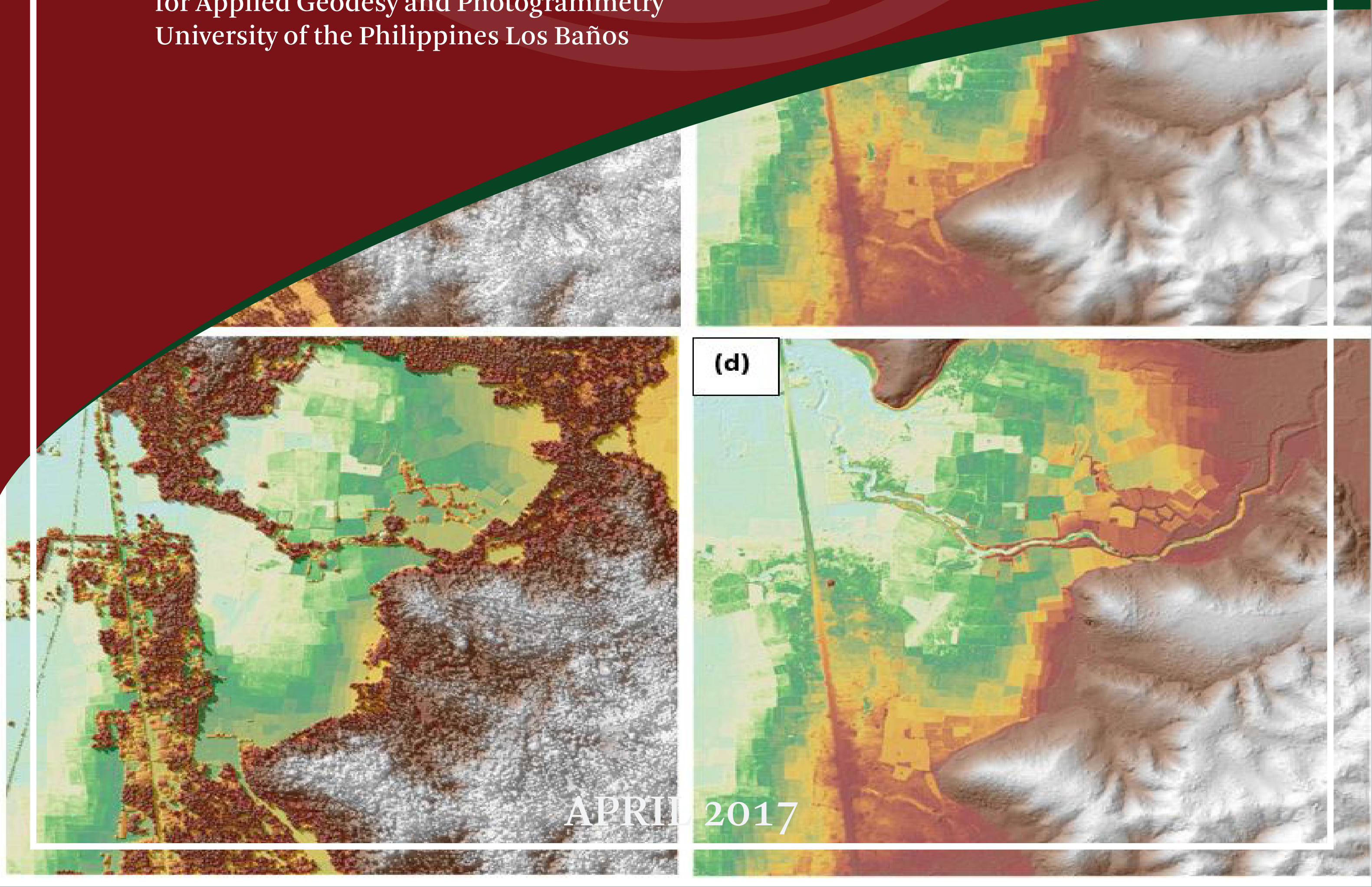
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR 1)

LiDAR Surveys and Flood Mapping of Boac River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of the Philippines Los Baños



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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
BSWM	Bureau of Soils and Water Management
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DA	Department of Agriculture
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
NSO	National Statistics Office
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
PSTC	Philippine Seafarers Training Center
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RBCO	River Basin Control Office
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
UPLB	University of the Philippines Los Baños
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 THE BOAC RIVER

Enrico C. Paringit, Dr. Eng. and Prof. Edwin R. Abucay, Cristino L. Tiburan, Jr.

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, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at a 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.

The program was also aimed at producing an up-to-date and detailed national elevation dataset suitable for a 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 the DOST. The methods applied in this report are thoroughly described in a separate publication entitled "Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods" (Paringit, et. al., 2017), available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Baños (UPLB). UPLB 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 forty-five (45) river basins in the Southern Tagalog Region. The university is located in the Municipality of Los Baños in the province of Laguna.

1.2 Overview of the Boac River Basin

The Boac River Basin is a 21,330-hectare watershed in the province of Marinduque that covers majority of the Municipality of Boac, and minor portions of the Municipalities of Mogpog, Santa Cruz, Torrijos, Buenavista, and Gasan. The Department of Environment and Natural Resources (DENR) - River Basin Control Office (RBCO) identified the basin to have a drainage area of 209 km², and an estimated 334 million cubic meters (MCM) in annual run-off (RBCO, 2015). The basin's main stem, the Boac River, is part of the forty-five (45) river systems in the Southern Tagalog Region under the Phil-LiDAR 1 partner higher education institution, UPLB.

The Boac River Basin encompasses the following barangays: Agot, Agumaymayan, Apitong, Balagasan, Balimbing, Bamban, Bantad, Bantay, Bayuti, Binunga, Boi, Boton, Canat, Catubugan, Daig, Daypay, Hinapulan, Isok I, Isok II Poblacion, Mahinhin, Mainit, Malbog, Malusak, Mansiwat, Mataas na Bayan, Maybo, Mercado, Murallon, Ogbac, Pawa, Poctoy, Poras, Puting Buhangin, Puyog, Sabong, San Miguel, Santol, Sawi, Tabi, Tabigue, Tagwak, Tambunan, Tampus, Tumagabok, and Tumapon in the Municipality of Boac; Bagtingon and Malbog in the Municipality of Buenavista; Tabionan and Tiguion in the Municipality of Gasan; Bocboc, Danao, Malayak, Anapog-SIbucao, Mampaitan, and Puting Buhangin in the Municipality of Mogpog; Kilo-kilo, Labo, Makulapnit, and San Antonio in the Municipality of Santa Cruz; and, Malibago, Sibuyao, and Talawan in the Municipality of Torrijos.

Barangay Sibuyao in the Municipality of Torrijos is the most populated barangay, based on the 2010 National Statistics Office (NSO) Census of Population and Housing records. And according to the 2015 national census of the NSO, the total population of residents within the immediate vicinity of the river is 7,149, distributed among eight (8) barangays in the Municipality of Boac.

Before the Marcopper Mining Disaster in 1996, which contaminated the Boac River with mine leaks, the province's economy was primarily fueled by its thriving mining industry. Today, agriculture and fishing are two of the principal sources of income of families residing in the vicinity of the river (http://www.nso.marinduque.ph/, 2010).

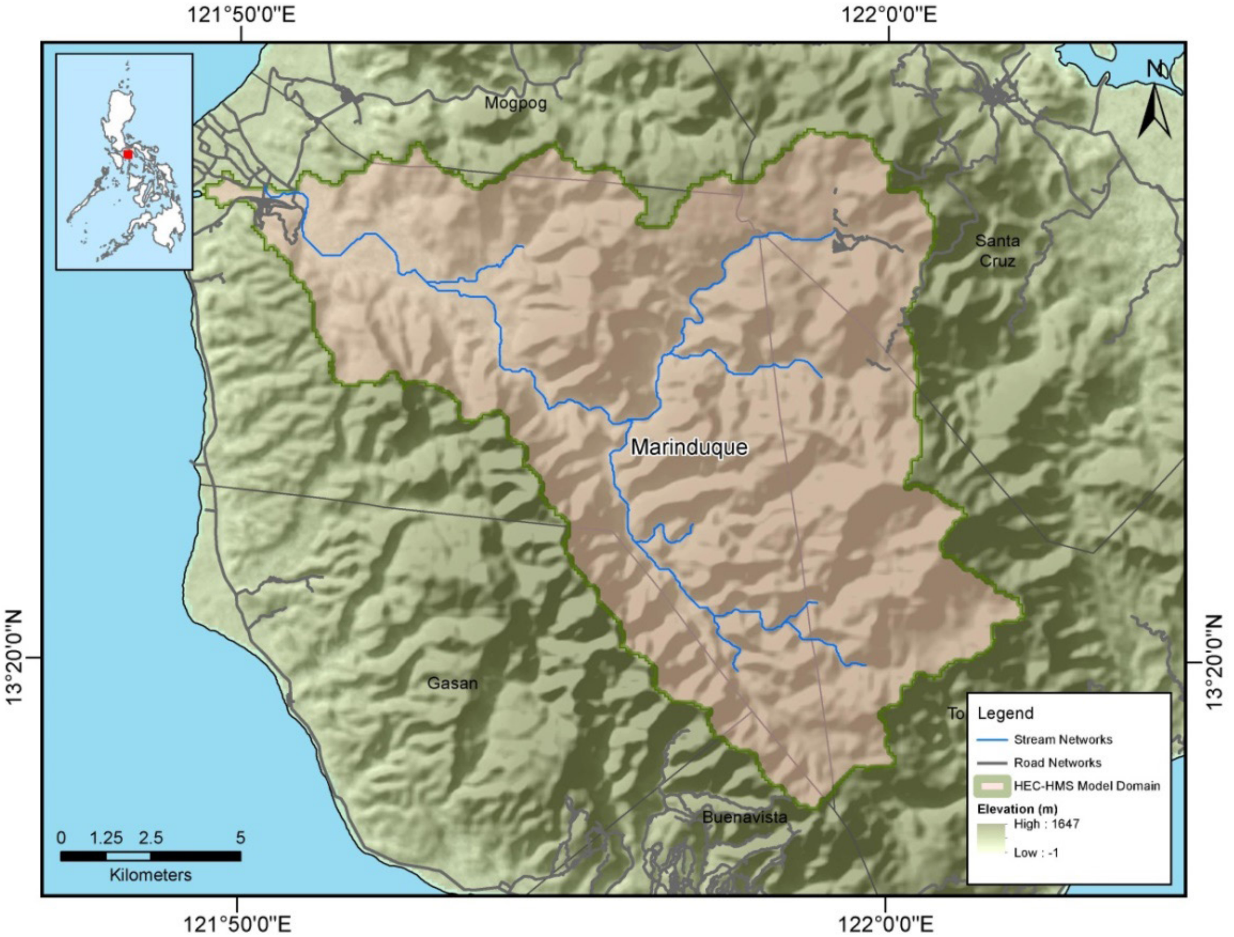

Figure 1. Location map of the Boac River Basin (in brown)

Climate Types I and III prevail in the region of MIMAROPA and Laguna, as per the Modified Corona Classification of Climates. Climate Type I is characterized by two (2) pronounced seasons – dry and wet. The dry season occurs in the months of November to April; and it is wet for the rest of the year, with maximum rains in the months of June to September. On the other hand, Climate Type III does not have a very pronounced maximum rain period. This climate type has a short dry season, lasting for only one to three months – in December to February, or in March to May.

The field surveys conducted by the Phil-LiDAR 1 validation team revealed that there have been a number of notable weather disturbances that have caused flooding in the area of the Boac River Basin. These events include Typhoon Herming in 1987, Typhoon Monang in 1993, Typhoons Caloy and Reming in 2006, Typhoon Frank in 2008, Typhoon Ofel in 2012, Super Typhoon Yolanda in 2013, Typhoon Glenda in 2014, and Typhoon Nona in 2015.During the incidence of tropical storm Hagupit (international name, Ruby) in December 2014, families within the locality of the Boac River were evacuated due to threats of flash floods and spillovers of mine tailings from the Marcopper Mining Disaster (http://newsinfo.inquirer.net/655977/ruby-dumps-rains-in-marinduque-boac-river-mogpog-river-swell, 2014).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE BOAC 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

To initiate the LiDAR acquisition survey of the Boac floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for the floodplain in the province of Marinduque. These missions were planned for sixteen (16) lines that ran for at most four and a half (4.5) hours, including take-off, landing and turning time. The Pegasus LiDAR system was used for the missions (See ANNEX 1 for the sensor specifications). The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 illustrates the flight plans for the Boac floodplain.

Table 1. Flight planning parameters for the 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)
BLK22A	1250, 1000	30	50	200	30	130	5
BLK22B	1250, 1000	30	50	200	30	130	5
BLK22C	1000	30	50	200	30	130	5

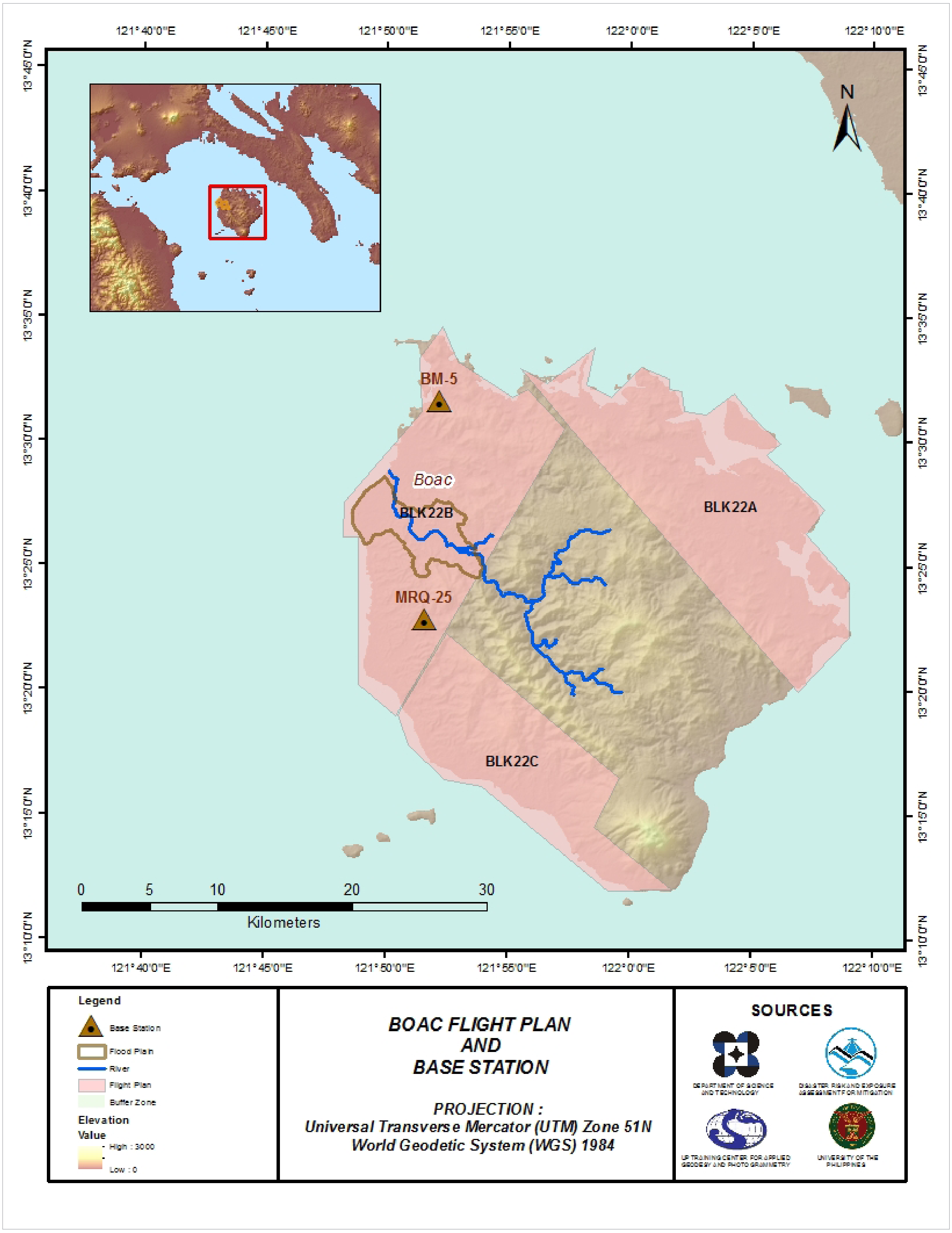

Figure 2. Flight plans and base stations used to cover the Boac floodplain survey

2.2 Ground Base Station

The field team for this undertaking was able to recover one (1) NAMRIA ground control point: MRQ-25, which is of second (2^{nd}) order accuracy. They also established one (1) ground control point. The certification for the NAMRIA reference point is found in ANNEX 2; while the baseline processing report for the established control point is provided in ANNEX 3. These were used as base stations during the flight operations for the entire duration of the survey, held on October 9, 12, and 15, 2015. The base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. The flight plans and locations of the base stations used during the aerial LiDAR acquisition in the Boac floodplain are shown in Figure 2. The composition of the project team is given in ANNEX 4.

Figure 3 exhibits the recovered NAMRIA control station within the area. In addition, Table 2 and Table 3 provide the details about the NAMRIA control station and the established point. Table 4 lists the ground control points occupied during the acquisition, with the corresponding dates of utilization.

(a) (b)

Figure 3. (a) GPS set-up over MRQ-25, at the top of the plant box near the gate of Tugos Elementary School in Barangay Tugos, Boac, Marinduque; and (b) NAMRIA reference point MRQ-25, as recovered by the field team

Table 2. Details of the recovered NAMRIA horizontal control point MRQ-25, used as a base station for the LiDAR acquisition

Station Name	**MRQ-25**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 22' 56.92806" 121° 51' 28.72673" 48.18293 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	592,932.786 m 1,480,020.839 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 22' 51.86815" North 121° 51' 33.72033" East 97.20100 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	376,341.19 m 1,479,627.07 m

Table 3. Details of the established horizontal control point, BM-5, used as a base station for the LiDAR acquisition

Station Name	BM-5	
Order of Accuracy	2^{nd}	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 31' 43.12821" 121° 52' 02.72781" 5.828 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 31' 38.03406" North 121° 52' 07.7085" East 54.472 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	377,438.371 m 1,295,788.872 m

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
October 9, 2015	10020P	1BLK22ABC282A	MRQ-25 and BM-5
October 12, 2015	10027P	1BLK22AB285A	MRQ-25 and BM-5
October 15, 2015	10032P	1BLK22AB288A	MRQ-25 and BM-5

2.3 Flight Missions

A total of four (4) flight missions were conducted to complete the LiDAR data acquisition in the Boac floodplain, for a total of twelve hours and thirty-one minutes (12+31) of flying time for RP-C9522. All missions were acquired using the Pegasus LiDAR system. The flight logs of the missions are presented in ANNEX 6. Table 5 indicates the total area of actual coverage and the corresponding flying hours per mission, while Table 6 summarizes the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for the LiDAR data acquisition in the Boac floodplain

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed outside the Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
October 9, 2015	10020P	599.56	170.93	10.39	160.54	NA	3	53
October 9, 2015	10021P	254.74	104.55	12.99	91.56	NA	2	11
October 12, 2015	10027P	461.82	283.36	20.68	262.68	NA	4	23
October 15, 2015	10032P	254.74	52.87	1.75	51.12	NA	2	4
TOTAL		**1570.86**	**611.71**	**45.81**	**565.90**	**NA**	**12**	**31**

Table 6. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (KHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
10020P	1000	30	50	200	30	130	5
10021P	1000	30	50	200	30	130	5
10027P	1250	30	50	200	30	130	5
10032P	1000	30	50	200	30	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Boac floodplain, located in the province of Marinduque, with the whole floodplain situated within the Municipality of Boac. The municipalities surveyed, with at least one (1) square kilometer coverage, are enumerated in Table 7. The actual coverage of the LiDAR acquisition for the Boac floodplain is presented in Figure 4. The flight status report is found in ANNEX 7.

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

Province	Municipality/City	Area of Municipality/ City (km²)	Total Area Surveyed (km²)	Percentage of Area Surveyed
Marinduque	Boac	182.07	90.95	49.95%
	Buenavista	83.22	2	2.40%
	Gasan	116.19	43.3	37.27%
	Mogpog	101.12	88.51	87.53%
	Santa Cruz	236.19	110.6	46.83%
	Torrijos	210.05	25.1	11.95%
Total		928.84	360.46	38.81%

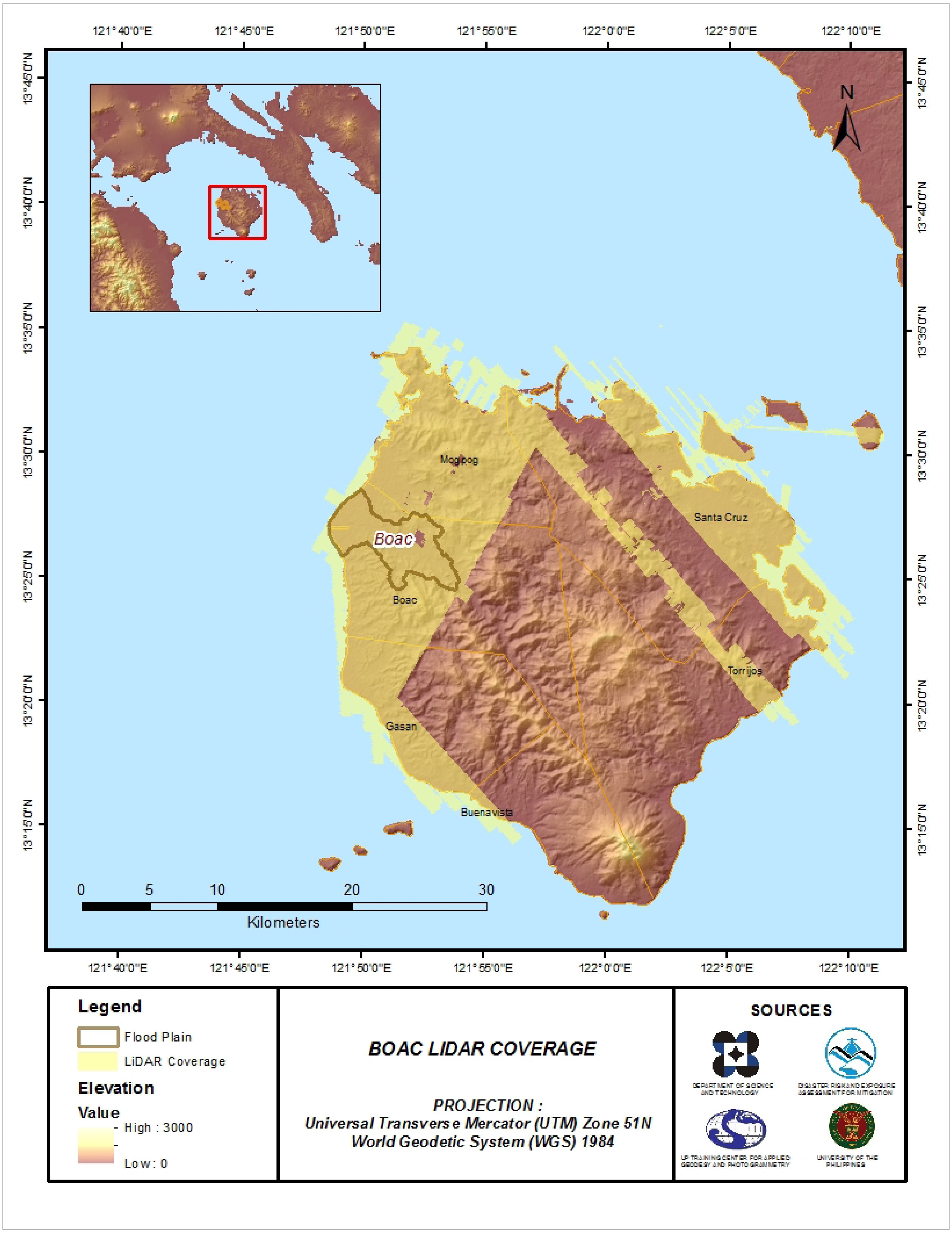

Figure 4. Actual LiDAR survey coverage for Boac Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE BOAC 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 DAC were 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 was done, in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification was performed to incorporate the correct position and orientation for each point acquired. The georectified LiDAR point clouds were subjected to quality checking to ensure that the required accuracies of the program, which are the minimum point density, and the vertical and horizontal accuracies, were met. The point clouds were then categorized into various classes before generating Digital Elevation Models (DEMs), such as the Digital Terrain Model (DTM) and the Digital Surface Model (DSM).

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

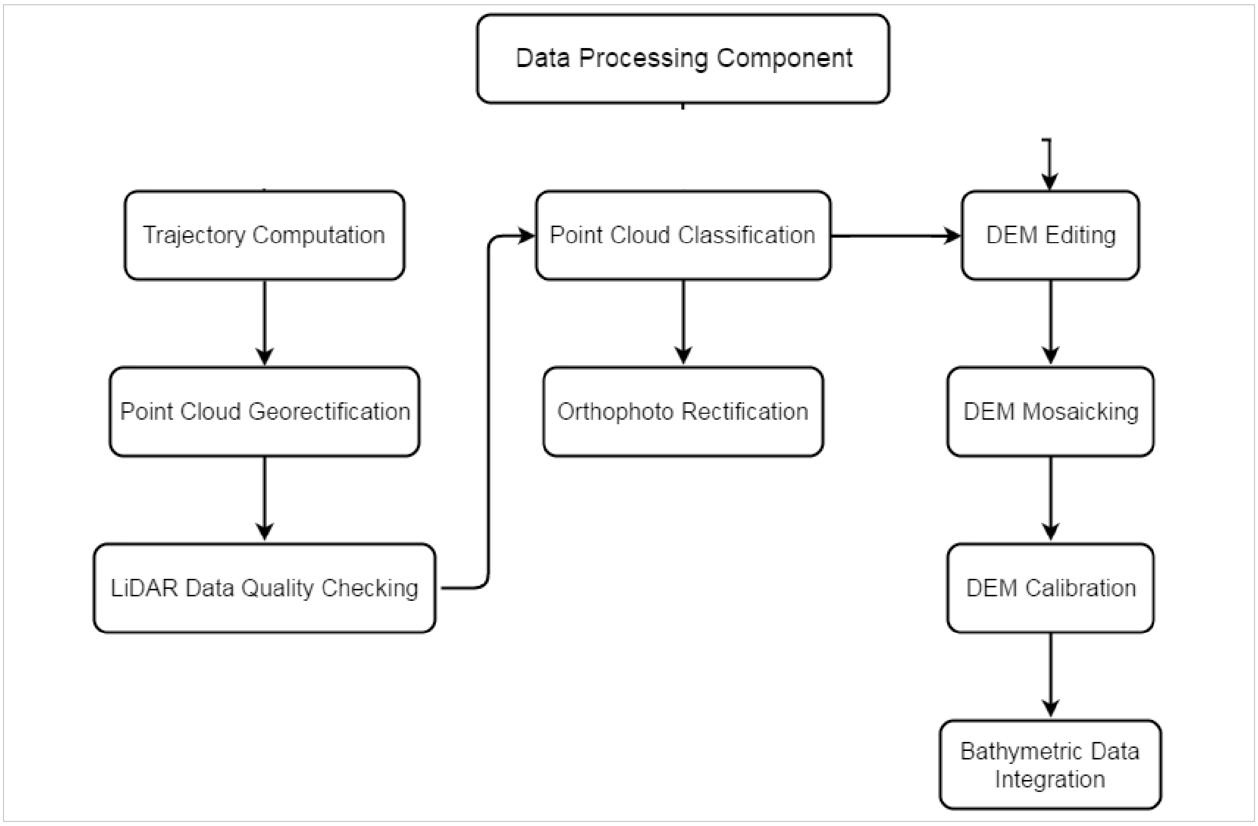


Figure 5. Schematic diagram for the Data Pre-Processing Component

These processes are summarized in the diagram in Figure 5.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all of the LiDAR missions for the Boac floodplain can be found in ANNEX 5. Missions flown over Boac, Marinduque for the survey conducted in October 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system. The DAC transferred a total of 67.58 Gigabytes of Range data, 782 Megabytes of POS data, 25.525 Megabytes of GPS base station data, and 1101.45 Gigabytes of raw image data to the data server on November 5, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for the Boac River survey was fully transferred on November 10, 2015, as indicated on the data transfer sheets for the Boac floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for Flight 10020P, one of the Boac flights, which are the North, East, and Down position RMSE values, are illustrated in Figure 6. 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 fell on October 9, 2015 at 00:00 hrs. on that week. The y-axis represents the RMSE value for that particular position.

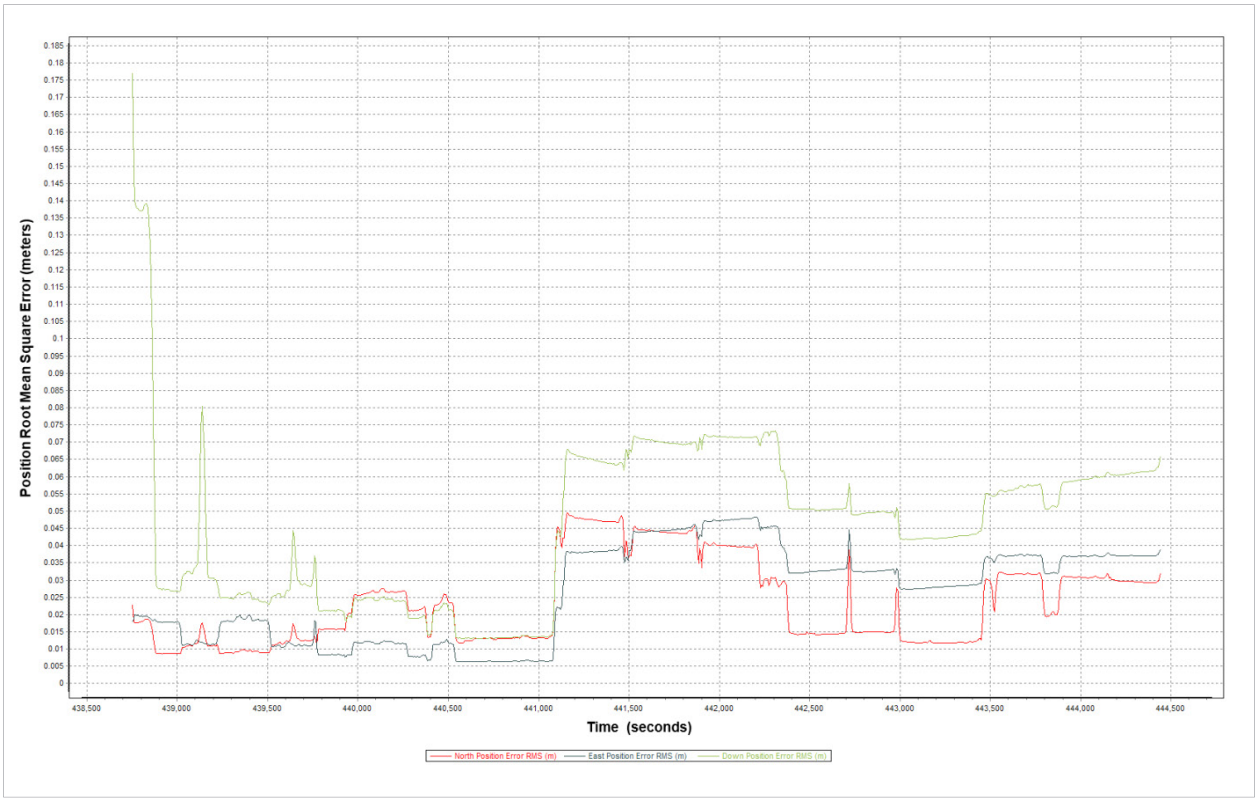


Figure 6. Smoothed Performance Metrics of Boac Flight 10020P

The time of flight was from 439000 seconds to 444500 seconds, which corresponds to the morning of October 9, 2015. The initial spike reflected on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system was starting to compute for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE values of the positions. The periodic increase in RMSE values from an otherwise smoothly curving set of RMSE values corresponds to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 6 demonstrates that the North position RMSE peaked at 5.00 centimeters, the East position RMSE peaked at 5.00 centimeters, and the Down position RMSE peaked at 8.00 centimeters, which are within the prescribed accuracies described in the methodology.

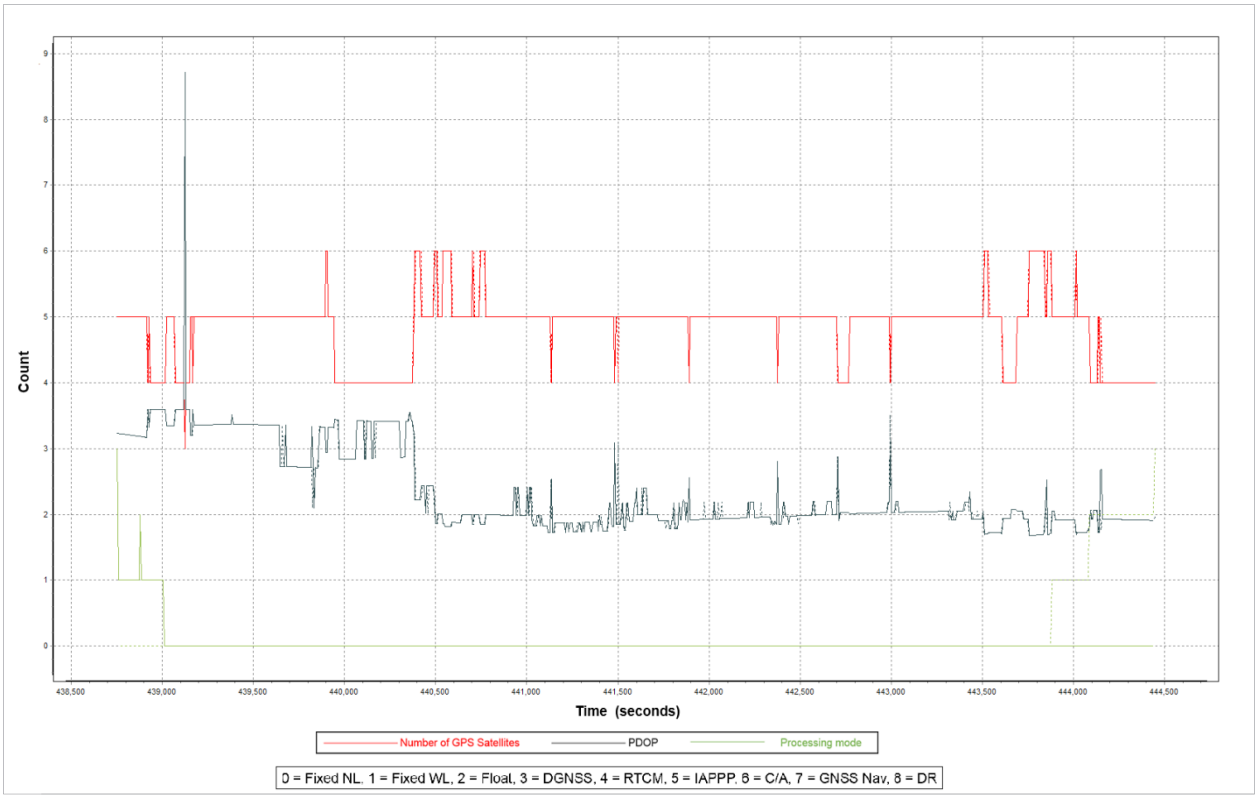


Figure 7. Solution Status Parameters of Boac Flight 10020P

The Solution Status parameters of Flight 10020P, one of the Boac flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are presented in Figure 7. The graphs indicate that the number of satellites during the acquisition did not go down to 3. Majority of the time, the number of satellites tracked was between 4 and 6. The PDOP value did not go above the value of 4, which indicates optimal GPS geometry. The processing mode remained at the value of 0 for majority of the survey, with some peaks to 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 satisfied the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Boac flights is exhibited in Figure 8.

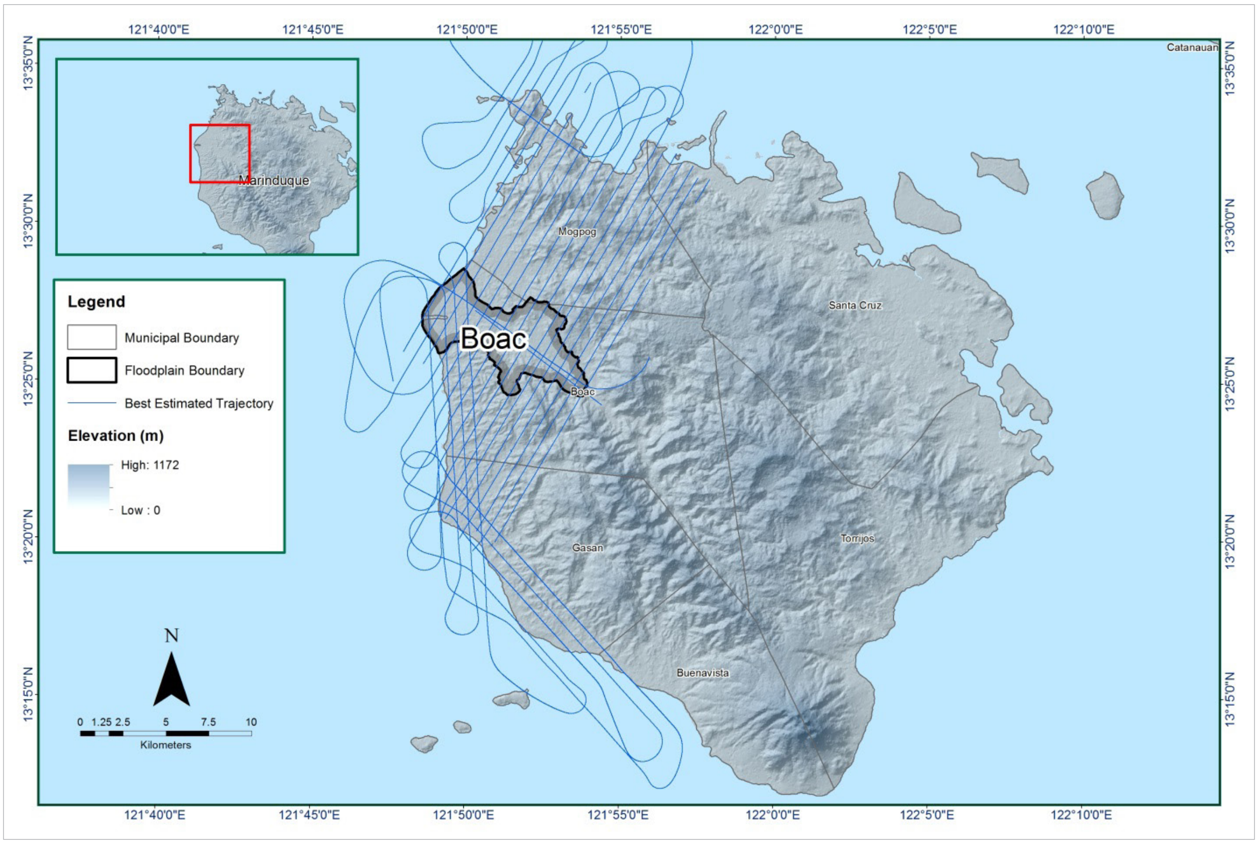


Figure 8. Best Estimated Trajectory for Boac Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains seventy (70) flight lines, with each flight line containing two (2) channels, since the Pegasus system contains two (2) channels. The summary of the self-calibration results for all flights over the Boac floodplain, obtained through LiDAR processing in the LiDAR Mapping Suite (LMS) software, is given in Table 8.

Table 8. Self-Calibration Results for Boac flights.

Parameter	Acceptable Value
Boresight Correction stdev (<0.001degrees)	0.000368
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000843
GPS Position Z-correction stdev (<0.01meters)	0.0082

Optimum accuracy was obtained for all Boac flights, based on the computed standard deviations of the corrections of the orientation parameters. The standard deviation values for the individual blocks are available in the ANNEX 8: Mission Summary Reports.

3.5 LiDAR Data Quality Checking

The boundaries of the processed LiDAR data on top of an SAR Elevation Data over the Boac floodplain are represented in Figure 9. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

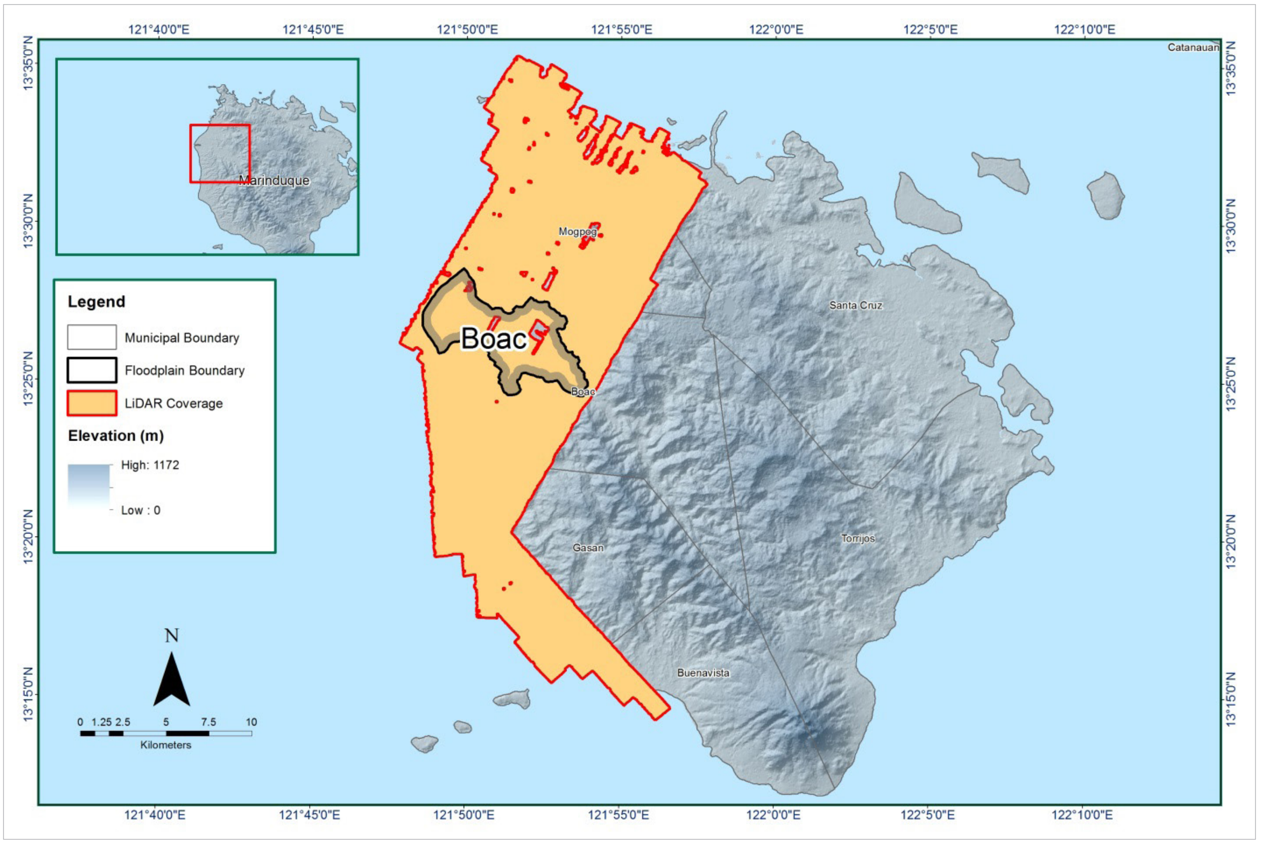


Figure 9. Boundary of the processed LiDAR data over Boac Floodplain

The total area covered by the Boac missions is 342.56 square kilometers, comprised of four (4) flight acquisitions that were grouped and merged into three (3) blocks, as outlined in Table 10.

Table 9. List of LiDAR blocks for Boac floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Marinduque_Blk22B	10020P	243.26
	10021P	
	10027P	
	10032P	
Marinduque_Blk22C	10020P	49.42
Marinduque_Blk22A_additional	10020P	49.88
TOTAL		342.56 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location, is depicted in Figure 10. Since the Pegasus system employs two (2) channels, It is expected to have 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 (3) or more overlapping flight lines.

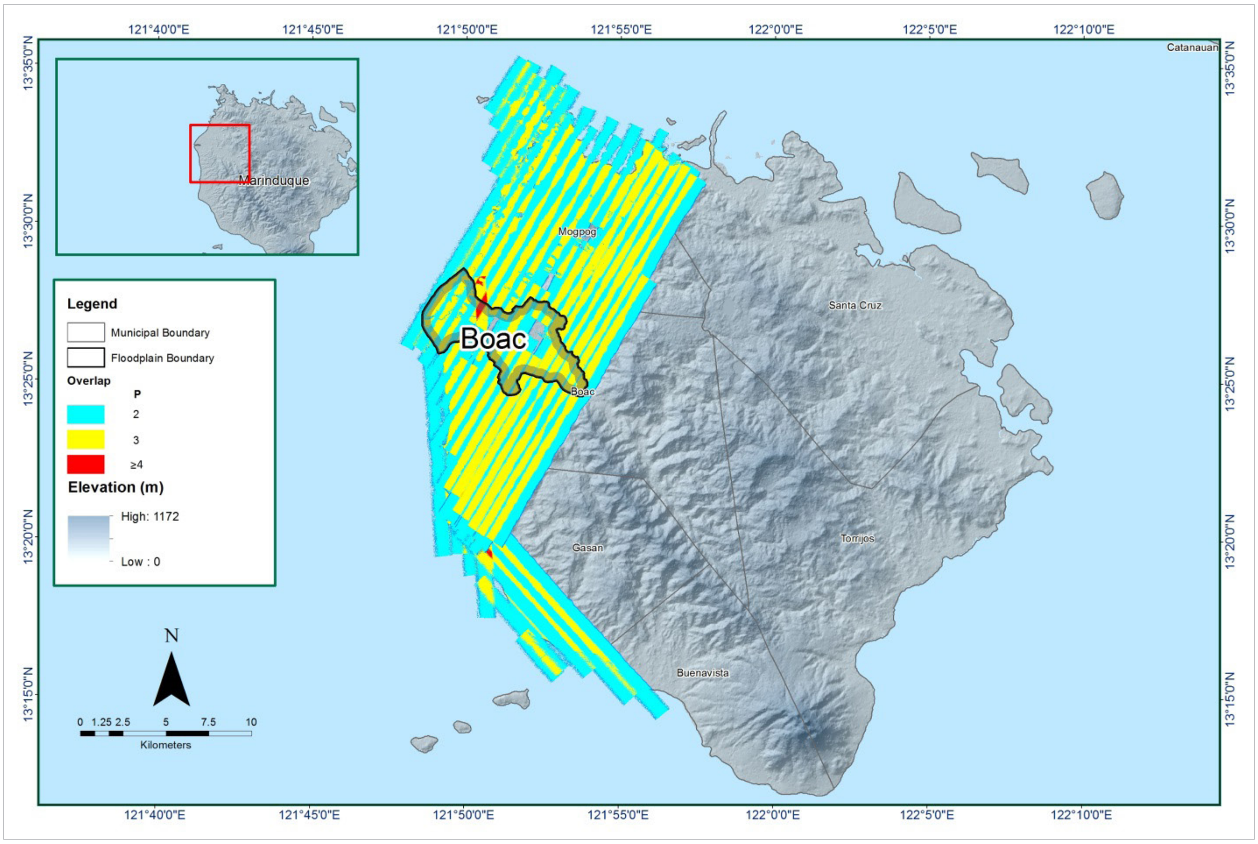


Figure 10. Image of data overlap for Boac Floodplain.

The overlap statistics per block for the Boac floodplain can be found in ANNEX 8. One (1) pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps were 30.09% and 52.50%, respectively, which satisfied the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the two (2) points per square meter criterion, is shown in Figure 11. It was determined that all LiDAR data for the Boac floodplain satisfy the point density requirement, and that the average density for the entire survey area is 2.82 points per square meter.

