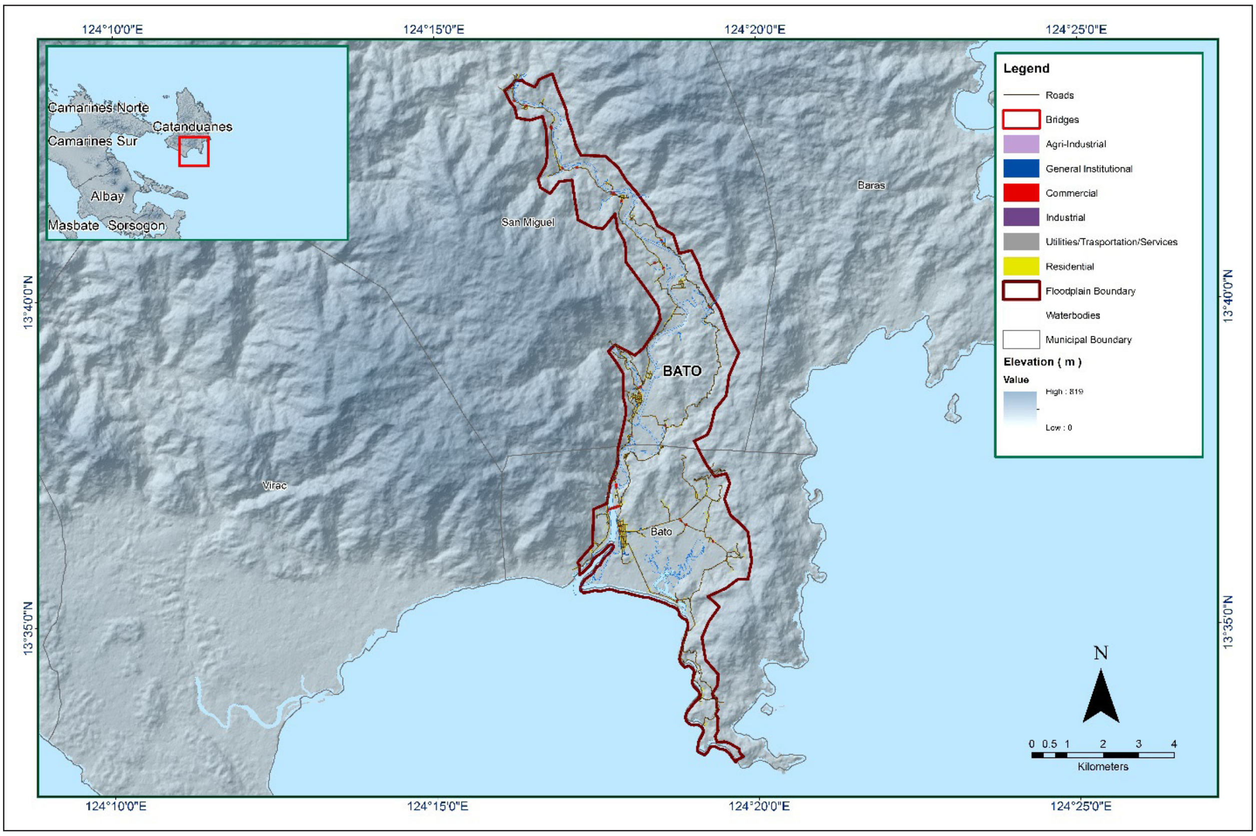


Figure 28. Extracted features for Bato floodplain.

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

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

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Bato River on April 8 to 22, 2016 with the following scope of work: reconnaissance; control survey; cross-section survey at the deployment site in Brgy. Tilis; validation points acquisition of about 87 km covering the Bato River Basin area; and bathymetric survey from its upstream in Brgy. Katipunan, in municipality of San Miguel down to the mouth of the river in Brgy. Cabugao, in Municipality of Bato, with an approximate length of 9.177 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique as shown in Figure 29.

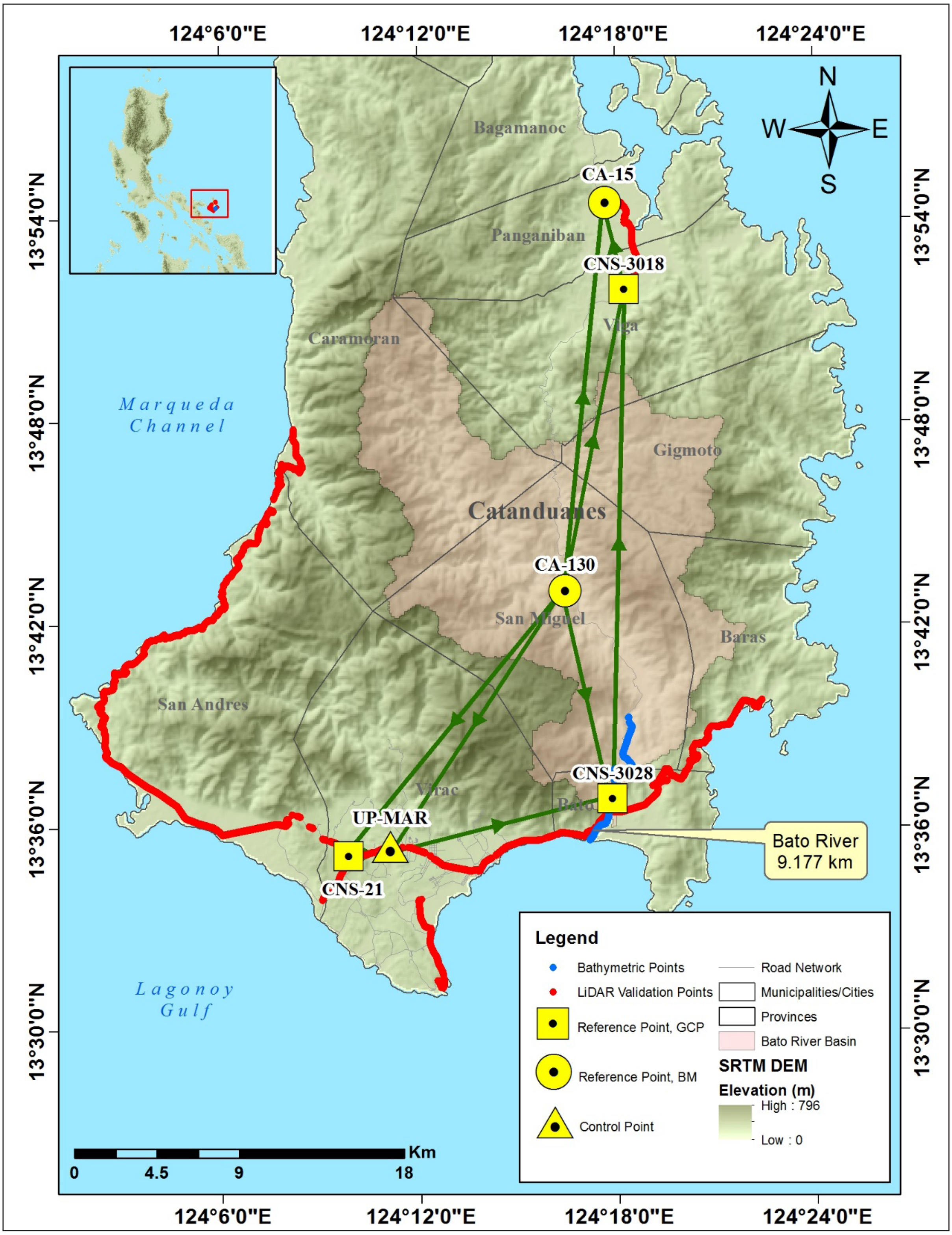


Figure 29. Survey extent for Bato River Basin

4.2 Control Survey

The GNSS network used for Bato River Basin is composed of four (4) loops established on April 9 and 10, 2016 occupying the following reference points: CNS-21, a second-order GCP, in Brgy. Palta Small, Municipality of Virac; and CA-130, a first order BM in Brgy. Balatohan, Municipality of San Miguel.

The UP established control point UP-MAR located at the approach of Marcos Bridge in Brgy Bigaa, Municipality of Virac; and NAMRIA established control points, namely CA-15 in Brgy. Sta. Maria, Municipality of Panganiban, CNS-3018 in Brgy. San Isidro, Muncipality of Viga, and CNS-3028 in Brgy. Tilis, in Municipality of Bato were also occupied and used as marker for the network.

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

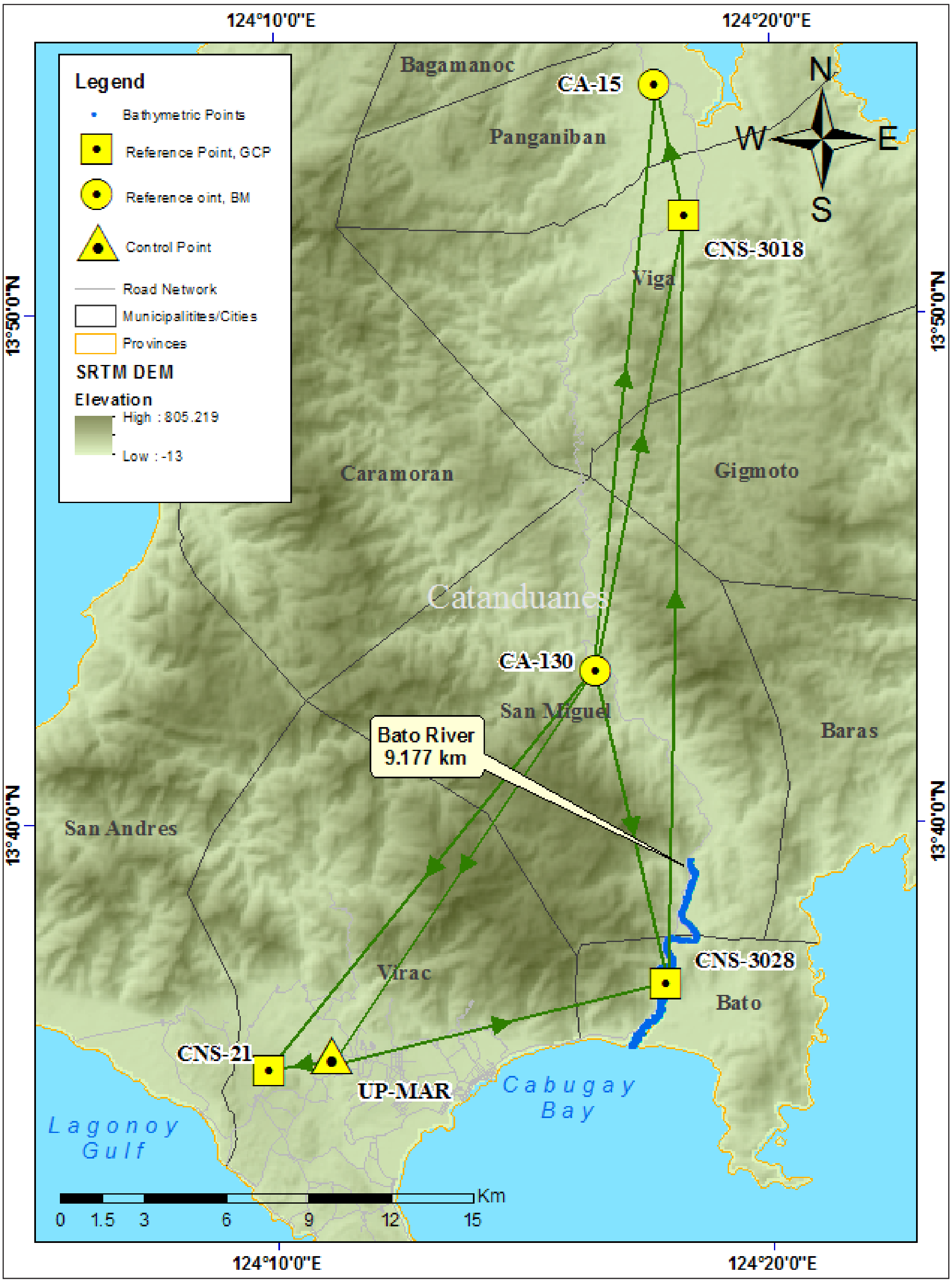


Figure 30. GNSS Network of Bato River field survey

Table 20. List of reference and control points occupied for Bato River Survey
(Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date Established
CNS-21	2nd Order, GCP	13°35'09.45275" N	124°09'50.36457"	136.082	-	2007
CA-130	1st order Order, BM	-	-	90.506	37.6703	2008
CA-15	Used as Marker	-	-	-	-	2008
CNS-3018	Used as Marker	-	-	-	-	2007
CNS-3028	Used as Marker	-	-	-	-	2007
UP-MAR	UP Established	-	-	-	-	04-09-06

The GNSS set up made in the location of the reference and control points are exhibited are shown in Figure 34 to Figure 36.

Figure 31. GNSS base set up, Trimble® SPS 882, at CNS-21, located at Palta Bridge in Brgy. Palta Small, Municipality of Virac, Catanduanes

Figure 32. GNSS base set up, Trimble® SPS 882, at CA-130, located at the end of pathwalk in Brgy. Balatohan, Municipality of San Miguel, Catanduanes

Figure 33. GNSS base set up, Trimble® SPS 882, at CA-15, is located at the approach of the left side of Kanparel Bridge in Brgy. Santa Maria, Municipality of Panganiban, Catanduanes

Figure 34. GNSS base set up, Trimble® SPS 882, at CNS-3018, located at the approach of Pilot Bridge along Catanduanes Circumferential Road in Brgy. San Isidro, Municipality of Viga, Catanduanes

Figure 35. GNSS base set up, Trimble® SPS 852, at CNS-3028, located at the approach of Bato Bridge along Catanduanes Circumferential Road in Brgy. Tilis, Municipality of Bato, Province of Catanduanes

Figure 36. GNSS base set up, Trimble® SPS 852, at UP-MAR, located at the approach of the right side of Marcos Bridge in Brgy. Bigaa, Municipality of Virac, Catanduanes

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 Bato River Basin is summarized in Table 21 generated by TBC software.

Table 21. Baseline Processing Report for Bato River Basin Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)
CNS-3018--- CA-15	04-10-16	Fixed	0.003	0.016	347°50’15”	4831.606
CNS-3028--- CNS-3018	04-10-16	Fixed	0.002	0.014	1°35’28”	27798.226
CA-130 --- CNS-3028	04-09-16	Fixed	0.004	0.024	167°24’47”	11614.119
CNS-3028--- CA-130	04-09-16	Fixed	0.003	0.012	167°24’48”	11614.112
CA-130 --- CNS-21	04-09-16	Fixed	0.003	0.016	219°31’42”	18701.297
CA-130 --- CA-15	04-10-16	Fixed	0.003	0.006	6°08’58”	21298.173
CA-130 --- CNS-3018	04-10-16	Fixed	0.003	0.015	11°20’31”	16780.283
CA-130 --- CNS-3018	04-10-16	Fixed	0.003	0.014	11°20’31”	16780.296
UP-MAR --- CNS-3028	04-09-16	Fixed	0.004	0.023	78°00’02”	12411.353
UP-MAR --- CA-130	04-09-16	Fixed	0.003	0.011	34°37’02”	16907.625
UP-MAR --- CNS-21	04-09-16	Fixed	0.002	0.009	77°20’46”	2349.293

As shown in Table21, a total of eleven (11) baselines were processed with reference points CNS-21 fixed for grid values; and CA-130 held fixed for elevation. 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 23 of the TBC generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 cm and z less than 10 cm or in equation form:

$$z_e < 10\ cm_{<20cm} \text{ and } z_e < 10\ cm$$

Where:

x_e is the Easting error,

y_e is the Northing error, and

z_e is the Elevation error

for each control point. See the Network Adjustment Report shown in Table 22 to Table 24 for the complete details.

The six (6) control points, CNS-21, CA-130, CA-15, CNS-3018, CNS-3028, and UP-MAR were occupied and observed simultaneously to form a GNSS loop. Elevation value of CA-130 and coordinates of point CNS-21 were held fixed during the processing of the control points as presented in Table 22. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 22. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
CNS-21	Local	Fixed	Fixed		
CA-130	Grid				Fixed
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 23. The fixed control points CNS-21 and CA-130 has no values for grid and elevation errors, respectively.

Table 23. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CNS-21	625929.75	?	1502236.721	?	83.792	0.087	LL
CA-130	637754.30	0.014	1516720.821	0.012	37.67	?	e
CA-15	639923.02	0.020	1537904.832	0.017	9.219	0.048	
CNS-3018	640966.62	0.017	1533188.045	0.014	9.300	0.067	
CNS-3028	640344.33	0.018	1505401.099	0.014	12.262	0.073	
UP-MAR	628219.04	0.012	1502762.192	0.010	20.754	0.074	

The network is fixed at reference point CNS-21 with known coordinates, and CA-130 with known elevation. As shown in Table 23, the standard errors (*xe* and *ye*) of CA-130 are 1.40 cm and 1.2 cm; CA-15 are 2.0 cm and 1.7 cm; CNS-3018 are 1.7 cm and 1.40 cm; CNS-3028 are 1.80 cm and 1.40cm; and UP-MAR are 1.20 cm and 1 cm. With the mentioned equation, for horizontal and for the vertical; the computation for the accuracy are as follows:

a. CNS-21

horizontal accuracy	=	Fixed
vertical accuracy	=	8.7 cm < 10 cm

b. CA-130

horizontal accuracy	=	$\sqrt{((1.40)^2 + (1.20)^2}$
	=	$\sqrt{(1.96 + 1.44)}$
	=	1.84cm < 20 cm
vertical accuracy	=	Fixed

c. CA-1

horizontal accuracy	=	$\sqrt{((2.0)^2 + (1.70)^2}$
	=	$\sqrt{(4+ 2.89)}$
	=	2.62cm < 20 cm
vertical accuracy	=	4.8 cm < 10 cm

d. CNS-30180

horizontal accuracy = $\sqrt{(1.70)^2 + (1.40)^2}$

= $\sqrt{(2.89 + 1.96)}$

= 2.20 cm < 20 cm

vertical accuracy = 6.7 cm < 10 cm

e. CNS-3028

horizontal accuracy = $\sqrt{(1.80)^2 + (1.40)^2}$

= $\sqrt{(3.24 + 1.96)}$

= 2.28 cm < 20 cm

vertical accuracy = 7.3 cm < 10 cm

f. UP-MAR

horizontal accuracy = $\sqrt{(1.20)^2 + (1.00)^2}$

= $\sqrt{(1.44 + 1.00)}$

= 1.56 cm < 20 cm

vertical accuracy = 7.4 cm < 10 cm

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

Table 24. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Ellipsoidal Height (Meter)	Height Error (Meter)	Constraint
CNS-21	13°35'09.45275" N	124°09'50.36457" E	136.082	0.087	LL
CA-130	13°42'58.90071" N	124°16'26.29487" E	90.506	?	e
CA-15	13°54'27.92390" N	124°17'42.29172" E	61.912	0.048	
CNS-3018	13°51'54.24025" N	124°18'16.19947" E	62.000	0.067	
CNS-3028	13°36'50.06664" N	124°17'50.49382" E	64.549	0.073	
UP-MAR	13°35'26.19548" N	124°11'06.61522" E	73.091	0.074	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in 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 and control points used is indicated in Table 25.

Table 25. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
CNS-21	2nd Order, GCP	13°35’09.45275”	124°09’50.36457”	136.082	1502236.721	625929.746	83.792
CA-130	1st order Order, BM	13°42’58.90071”	124°16’26.29487”	90.506	1516720.821	637754.301	37.670
CA-15	Used as Marker	13°54’27.92390”	124°17’42.29172”	61.912	1537904.832	639923.023	9.219
CNS-3018	Used as Marker	13°51’54.24025”	124°18’16.19947”	62.000	1533188.045	640966.615	9.300
CNS-3028	Used as Marker	13°36’50.06664”	124°17’50.49382”	64.549	1505401.099	640344.326	12.262
UP-MAR	UP Established	13°35’26.19548”	124°11’06.61522”	73.091	1502762.192	628219.036	20.754

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

Cross-section survey was conducted at the downstream part of Bato Bridge in Brgy. Tilis, Municipality of Bato, on April 11, 2016 using a GNSS receiver, Trimble® SPS 882, in PPK survey technique.

Figure 37. Cross-Section Survey for Bato River

The cross-sectional line length of the deployment site is about 354.832 m with 66 cross-sectional points acquired using CNS-3028 as the GNSS base station. The cross-section diagram is illustrated in Figure 39.

Water surface elevation in MSL of Bato River was determined using Trimble® SPS 882 in PPK mode technique on April 11, 2016 at 11:39 AM with a value of 0.996 m in MSL. This will be translated onto marking by the VSU after renovation of the dike. The markings will serve as their reference for flow data gathering and depth gauge deployment for Bato River.

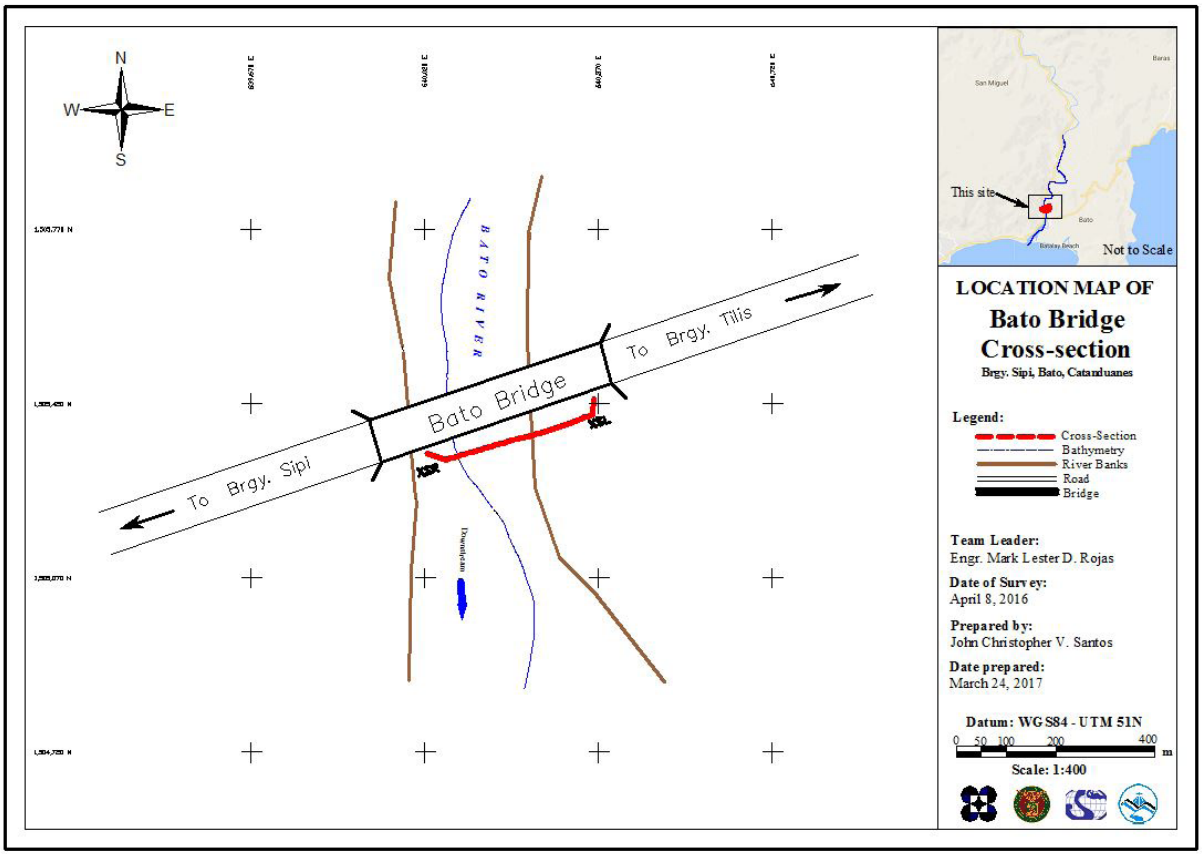


Figure 38. Location map of Bato Bridge Cross Section Survey

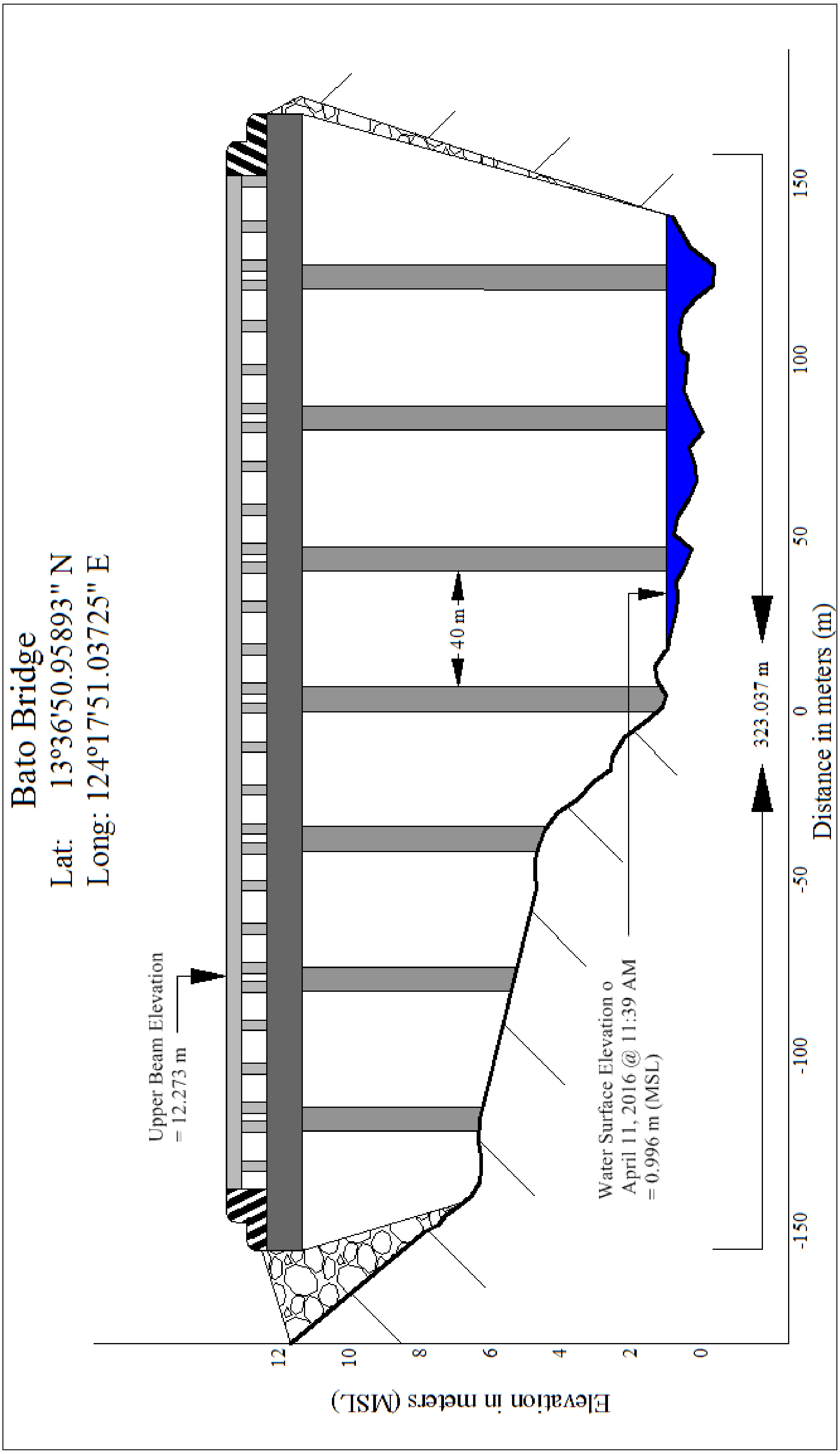
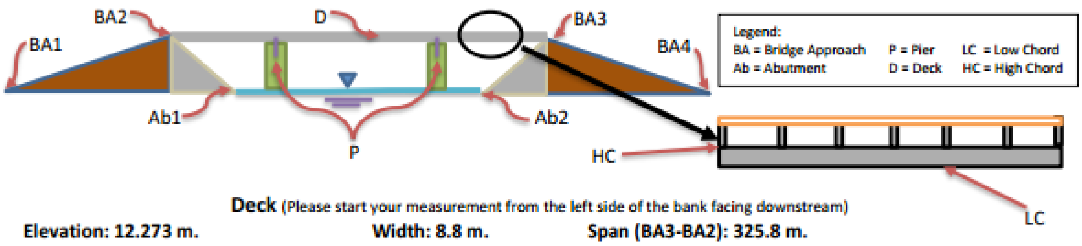


Figure 39. Bato Bridge Cross-section, Diagram

Bridge Data Form

Bridge Name: Bato Bridge	**Date: April 12, 2016**
River Name: Bato River	**Time: 10:30 AM**
Location: Brgy. Sipi, Bato, Catanduanes	
Survey Team: Mark Lester Rojas, Marla Tricia Joy Morris, Marck Lorenz Taguse	
Flow condition: low ✓ normal high	**Weather Condition:** ✓ fair rainy
Latitude: 13°36'50.95893"N	**Longitude: 124°17'51.03725"E**



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

Elevation: 12.273 m. **Width: 8.8 m.** **Span (BA3-BA2): 325.8 m.**

	Station	High Chord Elevation	Low Chord Elevation
1	67.4	12.299	9.699
2	107.0964	12.285	9.685
3	186.826	12.268	9.668
4	226.6445	12.265	9.665
5	306.7884	12.264	9.664

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	11.628	BA3	349.6519	12.135
BA2	26.61454	12.289	BA4	354.8321	11.364

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

	Station (Distance from BA1)	Elevation
Ab1	40.720	6.505
Ab2	N/A	N/A

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

Shape: Cylindrical Number of Piers: 7 Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	67.400	12.299	1.8
Pier 2	107.096	12.285	1.8
Pier 3	147.012	12.269	1.8
Pier 4	186.826	12.268	1.8
Pier 5	226.716	12.265	1.8
Pier 6	306.788	12.267	1.8
Pier 7	348.652	12.264	1.8

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

Figure 40. Bato Bridge Data Form

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on April 9, 10 11, and 12, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on the roof of the vehicle as shown in Figure 41. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was 1.935 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with UP-MAR, CNS-3028, and CNS-3018 occupied as the GNSS base stations in the conduct of the survey.

Figure 41. Validation points acquisition survey set up

The survey started from Brgy. Inalmasinan in the Municipality of Caramoan, going south towards the municipalities of San Andres, Virac, Bato, and ended in Brgy. Bagong Sirang, Municipality of Baras. This route aims to cut flight strips perpendicularly. The survey gathered 10,379 points with approximate length of 87.267 km using UP-MAR, CNS-3028, and CNS-3018 as GNSS base stations for the entire extent validation points acquisition survey as illustrated in the map in Figure 42.

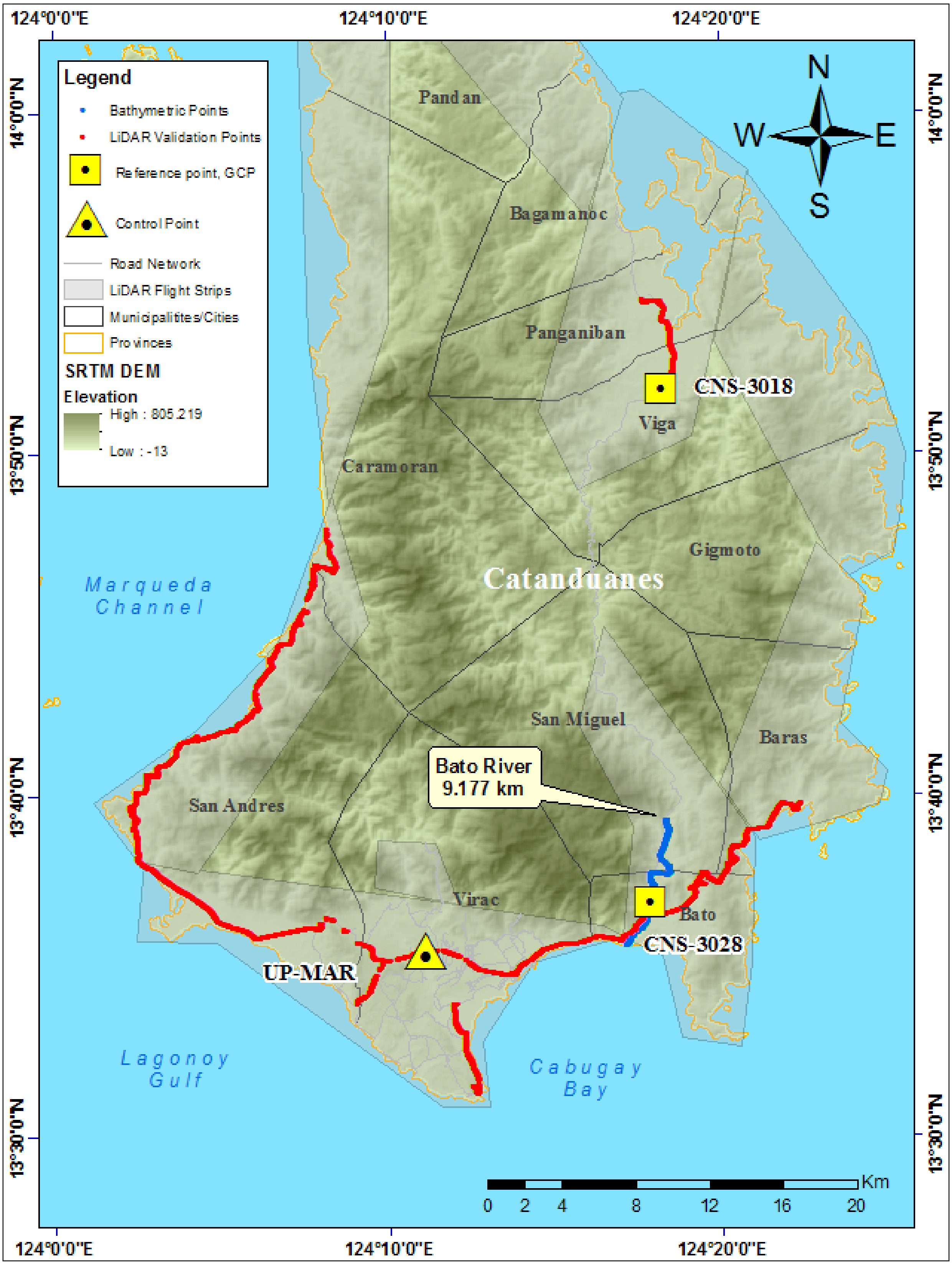


Figure 42. Validation point acquisition survey for the Bato River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on April 13, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure 43. The extent of the survey is from the mid part of the river in Brgy Sibacungan, Municipality of Bato with coordinates 13°37›42.86204»N, 124°17›55.47360»E, down to the mouth of the river in Brgy. San Andrea, also in Municipality of Bato with coordinates 12°35›35.26423”N, 124°17›11.49144»E.

Figure 43. Bathymetry by boat set up for Bato River survey

Manual Bathymetric survey was executed on April 11, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique. The extent of the survey is from the upstream in Brgy. Katipunan, Municipality of San Miguel with coordinates 13°39’15.24797”N, 124°18’21.10929”E, traversed down by foot and ended at the starting point of bathymetric survey using boat started.

A CAD drawing was also produced to illustrate the riverbed profile of Bato River. As shown in Figure 45, the highest and lowest elevation has a 8-meter difference. The highest elevation observed is 7.975 m above MSL located at the upstream portion of the river in Brgy. Katipunan, Municipality of San Miguel while the lowest elevation observed is 0.249 m below MSL located at the mid downstream portion of the river in Brgy. Ohuis, Municipality of Bato. The bathymetric survey gathered a total of 9,060 points covering 9.177 km of the river traversing six barangays in Municipality of San Miguel; and nine barangays in Municipality of Bato.

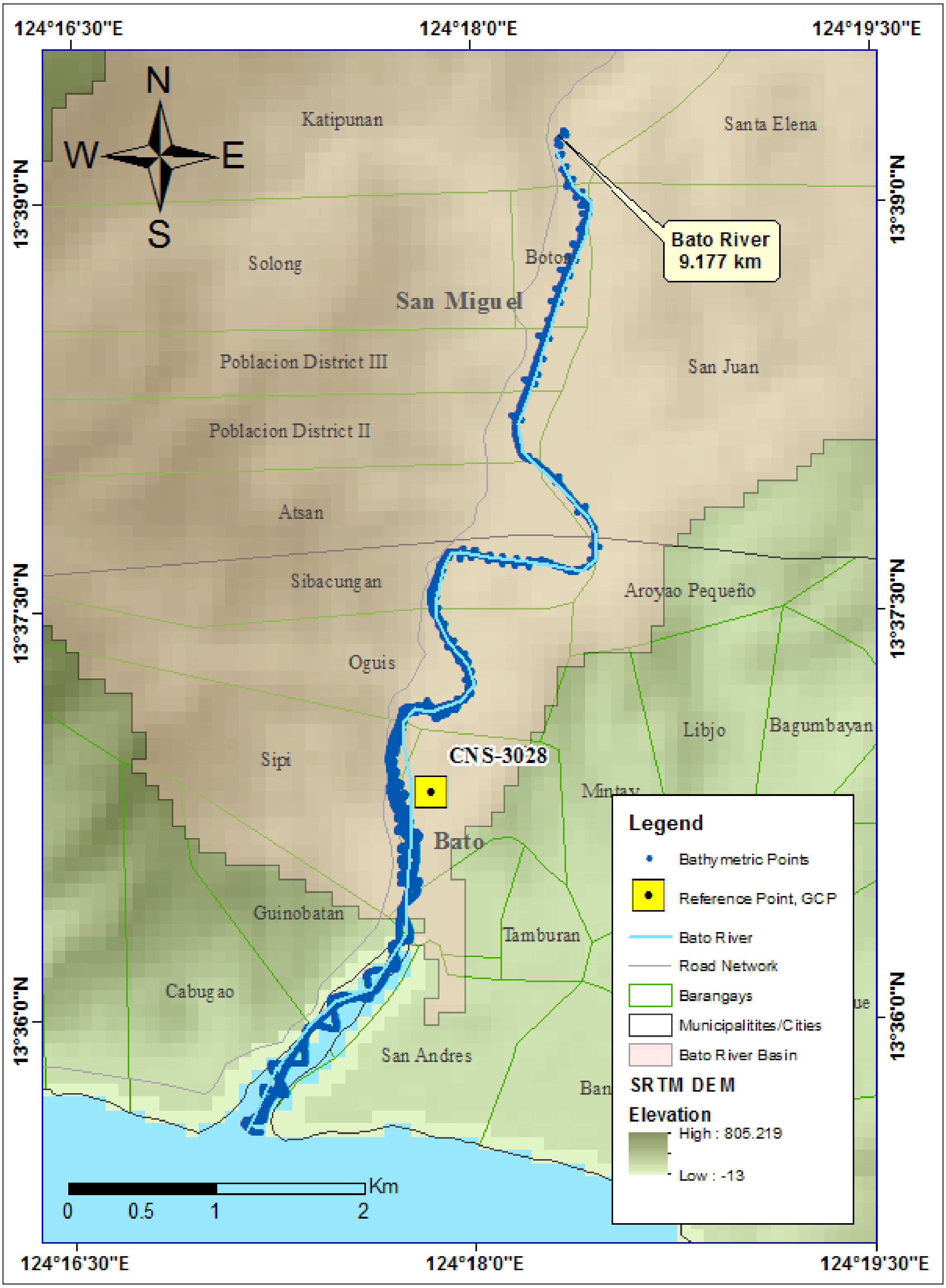


Figure 44. Bathymetric survey of Bato River

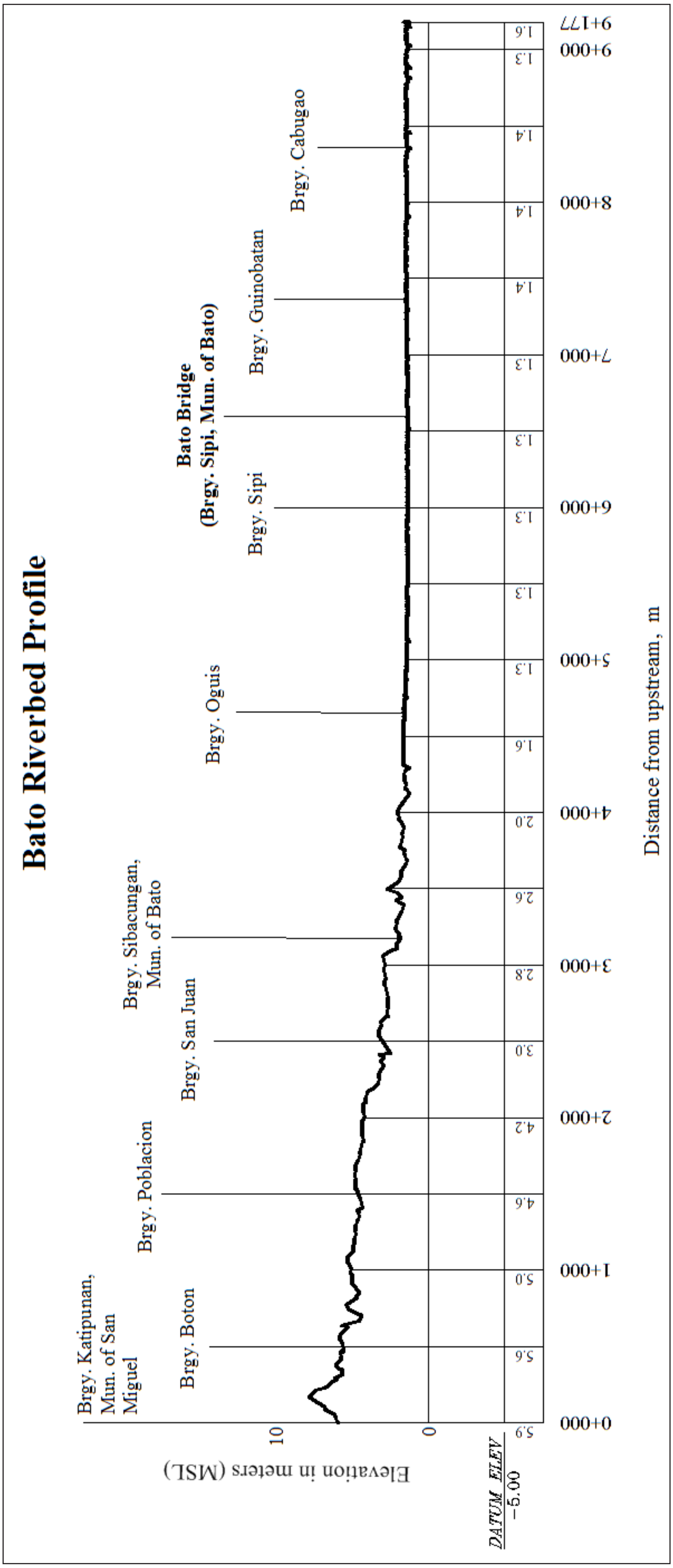


Figure 45. Riverbed profile of Bato River

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Gianni Sumajit, Mark D. Delloro, Julius Hector S. Manchete, John Paul B. Obina, Engr. Herminio Magpantay, Lech Fidel C. Pante, Aaron San Andres, and Engr. Ferdinand E. Bien

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All components and data that affect the hydrologic cycle of the Bato 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 Bato 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 Brgy. Hicming (Figure 46). The precipitation data collection started from October 15, 2016 at 12:00 AM to October 16, 2016 at 12:00 AM with a 15-minute recording interval.

The total precipitation for this event in Brgy. Hicming ARG is 355mm. It has a peak rainfall of 14mm on October 15, 2016, at 7:15 AM. The lag time between the peak rainfall and discharge is 5 hours and 45 minutes.

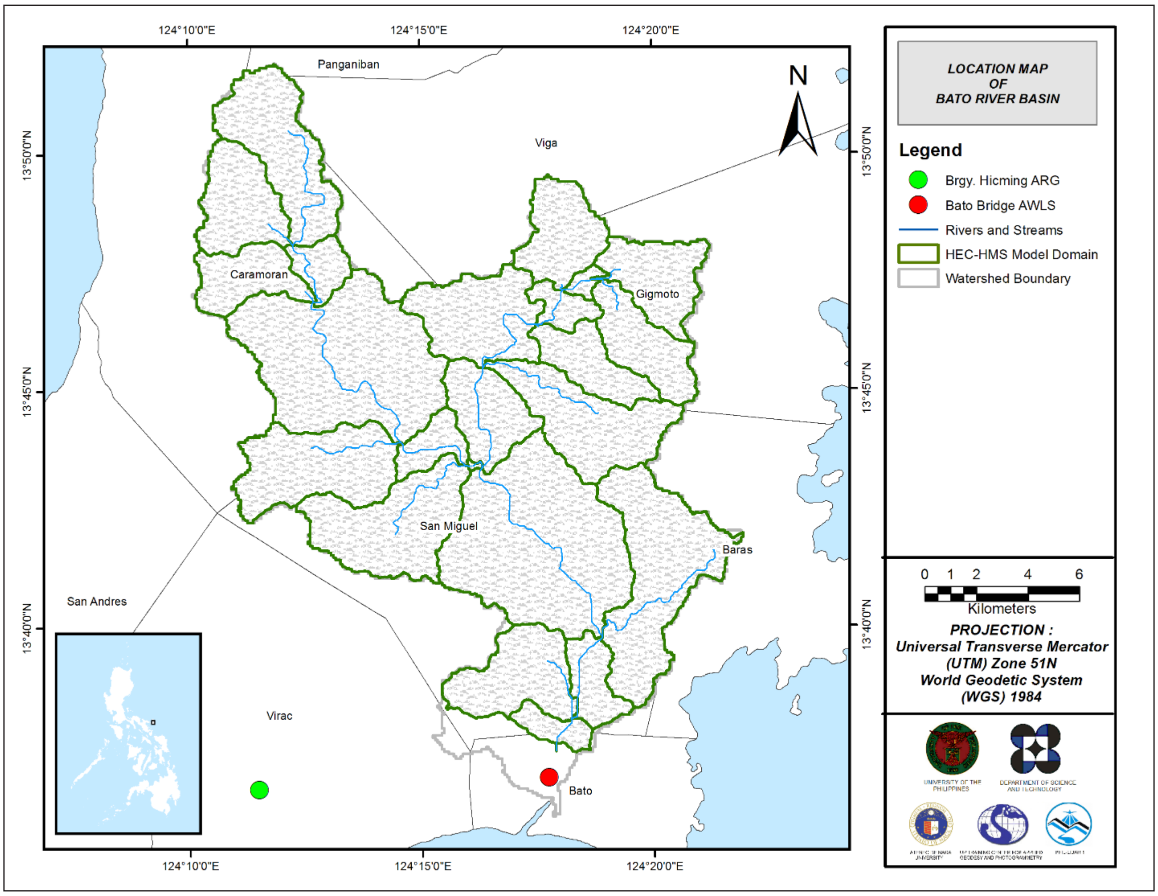


Figure 46. The location map of Bato HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Bato Bridge, Bato, Catanduanes (13°36’48.24”N, 124°17’43.47”E). It gives the relationship between the observed water levels at Bato Bridge and outflow of the watershed at this location.

