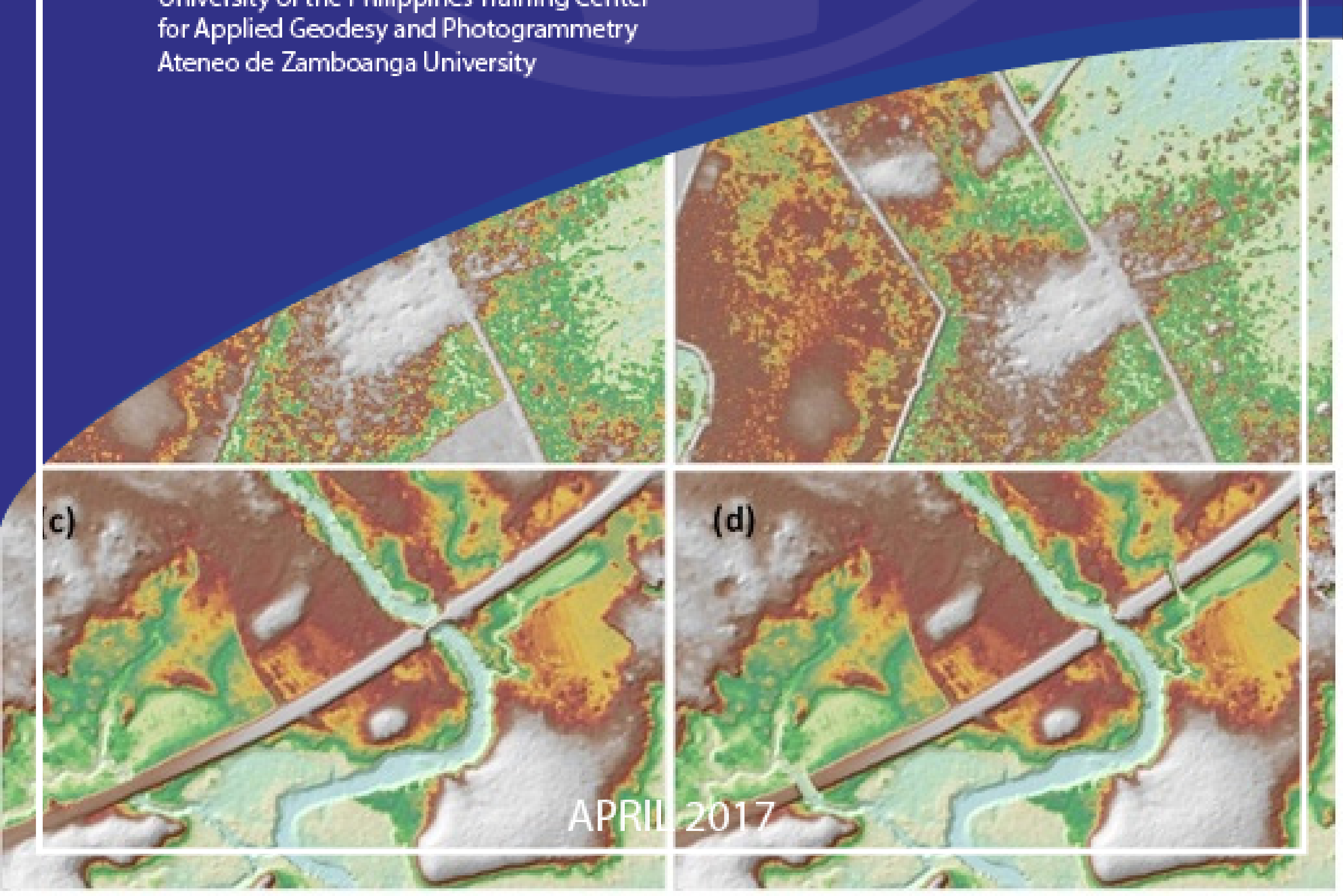
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Tupilac River

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



APRIL 2017

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

LIDAR SURVEYS AND FLOOD MAPPING OF TUPILAC River

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

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

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND TUPILAC RIVER

Mr. Mario S. Rodriguez , and Enrico C. Paringit, Dr. Eng.

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the 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 18 river basins in the Zamboanga Peninsula.The university is located in the City of Zamboanga.

1.2 Overview of the Tupilac River Basin

Tupilac River is located in between the municipalities of Tungawan and Roseller T. Lim of the province of the Zamboanga Sibugay. The river which has a total area of 97.28 sqkm and traverses through both municipalities, also serves as the municipalities’ political boundary.

The name of the river came from one of the barangays of Roseller T. Lim, Barangay Tupilac, where the river is located. According to the National Water Resources Board (NWRB), Tupilac River is considered as one of the principal rivers in Region IX.

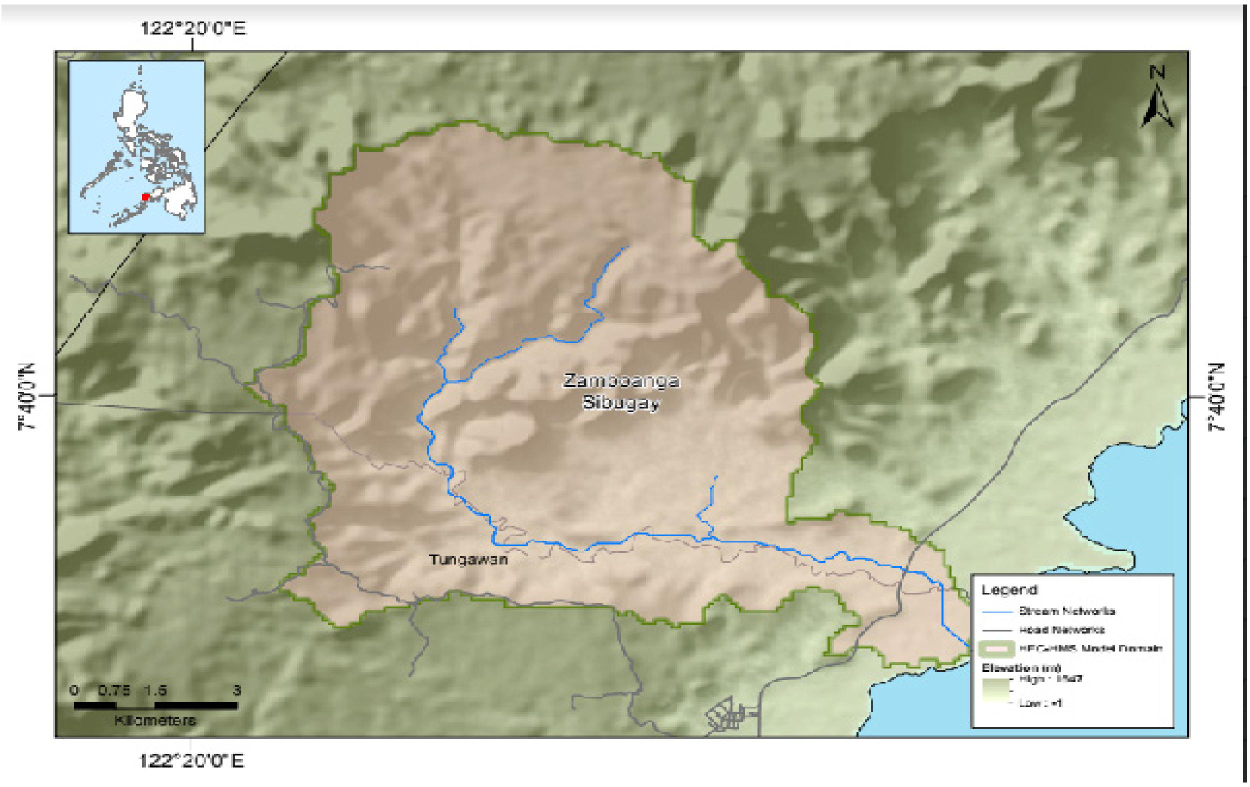


Figure 1. Map of the Tupilac River Basin (in brown)

Flooding Incidence

The Local Disaster Risk Reduction and Management Office of Roseller T. Lim and Tungawan have identified 2 major flooding incidents brought about by heavy rain fall and presence of typhoon. In 2012, around 50 families from the municipality of Roseller T. Lim were affected by the river swelling, as an effect of the presence of Typhoon Lawin.

In October 2013, Typhoon Quedan also brought massive destruction in the Municipality of Tungawan. Accordingly, the road and bridge connecting the municipality of Tungawan and Roseller T. Lim was heavily flooded. Several barangays of the municipality also suffered from landslide. The LDRRM Office of the municipality of Tungawan has recorded around 130 households affected. Economic activities related to farming and fishponds were also destructed.

Economic Activity

Agriculture is the one of main sources of livelihood in both municipalities of Tungawan and Roseller T Lim. To support this main economic activity, the river serves as the main source of water for irrigation purposes. In 2016, the National Irrigation Administration (NIA) of Region IX has identified several irrigation projects in order to intensify the agricultural activities in the 2 municipalities.

Aside from farming, small scale and large scale mining are also present in both municipalities. Gold, Copper and Manganese are just some of the minerals present in the area. Currently, several mining companies are still in the process of accessing permit in order to start their activities. On the other hand, registered small scale miners have already explored and started their respective mining activities.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE TUPILAC FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Julie Pearl S. Mars, Ms. Kristine Joy P. Andaya

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 Tupilac floodplain in Zamboanga. Each flight mission has an average of 14 lines and run for at most four and a half (4.5) hours including take-off, landing and turning time. The parameter used in the LiDAR system for acquisition is found in Table 1. Figure 1 shows the flight plans for Tupilac Floodplain.

Table 1.Flight planning parameters for Pegasus LiDAR system

Block Name	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK75A	1200	30	50	200	30	130	5
BLK75C	1100/1200	30	50	200	30	130	5
BLK75D	1100	30	50	200	30	130	5
BLK75E	1100	30	50	200	30	130	5

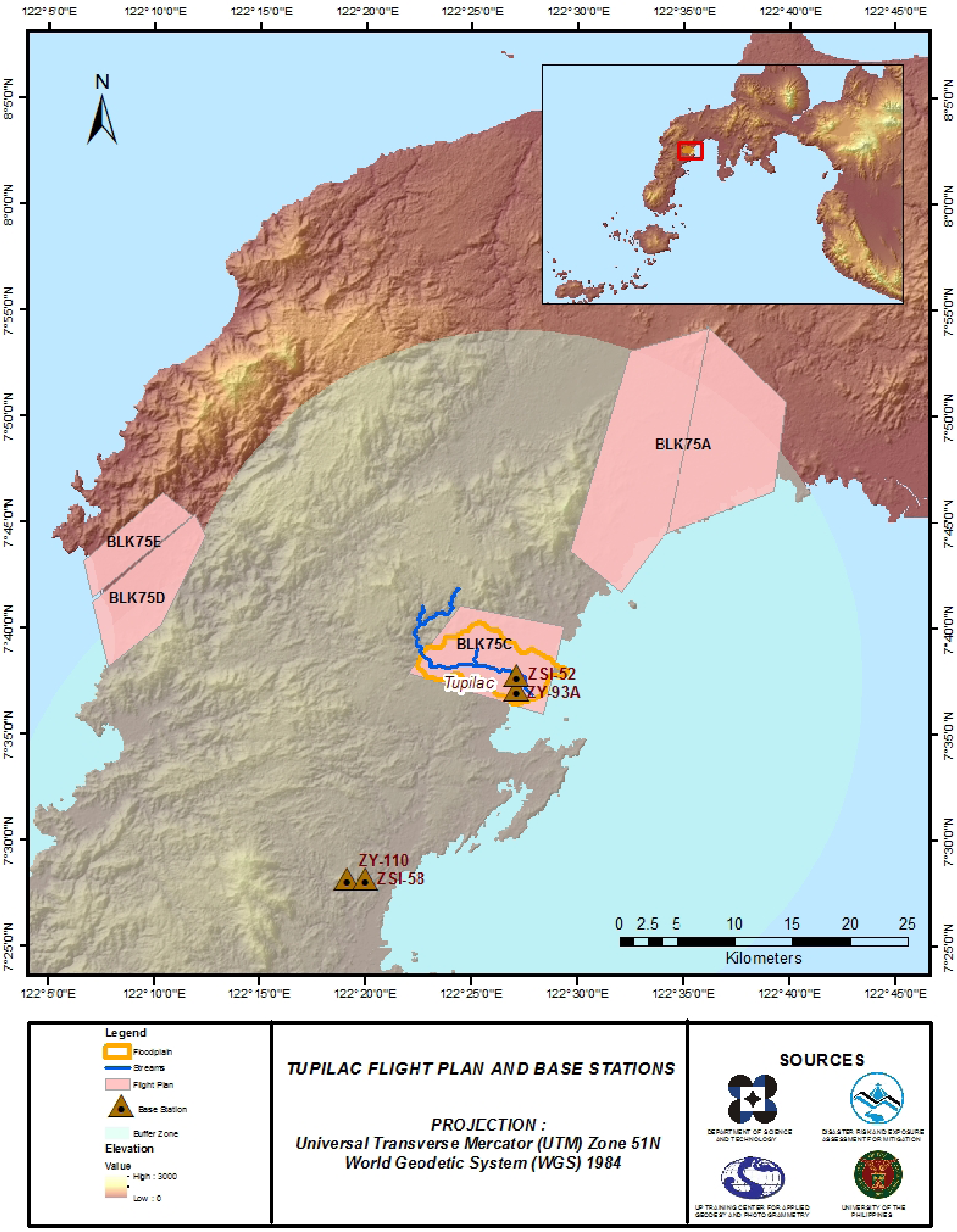
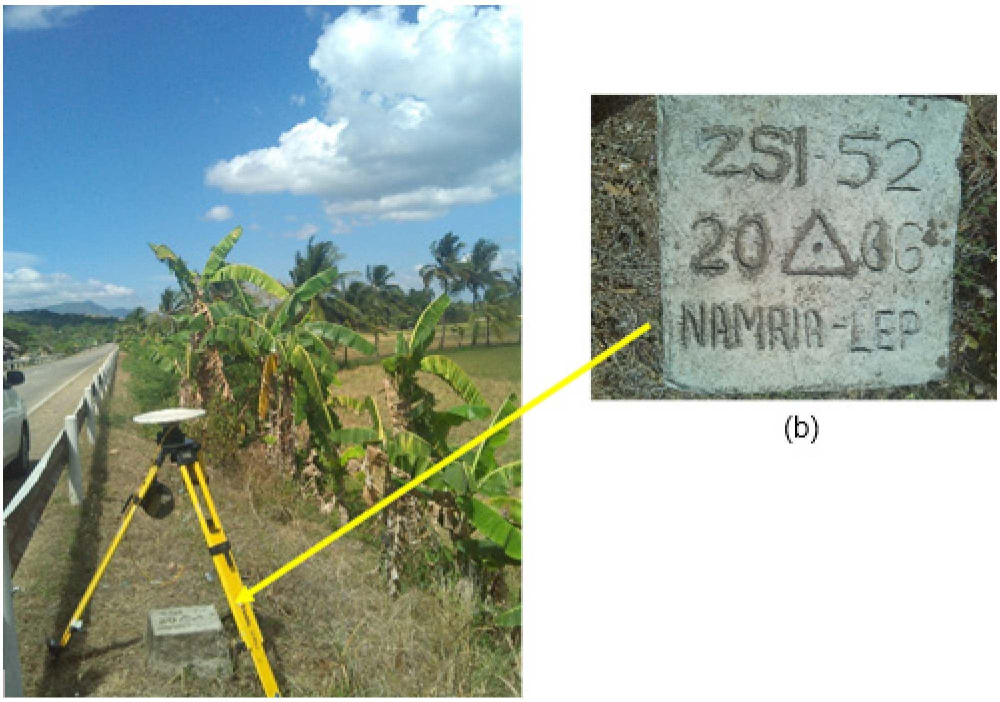


Figure 2. Flight plan and base stations used for Tupilac Floodplain.

2.2 Ground Base Station

The project team was able to recover two (2) NAMRIA ground control points: ZSI-52 and ZSI-58 which are of second (2nd) order accuracy and two (2) established control points: ZY-93A and ZY-110. The certifications for the NAMRIA reference points and processing report for the established points are found in Annex B. These were used as base stations during flight operations for the entire duration of the survey (January 29-Febuary 12, 2015; May 19-31, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882, SPS 852, SPS 985, and TOPCON GR-5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tupilac Floodplain are also shown in Figure 2.

Figure 3 to Figure 5 show the recovered NAMRIA control stations within the area, in addition Table 2 to Table 5 show the details about the following NAMRIA control stations and established points, Table 6 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey.



(b)

(a)

Figure 3. GPS set-up over ZSI-52 (a) in Brgy. Tupilac, Zamboanga Sibugay and NAMRIA reference point ZSI-52 (b) as recovered by the field team

Table 2. Details of the recovered NAMRIA horizontal control point ZSI-52 used as base station for the LiDAR data acquisition.

Station Name	ZSI-52	
Order of Accuracy	2rd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 37’ 50.78279”North 122° 27’ 1.47785”East 10.413 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting Northing	439359.616 meters 843760.188meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 37’ 47.22473” North 122° 27’ 6.97710” East 74.257 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	439380.84 meters 843464.86 meters

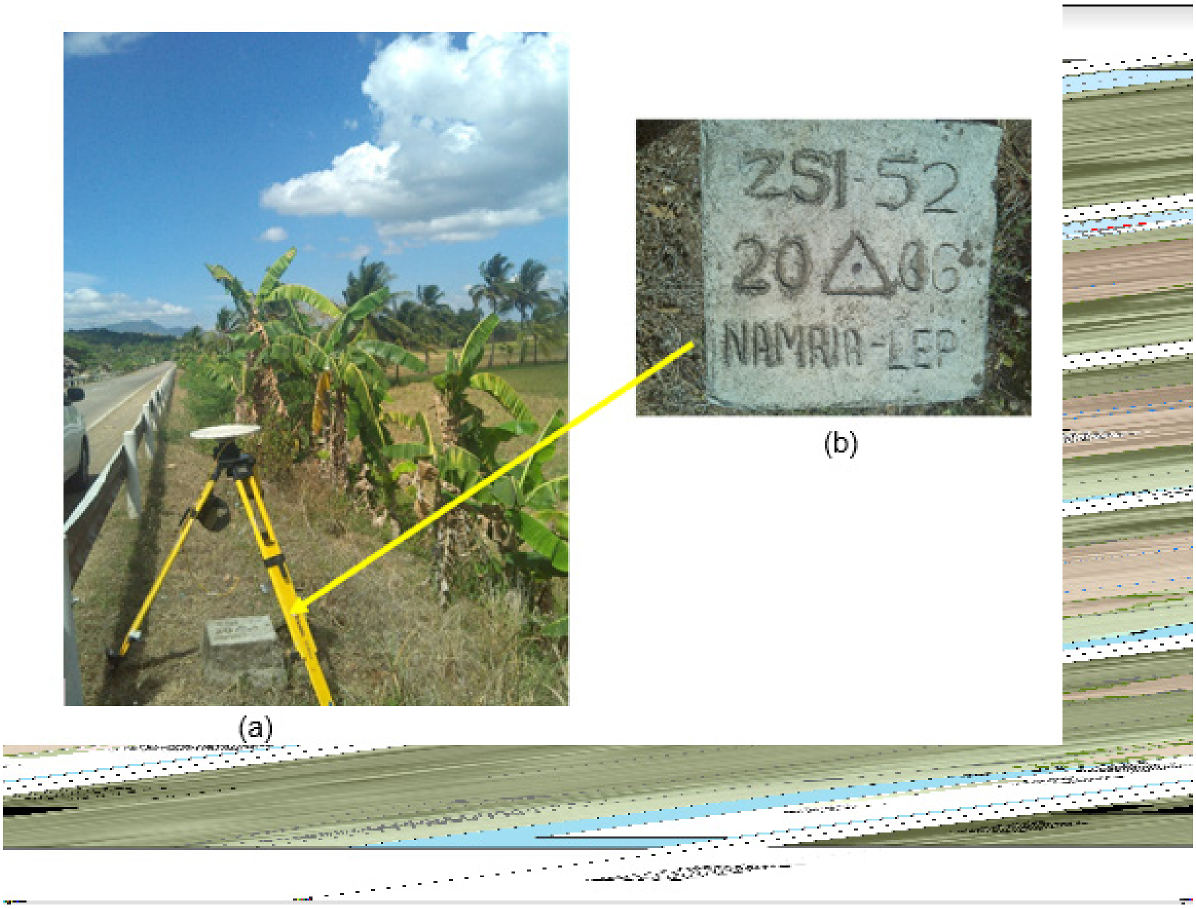


Figure 4. GPS set-up over ZSI-58 (a) in Brgy. Licomo, Zamboanga Sibugay and NAMRIA reference point ZSI-58 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point ZSI-58 used as base station for the LiDAR data acquisition.

Station Name	ZSI-58	
Order of Accuracy	2rd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 28’ 13.32387”North 122° 19’ 53.76709”East 82.90600 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984	Easting Northing	426222.848 meters 826039.734 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7° 28’ 9.79725” North 122° 19’ 59.28169” East 146.76200 meters

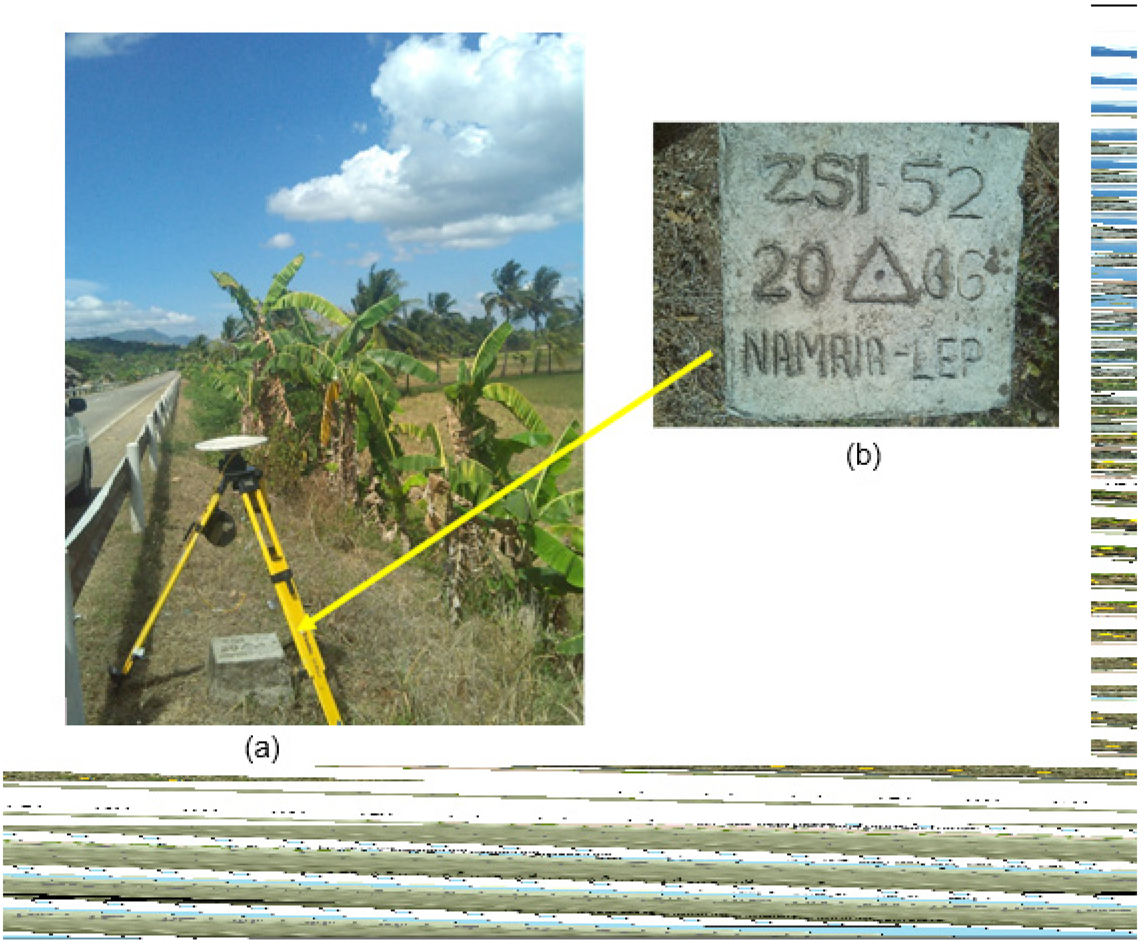


Figure 5. (a) GPS set-up over ZY-110 in Zamboanga Sibugay and BM reference point ZY-110 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point ZY-110 used as base station for the LiDAR data acquisition.

Station Name	ZY-110	
Order of Accuracy	2rd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7° 28' 13.32387"North 122° 19' 53.76709"East 82.90600 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984	Easting Northing	429720.383 meters 830666.222 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°30'50.03168" North 122°21'52.30920"East 81.775 meters

Table 5. Details of the recovered NAMRIA horizontal control point ZY-93A used as base station for the LiDAR data acquisition.

Station Name	ZY-93-A	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	7°37'46.78582"North 122°27'00.08763"East 10.662 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984	Easting Northing	439338.090 meters 843342.174 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	7°37'43.22802" North 122°27'05.58699"East 74.508 meters

Table 6. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
February 9, 2015	2549P	1BLK75A040A	ZSI-52 and ZY-93A
February 10, 2015	2553P	1BLK75A041A	ZSI-52 and ZY-93A
May 27, 2016	23398P	1BLK75CSDE148B	ZSI-58 and ZY-110
May 30, 2016	23410P	1BLK75CS151B	ZSI-58 and ZY-110

2.3 Flight Missions

Four (4) missions were conducted to complete LiDAR data acquisition in Tupilac Floodplain, for a total of 15 hours and 50 minutes (15+50) of flying time for RP-C9022. All missions were acquired using the Pegasus System. Table 7 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 8 presents the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for LiDAR data acquisition in Tupilac 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 9, 2015	2549P	143.62	145.50	_	131.3	482	4	23
February 10, 2015	2553P	108.60	217.17	79.59	141.03	488	4	11
May 27, 2016	23398P	121.12	201.55	19.77	180	557	4	11
May 30, 2016	23410P	121.12	145.32	142.63	_	282	3	5
TOTAL		494.46	709.54	241.99	452.33	1809	15	50

Table 8. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
2549P	1200	30	50	200	30	130	5
2553P	1200	30	50	200	30	130	5
23398P	1100	30	50	200	30	130	5
23410P	1100	30	50	200	30	130	5

2.4 Survey Coverage

Tupilac Floodplain is located in the province of Zamboanga Sibugay with the floodplain situated within the Municipalities of Roseller Lim and Tungawan. The list of municipalities and cities surveyed with at least one (1) square kilometer coverage, is shown in Table 9. The actual coverage of the LiDAR acquisition for Tupilac Floodplain is presented in Figure 6.

Table 9. List of municipalities and cities surveyed in Tupilac Floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed =(Total Area covered/ Area of Municipality)*100
Zamboanga del Norte	Baliguian	462.61	32.31	7%
	Kalawit	329.51	8.34	3%
	Siocon	248.94	96.96	39%
Zamboanga Sibugay	Ipil	134.32	126.32	97%
	Naga	164.18	6	4%
	Roseller Lim	272.39	120.54	44%
	Titay	176.50	104	59%
	Tungawan	441.86	112.73	26%
Total		2230.31	607.2	27.22%

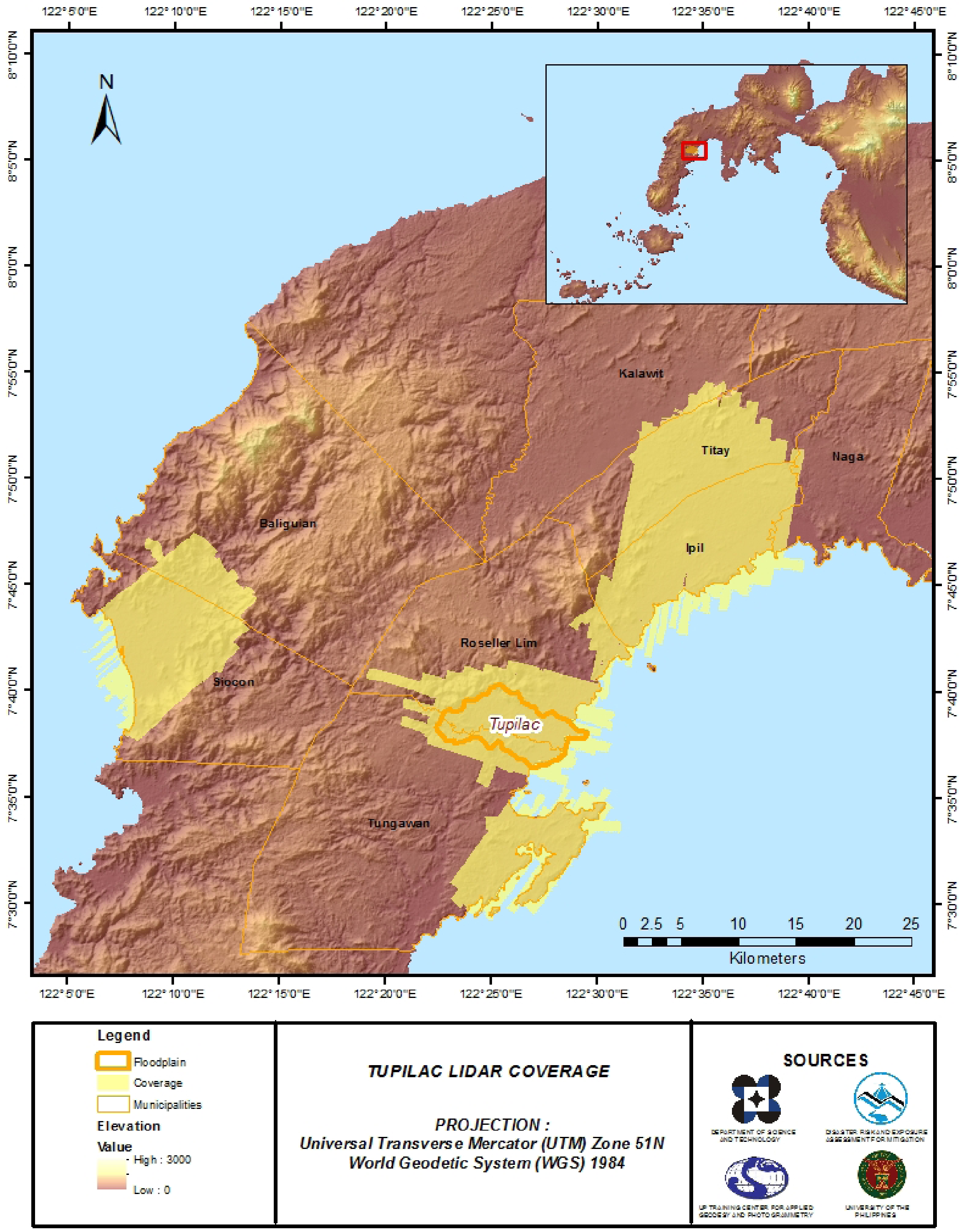


Figure 6. Actual LiDAR survey coverage for Tupilac Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE TUPILAC FLOODPLAIN

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

3.1 Overview of the LIDAR Data Pre-Processing

After the acquisition of LiDAR data, the latter is transmitted to the DPPC. Upon acceptance of the field data, the DPPC checks it for completeness and accuracy based on the list of raw files needed to proceed with its pre-processing. After which, the flight trajectory is georeferenced to obtain the exact location of the LiDAR sensor when the laser was shot.

Subsequently, the point cloud georectification is performed to incorporate the correct position and orientation for each point acquired. The georectified LiDAR point clouds are then subjected to a quality check to ensure that the required accuracies of the program, namely the minimum point density and vertical and horizontal accuracies, are met. These point clouds are then classified into various classes, which are integral in the generation of Digital Elevation Models (DEMs) such as the Digital Terrain Model (DTM) and the Digital Surface Model (DSM).

After this, the LiDAR-derived digital models are calibrated using the elevation of points gathered in the field. Parts of the river basin that were barely penetrated by the LiDAR system are then replaced by the actual river geometry measured from the field by the DVBC. Temporally acquired LiDAR data are then mosaicked to completely cover the target river systems in the Philippines. Images acquired from the field are orthorectified simultaneously with the LiDAR data through the help of the georectified point clouds and the metadata containing the time the image was captured.

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

Specific details of the LIDAR data processing methodology are found in UP TCAGP (2014)

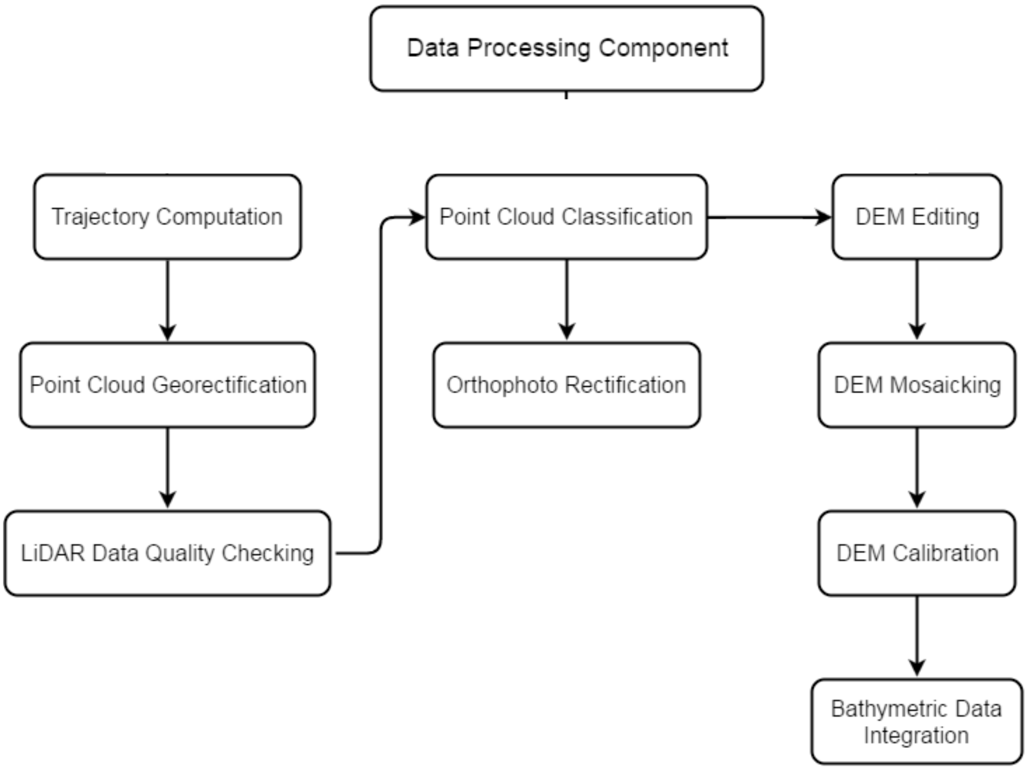


Figure 7. Schematic diagram for Data Pre-processing Component

3.2 Transmittal of Acquired LIDAR Data

Data transfer sheets for all the LiDAR missions for Tupilac Floodplain can be found in Annex 5. Missions flown during the first survey conducted on February 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system. Missions acquired during the second survey on May 2016 were flown using the same system over Tungawan and Roseller Lim, Zamboanga Sibugay. The Data Acquisition Component (DAC) transferred a total of 79.9 Gigabytes of Range data, 0.94 Gigabytes of POS data, 335.18 Megabytes of GPS base station data, and 109.8 Gigabytes of raw image data to the data server on March 13, 2015 for the first survey and July 14, 2016 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tupilac was fully transferred on July 14, 2016, as indicated on the Data Transfer Sheets for Tupilac Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 2553P, one of the Tupilac flights, which is the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on February 10, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

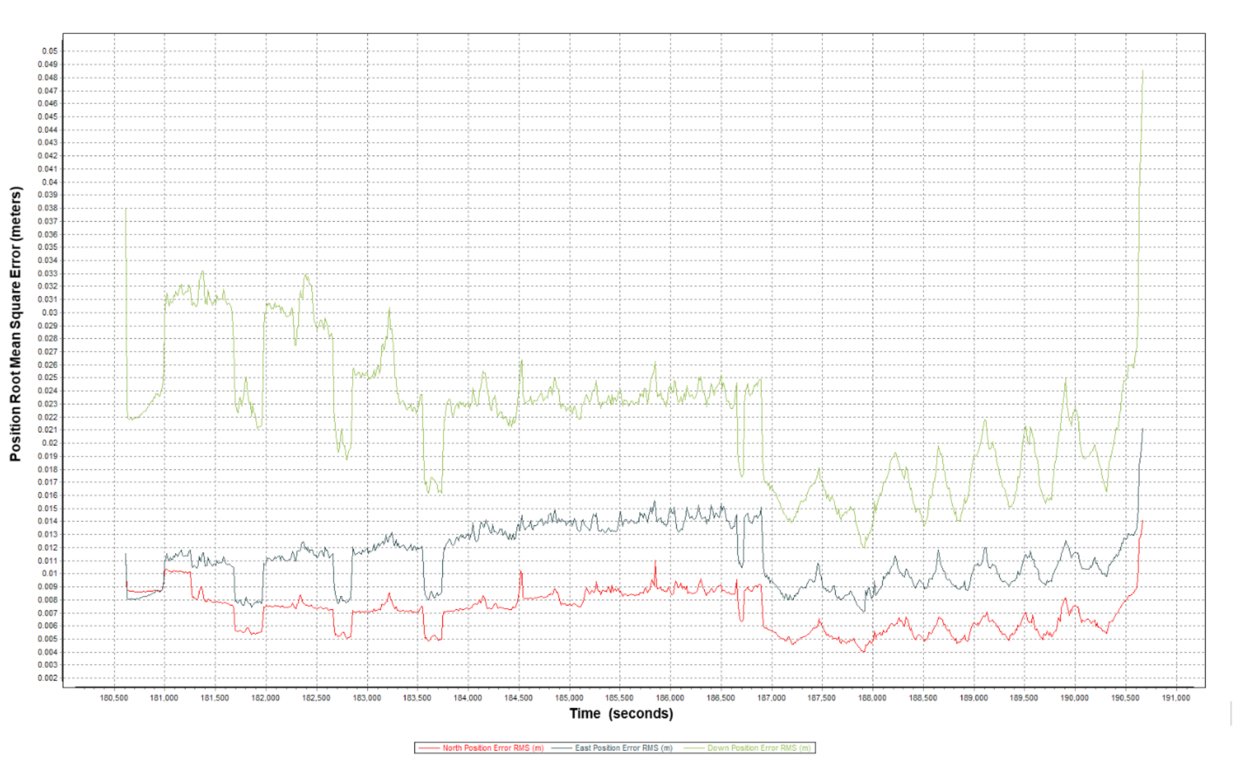


Figure 8. Smoothed Performance Metric Parameters of a Tupilac Flight 2553P.

The time of flight was from 180500 seconds to 190750 seconds, which corresponds to morning of February 10, 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 8 shows that the North position RMSE peaks at 1.11 centimeters, the East position RMSE peaks at 1.56 centimeters, and the Down position RMSE peaks at 2.64 centimeters, which are within the prescribed accuracies described in the methodology.

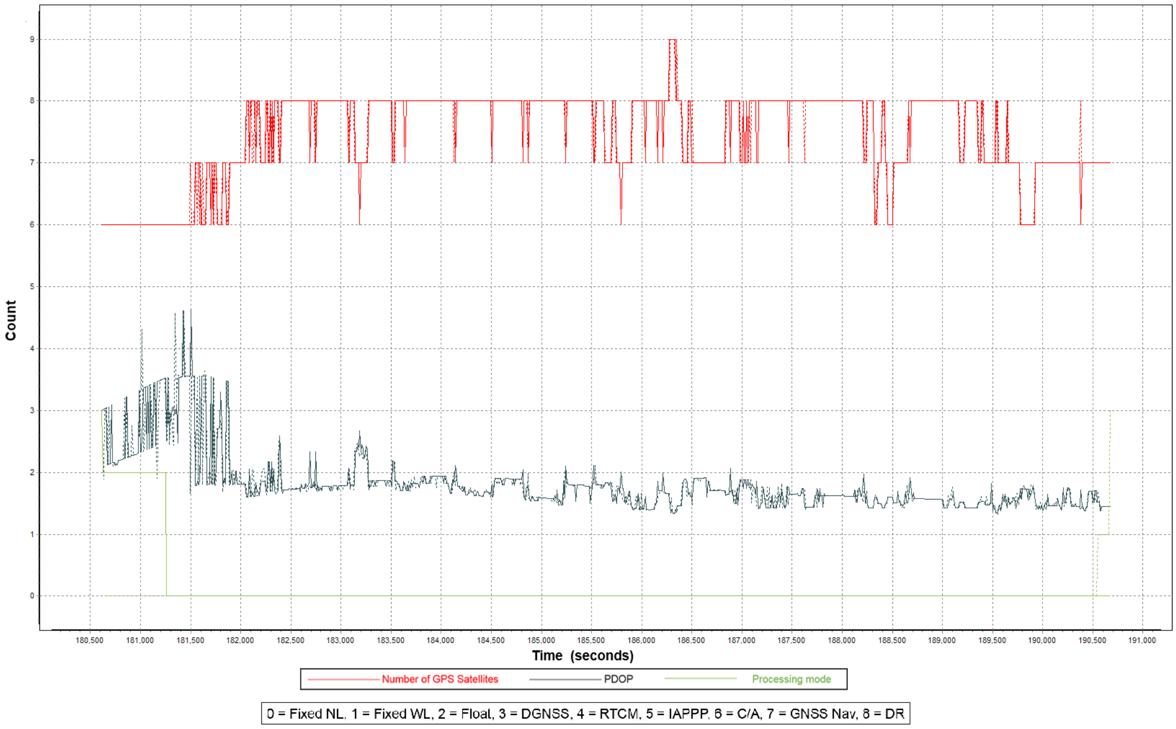


Figure 9. Solution Status Parameters of Tupilac Flight 2553P.

