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

LiDAR Surveys and Flood Mapping of Tawiran-Tagum River

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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
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
UPLB	University of the Philippines Los Baños
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 TAWIRAN-TAGUM RIVER

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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, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST.

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

1.2 Overview of the Tawiran-Tagum River Basin

The Tawiran-Tagum River Basin is a 79,170-hectare watershed located in Marinduque. It covers two (2) municipalities in Marinduque namely: Santa Cruz and Torrijos. It encompasses the barangays of Baguidbirin, Banogbog, Biga, Buyabod, Devilla, Haguimit, Jolo, Kaganhao, Kilo-kilo, Kitaman, Labo, Libjo, Makulapnit, Masalukot, Matalaba, Napo, Pantayin, Pulong-Parang, Tambangan, and Tawiran in Santa Cruz municipality; and, Bangwayin, Maranlig, Nangka, Pakaskasan and Sibuyao in Torrijos. The DENR River Basin Control Office identified the basin to have a drainage area of 58 km2 and an estimated 92 million cubic meter (MCM) annual run-off (RBCO, 2015).

As for the climate, Climate Type I and III prevails in MIMAROPA and Laguna based on the Modified Corona Classification of climate. Type I has two pronounced seasons, dry from November to April, and wet the rest of the year with maximum rain period from June to September. On the other hand, Type III has no very pronounced maximum rain period and with short dry season lasting only from one to three months, during the period from December to February or from March to May.

The river basin is generally characterized by 30-50% slope and elevation of up to 800 meters above mean sea level. The soil types in the river basin are Banto clay loam, Tagum clay loam, Faraon clay, Cabahuan clay and San Manuel sandy loam. Cultivated area mixed with brushland/grassland is predominant in the area followed by coconut plantations, mangrove forest and cropland mixed with coconut plantation.

Its main stem, Tawiran-Tagum River, is part of the forty-five (45) river systems in the Southern Tagalog region under the PHIL-LIDAR 1 partner HEI, University of the Philippines Los Baños (UPLB). Tawiran-Tagum River passes through Baguidbirin, Banogbog, Biga, Buyabod, Devilla, Haguimit, Jolo, Kaganhao, Kilo-kilo, Kitaman, Labo, Libjo, Makulapnit, Masalukot, Matalaba, Napo, Pantayin, Pulong-Parang, Tambangan, and Tawiran in the Municipality of Santa Cruz; and Bangwayin, Maranlig, Nangka, Pakaskasan, and Sibuyao in Torrijos.

According to the 2015 national census of NSO, a total of 5,047 persons are residing within the immediate vicinity of the river which is distributed among four barangays in the Municipality of Santa Cruz, namely: Pantayin, Matalaba, Biga, and Buyabod.

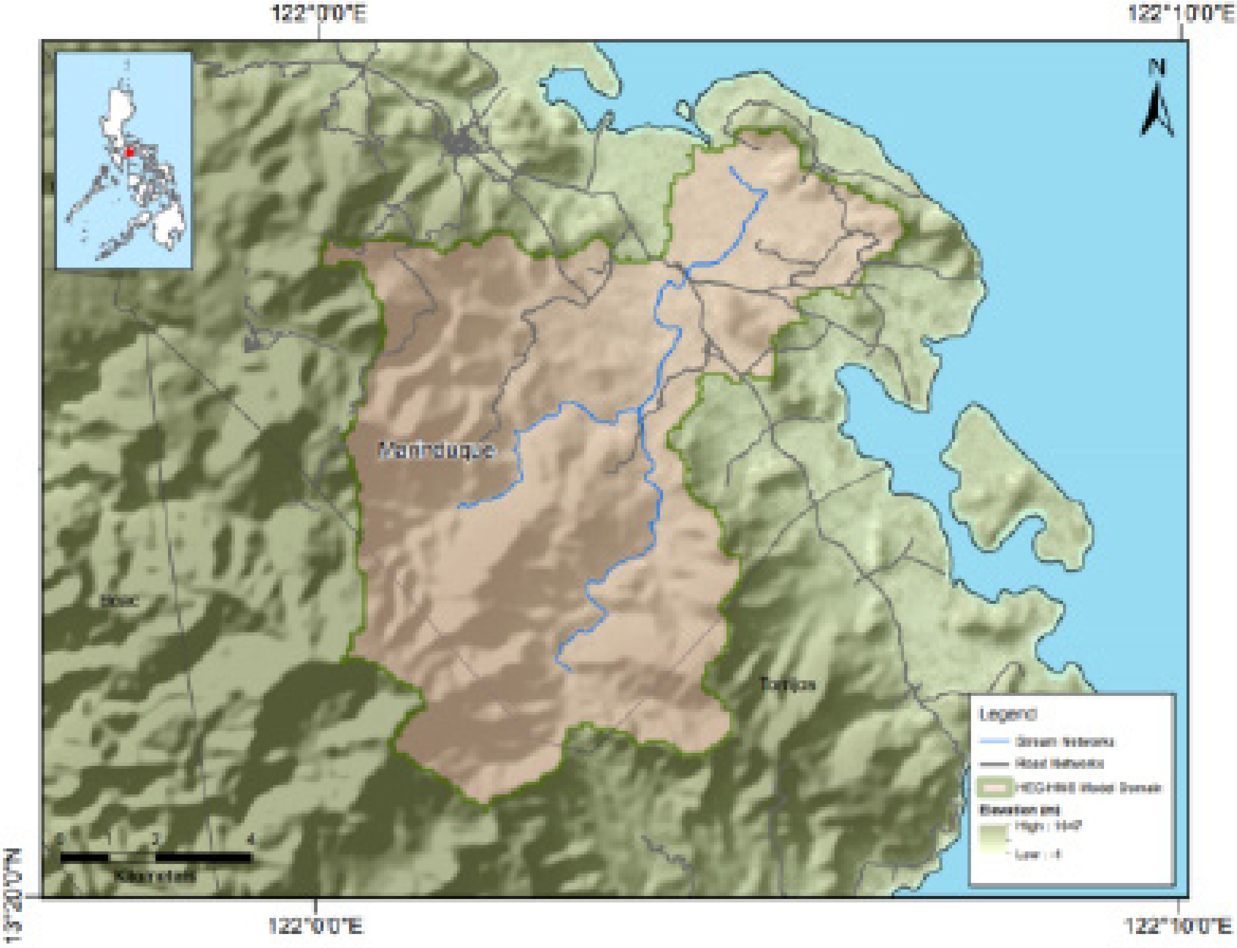

Figure 1. Map of the Tawiran-Tagum River Basin (in brown)

Meanwhile, the economy of the province relies mostly on agriculture specifically growing rice and coconuts. However, two decades ago, mining played an important role in the economy of the province; until a mining accident happened where it brought disastrous social, economic, and environmental consequences (http://umich.edu/~snre492/Jones/marcopper.htm, 2016).

Based on the studies conducted by the Mines and Geosciences Bureau, both Santa Cruz and Torrijos municipality possess low to high risk susceptibility when it comes to flood and landslide disasters. The field surveys conducted by the PHIL-LiDAR 1 validation team showed that there were several notable weather disturbances that caused flooding in 1993 (Monang), 2006 (Reming), 2008 (Frank), 2013 (Yolanda), and 2014 (Glenda and Ruby). In July 2014, the province of Marinduque experienced heavy damages in agriculture and personal properties during typhoon Rammasun, locally known as Glenda. The heavily affected residents of the Municipality of Santa Cruz were issued an evacuation order during the typhoon (http://www.marinduquemovers.com/marinduque-pagkatapos-ng-bagyong-glenda/).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE TAWIRAN-TAGUM FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Tawiran-Tagum floodplain in Marinduque. These missions were planned for 16 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 shows the flight plan for Tawiran-Tagum floodplain

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK22A	1250, 1000	30	50	200	30	130	5
BLK22B	1250, 1000	30	50	200	30	130	5
BLK22C	1000	30	50	200	30	130	5

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

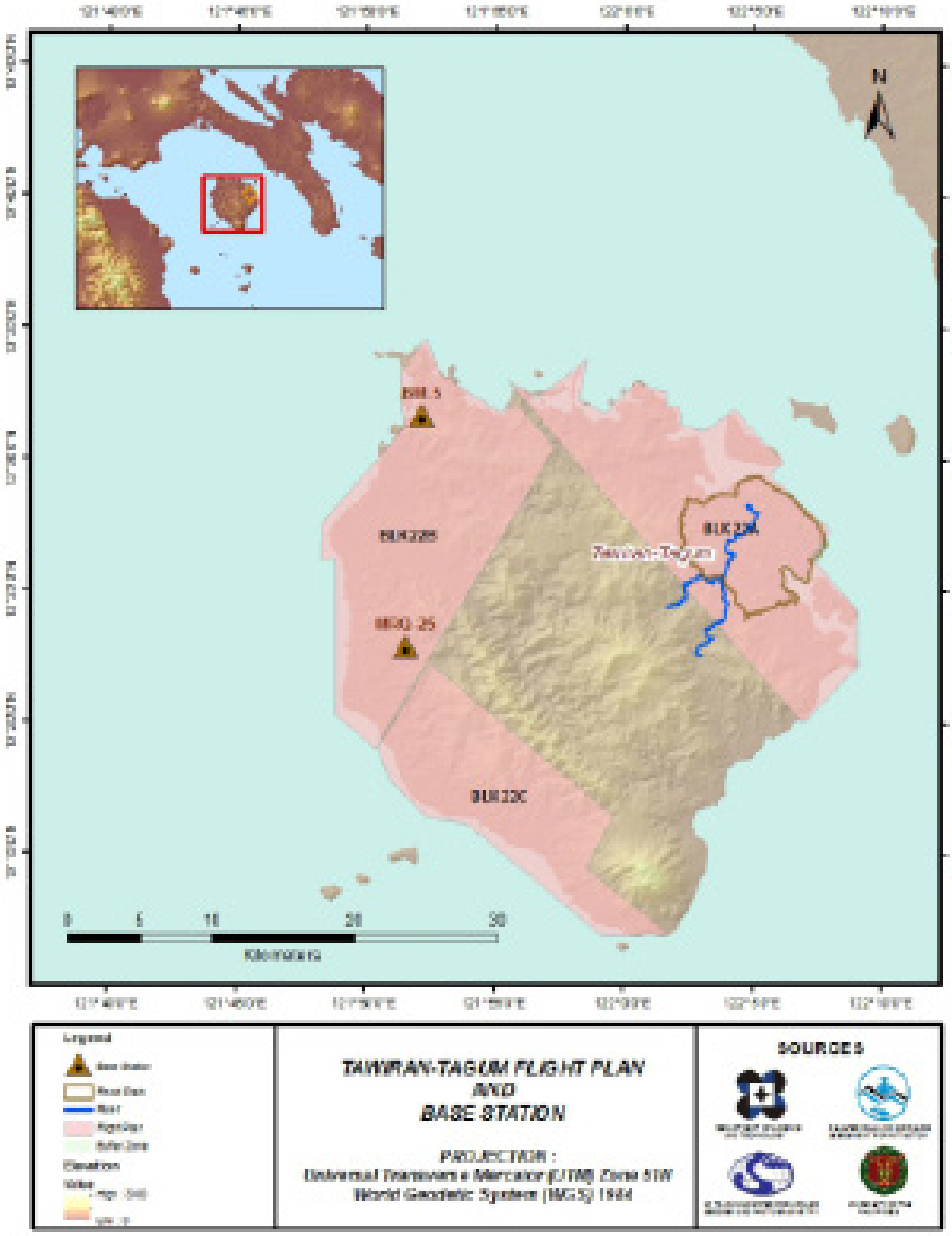

Figure 2. Flight Plan and base stations used for the Tawiran-Tagum Floodplain survey.

2.2 Ground Base Stations

The project team was able to recover one (1) NAMRIA ground control point: MRQ-25 which is of second (2nd) order accuracy. They also established one (1) ground control point. The certification for the NAMRIA reference is found in Annex 2 while the baseline processing report for the established control point is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (October 9, 12 and 15, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 852. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tawiran-Tagum floodplain are shown in Figure 2. The list of team members are shown in Annex 4.

Figure 3 showed the recovered NAMRIA control station within the area. In addition Table 2 to Table 3 show the details about the following NAMRIA control station and established point. Table 4 shows the list of ground control points occupied during the acquisition with corresponding dates of utilization.

(a)

(b)

Figure 3. GPS set-up over MRQ-25 at the top of the plant box near the gate of Tugos Elementary School, Barangay Tugos, Boac, Marinduque (a) and NAMRIA reference point MRQ-25 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point MRQ-25 used as base station for the LiDAR Acquisition.

Station Name	MRQ-25	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 22’ 56.92806” 121° 51’ 28.72673” 48.18293 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	592,932.786 m 1,480,020.839 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	3° 22’ 51.86815” North 121° 51’ 33.72033” East 97.20100 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	376,341.19 m 1,479,627.07 m

Table 3. Details of the established horizontal control point BM-5 used as base station for the LiDAR Acquisition.

Station Name	BM-5	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 31' 43.12821" 121° 52' 02.72781" 5.828 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 31' 38.03406" North 121° 52' 07.7085" East 54.472 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	377,438.371 m 1,295,788.872 m

Table 4. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
October 9, 2015	10020P	1BLK22ABC282A	MRQ-25 and BM-5
October 12, 2015	10027P	1BLK22AB285A	MRQ-25 and BM-5
October 15, 2015	10032P	1BLK22AB288A	MRQ-25 and BM-5

2.3 Flight Missions

Three (3) missions were conducted to complete the LiDAR Data Acquisition in Tawiran-Tagum floodplain, for a total of ten hours and twenty minutes (10+20) of flying time for RP-C9522. All missions were acquired using the Pegasus LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 shows the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Tawiran-Tagum 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
October 9, 2015	10020P	599.56	170.93	21.17	149.76	NA	3	53
October 12, 2015	10027P	461.82	283.36	41.64	241.72	NA	4	23
October 15, 2015	10032P	254.74	52.87	21.68	31.19	NA	2	4
TOTAL		1316.12	507.16	84.49	422.67	NA	10	20

Table 6. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
10020P	1000	30	50	200	30	130	5
10027P	1250	30	50	200	30	130	5
10032P	1000	30	50	200	30	130	5

2.4 Survey Coverage

Tawiran-Tagum floodplain is located in the province of Marinduque with the whole the floodplain situated within the municipality of Santa Cruz. The list municipalities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Tawiran-Tagum floodplain is presented in Figure 4.

Table 7. List of municipalities and cities surveyed during the Napayawan Floodplain LiDAR survey.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Marinduque	Boac	182.07	52.05	28.59%
	Buenavista	83.22	2	2.40%
	Gasan	116.19	34.27	29.49%
	Mogpog	101.12	66.43	65.69%
	Santa Cruz	236.19	107.36	45.45%
	Torrijos	210.05	25.1	11.95%
Total		**928.84**	**287.21**	**30.92%**

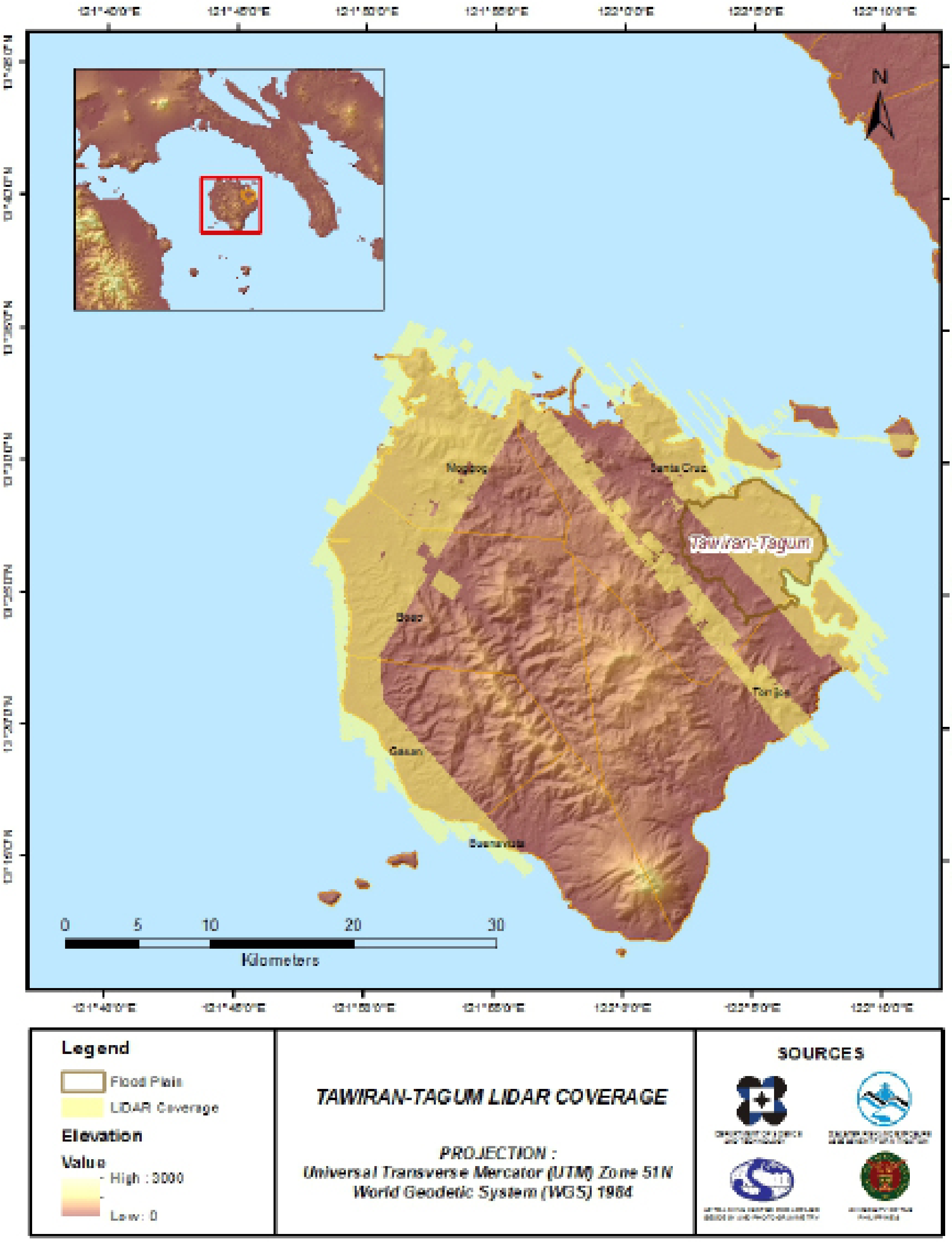

Figure 4. Actual LiDAR survey coverage for Tawiran-Tagum Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE TAWIRAN-TAGUM FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

These processes are summarized in the flowchart shown in Figure 5.

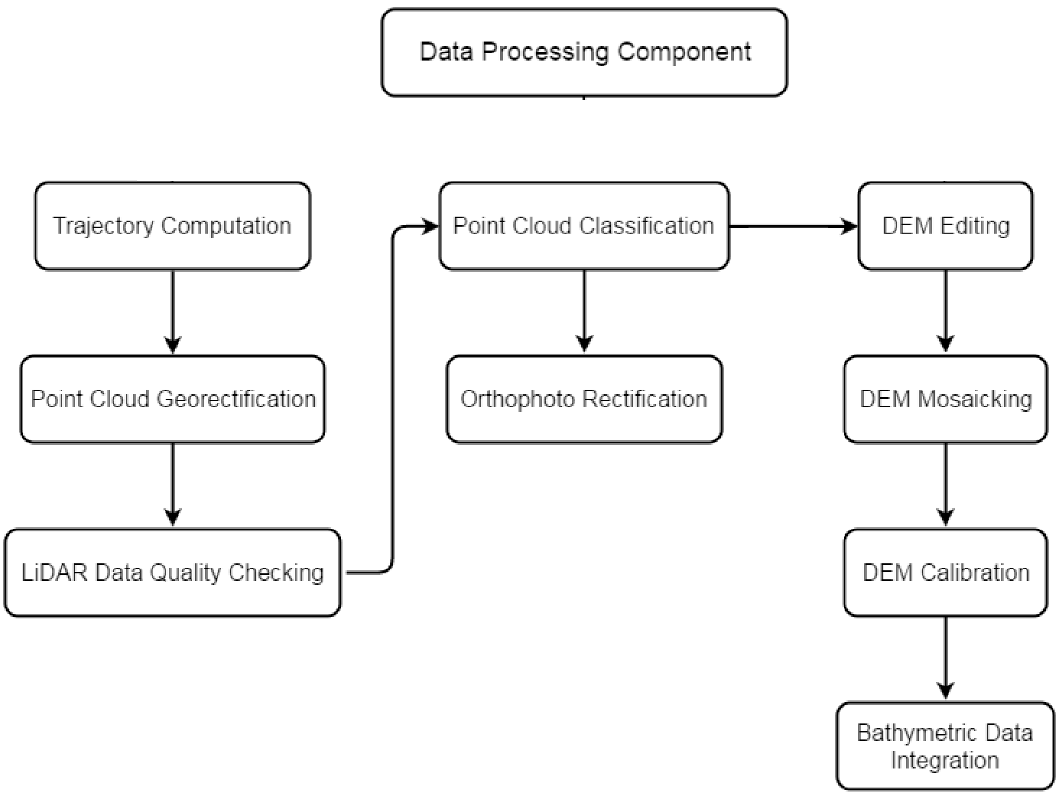


Figure 5. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Tawiran-Tagum floodplain can be found in Annex 5. Missions flown during the first survey conducted on October 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Sta. Cruz, Marinduque.

The Data Acquisition Component (DAC) transferred a total of 55.98 Gigabytes of Range data, 646 Megabytes of POS data, 17.23 Megabytes of GPS base station data, and 1100.2 Gigabytes of raw image data to the data server on November 5, 2015. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tawiran-Tagum was fully transferred on November 10, 2015, as indicated on the Data Transfer Sheets for Tawiran-Tagum floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 10020P, one of the Tawiran-Tagum flights, which is the North, East, and Down position RMSE values are shown in Figure 6. 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 October 9, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

Figure 6. Smoothed Performance Metrics of Tawiran-Tagum Flight 10020P.

The time of flight was from 435500 seconds to 437500 seconds, which corresponds to morning of October 9, 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 6 shows that the North position RMSE peaks at 2.50 centimeters, the East position RMSE peaks at 1.50 centimeters, and the Down position RMSE peaks at 4.80 centimeters, which are within the prescribed accuracies described in the methodology.

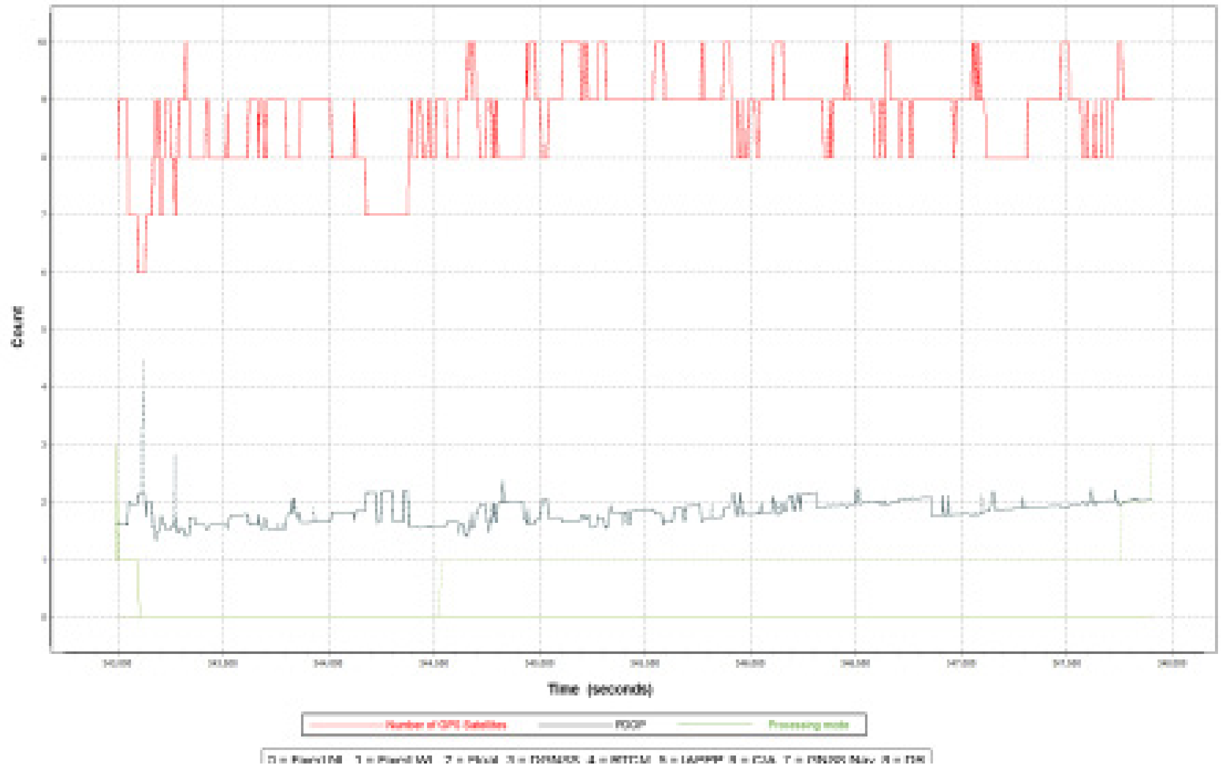


Figure 7. Solution Status Parameters of Tawiran-Tagum Flight 10020P.

The Solution Status parameters of flight 10020P, one of the Tawiran-Tagum flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 7. 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 Tawiran-Tagum flights is shown in Figure 8.

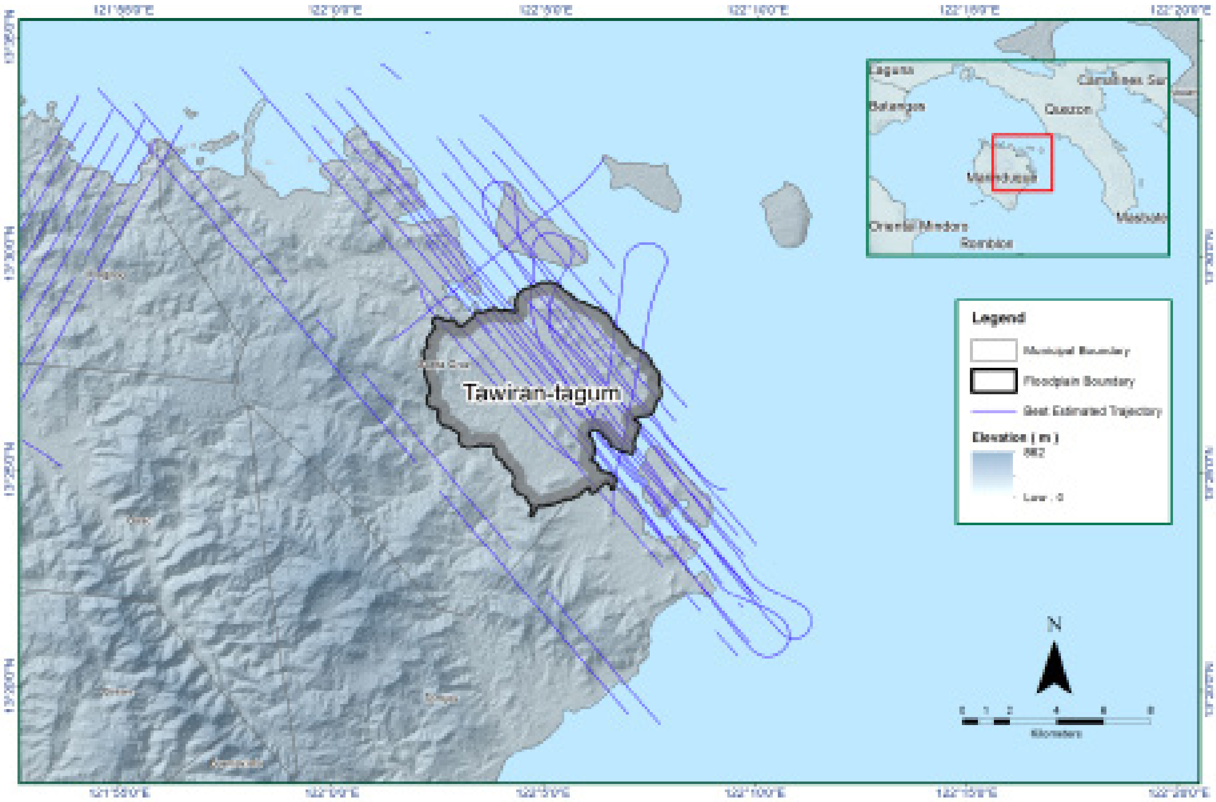


Figure 8. Best Estimated Trajectory for Tawiran-Tagum Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 64 flight lines, with each flight line containing two channels, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tawiran-Tagum floodplain are given in Table 8.

Table 8. Self-Calibration Results values for Tawiran-Tagum flights.

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000368
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000999
GPS Position Z-correction stdev	<0.01meters	0.0088

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Tawiran-Tagum Floodplain is shown in Figure 9. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

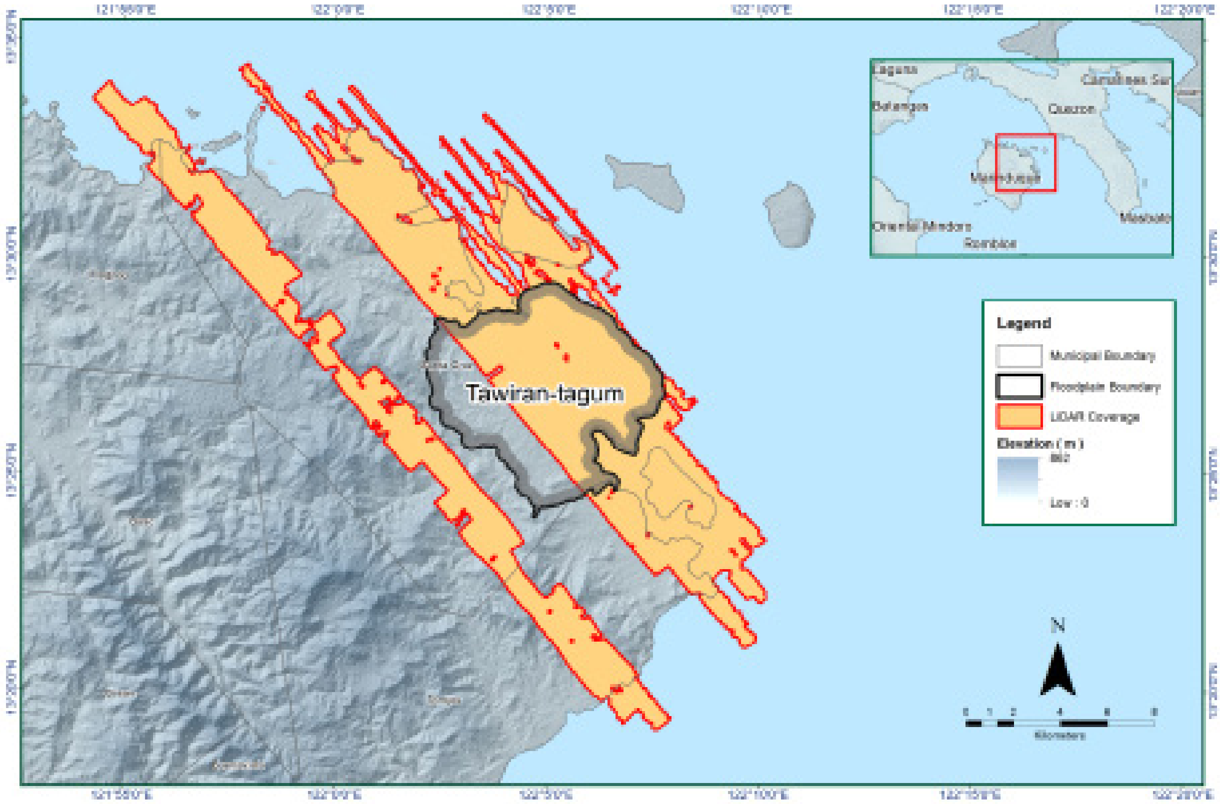


Figure 9. Boundary of the processed LiDAR data over Tawiran-Tagum Floodplain

The total area covered by the Tawiran-Tagum missions is 166.16 sq.km that is comprised of three (3) flight acquisitions grouped and merged into one (8) block as shown in Table 9.

Table 9. List of LiDAR blocks for Tawiran-Tagum Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Marinduque_Blk22A	10020P	166.16
	10027P	
	10032P	
TOTAL		1070.01 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 20. Since the Pegasus system employ 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.

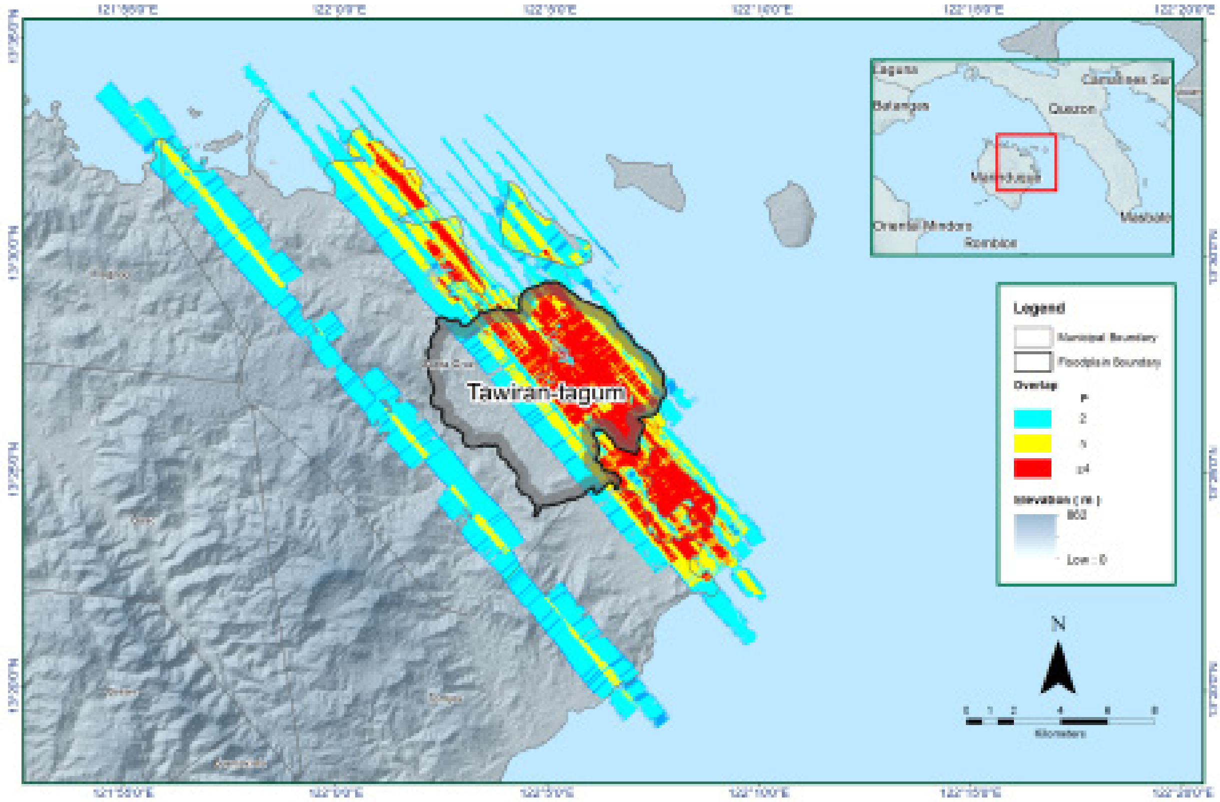


Figure 10. Image of data overlap for Tawiran-Tagum Floodplain.

The overlap statistics per block for the Tawiran-Tagum floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 44.30%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 11. It was determined that all LiDAR data for Tawiran-Tagum floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.85 points per square meter.

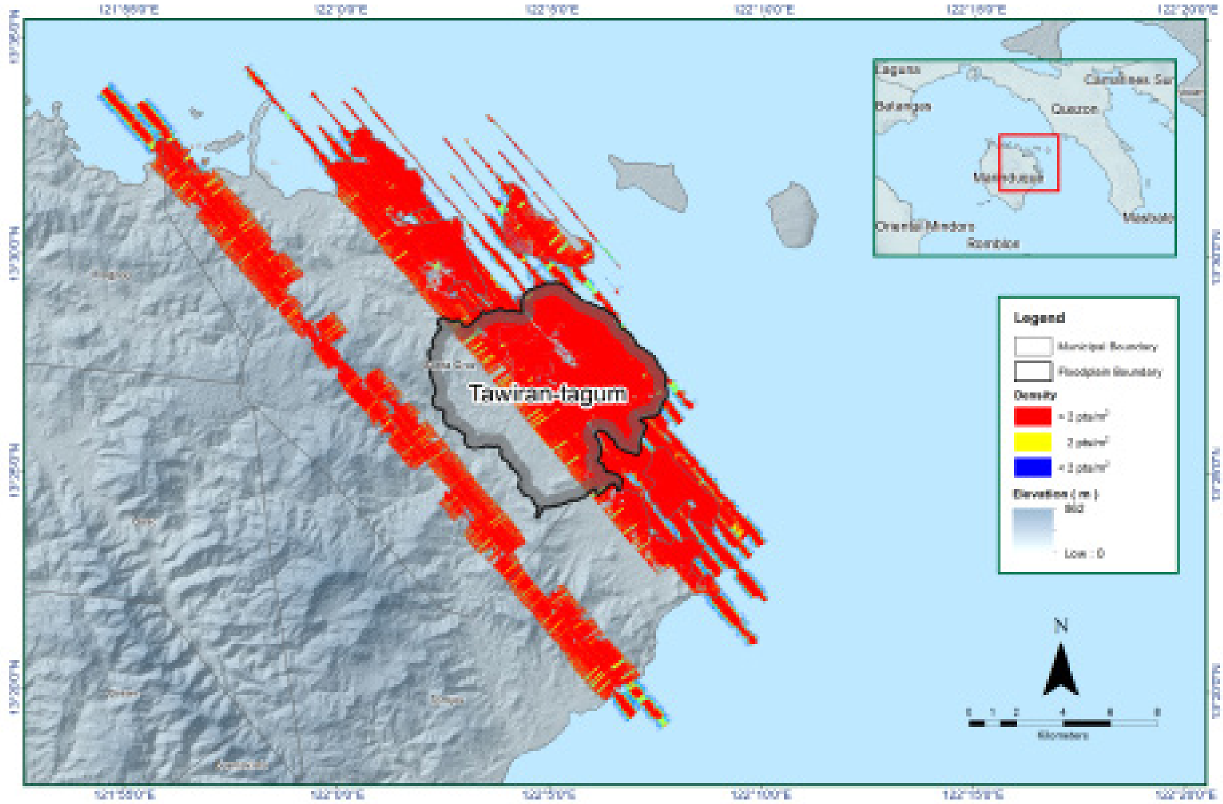


Figure 11. Pulse density map of merged LiDAR data for Tawiran-Tagum Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 12. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

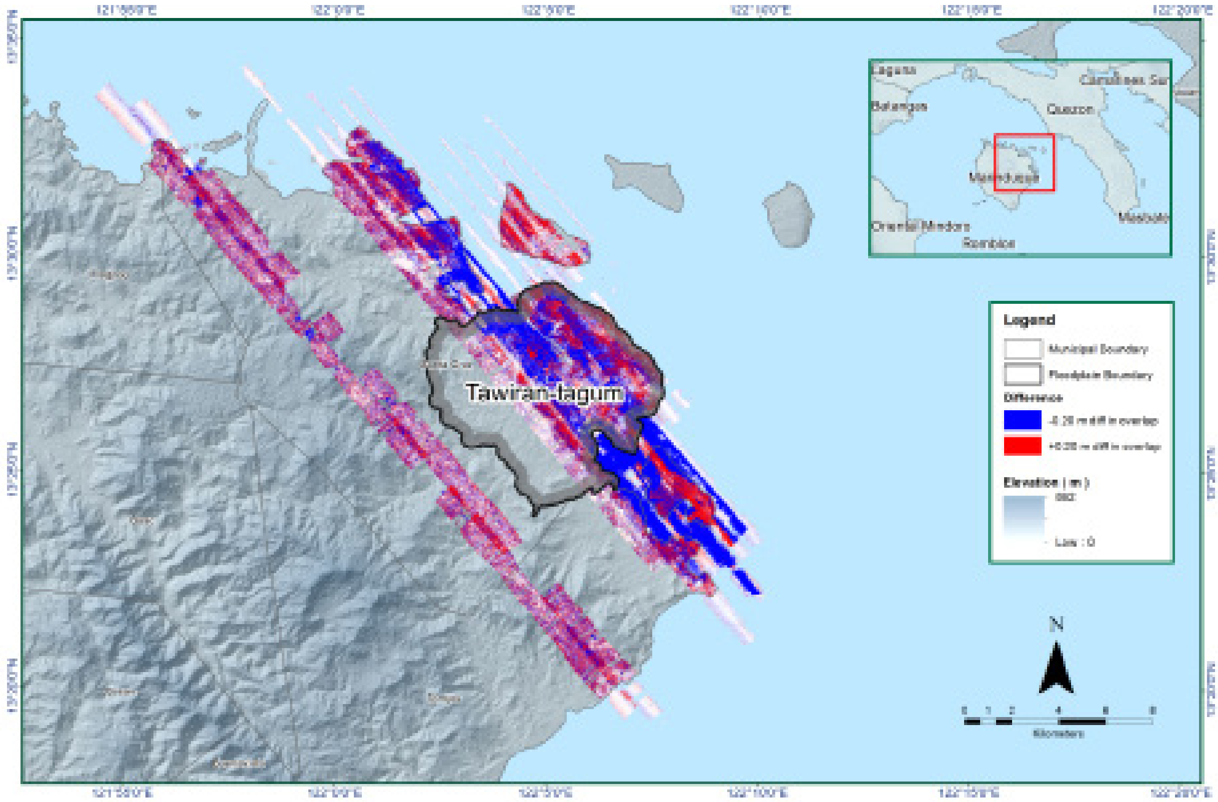


Figure 12. Elevation difference map between flight lines for Tawiran-Tagum Floodplain.

