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

LiDAR Surveys and Flood Mapping of Tigbao River

University of the Philippines Training Center for Applied Geodesy and Photogrammetry
Ateneo de Zamboanga University

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ADNU	Ateneo de Zamboanga University
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
CSU	Caraga State University
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord

IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
NAMRIA	National Mapping and Resource Information Authority
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: INTRODUCTION

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.

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

The implementing partner university for the Phil-LiDAR 1 Program is the Ateneo de Zamboanga University (ADZU). ADZU 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 Tigbao river basin in the Zamboanga Peninsula Region. The university is located in Zamboanga City in the province of Zamboanga Sibugay.

1.2 Overview of the Mainit-Tubay River Basin

Tigbao River Basin is located in the lower area of Zamboanga del Sur and encompasses the Barangays of Licomo, Tictapul, San Pedro, and Tigpalayas.. It has a catchment area of approximately 102.56 km2 covering the uplands and coastlines of Barangay Licomo and Tictapul based on the Flood Modeling Component and 80MCM annual run-off based from the DENR-RBCO.

Its main stem, the Tigbao River channel, with an estimated length of 16km is among the river systems in Zamboanga City. Tigbao River lies on the extreme northeastern part of Zamboanga City, cutting through the boundary between the city and Zamboanga Sibugay. It is bounded by Brgy. San Pedro in the north, Municipality of Sibuco in the west, Zamboanga City in the south, and Moro Gulf in the east.

With moderately forested watershed, Tigbao River produces 271, 296 cubic meters of water daily. It serves as the prime water source for domestic and agricultural use for the local residents. This flow rate was measured in June 2016 at the Tigbao Bridge (7.442090N, 122.320507E) in Licomo.

Its water, according to its beneficial use is categorized as Class B with uses for surface water recreation and drinking according to the Department of Environmental Management.

Tigbao is rich in natural resources. During the Spanish era in Zamboanga, farmers planted crops under the Spanish rule. In the uplands of Tictapul were grown crops such as coconut, abaca and acacia. Later, rubber trees, bananas and different varieties of rice were introduced by the Americans. However, these colonizers were also responsible of the exploitation of Tigbao's indigenous resources. Logging operations owned by American and Chinese businessmen were allowed in the 1920's and continued for more years. Today, the watershed is in recovery and satellite images reveal considerable portions of green, reforested areas.

The river also drains into a wide stretch of mangrove areas. In 1981, under Proclamation 2152, these mangrove areas starting from the coastlines of Tagasilay to Tigbao's mouth in Licomo, including east of the Vitali Island, were declared as Mangrove Swamp Forest Reserves.

Figure 1. Mangrove forest in the coastlines of Vitali to Licomo

However, areas within the immediate vicinity of the Tigbao River Basin such as Barangays Tigpalay and San Pedro are classified into high susceptibility to flooding as identified by the Mines and Geosciences Regional Office. It has an estimated population of 2,651 based from LGU Zamboanga City which suffered flash floods due to immense rainfall produced by Typhoon Quedan last October 8, 2013, which put them under the state of calamity and affected 2,869 families.

Licomo and Tictapul has high flood susceptibility rate according to an assessment conducted by the Environmental Management Bureau of DENR 9. This is on account of the regular swelling of Tigbao during rainy seasons. However,Licomo and Tictapul have population density of 4 people/ha and 18 people/ha respectively, relatively smaller compared to the 87/ha and 96/ha of Guiwan and Tetuan, both lie in the floodplains of Tumaga (PSA 2015). Though Licomo and Tictapul have high flood susceptibility rates, they have lesser exposed population and thus a lower flood risk index. Most floods in Tigbao are considerably of lesser damage and casualties compared to other rivers.

In July 2014, a lady farmer was carried away dead by a flash flood in Licomo. She was going home early with her husband from the farm because of the heavy rain and was unfortunately caught in the rushing water while attempting to cross the river. It is also noteworthy that Tigbao Bridge, located along the national highway, is the only usable bridge in the entire river system.

Figure 2.Tigbao Bridge in Licomo, ZC

Tigbao was named after the "tigbao" grass which was abundant in the area several years back. It's a tall grass that grows in a wide range of soil types form prairie soils or grassland to sandy loam and is usually found in riverbanks. It also thrives in a wide rainfall range and survives long drought periods.

Sources:
Biodiversity Management Bureau, DENR
Inquirer.net
Wikipedia.org
Zamboanga.com
Zamboanga.gov.ph
Zamboangacity.gov.ph
Zamboanga Today Online

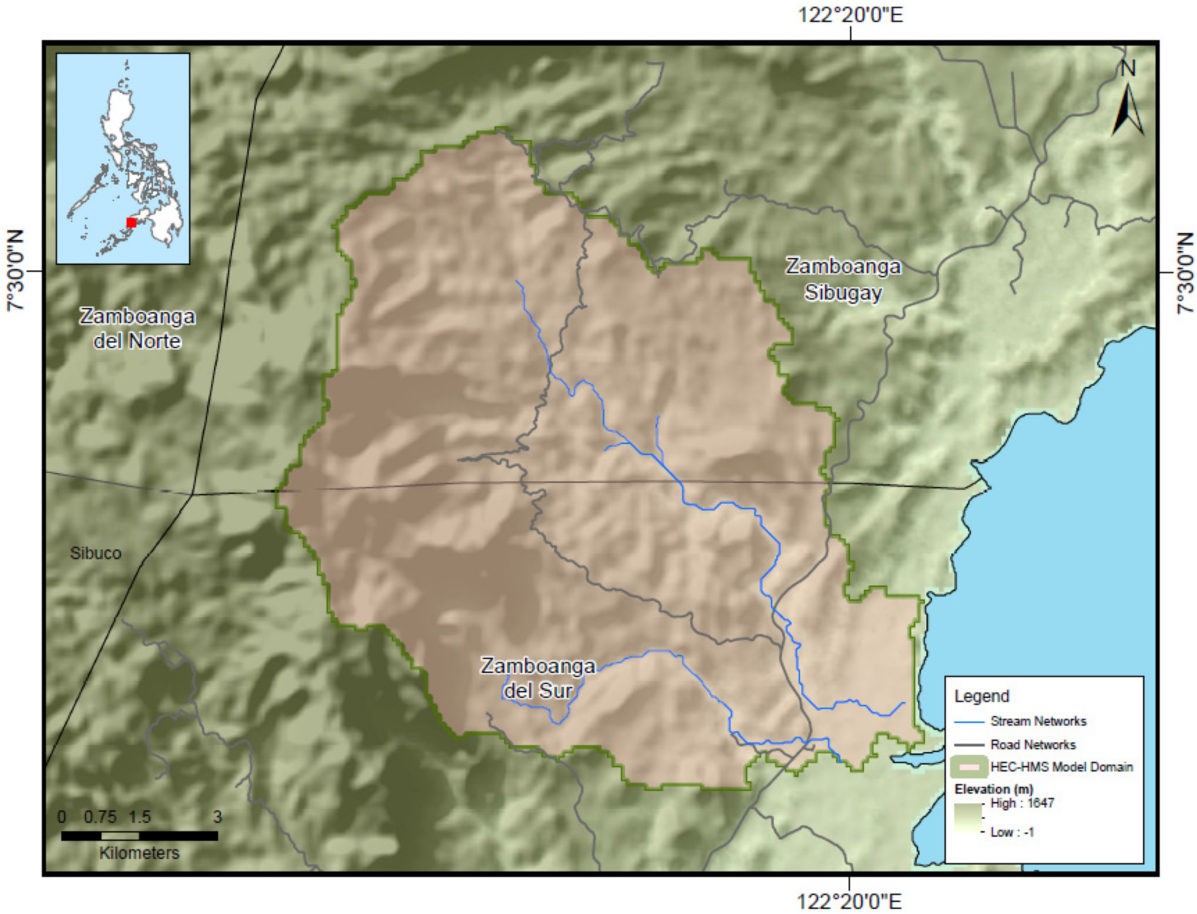


Figure 3.Map of Tigbao River Basin (in brown)

CHAPTER 2: LIDAR DATA ACQUISITION IN SAN JOSE FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Engr. Grace B. Sinadjan, Ms. Sandra C. Poblete

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 Tigbao Floodplain in Zamboanga City. These missions were planned for 12 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 4 shows the flight plan for Tigbao Floodplain survey.

Table 1. Flight planning parameters for Pegasus 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)
BLK75C	1000/1100	15/25	50	200	30	130	5
BLK75D	1000/1100	15/25	50	200	30	130	5
BLK75E	1000/1100	15/25	50	200	30	130	5
BLK75FS	1000/1100	15/25	50	200	30	130	5
BLK75GS	1100	15	50	200	30	130	5

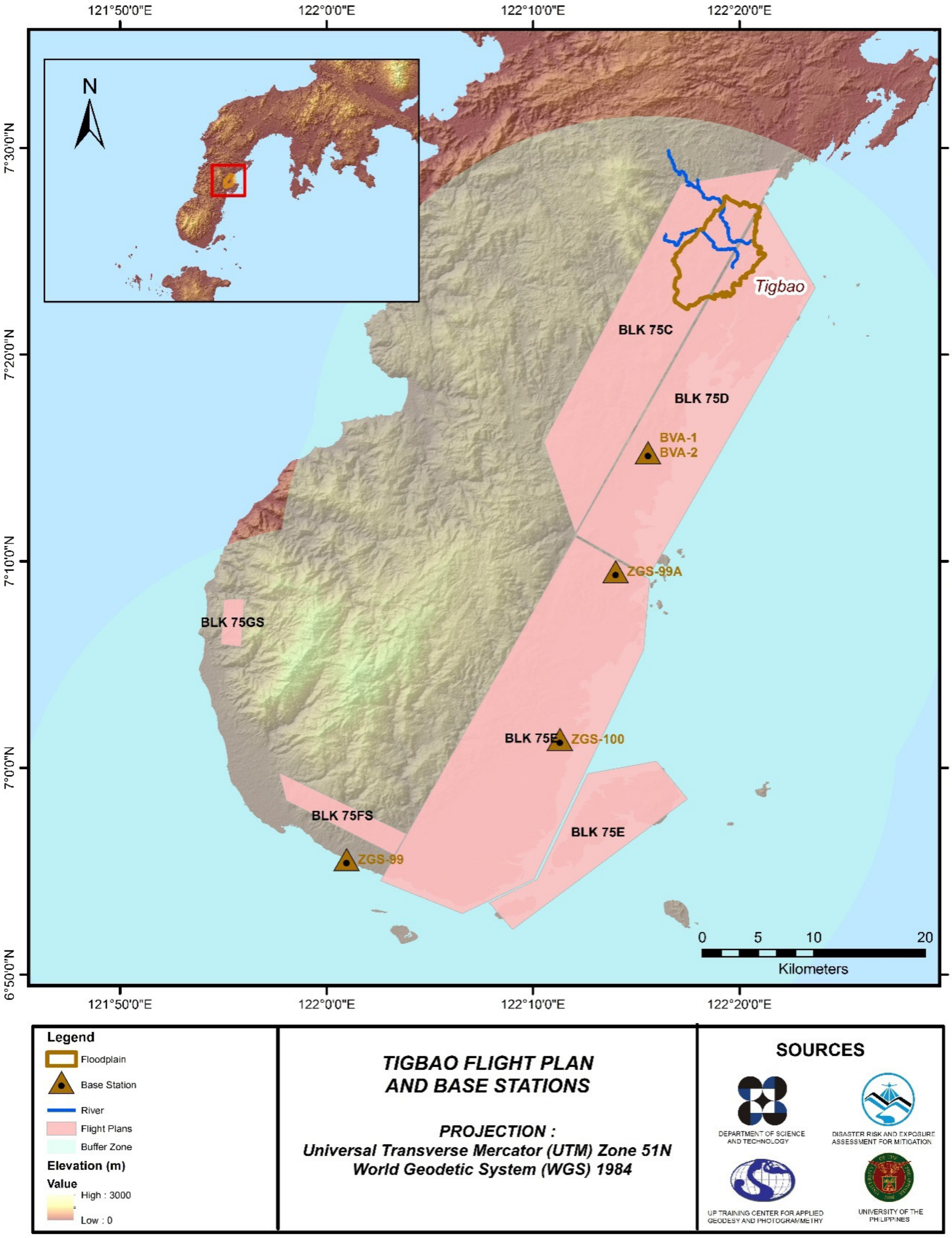
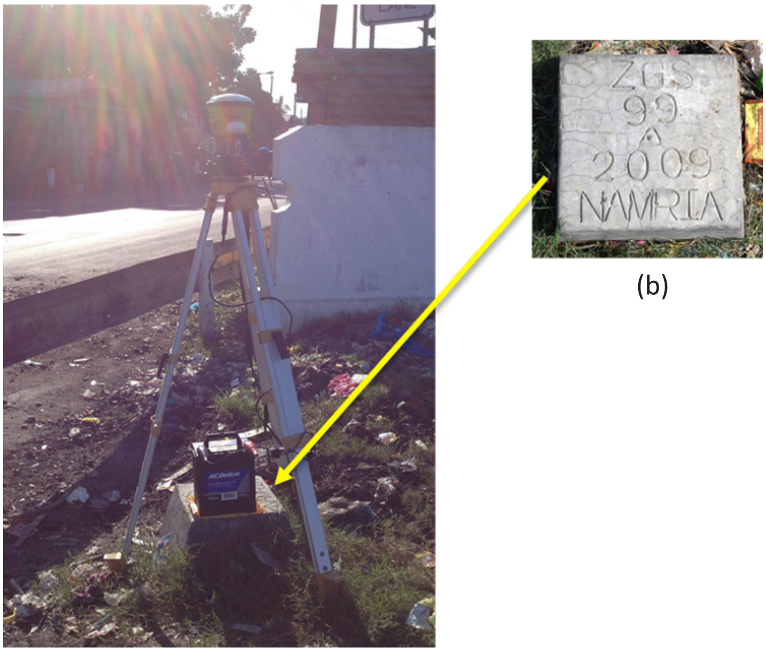


Figure 4. Flight plan and base stations used to cover Tigbao Floodplain.

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA ground control points: ZGS-99 and ZGS-100 which are of second (2nd) order accuracy. The project team also established three (3) ground control points: BVA-1, BVA-2 and ZGS-99A. The certifications for the NAMRIA reference points are found in Annex 2 while the baseline processing reports for the established control points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (February 5 to 11, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TRIMBLE SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tigbao Floodplain are shown in Figure 4.

Figure 5 to Figure 8 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 6 present the details about the following NAMRIA control stations, while Table 7 lists all ground control points occupied during the acquisition together with the corresponding dates of utilization.



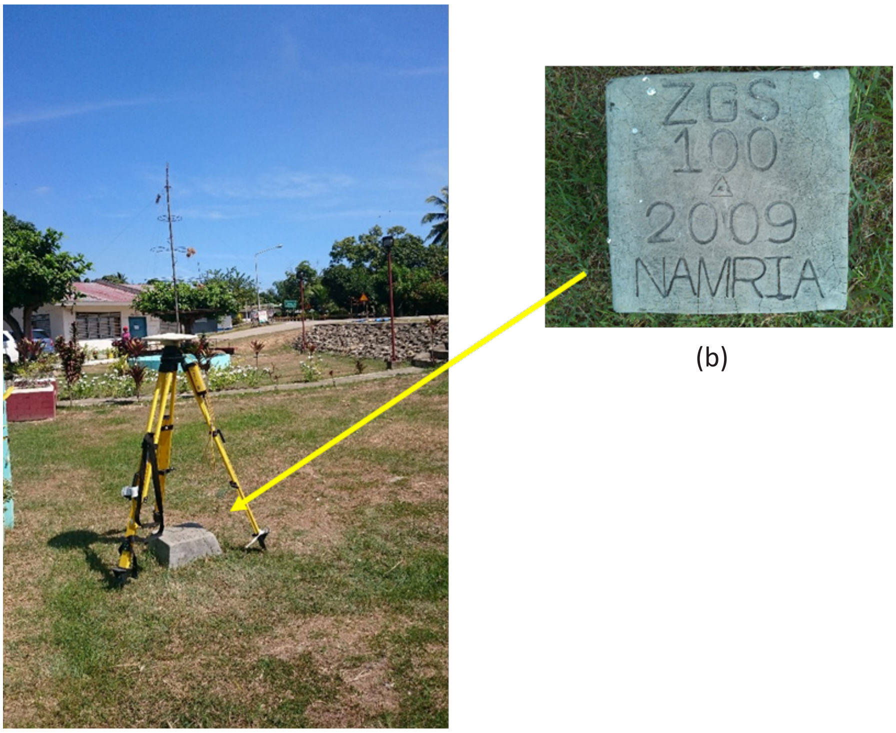
(b)

(a)

Figure 5. GPS set-up over ZGS-99 beside the seawall in Calarian, Zamboanga City (a) and NAMRIA reference point ZGS-99 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point ZGS-99 used as base station for the LiDAR acquisition.

Station Name	**ZGS-99**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	6° 55’ 37.48971” North 122° 0’ 52.66431” East 8.149 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	391,103.346 meters 766,020.391 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	6° 55’ 34.07737” North 122° 0’ 58.23072” East 72.23 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	391,141.46 meters 765,752.27 meters

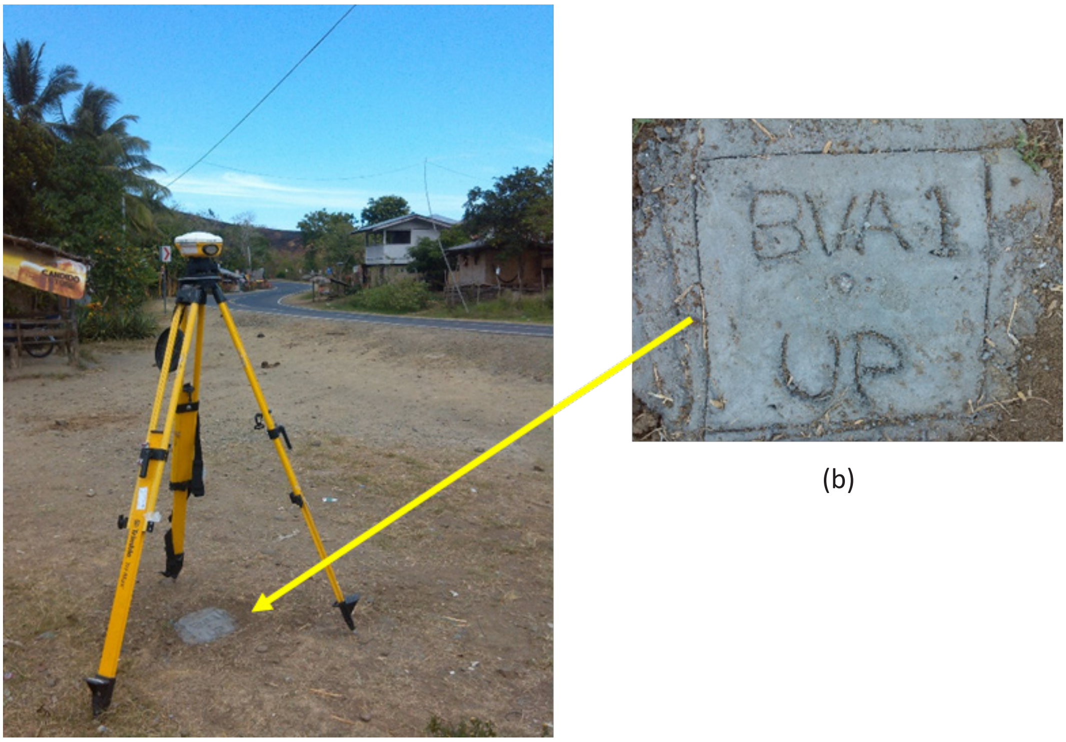


(a) (b)

Figure 6. GPS set-up over ZGS-100 in Brgy. Manicahan, Zamboanga City located at the road intersections going to Cagayan de Oro, Butuan City and Iligan City (a) and NAMRIA reference point ZGS-100 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point ZGS-100 used as base station for the LiDAR acquisition.

Station Name	ZGS-100	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 1’ 26.72368” North 122° 11’ 12.74401” East 11.27 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	410,158.521 meters 776,712.542 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 1’ 23.30149” North 122° 11’ 18.30044” East 75.603 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	410,189.97 meters 776,440.68 meters



(b)

(a)

Figure 7. GPS set-up over BVA-1 at Brgy. Buenavista, Zamboanga City (a) and reference point BVA-1 (b) as established by the field team.

Table 4. Details of the established control point BVA-1 used as base station for the LiDAR acquisition.

Station Name	BVA-1	
Order of Accuracy	2nd (established control point)	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 15' 19.31910" North 122° 15' 28.78738" East 82.446 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	417,939.856 meters 802,333.522 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 15' 15.84241" North 122° 15' 34.32212" East 146.526 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	418,087.142 meters 801,995.112 meters

(a)

(b)

Figure 8. GPS set-up over BVA-2 as established near a waiting shed in Brgy. Buenavista, Zamboanga City (a) and reference point BVA-2 (b) as established by the field team.

Table 5. Details of the established control point BVA-2 used as base station for the LiDAR acquisition.

Station Name	**BVA-2**	
Order of Accuracy	**2nd (established control point)**	
Relative Error (Horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°15’19.25198” North 122°15’28.73303” East 82.524 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°15’15.77529” North 122°15’34.26776” East 146.603 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	418,085.472 meters 801,993.053 meters

Table 6. Details of the established control point ZGS-99A used as base station for the LiDAR acquisition.

Station Name	ZGS-99A	
Order of Accuracy	2nd (established control point)	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 09' 33.60926" North 122° 13' 54.54820" East 124.333 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 09' 30.15553" North 122° 14' 00.09187" East 188.527 meters
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	415179.269 meters 791383.716 meters

Table 7. Ground Control Points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
February 6, 2015	2537P	1BLK75C37A	BVA-1, BVA-2
February 6, 2015	2539P	1BLK75C37B	BVA-1, BVA-2
February 8, 2015	2545P	1BLK75C39A	ZGS-100, BVA-1
February 11, 2015	2557P	1BLK75S42A	ZGS-99, ZGS-99A

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Tigbao floodplain, for a total of sixteen hours and two minutes (16+2) of flying time for RP-C9022. All missions were acquired using the Pegasus LiDAR system. Table 8 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 9 presents the actual parameters used during the LiDAR data acquisition.

Table 8. Flight missions for LiDAR data acquisition in Tigbao 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
February 6, 2015	2537P	315.50	469.74	47.97	421.77	811	3	5
February 6, 2015	2539P	315.50	249.33	0.9974	248.33	439	4	23
February 8, 2015	2545P	68.50	284.69	9.05	275.64	609	4	11
February 11, 2015	2557P	99.50	250.97	11.20	239.77	474	4	23
TOTAL		799	1254.73	69.22	1185.51	2333	16	2

Table 9. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (kHz)	Scan Frequency (Hz)	Average Speed (Kts)	Average Turn Time (Minutes)
2537P	1100	25	50	200	30	130	5
2539P	1100	25	50	200	30	130	5
2545P	1000	15	50	200	30	130	5
2557P	1100	15	50	200	30	130	5

2.4 Survey Coverage

This certain LiDAR acquisition survey covered the Tigbao Floodplain (See Annex 7). Tigbao floodplain is located along the province of Zamboanga del Sur with majority of the floodplain situated within the municipality of Zamboanga City. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 10. The actual coverage of the LiDAR acquisition for Tigbao Floodplain is presented in Figure 9.

Table 10. List of municipalities and cities surveyed during Tigbao Floodplain LiDAR survey.

Province	Municipality/ City	Area of Municipality/City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Zamboanga del Sur	Zamboanga City	1461.04	505.46	34.60%
Zamboanga Sibugay	Tungawan	441.86	64.96	14.70%
Zamboanga del Norte	Sibuco	600.1	0.6598	0.11%
Total		2503.00	571.080	22.82%

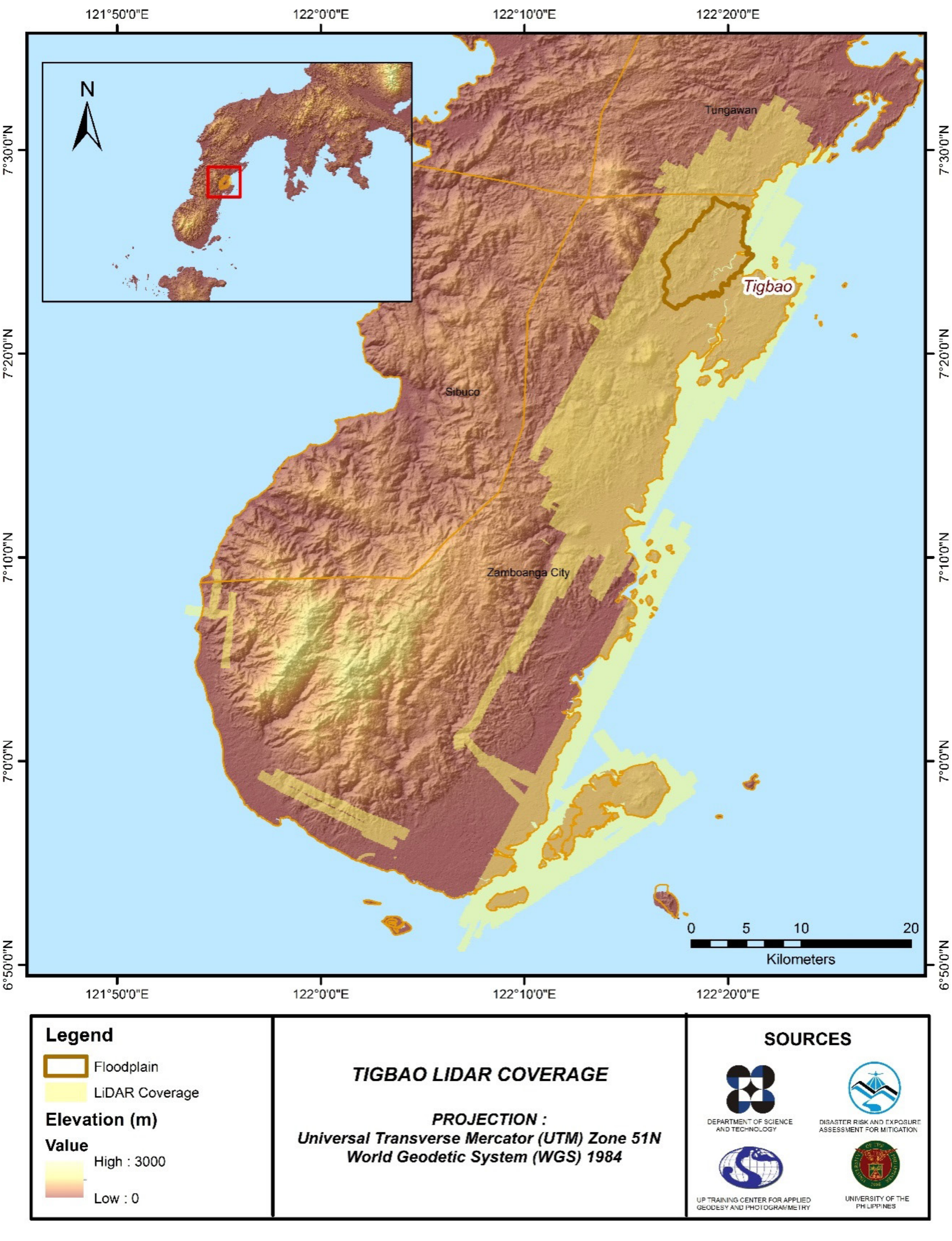


Figure 9. Actual LiDAR survey coverage for Tigbao Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR TIGBAO 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).

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 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,which are the minimum point density, vertical and horizontal accuracies, are met. 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 are 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 10.

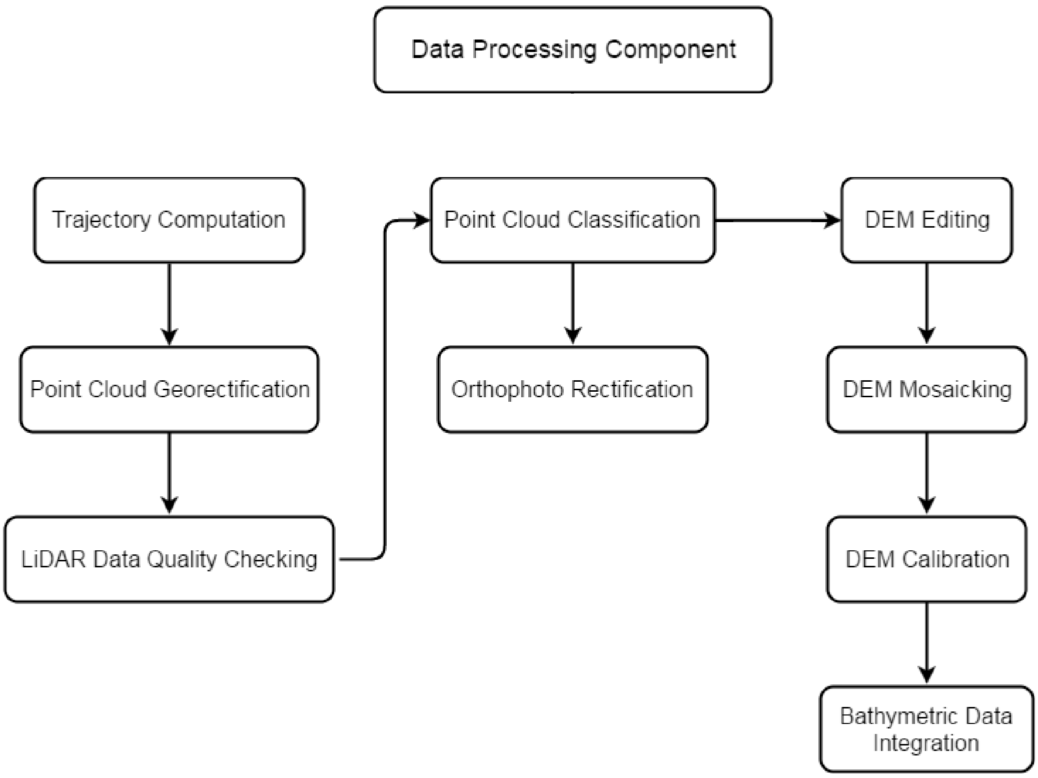


Figure 10. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Tigbao floodplain can be found in Annex 5. Data Transfer Sheets. Missions flown during the survey conducted in February 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Zamboanga City. The Data Acquisition Component (DAC) transferred a total of 100.10 Gigabytes of Range data, 0.952 Gigabytes of POS data, 32.64 Megabytes of GPS base station data, and 154.20 Gigabytes of raw image data to the data server on March 3, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tigbao was fully transferred on March 3, 2015, as indicated in the Data Transfer Sheets for Tigbao Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 2537P, one of the Tigbaoflights, which is the North, East, and Down position RMSE values are shown in Figure 11. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell onFebruary 6, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

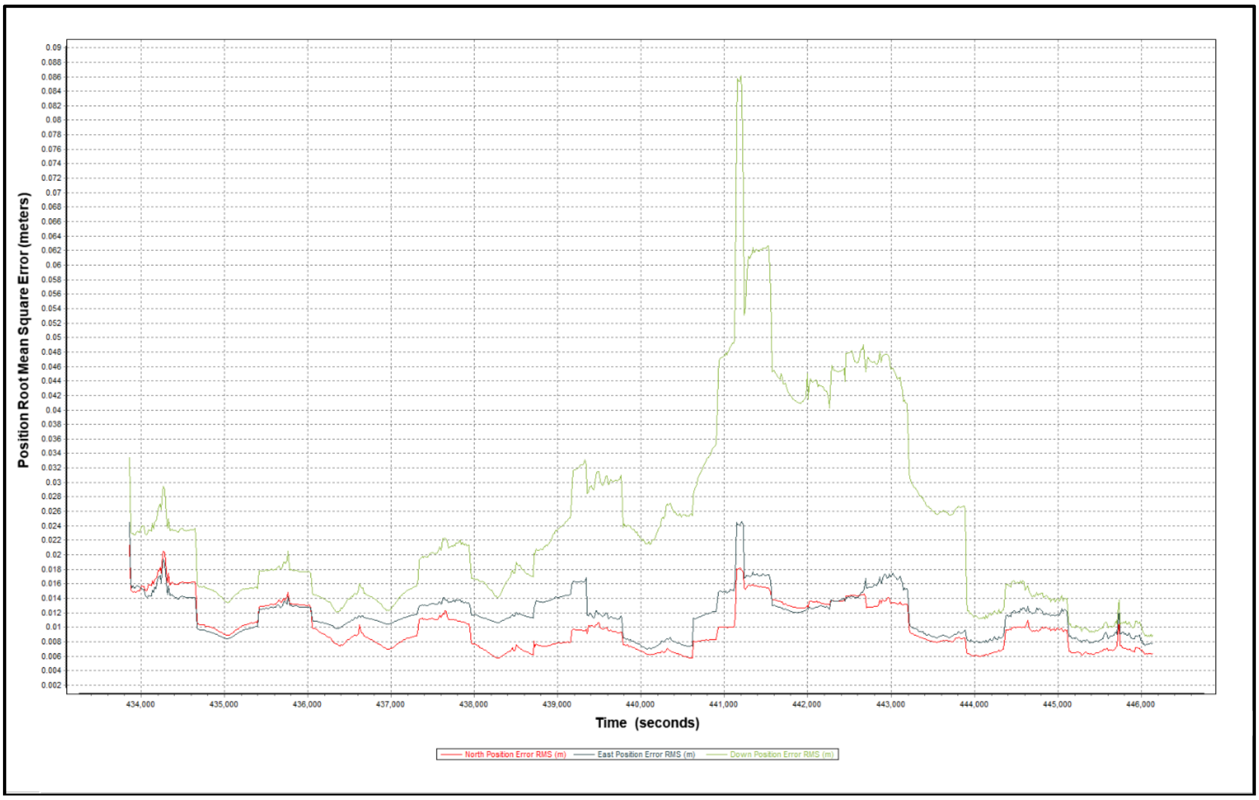


Figure 11. Smoothed Performance Metrics of a Tigbao Flight 2537P.

The time of flight was from 433900 seconds to 446200 seconds, which corresponds to morning of February 6, 2015. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 11 shows that the North position RMSE peaks at 2.22centimeters, the East position RMSE peaks at 2.40centimeters, and the Down position RMSE peaks at 8.60centimeters, which are within the prescribed accuracies described in the methodology.

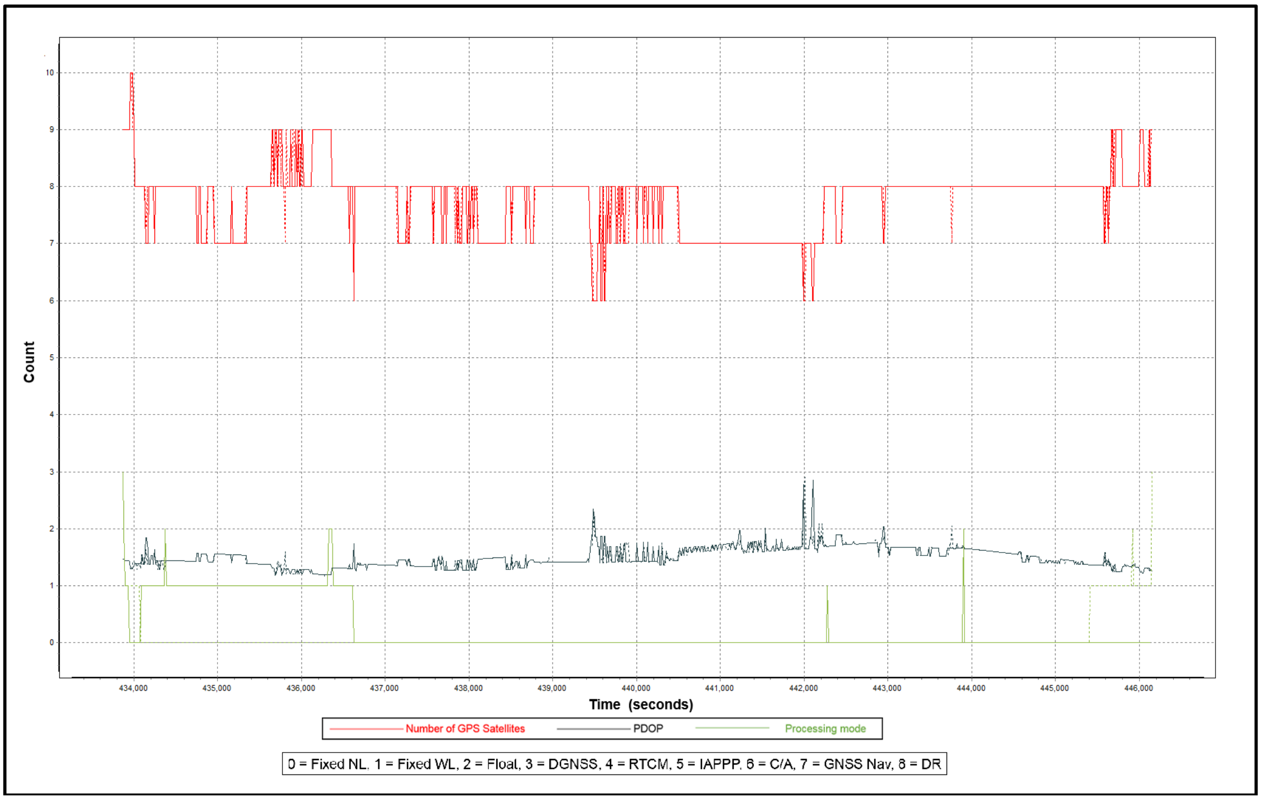


Figure 12. Solution Status Parameters of Tigbao Flight 2537P.

The Solution Status parameters of flight 2537P, one of the Tigbao flights, which indicate the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 12. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Most of the time, the number of satellites tracked was between 7 and 8. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Tigbao flights is shown in Figure 13.

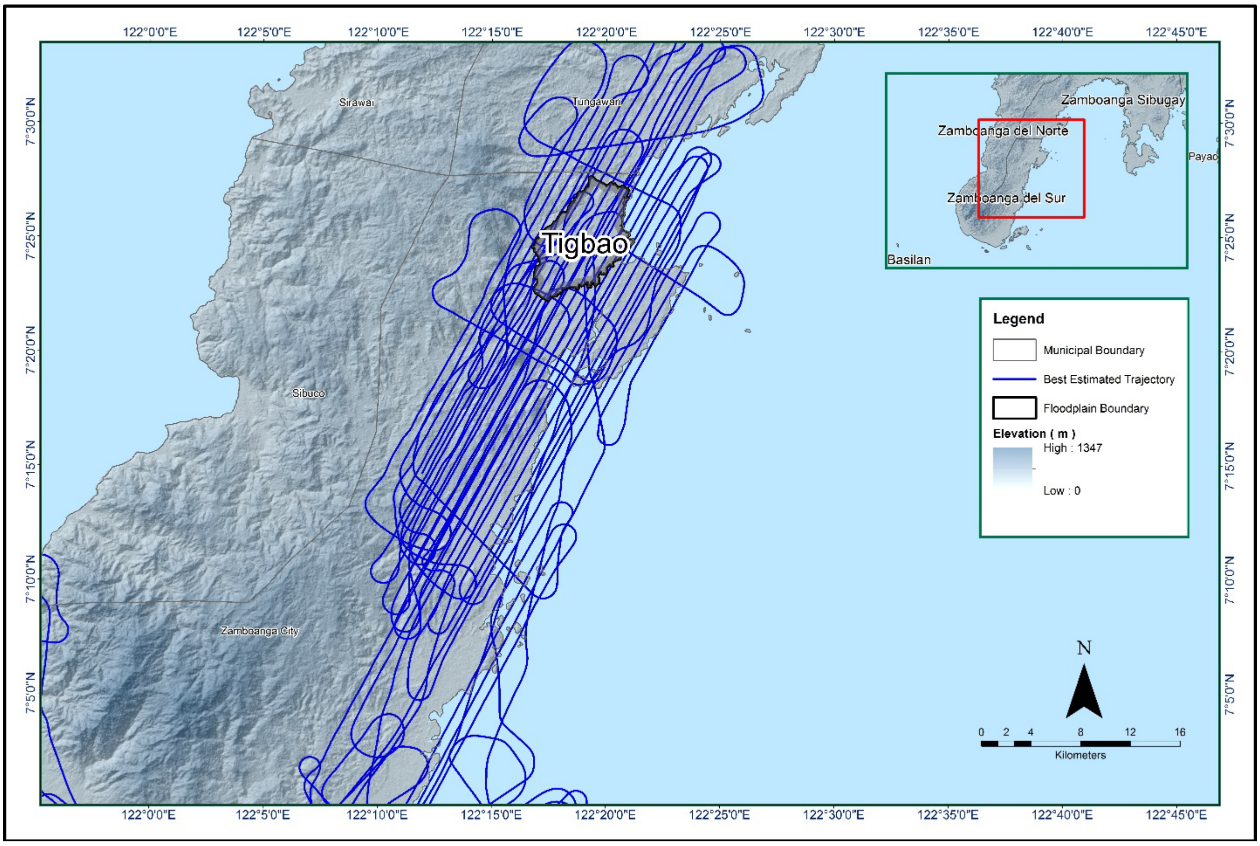


Figure 13.Best estimated trajectory of the LiDAR missions conducted over the Tigbao Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 40 flight lines, with each flight line containing two channels, since the Pegasus systems contain two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tigbao Floodplain are given in Table 11.

Table 11. Self-Calibration Results values for Tigbao flights.

Parameter	Value
Boresight Correction stdev(<0.001degrees)	0.000178
IMU Attitude Correction Roll and Pitch Corrections stdev(<0.001degrees)	0.000630
GPS Position Z-correction stdev(<0.01meters)	0.0043

The optimum accuracy was obtained for all Tigbao flights based on the computed standard deviationsof the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex 8.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data is shown in Figure 14. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

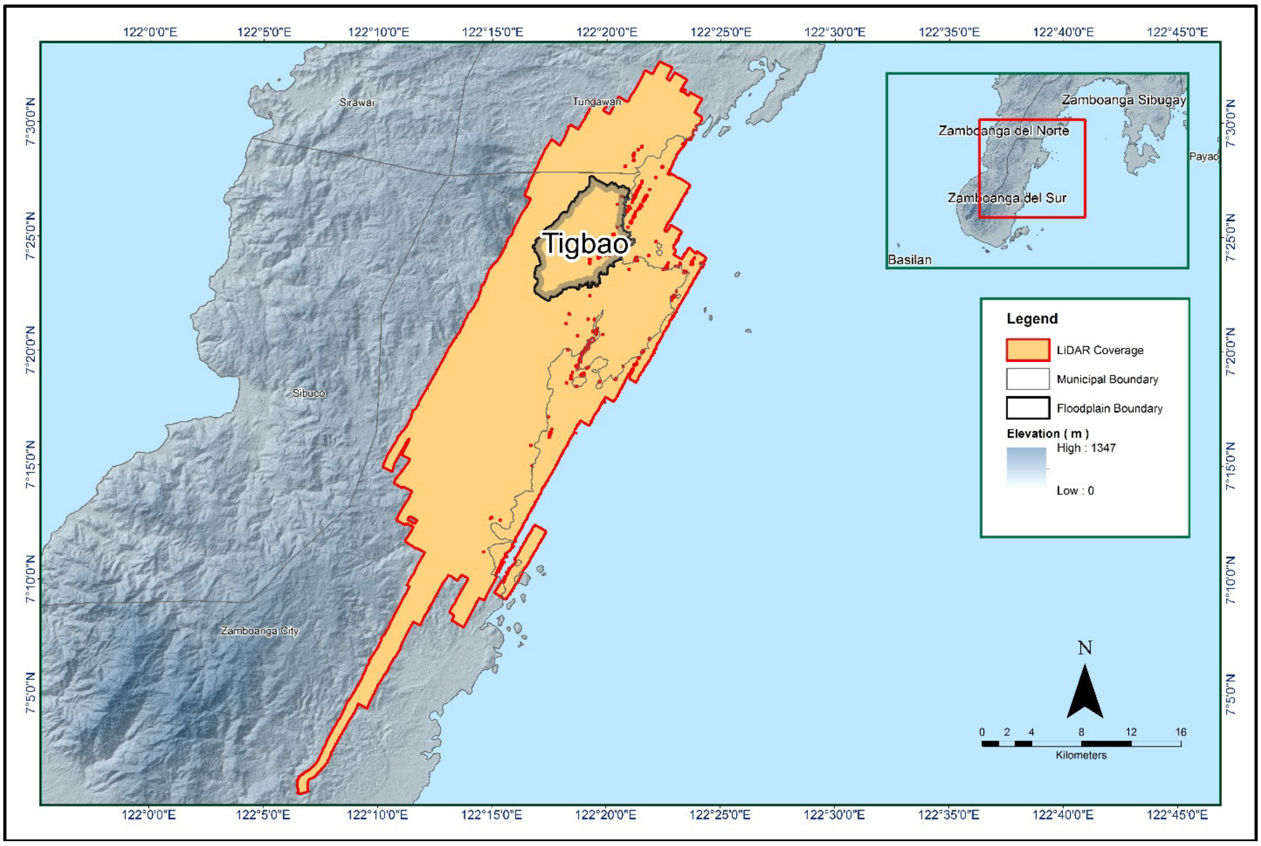


Figure 14. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Tigbao Floodplain.

