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

LiDAR Surveys and Flood Mapping of Tibiao River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of the Philippines Cebu

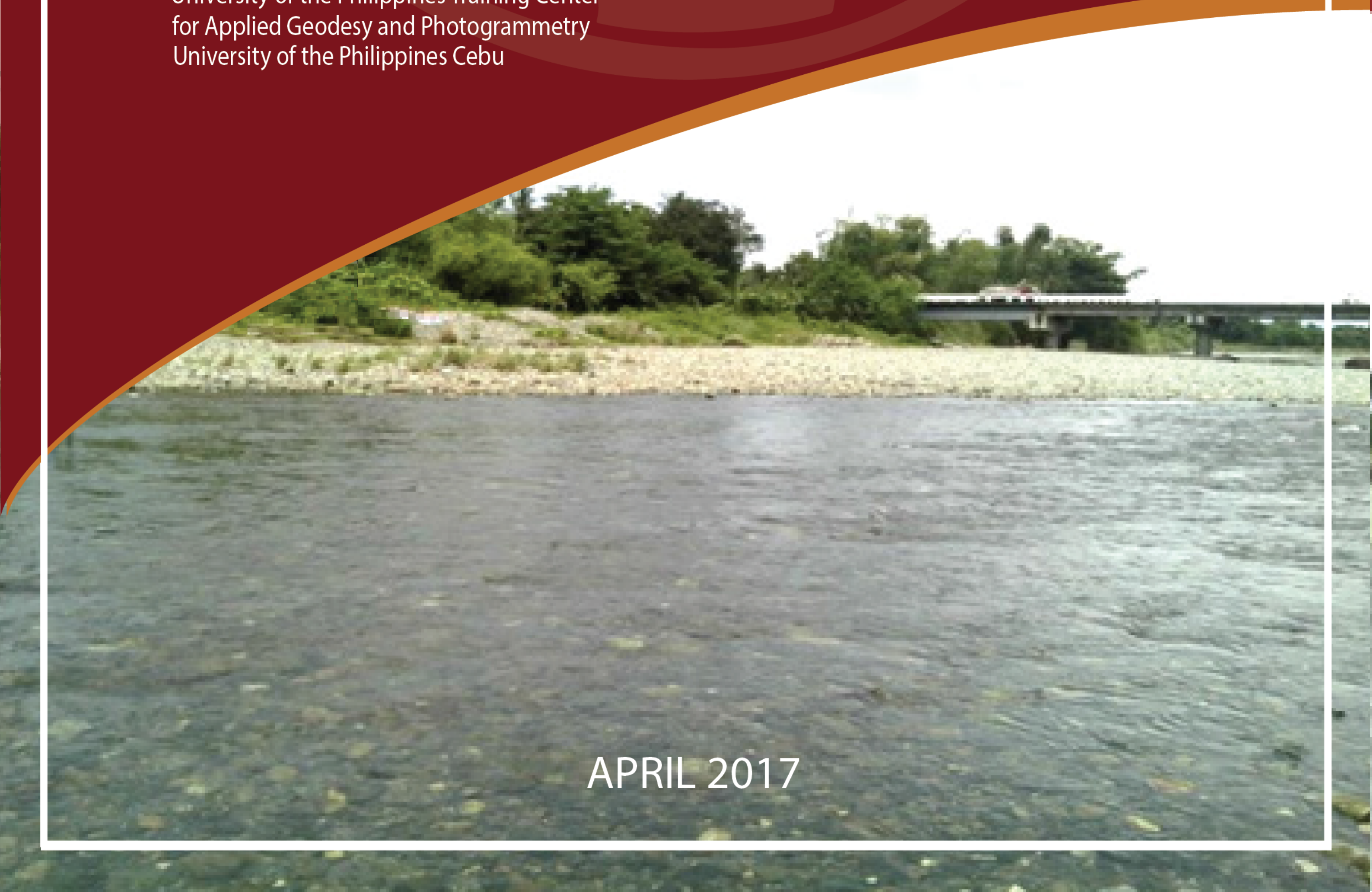

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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]
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
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND TIBIAO RIVER

Enrico C. Paringit, Dr. Eng. and Jonnifer Sinogaya, PhD.

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Cebu (UPC). UPC 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 22 river basins in the Western Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Tibiao River Basin

Tibiao River Basin covers portions of the Municipalities of Tibiao and Culasi, Province of Antique. The DENR River Basin Control Office (RBCO) identified it to be one of the 421 river basins in the Philippines, having a drainage area of 119 km2 and an estimated 151 million cubic meter annual run-off. It is also one of the seven (7) major river basins in Antique.

Its main stem, Tibiao River, passes along the Municipality of Tibiao. The river is part of the 23 river systems in Western Visayas Region. According to the 2010 National Census, there are a total of 8,579 people residing in the immediate vicinity of the river which is distributed among five (5) barangays, namely: Bandoja, Importante, Martinez, Poblacion, and Santa Justa.

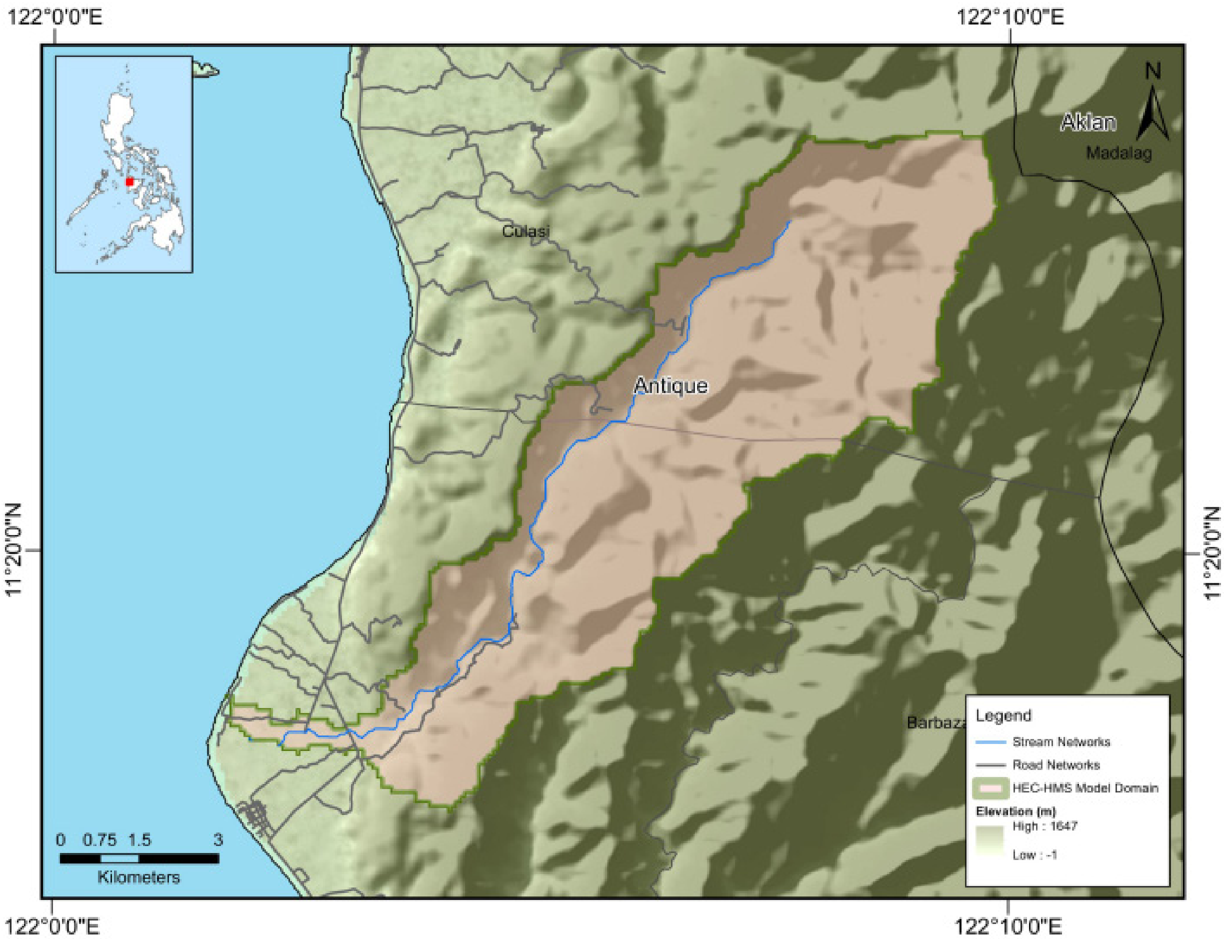

Figure 1. Map of Tibiao River Basin (in brown)

CHAPTER 2: LIDAR DATA ACQUISITION OF THE TIBIAO FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Tibiao floodplain in Antique, Western Visayas. These missions were planned for 10 lines that ran for four (4) hours at most, including take-off, landing and turning time. The flight planning parameters for Gemini LiDAR system is found in Table 1. Figure 2 shows the flight plan for Tibiao floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK43A	1000/1500	40	40	70/100	50	115/130	5

[1] The explanation of the parameters used are in the volume "LiDAR Surveys and Flood Mapping in the Philippines: Methods."

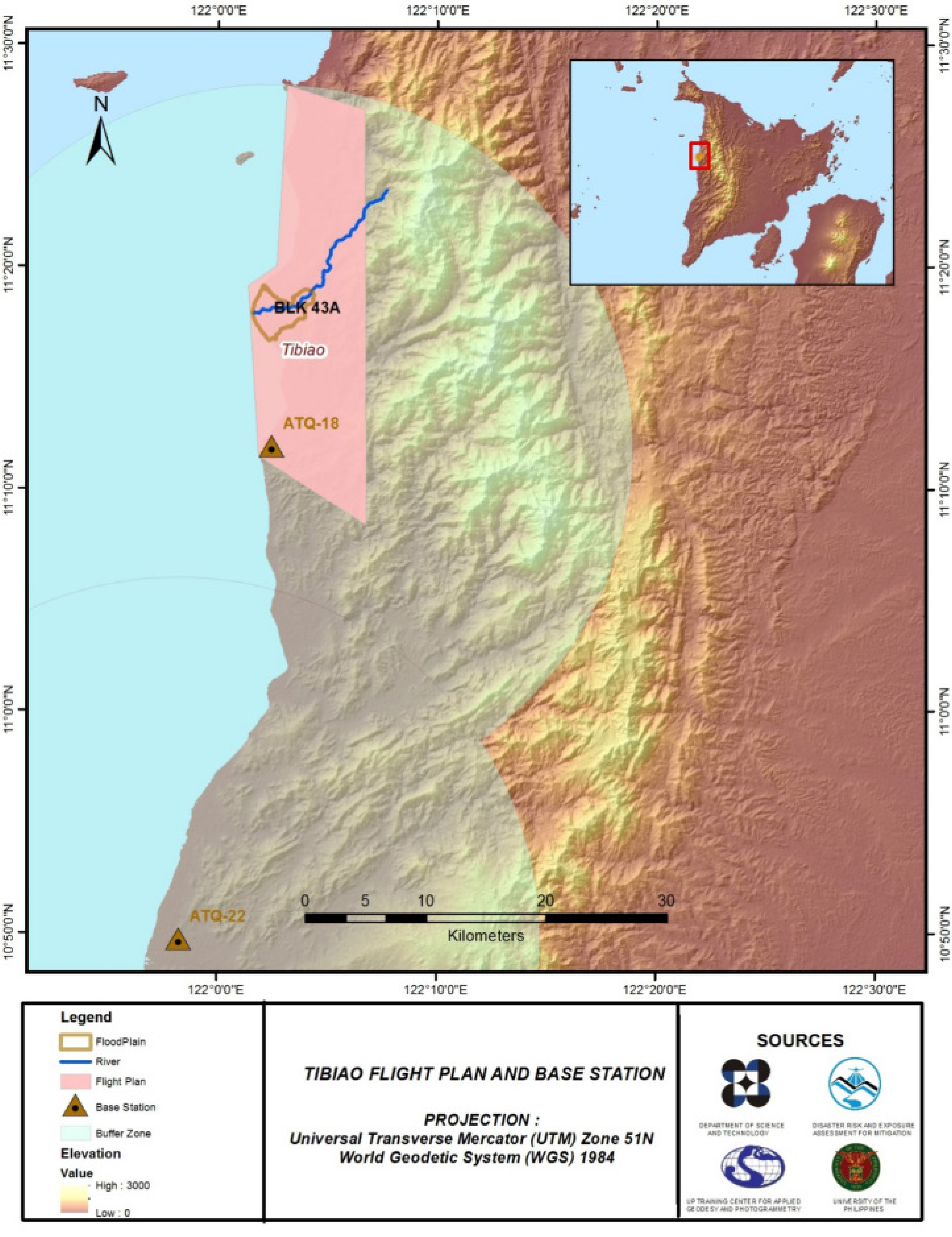

Figure 2. Flight Plan and base stations used for the Tibiao Floodplain survey.

2.2 Ground Base Stations

The project team recovered two (2) NAMRIA reference points: ATQ-18 and ATQ-22 which are of second (2nd) order accuracy. The certifications for the base stations are found in Annex 2. These were used as base stations during flight operations for the entire duration of the survey (February 20 - 22, 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 Tibiao Floodplain are shown in Figure 2.

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

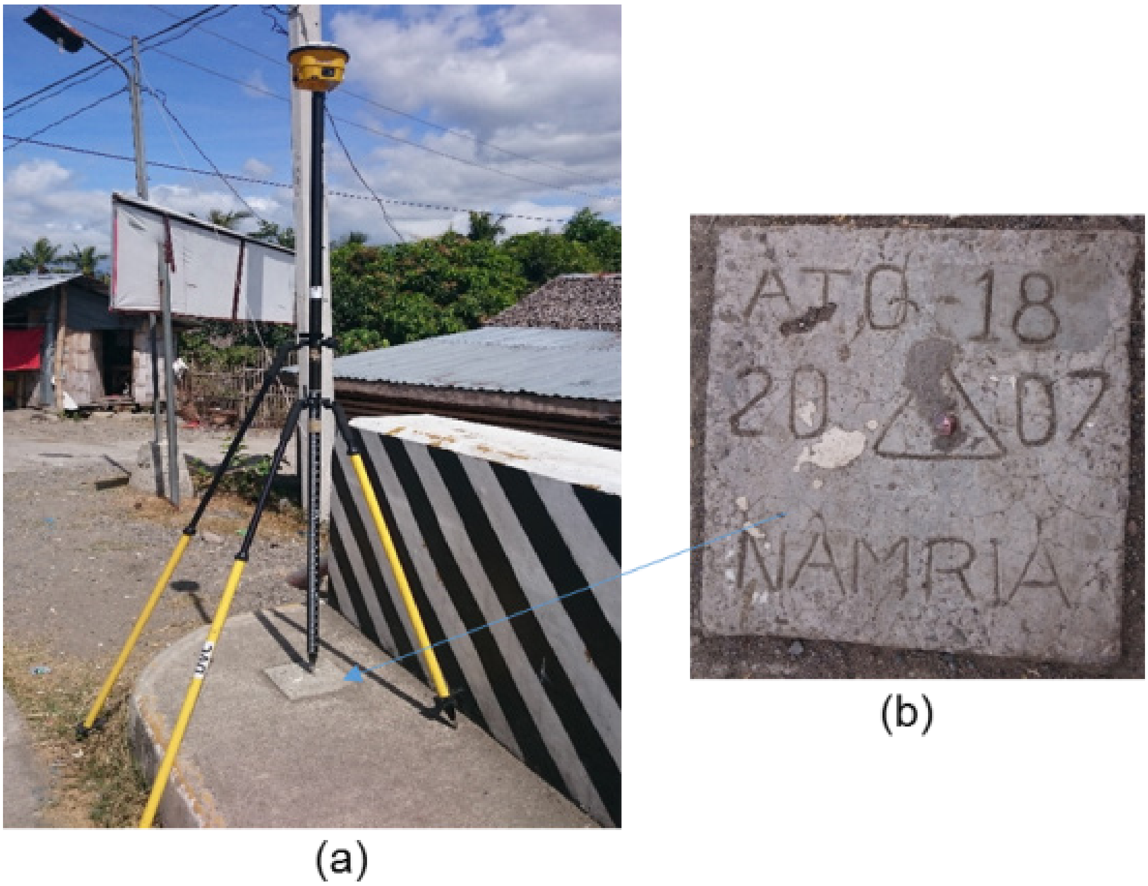

Figure 3. GPS set-up over ATQ-18 in Binangbang Bridge of Barangay Cubay, Barbaza, Province of Antique (a) and NAMRIA reference point ATQ-18 (b) as recovered by the field team

Table 2. Details of the recovered NAMRIA horizontal control point ATQ-18 used as base station for the LiDAR data acquisition.

Station Name	ATQ-18	
Order of Accuracy	**2nd Order**	
Relative Error (Horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	11° 11’ 58.67081” North 122° 2’ 22.83300” East 10.902 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	395155.157 meters 1238579.674 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	11° 11’ 54.16068” North 122° 2’ 28.01549” East 65.961 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	395155.87 meters 1238146.15 meters

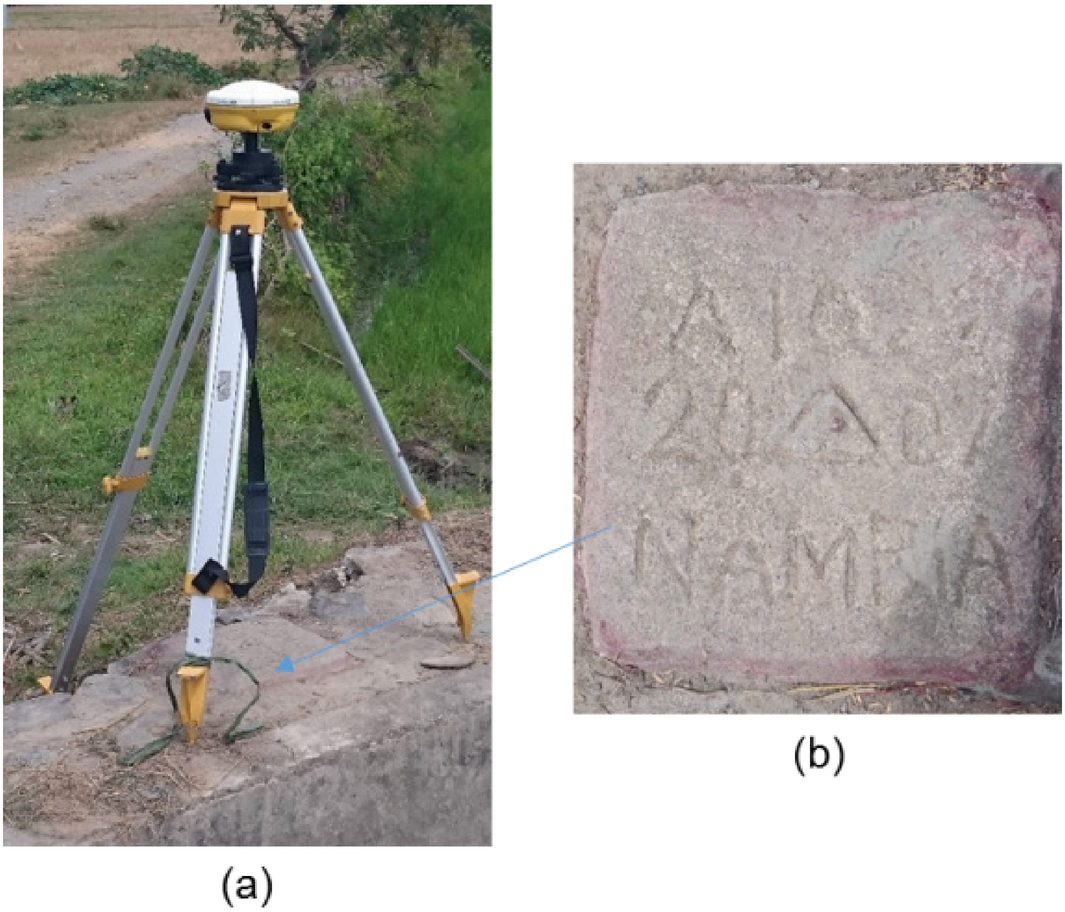

Figure 4. GPS set-up over ATQ-22 on an irrigation canal in Barangay Concepcion, Belison, Province of Antique (a) and NAMRIA reference point ATQ-22 (b) as recovered by the field team

Table 3. Details of the recovered NAMRIA horizontal control point ATQ-22 used as base station for the LiDAR data acquisition.

Station Name	**ATQ-22**	
Order of Accuracy	**2nd Order**	
Relative Error (Horizontal positioning)	**1:50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	10° 49’ 46.66618” North 121° 58’ 11.90221” East 12.250 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	387365.279 meters 1197676.056 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	10° 49’ 42.24271” North 121° 58’ 17.11770” East 68.022 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	387404.70 meters 1197256.85 meters

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

Date Surveyed	Flight Number	Mission Name	Ground Control Points
20 FEB 15	2582G	2BLK43A051A	ATQ-18 & ATQ-22
21 FEB 15	2586G	2BLK43A052A	ATQ-18 & ATQ-22
22 FEB 15	2590G	2BLK43A053A	ATQ-18 & ATQ-22

2.3 Flight Missions

Three (3) missions were conducted to complete the LiDAR Data Acquisition in Tibiao floodplain, for a total of eleven hours and three minutes (11+3) of flying time for RP-C9022. All missions were acquired using the Gemini LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Tibiao 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
20 Feb 2015	2582G	298.56	36.48	0.65	35.8333	113	2	59
21 Feb 2015	2586G	310.87	137.71	12.01	125.696	224	3	59
22 Feb 2015	2590G	310.87	200.82	0.87	199.9456	317	4	5
TOTAL		920.3	375.01	13.53	361.48	654	11	3

Table 6. Actual parameters used during the LiDAR data acquisition of the Tibiao Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
2582G	1000	40	40	100	50	115/130	5
2586G	1500	40	40	70	50	115/130	5
2590G	1500	40	40	70	50	115/130	5

2.4 Survey Coverage

Tibiao floodplain is situated within the municipality of Tibiao, Province of Antique. The municipality of Tibiao was mostly covered during the survey. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Tibiaof loodplain is presented in Figure 5.

Table 7. List of municipalities and cities surveyed of the Tibiao Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Antique	Tibiao	95.95	80.39	83.78%
	Barbaza	171.23	70.92	41.42%
	Culasi	201.84	74.72	37.02%
	Lauan-An	165.65	31.63	19.09%
Total		**634.67**	**257.66**	**45.33%**

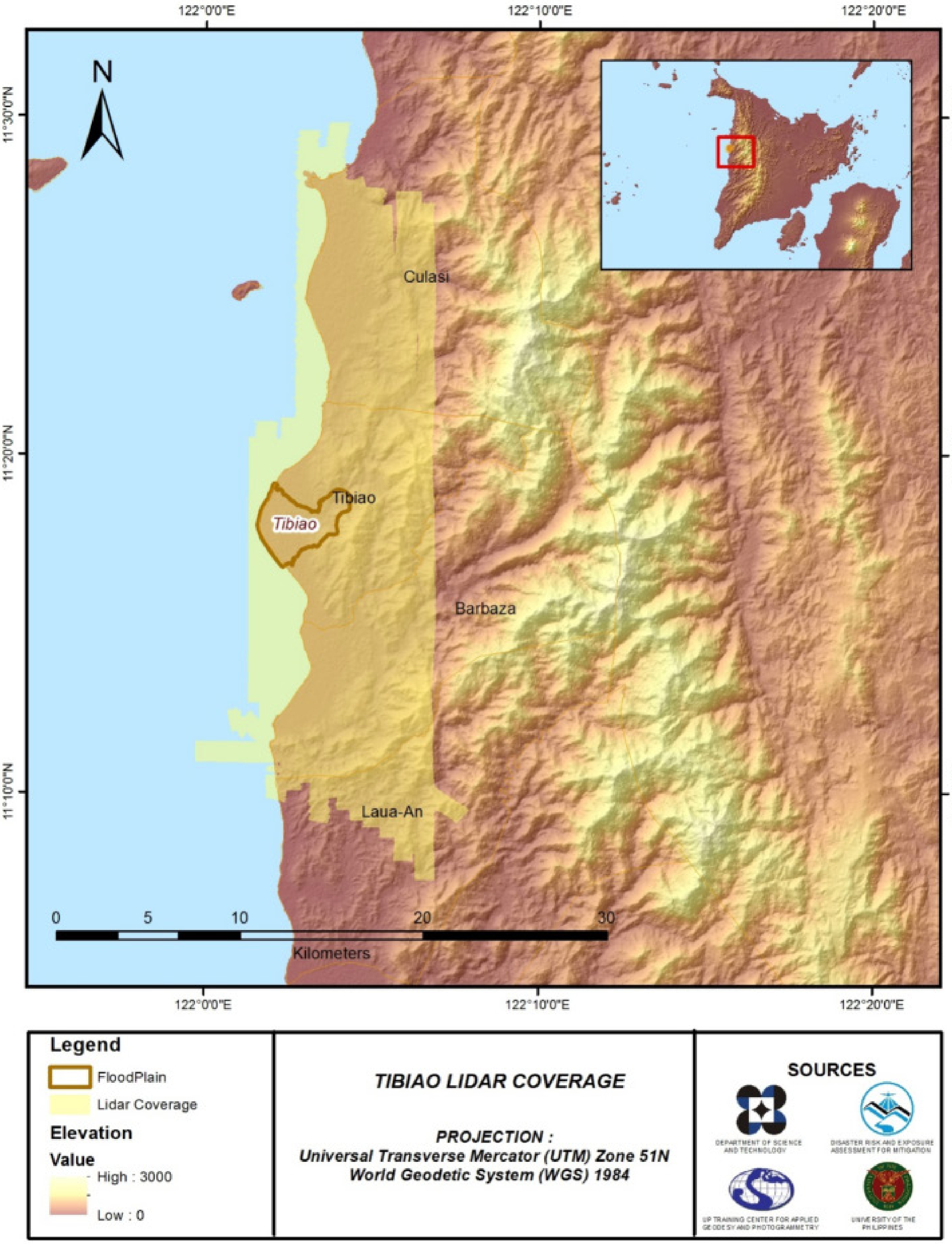

Figure 5. Actual LiDAR survey coverage of the Tibiao Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE TIBIAO 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 were checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory was done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification was performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds were subject for quality checking to ensure that the required accuracies of the program, were met. These are: Minimum point density, vertical and horizontal accuracies. The point clouds were 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 were calibrated. Portions of the river that were barely penetrated by the LiDAR system were replaced by the actual river geometry measured from the field by the Data Validation and Bathymetry Component. LiDAR acquired temporally were then mosaicked to completely cover the target river systems in the Philippines. Orthorectification of images acquired simultaneously with the LiDAR data was done through the help of the georectified point clouds and the metadata containing the time the image was captured.

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

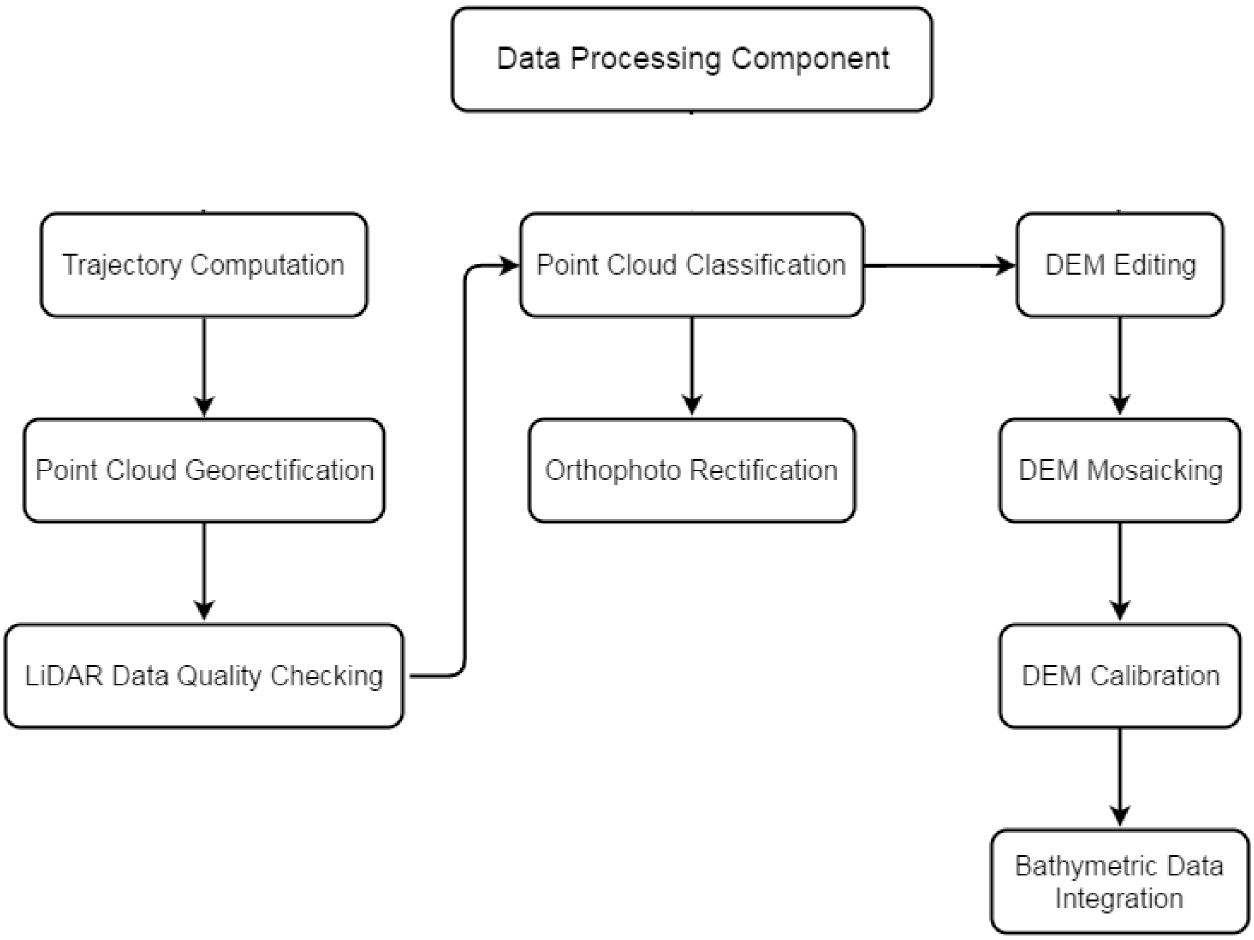

Figure 6. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

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

The Data Acquisition Component (DAC) transferred a total of 25.05 Gigabytes of Range data, 486 Megabytes of POS data, 39.5 Megabytes of GPS base station data, and 43.44 Gigabytes of raw image data to the data server on March 23, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tibiao was fully transferred on March23, 2015 as indicated on the Data Transfer Sheets for Tibiao floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 2590G, one of the Tibiao flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of flight, measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on February 22, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

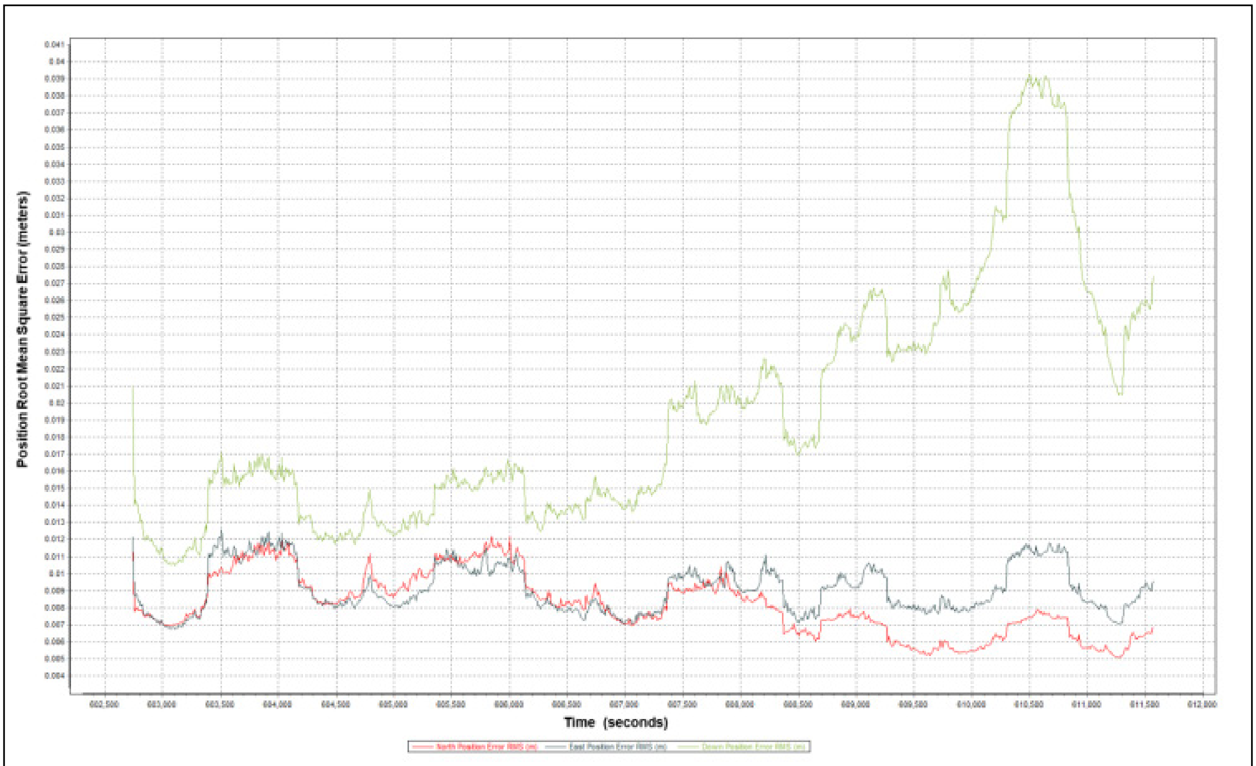

Figure 7. Smoothed Performance Metrics of Tibiao Flight 2590G.

The time of flight was from 602,500 seconds to 612,000 seconds, which corresponds to morning of February 22, 2015. The initial spike that seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft.

Redundant measurements from the POS system quickly minimize the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values corresponds to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 7 shows that the North position RMSE peaks at 1.22 centimeters, the East position RMSE peaks at 1.25 centimeters, and the Down position RMSE peaks at 3.92 centimeters, which are within the prescribed accuracies described in the methodology.

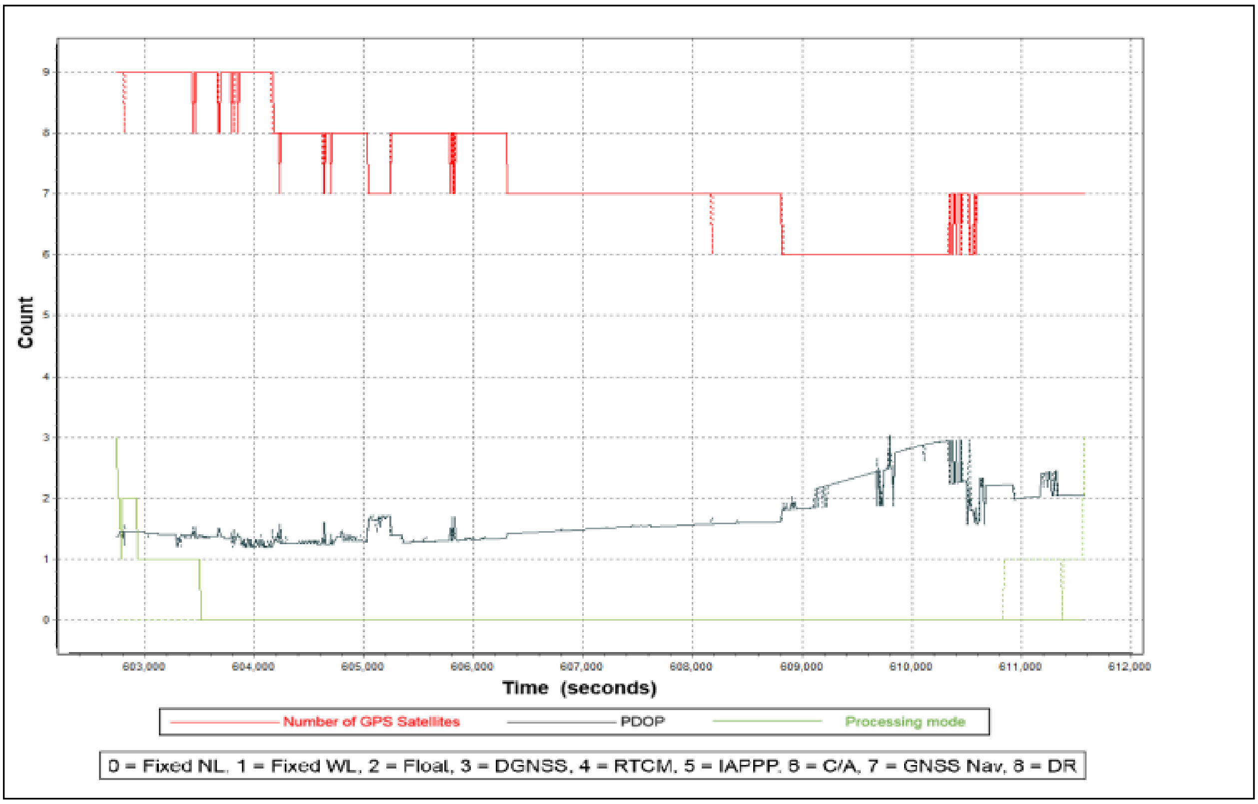

Figure 8. Solution Status Parameters of Tibiao Flight 2590G

The Solution Status parameters of flight 2590G, one of the Tibiao flights, which indicate the number of GPS satellites, Positional Dilution of Precision, and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go below 6. Most of the time, the number of satellites tracked was between 6 and 9. The PDOP value also did not go above the value of 3, which still indicated optimal GPS geometry. The processing mode remained at 0 for almost the entire survey time with sudden peaks up to 1 attributed to the turn 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 Tibiao flights is shown in Figure 9.

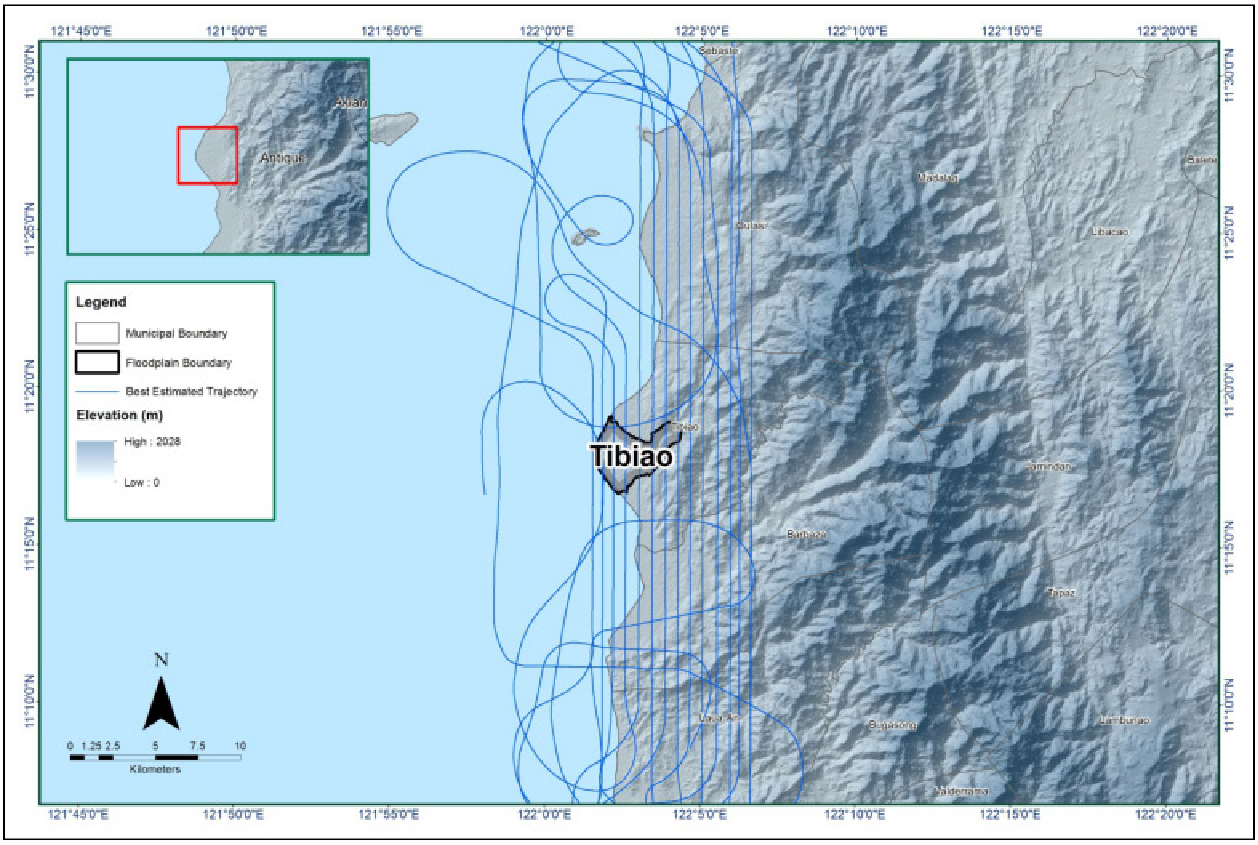

Figure 9. Best estimated trajectory of the LiDAR missions conducted over the Tibiao Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 17 flight lines, with each flight line containing one channel, since the Gemini system contains only one channel. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tibiao floodplain are given in Table 8.

Table 8. Self-calibration Results values for Tibiao flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000592
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000705
GPS Position Z-correction stdev	<0.01meters	0.0075

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

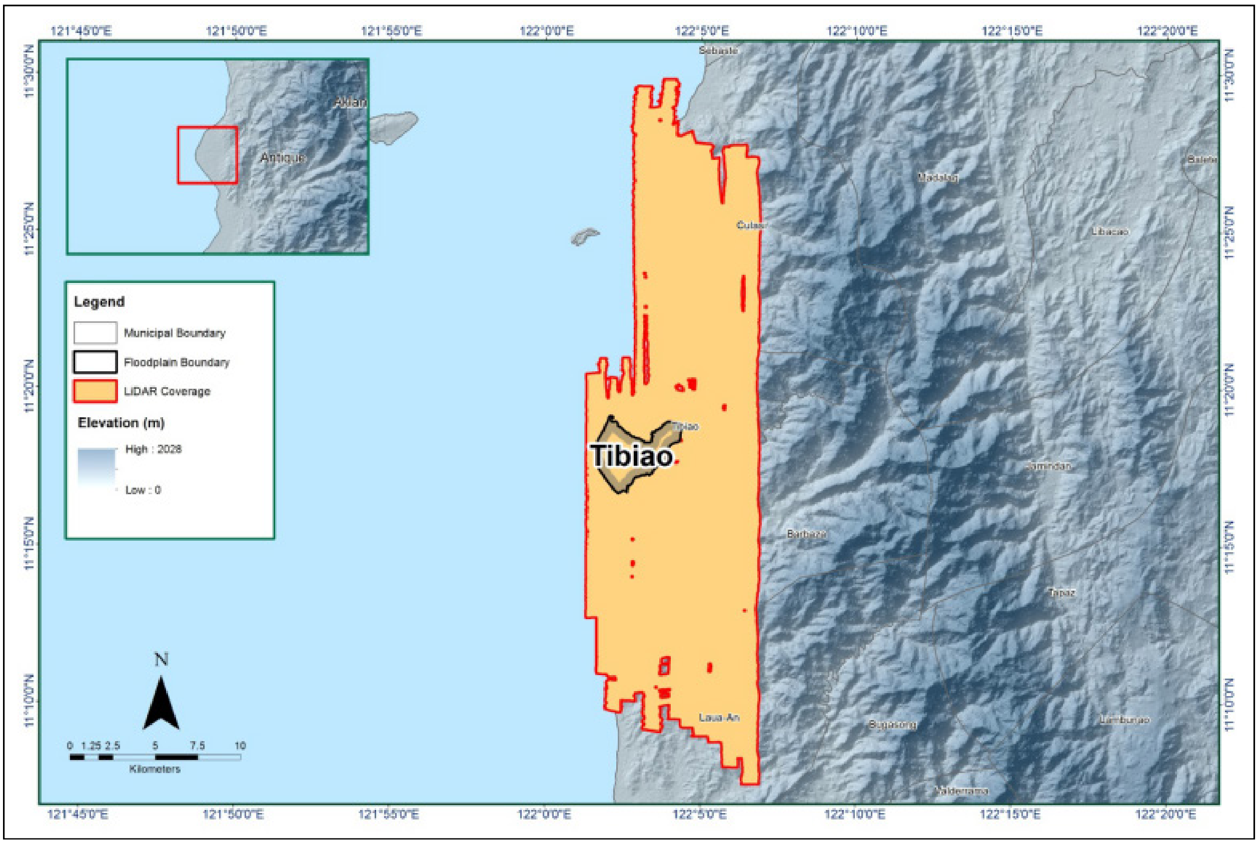

Figure 10. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Tibiao Floodplain.

The total area covered by the Tibiao missions is 297.50 sq.km that is comprised of three (3) flight acquisitions grouped and merged into one (1) block as shown in Table 9.

Table 9. List of LiDAR blocks for Tibiao Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Iloilo_Blk43A	2582G	297.50
	2586G	
	2590G	
TOTAL		**294.50**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 11. Since the Gemini system employs only one channel, it is expected that 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.

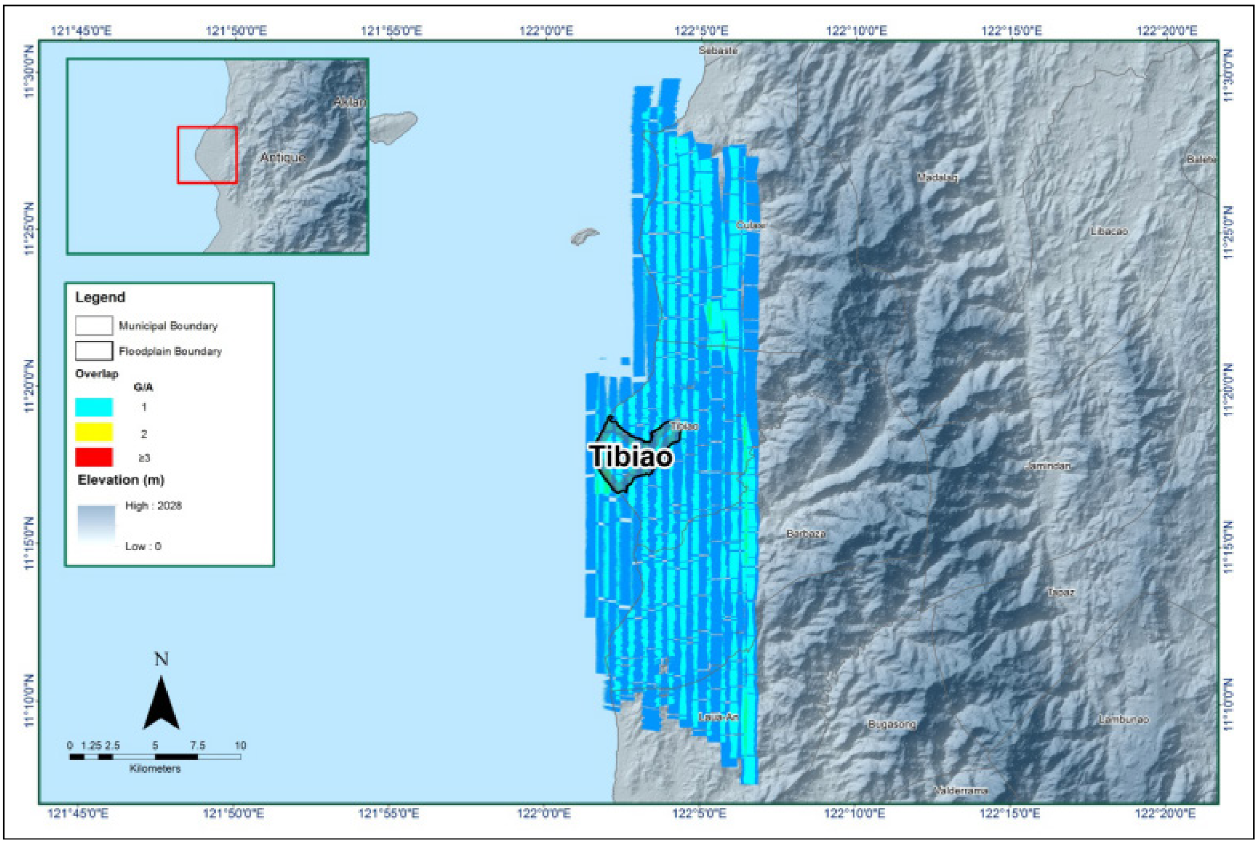

Figure 11. Image of data overlap for Tibiao Floodplain.

The overlap statistics per block for the Tibiao floodplain is found in Annex 8. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 38.72%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 12. It was determined that all LiDAR data for Tibiao floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.06 points per square meter.

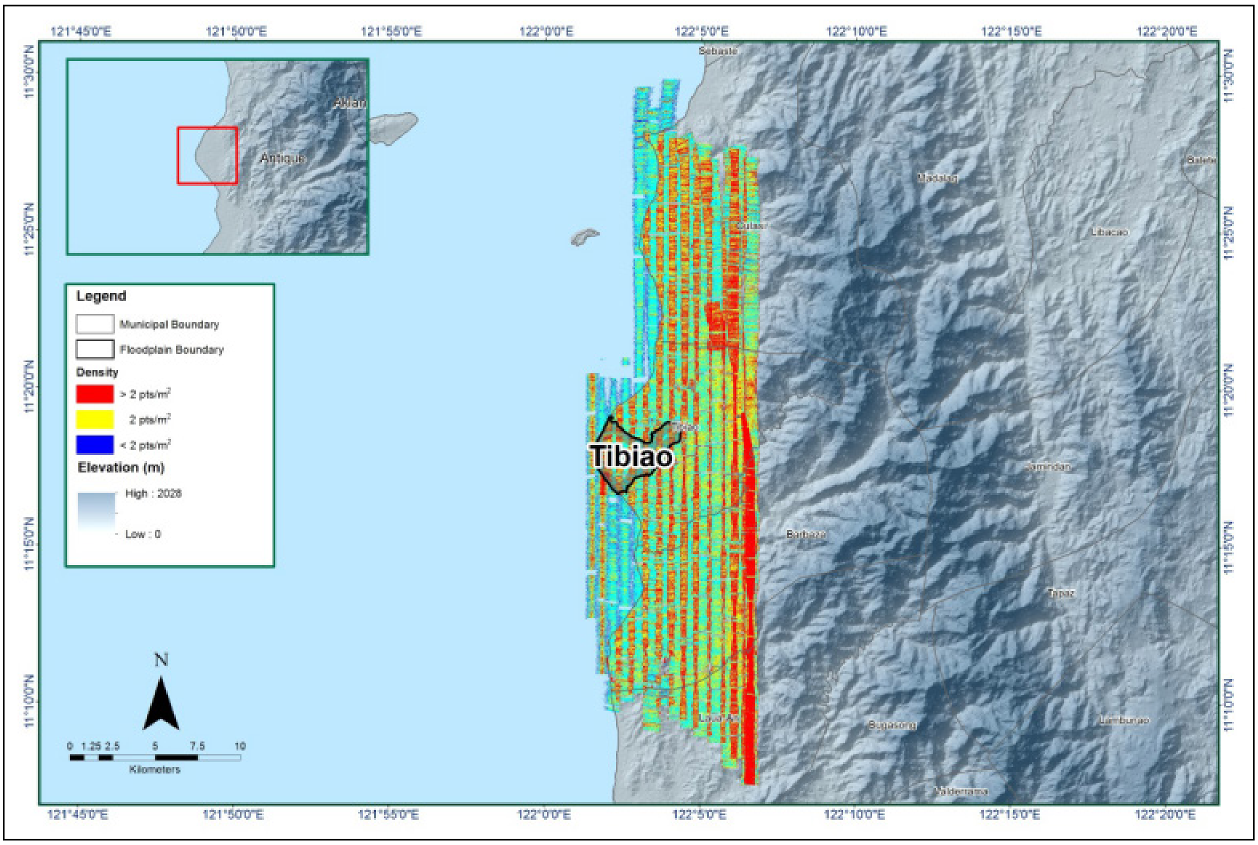

Figure 12. Pulse density map of merged LiDAR data for Tibiao Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. 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.

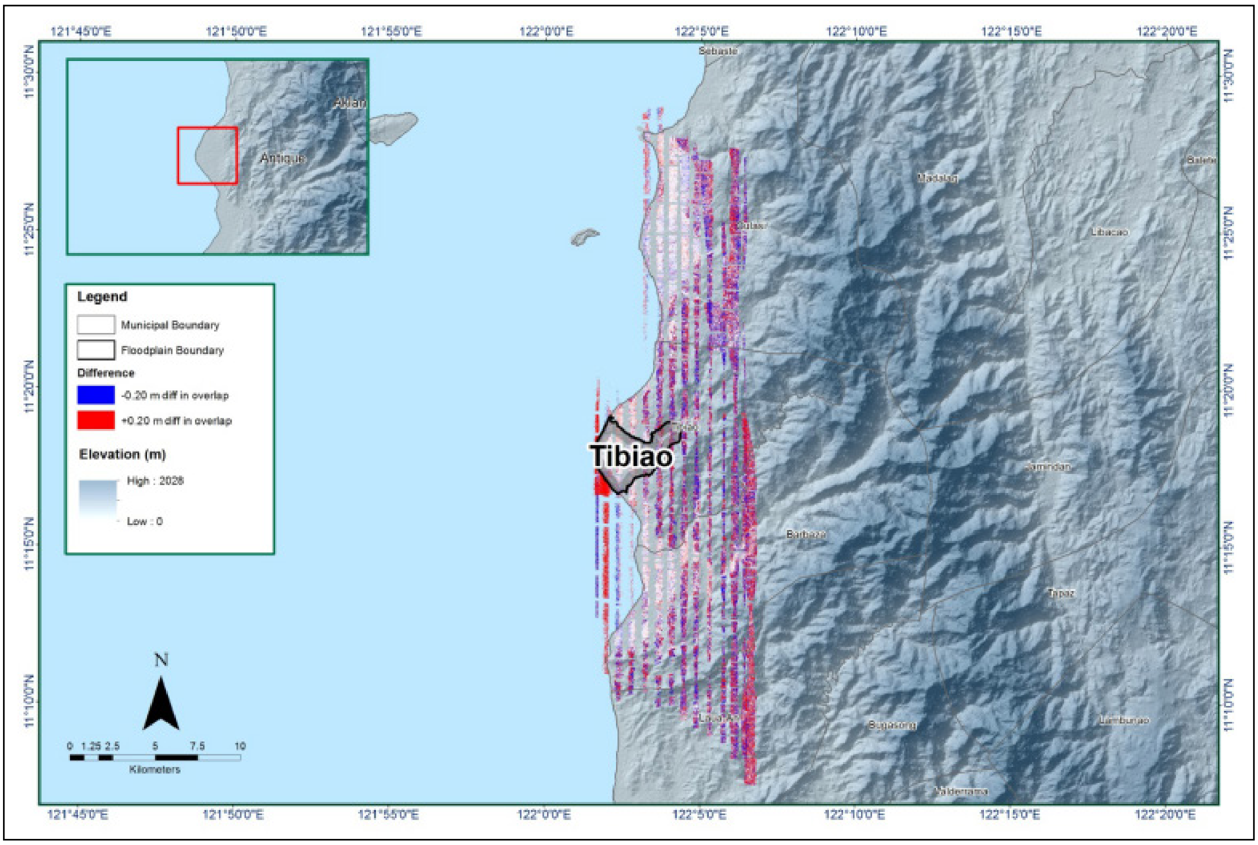

Figure 13. Elevation Difference Map between flight lines for Tibiao Floodplain Survey.

A screen capture of the processed LAS data from a Tibiao flight 2590G loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

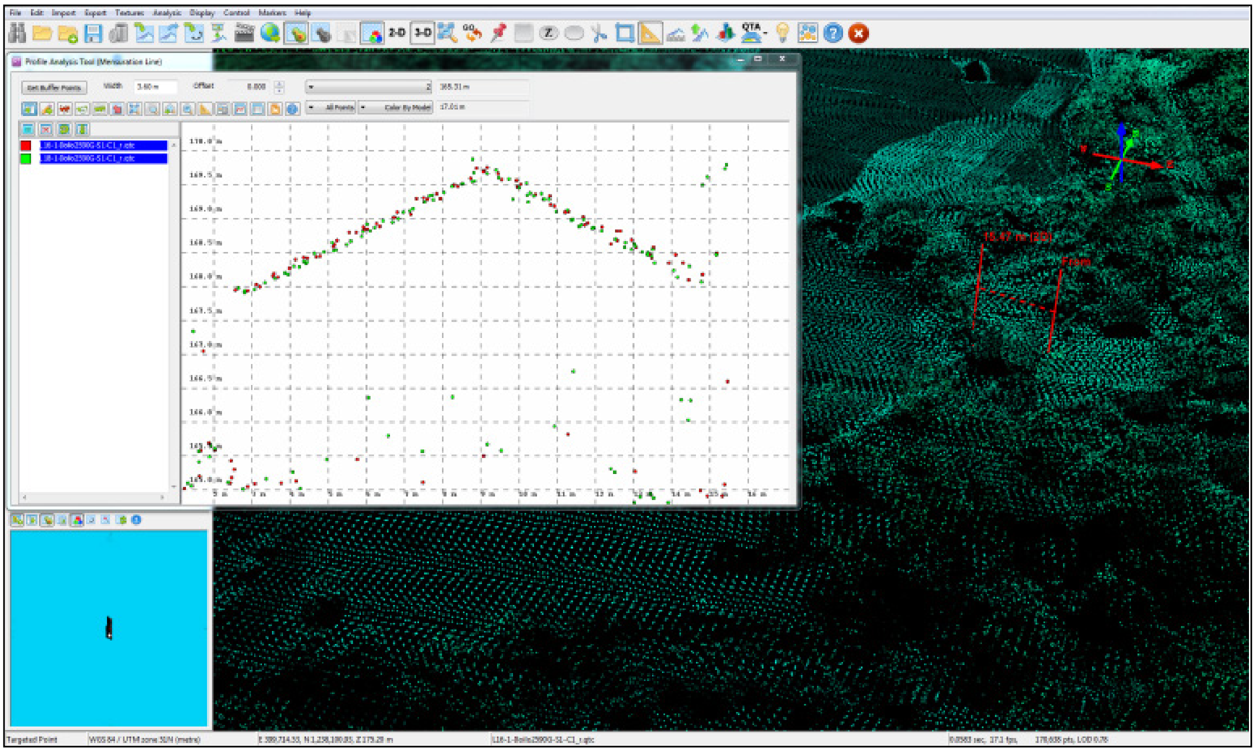

Figure 14. Quality checking for a Tibiao flight 2590G using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Tibiao classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	40,031,989
Low Vegetation	18,192,805
Medium Vegetation	47,956,243
High Vegetation	30,567,353
Building	26,127,578

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tibiao floodplain is shown in Figure 15. A total of 109 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 881.61 meters and 54.56 meters respectively.

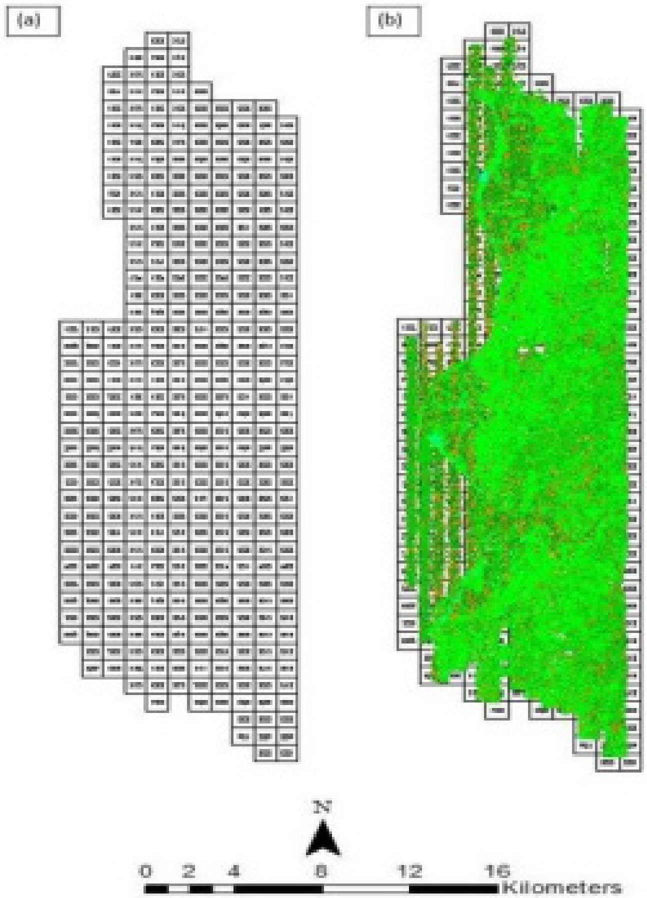

Figure 15. Tiles for Tibiao Floodplain (a) and classification results (b) in TerraScan.