For Bato Bridge, the rating curve is expressed as Q=22.372e0.5584h as shown in Figure 48.

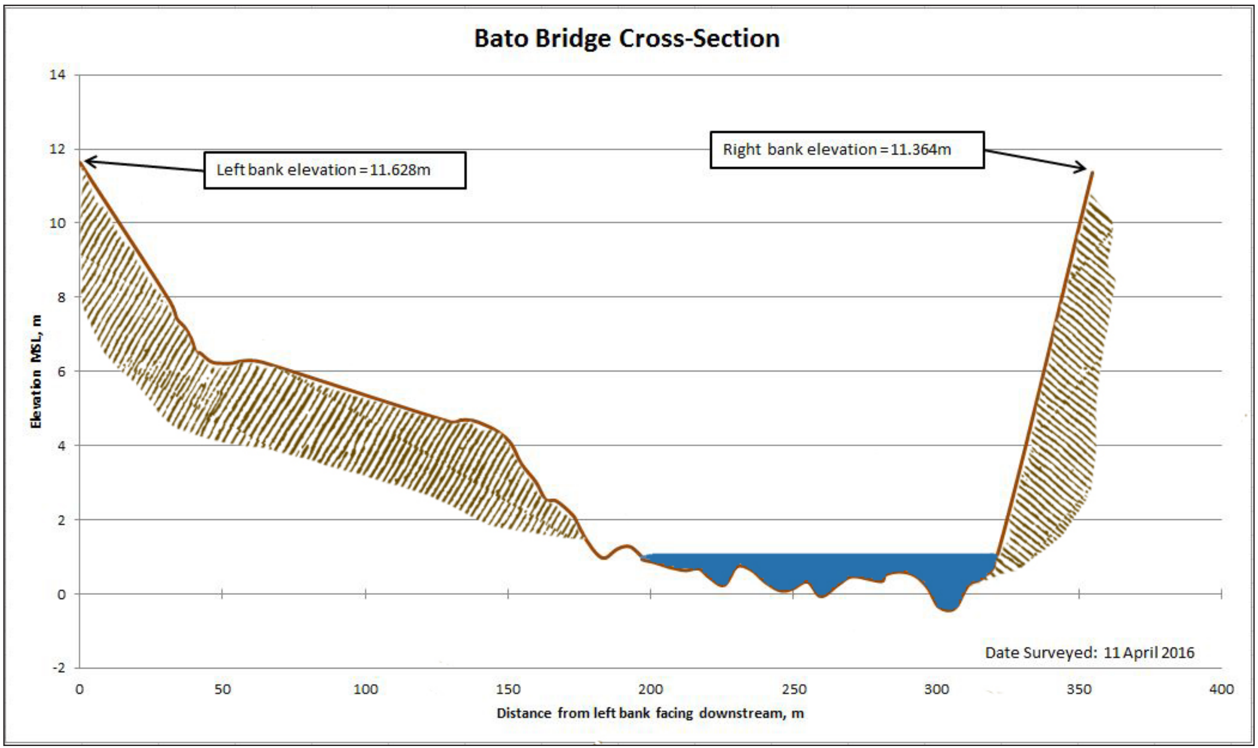


Figure 47. Cross-Section Plot of Bato Bridge

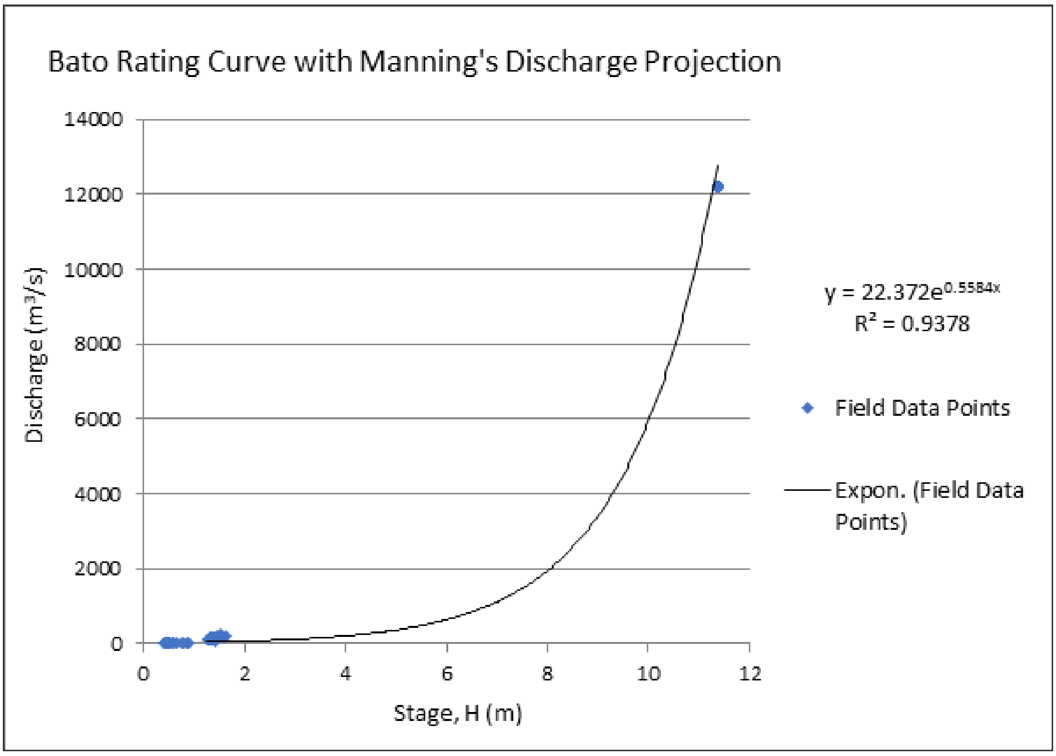


Figure 48. The rating curve for Bato Bridge in Bato, Catanduanes

This rating curve equation was used to compute the river outflow at Bato Bridge for the calibration of the HEC-HMS model shown in Figure 49. The total rainfall for this event is 355mm and the peak discharge is 116.96 m^3/s at 1:00 PM, October 15, 2016.

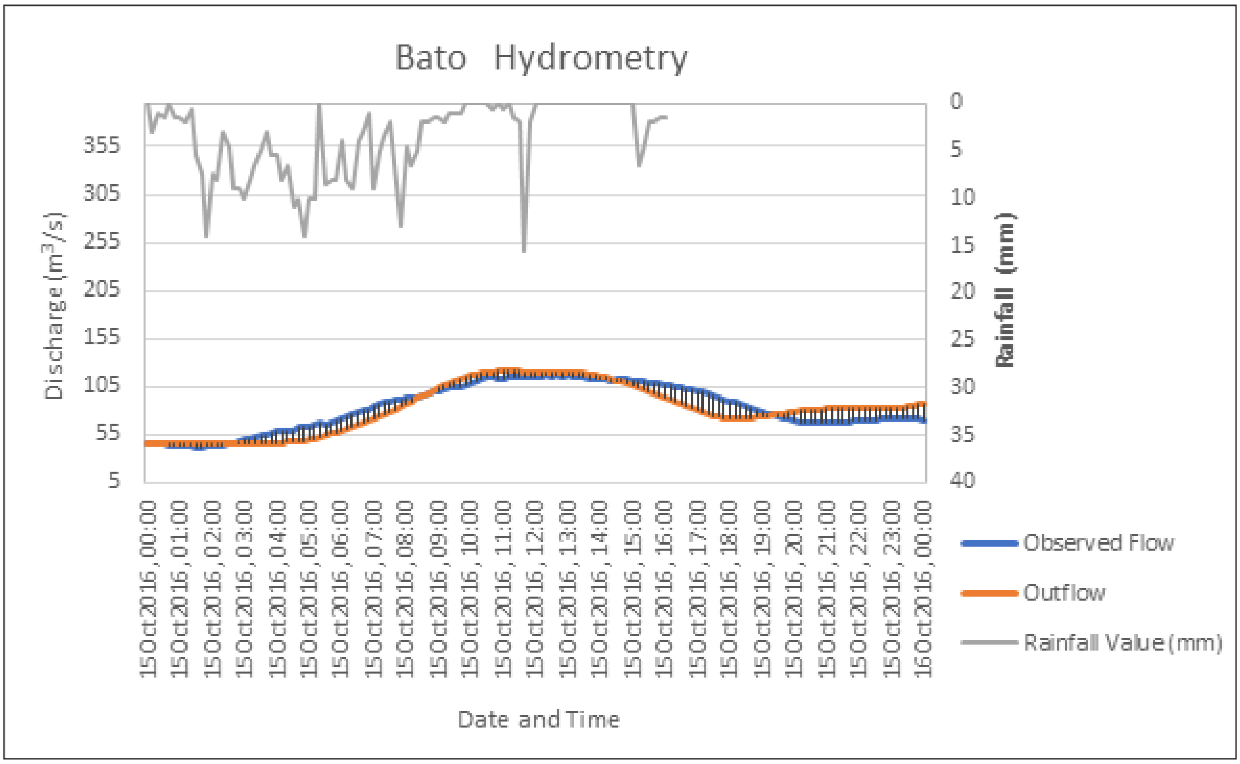


Figure 49. Rainfall and outflow data of the Bato River Basin, which was used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Virac 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 Bato watershed. The extreme values for this watershed were computed based on a 26-year record.

Table 26. RIDF values for Virac Rain Gauge computed by PAG-ASA

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	24	36.2	44.9	60	85.1	100.5	133.3	167.2	195.6
5	35.2	52.7	65.5	87.6	126.6	150.8	200.7	251.3	297
10	42.7	63.6	79.2	105.9	154.1	184.1	245.3	307.1	364.1
15	46.8	69.7	86.9	116.2	169.6	202.8	270.5	338.5	402
20	49.8	74	92.3	123.4	180.4	216	288.1	360.5	428.6
25	52	77.3	96.4	129	188.8	226.1	301.7	377.4	449
50	59	87.5	109.2	146.1	214.6	257.4	343	429.7	511.9
100	65.9	97.7	122	163.1	240.1	288.3	385	481.5	574.4

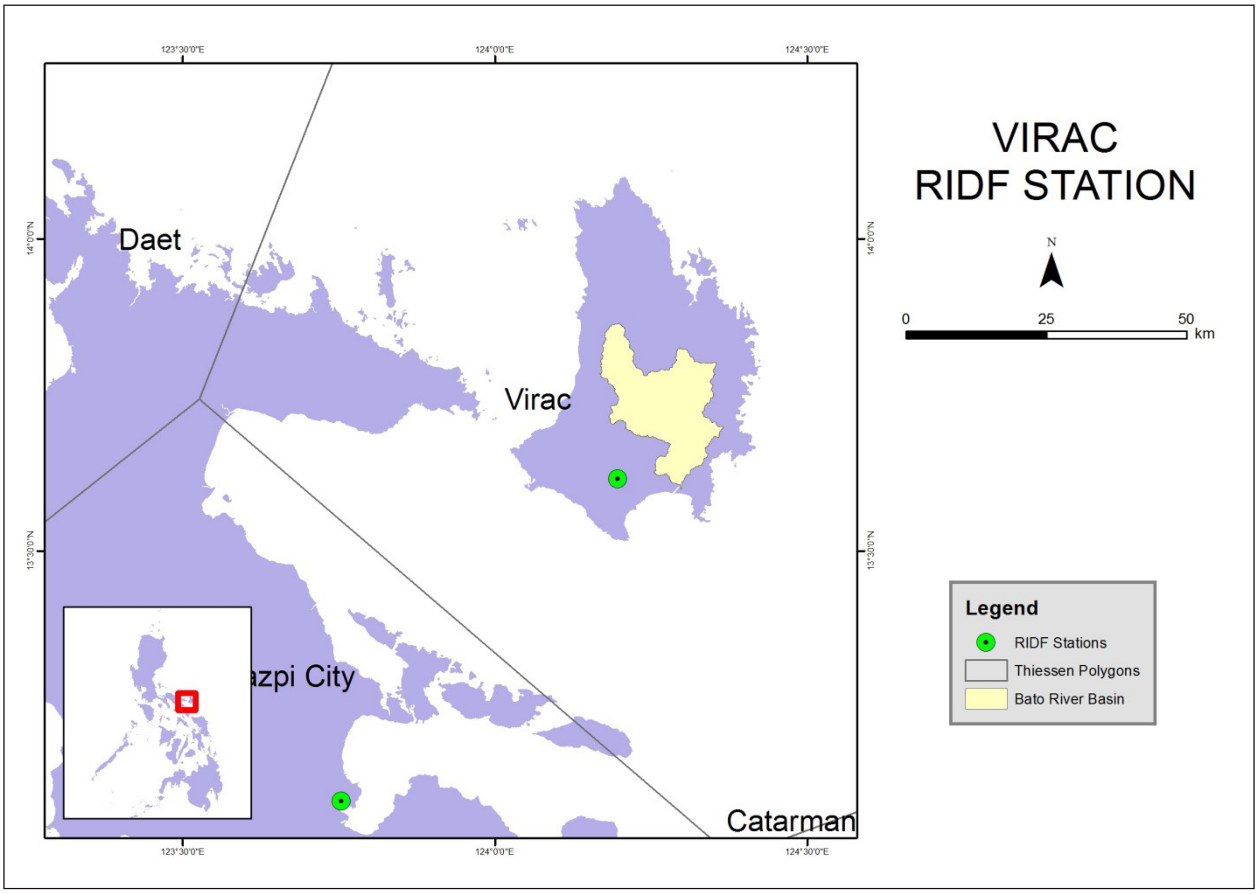


Figure 50. The location of the Virac RIDF station relative to the Bato River Basin

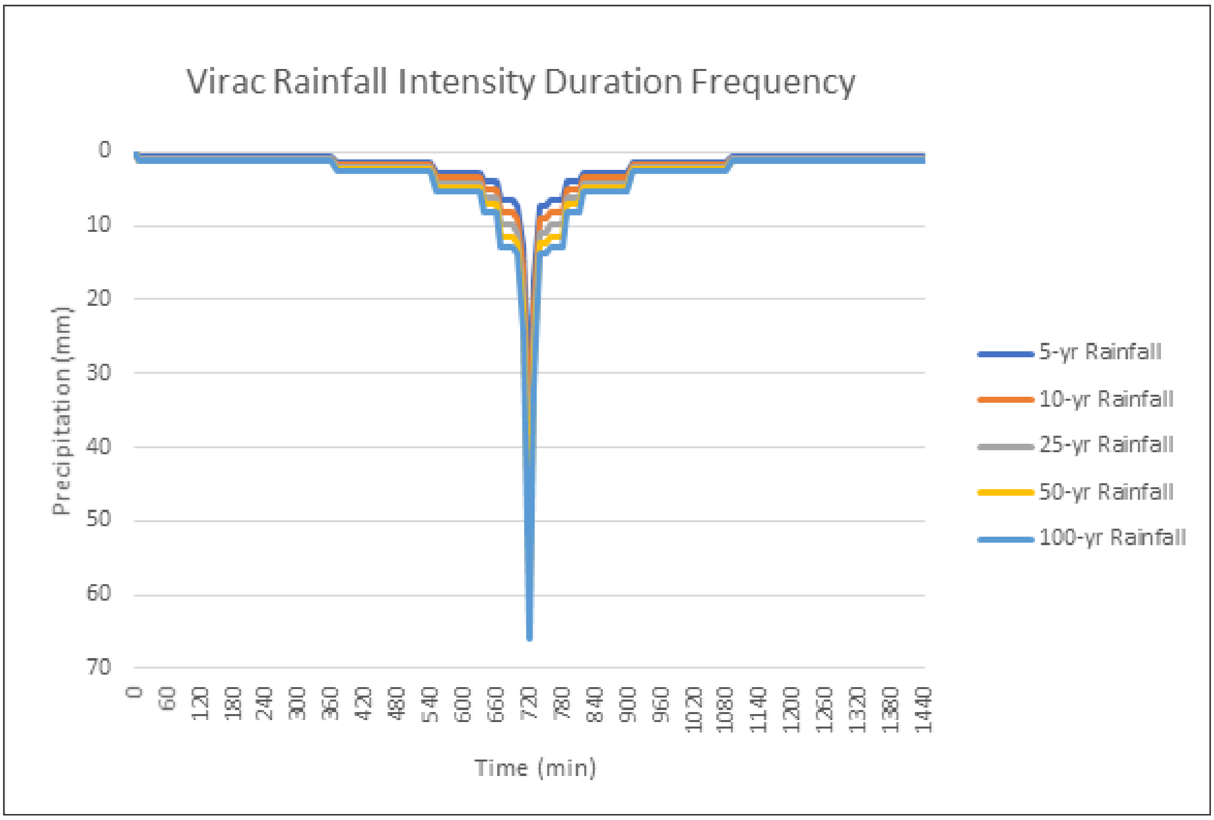


Figure 51. The synthetic storm generated for a 24-hour period rainfall for various return periods

5.3 HMS Model

The soil shapefile was taken on 2004 from the Bureau of Soils; this is under the Department of Environment and Natural Resources Management (DENR). The land cover shape file is from the National Mapping and Resource Information Authority (NAMRIA). The soil and land cover of the Bato River Basin are shown in Figures 7 and 8, respectively.

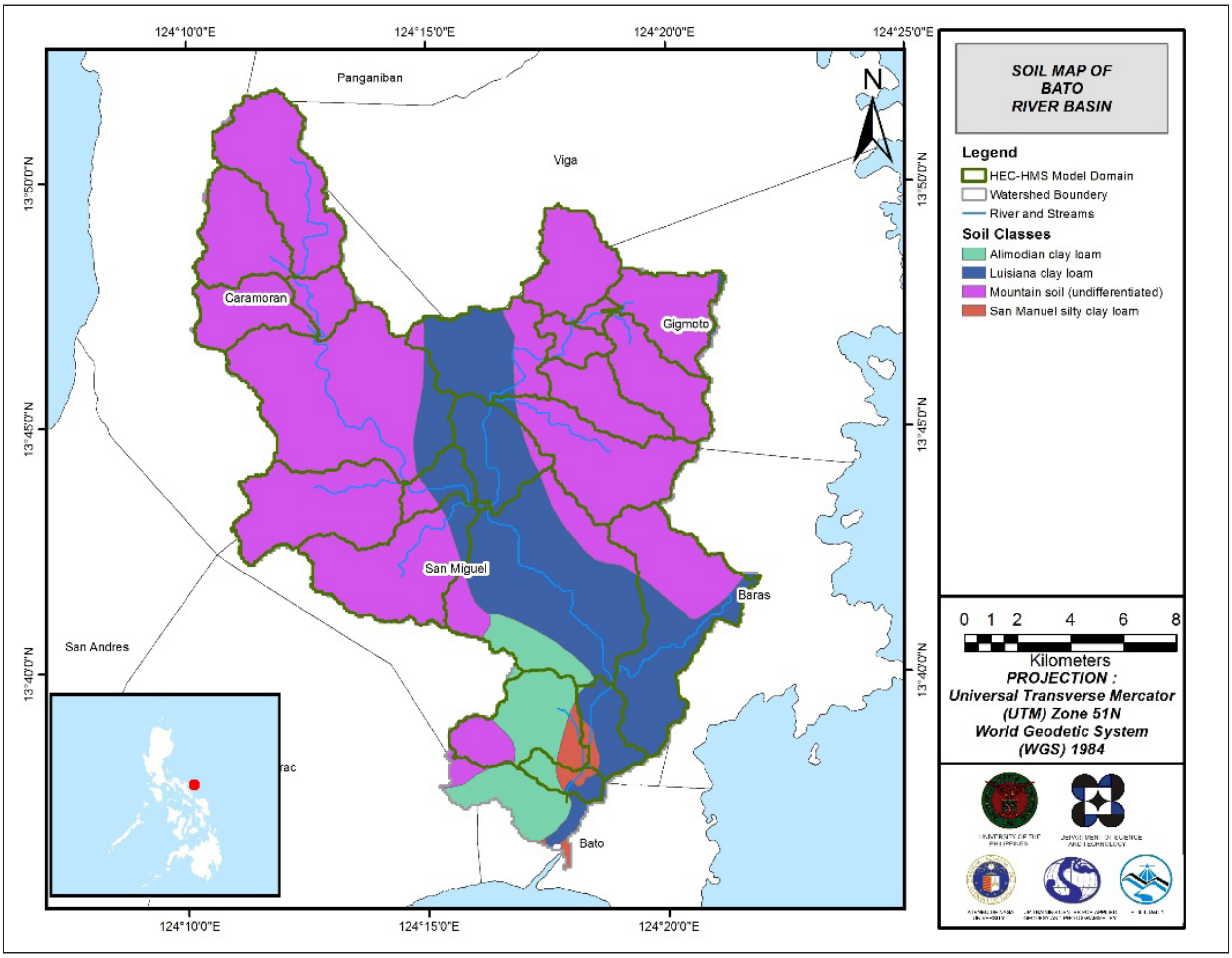


Figure 52. Soil map of Bato River Basin

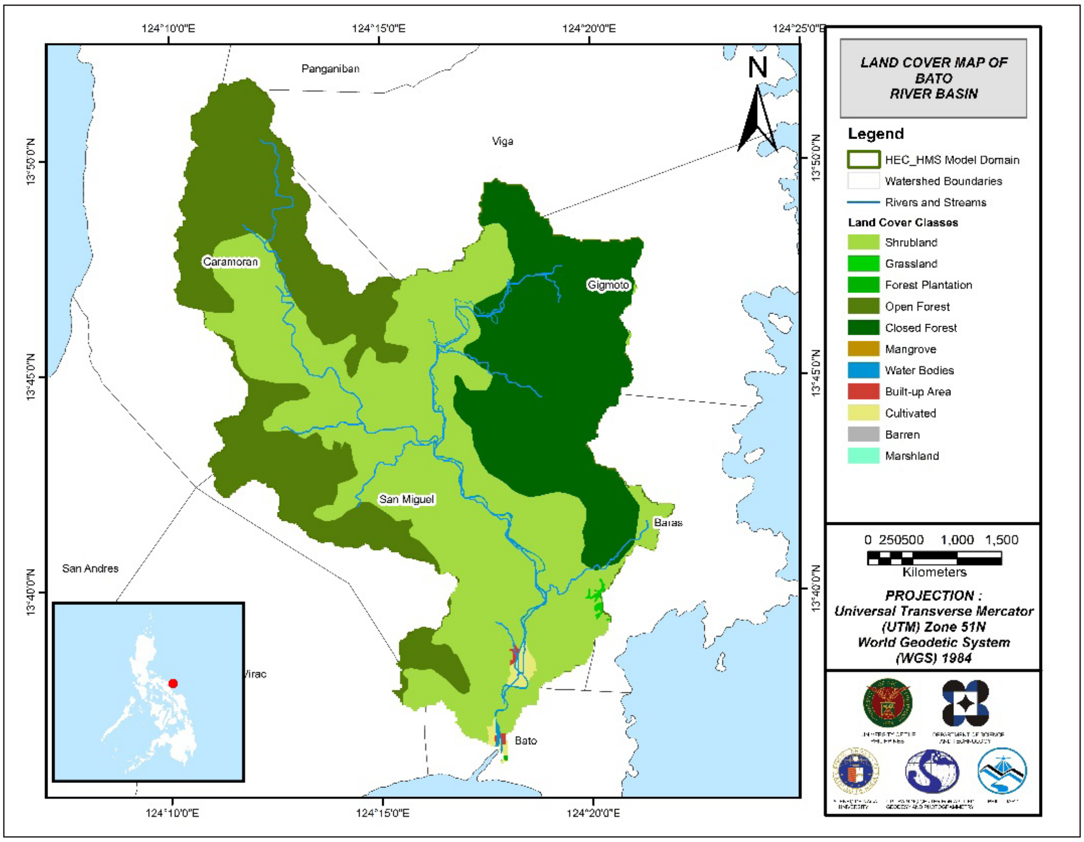


Figure 53. Land cover map of Bato River Basin

For Bato, four soil classes were identified. These are Alimodian clay loam, Luisiana clay loam, San Manuel silty clay loam, and undifferentiated mountain soil. Moreover, six land cover classes were identified. These are shrubland, grassland, open and closed forests, cultivated, and built-up areas.

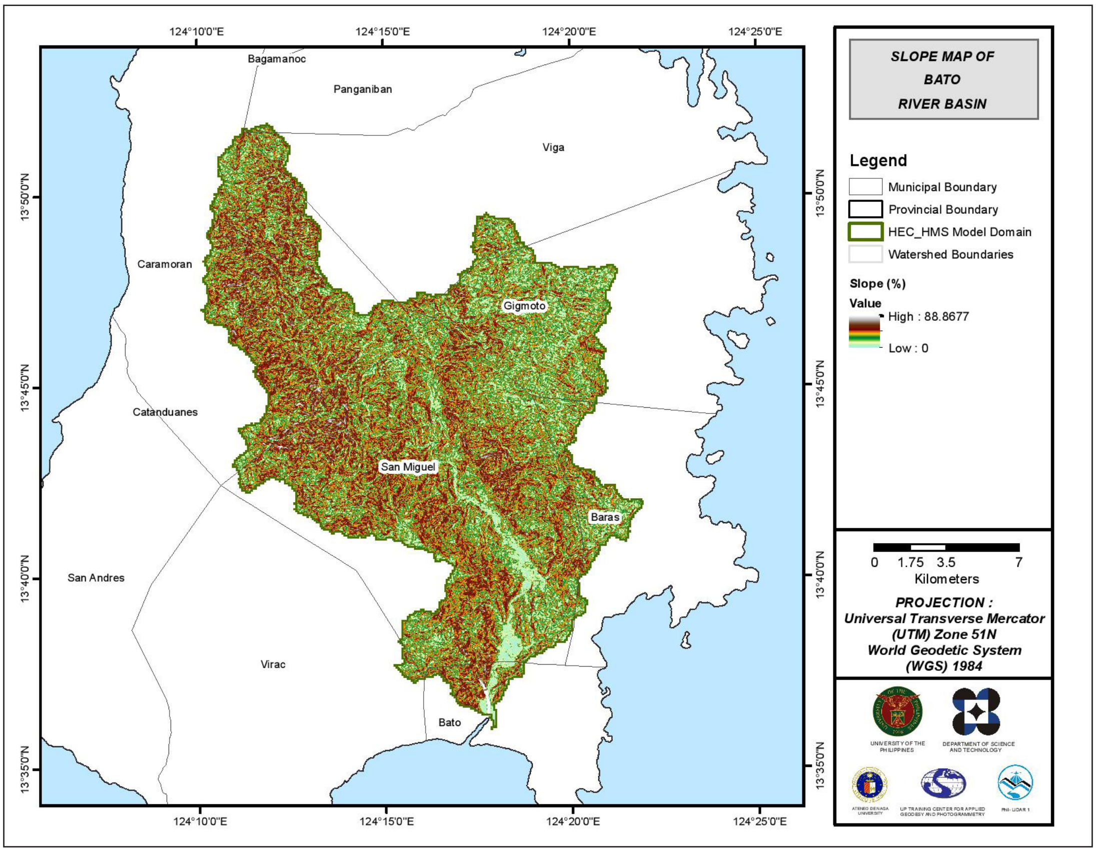


Figure 54. Slope map of Bato River Basin

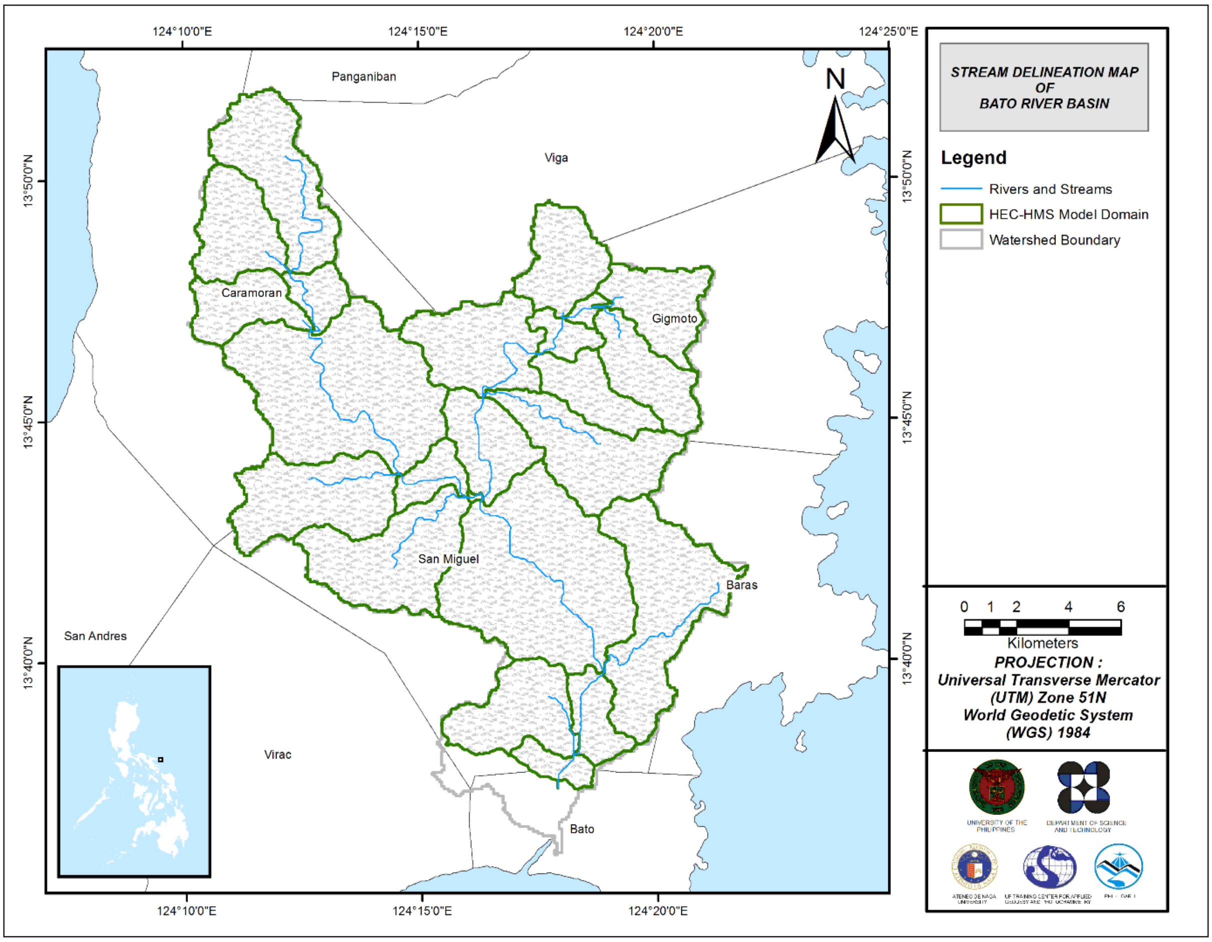


Figure 55. Stream delineation map of Bato River Basin

Using the SAR-based DEM, the Bato basin was delineated and further divided into subbasins. The model consists of 23 sub basins, 11 reaches, and 11 junctions, as shown in Figure 11. The main outlet is Bato Bridge.

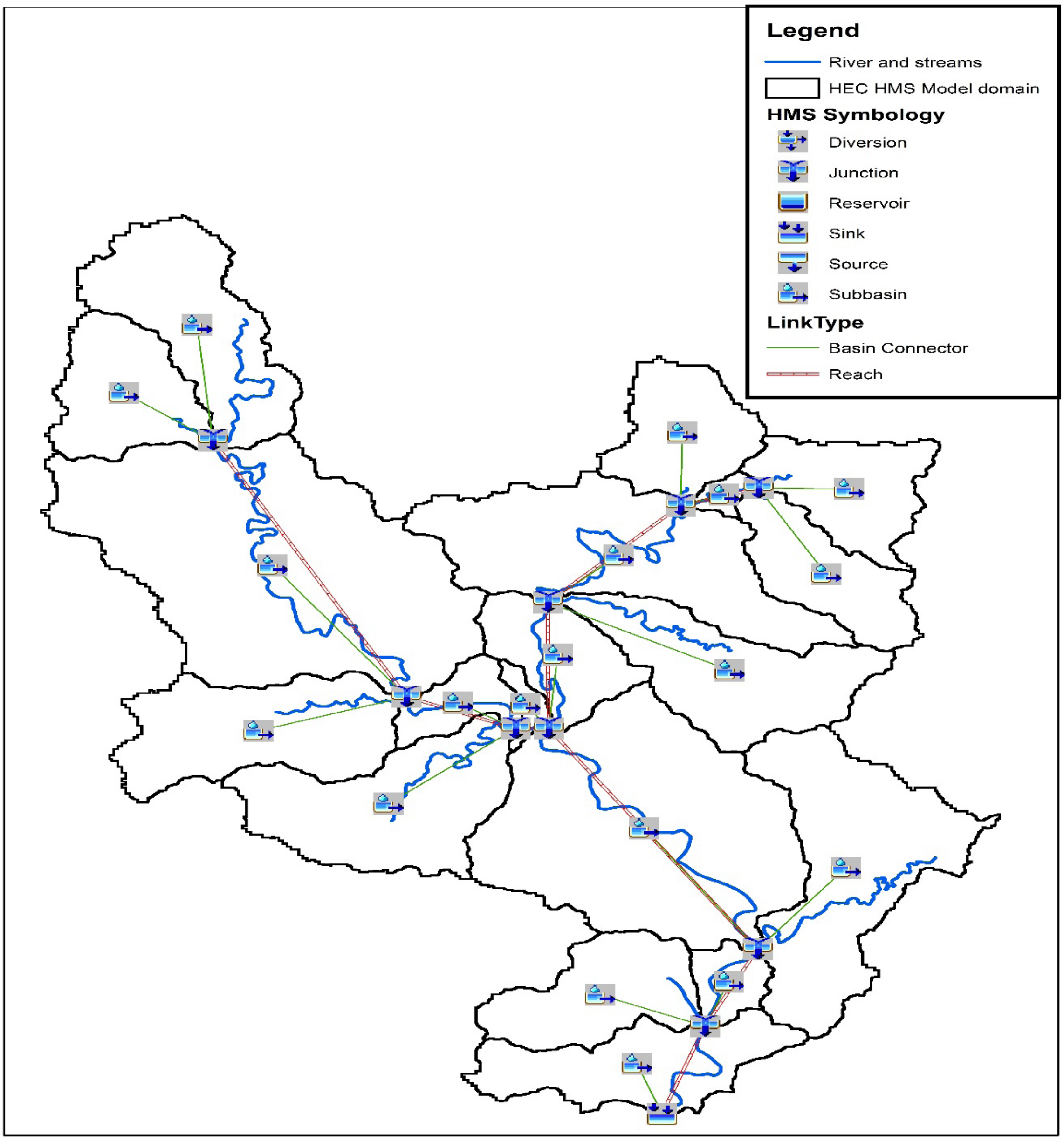


Figure 56. The Bato River Basin model generated in HEC-HMS

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.

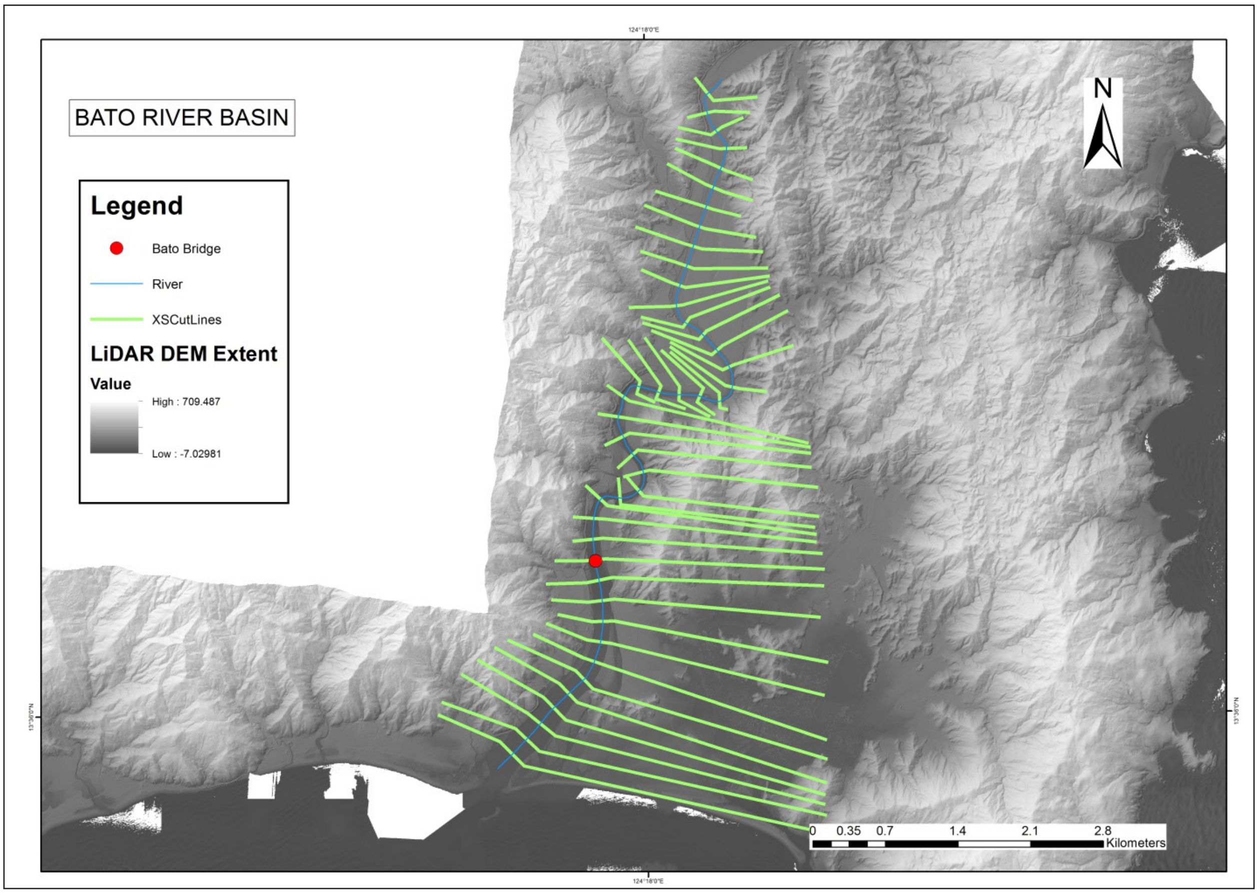


Figure 57. River cross-section of Bato River generated through Arcmap HEC GeoRAS tool

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

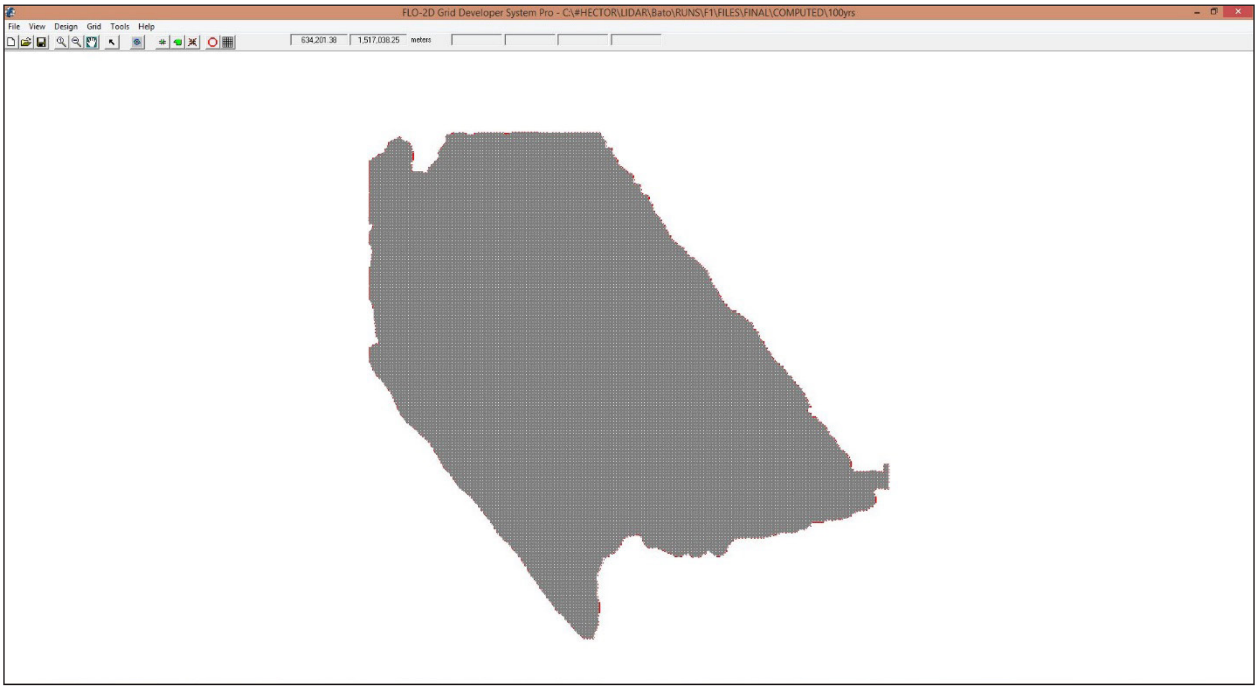


Figure 58. Screenshot of subcatchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 69.41797 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum *h* (Maximum depth) is set at 0.2 m while the minimum *vh* (Product of maximum velocity *(v)* times maximum depth *(h)*) is set at 0 m^2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 21,687,800.00m^2. The generated hazard maps for Bato are in Figures 18, 20, and 22.

There is a total of 104,163,225.63m^3 of water entering the model. Of this amount, 12,219,345.75m^3 is due to rainfall while 91,943,879.88m^3 is inflow from other areas outside the model. 2,077,400.12m^3 of this water is lost to infiltration and interception, while 2,719,424.53m^3 is stored by the flood plain. The rest, amounting up to 99,366,389.03m^3, is outflow. The generated flood depth maps for Bato are in Figures 19, 21, and 23.

5.6 Results of HMS Calibration

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

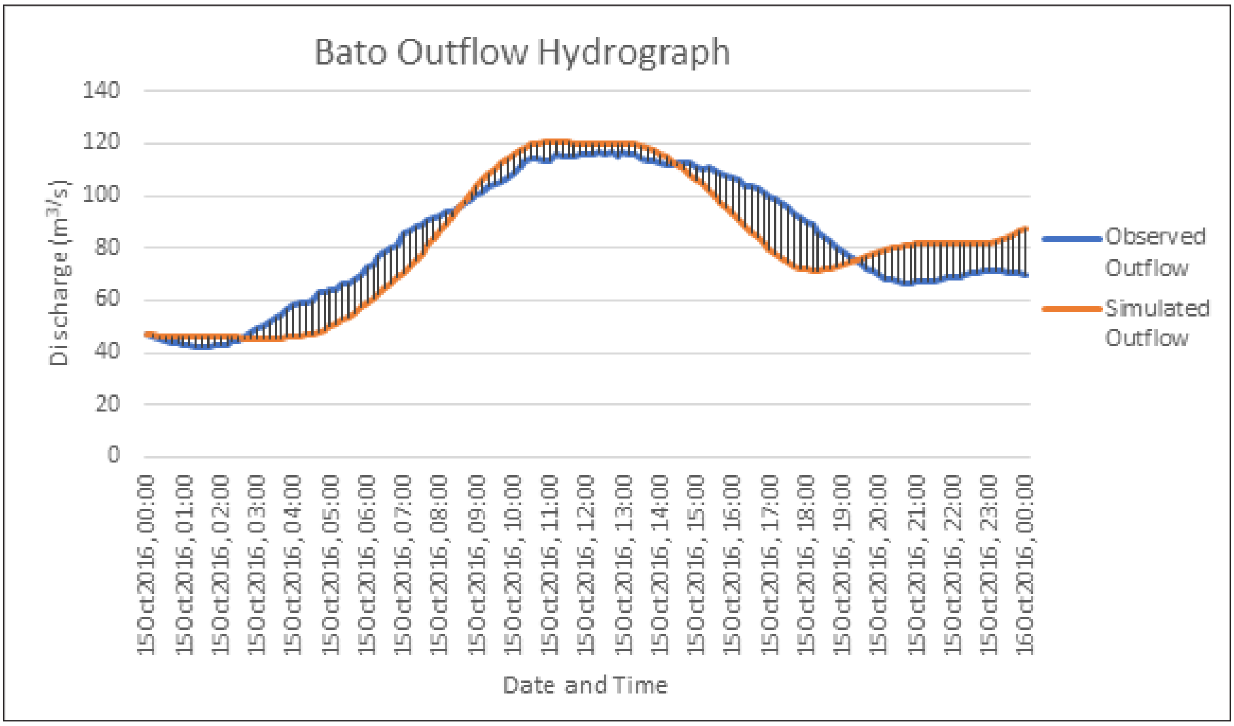


Figure 59. Outflow Hydrograph of Bato produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 2 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 27. Range of Calibrated Values for Bato

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.005 - 490
			Curve Number	35 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.02 - 545
			Storage Coefficient (hr)	0.06 - 473
	Baseflow	Recession	Recession Constant	0.00001 - 0.1
			Ratio to Peak	0.0001 - 1
Reach	Routing	Muskingum-Cunge	Slope	0.0006 - 0.02
			Manning's n	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 0.005 mm to 490 mm means that there is minimal to high amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 35 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 Bato, the basin mostly consists of shrubland and the soil consists of undifferentiated mountain soil, Luisiana clay loam, and Alimodian clay loam.