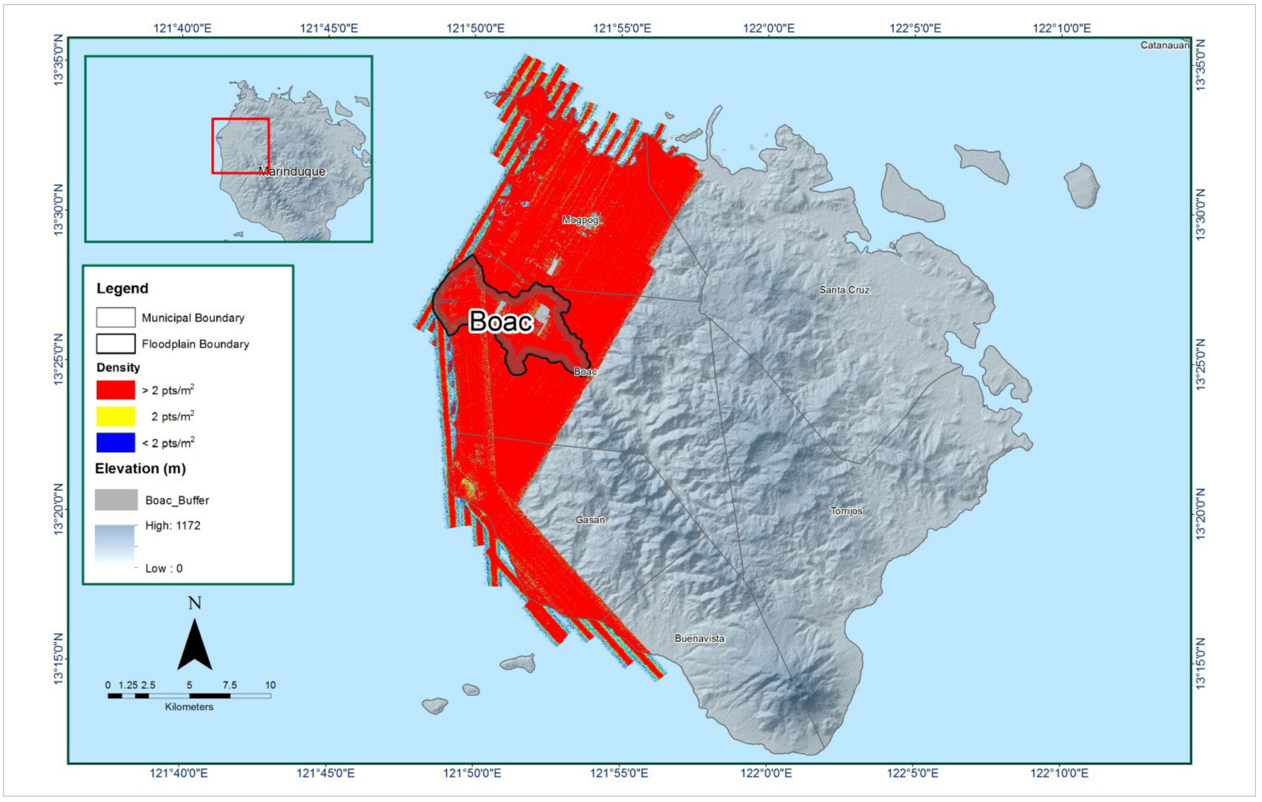


Figure 11. Pulse density map of merged LiDAR data for Boac Floodplain.

The elevation difference between overlaps of adjacent flight lines is illustrated in Figure 12. The default color range is from blue to red. Bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20 meters relative to the elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20 meters relative to the elevations of its adjacent flight line. Areas with bright red or bright blue colors were investigated further using the Quick Terrain (QT) Modeler software.

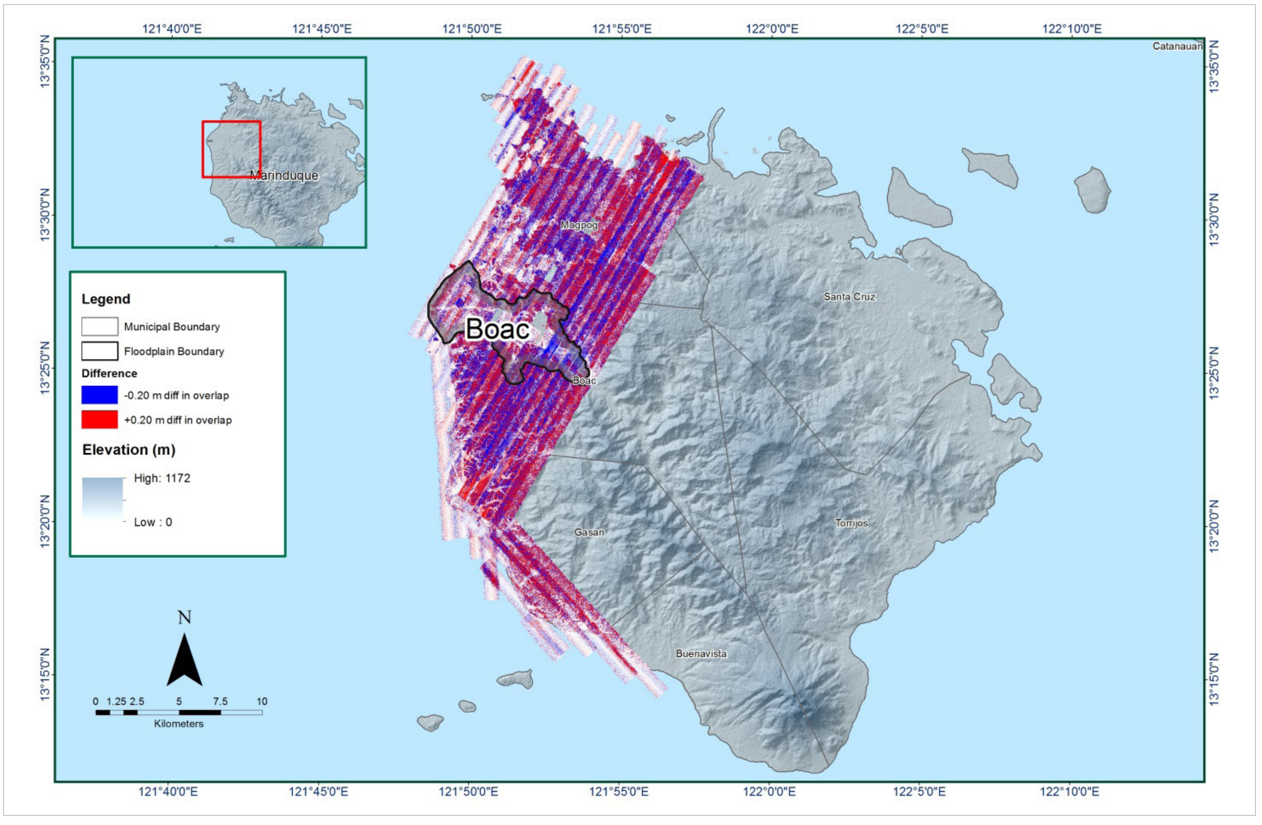


Figure 12. Elevation difference map between flight lines for Boac Floodplain.

A screen capture of the processed LAS data from a Boac flight 10020P loaded in the QT Modeler is provided in Figure 13. The upper left image shows the elevations of the points from two (2) 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 were differences in elevation, but the differences did not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data became satisfactory. No reprocessing was done for this LiDAR dataset.

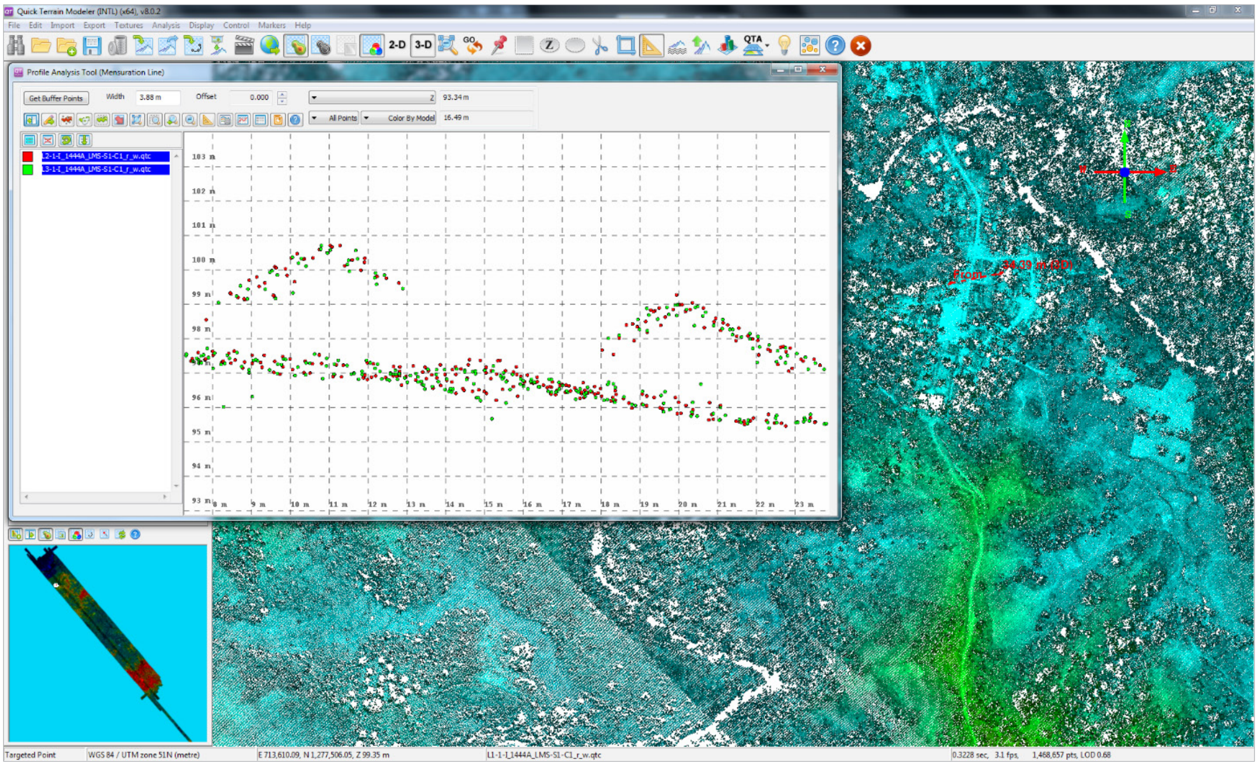


Figure 13. Quality checking for a Boac flight 7401GC using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Boac classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	218,494,905
Low Vegetation	156,518,247
Medium Vegetation	326,439,548
High Vegetation	1,347,288,813
Building	25,095,355

The tile system that the TerraScan employed for the LiDAR data, as well as the final classification image for a block in the Boac floodplain, are presented in Figure 14. A total of 480 1km by 1km tiles were produced. The number of points classified according to the pertinent categories is illustrated in Table 10. The point cloud had a maximum and minimum height of 284.36 meters and 42.28 meters, respectively.

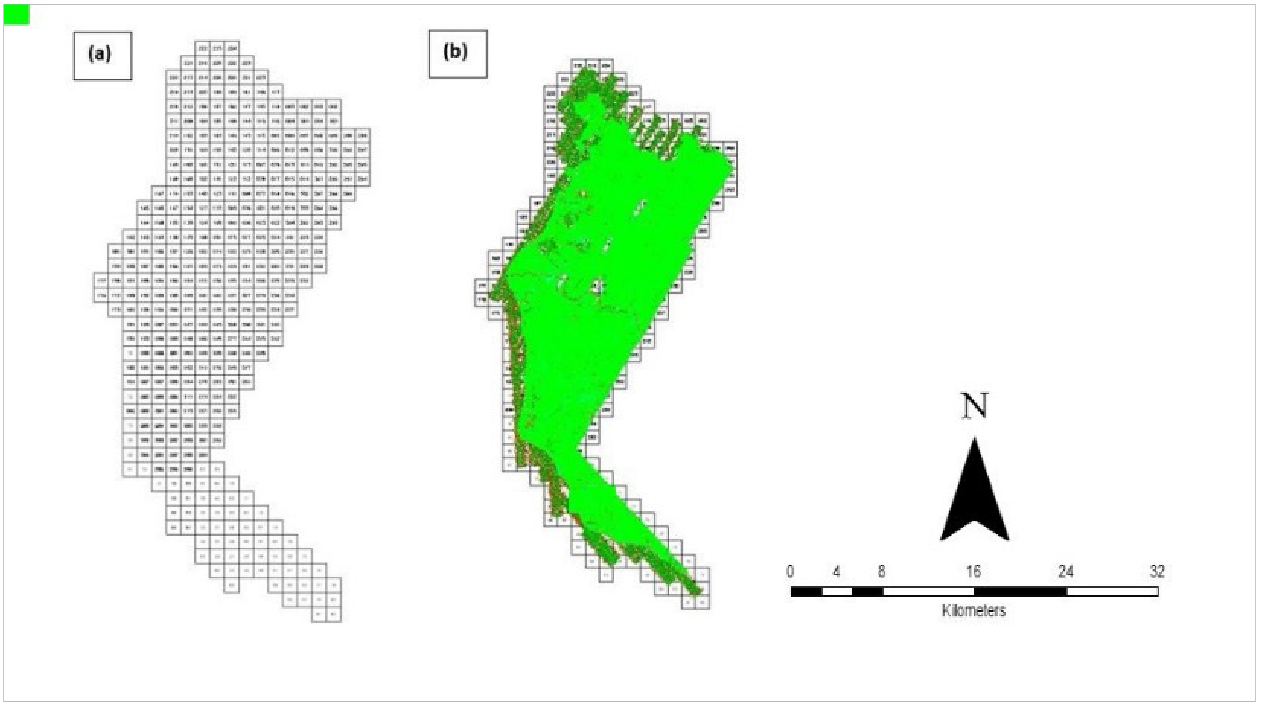


Figure 14. Tiles for Boac Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 15. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It is visible that the residential structures adjacent or even below canopy were classified correctly, due to the density of the LiDAR data.

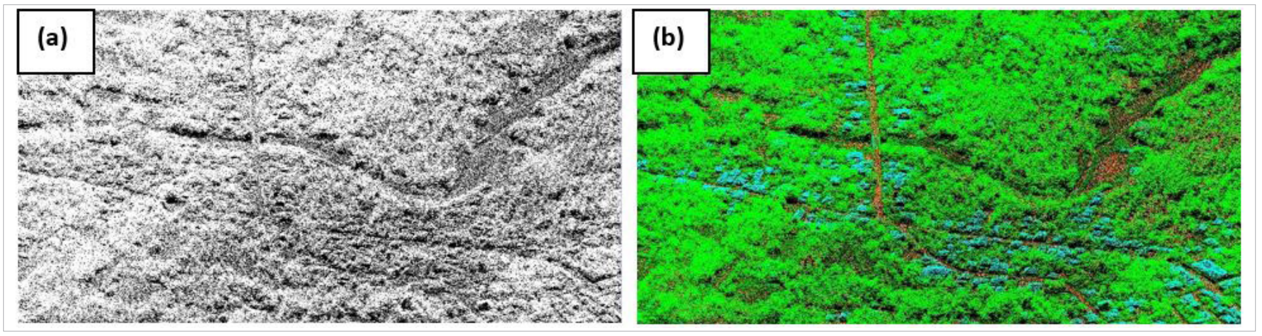


Figure 15. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, and the first (S_ ASCII) and last (D_ ASCII) return DSM of the area are illustrated in Figure 16, in top view display. The images depict that the DTMs are a representation of the bare earth; while the DSMs reflect all features that are present, such as buildings and vegetation.

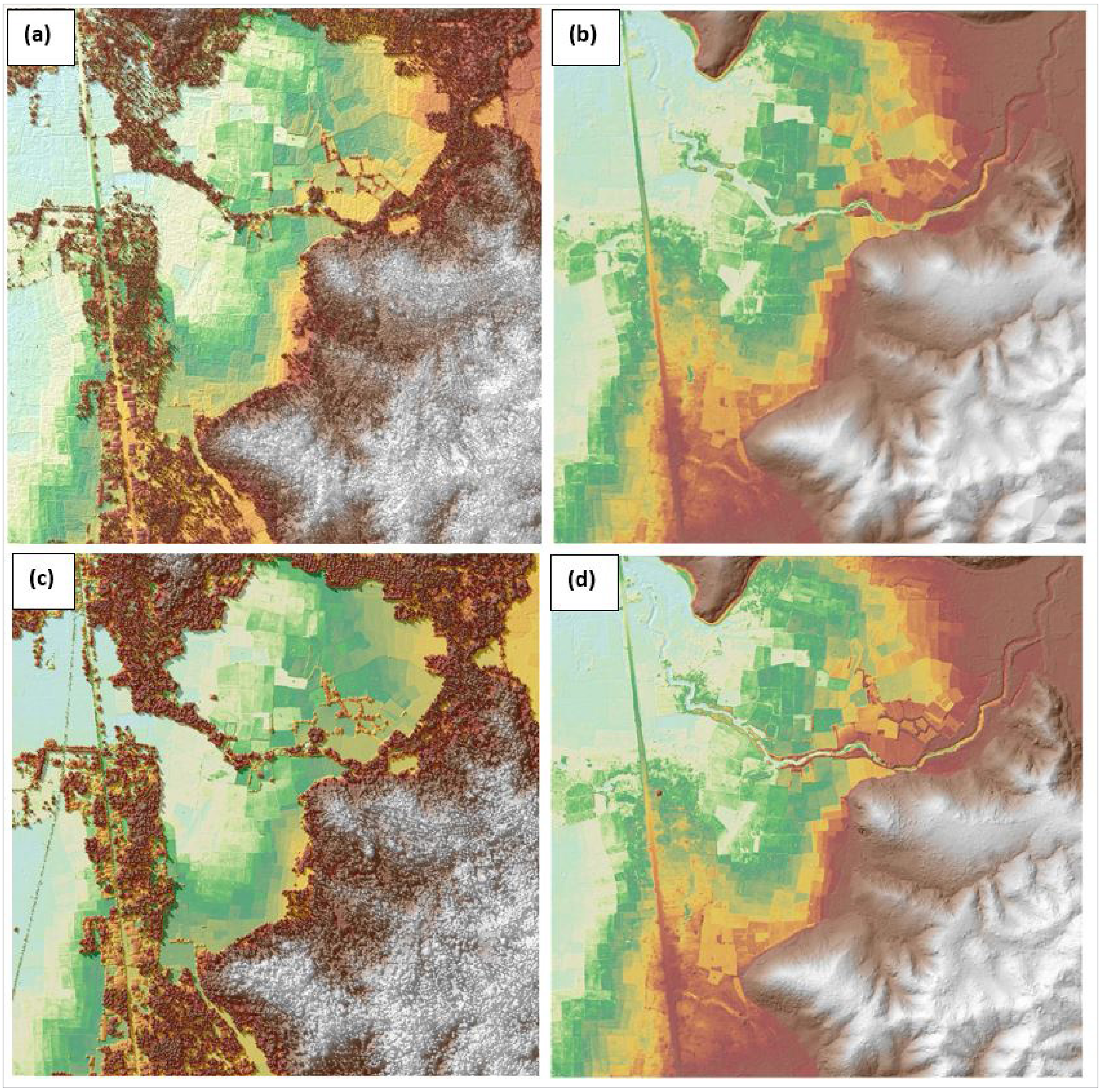


Figure 16. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Boac Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 311 1km by 1km tiles area covered by the Boac floodplain is exhibited in Figure 17. After employing tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Boac floodplain survey attained a total of 293.25 square kilometers in orthophotographic coverage, comprised of 876 images. Zoomed-in versions of sample orthophotographs, identified by their tile numbers, are provided in Figure 18.

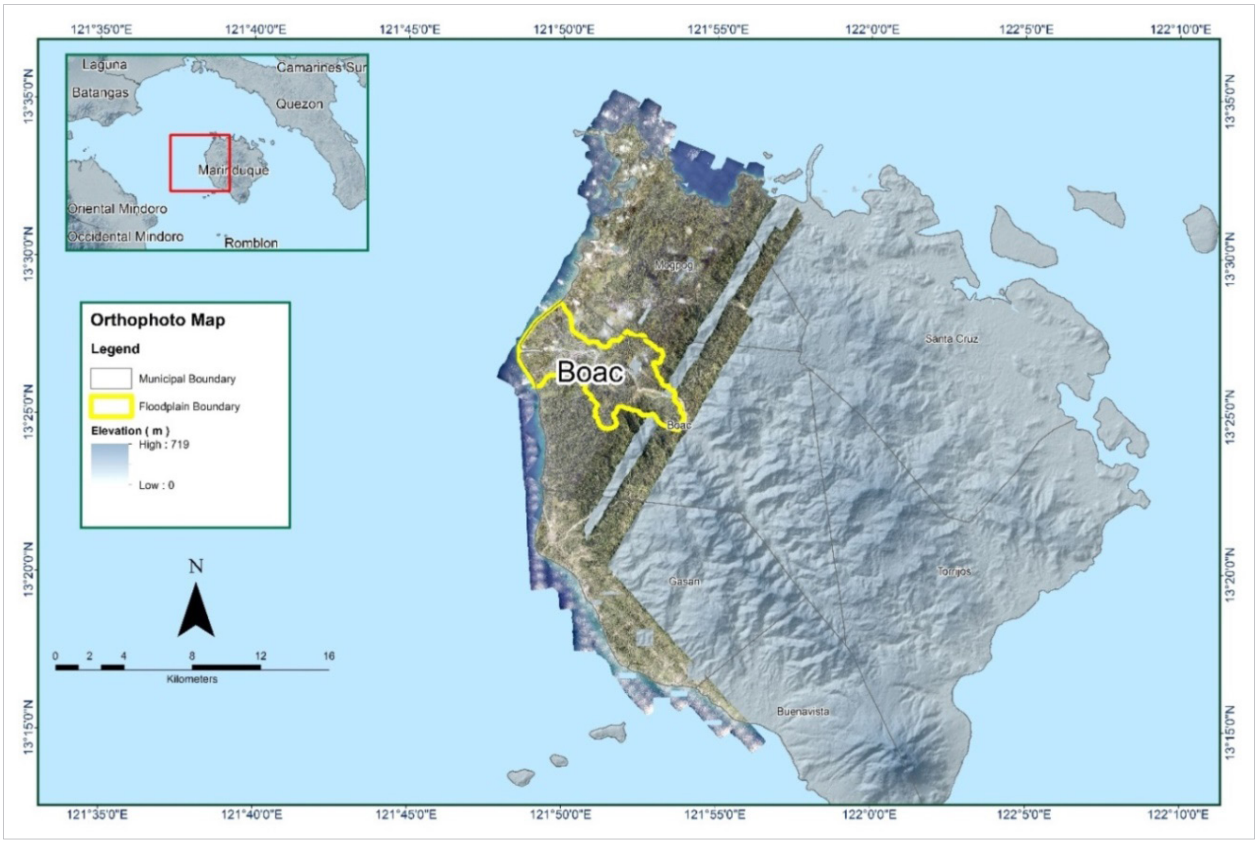


Figure 17. The Boac Floodplain, with available orthophotographs

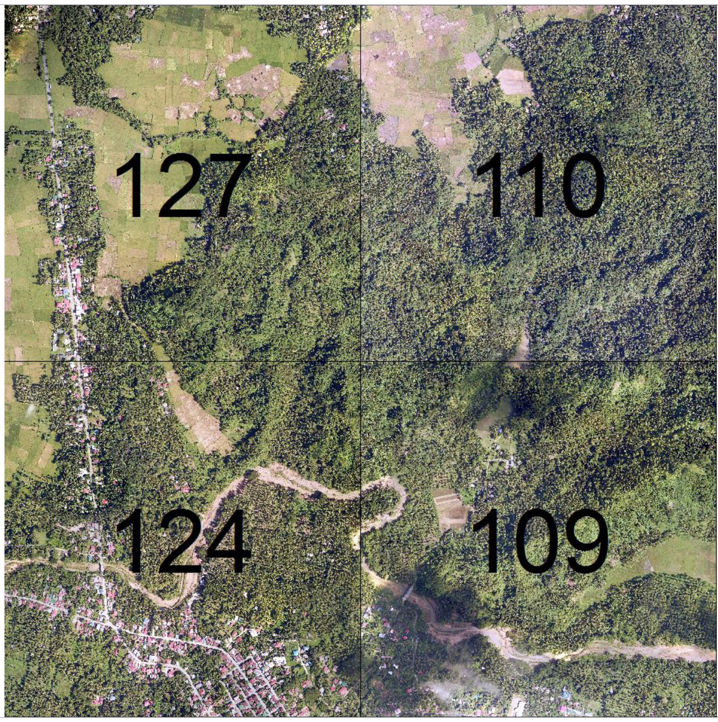


Figure 18. Sample orthophotograph tiles for the Boac Floodplain

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for the Boac floodplain. These blocks are composed of Marinduque blocks, with a total area of 342.56 square kilometers. Table 11 outlines the names and corresponding areas of the blocks, in square kilometers.

Table 11. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Marinduque_Blk22B	243.26
Marinduque_Blk22C	49.42
Marinduque_Blk22A_additional	49.88
TOTAL	**342.56 sq.km**

Portions of DTM before and after manual editing are presented in Figure 19. The bridge (Figure 19a) was considered to be an obstruction to the flow of water along the river, and had to be removed (Figure 19b) in order to hydrologically correct the river. The data gap (Figure 19c) was filled to complete the surface (Figure 19d), in order to allow for the correct flow of water.

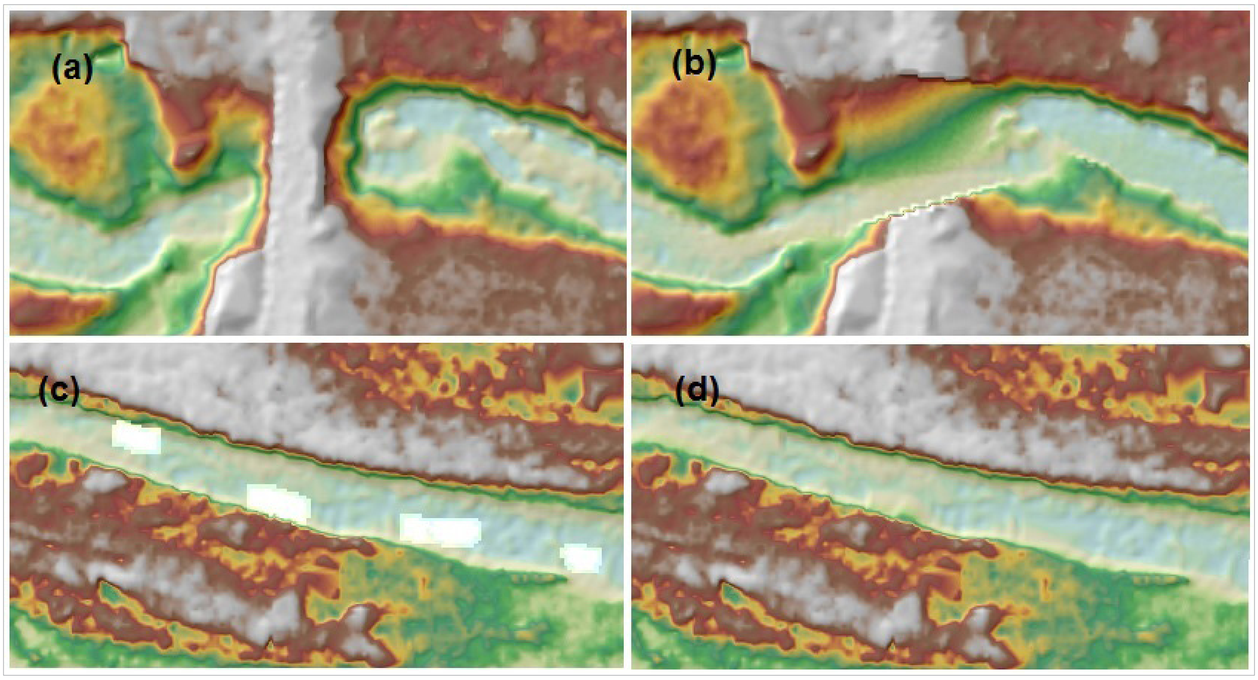


Figure 19. Portions in the DTM of the Boac Floodplain – a bridge (a) before and (b) after manual editing; and a data gap (c) before and (d) after data retrieval

3.9 Mosaicking of Blocks

The Marinduque_Blk22B block was used as the reference block at the start of mosaicking, as it was the first block mosaicked to the larger DTM of Marinduque. Upon inspection of the blocks mosaicked for the Boac floodplain, it was concluded that the elevations of the Marinduque_Blk22C and Marinduque_Blk22A_ additional blocks needed to be adjusted. Table 12 enumerates the shift values applied to the blocks during the mosaicking process.

The mosaicked LiDAR DTM for the Boac floodplain is depicted in Figure 20. The Boac floodplain was 95.93% covered by LiDAR data; while portions without LiDAR data were patched with the available IFSAR data.

Table 12. Shift Values of each LiDAR Block of Boac floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
Mariduque_Blk22B	0.00	0.00	0.00
Marinduque_Blk22C	0.00	0.00	-0.31
Marinduque_Blk22A_additional	0.00	0.00	-0.31

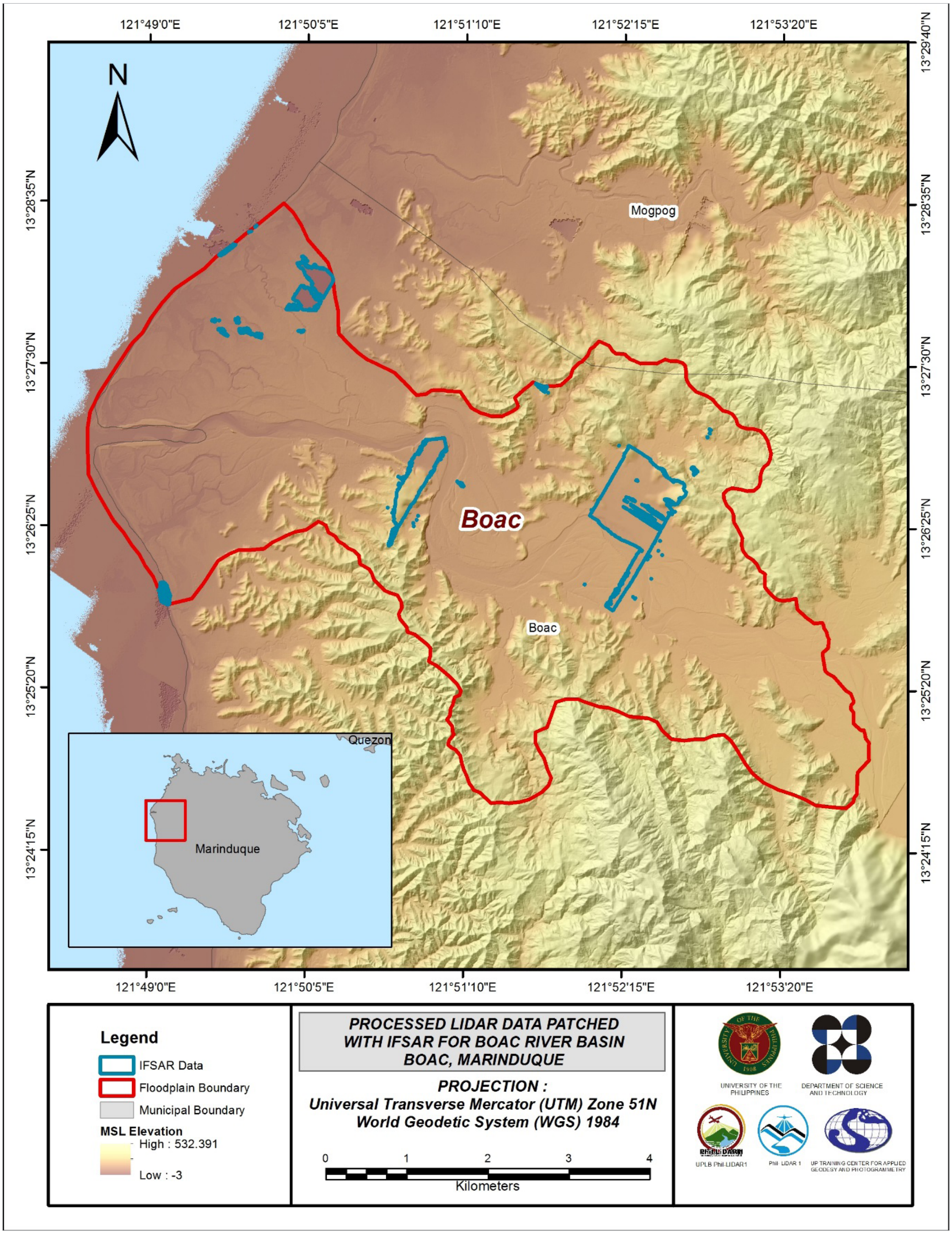


Figure 20. Map of Processed LiDAR Data for Boac Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

To undertake the data validation of the Mosaicked LiDAR DEMs, the DVBC conducted a validation survey along the Boac floodplain. The extent of the validation survey done in the Boac River to collect points with which the LiDAR dataset was validated is illustrated in Figure 21, with the validation survey points highlighted in green.

A total of 2,215 survey points were used for the calibration and validation of the Boac LiDAR data. Random selection of 80% of the survey points resulted in 1,773 points, which were used for calibration. A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is reflected in Figure 22. Statistical values were computed from extracted LiDAR values using the selected points, to assess the quality of the data and to obtain the values for vertical adjustment. The computed height difference between the LiDAR DTM and the calibration elevation values is 3.69 meters, with a standard deviation of 0.18 meters. Calibration of the Boac LiDAR data was executed by subtracting the height difference value, 3.69 meters, from the Boac mosaicked LiDAR data. Table 13 indicates the statistical values of the compared elevation values between the LiDAR data and the calibration data.

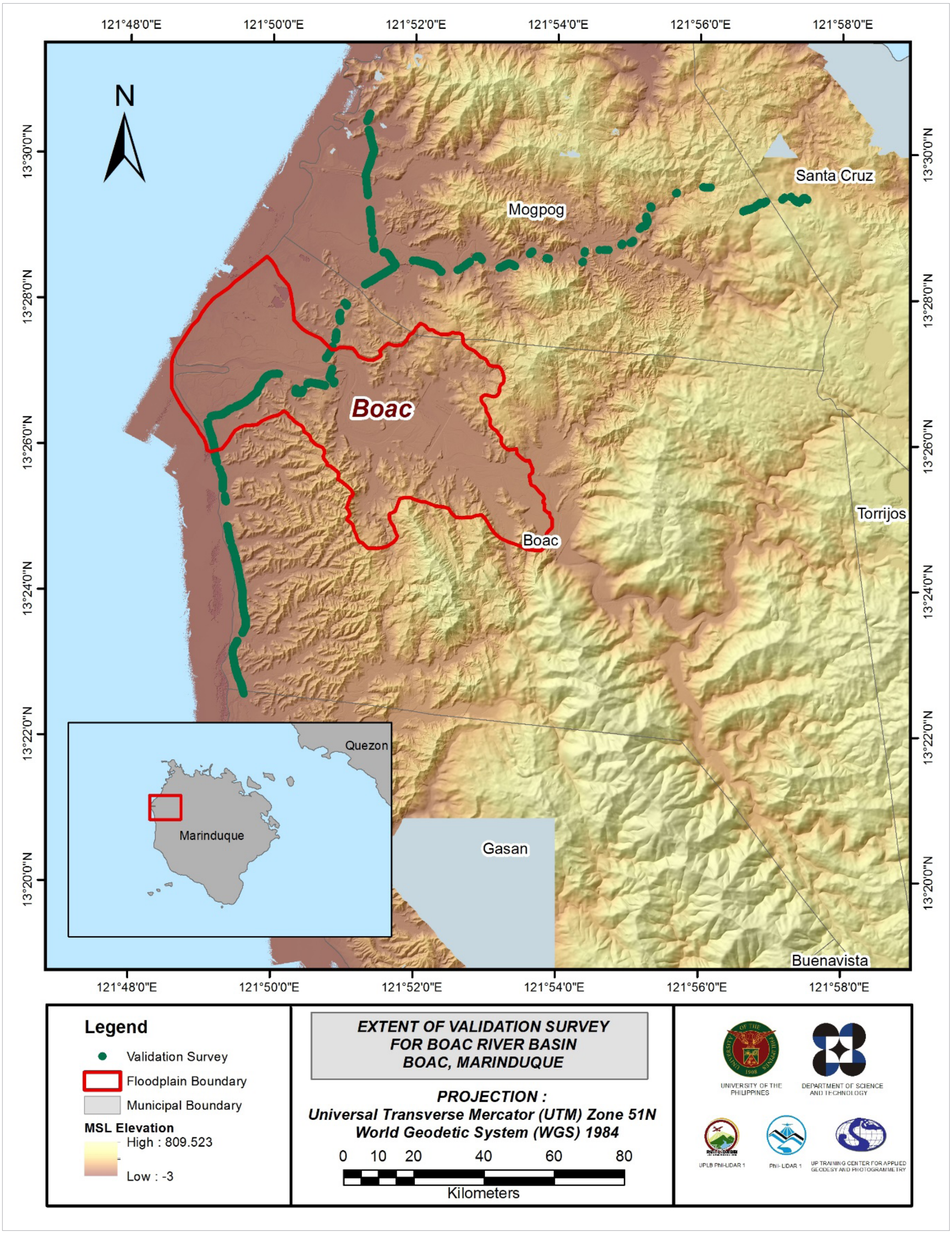


Figure 21. Map of Boac Floodplain with the validation survey points in green.

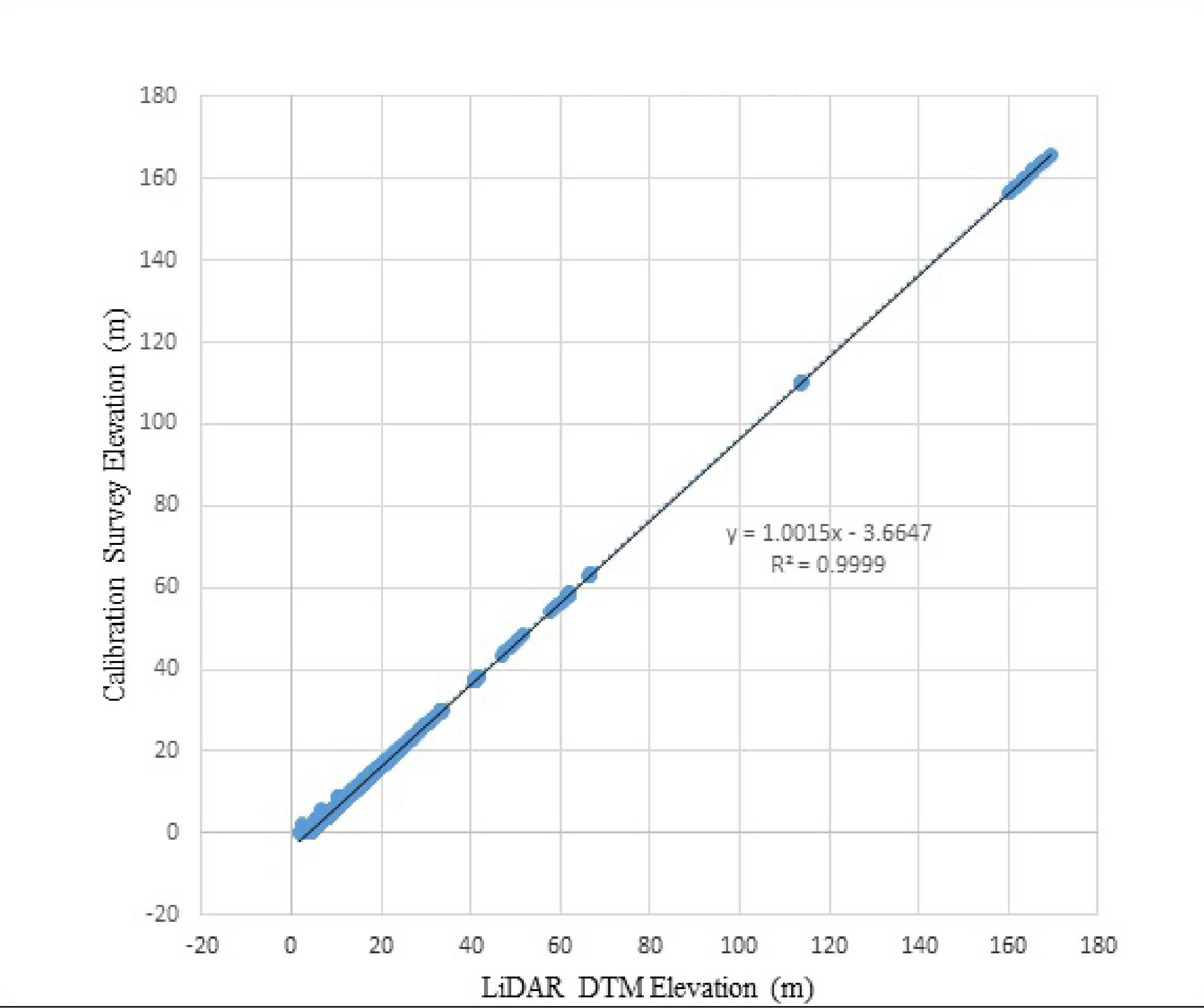


Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	3.69
Standard Deviation	0.18
Average	-3.68
Minimum	-4.05
Maximum	-3.32

The remaining 20% of the total survey points, resulting in 108 points, were used for the validation of the calibrated Boac 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 demonstrated in Figure 23. The computed RMSE between the calibrated LiDAR DTM and the validation elevation values is 0.10 meters, with a standard deviation of 0.07 meters, as expressed in Table 14.

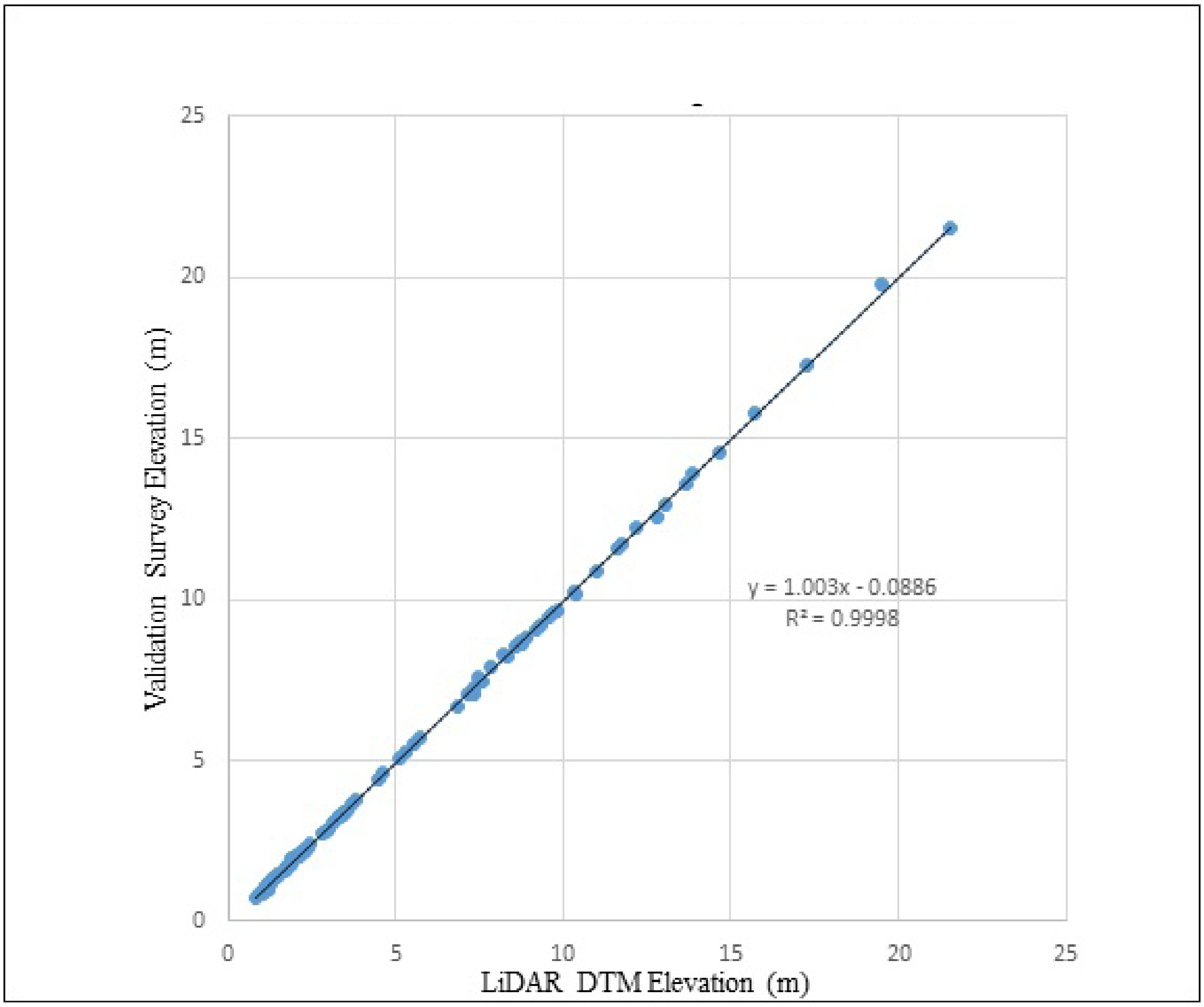


Figure 23. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

Calibration Statistical Measures	Value (meters)
RMSE	0.10
Standard Deviation	0.07
Average	-0.07
Minimum	-0.26
Maximum	0.28

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathymetric data integration, only centerline and cross-section data were available for the Boac survey. There were 7,766 and 1,723 survey points for the centerline and cross-section surveys, respectively; resulting in a total of 9,489 survey points. The resulting raster surface produced was obtained through the 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 0.31 meters. The extent of the bathymetric survey performed by the DVBC in Boac, integrated with the processed LiDAR DEM, is shown in Figure 24.

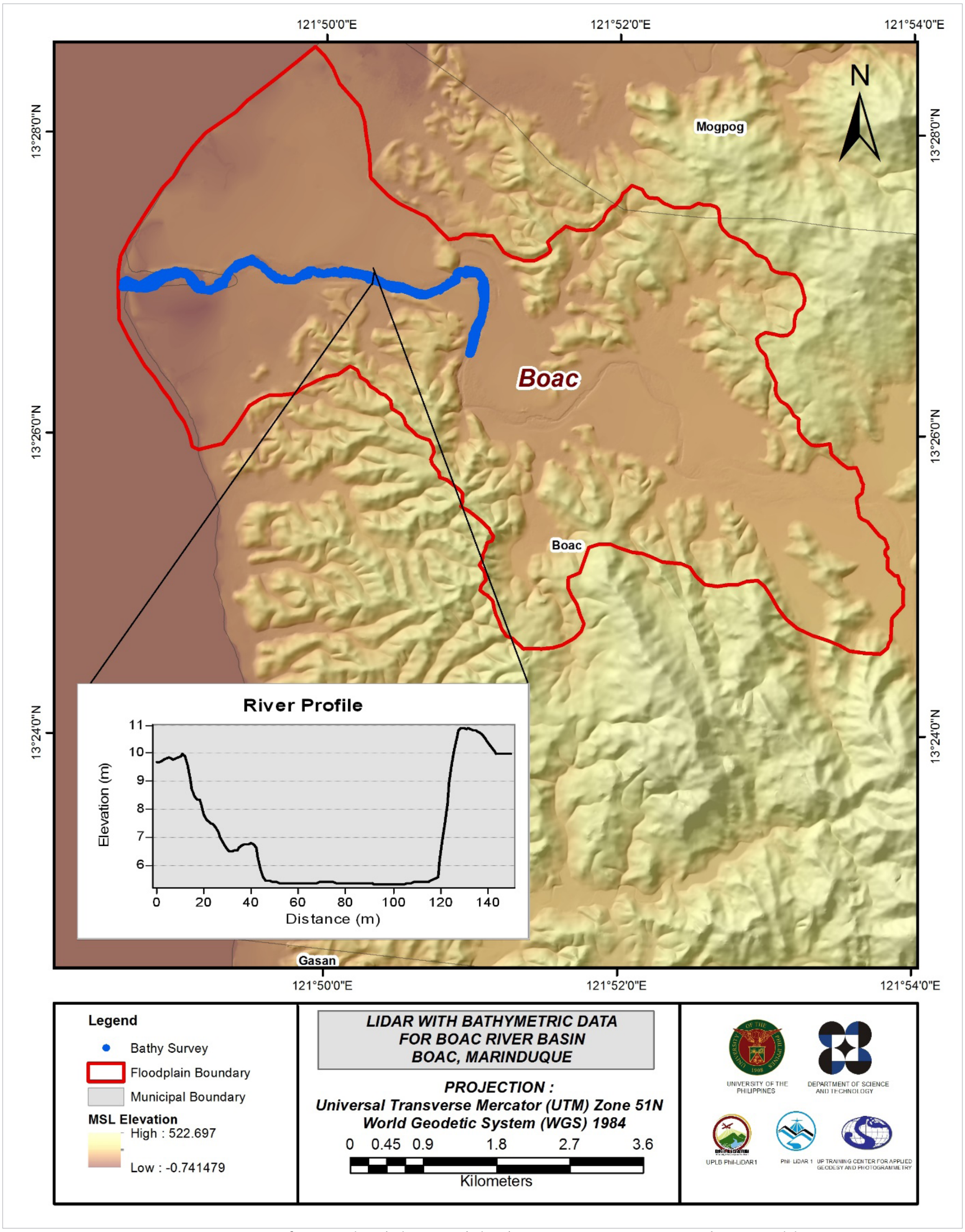


Figure 24. Map of Boac Floodplain with bathymetric survey points shown in blue.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, and For. Rodel C. Alberto

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 DVBC conducted field surveys in the Boac River on August 9 – 20, 2016. The scope of work was comprised of: (i.) initial reconnaissance; (ii.) control point survey; (iii.) cross-section and bridge as-built surveys at the Biglang Awa Bridge in Barangay Mataas na Bayan, Boac, Marinduque; (iv.) validation points acquisition of about 31 kilometers, covering the Boac River Basin area; and (v.) bathymetric survey from the river's upstream portion in Barangay Sawi, down to the mouth of the river located in Barangay Tabigue, both in the Municipality of Boac, with an approximate length of 6.086 kilometers using a Hi-Target™ single beam echo sounder and Trimble® SPS 985 GNSS in PPK survey technique. The extent of the field surveys are illustrated in Figure 25.

