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

LiDAR Surveys and Flood Mapping of Abongan River

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

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LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND ABONGAN RIVER

Prof. Edwin R. Abucay, and Enrico C. Paringit, Dr. Eng.

1.1 Background of the Phil-LIDAR 1 Program

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

The program was also 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 titled Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods (Paringit et al., 2017).

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Banos (UPLB). UPLB is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 45 river basins in the MIMAROPA Region. The university is located at Los Banos, Laguna.

1.2 Overview of the Abongan River Basin

Abongan River Basin covers Barangays Alimanguan and Santo Niño in Municipality of San Vicente, and Barangays Abongan, Alacalian, Bato, Calawag, Libertad and Paglaum in Municipality of Taytay. The DENR River Basin Control Office identified the basin to have a drainage area of 69 km2 and an estimated 110 million cubic meter (MCM) annual run-off (RBCO, 2015).

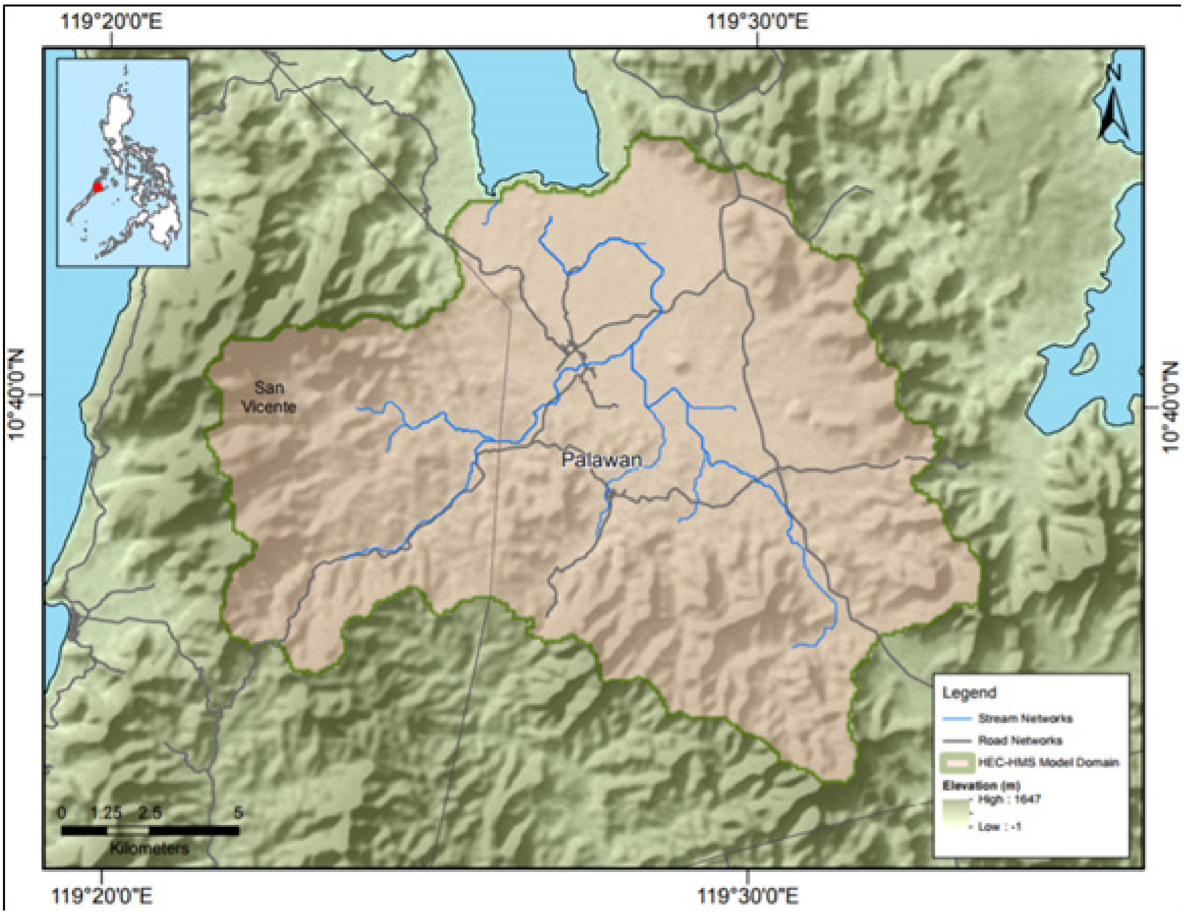

Figure 1. Map of Abongan River Basin (in brown).

Its main stem, Abongan River, is part of the river systems in MIMAROPA Region. According to the 2015 national census of NSO, a total of 4,011 persons are residing within the immediate vicinity of the river in Brgy. Abongan, in the Municipality of Taytay (NSO, 2015). The major sources of livelihood in the area is fishing but some people of the community also depends on farming. Agriculture is the second source of income and livelihood. Major crops include rice, corn, coconuts, bannas, cashew and other fruits. (Source: http://mimaropa.denr.gov.ph/index.php/malampaya-sound-protected-landscape-and-seascape, 2015). Last November 2013, before exiting the country, super typhoon Yolanda, internationally known as Haiyan, made landfall on the region of Palawan. The Provincial Disaster Risk Reduction of Palawan released a report stating that fourteen (14) municipalities were placed under state of calamity, one of them was the Municipality of Roxas. At least 20,000 families from the municipalities placed under state of calamity were affected by the storm (Source: http://www.rappler.com/move-ph/issues/disasters/typhoon-yolanda/43901-palawan-towns-state-calamity).

CHAPTER 2: LIDAR ACQUISITION IN ABONGAN 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).

2.1 Flight Plans

To initiate the LiDAR acquisition survey of the Abongan floodplain, the Data Acquisition Component (DAC) created flight plans within the delineated priority area for Abongan Floodplain in Puerto Princesa. These flight missions were planned for 14 lines and ran for at most four and a half hours (4.5) including take-off, landing and turning time using one sensor – the Gemini (see Annex 1 for sensor specifications). The flight planning parameters for the LiDAR system are outlined in Table 1. Figure 2, on the other hand, shows the flight plan for Abongan floodplain survey.

Table 1. Flight planning parameters for Gemini 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)
BLK40A	1200	35	24	100	50	130	5
BLK42B	1000	35	40	125	50	130	5

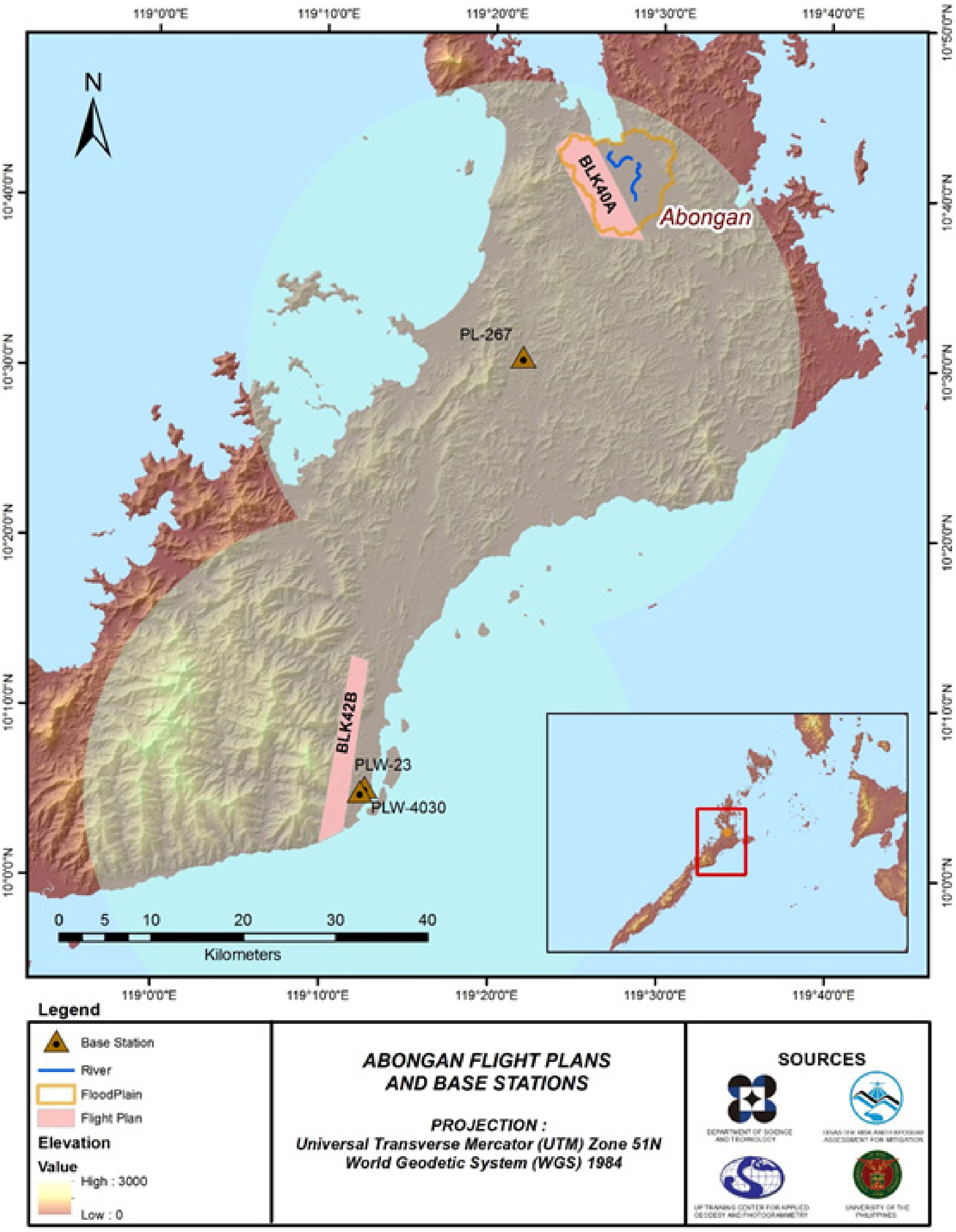


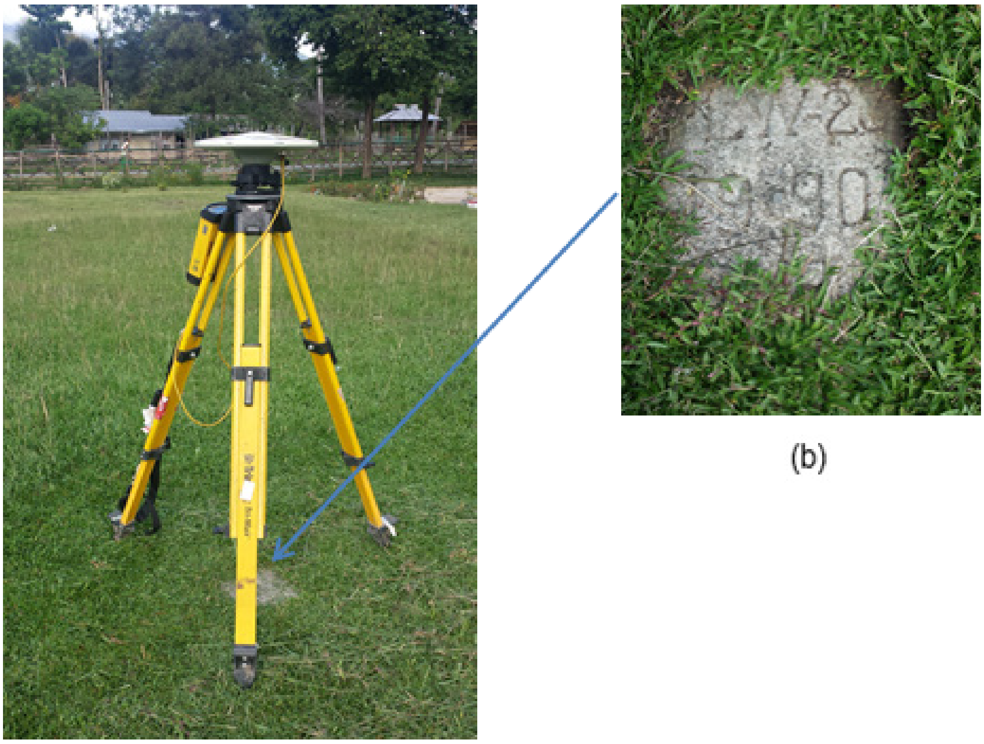
Figure 2. Flight plans and base stations used for Abongan floodplain using the Gemini sensor.

2.2 Ground Base Stations

The project team was able to recover three (3) NAMRIA ground control points, PLW-23 which is of first (1st), PLW-4030 which is of fourth (4th) order accuracy and PL-267 which is a benchmark. The bench mark and 4th order ground control point where then re-processed to obtain coordinates of 2nd order accuracy.

The certification for the NAMRIA reference points and benchmarks are found in Annex 2 while the baseline processing reports for the established control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey from November 28, 2015. Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TRIMBLE SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Abongan 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 Abongan Floodplain LiDAR Survey. Figure 3 to Figure 5 show the recovered NAMRIA reference points within the area of the floodplain, while Table 2 to Table 4 show the details about the following NAMRIA control stations and established points. Table 9, on the other hand, shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.



(b)

(a)

Figure 3. GPS set-up over PLW-23 as located] at Andres Soriano Memorial Elementary School (a) and NAMRIA reference point PLW-23 (b) as recovered by the field team.

Table 2. Details of the reprocessed NAMRIA horizontal control point PLW-23 used as base station for the LiDAR acquisition.

Station Name	PLW-23	
Order of Accuracy	1st Order	
Relative Error (horizontal positioning)	1:100,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10°5’19.52517” North 119°12’33.72062” East 10.427 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	577752.254 meters 1115630.596 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10°5’15.04804” North 119°12’39.01413” East 61.0726 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	742130.31 meters 1115973.89 meters

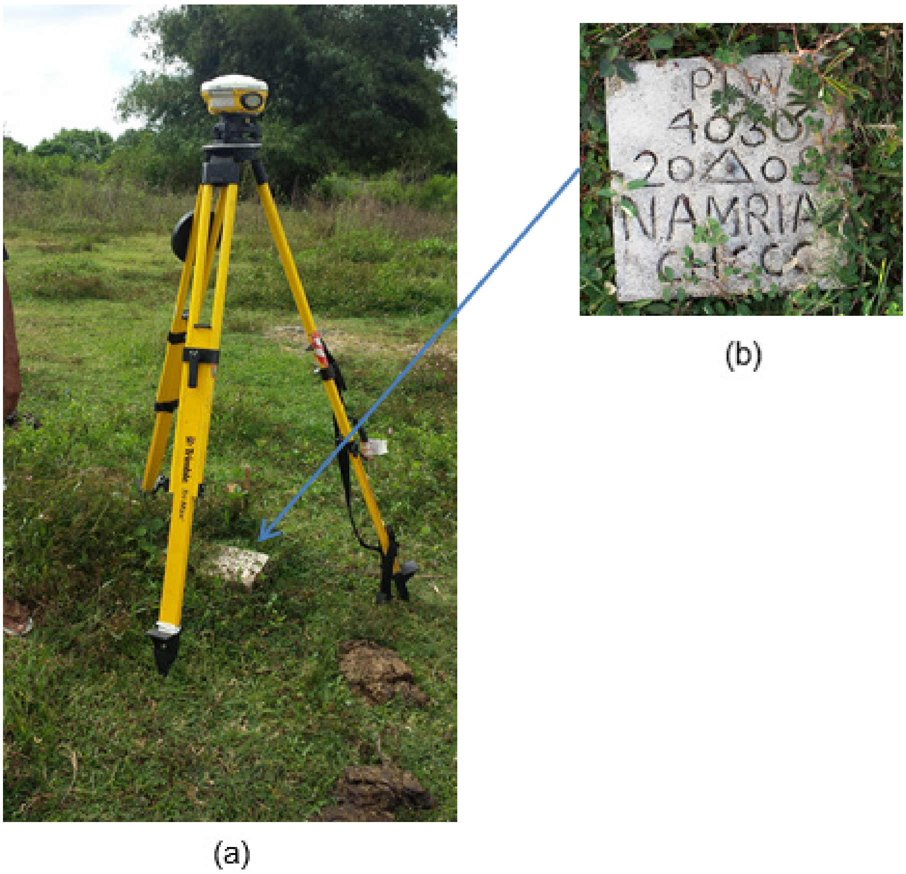
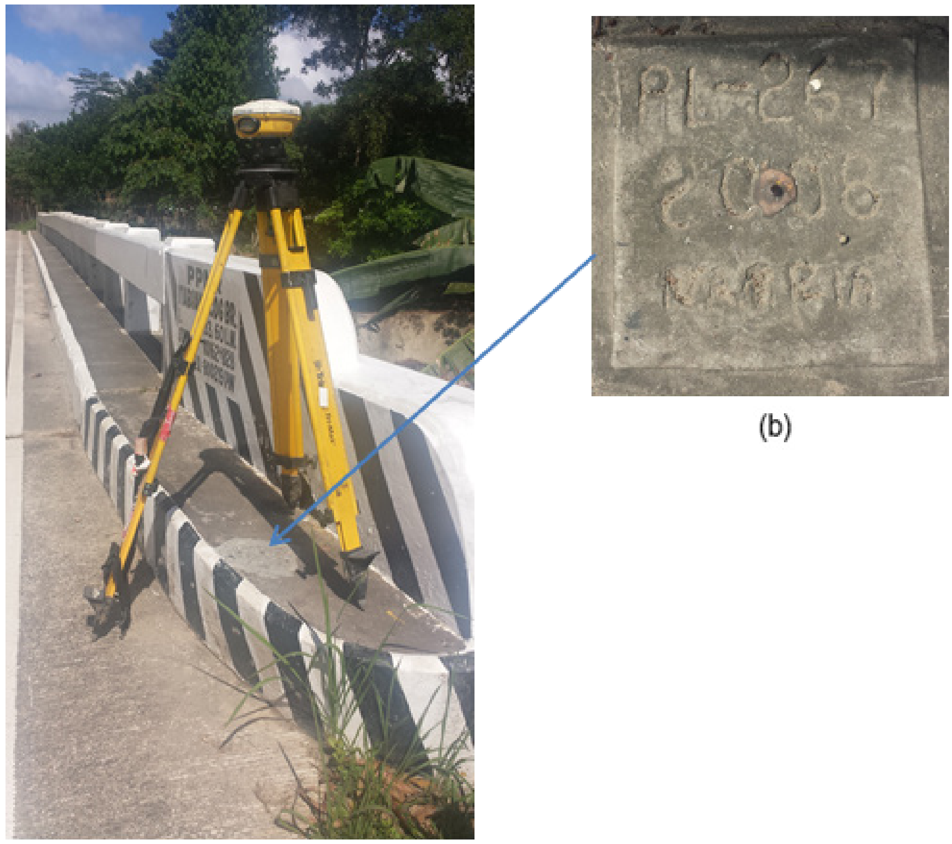


Figure 4. GPS set-up over PLW-4030 located at Mr. Gaudencio Gonzales' lot near KM Post 94+900 (a) and NAMRIA reference point PLW-4030 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point PLW-4030 used as base station for the LiDAR acquisition.

Station Name	PLW-4030	
Order of Accuracy	4th Order	
Relative Error (horizontal positioning)	1:10,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10°4'56.95146" North 119°12'22.75235" East 11.11299 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10°4'52.47561" North 119°12'28.04647" East 61.765 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	577419.789 meters 1114936.333 meters



(a) (b)

Figure 5. GPS set-up over PL-267 located in Sitio Itabiak, Brgy. Dumarao along Roxas (a) and NAMRIA reference point PL-267 (b) as recovered by the field team.

Table 4. Details of the reprocessed NAMRIA horizontal control point PL-267 used as base station for the LiDAR Acquisition.

Station Name	PL-267	
Order of Accuracy	2^{nd} Order	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10°30'40.21529" North 119°21'48.02348" East 34.545 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	101820.908 meters 1164164.984 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	10°30'35.64621" North 119°21'53.27911" East 84.611 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
November 28, 2015	3545G	2BLK42B40A332A	PLW-23, PLW-267 and PLW-4030

2.3 Flight Missions

A total of one (1) mission was conducted to complete the LiDAR data acquisition in Abongan floodplain, for a total of three hours and fifty minutes (3+50) minutes of flying time for RP-C9022 (See Annex 6). All mission was acquired using the Gemini 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 6. Flight missions for LiDAR data acquisition in Abongan floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	**No. of Images (Frames)**	**Flying Hours**	
							Hr	**Min**
November 28, 2015	3545G	96.446	95.849	32.316	63.533	--	3	50

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)**
3545G	1000/1200	35	24/40	100/125	50	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Abongan floodplain (See Annex 7). It is situated within the provinces of Palawan, specifically within the municipality of Roxas. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage, is shown in Table 8. Figure 6, on the other hand, shows the actual coverage of the LiDAR acquisition for the Abongan floodplain.

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

Province	**Municipality/City**	**Area of Municipality/City (km2)**	**Total Area Surveyed (km2)**	**Percentage of Area Surveyed**
Palawan	Roxas	1007.73	47.570	5 %
	Taytay	1325	38.523	3 %
	San Vicente	870.447	2.891	1 %
	Puerto Princesa City	2186.36	2.276	1 %
Total		**5389.54**	**91.26**	**1.69%**

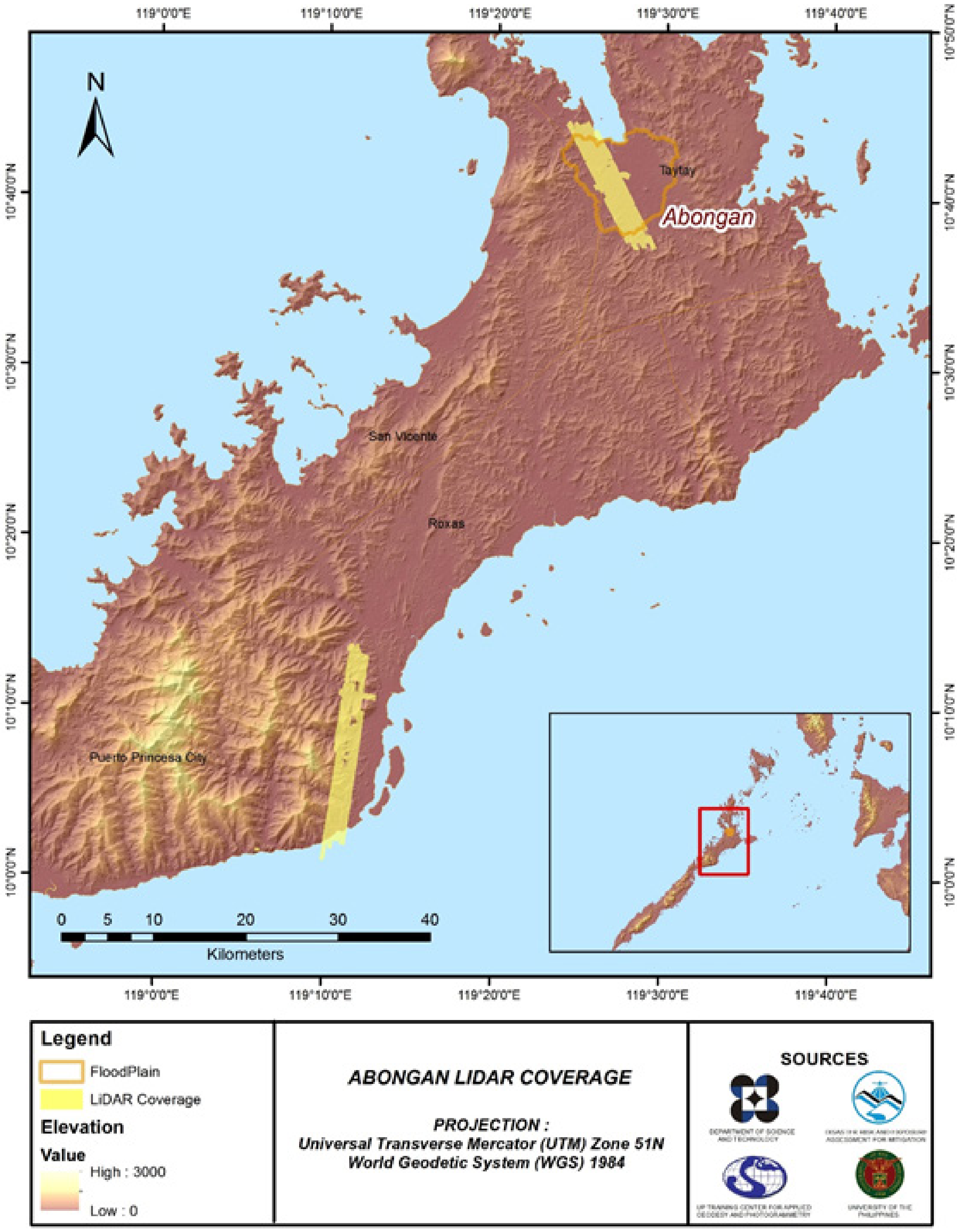


Figure 6. Actual LiDAR survey coverage for Abongan floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR ABONGAN FLOODPLAIN

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

3.1 Overview of the LIDAR Data Pre-Processing

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

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

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

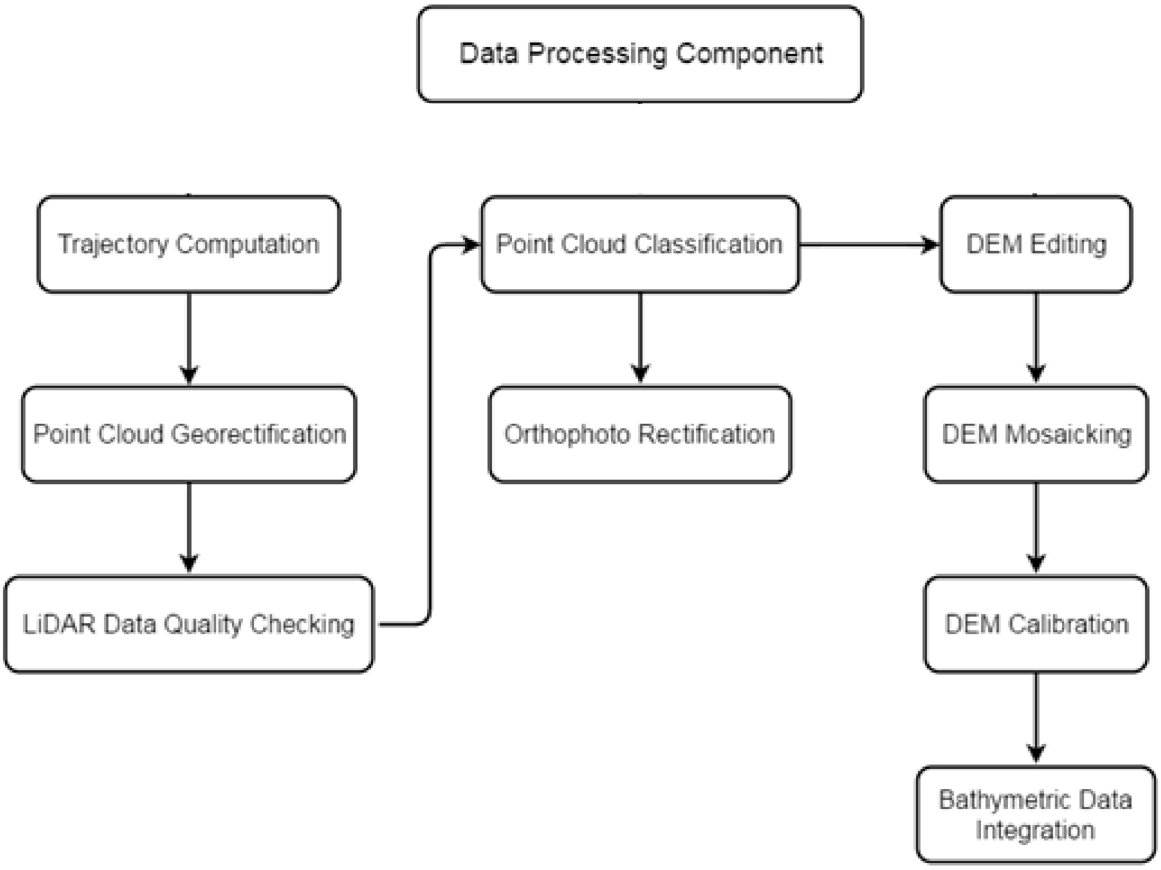

Figure 7. Schematic diagram for the data pre-processing.

3.2 Transmittal of Acquired LiDAR Data

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

The Data Acquisition Component (DAC) transferred a total of 15.80 Gigabytes of Range data, 228 Gigabytes of POS data, and 10.10 Megabytes of GPS base station data to the data server on December 8, 2015 for the. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Abongan was fully transferred on December 8, 2015, as indicated on the Data Transfer Sheets for Abongan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 7108GC, one of the Abongan flights, which is the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on November 28, 2015 00:00 AM. The y-axis is the RMSE value for that particular position.

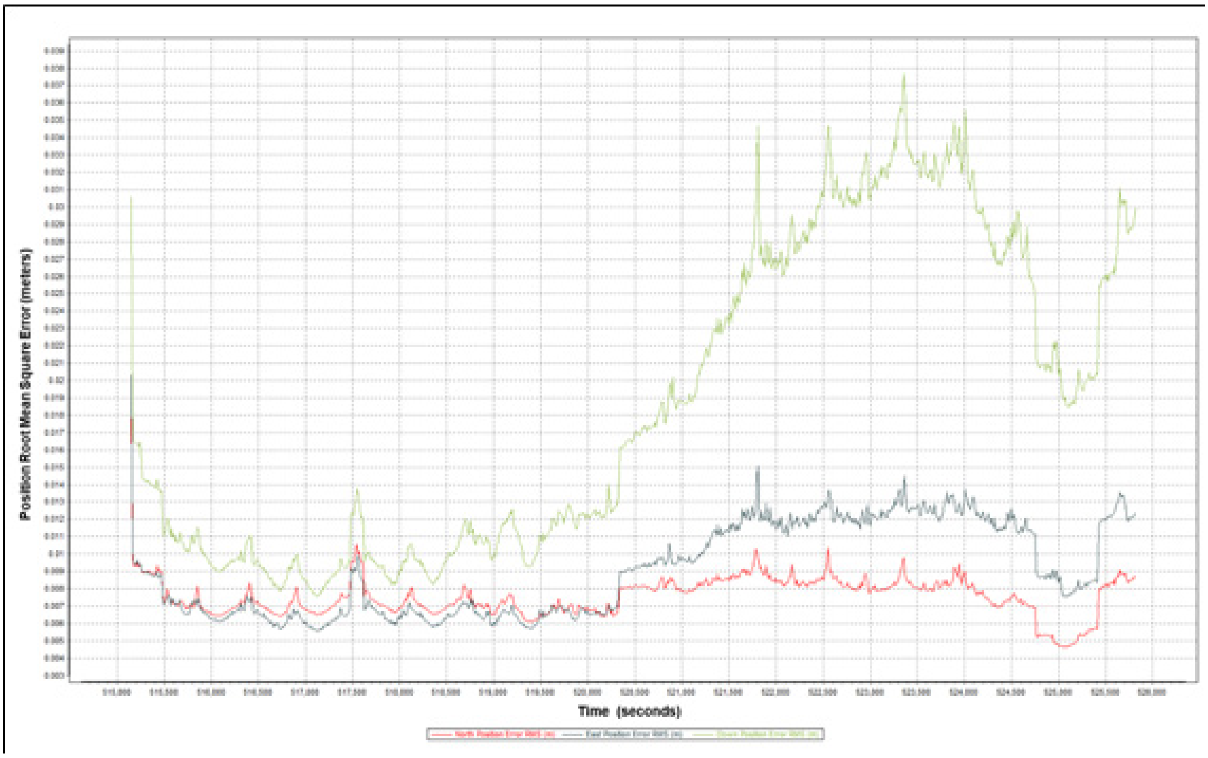

Figure 8. Smoothed Performance Metrics of a Abongan Flight 3545GC.

The time of flight was from 515,000 seconds to 526,000 seconds, which corresponds to afternoon of November 28, 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 9 shows that the North position RMSE peaks at 1.05 centimeters, the East position RMSE peaks at 1.50 centimeters, and the Down position RMSE peaks at 3.75 centimeters, which are within the prescribed accuracies described in the methodology.

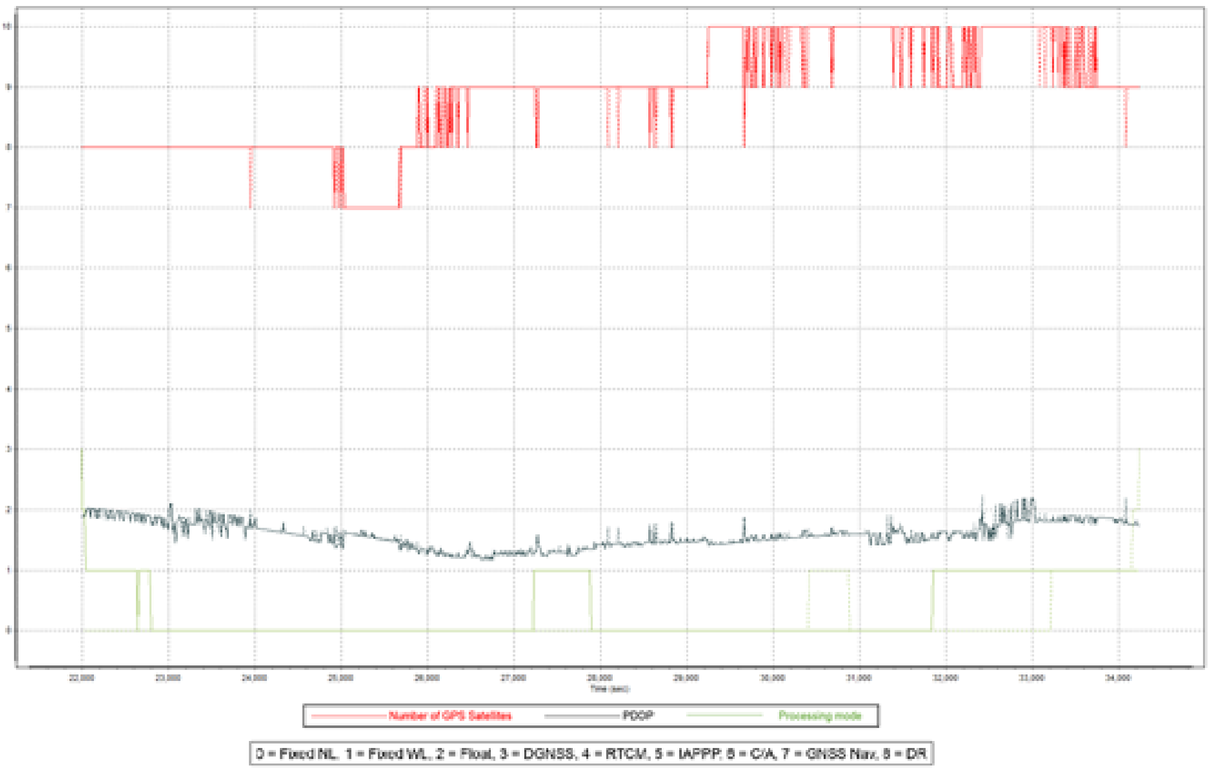

Figure 9. Solution Status Parameters of Abongan Flight 3545GC.