A screen capture of the processed LAS data from a Tawiran-Tagum flight 10020P loaded in QT Modeler is shown in Figure 13. 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.

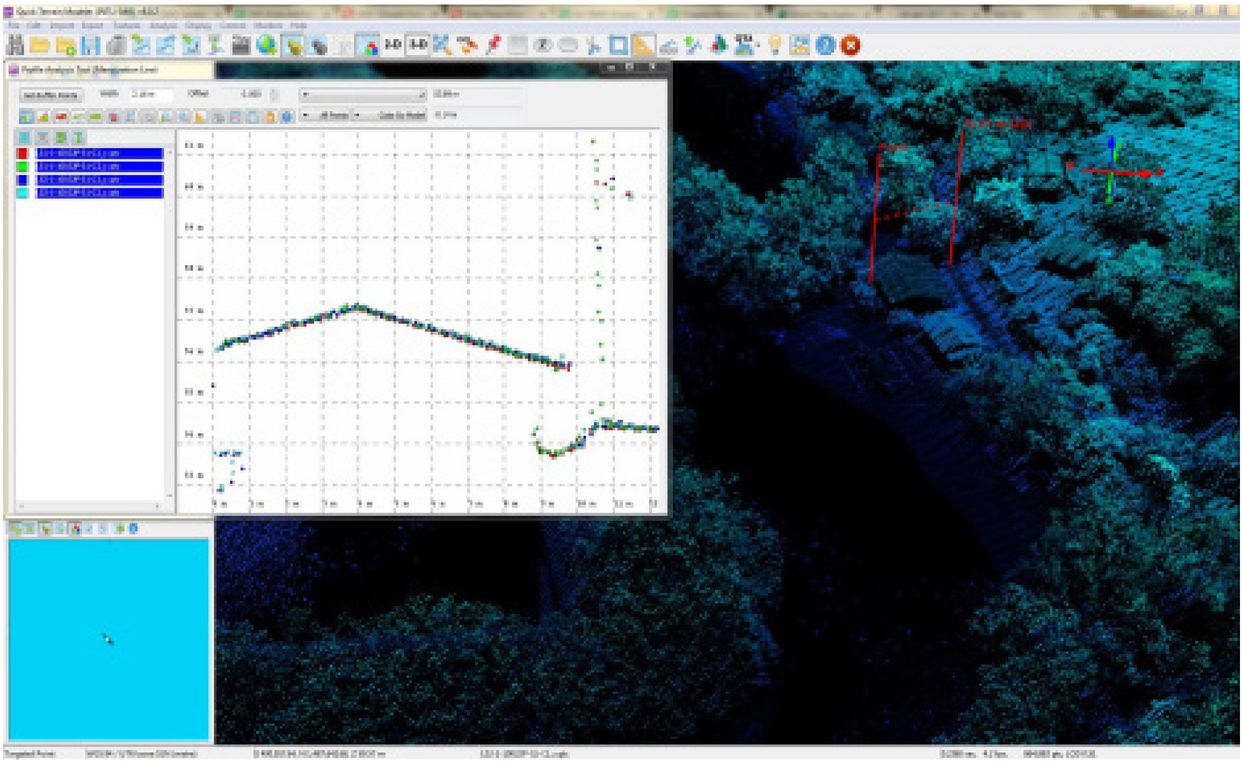


Figure 13. Quality checking for Tawiran-Tagum flight 10020P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Tawiran-Tagum classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	134,073,823
Low Vegetation	132,208,304
Medium Vegetation	291,984,269
High Vegetation	394,146,942
Building	15,113,236

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tawiran-Tagum floodplain is shown in Figure 14. A total of 328 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 673.85 meters and 2.43 meters respectively.

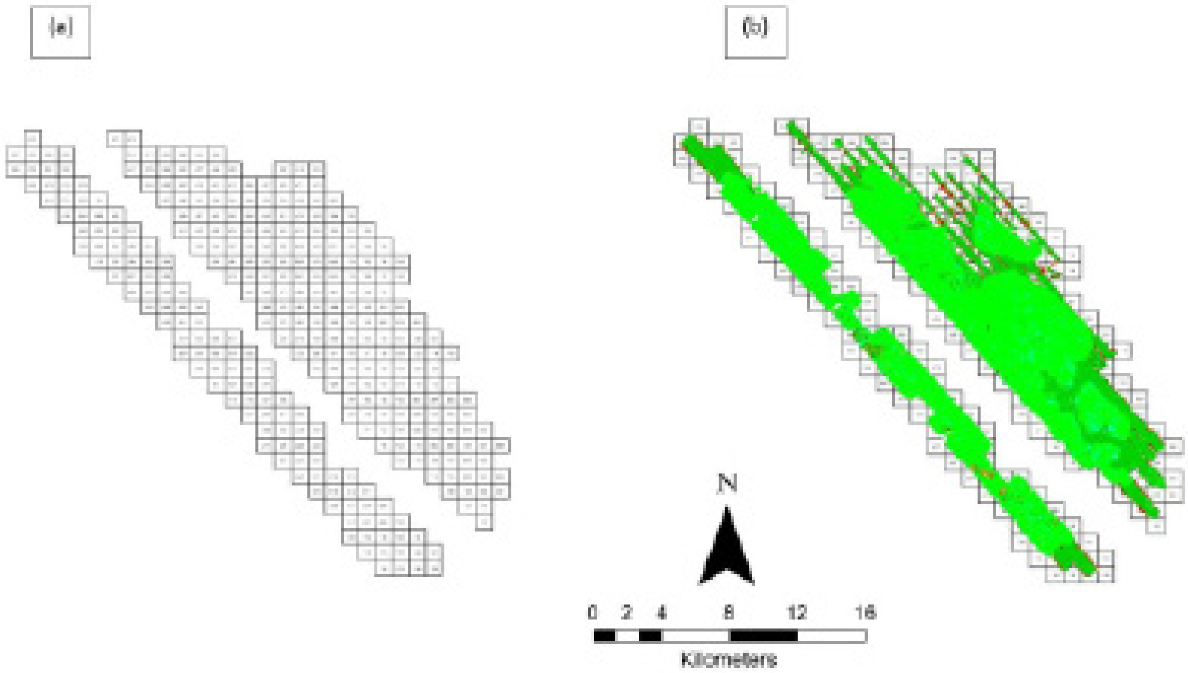


Figure 14. Tiles for Tawiran-Tagum Floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 15. 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.

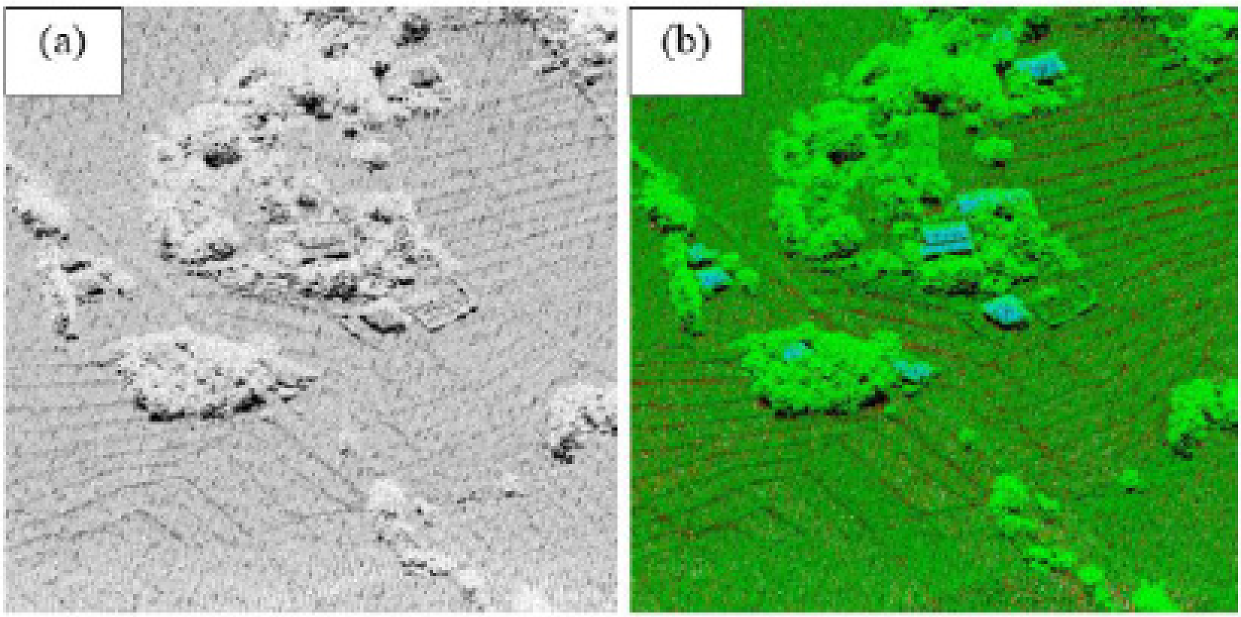


Figure 15. Point cloud before (a) and after (b) classification.

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

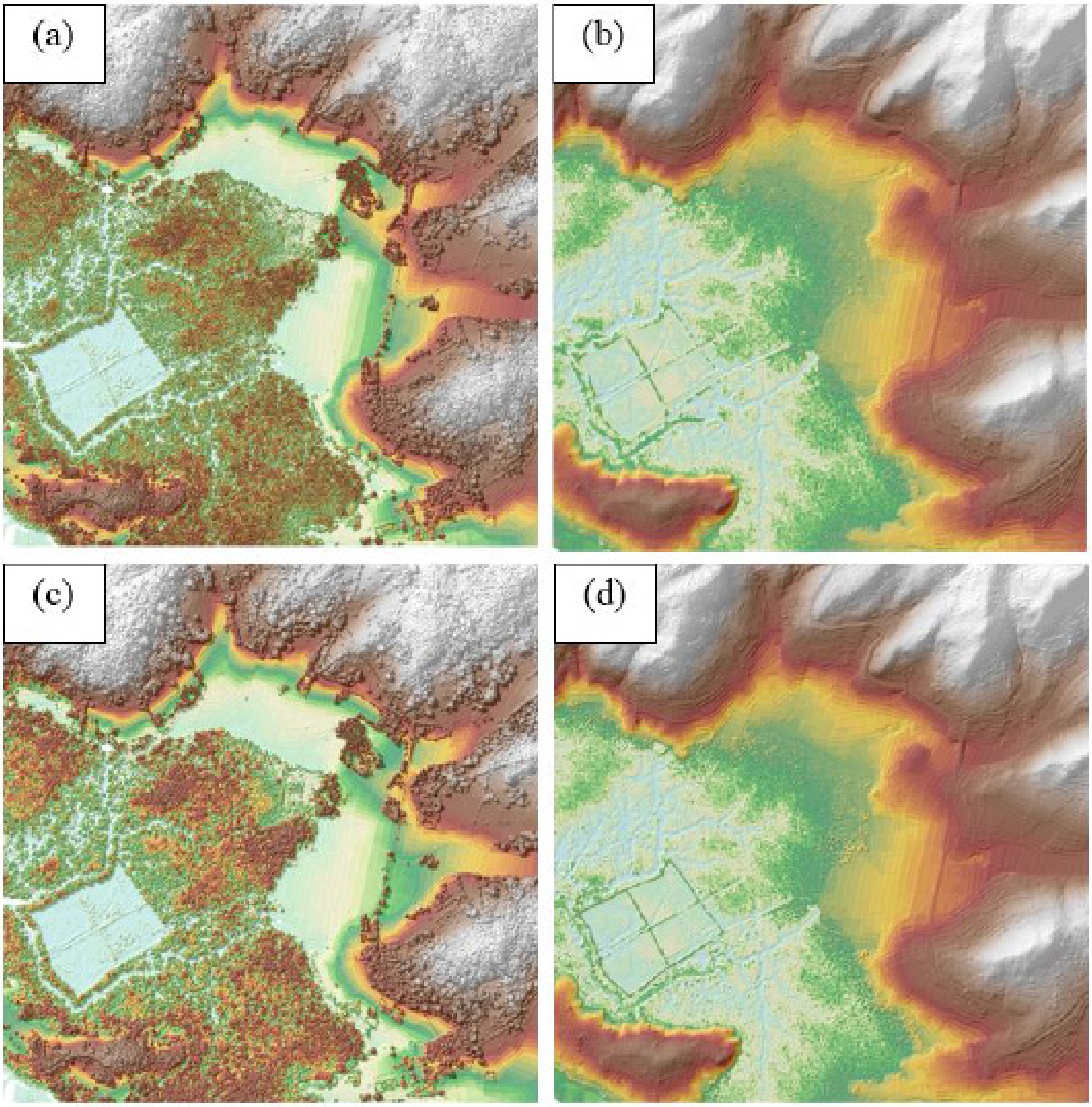


Figure 16. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tawiran-Tagum Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 321 1km by 1km tiles area covered by Tawiran-Tagum floodplain is shown in Figure 17. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Tawiran-Tagum floodplain has a total of 204.34 sq.km orthophotogaph coverage comprised of 483 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 18.

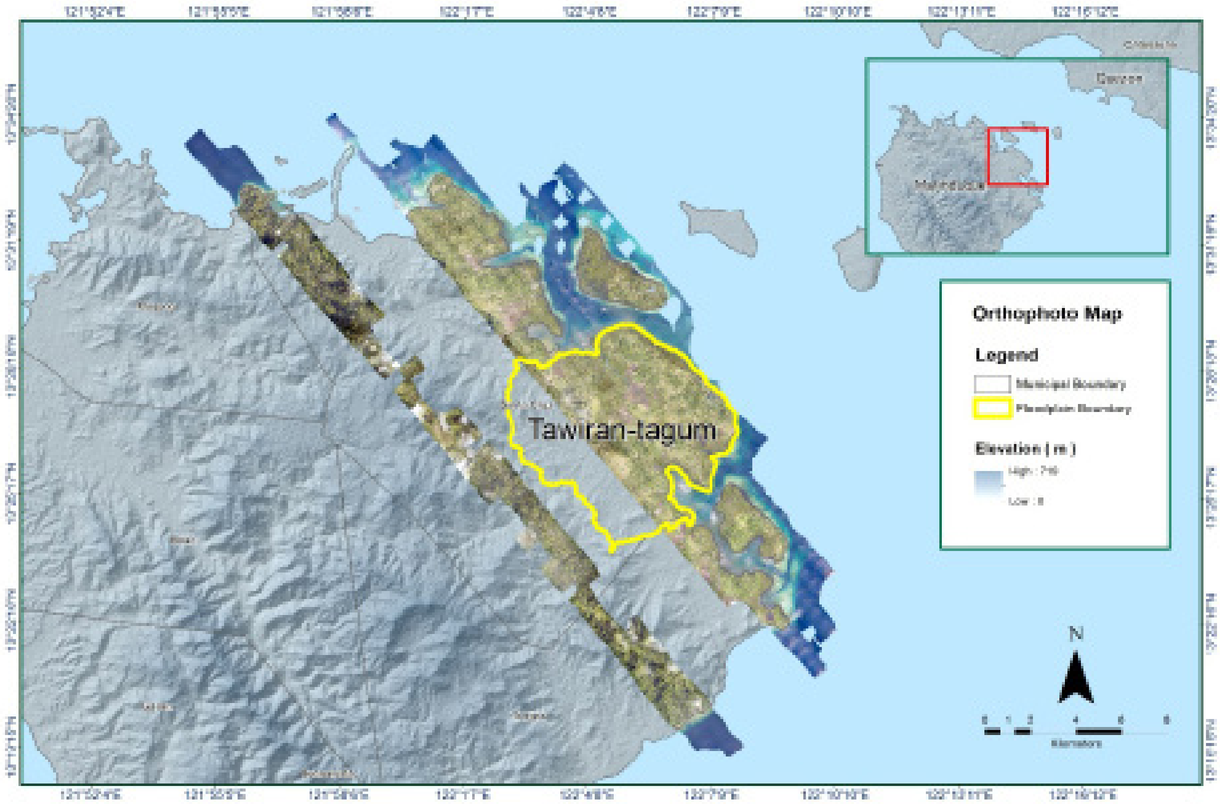


Figure 17. Tawiran-Tagum Floodplain with available orthophotographs

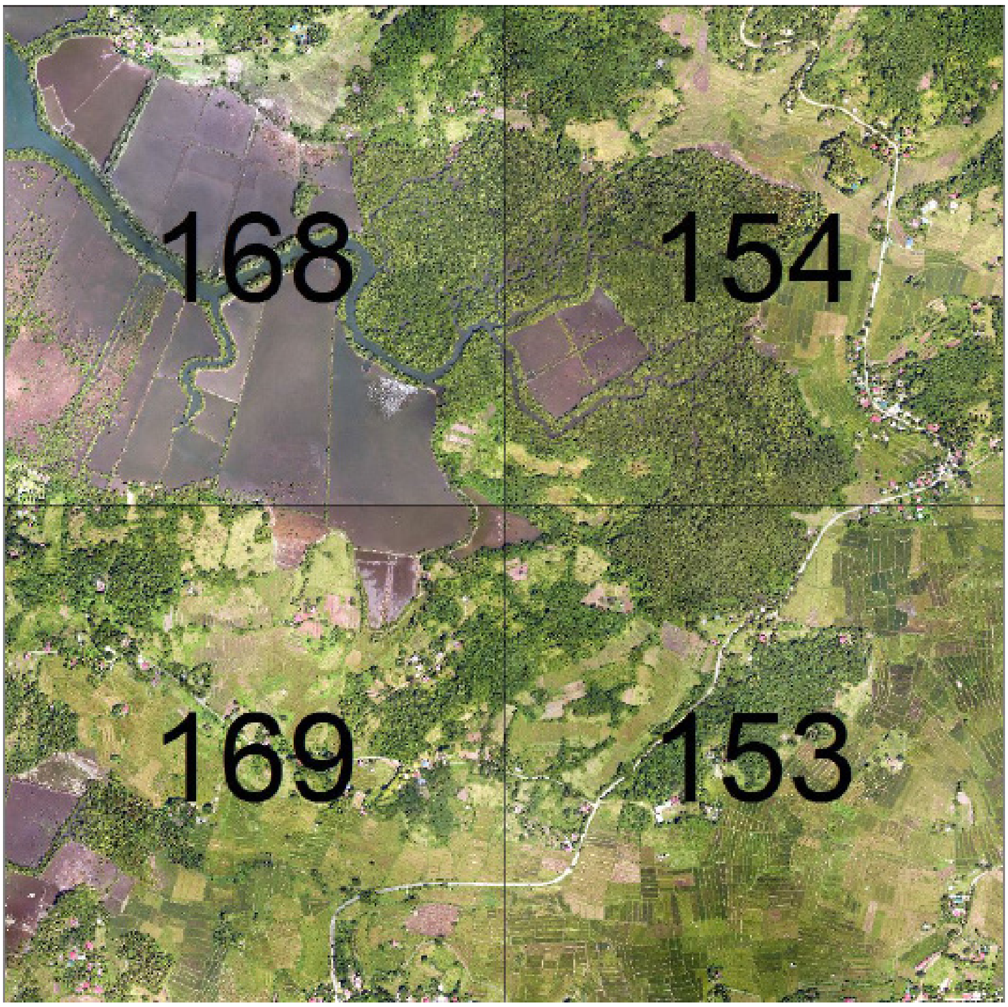


Figure 18. Sample orthophotograph tiles for Tawiran-Tagum Floodplain

3.8 DEM Editing and Hydro-Correction

One (1) blocks were processed for Tawiran-Tagum floodplain. These blocks are composed of a Marinduque block with a total area of 166.16 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Marinduque_Blk22A	166.16
TOTAL	166.16 sq.km

Portions of DTM before and after manual editing are shown in Figure 19. Data gap (Figure 19a) has been filled to complete the surface (Figure 19b). The bridge (Figure 19c) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 19d) in order to hydrologically correct the river.

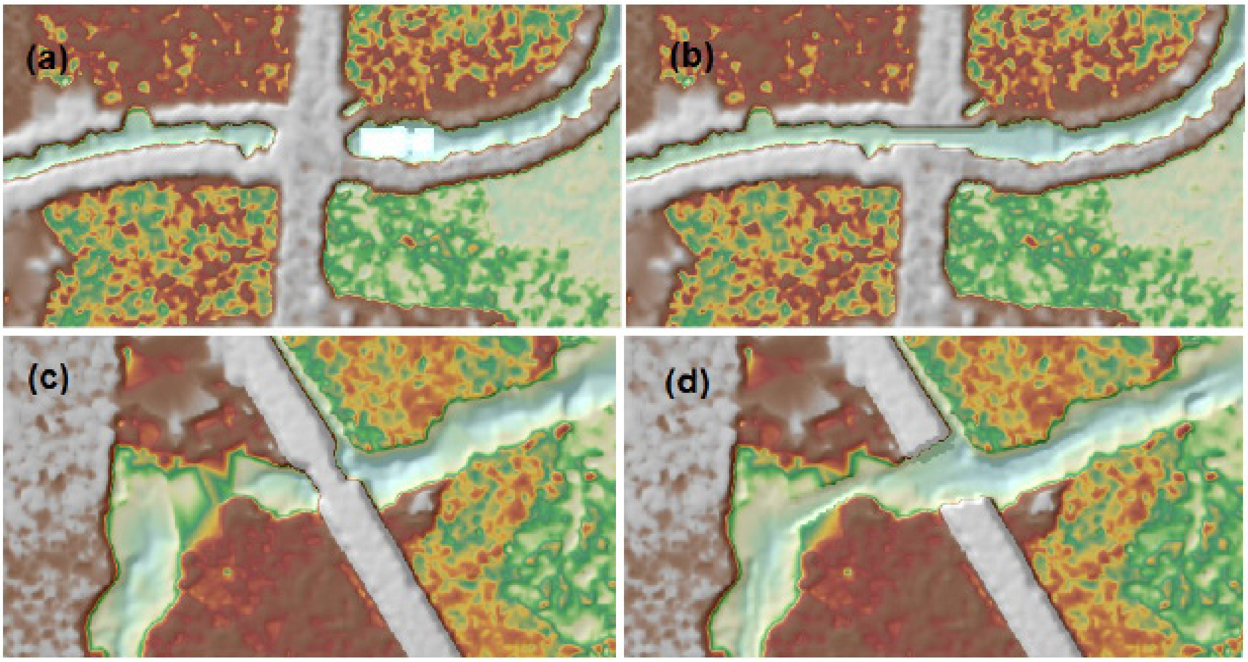


Figure 19. Portions in the DTM of Tawiran-Tagum Floodplain – a data gap before (a) and after (b) filling; and a bridge before (c) and after (d) manual editing.

3.9 Mosaicking of Blocks

Marinduque_Blk22B was used as the reference block at the start of mosaicking because it was the first block mosaicked to the larger DTM of Marinduque. Upon inspection of the blocks mosaicked for the Tawiran-Tagum floodplain, it was concluded that the elevation of Marinduque_Blk22A has to be adjusted. Table 12 shows the shift values applied to the LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Tawiran-Tagum floodplain is shown in Figure 20. The entire Tawiran-Tagum floodplain is 69.23% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 12. Shift Values of each LiDAR Block of Tawiran-Tagum Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Marinduque_Blk22A	0.00	0.00	49.63

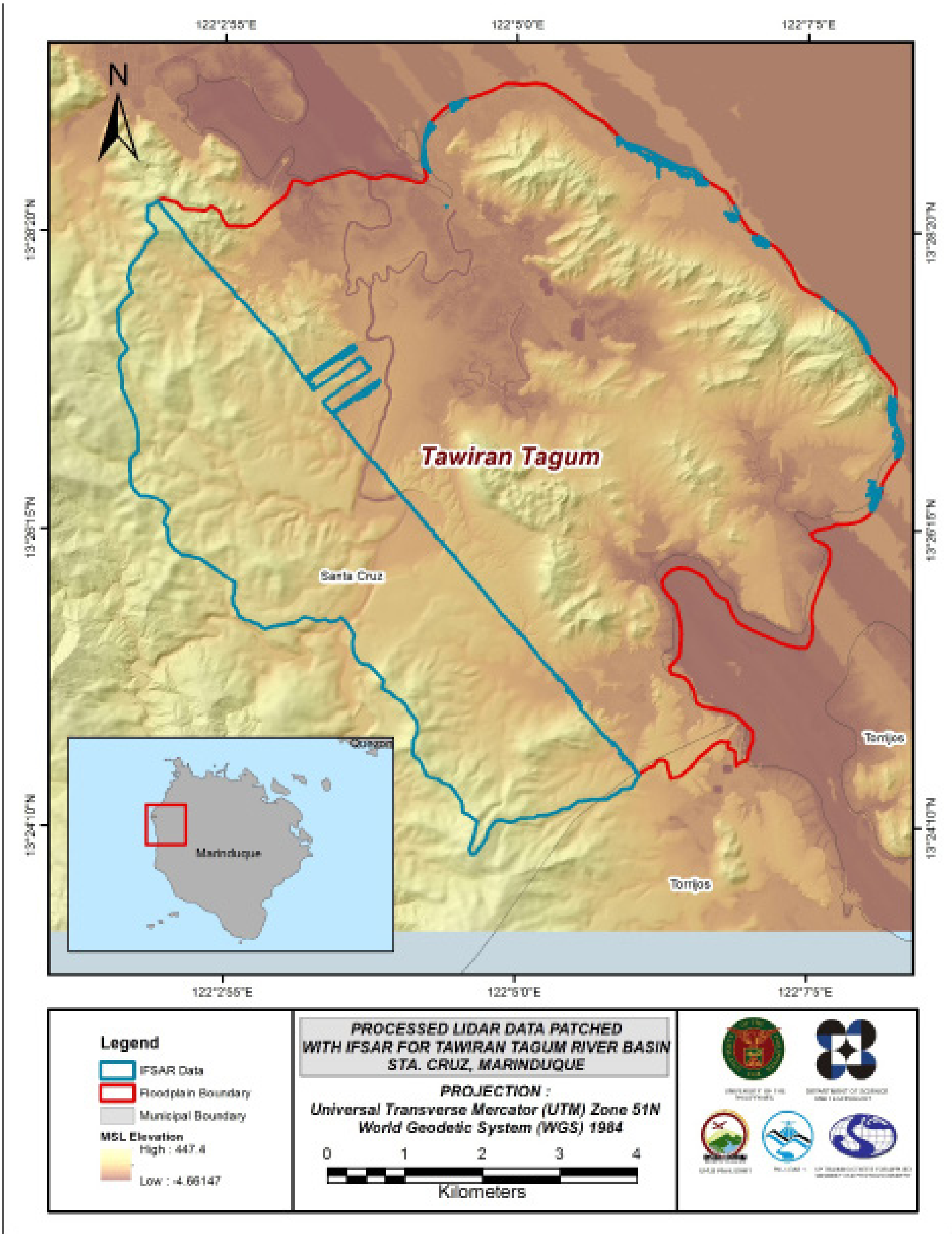


Figure 20. Map of Processed LiDAR Data for Tawiran-Tagum Floodplain.

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

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Tawiran-Tagum to collect points with which the LiDAR dataset is validated is shown in Figure 21. A total of 938 survey points were used for calibration and validation of Tawiran-Tagum LiDAR data. Random selection of 80% of the survey points, resulting to 750 points, was used for calibration.

The good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 22. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 3.53 meters with a standard deviation of 0.20 meters. Calibration of Tawiran-Tagum LiDAR data was done by subtracting the height difference value, 3.53 meters, to Tawiran-Tagum mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

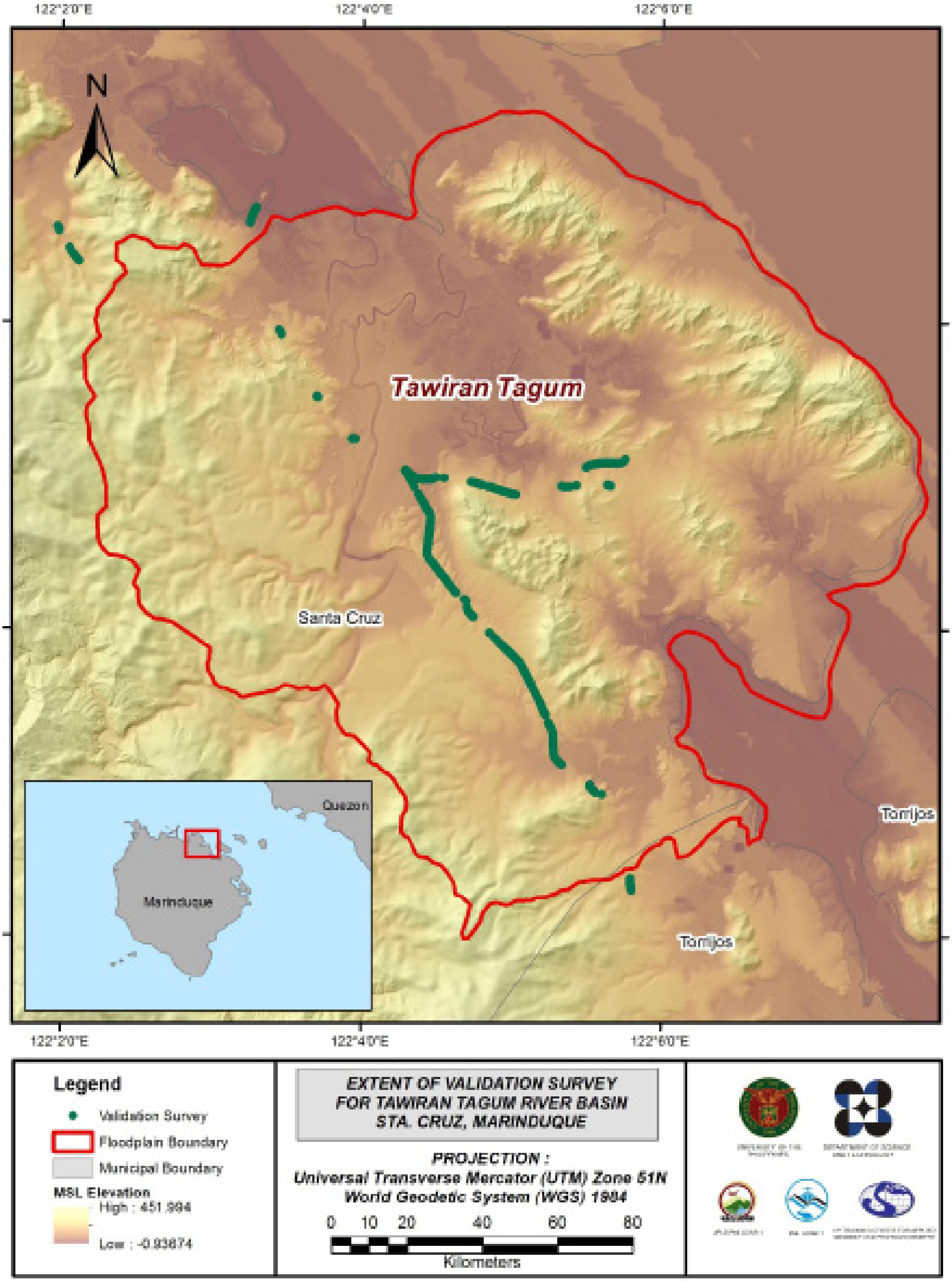


Figure 21. Map of Tawiran-Tagum Floodplain with validation survey points in green.

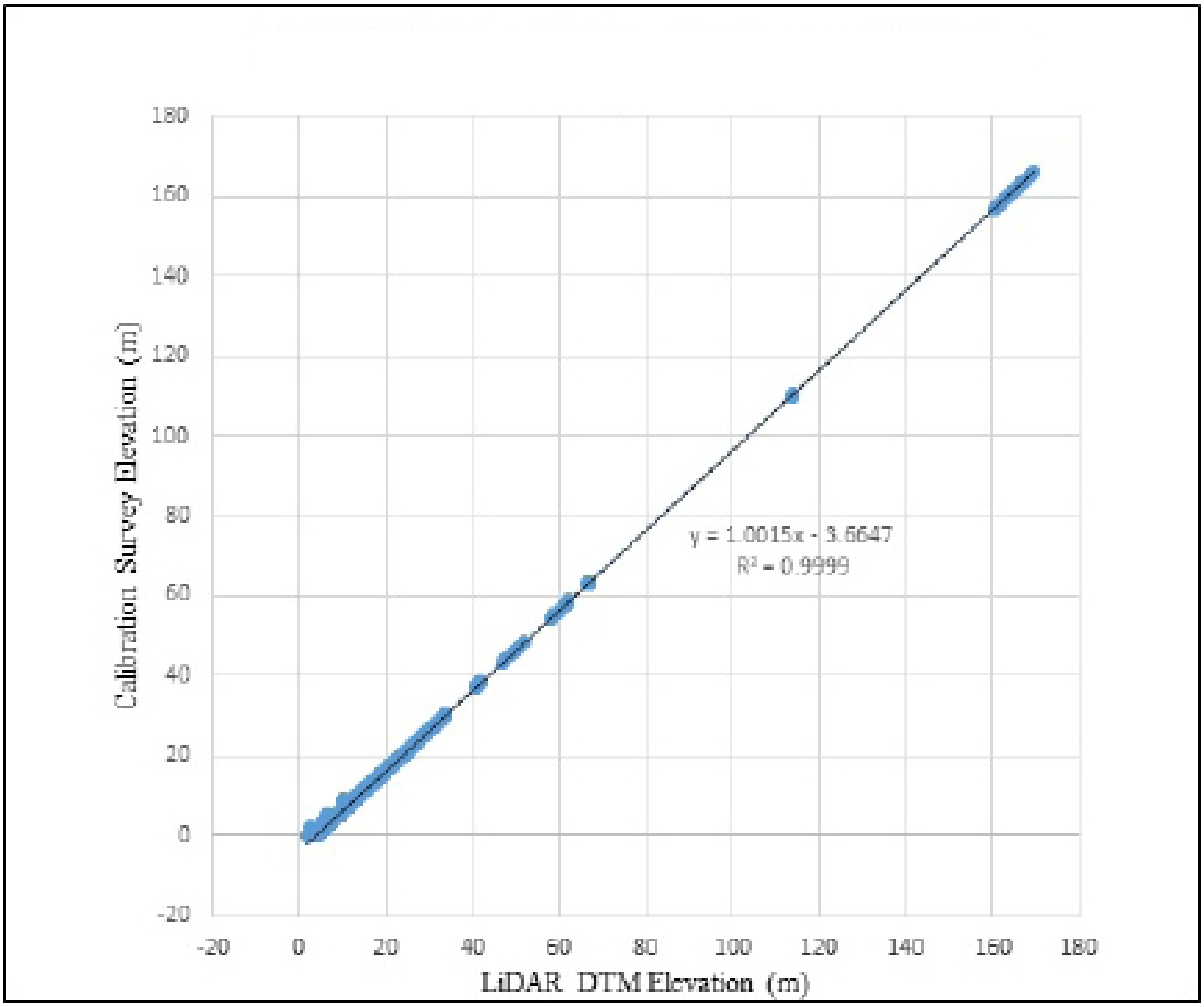


Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	3.53
Standard Deviation	0.20
Average	-3.52
Minimum	-3.92
Maximum	-3.13

The remaining 20% of the total survey points, resulting to 171, were used for the validation of calibrated Tawiran-Tagum DTM. The good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.11 meters with a standard deviation of 0.09 meters, as shown in Table 14.

