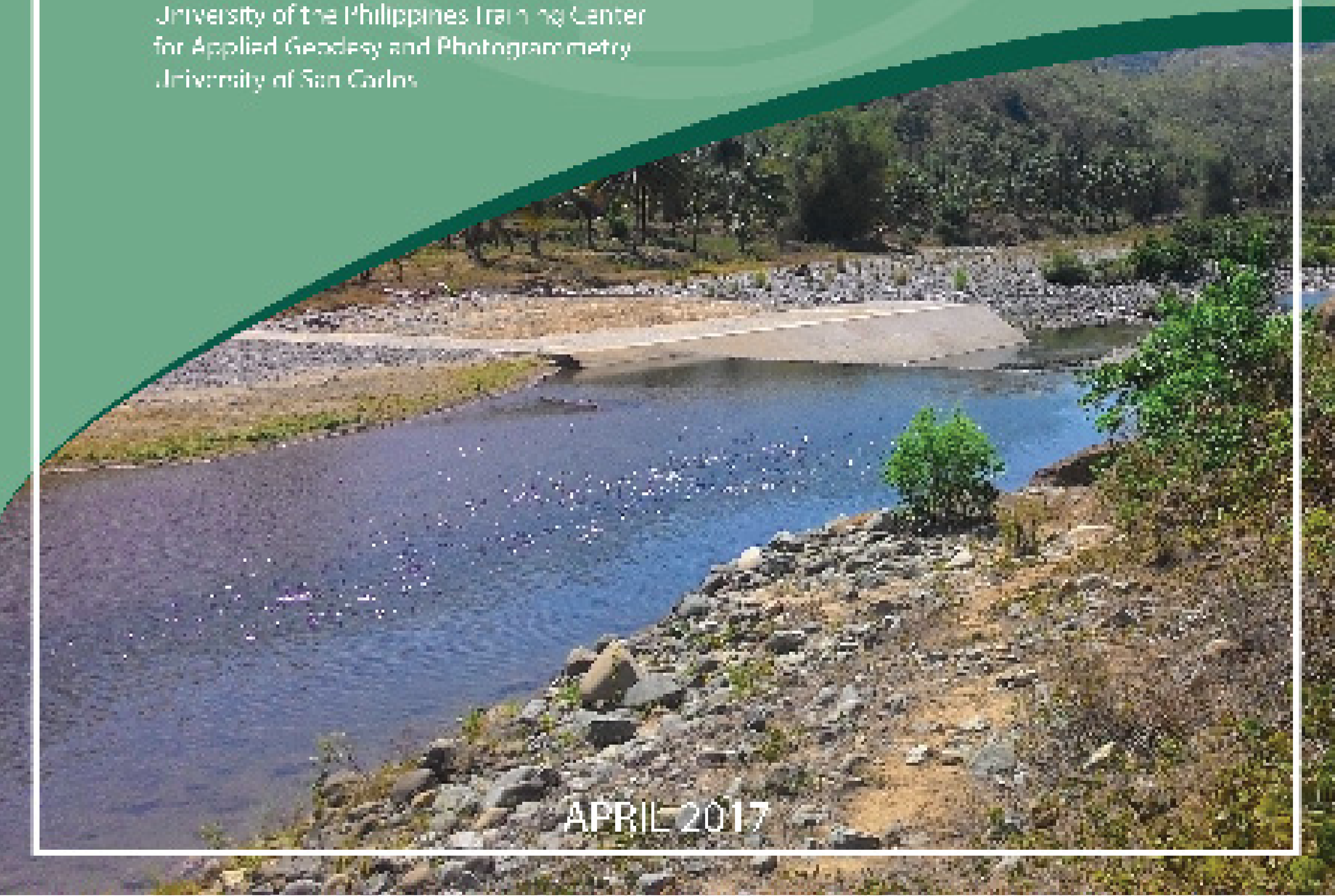
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Tiabanan River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of San Carlos



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LIST OF ACRONYMS AND ABBREVIATIONS

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

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND TIABANAN RIVER

Enrico C. Paringit, Dr. Eng., Dr. Roland Otadoy, and Engr. Aure Flo Oraya

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 San Carlos (USC). USC 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 26 river basins in the Central Visayas Region. The university is located in Cebu City in the province of Cebu.

1.2 Overview of the Tiabanan River Basin

The Tiabanan River Basin covers the Municipality of Basay in Negros Oriental, and the Municipalities of Hinoba-An and Candoni in Negros Occidental. According to DENR - River Basin Control Office, it has a drainage area of 116 km2 and an estimated 70 million cubic meter (MCM) annual run-off of (RCBO, 2015). The weather in the river basin area is classified under Type I weather in the Corona climate classification. It has two pronounced seasons. It is dry from November to April and wet during the rest of the year.

The Tiabanan River Basin's main stem, the Tiabanan River, is part of the 19 river systems in the Negros Island Region. The Tiabanan River has its floodplain in Negros Oriental in the Municipality of Basay while its head waters are in Negros Occidental covering the Municipality of Hinoba-an. According to the 2015 national census of NSO, a total of 6,797 locals are residing in the immediate vicinity of the river which are distributed within Brgy. Sangke, Hinoba-an, Negros Occidental and Brgy. Bongalonan, Basay, Negros Oriental.

Mat weaving is the main source of livelihood of the people of Basay. The municipality also has a vast water resources where shrimps, crabs, and lobsters can be found. The major agricultural products include palay, banana, coconut, vegetables, and root crops. Aside from agriculture, mining plays a role in the economy of the town.

The most recent flooding in the area was on November 2013 cause by typhoon Haiyan internationally known as "*Yolanda*". The floods affected many communities, including Basay, which is a 4th income class municipality with a population of 24,913 based on the 2010 census. Basay was previously part of Bayawan. Basay is the last town of Negros Oriental in the south, while Hinoba-An is the last town in Negros Occidental in the south. Hinoba-An is a 1st class municipality with a population of 54,624 based on the 2010 census.

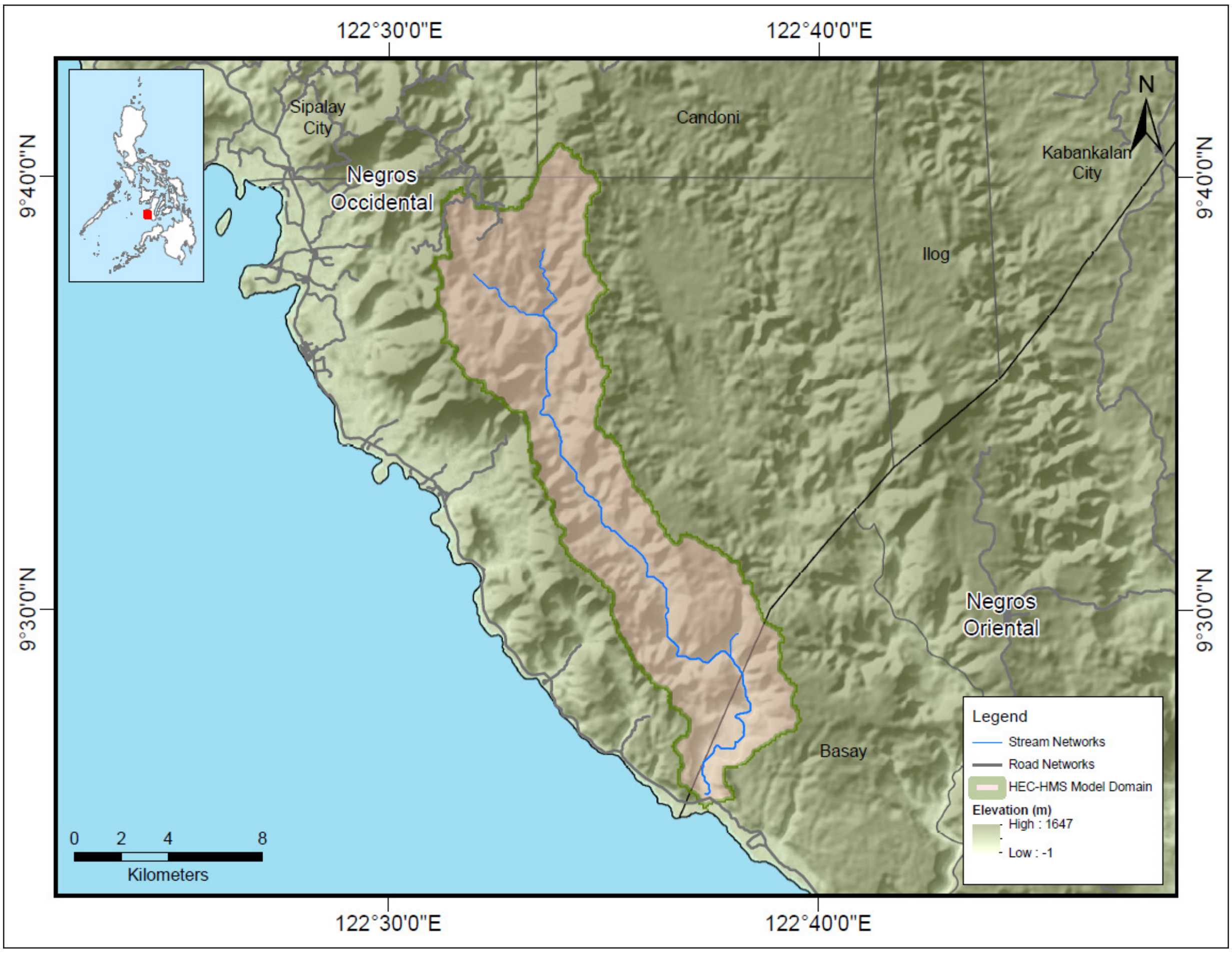

Figure 1. Map of Tiabanan River Basin (in brown)

CHAPTER 2: LIDAR DATA ACQUISITION OF THE TIABANAN FLOODPLAIN

gr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Engr. Grace B. Sinadjan, and Engr. Millie Shane R. Reyes

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 Tiabanan floodplain located along the boundary of Negros Occidental and Negros Oriental. These missions were planned for 12 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the Gemini LiDAR system is found in Table 1. Figure 2 shows the flight plans for Tiabanan floodplain survey.

Table 1. Flight planning parameters for Gemini LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 53D	1000	60	40	100	50	130	5
BLK 53E	1000	60	40	100	50	130	5
BLK 53F	1000	60	40	100	50	130	5
BLK 53G	1000	60	40	100	50	130	5
BLK 53H	1000	60	40	100	50	130	5

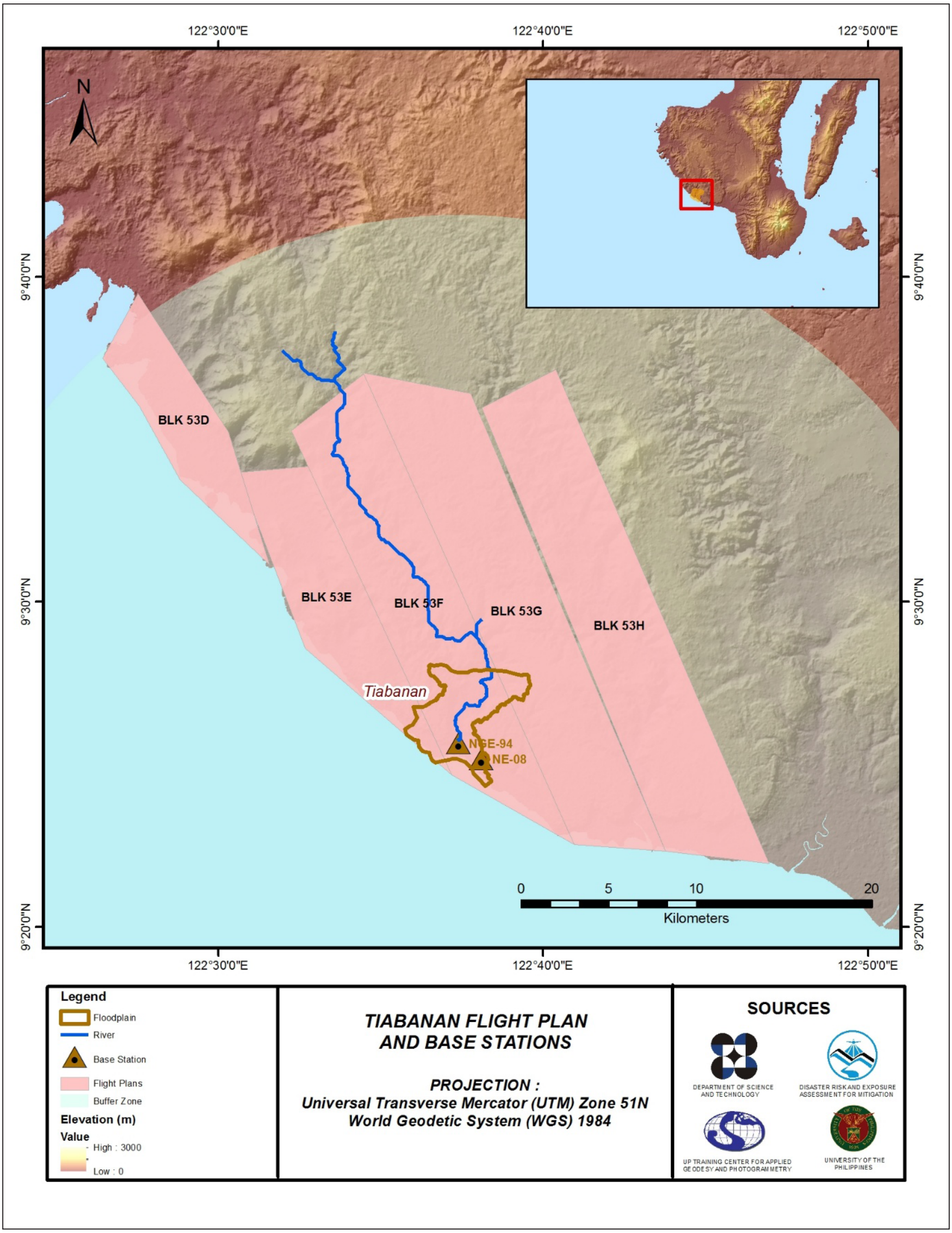

Figure 2. Flight plans and base stations used for Tiabanan Floodplain

2.2 Ground Base Station

The project team was able to recover one (1) NAMRIA ground control point: NGE-94 which is of second (2nd) order accuracy. The project team also recovered one (1) benchmark, NE-08. The certification for the NAMRIA reference point is found in Annex 2 while the baseline processing report for the benchmark is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (September 24 to October 6, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and TRIMBLE SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tiabanan floodplain are shown in Figure 2. The list of LiDAR data acquisition team members are found in Annex 4.

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

Figure 3. GPS set-up over NGE-94 on the south approach of Tiabanan's bridge wingwall sidewalk in Barangay Bal-OS under the municipality of Basay (a) and NAMRIA reference point NGE-94 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point NGE-94 used as base station for the LiDAR acquisition.

Station Name	NGE-94	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9° 25' 41.58333" North
	Longitude	122° 37' 17.78349" East
	Ellipsoidal Height	8.567 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting	238,729.951 meters
	Northing	1,043,383.312 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 25' 37.57296" North
	Longitude	122° 37' 23.11929" East
	Ellipsoidal Height	69.141 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting	458,583.555 meters
	Northing	1,042,090.797 meters

Figure 4. GPS set-up over NE-08 on top center of reinforced concrete pipe culvert about 7 meters from the roadline located in the municipality of Basay, Barangay Nagbualao along the national road going to Hinoba-An (a) and NAMRIA reference point NE-08 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA benchmark NE-08 with processed coordinates used as base station for the LiDAR acquisition.

Station Name	NE-08	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9° 25' 12.20140" North
	Longitude	122° 38' 0.55785" East
	Ellipsoidal Height	8.582 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 25' 8.19418" North
	Longitude	122° 38' 5.89430" East
	Ellipsoidal Height	69.203 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 84)	Easting	459,925.13 meters
	Northing	1,041,190.75 meters

Table 4. Ground Control Points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
October 22, 2014	7570G	2BLK53J295A	NE-08 & NGE-94
October 24, 2014	7574G	2BLK53I297A	NE-08 & NGE-94
October 25, 2014	7576G	2BLK53I298A	NE-08 & NGE-94
October 26, 2014	7578G	2BLK53HSGF299A	NE-08 & NGE-94

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Tiabanan floodplain, for a total of sixteen hours and fifty-six minutes (16+56) of flying time for RP-C9322. The missions were acquired using the Gemini LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Tiabanan Floodplain

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed Outside the Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
October 22, 2014	7570G	142.35	148.87	NA	148.87	NA	4	23
October 24, 2014	7574G	139.57	290.96	1.10	289.86	NA	4	17
October 25, 2014	7576G	123.94	118.30	15.06	103.24	NA	3	53
October 26, 2014	7578G	233.10	252.17	21.55	230.62	NA	4	23
TOTAL		638.96	810.30	37.71	772.60	NA	16	56

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)
7570G	1000	60	40	100	50	130	5
7574G	1000	60	40	100	50	130	5
7576G	1000	60	40	100	50	130	5
7578G	1000	60	40	100	50	130	5

2.4. Survey Coverage

Tiabanan floodplain is located along the boundary of the provinces of Negros Occidental and Negros Oriental with majority of the floodplain situated within the municipality of Basay. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Tiabanan floodplain is presented in Figure 5.