Figure 25. Extent of the bathymetric survey (in blue line) in the Boac River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used for the Boac River Basin is composed of a single loop established on August 11, 2016, occupying the following reference points in the province of Marinduque: (i.) MRQ-34, a second-order GCP, in Barangay Napo, Municipality of Sta. Cruz; and (ii.) MQ-13, a first-order BM, in Barangay Mataas na Bayan, Municipality of Boac.

A NAMRIA-established control point, MQ-120, located at the approach of the Mangamnan Bridge in Barangay Butansapa, Municipality of Mogpong, Marinduque; was also occupied and used as a marker.

The summary of reference and control points and their corresponding locations is provided in Table 15; while the established GNSS network is illustrated in Figure 26 .

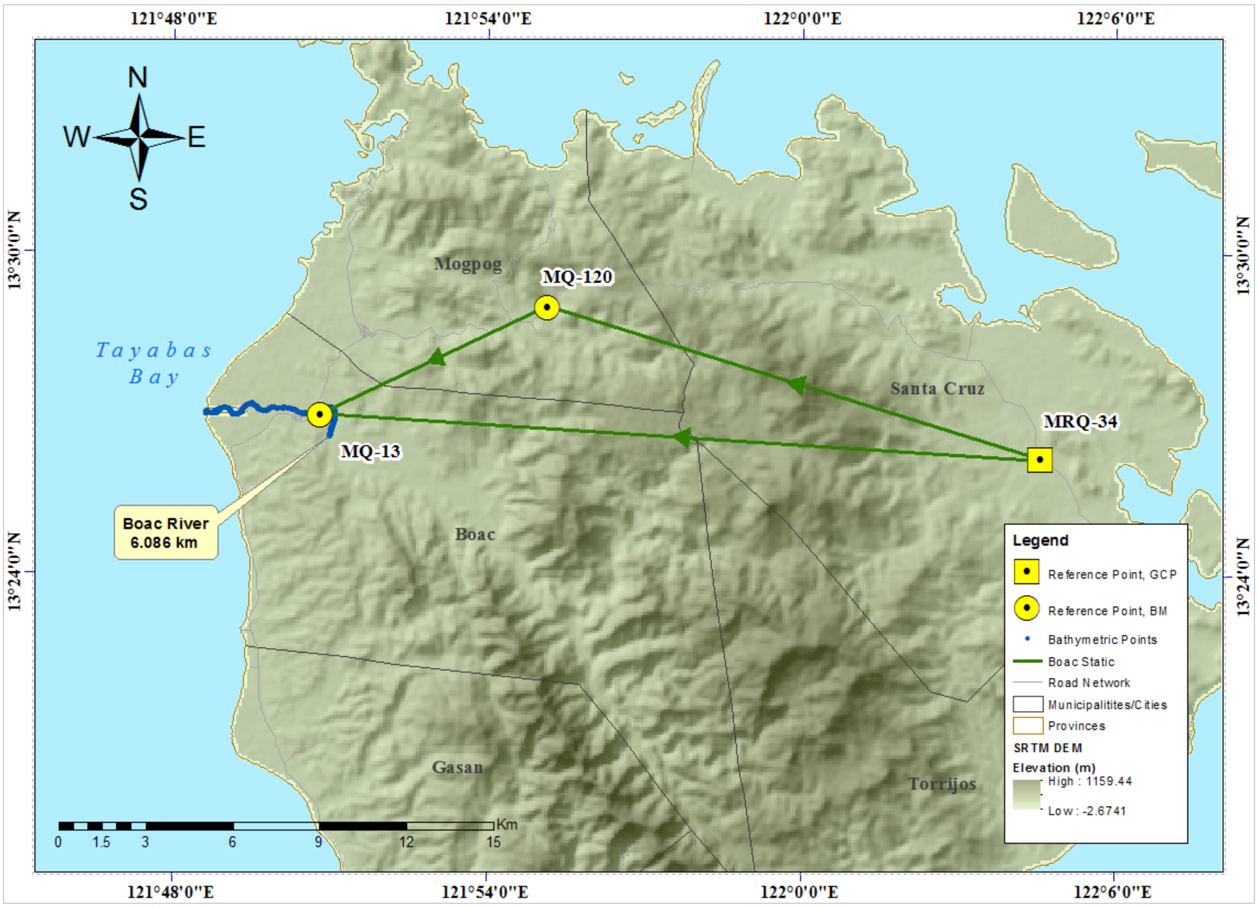


Figure 26. GNSS network covering the Boac River

Table 15. Reference and control points occupied for the Boac River survey

Control Point	Order of Accuracy	Geographic Coordinates (WGS UTM Zone 52N)				
		Latitude	Longitude	Ellipsoid Height (m)	Elevation (MSL) (m)	Date of Establish-ment
MRQ-34	2^{nd} order, GCP	13°26'09.54636"N	122°04'33.94310"E	64.236	-	2016
MQ-13	1^{st} order, BM	-	-	63.211	13.916	2016
MQ-120	Used as Marker	-	-	-	-	2016 8-11-16 2:12PM

The GNSS set-ups on the recovered reference points and established control points in the Boac River are exhibited in FIgure 27 to Figure 29.

Figure 27. GNSS base set-up, Trimble® SPS 985 at MRQ-34, located near the Rizal statue inside Makapuyat Elementary School in Barangay Napo, Sta. Cruz, Marinduque

Figure 28. GNSS receiver set-up, Trimble® SPS 985 at MQ-13, located at the approach of the Biglang Awa Bridge in Barangay Mataas na Bayan, Boac, Marinduque

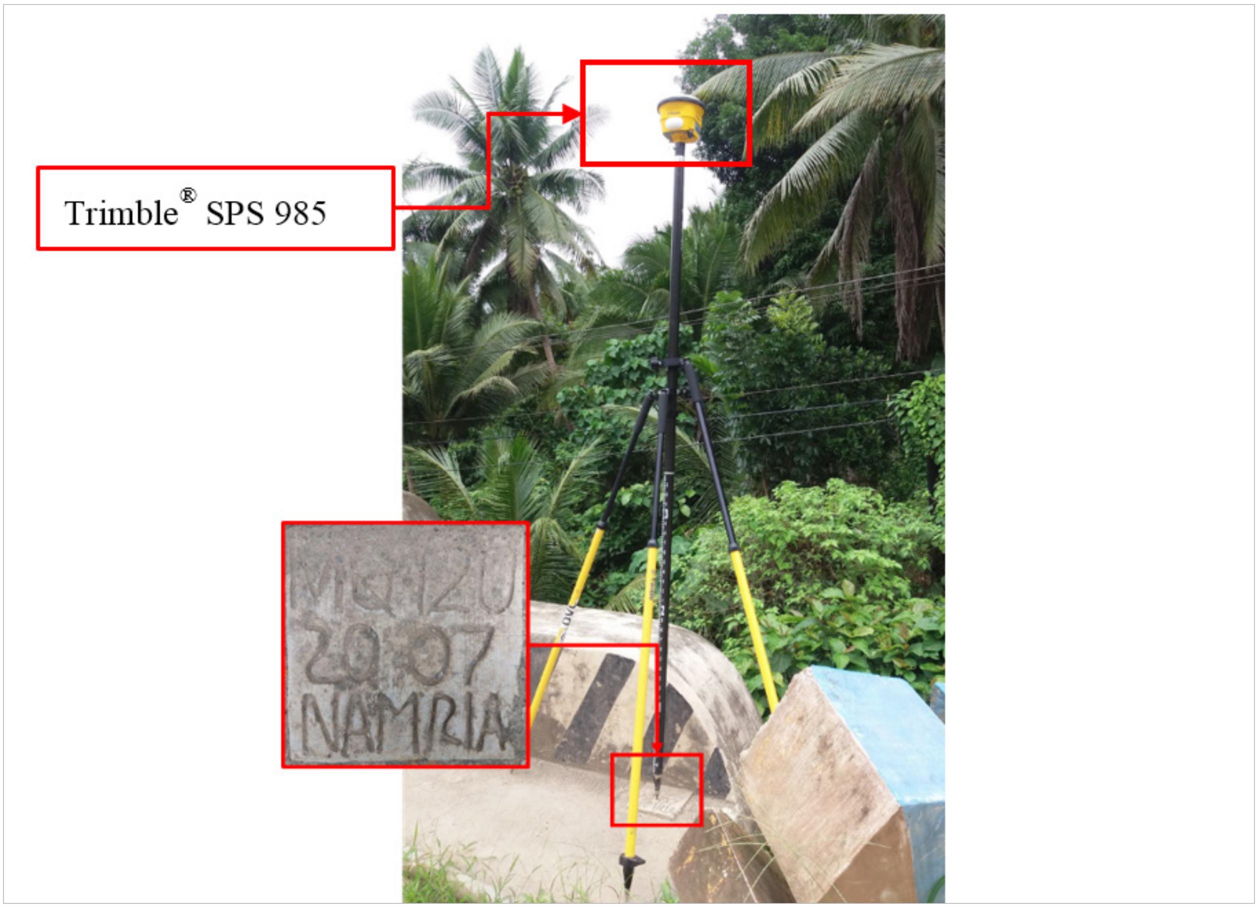


Figure 29. GNSS receiver set-up, Trimble® SPS 985 at MQ-120, located at the approach of the Mangamnan Bridge in Barangay Butansapa, Mogpong, Marinduque

4.3 Baseline Processing

The GNSS baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions, with horizontal and vertical precisions within the +/- 20-centimeter, and +/- 10-centimeter requirement, respectively. In cases where one or more the baselines did not meet all of these criteria, masking was performed. Masking is the removal of portions of 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, a re-survey is initiated. The baseline processing results of the control points in the Boac River Basin, generated by the TBC software, are summarized in Table 16.

Table 16. Baseline processing report for the Boac River survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Δ Height (m)
MQ-13 --- MRQ-34	08-11-2016	Fixed	0.011	0.034	273°23'02"	24859.031	-1.024
MQ-120 --- MRQ-34	08-11-2016	Fixed	0.009	0.038	286°58'51"	17779.150	23.128
MQ-120 --- MQ-13	08-11-2016	Fixed	0.006	0.026	244°28'06"	8654.408	-24.145

As reflected in , a total of three (3) baselines were processed, with reference points MRQ-34 held fixed for coordinate values, and MQ-13 fixed for elevation values. All of the baselines passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment was performed using the TBC. Looking at the adjusted grid coordinates table of the TBC-generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 centimeters, and z less than 10 centimeters, or as expressed in equation form:

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

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 presented in Table 17 to Table 20 for complete details.

The three (3) control points – MRQ-34, MQ-13, and MQ-120 – were occupied and observed simultaneously to form a GNSS loop. The coordinates of MRQ-34 and the elevation values of MQ-13 were held fixed during the processing of the control points, as demonstrated in . Through these reference points, the coordinates and elevation values of the unknown control points were computed.

Table 17. Constraints applied to the adjustments of the control points

Point ID	Type	North (Meter)	East (Meter)	Height (Meter)	Elevation (Meter)
MRQ-34	Local	Fixed	Fixed		
MQ-13	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 . The fixed controls, MRQ-34 and MQ-13, have no values for grid errors and elevation errors, respectively.

Table 18. Adjusted grid coordinates for the control points used in the Boac Floodplain survey

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
MQR-34	399984.398	?	1485537.871	?	14.100	0.044	LL
MQ-13	375180.421	0.010	1487097.828	0.006	13.916	?	e
MQ-120	383004.307	0.010	1490792.799	0.006	37.551	0.037	

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

1. MRQ-34

Horizontal Accuracy = Fixed
Vertical Accuracy = 4.4 cm < 10 cm

2. MQ-13

Horizontal Accuracy = $\sqrt{((1.0)^2 + (0.6)^2}$
= $\sqrt{(1.0 + 0.36)}$
= 1.17 < 20 cm
Vertical Accuracy = Fixed

3. MQ-120

Horizontal Accuracy = $\sqrt{((1.0)^2 + (0.6)^2}$
= $\sqrt{(1.0 + 0.36)}$
= 1.17 < 20 cm
Vertical Accuracy = 3.7 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy results of the two (2) occupied control points are within the required precision.

Table 19. Adjusted geodetic coordinates for control points used in the Boac River Floodplain validation

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
MRQ-34	N13°26'09.54636"	E122°04'33.94310"	64.236	0.044	LL
MQ-13	N13°26'56.91664"	E121°50'48.94103"	63.211	?	e
MQ-120	N13°28'58.33069"	E121°55'08.56221"	87.362	0.037	

The corresponding geodetic coordinates of the observed points are within the required accuracy, as shown in Table 19. Based on the results of the computations, the accuracy conditions are satisfied; hence, the required accuracy for the program was met.

The computed coordinates of the reference and control points utilized in the Boac River GNSS Static Survey are indicated in Table 20.

Table 20. Reference and control points used in the Boac River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoid Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
MRQ-34	2nd order, GCP	13°26'09.54636"	122°04'33.94310"	64.236	1485537.871	399984.398	14.100
MQ-13	1st order, BM	13°26'56.91664"	121°50'48.94103"	63.211	1487097.828	375180.421	13.916
MQ-120	Used as Marker	13°28'58.33069"	121°55'08.56221"	87.362	1490792.799	383004.307	37.551

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

The cross-section and bridge as-built surveys were conducted on August 11, 2016 at the downstream side of the Biglang Awa Bridge in Barangay Mataas na Bayan, Municipality of Boac, Marinduque, as depicted in Figure 30. A Total Station through open traverse method and a Trimble® SPS 985 GNSS in PPK survey technique were utilized for this survey, as demonstrated in Figure 31.

Figure 30. Biglang Awa Bridge, facing upstream

Figure 31. Bridge as-built survey, using PPK Technique

The length of the cross-sectional line surveyed in the Biglang Awa Bridge is about 169.976 meters with sixty-nine (69) cross-sectional points, using the control point MQ-13 as the GNSS base station. The location map, cross-section diagram, and the bridge data form are presented in Figure 32 to Figure 34, respectively.

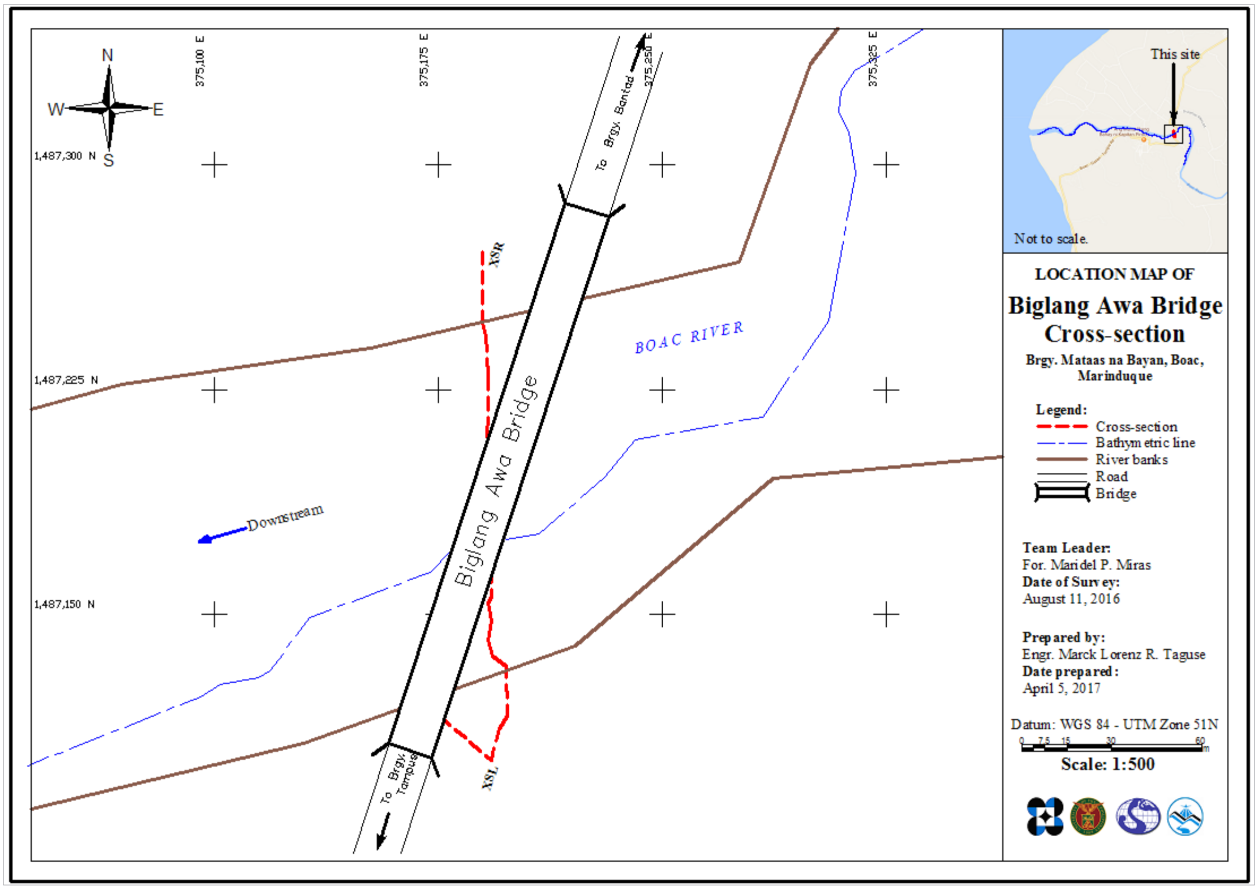


Figure 32. Biglang Awa Bridge cross-section location map

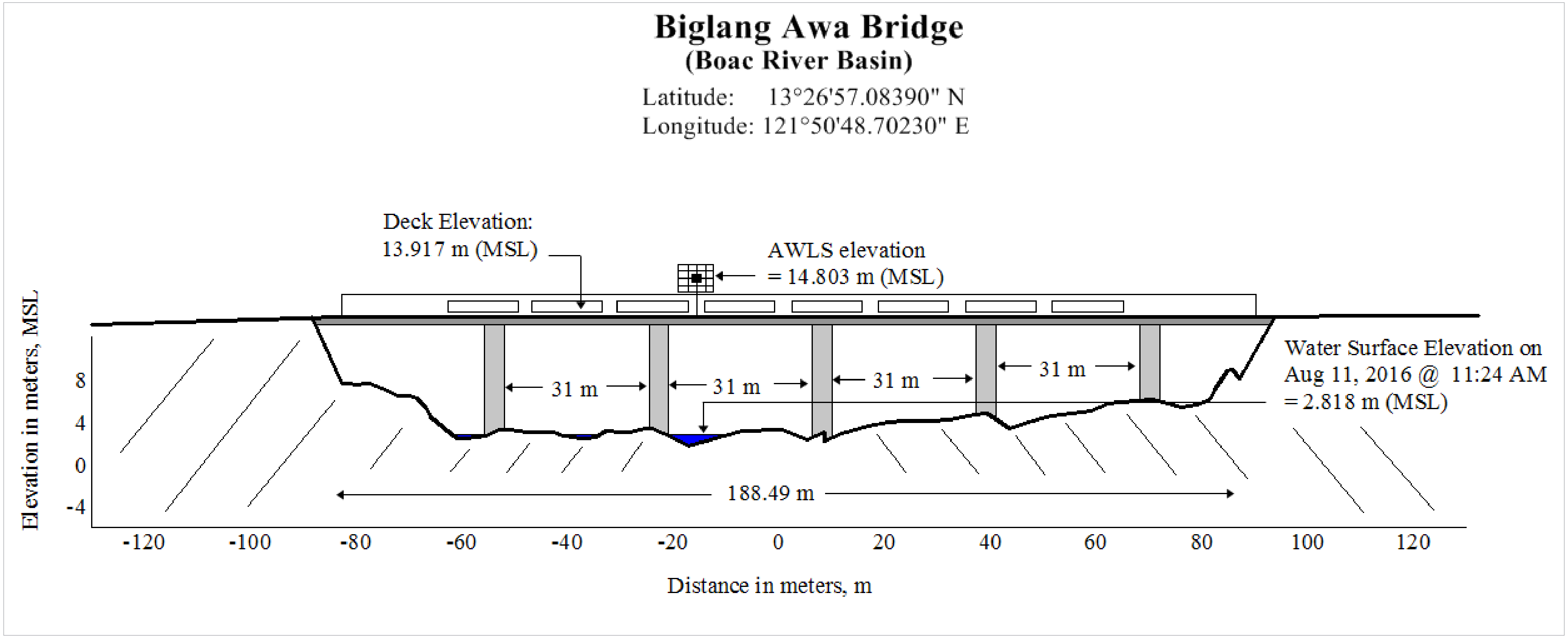


Figure 33. Biglang Awa Bridge cross-section diagram

Bridge Data Form

Bridge Name: **Biglang Awa Bridge** — **Date:** **August 11, 2016**

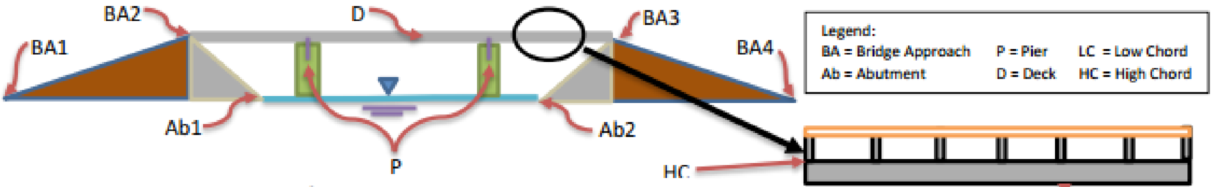
River Name: **Boac River** — **Time:** **11:24 AM**

Location (Brgy, City,Region): **Brgy. Mataas na Bayan, Municipality of Boac, Marinduque**

Survey Team: **Maridel Miras, Caren Ordoña, Randell Pabroquez**

Flow condition: normal — **Weather Condition:** fair

Latitude: **13°26'57.08390" N** — **Longitude:** **121°50'48.70230" E**



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

Elevation: **13.917 m** **Width:** _8.12__ **Span (BA3-BA2):** **188.490 m**

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	13.128 m	BA3	Not available	NA
BA2	47.182 m	13.917 m	BA4	262.375 m	13.941 m

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

	Station (Distance from BA1)	Elevation
Ab1	Not available	Not available
Ab2	Not available	Not available

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

Shape: cylinder Number of Piers: 5 Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	77.947 m	13.916 m	2 m
Pier 2	109.002 m	13.904 m	2 m
Pier 3	139.934 m	13.878 m	2 m
Pier 4	170.914 m	13.390 m	2 m
Pier 5	201.842 m	13.891 m	2 m

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

Figure 34. Bridge as-built form of the Biglang Awa Bridge

The water surface elevation of the Boac River was determined using a survey-grade GNSS receiver Trimble® SPS 985 in PPK survey technique on August 11, 2016 at 23:24 hrs. The surface elevation value obtained was 2.818 meters in MSL, as reflected in . This was translated into markings on the bridge's deck using the same technique, as exhibited in Figure 35. The markings, with a value of 16.675 meters in MSL, served as a reference for flow data gathering and depth gauge deployment of the UPLB Phil-LiDAR 1 Team.

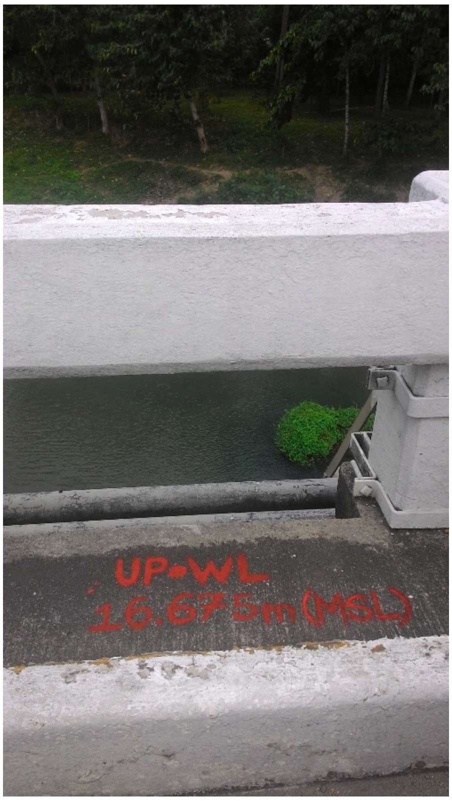


Figure 35. Water-level markings at the Biglang Awa Bridge

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on August 13, 2016, using a survey-grade GNSS Rover receiver, Trimble® SPS 985. The receiver was mounted on top of a vehicle, as shown in Figure 36. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.026 meters, measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode, with MQ-13 occupied as the GNSS base station.

Figure 36. Validation points acquisition survey set-up along the Boac River Basin

The survey started at the Biglang Awa Bridge in Barangay Mataas na Bayan, Municipality of Boac. Heading south west, the survey traversed fifteen (15) barangays in the Municipality of Boac; and ended in Barangay Bahi, Municipality of Gasan. The survey then traveled north west and traversed ten (10) barangays in the Municipality of Mogpog, and ended in Barangay Ino. The survey then went north east and traversed ten (10) more barangays, and ended in Barangay Lamesa, Municipality of Sta. Cruz. All of the municipalities covered are located in the province of Marinduque. A total of 2,412 points were gathered with an approximate length of 28 kilometers, using MQ-13 as the GNSS base station for the entire extent of the validation points acquisition survey. The scope of the survey is illustrated in the map in Figure 37.

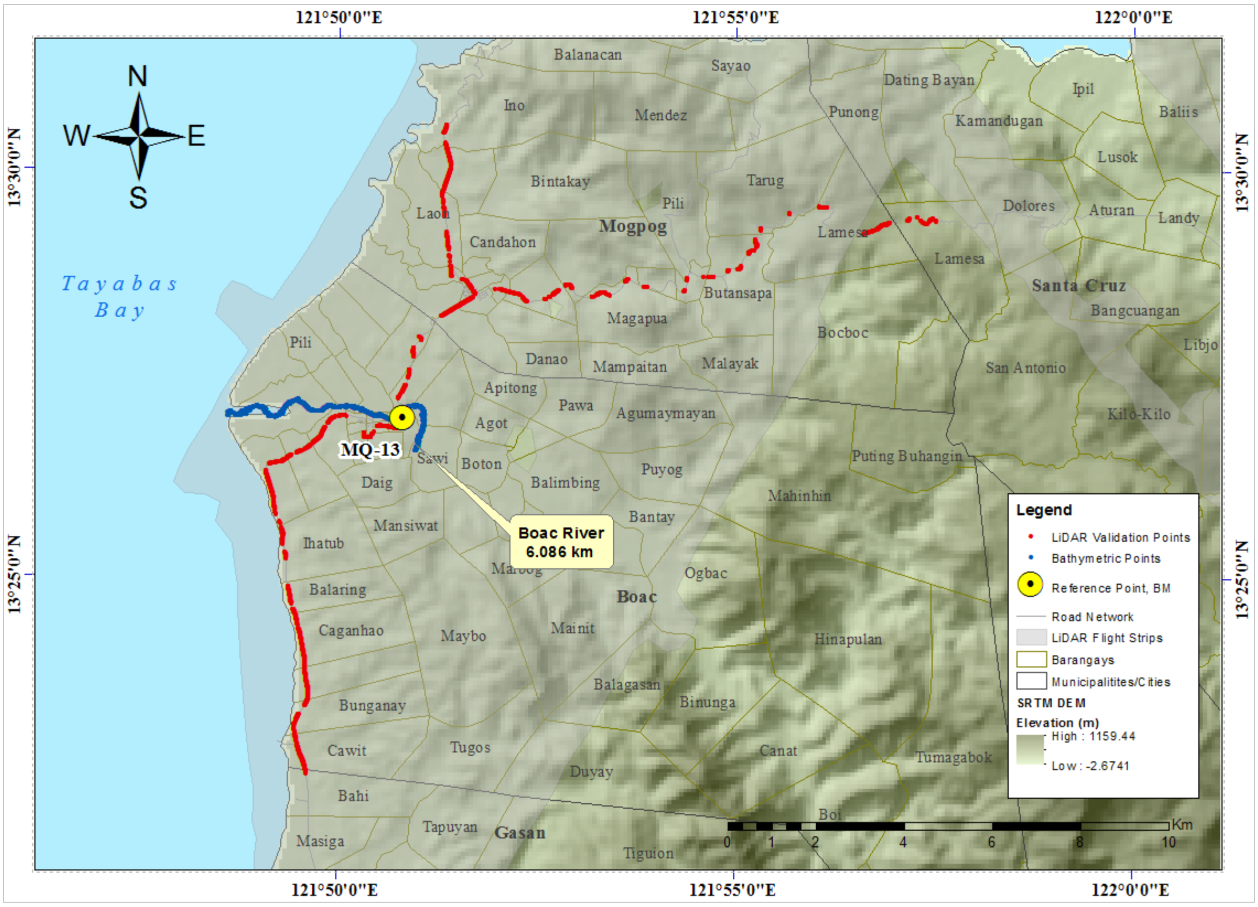


Figure 37. Extent of the LiDAR ground validation survey of the Boac River Basin

4.7 Bathymetric Survey

A bathymetric survey was executed on August 13, 2016 using a Hi-Target™ single beam echo sounder and Trimble® SPS 985 in GNSS PPK survey technique in continuous topo mode, as depicted in Figure 38. The survey started at the upper part of Barangay Tabigue, with coordinates 13°26'57.27640"N, 121°49'11.09572"E; and ended at the mouth of the river in the same barangay with coordinates 13°26'58.06181"N, 121°48'36.93203"E.

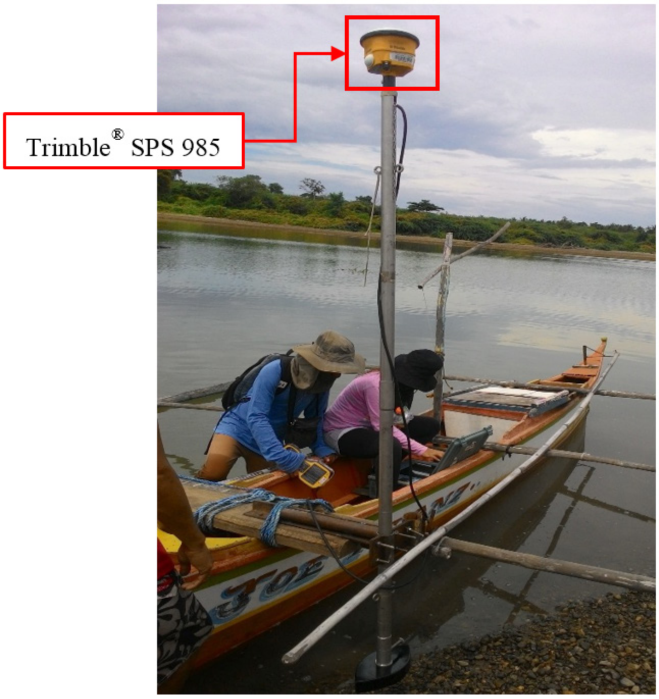


Figure 38. Bathymetric survey using Hi-Target™ single beam echo sounder in the Boac River

A manual bathymetric survey was executed on August 12, 2016 using Trimble® SPS 985 in GNSS PPK survey technique set in continuous topo mode (Figure 39). The survey started in Barangay Sawi, with coordinates 13°26'32.16735"N, 121°50'58.85876"E; and ended at the starting point of the bathymetric survey via boat. The control point MQ-13 was used as the GNSS base station throughout the survey.

Figure 39. Bathymetric survey using Trimble® SPS 985 in GNSS PPK survey technique in the Boac River

The bathymetric survey for the Boac River gathered a total of 9,655 points covering 6.086 kilometers of the river, traversing nine (9) barangays in Municipality of Boac, Marinduque. A CAD drawing was also produced to illustrate the riverbed profile of the Boac River, presented in Figure 41 . The profile shows that the highest and lowest elevation had a 10-meter difference. The highest elevation observed was 6.644 meters in MSL located in Barangay Sawi; while the lowest was -4.352 meters below MSL located at the downstream portion of the river, located in Barangay Tabigue. Both sites are in the Municipality of Boac. The uppermost 1 kilometer of the delineated bathymetric line was cut due to the availability of its LiDAR DEM, as advised by the DPPC. The scope of the survey is illustrated in Figure 40.

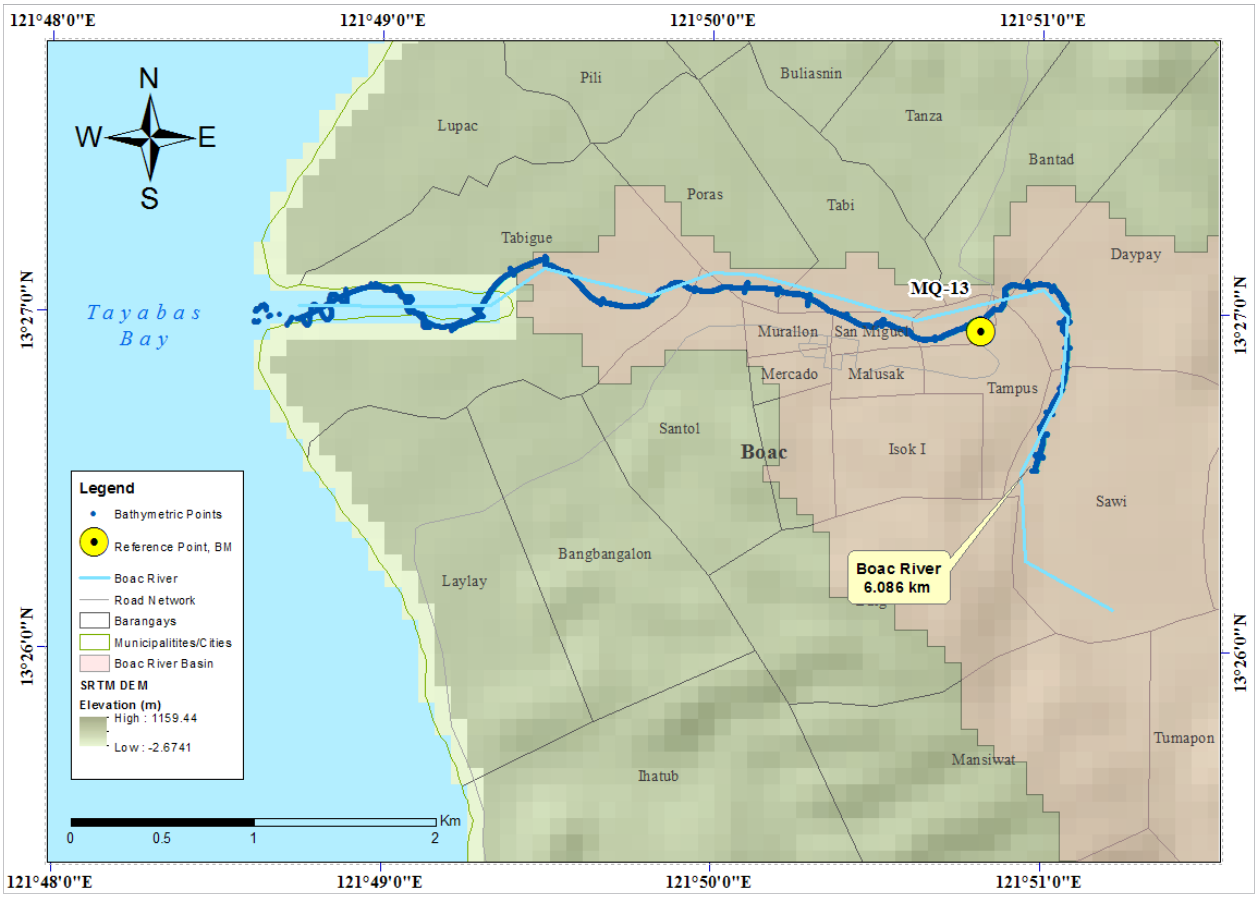


Figure 40. Extent of the bathymetric survey of the Boac River

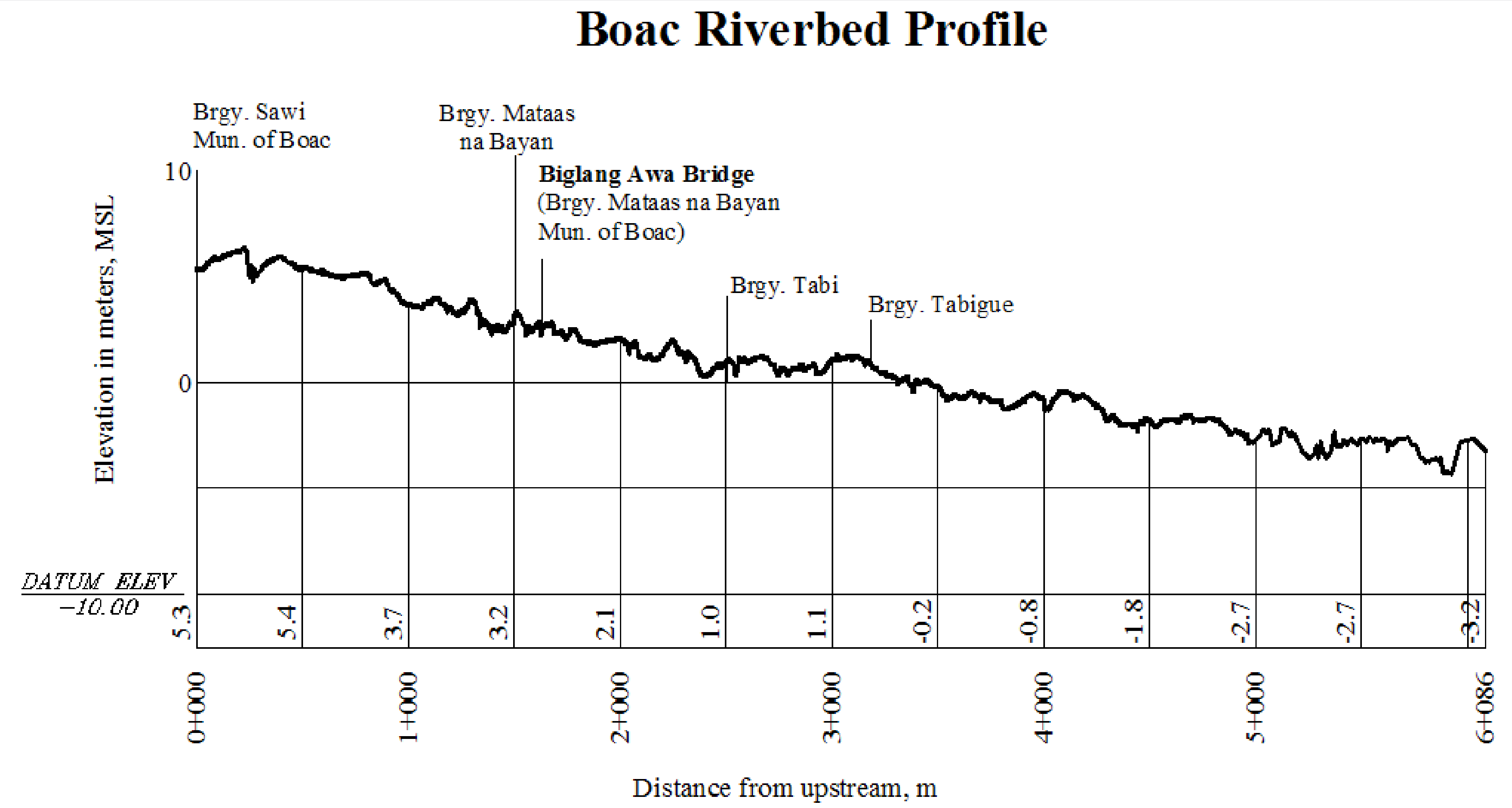


Figure 41. Boac riverbed profile

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, and Khristoffer Quinton, John Alvin B. Reyes, Alfi Lorenz B. Cura, Angelica T. Magpantay, Maria Michaela A.Gonzales Paulo Joshua U. Quilao, Jayson L. Arizapa, Kevin M. Manalo

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 Boac 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 Boac River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from the Automatic Rain Gauge (ARG) Stations installed in the Philippine Seafarers Training Center (PSTC) (13.364229° N, 121.947311° E) and Puting Buhangin (13.454000°N, 121.959000°E). The location map of the rain gauges is seen in Figure 42.

The total precipitation collections from the rain gauges are as follows: 89.0 millimeters in the PSTC ARG; and 74.8 millimeters in the Puting Buhangin ARG. The peak rainfall are as follows: 4.80 millimeters on

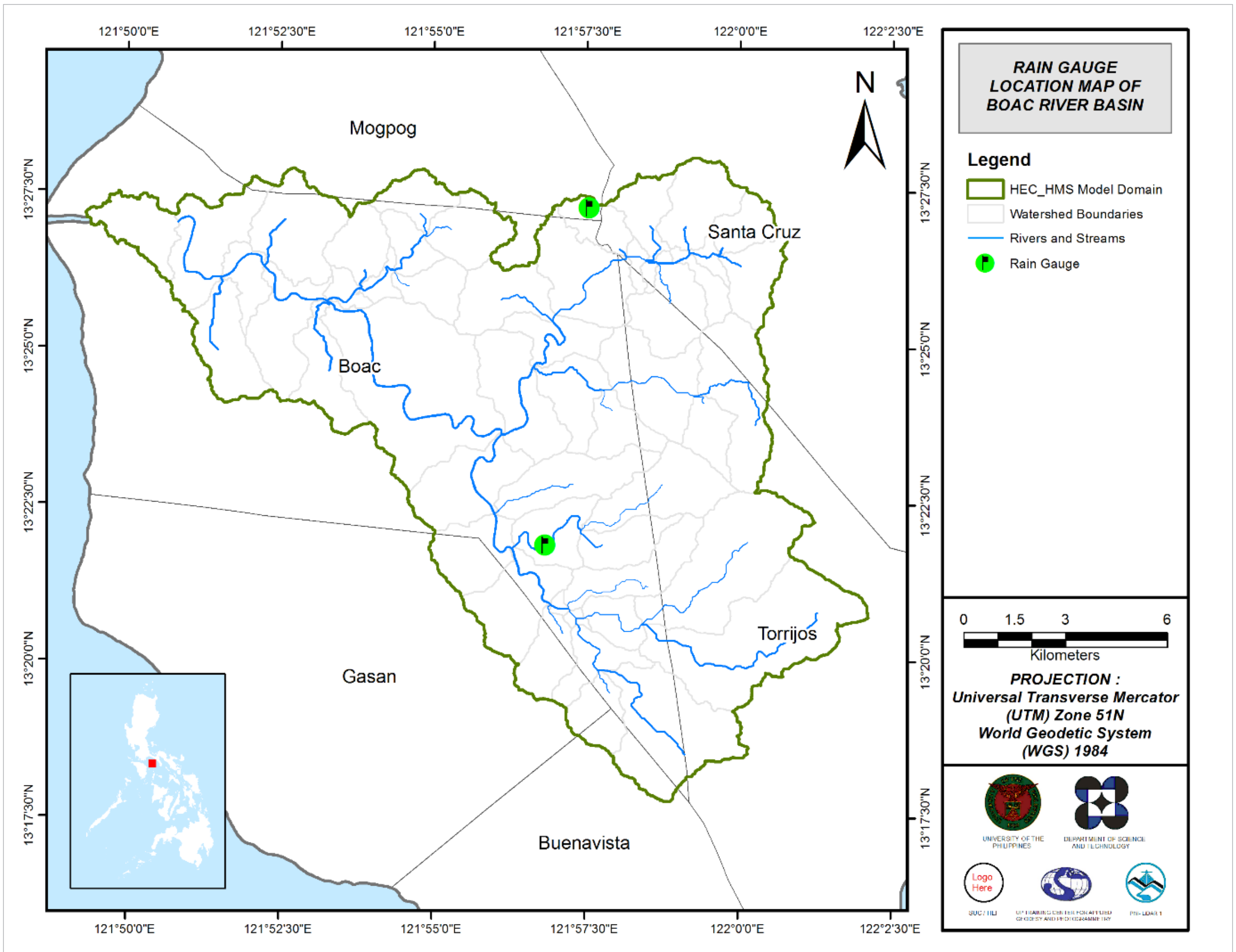


Figure 42. Location map of the Boac HEC-HMS model, used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was computed using the prevailing cross-section (Figure 45) at the Biglang Awa Bridge, Boac, Marinduque (13.449800°N, 121.847000°E) to establish the relationship between the observed water levels (H) from the Biglang Awa Bridge and the outflow (Q) of the watershed at this location. The Bankful Method in Manning's Equation was applied for this computation.

For the Biglang Awa Bridge, the rating curve is expressed as $Q = 0.2685e^{0.9638x}$, as illustrated in Figure 44.

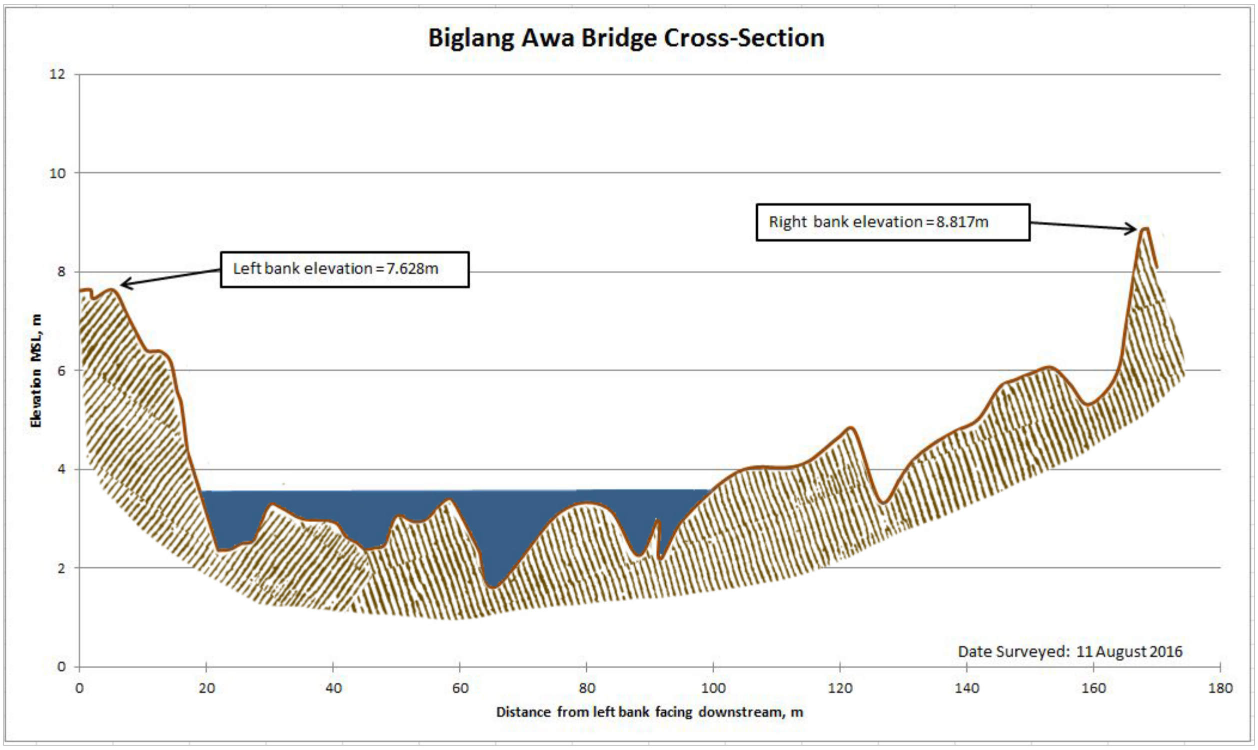


Figure 43. Cross-section plot of the Biglang Awa Bridge

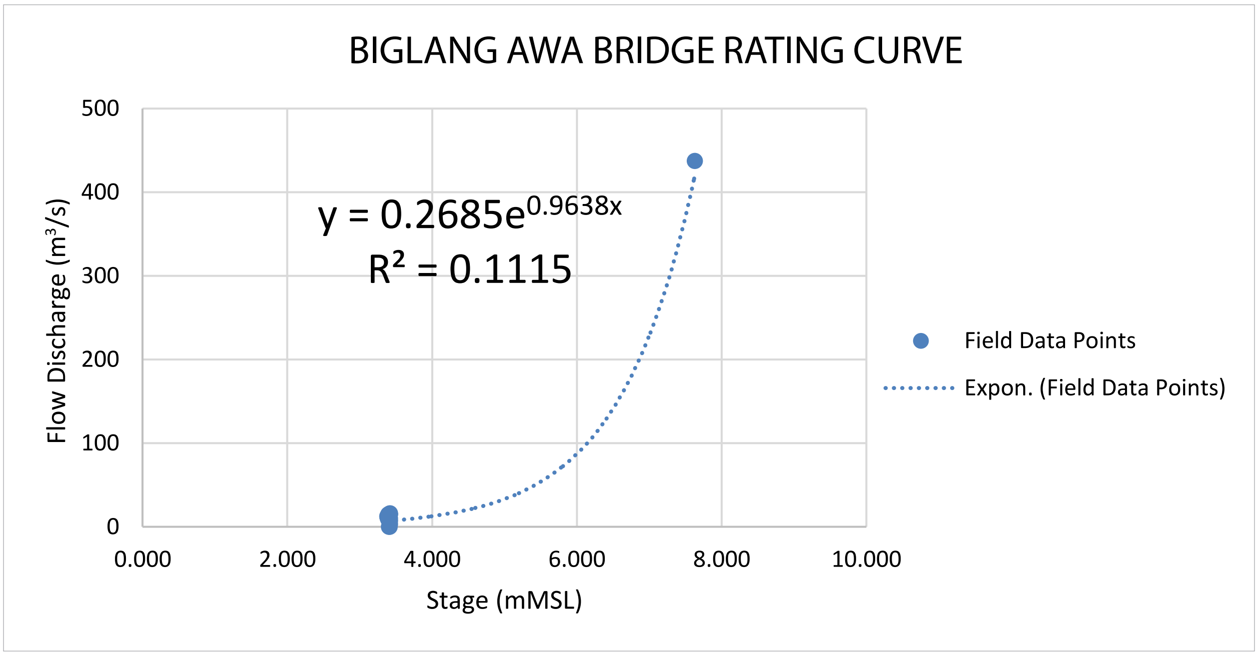


Figure 44. Rating curve at the Biglang Awa Bridge, Boac, Marinduque

For the calibration of the HEC-HMS model, presented in Figure 45, actual flow discharge during a rainfall event was collected in the Biglang Awa bridge. The peak discharge was at 14.2 cu.m/s on January 18, 2015 at 15:50 hrs.