The total area covered by the Tigbao missions is 578.26 sq.km that is comprised of four (4) flight acquisitions grouped and merged into two (2) blocks as shown in Table 12.

Table 12. List of LiDAR blocks for Tigbao Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Zamboanga_Blk75C	2537P	382.73
	2545P	
	2557P	
Zamboanga_Blk75D	2539P	195.53
	2557P	
TOTAL		**578.26 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 15. Since the Pegasus system employ two channels, an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines are expected.

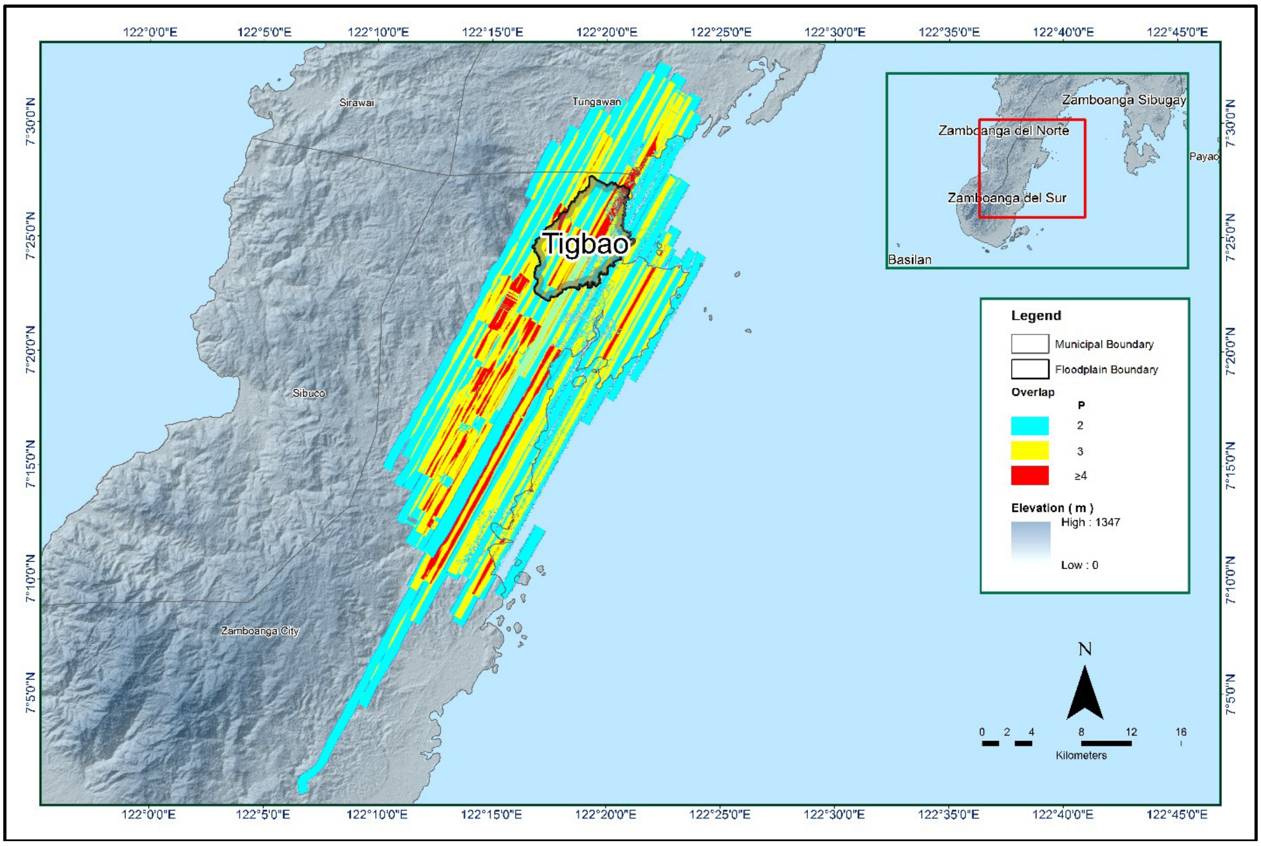


Figure 15. Image of data overlap for Tigbao Floodplain.

The overlap statistics per block for the Tigbao Floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 40.89% and 54.88% respectively, 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 16. It was determined that all LiDAR data for Tigbao Floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.455 points per square meter.

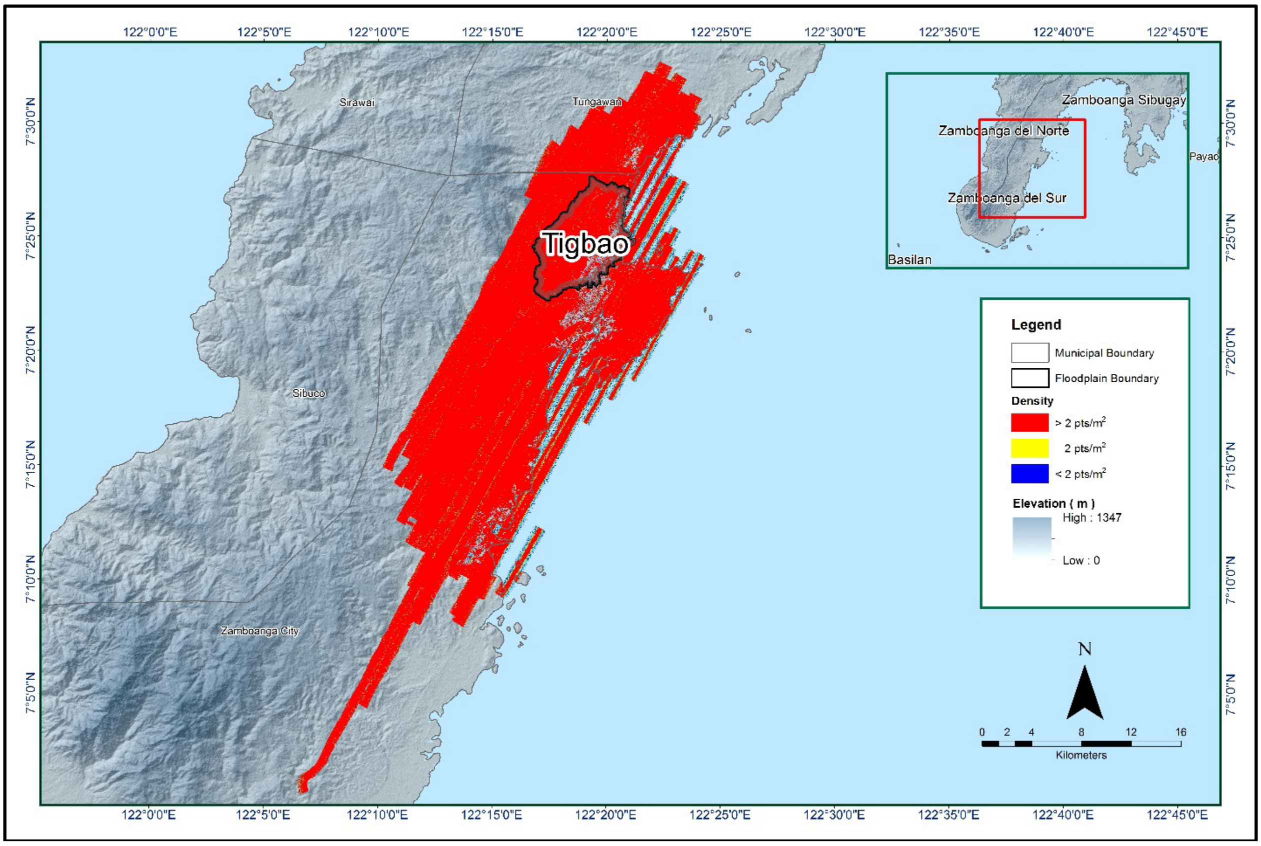


Figure 16. Pulse density map of merged LiDAR data for Tigbao Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 17. 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.

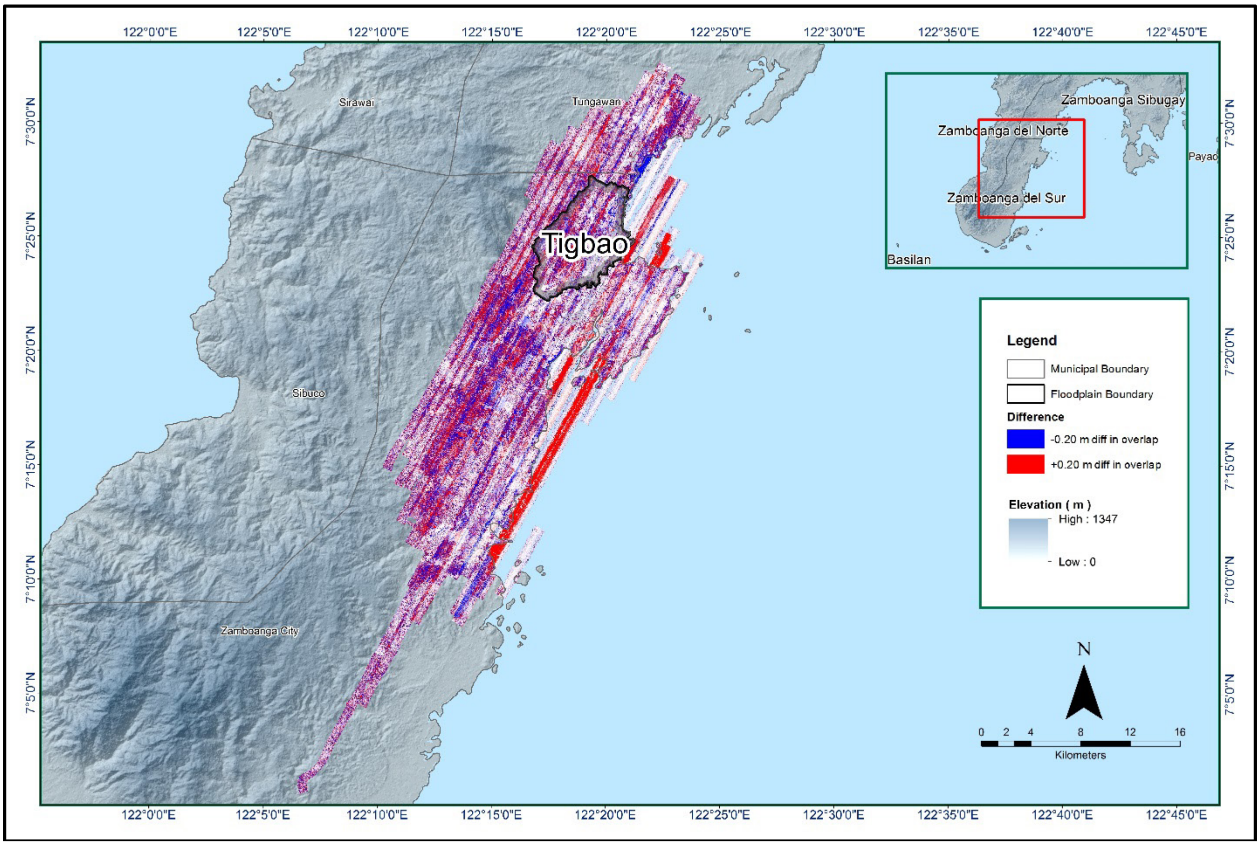


Figure 17. Elevation difference map between flight lines for Tigbao Floodplain.

A screen capture of the processed LAS data from a Tigbao flight 2537P loaded in QT Modeler is shown in Figure 18. 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.

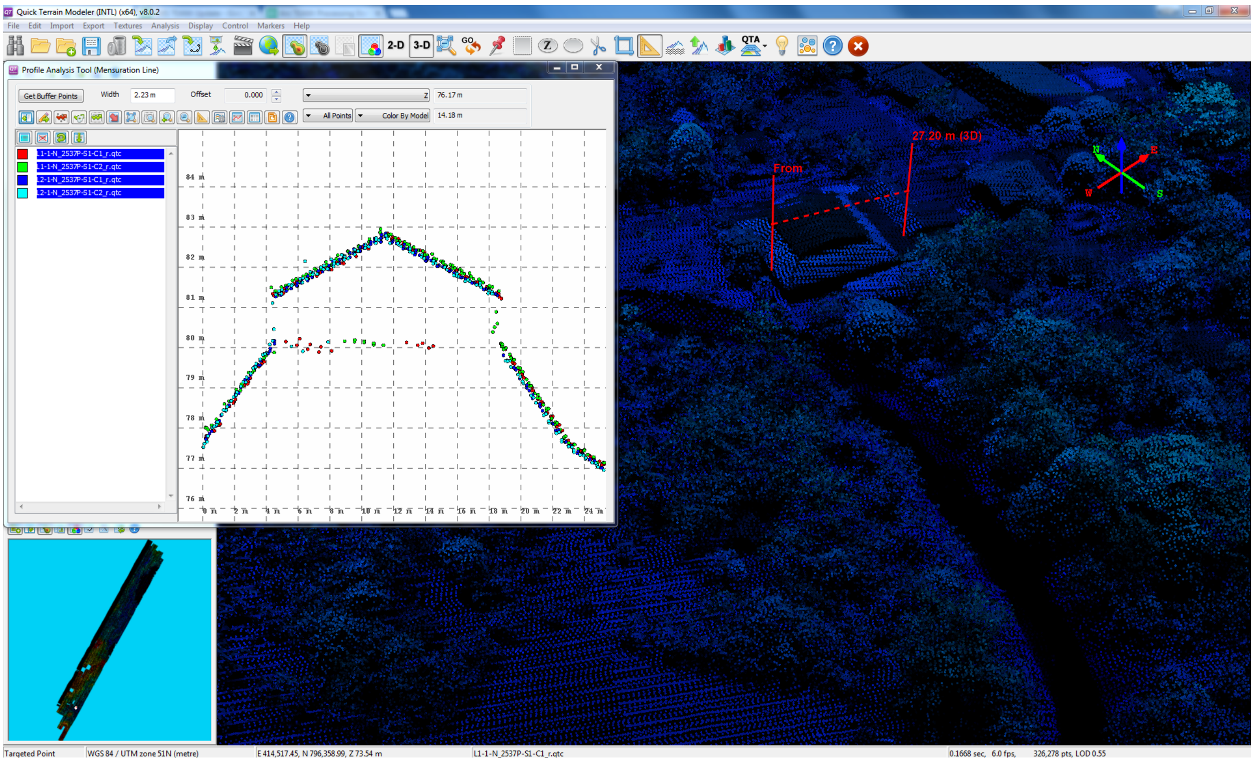


Figure 18.Quality checking for a Tigbao flight 2537P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 16. Tigbao classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	634,496,404
Low Vegetation	589,517,503
Medium Vegetation	1,014,650,330
High Vegetation	1,740,353,184
Building	18,099,718

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tigbao Floodplain is shown in Figure 19. A total of 781 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 13. The point cloud has a maximum and minimum height of 587.21 meters and 67.64 meters respectively.

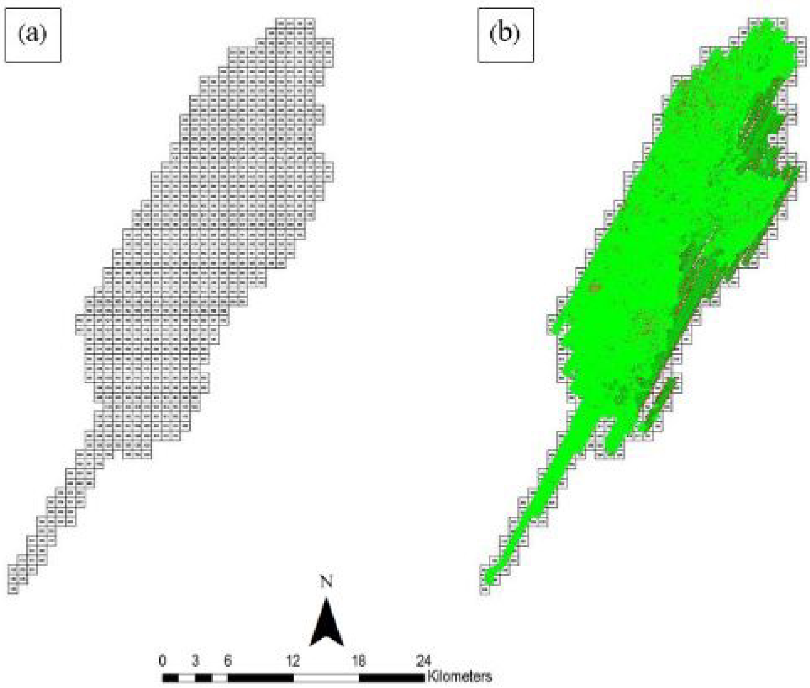


Figure 19. Tiles for Tigbao Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 20. 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.

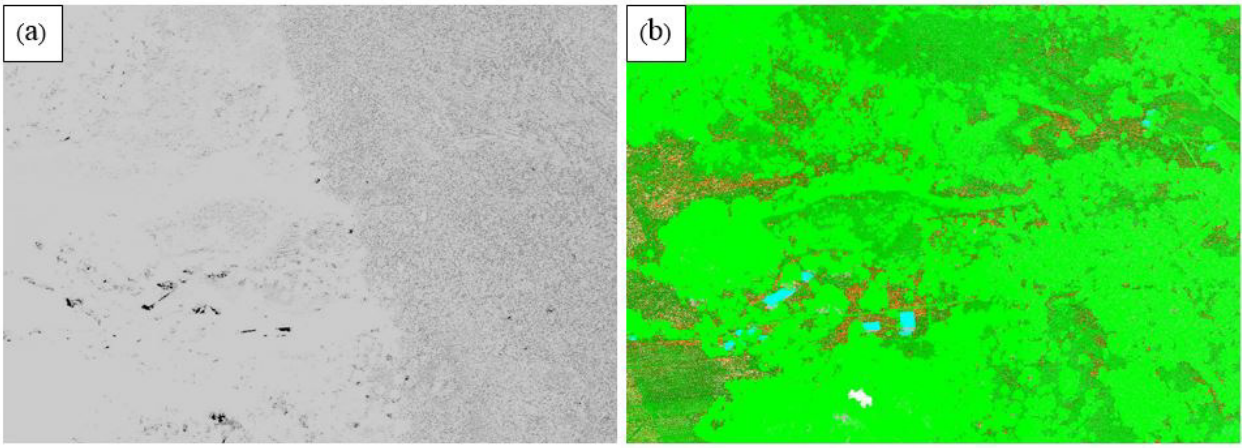


Figure 20. Point cloud before (a) and after (b) classification.

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 21. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

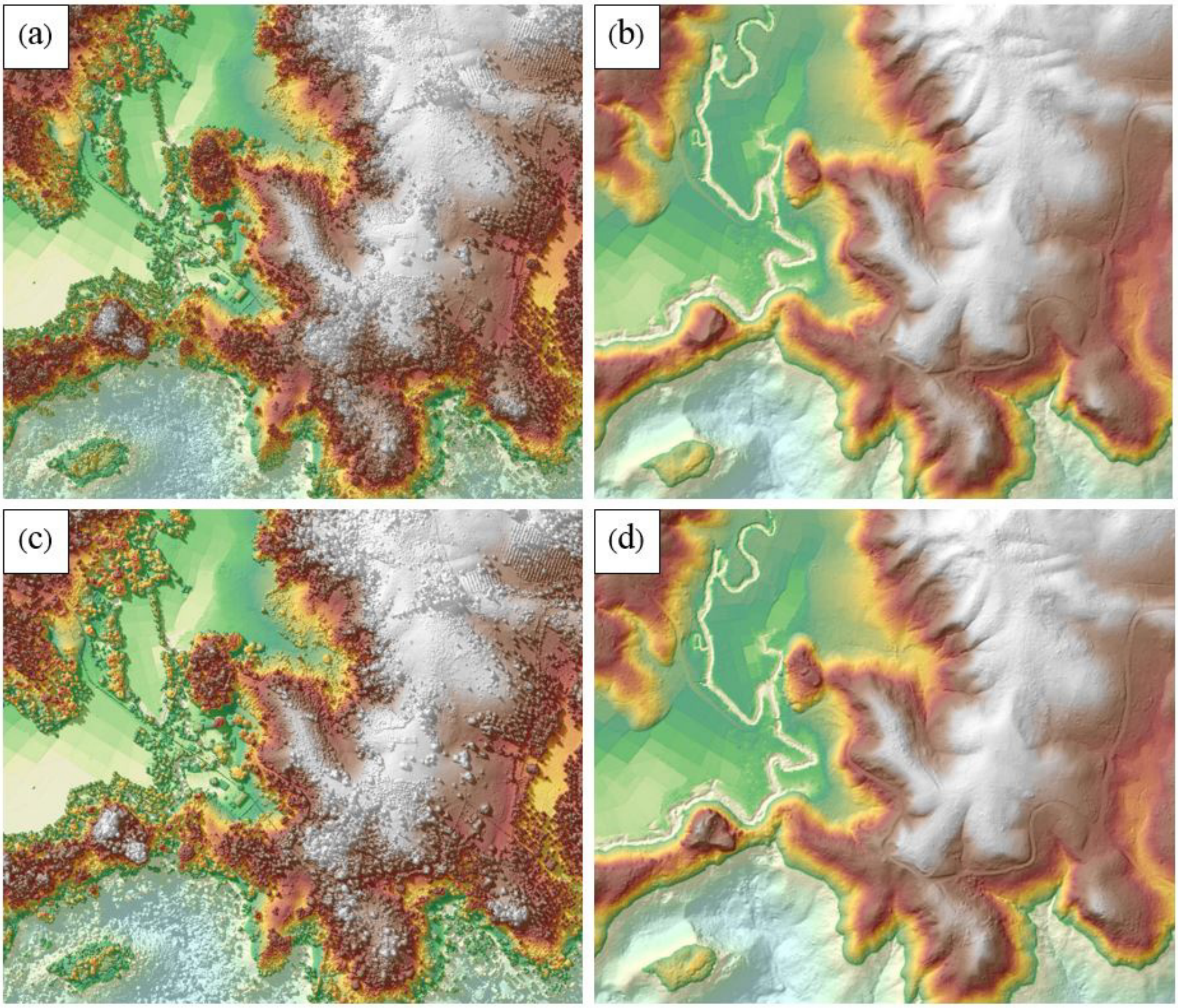


Figure 21. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tigbao Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 746 1km by 1km tiles area covered by Tigbao floodplain is shown in Figure 22. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Tigbao Floodplain has a total of 580.23 sq.km orthophotogaph coverage comprised of 1,728 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 23.

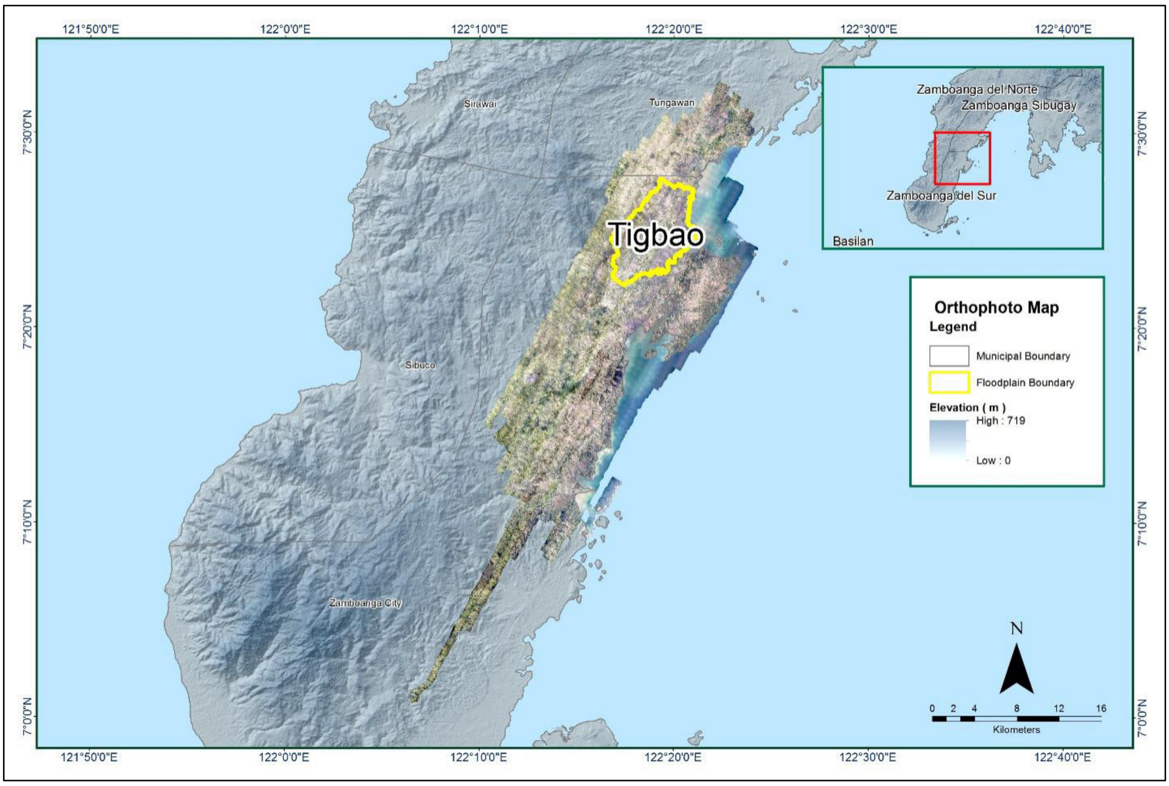


Figure 22. Tigbao Floodplain with available orthophotographs.

Figure 23. Sample orthophotograph tiles for Tigbao Floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Tigbao Floodplain. These blocks are composed of Zamboanga blocks with a total area of 578.26 square kilometers. Table 14 shows the name and corresponding area of each block in square kilometers.

Table 17. LiDAR blocks with its corresponding area

LiDAR Blocks	Area (sq.km)
Zamboanga_Blk75C	382.73
Zamboanga_Blk75D	195.53
TOTAL	**578.26 sq.km**

Portions of DTM before and after manual editing are shown in Figure 24. The river embankment (Figure 24a) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 24b) to allow the correct flow of water. The bridge (Figure 24c) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 24d) in order to hydrologically correct the river.

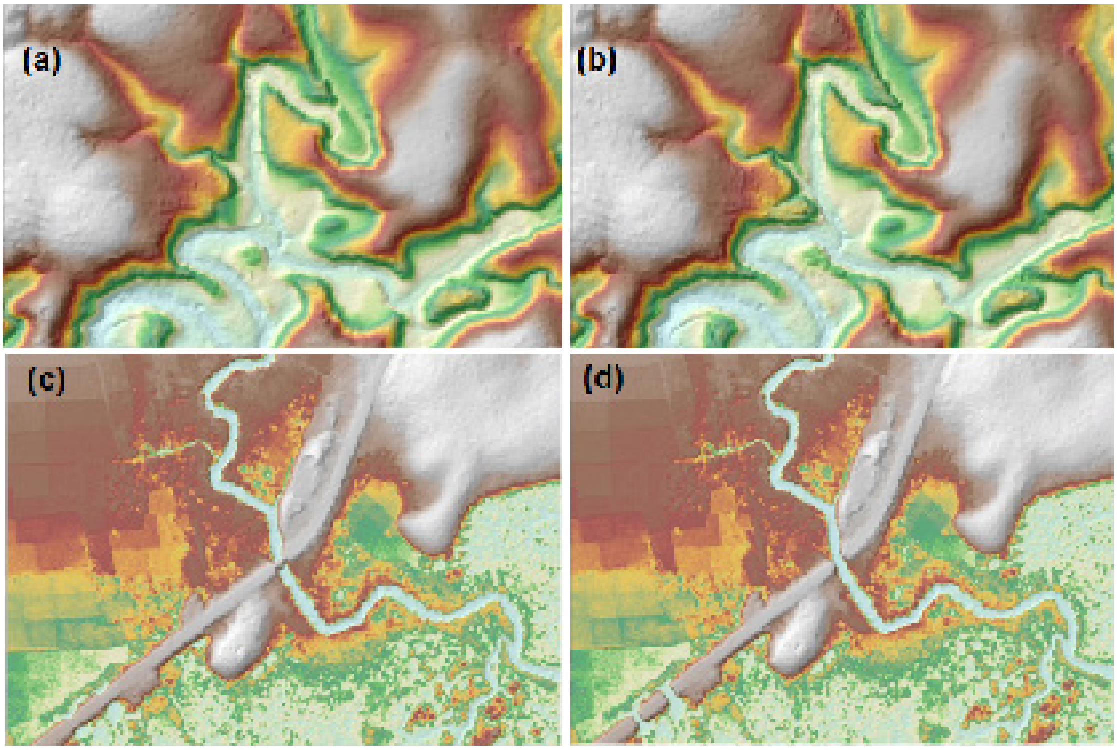


Figure 24.Portions in the DTM of Tigbao Floodplain – a river embankment before (a) and after (b) data retrieval; a road before (c) and after (d) manual editing.

3.9 Mosaicking of Blocks

Simultaneous mosaicking was done to all the available LiDAR data (Zamboanga_Blk75G, Zamboanga_Blk75F, Zamboanga_Blk75E, Zamboanga_Blk75F_additional, Zamboanga_Blk75D, Zamboanga_Blk75C and Zamboanga_Sacol). Zamboanga_Blk75G was used as the reference block at the start of mosaicking because it is the first available LiDAR data. The shift values applied to each LiDAR block during mosaicking is shown in Table 15.

Mosaicked LiDAR DTM for Tigbao Floodplain is shown in Figure 25. It can be seen that the entire Tigbao Floodplain is 100% covered by LiDAR data.

Table 18. Shift Values of each LiDAR Block of Mainit-Tubay floodplain

Mission Blocks	Shift Values		
	x	y	z
Zamboanga_Blk75C	0.00	0.00	0.47
Zamboanga_Blk75D	0.00	0.00	0.47

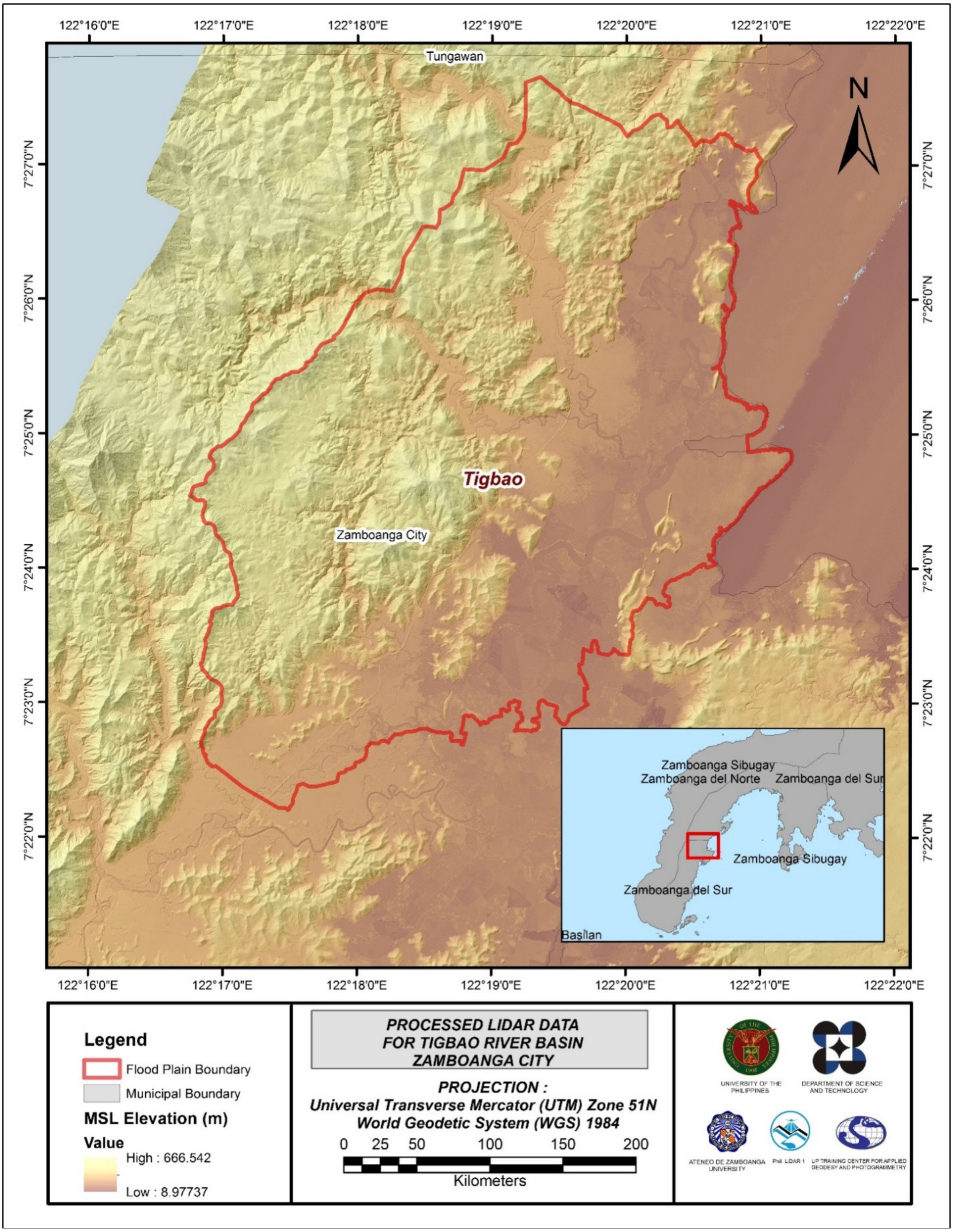


Figure 25. Map of Processed LiDAR Data for Tigbao Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Tigbao Floodplains to collect points with which the LiDAR dataset is validated is shown in Figure 26.

Simultaneous mosaicking was done for the Zamboanga LiDAR blocks and the only available data that time was for Tumaga. The Tigbao Floodplain is included in the set of blocks previously mosaicked; therefore, the Tumaga calibration data and methodology was used.

A total of 1739 survey points from Tumaga data were used for calibration and validation of all the blocks of Zamboanga LiDAR data. Random selection of 80% of the survey points, resulting in 1,391 points, were used for calibration. A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 27. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 8.06meters with a standard deviation of 0.07 meters. Calibration of Zamboanga LiDAR data was done by adding the height difference value, 8.06 meters, to Zamboanga mosaicked LiDAR data. Table 16 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

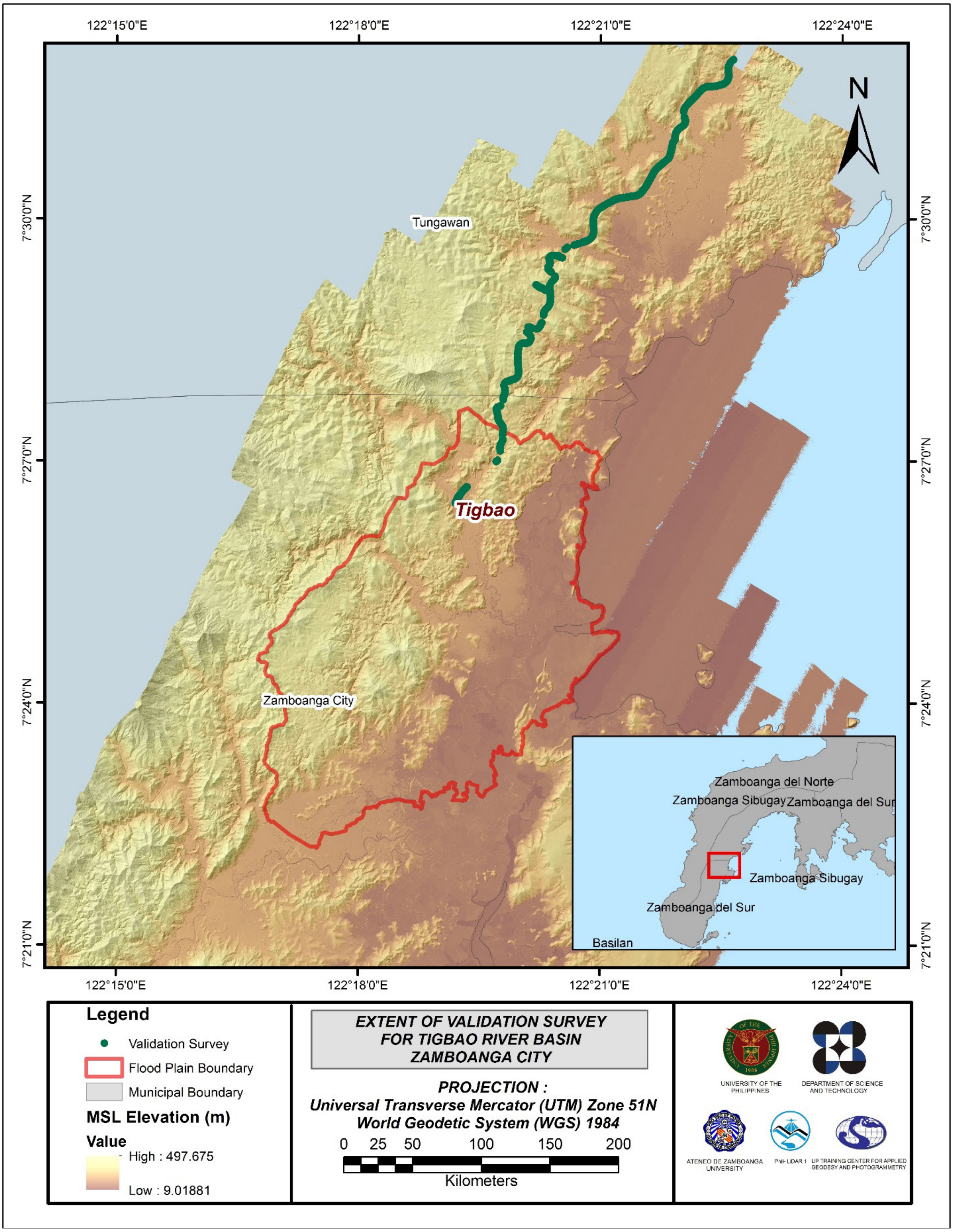


Figure 26. Map of Tigbao Floodplain with validation survey points in green.

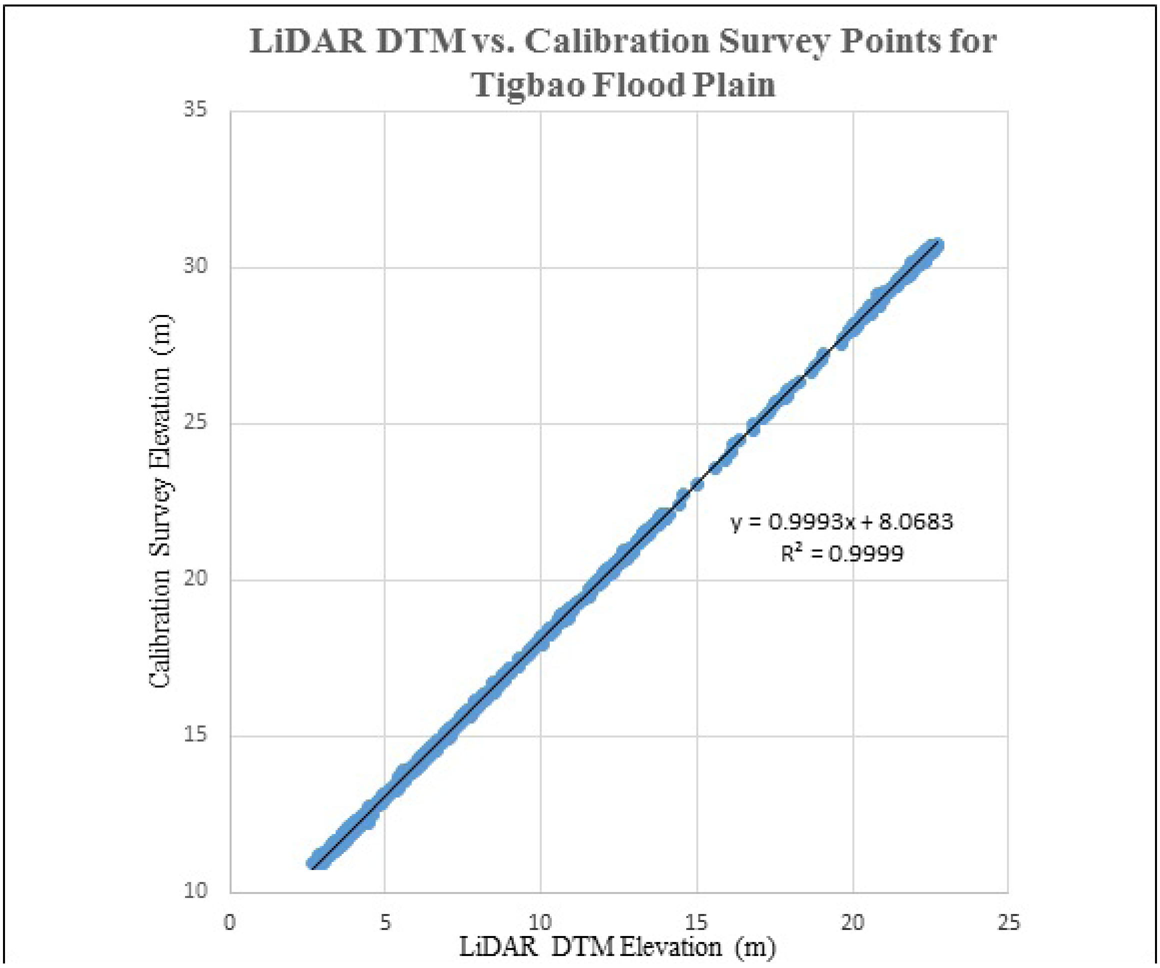


Figure 27. Correlation plot between calibration survey points and LiDAR data.

Table 16. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	8.06
Standard Deviation	0.07
Average	8.06
Minimum	7.91
Maximum	8.20

The Tigbao Floodplain has a total of 1646 survey points andonly 20% of the total survey points, resulting in 330 points, were randomly selected and used for the validation of calibrated Tigbao 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 28. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20meters with a standard deviation of 0.04meters, as shown in Table 17.