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 545 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 Bato, it will take at least 7 hours from the peak discharge to go back to the initial discharge.

Manning's roughness coefficient of 0.0001 corresponds to the common roughness of Philippine watersheds. Bato river basin is determined to be built-up area that is concrete and float-finished (Brunner, 2010).

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

Accuracy Measure	Value
RMSE	10.47
r^2	0.84
NSE	0.81
PBIAS	1.57
RSR	0.43

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 10.47 (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 0.84.

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 0.81.

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 1.57.

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 0.43.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 60) shows the Bato outflow using the synthetic storm events using the Virac 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 126.6m^3/s in a 5-year return period to 290.1m^3/s in a 100-year return period.

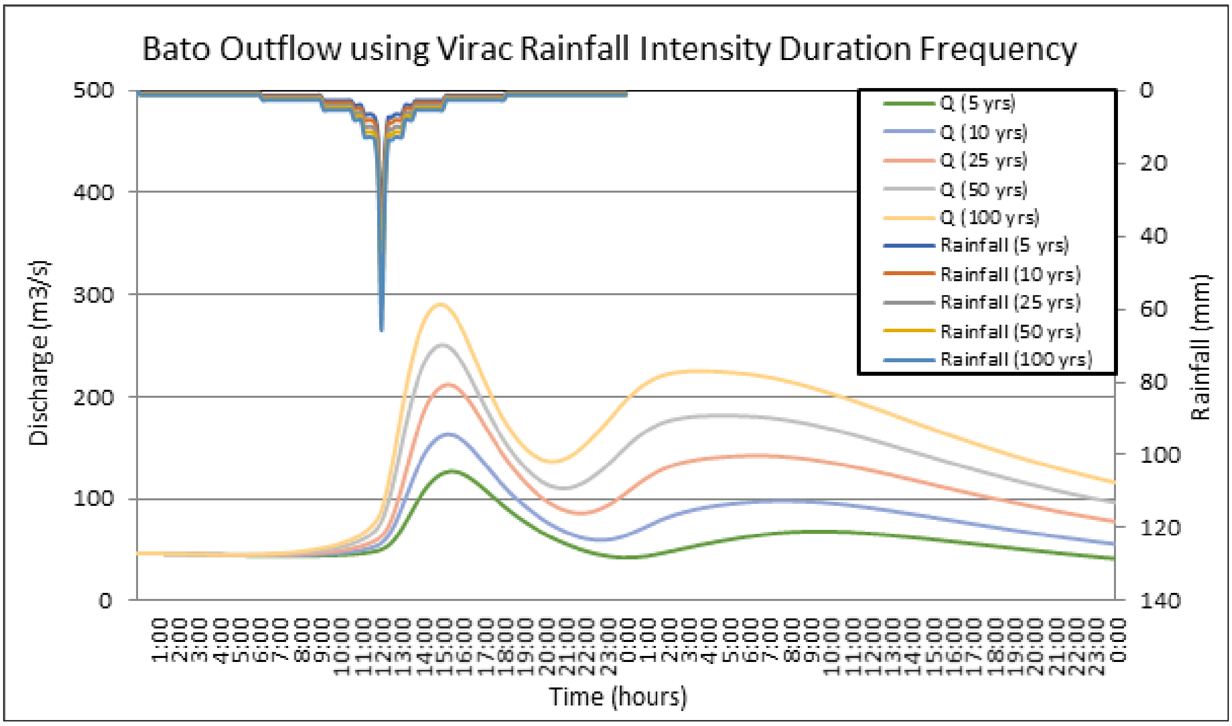


Figure 60. The outflow hydrograph at the Bato Basin, generated using the simulated rain events for 24-hour period for Virac station

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

Table 29. Peak values of the Bato HEC-HMS Model outflow using the Virac RIDF 24-hour values

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak
5-Year	297	35.2	126.6	3 hours, 30 minutes
10-Year	364.1	42.7	162.8	3 hours, 20 minutes
25-Year	449	52	211.7	3 hours, 20 minutes
50-Year	511.9	59	250.5	3 hours
100-Year	574.4	65.9	290.1	2 hours, 50 minutes

Discharge Values using Dr. Horritt's Recommended Hydrological Method

The river discharges for the two rivers entering the flood plain are shown in Figure 16 and the peak values are summarized in Table 30.

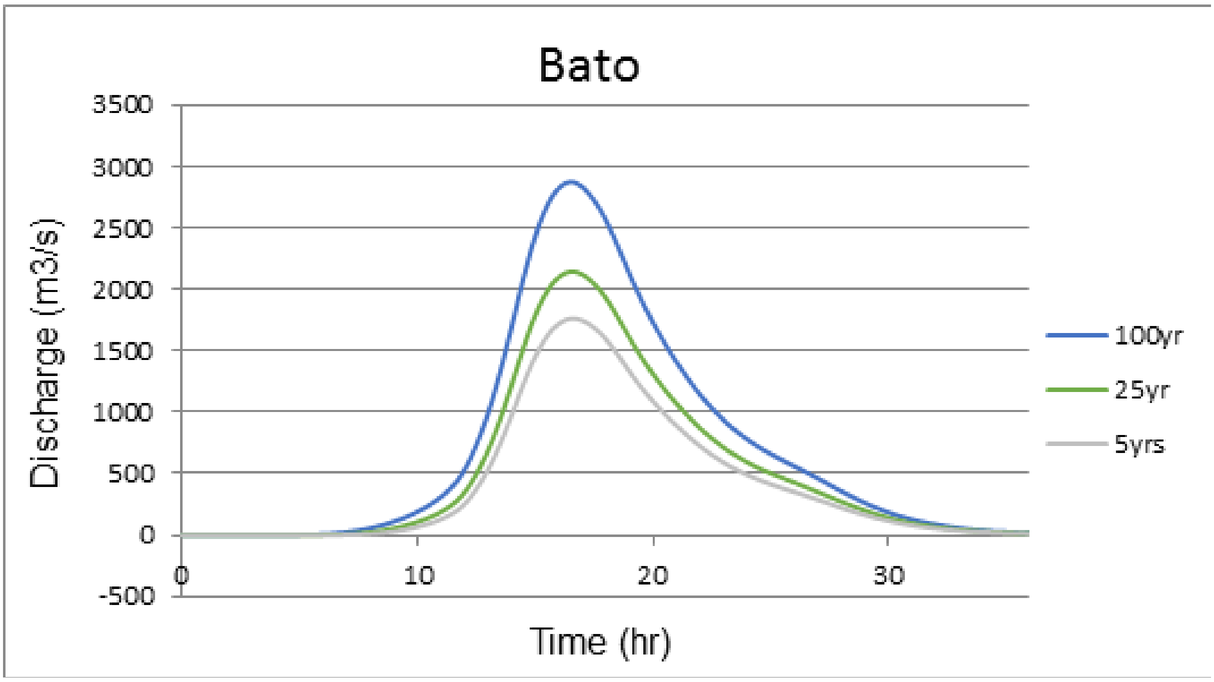


Figure 61. Bato River generated discharge using interpolated 5-, 25-, and 100-year Virac rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 30. Summary of Bato river discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	2875.6	16 hours, 30 minutes
25-Year	2146	16 hours, 30 minutes
5-Year	1763.3	16 hours, 40 minutes

Table 31. alidation of river discharge estimates

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Bato	1551.704	1236.947	966.360	PASS	FAIL

From HEC-HMS river discharge estimate, it was able to satisfy the conditions for validation using the bankful discharge methods only while it did not pass specific discharge methods and will need further recalculation. These values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown, since only the ADNU-DVC base flow was calibrated. Figure 62 shows a generated sample map of the Bato River using the calibrated HMS base flow.

Figure 62. The sample output map of the Bato RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figures 18 to 23 show the 5-, 25-, and 100-year rain return scenarios of the Bato flood plain. The flood plain, with an area of 76.92km^2, covers four (4) municipalities, namely Baras, Bato, San Miguel, and Virac. Table 32 shows the percentage of area affected by flooding per municipality.

Table 32. Municipalities affected in Bato flood plain

Municipality	Total Area (km^2)	Area Flooded (km^2)	% Flooded
Baras	75.39	0.08	0.11
Bato	45.83	29.22	63.77
San Miguel	174.25	47.6	27.32
Virac	175.3	0.006	0.0003

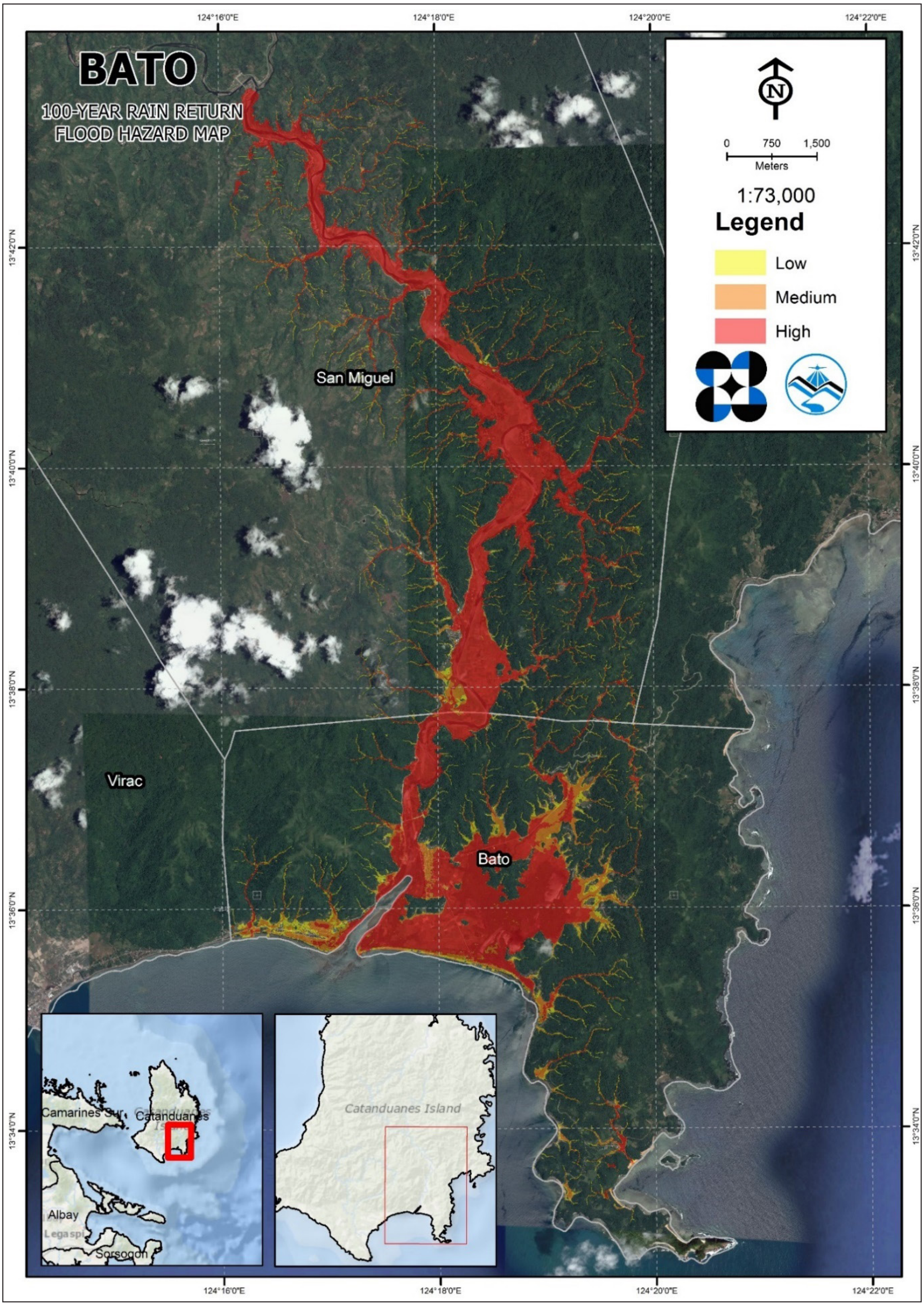


Figure 63. 100-year flood hazard map for the Bato flood plain overlaid on Google Earth imagery

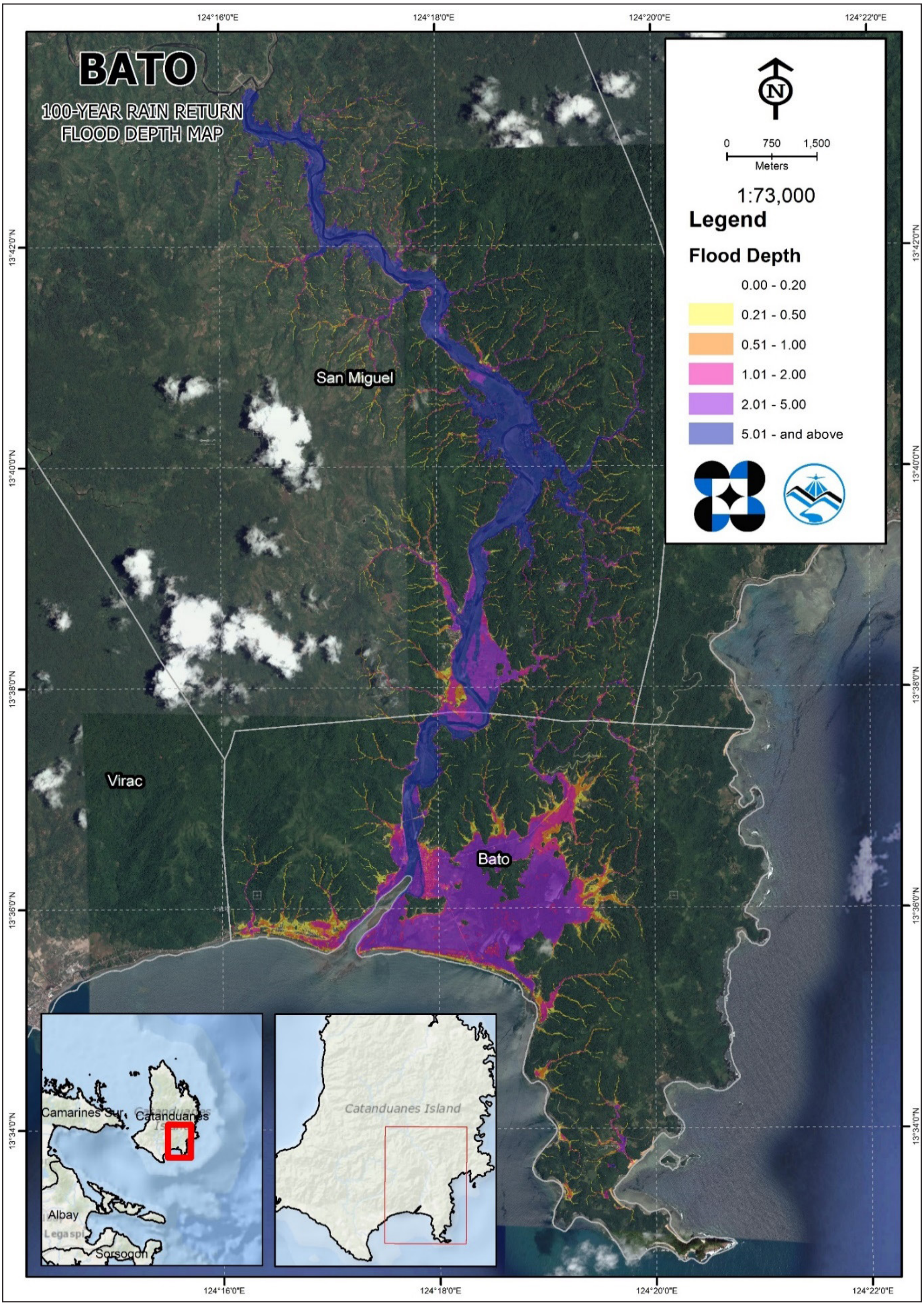


Figure 64. 100-year flow depth map for the Bato flood plain overlaid on Google Earth imagery

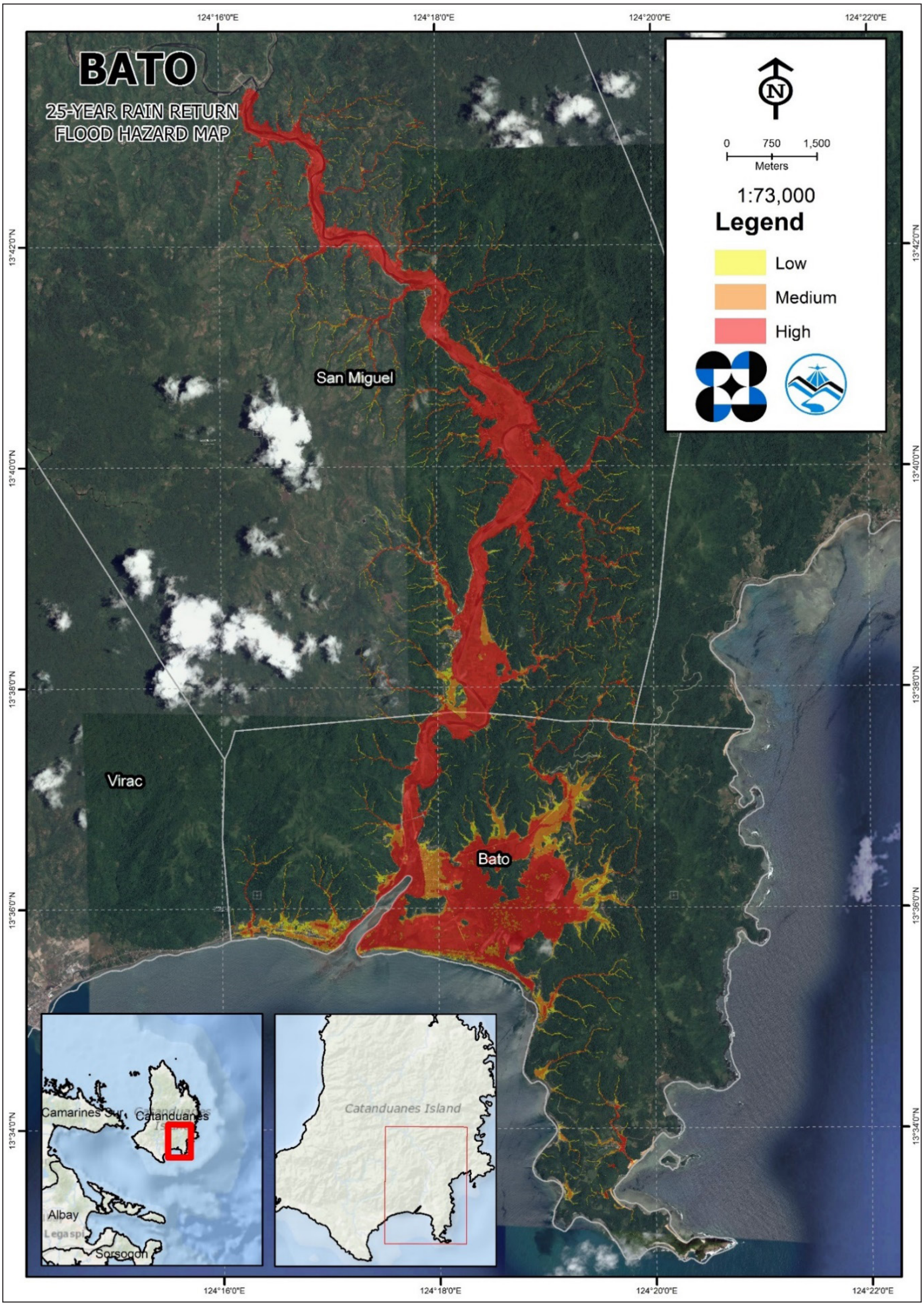


Figure 65. 25-year flood hazard map for the Bato flood plain overlaid on Google Earth imagery

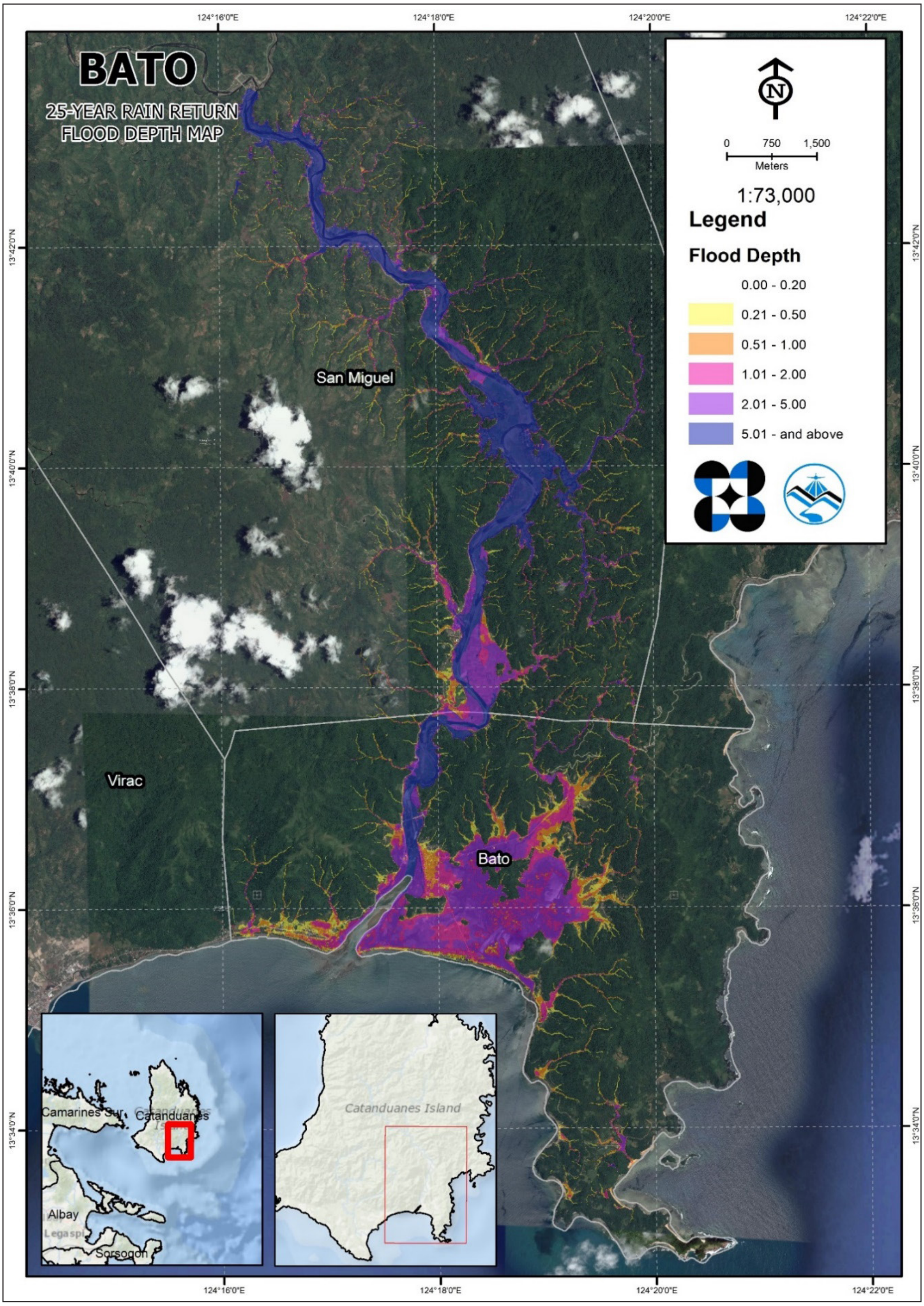


Figure 66. 25-year flow depth map for the Bato flood plain overlaid on Google Earth imagery

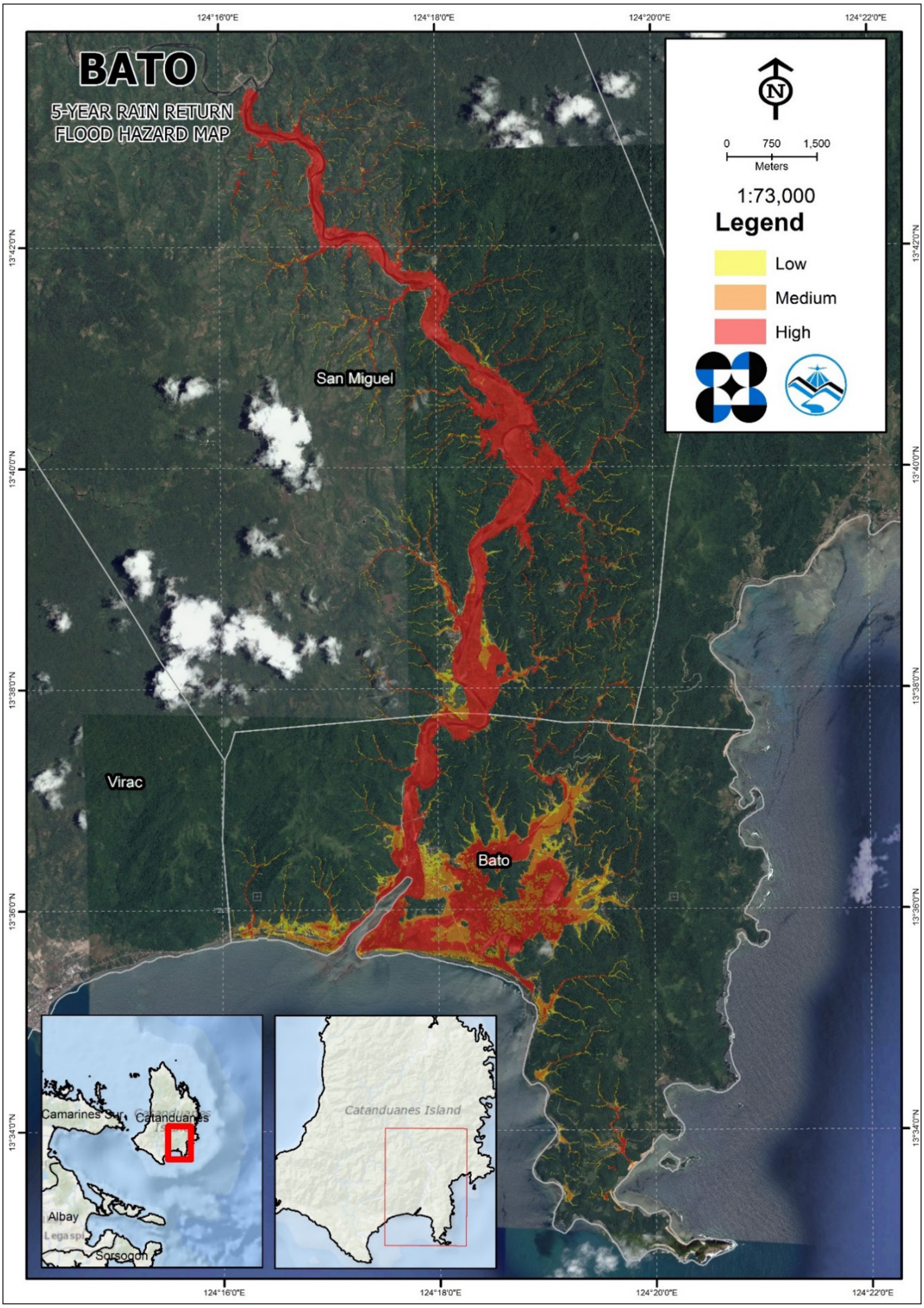


Figure 67. 5-year flood hazard map for the Bato flood plain overlaid on Google Earth imagery

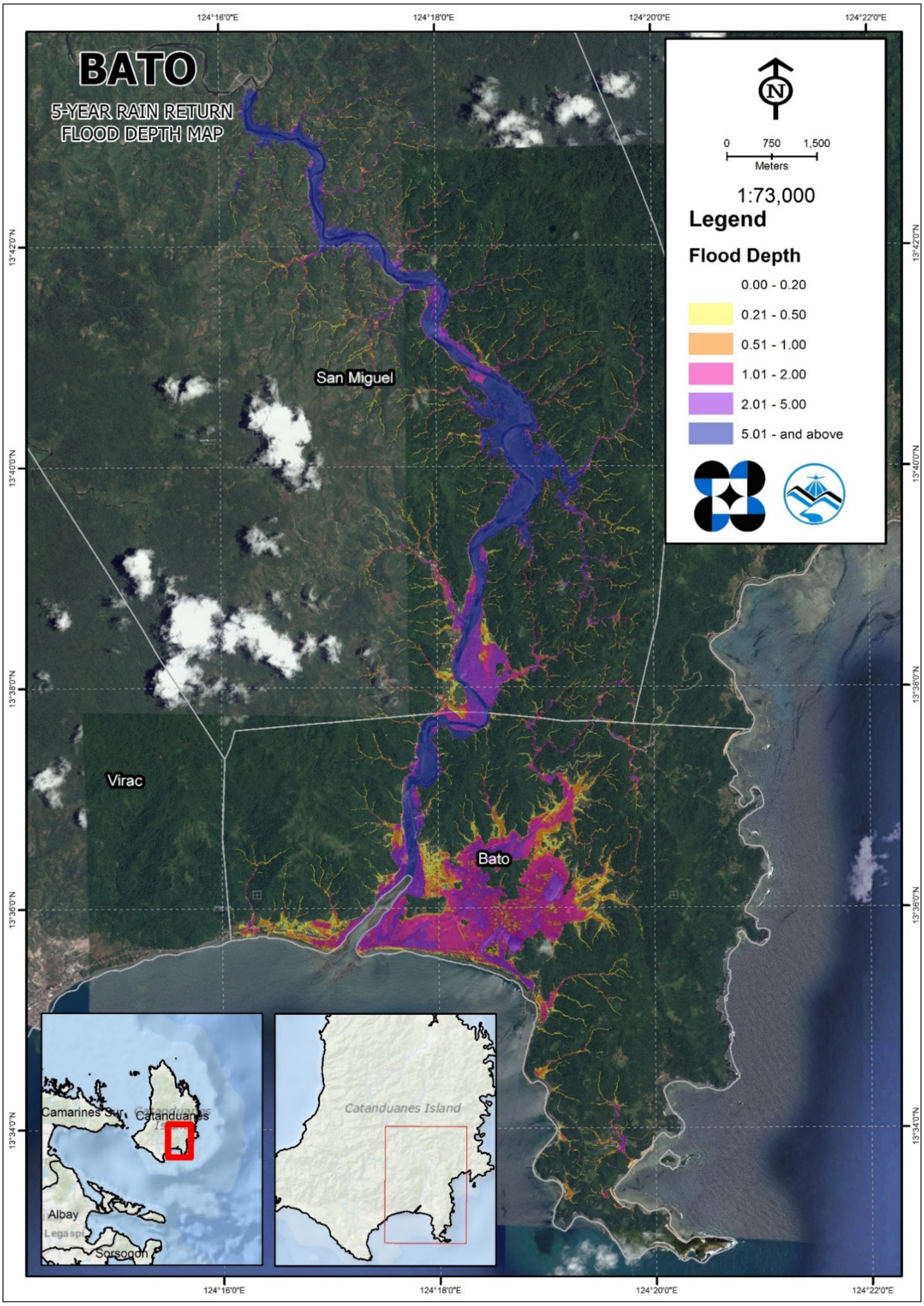


Figure 68. 5-year flow depth map for the Bato flood plain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Bato River basin, grouped accordingly by municipality. For the said basin, four (4) municipalities consisting of 49 barangays are expected to experience flooding when subjected to the three scenarios of rainfall return period.

For the 5-year rainfall return period, 0.11% of the municipality of Baras with an area of 75.39 sq. km. will experience flood levels of less than 0.20 meters. 0.002% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.0007%, 0.0004%, and 0.0003% 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. Table 32 depicts the areas affected in Baras in square kilometers by flood depth per barangay.

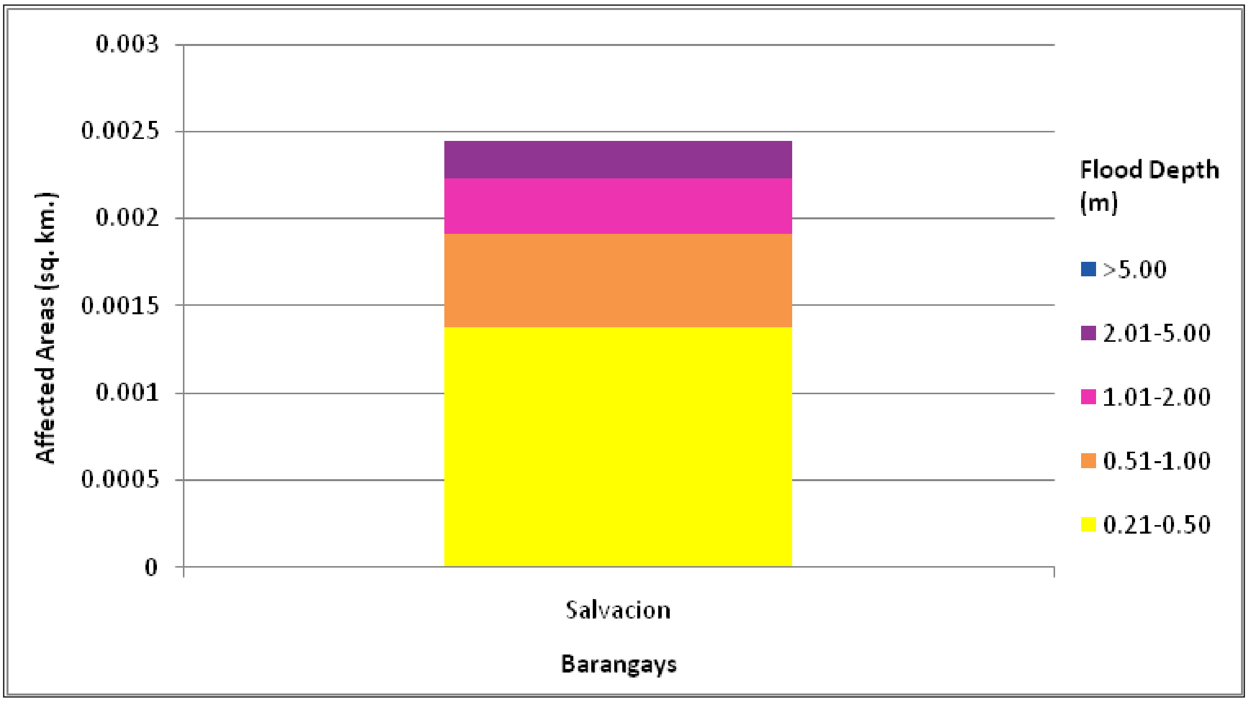


Figure 69. Affected Areas in Baras, Catanduanes during the 5-year Rainfall Return Period

For the municipality of Bato with an area of 45.83 sq. km., 44.1% will experience flood levels of less than 0.20 meters. 3.38% of the area will experience flood levels of 0.21 to 0.50 meters, while 3.65%, 6.93%, 4.1%, and 1.58% 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. Tables 9 and 10 depict the areas affected in Bato in square kilometers by flood depth per barangay.

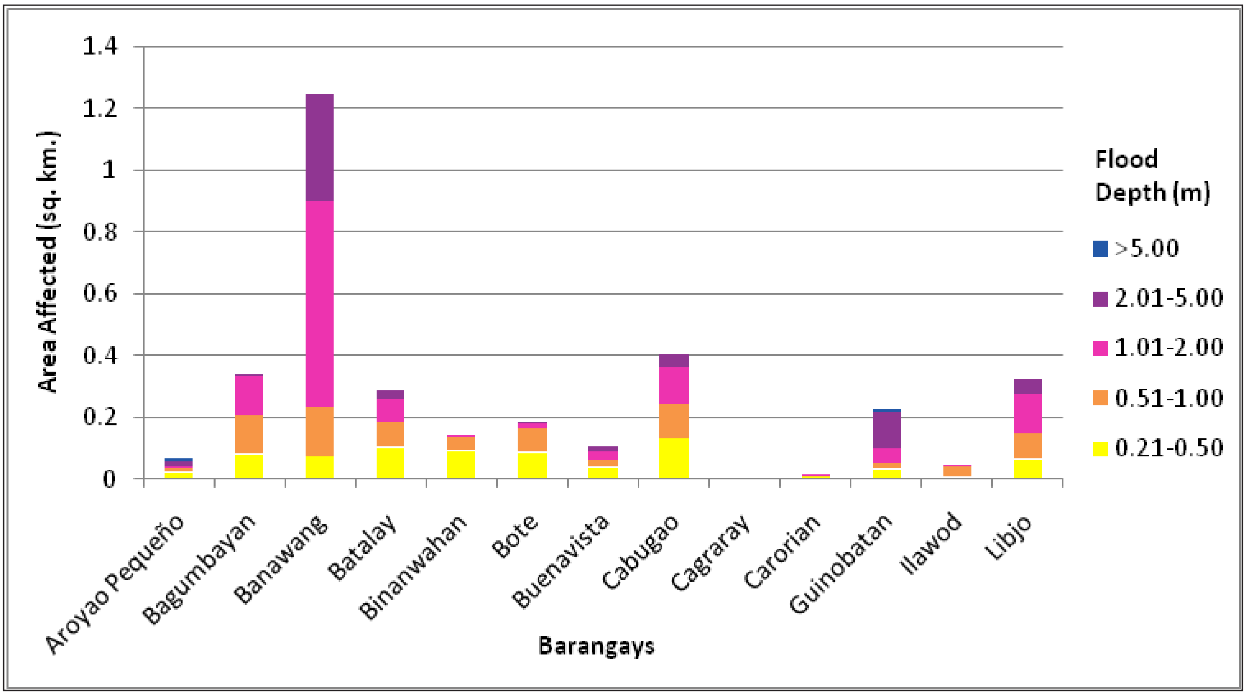


Figure 70. Affected Areas in Bato, Catanduanes during the 5-year Rainfall Return Period

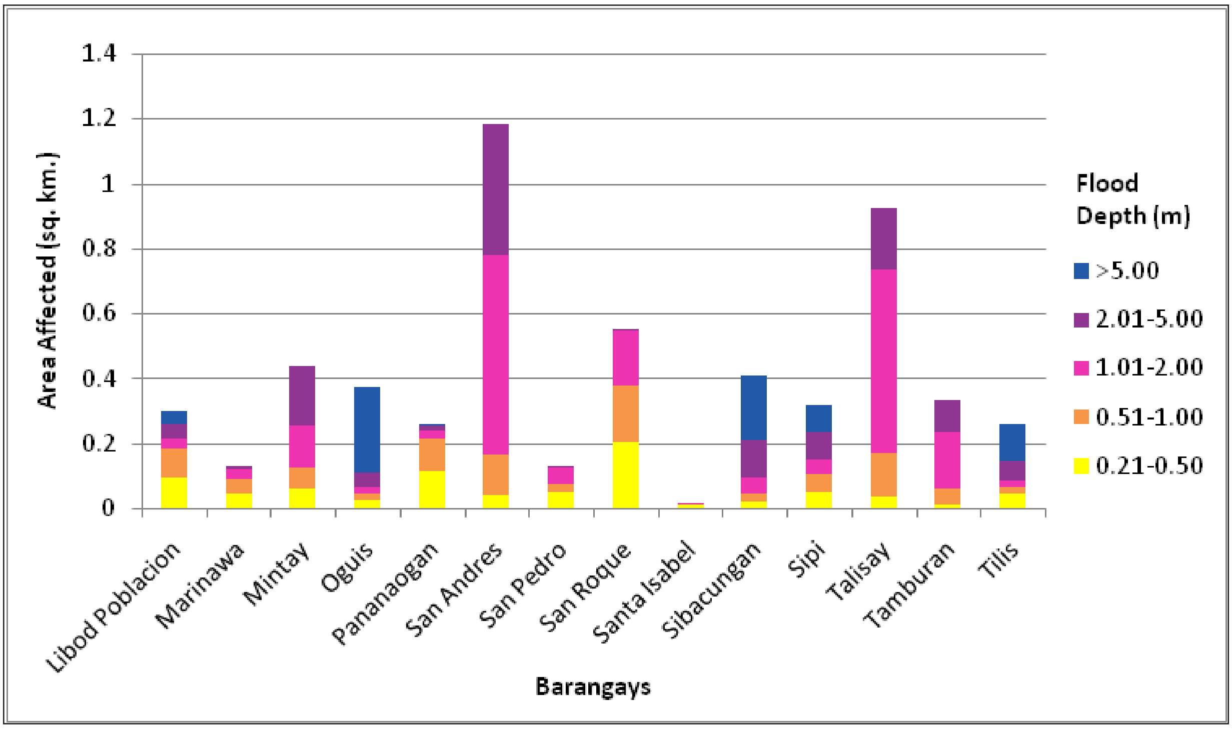


Figure 71. Affected Areas in Bato, Catanduanes during the 5-year Rainfall Return Period

For the municipality of San Miguel with an area of 174.25 sq. km., 22.37% will experience flood levels of less than 0.20 meters. 0.78% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.5%, 0.49%, 0.94%, and 2.28% 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. Tables 11 and 12 depict the areas affected in San Miguel in square kilometers by flood depth per barangay.

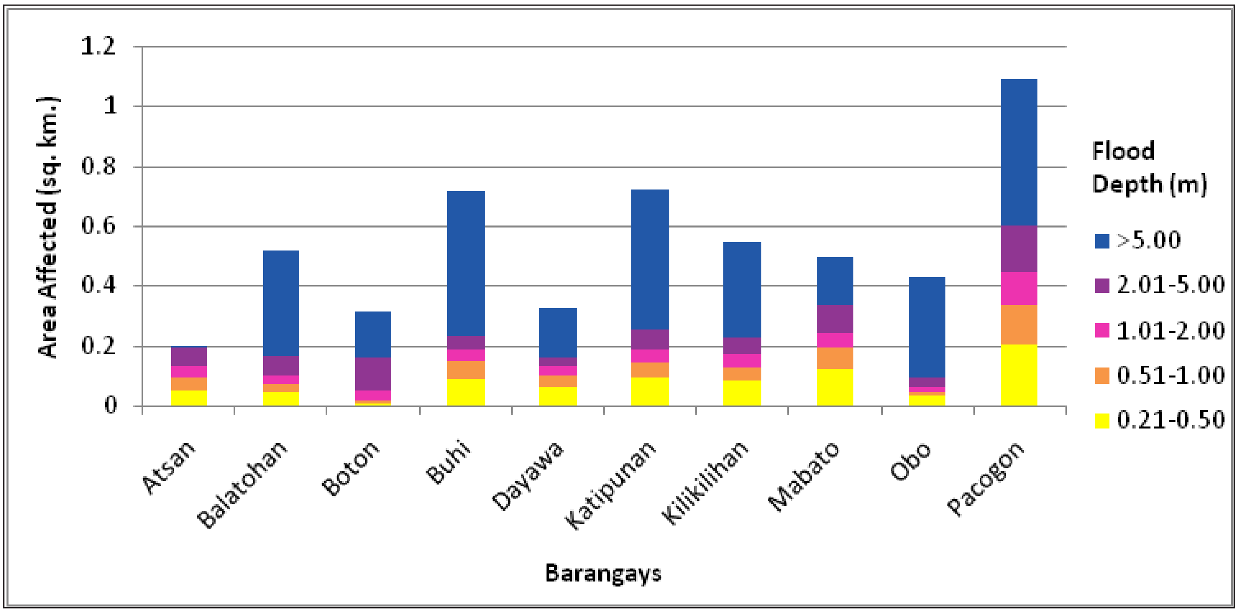


Figure 72. Affected Areas in San Miguel, Catanduanes during the 5-Year Rainfall Return Period

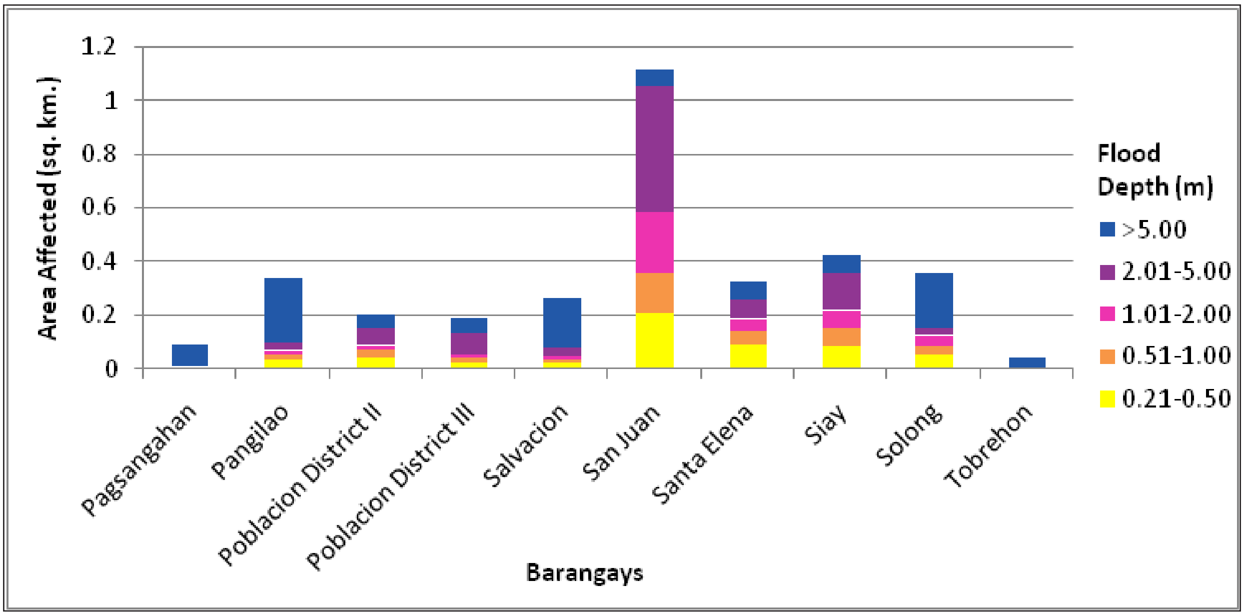


Figure 73. Affected Areas in San Miguel, Catanduanes during the 5-Year Rainfall Return Period

For the municipality of Virac with an area of 175.3 sq. km., 0.0003% will experience flood levels of less than 0.20 meters, and 0.00009% of the area will experience flood levels of 0.21 to 0.50 meters. Table 13 depicts the areas affected in Virac in square kilometers by flood depth per barangay.