The Solution Status parameters of flight 2553P, one of the Tupilac flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 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 Tupilac flights is shown in Figure 10.

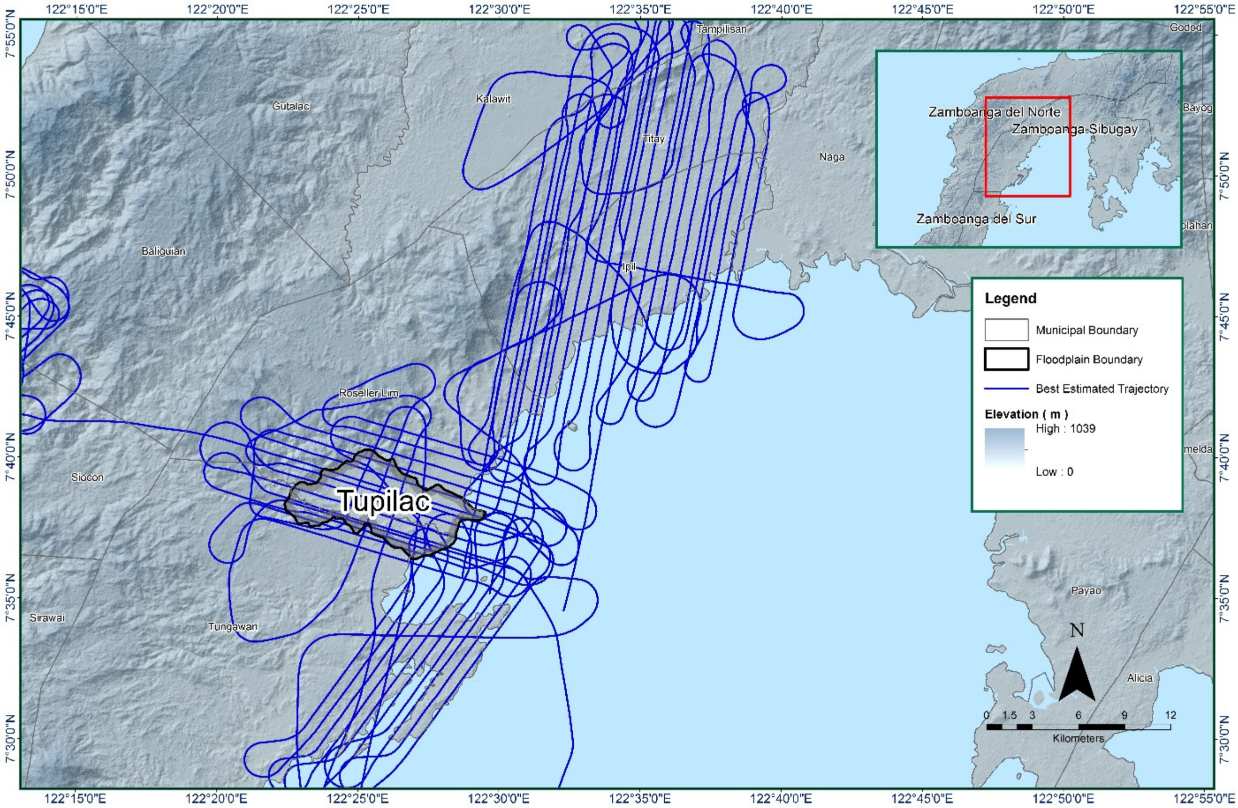


Figure 10. Best Estimated Trajectory for Tupilac Floodplain

3.4 LIDAR Point Cloud Computation

The produced LAS data contains 52 flight lines, with each flight line containing two channels, since the Pegasus system contains two. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tupilac Floodplain are given in Table 10.

Table 10. Self-Calibration Results values for Tupilac flights.

Parameter		Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000145
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000338
GPS Position Z-correction stdev	(<0.01meters)	0.0015

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

3.5 LIDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Tupilac Floodplain is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

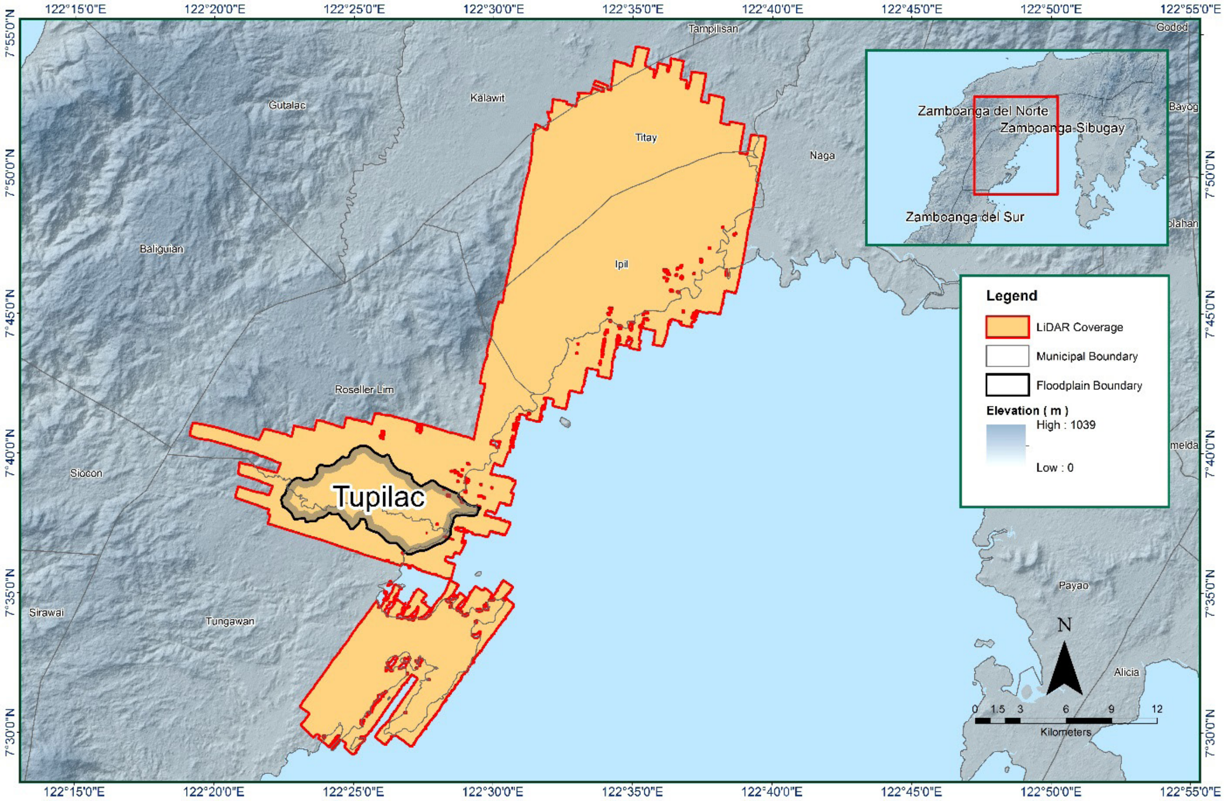


Figure 11. Boundary of the processed LiDAR data over Tupilac Floodplain

The total area covered by the Tupilac missions is 573.17 sq.km that is comprised of four (4) flight acquisitions grouped and merged into five (5) blocks as shown in Table 11.

Table 11. List of LiDAR blocks for Tupilac Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Zamboanga_Blk75A	2549P	331.71
	2553P	
Zamboanga_Blk75A_supplement	2553P	53.78
Zamboanga_Blk75A_additional	2553P	1.16
Zamboanga_reflights_Blk75A	23398P	104.51
	23410P	
Zamboanga_reflights_Blk75B	23410P	82.01
	TOTAL	**573.17 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 12. Since the Pegasus System employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

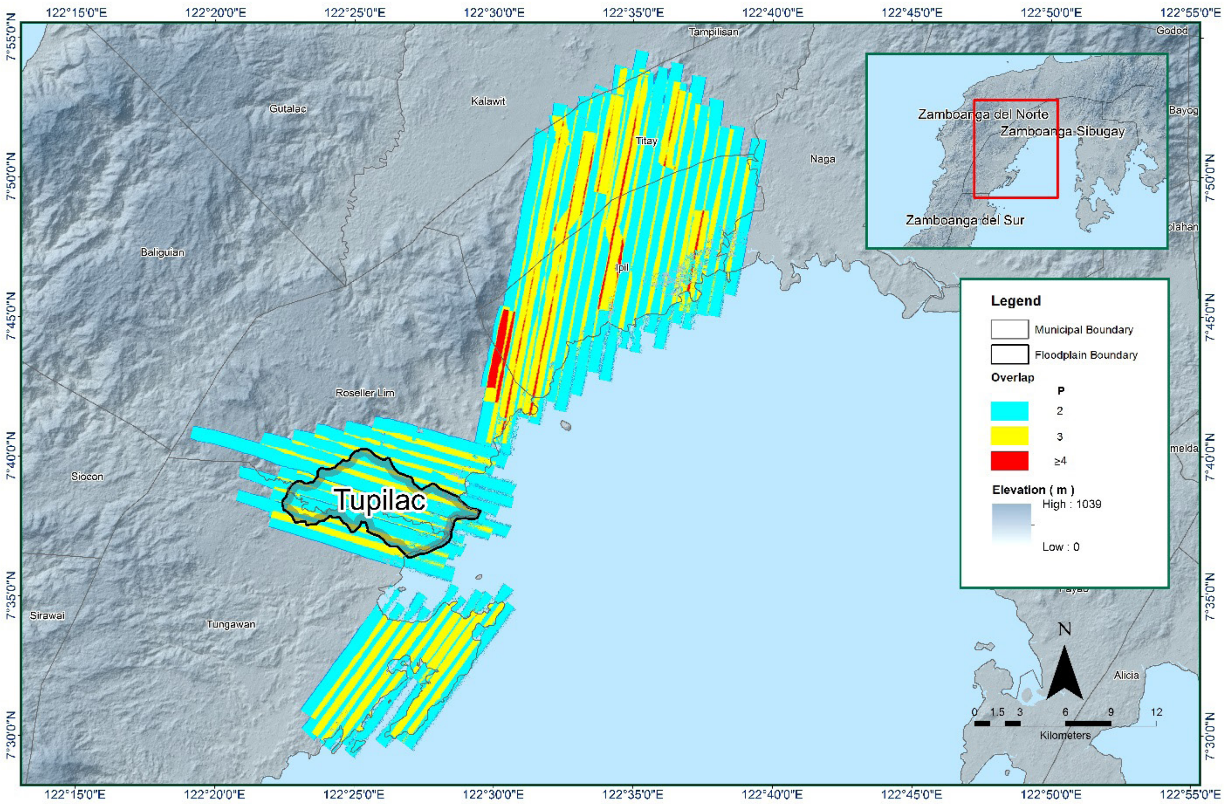


Figure 12. Image of data overlap for Tupilac Floodplain.

The overlap statistics per block for the Tupilac Floodplain can be found in Annex 7. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 25.25% and 95.41% respectively, which passed the 25% requirement.

The 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 13. It was determined that all LiDAR data for Tupilac floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.90 points per square meter.

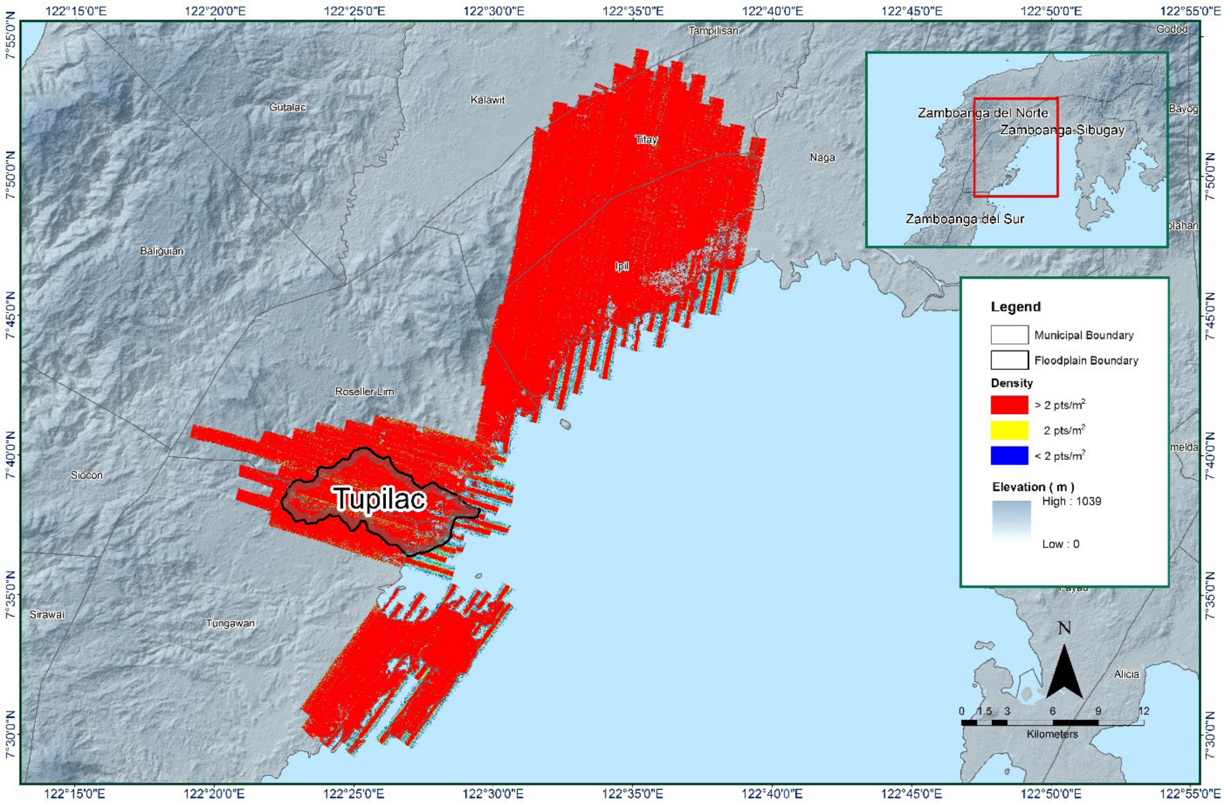


Figure 13. Density map of merged LiDAR data for Tupilac Floodplain.

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

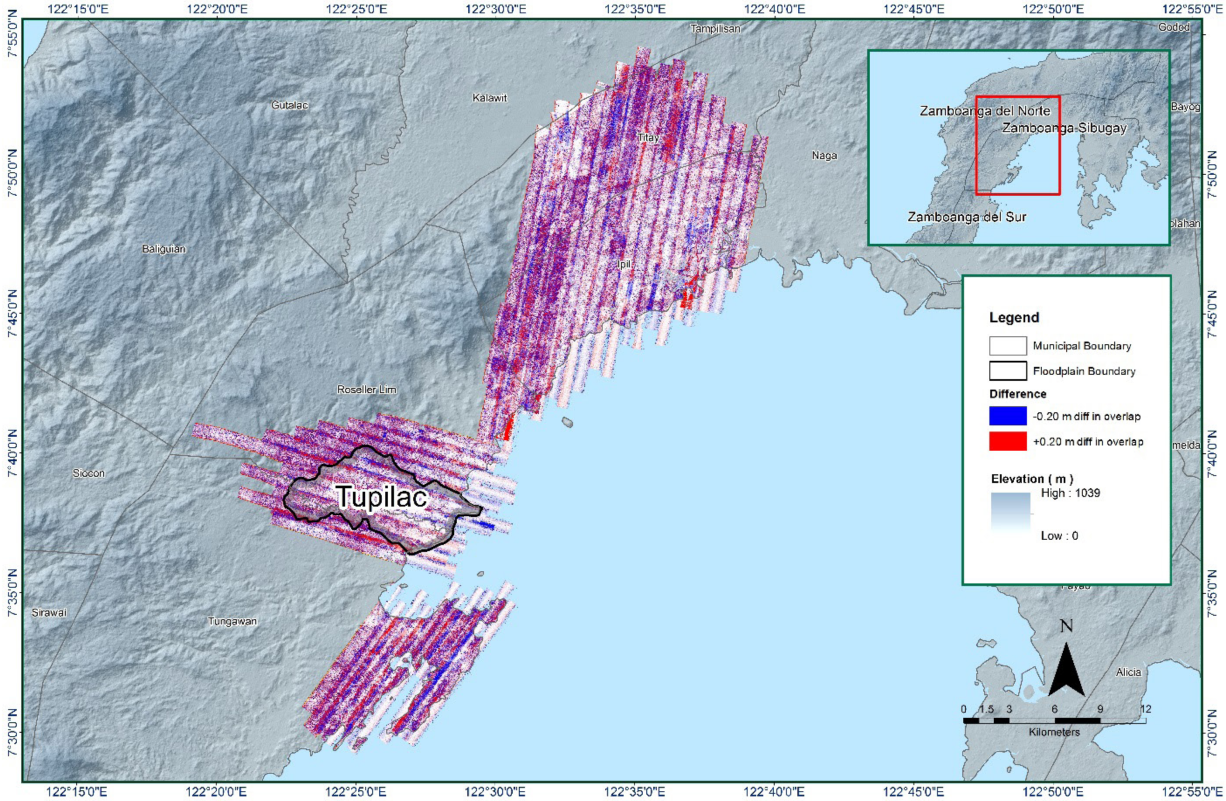


Figure 14. Elevation difference map between flight lines for Tupilac Floodplain.

A screen capture of the processed LAS data from a Tupilac flight 2553P loaded in QT Modeler is shown in Figure 15. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

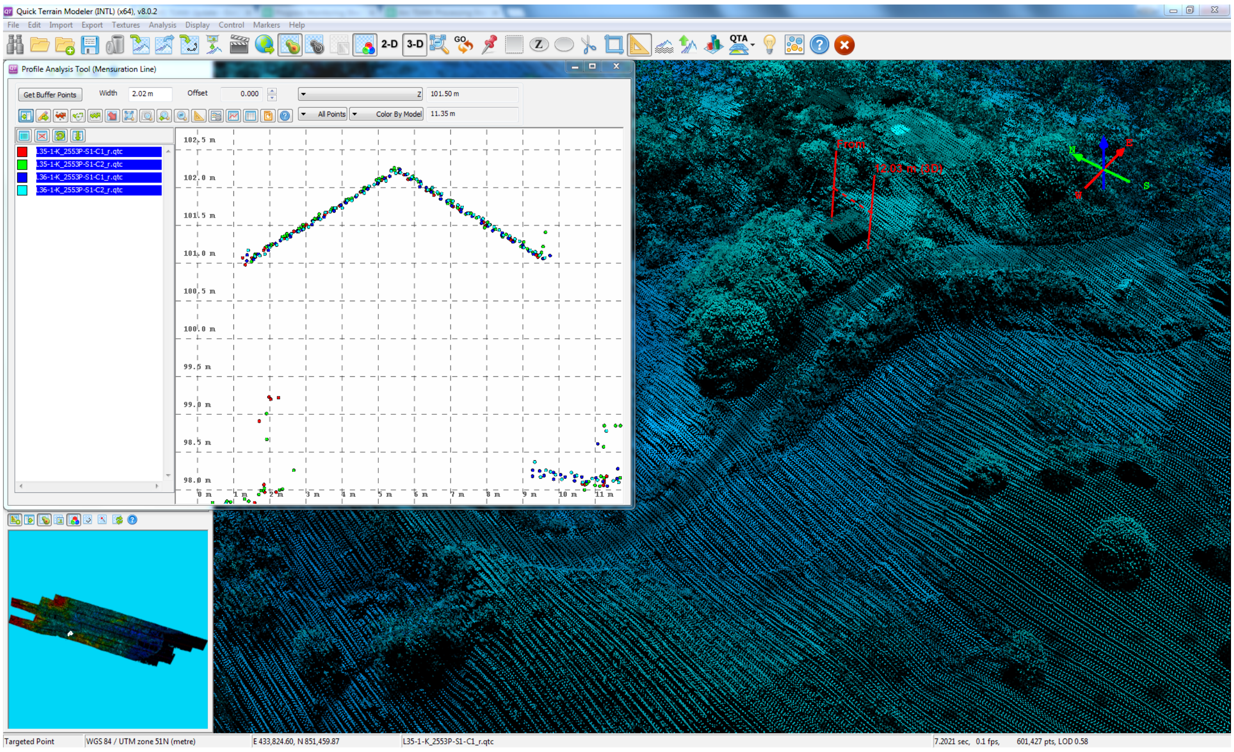


Figure 15. Quality checking for a Tupilac flight 2553P using the Profile Tool of QT Modeler.

3.6 LIDAR Point Cloud Classification and Rasterization

Table 12. Tupilac classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	505,605,649
Low Vegetation	417,973,810
Medium Vegetation	732,050,978
High Vegetation	1,591,351,682
Building	17,401,647

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tupilac Floodplain is shown in Figure 16. A total of 727 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 12. The point cloud has a maximum and minimum height of 557.70 meters and 56.22 meters respectively.

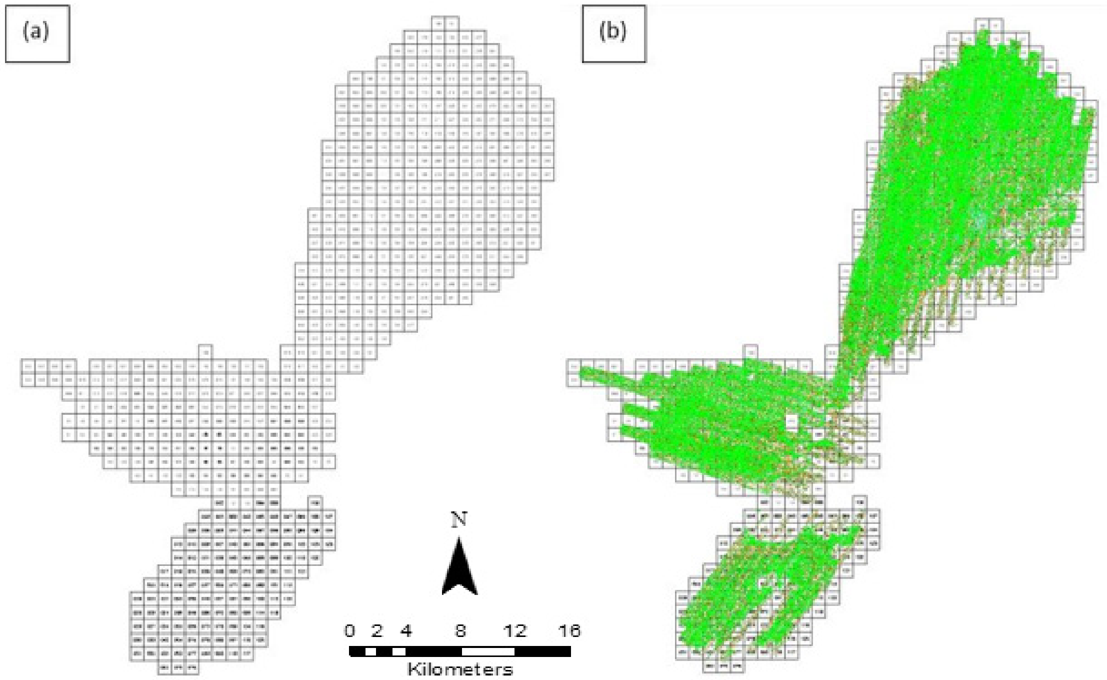


Figure 16. Tiles for Tupilac Floodplain (a) and classification results (b) in TerraScan.

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

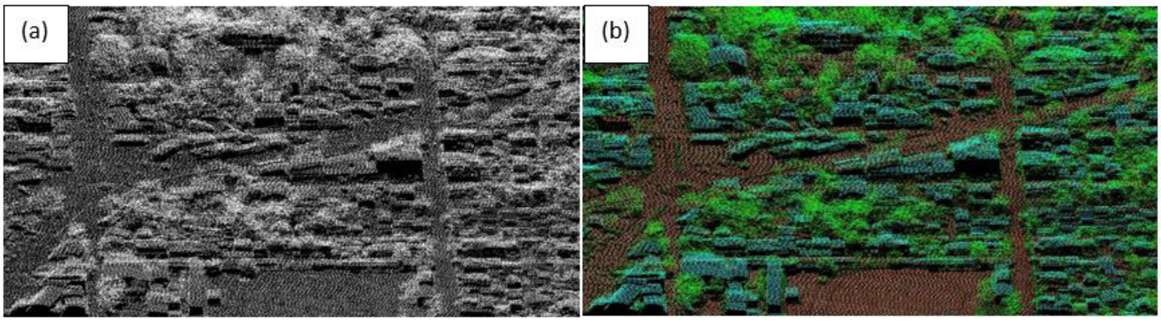


Figure 17. Point cloud before (a) and after (b) classification.

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

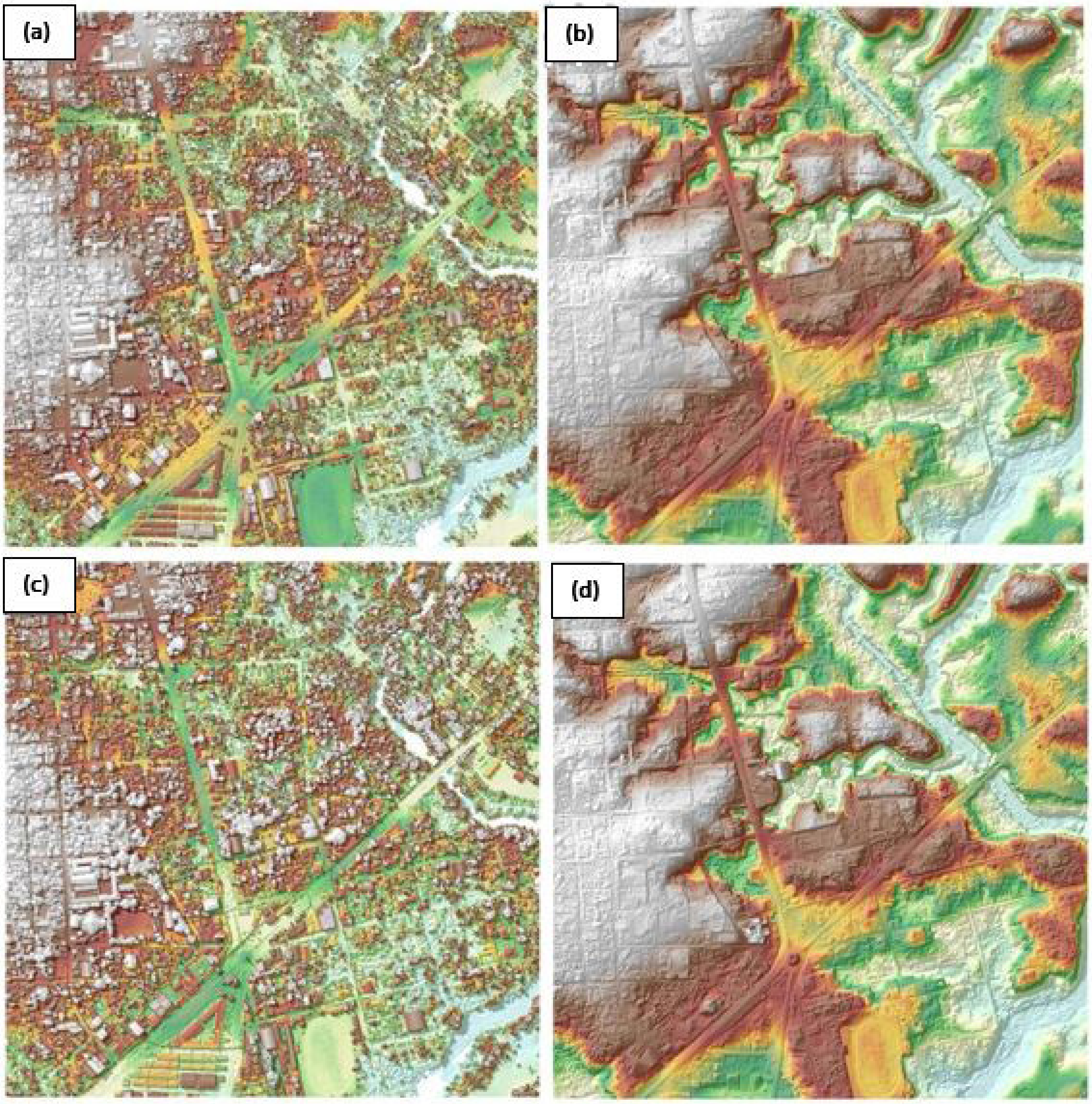


Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tupilac Floodplain.

3.7 LIDAR Image Processing and Orthophotograph Rectification

The 619 1km by 1km tiles area covered by Tupilac Floodplain is shown in Figure 19. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Tupilac Floodplain has a total of 444.372 sq.km orthophotogaph coverage comprised of 1,174 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 20.

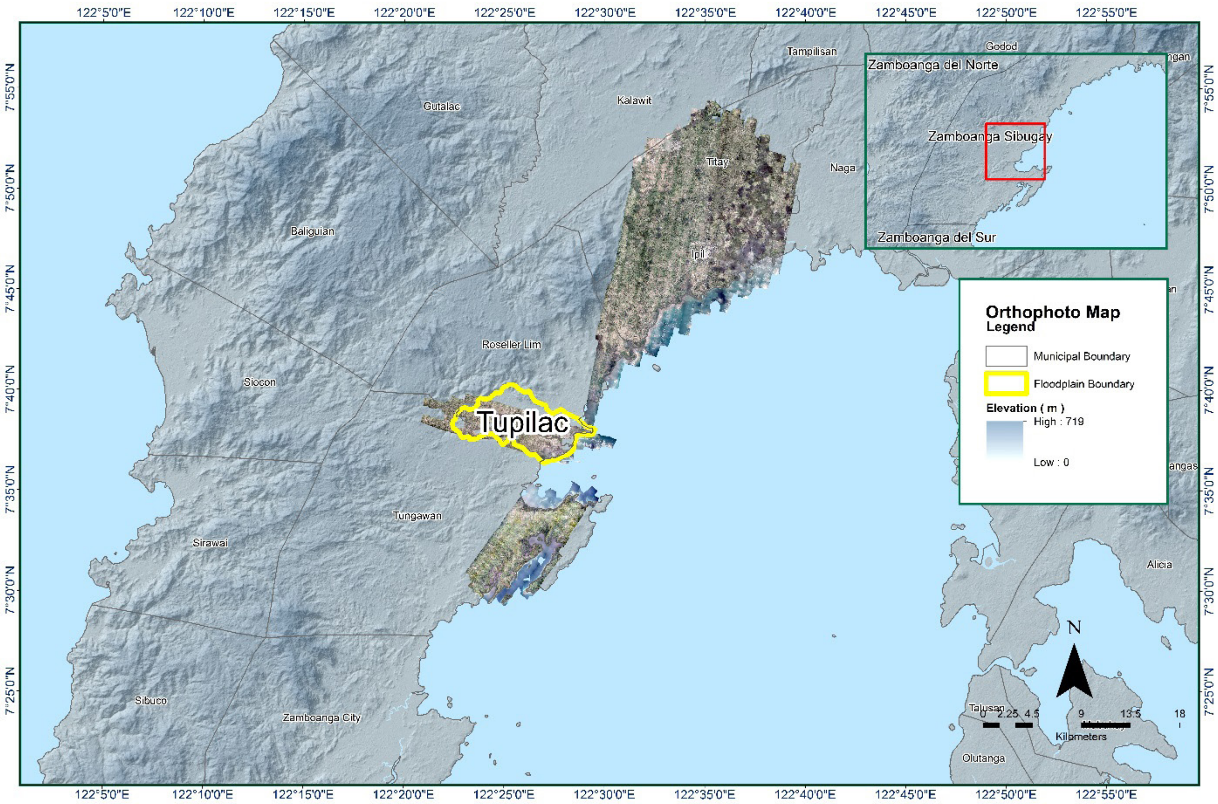


Figure 19. Tupilac Floodplain with available orthophotographs.

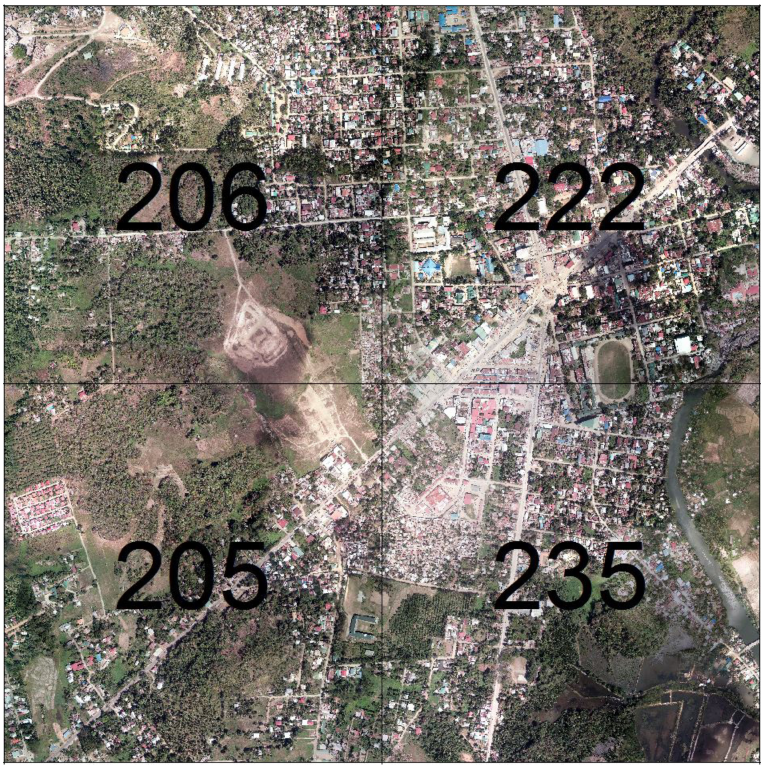


Figure 20. Sample orthophotograph tiles for Tupilac Floodplain.

3.8 DEM Editing and Hydro-Correction

Five (5) mission blocks were processed for Tupilac Floodplain. These blocks are composed of Zamboanga and Zamboanga_reflights blocks with a total area of 573.17 square kilometers. Table 13 shows the name and corresponding area of each block in square kilometers.

Table 13. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Zamboanga_Blk75A	331.71
Zamboanga_Blk75A_supplement	53.78
Zamboanga_Blk75A_additional	1.16
Zamboanga_reflights_Blk75A	104.51
Zamboanga_reflights_Blk75B	82.01
TOTAL	**573.17 sq.km**

Portions of DTM before and after manual editing are shown in Figure 21. The rice field or fishpond embankment (Figure 21a) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 21b) to allow the correct flow of water. The bridge (Figure 21c) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 21d) in order to hydrologically correct the river.

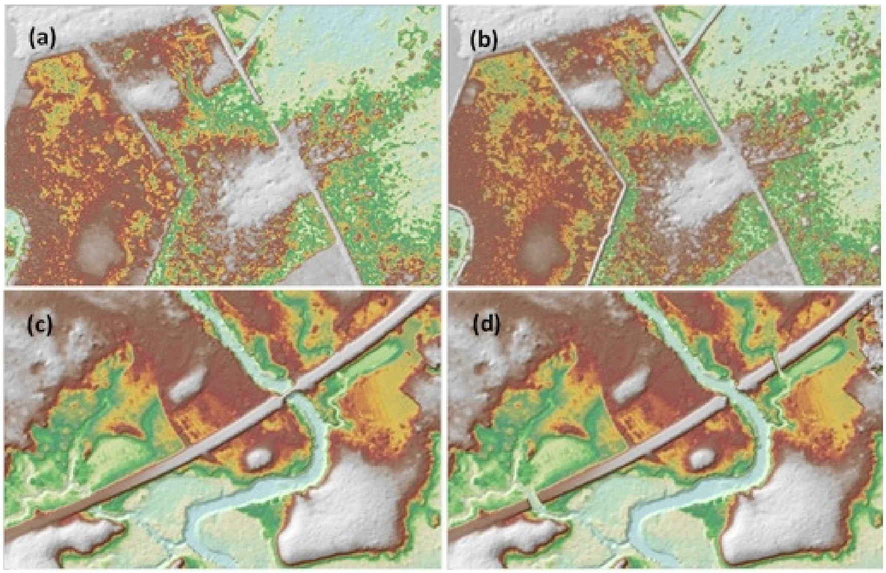


Figure 21. Portions in the DTM of Tupilac Floodplain – a paddy field before (a) and after (b) data retrieval; a bridge before (c) and after (d) manual editing.

3.9 Mosaicking of Blocks

Zamboanga_Blk75A was used as the reference block at the start of mosaicking because it is the first available data. All other blocks adjacent to the reference block were simultaneously mosaicked.

Mosaicked LiDAR DTM for Tupilac Floodplain is shown in Figure 22. It can be seen that the entire Tupilac Floodplain is 100% covered by LiDAR data.