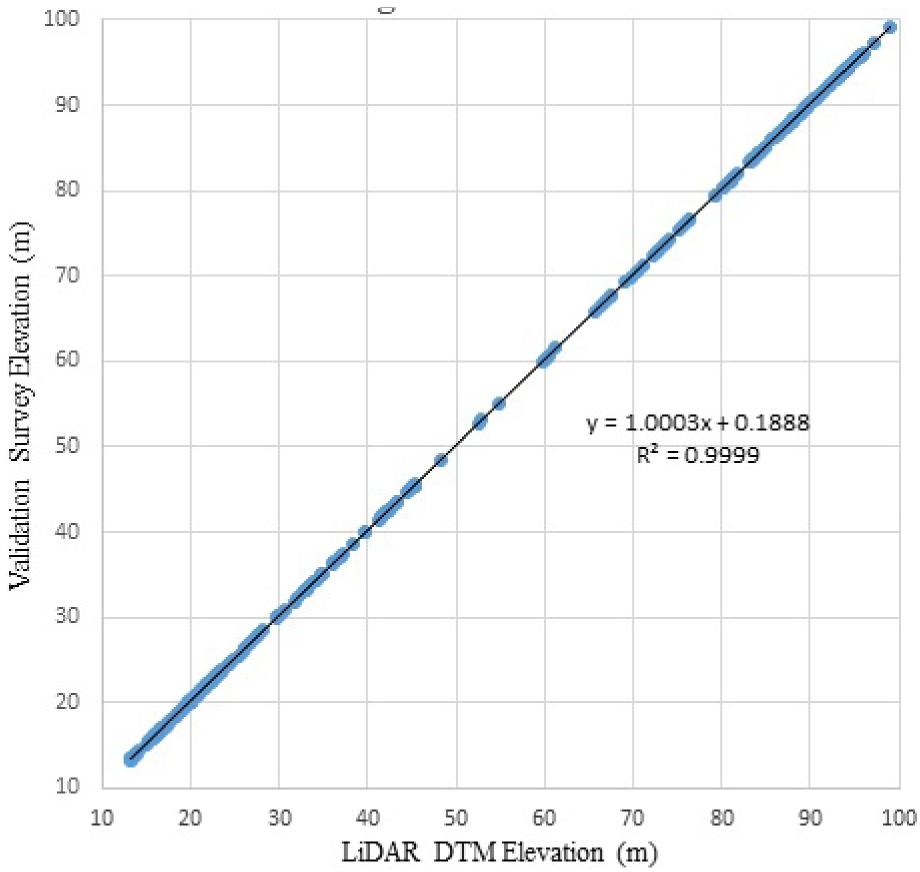


Figure 28. Correlation plot between validation survey points and LiDAR data.

Table 17. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.04
Average	0.20
Minimum	0.11
Maximum	0.29

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Tigbao with 4451 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 0.14 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tigbao integrated with the processed LiDAR DEM is shown in Figure 29.

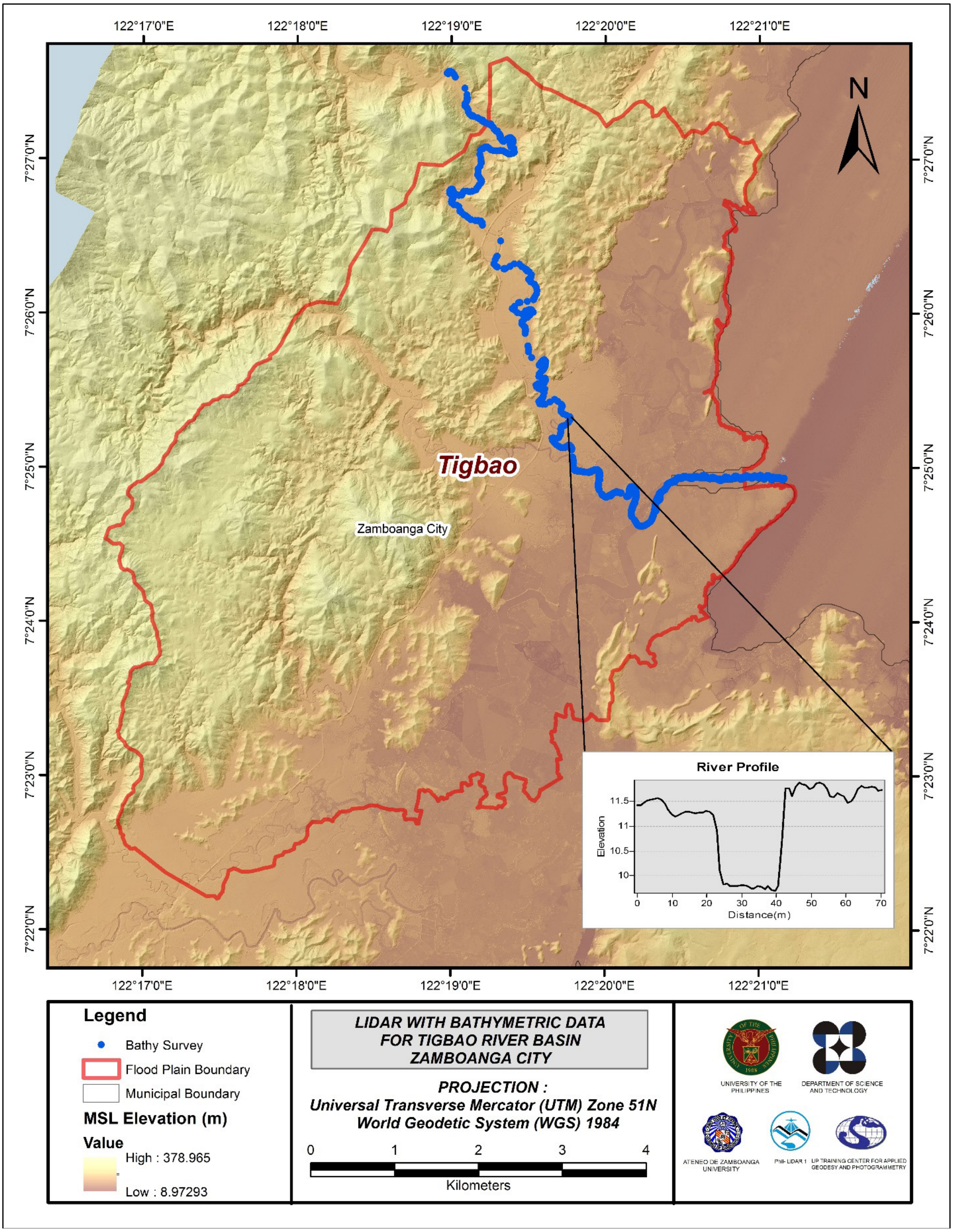


Figure 29. Map of Tigbao Floodplain with bathymetric survey points shown in blue.

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

Tigbao Floodplain, including its 200 m buffer, has a total area of 55.22sq km. For this area, a total of 5.0sq km, corresponding to a total of 456 building features, are considered for QC. Figure 30 shows the QC blocks for Tigbao Floodplain.

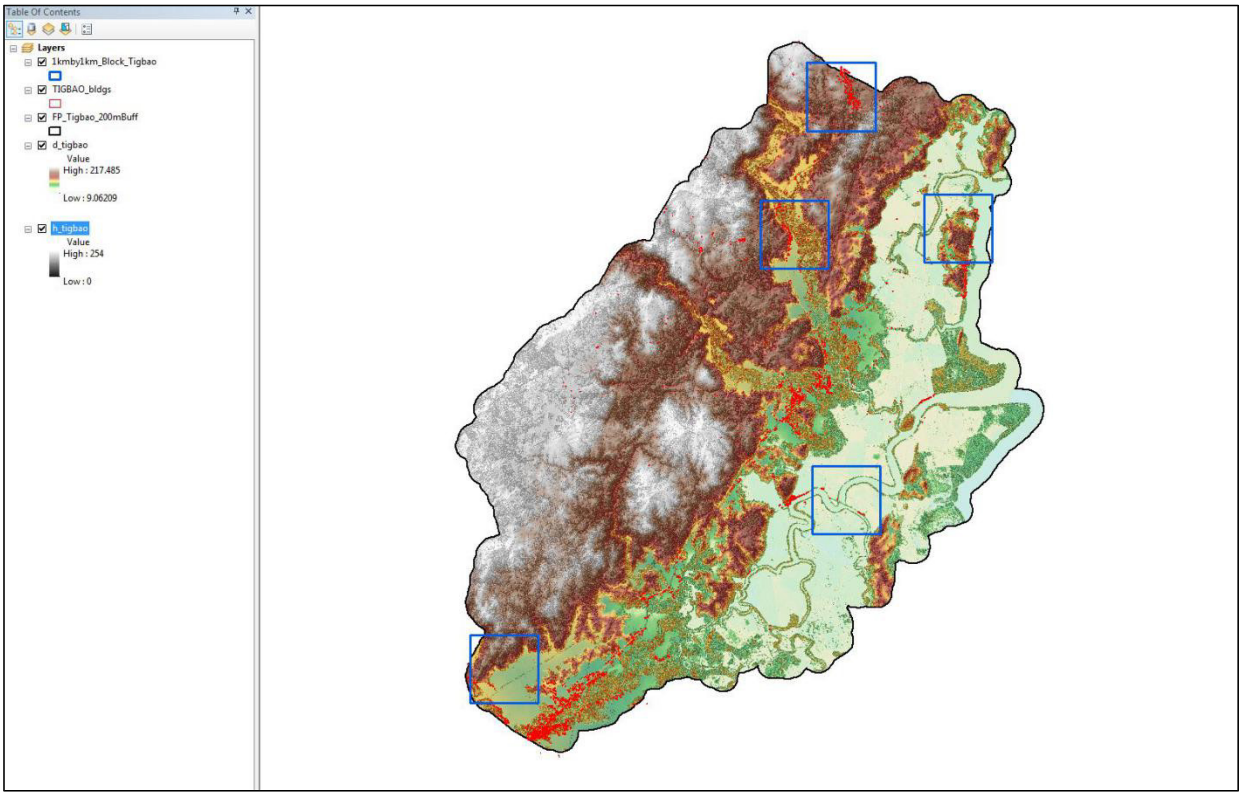


Figure 30. Blocks (in blue) of Tigbao building features that were subjected in QC.

Quality checking of Tigbao building features resulted in the ratings shown in Table 18.

Table 18.Quality Checking Ratings for Tigbao Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tigbao	97.23	100.00	83.77	PASSED

3.12.2 Height Extraction

Height extraction was done for 2659 building features in Tigbao Floodplain. Of these building features, none was filtered out after height extraction, resulting in 2,659 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 6.08 m.

3.12.3 Feature Attribution

One of the Research Associates of ADZU Phil LiDAR 1 was able to develop GEONYT, an offline web-based application for feature attribution extracted from a LiDAR-based Digital Surface Model and which attribution is conducted by combining automatic data consolidation, geotagging and offline navigation. The app is conveniently integrated in a smart phone/ tablet. The data collected are automatically stored in database and can be viewed as CSV (or excel) and KML (can viewed via google earth). The Geonyt App was the main tool used in all feature attribution activity of the team.

The team, through the endorsement of the Local Government Units of the Municipality/ City hired a number of enumerators who conducted the house-to-house survey of the features using the GEONYT application. The team provided the enumerators smart tablets where the GEONYT is integrated. The number of days by which the survey was conducted was dependent on the number of features of the floodplain of the riverbasin; likewise, the number of enumerators was also dependent on the availability of the tablet and the number of features of the floodplain.

Table 19 summarizes the number of building features per type. On the other hand, Table 20 shows the total length of each road type, while Table 21 shows the number of water features extracted per type.

Table 19.Building Features Extracted for Tigbao Floodplain.

Facility Type	No. of Features
Residential	2518
School	79
Market	35
Agricultural/Agro-Industrial Facilities	2
Medical Institutions	0
Barangay Hall	2
Military Institution	1
Sports Center/Gymnasium/Covered Court	3
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	1
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	1
Water Supply/Sewerage	0
Religious Institutions	11
Bank	0
Factory	0
Gas Station	1
Fire Station	0
Other Government Offices	2
Other Commercial Establishments	3
Total	**2659**

Table 20. Total Length of Extracted Roads for Tigbao Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Tigbao	14.51	4.95	0.00	15.04	0.00	**29.55**

Table 21. Number of Extracted Water Bodies for Tigbao Floodplain

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Tigbao	41	0	0	0	0	41

A total of 7 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 31 shows the Digital Surface Model (DSM) of Tigbao Floodplain overlaid with its ground features.

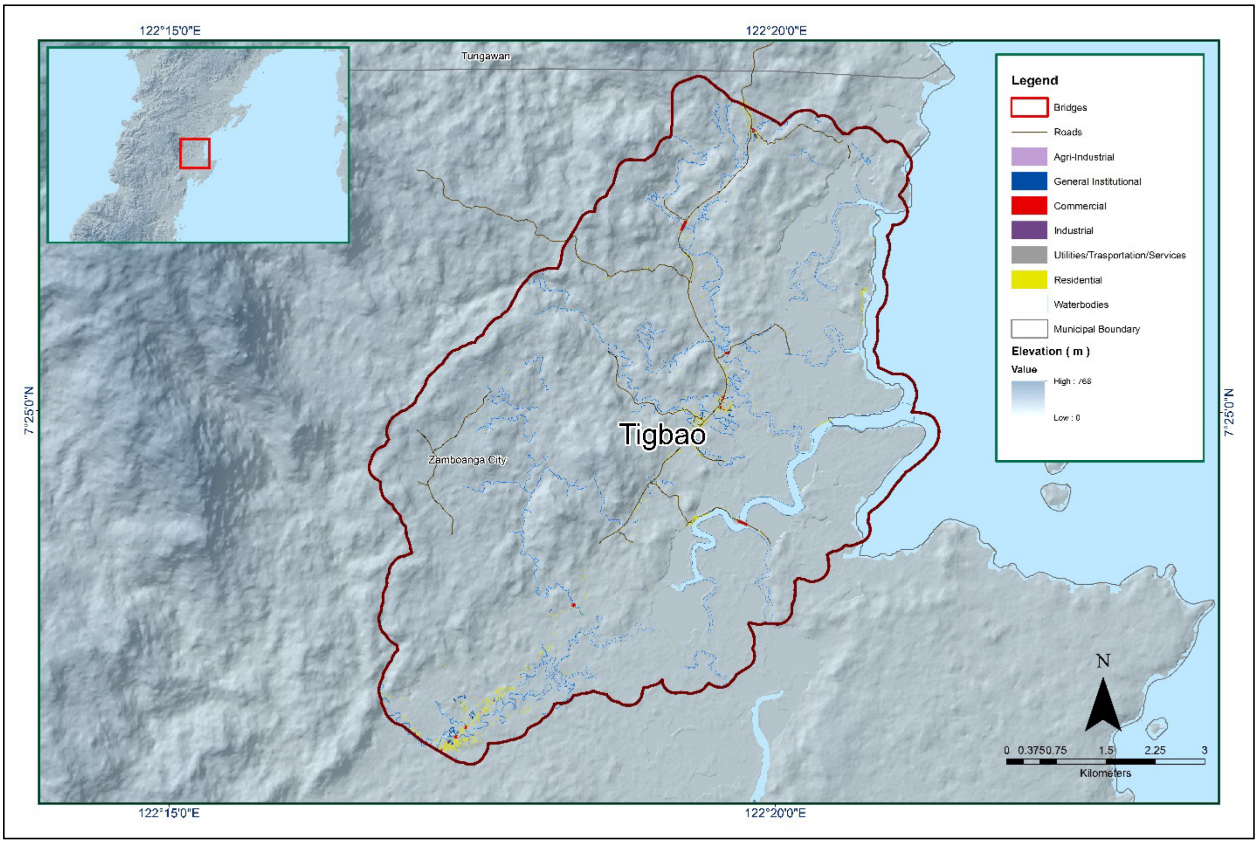


Figure 31. Extracted features for Tigbao Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Dexter T. Lozano, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, For. Rodel C. Alberto

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).

4.1 Summary of Activities

The DVBC conducted a field survey in Tigbao River on September 24 to October 8, 2015 with the following scope of work: reconnaissance survey to determine the viability of traversing the planned routes for bathymetric survey; courtesy call to LGU Zamboanga City; control survey for the establishment of control point UP-TIG at Tigbao bridge approach occupied as base station for GNSS surveys; cross-section, bridge-as-built and MSL water level marking; validation points data acquisition for LiDAR data with estimated distance of 28.4 km; and bathymetric survey of Tigbao river starting from the upstreamof Brgy. Tictapul, to Tigbao Bridge and then to the Brgy. Licomo with an approximate length of 11.1km utilizing GNSS PPK survey technique. The entire survey extent is illustrated in Figure 32.

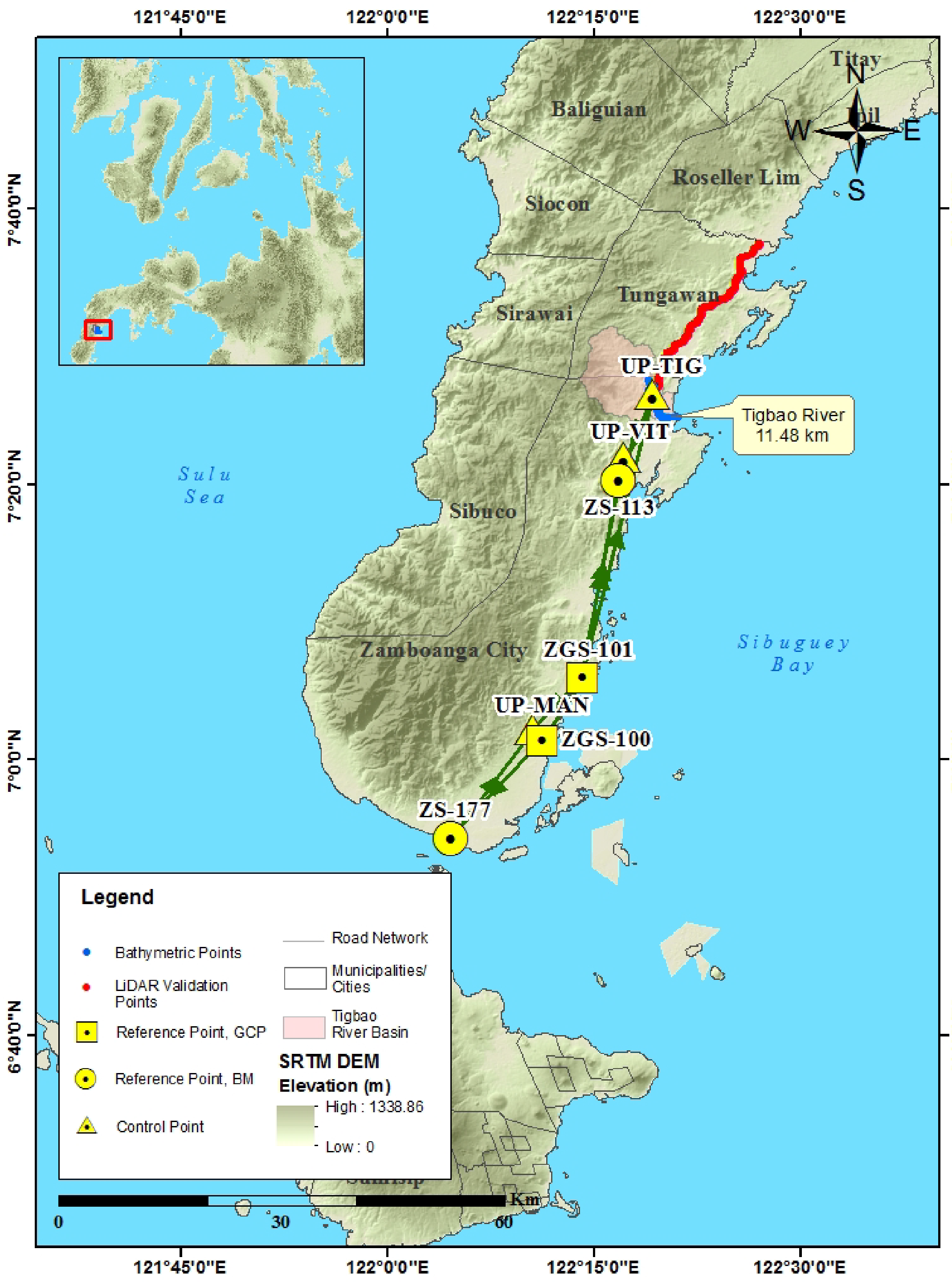


Figure 32. Tigbao River Survey Extent

4.2 Control Survey

The GNSS network used for Tigbao River Basin is composed of four (4) loops established on September 26, October 3 and 8, 2015, occupying the following points: ZGS-101, a second-order GCP located within the perimeter of Bolong Elementary School; ZS-113, a first order benchmark in Brgy. Tigbalagbag, Zamboanga City; and ZS-177, a first-order benchmark on the back of the central monument at Rizal Park in front of Zamboanga City Hall.

Three control points were also established along the approach of the bridges namely: UP-MAN, situated on Manicahan Steel Bridge in Brgy. Cacap, Zamboanga City; UP-TIG, in Tigbao Bridge in Brgy. Tictapul, Zamboanga City; and UP-VIT in Vitali Bridge in Brgy. Vitali, Zamboanga City. A NAMRIA established control point namely ZGS-100, located in front of Vitali Barangay Hall, was also occupied to use as marker during the survey.

The summary of reference and control points and its location is summarized in Table 22 while the GNSS network established is illustrated in Figure 33.

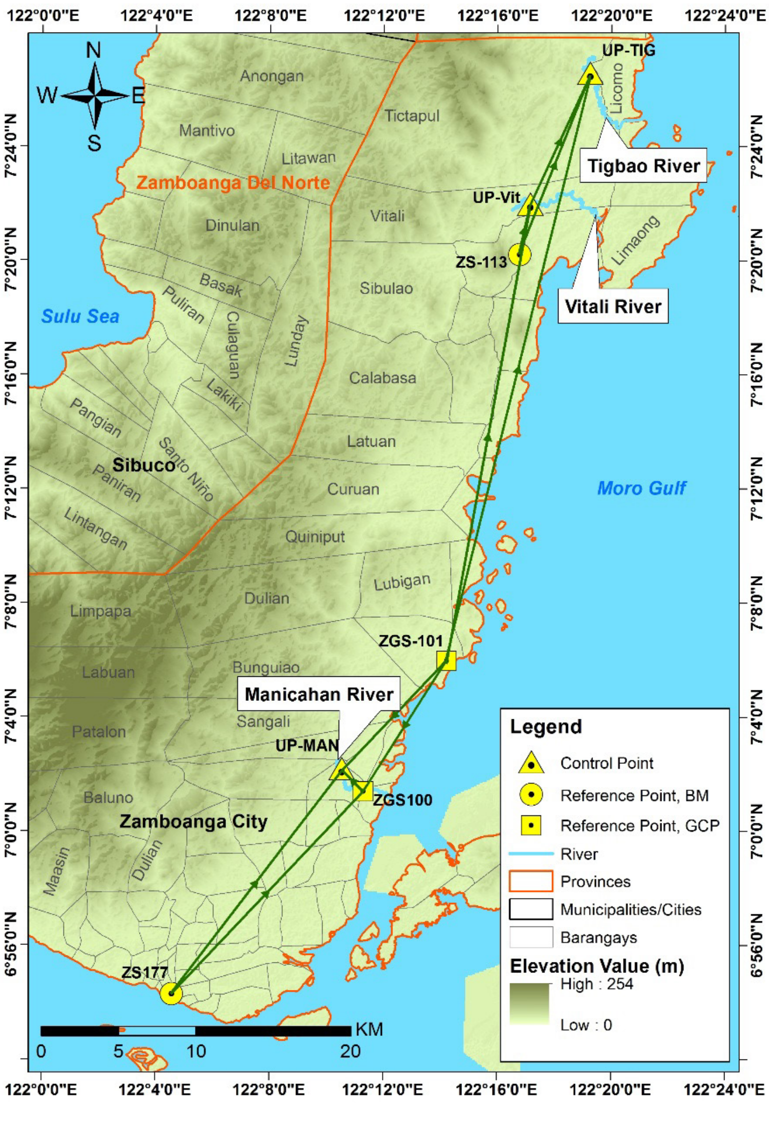


Figure 33. GNSS Network of Zamboanga City Field Survey

Table 22. List of Reference and Control points used for Control Network in Zamboanga Field Survey (Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date established
ZGS-101	2nd Order, GCP	7°05'57.59221"	122°14'13.79610"	80.222	-	2009
ZS-177	1st Order, BM	-	-	80.002	12.311	2007
ZS-113	1st Order, BM	-	-	219.481	151.585	2007
ZGS-100	Used as marker	-	-	-	-	2009
UP-MAN	UP Established	-	-	-	-	October 3, 2015
UP-TIG	UP Established	-	-	-	-	August 1, 2015
UP-VIT	UP Established	-	-	-	-	August 1, 2015

The GNSS set-ups on recovered reference points and established control points in Tigbao River are shown in Figure 34 to Figure 40.

Figure 34. Trimble® SPS 852 set-up at ZGS-101 located at Bolong Elementary School, Brgy. Bolong, Zamboanga City

Figure 35.Trimble® SPS 852 set-up at ZS-177 located at the stair of Rizal's Park in Brgy. Poblacion, Zamboanga City

Figure 36.Trimble SPS® 882 set-up at ZGS-100 located at Manicahan Barangay Hall, Zamboanga City

Figure 37. Trimble SPS® 882 set-up at ZS-113 located along Tagasilay-Vitali Road, Brgy. Tigbalabag, Zamboanga City

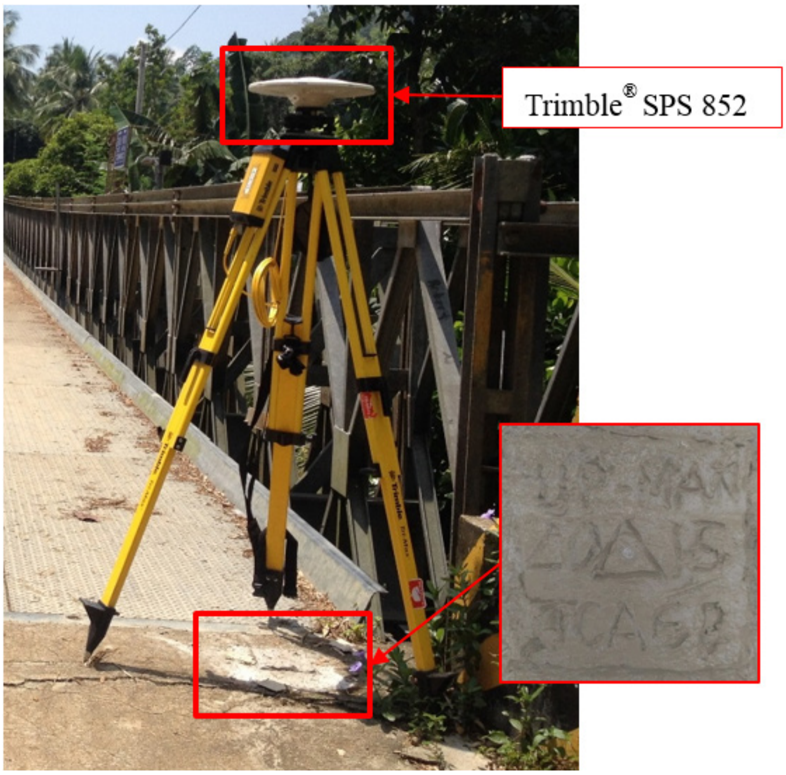


Figure 38.Trimble SPS® 852 set-up at UP-MAN located at the approach of Manicahan Steel Bridge in Brgy. Cacap, Zamboanga City

Figure 39.Trimble SPS® 882 set-up at UP-TIG located at the approach of Tigbao Bridge in Brgy. Tictapul, Zamboanga City

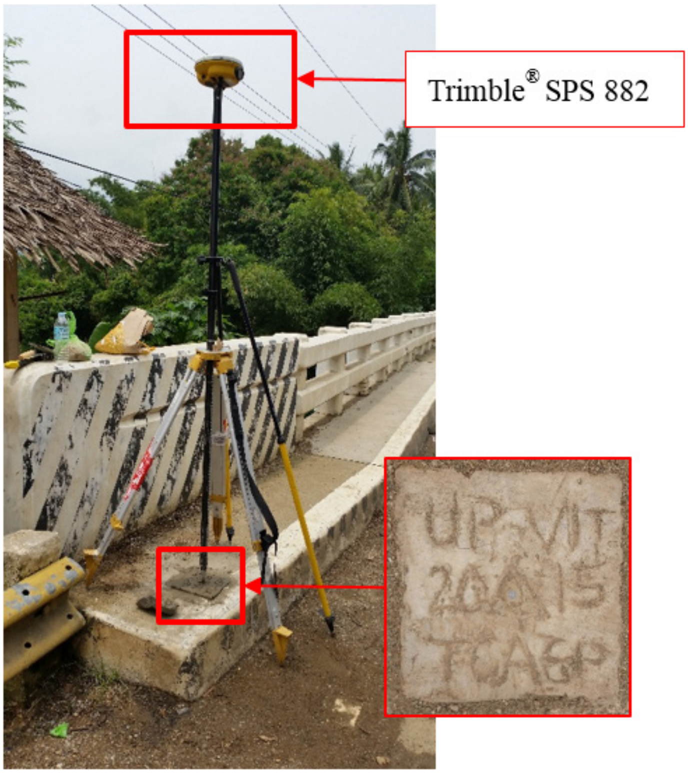


Figure 40. Trimble® SPS 882 set-up at UP-VIT located at the approach of Vitali Bridge in Brgy. Vitali, Zamboanga City

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 Tigbao River Basin is summarized in Table23 generated by TBC software.

Table 23. Baseline Processing Summary Report for Tigbao River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
ZGS101 --- UPTIG	09-26-2015	Fixed	0.003	0.018	13°40'16"	39078.38	9.652
ZGS101 --- ZS113	09-26-2015	Fixed	0.003	0.023	10°06'59"	26671.69	139.258
ZGS101 --- UPVIT	09-26-2015	Fixed	0.003	0.027	10°18'43"	30022.53	6.491
ZGS101 --- UPMAN	10-03-2015	Fixed	0.006	0.026	224°10'56"	9709.698	16.669
ZGS101 --- ZGS100	10-03-2015	Fixed	0.004	0.023	212°35'19"	10000.29	4.51
UPTIG --- ZS113	09-26-2015	Fixed	0.004	0.032	201°14'35"	12567.26	129.543
UPTIG --- UPVIT	09-26-2015	Fixed	0.004	0.029	204°36'51"	9275.764	-3.206
ZS113 --- UPVIT	09-26-2015	Fixed	0.003	0.018	11°52'24"	3352.211	-132.76
ZS177 --- ZGS100	10-08-2015	Fixed	0.007	0.027	223°21'49"	18026.23	-4.678
ZGS100 --- UPMAN	10-08-2015	Fixed	0.005	0.018	316°38'30"	2011.6	12.124
ZGS100 --- UPMAN	10-03-2015	Fixed	0.005	0.023	316°38'33"	2011.599	12.107
ZS177 --- UPMAN	10-08-2015	Fixed	0.011	0.036	37°01'59"	18252.08	16.837

All baselines that formed the GNSS network for the static survey setup acquired fixed solutions and passed the required ±20cm and ±10cm for horizontal and vertical precision respectively as shown in Table 23.

4.4 Network Adjustment

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

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

Where:

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

for each control point. The results of GNSS processing is shown in Table 24 to Table 26. The control point ZGS-101 was held fixed for the coordinate values, and ZS-177 and ZS-113 were held fixed for the elevation during the processing of the control point as presented in Table 24.

Table 24.Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
ZGS101	Global	Fixed	Fixed		
ZS113	Grid				Fixed
ZS177	Grid				Fixed
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 25. All fixed control points have no values for grid and elevation errors.

Table 25.Adjusted grid coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
UPMAN	408983.223	0.015	777849.044	0.011	28.988	0.081	
UPTIG	425056.716	0.009	822742.326	0.008	22.012	0.077	
UPVIT	421181.693	0.009	814318.080	0.008	18.825	0.067	
ZGS100	410361.342	0.013	776384.498	0.011	16.872	0.077	
ZGS101	415759.669	?	784798.916	?	12.345	0.064	LL
ZS113	420486.928	0.009	811039.756	0.008	151.585	?	e
ZS177	397965.109	0.025	763304.272	0.017	12.311	?	e

The network is fixed at reference points. The list of adjusted coordinates of the network is shown in Table 26. Using the equation $\sqrt{((x_e)^2 + (y_e)^2)} < 20cm$ for horizontal and $z_e < 10\ cm$ for the vertical; below is the computation for the accuracy that passed the required precision:

ZGS-101
horizontal accuracy = Fixed
vertical accuracy = 6.4 cm< 10 cm

ZGS-100
horizontal accuracy = $\sqrt{((1.30)^2 + (1.10)^2}$
= $\sqrt{(1.69 + 1.21)}$
= 1.70 cm< 20 cm
vertical accuracy = 7.7 cm < 10 cm

ZS-113
horizontal accuracy = $\sqrt{((0.90)^2 + (0.80)^2}$
= $\sqrt{(0.81 + 0.64)}$
= 1.20 cm< 20 cm
vertical accuracy = Fixed

ZS-177
horizontal accuracy = $\sqrt{((2.50)^2 + (1.70)^2}$
= $\sqrt{(6.25 + 2.89)}$
= 3.02 cm< 20 cm
vertical accuracy = Fixed

UP-MAN
horizontal accuracy = $\sqrt{((1.50)^2 + (1.10)^2}$
= $\sqrt{(2.25 + 1.21)}$
= 1.86 cm< 20 cm
vertical accuracy = 8.10 cm< 10 cm

UP-TIG
horizontal accuracy = $\sqrt{((0.90)^2 + (0.80)^2}$
= $\sqrt{(0.81 + 0.64)}$
= 1.20 cm< 20 cm
vertical accuracy = 7.70 cm< 10 cm

UP-VIT
horizontal accuracy = $\sqrt{((0.90)^2 + (0.80)^2}$
= $\sqrt{(0.81 + 0.64)}$
= 1.20 cm< 20 cm
vertical accuracy = 6.70 cm< 10 cm

Table 26. Adjusted geodetic coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
UPMAN	N7°02'10.91288"	E122°10'33.30241"	96.857	0.081	
UPTIG	N7°26'33.60615"	E122°19'15.00531"	89.890	0.077	
UPVIT	N7°21'59.09413"	E122°17'09.03227"	86.709	0.067	
ZGS100	N7°01'23.30256"	E122°11'18.30194"	84.730	0.077	
ZGS101	N7°05'57.59221"	E122°14'13.79610"	80.222	0.064	LL
ZS113	N7°20'12.30776"	E122°16'46.54305"	219.481	?	e
ZS177	N6°54'16.64645"	E122°04'35.12376"	80.002	?	e

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 26. 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 is indicated in Table 27.

Table 27. References and Control Points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
ZGS100	2nd Order, GCP	7°01'23.30256"	122°11'18.30194"	84.73	776384.5	410361.3	16.872
ZGS101	2nd Order, GCP	7°05'57.59221"	122°14'13.79610"	80.222	784798.9	415759.7	12.345
ZS177	1st Order, BM	6°54'16.64645"	122°04'35.12376"	80.002	763304.3	397965.1	12.311
ZS113	Used as marker	7°20'12.30776"	122°16'46.54305"	219.481	811039.8	420486.9	151.585
UPMAN	UP Established	7°02'10.91288"	122°10'33.30241"	96.857	777849	408983.2	28.988
UPTIG	UP Established	7°26'33.60615"	122°19'15.00531"	89.89	822742.3	425056.7	22.012
UPVIT	UP Established	7°21'59.09413"	122°17'09.03227"	86.709	814318.1	421181.7	18.825

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

Cross-section and as-built surveys for Tigbao Bridge in Brgy. Tictapul across Tigbao River in Zamboanga City, were conducted on September 29, 2015 as shown in Figure 41. A GNSS receiver Trimble® SPS 882 in PPK survey technique was used to acquire the cross section of the river along the upstream side of Tigbao Bridge as shown in Figure 42 using UP-TIG as base station. Bridge as-built features determination was also performed to get the distance of piers and abutments from the bridge approach. The bridge deck was measured using GNSS receiver Trimble® SPS 882 to get the high chord and meter tapes to get its low chord elevation.

Figure 41. Upstream portion of Tigbao Bridge for cross-section

Figure 42.Cross-section Survey at Tigbao Bridge in Brgy. Tictapul, Zamboanga City.

The cross-sectional line length in Tigbao Bridge is about 211 meters with 1,230cross-sectional points using UP-TIG as the GNSS base station. The cross-section diagram, location map and collected as-built data for Tigbao Bridge are displayed in Figure 43 to Figure 45, respectively.

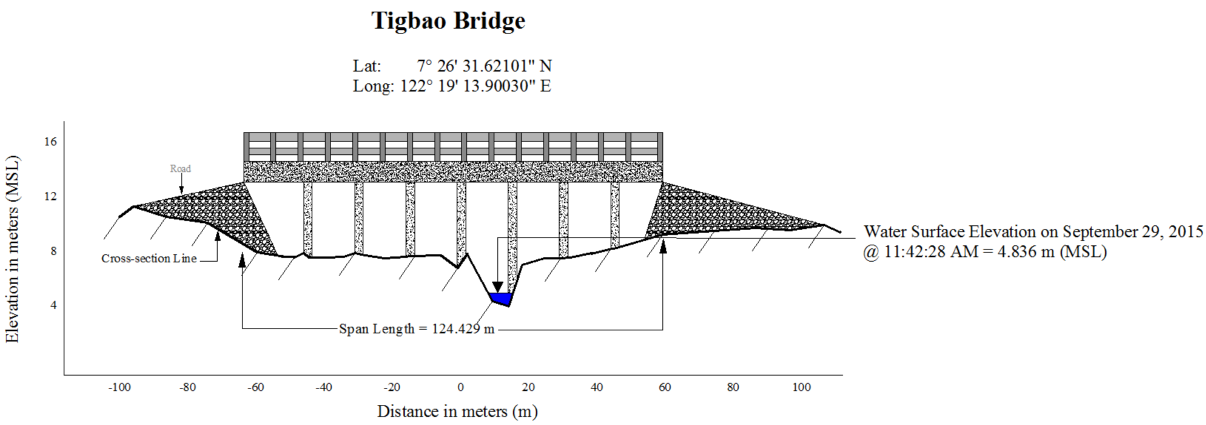


Figure 43. Tigbao River cross-sectional diagram

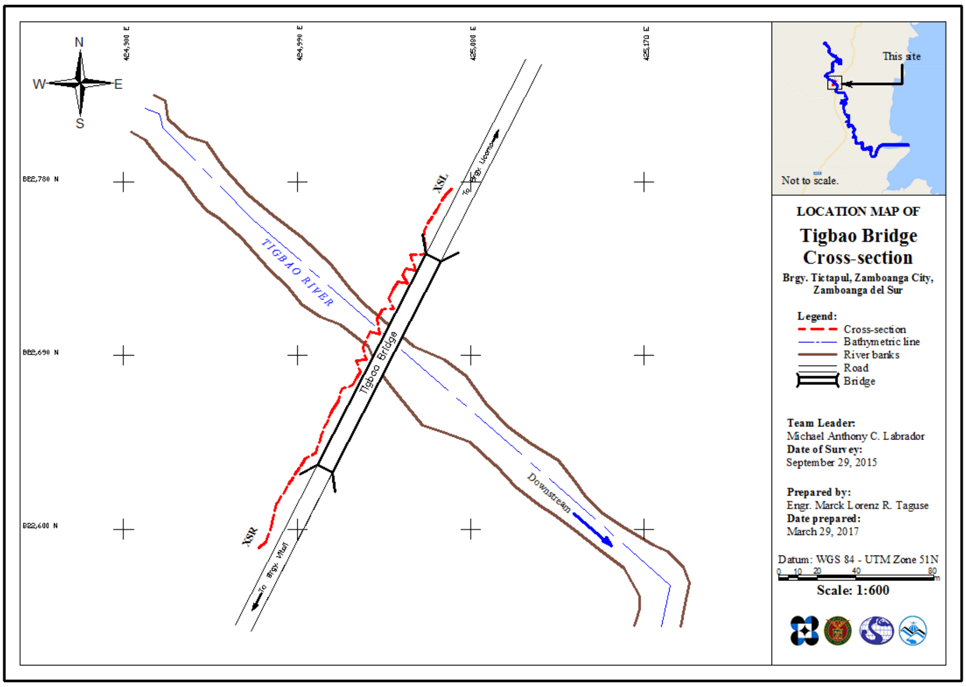


Figure 44. Tigbao bridge cross-section location map

Bridge Data Form

Bridge Name: Tigbao Bridge | Date: September 29, 2015

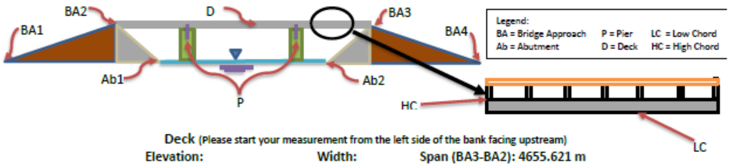
River Name: Tigbao River | Time: 10:14 AM

Location (Brgy, City,Region): Brgy. Tictapul , Zamboanga City, Zamboanga Peninsula

Survey Team: Michael Anthony Labrador, Precious Annie Lopez, Anthony Abogado, Kim Patrick Tort

Flow condition: low ✓ normal high | Weather Condition: ✓ fair rainy

Latitude: | Longitude:



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

Elevation: | Width: | Span (BA3-BA2): 4655.621 m

	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 upstream)

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	16.260	BA3	4870.018	12.983
BA2	214.397	13.441	BA4	10207.259	15.136

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

	Station (Distance from BA1)	Elevation
Ab1	397.565	13.664
Ab2		

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

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	531.623	18.895	
Pier 2	924.070	19.118	
Pier 3	1415.496	19.254	
Pier 4	1991.584	19.310	
Pier 5	2652.689	19.332	
Pier 6	3411.085	19.214	
Pier 7	4197.288	19.024	

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

Figure 45. Tigbao Bridge Data Form

Water surface elevation in MSL of Tigbao River was determined using Trimble® SPS 882 in PPK mode survey on September 29, 2015 at 11:42AM. This was translated onto marking the bridge’s pier using a digital level. The resulting water surface elevation data is 4.836 m above MSL. The markings on the bridge pier are shown in Figure 46. This serves as a reference for flow data gathering and depth gauge deployment of ADZU PHIL-LiDAR 1.

Figure 46. Water-level marking at Tigbao Bridge’s Footing

4.6. Validation Points Acquisition Survey

Validation Points Acquisition Survey was conducted on September 29 and October 4, 2015 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached in front of the vehicle as seen in Figure 47. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height of 2.209 m was measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The survey was conducted using PPK technique on a continuous topography mode using UP-TIG as base station.

Figure 47. Trimble® SPS 882 set-up for validation points acquisition survey

Within the two (2) days of ground validation, the team covered the major roads of Tictapul, Baluran, Libertad, Tigbanuang, Langon, Upper Tungawan, and San Pedro. The survey acquired 3,854 ground validation points with an approximate length of 28.4 km presented in Figure 48. The gaps in the validation line as seen from Figure 48 were due to some difficulties in receiving satellite signals because of the presence of obstruction such as dense canopy cover of trees along the roads.