Table 7. List of municipalities and cities surveyed during Tiabanan floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Negros Oriental	Basay	132.30	131.83	99.64%
	Bayawan City	683.21	69.427	10.16%
Negros Occidental	Hinoba-an	464.36	289.976	61.80%
Total		1279.88	491.23	57.20%

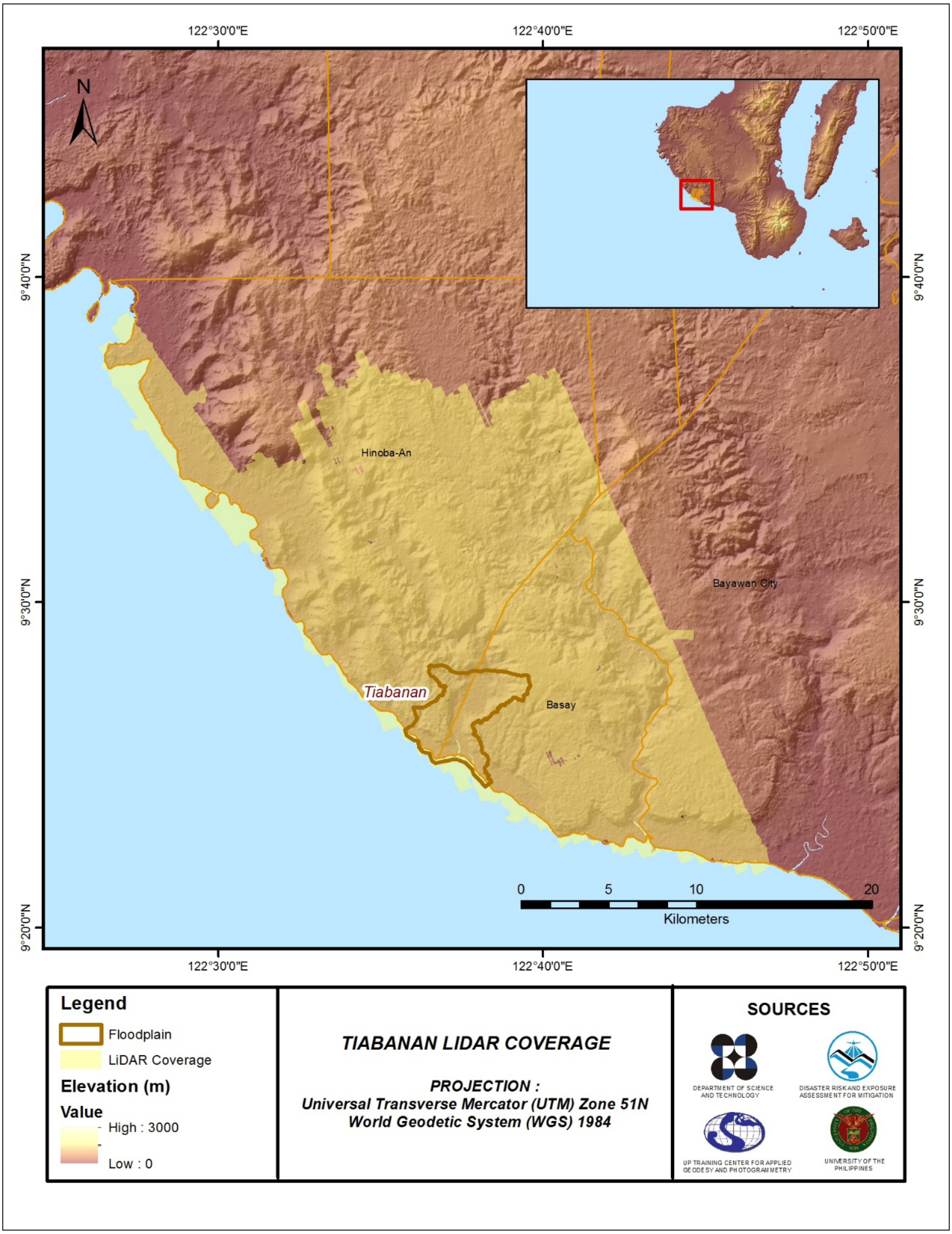

Figure 5. Actual LiDAR survey coverage for Tiabanan Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE TIABANAN 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 6.

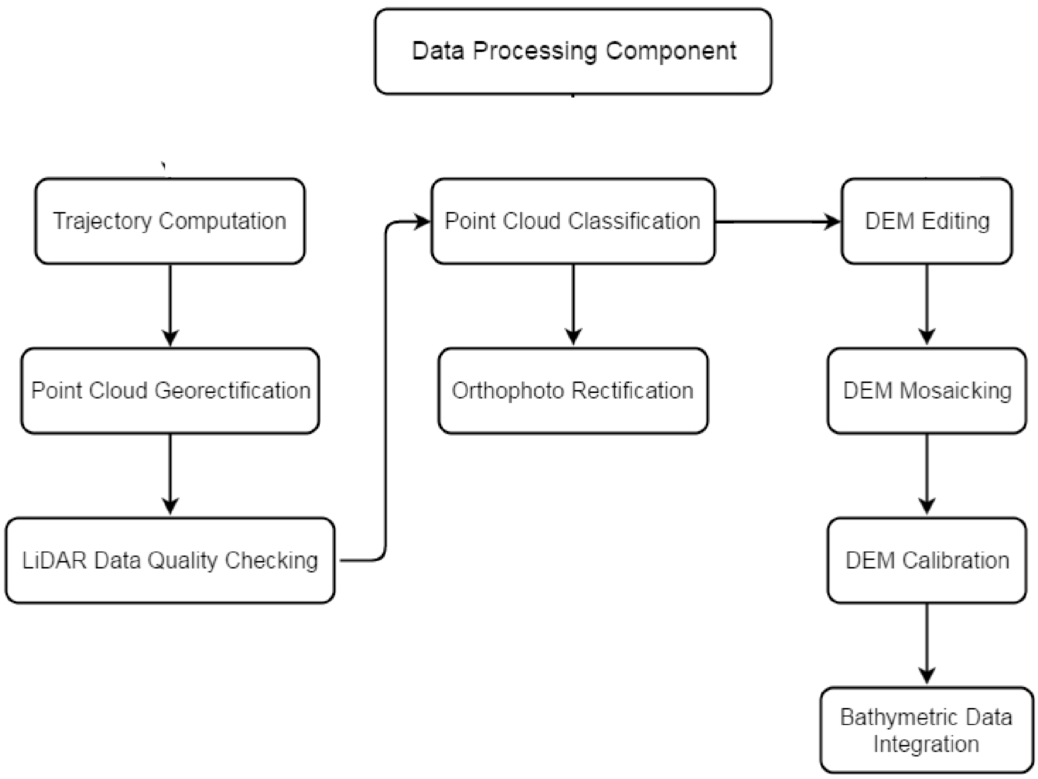

Figure 6. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Tiabanan floodplain can be found in Annex 5. Missions flown during the first survey conducted on October 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Basay, Negros Oriental.

The Data Acquisition Component (DAC) transferred a total of 95.0 Gigabytes of Range data, 1.25 Gigabytes of POS data, 29.62 Megabytes of GPS base station data, and 75.7 Gigabytes of raw image data to the data server on November 6, 2014. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tiabanan was fully transferred on November 6, 2014, as indicated on the Data Transfer Sheets for Tiabanan floodplain.

3.3 Trajectory Computation

The *Smoothed Performance Metric* parameters of the computed trajectory for flight 7578G, one of the Tiabanan flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of flight, 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 26, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

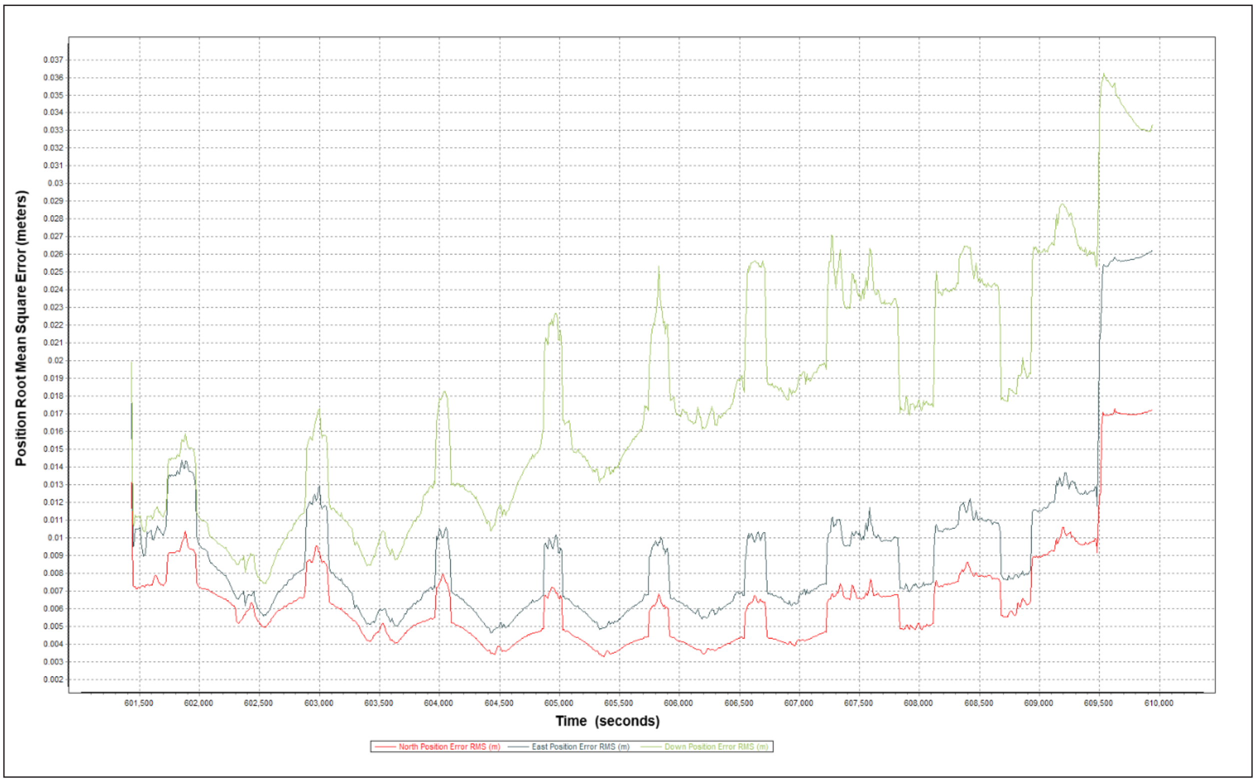

Figure 7. Smoothed Performance Metric Parameters of Tiabanan Flight 7578G.

The time of flight was from 601500 seconds to 609500 seconds, which corresponds to morning of October 26, 2014. 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 7 shows that the North position RMSE peaks at 1.72 centimeters, the East position RMSE peaks at 2.58 centimeters, and the Down position RMSE peaks at 3.64 centimeters, which are within the prescribed accuracies described in the methodology.

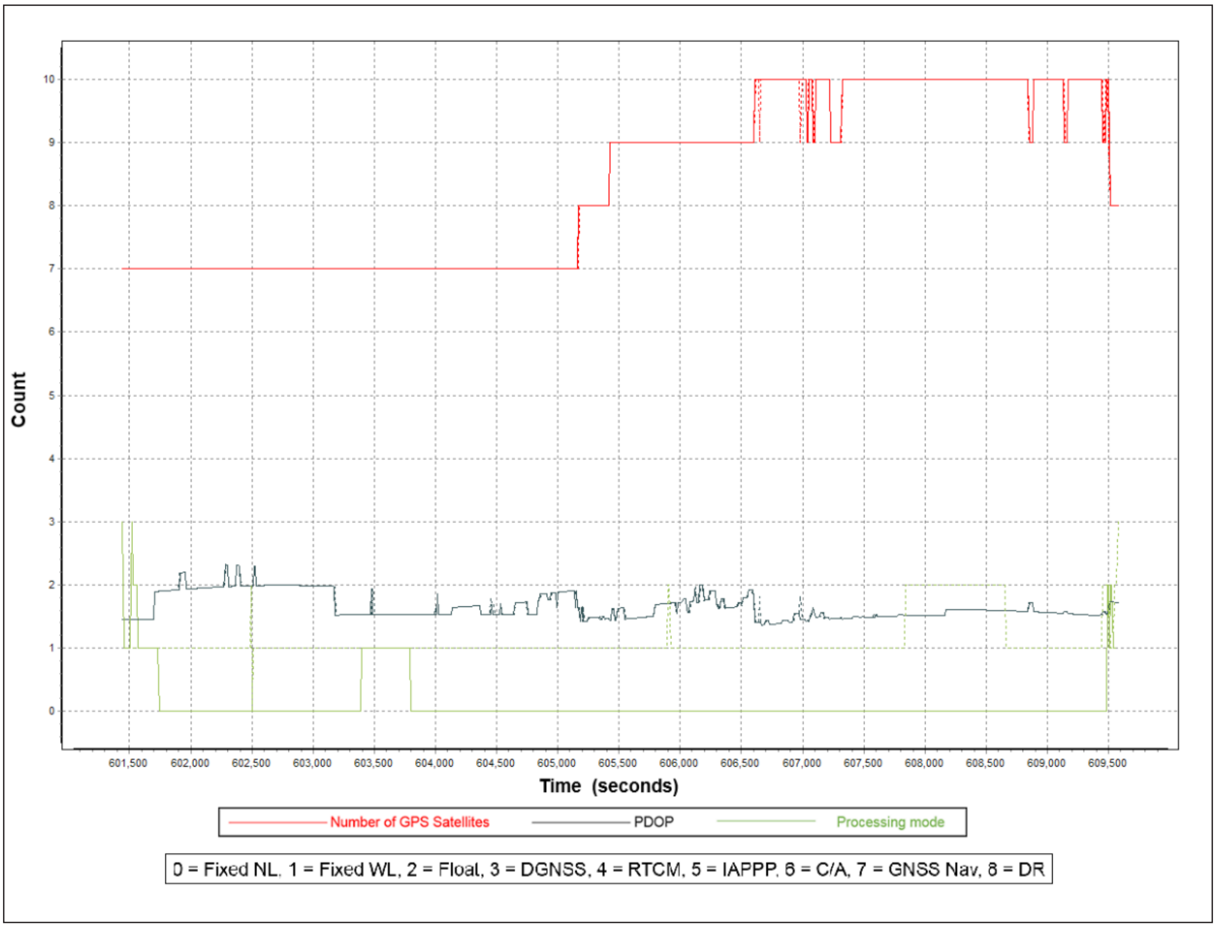

Figure 8. Solution Status Parameters of Tiabanan Flight 7578G.

The *Solution Status* parameters of flight 7578G, one of the Tiabanan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to 7. Majority of the time, the number of satellites tracked was between 7 and 10. The PDOP value also did not go above the value of 2, 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 Tiabanan flights is shown in Figure 9.

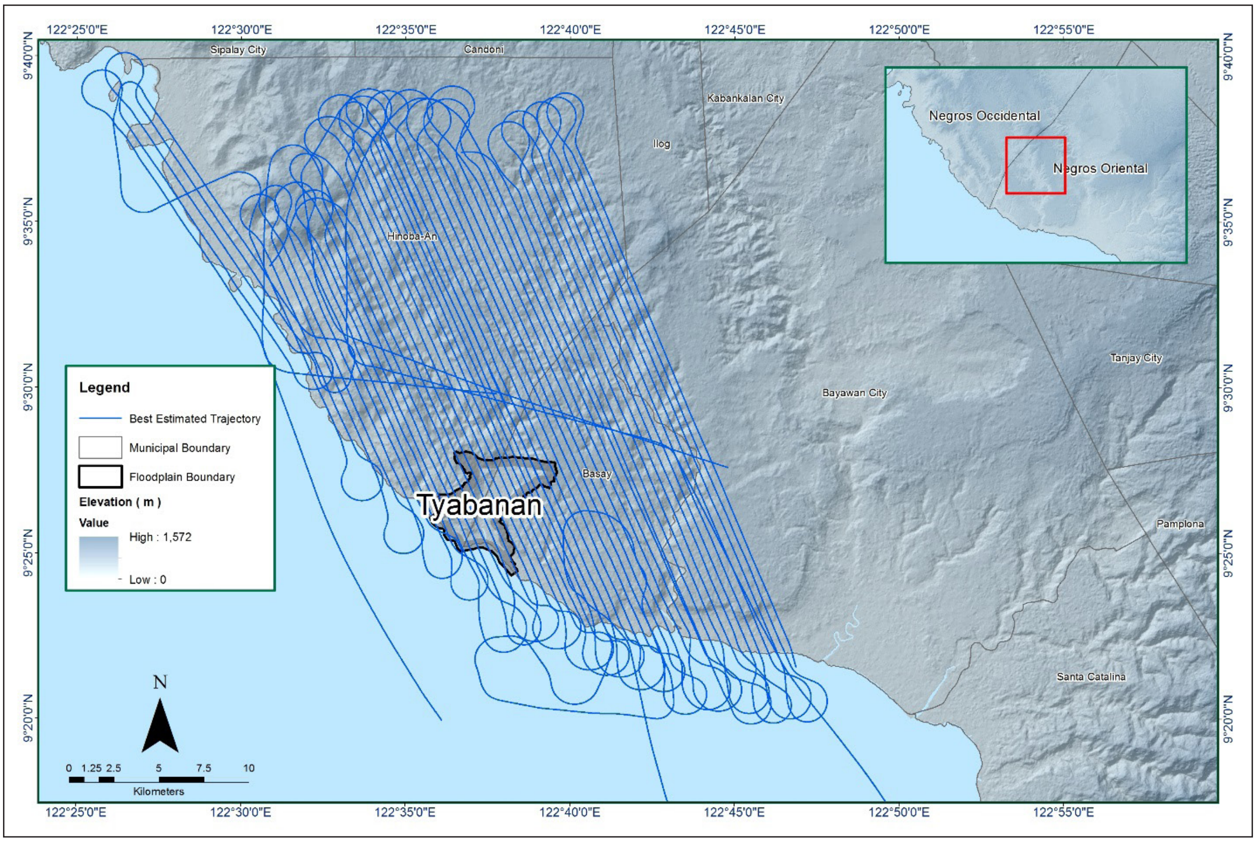

Figure 9. Best Estimated Trajectory for Tiabanan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 85 flight lines, with each flight line containing one channel, since the Gemini system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tiabanan floodplain are given in Table 8.