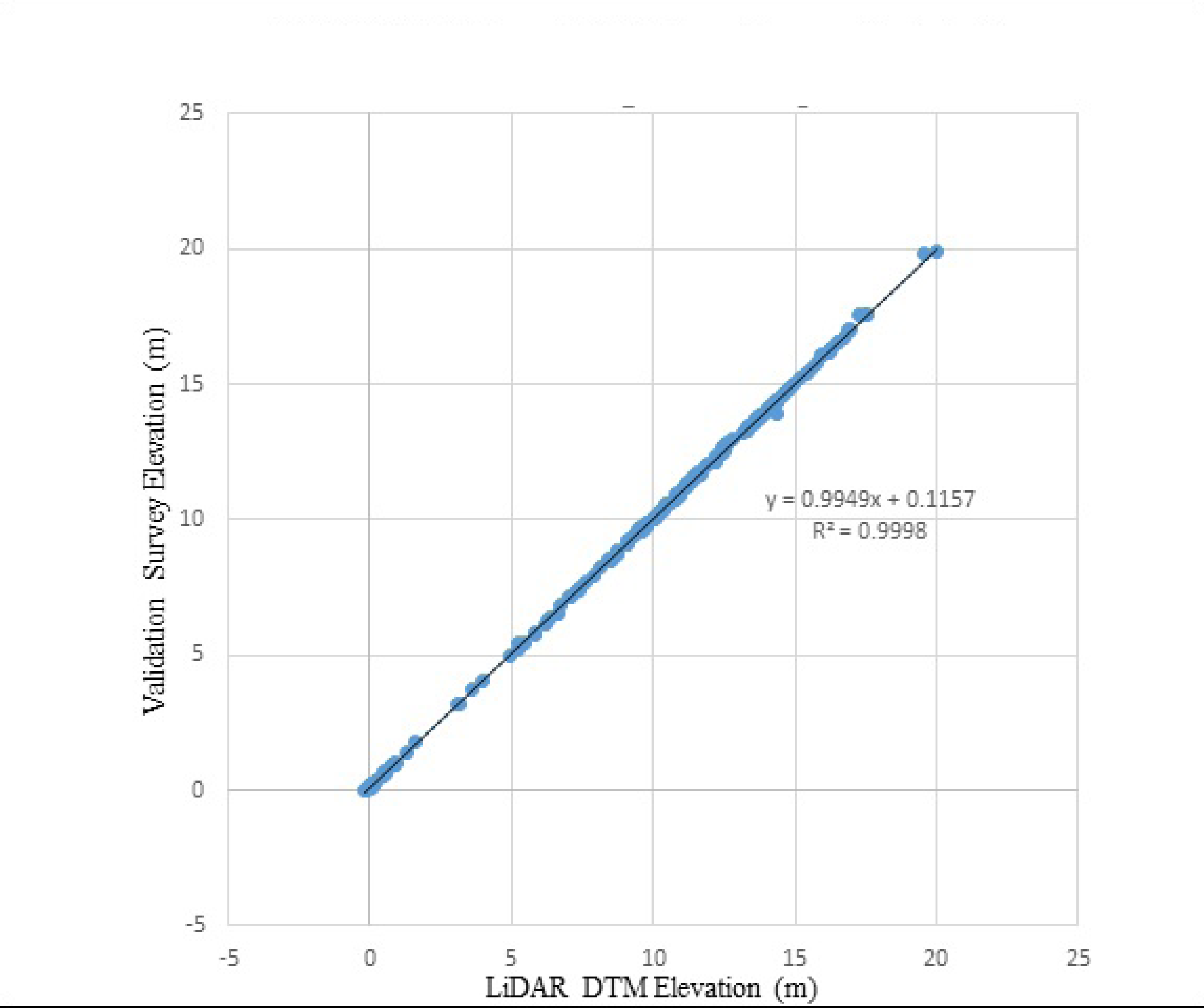


Figure 23. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.11
Standard Deviation	0.09
Average	0.07
Minimum	-0.43
Maximum	0.30

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathymetric data integration, centerline, zigzag, and cross section were available for Tawiran-Tagum with a total of 2,135 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 0.45 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tawiran-Tagum integrated with the processed LiDAR DEM is shown in Figure 24.

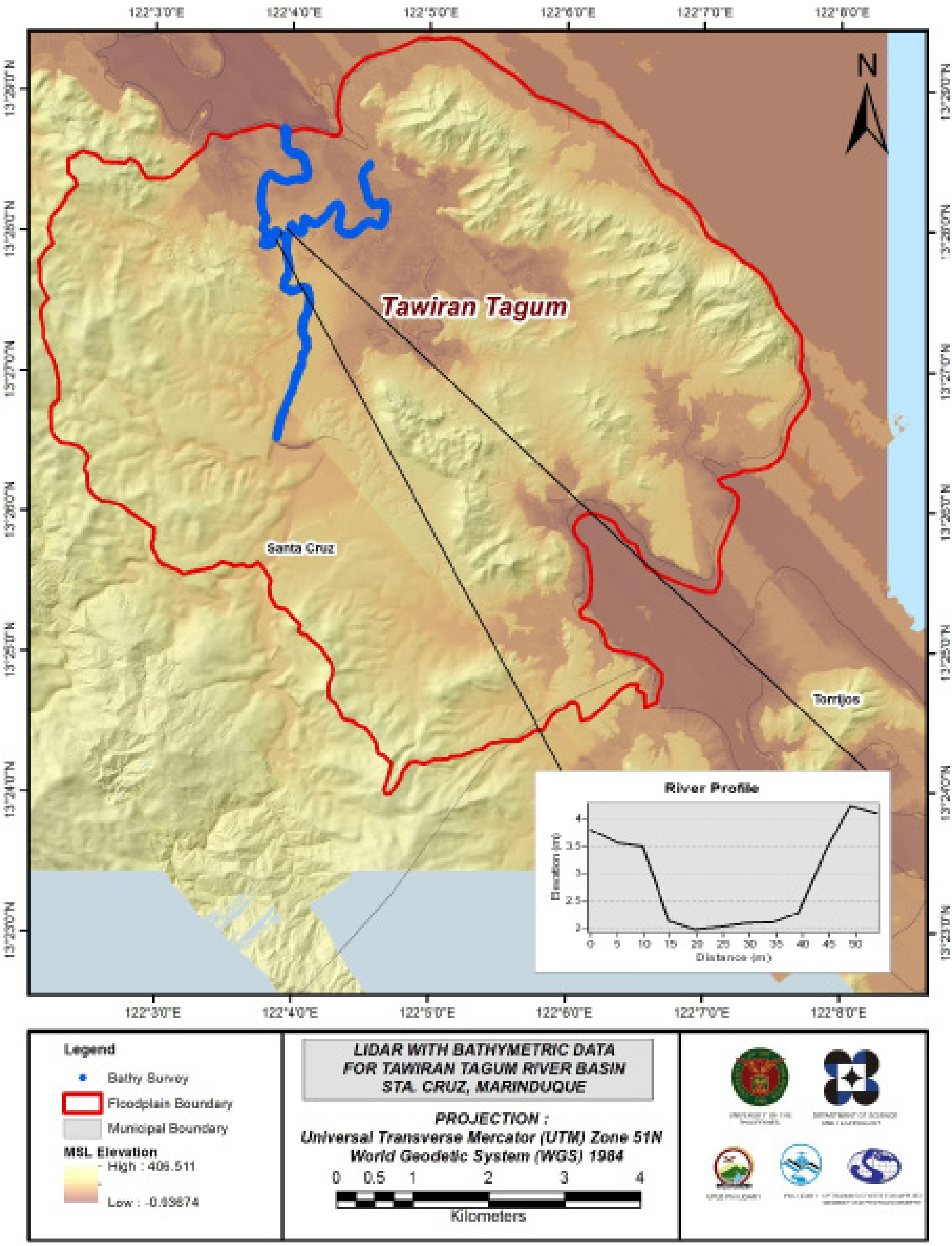


Figure 24. Map of Tawiran-Tagum Floodplain with bathymetric survey points shown in blue.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE TAWIRAN-TAGUM RIVER BASIN

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, and For. Rodel C. Alberto

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Tawiran-Tagum River on August 9 – 20, 2016 with the following scope of work: reconnaissance; control survey; cross-section and as-built survey at Tawiran Bridge in Brgy. Matalaba, Sta. Cruz, Marinduque; validation points acquisition of about 13 km covering the Tawiran-Tagum River Basin area; and bathymetric survey from its upstream in Brgy. Pantayin, down to the two mouths of the river located in Brgy. Buyabod and Brgy, Biga, both in the Municipality of Sta. Cruz, with an approximate total length of 9.190 km using Hi™ single beam echo sounder and Trimble® SPS 985 GNSS PPK survey technique. The entire survey extent is illustrated in Figure 25.

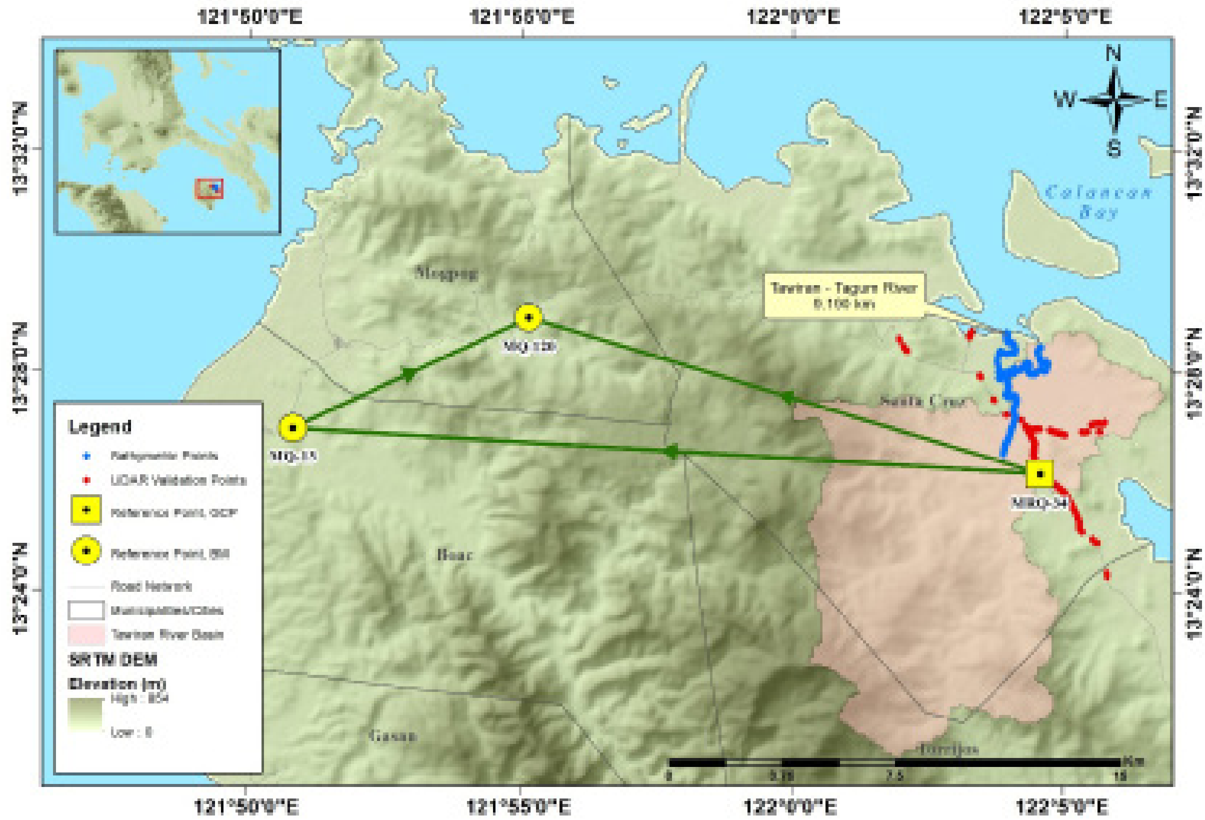


Figure 25. Tawiran-Tagum River Survey Extent

4.2 Control Survey

The GNSS network used for Tawiran-Tagum River Basin is composed of a single loop established on August 11, 2016 occupying the following reference points: MRQ-34, a second-order GCP in Brgy. Napo, Municipality of Sta. Cruz; and MQ-13, a first order BM, in Brgy. Mataas na Bayan, Municipality of Boac, both in Marinduque.

A NAMRIA-established control point namely MQ-120, located at the approach of Mangamnan Bridge, in Brgy. Butansapa, Municipality of Mogpong, Marinduque; was also occupied and used as marker.

The summary of reference and control points and its location is summarized in Table 15 while the GNSS network established is illustrated in Figure 26.

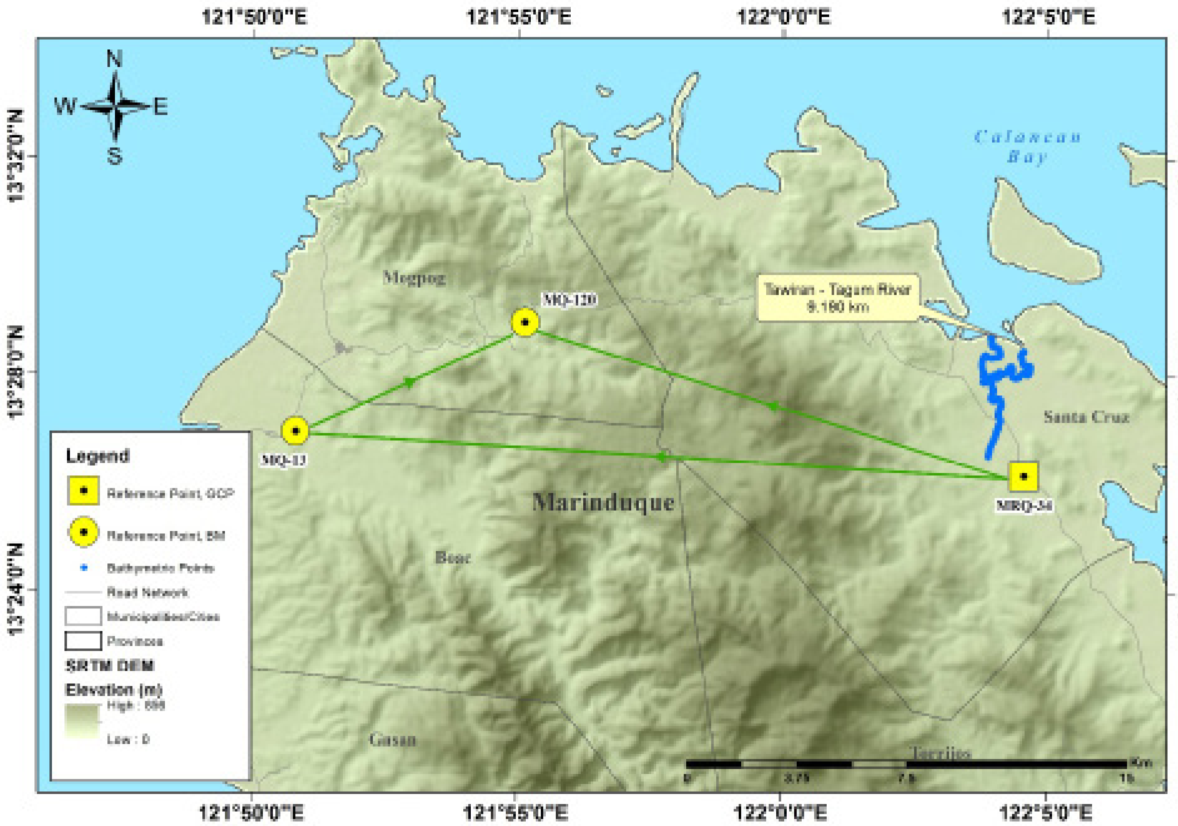


Figure 26. GNSS Network covering Tawiran-Tagum River

Table 15. List of reference and control points used during the survey in Tawiran-Tagum River (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
MRQ-34	2nd order, GCP	13°26'09.54636"N	122°04'33.94310"E	64.236	-	2016
MQ-13	1st order, BM	-	-	63.211	13.916	2016
MQ-120	Used as Marker	-	-	-	-	2016 08-11-16 2:12 PM

The GNSS set-ups on recovered reference points and established control points in Tawiran-Tagum River are shown in Figure 27 to Figure 29.

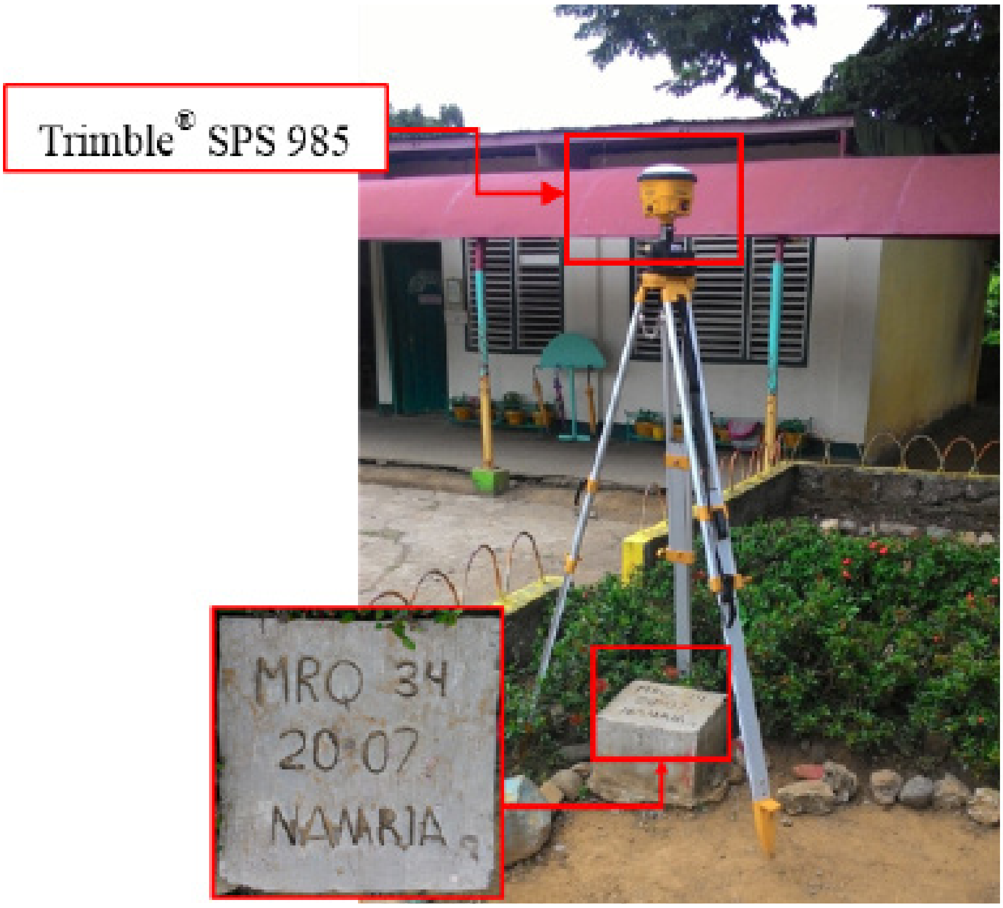


Figure 27. GNSS base set up, Trimble® SPS 985, at MRQ-34 located near the Rizal statue inside Makapuyat Elementary School in Brgy. Napo, Sta. Cruz, Marinduque

Figure 28. GNSS receiver setup, Trimble® SPS 985, at MQ-13 located at the approach of Biglang-Awa Bridge, Brgy. Mataas na Bayan, Boac, Marinduque

Figure 29. GNSS receiver setup, Trimble® SPS 985, at MQ-120 located at the approach Mangamnan Bridge, Brgy. Butansapa, Mogpong, Marinduque

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Tawiran-Tagum River Basin is summarized in Table 16 generated by TBC software.

Table 16. Baseline Processing Report for Tawiran-Tagum River Static Survey
(Source: NAMRIA, UP-TCAGP)

Observation	Date of Observation		Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
	From	To						
MQ-13 --- MRQ-34	MRQ-34	MQ-13	Fixed	0.011	0.034	273°23'02"	24859.031	-1.024
MQ-120 --- MRQ-34	MRQ-34	MQ-120	Fixed	0.009	0.038	286°58'51"	17779.150	23.128
MQ-120 --- MQ-13	MQ-120	MQ-13	Fixed	0.006	0.026	244°28'06"	8654.408	-24.145

As shown Table 16, a total of three (3) baselines were processed. 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:

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

Where:

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

for each control point. See the Network Adjustment Report shown in Table 17 to Table 20 for complete details.

The three (3) control points, MRQ-34, MQ-13 and MQ-120 were occupied and observed simultaneously to form a GNSS loop. Coordinates of MRQ-34; and elevation value of MQ-13 were held fixed during the processing of the control points as presented in Table 17. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 17. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
MRQ-34	Local	Fixed	Fixed		
MQ-13	Grid				Fixed
Fixed = 0.000001 (Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 18. The fixed controls MRQ-34 has no value for grid error while MQ-13 has no value for elevation error.

Table 18. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
MQR-34	399984.398	?	1485537.871	?	14.100	0.044	LL
MQ-13	375180.421	0.010	1487097.828	0.006	13.916	?	e
MQ-120	383004.307	0.010	1490792.799	0.006	37.551	0.037	

With the mentioned equation, for horizontal and for the vertical; the computation for the accuracy are as follows:

a.MRQ-34

horizontal accuracy	=	Fixed
vertical accuracy	=	4.4 cm < 10 cm

b.MQ-13

horizontal accuracy	=	$\sqrt{((1.0)^2 + (0.6)^2}$
	=	$\sqrt{(1.0 + 0.36)}$
	=	1.17 < 20 cm
vertical accuracy	=	Fixed

c.MQ-120

horizontal accuracy	=	$\sqrt{((1.0)^2 + (0.6)^2}$
	=	$\sqrt{(1.0 + 0.36)}$
	=	1.17 < 20 cm
vertical accuracy	=	3.7 cm < 10 cm

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

Table 19. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
MRQ-34	N13°26'09.54636"	E122°04'33.94310"	64.236	0.044	LL
MQ-13	N13°26'56.91664"	E121°50'48.94103"	63.211	?	e
MQ-120	N13°28'58.33069"	E121°55'08.56221"	87.362	0.037	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 19. Based on the result of the computation, the accuracy condition is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 20.

Table 20. Reference and control points and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
MRQ-34	2nd order, GCP	13°26'09.54636"	122°04'33.94310"	64.236	1485537.871	399984.398	14.100
MQ-13	1st order, BM	13°26'56.91664"	121°50'48.94103"	63.211	1487097.828	375180.421	13.916
MQ-120	Used as Marker	13°28'58.33069"	121°55'08.56221"	87.362	1490792.799	383004.307	37.551

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

Cross-section and as-built survey were conducted on August 14, 2016 at the downstream side of Tawiran Bridge in Brgy. Matalaba, Municipality of Santa Cruz, Marinduque as shown in Figure 30. A Trimble® SPS 985 GNSS PPK survey technique were utilized for this survey as shown in Figure 31.

Figure 30. Tawiran Bridge facing upstream

Figure 31. Bridge As-Built Survey using PPK Technique.

The cross-sectional line of Tawiran Bridge is about 113.549 m with twenty-seven (27) cross-sectional points using the control point MRQ-34 as the GNSS base station. The location map, cross-section diagram, and the bridge data form are shown in Figure 32 to Figure 34, respectively.

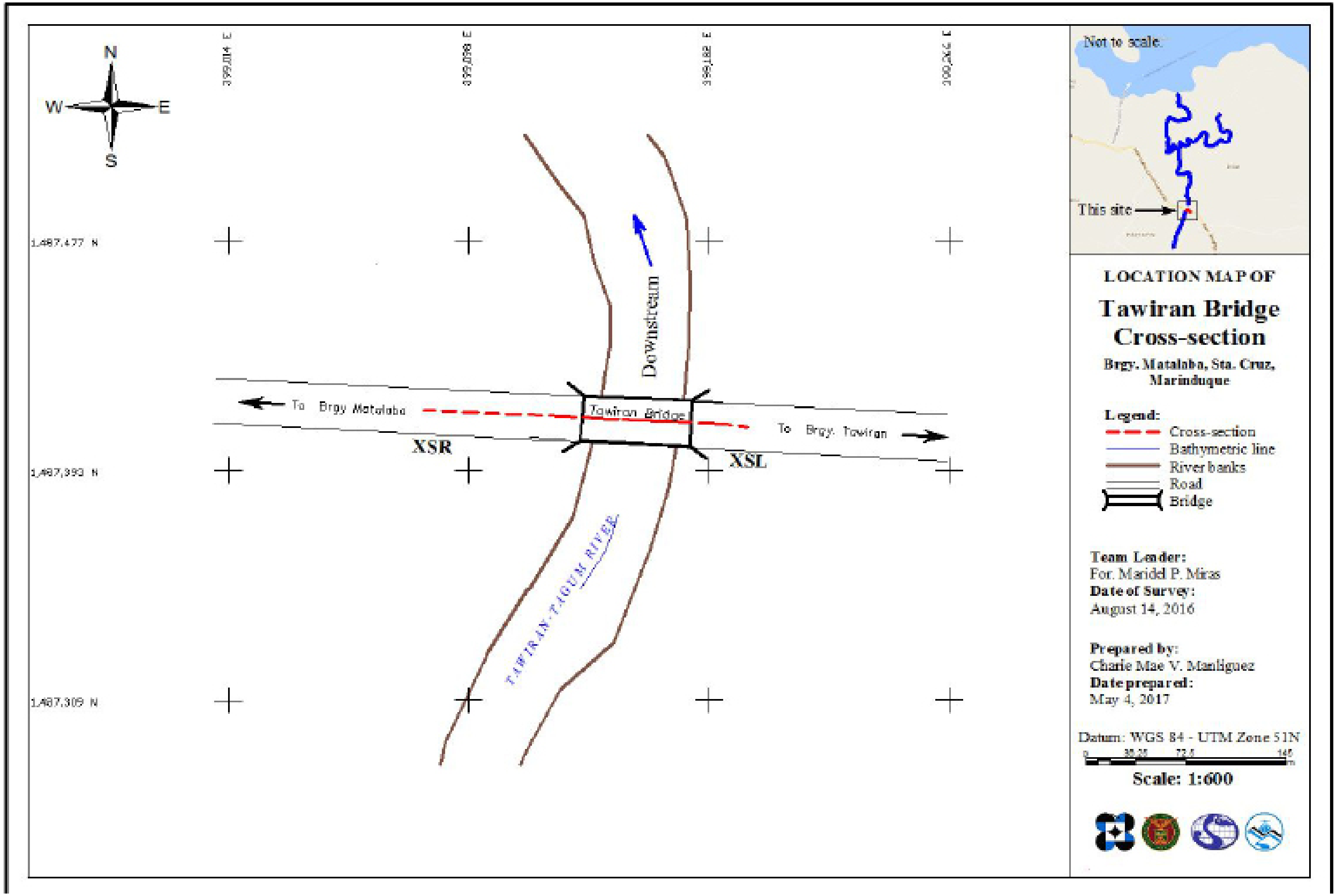


Figure 32. Location Map of Tawiran Bridge River Cross-Section survey

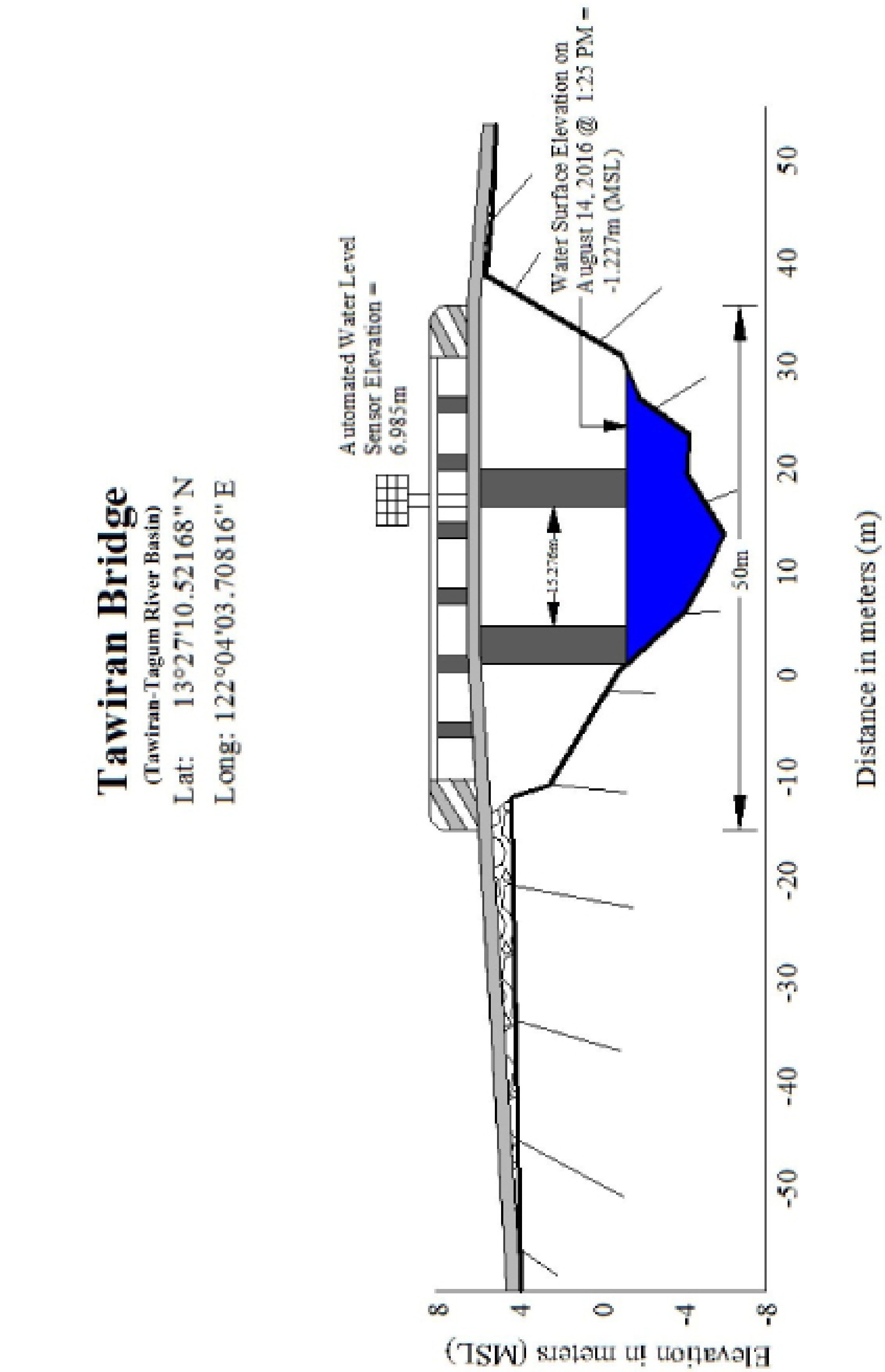


Figure 33. Tawiran Bridge cross-section diagram

Bridge Data Form

Bridge Name: Tawiran Bridge **Date:** August 14, 2016

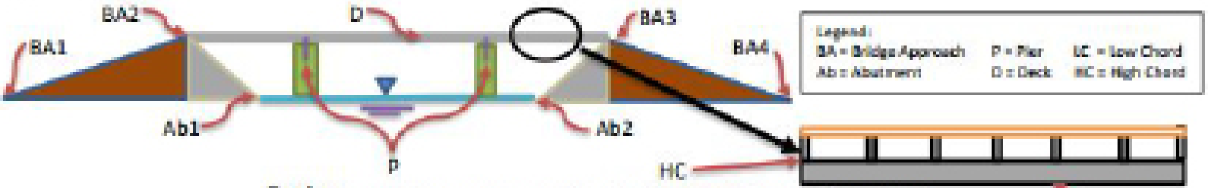
River Name: Tawiran-Tagum River **Time:** 1:25 AM

Location (Brgy, City,Region): Brgy. Matalaba, Municipality of Sta. Cruz, Marinduque

Survey Team: Maridel Miras, Caren Ordoña, Randell Pabroquez

Flow condition: normal **Weather Condition:** fair

Latitude: 13°27'10.52168" N **Longitude:** 122°04'03.70816" E



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

Elevation: 5.907 m **Width:** 7.3 m **Span (BA3-BA2):** 50 m

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	3.932 m	BA3	95.804 m	5.873 m
BA2	Not available	Not available	BA4	113.367 m	5.105 m

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

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

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

Shape: rectangular Number of Piers: 2 Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	62.748 m	5.907 m	1.20 m
Pier 2	78.014 m	5.882 m	1.20 m

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

Figure 34. Bridge as-built form of Tawiran Bridge

Water surface elevation of Tawiran-Tagum River was determined using a survey grade GNSS receiver Trimble® SPS 985 in PPK survey technique on August 14, 2016 at 1:25 PM with a value of -1.227 m in MSL as shown in Figure 33. This was translated into marking on the bridge's deck using the same technique as shown in Figure 35. The marking, with a value of 5.89 m in MSL, will serve as reference for flow data gathering and depth gauge deployment of partner HEI responsible for Tawiran-Tagum river, the UPLB.

Figure 35. Water-level markings on Tawiran Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on August 13, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 985, mounted on top of a vehicle as shown in Figure 36. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.026 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with MQ-13 occupied as the GNSS base station.

Figure 36. Validation points acquisition survey set-up along Tawiran-Tagum River Basin

The survey started from Tawiran Bridge in Brgy. Matalaba, Municipality of Santa Cruz; going south it traversed Barangays Tawiran, Napo, Taytay, Masaguisi and ended in Brgy. Mabuhay, Municipality of Torrijos; going east it traversed Brgy. Tamayo; and going north it traversed Barangays Matalaba, Buyabod, Manlibunan, and ended in Brgy. Lapu-lapu Poblacion, Municipality of Sta. Cruz, all in Marinduque. A total of 1,042 points were gathered with approximate length of 13 km using MRQ-34 as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 37.

Figure 37. Validation point acquisition survey of Tawiran-Tagum River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on August 16 and 18, 2016 using an Hi-Target™ single beam echo sounder and Trimble® SPS 985 in GNSS PPK survey technique in continuous topo mode as illustrated in Figure 38. The survey started at the upper part of Brgy. Matalaba, Municipality of Santa Cruz with coordinates 13°27'34.44725"N, 122°04'01.80281"E, and ended at two different mouths of the river: one in Brgy. Buyabod with coordinates 13°28'43.95859"N, 122°03'56.35351"E and anothe in Brgy. Biga with coordinates 13°28'28.42534"N, 122°04'32.86961"E.

Figure 38. Bathymetric survey using Hi-Target™ single beam echo sounder in Tawiran-Tagum River

Figure 39. Bathymetric survey using Trimble® SPS 882 in GNSS PPK survey technique in Tawiran-Tagum River

Figure 40. Gathering of random bathymetric points along Tawiran-Tagum River

The bathymetric survey for Tawiran-Tagum River gathered a total of 2,198 points covering a total estimated length of 9.190 km of the river traversing Barangays Buyabod, Biga, Matalaba, Tawiran and Pantayon in Municipality of Santa Cruz (Figure 41). A CAD drawing was also produced to illustrate the riverbed profile of Tawiran-Tagum River. As shown in Figure 42 and Figure 43, the highest and lowest elevation has a 5-m difference. The highest elevation observed was -1.621 m in MSL located in Brgy. Matalaba, while the lowest was -6.506 m below MSL located at the downstream portion of the river located in Brgy. Biga, both in Municipality of Santa Cruz. The left outlet of the river, locally known as Tagum, was also surveyed, adding 2.5 km to the total bathymetric surveyed. This tributary also contributes water outflow according to the UPLB.

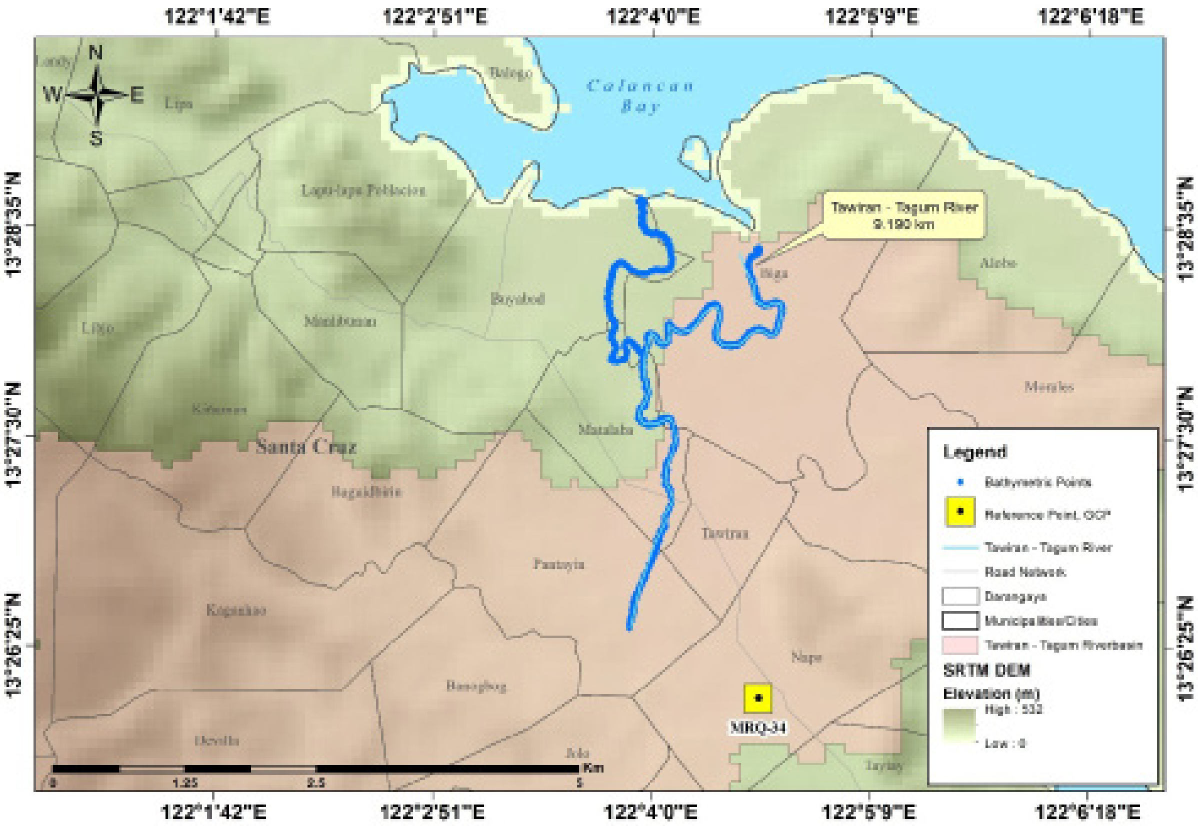


Figure 41. Bathymetric survey of Tawiran-Tagum River

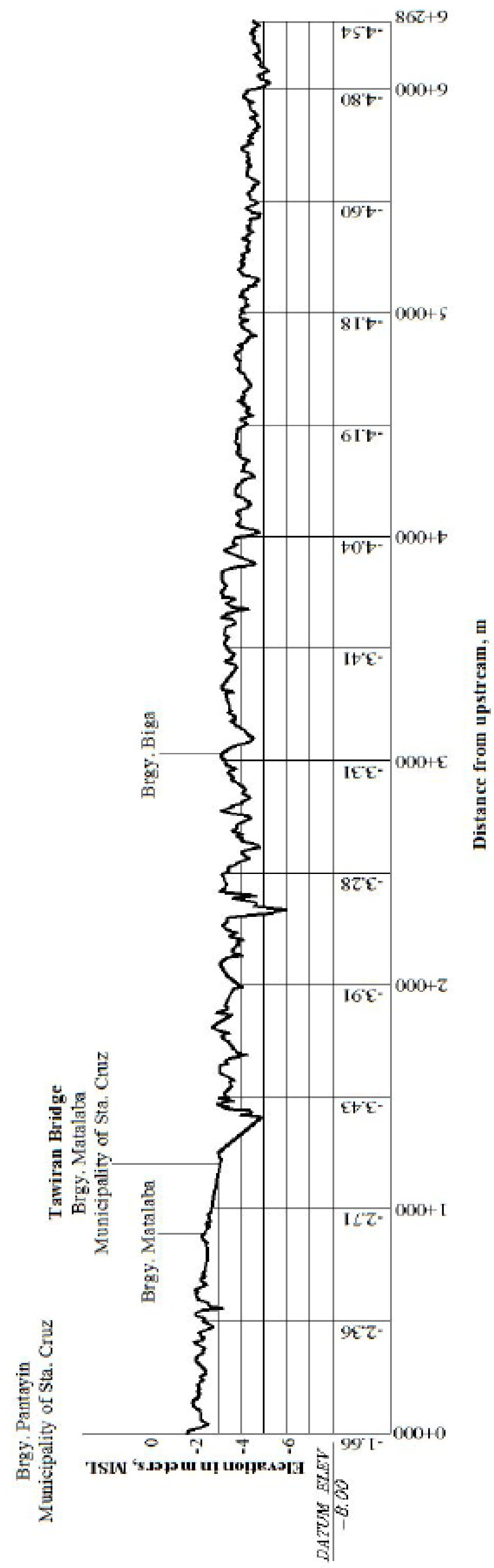


Figure 42. Tawiran-Tagum Riverbed Profile, right mouth

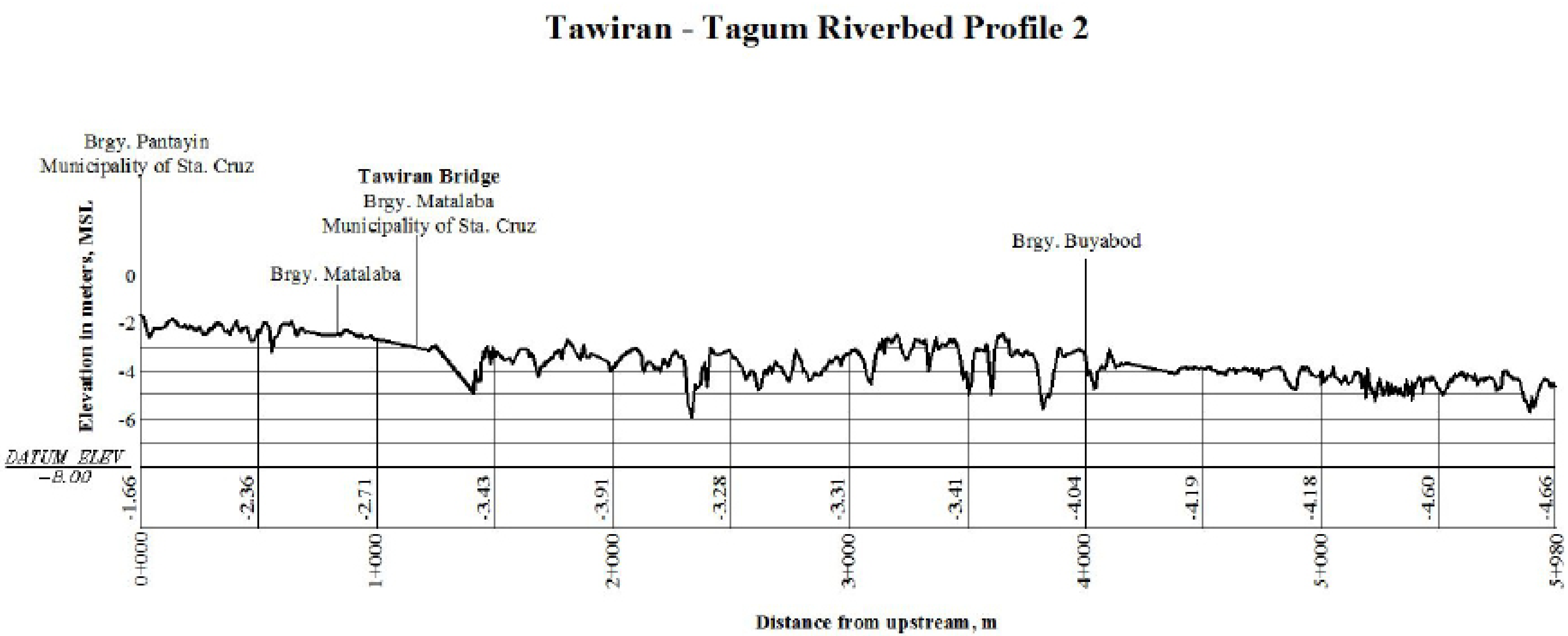


Figure 43. Tawiran-Tagum Riverbed Profile, left mouth

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Khristoffer Quinton, John Alvin B. Reyes, Alfi Lorenz B. Cura, Angelica T. Magpantay, Maria Michaela A. Gonzales Paulo Joshua U. Quilao, Jayson L. Arizapa, and Kevin M. Manalo

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 Tawiran-Tagum River Basin were monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Tawiran-Tagum River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an Automatic Rain Gauge (ARG). The ARG was installed on Brgy. Devilla (13.413028°N, 122.031806°E). The location of the rain gauges is seen in Figure 44.

