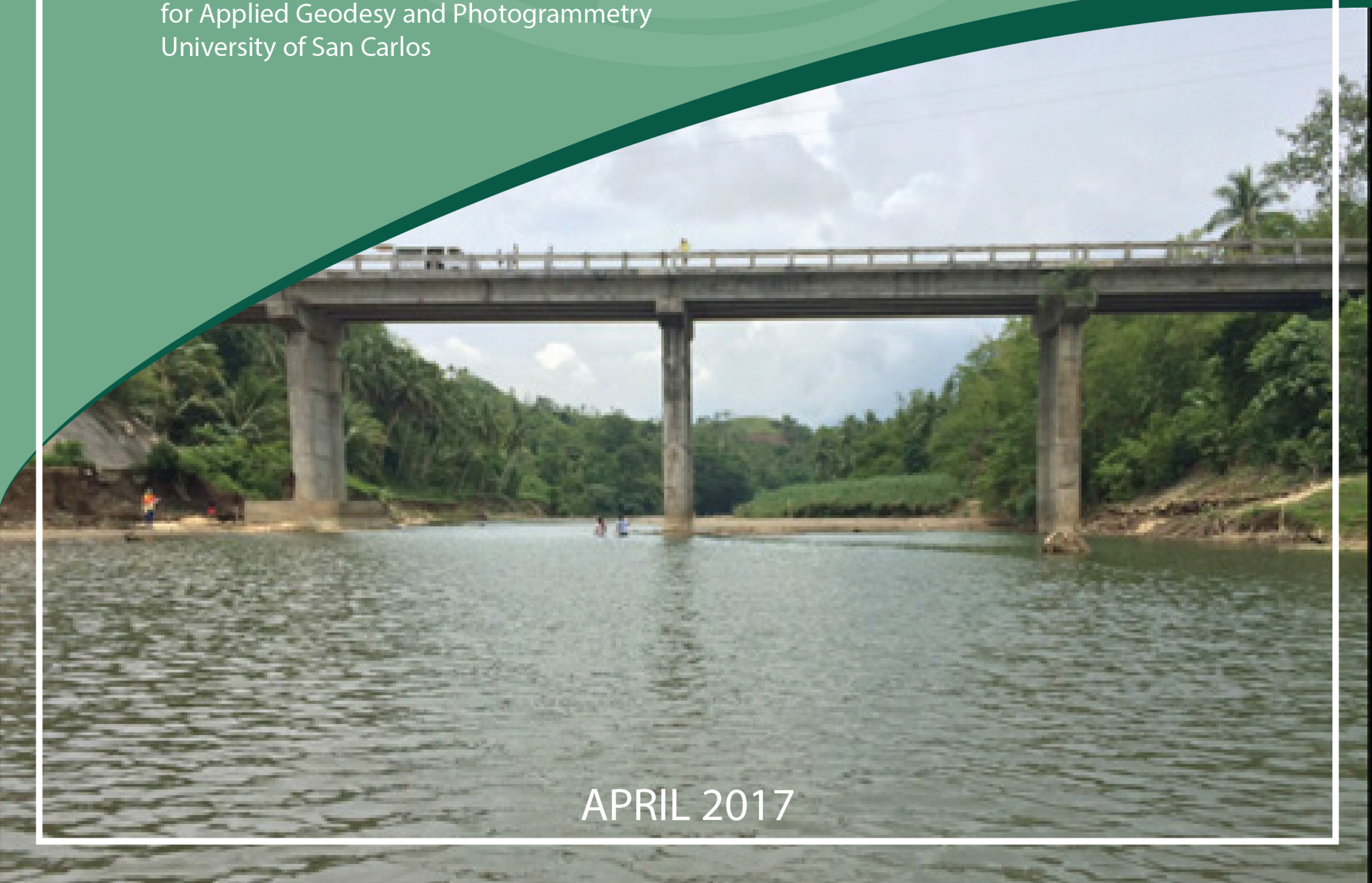
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Inabanga River

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



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LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND INABANGA RIVER

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

1.1 Background of the Phil-LIDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program in 2014 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 sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied in this report are thoroughly described in a separate publication entitled "FLOOD MAPPING OF RIVERS IN THE PHILIPPINES USING AIRBORNE LIDAR: METHODS (Paringit, et. al. 2017) available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of San Carlos (USC). USC is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 17 river basins in the Central Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Inabanga River Basin

The Inabanga River Basin is located in the northwestern area of Bohol. It has a catchment area of approximately 612.7 square kilometres based from the Flood Modelling Component database.

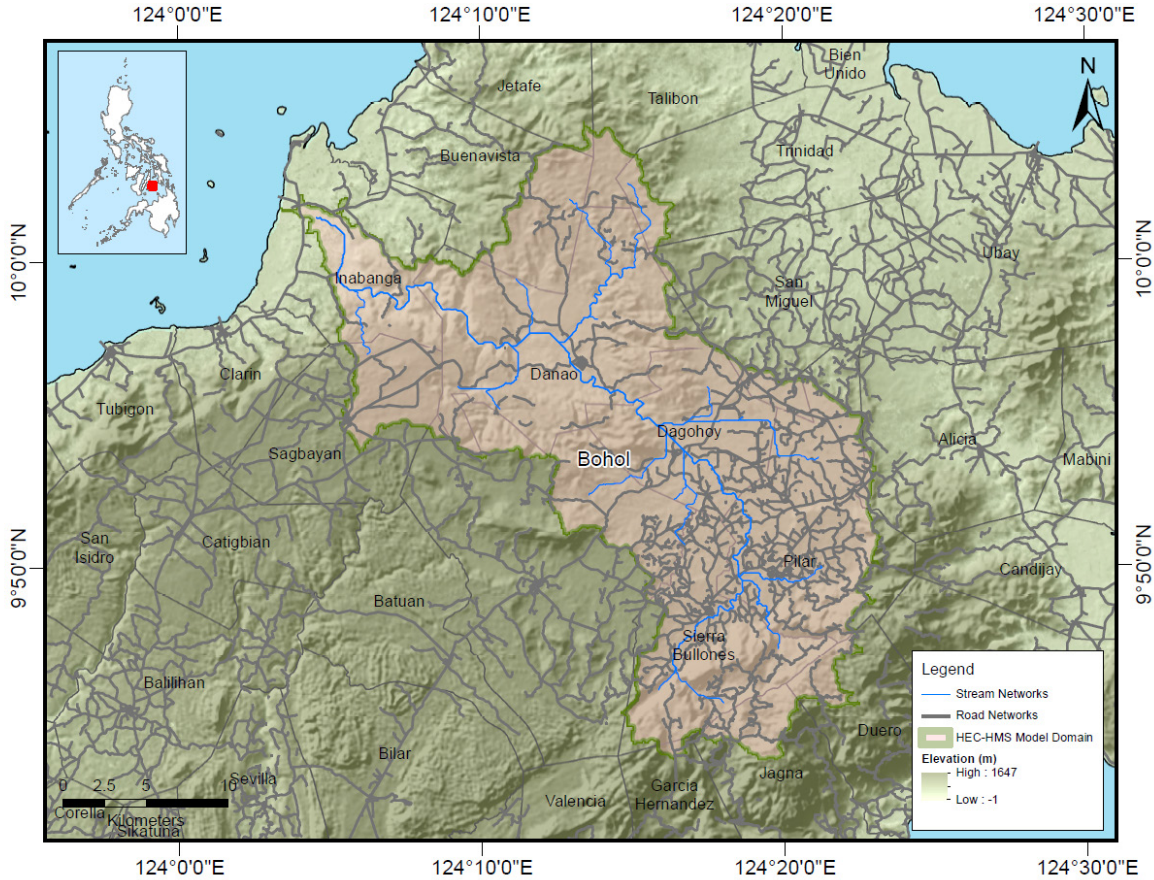

Figure 1. Map of Inabanga River Basin (in brown).

Its main stem, Inabanga River, encompasses the Municipalities of Sierra Bullones, Pilar, Dagohoy, Danao and Inabanga with an estimated population of 43, 291 according to the 2010 Census of Population and Housing of the National Statistics Office. The riverside of Inabanga River has a high susceptibility to flooding according to the 2007 Mines and Geosciences Bureau (MGB)'s Bohol Geohazard Assessment Flood Prone Areas. Barangays Baguhan, Lomboy and Ilaya are classified with moderate flood susceptibility. Other barangays within the vicinity of Inabanga River are classified with low flood susceptibility. Recent flooding event occured last December 30, 2014 due to Typhoon Seniang which killed 7 people and affected 1,700 people in Bohol.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE INABANGAFLOODPLAIN

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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 Inabanga floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Inabanga Floodplain in Bohol. These flight missions were planned for 10 lines and ran for at most four and a half hours (4.5) including take-off, landing and turning time. The flight planning parameters for the LiDAR system are outlined in Table 1. Figure 2 shows the flight plan for Inabanga floodplain survey.

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)
BLK51B	850/1000	30	50	200	30	130	5
BLK51S	850/1000	30	50	200	30	130	5

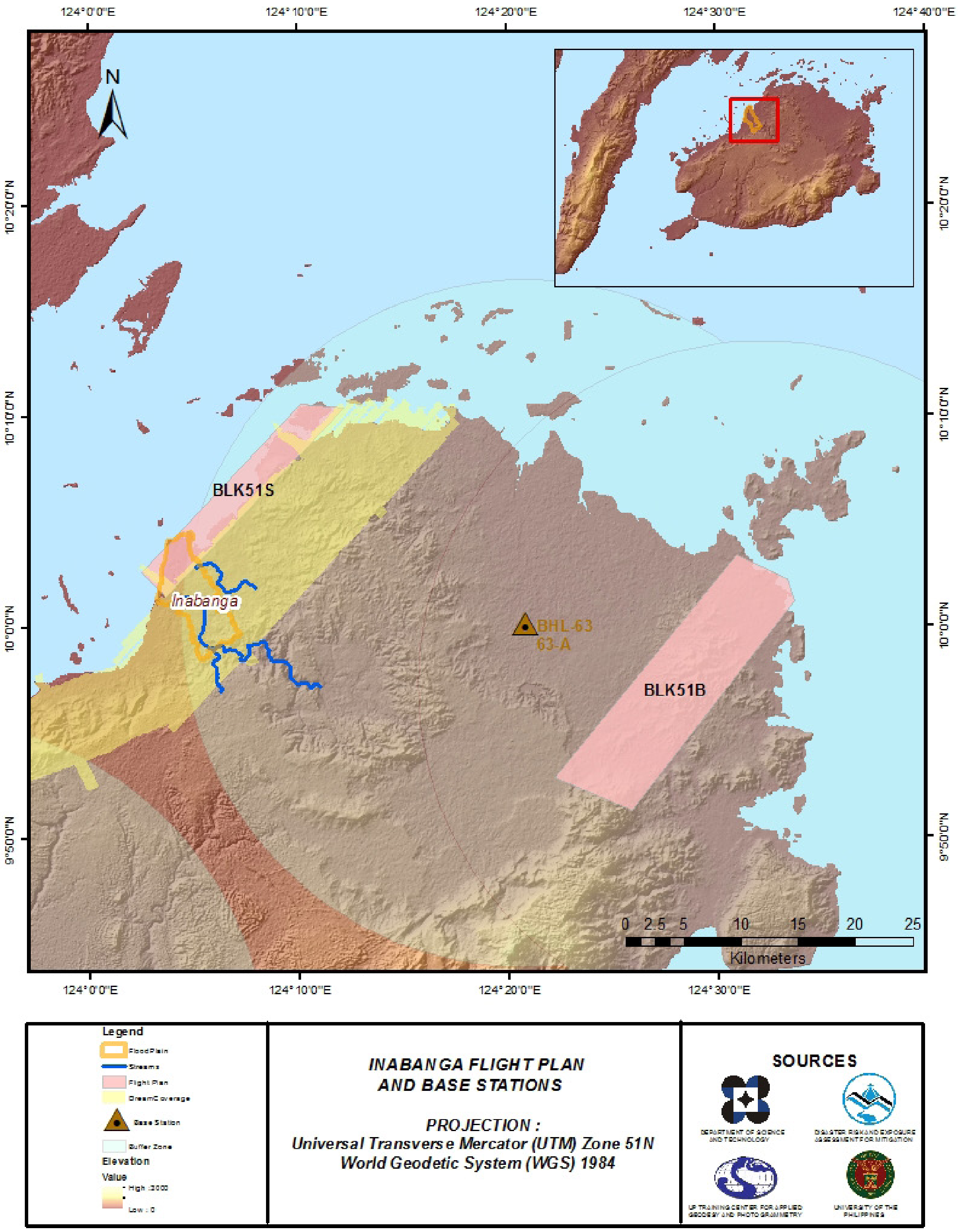


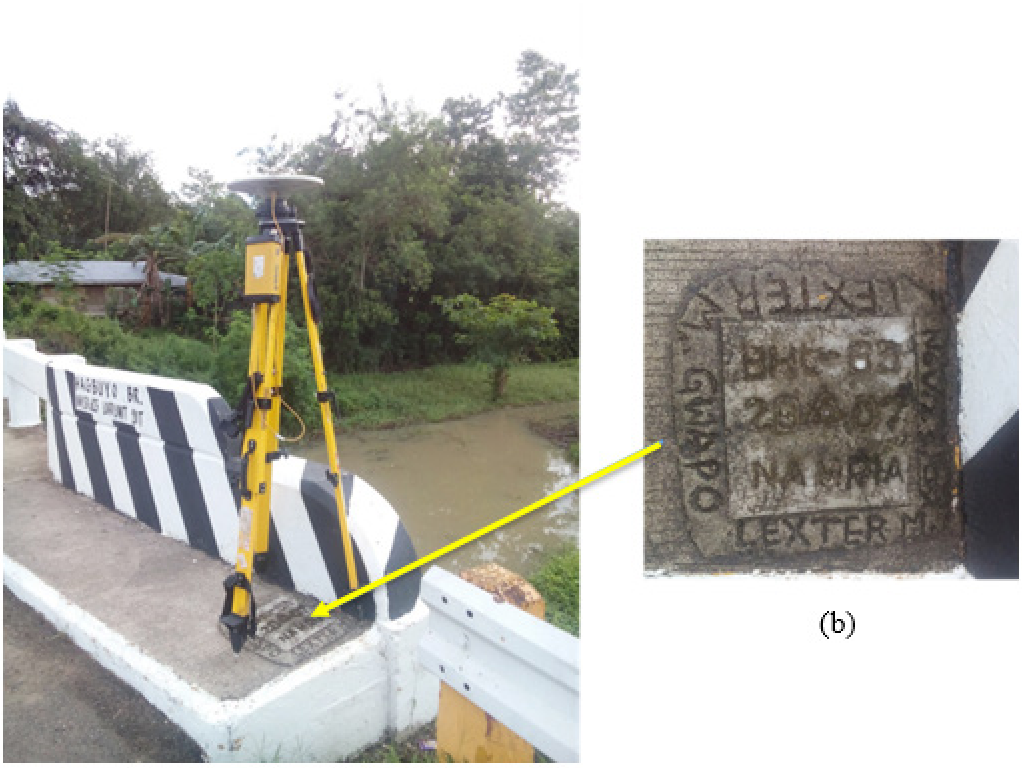
Figure 2. Flight plans and base stations used for Inabanga floodplain using Pegasus LiDAR system.

2.2 Ground Base Stations

The project team was able to recover one (1) NAMRIA horizontal ground control point: BHL-63 which is of first (1^{st}) order accuracy.One (1) established point: BHL-63A was recovered.

The certifications for the base stations are found in Annex 2 while the baseline processing reports for the established control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey on September 13-23, 2015. Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Inabanga floodplain are shown in Figure 2.

The succeeding sections depict the sets of reference points, control stations and established points, and the ground control points for the entire Inabanga Floodplain LiDAR Survey. Figure 3 to Figure 4 show the recovered NAMRIA reference points within the area of the floodplain, while Table 2 to Table 3 show the details about the following NAMRIA control stations and established points. Table 4, on the other hand, shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.



(a) (b)

Figure 3. GPS set-up over BHL-63 in Hagbuyo Bridge in Brgy. Hagbuyo, San Miguel, Bohol (a) and NAMRIA reference point BHL-63 (b) as recovered by the team.

Table 2. Details of the recovered NAMRIA horizontal control point BHL-63 used as base station for the LiDAR acquisition.

Station Name	BHL-63	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10° 0’ 13.31407” 124° 20’ 43.46219” 20.48700 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	428232.81 meters 1106210.364 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 0’ 9.30688” North 124° 20’ 48.73327” East 84.04100 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS1992)	Easting Northing	647,463.40 meters 1,106,052.78 meters

Figure 4. GPS set-up over established point BHL-63A in Hagbuyo Bridge, Brgy, Hagbuyo, San Miguel, Bohol (a).

Table 3. Details of the recovered NAMRIA horizontal control point BHL-63A used as base station for the LiDAR acquisition.

(b)

Station Name	BHL-63A	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10° 00’ 13.84084” 124° 20’ 58209” 20.464 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10°00’ 09.83363” 124° 20’ 85315” 84.018 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS1992)	Easting Northing	647466.981 meters 1106068.972 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
September 12, 2015	3409P	1BLK51B255A	BHL-63 and 63A

2.3 Flight Missions

A total of three (3) missions under DREAM program covered around 36.96 km² as shown in Table 5 within Ibanga floodpalain. One (1) mission was conducted to complete the LiDAR data acquisition in Inabanga floodplain, for a total of four hours and twenty-three minutes (4+23) of flying time for RP-C9022 (See Annex 6). All missions were acquired using Pegasus LiDAR system. As shown below, the total area of actual coverage per mission and the corresponding flying hours are depicted in Table 6, while the actual parameters used during the LiDAR data acquisition are presented in Table 7.

Table 5. Flight missions under DREAM program which covers Inabanga floodplain.

Flight Number	**Mission Name**	**Area Surveyed within the Floodplain (km²)**
799P	1BHL1A330A	15.55
803P	1BHL1AS331A	21.41
829P	1BHL1FS337A	0
TOTAL		36.96

Table 6. Flight missions for LiDAR data acquisition in Inabanga floodplain.
(b)

Date Surveyed	Flight Number	Flight Plan Area (km²)	Surveyed Area (km²)	Area Surveyed within the Floodplain (km²)	Area Surveyed Outside the Floodplain (km²)	No. of Images (Frames)	Flying Hours	
							Hr	**Min**
September 12, 2015	3409P	230.8	270.21	18.16	252.05	NA	4	23
TOTAL		230.8	270.21	18.16	252.05	NA	4	23

Table 7. 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)**
3409P	850/1000	30	50	200	30	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Inabanga floodplain (See Annex 7). It is located in the province of Bohol with majority of the floodplain situated within the municipalities Alicia, Buenavista, Inabanga, Jafete, Mabini, Pilar, Pres Carlos P. Garcia and Ubay. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown inTable 8. Figure 5, on the other hand, shows the actual coverage of the LiDAR acquisition for the Inabanga floodplain.

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

Province	Municipality/City	Area of Municipality/ City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Bohol	Alicia	118.35	74	63%
	Buenavista	107.95	7.43	7%
	Inabanga	103.67	19.08	18%
	Jafete	99.31	17.96	18%
	Mabini	87.74	4.31 (b)	5%
	Pilar	121.42	2.88	2%
	Pres.Carlos P. Garcia	48.06	2.22	5%
	Ubay	232.66	84.88	36%
	Sual	162.96	147.96	91%
Total		**1082.12**	**360.72**	**33.33%**

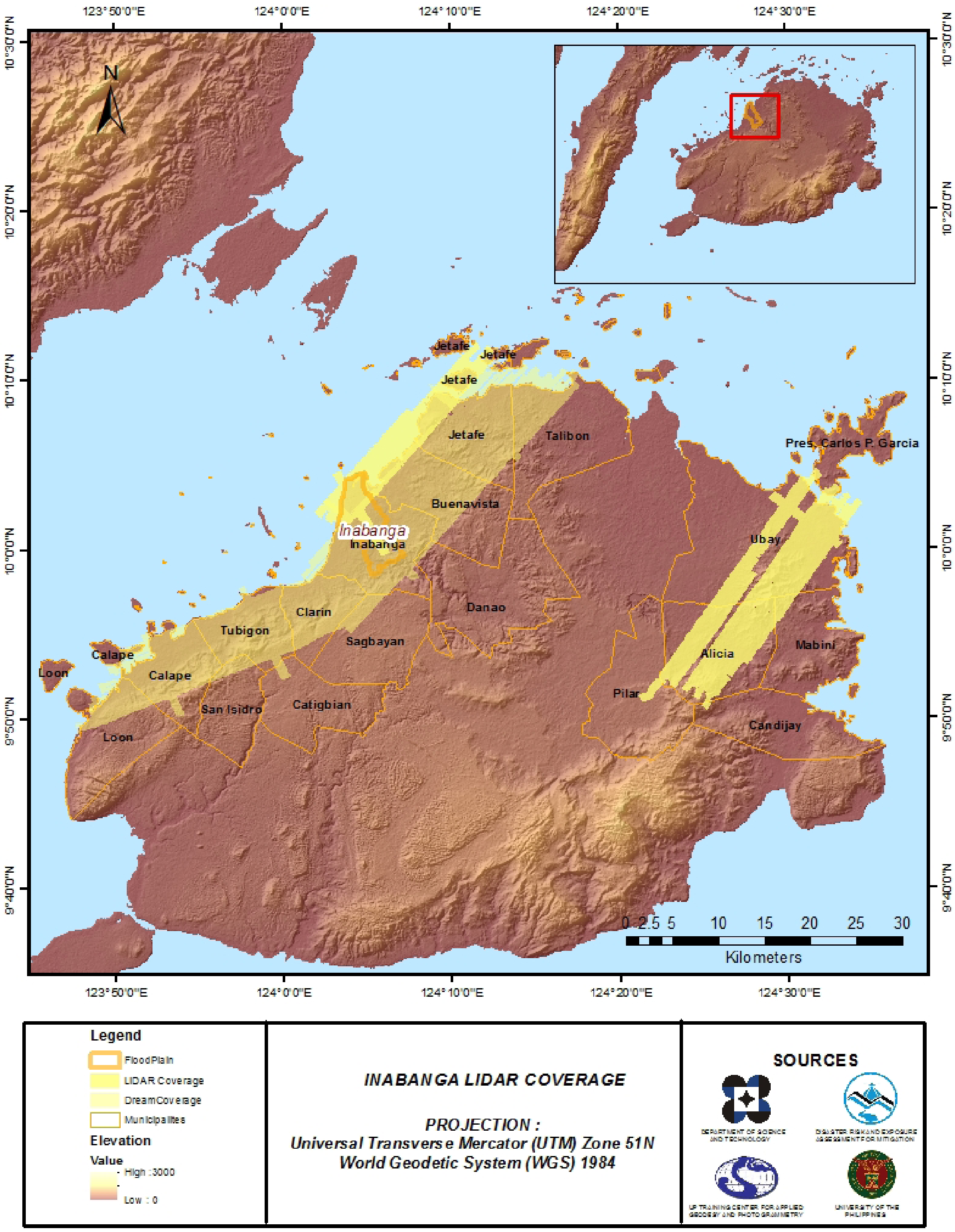


Figure 5. Actual LiDAR survey coverage for Inabanga floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE INABANGA FLOODPLAIN

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

3.1 Overview of the LIDAR Data Pre-Processing

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

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

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

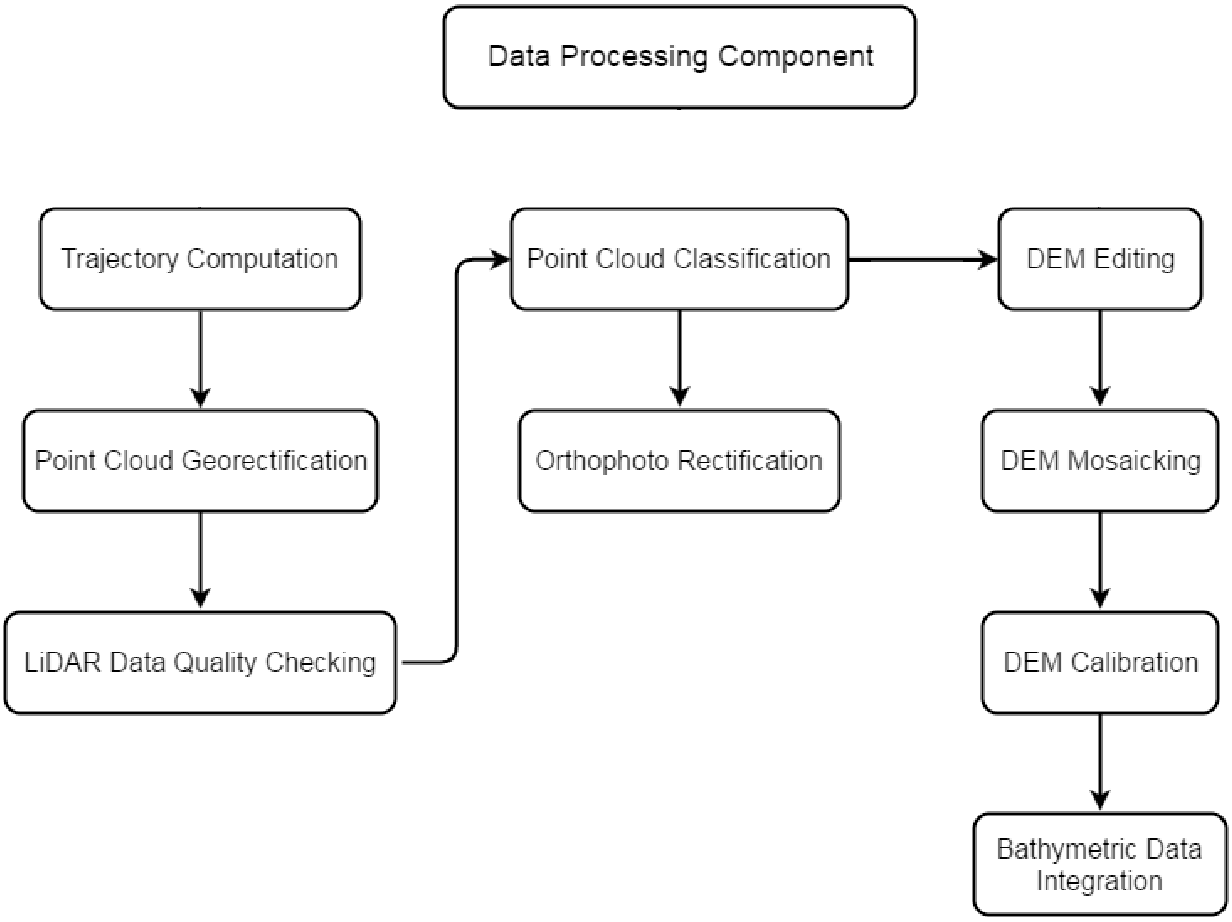

Figure 6. Schematic diagram for the data pre-processing.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions of the Inabanga Floodplain can be found in Annex 5. The missions flown during the first survey in December 2013 and second survey on September 2015 utilized the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Inabanga, Bohol.

The Data Acquisition Component (DAC) transferred a total of 32.80 Gigabytes of Range data, 0.52Gigabytes of POS data, 22.17 Megabytes of GPS base station data, and no raw image data to the data server on December 11, 2013 for the first survey and September 17, 2015 on the second survey which was verified for accuracy and completeness by the DPPC. The whole dataset for the Inabanga Floodplain was fully transferred on September 21, 2015, as indicated on the Data Transfer Sheets for the Inabanga floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for Flight 3409P, one of the Inabanga flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of the flight, which was measured by the number of seconds from the midnight of the start of the GPS week, which fell on the date and time of September 12, 2015 00:00AM. The y-axis, on the other hand, represents the RMSE value for that particular position.

Figure 7. Smoothed Performance Metrics of Inabanga Flight 3409P.

The time of flight was from 513,500 seconds to 519,500 seconds, which corresponds to afternoon of September 12, 2015. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft.

Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8shows that the North position RMSE peaks at 1.00 centimeter, the East position RMSE peaks at 1.60 centimeters, and the Down position RMSE peaks at 2.60 centimeters, which are within the prescribed accuracies described in the methodology.

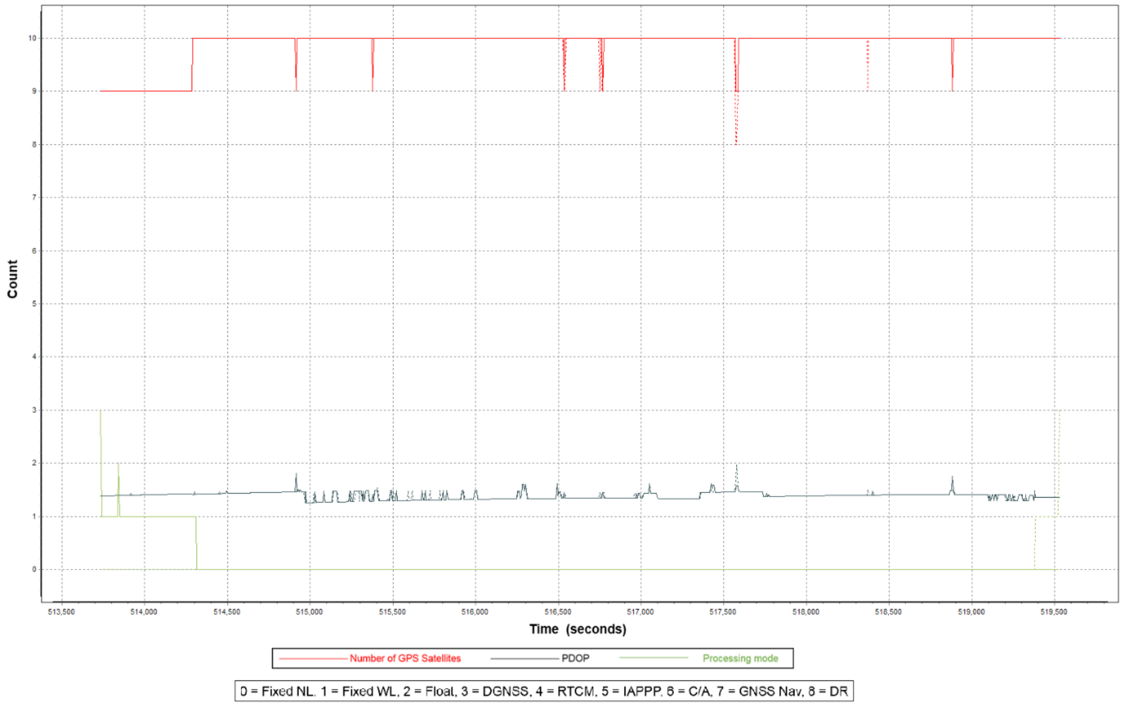

Figure 8. Solution Status Parameters of Inabanga Flight 3409P.

The Solution Status parameters, which indicate the number of GPS satellites; Positional Dilution of Precision (PDOP); and the GPS processing mode used for Inabanga Flight 3409P are shown in Figure 8. For the Solution Status parameters, the figure above signifies that the number of satellites utilized and tracked during the acquisition were between 8 and 10, not going lower than 8. Similarly, the PDOP value did not go above the value of 2, which indicates optimal GPS geometry. The processing mode also stayed at the value of 0 for the majority of the survey stayed at the value of 0 for majority of the surveywith some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane Mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for the POSPAC MMS. Fundamentally, all of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Inabanga flights is shown in Figure 9.

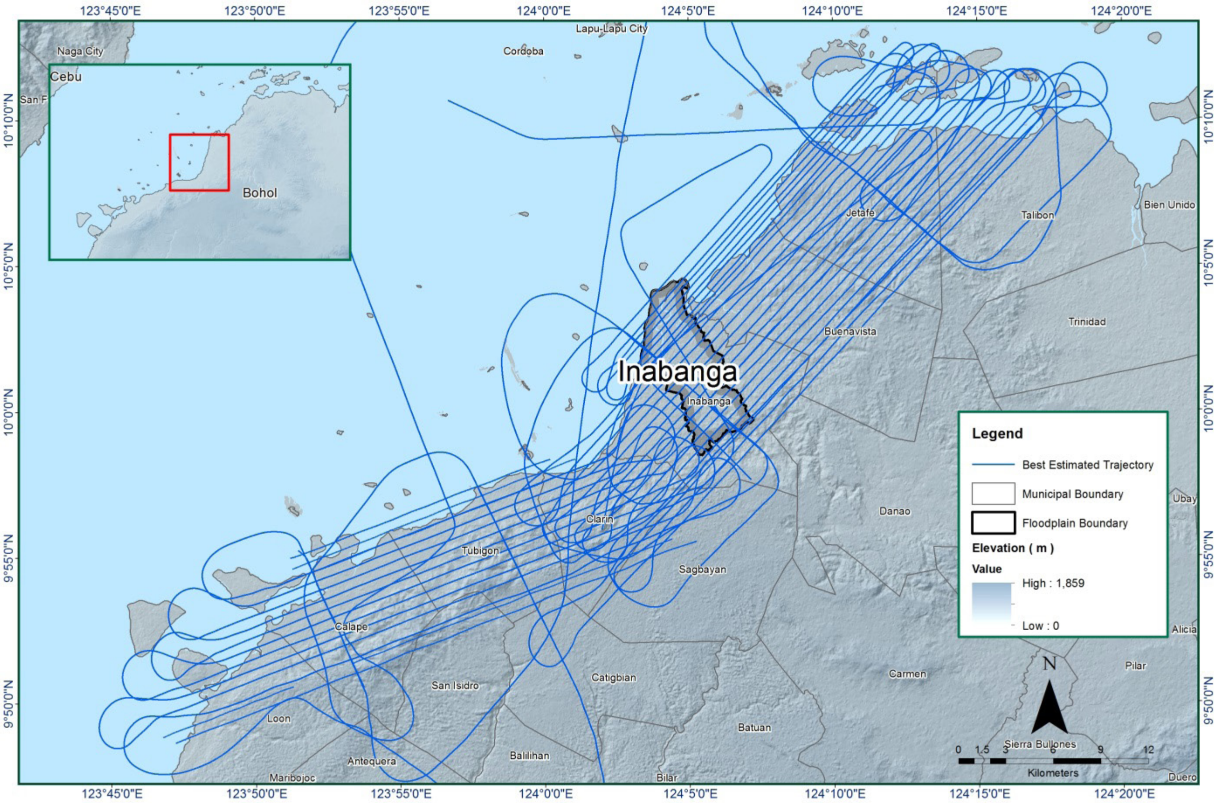

Figure 9. Best Estimated Trajectory of the LiDAR missions conducted over the Inabanga Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 43 flight lines, with each flight line contains two channels, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in the LiDAR Mapping Suite (LMS) software for all flights over the Inabanga floodplain are given in Table 9.

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

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev)	<0.001degrees	0.000436
IMU Attitude Correction Roll and Pitch Corrections stdev)	<0.001degrees	0.000812
GPS Position Z-correction stdev)	<0.01meters	0.0016

The optimum accuracy values for all Inabanga flights were also calculated, which are based on the computed standard deviations of the corrections of the orientation parameters. The standard deviation values for individual blocks are presented in the Mission Summary Reports (Annex 8).

3.5 LiDAR Quality Checking

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

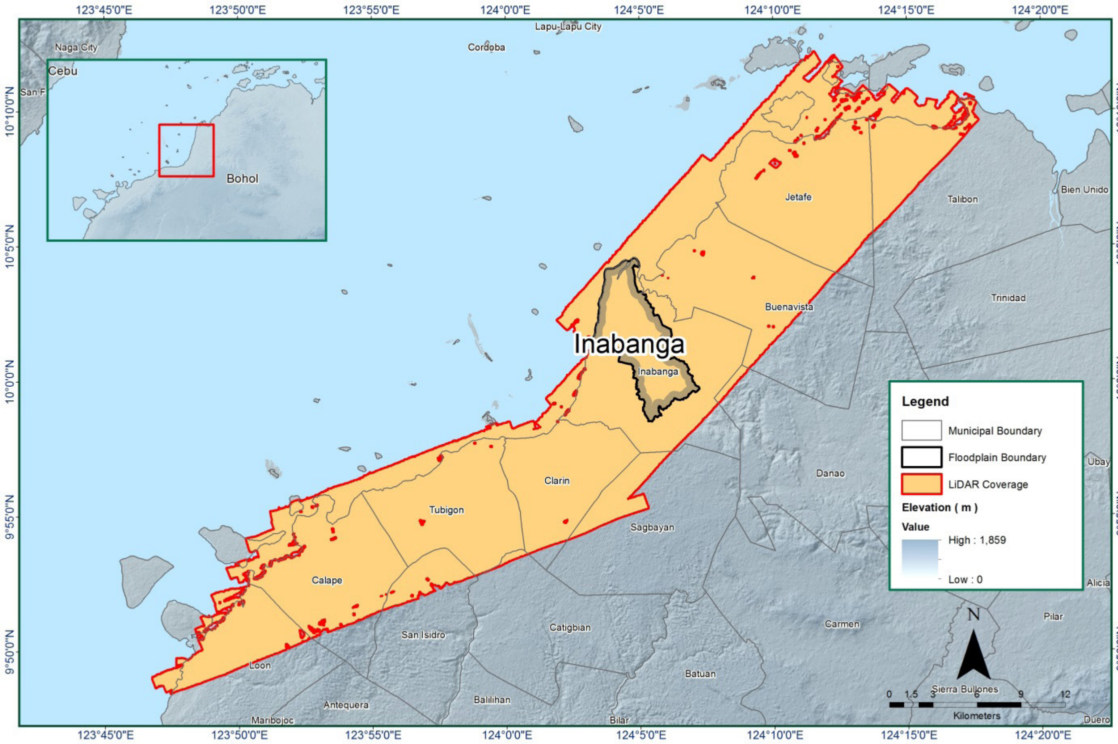

Figure 10. Boundaries of the processed LiDAR data over the Inabanga Floodplain.

A total area of 698.82 square kilometers (sq. kms.) were covered by the Inabanga flight missions as a result of five (5) flight acquisitions, which were grouped and merged into five (5) block accordingly, as portrayed in Table 10.

Table 10. List of LiDAR blocks for the Inabanga floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Bohol_Blk51S	3409P	86.88
Bohol_Blk1A	799P	174.94
Bohol_Blk1A_supplement	803P	154.20
Bohol_Blk1F	815P	88.12
Bohol_Blk1F_supplement	829P	194.68
TOTAL		**698.82 sq.km**

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

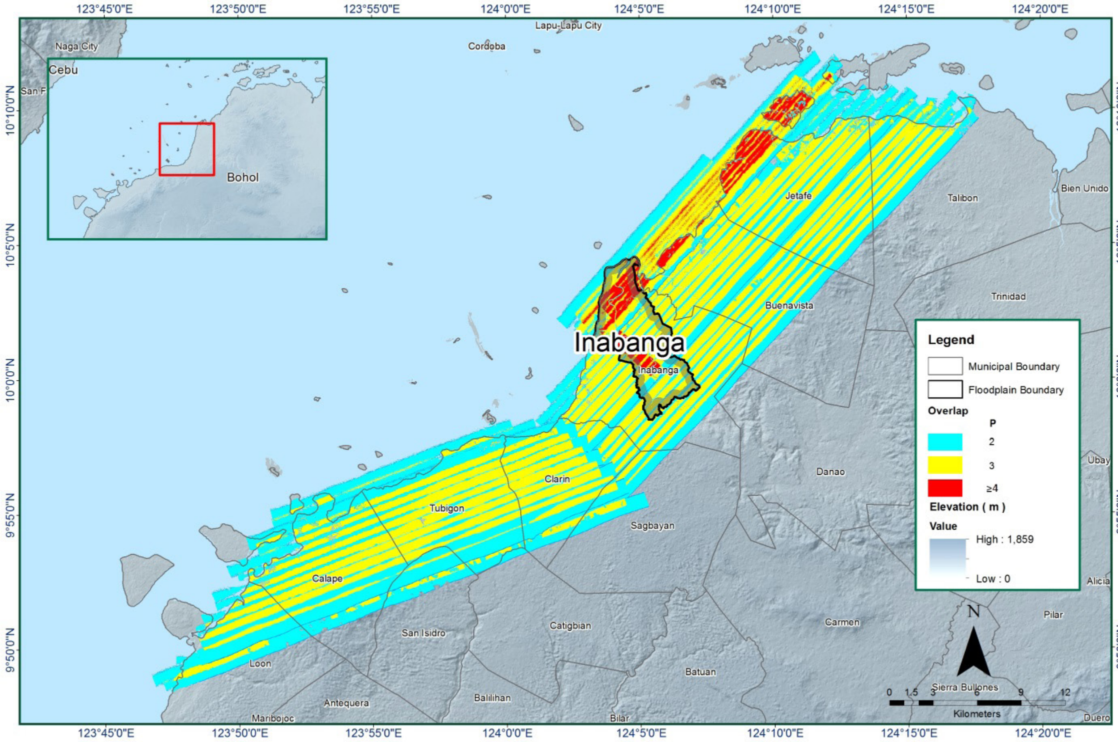

Figure 11. Image of data overlap for Inabanga floodplain.

The overlap statistics per block for the Inabanga floodplain can be found in the Mission Summary Reports (Annex 8). One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlaps are 53.91% and 65.39% which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the two (2) points per square meter criterion is shown in Figure 12. As seen in the figure below, it was determined that all LiDAR data for the Inabanga Floodplain Survey satisfy the point density requirement, as the average density for the entire survey area is 3.09 points per square meter.

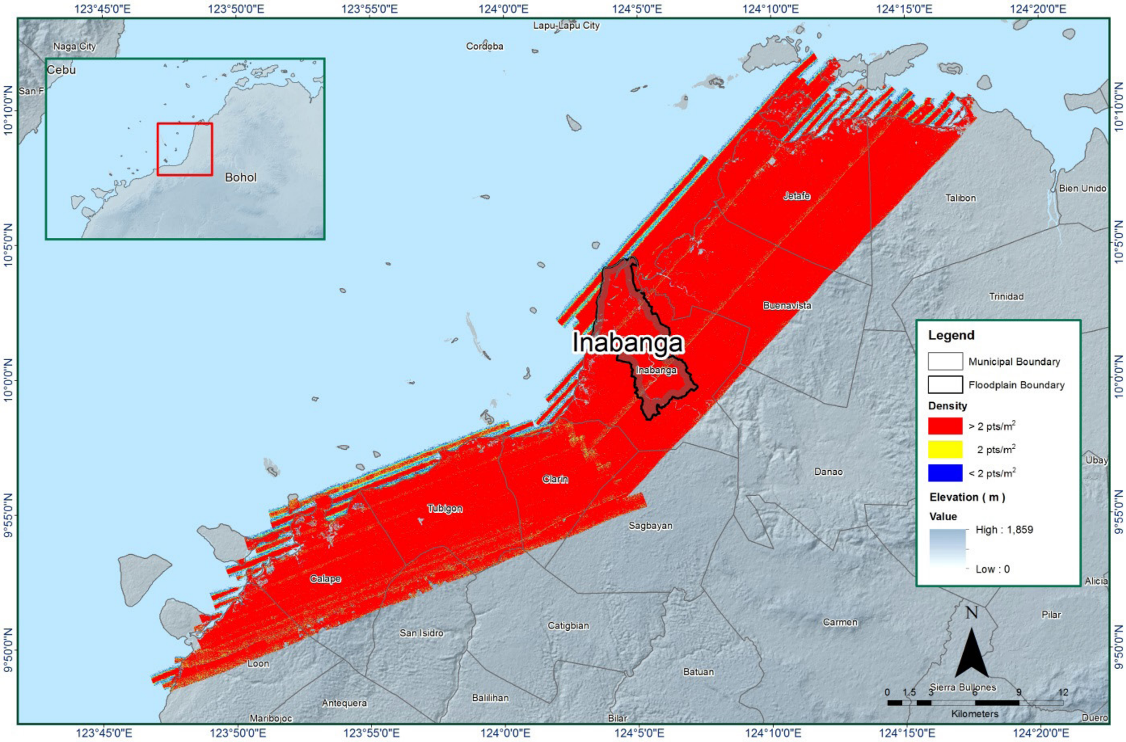

Figure 12. Pulse density map of the merged LiDAR data for Inabanga floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. The default color range is blue to red, where bright blue areas correspond to portions where elevations of a previous flight line are higher by more than 0.20m, as identified by its acquisition time; which is relative to the elevations of its adjacent flight line. Similarly, bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m, relative to the elevations of its adjacent flight line. Areas highlighted in bright red or bright blue necessitate further investigation using the Quick Terrain Modeler software.

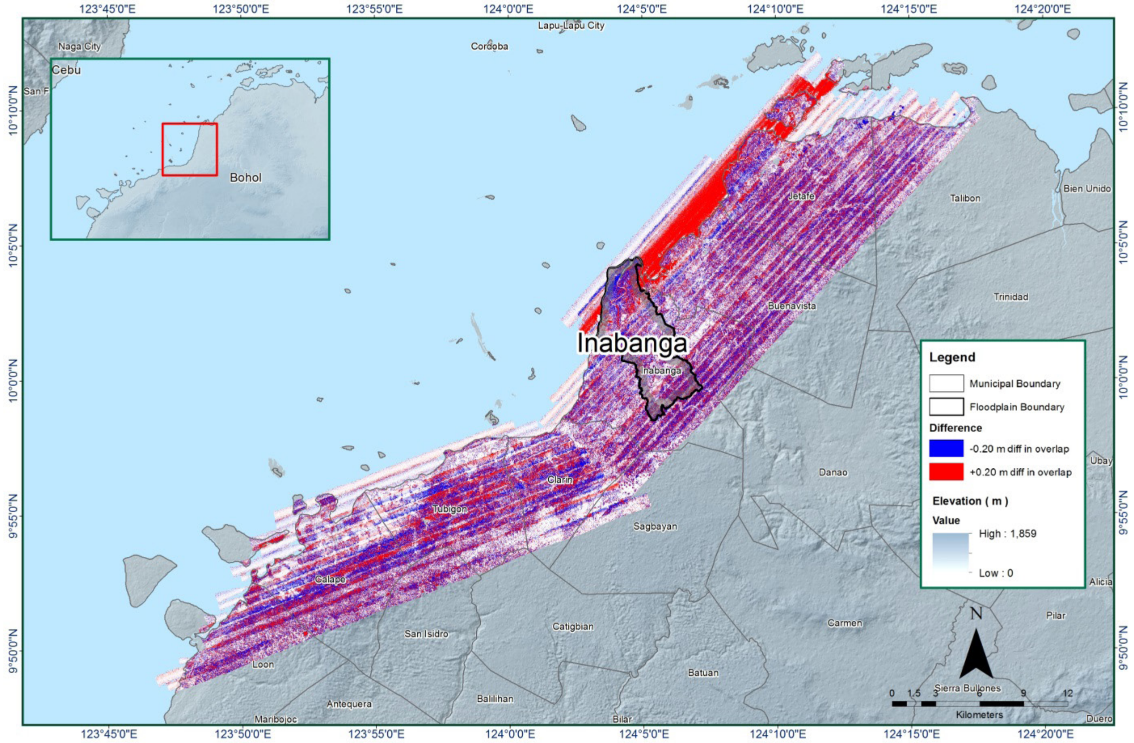

Figure 13. Elevation difference Map between flight lines for the Inabanga Floodplain Survey.

A screen-capture of the processed LAS data from Inabanga flight 3409P loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data generated satisfactory results. No reprocessing was done for this LiDAR dataset.

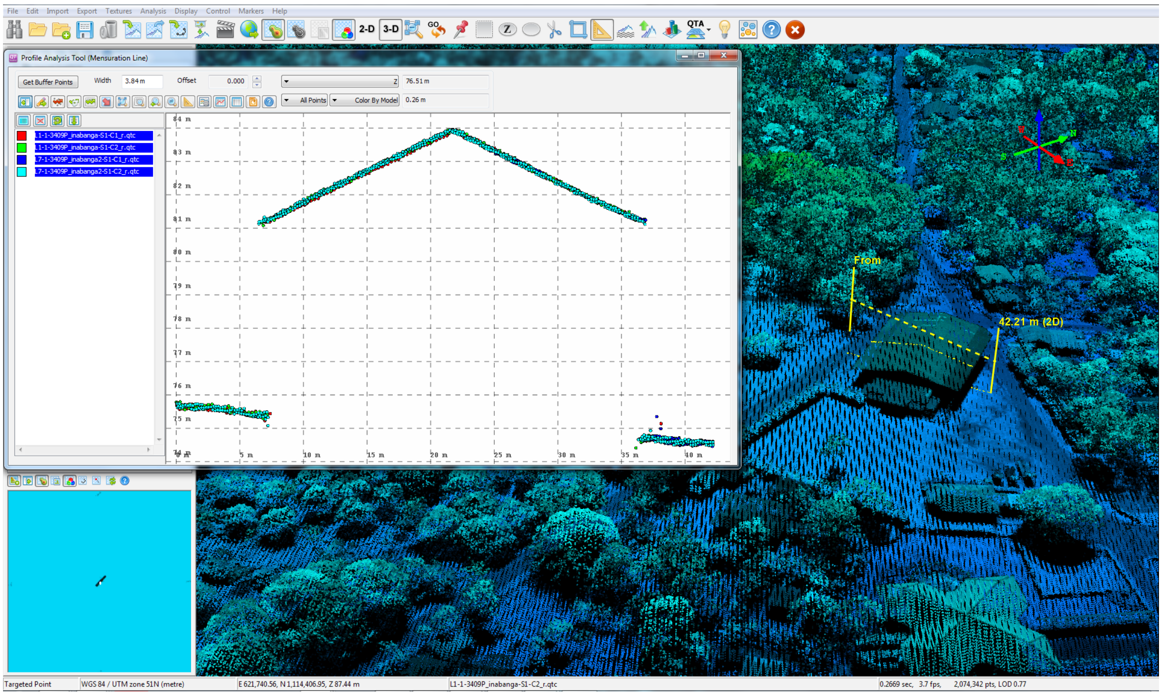

Figure 14. Quality checking for Inabanga flight 3409P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Inabanga classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	639,842,425
Low Vegetation	512,484,514
Medium Vegetation	957,363,989
High Vegetation	843,310,798
Building	24,622,636

The tile system that TerraScan employed for the LiDAR data as well as the final classification image for a block of the Inabanga floodplain is shown in Figure 15. A total of 1,005 tiles with 1 km. X 1 km. (one kilometer by one kilometer) size were produced. Correspondingly, Table 11 summarizes the number of points classified to the pertinent categories. The point cloud has a maximum and minimum height of 557.55 meters and 55.11 meters respectively.

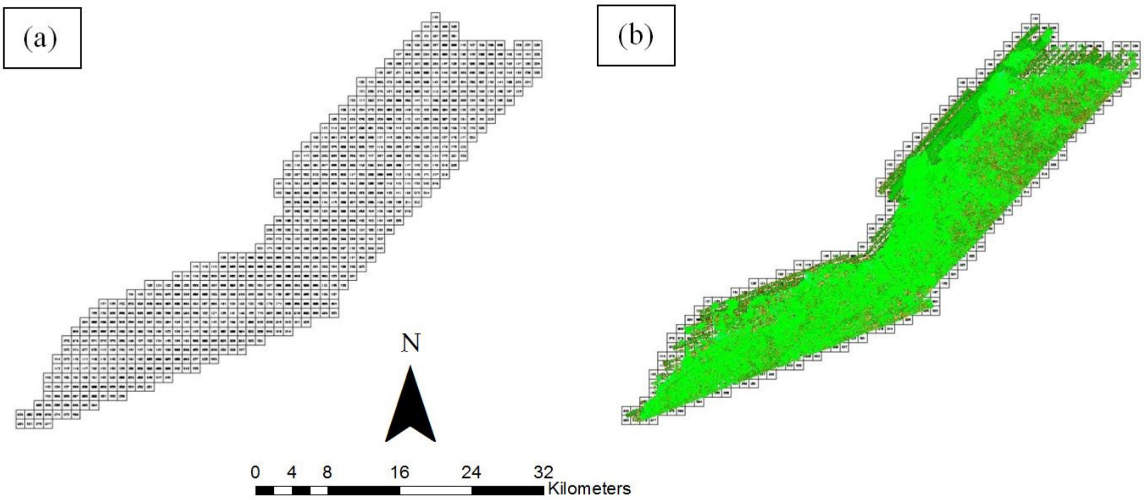

Figure 15. Tiles for Inabanga floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 16. The ground points are highlighted in orange, while the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below the canopy are classified correctly, due to the density of the LiDAR data.