The Solution Status parameters of flight 3545GC one of the Abongan flights, which indicate the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 7. Most of the time, the number of satellites tracked was between 7 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Abongan flights is shown in Figure 10.

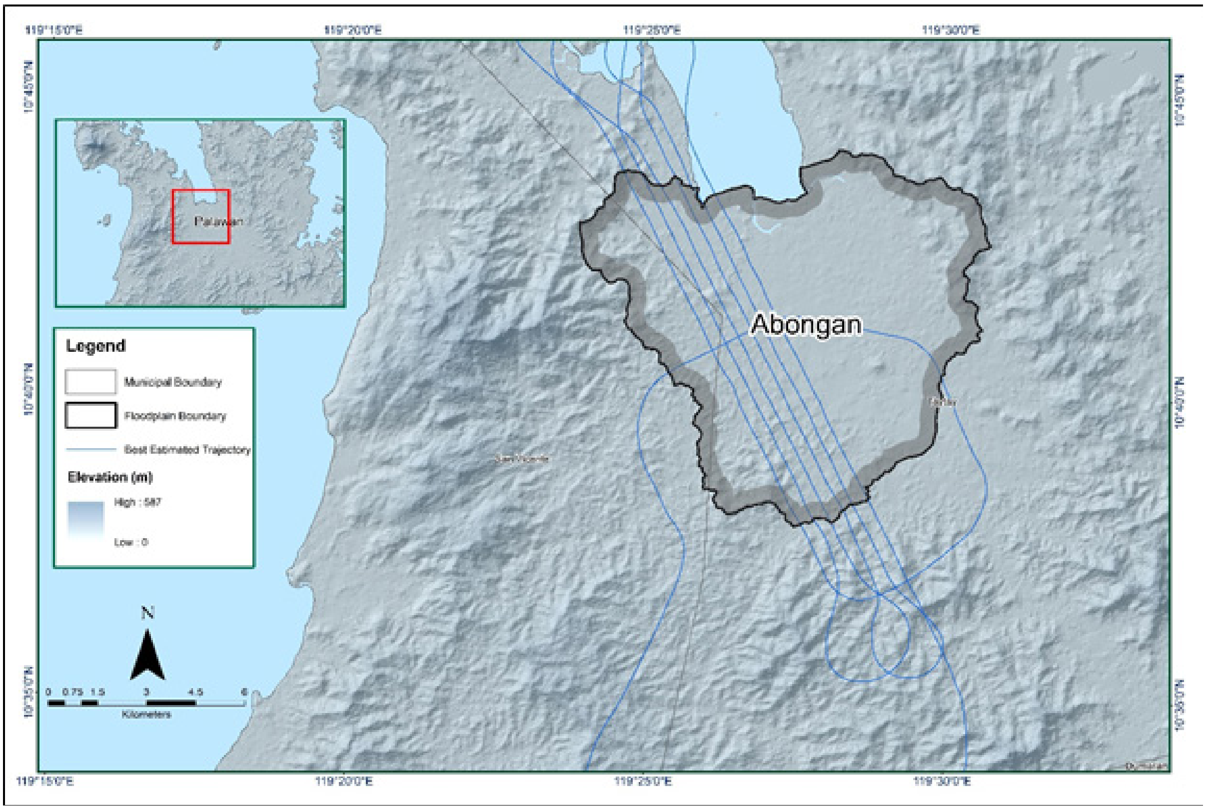

Figure 10. Best estimated trajectory of the LiDAR missions conducted over the Abongan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS contains 6 flight lines, with each flight line containing one channel, since the Gemini system contain one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over the Abongan floodplain are given in Table 9.

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

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev)	<0.001degrees	0.000199
IMU Attitude Correction Roll and Pitch Corrections stdev)	<0.001degrees	0.0000117985
GPS Position Z-correction stdev)	<0.01meters	0.0071

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

3.5 LiDAR Quality Checking

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

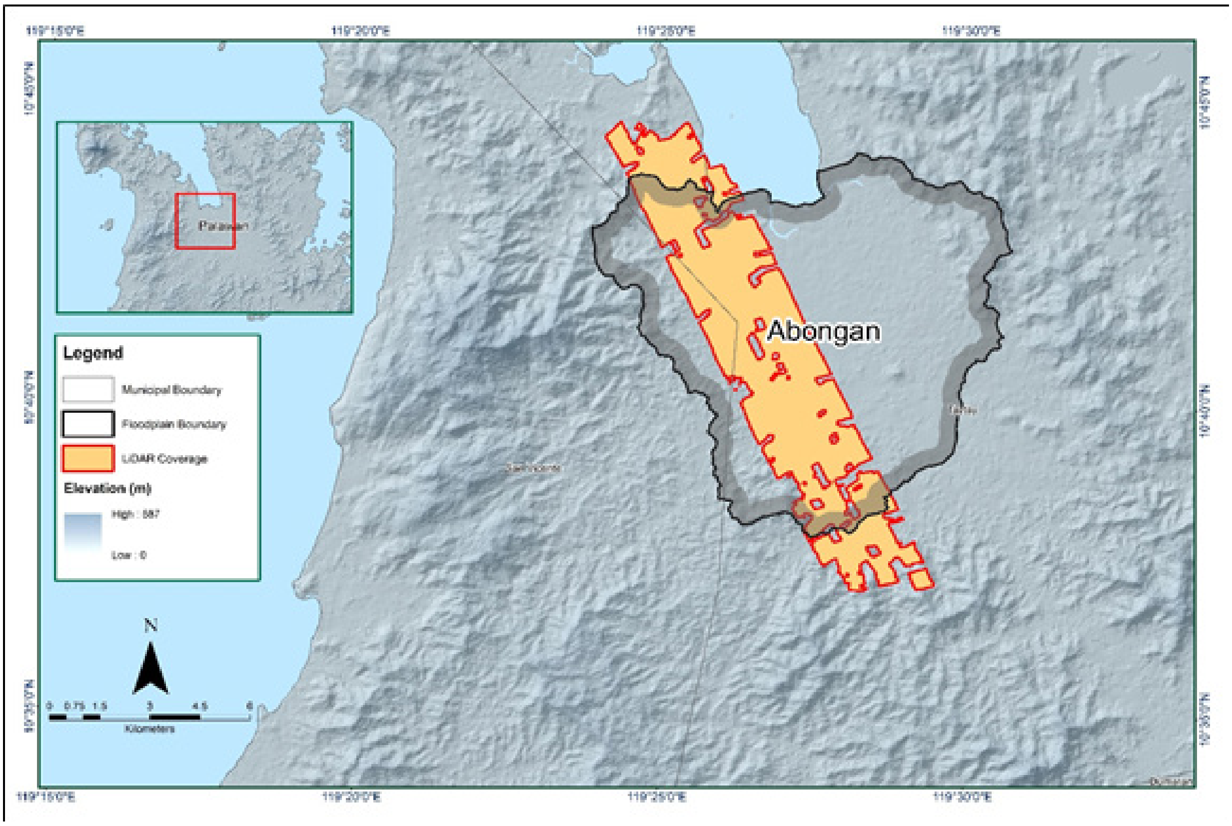

Figure 11. Boundaries of the processed LiDAR data on top of the SAR Elevation Data over the Abongan Floodplain.

The total area covered by the Abongan missions is 35.16 square kilometers (sq. kms.) that is comprised of one (1) flight acquisition grouped and merged into one (1) blocks as shown in Table 10.

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

LiDAR Blocks	Flight Numbers	Area (sq.km)
Palawan_reflights_Blk40A	3545G	35.16
TOTAL		**35.16 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 12. Since the Gemini system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

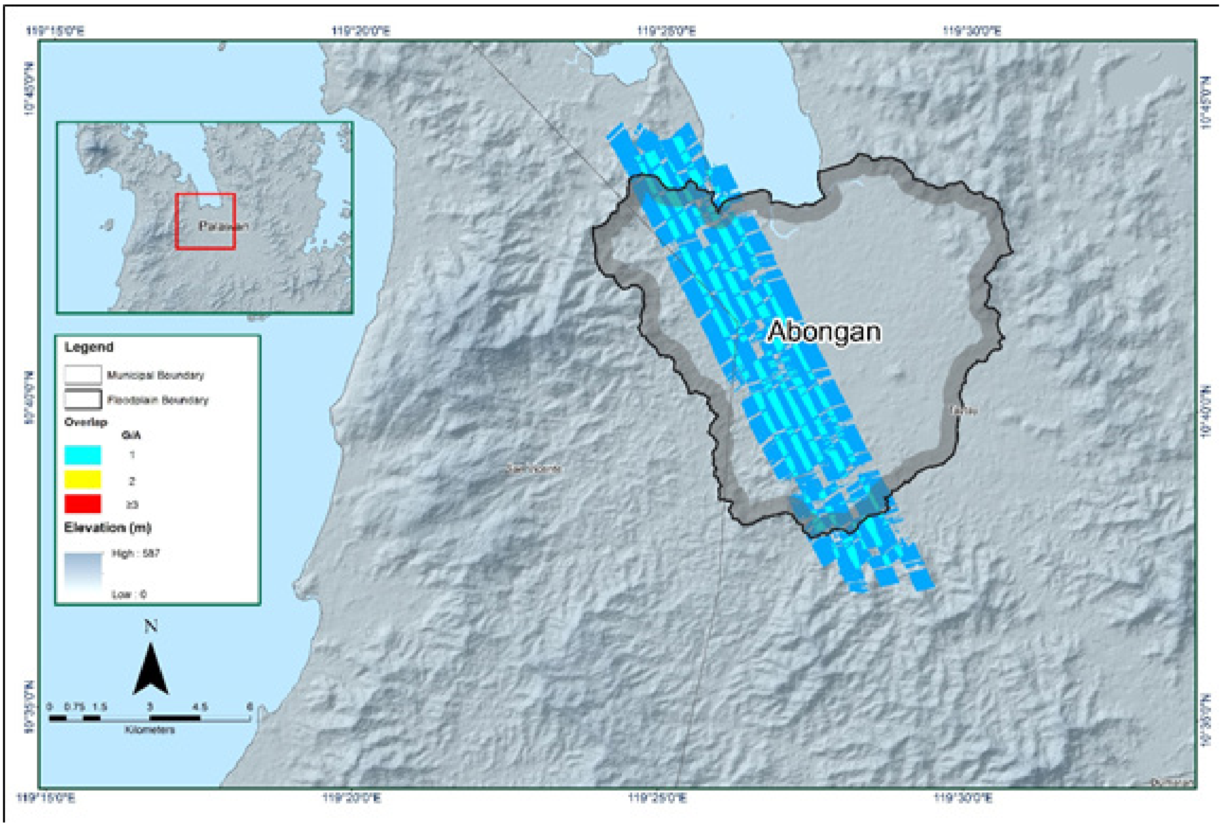

Figure 12. Image of data overlap for Abongan floodplain.

The overlap statistics per block for the Abongan floodplain can be found in the Mission Summary Reports (Annex 8). One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps is 24.74%.

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 13. It was determined that all LiDAR data for the Abongan floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.99 points per square meter.

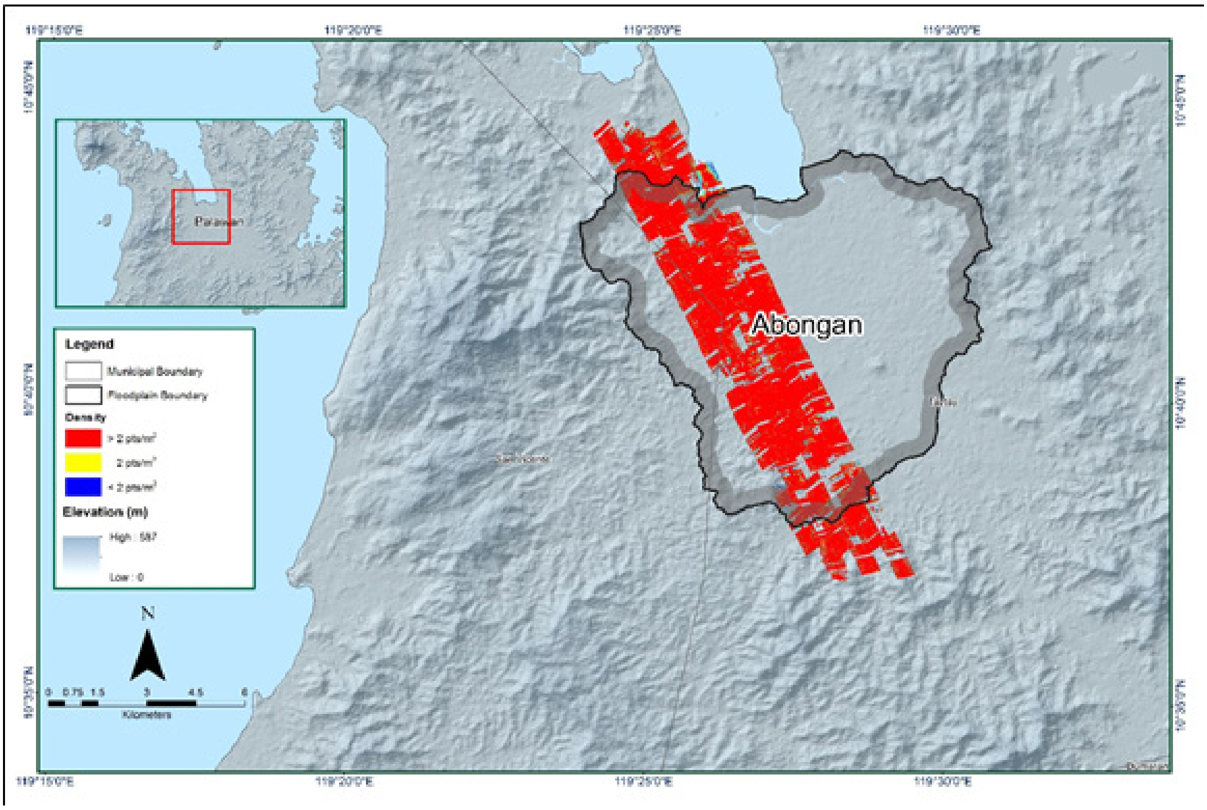

Figure 13. Pulse density map of the merged LiDAR data for Abongan floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 14. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

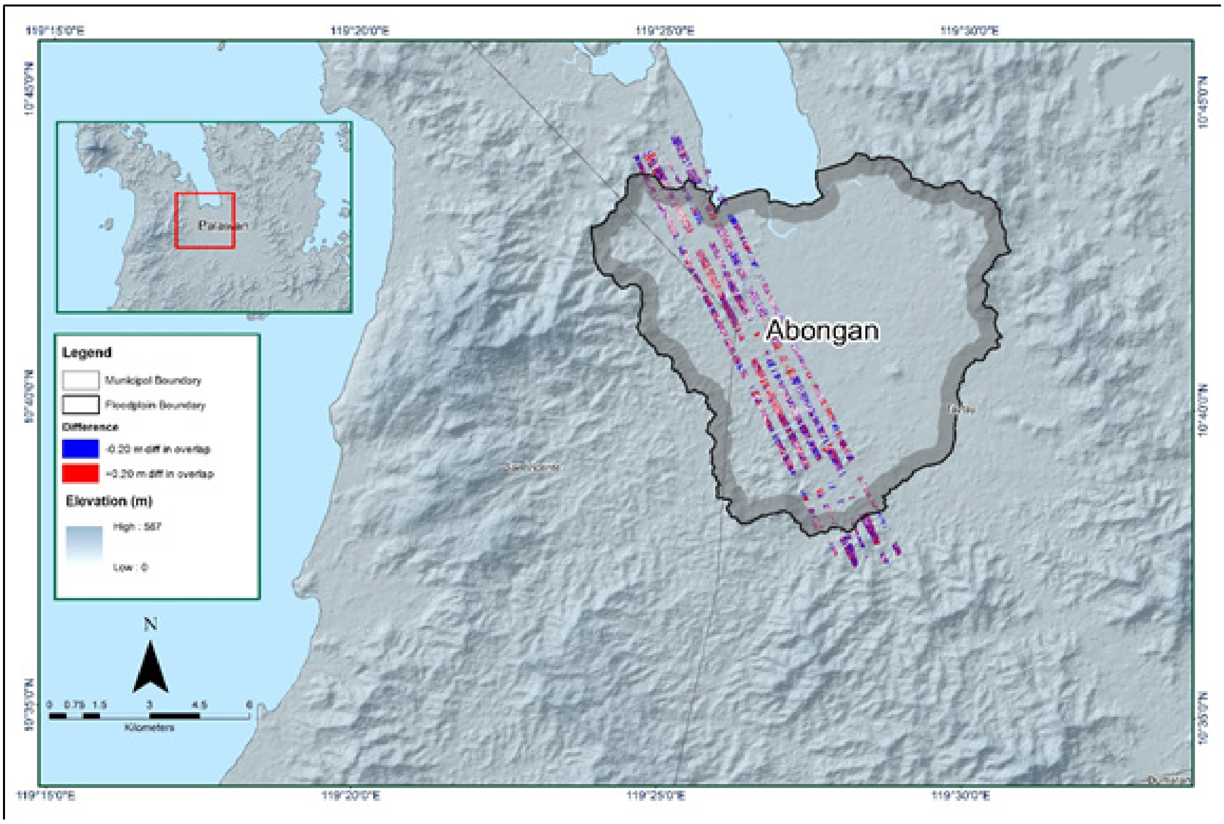

Figure 14. Elevation difference Map between flight lines for the Abongan Floodplain Survey.

A screen capture of the processed LAS data from Abongan flight 3545GC loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

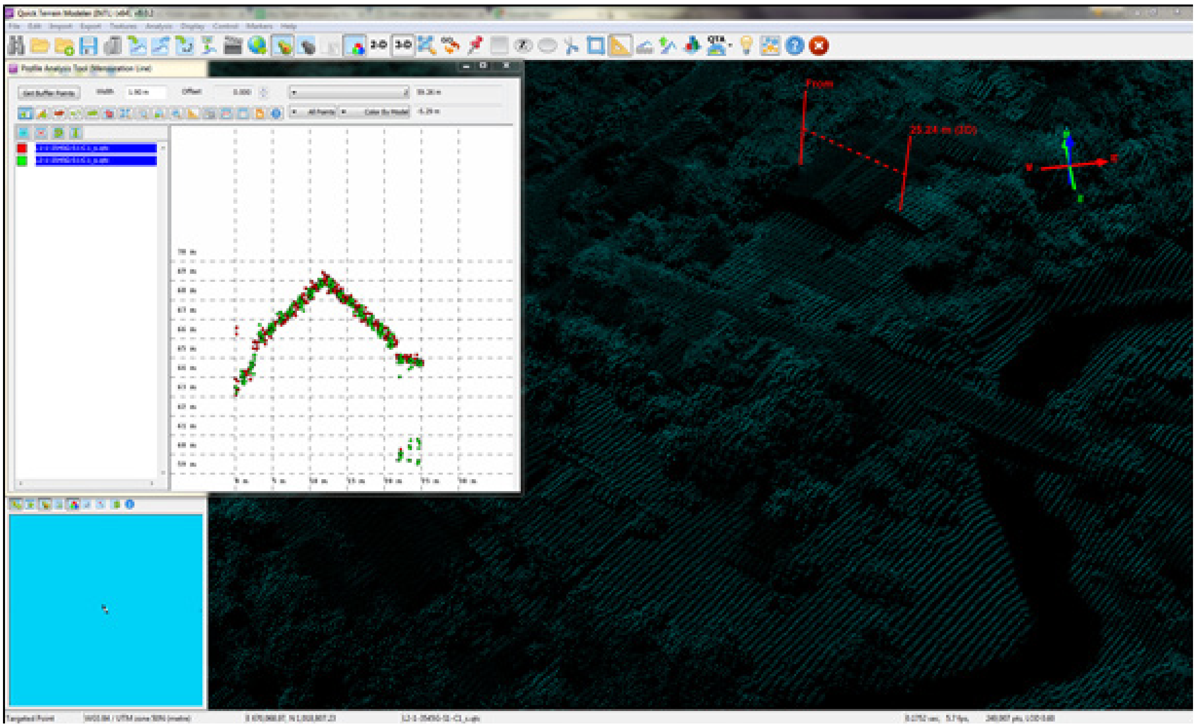

Figure 15. Quality checking for aAbongan flight 7108GC using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Abongan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	7,140,523
Low Vegetation	6,080,343
Medium Vegetation	52,688,726
High Vegetation	74,191,722
Building	8,672

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Abongan floodplain is shown in Figure 16. A total of 70 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 317.70 meters and 50.38 meters, respectively.

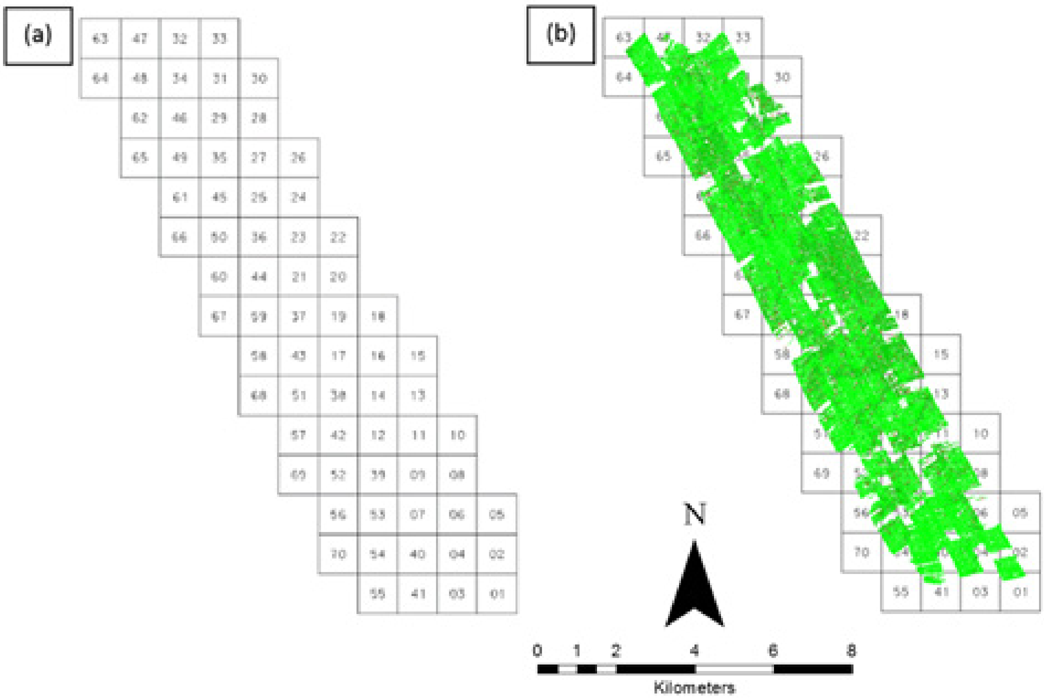

Figure 16. Tiles for Abongan floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. The ground points are in orange, 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.

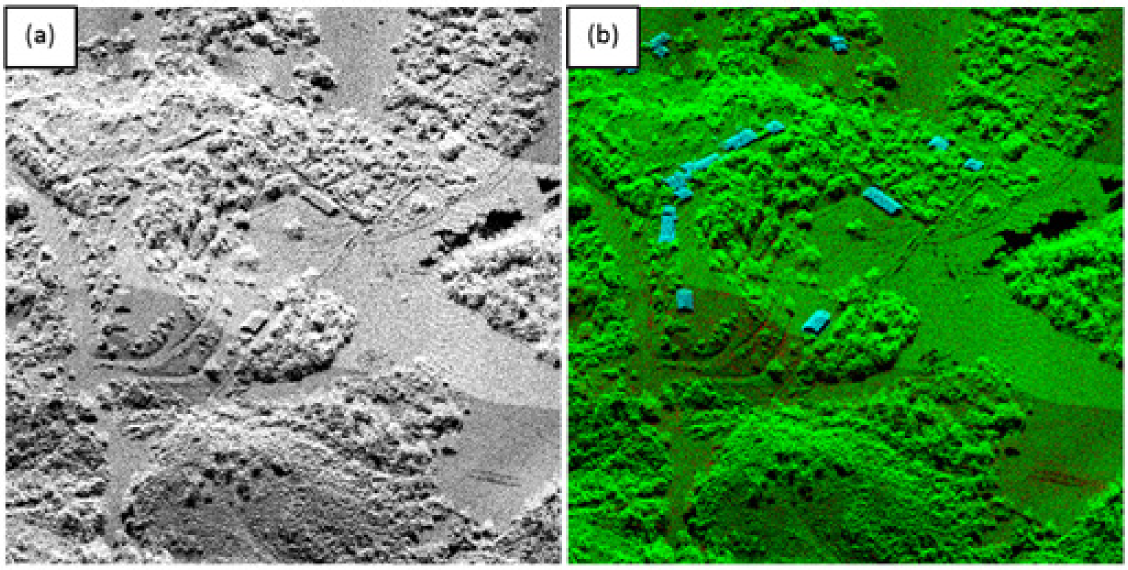

Figure 17. Point cloud before (a) and after (b) classification.

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

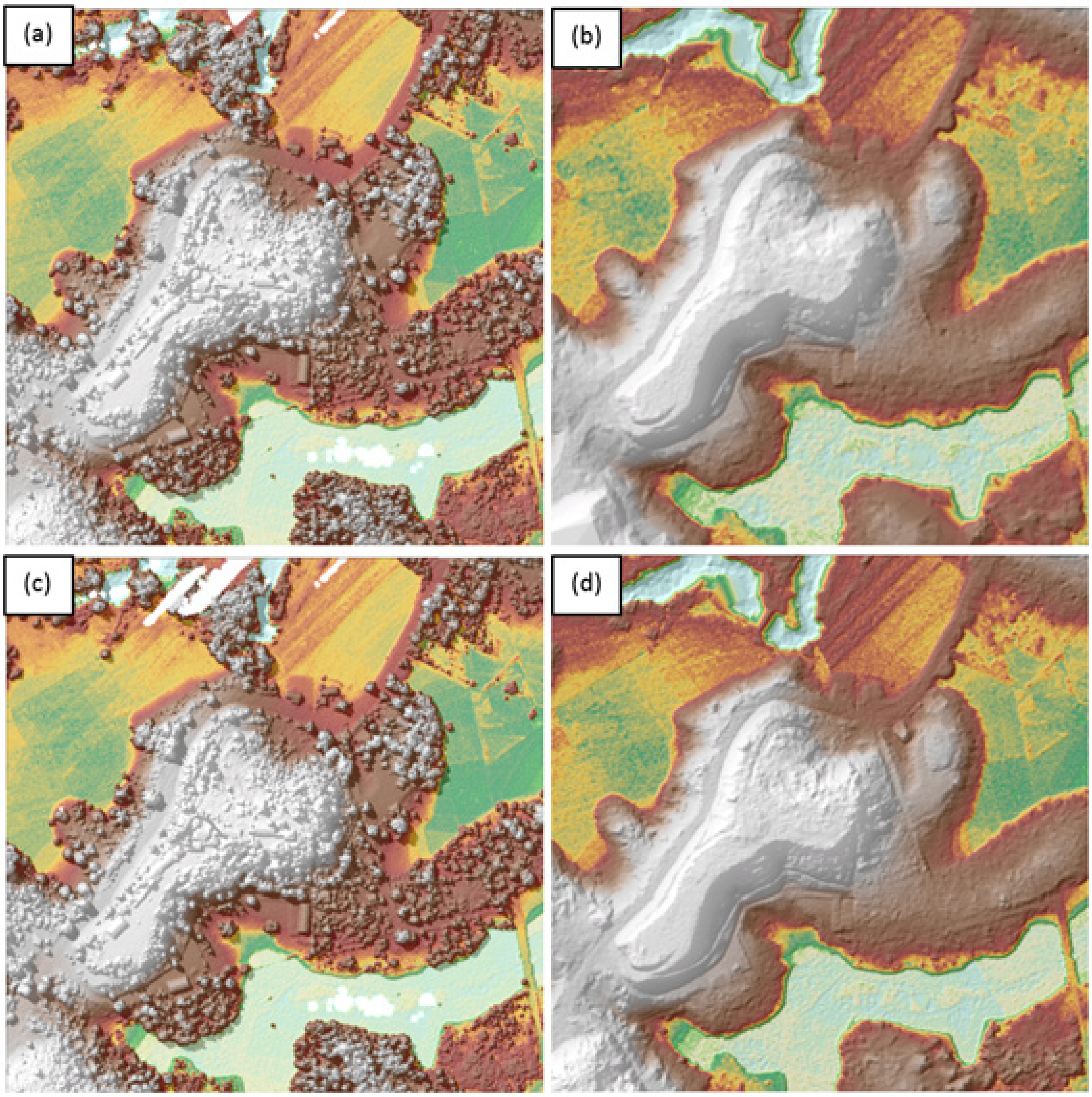

Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Abongan floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Abongan floodplain.

3.8 DEM Editing and Hydro-Correction

One (1) mission block was processed for Abongan flood plain. This block is composed of Palawan block with a total area of 35.16 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.)
Palawan_reflights_Blk40A	35.16
TOTAL	35.16 sq.km

Figure 19 shows portions of a DTM before and after manual editing. As evident in the figure, the building is still present in the DTM after classification (Figure 19a) and has to be removed through manual editing (Figure 19b). The data gap (Figure 19c) has been filled to complete the surface (Figure 19d) to allow the correct flow of water.

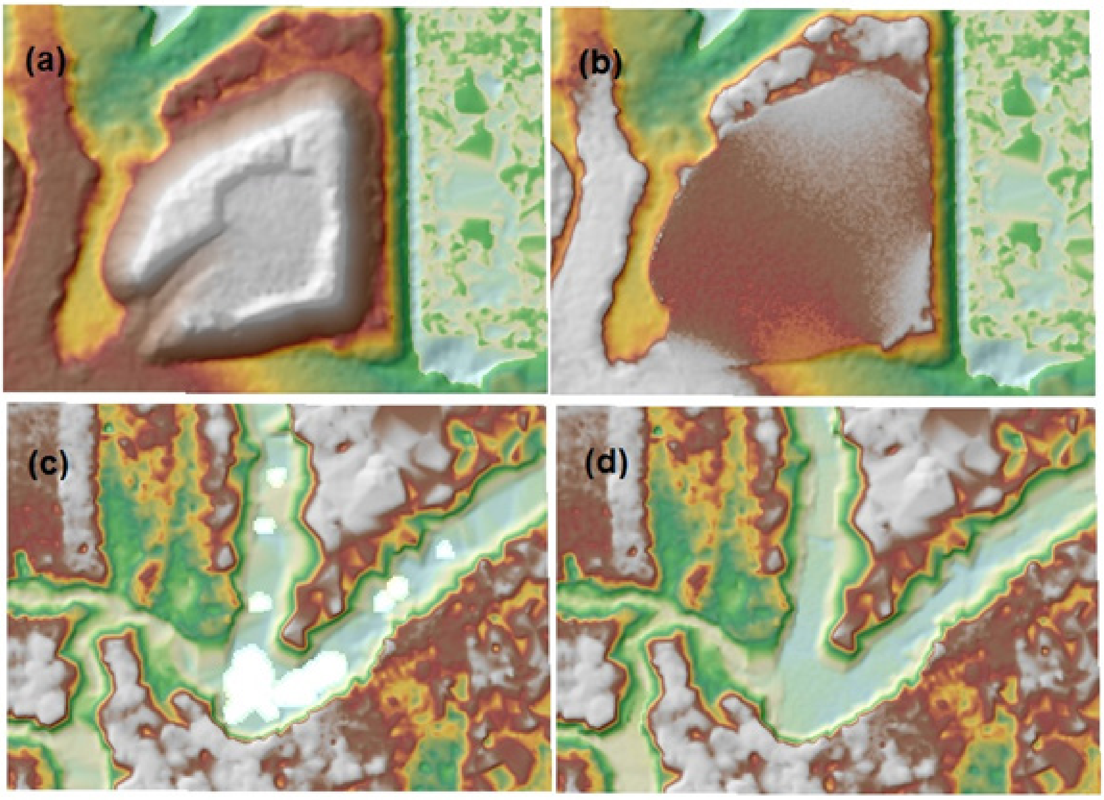

Figure 19. Portions in the DTM of the Abongan Floodplain – a building before (a) and after (b) manual editing; and a data gap before (c) and after (d) filling.

3.9 Mosaicking of Blocks

Palawan_Blk42A was used as the reference block at the start of mosaicking because this block was referred to a base with an acceptable order of accuracy. Table 13 shows the shift values applied to each LiDAR block

Mosaicked LiDAR DTM for Abongan floodplain is shown in Figure 20. It can be seen that the entire Abongan floodplain is 29.55% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Palawan_Reflight_Blk40A	0.00	0.00	0.00

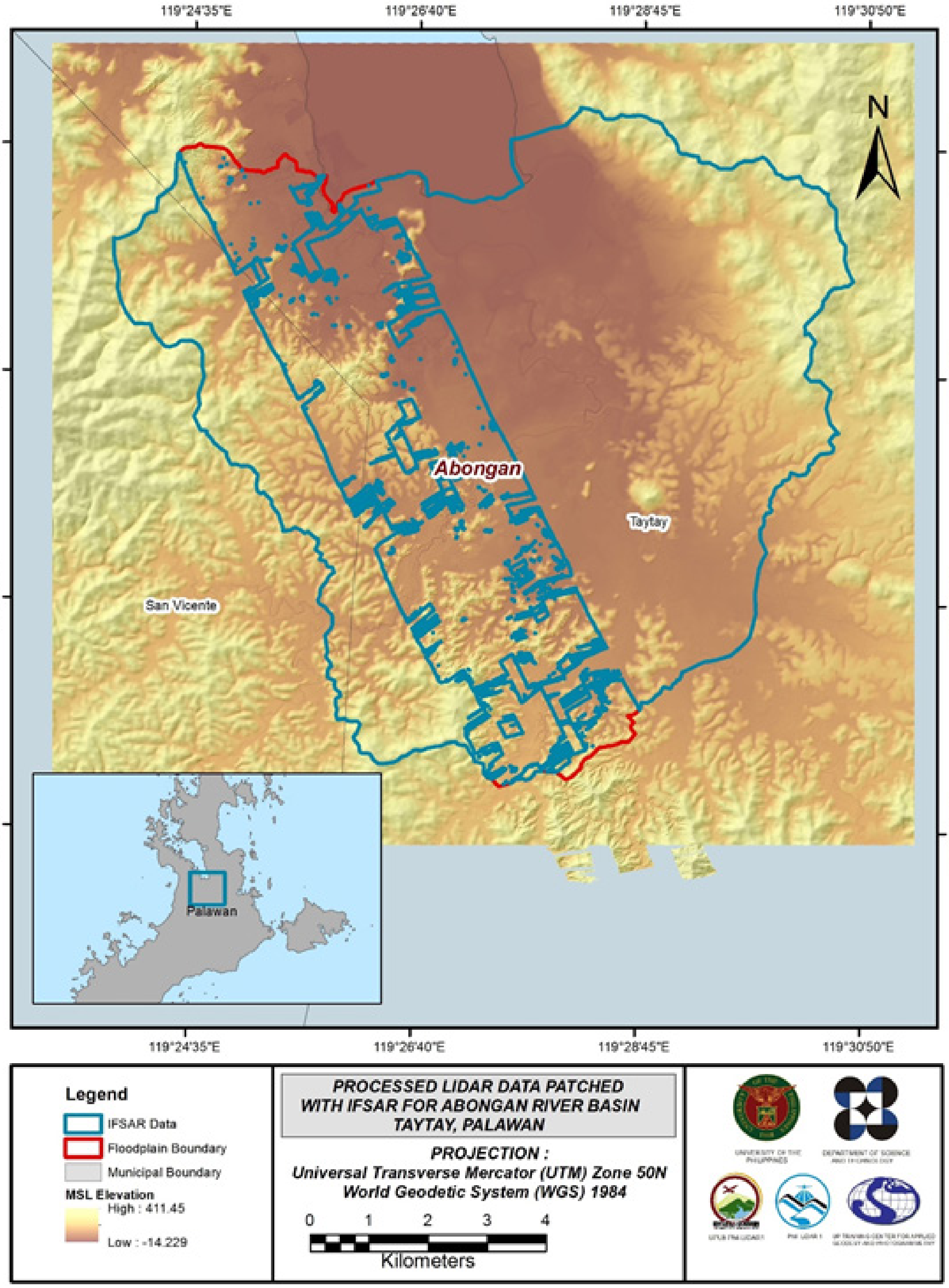

Figure 20. Map of processed LiDAR data for the Abongan Floodplain.