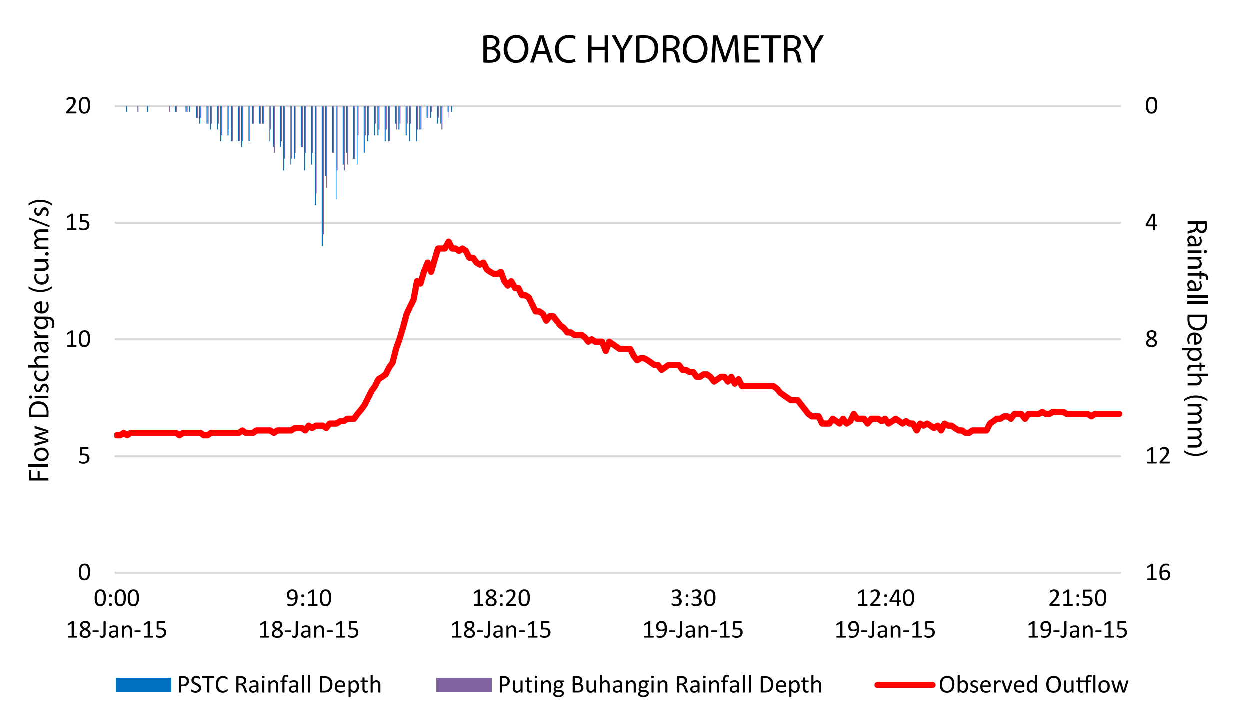


Figure 45. Rainfall and outflow data at the Boac River, which were used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed for the Rainfall Intensity Duration Frequency (RIDF) values for the Tayabas Rain Gauge (Table 25). This station was selected based on its proximity to the Boac watershed (Figure 46). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values such that certain peak values were attained at a certain time. The extreme values for this watershed were computed based on a 41-year record.

Table 21. RIDF values for Tayabas Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	21	32.7	42	59.3	83	99.9	128.2	161.5	195.9
5	29.6	42.1	52.5	77.3	116.1	143	192.6	232.3	279.5
10	35.4	48.3	59.4	89.2	138	171.5	235.2	279.3	334.9
15	38.6	51.8	63.3	96	150.3	187.6	259.3	305.7	366.1
20	40.9	54.3	66.1	100.7	159	198.9	276.1	324.3	388
25	42.6	56.2	68.2	104.3	165.7	207.5	289.1	338.5	404.8
50	48	62	74.7	115.5	186.2	234.3	329.1	382.5	456.7
100	53.4	67.8	81.1	126.6	206.6	260.8	368.8	426.2	508.3

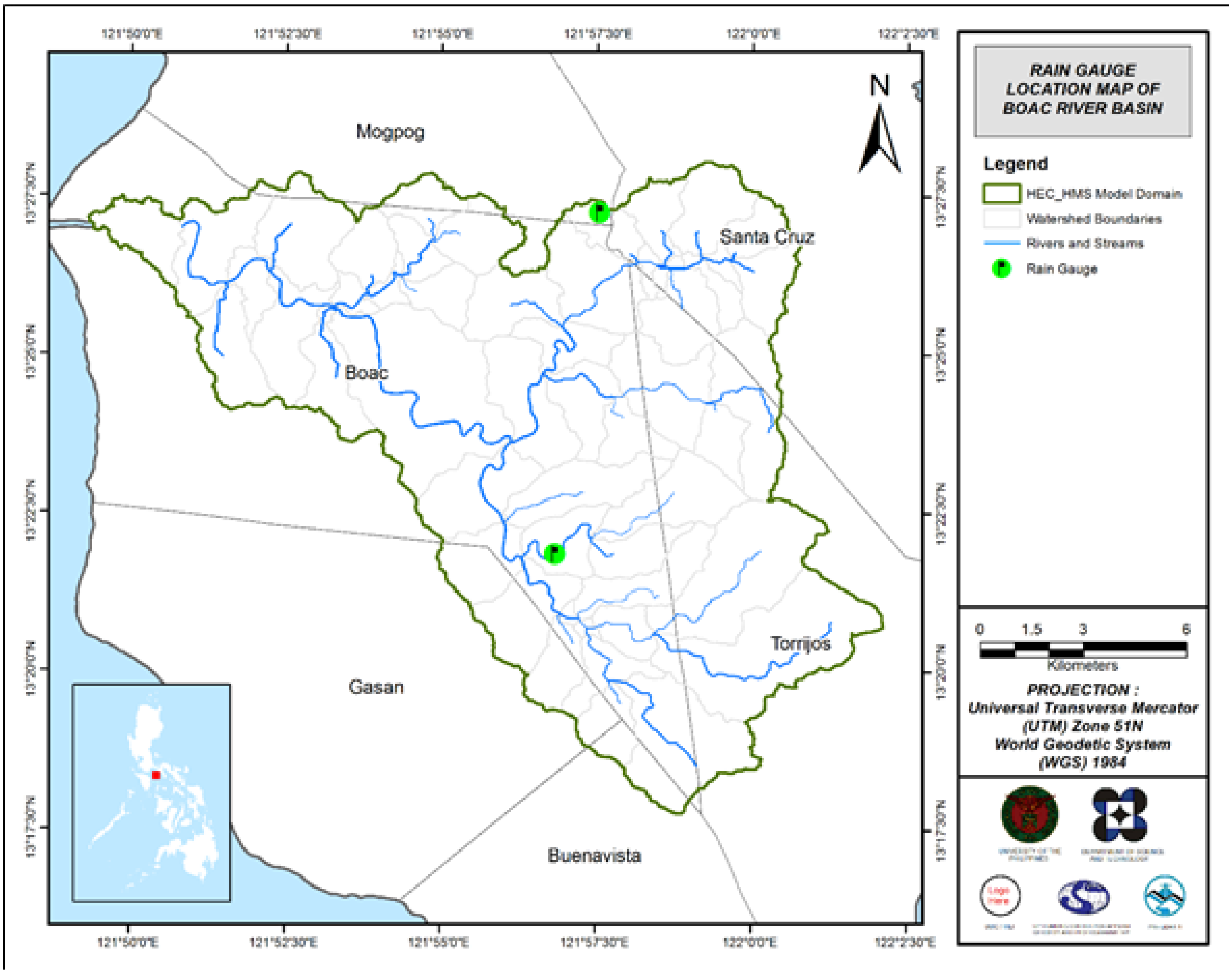


Figure 46. Location of the Tayabas RIDF Station relative to the Boac River Basin

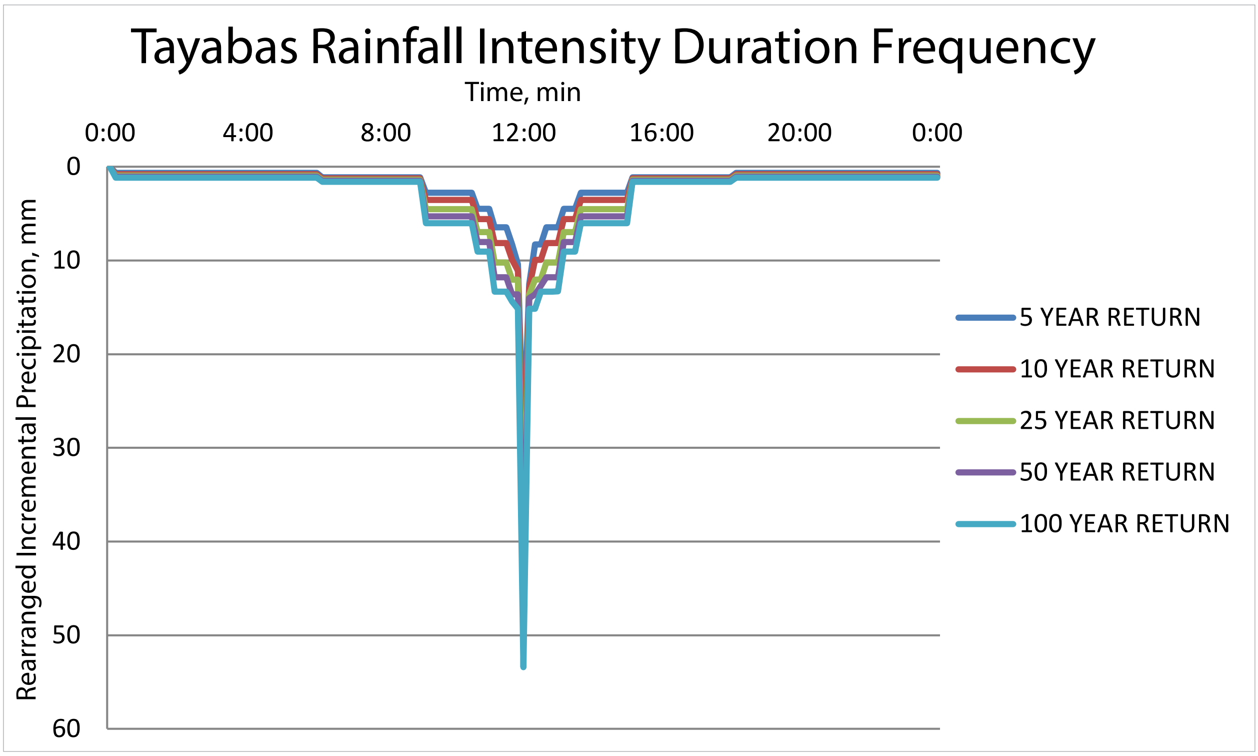


Figure 47. Synthetic storm generated from a 24-hour period rainfall, for various return periods

5.3 HMS Model

The soil dataset was taken from the Bureau of Soils and Water Management (BSWM) under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). These soil datasets were taken before 2004. The soil and land cover maps are presented in Figures 48 and 49, respectively.

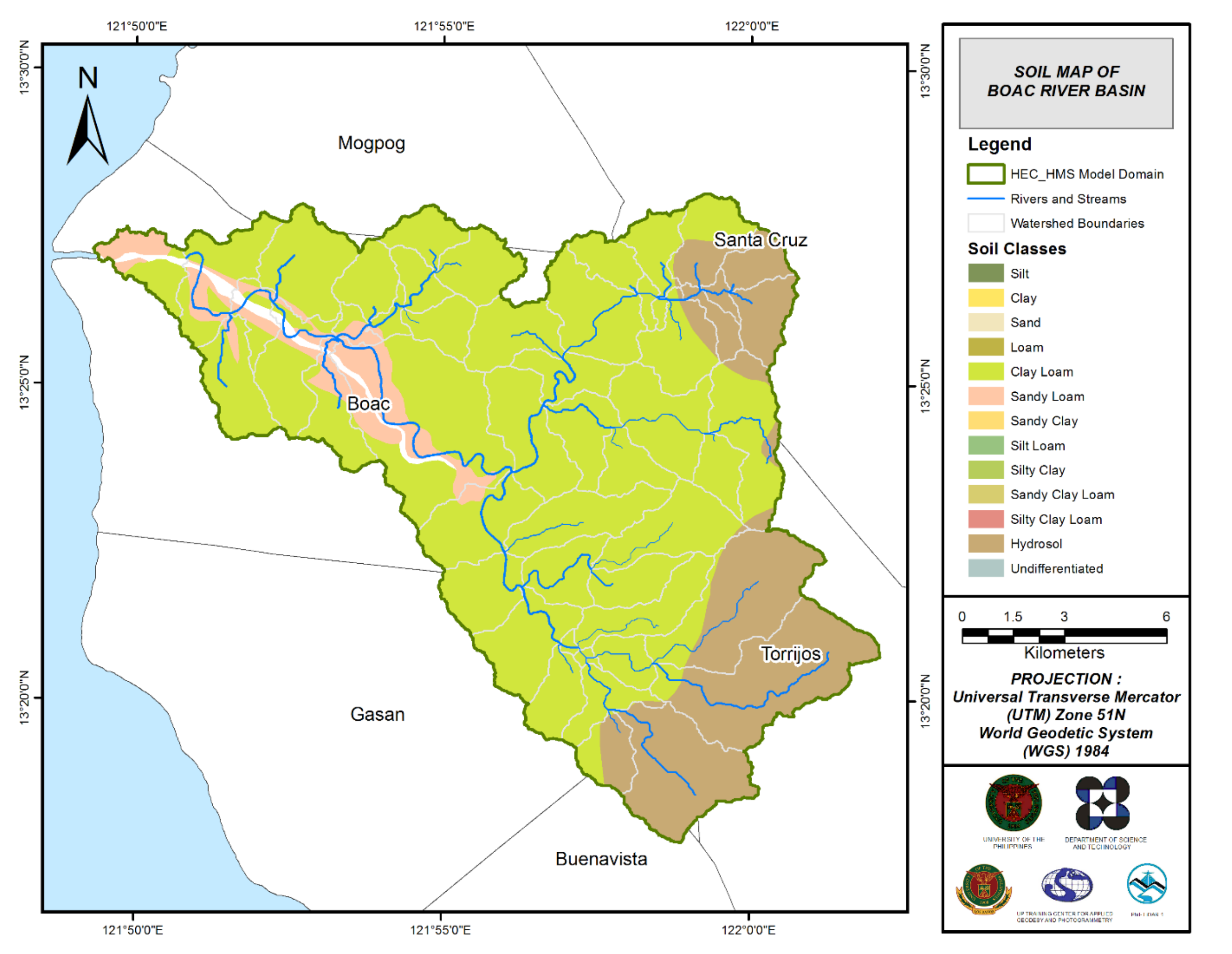


Figure 48. Soil map of the Boac River Basin, used for the estimation of the CN parameter (Source: DA)

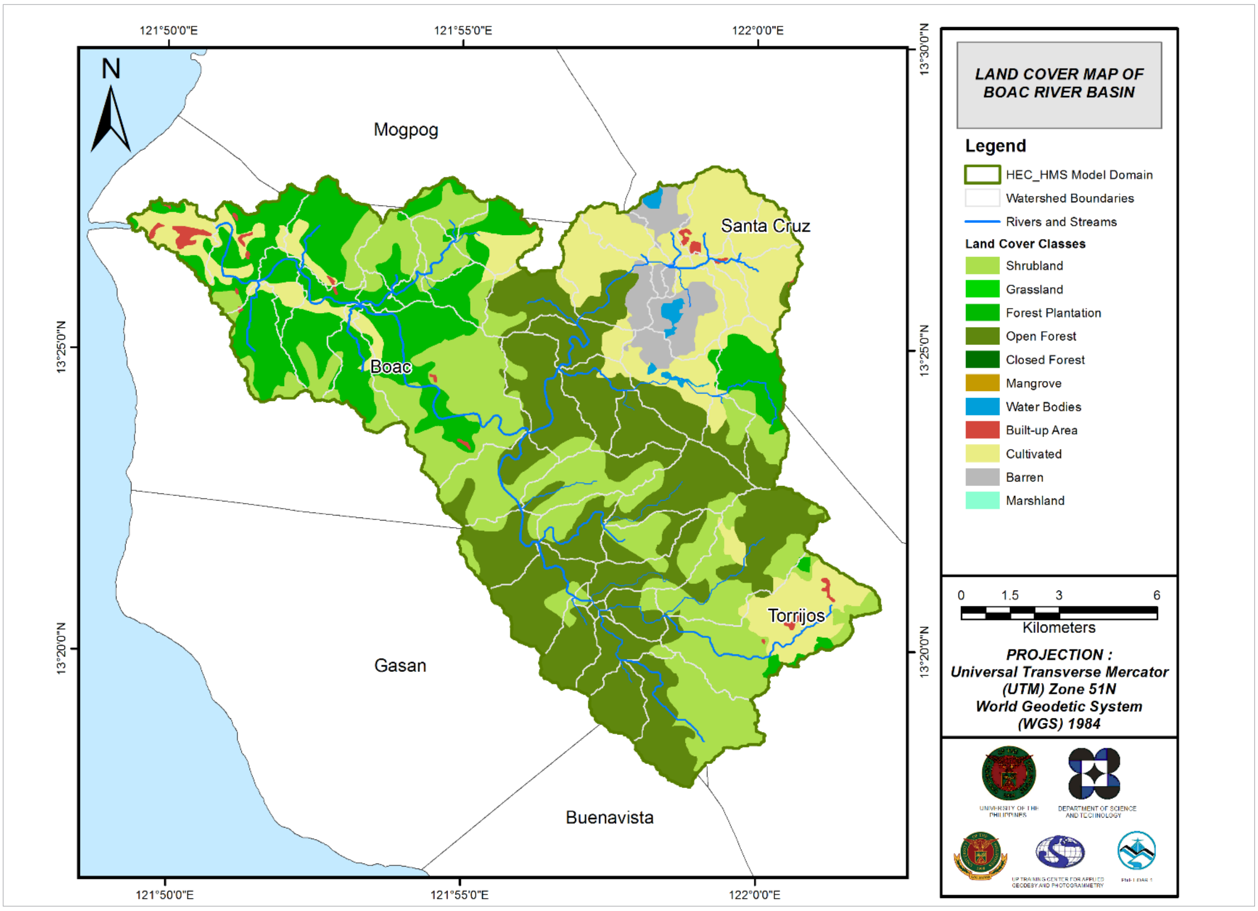


Figure 49. Land cover map of the Boac River Basin, used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model (Source: NAMRIA)

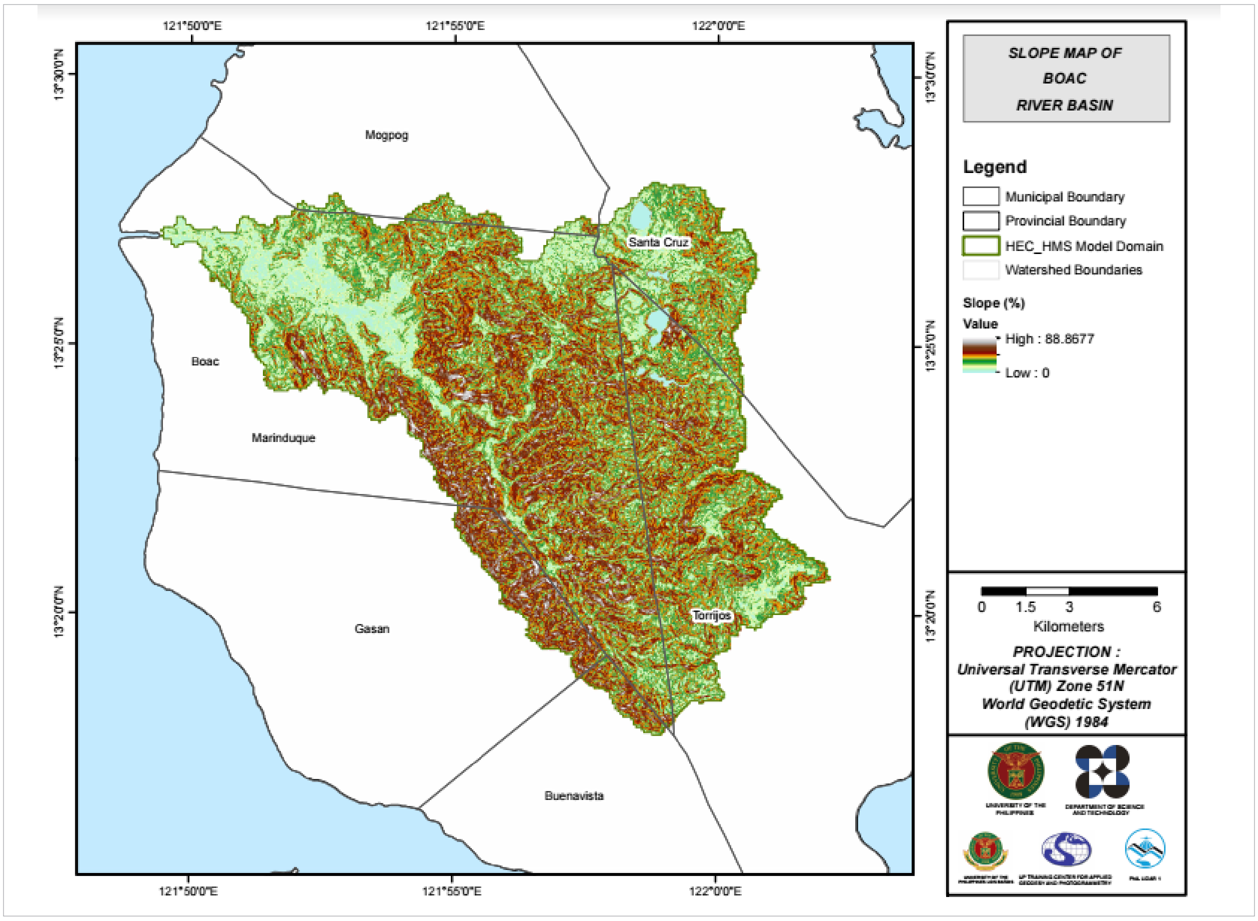


Figure 50. Slope map of the Boac River Basin

The river basin is generally characterized as having a 30-50% slope. Its soil types are comprised of Banto clay loam, Banhigan clay loam, Boac clay loam, Mogpog clay loam, and San Manuel sandy loam. The land cover types in the area include cultivated areas mixed with brushlands and grasslands, coconut plantations, and crop lands mixed with coconut plantations and quarries.

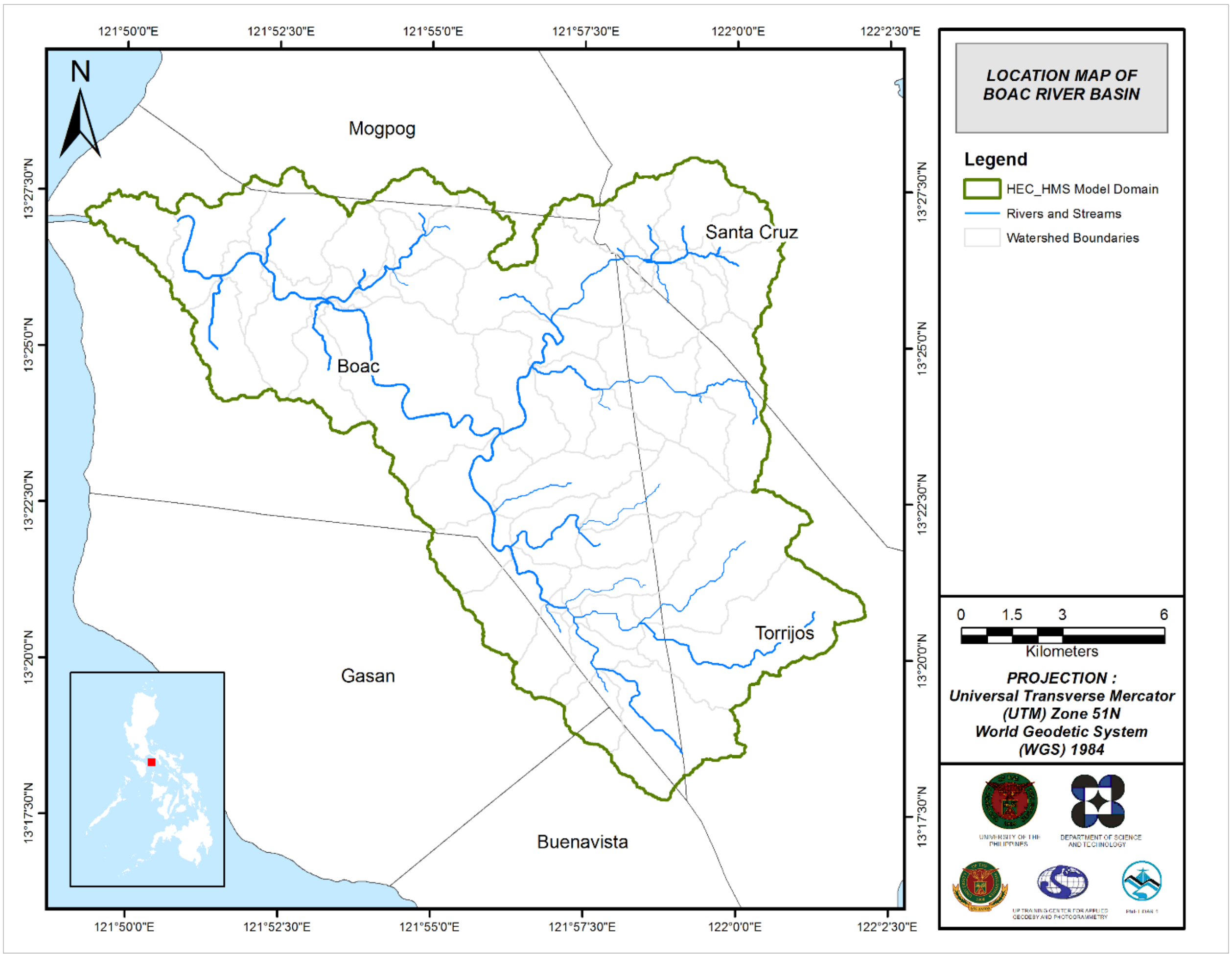


Figure 51. Stream delineation map of the Boac River Basin

Using the SAR-based DEM, the Boac basin was delineated and further subdivided into sub-basins. The model consists of fifty-two (52) sub-basins, twenty-six (26) reaches, and twenty-six (26) junctions. The basin model is illustrated in Figure 52, where the main outlet is labeled as 162. The basins were identified based on the soil and land cover characteristics of the area. Precipitation was taken from an ARG Station installed in the PSTC and in Puting Buhangin. Finally, the model was calibrated using the flow data collected from the Biglang Awa Bridge. The Boac Model Reach Parameters are found in Annex 10.

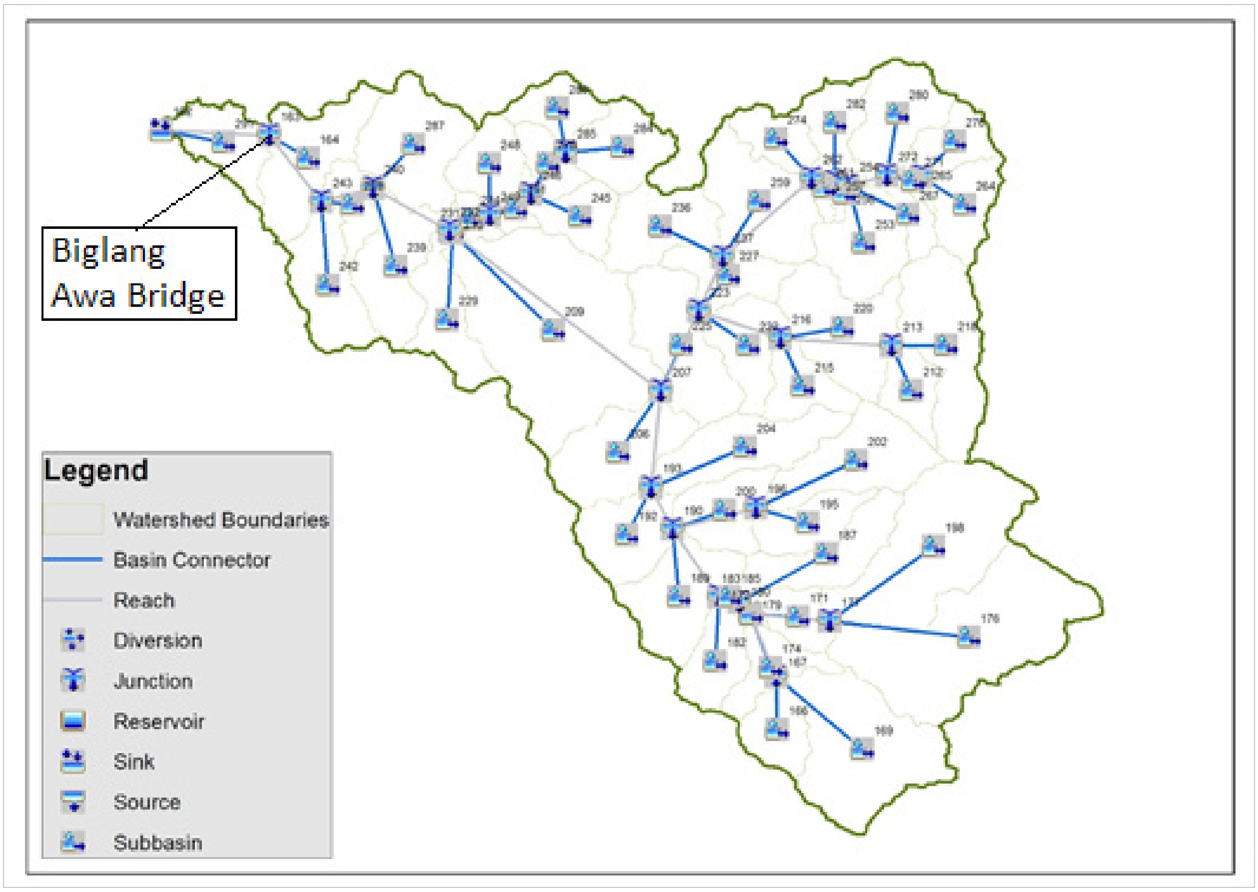


Figure 52. The Boac River Basin model generated using HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed were necessary in the HEC-RAS model set-up. The cross-section data for the HEC-RAS model were derived from the LiDAR DEM data. These were defined using the Arc GeoRAS tool, and post-processed in ArcGIS (Figure 53).

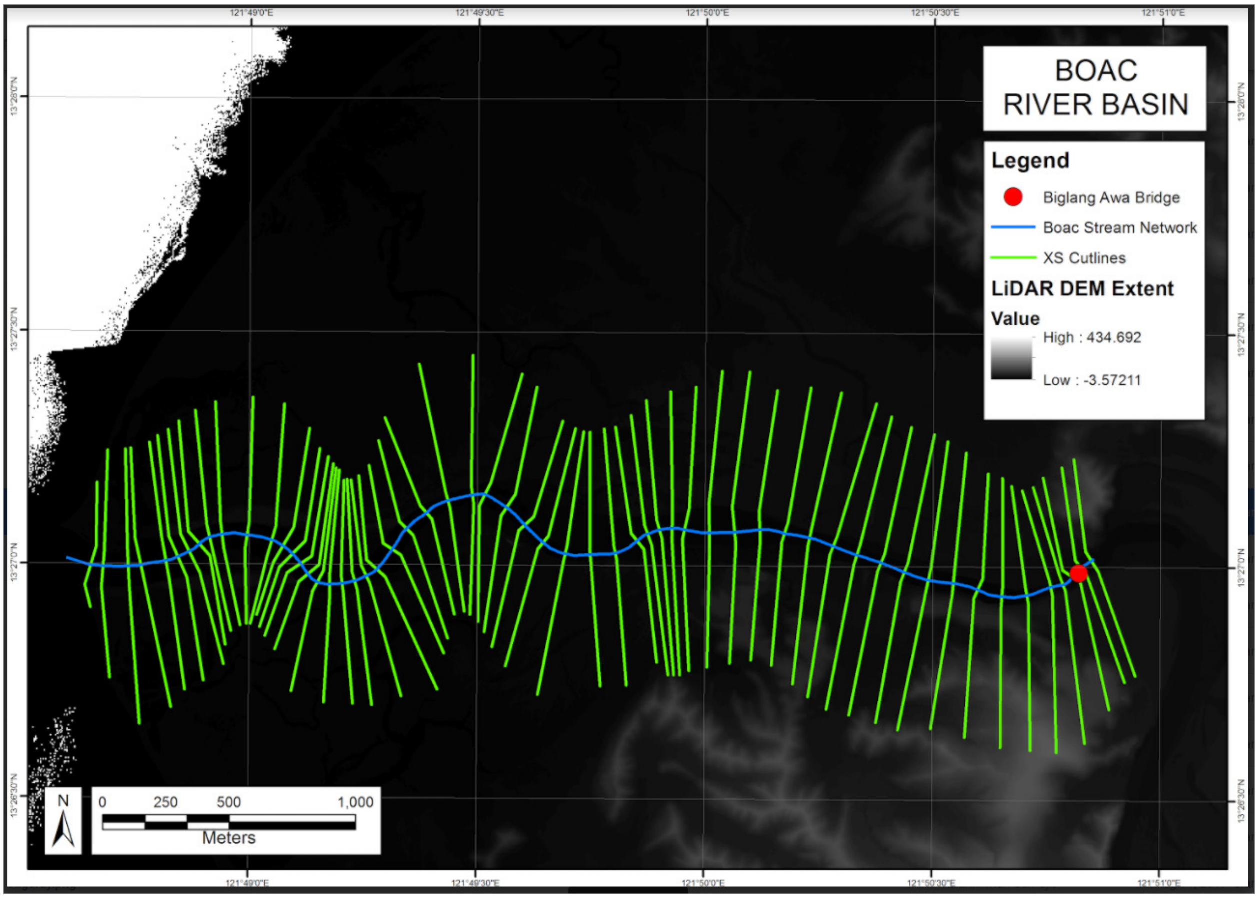


Figure 53. River cross-section of the Boac River, generated through the ArcMap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modeling process allowed 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 was divided into square grid elements, 10 meters by 10 meters in size. Each element was assigned a unique grid element number, which served as its identifier. The elements were then attributed with the parameters required for modeling, such as x- and y-coordinates of centroid, names of adjacent grid elements, Manning's coefficient of roughness, infiltration, and elevation values. The elements were arranged spatially to form the model, allowing the software to simulate the flow of water across the grid elements in eight (8) directions (i.e., north, south, east, west, northeast, northwest, southeast, and southwest).

Based on the elevation and flow direction, it was observed that the water will generally flow from the southeast of the model to the northwest and west, following the main channel. As such, boundary elements in those particular regions of the model were assigned as inflow and outflow elements respectively.

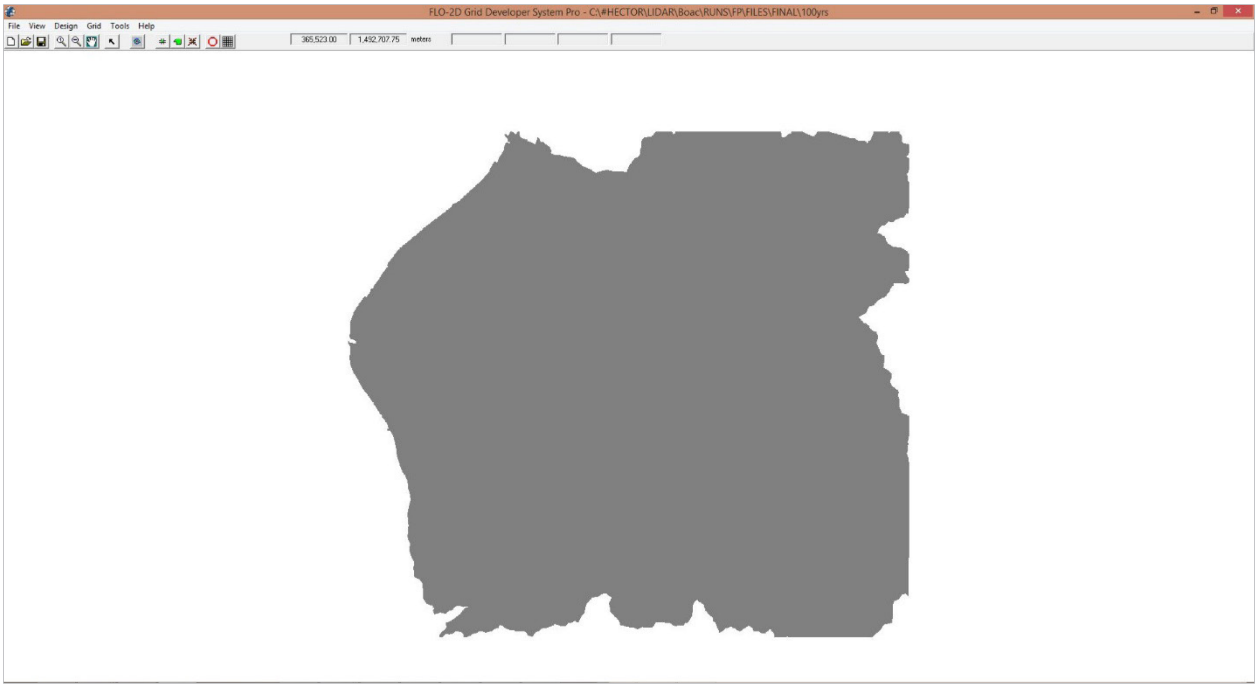


Figure 54. A screenshot of a sub-catchment, with the computational area to be modeled in the FLO-2D GDS Pro

The simulation was then run through the FLO-2D GDS Pro. This particular model had a computer run time of 90.93103 hours. After the simulation, the FLO-2D Mapper Pro was 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 generated the flood hazard map. Most of the default values given by the FLO-2D Mapper Pro were used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) was set at 0.2 meters while the minimum vh (Product of maximum velocity (v) and maximum depth (h)) was set at 0 m²/s.

The creation of a flood hazard map from the model also automatically created a flow depth map, depicting the maximum amount of inundation for every grid element. The legend used by default in the Flo-2D Mapper was not a good representation of the range of flood inundation values, so a different legend was used for the layout. In this particular model, the inundated parts cover a maximum land area of 83 841 984.00 m².

There was a total of 94 458 540.67 m³ of water that entered the model. Of this amount, 34 356 865.96 m³ was due to rainfall, while 60 101 674.71 m³ was inflow from other areas outside the model. 11 546 124.00 m³ of this water was lost to infiltration and interception, while 8 541 413.02 m³ was stored by the floodplain. The rest, amounting to up to 74 368 975.32 m³, was outflow.

5.6 Results of HMS Calibration

After calibrating the Boac HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 55 reflects the comparison between the two (2) discharge data. See ANNEX 9 for the Boac Model Basin Parameters.

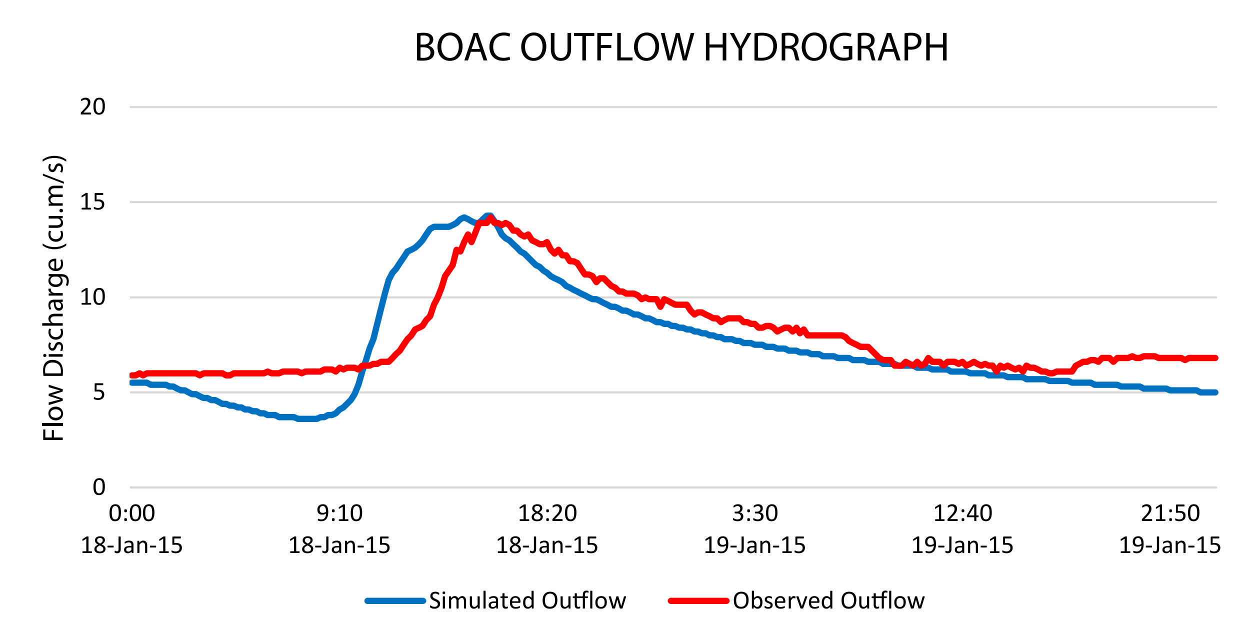


Figure 55. Outflow Hydrograph of Boac produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 22 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 22. Range of calibrated values for the Boac River Basin model

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.02 - 136
			Curve Number	42 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.03 - 2
			Storage Coefficient (hr)	0.07 - 99
	Baseflow	Recession	Recession Constant	0.09 - 1
			Ratio to Peak	0.004 – 0.8
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.002

The initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as the initial abstraction decreases. The range of values from 0.02 to 136 millimeters means that there is a high amount of infiltration or rainfall interception by vegetation.

The curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as the curve number increases. The range of 42 to 99 for the curve number is advisable for Philippine watersheds, depending on the soil and land cover of the area (M. Horritt, personal communication, 2012).

The time of concentration and the storage coefficient are the travel time and the index of temporary storage of runoff in a watershed. The range of calibrated values from 0.03 to 99 hours determines the reaction time of the model, with respect to the rainfall. The peak magnitude of the hydrograph decreases when these parameters are increased.

The recession constant is the rate at which the baseflow recedes between storm events; and ratio to peak is the ratio of the baseflow discharge to the peak discharge. For the Boac River Basin, the values are diverse, depending on the characteristic of the sub-basin.

A Manning's roughness coefficient of 0.002 is relatively low compared to the common roughness of watersheds (Brunner, 2010).

Table 23. Efficiency Test of the Boac HMS Model

Root Mean Square Error (RMSE)	1.605
Pearson Correlation Coefficient (r^2)	0.868
Nash-Sutcliffe (E)	0.519
Percent Bias (PBIAS)	8.317
Observation Standard Deviation Ratio (RSR)	0.694

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 1.605.

The Pearson correlation coefficient (r^2) assesses the strength of the linear relationship between the observations and the model. A coefficient value close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC-HMS model. Here, it was measured as 0.868.

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 0.519.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate a bias towards over-prediction. The optimal value is 0. In the model, the PBIAS is 8.317.

The Observation Standard Deviation Ratio (RSR) is an error index. A perfect model attains a value of 0 when the error units of the values are quantified. The model has an RSR value of 0.694.

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 in Figure 56 depicts the Boac outflow using the Tayabas RIDF curves in five (5) different return periods (i.e., 5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series), based on the data from PAGASA. The simulation results reveal a significant increase in outflow magnitude as the rainfall intensity increases, for a range of durations and return periods.

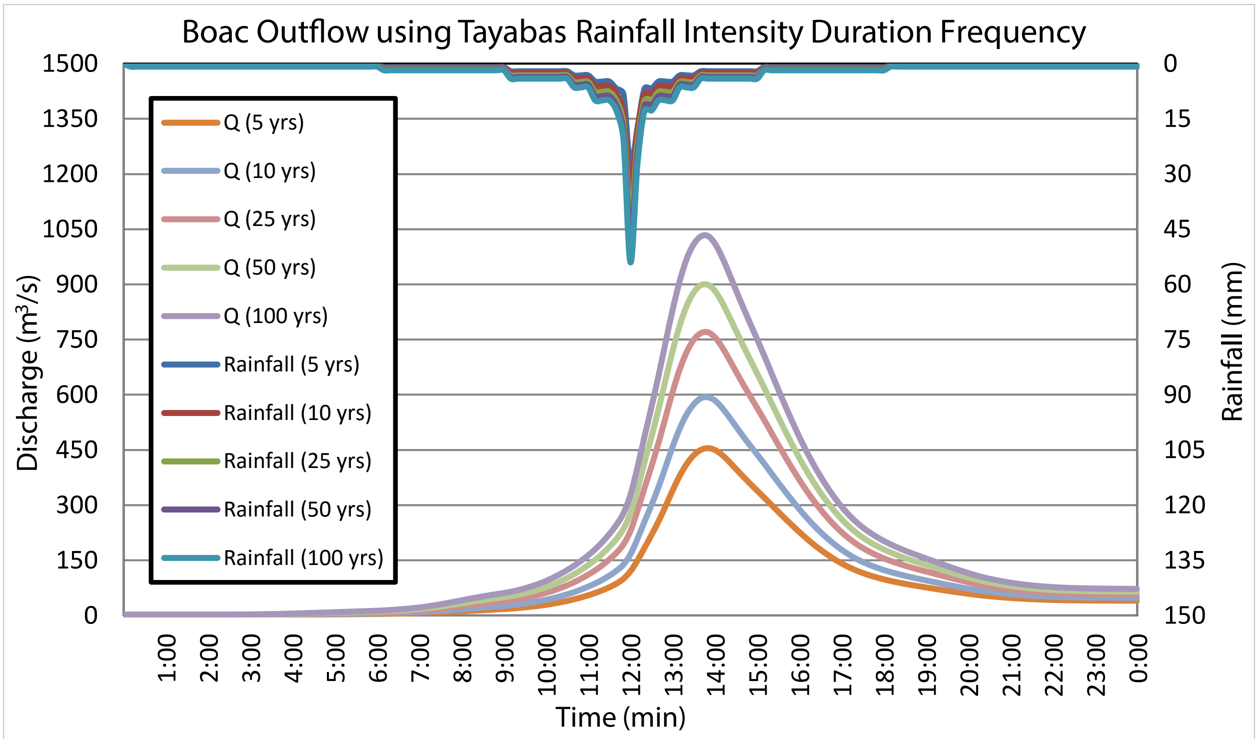


Figure 56. Outflow hydrograph at the Boac Station generated using the Tayabas RIDF, simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, time to peak, and lag time of the Boac discharge using the Tayabas RIDF curves in five (5) different return periods is provided in Table 24.