Table 14. Shift Values of each LiDAR Block of Tupilac Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Zamboanga_Blk75A	0.00	0.00	0.00
Zamboanga_Blk75A_supplement	0.00	0.00	0.00
Zamboanga_Blk75A_additional	-1.00	1.00	0.00
Zamboanga_reflights_Blk75A	0.00	0.00	-0.20
Zamboanga_reflights_Blk75B	1.00	0.00	1.34

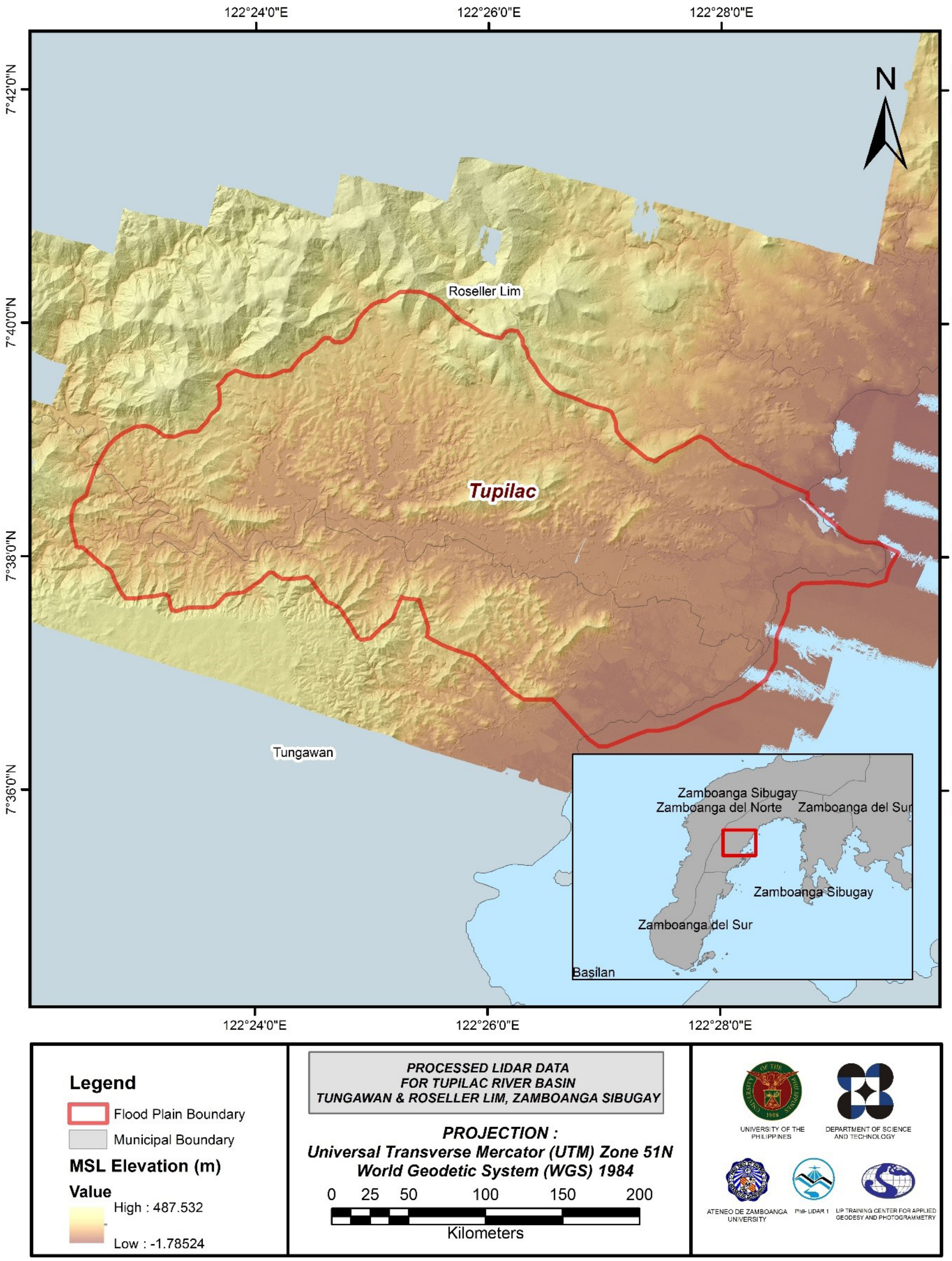


Figure 22. Map of Processed LiDAR Data for Tupilac Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

A total of 3526 survey points from Sanito data were used for calibration and validation of all the blocks of Zamboanga_Pagadian LiDAR data. Random selection of 80% of the survey points, resulting to 2820 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 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 9.10 meters with a standard deviation of 0.05 meters. Calibration for Zamboanga_Pagadian LiDAR data was done by adding the height difference value, 9.10 meters, to Zamboanga mosaicked LiDAR data. Table 15 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

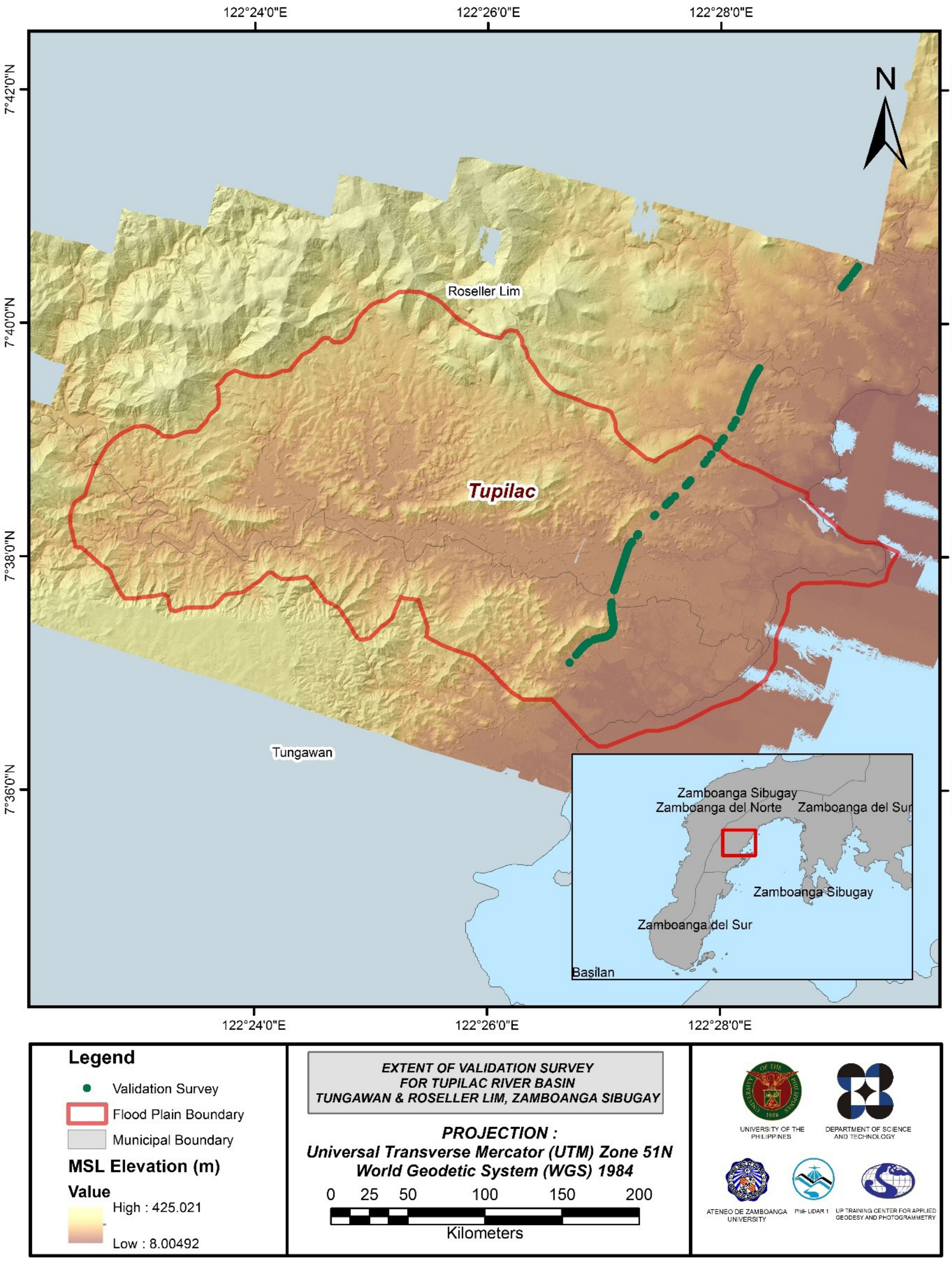


Figure 23. Map of Tupilac Floodplain with validation survey points in green.

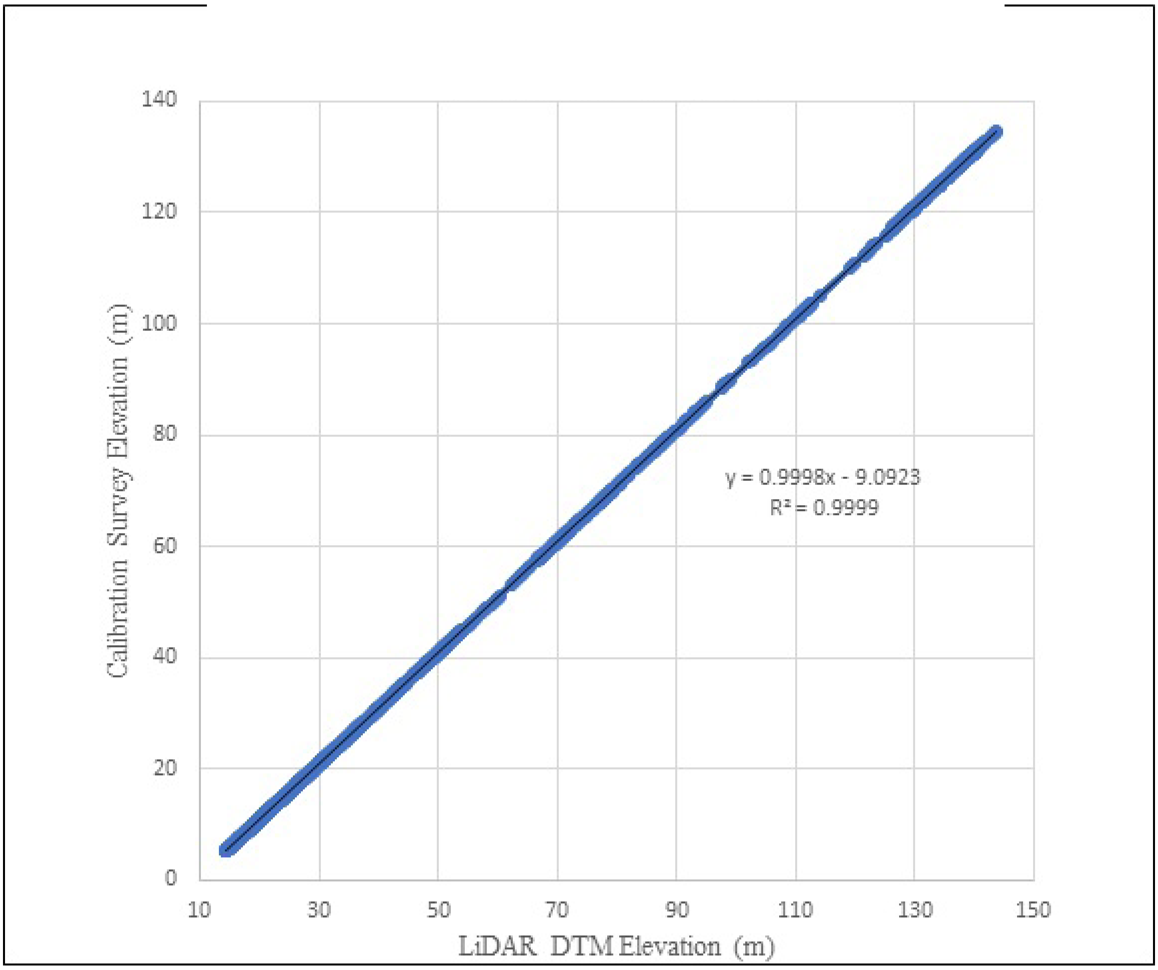


Figure 24. Correlation plot between calibration survey points and LiDAR data.

Table 15. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	9.10
Standard Deviation	0.05
Average	9.10
Minimum	8.99
Maximum	9.20

The Tupilac Floodplain has a total of 654 survey points and only 20% of the total survey points, resulting to 131 points, were randomly selected and used for the validation of calibrated Tupilac 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 25. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.11 meters with a standard deviation of 0.06 meters, as shown in Table 16.

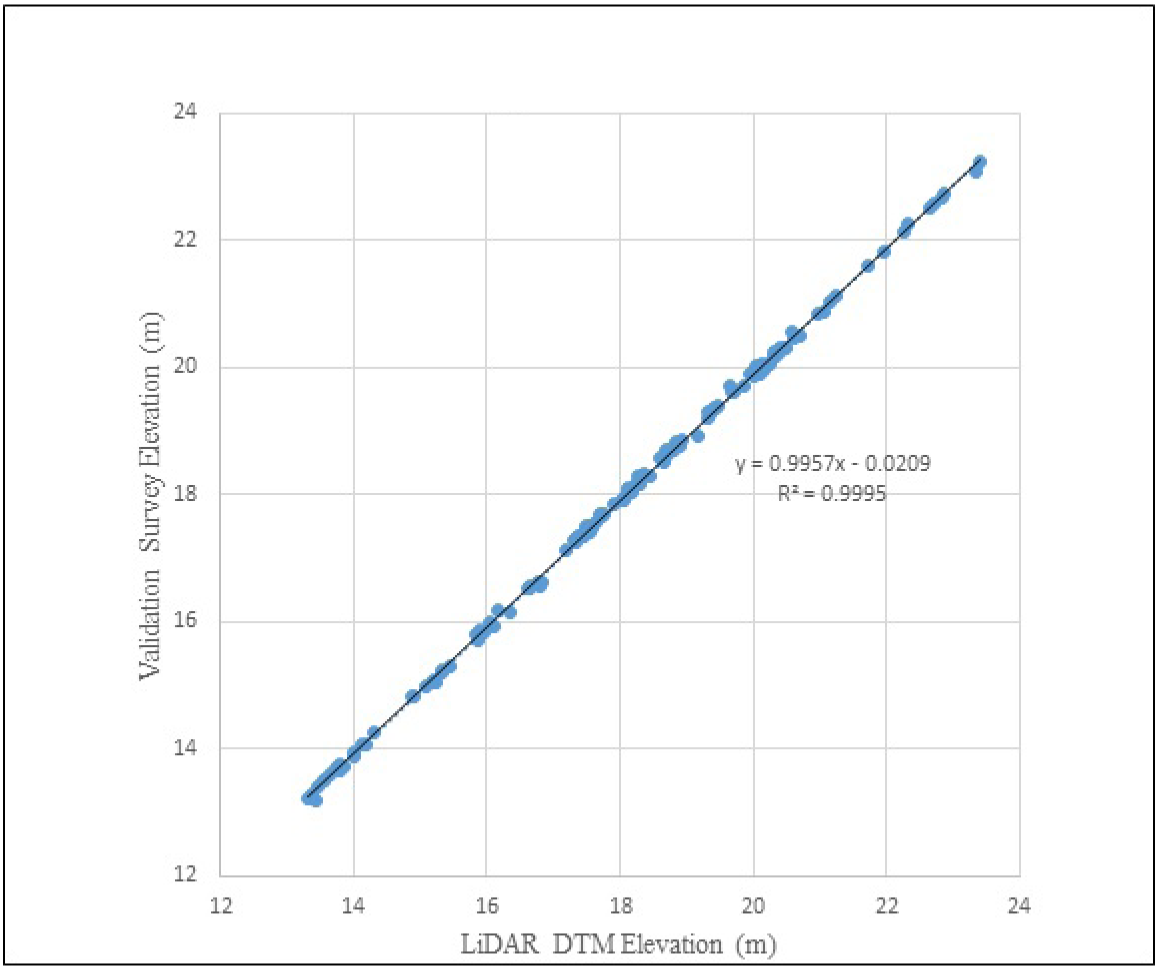


Figure 25. Correlation plot between validation survey points and LiDAR data.

Table 16. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.11
Standard Deviation	0.06
Average	0.09
Minimum	-0.02
Maximum	0.22

3.11 Integration of Bathymetric Data into the LIDAR Digital Terrain Model

For bathy integration, centerline and zigzag data was available for Tupilac with 1380 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 0.28 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tupilac integrated with the processed LiDAR DEM is shown in Figure 26.

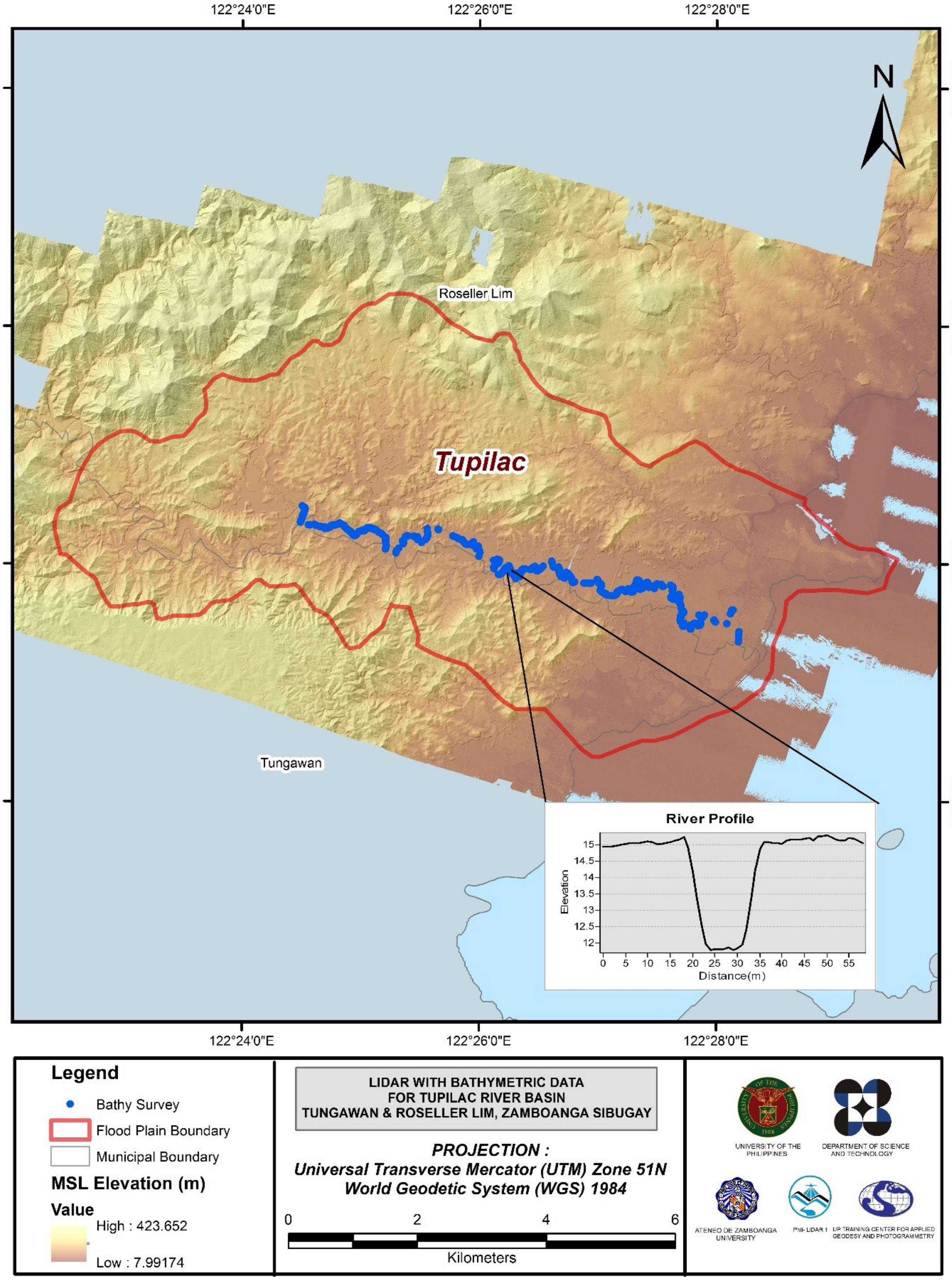


Figure 26. Map of Tupilac Floodplain with bathymetric survey points shown in blue.

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

Tupilac Floodplain, including its 200 m buffer, has a total area of 54.11 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 760 building features, are considered for QC. Figure 27 shows the QC blocks for Tupilac Floodplain.

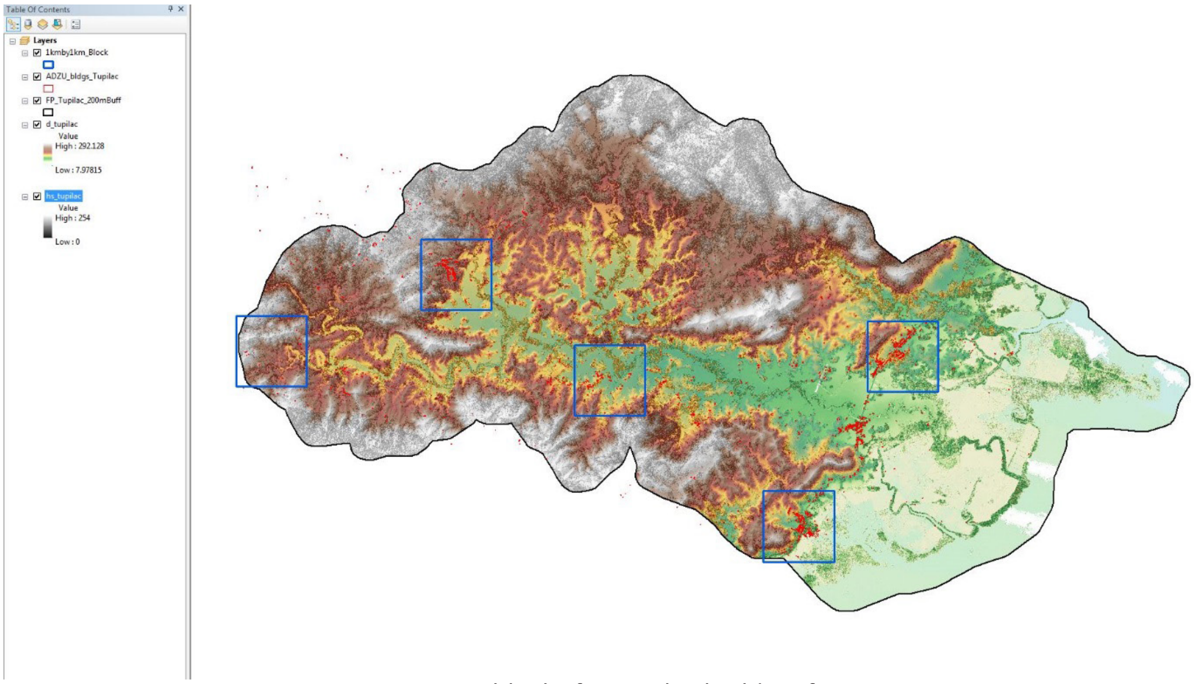


Figure 27. QC blocks for Tupilac building features.

Quality checking of Tupilac building features resulted in the ratings shown in Table 17.

Table 17. Quality Checking Ratings for Tupilac Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tupilac	98.57	99.87	94.33	PASSED

3.12.2 Height Extraction

Height extraction was done for 1,815 building features in Tupilac Floodplain. Of these building features, none was filtered out after height extraction, resulting to 1,815 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 6.80 m.

3.12.3 Feature Attribution

One of the Research Associate 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, thru 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 flood plain of the river basin; likewise, the number of enumerators are also dependent on the availability of the tablet and the number of features of the flood plain. But unfortunately, not all LGU's were cooperative, therefore the team has gather very minimal data for the feature attribution with consideration of the specific feature types stated in the manual. Some features only have feature types but not the names of the building itself.

Table 18 summarizes the number of building features per type. On the other hand, Table 19 shows the total length of each road type, while Table 20 shows the number of water features extracted per type.

Table 18. Building Features Extracted for Tupilac Floodplain.

Facility Type	No. of Features
Residential	1,557
School	34
Market	15
Agricultural/Agro-Industrial Facilities	123
Medical Institutions	2
Barangay Hall	3
Military Institution	0
Sports Center/Gymnasium/Covered Court	8
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	8
Power Plant/Substation	0
NGO/CSO Offices	3
Police Station	0
Water Supply/Sewerage	6
Religious Institutions	20
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	33
Other Commercial Establishments	**3**
Total	**1, 815**

Table 19. Total Length of Extracted Roads for Tupilac Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tupilac	3.81	16.58	0.00	5.91	0.00	26.30

Table 20. Number of Extracted Water Bodies for Tupilac Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tupilac	34	0	1	0	124	159

A total of 3 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 28 shows the Digital Surface Model (DSM) of Tupilac Floodplain overlaid with its ground features.

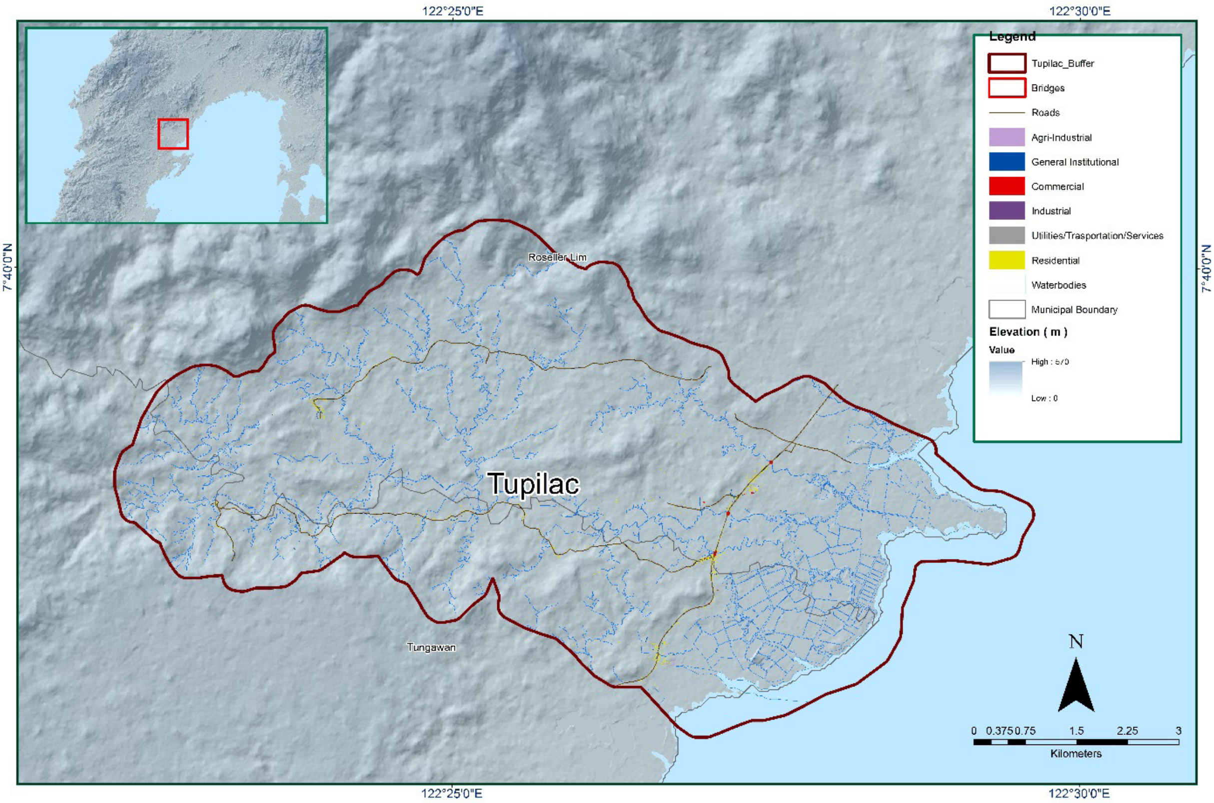


Figure 28. Extracted features for Tupilac Floodplain.

CHAPTER4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE TUPILAC RIVER BASIN

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Dexter T. Lozano, Engr. Kristine Ailene B. Borromeo, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, For. Rodel C. Alberto, Cybil Claire Atacador, Engr. Lorenz R. Taguse

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

4.1 Summary of Activities

The DVBC field survey in Tupilac River was conducted on July 23, 2015 to August 7, 2015 and January 14-28, 2016 with the following scope of work: reconnaissance; control survey; cross-section of Tupilac Bridge in Brgy. Tupilac, Municipality of RT Lim, Zamboaga Sibugay; validation points acquisition of about 8 km covering the survey area; and bathymetric survey from Brgy. Casacon, Municipality of Rodeller Lim down to Brgy. Baluran, Municipality of Tungawan, with an estimated length of 12.173 km using Trimble® SPS 882 GNSS RTK and PPK survey technique and open traverse method using total station. (See Figure 29).

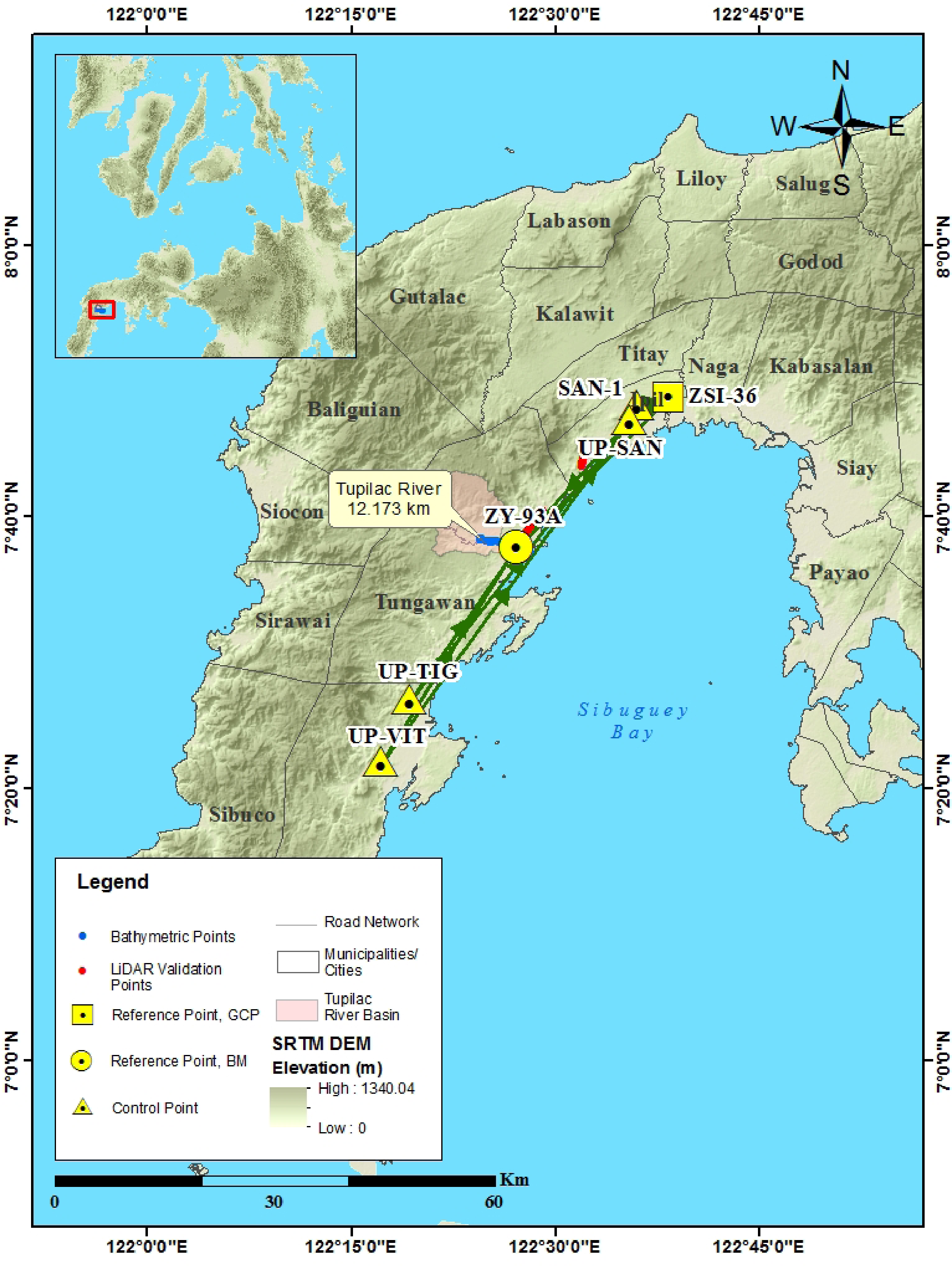


Figure 29. Extent of the Tupilac River Bathymetric Survey

4.2 Control Survey

A GNSS network from Amburayan River Survey was established on September 26 and October 3, 2015 occupying the control points ZGS-101, a second order GCP in Brgy. Bolong, Zamboanga City; and ZG-177, a first order BM in Brgy. Poblacion, both in Zamboanga City.

The GNSS network for Tupilac survey is composed of three (3) loops established on August 1, 2015 and January 15, 2016 occupying the following reference points fixed from the static survey in Zamboanga Del Sur: UP-TIG, located at the approach of Tigbao Bridge in Brgy. Tictapul, Zamboanga City; and UP-VIT, located at the approach of Vitali Bridge in Brgy. Vitali, Zamboanga City.

Two (2) control points were established along the approach of bridges namely SAN-1 located on a bridge along Maharlikha Highway, Brgy. Sanito, Municipality of Ipil; and UP-SAN at Sanito Bridge in Brgy. Sanito, also in Municipality of Ipil, all of which in Zamboanga Sibugay. The NAMRIA control points ZSI-36, in Brgy. Bacalan and ZY-93A, in Brgy. Tupilac, Municipality of Roseller Lim, were also occupied to use as markers for the network.

The summary of reference and control points and its location is summarized in Table 21, while the GNSS network established is illustrated in Figure 30.

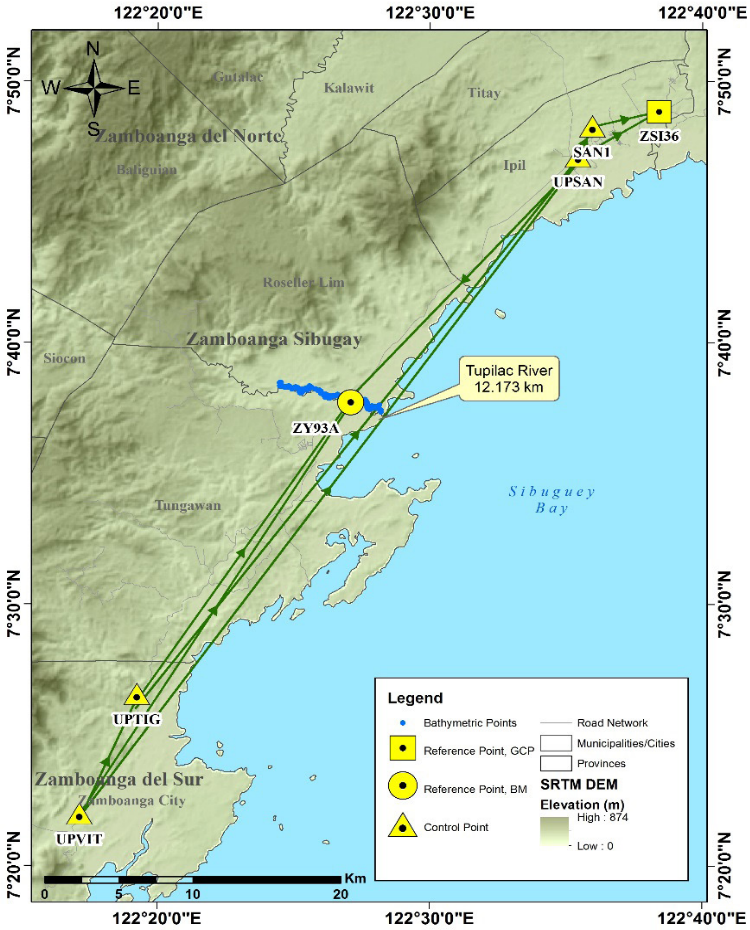


Figure 30. GNSS Network covering Tupilac River

Table 21. List of Reference and Control Points used in Tupilac River (Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date Established
UP-TIG	UP Established	7°26'33.60923"N	122°19'15.00843"E	89.917	22.039	Aug. 1, 2015
UP-VIT	UP Established	7°21'59.09659"N	122°17'09.03461"E	86.703	18.819	Aug. 1, 2015
ZSI-36	Used as marker	-	-	-	-	2006
ZY-93A	Used as marker	-	-	-	-	2013
SAN-1	UP Established	-	-	-	-	Aug. 1, 2015
UP-SAN	UP Established	-	-	-	-	Aug. 1, 2015

The GNSS set up made in the location of the reference and control points are exhibited in Figure 31 to Figure 38.

Figure 31. GNSS base set up, Trimble® SPS 882, at UP-TIG, located at the approach of Tigbao Bridge, Brgy. Tictapul, Zamboanga City, Zamboanga Del Sur

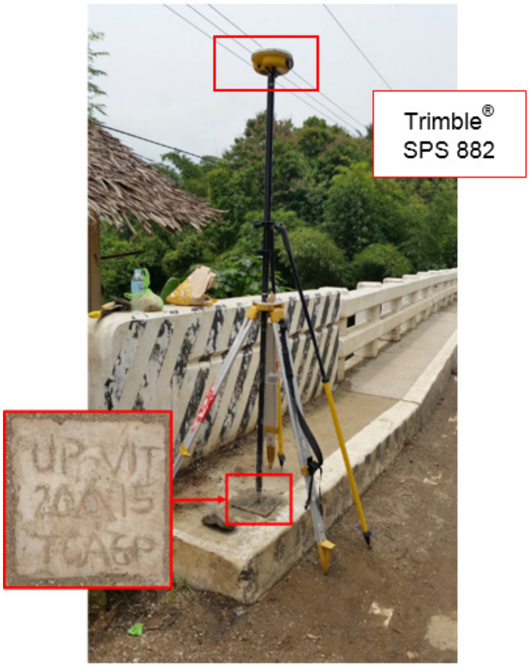


Figure 32. GNSS base set up, Trimble® SPS 882, at UP-VIT, located at the approach of Vitali Bridge in Brgy. Vitali, Zamboanga City, Zamboaga Del Sur

Figure 33. GNSS base set up, Trimble® SPS 882, at SAN-1, located at the approach of an unknown bridge found between Alibutdan and Diversion Rd, in Brgy. Pangi, Municipality of Ipi, Zamboanga Sibugay

Figure 34. GNSS base set up, Trimble® SPS 882, at UP-SAN, located at the approach of Sanito Bridge in Brgy. Sanito, Municipality of Ipil, Zamboanga Sibugay

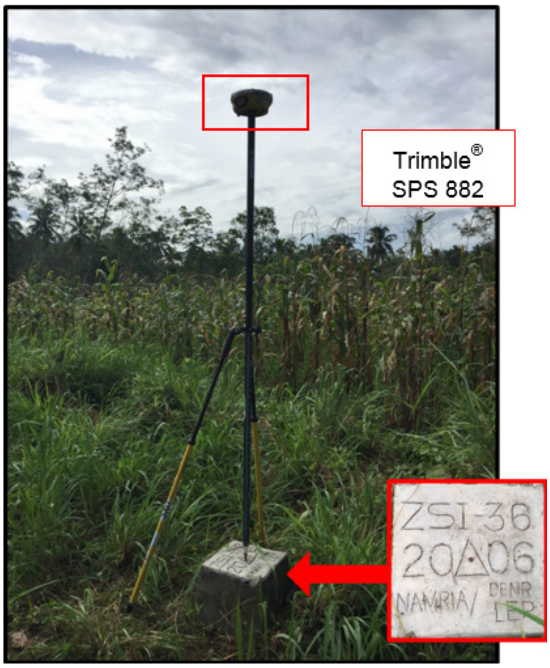


Figure 35. GNSS base set up, Trimble® SPS 882, at ZSI-36, located in front of an Iglesia ni Cristo church along the national highway in Brgy. Bacalan, Municipality of Ipil, Zamboanga Sibugay

Figure 36. GNSS base set up, Trimble® SPS 852, at ZY-93A, located at the approach of Tupilac Bridge, in Brgy. Tupilac, Municipality of Roseller Lim, Zamboanga Sibugay

Figure 37. GNSS base set up, Trimble® SPS 852, at ZGS-101, located inside Brgy. Bolong Elementary School, Zamboanga City, Zamboanga Del Sur

Figure 38. GNSS base set up, Trimble® SPS 852, at ZS-177, located at the stair of Rizal's Park along the Butuan-Zamboanga National Road, Brgy Zone 4, Zamboanga City, Zamboanga Del Sur

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 results of control points in Tupilac River Basin is summarized in Table 22 generated by TBC software.

Table 22. Baseline Processing Summary Report for Tupilac River Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
SAN1 --- ZSI36	08-01-2015	Fixed	0.009	0.034	77°13'23"	4622.418	12.148
UPTIG --- ZY93A	01-15-2016	Fixed	0.003	0.013	35°01'58"	25125.083	-5.986
UPSAN --- UPTIG	01-15-2016	Fixed	0.003	0.016	38°05'58"	48232.804	-1.932
UPSAN --- ZY93A	01-15-2016	Fixed	0.003	0.015	221°27'34"	23182.704	-4.059
UPSAN --- ZSI36	08-01-2015	Fixed	0.006	0.022	60°18'25"	6301.271	15.905
UPSAN --- SAN1	08-01-2015	Fixed	0.007	0.028	24°42'41"	2310.557	3.792
UPVIT --- UPTIG	01-15-2016	Fixed	0.004	0.015	24°36'35"	9275.798	3.190
UPVIT --- ZY93A	01-15-2016	Fixed	0.003	0.015	32°13'27"	34289.007	-2.792
UPVIT --- UPSAN	01-15-2016	Fixed	0.007	0.024	35°55'53"	57293.714	1.246

As shown in Table 22, a total of eight (8) baselines were processed. The reference points UP-TIG and UP-VIT with values from ZGS-101 and ZS-177 were held fixed. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

x_e is the Easting Error,

y_e is the Northing Error, and

z_e is the Elevation Error

for each control point. See the Network Adjustment Report shown in Table 23 to Table 25 for complete details.

The reference points UP-TIG and UP-VIT were held fixed during the processing of the control point as presented in Table 23. Through these reference point, the coordinates of the unknown control points will be computed

Table 23. Control Point Constraints

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

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 24. All fixed control points UP-TIG and UP-VIT has no values for standard error.

Table 24. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Cons traint
SAN1	-3404725.823	0.042	5323941.850	0.056	860405.799	0.025	
UPSAN	-3404063.348	0.027	5324698.912	0.026	858325.690	0.022	
UPTIG	-3381639.907	?	5344921.030	?	820713.025	?	LLe
UPVIT	-3378953.745	?	5347901.429	?	812349.736	?	LLe
ZSI36	-3408454.446	0.040	5321404.865	0.050	861420.032	0.026	
ZY93A	-3392374.040	0.018	5334910.856	0.020	841105.700	0.013	

The network is fixed at reference points UP-TIG and UP-VIT with known coordinates. Using the equation for horizontal and for the vertical; the computation for the accuracy of other control points are as follows:

a. SAN-1
horizontal accuracy = $\sqrt{(4.2)^2 + (2.5)^2}$
= $\sqrt{17.64 + 6.25}$
= 4.89 cm < 20 cm
vertical accuracy = 2..5 cm < 10 cm

b. UP-SAN
horizontal accuracy = $\sqrt{(2.7)^2 + (2.6)^2}$
= $\sqrt{7.29 + 6.76}$
= 3.75 cm < 20 cm
vertical accuracy = 2.2 cm < 10 cm

c. UP-TIG
horizontal accuracy = Fixed
vertical accuracy = Fixed

d. UP-VIT
horizontal accuracy = Fixed
vertical accuracy = Fixed

e. ZSI-36
horizontal accuracy = $\sqrt{(4)^2 + (5)^2}$
= $\sqrt{16 + 25}$
= 6.40 cm < 20 cm
vertical accuracy = 2.6 cm < 10 cm

f. ZY-93A
horizontal accuracy = $\sqrt{(1.8)^2 + (2)^2}$
= $\sqrt{3.24 + 4}$
= 2.69 cm < 20 cm
vertical accuracy = 1.3 cm < 10 cm

Table 25. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
SAN1	N7°48'17.16863"	E122°35'57.88173"	91.755	0.063	
UPSAN	N7°47'08.84467"	E122°35'26.35418"	87.976	0.026	
UPTIG	N7°26'33.60923"	E122°19'15.00843"	89.917	?	LLe
UPVIT	N7°21'59.09659"	E122°17'09.03461"	86.703	?	LLe
ZSI36	N7°48'50.43758"	E122°38'25.02370"	103.890	0.056	
ZY93A	N7°37'43.22499"	E122°27'05.57385"	83.921	0.022	

The adjusted geodetic coordinates is presented in Table 25. The network is fixed at the reference points UP-TIG and UP-VIT. After the processing has been made, the geodetic coordinates of the control point were derived.