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

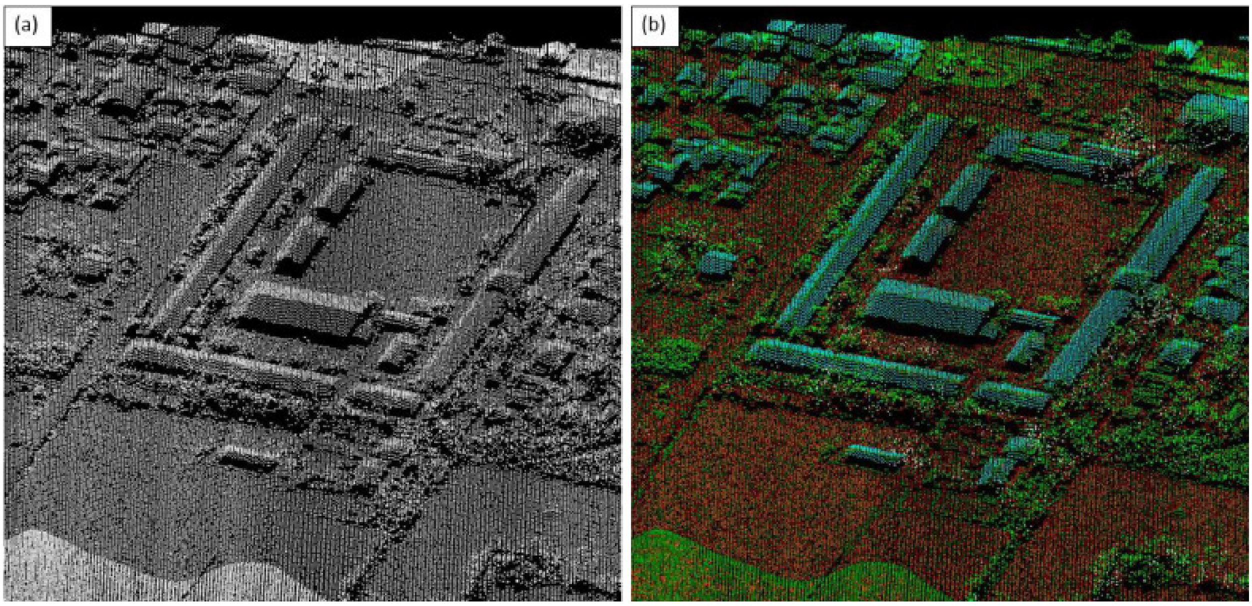

Figure 16. Point cloud before (a) and after (b) classification

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

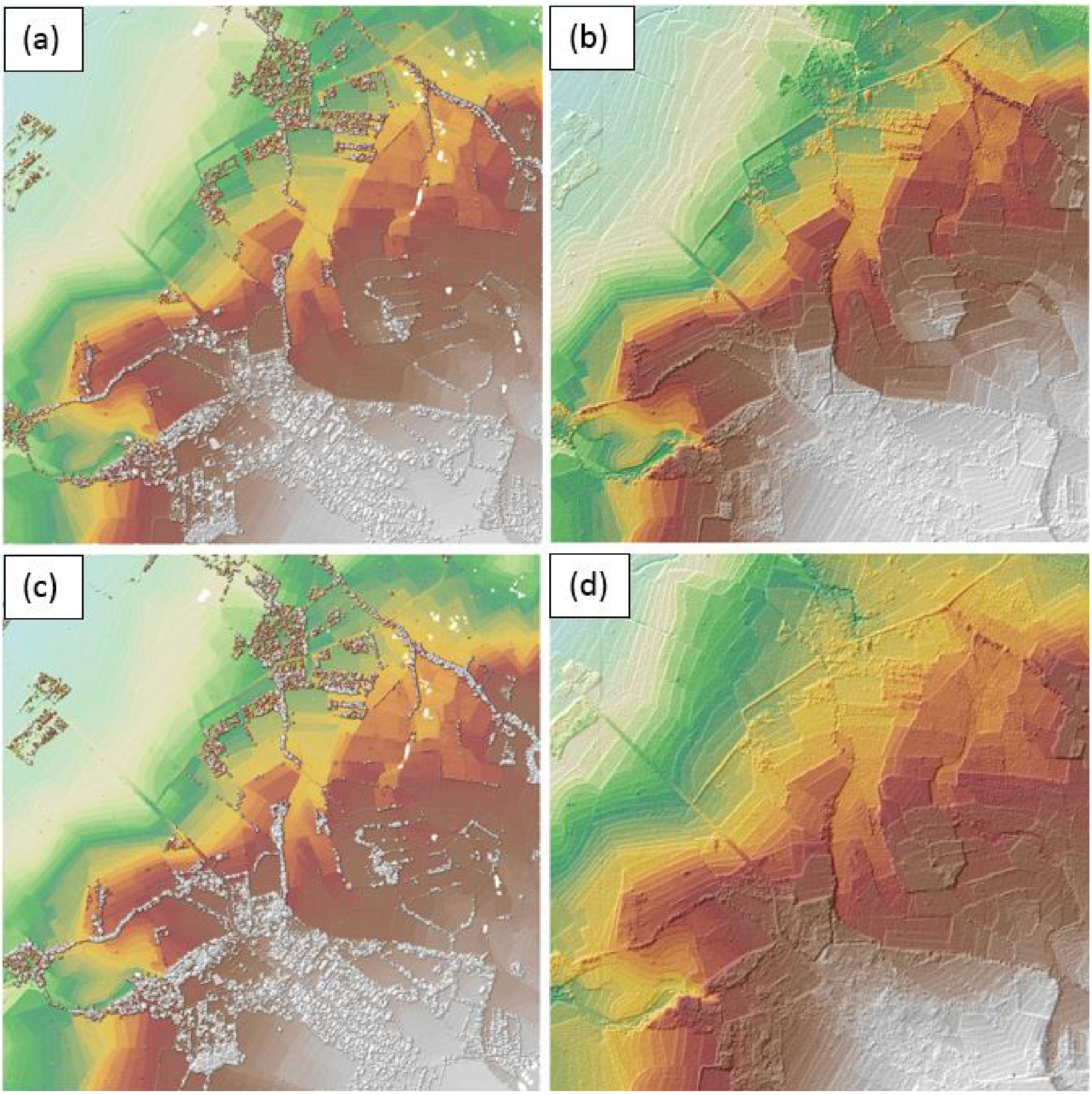

Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tibiao Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 648 1km by 1km tiles area covered by Tibiao floodplain is shown in Figure 18. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Tibiao floodplain has a total of 292.90 sq.km orthophotogaph coverage comprised of 507 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 19.

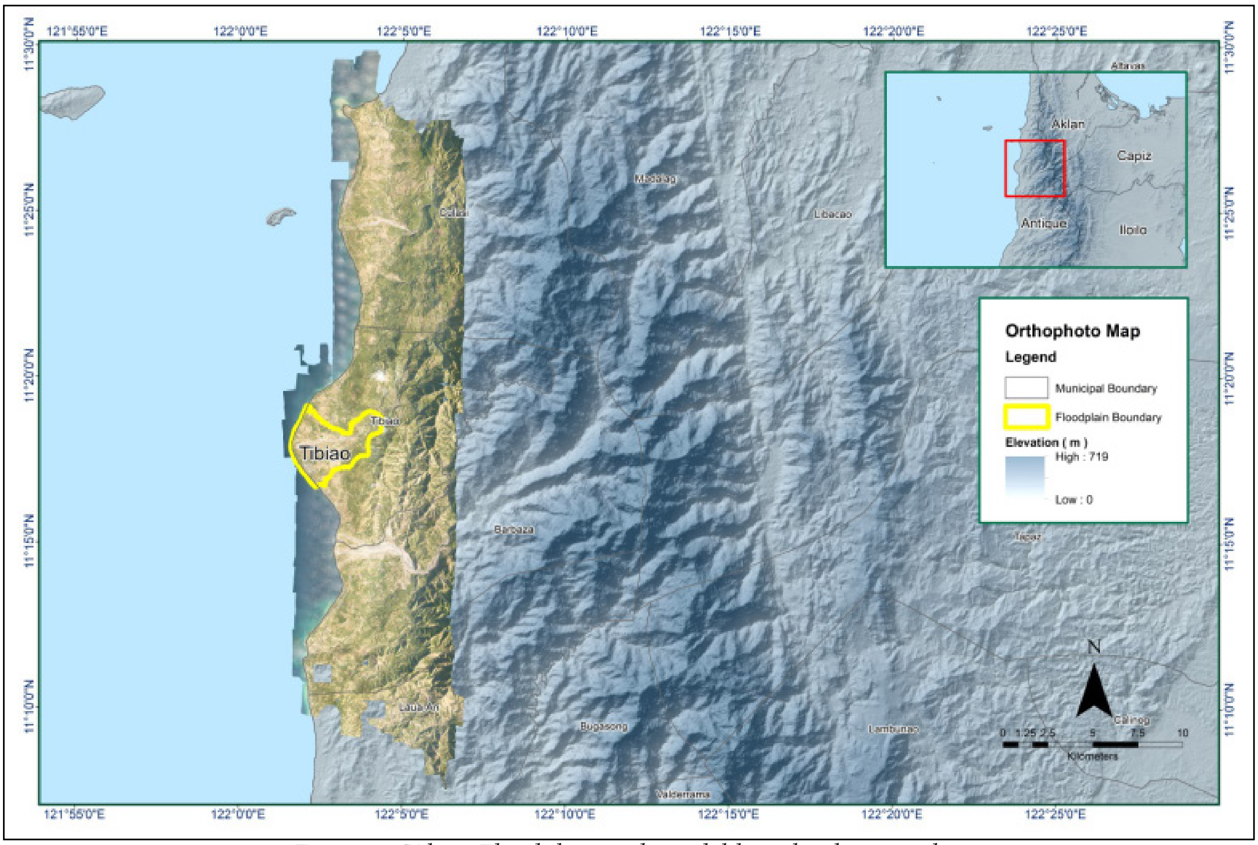

Figure 18. Tibiao Floodplain with available orthophotographs.

Figure 19. Sample orthophotograph tiles for Tibiao Floodplain.

3.8 DEM Editing and Hydro-Correction

One (1) mission block was processed for Tibiao flood plain. This block is composed of the Iloilo block with a total area of 297.50 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Iloilo_Blk43A	297.50
TOTAL	**297.50**

Portions of DTM before and after manual editing are shown in Figure 20. The bridges (Figure 20a) were an impedance to the flow of water along the river and had to be removed (Figure 20b) in order to hydrologically correct the river. It shows that the paddy field (Figure 20c) had been misclassified and removed during classification process and had to be retrieved to complete the surface (Figure 20d).

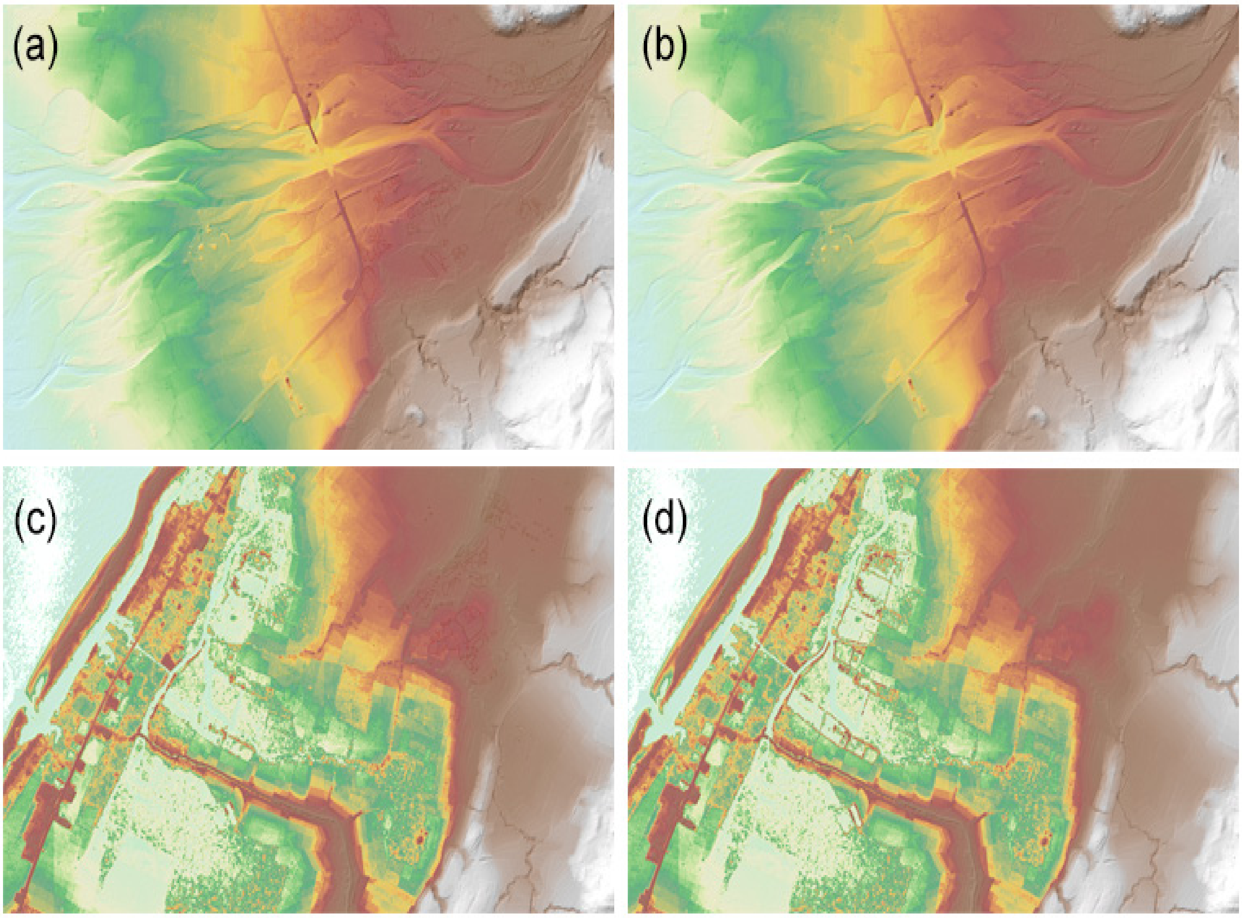

Figure 20. Portions in the DTM of Tibiao Floodplain – bridges before (a) and after (b) manual editing; paddy fields before (c) and after (d) data retrieval

3.9 Mosaicking of Blocks

IloIlo_Blk43B was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 12 shows the area of LiDAR block and the shift values applied during mosaicking.

Mosaicked LiDAR DTM for Tibiao floodplain is shown in Figure 21. It can be seen that the entire Tibiao floodplain is 100% covered by LiDAR data.

Table 12. Shift values of each LiDAR block of Tibiao Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Iloilo_Blk43A	0.00	0.00	-1.29

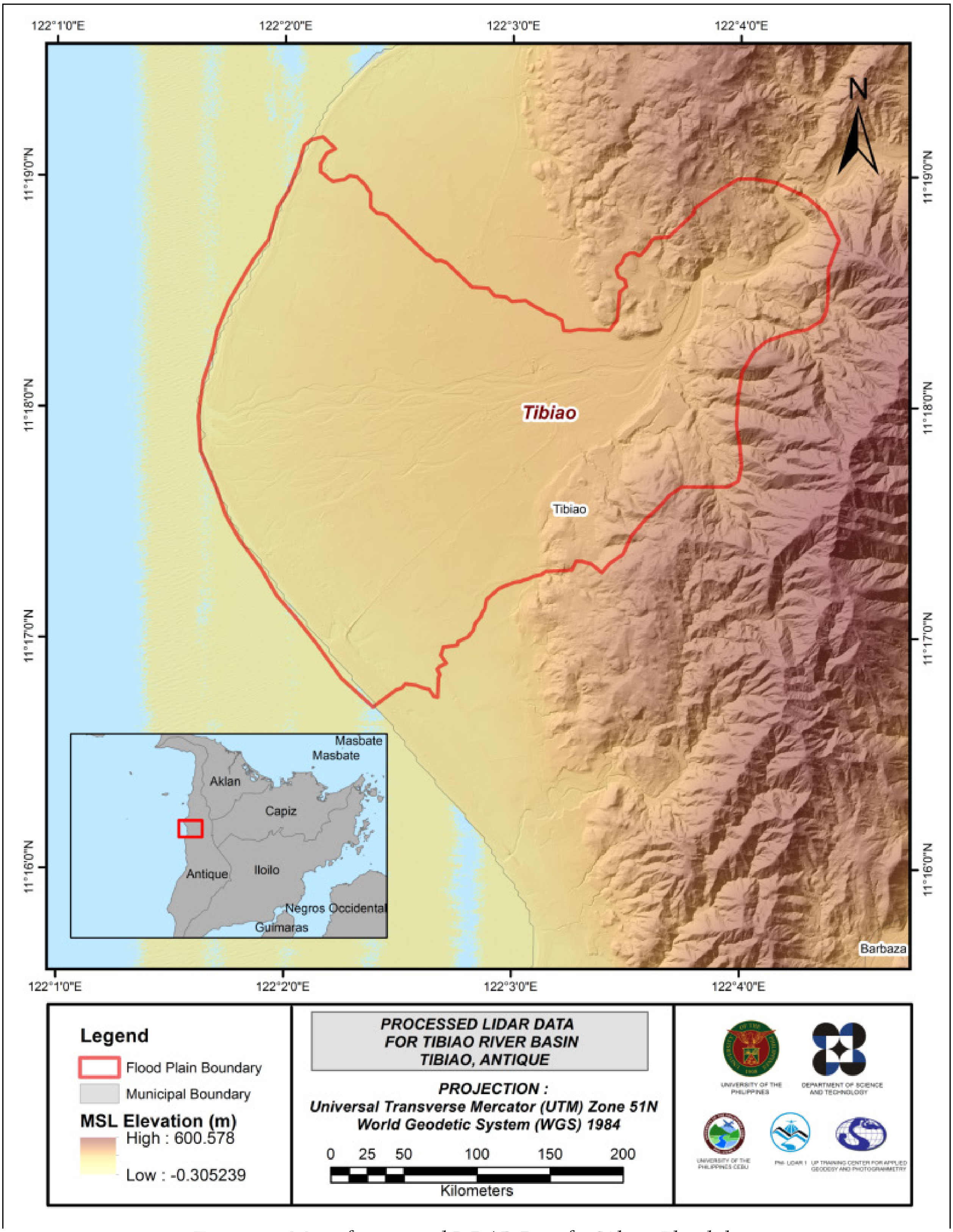

Figure 21 . Map of Processed LiDAR Data for Tibiao Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model (DEM)

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Tibiao to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 7511 points were gathered for all the floodplains within the Province of Antique wherein the Tibiao is located. However, the point dataset was not used for the calibration of the LiDAR data for Tibiao because during the mosaicking process, each LiDAR block was referred to the calibrated Jalaur DEM. Therefore, the mosaicked DEM of Tibiao can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Jalaur LiDAR DTM and ground survey elevation values is shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 1.71 meters with a standard deviation of 0.17 meters. Calibration of Jalaur LiDAR data was done by subtracting the height difference value, 1.71 meters, to Jalaur mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between Jalaur LiDAR data and calibration data. These values were also applicable to the Tibiao DEM.

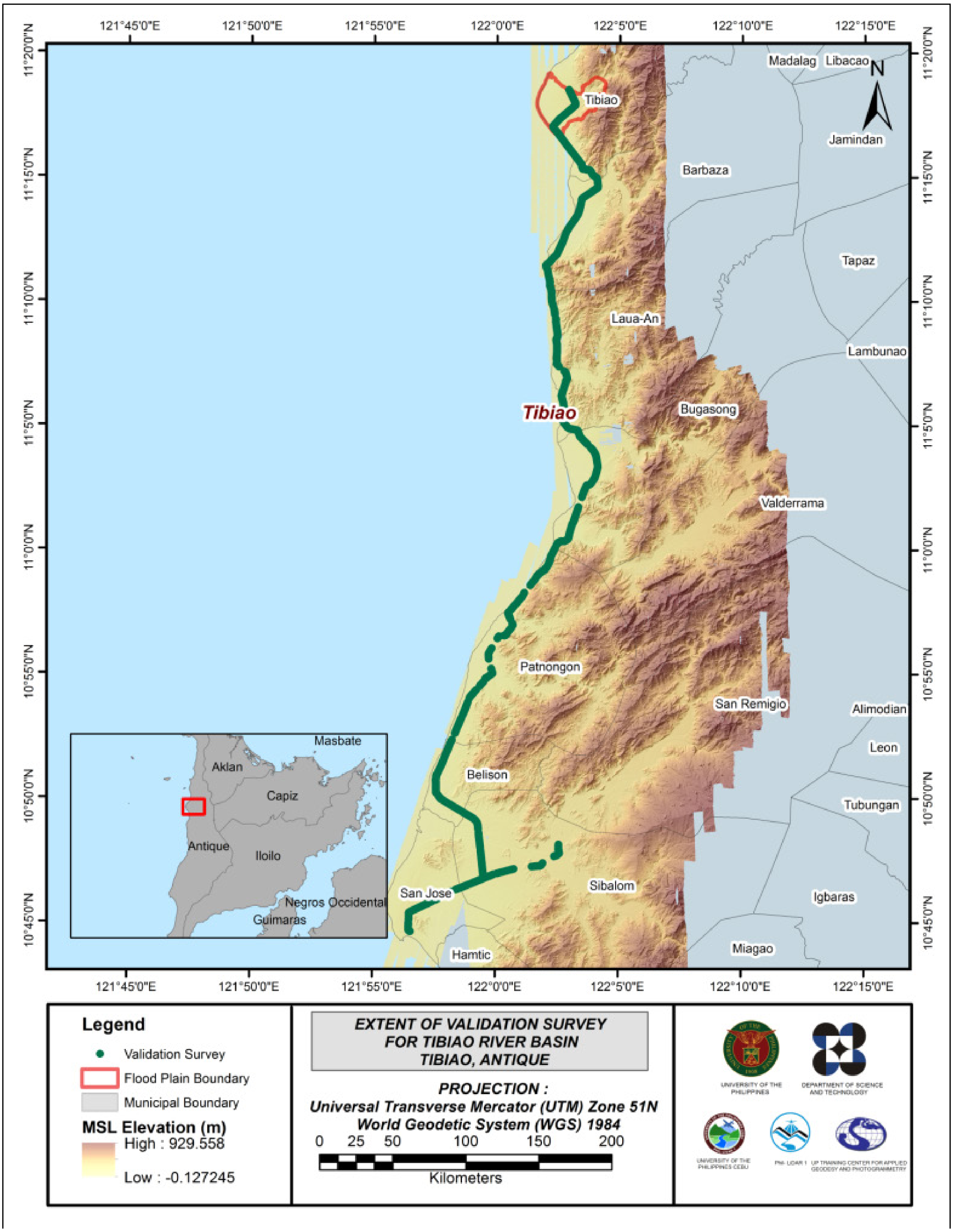

Figure 22. Map of Tibiao Floodplain with validation survey points in green.

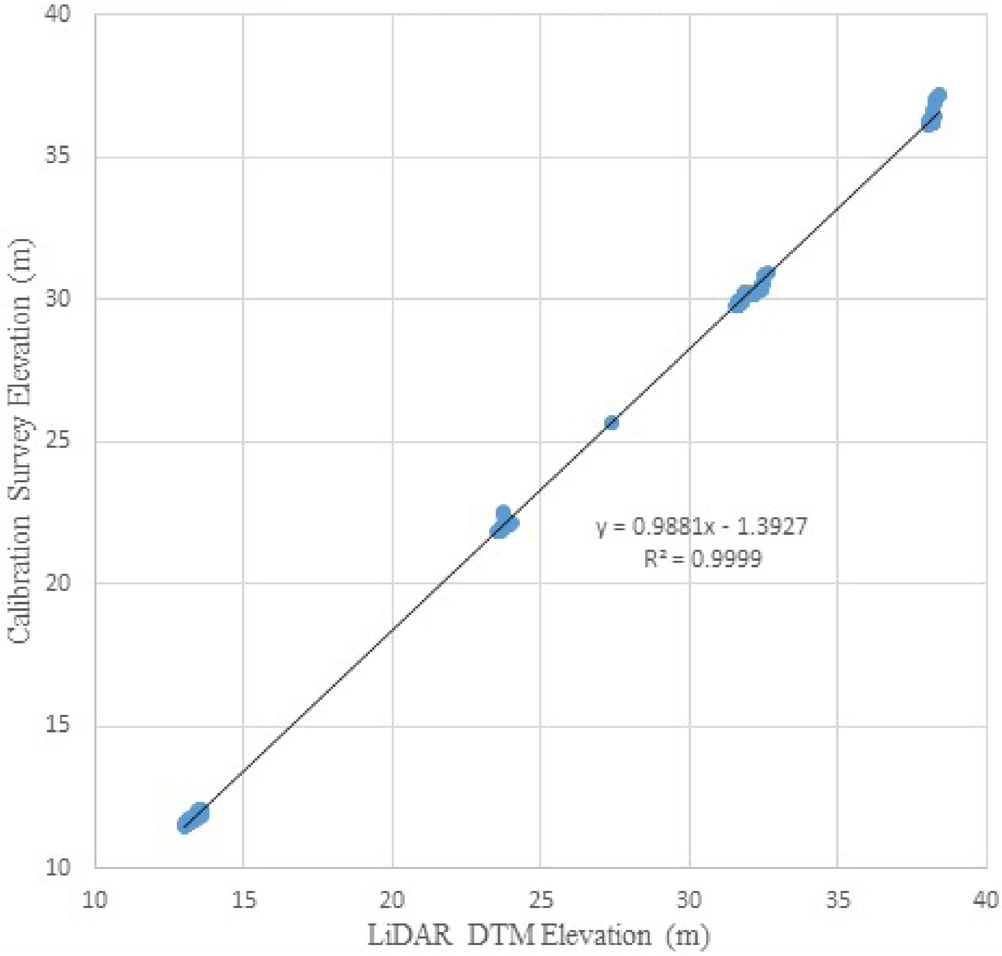

Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	1.71
Standard Deviation	0.17
Average	-1.70
Minimum	-2.13
Maximum	-1.16

A total of 208 survey points that are near Tibiao flood plain were used for the validation of the calibrated Tibiao 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 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.03 meters with a standard deviation of 0.03 meters, as shown in Table 14.

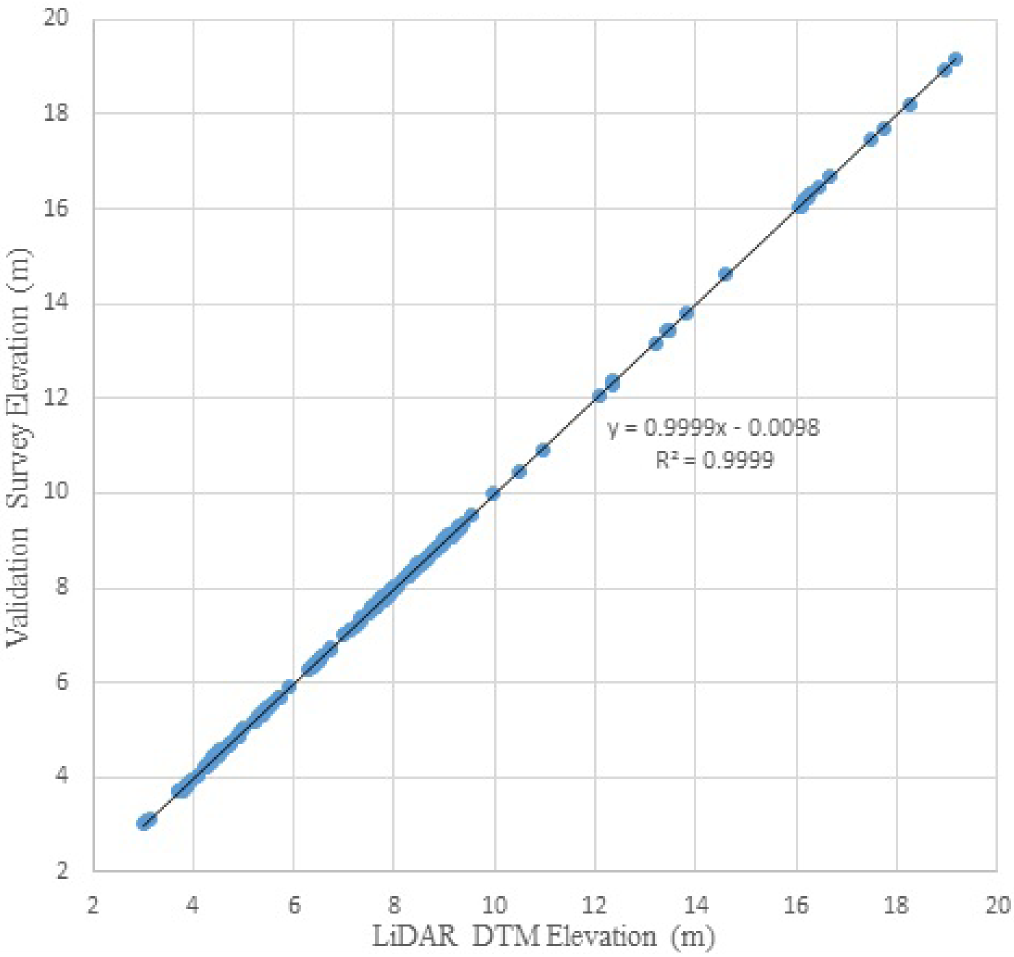

Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.03
Standard Deviation	0.03
Average	-0.01
Minimum	-0.04
Maximum	-0.01

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline data was available for Tibiao with 196 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.0017meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tibiao integrated with the processed LiDAR DEM is shown in Figure 25.

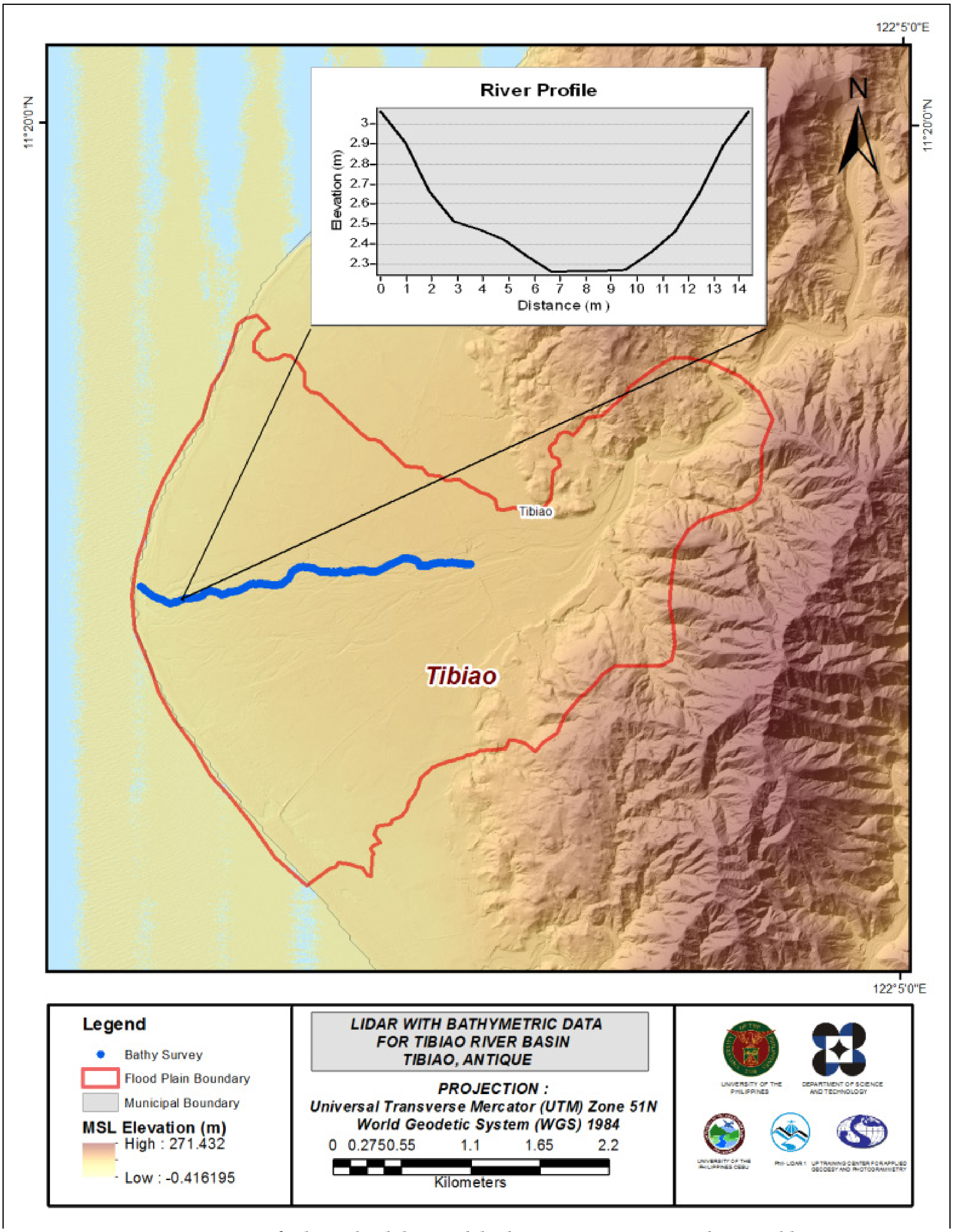

Figure 25. Map of Tibiao Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Tibiao floodplain, including its 200 m buffer, has a total area of 15.97 sq km. For this area, a total of 5.00 sq km, corresponding to a total of 2,145 building features, are considered for QC. Figure 26 shows the QC blocks for Tibiao floodplain.

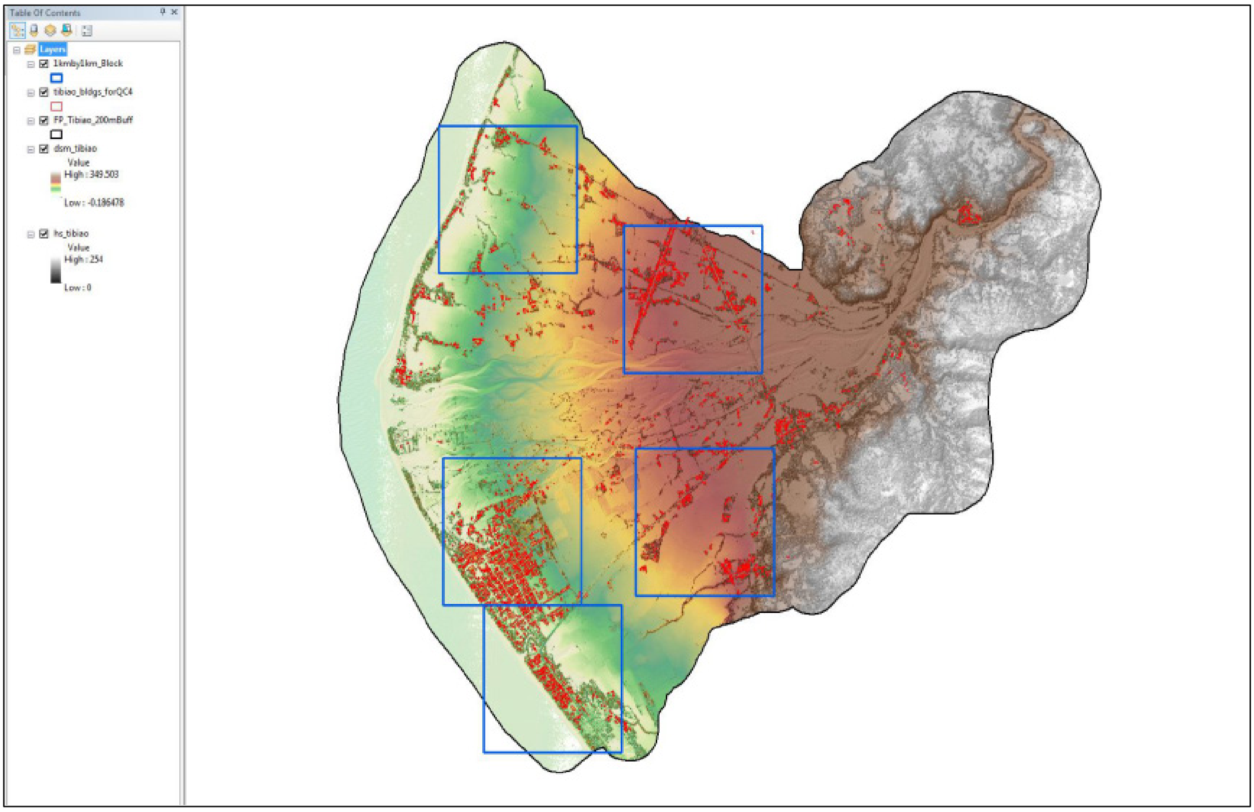

Figure26. Blocks (in blue) of Tibiao building features that were subjected to QC

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

Table 15. Quality Checking Ratings for Tibiao Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tibiao	99.95	99.95	99.72	PASSED

3.12.2 Height Extraction

Height extraction was done for 3,104 building features in Tibiao Floodplain. Of these building features, 54 were filtered out after height extraction, resulting to 3,050 buildings with height attributes. The lowest building height is at 2.0 m, while the highest building is at 6.99 m.

3.12.3 Feature Attribution

The feature attribution survey was conducted through a participatory community-based mapping in coordination with the Local Government Units of the Municipality/City. The research associates of Phil-LiDAR 1 team visited local barangay units and interviewed key local personnel and officials who possessed expert knowledge of their local environments to identify and map out features.

Maps were displayed on a laptop and were presented to the interviewees for identification. The displayed map include the orthophotographs, Digital Surface Models, existing landmarks, and extracted feature shapefiles. Physical surveys of the barangay were also done by the Phil-LiDAR 1 team after every interview for validation. The number of days by which the survey was conducted was dependent on the number of features and number of barangays included in the flood plain of the river basin.

Table 16 summarizes the number of building features per type. On the other hand, Table 17 shows the total length of each road type, while Table 18 shows the number of water features extracted per type.

Table 16. Building Features Extracted for Tibiao Floodplain.

Facility Type	No. of Features
Residential	3,919
School	70
Market	2
Agricultural/Agro-Industrial Facilities	2
Medical Institutions	3
Barangay Hall	9
Military Institution	0
Sports Center/Gymnasium/Covered Court	6
Telecommunication Facilities	4
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	14
Bank	0
Factory	0
Gas Station	2
Fire Station	0
Other Government Offices	3
Other Commercial Establishments	2
Total	**4,036**

Table 17. Total Length of Extracted Roads for Tibiao Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tibiao	23.53	1.03	4.81	5.02	0.00	34.39

Table 18. Number of Extracted Water Bodies for Tibiao Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Tibiao	3	0	0	0	0	3

A total of 9 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 27 shows the Digital Surface Model (DSM) ofTibiao floodplain overlaid with its ground features.

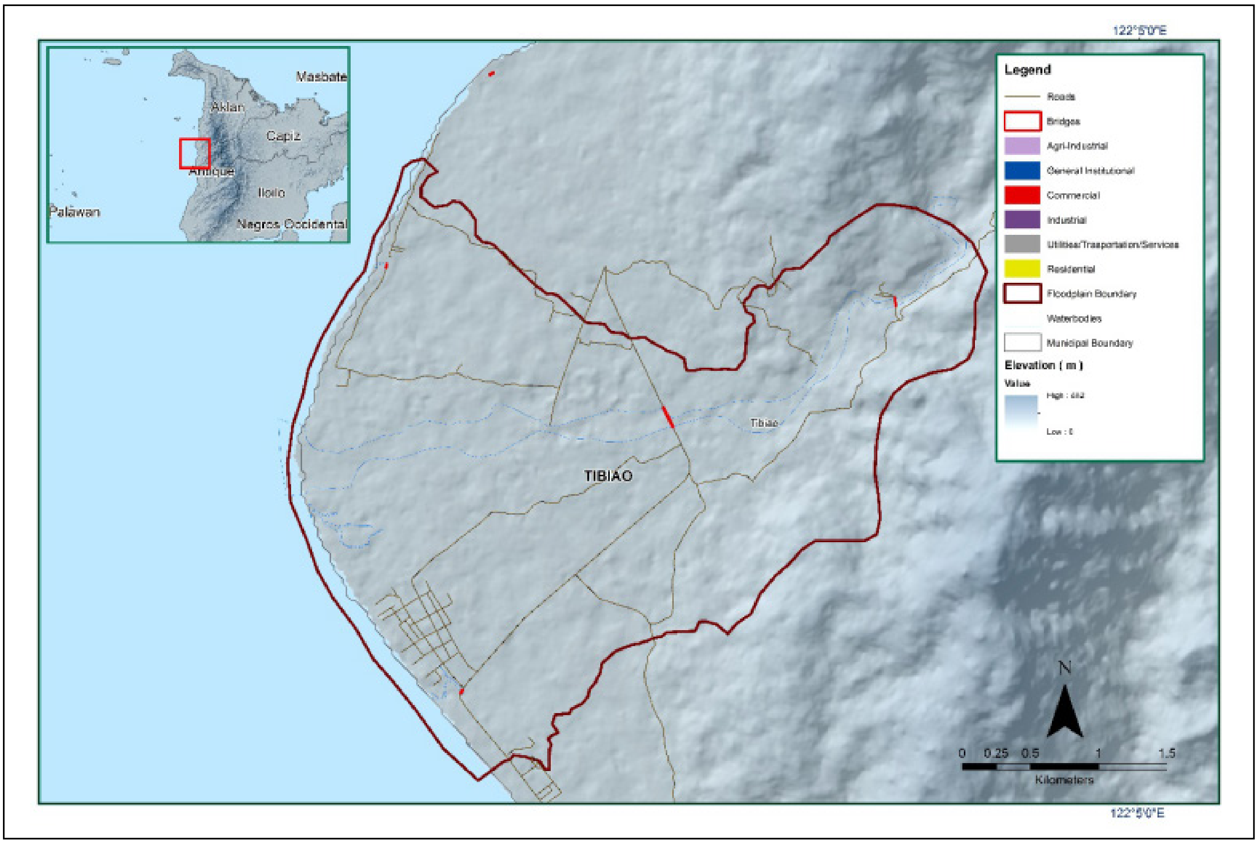

Figure 27. Extracted features for Tibiao Floodplain.

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

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Tibiao River from September 25 to October 9, 2014 with the following scope of work: reconnaissance; control survey for the establishment of a control point; cross-section, bridge as-built and water level marking in MSL of Tibiao Bridge piers; ground validation data acquisition survey of about 82.264 km for the whole province of Antique; and bathymetric survey from Brgy. Importante, Municipality of Tibiao, Antique down to the mouth of the river in Brgy. Martinez, Municipality of Tibiao, Antique with an estimated length of 2.88 km using GNSS PPK survey technique.

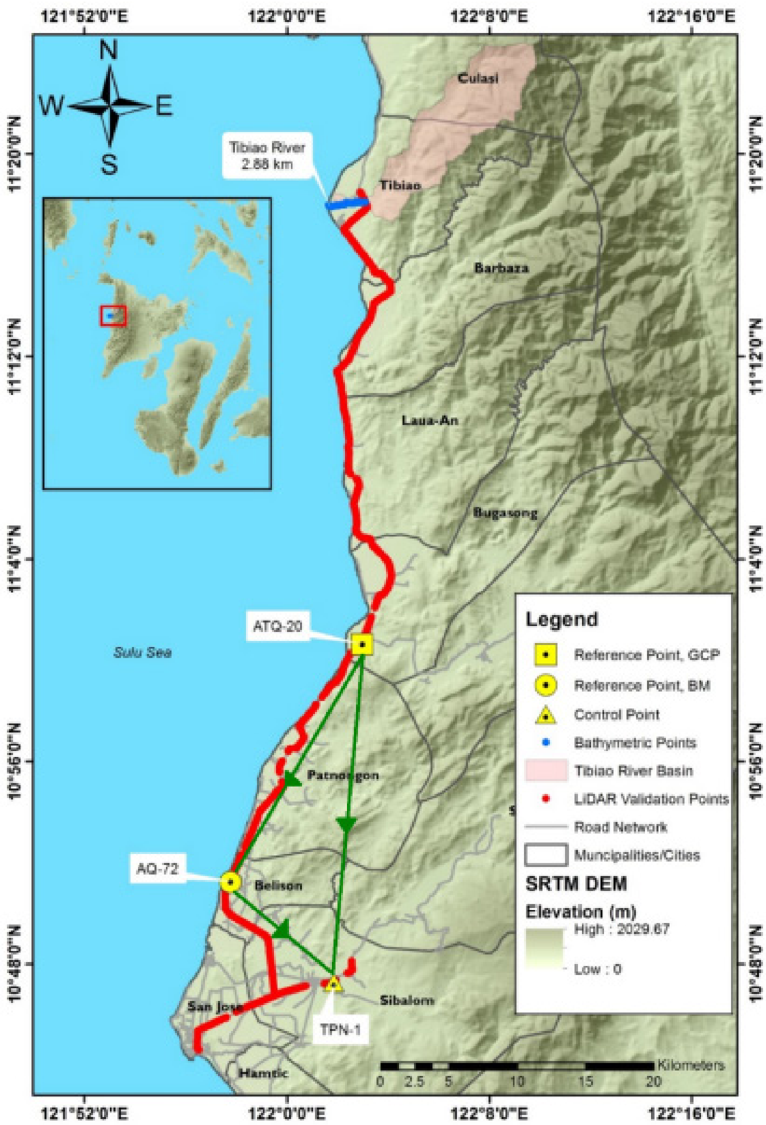


Figure 28. Extent of the bathymetric survey (in blue line) in Tibiao River and the LiDAR data validation survey (in red).

4.2 Control Survey

The GNSS network used in Tibiao River Survey is composed of a single loop established on September 26, 2014 occupying the following reference points: ATQ-20, a second-order GCP, located in Brgy. Zaragoza, Municipality of Bugasong, Antique; and AQ-72, a first-order BM, located in Brgy. Delima, Municipality of Belison, Antique.

A control point was established on the approach of Tipuluan Bridge, namely: TPN-1, in Brgy. Pasong, Brgy. Sibalom, Antique, to use as marker during the survey.

The summary of references and control points used in Tibiao Survey is shown in Table 19, while the GNSS network established is illustrated in Figure 29.

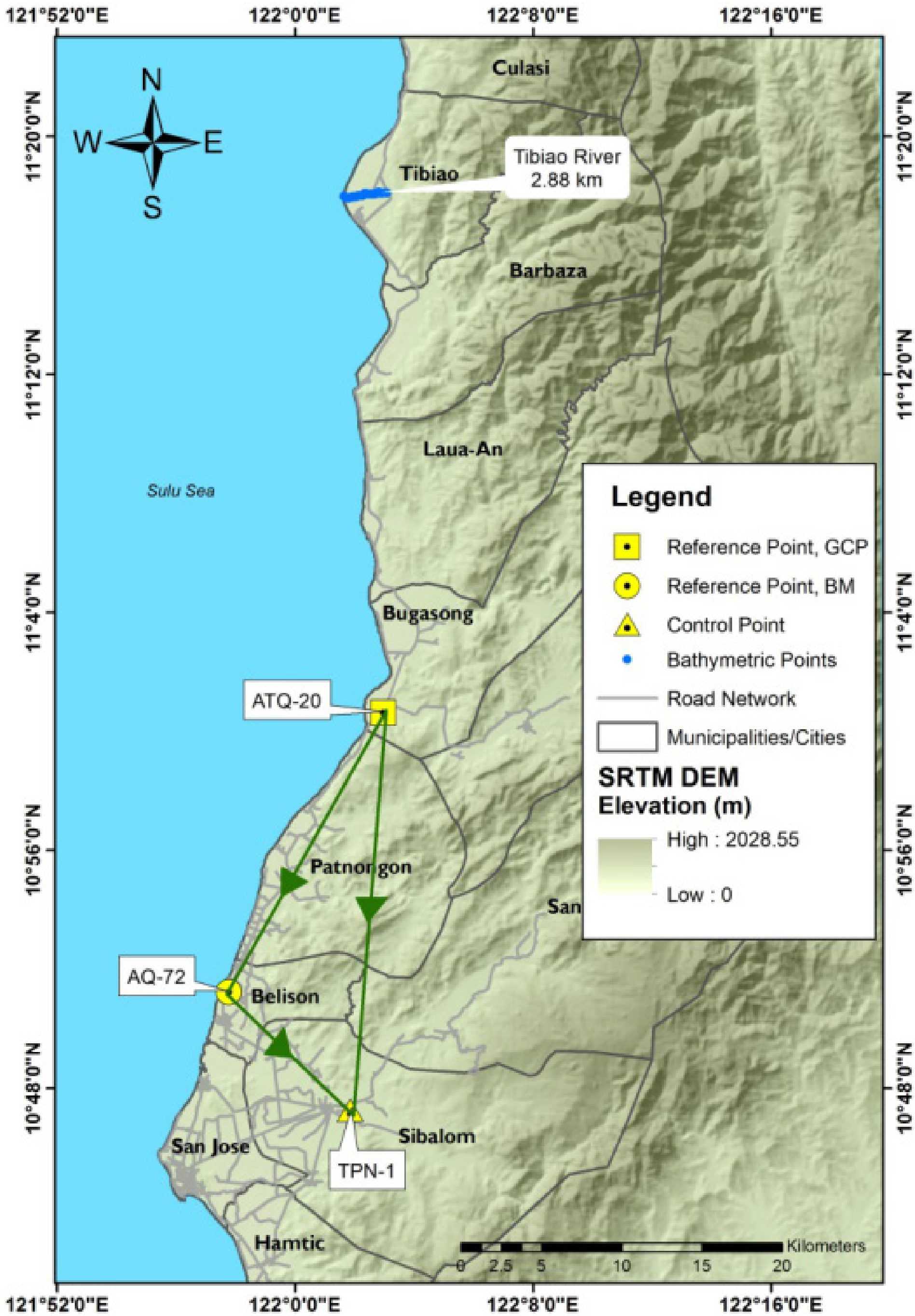


Figure 29. The GNSS Network established in the Tibiao River Survey.

Table 19. List of Reference and Control Points occupied for Tibiao River Survey

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
ATQ-20	2nd	11°00'38.44240" N	122°02'59.27039" E	66.094	-	2009
AQ-72	1st	-	-	61.541	5.5842	2007
TPN-1	-	-	-	--	-	September 26, 2014

The GNSS set-ups on recovered reference points and established control points in Tibiao River are shown in Figure 30 to Figure 32.

Figure 30. GNSS base receiver setup, Trimble® SPS 852 at ATQ-20 in Brgy. Zaragoza, Municipality of Bugasong, Antique

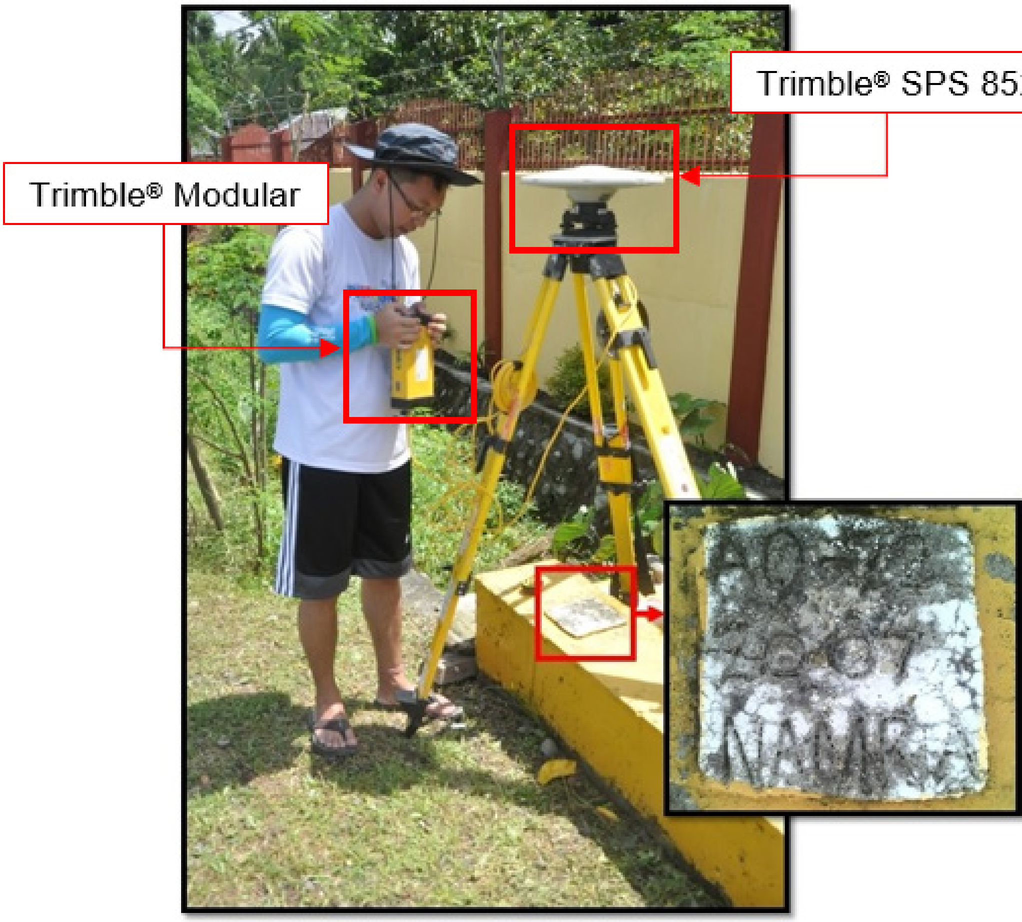


Figure 31. Benchmark, AQ-72, with Trimble® SPS 852 in Brgy. Delima, Municipality of Belison, Antique

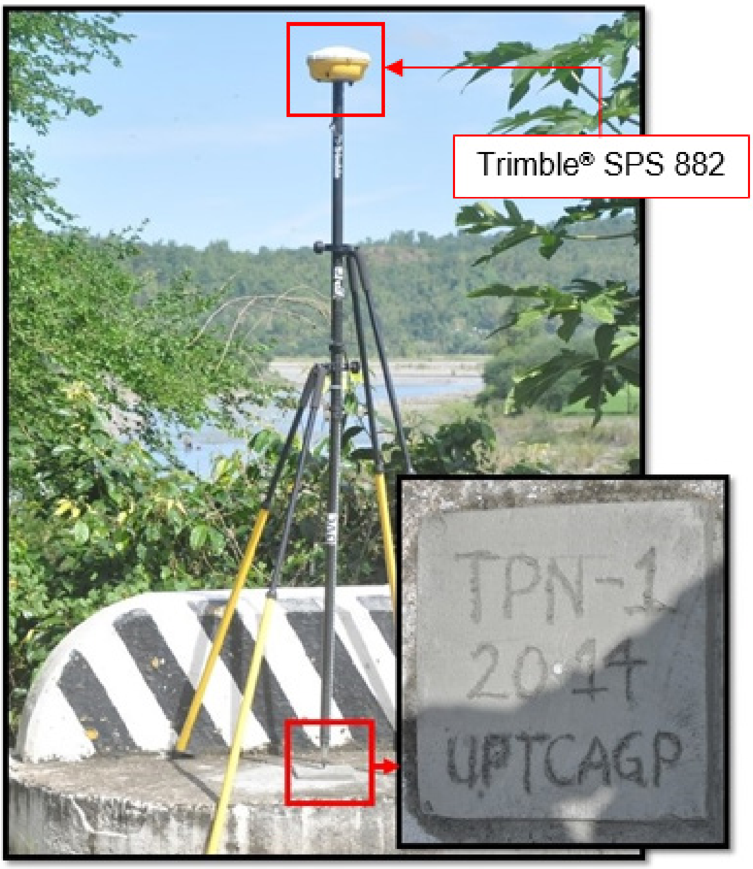


Figure 32. UP-TCAGP established control point, TPN-1, with Trimble® SPS 882 on Tipuluan Bridge in Brgy. Pasong, Municipality of Sibalom, Antique

4.3 Baseline Processing

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

Table 20. Baseline Processing Summary Report for Tibiao River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
ATQ-20 --- AQ-72 (B4775)	09-26-2014	Fixed	0.007	0.022	208°43'33"	19743.041	-4.554
ATQ-20 --- TPN-1 (B4775)	09-26-2014	Fixed	0.006	0.021	184°45'37"	24723.786	22.496
AQ-72 --- TPN-1 (B4776)	09-26-2014	Fixed	0.005	0.014	134°32'57"	10438.795	27.074

As shown in Table 20, a total of three (3) baselines were processed with reference points ATQ-20 and AQ-72 held fixed for coordinate and elevation values, respectively. All of them passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is performed using TBC. Looking at the Adjusted Grid Coordinates (Table 22) of the TBC generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 cm and z less than 10 cm or in equation form:

<20cm and

where:

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

for each control point. Table 21 to Table 23 show the results of GNSS network adjustment.

The control point in which the coordinates were fixed during the network adjustment is shown in Table . A difference in elevation of 0.9288 m between geoid (EGM2008) and MSL values of the reference point AQ-72 was applied for referring the elevation of the control points to MSL. Through this reference point, the coordinates of the unknown control points were computed.

Table 21. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
ATQ-20	Global	Fixed	Fixed	Fixed	
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22. The fixed control point, ATQ-20, has no values for standard errors.

Table 22. Adjusted grid coordinates for the control points used in the Tibiao River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
AQ-72	386654.679	0.063	1200045.589	0.033	6.513	0.256	
ATQ-20	396195.506	?	1217324.5 63	?	10.798	?	LLh
TPN-1	394067.041	0.058	1192699.1 27	0.031	33.065	0.259	

The network is fixed at the reference point, ATQ-20, with known coordinates. With the mentioned equation, for horizontal and for the vertical; the computation for the horizontal and vertical accuracy are as follows:

a. AQ-72

horizontal accuracy = √((6.3)² + (3.3)²
= √(39.69 + 10.89)
= 7.11 cm < 20 cm

b. TPN-1

horizontal accuracy = √((5.8)² + (3.1)²
= √(33.64 + 9.61)
= 6.58 cm < 20 cm

The list of adjusted geodetic coordinates: Latitude, Longitude, Height and computed standard errors of the control points in the network are shown in Table 23.

Table 23. Adjusted geodetic coordinates for control points used in the Tibiao River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
AQ-72	N10°51'14.92748"	E121°57'46.85471"	61.541	0.256	
ATQ-20	N11°00'38.44240"	E122°02'59.27039"	66.094	?	LLh
TPN-1	N10°47'16.56550"	E122°01'51.73167"	88.644	0.259	

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

The summary of reference and control points used is indicated in Table 24.

Table 24. The reference and control points utilized in the Tibiao 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	Ellipso -idal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
ATQ-20	2nd Order GCP	11°00'38.44240" N	122°02'59.27039" E	66.094	1217324.563	396195.506	9.8692
AQ-72	1st Order BM	10°51'14.92748" N	121°57'46.85471" E	61.541	1200045.589	386654.679	5.5842
TPN-1	UP Established	10°47'16.56550" N	122°01'51.73167" E	88.644	1192699.127	394067.041	32.1362

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

Cross-section and as-built survey were conducted on September 30, 2014 along the downstream side of Tibiao Bridge in Brgy. Importante, Tibiao, Antique using a GNSS rover receiver Trimble® SPS 882 in PPK survey technique as shown in Figure 33.

Figure 33. Cross-section survey across Tibiao River about 254 m downstream of Tibiao Bridge in Tibiao, Antique

The cross-sectional line is about 254 m with 23 gathered points gathered using ATQ-20 as GNSS base station. The cross-section diagram, location map of the bridge, and the bridge as-built form are illustrated in Figure 34 to Figure 37, respectively.

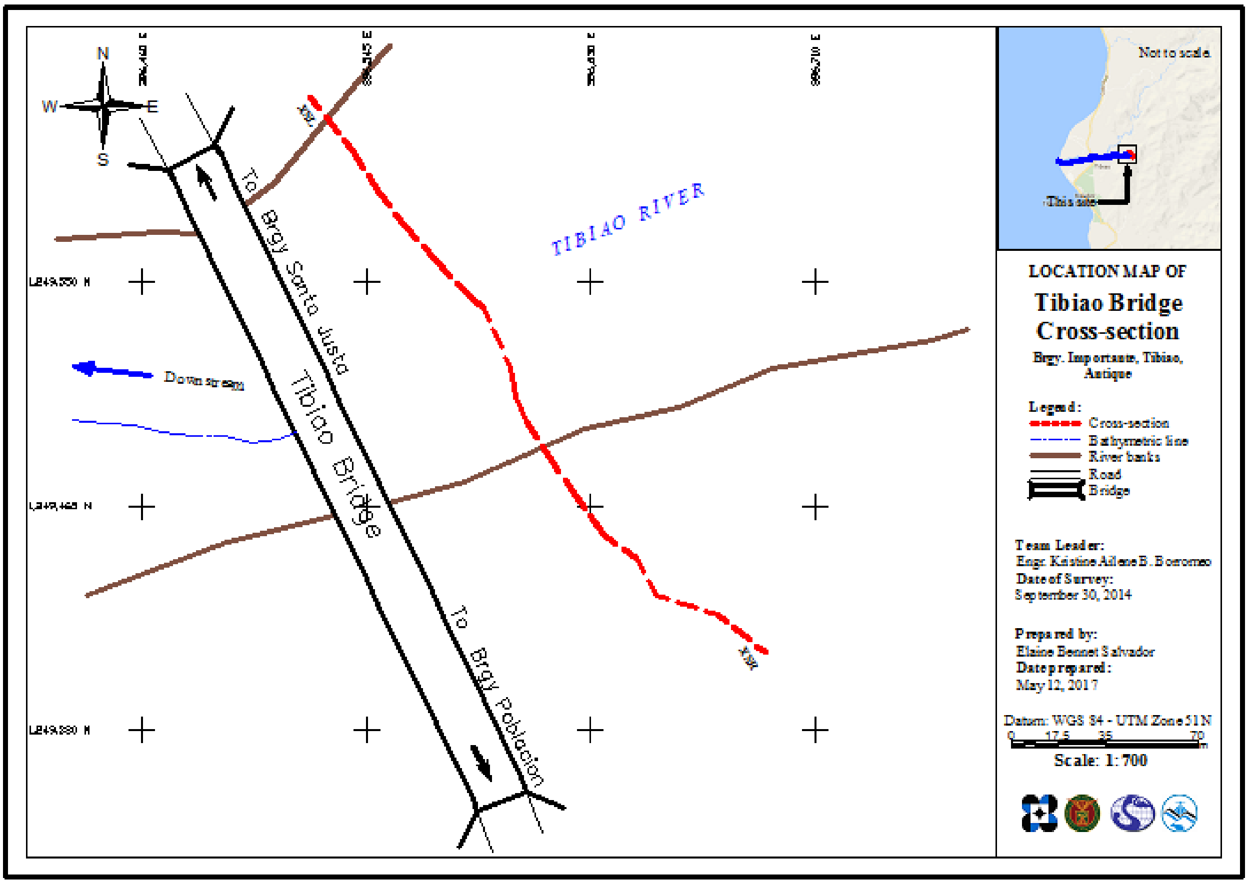


Figure 34. Tibiao bridge cross-section location map

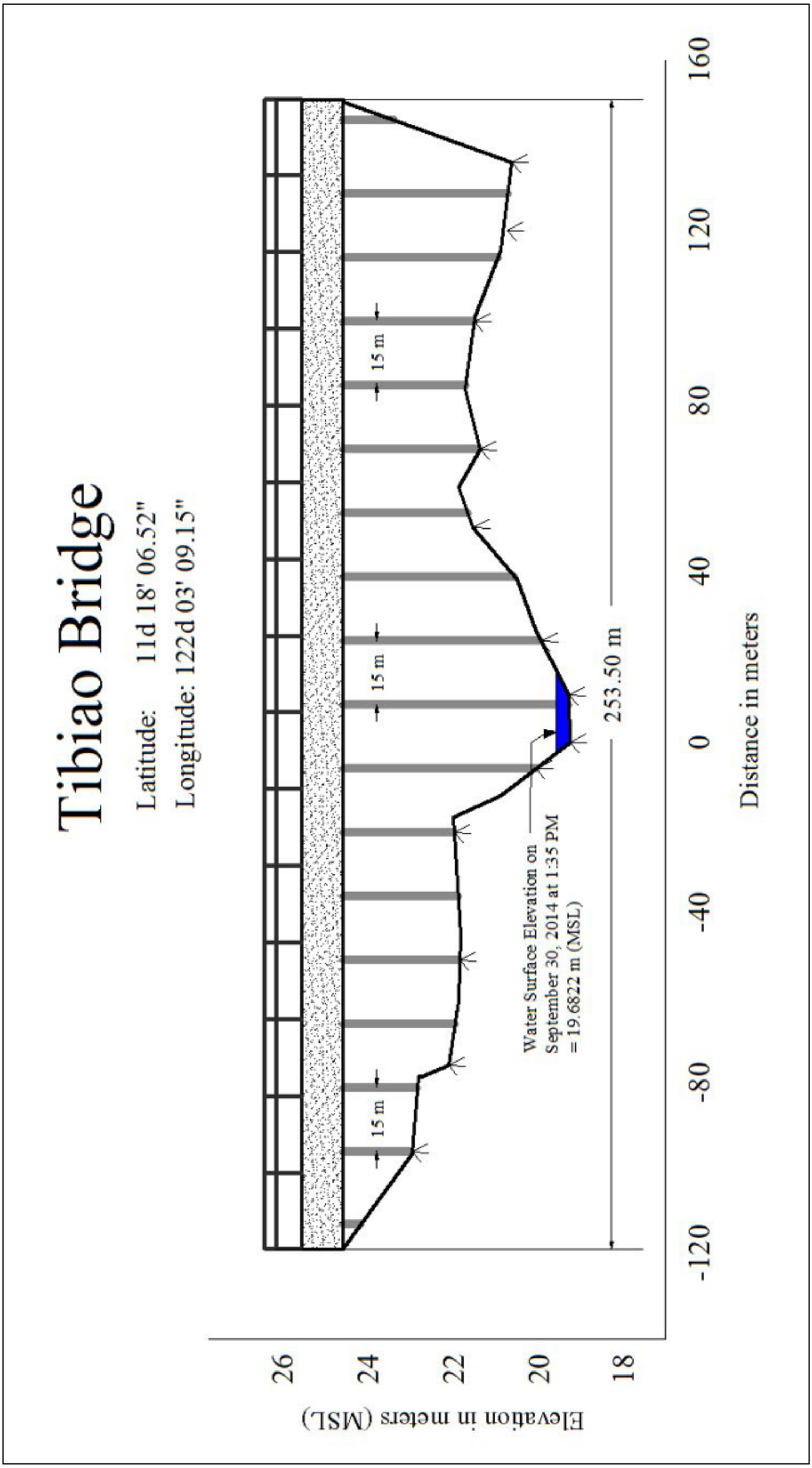
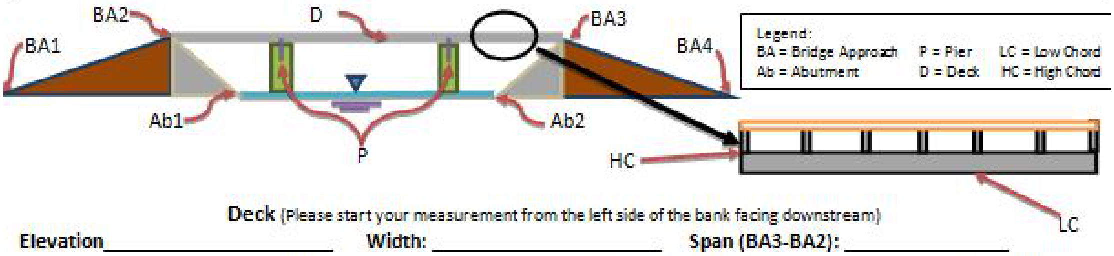


Figure 35. Tibiao Bridge cross-section diagram

Bridge Data Form

Bridge Name: Tibiao Bridge	Date: September 30, 2014
River Name: Tibiao River	Time: 12:45 PM
Location (Brgy, City, Region): Tibiao, Antique, Region 6	
Survey Team: Antique Survey Team	
Flow condition: low **normal** high	Weather Condition: **fair** rainy
Latitude: 11d 18' 06.51"	Longitude: 122d 03' 09.15"



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

Elevation ____________ Width: ____________ Span (BA3-BA2): ____________

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

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

	Station(Distance from BA1)	Elevation (MSL)		Station(Distance from BA1)	Elevation (MSL)
BA1	0	24.38m	BA3	265.5m	24.65m
BA2	6.10m	24.67m	BA4	269.83m	24.30m

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

	Station (Distance from BA1)	Elevation
Ab1	n/a	n/a
Ab2	n/a	n/a

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

Shape: Circular Number of Piers: 16 Height of column footing: ____________

	Station (Distance from BA1)	Elevation (MSL)	Pier Width
Pier 1	23.25 m	24.5952 m	
Pier 2	38.35 m	24.6782 m	
Pier 3	53.23 m	24.5662 m	
Pier 4	68.25 m	24.5692 m	
Pier 5	83.23 m	24.5582 m	
Pier 6	98.19 m	24.5302 m	
Pier 7	113.20 m	24.5582 m	
Pier 8	128.14 m	24.6012 m	
Pier 9	143.20 m	24.5952 m	
Pier 10	158.17 m	24.5972 m	
Pier 11	173.23 m	24.5932 m	
Pier 12	188.15 m	24.6062 m	
Pier 13	203.11 m	24.6052 m	
Pier 14	218.22 m	24.6482 m	
Pier 15	233.19 m	24.6382 m	
Pier 16	248.12 m	24.6082 m	

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

Figure 36. Bridge as-built form of Tibiao Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted using a survey grade GNSS rover, Trimble® SPS 882 mounted on a pole which was attached in front of the vehicle as shown in Figure .It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The 1.53 m height was measured from the ground up to the bottom of notch of the GNSS rover receiver.