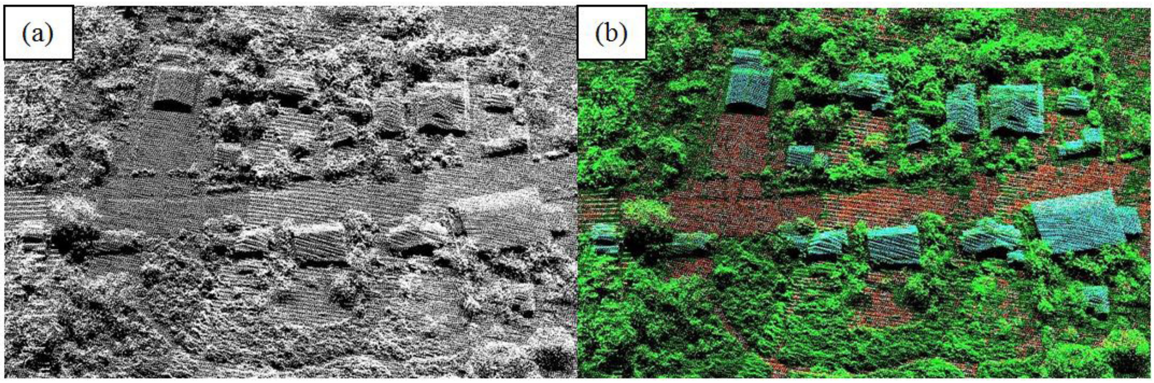

Figure 16. Point cloud before (a) and after (b) classification.

The production of the last return (V_ASCII) and secondary (T_ ASCII) DTM as well as the first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are show in Figure 17. It shows that DTMs are the representation of the bare earth, while on the DSMs, all features are present, such as buildings and vegetation.

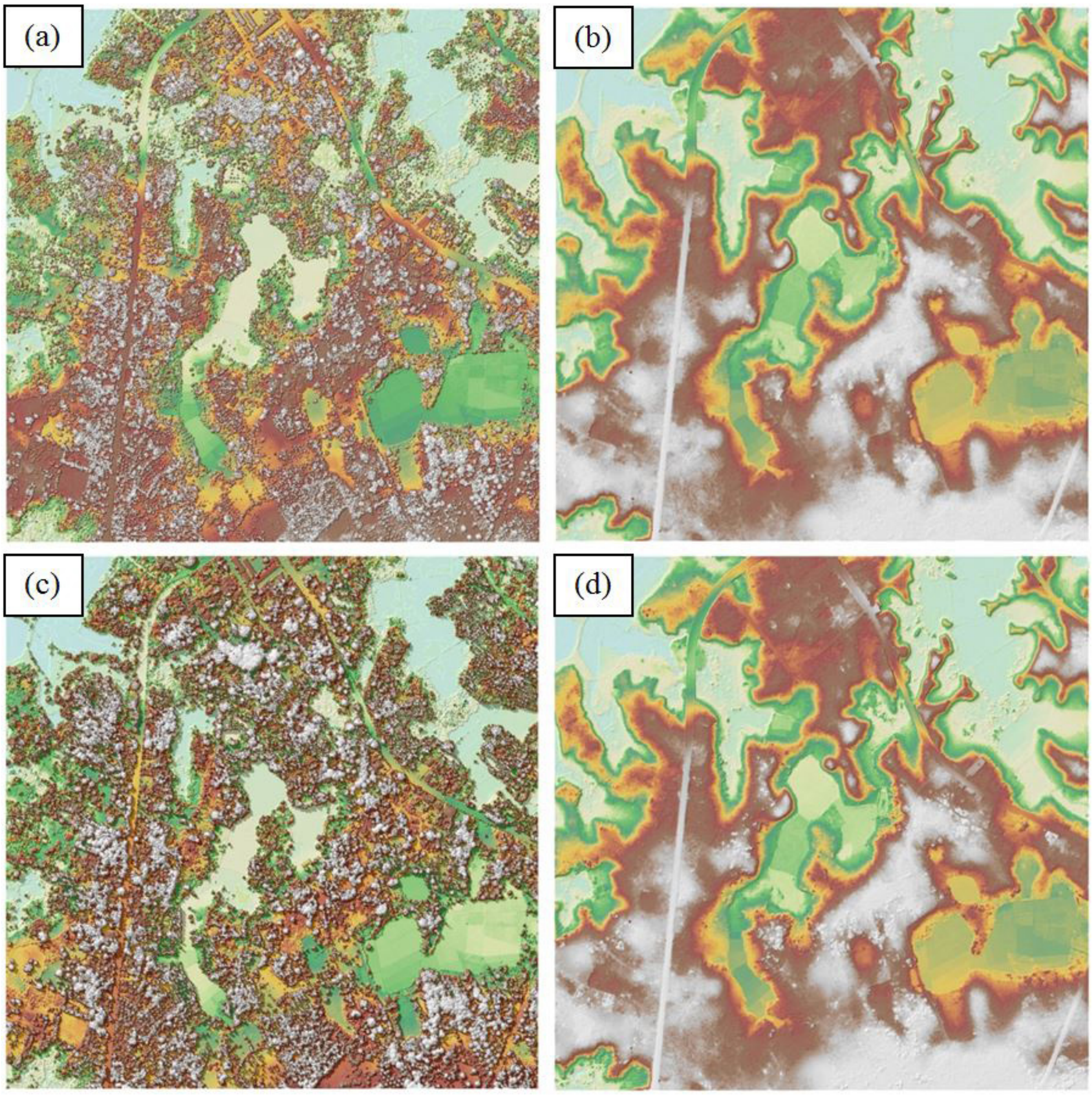

Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Inabanga floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Inabanga floodplain.

3.8 DEM Editing and Hydro-Correction

Five (5) mission blocks were processed for the Inabanga Floodplain Survey. The block is from the Bohol mission with a total area of 698.82 square kilometers. Table 12 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq. km.)
Bohol_Blk51S	86.88
Bohol_Blk1A	174.94
Bohol_Blk1A_supplement	154.20
Bohol_Blk1F	88.12
Bohol_Blk1F_supplement	194.68
TOTAL	**698.82 sq.km**

Figure 18 shows portions of a DTM before and after manual editing. As evident in the figure, the bridge (Figure 18a) has obstructed the flow of water along the river. To correct the river hydrologically, the bridge was removed through manual editing (Figure 18b). The paddy field (Figure 18c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 18d) to allow the correct flow of water.

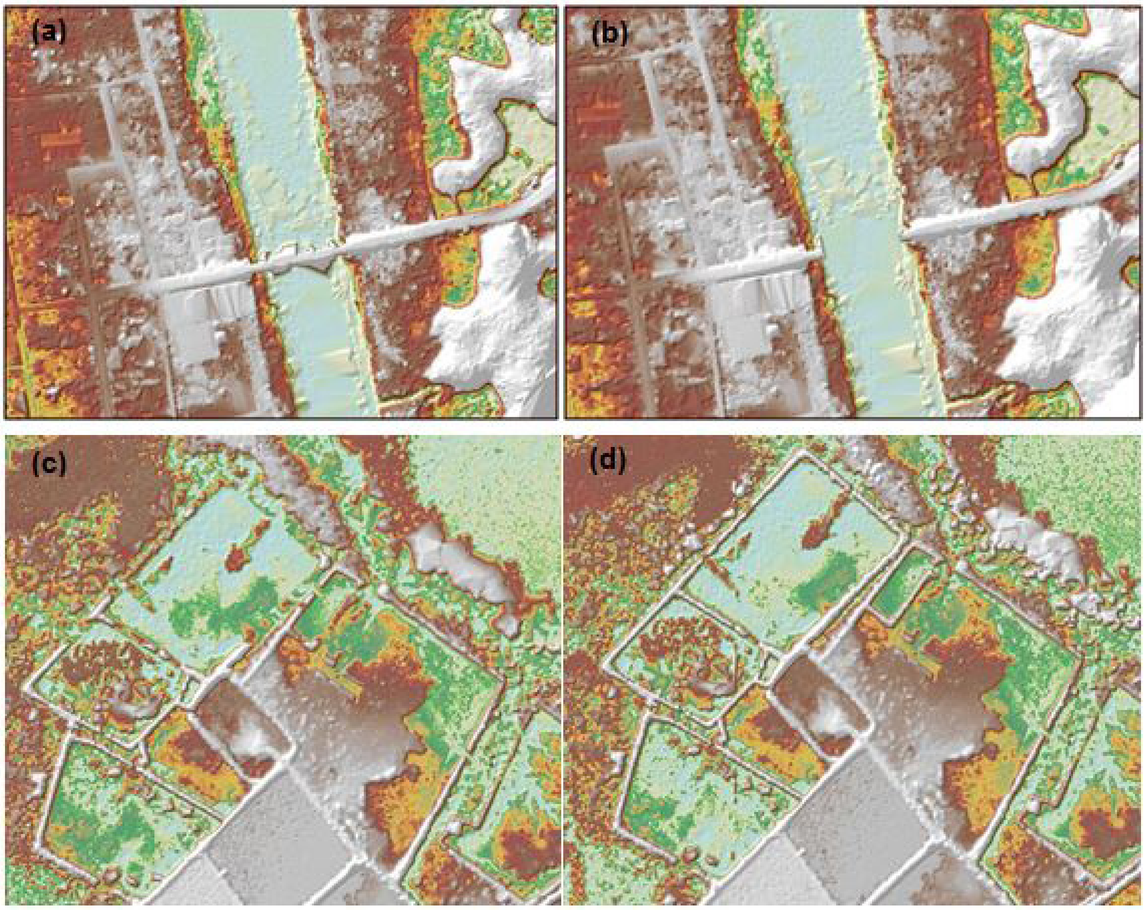

Figure 18. Portions in the DTM of the Inabanga Floodplain – a bridge before (a) and after (b) manual editing; a paddy field before (c) and after (d) data retrieval.

3.9 Mosaicking of Blocks

No assumed reference block was used in mosaicking because the identified reference for shifting was an existing calibrated Bohol DEM overlapping with the blocks to be mosaicked.Table 13shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Inabanga Floodplain is shown in Figure 19. It can be seen that the entire Inabanga floodplain is 100% covered by LiDAR data.

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Bohol_Blk51S	0.00	0.00	-4.10
Bohol_Blk1A	0.00	0.00	0.00
Bohol_Blk1A_supplement	0.00	0.00	0.00
Bohol_Blk1F	0.00	0.00	0.02
Bohol_Blk1F_supplement	0.00	18.10	0.67

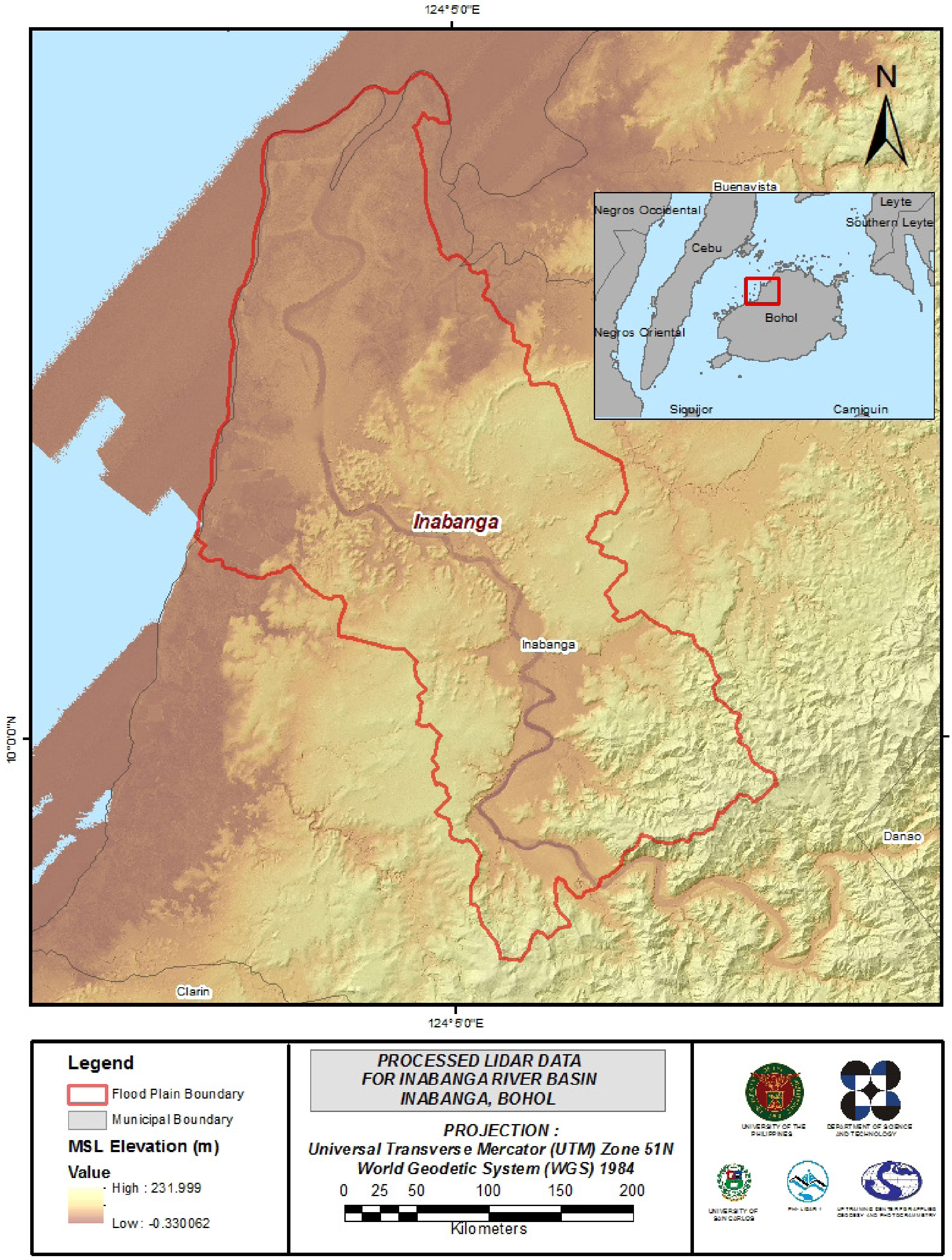

Figure 19. Map of processed LiDAR data for the Inabanga Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Inabanga to collect points with which the LiDAR dataset is validated is shown in Figure 20. A total of 3039 survey points were gathered for calibration and validation of Inabanga LiDAR data. However, the point dataset was not used for the calibration of the LiDAR data for Inabanga because during the mosaicking process, each LiDAR block was referred to the calibrated Bohol DEM. Therefore, the mosaicked DEM of Inabanga can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Bohol LiDAR DTM and ground survey elevation values is shown in Figure 21. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 1.29 meters with a standard deviation of 0.19 meters. Calibration of Bohol LiDAR data was done by subtracting the height difference value, 1.29 meters, to Bohol mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between Bohol LiDAR data and calibration data. These values were also applicable to the Inabanga DEM.

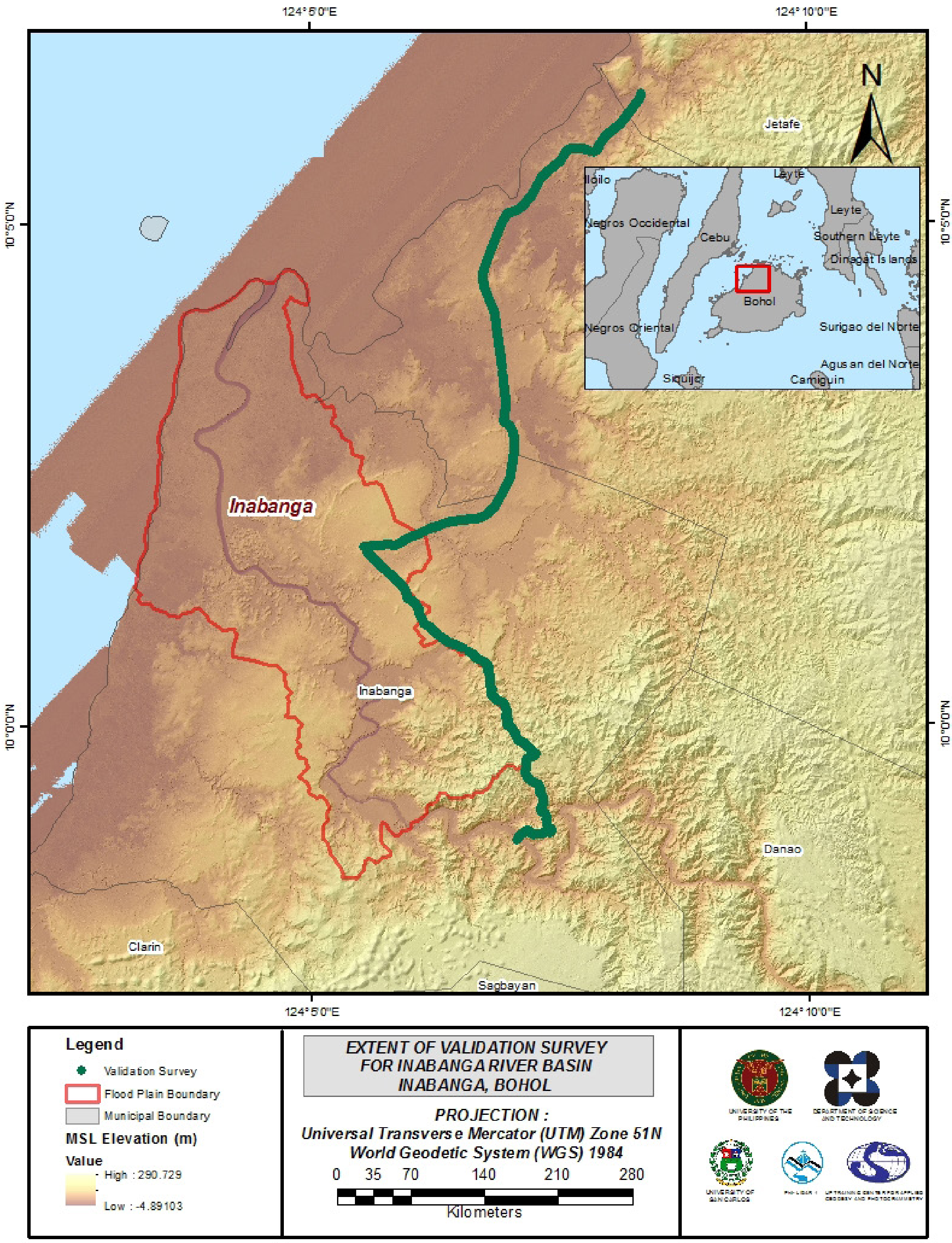

Figure 20. Map of Inabanga Floodplain with validation survey points in green.

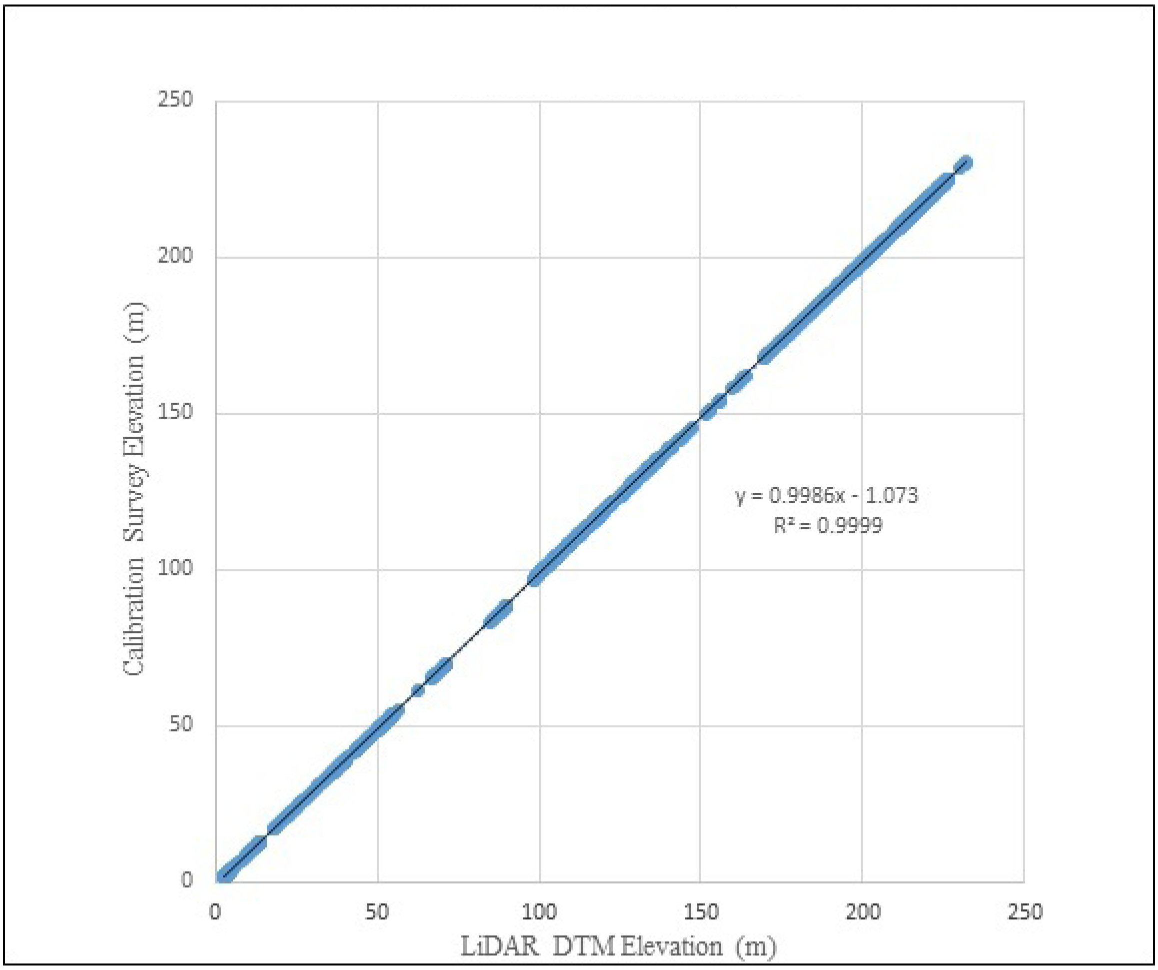

Figure 21. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	1.29
Standard Deviation	0.19
Average	-1.28
Minimum	-1.65
Maximum	-0.86

All survey points were used for the validation of calibrated Inabanga DTM. The good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 22. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.17 meters with a standard deviation of 0.17 meters, as shown in Table 15.

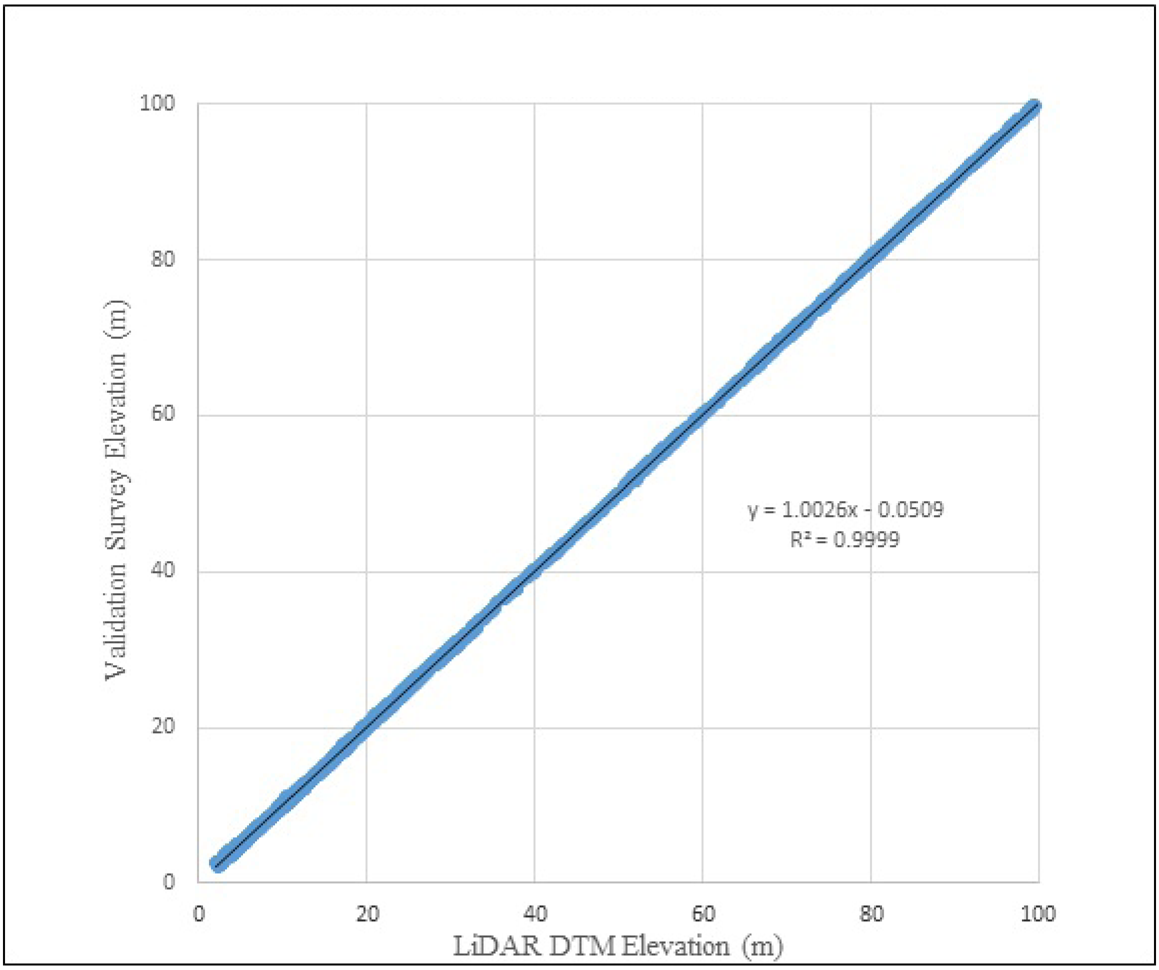

Figure 22. Correlation plot between the validation survey points and the LiDAR data.

Table 15. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.17
Standard Deviation	0.17
Average	0.04
Minimum	-0.39
Maximum	0.68

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Inabanga with a total of 1,236 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.03 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Inabanga integrated with the processed LiDAR DEM is shown in Figure 23.

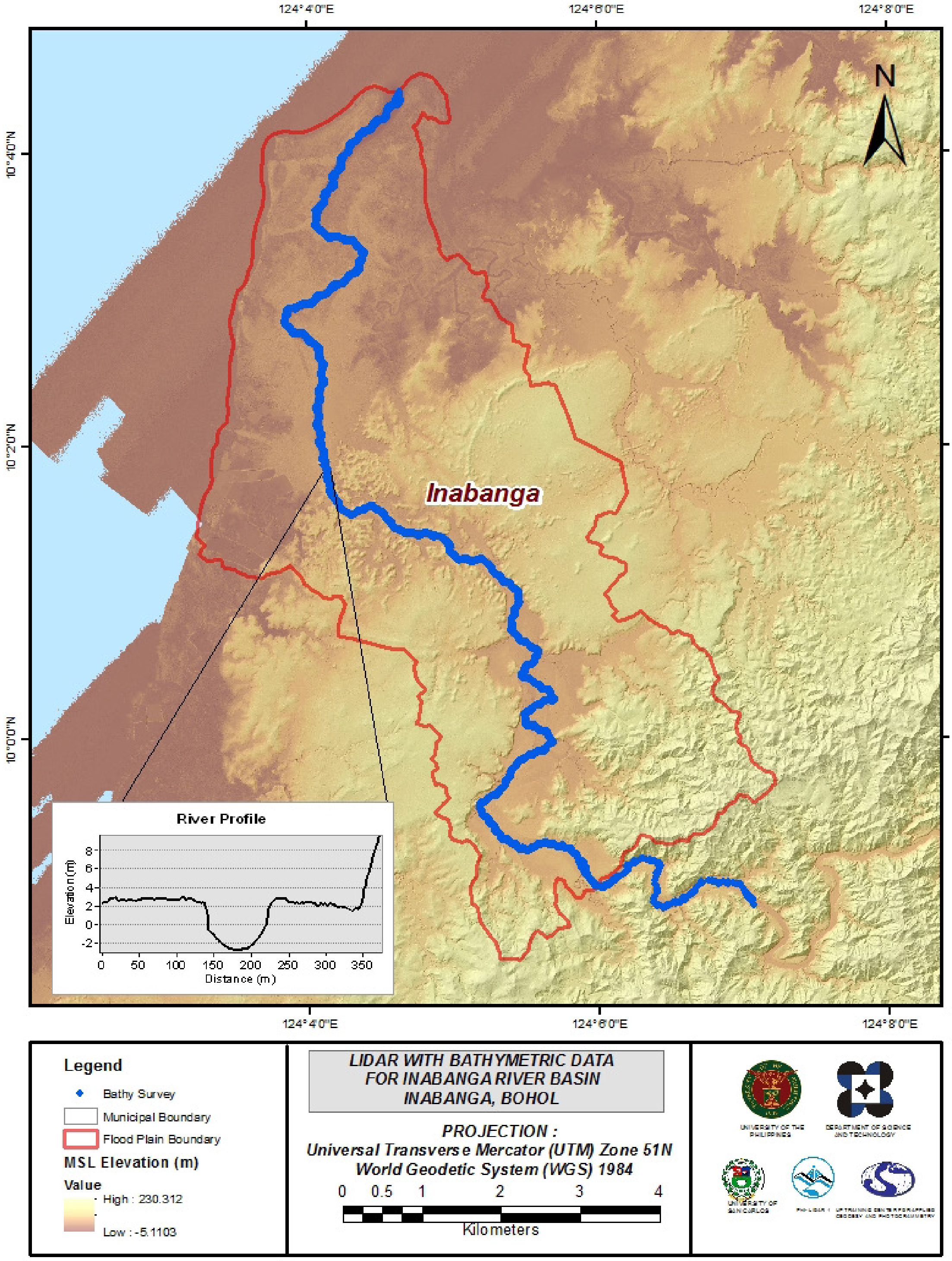

Figure 23. Map of Inabanga floodplain with bathymetric survey points in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking (QC) of Digitized Features' Boundary

Inabanga floodplain, including its 200-m buffer, has a total area of 42.55sq km. For this area, a total of 5.0 sq. km., corresponding to a total of 1715 building features, were considered for QC. Figure 24 shows the QC block for the Inabanga floodplain.

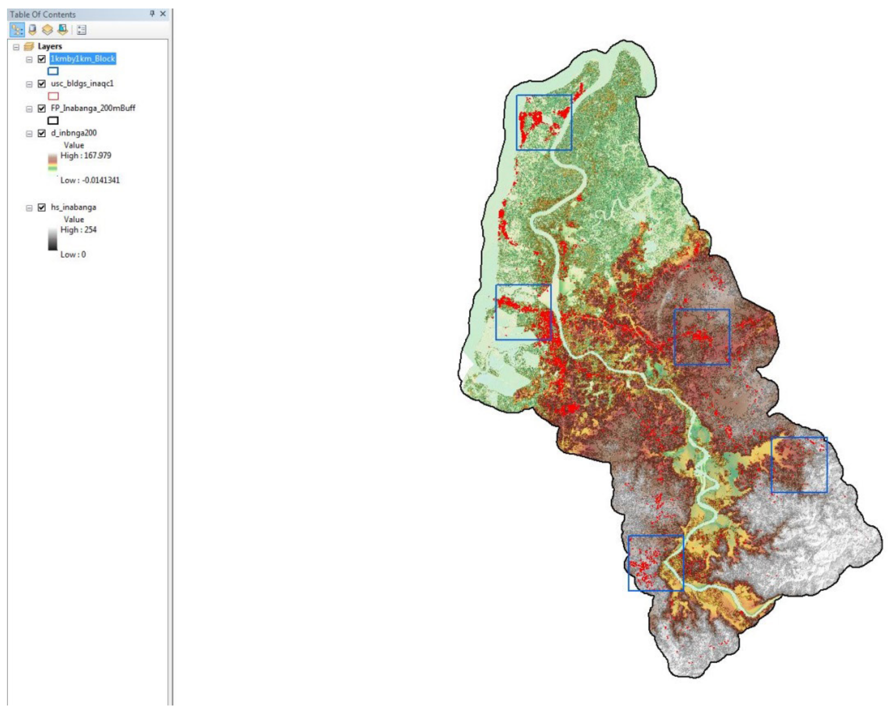

Figure 24. Block (in blue) of Inabanga building features that was subjected to QC.

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

Table 16. Details of the quality checking ratings for the building features extracted for the Inabanga River Basin

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Inabanga	99.95	100.00	99.60	PASSED

3.12.2 Height Extraction

Height extraction was done for 4,862 building features in Inabanga floodplain. Of these building features, 618 were filtered out after height extraction, resulting to 4,244 buildings with height attributes. The lowest building height is at 2.00 meters, while the highest building is at 8.08 meters.

3.12.3 Feature Attribution

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

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

Table 17. Building features extracted for Inabanga Floodplain.

Facility Type	No. of Features
Residential	4,121
School	40
Market	18
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	7
Barangay Hall	13
Military Institution	0
Sports Center/Gymnasium/Covered Court	3
Telecommunication Facilities	0
Transport Terminal	3
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	13
Bank	2
Factory	0
Gas Station	2
Fire Station	0
Other Government Offices	7
Other Commercial Establishments	15
Total	**4,244**

Table 18. Total length of extracted roads for Inabanga Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Inabanga	33.62	7.87	0.00	5.7455	0.00	**47.23**

Table 19. Number of extracted water bodies for Inabanga Floodplain.

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/ Ponds	Sea	Dam	Fish Pen	
Inabanga	10	38	0	0	128	**176**

Only one (1) bridge over small channels that are part of the river network was also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

All extracted ground features were given the complete required attributes. Respectively, all these output features comprise the flood hazard exposure database for the floodplain. The final quality checking completes the feature extraction phase of the project.

Figure 25 shows the completed Digital Surface Model (DSM) of the Inabanga floodplain overlaid with its ground features.

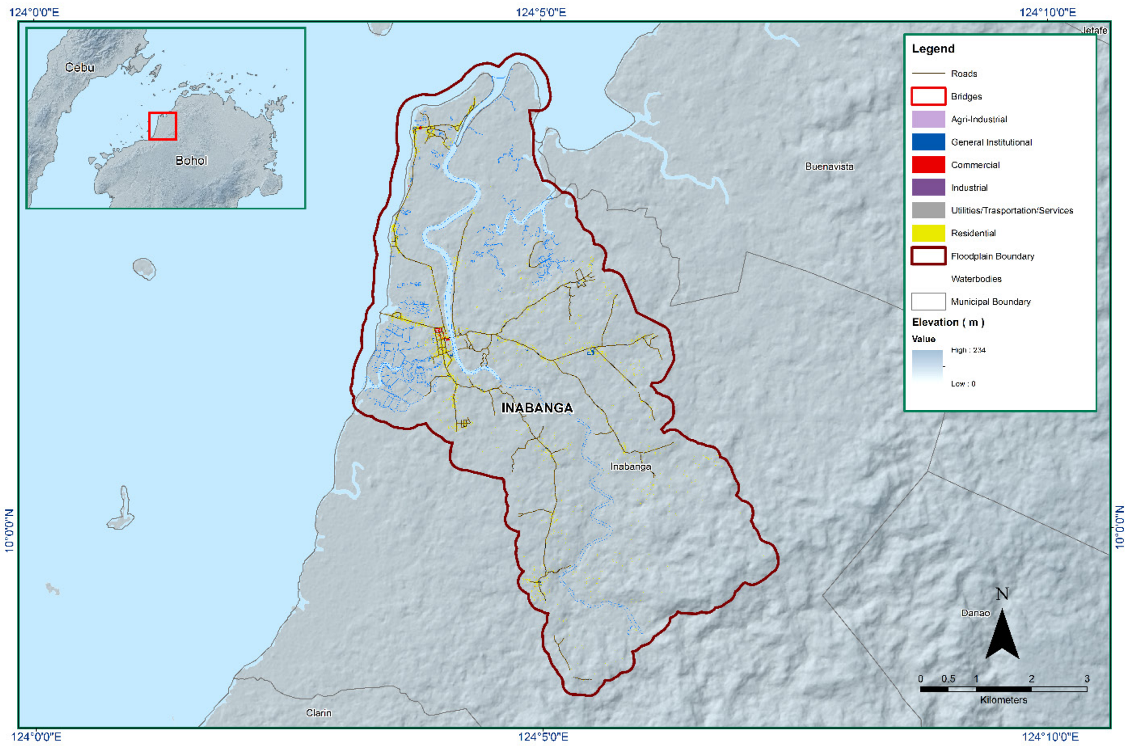

Figure 25. Extracted features of the Inabanga Floodplain.

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

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Inabanga River on June 4 to 14, 2015 with the following scope: reconnaissance; control survey; cross-section and as-built survey at Inabanga Bridge in Brgy. Canlinte, Municipality of Inabanga; validation points acquisition of about 19.35 km; and bathymetric survey from Brgy. Cagayan down to Brgy. Bugang with approximate length of 18.1 km. The entire survey extent is illustrated inFigure 26.

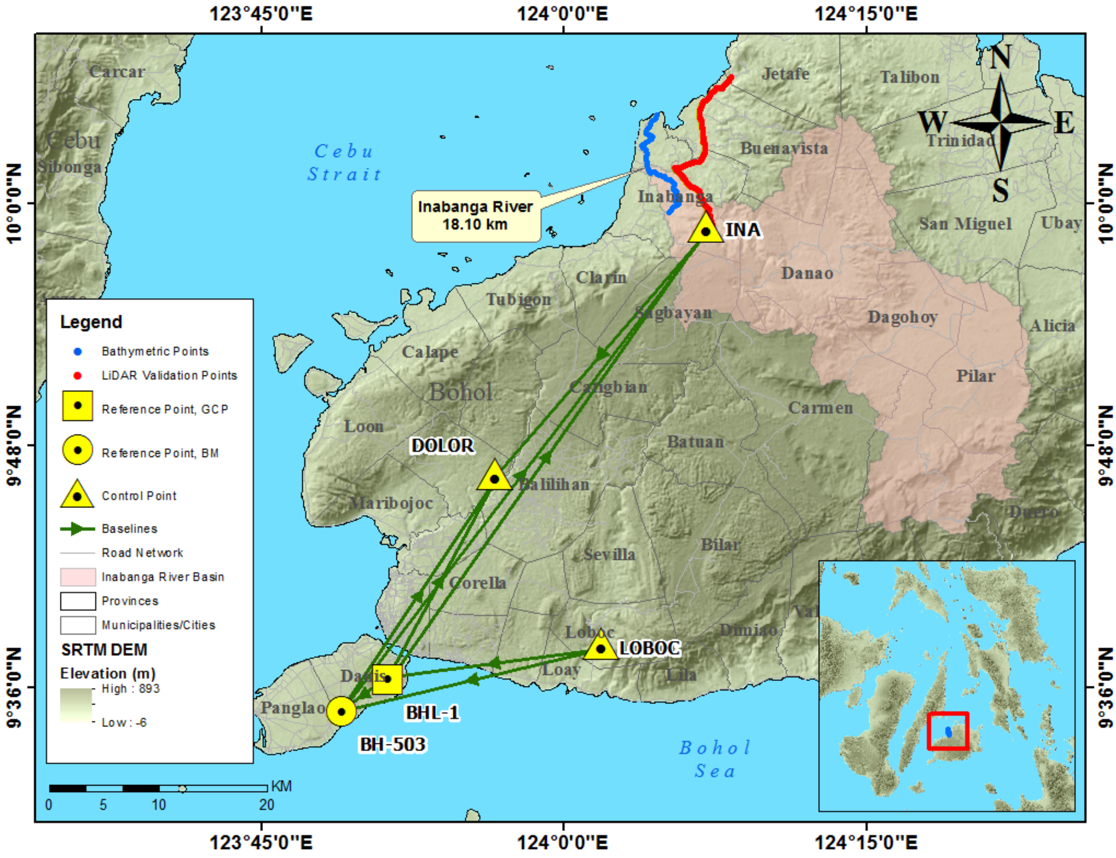


Figure 26. Inabanga River Survey Extent.

4.2 Control Survey

The GNSS network used for Inabanga River survey is composed of three (3) loops established on June 7 and 10, 2015, occupying the following reference points: BHL-1, a 1st order NAMRIA GCP in Brgy. Catarman, Municipality of Dauis; BH-503, a 1st order NAMRIA BM in Brgy. Dao, also in Municipality of Dauis.

Three (3) control points were established along the approach of bridges, namely: DOLOR, located in Dorol Bridge in Brgy.Dorol, Municipality of Angilan; INA, located in Baguhan Bridge in Brgy. Baguhan, Municipality of Inabanga; and LOBOC, located in Loboc Bridge in Brgy. Poblacio Sawang, Municipality of Loboc; all in Bohol.

Table 20depicts the summary of reference and control points utilized, with their corresponding locations, whileFigure 27 shows the GNSS network established in the Inabanga River Survey.

Table 20. List of reference and control points used during the survey in Inabanga River (Source: NAMRIA, UP-TCAGP).

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date of Establishment
Control Survey on June 5 and 8, 2015						
BHL-01	1st order, GCP	9°36’22.43560”	123°51’15.91256”	247.563	-	2007
BH-503	1st order, BM	-	-	85.726	22.328	2008
DOLOR	UP Established	-	-	-	-	6-7-2015
INA	UP Established	-	-	-	-	6-7-2015
LOBOC	UP Established	-	-	-	-	6-10-2015

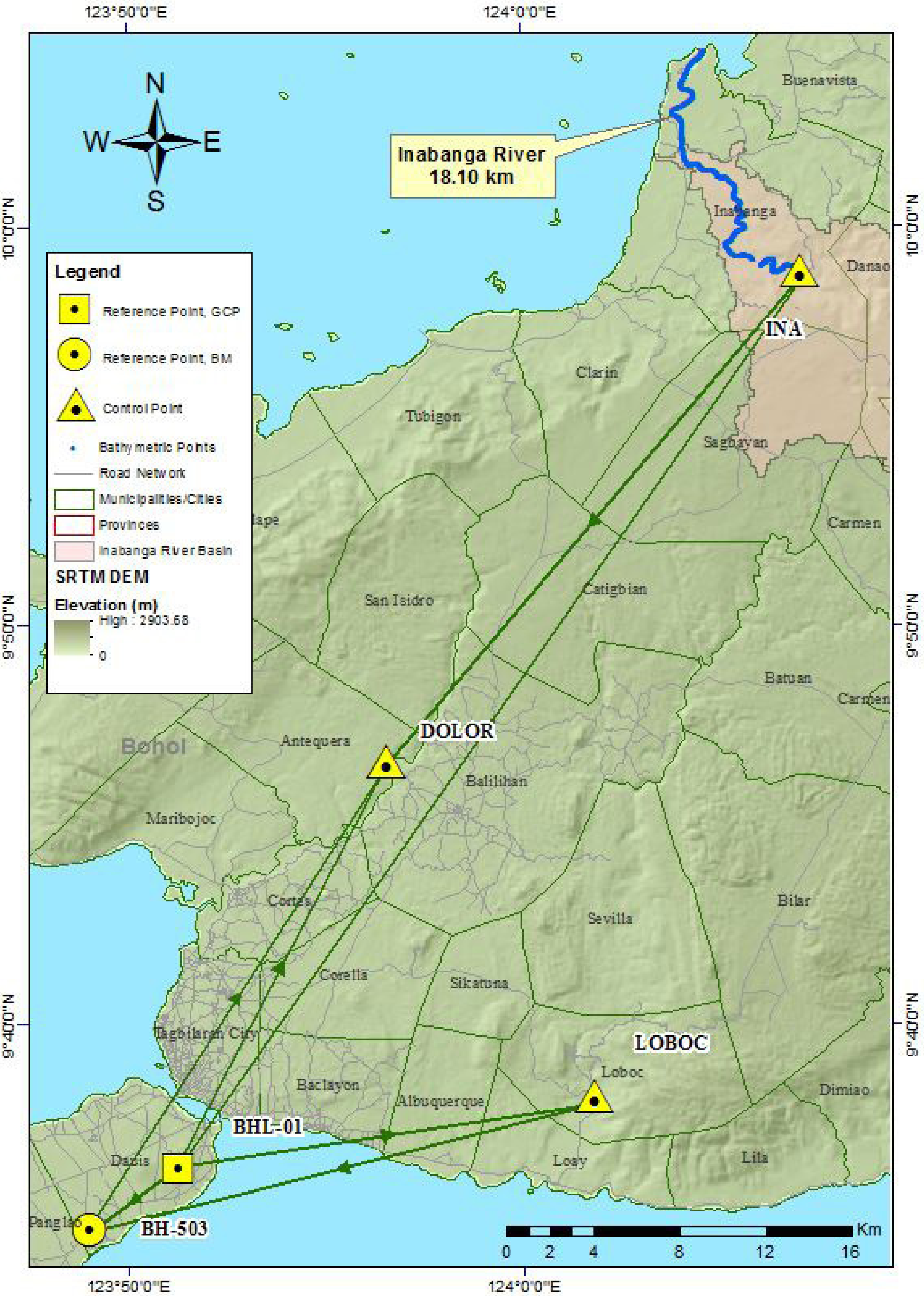


Figure 27. Inabanga River Basin Control Survey Extent.

Figure 28 toFigure 32depict the setup of the GNSS on recovered reference points and established control points in the Inabanga River.

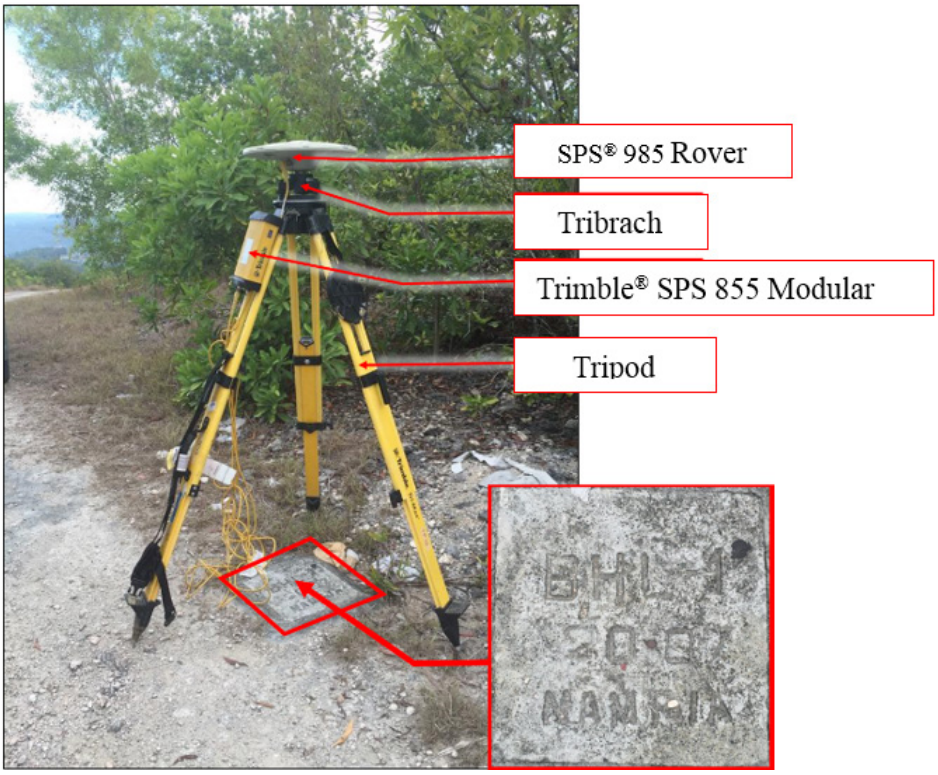


Figure 28. GNSS receiverset up, Trimble® SPS 985 at BHL-01 near a telecommunication antennae in Brgy. Catarman, Municipality of Dauis, Bohol.

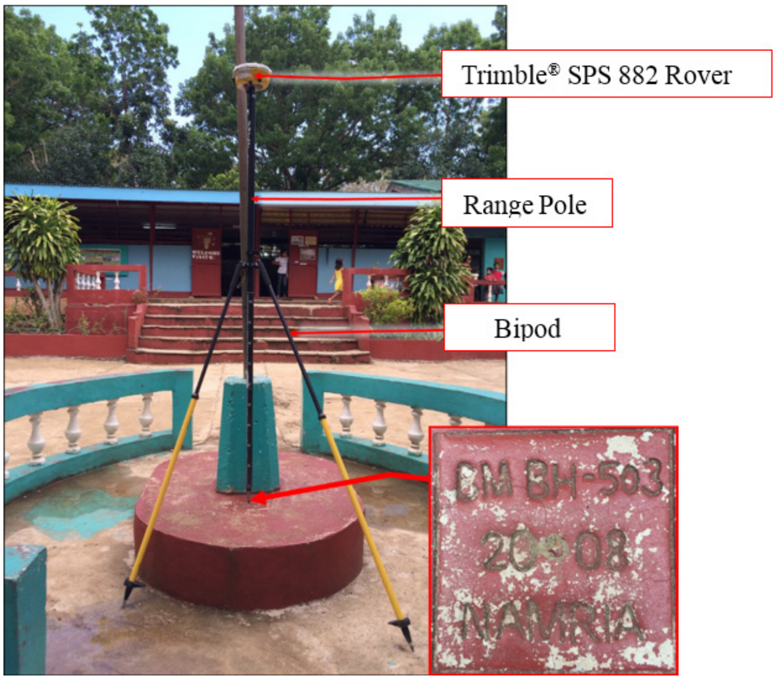


Figure 29. GNSS receiver set up, Trimble® SPS 882 at BH-503 located inside the campus of Dao Elementary School, Brgy. Dao, Municipality of Dauis, Bohol.

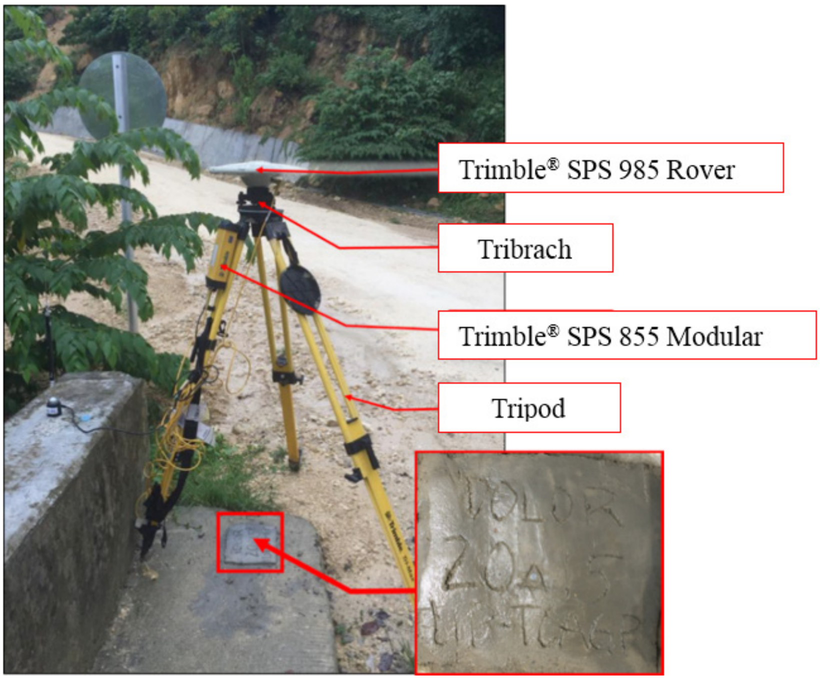


Figure 30. GNSS receiver set up, Trimble® SPS 985 at control point DOLOR, located at the left most (facing downstream) Baguhan Bridge approach, across Inabanga River located in Brgy. Dorol, Municipality of Angilan, Bohol.