Based on the result of the computation, the horizontal and vertical accuracies of the occupied control points are within the required accuracy of the program.

The summary of reference and control points used is indicated in Table 26.

Table 26. Reference and control points and their locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Ellipsoidal Height (m)	Easting (m)	MSL Elevation (m)
UP-TIG	UP established	7°26'33.60923"N	122°19'15.00843"E	89.917	822742.4	425056.8	22.039
UP-VIT	UP established	7°21'59.09659"N	122°17'09.03461"E	86.703	814318.2	421181.8	18.819
ZSI-36	Used as marker	7°48'50.43758"	122°38'25.02370"	103.89	863753.4	460341.6	35.673
ZY-93A	Used as marker	7°37'43.22499"	122°27'05.57385"	83.921	843285.9	439506.7	15.745
SAN-1	UP Established	7°48'17.16863"	122°35'57.88173"	91.755	862735.8	455834.4	23.469
UP-SAN	UP Established	7°47'08.84467"	122°35'26.35418"	87.976	860638.6	454866.8	19.651

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

Cross-section survey was conducted at the downstream part of Tupilac Bridge in Brgy. Tupilac, Municipality of RT Lim, Zamboaga Sibugay on September 4, 2015 using a Trimble® SPS 882 GNSS receiver in PPK survey technique as shown in Figure 39.

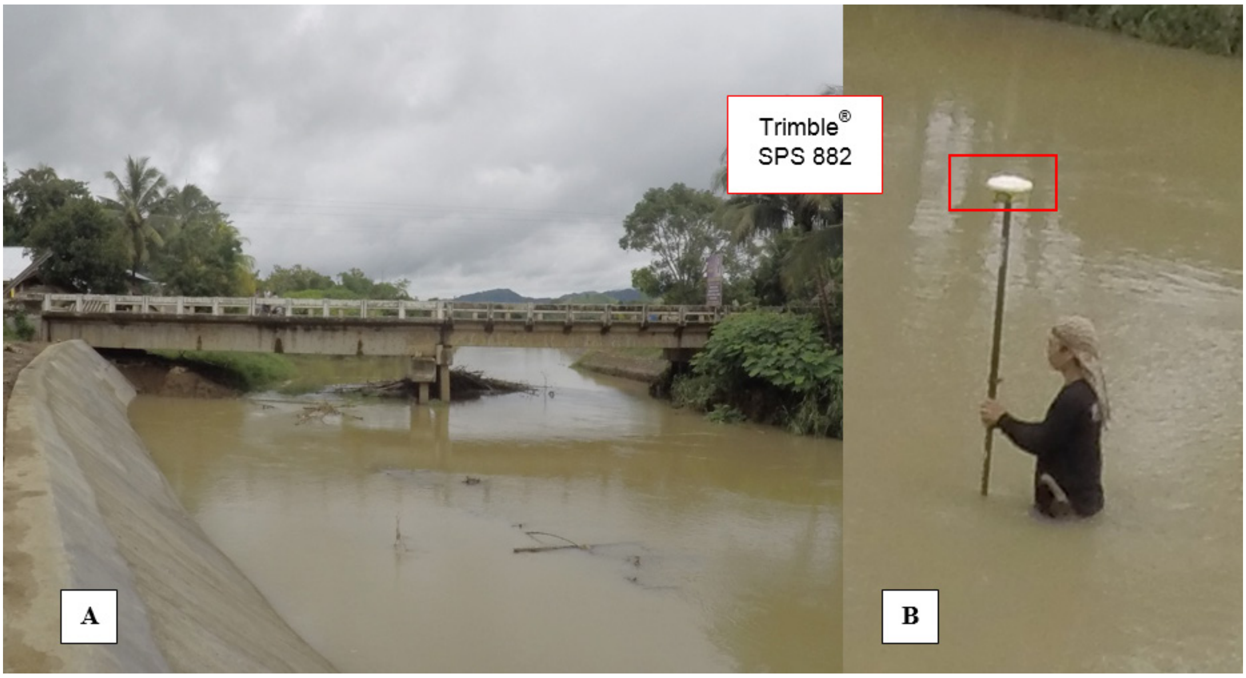


Figure 39. A) Tupilac Bridge facing upstream, and B) Bridge cross-section survey of Tupilac Bridge

The cross-sectional line for the Tupilac Bridge is about 89.580 m with- thirty-three (33) cross-sectional points acquired using ZY-39A as the GNSS base station. The cross-section diagram, location map and bridge as-built form are shown in Figure 40 to Figure 42, respectively.

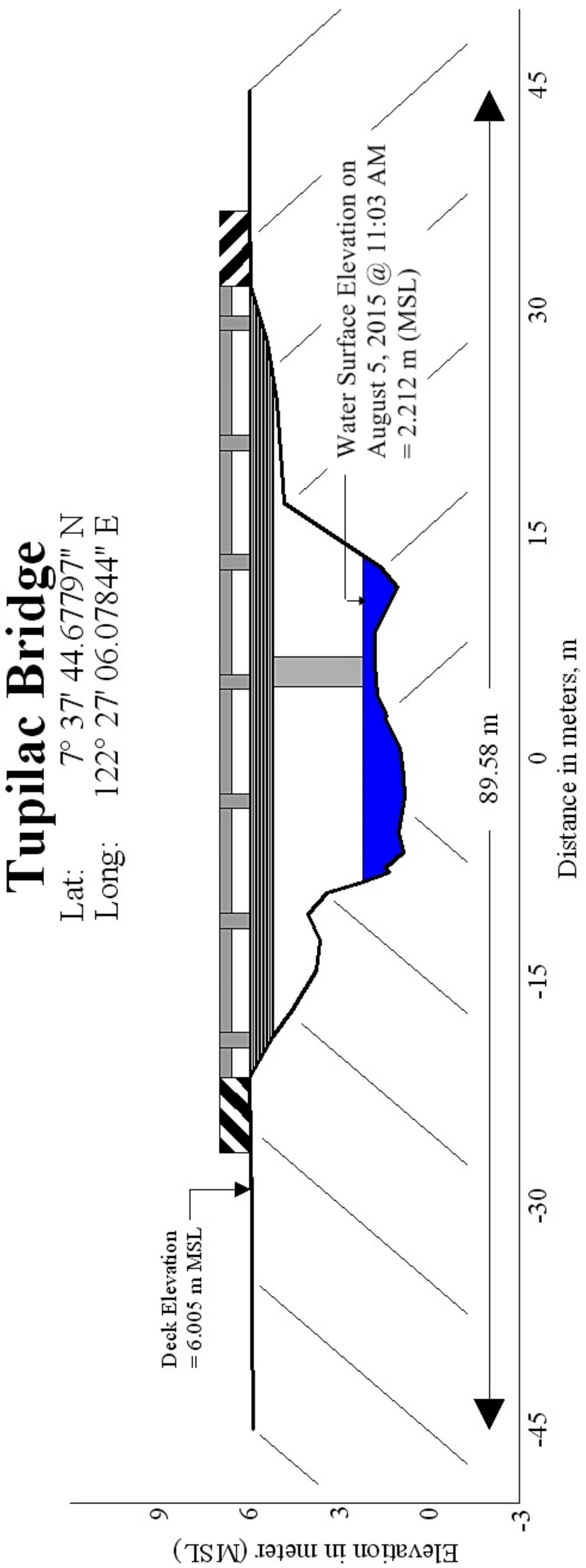


Figure 40. Tupilac Bridge cross-section diagram

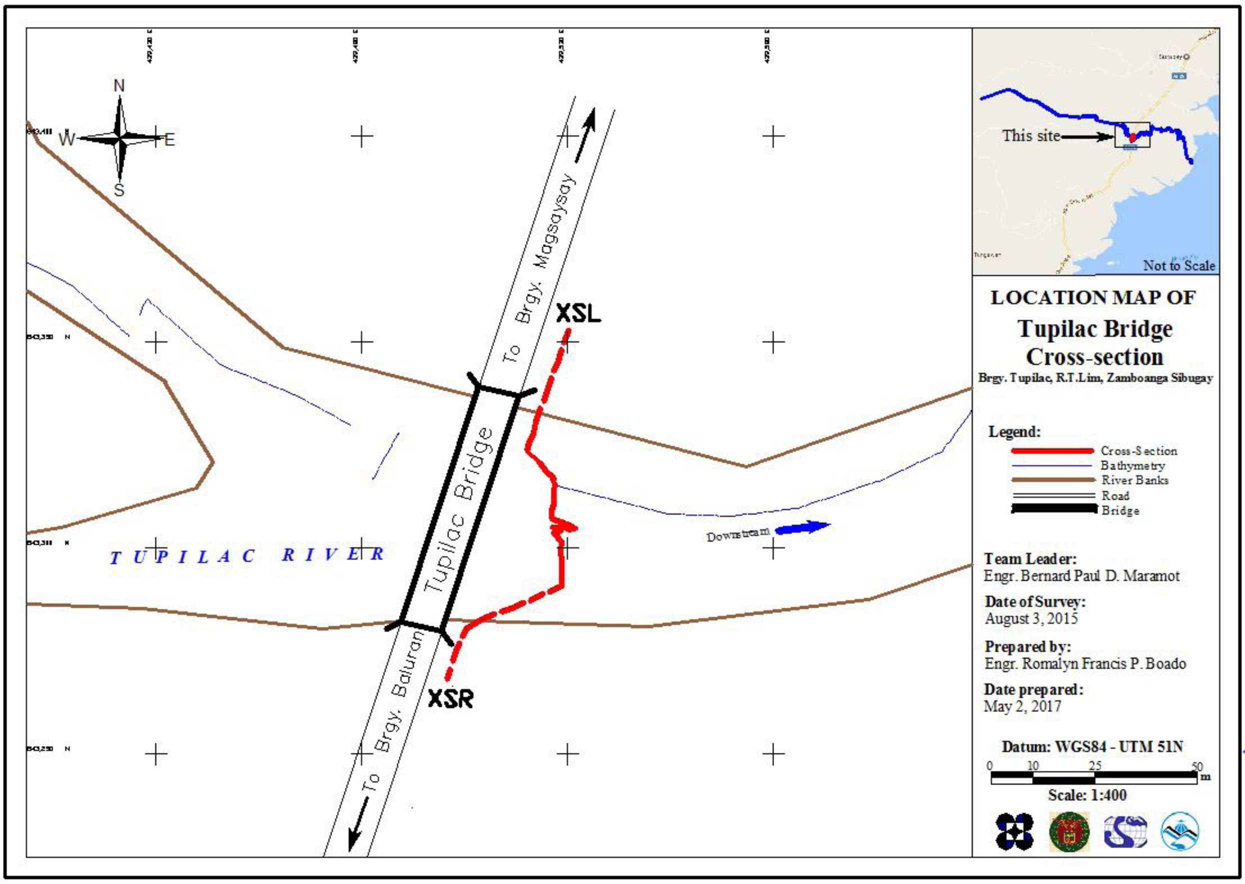


Figure 41 Tupilac bridge cross-section location map

Bridge Data Form

Bridge Name: Tupilac Bridge **Date:** August 3, 2015

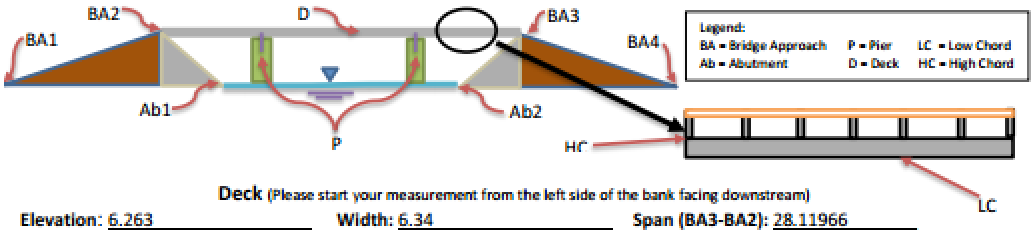
River Name: Tupilac River **Time:** 3:32 P.M.

Location (Brgy, City, Region): R.T. Lim, Zamboanga Sibugay

Survey Team: Team Bernard

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

Latitude: 7d37'43.22323" **Longitude:** 122d27'05.58480"



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

Elevation: 6.263 **Width:** 6.34 **Span (BA3-BA2):** 28.11966

	Station	High Chord Elevation	Low Chord Elevation
1		11.912	11.367
2			
3			
4			
5			

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	6.651	BA3	113.6147	6.027
BA2	111.3981	6.366	BA4	169.3413	7.664

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

	Station (Distance from BA1)	Elevation
Ab1	75.48642	4.151
Ab2	111.0698	4.88

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

Shape: ________ **Number of Piers:** 2 **Height of column footing:** ________

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	91.995	6.103	
Pier 2	105.9365	5.992	
Pier 3			
Pier 4			
Pier 5			
Pier 6			

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

Figure 42 Tupilac bridge as-built form

Water surface elevation in MSL of Tupilac River was determined using GNSS receiver, Trimble® SPS 882, in PPK survey technique on Ausgust 5, 2015 at 11:03 AM with a value of 2.212 m in MSL. This was translated onto marking on the dike near to the bridge using the same technique as shown in Figure 43. The markings will serve as their reference for flow data gathering and depth gauge deployment of ADZU for Tupilac River.

Figure 43. Water-level marking for Tupilac River

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on August 3, 2015 using a survey-grade GNSS rover receiver, Trimble® SPS 882, mounted on a pole which was attached to the front of the vehicle as shown in Figure 44. It was secured with cable ties to ensure that it was horizontally and vertically balanced. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with ZY-39A occupied as the GNSS base stations all throughout the conduct of the survey.

Figure 44. Validation point acquisition survey set-up

The validation points acquisition survey for the Tupilac River Basin traversed nine (9) barangays in Zamboanga Sibugay. The survey started from Brgy. Baluran, Municipality of Tungawan going north east, and ended in Brgy. Makilas, Municipality of Ipil. The route of the survey aims to traverse LiDAR flight strips perpendicularly for the basin. A total of 680 points with an approximate length of 8 km was acquired for the validation point acquisition survey as shown in the map in Figure 45. Data gaps are caused by very thick canopy and road inaccessibility due to bushes.

Figure 45. Validation point acquisition survey of Tupilac River Basin

4.7 River Bathymetric Survey

Manual bathymetric survey using a Trimble® SPS 882 GNSS PPK technique was executed on August 3 and 5, 2015 starting from the upstream in Brgy. Casacon with coordinates 7°38'28.50933"N 122°24'29.08662"E traversed the river by foot and ended in Brgy. Tupilac with coordinates 7°37'20.73467"N 122°28'11.20419"E as shown in Figure 46. The control point ZY-39A was used as GNSS base station for the whole conduct of the survey.

Manual bathymetry resurvey using Trimble® SPS 882 GNSS PPK technique was executed on January 16 and18, 2016 to fill in data gaps from the August 2015 survey. Other areas which had signal problems due to very thick canopy was resurveyed using a total station through open traverse method. The resurvey traversed the same route and the same GNSS base station with the previous survey.

Figure 46. Bathymetric survey using PPK technique set-up in Tupilac River

A total of 1,619 bathymetric points with an approximate length of 12.173 km were acquired for Tupilac river as illustrated in Figure 47. There are patches not covered due to dense canopy and its inaccessibility. A CAD drawing was also produced to illustrate the riverbed centerline profile as shown in Figure 48. There is about a 8-m change in elevation observed within the whole extent of the bathymetric data from its upstream in Brgy. Cacao down to the mouth of the river in Brgy. Manicahan, Zamboanga City. The highest elevation is 15.856 m measured in Brgy. Gaycon, Municipality of Roseller Lim; and the lowest was 7.527 m located at the downstream part of the river in Brgy. Tupilac, Municipality of Tungawan.

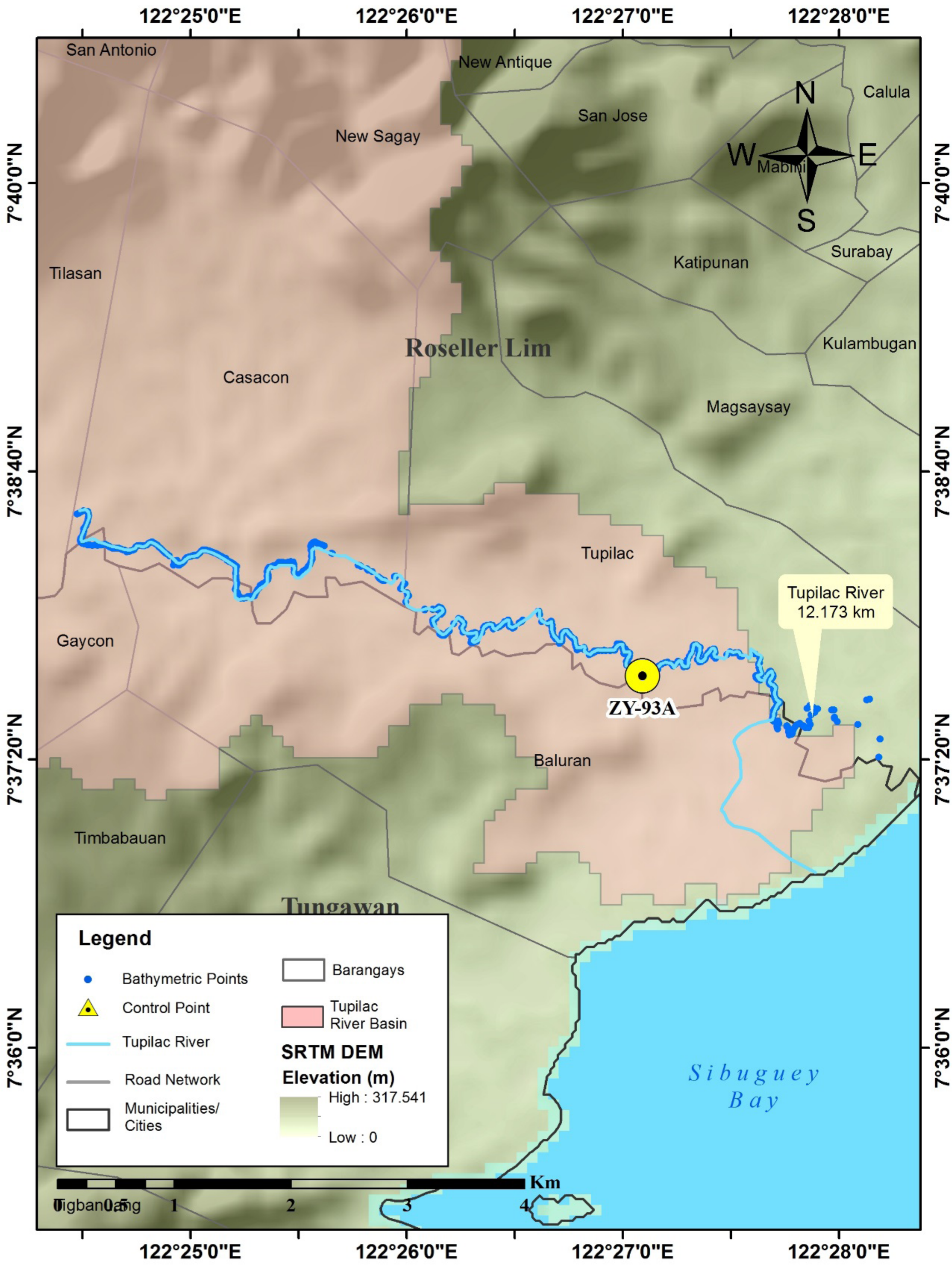


Figure 47. Bathymetric survey in Tupilac River

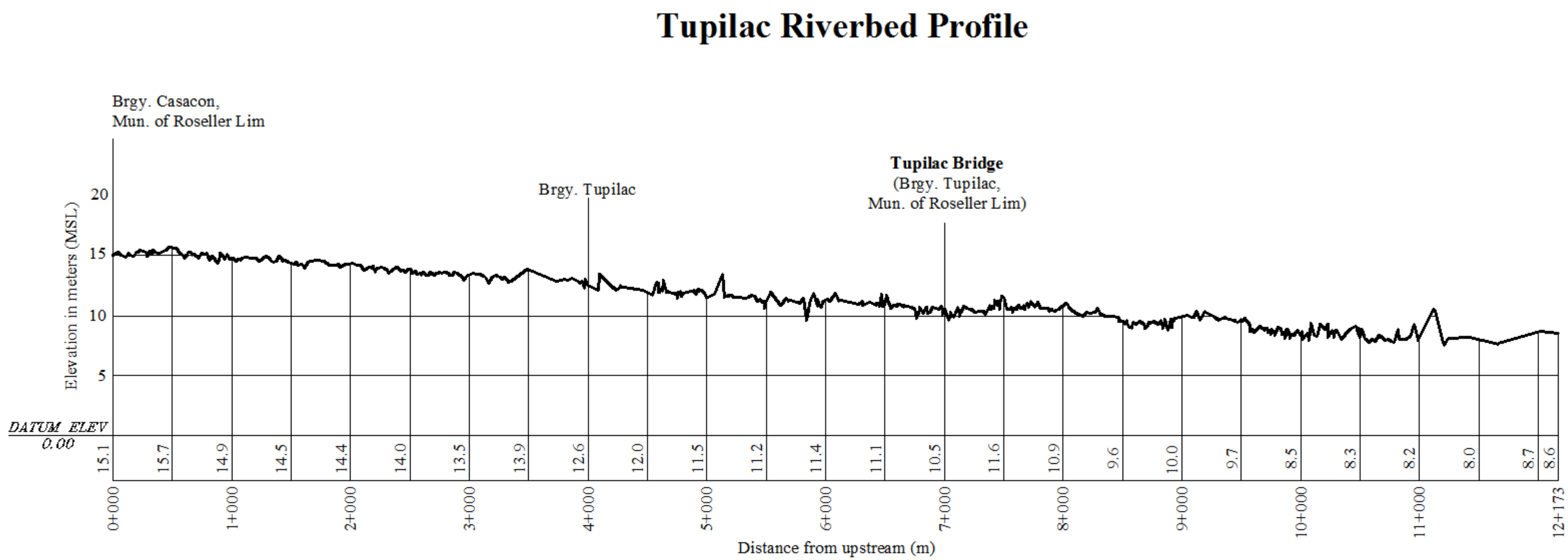


Figure 48. Bathymetric survey of Tupilac River

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 (Lagmay, et al., 2014) and further enhanced and updated in Paringit, et al. (2017)

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All Components and data that affect the hydrologic cycle of the Tupilac River Basin were monitored, collected, and analyzed. These include the rainfall, water level, and flow in a certain period of time.

5.1.2 Precipitation

Precipitation data was taken from a manually read Rain Gauge at Brgy. Casacon, Roselier T. Lim, Zamboanga Sibugay (7° 42’ 39.57” N, 122° 8’ 18.76” E). The precipitation data collection started from October 5, 2016 at 3:00 PM to October 6, 2016 at 3:00 PM with 10 minutes recording interval. The location of the rain gauge is shown in Figure 49 below.

The total precipitation for this event in Brgy. Casacon was 84.2 mm. It has a peak rainfall of 17 mm. on October 5, 2016 at 4:40 PM. The lag time between the peak rainfall and discharge is 6 hours and 20 minutes

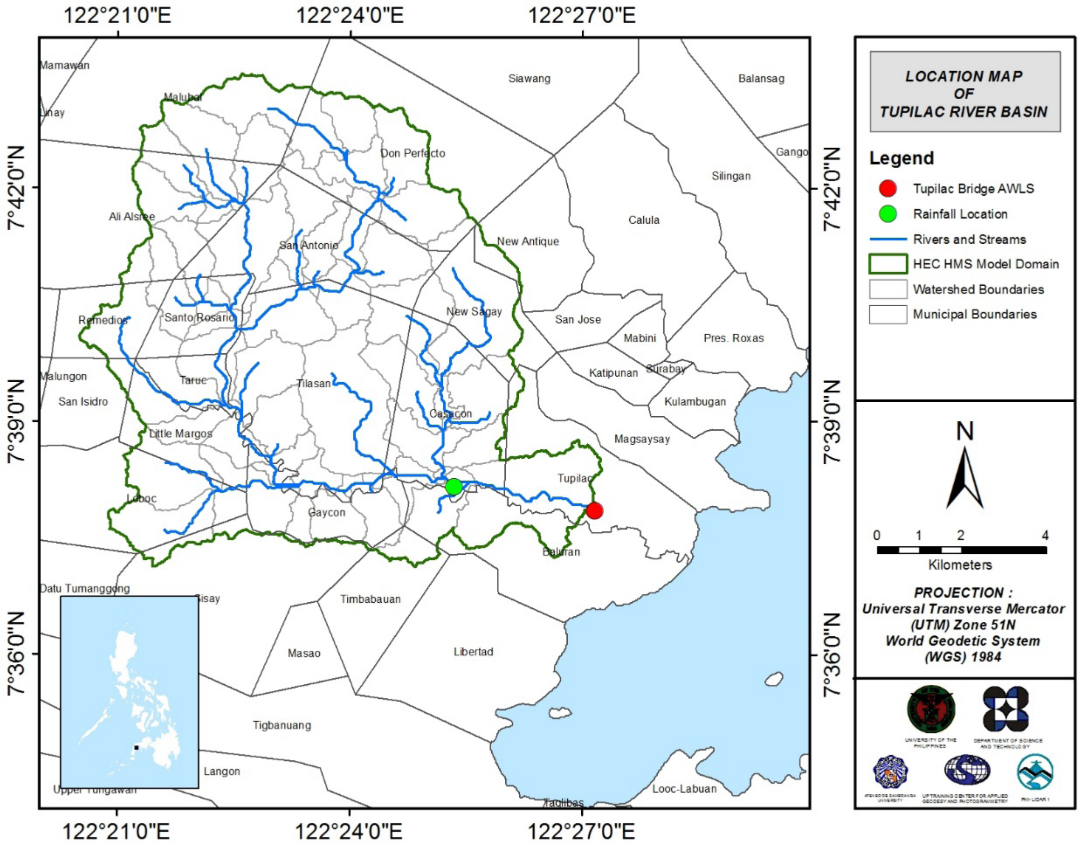


Figure 49. The location map of Tupilac HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Tupilac Bridge, Brgy. Malipot, Tupilac, Zamboanga del Norte (7° 38' 7.11" N, 122° 23' 3.58" E). It gives the relationship between the observed water levels at Tupilac Bridge and outflow of the watershed at this location. For Tupilac Bridge, the rating curve is expressed as Q = 3E-26e0.8182h as shown in Figure 50.

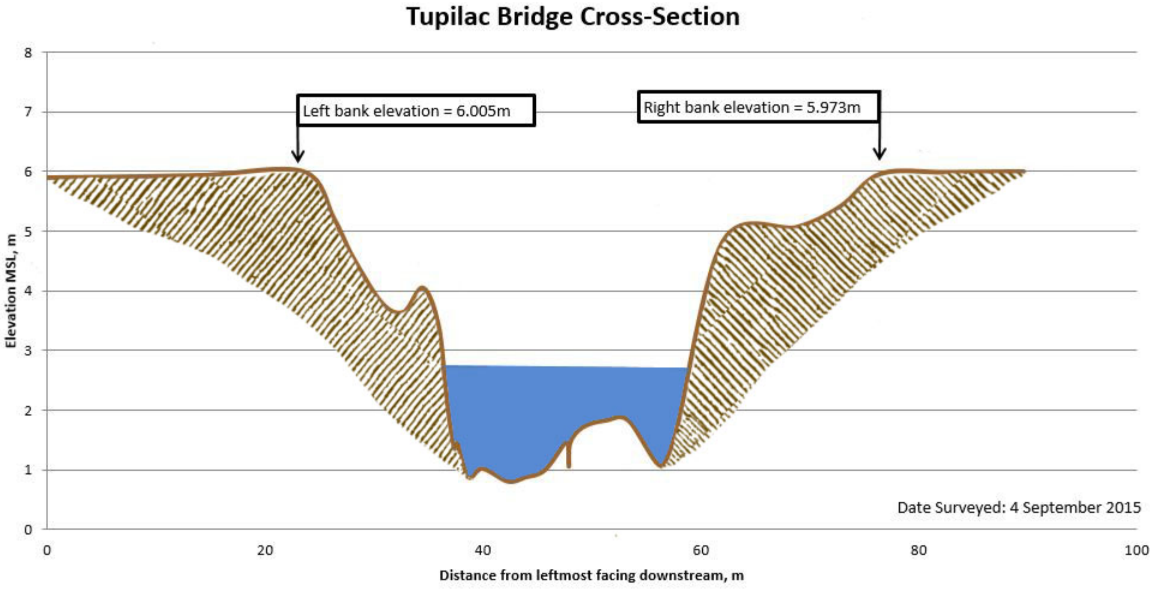


Figure 50. Cross-Section Plot of Tupilac Bridge

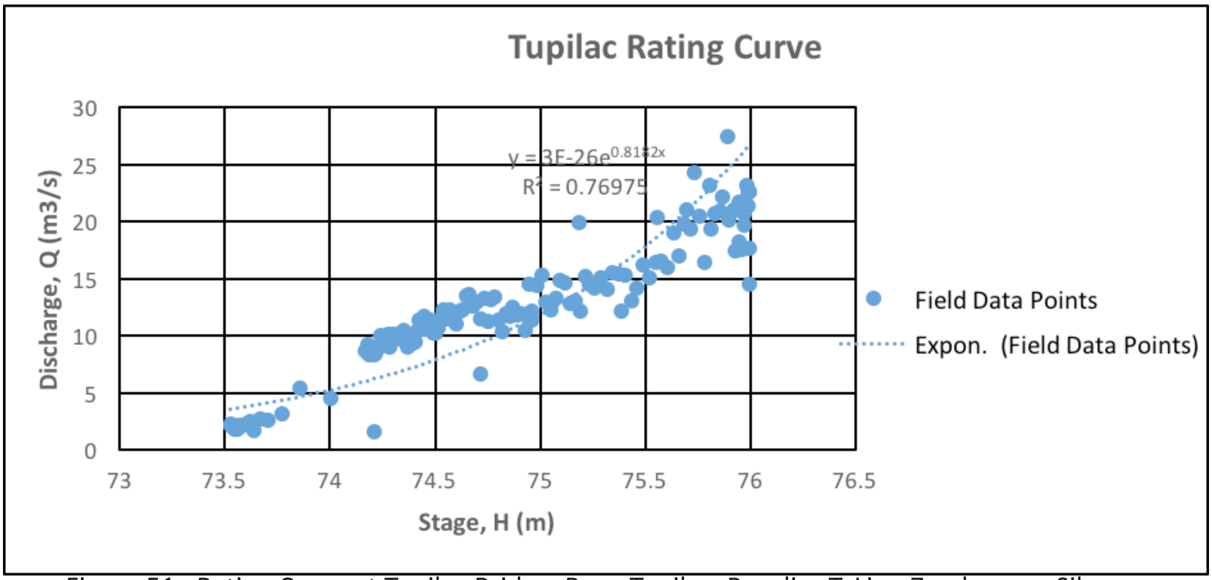


Figure 51. Rating Curve at Tupilac Bridge, Brgy. Tupilac, Roselier T. Lim, Zamboanga Sibugay

This rating curve equation was used to compute the river outflow at Tupilac Bridge for the calibration of the HEC-HMS model as shown in Figure 51. The peak discharge is 27.4 cubic meters per second at 11:00 PM, on October 5, 2016.

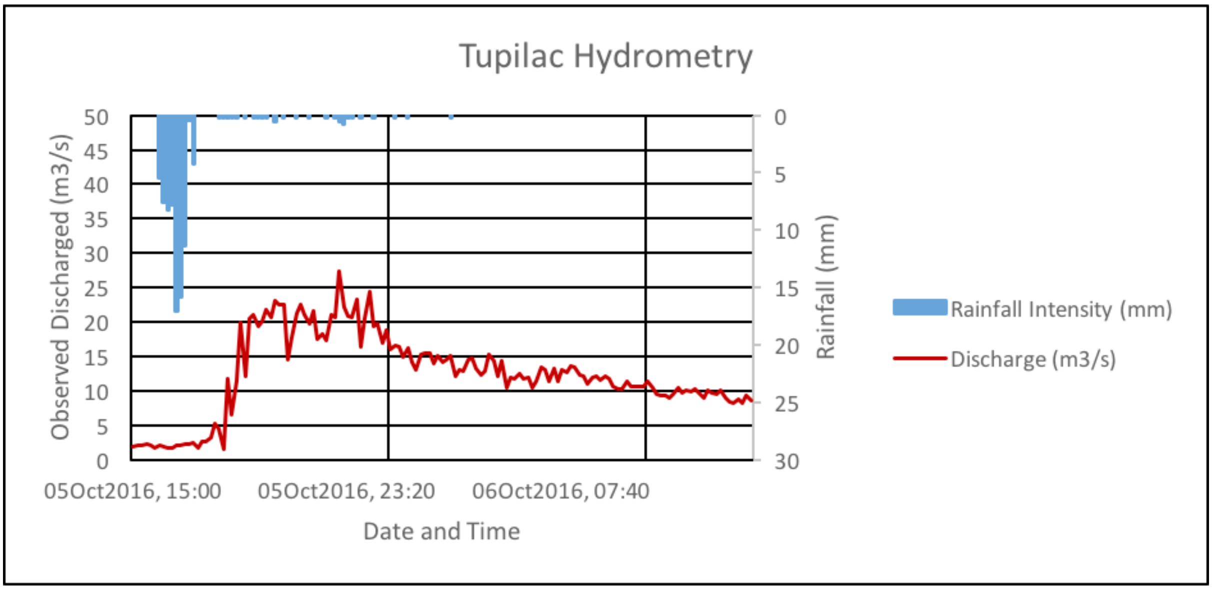


Figure 52. Rainfall and outflow data at Tupilac Bridge used for modeling

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 Tupilac watershed. The extreme values for this watershed were computed based on a 59-year record.

Table 27. RIDF values for Zamboanga City Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	**10 mins**	**20 mins**	**30 mins**	**1 hr**	**2 hrs**	**3 hrs**	**6 hrs**	**12 hrs**	**24 hrs**
2	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

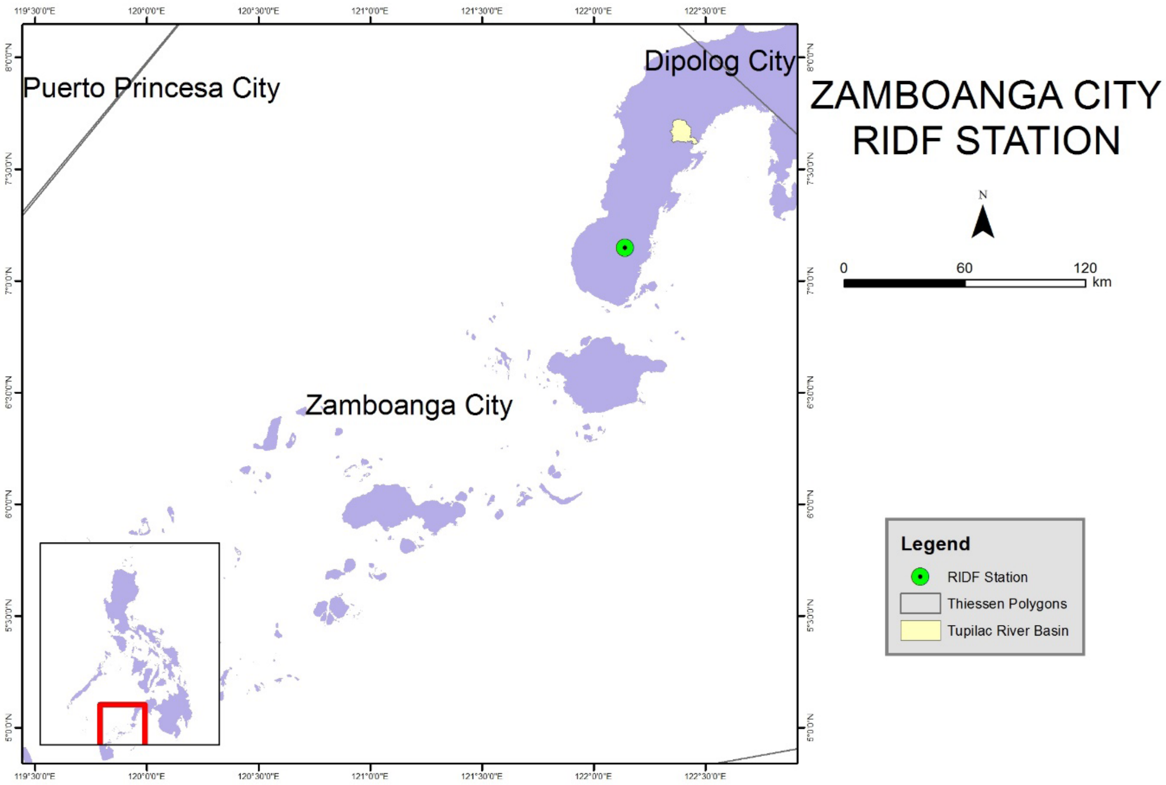


Figure 53. Zamboanga City RIDF location relative to Tupilac River Basin

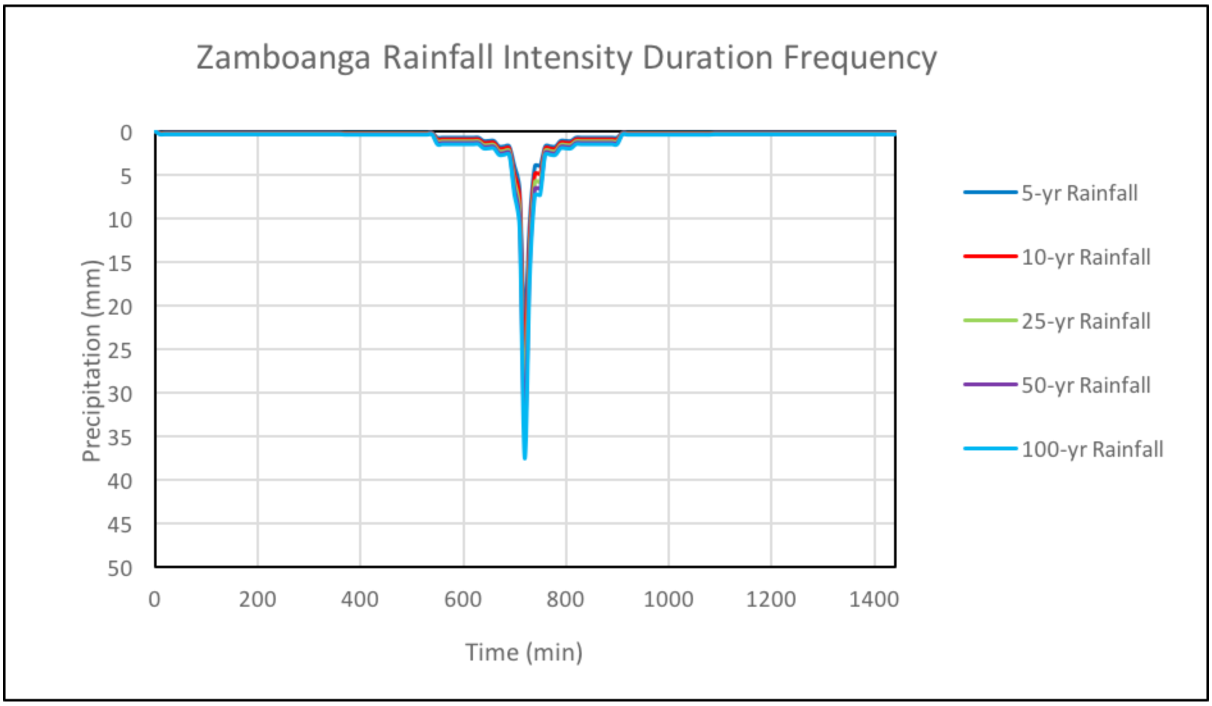


Figure 54. Synthetic storm generated for a 24-hr period rainfall for various return periods

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 Tupilac River Basin are shown in Figures 55 and 56, respectively.