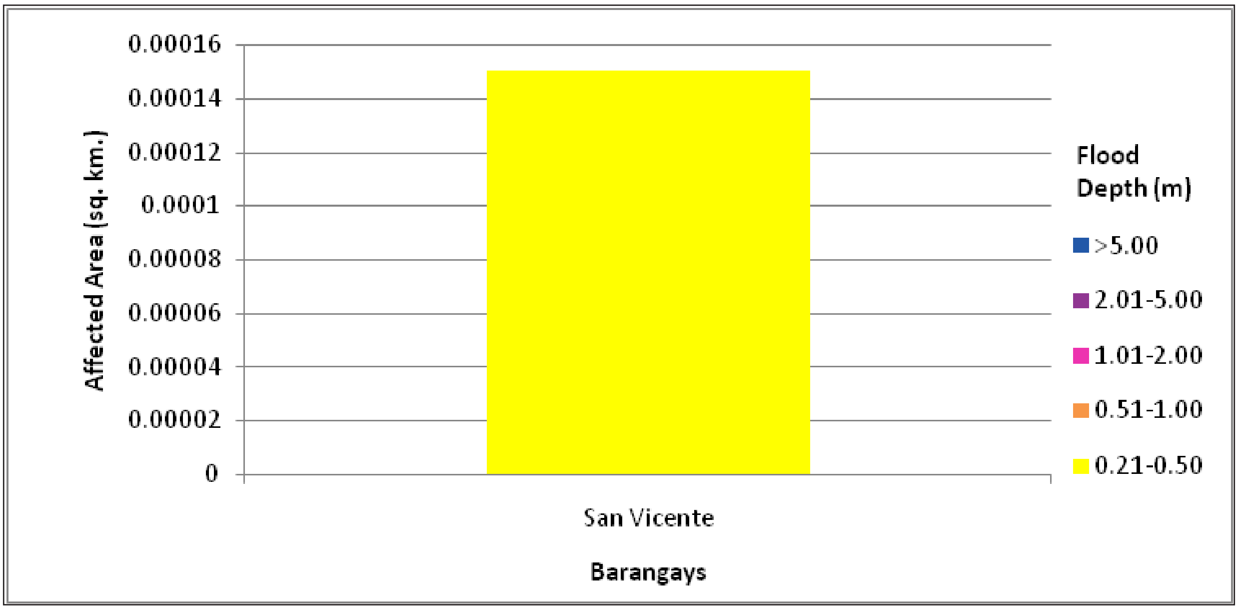


Figure 74. Affected Area in Virac, Catanduanes during the 5-Year Rainfall Return Period

For the 25-year rainfall return period, 0.11% of the municipality of Baras with an area of 75.39 sq. km. will experience flood levels of less than 0.20 meters. 0.002% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.0007%, 0.0004%, and 0.0003% 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. Table 14 depicts the areas affected in Baras in square kilometers by flood depth per barangay.

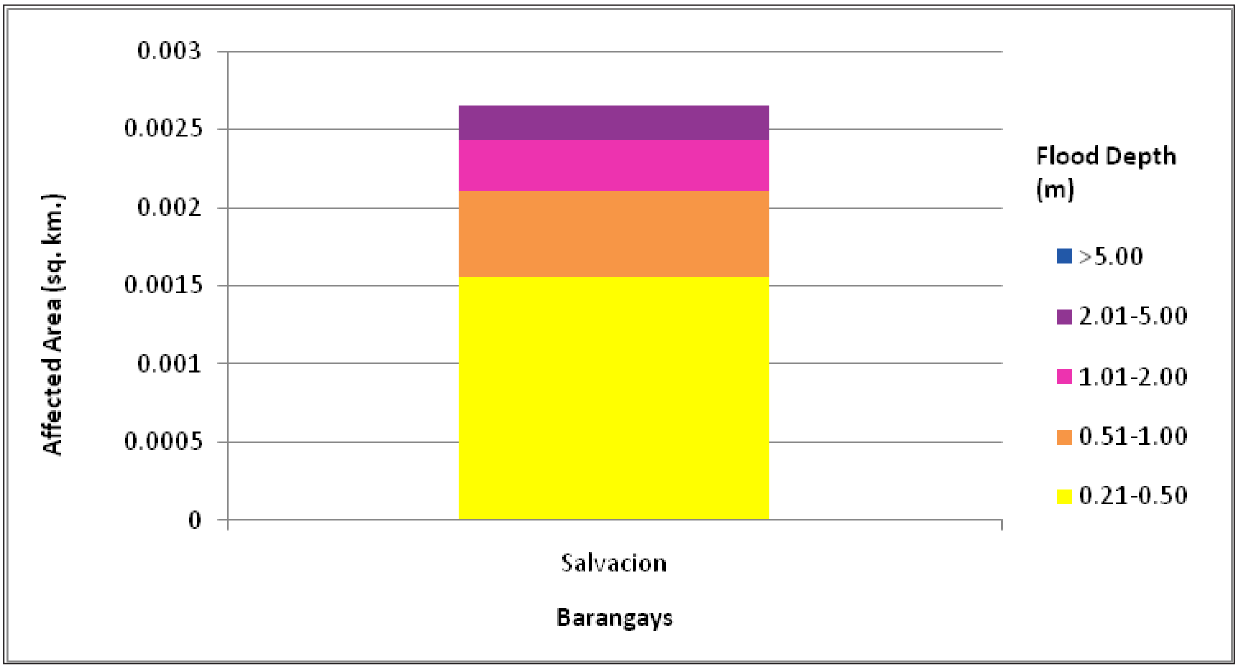


Figure 75. Affected areas in Baras, Catanduanes during the 25-Year Rainfall Return Period

For the municipality of Bato with an area of 45.83 sq. km., 43.28% will experience flood levels of less than 0.20 meters. 2.96% of the area will experience flood levels of 0.21 to 0.50 meters, while 3.04%, 5.19%, 7.75%, and 1.76% 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. Tables 15 and 16 depict the areas affected in Bato in square kilometers by flood depth per barangay.

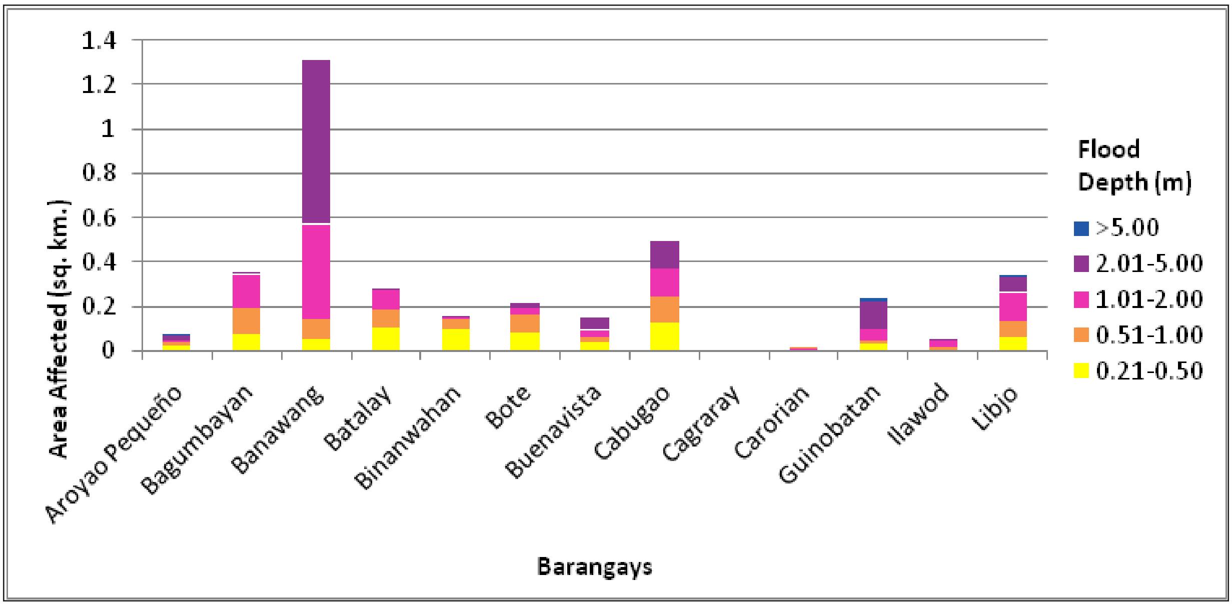


Figure 76. Affected areas in Bato, Catanduanes during the 25-Year Rainfall Return Period

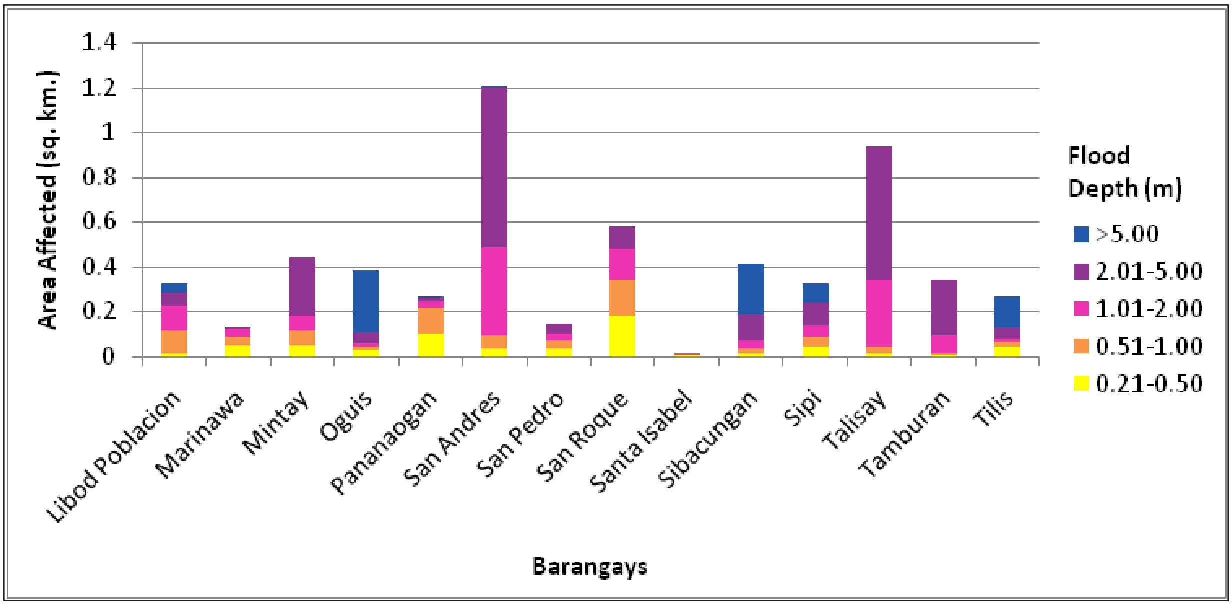


Figure 77. Affected areas in Bato, Catanduanes during the 25-Year Rainfall Return Period

For the municipality of San Miguel with an area of 174.25 sq. km., 22.05% will experience flood levels of less than 0.20 meters. 0.79% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.52%, 0.5%, 0.97%, and 2.51% 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. Tables 17 and 18 depict the areas affected in San Miguel in square kilometers by flood depth per barangay.

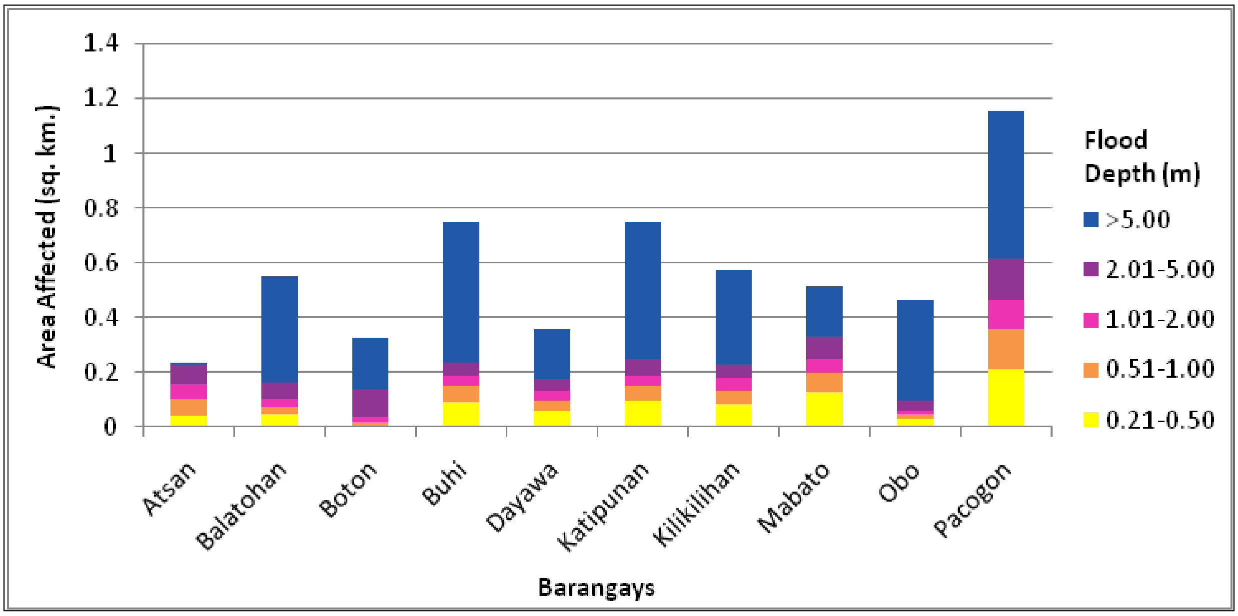


Figure 78. Affected areas in San Miguel, Catanduanes during the 25-Year Rainfall Return Period

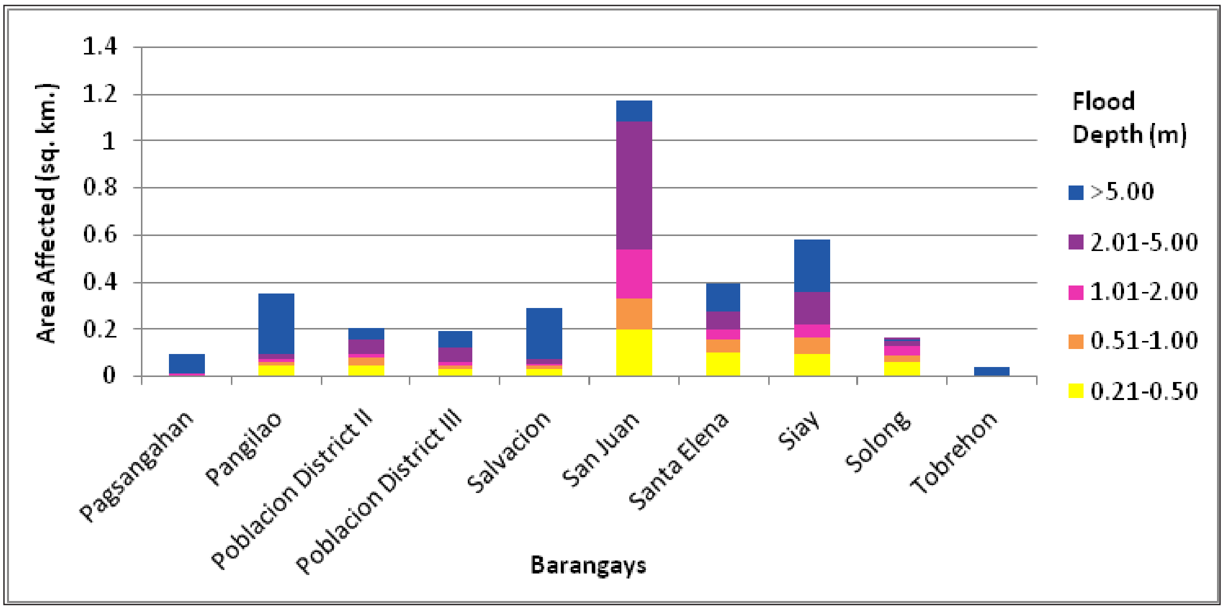


Figure 79. Affected areas in San Miguel, Catanduanes during the 25-Year Rainfall Return Period

For the municipality of Virac with an area of 175.3 sq. km., 0.003% will experience flood levels of less than 0.20 meters, and 0.00009% of the area will experience flood levels of 0.21 to 0.50 meters. Table 19 depicts the areas affected in Virac in square kilometers by flood depth per barangay.

Figure 80. Affected Area in Virac, Catanduanes during the 25-Year Rainfall Return Period

For the 100-year rainfall return period, 0.1% of the municipality of Baras with an area of 75.39 sq. km. will experience flood levels of less than 0.20 meters. 0.002% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.0009%, 0.0003%, and 0.0004% 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. Table 20 depicts the areas affected in Baras in square kilometers by flood depth per barangay.

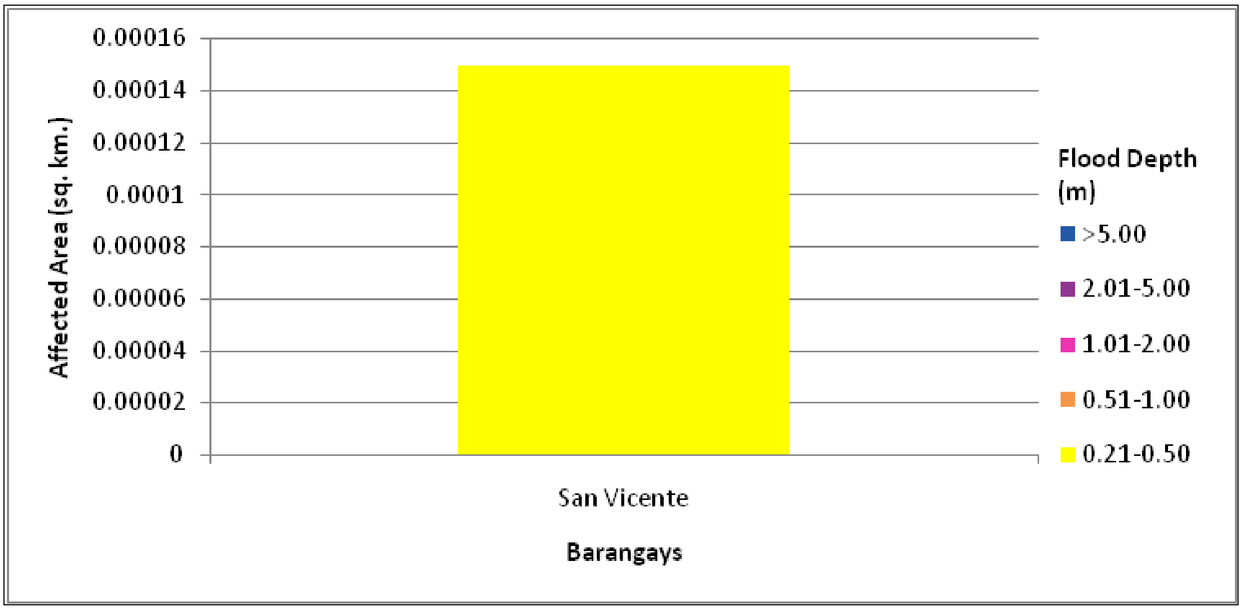


Figure 81. Affected Area in Baras, Catanduanes during the 100-Year Rainfall Return Period

For the municipality of Bato with an area of 45.83 sq. km., 42.33% will experience flood levels of less than 0.20 meters. 2.79% of the area will experience flood levels of 0.21 to 0.50 meters, while 2.64%, 3.86%, 10.16%, and 2% 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. Tables 21 and 22 depict the areas affected in Bato in square kilometers by flood depth per barangay.

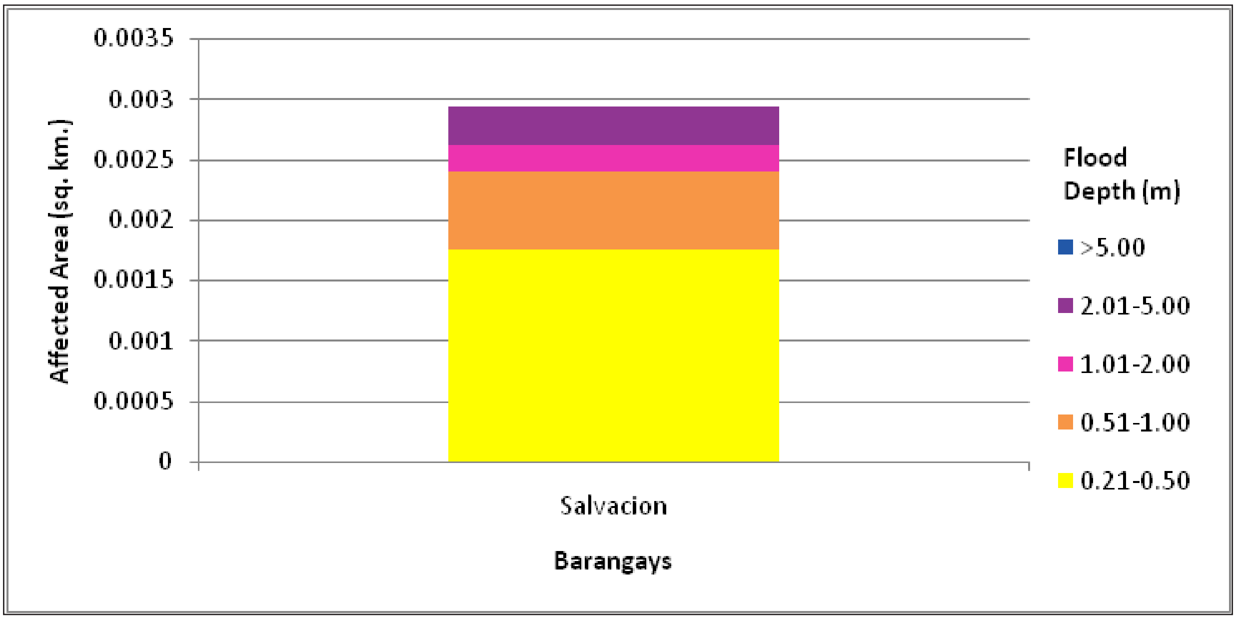


Figure 82. Affected Area in Bato, Catanduanes during the 100-Year Rainfall Return Period

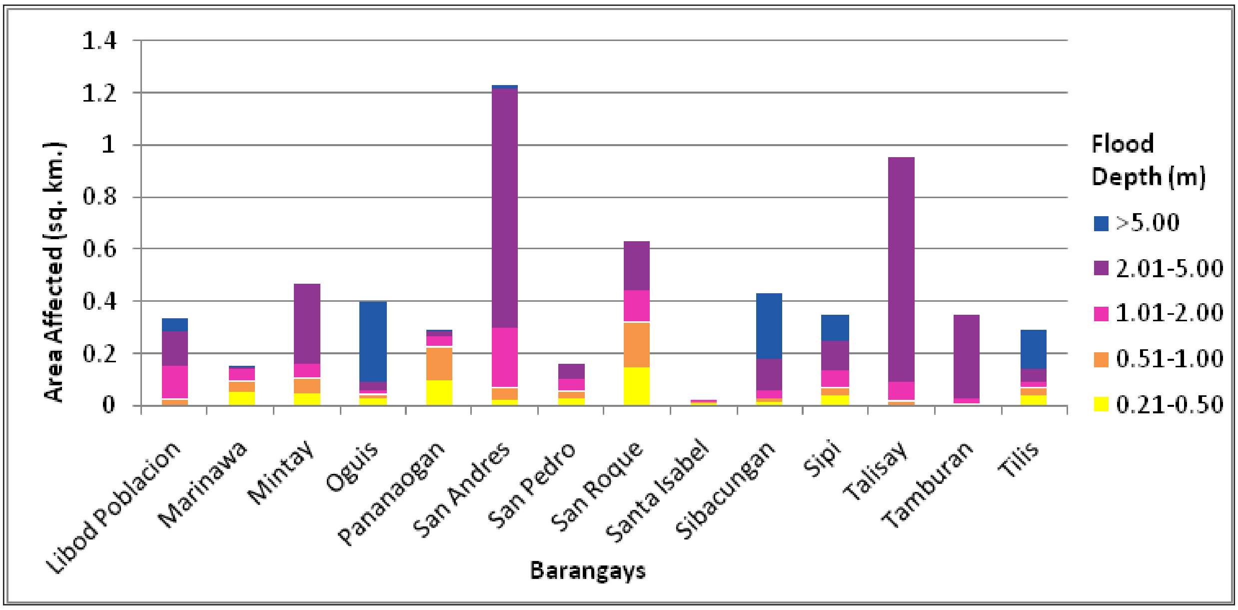


Figure 83. Affected Area in Bato, Catanduanes during the 100-Year Rainfall Return Period

For the municipality of San Miguel with an area of 174.25 sq. km., 21.59% will experience flood levels of less than 0.20 meters. 0.83% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.52%, 0.5%, 0.93%, and 2.94% 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. Tables 23 and 24 depict the areas affected in San Miguel in square kilometers by flood depth per barangay.

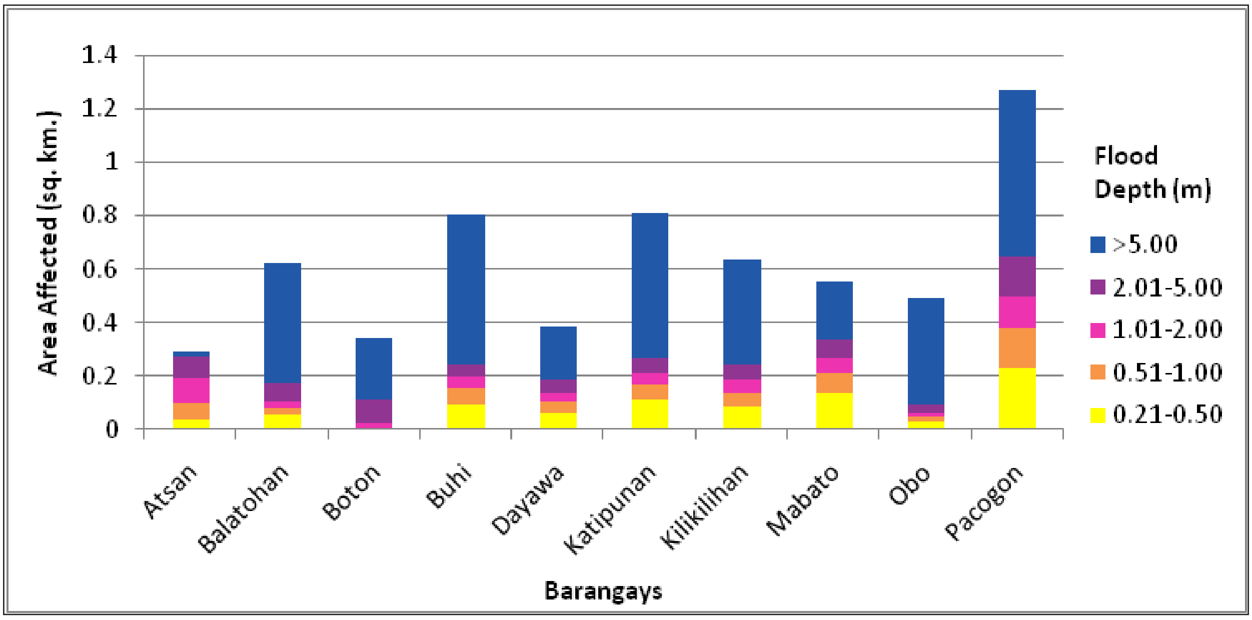


Figure 84. Affected Area in San Miguel, Catanduanes during the 100-Year Rainfall Return Period

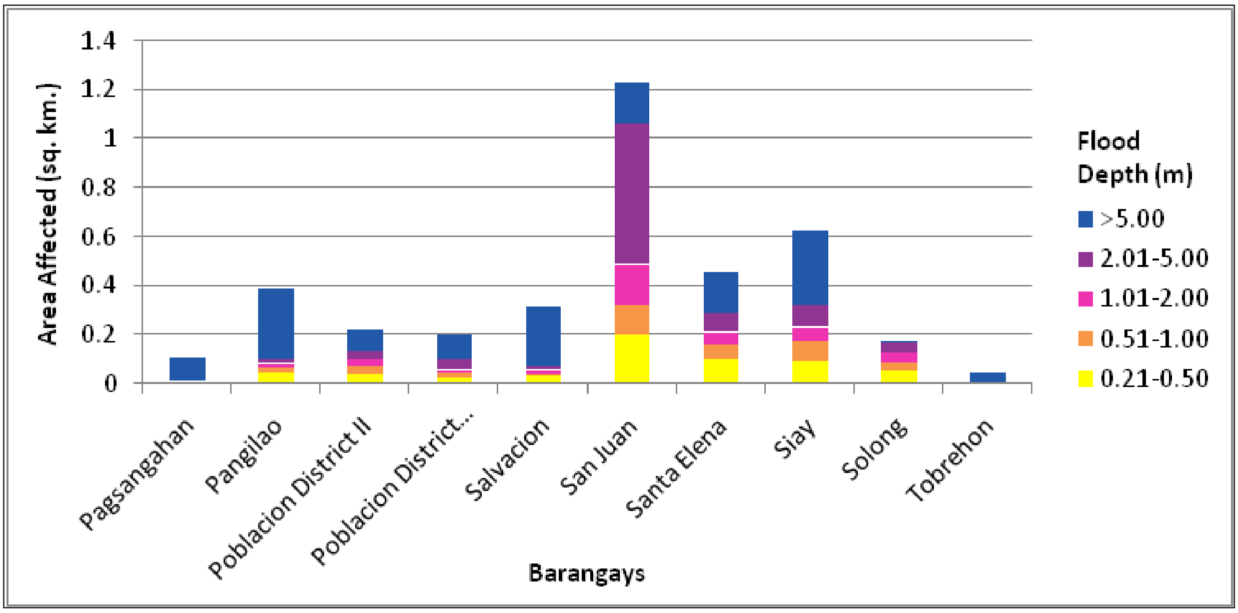


Figure 85. Affected Area in San Miguel, Catanduanes during the 100-Year Rainfall Return Period

For the municipality of Virac with an area of 175.3 sq. km., 0.003% will experience flood levels of less than 0.20 meters, and 0.00009% of the area will experience flood levels of 0.21 to 0.50 meters. Table 25 depicts the areas affected in Virac in square kilometers by flood depth per barangay.

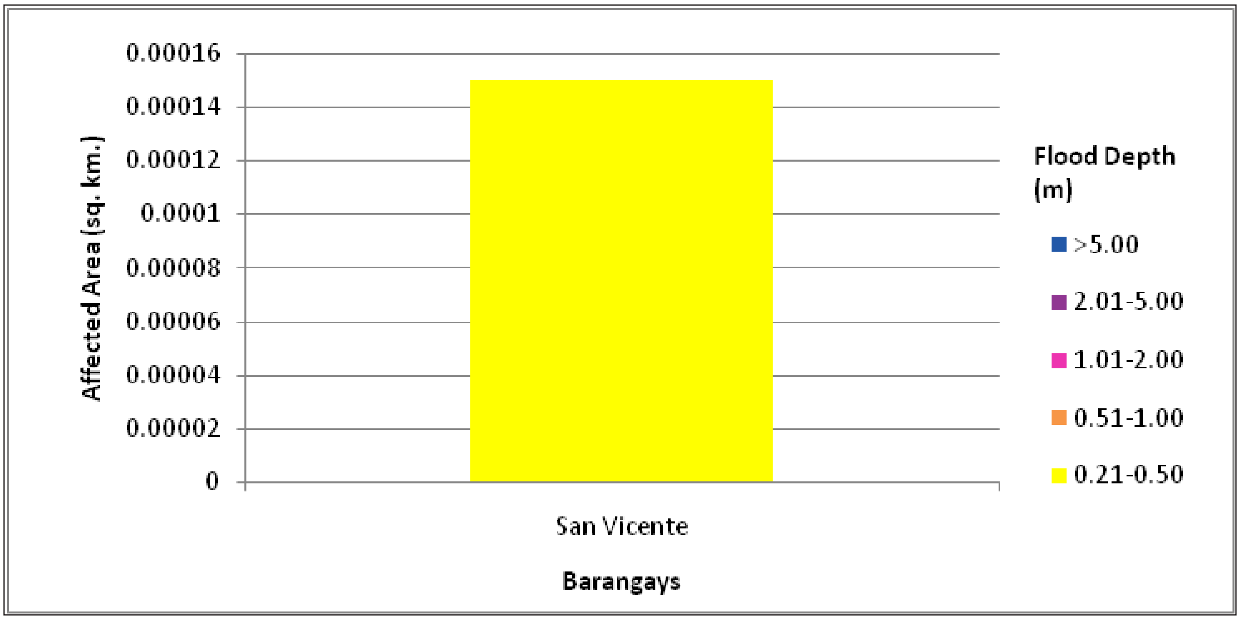


Figure 86. Affected Area in Virac, Catanduanes during the 100-Year Rainfall Return Period

Among the barangays in the municipality of Baras, only Salvacion will experience flood levels at 0.1%.

Among the barangays in the municipality of Bato, Batalay is projected to have the highest percentage of area that will experience flood levels at 4.96%. Meanwhile, Bote posted the second highest percentage of area that may be affected by flood depths at 4.64%.

Among the barangays in the municipality of San Miguel, Pacogon is projected to have the highest percentage of area that will experience flood levels of at 4.7%. Meanwhile, San Juan posted the second highest percentage of area that may be affected by flood depths of at 3.85%.

Among the barangays in the municipality of Virac, only San Vicente will experience flood levels of at 0.0003%.

Moreover, the generated flood hazard maps for the Bato Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA for hazard maps - "Low", "Medium", and "High" - the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, and 100 yr).

Table 33. Area covered by each warning level with respect to rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	2.69	2.48	2.46
Medium	4.41	3.69	3.27
High	10.67	12.54	14.22

Of the 42 identified Educational Institutions in Bato flood plain, 6 were assessed to be exposed to both low and medium, while 13 were assessed to be exposed to high level flooding during the 5-year scenario. In the 25-year scenario, 6 were assessed to be exposed to low, 5 to medium, and 18 to high level flooding. In the 100-year scenario, 4 were assessed to be exposed to low, 3 to medium, and 22 to high level flooding.

Of the 7 identified Medical Institutions in Bato flood plain, none was assessed to be exposed to low, 3 to medium, and 2 to high level flooding in the 5-year scenario. In the 25-year scenario, 1 was assessed to be exposed to both low and medium, while 4 were assessed to be exposed to high level flooding. In the 100-year scenario, none was assessed to be exposed to low, 2 to medium, and 4 to high level flooding.

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 gather 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 are identified for validation.

The validation personnel will then go to the specified points identified in a river basin and will gather data regarding the actual flood level in each location. Data gathering can be 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 will be 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 consists of 206 points randomly selected all over the Bato flood plain. It has an RMSE value of 5.944540573.

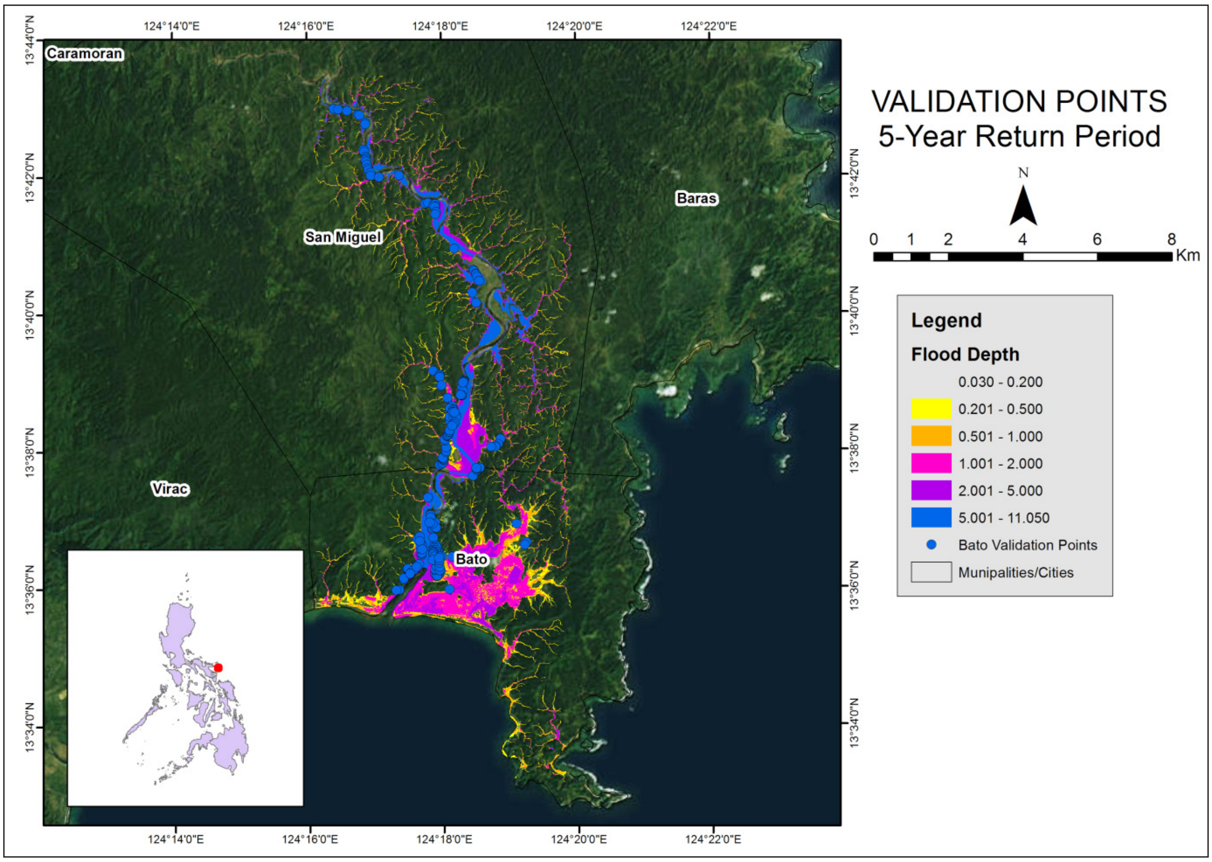


Figure 87. The validation points for the 5-Year flood depth map of the Bato flood plain

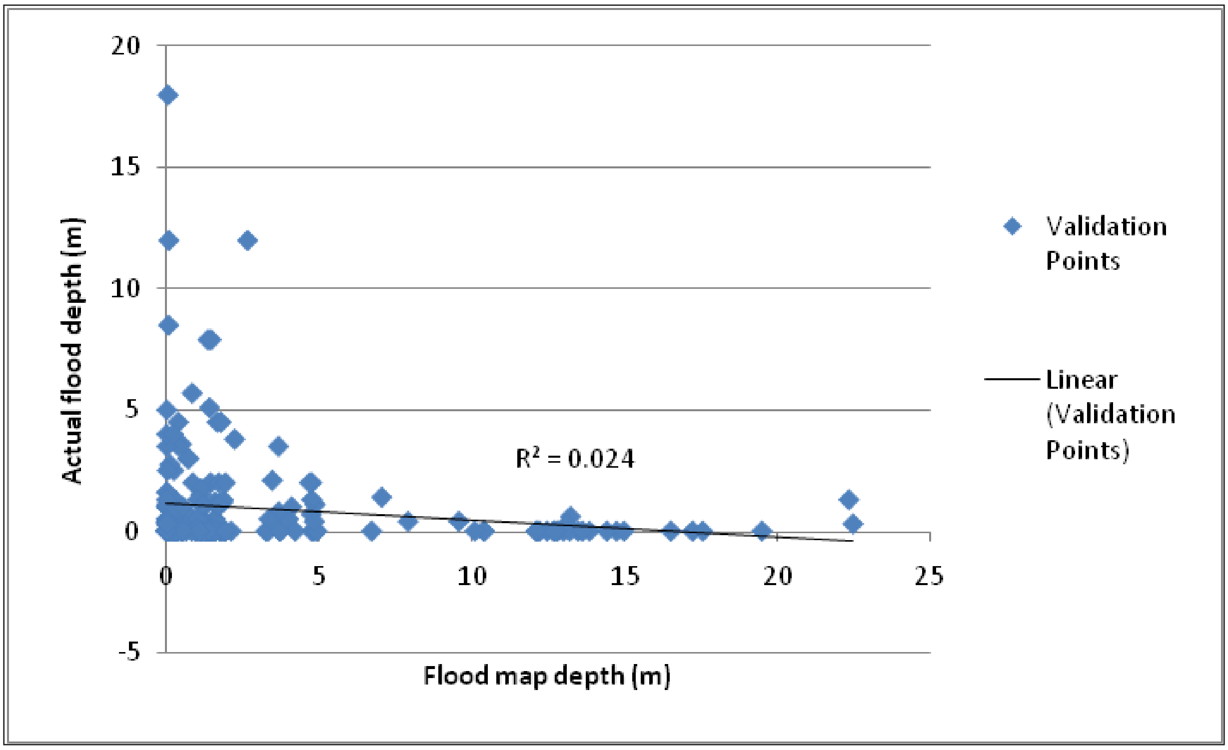


Figure 88. Flood map depth vs. Actual flood depth

Table 34. Actual flood vs. Simulated flood depth at different levels in the Bato River Basin

BATO		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
Actual Flood Depth (m)	0-0.20	26	13	7	33	89	25	193
	0.21-0.50	12	1	1	6	4	4	28
	0.51-1.00	4	2	2	2	3	1	14
	1.01-2.00	6	1	1	11	4	2	25
	2.01-5.00	5	4	3	2	3	0	17
	> 5.00	3	0	1	3	1	0	8
	Total	56	21	15	57	104	32	285

The overall accuracy generated by the flood model is estimated at 15.09%, with 43 points correctly matching the actual flood depths. In addition, there were 38 points estimated one level above and below the correct flood depths, 29 points estimated two levels above and below, and 175 points estimated three or more levels above and below the correct flood depths. A total of 194 points were overestimated while a total of 48 points were underestimated in the modelled flood depths of Bato. Table 35 depicts the summary of the accuracy assessment in the Bato River Basin survey.