Table 8. Self-Calibration Results values for Tiabanan flights.

Parameter	Computed Value
Boresight Correction stdev (<0.001degrees)	0.000168
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000941
GPS Position Z-correction stdev (<0.01meters)	0.0099

The optimum accuracy is obtained for all Tiabanan 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 Tiabanan Floodplain is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

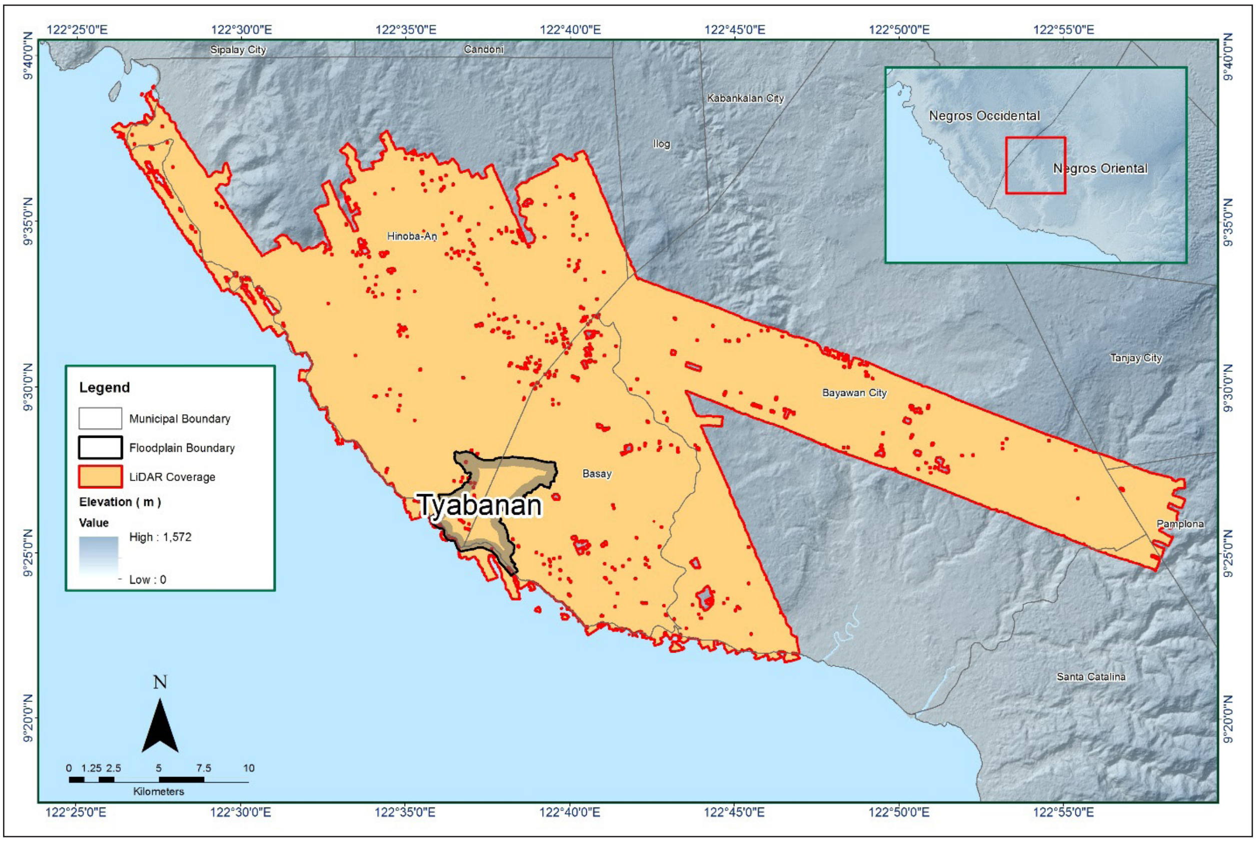

Figure 10. Figure 10. Boundary of the processed LiDAR data over Tiabanan Floodplain

The total area covered by the Tiabanan missions is 816.95 sq.km that is comprised of four (4) flight acquisitions grouped and merged into three (3) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Tiabanan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Dumaguete_Blk53I	7574G	304.96
Dumaguete_Blk53H	7570G	383.22
	7576G	
	7578G	
Dumaguete_Blk53FG	7578G	128.76
TOTAL		816.95 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 11. Since the Gemini system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

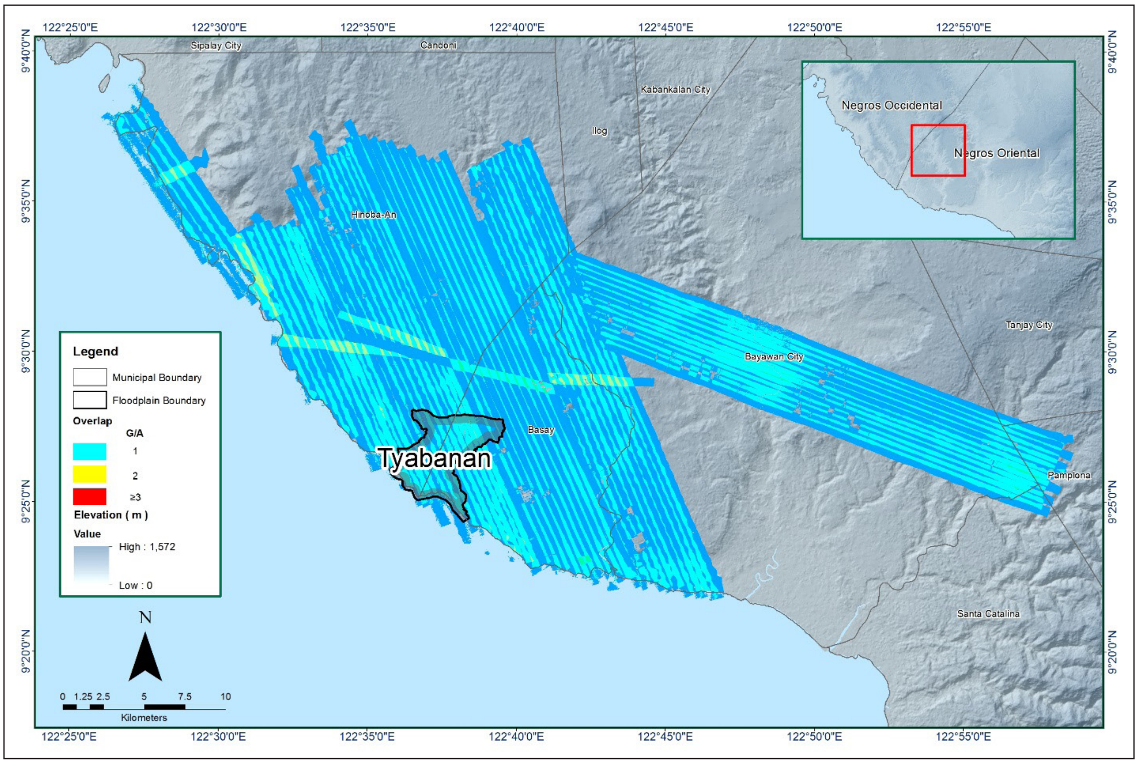

Figure 11. Image of data overlap for Tiabanan Floodplain.

The overlap statistics per block for the Tiabanan floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 36.98% and 42.05% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 12. It was determined that all LiDAR data for Tiabanan floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.9 points per square meter.

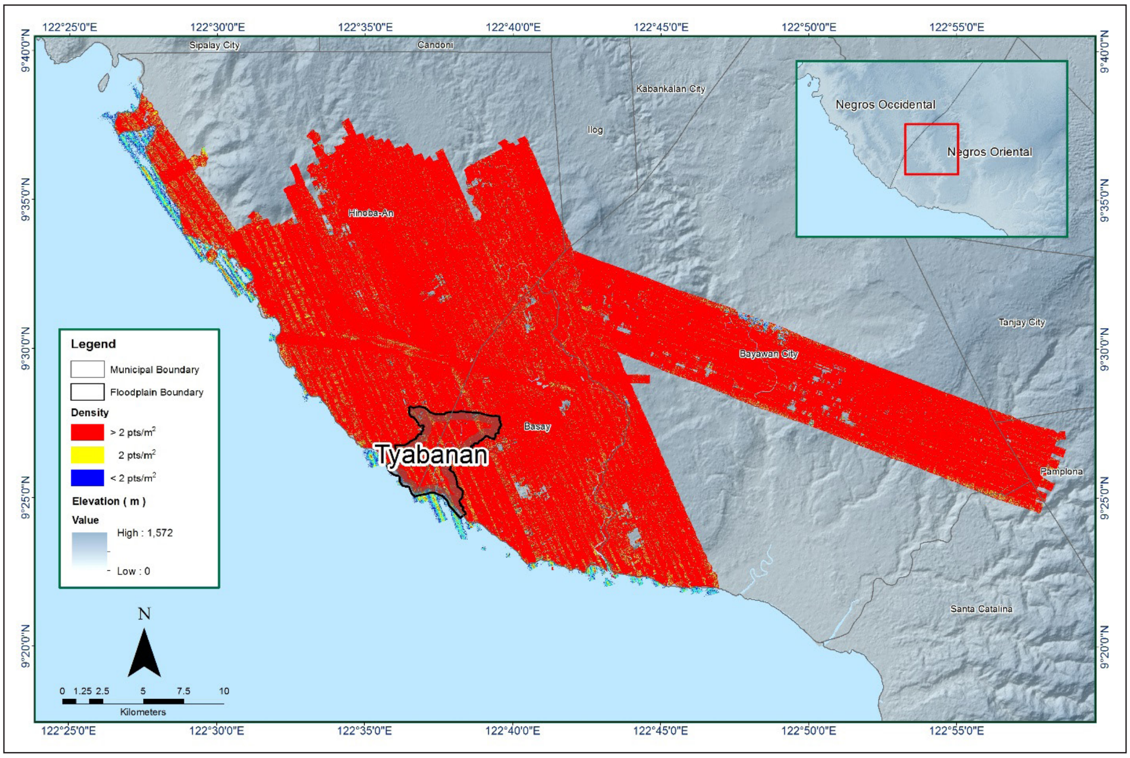

Figure 12. Pulse density map of merged LiDAR data for Tiabanan Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

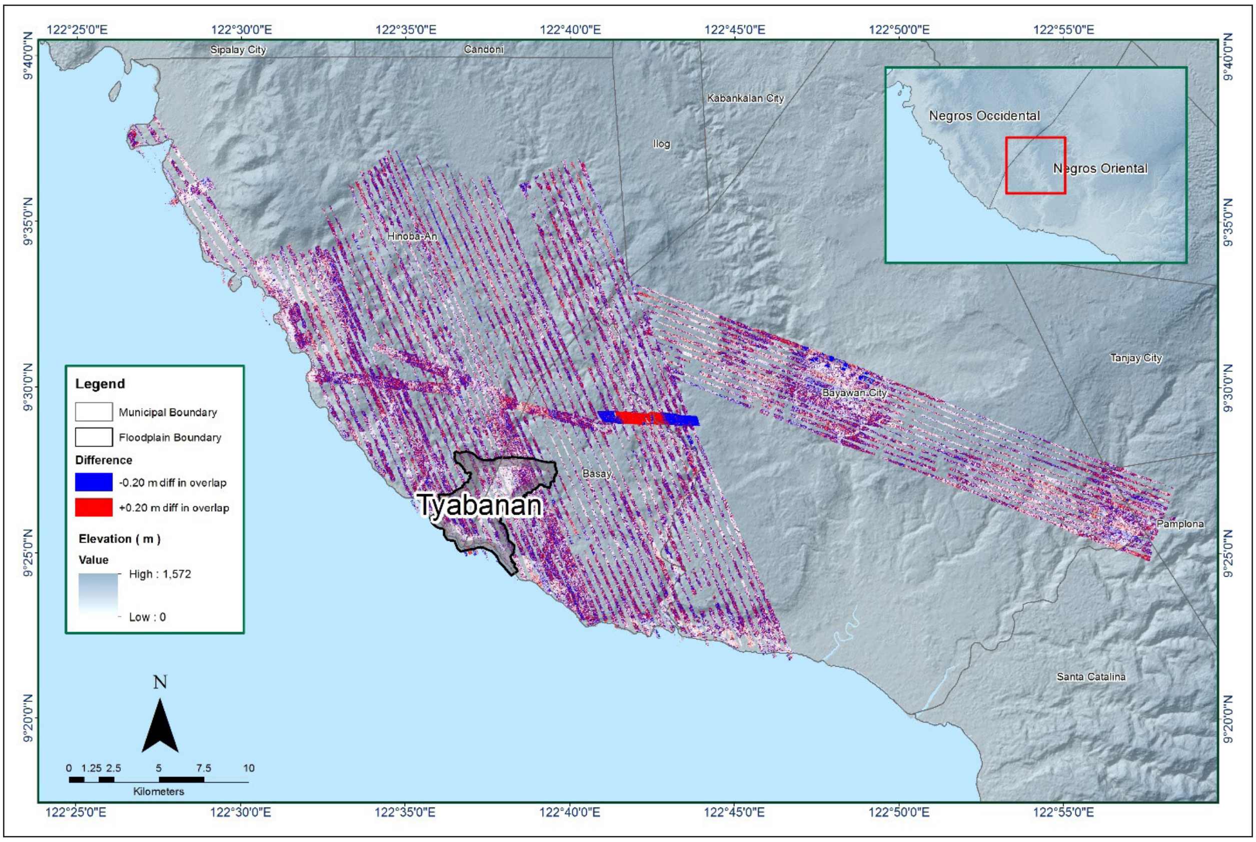

Figure 13. Elevation difference map between flight lines for Tiabanan Floodplain.

A screen capture of the processed LAS data from a Tiabanan flight 7578G loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

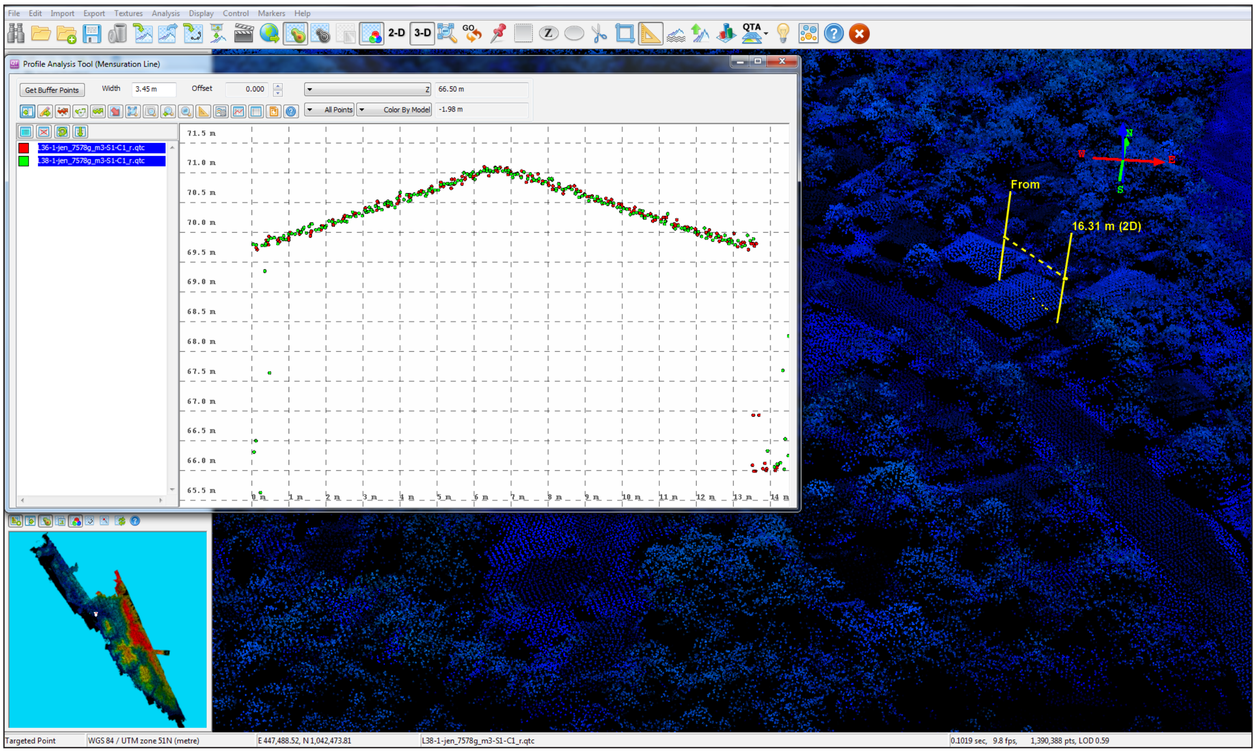

Figure 14. Quality checking for Tiabanan Flight 7578G using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Tiabanan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	373,154,327
Low Vegetation	346,002,381
Medium Vegetation	920,959,030
High Vegetation	1,288,930,677
Building	26,127,578

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tiabanan floodplain is shown in Figure 15. A total of 1,125 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 583.91 meters and 60.27 meters respectively.