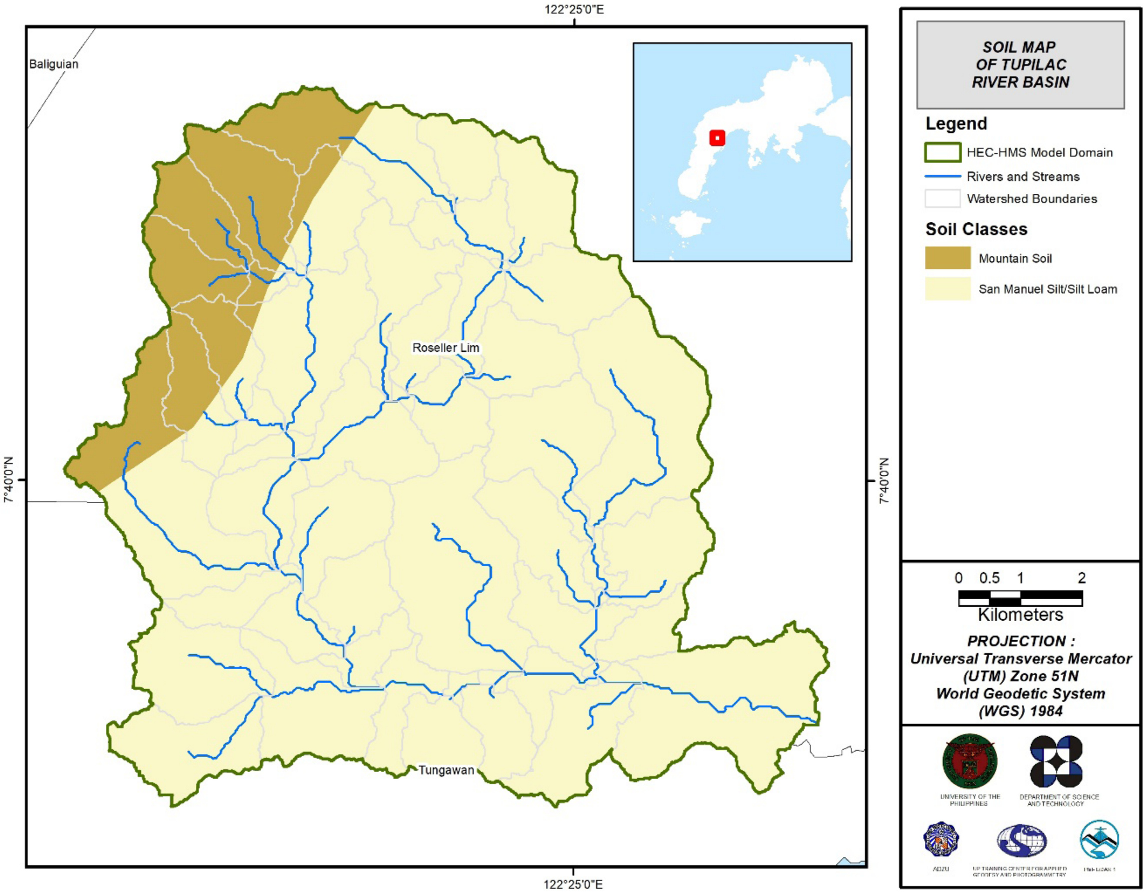


Figure 55. Soil Map of Tupilac River Basin

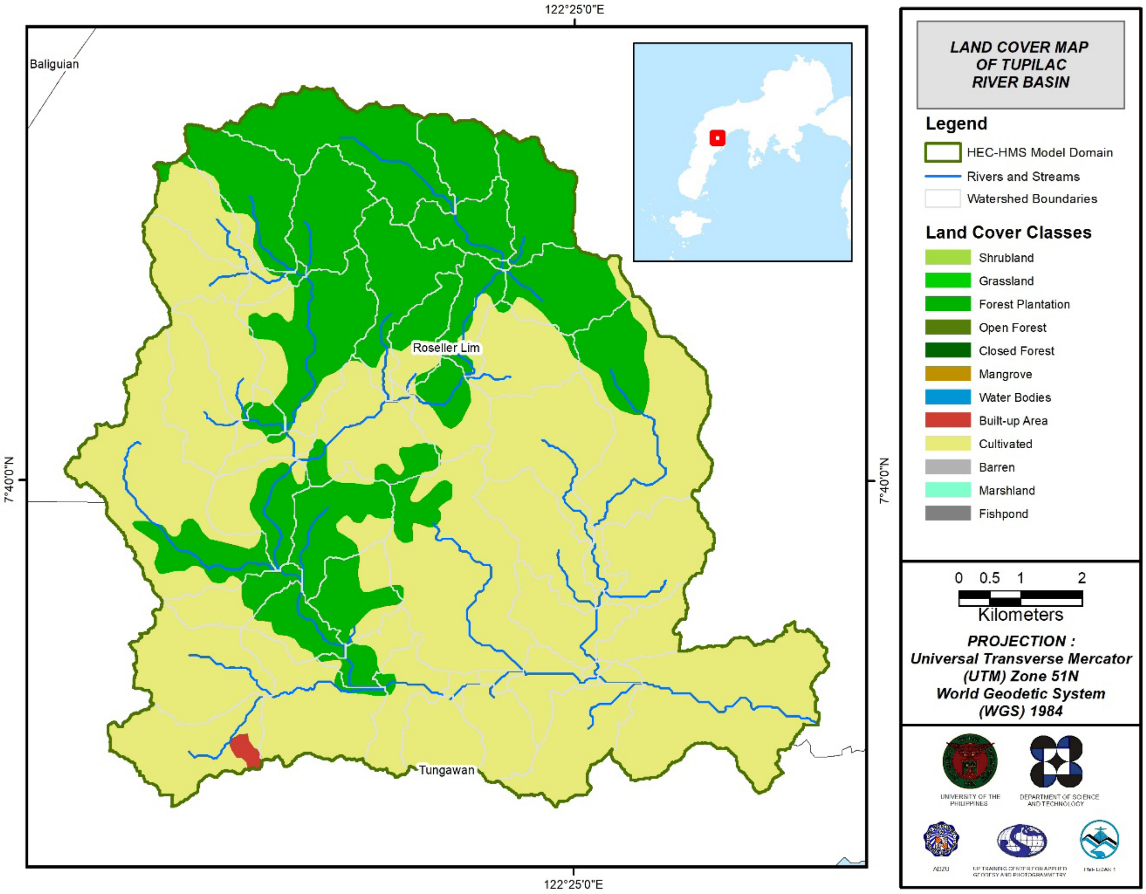


Figure 56. Land Cover Map of Tupilac River Basin

For Tupilac, the soil classes identified were silt, silt loam and undifferentiated mountain soil. The land cover types identified were cultivated areas, built-up areas and forest plantations.

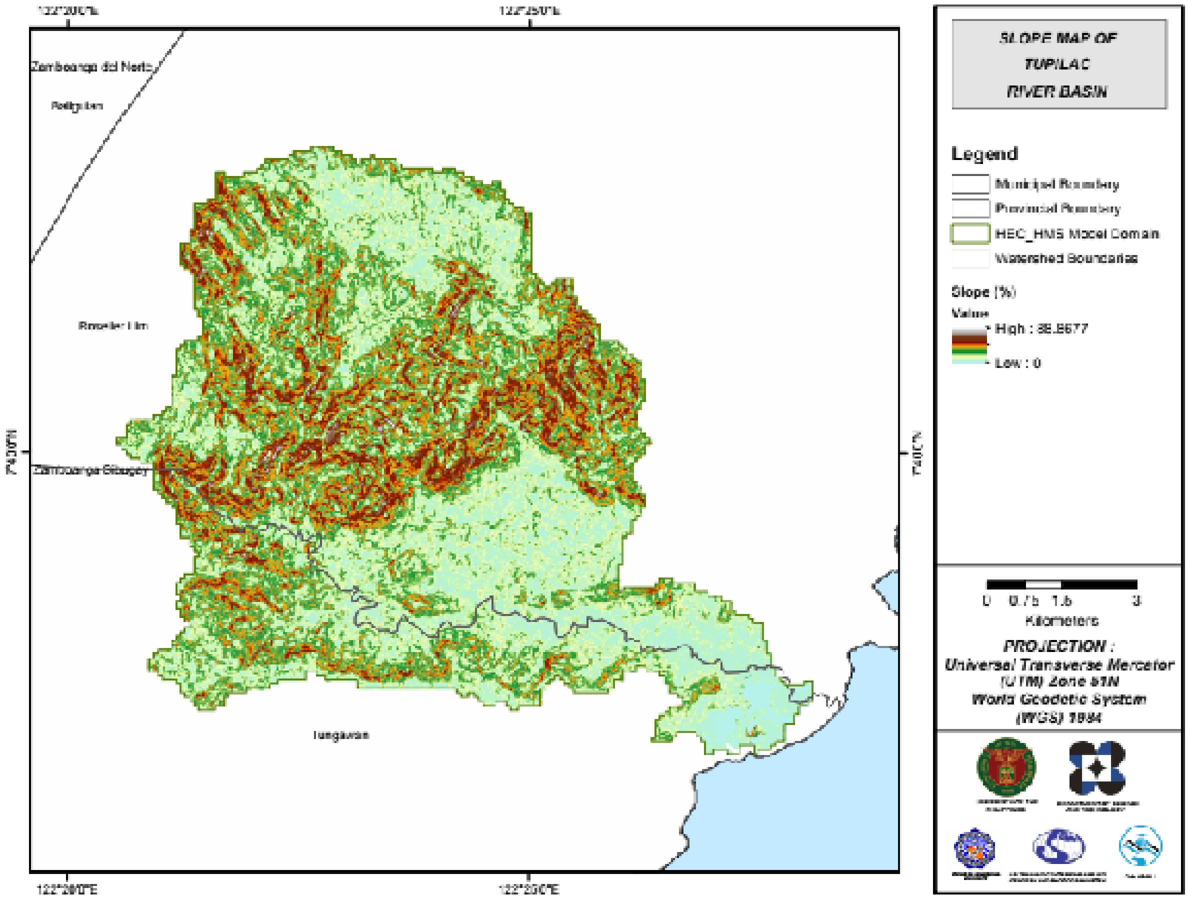


Figure 57. Slope Map of Tupilac River Basin

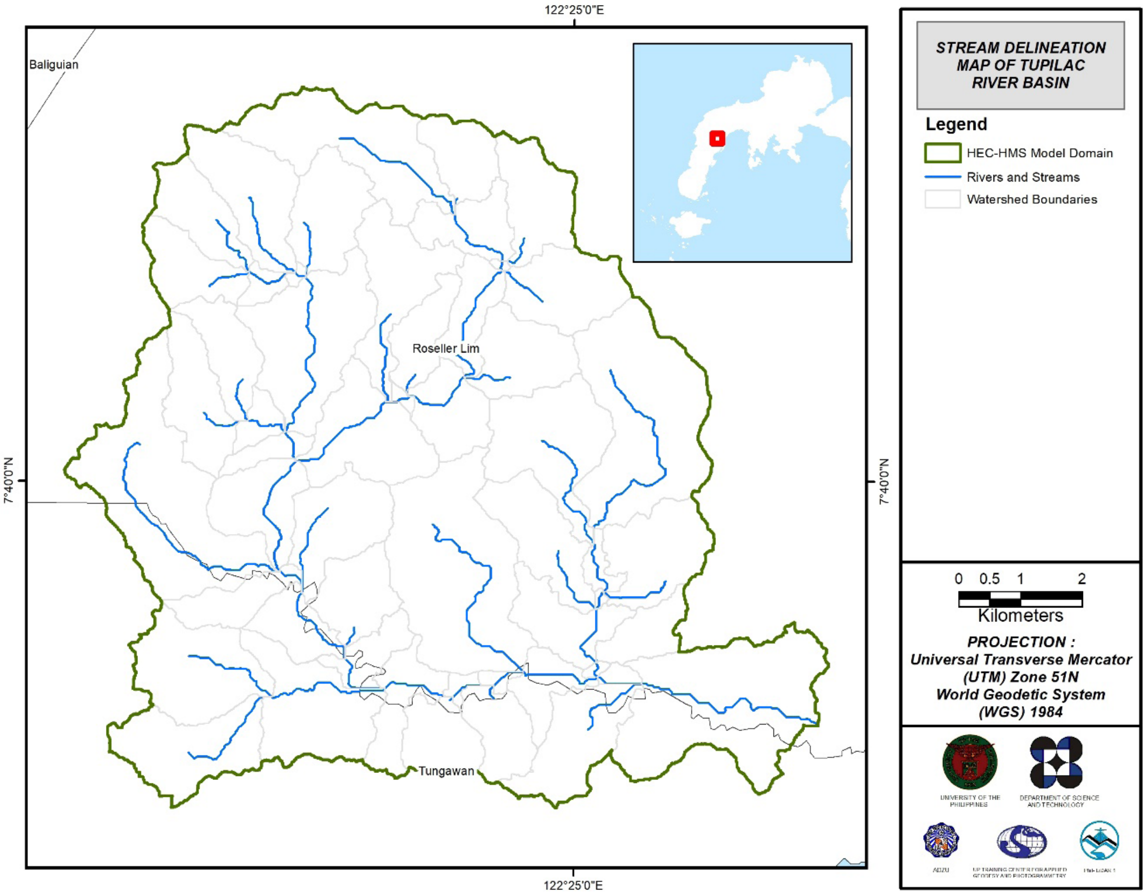


Figure 58. Stream delineation map of Tupilac river basin

Using the SAR-based DEM, the Tupilac basin was delineated and further subdivided into subbasins. The model consists of 53 sub basins, 26 reaches, and 26 junctions as shown in Figure 59. The main outlet is at Tupilac Bridge, Brgy. Tupilac, Roselier T. Lim, Zamboanga Sibugay.

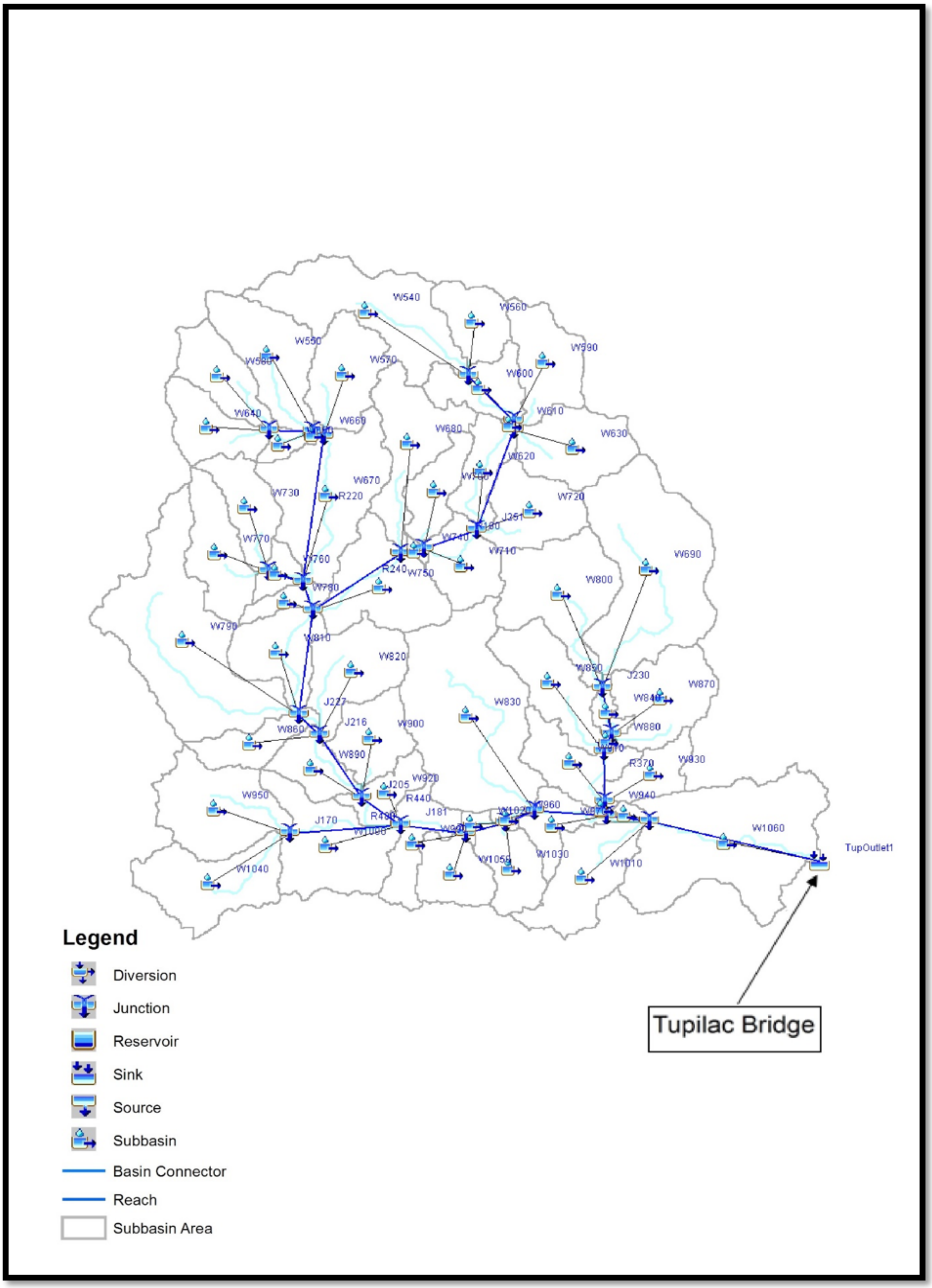


Figure 59. The Tupilac river basin model generated using HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS.

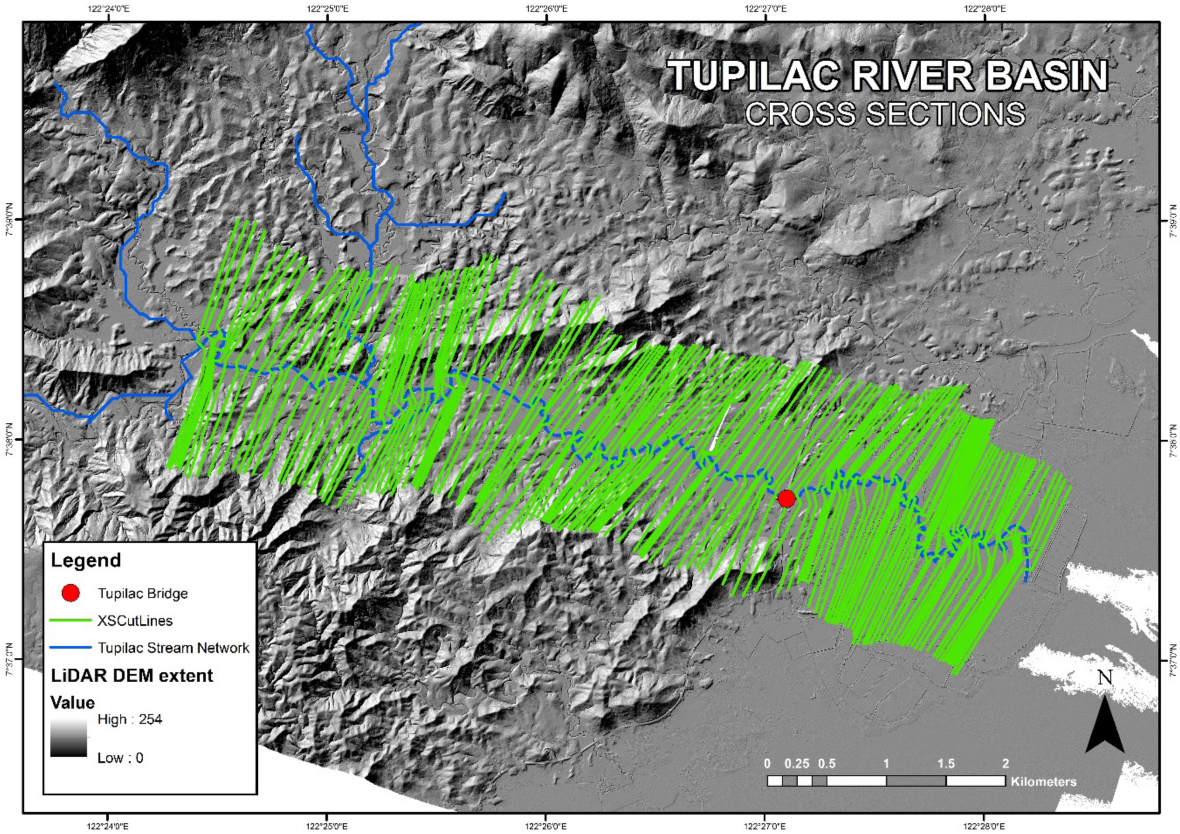


Figure 60. River cross-section of Tupilac River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

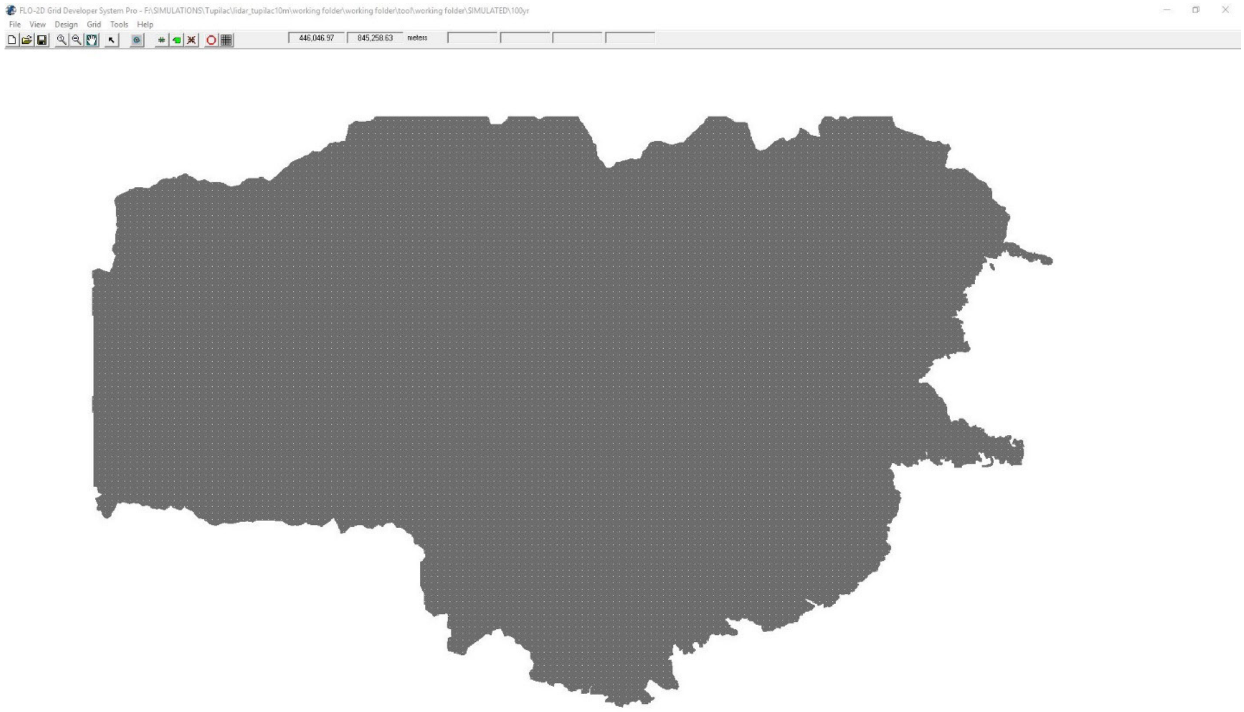


Figure 61. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 59.68213 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

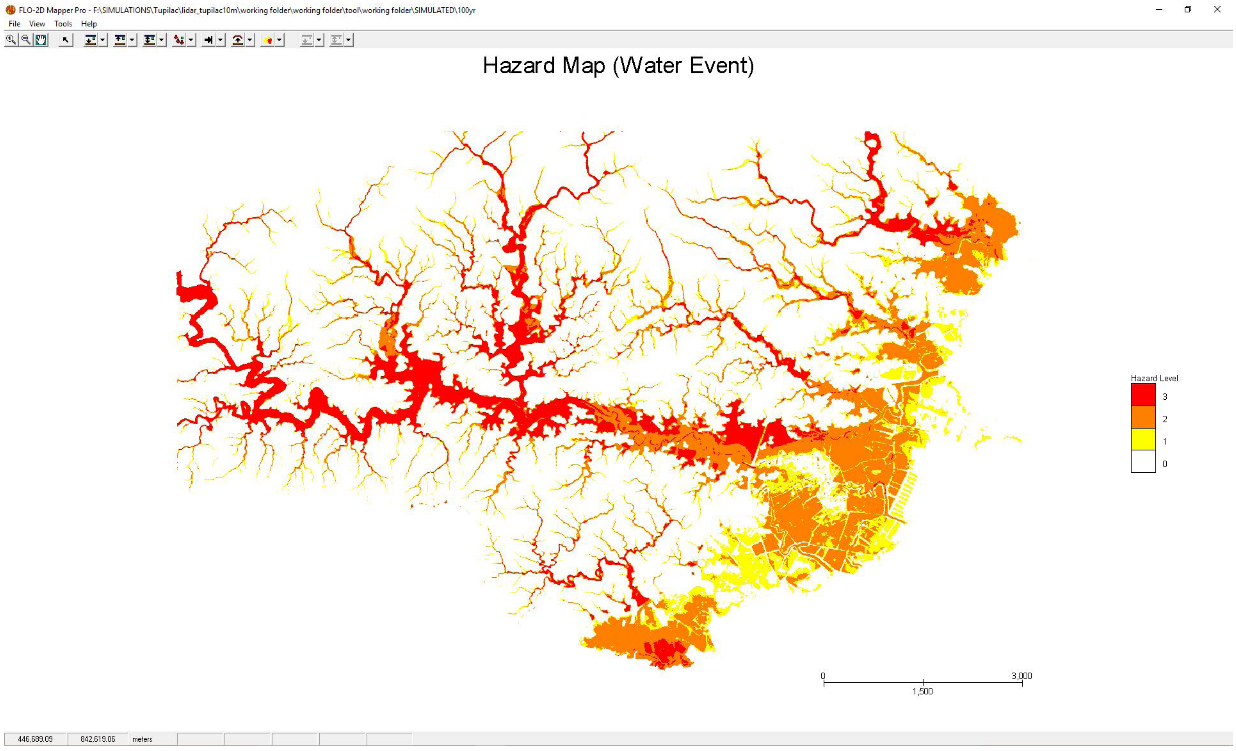


Figure 62. Generated 100-year rain return hazard map from FLO-2D Mapper

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 73299840.00 m2.

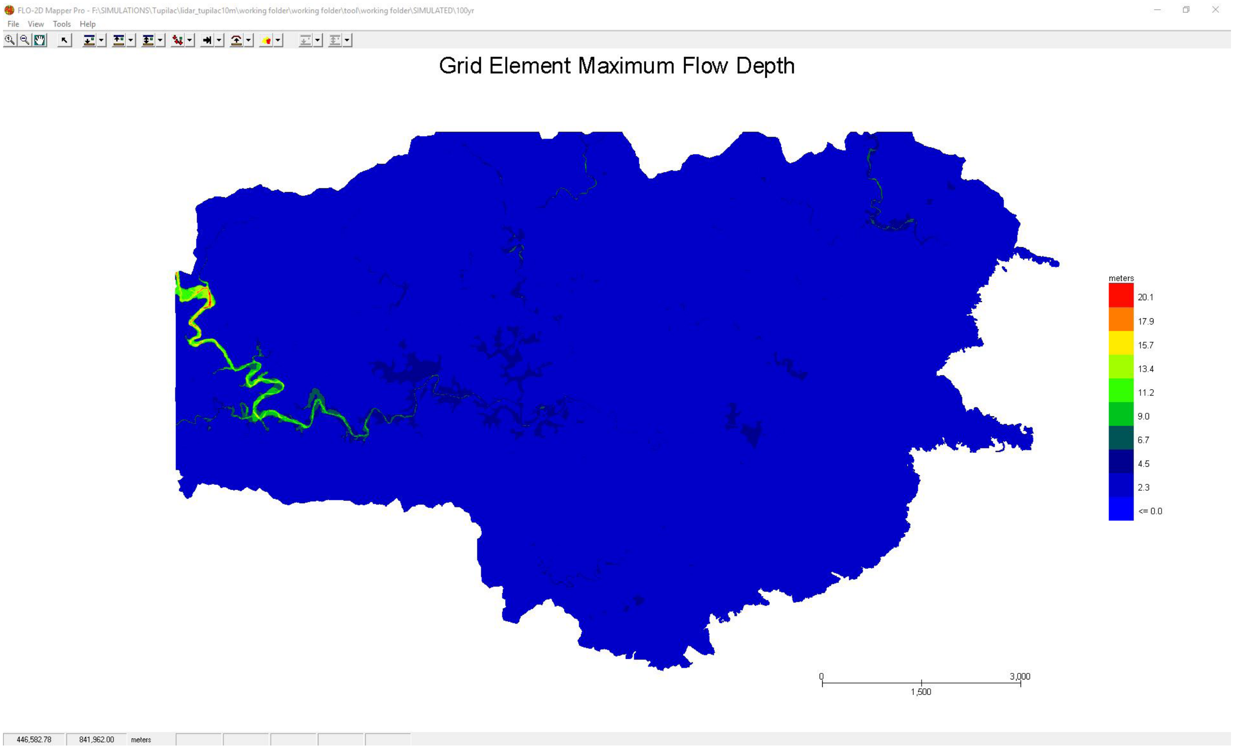


Figure 63. Generated 100-year rain return flow depth map from FLO-2D Mapper

There is a total of 22478273.87 m3 of water entering the model. Of this amount, 14450734.28 m3 is due to rainfall while 8027539.59m3 is inflow from other areas outside the model. 6057385.50 m3 of this water is lost to infiltration and interception, while 8747025.32 m3 is stored by the flood plain. The rest, amounting up to 7673827.12 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Tupilac HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 64 shows the comparison between the two discharge data.

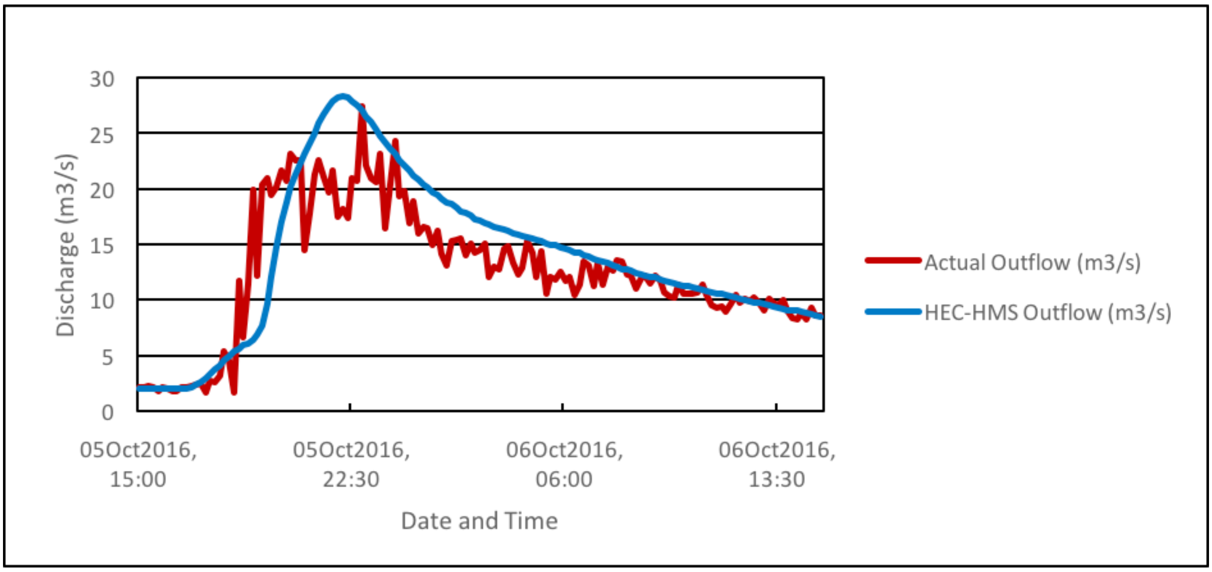


Figure 64. Outflow Hydrograph of Tupilac produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 28 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 28. Range of Calibrated Values for Tupilac

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	45.81 – 85.05
			Curve Number	67.98 – 80.63
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.16 – 3.10
			Storage Coefficient (hr)	0.26 – 5.05
	Baseflow	Recession	Recession Constant	0.23
			Ratio to Peak	0.25
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.093

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 45.81mm to 85.05mm means that there is a considerable 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 range of curve numbers in this area is 67.98 – 80.63.The magnitude of the outflow hydrograph increases as curve number increases. For Tupilac, the soil classes identified were silt, silt loam and undifferentiated mountain soil. The land cover types identified were cultivated areas, built-up areas and forest plantations.

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 0.16 hours to 5.05hours 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 0.23 indicates that the basin is moderately likely to go back to its original discharge. Ratio to peak of 0.25 indicates a shallower receding limb of the outflow hydrograph.

Table 29. Summary of the Efficiency Test of Tupilac HMS Model

RMSE	12.25847
r2	0.7697
NSE	0.614193
PBIAS	0.621134
RSR	0.402172

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 44.80268 (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 0.7697.

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 0.614193.

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 0.621134.

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 -10.00.

5.7 Calculated Outflow Hydrographs and Discharge Values for Different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 65) shows the Tupilac 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 Philippine Atmospheric Geophysical and Astronomical Services Administration (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.

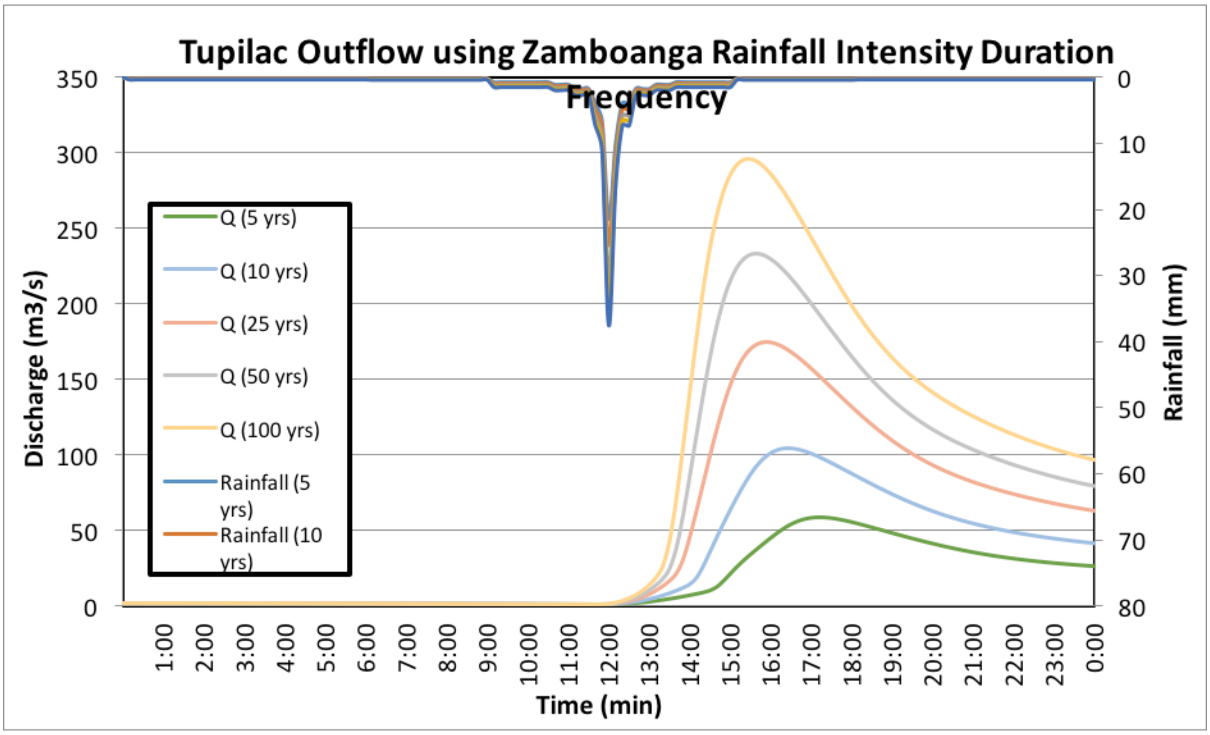


Figure 65. Outflow hydrograph at Tupilac Bridge Station generated using Zamboanga City RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Tupilac discharge using the Zamboanga City Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 30.

Table 30. Peak values of the Tupilac HECHMS Model outflow using the Zamboanga City RIDF

RIDF Period	Total Precipitation (mm)	Peak Rainfall (mm)	Peak Outflow (m3/s)	Time to Peak
5-year RIDF	107.8	21.4	58.62	17 hours 10 minutes
10-year RIDF	127.9	25.3	104.50	16 hours 30 minutes
25-year RIDF	153.4	30.2	174.57	15 hours 50 minutes
50-year RIDF	172.3	33.9	233.60	15 hours 40 minutes
100-year RIDF	191.1	37.5	296.01	15 hours 30 minutes

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample generated map of Tupilac River using the calibrated HMS base flow is shown in Figure 66.

Figure 66. Sample output of Tupilac RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. Figure 67 to Figure 72 shows the 5-, 25-, and 100-year rain return scenarios of the Tupilac Floodplain.