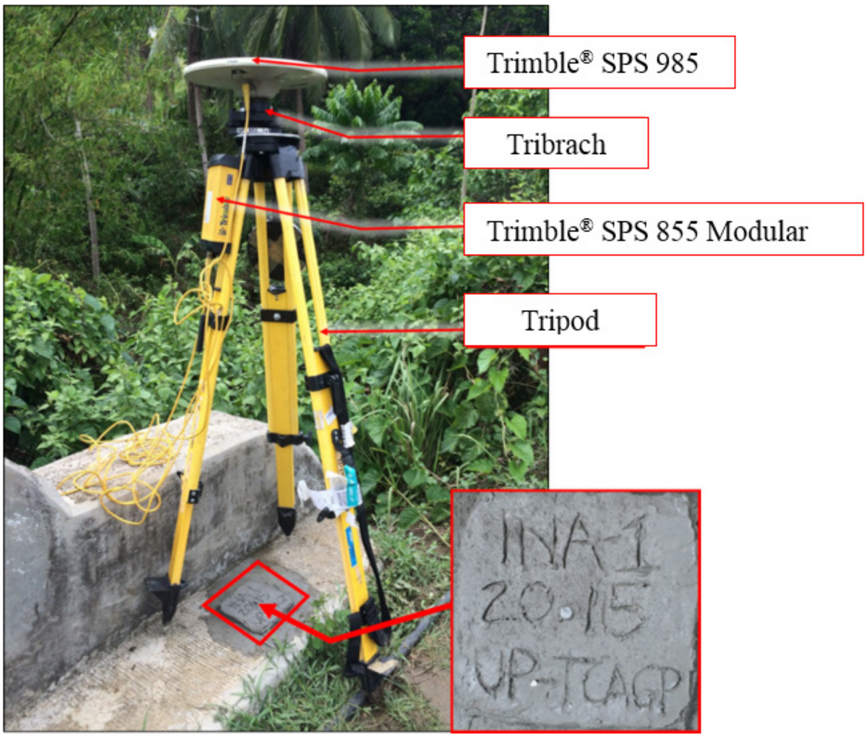


Figure 31. GNSS receiver set up, Trimble® SPS 985 at INA-1 at the Inabanga Bridge approach, Brgy. Baguhan, Inabanga, Bohol.

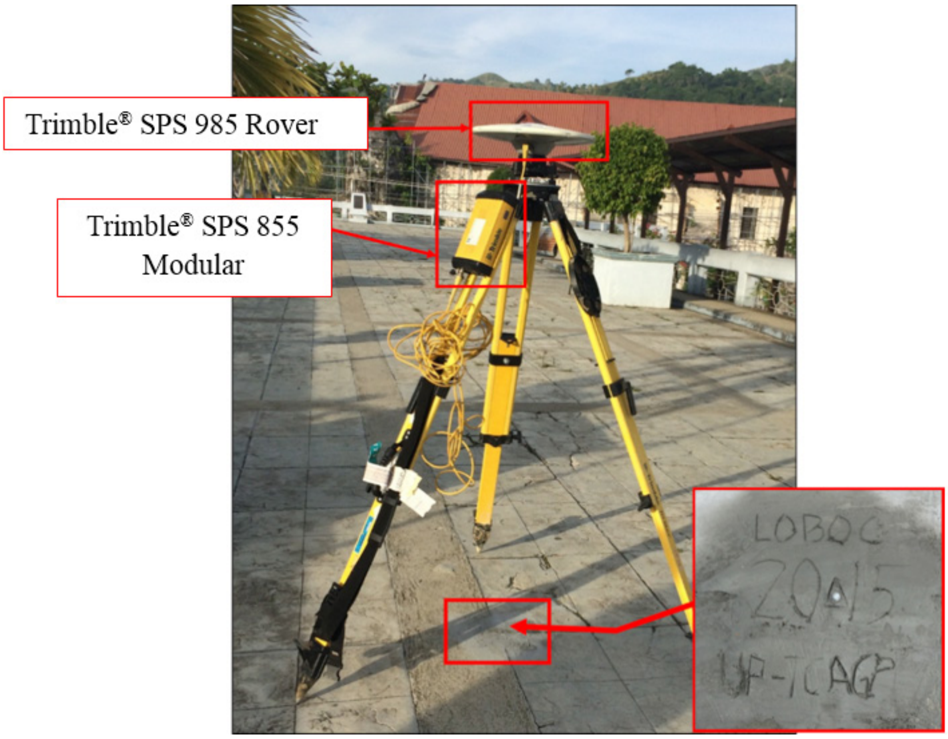


Figure 32. GNSS receiver set up, Trimble® SPS 852 on LOBOC, located on the incomplete bridge across the Loboc River near the municipality town plaza of Loboc in Brgy. Poblacion.

4.3 Baseline Processing

The GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement respectively. In cases where one or more baselines did not meet all of these criteria, masking was performed. Masking is the removal or covering of portions of the baseline data using the same processing software. The data is then repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, a resurvey is initiated. Table 21presents the baseline processing results of control points in the Inabanga River Basin, as generated by the TBC software.

Table 21. The Baseline processing report for the Inabanga River GNSS static observation survey.

Observation	Date of Observation	Solution Type	H.Prec. (Meter)	V.Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Height (Meter)
BHL1 --- BH503	6-7-2015	Fixed	0.005	0.022	235°34’43”	5045.794	-161.828
BHL1 --- DOLOR	6-7-2015	Fixed	0.006	0.039	27°08’58”	21145.711	-173.237
BH503 --- DOLOR	6-10-2015	Fixed	0.010	0.064	32°30’26”	25695.545	-11.413
INA --- DOLOR	6-7-2015	Fixed	0.010	0.060	220°21’08”	29699.597	-7.535
BHL1 --- INA	6-10-2015	Fixed	0.009	0.027	34°50’24”	50519.954	-165.707
BH503 --- INA	6-10-2015	Fixed	0.013	0.043	36°41’11”	55267.714	-3.844
BHL1 --- BH503	6-7-2015	Fixed	0.004	0.038	235°34’43”	5045.804	-161.825

LOBOC --- BHL1	6-7-2015	Fixed	0.004	0.027	80°13'56"	19591.794	-173.810
LOBOC --- BH503	6-10-2015	Fixed	0.006	0.076	255°17'11"	24269.112	11.864

4.4 Network Adjustment

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

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

where:

x_e is the Easting Error,

y_e is the Northing Error, and

z_e is the Elevation Error

For complete details, see the Network Adjustment Report shown inTable 22to Table 25.

The five (5) control points, BHL-1, BH-503, DOLOR, INA and LOBOC were occupied and observed simultaneously to form a GNSS loop. All nine (9) baselines acquired fixed solutions and passed the required ±20cm and ±10cm for horizontal and vertical precisions, respectivelyas presented inTable 21. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

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

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
BH503	Grid				Fixed
BHL1	Global	Fixed	Fixed		
Fixed = 0.000001(Meter)					

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

Table 23. Adjusted grid coordinates for the control points used in the Inabanga River flood plain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
H503	589600.481	0.005	1059131.546	0.005	22.328	?	e
BHL1	593754.454	?	1061993.296	?	184.054	0.049	LL
DOLOR	603353.551	0.011	1080828.082	0.007	10.331	0.089	
INA	622503.084	0.018	1103520.295	0.011	17.794	0.093	
LOBOC	613048.755	0.007	1065364.372	0.007	9.787	0.083	

The results of the computation for accuracy are as follows:

a. **BHL-1**

Horizontal accuracy = Fixed

Vertical accuracy = 4.9 cm < 10 cm

b. **BH-503**

Horizontal accuracy = √ ((0.5) ² + (0.5) ²

= √(0.25 + 0.25)

= 0.61 cm < 20 cm

Vertical accuracy = Fixed

c. **DOLOR**

Horizontal accuracy = √ ((1.1) ² + (0.7) ²

= √(1.21+ 0.49)

= 1.30 cm < 20 cm

Vertical accuracy = 8.9 cm < 10 cm

d. **INA**

Horizontal accuracy = √ ((1.8) ² + (1.1) ²

= √(3.24 + 1.21)

= 2.11 cm < 20 cm

Vertical accuracy = 9.3 cm < 10 cm

e. **LOBOC**

Horizontal accuracy = √ ((0.7) ² + (0.7) ²

= √(0.49 + 0.49)

= 0.99 cm < 20 cm

Vertical accuracy = 8.3 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the nine (9) occupied control points are within the required precision.

Table 24. Adjusted geodetic coordinates for control points used in the Inabanga River Flood Plain validation.

Point ID	Latitude	Longitude	Ellipsoid Height (Meter)	Height Error (Meter)	Constraint
BH503	N9°34'49.59212"	E123°48'59.41509"	85.726	?	e
BHL1	N9°36'22.43560"	E123°51'15.91256"	247.563	0.049	LL
DOLOR	N9°46'34.81522"	E123°56'32.52432"	74.335	0.089	
INA	N9°58'51.64572"	E124°07'03.51400"	81.908	0.093	
LOBOC	N9°38'10.45985"	E124°01'49.19123"	73.769	0.083	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown inTable 24. Based on the results of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met. The computed coordinates of the reference and control points utilized in the Inabanga River GNSS Static Survey are seen inTable 25.

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
BHL-1	1st order, GCP	9°36’22.43560”	123°51’15.91256”	247.563	1061993	593754.5	184.054
BH-503	1st order, BM	9°34’49.59212”	123°48’59.41509”	85.726	1059132	589600.5	22.328
DOLOR	UP Established	9°46’34.81522”	123°56’32.52432”	74.335	1080828	603353.6	10.331
INA	UP Established	9°58’51.64572”	124°07’03.51400”	81.908	1103520	622503.1	17.794
LOBOC	UP Established	9°38’10.45985”	124°01’49.19123”	73.769	1065364	613048.8	9.787

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

The bridge cross-section and as-built surveys were conducted on June 6, 2015 along the downstream side of Baguhan Bridge in Brgy. Canlinte, Municipality of Inabanga. GNSS receiver Trimble® SPS 882 in PPK survey technique was utilized for this surveyas shown in Figure 33.

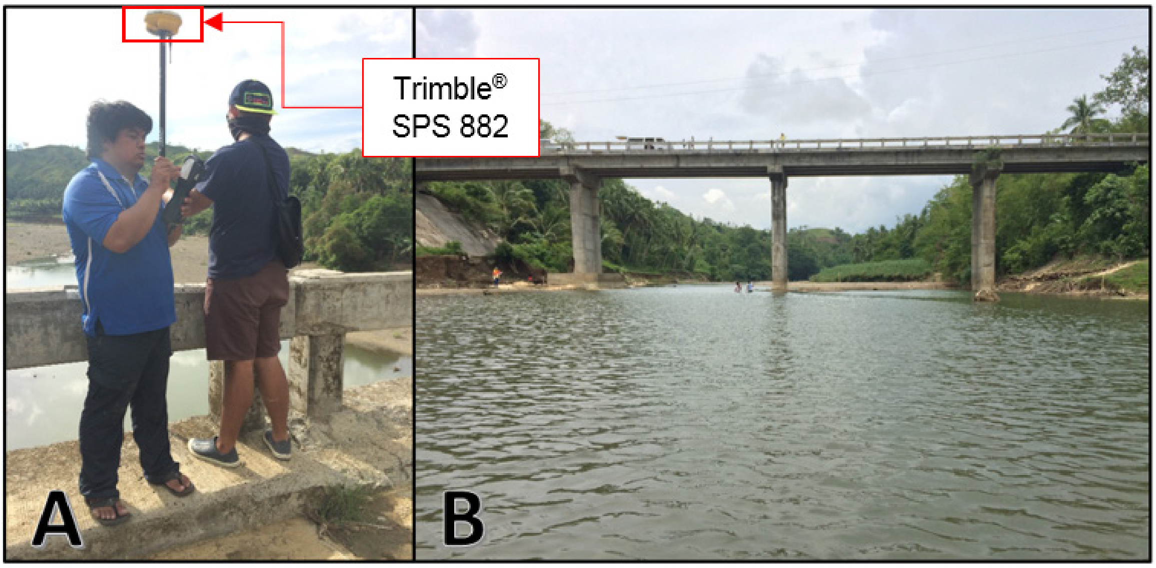


Figure 33. Cross-section and bridge as-built survey (a) for Baguhan Bridge, Brgy. Inabanga, Balilihan Bohol; Panoramic view (b) of the Baguhan Bridge.

The length of the cross-sectional line surveyed atInabanga Bridge is about 89.97 meters with 29 cross-sectional pointsacquired using the control point BH-503 as the GNSS base station. Thelocation map, cross-section diagram and the accomplished bridge data formfor Baguhan Bridge are shown inFigure 34, 35, and 36.

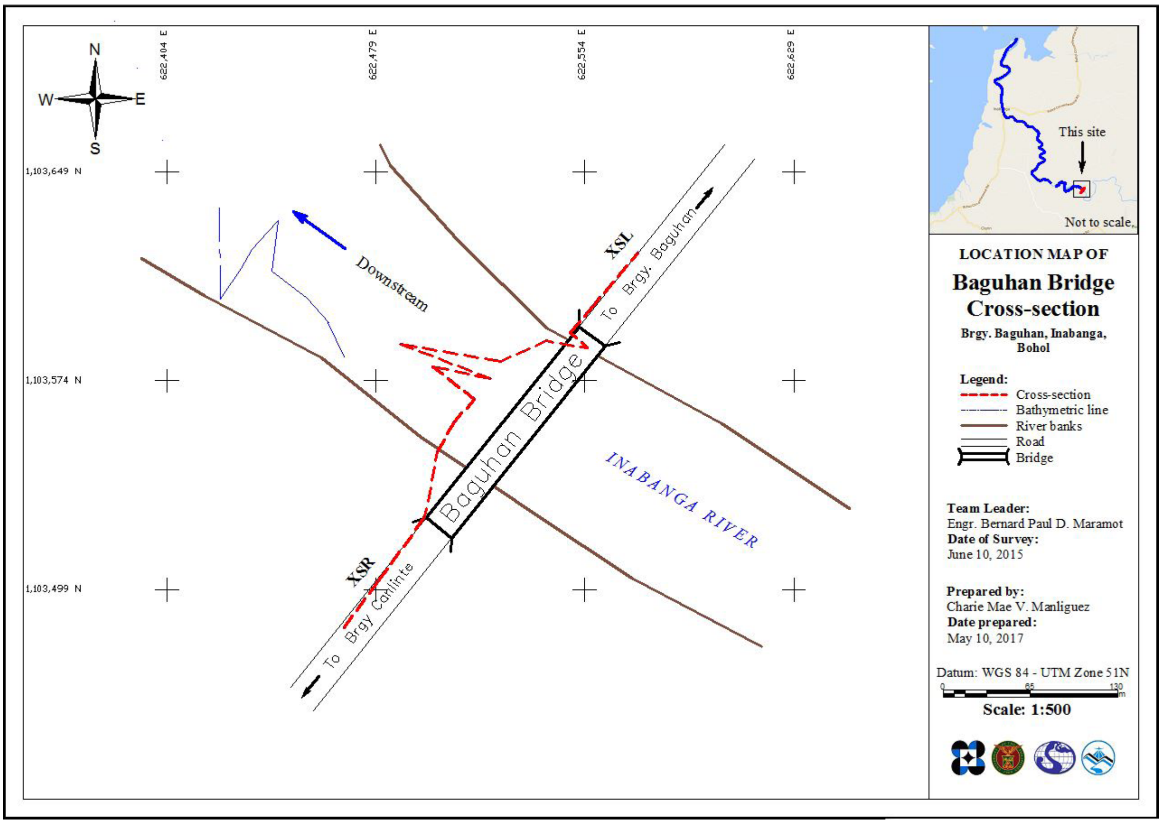


Figure 34. Location map of the Baguhan Bridge Cross Section.

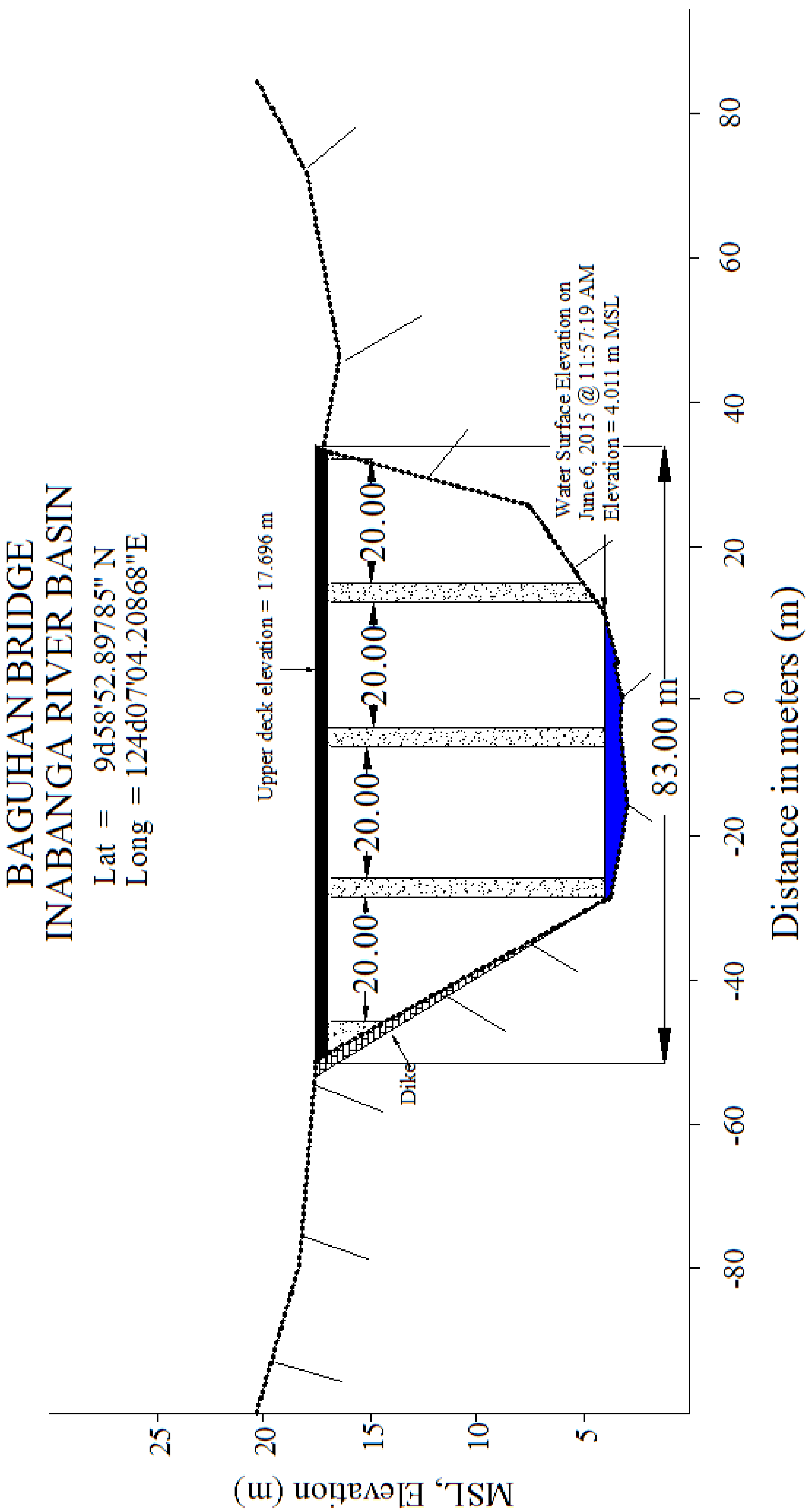


Figure 35. The BaguhanBridge cross-section diagram.

Bridge Data Form

Bridge Name: Baguhan Bridge **Date:** June 6, 2015

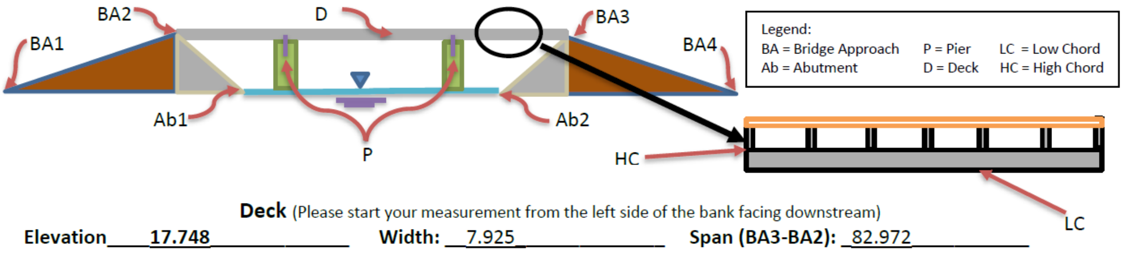
River Name: Inabanga River **Time:** 11:57 A.M.

Location (Brgy, City, Region): Brgy. Baguhan, Municipality of Inabanga, Bohol

Survey Team: Team Bernard

Flow condition: low normal high **Weather Condition:** fair rainy

Latitude: 9d58'51.64528" **Longitude:** 124d07'03.51341"



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

Elevation 17.748 **Width:** 7.925 **Span (BA3-BA2):** 82.972

	Station	High Chord Elevation	Low Chord Elevation
1		17.696	17.038
2			
3			
4			
5			

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	20.407	**BA3**	133.468	17.413
BA2	49.185	17.549	**BA4**	171.100	17.974

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

	Station (Distance from BA1)	Elevation
Ab1	71.440	3.805
Ab2	110.716	4.011

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

Shape: Rectangular **Number of Piers:** 3 **Height of column footing:**

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	72.749	17.616	
Pier 2	93.273	17.617	
Pier 3	113.792	17.463	
Pier 4			
Pier 5			
Pier 6			

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

Figure 36. The Baguhan Bridge as-built survey data.

The water surface elevation of Inabanga River was determined by a survey grade GNSS receiver Trimble® SPS 882 in PPK survey technique on June 6, 2015 at 11:57 AM with a value of 4.011 m in MSL. This was translated into marking on the bridge's pier as shown inFigure 37. It now serves as the reference for flow data gathering and depth gauge deployment of the University of San Carlos, the partner HEI responsible for the monitoring of the Inabanga River.

Figure 37. Water-level markings on the post of Baguhan Bridge.

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on June 10, 2015 using a survey GNSS rover receiver Trimble® SPS 882 mounted on a range pole, which was attached in front of the vehicle as shown inFigure 38. It was secured with a cable-tie to ensurethat it was horizontally and vertically balanced. The antenna height was 2.330 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver.

Figure 38. GNSS Receiver Trimble® SPS 882 installed on a vehicle for Ground Validation Survey.

The survey started from Brgy. Campao Occidental, Municipality of Jetafe along the main roads to Brgy. Canlinte, Municipality of Inabanga. A total of 3,258 validation points were gathered with approximate length of 19.35km. as illustrated in the map in Figure 39.

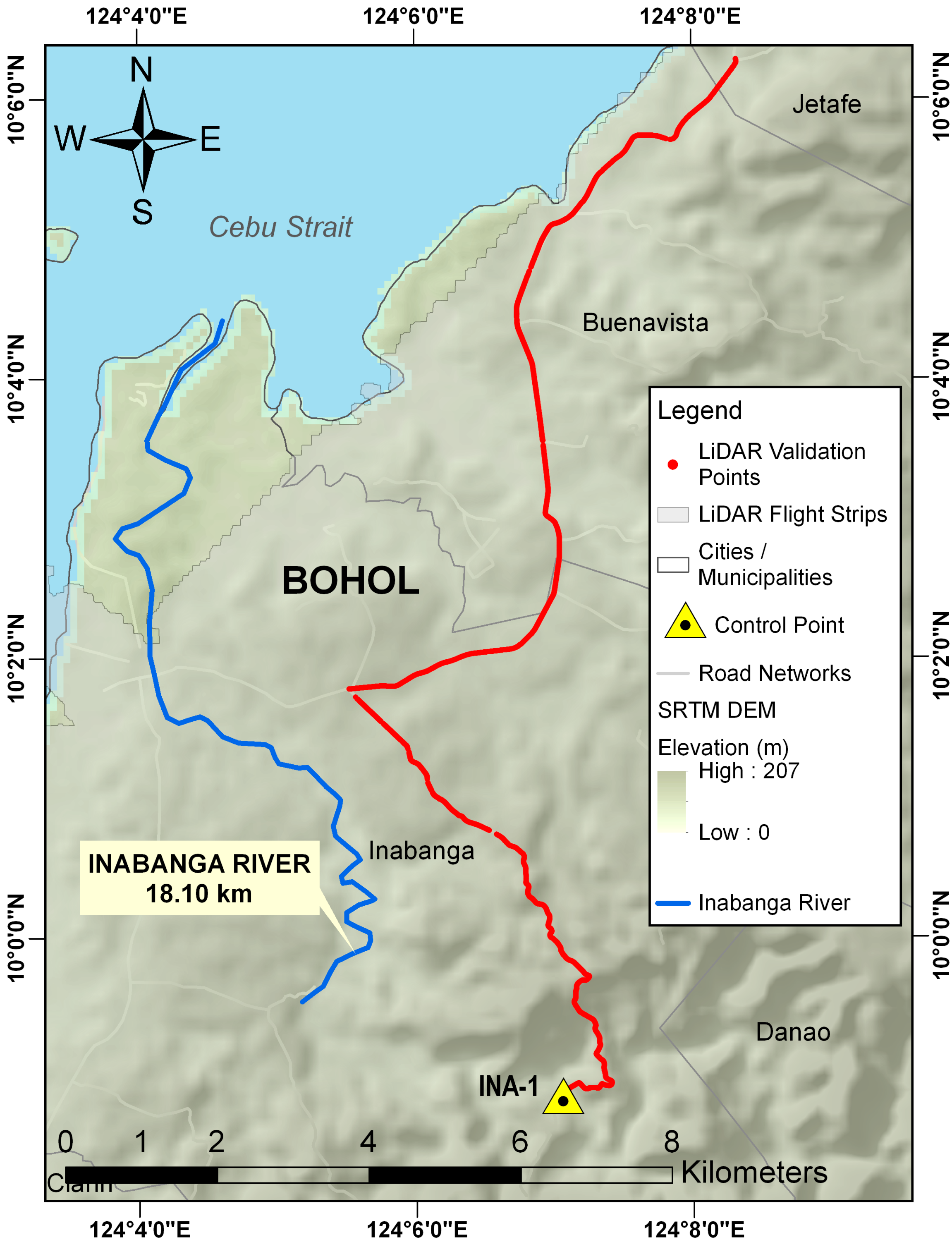


Figure 39. The extent of the LiDAR ground validation survey (in red) for Inabanga River Basin.

4.7 River Bathymetric Survey

A bathymetric survey was performedon June 6, 2015 using Trimble® SPS 882 in GNSS PPK survey technique in continuous topo modeas shown inFigure 40.

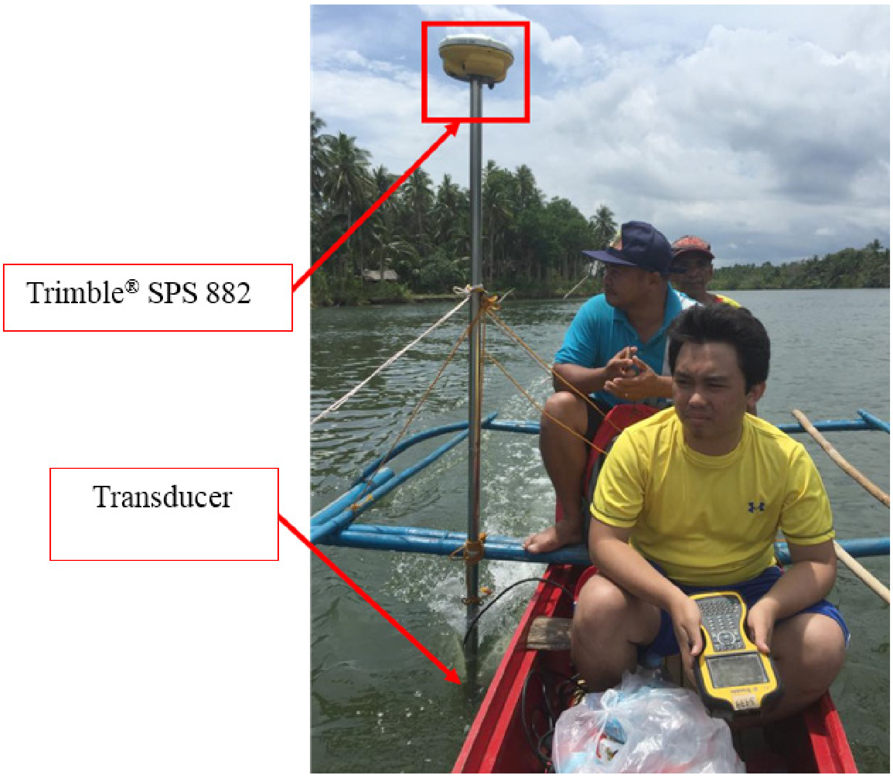


Figure 40. Set up of the bathymetric survey at Inabanga River using Trimble® SPS 882 in GNSS PPK survey technique.

The survey started in the upstream part of the river in Brgy. Riverside, Municipality of Inabanga with coordinates 9°58’52.89787” 124°07’04.20870”, down to the mouth of the river in Brgy. Bugang, also in Municipality of Inabanga with coordinates 10°04’24.56589” 124°04’37.85960”. The control point INA-1 was occupied to use as GNSS base stationall throughout the entire survey.

Overall, the bathymetric survey for Inabanga River gathered a total of 1,522 points, covering18 barangays in Municipality of Inabanga.The extent of the bathymetric survey for the Inabanga River is shown inFigure 41. To further illustrate this, a CAD drawing of the riverbed profile of the Inabanga River was produced. As seen inFigure 42, the highest and lowest elevation has a 31-m difference. The highest elevation observed was 20.381 m in MSL located near Baguhan Bridge in Brgy. Canlinte; while the lowest was-11.92 m below MSL located in Brgy. Tambook.An elevation drop of 2.4 meters was observed within the distance of approximately 18.1 km with a total of 2,568 bathymetric points. The surveyed portion of the river passed Brgy. Cagayan, and Brgy. Bugang.

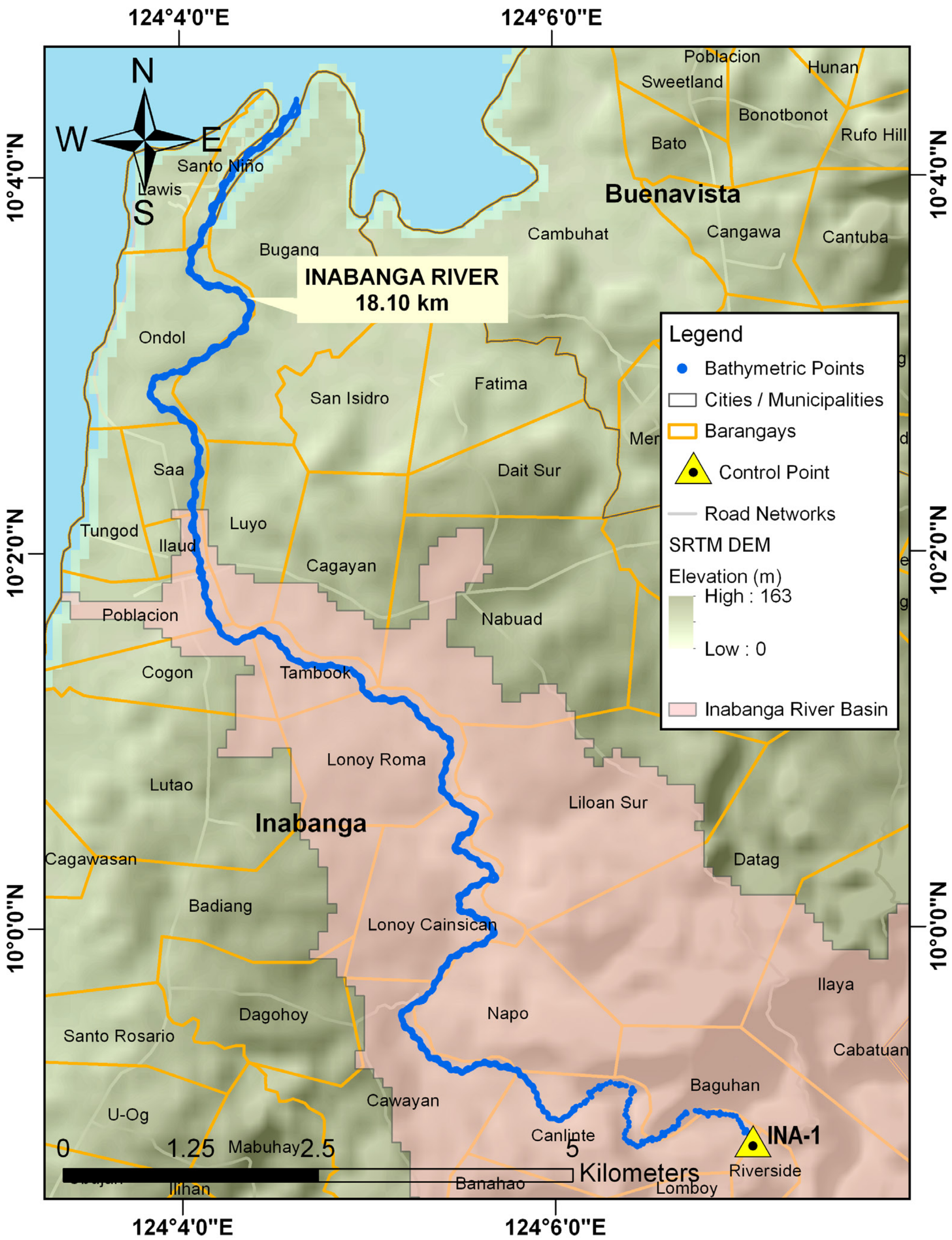


Figure 41. The extent of the Inabanga River Bathymetry Survey.

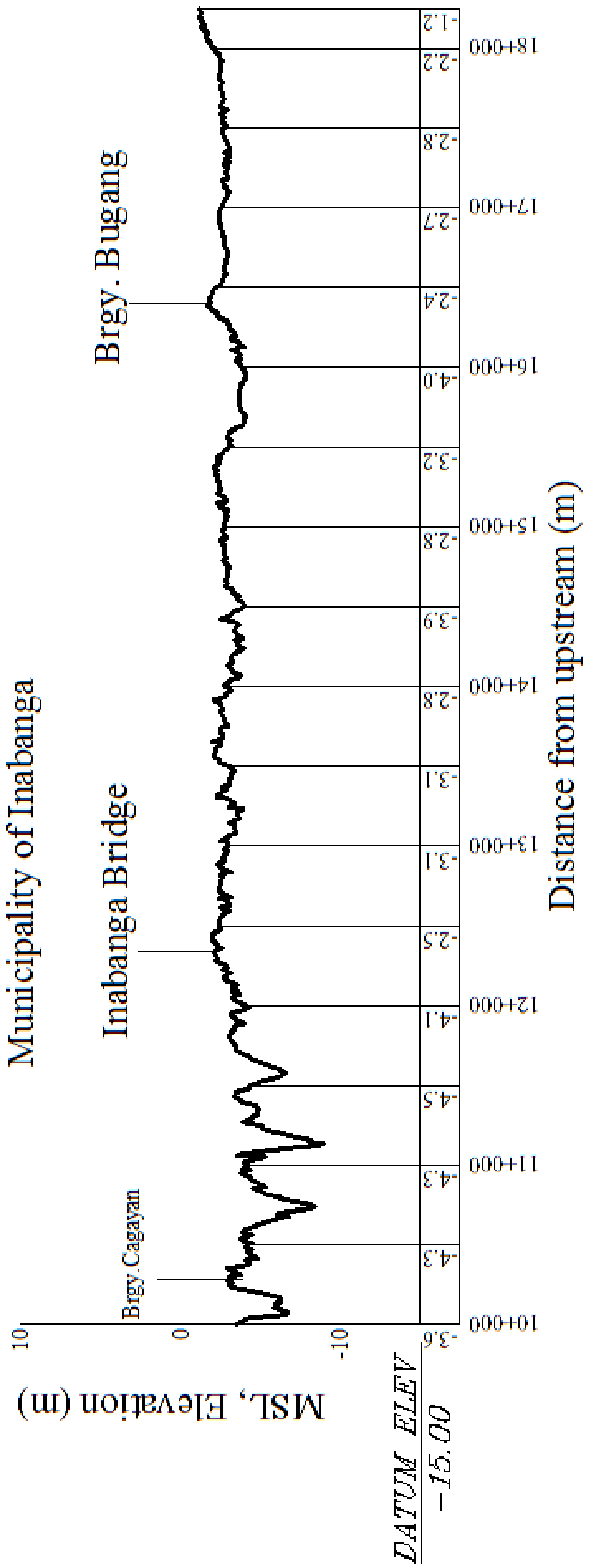


Figure 42. The Inabanga Riverbed Profile.

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 Pauline Racoma

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All components and data, such as rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Inabanga River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an installed Automatic Rain Gauges (ARG) by the Department of Science and Technology - Advanced Science and Technology Institute (DOST-ASTI). Three gauge stations installed are within the watershed of Inabanga River. They are located in the municipalities of Catigbian, Pilar and San Miguel. However, during the acquisition of event flow data, only the station in San Miguel was transmitting data. Another station located at the floodplain Inabanga River was used in calibration. The station is located in Talibon. The location of these stations in the watershed is illustrated inFigure 43.

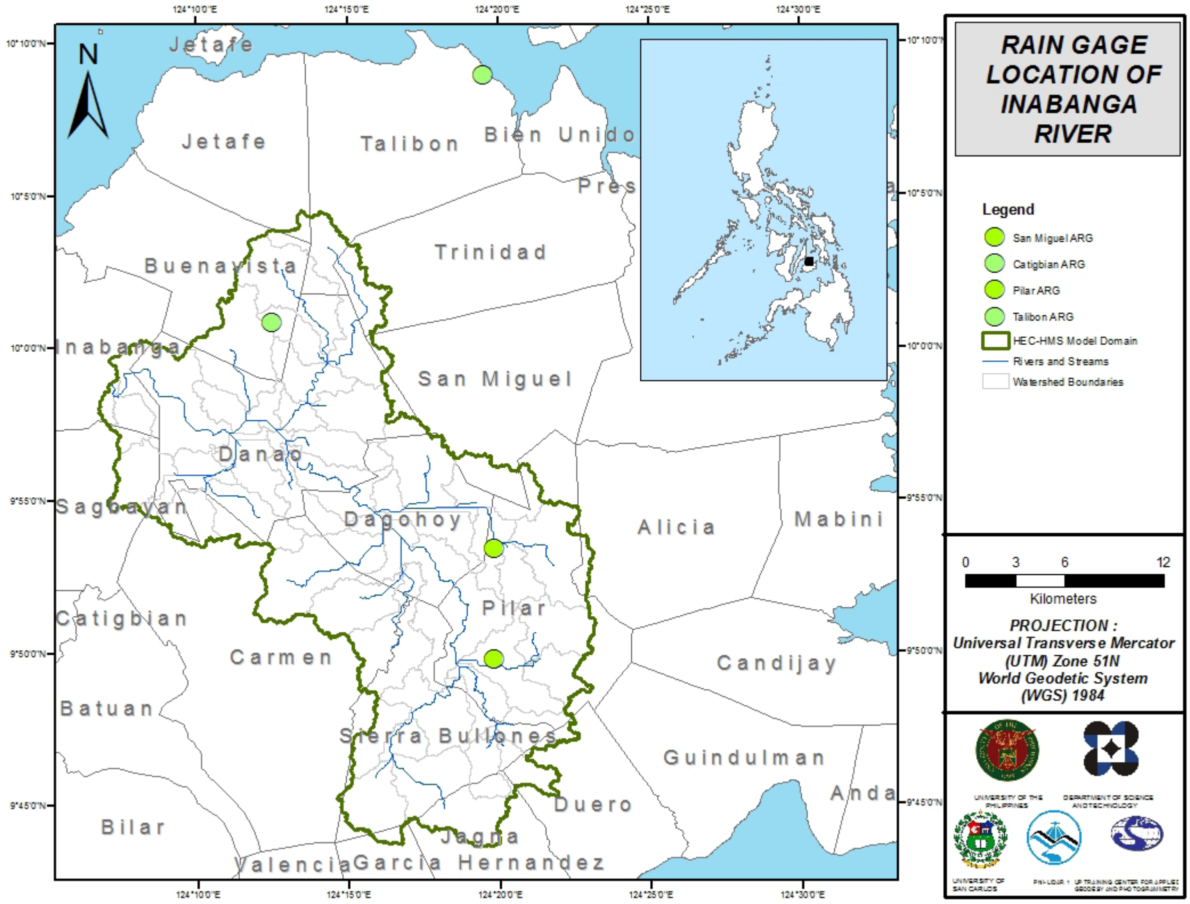


Figure 43. Location Map of the Inabanga HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Baguhan Bridge(9°58’52.9”, 124°7’4.80”E), Inabanga, Bohol to establish the relationship between the observed water levels (H) and outflow (Q) of the watershed at this location.

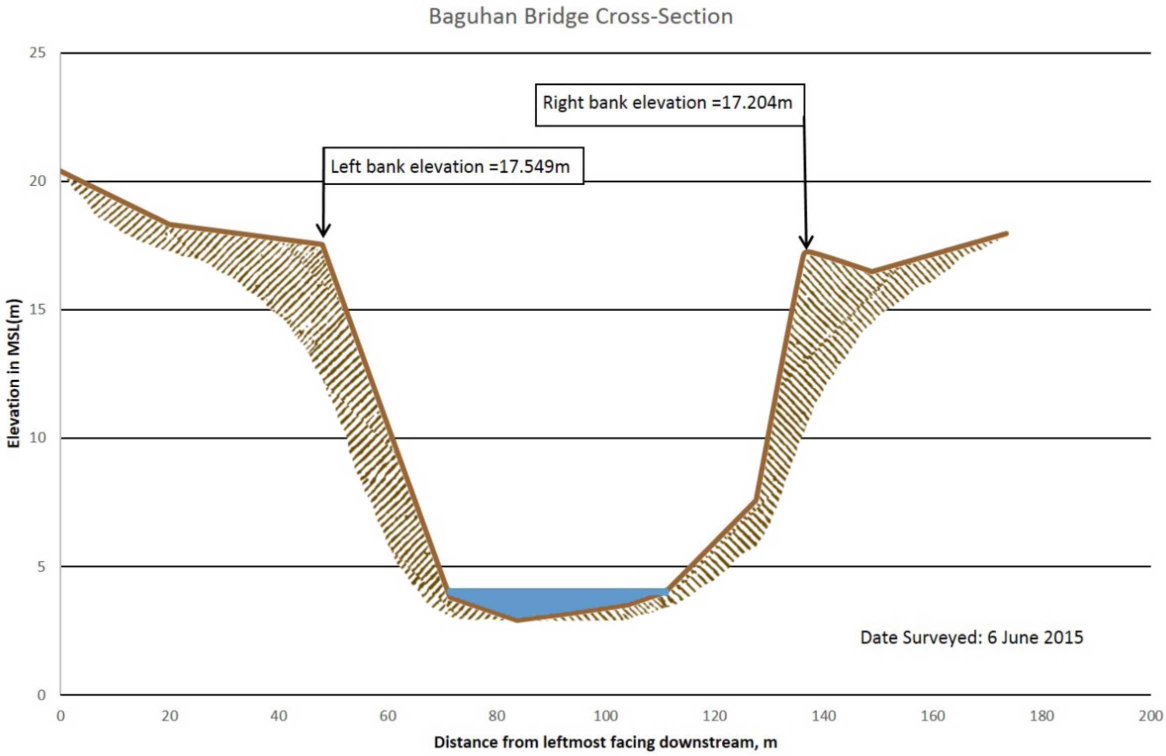


Figure 44. Cross-Section Plot of Baguhan Bridge.

For Baguhan Bridge, the rating curve is expressed as shown inFigure 45.

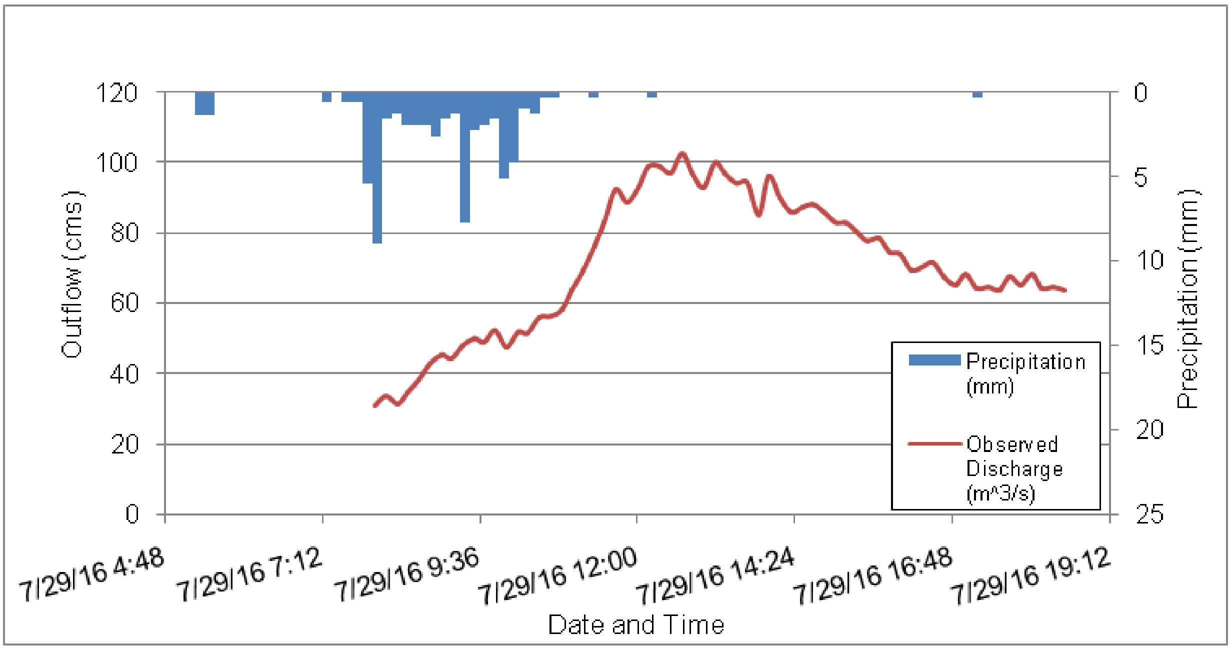


Figure 45. The rating curve at Baguhan Bridge, Inibanga, Bohol.

This rating curve equation was used to compute the river outflow at Baguhan Bridge for the calibration of the HEC-HMS model for Inabanga shown inFigure 46. The peak dischargeis 99.9m³/s at 12:40 PM of July 29, 2016.

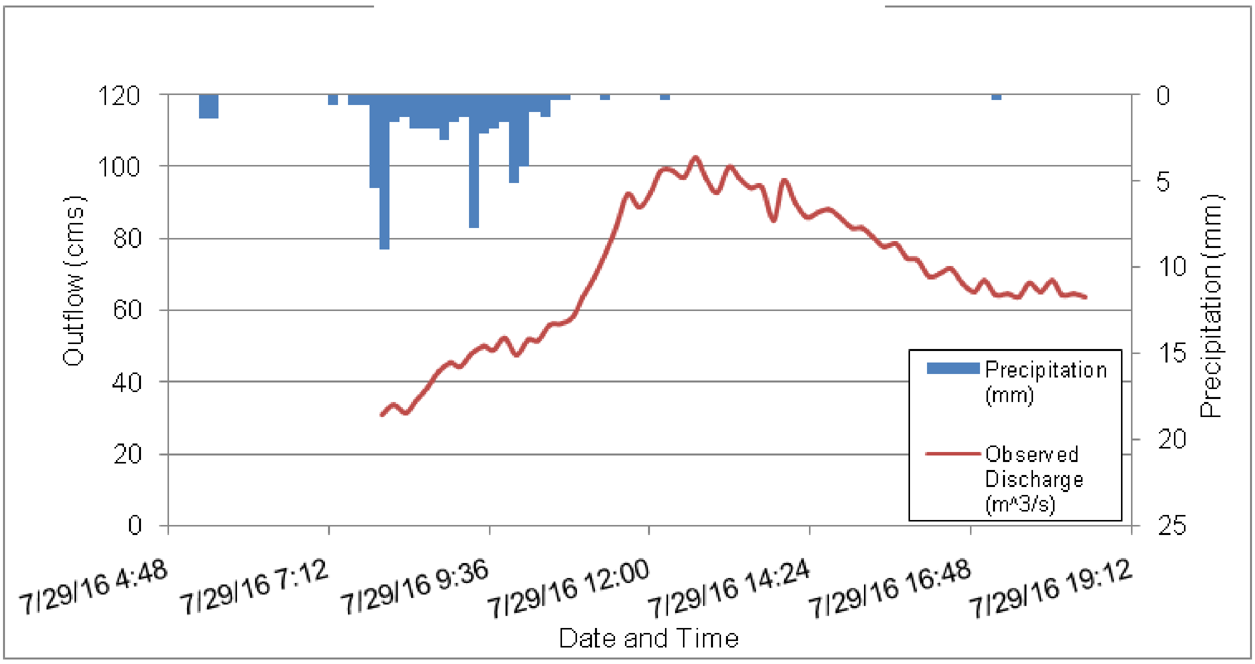


Figure 46. Rainfall and outflow data at Baguhan Bridge, which was used for modeling.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Tagbilaran Point Gauge (Table 26). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values in such a way that certain peak values will be attained at a certain time (Figure 48). This station was selected based on its proximity to the Inabanga watershed. The extreme values for this watershed were computed based on a 39-year record.

Table 26. RIDF values for the Inabanga River Basin based on average RIDF data of Tagbilaran station, as computed by PAGASA.