Figure 37 A) Setup of Trimble® SPS 882 in a van and (B) occupation of GNSS base station at ATQ-20

Ground validation started from the Municipality of Tibiao traversing the major roads which ended in the Municipality of San Jose. It acquired 9,787 ground validation points with an approximate length of 82.264 km as shown in Figure . Point ATQ-20 was occupied as the GNSS base station throughout the conduct of survey.

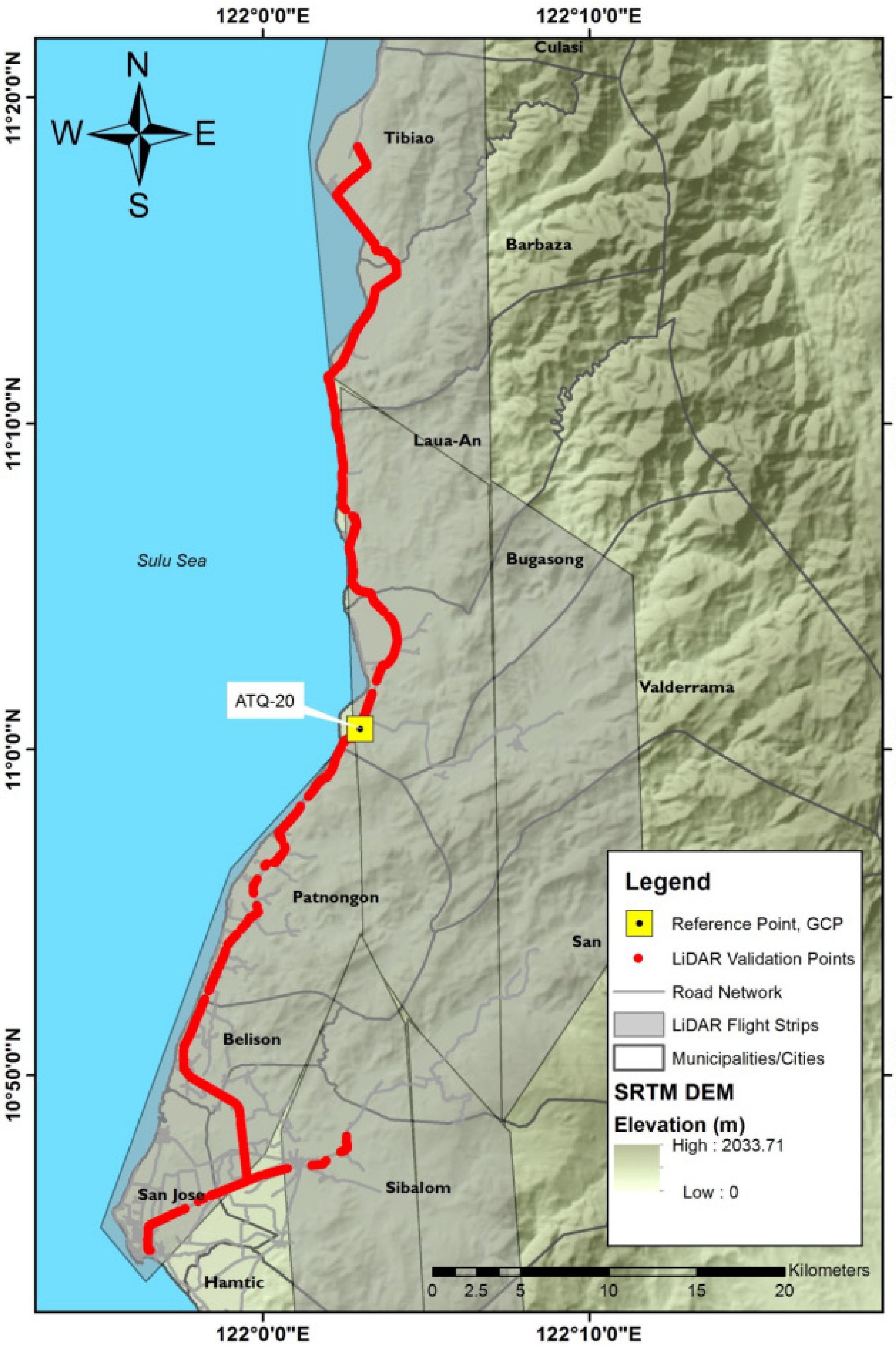


Figure 38. Validation point acquisition survey of Tibiao River basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on September 30, 2014 using Trimble® SPS 882 in GNSS PPK survey technique as shown in Figure . The survey in Tibiao River started from the bridge in Brgy. Importante, Municipality of Tibiao with coordinates 11°18'05.72009"122°03'06.51277" traversing downstream by foot and ended in Brgy. Martinez, also in Tibiao with coordinates 11°17'59.34145"122°01'39.83894".

Figure 39. Manual bathymetric survey along Tibiao River

The bathymetric line survey has an estimated length of 2.88 km with about 279 points gathered using ATQ-20 as GNSS base station.

The processed data were generated into a map using GIS and processed further using CAD for plotting the centerline of the river. Figure 40 shows the generated map that exhibits the bathymetric survey coverage while Figure 41 illustrates the Tibiao riverbed profile. There is an abrupt change in elevation of about 18.79 m MSL from upstream to downstream within the 2.88 km length covered during the bathymetric survey. The highest elevation was 18.79 m in MSL located in the upstream barangays, while the lowest elevation was -1.19 m below MSL located near the mouth of the river.

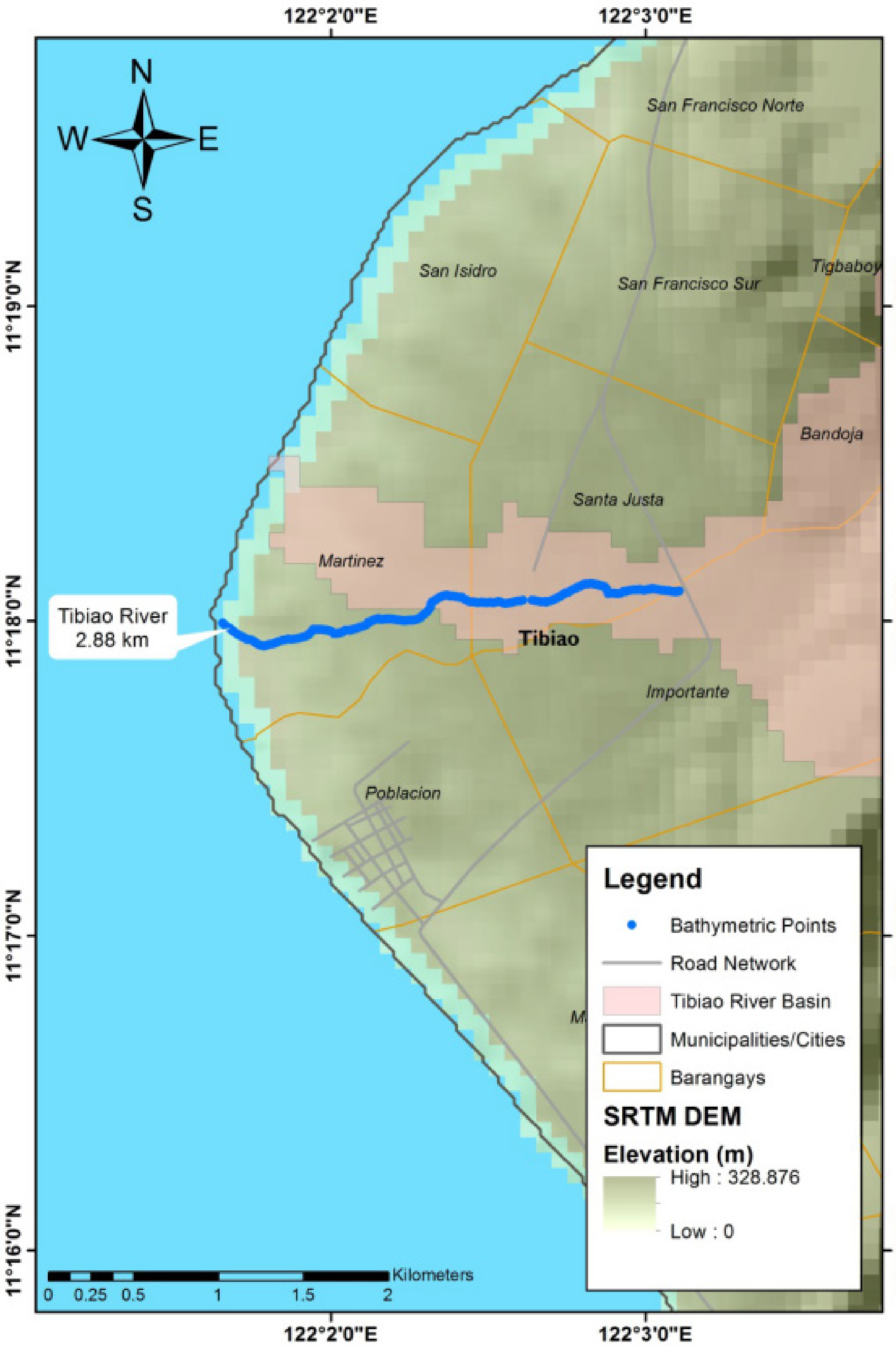


Figure 40. Extent of the Tibiao River Bathymetry Survey

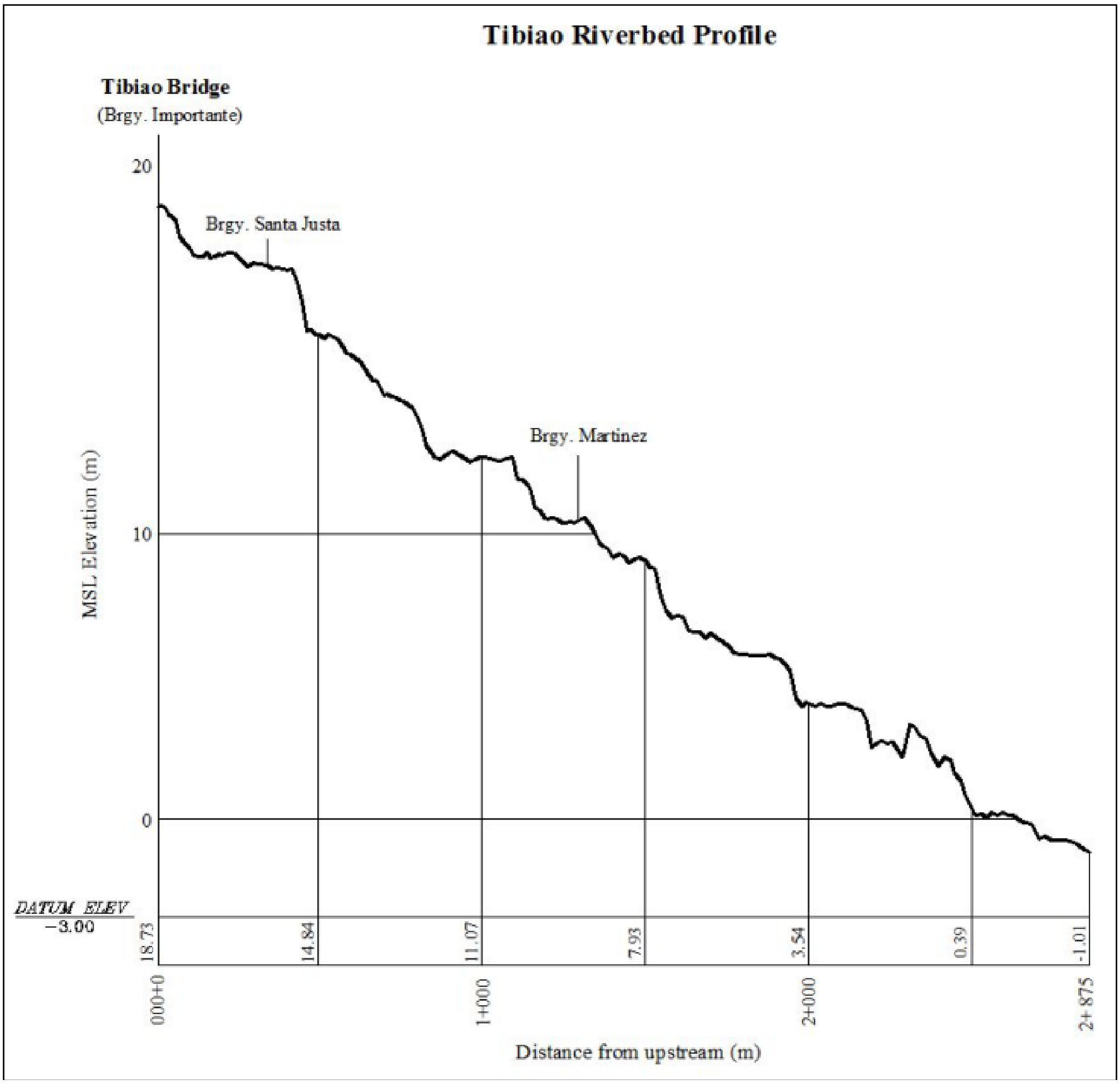


Figure 41. Tibiao riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

Alfredo Mahar Francisco A. Lagmay, Enrico C. Paringit, Dr. Eng., Christopher Noel L. Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil R. Tingin, Narvin Clyd Tan, and Marvin Arias

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All data that affect the hydrologic cycle of the Silaga River Basin were monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Silaga River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) deployed by the UP Cebu Flood Modeling Component (FMC) team. The ARG was installed in Brgy. Tuno, Tibiao, Antique (Figure 42). The precipitation data collection started on December 06, 2016 at 6:30 PM to December 7, 2016 at 2:50 AM with 5 minutes recording interval.

The total precipitation for this event in BrgyTuno ARG was 23.6 mm. It had a peak rainfall of 1.4 mm. on December 06, 2016 at 11:05in the evening. The lag time between the peak rainfall and discharge was 7 hours and 35 minutes.

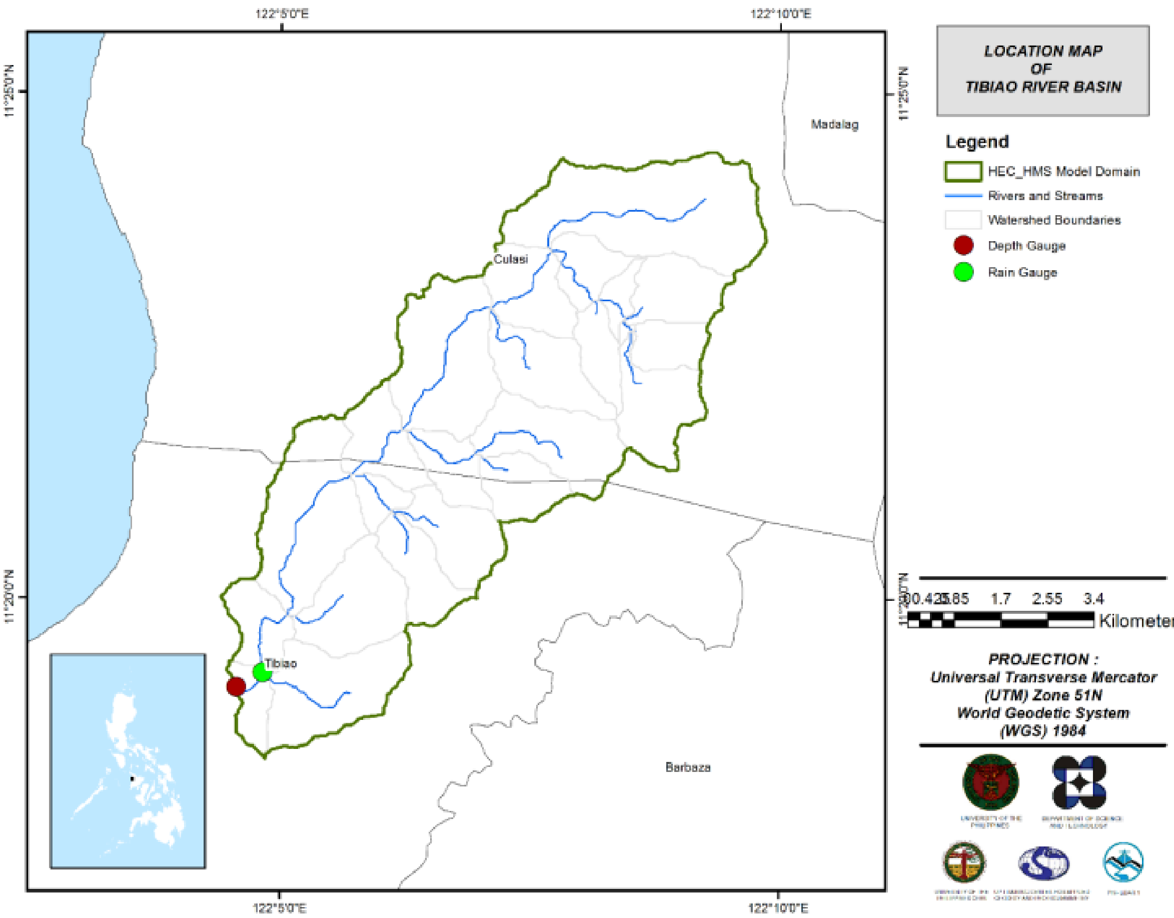


Figure 42. Location map of the Tibiao HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Tuno Foootbridge, Tibiao, Antique (11°19'6.62"N, 122° 4'33.58"E). FIgure 43 presents the cross section plot of Tuno Bridge in Tibiao, while the rating curve in FIgure 44 shows the relationship between the observed water levels at Tuno Bridge and outflow of the watershed at this location.

For Tibiao Bridge, the rating curve is expressed as Q = 7.7678x - 514.33 [see y formula] as shown in Figure 44.

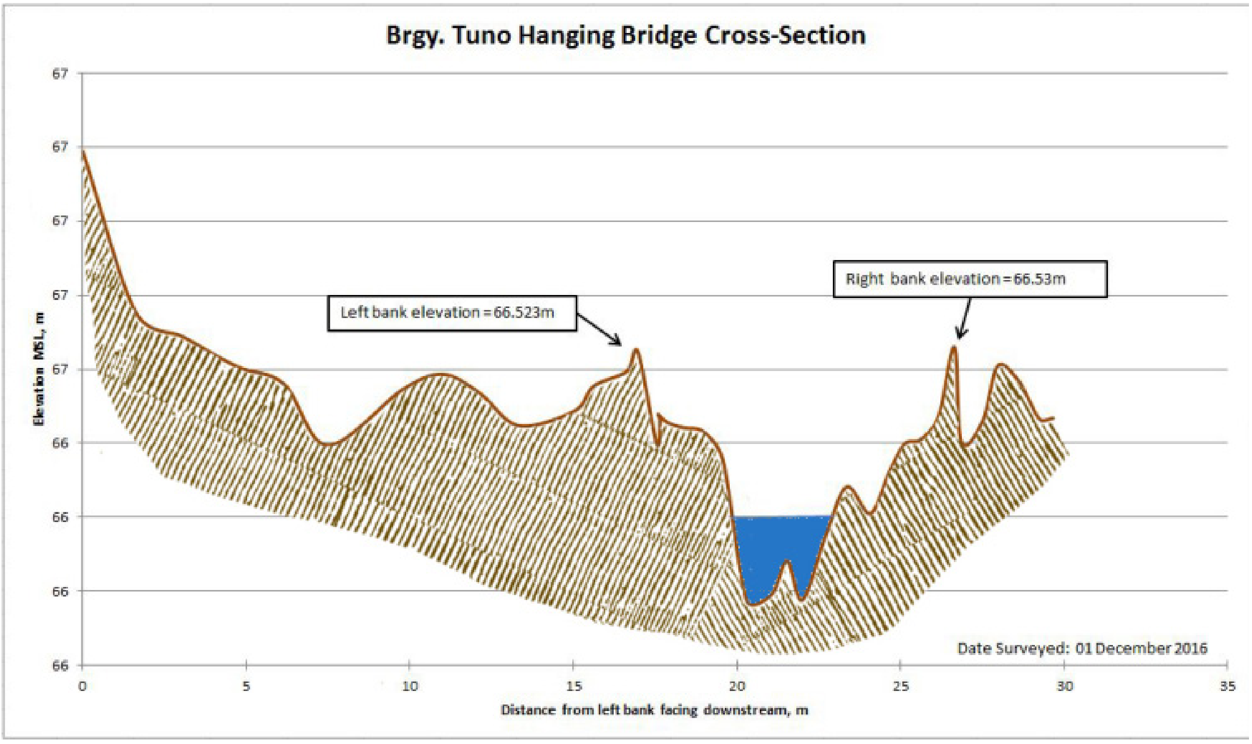


Figure 43. Cross-section plot of Tibiao Bridge

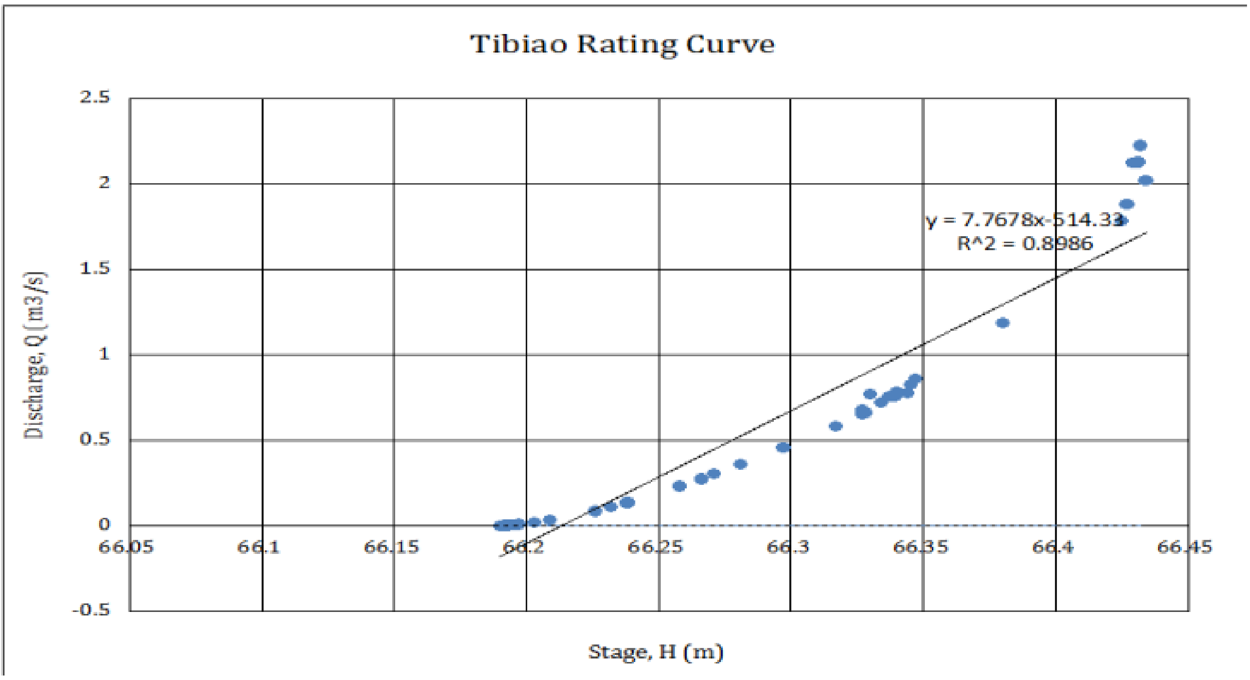


Figure 44. Rating curve at Tuno footbridge, Tibiao, Antique

This rating curve equation in Figure 44 was used to compute the river outflow at Tuno Bridge for the calibration of the HEC-HMS model shown in Figure 45. Peak discharge was 2.259 cubic meters per second at 1:40AM, December 06, 2016.

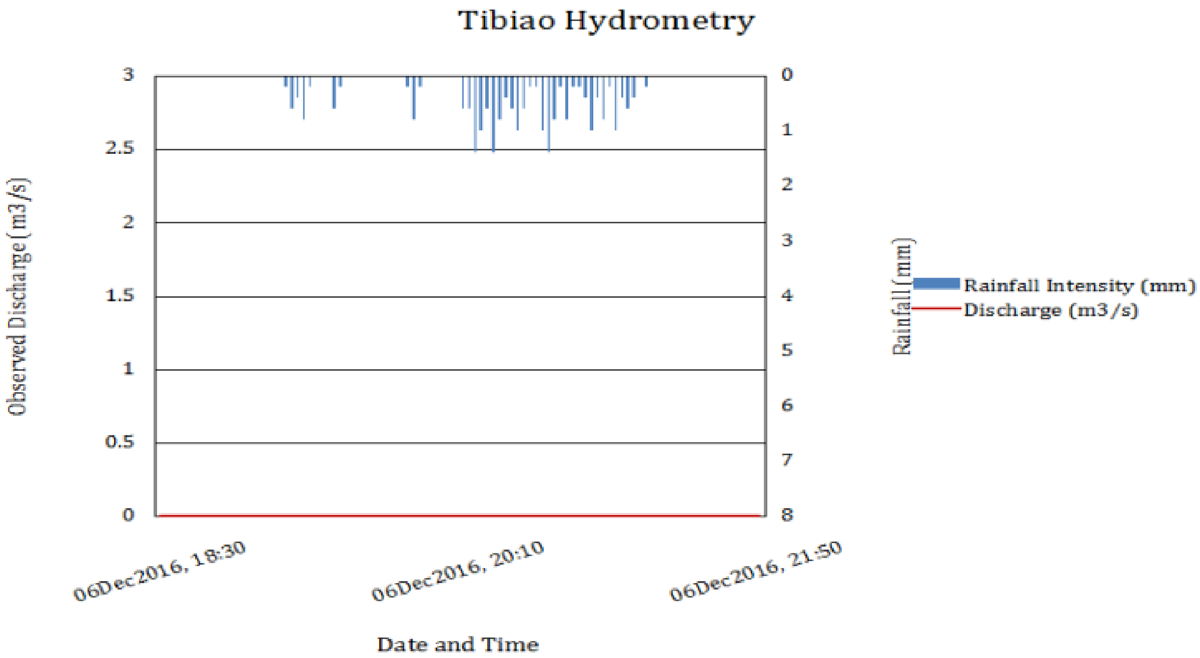


Figure 45. Rainfall and outflow data of Tibiao River Basin used for modeling.

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Roxas Rain Gauge.The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way that a certain peak value was attained at a certain time. This station chosen based on its proximity to the Tibiao watershed. The extreme values for this watershed were computed based on a 59-year record.

Table 25. RIDF values for Roxas Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
5	26.6	40.5	51.3	72.1	98	115.5	142.8	165.9	186.2
10	31.3	47.8	60.7	86.2	118	139.4	172.3	200.1	224.6
25	37.4	57	72.5	104	143.1	169.6	209.7	243.4	273
50	41.8	63.8	81.3	117.2	161.8	192	237.4	275.4	308.9
100	46.2	70.5	90	130.2	180.3	214.2	264.9	307.2	344.6

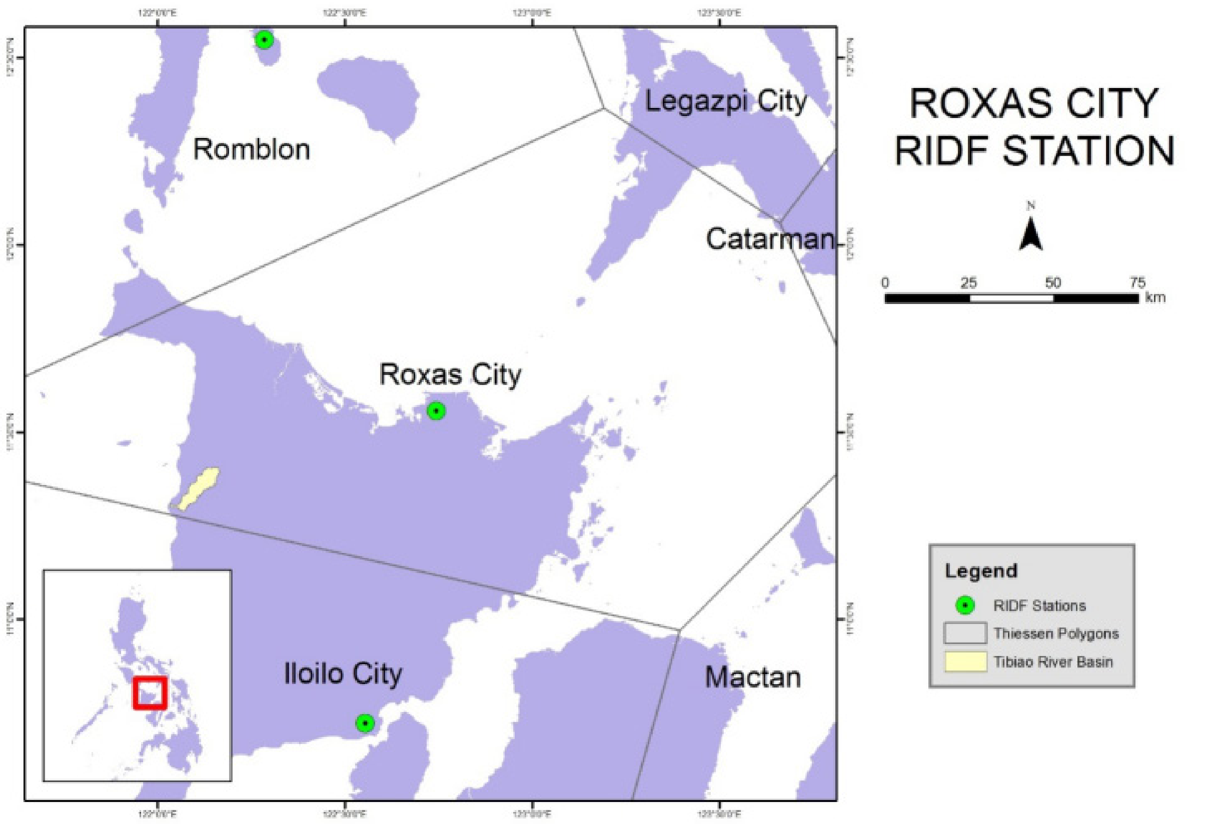


Figure 46. Location of Iloilo RIDF Station relative to Tibiao River Basin

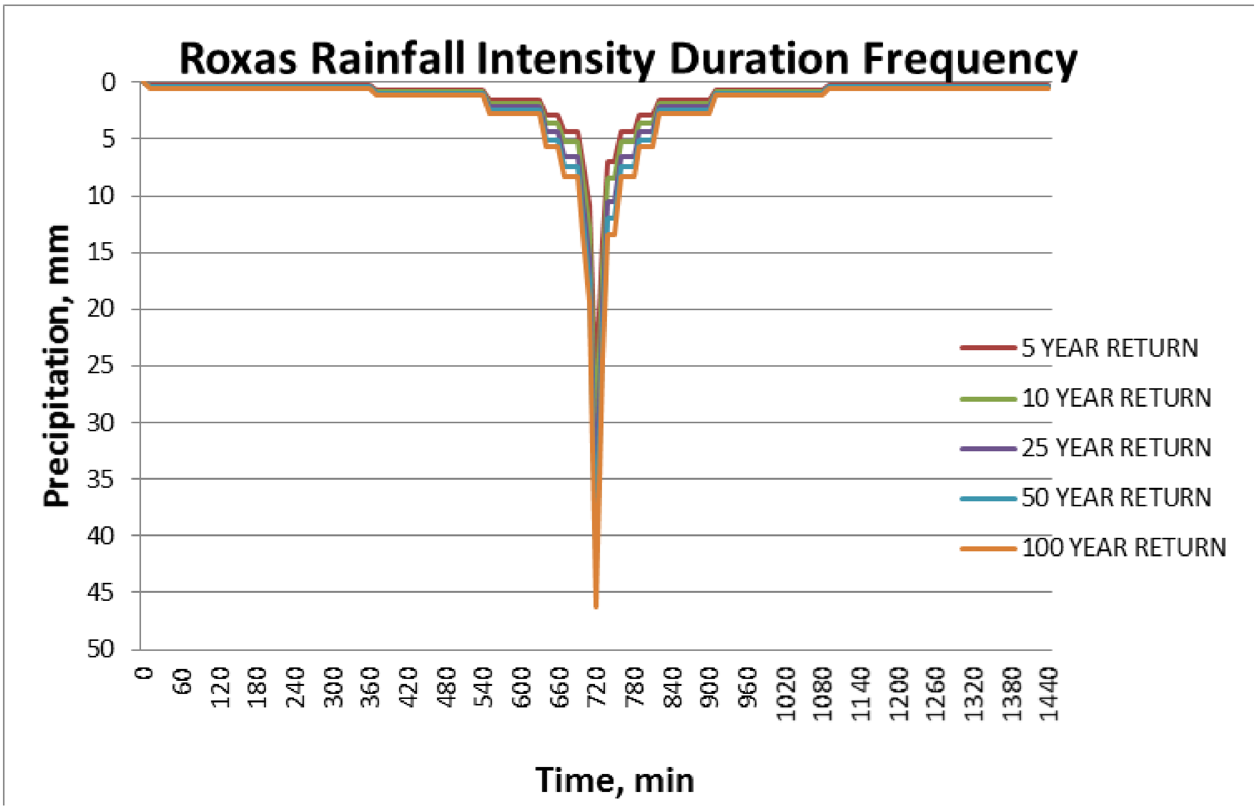


Figure 47. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was taken before 2004 from the Bureau of Soils under the Department of Agriculture. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Tibiao River Basin are shown in Figure 48 and Figure 49, respectively.

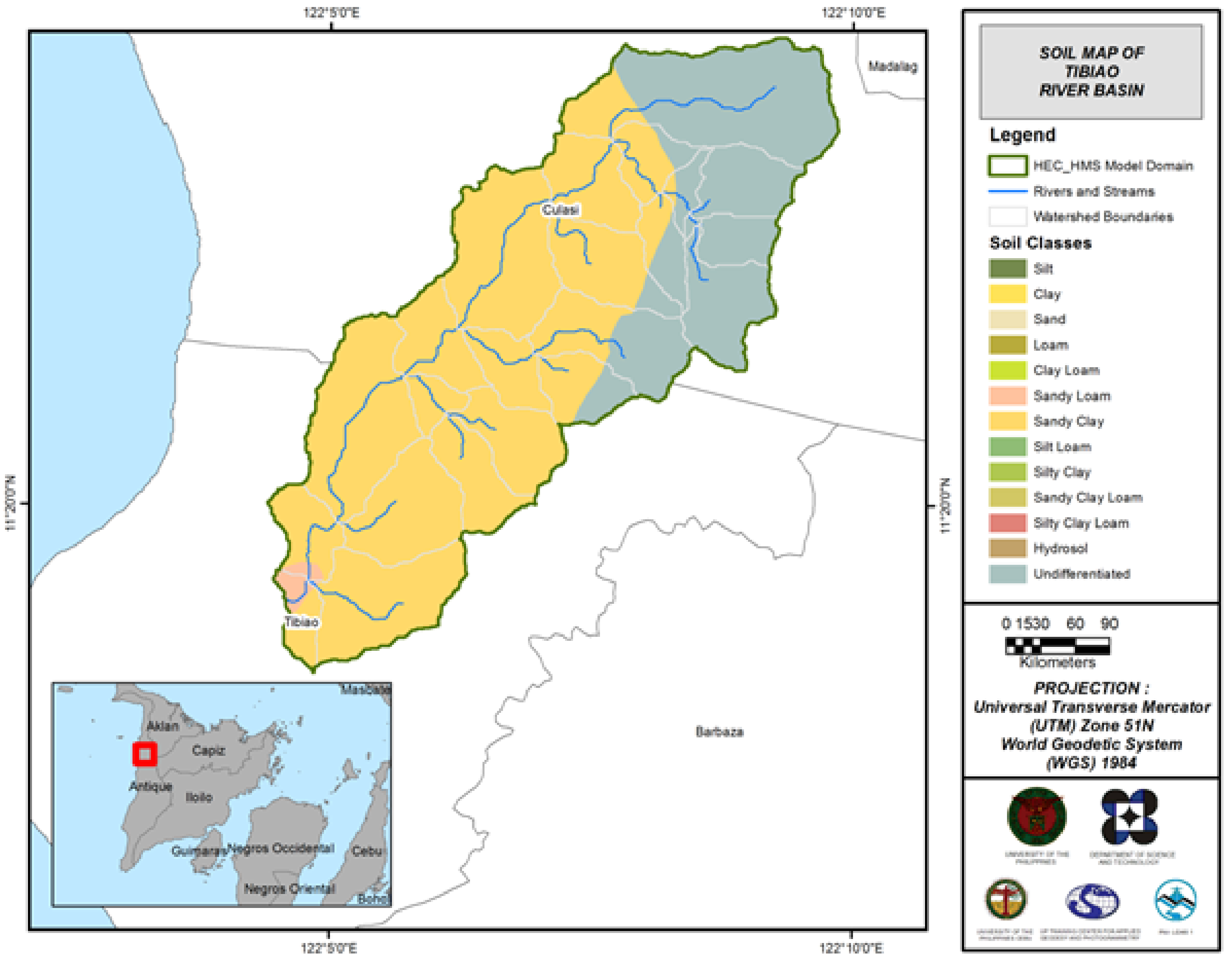


Figure 48. Soil Map of Tibiao River Basin

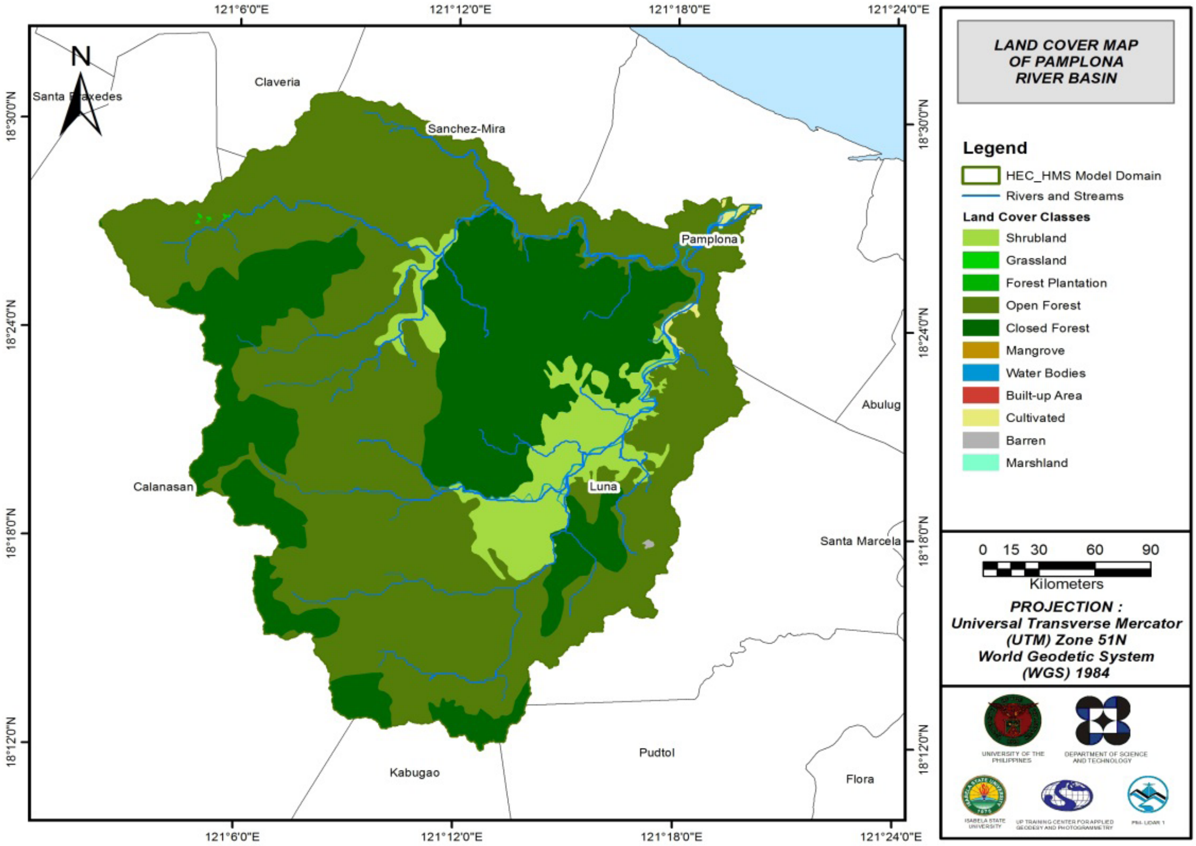


Figure 49. Land Cover Map of Tibiao River Basin

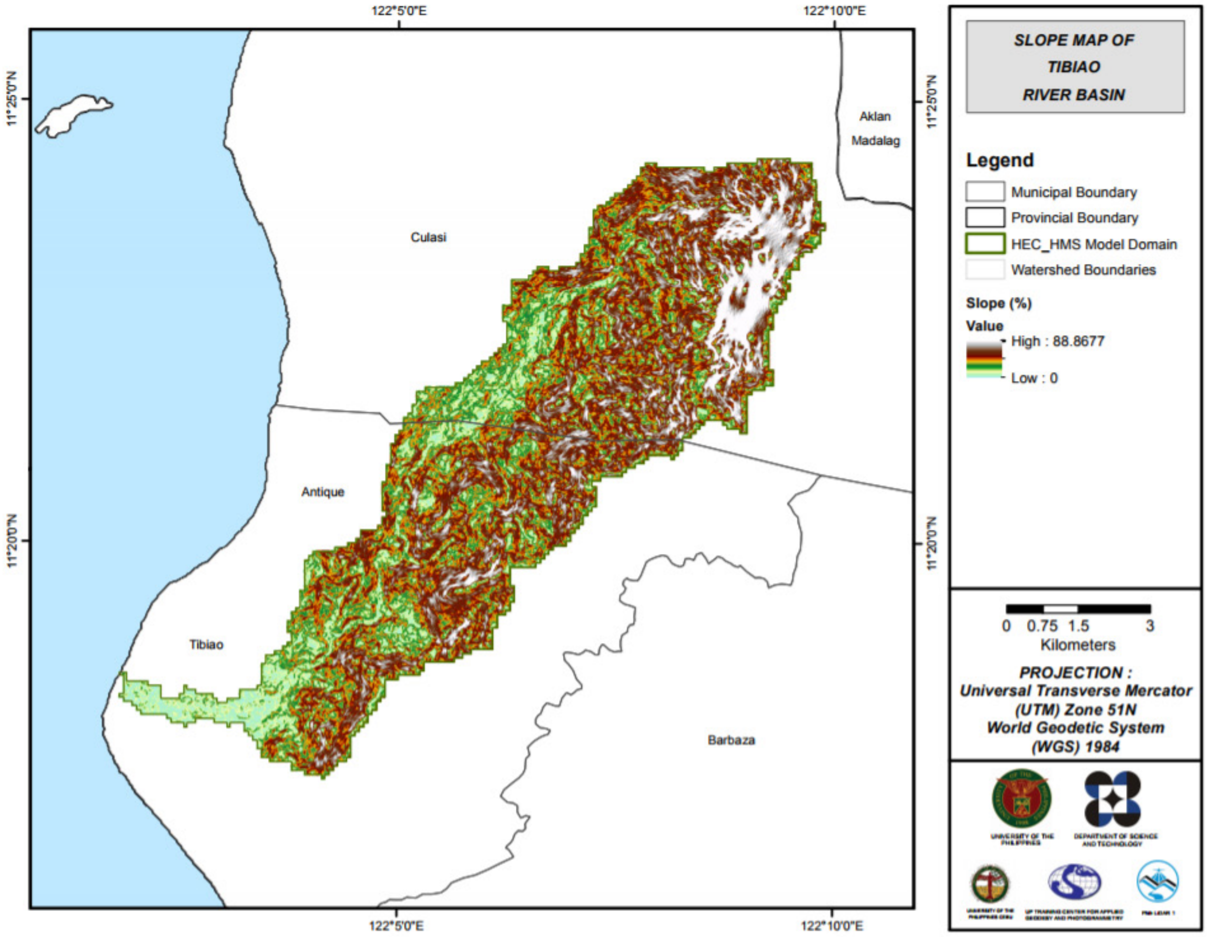


Figure 50. Slope Map of Tibiao River Basin

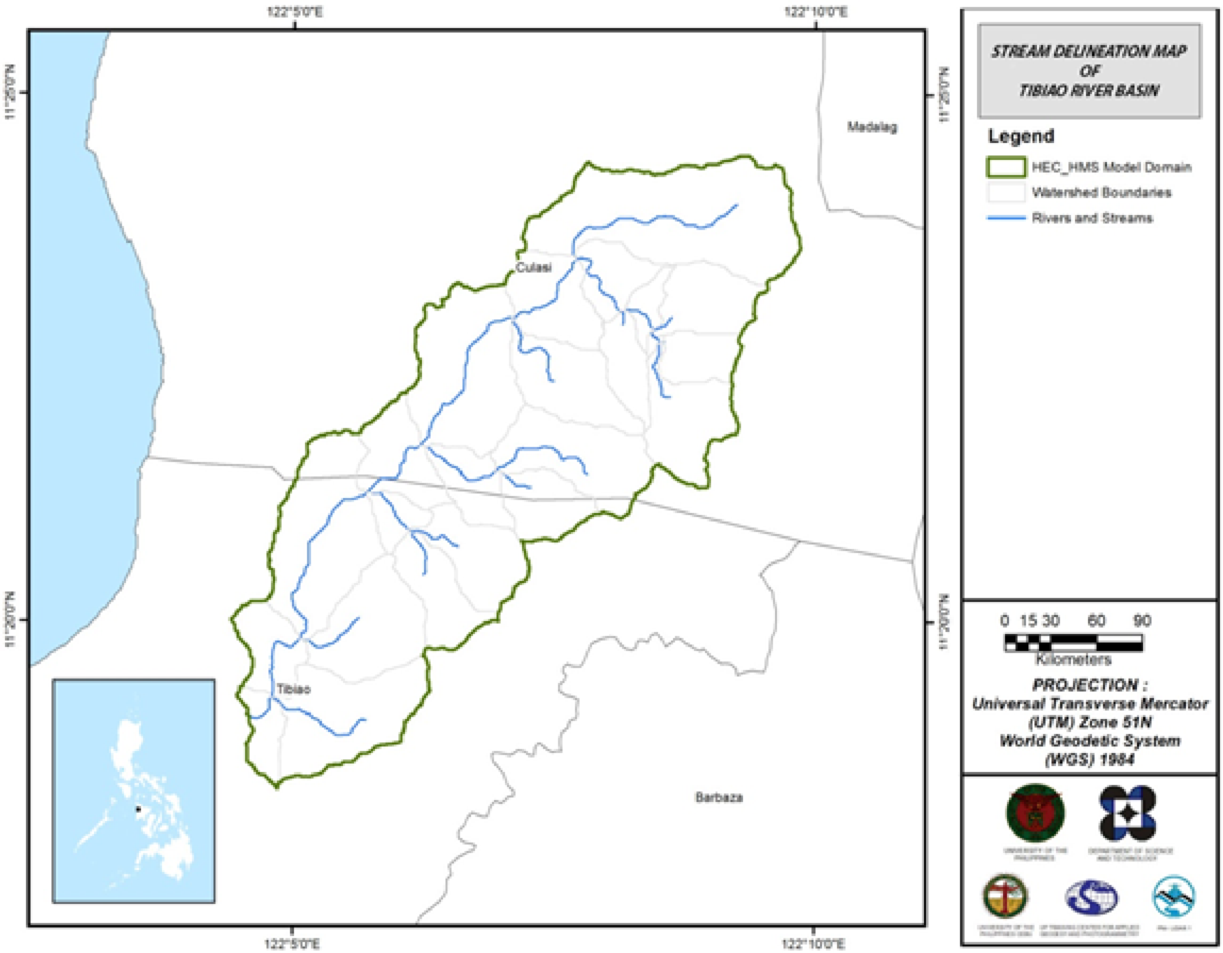


Figure 51. Stream Delineation Map of Tibiao River Basin

Using the SAR-based DEM, the Tibiao basin was delineated and further subdivided into sub-basins. The model consists of 23 sub-basins, 11 reaches, and 11as shown in Figure 52. The main outlet is at Tuno Bridge.

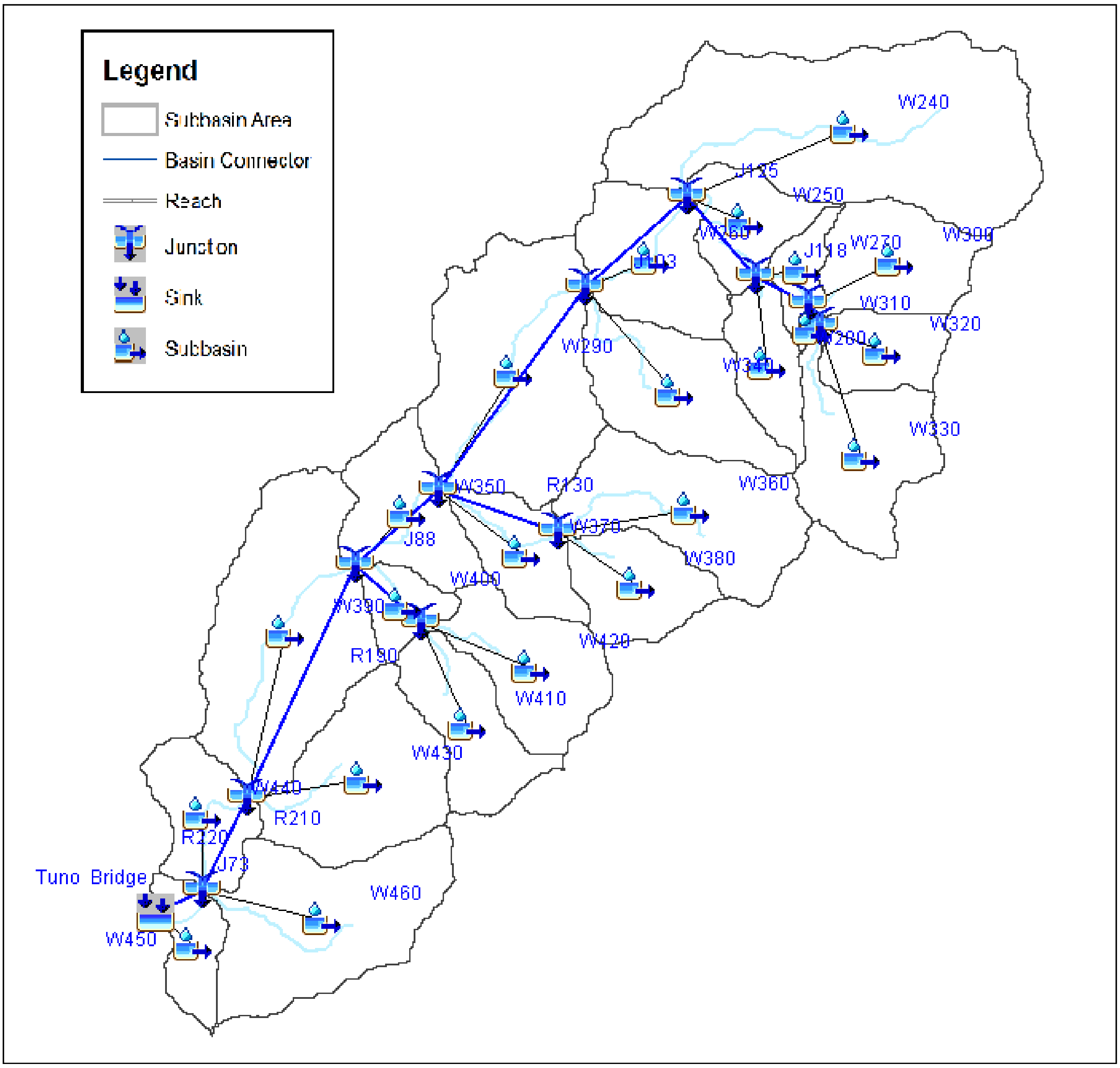


Figure 52.Tibiao River Basin model generated in HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed were crucial in the HEC-RAS model set-up. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS. This is illustrated in Figure 53.

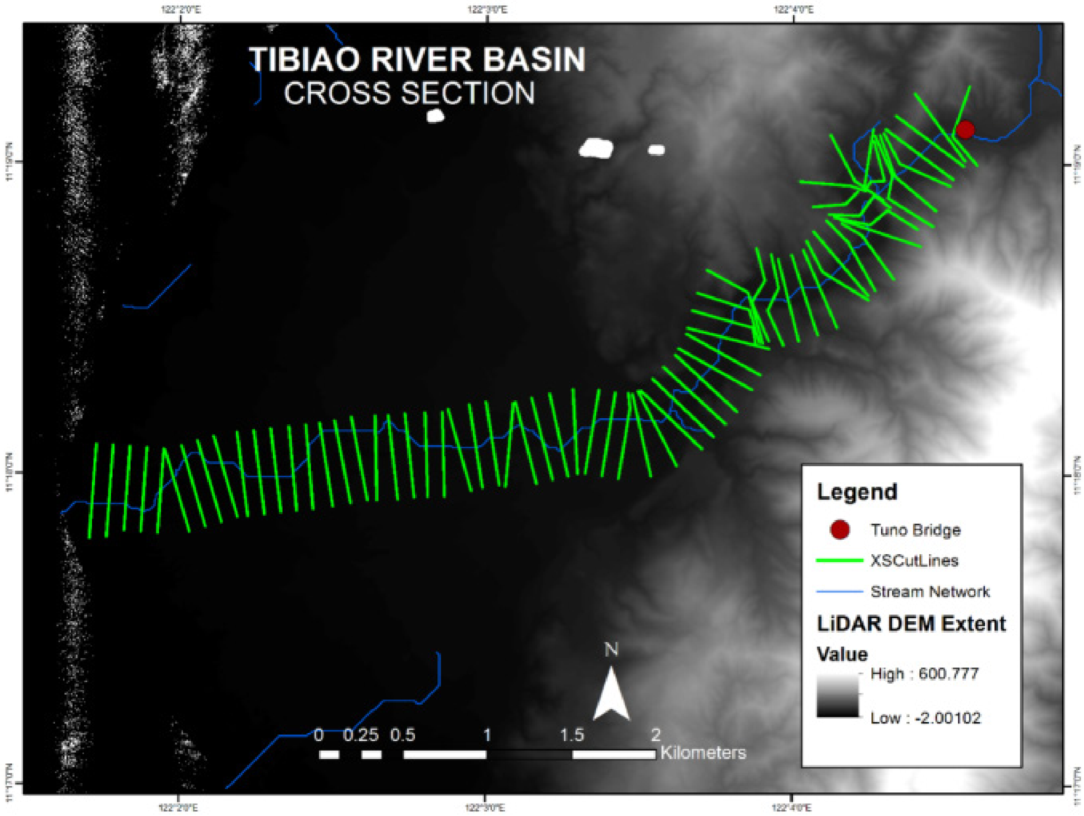


Figure 53. River cross-section of Tibiao River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modeling 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 northeast, following the main channel. As such, boundary elements in those particular regions of the model were assigned as inflow and outflow elements respectively.

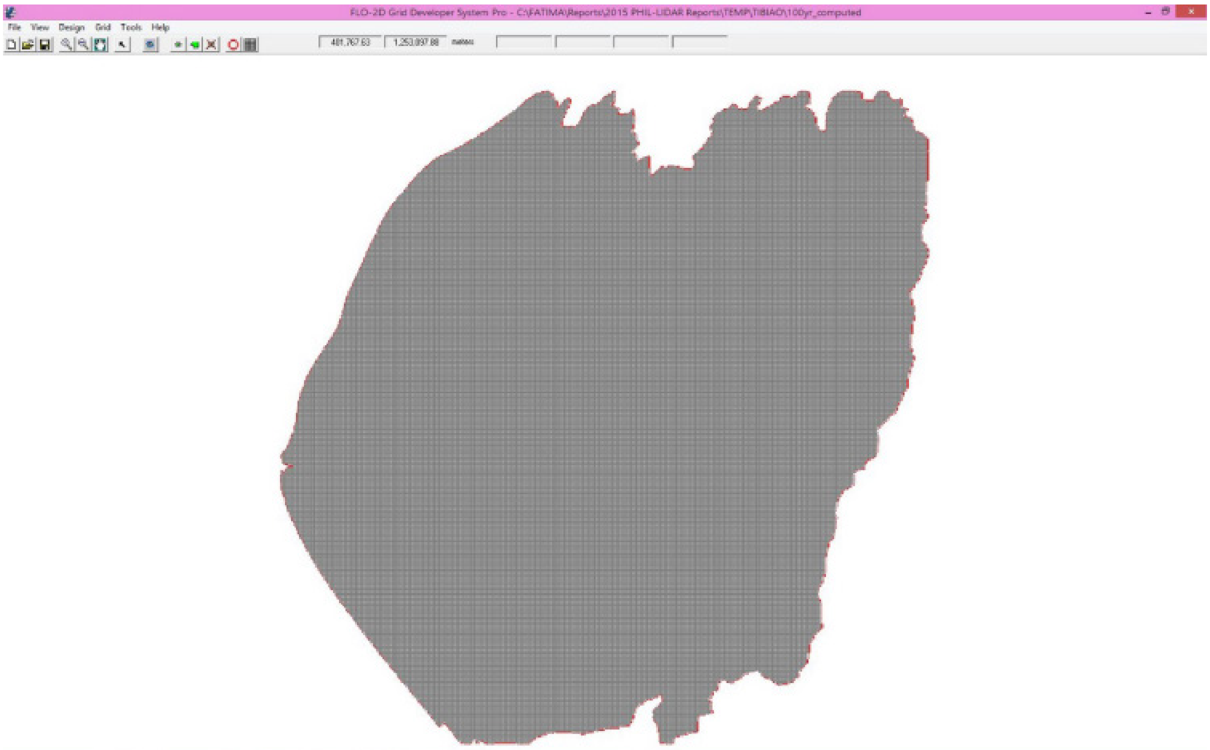


Figure 54. Screenshot of river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro as shown in Figure 54. The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 79.85010 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.

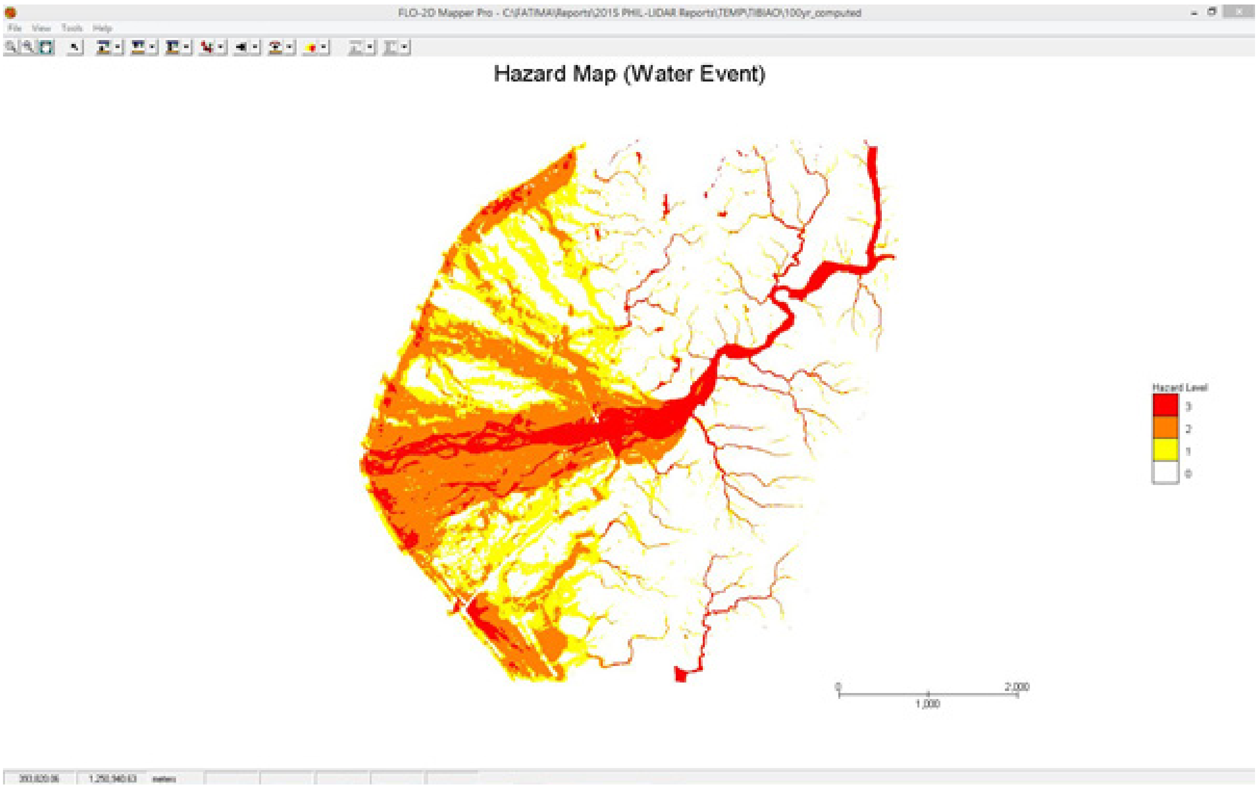


Figure 55. Generated 100-year rain return hazard map from FLO-2D Mapper

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 27646800.00 m2.