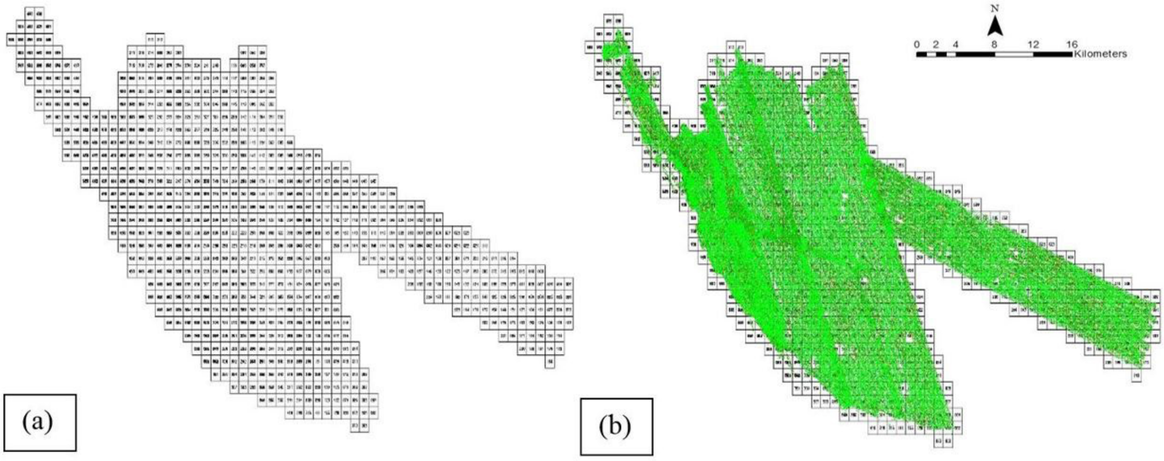

Figure 15. Tiles for Tiabanan Floodplain (a) and classification results (b) in TerraScan.

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

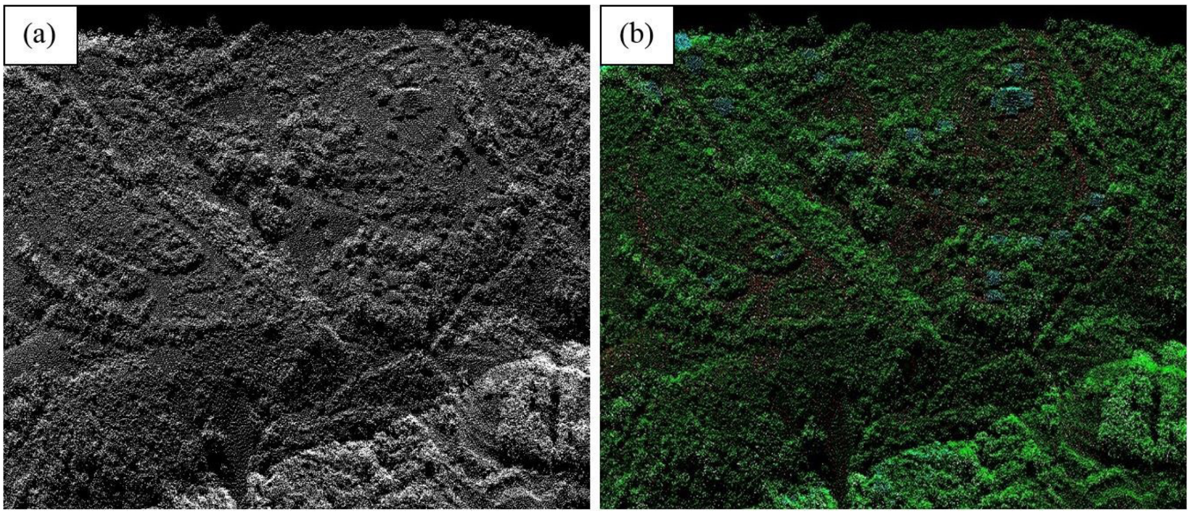

Figure 16. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in **Error! Reference source not found.**. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

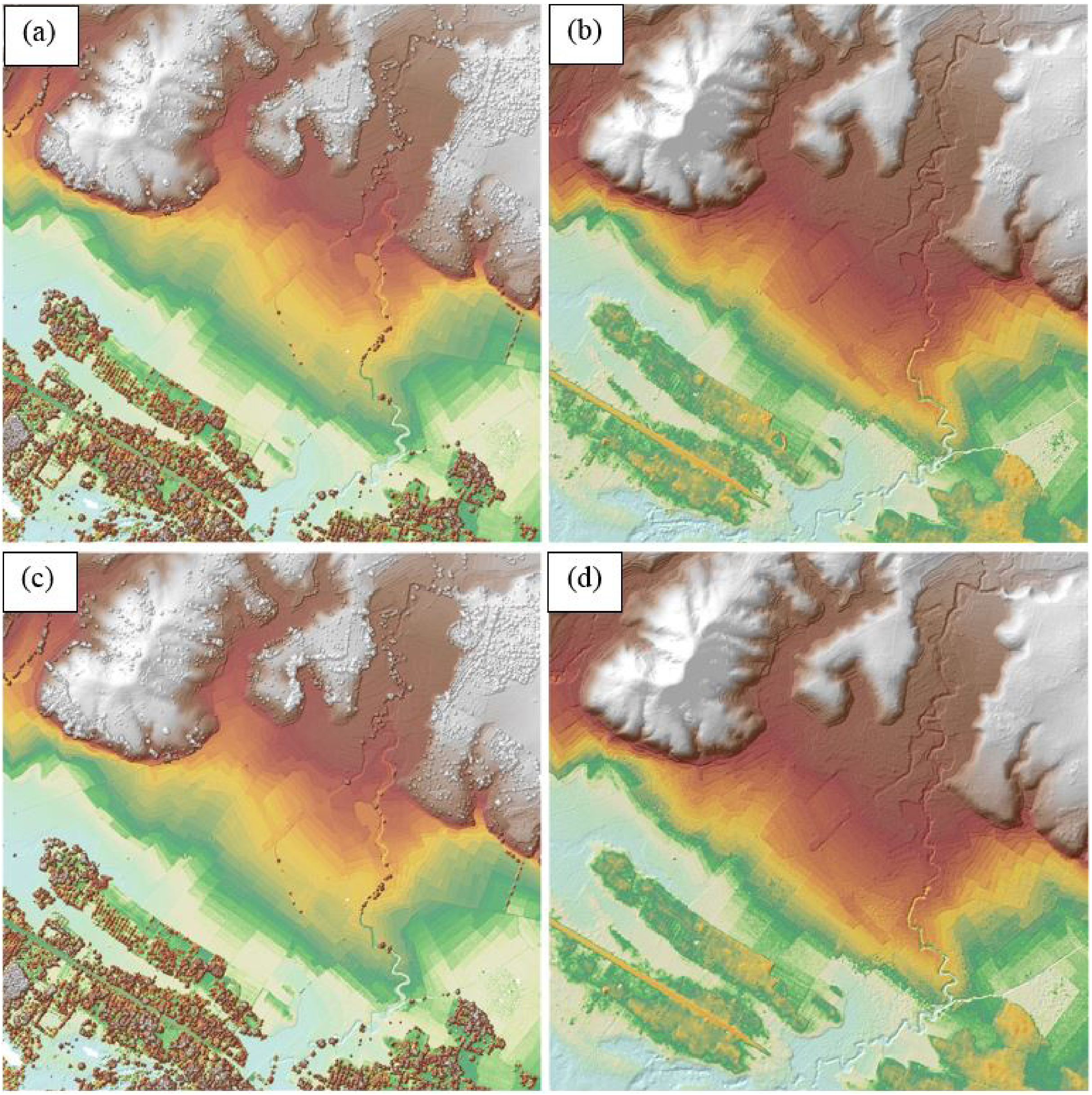

Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tiabanan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Tiabanan floodplain.

3.8 DEM Editing and Hydro-Correction

Three (3) mission blocks were processed for Tiabanan flood plain. These blocks are composed of Dumaguete blocks with a total area of 816.95 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)
Dumaguete_Blk53I	304.96
Dumaguete_Blk53H	383.22
Dumaguete_Blk53FG	128.76
TOTAL	**816.95 sq.km**

Portions of DTM before and after manual editing are shown in Figure 18. The bridge (Figure 18a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 18b) in order to hydrologically correct the river. Retrieval of data along hilly areas has been done, as well (Figure 18c and Figure 18d).

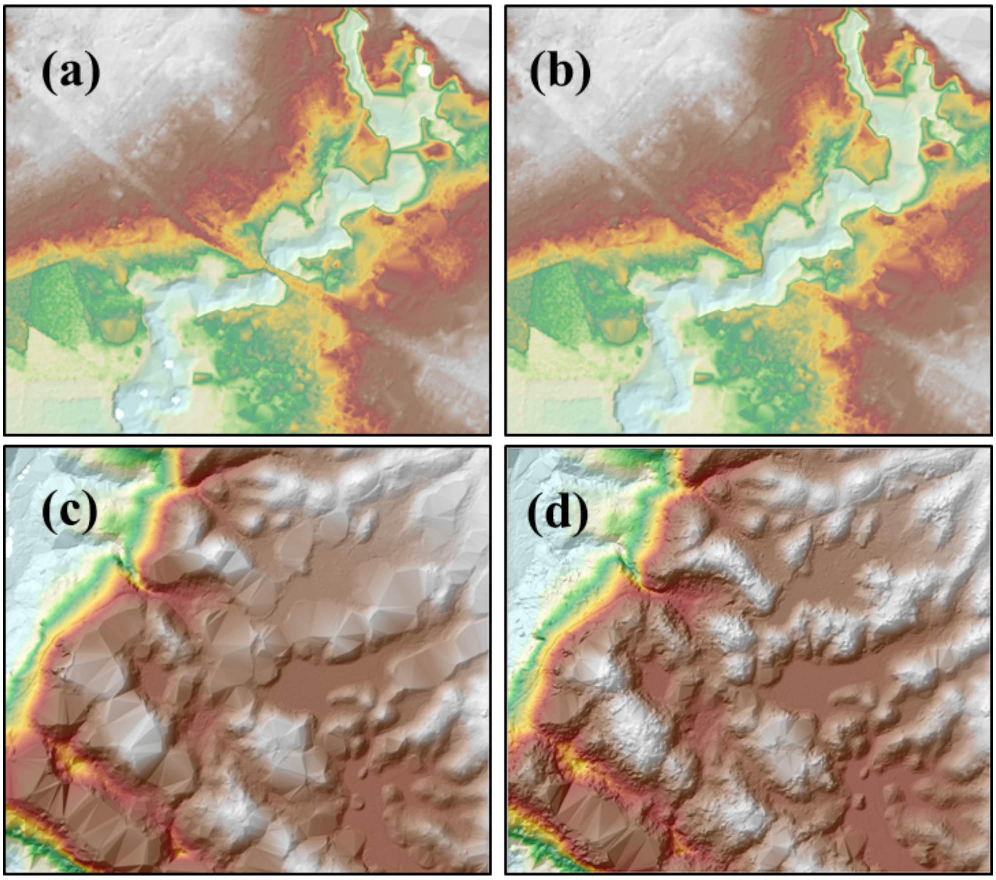

Figure 18. Portions in the DTM of Tiabanan Floodplain – a bridge before (a) and after (b) manual editing; hills before (c) and after (d) data retrieval

3.9 Mosaicking of Blocks

Table 12

shown in Figure 19. It can be seen that the entire Tiabanan floodplain is 100% covered by LiDAR data.

Table 12. Shift Values of each LiDAR Block of Tiabanan floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Dumaguete_Blk53I	0.00	0.00	-0.26
Dumaguete_Blk53H	0.00	0.00	0.00
Dumaguete_Blk53FG	0.00	0.00	-0.04

Figure 19. Map of Processed LiDAR Data for Tiabanan Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Tiabanan to collect points with which the LiDAR dataset is validated is shown in Figure 20. A total of 14,047 survey points were gathered for all the flood plains within the provinces of Negros Oriental and Negros Occidental wherein the Tiabanan floodplain is located. Random selection of 80% of the survey points, resulting to 11,237 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 21. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 0.35 meters with a standard deviation of 0.18 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 0.35 meters, to the mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

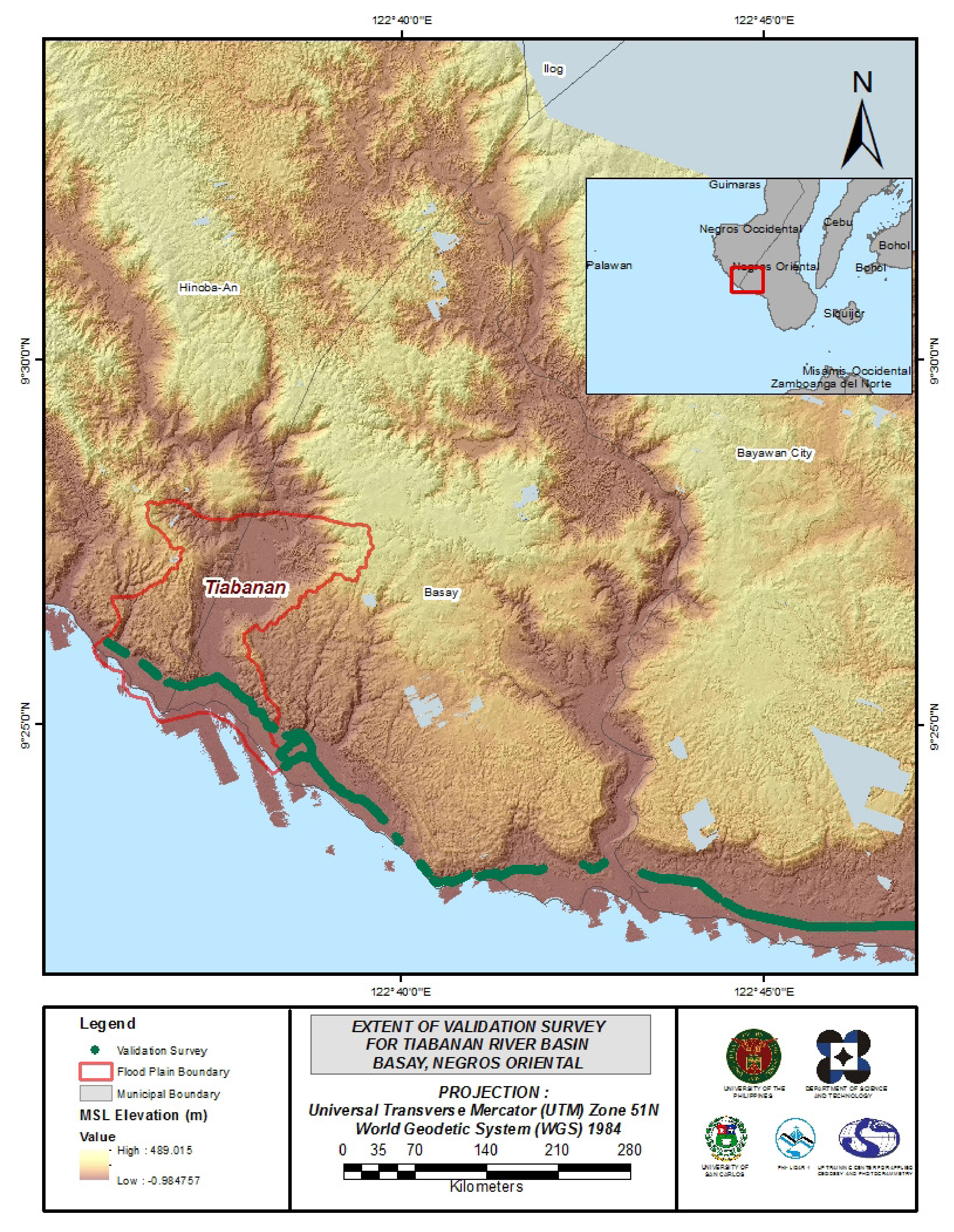

Figure 20. Map of Tiabanan Floodplain with validation survey points in green.