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	**10 mins**	**20 mins**	**30 mins**	**1 hr**	**2 hrs**	**3 hrs**	**6 hrs**	**12 hrs**	**24 hrs**
2	14.4	21.9	26.5	34	43.7	50.4	62.6	73.8	84.1
5	23.1	35.4	41.8	54.6	65.1	76.5	95.1	108.2	121.2
10	28.8	44.3	52	68.3	79.3	93.7	116.7	131	145.7
15	32.1	49.3	57.7	76.1	87.3	103.5	128.8	143.9	159.6
20	34.3	52.8	61.7	81.5	92.9	110.3	137.3	152.9	169.3
25	36.1	55.5	64.8	85.6	97.3	115.5	143.8	159.8	176.7
50	41.5	63.8	74.4	98.5	110.6	131.7	164	181.1	199.7
100	46.8	72.1	83.8	111.2	123.8	147.7	184	202.3	222.6

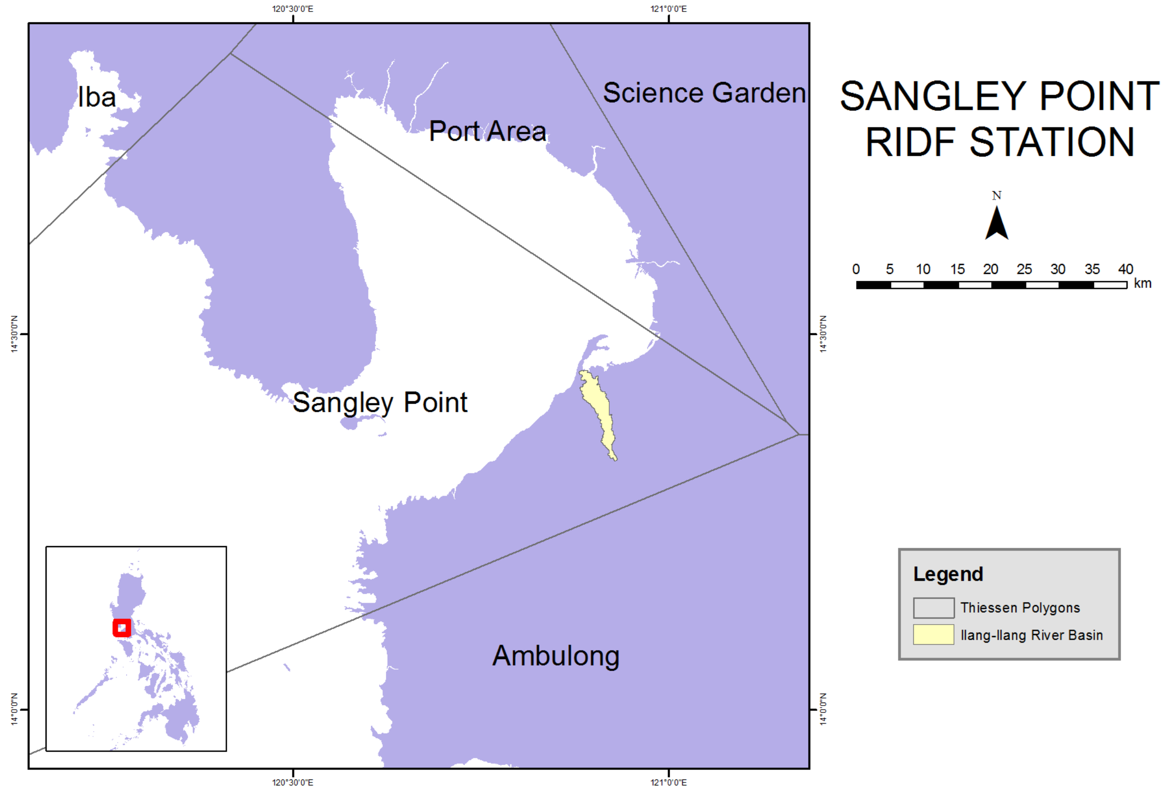


Figure 47. The location of the Tagbilaran RIDF station relative to the Inabanga River Basin.

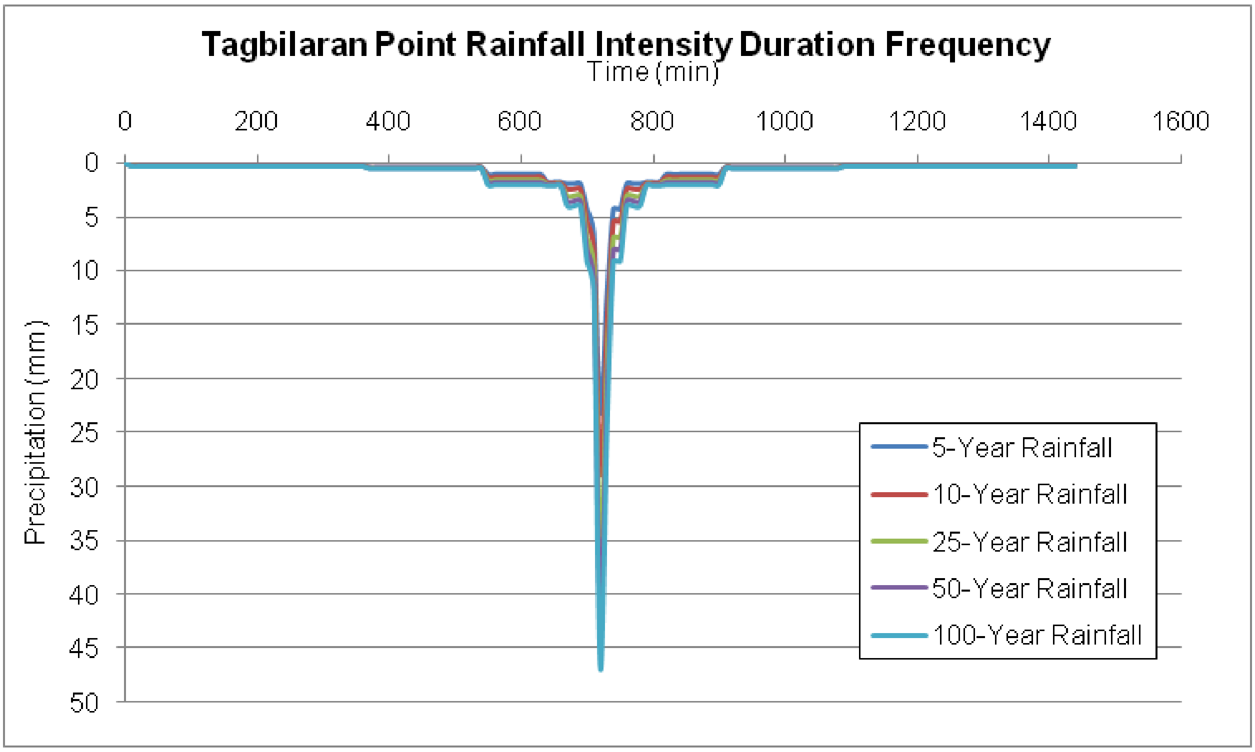


Figure 48. The synthetic storm generated for a 24-hour period rainfall for various return periods.

5.3 HMS Model

The soil dataset was taken on 2004 from the Bureau of Soils and Water Management (BSWM). It is under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Inabanga River Basin are shown in Figure 49 andFigure 50,respectively.

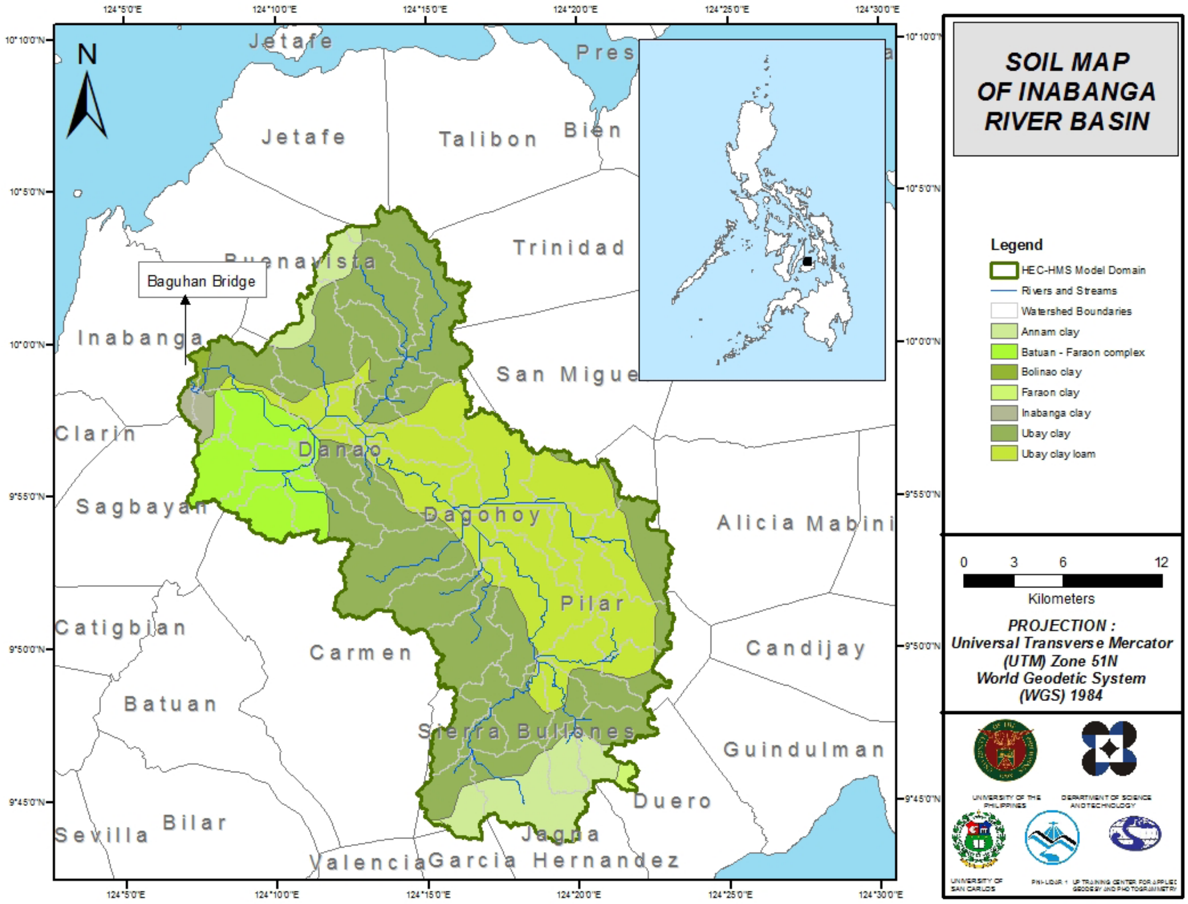


Figure 49. Soil Map of Inabanga River Basin.

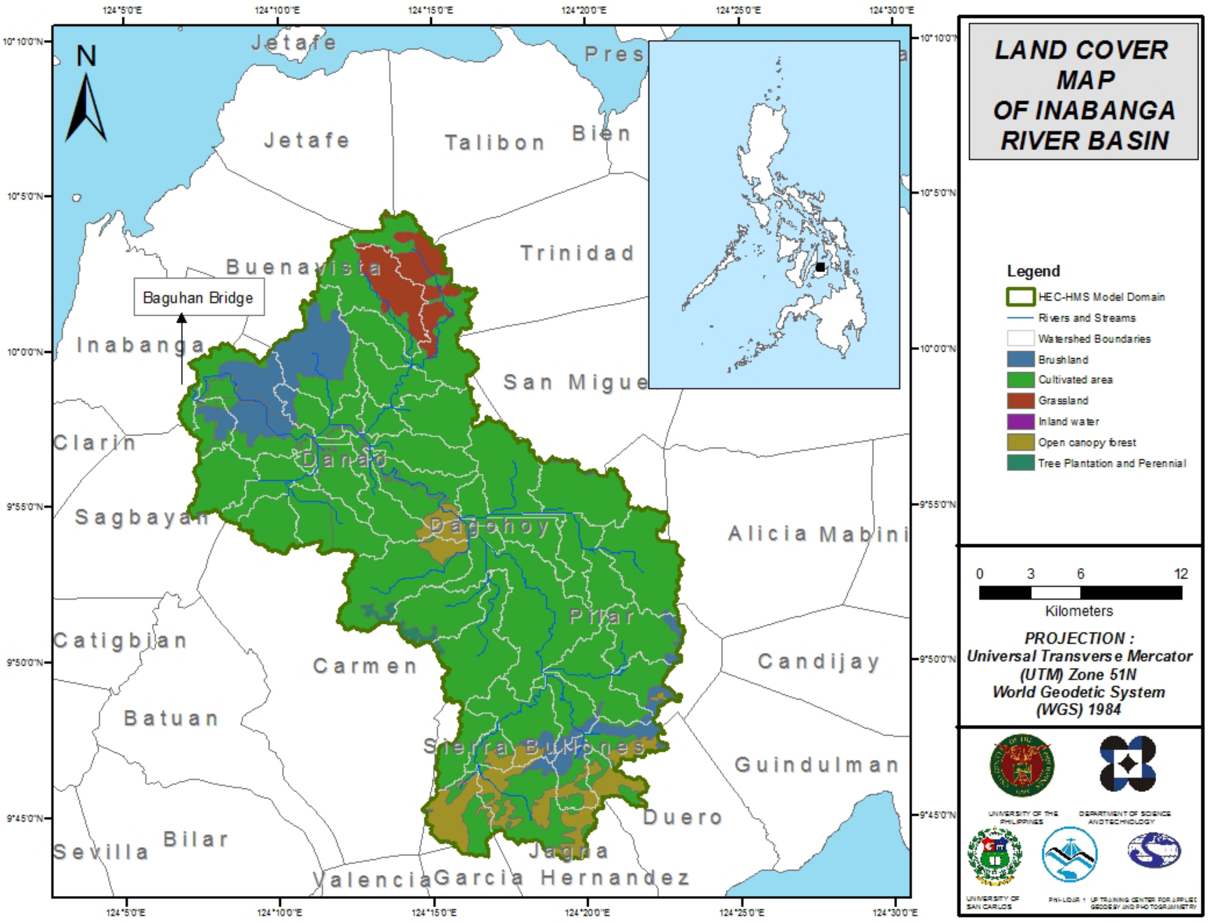


Figure 50. Land Cover Map of Inabanga River Basin.

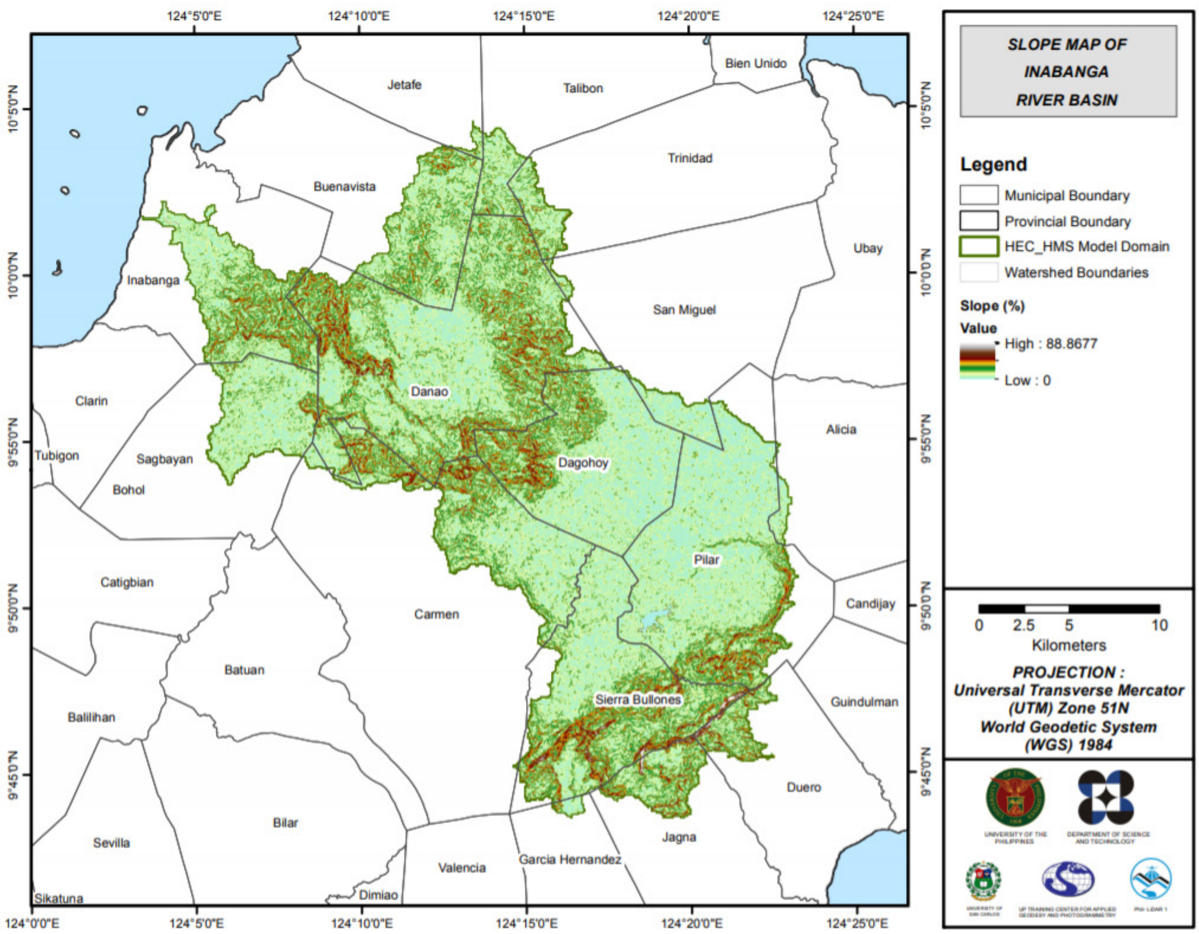


Figure 51. Slope Map of Inabanga River Basin.

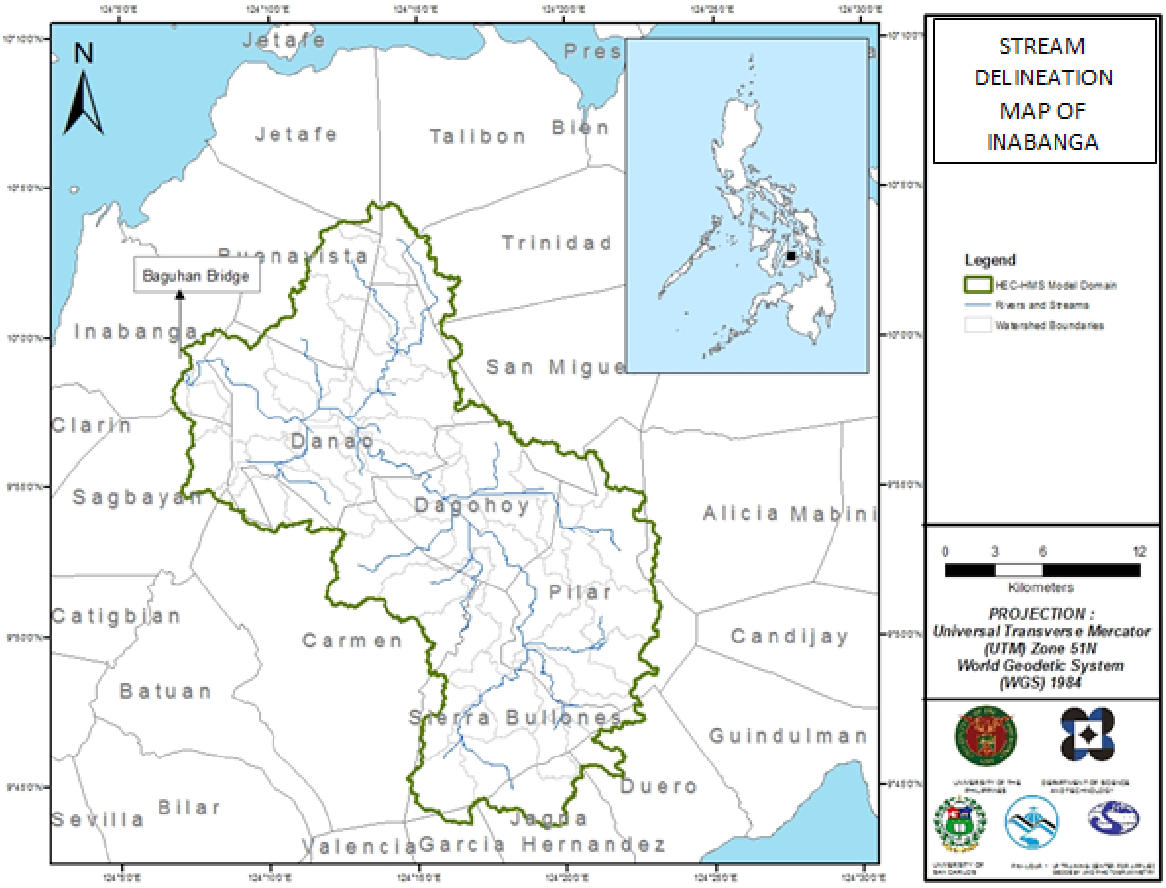


Figure 52. Stream Delineation Map of Inabanga River Basin.

Using the SAR-based DEM, the Inabanga basin was delineated and further subdivided into subbasins. The model consists of53 sub basins, 26 reaches, and 26 junctions as shown in Figure 53. The main outlet is Outlet 1. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed Rain Gauge near and inside the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in the Baguhan Bridge.

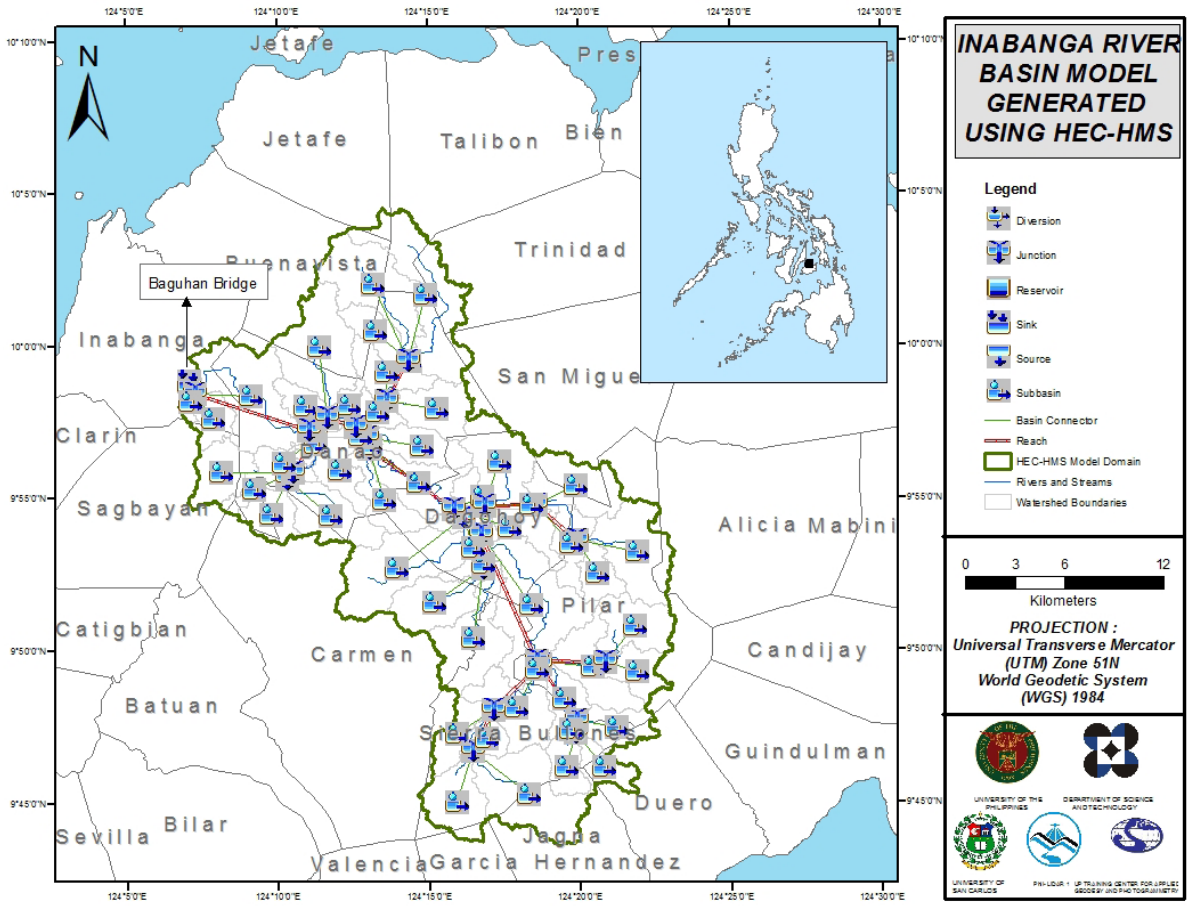


Figure 53. Inabanga river basin model generated in HEC-HMS.

5.4 Cross-section Data

The riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data, which was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 54).

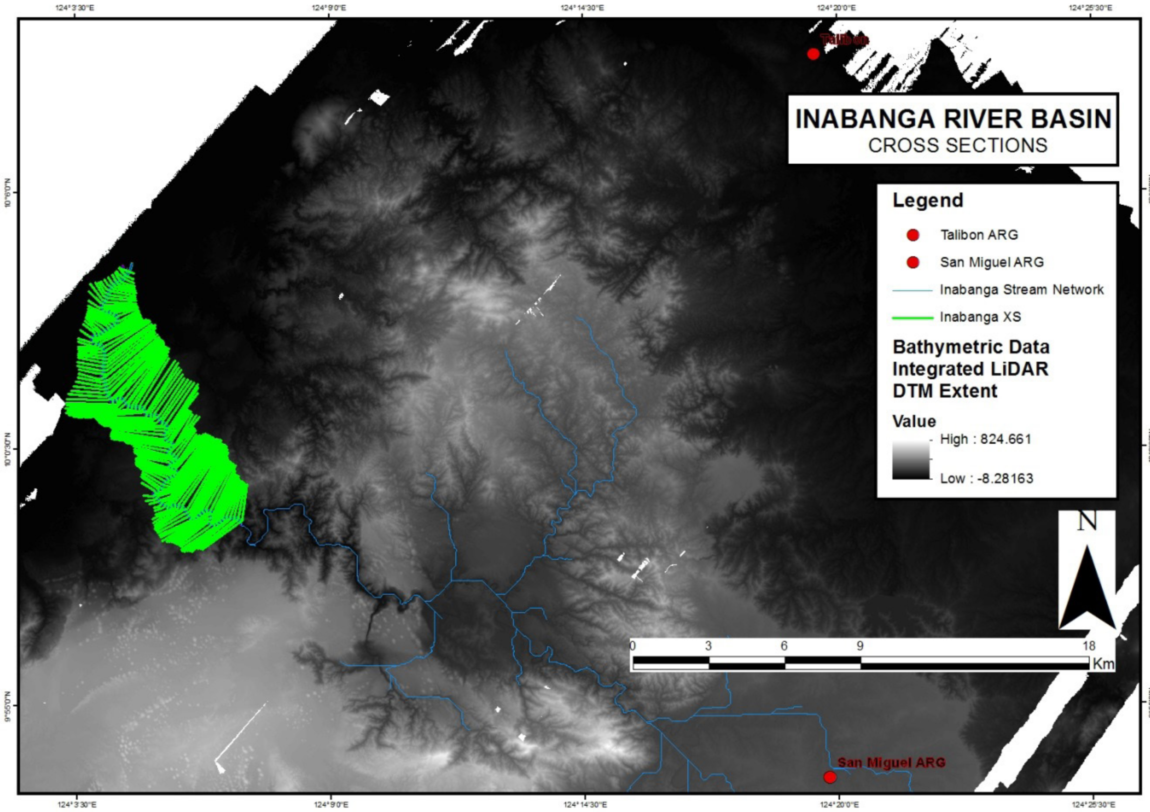


Figure 54. River cross-section of the Inabanga River through the ArcMap HEC GeoRas tool.

5.5 Flo 2D Model

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

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

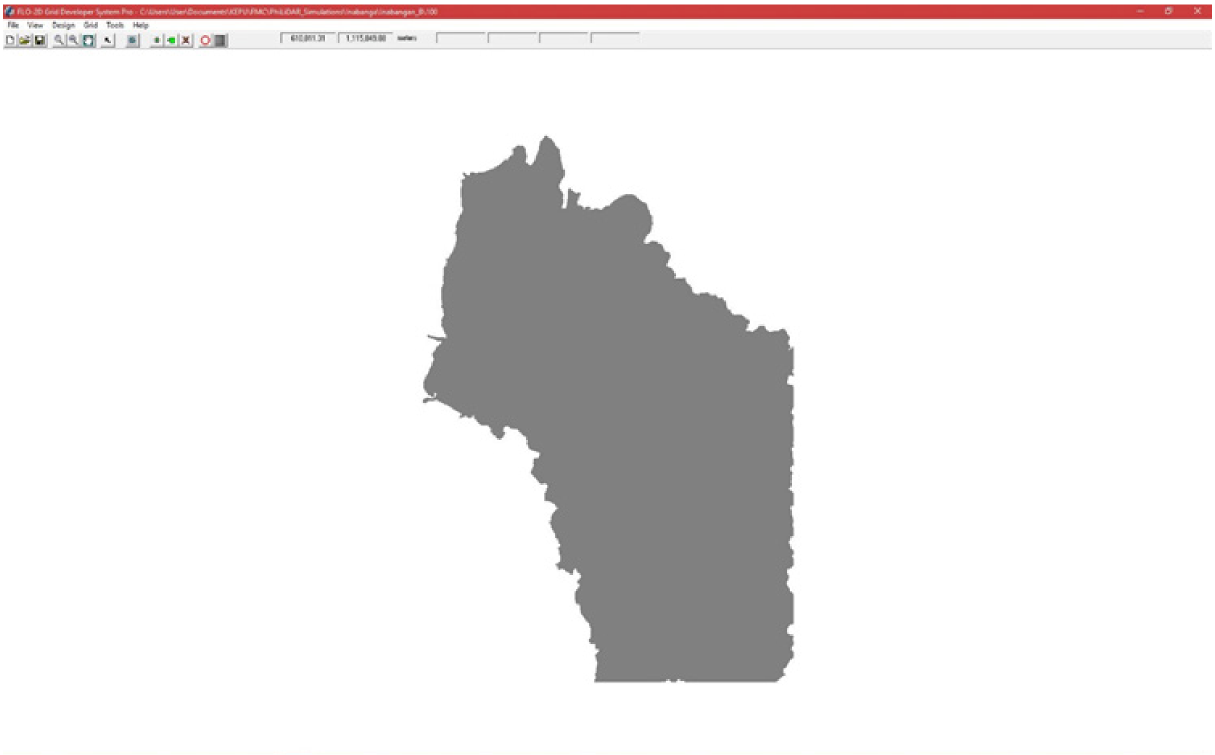


Figure 55. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro).

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 189.95056 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 63819600.00 m2.

There is a total of 93000960.00 m3 of water entering the model. Of this amount, 13992284.19 m3 is due to rainfall while 79008662.31 m3 is inflow from other areas outside the model. 8513021.00 m3 of this water is lost to infiltration and interception, while 73642130.10 m3 is stored by the flood plain. The rest, amounting up to 10845802.59 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Inabanga HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 56 shows the comparison between the two discharge data.

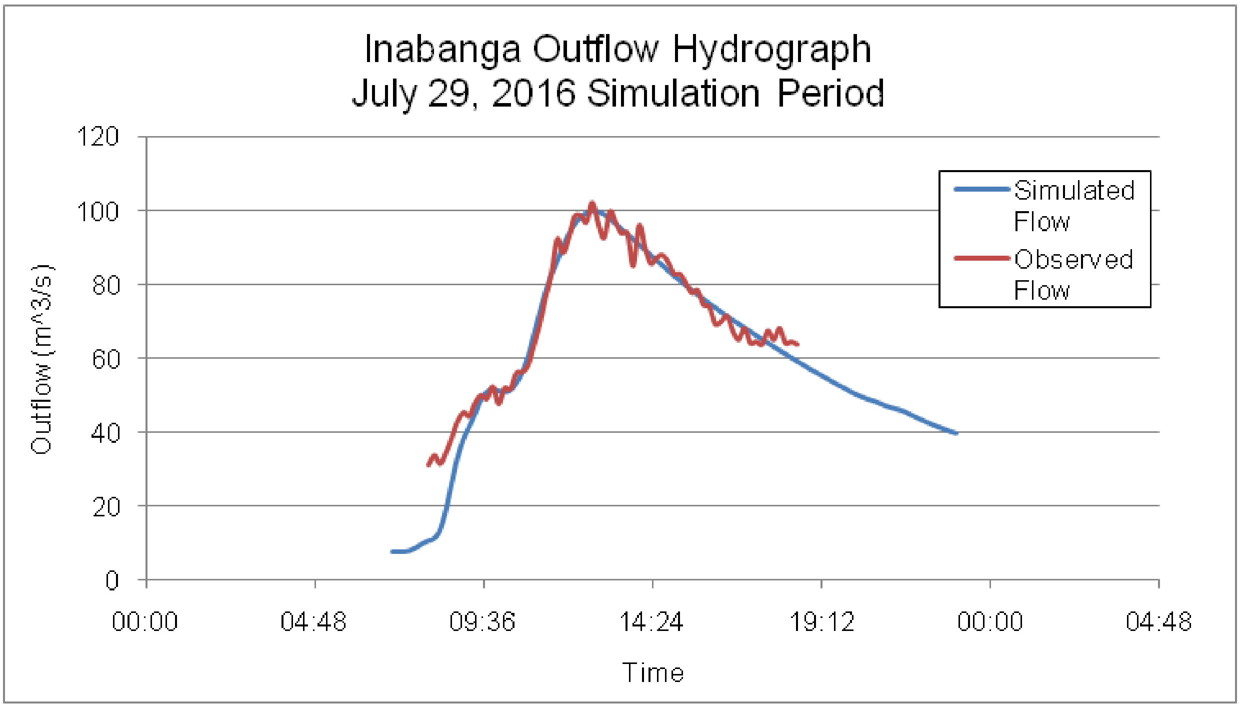


Figure 56. Outflow Hydrograph of Inabanga produced by the HEC-HMS model compared with observed outflow.

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

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

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	4.74-19.99
			Curve Number	55.60-99
			Impervious (%)	0
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.04-4.65
			Storage Coefficient (hr)	0.04-3.46
	Baseflow	Recession	Recession Constant	0.06-0.09
			Ratio to Peak	0.13-0.29
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.01-0.04

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values 4.74 to 19.99 mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 65 to 90 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For the Inabanga River, the curve numbers range from 55.60 to 99.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated 0.04 to 4.65 minutes determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.06 to 0.09 indicates that the basin will quickly go back to its original discharge Ratio to peak of 0.13 to 0.29 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.01 to 0.04 corresponds to the common roughness in Inabanga, which is determined to be cultivated with mature field crops (Brunner, 2010).

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

Accuracy measure	Value
RMSE	6.0149
r^2	0.9776
NSE	0.9049
PBIAS	2.6436
RSR	0.3084

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 6.0149m3/s.

The Pearson correlation coefficient (assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9776.

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 0.9049.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 2.6436.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.3084.

5.7 Calculated Outflow hydrographys and Discharge Values for different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 57) shows the Inabanga outflow using the TagbilaranRainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal increasing outflow magnitude as the rainfall intensity increases for a range of duration of 24 hours and varying return periods.

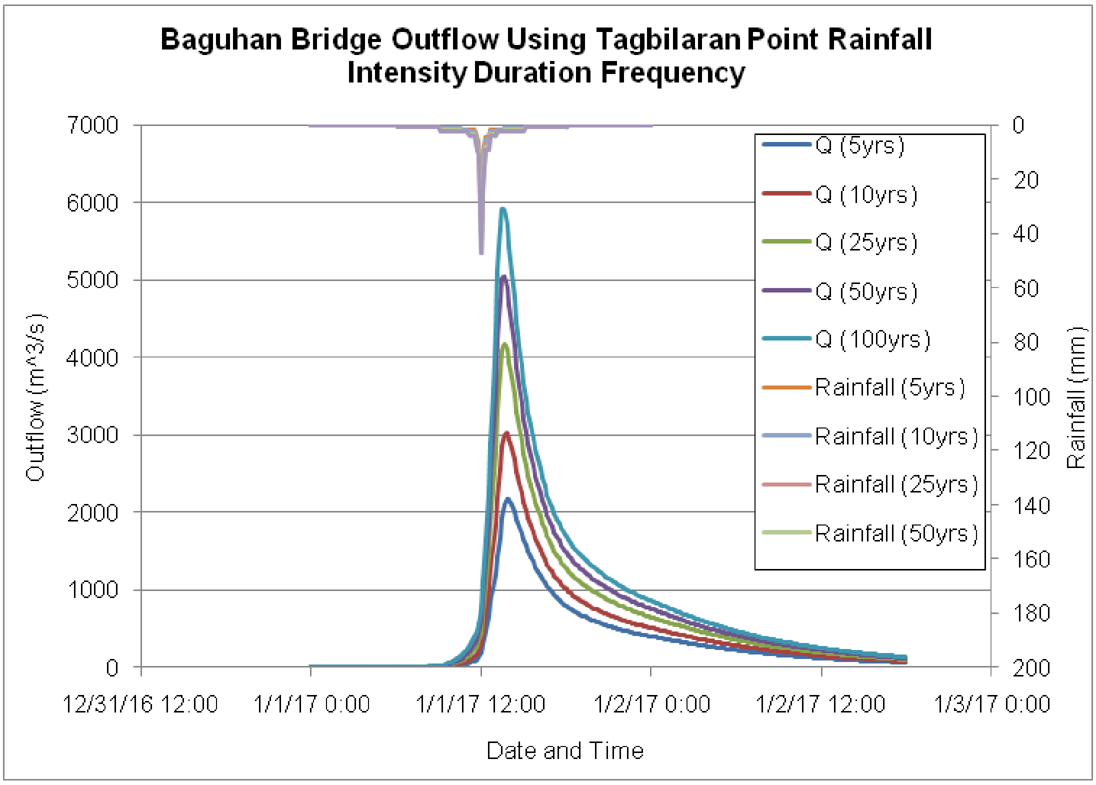


Figure 57. The Outflow hydrograph at the Baguhan Bridge, Inabanga generated using the Tagbilaran Point RIDF simulated in HEC-HMS.

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

Table 29. The peak values of the Inabanga HEC-HMS Model outflow using the Tagbilaran Point RIDF.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak
5-Year	121.2	23.100	2,177.136	1 hour, 50 minutes
10-Year	145.7	28.800	3,023.827	1 hour, 50 minutes
25-Year	176.7	36.100	4,172.682	1 hour, 40 minutes
50-Year	199.7	41.500	5,044.478	1 hour, 40 minutes
100-Year	222.6	46.800	5,913.674	1 hour, 30 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. Figure 58 shows a generated sample map of the Inabanga River using the calibrated event flow.

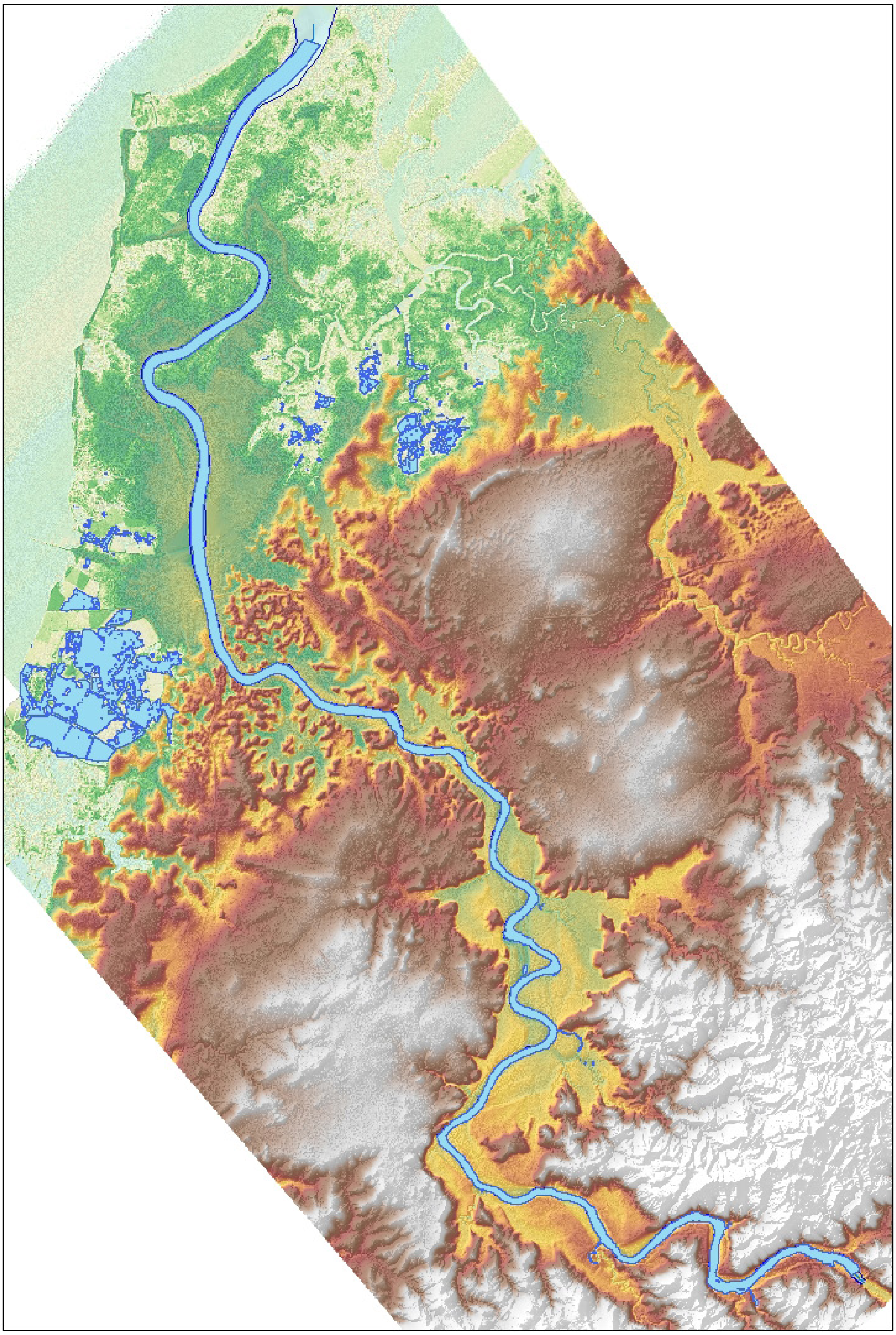


Figure 58. Sample output map of the Inabanga RAS Model.

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 59 to Figure 64 shows the 5-, 25-, and 100-year rain return scenarios of the Inabanga floodplain. The floodplain, with an area of 54.62 sq. km., covers three municipalites namely San Julian, Inabanga, and Taft. Table 30shows the percentage of area affected by flooding per municipality.

Table 30. Municipalities affected in Inabanga floodplain.

Municipality	Total Area	Area Flooded	% Flooded
San Julian	127.43	1.79	1%
Inabanga	150.05	50.14	33%
Taft	230.27	2.68	1%

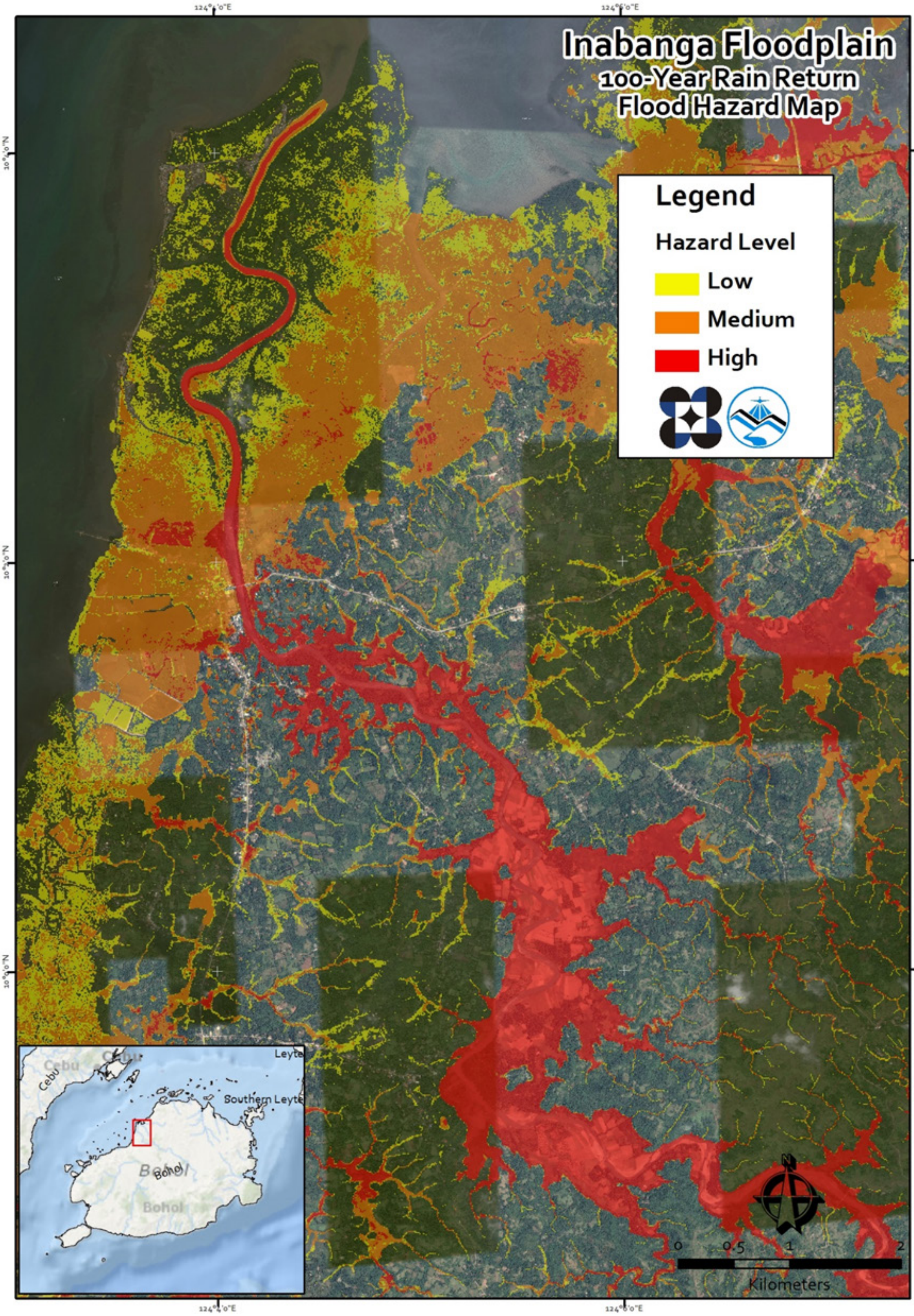


Figure 59. A 100-year Flood Hazard Map for Inabanga Floodplain overlaid on Google Earth imagery.

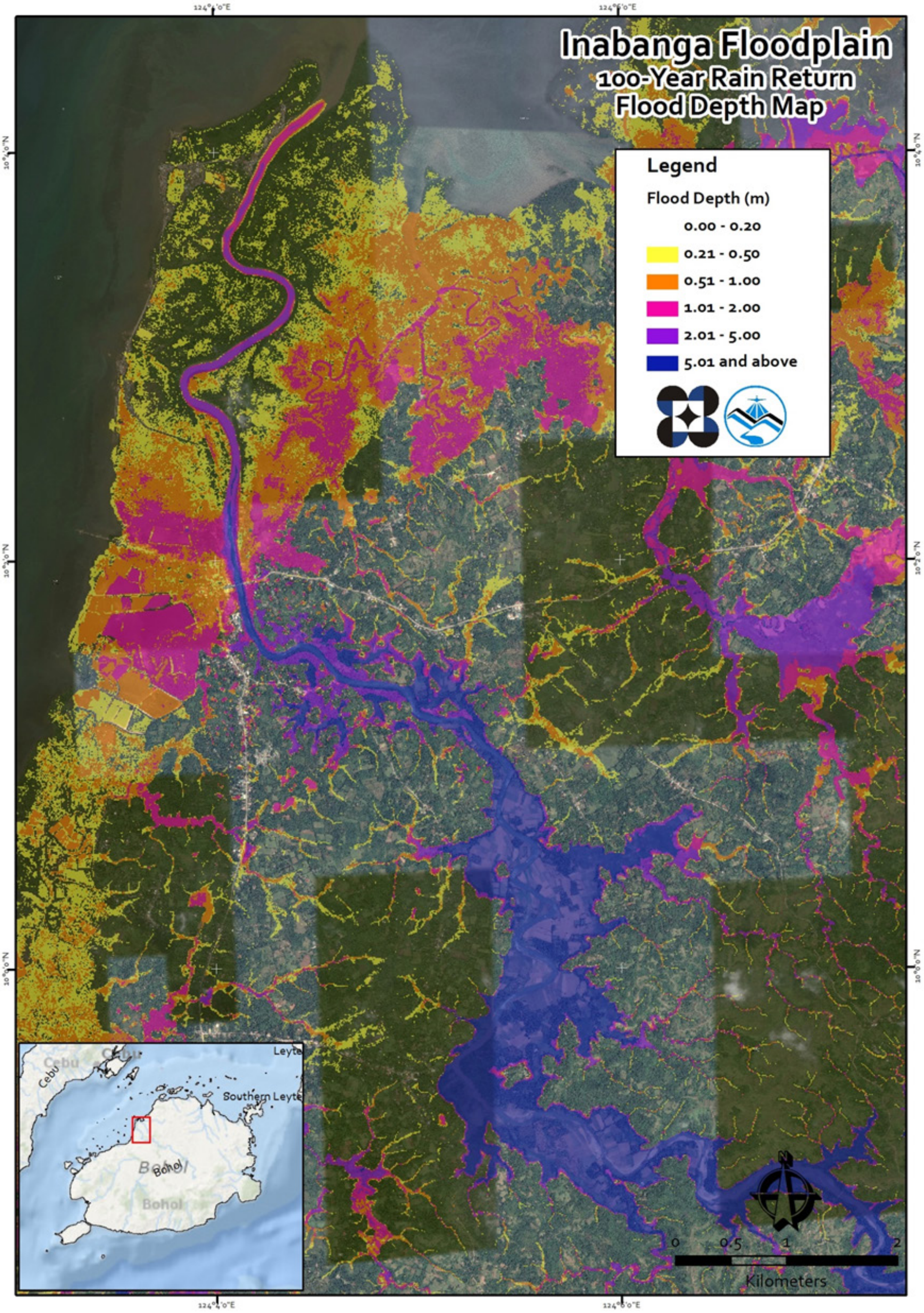


Figure 60. A 100-year Flow Depth Map for Inabanga Floodplain overlaid on Google Earth imagery.

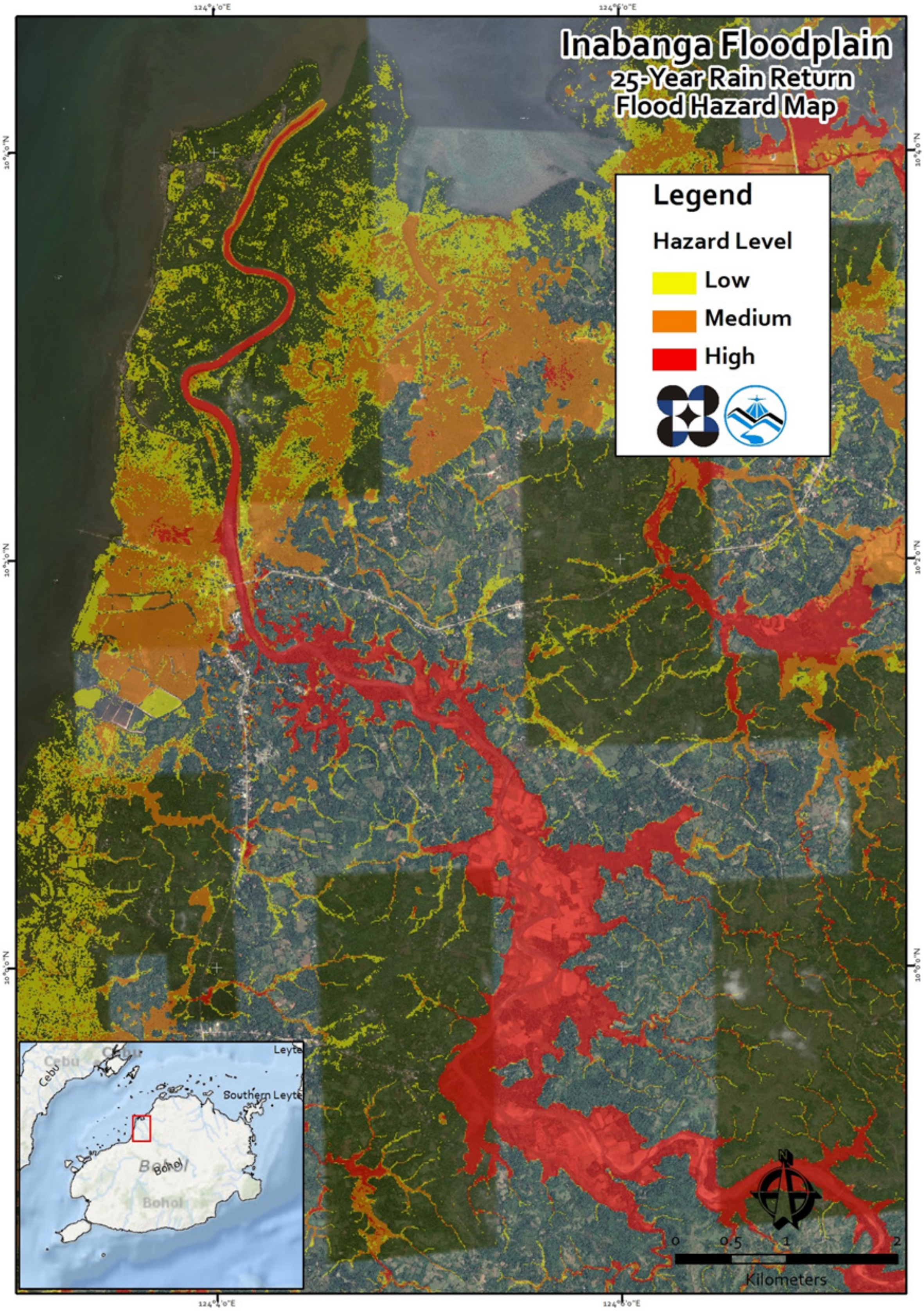


Figure 61. A 25-year Flood Hazard Map for Inabanga Floodplain overlaid on Google Earth imagery.