The total precipitation for this event is 230.0 mm. It has a peak rainfall of 6.0 mm. on January 1, 2015 at 8:00 am, as seen in Figure 46.

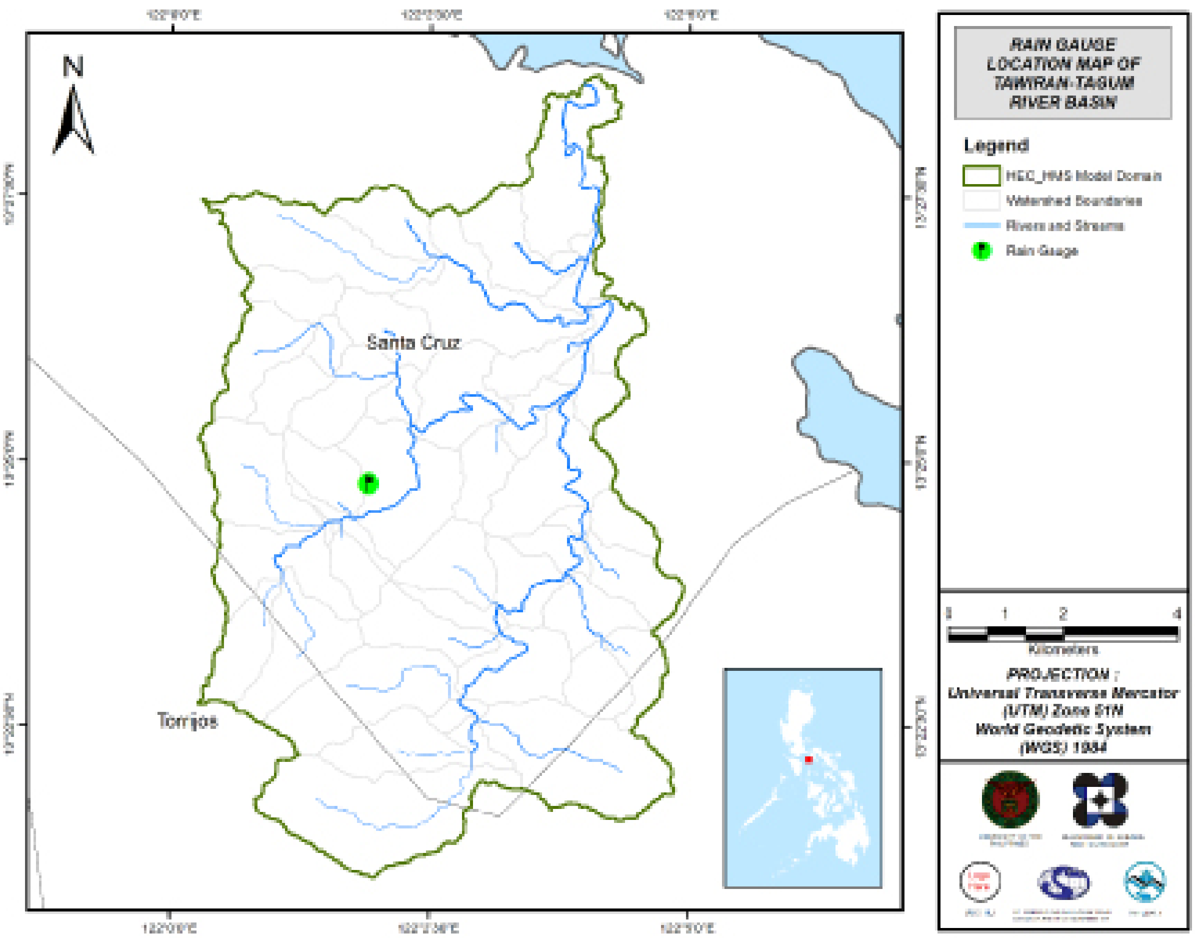


Figure 44. The location map of Tawiran-Tagum HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Sta. Cruz Bridge, Tawiran Tagum, Marinduque (13.453500° N, 122.068000° E) using Manning's Bankfull Method. It gives the relationship between the observed change in water and the outflow of the watershed at this location.

For Sta. Cruz Bridge, the rating curve is expressed as Q = 0.0113x2 +0.0654x -0.1716 as shown in Figure 46.

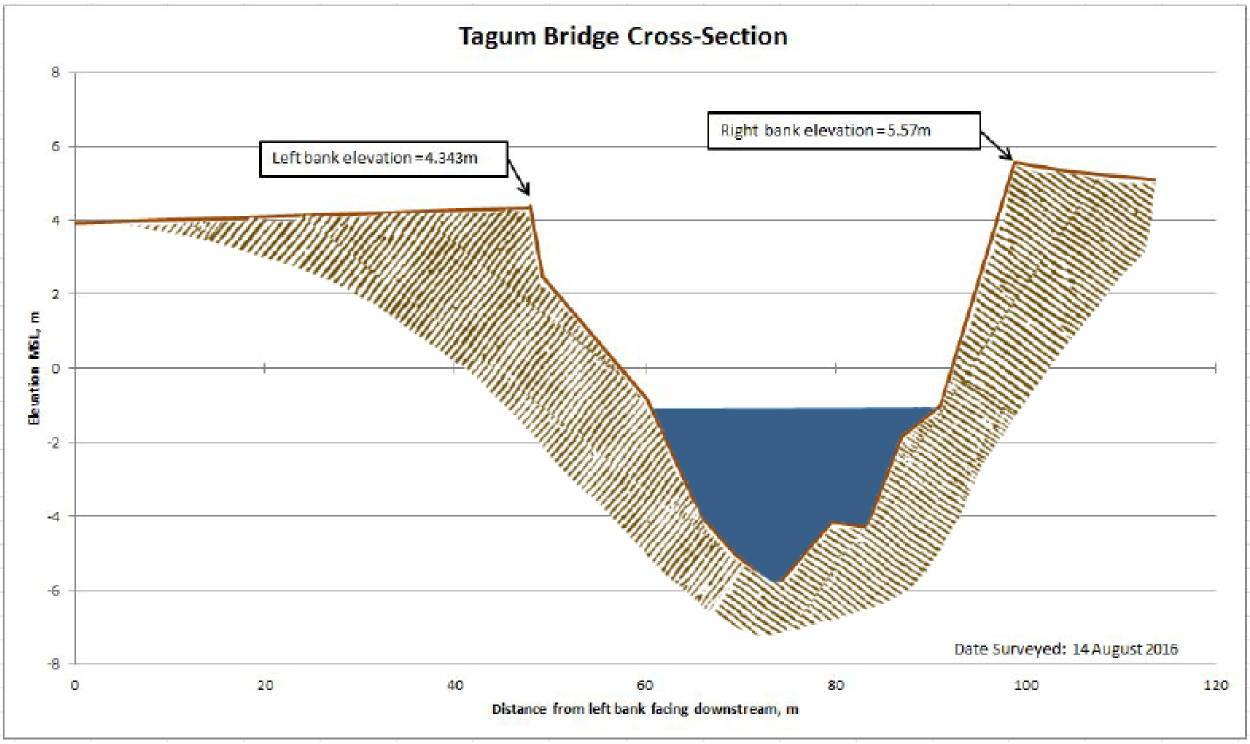


Figure 45. Cross-Section Plot of Sta. Cruz Bridge

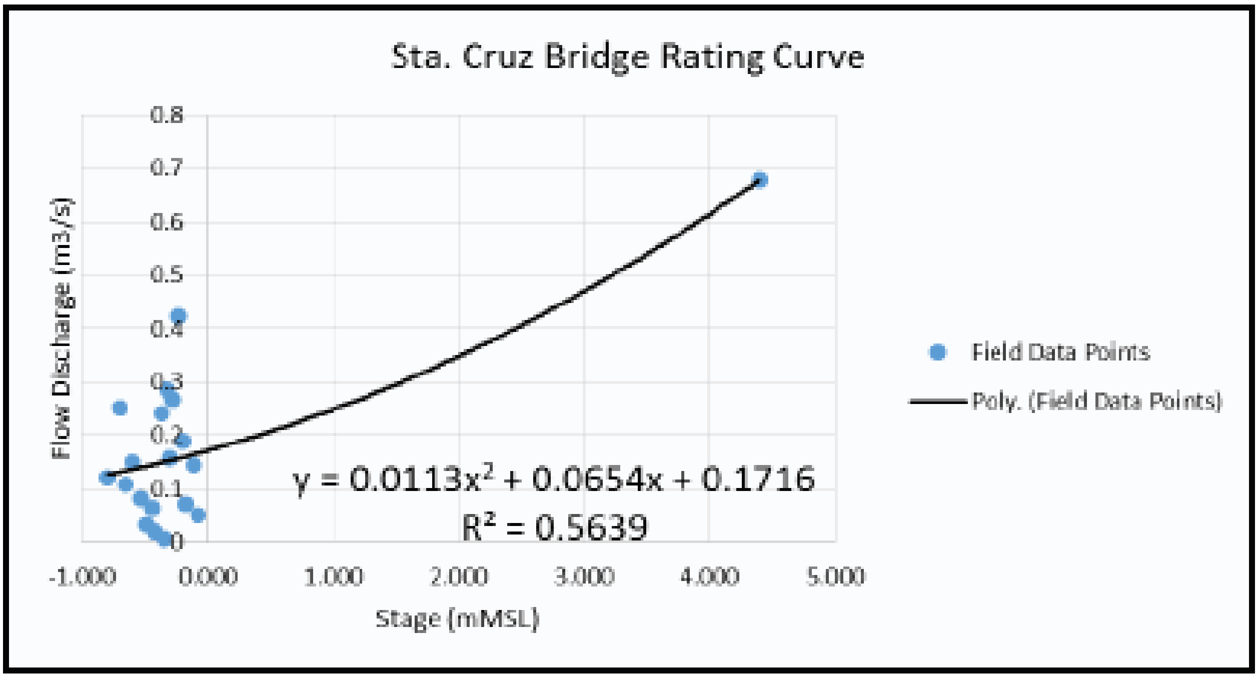


Figure 46. Rating curve at Sta. Cruz Bridge, Tawiran Tagum, Marinduque

For the calibration of the HEC-HMS model, shown in Figure 47, actual flow discharge during a rainfall event was collected in the Sta. Cruz Bridge. Peak discharge is 58.0 cu.m/s on January 1, 2015 at 12:50 pm.
The Pamplona River Rating Curve measured at Pamplona Bridge is expressed as Q = 305.63e0.5029x (Figure 50).

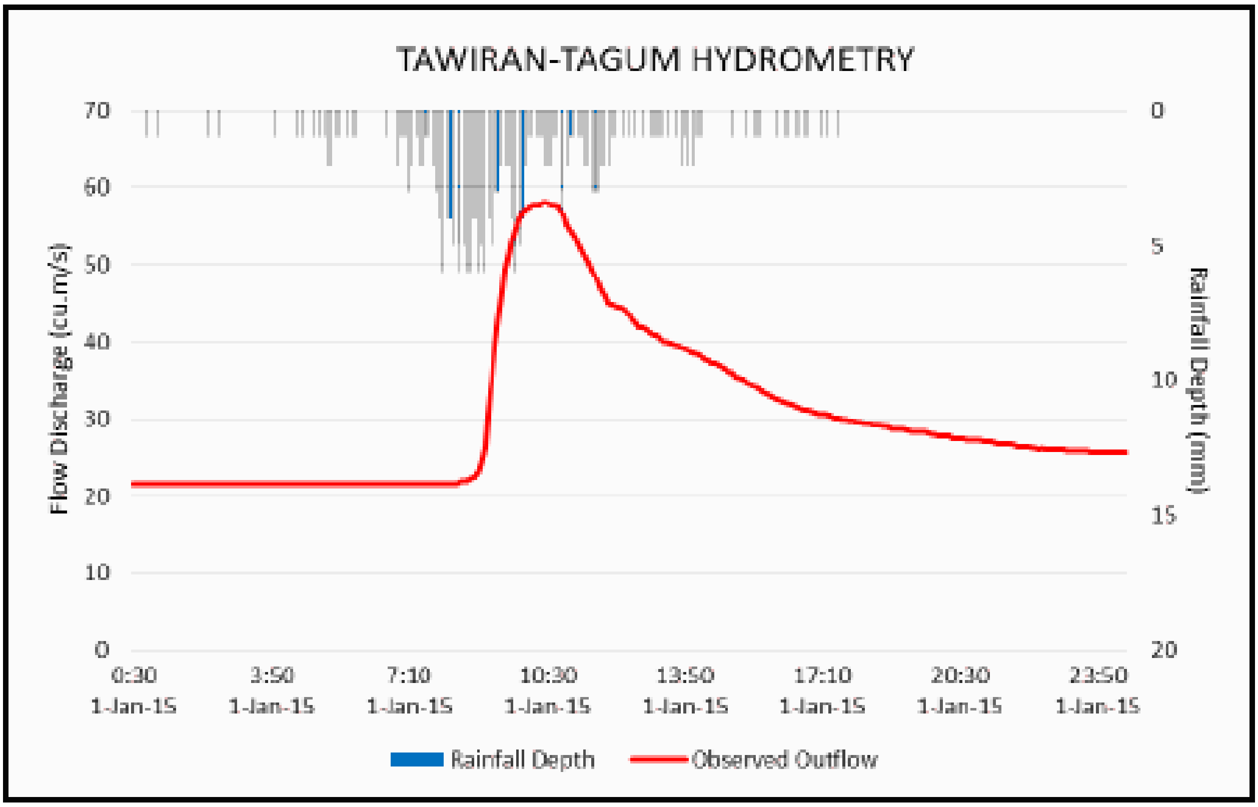


Figure 47. Rainfall and outflow data at Tawiran-Tagum River Basin used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Alabat Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station chosen based on its proximity to the Tawiran Tagum watershed. The extreme values for this watershed were computed based on a 31-year record, with the computed extreme values shown in Table 21.

Table 21. RIDF values for Tawiran-Tagum 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	20.9	31.3	39.8	55.3	77	94.2	118.3	143.2	173.4
5	27.6	41.3	52.9	74.6	108.5	134.8	172.8	208.6	252
10	32.1	48	61.6	87.3	129.4	161.6	209	251.9	303.9
15	34.6	51.8	66.5	94.5	141.1	176.8	229.3	276.3	333.3
20	36.4	54.4	69.9	99.6	149.4	187.4	243.6	293.4	353.8
25	37.7	56.5	72.6	103.5	155.7	195.6	254.6	306.6	369.6
50	41.9	62.7	80.7	115.4	175.3	220.7	288.4	347.2	418.4
100	46.1	69	88.8	127.3	194.7	245.7	322	387.5	466.7

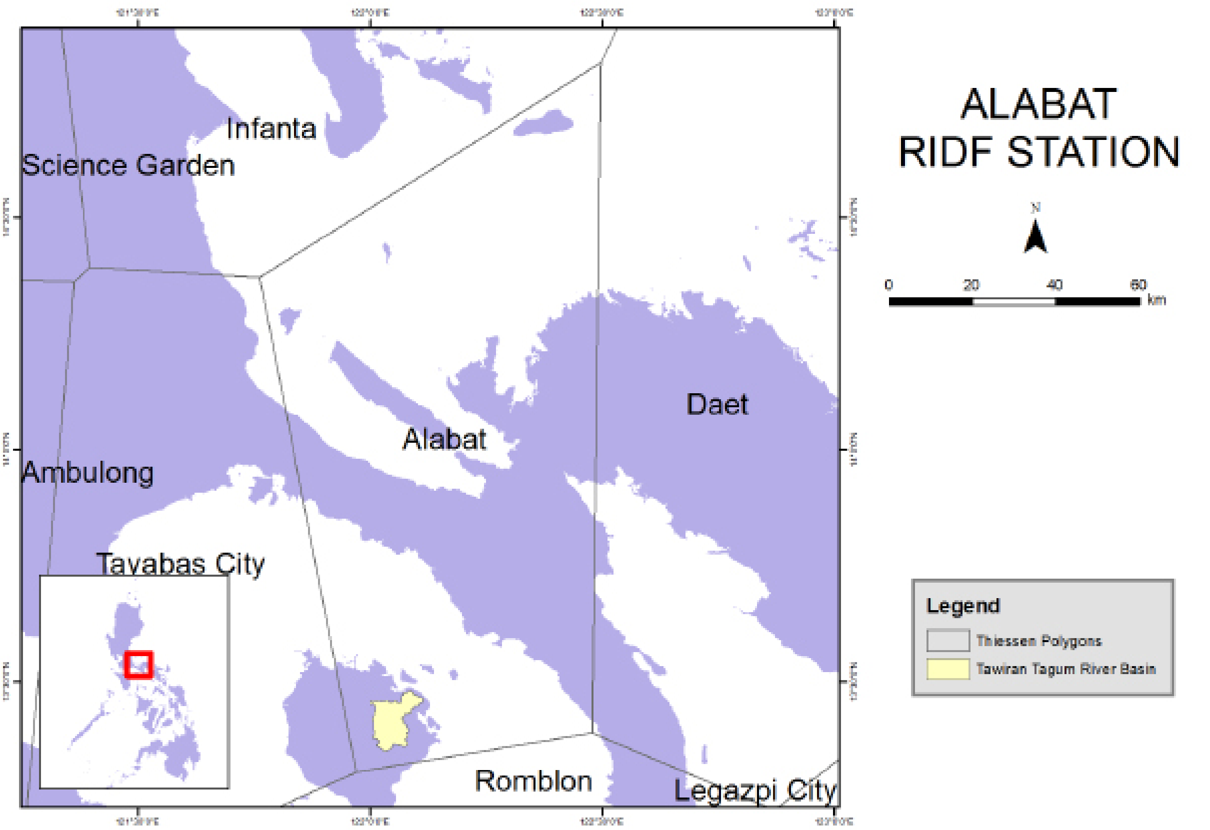


Figure 48. Location of Alabat RIDF relative to Tawiran-Tagum River Basin

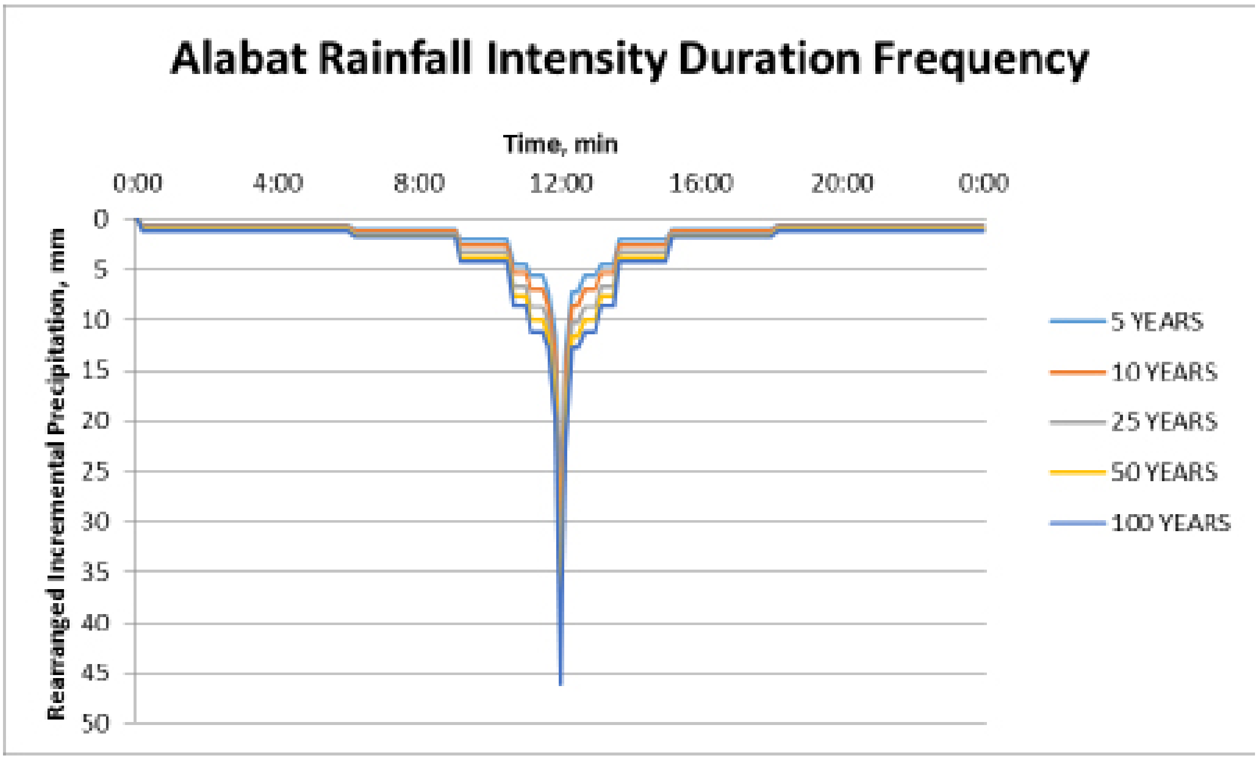


Figure 49. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 by the Bureau of Soils and Water Management under the Department of Agriculture (DA-BSWM). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Tawiran-Tagum River Basin are shown in Figure 50 and Figure 51, respectively.

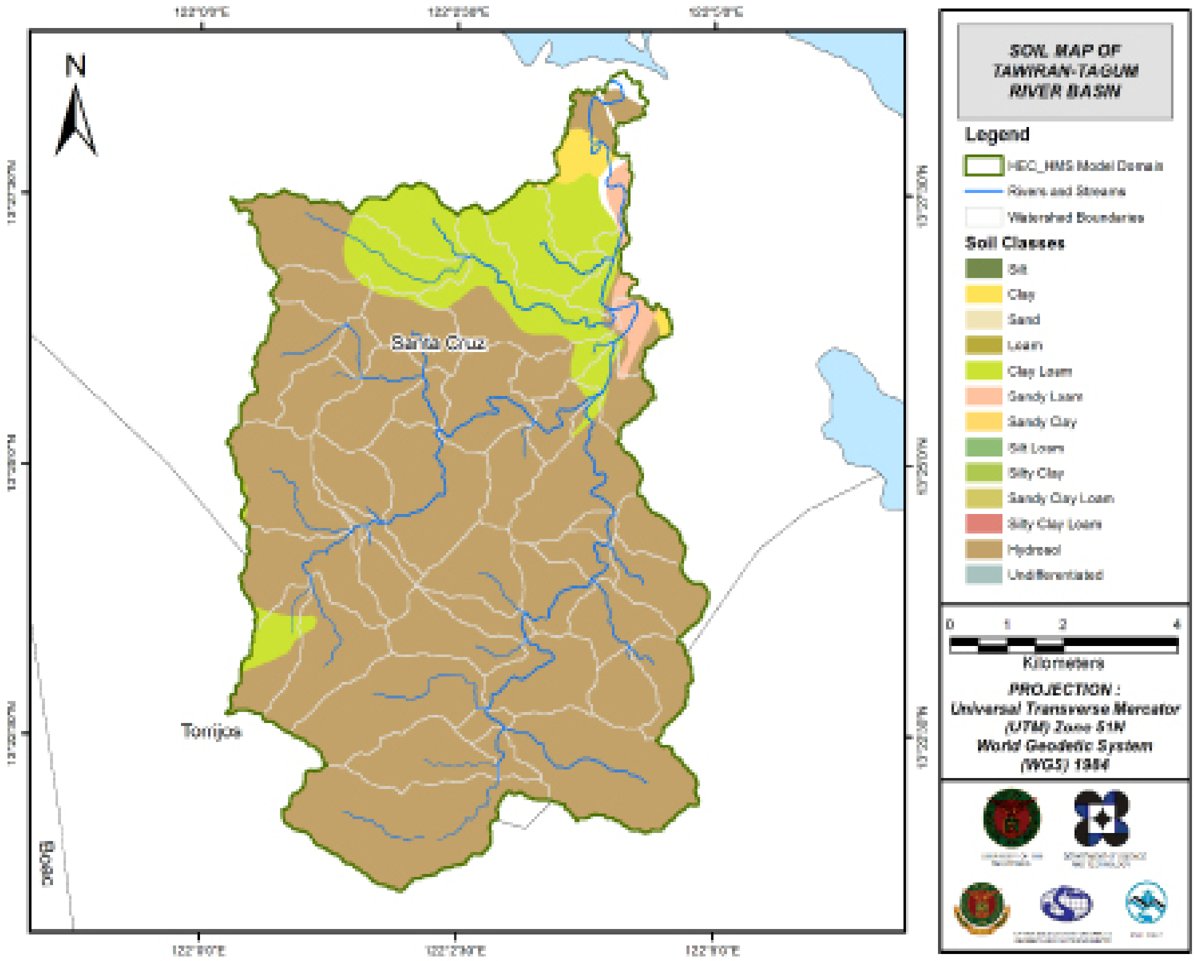


Figure 50. Soil map of Tawiran-Tagum River Basin used for the estimation of the CN parameter. (Source: DA)

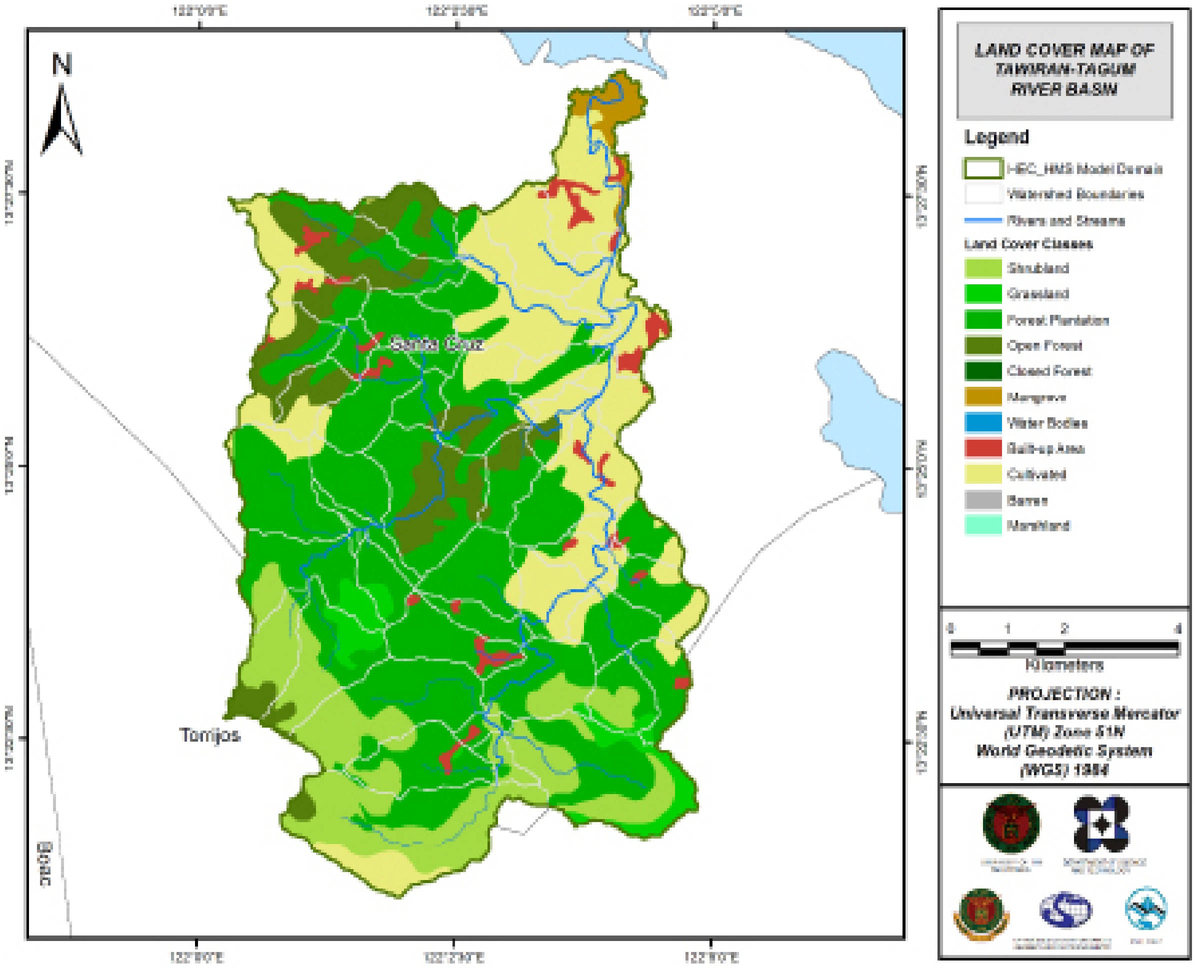


Figure 51. Land cover map of Tawiran-Tagum River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

Tawiran-Tagum river basin has at least four (4) identified soil classes. It is mostly hydrosol and clay loam, with portions of clay and sandy loam. Moreover, seven (7) land cover classes were identified. The area is largely forest plantation and cultivated land, while other land cover are open forest, grassland, shrubland, built-up area, and mangrove.

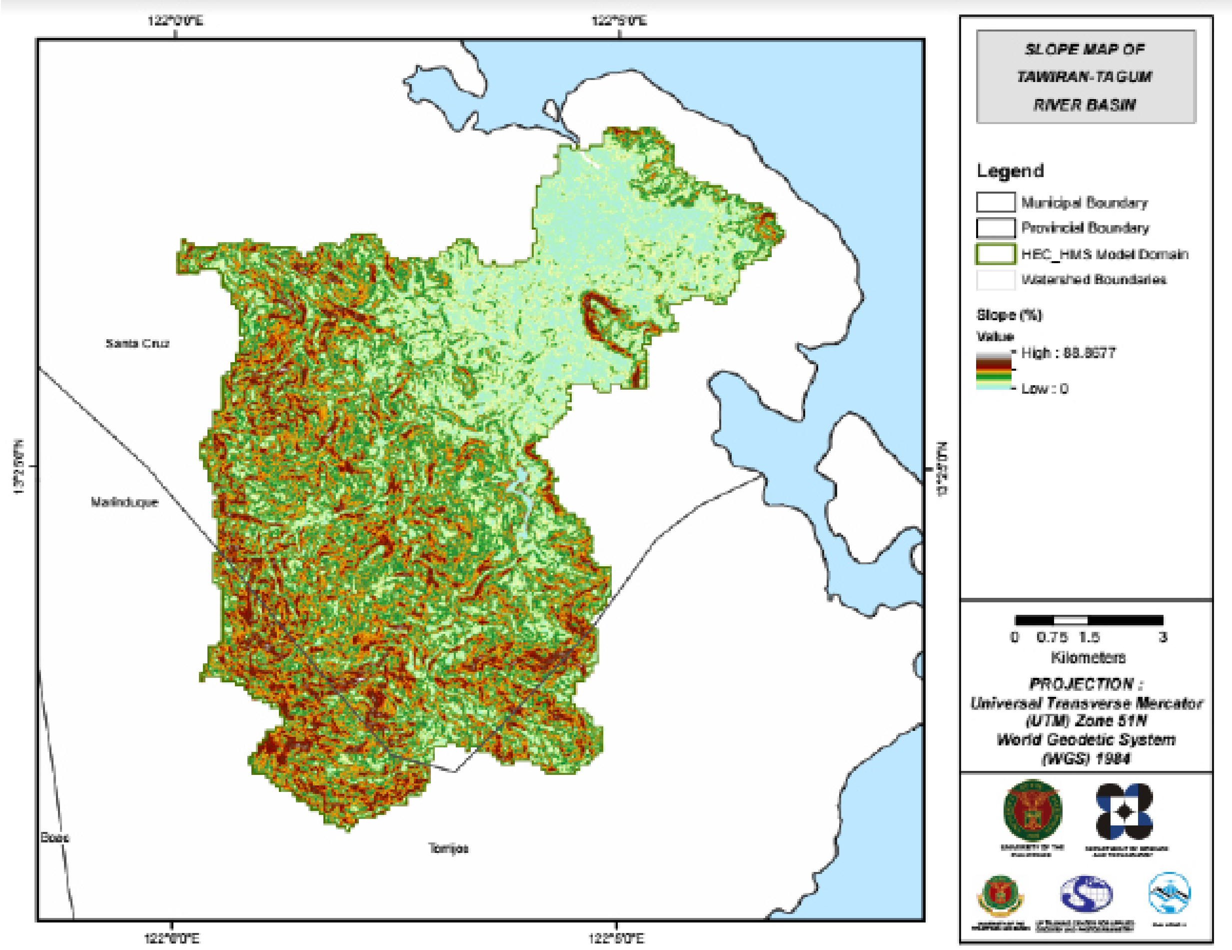


Figure 52. Slope map of Tawiran-Tagum River Basin

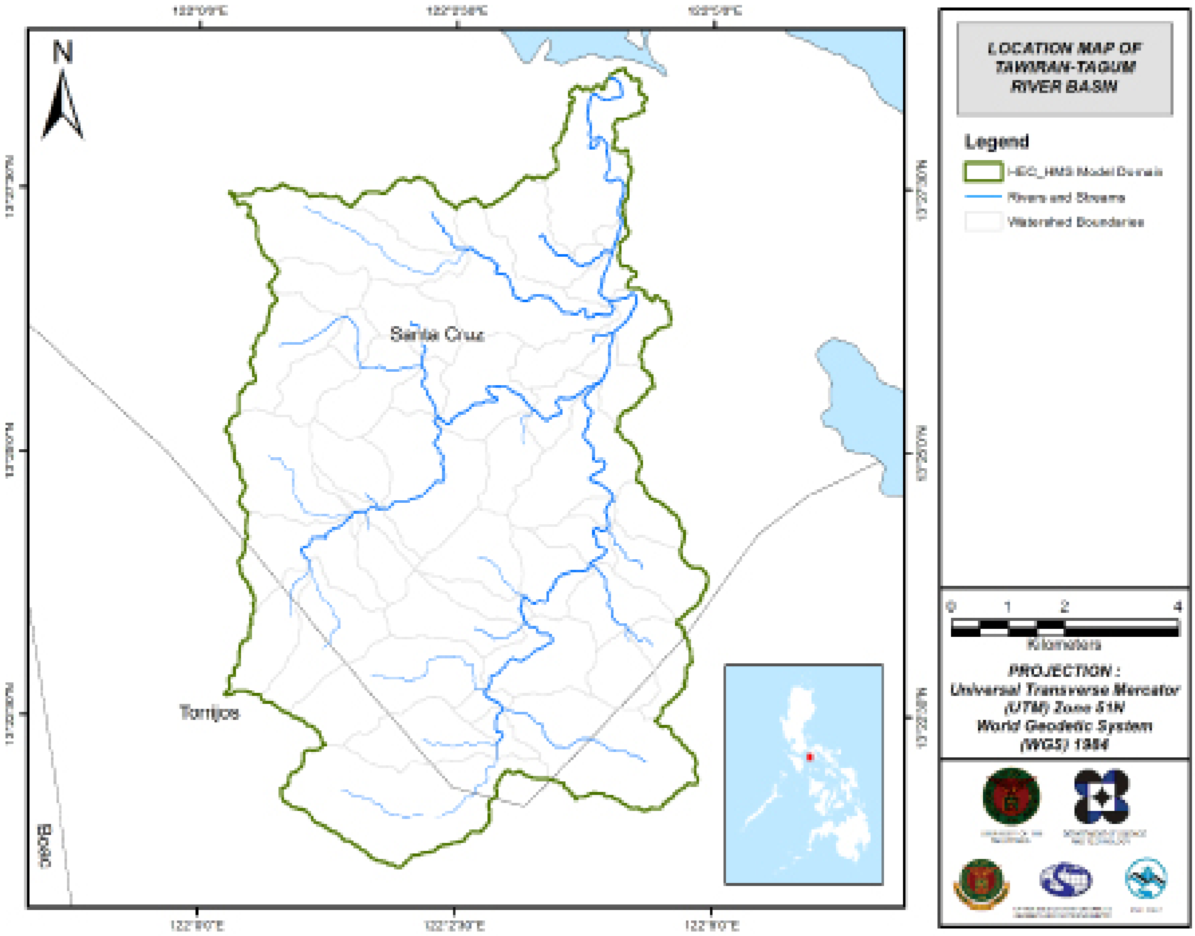


Figure 53. Stream delineation map of Tawiran-Tagum River Basin

Using SAR-based DEM, the Tawiran-Tagum basin was delineated and further subdivided into subbasins. The model consists of 48 sub basins, 24 reaches, and 24 junctions. The main outlet is labelled as 41. This basin model is illustrated in Figure 54. The basins were identified based on soil and land cover characteristics of the area. Precipitation was taken from an Automatic Rain Gauge (ARG) Station at Brgy. Devilla, Tawiran-Tagum. Finally, it was calibrated using the flow data collected from the Sta. Cruz Bridge.