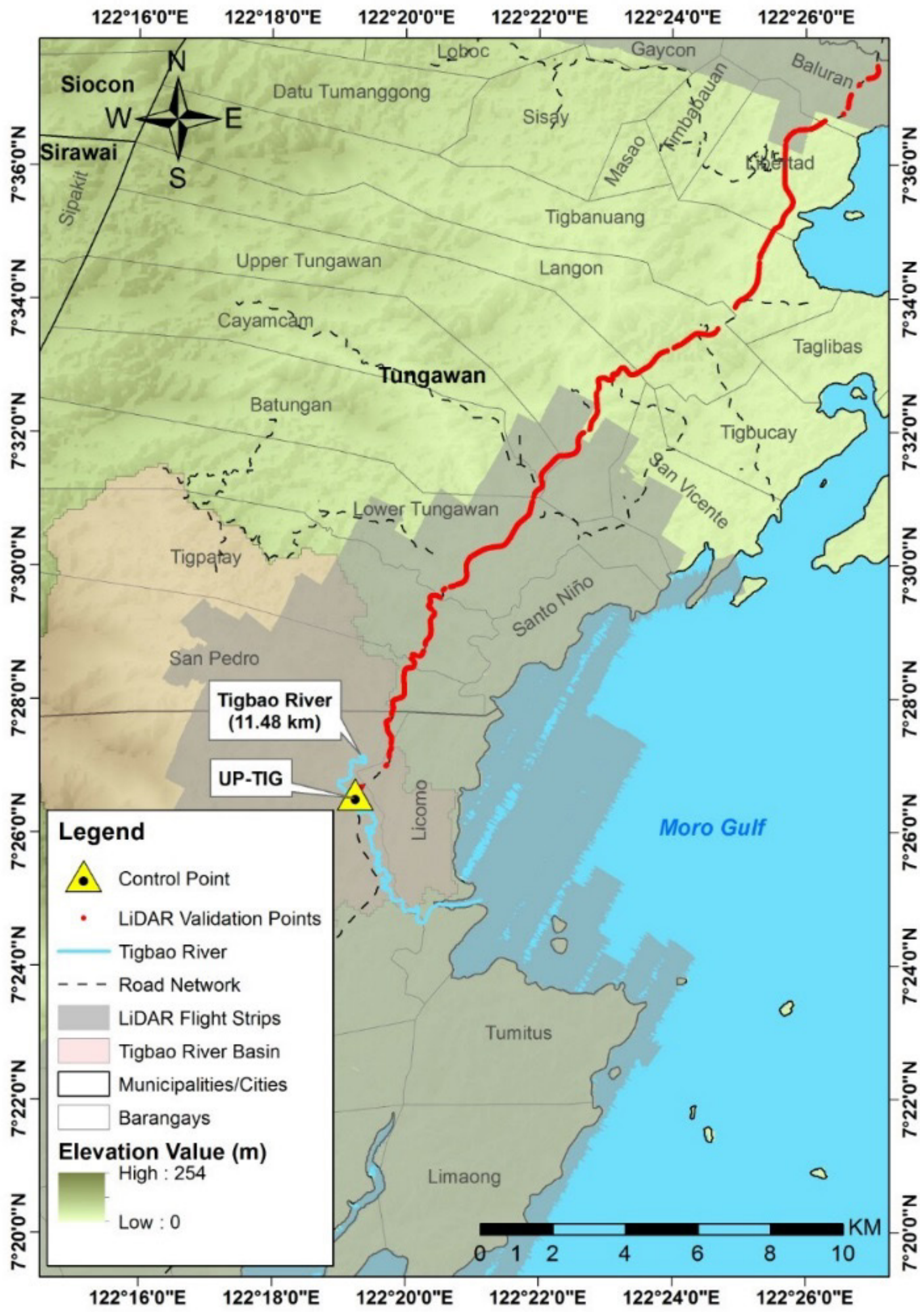


Figure 48. Validation point acquisition survey coverage along Brgy. Licomo to Brgy. Baluran, Tungawan, Zamboanga City

4.7 Bathymetric Survey

Bathymetric survey of Tigbao River was conducted on September 29, 2015 using Trimble® SPS 882 in GNSS PPK survey technique and an OHMEX™ Single beam echosounder mounted on a boat as shown in Figure 49. The survey started in the midstream part of the river in Brgy. Tictapul in Zamboanga City, with coordinates 7°25'16.19531"122°19'43.93392", and ended at the mouth of the river in Brgy. Licomo also in Zamboanga City, with coordinates 7°24'55.34096"122°21'09.40594".

Figure 49. OHMEX™ single beam echo sounder set up on a boat for Tigbao River bathymetric survey

Manual bathymetric survey on the other hand was conducted on September 28 and 30, 2015 using Trimble® SPS 882 in GNSS PPK survey technique as shown in Figure 50. The survey started in the upstream portion of the river in Brgy. Tictapul, with coordinates 7°27'33.09482"122°18'58.60058", traversed down the river by foot, and ended at the starting point of the bathymetric survey using boat. The control point UP-TIG was used as the GNSS base station all throughout the survey.

Figure 50. Manual bathymetry survey for Tigbao River

The bathymetric line length is about 11.16 km, with a total of 4,638 bathymetric points. The reference point, UP-TIG, was occupied as GNSS base station for the survey. The gaps in the Bathymetric Survey of Tigbao River as shown in Figure 51, were due to the difficulties in receiving satellite signals because of the presence of obstruction such as dense canopy cover of trees along the path during the survey.

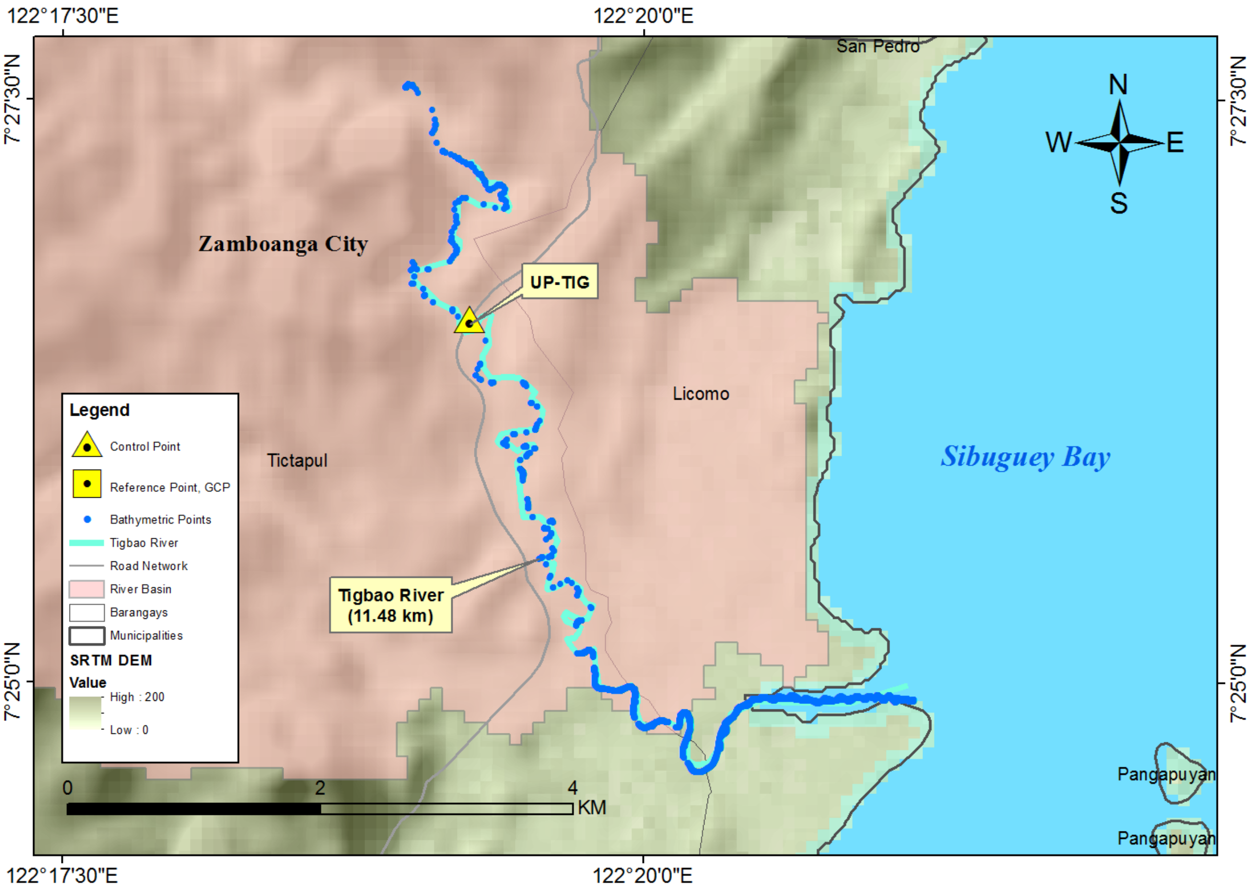


Figure 51. Bathymetric points gathered from Tigbao River

A CAD drawing illustrating the Tigbao riverbed profile where the highest elevation record is found in Brgy. Tictapul and the lowest is at Brgy. Licomo is shown in Figure 52. An elevation drop of 11.6 meters was observed within the distance of approximately 11.16km. The bathymetry survey traverses the Barangayof Tictapul, Tigbao Bridge then Brgy. Licomo with a total of 4,368 bathymetric point gathered..

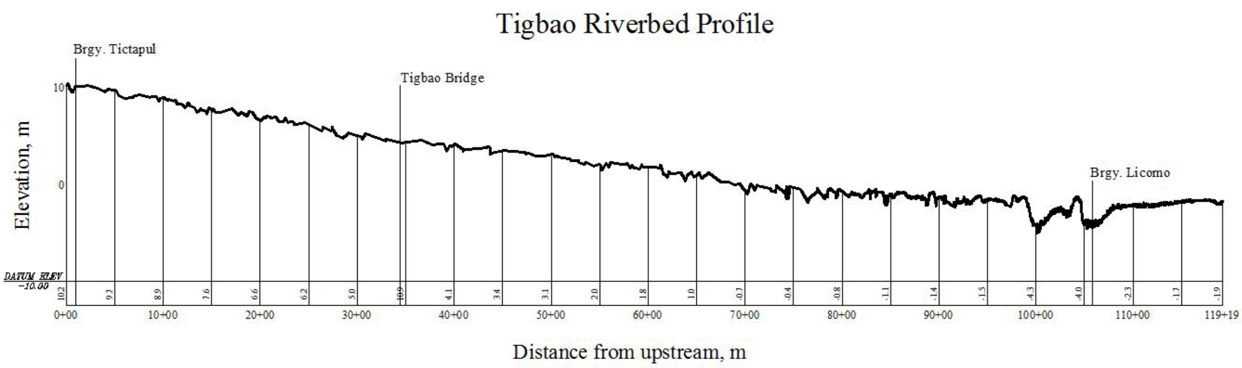


Figure 52. Tigbao riverbed profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin

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).

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

Components and data that affect the hydrologic cycle of the Tigbao 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 Tigbao River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from a manually read Rain Gauge at Brgy. Tictapul, Zamboanga City (Figure 53). The precipitation data collection started from June 22, 2016 at 2:00 PM to June 23, 2016 at 11:40AM with 10 minutes recording interval.

The total precipitation for this event inBrgy. Tictapul was 15.8 mm. It has a peak rainfall of 2.6 mm. on June22, 2016 at 4:00PM. The lag time between the peak rainfall and discharge is 7 hours and 30 minutes.

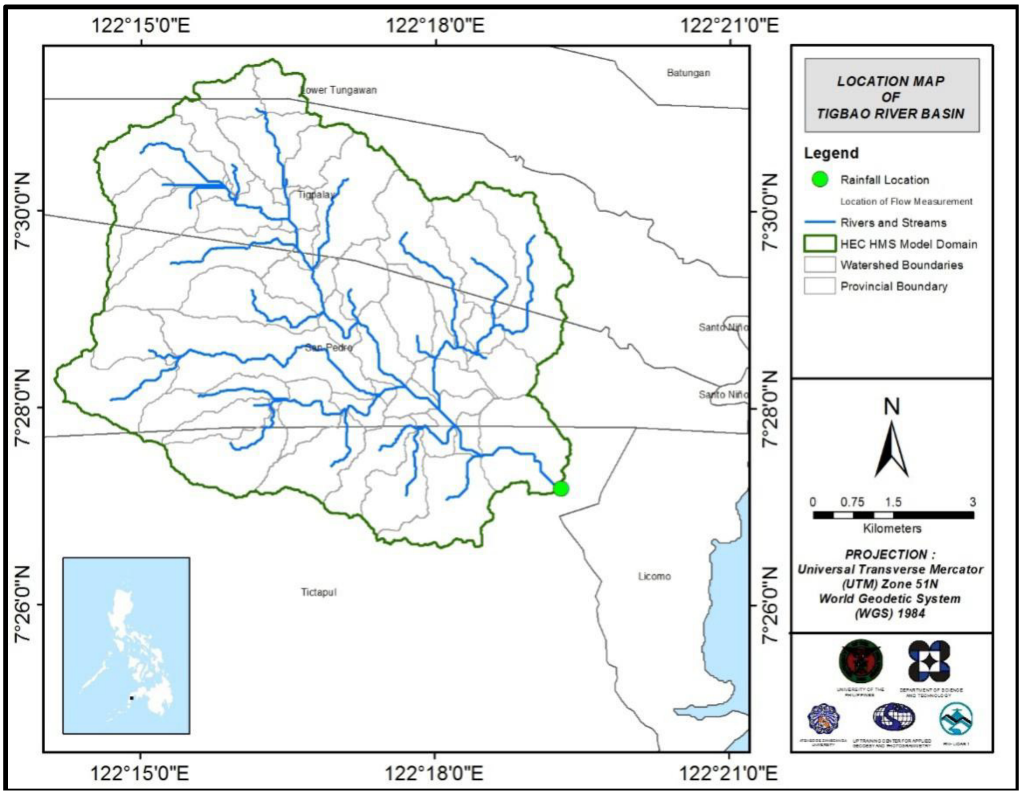


Figure 53. The location map of Tigbao HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Tigbao Bridge, Brgy. Licomo, Zamboanga City(7° 29' 2.05" N, 122° 16' 52.50" E). It gives the relationship between the observed water levels at Tigbao Bridge and outflow of the watershed at this location.

INSERT CROSS SECTION PLOT

Figure 54. Cross-Section Plot of Tigbao Bridge

For Tigbao Bridge, the rating curve is expressed as Q = 8E-63e1.867h as shown in Figure 55.

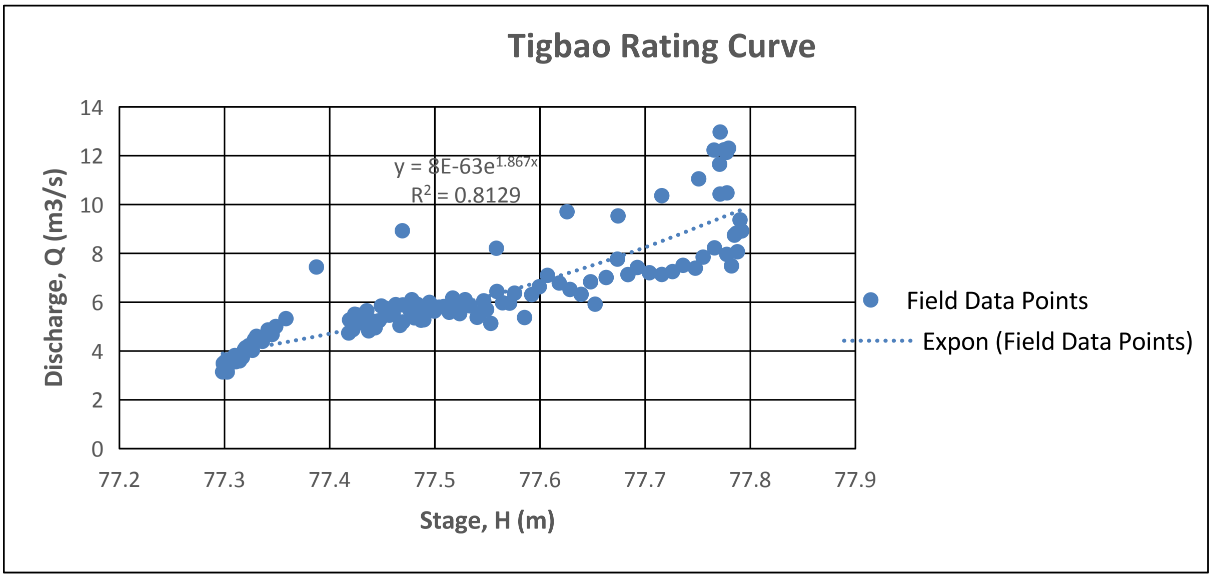


Figure 55. Tigbao Bridge, Brgy. Licomo, Zamboanga City

This rating curve equation was used to compute the river outflow at Tigbao Bridge for the calibration of the HEC-HMS model shown in Figure 56. Peak discharge is 9.52 cubic meters per second at 11:30 PM, June 22, 2016.

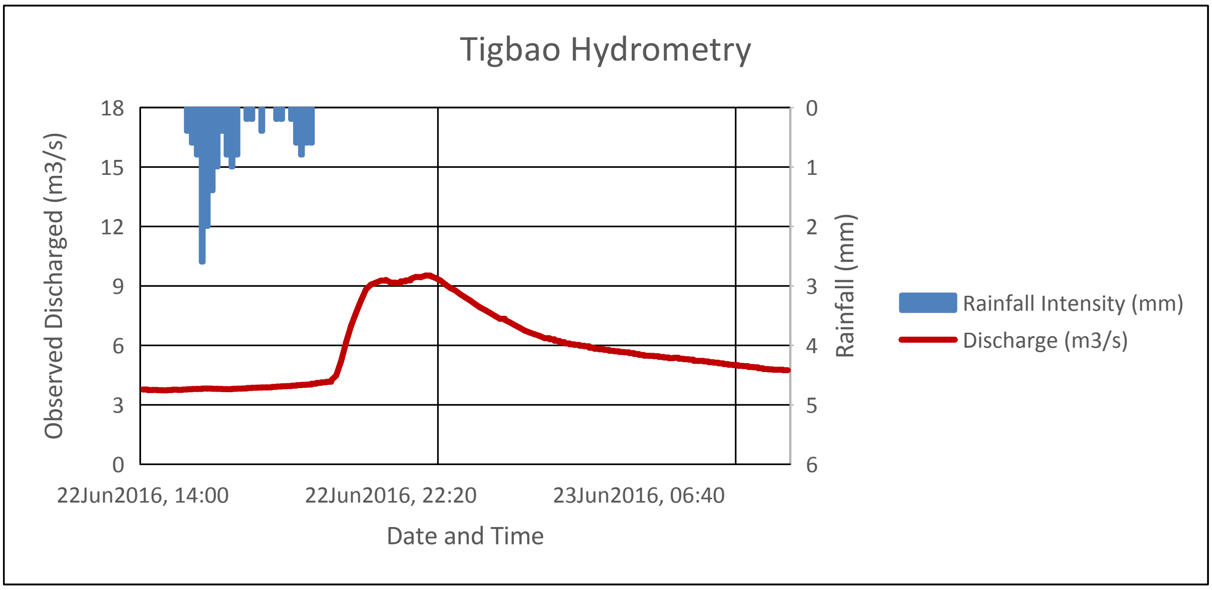


Figure 56. Rainfall and outflow data at Tigbao Bridge used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Zamboanga City 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 certain peak value will be attained at a certain time. This station chosen based on its proximity to the Tigbao watershed. The extreme values for this watershed were computed based on a 59-year record.

Table 32. Computed extreme values (in mm) of precipitation at Mainit-Tubay river basin based on average RIDF data of Butuan and Surigao stations

T (yrs)	10 min	20 min	30 min	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	15.5	23.3	28.4	36.9	45.6	50.7	60	66.1	77.3
5	21.4	31.6	38.3	50.4	61.2	38.2	82.5	91.5	107.8
10	25.3	37.1	44.8	59.4	71.6	79.8	97.5	108.3	127.9
15	27.5	40.2	48.5	64.4	77.4	86.4	105.9	117.8	139.3
20	29	42.3	51.1	68	81.5	91	111.8	124.4	147.3
25	30.2	44	53.1	70.7	84.7	94.5	116.3	129.5	153.4
50	33.9	49.1	59.2	79.1	94.4	105.4	130.4	145.3	172.3
100	37.5	54.2	65.3	87.4	104	116.2	144.3	161	191.1

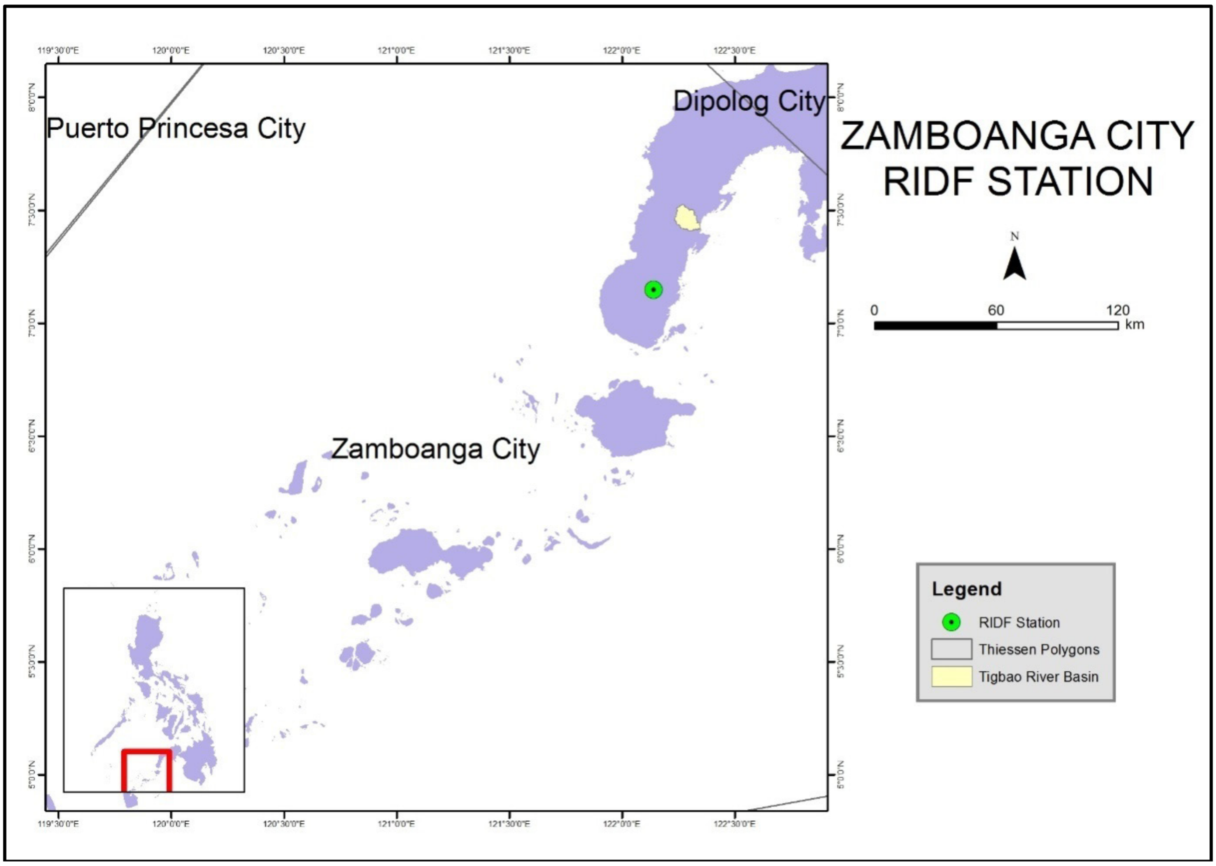


Figure 57. Zamboanga City RIDF location relative to Tigbao River Basin

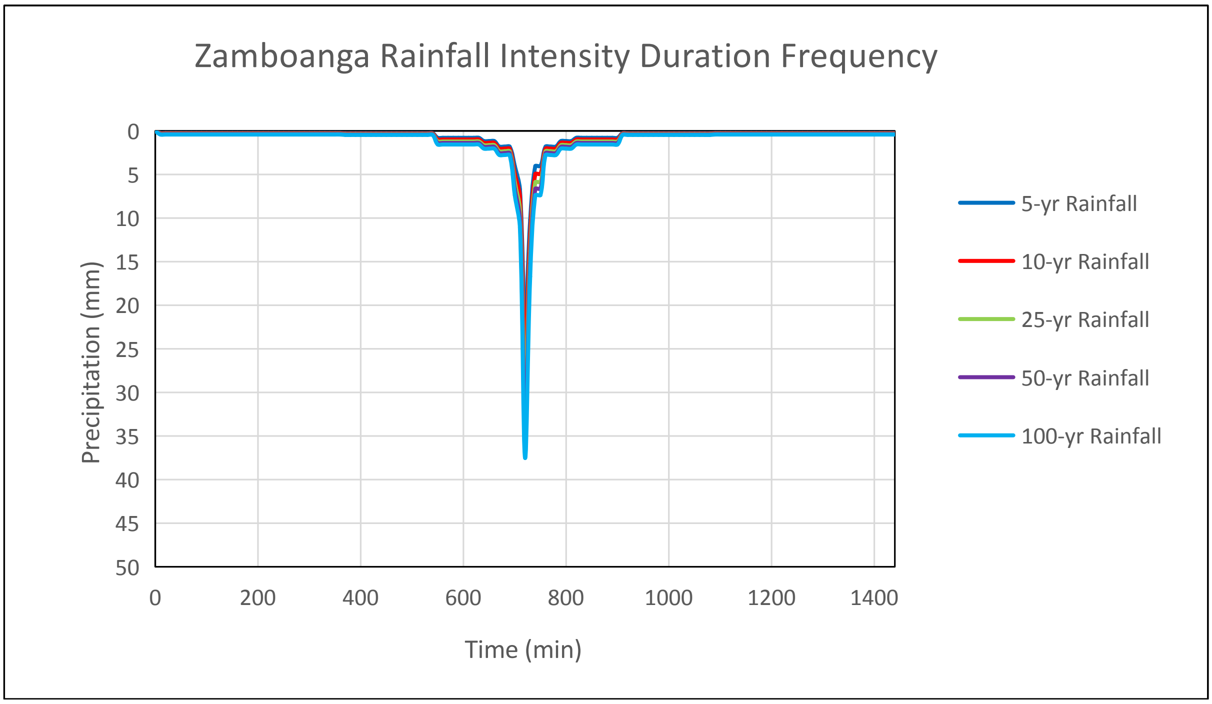


Figure 58. Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Tigbao River Basin are shown in Figure 59 and Figure 60, respectively.

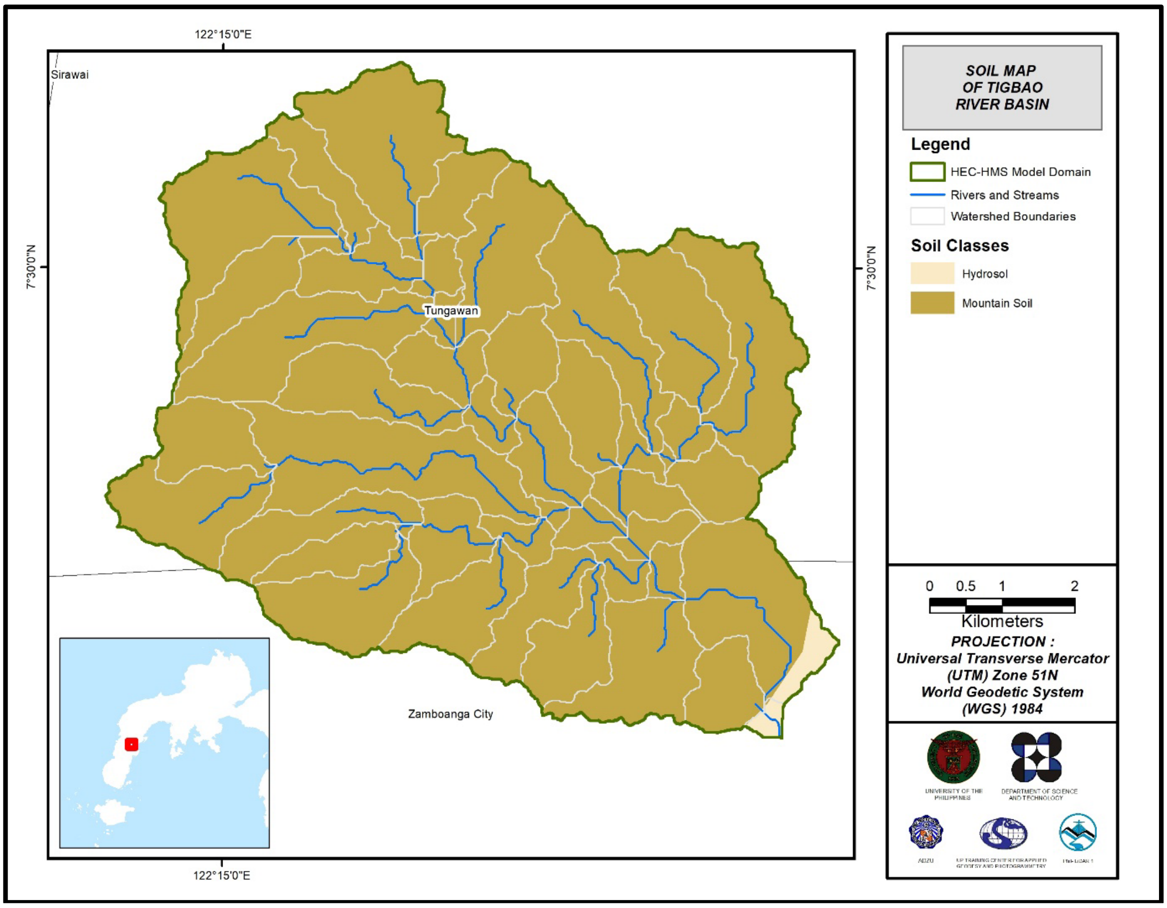


Figure 59. Soil Map of Tigbao River Basin

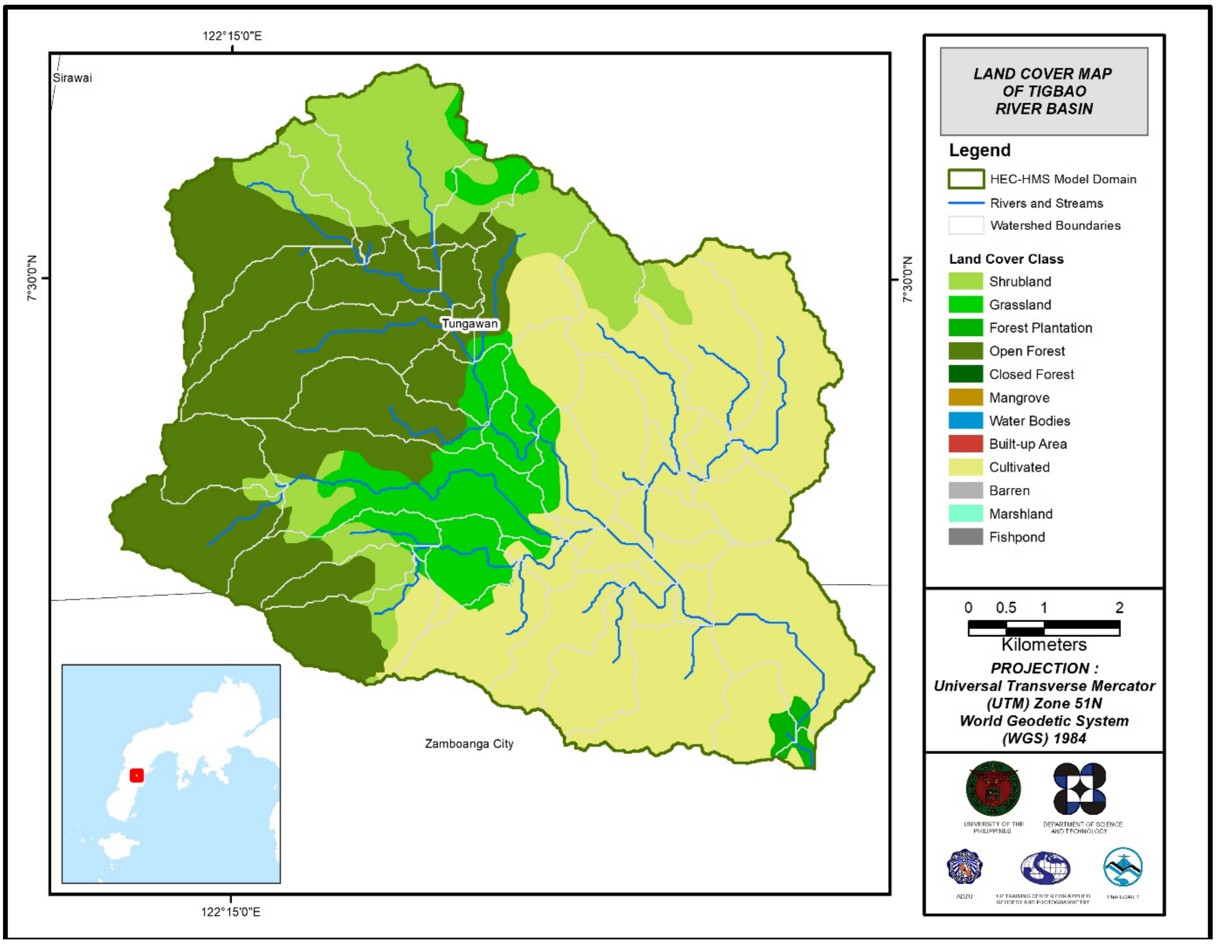


Figure 60. Land Cover Map of Tigbao River Basin

For Tigbao, the soil classes identified were hydrosols and undifferentiated mountain soil. The land cover types identified were cultivated areas, open canopy forests, shrubland and forest plantations.

Figure 61. [insert Slope Map]

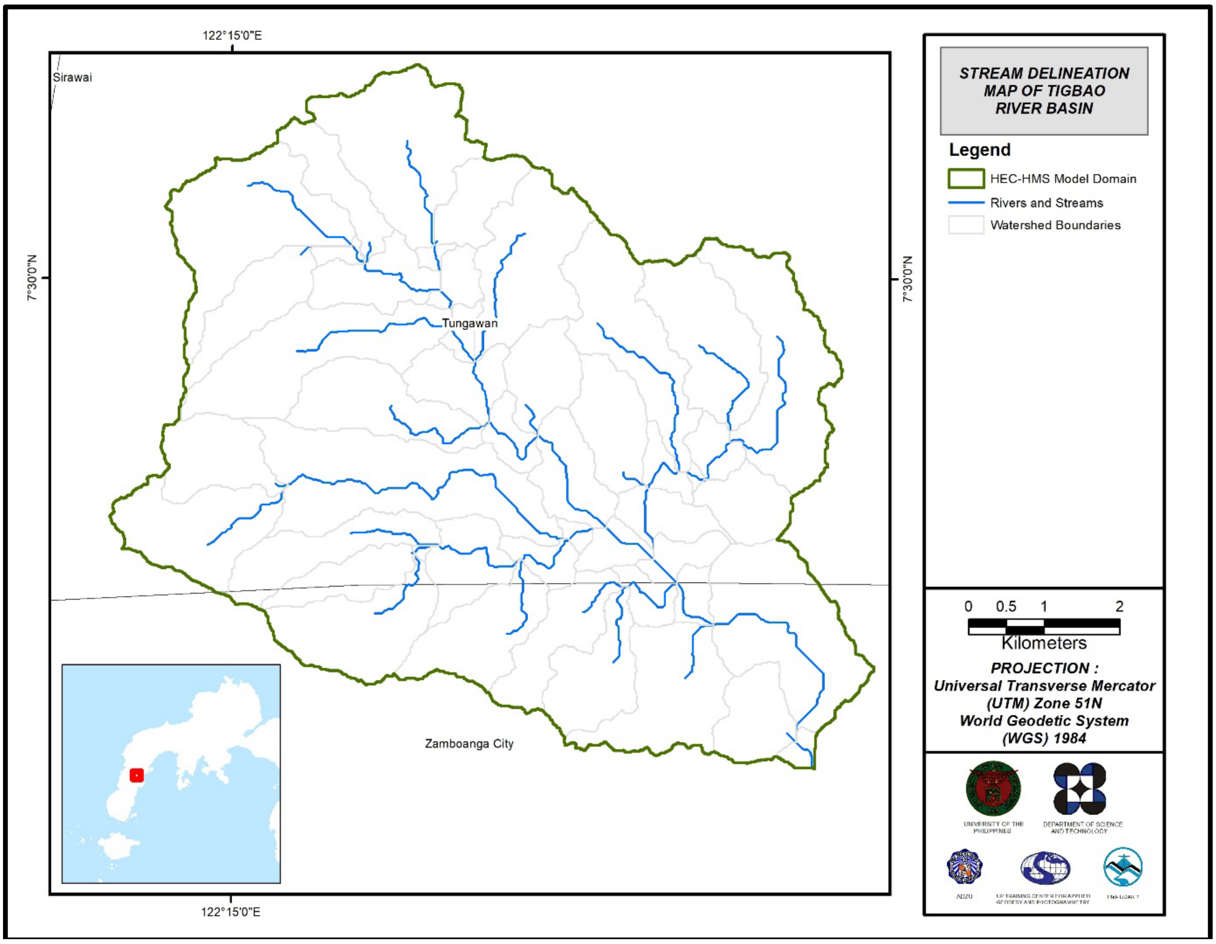


Figure 62. Stream delineation map of Tigbao river basin

Using the SAR-based DEM, the Tigbao basin was delineated and further subdivided into subbasins. The model consists of 47 sub basins, 23 reaches, and 23 junctions as shown in Figure 63 (See Annex 10). The main outlet is at Tigbao Bridge.

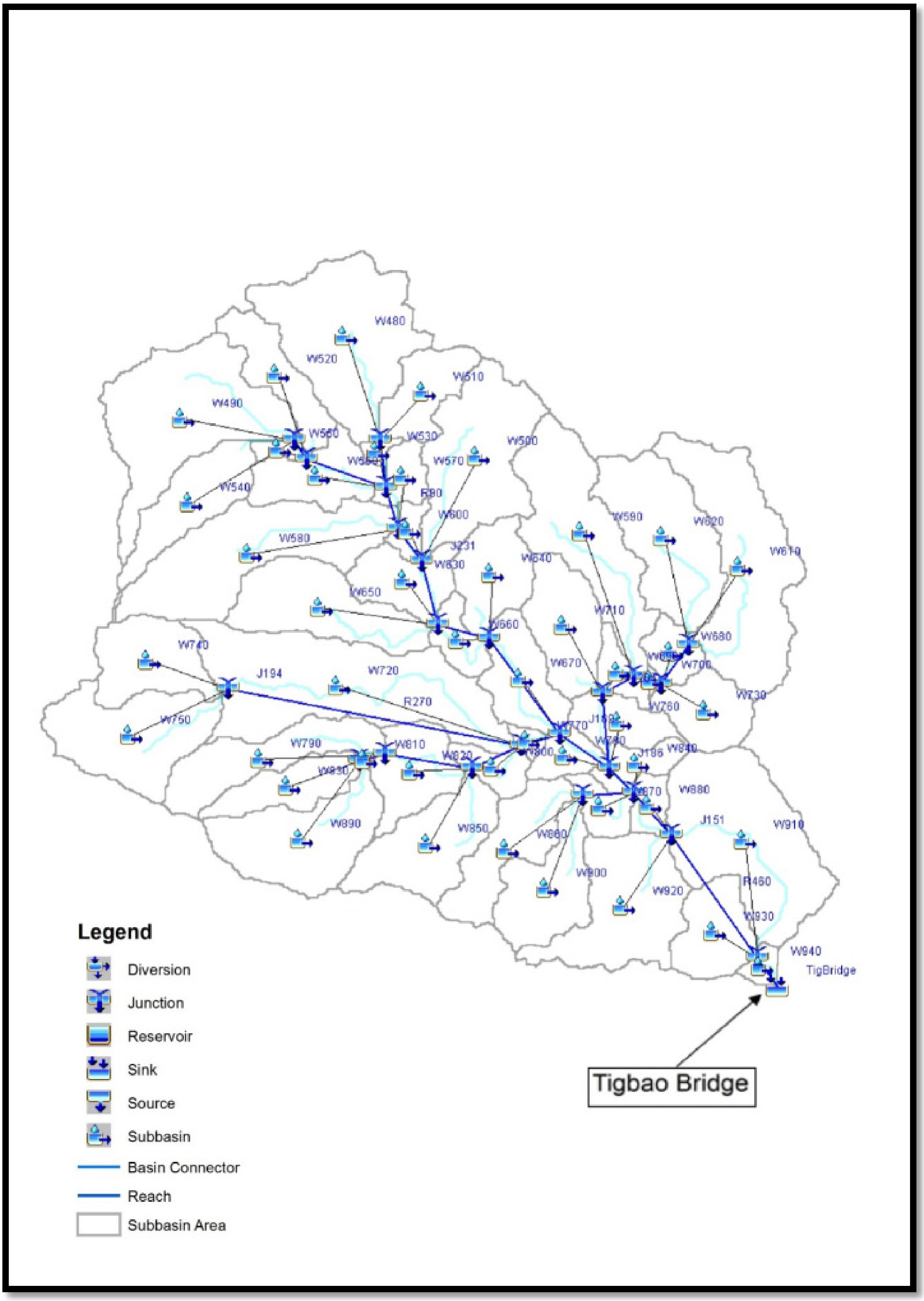


Figure 63.The Tigbao river basin model generated using HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data which was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 64).

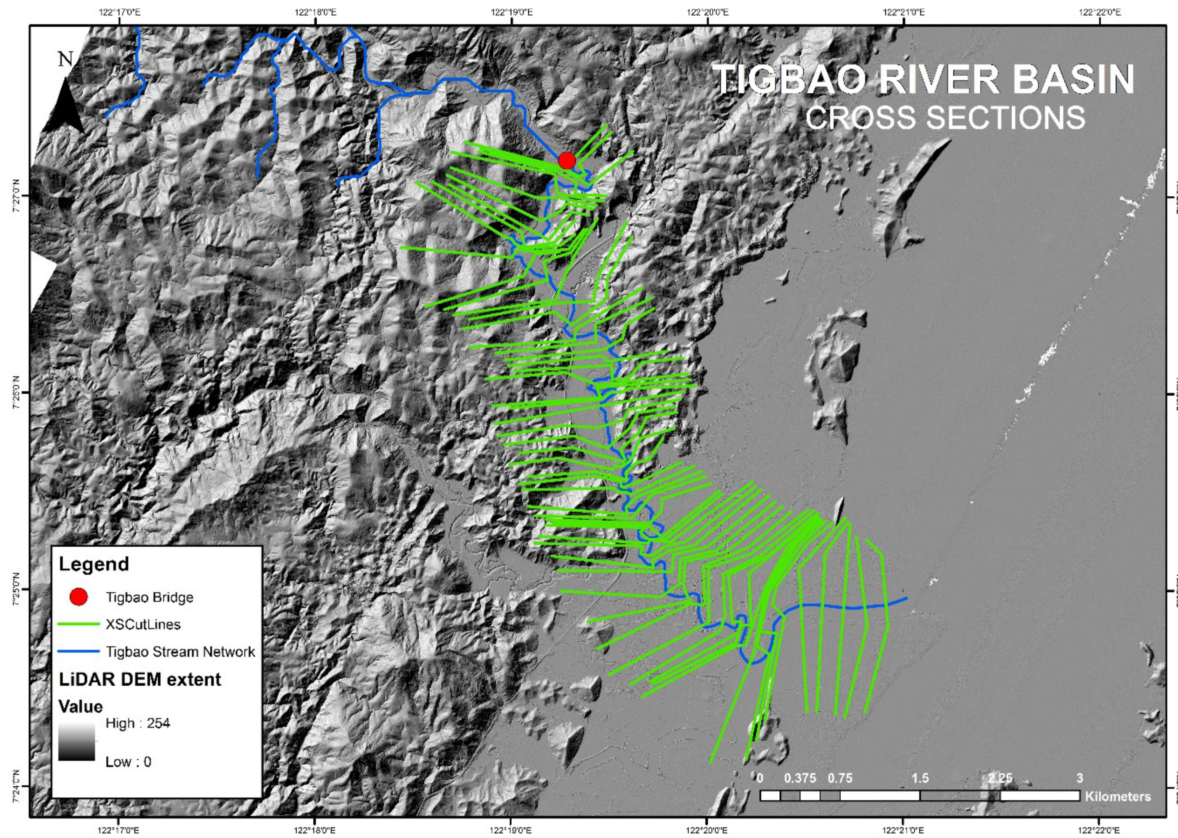


Figure 64. River cross-section of Tigbao River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modelling process allowed for the creation of a model with boundaries that are almost exactly coincidental with that of the catchment area. As such, they have approximately the same land area and location. The entire area was divided into square grid elements, 10 meter by 10 meter in size. Each element was assigned a unique grid element number which served as its identifier, then attributed with the parameters required for modeling such as x-and y-coordinate of centroid, names of adjacent grid elements, Manning coefficient of roughness, infiltration, and elevation value. The elements were 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 was seen that the water will generally flow from the northwest side of the model to the southeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements, respectively.