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 Abongan to collect points with which the LiDAR dataset is validated is shown in Figure 21, with the validation survey points highlighted in green. A total of 1,206 survey points were gathered within Palawan wherein the Abongan floodplain is located. Random selection of 80% of the survey points, resulting to 969 points, was used for calibration.

A good correlation between the uncalibrated Abongan LiDAR DTM and ground survey elevation values is shown in Figure 22. 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 13.17 meters with a standard deviation of 0.20 meters. Calibration of Abongan LiDAR data was done by subtracting the height difference value, 13.17

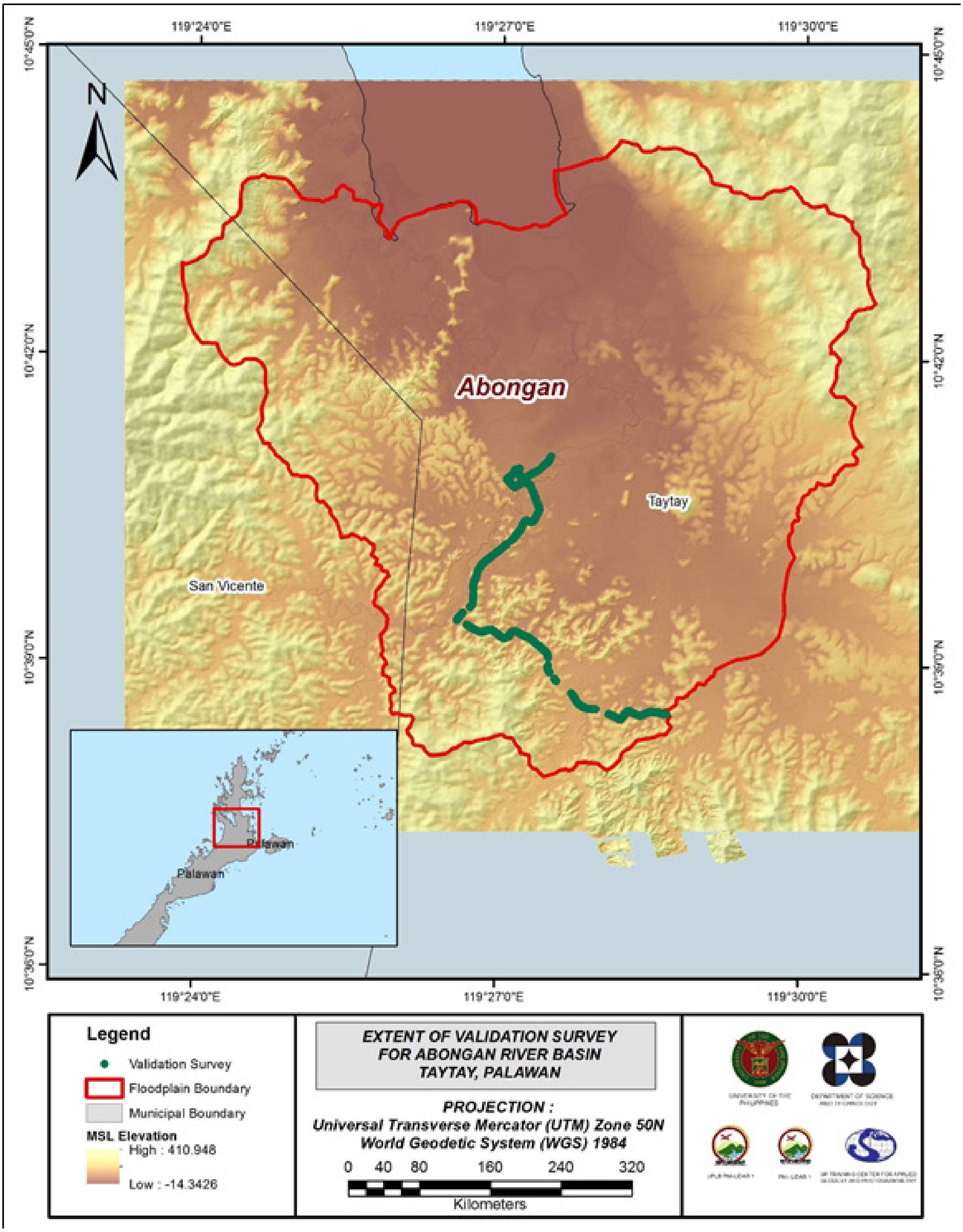

Figure 21. Map of Abongan Floodplain with validation survey points in green.

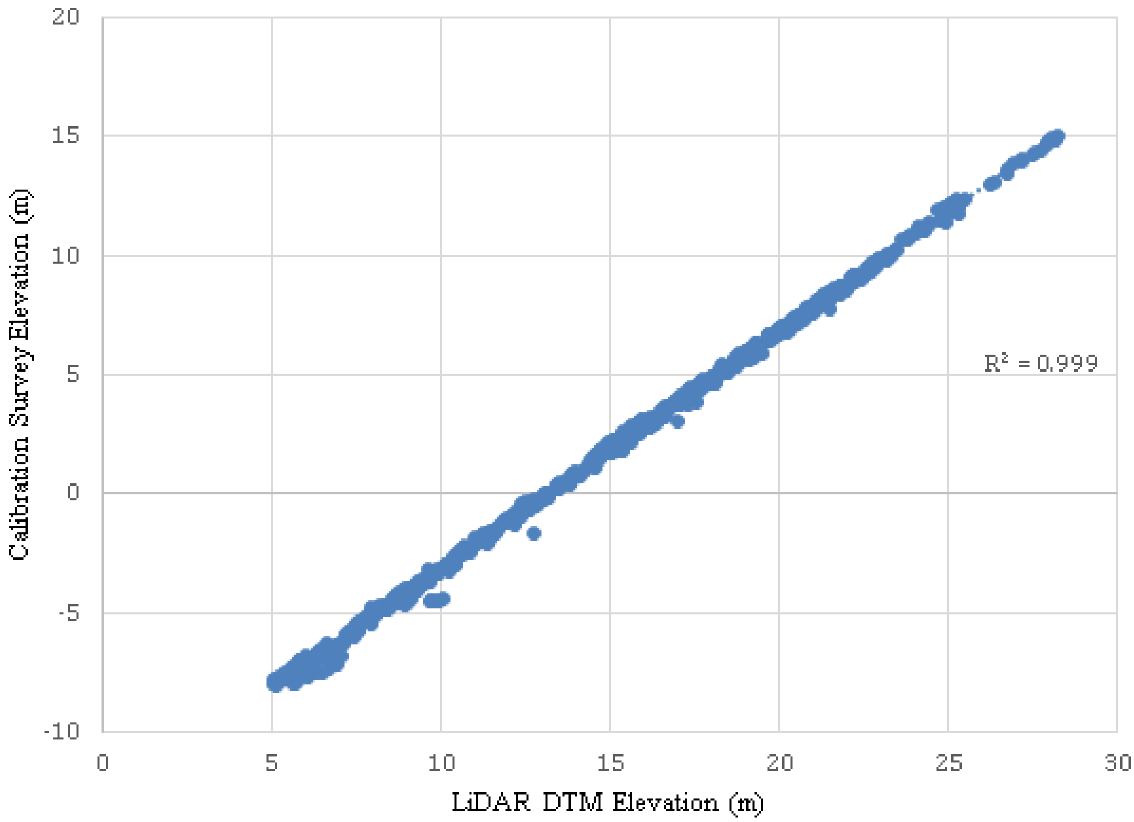

Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	13.17
Standard Deviation	0.20
Average	13.17
Minimum	12.78
Maximum	13.56

A total of 237 points were used for the validation of calibrated Abongan DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.19 meters with a standard deviation of 0.19 meters, as shown in Table 15.

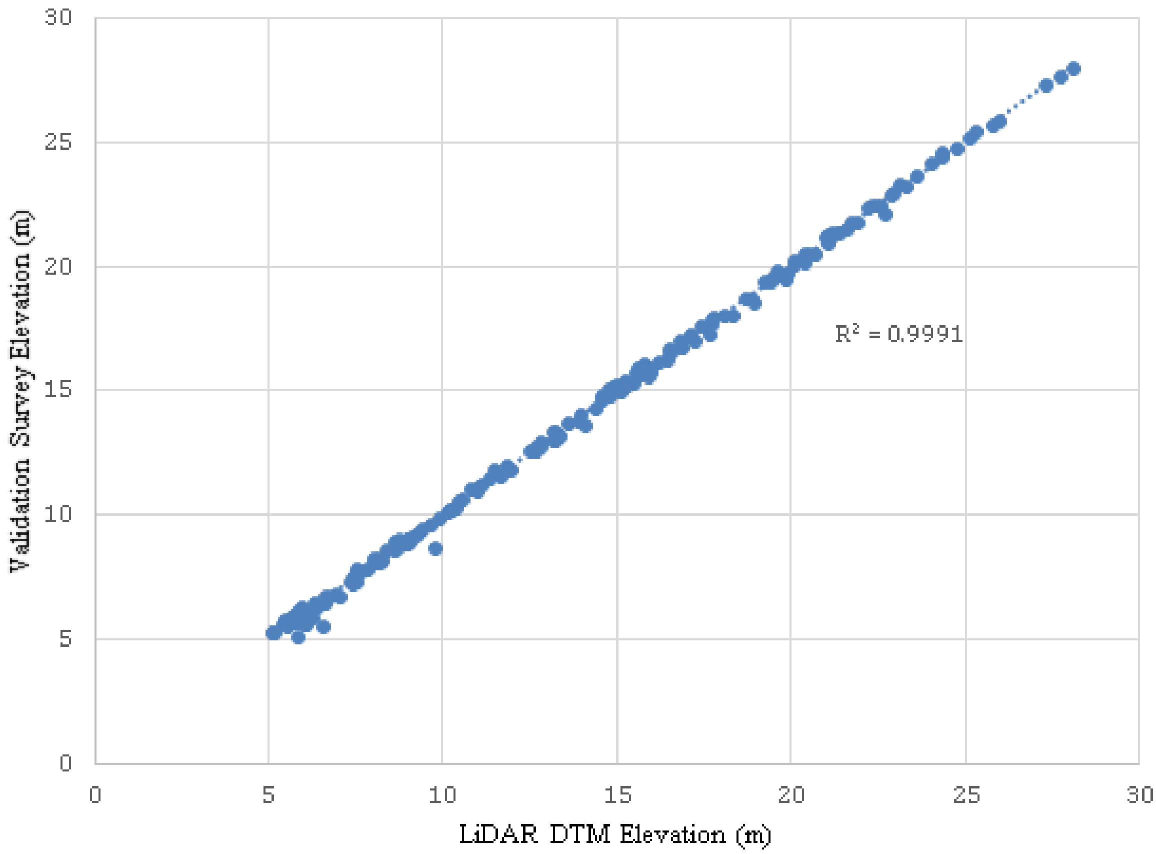

Figure 23. Correlation plot between the validation survey points and the LiDAR data.

Table 15. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.19
Standard Deviation	0.19
Average	0.01
Minimum	-0.37
Maximum	0.39

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and cross-section data were available for Abongan with 3,128 bathymetric survey points. The resulting raster surface produced was done by Barrier method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.41 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Abongan integrated with the processed LiDAR DEM is shown in Figure 24.

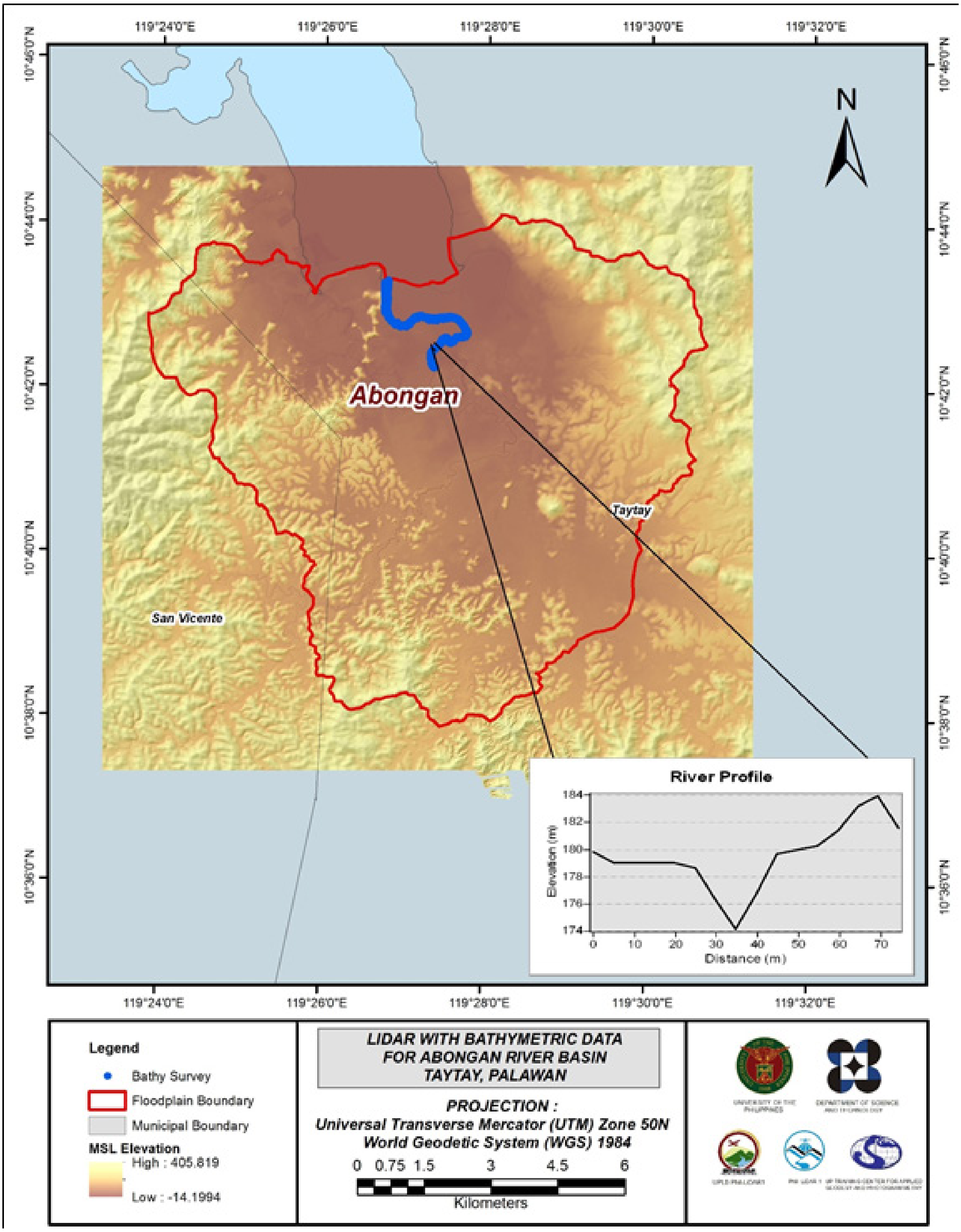

Figure 24. Map of Abongan floodplain with bathymetric survey points in blue.

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

Abongan floodplain, including its 200 m buffer, has a total area of 101.31 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 304 building features, are considered for QC. Figure 24 shows the QC blocks for Abongan floodplain.

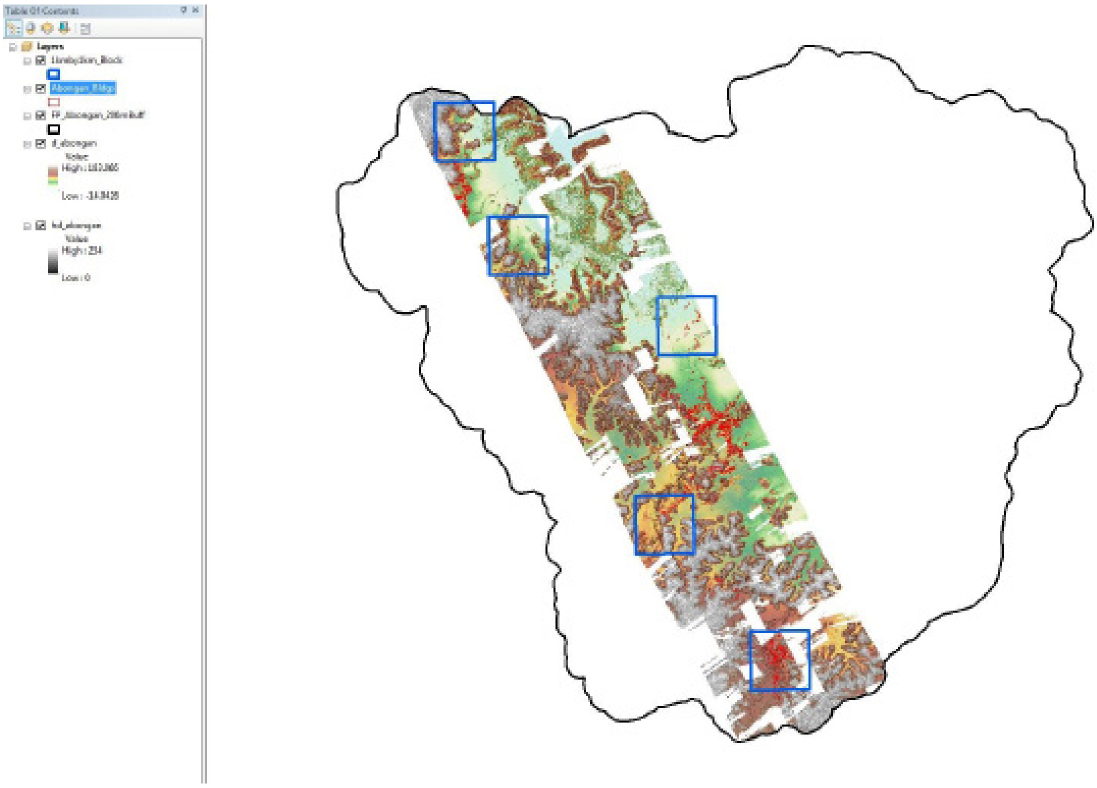

Figure 25. Blocks (in blue) of Abongan building features that was subjected to QC.

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

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

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Abongan	99.35	100.00	97.37	PASSED

3.12.2 Height Extraction

Height extraction was done for 51,234 building features in Abongan floodplain. Of these building features, 843 were filtered out after height extraction, resulting to 50,391 buildings with height attributes. The lowest building height is at 2.00 meters, while the highest building is at 14.87 meters.

3.12.3 Feature Attribution

A field team was deployed to the floodplain areas to gather attribute data for the features. Point features in .gpx format were generated from the feature shapefiles. These were loaded into OsmAnd, a mobile mapping application that uses OpenStreetMap (OSM) data as base map. Attributes of feature points of interest (POIs) such as government institutions, social service facilities, agro-industrial facilities, commercial buildings, and transportation and utility offices were recorded. These attributes include building types and names. Names and types of roads were also noted. For water bodies and bridges, only the names were recorded.

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

Table 17. Building features extracted for Abongan Floodplain.

Facility Type	No. of Features
Residential	1146
School	36
Market	3
Agricultural/Agro-Industrial Facilities	23
Medical Institutions	5
Barangay Hall	4
Military Institution	0
Sports Center/Gymnasium/Covered Court	4
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	9
Bank	0
Factory	0
Gas Station	1
Fire Station	0
Other Government Offices	6
Other Commercial Establishments	10
Total	1247

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Abongan	9.22	10.33	5.25	10.25	0.00	35.05

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

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Abongan	1	0	1	0	0	2

A total of one bridge over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 26 shows the completed Digital Surface Model (DSM) of the Abongan floodplain overlaid with its ground features.

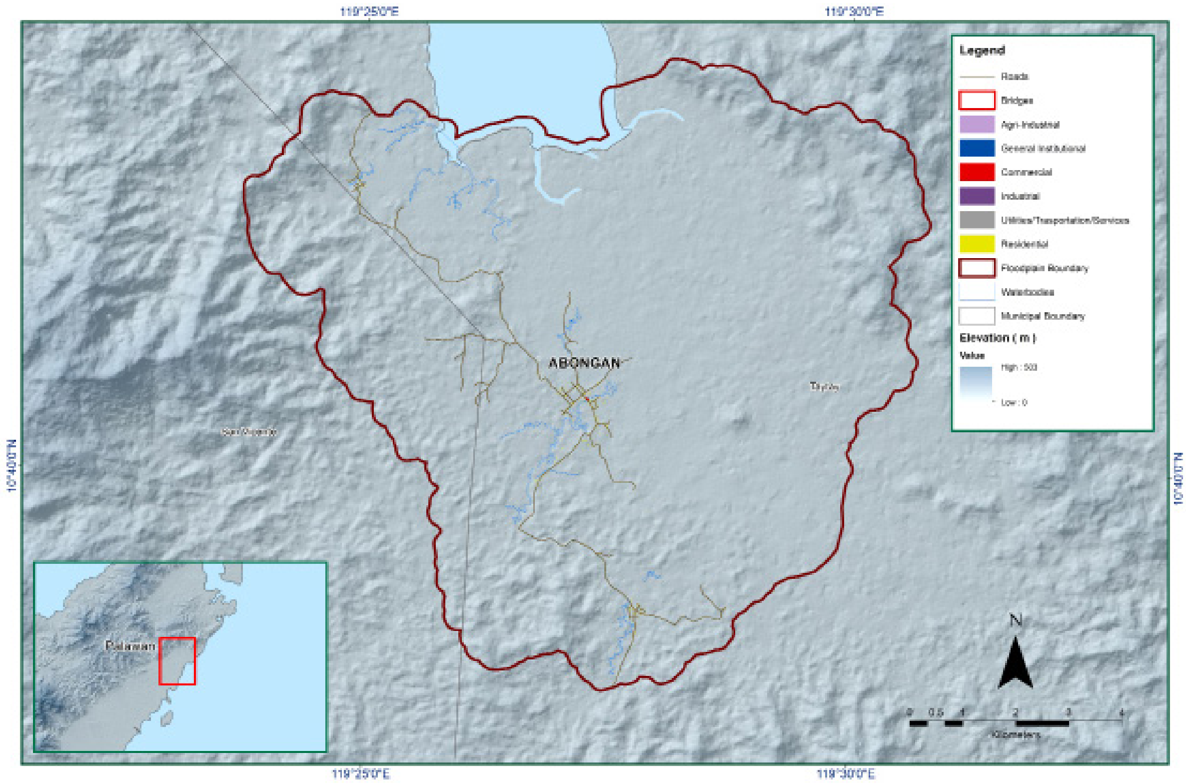

Figure 26. Extracted features of the Abongan Floodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS IN THE ABONGAN RIVER BASIN

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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).

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Abongan River on November 15 to 29, 2016. Generally, the scope of work was comprised of (i) initial reconnaissance; (ii) control point survey for the establishment of a control point; (iii) the cross section survey and bridge as-built survey, and water level marking in the Mean Sea Level (MSL) at Tabuan Bridge in Brgy. Abongan, Municipality of Taytay; (iv) validation points acquisition of about 22 km covering the Barangays: Bato, Abongan and Libertad in the Municipality of Taytay; and (v) bathymetric survey from its upstream in Brgy. Abongan, in the Municipality of Taytay, to the mouth of the river in the same barangay, with an approximate length of 4.445 km using Trimble® SPS 985 GNSS PPK survey technique. Figure 27 illustrates the extent of the entire survey in Abongan River.

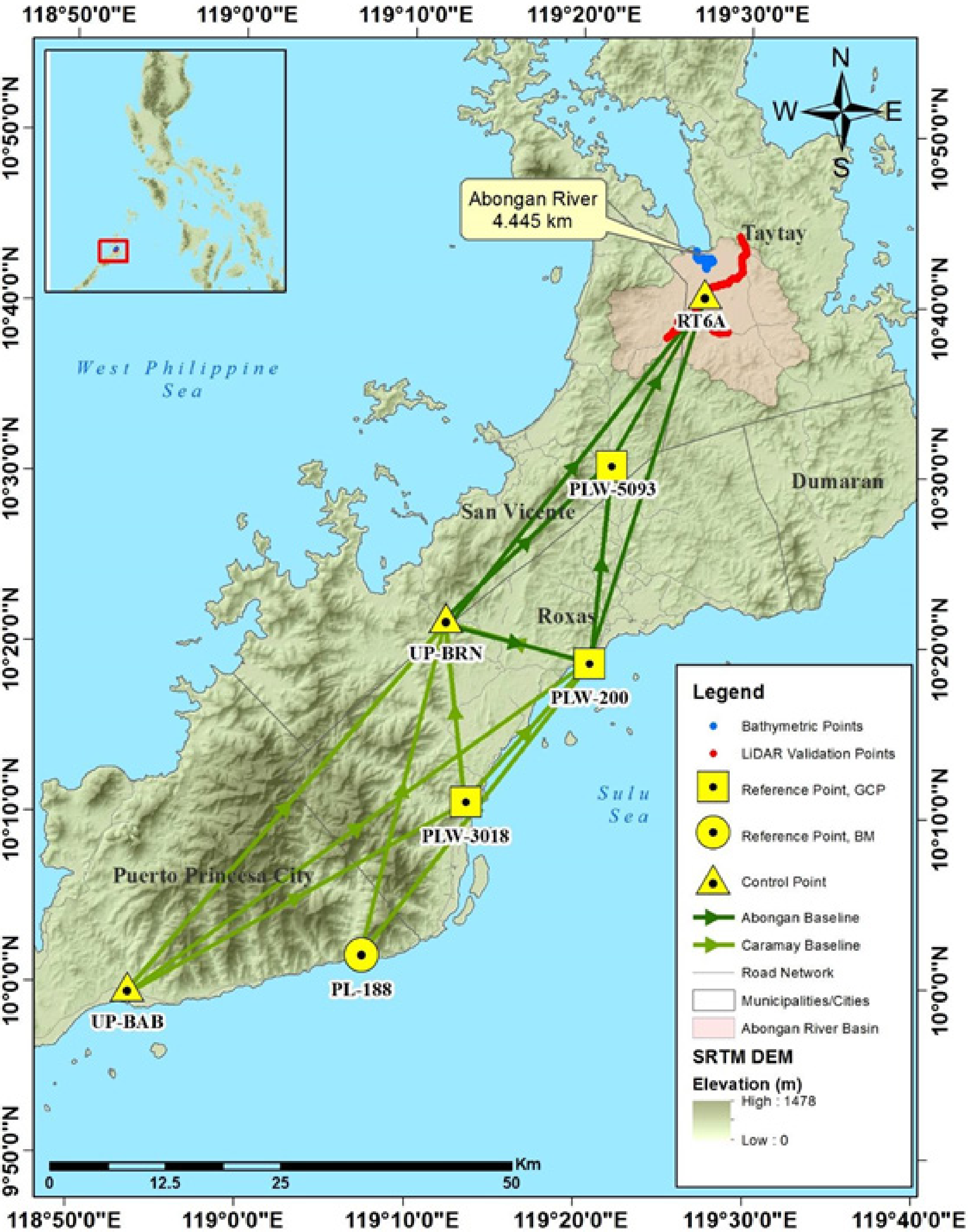


Figure 27. Abongan River Survey Extent.

4.2 Control Survey

A GNSS network was established for another PHIL-LIDAR 1 DVBC fieldwork in Caramay River on November 16, 2016 occupying the control points PL-188, a 1st order BM in Brgy. Langogan, Puerto Prinsesa City; and UP-BAB, a UP established control point in Brgy. Babuyan, Puerto Prinsesa City in Palawan, both values fixed from another PHIL-LIDAR1 survey in Babuyan River.

The GNSS network utilized for the Abongan River Basin is composed of three (3) loops and a baseline that was established on November 16 and 17, 2016, which occupied the following reference points: PL-200, a 1st order BM in Brgy. 1 Poblacion, Municipality of Roxas; and UP-BRN, a UP established control point in in Brgy. Port Barton, Municipality of San Vicente, Palawan, both fixed from Caramay Survey.

An LMS established control point namely, PLW-PLW-5093, in Brgy. New Agutaya, Municipality of San Vicente, and RT-6-A, in Brgy. Abongan, Municipality of taytay, both Palawan; were also occupied to use as markers for the survey.

Table 20 depicts the summary of reference and control points utilized, with their corresponding locations, while Figure 28 shows the GNSS network established in the Abongan River Survey.

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoid Height (m)	Elevation (MSL) (m)	Date of Establishment
Control Survey on November 17, 2016						
PLW-200	Fixed	10°18'57.78651"	119°20'41.94774"	53.649	2.161	11-15-16
UP-BRN	Fixed	10°21'34.63416"	119°12'10.84686"	87.058	36.026	11-16-16
PLW-5093	Used as marker	-	-		-	11-17-16
RT-6-A	Used as marker	-	-		-	11-17-16
Control Survey on November 16, 2016						
PL-188	1st Order, BM	10°01'44.89299"	119°07'24.55685"	57.865	6.467	11-06-15
UP-BAB	Fixed	09°59'43.61062"	118°53'35.10633"	58.982	6.906	11-06-15

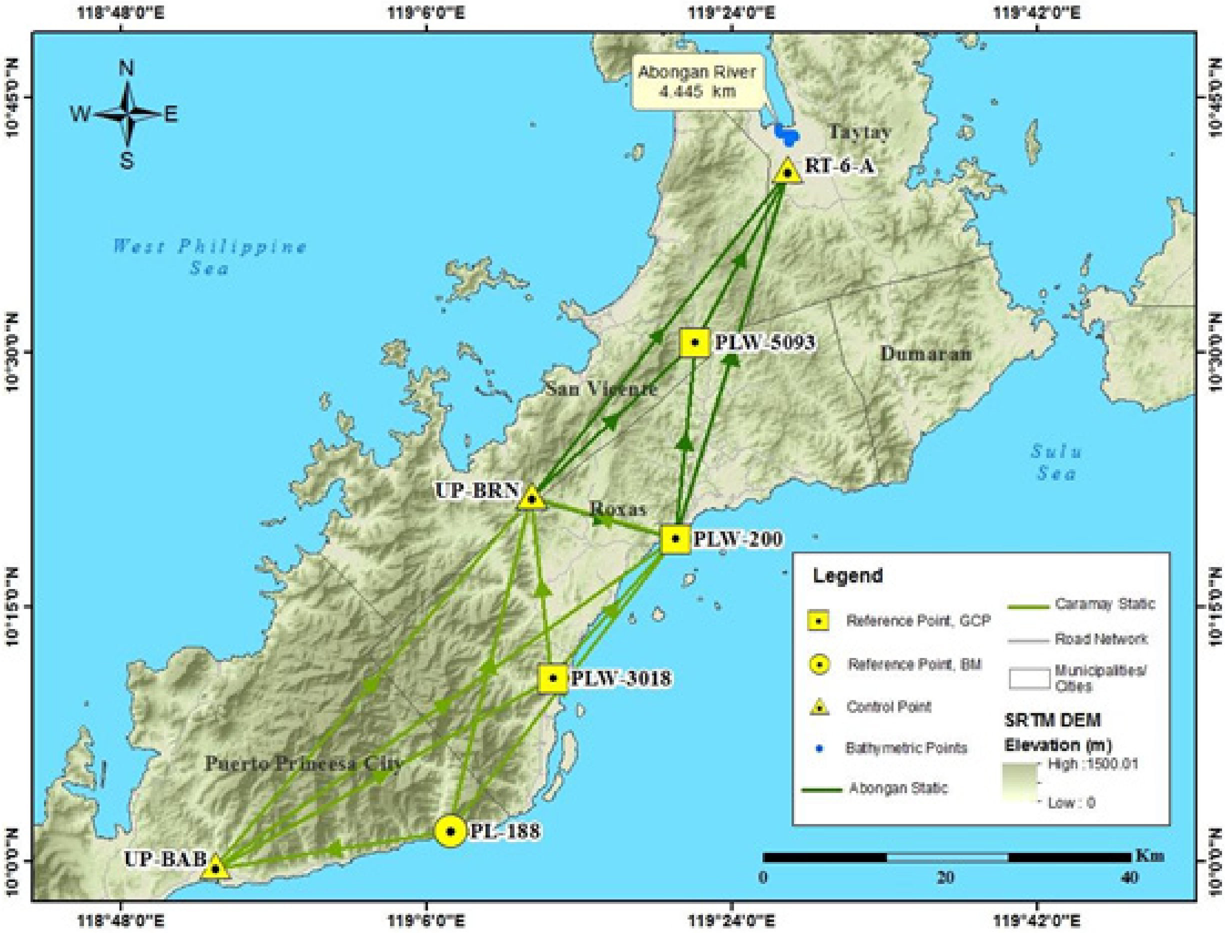


Figure 28. Abongan River Basin Control Survey Extent.

Figure 29 to Figure 34 depict the setup of the GNSS on recovered reference points and established control points in the Abongan River.

Figure 29. GNSS receiver setup, Trimble® SPS 985 at PLW-200, located along the shoreline in Brgy. 1 Poblacion, Municipality of Roxas, Palawan.

Figure 30. GNSS receiver setup, Trimble® SPS 852, at UP-BRN, located near Port Barton in Brgy. Port Barton, Municipality of San Vicente, Palawan.

Figure 31. GNSS receiver setup, Trimble® SPS 985 at PLW-5093, located at the approach of Itabiak Bridge in Brgy. New Agutaya, Municipality of San Vicente, Palawan.