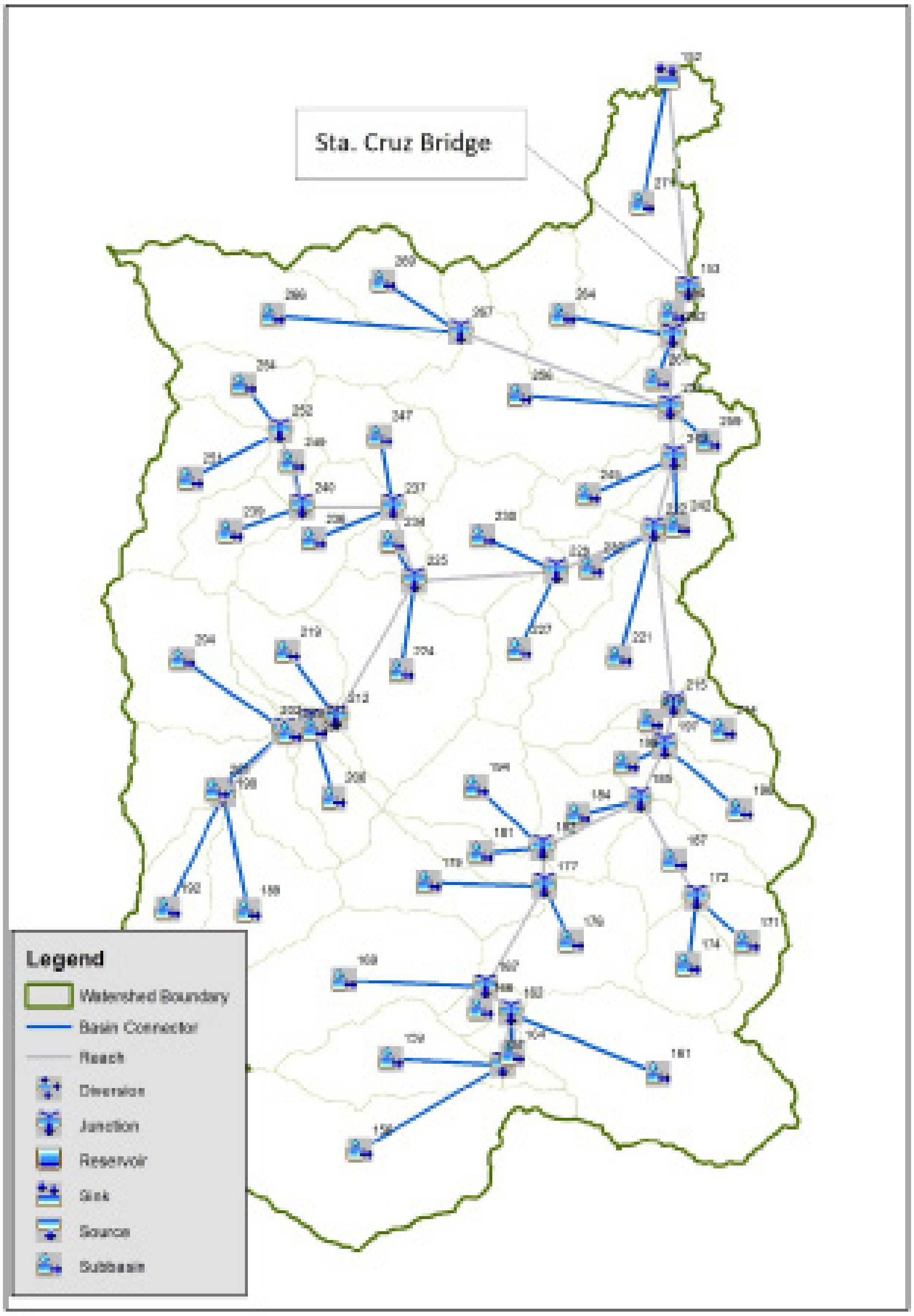


Figure 54. HEC-HMS generated Tawiran-Tagum River Basin Model.

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.

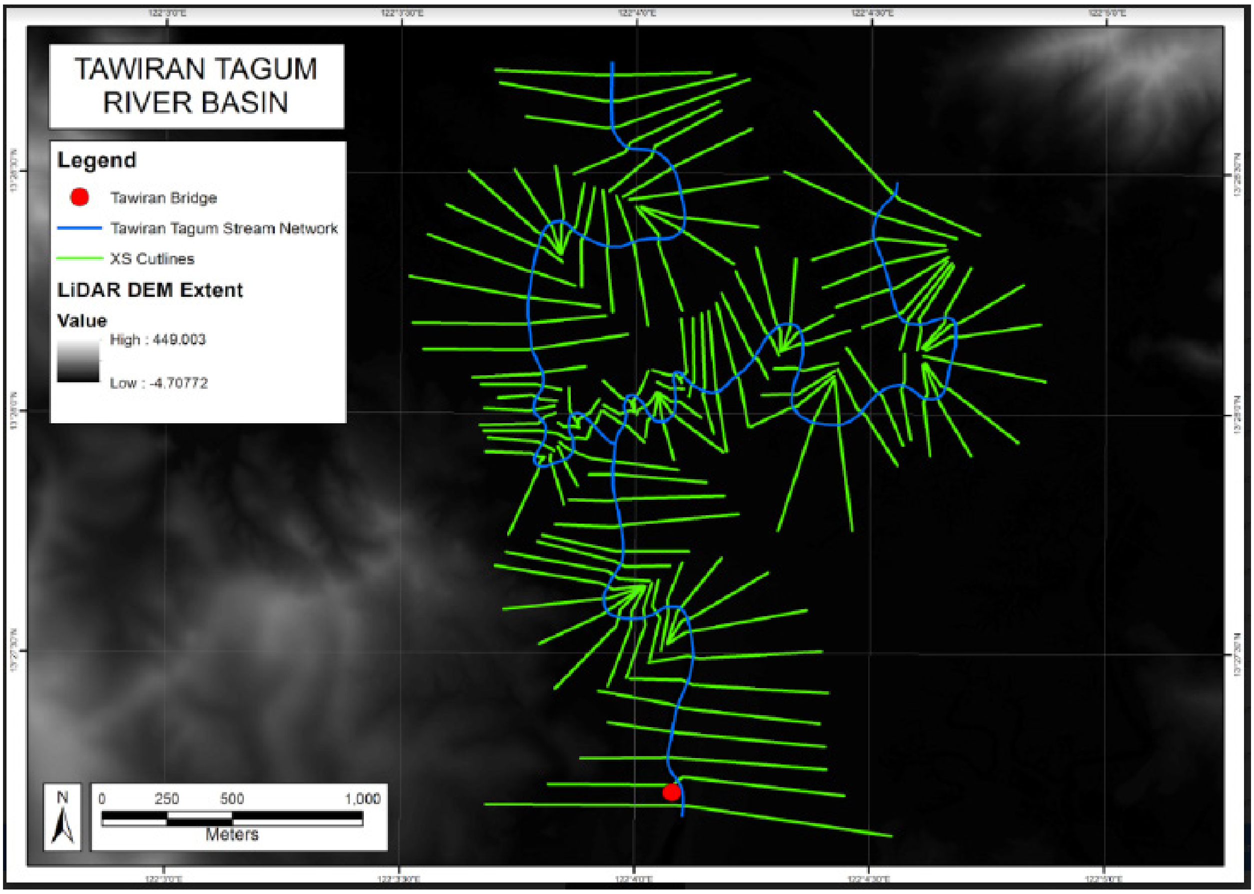


Figure 55. River cross-section of Tawiran-Tagum River generated through Arcmap HEC GeoRAS tool

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

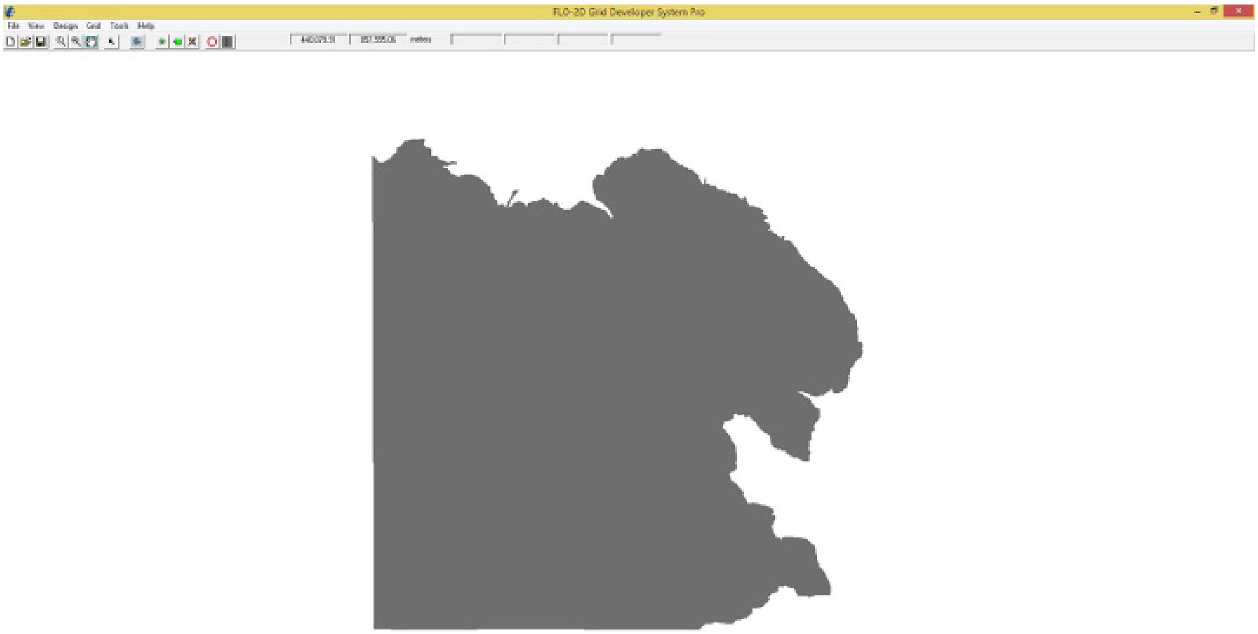


Figure 56. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 148.99963 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s. The generated hazard maps for Tawiran-Tagum are in Figures 60, 62, and 64.

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 97,036,800.00 m2. The generated flood depth maps for Tawiran-Tagum are in Figures 61, 63, and 65.

There is a total of 53,172,050.60 m3 of water entering the model. Of this amount, 38,752,394.19 m3 is due to rainfall while 14,419,656.41 m3 is inflow from other areas outside the model. 10,524,692.00 m3 of this water is lost to infiltration and interception, while 13,402,554.73 m3 is stored by the flood plain. The rest, amounting up to 29,244,839.51 m3, is outflow.

5.6 Results of HMS Calibration

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

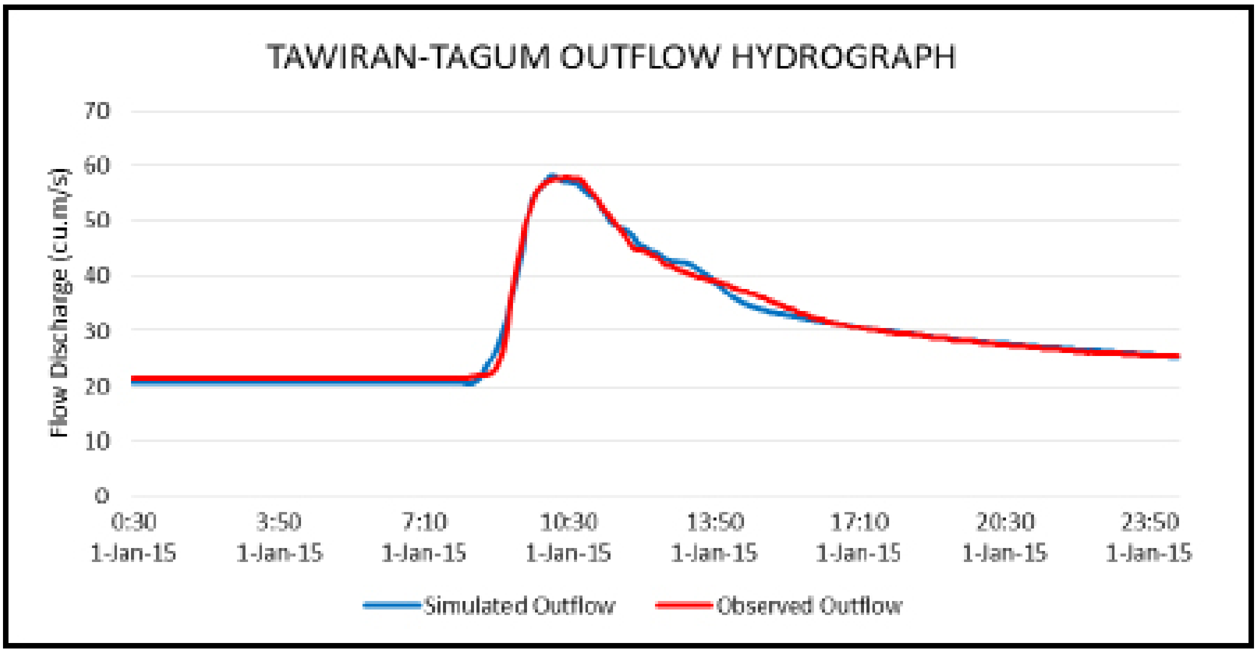


Figure 57. Outflow Hydrograph of Tawiran-Tagum produced by the HEC-HMS model compared with observed outflow.

Enumerated in Table 22 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 22. Range of calibrated values for Tawiran-Tagum River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	1 - 192
			Curve Number	35 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.1 - 75
			Storage Coefficient (hr)	0.06 - 43
	Baseflow	Recession	Recession Constant	0.04 - 1
			Ratio to Peak	0.02 – 0.7
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.02 – 0.1

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 1 to 192mm means that there is a high amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 35 to 99 for curve number means that there is a diverse characteristic for this watershed depending on its subbasin.

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 0.06 hours to 75 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Same as the curve number, the characteristics of this watershed differs per subbasin.

Manning's roughness coefficient of 0.02 to 0.1 also indicates different characteristics of the river reaches (Brunner, 2010).

Table 23. Summary of the Efficiency Test of Tawiran-Tagum HMS Model

Accuracy measure	Value
RMSE	0.977
r2	0.995
NSE	0.991
PBIAS	0.017
RSR	0.097

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.977.

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 0.995.

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 0.991.

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 0.017.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.097.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

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

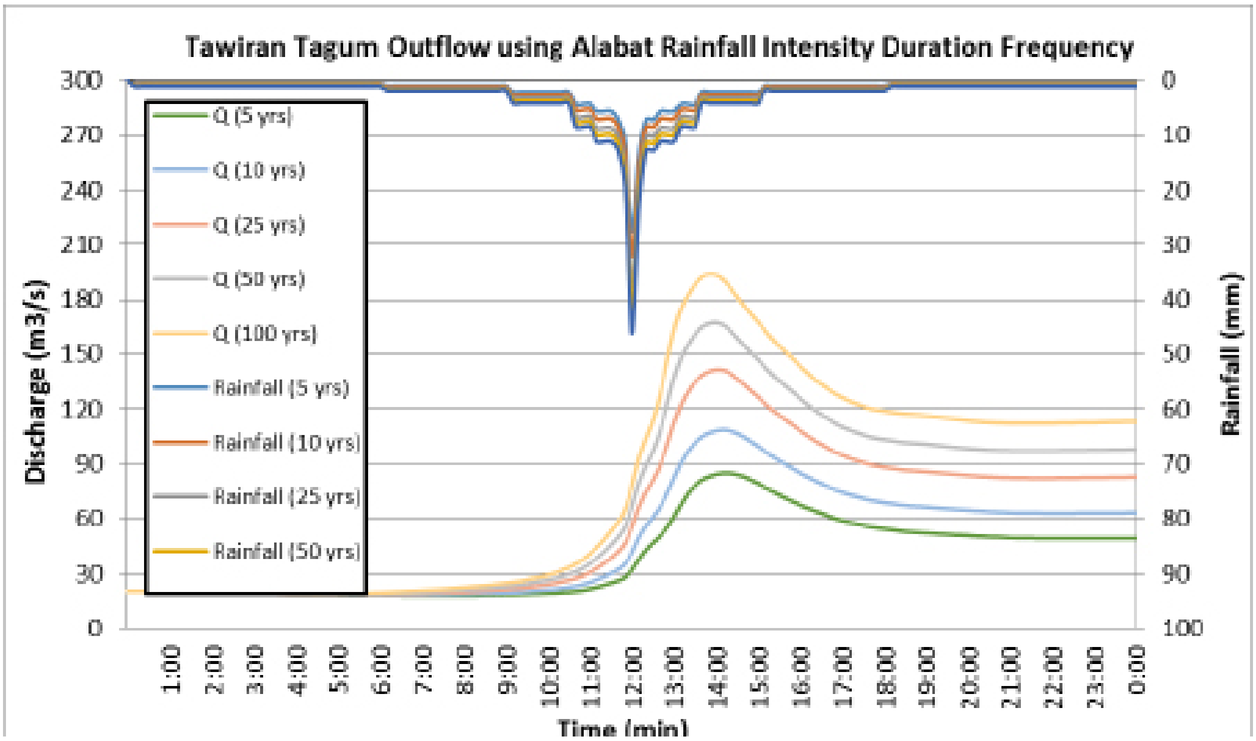


Figure 58. Outflow hydrograph at the Tawiran-Tagum Station generated using the simulated rain events for 24-hour period for Legazpi station

A summary of the total precipitation, peak rainfall, peak outflow, time to peak and lag time of the Tawiran Tagum discharge using the Alabat Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 24.

Table 24. Peak values of the Tawiran-Tagum HECHMS Model outflow using the Alabat RIDF 24-hour values

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak	Lag Time
5-Year	252.0	27.60	85.0	14 hours 10 minutes	2 hours 10 minutes
10-Year	303.90	32.10	108.80	14 hours 10 minutes	2 hours 10 minutes
25-Year	369.6	37.70	141.60	14 hours	2 hours
50-Year	418.40	41.90	167.40	14 hours	2 hours
100-Year	466.70	46.10	193.90	15 hours 50 minutes	3 hours 50 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample map of Tawiran Tagum River using the HMS base flow is shown on Figure 59 below.

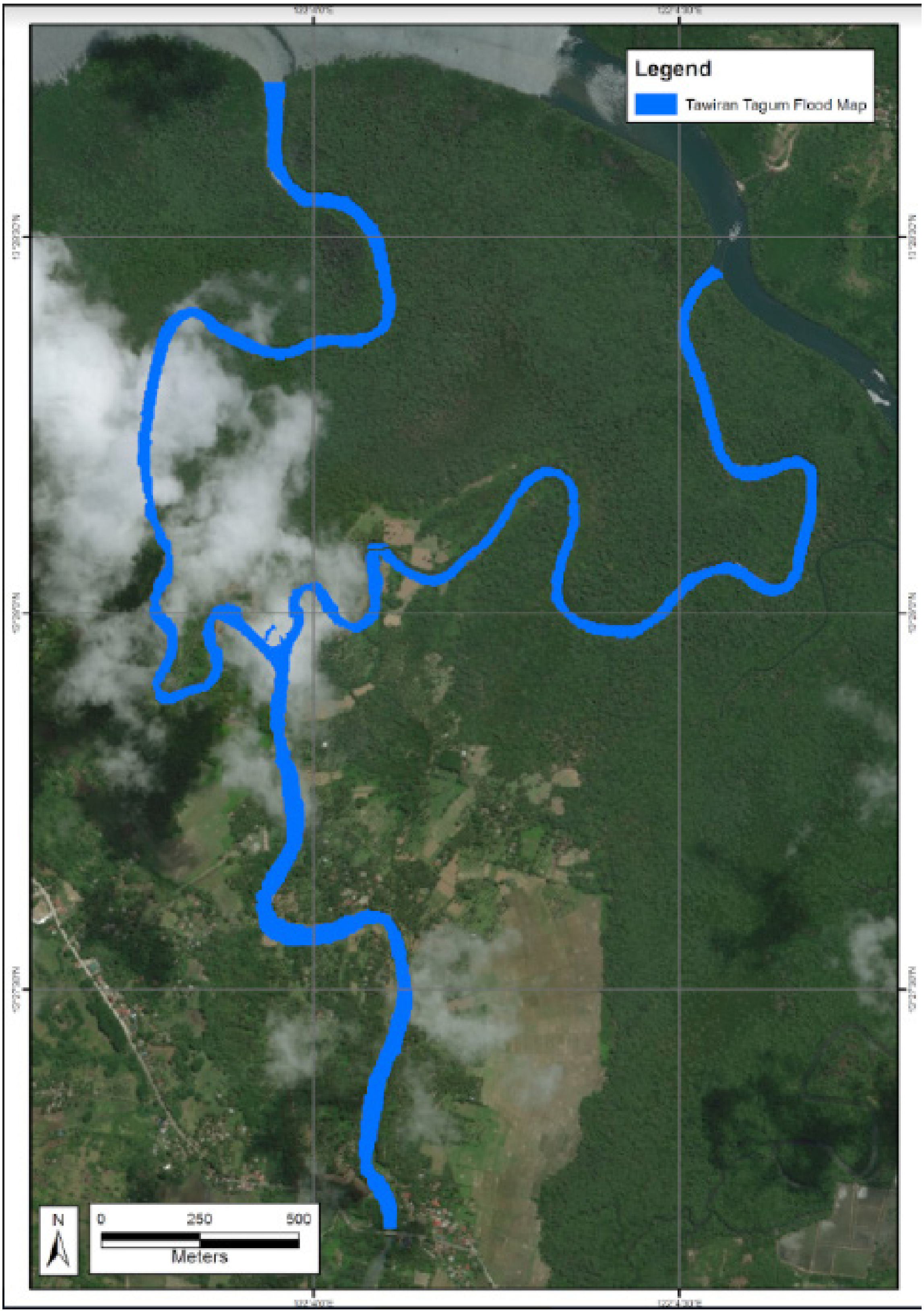


Figure 59. Sample output of Tawiran-Tagum RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. The generated flood hazard maps for the Tambang Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAGASA 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). The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Tawiran-Tagum floodplain are shown in Figure 60 to Figure 65. The floodplain, with an area of 99.49 sq. km., covers two municipalities namely Santa Cruz, and Torrijos. Table 25 shown the percentage of area affected by flooding per municipality.

Table 25. Municipalities affected in Tawiran-Tagum Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Santa Cruz	236.19	93.26	39.48
Torrijos	210.05	6.15	2.93

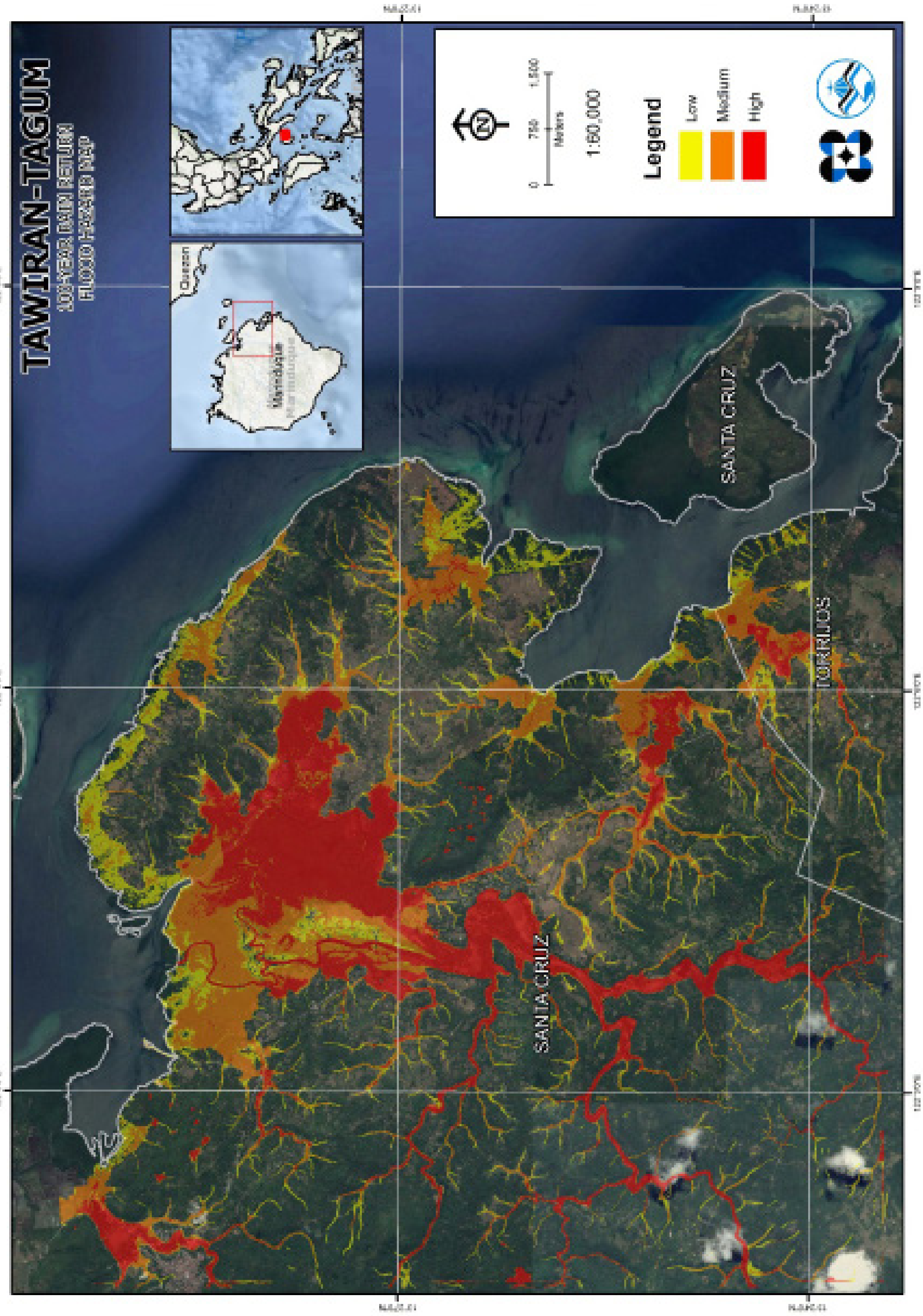


Figure 60. 100-year Flood Hazard Map for Tawiran-Tagum Floodplain overlaid on Google Earth imagery

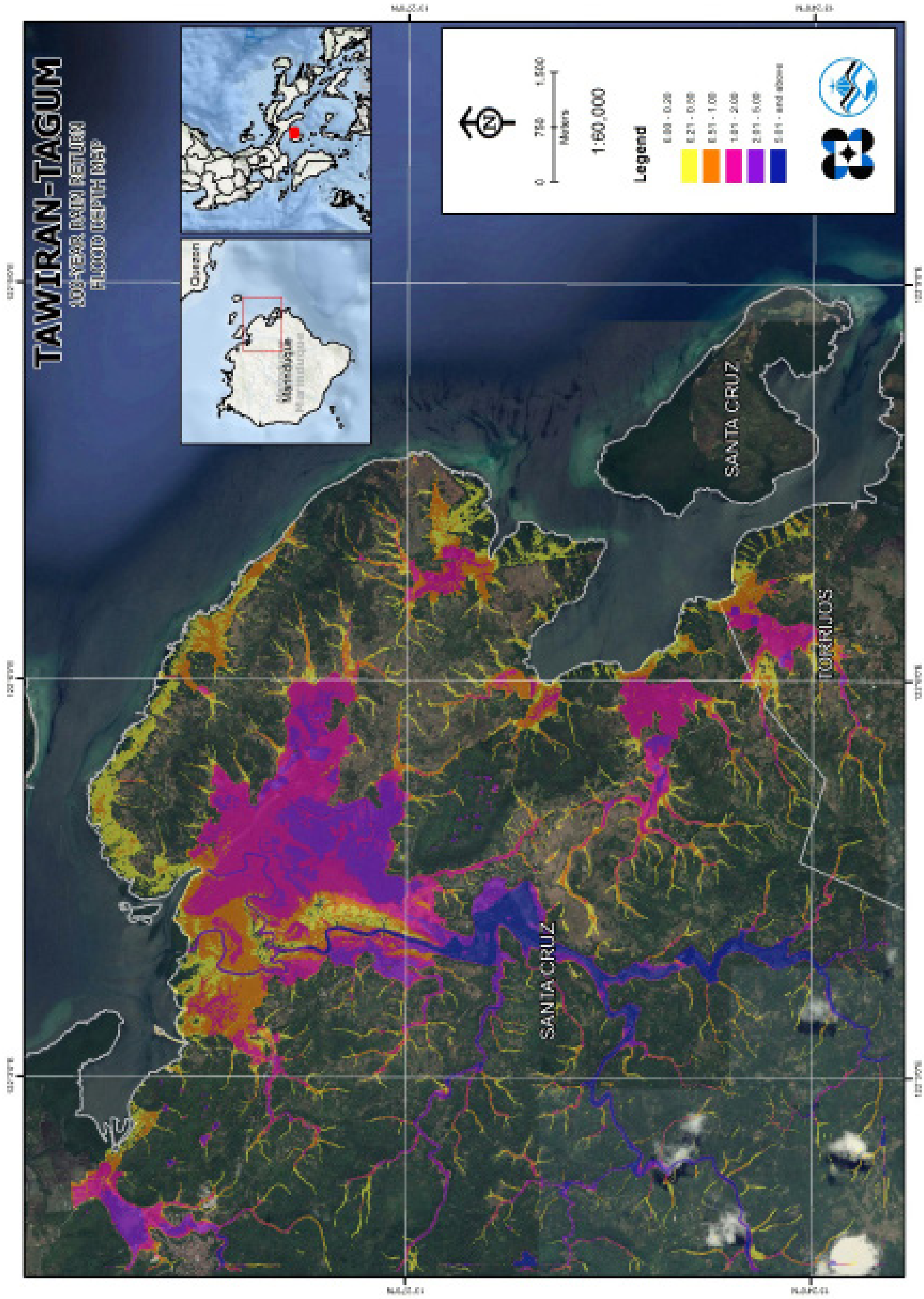


Figure 61. 100-year Flow Depth Map for Tawiran-Tagum Floodplain overlaid on Google Earth imagery

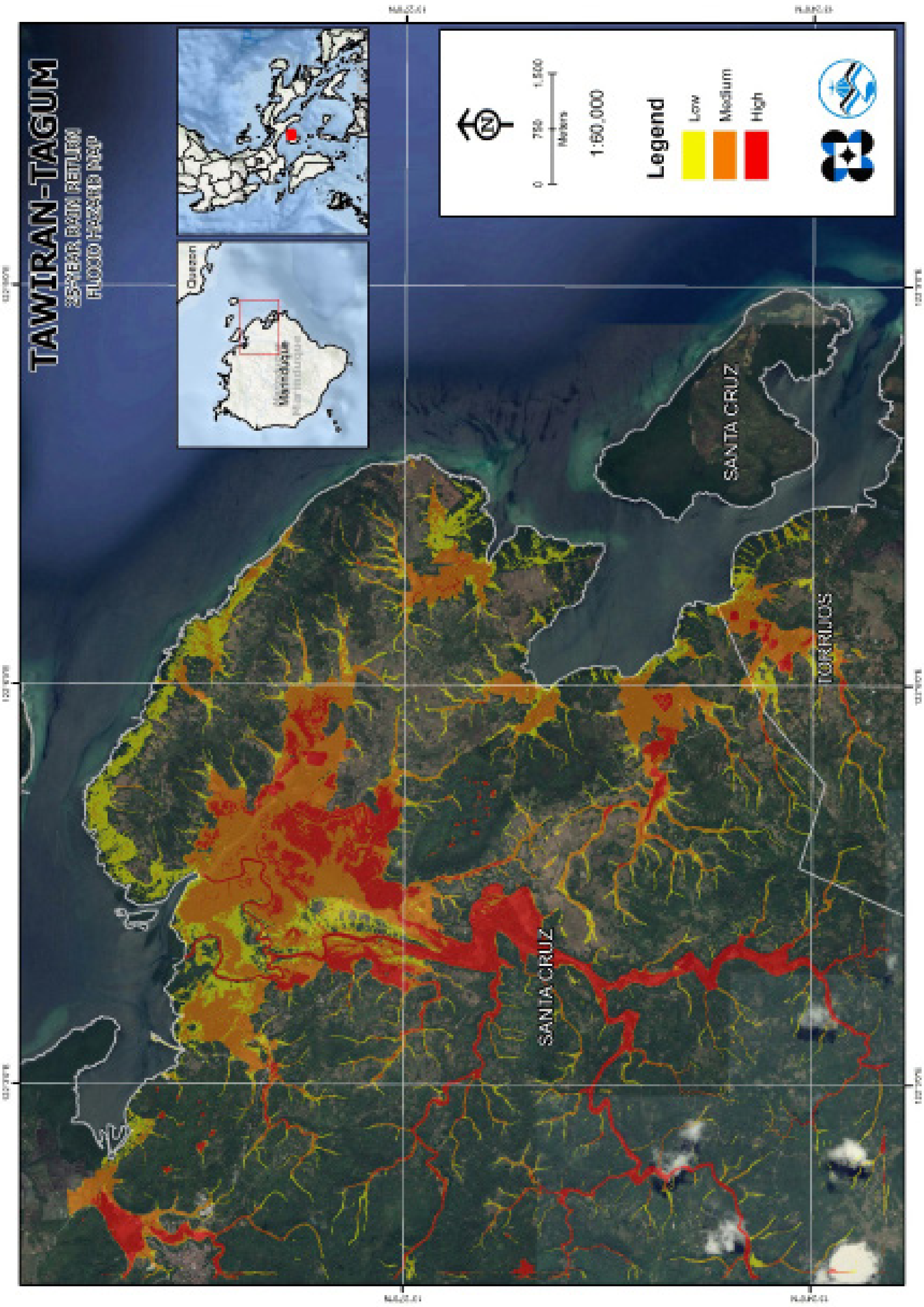


Figure 62. 25-year Flood Hazard Map for Tawiran-Tagum Floodplain overlaid on Google Earth imagery

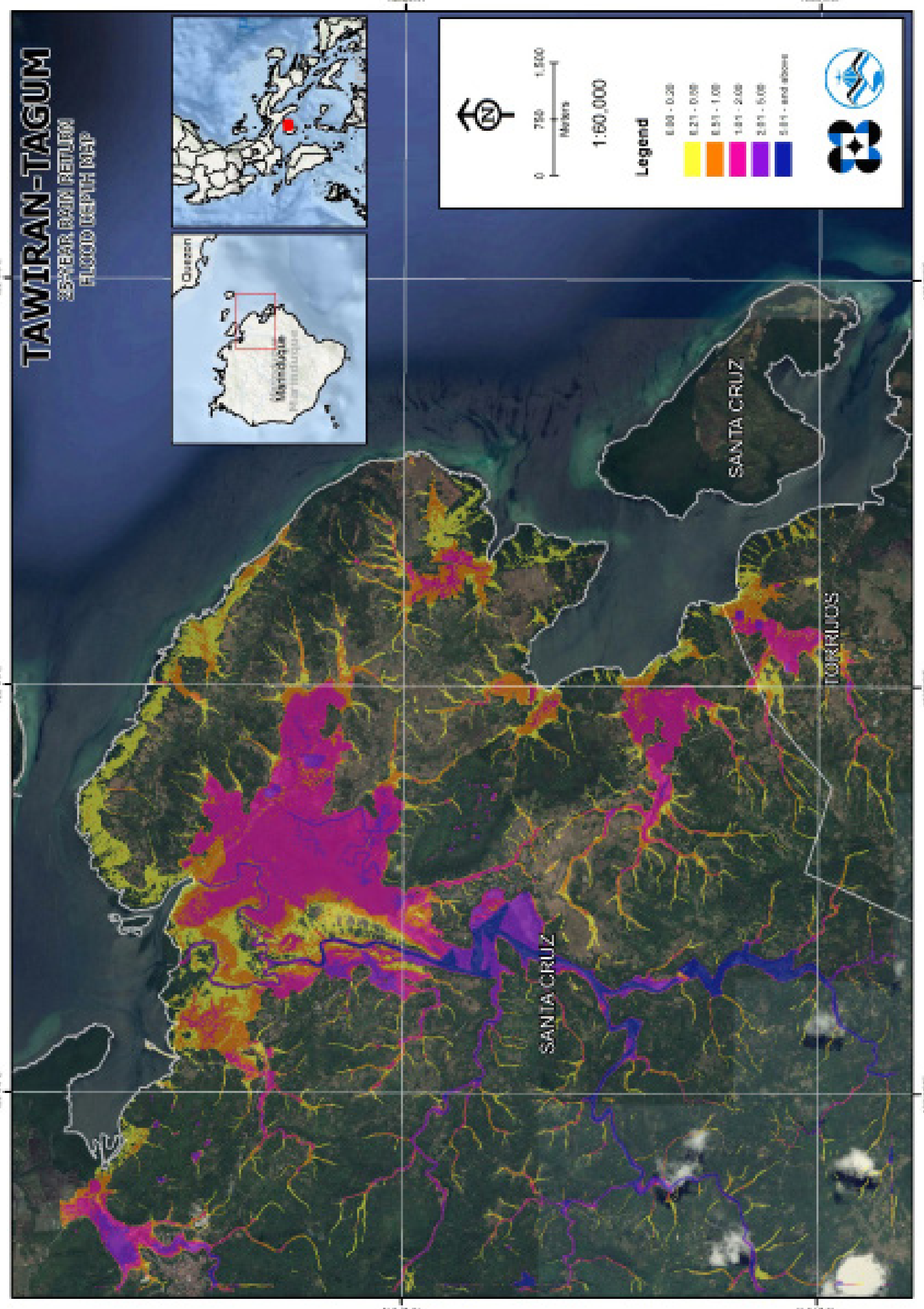


Figure 63. 25-year Flow Depth Map for Tawiran-Tagum Floodplain overlaid on Google Earth imagery