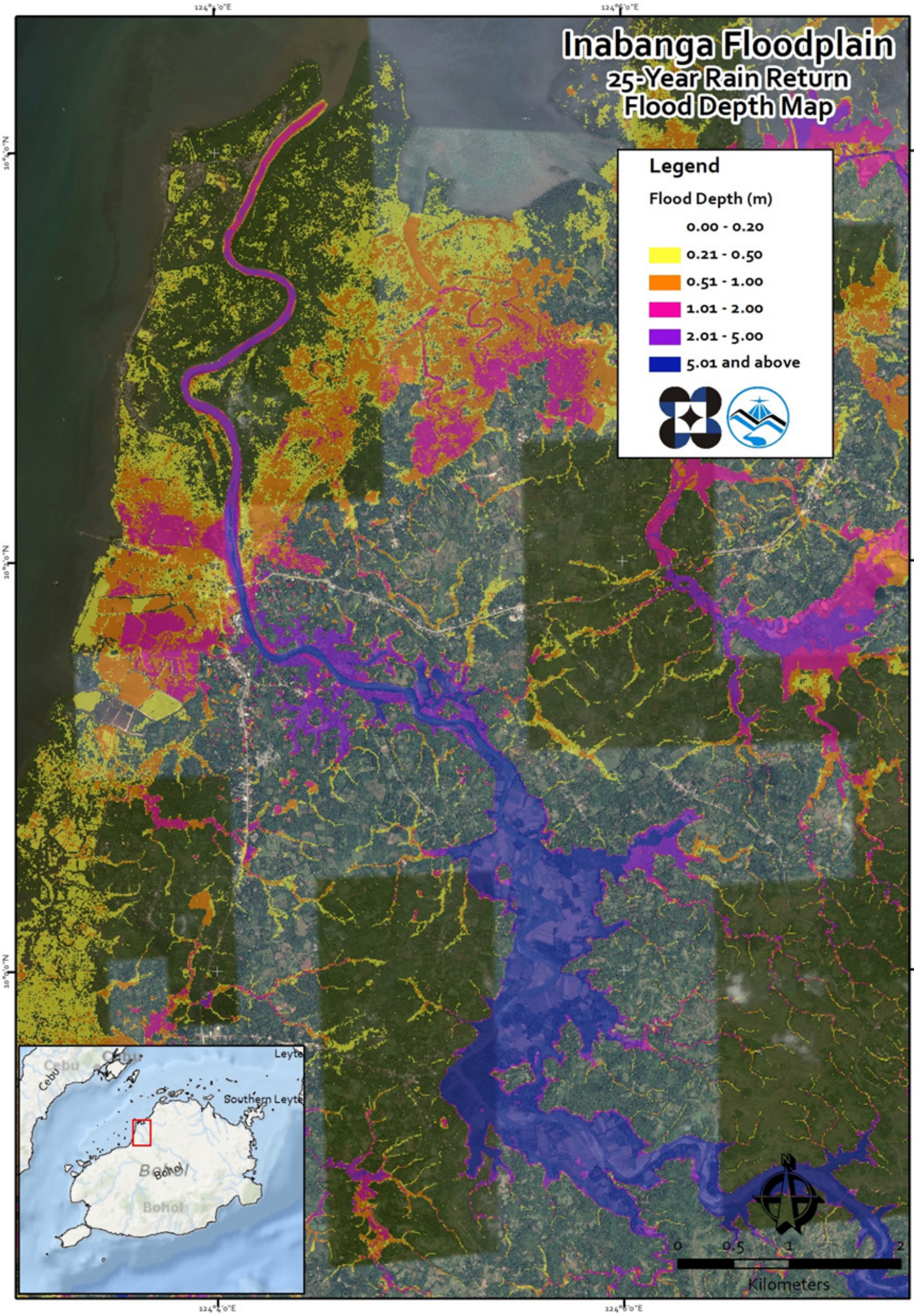


Figure 62. A 25-year Flow Depth Map for Inabanga Floodplain overlaid on Google Earth imagery.

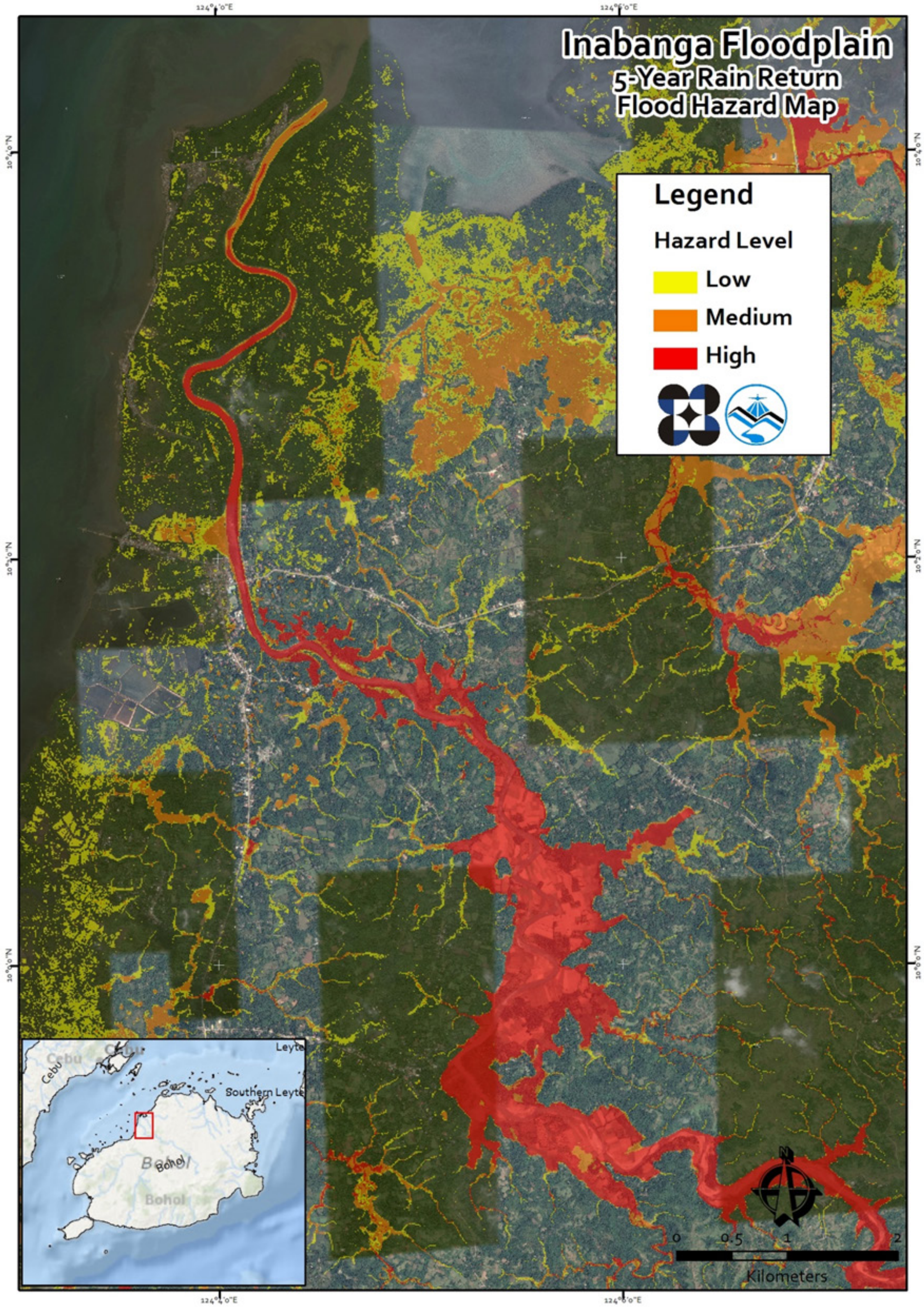


Figure 63. A 5-year Flood Hazard Map for Inabanga Floodplain overlaid on Google Earth imagery.

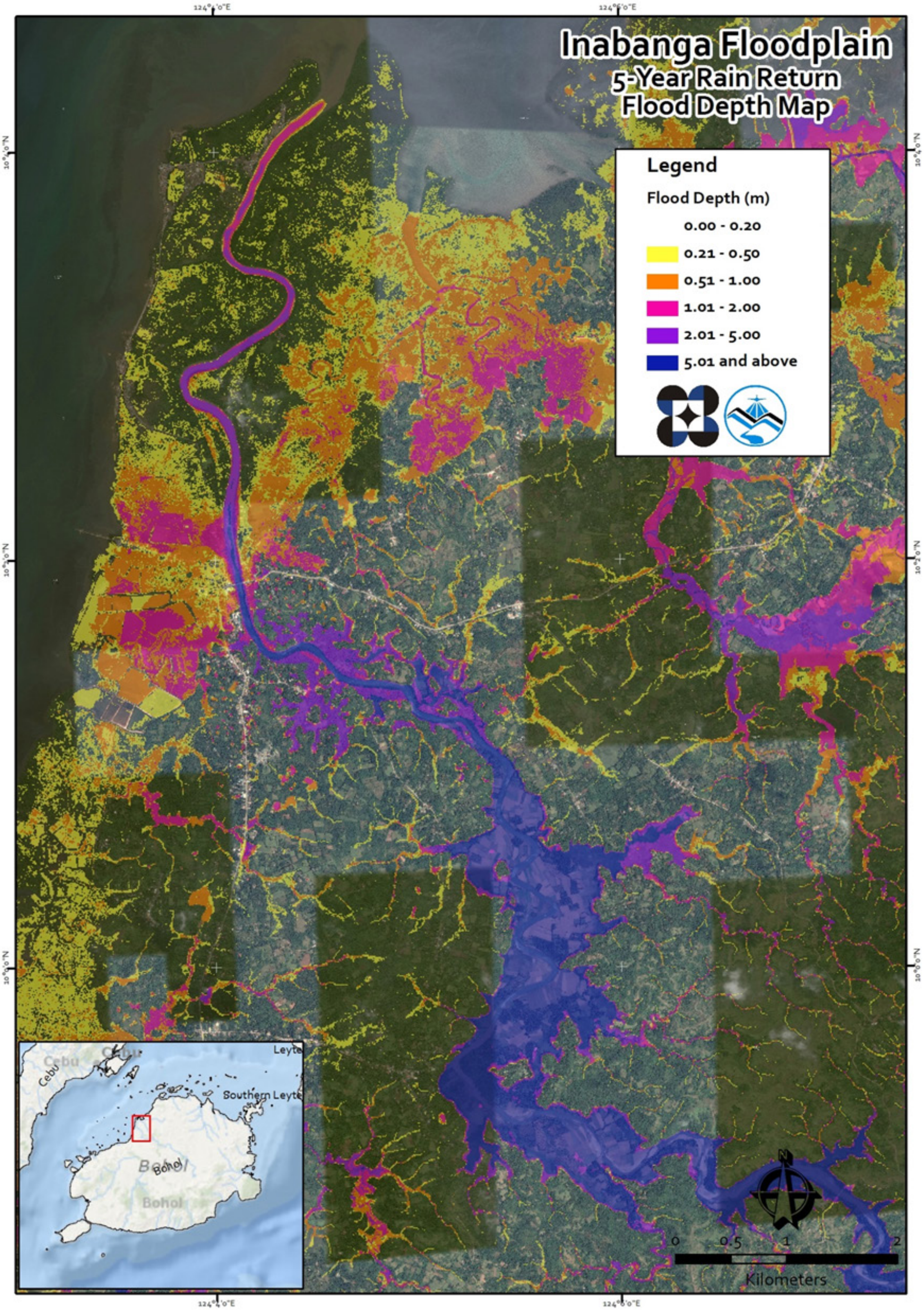


Figure 64. A 5-year Flood Depth Map for Inabanga Floodplain overlaid on Google Earth imagery.

5.10 Inventory of Areas Exposed to Flooding of Affected Areas

Listed below are the affected barangays in the Inabanga River Basin, grouped accordingly by municipality. For the said basin, four municipalities consisting of 64 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 11.08% of the municipality of Buenavista with an area of 109 sq. km. will experience flood levels of less 0.20 meters. 2.24% of the area will experience flood levels of 0.21 to 0.50 meters while 1.4%, 0.55%, 0.14, and 0.008% 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 are the affected areas in Buenavista in square kilometers by flood depth per barangay. Annex 12 and Annex 13 show the educational and health institutions exposed to flooding.

Table 31. Affected Areas in Buenavista, Bohol during 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)							
	Asinan	Bato	Bonot-bonot	Bugaong	Cambu-hat	Cam-bus-Oc	Cangawa	Canto-mugcad
0.03-0.20	0.011	0.49	0.82	0.51	3.73	0.011	0.91	0.17
0.21-0.50	0.001	0.032	0.1	0.05	1.22	0	0.16	0.013
0.51-1.00	0.0012	0.031	0.089	0.0067	0.91	0	0.18	0.0013
1.01-2.00	0.0001	0.1	0.1	0.003	0.17	0	0.099	0
2.01-5.00	0	0.034	0.047	0.0007	0.0001	0	0.023	0
> 5.00	0	0	0.000012	0	0	0	0.0022	0

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)							
	Cantu-ba	Dait	Hunan	Lapacan Sur	Merry-land	Pobla-cion	Rufo Hill	Sweet-land
0.03-0.20	0.9	1.05	0.64	0.2	1.12	0.6	0.069	0.86
0.21-0.50	0.028	0.27	0.19	0.13	0.073	0.089	0.0011	0.079
0.51-1.00	0.016	0.14	0.0017	0.038	0.077	0.025	0.00052	0.012
1.01-2.00	0.05	0.0064	0	0	0.055	0.0089	0.0003	0.0058
2.01-5.00	0.041	0	0	0	0.0002	0	0	0.0051
> 5.00	0.0062	0	0	0	0	0	0	0

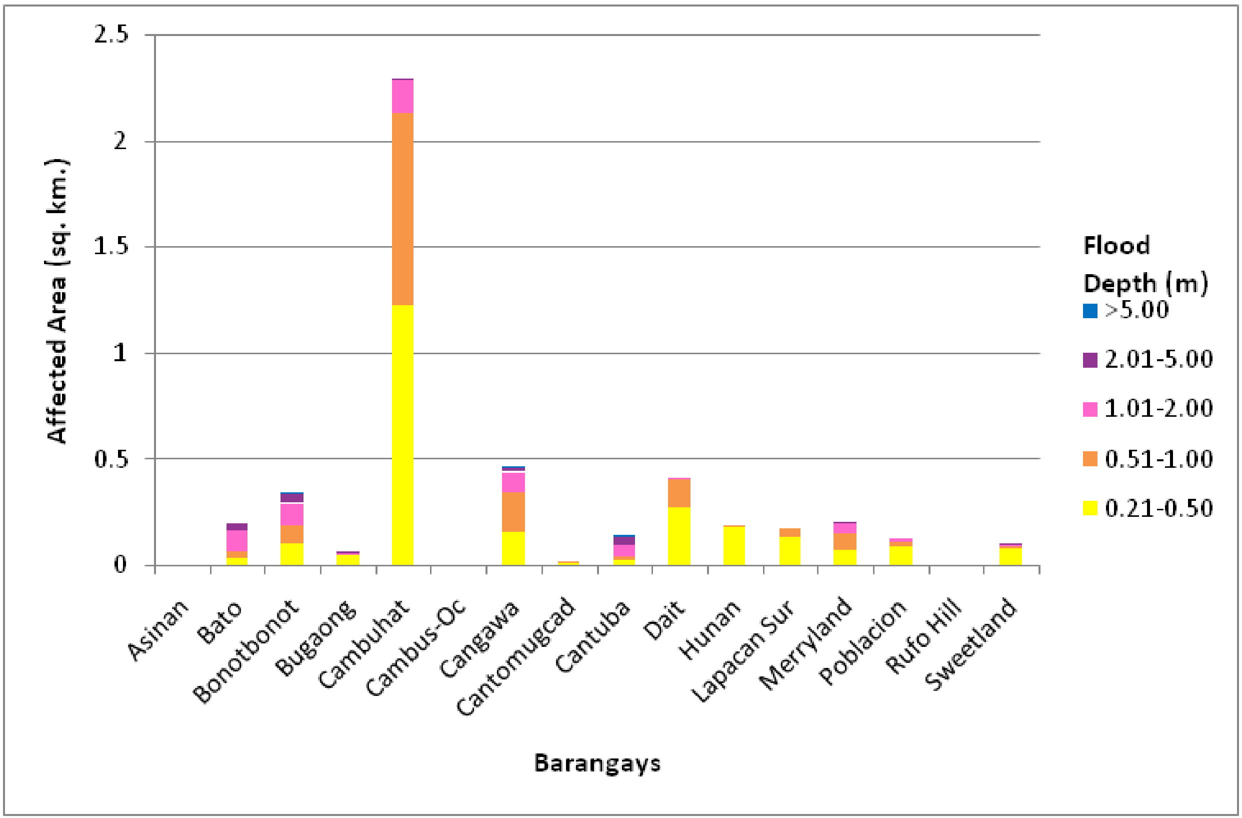


Figure 65. Affected Areas in Buenavista, Bohol during 5-Year Rainfall Return Period.

For the municipality of Clarin, with an area of 45.02 sq. km., 3.55% will experience flood levels of less 0.20 meters. 0.27% of the area will experience flood levels of 0.21 to 0.50 meters while 0.18%, 0.16%, 0.26%, and 0.009% 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 32 are the affected areas in Clarin in square kilometers by flood depth per barangay.

Table 32. Affected Areas in Clarin, Boholduring 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Clarin (in sq. km.)		
	Cantoyoc	Nahawan	Villaflor
0.03-0.20	1.02	0.58	0.0019
0.21-0.50	0.044	0.078	0
0.51-1.00	0.024	0.057	0
1.01-2.00	0.029	0.041	0
2.01-5.00	0.037	0.081	0
> 5.00	0.0012	0.0027	0

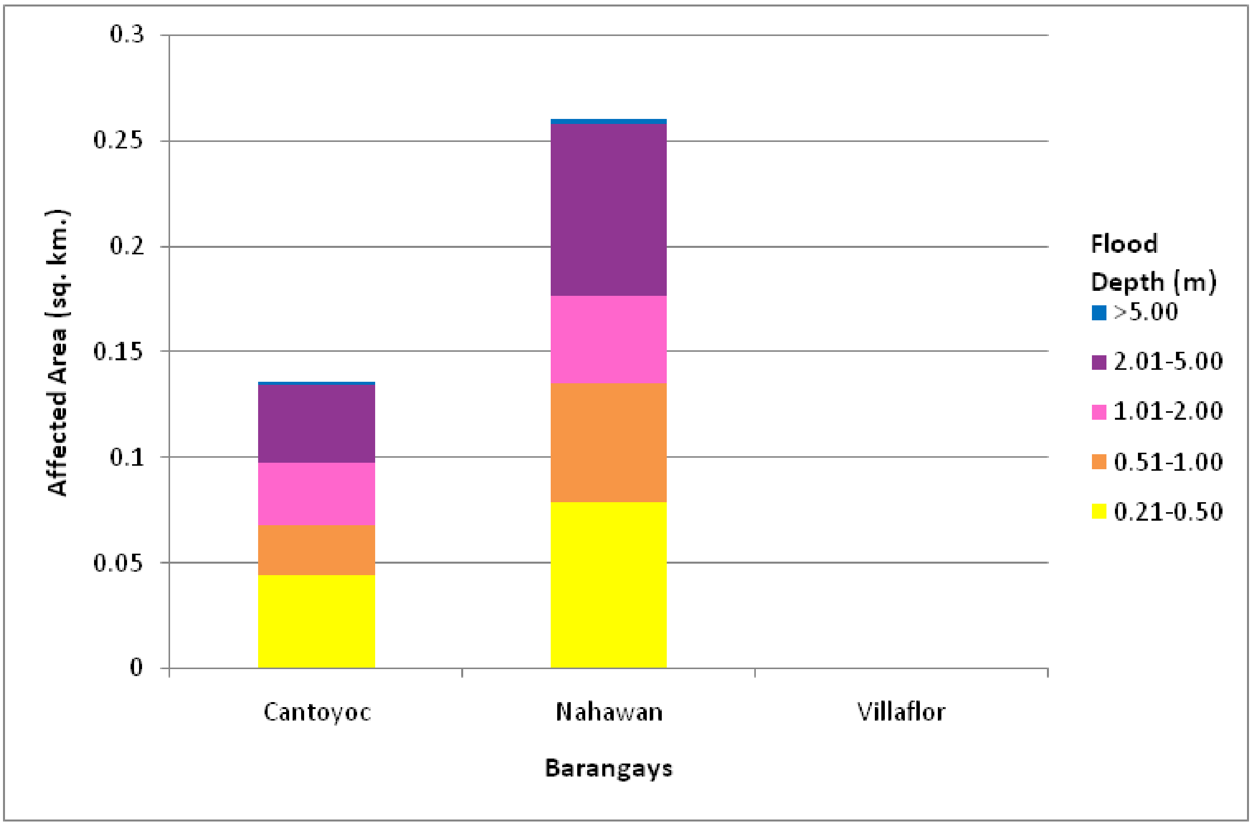


Figure 66. Affected Areas in Clarin, Bohol during 5-Year Rainfall Return Period.

For the municipality of Danao, with an area of 109.04 sq. km., 0.003% will experience flood levels of less 0.20 meters. 0.000002% of the area will experience flood levels of 0.21 to 0.50 meters and 0.00009% of the area will experience flood depths of 2.01 to 5 meters, respectively. Listed in Table 33 are the affected areas in Danao in square kilometres by flood depth per barangay.

Table 33. Affected Areas in Danao, Bohol during 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Danao (in sq. km.)
	Cabatuan
0.03-0.20	0.0035
0.21-0.50	0.000002
0.51-1.00	0.000094
1.01-2.00	0
2.01-5.00	0
> 5.00	0

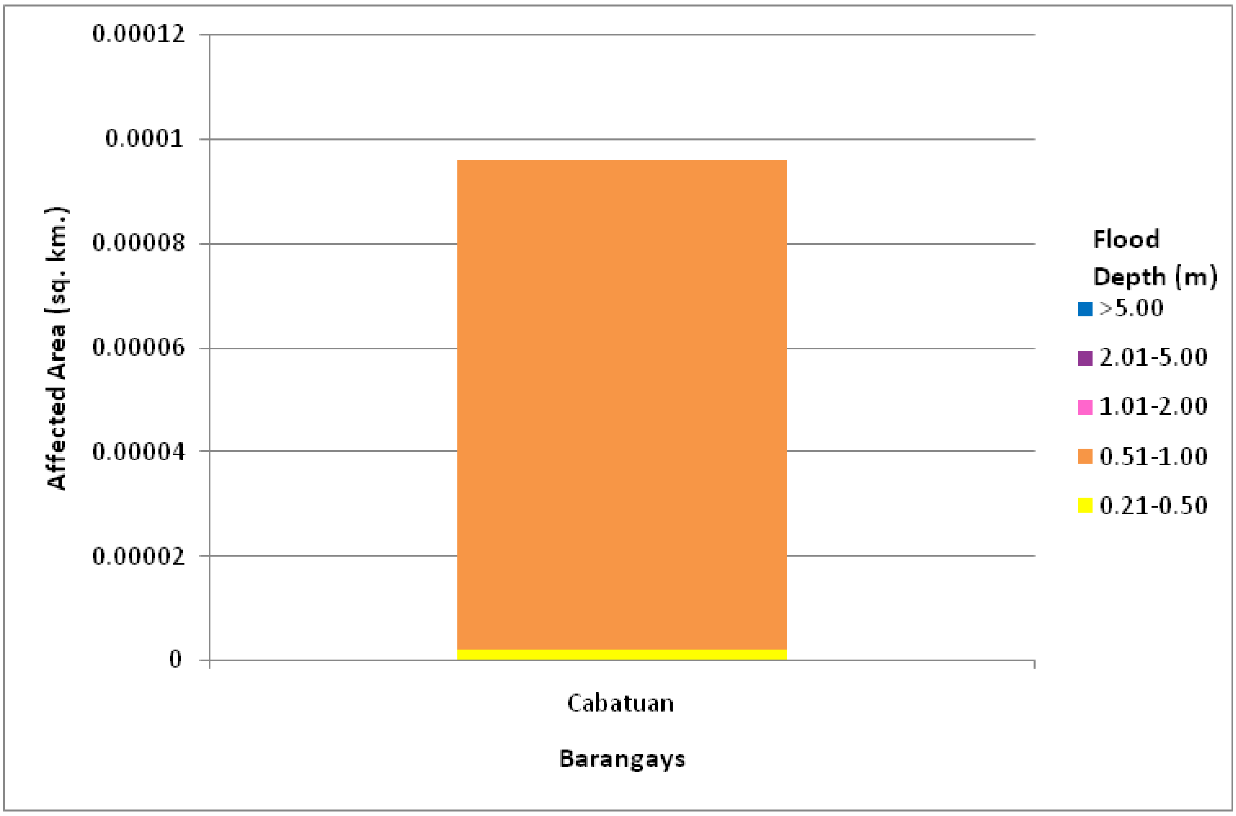


Figure 67. Affected Areas in Danao, Bohol during 5-Year Rainfall Return Period.

For the municipality of Inabanga, with an area of 108 sq. km., 59.62% will experience flood levels of less 0.20 meters. 6.08% of the area will experience flood levels of 0.21 to 0.50 meters while 3.19%, 2%, 3.13%, and 1.83% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 34 are the affected areas in Inabanga in square kilometers by flood depth per barangay.

Table 34. Affected Areas in Inabanga, Bohol during 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Anonang	Badiang	Baguhan	Bahan	Banahao	Baogo	Bugang	Caga-wasan	Cagayan	Cambitoon	Canlinte
0.03-0.20	0.036	3.65	2.02	0.14	1.93	1.48	3.21	0.86	1.6	0.064	1.23
0.21-0.50	0.00081	0.5	0.032	0.0045	0.078	0.12	0.63	0.19	0.11	0.0007	0.028
0.51-1.00	0.00035	0.12	0.02	0.0001	0.05	0.18	0.079	0.0023	0.065	0.0005	0.036
1.01-2.00	0.00031	0.021	0.023	0	0.041	0.18	0.015	0	0.032	0.0001	0.11
2.01-5.00	0	0.0002	0.061	0	0.014	0.0056	0.025	0	0.09	0.000001	0.37
> 5.00	0	0	0.32	0	0	0	0	0	0	0	0.37

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Cawayan	Cogon	Dagohoy	Dait Sur	Datag	Fatima	Ilaud	Ilaya	Ilihan	Lapacan Sur	Lawis
0.03-0.20	2.39	1.13	1.77	1.33	4.98	0.56	0.12	2.3	1.17	1.24	0.63
0.21-0.50	0.071	0.087	0.091	0.11	0.18	0.32	0.048	0.053	0.046	0.13	0.046
0.51-1.00	0.067	0.048	0.031	0.13	0.13	0.58	0.067	0.029	0.053	0.17	0.0003
1.01-2.00	0.06	0.017	0.024	0.066	0.098	0.14	0.012	0.025	0.051	0.19	0
2.01-5.00	0.39	0.011	0.011	0.01	0.028	0.0019	0.047	0.024	0.023	0.015	0
> 5.00	0.16	0.02	0	0	0.0001	0	0.00065	0.13	0	0	0

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Liloan Norte	Liloan Sur	Lomboy	Lonoy Cainsi-can	Lonoy Roma	Lutao	Luyo	Mabu-hay	Maria Rosario	Nabuad	Napo
0.03-0.20	1.64	3.21	1.49	1.09	1.47	3.2	1.17	1.99	0.48	3.94	1.05
0.21-0.50	0.19	0.18	0.031	0.054	0.077	0.42	0.17	0.089	0.01	0.27	0.038
0.51-1.00	0.21	0.12	0.017	0.017	0.048	0.17	0.039	0.11	0.003	0.086	0.037
1.01-2.00	0.25	0.088	0.018	0.024	0.046	0.024	0.013	0.087	0.0004	0.1	0.11
2.01-5.00	0.049	0.46	0.0075	0.47	0.17	0.0037	0.028	0.023	0.0003	0.11	0.56
> 5.00	0.0013	0.12	0	0.3	0.14	0	0	0.0001	0	0.00074	0.1

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Ondol	Pobla-cion	River-side	Saa	San Isidro	Santo Niño	Santo Rosario	Tam-book	Tungod	Ubujan	U-Og
0.03-0.20	1.54	0.99	0.9	0.51	0.72	0.37	1.12	0.28	0.71	1.21	1.52
0.21-0.50	0.17	0.092	0.03	0.067	0.5	0.022	0.57	0.032	0.089	0.21	0.4
0.51-1.00	0.019	0.013	0.02	0.013	0.46	0.0057	0.15	0.045	0.016	0.31	0.31
1.01-2.00	0.055	0.0049	0.024	0.013	0.049	0.011	0.017	0.068	0	0.03	0.011
2.01-5.00	0.076	0.028	0.048	0.064	0	0.0013	0.039	0.11	0	0.0069	0.0022
> 5.00	0	0.021	0.23	0	0	0	0.0008	0.079	0	0.0002	0

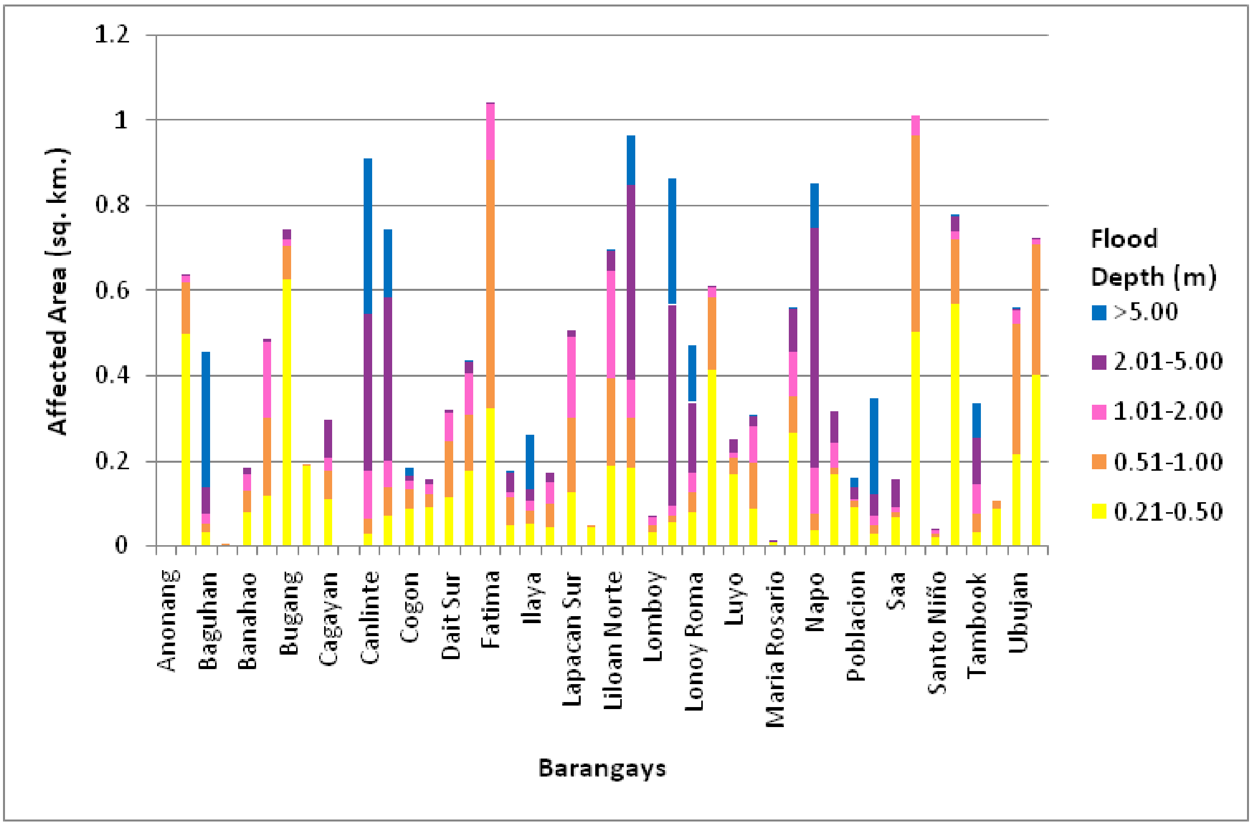


Figure 68. Affected Areas in Inabanga, Bohol during 5-Year Rainfall Return Period.

For the 25-year return period, 9.96% of the municipality of Buenavista with an area of 109 sq. km. will experience flood levels of less 0.20 meters. 2.11% of the area will experience flood levels of 0.21 to 0.50 meters while 1.91%, 1.21%, 0.21, and 0.015% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 35 are the affected areas in Buenavista in square kilometers by flood depth per barangay.

Table 35. Affected Areas in Buenavista, Bohol during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)							
	Asinan	Bato	Bonotbonot	Bugaong	Cambu-hat	Cam-bus-Oc	Cangawa	Canto-mugcad
0.03-0.20	0.01	0.48	0.79	0.49	3.08	0.011	0.83	0.17
0.21-0.50	0.00096	0.035	0.086	0.063	1.12	0	0.14	0.016
0.51-1.00	0.0008	0.02	0.093	0.01	1.15	0	0.17	0.0014
1.01-2.00	0.0012	0.1	0.13	0.0039	0.67	0	0.2	0
2.01-5.00	0	0.053	0.069	0.0009	0.00089	0	0.029	0
> 5.00	0	0	0.000061	0	0	0	0.0027	0

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)							
	Cantuba	Dait	Hunan	Lapacan Sur	Merry-land	Pobla-cion	Rufo Hill	Sweet-land
0.03-0.20	0.89	0.89	0.52	0.16	1.08	0.55	0.069	0.83
0.21-0.50	0.027	0.2	0.26	0.07	0.079	0.098	0.0015	0.098
0.51-1.00	0.017	0.31	0.044	0.13	0.063	0.045	0.00062	0.023
1.01-2.00	0.021	0.057	0.0001	0.0051	0.099	0.025	0.00032	0.0065
2.01-5.00	0.074	0	0	0	0.0002	0.0002	0	0.0063
> 5.00	0.013	0	0	0	0	0	0	0

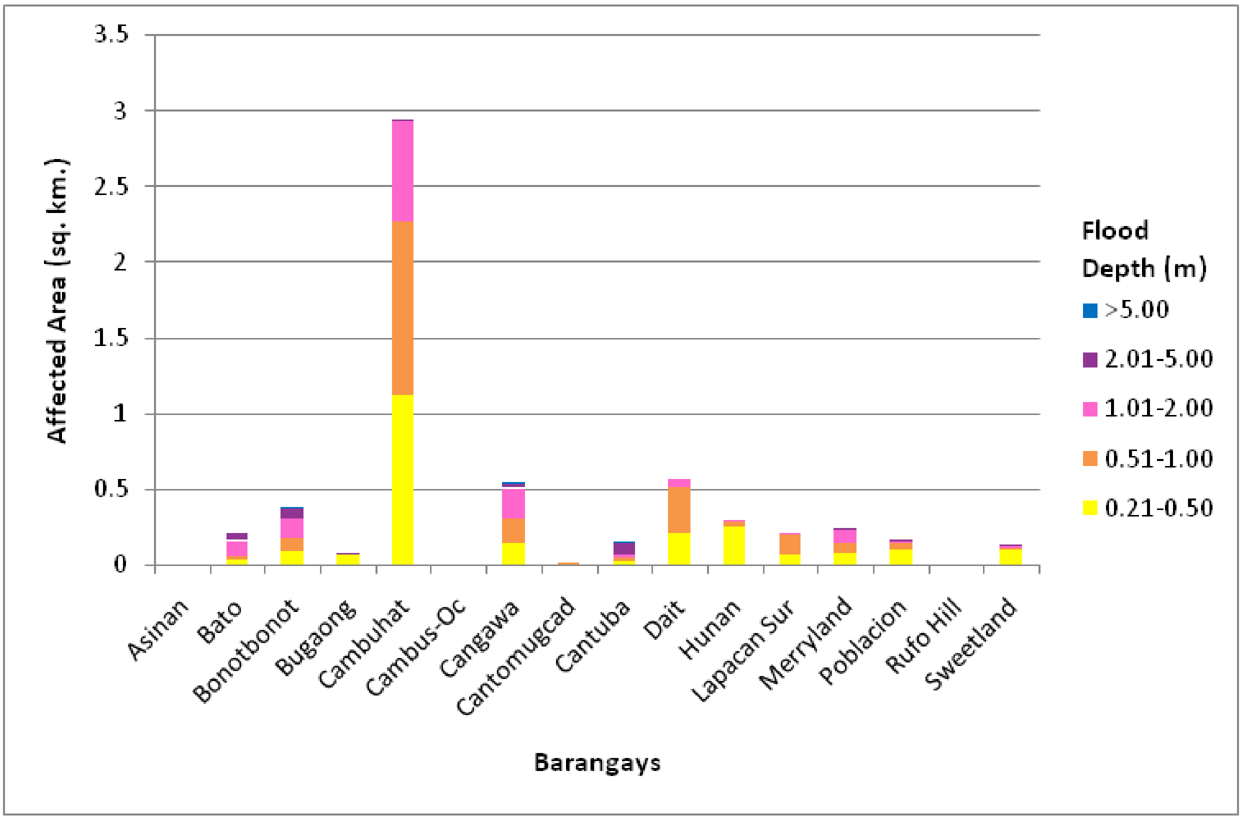


Figure 69. Affected Areas in Buenavista, Bohol during 25-Year Rainfall Return Period.

For the municipality of Clarin, with an area of 45.02 sq. km., 3.33% will experience flood levels of less 0.20 meters. 0.31% of the area will experience flood levels of 0.21 to 0.50 meters while 0.24%, 0.17%, 0.3%, and 0.08% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 36 are the affected areas in Clarin in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Clarin, Bohol during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Clarin (in sq. km.)		
	Cantoyoc	Nahawan	Villaflor
0.03-0.20	0.97	0.52	0.0019
0.21-0.50	0.045	0.092	0
0.51-1.00	0.032	0.075	0
1.01-2.00	0.03	0.047	0
2.01-5.00	0.066	0.071	0
> 5.00	0.0062	0.03	0

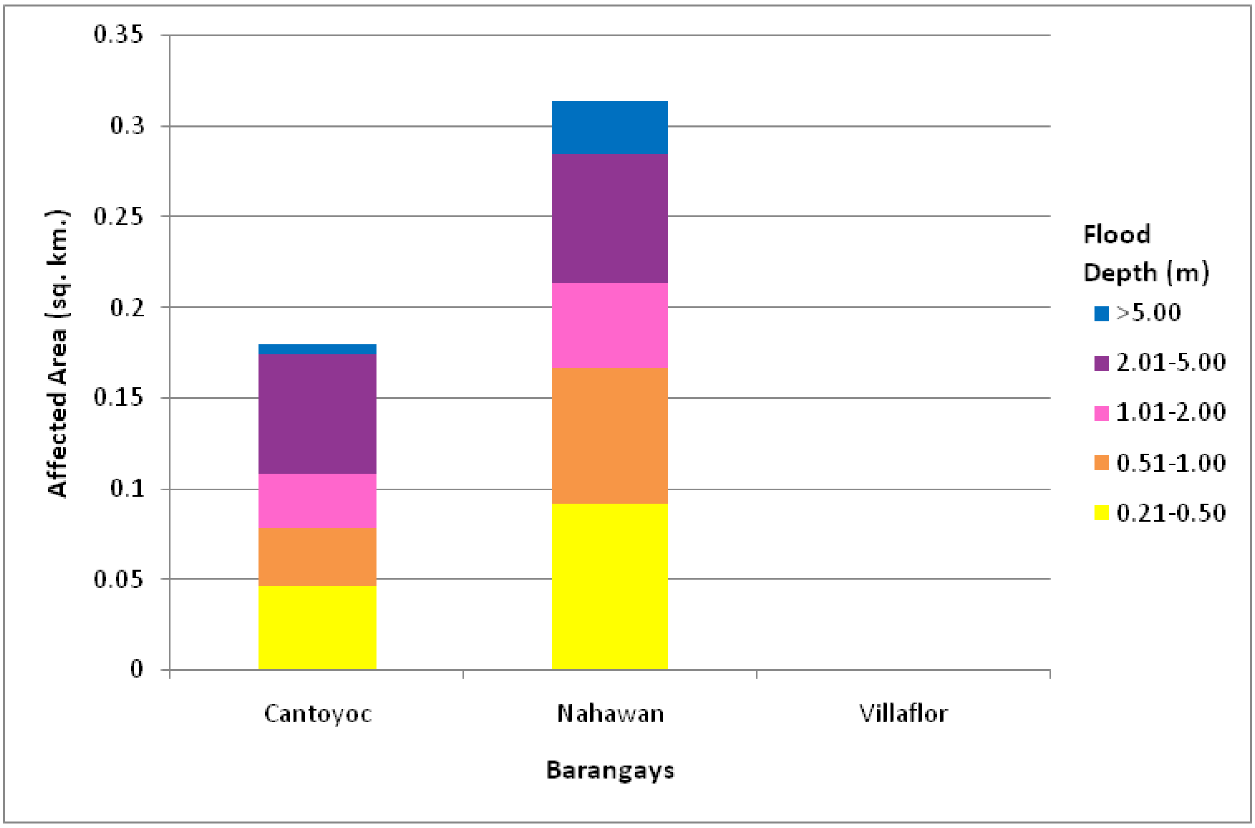


Figure 70. Affected Areas in Clarin, Bohol during 25-Year Rainfall Return Period.

For the municipality of Danao, with an area of 109.04 sq. km., 0.003% will experience flood levels of less 0.20 meters. 0.000002% of the area will experience flood levels of 0.21 to 0.50 meters and 0.00009% of the area will experience flood depths of 2.01 to 5 meters, respectively. Listed in Table 37 are the affected areas in Danao in square kilometres by flood depth per barangay.

Table 37. Affected Areas in Danao, Bohol during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Danao (in sq. km.)
	Cabatuan
0.03-0.20	0.0035
0.21-0.50	0.000002
0.51-1.00	0.000094
1.01-2.00	0
2.01-5.00	0
> 5.00	0

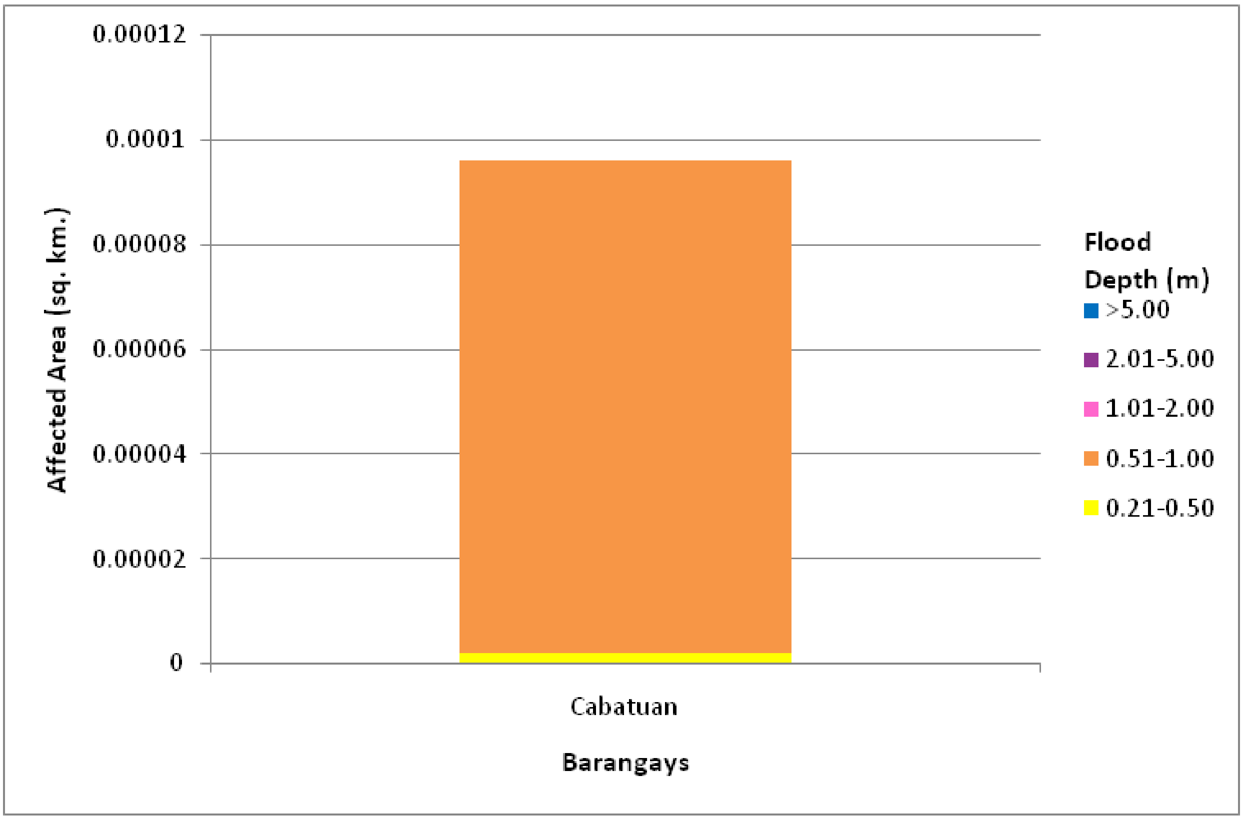


Figure 71. Affected Areas in Danao, Bohol during 25-Year Rainfall Return Period.

For the municipality of Inabanga, with an area of 108 sq. km., 52.74% will experience flood levels of less 0.20 meters. 7.06% of the area will experience flood levels of 0.21 to 0.50 meters while 6.38%, 3.37%, 2.33%, and 4.55% 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 are the affected areas in Inabanga in square kilometers by flood depth per barangay.

Table 38. Affected Areas in Inabanga, Bohol during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Anonang	Badiang	Baguhan	Bahan	Banahao	Baogo	Bugang	Caga-wasan	Cagayan	Cambitoon	Canlinte
0.03-0.20	0.036	3.65	2.02	0.14	1.93	1.48	3.21	0.86	1.6	0.064	1.23
0.21-0.50	0.00081	0.5	0.032	0.0045	0.078	0.12	0.63	0.19	0.11	0.0007	0.028
0.51-1.00	0.00035	0.12	0.02	0.0001	0.05	0.18	0.079	0.0023	0.065	0.0005	0.036
1.01-2.00	0.00031	0.021	0.023	0	0.041	0.18	0.015	0	0.032	0.0001	0.11
2.01-5.00	0	0.0002	0.061	0	0.014	0.0056	0.025	0	0.09	0.000001	0.37
> 5.00	0	0	0.32	0	0	0	0	0	0	0	0.37

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Cawayan	Cogon	Dagohoy	Dait Sur	Datag	Fatima	Ilaud	Ilaya	Ilihan	Lapacan Sur	Lawis
0.03-0.20	2.39	1.13	1.77	1.33	4.98	0.56	0.12	2.3	1.17	1.24	0.63
0.21-0.50	0.071	0.087	0.091	0.11	0.18	0.32	0.048	0.053	0.046	0.13	0.046
0.51-1.00	0.067	0.048	0.031	0.13	0.13	0.58	0.067	0.029	0.053	0.17	0.0003
1.01-2.00	0.06	0.017	0.024	0.066	0.098	0.14	0.012	0.025	0.051	0.19	0
2.01-5.00	0.39	0.011	0.011	0.01	0.028	0.0019	0.047	0.024	0.023	0.015	0
> 5.00	0.16	0.02	0	0	0.0001	0	0.00065	0.13	0	0	0

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Liloan Norte	Liloan Sur	Lomboy	Lonoy Cainsi-can	Lonoy Roma	Lutao	Luyo	Mabu-hay	Maria Rosario	Nabuad	Napo
0.03-0.20	1.64	3.21	1.49	1.09	1.47	3.2	1.17	1.99	0.48	3.94	1.05
0.21-0.50	0.19	0.18	0.031	0.054	0.077	0.42	0.17	0.089	0.01	0.27	0.038
0.51-1.00	0.21	0.12	0.017	0.017	0.048	0.17	0.039	0.11	0.003	0.086	0.037
1.01-2.00	0.25	0.088	0.018	0.024	0.046	0.024	0.013	0.087	0.0004	0.1	0.11
2.01-5.00	0.049	0.46	0.0075	0.47	0.17	0.0037	0.028	0.023	0.0003	0.11	0.56
> 5.00	0.0013	0.12	0	0.3	0.14	0	0	0.0001	0	0.00074	0.1

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Ondol	Poblacion	Riverside	Saa	San Isidro	Santo Niño	Santo Rosario	Tambook	Tungod	Ubujan	U-Og
0.03-0.20	1.54	0.99	0.9	0.51	0.72	0.37	1.12	0.28	0.71	1.21	1.52
0.21-0.50	0.17	0.092	0.03	0.067	0.5	0.022	0.57	0.032	0.089	0.21	0.4
0.51-1.00	0.019	0.013	0.02	0.013	0.46	0.0057	0.15	0.045	0.016	0.31	0.31
1.01-2.00	0.055	0.0049	0.024	0.013	0.049	0.011	0.017	0.068	0	0.03	0.011
2.01-5.00	0.076	0.028	0.048	0.064	0	0.0013	0.039	0.11	0	0.0069	0.0022
> 5.00	0	0.021	0.23	0	0	0	0.0008	0.079	0	0.0002	0

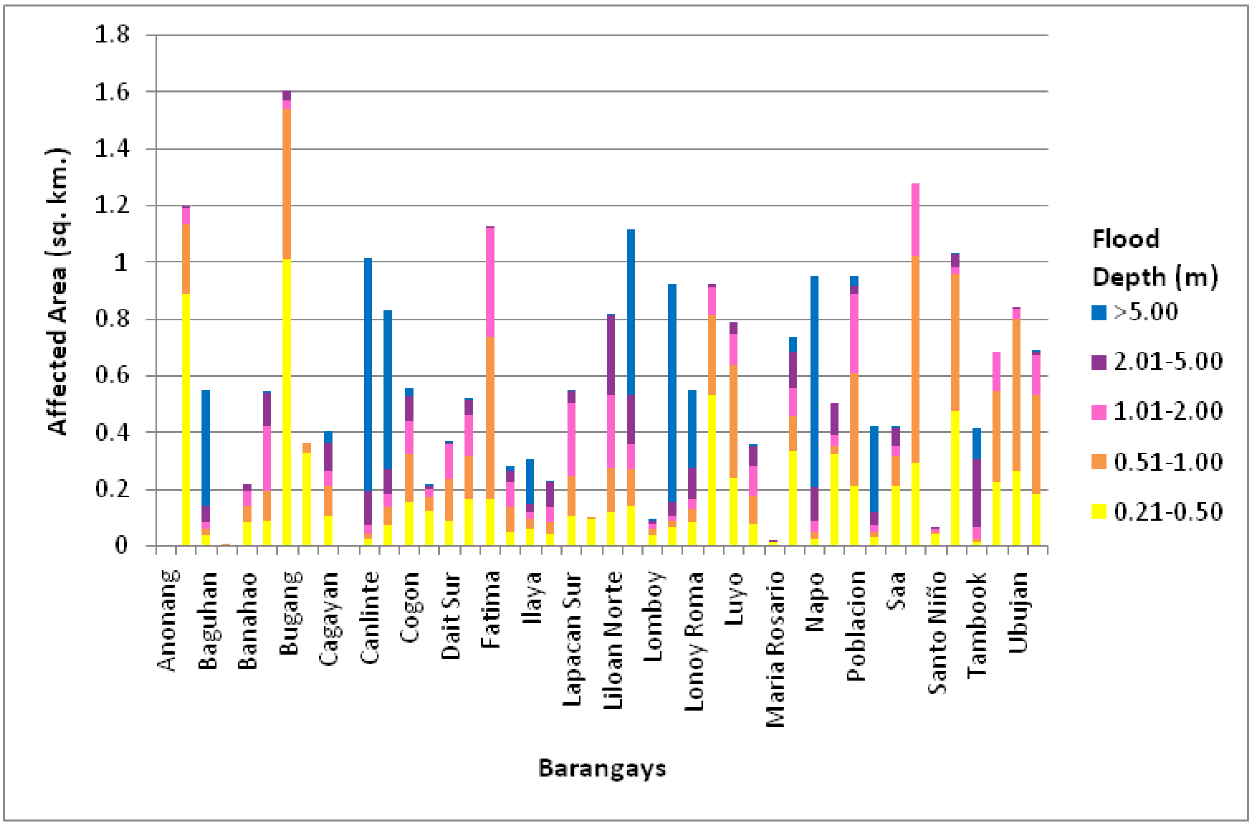


Figure 72. Affected Areas in Inabanga, Bohol during 25-Year Rainfall Return Period.