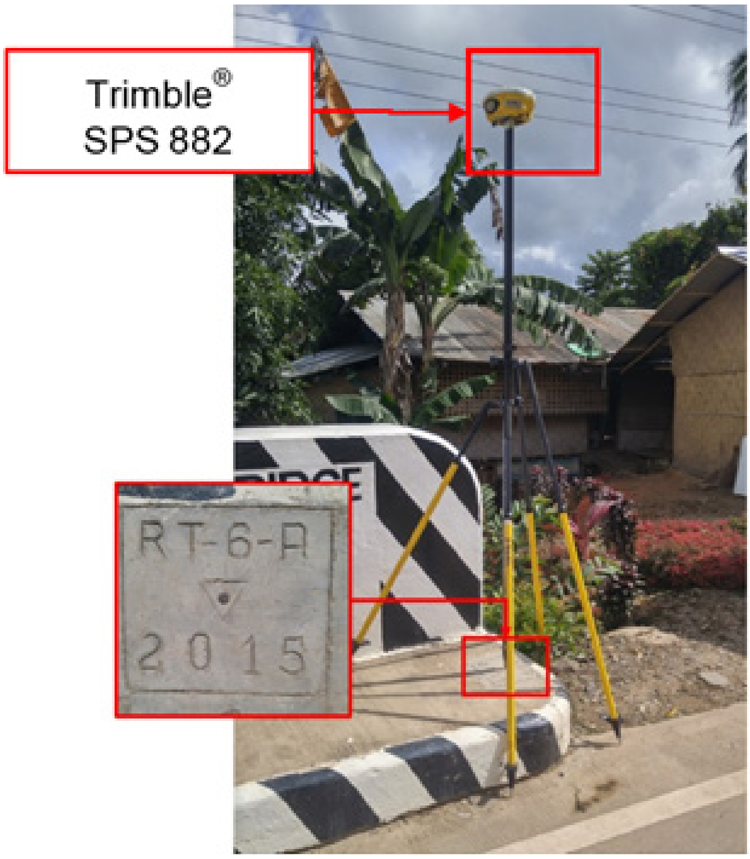


Figure 32. GNSS receiver setup, Trimble® SPS 882, at RT-6-A, located at the approach of Abongan Bridge in Brgy. Abongan, Municipality of Taytay, Palawan.

Figure 33. GNSS receiver setup, Trimble® SPS 985, at PL-188, located at the approach of Langogan Bridge in Brgy. Langogan, Puerto Prinsesa City, Palawan

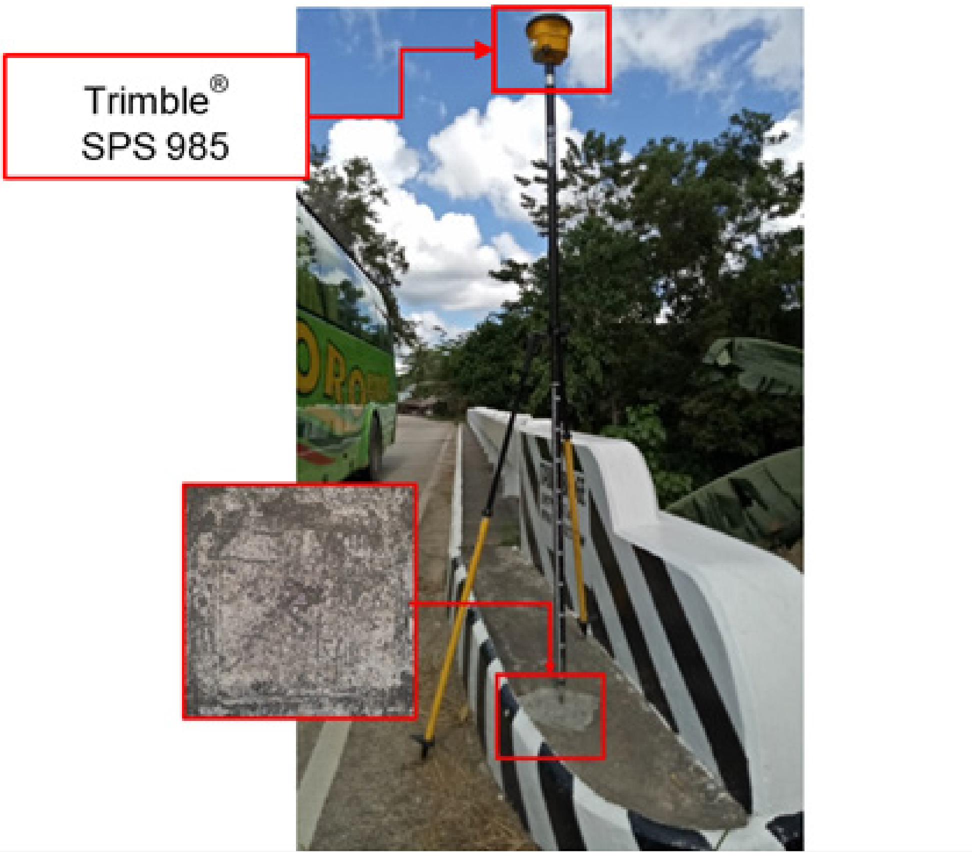


Figure 34. GNSS receiver setup, Trimble® SPS 985, at UP-BAB, located at the approach of Babuyan Bridge in Brgy. Babuyan, Puerto Prinsesa City, Palawan.

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 21 presents the baseline processing results of control points in the Abongan River Basin, as generated by the TBC software.

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

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)
UP-BRN --- RT-6-A (B20)	11-17-16	-	-	-	-	-
RT-6-A --- PLW-200 (B21)	11-17-16	Fixed	0.003	0.018	37°57'36"	44837.055
PLW-5093 --- PLW-200 (B30)	11-16-16	Fixed	0.004	0.019	16°41'52"	41929.568
PLW-5093 --- RT-6-A (B28)	11-17-16	Fixed	0.003	0.020	5°45'52"	21515.488
UP-BRN --- PLW-5093 (B29)	11-17-16	Fixed	0.003	0.021	27°47'55"	21201.041
PLW-200 --- UP-BRN (B9)	11-17-16	Fixed	0.003	0.022	46°51'14"	24262.177
UP-BRN --- PLW-200 (B16)	11-16-16	Fixed	0.004	0.030	107°12'24"	16279.093

As shown in Table 21, a total of seven (7) baselines were processed with the coordinates and elevation of PLW-200 and UP-BRN, both from previous PHIL-LIDAR1 survey in Caramay River held fixed; it is apparent that all baselines passed the required accuracy.

4.4 Network Adjustment

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

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

where:

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

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

The four (4) control points, MSW-16, MW-42, UP-CLA, and UP-OZA2 were occupied and observed simultaneously to form a GNSS loop. Coordinates of MSW-16 and MW-42; elevation value of MSW-16 and MW-42; and fixed values of MSW-16 and MW-42 were held fixed during the processing of the control points as presented in Table 22. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

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

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
PLW-200	Grid	Fixed	Fixed		Fixed
UP-BRN	Grid	Fixed	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 in Table 23. All fixed control points have no value for grid and elevation error.

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

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
PLW-200	99564.013	?	1142646.180	?	2.161	?	ENe
PLW-5093	101975.793	0.016	1164060.075	0.017	32.014	0.090	
RT-6-A	112096.854	0.026	1182725.718	0.031	9.154	0.084	
UP-BRN	84046.211	?	1147655.023	?	36.026	?	ENe
PLW-200	99564.013	?	1142646.180	?	2.161	?	ENe

The results of the computation for accuracy are as follows:

a. **PLW-200**
horizontal accuracy = Fixed
vertical accuracy = Fixed

b. **UP-BRN**
horizontal accuracy = Fixed
vertical accuracy = Fixed

c. **PLW-5093**
horizontal accuracy = $\sqrt{((1.6)^2 + (1.7)^2}$
= $\sqrt{(2.56 + 2.89)}$
= 2.33 < 20 cm
vertical accuracy = 9.0 < 10 cm

d. **RT-6-A**
horizontal accuracy = $\sqrt{((2.6)^2 + (3.1)^2}$
= $\sqrt{(6.76 + 9.61)}$
= 4.04 < 20 cm
vertical accuracy = 8.4 cm < 10 cm

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

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

Point ID	Latitude	Longitude	Ellipsoid Height (Meter)	Height Error (Meter)	Constraint
PLW-200	N10°18'57.78651"	E119°20'41.94774"	53.649	?	ENe
PLW-5093	N10°30'34.49823"	E119°21'53.01759"	83.163	0.090	
RT-6-A	N10°40'44.83153"	E119°27'18.36843"	60.025	0.084	
UP-BRN	N10°21'34.63416"	E119°12'10.84686"	87.058	?	ENe

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 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 Abongan River GNSS Static Survey are seen in Table 25.

Table 25. The reference and control points utilized in the Abongan 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	Ell Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
Control Survey on November 16, 2016							
PLW-200	Fixed	10°18’57.78651”	119°20’41.94774”	53.649	1142646.180	99564.013	2.161
UP-BRN	Fixed	10°21’34.63416”	119°12’10.84686”	87.058	1147655.023	84046.211	36.026
PLW-5093	Used as marker	10°30’34.49823”	119°21’53.01759”	83.163	1164060.075	101975.793	32.014
RT-6-A	Used as marker	10°40’44.83153”	119°27’18.36843”	60.025	1182725.718	112096.854	9.154
Control Survey on November 6, 2015							
PL-188	1st Order, BM	10°01’44.89299”	119°07’24.55685”	57.865	1111141.315	74882.789	6.467

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

The bridge cross-section and as-built survey were conducted on November 21 and November 28, 2016 at the downstream side of Tabuan bridge in Brgy. Abongan, Municipality of Taytay, Palawan. Asurvey grade GNSS receiver Trimble® SPS 985 in PPK survey technique (Figure 35 and Figure 36).

Figure 35. Tabuan Bridge facing upstream.

Figure 36. Bridge As-Built Survey using PPK Technique.

The length of the cross-sectional line surveyed at Tabuan Juan Bridge is about 103 m. (Figure 38) with seventy-six (76) cross-sectional points using the control point RT-6-A as the GNSS base station. The location map, cross-section diagram, and the accomplished bridge data form are shown in Figure 37 and Figure 39.

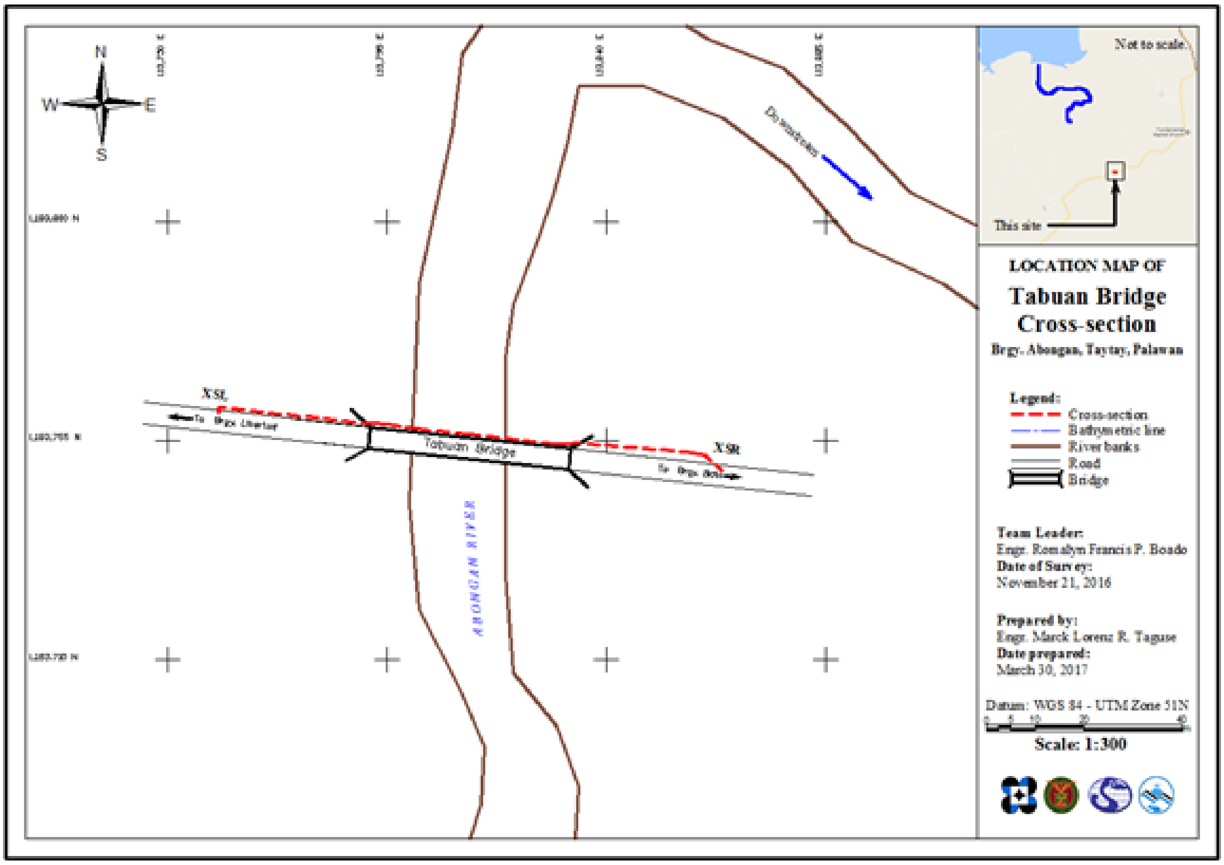


Figure 37. Location map of the Tabuan Bridge Cross Section.

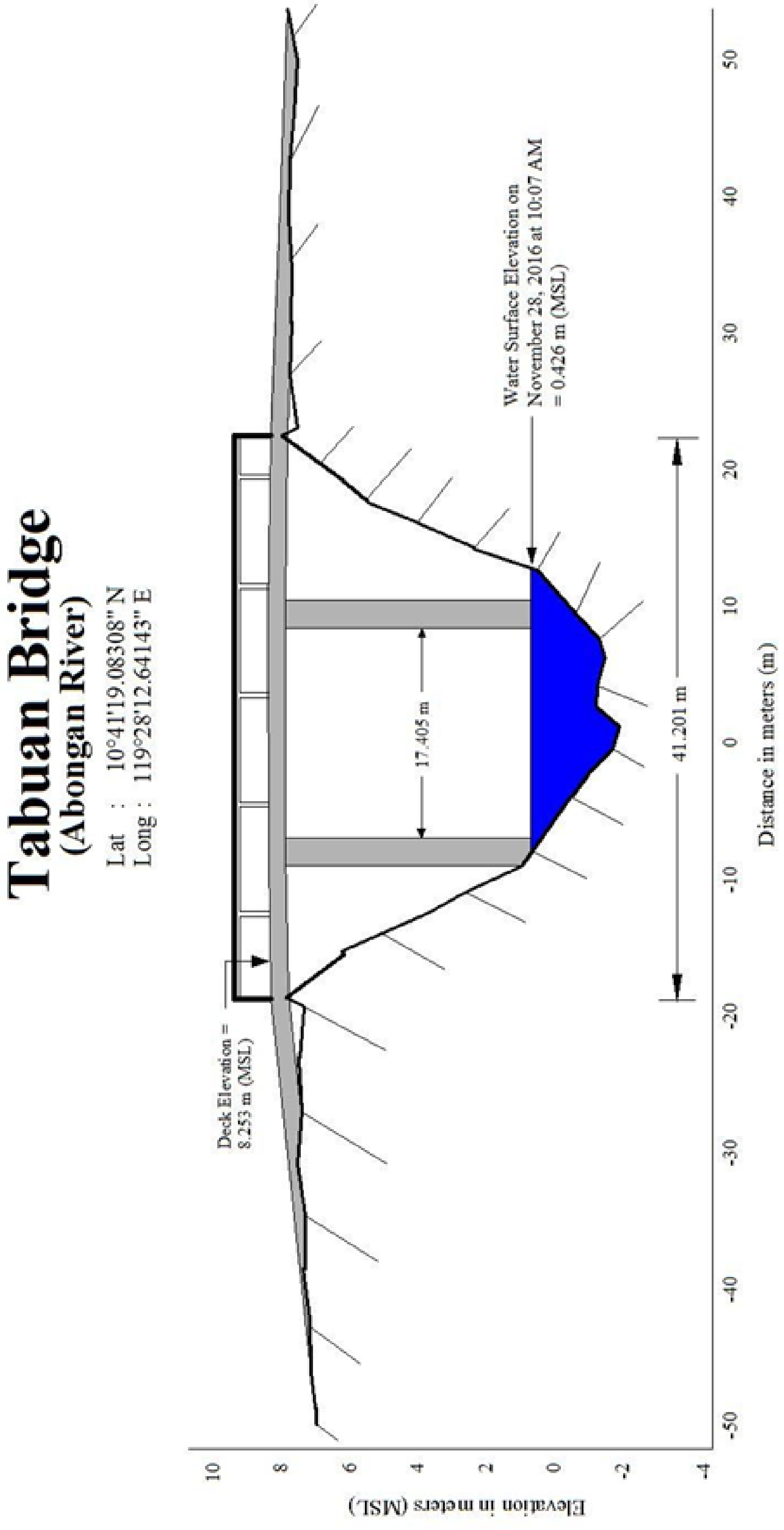


Figure 38. The Tabuan Bridge cross-section survey drawn to scale.

Bridge Data Form

Bridge Name: Tabuan Bridge **Date:** November 21 and 28, 2016

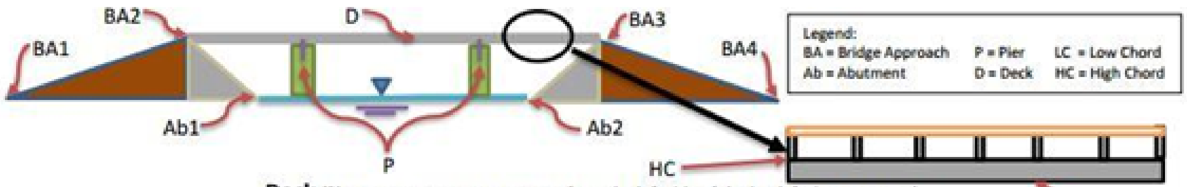
River Name: Abongan River **Time:** 10:07 AM

Location (Brgy, City,Region): Brgy. Abongan, Taytay, Palawan

Survey Team: Romalyn Francis Boado, Marck Lorenz Taguse, Cibyl Atacador

Flow condition: average **Weather Condition:** fair

Latitude: 10°41'19.08308"N **Longitude:** 119°28'12.64143"E



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

Elevation: 8.253 m **Width:** not available **Span (BA3-BA2):** 41.201 m

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	6.938 m	BA3	72.416 m	8.278 m
BA2	31.215 m	8.253	BA4	103.683 m	7.776 m

Abutment: Is the abutment sloping? ; If yes, fill in the following information:

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

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

Shape: round Number of Piers: 2 Height of column footing: Not available

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	41.975 m	8.335 m	
Pier 2	59.380 m	8.344 m	

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

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

Water surface elevation of Caramay River was determined by a survey grade GNSS receiver Trimble® SPS 985 in PPK survey technique on November 28, 2016 at 10:07 AM at Caramay Bridge with a value of 0.426 m in MSL as shown in Figure 38. This was translated into marking on the bridge's abutment as shown in Figure 40. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Caramay River, the University of the Philippines Los Baños.

Figure 40. Water level markings on Tabuan Bridge.

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on November 21, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 985, mounted in front of a vehicle as shown in Figure 41. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.22 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with RT-6-A occupied as the GNSS base station in the conduct of the survey.

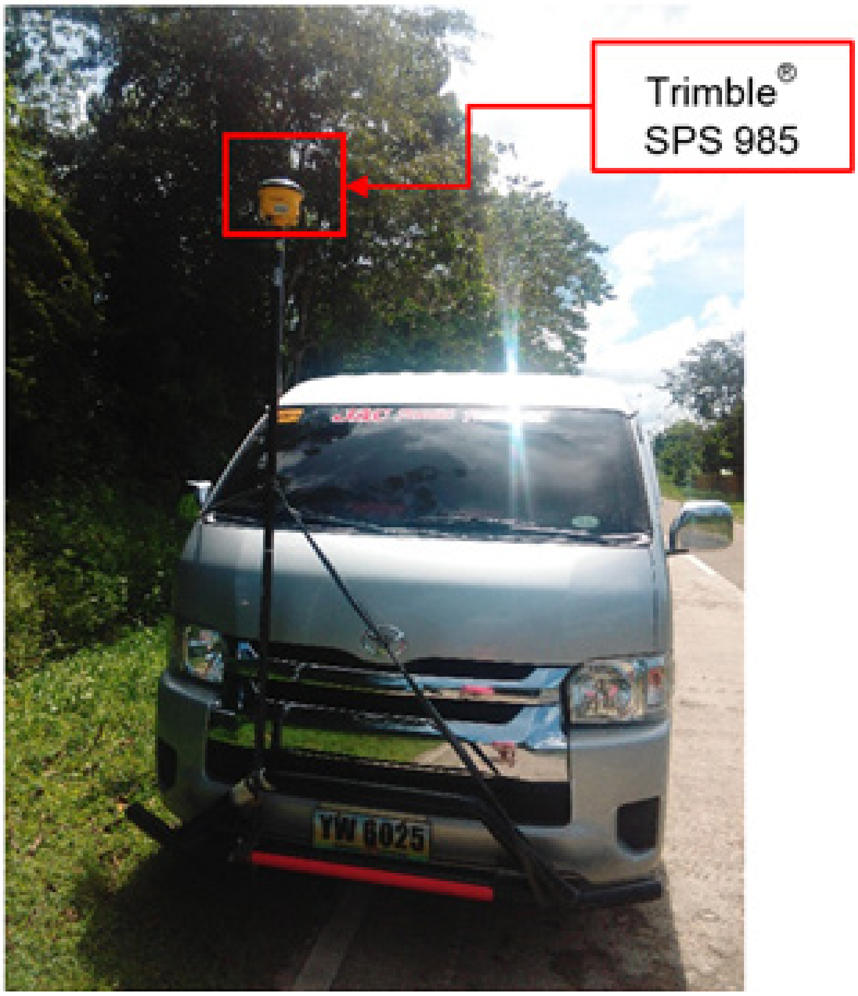


Figure 41. GNSS Receiver Trimble® SPS 985 installed on a vehicle for Ground Validation Survey.

The survey started in Brgy. Bato, Municipality of Taytay going south along national highway covering barangays Abongan, and ended in barangays Alimanguan and Libertad, both in Municipality of Taytay, Palawan. A total of 3,153 points with approximate length of 22 km using RT-6-A as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 42.

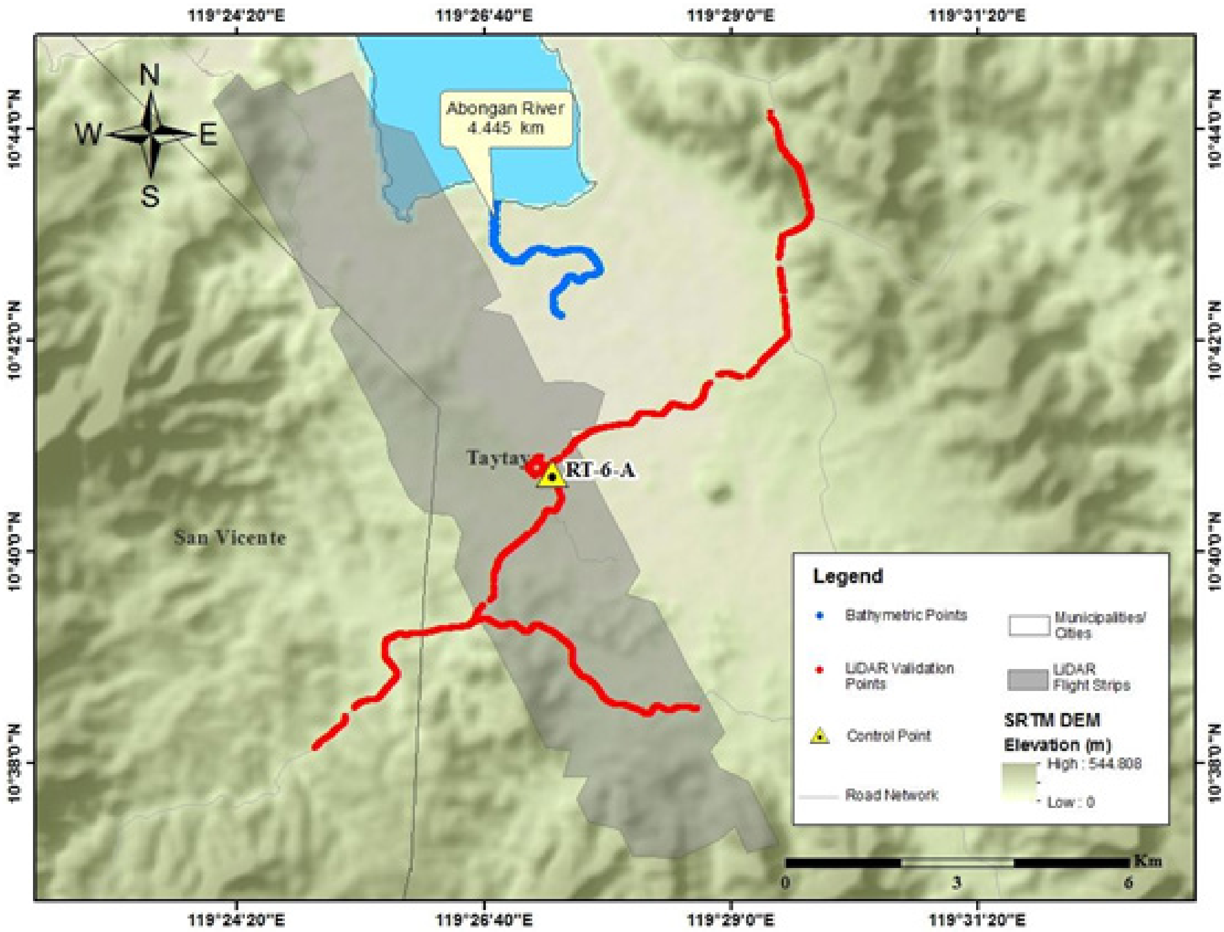


Figure 42. The extent of the LiDAR ground validation survey (in red) for Abongan River Basin.

4.7 River Bathymetric Survey

A bathymetric survey was performed on November 28, 2016 using a Trimble® SPS 985 in GNSS PPK survey technique in continuous topo mode and Ohmex™ single beam echo sounder, as illustrated in Figure 43. It started in Brgy. Abongan, Municipality of Taytay with coordinates 10°42'13.79230"N, 119°27'23.61903"E, traversed down the river by boat and ended at the mouth of the river in the same barangay with coordinates 10°43'18.58610"N, 119°26'46.59852"E, as shown in the map in Figure 44.

Figure 43. Set up of the bathymetric survey at Abongan River using Ohmex™ single beam echo sounder.

The bathymetric survey for Abongan River gathered a total of 6,283 points covering 4.445 km of the river traversing Brgy. Abongan, Municipality of Taytay, Palawan. A CAD drawing was also produced to illustrate the riverbed profile of Abongan River. As shown in Figure 45, the highest and lowest elevation has a 4-m difference. The highest elevation observed was -0.549 m above MSL located 500 m from the mouth of the river; while the lowest was –4.504 m below MSL located a kilometer from the starting point of the river upstream.

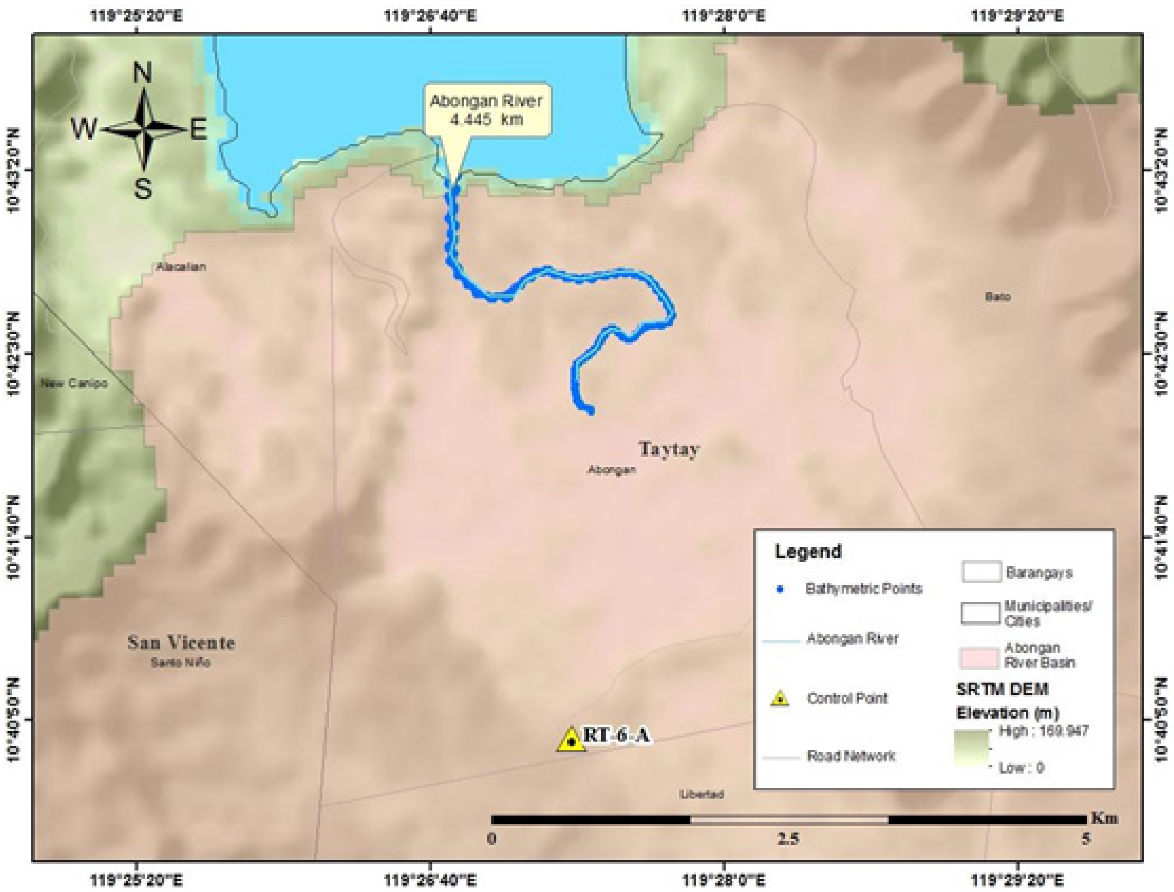


Figure 44. The extent of the Abongan River Bathymetry Survey.

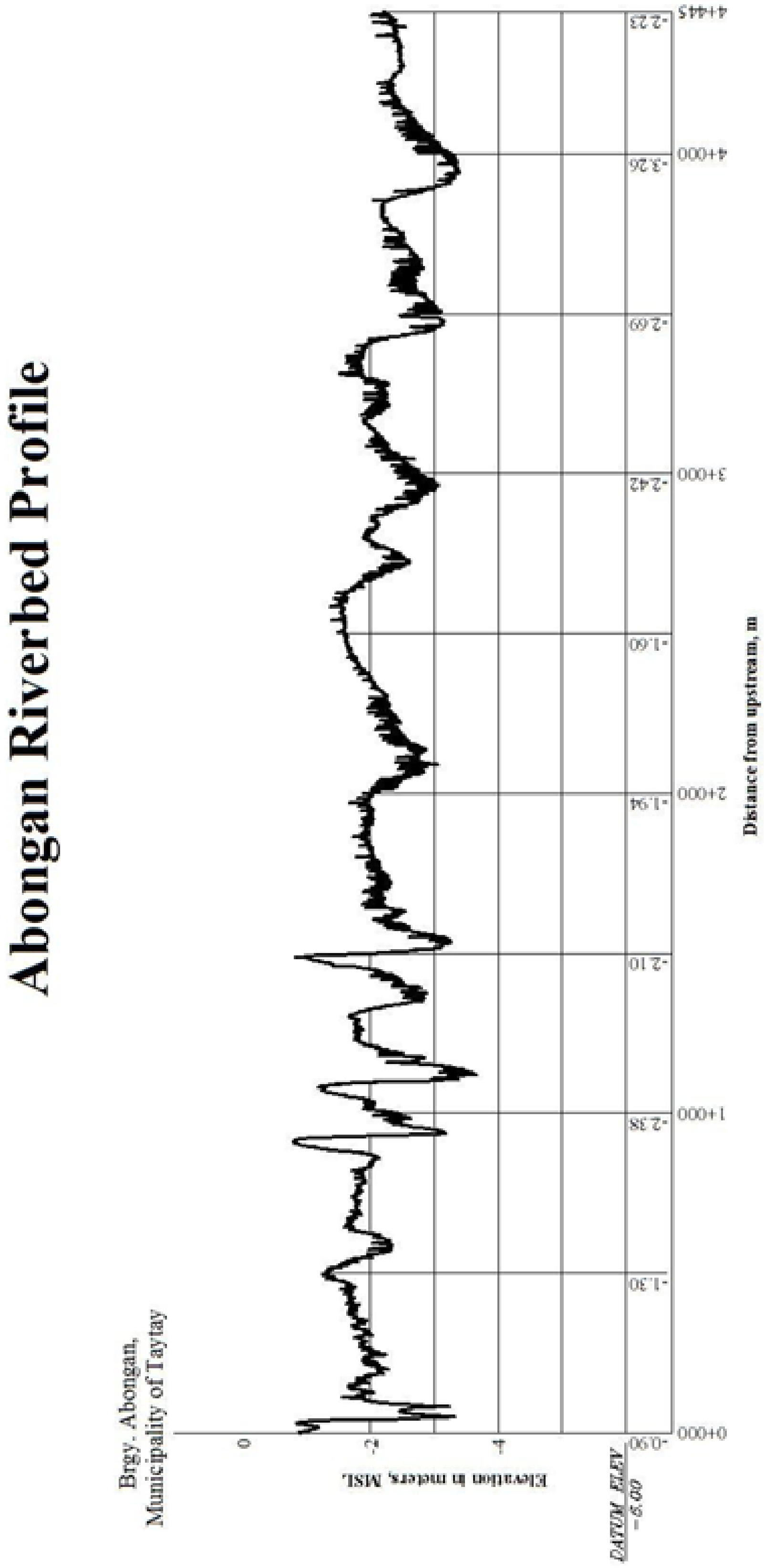


Figure 45. The Abongan Riverbed Profile.

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

The methods applied in this chapter were based on the DREAM methods manual (Ang, 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

No gathered rainfall data for Abongan river basin. The HMS model is not calibrated. The values generated HMS models are by default.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Puerto Princesa Rain 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 47). This station was selected based on its proximity to the Abongan watershed. The extreme values for this watershed were computed based on a 58-year record.

Table 26. RIDF values for the Laoag Rain Gauge, as computed by PAGASA.