The generated flood hazard maps for the Tupilac 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 31. Municipalities affected in Tupilac Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Liloy	122.49	88.03	72%
Kalawit	248.64	16.21	7%
Labason	159.43	15.22	10%
Tampilisan	144.44	5.02	3%

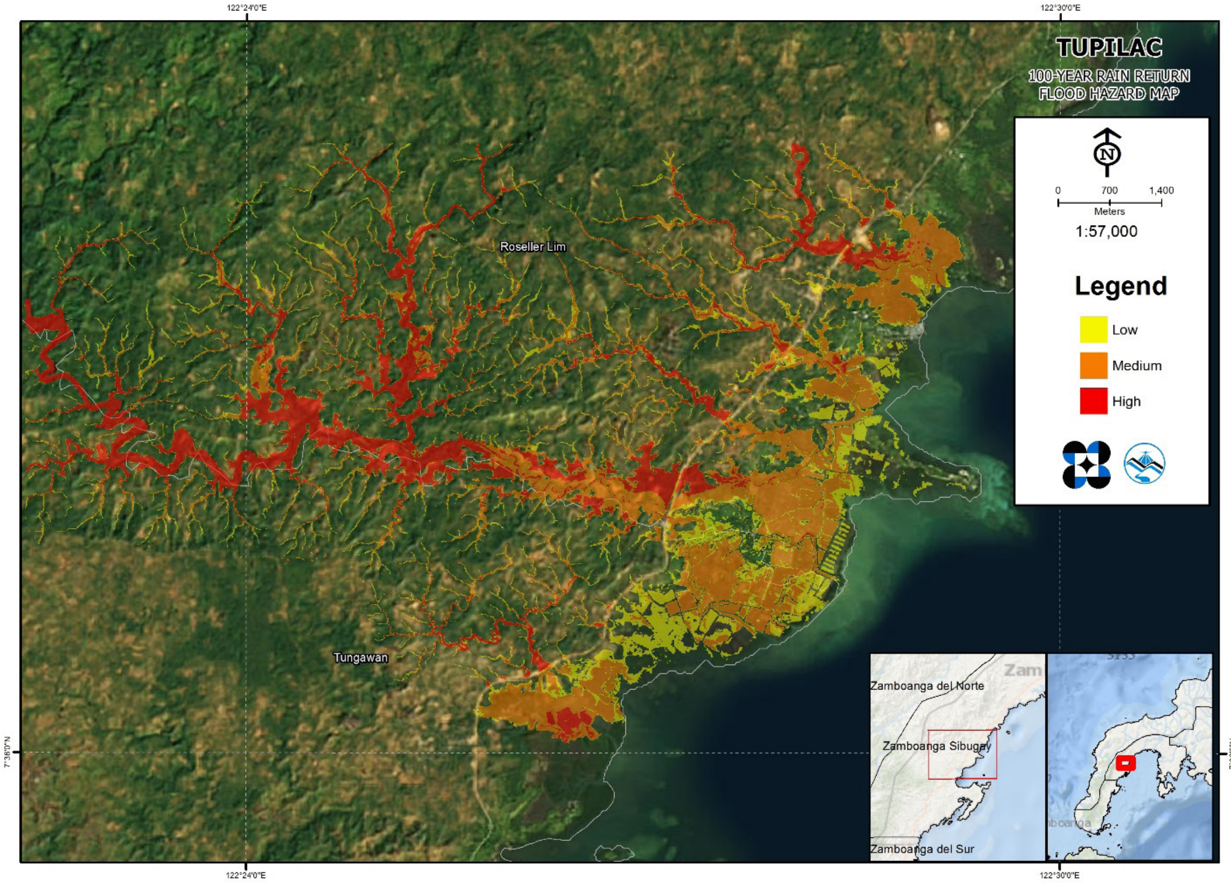


Figure 67. 100-year Flood Hazard Map for Tupilac Floodplain

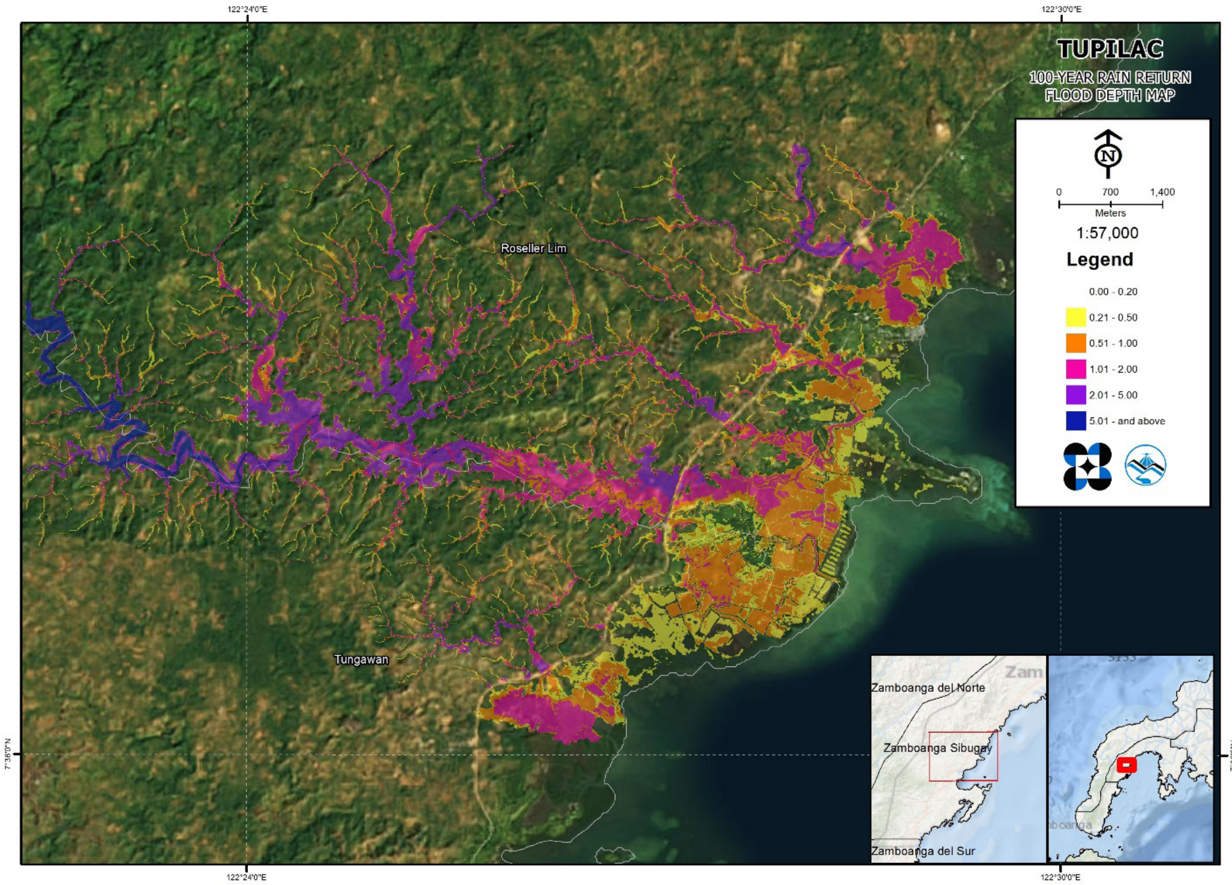


Figure 68. 100-year Flow Depth Map for Tupilac Floodplain

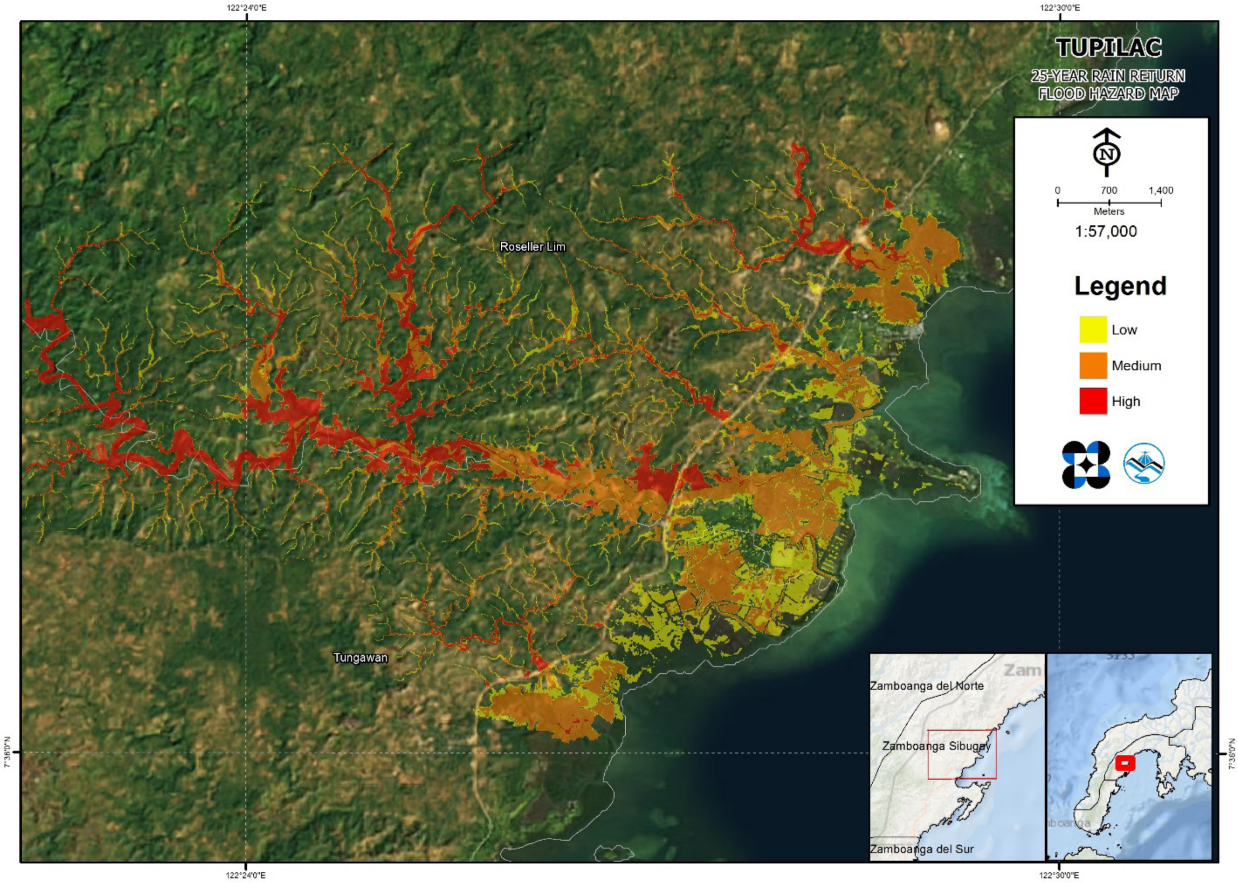


Figure 69. 25-year Flood Hazard Map for Tupilac Floodplain

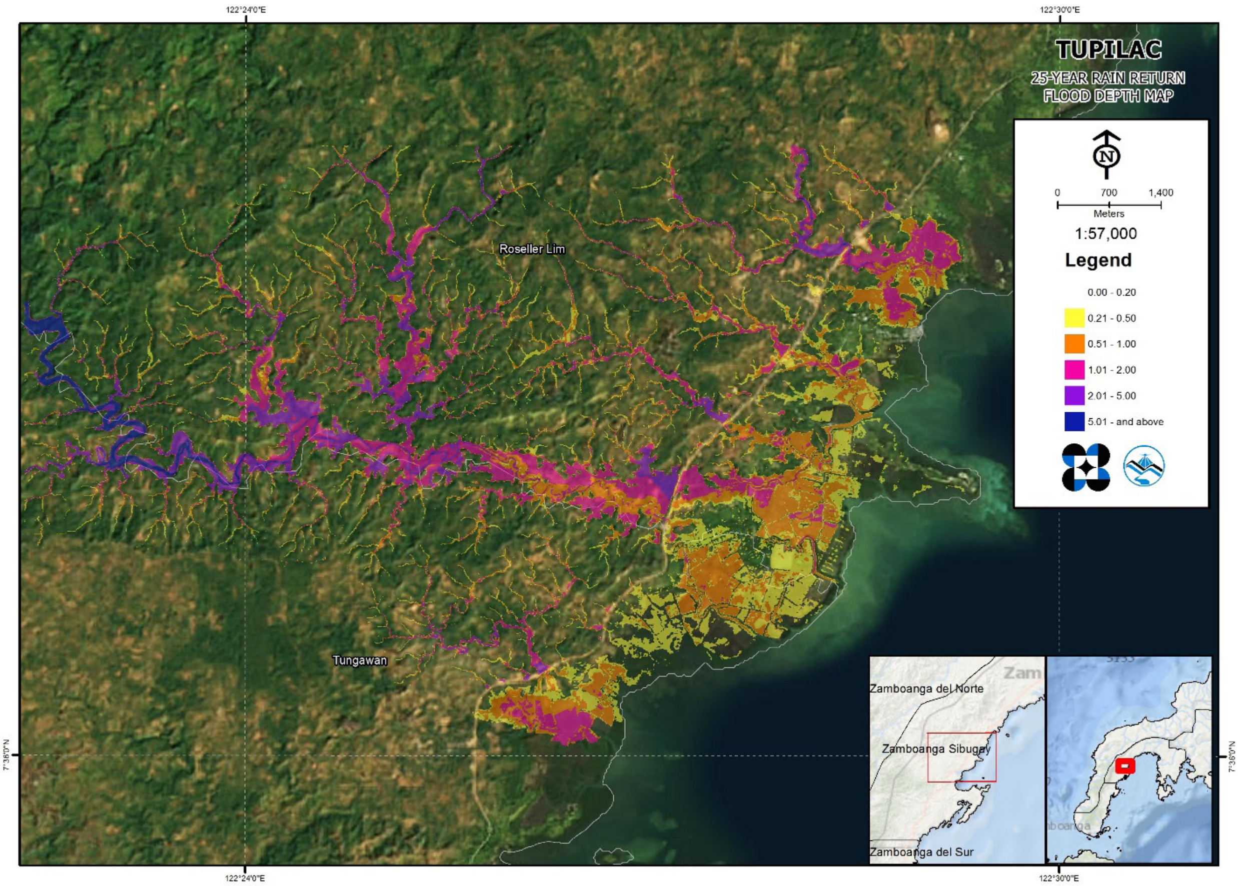


Figure 70. 25-year Flow Depth Map for Tupilac Floodplain

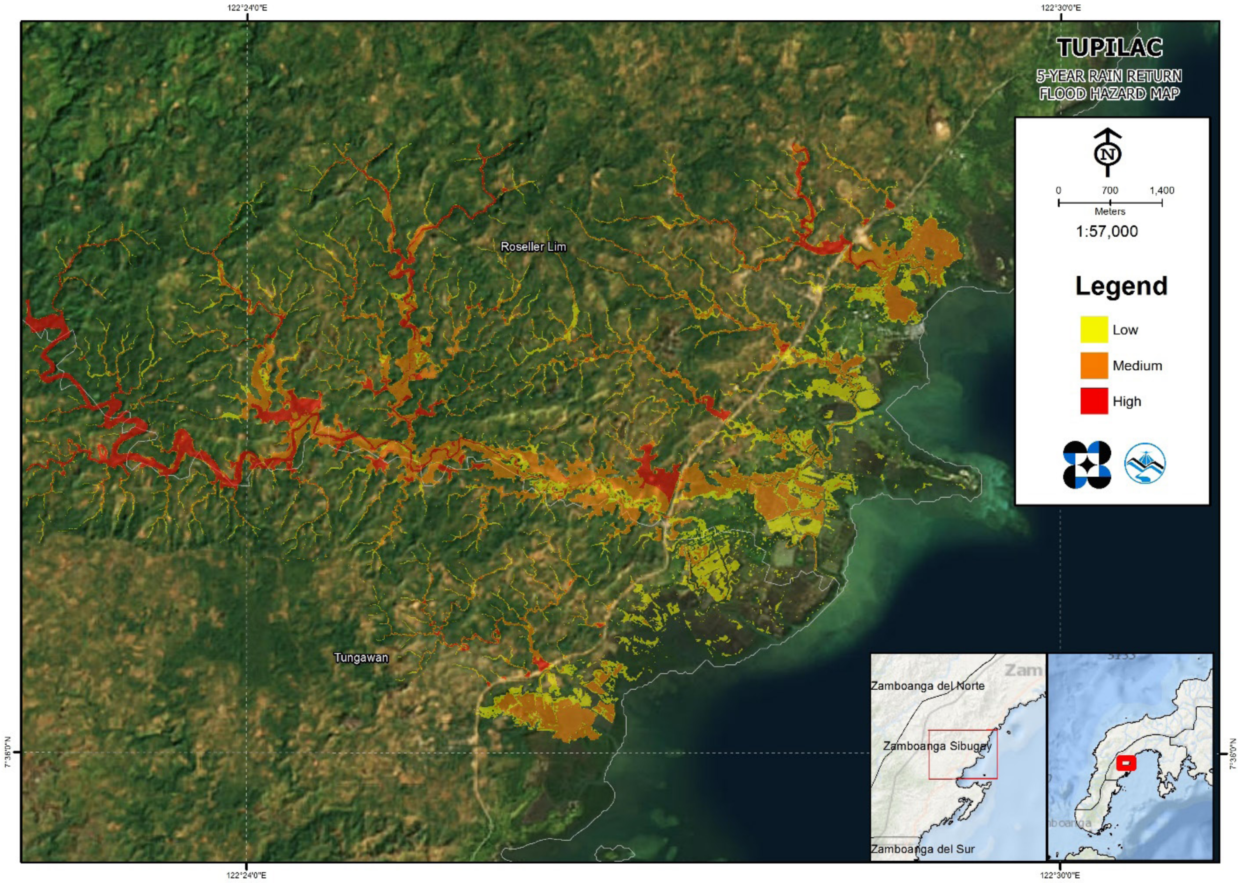


Figure 71. 5-year Flood Hazard Map for Tupilac Floodplain

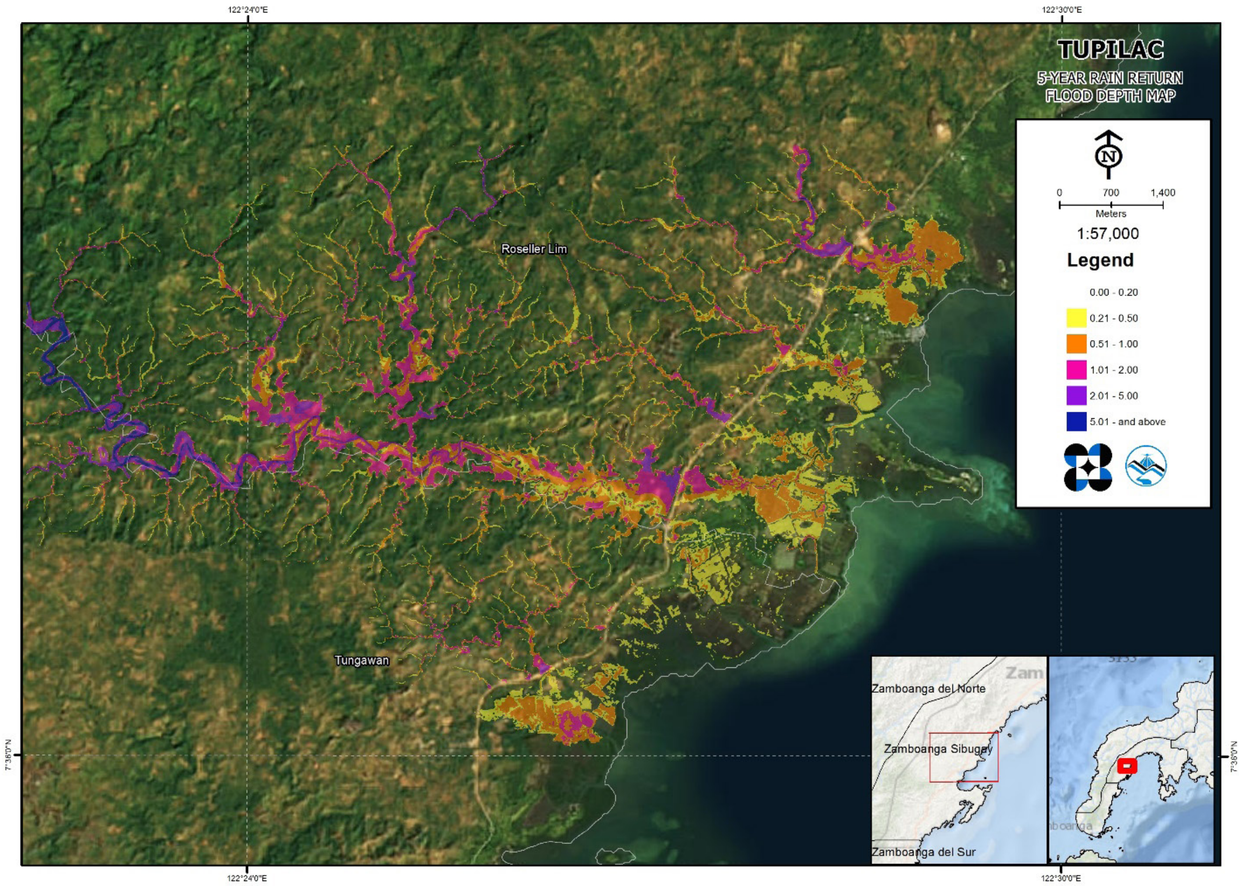


Figure 72. 5-year Flood Depth Map for Tupilac Floodplain

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Salug 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 the flood hazard scenarios.

For the 5-year return period, 33.85% of the Municipality of Roseller Lim with an area of 122.4937 sq. km. will experience flood levels of less than 0.20 meters. 2.72% of the area will experience flood levels of 0.21 to 0.50 meters while 2.81%, 1.90%, 0.69%, and 0.10% 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 32. Affected Areas in Roseller Lim, Zamboanga Sibugay during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)		Area of affected barangays in Roseller Lim (in sq. km.)										
		Calula	Casacon	Katipunan	Kulambugan	Mabini	Magsaysay	New Sagay	Pres. Roxas	San Antonio	San Jose	Surabay
Affected Area (sq. km.)	1	0.31	7.34	1.83	1.8	1.16	5.83	2.53	1.55	0.013	1.18	0.15
	2	0.013	0.37	0.081	0.39	0.049	0.72	0.046	0.11	0.0011	0.021	0.006
	3	0.013	0.68	0.062	0.37	0.024	0.3	0.025	0.38	0.00039	0.014	0.012
	4	0.032	0.89	0.035	0.065	0.02	0.089	0.019	0.1	0	0.0097	0.028
	5	0.022	0.14	0.00073	0.015	0.005	0.0081	0.031	0.035	0	0.0021	0.053
	6	0.0012	0.0005	0	0	0.000066	0	0.0005	0.0023	0	0	0.00016

Table 33. Affected Areas in Roseller Lim, Zamboanga Sibugay during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)		Area of affected barangays in Roseller Lim (in sq. km.)		
		Taruc	Tilasan	Tupilac
Affected Area (sq. km.)	1	0.026	11.23	6.52
	2	0.0007	0.41	1.12
	3	0.0012	0.4	1.16
	4	0.004	0.51	0.52
	5	0.042	0.38	0.11
	6	0.0072	0.11	0

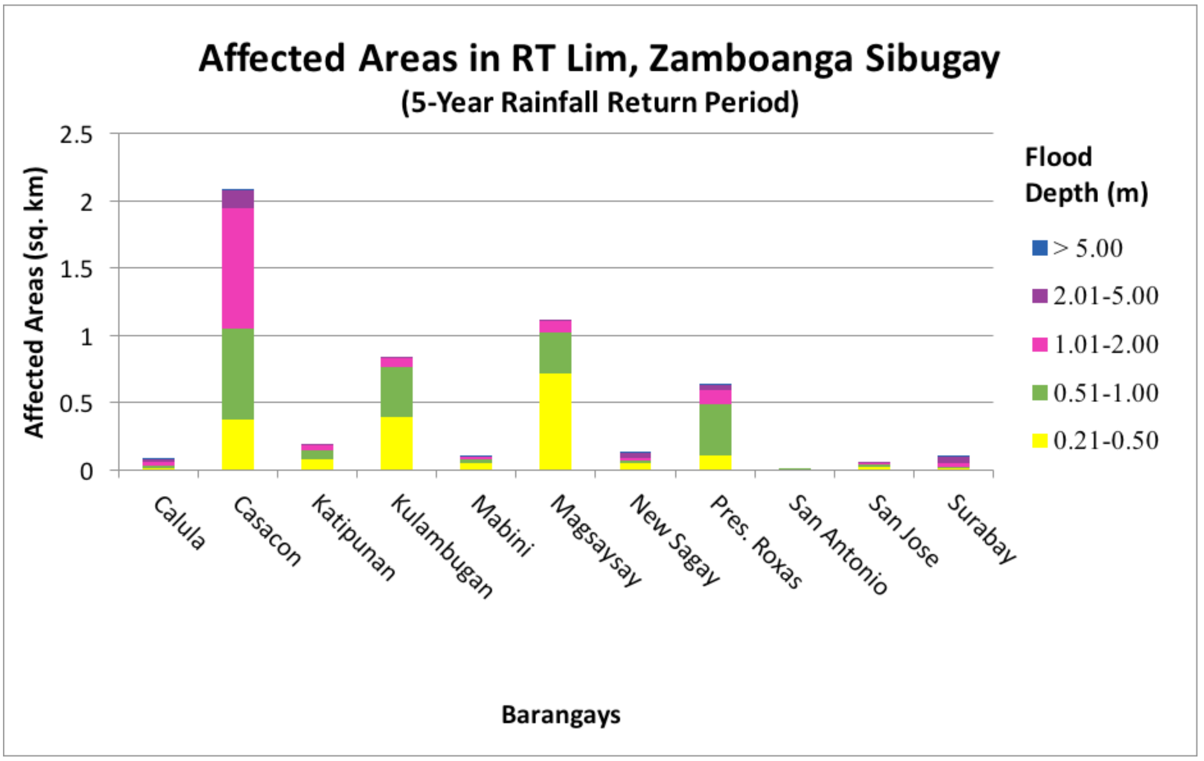


Figure 73. Affected Areas in Roseller Lim, Zamboanga Sibugay during 5-Year Rainfall Return Period

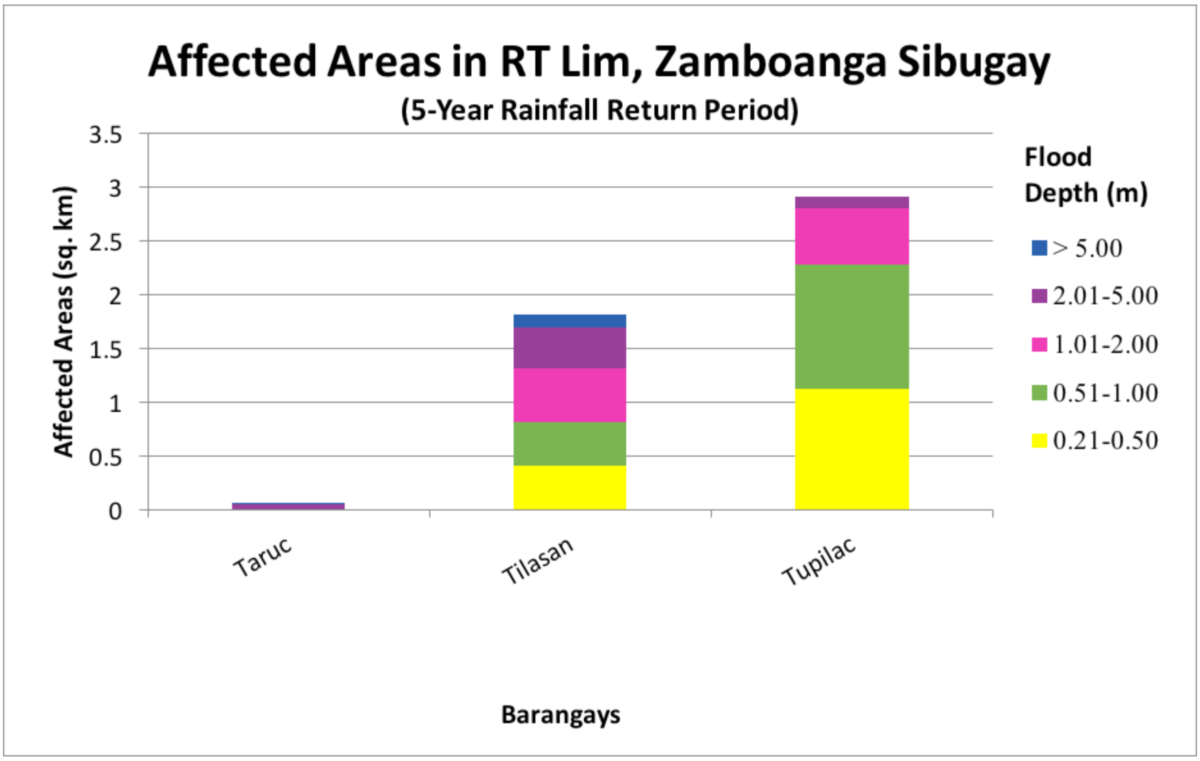


Figure 74. Affected Areas in Roseller Lim, Zamboanga Sibugay during 5-Year Rainfall Return Period

For the 5-year return period, 7.44% of the municipality of Tungawan with an area of 248.6416 sq. km. will experience flood levels of less than 0.20 meters. 0.60% of the area will experience flood levels of 0.21 to 0.50 meters while 0.43%, 0.23%, 0.09%, and 0.05% 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 Period

Affected area (sq. km.) by flood depth (in m.)		Area of affected barangays in Tungawan (in sq. km.)						
		Baluran	Gaycon	Libertad	Little Margos	Loboc	Sisay	Timbabauan
Affected Area (sq. km.)	1	9.37	4.29	2.35	0.84	0.35	0.4	0.9
	2	0.91	0.14	0.39	0.019	0.0098	0.0073	0.022
	3	0.44	0.11	0.49	0.014	0.0083	0.0013	0.0083
	4	0.25	0.13	0.17	0.014	0.0076	0	0.002
	5	0.0068	0.16	0.022	0.028	0.012	0	0
	6	0	0.069	0	0.053	0	0	0

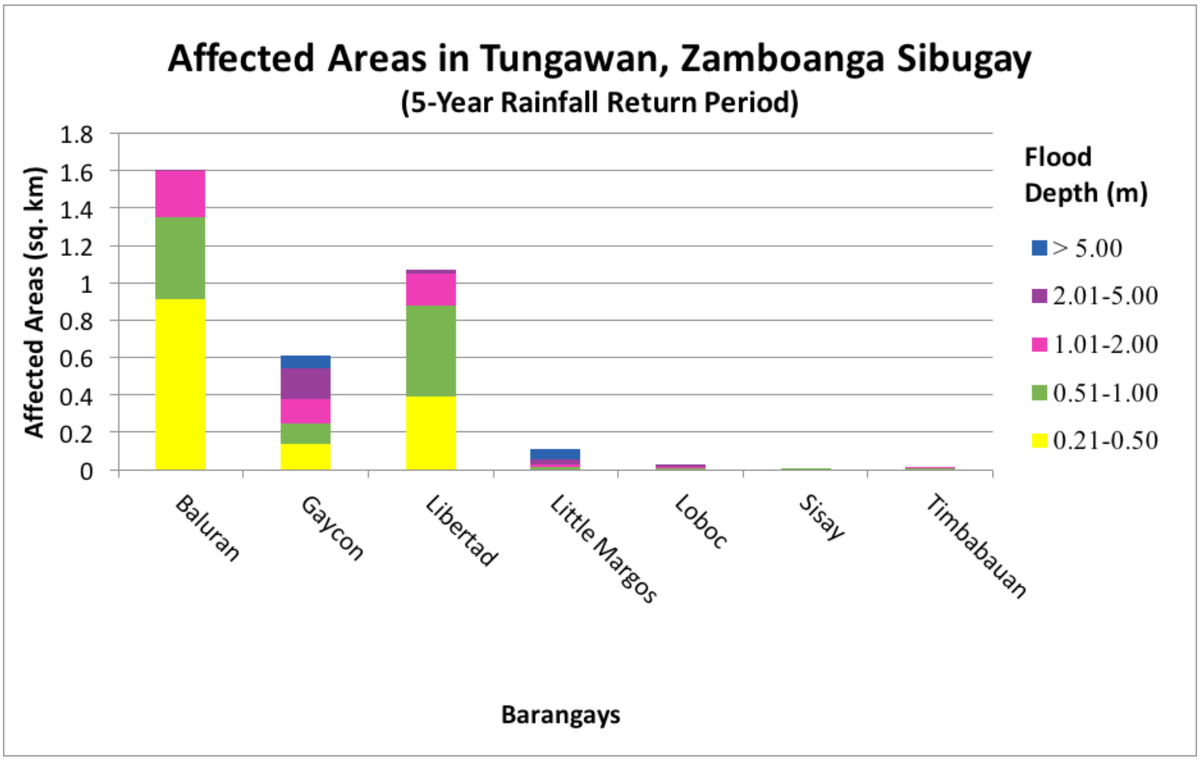


Figure 75. Affected Areas in Tungawan, Zamboanga Sibugay during 5-Year Rainfall Return Period

For the 25-year return period, 31.86% of the municipality of Roseller Lim with an area of 122.4937 sq. km. will experience flood levels of less than 0.20 meters. 2.57% of the area will experience flood levels of 0.21 to 0.50 meters while 3.07%, 3.06%, 1.29%, and 0.24% 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 Roseller Lim, Zamboanga Sibugay during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)		Area of affected barangays in Roseller Lim (in sq. km.)										
		Calula	Casacon	Katipunan	Kulambugan	Mabini	Magsaysay	New Sagay	Pres. Roxas	San Antonio	San Jose	Surabay
Affected Area (sq. km.)	1	0.3	7.09	1.78	1.57	1.14	5.28	2.5	1.45	0.013	1.17	0.14
	2	0.015	0.29	0.08	0.31	0.049	0.84	0.054	0.11	0.00078	0.026	0.0052
	3	0.011	0.41	0.077	0.48	0.032	0.61	0.03	0.16	0.00079	0.015	0.0097
	4	0.03	1.1	0.055	0.26	0.023	0.2	0.023	0.41	0	0.016	0.023
	5	0.034	0.54	0.012	0.02	0.013	0.024	0.041	0.048	0	0.0041	0.072
	6	0.0024	0.003	0	0.00003	0.00017	0	0.002	0.0042	0	0	0.0011

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

Affected area (sq. km.) by flood depth (in m.)		Area of affected barangays in Roseller Lim (in sq. km.)		
		Taruc	Tilasan	Tupilac
Affected Area (sq. km.)	1	0.019	10.98	5.59
	2	0.0003	0.39	0.98
	3	0.0008	0.35	1.57
	4	0.0016	0.51	1.1
	5	0.0044	0.58	0.19
	6	0.054	0.23	0

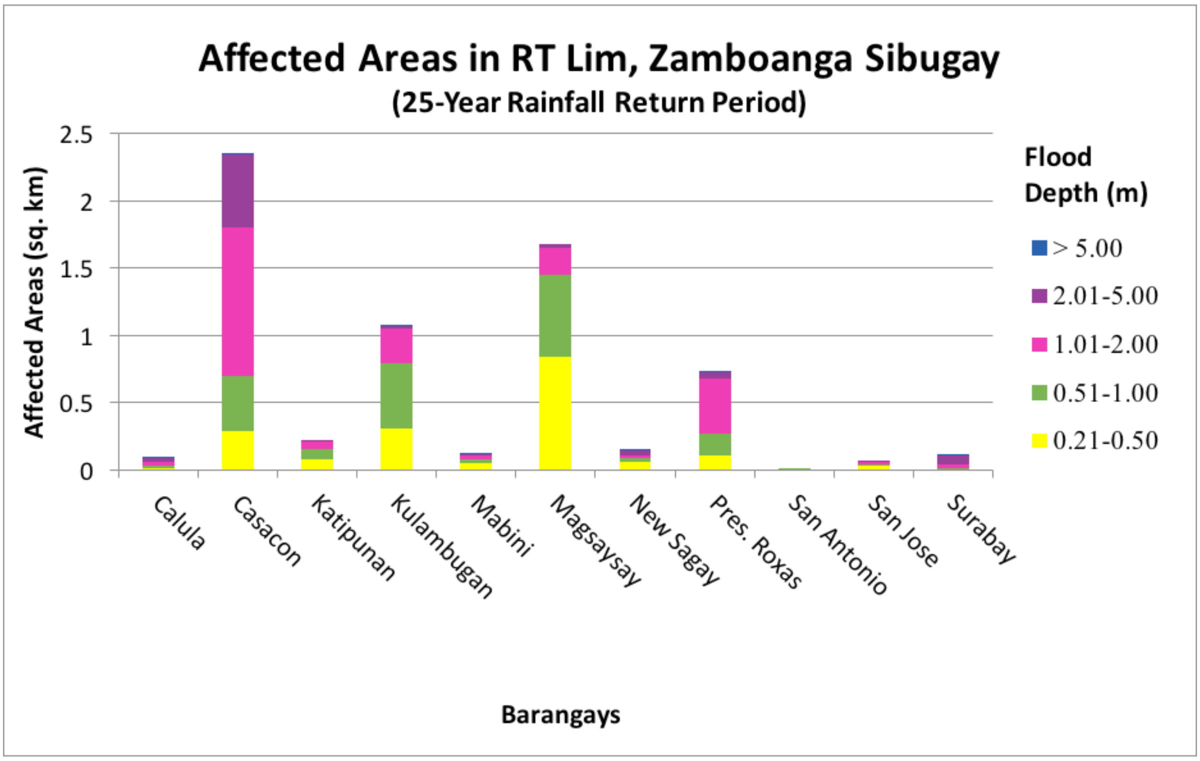
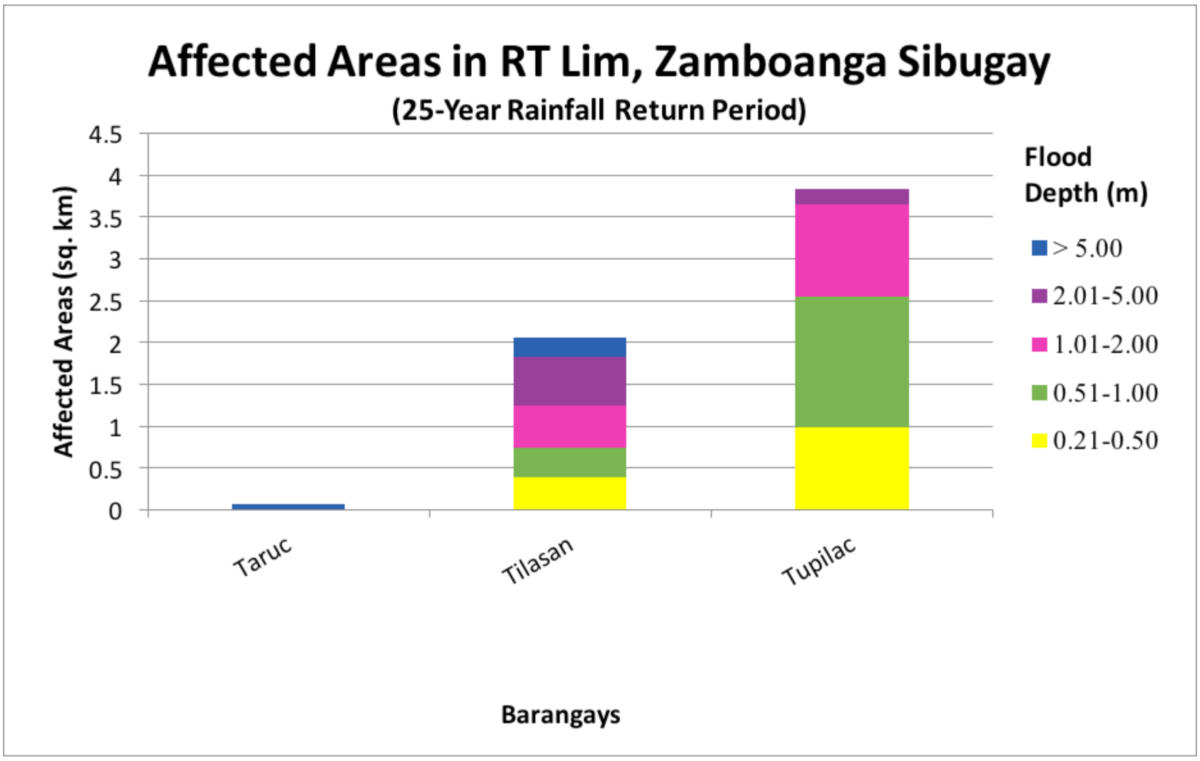


Figure 76. Affected Areas in Roseller Lim, Zamboanga Sibugay during 25-Year Rainfall Return Period



77. Affected Areas in Roseller Lim, Zamboanga Sibugay during 25-Year Rainfall Return Period

For the 25-year return period, 6.63% of the municipality of Tungawan with an area of 248.6416 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 0.71%, 0.40%, 0.15%, 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 37. 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.)						
		Baluran	Gaycon	Libertad	Little Margos	Loboc	Sisay	Timbabauan
Affected Area (sq. km.)	1	7.78	4.18	2.08	0.81	0.34	0.4	0.89
	2	1.6	0.15	0.33	0.02	0.012	0.0088	0.025
	3	1.09	0.11	0.53	0.016	0.0096	0.0026	0.011
	4	0.42	0.13	0.42	0.016	0.011	0.0001	0.0036
	5	0.08	0.19	0.057	0.027	0.015	0	0.0003
	6	0	0.14	0	0.073	0.0009	0	0

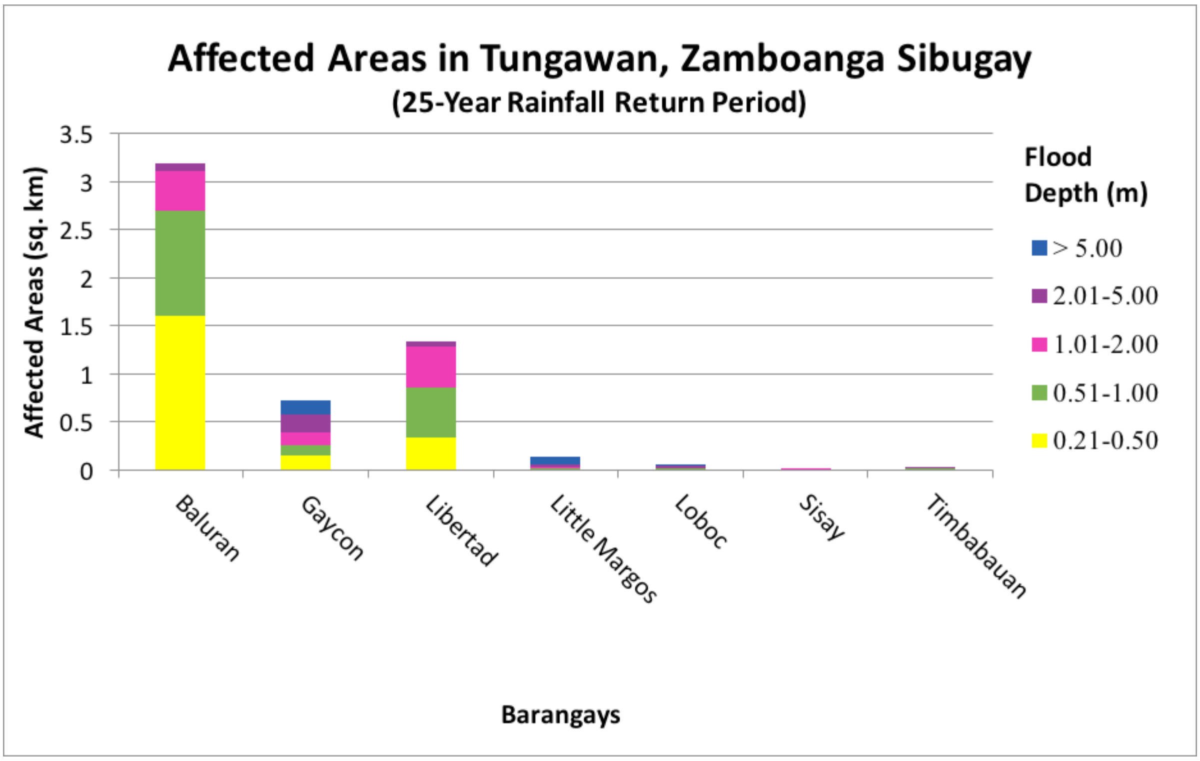


Figure 78. Affected Areas in Tungawan, Zamboanga Sibugay during 25-Year Rainfall Return Period

For the 100-year return period, 30.88% of the municipality of Roseller Lim with an area of 122.4937 sq. km. will experience flood levels of less than 0.20 meters. 2.37% of the area will experience flood levels of 0.21 to 0.50 meters while 3.13%, 3.37%, 2.00%, and 0.34% 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 Roseller Lim, Zamboanga Sibugay during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)		Area of affected barangays in Roseller Lim (in sq. km.)										
		Calula	Casacon	Katipunan	Kulambugan	Mabini	Magsaysay	New Sagay	Pres. Roxas	San Antonio	San Jose	Surabay
Affected Area (sq. km.)	1	0.29	6.94	1.75	1.47	1.12	4.97	2.48	1.41	0.013	1.16	0.14
	2	0.016	0.28	0.086	0.28	0.048	0.82	0.057	0.1	0.00088	0.033	0.0041
	3	0.012	0.34	0.079	0.47	0.036	0.76	0.035	0.14	0.00099	0.014	0.0081
	4	0.011	0.81	0.065	0.39	0.022	0.37	0.025	0.47	0.000001	0.018	0.021
	5	0.054	1.05	0.021	0.039	0.024	0.042	0.043	0.059	0	0.0062	0.08
	6	0.0078	0.0087	0	0.00003	0.00067	0	0.0067	0.0068	0	0	0.0035