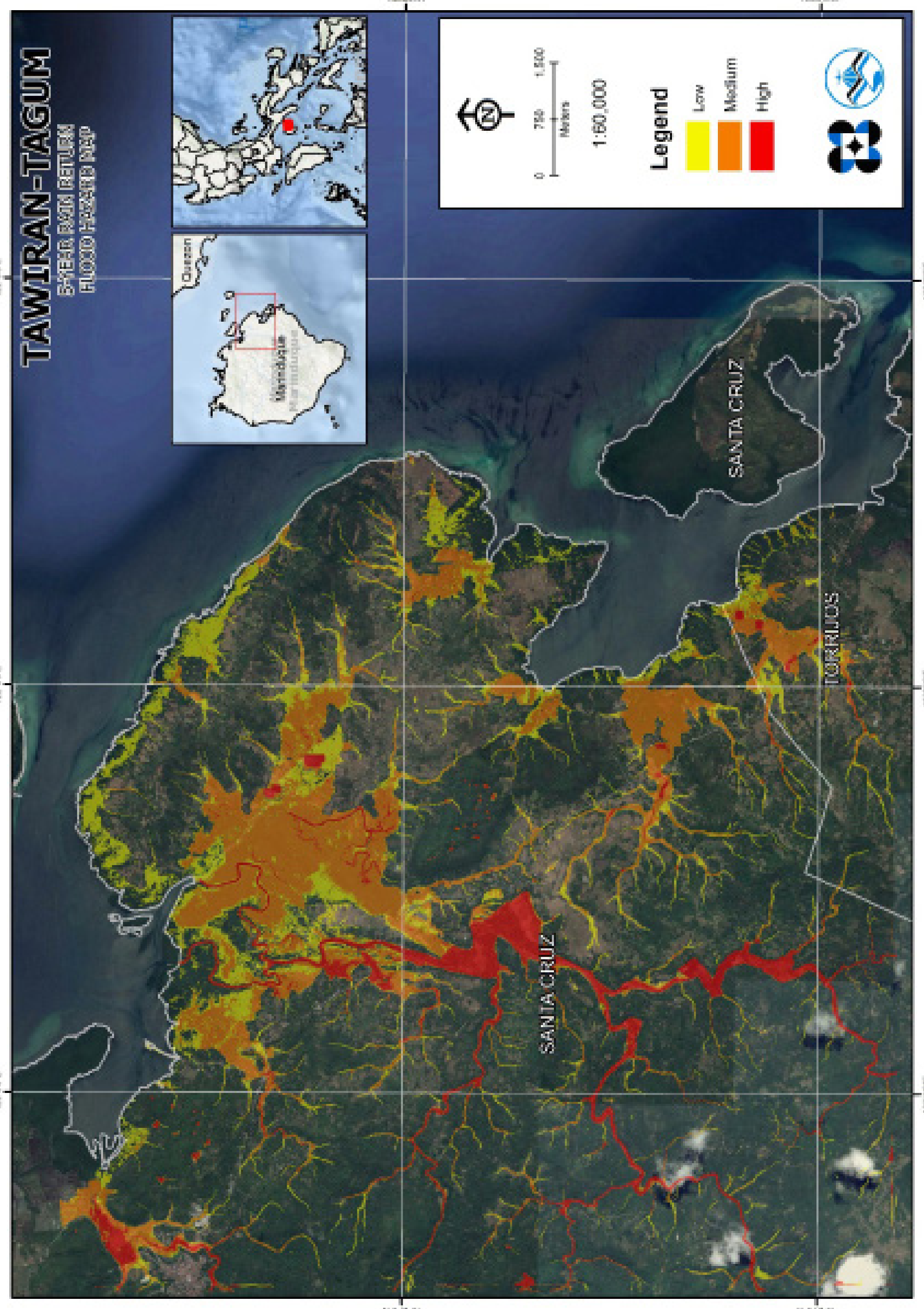


Figure 64. 5-year Flood Hazard Map for Tawiran-Tagum Floodplain overlaid on Google Earth imagery

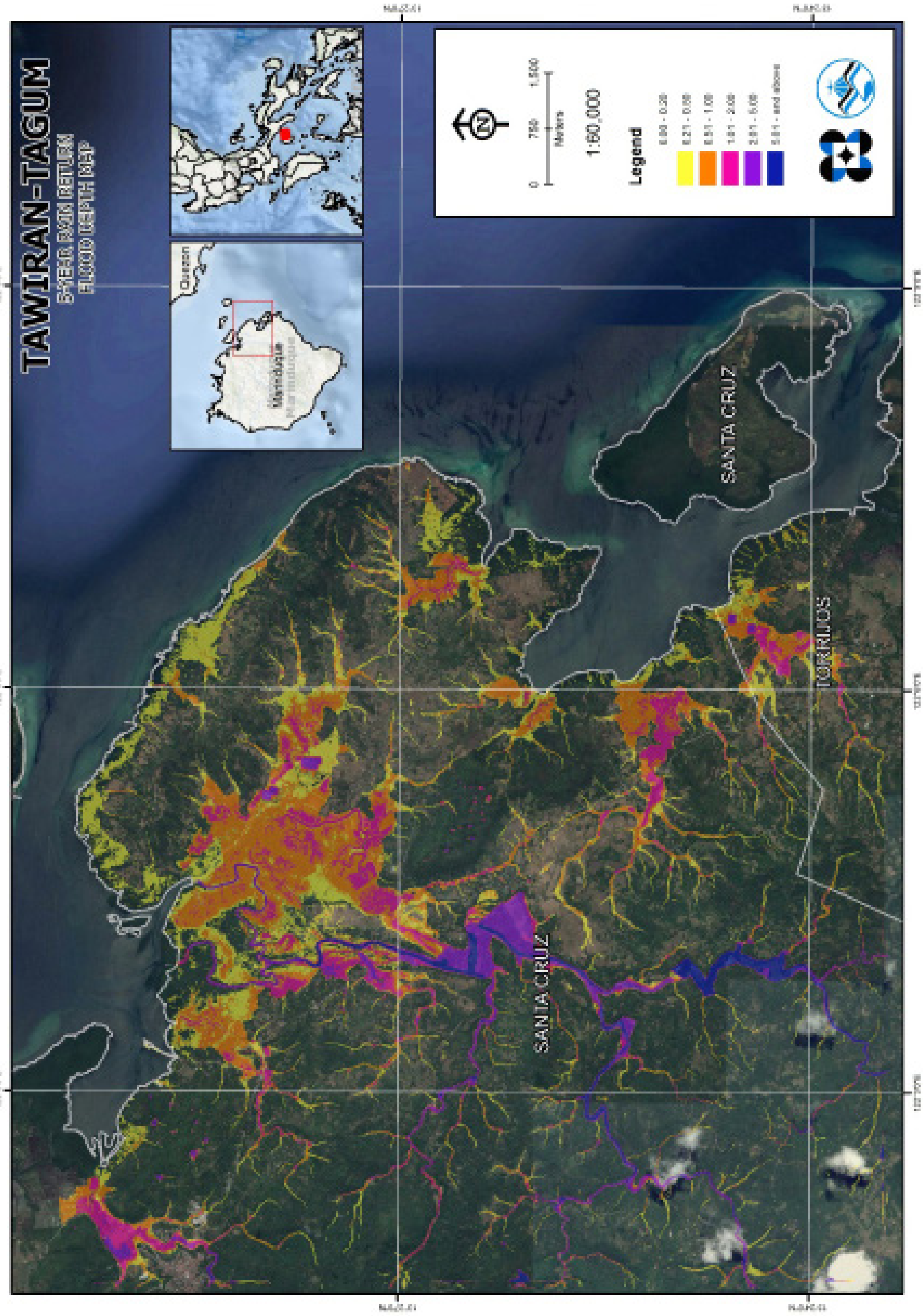


Figure 65. 5-year Flood Depth Map for Tawiran-Tagum Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Tawiran Tagum River Basin, grouped accordingly by municipality. For the said basin, two (2) municipalities consisting of 35 barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 31.31% of the municipality of Santa Cruz with an area of 236.19 sq. km. will experience flood levels of less 0.20 meters, while 2.93% of the area will experience flood levels of 0.21 to 0.50 meters; 2.85%, 1.33%, 0.73%, and 0.35% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Listed in Table 26 to Table 29 and shown in Figure 66 are the affected areas in Santa Cruz in square kilometres by flood depth per barangay.

Table 26. Affected Areas in Santa Cruz, Marinduque during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Alobo	Angas	Bagong Silang Poblacion	Baguidbirin	Banahaw Poblacion	Banogbog	Biga	Buyabod
0.03-0.20	2.85	3.63	0.16	2.43	0.13	2.07	2.73	2.52
0.21-0.50	0.55	0.44	0.029	0.058	0.002	0.08	1.42	0.52
0.51-1.00	0.24	0.31	0.03	0.031	0.000023	0.046	2.06	0.53
1.01-2.00	0.038	0.035	0.036	0.032	0	0.034	0.54	0.13
2.01-5.00	0.011	0	0.011	0.0077	0	0.062	0.11	0.038
> 5.00	0	0	0	0	0	0.0054	0.005	0

Table 27. Affected Areas in Santa Cruz, Marinduque during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Devilla	Haguimit	Jolo	Kaganhao	Kiñaman	Lapu-lapu Poblacion	Libjo	Lipa
0.03-0.20	5.29	4.74	1.68	2.53	2.29	2.1	0.09	0.46
0.21-0.50	0.13	0.16	0.062	0.07	0.049	0.15	0.0076	0.033
0.51-1.00	0.089	0.083	0.041	0.038	0.019	0.11	0.0064	0.11
1.01-2.00	0.086	0.026	0.046	0.046	0.0068	0.12	0.0051	0.15
2.01-5.00	0.14	0.015	0.066	0.029	0.0084	0.02	0.0055	0.045
> 5.00	0.056	0.018	0.072	0.0014	0.0049	0.0012	0.0021	0

Table 28. Affected Areas in Santa Cruz, Marinduque during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Maharlika Poblacion	Makulapnit	Manlibunan	Masaguisi	Masalukot	Matalaba	Morales	Napo
0.03-0.20	0.11	0.0087	1.38	2.05	5.3	0.99	3.27	3.46
0.21-0.50	0.012	0.0016	0.065	0.17	0.16	0.19	0.55	0.18
0.51-1.00	0.022	0.0021	0.04	0.15	0.051	0.19	0.47	0.16
1.01-2.00	0.064	0.0035	0.02	0.08	0.029	0.26	0.15	0.1
2.01-5.00	0.015	0.0063	0.0013	0.0009	0.035	0.13	0.011	0.37
> 5.00	0	0	0	0	0.024	0.055	0	0.043

Table 29. Affected Areas in Santa Cruz, Marinduque during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Pag-Asa Poblacion	Pantayin	Pulong-Parang	Tagum	Tamayo	Tambangan	Tawiran	Taytay
0.03-0.20	0.1	2.85	8.16	3.21	2.32	1.18	0.49	3.38
0.21-0.50	0.0017	0.16	0.26	0.47	0.45	0.021	0.18	0.27
0.51-1.00	0.0044	0.17	0.11	0.35	0.42	0.016	0.28	0.55
1.01-2.00	0.0068	0.16	0.085	0.071	0.19	0.017	0.24	0.33
2.01-5.00	0.0036	0.3	0.21	0.0004	0.034	0.041	0.0024	0.0016
> 5.00	0.000019	0.11	0.4	0	0	0.034	0	0

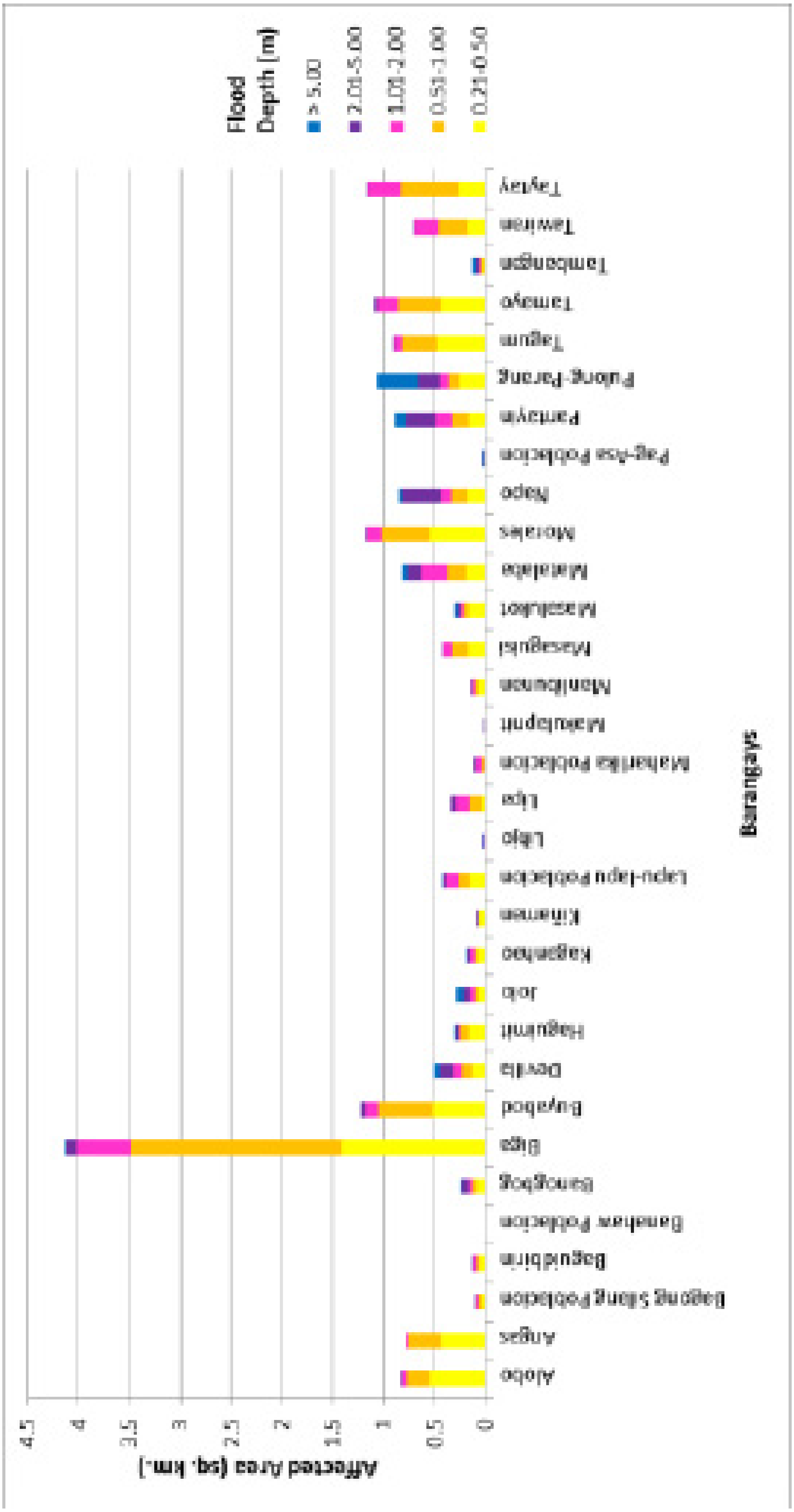


Figure 66. Affected Areas in Santa Cruz, Marinduque during 5-Year Rainfall Return Period

For the municipality of Torrijos, with an area of 210.05 sq. km., 2.28% will experience flood levels of less 0.20 meters. 0.29% of the area will experience flood levels of 0.21 to 0.50 meters while 0.25%, 0.10%, and 0.01% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 30 and shown in Figure 67 are the affected areas in square kilometres by flood depth per barangay.

Table 30. Affected Areas in Torrijos, Marinduque during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Torrijos (in sq. km.)		
	Mabuhay	Matuyatuya	Suha
0.03-0.20	2.3	0.58	1.92
0.21-0.50	0.24	0.075	0.29
0.51-1.00	0.096	0.074	0.35
1.01-2.00	0.046	0.032	0.13
2.01-5.00	0.0034	0.00089	0.02
> 5.00	0	0	0

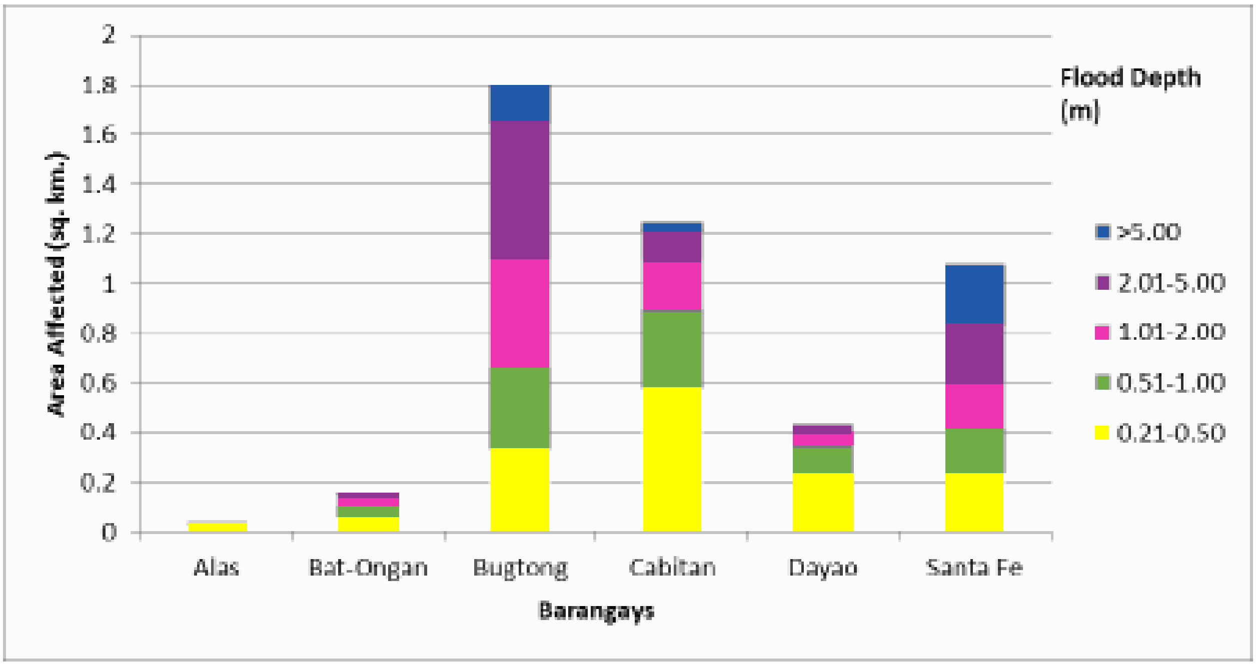


Figure 67. Affected Areas in Torrijos, Marinduque during 5-Year Rainfall Return Period

For the 25-year return period, 29.97% of the municipality of Santa Cruz with an area of 236.19 sq. km. will experience flood levels of less 0.20 meters, while 2.68% of the area will experience flood levels of 0.21 to 0.50 meters; 2.12%, 3.10%, 1.06%, and 0.58% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Listed in Table 31 to Table 34 and shown in Figure 68 are the areas affected in Santa Cruz in square kilometers by flood depth per barangay.

Table 31. Affected Areas in Santa Cruz, Marinduque during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Alobo	Angas	Bagong Silang Poblacion	Baguidbirin	Banahaw Poblacion	Banogbog	Biga	Buyabod
0.03-0.20	2.73	3.46	0.15	2.4	0.13	2.04	2.1	2.24
0.21-0.50	0.53	0.46	0.016	0.068	0.0036	0.085	1.23	0.57
0.51-1.00	0.2	0.42	0.028	0.03	0.00031	0.055	0.86	0.64
1.01-2.00	0.2	0.079	0.041	0.037	0	0.039	2.42	0.23
2.01-5.00	0.016	0.0004	0.033	0.024	0	0.066	0.24	0.054
> 5.00	0	0	0	0.00014	0	0.019	0.0054	0

Table 32. Affected Areas in Santa Cruz, Marinduque during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Devilla	Haguimit	Jolo	Kaganhao	Kiñaman	Lapu-lapu Poblacion	Libjo	Lipa
0.03-0.20	5.18	4.67	1.62	2.49	2.26	2.04	0.087	0.44
0.21-0.50	0.14	0.19	0.067	0.082	0.063	0.15	0.0059	0.025
0.51-1.00	0.091	0.097	0.041	0.037	0.022	0.12	0.0076	0.084
1.01-2.00	0.088	0.046	0.054	0.045	0.012	0.12	0.0072	0.14
2.01-5.00	0.15	0.018	0.083	0.063	0.007	0.078	0.0067	0.11
> 5.00	0.14	0.025	0.11	0.0037	0.01	0.0041	0.0028	0

Table 33. Affected Areas in Santa Cruz, Marinduque during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Maharlika Poblacion	Makulapnit	Manlibunan	Masaguisi	Masalukot	Matalaba	Morales	Napo
0.03-0.20	0.088	0.0066	1.35	1.99	5.22	0.85	3.16	3.33
0.21-0.50	0.0053	0.0012	0.072	0.18	0.19	0.18	0.33	0.15
0.51-1.00	0.014	0.0018	0.045	0.11	0.072	0.22	0.31	0.13
1.01-2.00	0.055	0.003	0.032	0.17	0.038	0.29	0.6	0.18
2.01-5.00	0.061	0.0096	0.0037	0.0013	0.038	0.2	0.049	0.39
> 5.00	0	0.00013	0	0	0.047	0.057	0	0.14

Table 34. Affected Areas in Santa Cruz, Marinduque during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Pamplona (in sq. km.)							
	Pag-Asa Poblacion	Pantayin	Pulong-Parang	Tagum	Tamayo	Tambangan	Tawiran	Taytay
0.03-0.20	0.099	2.71	7.98	3.06	2.2	1.16	0.29	3.25
0.21-0.50	0.0011	0.16	0.27	0.48	0.18	0.023	0.14	0.26
0.51-1.00	0.0029	0.12	0.14	0.39	0.2	0.016	0.2	0.3
1.01-2.00	0.0056	0.23	0.087	0.17	0.69	0.017	0.49	0.7
2.01-5.00	0.0095	0.34	0.19	0.0008	0.14	0.044	0.061	0.021
> 5.00	0.0018	0.18	0.56	0	0	0.051	0	0

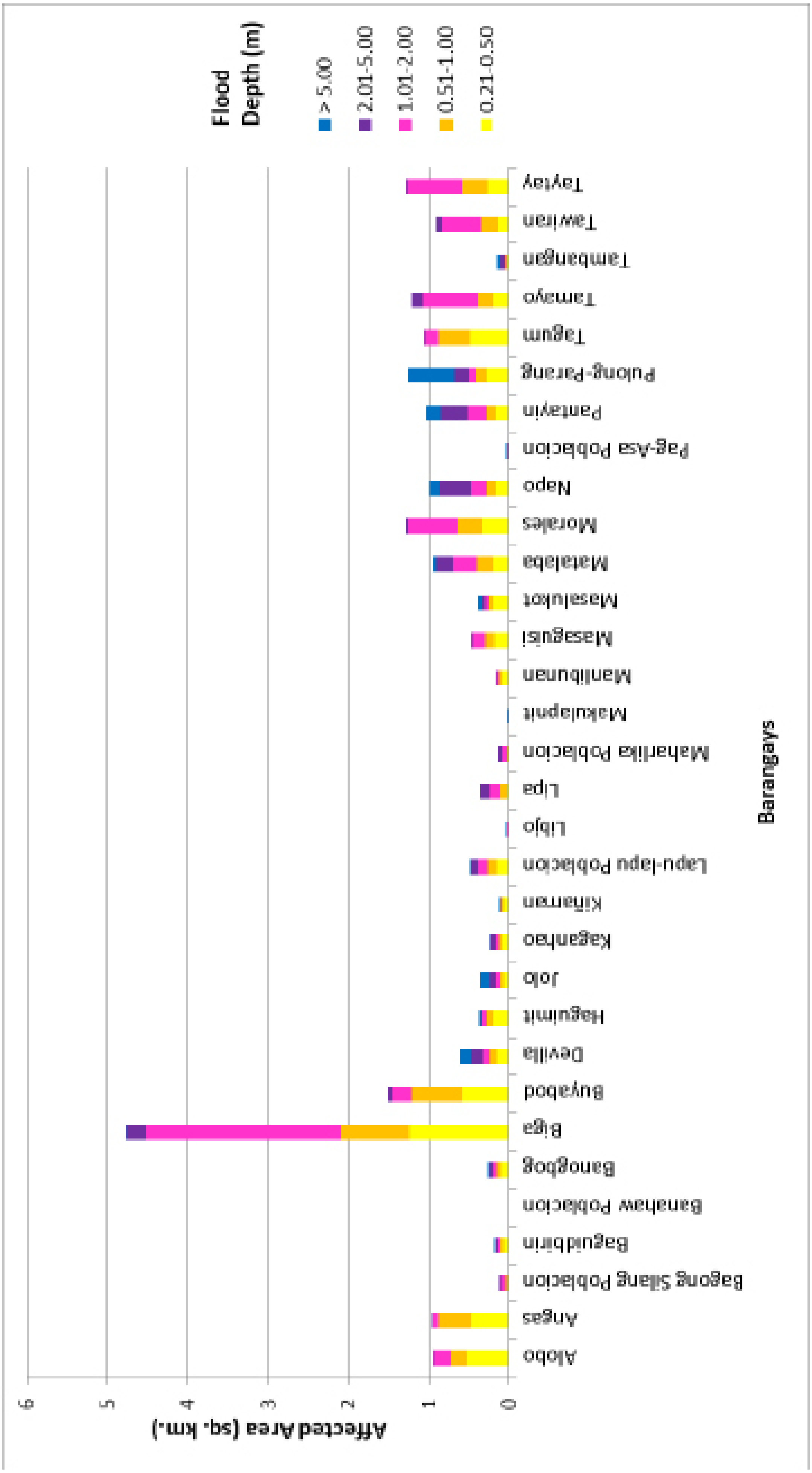


Figure 68. Affected areas in Santa Cruz, Marinduque during the 25-Year Rainfall Return Period

For the municipality of Torrijos, with an area of 210.05 sq. km., 2.20% will experience flood levels of less 0.20 meters. 0.28% of the area will experience flood levels of 0.21 to 0.50 meters while 0.23%, 0.20%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 35 and shown in Figure 69 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected Areas in Torrijos, Marinduque during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Torrijos (in sq. km)		
	Mabuhay	Matuyatuya	Suha
0.03-0.20	2.23	0.57	1.81
0.21-0.50	0.25	0.063	0.28
0.51-1.00	0.11	0.074	0.29
1.01-2.00	0.078	0.051	0.3
2.01-5.00	0.012	0.0053	0.027
> 5.00	0	0	0

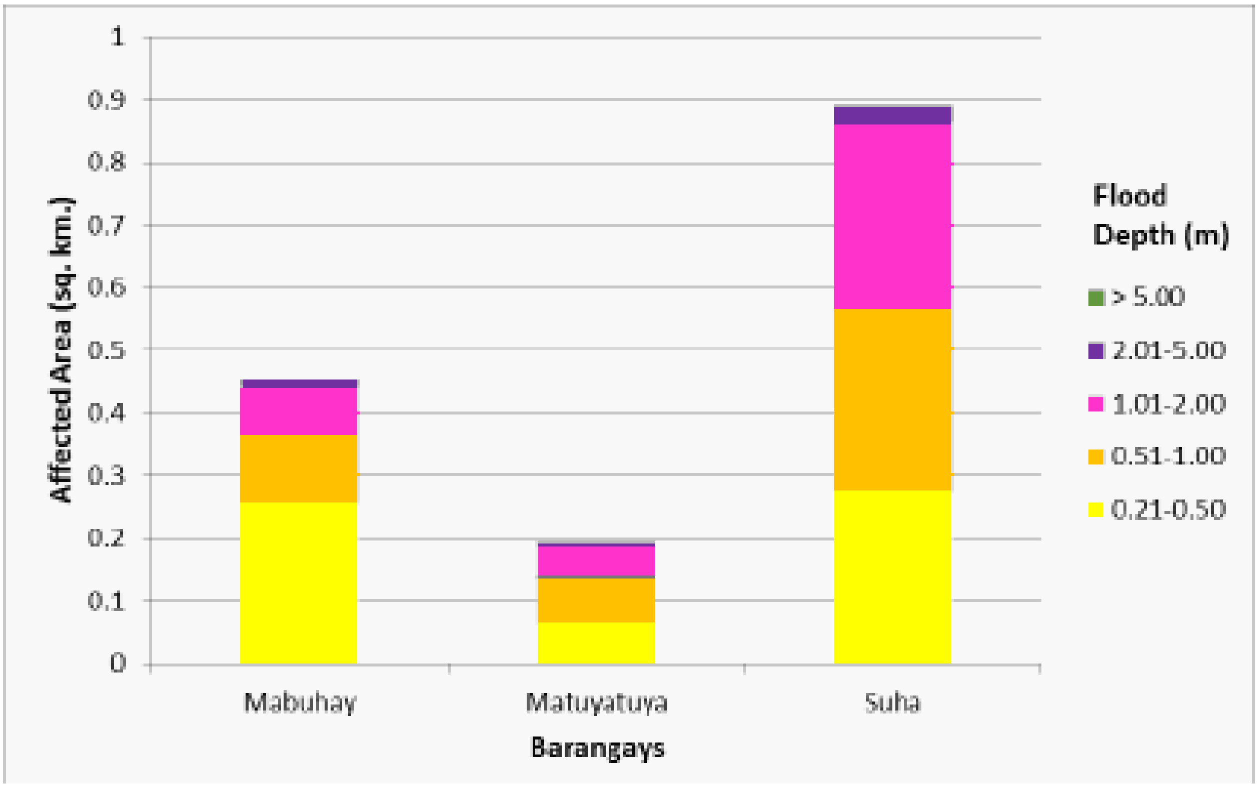


Figure 69. Affected Areas in Torrijos, Marinduque during 25-Year Rainfall Return Period

For the 100-year return period, 29.18% of the municipality of Santa Cruz with an area of 236.19 sq. km. will experience flood levels of less 0.20 meters, while 2.50% of the area will experience flood levels of 0.21 to 0.50 meters; 2.15%, 3.04%, 1.79%, and 0.84% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Listed in Table 36 to Table 39 and shown in Figure 70 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected Areas in Santa Cruz, Marinduque during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Alobo	Angas	Bagong Silang Poblacion	Baguidbirin	Banahaw Poblacion	Banogbog	Biga	Buyabod
0.03-0.20	2.66	3.35	0.14	2.37	0.12	2.01	1.84	2
0.21-0.50	0.46	0.49	0.01	0.075	0.005	0.089	0.99	0.48
0.51-1.00	0.29	0.43	0.026	0.032	0.00041	0.059	0.87	0.81
1.01-2.00	0.21	0.14	0.045	0.037	0	0.044	2.1	0.37
2.01-5.00	0.048	0.0008	0.044	0.036	0	0.064	1.06	0.071
> 5.00	0	0	0	0.0011	0	0.036	0.0054	0

Table 37. Affected Areas in Santa Cruz, Marinduque during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Devilla	Haguimit	Jolo	Kaganhao	Kiñaman	Lapu-lapu Poblacion	Libjo	Lipa
0.03-0.20	5.11	4.62	1.57	2.45	2.24	2	0.085	0.43
0.21-0.50	0.16	0.2	0.072	0.095	0.074	0.14	0.0058	0.026
0.51-1.00	0.094	0.1	0.042	0.04	0.022	0.13	0.0076	0.055
1.01-2.00	0.092	0.066	0.053	0.049	0.019	0.13	0.0081	0.15
2.01-5.00	0.16	0.027	0.09	0.075	0.0085	0.1	0.0062	0.14
> 5.00	0.19	0.03	0.15	0.0082	0.012	0.0077	0.004	0.0002

Table 38. Affected Areas in Santa Cruz, Marinduque during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Maharlika Poblacion	Makulapnit	Manlibunan	Masaguisi	Masalukot	Matalaba	Morales	Napo
0.03-0.20	0.082	0.0058	1.33	1.95	5.16	0.78	3.09	3.26
0.21-0.50	0.0051	0.00097	0.075	0.18	0.21	0.15	0.31	0.16
0.51-1.00	0.0088	0.0012	0.043	0.12	0.082	0.24	0.27	0.13
1.01-2.00	0.047	0.0033	0.04	0.2	0.044	0.34	0.56	0.14
2.01-5.00	0.08	0.0092	0.011	0.0043	0.046	0.25	0.22	0.24
> 5.00	0	0.0016	0	0	0.058	0.062	0	0.4

Table 39. Affected Areas in Santa Cruz, Marinduque during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Cruz (in sq. km.)							
	Pag-Asa Poblacion	Pantayin	Pulong-Parang	Tagum	Tamayo	Tambangan	Tawiran	Taytay
0.03-0.20	0.096	2.64	7.85	2.96	2.15	1.15	0.22	3.18
0.21-0.50	0.0018	0.14	0.29	0.48	0.17	0.024	0.1	0.27
0.51-1.00	0.002	0.13	0.15	0.38	0.13	0.015	0.12	0.24
1.01-2.00	0.0061	0.18	0.093	0.29	0.57	0.019	0.39	0.75
2.01-5.00	0.011	0.35	0.17	0.0025	0.41	0.037	0.36	0.1
> 5.00	0.0023	0.3	0.66	0	0	0.069	0	0

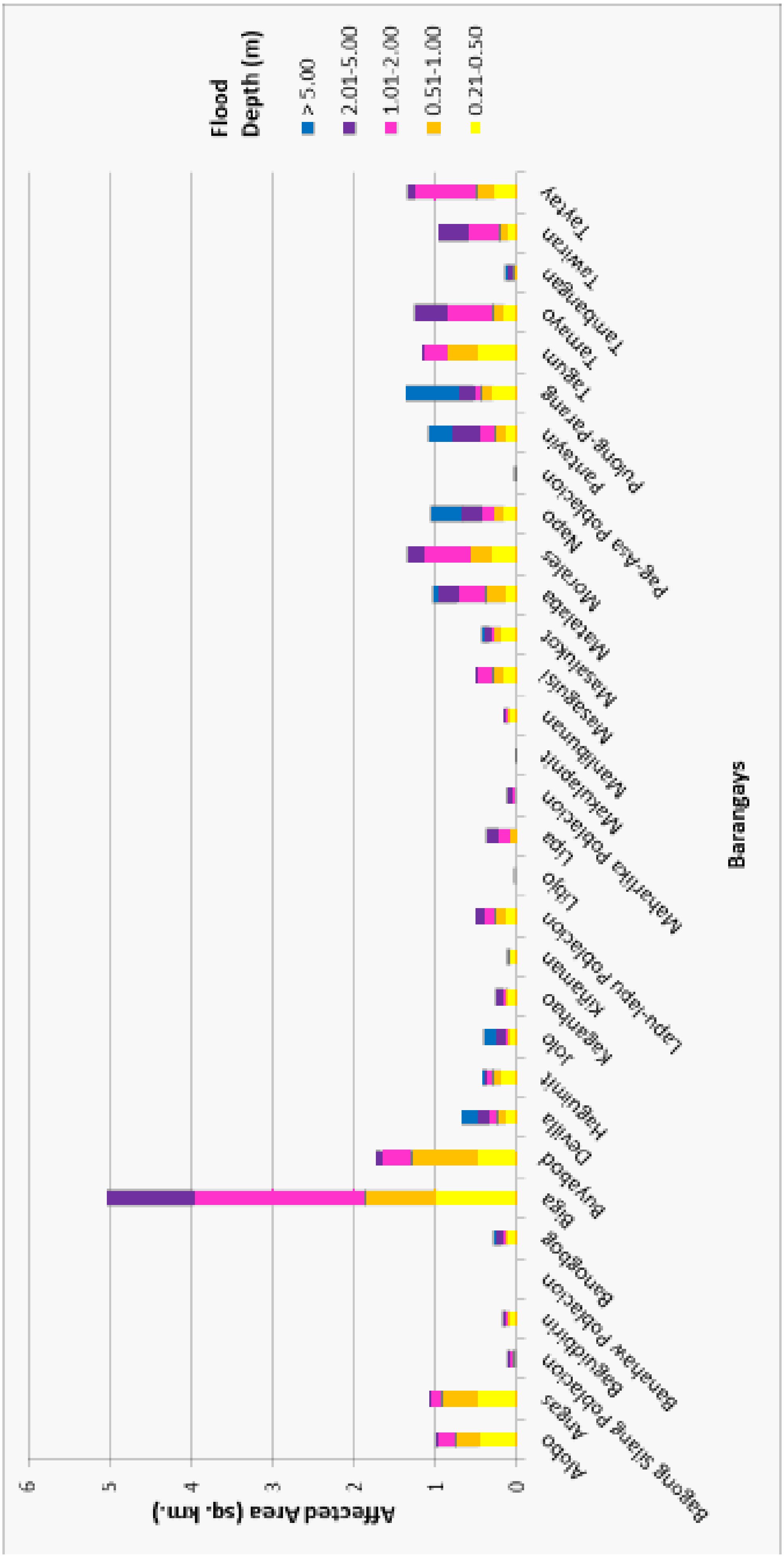


Figure 70. Affected Areas in Santa Cruz, Marinduque during 100-Year Rainfall Return Period

For the municipality of Torrijos, with an area of 210.05 sq. km., 2.13% will experience flood levels of less 0.20 meters. 0.28% of the area will experience flood levels of 0.21 to 0.50 meters while 0.24%, 0.25%, and 0.03% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, and more than 2 meters, respectively. Listed in Table 40 and shown in Figure 71 are the areas affected in Torrijos in square kilometers by flood depth per barangay.

Table 40. Affected areas in Torrijos, Marinduque during the 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Torrijos (in sq. km)		
	Mabuhay	Matuyatuya	Suha
0.03-0.20	2.18	0.56	1.74
0.21-0.50	0.25	0.054	0.28
0.51-1.00	0.14	0.073	0.28
1.01-2.00	0.092	0.067	0.36
2.01-5.00	0.025	0.012	0.037
> 5.00	0	0	0

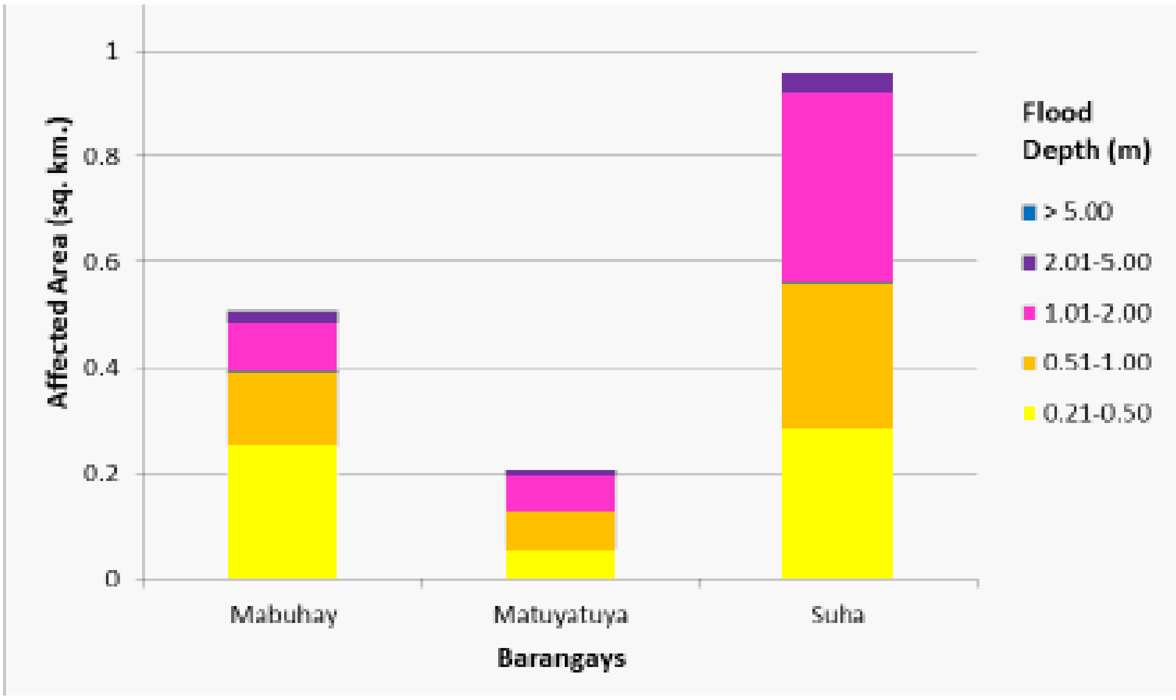


Figure 71. Affected Areas in Torrijos, Marinduque during 100-Year Rainfall Return Period

Among the barangays in the municipality of Santa Cruz, Pulong-Parang is projected to have the highest percentage of area that will experience flood levels at 3.90%. Meanwhile, Biga posted the second highest percentage of area that may be affected by flood depths at 2.90%.