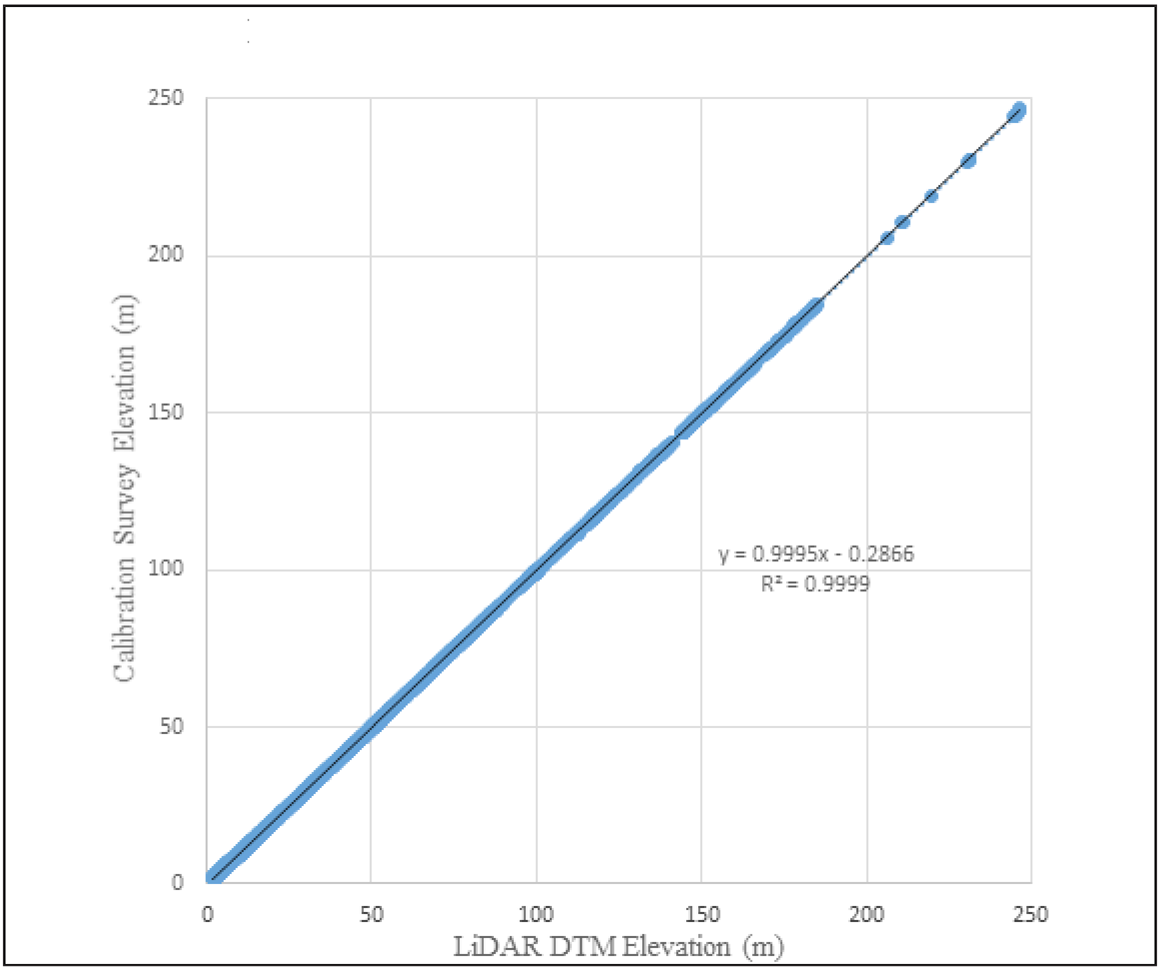

Figure 21. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	0.35
Standard Deviation	0.18
Average	-2.30
Minimum	-0.57
Maximum	0.30

The remaining 20% of the total survey points were intersected to the flood plain, resulting to 32 points, were used for the validation of calibrated Tiabanan DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM, is shown in Figure 22. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.19 meters with a standard deviation of 0.04 meters, as shown in Table 14.

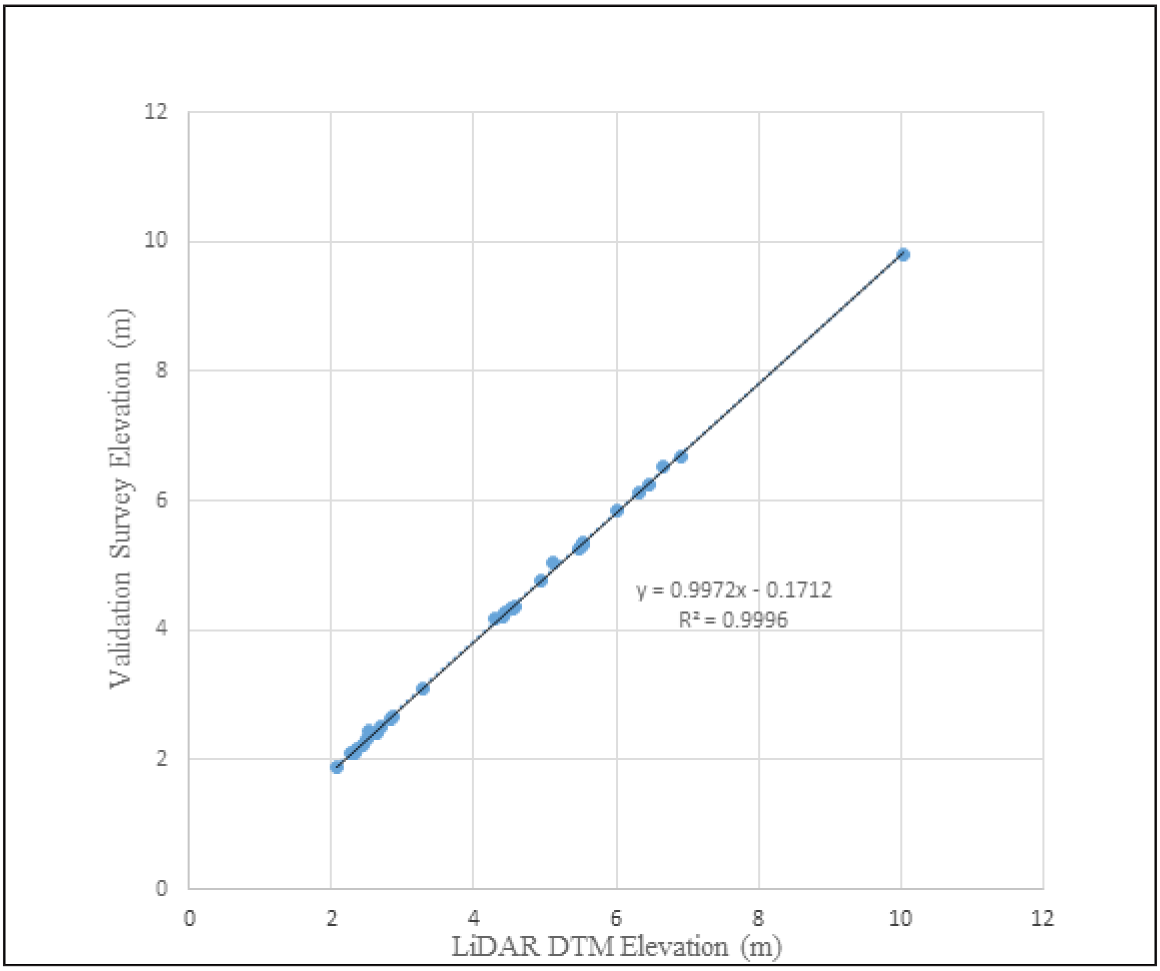

Figure 22. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.19
Standard Deviation	0.04
Average	-0.18
Minimum	-0.22
Maximum	-0.07

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, both centerline and zigzag data points were acquired for Tiabanan with 12,183 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.01 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tiabanan integrated with the processed LiDAR DEM is shown in Figure 23.

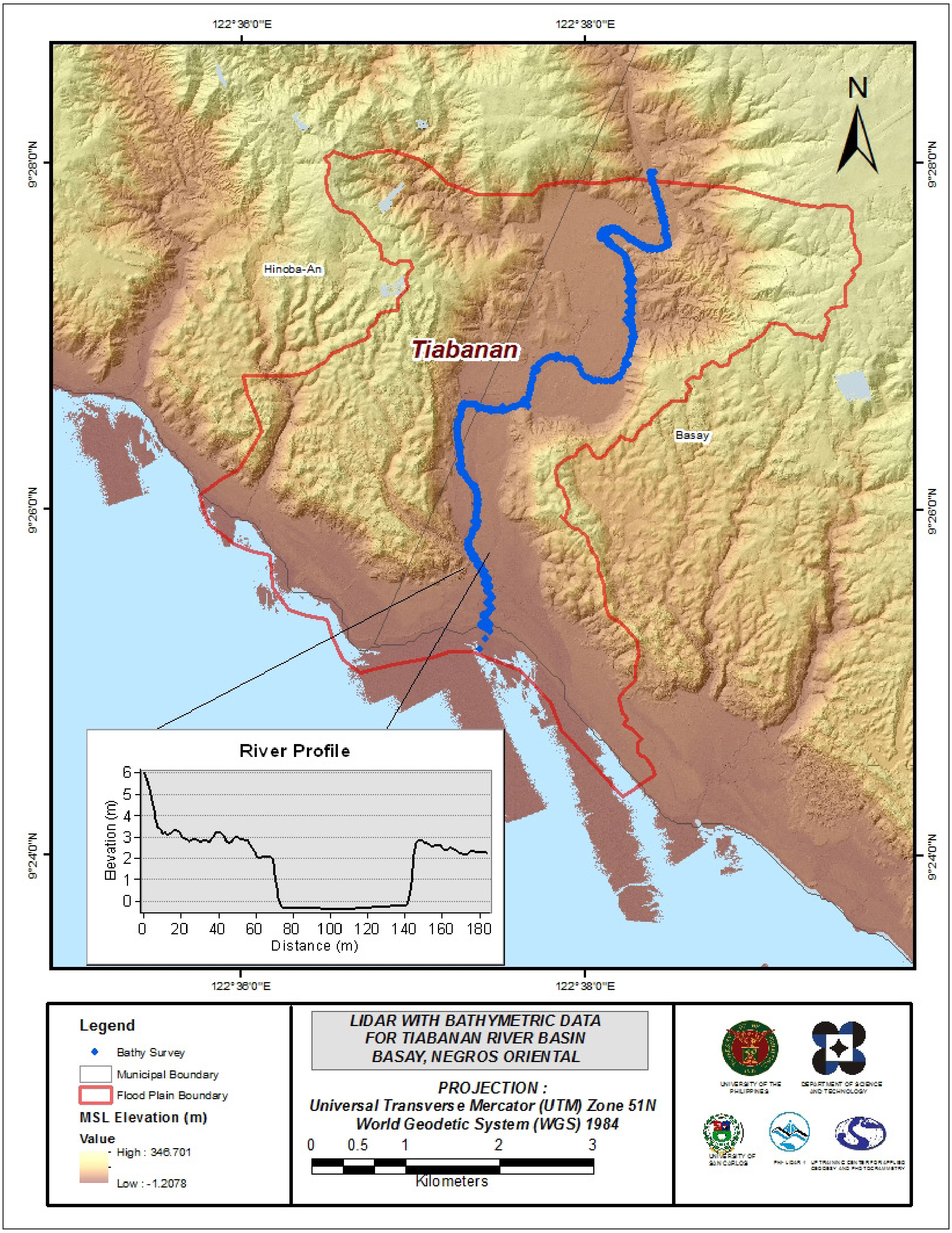

Figure 23. Map of Tiabanan Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Tiabanan floodplain, including its 200 m buffer, has a total area of 28.00 sq km. For this area, a total of 5.00 sq km, corresponding to a total of 655 building features, are considered for QC. Figure 24 shows the QC blocks for Tiabanan floodplain.

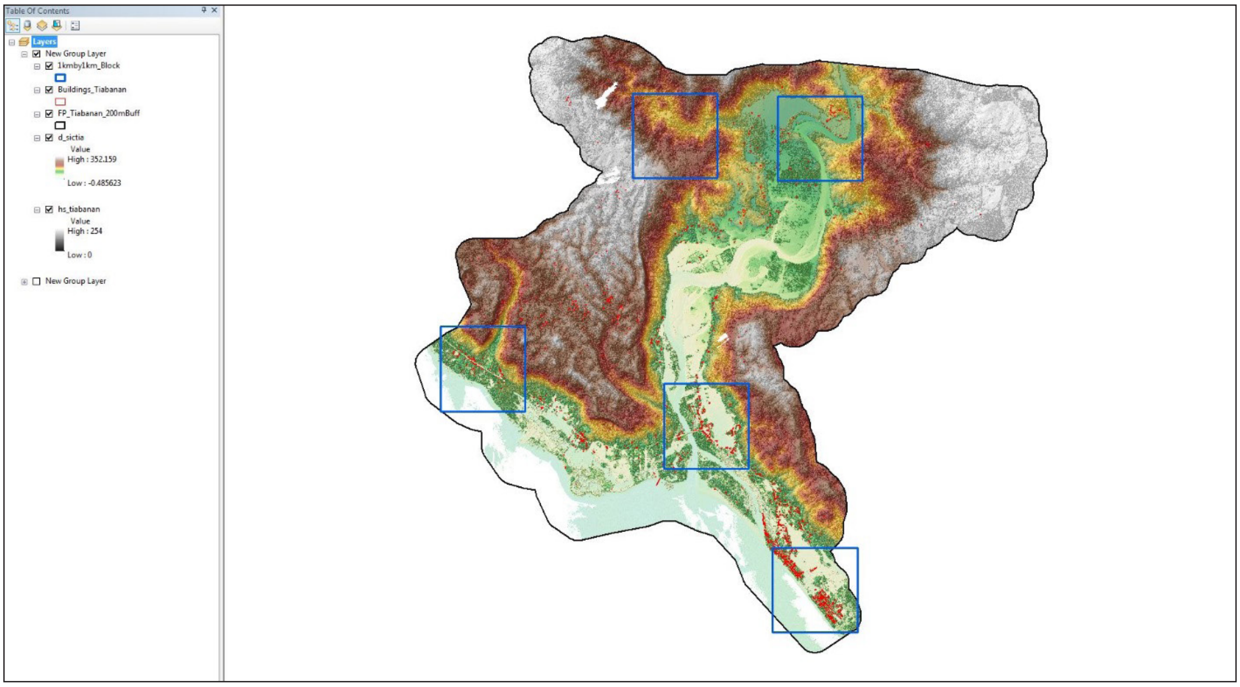

Figure 24. QC blocks for Tiabanan building features.

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

Table 15. Quality Checking Ratings for Tiabanan Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tiabanan	99.84	98.01	94.48	PASSED

3.12.2 Height Extraction

Height extraction was done for 1,374 building features in Tiabanan floodplain. Of these building features, 24 were filtered out after height extraction, resulting to 1,350 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 15.8 m.

3.12.3 Feature Attribution

In attribution, combination of participatory mapping and actual field validation was done. Representatives from LGU were invited to assist in the determination of the features. The remaining unidentified features were then validated on the field.

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

Table 16. Building Features Extracted for Tiabanan Floodplain.

Facility Type	No. of Features
Residential	1,299
School	42
Market	0
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	0
Barangay Hall	1
Military Institution	0
Sports Center/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	2
Water Supply/Sewerage	0
Religious Institutions	3
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	2
Other Commercial Establishments	1
Total	**1,350**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tiabanan	23.05	3.99	0.00	5.60	0.00	**32.64**

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

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

A total of 3 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 25 shows the Digital Surface Model (DSM) of Tiabanan floodplain overlaid with its ground features.