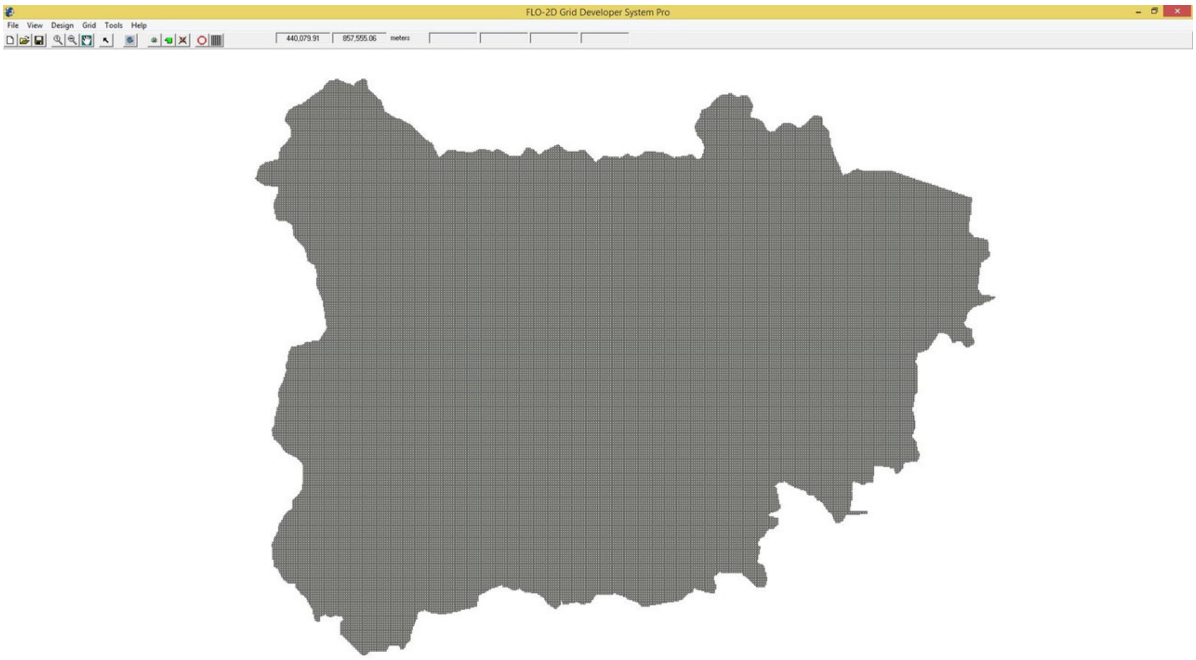


Figure 65. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 10.40424 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m^2/s.

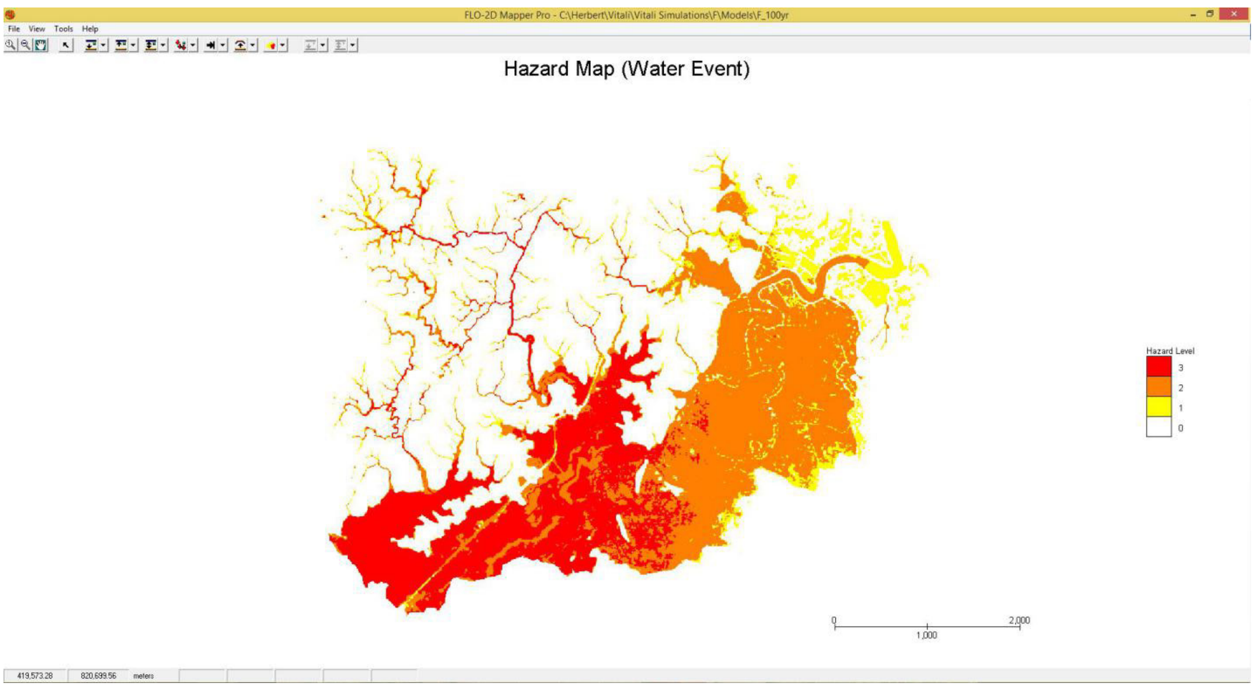


Figure 66. Generated 100-year rain return hazard map from FLO-2D Mapper

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 23,962,900.00 m^2.

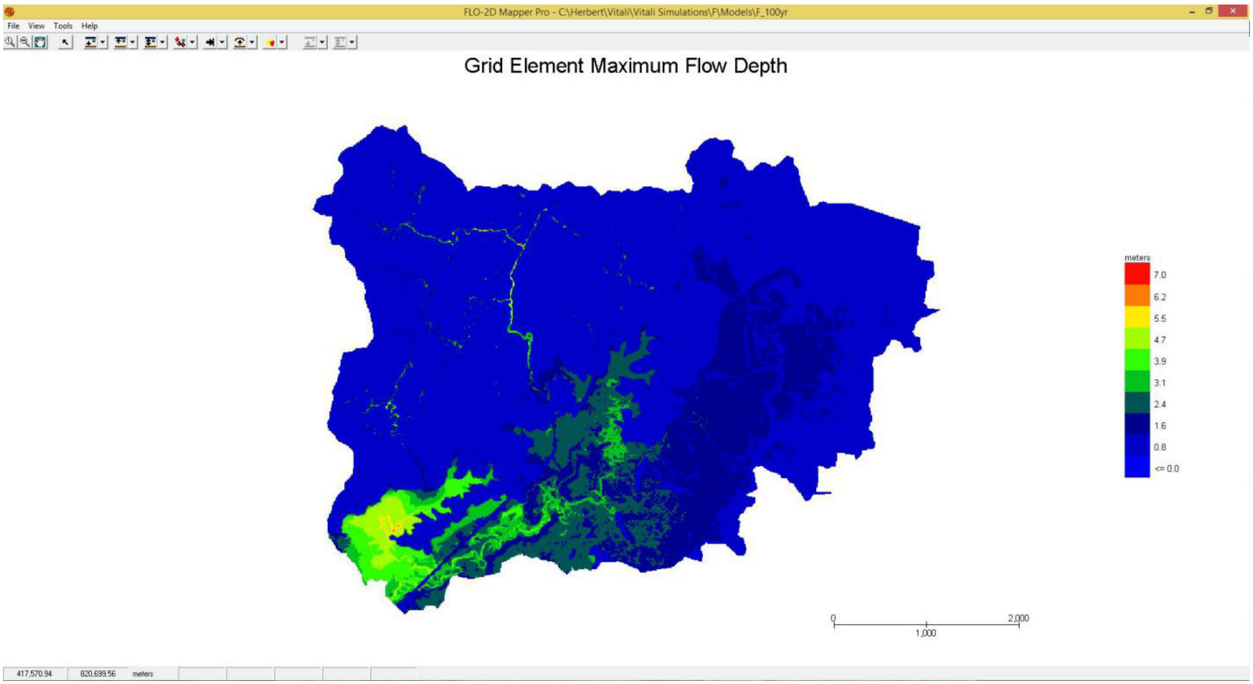


Figure 67. Generated 100-year rain return flow depth map from FLO-2D Mapper

There is a total of 27,331,265.67m^3 of water entering the model. Of this amount, 4,613,095.60m^3 is due to rainfall while 22,718,170.07m^3 is inflow from other areas outside the model. 3,270,871.50m^3 of this water is lost to infiltration and interception, while 7,935,769.15m^3 is stored by the floodplain. The rest, amounting up to 16,124,616.29m^3,is outflow.

5.6 Results of HMS Calibration

After calibrating the Tigbao HEC-HMS river basin model (See Annex 9), its accuracy was measured against the observed values. Figure 68 shows the comparison between the two discharge data.

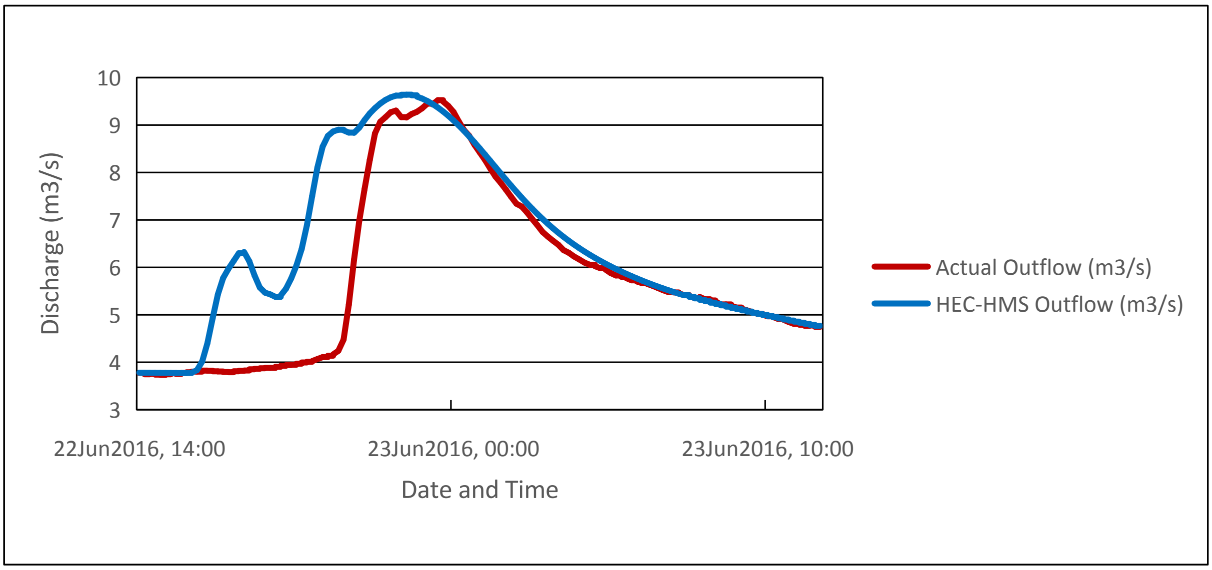


Figure 68. Outflow Hydrograph of Tigbao produced by the HEC-HMS model compared with observed outflow

The adjusted ranges of values of the parameters used in calibrating the model are enumerated in Table 29.

Table 29. Range of Calibrated Values for Tigbao

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.14 – 0.55
			Curve Number	55.91 – 90.48
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.30 – 3.27
			Storage Coefficient (hr)	0.039 – 0.43
	Baseflow	Recession	Recession Constant	0.545
			Ratio to Peak	0.25
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.3

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.14mm to 0.55mm means that there is a minimal 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 55.91 to 90.48 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area(M. Horritt, personal communication, 2012). For Tigbao, the basin mostly consists of cultivated and tree plantation areas and the soil consists of undifferentiated or mountain 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 0.039 hours to 3.27 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 0.545 indicates that the basin is moderately likely to go back to its original discharge. Ratio to peak of 0.25 indicates a moderate receding limb of the outflow hydrograph.

Table 30. Summary of the Efficiency Test of Mainit HMS Model

RMSE	15.46559
r2	0.8129
NSE	0.530562
PBIAS	-11.5329
RSR	0.685156

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as15.46559 (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 0.8129.

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 0.530562.

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 -11.5329.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.685156.

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

5.7.1 Hydrograph using the Rainfall Runoff Mode

The summary graph (Figure 69) shows the Tigbao outflow using the Zamboanga City 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 PAG-ASA data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

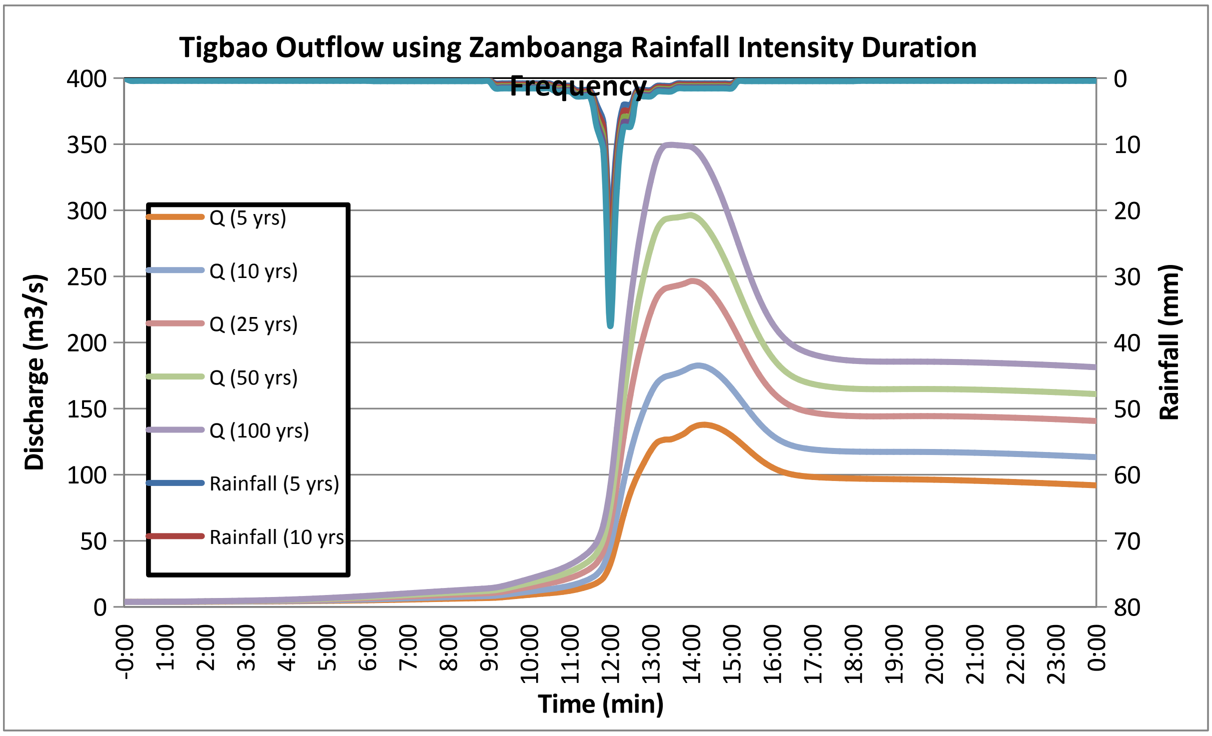


Figure 69. Outflow hydrograph at Guitu-an Bridge Station generated using Zamboanga City RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Tigbaodischarge using the Zamboanga City Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 31.

Table 31. Peak outflows of the Mainit-Tubay HECHMS Model at Puyo Bridge using the Butuan-Surigao RIDF

RIDF Period	Total Precipitation (mm)	Peak Rainfall (mm)	Peak Outflow (m^3/s)	Time to Peak
5-Year	107.8	21.4	137.78	14 hours 20 minutes
10-Year	127.9	25.3	182.59	14 hours 10 minutes
25-Year	153.4	30.2	246.46	14 hours
50-Year	172.3	33.9	296.32	14 hours
100-Year	191.1	37.5	349.50	13 hours 30 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model was used in determining the flooded areas within the model. The simulated model was 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 Tigbao River using the calibrated HMS base flow is shown in Figure 70.

Figure 70. Sample output of Tigbao RAS Model

5.9 Flood Hazard and Flow Depth

The resulting hazard and flow depth maps have a 10m resolution. Figure 71 to Figure 76 show the 5-, 25-, and 100-year rain return scenarios of the Tigbao Floodplain.

The generated flood hazard maps for the Tigbao 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 32. Municipalities affected in Mainit floodplain

Municipality	Total Area	Area Flooded	% Flooded
Zamboanga City	1496.29	195.07	13%
Tungawan	344.02	5.25	2%

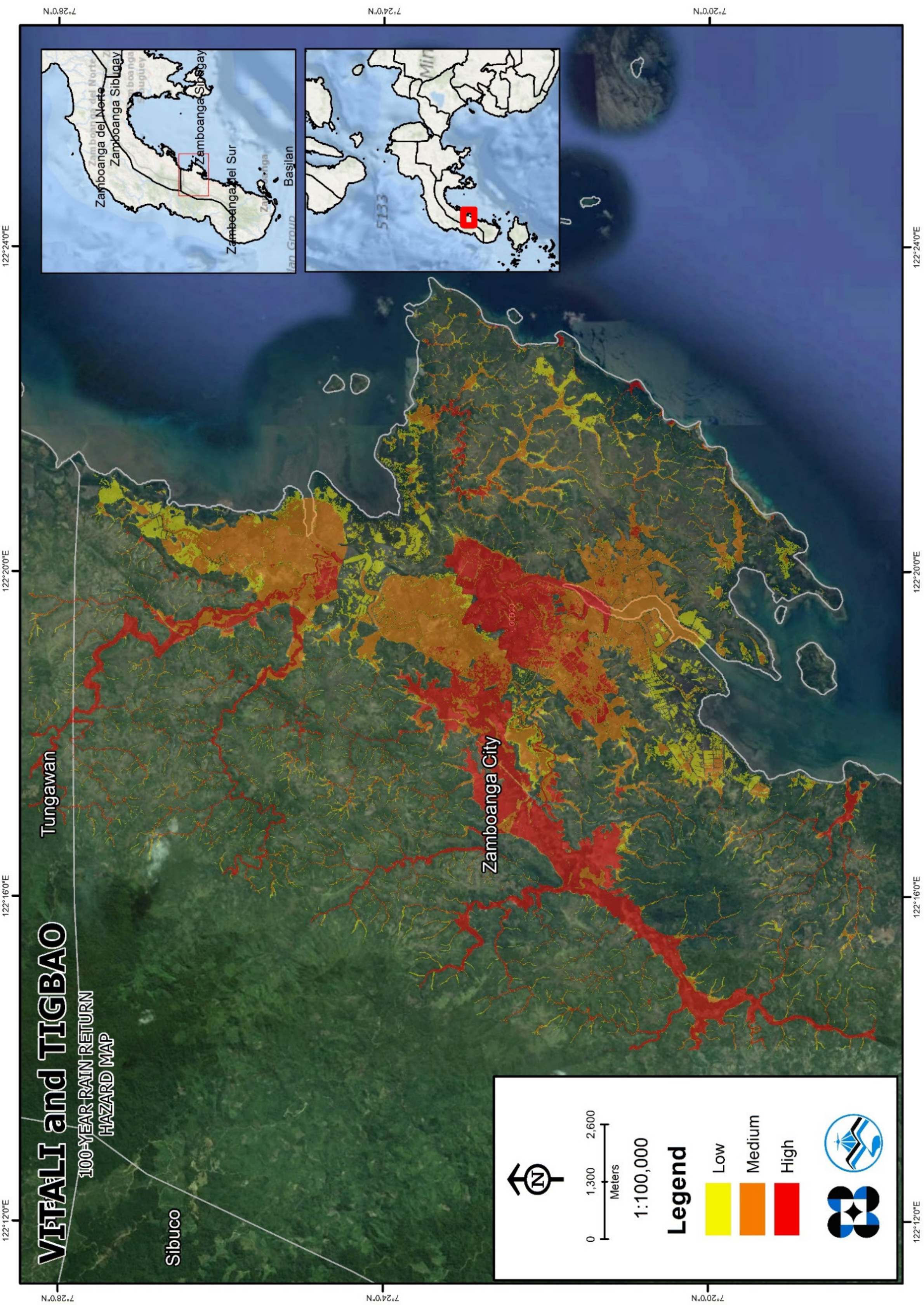


Figure 71. 100-year Flood Hazard Map for Tigbao Floodplain

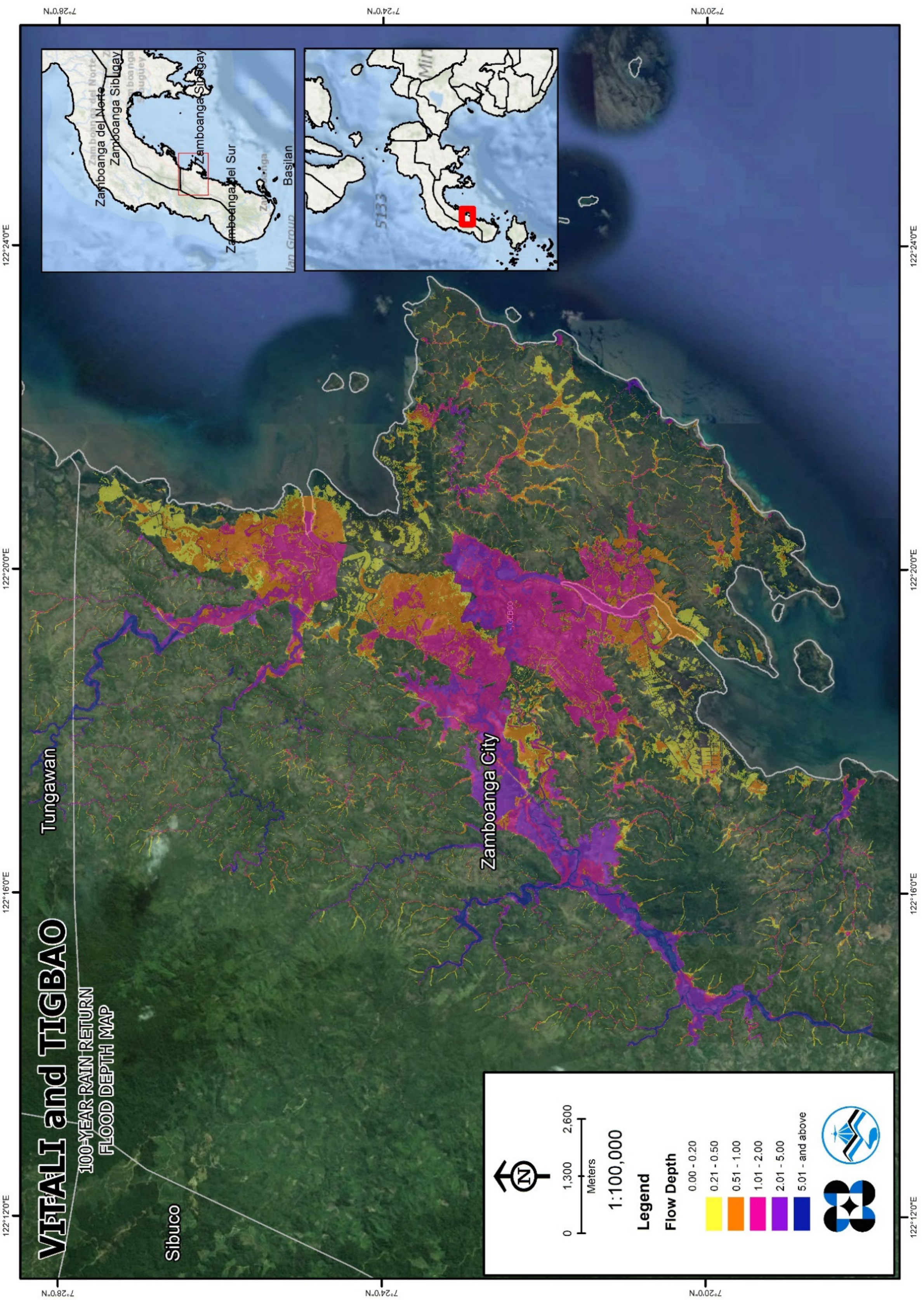


Figure 72. 100-year Flow Depth Map for Tigbao Floodplain

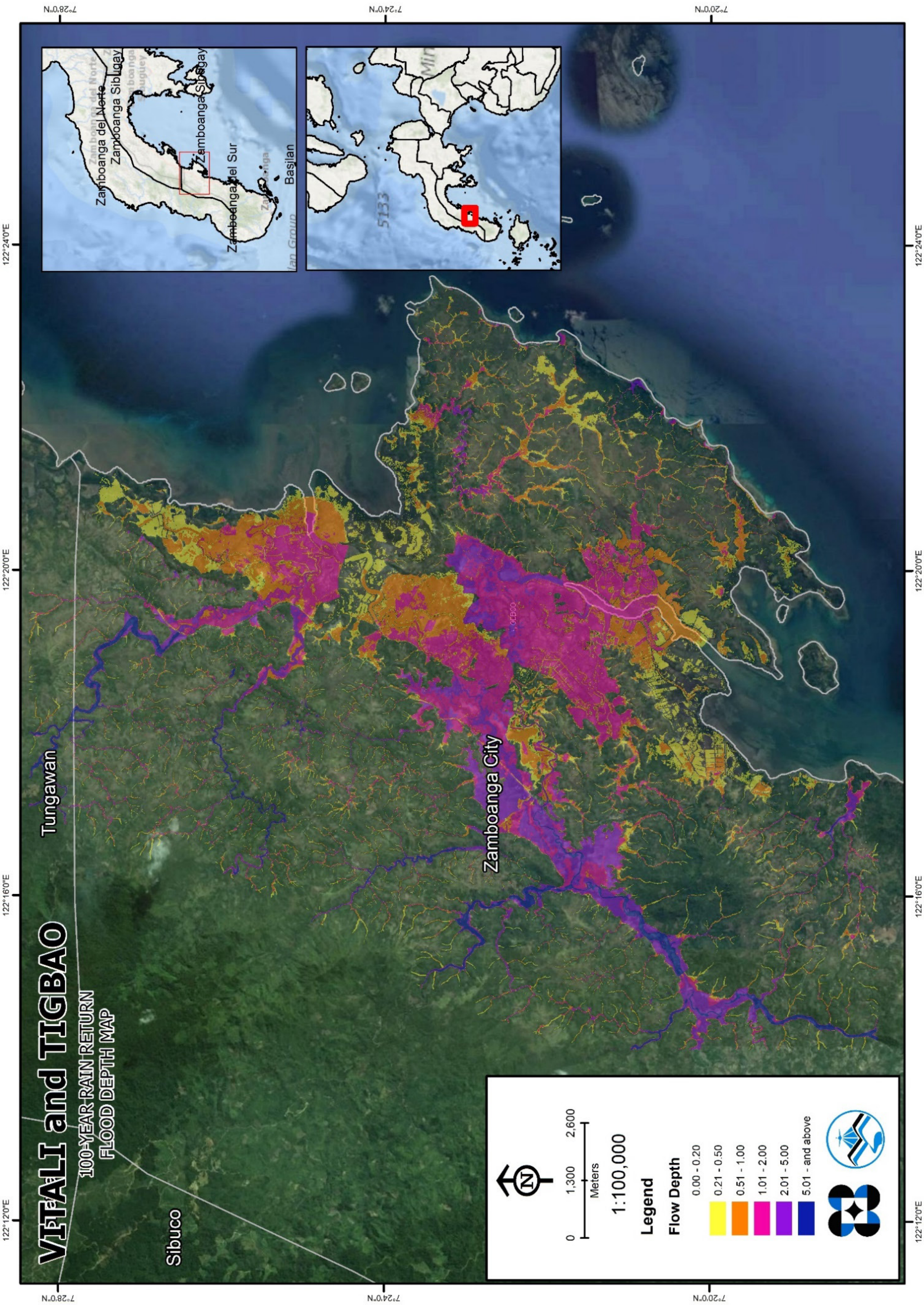


Figure 73. 25-year Flood Hazard Map for Tigbao Floodplain

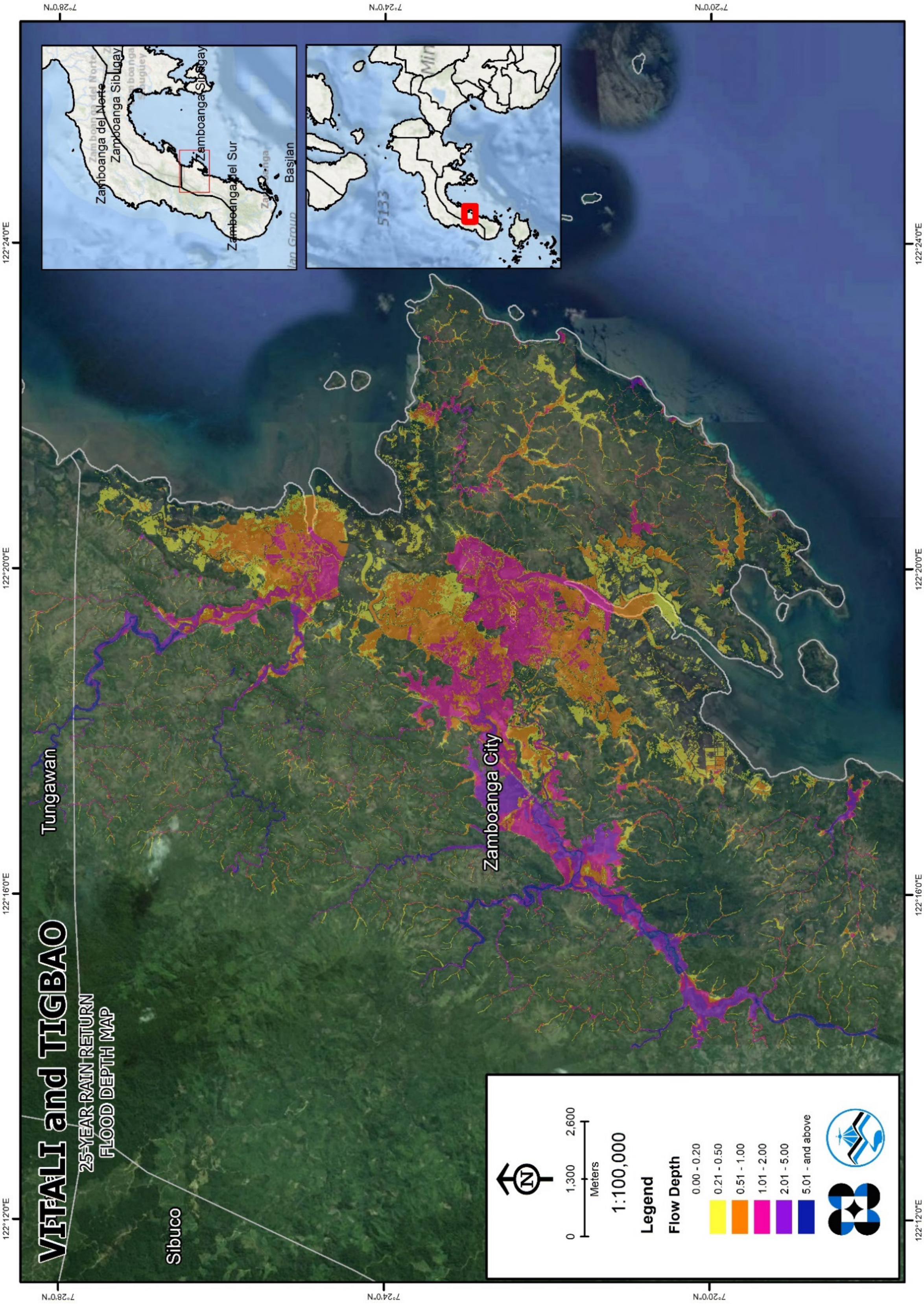


Figure 74. 25-year Flow Depth Map for Tigbao Floodplain

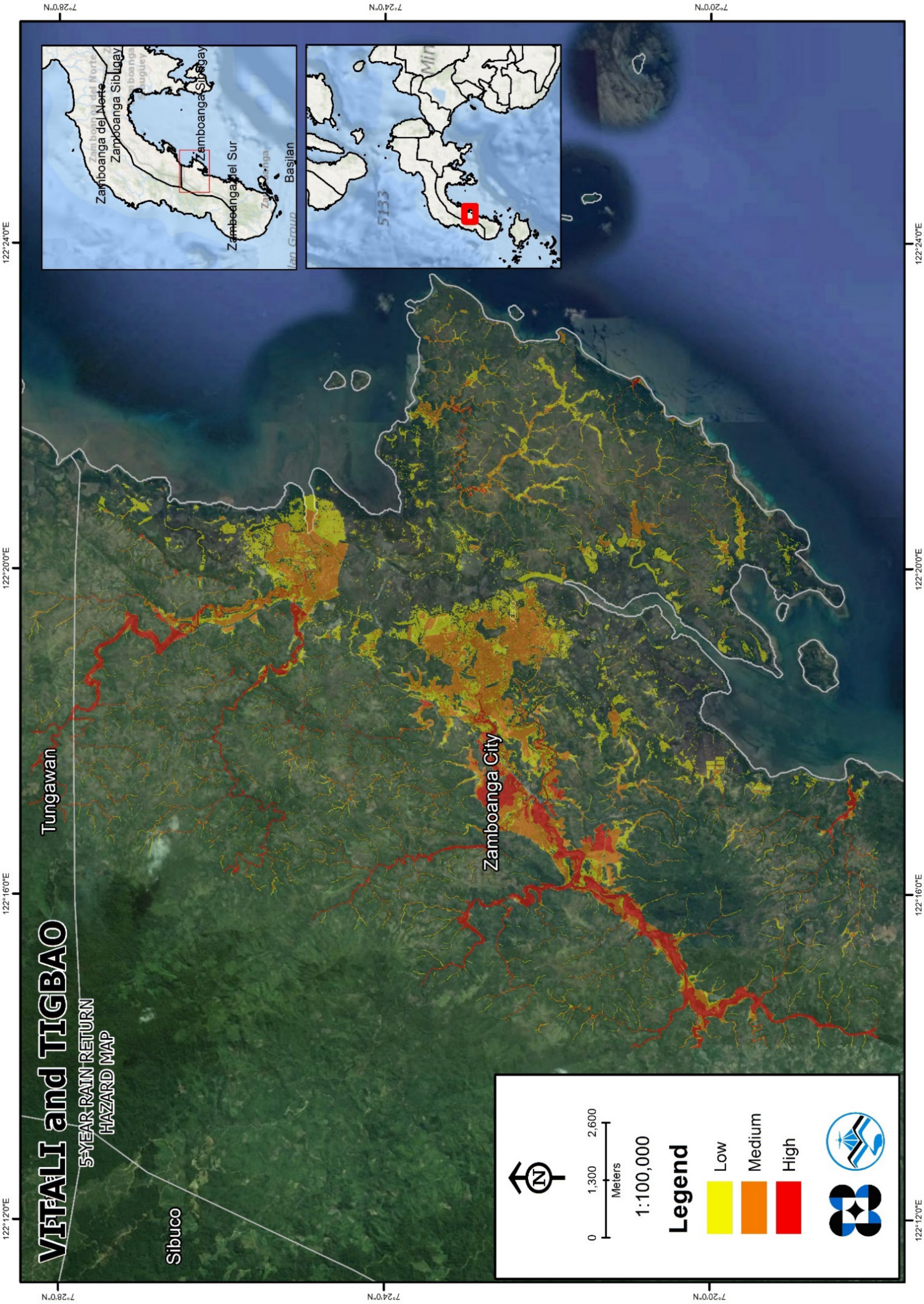


Figure 75. 5-year Flood Hazard Map for Tigbao Floodplain

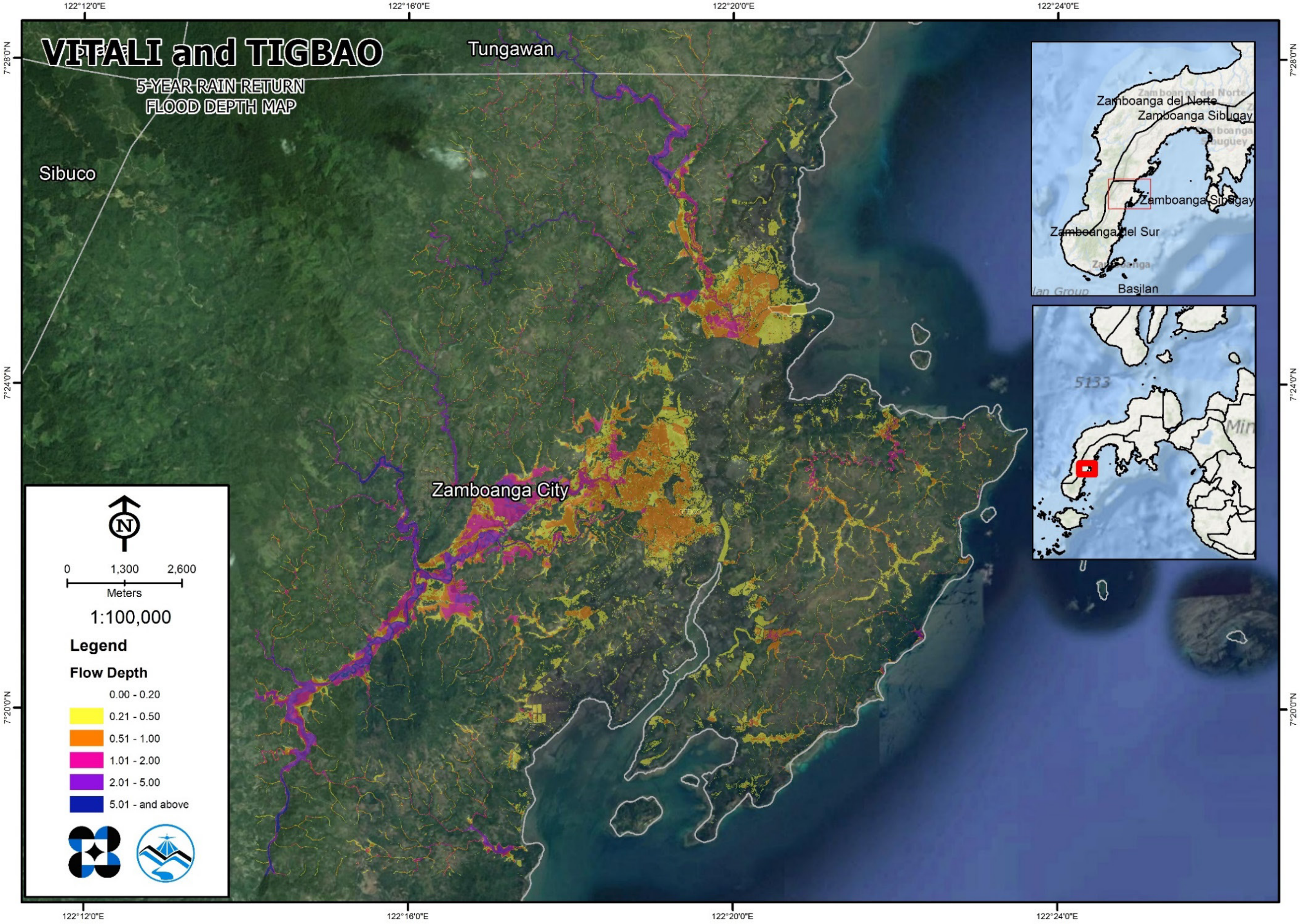


Figure 76. 5-year Flood Depth Map for Tigbao Floodplain

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Tigbao river basin, grouped by municipality, are listed below. For the said basin, 11 barangays in two municipalities are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 10.82% of the municipality of Zamboanga City with an area of 1496.293 sq. km. will experience flood levels of less than 0.20 meters; 0.96% of the area will experience flood levels of 0.21 to 0.50 meters while 0.67%, 0.34%, 0.21%, and 0.04% 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 the table are the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected Areas in Zamboanga City during 5-Year Rainfall Return Period

Affected Area (sq. km.) by flood depth (in m.)		Affected Barangays in Cabadbaran City (in sq. km)								
		Licomo	Limaong	Mangusu	Tagasilay	Taguiti	Tictapul	Tigbalabag	Tumitus	Vitali
Affected Area (sq. km.)	1	10.7	18.48	19.79	3.61	3.65	59.16	12.34	16.09	18.01
	2	2.05	1.73	1.96	0.13	0.14	3.54	0.54	1.46	2.85
	3	0.89	0.64	0.43	0.056	0.1	3.16	0.37	0.63	3.77
	4	0.084	0.14	0.11	0.015	0.11	1.89	0.44	0.27	2
	5	0.031	0.017	0.0066	0.0002	0.098	1.43	0.4	0.022	1.1
	6	0	0	0	0	0	0.32	0.054	0	0.16

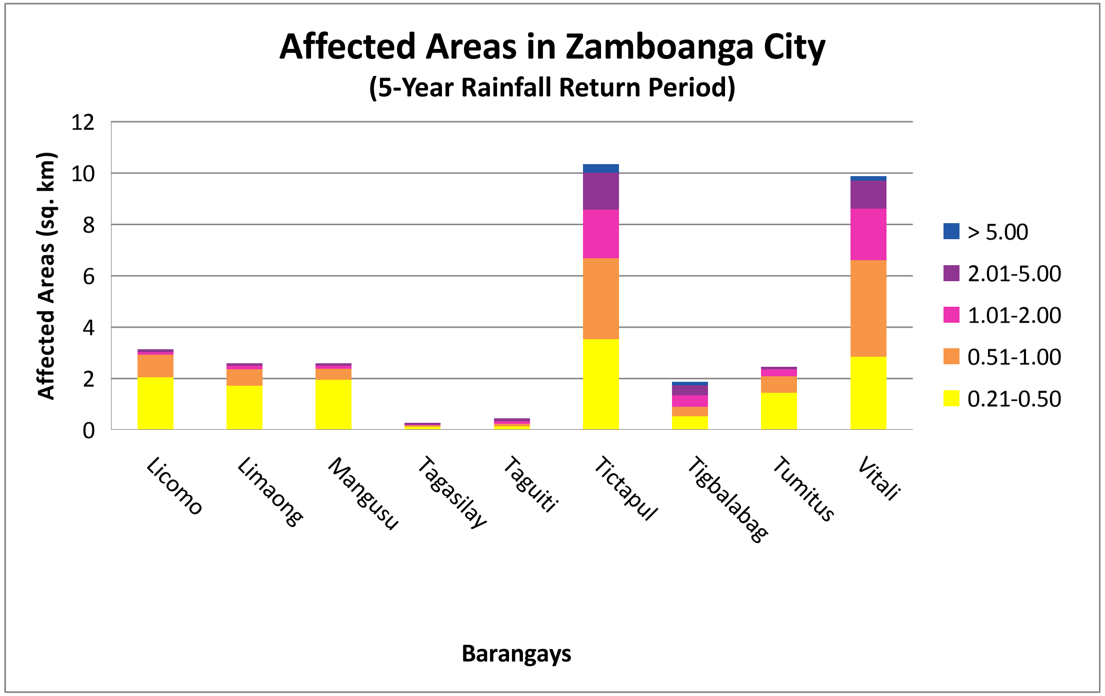


Figure 77.Affected Areas in Zamboanga City during 5-Year Rainfall Return Period

For the 5-year return period, 1.42% of the municipality of Tungawan with an area of 344.0154 sq. km. will experience flood levels of less than 0.20 meters; 0.02% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.01%, 0.03%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 34. Affected Areas in Tungawan, Zamboanga Sibugay during 5-Year Rainfall Return