Among the barangays in the municipality of Torrijos, Suha is projected to have the highest percentage of area that will experience flood levels at 1.29%. Meanwhile, Mabuhay posted the second highest percentage of area that may be affected by flood depths at 1.28%.

Moreover, the generated flood hazard maps for the Tawiran-Tagum 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).

5.11 Flood Validation

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

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

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

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 73.

The flood validation consists of 61 points randomly selected all over the Tawiran-Tagum floodplain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.557m. Table 41 shows a contingency matrix of the comparison.

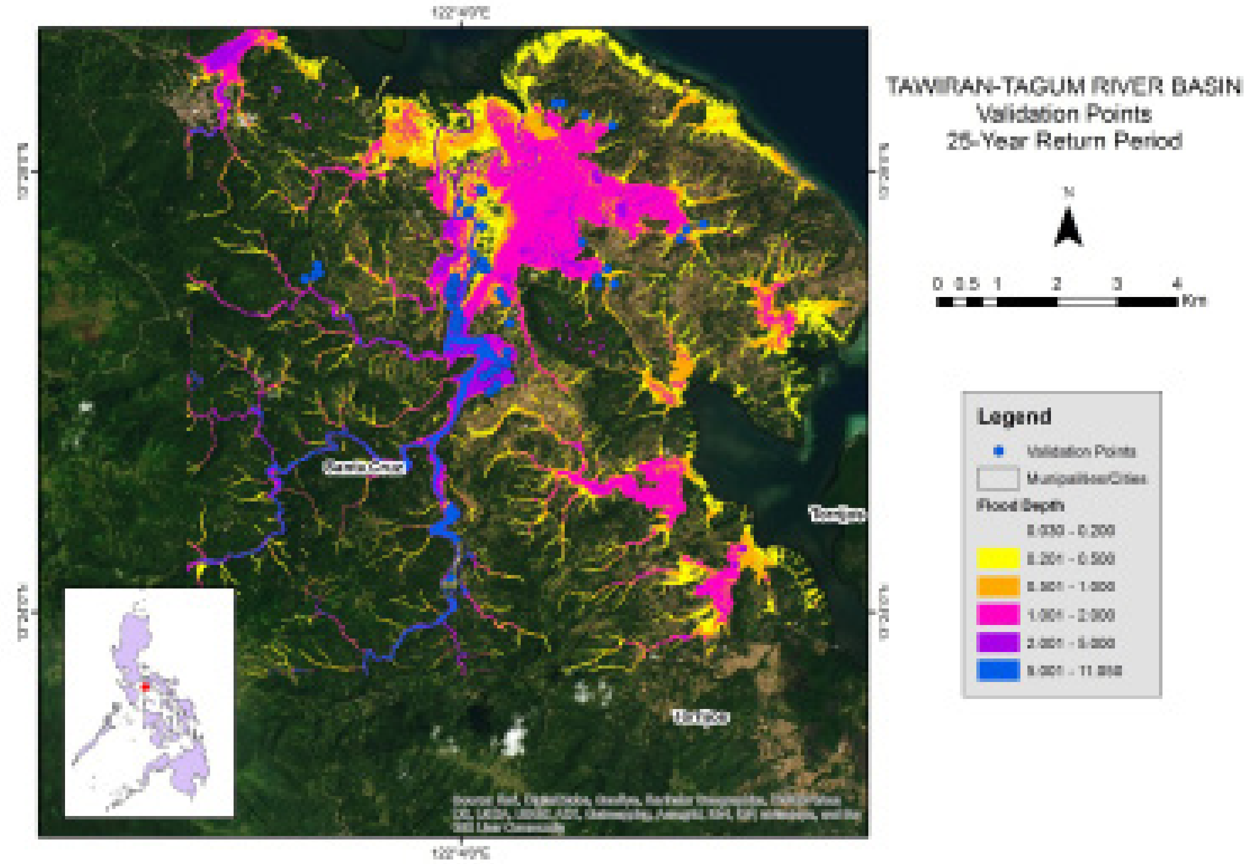


Figure 72. Validation points for the 5-Year flood depth map of the Tawiran-Tagum Floodplain

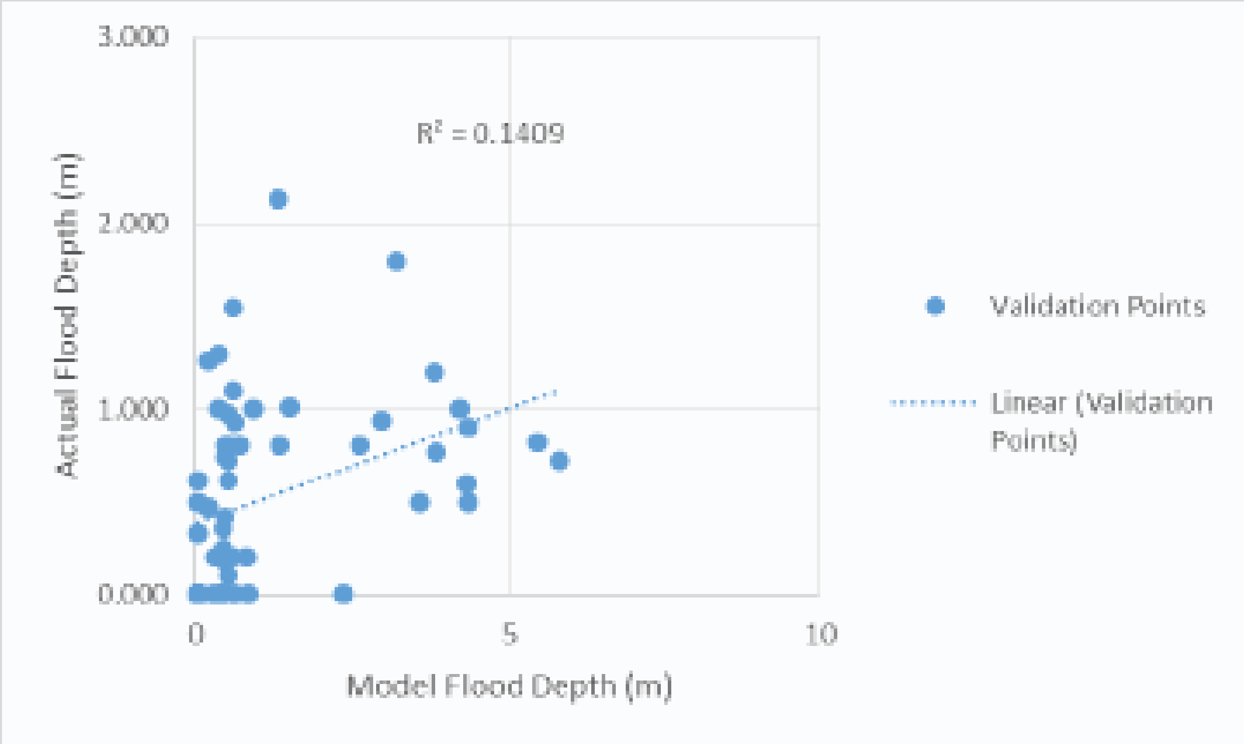


Figure 73. Flood map depth vs. actual flood depth

Table 41. Actual flood vs simulated flood depth at different levels in the Tawiran-Tagum River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	11	8	5	0	1	0	25
0.21-0.50	3	3	0	0	2	0	8
0.51-1.00	1	3	7	1	6	2	20
1.01-2.00	1	1	2	1	2	0	7
2.01-5.00	0	0	0	1	0	0	1
> 5.00	0	0	0	0	0	0	0
Total	16	15	14	3	11	2	61

The overall accuracy generated by the flood model is estimated at 36.07% with 22 points correctly matching the actual flood depths. In addition, there were 17 points estimated one level above and below the correct flood depths while there were 13 points and 6 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 12 points were underestimated in the modelled flood depths of Tawiran-Tagum. Table 42 depicts the summary of the Accuracy Assessment in the Tawiran-Tagum River Basin Survey.

Table 42. Summary of the Accuracy Assessment in the Tawiran-Tagum River Basin

	No. of Points	%
Correct	22	36.07
Overestimated	27	44.26
Underestimated	12	19.67
Total	61	100.00

REFERENCES

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ANNEXES

Annex 1. Optech Technical Specification of the Pegasus Sensor

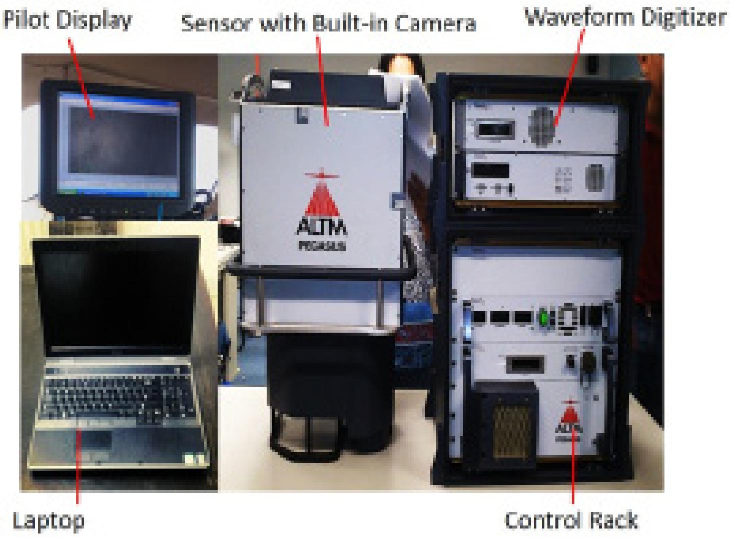


Figure A-1.1 Pegasus Sensor

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

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

1. MRQ-25

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

October 28, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **MARINDUQUE**	
	Station Name: **MRQ-25**	
	Order: **2nd**	
Island: LUZON	Barangay: TUGOS	
Municipality: BOAC (CAPITAL)	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **13° 22' 56.92806"**	Longitude: **121° 51' 28.72673"**	Ellipsoidal Hgt: **48.18293 m.**
	WGS84 Coordinates	
Latitude: **13° 22' 51.66815"**	Longitude: **121° 51' 33.72033"**	Ellipsoidal Hgt: **97.26100 m.**
	PTM / PRS92 Coordinates	
Northing: **1480026.039 m.**	Easting: **592932.786 m.**	Zone: **3**
	UTM / PRS92 Coordinates	
Northing: **1,479,627.07**	Easting: **376,341.19**	Zone: **51**

Location Description

MRQ-25

From Boac to Brgy. Tugos, approx. 16.6 Km. travel to reach Brgy. Tugos. Station is located at the top of the plant box of Tugos Elem. School near at the school gate. Mark is the head of a 4 in. copper nail flushed at the center of a cement patty with inscriptions, "MRQ-24, 2007, NAMRIA".

Requesting Party: **ENGR. CHRISTOPHER CRUZ**
Purpose: **Reference**
OR Number: **8088472 I**
T.N.: **2015-3528**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. MRQ-25

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

1. BM-5

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
MRQ-25 --- BM-5 (B1)	MRQ-25	BM-5	Fixed	0.047	0.034	3°37'04"	16202.444	-42.355

Acceptance Summary

Processed	Passed	Flag	Fail
1	1	0	0

Vector Components (Mark to Mark)

From:	MRQ-25				
Grid		Local		Global	
Easting	376341.198 m	Latitude	N13°22'56.92804"	Latitude	N13°22'51.86815"
Northing	1479627.069 m	Longitude	E121°51'28.72677"	Longitude	E121°51'33.72033"
Elevation	47.679 m	Height	48.183 m	Height	97.201 m

To:	BM-5				
Grid		Local		Global	
Easting	377438.371 m	Latitude	N13°31'43.12821"	Latitude	N13°31'38.03406"
Northing	1495788.872 m	Longitude	E121°52'02.72781"	Longitude	E121°52'07.70875"
Elevation	5.200 m	Height	5.828 m	Height	54.472 m

Vector					
ΔEasting	1097.173 m	NS Fwd Azimuth	3°37'04"	ΔX	1139.785 m
ΔNorthing	16161.802 m	Ellipsoid Dist.	16202.444 m	ΔY	-3770.308 m
ΔElevation	-42.479 m	ΔHeight	-42.355 m	ΔZ	15716.494 m

Standard Errors

Vector errors:					
σ ΔEasting	0.018 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.019 m
σ ΔNorthing	0.008 m	σ Ellipsoid Dist.	0.007 m	σ ΔY	0.016 m
σ ΔElevation	0.017 m	σ ΔHeight	0.017 m	σ ΔZ	0.008 m

Figure A-3.1. BM-5

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

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

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
	Research Associate (RA)	JERIEL PAUL ALAMBAN, GEOL.	UP-TCAGP
	RA	ENGR. IRO NIEL ROXAS	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	FOR. MA. REMEDIOS VILLANUEVA	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. BENJIE CARBOLLEDO	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. DEXTER CABUDOL	AAC

Annex 5. Data Transfer Sheet for Tawiran-Tagum Floodplain

DATA TRANSFER SHEET
[illegible]

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	
8-Oct	10019P	1BLK25ABC281A	Pegasus	559	na	11.6	250	30.1	207	16.1	na	8.85	1KB	1KB	46/53	na	Z:\DAC\RAW DATA
9-Oct	10021P	1BLK25B282B	Pegasus	1.26	NA	6.61	151	15.8	69/55/53/54	11.6	na	8.39	1KB	1KB	58	na	Z:\DAC\RAW DATA
13-Oct	10037P	1BLK23AAS286A	Pegasus	2.2	na	12.8	395	48.4	361	26.9	na	5.35	1KB	1KB	46/53	na	Z:\DAC\RAW DATA
15-Oct	10032P	1BLK22AS288A	Pegasus	703	na	4.1	122	16.8	120	7.75	na	3.73	1KB	1KB	55/56/51	na	Z:\DAC\RAW DATA

Received from

Name C. Joaquin
Position RA
Signature [signature]

Received by

Name AC Bongat
Position SSRS
Signature [signature] 11/10/15

Figure A-5.1. Data Transfer Sheet for Tawiran-Tagum Floodplain

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for 10020P Mission

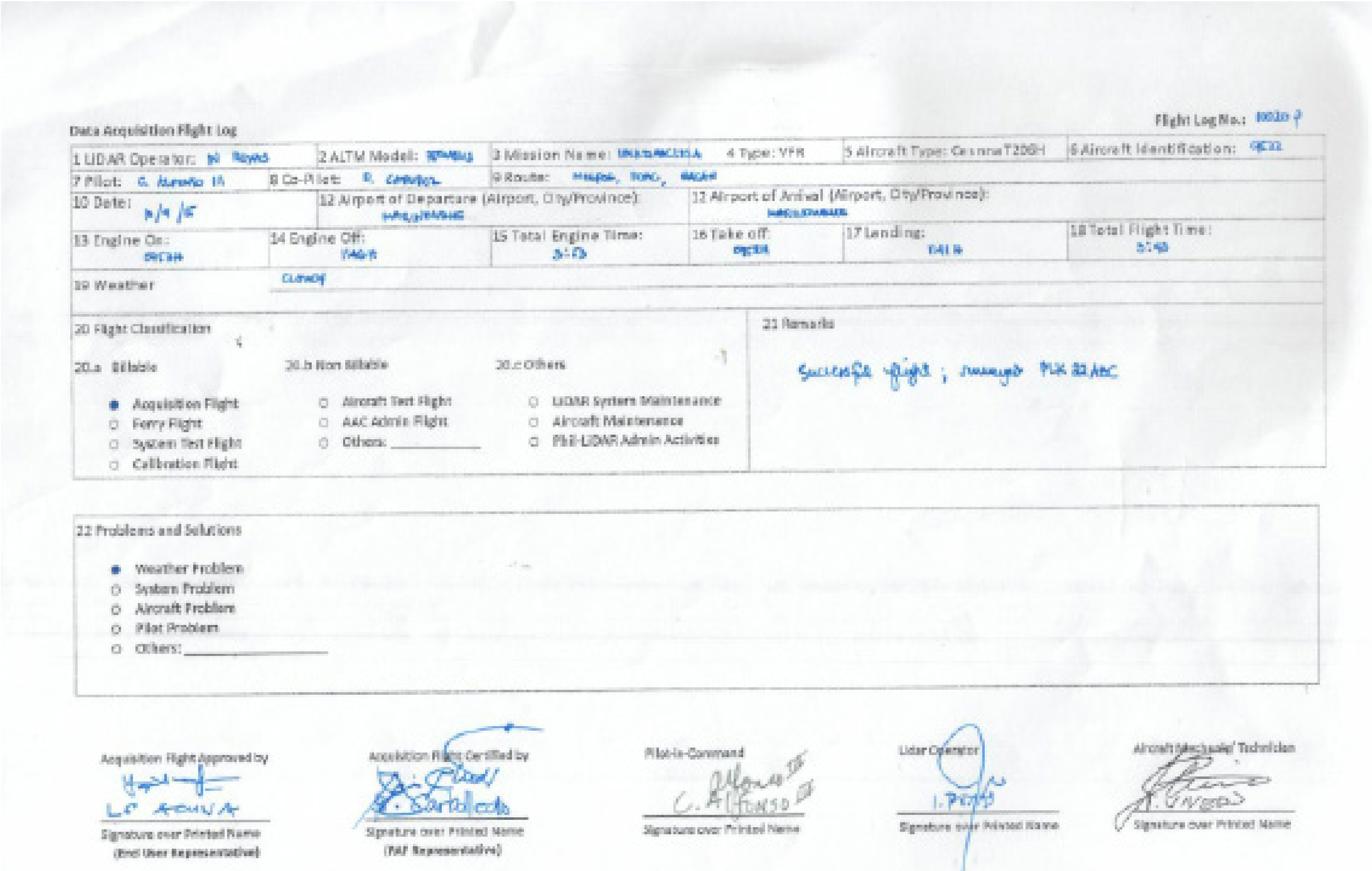
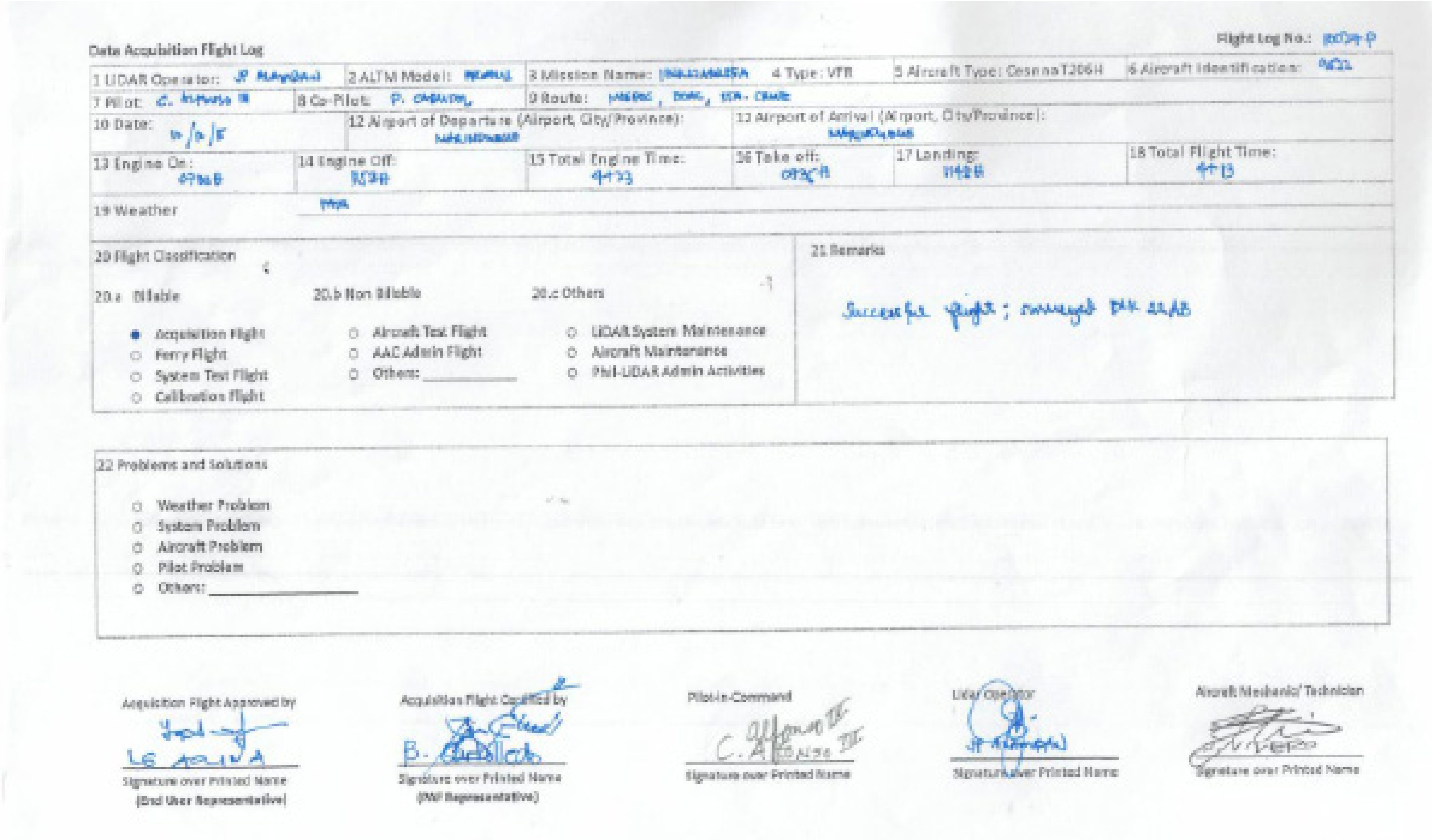


Figure A-6.1. Flight Log for 10020P Mission

2. Flight Log for 10027P Mission


Data Acquisition Flight Log

Flight Log No.:

1 LIDAR Operator:	2 ALTM Model:	3 Mission Name:	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification:
7 Pilot:	8 Co-Pilot:	9 Route:			
10 Date:	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
13 Engine On:	14 Engine Off:	15 Total Engine Time:	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather					

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

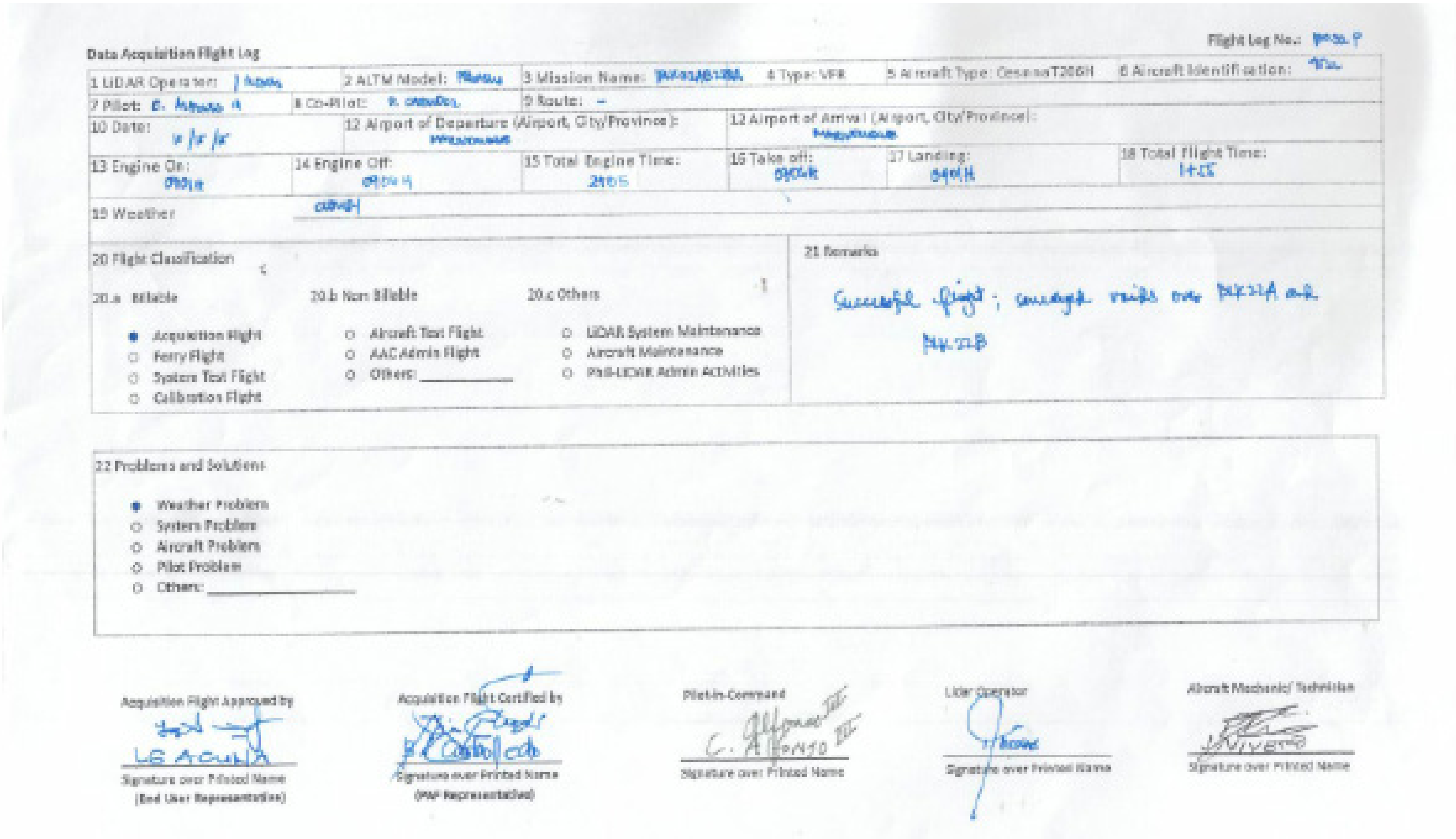
21 Remarks

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
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-6.2. Flight Log for 10027P Mission

3. Flight Log for 10032P Mission



Data Acquisition Flight Log

Flight Log No.: [illegible]

1 LiDAR Operator: [illegible]	2 ALTM Model: [illegible]	3 Mission Name: [illegible]	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: [illegible]
7 Pilot: [illegible]	8 Co-Pilot: [illegible]	9 Route: –			
10 Date: [illegible]	12 Airport of Departure (Airport, City/Province): [illegible]		12 Airport of Arrival (Airport, City/Province): [illegible]		
13 Engine On: [illegible]	14 Engine Off: [illegible]	15 Total Engine Time: [illegible]	16 Take off: [illegible]	17 Landing: [illegible]	18 Total Flight Time: [illegible]
19 Weather: [illegible]					

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

[illegible]

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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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-6.3. Flight Log for 10032P Mission

Annex 7. Flight Status Reports

MARINDUQUE
(October 9, 12 & 15, 2015)

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
10020P	BLK22A, BLK22B AND BLK22C	1BLK22ABC282A	I. Roxas	October 9, 2015	SURVEYED BLK 22ABC (BOAC FP); VOIDS DUE TO CLOUDS; 1000M ALT; OCCASIONAL LOST CHANNEL A; DIGI START UP PROBLEM DUE TO DISK ERROR
10027P	BLK22A AND BLK22B	1BLK22AB285A	J.P. Alamban	October 12, 2015	SURVEYED BLK 22AB (TAWIRAN-TAGUM FP & BOAC FP); VOIDS DUE TO CLOUDS; LASER NOT RESPONDING, RESTARTED LASER;ABNORMAL TERMINATION OF POSVIEW; DIGI START UP PROBLEM DUE TO DISK ERROR; 1250M ALT;
10032P	BLK22A AND VOIDS OVER BLK22B	1BLK22AB288A	I. Roxas	October 15, 2015	SURVEYED BLK 22AB (TAWIRAN-TAGUM FP & VOIDS OVER BOAC FP); VOIDS DUE TO CLOUDS; DIGI START UP PROBLEM DUE TO DISK ERROR;

LAS/SWATH BOUNDARIES PER MISSION FLIGHT

Flight No. :	10020P
Area:	BLK 22A, BLK 22B & BLK 22C BOAC FP
Mission Name:	1BLK22ABC282A
Parameters:	PRF 200 SF 30 FOV 50

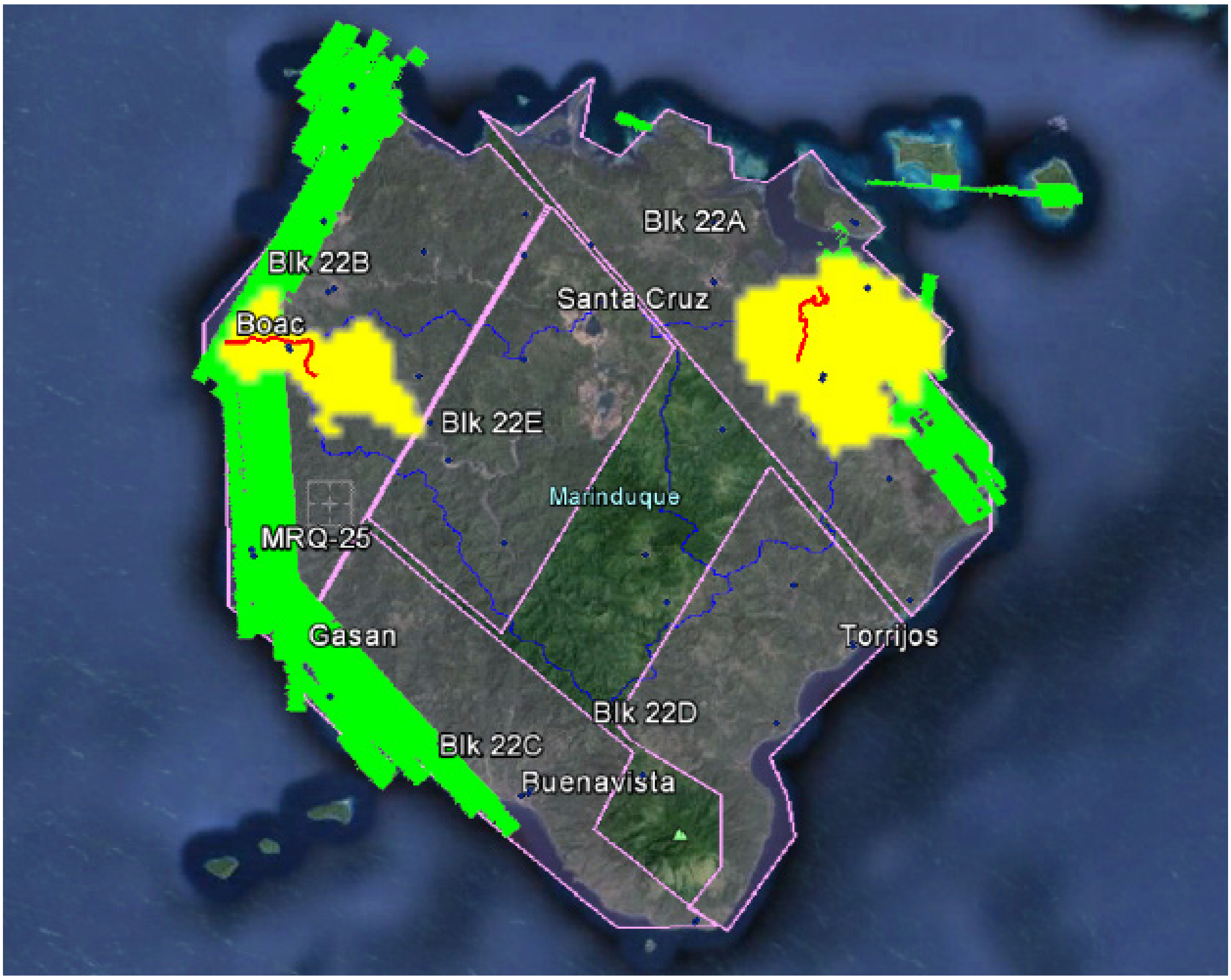


Figure A-7.1. Swath for Flight No. 10020P

Flight No. :	10027P
Area:	BLK22 A & BLK 22B BOAC FP; TAWIRAN-TAGUM FP
Mission Name:	1BLK22AB285A
Parameters:	PRF 200 SF 30 FOV 50

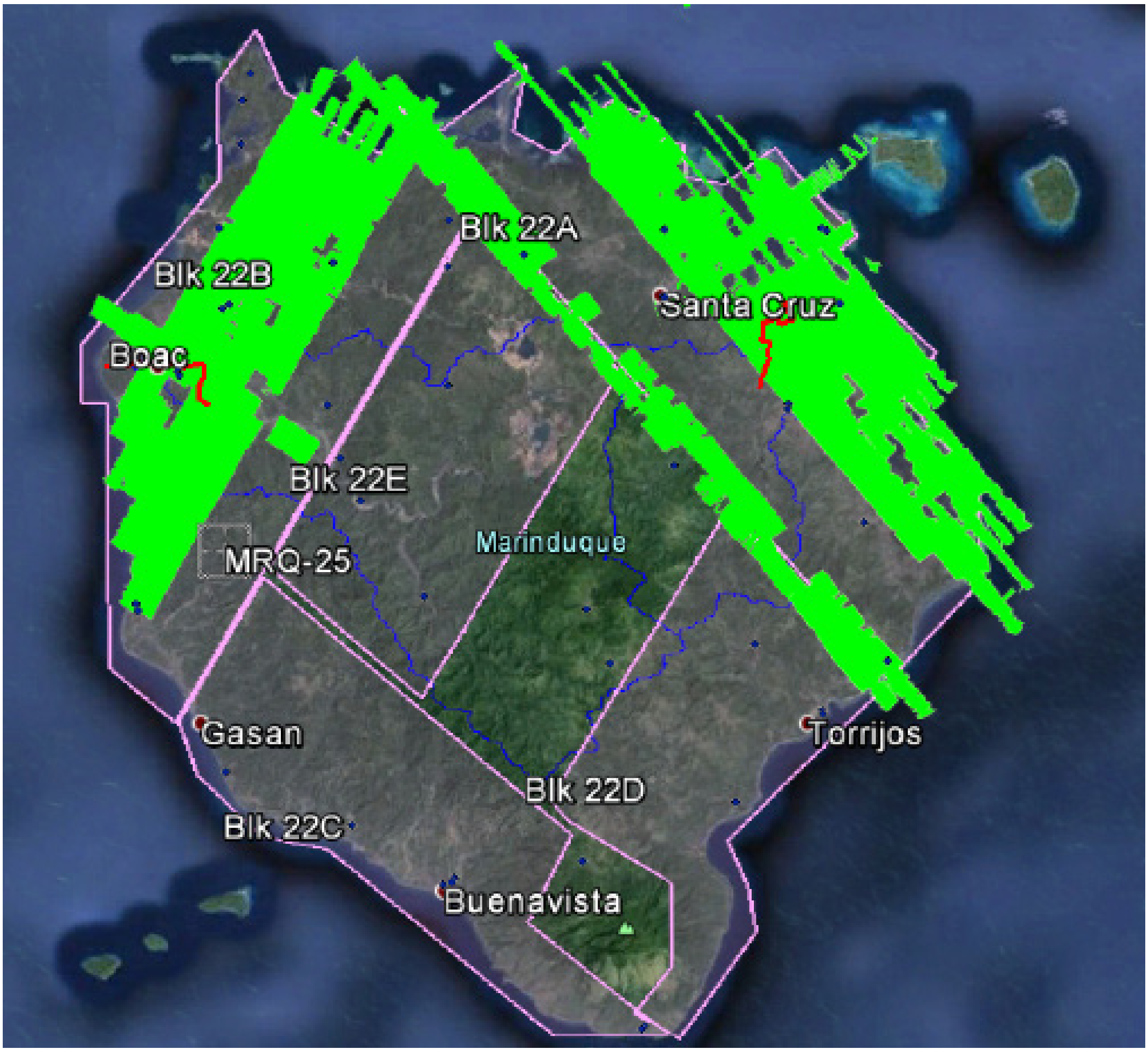


Figure A-7.2. Swath for Flight No. 10027P

Flight No. :	10032P
Area:	BLK22A & VOIDS OVER BLK 22B BOAC FP; TAWIRAN-TAGUM FP
Mission Name:	1BLK22AB288A
Parameters:	PRF 200 SF 30 FOV 50

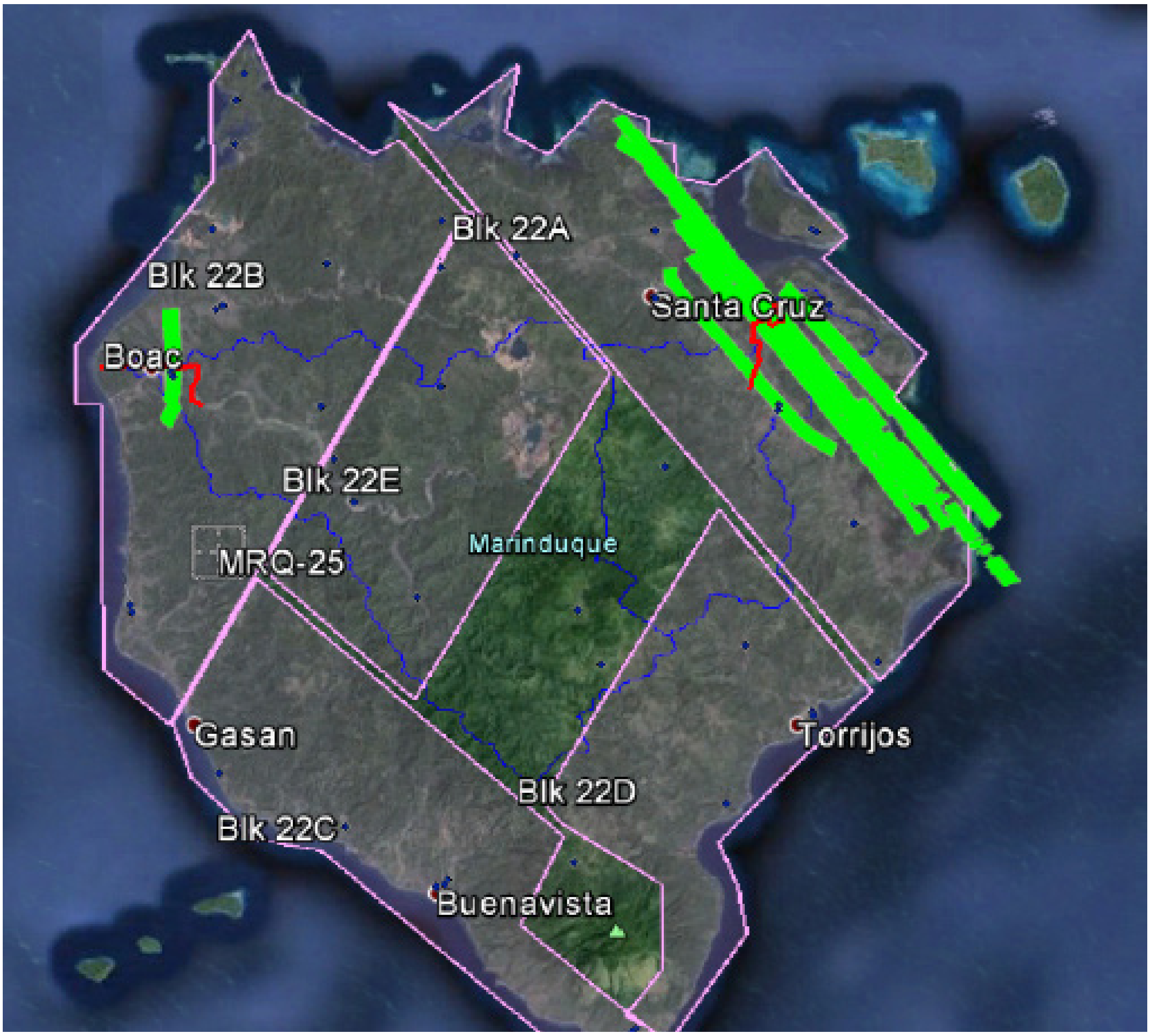


Figure A-7.3. Swath for Flight No. 10032P

Annex 8. Mission Summary Reports

Table A-8.1 Mission Summary Report for Mission Blk29H

Flight Area	Occidental Mindoro
Mission Name	**Blk29H**
Inclusive Flights	1136A
Range data size	15 GB
Base data size	15.8 MB
POS	256 MB
Image	86.5 GB
Transfer date	03/19/2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.5
RMSE for East Position (<4.0 cm)	1.4
RMSE for Down Position (<8.0 cm)	4.4
Boresight correction stdev (<0.001deg)	0.000355
IMU attitude correction stdev (<0.001deg)	0.074523
GPS position stdev (<0.01m)	0.0409
Minimum % overlap (>25)	37.19%
Ave point cloud density per sq.m. (>2.0)	2.58
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	174
Maximum Height	613.49 m
Minimum Height	39.16 m
Classification (# of points)	
Ground	53,263,528
Low vegetation	57,288,707
Medium vegetation	68,165,762
High vegetation	30,718,677
Building	1,782,193
Orthophoto	Yes
Processed by	Engr. Kenneth Solidum, Celina Rosete, Jovy Narisma