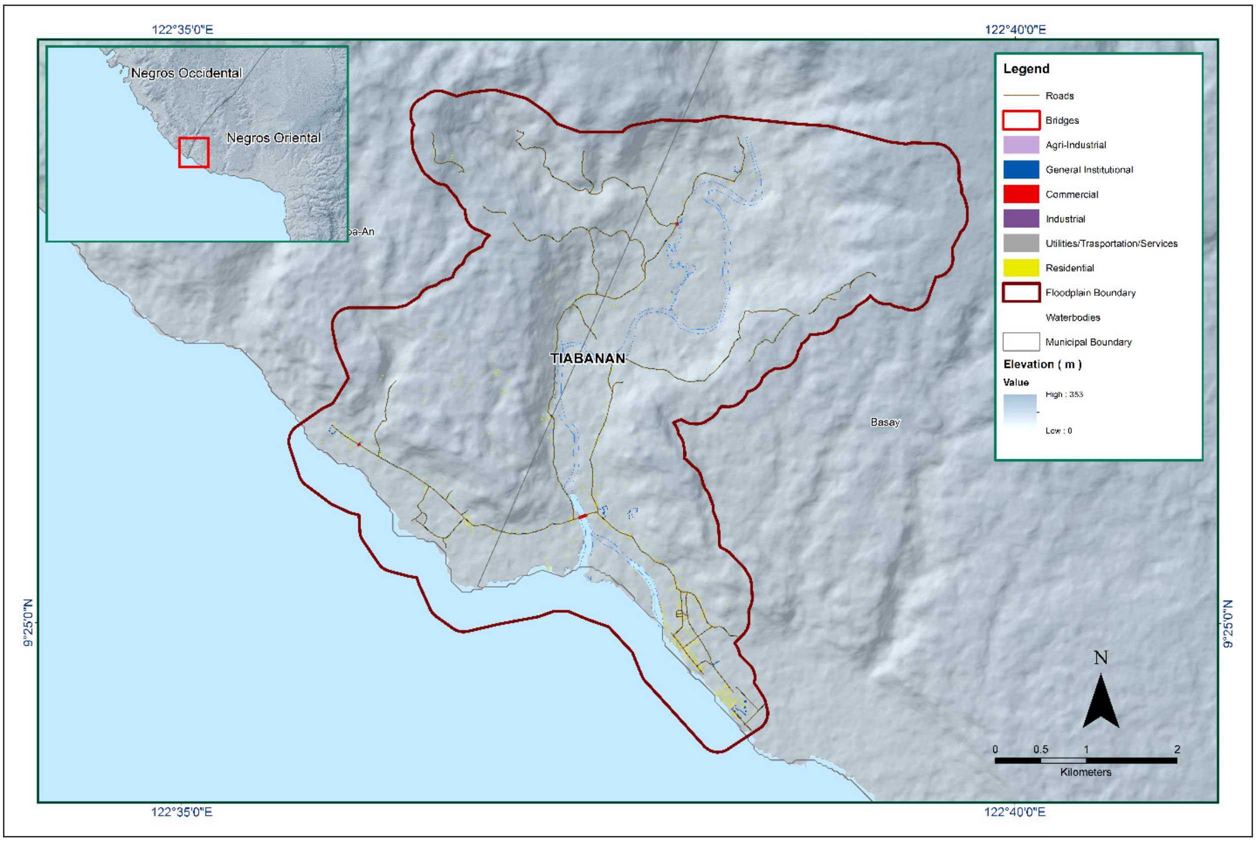

Figure 25. Extracted features for Tiabanan Floodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF TIABANAN RIVER BASIN

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo Ms. Jeline M. Amante, Marie Angelique R. Estipona, Charie Mae V. Manliguez, Engr. Janina Jupiter, Vie Marie Paola M. Rivera

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 Tiabanan River on March 9 to 23, 2016 with the following scope of work: reconnaissance; control survey; cross-section and water level marking in MSL of the depth gauge deployment site located in Barangay Bongalonan, Basay, Negros Oriental; LiDAR Validation points acquisition of about 36 km covering the Tiabanan River Basin area; and bathymetric survey from its upstream down to the mouth of the river both in Brgy. Bongalonan, Municipality of Basay, with an approximate length of 12.510 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique as shown in Figure 26.

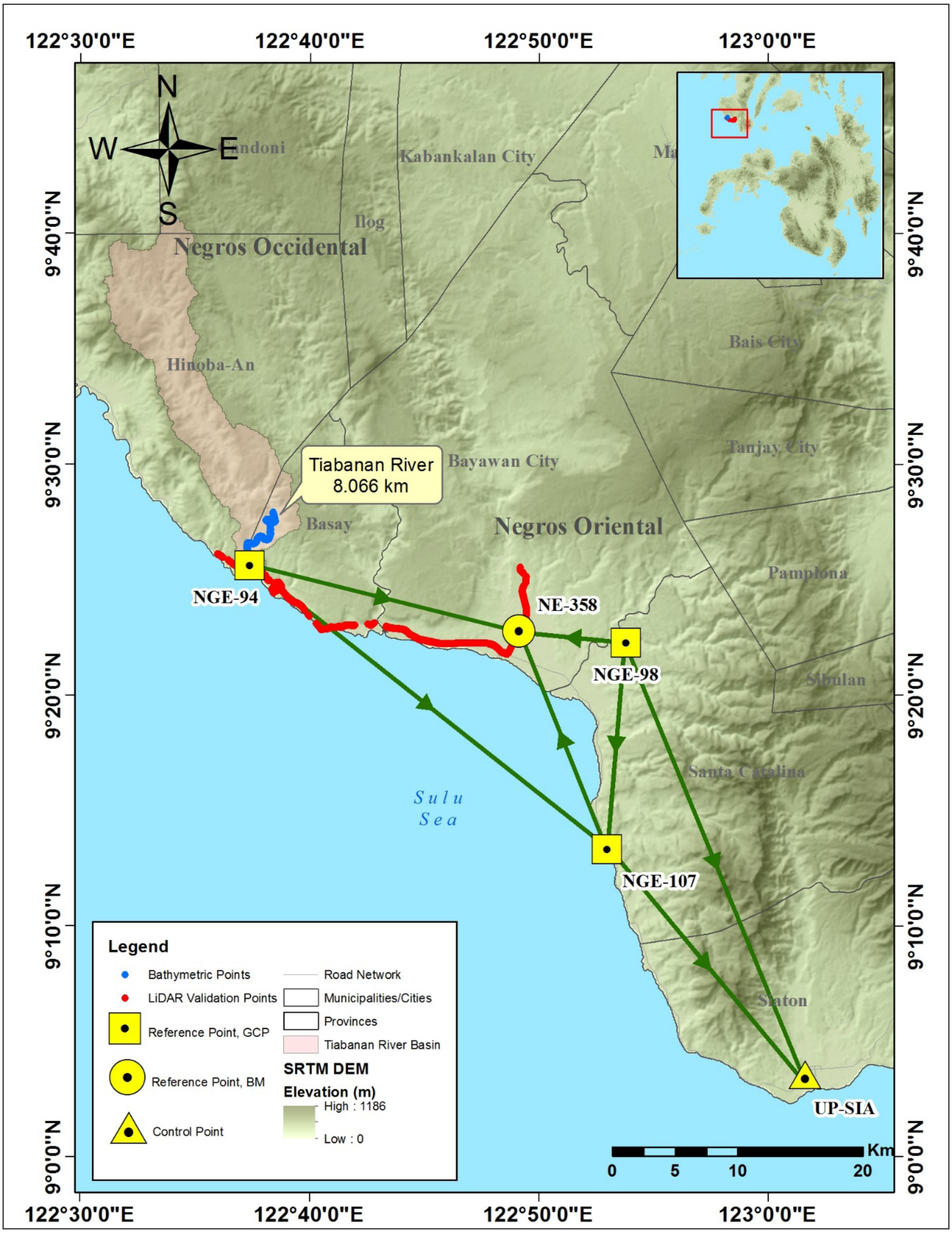

Figure 26. Tiabanan River Survey Extent

4.2 Control Survey

The GNSS network used for Tiabanan River Basin is composed of three (3) loops established on March 11, 2016 occupying the following reference points: NGE-98, a second-order GCP, in Brgy. Caranoche, Municipality of Santa Catalina; NGE-107, a second-order GCP, in Brgy. Manalongon, also in Municipality of Santa Catalina; and NE-358, a first-order BM, in Brgy. Ubos, Bayawan City.

A control point was established along the approach of Siaton Bridge, namely UP-SIA, at Brgy. Caticugan, Municiality of Siaton; and NAMRIA established control point, NGE-94 located in Brgy. Bongalonan, Municipality of Basay; were also occupied and used as marker for the network.

The summary of reference and control points and its location is summarized in Table 19 while GNSS network established is illustrated in Figure 27.

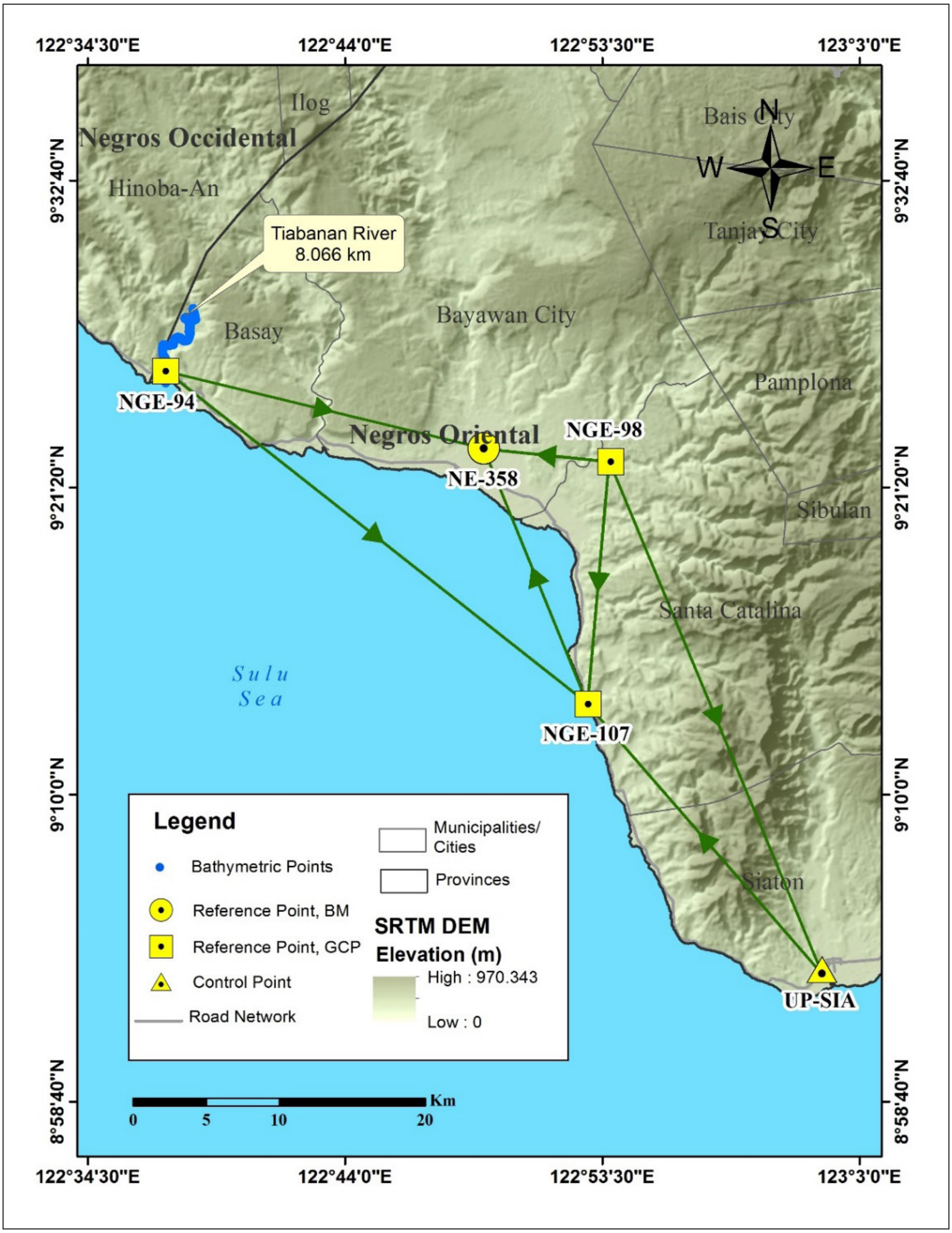

Figure 27. GNSS Network of Tiabanan River field survey

Table 19. List of reference and control points used in Tiabanan River Basin survey (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date Established
NGE-107	2nd Order, GCP	9°13'19.76274"N	122°52'59.03199"E	69.527	-	2007
NGE-98	2nd Order, GCP	9°22'16.41564"N	122°53'48.54064"E	132.087	7.414	2007
NE-358	1st Order, BM	-	-	67.723	5.116	2008
NGE-94	used as marker	-	-	-	-	2007
UP-SIA	Used as marker	-	-	-	-	March 2016

The GNSS set up made in the location of the reference and control points are exhibited are shown in Figure 28 to Figure 32.

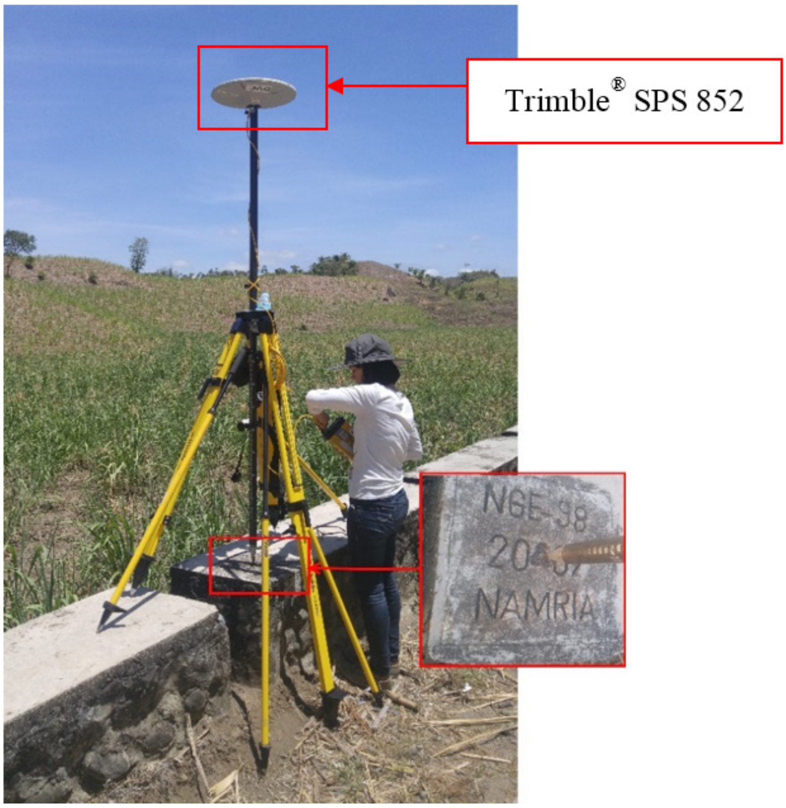

Figure 28. GNSS base set up, Trimble® SPS 852, at NGE-98 a second-order GCP located on top of a concrete block along Sta. Catalia-Pamplona Provincial Road in Brgy. Caranoche, Sta. Catalina, Negros Oriental

Figure 29. GNSS base set up, Trimble® SPS 882, at NE-107, a second-order GCP located at the approach of Manalongon Bridge in Brgy. Manalongon, Sta. Catalina, Negros Oriental

Figure 30. GNSS base set up, Trimble® SPS 855, at NE-358, a first-order BM, located on a culvert along Sta. Caalina-Bayawan Road in Brgy. Ubos, Bayawn City, Negros Oriental

Figure 31. GNSS base set up, Trimble® SPS 855, at NGE-94, a GCP used as marker, located at the approach of Tiabanan Bridge in Brgy. Bongalonan, Basay, Negros Oriental

Figure 32. GNSS receiver set up, Trimble® SPS 882, at UP-SIA, an established control point, located at the approach of Siaton Bridge in Brgy. Caticugan, Siaton, Negros Oriental

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 Tiabanan River Basin is summarized in Table 20 generated by TBC software.

Table 20. Baseline Processing Report for Tiabanan River Static Surve
(Source: NAMRIA, UP-TCAGP)

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
NE-358 --- NGE-98	03-11-2016	Fixed	0.004	0.020	276°04'18"	-64.370	-64.370
NGE-98 --- UP-SIA	03-11-2016	Fixed	0.003	0.019	157°29'24"	-61.895	-61.895
NGE-98 --- NGE-107	03-11-2016	Fixed	0.003	0.020	185°14'15"	-62.546	-62.546
NE-358 --- NGE-94	03-11-2016	Fixed	0.005	0.021	103°45'37"	-1.108	-1.108
NE-358 --- NGE-107	03-11-2016	Fixed	0.005	0.032	337°54'15"	-1.830	1.830
UP-SIA --- NGE-107	03-11-2016	Fixed	0.004	0.023	318°46'17"	-0.673	-0.673
NGE-94 --- NGE-107	03-11-2016	Fixed	0.003	0.029	128°25'03"	0.653	0.653

As shown in Table 20, a total of seven (7) baselines were processed with reference points NE-358 fixed for elevation; and NGE-98 and NGE 107 held fixed for grid values. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

x_e is the Easting Error,

y_e is the Northing Error, and

z_e is the Elevation Error

for each control point. See the Network Adjustment Report shown in Table 21 to Table 23 for the complete details.

The five (5) control points, NE-358, NGE-98, NE-107, NGE-94 and UP-SIA were occupied and observed simultaneously to form a GNSS loop. Elevation value of NE-358 and coordinates of points NGE-98 and NGE-107 were held fixed during the processing of the control points as presented in Table 21. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 21. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
NGE-98	Global	Fixed	Fixed		
NGE-107	Global	Fixed	Fixed		
NE-358	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 22. The fixed control point NE-358 has no values for elevation error; while NGE-98 and NGE-107 have no values for grid errors.