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	14.8	22	27.3	36.2	49.8	58.8	75.1	88	104.1
5	21.3	31.9	39.7	52.3	73	86.9	112.8	135.4	156.4
10	25.6	38.5	48	63	88.4	105.5	137.8	166.8	191.1
15	28.1	42.2	52.6	69	97	116	151.9	184.5	210.6
20	29.8	44.7	55.9	73.3	103.1	123.4	161.7	196.8	224.3
25	31.1	46.7	58.4	76.5	107.8	129.1	169.3	206.4	234.9
50	35.2	52.9	66.1	86.5	122.2	146.5	192.7	235.8	267.3
100	39.2	59	73.7	96.4	136.5	163.8	216	265	299.6

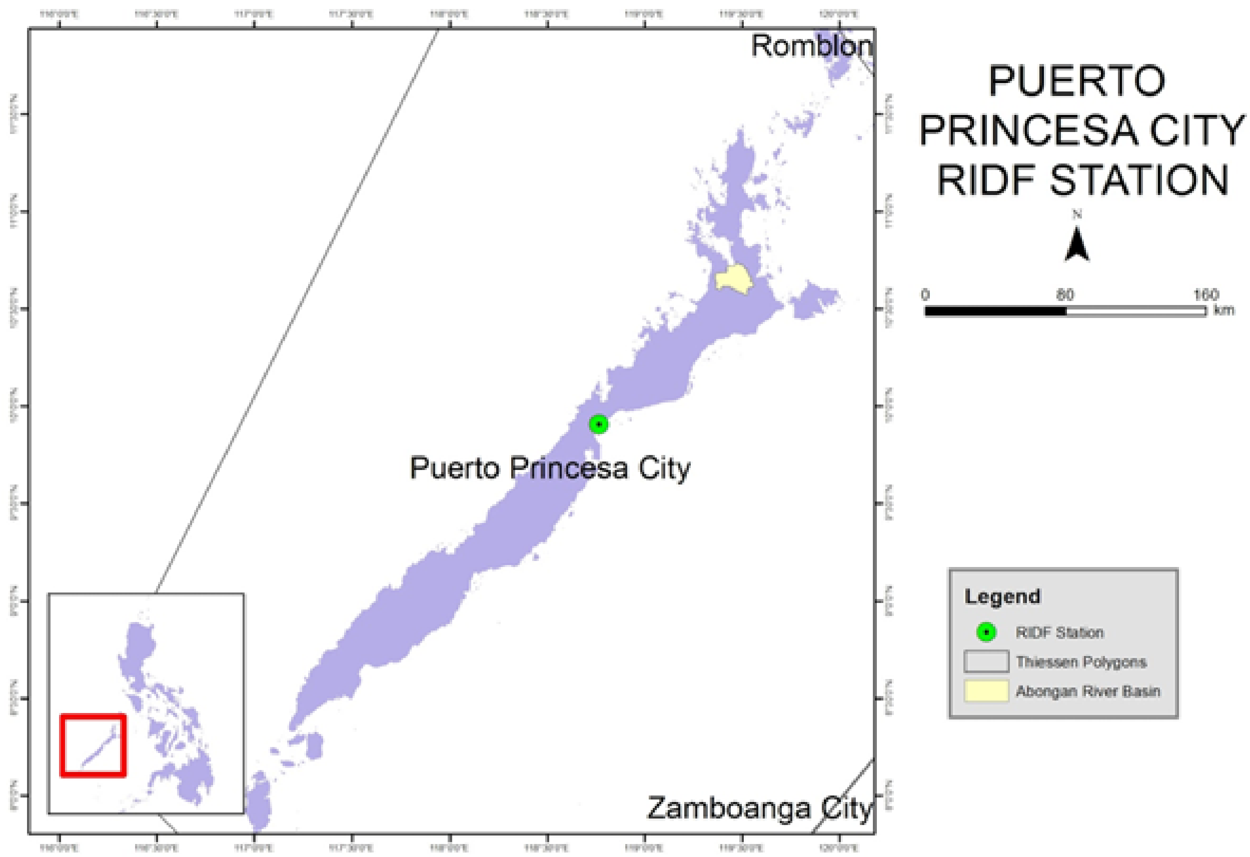


Figure 46. Location of Puerto Princesa RIDF Station relative to Abongan River Basin.

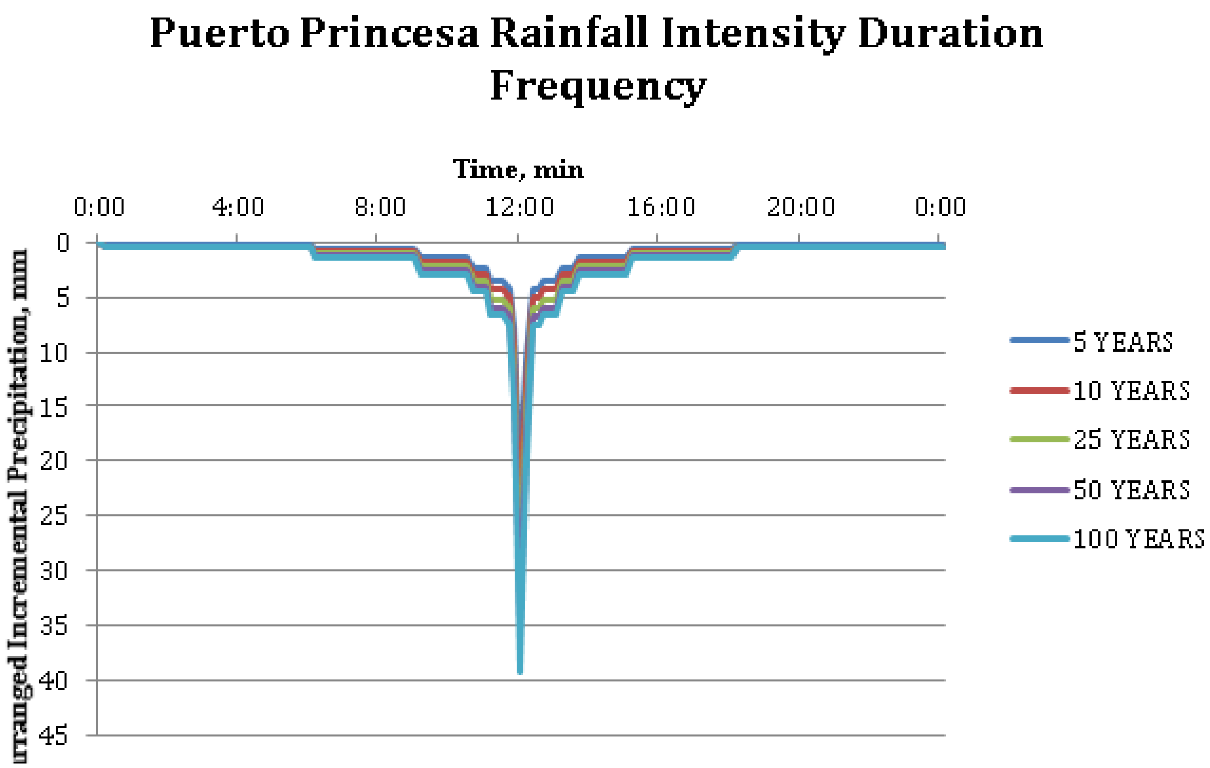


Figure 47. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 from the Bureau of Soils under the Department of Environment and Natural Resources Management. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Abongan River Basin are

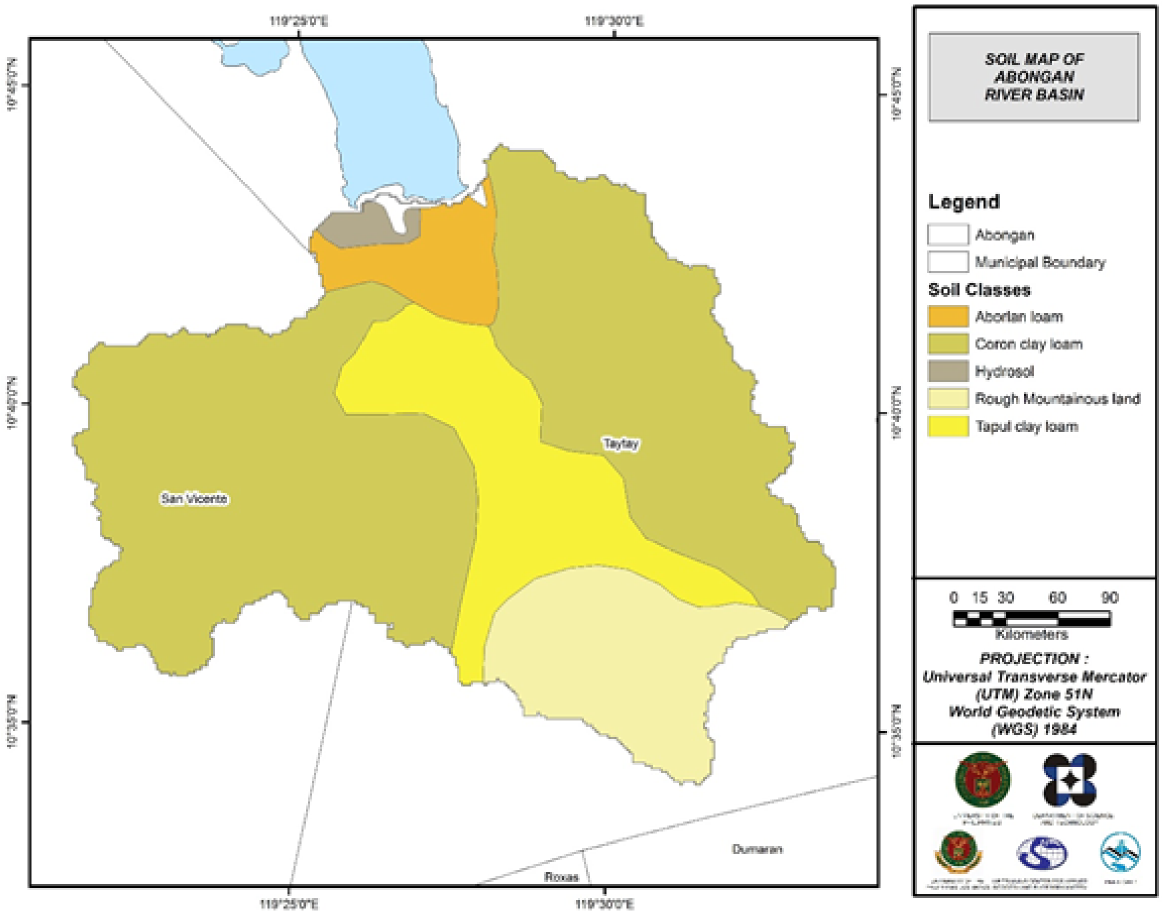


Figure 48. Soil Map of Abongan River Basin.

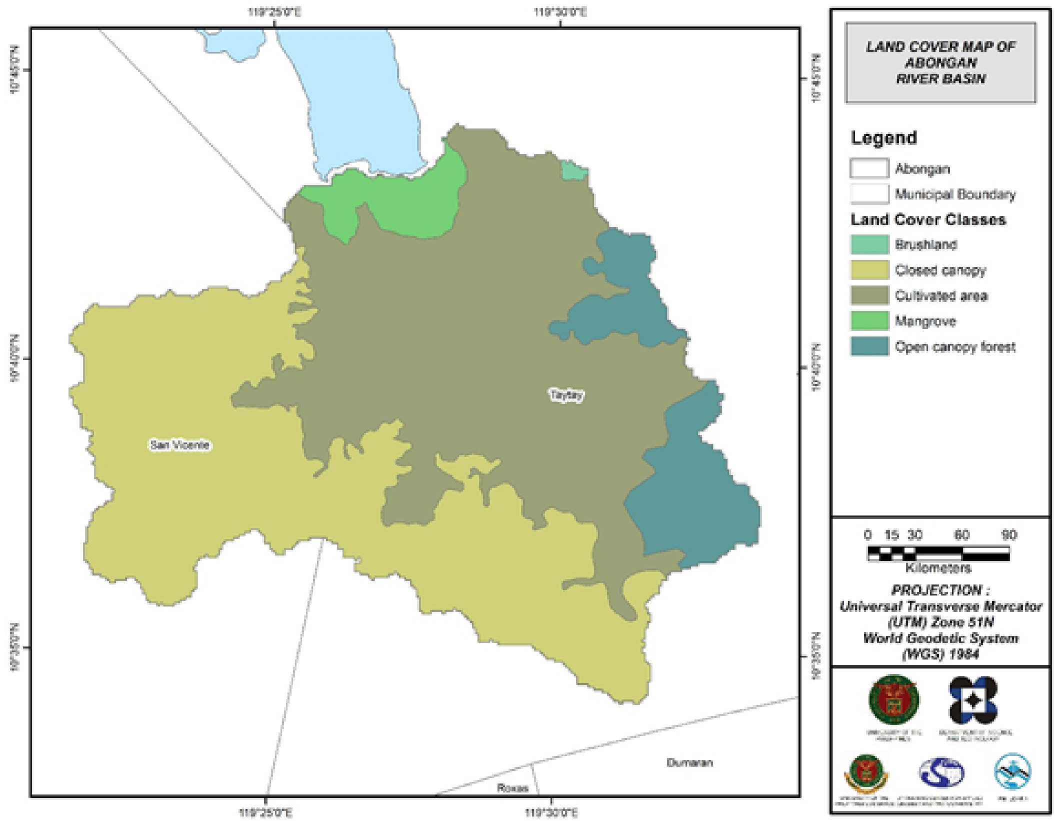


Figure 49. Land Cover Map of Abongan River Basin.

For Abongan, four (4) soil classes were identified. These are clay, clay loam, silt loam and undifferentiated land. Moreover, seven (7) land cover classes were identified. These are brushlands, built-up areas, cultivated areas, inland water, open areas, open canopy forests, and tree plantations.

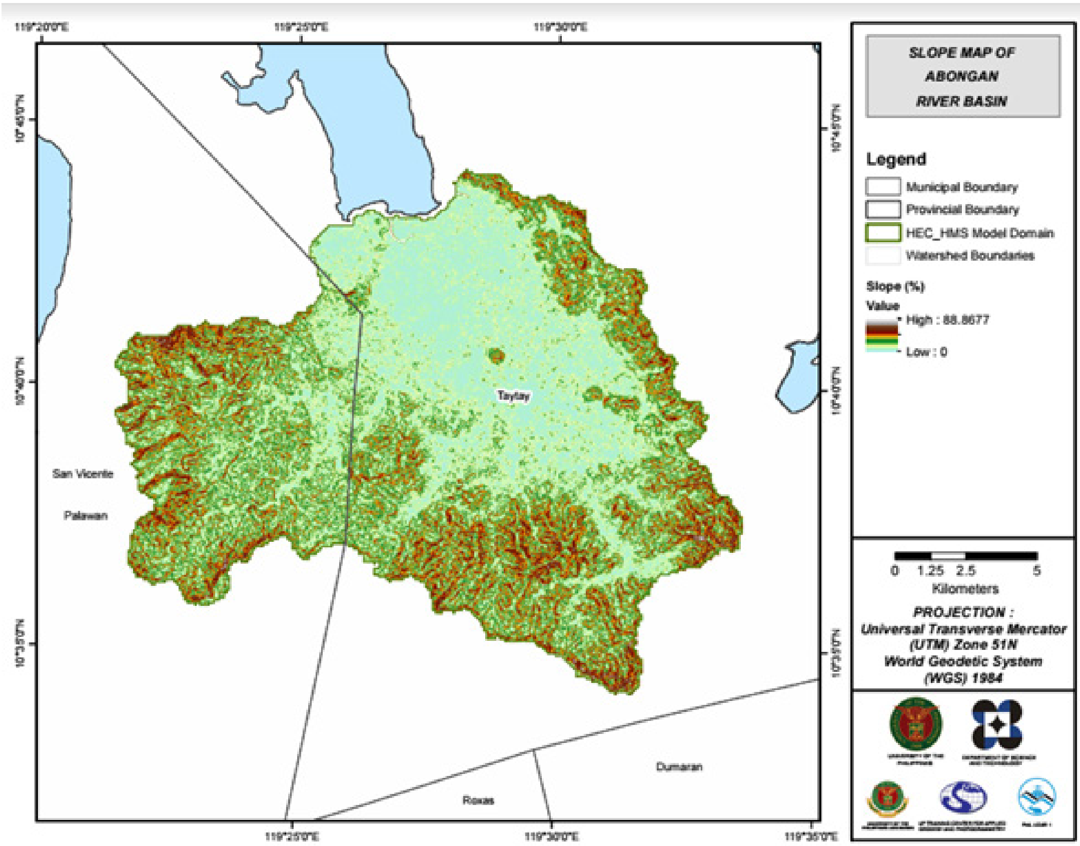


Figure 50. Slope Map of the Abongan River Basin.

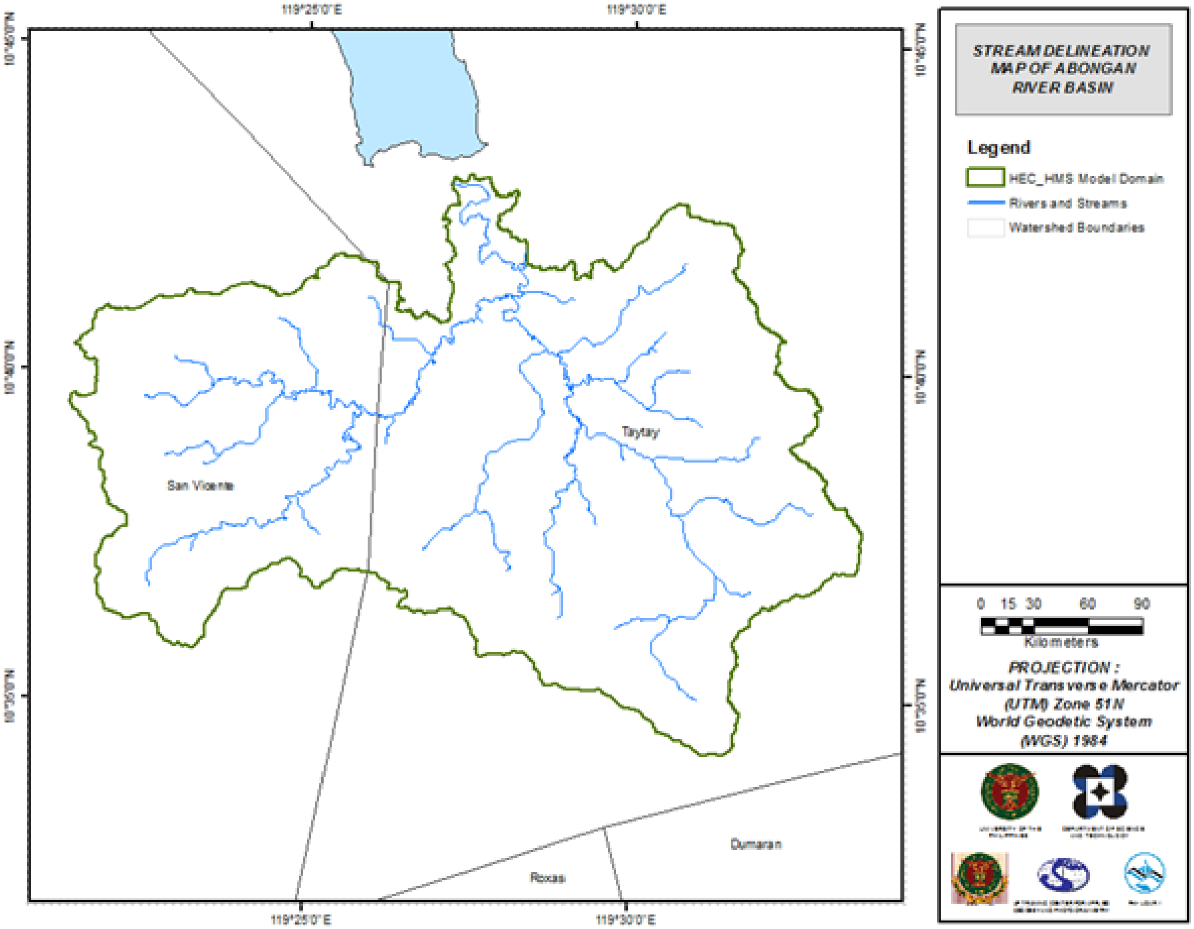


Figure 51. Stream Delineation Map of Abongan River Basin.

Using the SAR-based DEM, the Abongan basin was delineated and further subdivided into subbasins. The model consists of 62 sub basins, 32 reaches, and 29 junctions as shown in Figure 52 (See Annex 10). The main outlet is at 504.

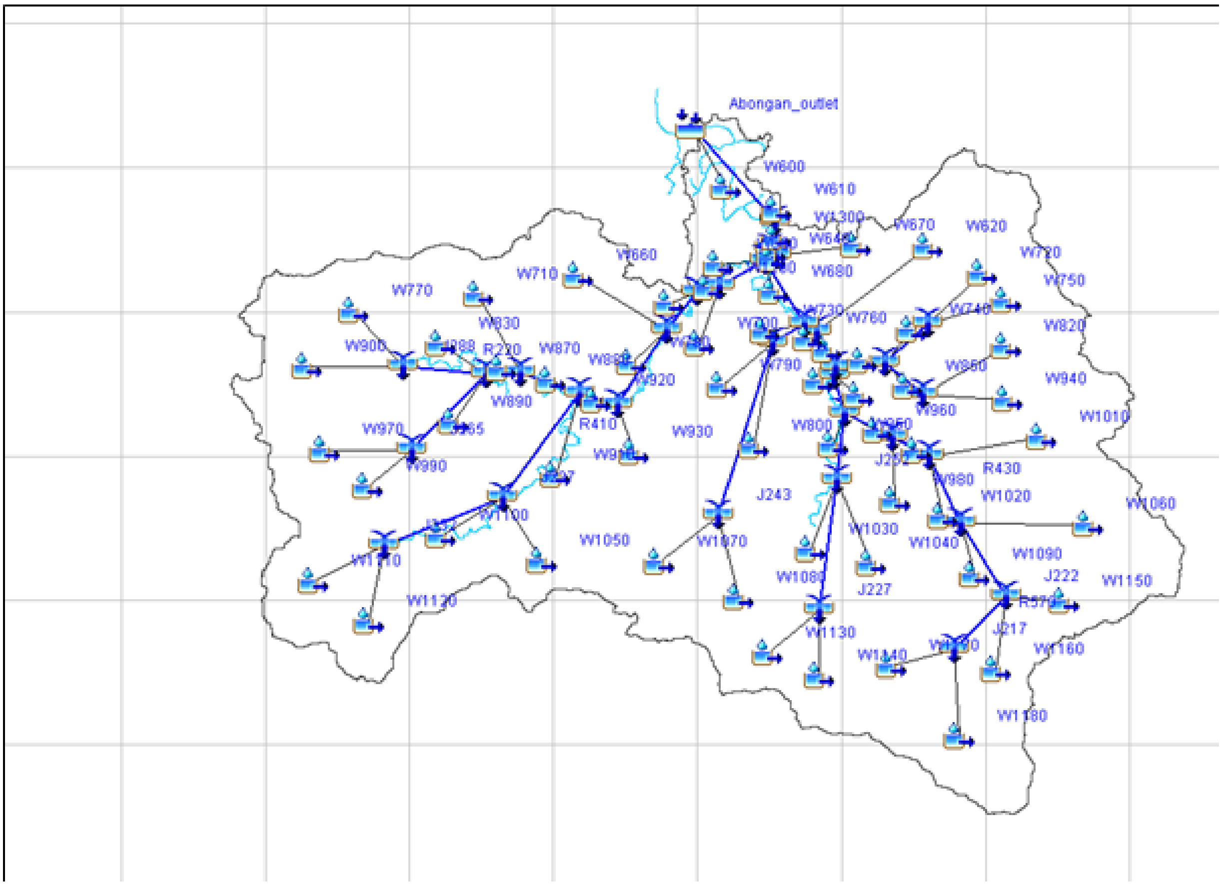


Figure 52. Abongan river basin model generated in HEC-HMS.

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 53).

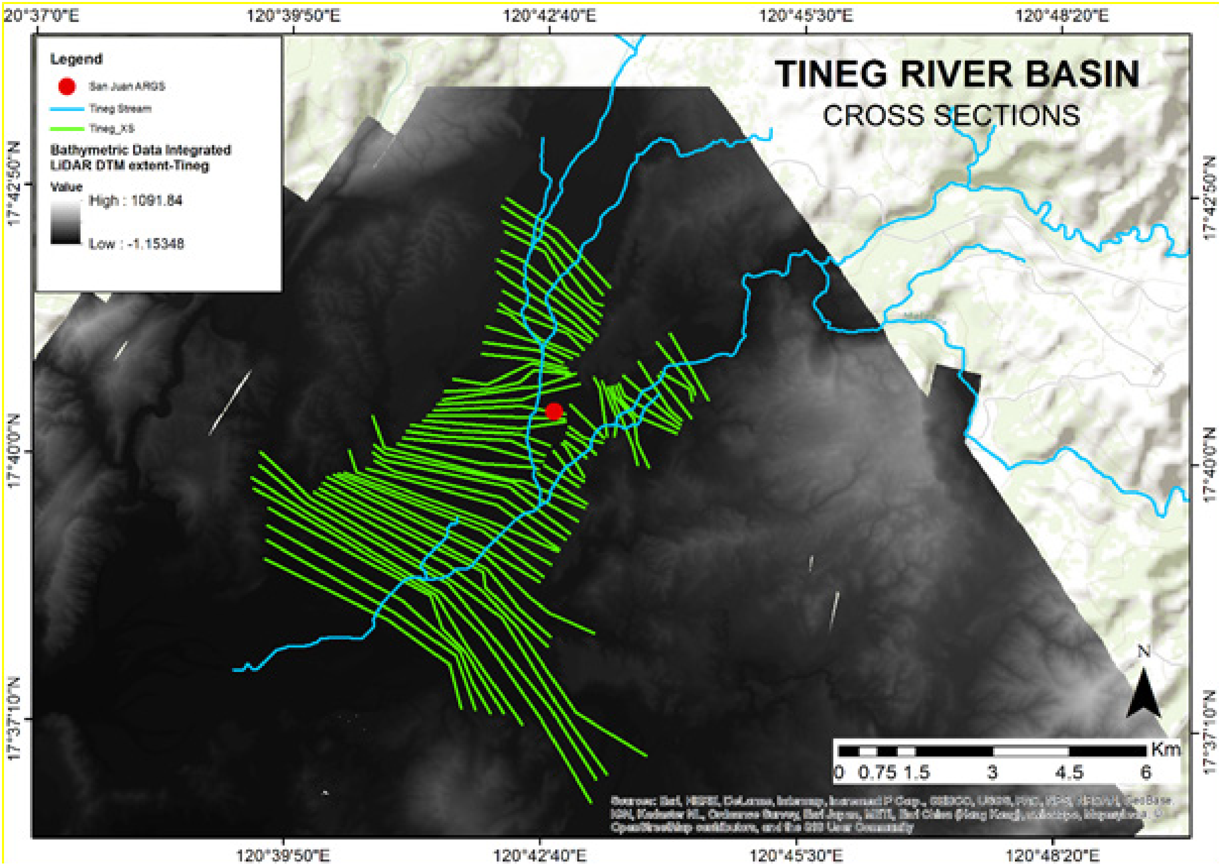


Figure 53. River cross-section of the Abongan River through the ArcMap HEC GeoRas tool.

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

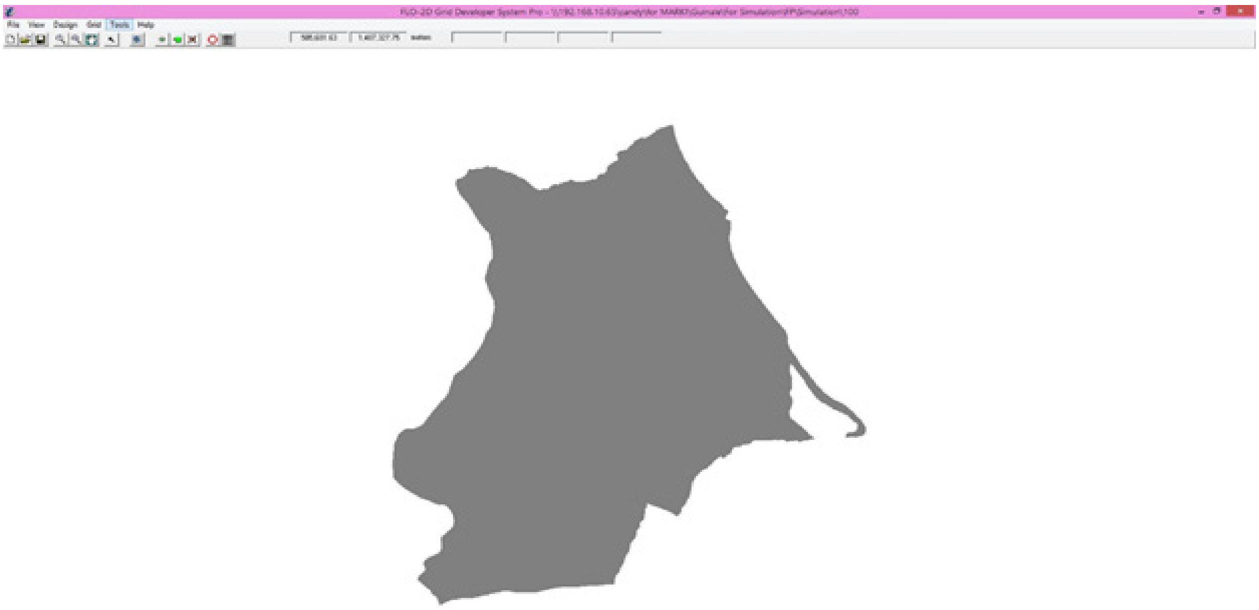


Figure 54. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro).

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 100.06329 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 generated hazard maps for Abongan are in Figure 68, 70, and 72.

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 63 792 800.00 m2. The generated flood depth maps for Abongan are in Figure 69, 71, and 73.

There is a total of 465 228 177.98 m3 of water entering the model. Of this amount, 25 253 779.51 m3 is due to rainfall while 439 974 398.47 m3 is inflow from other areas outside the model. 11 329 565.00 m3 of this water is lost to infiltration and interception, while 24 641 579.81 m3 is stored by the flood plain. The rest, amounting up to 429 257 024.59 m3, is outflow.

5.6 Results of HMS Calibration

The river discharge values for the three rivers entering the floodplain are shown in Figure 64 to Figure 66 and the peak values are summarized in Table 34 to Table 36

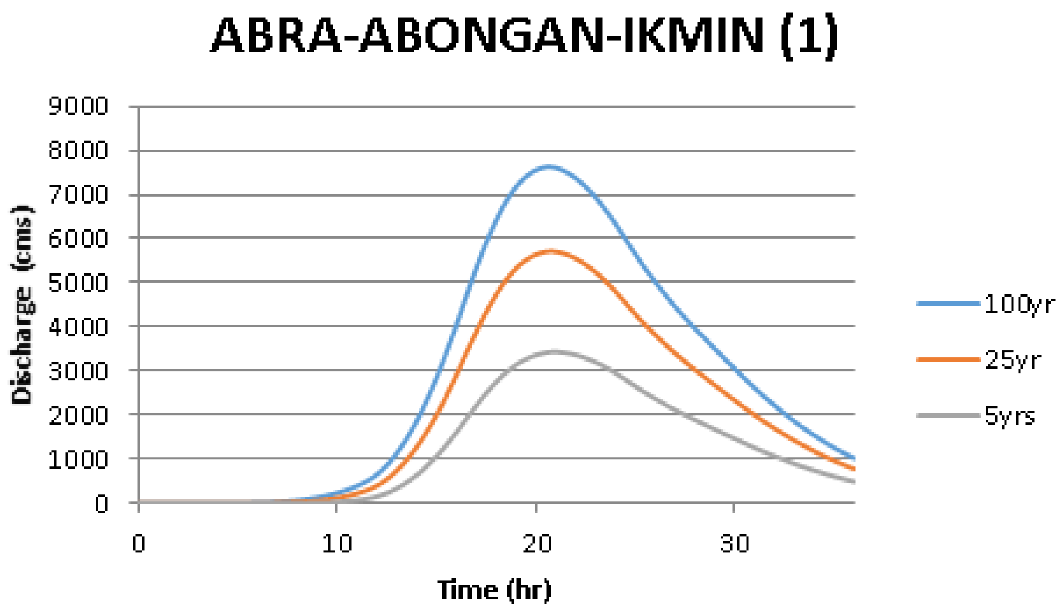


Figure 55. Abra-Abongan-Ikmin river (1) generated discharge using 5-, 25-, and 100-year Laoag rainfall intensity-duration-frequency (RIDF) in HEC-HMS.

Enumerated in Table 32 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 27. Summary of Abra-Abongan-Ikmin river (3) discharge generated in HEC-HMS.

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	10623.6	23 hours, 20 minutes
25-Year	7840.6	23 hours, 30 minutes
5-Year	4561.3	24 hours
50-Year	124.231	3 hours 10 minutes
100-Year	157.447	3 hours

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 37.

Table 28. Validation of river discharge estimates.

Discharge Point	$Q_{MED(SCS)}$, cms	$Q_{BANKFUL}$, cms	$Q_{MED(SPEC)}$, cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Abra-Abongan-Ikmin (1)	3017.872	1614.315	2473.269	Fail	Pass
Abra-Abongan-Ikmin (2)	684.376	26169.898	1093.832	Fail	Pass
Abra-Abongan-Ikmin (3)	4013.944	10866.502	3157.446	Fail	Pass

The results from the HEC-HMS river discharge estimates were not able to satisfy the conditions for validation using the bankful and specific discharge methods. The values are based on theory but are supported using other discharge computation methods so they were good to use for flood modeling. These values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.7 Calculated outflow hydrographs and Discharge values for different rainfall

5.7.1 Hydrograph using the Rainfall Runoff Modelreturn periods

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only

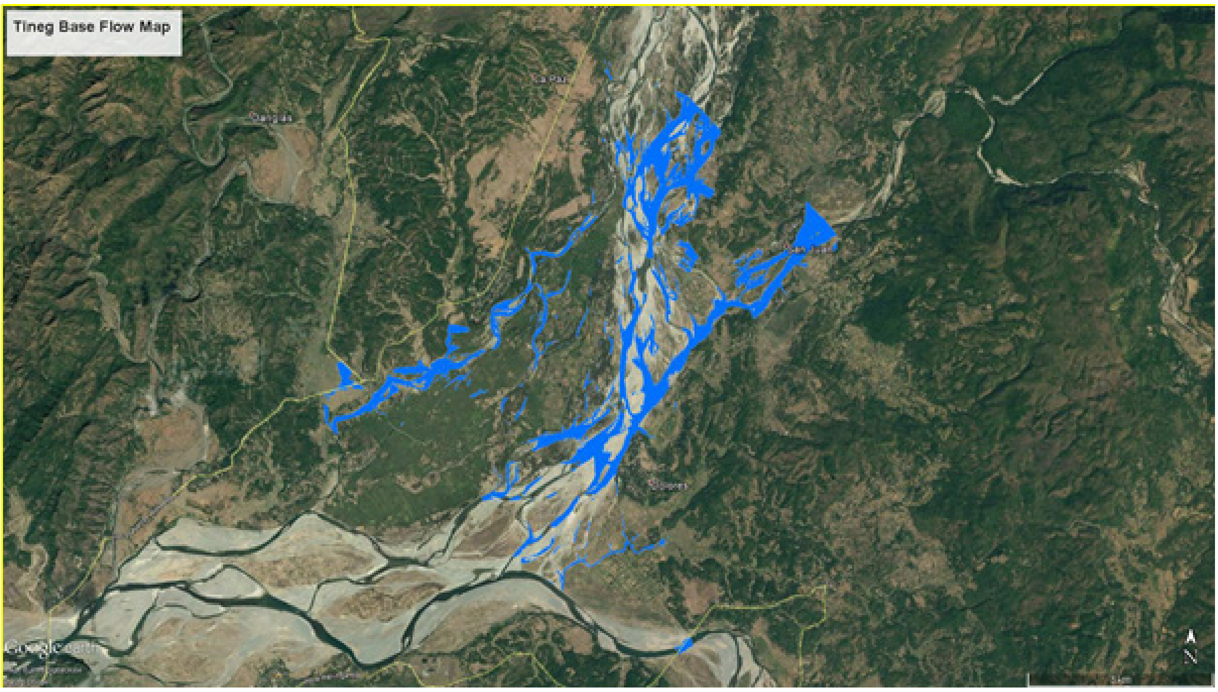


Figure 56. Sample output map of the Abongan RAS Model.