Table 35. The Summary of Accuracy Assessment in the Bato River Basin Survey

BATO	No. of Points	%
Correct	43	**15.09**
Overestimated	194	68.07
Underestimated	48	16.84
Total	285	100

REFERENCES

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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. Technical Specifications of the LIDAR Sensors used in the Bato Floodplain Survey

Figure A-1.1. Pegasus Sensor

Table A-1.1. Parameters and Specification of Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM); 220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)

Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

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

1. CNS-20

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

January 27, 2016

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: **CATANDUANES**
Station Name: **CNS-20**
Order: **2nd**

Island: **LUZON**
Municipality: **SAN MIGUEL**
Barangay: **PAGSANGAHAN**
MSL Elevation:

PRS92 Coordinates

Latitude: **13° 43' 8.77572"** Longitude: **124° 16' 9.57152"** Ellipsoidal Hgt: **43.75200 m.**

WGS84 Coordinates

Latitude: **13° 43' 3.83355"** Longitude: **124° 16' 14.51857"** Ellipsoidal Hgt: **97.73600 m.**

PTM / PRS92 Coordinates

Northing: **1517459.029 m.** Easting: **637300.168 m.** Zone: **4**

UTM / PRS92 Coordinates

Northing: **1,516,927.89** Easting: **637,252.11** Zone: **51**

Location Description

CNS-20

From Virac Town Proper, travel N passing through Mun. of San Miguel for about 25 Km. Station is located at NW wing of Malmag bridge along Circumferential Road going to Mun. of Viga. Mark is the head of a 4 in. copper nail centered on a drilled hole with cement putty, embedded at concrete bridge with inscriptions, "CNS-20, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8089687 I**
T.N.: **2016-0244**

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

9 9 0 1 2 7 2 0 1 6 1 5 1 3 3 5

CIP/4701/12/09/814

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. CNS-20

2. CNS-21

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

January 27, 2016

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: **CATANDUANES**
Station Name: **CNS-21**
Order: **2nd**

Island: **LUZON**
Municipality: **VIRAC (CAPITAL)**
Barangay: **PALTA SMALL**
MSL Elevation:

PRS92 Coordinates

Latitude:	**13° 35' 14.37180"**	Longitude:	**124° 9' 45.40531"**	Ellipsoidal Hgt:	**83.10600 m.**

WGS84 Coordinates

Latitude:	**13° 35' 9.45275"**	Longitude:	**124° 9' 50.36457"**	Ellipsoidal Hgt:	**137.19500 m.**

PTM / PRS92 Coordinates

Northing:	**1502820.29 m.**	Easting:	**625825.638 m.**	Zone:	**4**

UTM / PRS92 Coordinates

Northing:	**1,502,294.28**	Easting:	**625,781.60**	Zone:	**51**

Location Description

CNS-21

From Virac Town Proper, travel NW for about 9 Km. along Circumferential Road going to Mun. of San Andres. Station is located at Palta Bridge. It was established at SE approach of bridge along Circumferentail Road. Mark is the head of a 4 in. copper nail centered on a drilled hole with cement putty, embedded at concrete bridge with inscriptions, "CNS-21, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8089687 I**
T.N.: **2016-0245**

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

9 9 0 1 2 7 2 0 1 6 1 5 1 4 0 1

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
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Figure A-2.2. CNS-21

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

1. VIRAC-E0

Table A-3.1. VIRAC-E0

Vector Components (Mark to Mark)

From:	CNS-21				
Grid		Local		Global	
Easting	625781.597 m	Latitude	N13°35'14.37180"	Latitude	N13°35'09.45275"
Northing	1502294.277 m	Longitude	E124°09'45.40531"	Longitude	E124°09'50.36457"
Elevation	84.905 m	Height	83.106 m	Height	137.195 m

To:	VIRAC-E0				
Grid		Local		Global	
Easting	633250.707 m	Latitude	N13°35'03.52757"	Latitude	N13°34'58.61487"
Northing	1501997.753 m	Longitude	E124°13'53.85198"	Longitude	E124°13'58.81098"
Elevation	6.533 m	Height	4.565 m	Height	58.830 m

Vector					
ΔEasting	7469.110 m	NS Fwd Azimuth	92°32'48"	ΔX	-6178.777 m
ΔNorthing	-296.523 m	Ellipsoid Dist.	7476.432 m	ΔY	-4196.366 m
ΔElevation	-78.372 m	ΔHeight	-78.542 m	ΔZ	-342.164 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.010 m
σ ΔNorthing	0.003 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.014 m
σ ΔElevation	0.017 m	σ ΔHeight	0.017 m	σ ΔZ	0.006 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0001019463		
Y	-0.0001313494	0.0001848713	
Z	-0.0000508365	0.0000677488	0.0000313776

2

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. LOUIE BALICANTA	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 / Ground Survey / Data Download and Transfer	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	KENNETH QUISADO	UP-TCAGP
	RA	KRISTINE JOY ANDAYA	UP-TCAGP
	RA	NICOLAS ILEJAY	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. LEE JAY PUNZALAN	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. SHERWIN ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. JERICHO JECIEL	

Annex 5. Data Transfer Sheet for Bato Floodplain

DATA TRANSFER SHEET
Catanduanes 1/28/16

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
22-Jan	3010P	1BLK25A022A	pegasus	1.95	867/453	12.6	229	na	na	22.9	na	69.3	1KB	1KB	103/136/121/107	na	Z:\DAC\RAW DATA
23-Jan	3012P	1BLK25AC023A	pegasus	1.92	1196/399	12.1	263	27.9	219	22.1	na	95.7	1KB	1KB	190/158	na	Z:\DAC\RAW DATA
23-Jan	3014P	1BLK25BC023B	pegasus	1.1	2026/198	8.39	145	3.5/7.18	25/54	12	na	95.7	1KB	1KB	285/240	na	Z:\DAC\RAW DATA
24-Jan	3016P	1BLK25E024A	pegasus	1.3	491/290	6.79	167	na	na	14.6	na	82.4	1KB	1KB	240	na	Z:\DAC\RAW DATA

Received from
Name [illegible]
Position [illegible]
Signature

Received by
Name AC Bongat
Position [illegible]
Signature 1/28/16

Figure A-5.1. Transfer Sheet for Bato Floodplain

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 3010P

D R E A M | Data Acquisition Flight Log

Flight Log No.: 3010P

1 LiDAR Operator: Kenneth Quisado	2 ALTM Model: Pegasus	3 Mission Name: 1BLK25A022A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RPC9122
7 Pilot: S. Alfonso	8 Co-Pilot: J. Jeciel	9 Route: Virac Area			
10 Date: Jan 22, 2016	12 Airport of Departure (Airport, City/Province): Virac, Catanduanes		12 Airport of Arrival (Airport, City/Province): Virac, Catanduanes		
13 Engine On: 7:15	14 Engine Off: 11:20	15 Total Engine Time: 4+05	16 Take off: 7:20	17 Landing: 11:15	18 Total Flight Time: 3+55
19 Weather	Clear sky to cloudy				

20 Flight Classification

20.a Billable	20.b Non Billable	20.c Others
☑ Acquisition Flight	○ Aircraft Test Flight	○ LiDAR System Maintenance
○ Ferry Flight	○ AAC Admin Flight	○ Aircraft Maintenance
○ System Test Flight	○ Others: ____________	○ DREAM Admin Activities
○ Calibration Flight		

21 Remarks

Successful flight, surveyed a total of 17 lines over San Andres and Virac Area

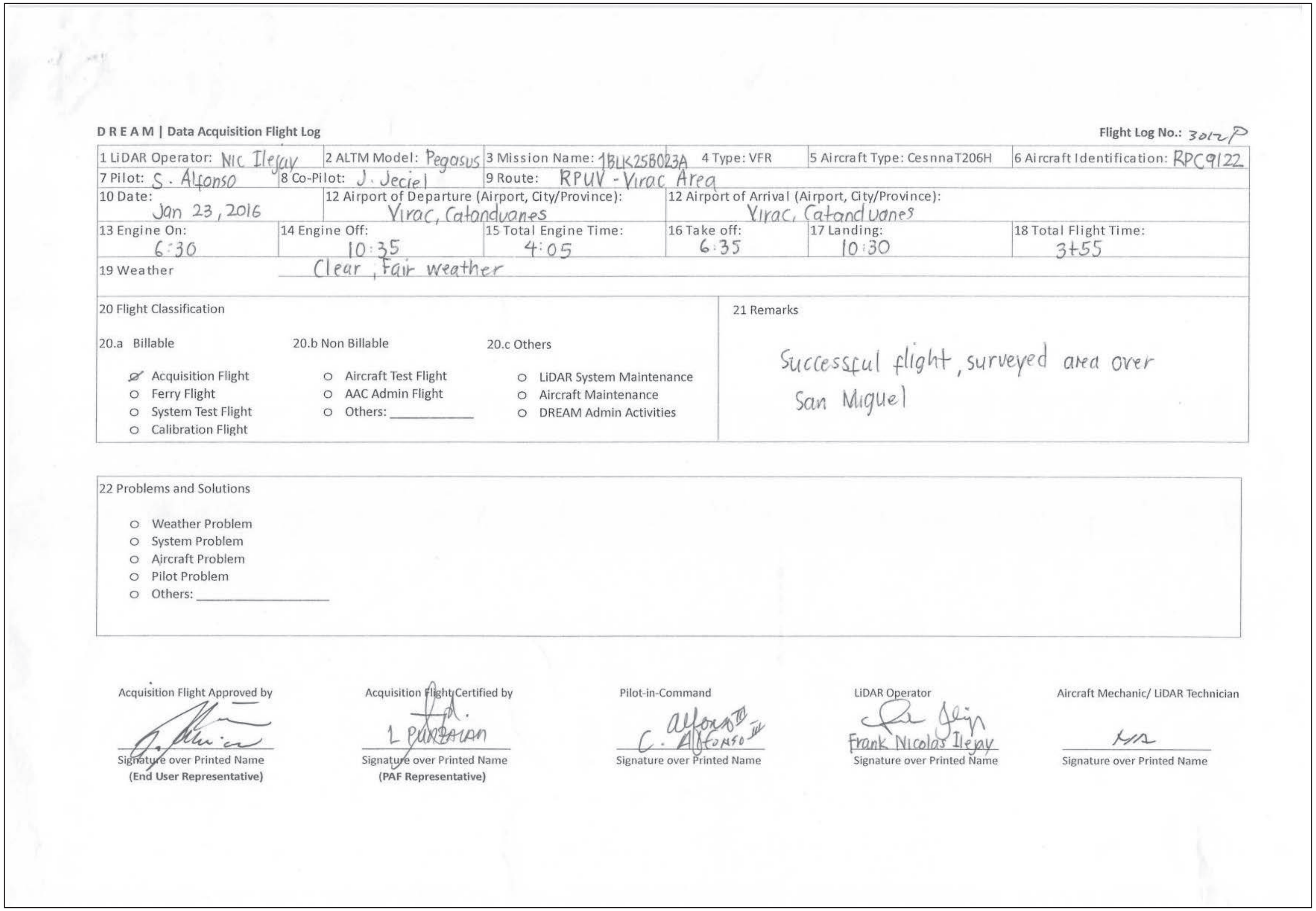
22 Problems and Solutions

- ○ Weather Problem
- ○ System Problem
- ○ Aircraft Problem
- ○ Pilot Problem
- ○ Others: ____________________

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Alviar	L. Purisima	C. Alfonso III	Kenneth Quisado	
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.1. Flight Log for Mission 3010P

2. Flight Log for Mission 3012P



DREAM | Data Acquisition Flight Log

Flight Log No.: 3012P

1 LiDAR Operator: Nic Ilejay	2 ALTM Model: Pegasus	3 Mission Name: 1BLK25B023A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RPC9122
7 Pilot: S. Alfonso	8 Co-Pilot: J. Jeciel	9 Route: RPUV - Virac Area			
10 Date: Jan 23, 2016	12 Airport of Departure (Airport, City/Province): Virac, Catanduanes		12 Airport of Arrival (Airport, City/Province): Virac, Catanduanes		
13 Engine On: 6:30	14 Engine Off: 10:35	15 Total Engine Time: 4:05	16 Take off: 6:35	17 Landing: 10:30	18 Total Flight Time: 3+55
19 Weather	Clear, Fair weather				

20 Flight Classification

20.a Billable
- ☑ Acquisition Flight
- ○ Ferry Flight
- ○ System Test Flight
- ○ Calibration Flight

20.b Non Billable
- ○ Aircraft Test Flight
- ○ AAC Admin Flight
- ○ Others: ____________

20.c Others
- ○ LiDAR System Maintenance
- ○ Aircraft Maintenance
- ○ DREAM Admin Activities

21 Remarks

Successful flight, surveyed area over San Miguel

22 Problems and Solutions
- ○ Weather Problem
- ○ System Problem
- ○ Aircraft Problem
- ○ Pilot Problem
- ○ Others: ____________

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
Signature over Printed Name (End User Representative)	L Pangilinan Signature over Printed Name (PAF Representative)	C. Alfonso III Signature over Printed Name	Frank Nicolas Ilejay Signature over Printed Name	Signature over Printed Name

Figure A-6.2. Flight Log for Mission 3012P

3. Flight Log for Mission 3014P

D R E A M | Data Acquisition Flight Log — Flight Log No.: 3014P

1 LiDAR Operator: Kenneth Quisado	2 ALTM Model: Pegasus	3 Mission Name: 1BLK25C023B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RPC9122
7 Pilot: S. Alfonso	8 Co-Pilot: J. Jeciel	9 Route: RPUV - San Miguel Area			
10 Date: Jan 23, 2016	12 Airport of Departure (Airport, City/Province): Virac, Catanduanes		12 Airport of Arrival (Airport, City/Province): Virac, Catanduanes		
13 Engine On: 1:10	14 Engine Off: 3:57	15 Total Engine Time: 2+47	16 Take off: 1:15	17 Landing: 3:52	18 Total Flight Time: 2+37
19 Weather	Cloudy				

20 Flight Classification

20.a Billable
- ⊘ Acquisition Flight
- o Ferry Flight
- o System Test Flight
- o Calibration Flight

20.b Non Billable
- o Aircraft Test Flight
- o AAC Admin Flight
- o Others: ___________

20.c Others
- o LiDAR System Maintenance
- o Aircraft Maintenance
- o DREAM Admin Activities

21 Remarks

Survey over San Miguel area, partially completed

22 Problems and Solutions
- o Weather Problem
- o System Problem
- o Aircraft Problem
- o Pilot Problem
- o Others: ___________

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Arian	L Paragan	C. Alfonso III	Kenneth Quisado	
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 3014P

4. Flight Log for Mission 3016P

DREAM | Data Acquisition Flight Log — Flight Log No.: 3016P

1 LiDAR Operator: Jas Alviar	2 ALTM Model: Pegasus	3 Mission Name: 1BLK25E024A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP C9122
7 Pilot: S. Alfonso	8 Co-Pilot: J. Jeciel	9 Route: RPUV - San Andres Area			
10 Date: Jan 24, 2016	12 Airport of Departure (Airport, City/Province): Virac, Catanduanes		12 Airport of Arrival (Airport, City/Province): Virac, Catanduanes		
13 Engine On: 6:35	14 Engine Off: 9:16	15 Total Engine Time: 2+41	16 Take off: 6:40	17 Landing: 9:11	18 Total Flight Time: 2+31
19 Weather	Cloudy				

20 Flight Classification

20.a Billable
- ⌀ Acquisition Flight
- o Ferry Flight
- o System Test Flight
- o Calibration Flight

20.b Non Billable
- o Aircraft Test Flight
- o AAC Admin Flight
- o Others: ____________

20.c Others
- o LiDAR System Maintenance
- o Aircraft Maintenance
- o DREAM Admin Activities

21 Remarks

Surveyed remaining areas over Virac and San Andres

22 Problems and Solutions
- o Weather Problem
- o System Problem
- o Aircraft Problem
- o Pilot Problem
- o Others: ____________

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Abrica	L Puzaran	C. Alfonso III	Jasmine Alviar	N/A
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.4. Flight Log for Mission 3016P

Annex 7. Flight Status Reports

FLIGHT STATUS REPORT

CATANDUANES

(January 20 – February 4, 2016)

Table A-7.1. Flight Status Report

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3010P	BLK 25AH PAJO FP	1BLK25A022A	KA QUISADO	January 22, 2016	SURVEYED BLK 25A AND BLK 25H 247.54 SQ.KM
3012P	BLK 25BAS PAJO AND BATO FP	1BLK25AC023A	FN ILEJAY	January 23, 2016	SURVEYED BLK 25B AND BLK 25AS; SEVERAL RESTARTS DUE TO TRANSITION ERROR 208.58 SQ.KM
3014P	BLK 25BC BATO FP	1BLK25BC023B	KA QUISADO	January 23, 2016	SURVEYED BLK 25BC; SEVERAL RESTARTS DUE TO TRANSITION ERROR 129.89 SQ.KM
3016P	BLK 25HABS GAP FILLING	1BLK25E024A	JT ALVIAR	January 24, 2016	GAP FILLING IN BLK 25A, B, H; TURNED OFF CAMERA TO AVOID TRANSITION ERROR 148.48 SQ.KM

LAS BOUNDARIES PER FLIGHT

Flight No. :	3010P		
Area:	BLK 25AH		
Mission Name:	1BLK25A022A		
Parameters:	Altitude: 1000m;	Scan Frequency:	30Hz;
Scan Angle:	25deg;	Overlap: 20%	

LAS

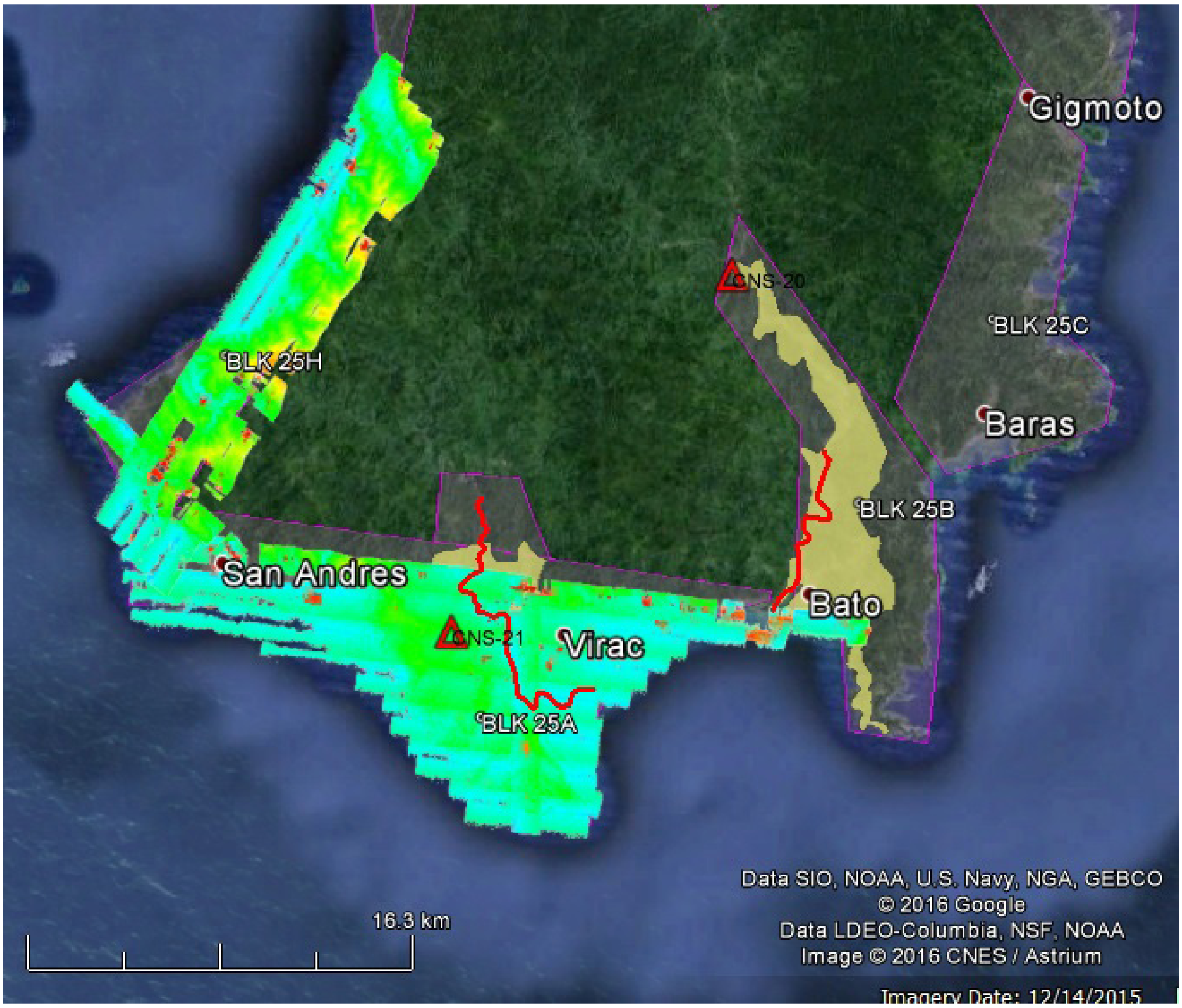


Figure A-7.1. Swath for Flight No.3010P

Flight No. : 3012P
Area: BLK 25BAS
Mission Name: 1BLK25AC023A
Parameters: Altitude: 1000m; Scan Frequency: 30Hz;
Scan Angle: 25deg; Overlap: 20%

LAS

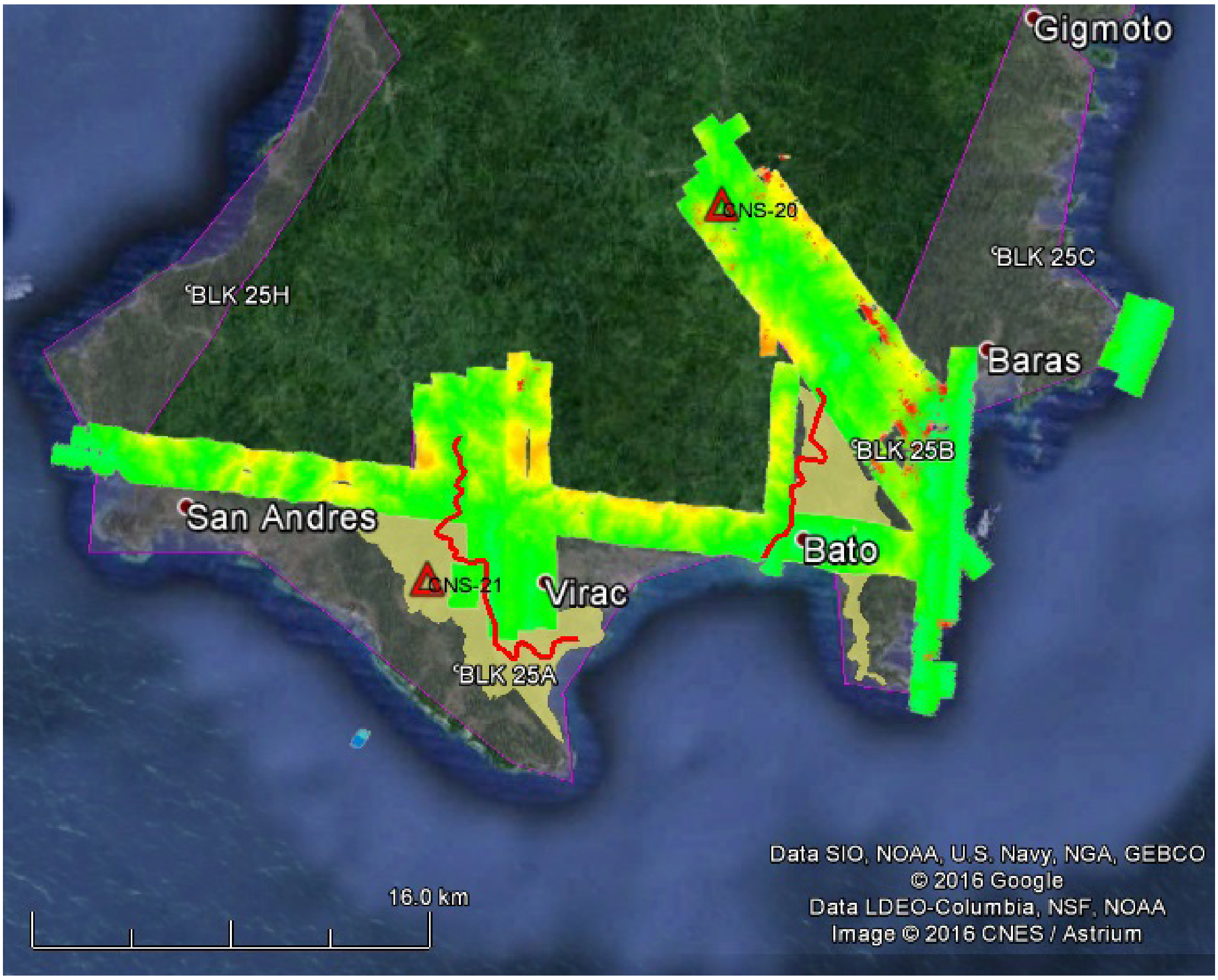


Figure A-7.2. Swath for Flight No.3012P

Flight No. : 3014P
Area: BLK 25BC
Mission Name: 1BLK25BC023B
Parameters: Altitude: 1000m; Scan Frequency: 30Hz;
Scan Angle: 25deg; Overlap: 20%

LAS

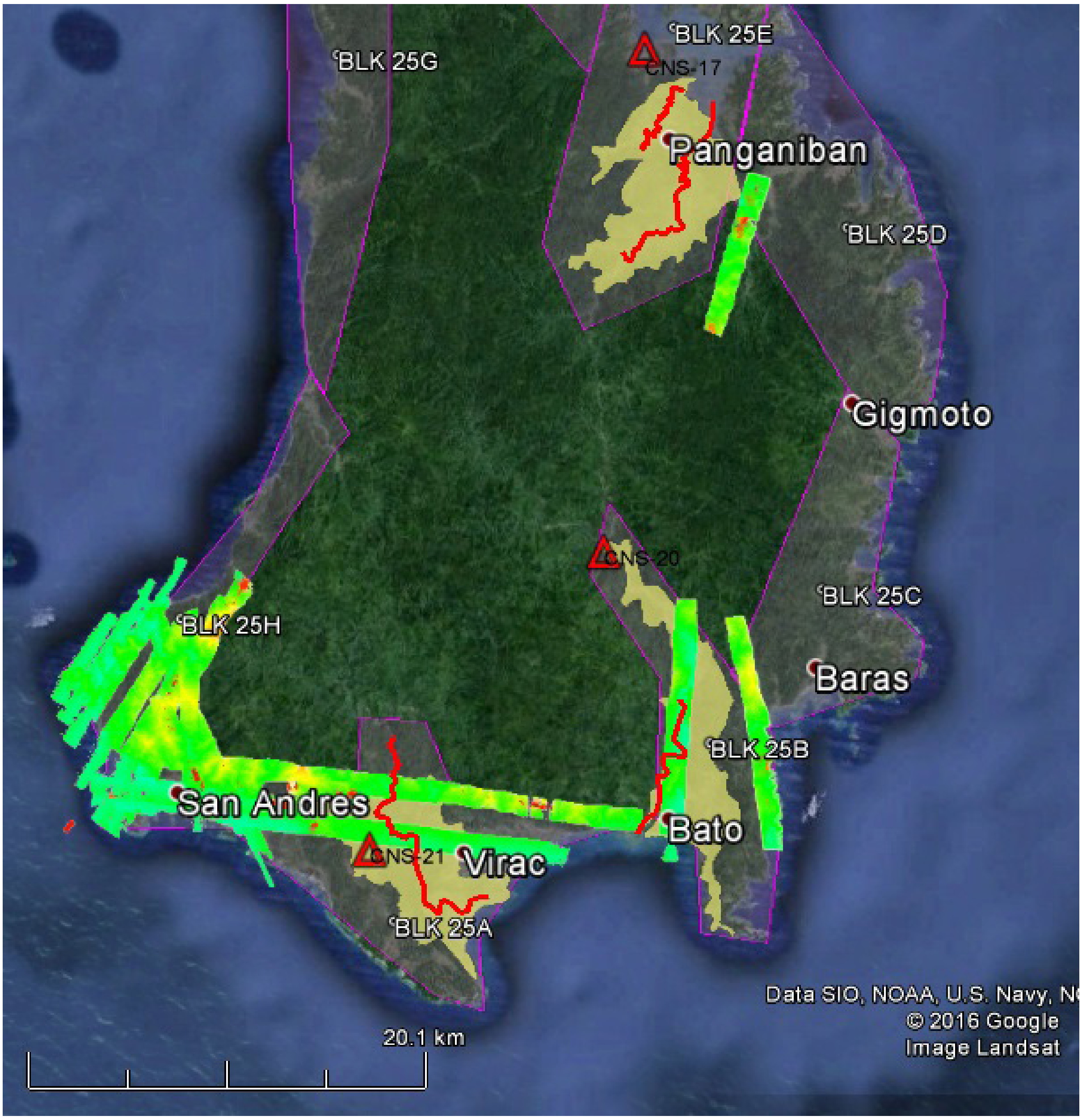


Figure A-7.3. Swath for Flight No.3014P

Flight No. :	3016P
Area:	BLK 25HABS
Mission Name:	1BLK25E024A
Parameters:	Altitude: 1000m; Scan Frequency: 30Hz;
Scan Angle:	25deg; Overlap: 20%

LAS

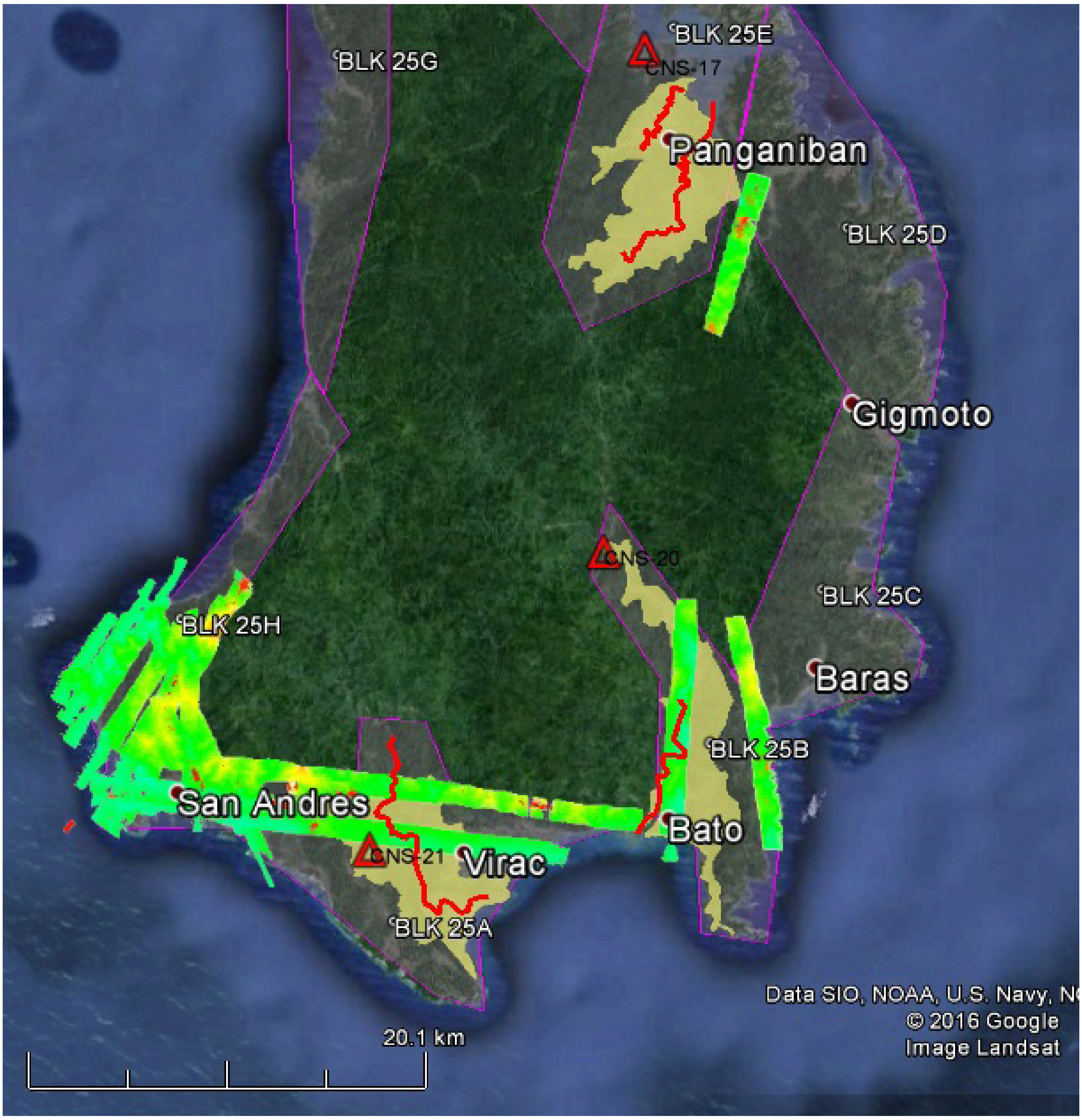


Figure A-7.4. Swath for Flight No.3016P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk25C

Flight Area	Catanduanes
Mission Name	Blk25C
Inclusive Flights	3028P/3014P/3012P
Range data size	38.88 GB
Base data size	255.9 MB
POS	543 MB
Image	35.08 B
Base Station	229.5 MB
Transfer date	February 12, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.7
RMSE for East Position (<4.0 cm)	3.0
RMSE for Down Position (<8.0 cm)	6.5
Boresight correction stdev (<0.001deg)	0.000304
IMU attitude correction stdev (<0.001deg)	0.000085
GPS position stdev (<0.01m)	0.0036
Minimum % overlap (>25)	20.01
Ave point cloud density per sq.m. (>2.0)	2.90
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	133
Maximum Height	626.59 m
Minimum Height	50.81 m
Classification (# of points)	
Ground	38,669,167
Low vegetation	22,112,270
Medium vegetation	57,933,497
High vegetation	244,223,294
Building	2,332,186
Orthophoto	No
Processed by	Engr. Abigail Joy Ching, Engr. Velina Angela Bemida, Alex John Escobido

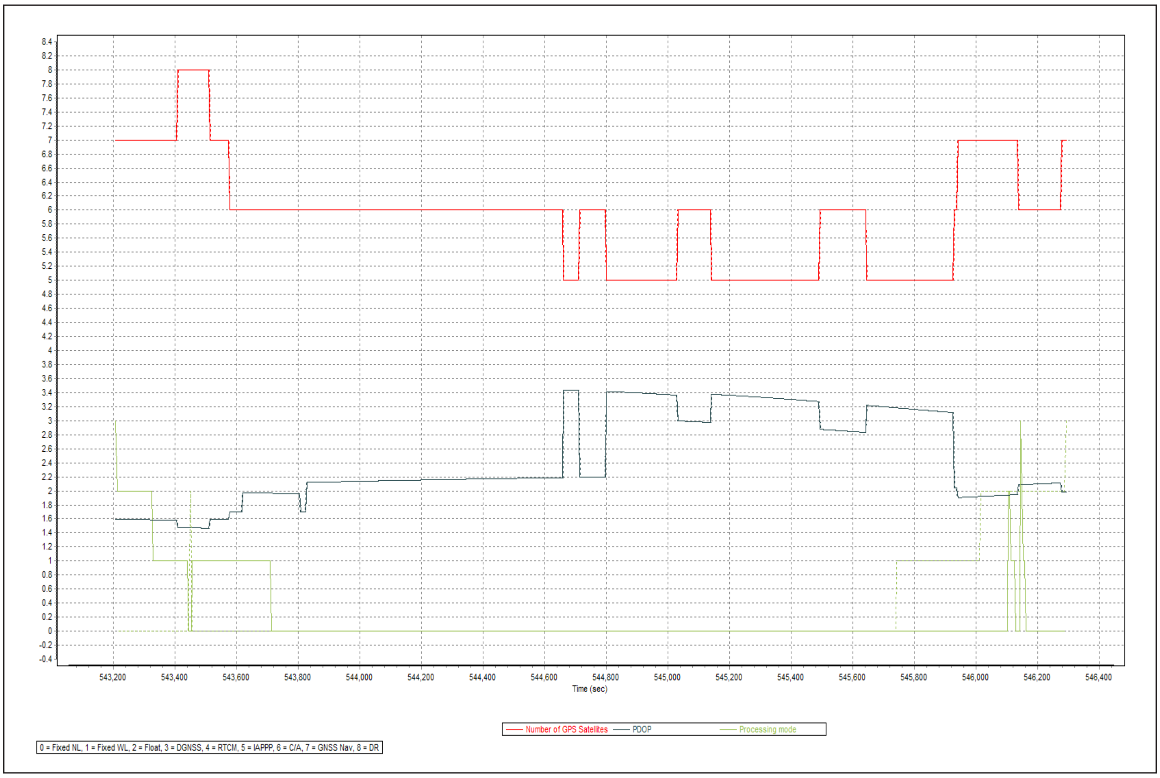


Figure A-8.1. Solution Status

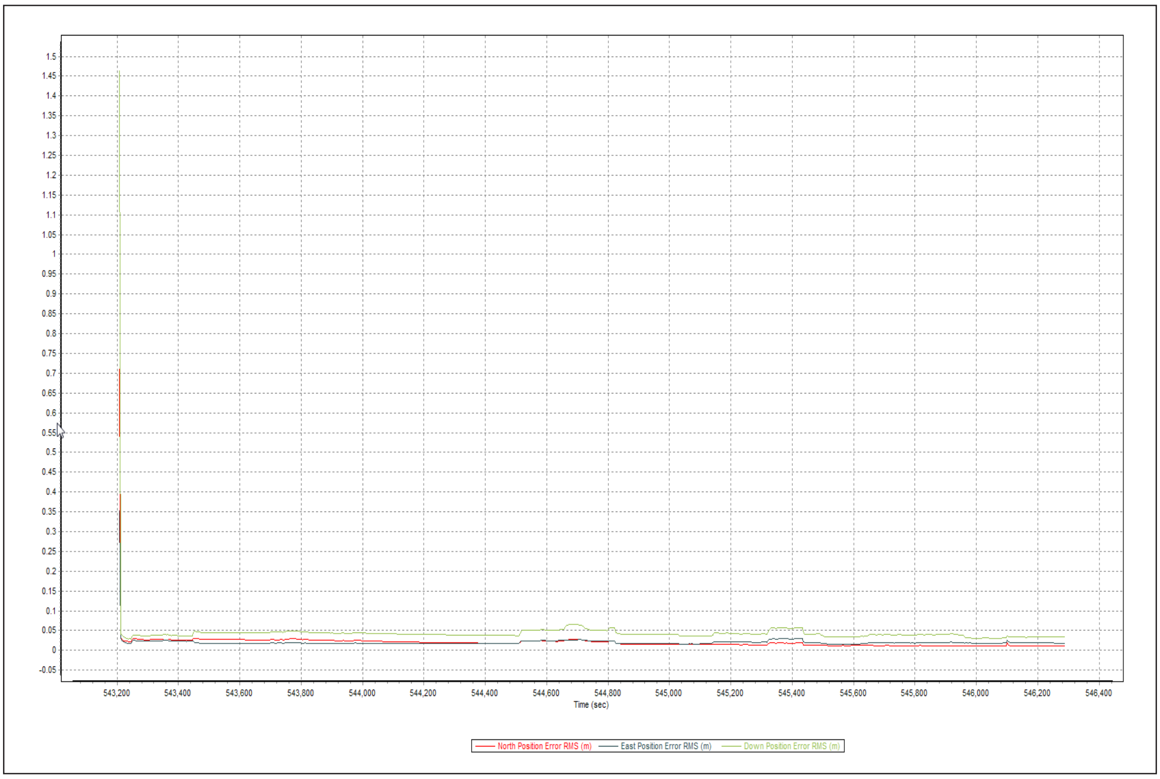


Figure A-8.2. Smoothed Performance Metric Parameters

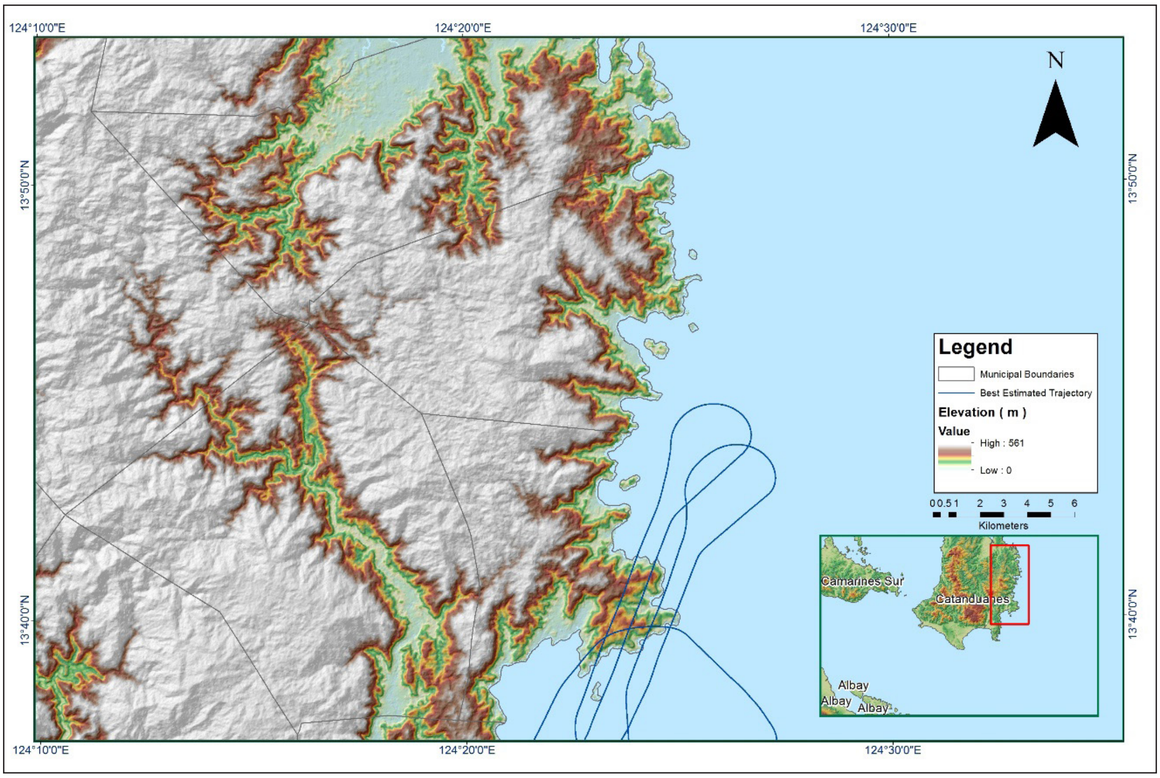


Figure A-8.3. Best Estimate Trajectory

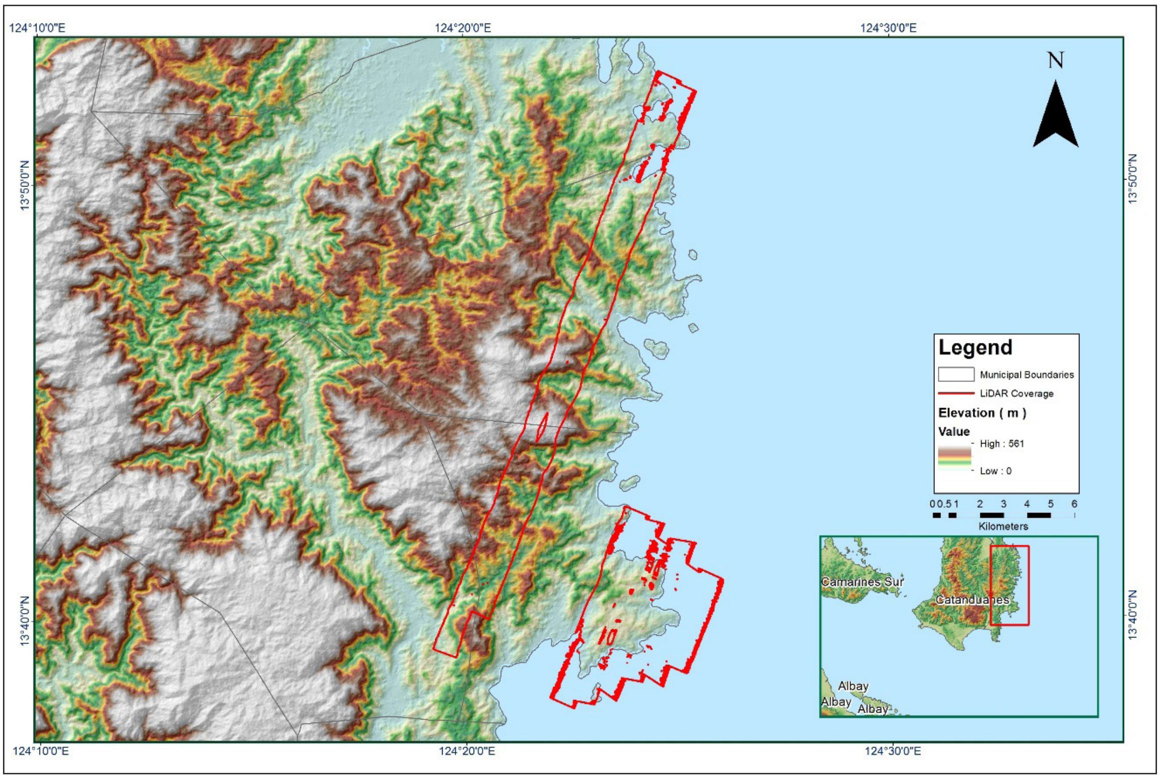


Figure A-8.4. Coverage of LiDAR data

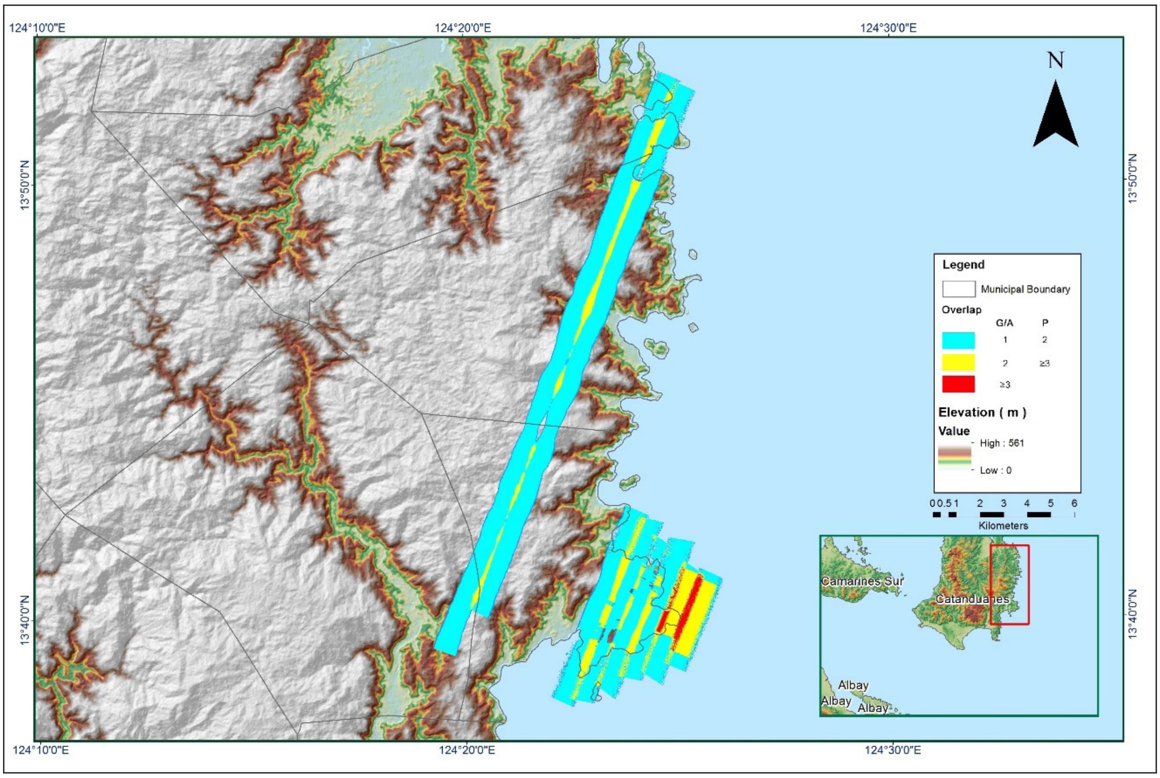


Figure A-8.5. Image of data overlap

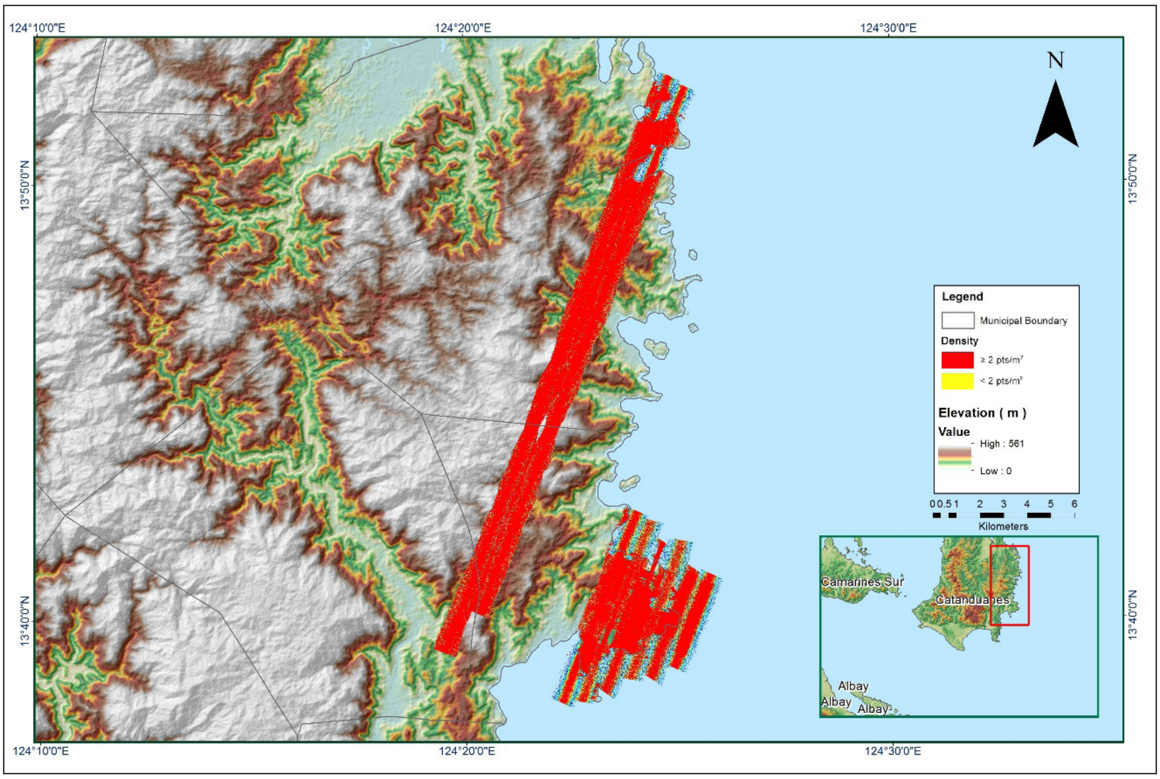


Figure A-8.6. Density Map of merged LiDAR data

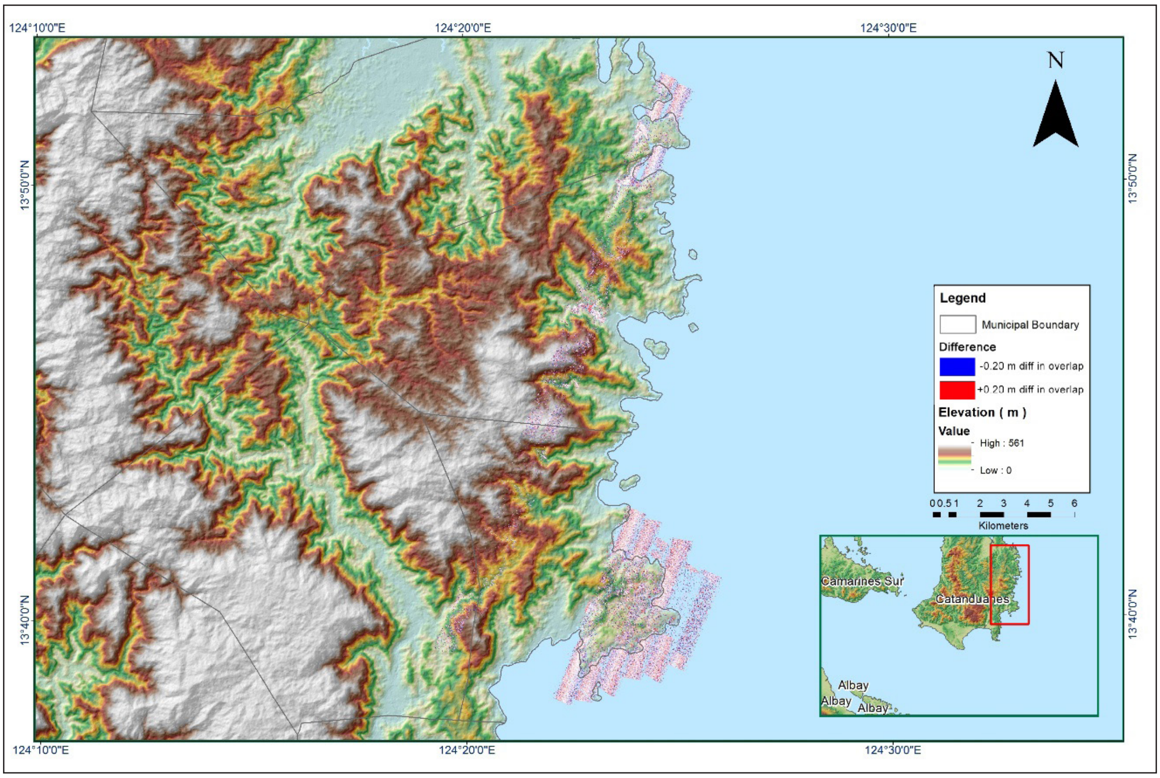


Figure A-8.7. Elevation Difference Between flight lines

Table A-8.2. Mission Summary Report for Mission Blk25B

Flight Area	Catanduanes
Mission Name	Blk25B
Inclusive Flights	3014P/3016P
Range data size	26.6 GB
Base data size	178.1 MB
POS	312 MB
Image	7.18 B
Base Station	178.1 MB
Transfer date	January 28, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.4
RMSE for East Position (<4.0 cm)	3.3
RMSE for Down Position (<8.0 cm)	4.2
Boresight correction stdev (<0.001deg)	0.000318
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	0.0009
Minimum % overlap (>25)	45.24
Ave point cloud density per sq.m. (>2.0)	4.21

Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	106
Maximum Height	468.06 m
Minimum Height	46.88 m
Classification (# of points)	
Ground	53,827,964
Low vegetation	35,373,437
Medium vegetation	108,004,811
High vegetation	441,826,373
Building	8,434,918
Orthophoto	Yes
Processed by	Engr. Don Matthew Banatiin, Engr. Justine Francisco, Marie Denise Bueno

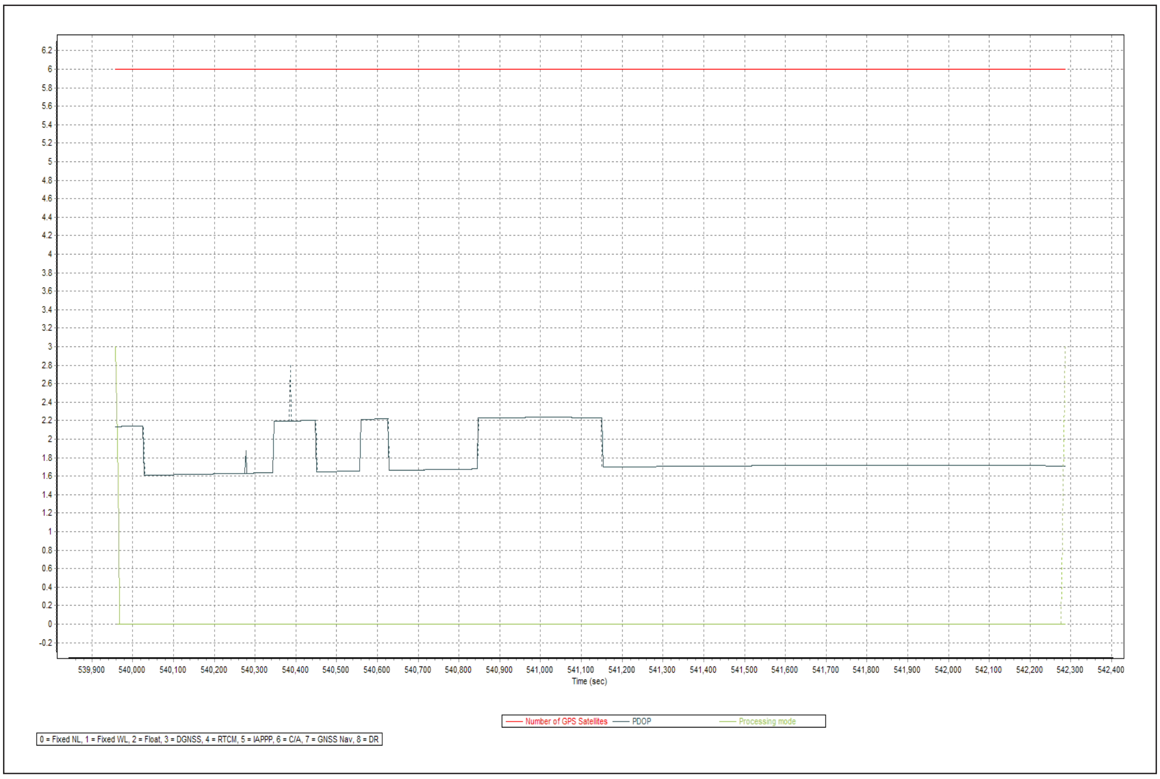


Figure A-8.8. Solution Status

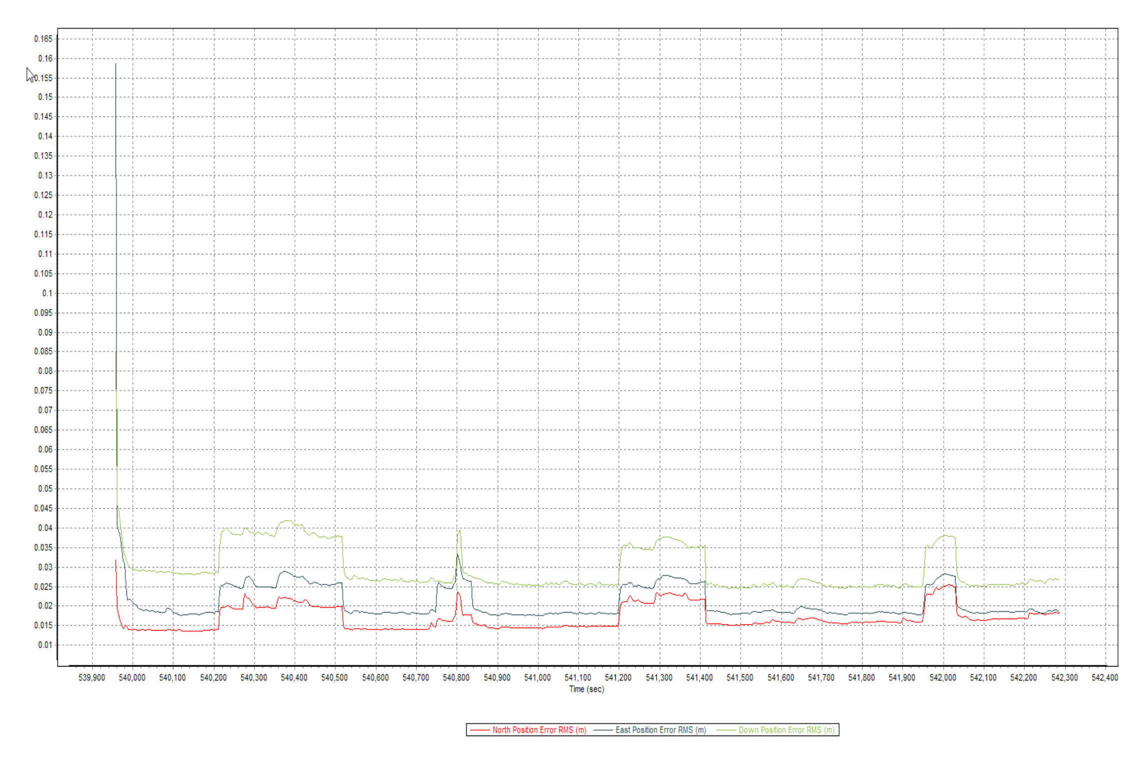


Figure A-8.9. Smoothed Performance Metric Parameters

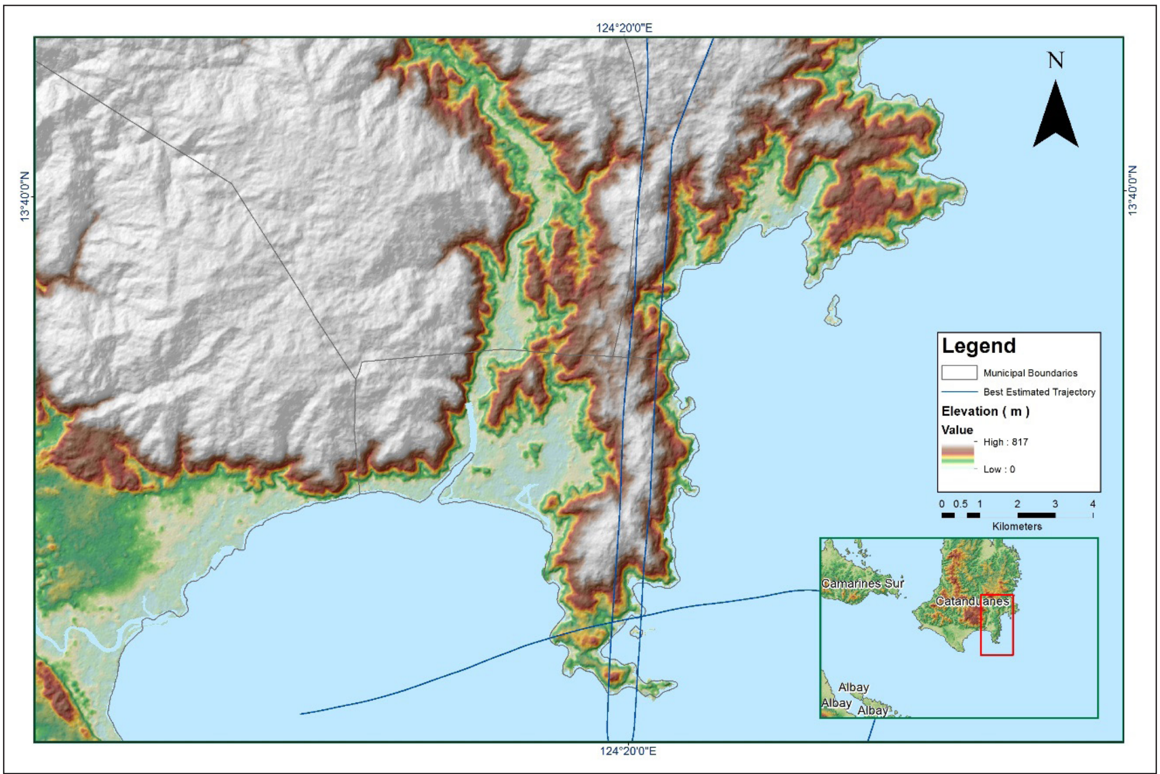


Figure A-8.10. Best Estimate Trajectory

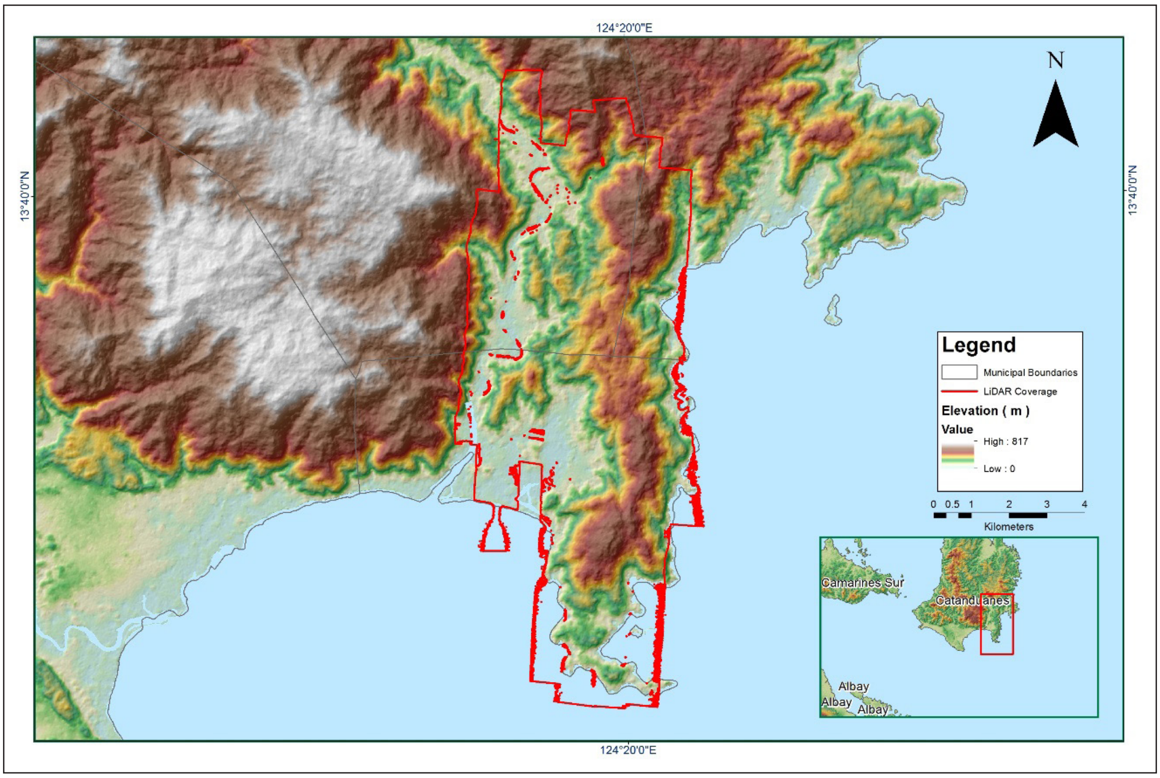


Figure A-8.11. Coverage of LiDAR data

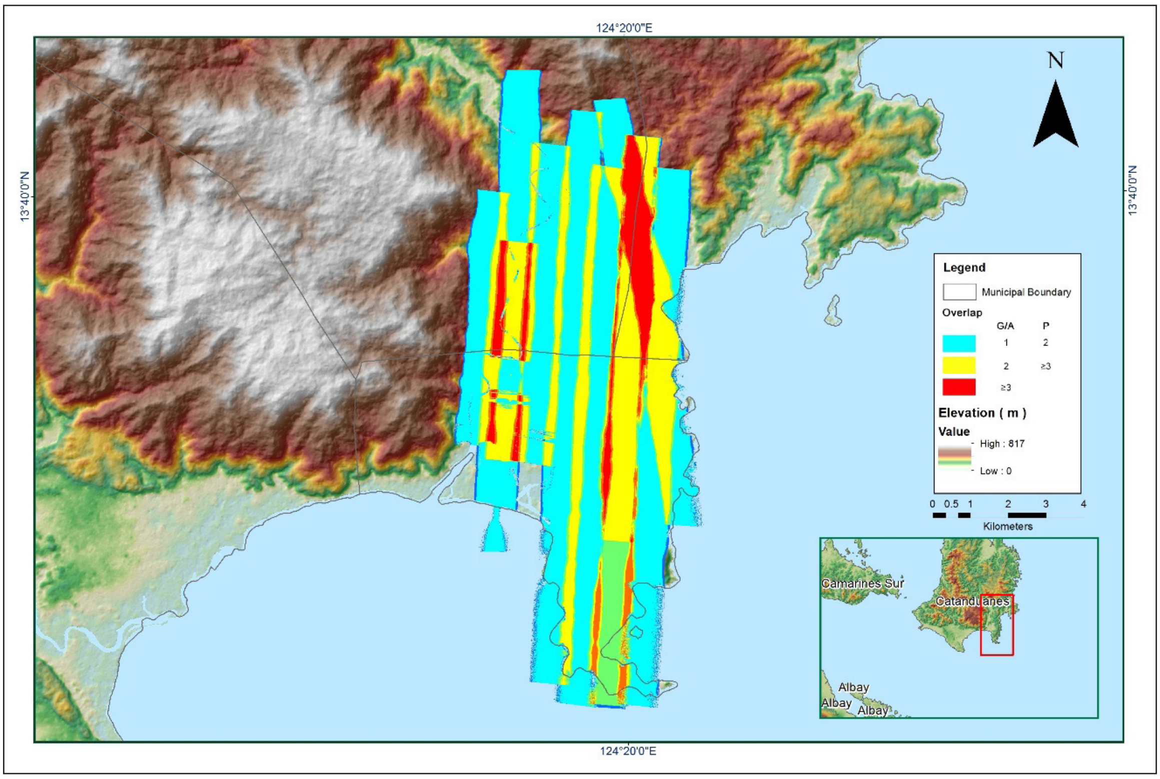


Figure A-8.12. Image of data overlap

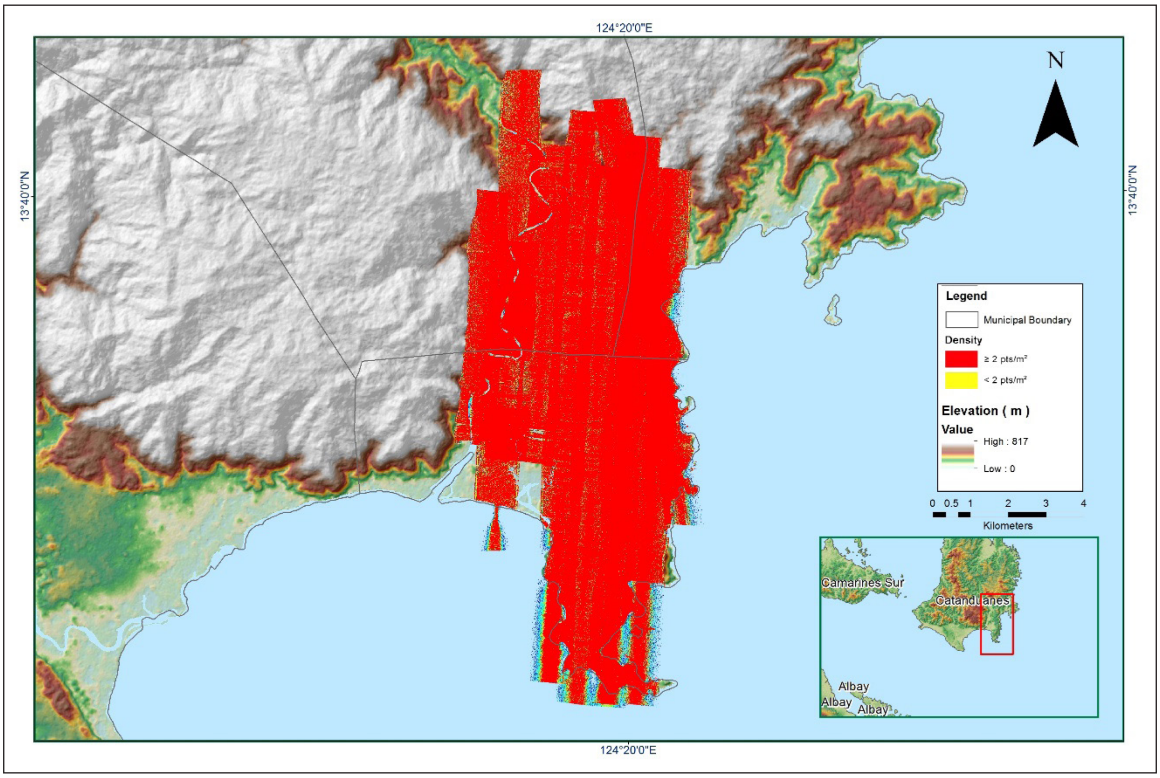


Figure A-8.31. Density Map of merged LiDAR data

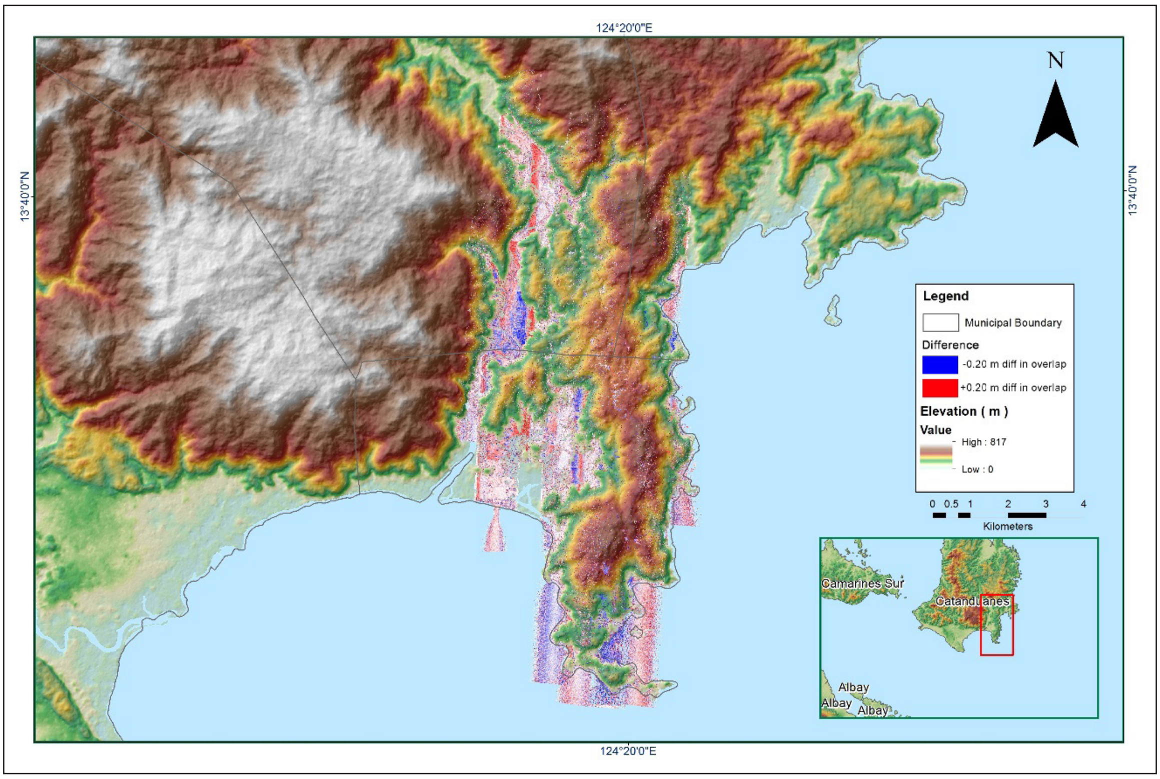


Figure A-8.14. Elevation Difference Between flight lines

Table A-8.3. Mission Summary Report for Mission Blk25B_Supplement

Flight Area	Catanduanes
Mission Name	Blk25B_Supplement
Inclusive Flights	3012P
Range data size	22.1 GB
Base data size	95.7 MB
POS	263 MB
Image	27.9 B
Base Station	95.7 MB
Transfer date	January 28, 2016
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)	3.8
RMSE for East Position (<4.0 cm)	4.6
RMSE for Down Position (<8.0 cm)	8.4
Boresight correction stdev (<0.001deg)	0.000504
IMU attitude correction stdev (<0.001deg)	0.001092
GPS position stdev (<0.01m)	0.0023
Minimum % overlap (>25)	25.58
Ave point cloud density per sq.m. (>2.0)	3.17
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	138
Maximum Height	581.26 m
Minimum Height	51.71 m
Classification (# of points)	
Ground	58,664,538
Low vegetation	21,264,518
Medium vegetation	70,693,520
High vegetation	318,077,525
Building	3,728,863
Orthophoto	Yes
Processed by	Engr. Regis Guhiting, Engr. Edgardo Gubatanga Jr., Maria Tamsyn Malabanan

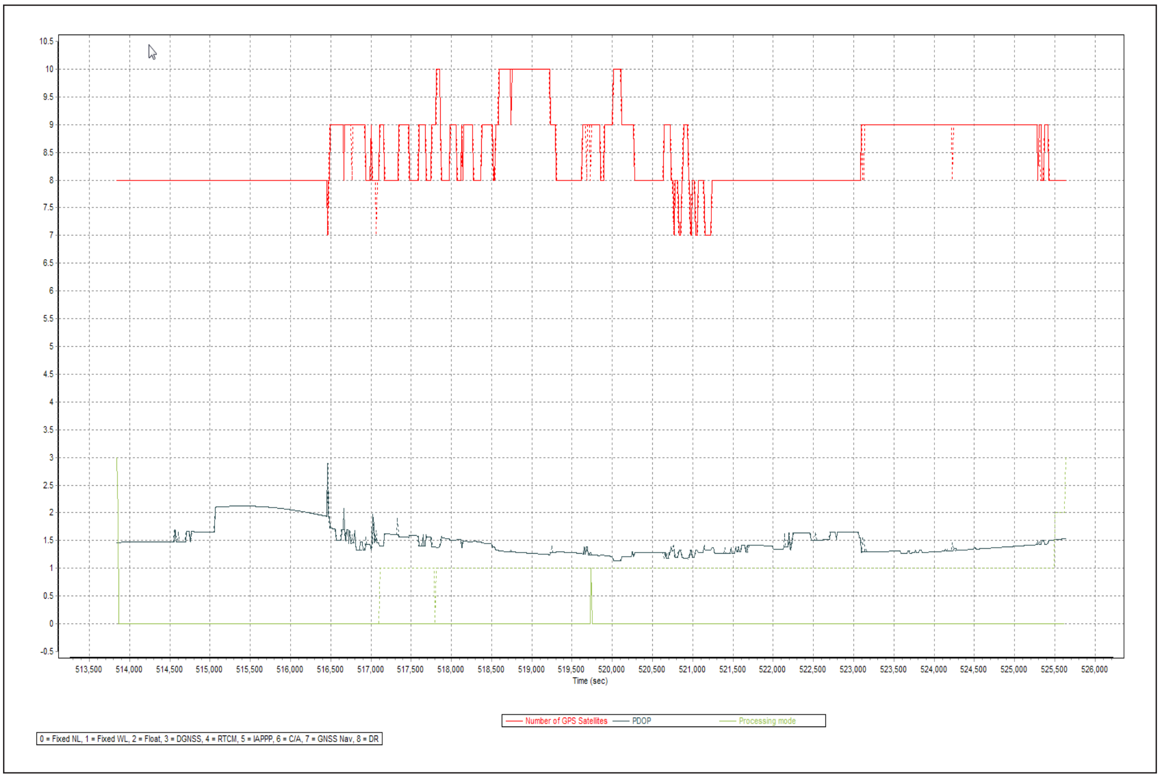


Figure A-8.15. Solution Status

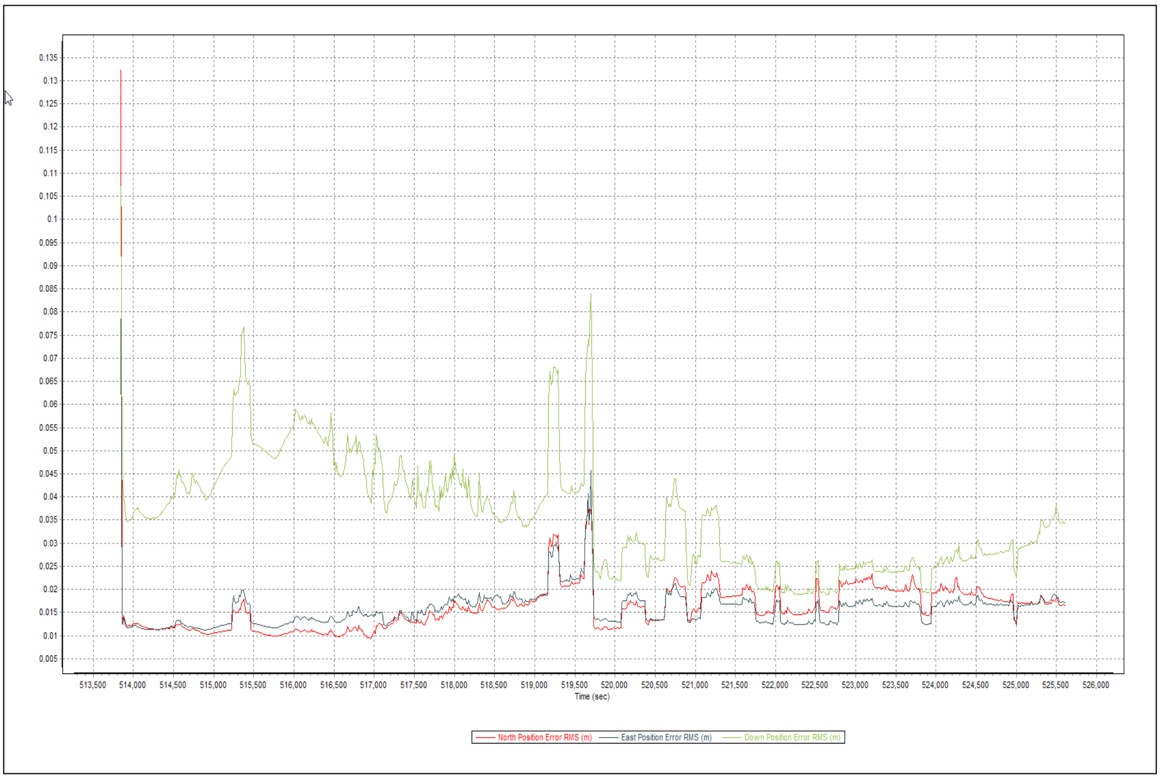


Figure A-8.16. Smoothed Performance Metric Parameters

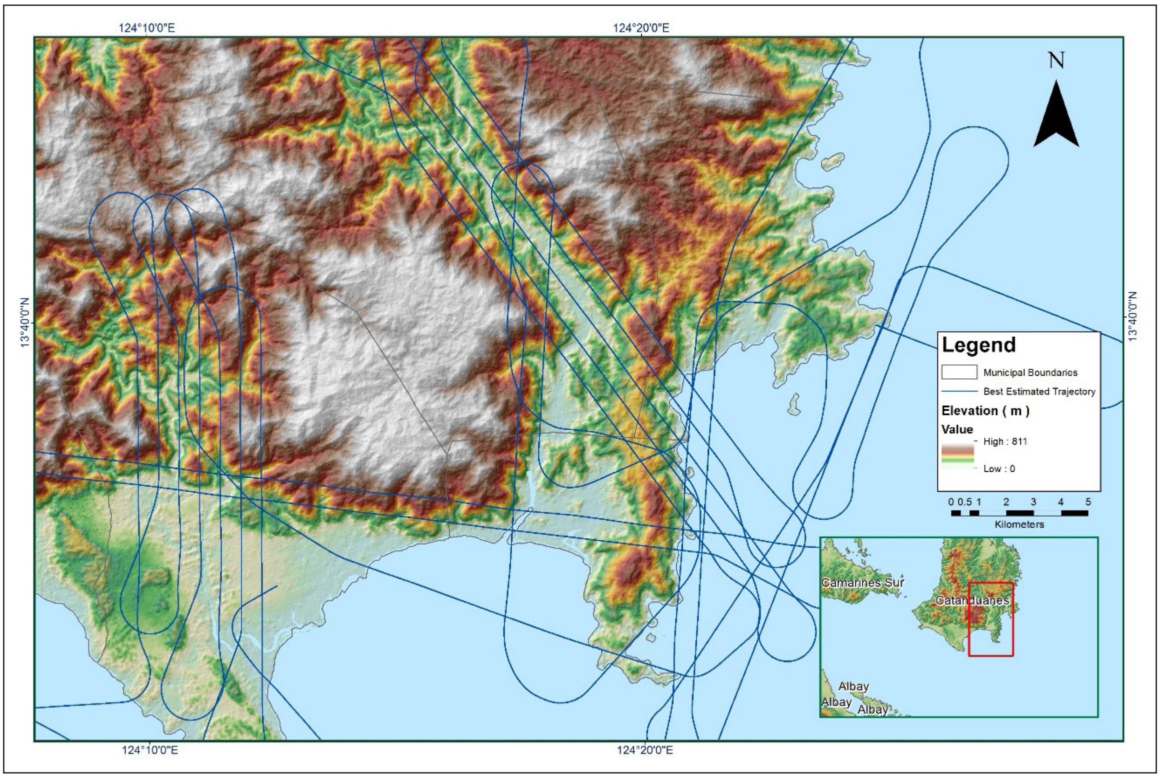


Figure A-8.17. Best Estimate Trajectory

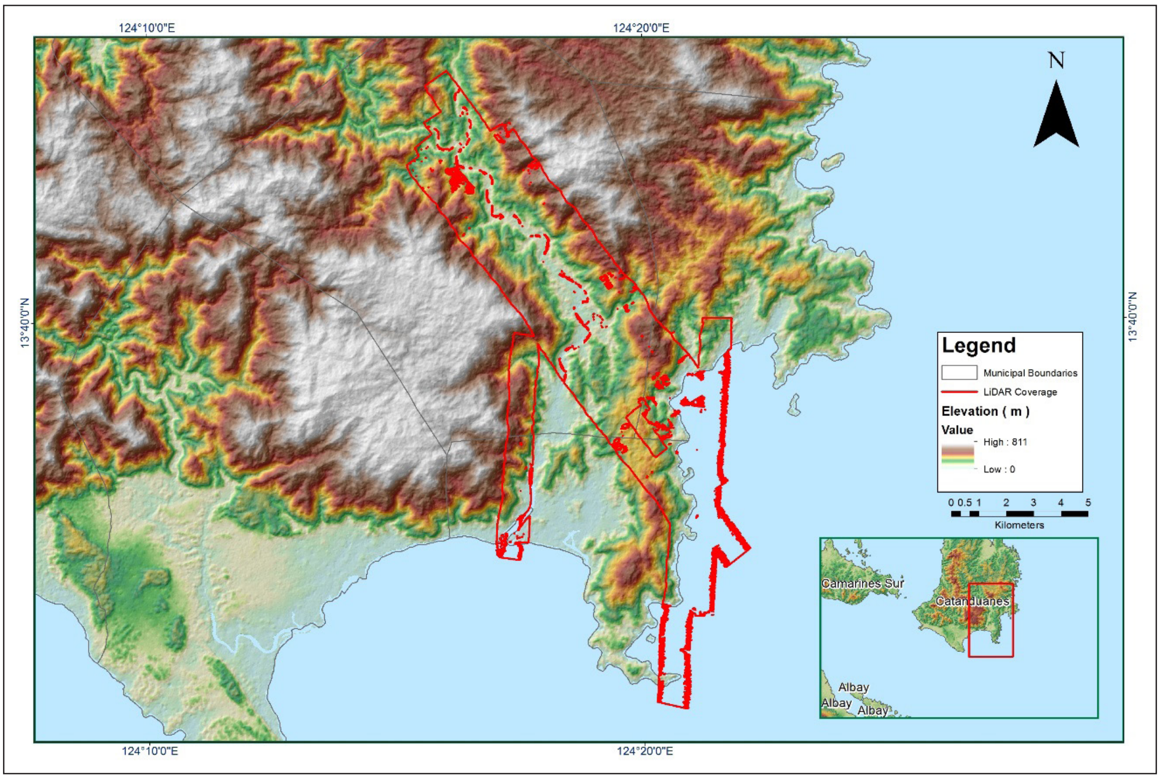


Figure A-8.18. Coverage of LiDAR data

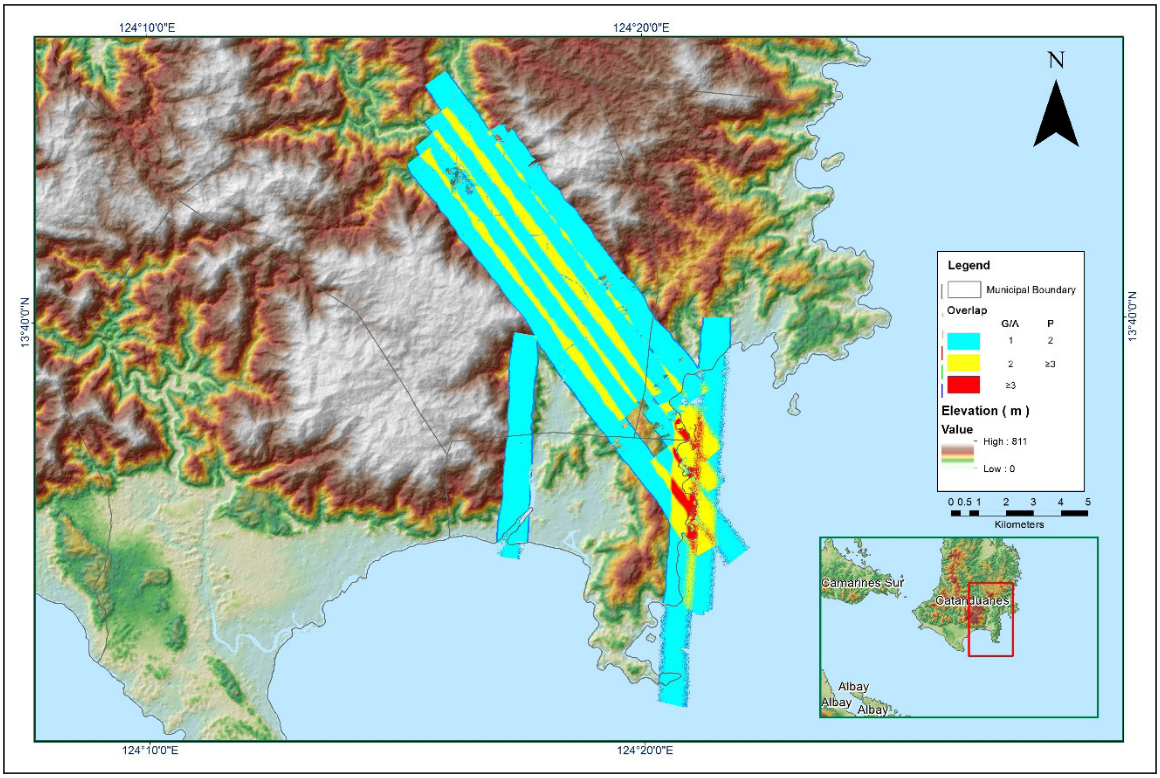


Figure A-8.19. Image of data overlap

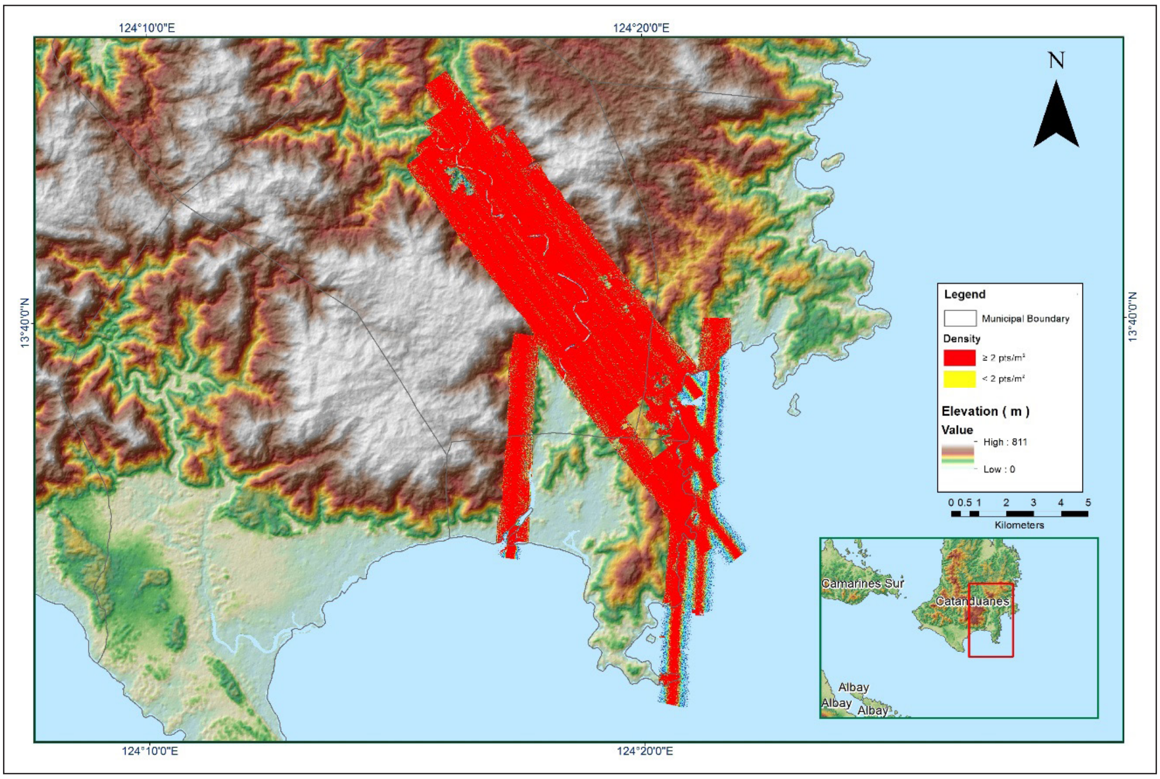


Figure A-8.20. Density Map of merged LiDAR data

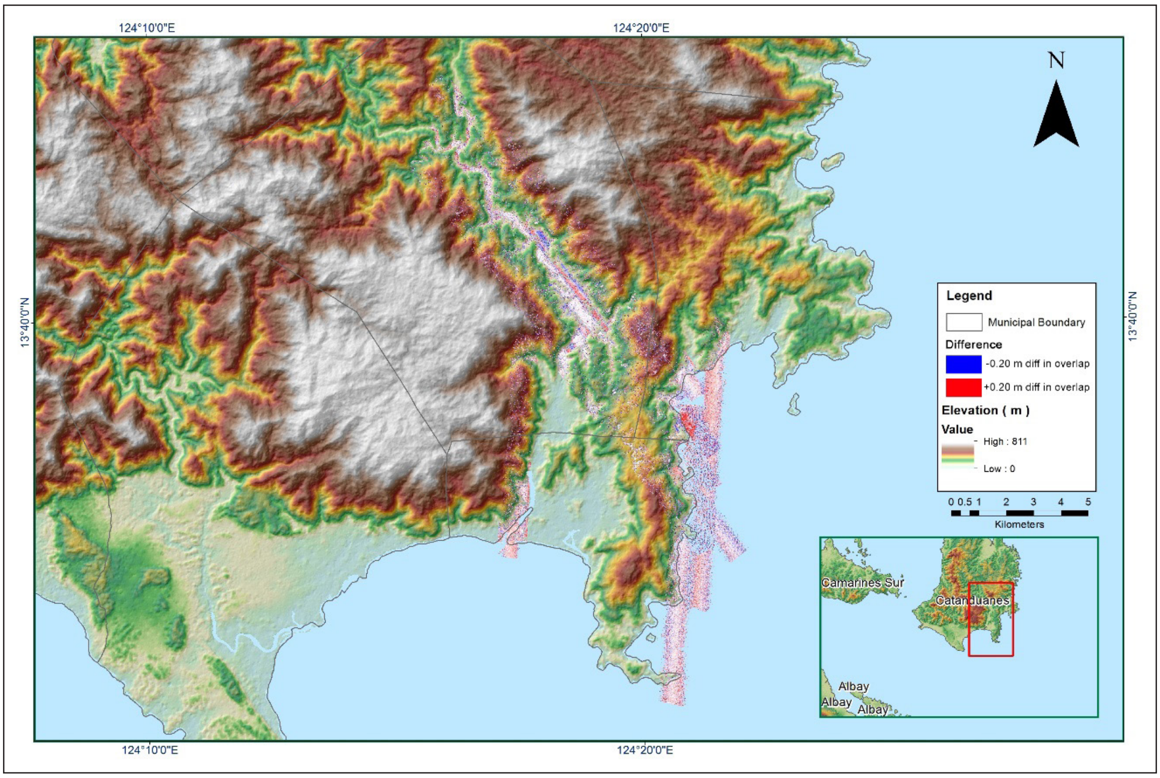


Figure A-8.21. Elevation Difference Between flight lines

Table A-8.4. Mission Summary Report for Mission Blk25A

Flight Area	Catanduanes
Mission Name	Blk25A
Inclusive Flights	3010P/3028P
Range data size	27.68 GB
Base data size	133.8 MB
POS	364 MB
Image	NA
Base Station	133.8 MB
Transfer date	February 12, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.0
RMSE for East Position (<4.0 cm)	1.1
RMSE for Down Position (<8.0 cm)	2.1
Boresight correction stdev (<0.001deg)	0.000261
IMU attitude correction stdev (<0.001deg)	0.000827
GPS position stdev (<0.01m)	0.0021
Minimum % overlap (>25)	22.64
Ave point cloud density per sq.m. (>2.0)	3.28

Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	209
Maximum Height	559.96 m
Minimum Height	47.95 m
Classification (# of points)	
Ground	140,462,027
Low vegetation	73,242,229
Medium vegetation	110,584,950
High vegetation	347,813,357
Building	10,845,125
Orthophoto	Yes
Processed by	Engr. Abigail Joy Ching, Engr. Velina Angela Bemida, Maria Tamsyn Malabanan

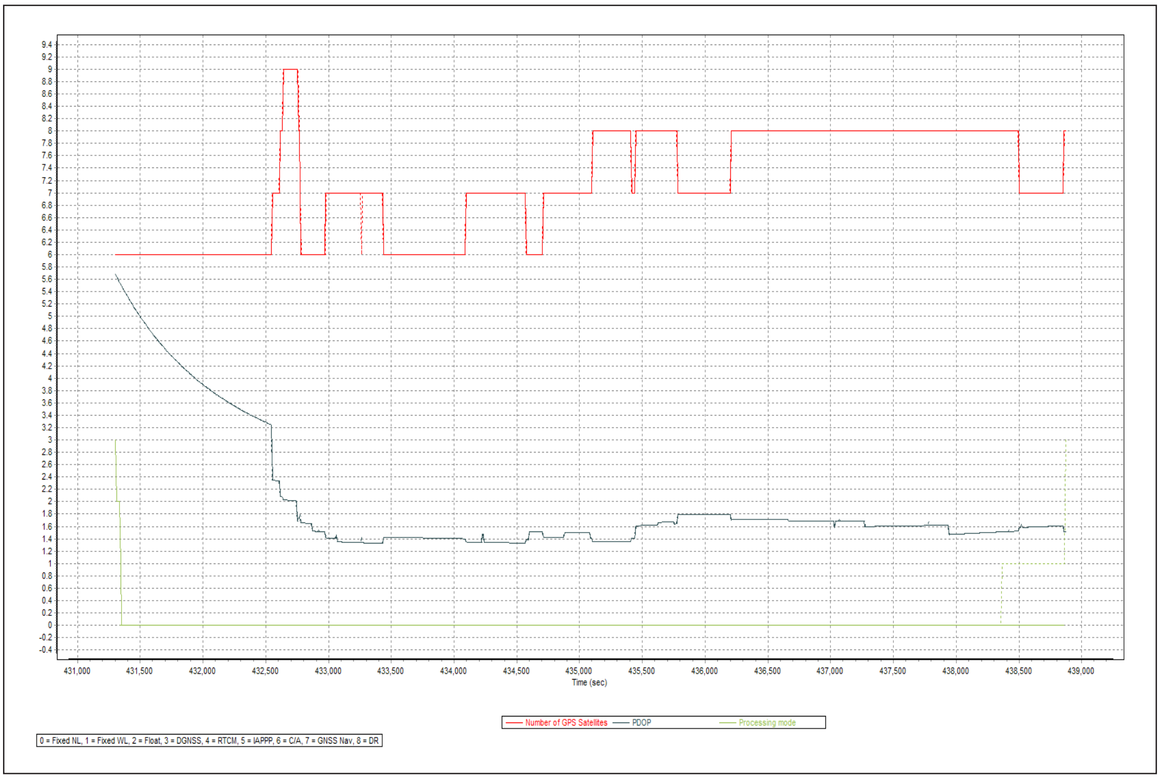


Figure A-8.22. Solution Status

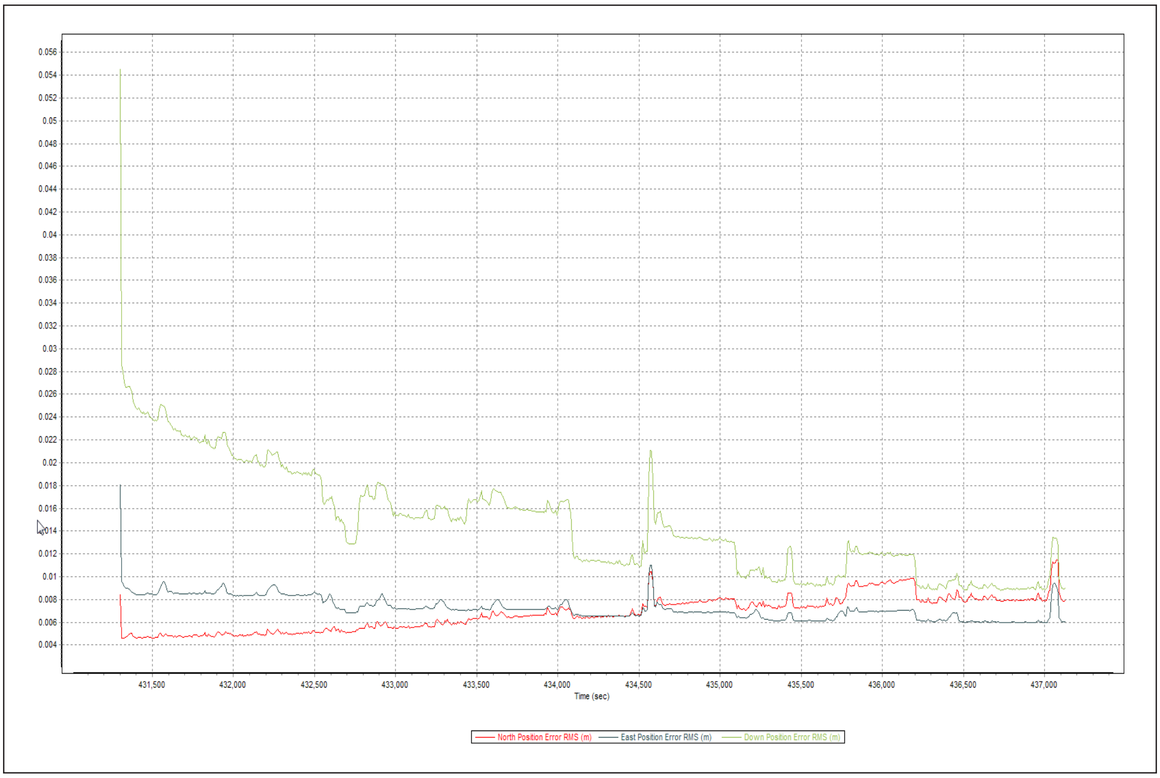


Figure A-8.23. Smoothed Performance Metric Parameters

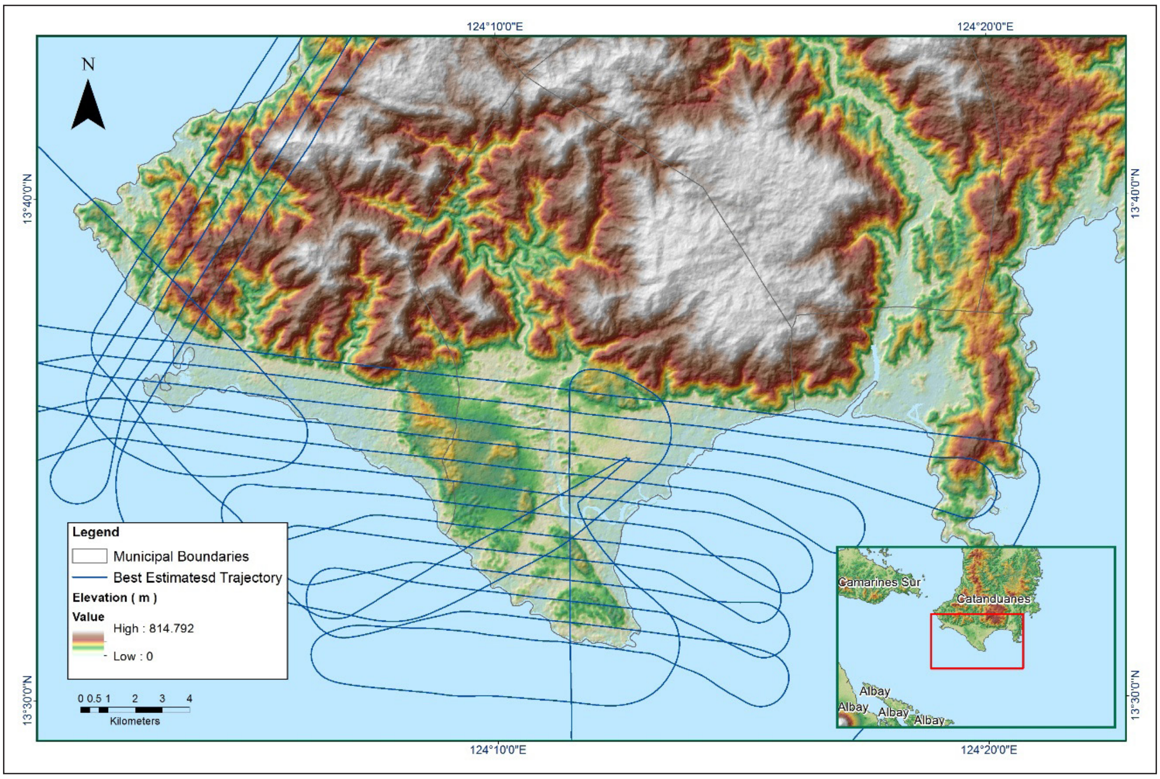


Figure A-8.24. Best Estimate Trajectory

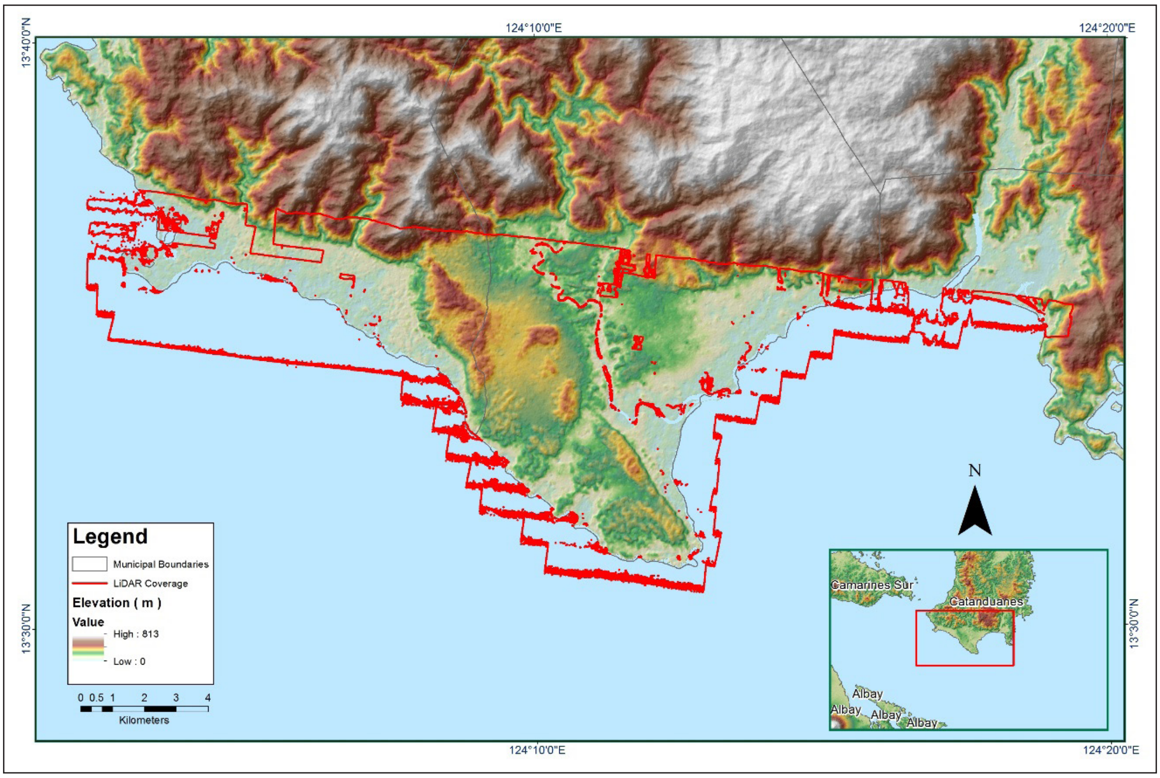


Figure A-8.25. Coverage of LiDAR data

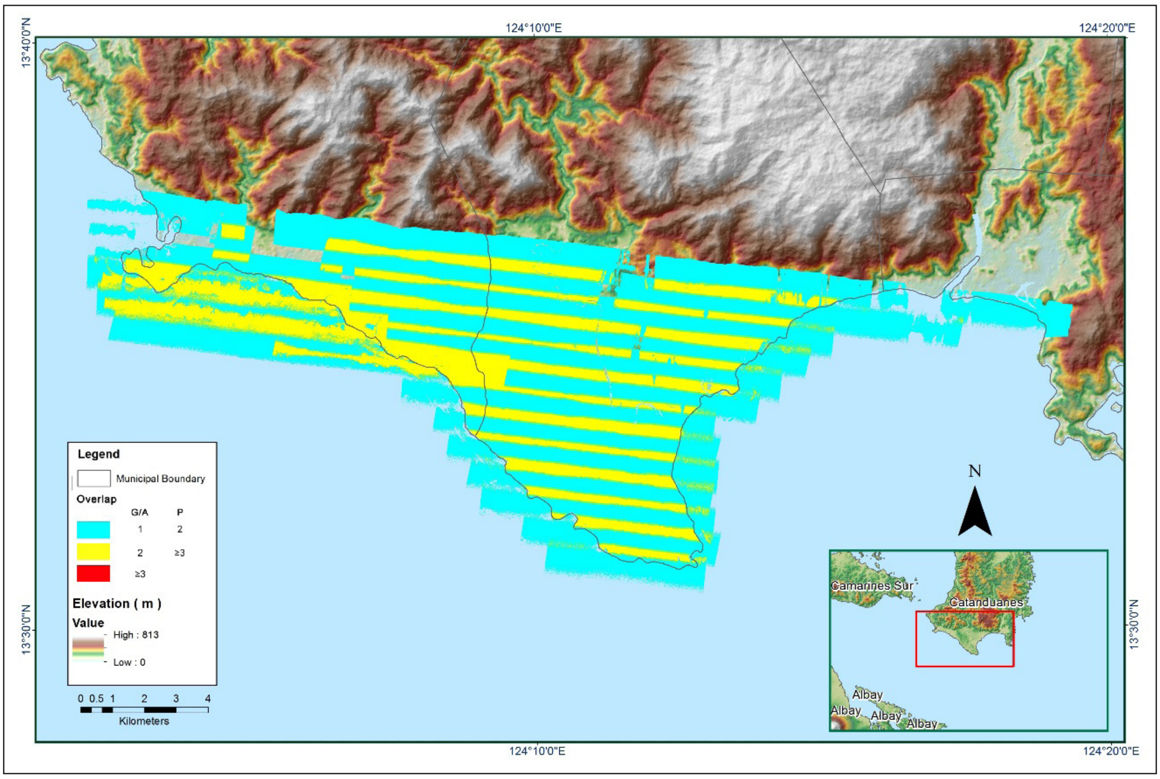


Figure A-8.26. Image of data overlap

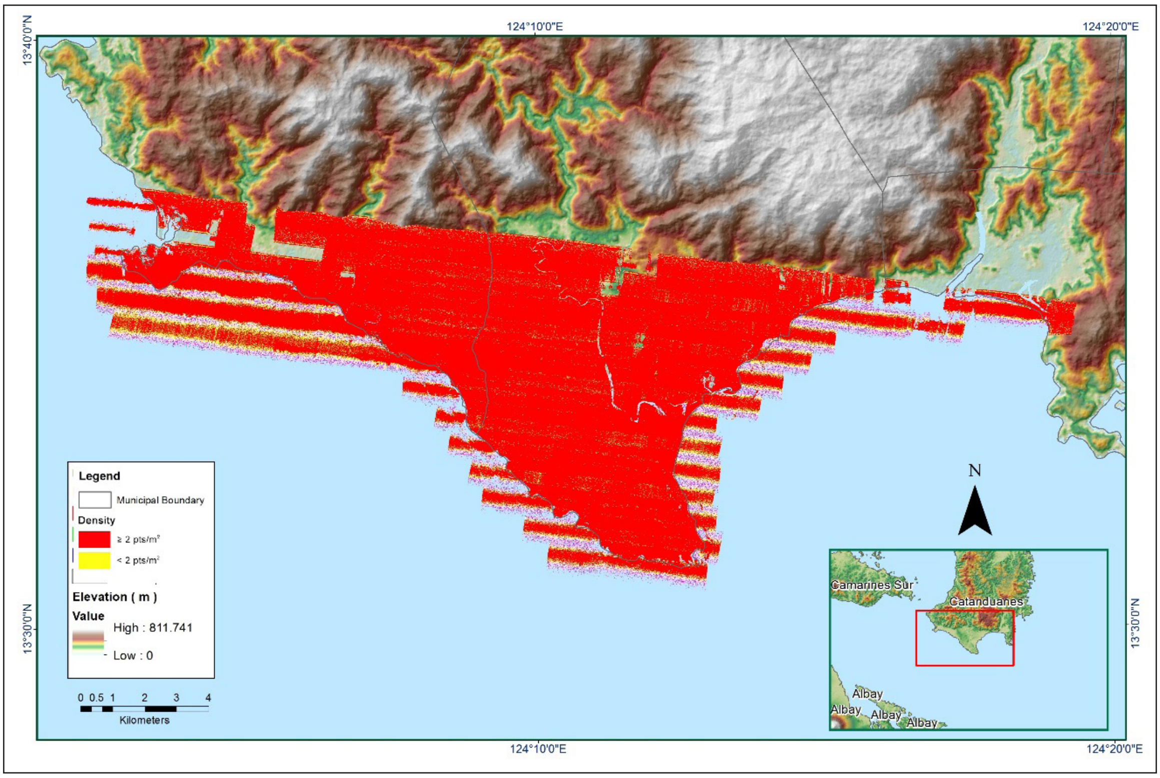


Figure A-8.27. Density Map of merged LiDAR data

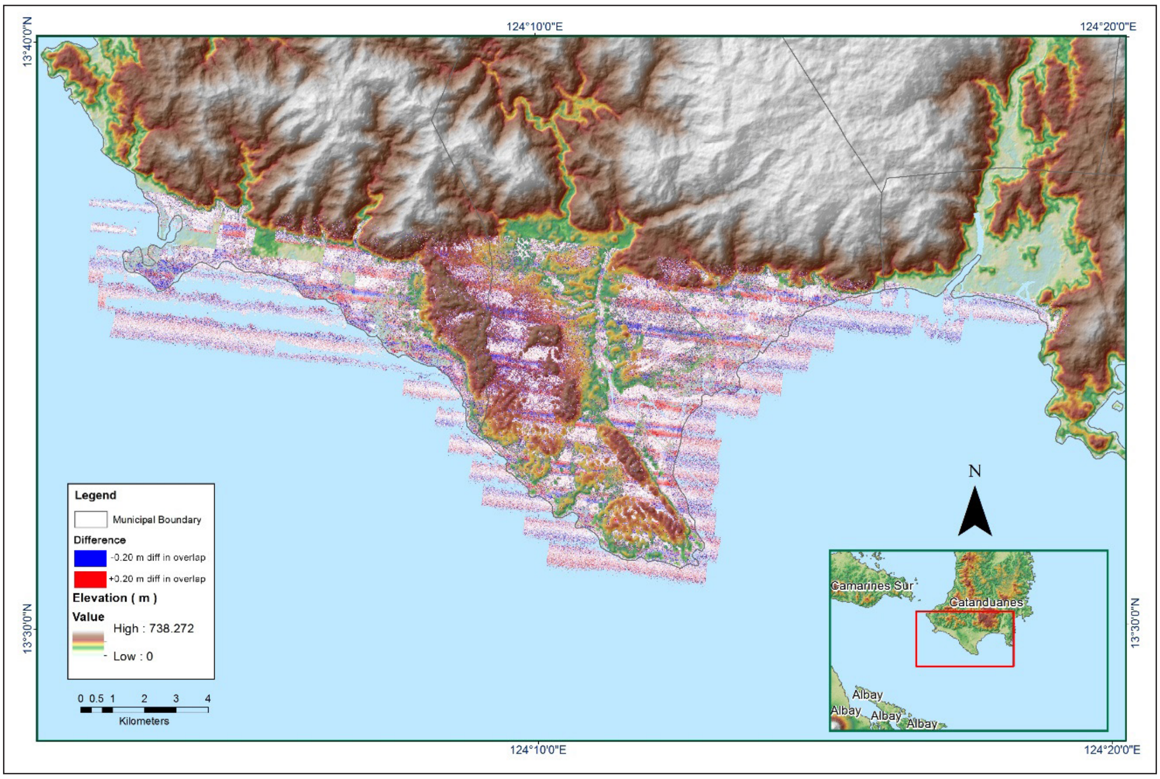


Figure A-8.28. Elevation Difference Between flight lines

Table A-8.5. Mission Summary Report for Mission Blk25A_Supplement

Flight Area	Catanduanes
Mission Name	Blk25A_Supplement
Inclusive Flights	3012P
Range data size	22.1 GB
Base data size	95.7 MB
POS	263 MB
Image	27.9 B
Base Station	95.7 MB
Transfer date	January 28, 2016
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)	3.8
RMSE for East Position (<4.0 cm)	4.6
RMSE for Down Position (<8.0 cm)	8.4
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	36.06
Ave point cloud density per sq.m. (>2.0)	2.71
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	148
Maximum Height	642.48 m
Minimum Height	52.79 m
Classification (# of points)	
Ground	59,518,090
Low vegetation	21,144,287
Medium vegetation	88,886,665
High vegetation	448,684,984
Building	8,146,424
Orthophoto	No
Processed by	Engr. Regis Guhiting, Ma. Joanne Balaga, Alex John Escobido

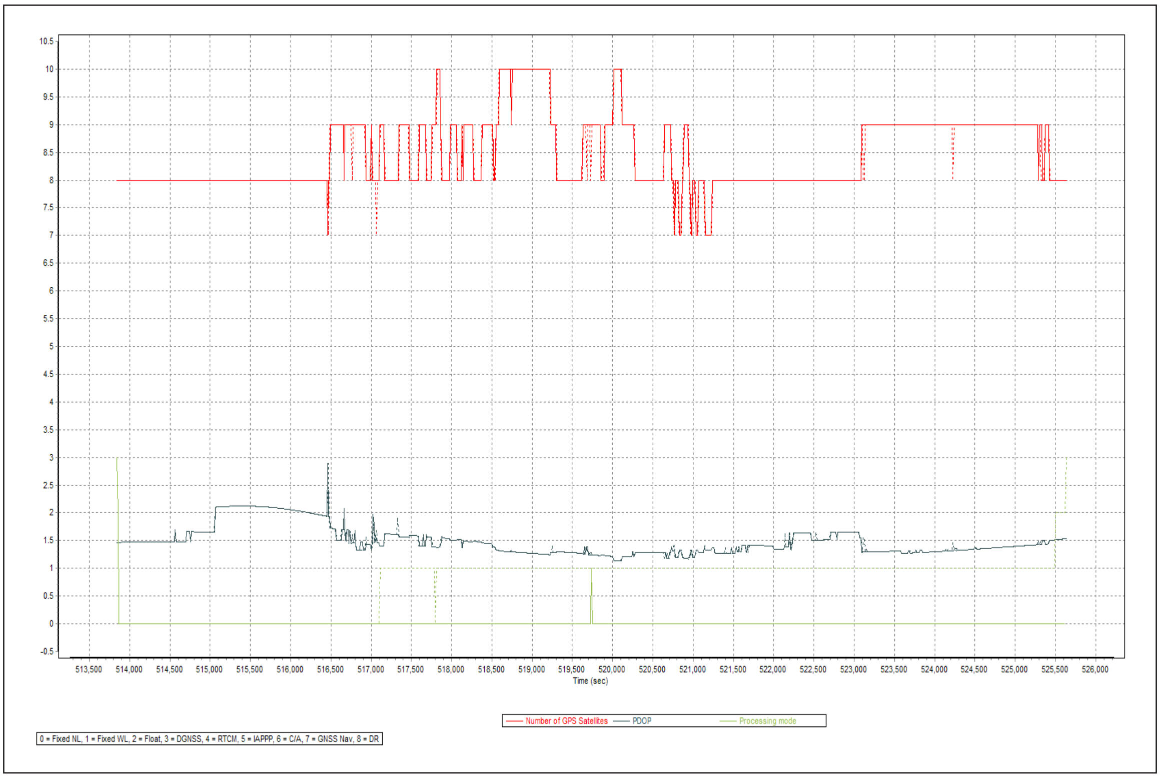


Figure A-8.29. Solution Status

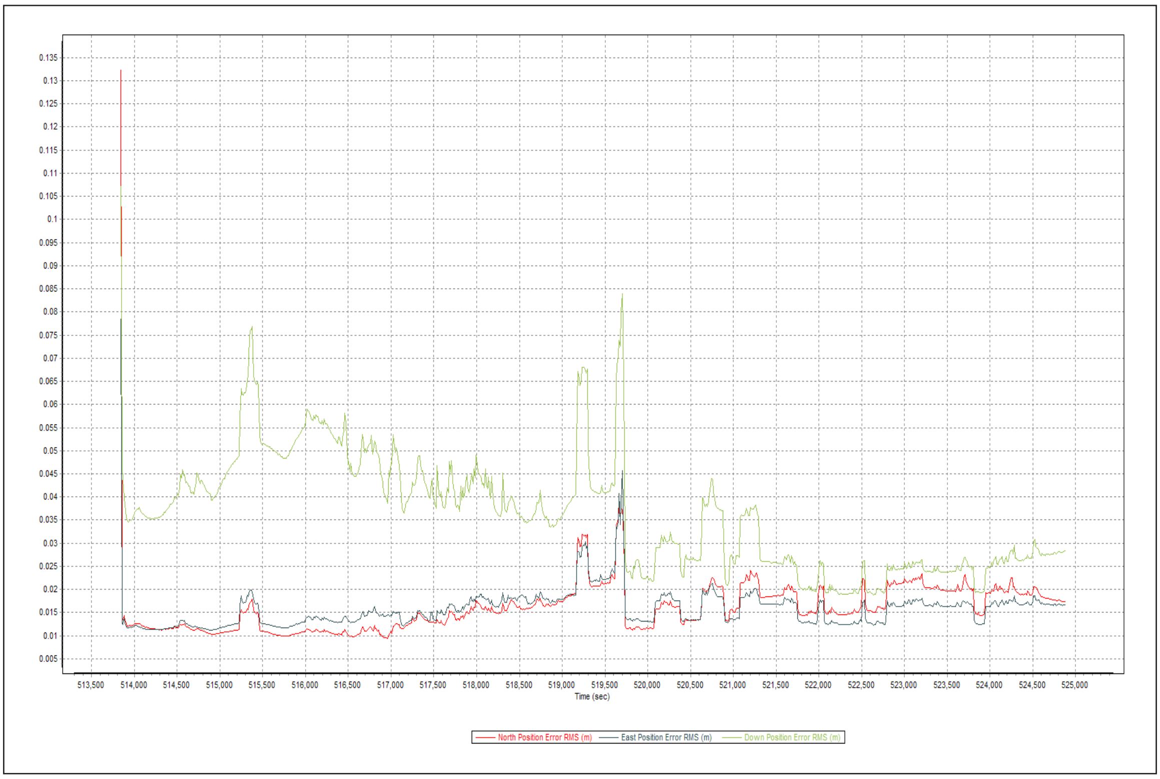


Figure A-8.30. Smoothed Performance Metric Parameters

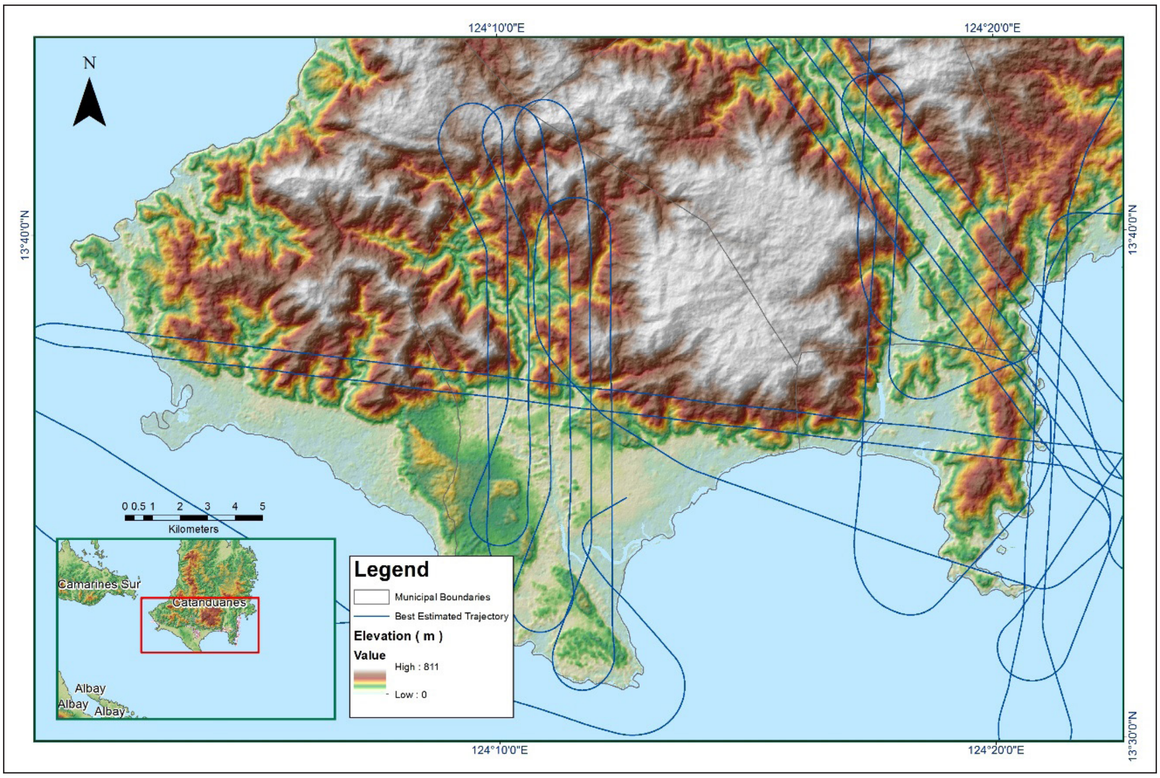


Figure A-8.31. Best Estimate Trajectory

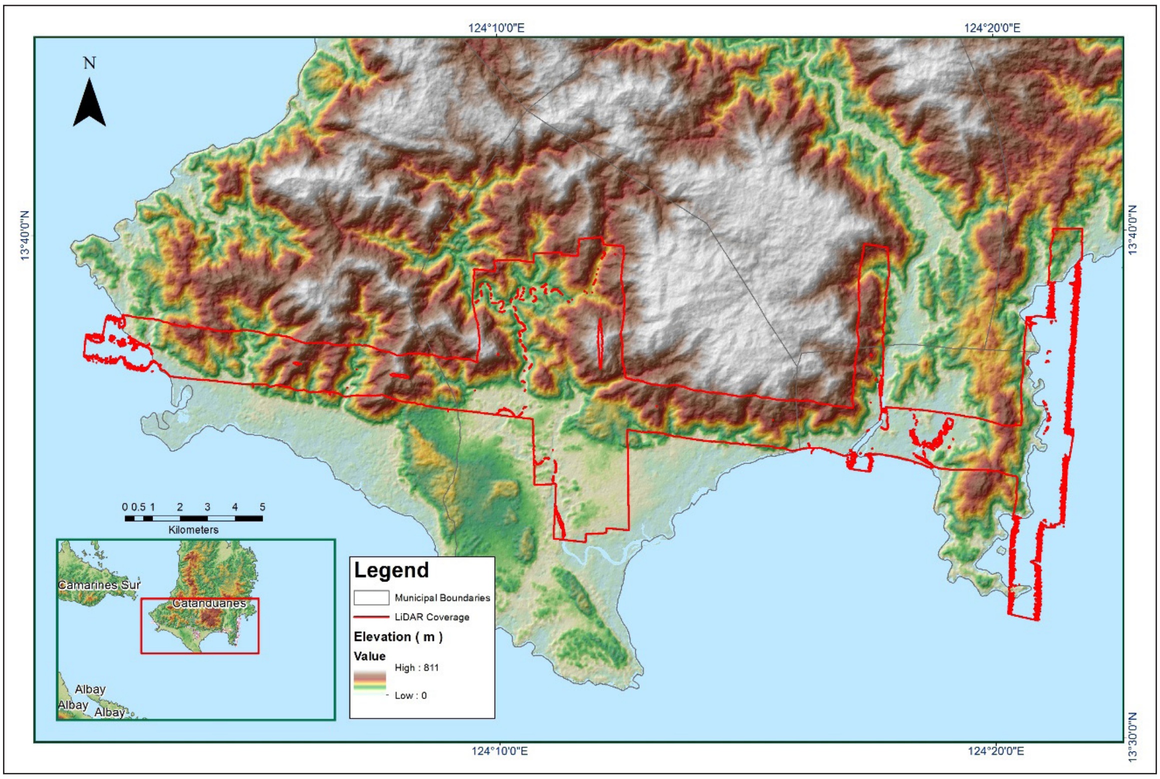


Figure A-8.32. Coverage of LiDAR data

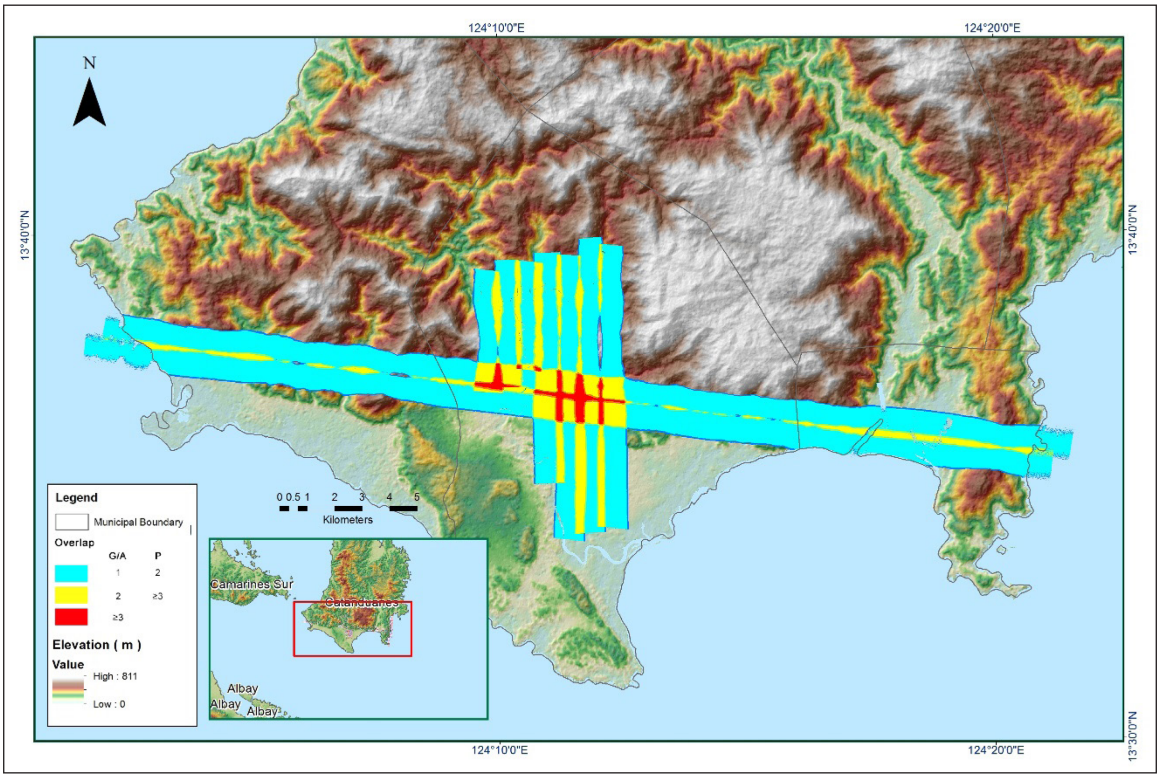


Figure A-8.33. Image of data overlap

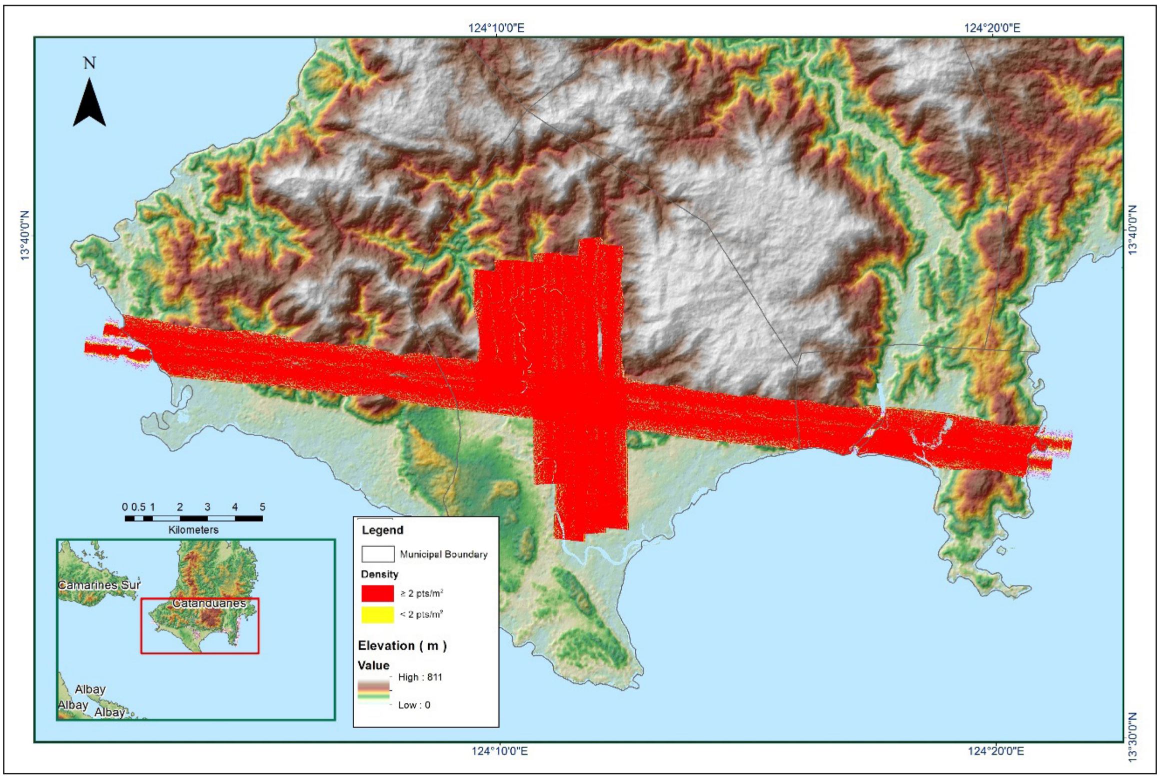


Figure A-8.34. Density Map of merged LiDAR data

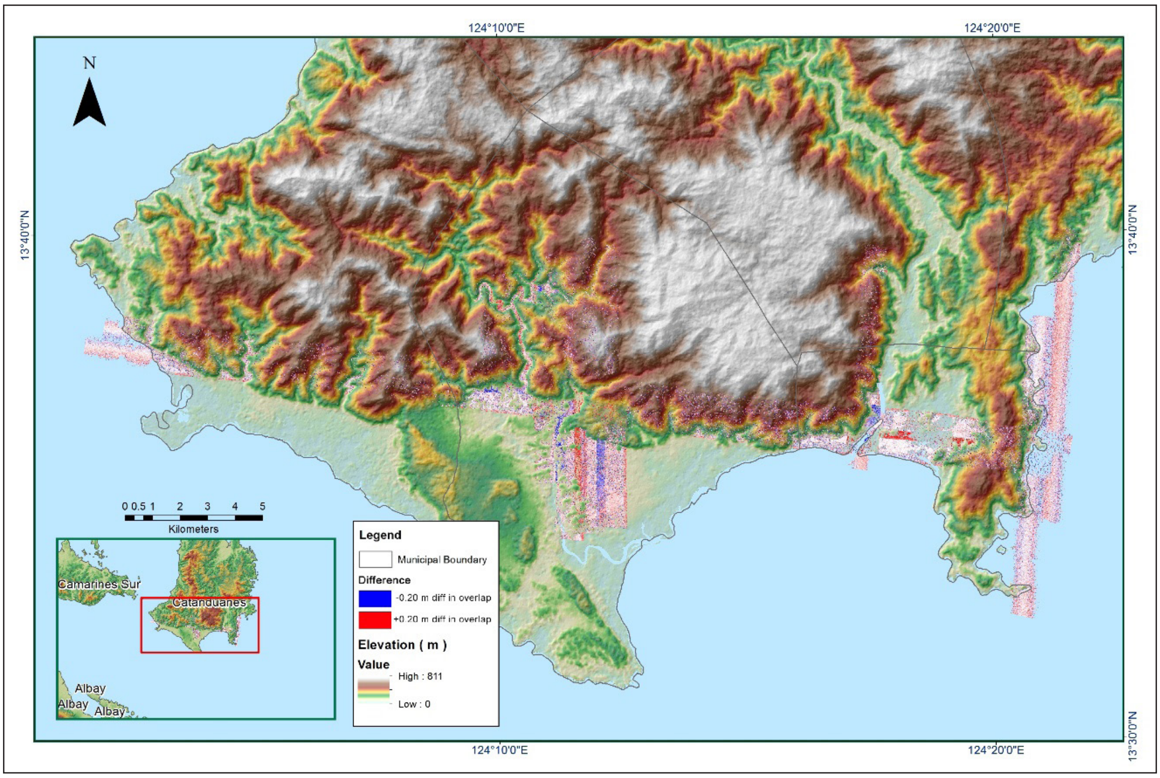


Figure A-8.35. Elevation Difference Between flight lines

Table A-8.6. Mission Summary Report for Mission Blk25H_Additional

Flight Area	Catanduanes
Mission Name	Blk25H_Additional
Inclusive Flights	3016P
Range data size	14.6 GB
Base data size	82.4MB
POS	167 MB
Image	NA
Base Station	82.4 MB
Transfer date	January 28, 2016
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)	2.2
RMSE for East Position (<4.0 cm)	2.9
RMSE for Down Position (<8.0 cm)	13.8
Boresight correction stdev (<0.001deg)	0.000376
IMU attitude correction stdev (<0.001deg)	0.001333
GPS position stdev (<0.01m)	0.0022
Minimum % overlap (>25)	15.26
Ave point cloud density per sq.m. (>2.0)	2.95
Elevation difference between strips (<0.20 m)	Yes