Table 22. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
NGE-98	488670.521	?	1035896.031	?	69.180	0.054	LL
NGE-107	487155.076	?	1019415.410	?	7.670	0.058	LL
NE-358	480099.830	0.009	1036810.192	0.008	5.116	?	e
NGE-94	458621.676	0.015	1042094.324	0.013	7.244	0.058	
UP-SIA	502963.760	0.013	1001378.367	0.011	8.267	0.070	

The network is fixed at reference point NE-358 with known elevation; and NGE-98 and NGE-107 with known coordinates. As shown in Table 22, the standard errors (x_e and y_e) of NE-358 are 0.90 cm and 0.80 cm; NGE-94 with 1.5 cm and 1.3 cm; and UP-SIA with 1.30 cm and 1.1 cm. With the mentioned equation, $\sqrt{((x_e)^2 + (y_e)^2)} < 20cm\sqrt{((x_e)^2 + (y_e)^2)} < 20cm$ for horizontal and $z_e < 10\ cmz_e < 10\ cm$ for the vertical; the computation for the accuracy are as follows:

a. NGE-98

horizontal accuracy = Fixed

vertical accuracy = 5.40 < 10 cm

b. NGE-107

horizontal accuracy = Fixed

vertical accuracy = 5.80 cm < 10 cm

c. NE-358

horizontal accuracy = √((0.90)² + (0.80)²

= √ (0.81 + 0.64)

= 1.20 cm < 20 cm

vertical accuracy = Fixed

d. NGE-94

horizontal accuracy = √((1.50)² + (1.30)²

= √ (2.25 + 1.69)

= 1.98 cm < 20 cm

vertical accuracy = 5.80 cm < 10 cm

e. UP-SIA

horizontal accuracy = $\sqrt{((1.30)^2 + (1.10)^2}$
= $\sqrt{(1.69 + 1.21)}$
= 1.70 cm < 20 cm

vertical accuracy = 7.0 cm < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the five (5) occupied control points are within the required precision.

Table 23. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Ellipsoidal Height (Meter)	Height Error (Meter)	Constraint
NGE-107	N9°13’19.76274”	E122°52’59.03199”	69.527	0.058	LL
NGE-98	N9°22’16.41564”	E122°53’48.54064”	132.087	0.054	LL
NE-358	N9°22’46.06928”	E122°49’07.51892”	67.723	?	e
NGE-94	N9°25’37.57022”	E122°37’23.12090”	68.846	0.058	
UP-SIA	N9°03’32.50400”	E123°01’37.08746”	70.195	0.070	

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

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

Table 24. 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	Easting	BM Ortho (m)
NGE-98	2nd order, GCP	9°22’16.41564”N	122°53’48.54064”E	132.087	1035896.031	488670.521	69.180
NGE-107	Used as marker	9°13’19.76274”N	122°52’59.03199”E	69.527	1019415.410	487155.076	7.670
NE-358	1st order, BM	9°22’46.06928”N	122°49’07.51892”E	67.723	1036810.192	480099.830	5.116
NGE-94	UP Established	9°25’37.57022”N	122°37’23.12090”E	68.846	1042094.324	458621.676	7.244
UP-SIA	UP-Established	9°03’32.50400”N	123°01’37.08746”E	70.195	1001378.367	502963.760	8.267

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

Cross-section survey was conducted on March 12, 2016 in the upstream of Tiabanan River in Brgy. Bongalonan, Basay using a GNSS receiver, Trimble® SPS 882, in PPK survey technique as shown in Figure 33. A structure for the installation of an AWLS and water elevation marking shall be constructed along the non-bridge flow measurement site identified by USC.

Figure 33. Deployment site of rain gauge and flow meter for Tiabanan River

The cross-sectional line length of the deployment site is about 74.106 m with 44 cross-sectional points acquired using NGE-94 as the GNSS base station. The location map and cross-section diagram are illustrated in Figure 34 and Figure 35.

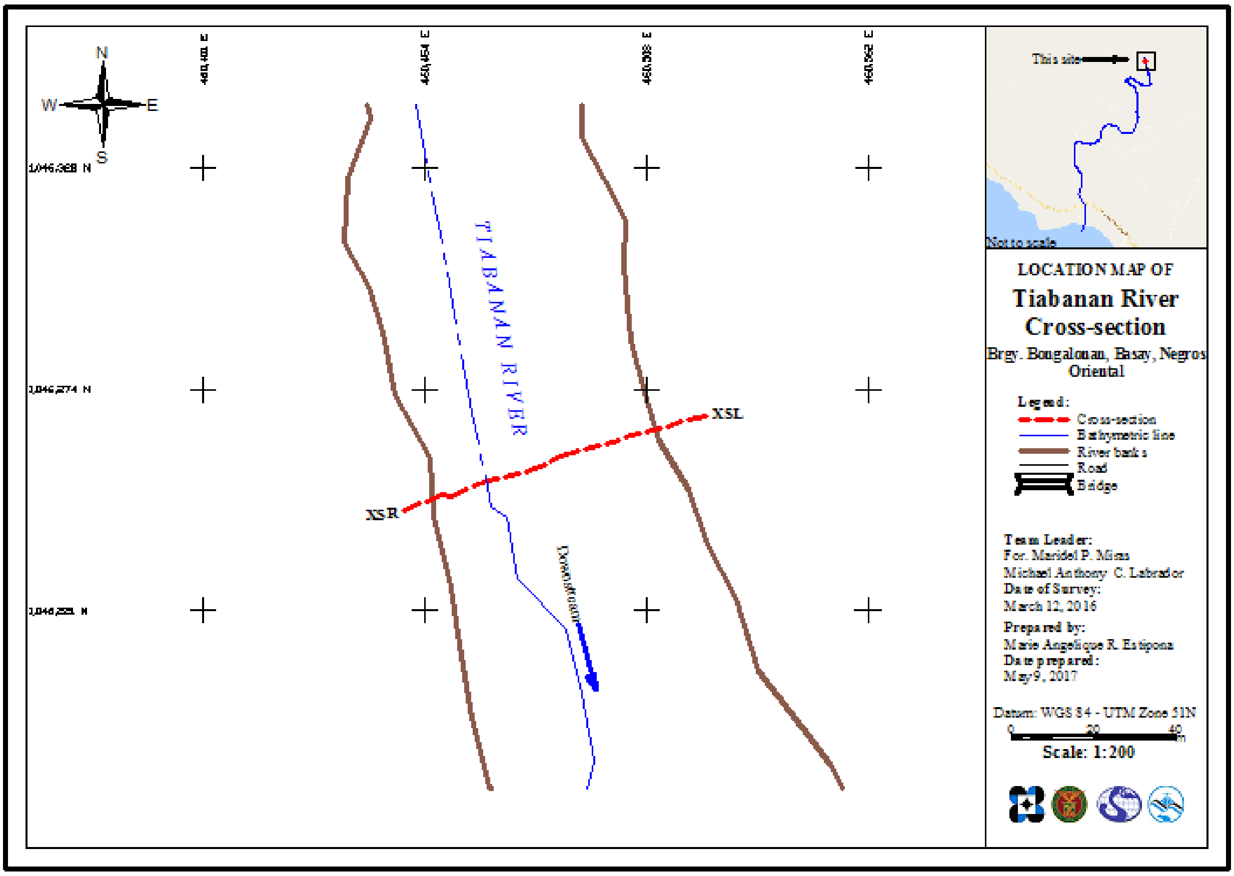

Figure 34. Location map of Tiabanan River cross-section survey

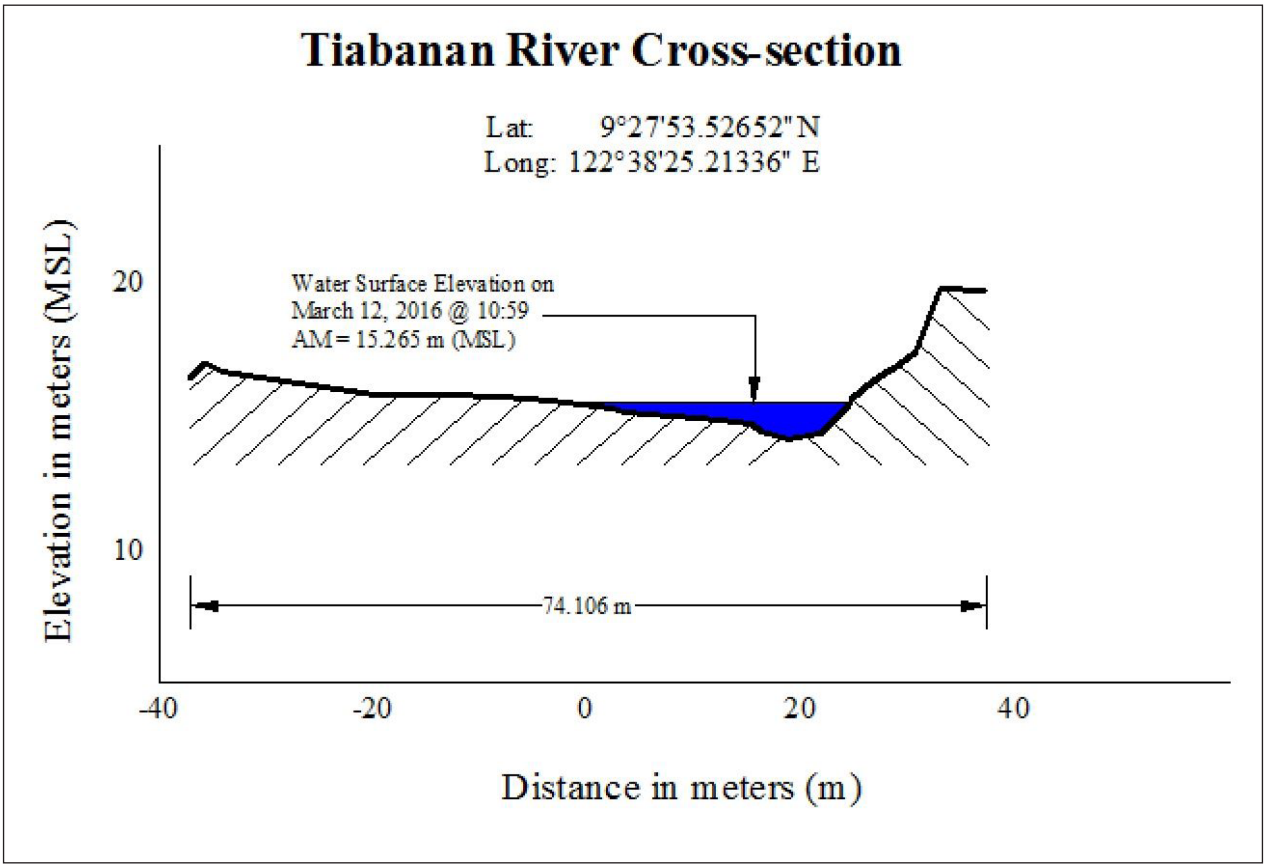

Figure 35. Tiabanan River Cross-section Diagram

Water surface elevation in MSL of Tiabanan River was determined using Trimble® SPS 882 in PPK mode technique on March 12, 2016 at 10:59 AM with a value of 15.265 m in MSL. This was translated onto marking done on the dike along the river using digital level as shown in Figure 36. The markings with corresponding values will serve as their reference for flow data gathering and depth gauge deployment for Tiabanan River.

Figure 36. Water-level marking on Tiabanan River

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on March 12, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached to the side of vehicle as shown in Figure 37. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 2.265 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 NGE-94 occupied as the GNSS base stations in the conduct of the survey.

Figure 37. Validation points acquisition survey set-up

The survey started from Brgy. Sangke in the Municipality of Hinoba-An going south towards the municipalities of Basay and ended in Brgy. Nangka, Bayawan City. This route aims to cut flight strips perpendicularly. It gathered 4,107 points with approximate length of 36.110 km using NGE-94 as GNSS base for the entire extent validation points acquisition survey, as illustrated in the map in Figure 38.

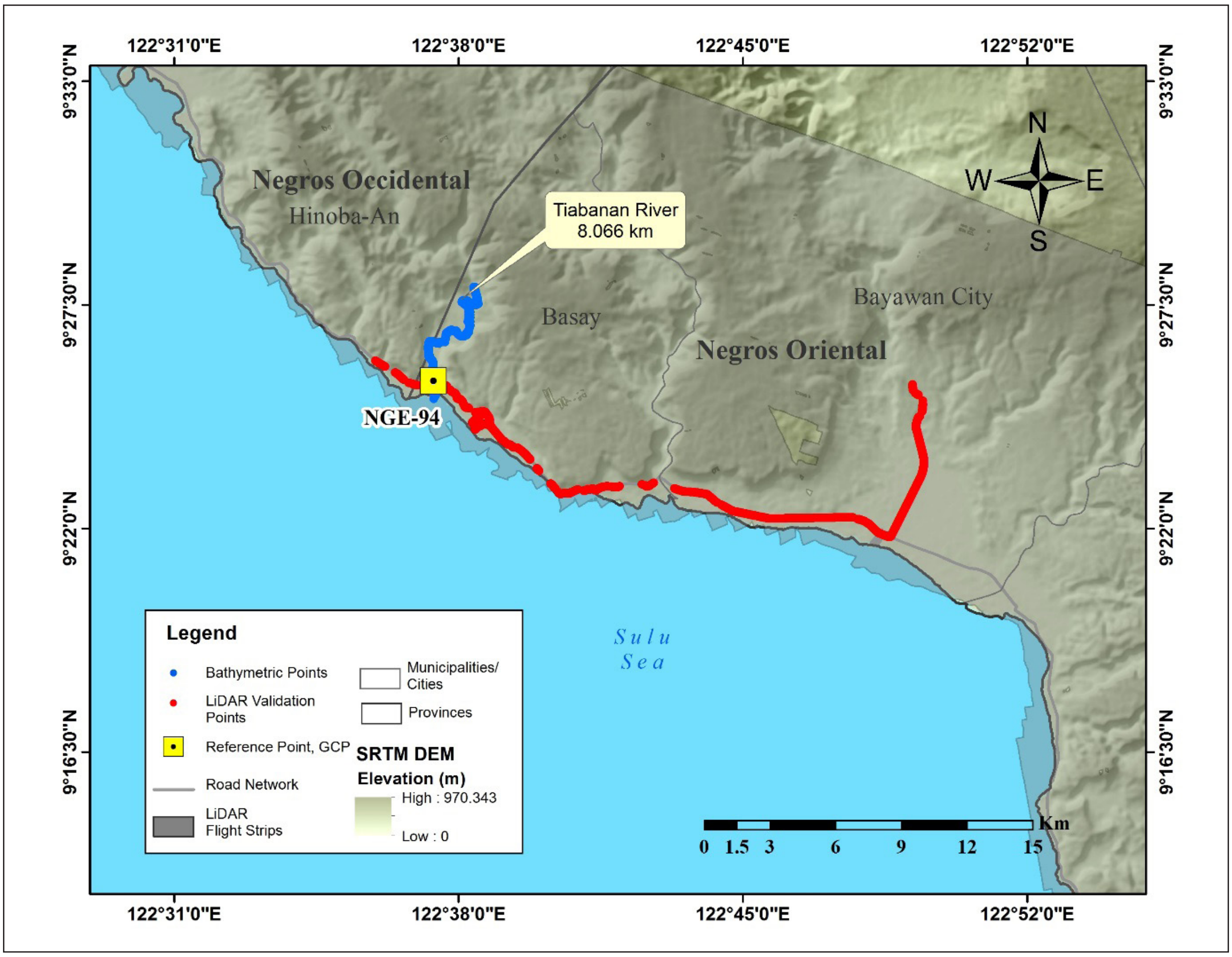

Figure 38. LiDAR Validation points acquisition survey for Tiabanan River Basin

4.7 Bathymetric Survey

Bathymetric survey was executed on March 12, 2016 using Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure 39.

Manual bathymetric survey was done on the same day using a Trimble® SPS 882 GNSS PPK survey technique, shown in Figure 40. The survey began from the upstream portion of the river in Brgy. Bongalonan in Municipality of Basay with coordinates 9°27’56.56444”N, 122°38’22.92083”E; and ended at the starting point of bathymetric survey using boat in the same barangay. The control point NGE-94, was occupied as the GNSS base station all throughout the surveys.