Table 24. Peak values of the Boac HEC-HMS Model outflow, using the Tayabas RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak	Lag Time
5-yr	279.50	29.60	214.14	12 hours 10 minutes	10 minutes
10-yr	334.90	35.40	298.55	12 hours 10 minutes	10 minutes
25-yr	404.80	42.60	418.98	12 hours 10 minutes	10 minutes
50-yr	456.70	48.0	517.25	12 hours 10 minutes	10 minutes
100-yr	508.30	53.40	619.91	12 hours 10 minutes	10 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS flood model produced a simulated water level at every cross-section, for every time step, for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining the extent of real-time flood inundation of the river, after it has been automated and uploaded on the DREAM website. The sample output map of the Boac River using the HMS base flow is presented in Figure 57.

Figure 57. Boac River HEC-RAS output map

5.9 Flow Depth and Flood Hazard

The resulting flood hazard and flow depth maps for the 5-year, 25-year, and 100-year rain return scenarios of the Boac floodplain are exhibited in Figures 58 to 63. The floodplain, with an area of 84.54 square kilometers, covers two (2) municipalities, namely Boac, and Mogpog. Table 25 indicates the percentage of area affected by flooding per municipality.

Table 25. Municipalities affected in the Boac Floodplain

Province	Municipality	Total Area	Area Flooded	% Flooded
Boac	182.07	65.74	36.10	1.50%
Mogpog	101.12	18.55	18.35	

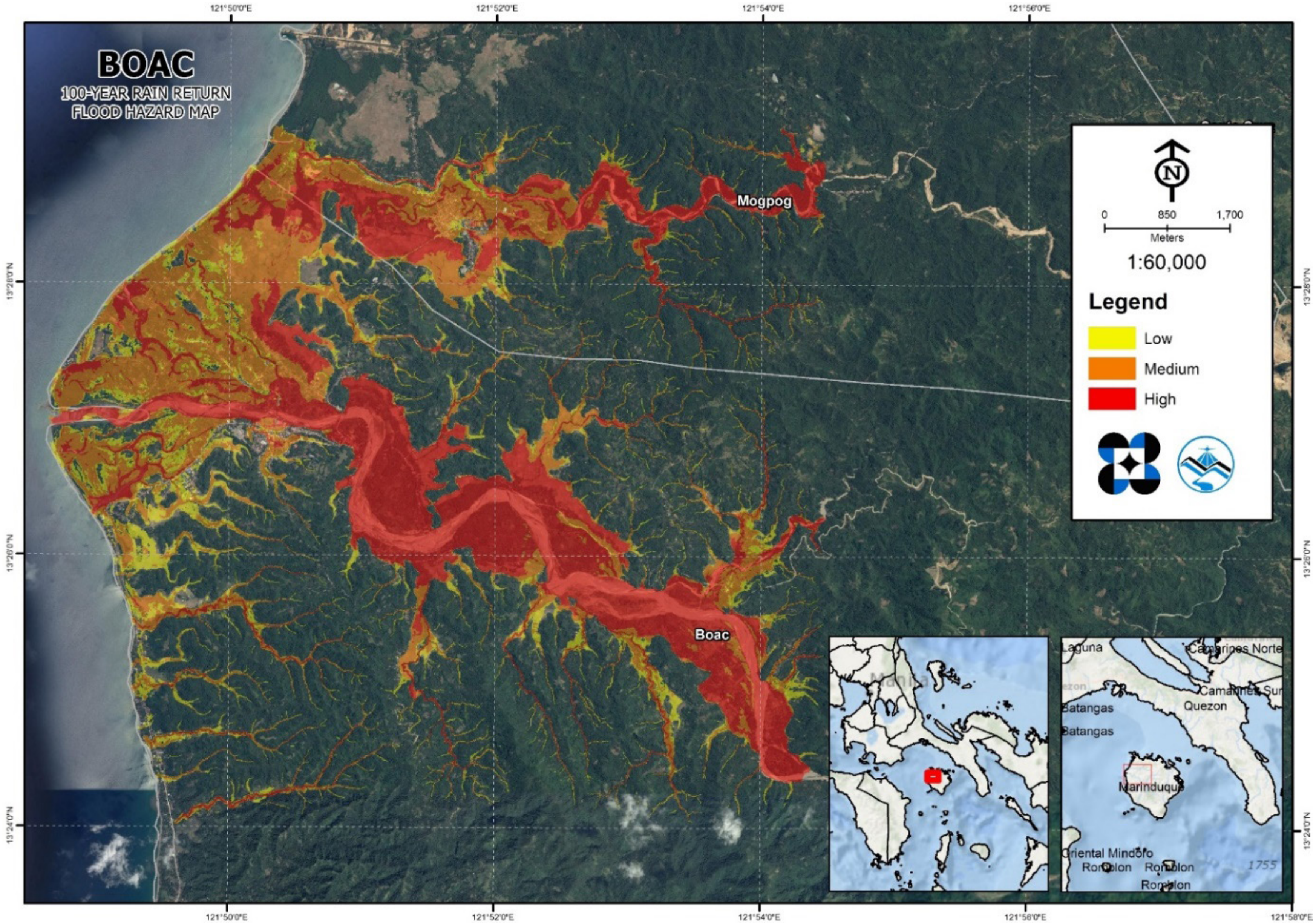


Figure 58. 100-year flood hazard map for the Boac floodplain

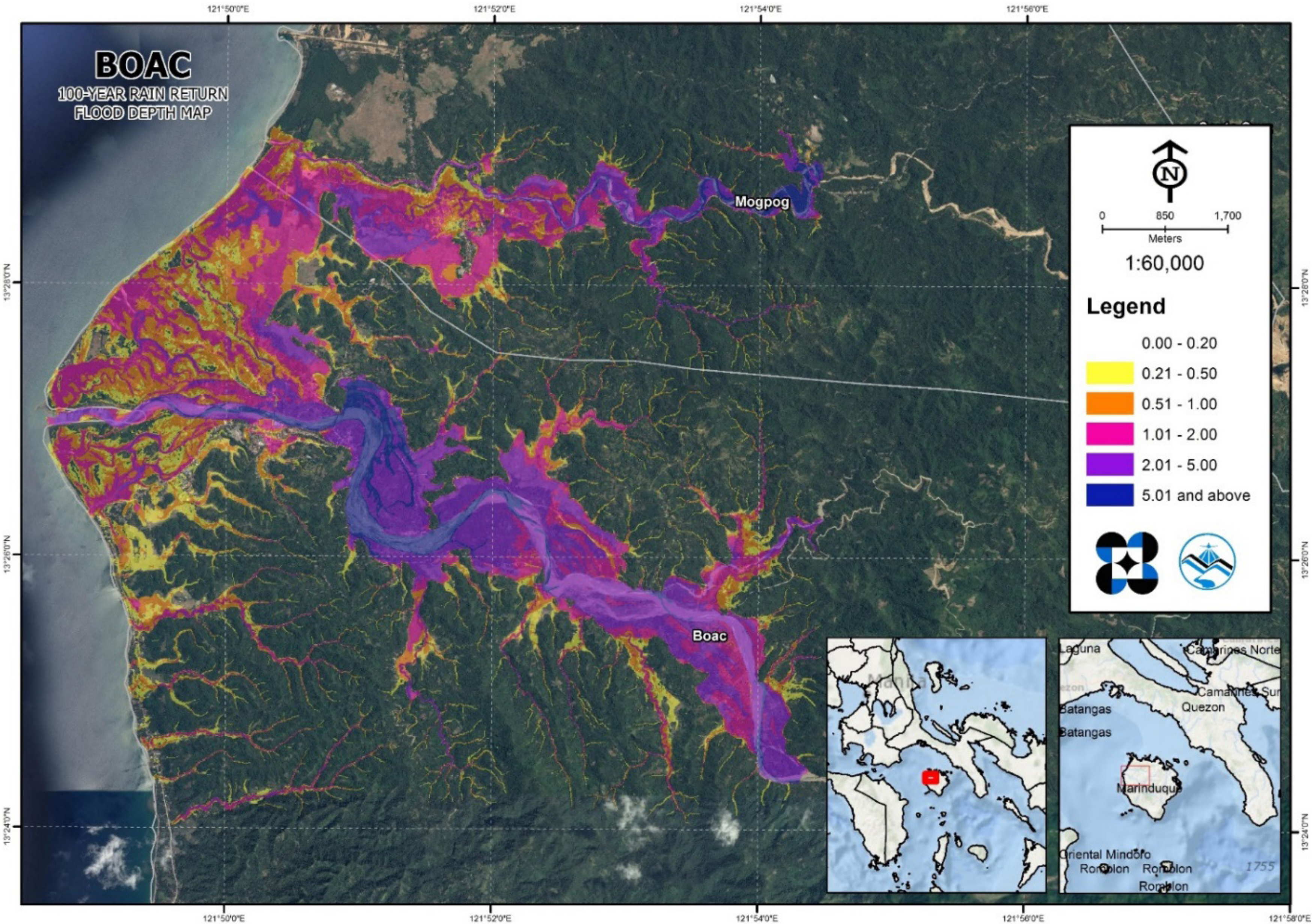


Figure 59. 100-year flow depth map for the Boac floodplain

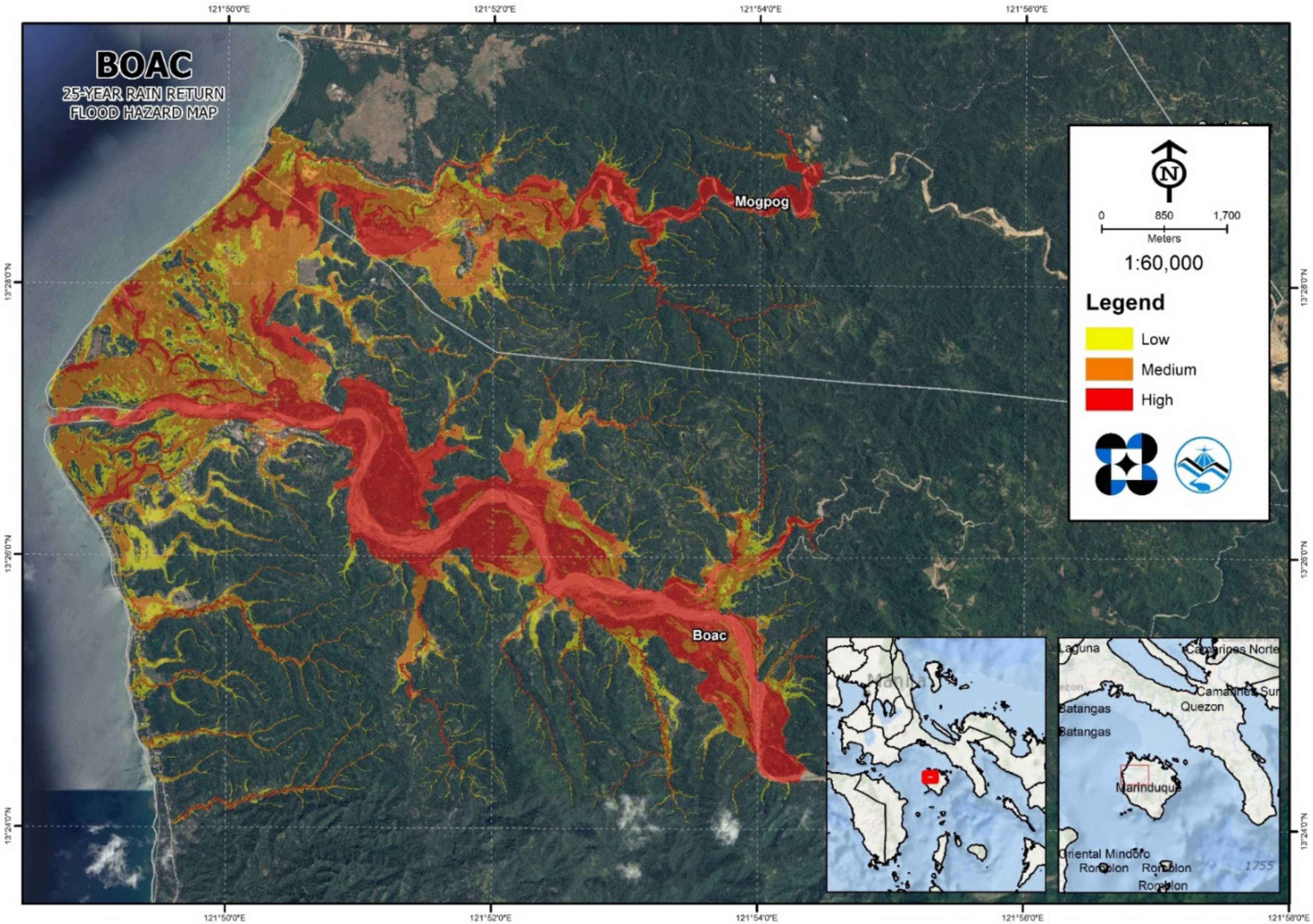


Figure 60. 25-year flood hazard map for the Boac floodplain

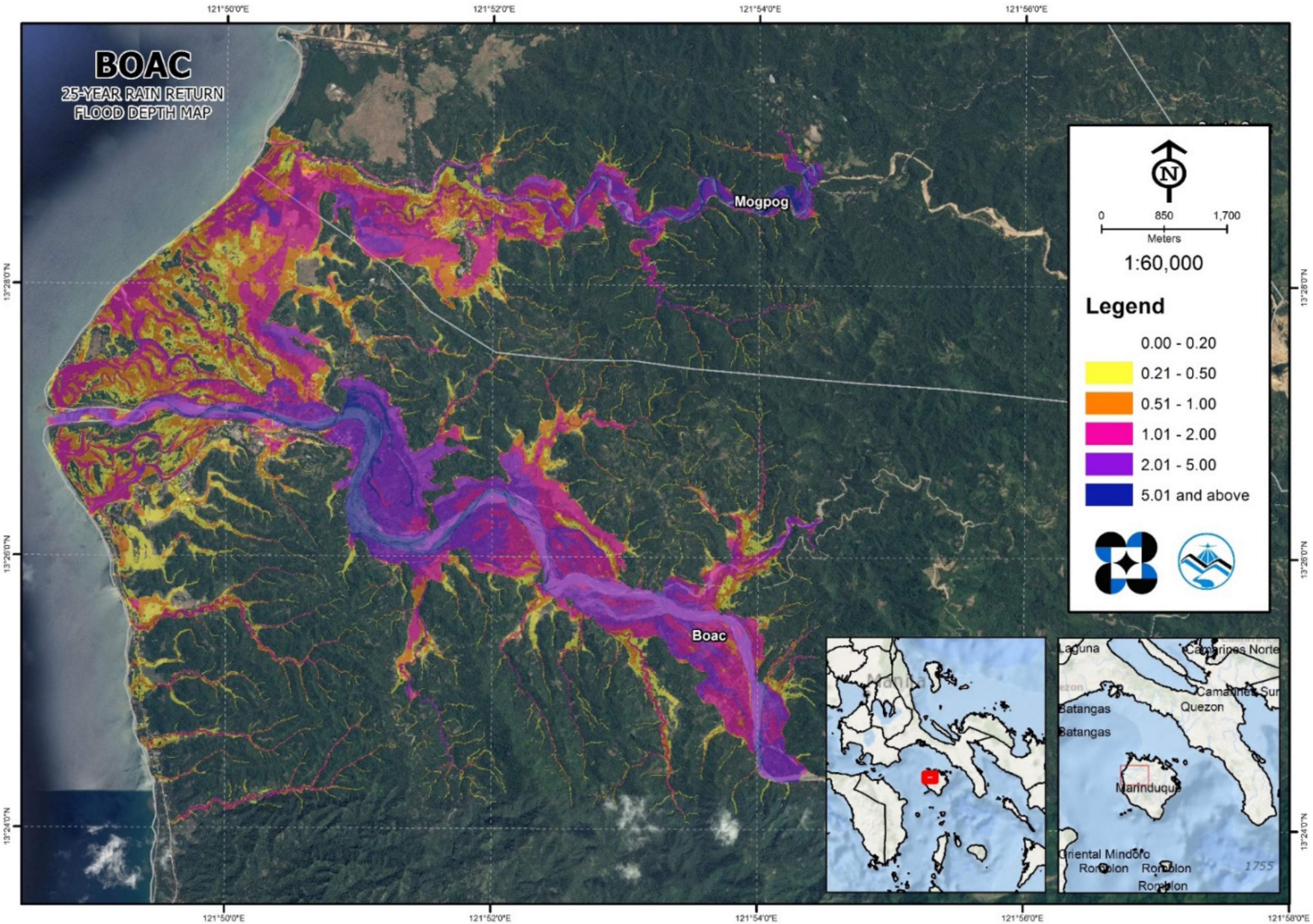


Figure 61. 25-year flow depth map for the Boac floodplain

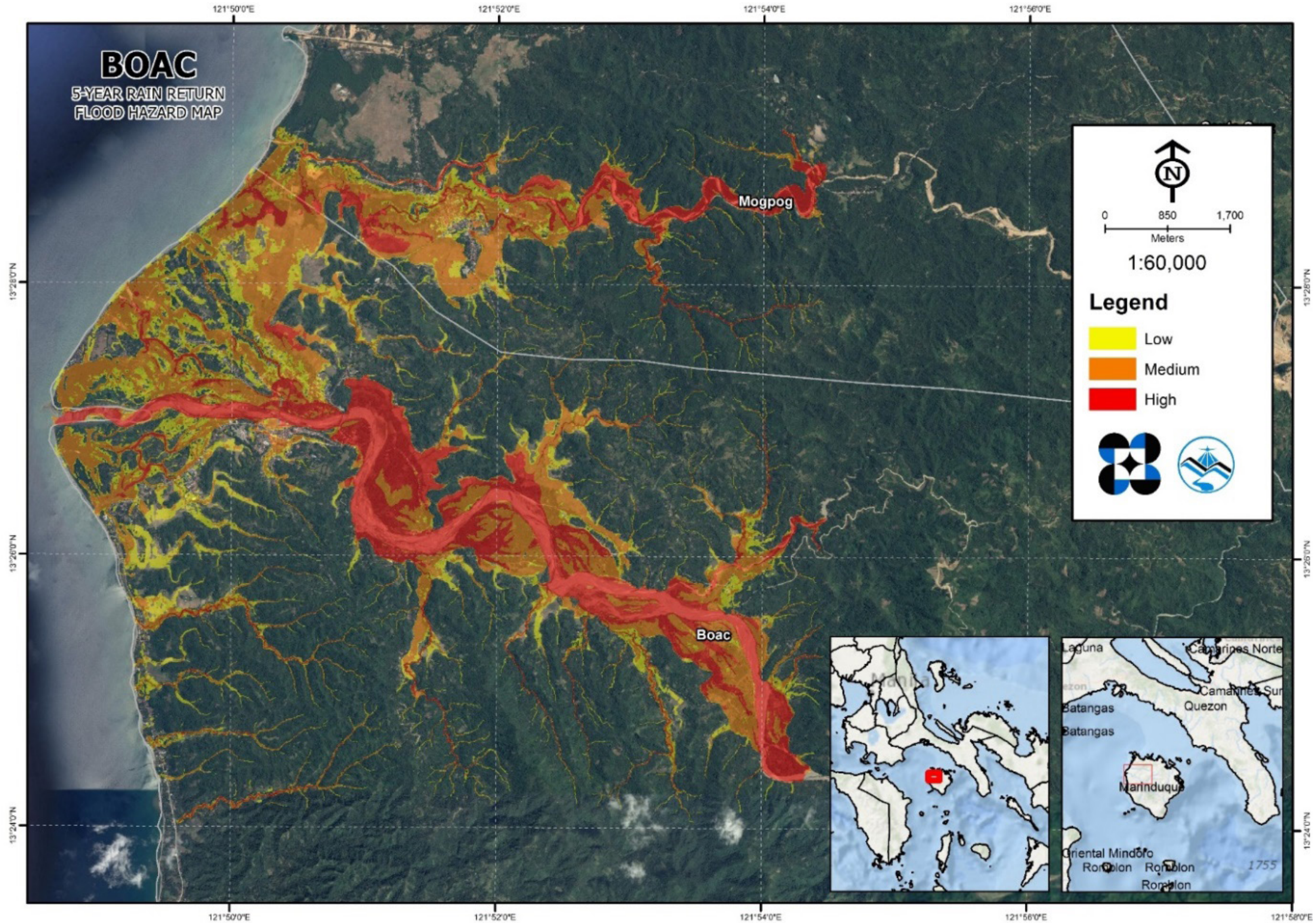


Figure 62. 5-year flood hazard map for the Boac floodplain

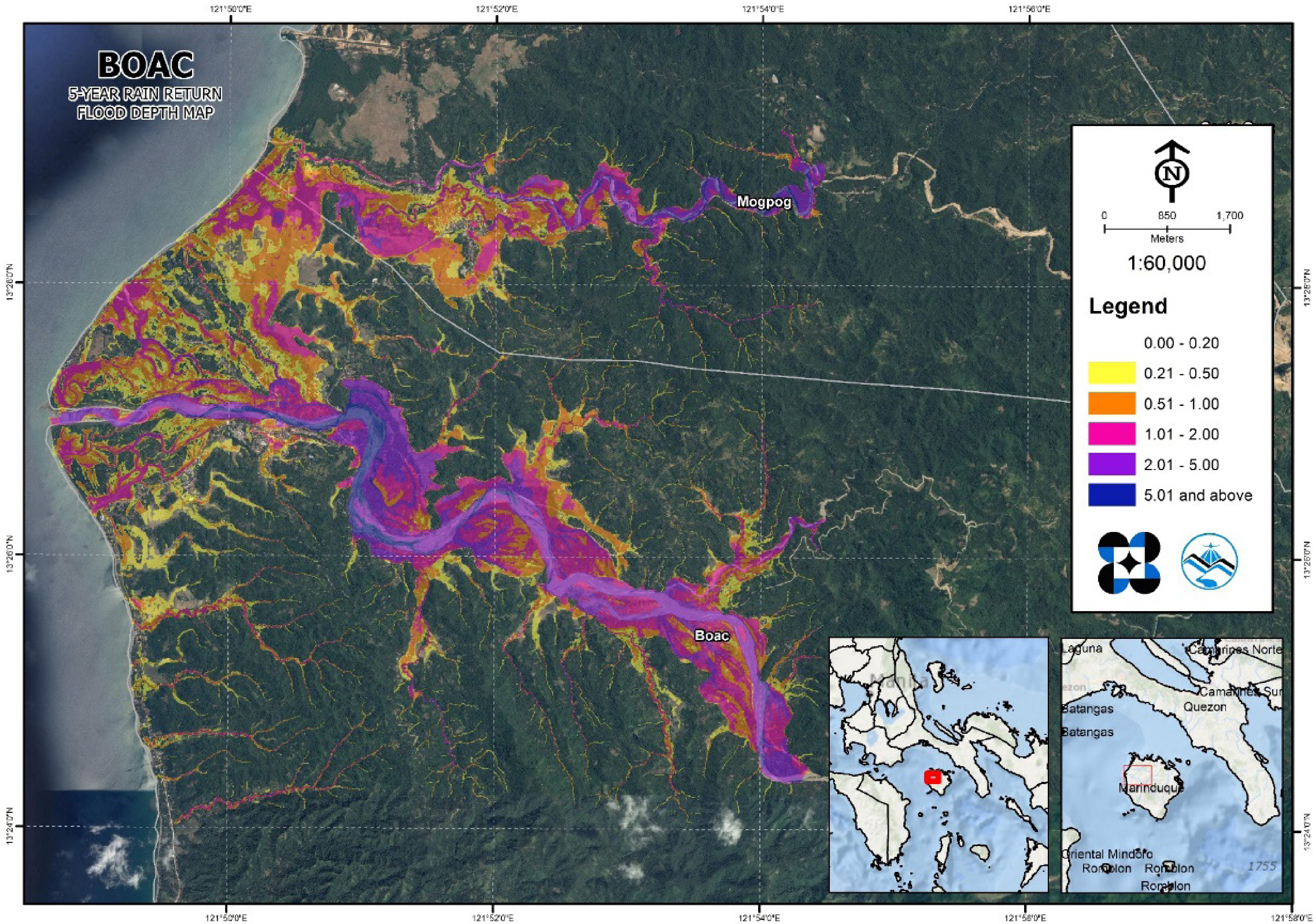


Figure 63. 5-year flow depth map for the Boac floodplain

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Boac River Basin, grouped by municipality, are listed below. For the said basin, two (2) municipalities consisting of sixty-seven (67) barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 24.31% of the Municipality of Boac, with an area of 182.07 square kilometers, will experience flood levels of less than 0.20 meters. 2.86% of the area will experience flood levels of 0.21 to 0.50 meters. Meanwhile, 3.14%, 3.18%, 2.24%, and 0.38% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 26 to Table 30 are the affected areas, in square kilometers, by flood depth per barangay.

Table 26. Affected areas in Boac, Marinduque during a 5-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Agot	Agumaymayan	Amoingon	Apitong	Balagasan	Balaring	Balimbing	Balogo	Bamban
0.03-0.20	0.81	2.24	0.044	1.31	0.68	1.67	1.75	0.35	0.82
0.21-0.50	0.096	0.046	0.0003	0.05	0.013	0.083	0.14	0.12	0.16
0.51-1.00	0.083	0.017	0.0005	0.051	0.003	0.045	0.33	0.071	0.12
1.01-2.00	0.095	0.0083	0.0001	0.013	0.0008	0.025	0.58	0.031	0.061
2.01-5.00	0.035	0.0013	0	0.0014	0	0.0006	0.56	0.0008	0.12
> 5.00	0	0	0	0	0	0	0.0047	0	0.0025

Table 27. Affected areas in Boac, Marinduque during a 5-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Bangbangalon	Bantad	Bantay	Boton	Buliasnin	Caganhao	Catubugan	Daig	Daypay
0.03-0.20	1	1.01	0.98	0.32	0.3	2.3	0.34	1.4	1.02
0.21-0.50	0.25	0.064	0.14	0.018	0.37	0.072	0.059	0.045	0.041
0.51-1.00	0.078	0.043	0.25	0.094	0.56	0.075	0.21	0.027	0.016
1.01-2.00	0.051	0.03	0.32	0.37	0.26	0.072	0.53	0.014	0.034
2.01-5.00	0.00085	0.08	0.18	0.4	0.0028	0.0036	0.42	0.0048	0.25
> 5.00	0	0.023	0.000004	0.035	0	0	0	0.0082	0.15

Table 28. Affected areas in Boac, Marinduque during a 5-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Ihatub	Isok I	Isok II Poblacion	Laylay	Lupac	Mainit	Malbog	Maligaya	Malusak
0.03-0.20	2.51	0.44	0.21	0.9	0.38	4.17	1.79	0.32	0.078
0.21-0.50	0.3	0.025	0.024	0.34	0.2	0.16	0.049	0.14	0.016
0.51-1.00	0.2	0.012	0.027	0.18	0.31	0.19	0.027	0.41	0.021
1.01-2.00	0.095	0.00091	0.0021	0.14	0.35	0.23	0.025	0.35	0.011
2.01-5.00	0.0036	0	0	0	0.018	0.0042	0.0041	0.016	0
> 5.00	0	0	0	0	0	0	0	0	0

Table 29. Affected areas in Boac, Marinduque during a 5-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Mansiwat	Mataas Na Bayan	Maybo	Mercado	Murallon	Ogbac	Pawa	Pili	Poctoy
0.03-0.20	1.93	0.0071	4.03	0.077	0.047	1.11	1.64	0.28	0.34
0.21-0.50	0.063	0.0018	0.15	0.0064	0.016	0.083	0.087	0.24	0.061
0.51-1.00	0.034	0.0016	0.1	0.011	0.022	0.062	0.12	0.2	0.17
1.01-2.00	0.033	0.0041	0.048	0.0097	0.018	0.22	0.042	0.073	0.16
2.01-5.00	0.044	0.032	0.018	0.0001	0.0058	0.38	0.0009	0	0.034
> 5.00	0	0.046	0	0	0.00021	0.036	0	0	0

Table 30. Affected areas in Boac, Marinduque during a 5-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac										
	Poras	Puyog	San Miguel	Santol	Sawi	Tabi	Tabigue	Tagwak	Tampus	Tanza	Tumapon
0.03-0.20	0.23	1.56	0.04	0.71	0.05	0.11	0.65	0.27	0.16	0.92	0.97
0.21-0.50	0.15	0.14	0.0028	0.15	0.0075	0.19	0.46	0.057	0.012	0.16	0.13
0.51-1.00	0.17	0.12	0.0029	0.082	0.092	0.16	0.47	0.098	0.013	0.19	0.16
1.01-2.00	0.12	0.12	0.0066	0.02	0.34	0.2	0.27	0.083	0.066	0.12	0.14
2.01-5.00	0.048	0.054	0.017	0.035	0.71	0.11	0.23	0.055	0.093	0	0.1
> 5.00	0.018	0	0.028	0.0087	0.27	0.024	0.022	0.0018	0.0074	0	0.012

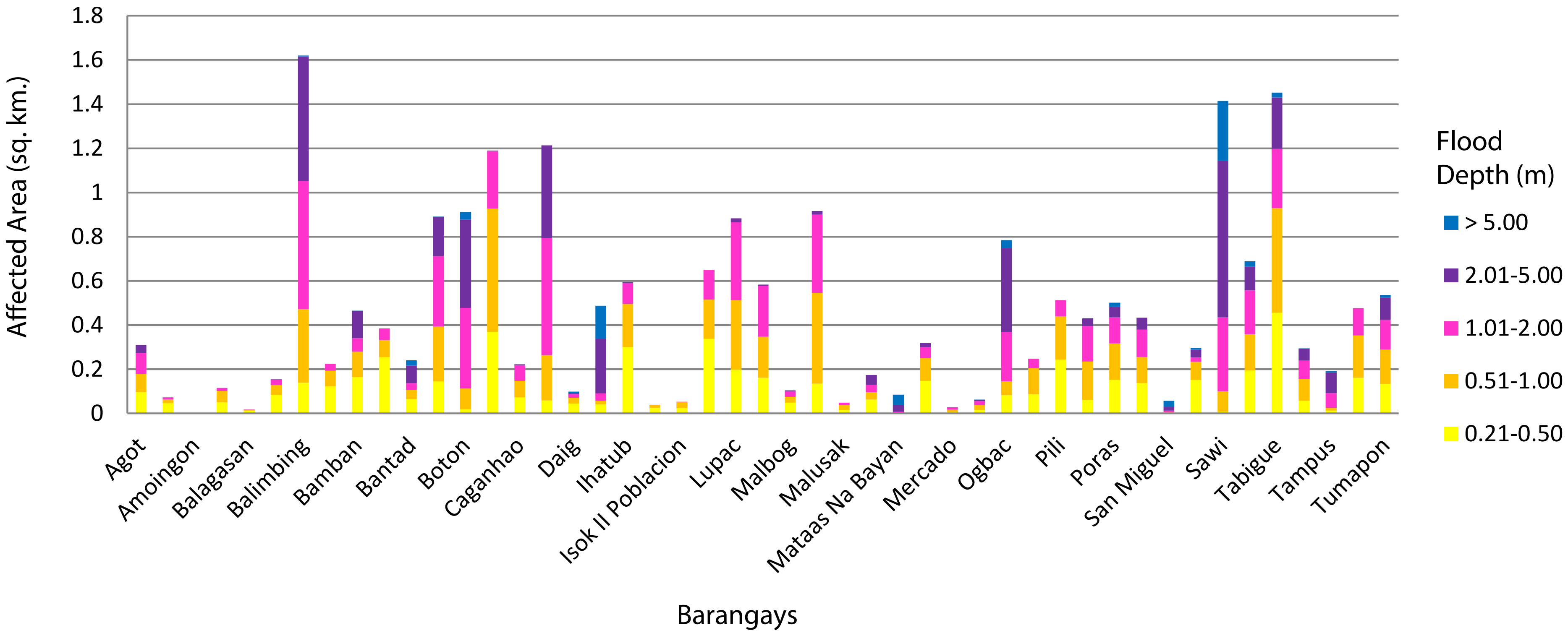


Figure 64. Affected areas in Boac, Marinduque during a 5-year rainfall return period

For the Municipality of Mogpog, with an area of 101.12 square kilometers, 12.74% will experience flood levels of less than 0.20 meters. 1.12% of the area will experience flood levels of 0.21 to 0.50 meters. Meanwhile, 1.75%, 1.64%, 0.90% and 0.21% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 31 to Table 32 are the affected areas, in square kilometers, by flood depth per barangay.

Table 31. Affected areas in Mogpog, Marinduque during a 5-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mogpog									
	Anapog-Sibucao	Banto	Candahon	Danao	Dulong Bayan	Gitnang Bayan	Janagdong	Laon	Magapua	Malayak
0.03-0.20	0.88	0.15	0.98	1.16	0.016	0.02	0.35	0.0034	2.7	0.11
0.21-0.50	0.15	0.0067	0.046	0.023	0.019	0.066	0.18	0.000037	0.083	0.0037
0.51-1.00	0.32	0.014	0.047	0.014	0.084	0.088	0.38	0.00045	0.08	0.0016
1.01-2.00	0.057	0.014	0.026	0.0024	0.042	0.034	0.66	0.00081	0.097	0.001
2.01-5.00	0	0.077	0.027	0	0.018	0.015	0.12	0.0017	0.17	0
> 5.00	0	0.019	0	0	0.0026	0.0057	0	0	0.053	0

Table 32. Affected areas in Mogpog, Marinduque during a 5-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mogpog									
	Malusak	Mampaitan	Mangyan-Mababad	Market Site	Mataas Na Bayan	Nangka I	Nangka II	Pili	Sumangga	Villa Mendez
0.03-0.20	0.29	1.66	2.1	0.15	1.11	0.15	0.084	0.3	0.58	0.094
0.21-0.50	0.011	0.054	0.077	0.063	0.07	0.077	0.018	0.015	0.11	0.053
0.51-1.00	0.009	0.026	0.067	0.13	0.057	0.12	0.0078	0.018	0.28	0.025
1.01-2.00	0.015	0.024	0.14	0.053	0.074	0.098	0.0076	0.029	0.26	0.022
2.01-5.00	0.095	0.012	0.15	0.000062	0.00047	0.011	0.0024	0.067	0.11	0.029
> 5.00	0.056	0	0.031	0	0	0	0	0.019	0.022	0.00042

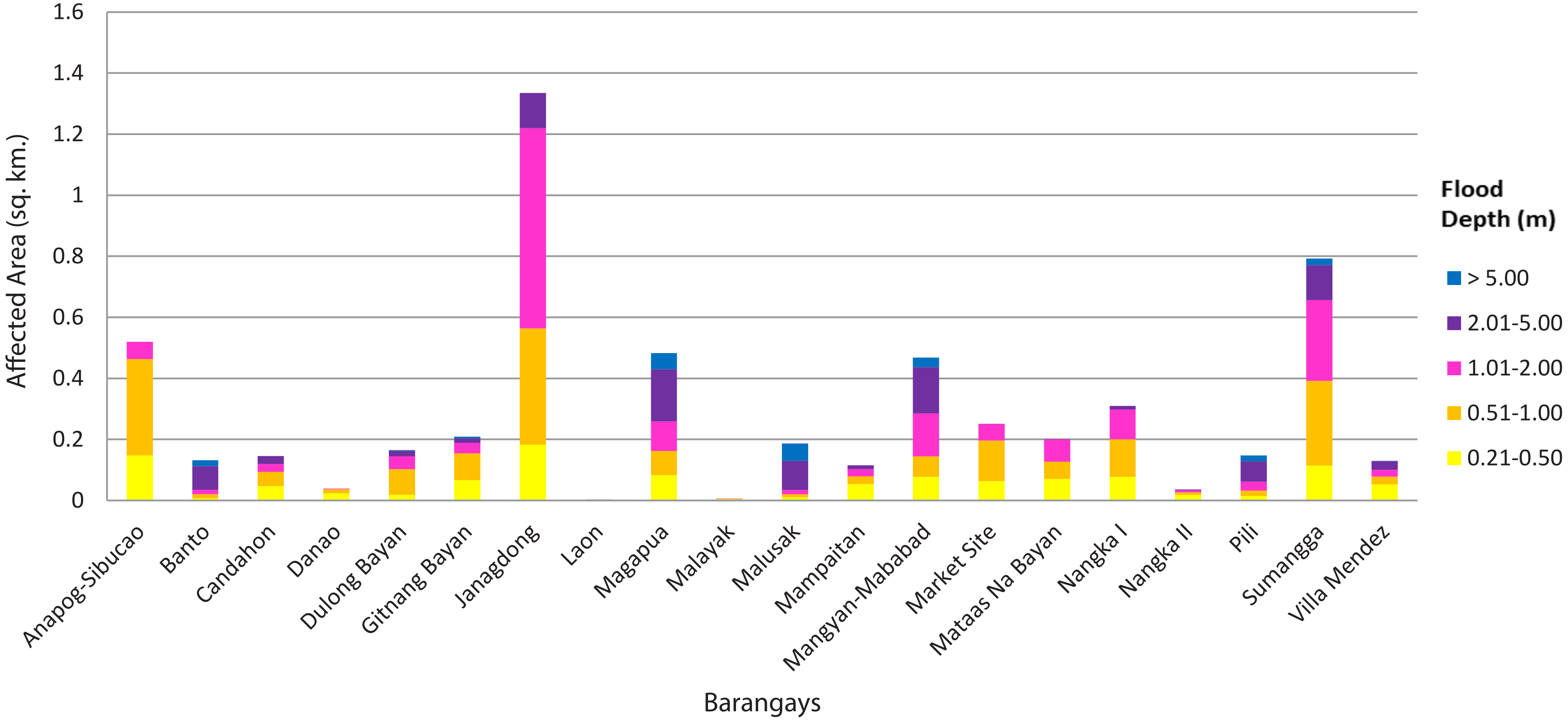


Figure 65. Affected areas in Mogpog, Marinduque during a 5-year rainfall return period

For the 25-year return period, 22.89% of the Municipality of Boac, with an area of 182.07 square kilometers, will experience flood levels of less than 0.20 meters. 2.62% of the area will experience flood levels of 0.21 to 0.50 meters. Meanwhile, 2.97%, 3.78%, 3.22%, and 0.62% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Tables 33- 37 are the affected areas, in square kilometers, by flood depth per barangay.

Table 33. Affected areas in Boac, Marinduque during a 25-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Agot	Agumaymayan	Amoingon	Apitong	Balagasan	Balaring	Balimbing	Balogo	Bamban
0.03-0.20	0.76	2.22	0.043	1.29	0.67	1.63	1.63	0.18	0.75
0.21-0.50	0.065	0.055	0.0003	0.051	0.018	0.11	0.11	0.18	0.17
0.51-1.00	0.08	0.022	0.0005	0.056	0.0039	0.054	0.13	0.16	0.12
1.01-2.00	0.1	0.011	0.0002	0.023	0.0018	0.031	0.72	0.058	0.1
2.01-5.00	0.11	0.003	0	0.0021	0	0.0026	0.75	0.0075	0.13
> 5.00	0	0	0	0	0	0	0.026	0	0.01

Table 34. Affected areas in Boac, Marinduque during a 25-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Bangbangalon	Bantad	Bantay	Boton	Buliasnin	Caganhao	Catubugan	Daig	Daypay
0.03-0.20	0.87	0.96	0.93	0.29	0.17	2.26	0.31	1.38	0.99
0.21-0.50	0.3	0.069	0.12	0.0056	0.21	0.091	0.04	0.05	0.043
0.51-1.00	0.13	0.073	0.17	0.013	0.54	0.072	0.054	0.03	0.02
1.01-2.00	0.055	0.026	0.4	0.18	0.53	0.095	0.46	0.022	0.023
2.01-5.00	0.022	0.084	0.25	0.63	0.052	0.011	0.68	0.0089	0.24
> 5.00	0	0.04	0.0041	0.1	0	0	0.001	0.0092	0.19

Table 35. Affected areas in Boac, Marinduque during a 25-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac									
	Ihatub	Isok I	Isok II Poblacion	Laylay	Lupac	Mainit	Malbog	Maligaya	Malusak	Mansiwat
0.03-0.20	2.4	0.43	0.2	0.71	0.27	4.09	1.77	0.27	0.072	1.9
0.21-0.50	0.3	0.026	0.021	0.41	0.17	0.19	0.057	0.073	0.013	0.074
0.51-1.00	0.26	0.017	0.036	0.24	0.31	0.11	0.03	0.24	0.019	0.036
1.01-2.00	0.14	0.0039	0.0039	0.19	0.48	0.32	0.03	0.57	0.022	0.032
2.01-5.00	0.011	0	0	0.0034	0.024	0.042	0.0084	0.08	0	0.058
> 5.00	0	0	0	0	0	0	0	0	0	0.0024

Table 36. Affected areas in Boac, Marinduque during a 25-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac									
	Mataas Na Bayan	Maybo	Mercado	Murallon	Ogbac	Pawa	Pili	Poctoy	Poras	Puyog
0.03-0.20	0.0028	3.97	0.074	0.038	1.08	1.62	0.13	0.32	0.075	1.49
0.21-0.50	0.0027	0.16	0.0072	0.011	0.092	0.08	0.18	0.039	0.16	0.15
0.51-1.00	0.002	0.12	0.0088	0.022	0.059	0.11	0.34	0.058	0.22	0.13
1.01-2.00	0.0036	0.067	0.014	0.028	0.14	0.082	0.15	0.27	0.2	0.14
2.01-5.00	0.027	0.032	0.00047	0.0098	0.47	0.0022	0.0014	0.083	0.057	0.086
> 5.00	0.055	0	0	0.00023	0.063	0	0	0	0.02	0

Table 37. Affected areas in Boac, Marinduque during a 25-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	San Miguel	Santol	Sawi	Tabi	Tabigue	Tagwak	Tampus	Tanza	Tumapon
0.03-0.20	0.036	0.65	0.044	0.044	0.45	0.25	0.15	0.86	0.93
0.21-0.50	0.0028	0.15	0.0011	0.087	0.4	0.044	0.0086	0.12	0.074
0.51-1.00	0.0039	0.12	0.0021	0.26	0.6	0.064	0.0068	0.14	0.11
1.01-2.00	0.0051	0.035	0.071	0.18	0.37	0.11	0.023	0.18	0.19
2.01-5.00	0.018	0.035	0.91	0.2	0.25	0.085	0.15	0.1	0.14
> 5.00	0.031	0.01	0.43	0.028	0.032	0.0056	0.0085	0	0.054

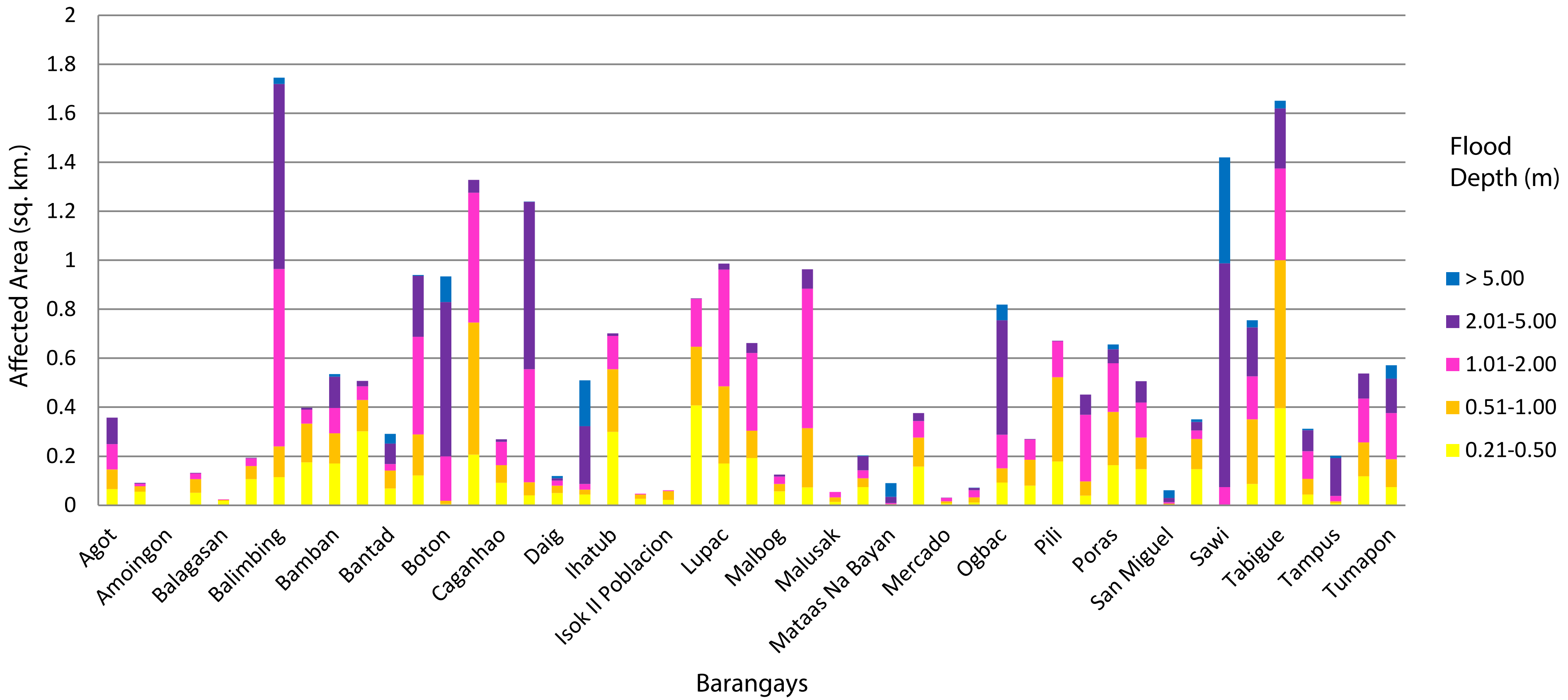


Figure 66. Affected areas in Boac, Marinduque during a 25-year rainfall return period

For the Municipality of Mogpog, with an area of 101.12 square kilometers, 12.22% will experience flood levels of less than 0.20 meters. 1.001% of the area will experience flood levels of 0.21 to 0.50 meters. Meanwhile, 1.39%, 2.06%, 1.21%, and 0.32% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 38 to Table 39 are the affected areas, in square kilometers, by flood depth per barangay.