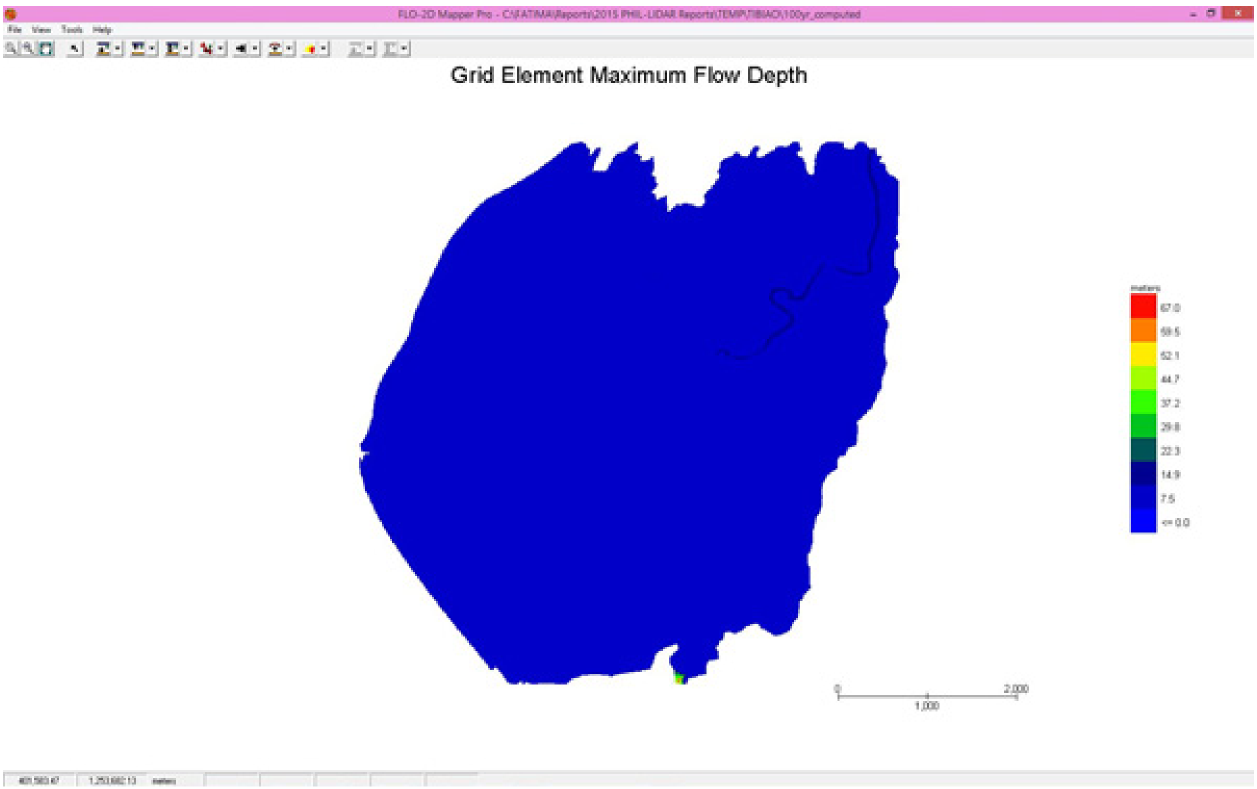


Figure 56. Generated 100-year rain return hazard map from FLO-2D Mapper

There is a total of 22164256.60 m3 of water entering the model. Of this amount, 9498539.32 m3 is due to rainfall while 12665717.29 m3 is inflow from other areas outside the model. 2475059.25 m3 of this water is lost to infiltration and interception, while 1842801.41 m3 is stored by the flood plain. The rest, amounting up to 17846375.81 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Tibiao HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 57 shows the comparison between the two discharge data.

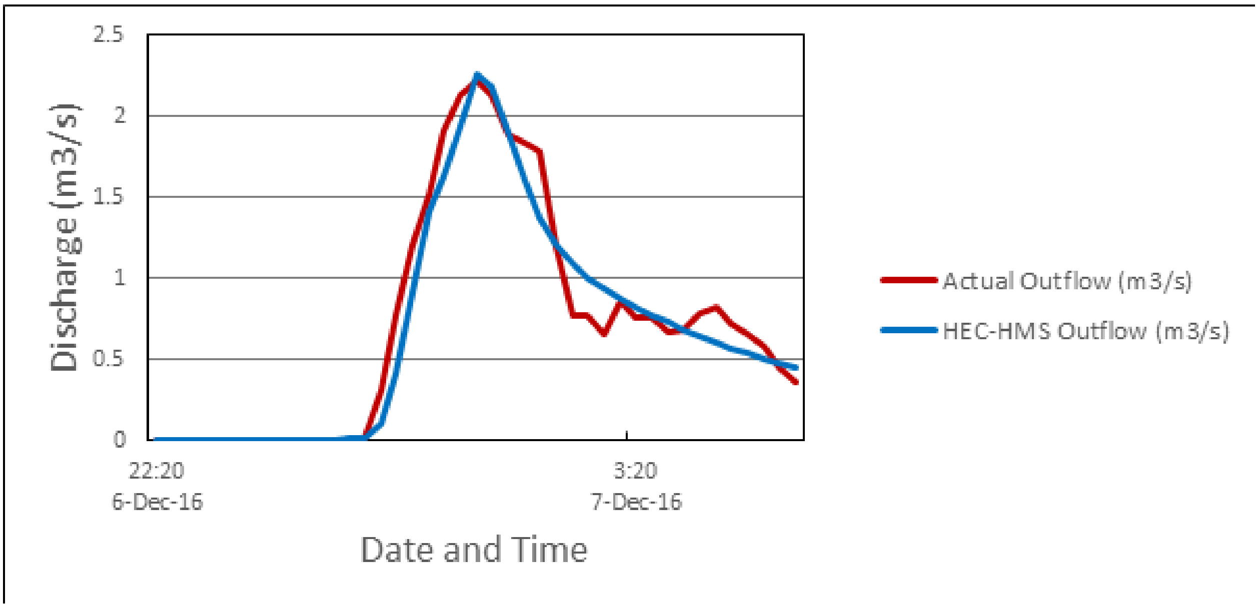


Figure 57. Outflow hydrograph of Tibiao produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 26 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 26. Range of calibrated values for the Tibiao River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	8.16-52.8
			Curve Number	41.25-66.7
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.016-0.073
			Storage Coefficient (hr)	0.02-0.11
	Baseflow	Recession	Recession Constant	0.0001
			Ratio to Peak	0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.01

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 8.16 mm to 52.8mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 41.25-66.7 for curve number falls short for the advisable range for Philippine watersheds depending on the soil and land cover of the area. For Tibiao, the basin mostly consists of closed and open forests, forest plantation, shrubland, and cultivated areas, and the soil consists of clay, sandy loam, and undifferentiated soil.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.016 hours to 0.11 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.0001 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.5 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.01 for the Tibiao river basin is lower than the usual Manning's n value in the Philippines.

Table 27. Summary of the Efficiency Test of the Tibiao HMS Model

Accuracy measure	Value
RMSE	0.2
r2	0.9775
NSE	0.95
PBIAS	0.22
RSR	5.53

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as0.2 (m3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9775.

The Nash-Sutcliffe (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of 0.95.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 5.53.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable are quantified. The model has an RSR value of 0.22.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 58) shows the Tibiao outflow using the Iloilo Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

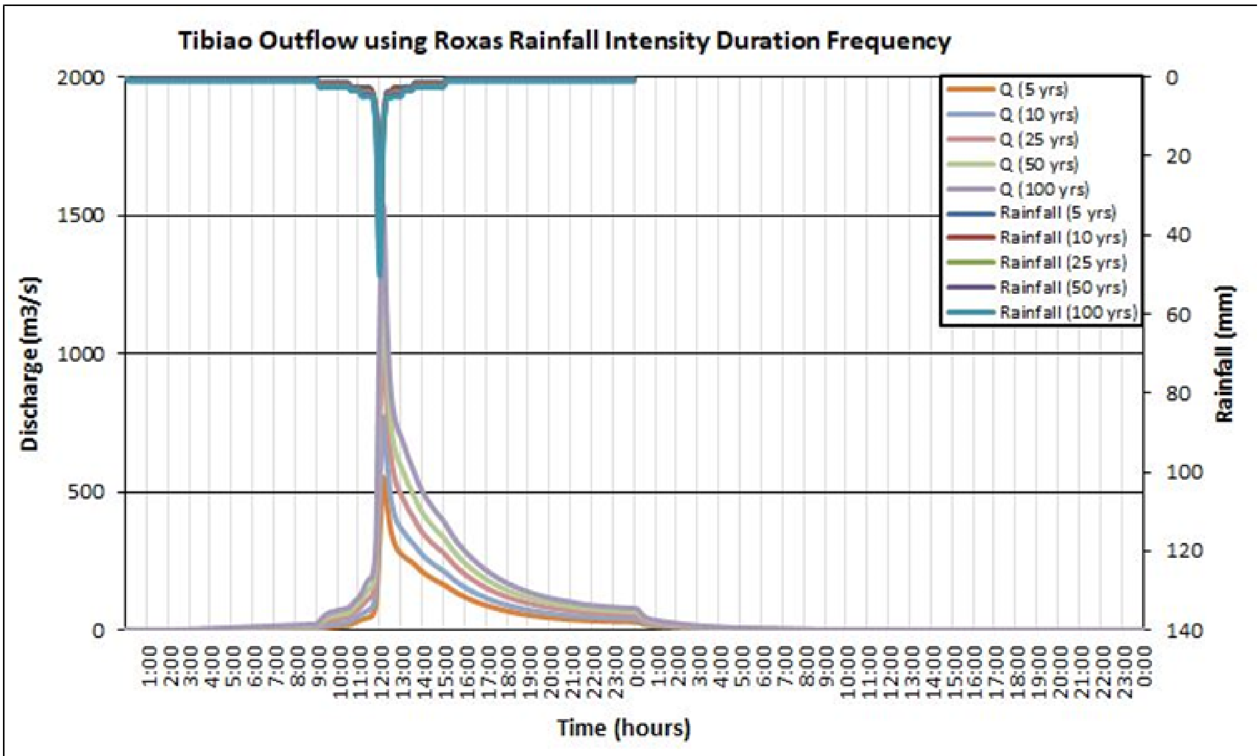


Figure 58. The Outflow hydrograph at Tibiao Station generated using Iloilo RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Tibiao discharge using the Iloilo Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 28.

Table 28. Peak values of the Tibiao HEC-HMS Model outflow using the Iloilo RIDF 24-hour values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	165.2	28.7	548.36	10 minutes
10-Year	198.9	33.9	770.68	10 minutes
25-Year	241.5	40.5	1070.86	10 minutes
50-Year	273.1	45.4	1301.9	10 minutes
100-Year	304.5	50.3	1537.56	10 minutes

5.7.2 Discharge data using Dr. Horritt's recommended hydrologic method

The river discharges entering the floodplain are shown in Figure 59 and the peak values are summarized in Table 29.

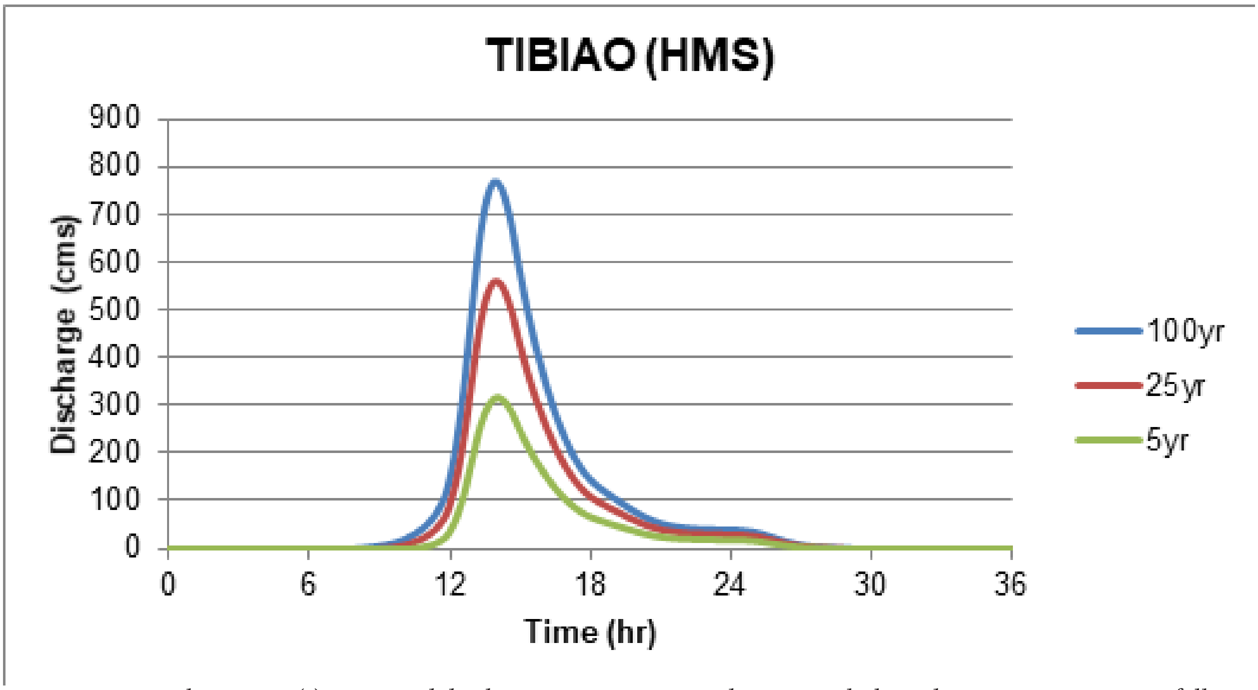


Figure 59. Tibiao river (1) generated discharge using 5-, 25-, and 100-year Iloilo and Mactan stations' rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 29. Summary of Tibiao river (1) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	769.3	14 hours
25-Year	561.2	14 hours
5-Year	315.8	14 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 30.

Table 30. Validation of river discharge estimates

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Tibiao (1)	277.904	280.106	154.020	Pass	Fail

The value from the HEC-HMS river discharge estimate was able to satisfy at least one of the conditions for validation using the bankful and specific discharge methods. The calculated value is based on theory but is supported using other discharge computation methods so it was good to use flood modeling. However, the value will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.8 River Analysis (RAS) Model Simulation

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

Figure 60. Sample output map of Tibiao RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 61 to Figure 66 show the 5-, 25-, and 100-year rain return scenarios of the Tibiao floodplain. The floodplain, with an area of 27.65 sq. km., covers the municipality of Tibiao. Table 31 shows the percentage of area affected by flooding in the municipality.

Table 31. Municipalities affected in Tibiao Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Tibiao	213.08	149.28	70.06%

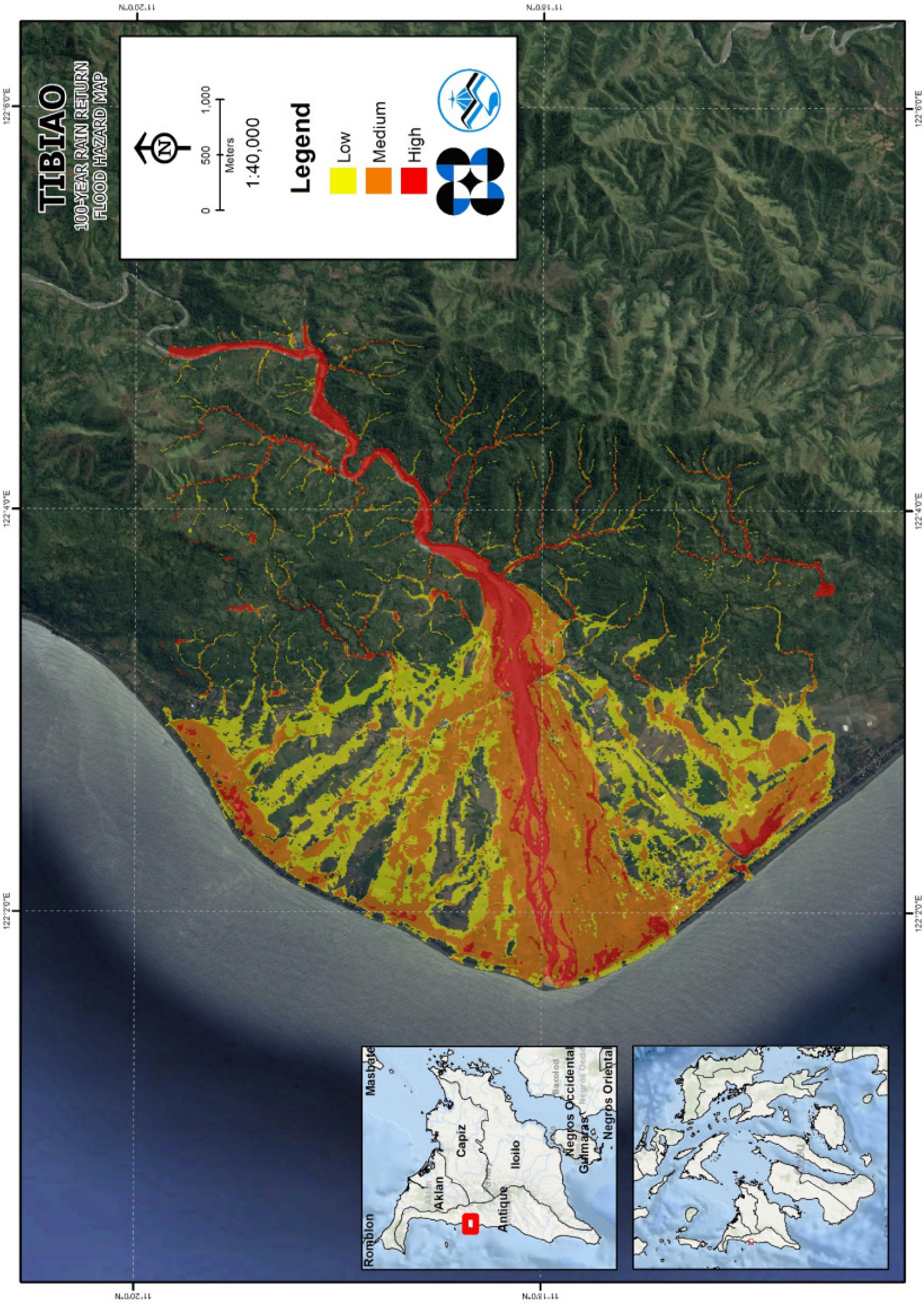


Figure 61. A 100-year flood hazard map for Tibiao Floodplain

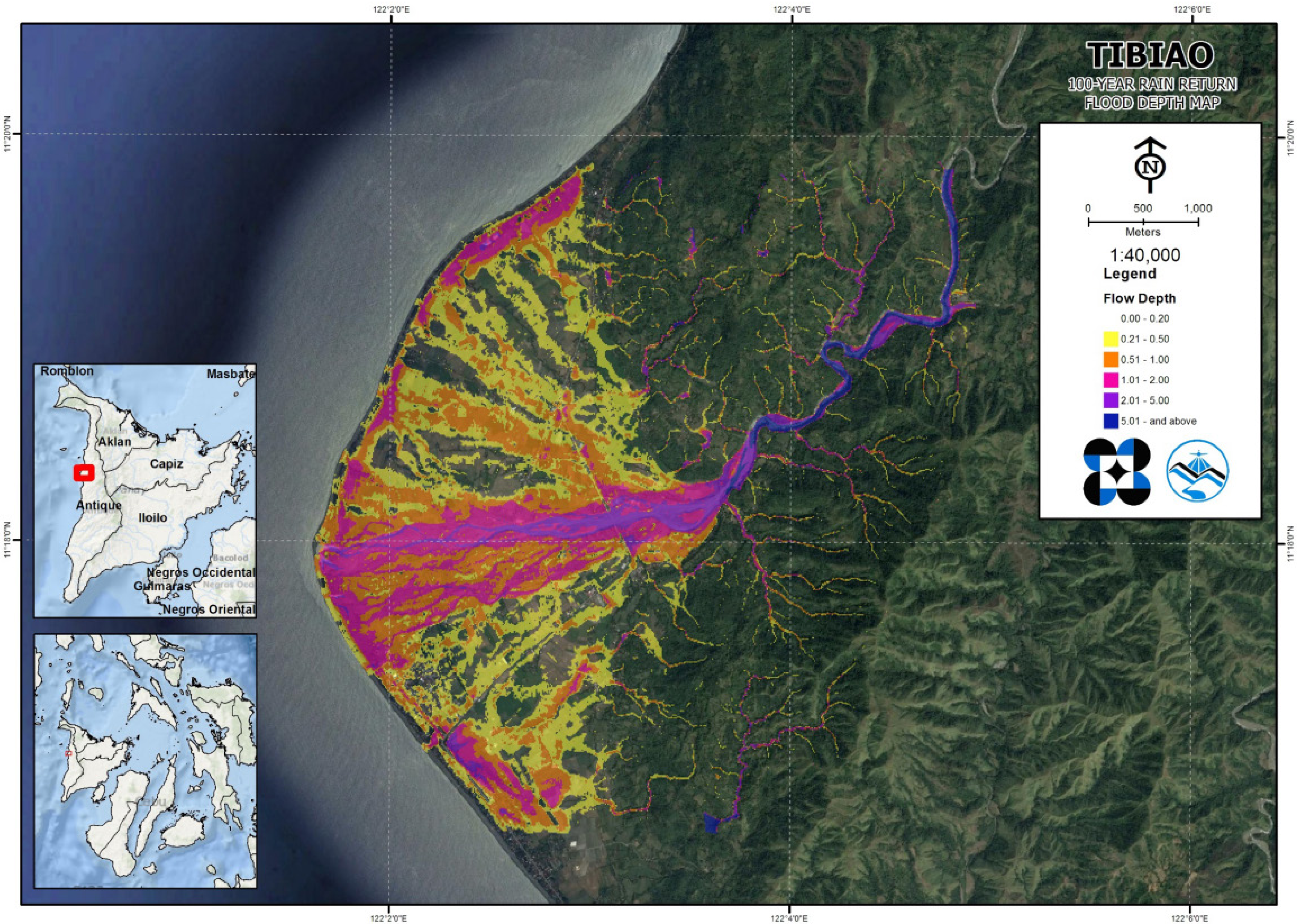


Figure 62. A 100-year Flow Depth Map for Tibiao Floodplain

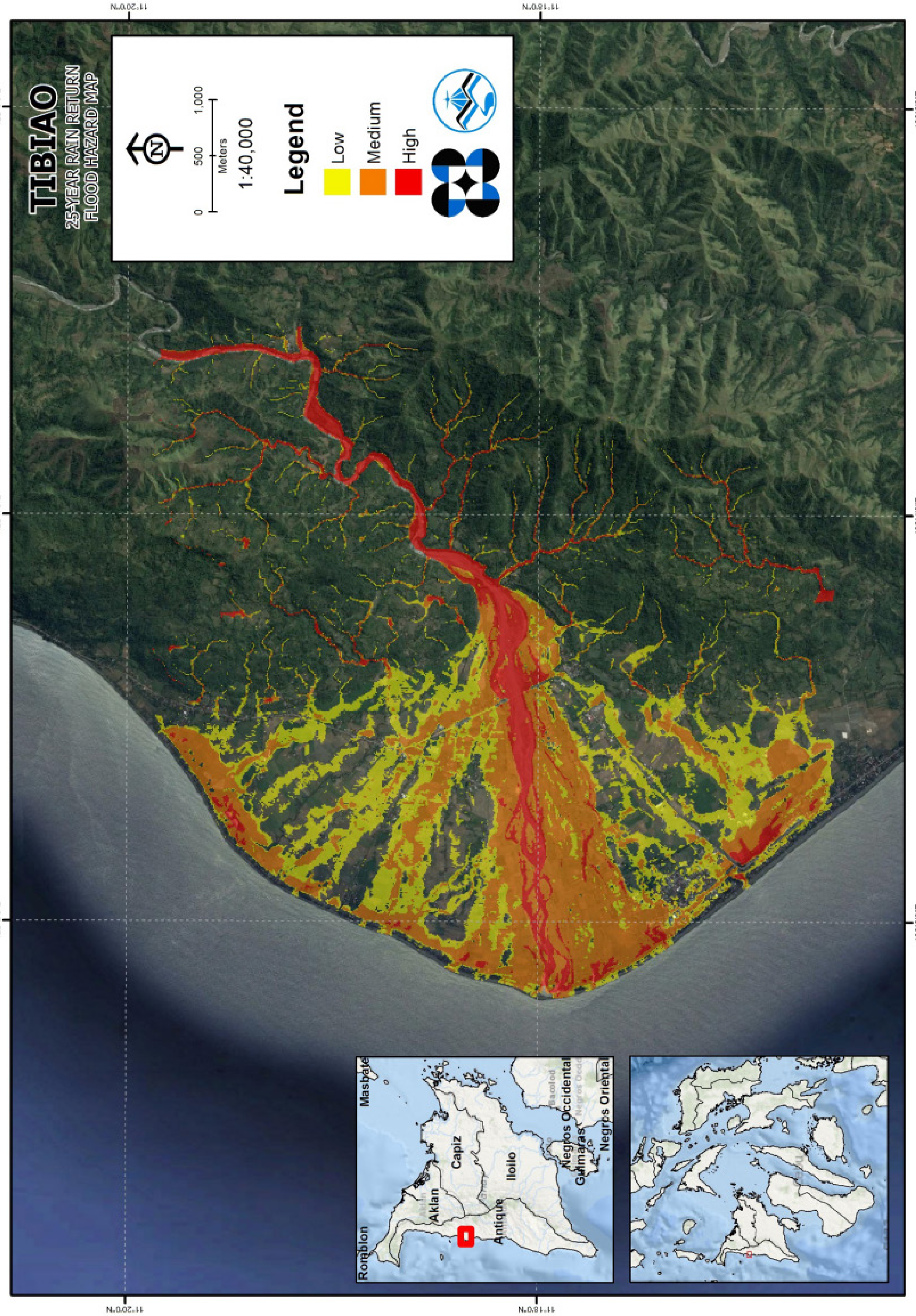


Figure 63. A 25-year Flood Hazard Map for Tibiao Floodplain

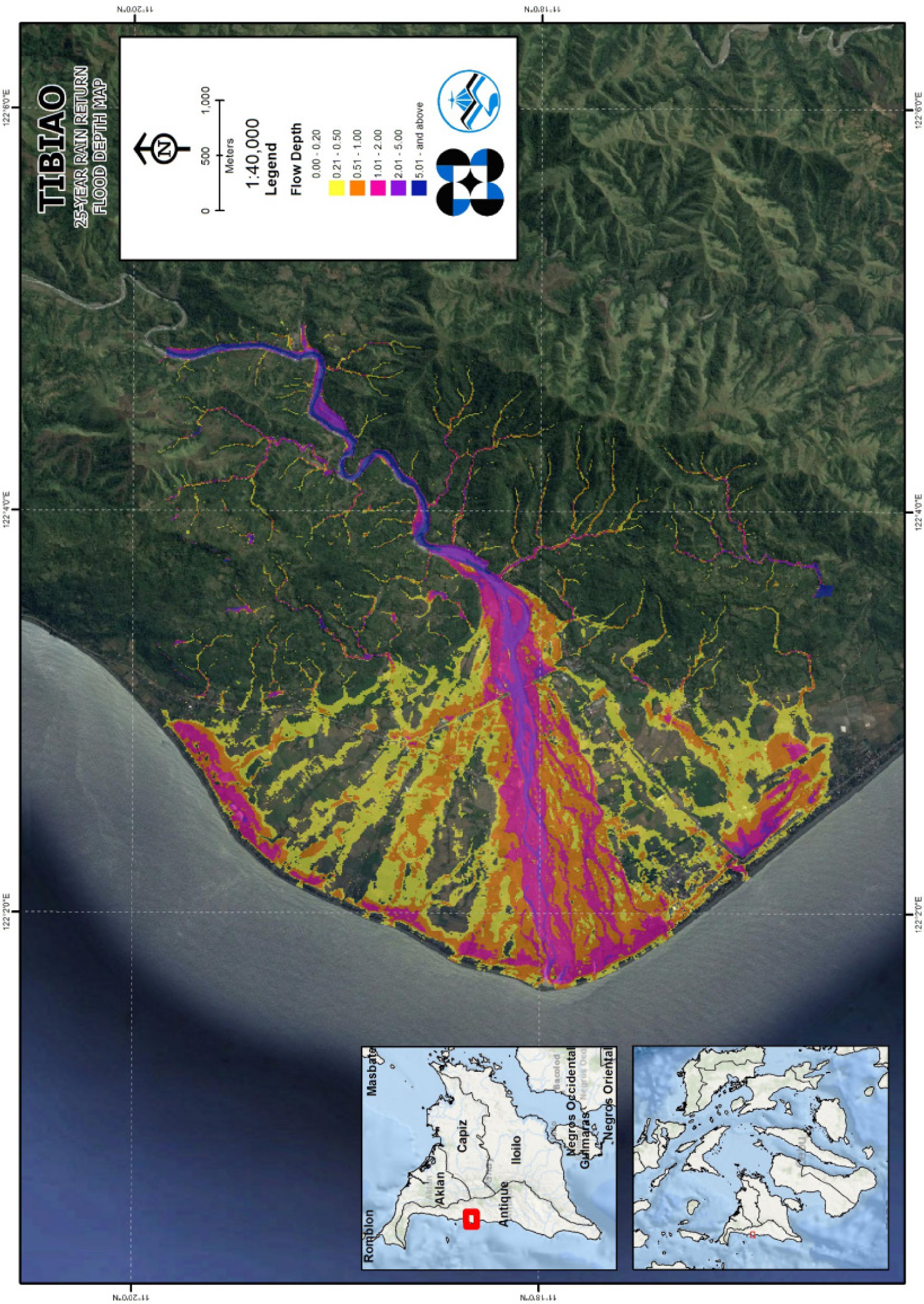


Figure 64. A 25-year Flow Depth Map for Tibiao Floodplain

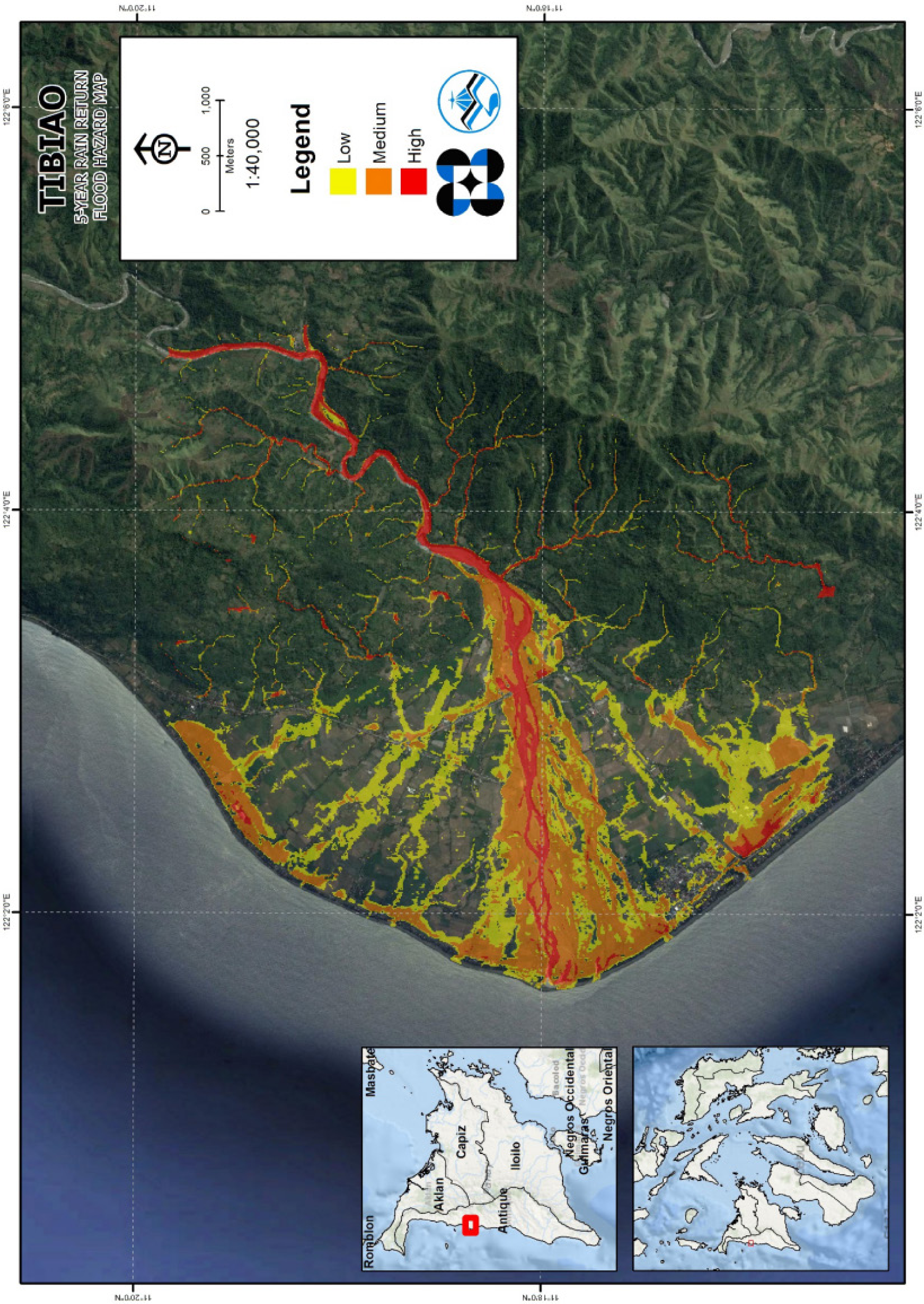


Figure 65. A 5-year Flood Hazard Map for Tibiao Floodplain

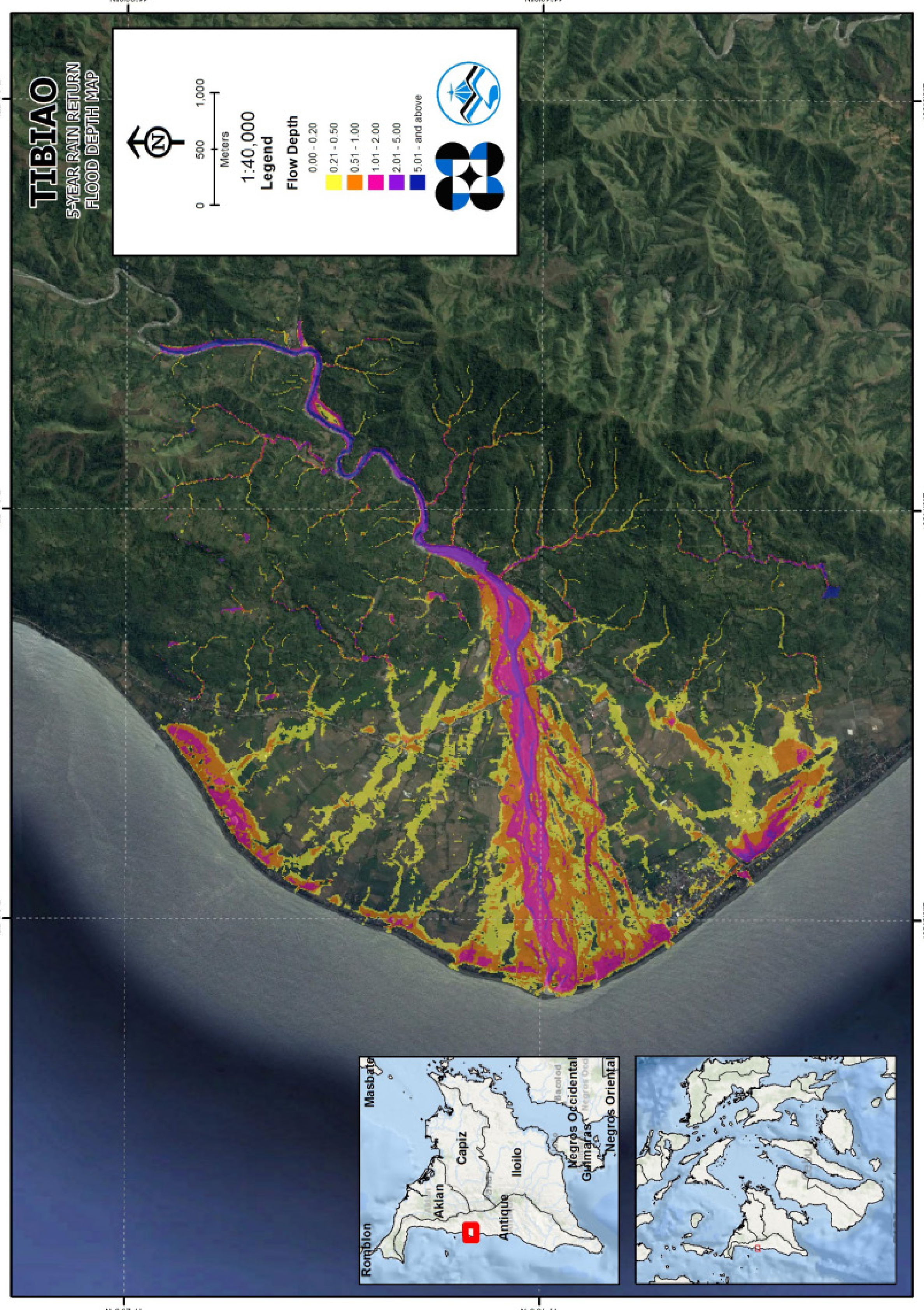


Figure 66. A 5-year Flow depth map for Tibiao Floodplain.

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Tibiao river basin within the municipality of Tibiao are shown in Figure 64 to Figure 66. For the said basin, one municipality consisting of 14 barangays is expected to experience flooding when subjected to 5-yr, 25-yr, and 100-yr rainfall return period.

For the 5-year return period, 20.89% of the municipality of Tibiao with an area of 98.868 sq. km. will experience flood levels of less 0.20 meters. 3.18% of the area will experience flood levels of 0.21 to 0.50 meters while 2.07%, 1.24%, 0.44%, and 0.13%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 and Table 33 are the affected areas in square kilometres by flood depth per barangay.

Table 32. Affected areas in Tibiao, Antique during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tibiao (in sq. km.)						
	Alegre	Amar	Bandoja	Importante	La Paz	Malabor	Martinez
0.03-0.20	0.63	2.48	0.75	4.54	0.0052	0.88	0.78
0.21-0.50	0.014	0.087	0.034	0.52	0.00049	0.48	0.49
0.51-1.00	0.007	0.035	0.018	0.41	0.00011	0.22	0.52
1.01-2.00	0.0076	0.01	0.0089	0.24	0.0001	0.084	0.38
2.01-5.00	0.012	0.0055	0.005	0.18	0.000014	0.019	0.031
> 5.00	0.012	0.0001	0	0.012	0	0	0

Table 33. Affected areas in Tibiao, Antique during a 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tibiao (in sq. km.)						
	Poblacion	San Francisco Norte	San Francisco Sur	San Isidro	Santa Justa	Tigbaboy	Tuno
0.03-0.20	1.02	0.78	1.86	1.24	1.2	4.48	0.0022
0.21-0.50	0.41	0.042	0.17	0.33	0.46	0.11	0
0.51-1.00	0.3	0.068	0.035	0.17	0.21	0.061	0
1.01-2.00	0.091	0.043	0.014	0.086	0.19	0.065	0
2.01-5.00	0.000013	0.0072	0.0068	0	0.06	0.1	0
> 5.00	0	0.0004	0.0019	0	0	0.1	0

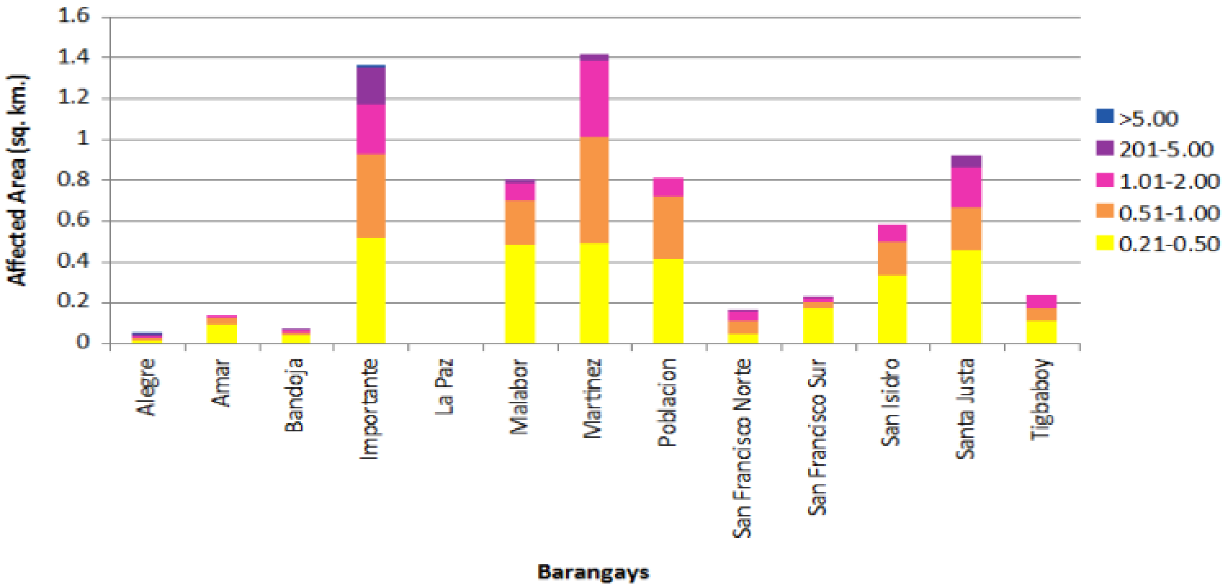


Figure 67. Affected Areas in Tibiao, Antique during 5-Year Rainfall Return Period

For the 25-year return period, 18.28% of the municipality of Tibiao with an area of 98.868 sq. km. will experience flood levels of less 0.20 meters. 3.90% of the area will experience flood levels of 0.21 to 0.50 meters while 2.85%, 2.02%, 0.66%, and 0.23%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 as shown in Figure 68. Listed in Table 34 and Table 35 are the affected areas in square kilometers by flood depth per barangay.

Table 34. Affected areas in Tibiao, Antique during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tibiao (in sq. km.)						
	Alegre	Amar	Bandoja	Importante	La Paz	Malabor	Martinez
0.03-0.20	0.61	2.44	0.72	4.2	0.005	0.71	0.43
0.21-0.50	0.018	0.12	0.042	0.52	0.00059	0.51	0.48
0.51-1.00	0.0067	0.043	0.02	0.47	0.00014	0.3	0.66
1.01-2.00	0.0076	0.014	0.02	0.42	0.00017	0.14	0.55
2.01-5.00	0.015	0.0068	0.011	0.25	0.000014	0.03	0.066
> 5.00	0.017	0.0002	0.00022	0.049	0	0	0

Table 35. Affected areas in Tibiao, Antique during a 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tibiao (in sq. km.)						
	Poblacion	San Francisco Norte	San Francisco Sur	San Isidro	Santa Justa	Tigbaboy	Tuno
0.03-0.20	0.69	0.74	1.68	0.85	0.61	4.39	0.0022
0.21-0.50	0.44	0.059	0.32	0.57	0.66	0.12	0
0.51-1.00	0.42	0.056	0.056	0.26	0.46	0.061	0
1.01-2.00	0.27	0.068	0.019	0.15	0.28	0.059	0
2.01-5.00	0.0032	0.0083	0.01	0.0031	0.12	0.13	0
> 5.00	0	0.0026	0.002	0	0	0.16	0

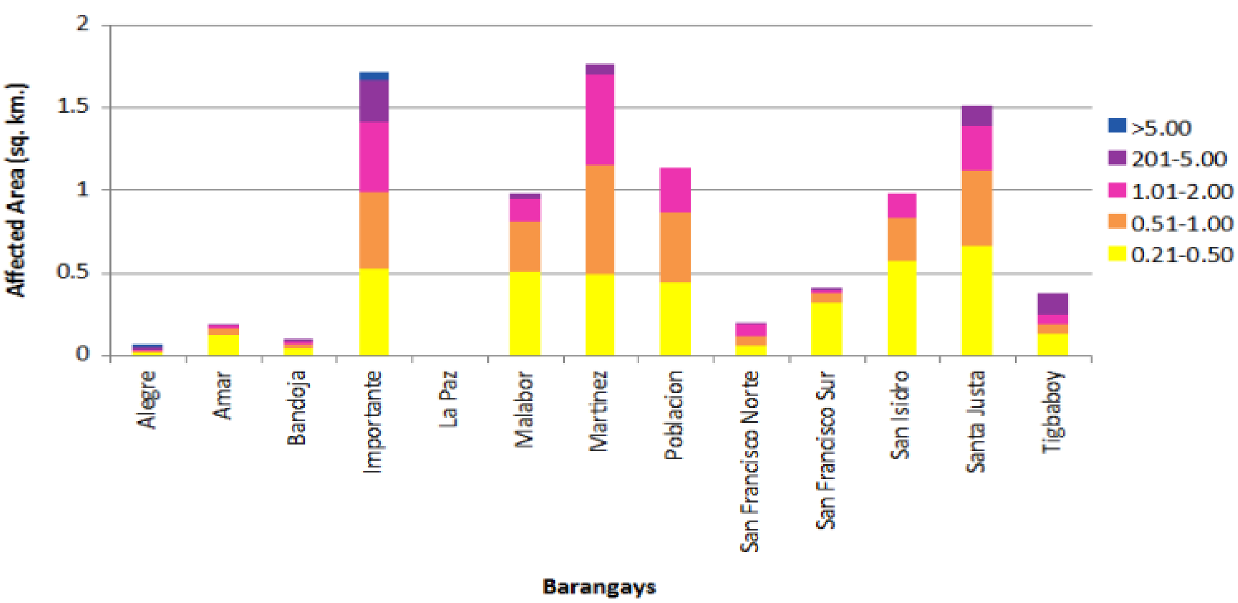


Figure 68. Affected Areas in Tibiao, Antique during 25-Year Rainfall Return Period

For the 100-year return period, 17.22% of the municipality of TIbiao with an area of 98.868 sq. km. will experience flood levels of less 0.20 meters. 4.19% of the area will experience flood levels of 0.21 to 0.50 meters while 3.24%, 2.27%, 0.75%, and 0.27%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 as shown in Figure 69. Listed in Table 36 and Table 37 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected Areas in Tibiao, Antique during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tibiao (in sq. km.)						
	Alegre	Amar	Bandoja	Importante	La Paz	Malabor	Martinez
0.03-0.20	0.61	2.41	0.71	4.03	0.005	0.62	0.35
0.21-0.50	0.02	0.14	0.045	0.59	0.00065	0.49	0.47
0.51-1.00	0.0084	0.048	0.023	0.47	0.00014	0.36	0.7
1.01-2.00	0.007	0.019	0.019	0.46	0.00017	0.18	0.6
2.01-5.00	0.016	0.0088	0.017	0.29	0.000014	0.036	0.075
> 5.00	0.02	0.0002	0.00042	0.063	0	0	0

Table 37. Affected areas in Tibiao, Antique during a 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tibiao (in sq. km.)						
	Poblacion	San Francisco Norte	San Francisco Sur	San Isidro	Santa Justa	Tigbaboy	Tuno
0.03-0.20	0.53	0.72	1.56	0.66	0.47	4.34	0.0022
0.21-0.50	0.51	0.075	0.41	0.64	0.61	0.14	0
0.51-1.00	0.46	0.053	0.073	0.34	0.6	0.063	0
1.01-2.00	0.32	0.079	0.02	0.18	0.3	0.065	0
2.01-5.00	0.0052	0.01	0.013	0.0055	0.14	0.13	0
> 5.00	0	0.0036	0.0023	0	0	0.18	0

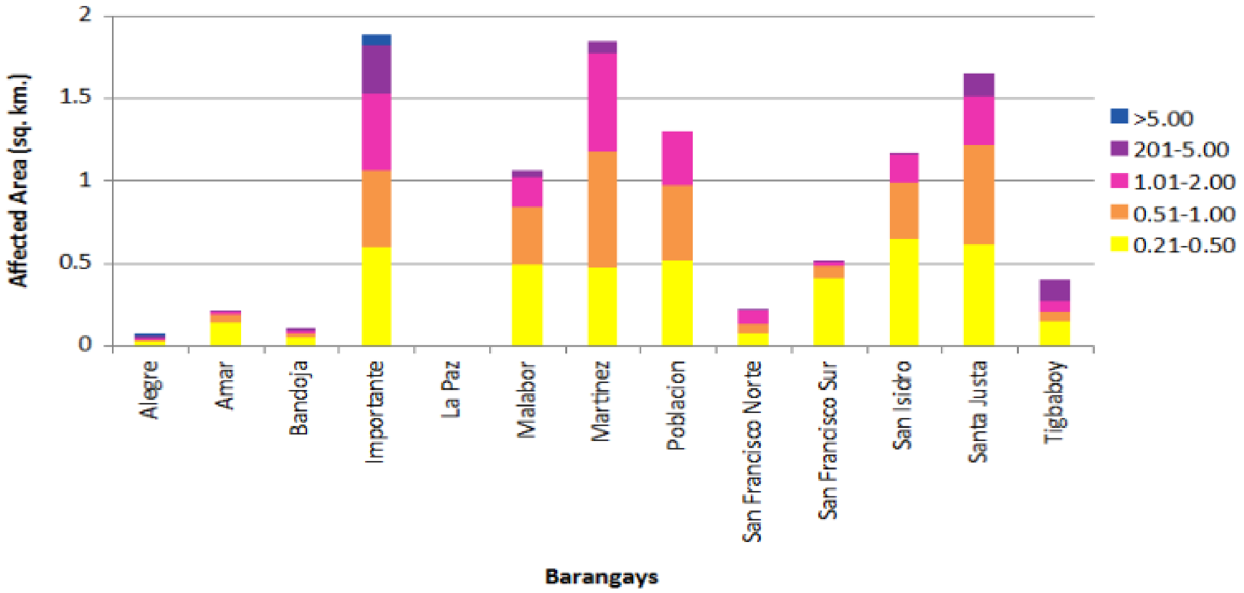


Figure 69. Affected Areas Tibiao, Antique during 100-Year Rainfall Return Period

Among the barangays in the municipality of Tibiao, Importante is projected to have the highest percentage of area to experience flood levels at 5.98%. Meanwhile, Tigbaboy posted the second highest percentage of area that may be affected by flood depths at 4.98%.

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

Table 38. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	3.23	3.91	4.16
Medium	2.92	4.23	4.78
High	1.013	1.604	1.85
TOTAL	**7.17**	**9.74**	**10.79**

Of the 17 identified educational institutions in the Tibiao Floodplain, 2 schools were assessed to be exposed to the Low level flooding during a 5 year scenario, while 1 school was assessed to be exposed to the Medium level flooding scenario. In the 25 year scenario, 1 school was assessed to be exposed to the Low level flooding scenario, while 2 schools were assessed to be exposed to Medium level flooding. For the 100 year scenario, 2 schools were assessed to be exposed to Low level flooding, while 2 schools were assessed to be exposed to Medium level flooding. The educational institutions exposed to flooding are shown in Annex 12.

Four (4) medical institutions were identified in the Tibiao Floodplain. One was assessed to be exposed to low level flooding during a 5 year scenario. In the 25 year scenario, 1 was assessed to be exposed to low level flooding, while 1 medical institution was assessed to be exposed to medium level flooding. In the 100 year scenario, 2 medical institutions were assessed to be exposed to medium level flooding. The medical institutions exposed to flooding are found in Annex 13.

5.11 Flood Validation

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

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

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood level in each location. Data gathering 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 flood validation points were obtained on December 13, 2016.

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

The flood validation consists of 220 points randomly selected all over the Tibiao floodplain. It has an RMSE value of 2.13.

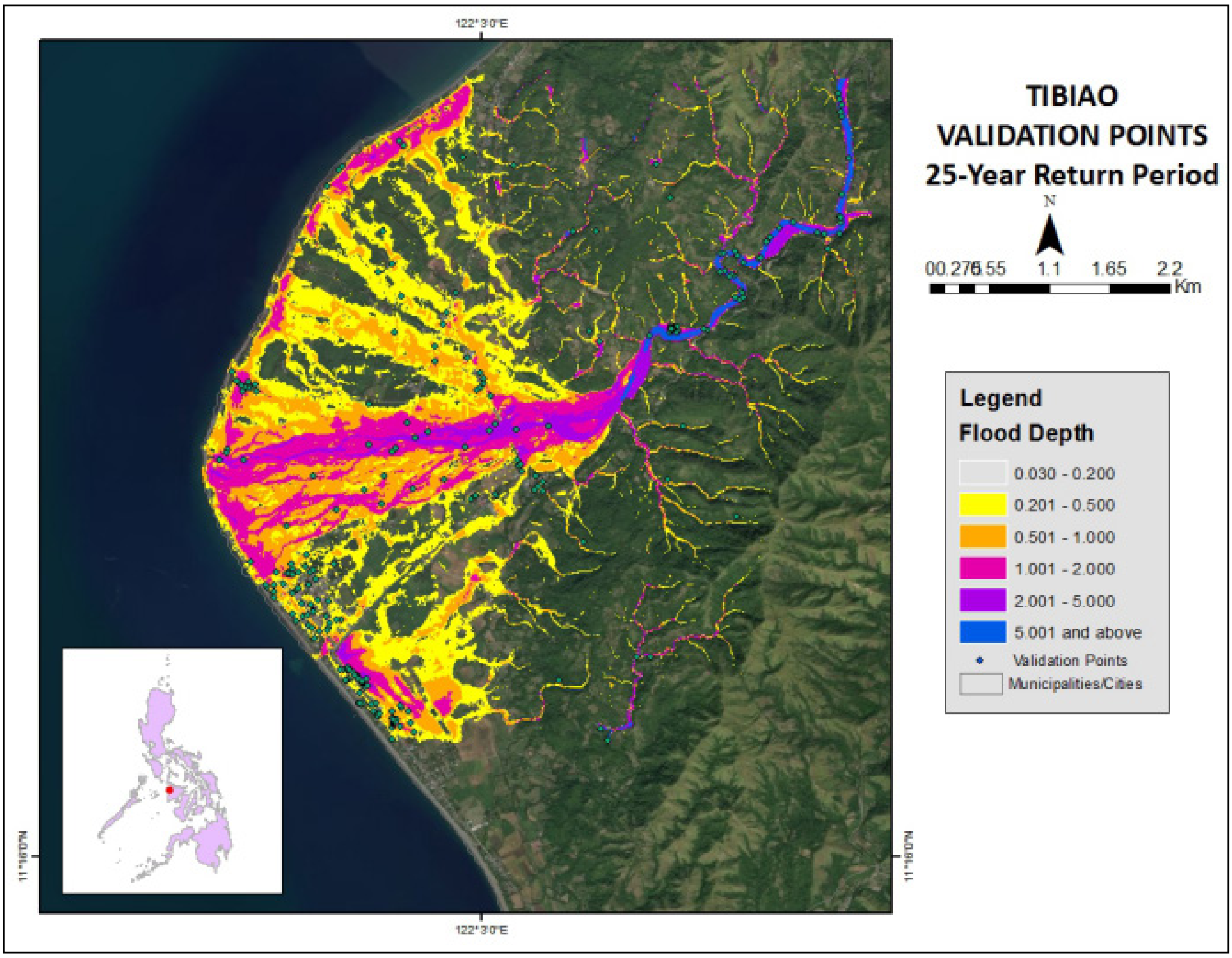


Figure 70. Tibiao Flood Validation Points

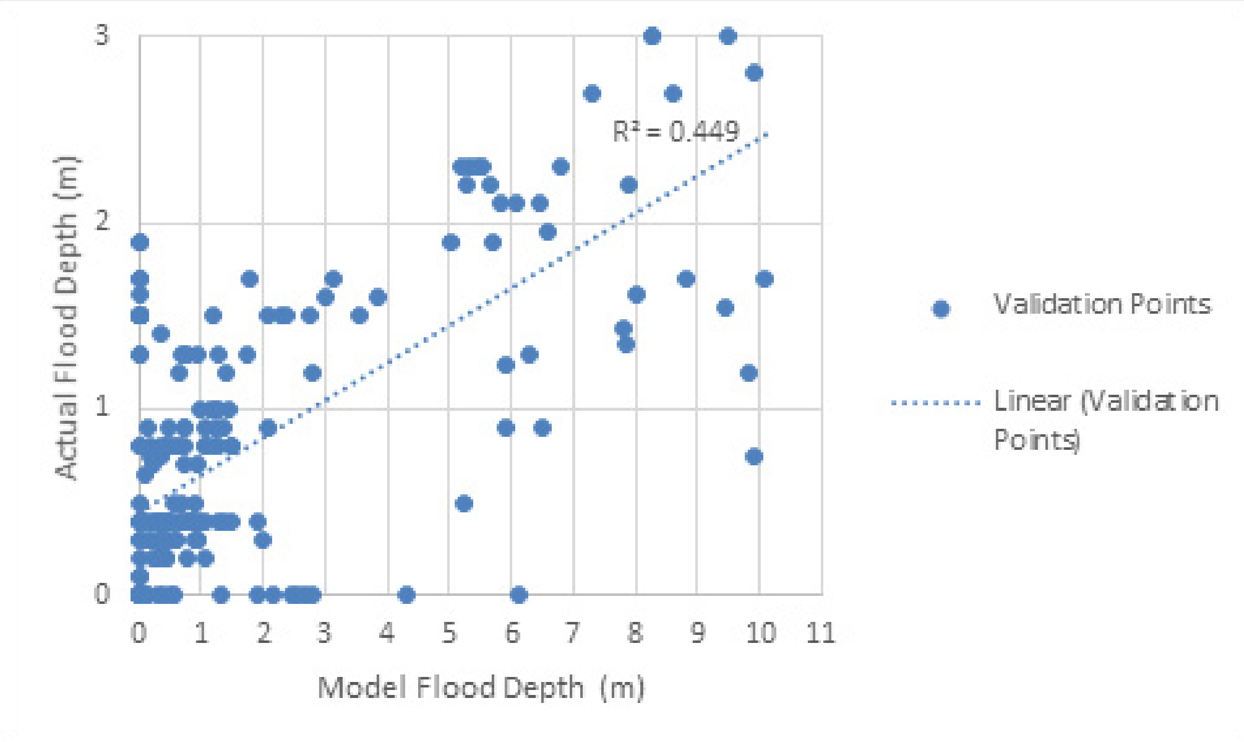


Figure 71. Flood map depth vs. actual flood depth

Table 39. Actual flood vs simulated flood depth at different levels in the Tibiao River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)					
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	Total
0-0.20	37	11	2	3	6	60
0.21-0.50	12	19	17	6	0	55
0.51-1.00	6	6	8	14	1	38
1.01-2.00	16	1	5	5	9	48
2.01-5.00	0	0	0	0	0	19
> 5.00	0	0	0	0	0	0
Total	71	37	32	28	16	220

The overall accuracy generated by the flood model is estimated at 31.36%, with 69 points correctly matching the actual flood depths. In addition, there were 234 points estimated one level above and below the correct flood depths while there were 35 points and 23 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 105 points were overestimated while a total of 46 points were underestimated in the modelled flood depths of Tibiao.

Table 40. Summary of the Accuracy Assessment in the Tibiao River Basin Survey

	No. of Points	%
Correct	69	31.36
Overestimated	105	47.73
Underestimated	46	20.91
Total	220	100

REFERENCES

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

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

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

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

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

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

ANNEXES

Annex 1. Optech Technical Specification of the Gemini Sensor

Figure A-1.1. Pegasus Sensor

Table A-1.1. Parameters and Specification of Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM);
220-channel dual frequency GPS/GNSS/ Galileo/L-Band receiver	Programmable, 0-75 ˚
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg
Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg	-10°C to +35°C
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

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

1. ATQ-18

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

March 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: **ANTIQUE**
Station Name: **ATQ-18**
Order: **2nd**

Island: **VISAYAS** | Barangay: **CUBAY**
Municipality: **BARBAZA** | MSL Elevation:

PRS92 Coordinates

Latitude: **11° 11' 58.67081"**	Longitude: **122° 2' 22.83300"**	Ellipsoidal Hgt: **10.90200 m.**

WGS84 Coordinates

Latitude: **11° 11' 54.16068"**	Longitude: **122° 2' 28.01549"**	Ellipsoidal Hgt: **65.96100 m.**

PTM / PRS92 Coordinates

Northing: **1238579.674 m.**	Easting: **395119.157 m.**	Zone: **4**

UTM / PRS92 Coordinates

Northing: **1,238,146.15**	Easting: **395,155.87**	Zone: **51**

Location Description

ATQ-18
From San Jose, travel N to the Mun. of Barbaza. Then from the town proper, proceed to Brgy. Cubay. Station is located on the NE approach of Binangbang Bridge, about 600 m. NE of Barbaza Town Hall, 4 m. from the road centerline, 50 m. SE of Barbaza Multi-Purpose Coop./Natco Network and 25 m. SE of a funeral service outlet. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. cement putty, with inscriptions "ATQ-18 2007 NAMRIA".

Requesting Party: **PHIL-LIDAR 1**
Purpose: **Reference**
OR Number: **8077754 I**
T.N.: **2015-0504**

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

9 9 0 3 0 2 2 0 1 5 1 3 1 3 4 6

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. ATQ-18

2. ATQ-22

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

March 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: **ANTIQUE**
Station Name: **ATQ-22**
Order: **2nd**

Island: **VISAYAS**		Barangay:	**CONCEPCION**		
Municipality: **BELISON**		MSL Elevation:			
		PRS92 Coordinates			
Latitude:	**10° 49' 46.66618"**	Longitude:	**121° 58' 11.90221"**	Ellipsoidal Hgt:	**12.25000 m.**
		WGS84 Coordinates			
Latitude:	**10° 49' 42.24271"**	Longitude:	**121° 58' 17.11770"**	Ellipsoidal Hgt:	**68.02200 m.**
		PTM / PRS92 Coordinates			
Northing:	**1197676.056 m.**	Easting:	**387365.279 m.**	Zone:	**4**
		UTM / PRS92 Coordinates			
Northing:	**1,197,256.85**	Easting:	**387,404.70**	Zone:	**51**

Location Description

ATQ-22

From San Jose, travel N to Belison for about 20 km. Station is located on top of the N edge of the NW draft on an irrigation canal, 60 m. NE to the nat'l. highway centerline, 120 m. N of the road going to the brgy. proper and about 300 m. E of Km. Post No. 110. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. cement putty, with inscriptions "ATQ-22 2007 NAMRIA".