For the 100-year return period, 9.94% of the municipality of Buenavista with an area of 109 sq. km. will experience flood levels of less 0.20 meters. 1.84% of the area will experience flood levels of 0.21 to 0.50 meters while 2.08%, 1.74%, 0.31, and 0.02% 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 39 are the affected areas in Buenavista in square kilometers by flood depth per barangay.

Table 39. Affected Areas in Buenavista, Bohol during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)							
	Asinan	Bato	Bonot-bonot	Bugaong	Cambu-hat	Cam-bus-Oc	Cangawa	Canto-mugcad
0.03-0.20	0.0096	0.47	0.77	0.48	2.81	0.011	0.79	0.16
0.21-0.50	0.0015	0.035	0.076	0.064	0.97	0	0.13	0.017
0.51-1.00	0.0004	0.023	0.098	0.018	1.21	0	0.15	0.0031
1.01-2.00	0.0016	0.084	0.12	0.0048	1.04	0	0.24	0
2.01-5.00	0	0.078	0.1	0.001	0.0019	0	0.05	0
> 5.00	0	0	0.00011	0	0	0	0.0037	0

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)							
	Cantuba	Dait	Hunan	Lapacan Sur	Merry-land	Pobla-cion	Rufo Hill	Sweet-land
0.03-0.20	0.88	0.84	0.45	0.15	1.06	0.53	0.068	0.81
0.21-0.50	0.028	0.14	0.23	0.063	0.082	0.065	0.0019	0.11
0.51-1.00	0.019	0.32	0.14	0.099	0.057	0.088	0.00072	0.033
1.01-2.00	0.012	0.16	0.0001	0.065	0.12	0.037	0.00032	0.0068
2.01-5.00	0.085	0	0	0	0.0087	0.0015	0	0.0069
> 5.00	0.017	0	0	0	0	0	0	0

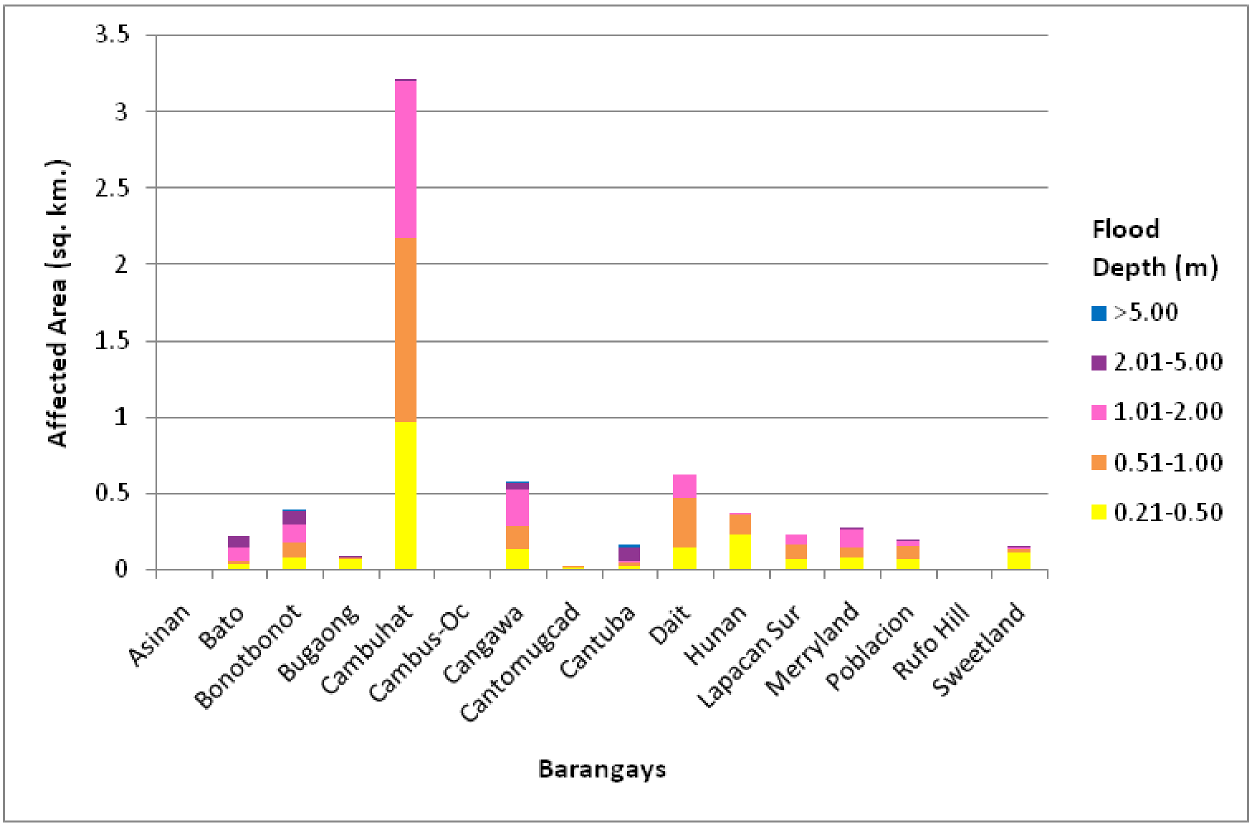


Figure 73. Affected Areas in Buenavista, Boho lduring 100-Year Rainfall Return Period.

For the municipality of Clarin, with an area of 45.02 sq. km., 3.18% will experience flood levels of less 0.20 meters. 0.32% of the area will experience flood levels of 0.21 to 0.50 meters while 0.25%, 0.21%, 0.25%, and 0.22% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 40 are the affected areas in Clarin in square kilometers by flood depth per barangay.

Table 40. Affected Areas in Clarin, Bohol during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Clarin (in sq. km.)		
	Cantoyoc	Nahawan	Villaflor
0.03-0.20	0.94	0.49	0.0019
0.21-0.50	0.045	0.098	0
0.51-1.00	0.032	0.08	0
1.01-2.00	0.034	0.059	0
2.01-5.00	0.077	0.035	0
> 5.00	0.025	0.074	0

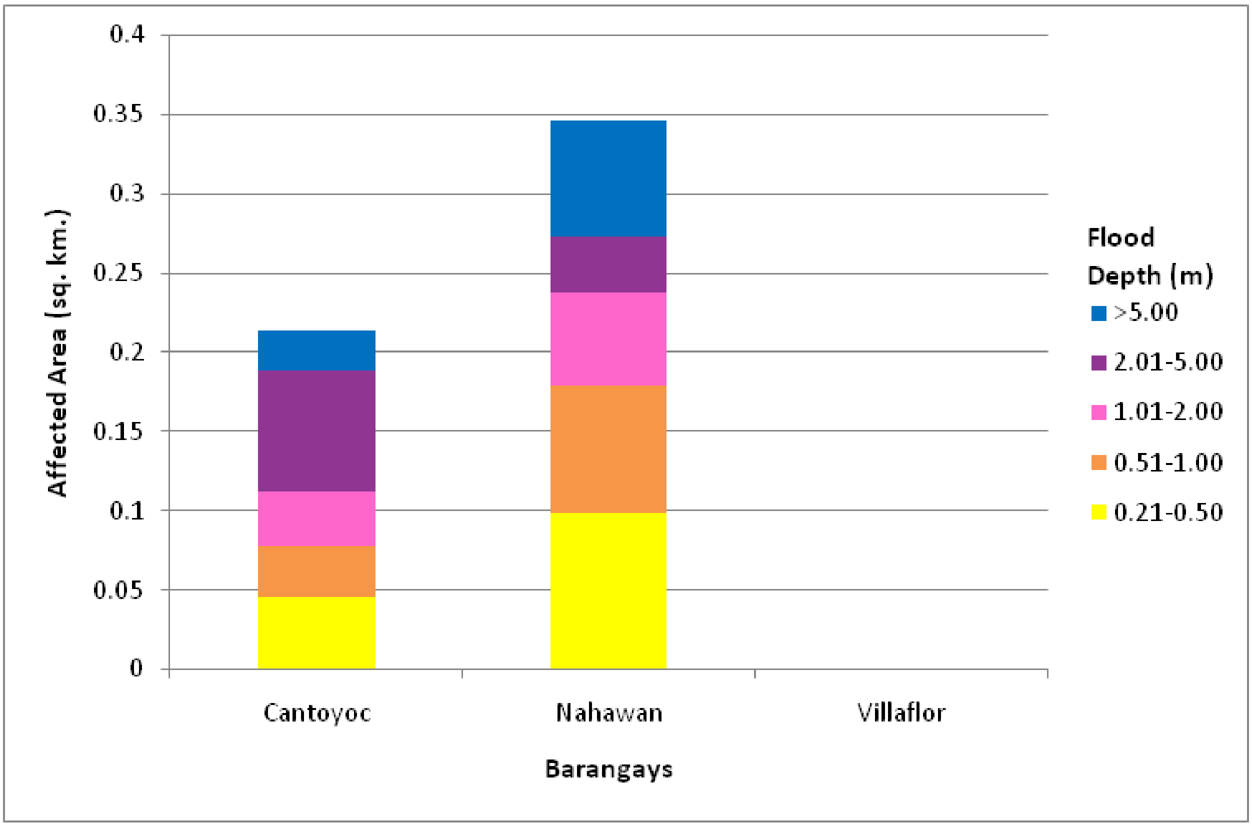


Figure 74. Affected Areas in Clarin, Boholduring 100-Year Rainfall Return Period.

For the municipality of Danao, with an area of 109.04 sq. km., 0.003% will experience flood levels of less 0.20 meters. 0.000002% of the area will experience flood levels of 0.21 to 0.50 meters and 0.00009% of the area will experience flood depths of 2.01 to 5 meters, respectively. Listed in Table 41 are the affected areas in Danao in square kilometres by flood depth per barangay.

Table 41. Affected Areas in Danao, Bohol during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Danao (in sq. km.)
	Cabatuan
0.03-0.20	0.0035
0.21-0.50	0.000002
0.51-1.00	0.000094
1.01-2.00	0
2.01-5.00	0
> 5.00	0

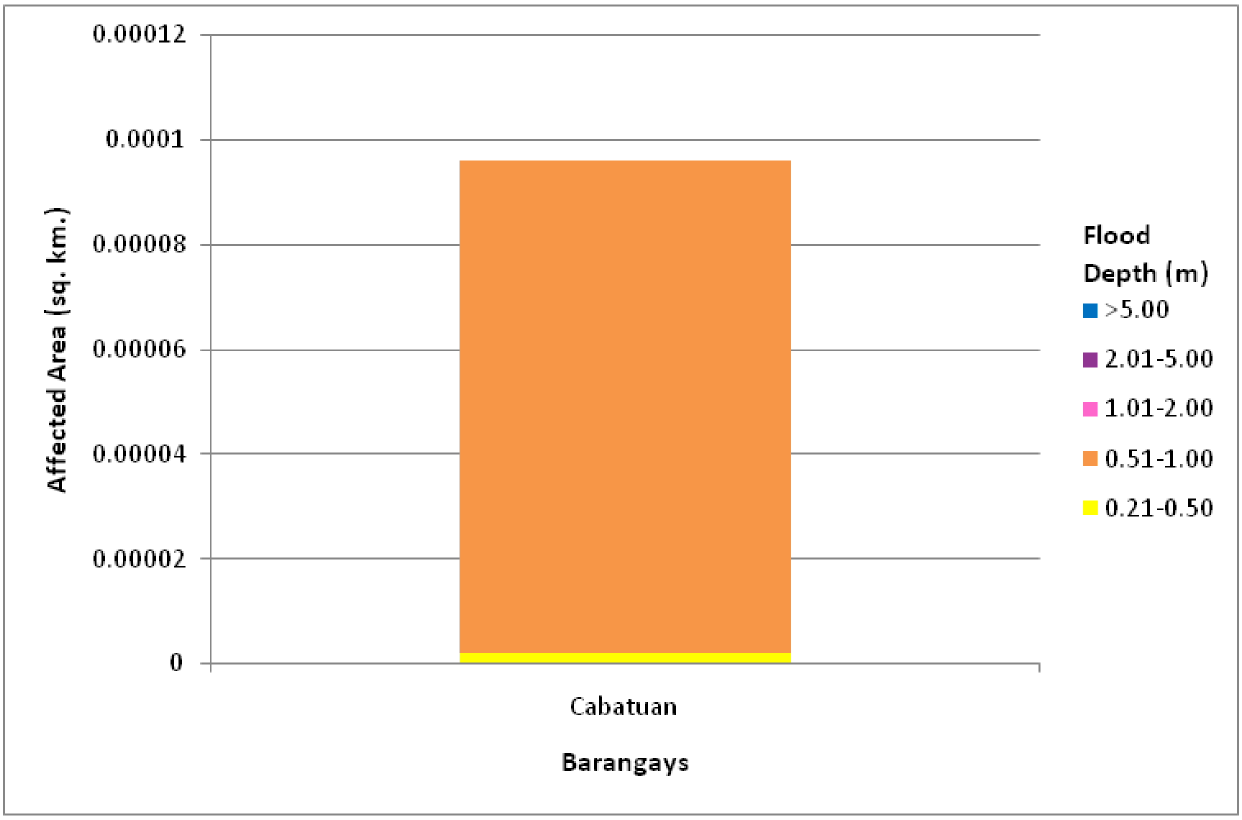


Figure 75. Affected Areas in Danao, Bohol during 100-Year Rainfall Return Period.

For the municipality of Inabanga, with an area of 108 sq. km., 49.49% will experience flood levels of less 0.20 meters. 6.67% of the area will experience flood levels of 0.21 to 0.50 meters while 7.23%, 4.96%, 2.70%, and 2.39% 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 42 are the affected areas in Inabanga in square kilometers by flood depth per barangay.

Table 42. Affected Areas in Inabanga, Bohol during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Anonang	Badiang	Baguhan	Bahan	Banahao	Baogo	Bugang	Caga-wasan	Cagayan	Cambi-toon	Canlinte
0.03-0.20	0.036	2.89	1.84	0.14	1.87	1.37	1.71	0.56	1.43	0.063	1.04
0.21-0.50	0.0011	0.82	0.036	0.0051	0.083	0.099	1.1	0.37	0.096	0.00056	0.022
0.51-1.00	0.00057	0.48	0.026	0.0011	0.065	0.066	0.89	0.12	0.12	0.0008	0.019
1.01-2.00	0.00068	0.1	0.031	0	0.057	0.14	0.22	0	0.075	0.0002	0.027
2.01-5.00	0	0.0015	0.058	0	0.038	0.29	0.037	0	0.084	0.00013	0.085
> 5.00	0	0	0.49	0	0.00011	0.00033	0	0	0.085	0.00013	0.94

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Cawayan	Cogon	Dagohoy	Dait Sur	Datag	Fatima	Ilaud	Ilaya	Ilihan	Lapacan Sur	Lawis
0.03-0.20	2.24	0.67	1.66	1.25	4.85	0.44	0.0021	2.21	1.09	1.16	0.53
0.21-0.50	0.072	0.11	0.15	0.1	0.15	0.12	0.019	0.058	0.045	0.11	0.14
0.51-1.00	0.065	0.22	0.054	0.11	0.16	0.46	0.092	0.038	0.038	0.12	0.0099
1.01-2.00	0.058	0.17	0.034	0.16	0.18	0.58	0.12	0.029	0.039	0.24	0
2.01-5.00	0.078	0.082	0.03	0.029	0.084	0.003	0.041	0.033	0.12	0.12	0
> 5.00	0.62	0.06	0.00055	0.0003	0.00089	0	0.021	0.19	0.017	0.0007	0

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Liloan Norte	Liloan Sur	Lomboy	Lonoy Cain-sican	Lonoy Roma	Lutao	Luyo	Mabu-hay	Maria Rosario	Nabuad	Napo
0.03-0.20	1.47	2.97	1.45	0.98	1.32	2.66	0.52	1.91	0.47	3.65	0.88
0.21-0.50	0.075	0.13	0.038	0.066	0.076	0.6	0.11	0.071	0.014	0.37	0.024
0.51-1.00	0.13	0.12	0.021	0.032	0.052	0.39	0.41	0.092	0.0062	0.17	0.023
1.01-2.00	0.22	0.11	0.027	0.021	0.053	0.15	0.33	0.11	0.0012	0.1	0.031
2.01-5.00	0.44	0.15	0.025	0.043	0.11	0.021	0.045	0.11	0.0004	0.13	0.097
> 5.00	0.0066	0.7	0.0034	0.8	0.33	0	0.0045	0.0017	0	0.085	0.84

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Inabanga (in sq. km.)										
	Ondol	Pobla-cion	River-side	Saa	San Isidro	Santo Niño	Santo Rosario	Tam-book	Tungod	Ubujan	U-Og
0.03-0.20	1.17	0.14	0.76	0.096	0.33	0.32	0.77	0.18	0.053	0.97	1.34
0.21-0.50	0.44	0.092	0.029	0.21	0.18	0.057	0.33	0.0073	0.16	0.19	0.21
0.51-1.00	0.077	0.34	0.019	0.23	0.68	0.0075	0.67	0.014	0.37	0.27	0.54
1.01-2.00	0.037	0.51	0.021	0.049	0.54	0.011	0.066	0.032	0.23	0.31	0.14
2.01-5.00	0.12	0.029	0.044	0.069	0	0.0079	0.045	0.2	0	0.022	0.0045
> 5.00	0	0.038	0.37	0.0077	0	0	0.016	0.19	0	0.0041	0

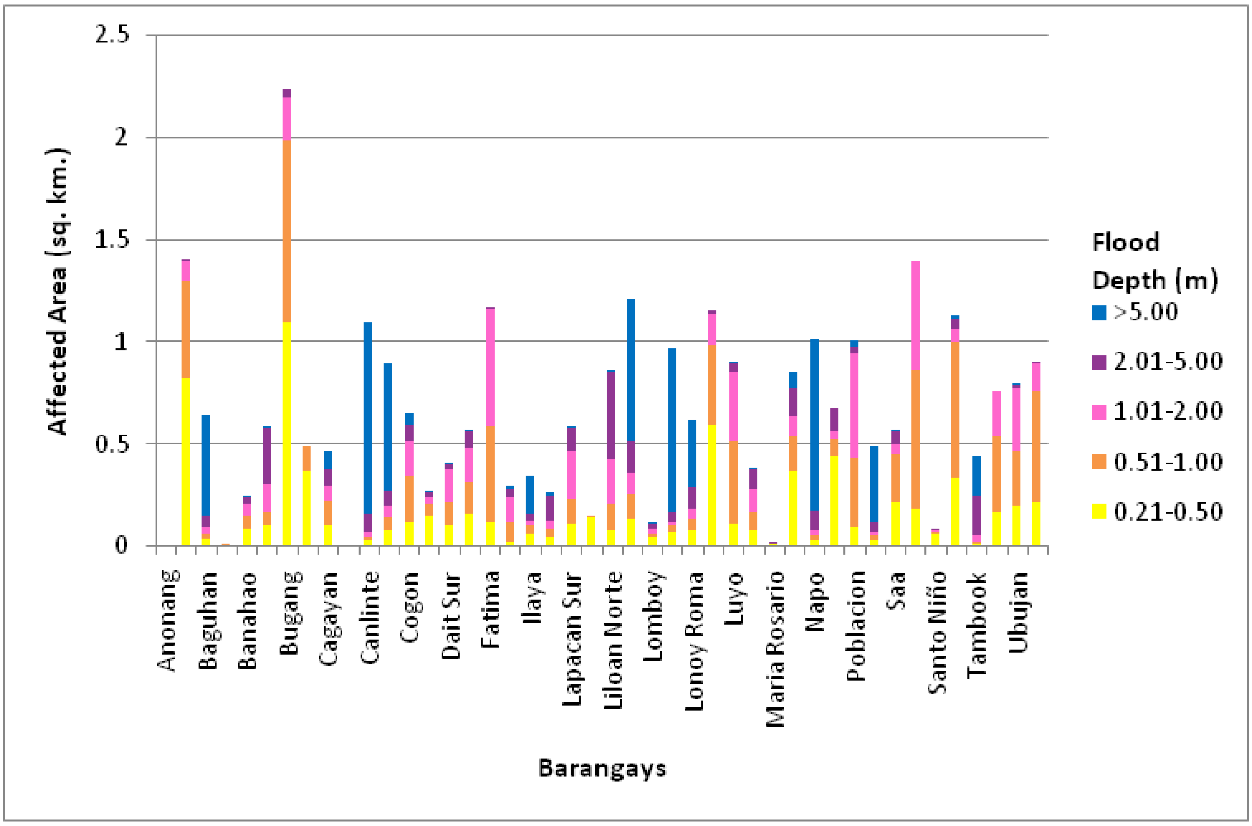


Figure 76. Affected Areas in Inabanga, Bohol during 100-Year Rainfall Return Period.

Among the barangays in the municipality of Buenavista, Cambuhat is projected to have the highest percentage of area that will experience flood levels at 5.52%. Meanwhile, Dait posted the second highest percentage of area that may be affected by flood depths at 1.34%.

Among the barangays in the municipality of Clarin, Cantoyoc is projected to have the highest percentage of area that will experience flood levels at 2.56%. Meanwhile, Nahawan posted the second highest percentage of area that may be affected by flood depths at 1.86%.

Among the barangays in the municipality of Danao, Cabatuan is projected to have the highest percentage of area that will experience flood levels at 0.003%.

Among the barangays in the municipality of Inabanga, Datag is projected to have the highest percentage of area that will experience flood levels at 5.01%. Meanwhile, Liloan Sur posted the second highest percentage of area that may be affected by flood depths at 3.87%.

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

Table 43. Area covered by each warning level with respect to the rainfall scenarios.

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	9.41	10.23	9.53
Medium	7.86	13.04	15.83
High	6.57	9.33	11.39
Total	**23.84**	**32.6**	**36.75**

Of the 18 identified Education Institutions in the Inabanga Floodplain, 2 schools were assessed to be exposed to Low level flooding during a 25 year scenario, while 1 school was assessed to be exposed to Medium level flooding in the same scenario. In the 100 year scenario, 2 schools were assessed to be exposed to Low level flooding, while 3 schools were assessed to be exposed to Medium level flooding in the same scenario.

Of the 6 identified Health Institutions in the Inabanga Floodplain, one health institution was assessed to be exposed to Low level flooding in both 25 and 100 year scenarios.

5.11 Flood Validation

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

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

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

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 its corresponding validation depths are shown in Figure 77.

Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 3.66 m. Table 44 shows a contingency matrix of the comparison. The validation points are found in Annex 11.

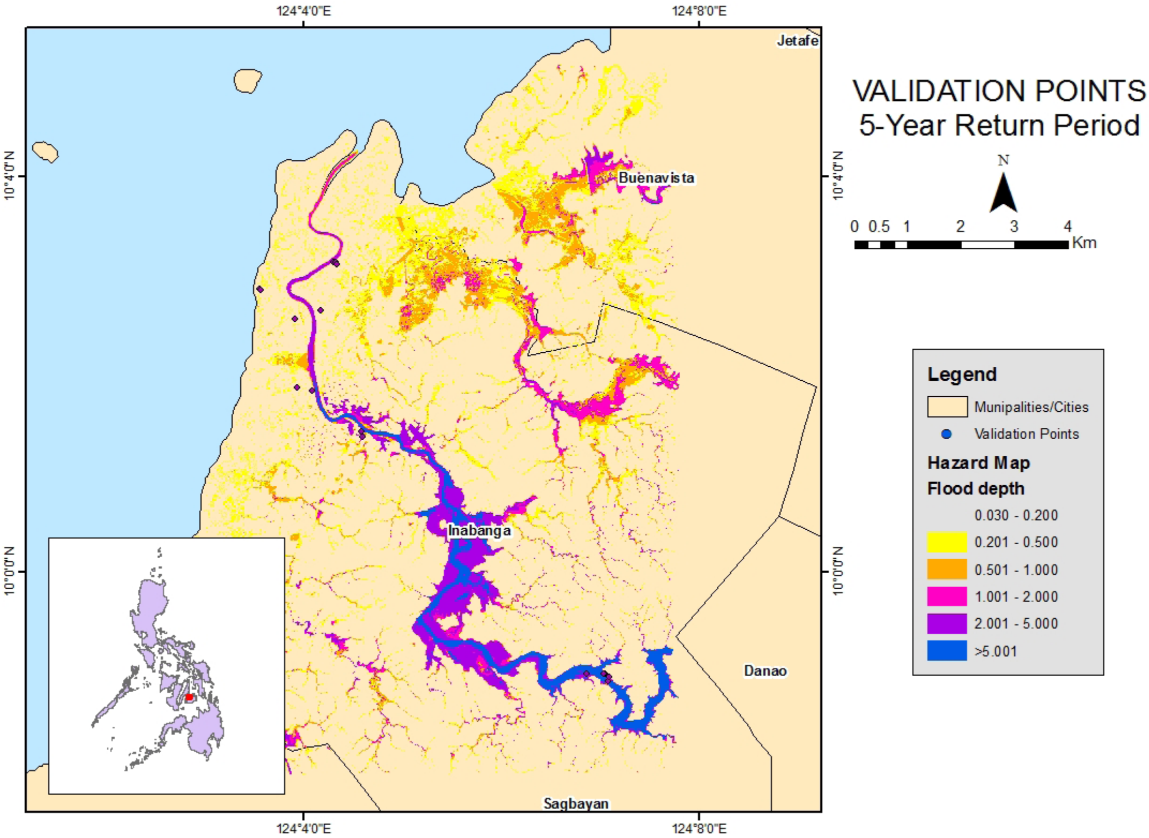


Figure 77. Validation points for a 5-year Flood Depth Map of the Inabanga Flood Plain.8

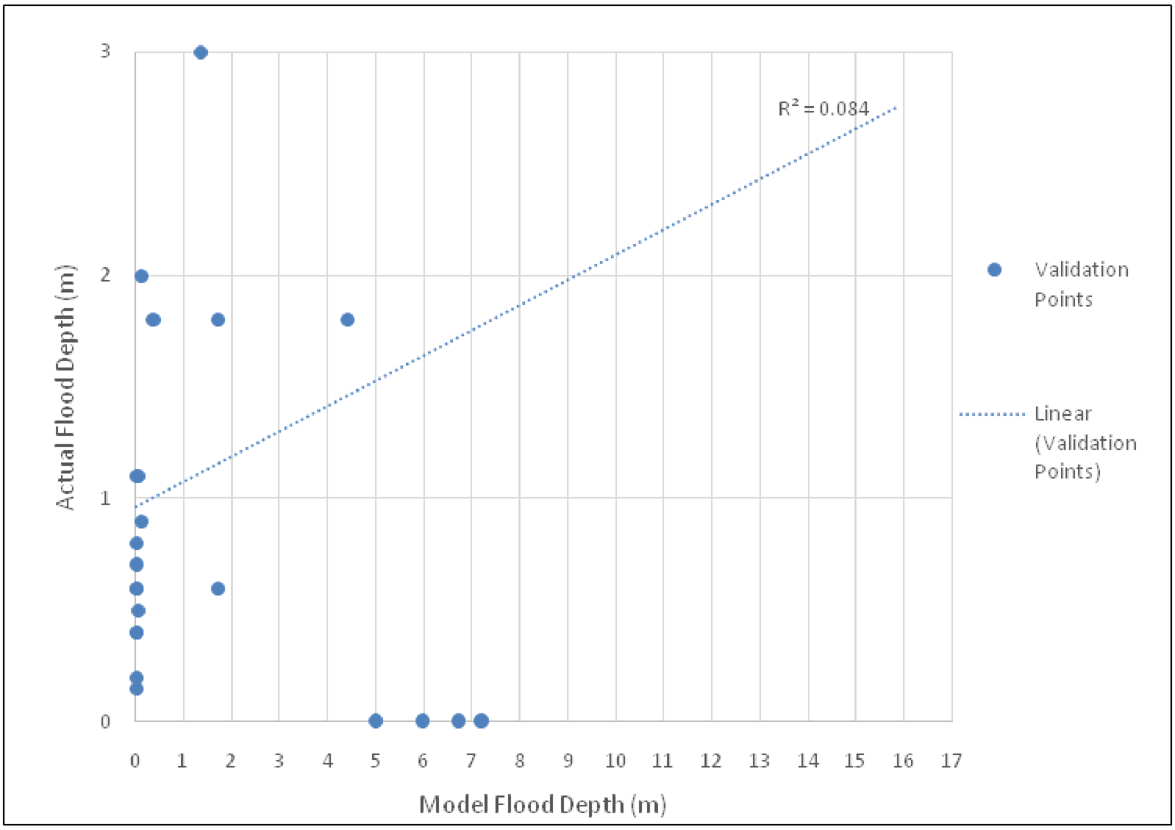


Figure 78. Flood Map depth versus Actual Flood Depth.

Table 44. Actual Flood Depth versus Simulated Flood Depth at different levels in the Inabanga 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	2	0	0	0	1	3	6
0.21-0.50	3	0	0	0	0	0	3
0.51-1.00	5	0	0	1	0	0	6
1.01-2.00	3	1	0	1	1	0	6
2.01-5.00	0	0	0	1	0	1	2
> 5.00	0	1	0	0	0	0	1
Total	13	2	0	3	2	4	24

On the whole, the overall accuracy generated by the flood model is estimated at 12.50% with 3 points correctly matching the actual flood depths. In addition, there were 7 points estimated one level above and below the correct flood depths while there were 6 points and 8 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 14 points were underestimated in the modelled flood depths of Inabanga.Table 45depicts the summary of the Accuracy Assessment in the Inabanga River Basin Flood Depth Map.

Table 45. Summary of the Accuracy Assessment in the Inabanga River Basin Survey.

	No. of Points	%
Correct	3	12.50
Overestimated	7	29.17
Underestimated	14	58.33
Total	24	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 LiDAR Sensors used in the Inabanga Floodplain Survey

Table A-1.1 Technical Specifications of the LiDAR Sensors used in the Inabanga Floodplain Survey

1. PEGASUS SENSOR

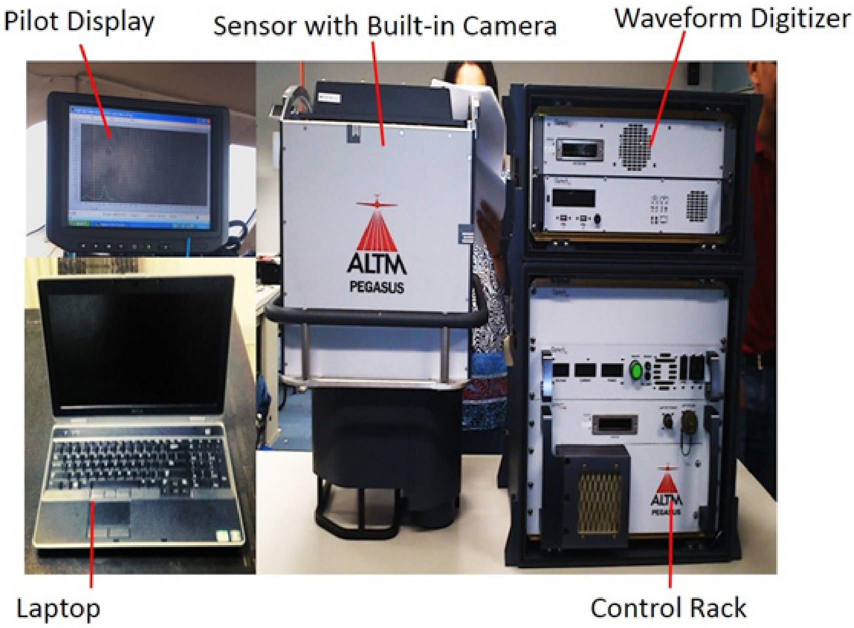


Figure A-1.1. Pegasus Sensor

Table A-1.1 Parameters and Specifications of Pegasus Sensor

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

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

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

1. BHL-63

Table A-2.1. NAMRIA Certification of Reference Points used in the LiDAR Survey

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

November 19, 2013

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: **BOHOL**
Station Name: **BHL-63**
Order: **2nd**

Island: **VISAYAS**
Municipality: **SAN MIGUEL**
Barangay: **HAGBUYO**

	PRS92 Coordinates	
Latitude: **10° 0' 13.39830"**	Longitude: **124° 20' 43.44081"**	Ellipsoidal Hgt: **17.31900 m.**
	WGS84 Coordinates	
Latitude: **10° 0' 9.39110"**	Longitude: **124° 20' 48.71189"**	Ellipsoidal Hgt: **80.87300 m.**
	PTM Coordinates	
Northing: **1106212.953 m.**	Easting: **428232.164 m.**	Zone: **5**
	UTM Coordinates	
Northing: **1,106,055.36**	Easting: **647,462.74**	Zone: **51**

Location Description

BHL-63

To reach the station travel from San Miguel Town Proper for about 2.5 Km. and look for Hagbuyo Bridge before Hagbuyo Primary School which is about 150 m NE. Mark is the head of a 3 in. copper nail set on a drilled hole on the concrete sidewalk of Hagbuyo Bridge Km. 131+630 embedded with concrete cement putty 30 cm x 30 cm x 15 cm with inscriptions"BHL-63, 2007, NAMRIA". Ref. no. 1 is an electric post about 30 m NW at the opposite side of the road; Ref. no. 2 is a 6.1 pipe with Bridge Tonage sign about 25 m SW.

Requesting Party: **UP-TCAGP/DOST**
Pupose: **Reference**
OR Number: **3947235 B**
T.N.: **2013-1253**

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

9 9 1 1 1 9 2 0 1 3 1 1 1 1 0 0

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

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

Figure A-2.1. BHL-63

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

Table A-3.1. Baseline Processing Reports of Control Points used in the LiDAR Survey

1. BHL-63A

Table A-3.1. BHL-63A

BHL-63 - BHL-63A (6:30:41 AM-9:52:18 AM) (S3)

Baseline observation:	BHL-63 --- BHL-63A (B3)
Processed:	1/4/2017 1:09:43 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.002 m
Vertical precision:	0.002 m
RMS:	0.011 m
Maximum PDOP:	1.840
Ephemeris used:	Broadcast
Antenna model:	Trimble Relative
Processing start time:	9/12/2016 6:30:41 AM (Local: UTC+8hr)
Processing stop time:	9/12/2016 9:52:18 AM (Local: UTC+8hr)
Processing duration:	03:21:37
Processing interval:	1 second

Vector Components (Mark to Mark)

From:	BHL-63				
Grid		Local		Global	
Easting	647463.396 m	Latitude	N10°00'13.31406"	Latitude	N10°00'09.30688"
Northing	1106052.775 m	Longitude	E124°20'43.46219"	Longitude	E124°20'48.73327"
Elevation	19.432 m	Height	20.487 m	Height	84.041 m

To:	BHL-63A				
Grid		Local		Global	
Easting	647466.981 m	Latitude	N10°00'13.84084"	Latitude	N10°00'09.83363"
Northing	1106068.972 m	Longitude	E124°20'43.58209"	Longitude	E124°20'48.85315"
Elevation	19.409 m	Height	20.464 m	Height	84.018 m

Vector					
ΔEasting	3.585 m	NS Fwd Azimuth	12°42'51"	ΔX	-1.416 m
ΔNorthing	16.197 m	Ellipsoid Dist.	16.591 m	ΔY	-4.400 m
ΔElevation	-0.023 m	ΔHeight	-0.023 m	ΔZ	15.934 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'10"	σ ΔX	0.001 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.001 m
σ ΔElevation	0.001 m	σ ΔHeight	0.001 m	σ ΔZ	0.001 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000011627		
Y	-0.0000004536	0.0000009291	
Z	-0.0000002192	0.0000000346	0.0000003582

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI S. SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
LiDAR Operation	Senior Science Research Specialist (SSRS)	LOVELY GRACIA ACUNA	UP-TCAGP
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
LiDAR Operation	Research Associate (RA)	ENGR. IRO NIEL ROXAS	UP-TCAGP
	RA	KRISTINE JOY ANDAYA	UP-TCAGP
Ground Survey	RA	MA. KATRINA RANESES	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. MIKE BERONILLA	PILIPPINE AIR FORCE (PAF)
LiDAR Operation	Pilot	CAPT. SHERWIN CESAR ALFONSO	ASIAN AEROSPACE CORPORATION (AAC)
LiDAR Operation	Pilot	CAPT. RANDY LAGCO	AAC

Annex 5. Data Transfer Sheet for Inabanga Floodplain

Table A-5.1. Data Transfer Sheet for the Inabanga Floodplain

DATA TRANSFER SHEET
bohol 9/17/15

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	
10-Sep	3401P	1BLK51LS253A	pegasus	1.7	657/318	7.44	163	na	na	17.4	na	10.2	1KB	1KB	38/55/25	na	Z:\DAC\RAW DATA
11-Sep	3405P	1BLK51LS254A	pegasus	1.87	2606/367	8.31	178	na	na	19.4	na	6.91	1KB	1KB	38/55/25	na	Z:\DAC\RAW DATA
12-Sep	3409P	1BLK51B255A	pegasus	1.6	525/635	14.1	302	na	na	32.8	na	15.7	1KB	1KB	42	na	Z:\DAC\RAW DATA
12-Sep	3411P	1BLK51C255B	pegasus	1.24	1826/263	5.78	151	na	na	12.9	na	15.7	1KB	1KB	na	na	Z:\DAC\RAW DATA

Received from
Name
Position
Signature
9/17/15

Received by
Name AC Bongat
Position SSRS
Signature 9/21/15

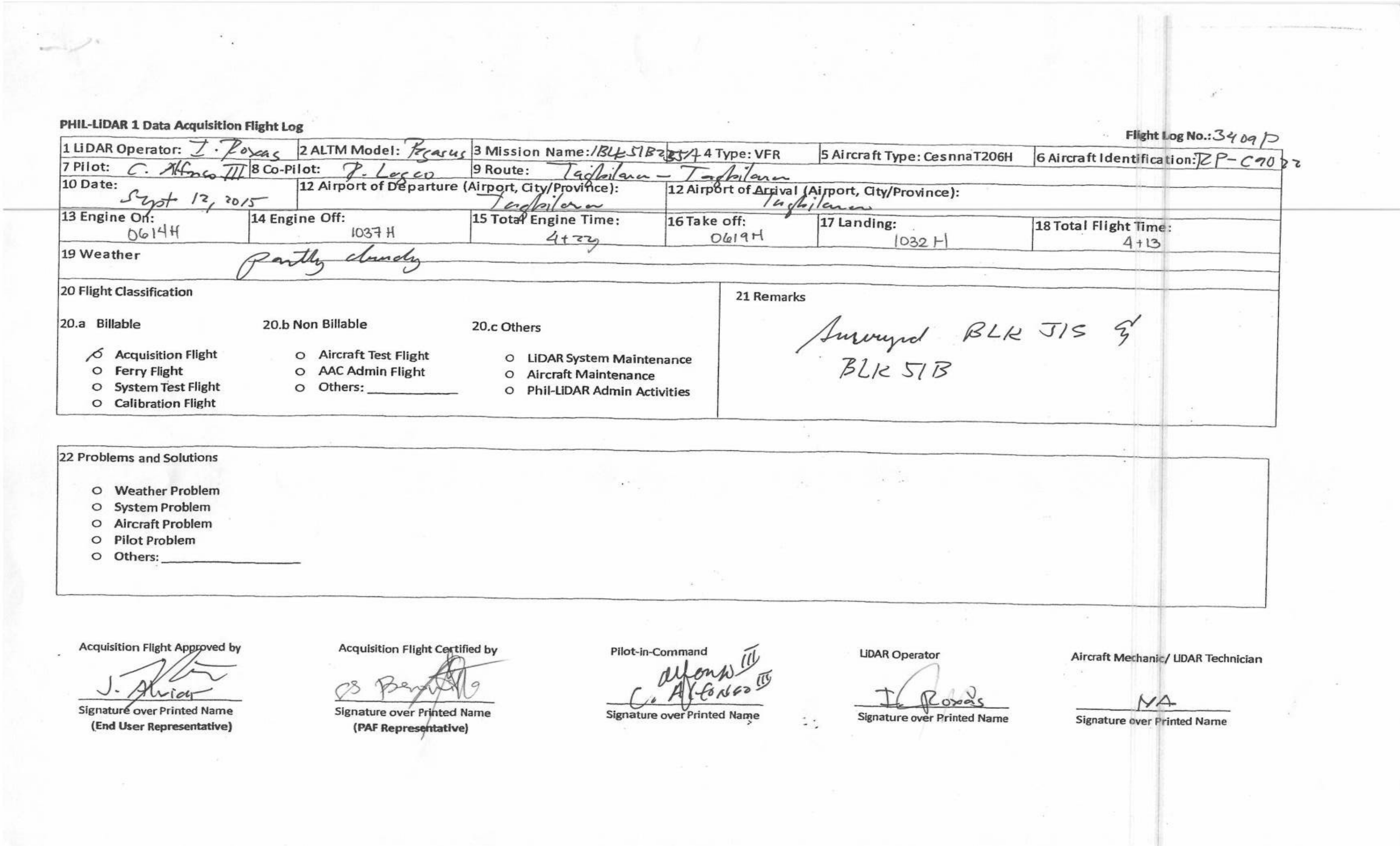
15-28

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

Annex 6. Flight logs for the flight missions

1. Flight Log for 3049P Mission

Table A-6.1. Flight Logs for the Flight Missions



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3409P

1 LiDAR Operator: I. Roxas	2 ALTM Model: Pegasus	3 Mission Name: 1BLK51B257A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso III	8 Co-Pilot: P. Lozeco	9 Route: Tagbilaran – Tagbilaran			
10 Date: Sept 12, 2015	12 Airport of Departure (Airport, City/Province): Tagbilaran		12 Airport of Arrival (Airport, City/Province): Tagbilaran		
13 Engine On: 0614H	14 Engine Off: 1037H	15 Total Engine Time: 4+23	16 Take off: 0619H	17 Landing: 1032H	18 Total Flight Time: 4+13
19 Weather: Partly 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

Surveyed BLK 51S & BLK 51B

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

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

Figure A-6.1. Flight Log for Mission 3049P

Annex 7. Flight status reports

Bohol Mission

September 12, 2015

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3409P	BLK 51S INABANGA FP AND BLK 51B MATULID FP	1BLK51B255A	I ROXAS	SEPT 12	SURVEYED BLK 51B AT 1000M THEN 850M ALT; ABNORMAL AVPOSVIEW TERMINATION; DIGI HD WRITING ERROR; SWATH NOT UPDATING – RESTARTED LASER –INC SWATH AND LAS 305.38 SQ.KM

SWATH PER FLIGHT MISSION

Flight No.:	3409P
Area:	BLK51S
Mission Name:	1BLK51B255A
Parameters:	Altitude: 850-1000m;
Scan Frequency:	30;
Scan Angle:	50

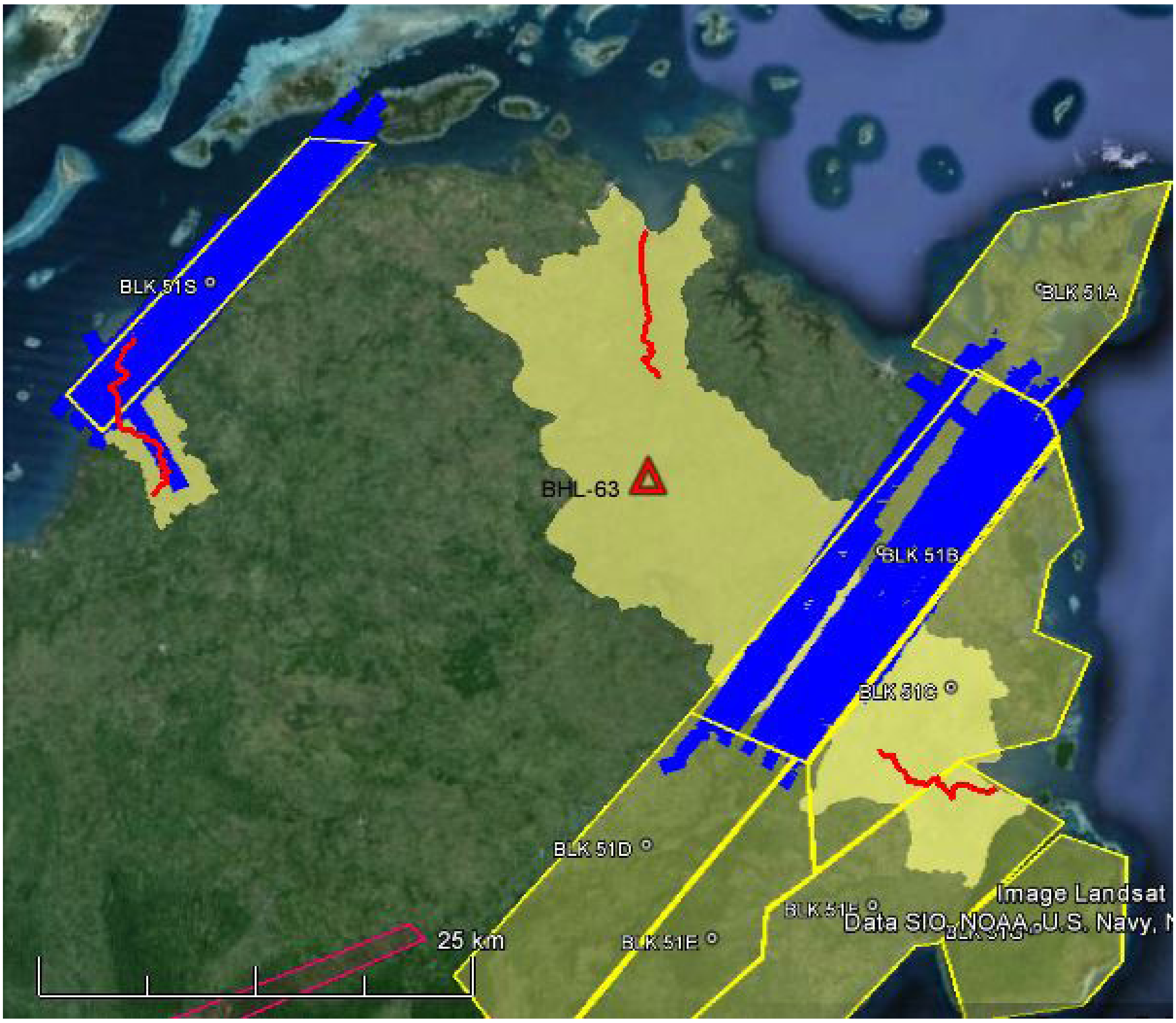


Figure A-7.1. Swath for Flight No. 3409P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Reports

Flight Area	Bohol
Mission Name	**Blk51S**
Inclusive Flights	3409P
Range data size	32.8 GB
POS data size	302 MB
Base data size	15.7 MB
Image	N/A
Transfer date	September 21, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.0
RMSE for East Position (<4.0 cm)	1.6
RMSE for Down Position (<8.0 cm)	2.6
Boresight correction stdev (<0.001deg)	0.000436
IMU attitude correction stdev (<0.001deg)	0.000812
GPS position stdev (<0.01m)	0.0016
Minimum % overlap (>25)	65.39
Ave point cloud density per sq.m. (>2.0)	3.04
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	132
Maximum Height	253.18 m
Minimum Height	67.55 m
Classification (# of points)	
Ground	27,452,451
Low vegetation	25,506,790
Medium vegetation	23,681,618
High vegetation	23,922,692
Building	1,313,900
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Aljon Rie Araneta, Kathryn Claudyn Zarate