Table 38. Affected areas in Mogpog, Marinduque during a 25-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mogpog									
	Anapog-Sibucao	Banto	Candahon	Danao	Dulong Bayan	Gitnang Bayan	Janagdong	Laon	Magapua	Malayak
0.03-0.20	0.84	0.14	0.96	1.15	0.014	0.012	0.23	0.0032	2.66	0.11
0.21-0.50	0.11	0.0067	0.055	0.026	0.0064	0.036	0.13	0.00024	0.09	0.005
0.51-1.00	0.24	0.0074	0.05	0.016	0.062	0.11	0.3	0.00035	0.057	0.0016
1.01-2.00	0.21	0.014	0.029	0.0051	0.074	0.045	0.71	0.0007	0.11	0.0012
2.01-5.00	0.00032	0.061	0.032	0	0.023	0.018	0.31	0.0019	0.2	0
> 5.00	0	0.051	0	0	0.0029	0.0061	0	0	0.073	0

Table 39. Affected areas in Mogpog, Marinduque during a 25-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mogpog									
	Malusak	Mampaitan	Mangyan-Mababad	Market Site	Mataas Na Bayan	Nangka I	Nangka II	Pili	Sumangga	Villa Mendez
0.03-0.20	0.28	1.63	2.07	0.1	1.09	0.099	0.064	0.28	0.55	0.076
0.21-0.50	0.0098	0.062	0.084	0.13	0.07	0.05	0.018	0.013	0.054	0.054
0.51-1.00	0.0081	0.03	0.053	0.0019	0.055	0.11	0.024	0.015	0.22	0.037
1.01-2.00	0.013	0.025	0.13	0	0.1	0.18	0.0077	0.022	0.38	0.023
2.01-5.00	0.076	0.021	0.19	0	0.0011	0.022	0.0054	0.08	0.14	0.033
> 5.00	0.089	0	0.045	0	0	0	0	0.032	0.027	0.00022

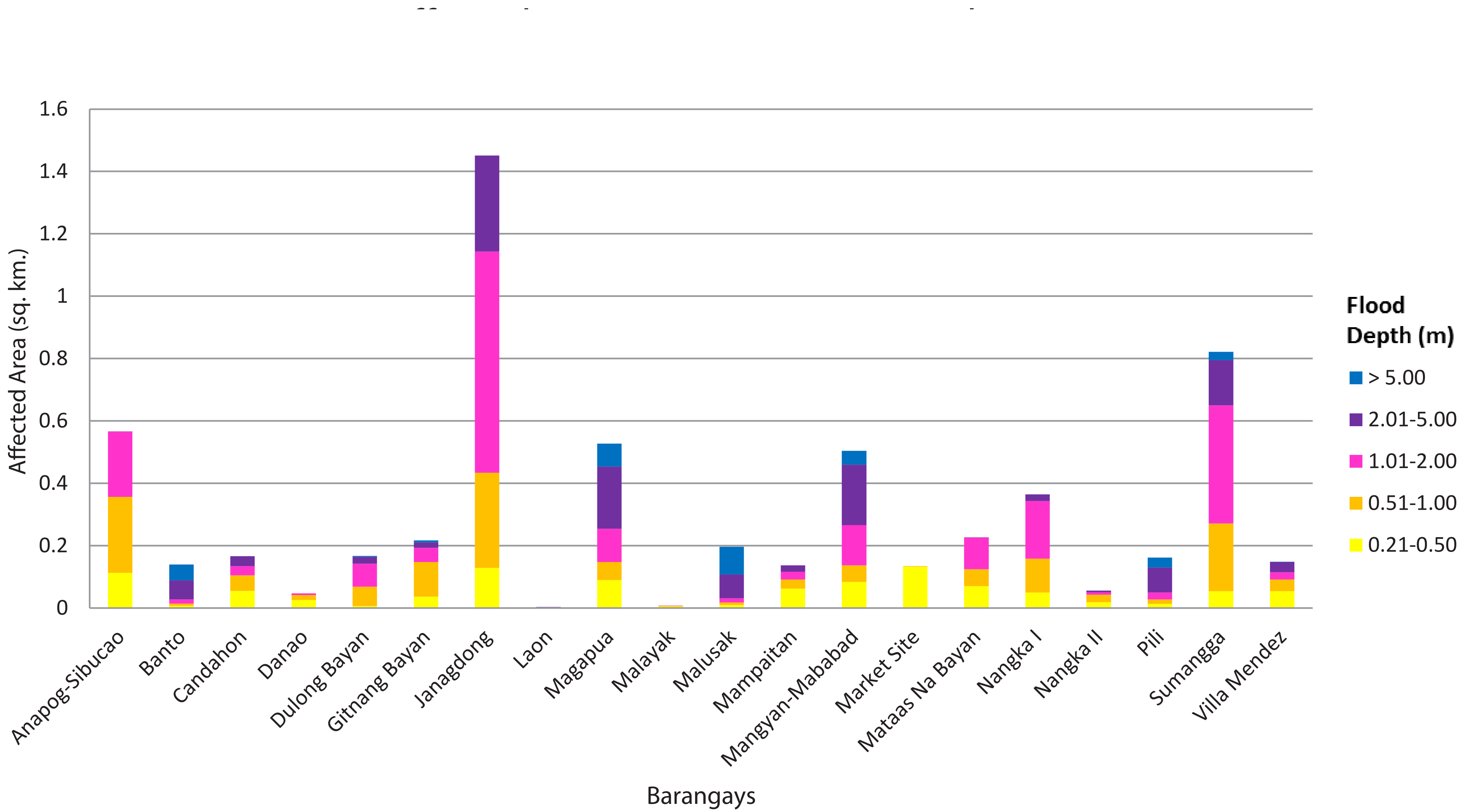


Figure 67. Affected areas in Mogpog, Marinduque during a 25-year rainfall return period

For the 100-year return period, 22.06% of the Municipality of Boac, with an area of 182.07 square kilometers, will experience flood levels of less than 0.20 meters. 2.43% of the area will experience flood levels of 0.21 to 0.50 meters. Meanwhile, 2.94%, 3.75%, 3.96%, and 0.92% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 40 to Table 44 are the affected areas, in square kilometers, by flood depth per barangay.

Table 40. Affected areas in Boac, Marinduque during a 100-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Agot	Agumaymayan	Amoingon	Apitong	Balagasan	Balaring	Balimbing	Balogo	Bamban
0.03-0.20	0.72	2.2	0.043	1.28	0.66	1.6	1.6	0.062	0.71
0.21-0.50	0.058	0.062	0.0003	0.051	0.021	0.12	0.085	0.19	0.17
0.51-1.00	0.055	0.027	0.0003	0.054	0.0046	0.061	0.082	0.22	0.13
1.01-2.00	0.1	0.012	0.0006	0.036	0.0023	0.04	0.46	0.093	0.13
2.01-5.00	0.18	0.0052	0	0.0036	0	0.0044	1.08	0.011	0.14
> 5.00	0	0	0	0	0	0	0.071	0	0.016

Table 41. Affected areas in Boac, Marinduque during a 100-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Bangbangalon	Bantad	Bantay	Boton	Buliasnin	Caganhao	Catubugan	Daig	Daypay
0.03-0.20	0.8	0.94	0.9	0.28	0.14	2.21	0.3	1.37	0.98
0.21-0.50	0.31	0.068	0.1	0.0066	0.11	0.11	0.035	0.05	0.044
0.51-1.00	0.18	0.075	0.14	0.0085	0.47	0.072	0.031	0.034	0.025
1.01-2.00	0.069	0.045	0.39	0.032	0.65	0.1	0.31	0.024	0.022
2.01-5.00	0.027	0.054	0.32	0.72	0.12	0.025	0.87	0.016	0.13
> 5.00	0	0.075	0.013	0.18	0	0	0.011	0.01	0.3

Table 42. Affected areas in Boac, Marinduque during a 100-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Ihatub	Isok I	Isok II Poblacion	Laylay	Lupac	Mainit	Malbog	Maligaya	Malusak
0.03-0.20	2.31	0.42	0.2	0.6	0.19	4.03	1.75	0.25	0.068
0.21-0.50	0.3	0.025	0.021	0.42	0.18	0.21	0.061	0.069	0.011
0.51-1.00	0.29	0.02	0.039	0.29	0.3	0.12	0.033	0.15	0.021
1.01-2.00	0.17	0.0064	0.0071	0.22	0.55	0.27	0.031	0.63	0.026
2.01-5.00	0.023	0.0013	0	0.017	0.036	0.12	0.015	0.14	0.0002
> 5.00	0	0	0	0	0	0	0.0001	0	0

Table 43. Affected areas in Boac, Marinduque during a 100-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac								
	Mansiwat	Mataas Na Bayan	Maybo	Mercado	Murallon	Ogbac	Pawa	Pili	Poctoy
0.03-0.20	1.87	0.0025	3.93	0.0074	0.033	1.06	1.6	0.053	0.31
0.21-0.50	0.082	0.00065	0.17	0.018	0.0086	0.1	0.078	0.1	0.031
0.51-1.00	0.036	0.0027	0.13	0.00077	0.02	0.057	0.092	0.36	0.028
1.01-2.00	0.039	0.0036	0.081	0	0.033	0.091	0.11	0.27	0.16
2.01-5.00	0.056	0.022	0.042	0	0.013	0.51	0.0055	0.0067	0.24
> 5.00	0.012	0.061	0.0005	0	0.00033	0.08	0	0	0.00023

Table 44. Affected areas in Boac, Marinduque during a 100-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Boac										
	Poras	Puyog	San Miguel	Santol	Sawi	Tabi	Tabigue	Tagwak	Tampus	Tanza	Tumapon
0.03-0.20	0.024	1.45	0.034	0.62	0.04	0.012	0.36	0.25	0.15	0.83	0.9
0.21-0.50	0.1	0.13	0.0028	0.15	0.00091	0.052	0.33	0.018	0.0081	0.092	0.068
0.51-1.00	0.26	0.14	0.0048	0.14	0.0021	0.19	0.66	0.054	0.0049	0.14	0.084
1.01-2.00	0.25	0.16	0.0056	0.05	0.0051	0.27	0.47	0.09	0.012	0.16	0.15
2.01-5.00	0.069	0.11	0.018	0.033	0.82	0.24	0.25	0.15	0.17	0.17	0.22
> 5.00	0.023	0.0001	0.033	0.012	0.6	0.031	0.038	0.0074	0.011	0	0.083

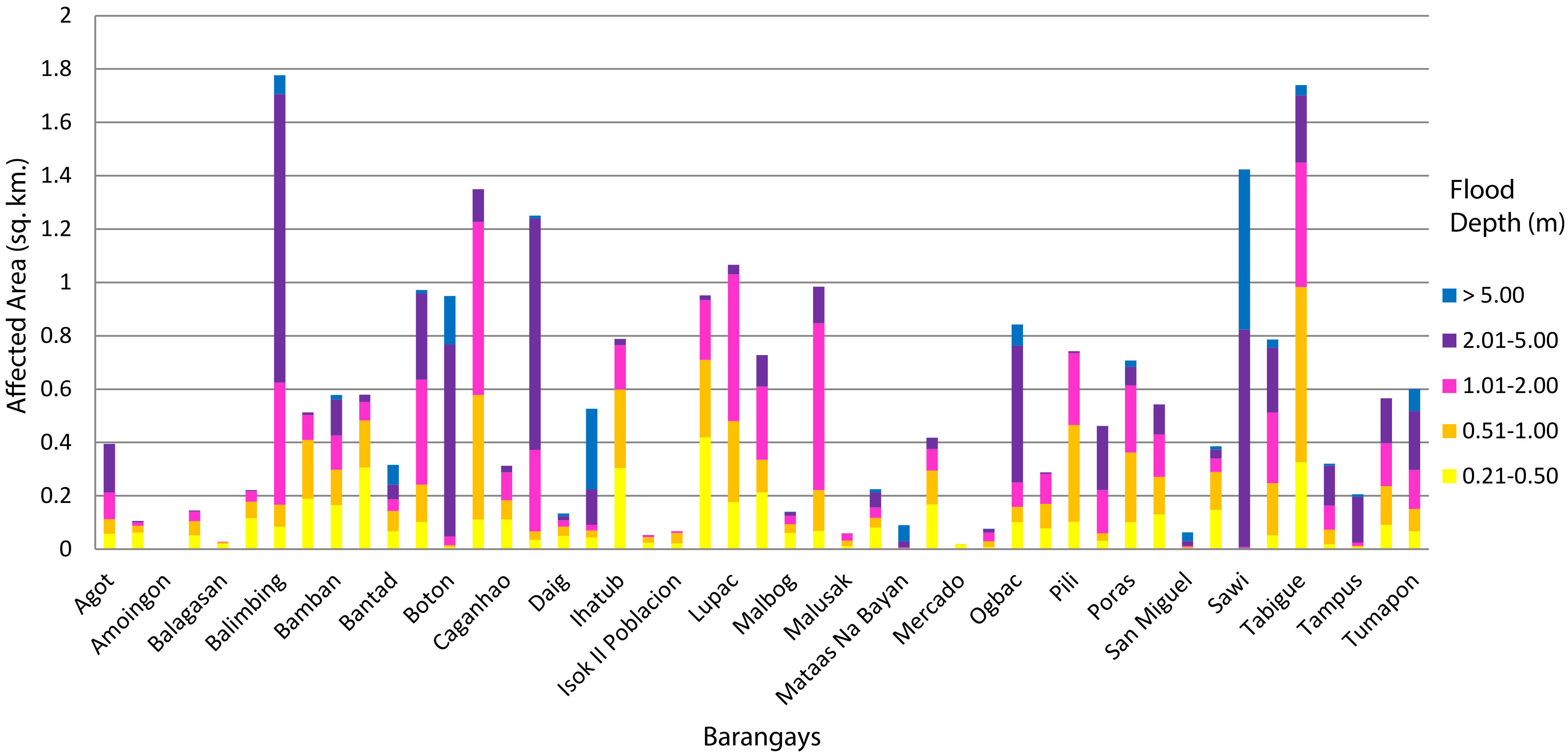


Figure 68. Affected areas Boac, Marinduque during a 100-year rainfall return period

For the Municipality of Mogpog, with an area of 101.12 square kilometers, 11.93% will experience flood levels of less than 0.20 meters. 0.80% of the area will experience flood levels of 0.21 to 0.50 meters. Meanwhile, 1.14%, 2.43%, 1.57%, and 0.48% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 45 to 45 are the affected areas, in square kilometers, by flood depth per barangay.

Table 45. Affected areas in Mogpog, Marinduque during a 100-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mogpog									
	Anapog-Sibucao	Banto	Candahon	Danao	Dulong Bayan	Gitnang Bayan	Janagdong	Laon	Magapua	Malayak
0.03-0.20	0.81	0.13	0.94	1.15	0.013	0.011	0.2	0.0028	2.63	0.11
0.21-0.50	0.096	0.0092	0.056	0.029	0.0016	0.021	0.07	0.0004	0.099	0.0056
0.51-1.00	0.14	0.0061	0.044	0.017	0.03	0.094	0.25	0.00024	0.051	0.0021
1.01-2.00	0.35	0.0079	0.045	0.0076	0.11	0.074	0.63	0.00091	0.099	0.0011
2.01-5.00	0.012	0.039	0.036	0	0.027	0.022	0.54	0.002	0.22	0.0002
> 5.00	0	0.089	0	0	0.0036	0.0062	0	0	0.094	0

Table 46. Affected areas in Mogpog, Marinduque during a 100-year rainfall return period

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mogpog									
	Malusak	Mampaitan	Mangyan-Mababad	Market Site	Mataas Na Bayan	Nangka I	Nangka II	Pili	Sumangga	Villa Mendez
0.03-0.20	0.27	1.62	2.04	0.094	1.07	0.068	0.047	0.27	0.54	0.063
0.21-0.50	0.0087	0.065	0.093	0.031	0.076	0.037	0.023	0.014	0.031	0.047
0.51-1.00	0.0085	0.034	0.047	0.077	0.045	0.087	0.028	0.01	0.14	0.05
1.01-2.00	0.0091	0.024	0.094	0.18	0.12	0.21	0.014	0.015	0.44	0.027
2.01-5.00	0.051	0.028	0.24	0.014	0.002	0.063	0.007	0.066	0.19	0.037
> 5.00	0.13	0.0002	0.06	0	0	0	0	0.068	0.034	0.00022

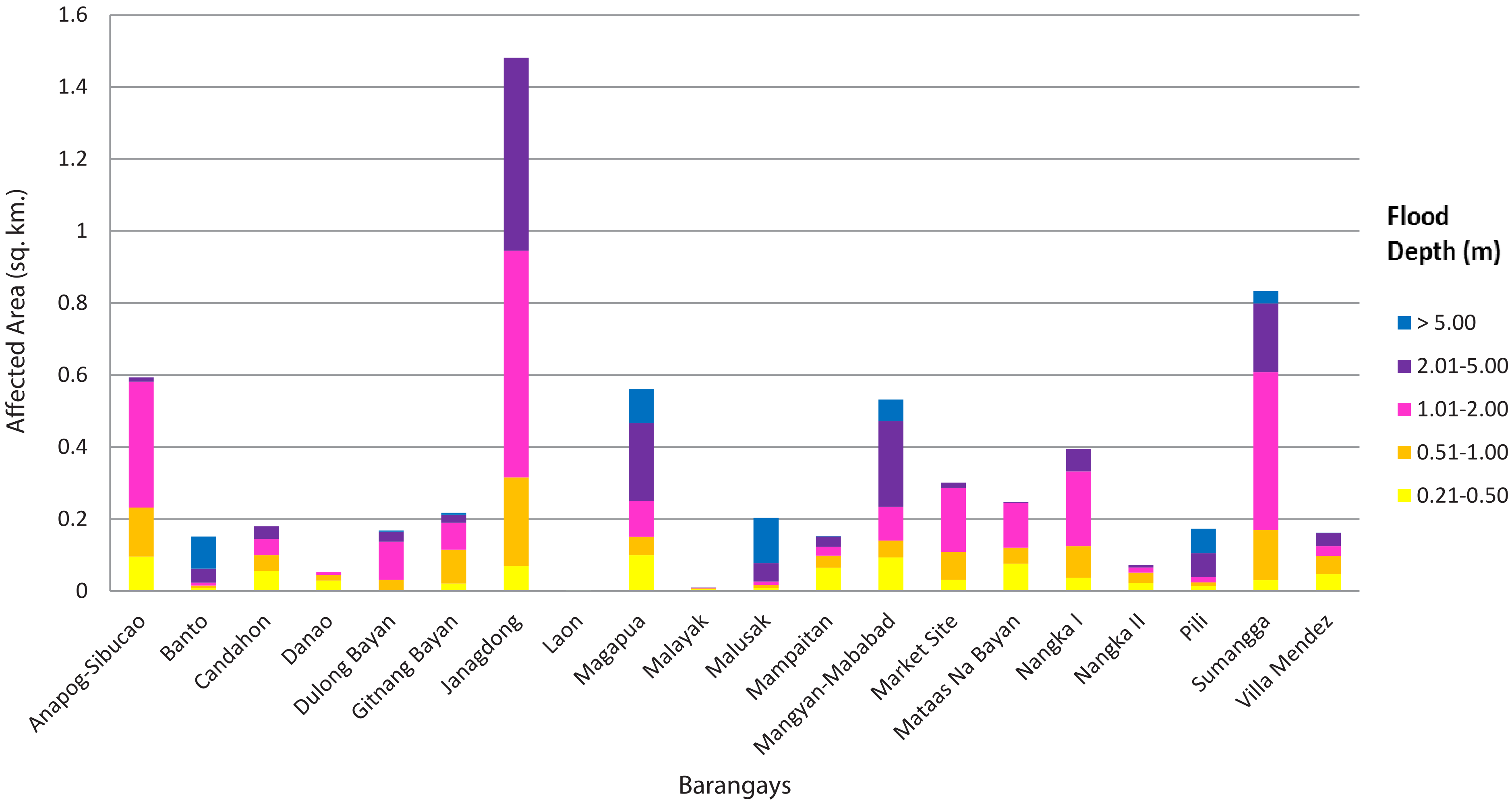


Figure 69. Affected areas in Mogpog, Marinduque during a 100-year rainfall return period

Among the barangays in the Municipality of Boac, Mainit is projected to have the highest percentage of area that will experience flood levels, at 2.61%. Meanwhile, Maybo posted the second highest percentage of area that may be affected by flood depths, at 2.39%.

Among the barangays in the Municipality of Mogpog, Magapua is projected to have the highest percentage of area that will experience flood levels, at 3.15%. Meanwhile, Mangyan-Mababad posted the second highest percentage of area that may be affected by flood depths, at 2.54%.

5.11 Flood Validation

In order to check and validate the extent of flooding in the different river systems, there is a need to perform validation survey work. For this purpose, field personnel gathered secondary data regarding flood occurrences in the respective areas within the major river systems in the Philippines.

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

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood levels in each location. Data gathering was conducted through assistance from a local DRRM office to obtain maps or situation reports about the past flooding events, or through interviews with some residents with knowledge or experience of flooding in a particular area.

After which, the actual data from the field were compared to the simulated data to assess the accuracy of the flood depth maps produced and to improve on the results of the flood map. The points in the flood map versus the corresponding validation depths are illustrated in Figure 70.

The flood validation consists of one hundred and nineteen (119) points, randomly selected all over the Boac floodplain. Comparing the points with the flood depth map of the nearest storm event, the map attained an RMSE value of 1.32 meters. Figure 71 presents a contingency matrix of the comparison. The Boac field validation points are found in Annex 11.

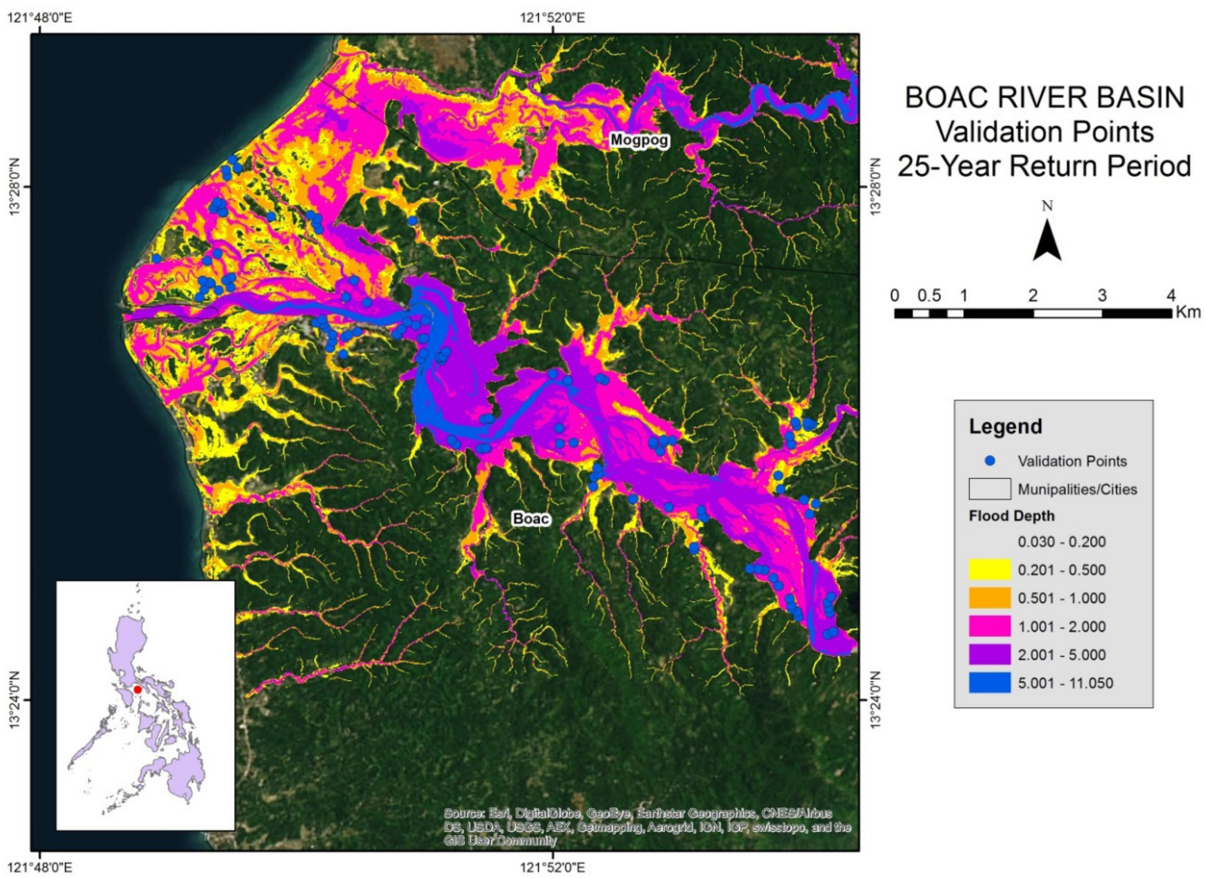


Figure 70. Validation points for a 25-year flood depth map of the Boac Floodplain

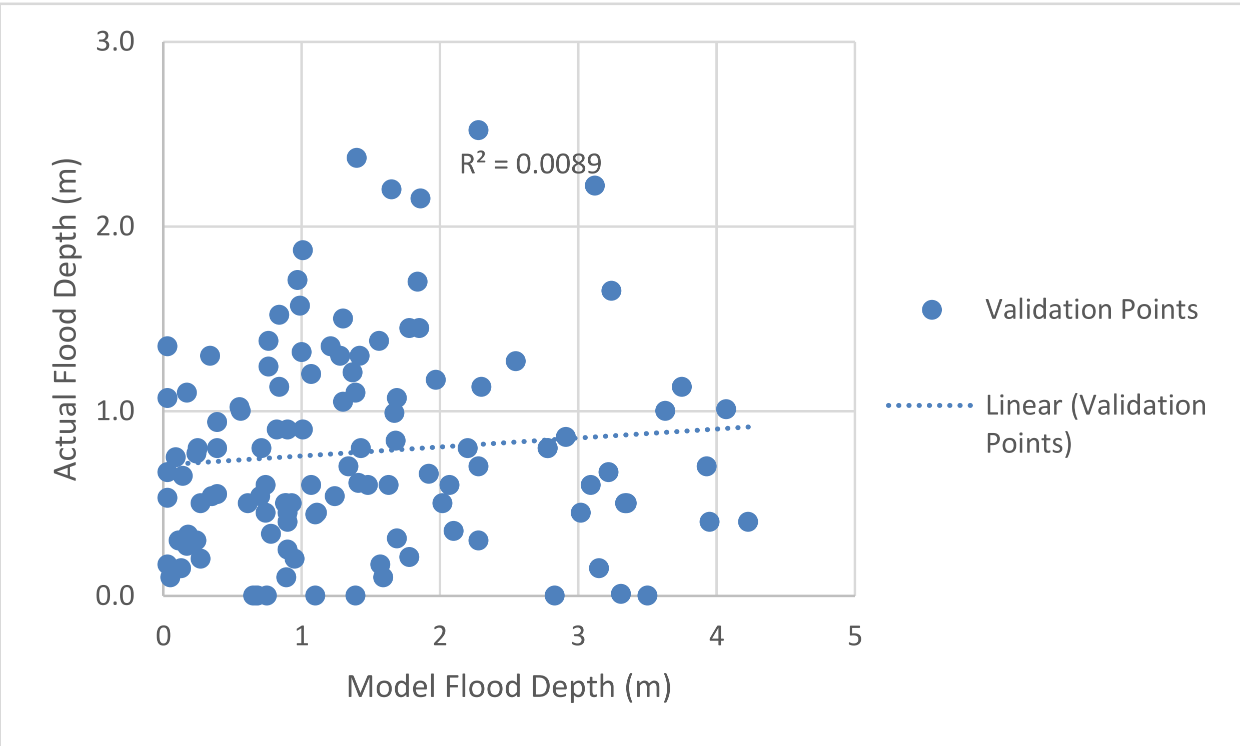


Figure 71. Flood map depth vs. actual flood depth

Table 47. Actual flood depth vs. simulated flood depth, at different levels in the Boac River Basin

Actual Flood Depth (m)	MODELED FLOOD DEPTH (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	3	1	6	4	4	0	**18**
0.21-0.50	4	2	9	4	8	0	**27**
0.51-1.00	4	6	6	11	10	0	**37**
1.01-2.00	3	1	8	15	5	0	**32**
2.01-5.00	0	0	0	3	2	0	**5**
> 5.00	0	0	0	0	0	0	**0**
Total	**14**	**10**	**29**	**37**	**29**	**0**	**119**

The overall accuracy generated by the flood model is estimated at 23.53%, with twenty-eight (28) points correctly matching the actual flood depths. In addition, there were forty-one (41) points estimated one (1) level above and below the correct flood depths. Meanwhile, there were twenty-five (25) points and nineteen (19) points estimated two (2) levels above and below, and three (3) or more levels above and below the correct flood levels, respectively. A total of four (4) points were overestimated, while a total of twenty-nine (29) points were underestimated in the modeled flood depths of the Boac floodplain. Error! Reference source not found. depicts the summary of the Accuracy Assessment in the Boac River Basin survey.

Table 48. Summary of the Accuracy Assessment in the Boac River Basin survey

	No. of Points	%
Correct	28	23.53
Overestimated	62	52.10
Underestimated	29	24.37
Total	**119**	**100.00**

REFERENCES

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

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

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

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

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

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

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

ANNEXES

ANNEX 1. Technical Specifications of the Pegasus LiDAR Sensor used in the Boac Floodplain Survey

Figure A-1.1. Pegasus Sensor

Table A-1.1. Specifications of the Pegasus sensor

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

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

ANNEX 2. NAMRIA Certification of Reference Points used in the LiDAR Survey

1. MRQ-25

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

October 28, 2015

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: **MARINDUQUE**	
	Station Name: **MRQ-25**	
	Order: **2nd**	
Island: **LUZON**	Barangay: **TUGOS**	
Municipality: **BOAC (CAPITAL)**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **13° 22' 56.92806"**	Longitude: **121° 51' 28.72673"**	Ellipsoidal Hgt: **48.18293 m.**
	WGS84 Coordinates	
Latitude: **13° 22' 51.86815"**	Longitude: **121° 51' 33.72033"**	Ellipsoidal Hgt: **97.20100 m.**
	PTM / PRS92 Coordinates	
Northing: **1480020.839 m.**	Easting: **592932.786 m.**	Zone: **3**
	UTM / PRS92 Coordinates	
Northing: **1,479,627.07**	Easting: **376,341.19**	Zone: **51**

Location Description

MRQ-25

From Boac to Brgy. Tugos, approx. 16.6 Km. travel to reach Brgy. Tugos. Station is located at the top of the plant box of Tugos Elem. School near at the school gate. Mark is the head of a 4 in. copper nail flushed at the center of a cement putty with inscriptions, "MRQ-24, 2007, NAMRIA".

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Purpose: **Reference**
OR Number: **8088472 I**
T.N.: **2015-3526**

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

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. MRQ-25

ANNEX 3. NAMRIA Certification of Reference Points used in the LiDAR Survey

1. BM-5

Table A-3.1. BM-5

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
MRQ-25 --- BM-5 (B1)	MRQ-25	BM-5	Fixed	0.047	0.034	3°37'04"	16202.444	-42.355

Acceptance Summary

Processed	Passed	Flag	Fail
1	1	0	0

Vector Components (Mark to Mark)

From:	MRQ-25				
Grid		Local		Global	
Easting	376341.198 m	Latitude	N13°22'56.92804"	Latitude	N13°22'51.86815"
Northing	1479627.069 m	Longitude	E121°51'28.72677"	Longitude	E121°51'33.72033"
Elevation	47.679 m	Height	48.183 m	Height	97.201 m

To:	BM-5				
Grid		Local		Global	
Easting	377438.371 m	Latitude	N13°31'43.12821"	Latitude	N13°31'38.03406"
Northing	1495788.872 m	Longitude	E121°52'02.72781"	Longitude	E121°52'07.70875"
Elevation	5.200 m	Height	5.828 m	Height	54.472 m

Vector					
ΔEasting	1097.173 m	NS Fwd Azimuth	3°37'04"	ΔX	1139.785 m
ΔNorthing	16161.802 m	Ellipsoid Dist.	16202.444 m	ΔY	-3770.308 m
ΔElevation	-42.479 m	ΔHeight	-42.355 m	ΔZ	15716.494 m

Standard Errors

Vector errors:					
σ ΔEasting	0.018 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.019 m
σ ΔNorthing	0.008 m	σ Ellipsoid Dist.	0.007 m	σ ΔY	0.016 m
σ ΔElevation	0.017 m	σ ΔHeight	0.017 m	σ ΔZ	0.008 m

ANNEX 4. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	ENGR. LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
	Research Associate (RA)	JERIEL PAUL ALAMBAN, GEOL.	UP-TCAGP
	RA	ENGR. IRO NIEL ROXAS	UP-TCAGP
Ground Survey	RA	FOR. MA. REMEDIOS VILLANUEVA	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. BENJIE CARBOLLEDO	Philippine Air Force (PAF)
	Pilot	CAPT. CESAR ALFONSO III	Asian Aerospace Corporation (AAC)
		CAPT. DEXTER CABUDOL	AAC

ANNEX 5. Data Transfer Sheets for the Boac Floodplain Flights

DATA TRANSFER SHEET
Marinduque 11/5/15

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	
9-Oct	10020P	1BLK22ABC282A	Pegasus	398	na	11.6	239	30.1	227	19.3	na	8.29	1KB	1KB	46/53	na	Z:\DAC\RAW DATA
9-Oct	10021P	1BLK22B282B	Pegasus	1.25	54	5.61	131	13.8	66/3/3/4/44	11.6	na	8.29	1KB	1KB	36	na	Z:\DAC\RAW DATA
12-Oct	10027P	1BLK22AB285A	Pegasus	2.2	na	12.8	285	44.4	361	28.9	na	5.22	1KB	1KB	46/53	na	Z:\DAC\RAW DATA
15-Oct	10032P	1BLK22AB288A	Pegasus	700	na	4.7	122	14.8	125	7.78	na	3.72	1KB	1KB	165/46/53	na	Z:\DAC\RAW DATA

Received from

Name C. Joaquin
Position RA
Signature

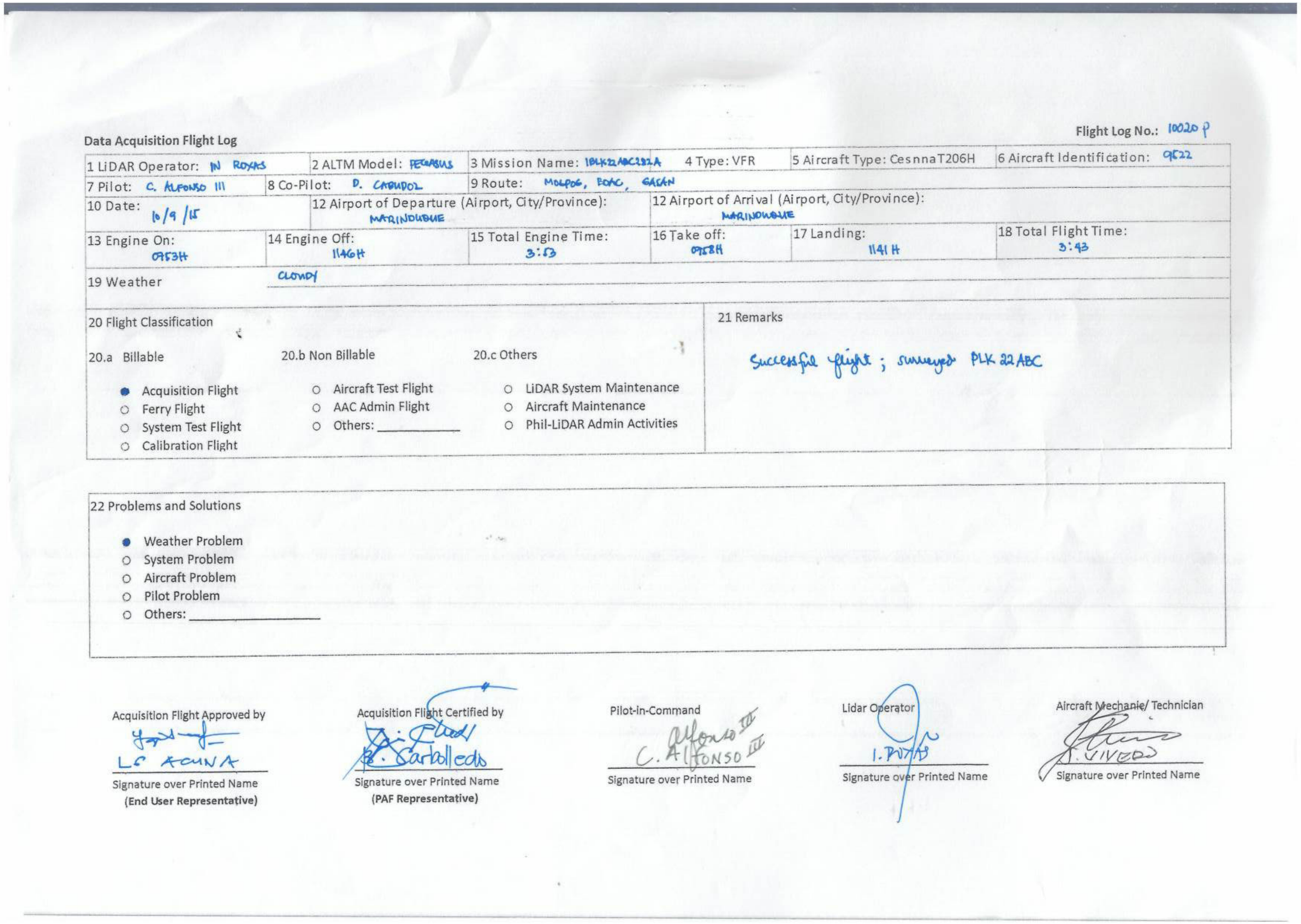
Received by

Name AC Bongat
Position SSRS
Signature 11/10/15

Figure A-5.1. Data Transfer Sheet for Boac Floodplain

ANNEX 6. Flight Logs for the Flight Missions

1. Flight Log for 10020P Mission



Data Acquisition Flight Log

Flight Log No.: 10020P

1 LiDAR Operator: IN ROXAS	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK22ABC282A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9522
7 Pilot: C. ALFONSO III	8 Co-Pilot: D. CABUDOL	9 Route: MOLPOG, BOAC, GASAN			
10 Date: 10/9/15	12 Airport of Departure (Airport, City/Province): MARINDUQUE		12 Airport of Arrival (Airport, City/Province): MARINDUQUE		
13 Engine On: 0753H	14 Engine Off: 1146H	15 Total Engine Time: 3:53	16 Take off: 0758H	17 Landing: 1141H	18 Total Flight Time: 3:43
19 Weather: CLOUDY					

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
- ○ Phil-LiDAR Admin Activities

21 Remarks

Successful flight; surveyed PLK 22ABC

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

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

Acquisition Flight Certified by: B. Caballeda — Signature over Printed Name (PAF Representative)

Pilot-in-Command: C. ALFONSO III — Signature over Printed Name

Lidar Operator: I. ROXAS — Signature over Printed Name

Aircraft Mechanic/ Technician: J. VIVERO — Signature over Printed Name

Figure A-6.1. Flight Log for Mission 10020P

2. Flight Log for 10021P Mission

Data Acquisition Flight Log — **Flight Log No.:** 10021P

1 LiDAR Operator: JP ALAMBAN	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK22B282B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9522
7 Pilot: C. ALFONSO III	8 Co-Pilot: D. CABUDOL	9 Route: MOGPOC, BOAC, GASAN			
10 Date: 10/9/15	12 Airport of Departure (Airport, City/Province): MARINDUQUE		12 Airport of Arrival (Airport, City/Province): MARINDUQUE		
13 Engine On: 1405H	14 Engine Off: 1616H	15 Total Engine Time: 2:11	16 Take off: 1410H	17 Landing: 1611 H	18 Total Flight Time: 2:01
19 Weather: FAIR					

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
- ○ Phil-LiDAR Admin Activities

21 Remarks

Successful flight ; surveyed BLK 22B

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/ Technician
LG ACUNA	[signature]	C. ALFONSO III	JP ALAMBAN	J. VIVERO
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-6.2. Flight Log for Mission 10021P

3. Flight Log for 10027P Mission

Data Acquisition Flight Log

Flight Log No.: 10027P

1 LiDAR Operator: JP ALAMBAN	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK22AB285A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9522
7 Pilot: C. ALFONSO III	8 Co-Pilot: P. CABUDOL	9 Route: MOGPOG, BOAC, STA. CRUZ			
10 Date: 10/12/15	12 Airport of Departure (Airport, City/Province): MARINDUQUE		12 Airport of Arrival (Airport, City/Province): MARINDUQUE		
13 Engine On: 0730H	14 Engine Off: 1153H	15 Total Engine Time: 4+23	16 Take off: 0735H	17 Landing: 1148H	18 Total Flight Time: 4+13
19 Weather: FAIR					

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
- ○ Phil-LiDAR Admin Activities

21 Remarks

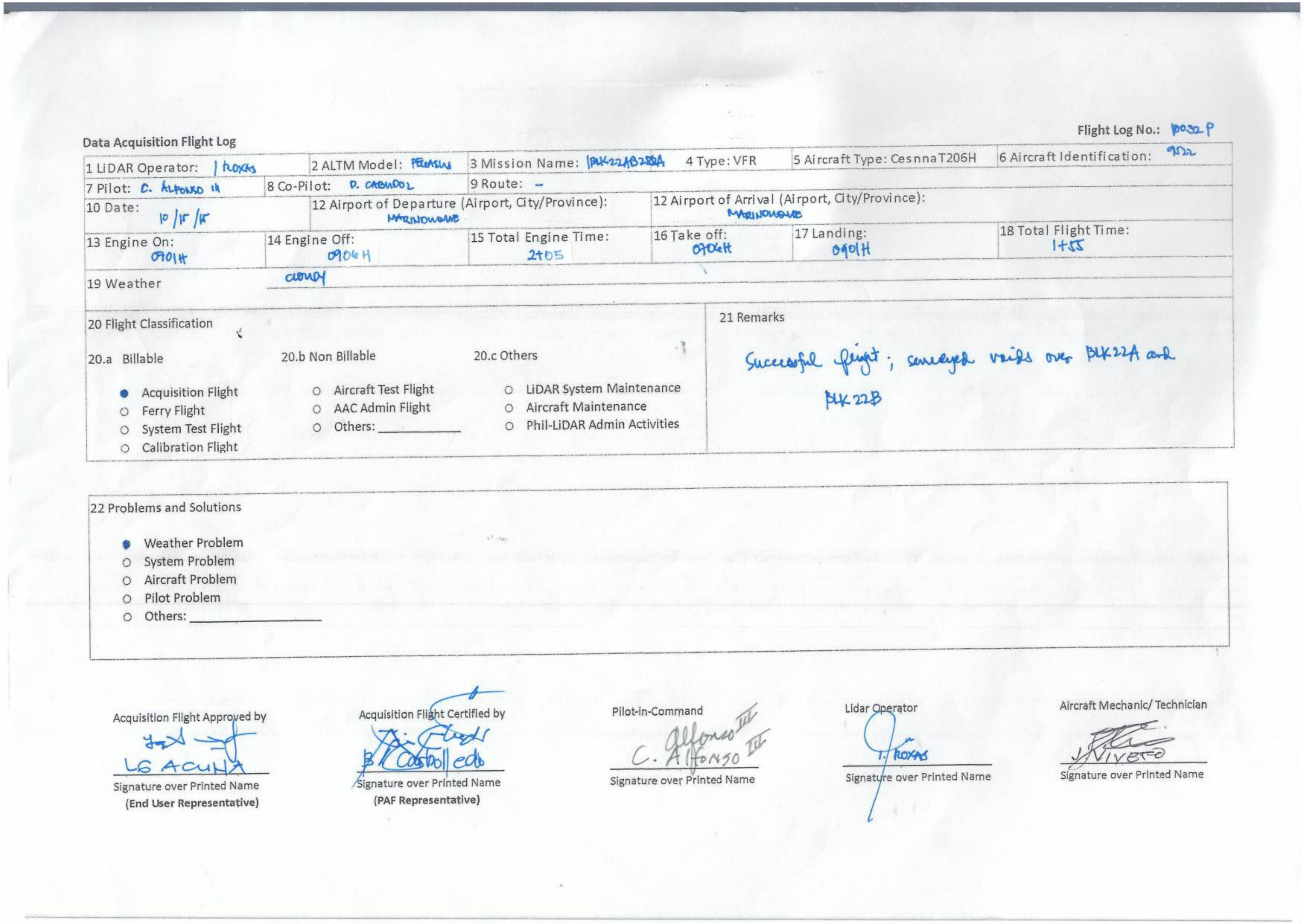
Successful flight; surveyed BLK 22AB

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/ Technician
LG AQUINA	B. CARBALLEDO	C. ALFONSO III	JP ALAMBAN	[illegible]
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 10027P

4. Flight Log for 10032P Mission



Data Acquisition Flight Log

Flight Log No.: 10032P

1 LiDAR Operator: J. Roxas	2 ALTM Model: Pegasus	3 Mission Name: 1BLK22AB288A / 4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9522
7 Pilot: C. Alfonso III	8 Co-Pilot: D. Cabudol	9 Route: –		
10 Date: 10/15/15	12 Airport of Departure (Airport, City/Province): Marinduque		12 Airport of Arrival (Airport, City/Province): Marinduque	
13 Engine On: 0701H	14 Engine Off: 0906H	15 Total Engine Time: 2+05	16 Take off: 0706H / 17 Landing: 0901H	18 Total Flight Time: 1+55
19 Weather: cloudy				

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
- ○ Phil-LiDAR Admin Activities

21 Remarks

Successful flight; surveyed voids over BLK22A and BLK22B

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/ Technician
LG Acuna	B. Castolledo	C. Alfonso III	J. Roxas	J. Nivero
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 10032P

ANNEX 7. Flight Status Reports

Table A-7.1. Flight Status Report

MARINDUQUE
(October 9, 12 & 15, 2015)

Flight No	Area	Mission	Operator	Date Flown	Remarks
10020P	BLK22A, BLK22B AND BLK22C	1BLK22ABC282A	I. Roxas	October 9, 2015	SURVEYED BLK 22ABC (BOAC FP); VOIDS DUE TO CLOUDS; 1000M ALT; OCCASIONAL LOST CHANNEL A; DIGI START UP PROBLEM DUE TO DISK ERROR 174.8 SQ. KM
10021P	BLK22B	1BLK22B282B	J.P. Alamban	October 9, 2015	SURVEYED BLK 22B (BOAC FP); LASER NOT RESPONDING & CAMERA ERROR; DIGI START UP PROBLEM DUE TO DISK ERROR; 1100M ALT; 102.3 SQ.KM
10027P	BLK22A AND BLK22B	1BLK22AB285A	J.P. Alamban	October 12, 2015	SURVEYED BLK 22AB (BOAC FP & BOAC FP); VOIDS DUE TO CLOUDS; LASER NOT RESPONDING, RESTARTED LASER;ABNORMAL TERMINATION OF POSVIEW; DIGI START UP PROBLEM DUE TO DISK ERROR; 1250M ALT; 270 SQ.KM
10032P	BLK22A AND VOIDS OVER BLK22B	1BLK22AB288A	I. Roxas	October 15, 2015	SURVEYED BLK 22AB (BOAC FP & VOIDS OVER BOAC FP); VOIDS DUE TO CLOUDS; DIGI START UP PROBLEM DUE TO DISK ERROR; 53.8 SQ.KM

Flight No. : 10020P
Area: BLK 22A, BLK 22B & BLK 22C BOAC FP
Mission Name: 1BLK22ABC282A
Parameters:
PRF 200
SF 30
FOV 50

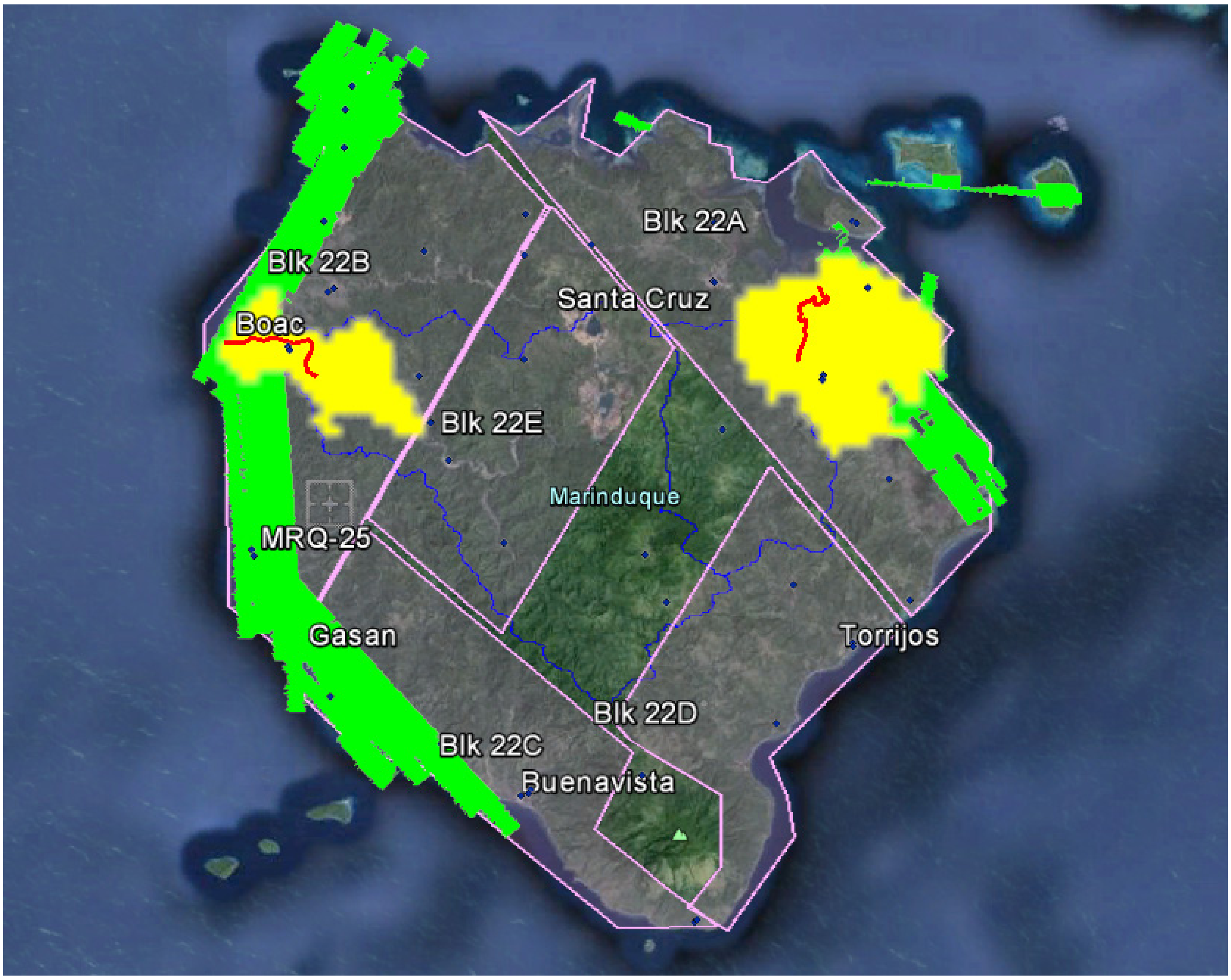


Figure A-7.1. Swath for Flight No. 10020P

Flight No. : 10021P
Area: BLK 22B BOAC FP
Mission Name: 1BLK22B282B
Parameters:
PRF 200
SF 30
FOV 50