Requesting Party:	**PHIL-LIDAR 1**
Purpose:	**Reference**
OR Number:	**8077754 I**
T.N.:	**2015-0503**

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

9 9 0 3 0 2 2 0 1 5 1 3 0 9 5 8

CIP/4701/12/09/814

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. ATQ-22

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

There are no Baseline Processing Reports for the Tibiao River Basin.

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

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

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	ENGR. GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	MA. VERLINA TONGA	UP-TCAGP
	RA	REGINA FELISMINO	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JONATHAN ALMALVEZ	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. LEE JAY PUNZALAN	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. BRYAN DONGUINES	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. ALBERT PAUL LIM	AAC

Annex 5. Data Transfer Sheet for Tibiao Floodplain

DATA TRANSFER SHEET
03/23/2015(Iloilo-gem)

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	
16-Feb-15	2566G	2BLK37V047A	gemini	na	1517	1.13	209	28	206	13	1.36	10.7	1KB	1KB	19	19	Z:\DAC\RAW DATA
16-Feb-15	2568G	2BLK37GSIV047B	gemini	na	952	1.34	222	46.8	383	21.9	2.12	6.61	1KB	1KB	7/4	15/12	Z:\DAC\RAW DATA
17-Feb-15	2570G	2BLK43H048A	gemini	na	1078	1.43	222	48.5	342	21.7	3.4	14.4	1KB	1KB	3	3	Z:\DAC\RAW DATA
19-Feb-15	2578G	2BLK43GV050A	gemini	na	586	891	184	8.07	67.8	19.4	na	11.1	1KB	1KB	7	na	Z:\DAC\RAW DATA
19-Feb-15	2580G	2BLK43F050B	gemini	na	740	990	163	25.6	203	16.2	3.29	4.11	1KB	1KB	4	8	Z:\DAC\RAW DATA
20-Feb-15	2582G	2BLK43A051A	gemini	na	169	254	106	6.84	57.4	4.65	ns	11	1KB	1KB	6	13	Z:\DAC\RAW DATA
21-Feb-15	2586G	2BLK43A052A	gemini	na	613	670	182	15.4	63.9	8.3	1.43	11.5	1KB	1KB	5	10	Z:\DAC\RAW DATA
22-Feb-15	2590G	2BLK43A053A	gemini	na	694	0.97	198	21.2	94.4/628	12.1	na	17	1KB	1KB	5	10	Z:\DAC\RAW DATA
23-Feb-15	2594G	2BLK43C054A	gemini	na	856	1.05	240	28.2	17.2/163	16.3	na	11.6	1KB	1KB	6	14	Z:\DAC\RAW DATA

Received from

Name C. Joaquin
Position FA
Signature

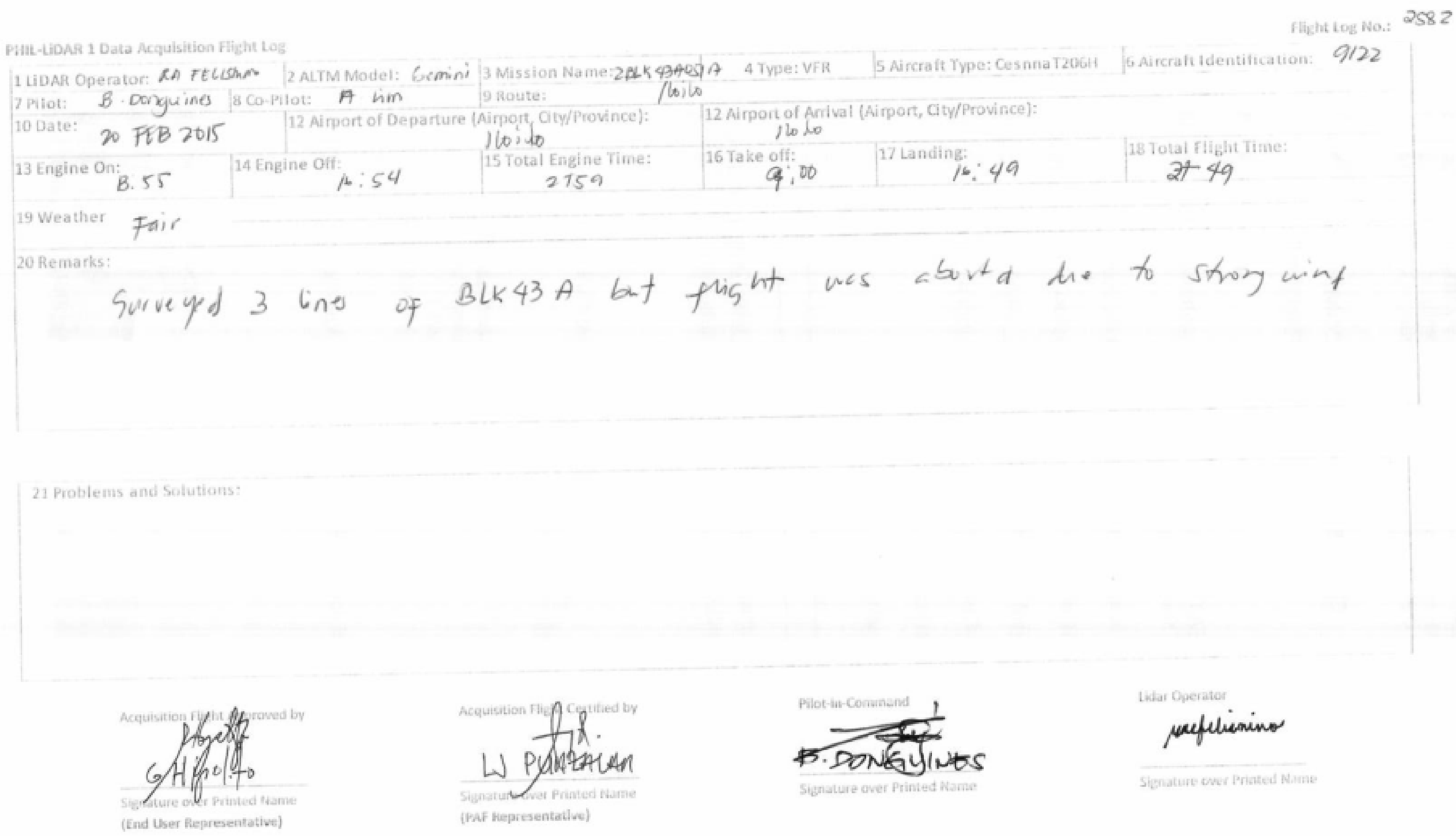
Received by

Name JOIDA F. PRIETO
Position SSRS
Signature
3/23/2015

Figure A-5.1. Transfer Sheet for Tibiao Floodplain

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for Mission 2BLK43A051A



Flight Log No.: 2582

PHIL-LIDAR 1 Data Acquisition Flight Log

1 LiDAR Operator: RA Fellsiano	2 ALTM Model: Gemini	3 Mission Name: 2BLK43A051A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: B. Donguines	8 Co-Pilot: A Lim	9 Route: Iloilo			
10 Date: 20 FEB 2015	12 Airport of Departure (Airport, City/Province): Iloilo		12 Airport of Arrival (Airport, City/Province): Iloilo		
13 Engine On: 8:55	14 Engine Off: 16:54	15 Total Engine Time: 2759	16 Take off: 9:00	17 Landing: 16:49	18 Total Flight Time: 2+49

19 Weather: Fair

20 Remarks:

Surveyed 3 lines of BLK43A but flight was aborted due to strong wind

21 Problems and Solutions:

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

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

Pilot-in-Command: B. Donguines — Signature over Printed Name

Lidar Operator: Fellsiano — Signature over Printed Name

Figure A-6.1. Flight Log for Mission 2BLK43A051A

2. Flight Log for 2BLK43A052A Mission

Flight Log No.: 2586

PHIL-LiDAR 1 Data Acquisition Flight Log

1 LiDAR Operator: MVE TONGA	2 ALTM Model: Gemini	3 Mission Name: 2BLK43A052A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: B. Dongguines	8 Co-Pilot: A. Lim	9 Route: Iloilo			
10 Date: 21 FEB 15	12 Airport of Departure (Airport, City/Province): Iloilo		12 Airport of Arrival (Airport, City/Province): Iloilo		
13 Engine On: 9:05	14 Engine Off: 13:04	15 Total Engine Time: 3+59	16 Take off: 9:10	17 Landing: 12:57	18 Total Flight Time: 3+49
19 Weather: Fair					
20 Remarks: Surveyed 6 lines of BLK43A					
21 Problems and Solutions:					

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Signature over Printed Name (End User Representative)	LJ PUNZALAN Signature over Printed Name (PAF Representative)	B. DONGGUINES Signature over Printed Name	Signature over Printed Name

Figure A-6.2. Flight Log for Mission 2BLK43A052A

3. Flight Log for2BLK43A053A Mission

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 2590

1 LIDAR Operator: RA Felismino | 2 ALTM Model: Gemini | 3 Mission Name: 2BLK43A053A | 4 Type: VFR | 5 Aircraft Type: Cesnna T206H | 6 Aircraft Identification: 9122

7 Pilot: B Donguines | 8 Co-Pilot: A Lim | 9 Route: Iloilo

10 Date: 22 FEB 2015 | 12 Airport of Departure (Airport, City/Province): Iloilo | 12 Airport of Arrival (Airport, City/Province): Iloilo

13 Engine On: 6:40 | 14 Engine Off: 10:45 | 15 Total Engine Time: 4+5 | 16 Take off: 6:45 | 17 Landing: 10:40 | 18 Total Flight Time: 3+55

19 Weather: Fair

20 Remarks:

Completed the remaining lines of BLK43A

21 Problems and Solutions:

Acquisition Flight Approved by: G. Hipolito — Signature over Printed Name (End User Representative)

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

Pilot-in-Command: B. Donguines — Signature over Printed Name

Lidar Operator: RAFelismino — Signature over Printed Name

Figure A-6.3. Flight Log for Mission 2BLK43A053A

Annex 7. Flight Status Reports

Iloilo, Antique, and Guimaras
February 20-22, 2015

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
2582G	BLK 43A	2BLK43A051A	RA FELISMINO	20 FEB 15	3 lines of BLK43A. Aborted due to strong winds
2586G	BLK 43A	2BLK43A052A	MVE TONGA	21 FEB 15	6 lines BLK 43A
2590G	BLK 43A	2BLK43A053A	RA FELISMINO	22 FEB 15	Completed remaining BLK 43A

LAS/ SWATH BOUNDARIES PER FLIGHT

Flight No. : 2582G
Area: BLK 43A
Mission Name: 2BLK43A051A
Parameters: Altitude: 1000m; Scan Frequency: 50Hz;
Scan Angle: 40deg; Overlap: 40%

LAS/ SWATH

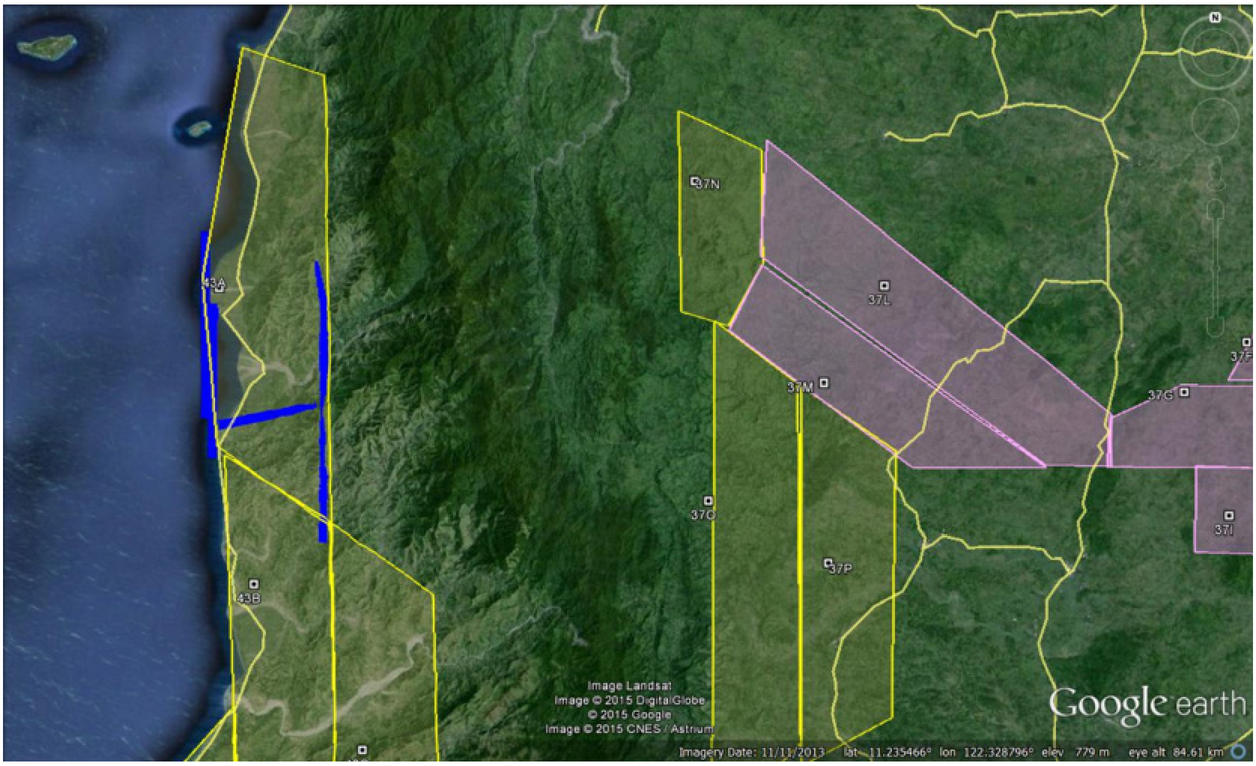


Figure A-7.1. Swath for Flight No. 2582G

Flight No. :	2586G		
Area:	BLK 43A		
Mission Name:	2BLK43A052A		
Parameters:	Altitude:	1500m;	Scan Frequency: 50Hz;
Scan Angle:	40deg;	Overlap: 40%	

LAS/ SWATH

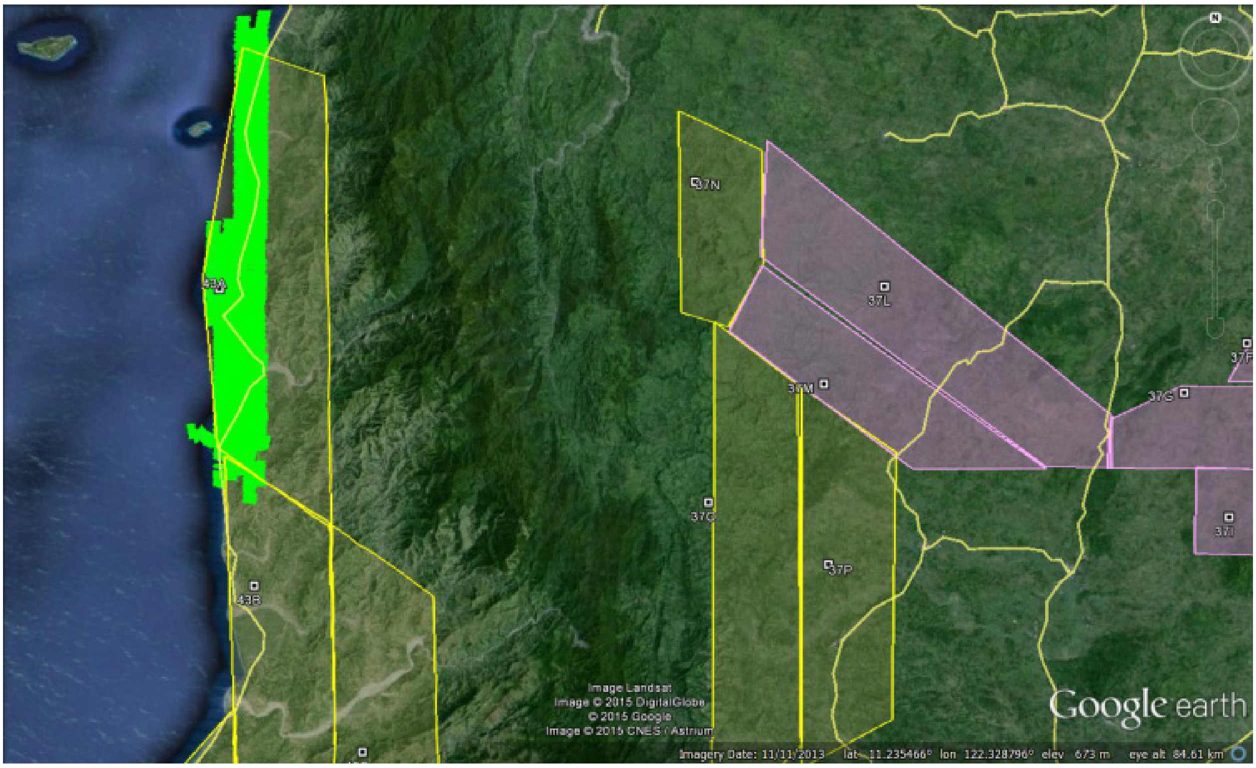


Figure A-7.2. Swath for Flight No. 2586G

Flight No. :	2590G		
Area:	BLK 43A		
Mission Name:	2BLK43A053A		
Parameters:	Altitude:	1500m;	Scan Frequency: 50Hz;
Scan Angle:	40deg;	Overlap: 40%	

LAS/ SWATH

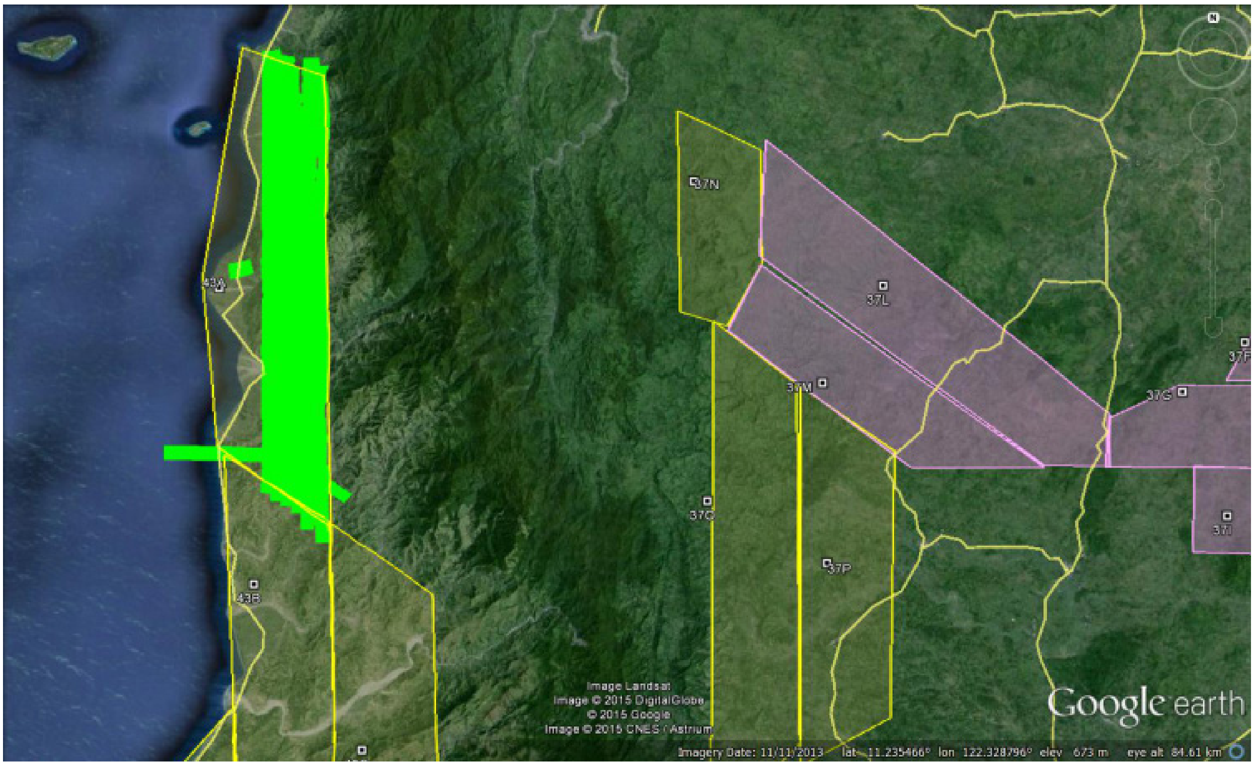


Figure A-7.3. Swath for Flight No. 2590G

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk2D_supplement

Flight Area	Cagayan Reflights(Tuguegarao)
Mission Name	Blk2D_supplement
Inclusive Flights	2850P
Range data size	23.3GB
POS	230MB
Image	35.2MB
Transfer date	November 24, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.17
RMSE for East Position (<4.0 cm)	1.62
RMSE for Down Position (<8.0 cm)	3.60
Boresight correction stdev (<0.001deg)	0.000255
IMU attitude correction stdev (<0.001deg)	0.001669
GPS position stdev (<0.01m)	0.0147
Minimum % overlap (>25)	51.38
Ave point cloud density per sq.m. (>2.0)	4.52
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	243
Maximum Height	629.94 m
Minimum Height	33.11 m
Classification (# of points)	
Ground	114,681,685
Low vegetation	86,249,217
Medium vegetation	179,801,226
High vegetation	1,312,535,704
Building	12,298,531
Orthophoto	Yes
Processed by	Engr. Jennifer B. Saguran, Engr. Chelou Prado, Marie Denise Bueno

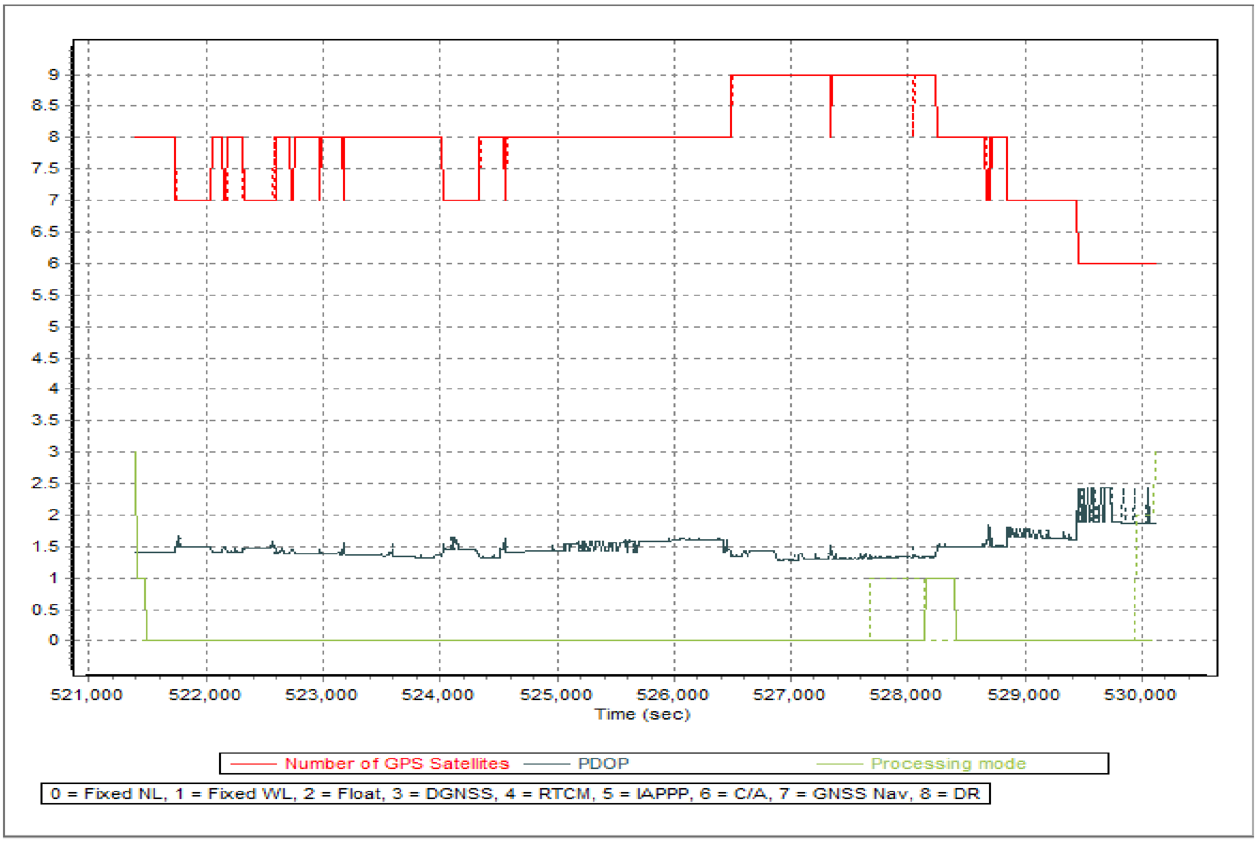


Figure A-8.1. Solution Status

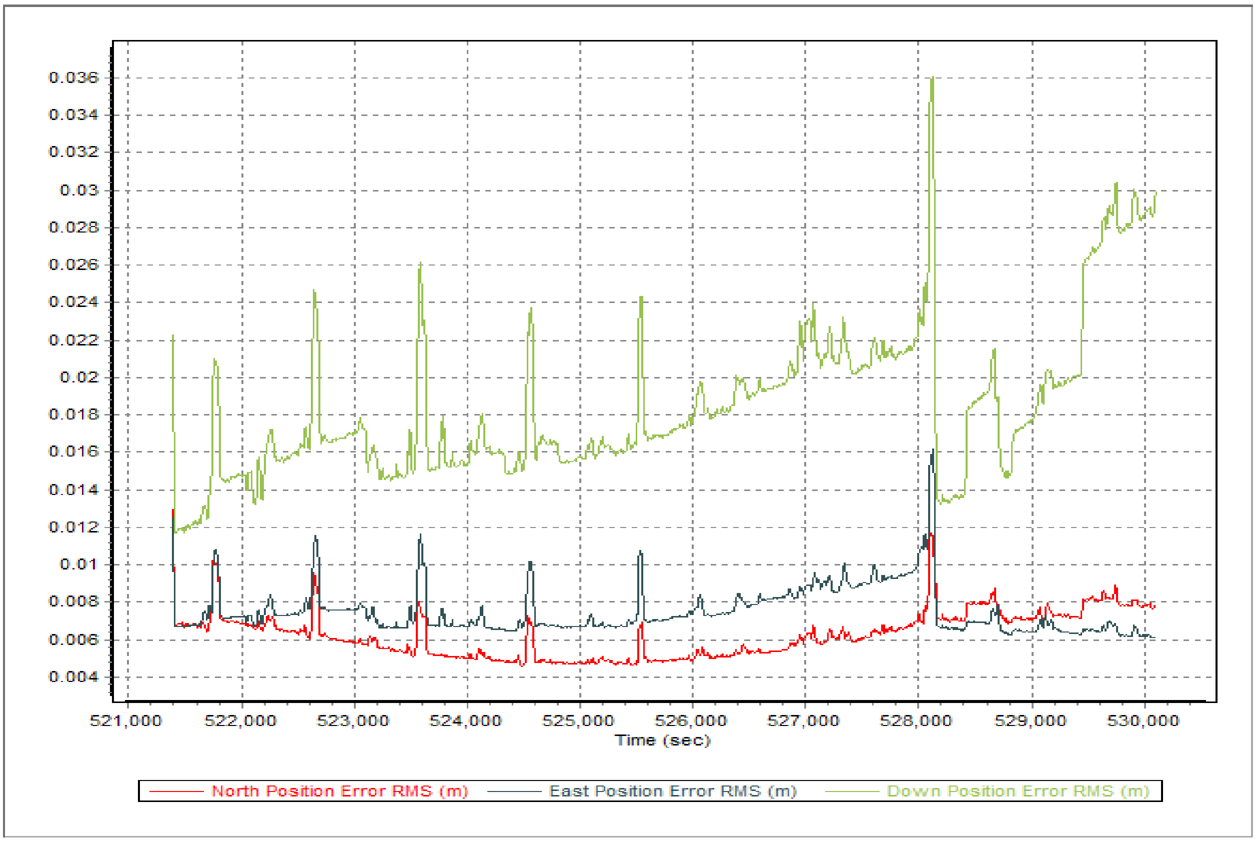


Figure A-8.2. Smoothed Performance Metrics Parameters

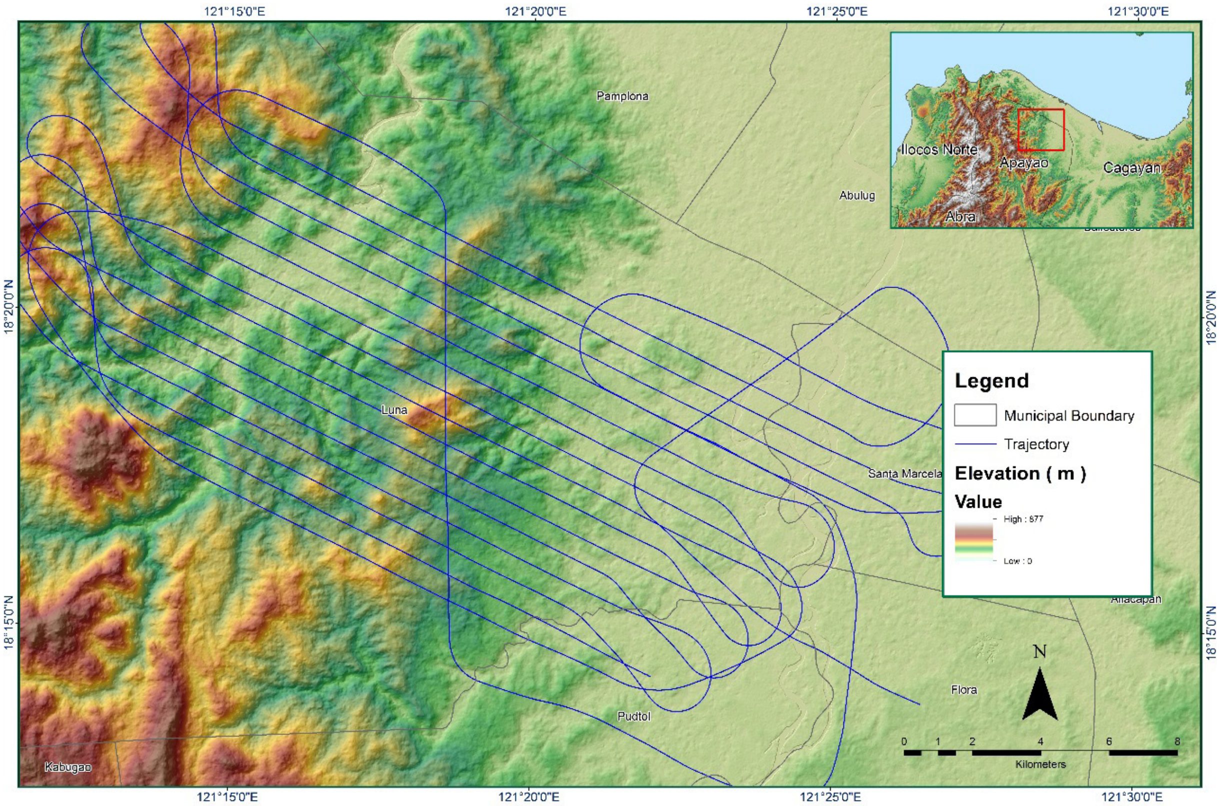


Figure A-8.3. Best Estimated Trajectory

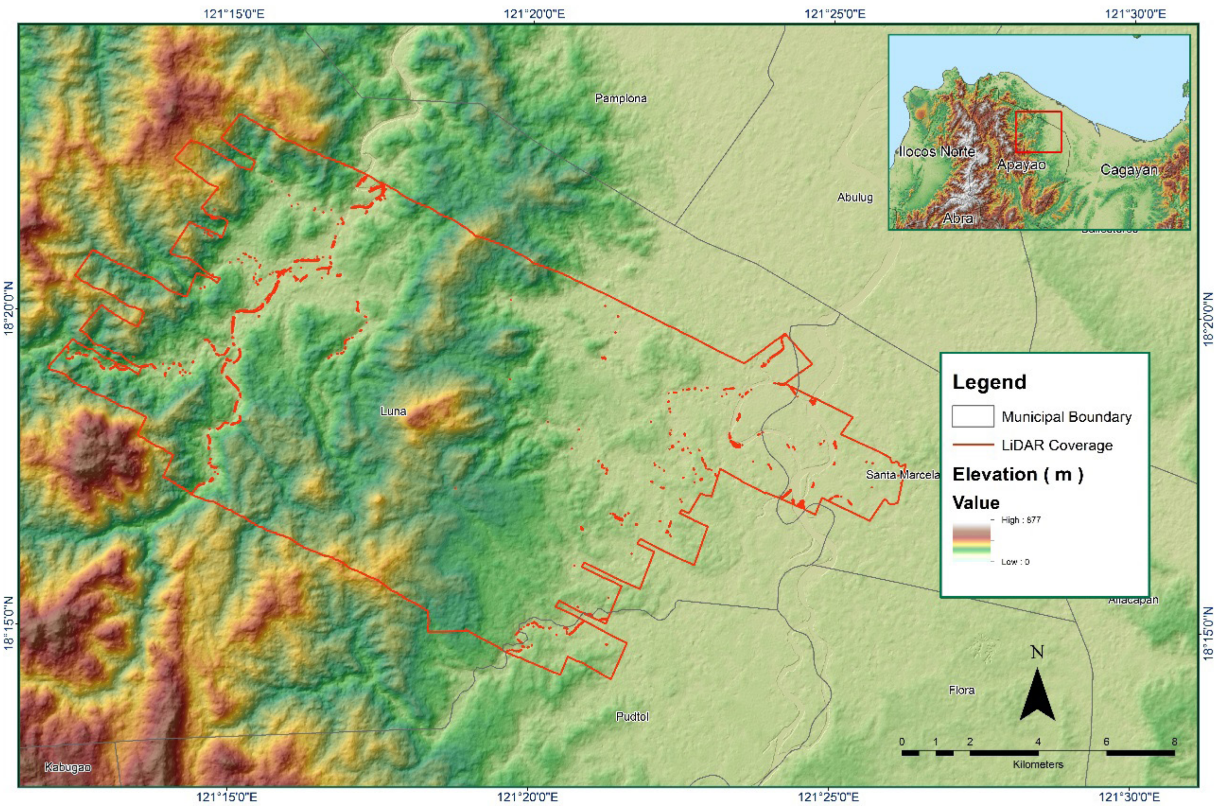


Figure A-8.4. Coverage of LiDAR data

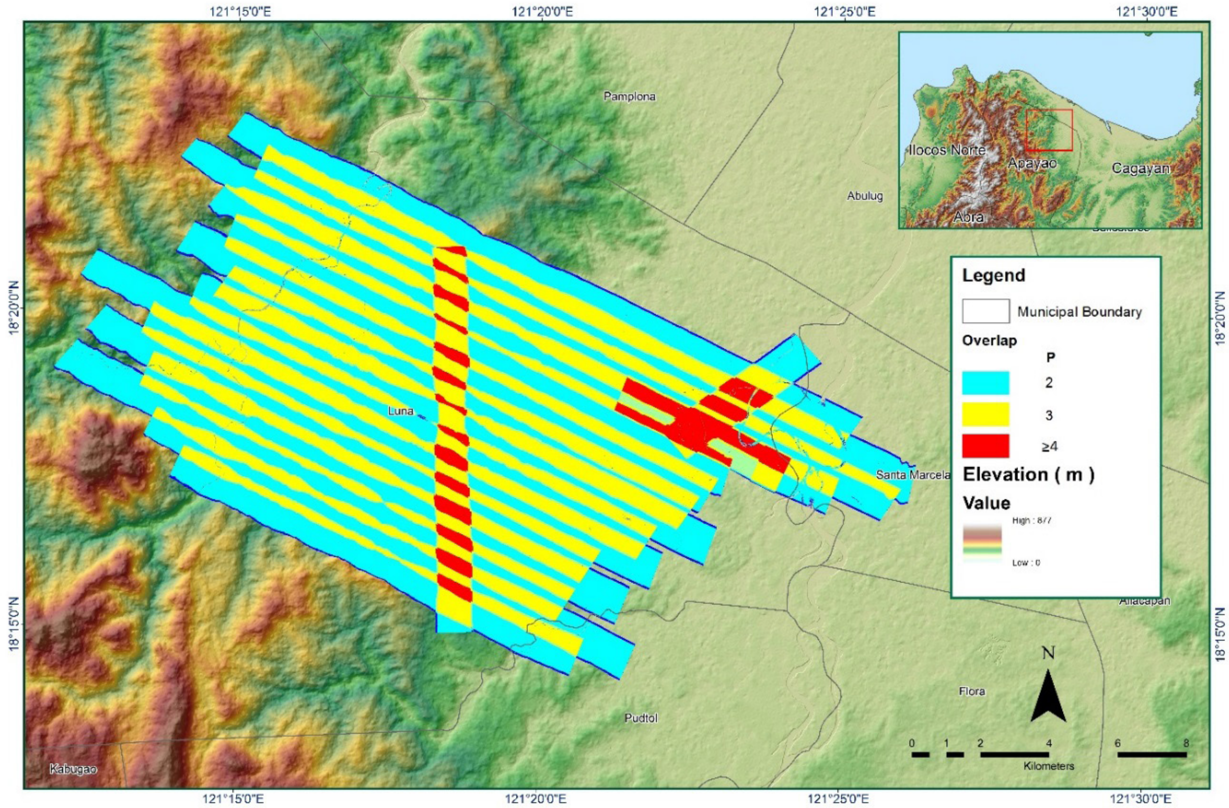


Figure A-8.5. Image of Data Overlap

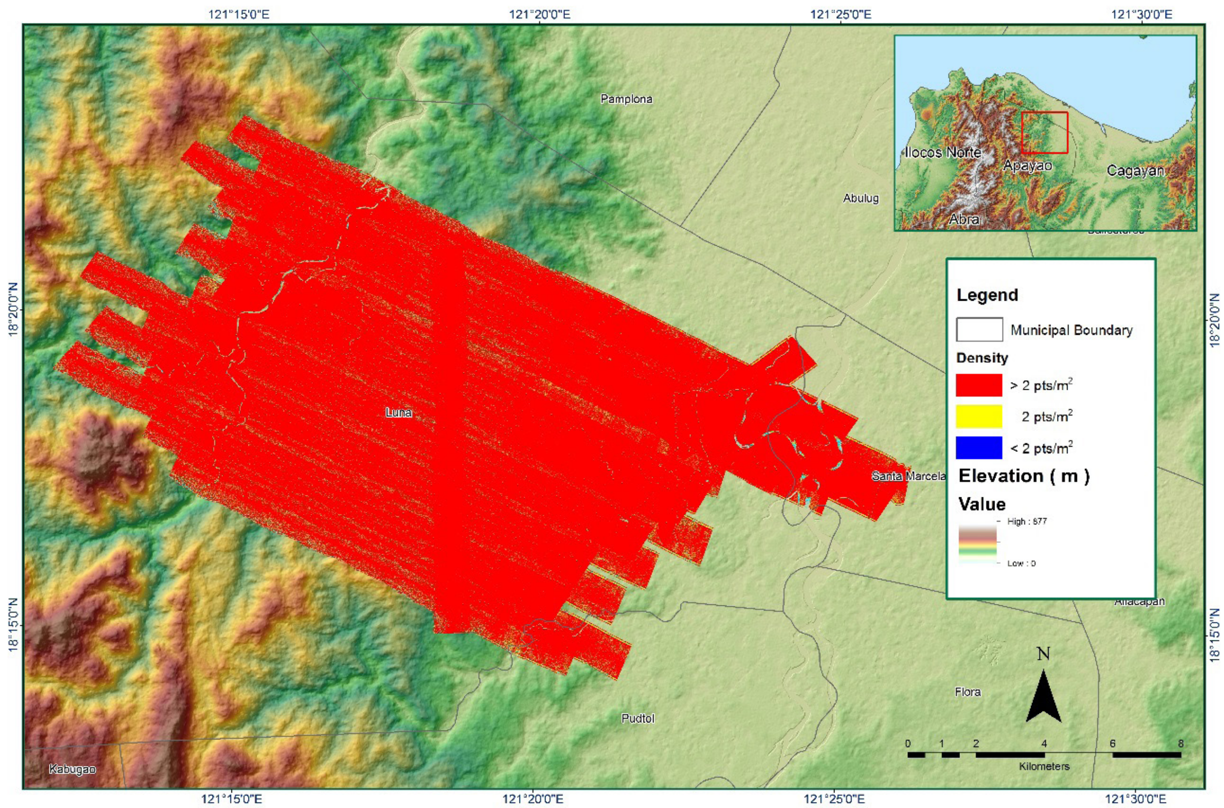


Figure A-8.6. Density map of merged LiDAR data

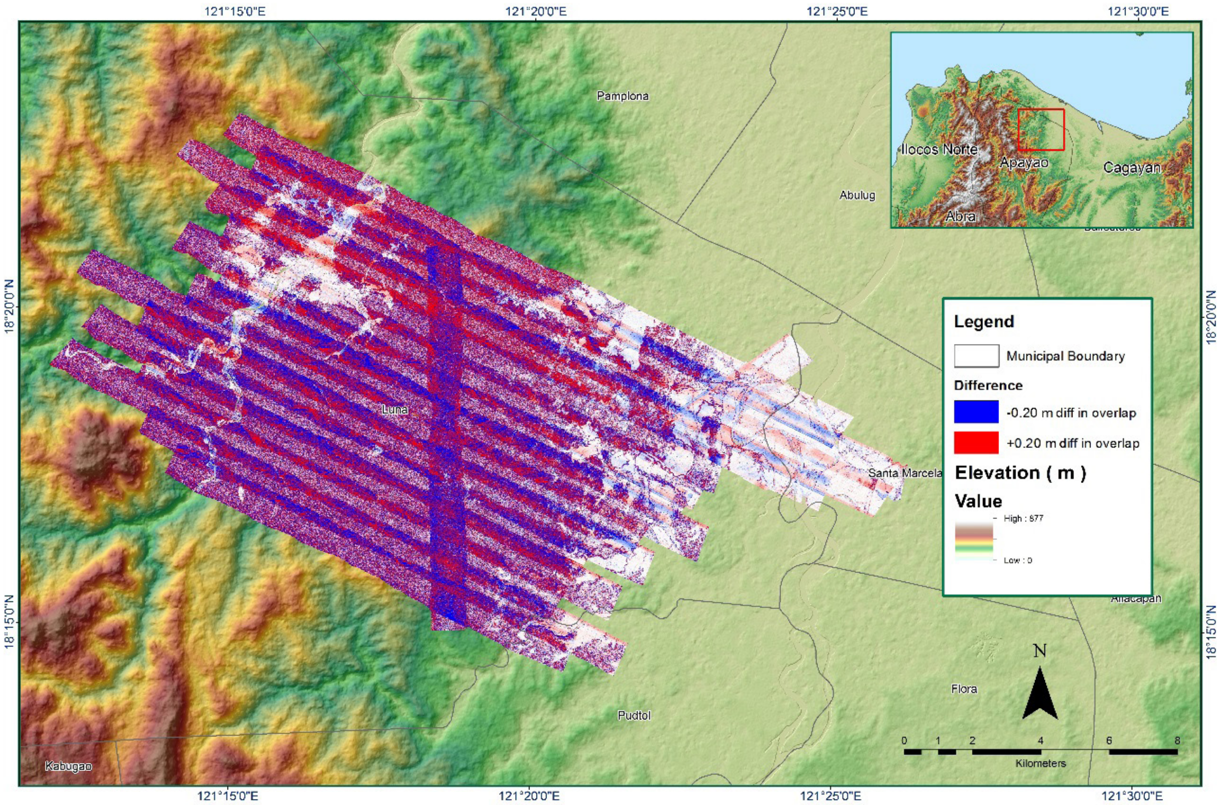


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk2B

Flight Area	Cagayan Reflights(Tuguegarao)
Mission Name	Blk2B
Inclusive Flights	2842P
Range data size	14.3GB
POS	185MB
Image	24.1MB
Transfer date	November 24, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.53
RMSE for East Position (<4.0 cm)	1.39
RMSE for Down Position (<8.0 cm)	3.00
Boresight correction stdev (<0.001deg)	0.000693
IMU attitude correction stdev (<0.001deg)	0.001224
GPS position stdev (<0.01m)	0.0024
Minimum % overlap (>25)	44.96
Ave point cloud density per sq.m. (>2.0)	3.25
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	182
Maximum Height	583.61 m
Minimum Height	35.45 m
Classification (# of points)	
Ground	141,569,019
Low vegetation	70,602,147
Medium vegetation	96,691,357
High vegetation	456,013,846
Building	4,544,117
Orthophoto	Yes
Processed by	Engr. Abigail Ching, Engr. Jovelle Canlas, Maria Tamsyn Malabanan

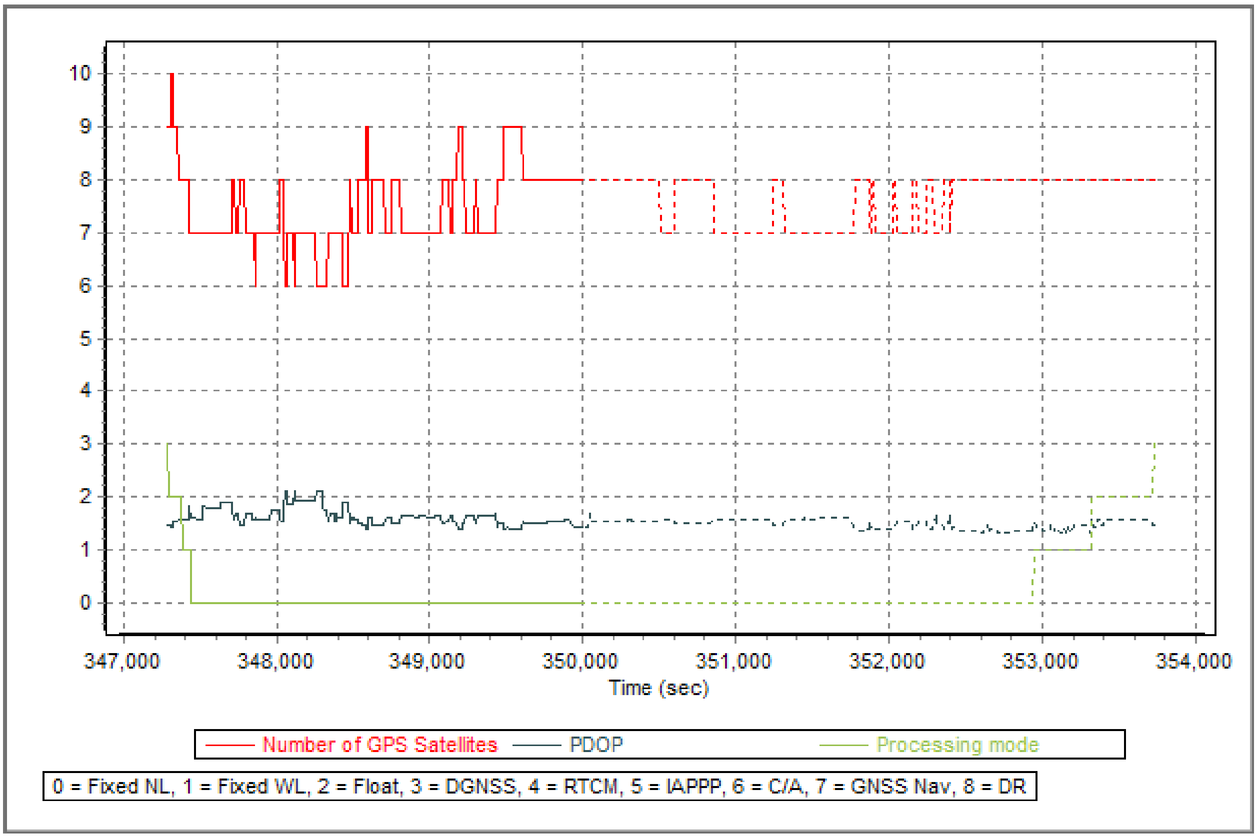


Figure A-8.8. Solution Status Parameters

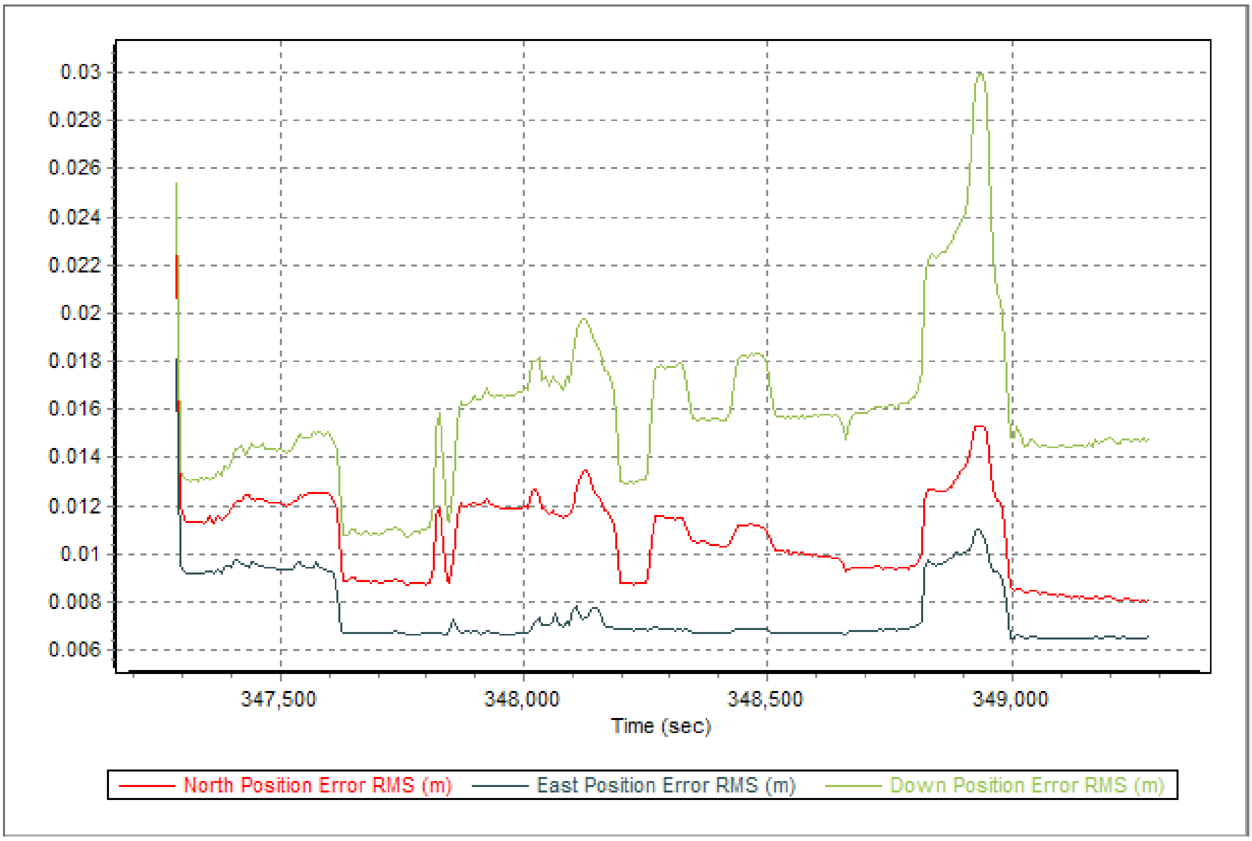


Figure A-8.9. Smoothed Performance Metrics Parameters

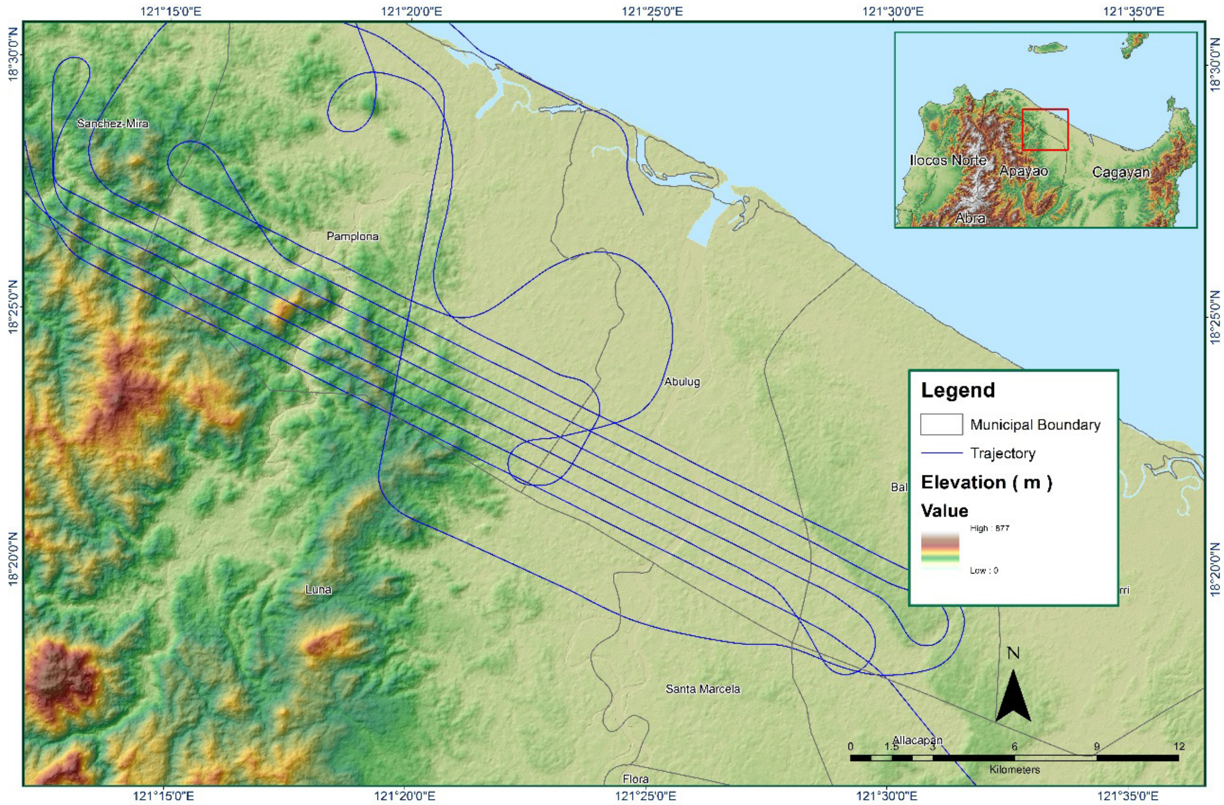


Figure A-8.10. Best Estimated Trajectory

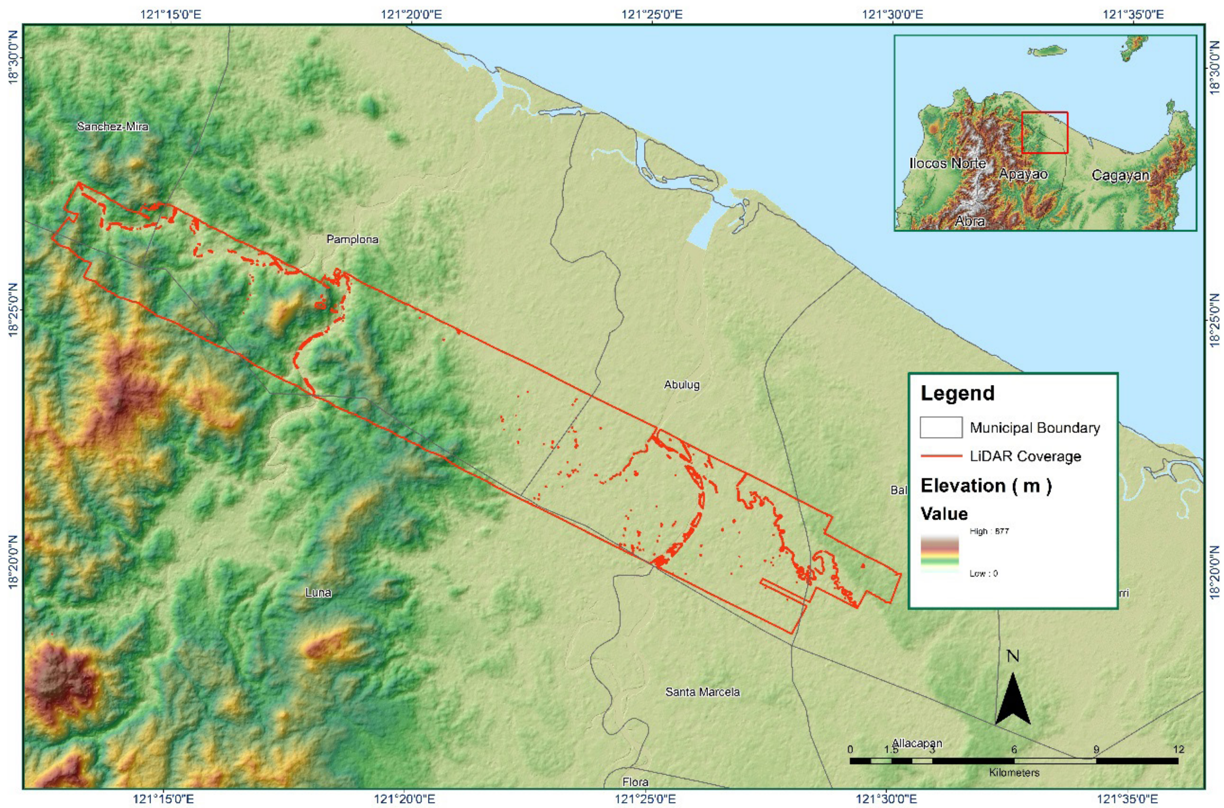


Figure A-8.11. Coverage of LiDAR data

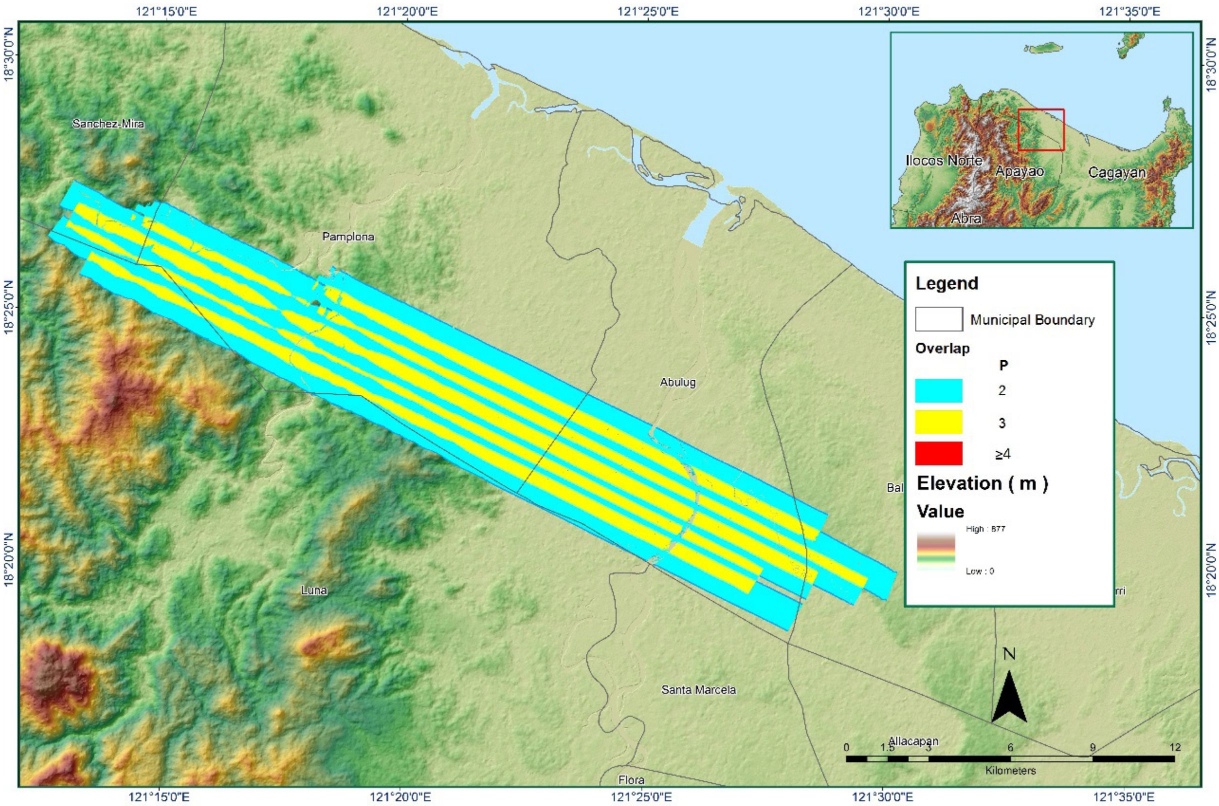


Figure A-8.12. Image of Data Overlap

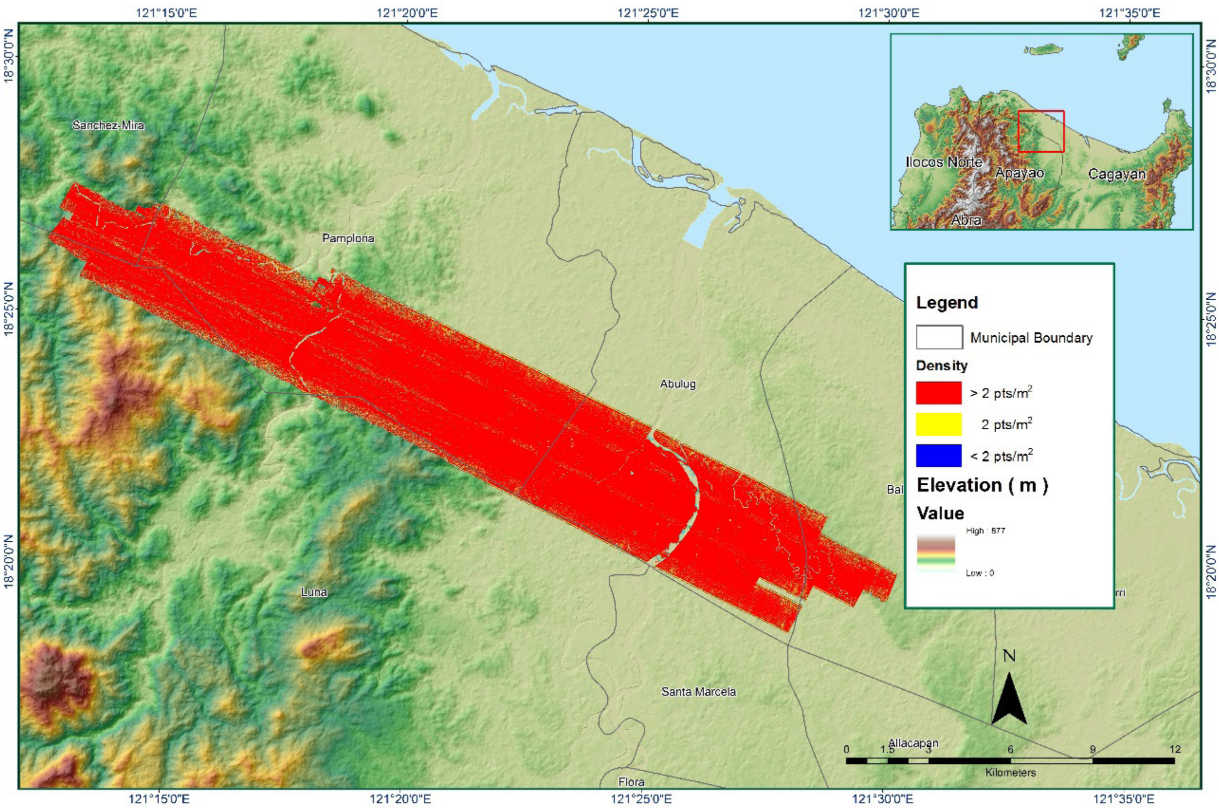


Figure A-8.13. Density map of merged LiDAR data

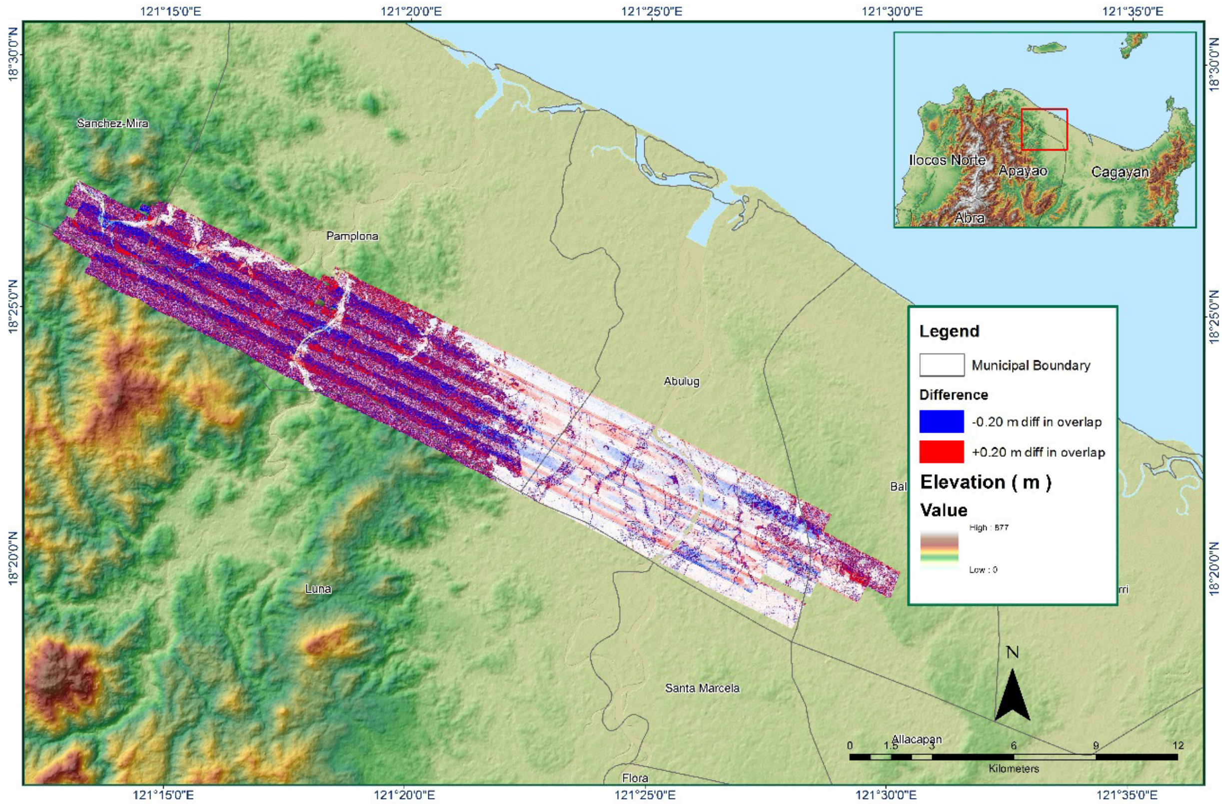


Figure A-8.14. Elevation difference between flight lines

Table A-8.3. Mission Summary Report for Mission Blk2E

Flight Area	Cagayan Reflights(Tuguegarao)
Mission Name	Blk2E
Inclusive Flights	2850P
Range data size	23.3GB
POS	230MB
Image	35.2MB
Transfer date	November 24, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.17
RMSE for East Position (<4.0 cm)	1.62
RMSE for Down Position (<8.0 cm)	3.60
Boresight correction stdev (<0.001deg)	0.000255
IMU attitude correction stdev (<0.001deg)	0.001669
GPS position stdev (<0.01m)	0.0147
Minimum % overlap (>25)	51.38
Ave point cloud density per sq.m. (>2.0)	4.52
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	243
Maximum Height	629.94 m
Minimum Height	33.11 m
Classification (# of points)	
Ground	114,681,685
Low vegetation	86,249,217
Medium vegetation	179,801,226
High vegetation	1,312,535,704
Building	12,298,531
Orthophoto	Yes
Processed by	Engr. Jennifer B. Saguran, Engr. Chelou Prado, Marie Denise Bueno