5.8 River Analysis (RAS) Model Simulation

The resulting hazard and flow depth maps have a 10m resolution. Figure 68 to Figure 73 show the 5-, 25-, and 100-year rain return scenarios of the Abongan floodplain. The floodplain, with an area of 189.18 sq. km., covers two municipalities namely San Vicente and Taytay. Table 38 shows the percentage of area affected by flooding per municipality.

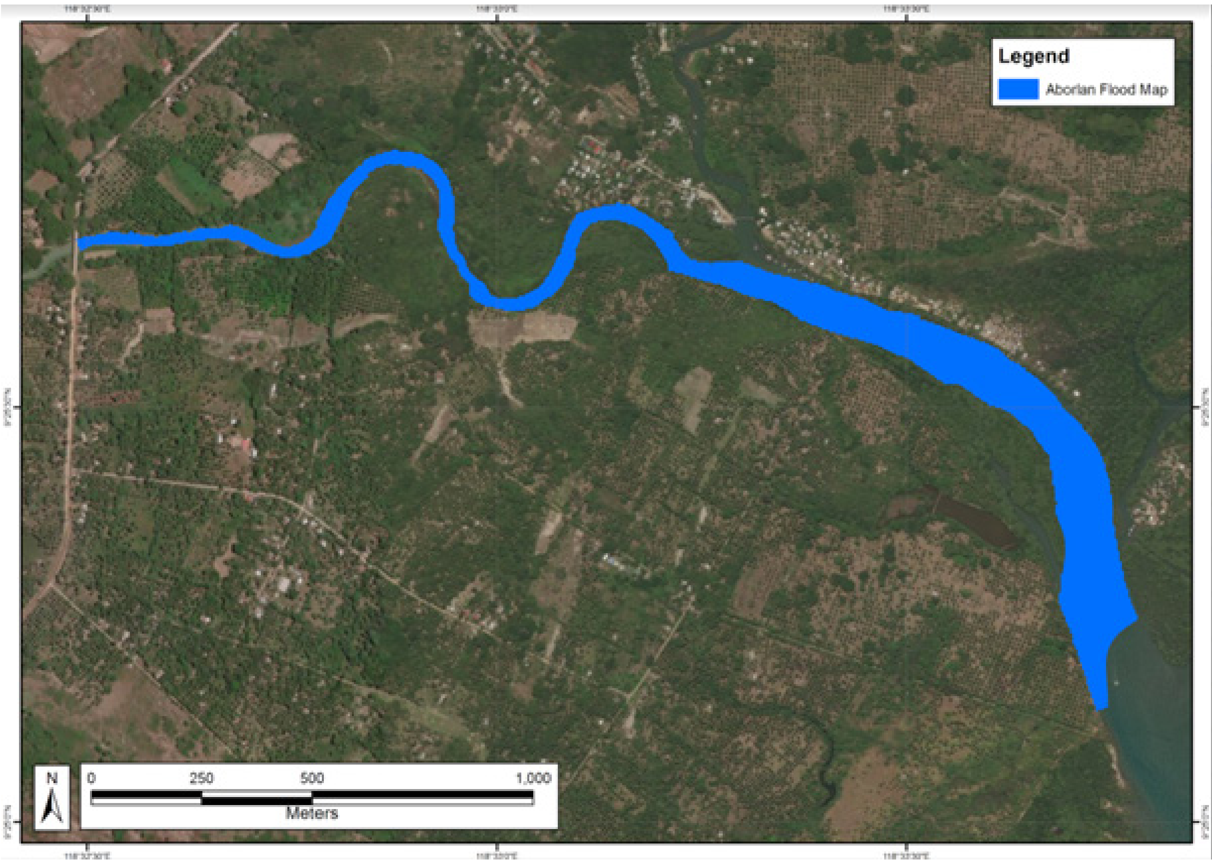


Figure 57. Sample output map of the Abongan RAS Model.

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Abongan floodplain are shown in Figure 58 t0 63. The floodplain, with an area of 189.18 sq. km., covers two municipalities namely San Vicente, and Taytay. Table shown the percentage of area affected by flooding per municipality.

Table 29. Municipalities affected in Abongan floodplain.

Municipality	Total Area	Area Flooded	% Flooded
San Vicente	870.447	52.90	6.08%
Taytay	1325	136.22	10.28%

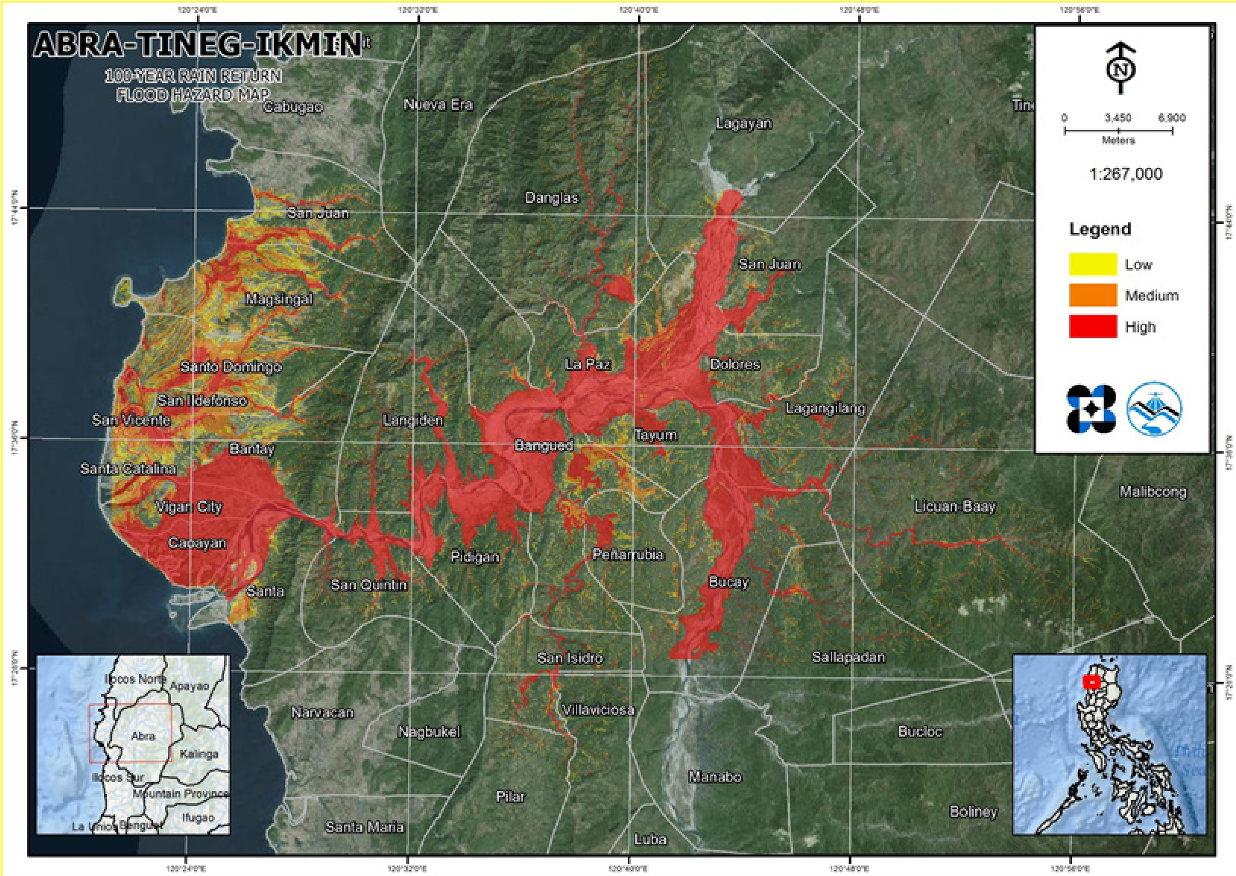


Figure 58. A 100-year Flood Hazard Map for Abongan Floodplain overlaid on Google Earth imagery.

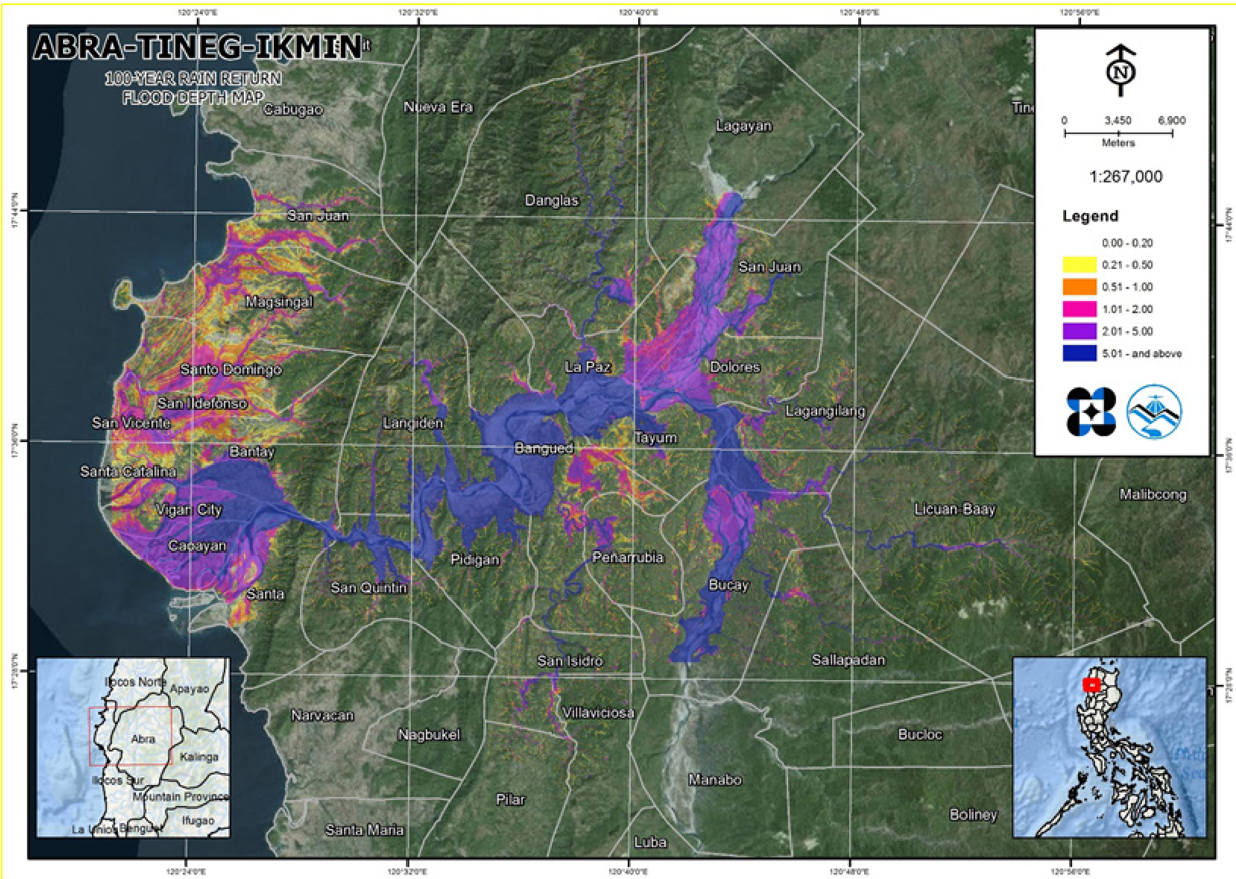


Figure 59. A 100-year Flow Depth Map for Abongan Floodplain overlaid on Google Earth imagery.

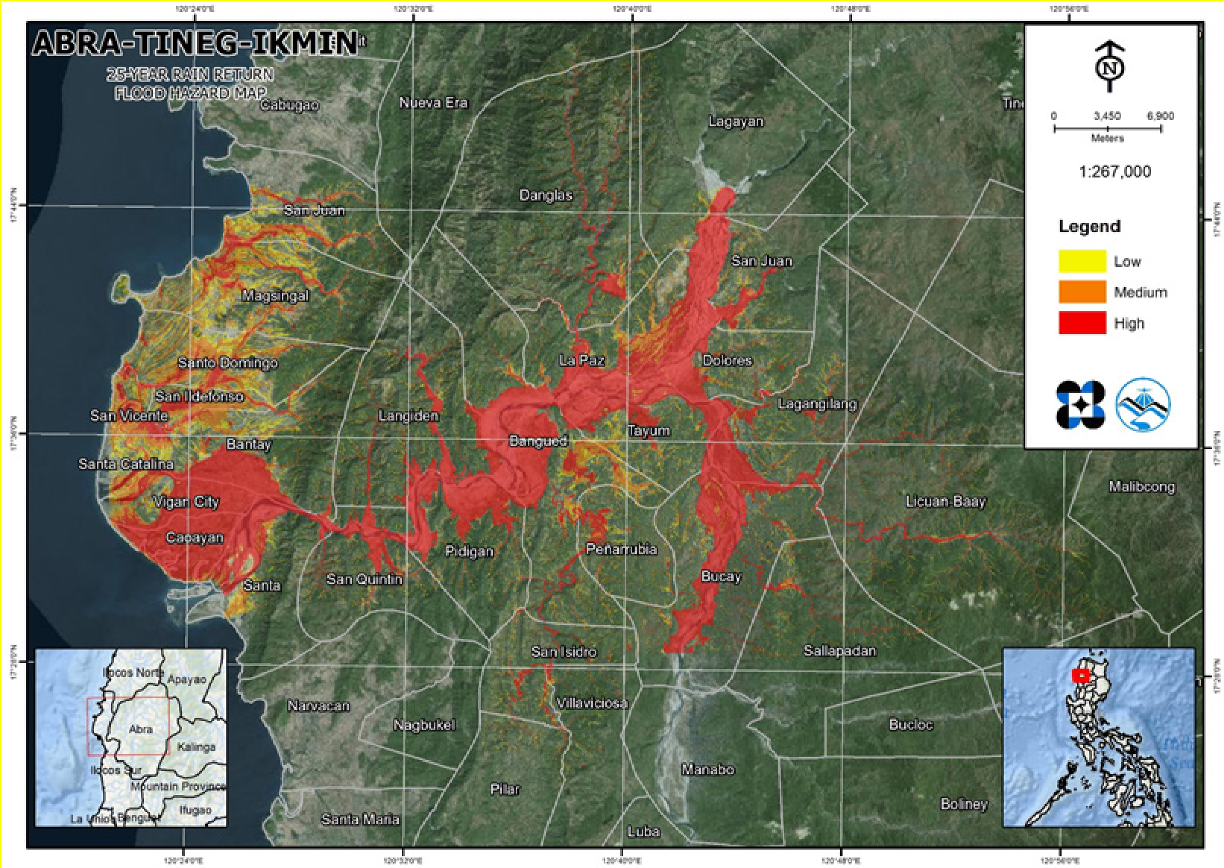


Figure 60. A 25-year Flood Hazard Map for Abongan Floodplain overlaid on Google Earth imagery.

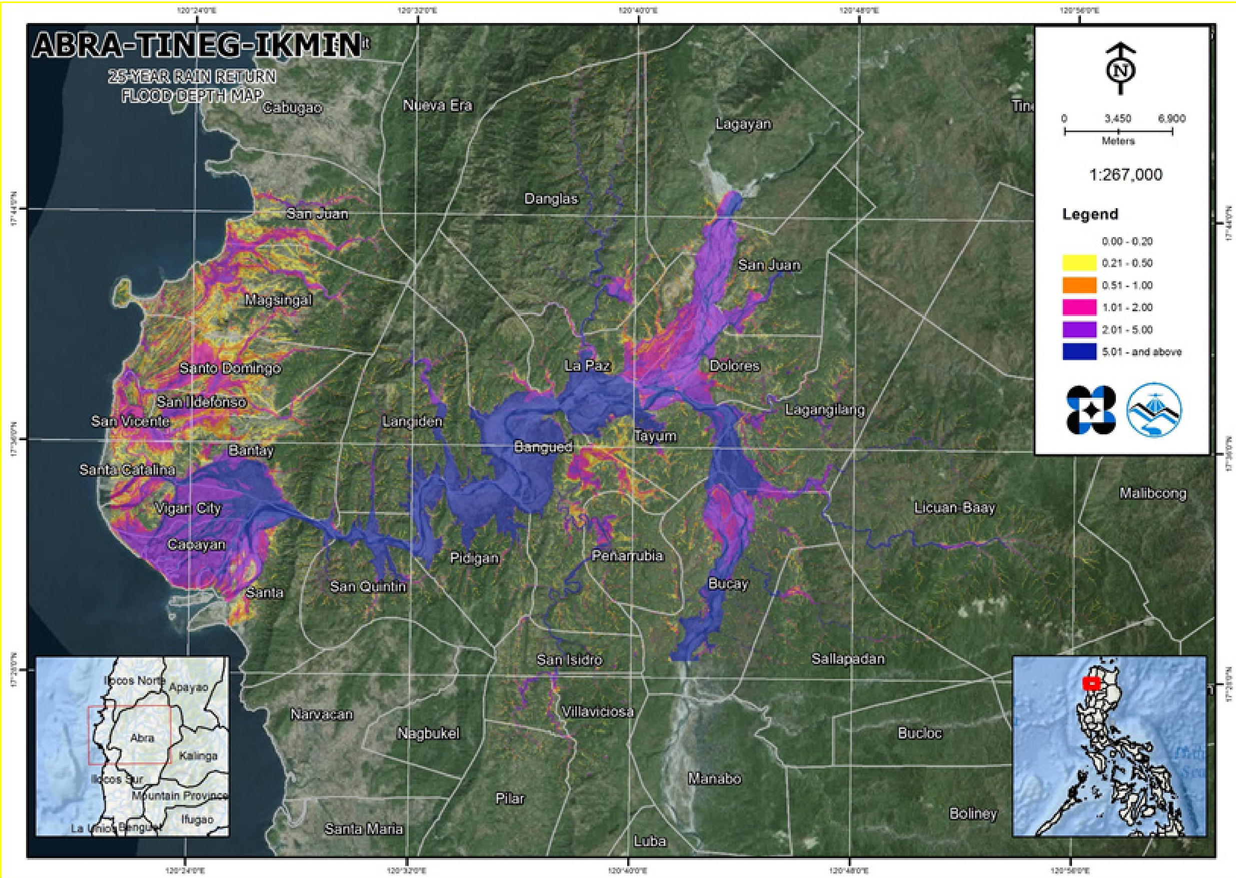


Figure 61. A 25-year Flow Depth Map for Abongan Floodplain overlaid on Google Earth imagery.

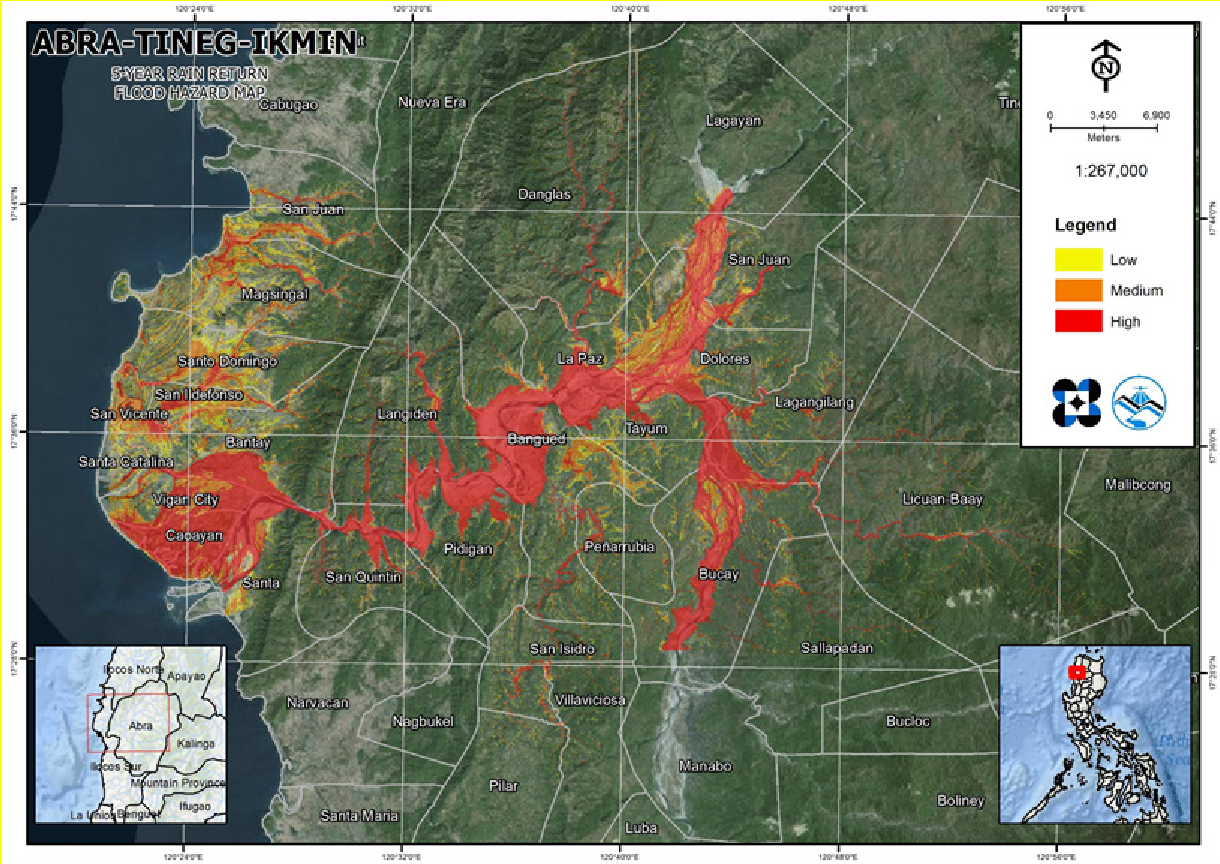


Figure 62. A 5-year Flood Hazard Map for Abongan Floodplain overlaid on Google Earth imagery.

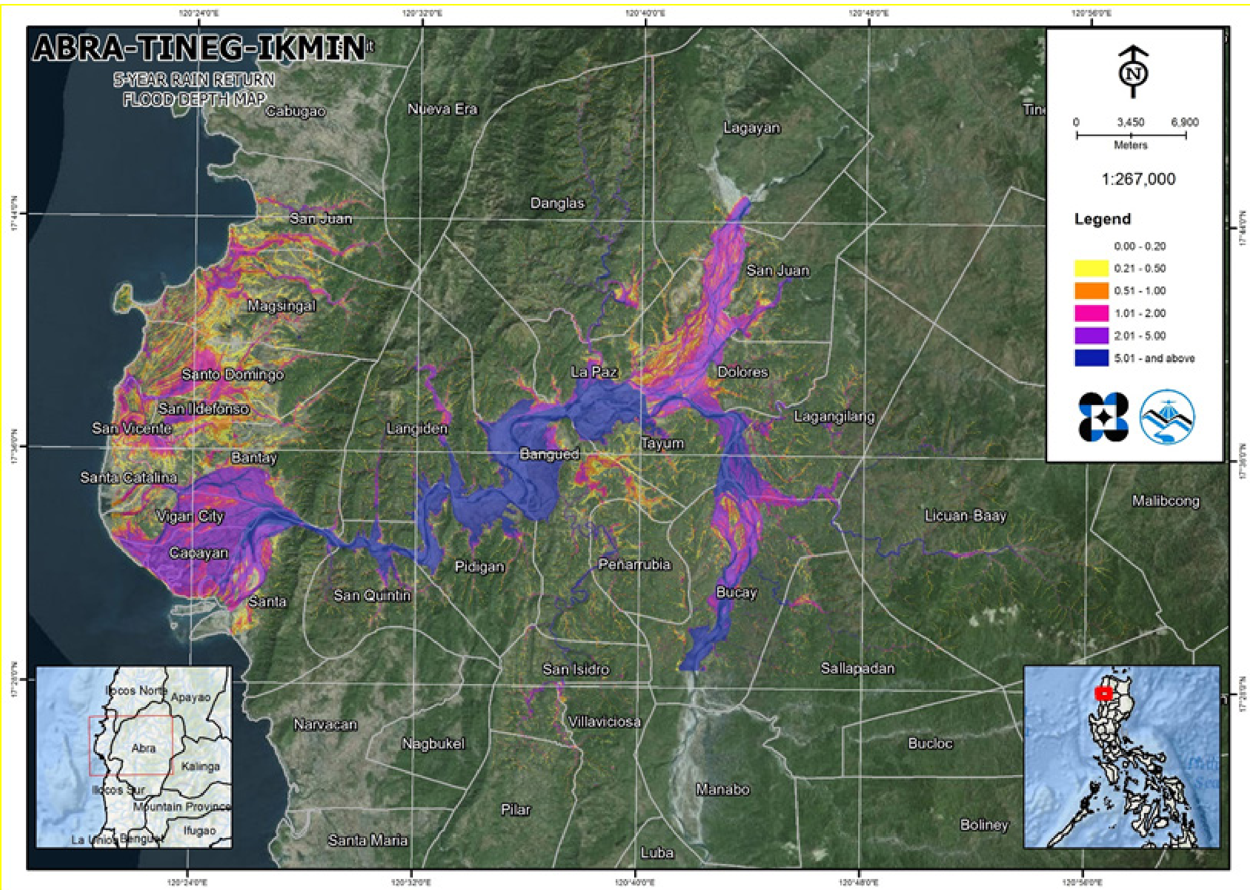


Figure 63. A 5-year Flood Depth Map for Abongan Floodplain overlaid on Google Earth imagery.

5.10 Inventory of Areas Exposed to Flooding

Listed below are the affected barangays in the Abongan River Basin, grouped accordingly by municipality. For the said basin, two municipalities consisting of 12 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 9.2% of the municipality of Basey with an area of 870.45 sq. km. 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 0.33%, 0.42%, 0.28%, and 0.03% 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 30 are the affected areas in square kilometres by flood depth per barangay. Annex 12 and Annex 13 show the educational and health institutions exposed to flooding.

Table 30. Affected Areas in San Vicente, Palawan during 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Affected Barangays in San Vicente			
	Alimanguan	Binga	New Canipo	Villa Aurora
0.03-0.20	40.48	0.87	10.1	28.99
0.21-0.50	1.26	0.028	0.47	0.9
0.51-1.00	1.23	0.032	0.69	0.94
1.01-2.00	1.94	0.04	0.72	1
2.01-5.00	1.75	0.016	0.17	0.52
> 5.00	0.26	0	0	0.0026

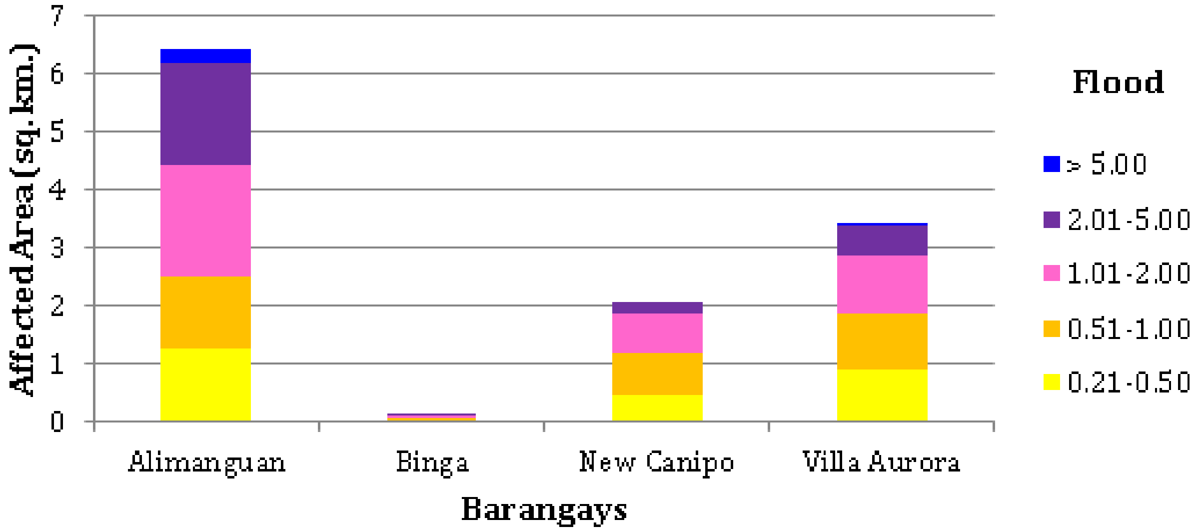


Figure 63. Affected Areas in San Vicente, Palawan during 5-Year Rainfall Return Period.

For the municipality of Taytay, with an area of 1325 sq. km., 11.65% will experience flood levels of less 0.20 meters. 1.26% of the area will experience flood levels of 0.21 to 0.50 meters while 1.55%, 1.36%, 0.36%, 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 square kilometres by flood depth per barangay

Table 31. Affected Areas in Taytay, Palawan during 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Affected Barangays in Taytay				
	Abongan	Alacalian	Bato	Calawag	Libertad
0.03-0.20	8.25	13.3	36.94	13.26	21.3
0.21-0.50	4.82	3.22	3	0.46	2
0.51-1.00	5.46	3.28	2.56	0.39	3.57
1.01-2.00	3.38	0.88	2.01	0.38	5.31
2.01-5.00	0.82	0.055	0.29	0.12	1.8
> 5.00	0.002	0	0	0	0.055

Affected area (sq. km.) by flood depth(in m.)	Affected Barangays in Taytay			
	New Guinlo	Paglaum	Talog	
0.03-0.20	6.66	15.39	39.22	
0.21-0.50	0.26	1.89	1.09	
0.51-1.00	0.26	3.88	1.18	
1.01-2.00	0.33	3.88	1.85	
2.01-5.00	0.07	0.5	1.12	
> 5.00	0	0.0007	0.052	

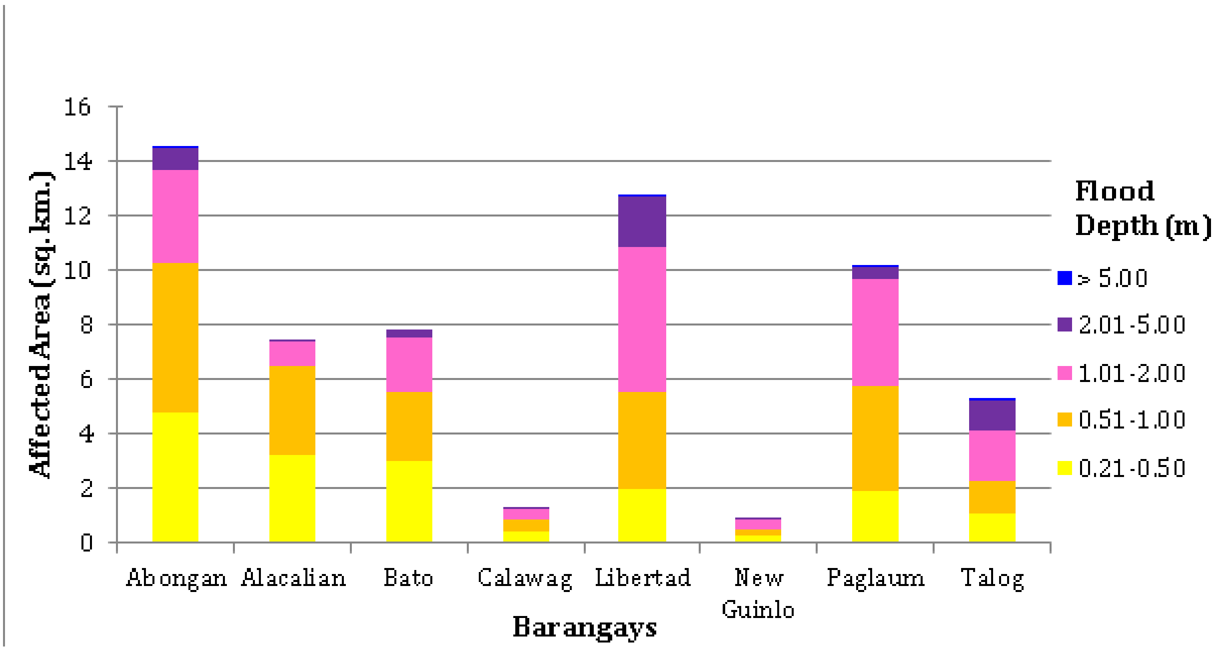


Figure 64. Affected Areas in Taytay, Palawan during 5-Year Rainfall Return Period.

For the 25-year return period, 9.07% of the municipality of San Vicente with an area of 870.45 sq. km. 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 0.29%, 0.42%, 0.46%, and 0.06% 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 square kilometres by flood depth per barangay.

Table 32. Affected Areas in San Vicente, Palawan during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Affected Barangays in San Vicente			
	Alimanguan	Binga	New Canipo	Villa Aurora
0.03-0.20	39.66	0.86	9.92	28.55
0.21-0.50	1.31	0.028	0.41	0.93
0.51-1.00	1.08	0.02	0.58	0.86
1.01-2.00	1.58	0.053	0.91	1.11
2.01-5.00	2.78	0.023	0.32	0.89
> 5.00	0.51	0.00075	0.0034	0.012

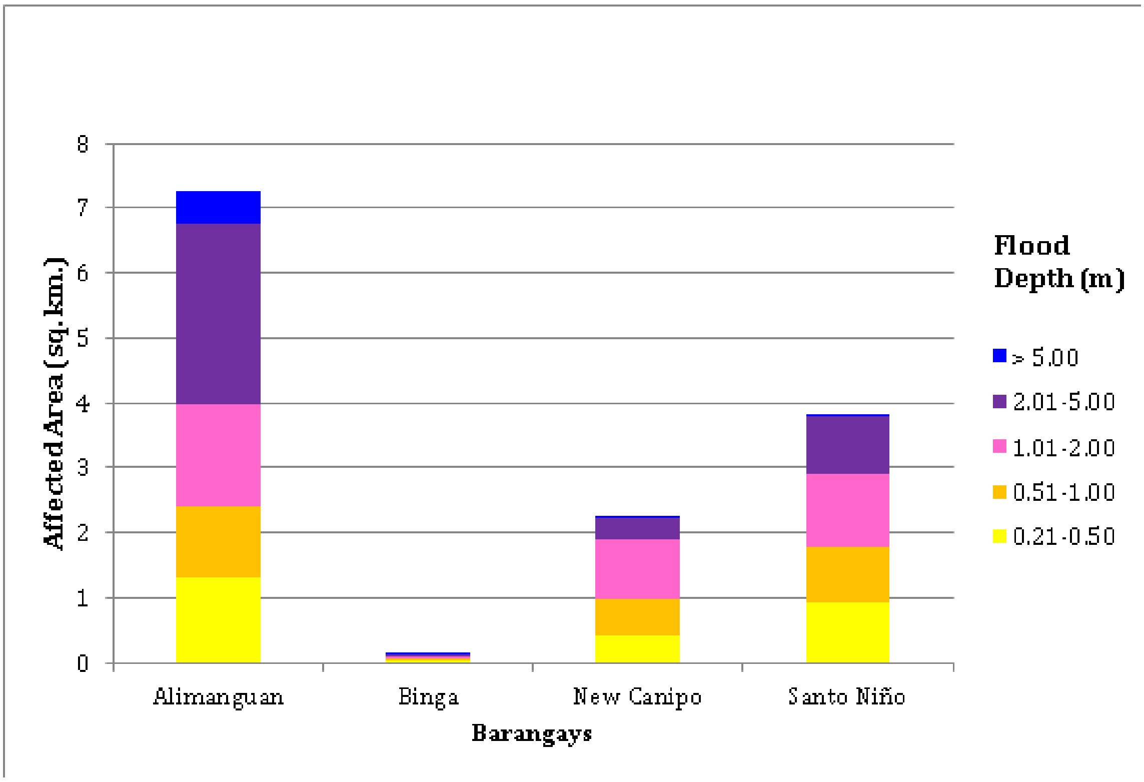


Figure 65. Affected Areas in San Vicente, Palawan during 25-Year Rainfall Return Period.