Figure A-7.2. Swath for Flight No. 10021P

Flight No. : 10027P
Area: BLK22 A & BLK 22B BOAC FP; BOAC FP
Mission Name: 1BLK22AB285A
Parameters:
PRF 200
SF 30
FOV 50

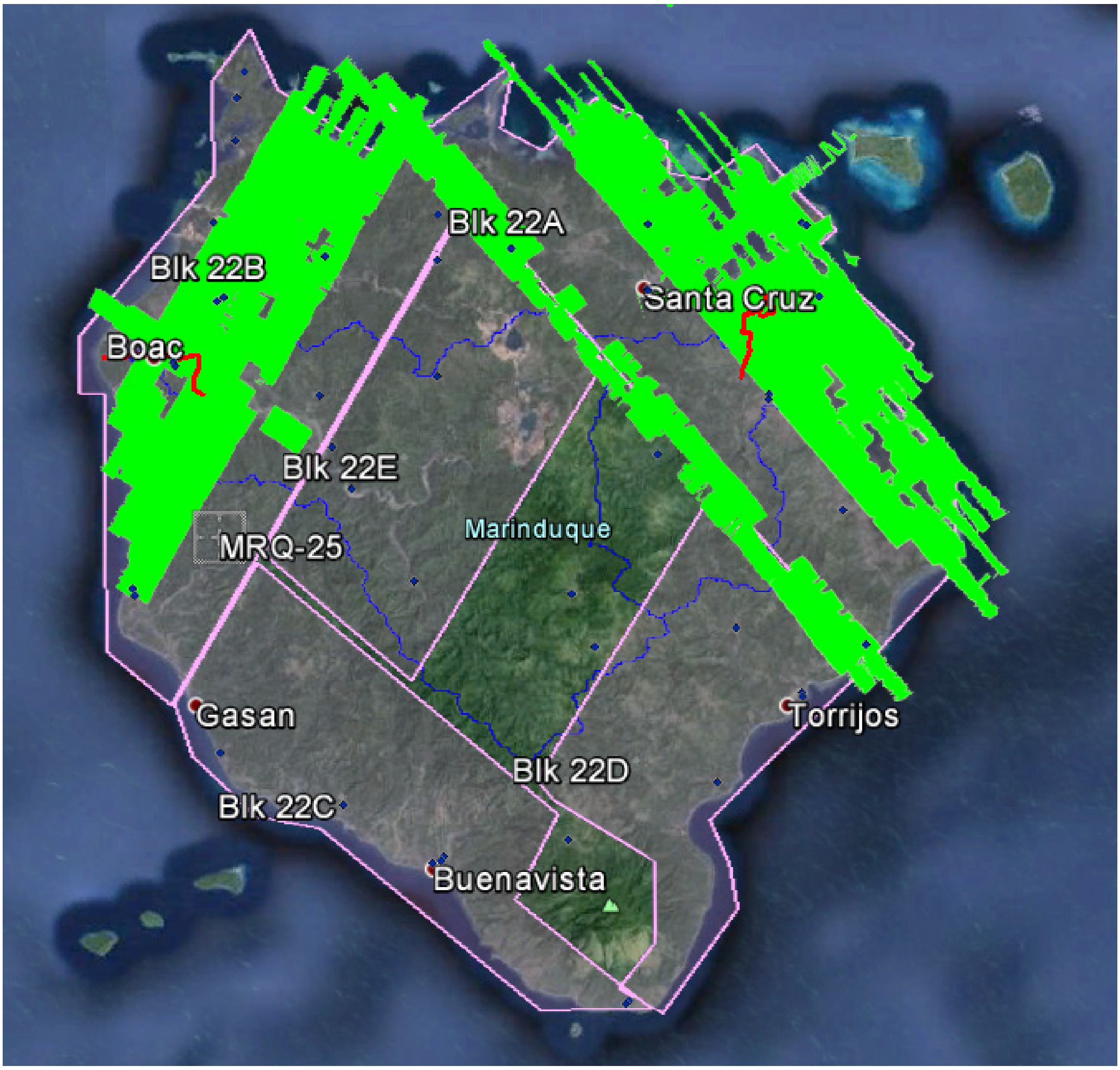


Figure A-7.3. Swath for Flight No. 10027P

Flight No. : 10032P
Area: BLK22A & VOIDS OVER BLK 22B BOAC FP; BOAC FP
Mission Name: 1BLK22AB288A
Parameters:
PRF 200
SF 30
FOV 50

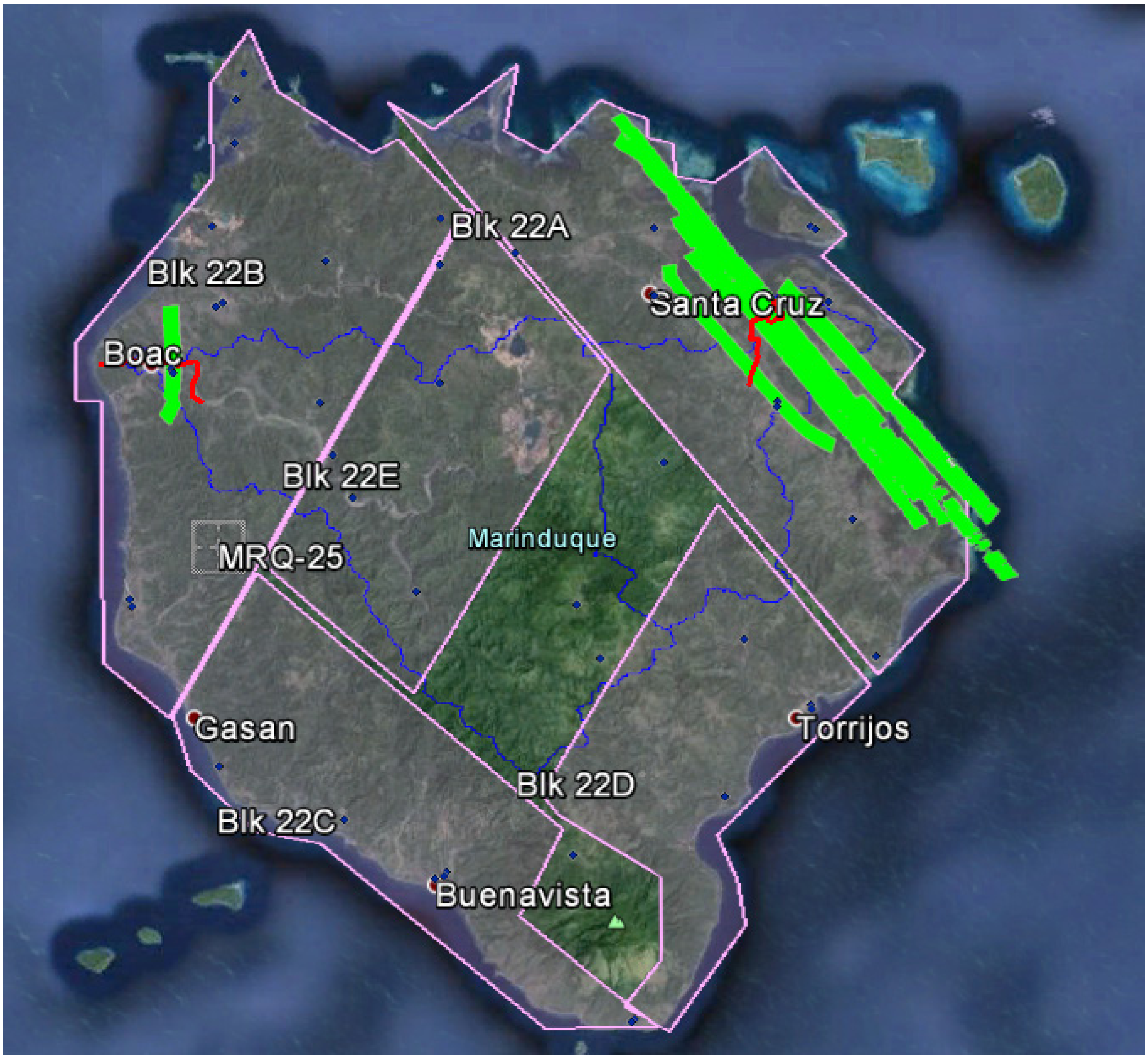


Figure A-7.4. Swath for Flight No. 10032P

ANNEX 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk22B

Flight Area	**Marinduque**
Mission Name	Blk22B
Inclusive Flights	10021P, 10020P, 10027P, 10032P
Range data size	28.9 GB
POS	285 MB
Image	44.4 MB
Transfer date	November 10, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.05
RMSE for East Position (<4.0 cm)	1.16
RMSE for Down Position (<8.0 cm)	2.51
Boresight correction stdev (<0.001deg)	0.000234
IMU attitude correction stdev (<0.001deg)	0.001939
GPS position stdev (<0.01m)	0.0025
Minimum % overlap (>25)	52.5
Ave point cloud density per sq.m. (>2.0)	3.59
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	315
Maximum Height	103.28 m
Minimum Height	50.38 m
Classification (# of points)	
Ground	141,610,678
Low vegetation	108,945,893
Medium vegetation	261,014,217
High vegetation	1,102,155,348
Building	18,187,526
Orthophoto	Yes
Processed by	Engr. Jennifer Saguran, Engr. Analyn Naldo, Abi, Engr. Mark Joshua Salvacion, Alex

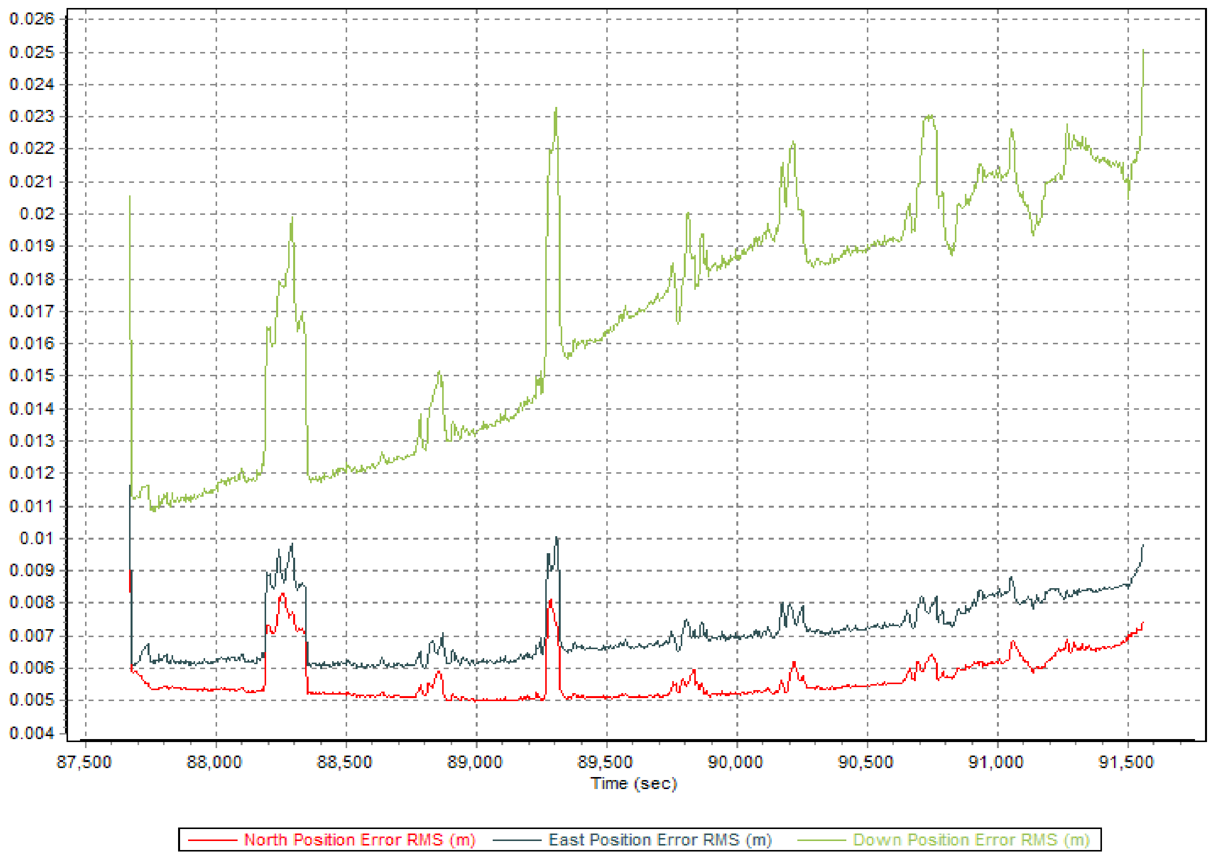


Figure A-8.1 Solution Status

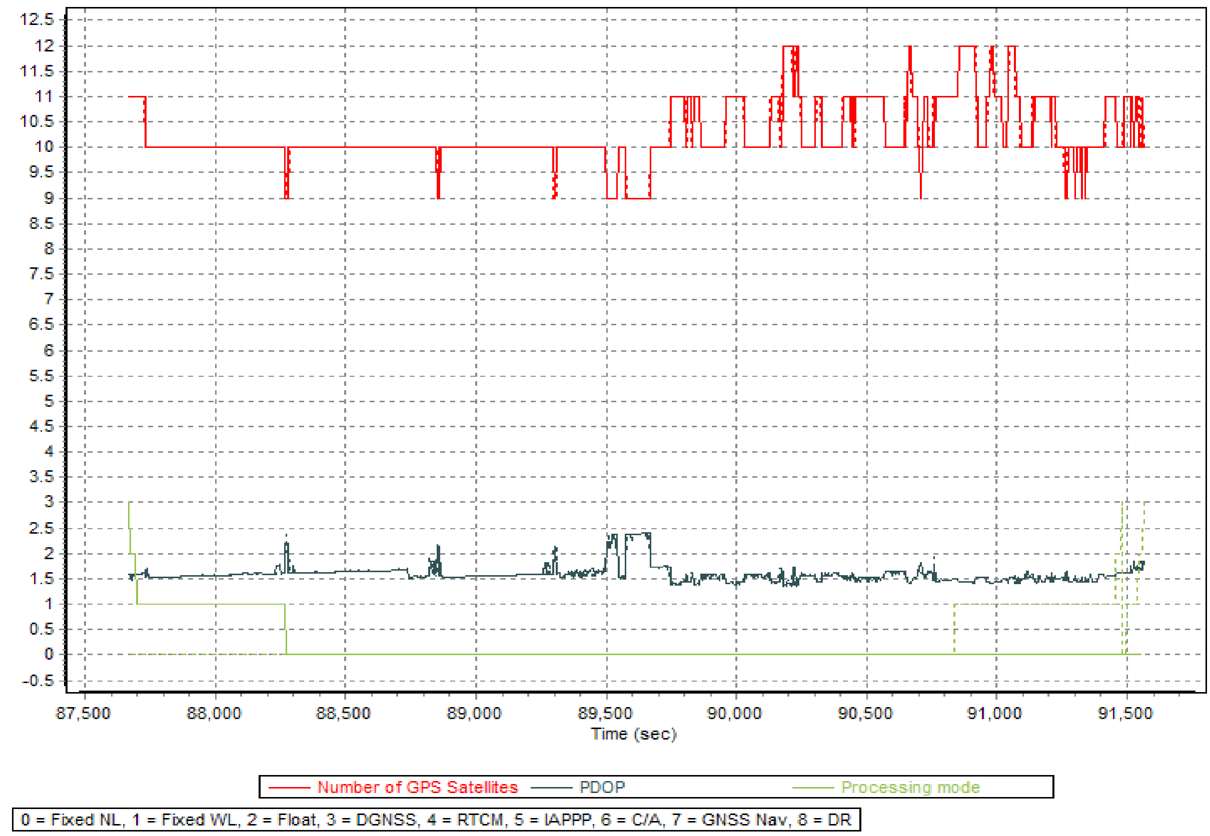


Figure A-8.2 Smoothed Performance Metric Parameters

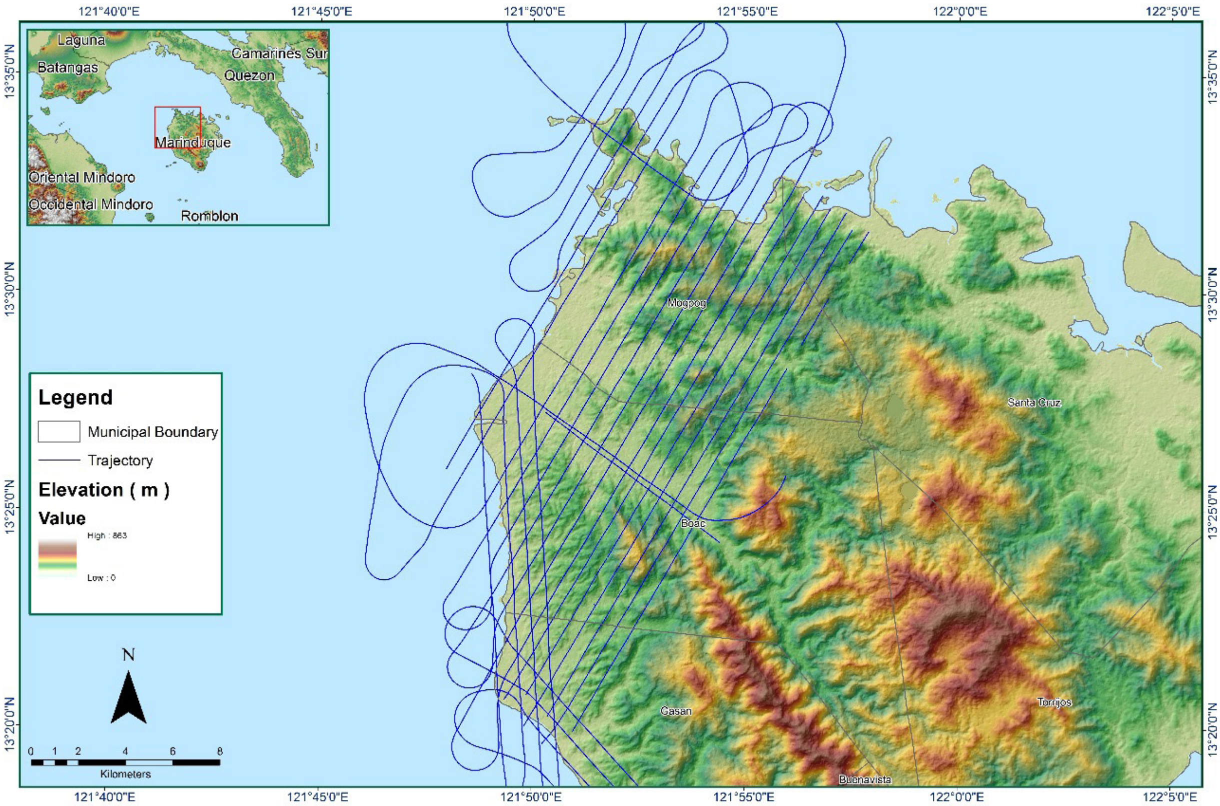


Figure A-8.3 Best Estimated Trajectory

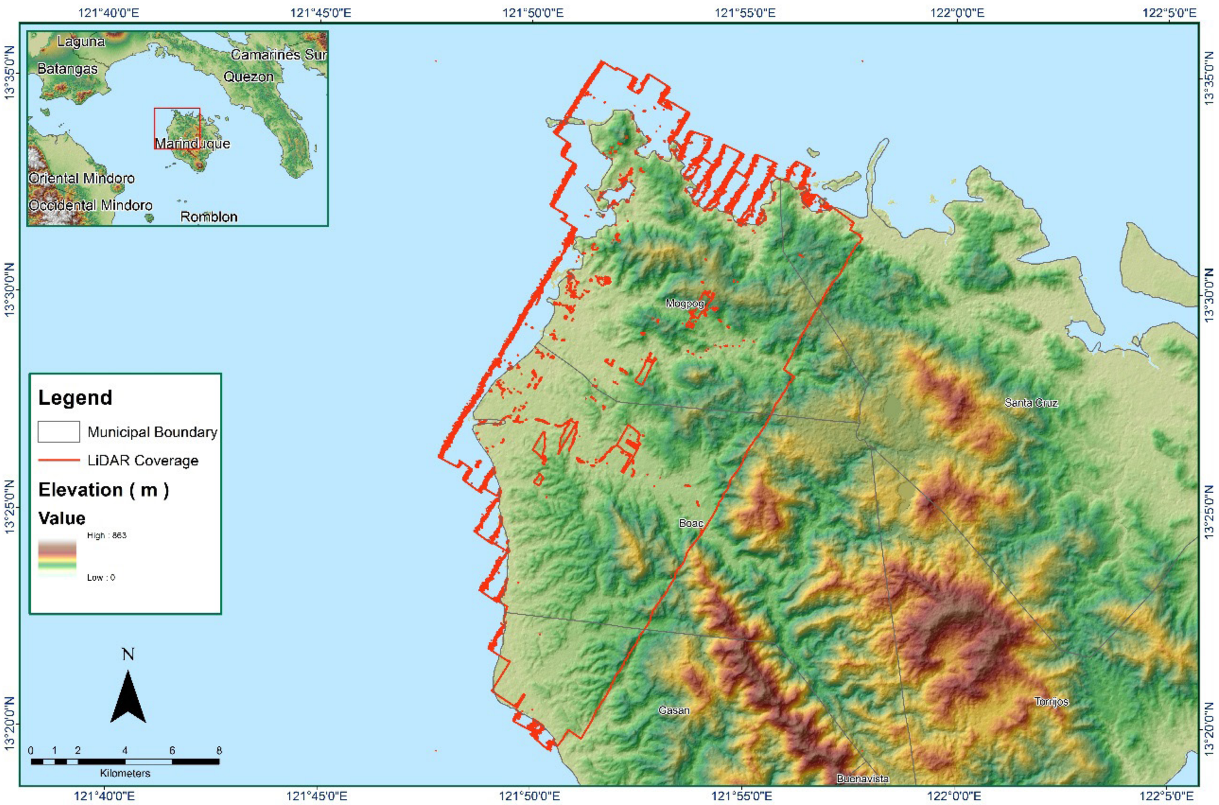


Figure A-8.4 Coverage of LiDAR data

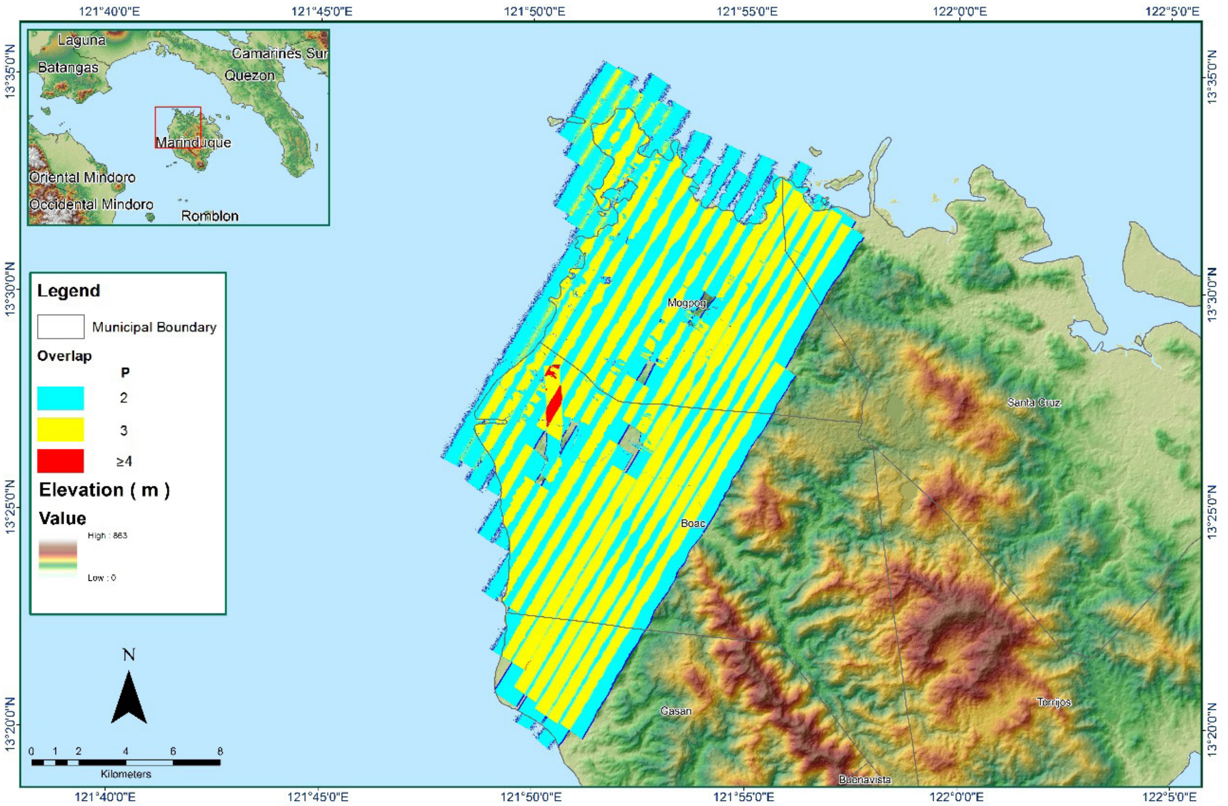


Figure A-8.5 Image of data overlap

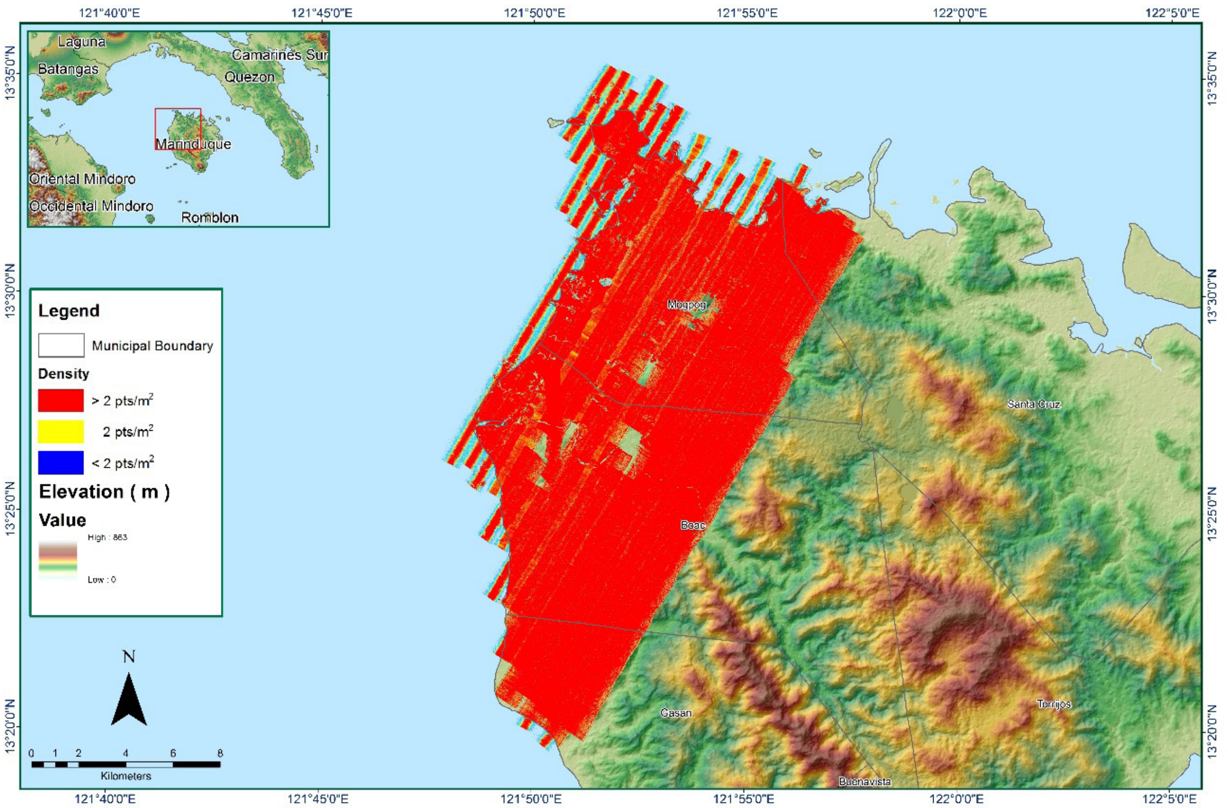


Figure A-8.6 Density map of merged LiDAR data

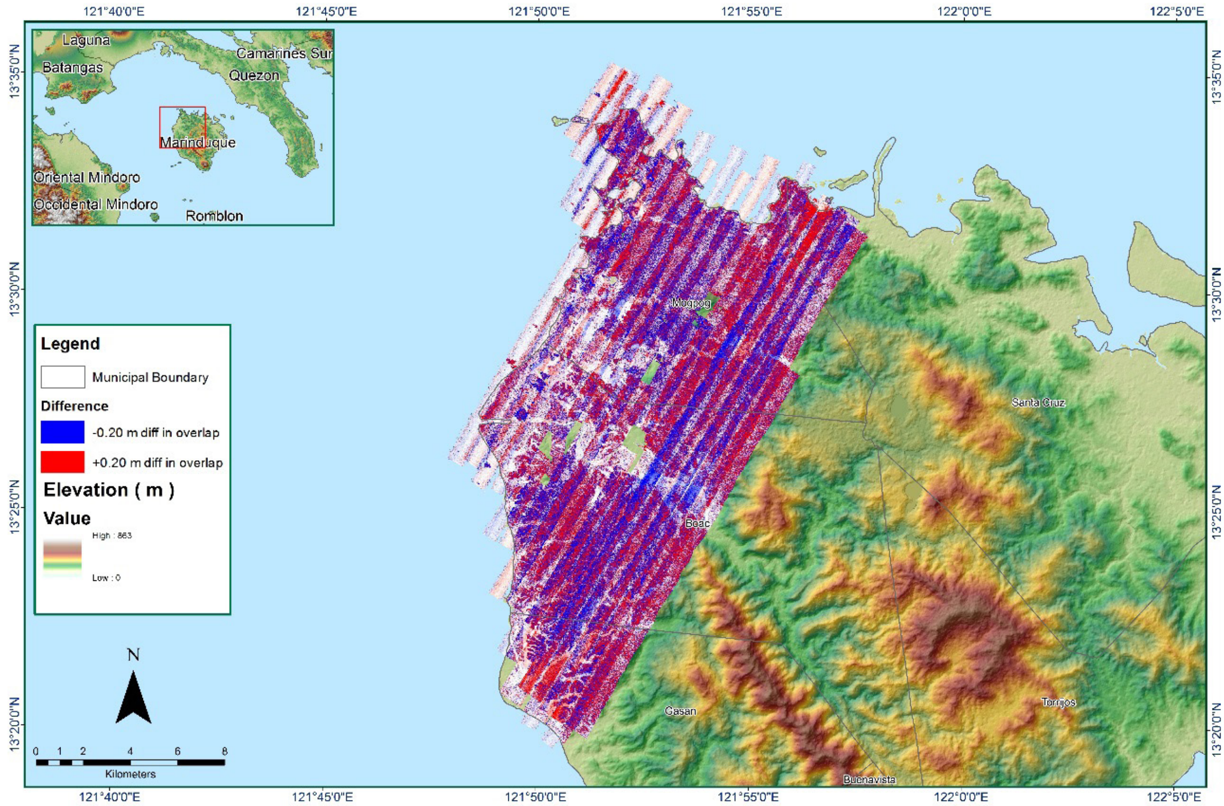


Figure A-8.7 Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk22C

Flight Area	Marinduque
Mission Name	Blk22C
Inclusive Flights	10020P
Range data size	19.3 GB
POS	239 MB
Image	30.1 MB
Transfer date	November 10, 2015
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)	9.29
RMSE for East Position (<4.0 cm)	5.52
RMSE for Down Position (<8.0 cm)	9.22
Boresight correction stdev (<0.001deg)	0.000318
IMU attitude correction stdev (<0.001deg)	0.002991
GPS position stdev (<0.01m)	0.0141
Minimum % overlap (>25)	30.09
Ave point cloud density per sq.m. (>2.0)	2.36
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	85
Maximum Height	284.36 m
Minimum Height	48.54 m
Classification (# of points)	
Ground	24,814,146
Low vegetation	25,045,302
Medium vegetation	35,101,710
High vegetation	115,034,834
Building	2,740,444
Orthophoto	Yes
Processed by	Engr. Jennifer Saguran, Engr. Velina Angela Bemida, Engr. Krisha Marie Bautista

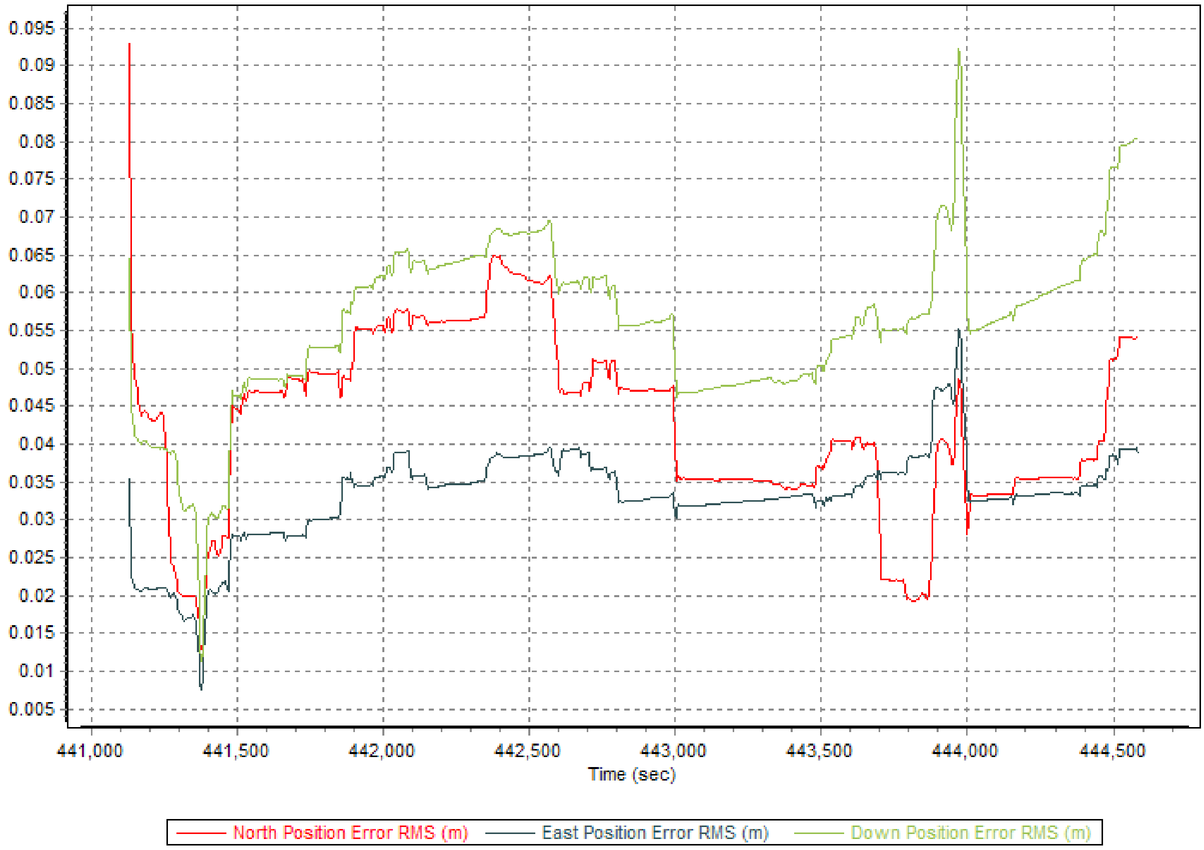


Figure A-8,8 Solution Status

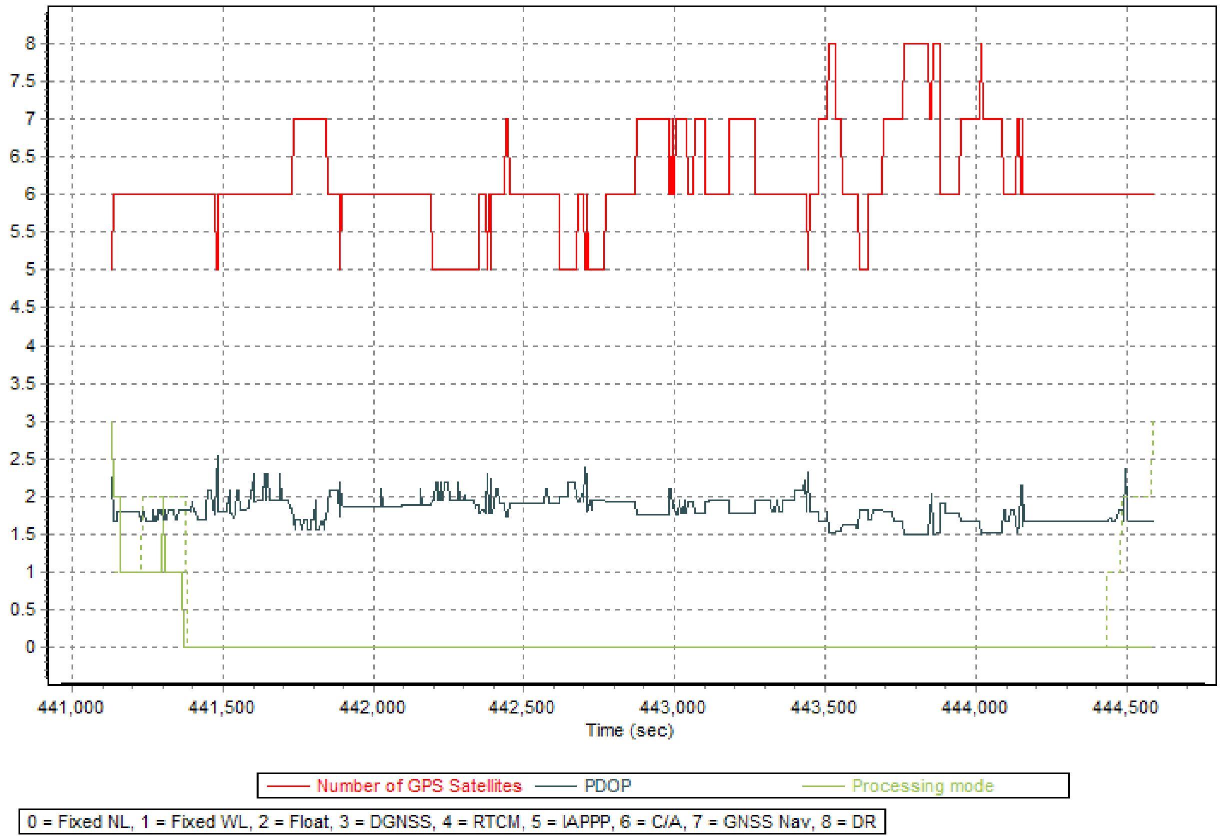


Figure A-8,9 Smoothed Performance Metric Parameters

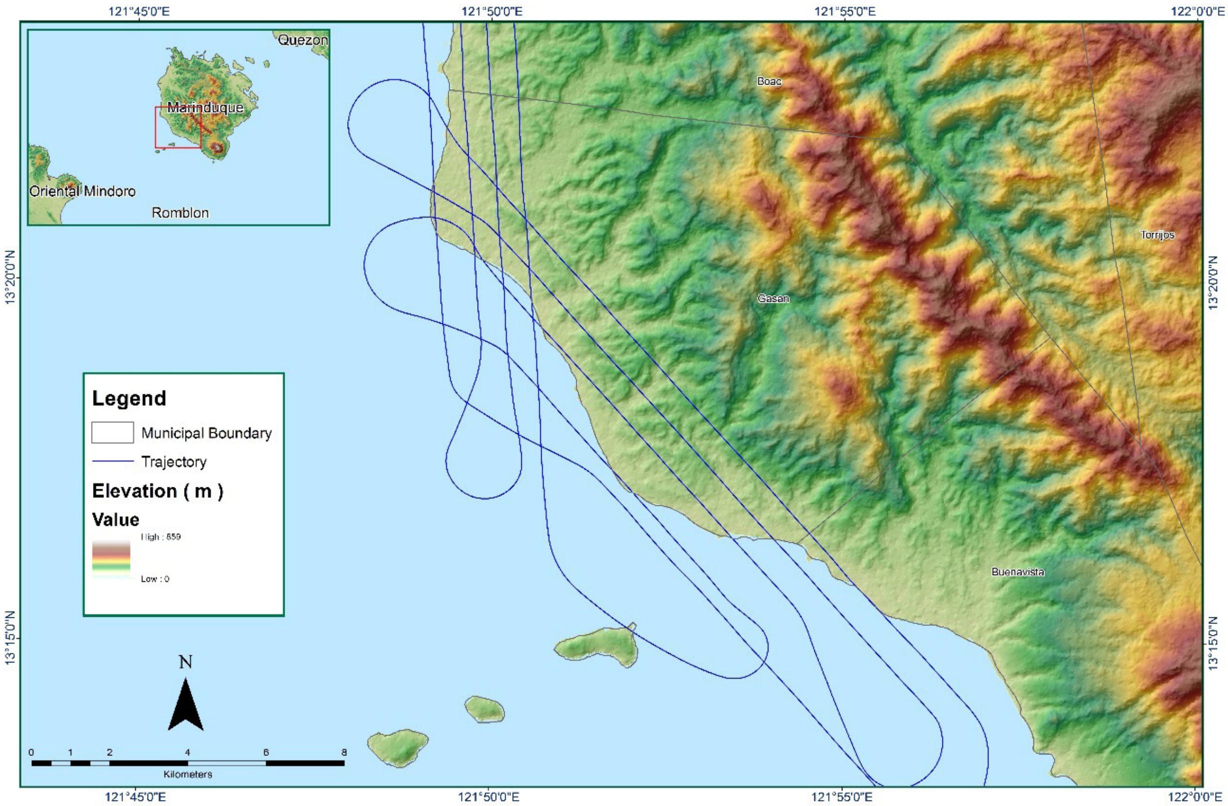


Figure A-8.10 Best Estimated Trajectory

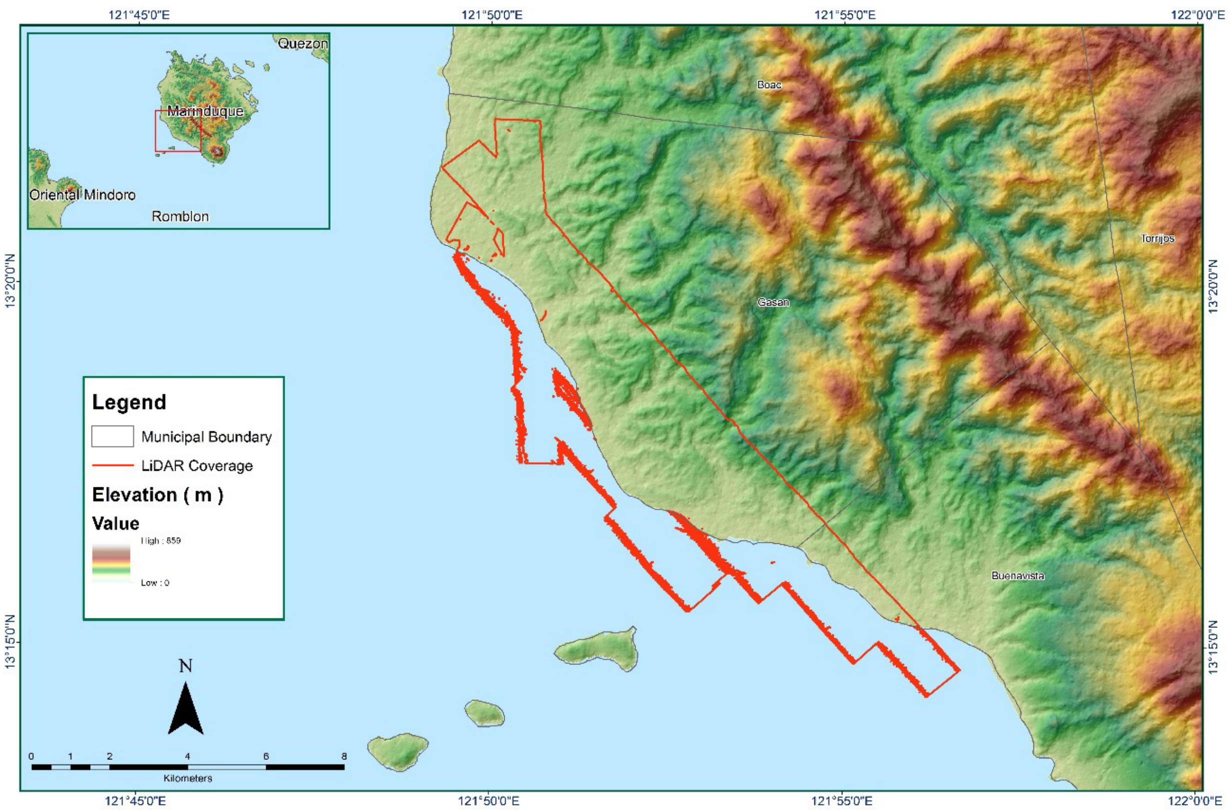


Figure A-8.11 Coverage of LiDAR data

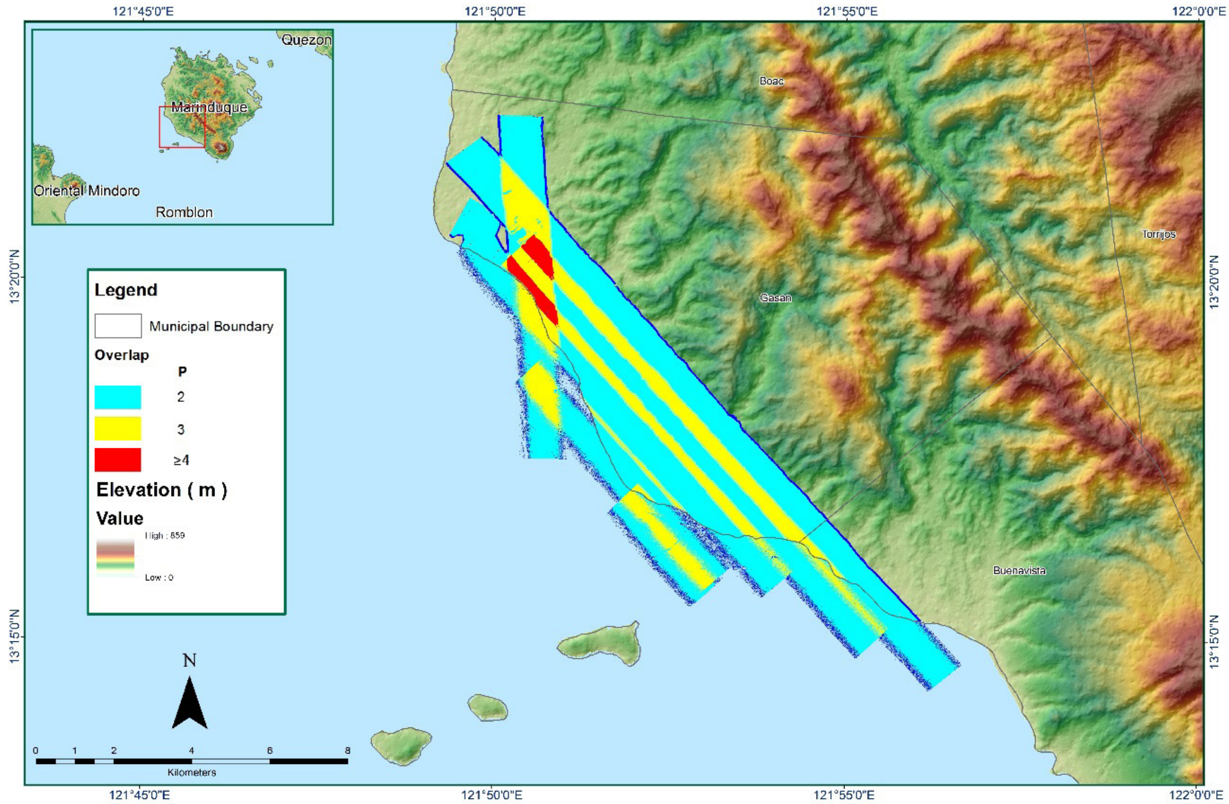


Figure A-8.12 Image of data overlap

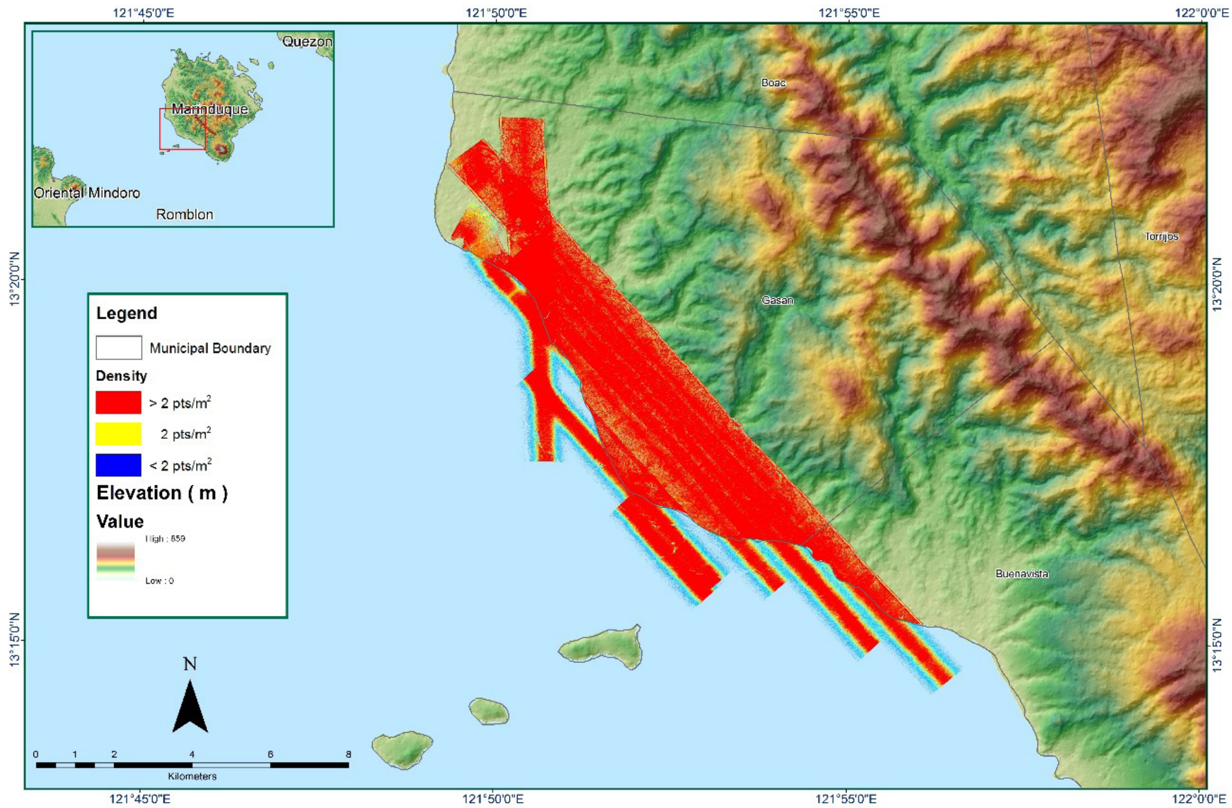


Figure A-8.13 Density map of merged LiDAR data

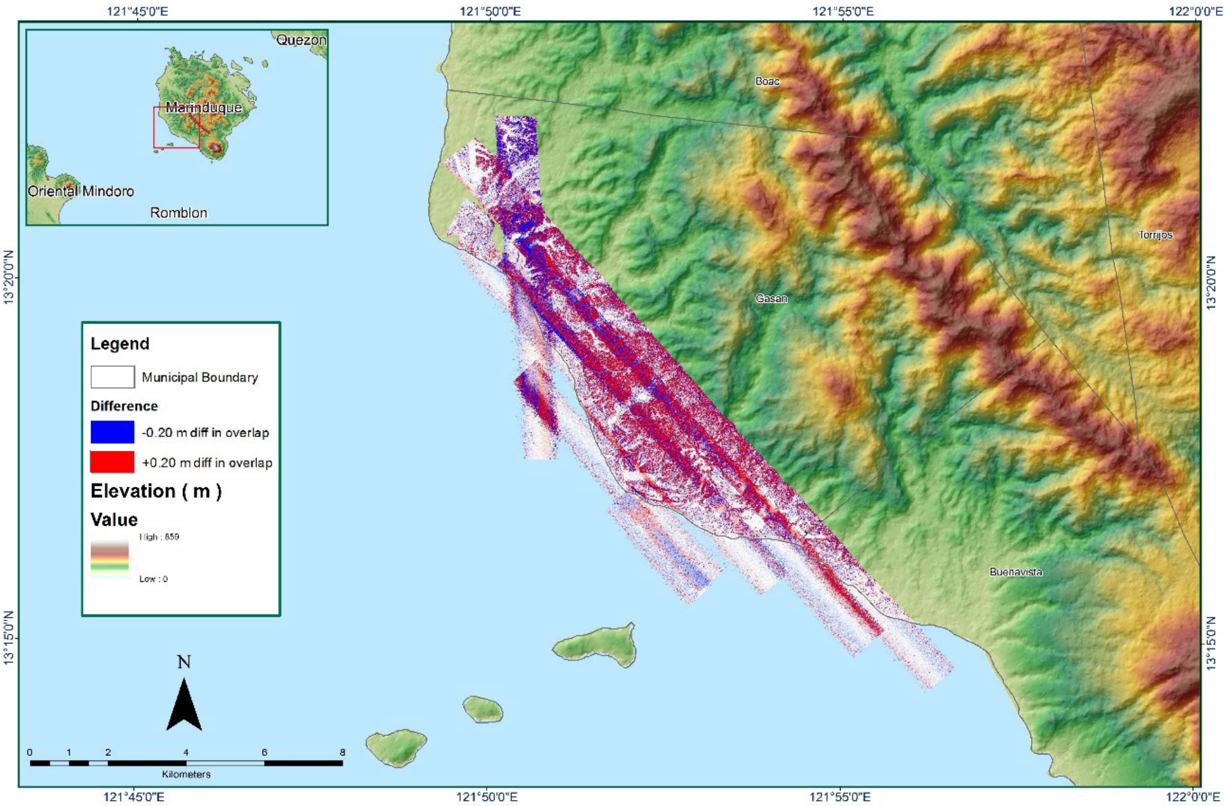


Figure A-8.14 Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk22A_additional