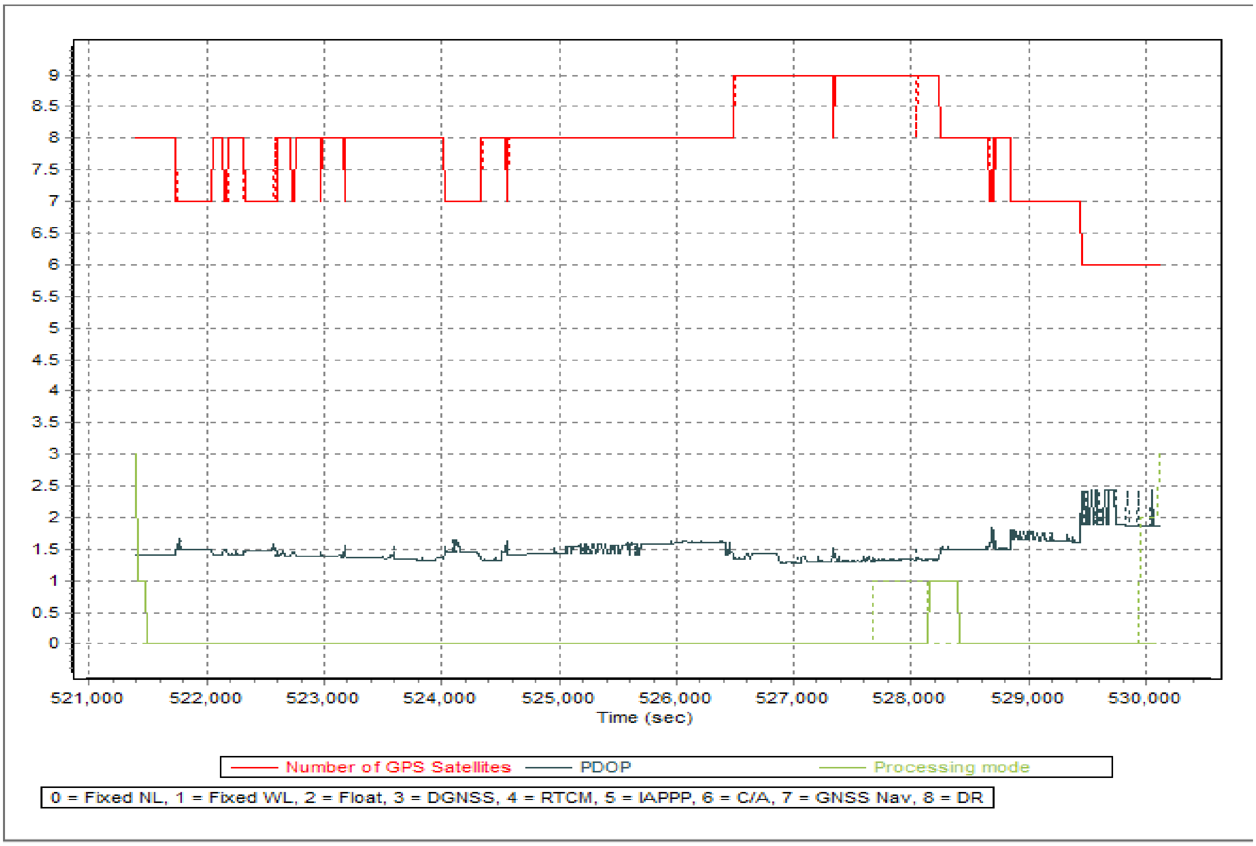


Figure A-8.15. Solution Status

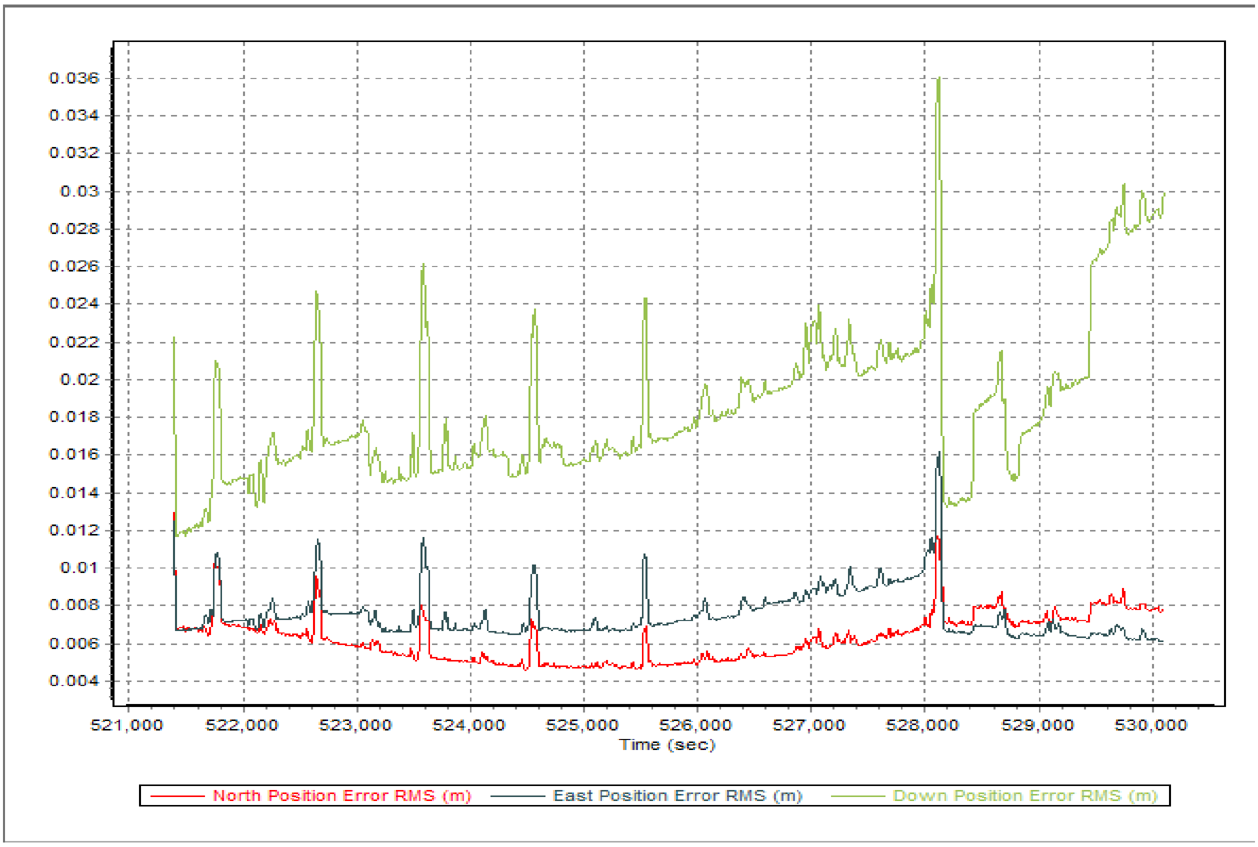


Figure A-8.16. Smoothed Performance Metric Parameters

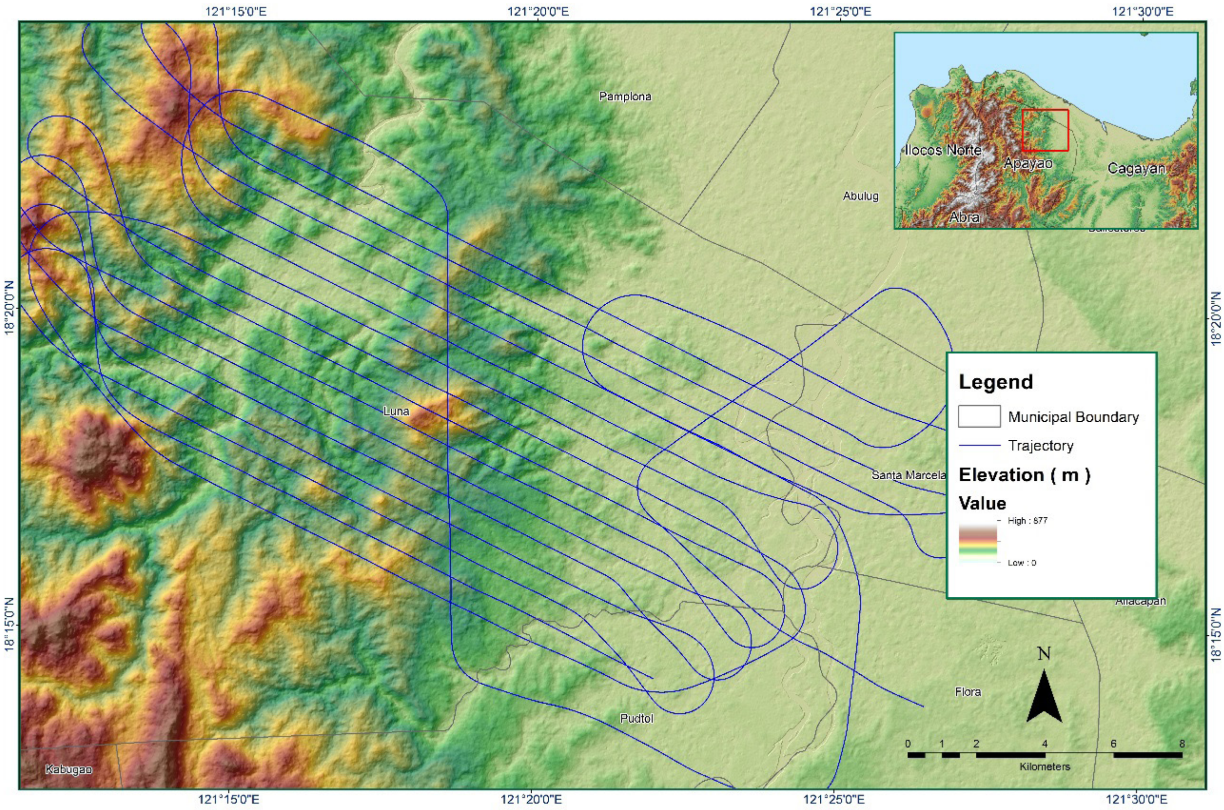


Figure A-8.17. Best Estimated Trajectory

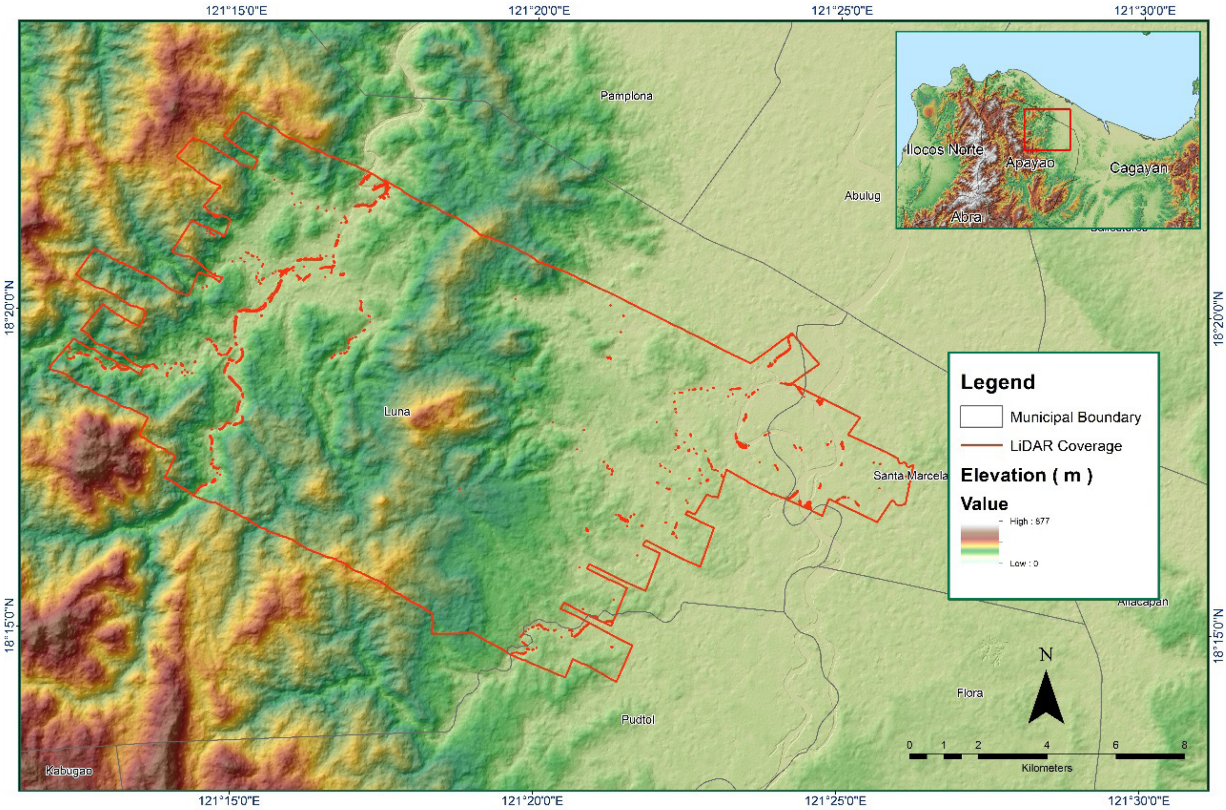


Figure A-8.18. Coverage of LiDAR data

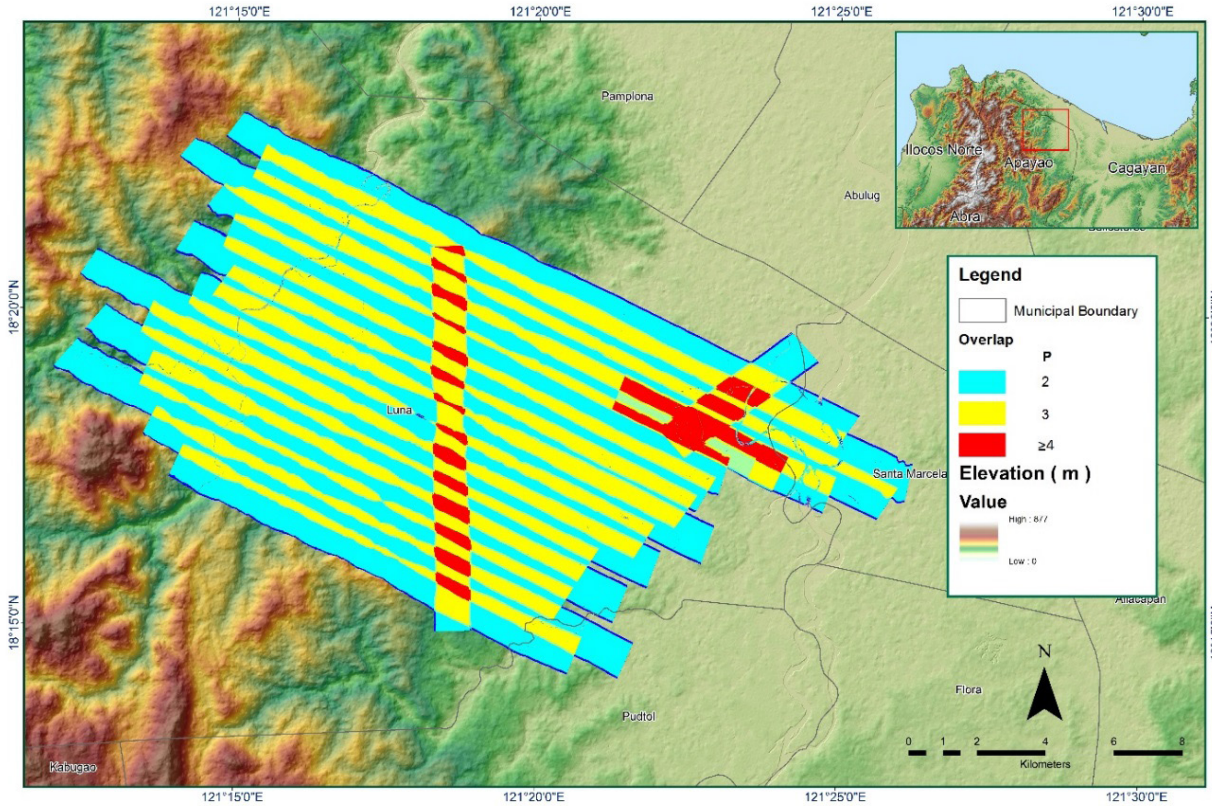


Figure A-8.19. Image of Data Overlap

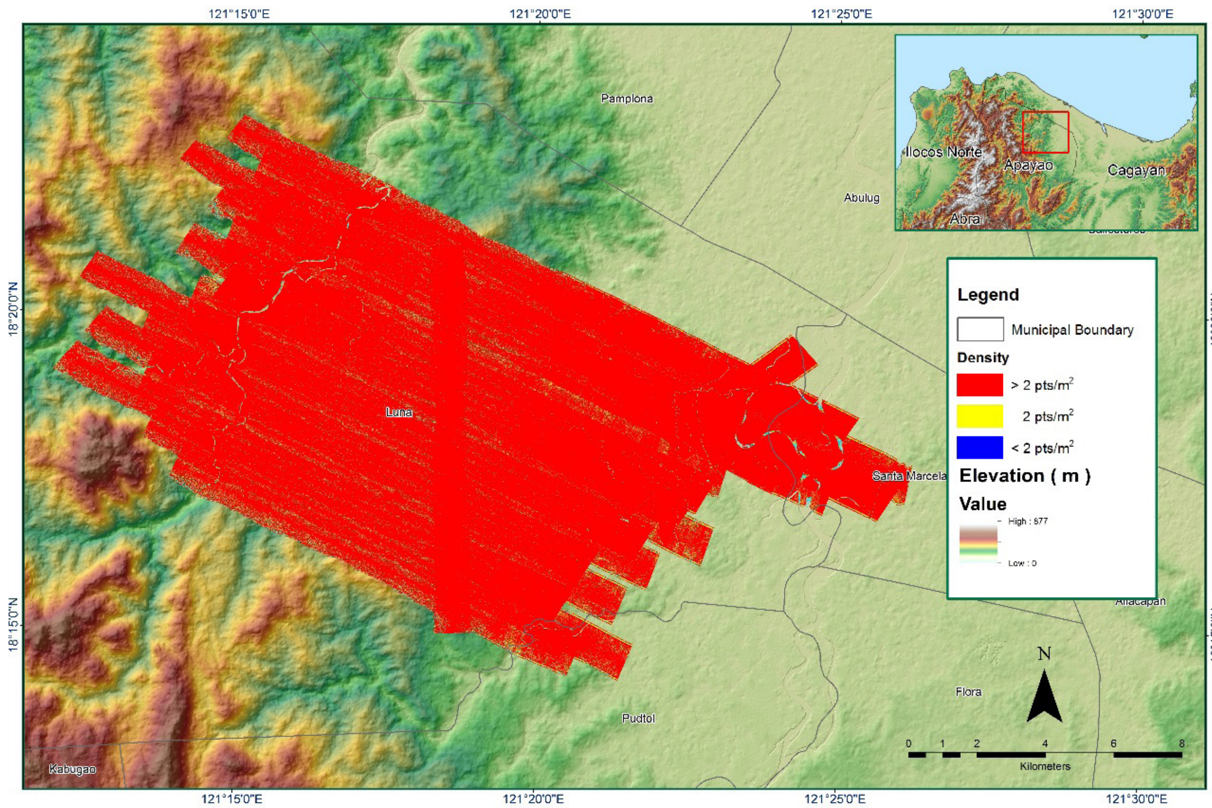


Figure A-8.20. Density map of merged LiDAR data

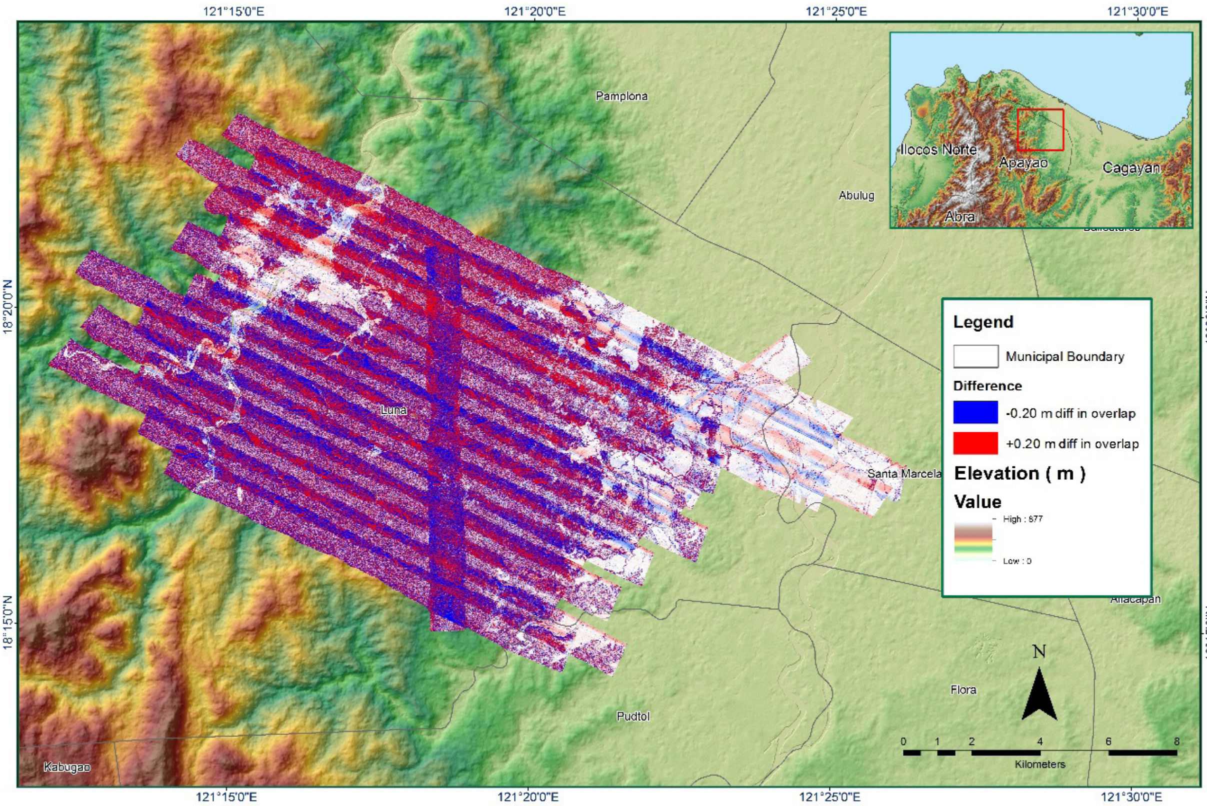


Figure A-8.21. Elevation difference between flight lines

Table A-8.4. Mission Summary Report for Mission Blk2D

Flight Area	Cagayan Reflights(Tuguegarao)
Mission Name	Blk2D
Inclusive Flights	2854P
Range data size	26.1GB
POS	247MB
Image	40.5MB
Transfer date	November 24, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.01
RMSE for East Position (<4.0 cm)	1.33
RMSE for Down Position (<8.0 cm)	2.99
Boresight correction stdev (<0.001deg)	0.000449
IMU attitude correction stdev (<0.001deg)	0.000777
GPS position stdev (<0.01m)	0.0096
Minimum % overlap (>25)	46.71
Ave point cloud density per sq.m. (>2.0)	4.135
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	113
Maximum Height	579.99 m
Minimum Height	42.78 m
Classification (# of points)	
Ground	54,696,025
Low vegetation	48,721,614
Medium vegetation	57,326,160
High vegetation	399,639,419
Building	5,543,063
Orthophoto	Yes
Processed by	Engr. Kenneth Solidum, Engr. Mark Joshua Salvacion, Kathryn Claudine Zarate

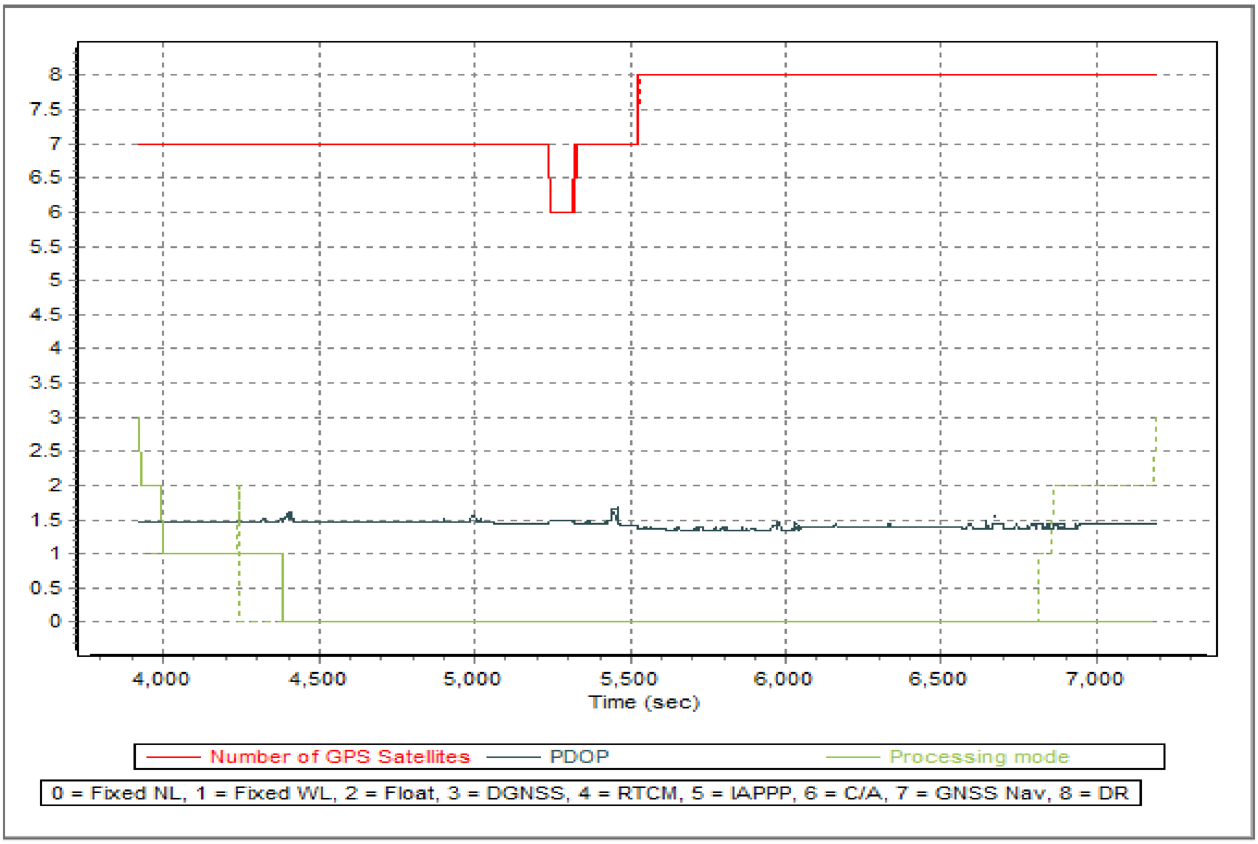


Figure A-8.22. Solution Status

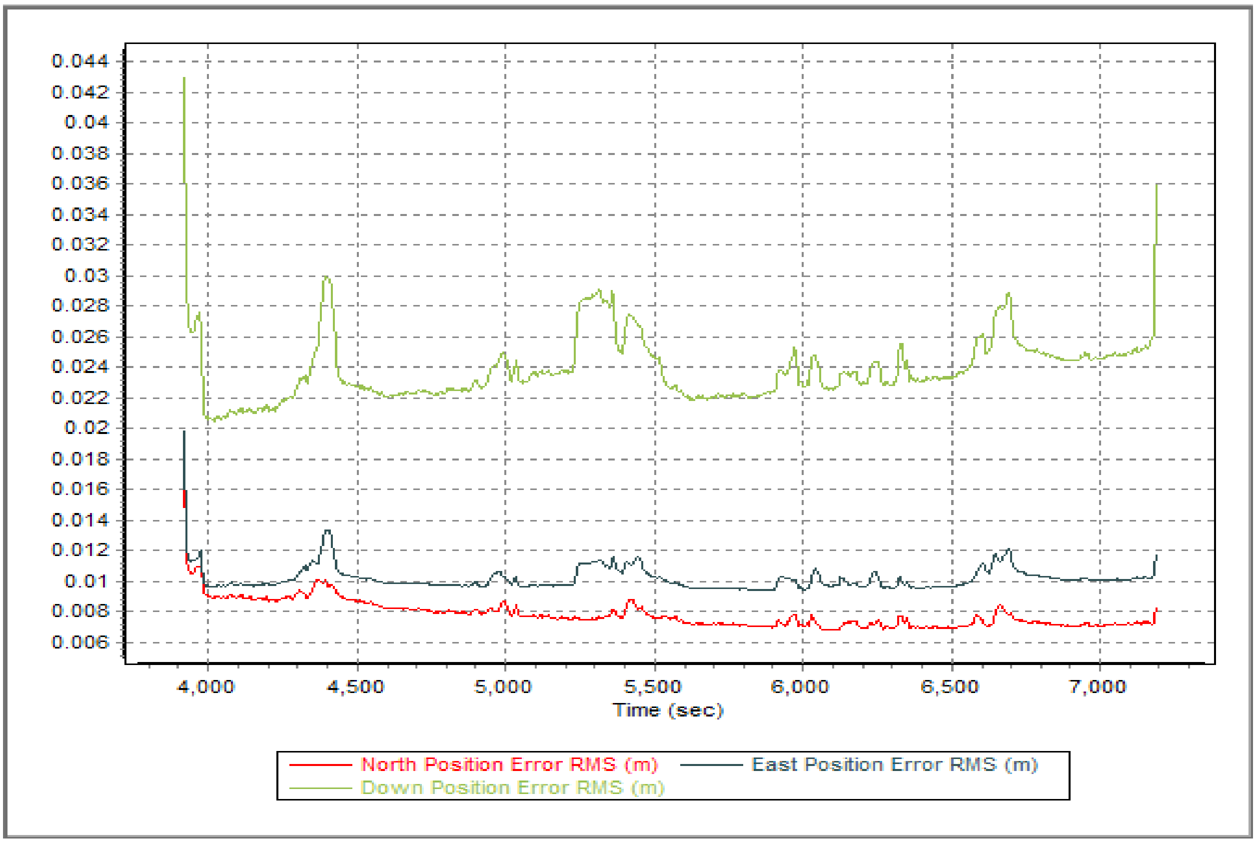


Figure A-8.23. Smoothed Performance Metric Parameters

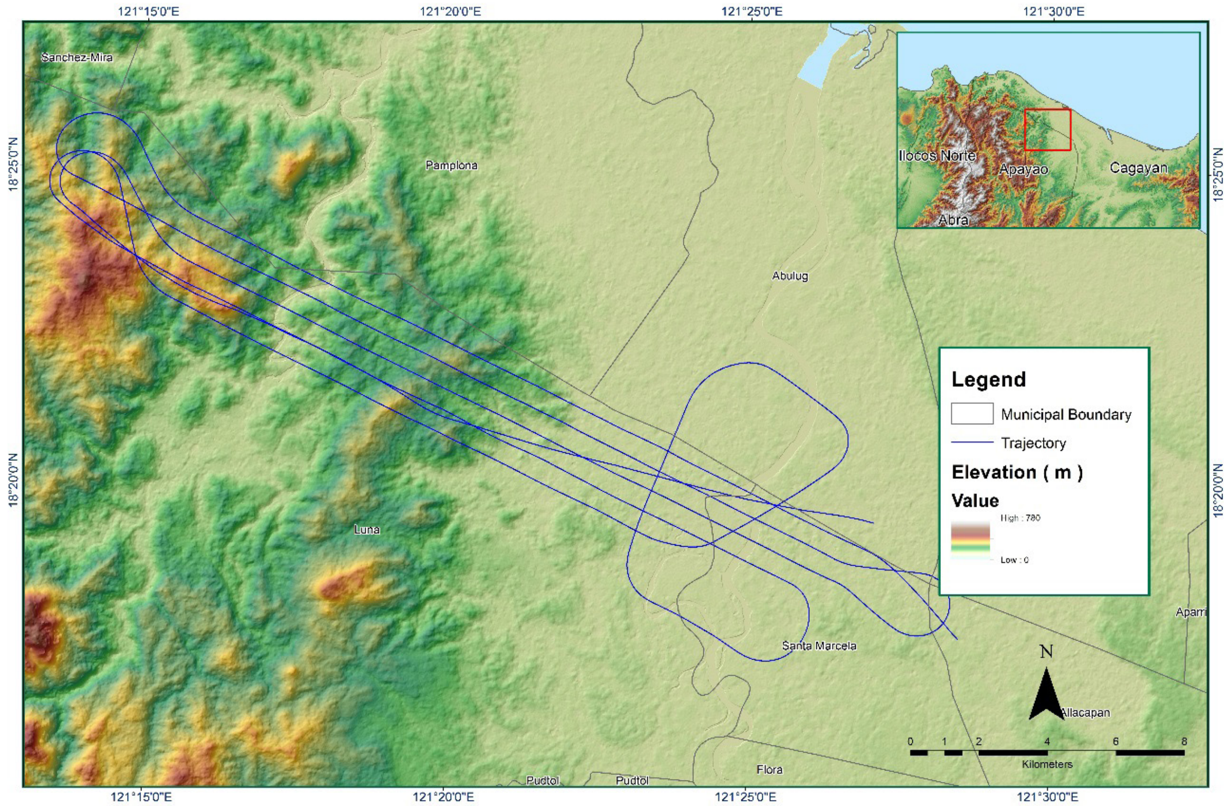


Figure A-8.24. Best Estimated Trajectory

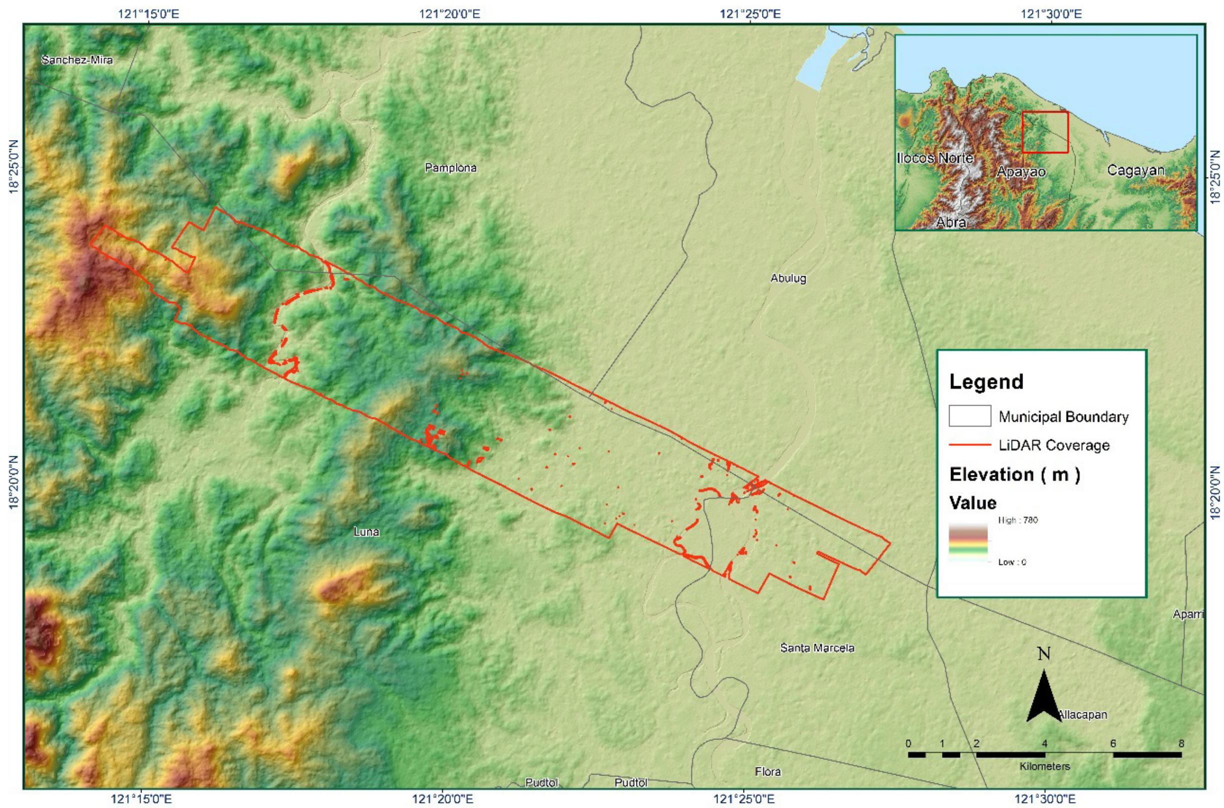


Figure A-8.25. Coverage of LiDAR data

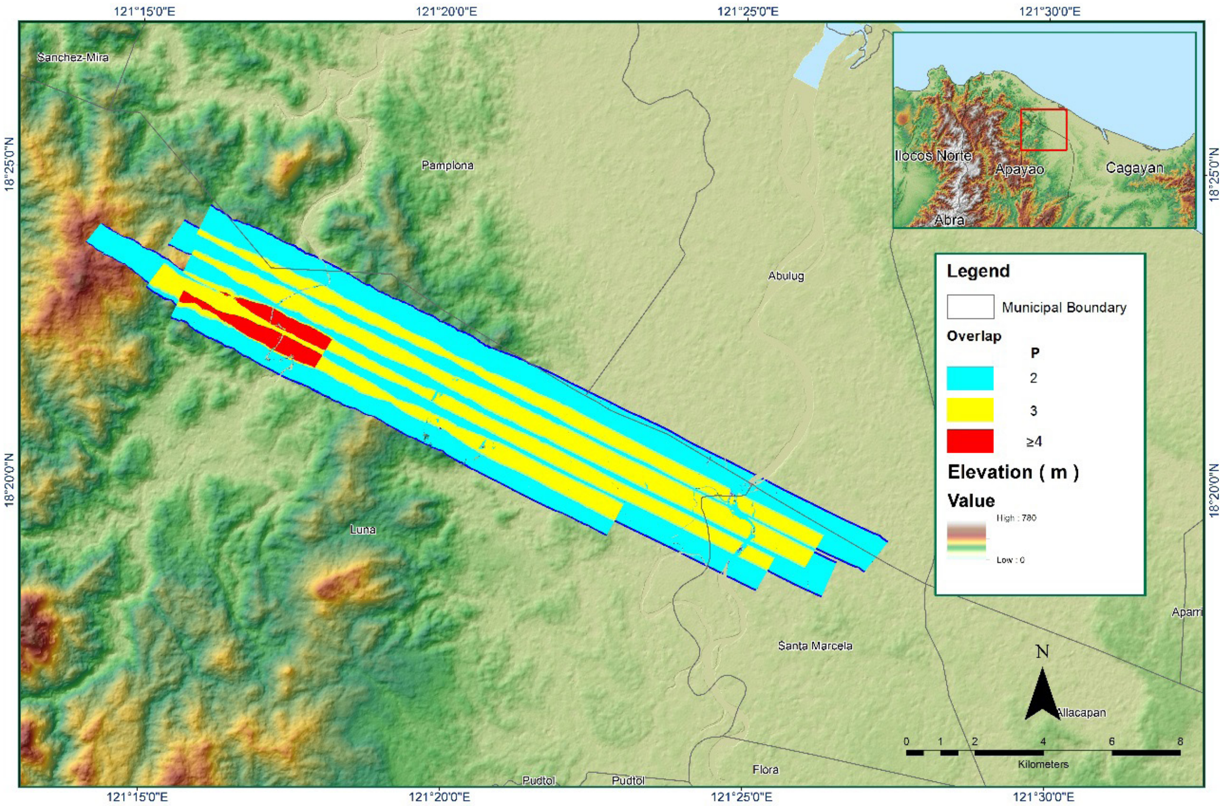


Figure A-8.26. Image of Data Overlap

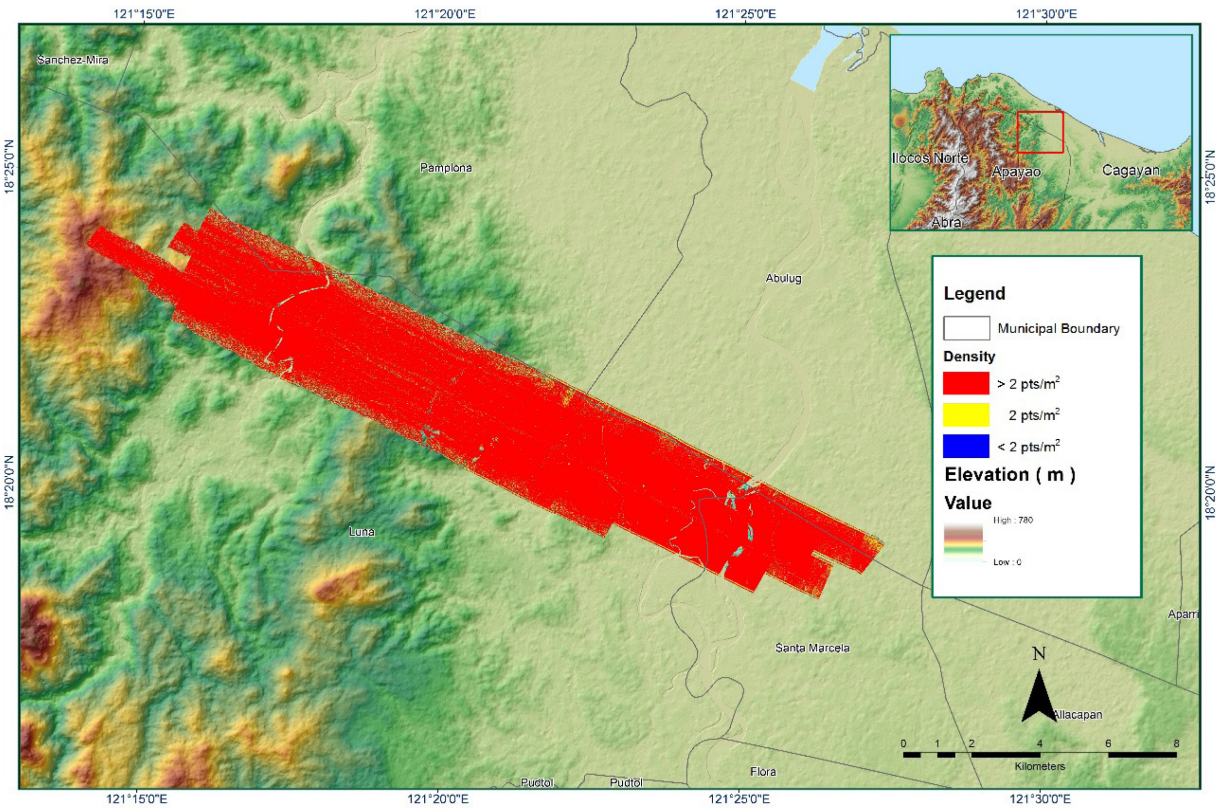


Figure A-8.27. Density map of merged LiDAR data

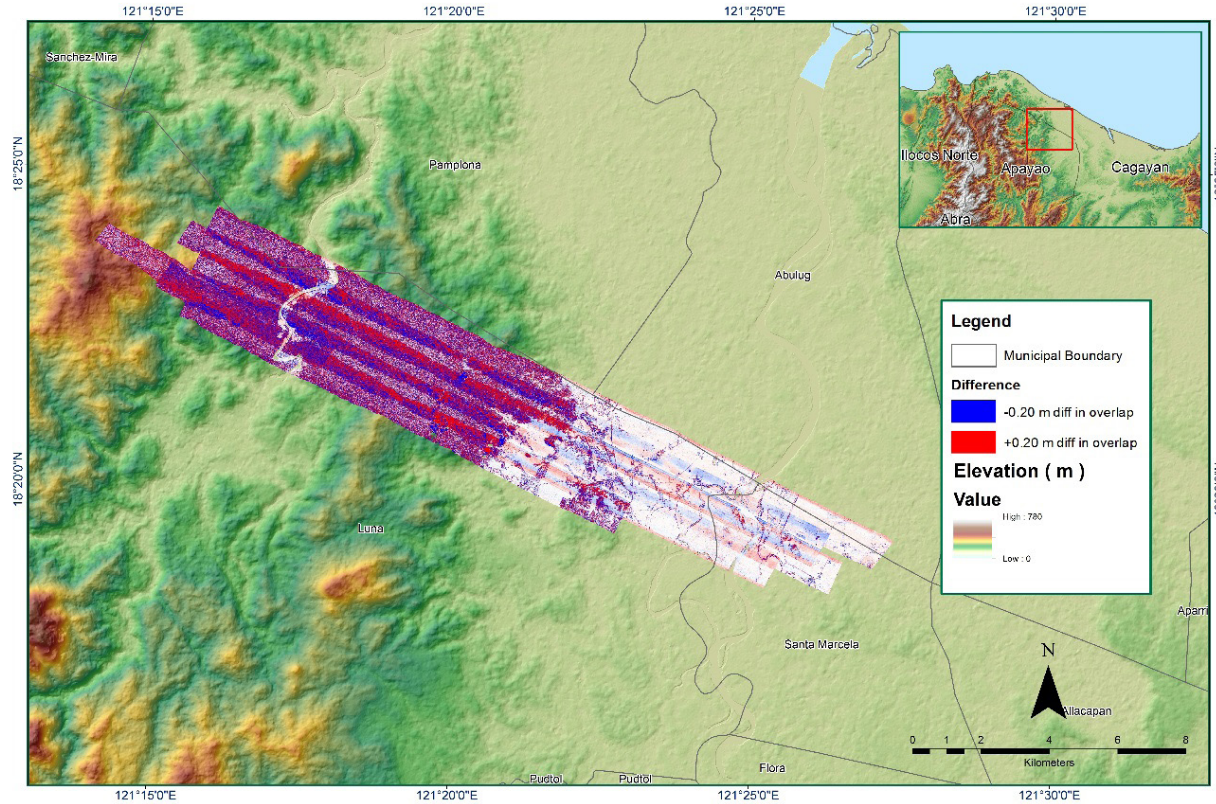


Figure A-8.28. Elevation difference between flight lines

Table A-8.5. Mission Summary Report for Mission Blk2B_supplement

Flight Area	Cagayan Reflights(Tuguegarao)
Mission Name	Blk2B_supplement
Inclusive Flights	2846P
Range data size	31.3GB
POS	299MB
Image	50.8MB
Transfer date	November 24, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.48
RMSE for East Position (<4.0 cm)	2.73
RMSE for Down Position (<8.0 cm)	8.94
Boresight correction stdev (<0.001deg)	0.000335
IMU attitude correction stdev (<0.001deg)	0.002483
GPS position stdev (<0.01m)	0.0025
Minimum % overlap (>25)	51.57
Ave point cloud density per sq.m. (>2.0)	3.165
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	40
Maximum Height	462.55 m
Minimum Height	43.63 m
Classification (# of points)	
Ground	11,786,737
Low vegetation	4,071,315
Medium vegetation	17,005,239
High vegetation	12,0302657
Building	1,496,293
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Edgardo Gubatanga Jr., Engr. Krisha Marie Bautista