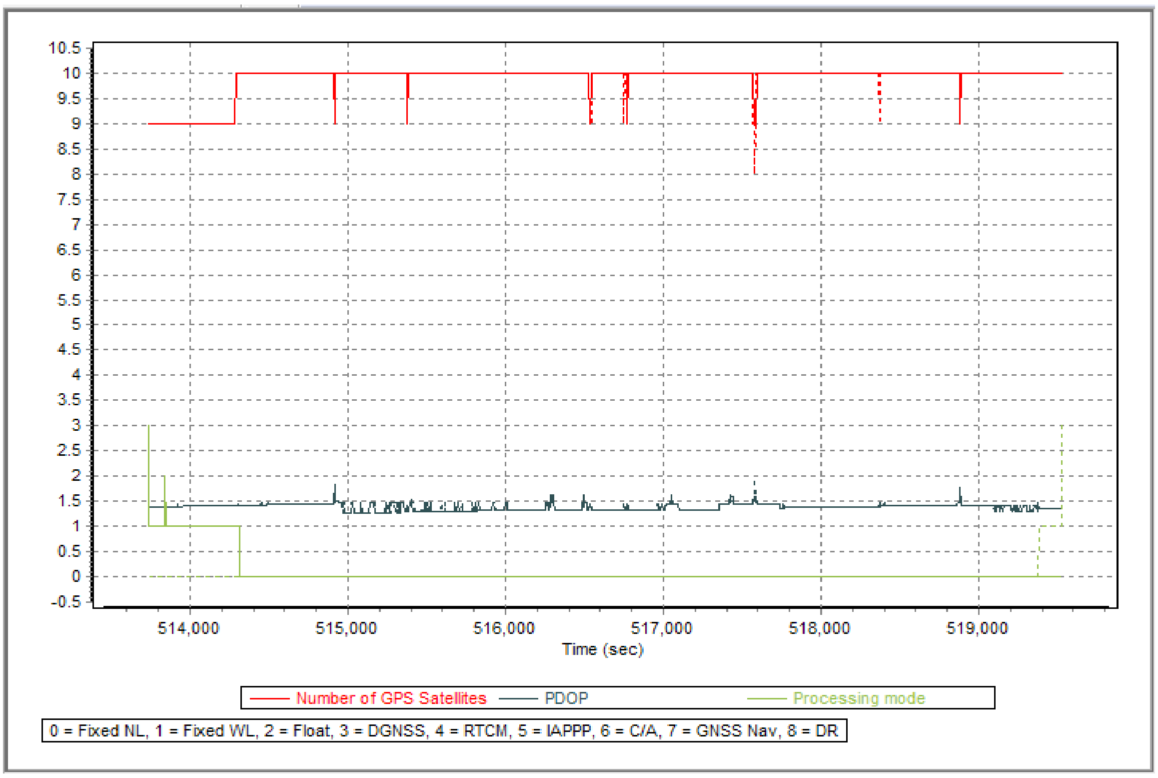


Figure 1.1.1. Solution Status

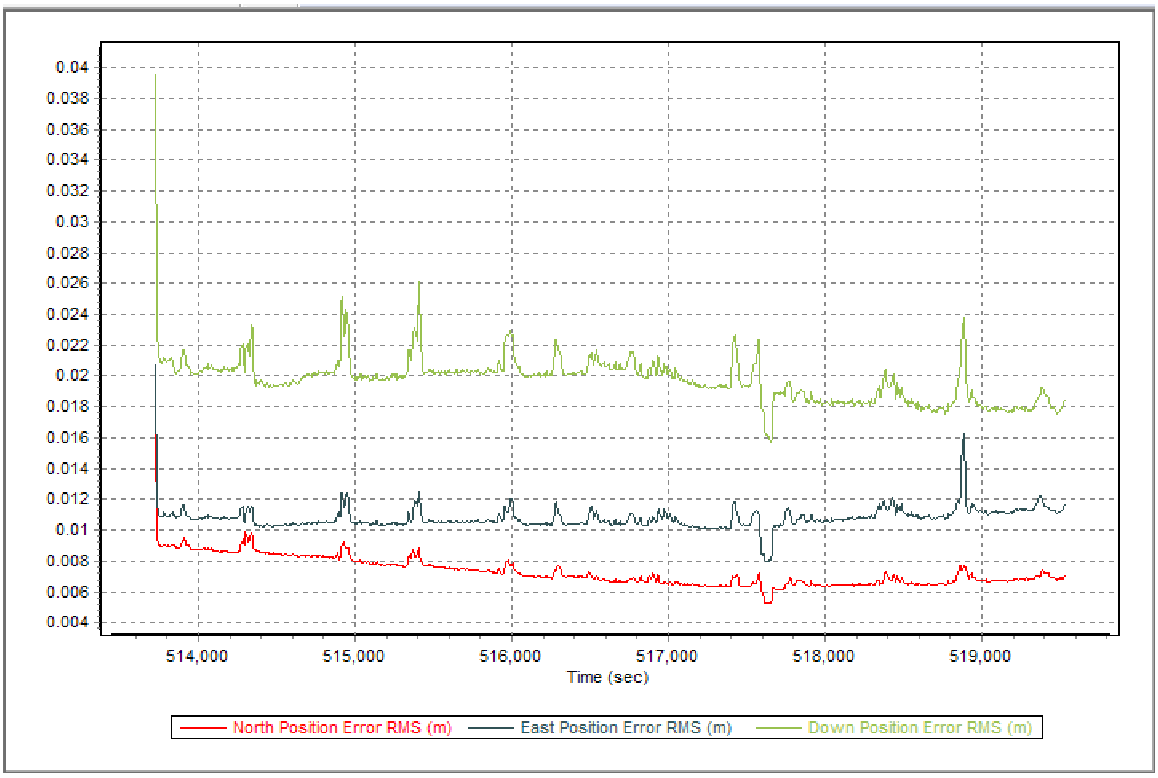


Figure 1.1.2. Smoothed Performance Metric Parameters

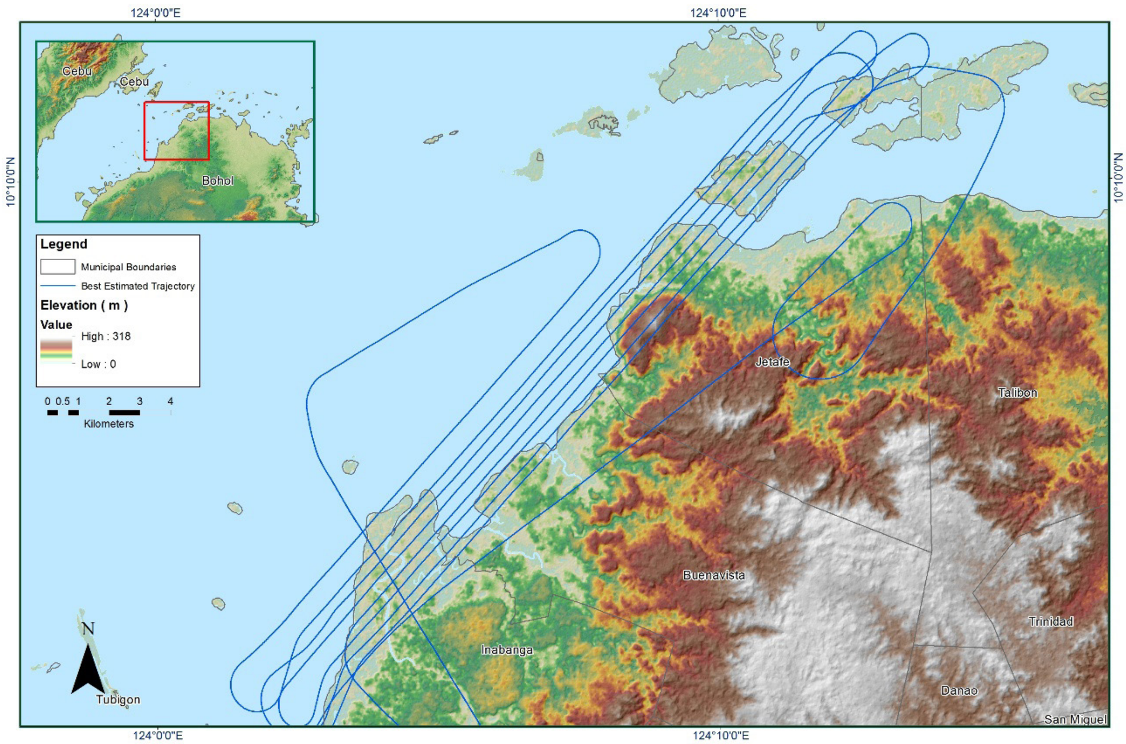


Figure 1.1.3. Best Estimated Trajectory

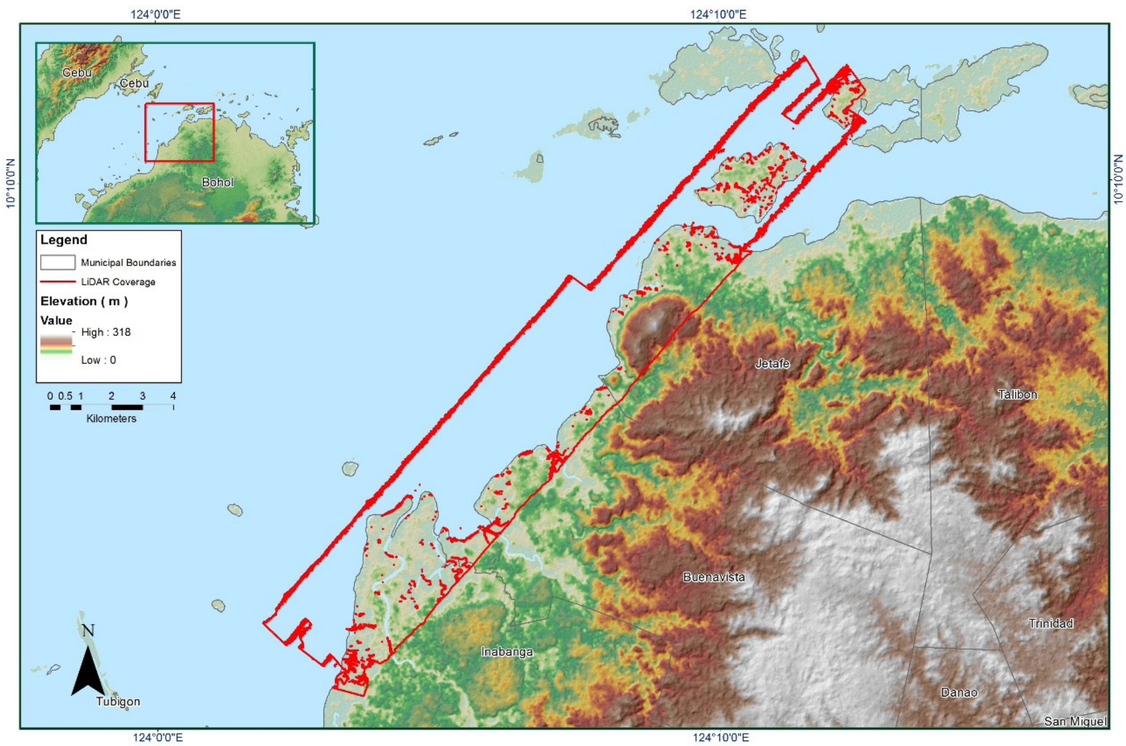


Figure 1.1.4. Coverage of LiDAR Data

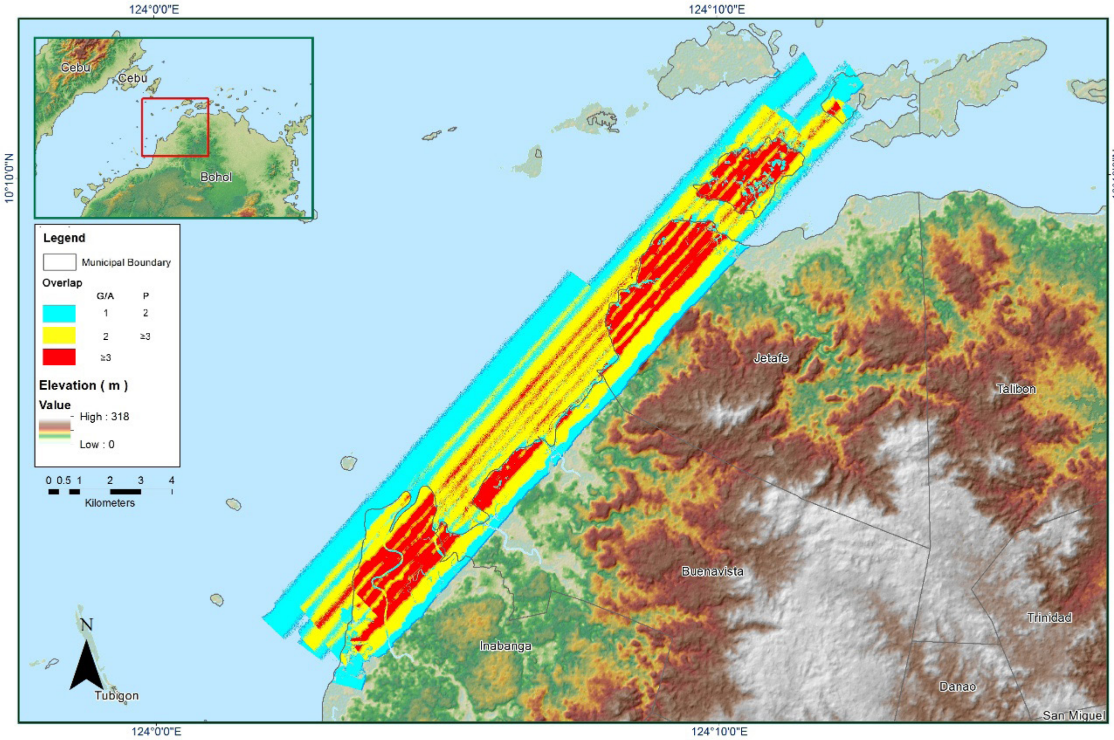


Figure 1.1.5. Image of data overlap

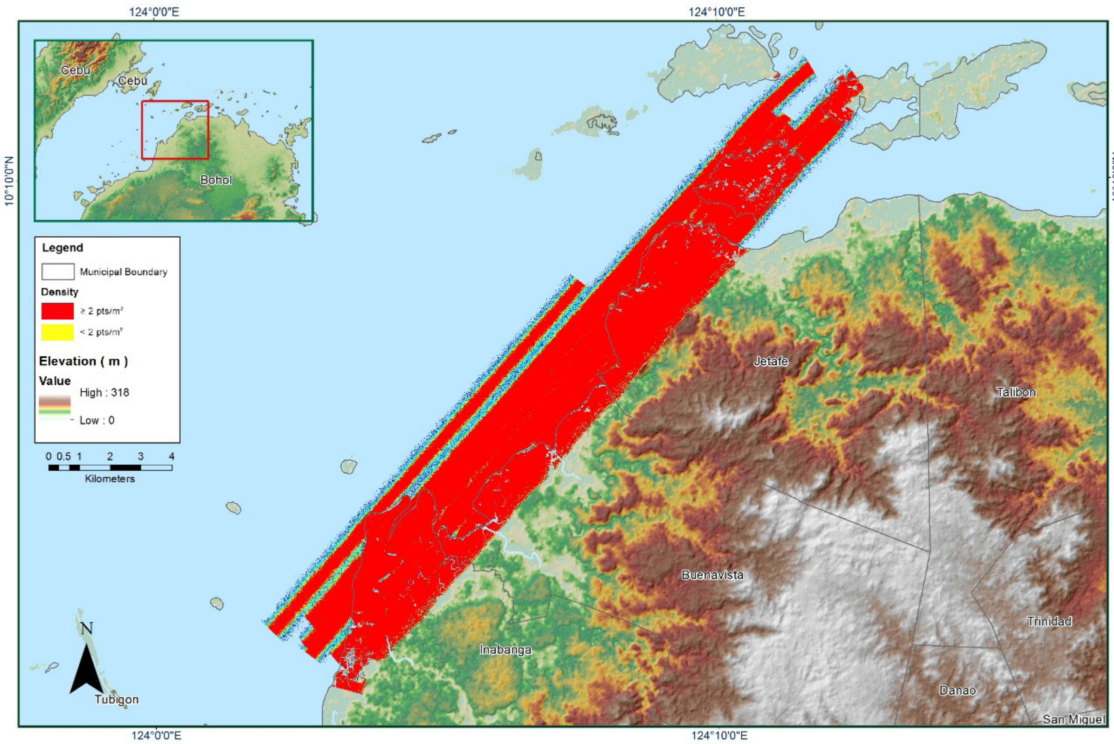


Figure 1.1.6. Density map of merged LiDAR data

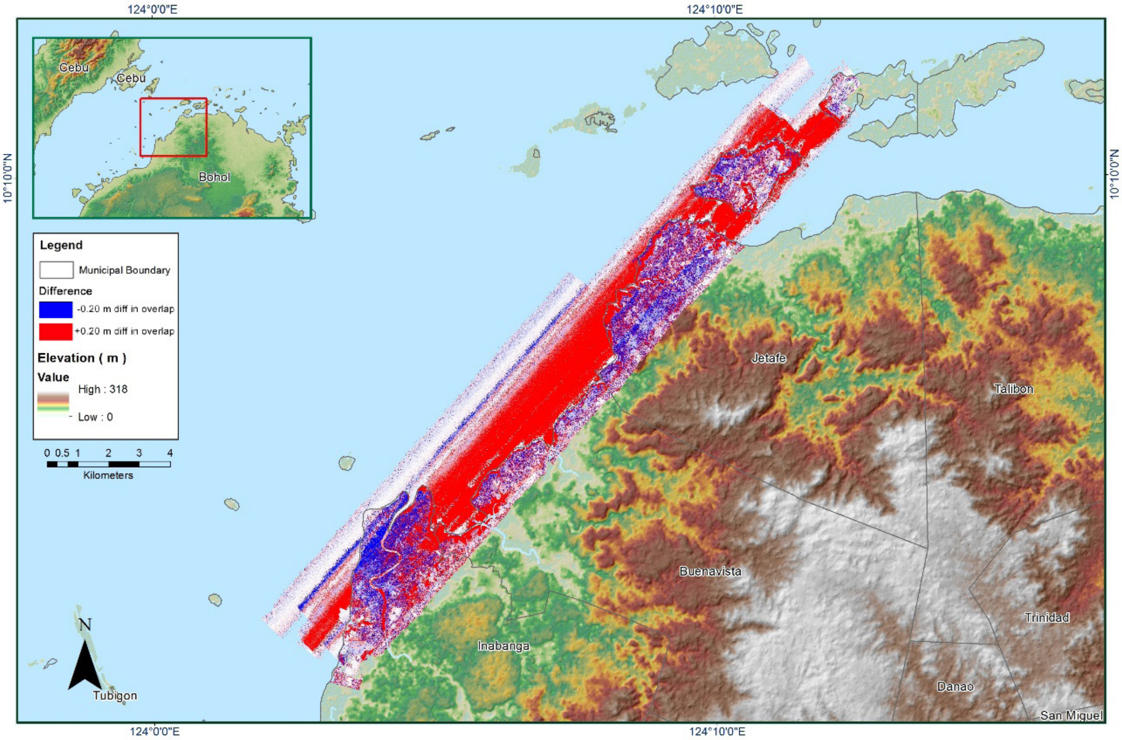


Figure 1.1.7. Elevation difference between flight line

Flight Area	Bohol
Mission Name	**Blk1A**
Inclusive Flights	799P
Range data size	24.5 GB
POS data size	191 MB
Base data size	12.6 MB
Image	N/A
Transfer date	January 9, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.6
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	4.8
Boresight correction stdev (<0.001deg)	0.000472
IMU attitude correction stdev (<0.001deg)	0.001071
GPS position stdev (<0.01m)	0.0079
Minimum % overlap (>25)	54.42%
Ave point cloud density per sq.m. (>2.0)	3.63
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	240
Maximum Height	371.23 m
Minimum Height	63.62 m
Classification (# of points)	
Ground	190,175,610
Low vegetation	149,200,241
Medium vegetation	280,527,841
High vegetation	204,148,141
Building	3,031,181
Orthophoto	No
Processed by	Engr. Benjamin Jonah Magallon, Eleyn Pama, Jovy Narisma

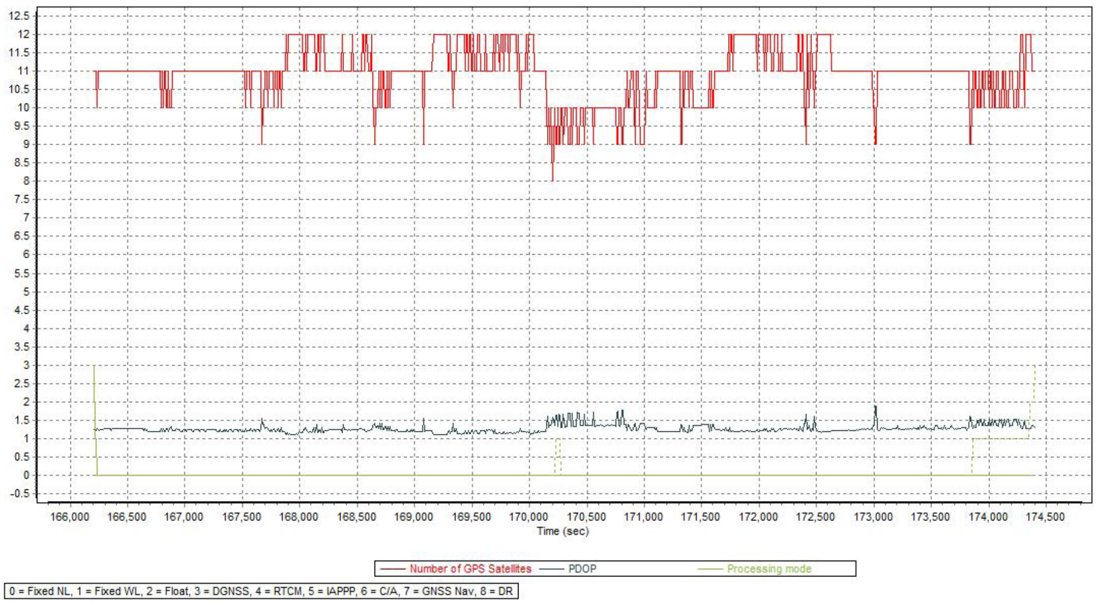


Figure 1.2.1. Solution Status

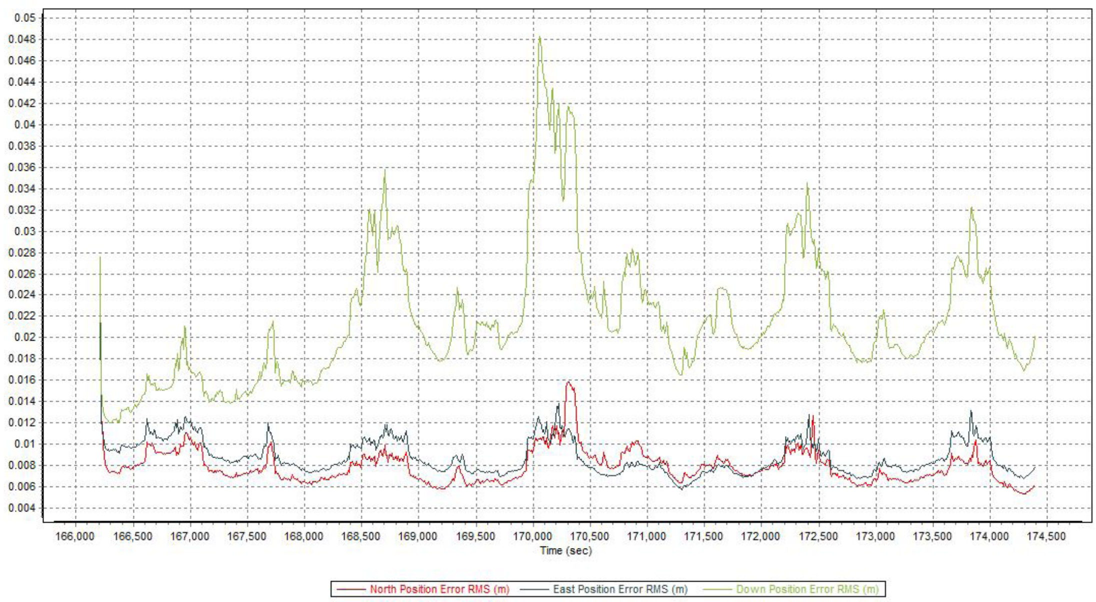


Figure 1.2.2. Smoothed Performance Metric Parameters

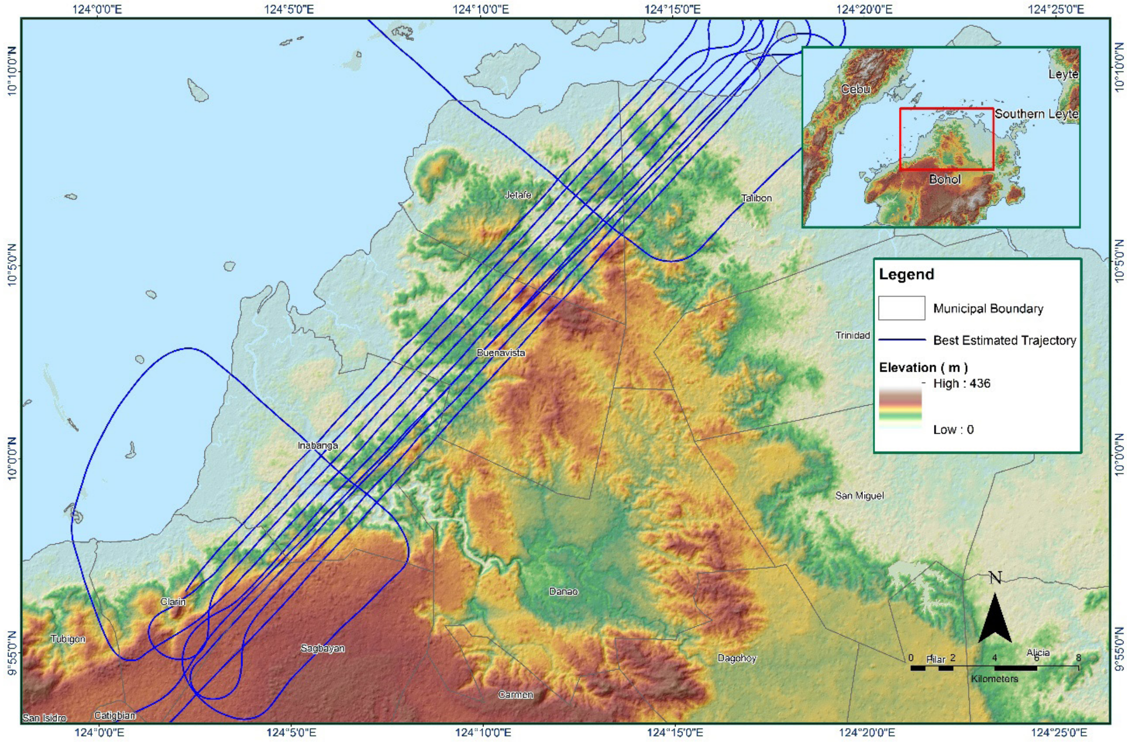


Figure 1.2.3. Best Estimated Trajectory

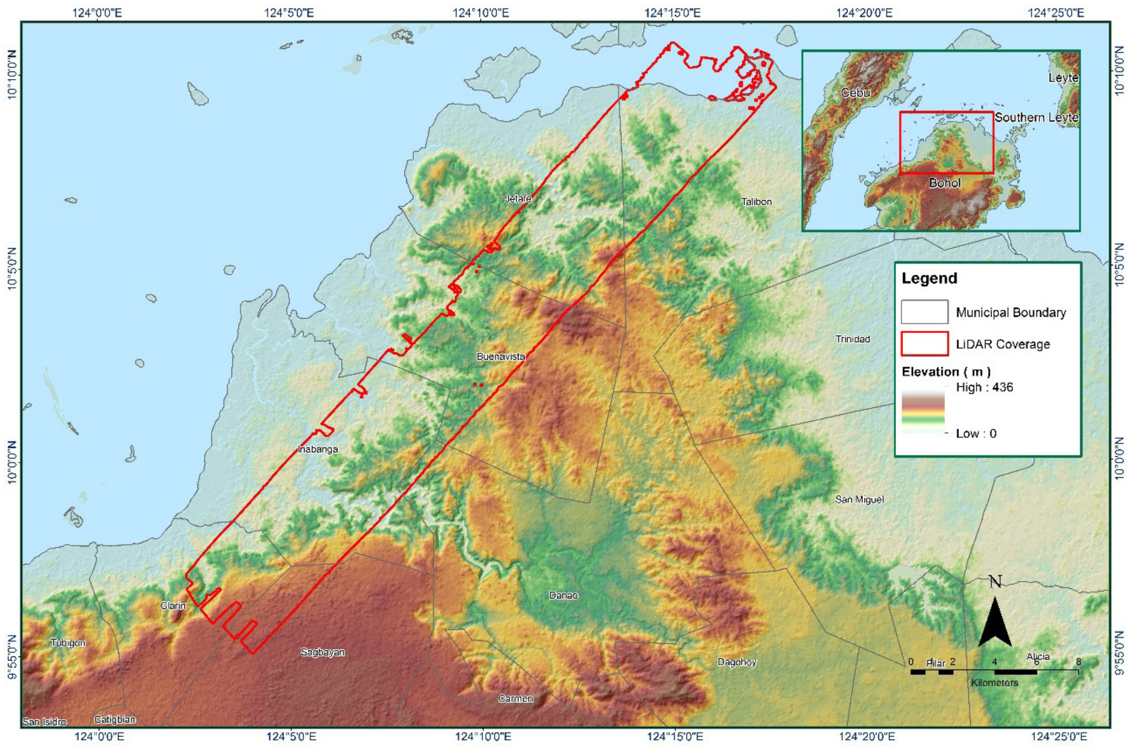


Figure 1.2.4. Coverage of LiDAR Data

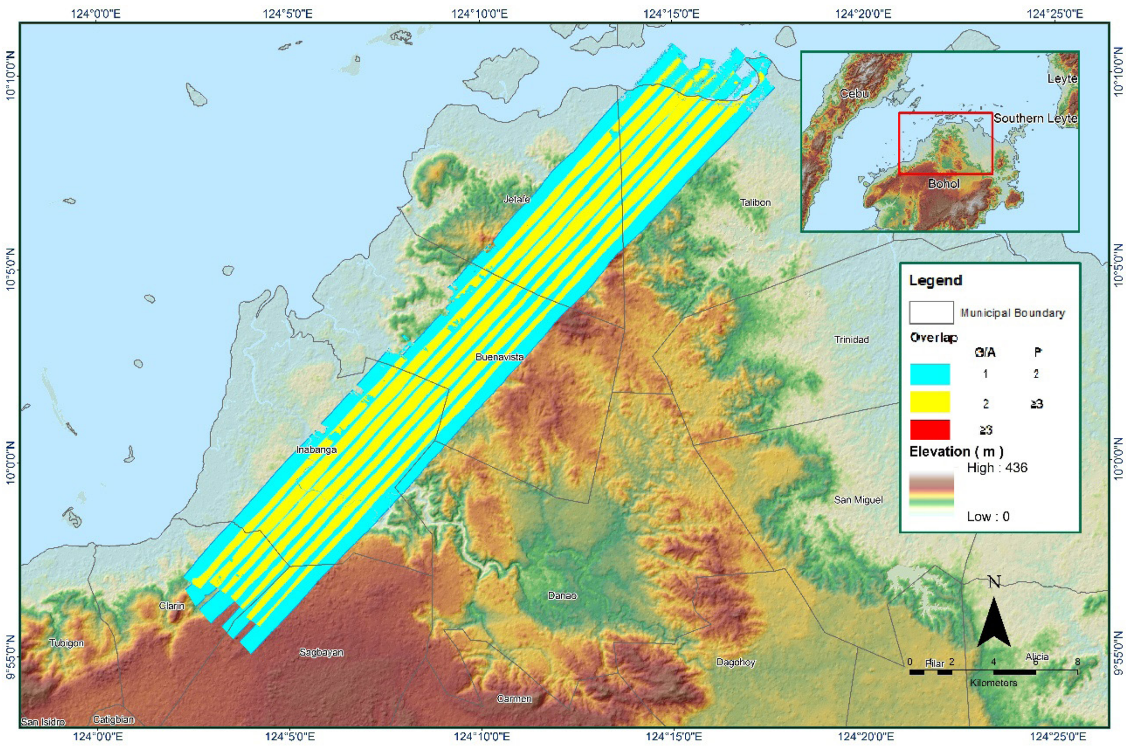


Figure 1.2.5. Image of data overlap

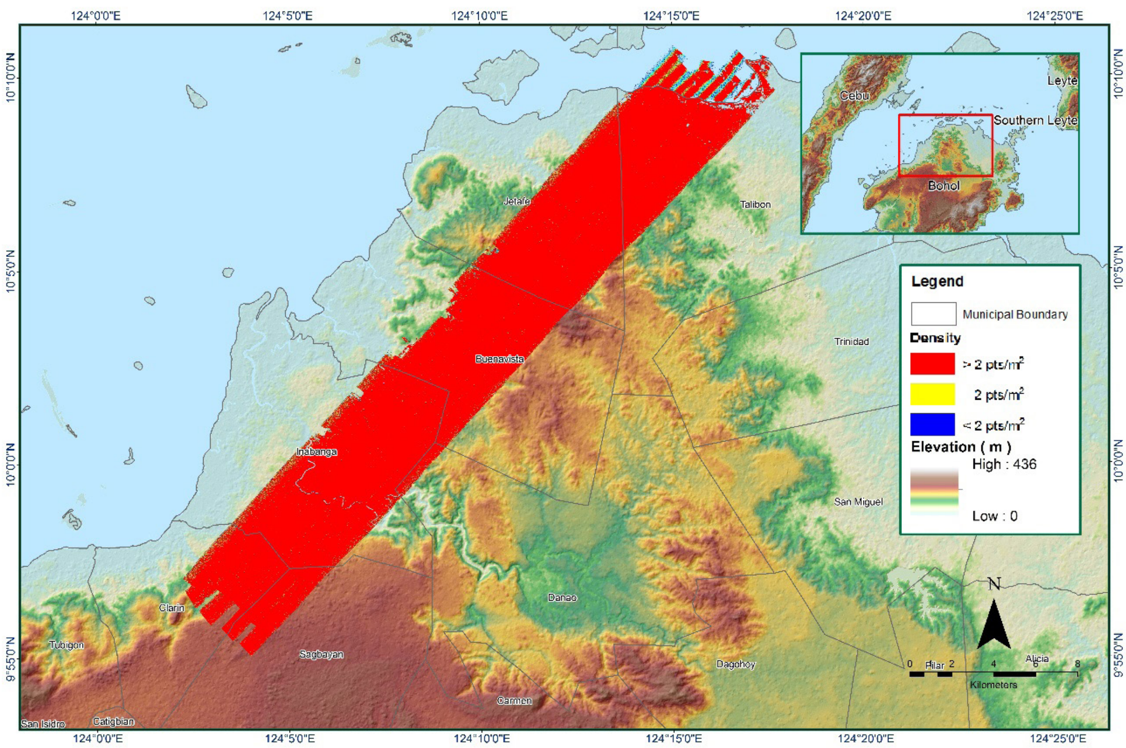


Figure 1.2.6. Density map of merged LiDAR data

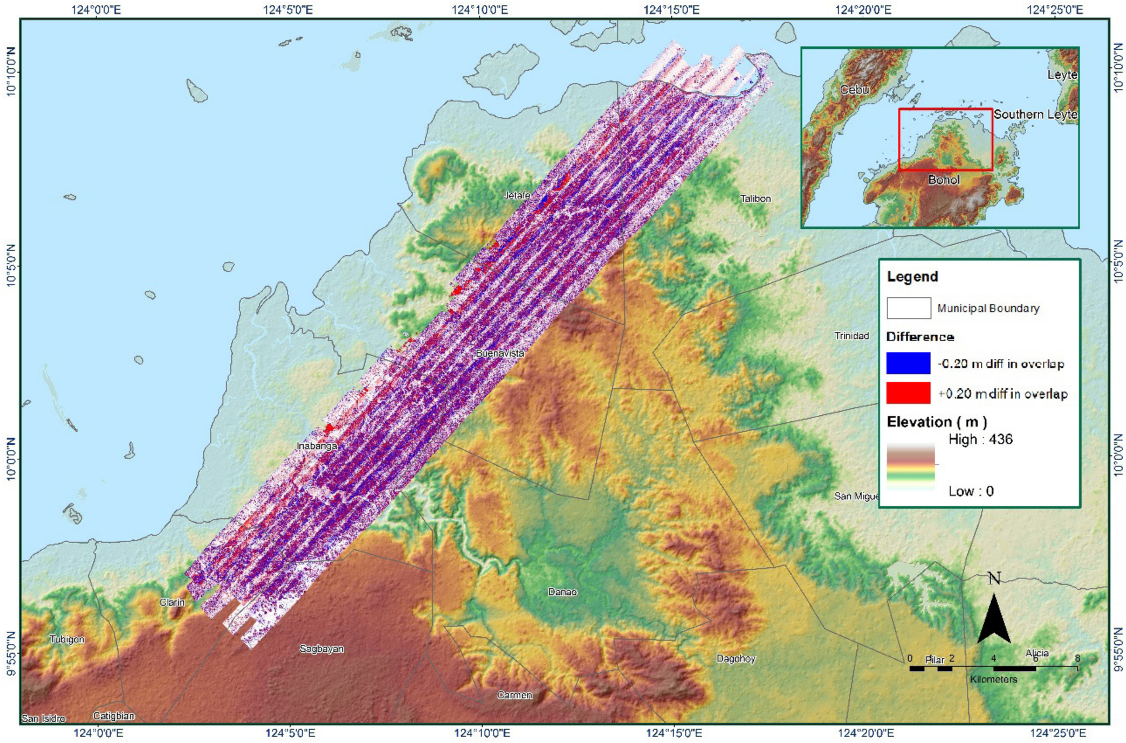


Figure 1.2.7. Elevation difference between flight line

MISSION SUMMARY REPORT

Flight Area	Bohol
Mission Name	**Blk1A_Supplement**
Inclusive Flights	803P
Range data size	20.1 GB
POS data size	171 MB
Base data size	6.2 MB
Image	N/A
Transfer date	January 9, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.6
RMSE for East Position (<4.0 cm)	1.7
RMSE for Down Position (<8.0 cm)	4.6
Boresight correction stdev (<0.001deg)	0.000450
IMU attitude correction stdev (<0.001deg)	0.002135
GPS position stdev (<0.01m)	0.0012
Minimum % overlap (>25)	59.84%
Ave point cloud density per sq.m. (>2.0)	3.515
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	216
Maximum Height	315.73
Minimum Height	54.09
Classification (# of points)	
Ground	146,153,973
Low vegetation	126,810,840
Medium vegetation	235,065,040
High vegetation	173,761,447
Building	4,356,444
Orthophoto	None
Processed by	Engr. Jennifer Saguran, Engr. Harmond Santos, Ma. Celina Rosete, Engr. Elainne Lopez

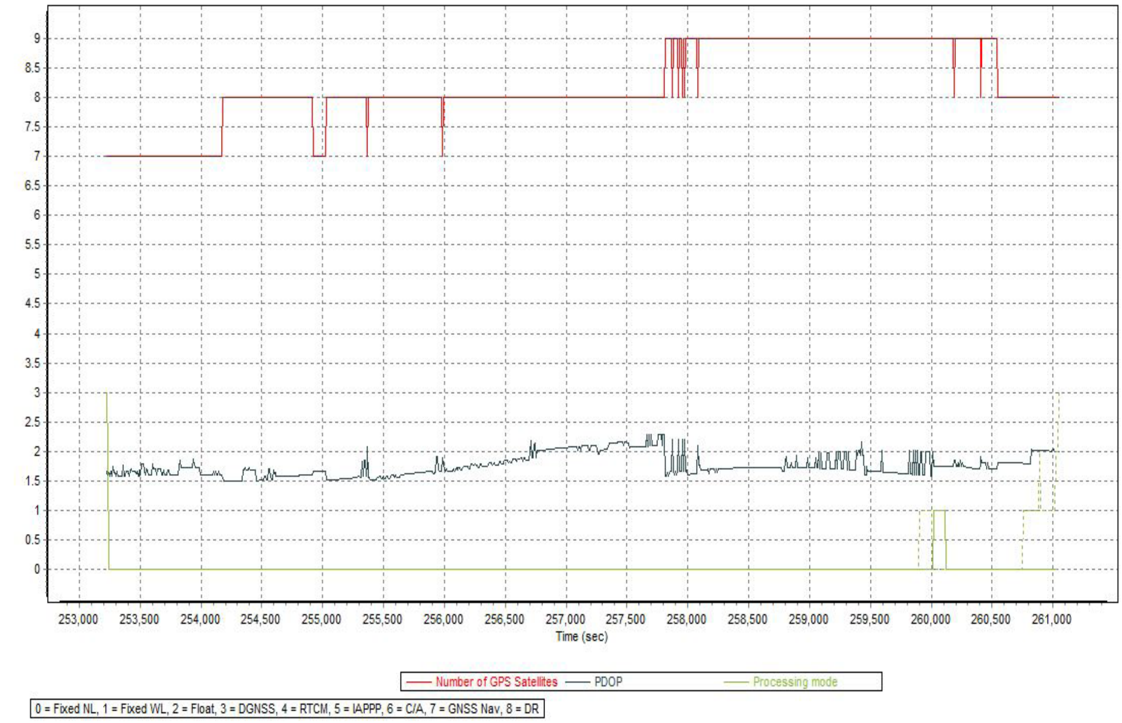


Figure 1.3.1. Solution Status

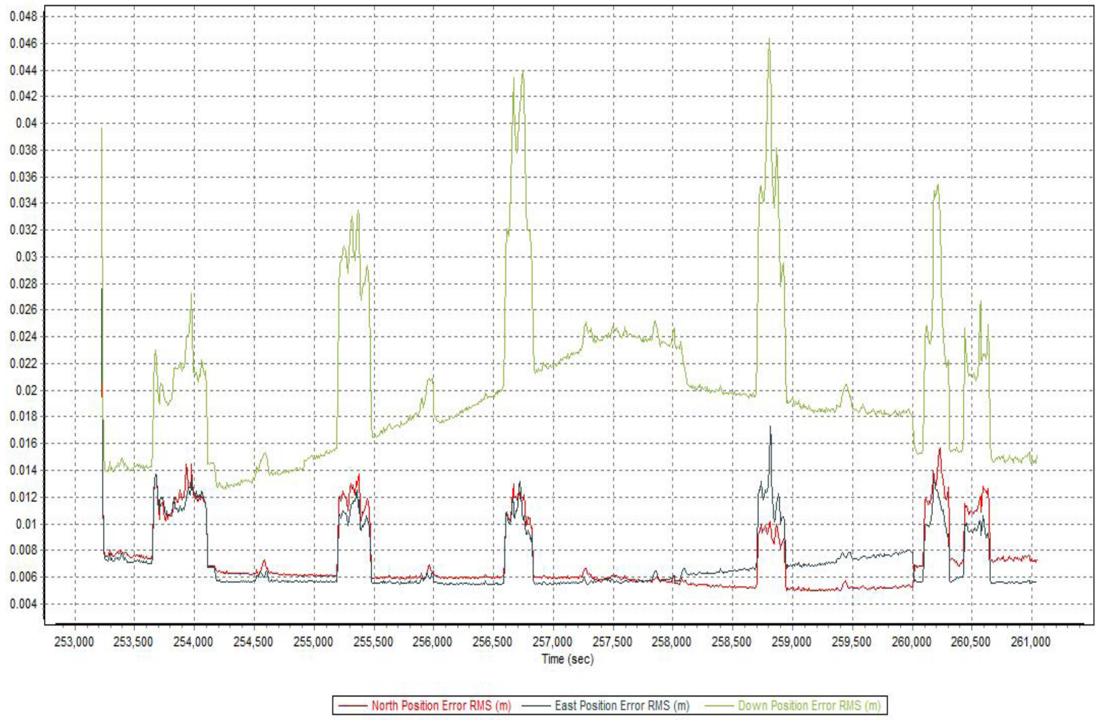


Figure 1.3.2. Smoothed Performance Metric Parameters

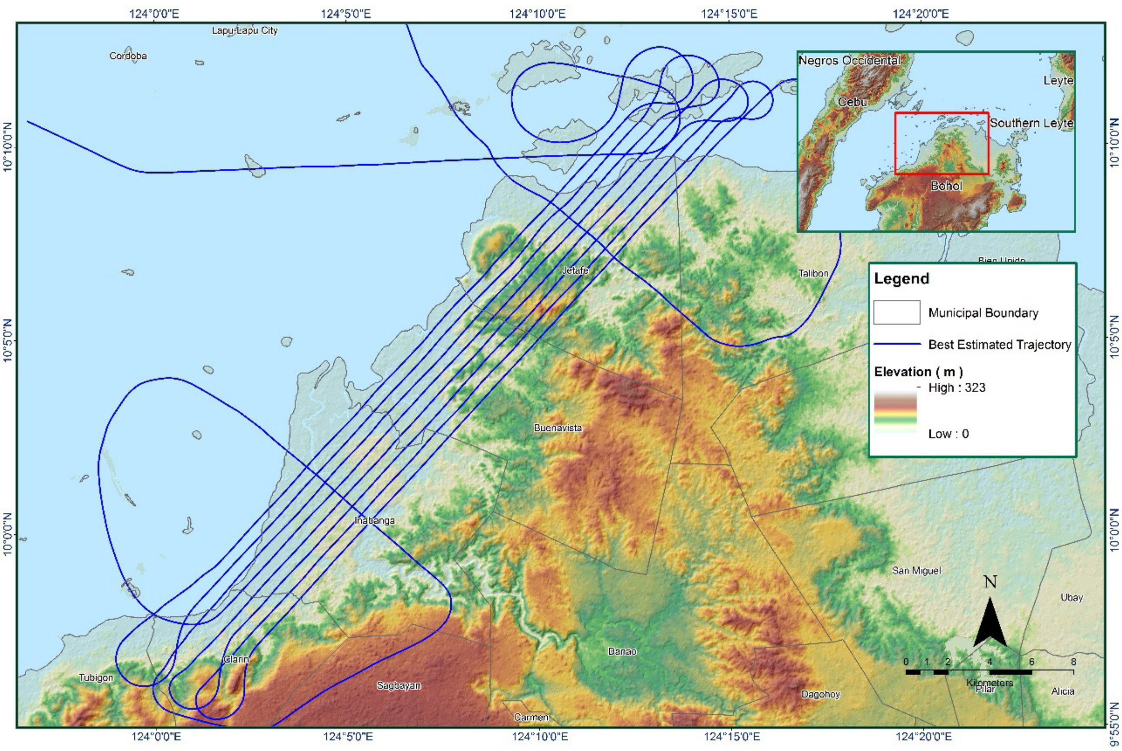


Figure 1.3.3. Best Estimated Trajectory

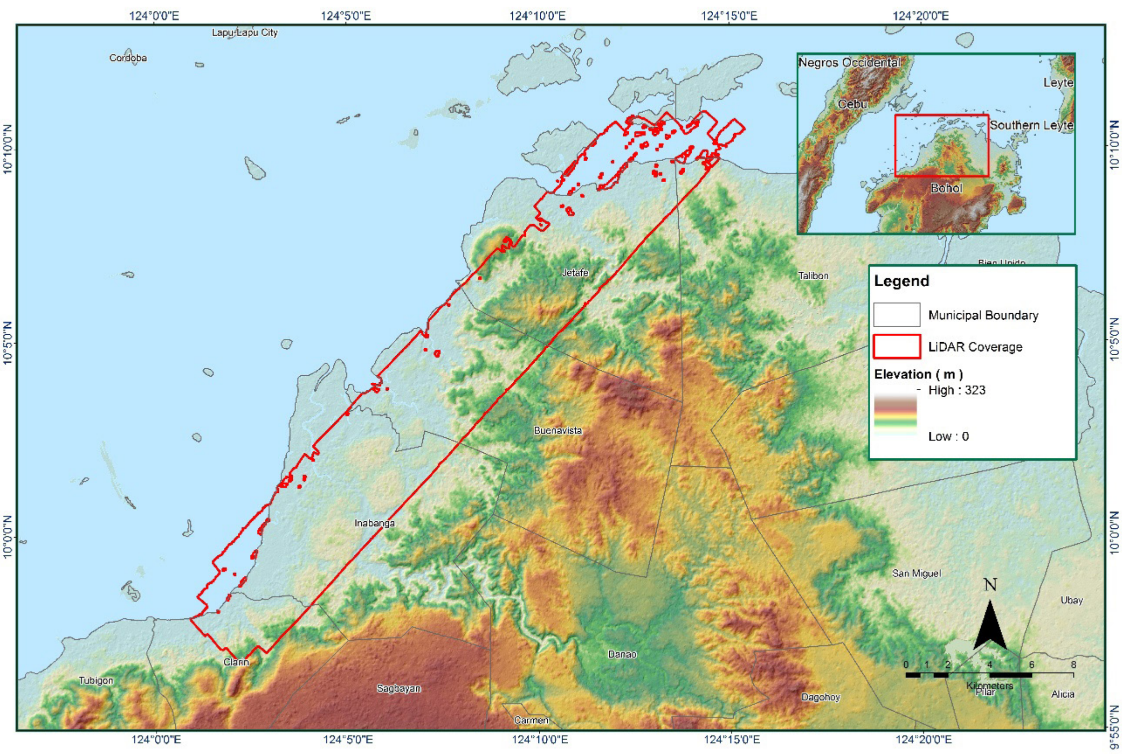


Figure 1.3.4. Coverage of LiDAR Data

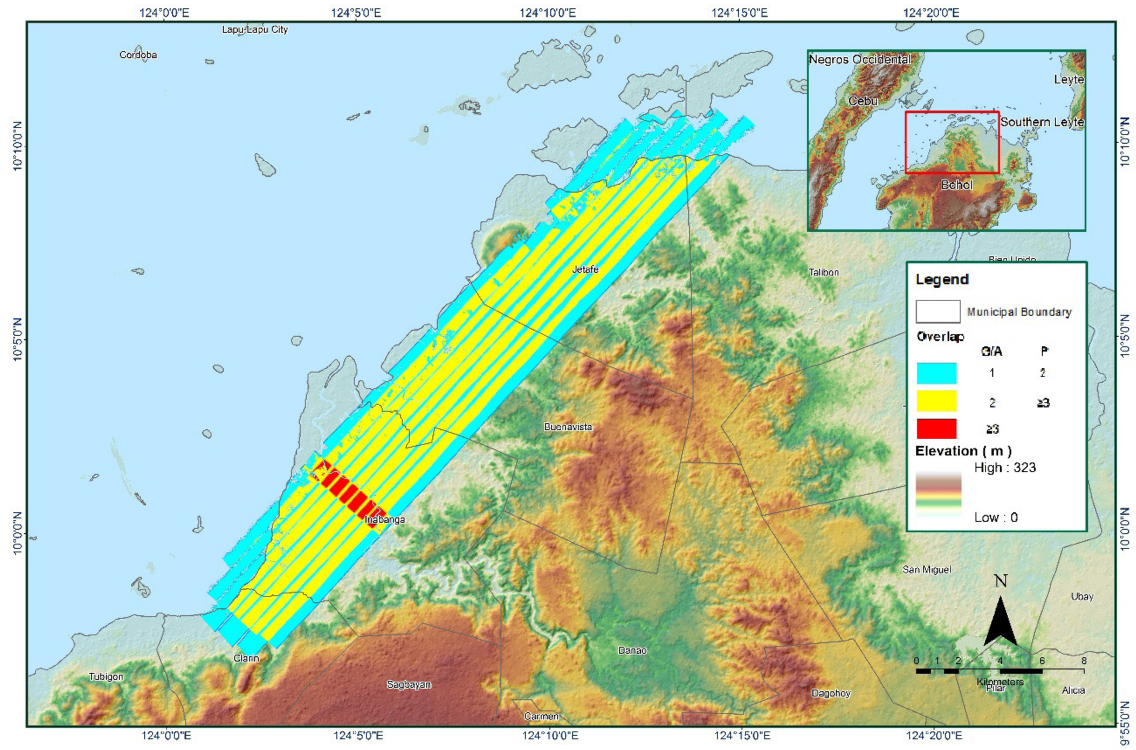


Figure 1.3.5. Image of data overlap

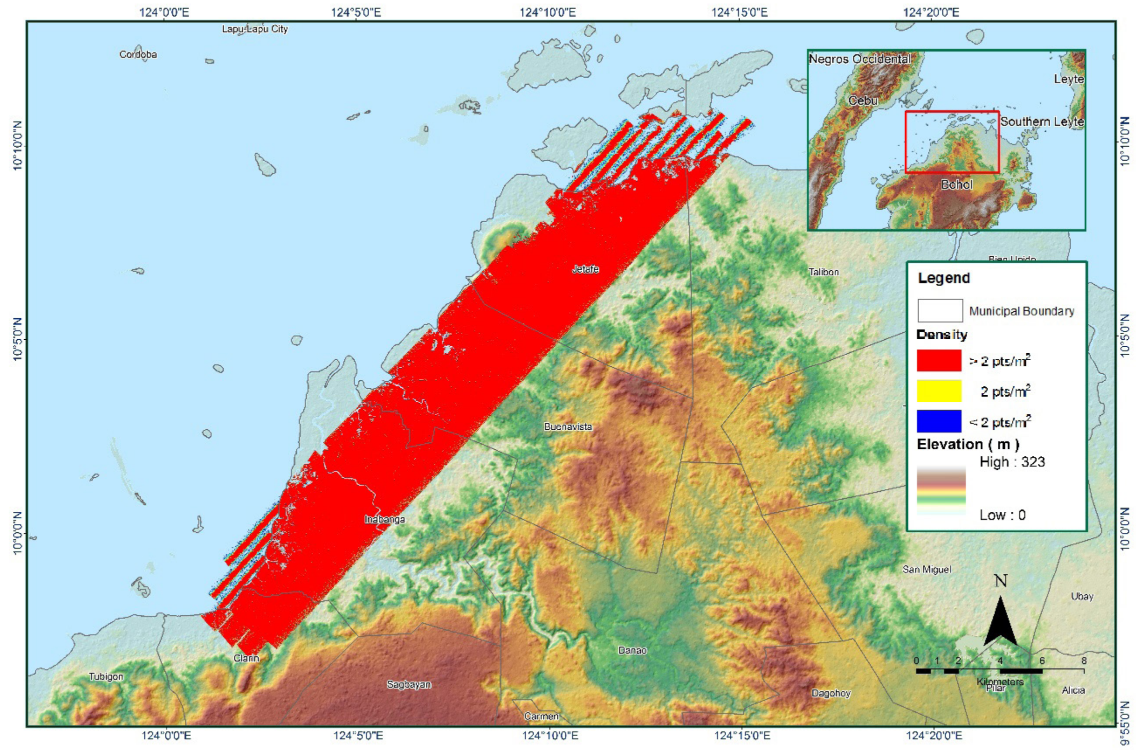


Figure 1.3.6. Density map of merged LiDAR data

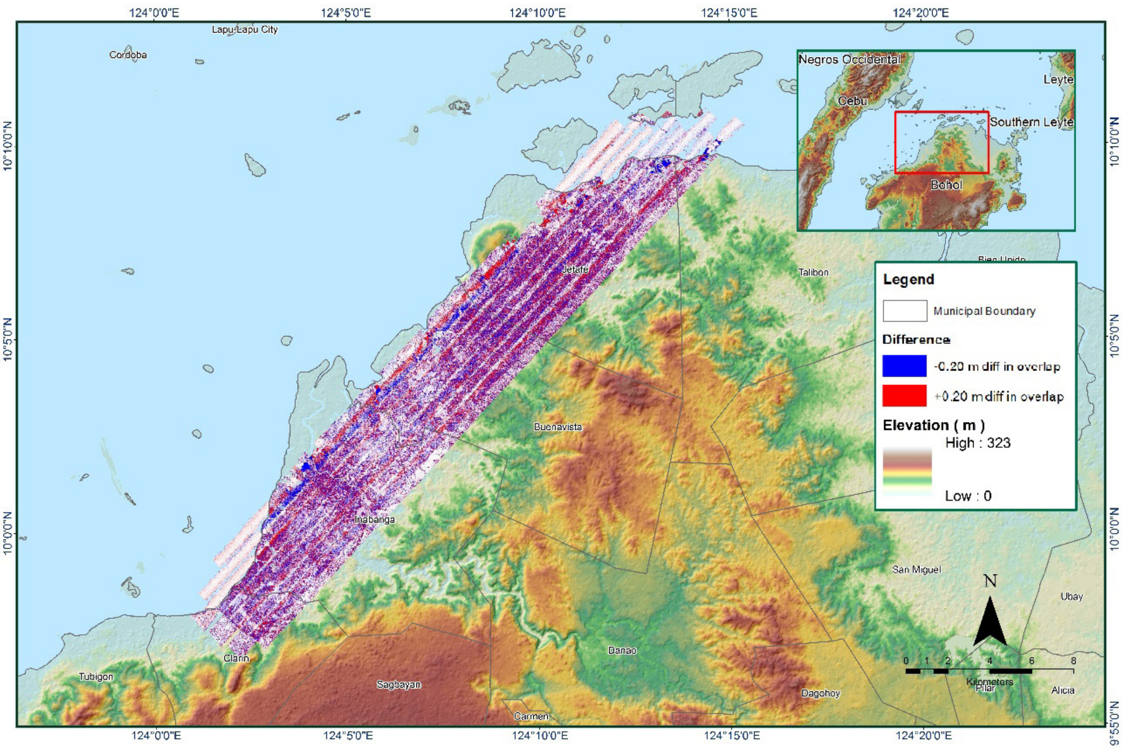


Figure 1.3.7. Elevation difference between flight line

MISSION SUMMARY REPORT

Flight Area	Bohol
Mission Name	**Blk1F**
Inclusive Flights	815P
Range data size	N/A
POS data size	N/A
Base data size	N/A
Image	N/A
Transfer date	N/A
Solution Status	
Number of Satellites (>6)	NA
PDOP (<3)	NA
Baseline Length (<30km)	NA
Processing Mode (<=1)	NA
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	NA
RMSE for East Position (<4.0 cm)	NA
RMSE for Down Position (<8.0 cm)	NA
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	19.97%
Ave point cloud density per sq.m. (>2.0)	2.115
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	173
Maximum Height	536.97
Minimum Height	55.11
Classification (# of points)	
Ground	63,382,369
Low vegetation	40,281,999
Medium vegetation	58,926,820
High vegetation	68,111,908
Building	1,940,961
Orthophoto	None
Processed by	Engr. Irish Cortez, Engr. Harmond Santos, Engr. Elainne Lopez