Affected Area (sq. km.) by flood depth (in m.)		Area of affected barangays in Tungawan (in sq. km.)
		San Pedro
Affected Area (sq. km.)	1	4.87
	2	0.084
	3	0.065
	4	0.049
	5	0.1
	6	0.074

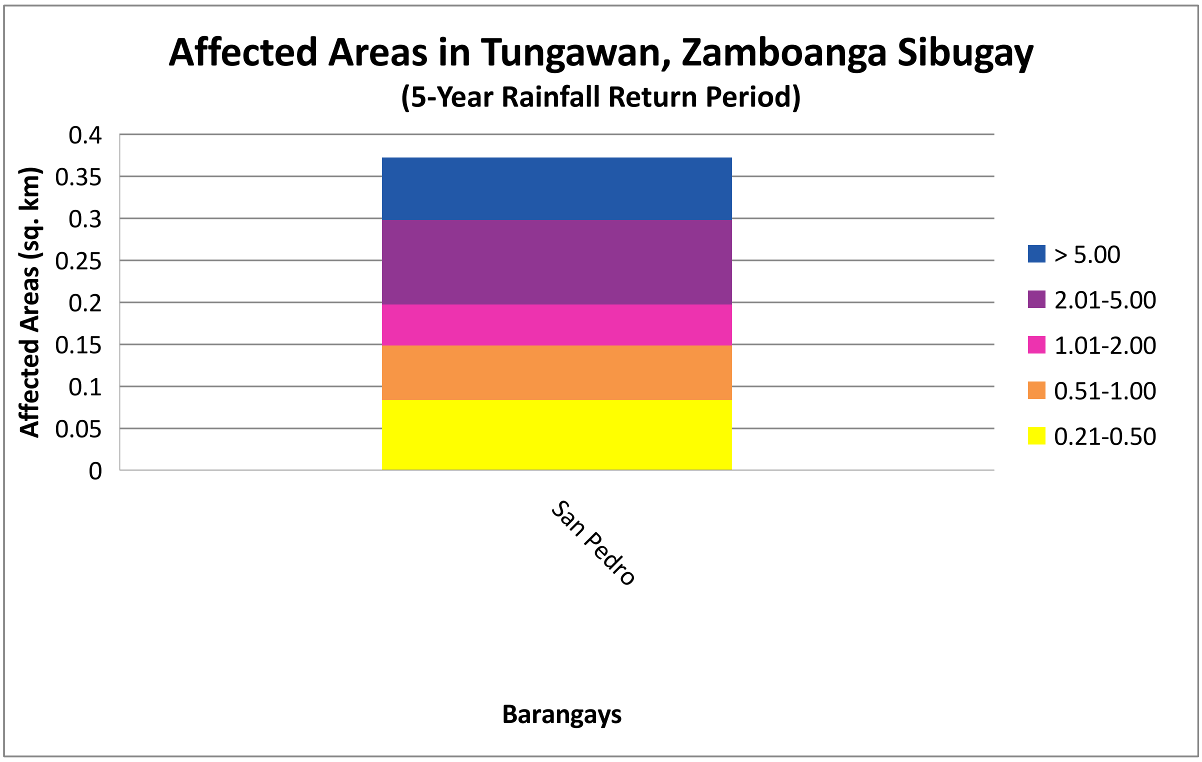


Figure 78. Affected Areas in Tungawan, Zamboanga Sibugay during 5-Year Rainfall Return Period

For the 25-year return period, 9.72% of the municipality of Zamboanga City with an area of 1496.293 sq. km. will experience flood levels of less than 0.20 meters; 0.96% of the area will experience flood levels of 0.21 to 0.50 meters while 1.08%, 0.83%, 0.36%, and 0.09% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected Areas in Zamboanga City during 25-Year Rainfall Return Period

Affected Area (sq. km.) by flood depth (in m.)		Affected Barangays in Cabadbaran City (in sq. km)								
		Licomo	Limaong	Mangusu	Tagasilay	Taguiti	Tictapul	Tigbalabag	Tumitus	Vitali
Affected Area (sq. km.)	1	8.01	17.06	15.97	3.56	3.53	55.27	12.05	14.99	15.07
	2	2.54	2.25	2.92	0.14	0.12	2.96	0.5	1.52	1.43
	3	2.63	1.3	2.76	0.082	0.12	4.81	0.32	1.04	3.07
	4	0.53	0.34	0.62	0.028	0.16	3.67	0.39	0.8	5.88
	5	0.063	0.051	0.023	0.0018	0.15	2.04	0.76	0.12	2.13
	6	0	0.0001	0	0	0.013	0.77	0.12	0	0.37

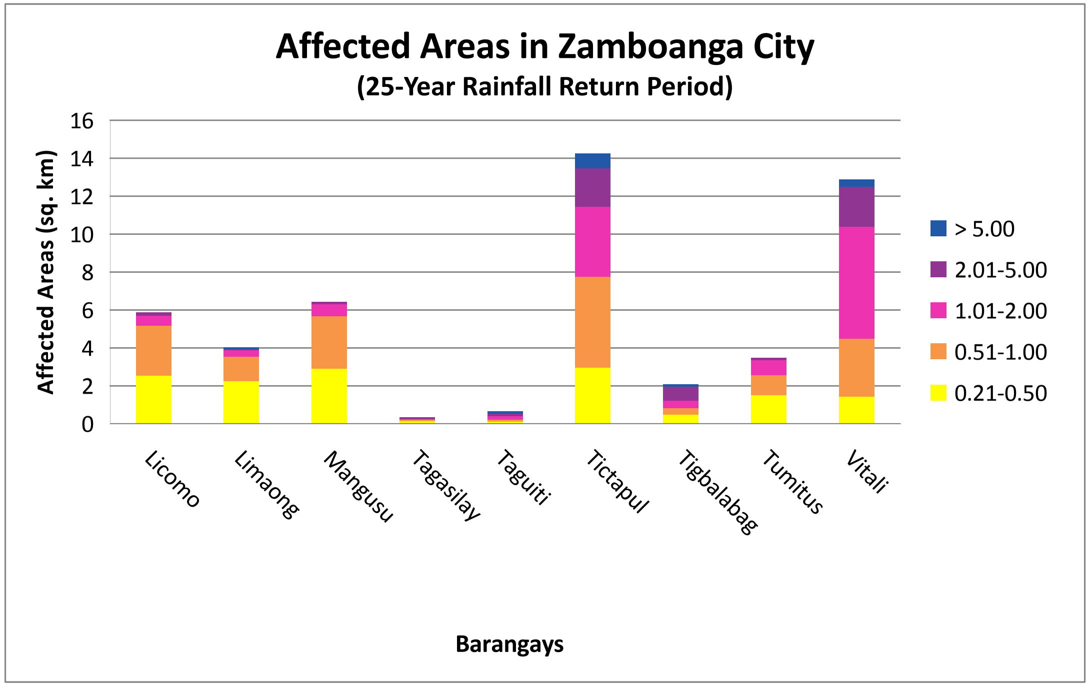


Figure 79. Affected Areas in Zamboanga City during 25-Year Rainfall Return Period

For the 25-year return period, 1.39% of the municipality of Tungawan with an area of 344.0154 sq. km. will experience flood levels of less than 0.20 meters; 0.03% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.02%, 0.03%, and 0.04% 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 the table are the affected areas in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Tungawan, Zamboanga Sibugay during 25-Year Rainfall Return Period

Affected Area (sq. km.) by flood depth (in m.)		Area of affected barangays in Tungawan (in sq. km.)
		San Pedro
Affected Area (sq. km.)	1	4.77
	2	0.1
	3	0.066
	4	0.064
	5	0.1
	6	0.14

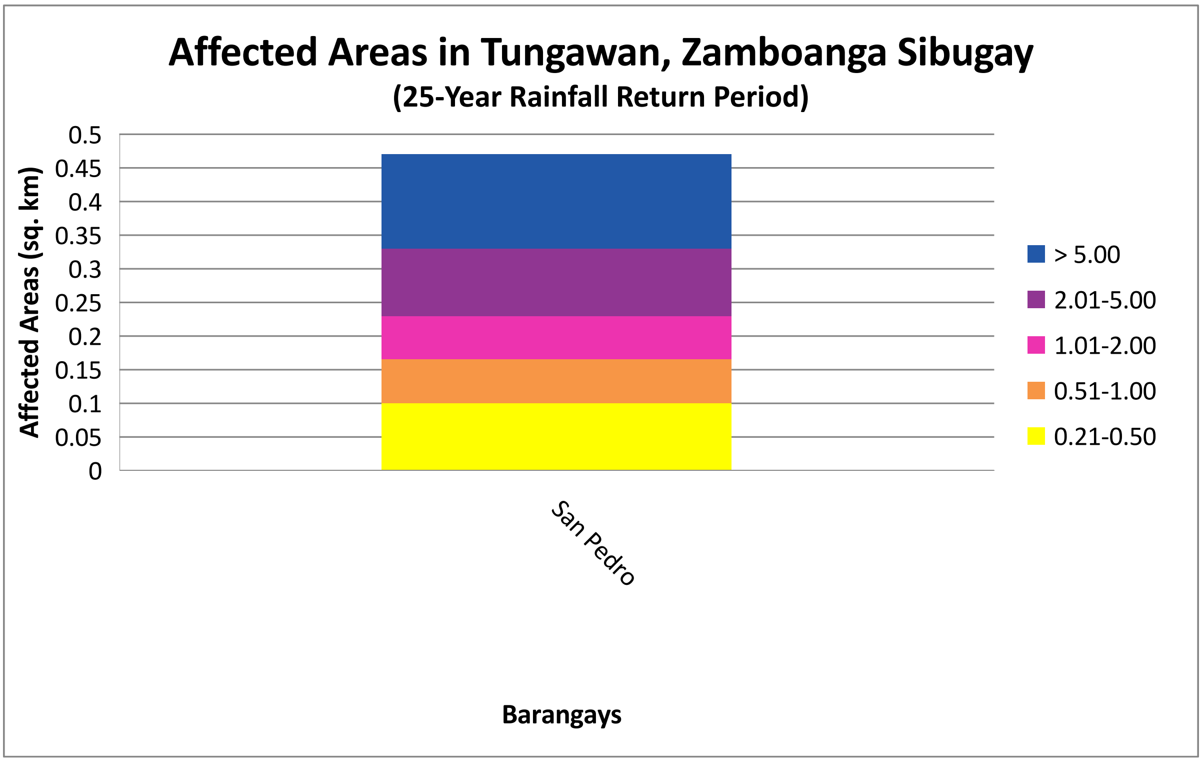


Figure 80. Affected Areas in Tungawan, Zamboanga Sibugay during 25-Year Rainfall Return Period

For the 100-year return period, 9.26% of the municipality of Zamboanga City with an area of 1496.293 sq. km. will experience flood levels of less than 0.20 meters; 0.86% of the area will experience flood levels of 0.21 to 0.50 meters while 0.97%, 1.23%, 0.59%, 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 the table are the affected areas in square kilometers by flood depth per barangay.

Table 37 .Affected Areas in Zamboanga City during 100-Year Rainfall Return Period

Affected Area (sq. km.) by flood depth (in m.)		Affected Barangays in Cabadbaran City (in sq. km)								
		Licomo	Limaong	Mangusu	Tagasilay	Taguiti	Tictapul	Tigbalabag	Tumitus	Vitali
Affected Area (sq. km.)	1	6.77	16.08	13.73	3.52	3.47	54.15	11.89	14.5	14.45
	2	2.47	1.61	2.87	0.15	0.13	2.46	0.5	1.53	1.1
	3	3.03	1.7	2.29	0.098	0.1	4.17	0.33	1.13	1.62
	4	1.41	1.52	3.32	0.035	0.18	4.91	0.3	0.84	5.95
	5	0.088	0.096	0.081	0.0044	0.2	2.71	0.9	0.47	4.26
	6	0.0027	0.0026	0	0	0.027	1.12	0.23	0.0021	0.56

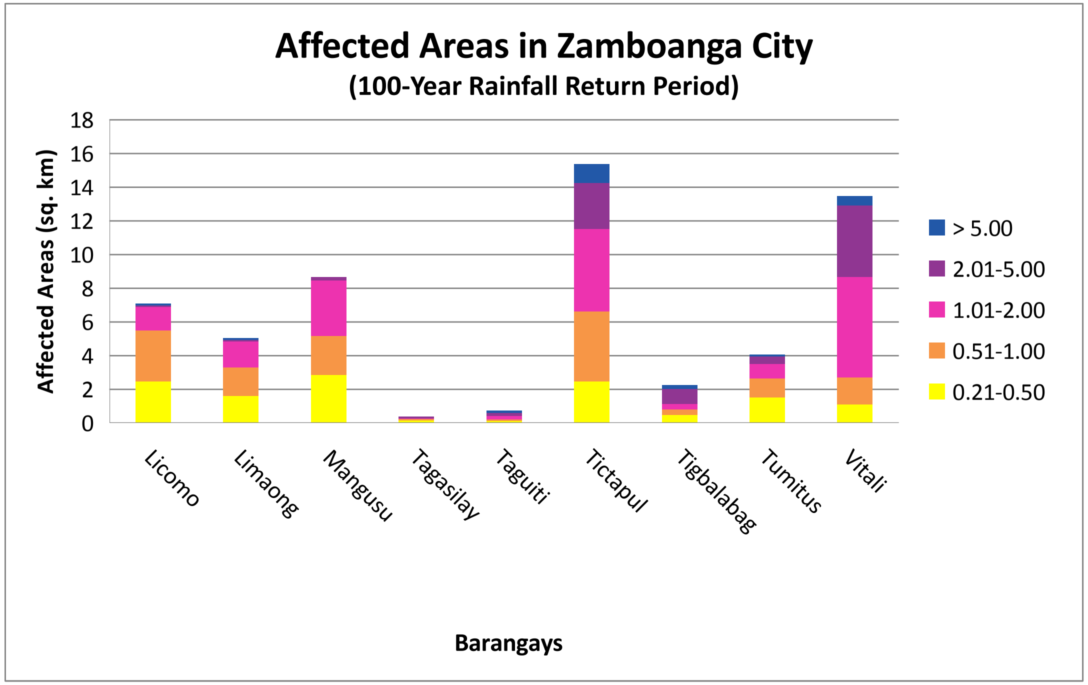


Figure 81. Affected Areas in Zamboanga City during 100-Year Rainfall Return Period

For the 100-year return period, 1.37% of the municipality of Tungawan with an area of 344.0154 sq. km. will experience flood levels of less than 0.20 meters; 0.03% of the area will experience flood levels of 0.21 to 0.50 meters while 0.02%, 0.02%, 0.03%, and 0.06% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected Areas in Tungawan, Zamboanga Sibugay during 100-Year Rainfall Return Period

Affected Area (sq. km.) by flood depth (in m.)		Area of affected barangays in Tungawan (in sq. km.)
		San Pedro
Affected Area (sq. km.)	1	4.71
	2	0.11
	3	0.07
	4	0.067
	5	0.099
	6	0.19

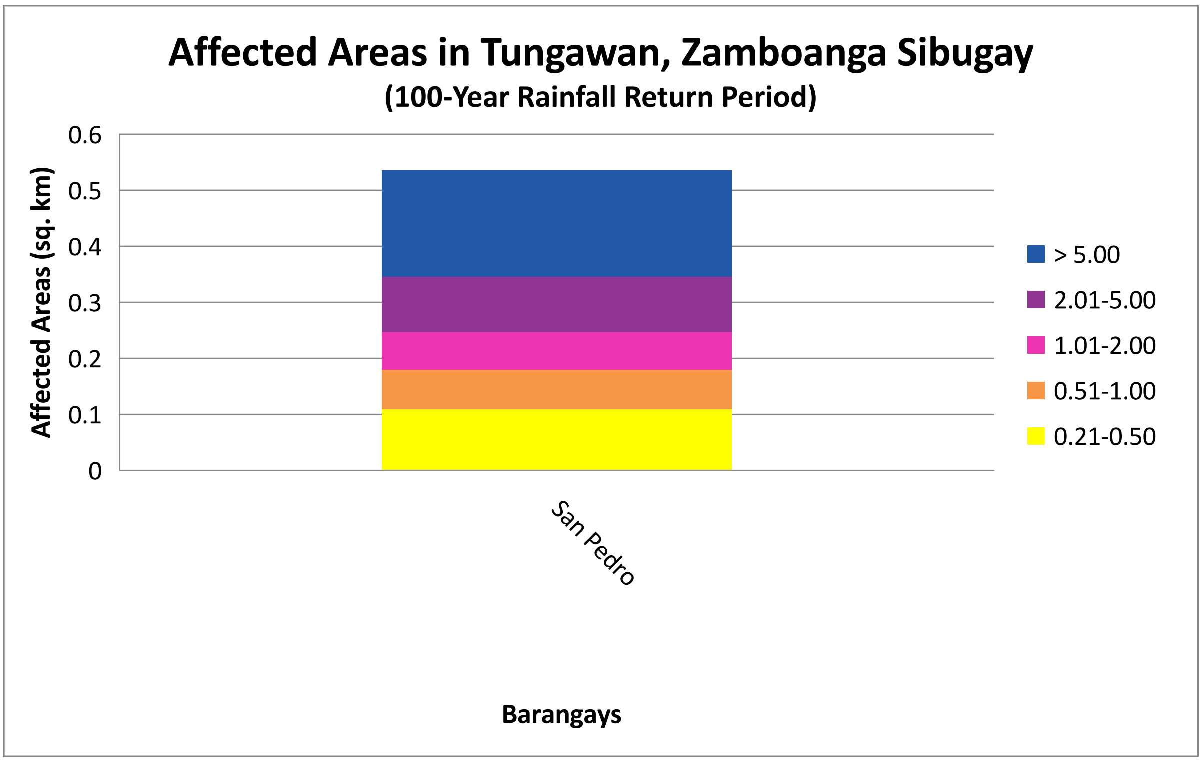


Figure 82. Affected Areas in Tungawan, Zamboanga Sibugay during 100-Year Rainfall Return Period

Moreover, the generated flood hazard maps for the Vitali-Tigbaofloodplain 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 39. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km		
	5 year	25 year	100 year
Low	2.1609	2.105264	1.586672
Medium	2.4831	4.573978	5.43313
High	1.5713	2.3118	3.01988

Of the 30 identified educational institutions in Vitali-Tigbao Floodplain, 3 were exposed to medium flood hazard levels while 10 were exposed to high flood hazard levels in the 5-year rain return period. The same 13 identified institutions were exposed to high flood hazard levels in the 25-year rain return period. For the 100-year rain return period, the same structures were exposed to the same hazard level while an additional 5 and 3 institutions were exposed to low and medium flood hazard levels, respectively.

The sole medical institution identified in the floodplain is the Health Center in Brgy. Vitali in Zamboanga City. It was assessed to be exposed to high level flooding for all flood hazard scenarios.

5.11 Flood Validation

The flood validation consists of 185 points randomly selected all over the Tigbao Floodplain. It has an RMSE value of 0.60. The validation points are found in Annex 11.

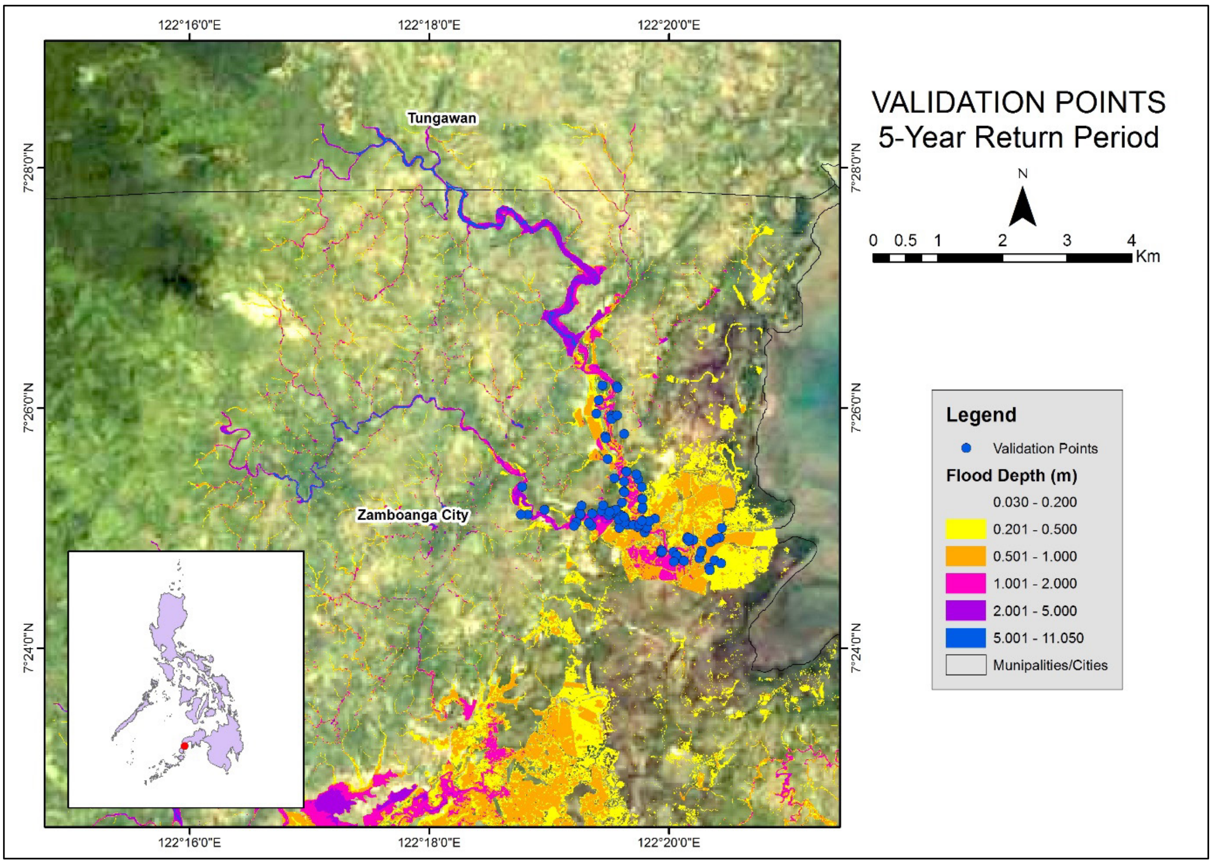


Figure 83. Validation points for 5-year Flood Depth Map of Tigbao Floodplain

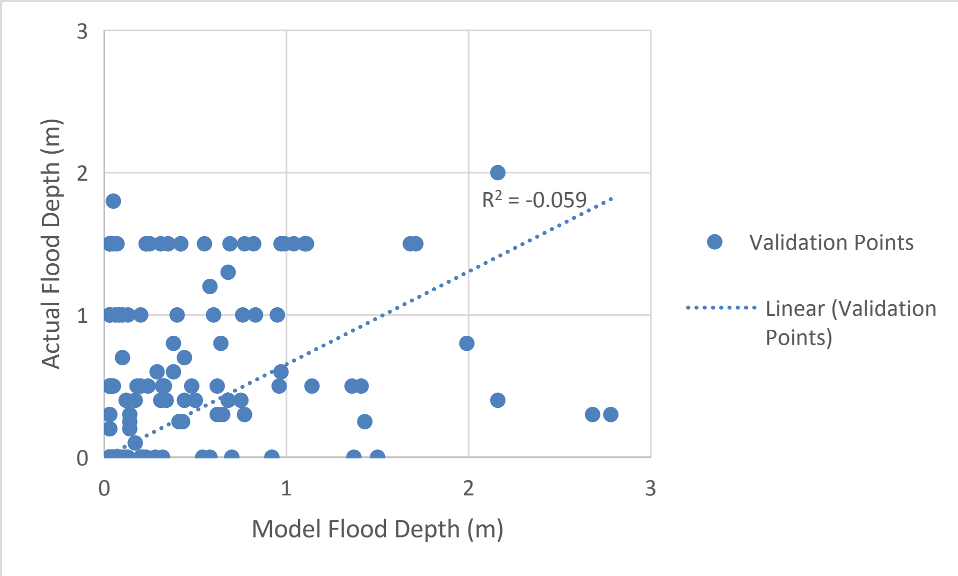


Figure 84. Flood map depth vs actual flood depth

Table 40. Actual Flood Depth vs Simulated Flood Depth in Tigbao

MAINIT-TUBAY BASIN		Modeled Flood Depth (m)						
		0-0.20	**0.21-0.50**	**0.51-1.00**	**1.01-2.00**	**2.01-5.00**	**>5.00**	**Total**
Actual Flood Depth (m)	**0-0.20**	86	5	4	2	0	0	97
	0.21-0.50	16	10	7	4	3	0	40
	0.51-1.00	9	5	6	1	0	0	21
	1.01-2.00	6	7	8	5	1	0	27
	2.01-5.00	0	0	0	0	0	0	0
	>5.00	0	0	0	0	0	0	0
	Total	117	27	25	12	4	0	185

The overall accuracy generated by the flood model is estimated at 57.84%, with 107 points correctly matching the actual flood depths. In addition, there were 38 points estimated one level above and below the correct flood depths while there were 24 points and 11 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 27 points were overestimated while a total of 51 points were underestimated in the modelled flood depths of Tigbao.

Table 41.Summary of Accuracy Assessment in Tigbao

	No. of Points	%
Correct	107	**57.84**
Overestimated	27	**14.59**
Underestimated	51	**27.57**
Total	185	**100.00**

REFERENCES

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

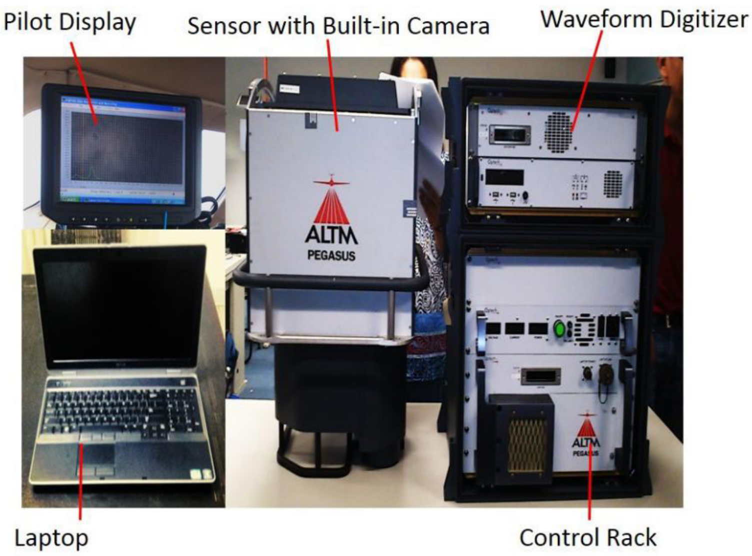
Sarmiento C., Paringit E.C., et al. 2014. DREAM Data Acquisition Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

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

LDRRM Office of Siay
Philippine Information Agency- IX
Mines and Geosciences Bureau- IX

ANNEXES

Annex 1. Technical Specifications of the LiDAR Sensors used in the Tigbao Floodplain Survey



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

Parameter	Specification
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

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

1. ZGS-99

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

August 29, 2014

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: **ZAMBOANGA DEL SUR**
Station Name: **ZGS-99**
Order: **2nd**

Island:	**MINDANAO**	Barangay:	**CALARIAN**		
Municipality:	**ZAMBOANGA CITY**	MSL Elevation:			
		PRS92 Coordinates			
Latitude:	**6° 55' 37.48971"**	Longitude:	**122° 0' 52.66431"**	Ellipsoidal Hgt:	**8.14900 m.**
		WGS84 Coordinates			
Latitude:	**6° 55' 34.07737"**	Longitude:	**122° 0' 58.23072"**	Ellipsoidal Hgt:	**72.23000 m.**
		PTM / PRS92 Coordinates			
Northing:	**766020.391 m.**	Easting:	**391103.346 m.**	Zone:	**4**
		UTM / PRS92 Coordinates			
Northing:	**765,752.27**	Easting:	**391,141.46**	Zone:	**51**

Location Description

ZGS-99

The station is located beside a seawall, 10 m from the centerline and 50 m from the Airforce Beach, in Brgy. Upper Calarian. It is marked by a 4" copper nail flushed at the center of a cement putty on a concrete open canal with inscriptions " ZGS-99, 2009, NAMRIA".

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Purpose: **Reference**
OR Number: **8799780 A**
T.N.: **2014-1901**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

2. ZGS-100

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

August 29, 2014

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: **ZAMBOANGA DEL SUR**	
	Station Name: **ZGS-100**	
	Order: **2nd**	
Island: **MINDANAO**	Barangay: **MANICAHAN**	
Municipality: **ZAMBOANGA CITY**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **7° 1' 26.72368"**	Longitude: **122° 11' 12.74401"**	Ellipsoidal Hgt: **11.27000 m.**
	WGS84 Coordinates	
Latitude: **7° 1' 23.30149"**	Longitude: **122° 11' 18.30044"**	Ellipsoidal Hgt: **75.60300 m.**
	PTM / PRS92 Coordinates	
Northing: **776712.542 m.**	Easting: **410158.521 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **776,440.68**	Easting: **410,189.97**	Zone: **51**

Location Description

The station is marked by an 4" copper nail with its head flushed at the center of an cement putty on a concrete open canal with inscription " ZGS-100, 2009 NAMRIA".Located at Manicahan Barangay Hal 7 meters South from the flag pole 7 meters km post 1916-ZC22

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Purpose: **Reference**
OR Number: **8799780 A**
T.N.: **2014-1902**

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

9 9 0 8 2 9 2 0 1 4 1 5 4 2 2 5

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

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CIP/4701/12/09/814

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

1. BVA-1

Vector Components (Mark to Mark)

From:	ZGS100				
Grid		Local		Global	
Easting	410189.967 m	Latitude	N7°01'26.72367"	Latitude	N7°01'23.30149"
Northing	776440.678 m	Longitude	E122°11'12.74401"	Longitude	E122°11'18.30044"
Elevation	7.745 m	Height	11.271 m	Height	75.603 m

To:	BVA1				
Grid		Local		Global	
Easting	418087.142 m	Latitude	N7°15'19.31910"	Latitude	N7°15'15.84241"
Northing	801995.112 m	Longitude	E122°15'28.78738"	Longitude	E122°15'34.32212"
Elevation	78.652 m	Height	82.446 m	Height	146.526 m

Vector					
ΔEasting	7897.175 m	NS Fwd Azimuth	17°04'19"	ΔX	-4988.546 m
ΔNorthing	25554.433 m	Ellipsoid Dist.	26755.117 m	ΔY	-6818.290 m
ΔElevation	70.906 m	ΔHeight	71.176 m	ΔZ	25386.506 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.004 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.005 m
σ ΔElevation	0.006 m	σ ΔHeight	0.006 m	σ ΔZ	0.001 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000123020		
Y	-0.0000172637	0.0000297982	
Z	-0.0000030673	0.0000052949	0.0000017042

2. BVA-2

Vector Components (Mark to Mark)

From:	BVA-1				
Grid		Local		Global	
Easting	418087.142 m	Latitude	N7°15'19.31910"	Latitude	N7°15'15.84241"
Northing	801995.112 m	Longitude	E122°15'28.78739"	Longitude	E122°15'34.32212"
Elevation	78.652 m	Height	82.446 m	Height	146.526 m

To:	BVA-2				
Grid		Local		Global	
Easting	418085.472 m	Latitude	N7°15'19.25198"	Latitude	N7°15'15.77529"
Northing	801993.053 m	Longitude	E122°15'28.73303"	Longitude	E122°15'34.26776"
Elevation	78.729 m	Height	82.524 m	Height	146.603 m

Vector					
ΔEasting	-1.670 m	NS Fwd Azimuth	218°57'49"	ΔX	1.230 m
ΔNorthing	-2.059 m	Ellipsoid Dist.	2.652 m	ΔY	1.175 m
ΔElevation	0.077 m	ΔHeight	0.077 m	ΔZ	-2.036 m

Standard Errors

Vector errors:					
σ ΔEasting	0.000 m	σ NS fwd Azimuth	0°00'28"	σ ΔX	0.001 m
σ ΔNorthing	0.000 m	σ Ellipsoid Dist.	0.000 m	σ ΔY	0.001 m
σ ΔElevation	0.001 m	σ ΔHeight	0.001 m	σ ΔZ	0.000 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000002792		
Y	-0.0000002286	0.0000005344	
Z	-0.0000000947	0.0000001357	0.0000001598

3. ZGS-99A

Vector Components (Mark to Mark)

From:	ZGS-99				
Grid		Local		Global	
Easting	391141.462 m	Latitude	N6°55'37.48971"	Latitude	N6°55'34.07737"
Northing	765752.270 m	Longitude	E122°00'52.66432"	Longitude	E122°00'58.23072"
Elevation	4.653 m	Height	8.149 m	Height	72.230 m

To:	ZGS-99A				
Grid		Local		Global	
Easting	391136.071 m	Latitude	N6°55'37.63895"	Latitude	N6°55'34.22659"
Northing	765756.864 m	Longitude	E122°00'52.48834"	Longitude	E122°00'58.05475"
Elevation	4.354 m	Height	7.850 m	Height	71.931 m

Vector					
ΔEasting	-5.391 m	NS Fwd Azimuth	310°19'07"	ΔX	5.031 m
ΔNorthing	4.594 m	Ellipsoid Dist.	7.085 m	ΔY	2.144 m
ΔElevation	-0.299 m	ΔHeight	-0.299 m	ΔZ	4.515 m

Standard Errors

Vector errors:					
σ ΔEasting	0.000 m	σ NS fwd Azimuth	0°00'11"	σ ΔX	0.000 m
σ ΔNorthing	0.000 m	σ Ellipsoid Dist.	0.000 m	σ ΔY	0.001 m
σ ΔElevation	0.001 m	σ ΔHeight	0.001 m	σ ΔZ	0.000 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000002239		
Y	-0.0000001250	0.0000004533	
Z	-0.0000000277	0.0000000071	0.0000000770

Annex 4. The LiDAR Survey Team Composition

Date Acquisition Component Sub-team	Designation	Name	Agency/Affiliation
PHIL-LiDAR 1	Program Leader	ENRICO C. PARINGIT, D. ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader –I	ENGR. CZAR JAKIRI S. SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		ENGR. LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	ENGR. IRO NIEL ROXAS	UP-TCAGP
		KRISTINE JOY ANDAYA	UP-TCAGP
Ground Survey, Data download and transfer	RA	ENGR. RENAN PUNTO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. RONALD MONTENEGRO	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR SHERWIN ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. JOHN BRYAN DONGUINES	AAC

Annex 5. Data Transfer Sheet Tigbao Floodplain

DATA TRANSFER SHEET
02/24/2015(Zamboanga)

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	
5-Feb-15	2535P	1BLK75E36A	PEGASUS	2.95	2608	12.7	232	43.6	360	30.7	NA	7.53	1KB	1KB	38	NA	Z:\DAC\RAW DATA
6-Feb-15	2537P	1BLK75C37A	PEGASUS	3.55	1872	13.9	263	52.4	410	35.8	NA	8.2	1KB	1KB	38	NA	Z:\DAC\RAW DATA
6-Feb-15	2539P	1BLK75C37B	PEGASUS	1.37	332	7.95	175	25.2	222	17.6	NA	8.2	1KB	1KB	38	NA	Z:\DAC\RAW DATA
7-Feb-15	2545P	1BLK75C39A	PEGASUS	2.33	473	11.3	259	41.7	305	26.2	NA	7.77	1KB	1KB	70/76	NA	Z:\DAC\RAW DATA
9-Feb-15	2549P	1BLK75A40A	PEGASUS	3.95	2608	10.9	230	32.6	244	22.3	NA	4.37	1KB	1KB	NA	NA	Z:\DAC\RAW DATA
10-Feb-15	2553P	1BLK75S41A	PEGASUS	2.03	566	11.3	256	31.9	247	22.4	NA	6.81	1KB	1KB	89	NA	Z:\DAC\RAW DATA
11-Feb-15	2557P	1BLK75S42A	PEGASUS	1.62	301	10.6	255	34.9	240	20.5	NA	8.47	1KB	1KB	31/88	NA	Z:\DAC\RAW DATA

Received from

Name C JOAQUIN
Position
Signature

Received by

Name AC BONGAT
Position GSRS
Signature

Annex 6. Flight Logs for the Flight Missions

Flight Log for 1BLK75C37A Mission

DREAM Data Acquisition Flight Log — **Flight Log No.:** 2559

1 LiDAR Operator: J. Alviar	2 ALTM Model: Pegasus	3 Mission Name: 1BLK75D37B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: B. Donguines	9 Route: Zambo - Zambo			
10 Date: Feb. 6 2015	12 Airport of Departure (Airport, City/Province): Zamboanga		12 Airport of Arrival (Airport, City/Province): Zambo		
13 Engine On: 1509H	14 Engine Off: 1814H	15 Total Engine Time: 3+05	16 Take off: 1514H	17 Landing: 1809H	18 Total Flight Time: 2+55
19 Weather: partly cloudy					
20 Remarks: Surveyed BLK 75-D					

21 Problems and Solutions:

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

Acquisition Flight Certified by: [signature] — Signature over Printed Name (PAF Representative)

Pilot-in-Command: Alfonso III — Signature over Printed Name

Lidar Operator: J. Alviar — Signature over Printed Name

Flight Log for 1BLK75C37B Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 2537

1 LiDAR Operator: I. Roxas	2 ALTM Model: Pegasus	3 Mission Name: 1BLK75C37A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: B. Dongiunes	9 Route: Zambo - Zambo			
10 Date: Feb. 6, 2016	12 Airport of Departure (Airport, City/Province): Zamboanga		12 Airport of Arrival (Airport, City/Province): Zambo		
13 Engine On: 0807 H	14 Engine Off: 1230 H	15 Total Engine Time: 4+23	16 Take off: 0812 H	17 Landing: 1225 H	18 Total Flight Time: 4+13
19 Weather: Cloudy					

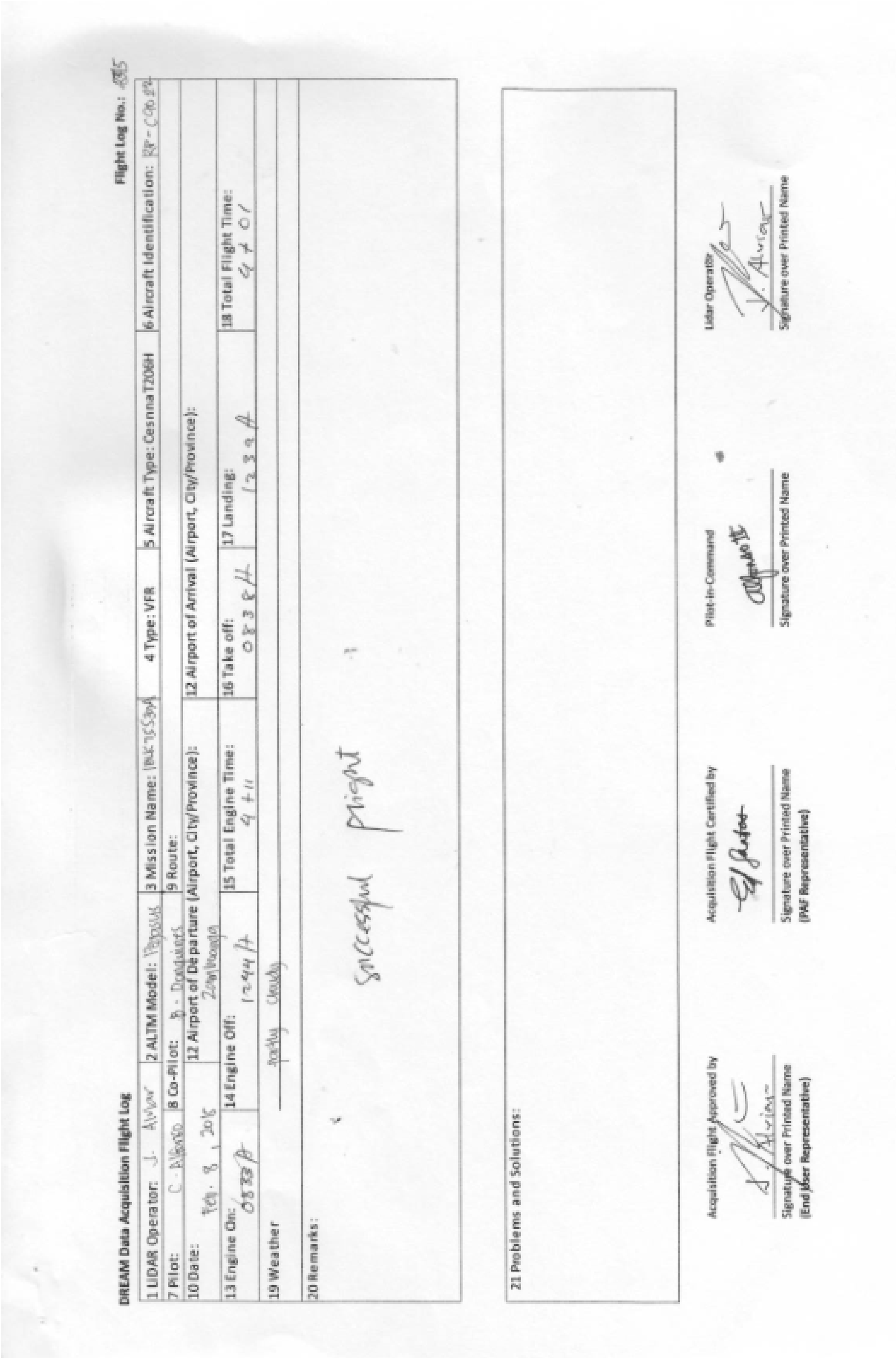
20 Remarks:

Surveyed BLK 75C

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	Ed Santos	Alfonso III	
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Flight Log for 1BLK75C39A Mission



DREAM Data Acquisition Flight Log — Flight Log No.: [illegible]

1 LIDAR Operator: J. Alviar	2 ALTM Model: Pegasus	3 Mission Name: 1BLK75C39A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9[illegible]
7 Pilot: C. Alfonso	8 Co-Pilot: B. Donguines	9 Route:			
10 Date: Feb. 8, 2016	12 Airport of Departure (Airport, City/Province): Zamboanga		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 0833H	14 Engine Off: 1244H	15 Total Engine Time: 4+11	16 Take off: 0838H	17 Landing: 1239H	18 Total Flight Time: 4+01
19 Weather: partly cloudy					
20 Remarks: successful flight					
21 Problems and Solutions:					