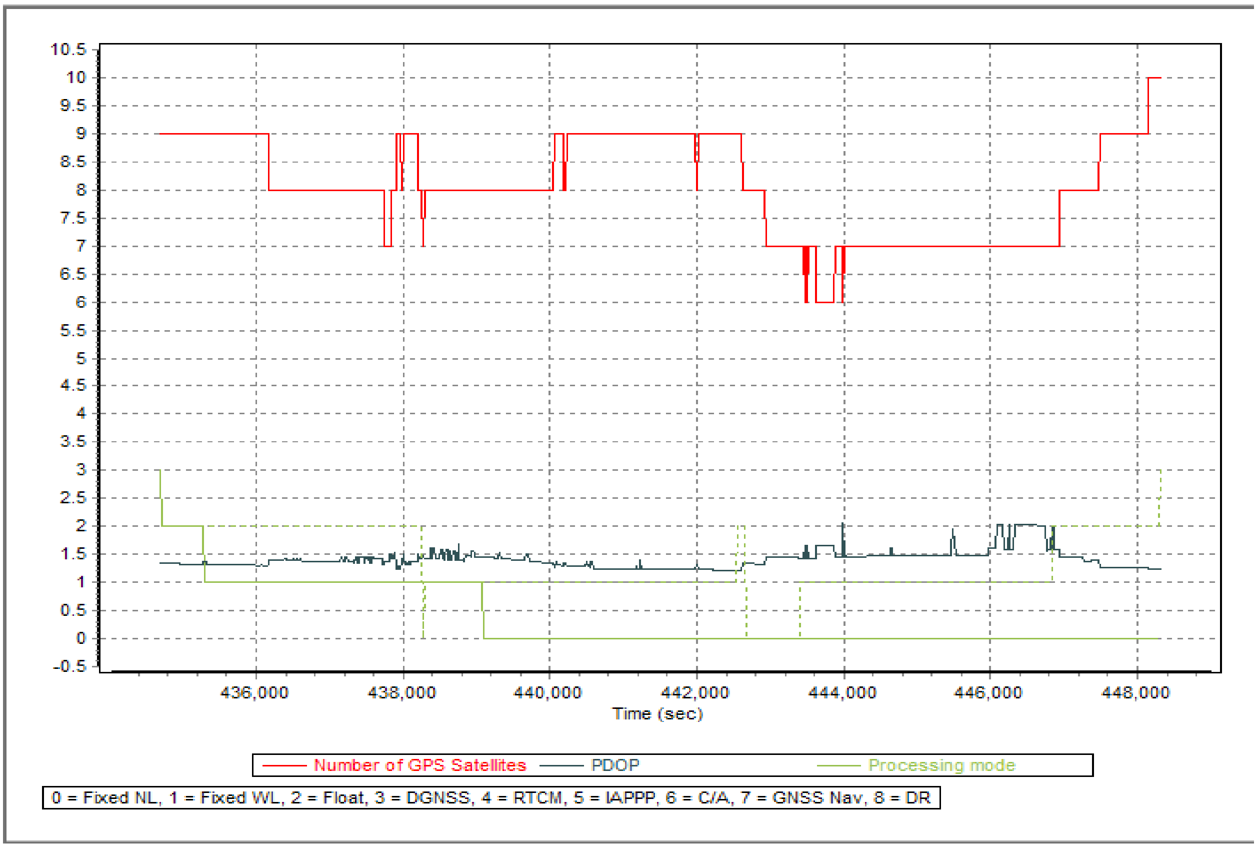


Figure A-8.29. Solution Status

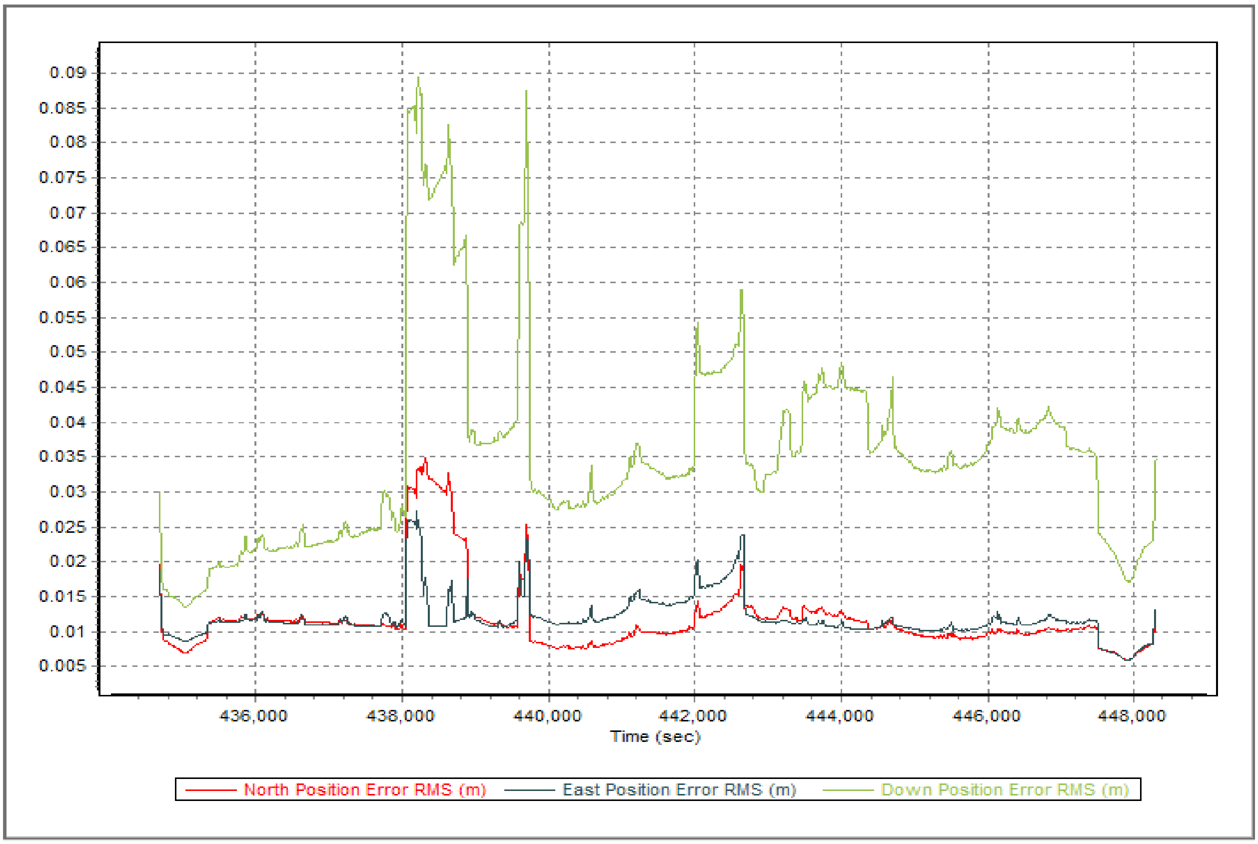


Figure A-8.30. Smoothed Performance Metric Parameters

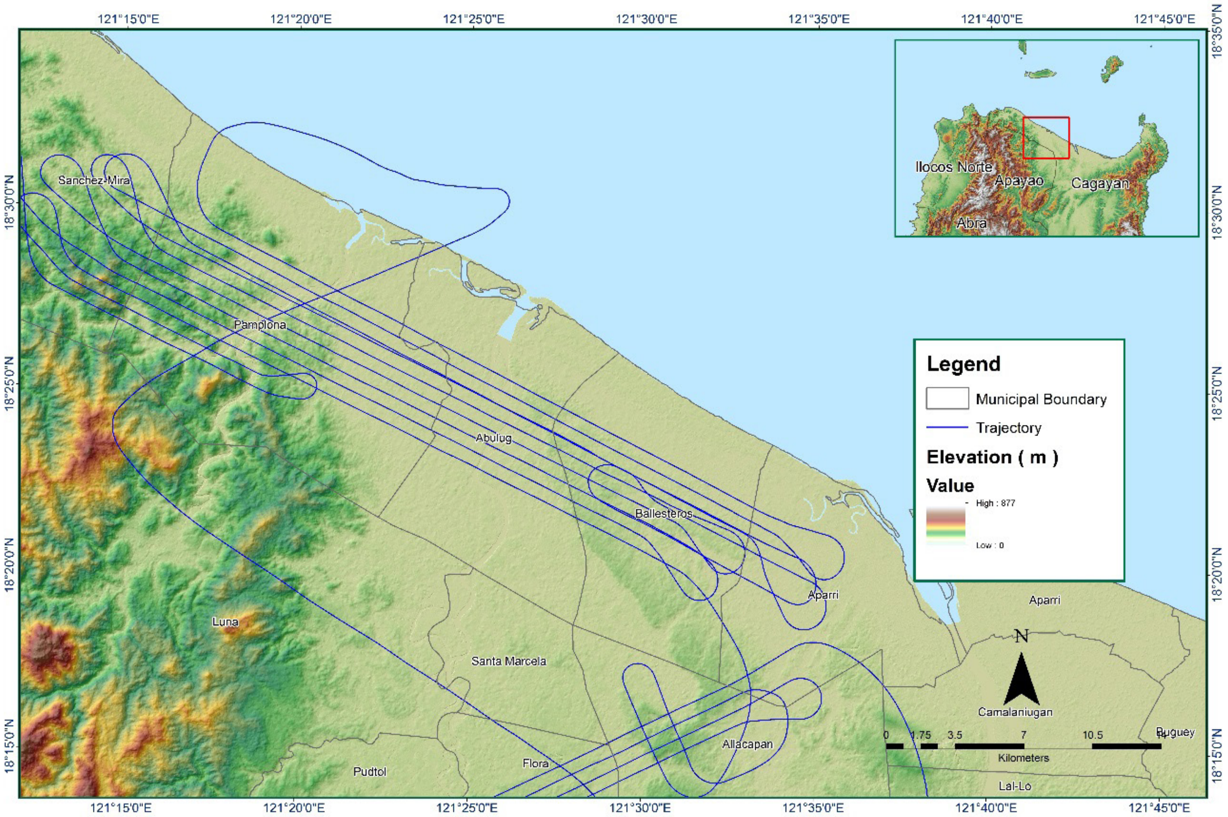


Figure A-8.31. Best Estimated Trajectory

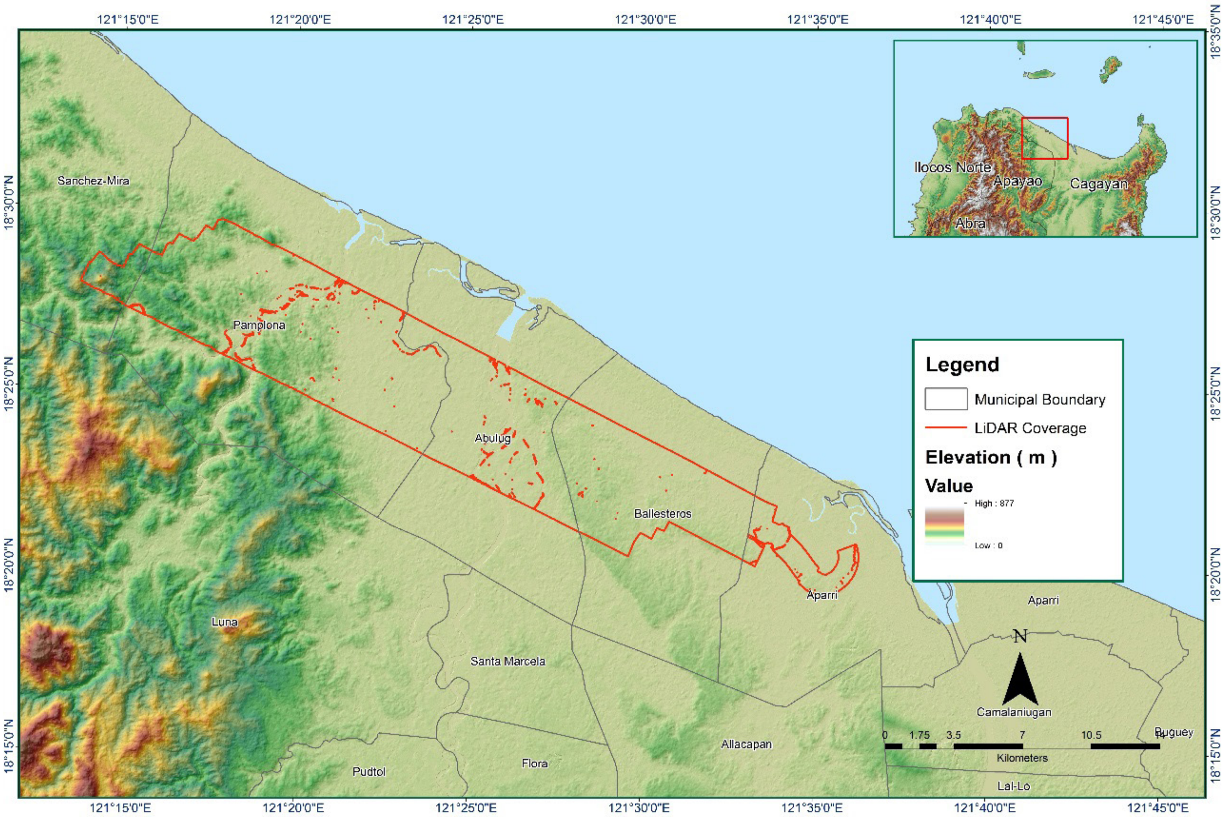


Figure A-8.32. Coverage of LiDAR data

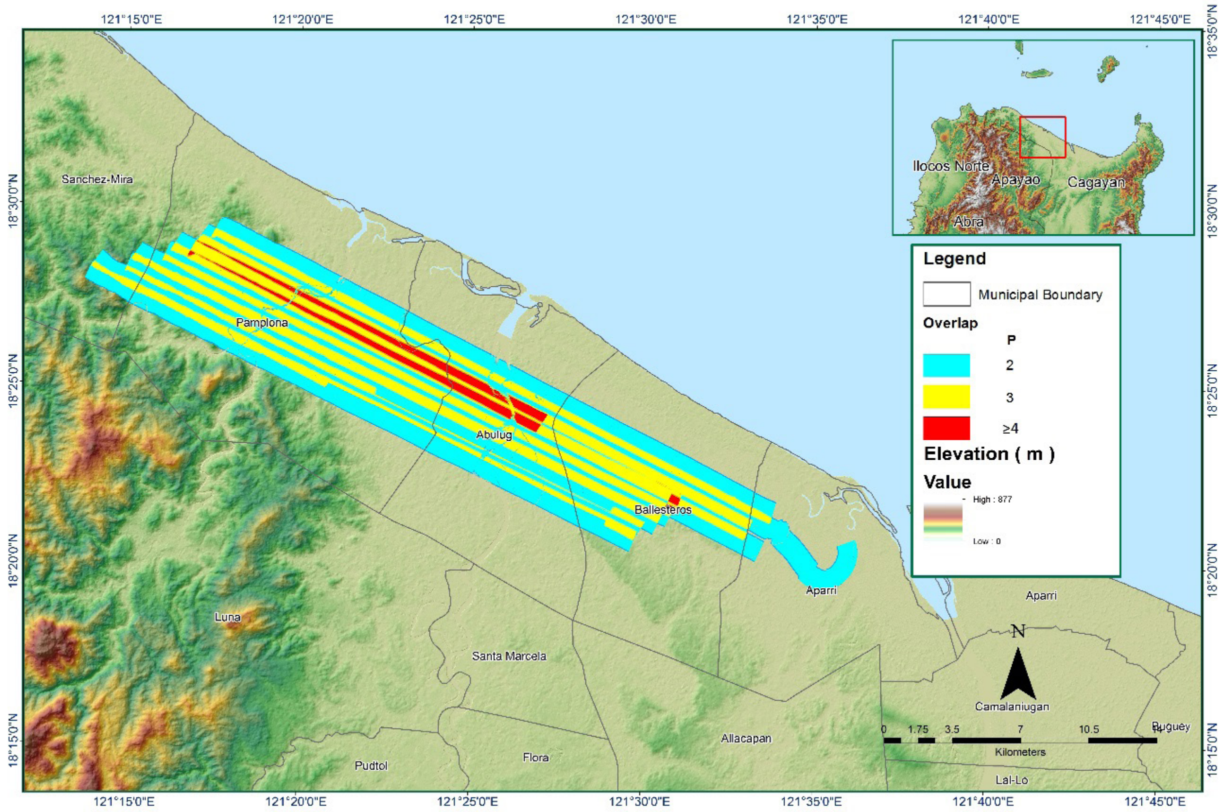


Figure A-8.33. Image of Data Overlap

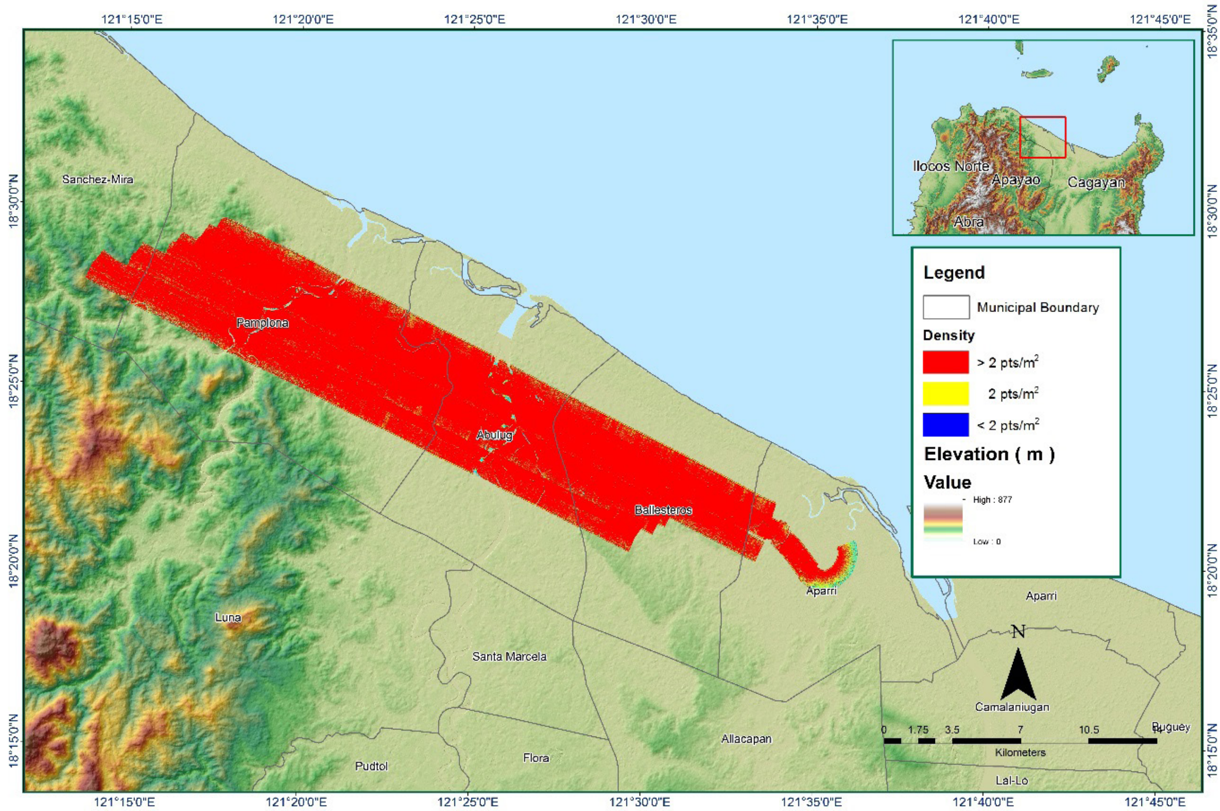


Figure A-8.34. Density map of merged LiDAR data

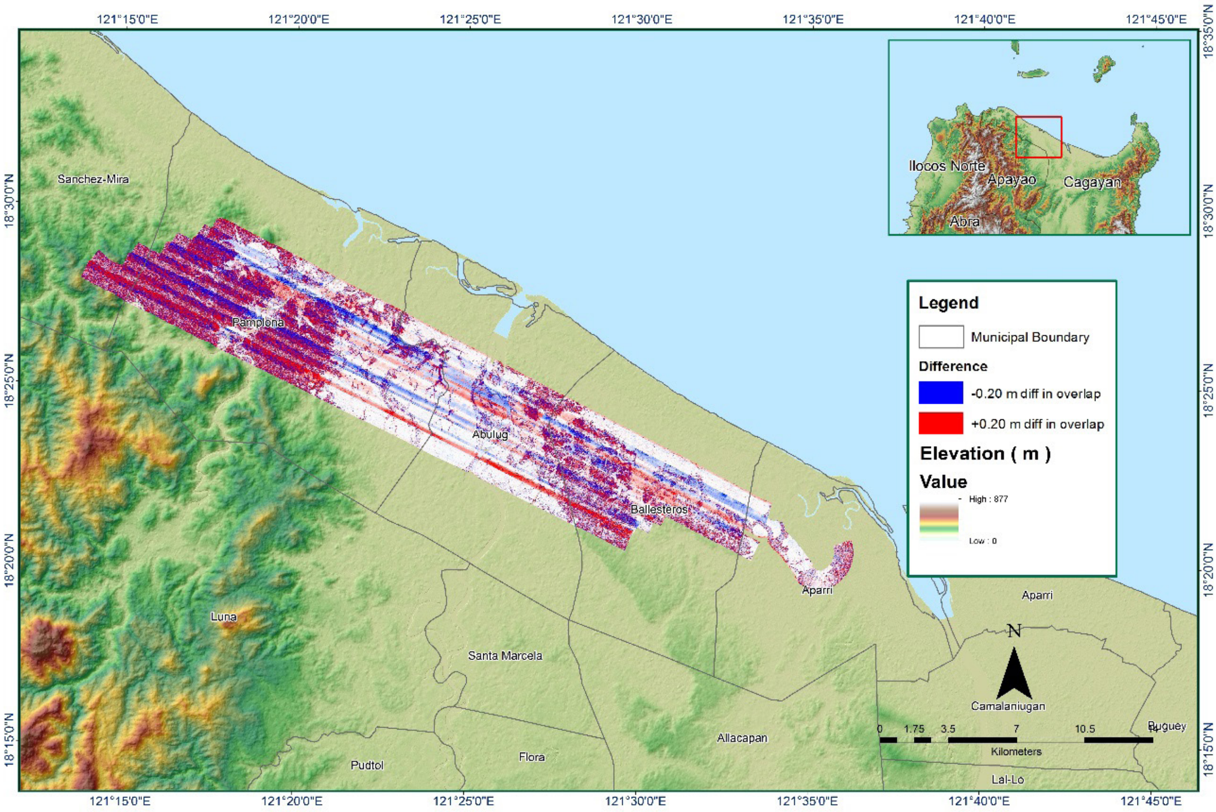


Figure A-8.35. Elevation difference between flight lines

Table A-8.6. Mission Summary Report for Mission Blk2A_supplement

Flight Area	Cagayan Reflights(Tuguegarao)
Mission Name	Blk2A_supplement
Inclusive Flights	2846P
Range data size	31.3GB
POS	299MB
Image	50.8MB
Transfer date	November 24, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.48
RMSE for East Position (<4.0 cm)	2.73
RMSE for Down Position (<8.0 cm)	8.94
Boresight correction stdev (<0.001deg)	0.000335
IMU attitude correction stdev (<0.001deg)	0.002483
GPS position stdev (<0.01m)	0.0025
Minimum % overlap (>25)	51.57
Ave point cloud density per sq.m. (>2.0)	3.165
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	267
Maximum Height	487.63 m
Minimum Height	38.22 m
Classification (# of points)	
Ground	199,764,057
Low vegetation	206,231,885
Medium vegetation	240,445,037
High vegetation	623,968,966
Building	16,265,221
Orthophoto	Yes
Processed by	Engr. Irish Cortez, Engr. Edgardo Gubatanga Jr., Engr. Krisha Marie Bautista

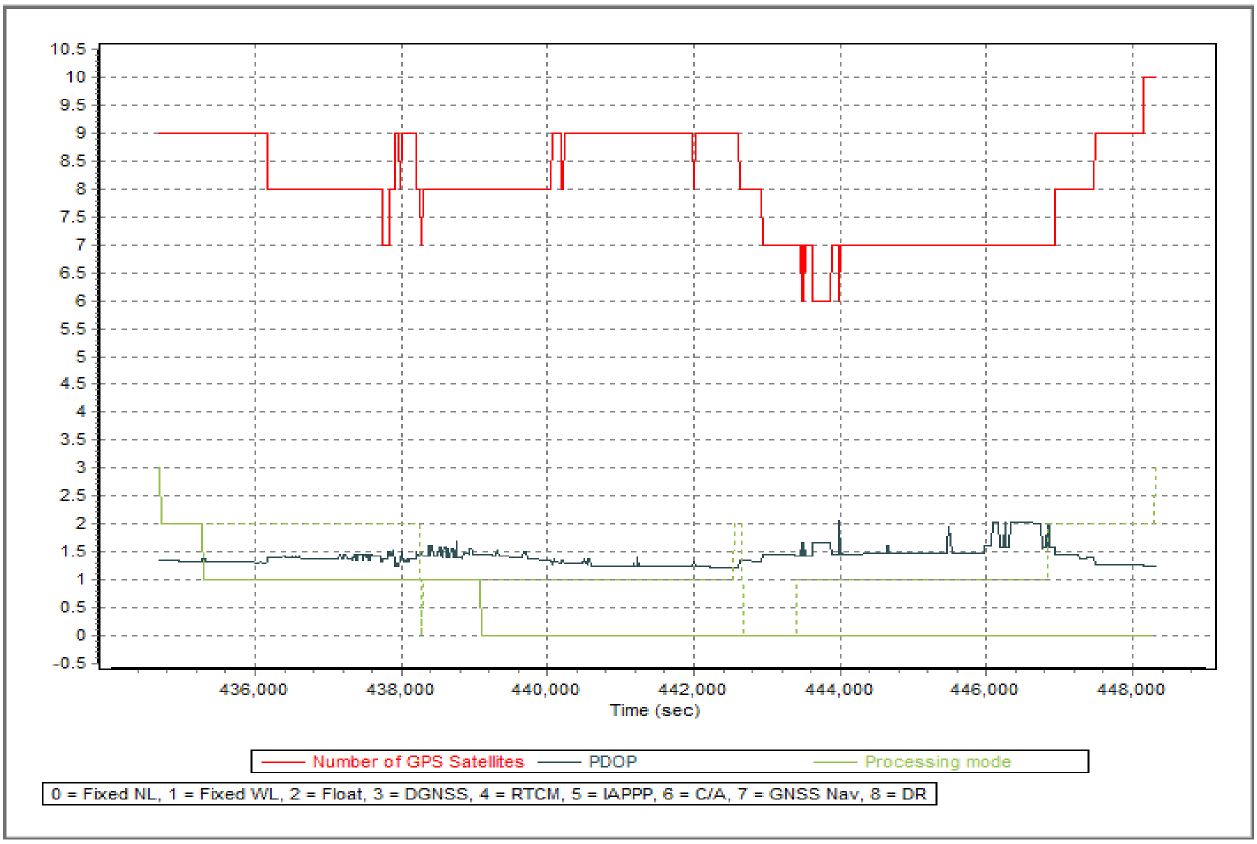


Figure A-8.36. Solution Status

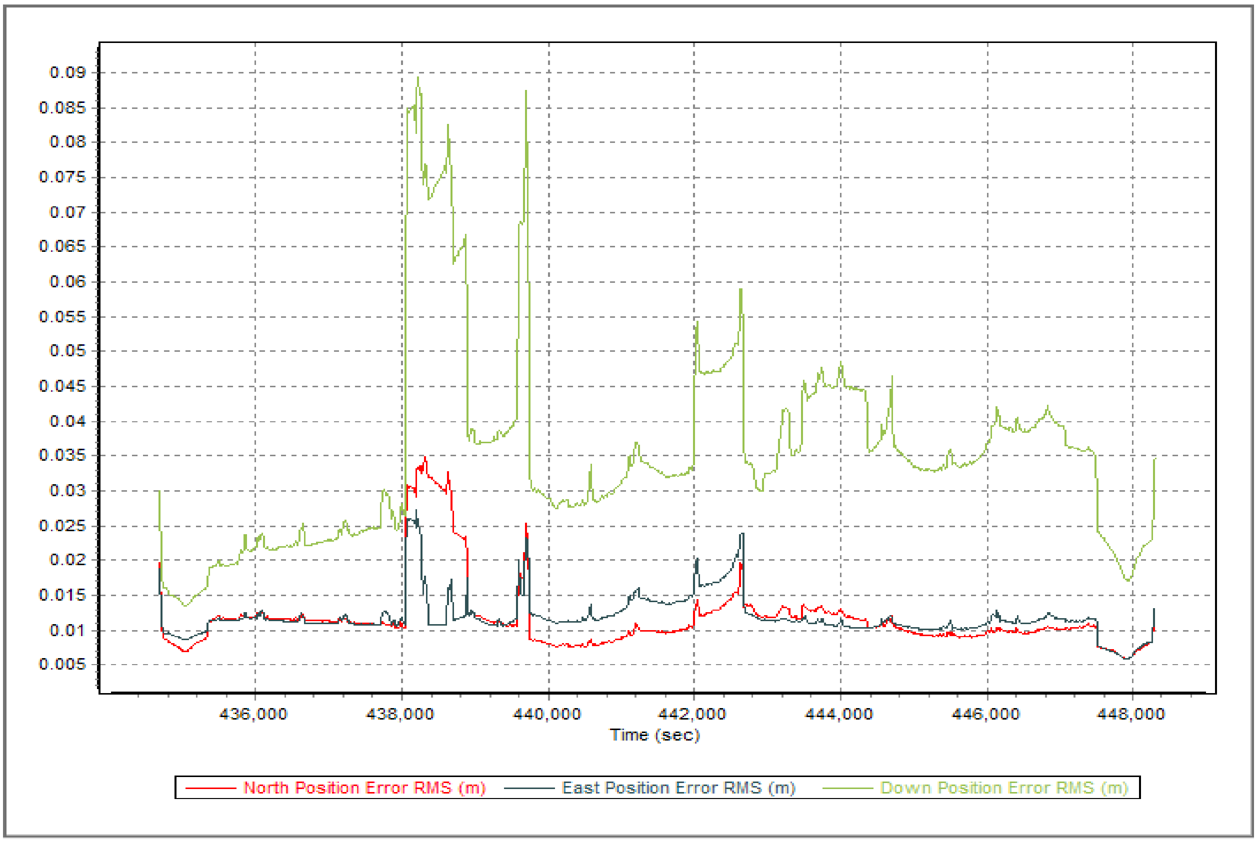


Figure A-8.37. Smoothed Performance Metric Parameters

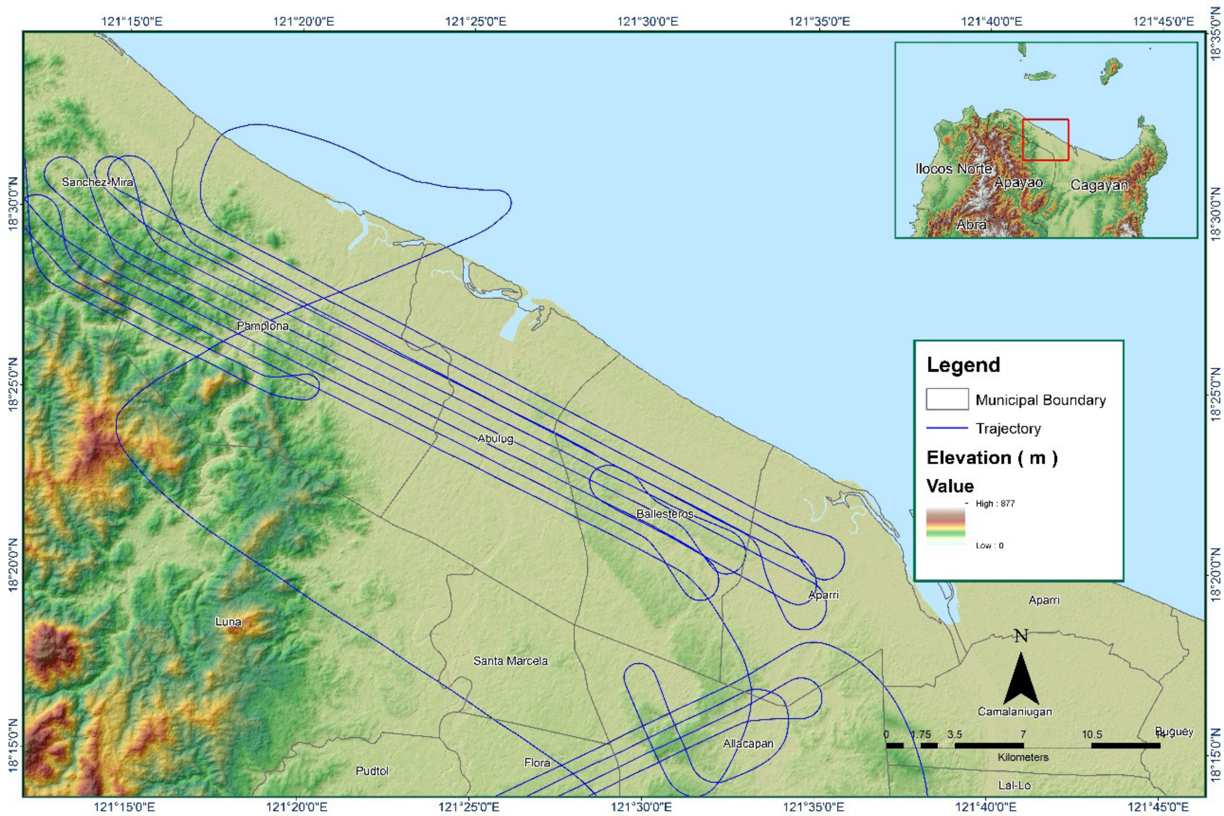


Figure A-8.38. Best Estimated Trajectory

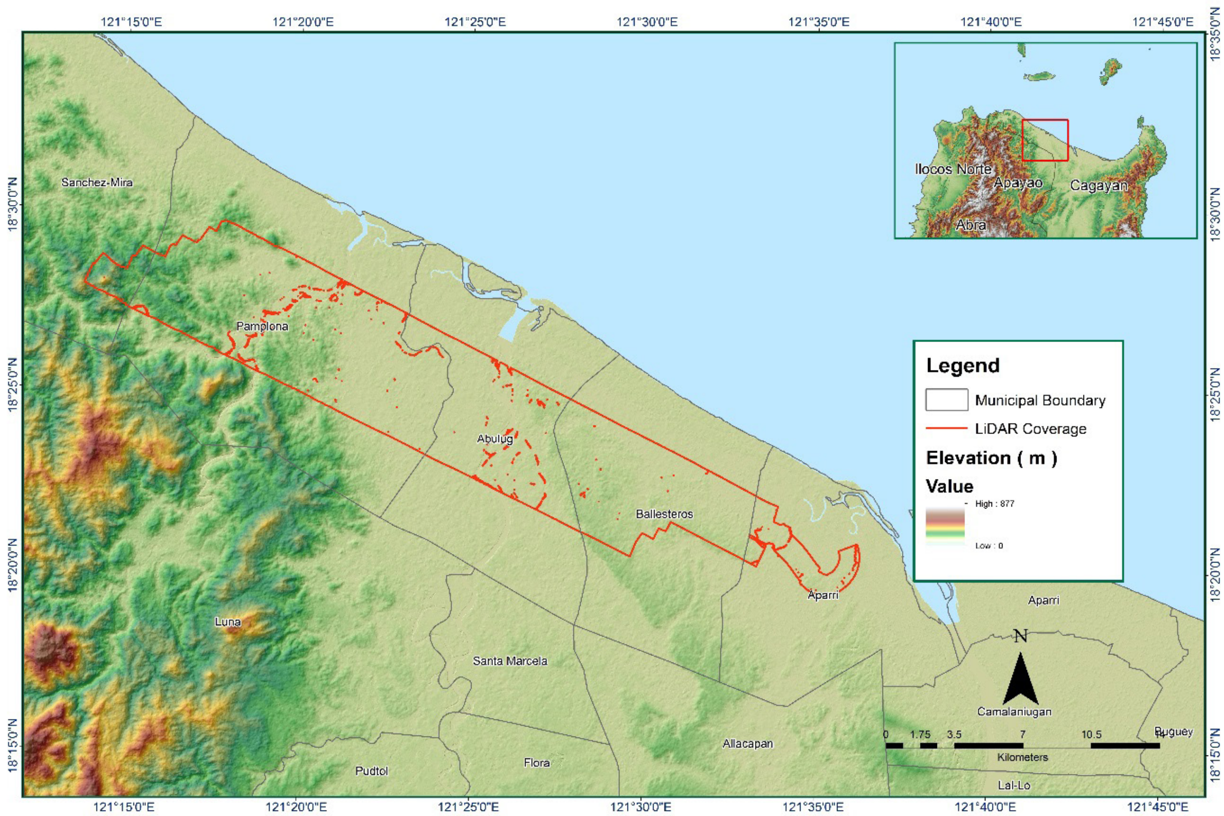


Figure A-8.39. Coverage of LiDAR data

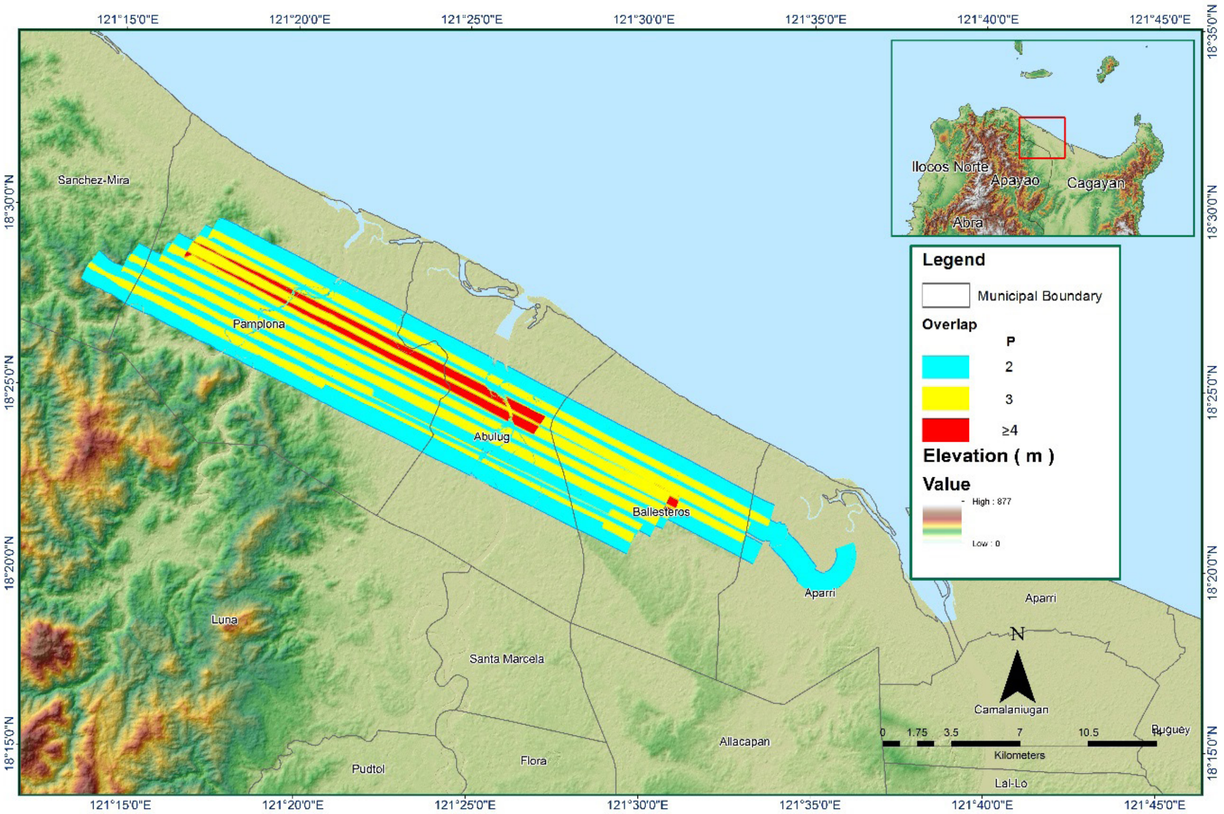


Figure A-8.40. Image of Data Overlap

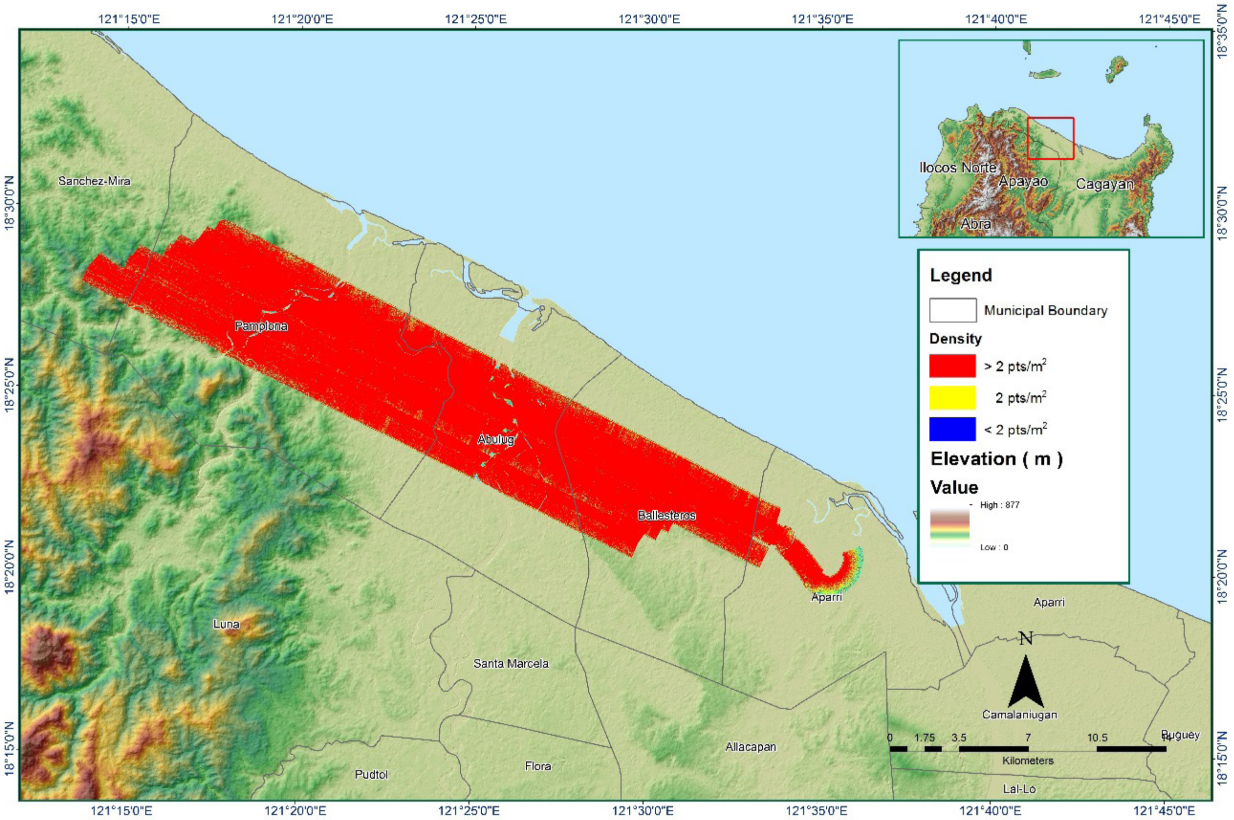


Figure A-8.41. Density map of merged LiDAR data

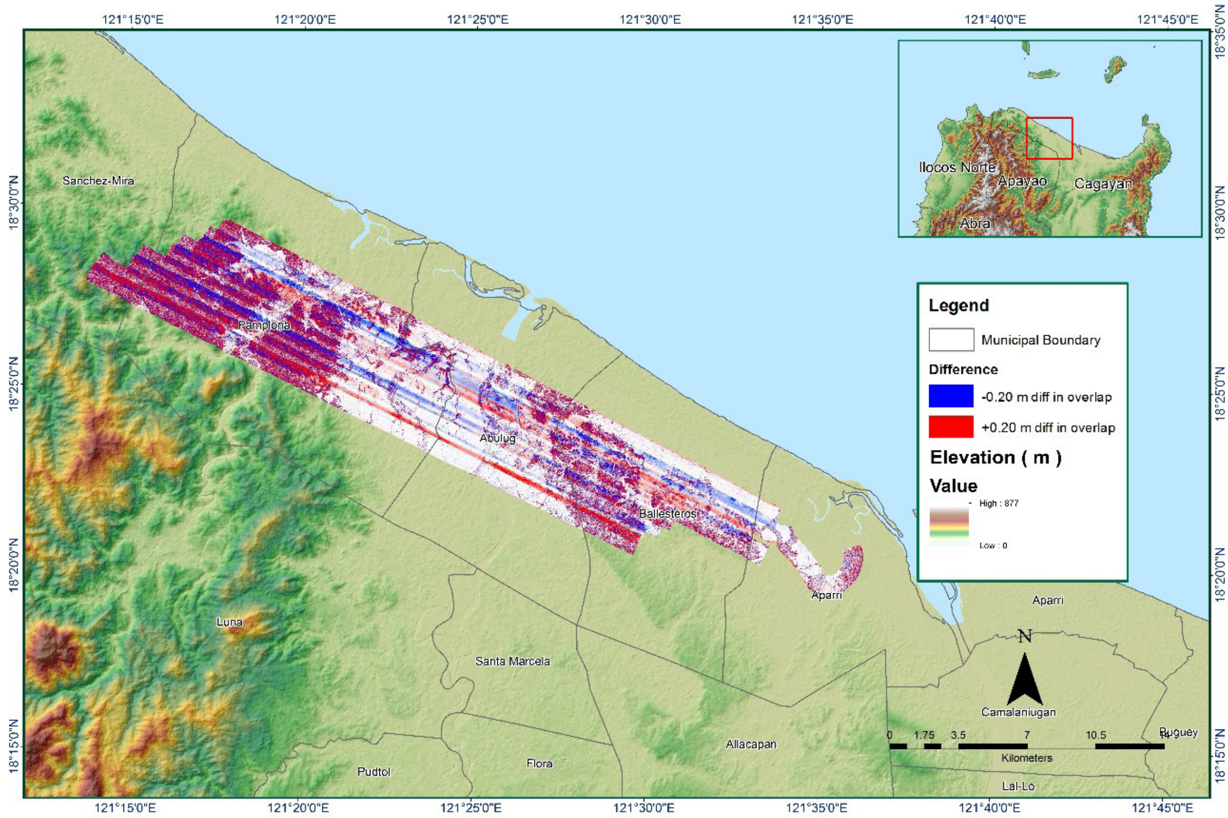


Figure A-8.42. Elevation difference between flight lines

Table A-8.7. Mission Summary Report for Mission Blk2A

Flight Area	Cagayan Reflights(Tuguegarao)
Mission Name	Blk2A
Inclusive Flights	2852P, 2848P
Range data size	17.63GB
POS	301MB
Image	28.87MB
Transfer date	November 24, 2015
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)	3.58
RMSE for East Position (<4.0 cm)	3.08
RMSE for Down Position (<8.0 cm)	5.22
Boresight correction stdev (<0.001deg)	0.000481
IMU attitude correction stdev (<0.001deg)	0.000374
GPS position stdev (<0.01m)	0.0021
Minimum % overlap (>25)	38.74
Ave point cloud density per sq.m. (>2.0)	1.82
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	183
Maximum Height	266.52 m
Minimum Height	40.70 m
Classification (# of points)	
Ground	193,048,741
Low vegetation	109,905,536
Medium vegetation	147,785,042
High vegetation	258,391,125
Building	5,416,447
Orthophoto	Yes
Processed by	Engr. Regis Guhiting, Engr. Mark Joshua Salvacion, Engr. Krisha Marie Bautista, Engr. Wilbert Ian San Juan

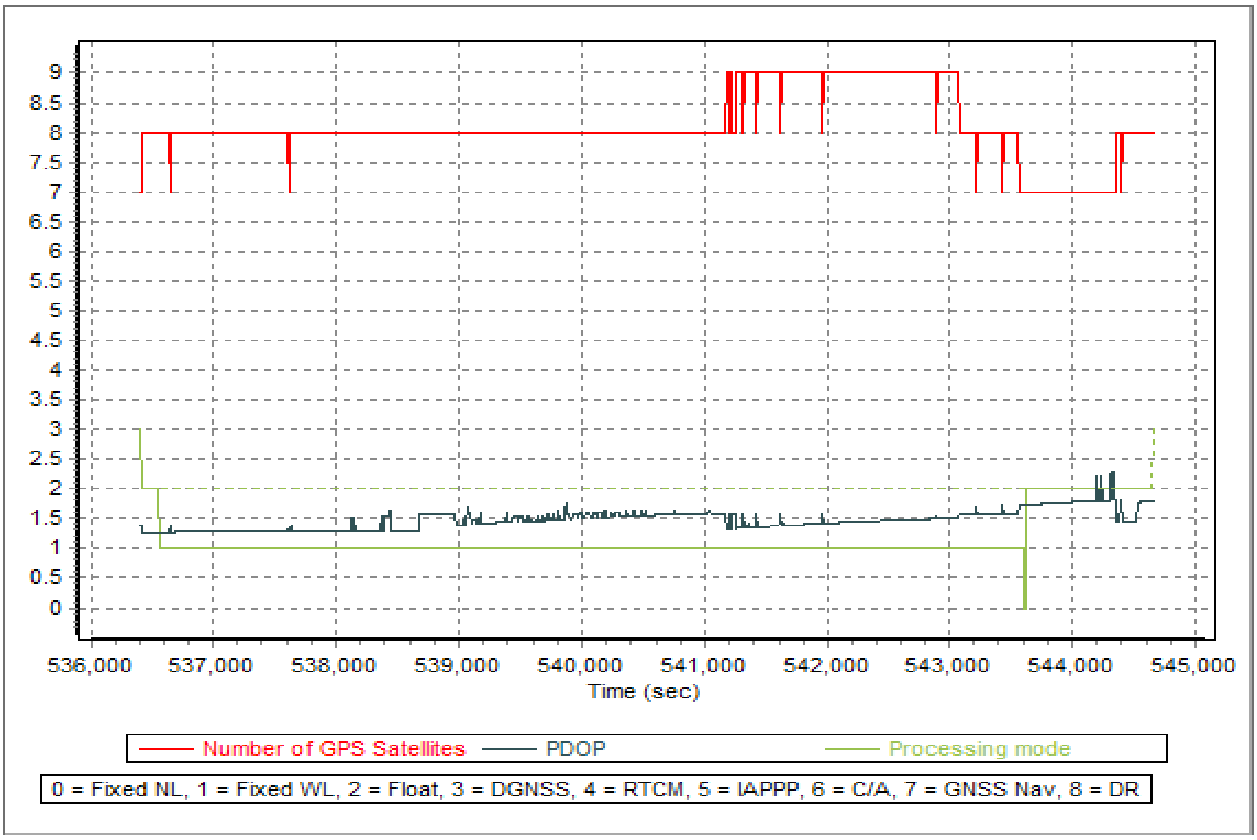


Figure A-8.43. Solution Status

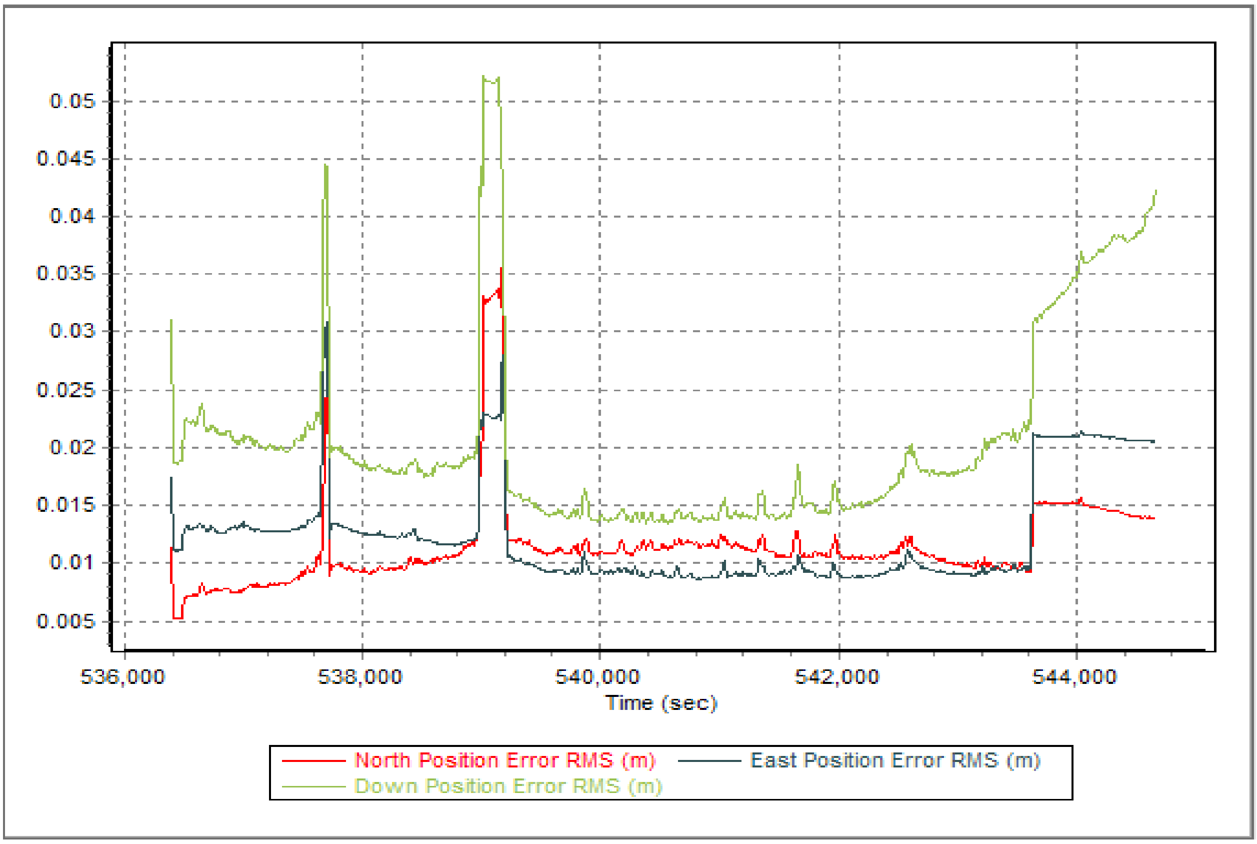


Figure A-8.44. Smoothed Performance Metric Parameters

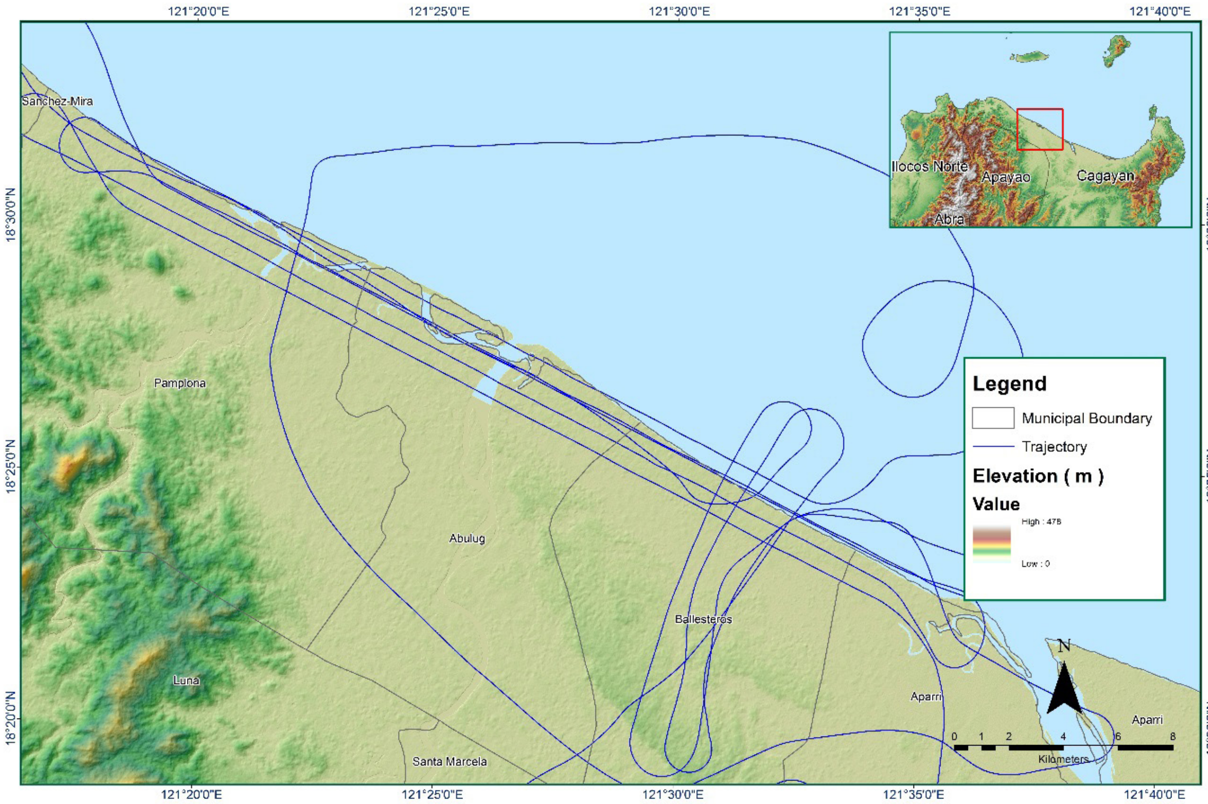


Figure A-8.45. Best Estimated Trajectory

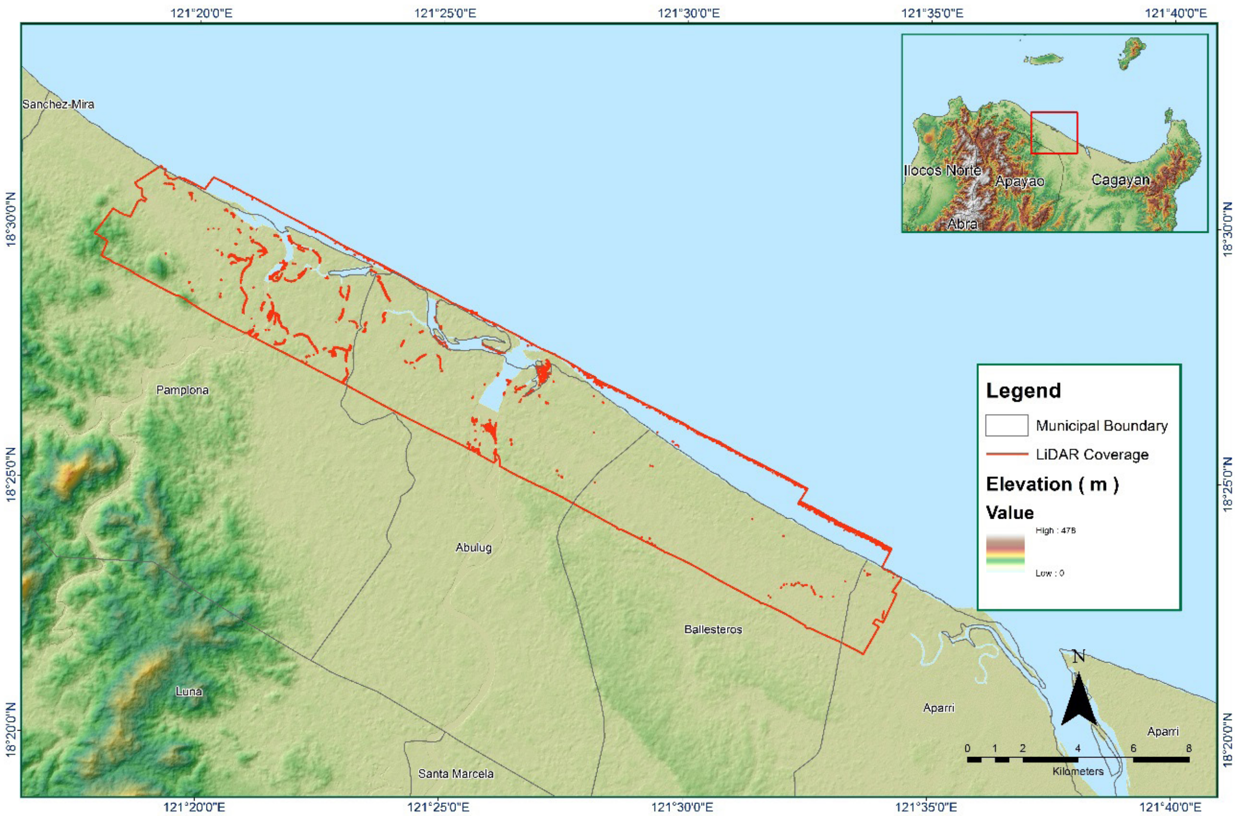


Figure A-8.46. Coverage of LiDAR data

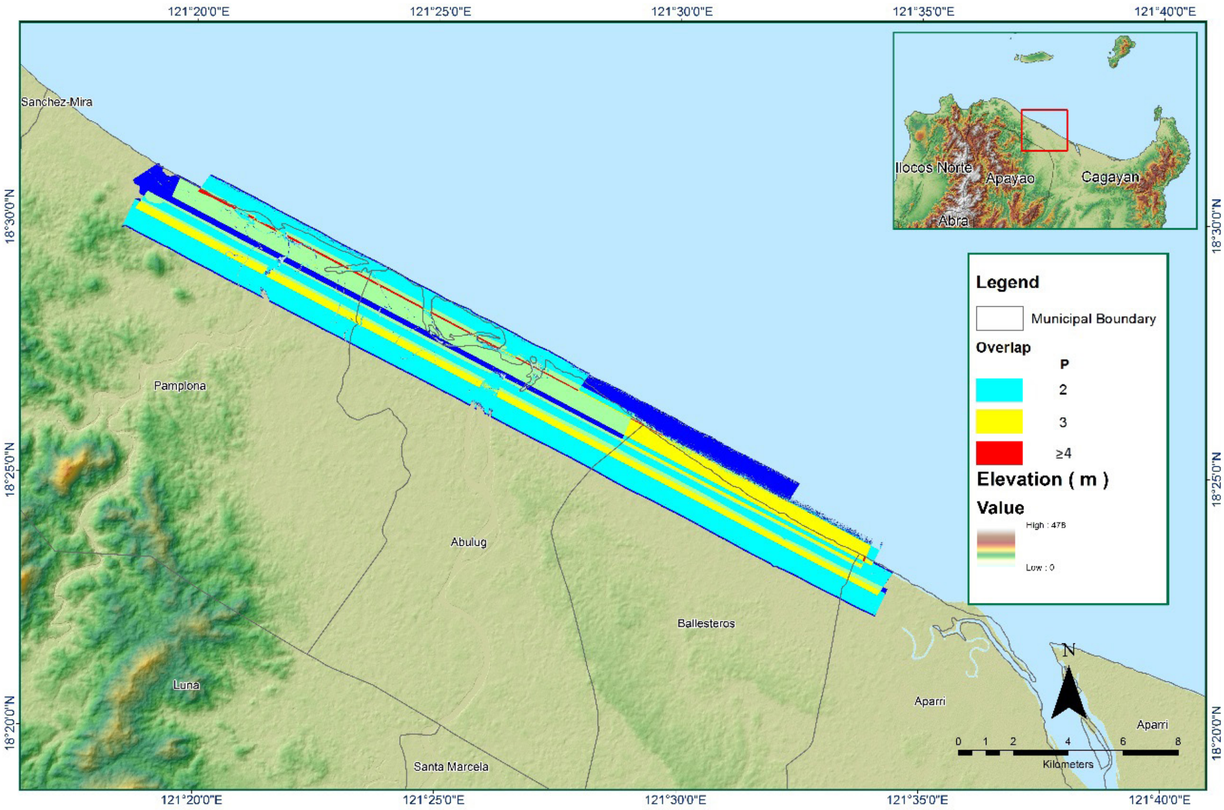


Figure A-8.47. Image of Data Overlap

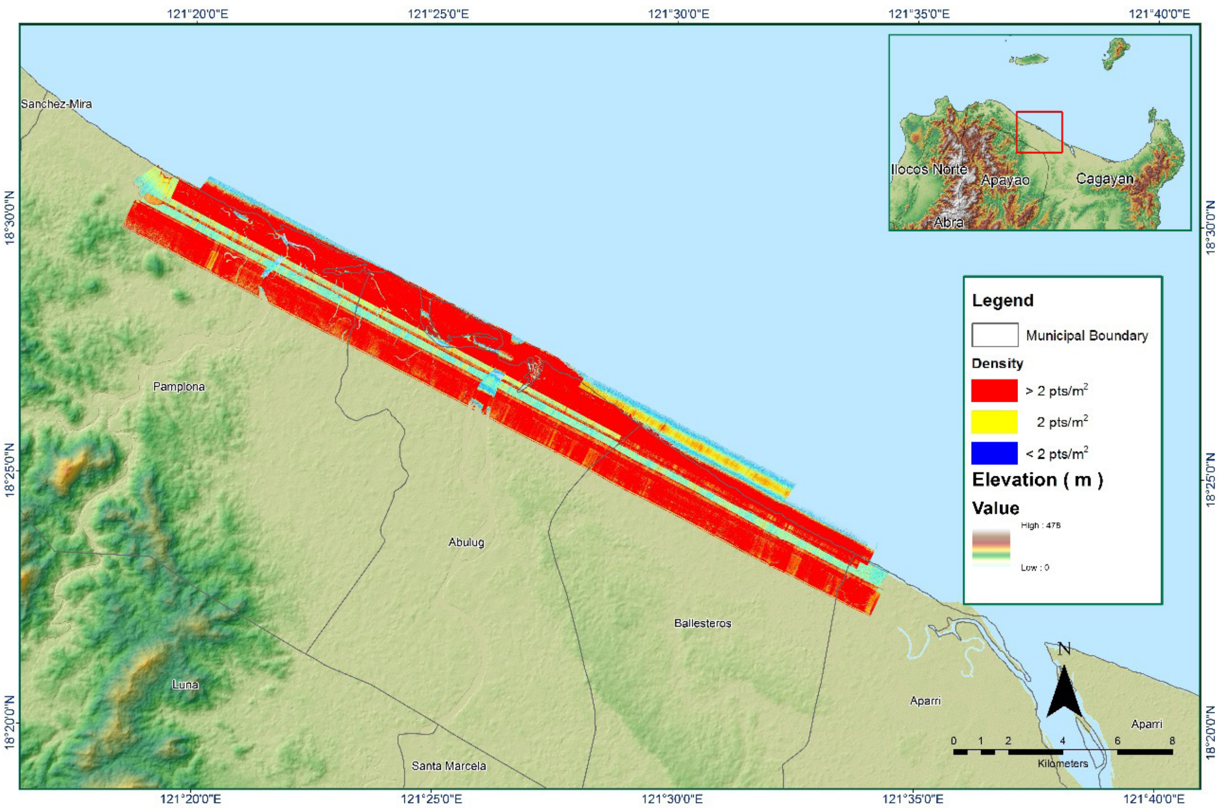


Figure A-8.48. Density map of merged LiDAR data

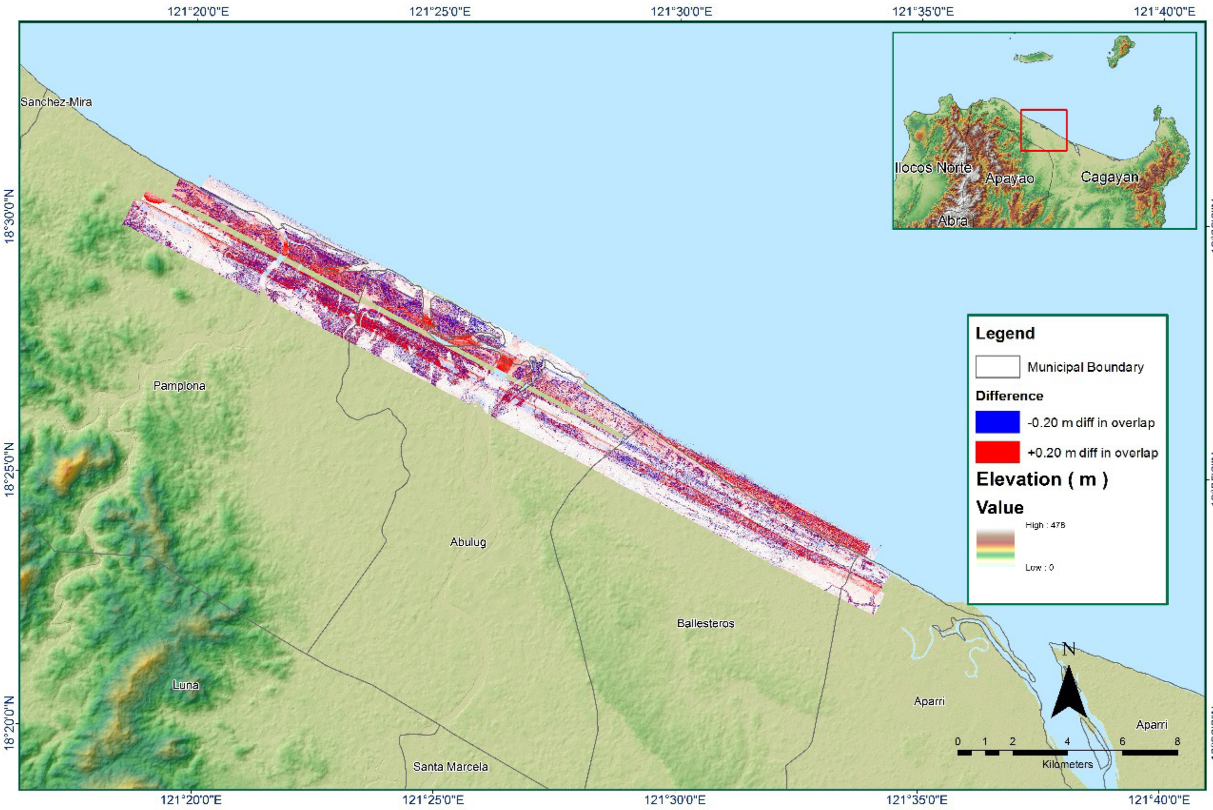


Figure A-8.49. Elevation difference between flight lines

Table A-8.8. Mission Summary Report for Mission Blk2A_additional

Flight Area	Cagayan_reflights(Tuguegarao)
Mission Name	Blk2A_additional
Inclusive Flights	2848P
Range data size	5.83 GB
Base data size	24.9 MB
POS	169 MB
Image	7.97 MB
Transfer date	November 24, 2015
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.3
RMSE for East Position (<4.0 cm)	1.1
RMSE for Down Position (<8.0 cm)	3.1
Boresight correction stdev (<0.001deg)	0.000481
IMU attitude correction stdev (<0.001deg)	0.000374
GPS position stdev (<0.01m)	0.0021
Minimum % overlap (>25)	6.85%
Ave point cloud density per sq.m. (>2.0)	1.81
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	101
Maximum Height	266.52 m.
Minimum Height	40.73 m.
Classification (# of points)	
Ground	53,937,277
Low vegetation	42,462,468
Medium vegetation	31,288,957
High vegetation	53,756,511
Building	485,048
Orthophoto	Yes
Processed by	Engr. Regis Guhiting