For the municipality of Taytay, with an area of 1325 sq. km., 11.65% will experience flood levels of less 0.20 meters. 1.26% of the area will experience flood levels of 0.21 to 0.50 meters while 1.55%, 1.36%, 0.36%, 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 33 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected Areas in Taytay, Palawan during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Affected Barangays in Taytay				
	Abongan	Alacalian	Bato	Calawag	Libertad
0.03-0.20	5.81	11.71	35.39	13.05	20.15
0.21-0.50	2.23	3.38	3.32	0.48	1.17
0.51-1.00	6.38	3.98	2.85	0.41	2.45
1.01-2.00	5.87	1.53	2.38	0.43	5.79
2.01-5.00	2.44	0.14	0.86	0.23	4.39
> 5.00	0.0024	0	0	0.0003	0.079

Affected area (sq. km.) by flood depth(in m.)	Affected Barangays in Taytay			
	New Guinlo	Paglaum	Talog	
0.03-0.20	6.55	14.59	38.51	
0.21-0.50	0.27	1.21	1.15	
0.51-1.00	0.24	2.77	1.02	
1.01-2.00	0.34	5.04	1.87	
2.01-5.00	0.18	1.93	1.84	
> 5.00	0	0.0043	0.12	

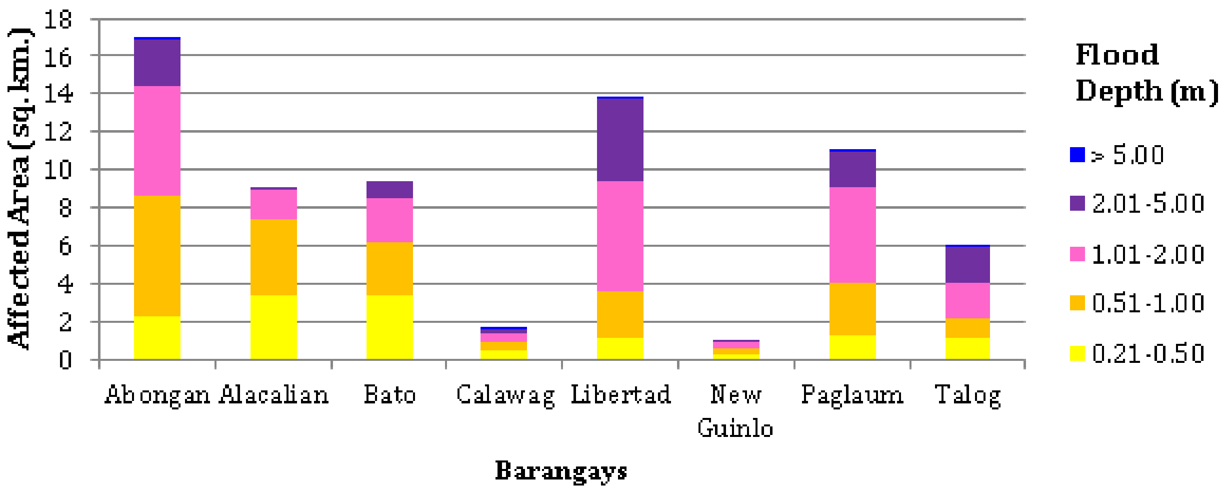


Figure 66. Affected Areas in Taytay, Palawan during 25-Year Rainfall Return Period.

For the 100-year return period, 8.96% of the municipality of San Vicente with an area of 870.45 sq. km. 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 0.27%, 0.41%, 0.57%, and 0.09% 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 square kilometres by flood depth per barangay.

Table 34. Affected Areas in San Vicente, Palawan during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Affected Barangays in San Vicente			
	Alimanguan	Binga	New Canipo	Villa Aurora
0.03-0.20	39.1	0.85	9.8	28.25
0.21-0.50	1.38	0.029	0.4	0.97
0.51-1.00	1.04	0.021	0.48	0.77
1.01-2.00	1.37	0.05	0.98	1.19
2.01-5.00	3.28	0.032	0.47	1.15
> 5.00	0.75	0.0016	0.0079	0.033

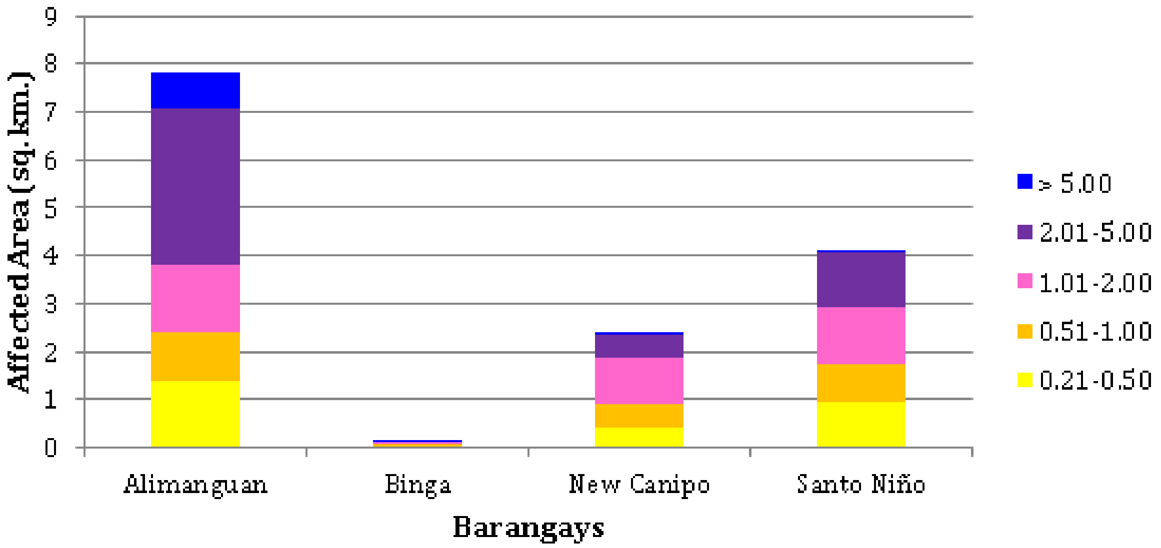


Figure 67. Affected Areas in San Vicente, Palawan during 100-Year Rainfall Return Period.

For the municipality of Taytay, with an area of 1325 sq. km., 10.68% will experience flood levels of less 0.20 meters. 0.92% of the area will experience flood levels of 0.21 to 0.50 meters while 1.23%, 1.95%, 1.39%, and 0.03% 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 square kilometres by flood depth per barangay.

Table 35. Affected Areas in Taytay, Palawan during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Affected Barangays in Taytay				
	Abongan	Alacalian	Bato	Calawag	Libertad
0.03-0.20	5.12	10.84	34.46	12.9	19.58
0.21-0.50	1.53	3.3	3.45	0.5	0.86
0.51-1.00	3.74	4.1	2.87	0.41	1.75
1.01-2.00	8.61	2.25	2.66	0.46	4.88
2.01-5.00	3.72	0.25	1.35	0.33	6.84
> 5.00	0.0043	0	0.003	0.0027	0.13

Affected area (sq. km.) by flood depth(in m.)	Affected Barangays in Taytay			
	New Guinlo	Paglaum	Talog	
0.03-0.20	6.46	14.13	38.02	
0.21-0.50	0.29	1.07	1.2	
0.51-1.00	0.23	2.18	0.98	
1.01-2.00	0.31	5	1.61	
2.01-5.00	0.29	3.14	2.47	
> 5.00	0	0.0077	0.23	

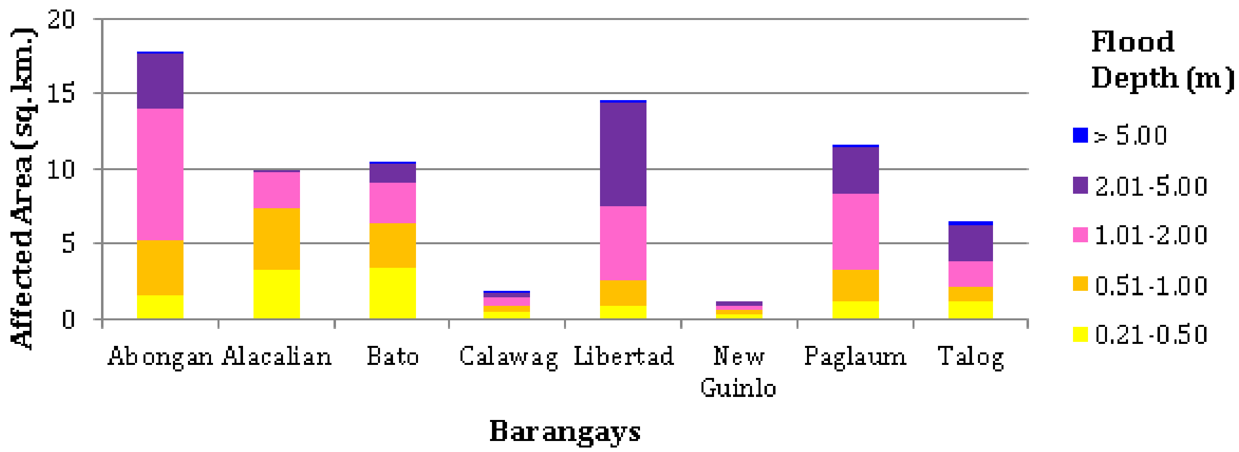


Figure 68. Affected Areas in Taytay, Palawan during 100-Year Rainfall Return Period.

Among the barangays in the municipality of San Vicente, Alimanguan is projected to have the highest percentage of area that will experience flood levels at 5.39%. Meanwhile, Santo Niño posted the second highest percentage of area that may be affected by flood depths at 3.72%.

Among the barangays in the municipality of Taytay, Bato is projected to have the highest percentage of area that will experience flood levels at 3.38%. Meanwhile, Talog posted the second highest percentage of area that may be affected by flood depths at 3.36%.

Table 36. 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	81.42	79.64	79.16
Medium	102.41	99.92	100.51
High	226.15	288.35	317.94

Of the 131 identified Educational Institutions in Abongan flood plain, 11 were assessed to be exposed to low, 17 to medium, and 16 to high level flooding during the 5-year scenario. In the 25-year scenario, 8 were assessed to be exposed to low, 12 to medium, and 42 to high level flooding. In the 100-year scenario, 7 were assessed to be exposed to low, 5 to medium, and 54 to high level flooding. See Annex 12 for a detailed enumeration of schools in the Abongan floodplain.

Of the 30 identified Medical Institutions in Abongan flood plain, 2 were assessed to be exposed to low, 1 to medium, and 1 to high level flooding in the 5-year scenario. In the 25-year scenario, 3 were assessed to be exposed to low, 3 to medium, and 1 to high level flooding. In the 100-year scenario, 5 were assessed to be exposed to low, 3 to medium, and 3 to high level flooding. See Annex 13 for a detailed enumeration of hospitals and clinics in the Abongan floodplain.

5.11 Flood Validation

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

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

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

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 74.

The flood validation survey was conducted in December 2016. The flood validation consists of 135 points randomly selected all over the Abongan flood plain. Comparing it with the flood depth of the nearest storm event, the map has an RMSE value of 1.13m. The validation points are found in Annex 11.

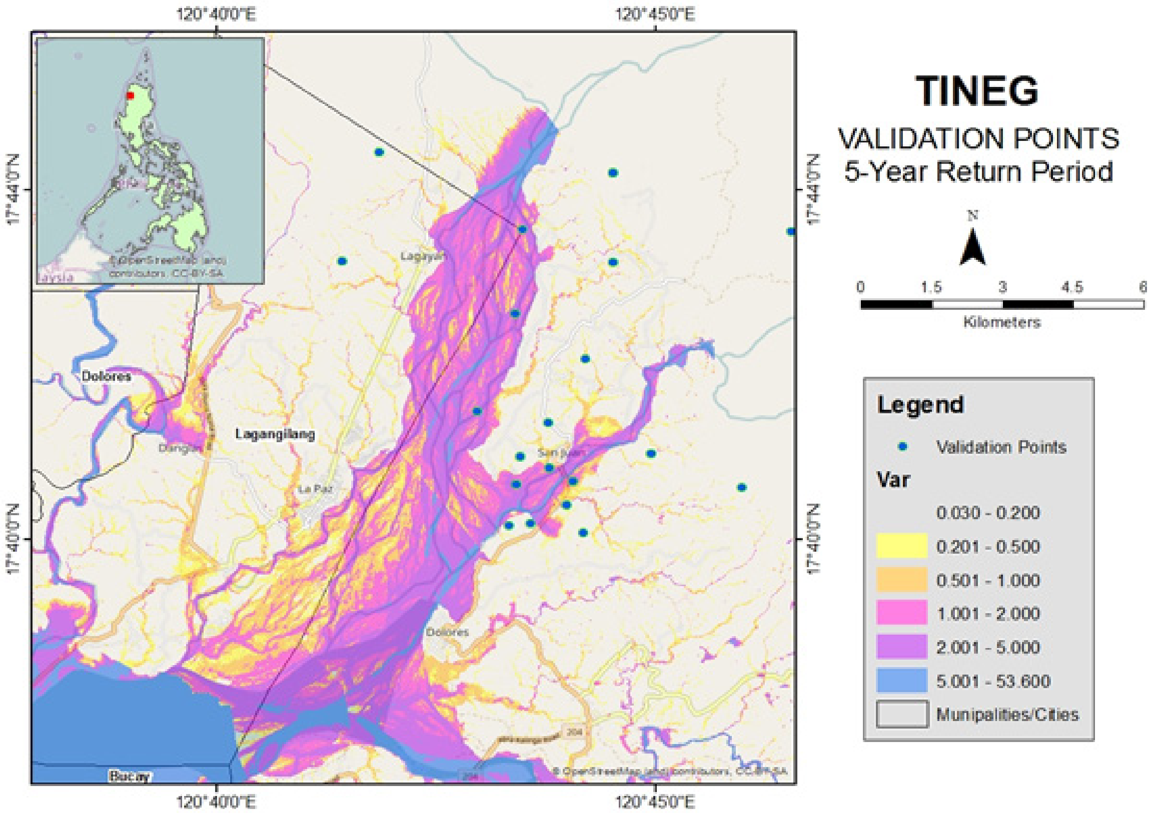


Figure 69. Validation Points for a 5-year Flood Depth Map of the Abongan Floodplain.

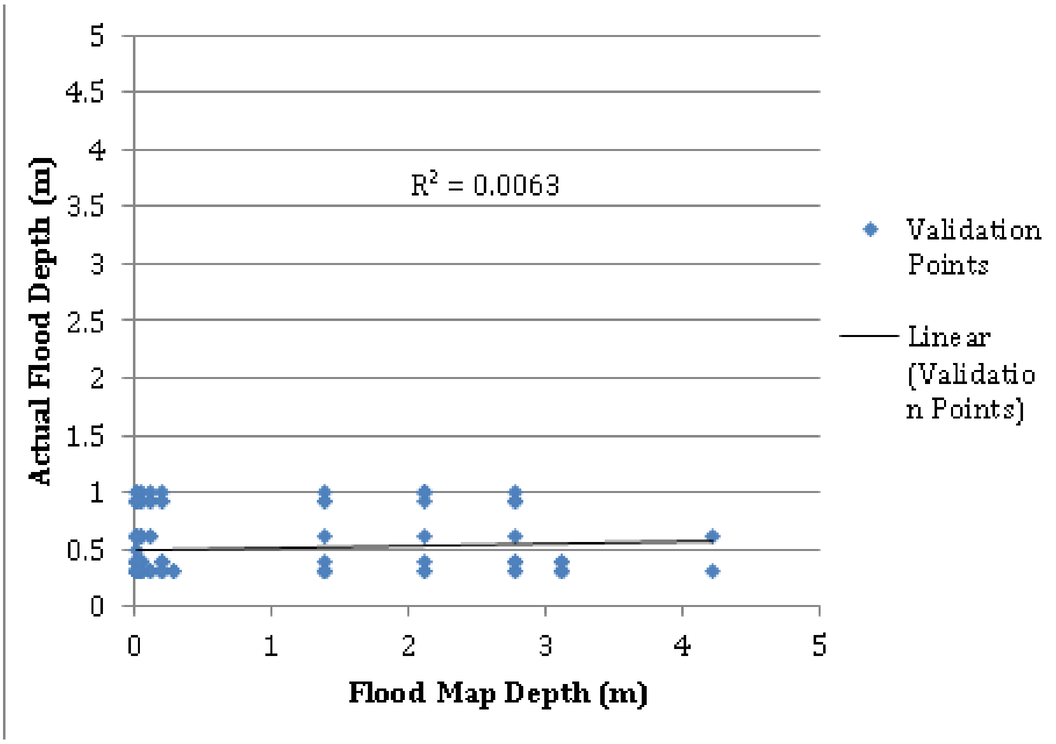


Figure 70. Flood depth map vs actual flood depth.

Table 37. Actual Flood Depth versus Simulated Flood Depth at different levels in the Abongan River Basin.

ABONGAN		Modeled Flood Depth (m)						
		180	10	11	1	0	0	202
Actual Flood Depth (m)	0-0.20	0	0	0	0	0	0	0
	0.21-0.50	56	9	0	6	15	0	86
	0.51-1.00	30	3	0	4	12	0	49
	1.01-2.00	0	0	0	0	0	0	0
	2.01-5.00	0	0	0	0	0	0	0
	> 5.00	0	0	0	0	0	0	0
	Total	86	12	0	10	27	0	135

On the whole, the overall accuracy generated by the flood model is estimated at 6.67%, with 9 points correctly matching the actual flood depths. In addition, there were 63 points estimated one level above and below the correct flood depths while there were 48 points and 15 points estimated two levels above and below, and three or more levels above and below the correct flood depth. A total of 37 points were overestimated while a total of 89 points were underestimated in the modelled flood depths of Abongan. Table 41 depicts the summary of the Accuracy Assessment in the Abongan River Basin Flood Depth Map.

Table 38. Summary of the Accuracy Assessment in the Abongan River Basin Survey.

LANANG	No. of Points	%
Correct	9	**6.67**
Overestimated	37	27.41
Underestimated	89	65.93
Total	135	100

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

ANNEXES

Annex 1. Technical Specifications of the LIDAR Sensors used in the Abongan Floodplain Survey

1. GEMINI SENSOR

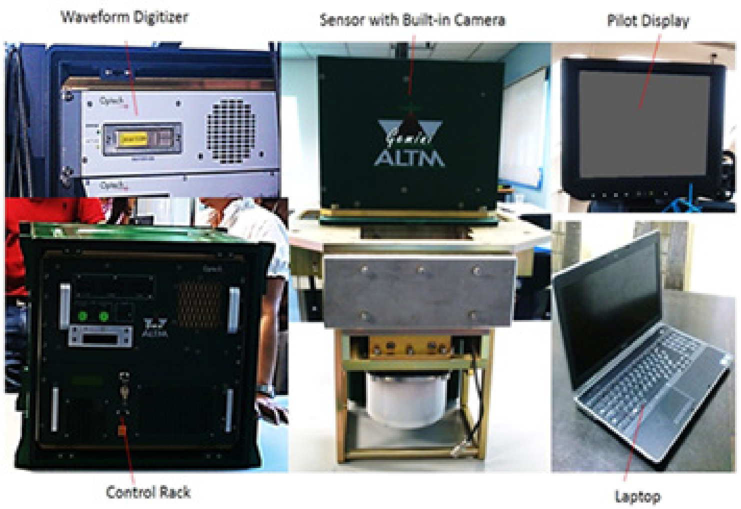


Figure A-1.1. Gemini Sensor

Table A-1.1. Parameters and Specifications of Gemini 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);
Scan width (WOV)	220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver
Scan frequency (5)	Programmable, 0-50˚
Sensor scan product	Programmable, 0-70 Hz (effective)
Beam divergence	1000 maximum
Roll compensation	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Range capture	Programmable, ±5˚ (FOV dependent)
Intensity capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Video Camera	Up to 4 intensity returns for each pulse, including last (12 bit)
Image capture	Internal video camera (NTSC or PAL)
Full waveform capture	Compatible with full Optech camera line (optional)
Data storage	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Power requirements	Removable solid state disk SSD (SATA II)
Dimensions and weight	28 V; 900 W;35 A(peak)
Operating temperature	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg
Relative humidity	Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
	-10˚C to +35˚C (with insulating jacket)
	0-95% no-condensing

Annex 2. NAMRIA certification of reference points used in the LiDAR survey

1. PLW-23

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

December 02, 2015

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

	Province: **PALAWAN**		
	Station Name: **PLW-23**		
	Order: **1st**		
Island: **LUZON**	Barangay: **JOLO**		
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**	MSL Elevation:		
	PRS92 Coordinates		
Latitude: **10° 5' 19.52517"**	Longitude: **119° 12' 33.72062"**	Ellipsoidal Hgt:	**10.42700 m.**
	WGS84 Coordinates		
Latitude: **10° 5' 15.04804"**	Longitude: **119° 12' 39.01413"**	Ellipsoidal Hgt:	**61.07260 m.**
	PTM / PRS92 Coordinates		
Northing: **1115630.596 m.**	Easting: **577752.254 m.**	Zone:	**1A**
	UTM / PRS92 Coordinates		
Northing: **1,115,973.89**	Easting: **742,130.31**	Zone:	**50**

Location Description

PLW-23
From the municipality of Roxas, on the intersection at Andres Soriano Memorial Elementary School, travel southwest along the provincial highway for 39.3 kilometers or 1 hour and 25 minutes drive to Jolo elementary School. The station is located inside the compound of Jolo elementary school. It is Norhtwest 10.00 meters of the school building. Station mark is a cross cut on top of a 0.15 m x 0.012 m in diameter brass rod centered in a 0.30 m x 0.30 m x 1.0 m concrete block, flush with the ground surface and inscribed with station name. Sub-surface mark is a bottle set on concrete block; 68 cm. below station. Reference mark nos. 1,2,3 and 4 are cross cut on top of 0.15 m x 0.01 m in diameter brass rod in a 0.30 m x 0.30 m x 1 meter concrete block, flush with the ground surface, and inscribed with the reference mark numbers and with arrows pointing to the station.

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8088735 I**
T.N.: **2015-3960**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. PLW-23

2. PL-267

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

December 02, 2015

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

	Province: **PALAWAN** Station Name: **PL-267**	
Island: **Luzon**	Municipality: **ROXAS**	Barangay: **DUMARAO**
Elevation: **32.2064 +/- 0.03 m.**	Order: **1st Order**	Datum: **Mean Sea Level**
Latitude:	Longitude:	

Location Description

Station Mark: Mark is the head of a four (4) inch copper nail, drilled on hole and set flushed on an cement putty with inscription: PL 267, 2008, NAMRIA. The station is located in Sitio Itabiak Brg. Dumarao along Roxas.

ACCESS: From Roxas travel south along the National Highway towards Taytay located in Itabiak Bridge on the left side of the road going to Taytay, 100 meters away from km post 163.

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8088735 I**
T.N.: **2015-3963**

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

9 9 1 2 0 2 2 0 1 5 1 0 5 7 5 2

CP/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

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Figure A-2.2. PL-267

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

1. PLW-4030

Table A-3.1. PLW-4030

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW-23 --- PLW-4030 (B1)	PLW-23	PLW-4030	Fixed	0.001	0.002	205°42'51"	769.753	0.756
PLW-23 --- PLW-4030 (B2)	PLW-23	PLW-4030	Fixed	0.001	0.002	205°42'52"	769.751	0.758
PLW-23 --- PL-267 (B3)	PLW-23	PL-267	Fixed	0.014	0.057	19°50'09"	49671.383	24.118
PLW-23 --- PLW-4030 (B4)	PLW-23	PLW-4030	Fixed	0.001	0.002	205°42'54"	769.752	0.745

Acceptance Summary

Processed	Passed	Flag	Fail
4	4	0	0

Vector Components (Mark to Mark)

From:	PLW-23				
Grid		Local		Global	
Easting	84385.264 m	Latitude	N10°05'19.52518"	Latitude	N10°05'15.04804"
Northing	1117566.788 m	Longitude	E119°12'33.72062"	Longitude	E119°12'39.01413"
Elevation	9.470 m	Height	10.427 m	Height	61.073 m

To:	PLW-4030				
Grid		Local		Global	
Easting	84042.662 m	Latitude	N10°04'56.95146"	Latitude	N10°04'52.47562"
Northing	1116875.986 m	Longitude	E119°12'22.75168"	Longitude	E119°12'28.04576"
Elevation	10.228 m	Height	11.183 m	Height	61.835 m

Vector					
ΔEasting	-342.602 m	NS Fwd Azimuth	205°42'51"	ΔX	231.869 m
ΔNorthing	-690.802 m	Ellipsoid Dist.	769.753 m	ΔY	269.625 m
ΔElevation	0.758 m	ΔHeight	0.756 m	ΔZ	-682.686 m

Standard Errors

Vector errors:					
σ ΔEasting	0.000 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.001 m
σ ΔNorthing	0.000 m	σ Ellipsoid Dist.	0.000 m	σ ΔY	0.001 m
σ ΔElevation	0.001 m	σ ΔHeight	0.001 m	σ ΔZ	0.000 m

2. PL-267

Table A-3.2. PL-267

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
PLW-23 --- PLW-4030 (B1)	PLW-23	PLW-4030	Fixed	0.001	0.002	205°42'51"	769.753	0.756
PLW-23 --- PLW-4030 (B2)	PLW-23	PLW-4030	Fixed	0.001	0.002	205°42'52"	769.751	0.758
PLW-23 --- PL-267 (B3)	PLW-23	PL-267	Fixed	0.014	0.057	19°50'09"	49671.383	24.118
PLW-23 --- PLW-4030 (B4)	PLW-23	PLW-4030	Fixed	0.001	0.002	205°42'54"	769.752	0.745

Acceptance Summary

Processed	Passed	Flag	Fail
4	4	0	0

Vector Components (Mark to Mark)

From:	PLW-23				
Grid		Local		Global	
Easting	84385.264 m	Latitude	N10°05'19.52518"	Latitude	N10°05'15.04804"
Northing	1117566.788 m	Longitude	E119°12'33.72062"	Longitude	E119°12'39.01413"
Elevation	9.470 m	Height	10.427 m	Height	61.073 m

To:	PL-267				
Grid		Local		Global	
Easting	101820.908 m	Latitude	N10°30'40.21529"	Latitude	N10°30'35.64621"
Northing	1164164.984 m	Longitude	E119°21'48.02348"	Longitude	E119°21'53.27911"
Elevation	33.463 m	Height	34.545 m	Height	84.611 m

Vector					
ΔEasting	17435.644 m	NS Fwd Azimuth	19°50'09"	ΔX	-10634.211 m
ΔNorthing	46598.197 m	Ellipsoid Dist.	49671.383 m	ΔY	-15515.024 m
ΔElevation	23.993 m	ΔHeight	24.118 m	ΔZ	45972.210 m

Standard Errors

Vector errors:					
σ ΔEasting	0.004 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.013 m
σ ΔNorthing	0.005 m	σ Ellipsoid Dist.	0.006 m	σ ΔY	0.026 m
σ ΔElevation	0.029 m	σ ΔHeight	0.029 m	σ ΔZ	0.005 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0001625016		
Y	-0.0003217825	0.0006901336	
Z	-0.0000343902	0.0000615645	0.0000255690

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader - I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
	Data Component Project Leader – I	ENGR. LOUIE BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	ENGR. GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	MARY CATHERINE ELIZABETH BALIGUAS	UP-TCAGP
	RA	JONATHAN ALMALVEZ	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	ENGR. IRO NIEL ROXAS	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. PRADYUMNA DAS RAMIREZ	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. MARK TANGONAN	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. RANDY LAGCO	AAC

Annex 5. Data Transfer Sheet for Abongan Floodplain

DATA TRANSFER SHEET
PALAWAN 12/08/15

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	
20-Nov-15	3513G	2BLK42sIAs324A	GEMINI	NA	176/846	991	180	1.81/13.3	10/74/33	8.14	NA	3.97	1KB	1KB	21/22/16/16/22	NA	Z:\DAC\RAW DATA
21-Nov-15	3517G	2BLK42B325A	GEMINI	NA	32	410	65	4.34	34	2.53	NA	4.14	1KB	1KB	21/22/18/16/19	NA	Z:\DAC\RAW DATA
26-Nov-15	3537G	2BLK42HJ330A	GEMINI	NA	18/218	709	199	NA	NA	11.9	NA	8.03	1KB	1KB	13/13/15/13	NA	Z:\DAC\RAW DATA
27-Nov-15	3541G	2BLK42I331A	GEMINI	NA	265	619	229	NA	NA	24.7	NA	5.79	1KB	1KB	13/13	NA	Z:\DAC\RAW DATA
28-Nov-15	3545G	2BLK42B40A332A	GEMINI	NA	760	667	228	NA	NA	15.8	NA	10.1	1KB	NA	22/21/22/16/16/22	NA	Z:\DAC\RAW DATA
30-Nov-15	3553G	2BLK42HJ334A	GEMINI	NA	202	389	187	NA	NA	16	NA	8.36	1KB	1KB	13/13/13/15	NA	Z:\DAC\RAW DATA
30-Nov-15	3555G	2BLK42JK334B	GEMINI	NA	76	495	238	NA	NA	19.1	NA	8.36	1KB	1KB	13/15	NA	Z:\DAC\RAW DATA
1-Dec-15	3557G	2BLK42HsL335A	GEMINI	NA	226	447	195	NA	NA	19	NA	4.3	1KB	1KB	22/24/22	NA	Z:\DAC\RAW DATA
3-Dec-15	3565G	2BLK42PQR337A	GEMINI	NA	NA	535	202	NA	NA	25.4	NA	6.96	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA

Received from

Name C Joaquin
Position
Signature

Received by

Name
Position
Signature

Figure A-5.1. Transfer Sheet for Aborlan Floodplain (A)

Annex 6. Flight logs for the flight missions

1. Flight Log for 3545GC Mission

Data Acquisition Flight Log

Flight Log No.: 3545GC

1 LiDAR Operator: J. ALMALVEZ	2 ALTM Model: GEMINI	3 Mission Name: 2BLK42B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot:	8 Co-Pilot: R. LACCA	9 Route: PPS - PPS			
10 Date: Nov. 26, 2015	12 Airport of Departure (Airport, City/Province): Puerto		12 Airport of Arrival (Airport, City/Province): Puerto		
13 Engine On: 0637	14 Engine Off: 1027	15 Total Engine Time: 3+50	16 Take off: 0642 H	17 Landing: 1022 H	18 Total Flight Time: 3+40

19 Weather: Cloudy

20 Flight Classification

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

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

20.c Others
- LiDAR System Maintenance
- Aircraft Maintenance
- Phil-LiDAR Admin Activities

21 Remarks

Surveyed 7 lines of BLK42C & 6 lines of BLK42B ; 40%

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

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

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

Pilot-in-Command: Signature over Printed Name

Lidar Operator: J. Almalvez, Signature over Printed Name

Aircraft Mechanic/ Technician: G. Antonio, Signature over Printed Name

Figure A-6.1. Flight Log for Mission 3545GC

Annex 7. Flight status reports

Palawan Missions
November 28, 2016

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3545G	BLK42B & BLK40A	2BLK42B40A332A	JM ALMALVEZ	November 28, 2015	Surveyed BLK42B but too cloudy and terrain problem so no tie line and moved to BLK40A; completes coverage of Caramay RB and DVBC's bathy line (BLK42A,B)

SWATH PER FLIGHT MISSION

Flight No. : 3545G
Area: BLK40A & BLK42B
Mission name: 2BLK42B40A332A
Parameters: Altitude: 1000 / 1200 m;
Scan Frequency: 50 Hz;
Scan Angle: 12 / 20 deg;
Area covered: 95.429 km2

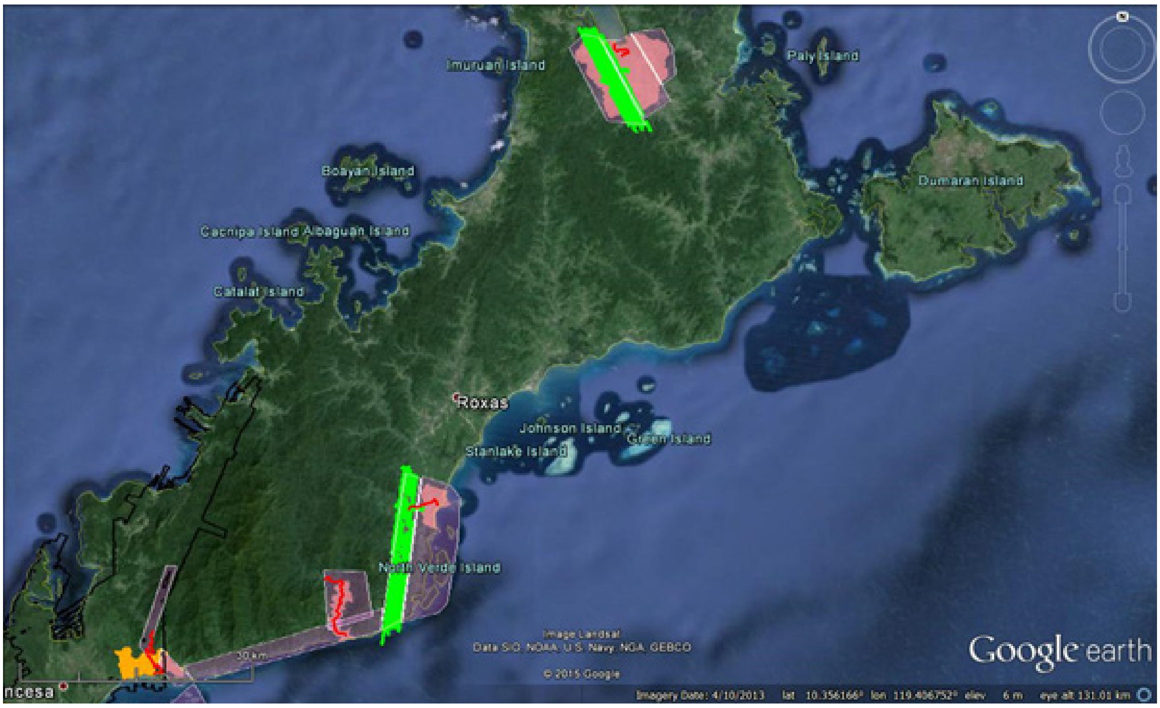

Figure A-7.1. Swath for Flight No. 3545GC

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk40_A

Flight Area	Palawan Reflights
Mission Name	Blk40A
Inclusive Flights	3545G
Range data size	15. 8 GB
Base data size	10.1 MB
POS	228 MB
Image	NA
Transfer date	January 4, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.06
RMSE for East Position (<4.0 cm)	1.51
RMSE for Down Position (<8.0 cm)	3.77
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	24.74%
Ave point cloud density per sq.m. (>2.0)	4.99
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	70
Maximum Height	317.7 m
Minimum Height	50.38 m
Classification (# of points)	
Ground	7,140,523
Low vegetation	6,080,343
Medium vegetation	52,688,726
High vegetation	74,191,722
Building	8,672
Ortophoto	No
Processed by	Engr. Sheila Maye Santillan, Engr. Mark Joshua Salvacion, Engr. Melissa Fernandez