Flight Area	Marinduque
Mission Name	Blk22A_additional
Inclusive Flights	10020P
Range data size	55.98 GB
Base data size	16.94 MB
POS	680 MB
Image	89.3
Transfer date	November 10, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.5
RMSE for Down Position (<8.0 cm)	6.5
Boresight correction stdev (<0.001deg)	0.000368
IMU attitude correction stdev (<0.001deg)	0.026050
GPS position stdev (<0.01m)	0.0208
Minimum % overlap (>25)	30.44%
Ave point cloud density per sq.m. (>2.0)	2.52
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	80
Maximum Height	220.42 m
Minimum Height	42.28 m
Classification (# of points)	
Ground	52,070,081
Low vegetation	22,527,052
Medium vegetation	30,323,621
High vegetation	130,098,631
Building	4,167,385
Orthophoto	Yes
Processed by	Engr. Jennifer Saguran, Engr. Chelou Prado, Engr. Elainne Lopez

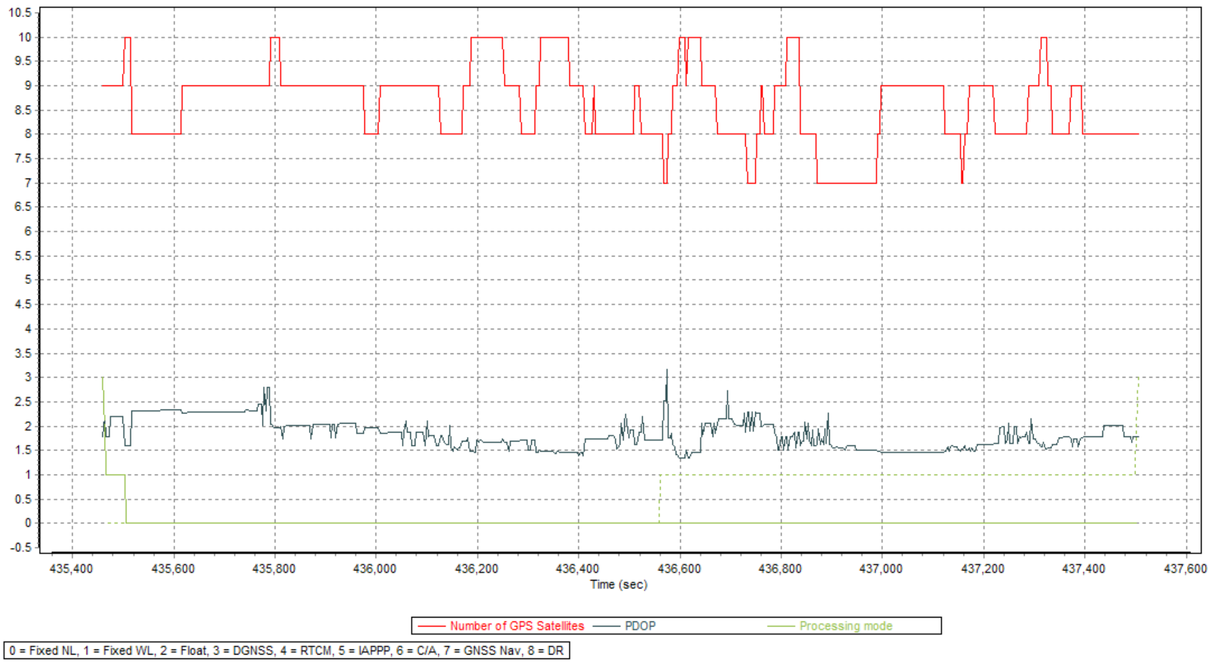


Figure A-8.15 Solution Status

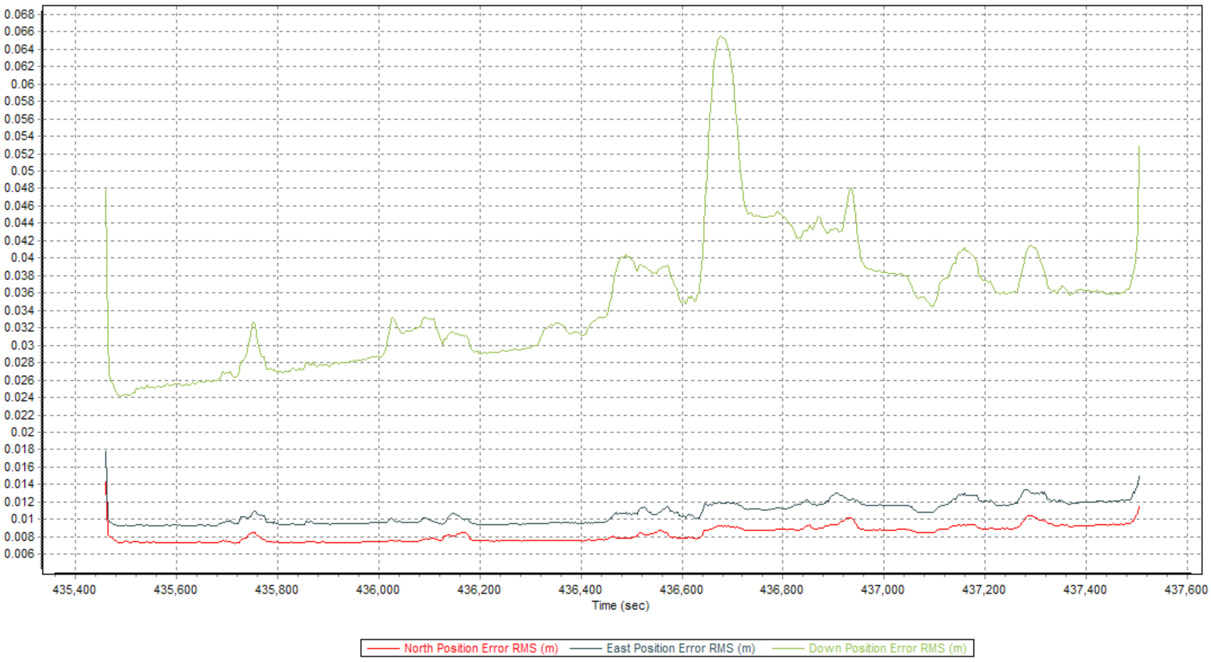


Figure A-8.16 Smoothed Performance Metric Parameters

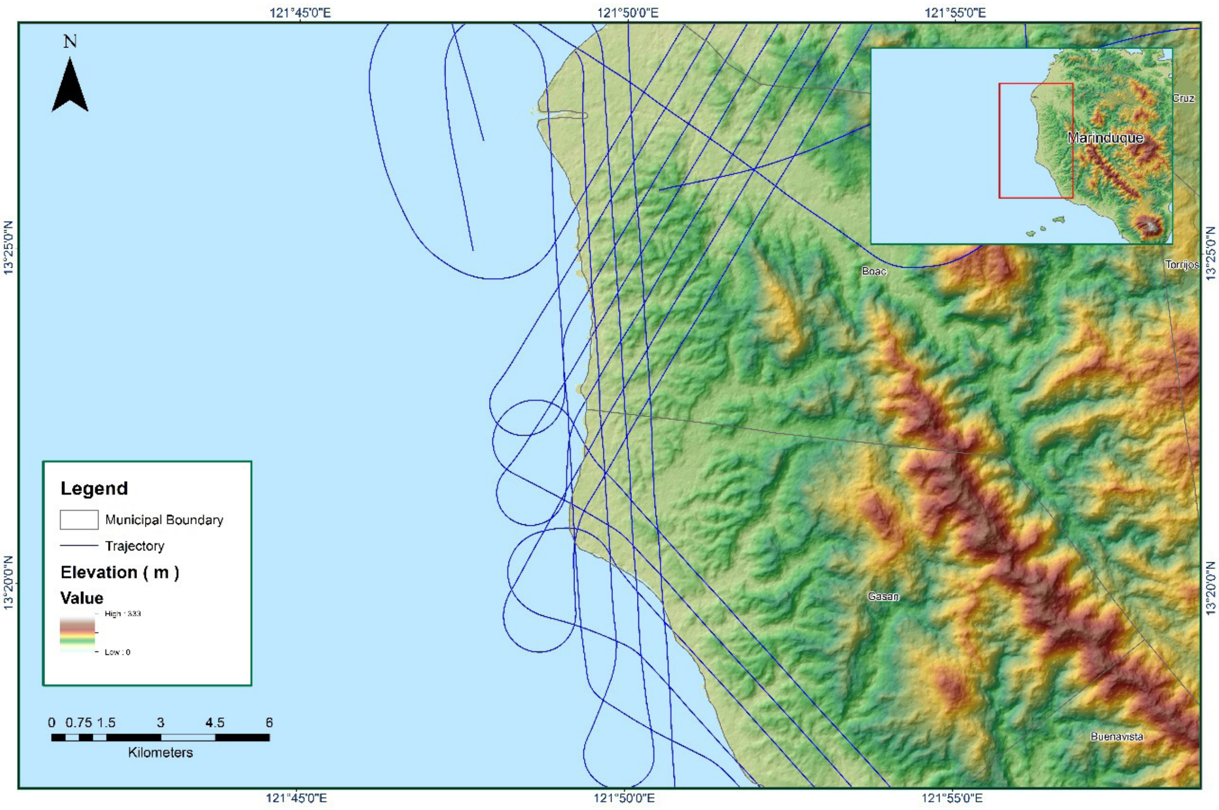


Figure A-8.17 Best Estimated Trajectory

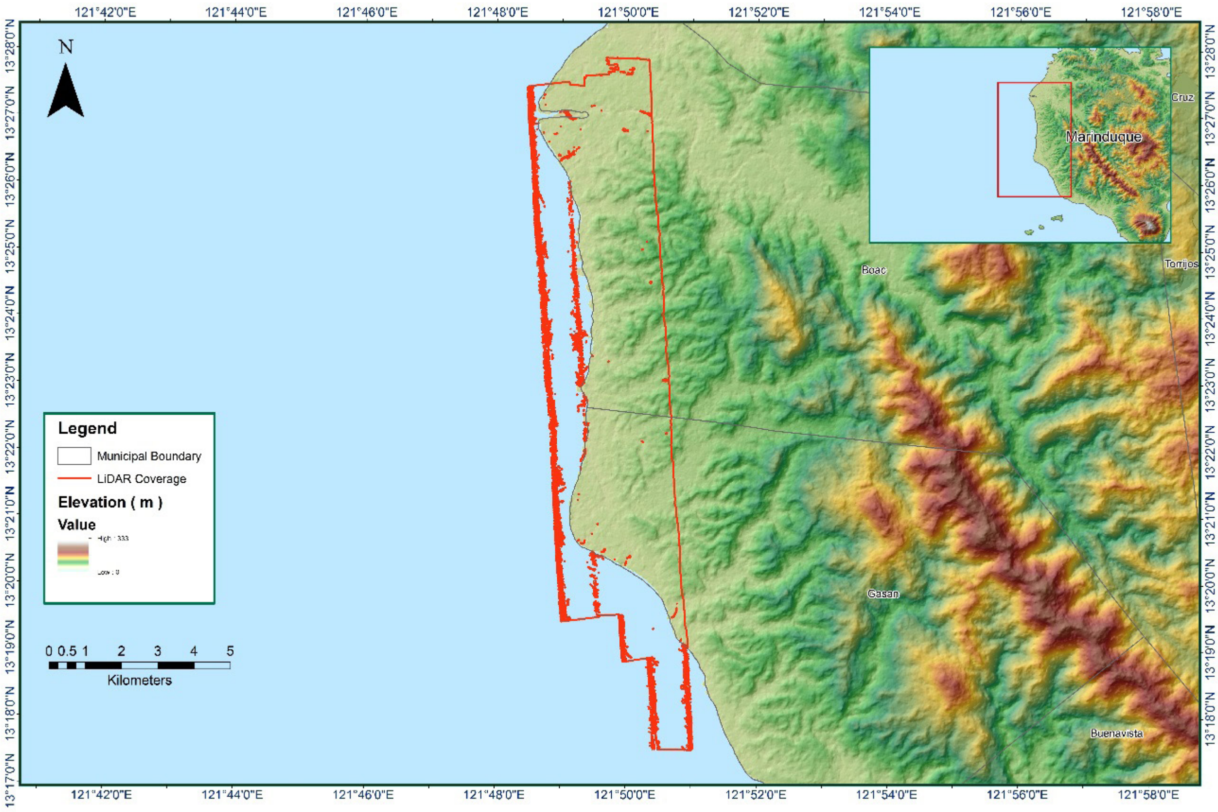


Figure A-8.18 Coverage of LiDAR data

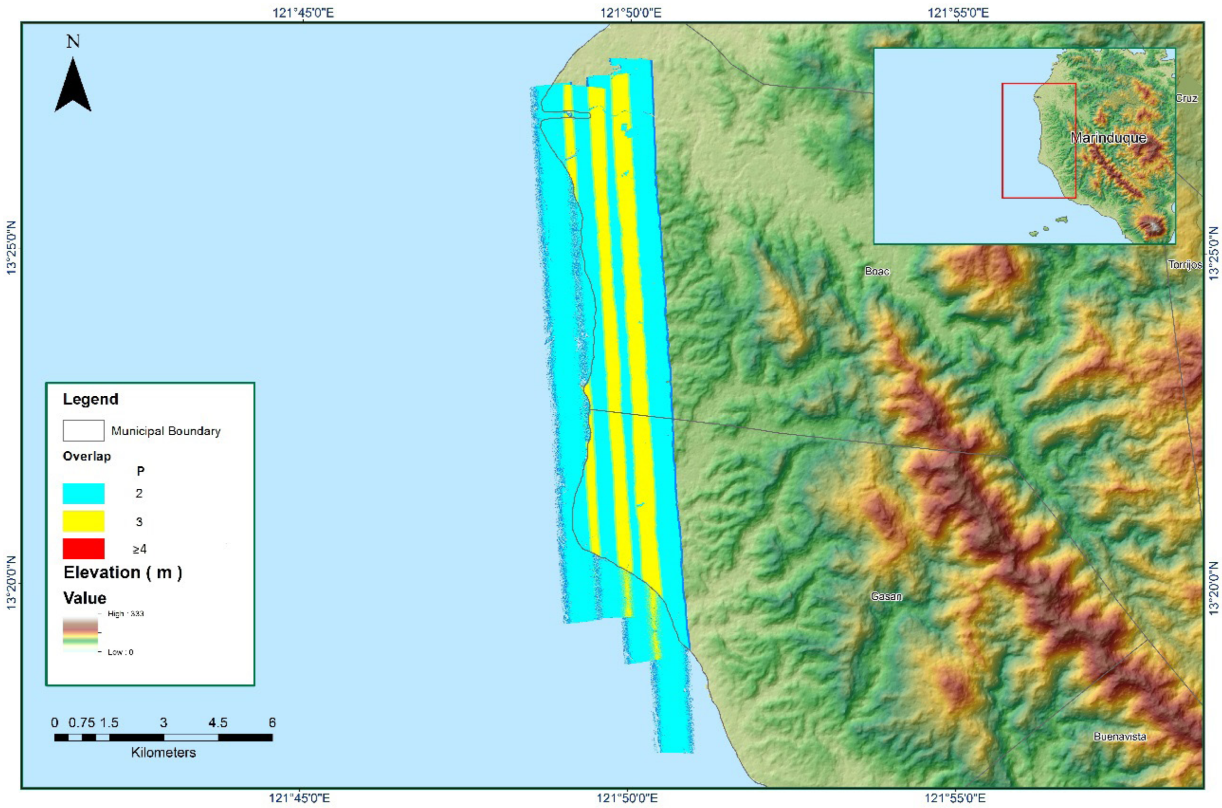


Figure A-8.19 Image of data overlap

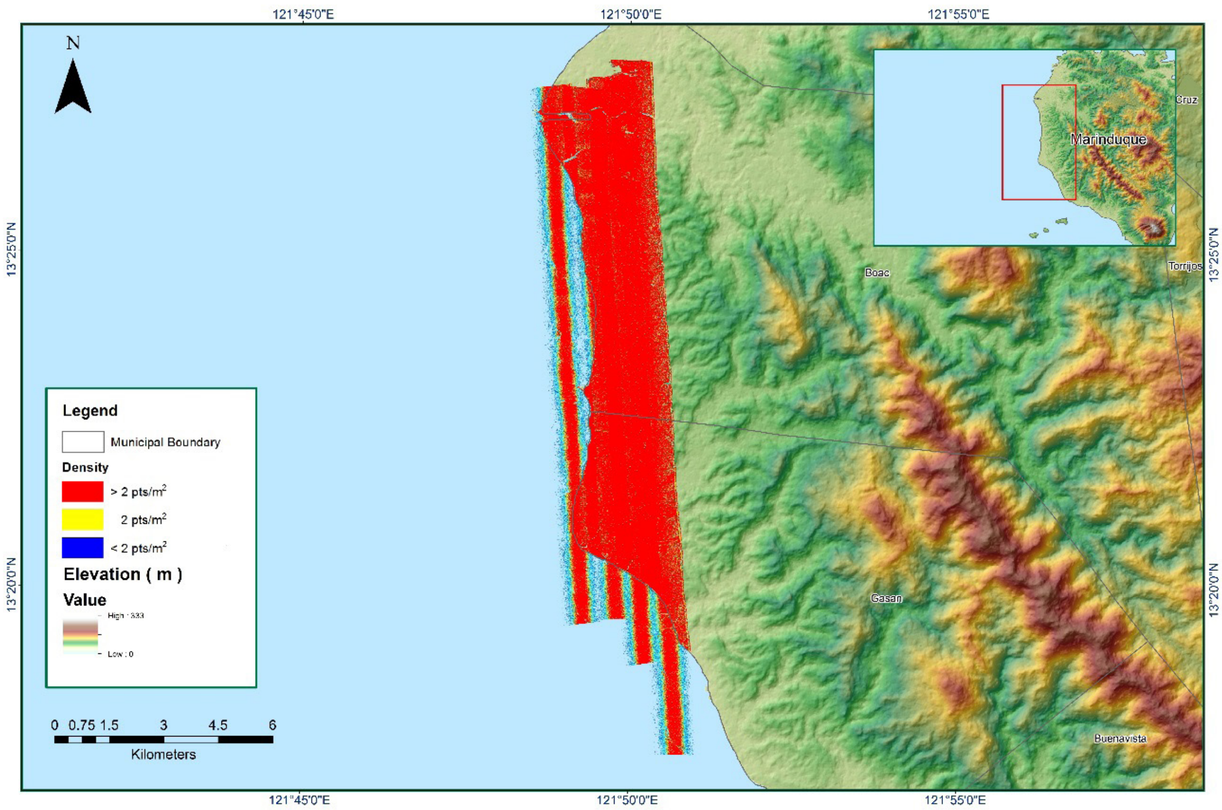


Figure A-8.20 Density map of merged LiDAR data

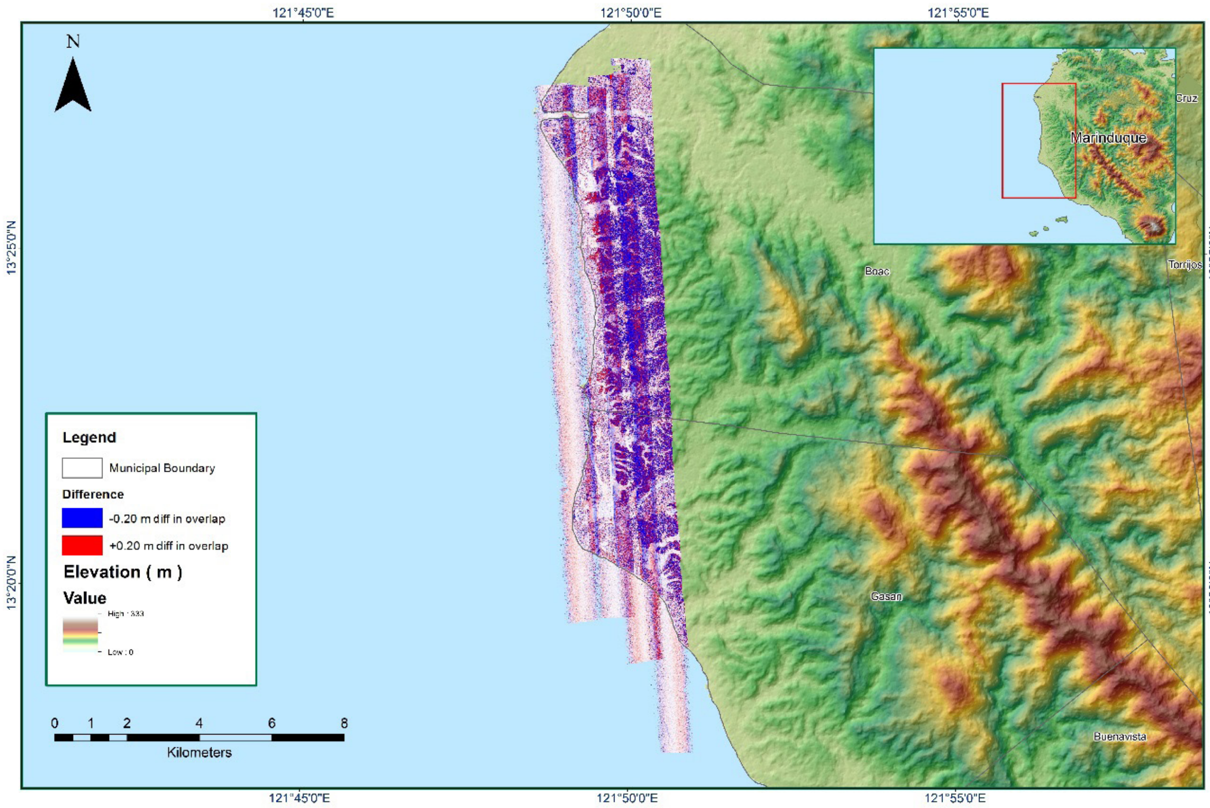


Figure A-8.21 Elevation difference between flight lines

ANNEX 9. Boac Model Basin Parameters

Table A-9.1. Boac Model Basin Parameters

Sub Basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow		
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (CU.M/S)	Recession Constant	Ratio to Peak
W1000	1.429	55.916	0.0	0.033	35.004	0.00603	0.850	0.8431
W1010	0.052	42.220	0.0	0.148	99.442	0.1035	0.186	0.5
W1020	2.745	42.110	0.0	0.033	99.474	0.005025	0.090	0.485
W1040	4.469	73.972	0.0	2.251	3.673	0.135	1.000	0.500
W1050	4.998	42.302	0.0	0.033	25.428	0.156	0.091	0.319
W530	91.804	42.290	0.0	0.033	94.050	0.22711	0.239	0.225
W540	31.067	42.306	0.0	0.033	0.065	0.14371	0.091	0.048
W550	13.323	42.260	0.0	0.033	81.175	0.015	1.000	0.224
W560	6.906	42.150	0.0	0.033	52.633	0.1545	0.091	0.097
W570	0.451	42.294	0.0	0.033	34.766	0.44718	0.148	0.386
W580	13.482	42.229	0.0	0.033	1.497	0.01809	0.091	0.004
W590	7.405	42.271	0.0	0.033	15.664	0.0070346	1.000	0.66339
W600	1.478	42.277	0.0	0.033	99.475	0.00804	0.121	0.334
W610	76.008	47.580	0.0	0.033	0.144	0.024	0.091	0.008
W620	25.282	42.319	0.0	0.033	33.439	0.017085	0.091	0.329
W630	15.477	42.098	0.0	0.033	25.905	0.003015	1.000	0.546
W640	2.208	42.259	0.0	0.033	99.479	0.138	0.196	0.313
W650	8.486	48.685	0.0	0.033	6.907	0.00201	1.000	0.449
W660	0.840	42.391	0.0	0.033	12.930	0.0360374	0.601	0.348
W670	11.007	46.700	0.0	0.033	0.073	0.011055	0.152	0.008

Sub Basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow		
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (CU.M/S)	Recession Constant	Ratio to Peak
W680	0.467	42.371	0.0	0.033	99.475	0.0465	0.090	0.379
W690	136.080	42.235	0.0	0.033	0.066	0.085	0.091	0.069
W700	28.867	42.211	0.0	0.033	0.264	0.078	0.185	0.037
W710	21.640	42.276	0.0	0.033	0.066	0.105	0.090	0.092
W720	2.197	42.030	0.0	0.033	55.902	0.0201	0.136	0.335
W730	16.687	42.215	0.0	0.033	43.452	0.0402	0.406	0.511
W740	6.824	42.389	0.0	0.033	61.274	0.0422099	0.090	0.264
W750	7.053	42.335	0.0	0.033	43.742	0.00402	0.392	0.518
W760	107.230	42.312	0.0	0.033	0.066	0.00201	0.091	0.096
W770	7.178	42.054	0.0	0.033	20.030	0.0470154	0.578	0.469
W780	2.002	42.226	0.0	0.033	36.786	0.043215	0.090	0.334
W790	3.090	42.222	0.0	0.033	9.135	0.024	0.927	0.329
W800	14.434	42.401	0.0	0.033	19.113	0.072	0.462	0.338
W810	2.789	42.313	0.0	0.033	98.529	0.2766	0.088	0.225
W820	0.964	42.030	0.0	0.033	56.402	0.20802	0.132	0.337
W830	4.580	42.158	0.0	0.033	31.252	0.015075	0.641	0.592
W840	4.024	42.421	0.0	0.033	17.921	0.0311232	0.176	0.322
W850	0.020	42.293	0.0	0.033	56.892	0.1485	0.662	0.758
W860	1.965	42.178	0.0	0.033	27.958	0.0211048	1.000	0.435
W870	3.890	42.214	0.0	0.038	44.992	0.03216	0.168	0.461
W880	1.039	42.050	0.0	0.033	82.342	0.033	0.679	0.755
W890	5.652	42.019	0.0	0.033	66.163	0.0632729	0.896	0.792

Sub Basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow		
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (CU.M/S)	Recession Constant	Ratio to Peak
W900	2.318	42.322	0.0	0.033	99.000	1.763	0.129	0.34
W910	1.693	42.317	0.0	0.033	88.842	0.005025	0.246	0.341
W920	3.484	42.002	0.0	0.033	50.584	0.007035	0.286	0.141
W930	9.796	42.054	0.0	0.033	1.489	0.2373	0.090	0.012
W940	3.375	42.377	0.0	0.033	58.904	0.0261289	0.242	0.487
W950	31.838	99.000	0.0	0.033	3.415	0.00402	0.270	0.025
W960	1.192	42.270	0.0	0.033	56.130	0.195	0.090	0.572
W970	45.860	42.341	0.0	0.033	16.532	0.005025	0.660	0.523
W980	0.037	42.227	0.0	0.039	99.000	0.267	0.090	0
W990	3.370	42.366	0.0	0.033	33.274	0.0150737	0.150	0.339

ANNEX 10. Boac Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	1043.6	0.0038331	0.002	Trapezoid	40.000	1
R1070	Automatic Fixed Interval	3425.2	0.0040402	0.002	Trapezoid	40.000	1
R130	Automatic Fixed Interval	1634.4	0.013842	0.002	Trapezoid	40.000	1
R140	Automatic Fixed Interval	1836.5	0.013842	0.002	Trapezoid	40.000	1
R150	Automatic Fixed Interval	3098.5	0.0148627	0.002	Trapezoid	40.000	1
R180	Automatic Fixed Interval	1538.2	0.0148627	0.002	Trapezoid	40.000	1
R190	Automatic Fixed Interval	2907.9	0.0060141	0.002	Trapezoid	40.000	1
R200	Automatic Fixed Interval	1276.1	0.0082786	0.002	Trapezoid	40.000	1
R210	Automatic Fixed Interval	104.85	0.0082786	0.002	Trapezoid	40.000	1
R240	Automatic Fixed Interval	3468.5	0.0325473	0.002	Trapezoid	40.000	1
R260	Automatic Fixed Interval	2872.2	0.0062032	0.002	Trapezoid	40.000	1
R280	Automatic Fixed Interval	2628.4	0.0211261	0.002	Trapezoid	40.000	1
R290	Automatic Fixed Interval	3229.8	0.0382846	0.002	Trapezoid	40.000	1
R330	Automatic Fixed Interval	2905.2	0.0085004	0.002	Trapezoid	40.000	1
R340	Automatic Fixed Interval	9642.8	0.0034526	0.002	Trapezoid	40.000	1
R350	Automatic Fixed Interval	3454.0	0.0078695	0.002	Trapezoid	40.000	1
R390	Automatic Fixed Interval	3740.6	0.0260323	0.002	Trapezoid	40.000	1
R400	Automatic Fixed Interval	1713.0	0.0094369	0.040	Trapezoid	40.000	1
R410	Automatic Fixed Interval	2563.8	0.0091091	0.002	Trapezoid	40.000	1

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R420	Automatic Fixed Interval	555.56	0.0167818	0.002	Trapezoid	40.000	1
R440	Automatic Fixed Interval	415.27	0.048027	0.002	Trapezoid	40.000	1
R460	Automatic Fixed Interval	2552.0	0.0384705	0.002	Trapezoid	40.000	1
R490	Automatic Fixed Interval	2131.1	0.0315589	0.002	Trapezoid	40.000	1
R60	Automatic Fixed Interval	1029.1	0.0240263	0.002	Trapezoid	40.000	1
R70	Automatic Fixed Interval	615.56	0.0525495	0.002	Trapezoid	40.000	1
R90	Automatic Fixed Interval	381.42	0.0029465	0.002	Trapezoid	40.000	1

ANNEX 11. Boac Field Validation Points

Table A-11.1. Boac Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Lat	Long						
1	13.40853800000	121.90240000000	3.350	0.500	-2.850	Glenda	Jul-14	25-Year
2	13.40886200000	121.90315000000	3.090	0.600	-2.490	Glenda	Jul-14	25-Year
3	13.41081200000	121.89862000000	0.680	0.000	-0.680			25-Year
4	13.41138400000	121.90263000000	1.920	0.660	-1.260	Glenda	Jul-14	25-Year
5	13.41150700000	121.89835000000	1.300	1.050	-0.250	Reming	Dec. 2006	25-Year
6	13.41186700000	121.89773000000	1.480	0.600	-0.880	Glenda	July, 2014	25-Year
7	13.41196400000	121.90250000000	2.020	0.500	-1.520	Glenda	Jul-14	25-Year
8	13.41230700000	121.89767000000	1.070	0.600	-0.470	Glenda	July, 2014	25-Year
9	13.41267600000	121.90235000000	2.200	0.800	-1.400	Glenda	Jul-14	25-Year
10	13.41319500000	121.89744000000	1.100	0.440	-0.660	Glenda	July, 2014	25-Year
11	13.41340000000	121.90284000000	2.070	0.600	-1.470	Glenda	Jul-14	25-Year
12	13.41486900000	121.89602000000	1.780	1.450	-0.330	Monang	Dec. 1993	25-Year
13	13.41587300000	121.89532000000	1.650	2.200	0.550	Monang	Dec. 1993	25-Year
14	13.41689000000	121.89422000000	1.840	1.700	-0.140	Monang	Dec. 1993	25-Year
15	13.41703500000	121.89339000000	1.860	2.150	0.290	Monang	Dec. 1993	25-Year
16	13.41707300000	121.89230000000	1.400	2.370	0.970	Monang	Dec. 1993	25-Year
17	13.41953100000	121.88502000000	0.550	1.020	0.470	Glenda	July, 2014	25-Year
18	13.41992000000	121.88504000000	0.390	0.800	0.410	Yolanda	Oct. 2013	25-Year
19	13.42366700000	121.88643000000	1.390	0.000	-1.390			25-Year
20	13.42392300000	121.88604000000	1.390	1.100	-0.290	Monang	Dec. 1993	25-Year
21	13.42414700000	121.90004000000	0.950	0.200	-0.750	Glenda	Jul-14	25-Year
22	13.42467000000	121.88594000000	1.670	0.990	-0.680	Reming	Dec. 2006	25-Year
23	13.42503500000	121.88172000000	1.970	1.170	-0.800	Ofel	Oct. 2012	25-Year
24	13.42552100000	121.90086000000	0.270	0.200	-0.070	Glenda	Jul-14	25-Year
25	13.42603300000	121.89935000000	0.340	1.300	0.960	Glenda	Jul-14	25-Year
26	13.42604900000	121.87700000000	1.110	0.450	-0.660	Glenda	July, 2014	25-Year
27	13.42617200000	121.87716000000	1.070	1.200	0.130	Monang	Dec. 1993	25-Year
28	13.42739800000	121.89630000000	0.140	0.650	0.510	Glenda	Jul-14	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Lat	Long						
29	13.42775400000	121.87193000000	0.740	0.600	-0.140	Glenda	July, 2014	25-Year
30	13.42896400000	121.87207000000	0.890	0.500	-0.390	Ofel	Oct. 2012	25-Year
31	13.42916900000	121.89594000000	0.350	0.540	0.190	Glenda	Jul-14	25-Year
32	13.42934300000	121.87265000000	1.280	1.300	0.020	Ruby	Dec. 2014	25-Year
33	13.43015700000	121.87246000000	0.030	1.070	1.040	Ofel	Oct. 2012	25-Year
34	13.43232100000	121.88061000000	1.370	1.210	-0.160			25-Year
35	13.43270900000	121.85732000000	2.280	0.300	-1.980	Glenda	July, 2014	25-Year
36	13.43273400000	121.85802000000	2.280	0.700	-1.580	Yolanda	Oct. 2013	25-Year
37	13.43318900000	121.89768000000	1.410	0.610	-0.800	Glenda	Jul-14	25-Year
38	13.43320200000	121.87974000000	1.780	0.210	-1.570			25-Year
39	13.43322200000	121.85407000000	3.220	0.670	-2.550	Reming	Dec. 2006	25-Year
40	13.43330400000	121.86759000000	1.630	0.600	-1.030	Reming	Dec. 2006	25-Year
41	13.43346500000	121.88114000000	0.700	0.540	-0.160	Glenda	Dec. 2015	25-Year
42	13.43345700000	121.86935000000	1.850	1.450	-0.400	Monang	Dec. 1993	25-Year
43	13.43352700000	121.87970000000	2.100	0.350	-1.750	Yolanda	Nov. 2013	25-Year
44	13.43370600000	121.88219000000	0.900	0.450	-0.450	Yolanda		25-Year
45	13.43381500000	121.88107000000	0.180	0.330	0.150	Yolanda	Nov. 2013	25-Year
46	13.43379100000	121.85349000000	3.340	0.500	-2.840	Nona	Dec. 2015	25-Year
47	13.43426700000	121.89744000000	1.430	0.800	-0.630	Glenda	Jul-14	25-Year
48	13.43535800000	121.86748000000	2.780	0.800	-1.980	Reming	Dec. 2006	25-Year
49	13.43554300000	121.89984000000	0.110	0.300	0.190	Glenda	Jul-14	25-Year
50	13.43562600000	121.89835000000	0.740	0.450	-0.290	Glenda	Jul-14	25-Year
51	13.43581500000	121.90040000000	0.130	0.150	0.020	Glenda	Jul-14	25-Year
52	13.43593200000	121.90008000000	0.240	0.300	0.060	Glenda	Jul-14	25-Year
53	13.43607400000	121.89974000000	0.270	0.500	0.230	Glenda	Jul-14	25-Year
54	13.43611500000	121.89817000000	0.710	0.800	0.090	Glenda	Jul-14	25-Year
55	13.43648600000	121.85773000000	1.680	0.840	-0.840			25-Year
56	13.43653200000	121.85856000000	2.300	1.130	-1.170		2006	25-Year
57	13.43661600000	121.85835000000	1.690	0.310	-1.380		2006	25-Year
58	13.44151100000	121.86862000000	3.930	0.700	-3.230	Glenda	Jul-14	25-Year
59	13.44154100000	121.87341000000	1.570	0.170	-1.400	Glenda	Jul-14	25-Year
60	13.44182600000	121.87278000000	1.690	1.070	-0.620	Yolanda	Nov. 8, 2013	25-Year
61	13.44236300000	121.86667000000	3.120	2.220	-0.900	Glenda	Jul-14	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Lat	Long						
62	13.44413100000	121.85219000000	3.310	0.010	-3.300	Glenda	Jul-14	25-Year
63	13.44426100000	121.84949000000	1.590	0.100	-1.490	Yolanda	Nov. 8, 2013	25-Year
64	13.44448800000	121.85211000000	3.630	1.000	-2.630	Glenda	Jul-14	25-Year
65	13.44456900000	121.85200000000	3.500	0.000	-3.500	Glenda	Jul-14	25-Year
66	13.44462700000	121.85244000000	4.070	1.010	-3.060			25-Year
67	13.44494200000	121.83944000000	0.030	0.170	0.140	Nona	Dec. 2015	25-Year
68	13.44500800000	121.84988000000	3.020	0.450	-2.570	Yolanda	Nov. 8, 2013	25-Year
69	13.44523700000	121.85281000000	3.240	1.650	-1.590			25-Year
70	13.44576400000	121.83774000000	0.170	1.100	0.930	Monang	Dec. 1993	25-Year
71	13.44661700000	121.83809000000	0.030	0.670	0.640	Glenda	July, 2014	25-Year
72	13.44691800000	121.84963000000	3.950	0.400	-3.550	Yolanda	Nov. 8, 2013	25-Year
73	13.44695100000	121.84994000000	4.230	0.400	-3.830	Yolanda	Nov. 8, 2013	25-Year
74	13.44715900000	121.83964000000	1.420	1.300	-0.120	Glenda	July, 2014	25-Year
75	13.44737100000	121.84652000000	1.560	1.380	-0.180	Frank		25-Year
76	13.44739500000	121.84011000000	0.840	1.130	0.290	Glenda	July, 2014	25-Year
77	13.44747800000	121.83801000000	0.160	0.300	0.140	Glenda	July, 2014	25-Year
78	13.44751700000	121.84635000000	3.750	1.130	-2.620	Glenda	Jul-14	25-Year
79	13.44786200000	121.84129000000	1.210	1.350	0.140	Nona	Dec. 2015	25-Year
80	13.44823400000	121.84702000000	3.150	0.150	-3.000	Nona	Dec-15	25-Year
81	13.44836500000	121.83717000000	0.900	0.400	-0.500	Glenda	July, 2014	25-Year
82	13.44870600000	121.84885000000	2.910	0.860	-2.050	Yolanda	Nov. 8, 2013	25-Year
83	13.448845	121.83687	0.030	0.530	0.500	Nona	Dec. 2015	25-Year
84	13.449082	121.84774	2.280	2.520	0.240	Glenda	Jul-14	25-Year
85	13.449031	121.83596	0.030	1.350	1.320	Monang	Dec. 1993	25-Year
86	13.449272	121.85012	2.780	0.800	-1.980	Yolanda	Nov. 8, 2013	25-Year
87	13.449427	121.83673	0.390	0.550	0.160	Monang	Dec. 1993	25-Year
88	13.451637	121.84253	2.550	1.270	-1.280	Nona	Dec-15	25-Year
89	13.452363	121.83978	1.100	0.000	-1.100			25-Year
90	13.452349	121.82078	0.250	0.800	0.550	Glenda	Jul-14	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return/ Scenario
	Lat	Long						
91	13.453243	121.82323	0.760	1.380	0.620	Nona	Dec. 2015	25-Year
92	13.453326	121.8214	0.990	1.570	0.580	Glenda	Jul-14	25-Year
93	13.453615	121.82483	0.760	1.240	0.480			25-Year
94	13.454094	121.82226	0.240	0.770	0.530	Glenda	Jul-14	25-Year
95	13.454231	121.82197	0.560	1.000	0.440	Glenda	Jul-14	25-Year
96	13.454532	121.84085	2.830	0.000	-2.830			25-Year
97	13.454501	121.82114	0.970	1.710	0.740	Glenda	Jul-14	25-Year
98	13.454538	121.82422	0.900	0.900	0.000	Glenda	Jul-14	25-Year
99	13.454912	121.82492	1.300	1.500	0.200	Glenda	Jul-14	25-Year
100	13.457031	121.82177	1.010	1.870	0.860	Glenda	Jul-14	25-Year
101	13.45735	121.81515	0.820	0.900	0.080	Reming	Nov. 2006	25-Year
102	13.458015	121.8231	0.840	1.520	0.680	Reming	Nov. 2006	25-Year
103	13.461113	121.83627	1.240	0.540	-0.700	Reming		25-Year
104	13.461915	121.83588	1.010	0.900	-0.110	Reming		25-Year
105	13.46227	121.84845	0.610	0.500	-0.110	Glenda	Jul-14	25-Year
106	13.462554	121.83608	1.34	0.7	-0.64	Reming		25-Year
107	13.462801	121.83009	0.17	0.27	0.1	Reming	Nov. 2006	25-Year
108	13.462986	121.83518	0.39	0.94	0.55	Reming		25-Year
109	13.463331	121.82389	0.89	0.1	-0.79		2005	25-Year
110	13.463401	121.82369	0.9	0.25	-0.65		2005	25-Year
111	13.463862	121.82256	0.75	0	-0.75			25-Year
112	13.46426	121.82323	0.65	0	-0.65			25-Year
113	13.464291	121.82286	0.67	0	-0.67			25-Year
114	13.464463	121.82363	0.93	0.5	-0.43	Yolanda	Nov. 8, 2013	25-Year
115	13.464673	121.82307	0.88	0.5	-0.38	Herming		25-Year
116	13.468062	121.82434	0.78	0.335	-0.445	Reming	Nov. 2006	25-Year
117	13.468845	121.8242	1	1.32	0.32	Caloy	May-06	25-Year
118	13.469144	121.82568	0.09	0.75	0.66	Nona	Dec. 2015	25-Year
119	13.470183	121.82505	0.05	0.1	0.05	Reming	Nov. 2006	25-Year

ANNEX 12. Educational Institutions Affected in Boac Floodplain

Table A-12.1. Educational Institutions Affected by Flooding in the Boac Floodplain

Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year

ANNEX 13. Medical Institutions Affected by Flooding in Boac Floodplain

Table A-13.1. Medical Institutions Affected by Flooding in the Boac Floodplain

Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year

Annex 14. Phil-LiDAR 1 UPLB Team Composition

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