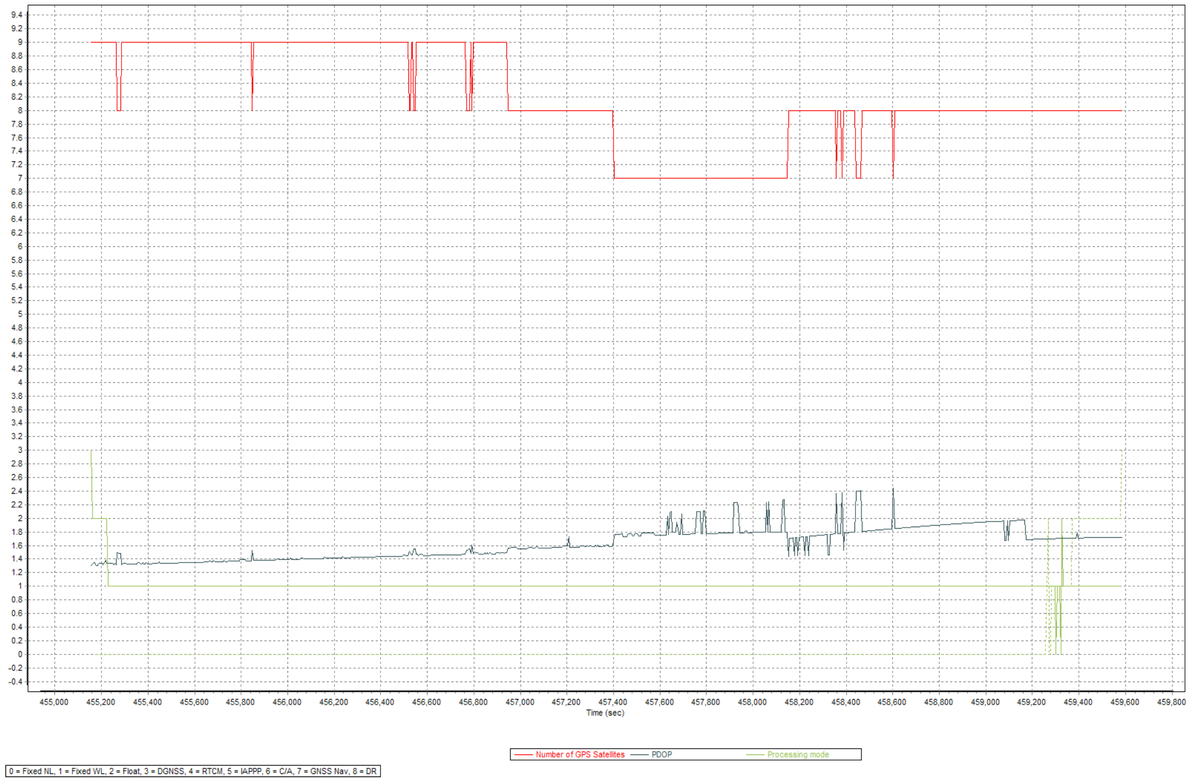


Figure A-8.50. Solution Status

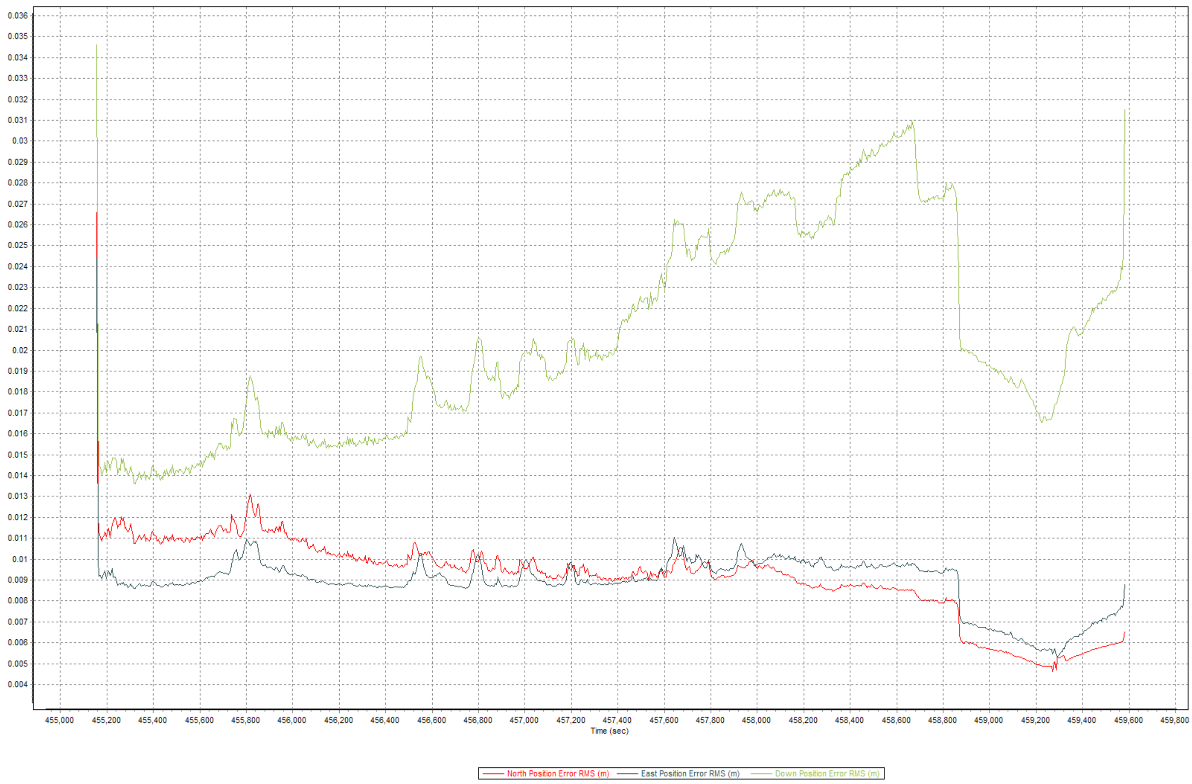


Figure A-8.51. Smoothed Performance Metric Parameters

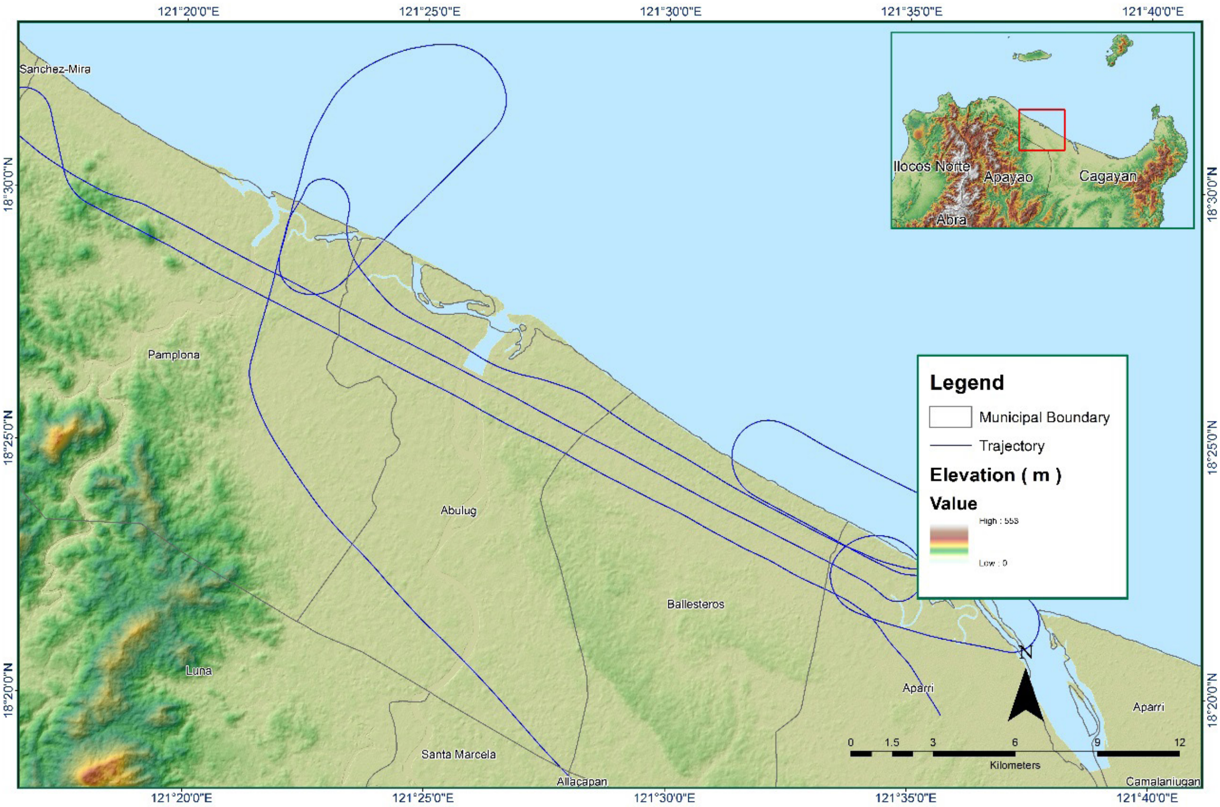


Figure A-8.52. Best Estimated Trajectory

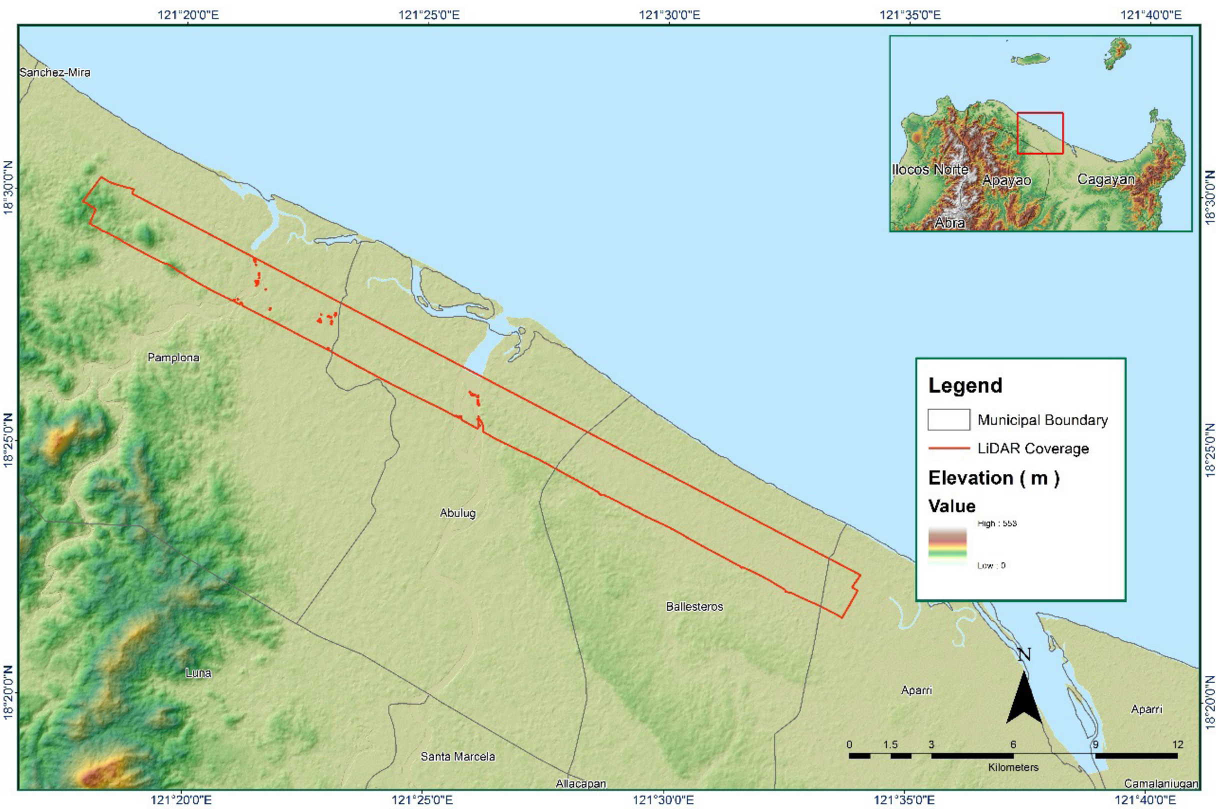


Figure A-8.53. Coverage of LiDAR data

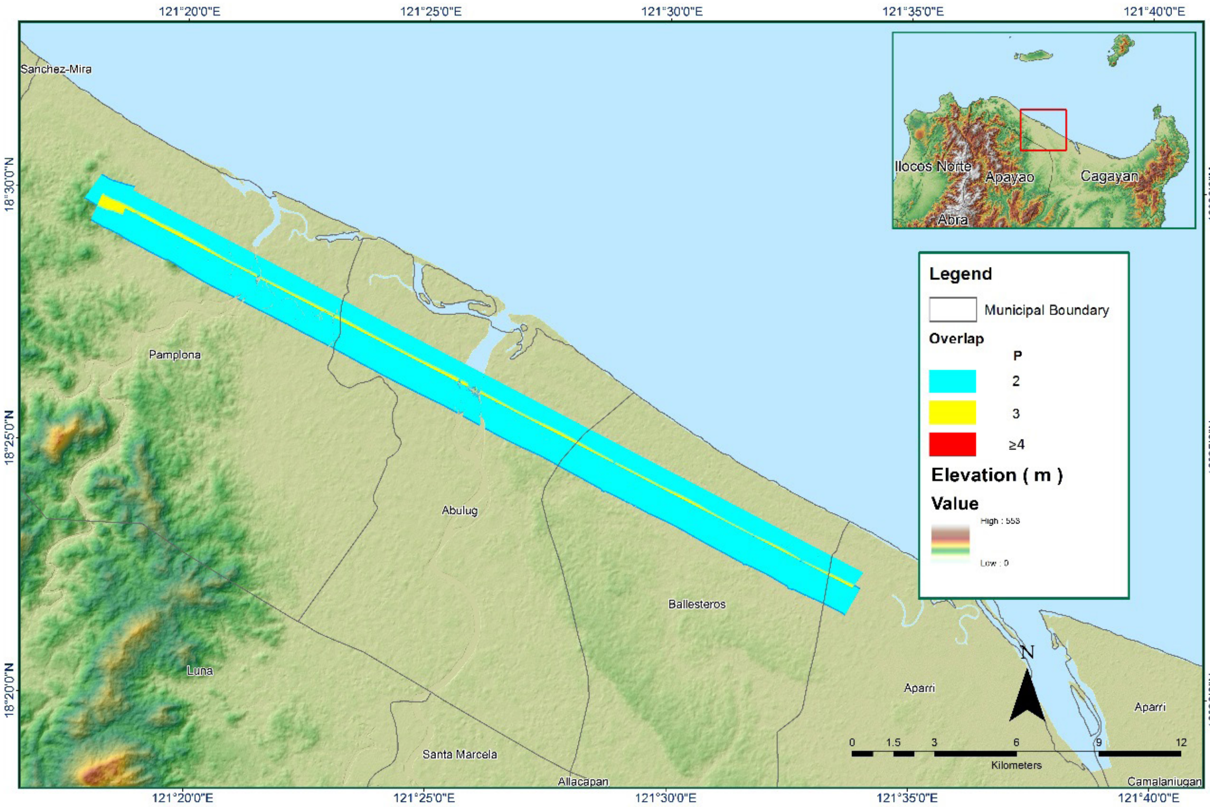


Figure A-8.54. Image of Data Overlap

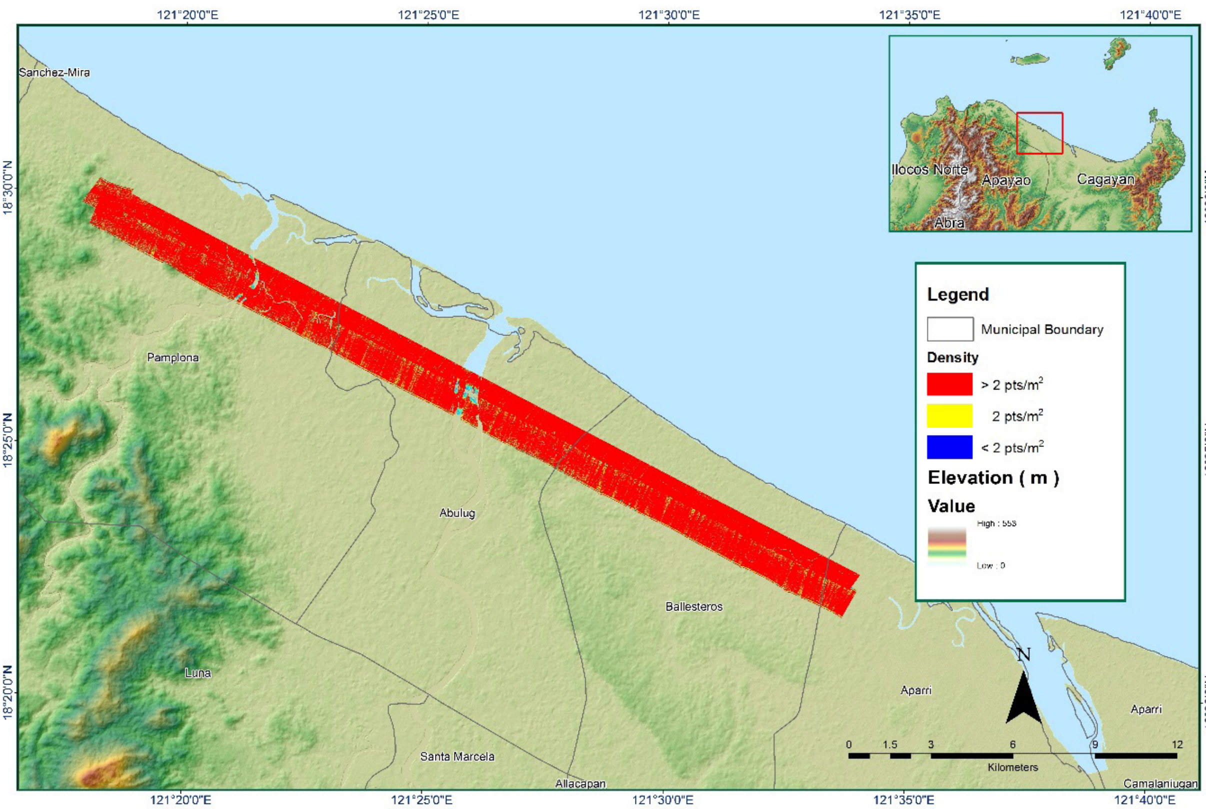


Figure A-8.55. Density map of merged LiDAR data

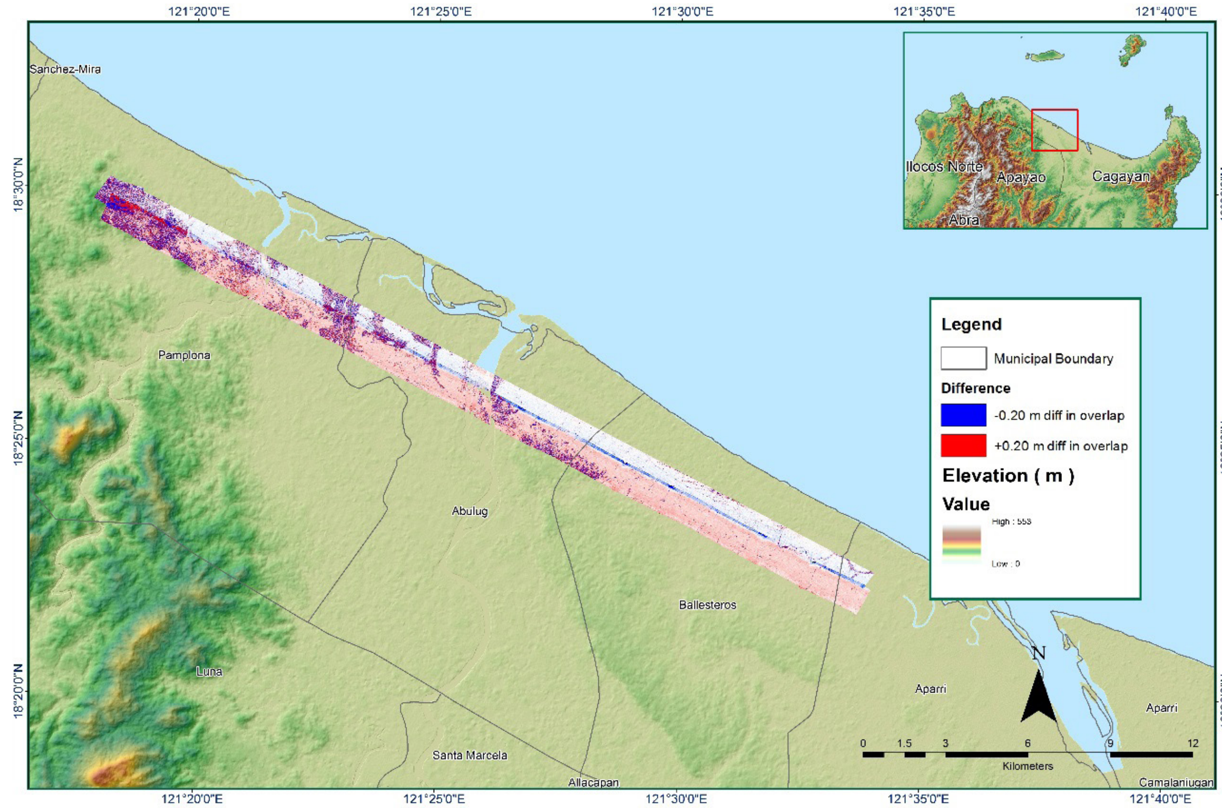


Figure A-8.56. Elevation difference between flight lines

Table A-8.9. Mission Summary Report for Mission Blk1D

Flight Area	Cagayan Reflights
Mission Name	Blk1D
Inclusive Flights	23696P
Range data size	8.9 GB
Base data size	5.71 MB
POS	192 MB
Image	NA
Transfer date	January 29, 2017
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.93
RMSE for East Position (<4.0 cm)	1.19
RMSE for Down Position (<8.0 cm)	2.05
Boresight correction stdev (<0.001deg)	0.001676
IMU attitude correction stdev (<0.001deg)	0.001341
GPS position stdev (<0.01m)	0.0188
Minimum % overlap (>25)	10.71
Ave point cloud density per sq.m. (>2.0)	1.27
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	71
Maximum Height	71.40 m
Minimum Height	39.07 m
Classification (# of points)	
Ground	35,403,186
Low vegetation	13,666,711
Medium vegetation	9,364,090
High vegetation	11,347,783
Building	156,416
Orthophoto	No
Processed by	

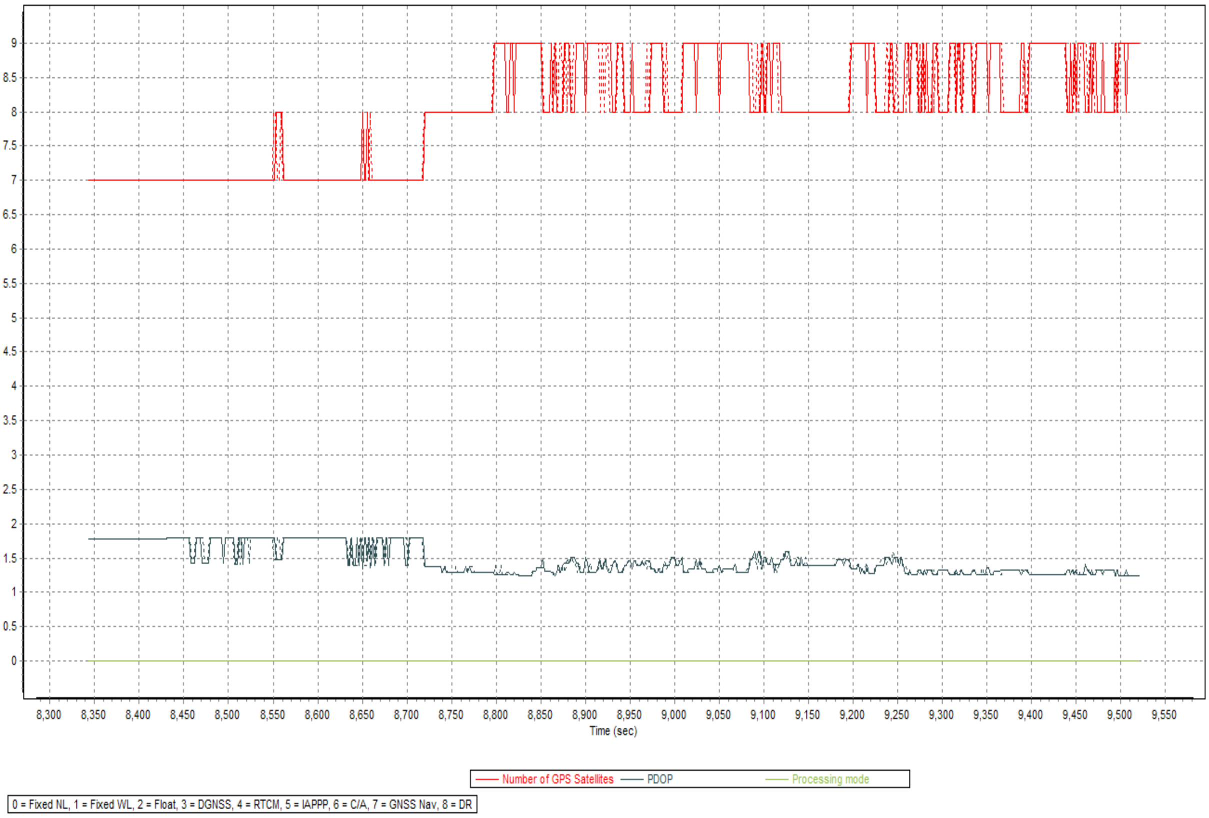


Figure A-8.57. Solution Status

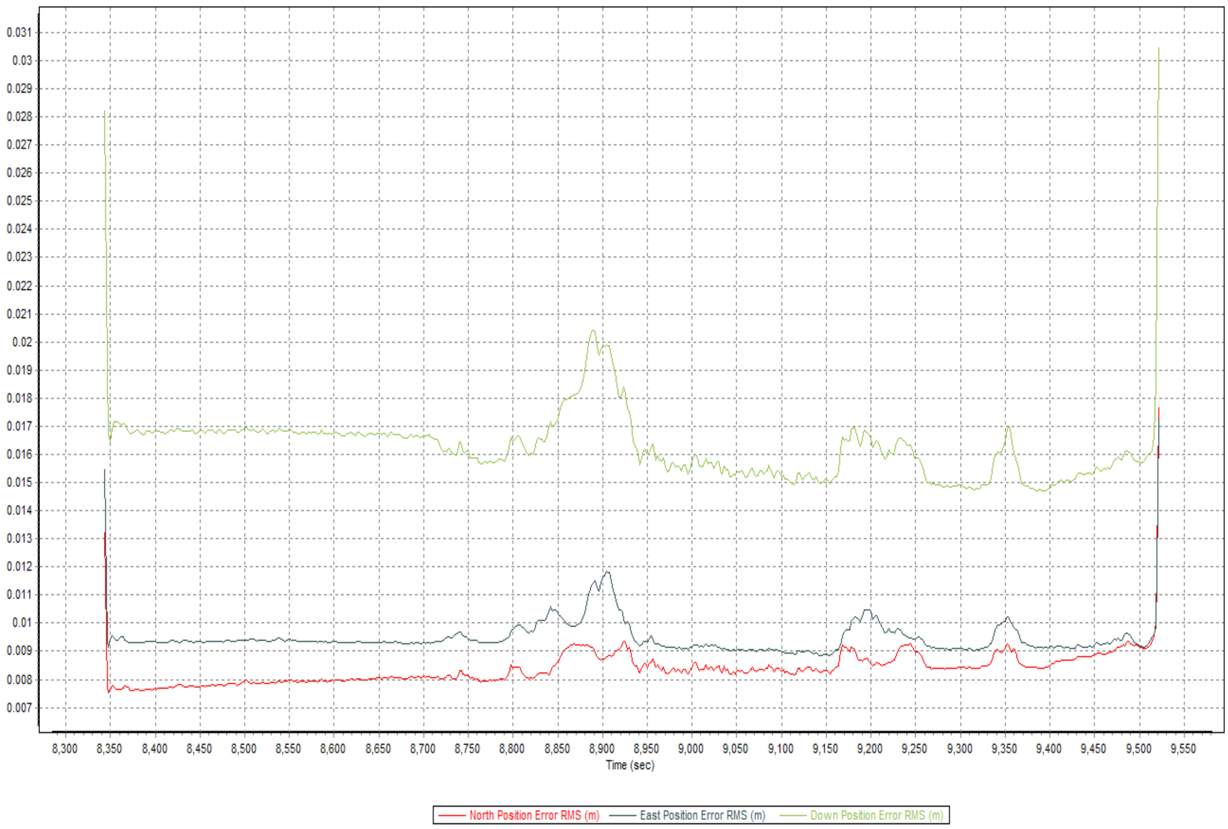


Figure A-8.58. Smoothed Performance Metric Parameters

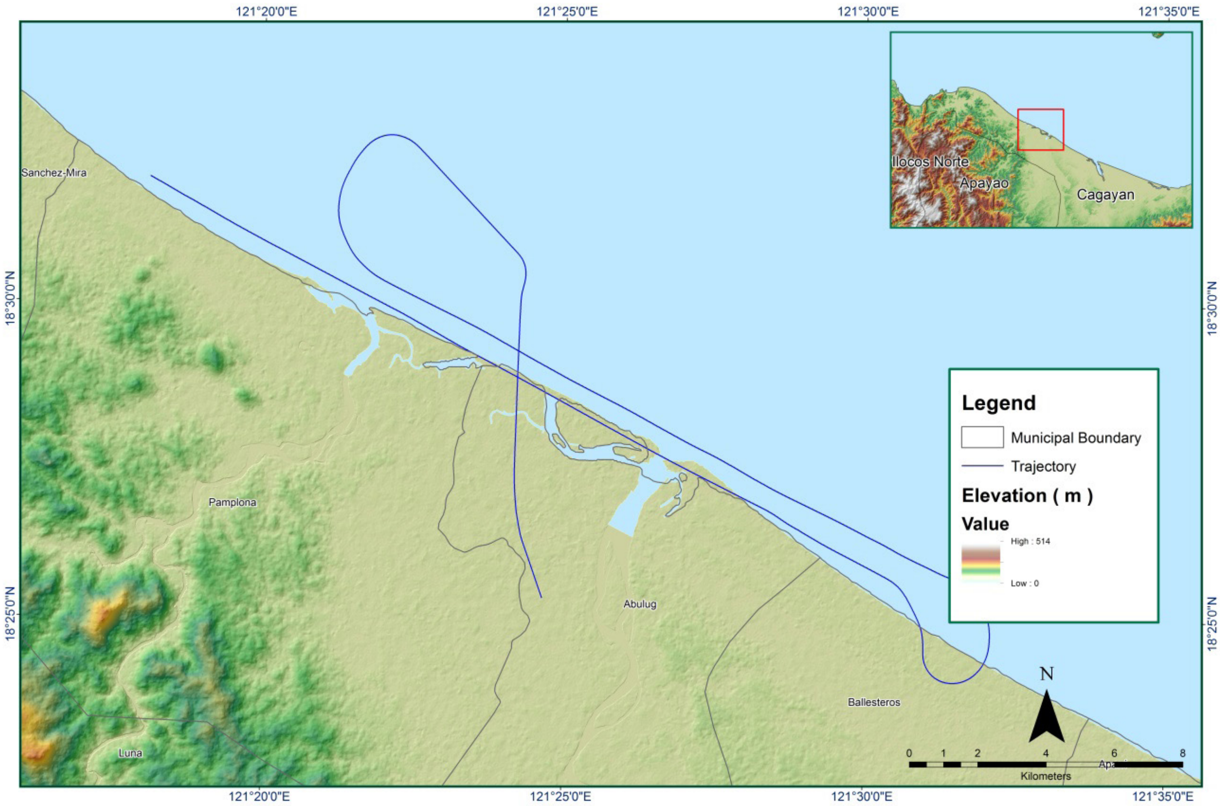


Figure A-8.59. Best Estimated Trajectory

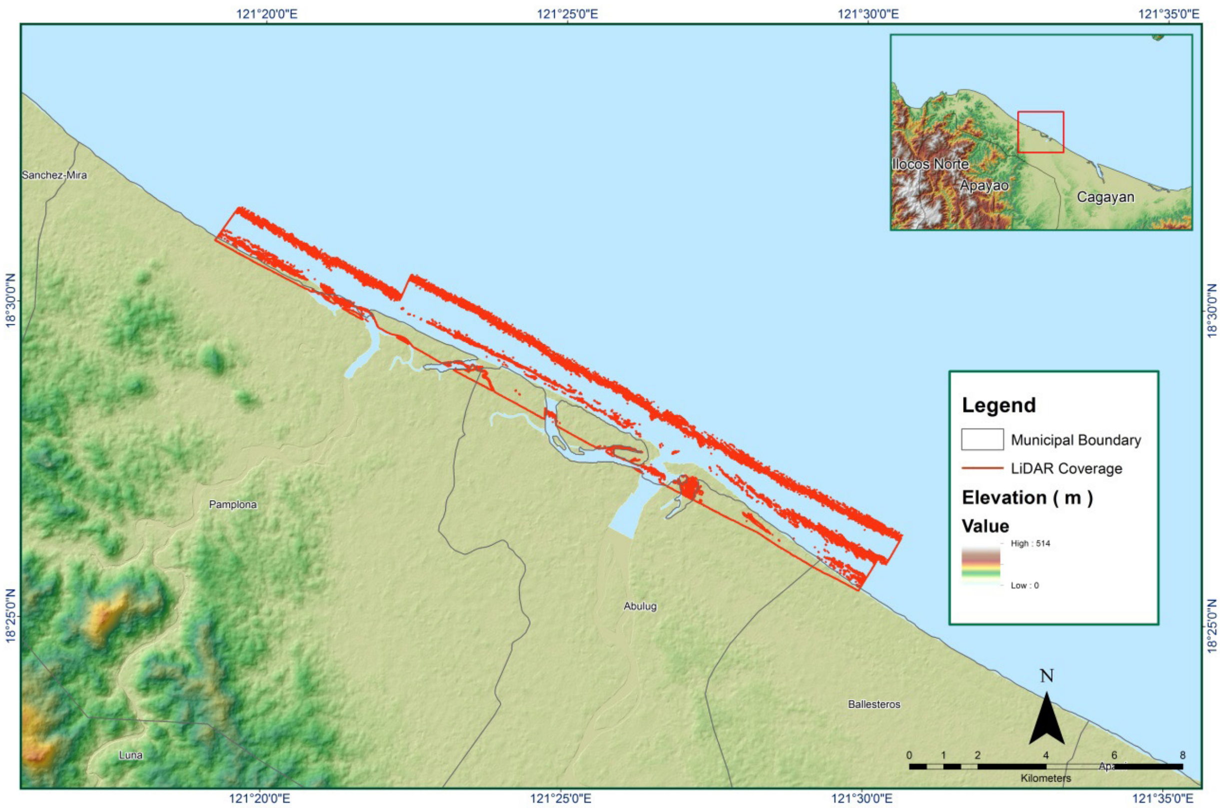


Figure A-8.60. Coverage of LiDAR data

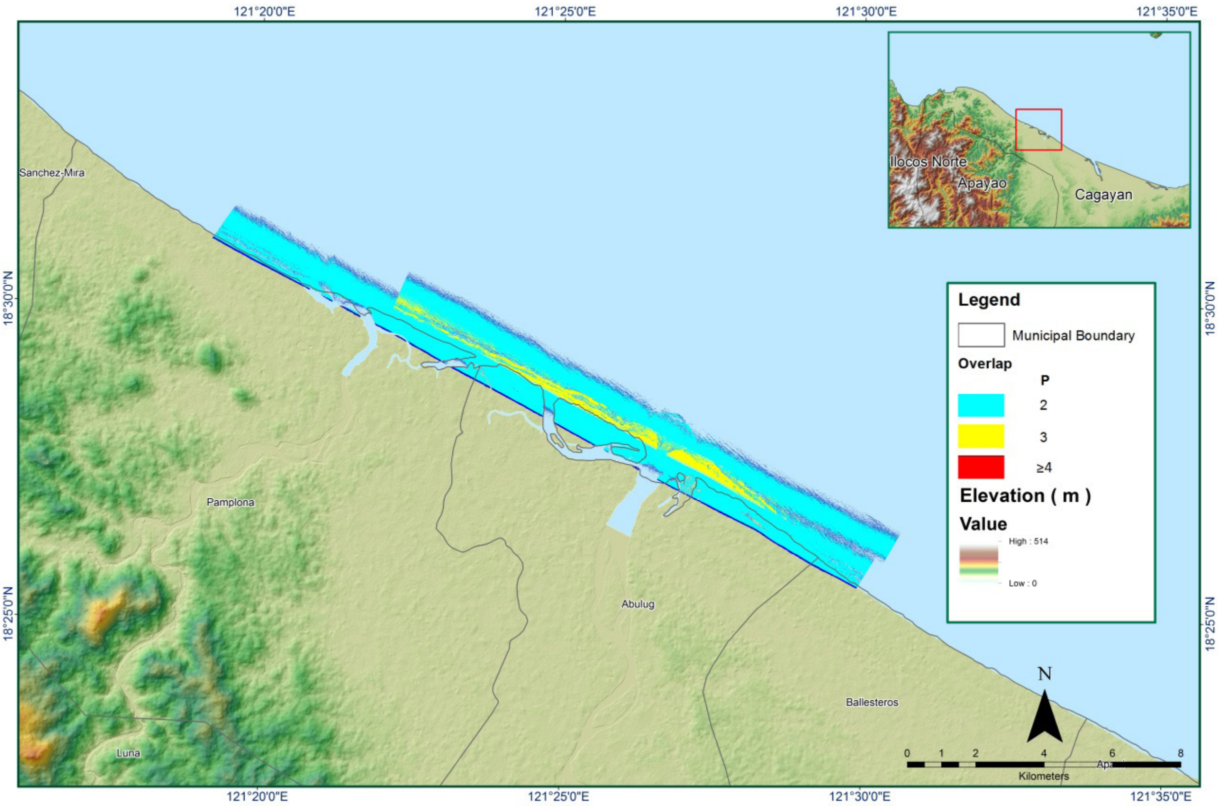


Figure A-8.61. Image of Data Overlap

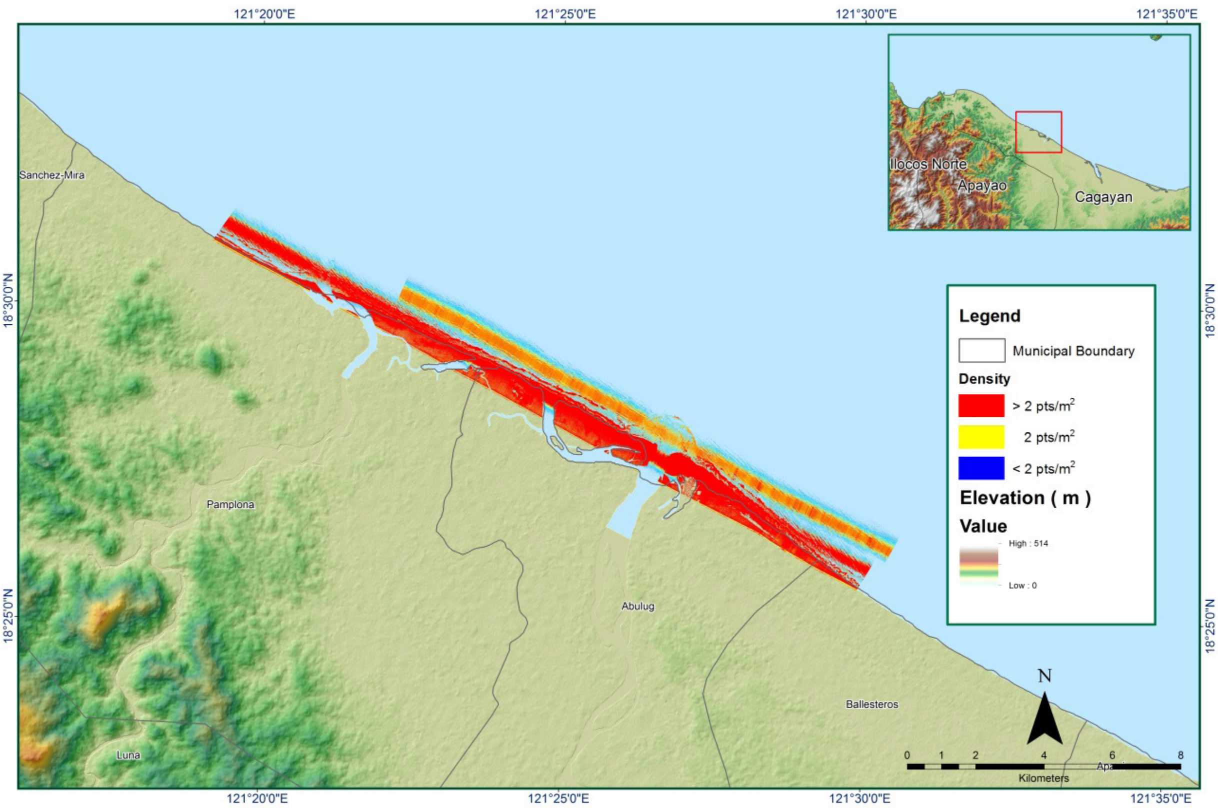


Figure A-8.62. Density map of merged LiDAR data

Figure A-8.63. Elevation difference between flight lines

Annex 9. Tibiao Model Basin Parameters

Table A-9.1. Tibiao Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W240	44.60052	44.41575	0	0.072845	0.106997	Discharge	0.0000548239	0.0001	Ratio to Peak	0.5
W250	21.89838	56.04975	0	0.026867	0.039461	Discharge	0.0000098005	0.0001	Ratio to Peak	0.5
W260	22.15389	55.88475	0	0.033308	0.048924	Discharge	0.0000162052	0.0001	Ratio to Peak	0.5
W270	39.64485	46.52325	0	0.020512	0.030128	Discharge	0.0000042852	0.0001	Ratio to Peak	0.5
W280	31.14009	50.649	0	0.031917	0.046881	Discharge	0.0000087025	0.0001	Ratio to Peak	0.5
W290	9.23049	65.6445	0	0.043262	0.06354	Discharge	0.0000358814	0.0001	Ratio to Peak	0.5
W300	47.96754	43.089	0	0.03584	0.052641	Discharge	0.0000142460	0.0001	Ratio to Peak	0.5
W310	49.44297	42.5325	0	0.01667	0.020214	Discharge	0.0000006656	0.0001	Ratio to Peak	0.5
W320	52.785	41.25	0	0.022666	0.033291	Discharge	0.0000086939	0.0001	Ratio to Peak	0.5
W330	46.19682	43.77675	0	0.05048	0.074142	Discharge	0.0000179641	0.0001	Ratio to Peak	0.5
W340	22.78272	55.4835	0	0.041014	0.060242	Discharge	0.0000187032	0.0001	Ratio to Peak	0.5
W350	8.16102	66.6075	0	0.038058	0.055899	Discharge	0.0000144134	0.0001	Ratio to Peak	0.5
W360	27.0096	52.92825	0	0.040987	0.060201	Discharge	0.0000235593	0.0001	Ratio to Peak	0.5
W370	13.00959	62.4555	0	0.022131	0.032506	Discharge	0.0000103668	0.0001	Ratio to Peak	0.5
W380	19.87368	57.39075	0	0.021369	0.031387	Discharge	0.0000118528	0.0001	Ratio to Peak	0.5
W390	12.97593	62.4825	0	0.06647	0.097637	Discharge	0.0000364992	0.0001	Ratio to Peak	0.5
W400	12.81987	62.60775	0	0.020089	0.029507	Discharge	0.0000053011	0.0001	Ratio to Peak	0.5
W410	13.2906	62.2305	0	0.027231	0.039996	Discharge	0.0000134968	0.0001	Ratio to Peak	0.5
W420	13.56039	62.016	0	0.02564	0.03766	Discharge	0.0000157821	0.0001	Ratio to Peak	0.5
W430	13.5201	62.04825	0	0.028506	0.04187	Discharge	0.0000227303	0.0001	Ratio to Peak	0.5
W440	28.42944	52.122	0	0.036994	0.054338	Discharge	0.0000111622	0.0001	Ratio to Peak	0.5
W450	38.89668	46.85925	0	0.029337	0.04309	Discharge	0.0000068012	0.0001	Ratio to Peak	0.5
W460	16.47351	59.79225	0	0.036286	0.053298	Discharge	0.0000280635	0.0001	Ratio to Peak	0.5

Annex 10. Tibiao Model Reach Parameters

Table A-10.1. Tibiao Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R20	Automatic Fixed Interval	1596.1	0.09568	0.01	Trapezoid	34.25	1
R30	Automatic Fixed Interval	1765.8	0.050244	0.01	Trapezoid	34.25	1
R50	Automatic Fixed Interval	789.41	0.17308	0.01	Trapezoid	34.25	1
R70	Automatic Fixed Interval	333.85	0.21771	0.01	Trapezoid	34.25	1
R110	Automatic Fixed Interval	3221.2	0.025069	0.01	Trapezoid	34.25	1
R130	Automatic Fixed Interval	1705.8	0.088237	0.01	Trapezoid	34.25	1
R150	Automatic Fixed Interval	1483.7	0.013354	0.01	Trapezoid	34.25	1
R160	Automatic Fixed Interval	1108.1	0.12133	0.01	Trapezoid	34.25	1
R190	Automatic Fixed Interval	3475	0.017288	0.01	Trapezoid	34.25	1
R210	Automatic Fixed Interval	1564.7	0.014312	0.01	Trapezoid	34.25	1
R220	Automatic Fixed Interval	706.84	0.024128	0.01	Trapezoid	34.25	1

Annex 11. Tibiao Field Validation Points

Table A-11.1. Tibiao Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/ Date	Rain Return / Scenario
	Lat	Long					
1	11.32172644	122.0373606	0.039999999	0.4	0.160	Frank	100-Year
2	11.30765521	122.0488905	0.349999994	0.4	0.160	Frank	100-Year
3	11.29678629	122.0543573	0.059999999	0	0.000		
4	11.28799141	122.0329715	0.219999999	0.7	0.490	Frank	100-Year
5	11.29006983	122.0358816	0.180000007	0.75	0.563	Frank	100-Year
6	11.29744969	122.0550787	0.029999999	0	0.000		
7	11.28750994	122.0352872	0.029999999	0.5	0.250	Yolanda	5-Year
8	11.27924455	122.0413638	0.029999999	0.4	0.160	Frank	100-Year
9	11.28126965	122.0391789	0.379999995	0.2	0.040	Frank	100-Year
10	11.28643538	122.0353233	0.319999993	0.2	0.040	Frank	100-Year
11	11.32336295	122.0385464	0.07	0.4	0.160	Frank	100-Year
12	11.29793748	122.0544887	0.07	0	0.000		
13	11.29708203	122.0546462	0.079999998	0	0.000		
14	11.28904063	122.0358415	0.129999995	0	0.000	Frank	100-Year
15	11.29638274	122.051238	0.029999999	0.3	0.090	Frank	100-Year
16	11.27916482	122.0401143	0.029999999	0	0.000		
17	11.31137859	122.0471652	0.340000004	0.2	0.040	Frank	100-Year
18	11.27929667	122.0403203	0.029999999	0	0.000		
19	11.29878432	122.0530328	0.140000001	0.9	0.810	Frank	100-Year
20	11.28564403	122.0358488	0.209999993	0.3	0.090	Frank	100-Year
21	11.28601359	122.0347737	0.219999999	0.2	0.040	Frank	100-Year
22	11.31301269	122.0479052	0.029999999	0.4	0.160	Frank	100-Year
23	11.27926006	122.0398851	0.029999999	0	0.000		
24	11.28641563	122.0372201	0.180000007	0.4	0.160	Frank	100-Year
25	11.28866033	122.0348541	0.029999999	0.1	0.010	Yolanda	5-Year
26	11.27628235	122.0427198	0.340000004	0.3	0.090	Frank	100-Year
27	11.27927891	122.0400316	0	0	0.000		
28	11.32306928	122.0382912	0.07	0.4	0.160	Frank	100-Year
29	11.29763074	122.0653431	0.389999986	0	0.000	Frank	100-Year
30	11.28119183	122.056443	0.090000004	0	0.000	Frank	100-Year
31	11.29252362	122.0584099	0.029999999	0	0.000	Frank	100-Year
32	11.31808272	122.0594259	0.079999998	0	0.000	Frank	100-Year
33	11.3207948	122.0655037	0.029999999	0	0.000	Frank	100-Year
34	11.29466277	122.070939	0.039999999	0	0.000	Frank	100-Year
35	11.30983177	122.0589237	0.029999999	0	0.000	Frank	100-Year
36	11.29646411	122.0511372	0	0.3	0.090	Frank	100-Year
37	11.30205313	122.0665786	0.029999999	0	0.000	Frank	100-Year
38	11.32414412	122.0484798	0.059999999	0	0.000		
39	11.27922443	122.0409414	0.029999999	0.4	0.160	Yolanda	5-Year
40	11.28832556	122.0345086	0.029999999	0	0.000		

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/ Date	Rain Return / Scenario
	Lat	Long					
41	11.2861609	122.038473	0.370000005	0.4	0.160	Yolanda	5-Year
42	11.29670379	122.0550396	0.029999999	0	0.000		
43	11.28951882	122.0364187	0.119999997	0.3	0.090	Yolanda	5-Year
44	11.28202421	122.0387299	0.340000004	0.4	0.160	Frank	100-Year
45	11.29608037	122.0491924	0.409999996	0.3	0.090	Frank	100-Year
46	11.28767782	122.0374884	0.370000005	0.4	0.160	Yolanda	5-Year
47	11.28018355	122.0400066	0.310000002	0	0.000		
48	11.28614889	122.03808	0.270000011	0.4	0.160	Yolanda	5-Year
49	11.28549587	122.0361304	0.400000006	0.3	0.090	Frank	100-Year
50	11.2902801	122.0362078	0.340000004	0.75	0.563	Frank	100-Year
51	11.29635579	122.0495167	0.370000005	0.3	0.090	Frank	100-Year
52	11.28875301	122.0350091	0.029999999	0.1	0.010	Yolanda	5-Year
53	11.27860132	122.0411506	0.349999994	1.4	1.960	Frank	100-Year
54	11.28772703	122.0365424	0.180000007	0.8	0.640	Frank	100-Year
55	11.30561299	122.0502282	0.560000002	0.8	0.640	Frank	100-Year
56	11.28905297	122.0337545	0.330000013	0.2	0.040	Frank	100-Year
57	11.30862521	122.0462444	0.419999987	0.8	0.640	Frank	100-Year
58	11.27822612	122.0414939	0.379999995	0.4	0.160	Frank	100-Year
59	11.28116571	122.0390113	0.430000007	0.2	0.040	Frank	100-Year
60	11.30981435	122.0429188	0.370000005	0.8	0.640	Frank	100-Year
61	11.2811788	122.0388913	0.449999988	0.2	0.040	Frank	100-Year
62	11.29053949	122.0355267	0.579999983	0.5	0.250	Frank	100-Year
63	11.28614588	122.0380905	0	0.4	0.160	Yolanda	5-Year
64	11.28585559	122.0375829	0.419999987	0.3	0.090	Frank	100-Year
65	11.28876871	122.0323688	0.629999995	1.2	1.440	Frank	100-Year
66	11.29927626	122.0529786	0.49000001	0.9	0.810	Frank	100-Year
67	11.29072908	122.0378981	0.280000001	0.4	0.160	Yolanda	5-Year
68	11.31469265	122.0415218	0.50999999	0.4	0.160	Frank	100-Year
69	11.3234749	122.0526696	0.029999999	0	0.000		
70	11.31534749	122.0426468	0.479999989	0.8	0.640	Yolanda	5-Year
71	11.30390026	122.0407946	0.349999994	0.3	0.090	Frank	100-Year
72	11.31806519	122.0418758	0.090000004	0.65	0.423	Yolanda	5-Year
73	11.28897059	122.0329959	0.779999971	0.2	0.040	Frank	100-Year
74	11.29036304	122.0345296	0.970000029	0.4	0.160	Frank	100-Year
75	11.28544609	122.0374258	0.810000002	0.4	0.160	Frank	100-Year
76	11.2865786	122.0344669	0.75999999	1.3	1.690	Frank	100-Year
77	11.28207117	122.0383745	0.75999999	0.4	0.160	Frank	100-Year
78	11.27770159	122.0441715	0.629999995	0.4	0.160	Frank	100-Year
79	11.27894099	122.0434281	0.670000017	0.4	0.160	Yolanda	5-Year
80	11.29000169	122.0349985	0.340000004	0.4	0.160	Yolanda	5-Year
81	11.3051547	122.0310782	0.949999988	0.3	0.090	Frank	100-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/ Date	Rain Return / Scenario
	Lat	Long					
82	11.27692294	122.0444602	0.75	0.9	0.810	Frank	100-Year
83	11.29006873	122.0342247	0.899999976	0.5	0.250	Yolanda	5-Year
84	11.27859142	122.0439718	0.409999996	0.4	0.160	Yolanda	5-Year
85	11.2788993	122.0434088	0.430000007	0.4	0.160	Yolanda	5-Year
86	11.30494651	122.0304117	0.980000019	1	1.000	Frank	100-Year
87	11.31042564	122.0468798	0.479999989	0.4	0.160	Frank	100-Year
88	11.30640277	122.0499696	1.100000024	0.8	0.640	Frank	100-Year
89	11.30490622	122.0315005	0.649999976	0.8	0.640	Frank	100-Year
90	11.27863091	122.0426708	0.819999993	0.4	0.160	Frank	100-Year
91	11.28523541	122.0366461	0.029999999	0.2	0.040	Yolanda	5-Year
92	11.29149462	122.0356062	0.670000017	0.5	0.250	Frank	100-Year
93	11.30595916	122.0501985	0.730000019	0.8	0.640	Frank	100-Year
94	11.28843998	122.032952	0.930000007	0.7	0.490	Frank	100-Year
95	11.2899373	122.0339723	0.850000024	0.4	0.160	Frank	100-Year
96	11.277255	122.0426955	0.550000012	0.3	0.090	Frank	100-Year
97	11.27844689	122.0415971	0.469999999	0.4	0.160	Frank	100-Year
98	11.28735904	122.0360571	0.620000005	0.3	0.090	Frank	100-Year
99	11.30521387	122.049917	0.709999979	1.3	1.690	Frank	100-Year
100	11.30742653	122.0462549	0.930000007	1.3	1.690	Frank	100-Year
101	11.27906315	122.0433468	0.949999988	0.3	0.090	Frank	100-Year
102	11.29570972	122.04186	1.070000052	0.2	0.040	Frank	100-Year
103	11.29688372	122.0444399	1.070000052	0.9	0.810	Frank	100-Year
104	11.30496337	122.0496768	0.680000007	1.3	1.690	Frank	100-Year
105	11.29002638	122.0331488	0.730000019	0.7	0.490	Frank	100-Year
106	11.29516187	122.0381349	0.889999986	0.4	0.160	Frank	100-Year
107	11.29679856	122.0404034	0.720000029	0.9	0.810	Frank	100-Year
108	11.2979551	122.0420001	1.360000014	0.9	0.810	Frank	100-Year
109	11.3023207	122.0438834	1.25	0.9	0.810	Frank	100-Year
110	11.30518646	122.0306581	1.230000019	1	1.000	Frank	100-Year
111	11.30562633	122.0308657	1.360000014	0.4	0.160	Frank	100-Year
112	11.31017165	122.0657597	2.660000086	0	0.000	Frank	100-Year
113	11.30018679	122.0291257	1.230000019	0.8	0.640	Frank	100-Year
114	11.30516818	122.0308596	0.879999995	0.3	0.090	Frank	100-Year
115	11.28194465	122.0390981	0.430000007	0.2	0.040	Frank	100-Year
116	11.2775361	122.042796	1.190000057	1.5	2.250	Frank	100-Year
117	11.30547038	122.0314039	1.25999999	0.4	0.160	Frank	100-Year
118	11.30984553	122.0662281	2.539999962	0	0.000	Frank	100-Year
119	11.30572196	122.0298855	1.080000043	0.8	0.640	Frank	100-Year
120	11.28524158	122.0373037	0.550000012	0	0.000		
121	11.2890433	122.0323364	1.399999976	1.2	1.440	Frank	100-Year
122	11.30531555	122.0306316	1.440000057	1	1.000	Frank	100-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/ Date	Rain Return / Scenario
	Lat	Long					
123	11.30568028	122.0299812	1.480000019	0.8	0.640	Frank	100-Year
124	11.30535602	122.0302989	1.269999981	0.8	0.640	Frank	100-Year
125	11.27752838	122.0427525	0	1.5	2.250	Frank	100-Year
126	11.28994745	122.0342041	1.080000043	0.4	0.160	Frank	100-Year
127	11.28065996	122.0405034	1.919999957	0.4	0.160	Yolanda	5-Year
128	11.27802141	122.0427792	2.769999981	1.5	2.250	Frank	100-Year
129	11.31038681	122.0656134	2.470000029	0	0.000	Frank	100-Year
130	11.2776315	122.0427364	2.069999933	1.5	2.250	Frank	100-Year
131	11.27739224	122.0433772	2	0.3	0.090	Frank	100-Year
132	11.28987565	122.0344527	1.5	0.4	0.160	Frank	100-Year
133	11.30449777	122.050741	1.269999981	1.3	1.690	Frank	100-Year
134	11.29986441	122.029039	1.080000043	0.8	0.640	Frank	100-Year
135	11.30580716	122.0299628	0	0.8	0.640	Frank	100-Year
136	11.31023291	122.0661018	2.170000076	0	0.000	Frank	100-Year
137	11.30534173	122.030308	0	0.8	0.640	Frank	100-Year
138	11.3255226	122.0432086	1.279999971	1	1.000	Yolanda	5-Year
139	11.31661762	122.0785453	1.340000033	0	0.000	Frank	100-Year
140	11.30897836	122.0597286	1.899999976	0	0.000	Frank	100-Year
141	11.3251024	122.043674	1.149999976	1	1.000	Yolanda	5-Year
142	11.28155452	122.0396479	2.809999943	1.2	1.440	Frank	100-Year
143	11.31011094	122.0656263	2.789999962	0	0.000	Frank	100-Year
144	11.30978466	122.0659928	0.5	0	0.000		
145	11.278001	122.0427287	0	1.5	2.250	Frank	100-Year
146	11.30980751	122.0655949	3.549999952	1.5	2.250	Frank	100-Year
147	11.27779947	122.0427612	0	1.5	2.250	Frank	100-Year
148	11.27791117	122.0430218	2.269999981	1.5	2.250	Frank	100-Year
149	11.28215474	122.0391385	1.769999981	1.7	2.890	Frank	100-Year
150	11.28156001	122.0397796	0	1.5	2.250	Frank	100-Year
151	11.27783903	122.0428077	0	1.5	2.250	Frank	100-Year
152	11.31014706	122.0656944	0	0	0.000	Frank	100-Year
153	11.28106215	122.0402034	1.75999999	1.3	1.690	Frank	100-Year
154	11.28154372	122.0396849	0	1.5	2.250	Frank	100-Year
155	11.31013586	122.0656769	0	0	0.000	Frank	100-Year
156	11.27776297	122.0429924	2.380000114	1.5	2.250	Frank	100-Year
157	11.28188083	122.0394162	2.069999933	0.9	0.810	Frank	100-Year
158	11.28159256	122.0397203	0	1.5	2.250	Frank	100-Year
159	11.28101751	122.0401968	0	1.3	1.690	Frank	100-Year
160	11.31007492	122.0655833	0	0	0.000	Frank	100-Year
161	11.28128529	122.0399336	1.49000001	0.8	0.640	Frank	100-Year
162	11.30997035	122.0656942	0	0	0.000	Frank	100-Year
163	11.28209243	122.0390822	0	1.7	2.890	Frank	100-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/ Date	Rain Return / Scenario
	Lat	Long					
164	11.27799296	122.0427507	0	1.5	2.250	Frank	100-Year
165	11.28223443	122.0391101	3.119999886	1.7	2.890	Frank	100-Year
166	11.30992992	122.0656022	0	0	0.000	Frank	100-Year
167	11.28105655	122.0402014	0	1.3	1.690	Frank	100-Year
168	11.31002281	122.0656428	0	0	0.000	Frank	100-Year
169	11.28159606	122.0396606	0	1.5	2.250	Frank	100-Year
170	11.28207296	122.0391134	0	1.7	2.890	Frank	100-Year
171	11.31801782	122.0575227	4.300000191	0	0.000	Frank	100-Year
172	11.32362359	122.0644364	6.119999886	0	0.000	Frank	100-Year
173	11.31717	122.070481	0.029999999	0	0.000		
174	11.316994	122.072151	0.029999999	0	0.000		
175	11.318176	122.075858	3.829999924	1.6	2.560	Frank	100-Year
176	11.319064	122.079822	5.900000095	0.9	0.810	Frank	100-Year
177	11.319849	122.079616	5.21999979	0.5	0.250	Frank	100-Year
178	11.31696583	122.0709818	0.07	0	0.000		
179	11.31715671	122.0708145	0.029999999	0	0.000		
180	11.31701608	122.0712554	0.059999999	0	0.000		
181	11.31675423	122.0714942	0.029999999	0	0.000		
182	11.31690326	122.0717812	0.029999999	0	0.000		
183	11.31692475	122.0719481	0	0	0.000		
184	11.31792806	122.0780437	8.619999886	2.7	7.290	Frank	100-Year
185	11.31894695	122.0798411	5.929999828	1.24	1.538	Frank	100-Year
186	11.32299257	122.0804546	10.09000015	1.7	2.890	Frank	100-Year
187	11.31818608	122.0768032	6.800000191	2.3	5.290	Frank	100-Year
188	11.31818894	122.0793509	7.829999924	1.35	1.823	Frank	100-Year
189	11.32054568	122.0797462	7.889999866	2.2	4.840	Frank	100-Year
190	11.32254886	122.0803141	9.899999619	2.8	7.840	Frank	100-Year
191	11.32362592	122.0805463	9.840000153	1.2	1.440	Frank	100-Year
192	11.31815051	122.0773142	7.809999943	1.43	2.045	Frank	100-Year
193	11.31964758	122.0794788	8.819999695	1.7	2.890	Frank	100-Year
194	11.32394477	122.0804392	9.460000038	1.55	2.403	Frank	100-Year
195	11.31876341	122.0795495	8.270000458	3	9.000	Frank	100-Year
196	11.32407065	122.0801623	10.18000031	3.75	14.063	Frank	100-Year
197	11.32007935	122.079548	6.070000172	2.1	4.410	Frank	100-Year
198	11.31779008	122.0784641	8.010000229	1.62	2.624	Frank	100-Year
199	11.31777998	122.0784486	0	1.62	2.624	Frank	100-Year
200	11.32285607	122.0805694	9.930000305	0.75	0.563	Frank	100-Year
201	11.3235328	122.0803389	9.5	3	9.000	Frank	100-Year
202	11.3198953	122.0795375	0	1.9	3.610	Frank	100-Year
203	11.31995543	122.0795128	0	1.9	3.610	Frank	100-Year
204	11.30840529	122.0636632	5.71999979	1.9	3.610	Frank	100-Year

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Valid-ation Points (m)	Error	Event/ Date	Rain Return / Scenario
	Lat	Long					
205	11.30894132	122.0637193	6.579999924	1.95	3.803	Frank	100-Year
206	11.30589924	122.0625049	5.329999924	2.3	5.290	Frank	100-Year
207	11.30744691	122.0628362	3.019999981	1.6	2.560	Frank	100-Year
208	11.30658205	122.0626246	5.619999886	3.3	10.890	Frank	100-Year
209	11.31009757	122.0641825	7.309999943	2.7	7.290	Frank	100-Year
210	11.30889487	122.0635158	5.190000057	2.3	5.290	Frank	100-Year
211	11.30919546	122.0637411	6.460000038	2.1	4.410	Frank	100-Year
212	11.30528264	122.0623031	5.010000229	1.9	3.610	Frank	100-Year
213	11.30426901	122.0616273	5.460000038	2.3	5.290	Frank	100-Year
214	11.31008447	122.0644492	8.25	3	9.000	Frank	100-Year
215	11.30641155	122.0625864	5.28000021	2.2	4.840	Frank	100-Year
216	11.30897691	122.0638841	5.840000153	2.1	4.410	Frank	100-Year
217	11.30956618	122.0641681	6.300000191	1.3	1.690	Frank	100-Year
218	11.30964081	122.0643296	6.480000019	0.9	0.810	Frank	100-Year
219	11.30846378	122.0634822	5.650000095	2.2	4.840	Frank	100-Year
220	11.30819975	122.0633818	5.539999962	2.3	5.290	Frank	100-Year

Annex 12. Educational Institutions affected by flooding in Tibiao Floodplain

Table A-12.1. Educational Institutions in Tibiao, Antique affected by flooding in Tibiao Floodplain

Antique				
Tibiao				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Amar Elementary School	Amar	Medium	Medium	Medium
Barangay Tigbaboy Daycare Center	Bandoja	Low	Medium	High
Barangay Daycare Center	Importante			
Importante Elementary School	Importante	Low	Low	Medium
Tigbaboy Elementary School	Importante		Medium	High
Malabor Elementary School	Malabor			
Maranatha Christian Academy	Malabor	Medium	Medium	Medium
St. Nicholas Parish Institute Inc.	Malabor	Low	Low	Medium
Barangay Martinez Daycare Center	Martinez	Medium	Medium	Medium
Martinez Elementary School	Martinez	Medium	Medium	Medium
Tario Lim Memorial College-Polytechnic State College of Antique	Poblacion			
Barangay Poblacion Day Care Center	Poblacion			Low
Guadalupe Parochial School	Poblacion	Medium	Medium	Medium
St. Nicholas Learning Center	Poblacion		Low	Low
Tario Lim Memorial College-Polytechnic State College of Antique	Poblacion			Low
Tario Lim Memorial High School	Poblacion	Low	Low	Medium
Tibiao Central School	Poblacion			Low
Barangay Daycare Center	Santa Justa		Medium	Medium
Sta. Justa Elementary School	Santa Justa	Medium	Medium	Medium
Sta. Justa National High School	Santa Justa		Low	Low

Annex 13. Health Institutions affected by flooding in Tibiao Floodplain

Table A-13.1. Health Institutions in Tibiao, Antique affected by flooding in Tibiao Floodplain

Antique				
Tibiao				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Medical Institutions(Health Center)	Importante			
Brgy. Health Center	Martinez	Low	Low	Medium
Medical Institutions	Poblacion		Low	Low
Medical Institutions	Poblacion	Low	Low	Medium

Annex 14. UPC Phil-LiDAR 1 Team Composition

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