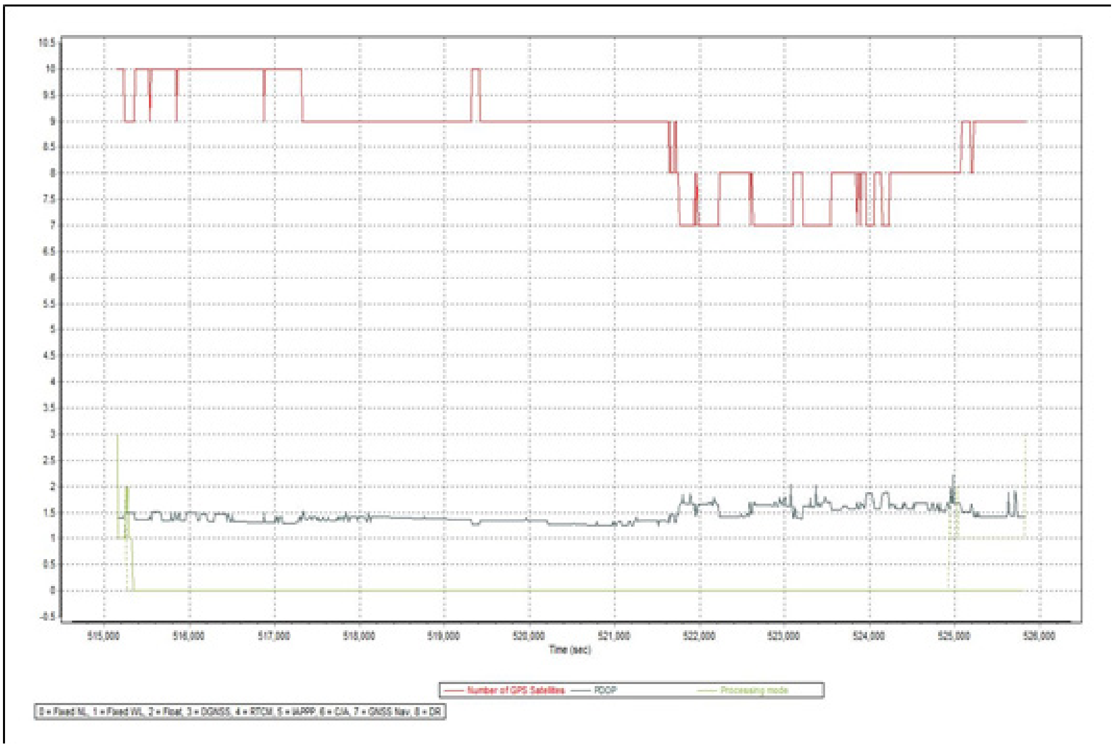

Figure A-8.1 Solution Status

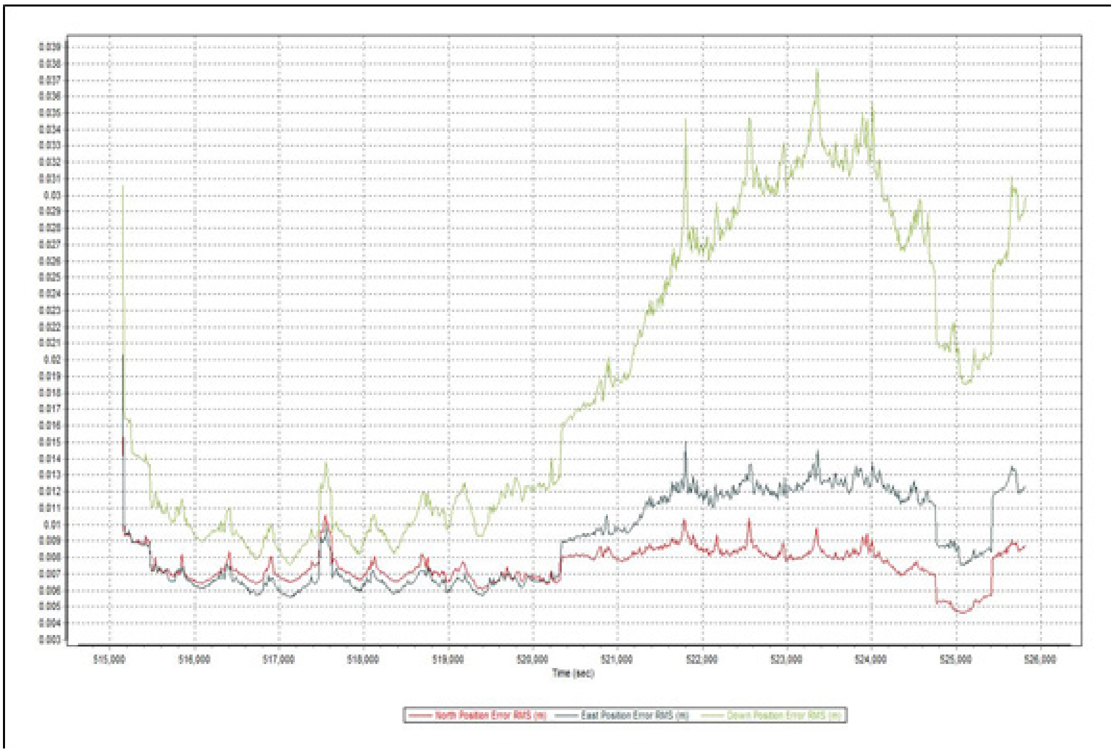

Figure A-8.2 Smoothed Performance Metric Parameters

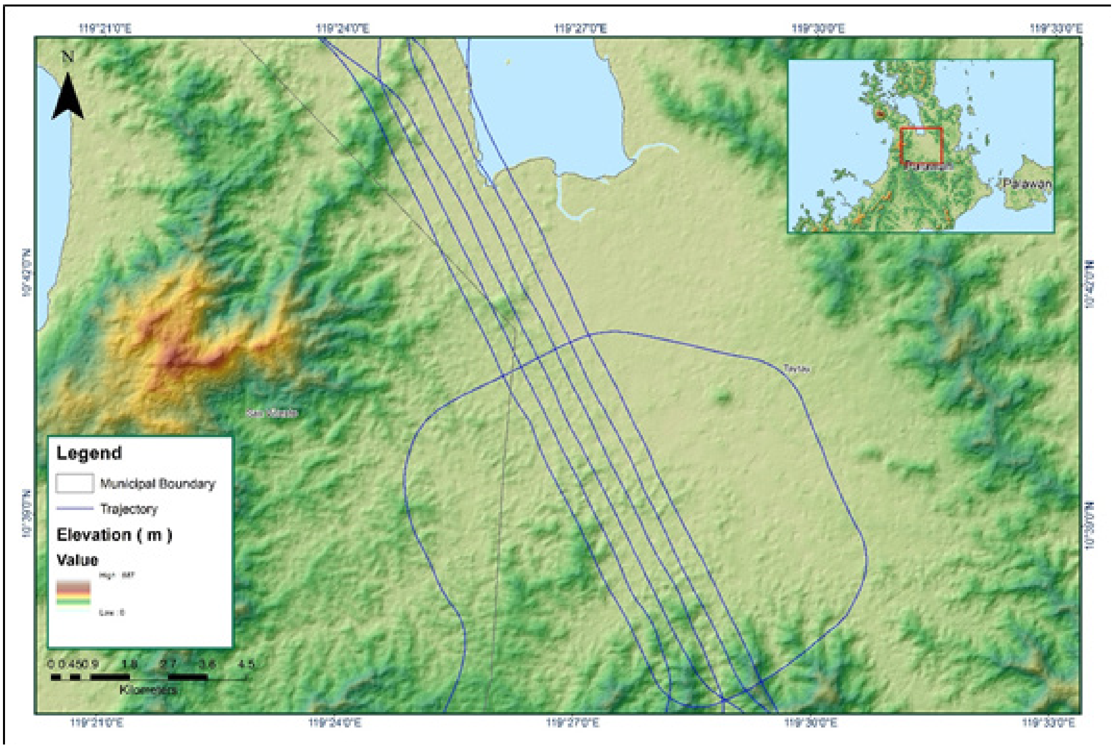

Figure A-8.3 Best Estimated Trajectory

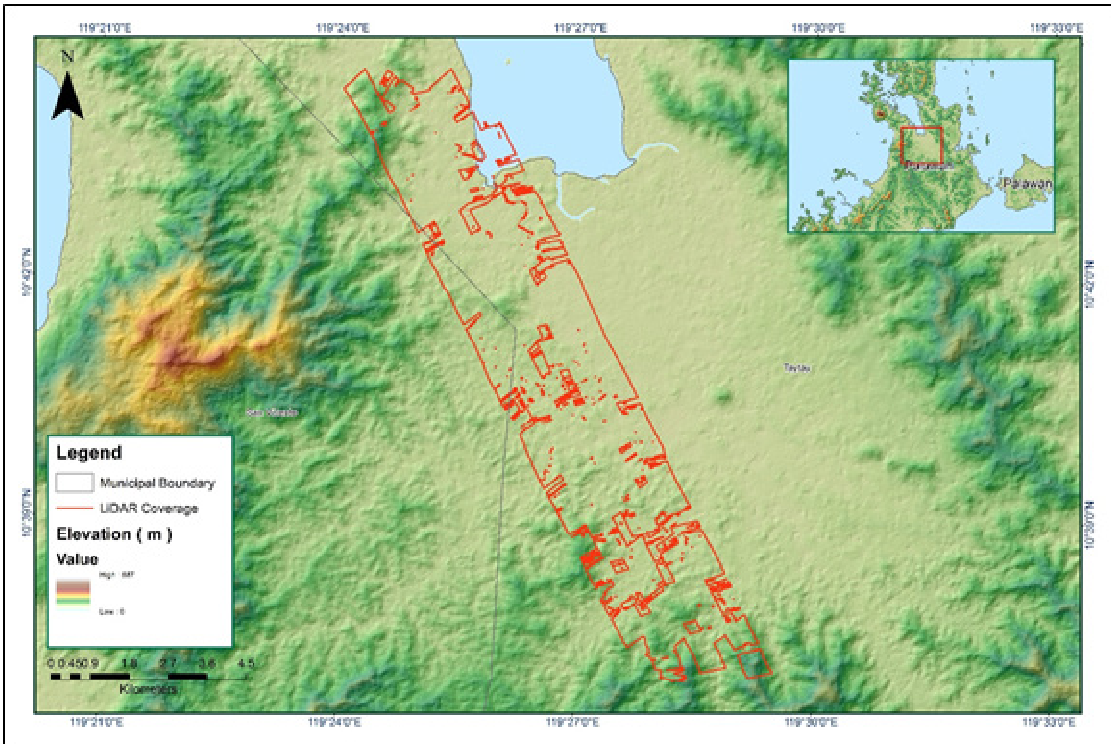

Figure A-8.4 Coverage of LiDAR data

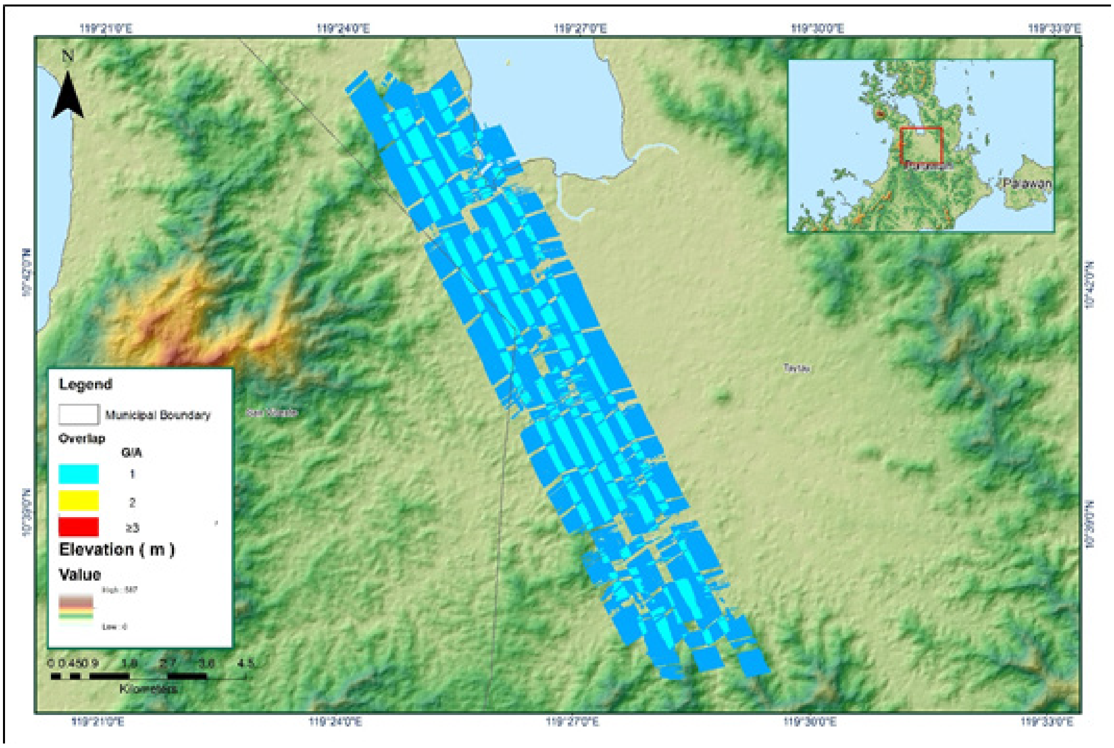

Figure A-8.5 Image of data overlap

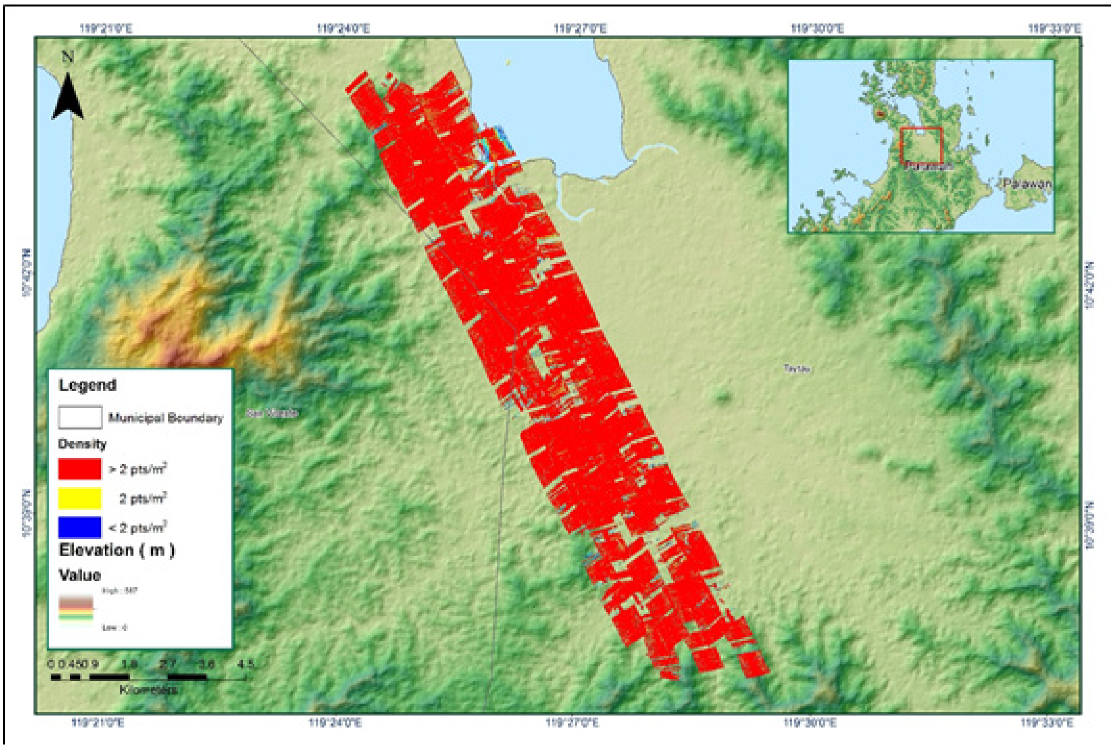

Figure A-8.6 Density map of merged LiDAR data

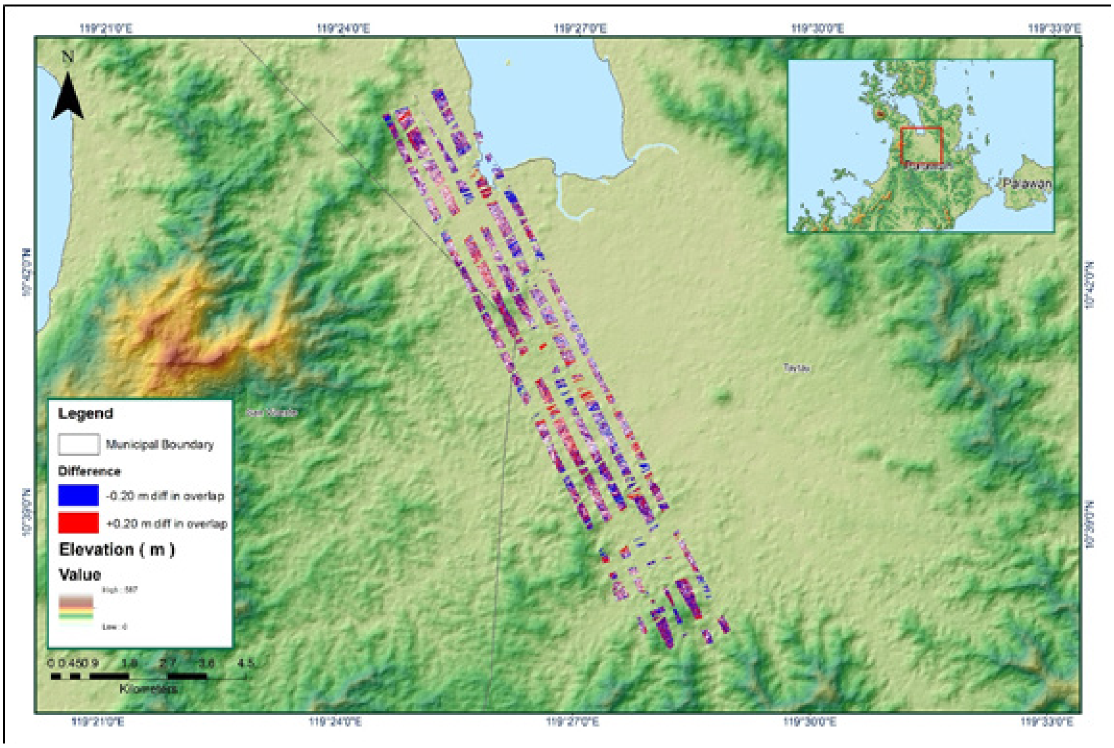

Figure A-8.7 Elevation difference between flight lines

Annex 9. Abongan Model Basin Parameters

Table A-9.1. Sta. Cruz Model Basin Parameters

Subbasin	SCS CURVE NUMBER LOSS			CLARK UNIT HYDROGRAPH TRANSFORM	
	Initial Abstraction (MM)	Curve Number	Imperviousness (%)	Time of Concentration (HR)	Storage Coefficient (HR)
W1000		89	0.0	1.3031	2.1267
W1010	1.55	86.664	0.0	2.0155	3.2893
W1020	1.9543	84.515	0.0	1.1568	1.8879
W1030	2.3269	71.528	0.0	2.3282	3.7996
W1040	5.0553	68.659	0.0	1.6672	2.7209
W1050	5.7972	77	0.0	1.5655	2.5549
W1060	3.75	81.173	0.0	2.0363	3.3232
W1070	2.9457	78.691	0.0	1.5156	2.4735
W1080	3.4391	78.486	0.0	1.5454	2.522
W1090	3.4813	77.535	0.0	1.6243	2.6509
W1100	3.6797	77	0.0	2.0754	3.3871
W1110	3.75	77	0.0	1.6214	2.6462
W1120	3.75	77	0.0	1.2456	2.0328
W1130	3.75	60.651	0.0	1.7079	2.7874
W1140	8.2393	55	0.0	2.3945	3.9078
W1150	10.35	74.003	0.0	1.5092	2.463
W1160	4.4615	67.412	0.0	1.9298	3.1494
W1170	6.1392	55	0.0	2.83	4.6185
W1180	10.35	55.471	0.0	2.6642	4.348
W1200	10.195	89	0.0	0.60934	0.99445
W1210	1.55	89	0.0	2.4161	3.9431
W660	1.55	89	0.0	1.	3.0131
W1250	1.55	89	0	0.91441	1.4923
W1260	1.55	89	0	2.5028	4.0845
W1300	1.8824	87.091	0	2.0024	3.268
W1310	1.55	89	0	2.6924	4.3941
W600	1.6786	88.326	0	8.8235	14.4
W610	1.6058	88.775	0	0.60914	0.99412
W620	1.9619	86.619	0	2.7873	4.5489
W640	1.55	89	0	0.62268	1.0162
W650	1.5723	88.983	0	3.6307	5.9254
W660	2.5361	83.355	0	1.9671	3.2102
W670	1.55	89	0	1.8705	3.0527
W680	1.55	89	0	4.2178	6.8835
W700	1.55	89	0	2.2846	3.7285
W710	3.748	77.213	0	1.6076	2.6237
W720	2.7968	81.952	0	1.264	2.0628
W730	1.55	89	0	1.8624	3.0394

Subbasin	SCS CURVE NUMBER LOSS			CLARK UNIT HYDROGRAPH TRANSFORM	
	Initial Abstraction (MM)	Curve Number	Imperviousness (%)	Time of Concentration (HR)	Storage Coefficient (HR)
W740	1.8105	89	0.0	1.8624	3.0394
W750	3.1887	87.523	0.0	2.2014	3.5926
W760	1.55	79.931	0.0	1.1651	1.9015
W770	3.75	89	0.0	0.73317	1.1965
W780	1.645	77	0.0	1.1597	1.8926
W790	1.55	88.532	0.0	2.3263	3.7965
W800	1.8493	89	0.0	1.4778	2.4118
W810	1.55	87.289	0.0	2.7773	4.5326
W820	1.9677	89	0.0	3.2867	5.3639
W830	3.75	86.585	0.0	1.8778	3.0646
W840	1.55	77	0.0	1.7366	2.8342
W850	1.55	89	0.0	1.7171	2.8023
W870	3.3652	89	0.0	1.3222	2.1578
W880	2.1618	79.053	0.0	0.73178	1.1943
W890	3.6308	85.454	0.0	1.1534	1.8823
			0.0		
W900	3.7973	76.982	0.0	1.5244	2.4878
W910	3.2362	79.693	0.0	3.7578	6.1328
W920	1.55	89	0.0	0.97031	1.5835
W930	2.0902	85.868	0.0	1.0009	1.6334
W940	1.55	89	0.0	1.6936	2.7639
W950	1.55	89	0.0	1.919	3.1318
W960	1.55	89		2.1668	3.5362
W970	3.75	77	0	1.4757	2.4083
W980	1.7549	87.86	0	1.0971	1.7904
W990	3.75	77	0	1.2132	1.98

Annex 10. Abongan Model Reach Parameters

Table A-10.1. Abongan Model Reach Parameters

REACH				
	Length (M)	Slope(M/M)	Shape	Side Slope (xH:1V))
R120	694.26	0.005205	Trapezoid	1
R1230	2086.5	0.005205	Trapezoid	1
R1280	1585.8	0.010124	Trapezoid	1
R130	463.85	0.015914	Trapezoid	1
R1320	341.42	0.005718	Trapezoid	1
R150	956.4	0.001673	Trapezoid	1
R170	1652.7	0.001673	Trapezoid	1
R180	1750.5	0.002276	Trapezoid	1
R20	7111.2	0.005242	Trapezoid	1
R200	1617.8	0.002276	Trapezoid	1
R220	3787.9	0.007858	Trapezoid	1
R230	1617.5	0.001024	Trapezoid	1
R270	1178.2	0.001024	Trapezoid	1
R280	2938.1	0.001615	Trapezoid	1
R290	3207.4	0.003147	Trapezoid	1
R30	1281.2	0.000844	Trapezoid	1
R300	1237.8	0.000764	Trapezoid	1
R330	472.84	0.010124	Trapezoid	1
R350	1596.1	0.000844	Trapezoid	1
R360	3035.6	0.003024	Trapezoid	1
R40	1107.4	0.002523	Trapezoid	1
R400	339.71	0.005242	Trapezoid	1
R410	2689.8	0.00256	Trapezoid	1
R420	5884.1	0.00152	Trapezoid	1
R430	5746.7	0.003644	Trapezoid	1
R470	2074.5	0.005708	Trapezoid	1
R510	4677.3	0.003776	Trapezoid	1
R530	2165.6	0.00139	Trapezoid	1
R570	2306.1	2306.1	Trapezoid	1
R60	2242.4	2242.4	Trapezoid	1
R80	3145.8	3145.8	Trapezoid	1

Annex 11. Abongan Field Validation Points

Table A-11.1. Abongan Field Validation Points

Point	Validation Coordinates		Model	Validation	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
								25-Year
1	10.63703	119.4827	1.99	0.49	-1.5	Lawin	Oct. 2016	25-Year
2	10.63813	119.4836	0.03	0.55	0.52	Lawin	Oct. 2016	25-Year
3	10.64071	119.4879	0.03	0.58	0.55	Lawin	Oct. 2016	25-Year
4	10.64105	119.4878	1.96	0.55	-1.41	Lawin	Oct. 2016	25-Year
5	10.64341	119.4961	0.36	2.2	1.84	LPA	Oct. 30, 2016	25-Year
6	10.6461	119.4986	0.03	0.8	0.77	Lawin	Oct. 2016	25-Year
7	10.64047	119.4893	0.03	0	-0.03			25-Year
8	10.64202	119.4836	0.03	0	-0.03			25-Year
9	10.64472	119.4802	1.94	0	-1.94			25-Year
10	10.64782	119.4747	1.12	0.75	-0.37	Lawin	Oct. 2016	25-Year
11	10.65003	119.4751	2.13	0.9	-1.23	Lawin	Oct. 2016	25-Year
12	10.648	119.4763	0.84	2.5	1.66	Lawin	Oct. 2016	25-Year
13	10.66005	119.4823	1.56	0.52	-1.04	LPA	Nov. 2016	25-Year
14	10.6613	119.4825	1.67	0.3	-1.37	LPA	Nov. 2016	25-Year
15	10.6616	119.4842	0.84	0.6	-0.24	LPA	Nov. 2016	25-Year
16	10.66099	119.4831	0.03	0.26	0.23	LPA	Nov. 2016	25-Year
17	10.65845	119.483	0.05	0	-0.05			25-Year
18	10.68388	119.4965	0.17	0	-0.17			25-Year
19	10.7121	119.4875	0.38	0	-0.38			25-Year
20	10.69389	119.4399	0.39	0.52	0.13	Yolanda	Nov. 2013	25-Year
21	10.67939	119.4573	0.46	0.45	-0.01	Lawin	Oct. 2016	25-Year
22	10.67929	119.4576	1.07	0.61	-0.46	Lawin	Oct. 2016	25-Year
23	10.67939	119.4583	0.03	0.4	0.37	Lawin	Oct. 2016	25-Year
24	10.67956	119.457	0.14	0.52	0.38	Yolanda	Nov. 2013	25-Year
25	10.68219	119.4573	0.36	0.5	0.14	Yolanda	Nov. 2013	25-Year
26	10.68318	119.4594	0.55	1	0.45	Nona	Dec. 2015	25-Year
27	10.68534	119.4611	1.23	0.9	-0.33	Yolanda	Nov. 2013	25-Year
28	10.68585	119.4633	0.06	0.46	0.4	Yolanda	Nov. 2013	25-Year
29	10.68862	119.47	0.03	0	-0.03	Lawin	Oct. 2016	25-Year
30	10.68051	119.4549	0.77	0.84	0.07	Yolanda	Nov. 2013	25-Year
31	10.67764	119.4518	0.62	0.5	-0.12	Ondoy	Sept. 2009	25-Year
32	10.70001	119.4529	0.53	0.3	-0.23	Yolanda	Nov. 2013	25-Year
33	10.69835	119.4518	0.03	0.65	0.62	Yolanda	Nov. 2013	25-Year
34	10.69583	119.4518	0.06	0	-0.06			25-Year
35	10.68862	119.4527	0.11	0	-0.11			25-Year
36	10.68975	119.4518	0.07	0	-0.07			25-Year
37	10.68602	119.4525	0.86	0	-0.86			25-Year
38	10.68172	119.4536	1.45	0.21	-1.24	Lawin	Oct. 2016	25-Year
39	10.67986	119.4553	1.07	0.95	-0.12	Yolanda	Nov. 2013	25-Year
40	10.67973	119.4555	0.66	0	-0.66	Yolanda	Nov. 2013	

Point	Validation Coordinates		Model Var (m)	Validation	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
								25-Year
41	10.64232	119.472	1.18	0			Nov. 2013	25-Year
42	10.6453	119.4621	0.25	0.4	-1.18	Lawin	Oct. 2016	25-Year
43	10.64213	119.4626	1.05	0.5	0.15	Lawin	Oct. 2016	25-Year
44	10.64159	119.4633	2.4	0.85	-0.55	Lawin	Oct. 2016	25-Year
45	10.68826	119.4721	0.03	1.85	-1.55		Dec. 2011	25-Year
46	10.68955	119.4736	0.05	0.31	1.82	Yolanda	Nov. 2013	25-Year
47	10.68955	119.4772	0.66	0	0.26			25-Year
48	10.69064	119.479	0.29	0	-0.66			25-Year
49	10.69222	119.4792	0.06	0	-0.29	Lawin	Oct. 2016	25-Year
50	10.71227	119.4877	0.04	0	-0.06			25-Year
51	10.71138	119.4877	0.06	0	-0.04			25-Year
52	10.71176	119.4897	0.15	0	-0.06			25-Year
53	10.71214	119.4856	0.22	0	-0.15			25-Year
54	10.71097	119.4877	0.42	0	-0.22			25-Year
55	10.71314	119.4859	0.16	0	-0.42			25-Year
56	10.71316	119.4849	0.23	0	-0.16			25-Year
57	10.71314	119.484	0.35	0	-0.23			25-Year
58	10.71101	119.4837	0.25	0	-0.35			25-Year
59	10.7116	119.484	0.14	0	-0.25			25-Year
60	10.71091	119.4847	0.07	0	-0.14			25-Year
61	10.71105	119.4863	0.4	0	-0.07			25-Year
62	10.71025	119.4842	0.69	0	-0.4			25-Year
63	10.71037	119.4849	0.11	0	-0.69			25-Year
64	10.71037	119.4855	0.05	0	-0.11			25-Year
65	10.70964	119.4854	0.33	0	-0.05			25-Year
66	10.70964	119.4861	0.04	0	-0.33			25-Year
67	10.70969	119.4868	0.14	0	-0.04			25-Year
68	10.70975	119.4874	0.04	0	-0.14			25-Year
69	10.71101	119.4887	0.1	0	-0.04			25-Year
70	10.71059	119.4895	0.43	0	-0.1			25-Year
71	10.71031	119.4896	0.05	0	-0.43			25-Year
72	10.71318	119.4875	0.03	0	-0.05			25-Year
73	10.71322	119.4879	0.03	0	-0.03			25-Year
74	10.71312	119.4883	0.03	0	-0.03			25-Year
75	10.71311	119.4895	0.08	0	-0.03			25-Year
76	10.71315	119.4901	0.07	0	-0.08			25-Year
77	10.71345	119.4895	0.03	0	-0.07			25-Year
78	10.7166	119.415	0.03	0	-0.03			25-Year
79	10.71354	119.4889	0.12	0	-0.03			25-Year
80	10.71129	119.4903	0.06	0	-0.12			

Point	Validation Coordinates		Model Var (m)	Validation	Error	Event	Date	Rain Return/ Scenario
	Latitude	Longitude						
	10.71117							25-Year
81	10.71064	119.4912	1.18	0.26	-0.26		Nov. 2013	25-Year
82	10.70755	119.4914	0.25	1.91	-1.91	Lawin	Oct. 2016	25-Year
83	10.70049	119.4914	1.05	1.37	-1.37	Lawin	Oct. 2016	25-Year
84	10.70064	119.4919	2.4	2.49	-2.49	Lawin	Oct. 2016	25-Year
85	10.70054	119.4921	0.03	1.91	-1.91		Dec. 2011	25-Year
86	10.70059	119.4924	0.05	2.01	-2.01	Yolanda	Nov. 2013	25-Year
87	10.7013	119.4931	0.66	0.05	-0.05			25-Year
88	10.70355	119.4922	0.29	0.03	-0.03			25-Year
89	10.70434	119.4924	0.06	0.04	-0.04	Lawin	Oct. 2016	25-Year
90	10.70484	119.4921	0.04	0.04	-0.04			25-Year
91	10.68856	119.4917	0.06	0.06	-0.06			25-Year
92	10.6885	119.4717	0.15	0.03	-0.03			25-Year
93	10.68926	119.4722	0.22	0.03	-0.03			25-Year
94	10.68952	119.4732	0.42	0.03	-0.03			25-Year
95	10.69016	119.4735	0.16	0.03	-0.03			25-Year
96	10.69134	119.4748	0.23	0.03	-0.03			25-Year
97	10.68936	119.4735	0.35	1.43	-1.43			25-Year
98	10.69058	119.4775	0.25	0.03	-0.03			25-Year
99	10.69121	119.479	0.14	1.48	-1.48			25-Year
100	10.69194	119.4791	0.07	0.03	-0.03			25-Year
101	10.69251	119.4789	0.4	0.03	-0.03			25-Year
102	10.69284	119.4788	0.69	0.41	-0.41			25-Year
103	10.69366	119.4792	0.11	0.44	-0.44			25-Year
104	10.69319	119.4777	0.05	0.03	-0.03			25-Year
105	10.69523	119.4797	0.33	0.03	-0.03			25-Year
106	10.69373	119.4823	0.04	0.03	-0.03			25-Year
107	10.69842	119.4855	0.14	0.07	-0.07			25-Year
108	10.6905	119.4896	0.04	0.03	-0.03			25-Year
109	10.7141	119.4993	0.1	0.66	-0.66			25-Year
110	10.69327	119.4133	0.43	0.06	-0.06			25-Year
111	10.71646	119.4968	0.05	0.34	-0.34			25-Year
112	10.69375	119.4151	0.03	0.04	-0.04			25-Year
113	10.69487	119.4964	0.03	0.63	-0.63			25-Year
114	10.71529	119.4977	0.03	0.04	-0.04			25-Year
115	10.7152	119.4158	0.08	1.25	-1.25			25-Year
116	10.71589	119.4165	0.07	0.04	-0.04			25-Year
117	10.71607	119.4155	0.03	0.03	-0.03			25-Year
118	10.71589	119.4151	0.03	1.07	-1.07			25-Year

ANNEX 12. Educational Institutions Affected by flooding in Abongan Floodplain

This river basin has no Medical institutions affected by flooding in Abongan Foodplain

ANNEX 13. Health Institutions Affected by flooding in Abongan Floodplain

This river basin has no Medical institutions affected by flooding in Abongan Foodplain

ANNEX 13. UP Los Banos Phil LiDAR 1 Team

Floodplain

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