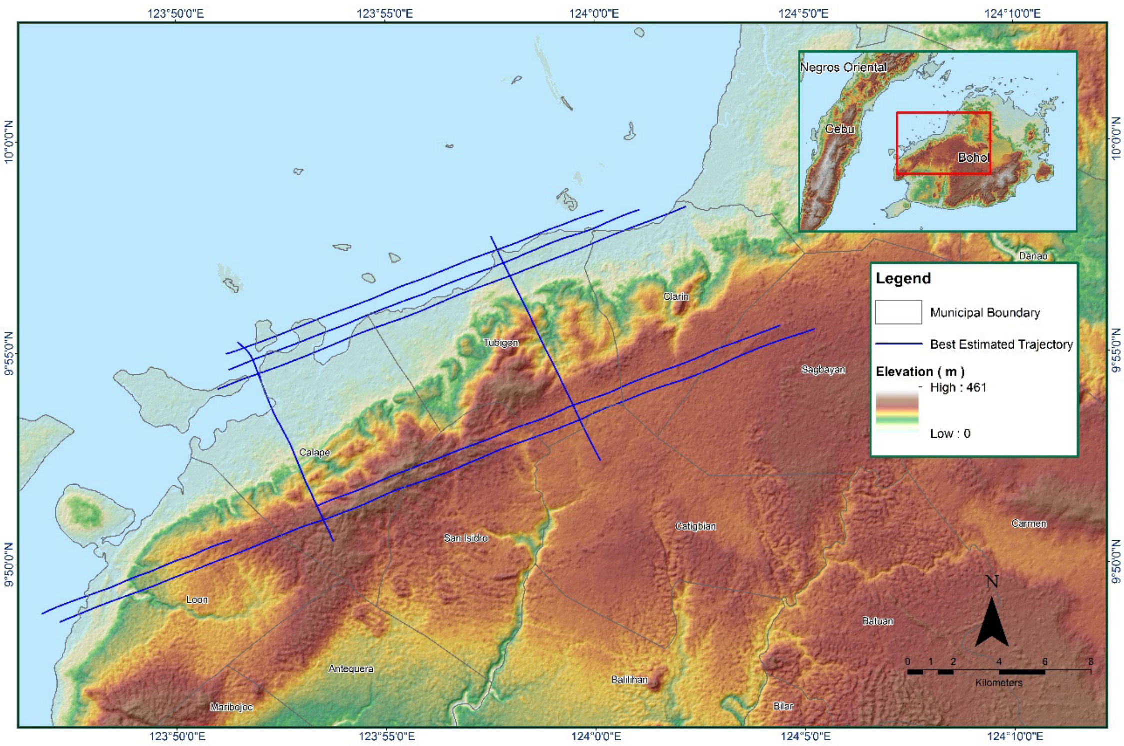


Figure 1.4.1. Best Estimated Trajectory

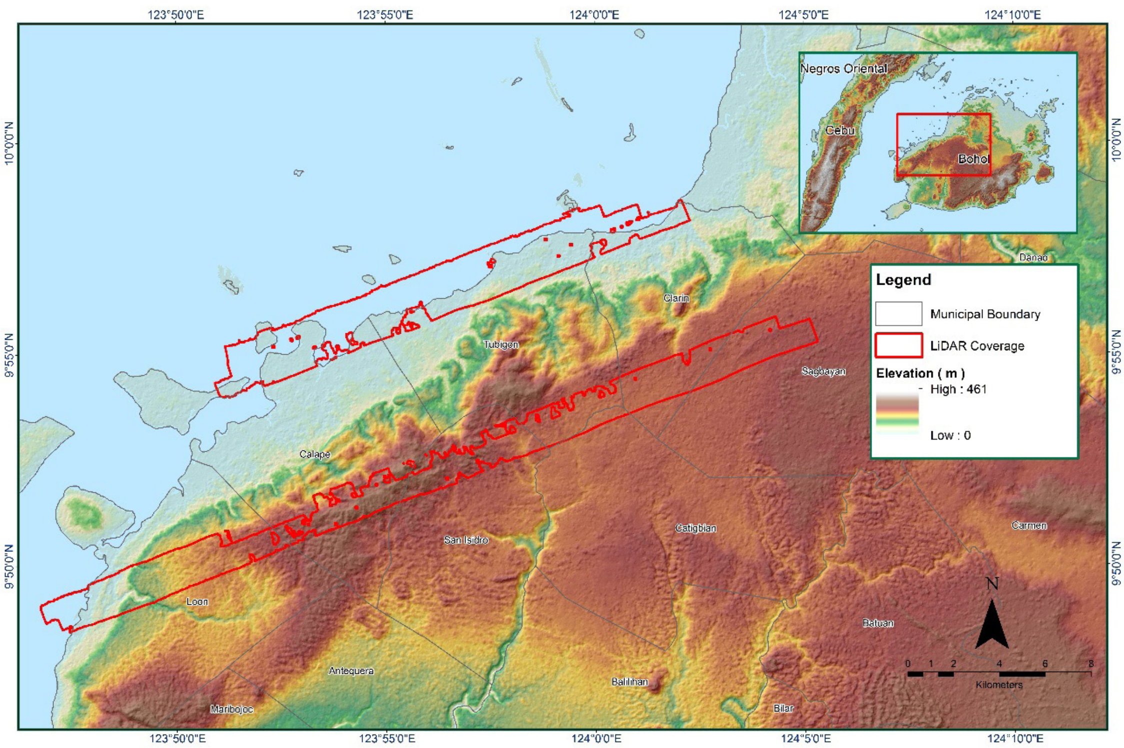


Figure 1.4.2. Coverage of LiDAR Data

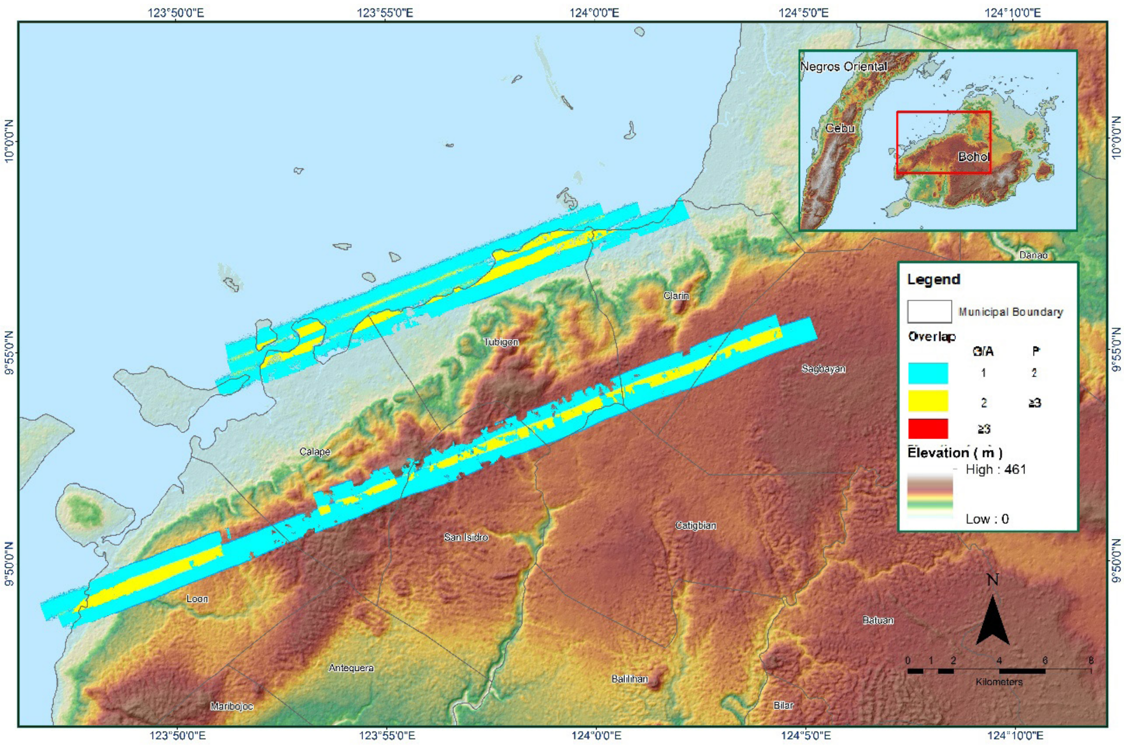


Figure 1.4.3. Image of data overlap

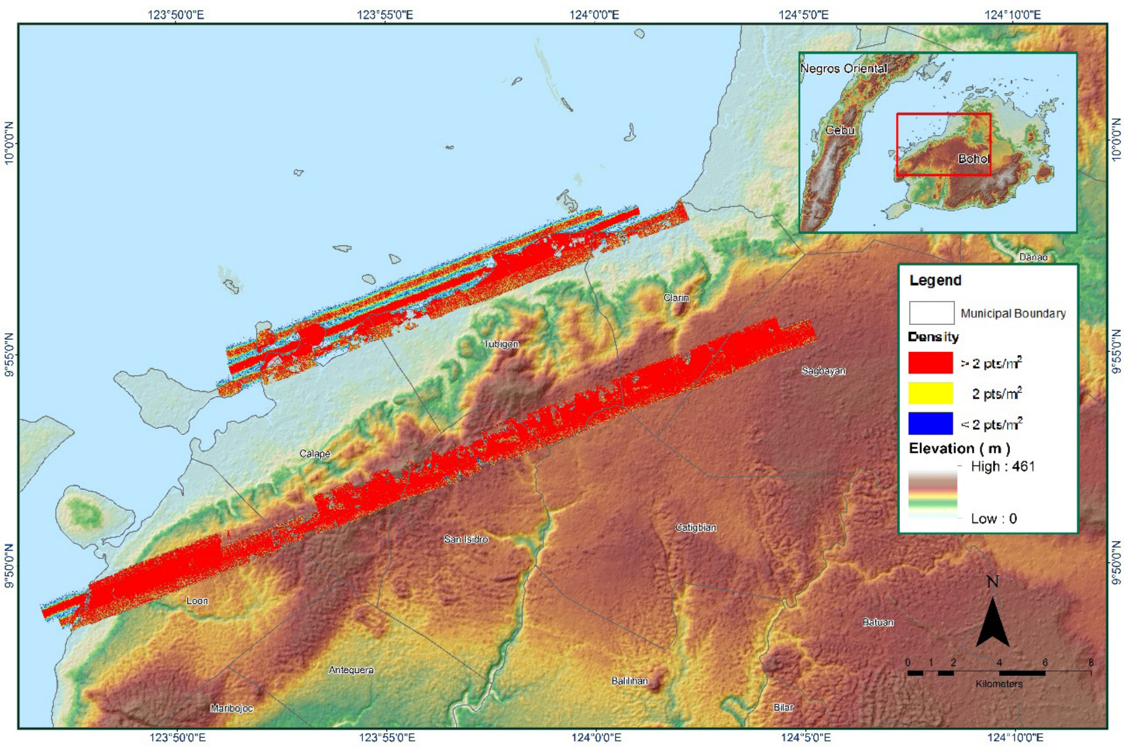


Figure 1.4.4. Density map of merged LiDAR data

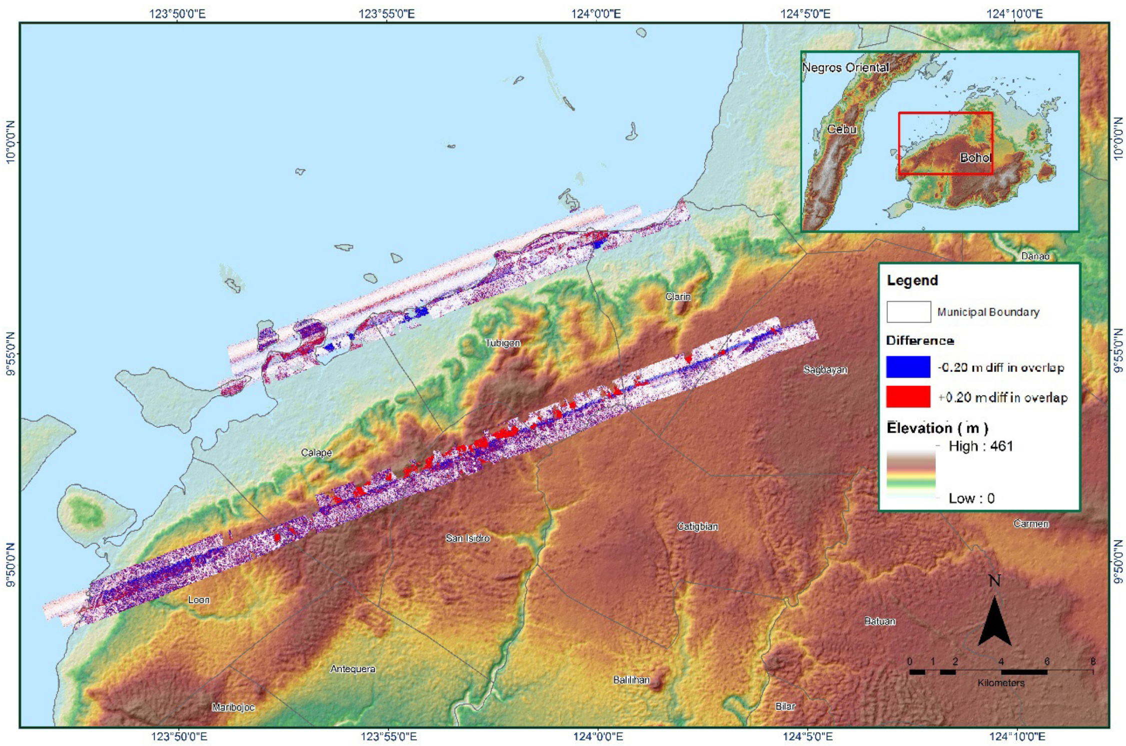


Figure 1.4.5. Elevation difference between flight line

MISSION SUMMARY REPORT

Flight Area	**Bohol**
Mission Name	**Blk1F_Supplement**
Inclusive Flights	829P
Range data size	21.5 GB
POS data size	219 MB
Base data size	6.47 MB
Image	N/A
Transfer date	December 11, 2013
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.8
RMSE for East Position (<4.0 cm)	1.8
RMSE for Down Position (<8.0 cm)	5.2
Boresight correction stdev (<0.001deg)	0.000353
IMU attitude correction stdev (<0.001deg)	0.000837
GPS position stdev (<0.01m)	0.0013
Minimum % overlap (>25)	53.91%
Ave point cloud density per sq.m. (>2.0)	3.17
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	244
Maximum Height	542.23
Minimum Height	63.63
Classification (# of points)	
Ground	154,524,547
Low vegetation	106,603,511
Medium vegetation	201,449,277
High vegetation	240,483,816
Building	5,700,845
Orthophoto	None
Processed by	Engr. Irish Cortez, Ma. Celina Rosete, Ailyn Biñas, Engr. Gladys Mae Apat

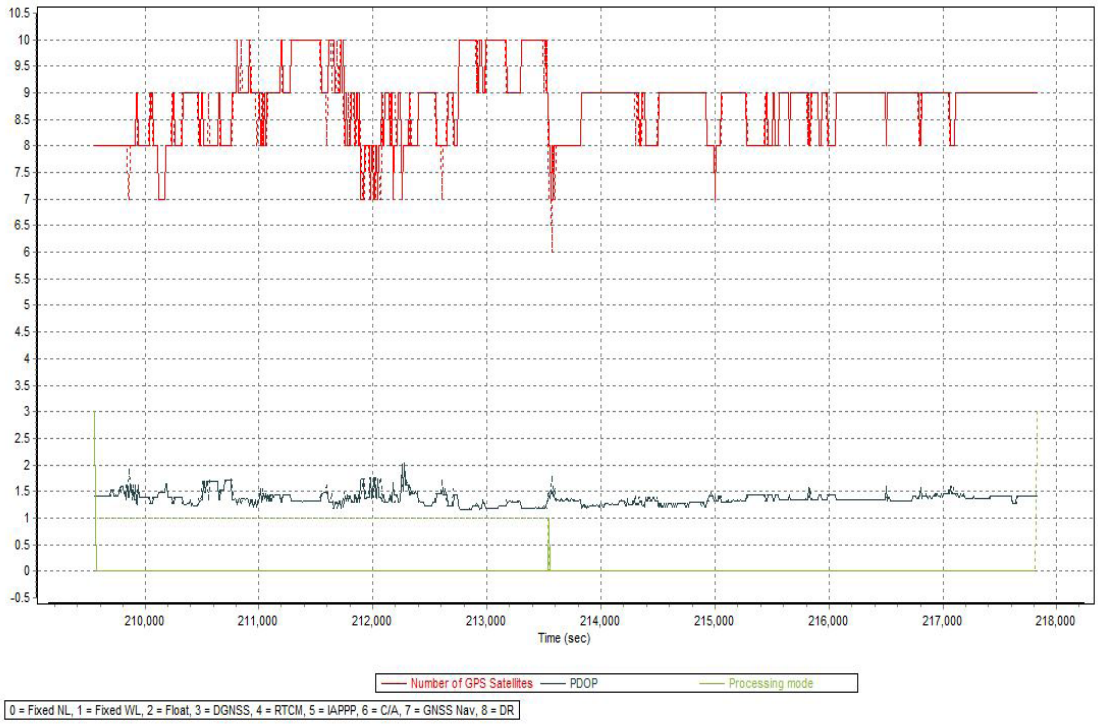


Figure 1.5.1. Solution Status

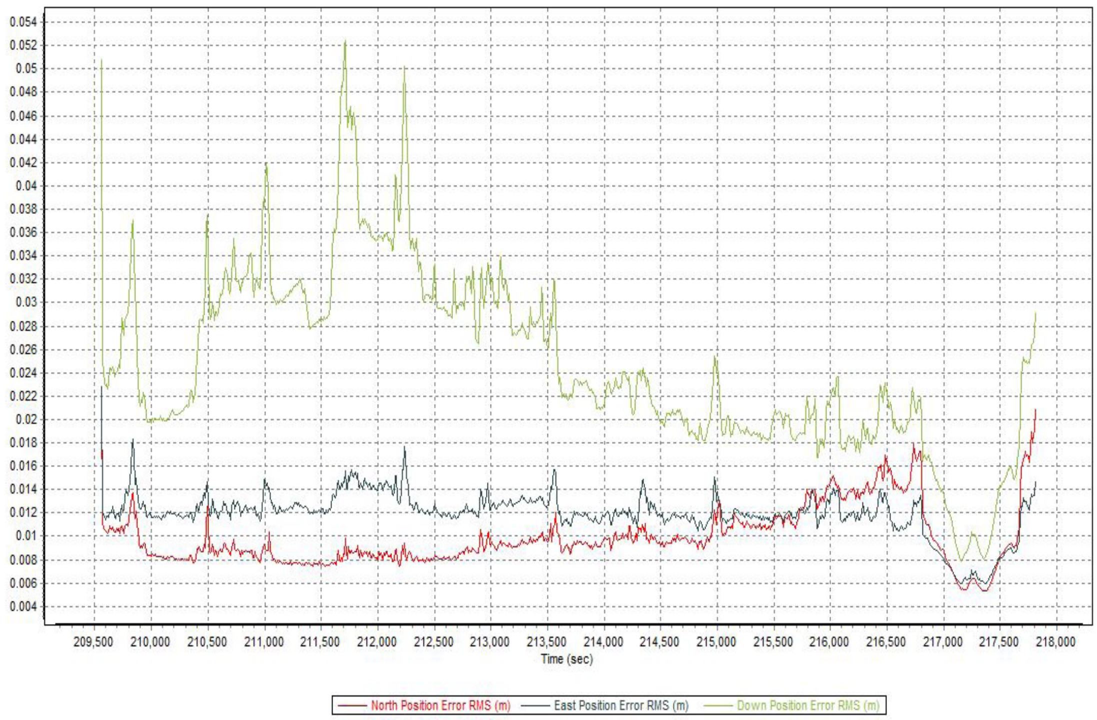


Figure 1.5.2. Smoothed Performance Metric Parameters

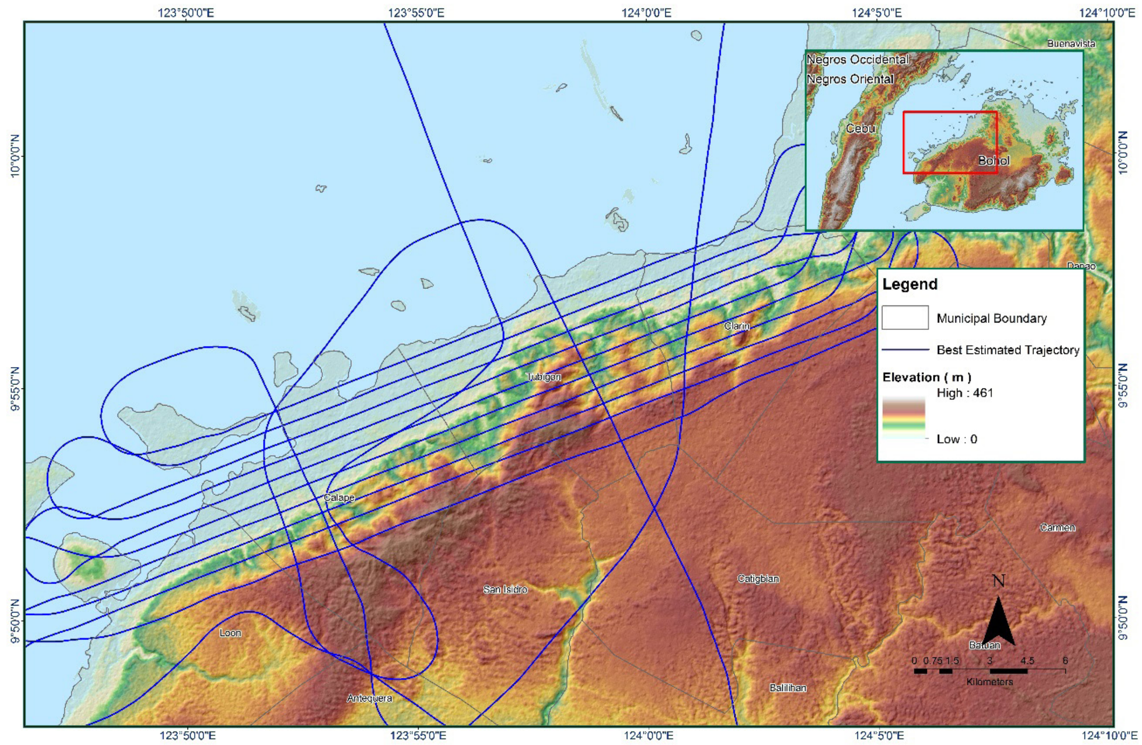


Figure 1.5.3. Best Estimated Trajectory

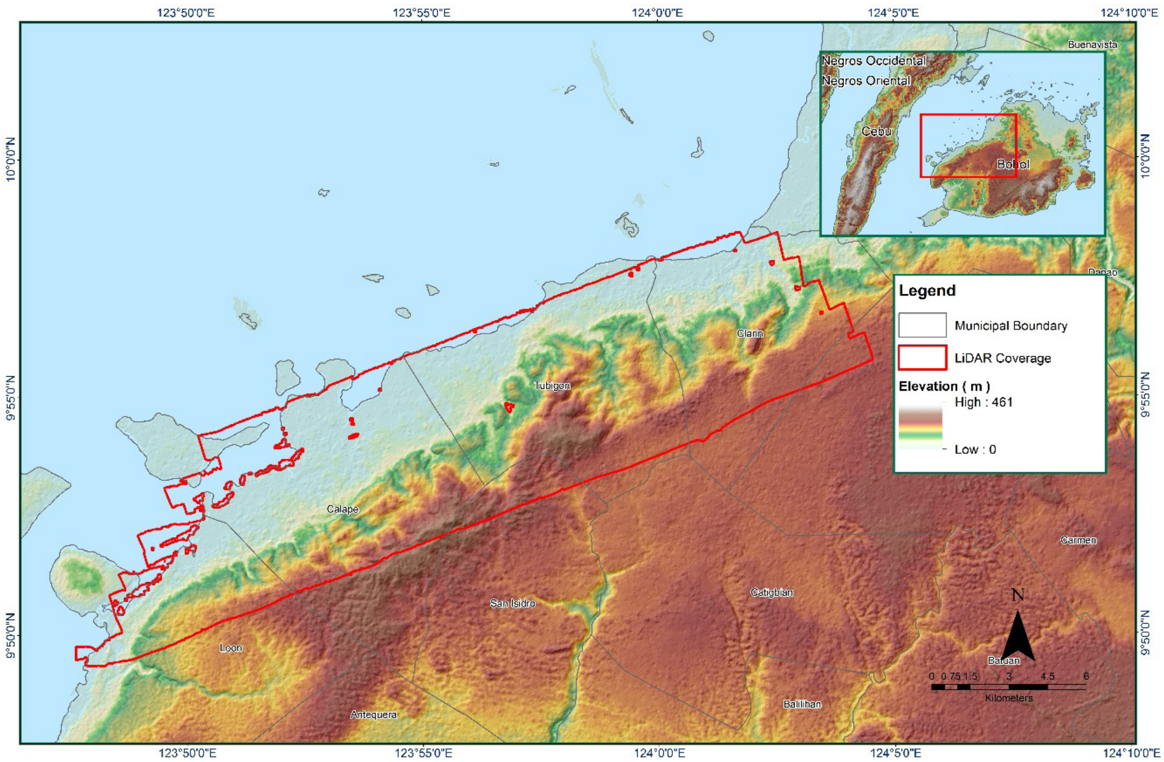


Figure 1.5.4. Coverage of LiDAR Data

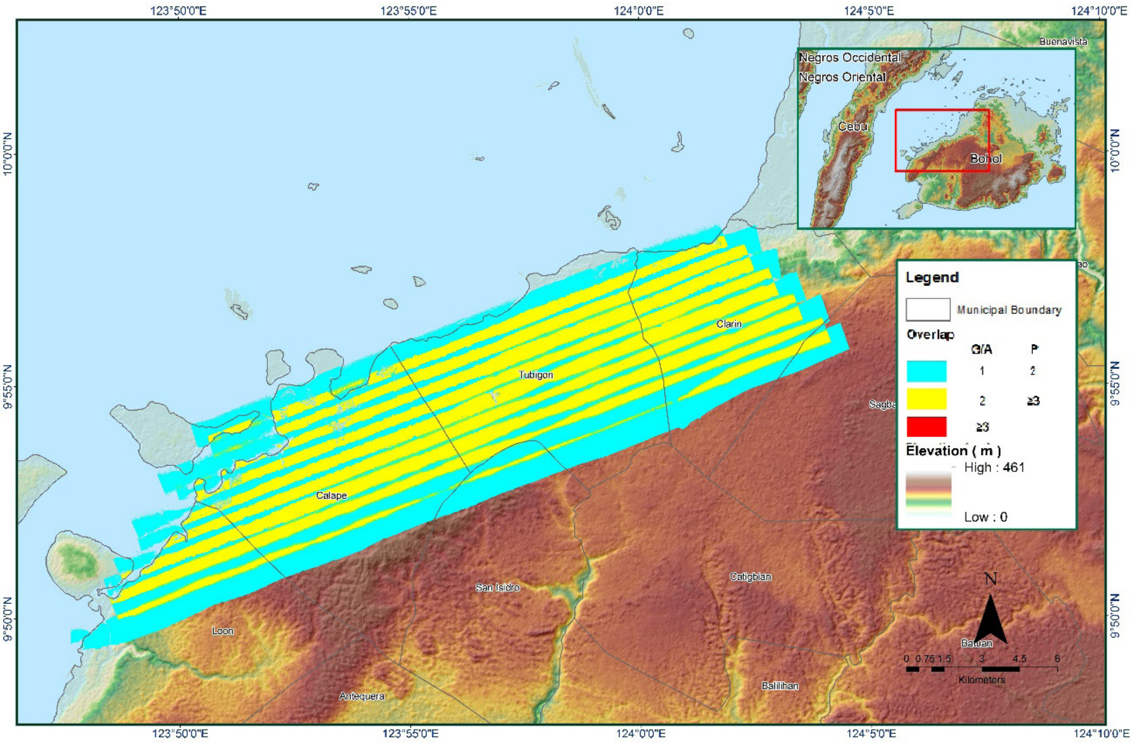


Figure 1.5.5. Image of data overlap

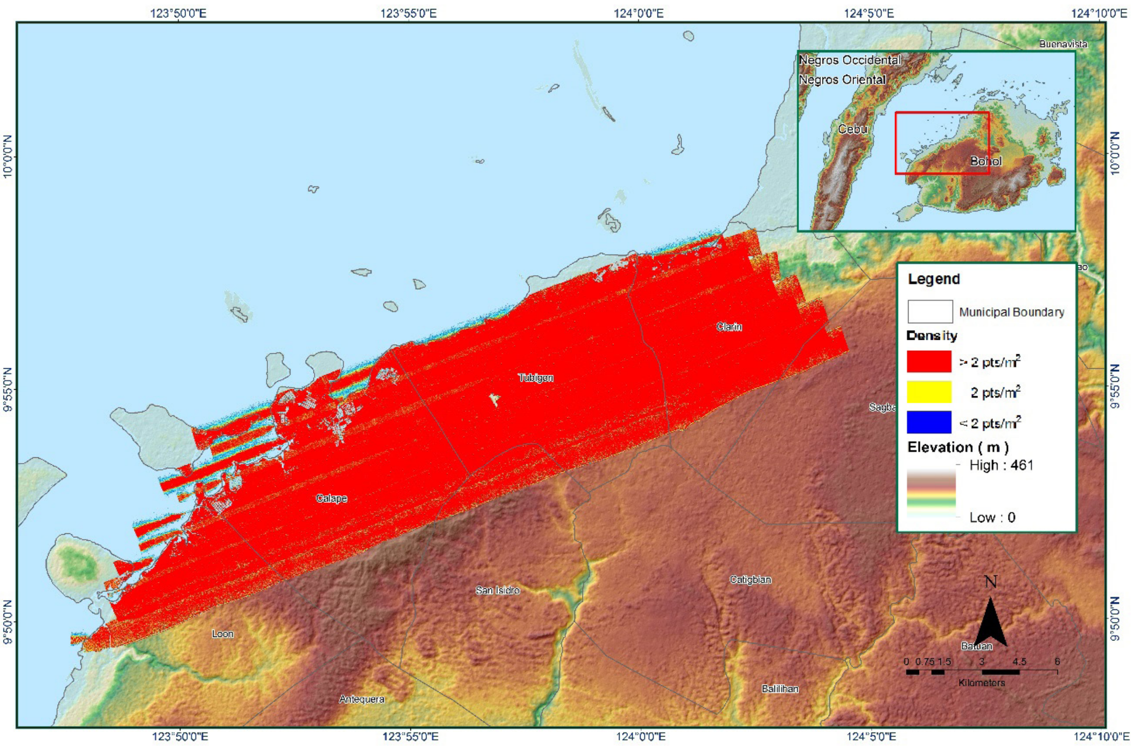


Figure 1.5.6. Density map of merged LiDAR data

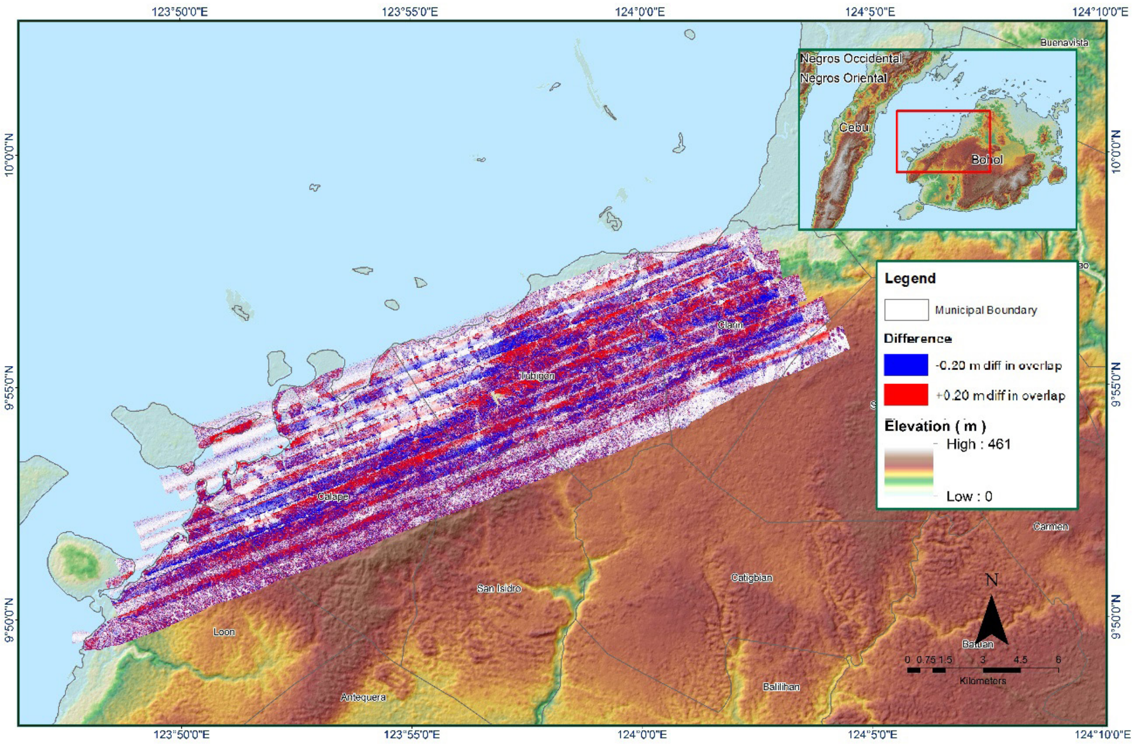


Figure 1.5.7. Elevation difference between flight line

Annex 9. Inabanga Model Basin Parameters

Table A-9.1. Inabanga Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)		Initial Abstraction (mm)	Curve Number	Impervious (%)		Initial Abstraction (mm)	Curve Number
W1000	6.2115	84.501	0	0.34807	0.35701	Discharge	0.068621	0.06	Ratio to Peak	0.13393
W1010	17.332	73.983	0	0.16423	0.14707	Discharge	0.008138	0.06	Ratio to Peak	0.134
W1020	12.848	78.925	0	0.55431	0.55558	Discharge	0.12143	0.081	Ratio to Peak	0.13067
W1030	12.027	80.293	0	0.45227	0.49247	Discharge	0.09607	0.081	Ratio to Peak	0.19695
W1040	11.784	81.171	0	0.62201	0.6074	Discharge	0.09318	0.081	Ratio to Peak	0.13067
W1050	13.488	79.617	0	1.0048	0.57963	Discharge	0.1807	0.0882	Ratio to Peak	0.13067
W1060	10.999	80.601	0	1.5529	1.5544	Discharge	0.34241	0.089541	Ratio to Peak	0.19208
W540	6.9947	81.224	0	1.5794	1.5729	Discharge	0.39682	0.06	Ratio to Peak	0.19208
W550	11.117	81.62	0	1.7163	1.3379	Discharge	0.30619	0.06	Ratio to Peak	0.19692
W560	14.707	77.999	0	1.1316	1.6892	Discharge	0.31407	0.06	Ratio to Peak	0.13399
W570	7.593	87.05	0	1.498	0.95464	Discharge	0.099178	0.06	Ratio to Peak	0.19695
W580	11.165	85.476	0	0.0367277	0.036728	Discharge	0.000217	0.06	Ratio to Peak	0.134
W590	7.4772	87.22	0	0.91303	1.3357	Discharge	0.13803	0.06	Ratio to Peak	0.19208
W600	19.994	79.642	0	2.5215	2.5215	Discharge	0.36826	0.0882	Ratio to Peak	0.2009
W610	7.1641	99	0	0.30194	0.30194	Discharge	0.026672	0.06	Ratio to Peak	0.294
W620	12.511	99	0	0.76782	0.35532	Discharge	0.087183	0.06	Ratio to Peak	0.19697
W630	11.164	85.477	0	0.38398	1.27	Discharge	0.059838	0.06	Ratio to Peak	0.19693

W640	7.4801	58.147	0	1.4778	0.965	Discharge	0.16011	0.06	Ratio to Peak	0.19693
W650	4.8875	99	0	0.41973	0.41973	Discharge	0.049631	0.06	Ratio to Peak	0.19184
W660	15.825	83.083	0	0.39799	0.88186	Discharge	0.086205	0.06	Ratio to Peak	0.19208
W670	4.7424	99	0	0.21152	0.21152	Discharge	0.019432	0.06	Ratio to Peak	0.19696
W680	8.0793	79.124	0	0.27618	0.27618	Discharge	0.035876	0.06	Ratio to Peak	0.19697
W690	7.4799	85.476	0	0.50873	1.6826	Discharge	0.137	0.06	Ratio to Peak	0.19208
W700	15.726	74.921	0	0.70293	1.0358	Discharge	0.067397	0.06	Ratio to Peak	0.1764
W710	5.2613	84.823	0	0.64133	0.62851	Discharge	0.11952	0.06	Ratio to Peak	0.1967
W720	10.968	85.669	0	0.25626	0.38438	Discharge	0.006336	0.06	Ratio to Peak	0.19698
W730	7.8862	84.887	0	0.88682	0.89105	Discharge	0.12942	0.06	Ratio to Peak	0.19208
W740	7.4794	85.476	0	1.4395	0.95964	Discharge	0.23528	0.06	Ratio to Peak	0.19695
W750	15.693	74.911	0	1.3413	0.99867	Discharge	0.14745	0.06	Ratio to Peak	0.13399
W760	15.729	76.44	0	1.1371	0.77352	Discharge	0.058026	0.06	Ratio to Peak	0.13399
W770	8.2556	86.079	0	0.8724	0.87498	Discharge	0.18838	0.06	Ratio to Peak	0.13067
W780	15.733	74.911	0	0.84531	0.77665	Discharge	0.11548	0.06	Ratio to Peak	0.19697
W790	11.406	81.718	0	1.0871	1.2291	Discharge	0.19933	0.06	Ratio to Peak	0.19696
W800	7.7768	85.044	0	1.4583	2.1299	Discharge	0.21679	0.06	Ratio to Peak	0.19696
W810	7.4805	85.476	0	4.6548	3.1041	Discharge	0.002517	0.06	Ratio to Peak	0.2
W820	7.4803	85.476	0	1.5438	1.5491	Discharge	0.11366	0.06	Ratio to Peak	0.19696
W830	7.4815	85.474	0	2.0245	2.0311	Discharge	0.06661	0.06	Ratio to Peak	0.20097
W840	8.7352	83.681	0	1.8443	2.7665	Discharge	0.14349	0.06	Ratio to Peak	0.13399

W850	8.4076	85.857	0	1.6376	1.0917	Discharge	0.34198	0.06	Ratio to Peak	0.19694
W860	7.4824	90.751	0	1.6182	1.6512	Discharge	0.078787	0.06	Ratio to Peak	0.13399
W870	7.4805	85.476	0	0.97262	0.64838	Discharge	0.002304	0.06	Ratio to Peak	0.134
W880	7.4803	85.476	0	0.70352	0.47479	Discharge	0.094055	0.06	Ratio to Peak	0.19697
W890	11.248	85.395	0	0.84424	0.84424	Discharge	0.27415	0.06	Ratio to Peak	0.19697
W900	7.4789	85.476	0	3.4565	3.4565	Discharge	0.4332	0.06	Ratio to Peak	0.20099
W910	7.8687	86.588	0	1.1593	0.77284	Discharge	0.18844	0.06	Ratio to Peak	0.19696
W920	7.5188	87.121	0	1.4083	2.1401	Discharge	0.26621	0.06	Ratio to Peak	0.294
W930	8.6655	83.74	0	1.5686	1.0475	Discharge	0.17842	0.06	Ratio to Peak	0.19694
W940	15.176	55.595	0	0.66181	0.45021	Discharge	0.10814	0.06	Ratio to Peak	0.19697
W950	7.2946	99	0	0.2198	0.22088	Discharge	0.008205	0.06	Ratio to Peak	0.19672
W960	7.8435	86.678	0	0.99548	0.44244	Discharge	0.19919	0.06	Ratio to Peak	0.19695
W970	9.6526	88.568	0	0.82755	0.811	Discharge	0.10235	0.0882	Ratio to Peak	0.19697
W980	9.436	83.714	0	1.0569	0.69049	Discharge	0.21169	0.0895461	Ratio to Peak	0.19696
W990	7.4787	86.259	0	0.8027	0.94194	Discharge	0.10393	0.0895486	Ratio to Peak	0.19694

Annex 10. Inabanga Model Reach Parameters

Table A-10.1. Inabanga 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	2002	0.0001	0.024985	Trapezoid	47.322	1
R110	Automatic Fixed Interval	2738.8	0.00138	0.024616	Trapezoid	47.322	1
R120	Automatic Fixed Interval	1398.9	0.0001	0.037666	Trapezoid	47.322	1
R130	Automatic Fixed Interval	11669	0.00487	0.011111	Trapezoid	47.322	1
R140	Automatic Fixed Interval	579.83	0.0001	0.025	Trapezoid	47.322	1
R150	Automatic Fixed Interval	930.95	0.0001	0.016743	Trapezoid	47.322	1
R180	Automatic Fixed Interval	736.27	0.0001	0.02459	Trapezoid	47.322	1
R200	Automatic Fixed Interval	3329.7	0.01862	0.01674	Trapezoid	47.322	1
R210	Automatic Fixed Interval	924.97	0.0001	0.025	Trapezoid	47.322	1
R260	Automatic Fixed Interval	3123.1	0.0001	0.019167	Trapezoid	47.322	1
R270	Automatic Fixed Interval	9383	0.00418	0.0245	Trapezoid	47.322	1
R280	Automatic Fixed Interval	2054.7	0.0001	0.021933	Trapezoid	47.322	1
R30	Automatic Fixed Interval	42.426	0.0001	0.024365	Trapezoid	47.322	1
R300	Automatic Fixed Interval	772.25	0.0001	0.0375	Trapezoid	47.322	1
R310	Automatic Fixed Interval	1504.9	0.0001	0.024851	Trapezoid	47.322	1
R320	Automatic Fixed Interval	4217.5	3.4E-05	0.016689	Trapezoid	47.322	1
R350	Automatic Fixed Interval	2109.7	0.0001	0.016733	Trapezoid	47.322	1

R390	Automatic Fixed Interval	11889	0.00257	0.02205	Trapezoid	47.322	1
R420	Automatic Fixed Interval	282.84	0.0001	0.0225	Trapezoid	47.322	1
R430	Automatic Fixed Interval	4941.3	0.00502	0.016718	Trapezoid	47.322	1
R450	Automatic Fixed Interval	5905	0.00604	0.025	Trapezoid	47.322	1
R460	Automatic Fixed Interval	5826.4	0.01462	0.037686	Trapezoid	47.322	1
R480	Automatic Fixed Interval	852.13	0.02751	0.02401	Trapezoid	47.322	1
R50	Automatic Fixed Interval	1100	0.00382	0.011111	Trapezoid	47.322	1
R510	Automatic Fixed Interval	3597.8	0.00921	0.016095	Trapezoid	47.322	1
R70	Automatic Fixed Interval	4003	0.00545	0.03675	Trapezoid	47.322	1

Annex 11. Inabanga Field Validation Points

Table A-11.1. Inabanga Field Validation Points

Validation Point	Validation Coordinates		Flood Depth based on Model	Actual Flood Depth	Error (5 year)	Event/Date	Return Period of Event
	Latitude	Longitude					
1	9.981377	124.117873	15.81	5	116.856	Seniang	100-Year
2	9.982143	124.118084	5.98	0	35.7604	Seniang	100-Year
3	9.982734	124.11732	5	0	25	Seniang	100-Year
4	9.98276	124.117265	7.23	0	52.2729	Seniang	100-Year
5	9.982738	124.114339	6.73	0	45.2929	Seniang	100-Year
6	10.04397	124.069416	0.06	0.5	0.1936	Seniang	100-Year
7	10.04397	124.069416	0.06	1.1	1.0816	Seniang	100-Year
8	10.05203	124.071709	0.03	0.6	0.3249	Seniang	100-Year
9	10.052046	124.072043	0.03	0.8	0.5929	Seniang	100-Year
10	10.051792	124.072147	0.14	2	3.4596	Ruping	100-Year
11	10.051792	124.072147	0.14	0.9	0.5776	Nitang	100-Year
12	10.030331	124.068058	1.36	3	2.6896	Seniang	100-Year
13	10.047519	124.059204	0.03	0.7	0.4489	Seniang	100-Year
14	10.047519	124.059204	0.03	0.4	0.1369	Ruby	100-Year
15	10.047417	124.059398	0.03	0.2	0.0289	Seniang	100-Year
16	10.047417	124.059398	0.03	0.4	0.1369	Seniang	100-Year
17	10.042436	124.065076	0.03	1.1	1.1449	Seniang	100-Year
18	10.042436	124.065076	0.03	0.6	0.3249	Ruping	100-Year
19	10.022588	124.076622	1.73	1.8	0.0049	Seniang	100-Year
20	10.022588	124.076622	1.73	0.6	1.2769	Ruping	100-Year
21	10.022535	124.076526	4.42	1.8	6.8644	Ruping	100-Year
22	10.023496	124.076398	0.41	1.8	1.9321	Ruping	100-Year
23	10.023496	124.076398	0.41	5.5	25.9081	Seniang	100-Year
24	10.030846	124.065487	0.03	0.15	0.0144	Seniang	100-Year

Annex 12. Educational Institutions affected by flooding in Inabanga Floodplain

Table A-12.1. Educational Institutions in Inabanga, Bohol affected by flooding in Inabanga Flood Plain

BOHOL				
INABANGA				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Cagayan Primary School	Cagayan			
Cagayan Elementary School	Cawayan			
Cogon Elementary School	Cogon			
Brgy Lawis Day Care Center	Lawis			Low
Lawis Day Care Center	Lawis			
Lawis Elementary School	Lawis			
Lawis Elementary School Ext	Lawis			
Lonoy Roma Primary School	Lonoy Roma			
Inabanga High School	Nabuad			
Nabuad Elementary School	Nabuad			
Ondol Day Care Center	Ondol			
Ondol Elementary School	Ondol			
St Paul Academy	Poblacion			
Brgy Saa Day Care Center	Saa		Low	Medium
Sto Nino Primary School	Santo Niño			
Tambook Day Care Center	Tambook			Medium
Tungod Old Day Care Center	Tungod		Low	Low
Tungod Primary School	Tungod		Medium	Medium

Annex 13. Health Institutions affected by flooding in Inabanga Floodplain

Table A-13.1. Health Institutions in Inabanga, Bohol affected by flooding in Inabanga Floodplain

BOHOL				
INABANGA				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
F. Dagohoy Municipal Hospital	Cagayan		Low	Low
Cawayan Health Center	Cawayan			
Cogon Health Center	Cogon			
Cogon Nutrition Center	Cogon			
Nabuad Health Center	Nabuad			
Sto Nino Brgy Clinic	Santo Niño			