Number of 1km x 1km blocks	185
Maximum Height	767.53 m
Minimum Height	53.54 m
Classification (# of points)	
Ground	54,421,428
Low vegetation	29,724,310
Medium vegetation	75,930,262
High vegetation	362,898,505
Building	7,347,715
Orthophoto	No
Processed by	Engr. Sheila-Maye Santillan, Engr. Chelou Prado, Alex John Escobido

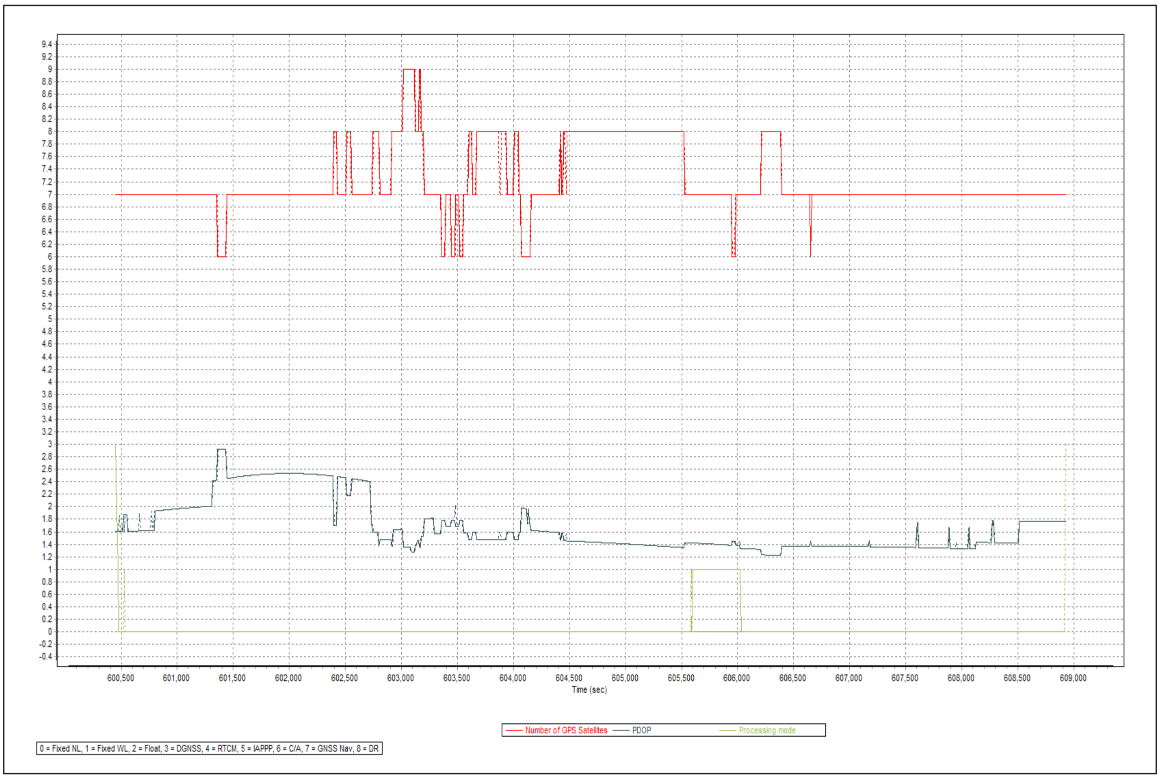


Figure A-8.36. Solution Status

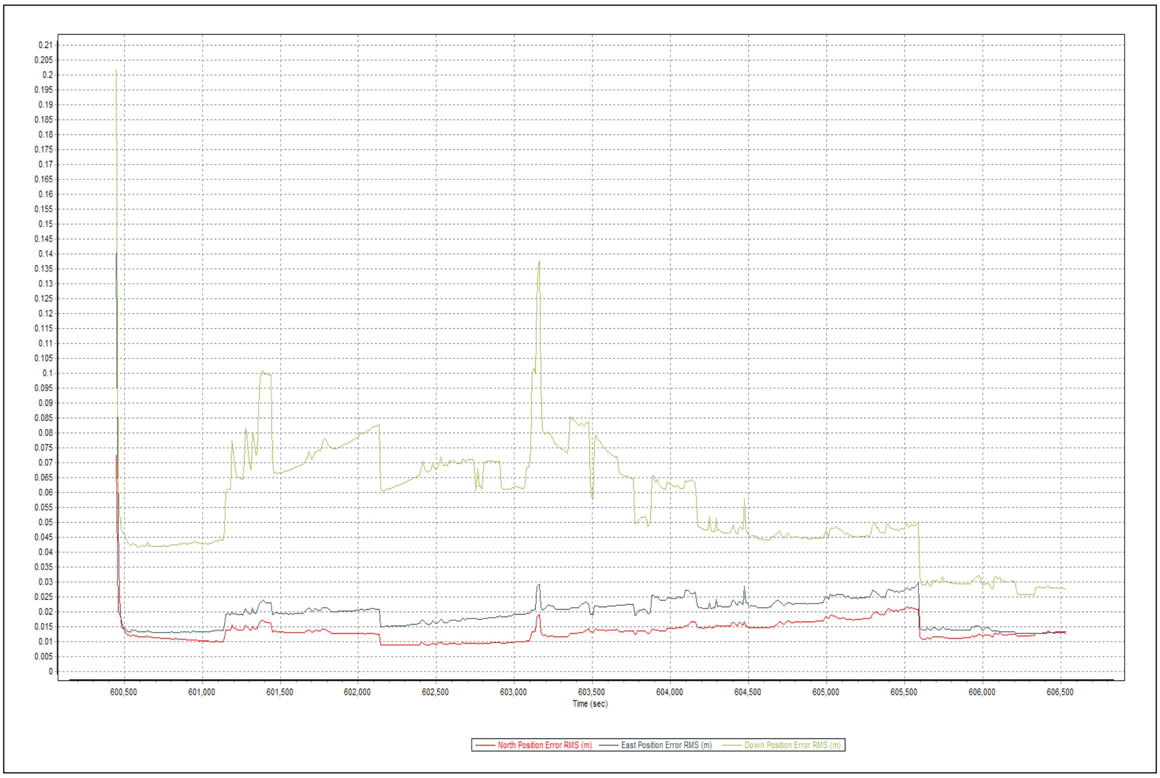


Figure A-8.37. Smoothed Performance Metric Parameters

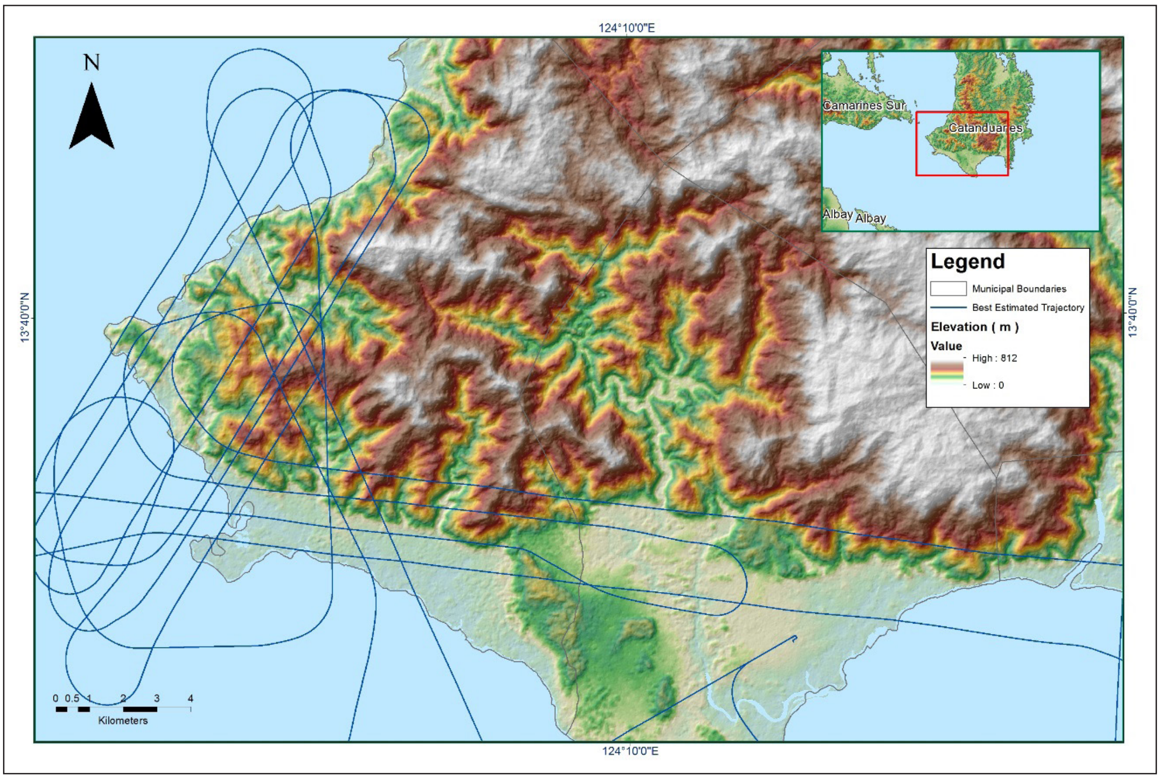


Figure A-8.38. Best Estimate Trajectory

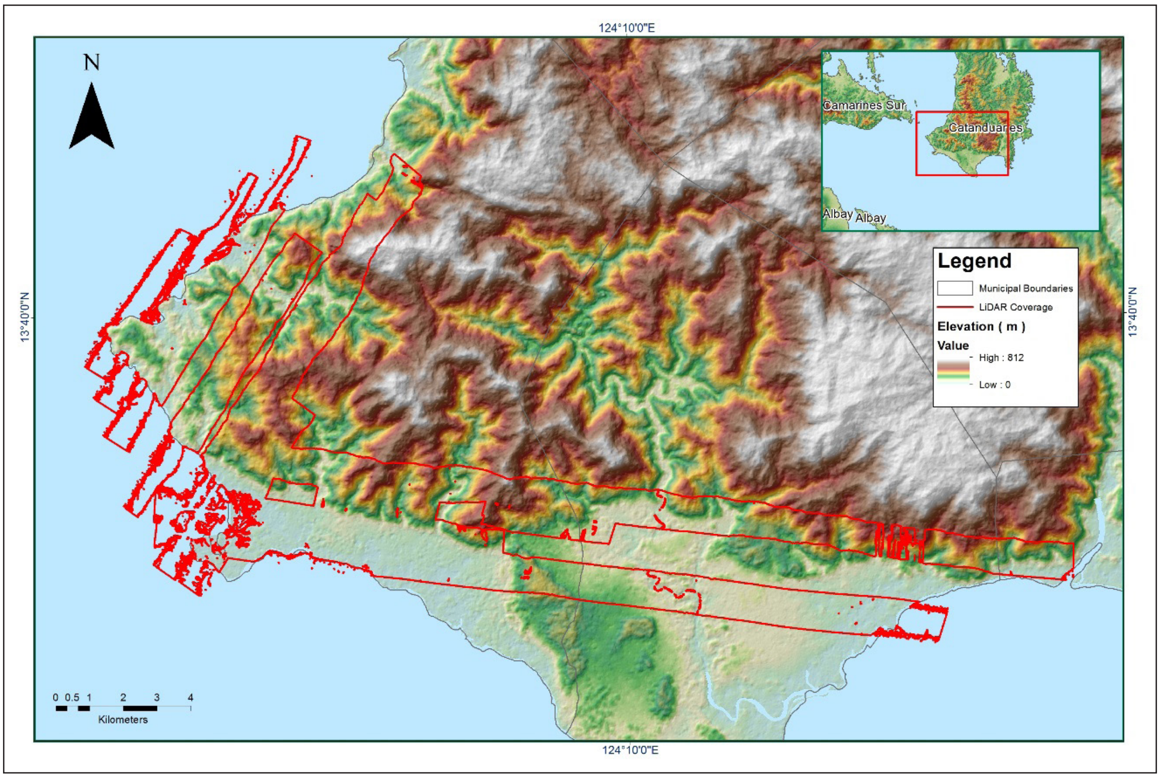


Figure A-8.39. Coverage of LiDAR data

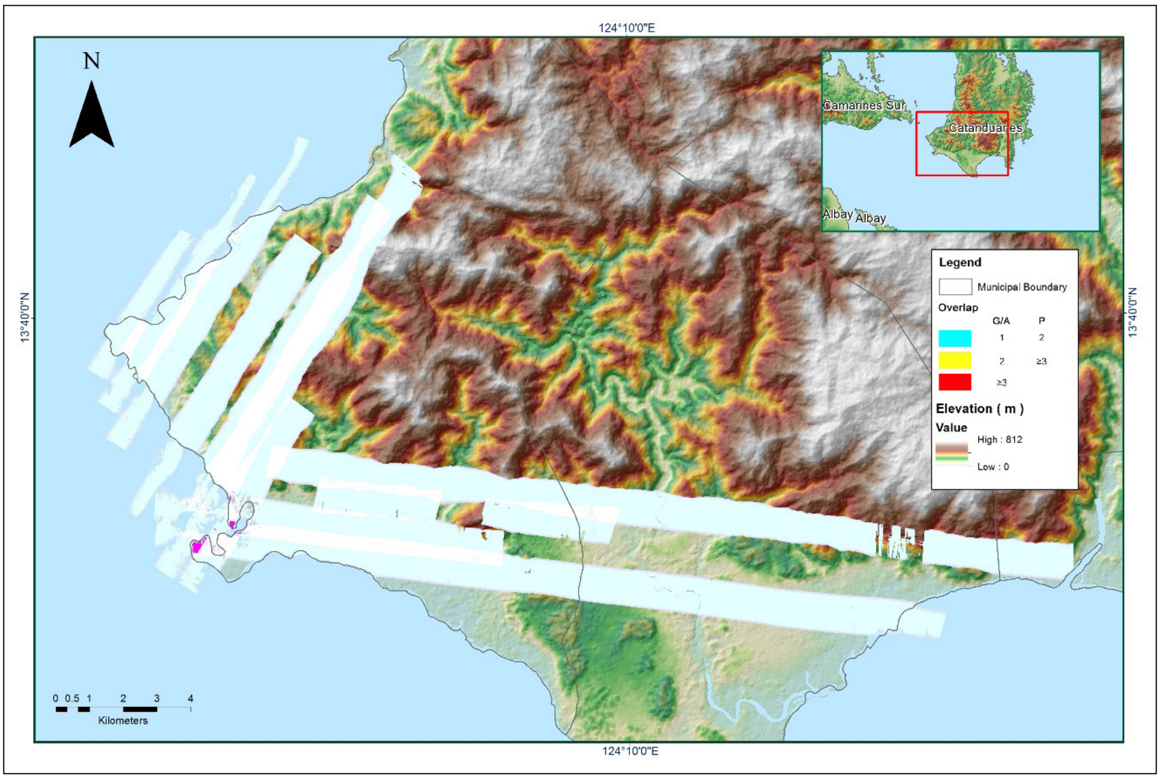


Figure A-8.40. Image of data overlap

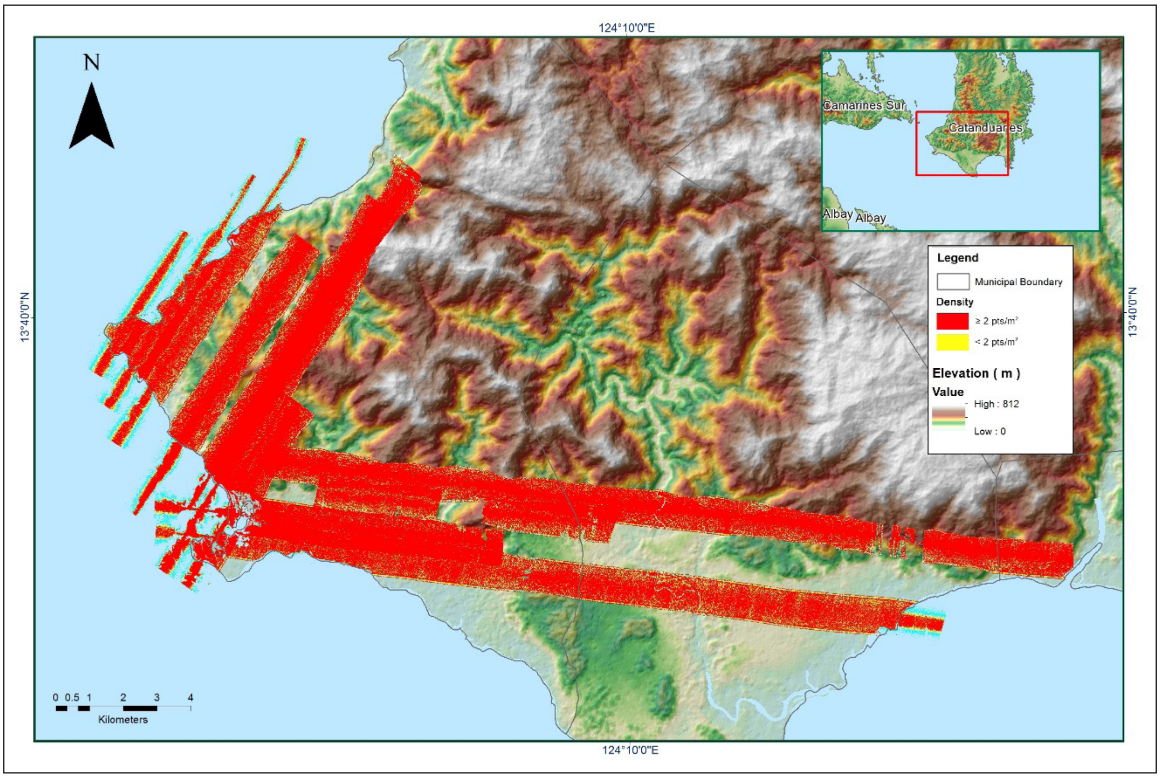


Figure A-8.41. Density Map of merged LiDAR data

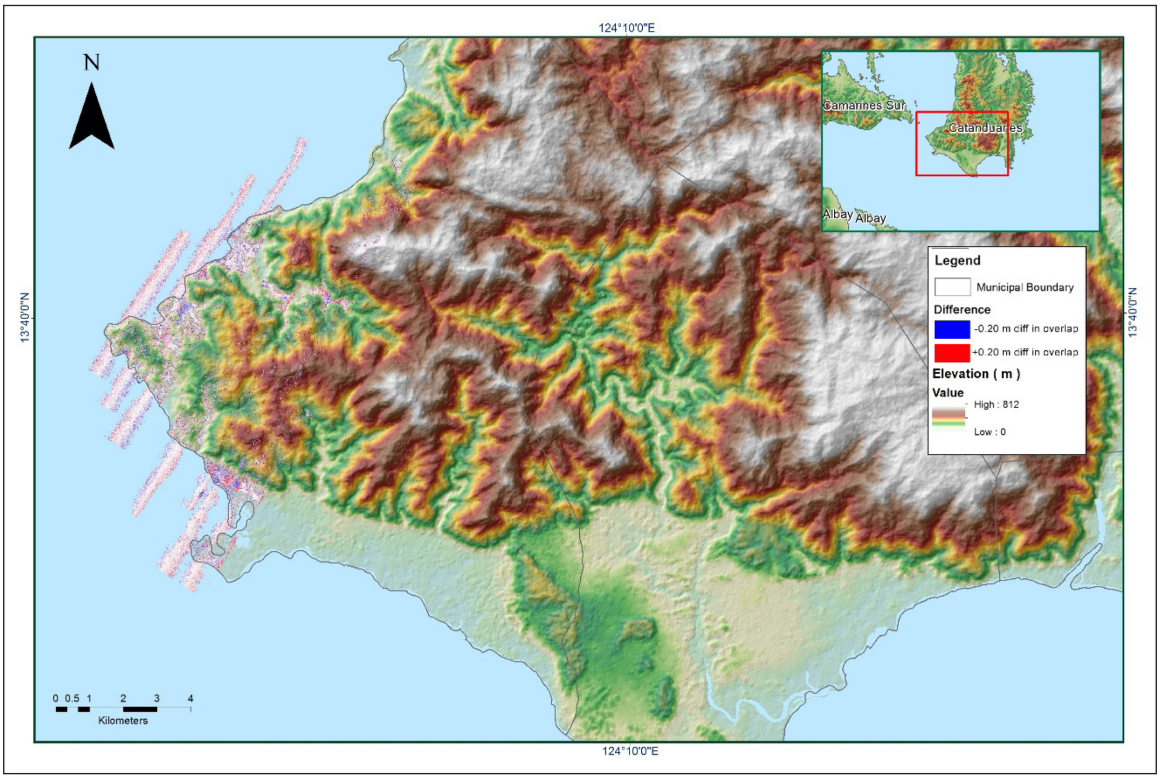


Figure A-8.42. Elevation Difference Between flight lines

Annex 9. Bato Model Basin Parameters

Table A-9.1. Bato Model Basin Parameters

Basin Number	Curve Number Loss			Clark Unit Hydrograph Transform		Recession Base flow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (m3/s)	Recession Constant	Threshold Type	Ratio to Peak
W240	13.063	99.000	0	365.960	201.63000	Discharge	2.7517	0.00001	Ratio to Peak	0.15318
W250	216.690	59.213	0	544.660	0.06164	Discharge	1.8150	0.00001	Ratio to Peak	0.00023
W260	307.450	35.347	0	0.166	461.51000	Discharge	0.6638	0.00001	Ratio to Peak	0.00033
W270	137.120	77.005	0	0.130	282.86000	Discharge	1.6603	0.00001	Ratio to Peak	0.08916
W280	29.845	56.745	0	181.180	39.77400	Discharge	1.6030	0.00001	Ratio to Peak	0.06617
W290	19.900	99.000	0	174.000	33.78600	Discharge	0.1870	0.00001	Ratio to Peak	0.00149
W300	0.346	99.000	0	290.020	118.40000	Discharge	1.6417	0.00001	Ratio to Peak	0.04084
W310	0.829	68.519	0	180.270	132.89000	Discharge	0.5268	0.00001	Ratio to Peak	0.00539
W320	490.020	66.000	0	5.641	349.78000	Discharge	1.3470	0.00001	Ratio to Peak	0.00820
W330	310.590	59.213	0	0.130	167.32000	Discharge	2.3826	0.00001	Ratio to Peak	0.00016
W340	479.970	99.000	0	0.147	209.25000	Discharge	1.3023	0.00001	Ratio to Peak	0.01960
W350	92.860	99.000	0	85.500	102.26000	Discharge	2.6867	0.00001	Ratio to Peak	0.18998
W360	141.850	53.524	0	50.973	66.58400	Discharge	1.5747	0.00001	Ratio to Peak	0.00014
W370	322.010	39.560	0	0.017	190.20000	Discharge	6.0195	0.00001	Ratio to Peak	0.13457
W380	0.080	99.000	0	166.000	176.14000	Discharge	2.7707	0.00001	Ratio to Peak	0.01834
W390	125.490	56.703	0	2.997	473.31000	Discharge	0.7013	0.00001	Ratio to Peak	0.00243
W400	57.983	58.222	0	0.017	5.48000	Discharge	0.0257	0.00001	Ratio to Peak	0.00023
W410	320.130	49.112	0	0.157	45.70400	Discharge	3.0198	0.00001	Ratio to Peak	0.07030
W420	19.858	35.079	0	1.284	12.14200	Discharge	6.4434	0.00001	Ratio to Peak	0.04323
W430	19.688	35.080	0	11.818	16.96100	Discharge	3.9822	0.00001	Ratio to Peak	0.20185
W440	0.005	51.026	0	4.111	0.06181	Discharge	0.9192	0.00001	Ratio to Peak	0.00049

Basin Number	Curve Number Loss			Clark Unit Hydrograph Transform		Recession Base flow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (m3/s)	Recession Constant	Threshold Type	Ratio to Peak
W450	14.192	39.211	0	0.148	1.46700	Discharge	2.0676	0.00001	Ratio to Peak	0.01602
W230	66.554	43.288	0	63.613	42.79800	Discharge	7.7089	0.00001	Ratio to Peak	1.00000
W240	55.842	47.636	0	44.212	26.53800	Discharge	4.2869	0.10323	Ratio to Peak	1.00000
W250	1.406	99.000	0	1.384	0.06671	Discharge	19.1140	0.10729	Ratio to Peak	0.93820
W260	48.937	50.934	0	44.205	20.72900	Discharge	12.7900	0.00001	Ratio to Peak	1.00000

Annex 10. Bato Model Reach Parameters

Table A-10.1. Bato Model Reach Parameters

Muskingum-Cunge Channel Routing								
	Reach Number	Time Step Method	Length (m)	Slope (m/m)	Manning's n	Shape	Width (m)	Side slope
1	R50	Automatic Fixed Interval	1323.6	0.00056	0.00661	Trapezoid	270.761	1
2	R70	Automatic Fixed Interval	3565.5	0.01833	0.02361	Trapezoid	270.761	1
3	R90	Automatic Fixed Interval	2216.8	0.01970	0.03260	Trapezoid	270.761	1
4	R110	Automatic Fixed Interval	5056.8	0.01617	0.00010	Trapezoid	270.761	1
5	R130	Automatic Fixed Interval	9591.4	0.00625	0.00010	Trapezoid	270.761	1
6	R150	Automatic Fixed Interval	3766.0	0.00625	0.00010	Trapezoid	270.761	1
7	R160	Automatic Fixed Interval	962.35	0.0111164	0.0001	Trapezoid	270.761	1
8	R170	Automatic Fixed Interval	4696.2	0.0047501	0.0001	Trapezoid	270.761	1
9	R190	Automatic Fixed Interval	10267	0.002878	0.03924	Trapezoid	270.761	1
10	R220	Automatic Fixed Interval	4563.2	0.0021254	1	Trapezoid	270.761	1
11	R230	Automatic Fixed Interval	1678.2	0.0021254	0.57906	Trapezoid	270.761	1

Annex 11. Bato Field Validation Points

Table A-11.1. Bato Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return/ Scenario
	Lat	Long					
1	13.60378833	124.2992567	0	0	0		5-Year
2	13.604275	124.2988517	0.3	0	0.3		5-Year
3	13.60342833	124.2988317	1.62	0	1.62		5-Year
4	13.603305	124.2988783	1.94	0	1.94		5-Year
5	13.6029	124.2985233	0.1	0	0.1		5-Year
6	13.60284333	124.29845	0.28	0	0.28		5-Year
7	13.60334333	124.297975	0.41	4.5	-4.09	TY Loleng	5-Year
8	13.60360167	124.2980017	1.68	4.5	-2.82	TY Loleng	5-Year
9	13.60297333	124.2984817	1.76	0	1.76		5-Year
10	13.67718833	124.3078467	1.81	0	1.81		5-Year
11	13.67695167	124.3080367	1.46	2	-0.54	TY Loleng	5-Year
12	13.67627167	124.3084167	1.73	2	-0.27		5-Year
13	13.67606167	124.308545	1.52	0	1.52		5-Year
14	13.67548667	124.3087617	1.6	0.5	1.1	TY Loleng	5-Year
15	13.67450667	124.3093117	1.38	7.9	-6.52	TY Loleng	5-Year
16	13.67167333	124.3076167	1.48	7.9	-6.42	TY Loleng	5-Year
17	13.669195	124.3085367	1.43	5.1	-3.67	TY Loleng	5-Year
18	13.64857333	124.3048517	1.4	0	1.4		5-Year
19	13.647745	124.3052683	0.86	5.7	-4.84	TY Loleng	5-Year
20	13.64209	124.302225	0.51	3.6	-3.09	TY Loleng	5-Year
21	13.64197667	124.3026617	0.09	8.5	-8.41	TY Loleng	5-Year
22	13.64232	124.3028267	0.07	18	-17.93	TY Loleng	5-Year
23	13.64188833	124.3033367	1.6	1.2	0.4	TY Loleng	5-Year
24	13.64075333	124.3026233	1.84	0	1.84		5-Year
25	13.64098667	124.3029317	1.15	0	1.15		5-Year
26	13.64061667	124.3018617	1.35	0	1.35		5-Year
27	13.64155833	124.3018117	0.25	0	0.25		5-Year
28	13.64130333	124.3027833	1.57	0	1.57		5-Year
29	13.64146	124.3033733	1.33	0	1.33		5-Year
30	13.64012667	124.3030733	0.36	0	0.36		5-Year
31	13.63965833	124.30268	0.33	0	0.33		5-Year
32	13.604585	124.291035	1.35	0	1.35		5-Year
33	13.60450167	124.2911467	1.17	0	1.17		5-Year
34	13.60427	124.2915533	1.24	1	0.24	TY Loleng	5-Year
35	13.61074833	124.2945383	0.88	2	-1.12	TY Loleng	5-Year
36	12.25764364	123.3179899	1	0	1		5-Year
37	13.60798833	124.2980694	1.6	0.5	1.1	TY Loleng	5-Year
38	13.60771769	124.2984822	1.21	0.5	0.71	TY Loleng	5-Year
39	13.60780659	124.2985954	1.38	0	1.38		5-Year

40	13.6080788	124.2984517	1.11	0.5	0.61		5-Year
41	13.60841688	124.2984081	1.62	0.1	1.52		5-Year
42	13.60872595	124.2984776	0.91	0.5	0.41	TY Loleng	5-Year
43	13.60896732	124.2988769	2.14	0	2.14		5-Year
44	13.60871692	124.2989301	1.22	0	1.22		5-Year
45	13.60835327	124.2989047	1.49	0	1.49		5-Year
46	13.71640239	124.2733494	1.87	1.2	0.67	TY Loleng	5-Year
47	13.71627187	124.2745	1.15	1.5	-0.35	TY Loleng	5-Year
48	13.71592159	124.2766951	0.53	0	0.53	TY Loleng, STY Rosing	5-Year
49	13.71501091	124.2793918	1.12	0	1.12		5-Year
50	13.71485811	124.2798087	1.01	0	1.01		5-Year
51	13.71309566	124.2811929	3.27	0	3.27		5-Year
52	13.71264628	124.281187	1.12	0.5	0.62	TY Loleng	5-Year
53	13.70647987	124.2807682	1.31	0	1.31		5-Year
54	13.70596853	124.2809332	1.38	0	1.38	TY Loleng	5-Year
55	13.70001603	124.2825622	3.46	0.5	2.96	TY Loleng	5-Year
56	13.70021775	124.2894868	1.15	1.75	-0.6	TY Loleng	5-Year
57	13.70021486	124.2894784	1.03	0.5	0.53	STY Rosing	5-Year
58	13.68235798	124.3031156	1.45	0	1.45	TY Loleng	5-Year
59	13.6502656	124.3052898	3.34	0	3.34		5-Year
60	13.65015956	124.305264	1.11	0	1.11	TY Loleng	5-Year
61	13.64668448	124.3048806	0.71	3	-2.29	TY Loleng	5-Year
62	13.64676392	124.3048268	1.18	0	1.18		5-Year
63	13.64687182	124.304551	0.76	3	-2.24	TY Loleng	5-Year
64	13.65275971	124.2977793	1.16	0	1.16		5-Year
65	13.65176329	124.2993689	1.16	0	1.16		5-Year
66	13.65148945	124.2994586	0.05	0	0.05		5-Year
67	13.65118667	124.2994043	0.97	0	0.97		5-Year
68	13.64898182	124.2996808	0.43	0.5	-0.07		5-Year
69	13.64924089	124.2998502	0.85	0	0.85		5-Year
70	13.64611623	124.3012569	4.01	0.5	3.51	TY Loleng	5-Year
71	13.64410086	124.3023417	1.04	1.3	-0.26	TY Loleng	5-Year
72	13.6441241	124.3023712	1.87	1.3	0.57	STY Rosing	5-Year
73	13.64362004	124.3018759	0.38	0.1	0.28		5-Year
74	13.64324801	124.3027356	0.42	3.5	-3.08	TY Loleng	5-Year
75	13.64318747	124.3026762	0.03	3.5	-3.47	TY Loleng	5-Year
76	13.64277572	124.3025493	3.68	3.5	0.18	TY Loleng	5-Year
77	13.64273372	124.302552	0.26	2.5	-2.24	STY Rosing	5-Year
78	13.64263337	124.3029565	1.8	4.5	-2.7	TY Loleng	5-Year
79	13.62198212	124.2963013	0.27	0.1	0.17	TY Loleng	5-Year
80	13.59963382	124.2890822	3.69	0.8	2.89	TY Loleng	5-Year
81	13.60230892	124.2903597	1.6	0	1.6		5-Year
82	13.60424237	124.2915589	0.03	0.3	-0.27	TY Loleng	5-Year
83	13.60395289	124.2916955	1.7	1	0.7	TY Loleng	5-Year

84	13.60391534	124.2917749	1.73	1.1	0.63	TY Loleng	5-Year
85	13.60476058	124.2913006	1.93	0	1.93		5-Year
86	13.60797203	124.2945829	0.03	5	-4.97	TY Loleng	5-Year
87	13.60833086	124.2946378	0.13	2.75	-2.62	TY Loleng	5-Year
88	13.6119702	124.2938523	4.88	1.1	3.78	TY Loleng	5-Year
89	13.61187916	124.2936395	0.03	4	-3.97	TY Sening	5-Year
90	13.61251667	124.2942418	0.57	0.9	-0.33	TY Loleng	5-Year
91	13.61092907	124.294276	0.03	1	-0.97	TY Loleng, STY Rosing	5-Year
92	13.62713407	124.3075252	0.27	0	0.27		5-Year
93	13.62858223	124.3086752	0.07	0.2	-0.13	TY Sening	5-Year
94	13.62861621	124.3085907	4.77	1.3	3.47	TY Sening	5-Year
95	13.62890493	124.3088179	0.04	0.5	-0.46	TY Loleng	5-Year
96	13.62913822	124.309178	1.29	0	1.29		5-Year
97	13.62891649	124.3083712	0.03	0.4	-0.37		5-Year
98	13.62904376	124.3083211	4.76	0.7	4.06	STY Rosing	5-Year
99	13.6159241	124.2981398	4.76	0	4.76		5-Year
100	13.61432712	124.2973259	0.25	4	-3.75		5-Year
101	13.61446898	124.2973514	0.28	0.7	-0.42	TY Loleng	5-Year
102	13.61474692	124.2978751	0.28	0	0.28		5-Year
103	13.61462351	124.2982847	0.39	0	0.39		5-Year
104	13.61219661	124.2976442	1.43	0	1.43		5-Year
105	13.60946597	124.2973562	0.14	0	0.14		5-Year
106	13.61012392	124.2976763	0.49	0	0.49		5-Year
107	13.61028953	124.2983939	0.07	0	0.07		5-Year
108	13.60984613	124.2984006	0.03	0	0.03		5-Year
109	13.60973788	124.2977863	0.03	0	0.03		5-Year
110	13.60929763	124.297812	0.05	0	0.05		5-Year
111	13.60904642	124.2975506	0.03	0	0.03		5-Year
112	13.60918218	124.2981789	0.04	0	0.04		5-Year
113	13.60874671	124.298061	0.04	0	0.04		5-Year
114	13.60879502	124.2981227	0.03	1	-0.97	TY Sening	5-Year
115	13.60872962	124.2977163	0.14	0.4	-0.26	TY Loleng	5-Year
116	13.60870567	124.2976056	0.04	0	0.04		5-Year
117	13.60844761	124.2975164	0.03	0.5	-0.47	TY Loleng	5-Year
118	13.6081746	124.2976086	0.06	0.5	-0.44	TY Loleng	5-Year
119	13.60763579	124.2978352	1.2	1.1	0.1	STY Rosing	5-Year
120	13.60440615	124.2980148	0.06	1.1	-1.04	TY Loleng	5-Year
121	13.60451189	124.2979823	0.3	1.3	-1	TY Loleng	5-Year
122	13.60599166	124.2982283	0.03	1	-0.97	STY Rosing	5-Year
123	13.60559211	124.2983176	0.1	1	-0.9	STY Rosing	5-Year
124	13.60520613	124.2983633	0.05	2.5	-2.45		5-Year
125	13.60672494	124.2985497	0.06	0	0.06		5-Year
126	13.60661998	124.2982789	0.08	1.2	-1.12	STY Reming 2006	5-Year

127	13.60680134	124.2974113	0.03	1.6	-1.57	TY Loleng	5-Year
128	13.69327863	124.2960222	0.04	1.1	-1.06	TY Loleng	5-Year
129	13.69348109	124.2967239	0.06	0	0.06		5-Year
130	13.69289302	124.2979396	0.3	0	0.3		5-Year
131	13.69317975	124.29848	0.08	0	0.08		5-Year
132	13.69259472	124.2984934	0.07	0	0.07		5-Year
133	13.69255327	124.2983011	0.03	0	0.03		5-Year
134	13.69133829	124.2986346	0.04	0	0.04		5-Year
135	13.69069447	124.2984641	0.03	0	0.03		5-Year
136	13.64999952	124.3053084	0.04	0	0.04		5-Year
137	13.62990062	124.2992847	0.03	0	0.03		5-Year
138	13.63011358	124.2997219	0.03	0.35	-0.32	TY Loleng	5-Year
139	13.63037432	124.3000534	0.03	0	0.03		5-Year
140	13.63099499	124.30029	0.1	12	-11.9	STY Rosing	5-Year
141	13.63119344	124.3001589	2.67	12	-9.33	STY Rosing, STY Reming 2006	5-Year
142	13.6313734	124.3001583	2.25	3.8	-1.55	TY Loleng	5-Year
143	13.63163369	124.3000538	4.23	0	4.23		5-Year
144	13.63297572	124.3008784	4.83	0	4.83		5-Year
145	13.63325895	124.3008763	3.73	0	3.73		5-Year
146	13.63408992	124.3008979	3.73	0	3.73		5-Year
147	13.62198691	124.2962876	4.93	0	4.93		5-Year
148	13.60210679	124.2902533	4.93	0	4.93		5-Year
149	13.60352984	124.2918684	0.24	0.9	-0.66	STY Rosing	5-Year
150	13.60384532	124.2920032	1.95	2	-0.05	STY Reming 2006	5-Year
151	13.60451339	124.292768	1.95	0	1.95		5-Year
152	13.60528629	124.2934372	1.01	0.1	0.91	TY Loleng	5-Year
153	13.60581065	124.294005	4.77	2	2.77	TY Loleng	5-Year
154	13.60850464	124.2946807	4.7	2	2.7	STY Rosing	5-Year
155	13.60949056	124.294408	4.85	0.4	4.45	TY Loleng	5-Year
156	13.61030511	124.2947844	3.48	2.1	1.38	TY Loleng	5-Year
157	13.61032185	124.2943799	0.06	0.3	-0.24	TY Loleng	5-Year
158	13.61142461	124.2942374	0.66	0	0.66		5-Year
159	13.636155	124.31435	0.53	0	0.53		5-Year
160	13.63484833	124.31373	1.11	0	1.11		5-Year
161	13.63447667	124.313135	0.56	1	-0.44		5-Year
162	13.63421333	124.3130483	0.03	0	0.03		5-Year
163	13.63423	124.3120867	0.03	0.5	-0.47		5-Year
164	13.61775	124.29689	0.19	0	0.19	TY Loleng	5-Year
165	13.61711	124.2969667	0.34	0	0.34		5-Year
166	13.61567	124.297345	0.56	0	0.56		5-Year
167	13.61589333	124.296685	0.03	0	0.03		5-Year
168	13.61554667	124.3182683	16.51	0	16.51		5-Year

169	13.611015	124.3206617	14.74	0	14.74		5-Year
170	13.61045833	124.3202783	17.22	0	17.22		5-Year
171	13.607615	124.302255	12.68	0	12.68		5-Year
172	13.60760333	124.2997883	13.48	0	13.48		5-Year
173	13.6076	124.299185	13.85	0	13.85		5-Year
174	13.59968	124.301575	13.23	0.6	12.63		5-Year
175	13.60432	124.299395	9.58	0.4	9.18		5-Year
176	13.60432167	124.2991117	0.03	0.4	-0.37		5-Year
177	13.60513667	124.2990867	4.11	1	3.11		5-Year
178	13.60614333	124.2990117	3.37	0.5	2.87		5-Year
179	13.60667333	124.2990383	0.03	0.4	-0.37		5-Year
180	13.60725833	124.29897	0.03	0.3	-0.27		5-Year
181	13.70471	124.2812933	0.03	1.6	-1.57	TY Loleng	5-Year
182	13.70434833	124.281325	0.03	1.3	-1.27	TY Loleng	5-Year
183	13.703965	124.2811517	6.73	0	6.73		5-Year
184	13.70359	124.2814483	7.06	1.4	5.66	TY Loleng	5-Year
185	13.70284833	124.2815533	7.92	0.4	7.52		5-Year
186	13.70200333	124.281825	12.81	0	12.81		5-Year
187	13.701505	124.2819883	13	0	13		5-Year
188	13.70092167	124.2825083	10.4	0	10.4		5-Year
189	13.70013333	124.2824717	10.4	0	10.4	TY Loleng	5-Year
190	13.69981167	124.2845217	12.12	0	12.12		5-Year
191	13.649815	124.3051583	13.1	0.3	12.8		5-Year
192	13.63574833	124.300725	13.2	0	13.2		5-Year
193	13.636075	124.3004633	13.62	0	13.62		5-Year
194	13.63683333	124.30119	12.77	0	12.77		5-Year
195	13.636975	124.30117	10.1	0	10.1		5-Year
196	13.637015	124.3013567	12.17	0	12.17		5-Year
197	13.63738667	124.3014967	12.46	0	12.46		5-Year
198	13.63775667	124.3015717	12.22	0	12.22		5-Year
199	13.637935	124.3017583	12.69	0	12.69		5-Year
200	13.63826167	124.3017617	12.1	0	12.1		5-Year
201	13.63933	124.302335	14.42	0	14.42		5-Year
202	13.59949833	124.2883733	14.98	0	14.98		5-Year
203	13.60239167	124.290205	17.55	0	17.55		5-Year
204	13.603485	124.2917583	19.49	0	19.49	TY Loleng	5-Year
205	13.60519	124.2934333	22.47	0.3	22.17	TY Loleng	5-Year
206	13.60936667	124.29479	22.33	1.3	21.03		5-Year

Annex 12. Educational Institutions affected by flooding in Bato Floodplain

Table A-12.1. Educational Institutions in Bato and San Miguel, Catanduanes affected by flooding in Bato Floodplain

Catanduanes				
Bato				
Name	Barangay	Rainfall Scenario		
		5-YR	25-YR	100-YR
Daycare Center	Aroyao Pequeño			
Bagumbayan Elem. School	Bagumbayan		Low	Low
San Pedro Elem. School	Bagumbayan			
Banawang School	Banawang	Medium	High	High
Batalay School	Banawang			
Bote School	Bote			
Guinobatan Elem. School	Guinobatan	Low	Low	Low
Daycare	Libjo			
Libjo Elem. School	Libjo			
Daycare	Libod Poblacion	Low	Medium	High
Libod Elem. School	Libod Poblacion	Low	Medium	High
Praise Leearning Center	Libod Poblacion	Medium	High	High
Mintay Elem. School	Mintay	Low	Low	Medium
Bato Rural Development Highschool	San Andres	Medium	Medium	Medium
San Roque Elem. School	San Roque			
Oguis Elem. School	Sibacungan	High	High	High
Sipi elem. School	Sipi	Medium	Medium	High
Child Development Center, Chapel	Tilis			
Ubod daycare	Tilis		Low	Medium
San Miguel				
Name	Barangay	Rainfall Scenario		
		5-YR	25-YR	100-YR
Sibacungan Elem. School	Atsan			
Balatohan Elem. School	Balatohan	High	High	High
District 3 Daycare	Boton	High	High	High
Buhi Elem. School	Buhi	High	High	High
Daycare	Buhi	High	High	High
Katipunan Elem. School	Katipunan	High	High	High
Solong Primary School	Katipunan			
Kilikilihan Elem. School	Kilikilihan	High	High	High
Mabato Highschool	Mabato			
Siay Elem. School	Mabato	High	High	High
Obo Daycare	Obo	High	High	High
Obo Elem. School	Obo	High	High	High
Mabato Central Elem. School	Pacogon	High	High	High
Pangilao elem. School	Pangilao	High	High	High
District 2 Daycare	Poblacion District III			
San Miguel Development Rural Highschool	Poblacion District III	Low	Low	Low
Patagan Elem. School	Salvacion		High	High

San Juan Daycare	San Juan	Medium	High	High
San Juan Elem. School	San Juan	Medium	Medium	High
Daycare	Santa Elena		High	High
Dayawa Elem. School	Siay			
San Miguel Central Elem. School	Solong	Low	Low	Low
Pagsangahan Elem. School	Tobrehon	High	High	High

Annex 13. Health Institutions affected by flooding in Bato Floodplain

Table A-13.1. Health Institutions in Bato and San Miguel, Catanduanes affected by flooding in Bato Floodplain

Catanduanes				
Bato				
Name	**Barangay**	**Rainfall Scenario**		
		5-YR	**25-YR**	**100-YR**
San Roque Health Center	San Roque			
Health Center	Sibacungan	High	High	High
Bato Maternity and Childrens Hospital	Tamburan	Medium	High	High
ARDC	Tilis	Medium	Medium	Medium
BAU	Tilis		Low	Medium
San Miguel				
Name	Barangay	Rainfall Scenario		
		5-YR	25-YR	100-YR
San Miguel Healthcenter	Boton	Medium	High	High
Obo Health Center	Obo	High	High	High