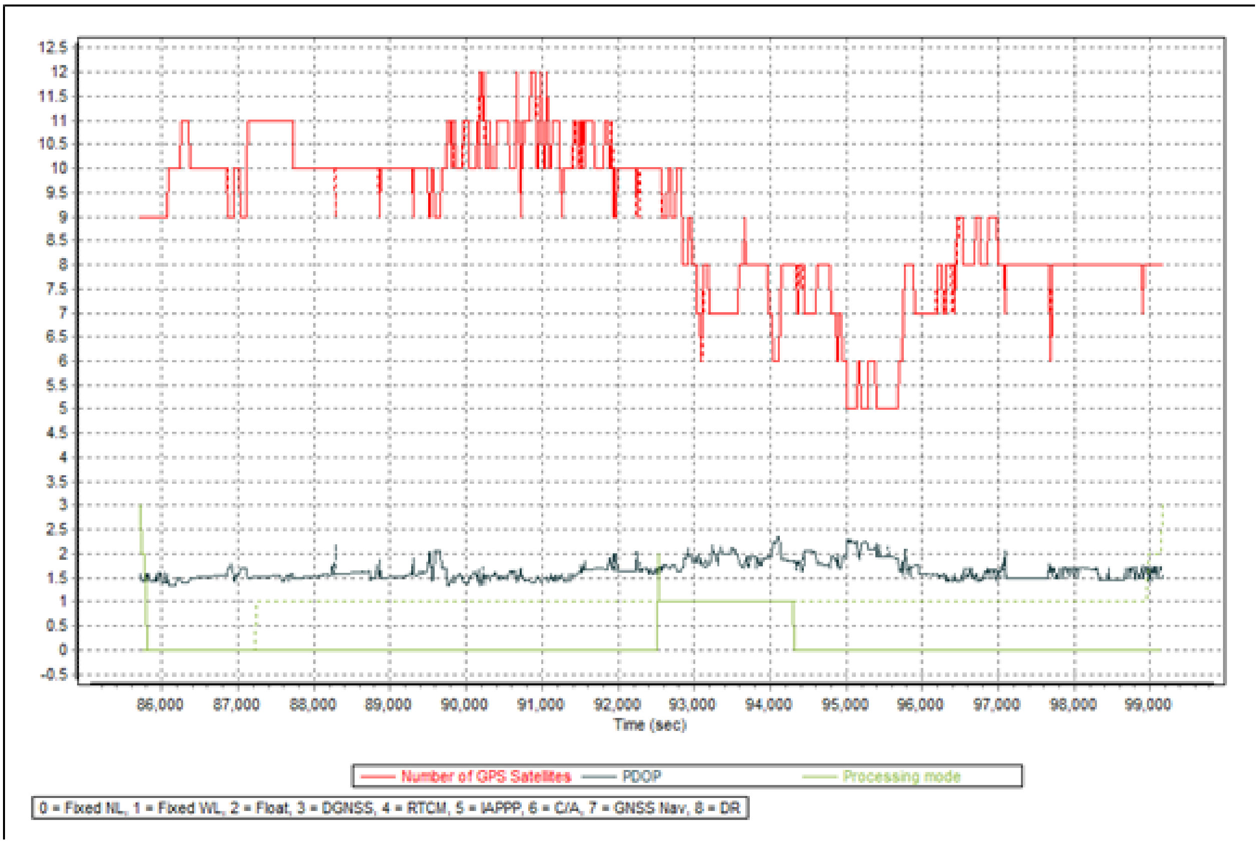


Figure A-8.1 Solution Status

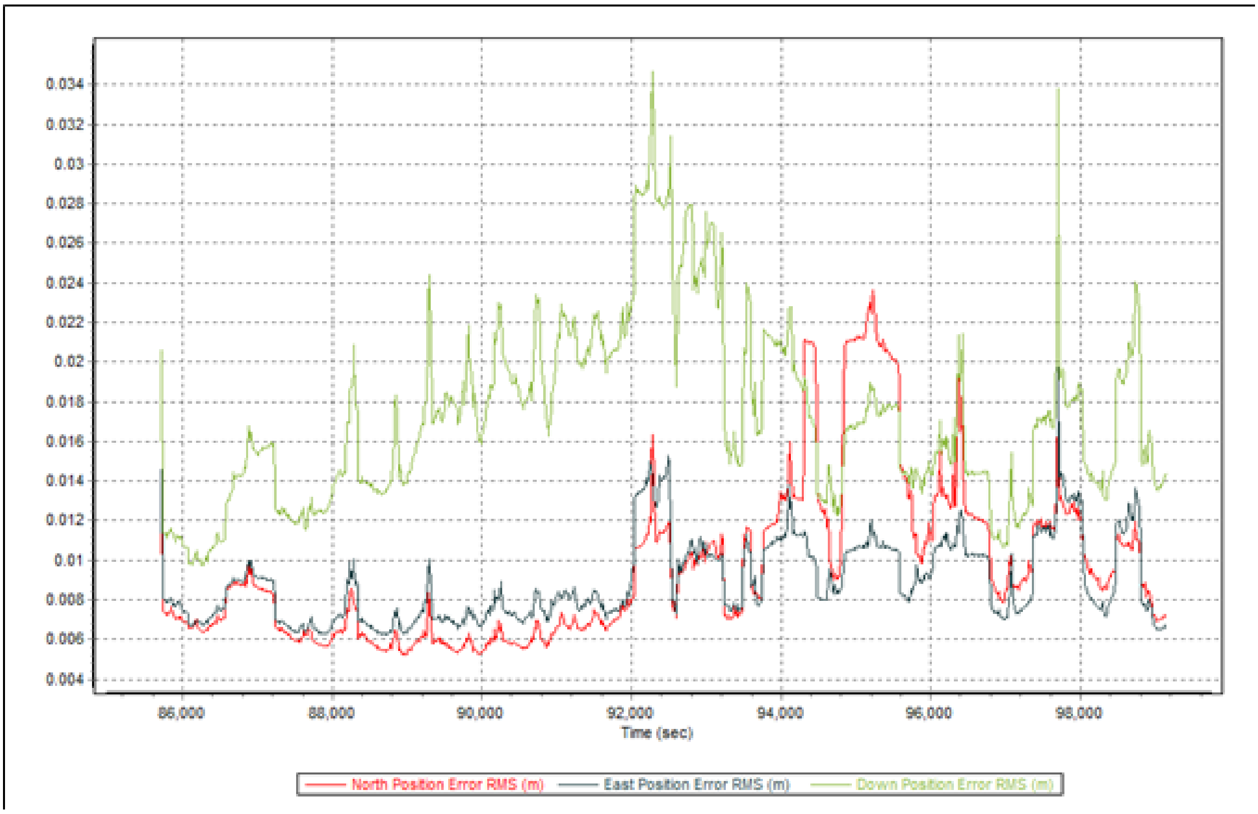


Figure A-8.2 Smoothed Performance Metric Parameters

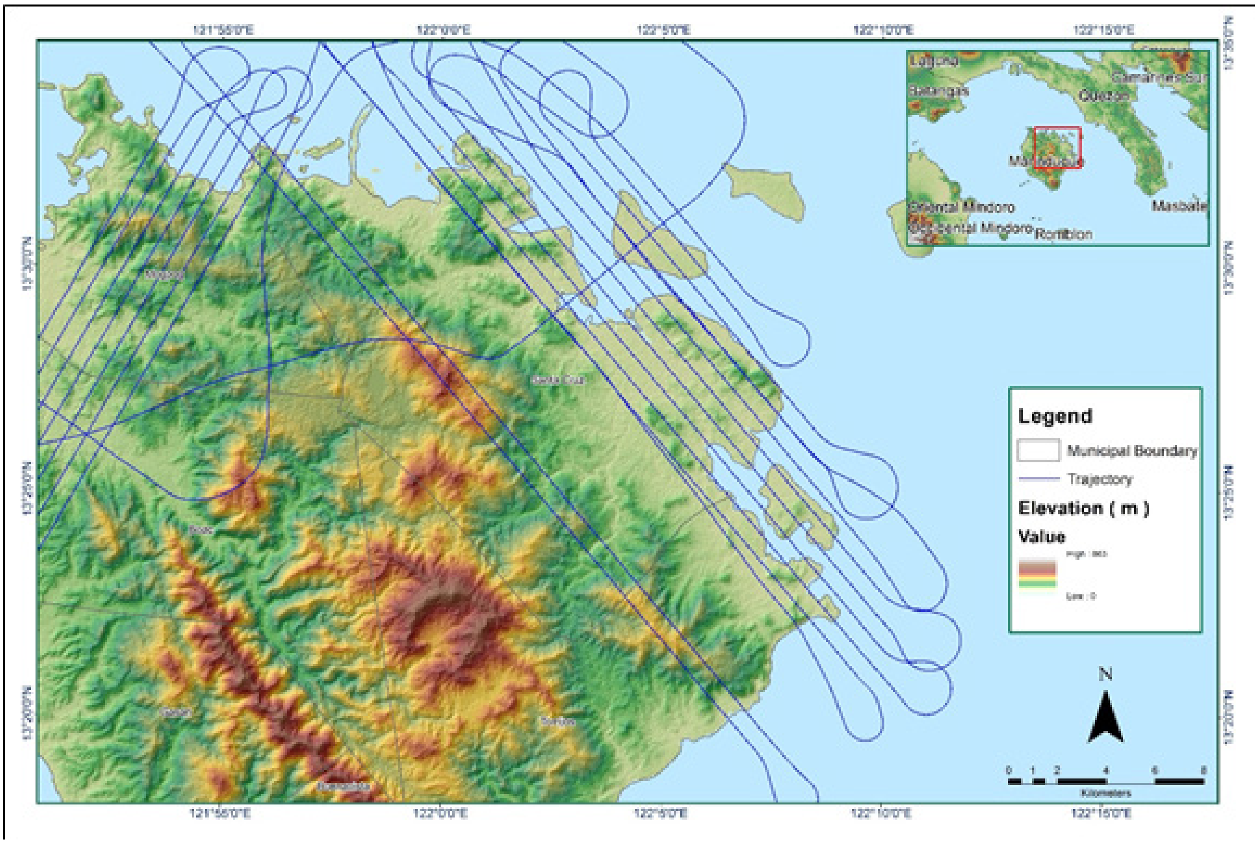


Figure A-8.3 Best Estimated Trajectory

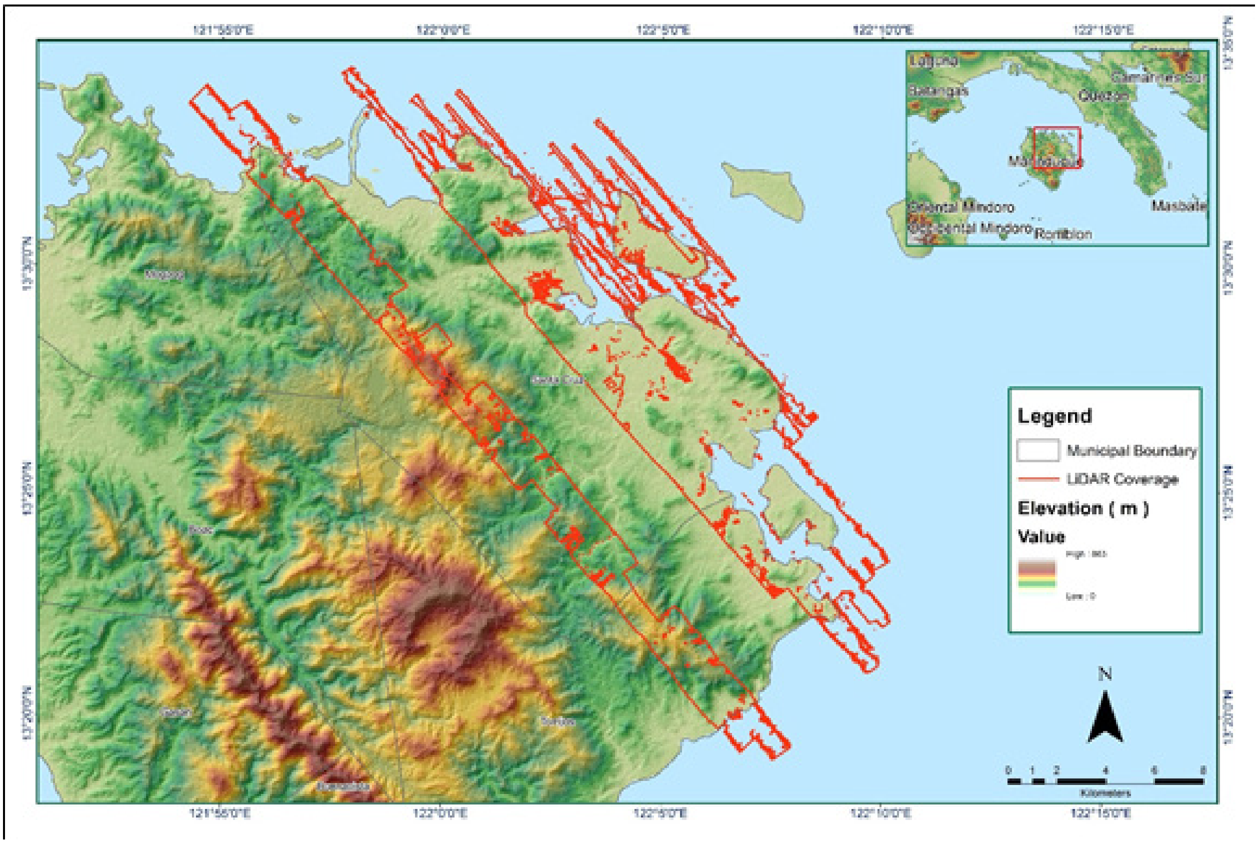


Figure A-8.4 Coverage of LiDAR data

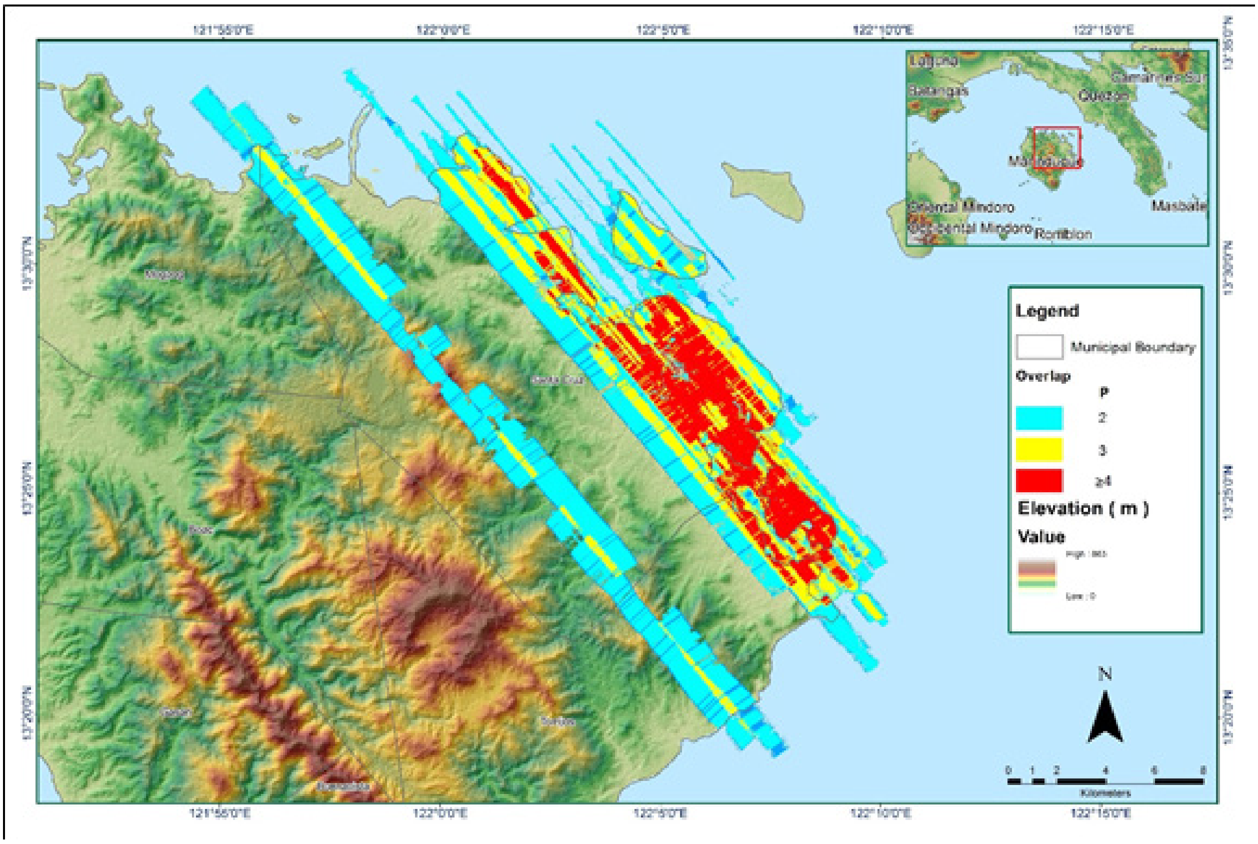


Figure A-8.5 Image of data overlap

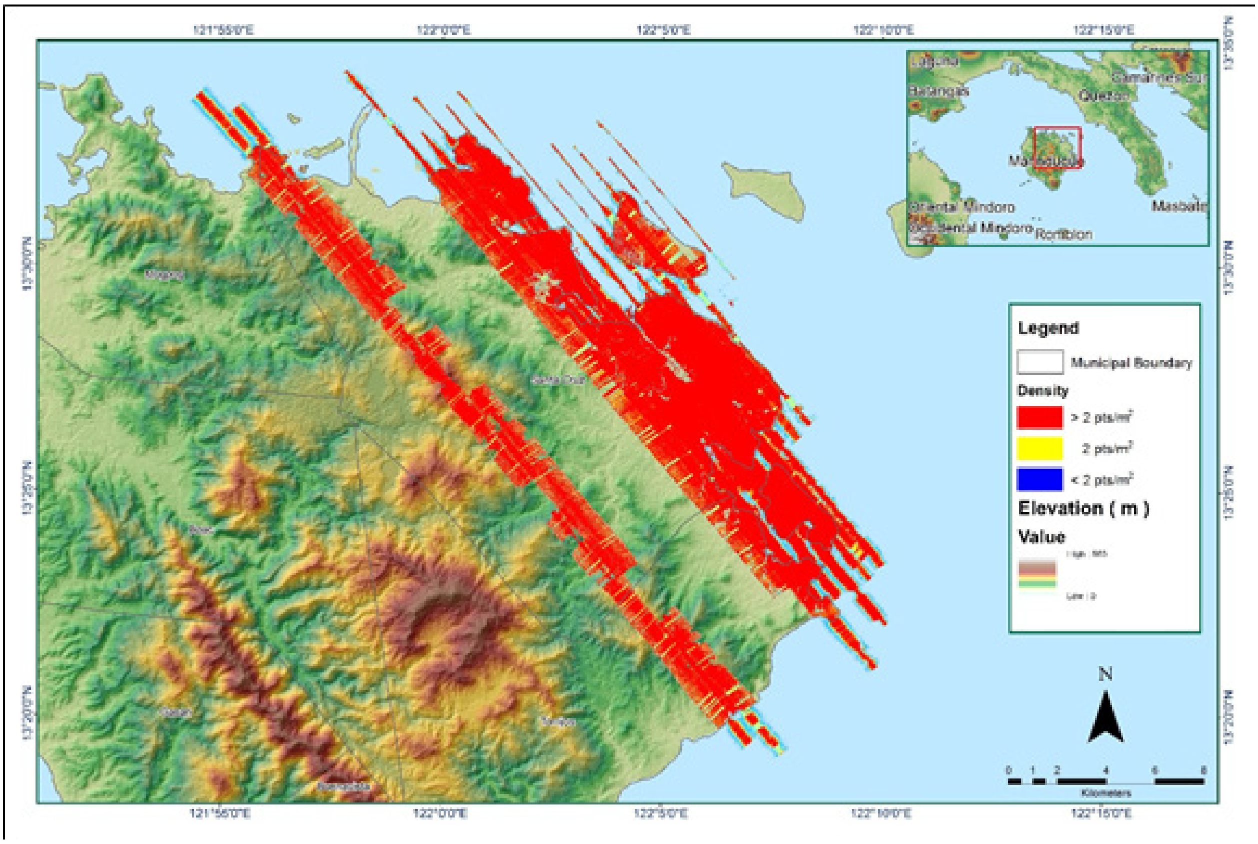


Figure A-8.6 Density map of merged LiDAR data

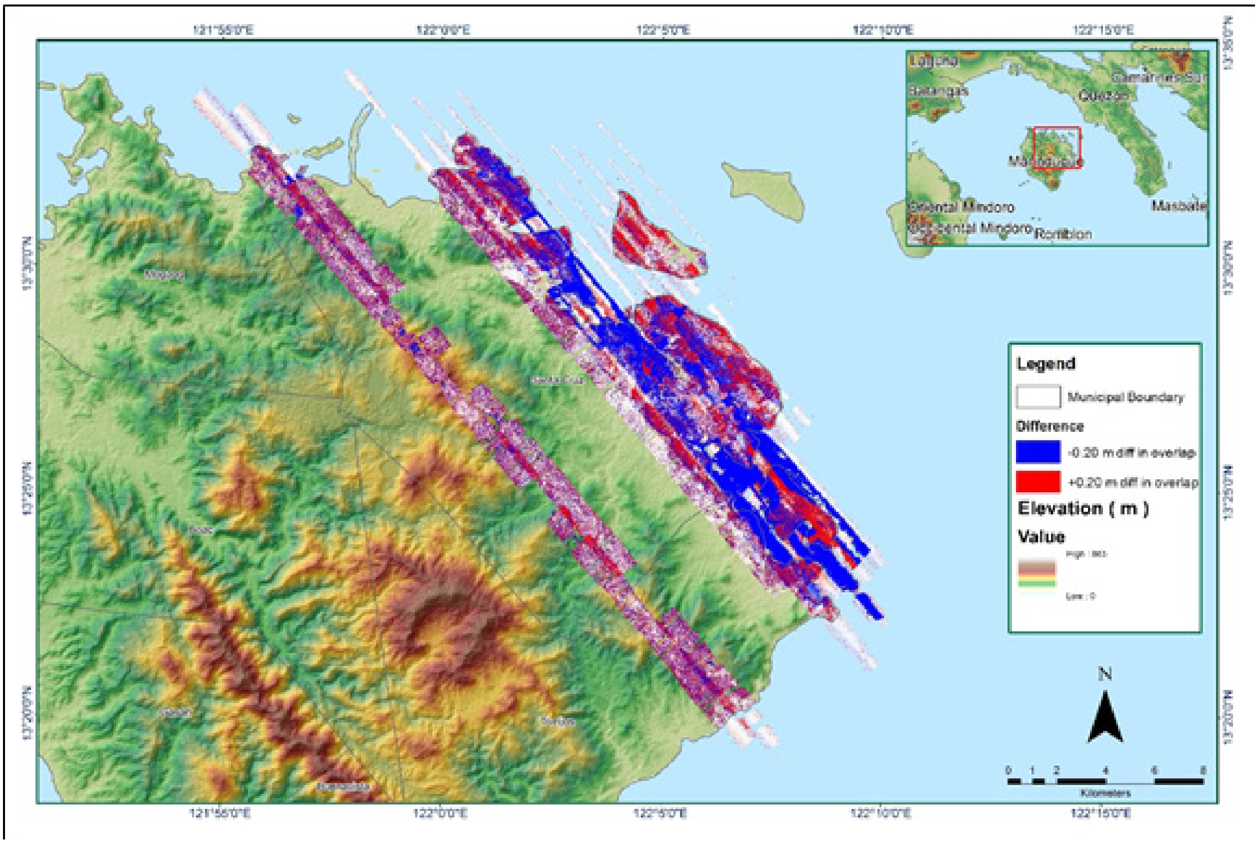


Figure A-8.7 Elevation difference between flight lines

Annex 9. Tawiran-Tagum Model Basin Parameters

Table A-9.1. Tawiran-Tagum 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 Discharge (M3/S)	Recession Constant	Ratio to Peak
W490	48.23	55.045	0.0	0.39255	3.8227	0.39772	0.44444	0.12672
W500	73.951	38.463	0.0	7.5753	42.61	0.98142	0.64027	0.30131
W510	60.99	92.752	0.0	0.14776	10.552	0.52224	0.19148	0.18156
W520	90.921	63.386	0.0	0.12669	1.0273	0.16811	0.0390193	0.018262
W530	11.368	53.76	0.0	47.128	10.332	0.24436	0.2963	0.094855
W540	21.593	88.04	0.0	0.14733	6.3512	0.97080	0.0552444	0.079463
W550	13.055	75.95	0.0	0.32267	0.52837	0.30191	0.43556	0.027825
W560	135.03	40.588	0.0	0.21787	8.4358	0.49514	0.0860356	0.042157
W570	34.336	52.54	0.0	10.794	17.704	0.14136	0.19063	0.063236
W580	22.763	51.531	0.0	38.37	3.329	0.43699	0.4465	0.061968
W590	86.582	36.807	0.0	0.30393	20.689	0.26435	0.2963	0.20087
W600	84.179	37.012	0.0	0.30463	20.668	0.26280	0.66667	0.13665
W610	9.6631	35.115	0.0	0.4944	2.8932	0.29317	0.12708	0.040010
W620	9.2357	52.486	0.0	74.585	17.036	0.46849	0.44644	0.13943
W630	23.738	78.068	0.0	46.192	23.33	0.18378	0.19063	0.043018
W640	26.979	52.467	0.0	43.906	14.631	0.23491	0.2963	0.063236
W650	15.063	49.292	0.0	58.342	13.114	0.58796	0.44656	0.092956
W660	22.383	58.257	0.0	0.48288	1.8329	0.32383	0.12703	0.083497
W670	11.847	40.022	0.0	42.383	13.99	0.95138	0.65638	0.092956
W680	7.5927	52.92	0.0	38.561	18.962	0.77893	0.6564	0.3013
W690	18.334	35.177	0.0	0.14607	0.75495	0.34387	0.12475	0.089278

W700	191.7	58.752	0.0	0.13166	0.74133	0.0760411	0.42895	0.041312
W710	16.914	52.622	0.0	0.26435	12.027	0.23394	0.44468	0.091099
W720	171.12	50.755	0.0	0.32252	0.52913	0.14157	0.42892	0.019119
W730	170.27	50.756	0.0	0.13009	0.26258	0.0215631	0.0882133	0.028105
W740	36.515	38.334	0.0	13.512	6.546	0.22967	1	0.060732
W750	20.207	48.553	0.0	43.261	14.562	0.72141	0.67219	0.13391
W760	78.561	39.159	0.0	19.373	6.6097	0.66332	0.2703	0.13665
W770	12.06	52.986	0.0	51.278	16.948	0.20140	0.0850963	0.091100
W780	17.966	53.011	0.0	55.964	18.85	0.39199	1	0.19685
W790	53.502	40.411	0.0	6.943	7.5791	0.46923	1	0.13391
W800	65.438	39.172	0.0	8.3826	14.446	0.42928	0.44661	0.65109
W810	76.345	35.329	0.0	54.631	18.299	0.67237	1	0.28937
W820	7.9154	35.126	0.0	26.419	20.58	0.38099	0.44664	0.061972
W830	15.594	35.343	0.0	13.868	10.73	0.36573	1	0.089278
W840	18.948	99	0.0	1.0417	0.46264	0.19222	0.28022	0.039648
W850	23.372	35.343	0.0	42.131	31.234	0.45410	1	0.20497
W860	6.9612	35.274	0.0	55.825	18.467	0.56805	0.44487	0.094855
W870	32.272	35.343	0.0	61.001	20.556	0.31582	1	0.13944
W880	58.662	37.998	0.0	20.451	6.9288	0.29694	0.98	0.063236
W890	9.3116	35.252	0.0	9.4409	23.18	0.99179	1	0.20497
W900	23.247	41.237	0.0	0.16508	0.0618529	0.0965994	0.0864474	0.028105
W910	18.318	35.188	0.0	13.713	24.869	0.12533	0.0384207	0.094855
W920	15.986	35.271	0.0	37.586	28.16	1.2182	0.68711	0.3013
W930	30.704	35.269	0.0	5.7133	31.812	0.53386	0.14318	0.13665
W940	23.132	35.194	0.0	57.072	28.157	1.4812	0.6719	0.14228
W960	1.5033	89.416	0.0	3.5596	5.8092	0.92061	1	0.5
W970	101.88	60.993	0.0	0.14599	0.28485	0.0600997	0.2963	0.027543

Annex 10. Tawiran-Tagum Model Reach Parameters

Table A-10.1. Tawiran-Tagum Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R110	Automatic Fixed Interval	1042.5	0.0580500	0.0387812	Trapezoid	45	1
R140	Automatic Fixed Interval	1208.4	0.0390724	0.0394409	Trapezoid	45	1
R150	Automatic Fixed Interval	947.70	0.0025528	0.0379399	Trapezoid	45	1
R160	Automatic Fixed Interval	1015.0	0.0171899	0.0383397	Trapezoid	45	1
R170	Automatic Fixed Interval	1784.8	0.0050876	0.0168539	Trapezoid	45	1
R180	Automatic Fixed Interval	2676.3	0.0137635	0.0253148	Trapezoid	45	1
R20	Automatic Fixed Interval	4411.4	0.0228382	0.04	Trapezoid	45	1
R200	Automatic Fixed Interval	2988.5	0.0044819	0.045496	Trapezoid	45	1
R230	Automatic Fixed Interval	2620.1	0.0192755	0.06	Trapezoid	45	1
R240	Automatic Fixed Interval	386.27	0.0337493	0.0902569	Trapezoid	45	1
R260	Automatic Fixed Interval	373.14	0.0229892	0.12897	Trapezoid	45	1
R270	Automatic Fixed Interval	581.13	0.0229892	0.0882	Trapezoid	45	1
R290	Automatic Fixed Interval	1477.8	0.0268340	0.0604035	Trapezoid	45	1
R300	Automatic Fixed Interval	1201.2	0.0092426	0.1035	Trapezoid	45	1
R330	Automatic Fixed Interval	1711.0	0.0153559	0.0257559	Trapezoid	45	1
R350	Automatic Fixed Interval	516.27	0.0107580	0.13522	Trapezoid	45	1
R360	Automatic Fixed Interval	1550.2	0.0352450	0.0898549	Trapezoid	45	1
R420	Automatic Fixed Interval	2371.8	0.0175926	0.13351	Trapezoid	45	1

R430	Automatic Fixed Interval	503.55	0.0146220	0.0907021	Trapezoid	45	1
R440	Automatic Fixed Interval	811.84	0.0228382	0.0604155	Trapezoid	45	1
R50	Automatic Fixed Interval	1070.8	0.0105189	0.0301586	Trapezoid	45	1
R70	Automatic Fixed Interval	3816.1	0.0111004	0.0261333	Trapezoid	45	1
R80	Automatic Fixed Interval	1366.1	.0001628897	0.0177634	Trapezoid	45	1
R980	Automatic Fixed Interval	634.56	0.0228382	0.0588	Trapezoid	45	1

Annex 11. Tawiran-Tagum Field Validation Points

Table A-11.1. Tawiran-Tagum Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	13.433288	122.070880	2.62	0.80	-1.82	Reming, Glenda / July, 2014	25-Year
2	13.433413	122.071130	3.20	1.80	-1.40	Reming	25-Year
3	13.433907	122.071960	2.35	0.00	-2.35		25-Year
4	13.434486	122.072160	3.85	0.77	-3.08	Glenda / July, 2014	25-Year
5	13.435643	122.070020	3.81	1.20	-2.61	Reming, Ruby	25-Year
6	13.436077	122.071000	4.35	0.50	-3.85	Ruby	25-Year
7	13.436632	122.072200	4.21	1.00	-3.21	Reming, Glenda, Yolanda, Ruby	25-Year
8	13.436654	122.071590	4.34	0.90	-3.44	Reming	25-Year
9	13.437482	122.073630	0.20	0.47	0.27	Glenda / July, 2014	25-Year
10	13.437918	122.073420	1.33	0.80	-0.53	Glenda / July, 2014	25-Year
11	13.439348	122.073670	1.32	2.13	0.81	Glenda / July, 2014	25-Year
12	13.442827	122.066180	4.32	0.60	-3.72	Reming / Dec. 2006	25-Year
13	13.443738	122.066120	5.46	0.82	-4.64	Reming / Dec. 2006	25-Year
14	13.443780	122.074050	0.03	0.00	-0.03		25-Year
15	13.444756	122.066270	5.82	0.72	-5.10	Reming / Dec. 2006	25-Year
16	13.445346	122.066330	3.58	0.50	-3.08	Reming / Dec. 2006	25-Year
17	13.446299	122.065150	0.03	0.00	-0.03	Glenda / July, 2014	25-Year
18	13.446795	122.073580	0.50	0.10	-0.40	Yolanda / Nov. 8, 2013	25-Year
19	13.447581	122.065520	0.26	0.00	-0.26	Glenda / July, 2014	25-Year
20	13.447722	122.065290	0.31	0.20	-0.11	Yolanda / Nov. 8, 2013	25-Year
21	13.447830	122.064980	0.38	0.00	-0.38		25-Year
22	13.447885	122.072800	0.80	0.20	-0.60	Yolanda / Nov. 8, 2013	25-Year
23	13.447929	122.065290	0.46	0.20	-0.26	Yolanda / Nov. 8, 2013	25-Year
24	13.448206	122.065150	0.39	0.00	-0.39	Yolanda / Nov. 8, 2013	25-Year
25	13.448372	122.072581	0.60	0.20	-0.40	Yolanda / Nov. 8, 2013	25-Year
26	13.448533	122.065520	0.43	0.18	-0.25	Yolanda / Nov. 8, 2013	25-Year
27	13.448740	122.065020	0.59	1.10	0.51	Yolanda / Nov. 8, 2013	25-Year
28	13.449471	122.087250	0.03	0.00	-0.03		25-Year
29	13.449491	122.065320	0.57	0.20	-0.37	Yolanda / Nov. 8, 2013	25-Year
30	13.449602	122.089630	0.03	0.61	0.58	Yolanda / Nov. 2013	25-Year
31	13.449633	122.065980	0.44	0.25	-0.19	Glenda / July, 2014	25-Year
32	13.449994	122.065800	0.42	0.35	-0.07	Glenda / July, 2014	25-Year
33	13.450269	122.043500	0.03	0.00	-0.03		25-Year
34	13.450604	122.065810	0.45	0.42	-0.03	Glenda / July, 2014	25-Year
35	13.450739	122.087110	0.03	0.50	0.47	Yolanda / Nov. 2013	25-Year
36	13.450689	122.044860	0.03	0.00	-0.03		25-Year

37	13.451196	122.044940	0.83	0.00	-0.83		25-Year
38	13.451261	122.045610	0.04	0.00	-0.04		25-Year
39	13.451377	122.068390	0.54	0.80	0.26		25-Year
40	13.451803	122.070200	0.51	0.61	0.10	Glenda / July, 2014	25-Year
41	13.451911	122.088570	0.58	1.55	0.97	Yolanda / Nov. 2013	25-Year
42	13.452048	122.070660	0.61	0.93	0.32	Reming / Dec. 2006	25-Year
43	13.452254	122.069720	0.19	1.26	1.07	Monang / Dec. 1993	25-Year
44	13.452491	122.045310	0.04	0.00	-0.04		25-Year
45	13.453118	122.069930	0.03	0.33	0.30	Reming / Dec. 2006	25-Year
46	13.454213	122.068600	0.92	1.00	0.08	Glenda / July, 2014	25-Year
47	13.455936	122.084880	1.50	1.01	-0.49	Reming / Nov. 2006	25-Year
48	13.456390	122.099460	0.63	0.00	-0.63		25-Year
49	13.457778	122.100420	0.52	0.97	0.45	Reming / Nov. 30. 2006	25-Year
50	13.458267	122.069840	0.36	1.00	0.64	Reming / Dec. 2006	25-Year
51	13.458614	122.103120	0.03	0.00	-0.03	Reming / Nov. 30. 2006	25-Year
52	13.460162	122.067680	0.52	0.72	0.20	Yolanda / Oct. 2013	25-Year
53	13.460551	122.067640	0.45	0.80	0.35	Reming / Dec. 2006	25-Year
54	13.460840	122.068190	0.70	0.80	0.10	Reming / Dec. 2006	25-Year
55	13.461958	122.066540	2.97	0.94	-2.03	Frank / June, 2008	25-Year
56	13.463626	122.069860	0.35	1.30	0.95	Glenda / July, 2014	25-Year
57	13.463932	122.069650	0.47	0.74	0.27	Glenda / July, 2014	25-Year
58	13.473482	122.089360	0.43	0.00	-0.43		25-Year
59	13.475128	122.085370	0.03	0.00	-0.03	Monang / Dec. 1993	25-Year
60	13.476839	122.081940	0.03	0.00	-0.03		25-Year
61	13.476870	122.080790	0.07	0.00	-0.07		25-Year

Annex 12. Phil-LiDAR 1 UPLB Team Composition

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