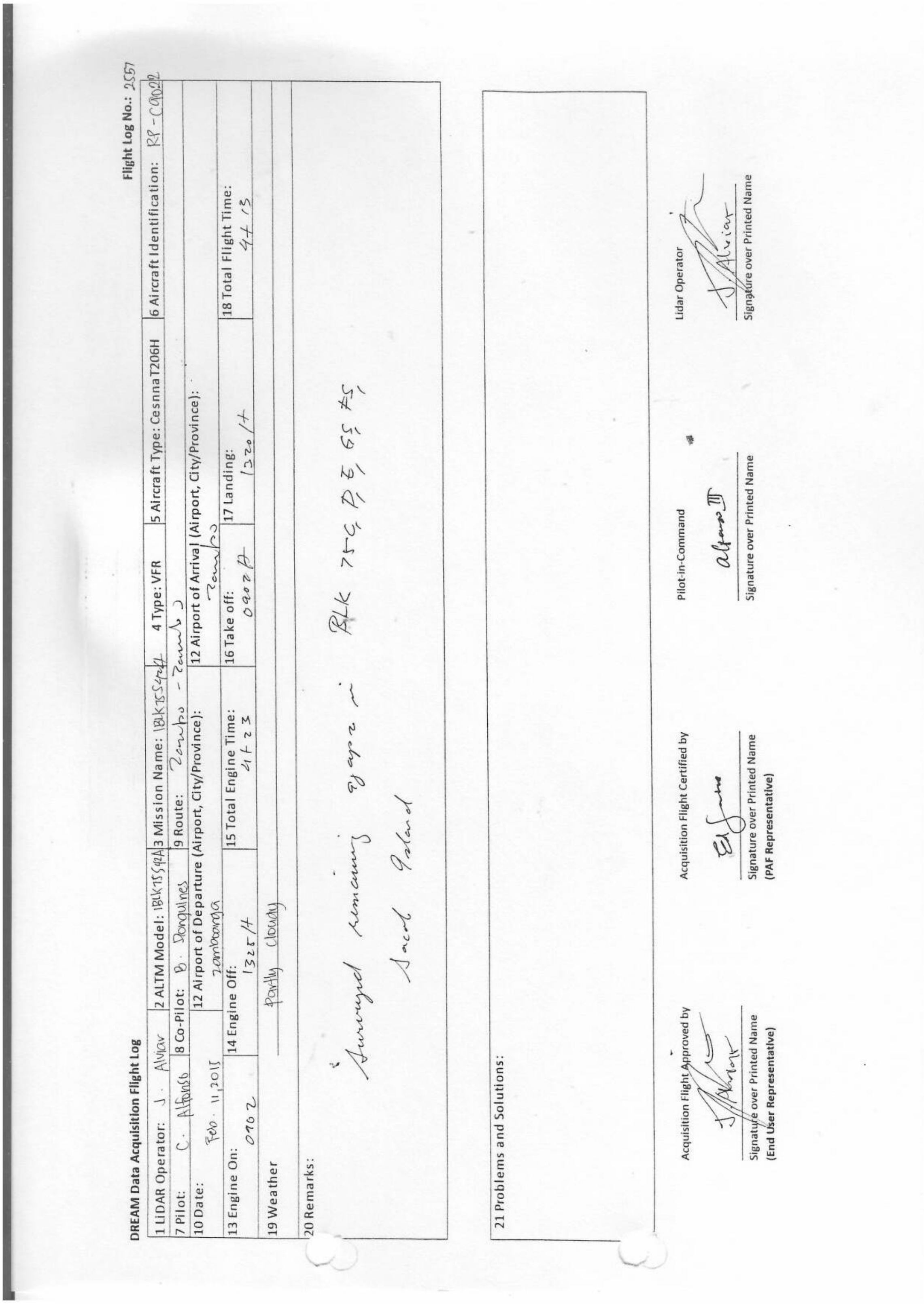
Acquisition Flight Approved by — Signature over Printed Name (End User Representative)

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

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Flight Log for 1BLK75S42A Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 2557

1 LiDAR Operator: J. Alviar	2 ALTM Model: 1BLK75S42A	3 Mission Name: 1BLK75S42A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: B. Dongulnes	9 Route: Zambo - Zambo			
10 Date: Feb. 11, 2015	12 Airport of Departure (Airport, City/Province): Zamboanga		12 Airport of Arrival (Airport, City/Province): Zambo		
13 Engine On: 0902	14 Engine Off: 1325H	15 Total Engine Time: 4+23	16 Take off: 0907H	17 Landing: 1320H	18 Total Flight Time: 4+13
19 Weather	Partly cloudy				

20 Remarks:

Surveyed remaining gaps in BLK 75C, D, E, 65, 75, Sacol Island

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
J. Alviar	[signature]	Alfonso III	J. Alviar
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Annex 7. Flight Status Reports

ZAMBOANGA CITY-ZAMBOANGA SIBUGAY
(February 5 to 11, 2015)

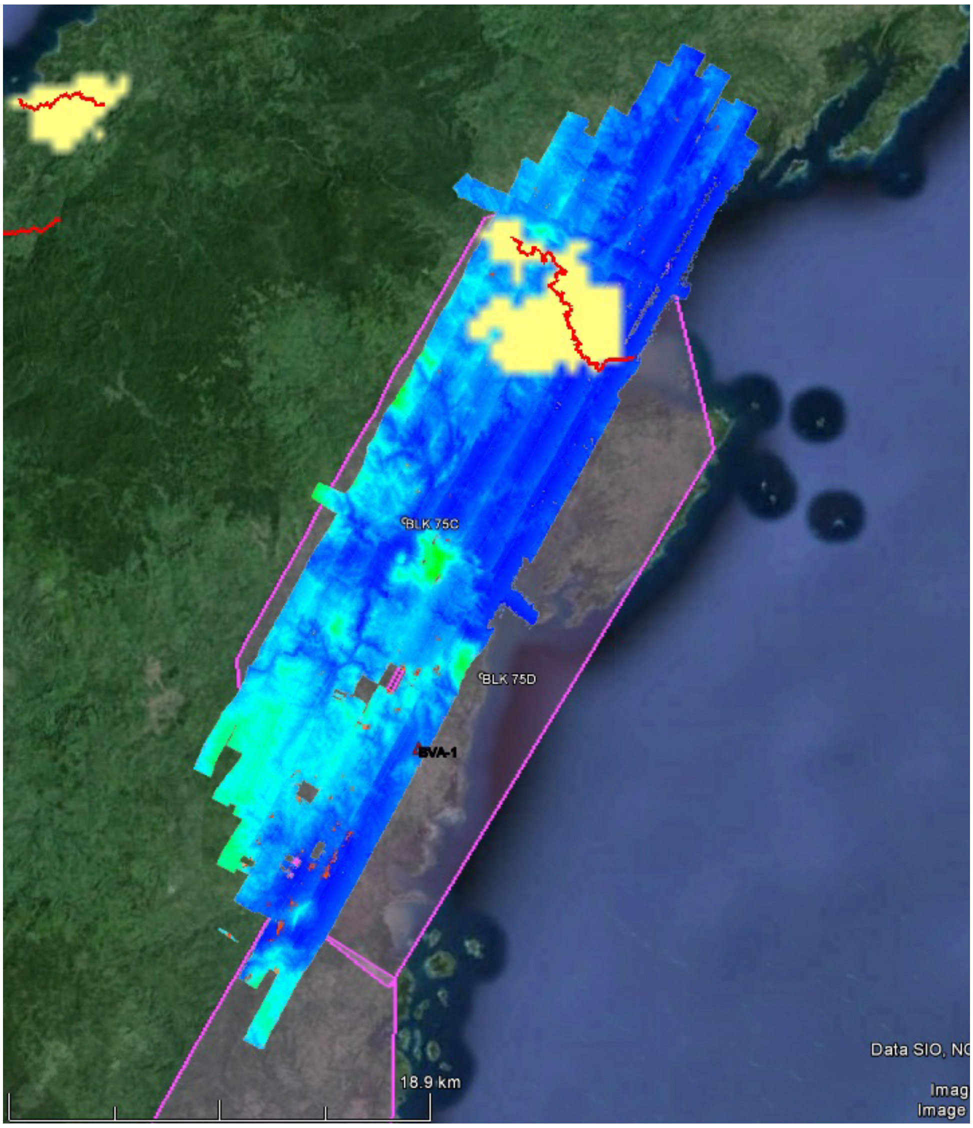
FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
2537P	BLK 75C	1BLK75C37A	I. Roxas	February 6, 2015	For completion and some gap filling (terrain)
2539P	BLK 75D	1BLK75C37B	J. Alviar	February 6, 2015	165.38 square kilometers
2545P	BLK 75C, 75D,75E, 75FS	1BLK75C39A	J. Alviar	February 8, 2015	Abnormal program termination (AVPOS) – AVPOSVIEW terminated – Reopened AVPOS
2557P	BLK 75C, 75D,75E, 75FS	1BLK75S42A	J. Alviar	February 11, 2015	Survey 6 descended to 1000 due to clouds Returned to 1100m for survey over Sacol Gaps due to clouds, descended to 1000m to fill up voids in Sacol and Blk 75EFG Added 1 small line (Corridor 18), descended to 800m Corridor 16 which should cover gap in Blk 75E, up to all lines in Blk 75FG @800m

LAS BOUNDARIES PER FLIGHT

Flight No.:	2537P
Area:	BLK 75C
Mission Name:	1BLK75C37A

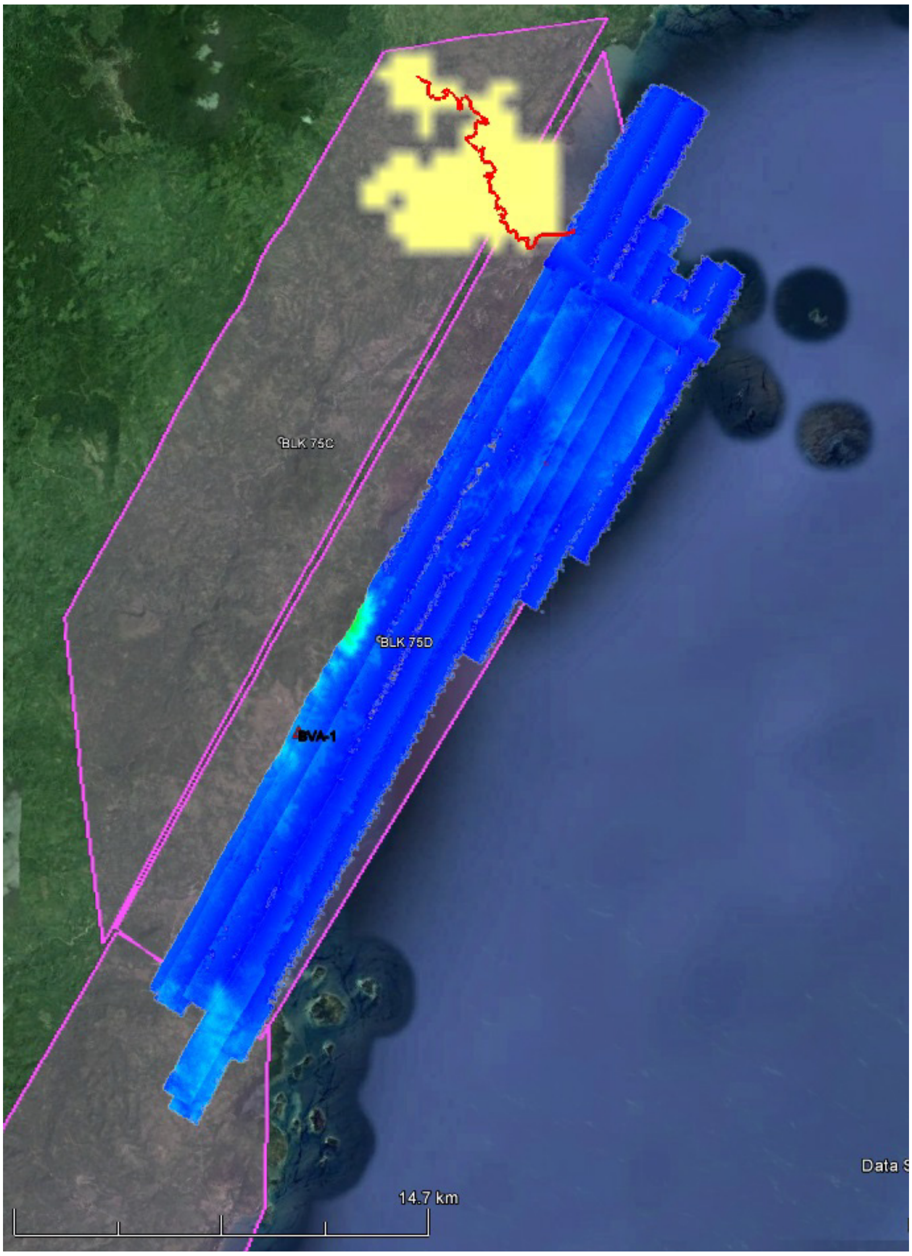
Parameters:	
Altitude:	1100 m
Scan Frequency:	30 Hz
Scan Angle:	25 deg
Overlap:	25%

LAS



Flight No.:	2539P
Area:	BLK 75D
Mission Name:	1BLK75C37B
Parameters:	
Altitude:	1100 m
Scan Frequency:	30 Hz
Scan Angle:	25 deg
Overlap:	25%

LAS



Flight No.:	2545P
Area:	BLK 75C, 75D,75E, 75FS
Mission Name:	1BLK75C39A
Parameters:	
Altitude:	1000 m
Scan Frequency:	30 Hz
Scan Angle:	25 deg
Overlap:	15%

LAS

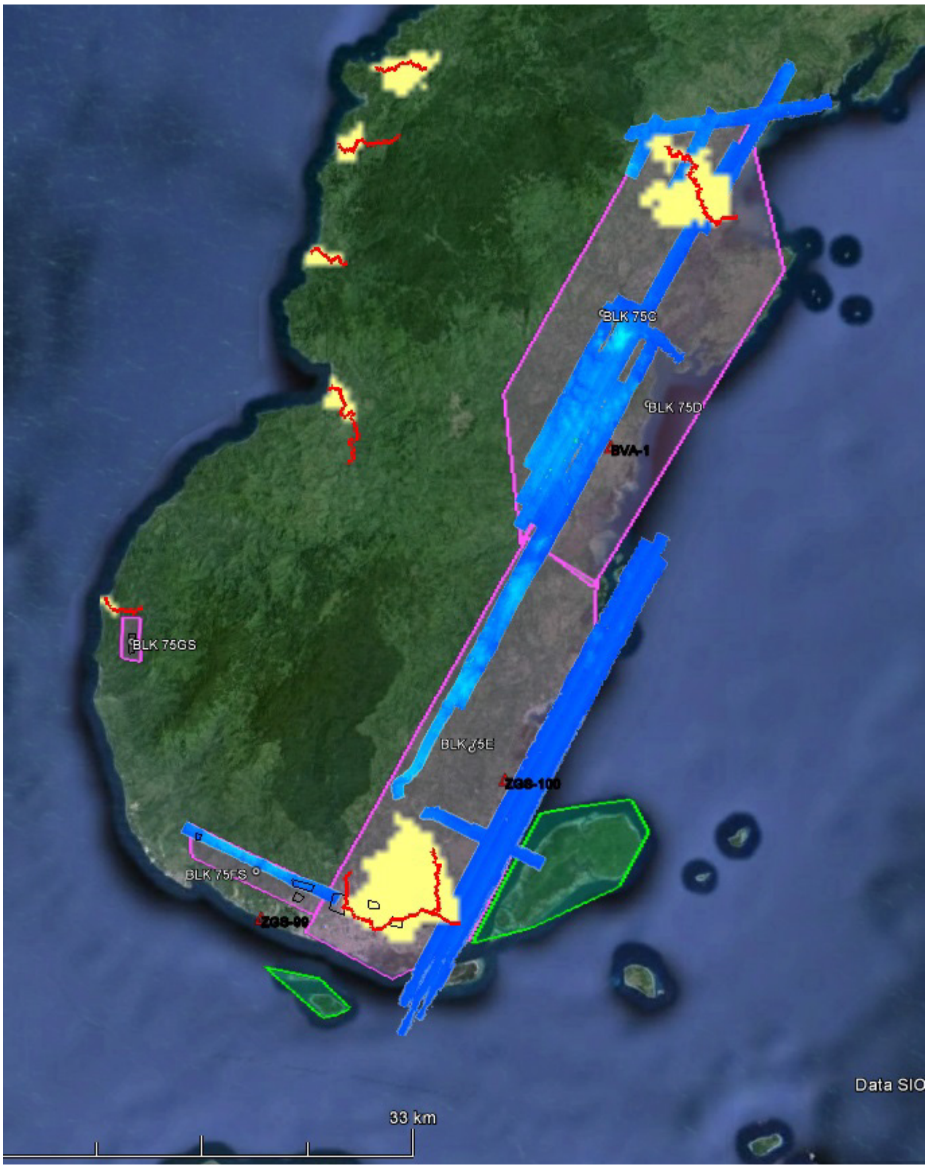
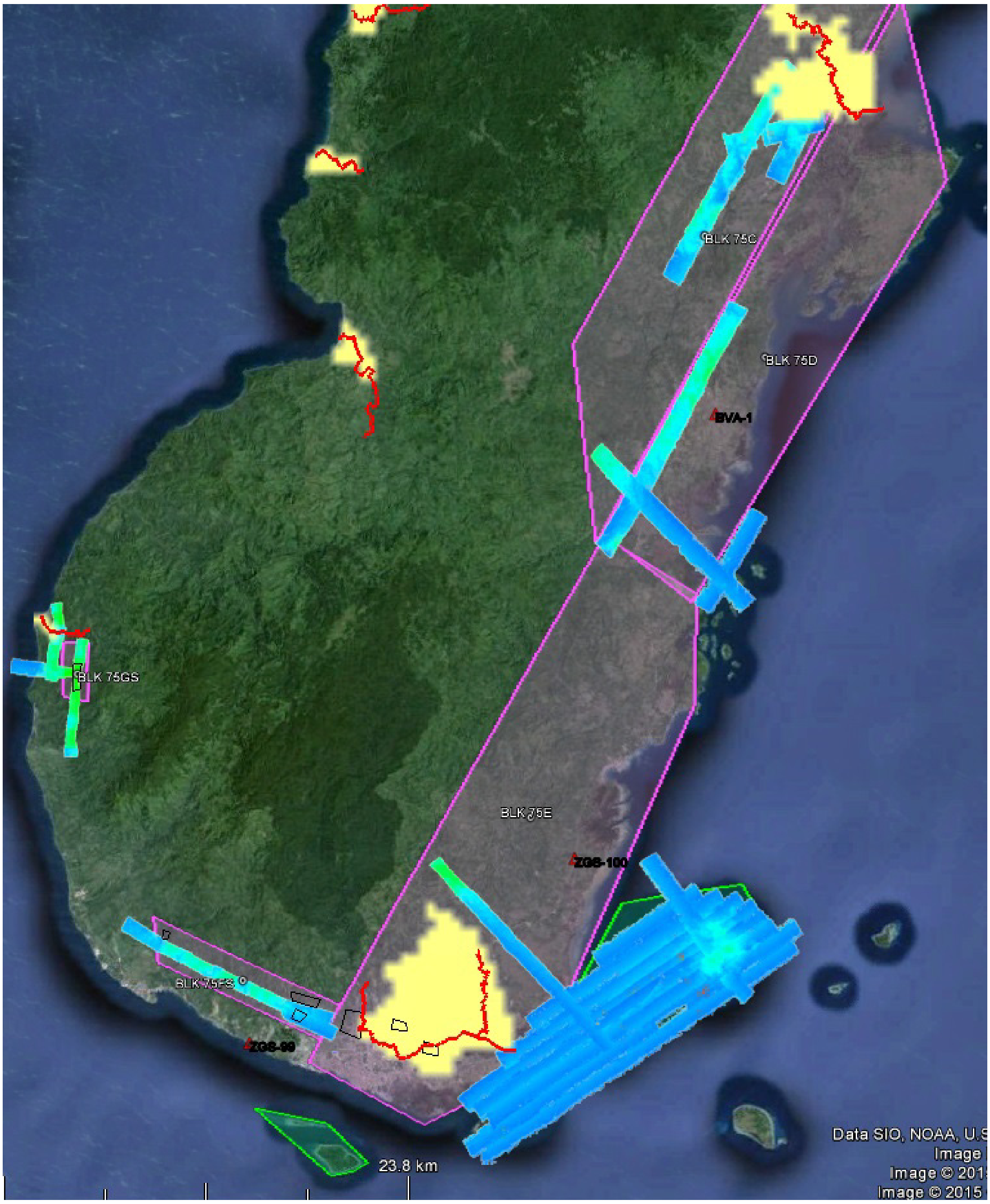


Figure A-7.3. Swath for Flight No. 7286GC

Flight No.: 2557P
Area: BLK 75C, 75D,75E, 75FS
Mission Name: 1BLK75S42A
Parameters:
Altitude: 1100 m;
Scan Frequency: 30 Hz;
Scan Angle: 25 deg;
Overlap: 15%

LAS



Annex 8. Mission Summary Reports

Flight Area	Zamboanga
Mission Name	Blk75C
Inclusive Flights	2537P, 2545P, 2557P
Range data size	82.5 GB
POS	777 MB
Image	129 GB
Base Data Size	24.44 MB
Transfer date	March 13, 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)	2.10
RMSE for East Position (<4.0 cm)	2.40
RMSE for Down Position (<8.0 cm)	8.50
Boresight correction stdev (<0.001deg)	0.000178
IMU attitude correction stdev (<0.001deg)	0.000630
GPS position stdev (<0.01m)	0.0043
Minimum % overlap (>25)	97.64%
Ave point cloud density per sq.m. (>2.0)	9.03
Elevation difference between strips (<0.20m)	Yes
Number of 1km x 1km blocks	490
Maximum Height	578.21 m
Minimum Height	67.64 m
Classification (# of points)	
Ground	462,127,429
Low vegetation	431,469,791
Medium vegetation	831,710,835
High vegetation	1,470,249,193
Building	16,154,276
Orthophoto	Yes
Processed by	Engr. Analyn Naldo, Engr. Chelou Prado, Engr. Krisha Marie Bautista

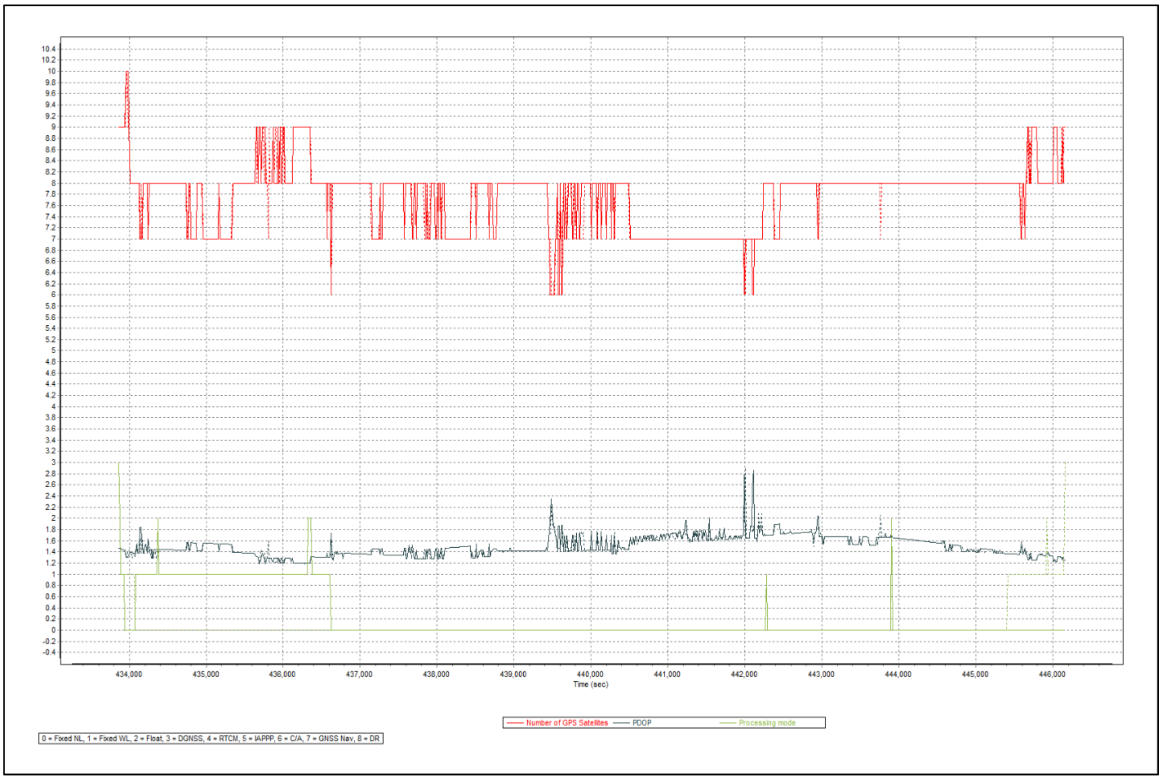


Figure A-8.1 Solution Status

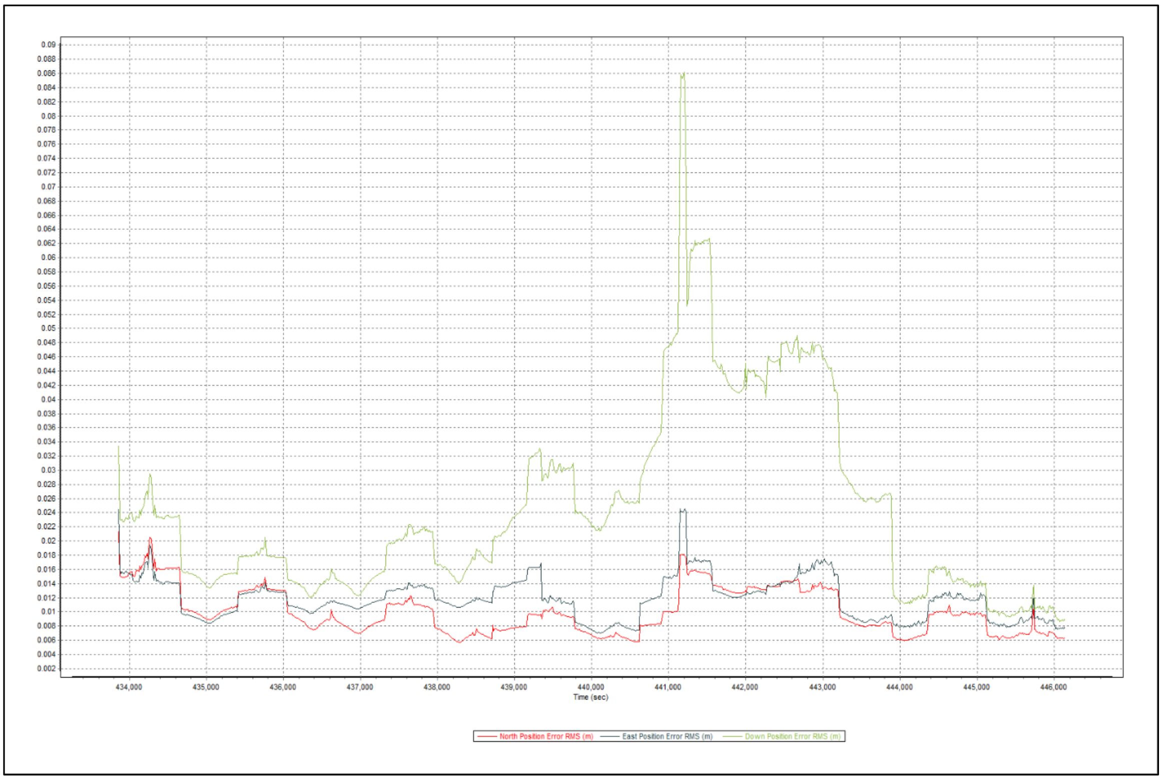


Figure A-8.2 Smoothed Performance Metric Parameters

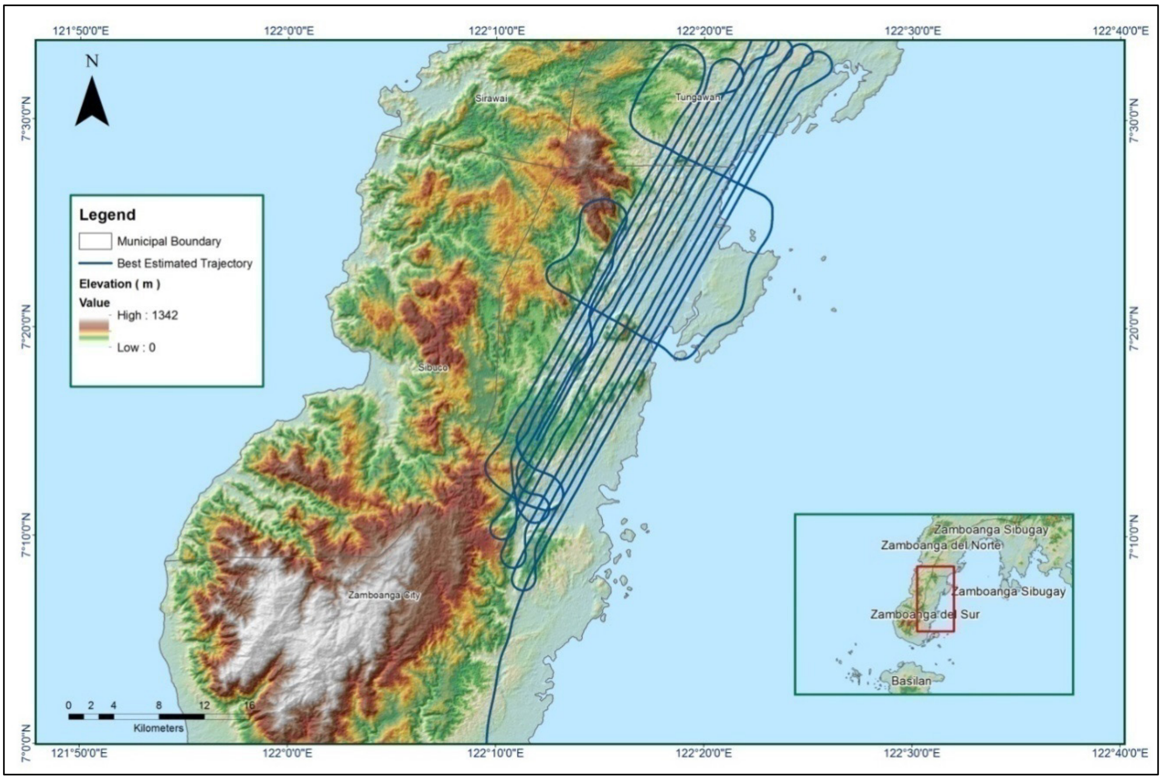


Figure A-8.3 Best Estimated Trajectory

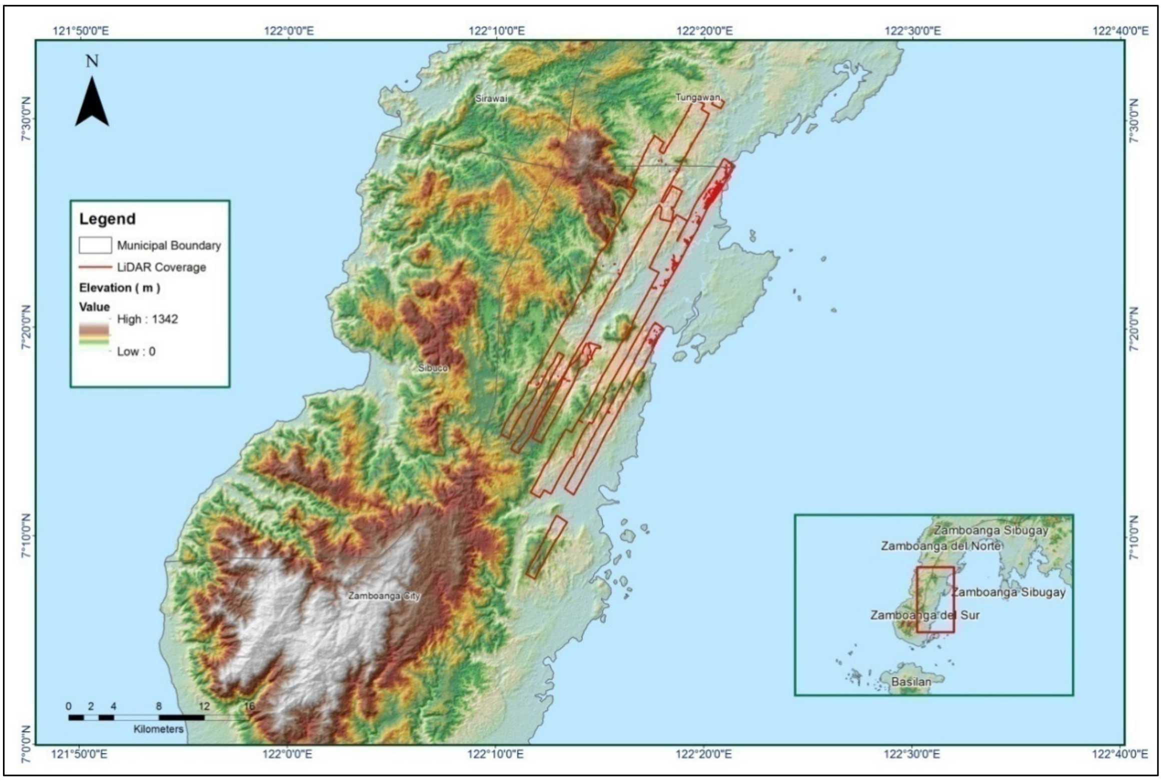


Figure A-8.4 Coverage LiDAR Data

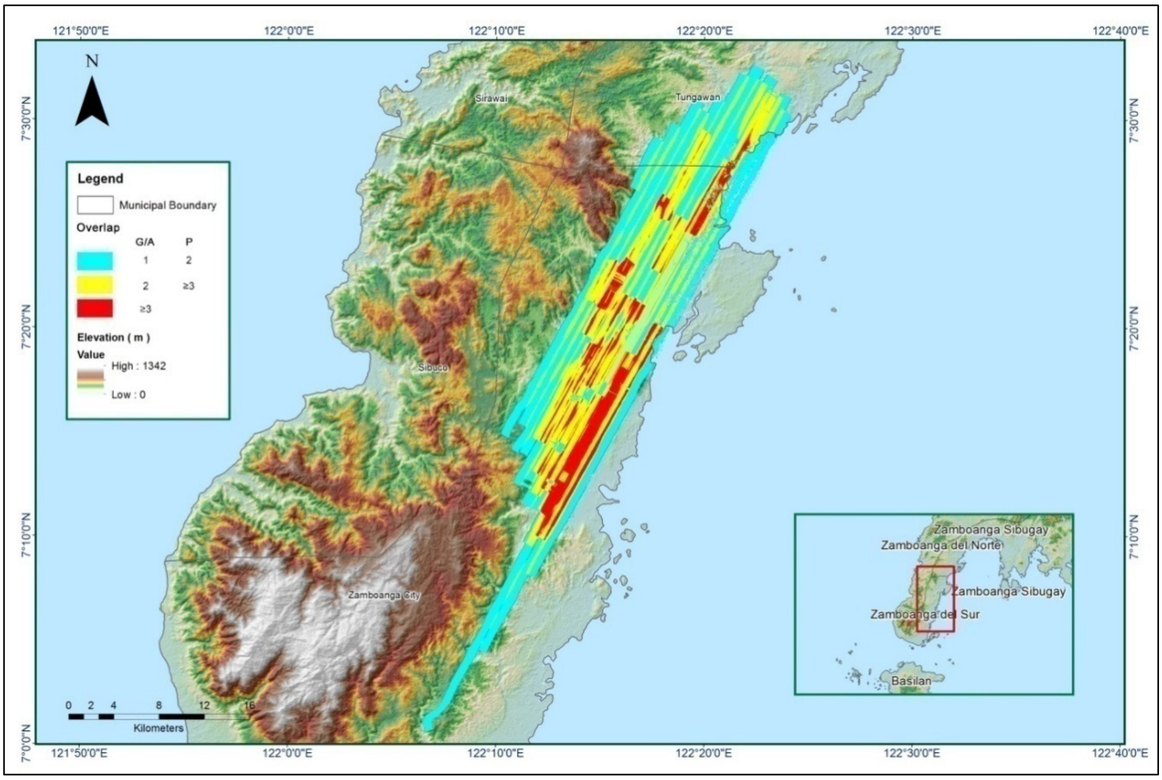


Figure A-8.5 Image Data Overlap

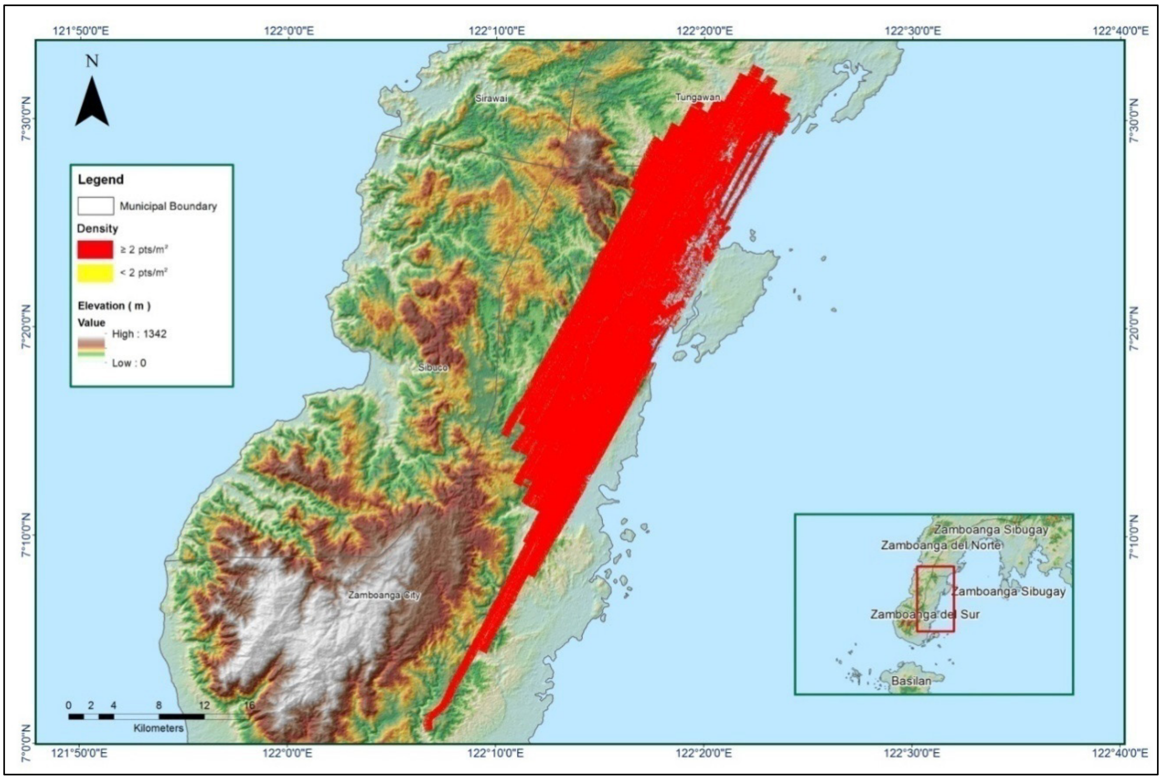


Figure A-8.6 Density Map of Merged LiDAR Data

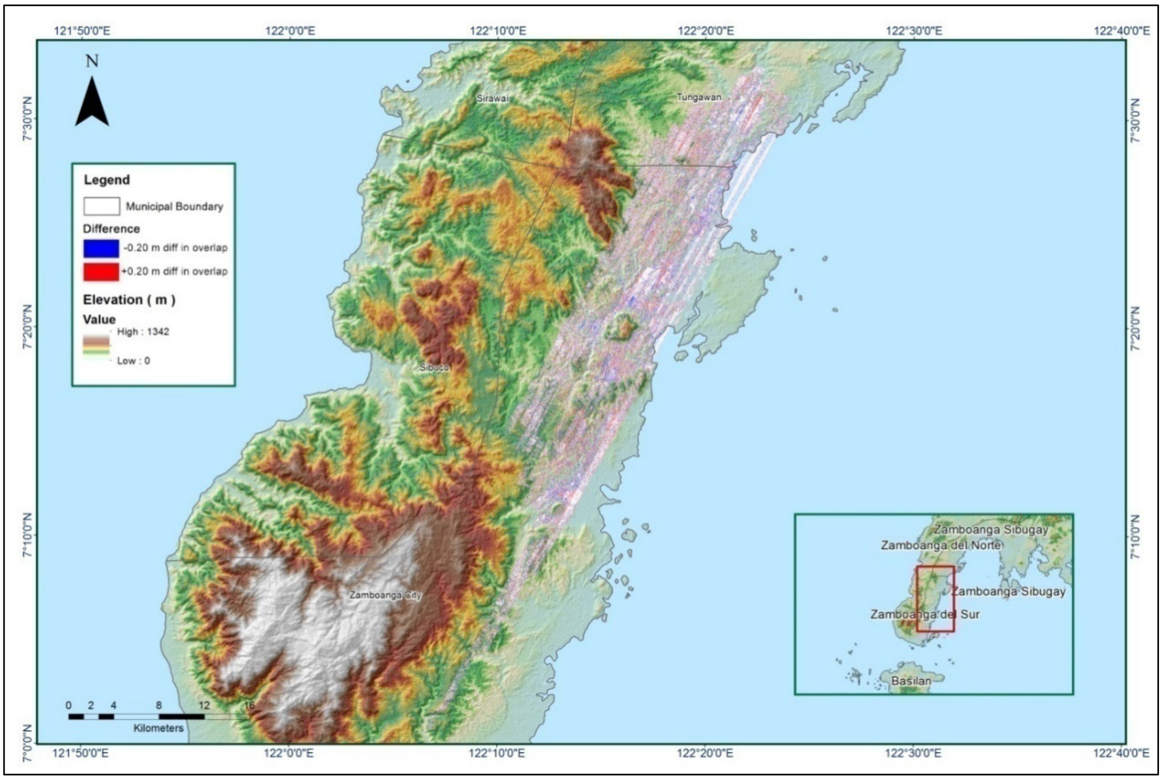


Figure A-8.7 Elevation difference between flightlines

Flight Area	Zamboanga
Mission Name	Blk75D
Inclusive Flights	2539P, 2557P
Range data size	38.1 GB
POS	430 MB
Image	60.1 GB
Base data size	16.67 MB
Transfer date	March 31, 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)	2.10
RMSE for East Position (<4.0 cm)	2.40
RMSE for Down Position (<8.0 cm)	8.50
Boresight correction stdev (<0.001deg)	0.000340
IMU attitude correction stdev (<0.001deg)	0.000781
GPS position stdev (<0.01m)	0.0081
Minimum % overlap (>25)	94.25%
Ave point cloud density per sq.m. (>2.0)	4.79
Elevation difference between strips (<0.20m)	Yes
Number of 1km x 1km blocks	294
Maximum Height	477.12 m
Minimum Height	67.95 m
Classification (# of points)	
Ground	172,368,975
Low vegetation	158,047,715
Medium vegetation	182,939,695
High vegetation	269,334,338
Building	2,718,053
Orthophoto	Yes
Processed by	Engr. Analyn Naldo, Engr. Mark Joshua Salvacion, Alex John Escobido