Table 39. Affected Areas in Roseller Lim, Zamboanga Sibugay during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)		Area of affected barangays in Roseller Lim (in sq. km.)		
		Taruc	Tilasan	Tupilac
Affected Area (sq. km.)	1	0.017	10.81	5.25
	2	0.0003	0.41	0.77
	3	0.0005	0.35	1.59
	4	0.0004	0.43	1.5
	5	0.004	0.72	0.31
	6	0.059	0.32	0

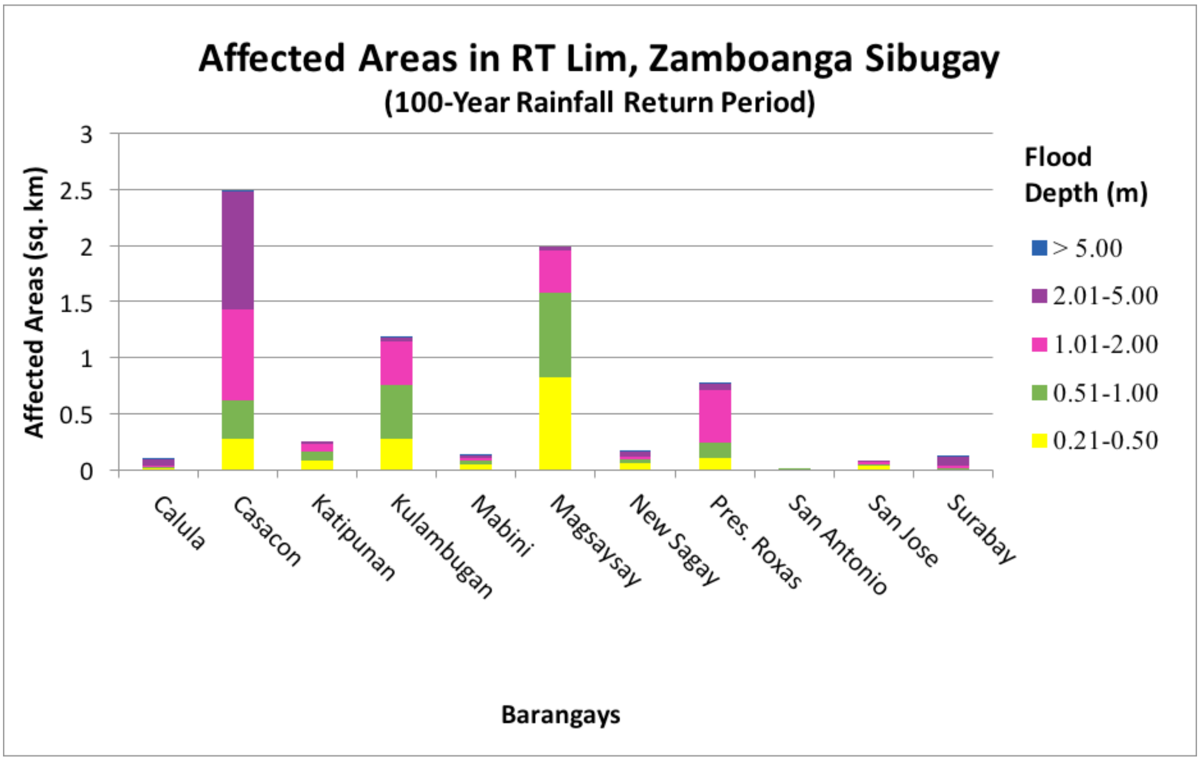


Figure 79. Affected Areas in Roseller Lim, Zamboanga Sibugay during 100-Year Rainfall Return Period

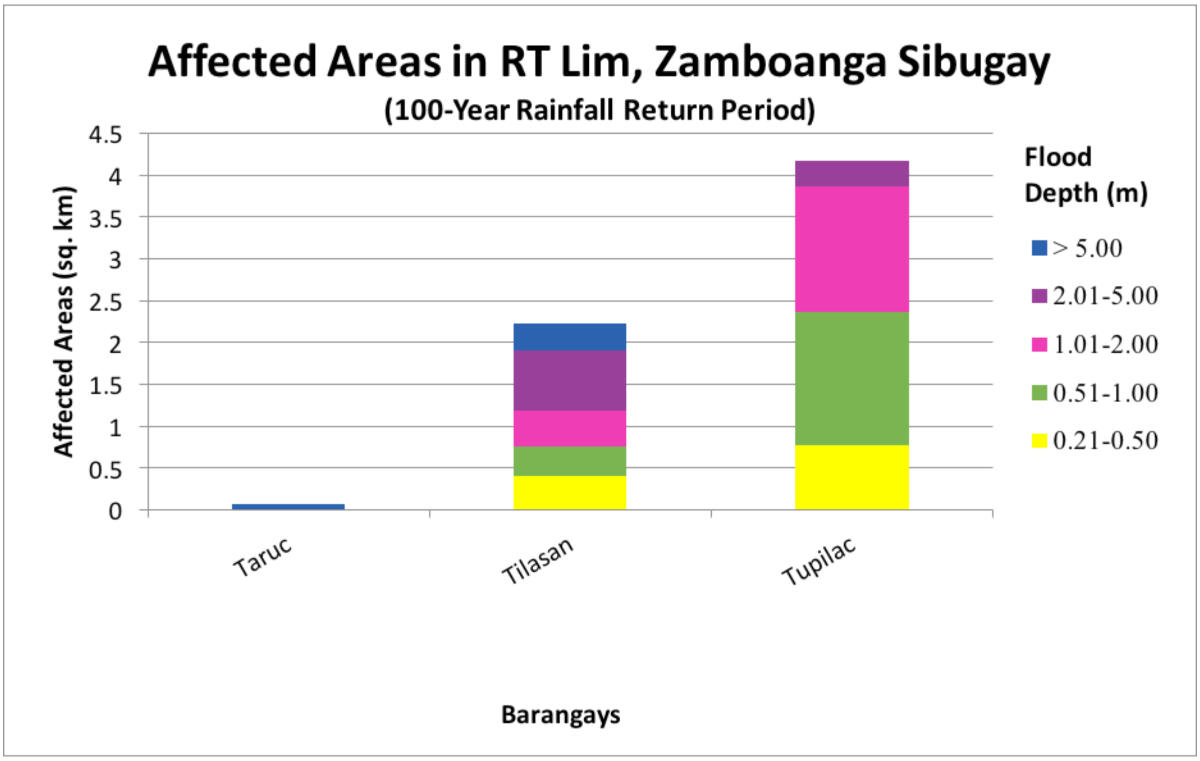


Figure 80. Affected Areas in Roseller Lim, Zamboanga Sibugay during 100-Year Rainfall Return Period

For the 100-year return period, 5.52% of the municipality of Kalawit with an area of 248.6416 sq. km. will experience flood levels of less than 0.20 meters. 0.20% of the area will experience flood levels of 0.21 to 0.50 meters while 0.21%, 0.24%, 0.26%, 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 40. 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.)						
		Baluran	Gaycon	Libertad	Little Margos	Loboc	Sisay	Timbabauan
Affected Area (sq. km.)	1	7.2	4.09	1.99	0.79	0.33	0.4	0.88
	2	1.65	0.17	0.23	0.021	0.013	0.01	0.027
	3	1.44	0.12	0.4	0.017	0.0089	0.0035	0.014
	4	0.52	0.12	0.7	0.018	0.012	0.0002	0.0053
	5	0.17	0.21	0.087	0.026	0.015	0	0.0005
	6	0.0002	0.2	0	0.09	0.0036	0	0

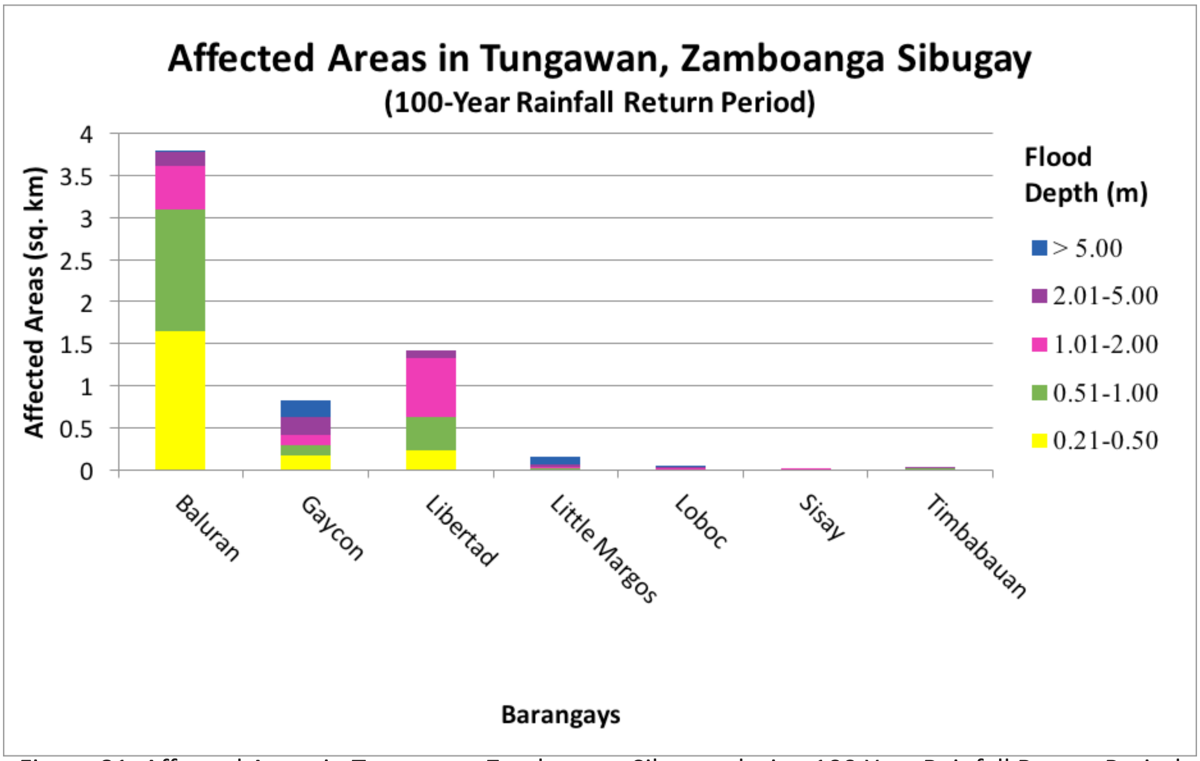


Figure 81. Affected Areas in Tungawan, Zamboanga Sibugay during 100-Year Rainfall Return Period

Moreover, the generated flood hazard maps for the Tupilac 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 41. 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	4.95	5.37	5.07
Medium	6.56	8.63	9.44
High	2.30	4.27	5.74
TOTAL	13.81	18.27	20.25

Of the 36 identified educational and medical institutions and buildings in Tupilac Floodplain only 1 medical institution was assessed to be exposed to flood hazard levels. The medical institution located in Brgy. Baluran, Tungawan was assessed to be exposed to low flood hazard levels for the 25- and 100-year scenarios. See Appendix D and E for a detailed enumeration of schools, hospitals and clinics in the Tupilac Floodplain.

5.11 Flood Validation

The flood validation consists of 193 points randomly selected all over the Tupilac Floodplain. It has an RMSE value of 0.22.

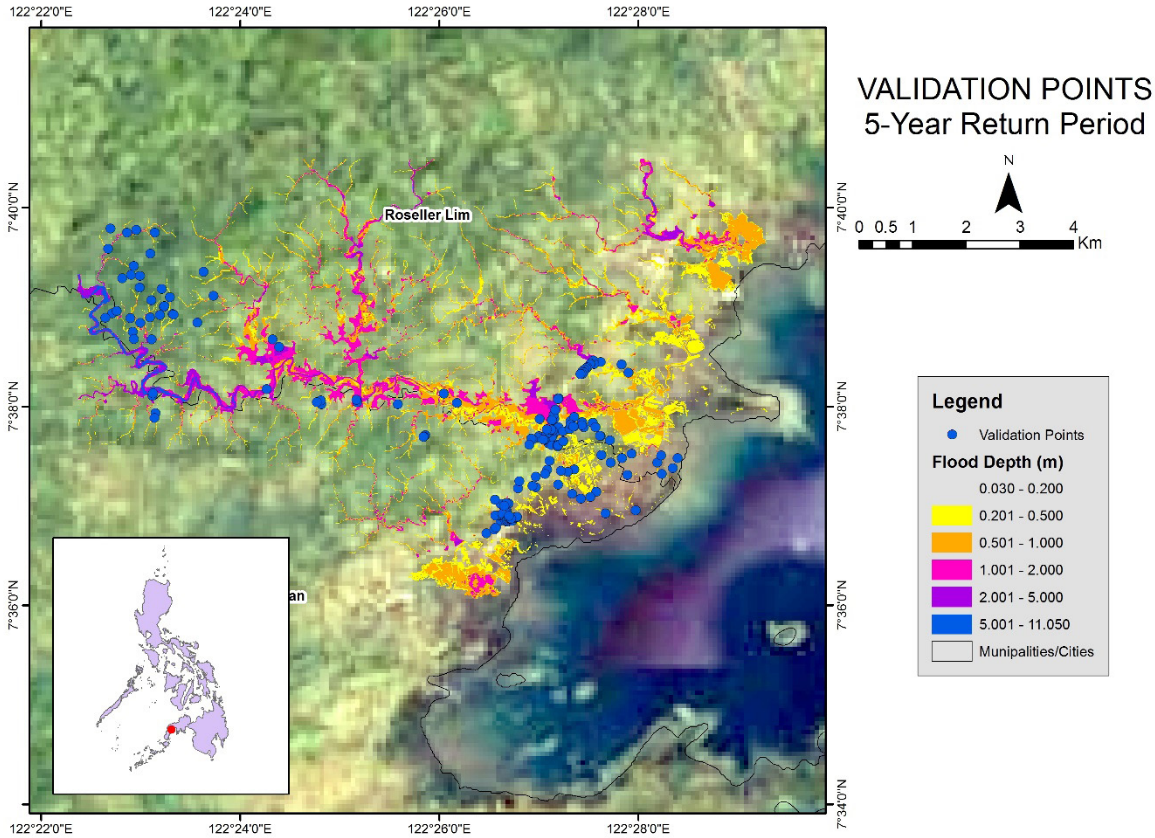


Figure 82. Validation points for 5-year Flood Depth Map of Tupilac Floodplain

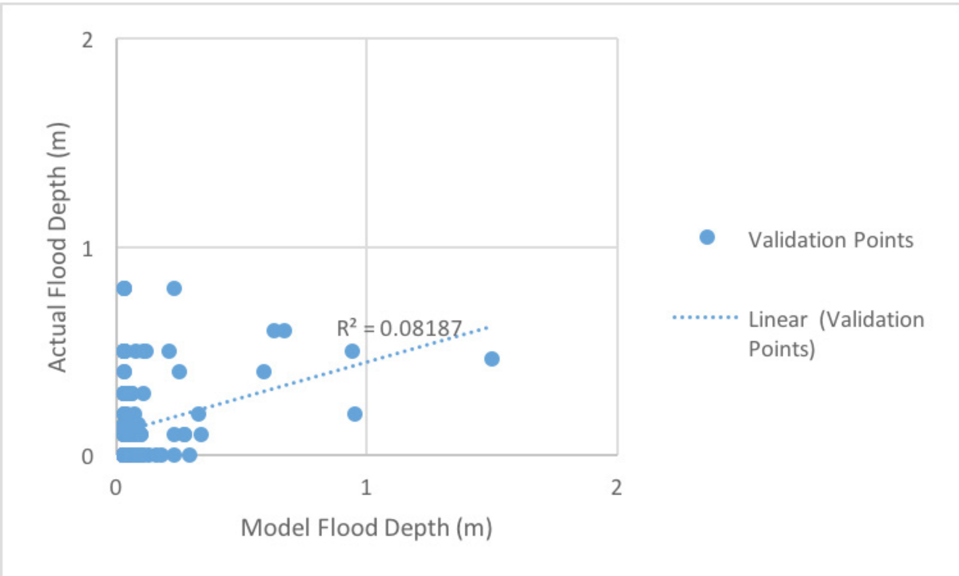


Figure 83. Flood map depth vs actual flood depth

Figure 83. Flood map depth vs actual flood depth

TUPILAC 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	139	7	1	0	0	0	147
	0.21-0.50	35	2	2	1	0	0	40
	0.51-1.00	3	1	2	0	0	0	6
	1.01-2.00	0	0	0	0	0	0	0
	2.01-5.00	0	0	0	0	0	0	0
	> 5.00	0	0	0	0	0	0	0
	Total	**177**	10	5	1	0	0	193

The overall accuracy generated by the flood model is estimated at 74.09%, with 143 points correctly matching the actual flood depths. In addition, there were 44 points estimated one level above and below the correct flood depths while there were 5 points estimated two levels above and below the correct flood. A total of 11 points were overestimated while a total of 39 points were underestimated in the modelled flood depths of Tupilac.

Table 43. Summary of Accuracy Assessment in Tupilac

	No. of Points	%
Correct	143	74.09
Overestimated	11	5.70
Underestimated	39	20.21
Total	193	100.00

REFERENCES

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

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

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

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

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

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

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

ANNEXES

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

1. Pegasus Sensor

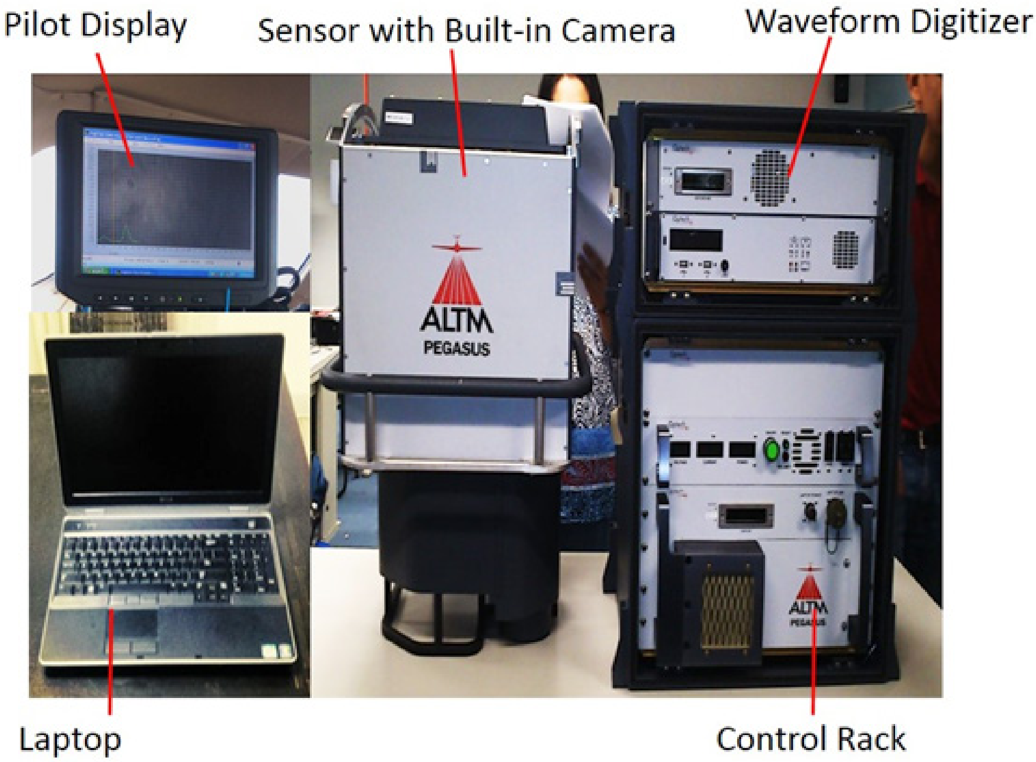


Figure A-1.1. Pegasus Sensor.

Table A-1.1. Parameters and Specification of Pegasus Sensor

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

1 Target reflectivity ≥20%

2 Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility

3 Angle of incidence ≤20°

4 Target size ≥ laser footprint5 Dependent on system configuration

2. D-8900 Aerial Digital Camera

Table A-1.2. Parameters and Specification of D-8900 Aerial Digital Camera

Parameter	Specification
Camera Head	
Sensor type	60 Mpix full frame CCD, RGB
Sensor format (H x V)	8, 984 x 6, 732 pixels
Pixel size	6μm x 6 μm
Frame rate	1 frame/2 sec.
FMC	Electro-mechanical, driven by piezo technology (patented)
Shutter	Electro-mechanical iris mechanism 1/125 to 1/500++ sec. f-stops: 5.6, 8, 11, 16
Lenses	50 mm/70 mm/120 mm/210 mm
Filter	Color and near-infrared removable filters
Dimensions (H x W x D)	200 x 150 x 120 mm (70 mm lens)
Weight	~4.5 kg (70 mm lens)
Controller Unit	
Computer	Mini-ITX RoHS-compliant small-form-factor embedded computers with AMD TurionTM 64 X2 CPU 4 GB RAM, 4 GB flash disk local storage IEEE 1394 Firewire interface
Removable storage unit	~500 GB solid state drives, 8,000 images
Power consumption	~8 A, 168 W
Dimensions	2U full rack; 88 x 448 x 493 mm
Weight	~15 kg
Image Pre-Processing Software	
Capture One	Radiometric control and format conversion, TIFF or JPEG
Image output	8,984 x 6,732 pixels 8 or 16 bits per channel (180 MB or 360 MB per image)

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

1. ZSI-52

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 SIBUGAY**	
	Station Name: **ZSI-52**	
	Order: **2nd**	
Island: **MINDANAO**	Barangay: **TUPILAC**	
Municipality: **TUNGAWAN**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **7° 37' 50.78279"**	Longitude: **122° 27' 1.47785"**	Ellipsoidal Hgt: **10.41300 m.**
	WGS84 Coordinates	
Latitude: **7° 37' 47.22473"**	Longitude: **122° 27' 6.97710"**	Ellipsoidal Hgt: **74.25700 m.**
	PTM / PRS92 Coordinates	
Northing: **843760.188 m.**	Easting: **439359.616 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **843,464.86**	Easting: **439,380.84**	Zone: **51**

Location Description

ZSI-52
Station is along the national highway (Zamboanga City - Ipil), right side when Ipil bound and about 50 m N of Tupilac Br. (KM 1824 + 692.738 m). Mark is the head of a 2" concrete nail flushed in a 30 cm x 30 cm x 20 cm cement block with inscriptions ZSI-52 2006 NAMRIA/LEP.

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Purpose: **Reference**
OR Number: **8799780 A**
T.N.: **2014-1900**

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

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

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

CIP/4701/12/09/814

Figure A-2.1. ZSI-52

2. ZSI-58

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

June 14, 2016

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 SIBUGAY**
Station Name: **ZSI-58**
Order: **2nd**

Island: **MINDANAO**	Barangay: **LICOMO**	
Municipality: **TUNGAWAN**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **7° 28' 13.32387"**	Longitude: **122° 19' 53.76709"**	Ellipsoidal Hgt: **82.90600 m.**
	WGS84 Coordinates	
Latitude: **7° 28' 9.79725"**	Longitude: **122° 19' 59.28169"**	Ellipsoidal Hgt: **146.76200 m.**
	PTM / PRS92 Coordinates	
Northing: **826039.734 m.**	Easting: **426222.848 m.**	Zone: **4**
	UTM / PRS92 Coordinates	
Northing: **825,750.61**	Easting: **426,248.67**	Zone: **51**

Location Description

ZSI-58
From Ipil City proper, travel south on the national highway going to Zamboanga City for approximately 45 mins. Station is located on the E side of the national highway about 150 m before reaching the provincial boundary between Zamboanga Sibugay and Zamboanga City. It is situated at about 1.5 m W of an unmarked concrete slab, 6 m from a pile of rocks and boulders, about 6 m from the road centerline and about 15 m SW of the nearest house. Station is intervisible with ZSI-57. Mark is the head of a 2" concrete nail flushed in a 30 cm x 30 cm x 20 cm cement block with inscriptions ZSI-58 2006 NAMRIA/LEP.

Requesting Party: **UP Lidar 1**
Purpose: **Reference**
OR Number: **8094772**
T.N.: **2016-1262**

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

9 9 0 6 1 4 2 0 1 6 1 6 2 8 5 4

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CIP/4701/12/09/814

Figure A-2.2. ZSI-58

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

1. ZY-93A

Table A-3.1. ZY-93A

ZSI-52 - ZY-93A (8:34:10 AM-1:16:29 PM) (S1)

Baseline observation:	ZSI-52 --- ZY-93A (B1)
Processed:	3/5/2015 7:02:45 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.001 m
Vertical precision:	0.002 m
RMS:	0.000 m
Maximum PDOP:	2.439
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	2/10/2015 8:34:34 AM (Local: UTC+8hr)
Processing stop time:	2/10/2015 1:16:29 PM (Local: UTC+8hr)
Processing duration:	04:41:55
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	ZSI-52				
Grid		Local		Global	
Easting	439380.842 m	Latitude	N7°37'50.78279"	Latitude	N7°37'47.22473"
Northing	843464.857 m	Longitude	E122°27'01.47785"	Longitude	E122°27'06.97710"
Elevation	6.077 m	Height	10.412 m	Height	74.257 m

To:	ZY-93A				
Grid		Local		Global	
Easting	439338.090 m	Latitude	N7°37'46.78582"	Latitude	N7°37'43.22802"
Northing	843342.174 m	Longitude	E122°27'00.08763"	Longitude	E122°27'05.58699"
Elevation	6.332 m	Height	10.662 m	Height	74.508 m

Vector					
ΔEasting	-42.752 m	NS Fwd Azimuth	199°08'21"	ΔX	27.074 m
ΔNorthing	-122.683 m	Ellipsoid Dist.	129.965 m	ΔY	36.828 m
ΔElevation	0.255 m	ΔHeight	0.250 m	ΔZ	-121.662 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'01"	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	0.0000003923		
Y	-0.0000001965	0.0000005184	
Z	-0.0000000756	0.0000000586	0.0000000887

2. ZY-110

Table A-3.2. ZY-110

Vector Components (Mark to Mark)

From:	ZSI-58				
Grid		Local		Global	
Easting	426248.671 m	Latitude	N7°28'13.32388"	Latitude	N7°28'09.79725"
Northing	825750.606 m	Longitude	E122°19'53.76709"	Longitude	E122°19'59.28169"
Elevation	78.880 m	Height	82.906 m	Height	146.762 m

To:	ZY-110				
Grid		Local		Global	
Easting	429720.359 m	Latitude	N7°30'53.56728"	Latitude	N7°30'50.03176"
Northing	830666.225 m	Longitude	E122°21'46.79802"	Longitude	E122°21'52.30841"
Elevation	13.942 m	Height	18.006 m	Height	81.856 m

Vector					
ΔEasting	3471.688 m	NS Fwd Azimuth	35°08'41"	ΔX	-2549.783 m
ΔNorthing	4915.619 m	Ellipsoid Dist.	6019.989 m	ΔY	-2450.835 m
ΔElevation	-64.938 m	ΔHeight	-64.900 m	ΔZ	4872.062 m

Standard Errors

Vector errors:					
σ ΔEasting	0.005 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.007 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.003 m	σ ΔY	0.009 m
σ ΔElevation	0.011 m	σ ΔHeight	0.011 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000451909		
Y	-0.0000400210	0.0000867246	
Z	-0.0000097402	0.0000144329	0.0000080220

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LIDAR Survey Team Composition

Data Acquisition Component Sub –Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	SSRS	ENGR. IRO ROXAS	UP-TCAGP
	Research Associate (RA)	ENGR. RENAN PUNTO	UP-TCAGP
	RA	KRISTINE JOY ANDAYA	UP-TCAGP
	RA	JONATHAN ALMALVEZ	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	SANDRA POBLETE	UP-TCAGP
	RA	FRANK NICOLAS ILEJAY	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. ERWIN DELOS SANTOS	PHILIPPINE AIR FORCE (PAF)
	Airborne Security	SSG. JAYCO MANZANO	PAF
	Pilot	CAPT. BRYAN DONGUINES	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. SHERWIN CESAR ALFONSO	AAC
		CAPT. ANTON DAYO	AAC

Annex 5. Data Transfer Sheet for Tupilac 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 [signature]

Received by

Name AC BONGAT 3/13/15
Position GSRS
Signature [signature]

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

DATA TRANSFER SHEET
ZAMBOANGA 7/11/2016

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	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	
May 25, 2016	23390P	1BLK75BS146A	PEGASUS	518	NA	4.08	91	NA	NA	5.63	NA	95.8	1KB	NA	53	NA	Z:\DAC\RAW DATA
May 26, 2016	23392P	1BLK75FG147A	PEGASUS	2.28	NA	11	253	NA	NA	24.7	NA	133	1KB	NA	89	NA	Z:\DAC\RAW DATA
May 26, 2016	23394P	1BLK75AS147B	PEGASUS	506	NA	3.37	101	NA	NA	5.13	NA	133	1KB	NA	NA	NA	Z:\DAC\RAW DATA
May 27, 2016	23398P	1BLK75CSDE148B	PEGASUS	2.09	NA	11.6	281	30	274	22.6	NA	153	1KB	NA	NA	NA	Z:\DAC\RAW DATA
May 30, 2016	23408P	1BLK75HI151A	PEGASUS	546	NA	6.09	173	8.73	69	7.88	NA	171	1KB	NA	NA	NA	Z:\DAC\RAW DATA
May 30, 2016	23410P	1BLK75CS151B	PEGASUS	1.1	NA	6.75	192	15.3	139	12.6	NA	171	1KB	NA	NA	NA	Z:\DAC\RAW DATA

Received from

Name R. PUNTO
Position RA
Signature

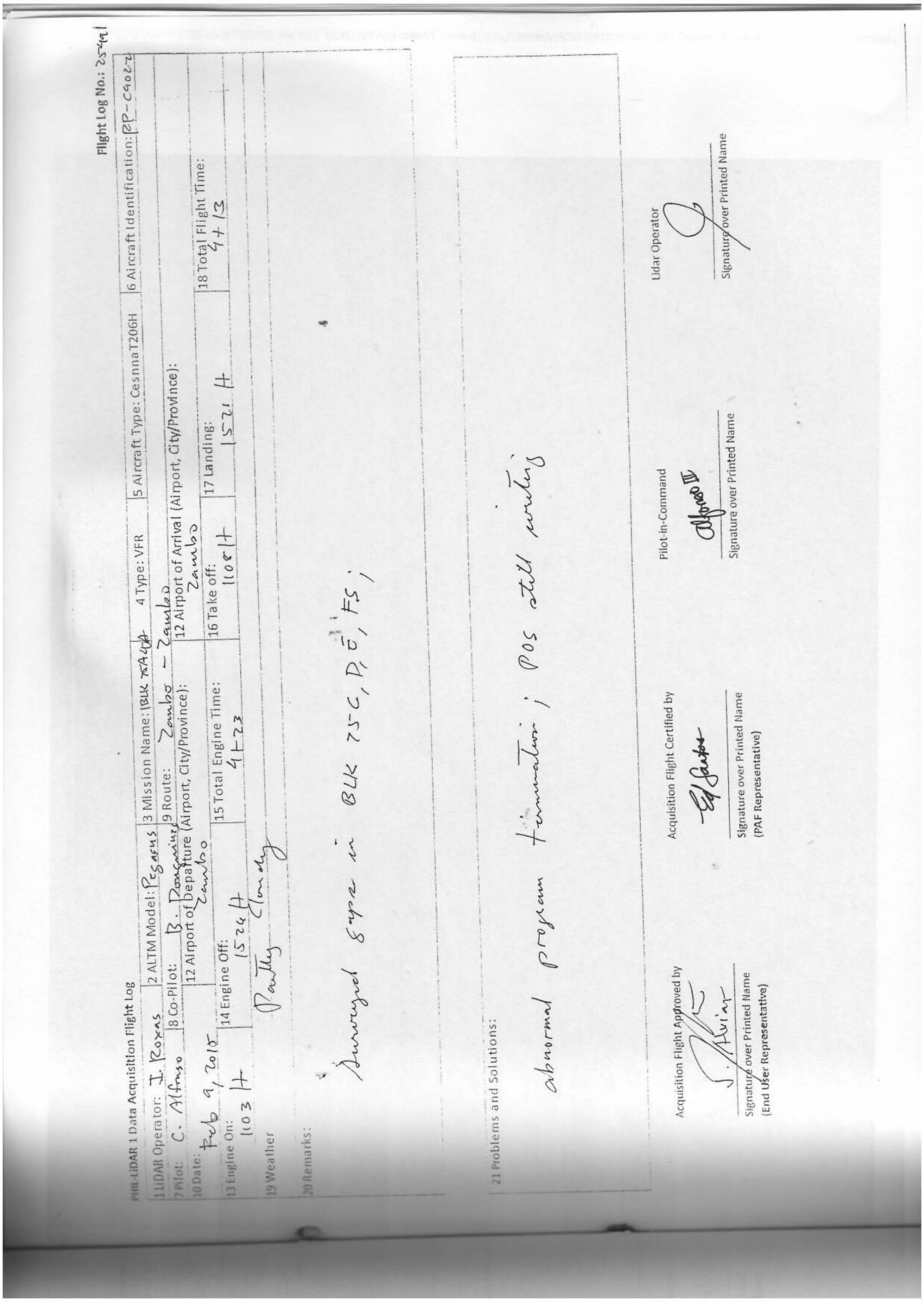
Received by

Name AC BONGAT
Position SSRS
Signature 7/14/16

Figure A-5.2. Transfer Sheet for Tupilac Floodplain-B

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for 2549P Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

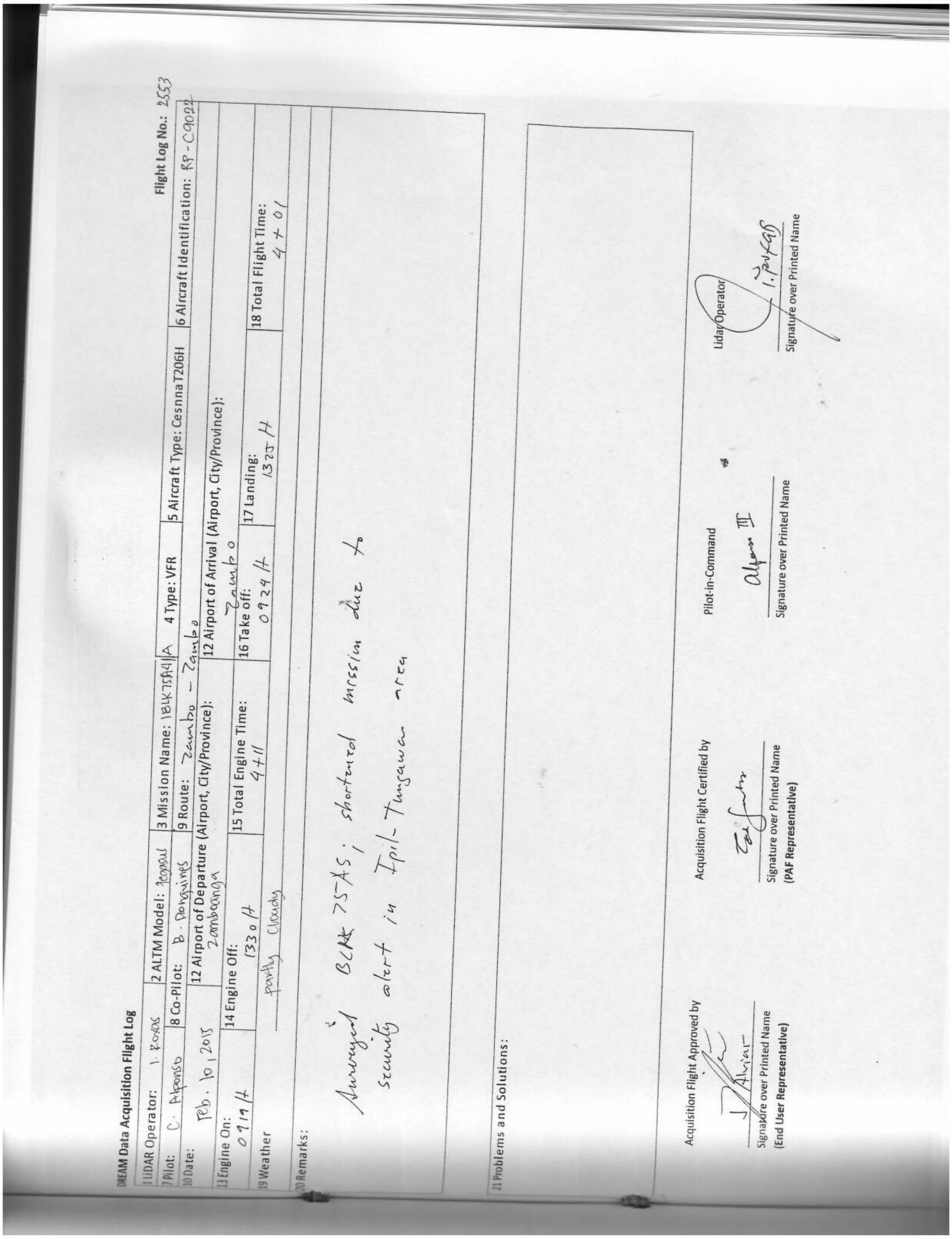
Flight Log No.: 2549

1 LiDAR Operator: I. Roxas
2 ALTM Model: Pegasus
3 Mission Name: 1BLK 75A4A
4 Type: VFR
5 Aircraft Type: Cesnna T206H
6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso
8 Co-Pilot: B. Dongui...
9 Route: Zambo – Zambo
10 Date: Feb 9, 2015
12 Airport of Departure (Airport, City/Province): Zambo
12 Airport of Arrival (Airport, City/Province): Zambo
13 Engine On: 1103 H
14 Engine Off: 1524 H
15 Total Engine Time: 4+23
16 Take off: 1108 H
17 Landing: 1521 H
18 Total Flight Time: 4+13
19 Weather: Partly Cloudy
20 Remarks: Surveyed gaps in BLK 75C, D, E, F5;
21 Problems and Solutions: abnormal program termination; POS still writing

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

Figure A-6.1. Flight Log for 2549P Mission

2. Flight Log for 2553P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 2553

1 LiDAR Operator: I. Roxas	2 ALTM Model: Pegasus	3 Mission Name: 1BLK75SA41A	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. 10, 2015	12 Airport of Departure (Airport, City/Province): Zamboanga	12 Airport of Arrival (Airport, City/Province): Zambo			
13 Engine On: 0919H	14 Engine Off: 1330H	15 Total Engine Time: 4+11	16 Take off: 0924H	17 Landing: 1325H	18 Total Flight Time: 4+01
19 Weather: partly cloudy					

20 Remarks:

Surveyed BLK 75AS; shortened mission due to security alert in Ipil-Tungawan area

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

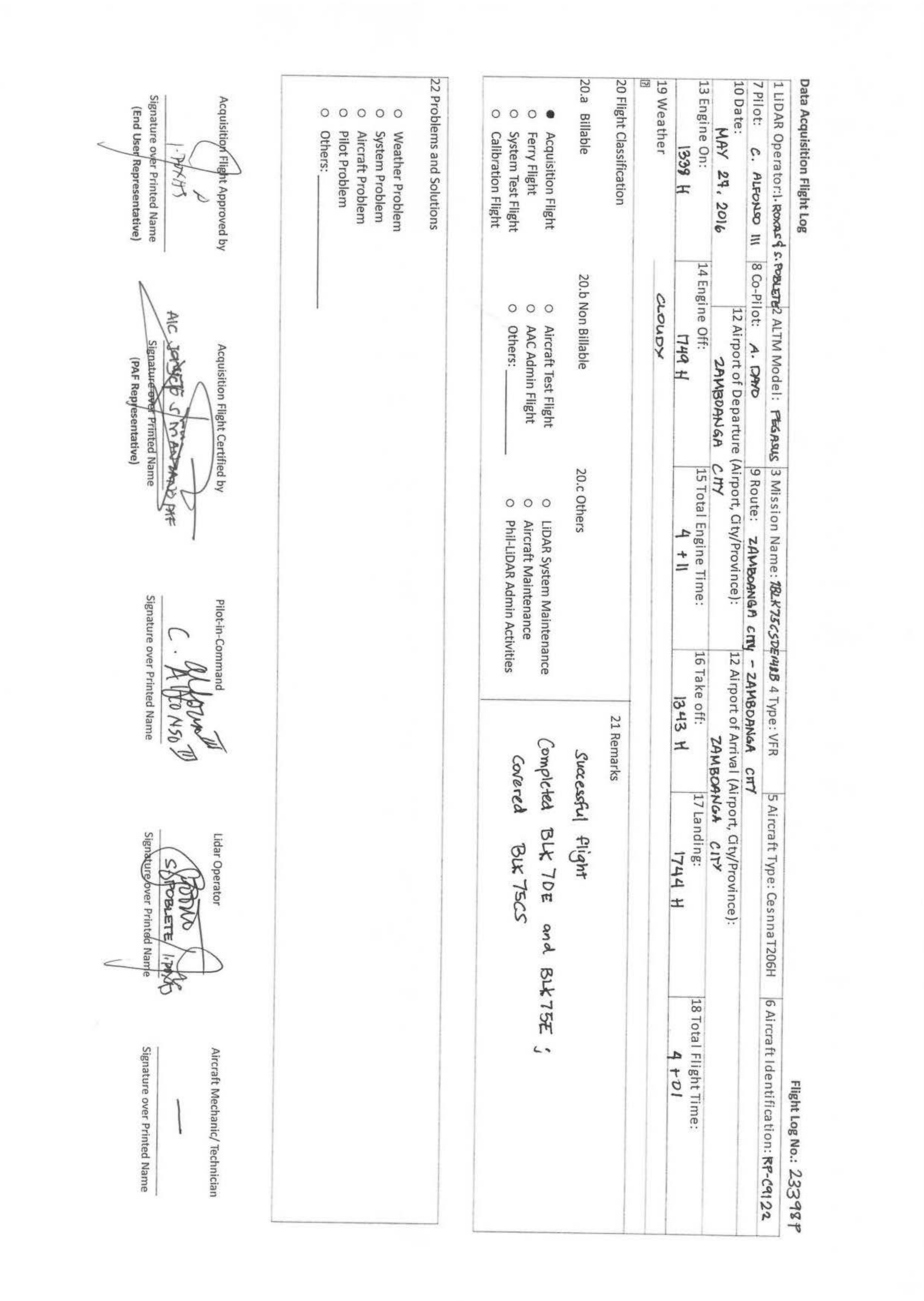
Signature over Printed Name

Lidar Operator

Signature over Printed Name

Figure A-6.2. Flight Log for 2553P Mission

3. Flight Log for 23398P Mission



Data Acquisition Flight Log — **Flight Log No.:** 23398P

1 LIDAR Operator: I. Roxas & S. Poblete	2 ALTM Model: Pegasus	3 Mission Name: 3BLK75CSDE148B	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9122
7 Pilot: C. Alfonso III	8 Co-Pilot: A. Dayo	9 Route: Zamboanga City - Zamboanga City			
10 Date: May 27, 2016	12 Airport of Departure (Airport, City/Province): Zamboanga City		12 Airport of Arrival (Airport, City/Province): Zamboanga City		
13 Engine On: 1339 H	14 Engine Off: 1749 H	15 Total Engine Time: 4 + 11	16 Take off: 1343 H	17 Landing: 1744 H	18 Total Flight Time: 4 + 01
19 Weather: Cloudy					