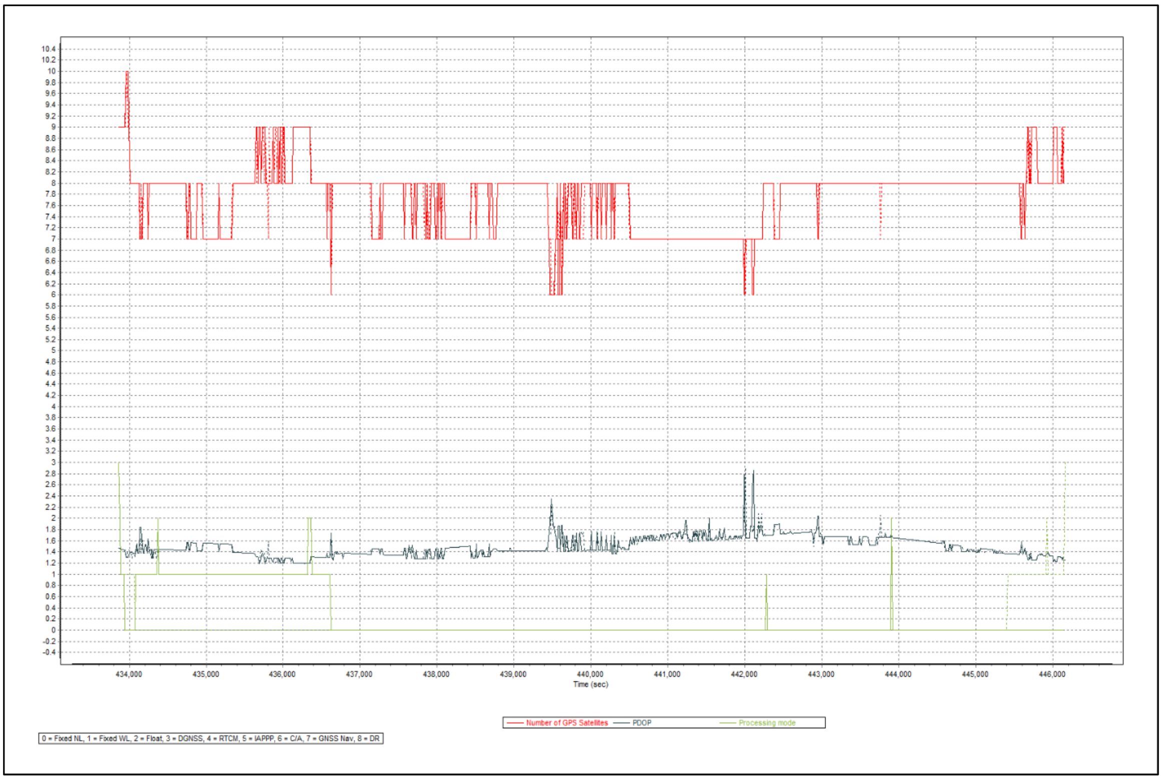


Figure A-8.8 Solution Status

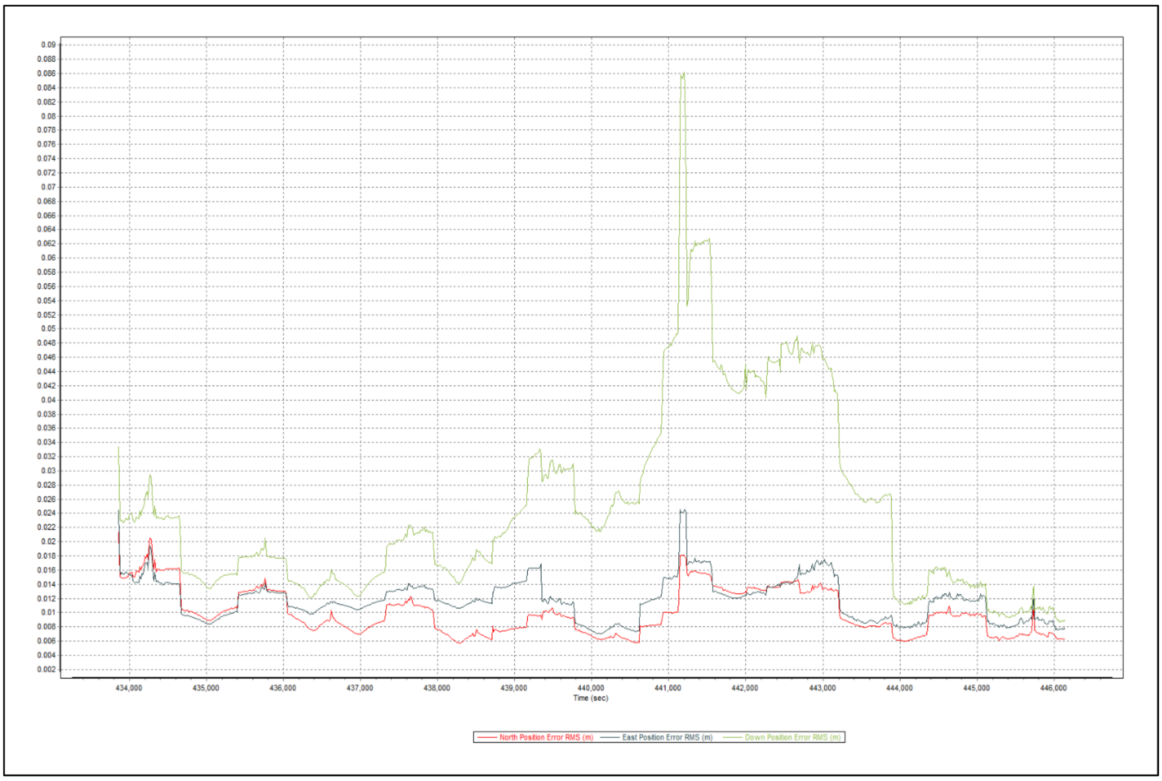


Figure A-8.9 Smoothed Performance Metric Parameters

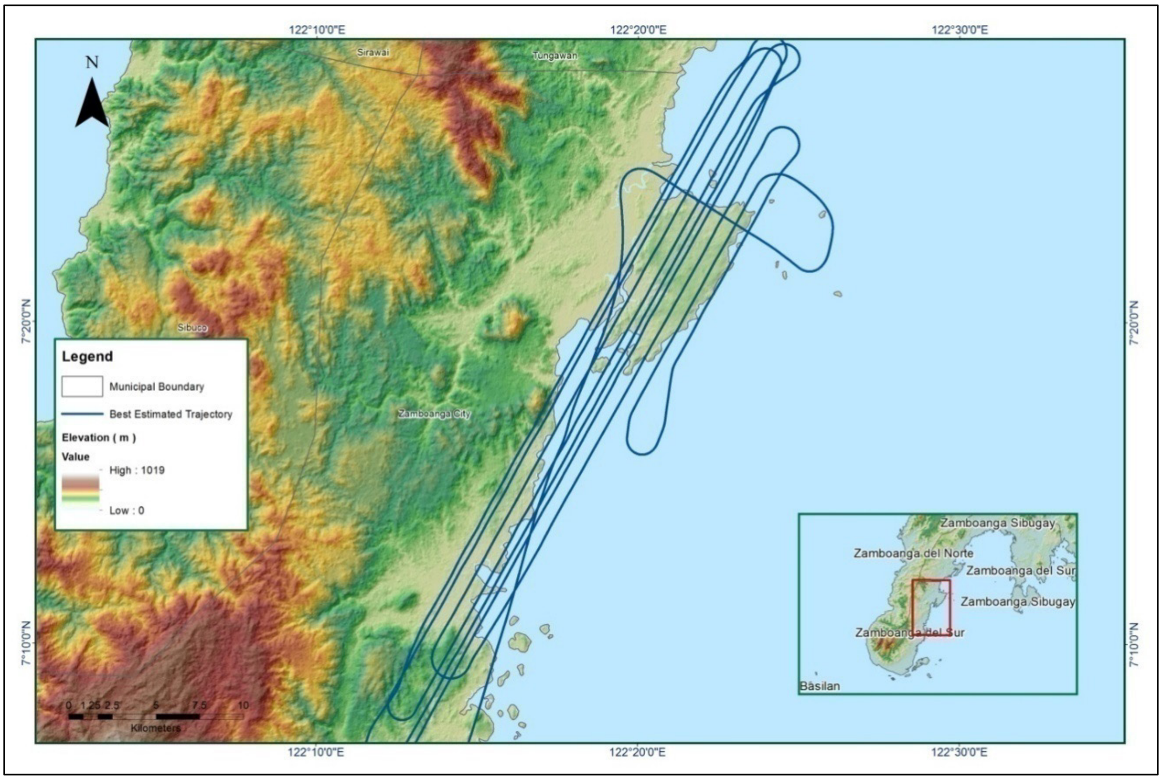


Figure A-8.10 Best Estimated Trajectory

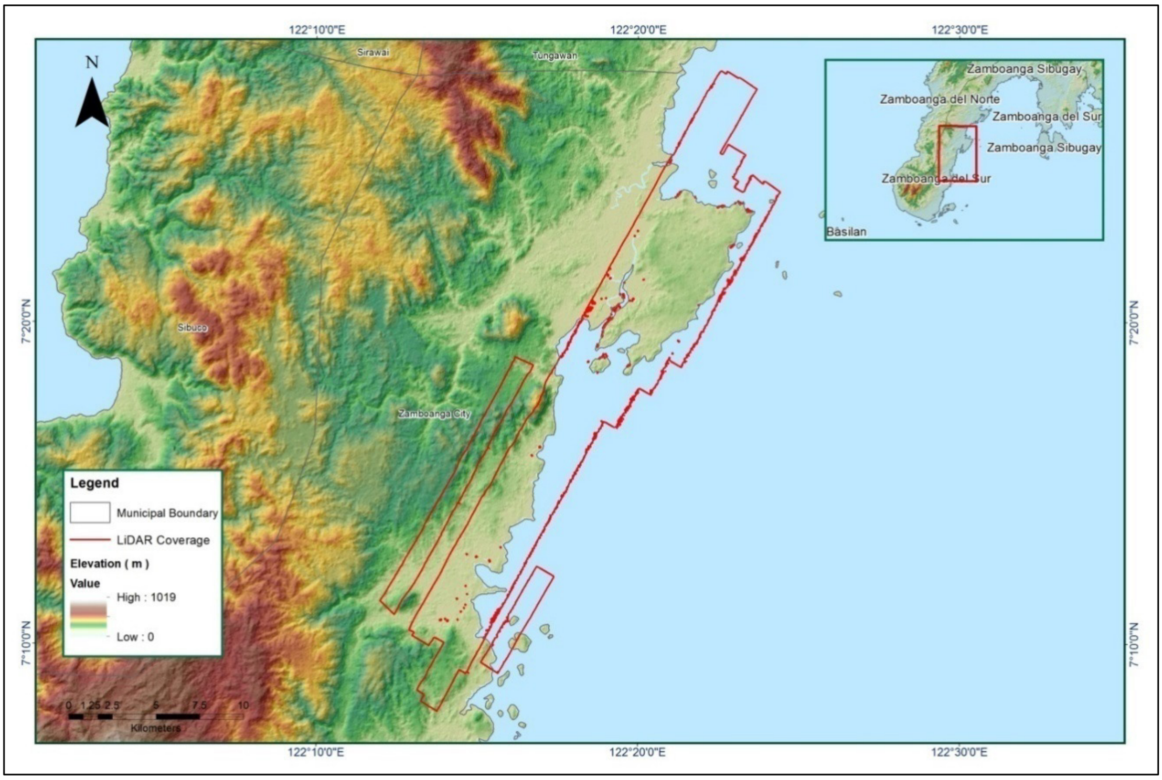


Figure A-8.11 Coverage of LiDAR Data

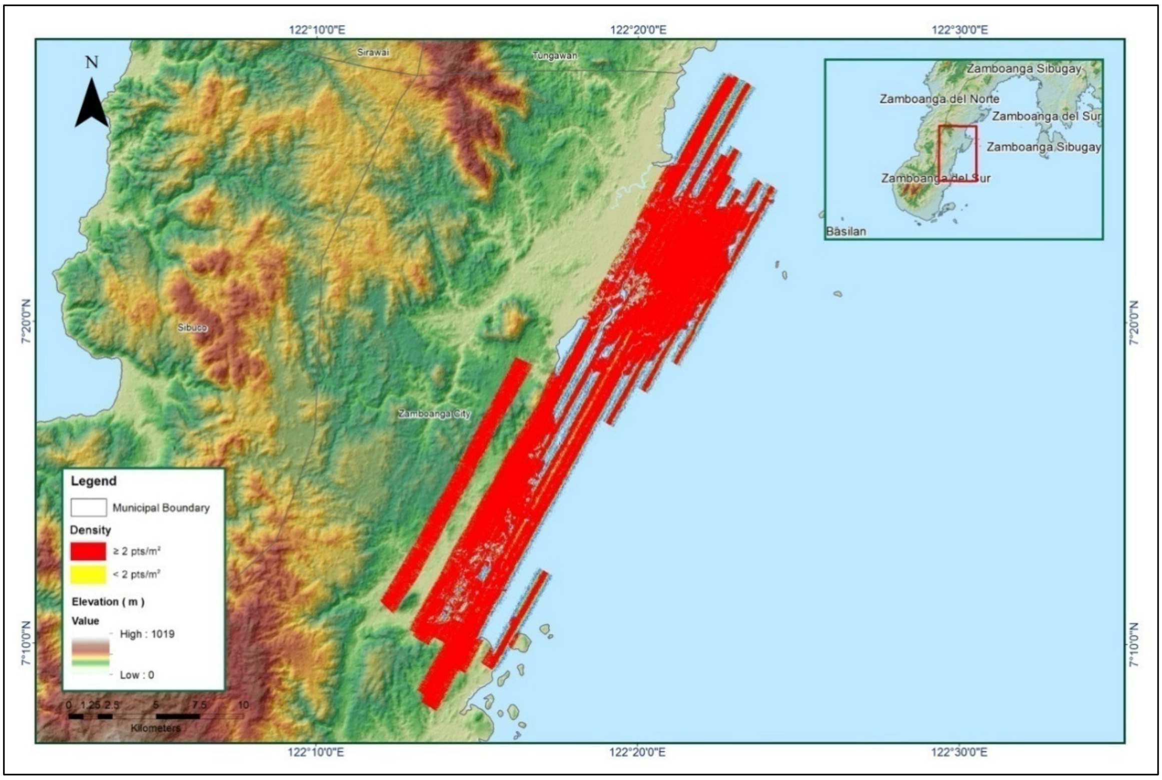


Figure A-8.12 Image Data Overlap

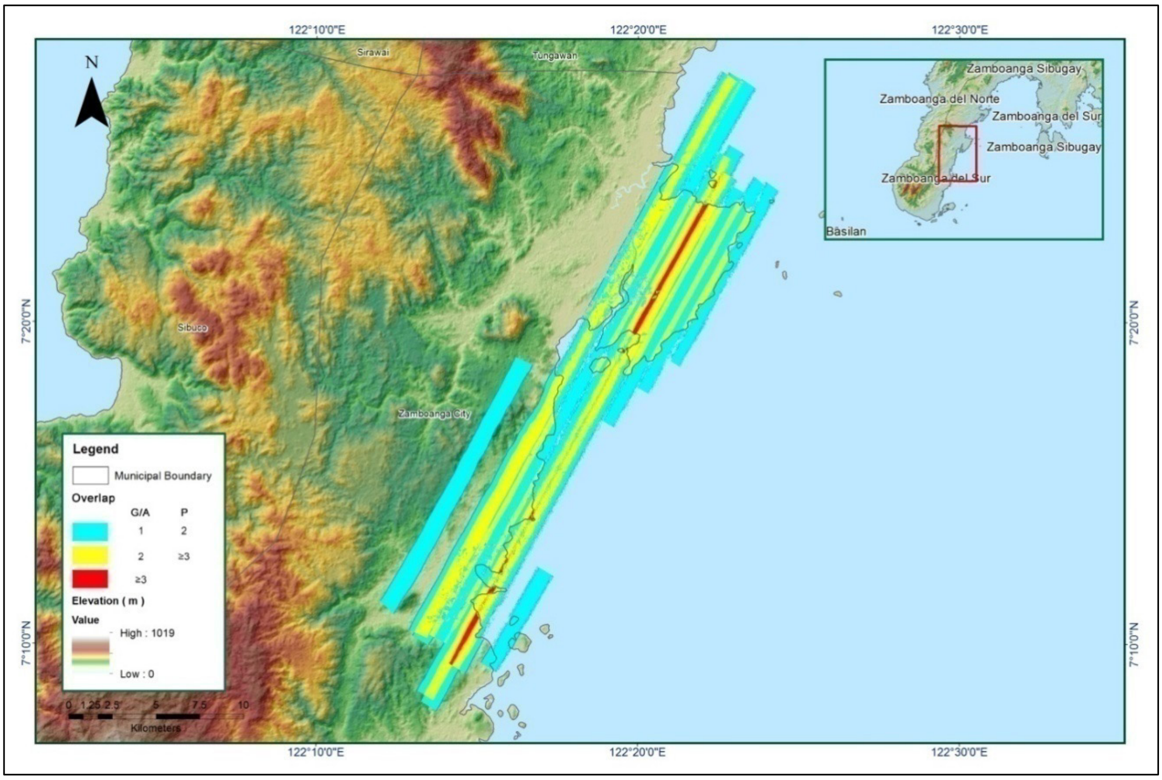


Figure A-8.13 Density map of merged LiDAR data

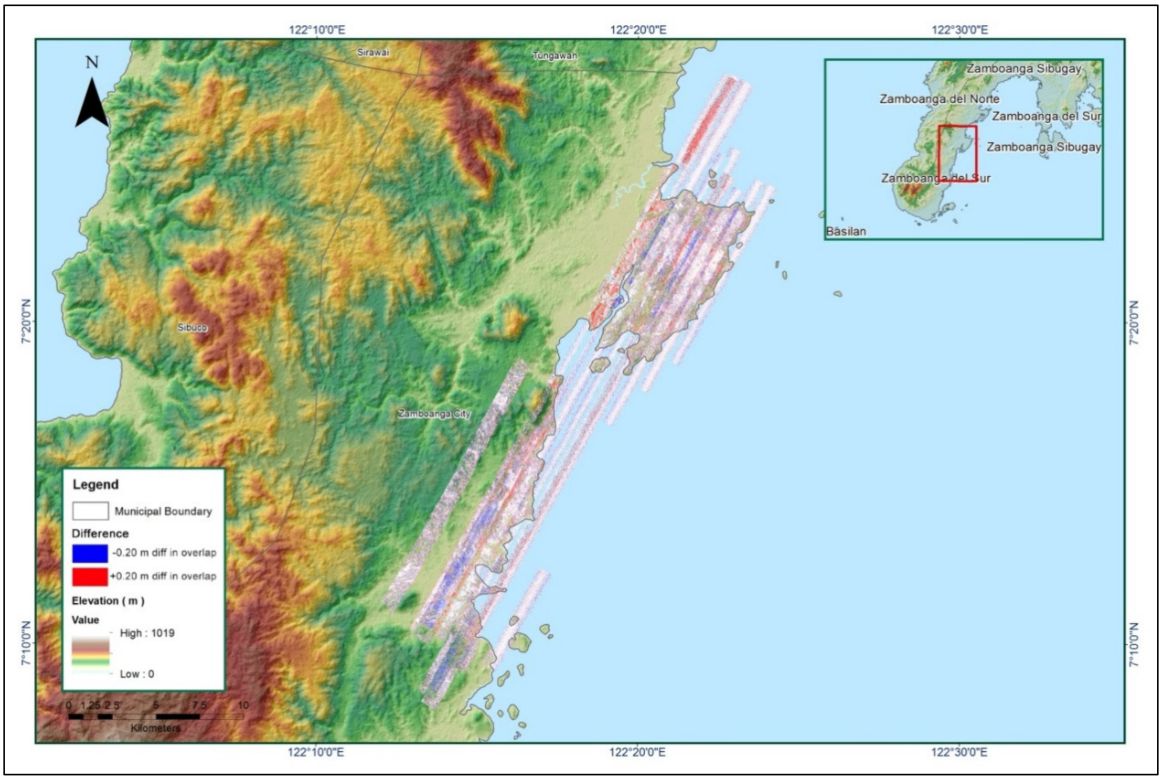


Figure A-8.14 Elevation difference between flight lines

Annex 9. Tigbao 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
W940	0.22291	81.1198663	0.0	0.43973	0.0574112	Discharge	0.0113233	0.545	Ratio to Peak	0.25
W930	0.14388	90.4092927	0.0	0.6702889	0.0875129	Discharge	0.0658202	0.545	Ratio to Peak	0.25
W920	0.14328	90.48	0.0	1.3999	0.18277	Discharge	0.13742	0.545	Ratio to Peak	0.25
W910	0.14436	90.353	0.0	1.3511	0.17639	Discharge	0.20510	0.545	Ratio to Peak	0.25
W900	0.14328	90.48	0.0	1.3527	0.17661	Discharge	0.0895581	0.545	Ratio to Peak	0.25
W890	0.38759	66.494	0.0	1.3857	0.18092	Discharge	0.12637	0.545	Ratio to Peak	0.25
W880	0.14328	90.48	0.0	0.58109	0.0758675	Discharge	0.0216499	0.545	Ratio to Peak	0.25
W870	0.14328	90.48	0.0	0.74252	0.0969432	Discharge	0.0269173	0.545	Ratio to Peak	0.25
W860	0.14328	90.48	0.0	1.1800	0.15407	Discharge	0.0837104	0.545	Ratio to Peak	0.25
W850	0.21710	83.091	0.0	1.0342	0.13502	Discharge	0.10511	0.545	Ratio to Peak	0.25
W840	0.14328	90.48	0.0	0.60449	0.0789224	Discharge	0.0296298	0.545	Ratio to Peak	0.25
W830	0.41623	64.491	0.0	1.1179	0.14596	Discharge	0.0574239	0.545	Ratio to Peak	0.25
W820	0.35151	69.105	0.0	1.5753918	0.20568	Discharge	0.0683750	0.545	Ratio to Peak	0.25
W810	0.37920	66.559	0.0	0.57644	0.0752604	Discharge	0.0023340	0.545	Ratio to Peak	0.25
W800	0.29283	75.031	0.0	1.0471	0.13671	Discharge	0.0276616	0.545	Ratio to Peak	0.25
W790	0.3875288	66.266	0.0	1.5786	0.20610	Discharge	0.0929393	0.545	Ratio to Peak	0.25
W780	0.14328	90.48	0.0	0.57995	0.0757178	Discharge	0.0281158	0.545	Ratio to Peak	0.25
W770	0.21353	83.223	0.0	0.47373	0.0618501	Discharge	0.0081881	0.545	Ratio to Peak	0.25
W760	0.14328	90.48	0.0	0.67895	0.0886439	Discharge	0.0457474	0.545	Ratio to Peak	0.25
W750	0.34490	69.190	0.0	1.6626	0.21707	Discharge	0.13074	0.545	Ratio to Peak	0.25
W740	0.33867	69.6	0.0	0.98171	0.12817	Discharge	0.0836788	0.545	Ratio to Peak	0.25
W730	0.14328	90.48	0.0	0.67727	0.0884247	Discharge	0.0588559	0.545	Ratio to Peak	0.25

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
W720	0.37177	67.309	0.0	2.9683	0.38754	Discharge	0.25083	0.545	Ratio to Peak	0.25
W710	0.14425	90.3800077	0.0	0.93830	0.12250	Discharge	0.0819630	0.545	Ratio to Peak	0.25
W700	0.14328	90.48	0.0	0.30211	0.0394435	Discharge	0.0033623	0.545	Ratio to Peak	0.25
W690	0.14328	90.48	0.0	0.58433	0.0762903	Discharge	0.0227475	0.545	Ratio to Peak	0.25
W680	0.14328	90.48	0.0	0.76687	0.10012	Discharge	0.0285574	0.545	Ratio to Peak	0.25
W670	0.30166	74.119	0.0	1.6656	0.21746	Discharge	0.0697818	0.545	Ratio to Peak	0.25
W660	0.36688	67.358	0.0	1.7189	0.22443	Discharge	0.0291252	0.545	Ratio to Peak	0.25
W650	0.33873	69.5951717	0.0	1.9329	0.25236	Discharge	0.11518	0.545	Ratio to Peak	0.25
W640	0.24945	79.468	0.0	1.2354	0.16129	Discharge	0.0683687	0.545	Ratio to Peak	0.25
W630	0.34262	69.286	0.0	1.3868	0.18106	Discharge	0.0593858	0.545	Ratio to Peak	0.25
W620	0.22747	83.282	0.0	2.2718	0.29661	Discharge	0.14247	0.545	Ratio to Peak	0.25
W610	0.14328	90.48	0.0	2.6168	0.34164	Discharge	0.19178	0.545	Ratio to Peak	0.25
W600	0.33867	69.6	0.0	1.2129	0.15836	Discharge	0.0163699	0.545	Ratio to Peak	0.25
W590	0.31098	76.143	0.0	2.8366	0.37035	Discharge	0.15648	0.545	Ratio to Peak	0.25
W580	0.33867	69.6	0.0	2.0346	0.26564	Discharge	0.18113	0.545	Ratio to Peak	0.25
W570	0.34212	69.373	0.0	1.4818	0.19347	Discharge	0.0263117	0.545	Ratio to Peak	0.25
W560	0.34698	69.053	0.0	1.8779	0.24517	Discharge	0.0683814	0.545	Ratio to Peak	0.25
W550	0.34141	69.420	0.0	1.1261	0.14702	Discharge	0.0097462	0.545	Ratio to Peak	0.25
W540	0.33867	69.6	0.0	1.7073	0.22291	Discharge	0.0821901	0.545	Ratio to Peak	0.25
W530	0.39808	65.693	0.0	0.95584	0.12479	Discharge	0.0071914	0.545	Ratio to Peak	0.25
W520	0.51707	57.8673669	0.0	2.5458	0.33237	Discharge	0.0610196	0.545	Ratio to Peak	0.25
W510	0.50053	58.847	0.0	1.6324	0.21312	Discharge	0.0582314	0.545	Ratio to Peak	0.25
W500	0.38065	67.873	0.0	2.4373	0.31821	Discharge	0.15512	0.545	Ratio to Peak	0.25
W490	0.38498	66.580	0.0	1.9655	0.25661	Discharge	0.1956123	0.545	Ratio to Peak	0.25
W480	0.54685	55.906	0.0	3.2672	0.42657	Discharge	0.19200	0.545	Ratio to Peak	0.25

Annex 10. Tigbao Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R50	Automatic Fixed Interval	343.85	0.0411833	0.3	Trapezoid	10	0.01
R70	Automatic Fixed Interval	1321.5	0.0065977	0.3	Trapezoid	10	0.01
R80	Automatic Fixed Interval	643.14	0.0057184	0.3	Trapezoid	10	0.01
R90	Automatic Fixed Interval	598.70	0.0071641	0.3	Trapezoid	10	0.01
R110	Automatic Fixed Interval	534.26	0.0150855	0.3	Trapezoid	10	0.01
R130	Automatic Fixed Interval	913.55	0.0449304	0.3	Trapezoid	10	0.01
R180	Automatic Fixed Interval	1151.2	0.0097849	0.3	Trapezoid	10	0.01
R200	Automatic Fixed Interval	381.42	0.0289229	0.3	Trapezoid	10	0.01
R210	Automatic Fixed Interval	710.12	0.0113985	0.3	Trapezoid	10	0.01
R250	Automatic Fixed Interval	694.97	0.0483095	0.3	Trapezoid	10	0.01
R260	Automatic Fixed Interval	1733.4	0.0184634	0.3	Trapezoid	10	0.01
R270	Automatic Fixed Interval	4876.3	0.0535634	0.3	Trapezoid	10	0.01
R280	Automatic Fixed Interval	547.99	0.0216627	0.3	Trapezoid	10	0.01

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R330	Automatic Fixed Interval	793.97	0.0004	0.3	Trapezoid	10	0.01
R340	Automatic Fixed Interval	1012.1	0.0140492	0.3	Trapezoid	10	0.01
R350	Automatic Fixed Interval	1485.7	0.0331880	0.3	Trapezoid	10	0.01
R360	Automatic Fixed Interval	1009.8	0.0239081	0.3	Trapezoid	10	0.01
R370	Automatic Fixed Interval	452.55	0.0004	0.3	Trapezoid	10	0.01
R380	Automatic Fixed Interval	1070.5	0.0062110	0.3	Trapezoid	10	0.01
R410	Automatic Fixed Interval	893.55	0.0174810	0.3	Trapezoid	10	0.01
R460	Automatic Fixed Interval	3049.1	0.0021724	0.3	Trapezoid	10	0.01
R470	Automatic Fixed Interval	481.63	0.0004	0.3	Trapezoid	10	0.01

Annex 11. Tigbao Field Validation Points

Point Number	Validation Coordinates		Validation Points (m)	Model Var (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	7.419066	122.325581	1.99	0.8	1.19	Ondoy	5 -Year
2	7.418934	122.325665	2.16	0.4	1.76	Ondoy	5 -Year
3	7.418286	122.326107	0.03	0.3	-0.27	Sendong	5 -Year
4	7.418086	122.32631	0.17	0.1	0.07	Sendong	5 -Year
5	7.417928	122.327204	0.83	1	-0.17	Sendong	5 -Year
6	7.417675	122.326975	0.5	0.4	0.10	Sendong	5 -Year
7	7.416878	122.330167	0.76	1	-0.24	Sendong	5 -Year
8	7.416043	122.329932	0.58	1.2	-0.62	Sendong	5 -Year
9	7.415096	122.33588	0.03	0.5	-0.47	Gener	5 -Year
10	7.413357	122.333971	0.44	0.7	-0.26	Gener	5 -Year
11	7.413644	122.332249	0.29	0.6	-0.31	Gener	5 -Year
12	7.413243	122.332203	0.62	0.3	0.32	Gener	5 -Year
13	7.417703	122.329631	0.97	0.6	0.37	Sendong	5 -Year
14	7.419006	122.323966	0.1	1	-0.90	Yolanda	5 -Year
15	7.415011	122.336696	0.2	1	-0.80	Gener	5 -Year
16	7.418462	122.3259	2.68	0.3	2.38	Sendong	5 -Year
17	7.41876	122.325546	2.78	0.3	2.48	Ondoy	5 -Year
18	7.413532	122.337892	0.62	0.5	0.12	Sendong	5 -Year
19	7.412485	122.337513	0.68	1.3	-0.62	Yolanda	5 -Year
20	7.415131	122.339837	0.54	0	0.54	Yolanda	5 -Year
21	7.421773	122.327027	0.34	0.4	-0.06	Yolanda	5 -Year
22	7.432323	122.32527	0.77	0.3	0.47	Yolanda	5 -Year
23	7.436369	122.326022	0.03	0.3	-0.27	Yolanda	5 -Year
24	7.42973	122.327098	0.03	0.2	-0.17	Yolanda	5 -Year
25	7.423464	122.329051	0.14	0.2	-0.06	Yolanda	5 -Year
26	7.418477	122.320967	0.1	0.7	-0.60	Ondoy	5 -Year
27	7.419198	122.316037	0.03	0.2	-0.17	Yolanda	5 -Year
28	7.422402	122.312916	0.04	0.5	-0.46	Yolanda	5 -Year
29	7.417115	122.327627	0.38	0.6	-0.22	Yolanda	5 -Year
30	7.418438	122.32677	0.65	0.3	0.35	Sendong	5 -Year
31	7.416687	122.34066	0.44	0.4	0.04	Yolanda	5 -Year
32	7.415368	122.335896	0.4	1	-0.60	Gener	5 -Year
33	7.424126	122.328813	0.12	0.4	-0.28	Gener	5 -Year
34	7.417964	122.33139	0.68	0.4	0.28	Gener	5 -Year
35	7.420182	122.326815	0.03	1	-0.97	Sendong	5 -Year
36	7.413316	122.332249	0.96	0.5	0.46	Gener	5 -Year
37	7.416816	122.328929	0.6	1	-0.40	Gener	5 -Year
38	7.424518	122.327394	0.03	0.5	-0.47	Yolanda	5 -Year
39	7.423088	122.327085	0.2	0.5	-0.30	Yolanda	5 -Year
40	7.412214	122.335261	0.75	0.4	0.35	Sendong	5 -Year
41	7.416668	122.330161	0.17	0.4	-0.23	Sendong	5 -Year
42	7.423587	122.325775	0.31	0.4	-0.09	Gener	5 -Year

Point Number	Validation Coordinates		Validation Points (m)	Model Var (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
43	7.41932	122.329594	0.32	0.5	-0.18	Yolanda	5 -Year
44	7.420709	122.329586	0.14	0.3	-0.16	Yolanda	5 -Year
45	7.417733	122.329652	1.41	0.5	0.91		5 -Year
46	7.426262	122.324781	0.42	1.5	-1.08	Yolanda	5 -Year
47	7.43256	122.323236	0.35	1.5	-1.15	Yolanda	5 -Year
48	7.432177	122.32564	0.03	1	-0.97	Yolanda	5 -Year
49	7.419113	122.320833	0.05	1.8	-1.75	Yolanda	5 -Year
50	7.419751	122.321177	0.03	1	-0.97	Yolanda	5 -Year
51	7.416942	122.32255	1.1	1.5	-0.40	Yolanda	5 -Year
52	7.418559	122.313709	0.08	1	-0.92	Yolanda	5 -Year
53	7.418517	122.312722	0.05	0.5	-0.45	Yolanda	5 -Year
54	7.436475	122.324095	0.13	1	-0.87	Yolanda	5 -Year
55	7.436135	122.326198	0.06	1	-0.94	Yolanda	5 -Year
56	7.434401	122.323537	0.95	1	-0.05	Yolanda	5 -Year
57	7.42939	122.32446	0.23	1.5	-1.27	Yolanda	5 -Year
58	7.429113	122.324567	0.42	1.5	-1.08	Yolanda	5 -Year
59	7.417123	122.328392	0.41	0.25	0.16	Ondoy	5 -Year
60	7.418925	122.325704	2.16	2	0.16	Ondoy	5 -Year
61	7.419192	122.325956	1.71	1.5	0.21	Ondoy	5 -Year
62	7.419836	122.324202	0.03	0.5	-0.47	Yolanda	5 -Year
63	7.418442	122.324964	1.36	0.5	0.86	Ferdy	5 -Year
64	7.418895	122.325082	1.68	1.5	0.18	Yolanda	5 -Year
65	7.418166	122.326498	0.38	0.8	-0.42	Pablo	5 -Year
66	7.417591	122.326466	0.18	0.5	-0.32	Pablo	5 -Year
67	7.416687	122.326434	0.33	0.5	-0.17	Hellen	5 -Year
68	7.417495	122.327131	0.25	1.5	-1.25	Sendong	5 -Year
69	7.417878	122.326369	0.07	1.5	-1.43	Julian	5 -Year
70	7.416772	122.330275	1.43	0.25	1.18	Yolanda	5 -Year
71	7.417623	122.330575	0.64	0.8	-0.16	Yolanda	5 -Year
72	7.413399	122.332356	0.69	1.5	-0.81	Hellen	5 -Year
73	7.418187	122.327088	0.55	1.5	-0.95	Yolanda	5 -Year
74	7.419538	122.329652	0.23	1.5	-1.27	Yolanda	5 -Year
75	7.414878	122.33609	0.03	1.5	-1.47	Gener	5 -Year
76	7.415283	122.336111	0.03	0.5	-0.47	Gener	5 -Year
77	7.418602	122.321026	0.05	1.5	-1.45	Igme	5 -Year
78	7.41741	122.322164	0.77	1.5	-0.73	Sendong	5 -Year
79	7.417495	122.320468	0.03	1.5	-1.47	Hellen	5 -Year
80	7.416953	122.320136	0.24	0.5	-0.26	Hellen	5 -Year
81	7.412878	122.334394	1.04	1.5	-0.46	Sendong	5 -Year
82	7.412027	122.334008	1.14	0.5	0.64	Sendong	5 -Year
83	7.41324	122.337785	0.43	0.25	0.18	Yolanda	5 -Year
84	7.41208	122.335414	0.99	1.5	-0.51	Yolanda	5 -Year
85	7.420666	122.329674	0.14	0.25	-0.11	Yolanda	5 -Year
86	7.431794	122.325382	0.03	1.5	-1.47	Yolanda	5 -Year

Point Number	Validation Coordinates		Validation Points (m)	Model Var (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
87	7.432305	122.326155	0.03	0.5	-0.47	Yolanda	5 -Year
88	7.424517	122.327399	0.03	0.5	-0.47	Yolanda	5 -Year
89	7.417155	122.329245	1.11	1.5	-0.39	Yolanda	5 -Year
90	7.417698	122.329583	0.97	1.5	-0.53	Yolanda	5 -Year
91	7.422358	122.329577	0.31	1.5	-1.19	Yolanda	5 -Year
92	7.421634	122.327142	0.48	0.5	-0.02	Yolanda	5 -Year
93	7.418666	122.322636	0.82	1.5	-0.68	Yolanda	5 -Year
94	7.447132	122.325797	0.2	0	0.20		5 -Year
95	7.44641	122.325546	0.03	0	0.03		5 -Year
96	7.448278	122.326757	0.03	0	0.03		5 -Year
97	7.444478	122.322644	0.7	0	0.70		5 -Year
98	7.442742	122.321051	0.03	0	0.03		5 -Year
99	7.435841	122.313946	0.03	0	0.03		5 -Year
100	7.436472	122.315261	0.03	0	0.03		5 -Year
101	7.436348	122.315854	0.03	0	0.03		5 -Year
102	7.434877	122.310162	0.03	0	0.03		5 -Year
103	7.4368	122.31014	0.03	0	0.03		5 -Year
104	7.437392	122.307671	0.03	0	0.03		5 -Year
105	7.436619	122.308439	0.03	0	0.03		5 -Year
106	7.435557	122.312125	0.03	0	0.03		5 -Year
107	7.438484	122.305801	0.03	0	0.03		5 -Year
108	7.438657	122.320703	0.03	0	0.03		5 -Year
109	7.441386	122.320148	1.5	0	1.50		5 -Year
110	7.427121	122.33005	0.04	0	0.04		5 -Year
111	7.436926	122.330327	0.03	0	0.03		5 -Year
112	7.438487	122.331017	0.03	0	0.03		5 -Year
113	7.439858	122.329835	0.03	0	0.03		5 -Year
114	7.427943	122.332557	0.09	0	0.09		5 -Year
115	7.430696	122.334791	0.03	0	0.03		5 -Year
116	7.432538	122.335805	0.03	0	0.03		5 -Year
117	7.434364	122.334941	0.03	0	0.03		5 -Year
118	7.438537	122.338815	0.03	0	0.03		5 -Year
119	7.442321	122.335995	0.13	0	0.13		5 -Year
120	7.440345	122.342889	0.06	0	0.06		5 -Year
121	7.434391	122.343304	0.03	0	0.03		5 -Year
122	7.434159	122.344448	0.04	0	0.04		5 -Year
123	7.431386	122.345275	0.03	0	0.03		5 -Year
124	7.42898	122.344927	0.03	0	0.03		5 -Year
125	7.430258	122.345276	0.03	0	0.03		5 -Year
126	7.433666	122.345261	0.03	0	0.03		5 -Year
127	7.43711	122.346324	0.03	0	0.03		5 -Year
128	7.439668	122.347026	0.03	0	0.03		5 -Year
129	7.428858	122.330426	0.12	0	0.12		5 -Year
130	7.443518	122.343836	0.03	0	0.03		5 -Year

Point Number	Validation Coordinates		Validation Points (m)	Model Var (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
131	7.444853	122.344879	0.03	0	0.03		5 -Year
132	7.444742	122.340454	0.03	0	0.03		5 -Year
133	7.445005	122.333358	0.08	0	0.08		5 -Year
134	7.451577	122.331445	0.03	0	0.03		5 -Year
135	7.452883	122.32965	0.03	0	0.03		5 -Year
136	7.454915	122.329221	0.03	0	0.03		5 -Year
137	7.457536	122.328719	0.28	0	0.28		5 -Year
138	7.458671	122.328779	0.03	0	0.03		5 -Year
139	7.460875	122.325164	0.03	0	0.03		5 -Year
140	7.462156	122.327099	0.03	0	0.03		5 -Year
141	7.459002	122.326791	0.03	0	0.03		5 -Year
142	7.462902	122.328621	0.04	0	0.04		5 -Year
143	7.46125	122.327859	0.03	0	0.03		5 -Year
144	7.45371	122.330816	0.03	0	0.03		5 -Year
145	7.436078	122.32196	0.03	0	0.03		5 -Year
146	7.437188	122.323031	0.21	0	0.21		5 -Year
147	7.444149	122.335726	0.03	0	0.03		5 -Year
148	7.441476	122.328476	0.03	0	0.03		5 -Year
149	7.437496	122.321778	0.03	0	0.03		5 -Year
150	7.426712	122.333652	0.06	0	0.06		5 -Year
151	7.433042	122.345209	0.05	0	0.05		5 -Year
152	7.42732	122.331343	0.32	0	0.32		5 -Year
153	7.428065	122.322996	0.03	0	0.03		5 -Year
154	7.424948	122.324916	0.03	0	0.03		5 -Year
155	7.425835	122.329504	0.03	0	0.03		5 -Year
156	7.424102	122.33114	0.04	0	0.04		5 -Year
157	7.422463	122.326152	0.03	0	0.03		5 -Year
158	7.42551	122.327599	0.07	0	0.07		5 -Year
159	7.430727	122.322061	0.03	0	0.03		5 -Year
160	7.432268	122.321484	0.03	0	0.03		5 -Year
161	7.435199	122.322027	0.23	0	0.23		5 -Year
162	7.436962	122.321993	0.03	0	0.03		5 -Year
163	7.435372	122.310012	0.03	0	0.03		5 -Year
164	7.440129	122.320294	1.37	0	1.37		5 -Year
165	7.440862	122.320542	0.58	0	0.58		5 -Year
166	7.437674	122.332241	0.03	0	0.03		5 -Year
167	7.439548	122.323359	0.92	0	0.92		5 -Year
168	7.437375	122.306438	0.03	0	0.03		5 -Year
169	7.434355	122.32159	0.04	0	0.04		5 -Year
170	7.433448	122.33528	0.03	0	0.03		5 -Year
171	7.435463	122.345918	0.05	0	0.05		5 -Year
172	7.427459	122.323548	0.03	0	0.03		5 -Year
173	7.435766	122.323292	0.1	0	0.10		5 -Year
174	7.429563	122.335586	0.03	0	0.03		5 -Year

Point Number	Validation Coordinates		Validation Points (m)	Model Var (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
175	7.431884	122.337563	0.03	0	0.03		5 -Year
176	7.437566	122.342993	0.04	0	0.04		5 -Year
177	7.439582	122.341409	0.21	0	0.21		5 -Year
178	7.442833	122.339211	0.03	0	0.03		5 -Year
179	7.44573	122.318626	0.03	0	0.03		5 -Year
180	7.436348	122.315854	0.03	0	0.03		5 -Year
181	7.436225	122.315124	0.03	0	0.03		5 -Year
182	7.435557	122.312125	0.03	0	0.03		5 -Year
183	7.435841	122.313946	0.03	0	0.03		5 -Year
184	7.435538	122.314401	0.03	0	0.03		5 -Year
185	7.436058	122.315217	0.03	0	0.03		5 -Year

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Annex 12. Educational Institutions affected by flooding in Tigbao Floodplain

Zamboanga City				
Barangay	Building	Rainfall Event		
		5-year	25-year	100-year
Mangusu	Manggusu Integrated School			Low
Mangusu	day care Center			Low
Mangusu	Dr.manuel S. DIAZ MEMORIAL ELEM. SCHOOL			Low
Mangusu	TRIBU DAY CARE CENTER			Low
Mangusu	Sibuktuk Elementary school			Low
Tumitus	Day care			Medium
Tumitus	Limaong national high school			Medium
Tumitus	Matarling Elementary School			Medium
Tictapul	Tictapul elementary school	Medium	High	High
Tictapul	TICTAPUL NATIONAL HIGH SCHOOL	Medium	High	High
Tictapul	Tamion Elementary School	Medium	High	High
Vitali	VITALI CENTRAL SCHOOL	High	High	High
Vitali	VITALI NATIONAL HIGH SCHOOL	High	High	High
Vitali	ZAMBOANGA CITY STATE POLYTECHNIC COLLEGE	High	High	High
Vitali	Tamion Daycare	High	High	High
Vitali	Asma Amsani	High	High	High
Vitali	School building	High	High	High
Vitali	Pananjung Montong	High	High	High
Vitali	TES ROOM	High	High	High
Vitali	TINDALO ELEMENTARY SCHOOL	High	High	High
Vitali	Vitali care center	High	High	High
Licomo	LICUMO CENTRAL SCHOOL			
Licomo	DAY CARE CENTER			
Licomo	Talaga elementary school			
Licomo	Dre care center			
Limaong	Limaong national high school			
Limaong	Matiti elementary school			
Tigbalabag	day care Center			
Tigbalabag	DayCare school			
Tigbalabag	Day care			

Annex 13. Health Institutions affected by flooding in Tigbao Floodplain

Agusan del Norte				
Jabonga				
Barangay	Building	Rainfall Scenario		
		5-year	25-year	100-year
Vitali	Vitali Center	High	High	High