20 Flight Classification

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

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

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

21 Remarks

Successful flight
Completed BLK 70E and BLK 75E ;
Covered BLK 75CS

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

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

Acquisition Flight Certified by: A/C Jaycee S Madrono? PAF — Signature over Printed Name (PAF Representative)

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

Lidar Operator: S. Poblete / I. Roxas — Signature over Printed Name

Aircraft Mechanic/ Technician: — Signature over Printed Name

Figure A-6.3. Flight Log for 23398P Mission

4. Flight Log for 23410P Mission

Data Acquisition Flight Log — Flight Log No.: 23410P

1 LiDAR Operator: J. ALMALVEZ	2 ALTM Model: PEGASUS	3 Mission Name: 1BLK75CS151B	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: RP-C9122
7 Pilot: C. ALFONSO III	8 Co-Pilot: A. DAYO	9 Route: ZAMBOANGA CITY - ZAMBOANGA CITY			
10 Date: MAY 30, 2016	12 Airport of Departure (Airport, City/Province): ZAMBOANGA CITY		12 Airport of Arrival (Airport, City/Province): ZAMBOANGA CITY		
13 Engine On: 1430 H	14 Engine Off: 1735 H	15 Total Engine Time: 3+05	16 Take off: 1435	17 Landing: 1730	18 Total Flight Time: 2+55
19 Weather: FAIR					

20 Flight Classification

20.a Billable	20.b Non Billable	20.c Others
● Acquisition Flight	○ Aircraft Test Flight	○ LiDAR System Maintenance
○ Ferry Flight	○ AAC Admin Flight	○ Aircraft Maintenance
○ System Test Flight	○ Others: ______	○ Phil-LiDAR Admin Activities
○ Calibration Flight		

21 Remarks

Successful flight
Completed BLK 75CS

22 Problems and Solutions

- ○ Weather Problem
- ○ System Problem
- ○ Aircraft Problem
- ○ Pilot Problem
- ○ Others: ______

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
I. Poyao	MC Jaycee F. Manzano PAF	C. Alfonso III	J. Almalvez	
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.4. Flight Log for 23410P Mission

Annex 7. Flight Status Reports

Table A-7.1. Flight Status Report

FLIGHT STATUS REPORT

Zamboanga-Zamboanga Sibugay

February 9-10, 2015; May 27 and 30, 2016

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
2549P	BLK 75A	1BLK75A40A	I. ROXAS	Feb. 9, 2015	AVPOSVIEW : ASSERTION FAILED; ABNORMAL PROGRAM TERMINATION
2553P	BLK 75A BLK75AS	1BLK75S41A	I. ROXAS	Feb. 10, 2015	AVPOSVIEW ERROR; ASSERTION FAILED
23398P	BLK75CS BLK75D BLK75E	1BLK75CS-DE148B	I. ROXAS	May 27, 2016	COMPLETED BLK7DE and BLK75E. COVERED BLK75CS
23410P	BLK75CS	1BLK75CS151B	J. ALMALVEZ	May 30, 2016	COMPLETED BLK75CS

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

Flight No.: 2549P

Area: BLK75A

Mission Name: 1BLK75A40A

Parameters: Altitude: 1200m; Scan Frequency: 30; Scan Angle: 50

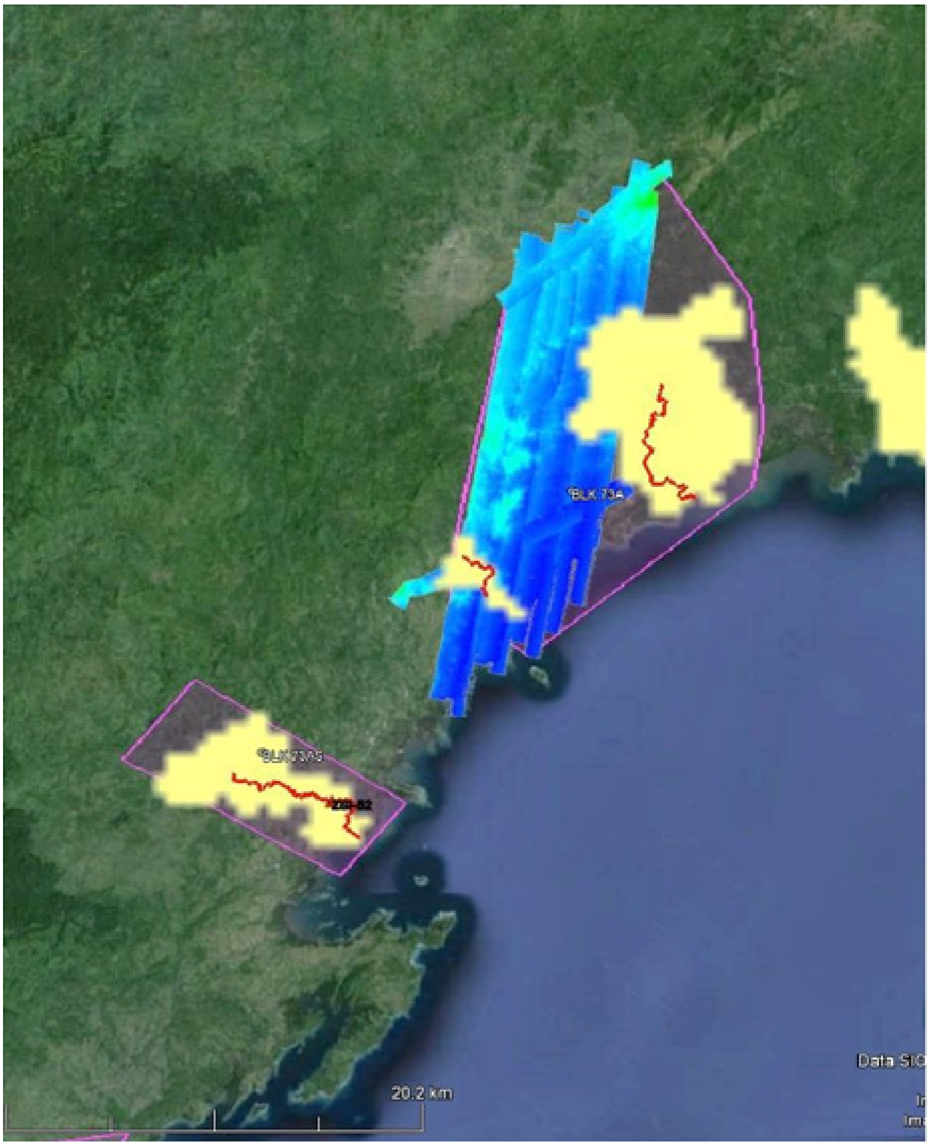


Figure A-7.1. Swath for Flight No. 2549P

Flight No.:	2553P
Area:	BLK75AS
Mission Name:	1BLK75AS41A
Parameters:	Altitude: 1200m; Scan Frequency: 30; Scan Angle: 50

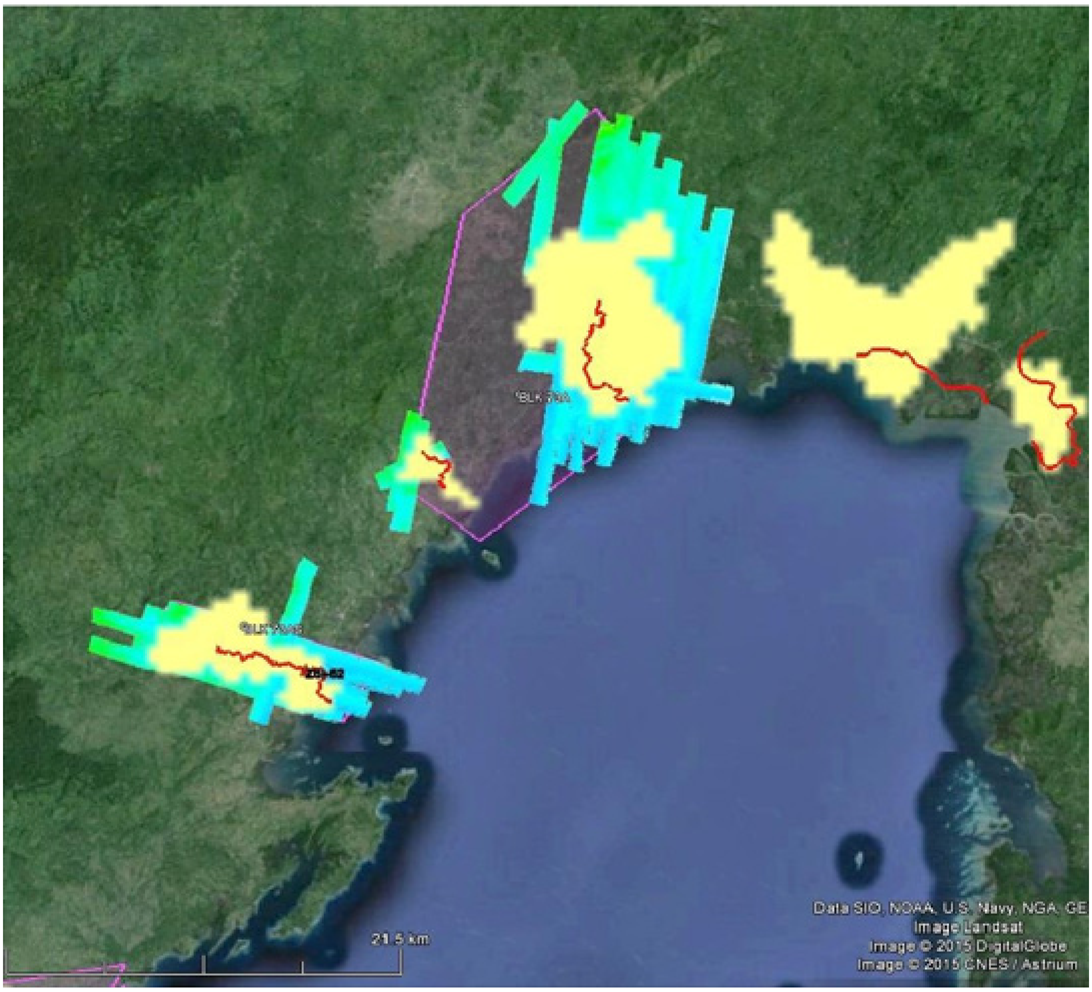


Figure A-7.2. Swath for Flight No. 2553P

Flight No. :	23398P
Area:	BLK75CS, BLK75D, BLK75E
Mission Name:	1BLK75CSDE148B
Parameters:	Altitude: 1100m; Scan Frequency: 30; Scan Angle: 50

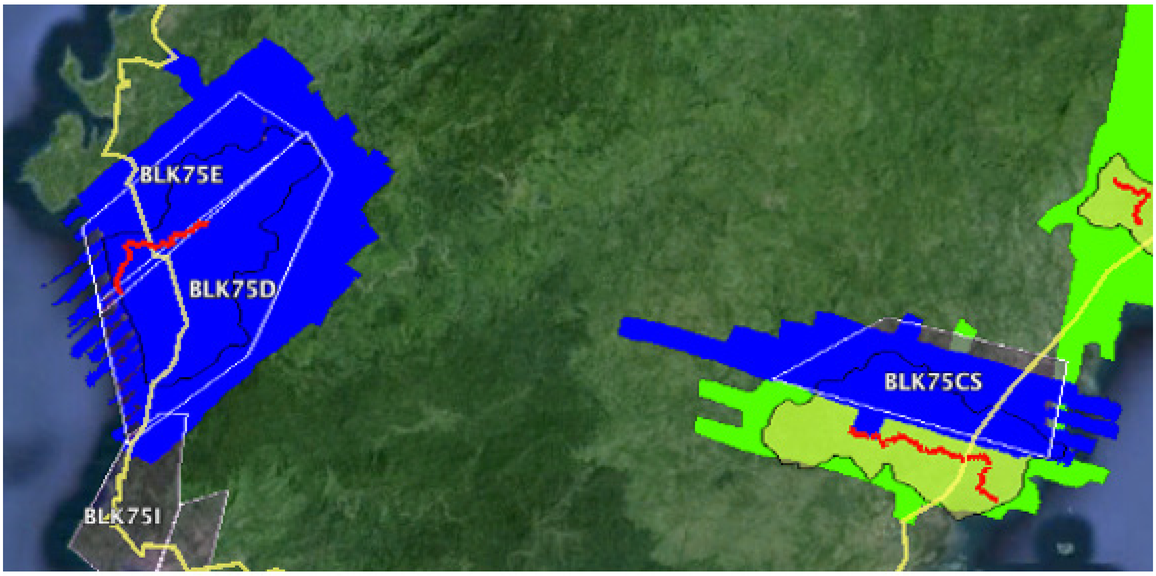


Figure A-7.3. Swath for Flight No. 23398P

Flight No. :	23410P
Area:	BLK75CS
Mission Name:	1BLK75CS151B
Parameters:	Altitude: 1100m; Scan Frequency: 30; Scan Angle: 50

Figure A-7.4. Swath for Flight No. 23410P

Annex 9. Tupilac Model Basin Parameters

Table A-9.1. Tupilac 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
W1060	46.567	80.34	0.0	2.129	3.4745	Discharge	0.12382	0.23	Ratio to Peak	0.25
W1050	47.149	80.11958	0.0	0.60733	0.99117	Discharge	0.0275687	0.23	Ratio to Peak	0.25
W1040	45.807	80.62943	0.0	1.2745	2.0801	Discharge	0.0542113	0.23	Ratio to Peak	0.25
W1030	46.567	80.34	0.0	0.83845	1.3684	Discharge	0.0274590	0.23	Ratio to Peak	0.25
W1020	46.567	80.34	0.0	0.6108	0.99682	Discharge	0.0037151	0.23	Ratio to Peak	0.25
W1010	46.567	80.34	0.0	1.4371	2.3454	Discharge	0.0462432	0.23	Ratio to Peak	0.25
W1000	48.511	79.6087	0.0	1.0981	1.7922	Discharge	0.0604917	0.23	Ratio to Peak	0.25
W990	52.983	77.97615	0.0	1.0415	1.6997	Discharge	0.0279780	0.23	Ratio to Peak	0.25
W980	46.567	80.34	0.0	0.45704	0.74589	Discharge	0.0038227	0.23	Ratio to Peak	0.25
W970	46.567	80.34	0.0	0.94479	1.5419	Discharge	0.0205922	0.23	Ratio to Peak	0.25
W960	46.567	80.34	0.0	0.53245	0.86896	Discharge	0.0033459	0.23	Ratio to Peak	0.25
W950	46.567	80.34	0.0	0.93754	1.5301	Discharge	0.0589411	0.23	Ratio to Peak	0.25
W940	46.567	80.34	0.0	0.19332	0.3155	Discharge	0.0016160	0.23	Ratio to Peak	0.25
W930	46.567	80.34	0.0	1.3016	2.1243	Discharge	0.0211385	0.23	Ratio to Peak	0.25
W920	68.935	72.66135	0.0	1.6271	2.6555	Discharge	0.0183918	0.23	Ratio to Peak	0.25
W910	46.567	80.34	0.0	2.0518	3.3485	Discharge	0.0325686	0.23	Ratio to Peak	0.25
W900	76.911	70.2666	0.0	0.85329	1.3926	Discharge	0.0320981	0.23	Ratio to Peak	0.25
W890	77.227	70.17493	0.0	0.96067	1.5678	Discharge	0.0230668	0.23	Ratio to Peak	0.25
W880	46.567	80.34	0.0	0.49015	0.79993	Discharge	0.0010147	0.23	Ratio to Peak	0.25
W870	46.567	80.34	0.0	0.99239	1.6196	Discharge	0.0473044	0.23	Ratio to Peak	0.25
W860	58.595	76.02018	0.0	1.011	1.6499	Discharge	0.0227566	0.23	Ratio to Peak	0.25
W850	46.567	80.34	0.0	0.9815	1.6018	Discharge	0.0434100	0.23	Ratio to Peak	0.25
W840	46.567	80.34	0.0	0.72396	1.1815	Discharge	0.0074217	0.23	Ratio to Peak	0.25
W830	53.283	77.86903	0.0	1.8484	3.0166	Discharge	0.12536	0.23	Ratio to Peak	0.25
W820	77.025	70.23364	0.0	1.2019	1.9615	Discharge	0.0446842	0.23	Ratio to Peak	0.25
W810	54.939	77.28296	0.0	1.0727	1.7507	Discharge	0.0377857	0.23	Ratio to Peak	0.25
W800	46.567	80.34	0.0	1.114	1.8181	Discharge	0.0655886	0.23	Ratio to Peak	0.25
W790	51.655	78.45407	0.0	1.9433	3.1715	Discharge	0.12356	0.23	Ratio to Peak	0.25
W780	61.077	75.18588	0.0	0.67581	1.1029	Discharge	0.0109279	0.23	Ratio to Peak	0.25
W770	46.567	80.34	0.0	0.73352	1.1971	Discharge	0.0394523	0.23	Ratio to Peak	0.25
W760	53.570	77.76706	0.0	0.38778	0.63286	Discharge	0.0102254	0.23	Ratio to Peak	0.25
W750	51.826	78.39227	0.0	1.0493	1.7124	Discharge	0.0560277	0.23	Ratio to Peak	0.25
W740	47.455	80.00422	0.0	0.25081	0.40932	Discharge	0.0021750	0.23	Ratio to Peak	0.25
W730	46.567	80.34	0.0	0.81539	1.3307	Discharge	0.0294505	0.23	Ratio to Peak	0.25
W720	51.7943773	78.4036	0.0	0.80056	1.3065	Discharge	0.0388405	0.23	Ratio to Peak	0.25
W710	61.832	74.93559	0.0	0.70966	1.1582	Discharge	0.0312332	0.23	Ratio to Peak	0.25
W700	77.612	70.06369	0.0	1.0053	1.6406	Discharge	0.0242165	0.23	Ratio to Peak	0.25
W690	58.253	76.13657	0.0	1.6139	2.6338	Discharge	0.11752	0.23	Ratio to Peak	0.25
W680	83.605	68.37552	0.0	1.6152	2.6359	Discharge	0.0491629	0.23	Ratio to Peak	0.25
W670	70.0684353	72.31115	0.0	1.679	2.7402	Discharge	0.0780839	0.23	Ratio to Peak	0.25
W660	85.052	67.98	0.0	0.27117	0.44254	Discharge	0.0015717	0.23	Ratio to Peak	0.25
W650	49.060	79.40476	0.0	0.41718	0.68084	Discharge	0.0071685	0.23	Ratio to Peak	0.25
W640	46.567	80.34	0.0	0.64751	1.0567	Discharge	0.0308935	0.23	Ratio to Peak	0.25
W630	84.014	68.26325	0.0	1.2038	1.9645	Discharge	0.0441420	0.23	Ratio to Peak	0.25
W620	83.950	68.28076	0.0	1.2927	2.1096	Discharge	0.0250962	0.23	Ratio to Peak	0.25
W610	85.052	67.98	0.0	0.15993	0.261	Discharge	.000894486	0.23	Ratio to Peak	0.25
W600	85.052	67.98	0.0	1.3017	2.1244	Discharge	0.0279801	0.23	Ratio to Peak	0.25
W590	85.052	67.98	0.0	1.4563	2.3766	Discharge	0.0394966	0.23	Ratio to Peak	0.25
W580	52.940	77.9916	0.0	0.90156	1.4713	Discharge	0.0319462	0.23	Ratio to Peak	0.25
W570	85.052	67.98	0.0	1.3121	2.1413	Discharge	0.0413678	0.23	Ratio to Peak	0.25
W560	85.052	67.98	0.0	1.3144	2.1451	Discharge	0.0272966	0.23	Ratio to Peak	0.25
W550	78.6943917	69.75263	0.0	1.3145	2.1453	Discharge	0.0509519	0.23	Ratio to Peak	0.25
W540	85.052	67.98	0.0	3.0969	5.0541	Discharge	0.0779278	0.23	Ratio to Peak	0.25

Annex 10. Tupilac Model Reach Parameters

Table A-10.1. Tupilac Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R30	Automatic Fixed Interval	1324.7	0.0566784	0.093	Trapezoid	30	0.01
R50	Automatic Fixed Interval	166.57	0.0390724	0.093	Trapezoid	30	0.01
R80	Automatic Fixed Interval	203.14	0.0924224	0.093	Trapezoid	30	0.01
R100	Automatic Fixed Interval	906.69	0.0554166	0.093	Trapezoid	30	0.01
R130	Automatic Fixed Interval	2436.6	0.0494015	0.093	Trapezoid	30	0.01
R170	Automatic Fixed Interval	434.85	0.0151141	0.093	Trapezoid	30	0.01
R180	Automatic Fixed Interval	1236.4	0.0319159	0.093	Trapezoid	30	0.01
R210	Automatic Fixed Interval	764.56	0.0664243	0.093	Trapezoid	30	0.01
R220	Automatic Fixed Interval	3080.5	0.0423029	0.093	Trapezoid	30	0.01
R230	Automatic Fixed Interval	564.56	0.0372567	0.093	Trapezoid	30	0.01
R240	Automatic Fixed Interval	1981.4	0.0221801	0.093	Trapezoid	30	0.01
R280	Automatic Fixed Interval	2229.4	0.0118260	0.093	Trapezoid	30	0.01
R290	Automatic Fixed Interval	990.83	0.0133984	0.093	Trapezoid	30	0.01
R300	Automatic Fixed Interval	604.56	0.0062959	0.093	Trapezoid	30	0.01
R340	Automatic Fixed Interval	339.71	0.0040483	0.093	Trapezoid	30	0.01
R350	Automatic Fixed Interval	1643.7	0.0094137	0.093	Trapezoid	30	0.01
R370	Automatic Fixed Interval	1128.8	0.0012812	0.093	Trapezoid	30	0.01
R400	Automatic Fixed Interval	313.85	0.0134138	0.093	Trapezoid	30	0.01
R410	Automatic Fixed Interval	1399.4	0.0043995	0.093	Trapezoid	30	0.01
R420	Automatic Fixed Interval	751.42	.00038579153705667346	0.093	Trapezoid	30	0.01
R430	Automatic Fixed Interval	571.13	0.0012812	0.093	Trapezoid	30	0.01
R440	Automatic Fixed Interval	1127.7	0.0027485	0.093	Trapezoid	30	0.01
R460	Automatic Fixed Interval	1240.8	0.0038454	0.093	Trapezoid	30	0.01
R470	Automatic Fixed Interval	734.56	0.0012812	0.093	Trapezoid	30	0.01
R480	Automatic Fixed Interval	2209.2	0.0098225	0.093	Trapezoid	30	0.01
R510	Automatic Fixed Interval	3478.9	0.0018531	0.093	Trapezoid	30	0.01

Annex 11. Tupilac Field Validation Points

Table A-11.1 Tupilac Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	7.629196	122.4516	0.03	0.5	-0.47	Typhoon	5 -Year
2	7.628328	122.45127	0.03	0	0.03	Typhoon	5 -Year
3	7.628521	122.45166	0.03	0.5	-0.47		5 -Year
4	7.628382	122.45165	0.03	0	0.03		5 -Year
5	7.628382	122.45189	0.29	0	0.29		5 -Year
6	7.628661	122.45186	0.03	0.5	-0.47		5 -Year
7	7.628632	122.45225	0.34	0.1	0.24		5 -Year
8	7.628681	122.45244	0.27	0.1	0.17		5 -Year
9	7.629049	122.45281	0.07	0.1	-0.03		5 -Year
10	7.628267	122.45052	0.03	0.5	-0.47		5 -Year
11	7.628193	122.45003	0.03	0.1	-0.07		5 -Year
12	7.628319	122.45001	0.03	0.1	-0.07		5 -Year
13	7.628113	122.4498	0.03	0.15	-0.12		5 -Year
14	7.627815	122.449	0.03	0	0.03		5 -Year
15	7.627906	122.44873	0.03	0.5	-0.47		5 -Year
16	7.6269	122.44843	0.03	0	0.03		5 -Year
17	7.627128	122.45165	0.1	0	0.10		5 -Year
18	7.626832	122.45211	0.03	0	0.03		5 -Year
19	7.624194	122.45178	0.03	0	0.03		5 -Year
20	7.622691	122.45141	0.03	0	0.03		5 -Year
21	7.621978	122.45107	0.03	0	0.03		5 -Year
22	7.619783	122.44947	0.16	0	0.16		5 -Year
23	7.62001	122.44893	0.03	0	0.03		5 -Year
24	7.617035	122.44496	0.03	0	0.03		5 -Year
25	7.616669	122.44404	0.04	0	0.04		5 -Year
26	7.61702	122.44355	0.03	0	0.03		5 -Year
27	7.617703	122.44266	0.03	0	0.03		5 -Year
28	7.615711	122.44465	0.03	0	0.03		5 -Year
29	7.615522	122.44462	0.03	0	0.03		5 -Year
30	7.612077	122.44121	0.03	0	0.03		5 -Year
31	7.612701	122.44253	0.03	0	0.03		5 -Year
32	7.613031	122.44285	0.09	0	0.09		5 -Year
33	7.614162	122.44363	0.08	0	0.08		5 -Year
34	7.61483	122.4438	0.03	0	0.03		5 -Year
35	7.615128	122.44354	0.03	0	0.03		5 -Year
36	7.615035	122.44273	0.03	0	0.03		5 -Year
37	7.61512	122.44396	0.03	0	0.03		5 -Year
38	7.615339	122.44393	0.03	0	0.03		5 -Year
39	7.640763	122.46038	0.03	0	0.03		5 -Year
40	7.640343	122.46387	0.03	0	0.03		5 -Year
41	7.638952	122.46501	0.07	0	0.07		5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
42	7.640977	122.45917	0.04	0	0.04		5 -Year
43	7.640395	122.45929	0.03	0	0.03		5 -Year
44	7.640481	122.4587	0.03	0	0.03		5 -Year
45	7.640367	122.4586	0.04	0	0.04		5 -Year
46	7.639892	122.4581	0.04	0	0.04		5 -Year
47	7.639694	122.45795	0.03	0	0.03		5 -Year
48	7.639463	122.4576	0.04	0	0.04		5 -Year
49	7.639186	122.45729	0.03	0	0.03		5 -Year
50	7.639006	122.45747	0.03	0	0.03		5 -Year
51	7.638744	122.45726	0.03	0	0.03		5 -Year
52	7.63874	122.45694	0.04	0	0.04		5 -Year
53	7.628497	122.431	0.03	0	0.03		5 -Year
54	7.628235	122.43075	0.13	0	0.13		5 -Year
55	7.628188	122.43069	0.18	0	0.18		5 -Year
56	7.633658	122.42638	0.03	0	0.03		5 -Year
57	7.629777	122.45312	0.03	0.5	-0.47		5 -Year
58	7.629802	122.45326	0.03	0.1	-0.07		5 -Year
59	7.630876	122.4553	0.03	0.2	-0.17		5 -Year
60	7.631539	122.45595	0.27	0.1	0.17	Lawin	5 -Year
61	7.630689	122.45727	0.03	0.15	-0.12		5 -Year
62	7.630534	122.45905	0.07	0.15	-0.08		5 -Year
63	7.628219	122.45222	0.25	0.4	-0.15		5 -Year
64	7.634005	122.4196	0.03	0	0.03		5 -Year
65	7.634413	122.41942	0.03	0	0.03		5 -Year
66	7.633679	122.41358	0.03	0	0.03		5 -Year
67	7.634315	122.41351	0.03	0	0.03		5 -Year
68	7.633989	122.41281	0.03	0	0.03		5 -Year
69	7.643291	122.4065	1.5	0.46	1.04	Ondoy	5 -Year
70	7.644518	122.40542	0.63	0.6	0.03	Ondoy	5 -Year
71	7.629214	122.45213	0.04	0.1	-0.06		5 -Year
72	7.629228	122.45229	0.03	0.1	-0.07		5 -Year
73	7.629345	122.45204	0.06	0.1	-0.04		5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
74	7.631236	122.45258	0.03	0.1	-0.07	Lawin..	5 -Year
75	7.631864	122.45247	0.94	0.5	0.44		5 -Year
76	7.632743	122.4528	0.33	0.2	0.13		5 -Year
77	7.62943	122.45152	0.59	0.4	0.19		5 -Year
78	7.614171	122.44455	0.03	0.1	-0.07		5 -Year
79	7.614044	122.4446	0.07	0.1	-0.03		5 -Year
80	7.614089	122.44452	0.04	0.1	-0.06		5 -Year
81	7.614021	122.44478	0.06	0.1	-0.04		5 -Year
82	7.61445	122.44528	0.03	0.1	-0.07		5 -Year
83	7.614347	122.44558	0.03	0.1	-0.07		5 -Year
84	7.614142	122.44553	0.23	0.1	0.13		5 -Year
85	7.614648	122.44605	0.06	0.1	-0.04		5 -Year
86	7.614807	122.44635	0.03	0.1	-0.07		5 -Year
87	7.614809	122.44624	0.07	0.1	-0.03		5 -Year
88	7.614752	122.44628	0.03	0.1	-0.07		5 -Year
89	7.614831	122.44636	0.03	0.1	-0.07		5 -Year
90	7.629143	122.45183	0.03	0.5	-0.47		5 -Year
91	7.629089	122.45174	0.03	0.5	-0.47		5 -Year
92	7.629347	122.45156	0.03	0.15	-0.12	Lawin	5 -Year
93	7.636214	122.40444	0.95	0.2	0.75	Lawin	5 -Year
94	7.629789	122.45752	0.03	0.14	-0.11		5 -Year
95	7.630149	122.4572	0.03	0.1	-0.07	Lawin	5 -Year
96	7.629927	122.45586	0.03	0.1	-0.07	Lawin	5 -Year
97	7.6295	122.45509	0.03	0.12	-0.09	Lawin	5 -Year
98	7.629128	122.45403	0.03	0.15	-0.12	Lawin	5 -Year
99	7.62951	122.45518	0.03	0.2	-0.17	Lawin	5 -Year
100	7.630294	122.45537	0.03	0.2	-0.17	100	5 -Year
101	7.629922	122.45585	0.03	0.3	-0.27	101	5 -Year
102	7.634615	122.45326	0.03	0.5	-0.47	102	5 -Year
103	7.634713	122.45327	0.03	0.5	-0.47	103	5 -Year
104	7.628626	122.45131	0.03	0.1	-0.07	104	5 -Year
105	7.629342	122.45188	0.03	0.4	-0.37	105	5 -Year
106	7.629403	122.45208	0.06	0.3	-0.24	106	5 -Year
107	7.629498	122.45132	0.67	0.6	0.07	107	5 -Year
108	7.627681	122.45097	0.04	0.2	-0.16	108	5 -Year
109	7.62773	122.45095	0.07	0.2	-0.13	109	5 -Year
110	7.627725	122.45075	0.03	0.3	-0.27	110	5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
111	7.626609	122.45318	0.03	0.5	-0.47	111	5 -Year
112	7.62687	122.45315	0.12	0.5	-0.38	112	5 -Year
113	7.626742	122.45323	0.08	0.5	-0.42	113	5 -Year
114	7.627445	122.45408	0.03	0.1	-0.07	114	5 -Year
115	7.635124	122.38532	0.03	0	0.03	115	5 -Year
116	7.63551	122.38541	0.03	0	0.03	116	5 -Year
117	7.632191	122.38582	0.03	0	0.03	117	5 -Year
118	7.631369	122.38564	0.03	0	0.03	118	5 -Year
119	7.633881	122.43627	0.09	0.15	-0.06	119	5 -Year
120	7.63544	122.4341	0.23	0.8	-0.57	120	5 -Year
121	7.634551	122.45325	0.03	0.4	-0.37	121	5 -Year
122	7.631211	122.45013	0.21	0.5	-0.29	122	5 -Year
123	7.651852	122.39555	0.04	0	0.04	123	5 -Year
124	7.655825	122.39389	0.03	0	0.03	124	5 -Year
125	7.651627	122.38826	0.03	0	0.03	125	5 -Year
126	7.652969	122.38682	0.03	0	0.03	126	5 -Year
127	7.650008	122.38721	0.03	0	0.03	127	5 -Year
128	7.650123	122.3873	0.03	0	0.03	128	5 -Year
129	7.648629	122.38654	0.03	0	0.03	129	5 -Year
130	7.648807	122.38871	0.05	0	0.05	130	5 -Year
131	7.648681	122.38889	0.03	0	0.03	131	5 -Year
132	7.647328	122.39282	0.03	0	0.03	132	5 -Year
133	7.651057	122.38512	0.07	0	0.07	133	5 -Year
134	7.653202	122.38318	0.03	0	0.03	134	5 -Year
135	7.655312	122.38176	0.03	0	0.03	135	5 -Year
136	7.654784	122.38024	0.03	0	0.03	136	5 -Year
137	7.656822	122.3822	0.03	0	0.03	137	5 -Year
138	7.655166	122.38324	0.03	0	0.03	138	5 -Year
139	7.658924	122.38495	0.04	0	0.04	139	5 -Year
140	7.659717	122.37786	0.03	0	0.03	140	5 -Year
141	7.662395	122.38567	0.03	0	0.03	141	5 -Year
142	7.662423	122.38104	0.03	0	0.03	142	5 -Year
143	7.663103	122.3783	0.04	0	0.04	143	5 -Year
144	7.66285	122.38262	0.03	0	0.03	144	5 -Year
145	7.644542	122.38516	0.03	0	0.03	145	5 -Year
146	7.648212	122.38489	0.03	0	0.03	146	5 -Year
147	7.64731	122.38327	0.03	0	0.03	147	5 -Year
148	7.648112	122.38163	0.03	0	0.03	148	5 -Year
149	7.645803	122.382	0.07	0	0.07	149	5 -Year
150	7.648921	122.37855	0.03	0	0.03	150	5 -Year
151	7.648158	122.37744	0.03	0	0.03	151	5 -Year
152	7.644576	122.38222	0.03	0	0.03	152	5 -Year
153	7.649285	122.37932	0.03	0	0.03	153	5 -Year
154	7.629831	122.45948	0.03	0.1	-0.07	154	5 -Year
155	7.628305	122.46035	0.03	0.8	-0.77	155	5 -Year
156	7.628366	122.46025	0.03	0.8	-0.77	156	5 -Year
157	7.623913	122.46201	0.11	0.5	-0.39	157	5 -Year
158	7.624636	122.46393	0.03	0.1	-0.07	158	5 -Year
159	7.625147	122.46046	0.03	0.5	-0.47	159	5 -Year
160	7.625377	122.46553	0.11	0.3	-0.19	160	5 -Year
161	7.627651	122.46194	0.03	0.8	-0.77	161	5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
162	7.621798	122.46483	0.07	0	0.07	162	5 -Year
163	7.623908	122.46984	0.03	0.3	-0.27	163	5 -Year
164	7.621987	122.47058	0.03	0.3	-0.27	164	5 -Year
165	7.625086	122.4705	0.03	0.3	-0.27	165	5 -Year
166	7.622962	122.47243	0.03	0.3	-0.27	166	5 -Year
167	7.624651	122.47322	0.03	0.3	-0.27	167	5 -Year
168	7.615381	122.46116	0.03	0	0.03	168	5 -Year
169	7.615909	122.46621	0.03	0	0.03	169	5 -Year
170	7.618987	122.4596	0.03	0	0.03	170	5 -Year
171	7.618147	122.45863	0.03	0	0.03	171	5 -Year
172	7.617856	122.45701	0.03	0	0.03	172	5 -Year
173	7.618688	122.45558	0.03	0	0.03	173	5 -Year
174	7.620202	122.45322	0.03	0	0.03	174	5 -Year
175	7.622741	122.45594	0.11	0	0.11	175	5 -Year
176	7.62236	122.45482	0.23	0	0.23	176	5 -Year
177	7.622519	122.45371	0.03	0	0.03	177	5 -Year
178	7.631038	122.45213	0.1	0.1	0.00	178	5 -Year
179	7.631025	122.4522	0.1	0.1	0.00	179	5 -Year
180	7.614327	122.44471	0.05	0.3	-0.25	180	5 -Year
181	7.614258	122.44467	0.03	0.3	-0.27	181	5 -Year
182	7.614417	122.44479	0.06	0.3	-0.24	182	5 -Year
183	7.614559	122.44494	0.03	0.3	-0.27	183	5 -Year
184	7.614466	122.44508	0.03	0.3	-0.27	184	5 -Year
185	7.6145	122.44518	0.03	0.3	-0.27	185	5 -Year
186	7.614521	122.4453	0.03	0.3	-0.27	186	5 -Year
187	7.614506	122.44535	0.03	0.3	-0.27	187	5 -Year
188	7.615005	122.44504	0.03	0.3	-0.27	188	5 -Year
189	7.617116	122.44456	0.03	0	0.03	189	5 -Year
190	7.616658	122.4442	0.03	0	0.03	190	5 -Year
191	7.619567	122.44648	0.03	0	0.03	191	5 -Year
192	7.620794	122.44677	0.03	0	0.03	192	5 -Year
193	7.621567	122.44949	0.03	0	0.03	193	5 -Year
				RMSE	0.22		

Annex 12. Educational Institutions affected by flooding in Tupilac Floodplain

Table A-12.1. Educational Institutions affected by flooding in Tupilac Floodplain

Tungawan					
			Rainfall Scenario		
Barangay	Longitude	Latitude	5-year	25-year	100-year
Gaycon	122.3963	7.630373			
Gaycon	122.3958	7.629375			
Gaycon	122.3957	7.629418			
Gaycon	122.3974	7.631607			
Baluran	122.4427	7.617688			
Baluran	122.4425	7.617488			
Baluran	122.4424	7.617297			
Baluran	122.4424	7.617168			
Baluran	122.4424	7.616958			
Baluran	122.4434	7.616133			
Baluran	122.4166	7.633265			
Baluran	122.4167	7.633142			
Baluran	122.4168	7.63318			
Baluran	122.417	7.633174			
Baluran	122.4174	7.633406			
Baluran	122.4168	7.633407			
Baluran	122.4172	7.633313			

Roseller Lim					
			Rainfall Scenario		
Barangay	Longitude	Latitude	5-year	25-year	100-year
Tupilac	122.4568	7.636899			
Tupilac	122.4538	7.637301			
Tupilac	122.4538	7.637176			
Tupilac	122.4537	7.636909			
Tupilac	122.4537	7.636759			
Tupilac	122.4539	7.636548			
Tupilac	122.4542	7.636476			
Tupilac	122.4543	7.63638			
Tilasan	122.3994	7.647401			
Tilasan	122.3993	7.647691			
Tilasan	122.399	7.648136			
Tilasan	122.3988	7.646737			
Tilasan	122.3987	7.646978			
Tilasan	122.3987	7.647117			
Tilasan	122.3987	7.647297			
Tilasan	122.3987	7.647515			
Tilasan	122.3989	7.647516			

Annex 13. Health Institutions affected by flooding in Tupilac Floodplain

Table A-13.1. Health Institutions affected by flooding in Tupilac Floodplain

Tungawan					
			Rainfall Scenario		
Barangay	Longitude	Latitude	5-year	25-year	100-year
Baluran	122.4518	7.626196		Low	Low

Roseller Lim					
			Rainfall Scenario		
Barangay	Longitude	Latitude	5-year	25-year	100-year
Tupilac	122.457	7.637101			