Figure 39. Bathymetry by boat set-up for Tiabanan River survey

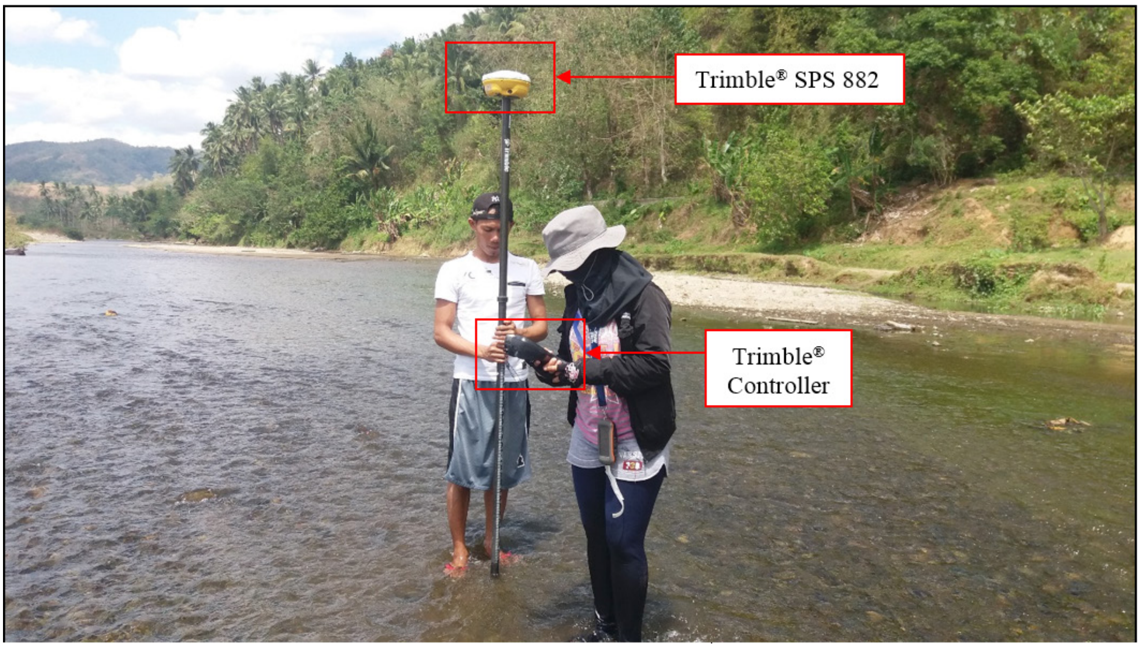

Figure 40. Manual bathymetry set-up for Tiabanan River survey

The extent of the survey is from the upstream in Brgy. Bongalonan, Municipality of Basay with coordinates 9°25'54.41786" N, 122°37'22.25702"E, down to the mouth of the river also in the same Barangay with coordinates 9°25'17.51217"N, 122°37'26.74280"E, as shown in the map in Figure 41. The bathymetric survey gathered a total of 12,271 points covering 8.066 km of the river traversing the Brgy. Bongalonan, Basay, Negros Oriental, and a small portion of Brgy. Sangke, Hinoba-An, Negros Occidental.

Figure 41. Bathymetric survey of Tiabanan River

A CAD drawing was also produced to illustrate the riverbed profile of Tiabanan River. As shown in Figure 42, the highest and lowest elevation has a 16.9-meter difference. The highest elevation observed was 15.588 m above MSL located at the upmost portion of the river while the lowest was -1.331 m below MSL located at the downstream portion of the river near Tiabanan Bridge, both in Brgy. Bongalonan, in Municipality of Basay.

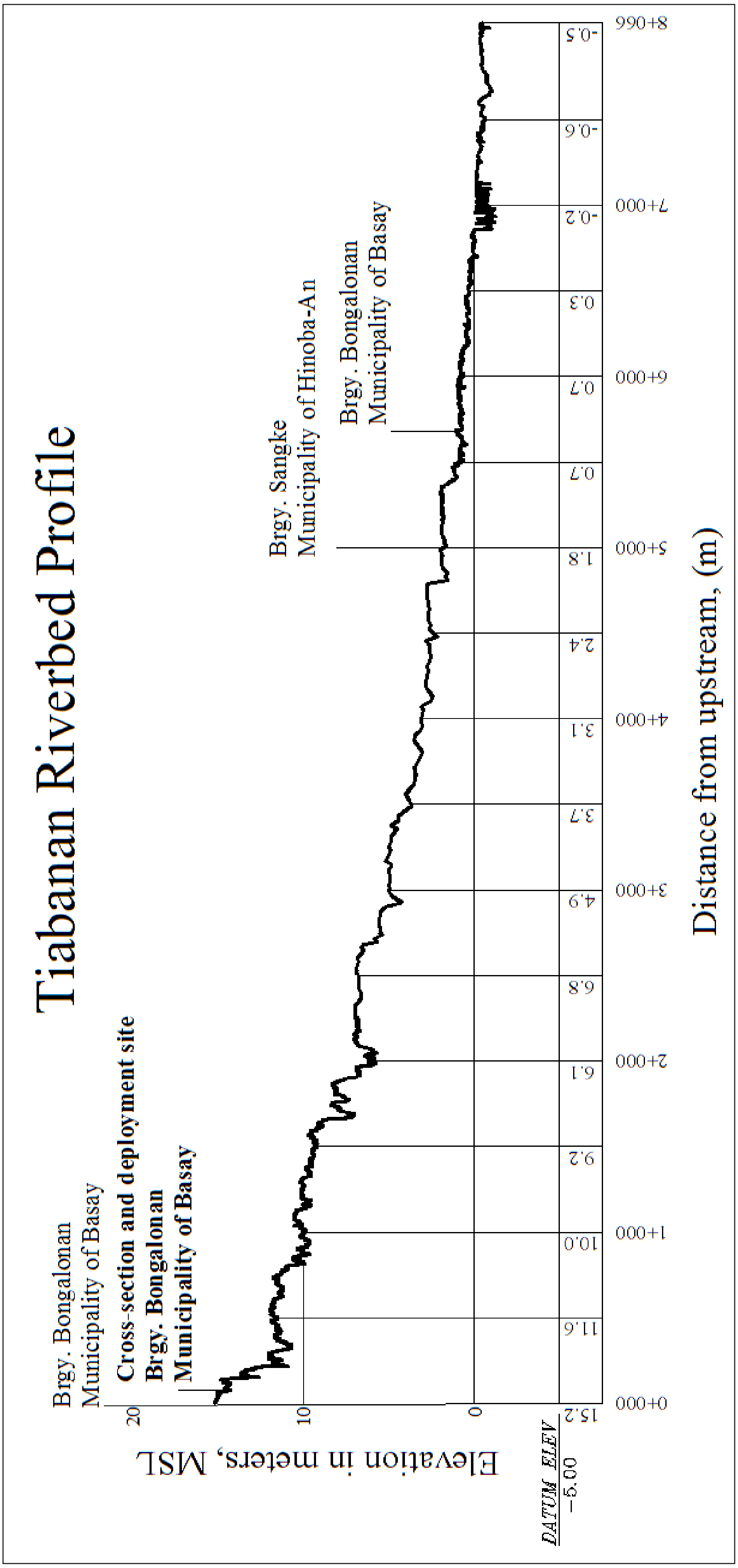

Figure 42. Tiabanan Riverbed Profil

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, and Pauline Racoma

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 in Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from a data logging rain gauge installed by the University of San Carlos Phil LiDAR Project. The rain gauge was installed in the Brgy Maglinao, Basay with geographic coordinates of 9.47009°N and 122.661°E. The location of the rain gage in the watershed in presented in Figure 43. The total precipitation data used for calibration is 3.4 mm. The rainfall event was used started at 4:00 in the morning and ended at 5:30 in the morning on April 16, 2017.

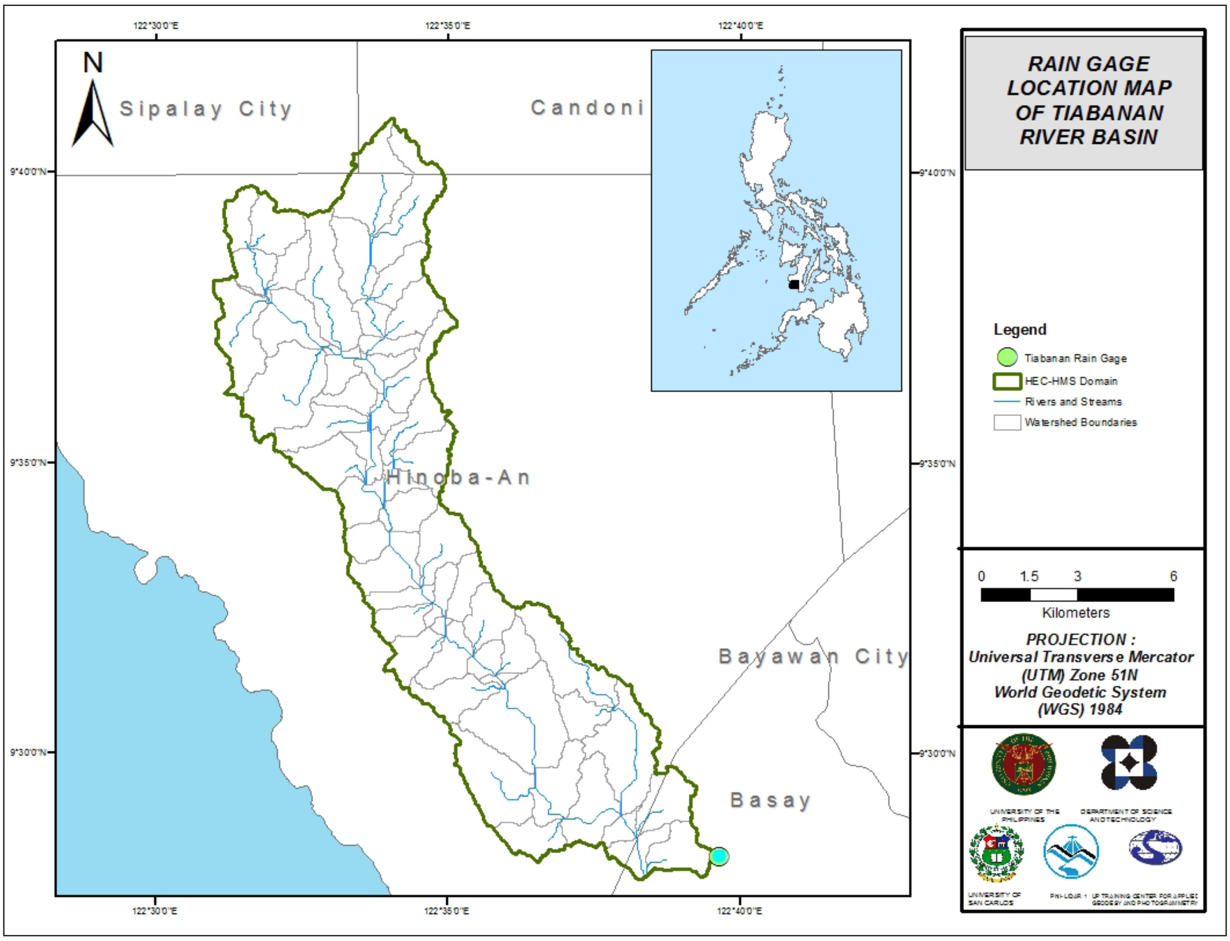

Figure 43. Location map of Tiabanan HEC-HMS model used for calibration.

5.1.3 Rating Curve and River Outflow

A rating curve was developed at Brgy. Bungalunan (9.46453° N and 122.64°E). It gives the relationship between the observed water levels and outflow of the watershed at this location.

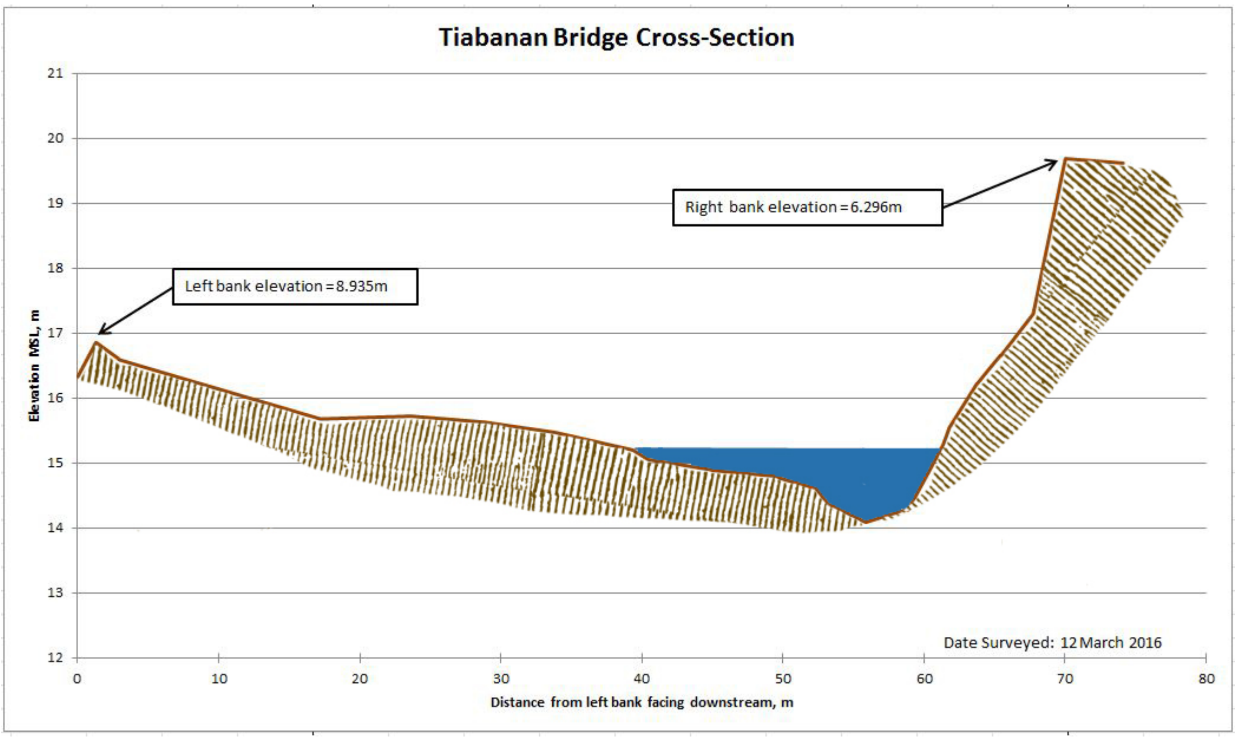

Figure 44. Cross-Section Plot of Tiabanan Bridge

For Brgy Bungalunan, the rating curve is expressed $y = 9E - 16e^{2.4193x} y = 9E - 16e^{2.4193x}$ as shown in Figure 45.

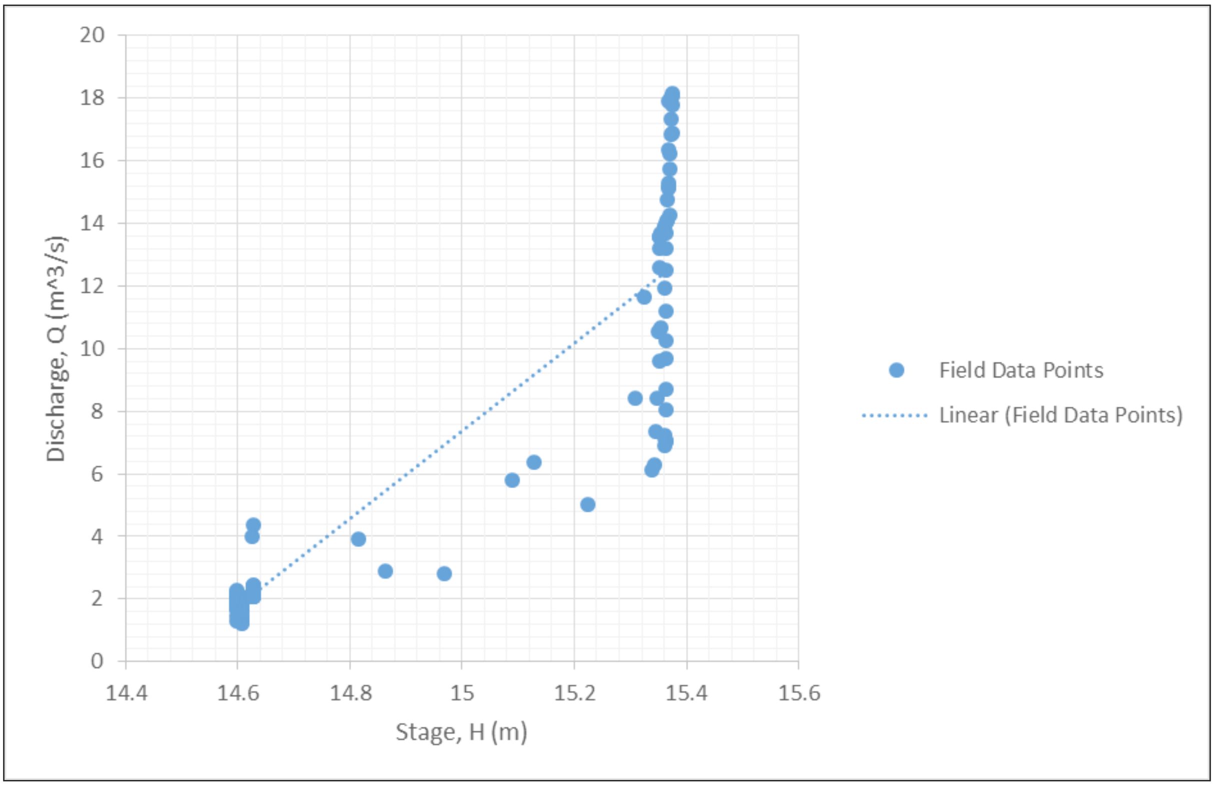

Figure 45. Rating curve at Brgy. Bungalunan in Tiabanan River

This rating curve equation was used to compute the river outflow at Brgy. Bungalunan for the calibration of the HEC-HMS model shown in Figure 46. Peak discharge is 18.168 m^3/s at 8:00, April 16, 2017.

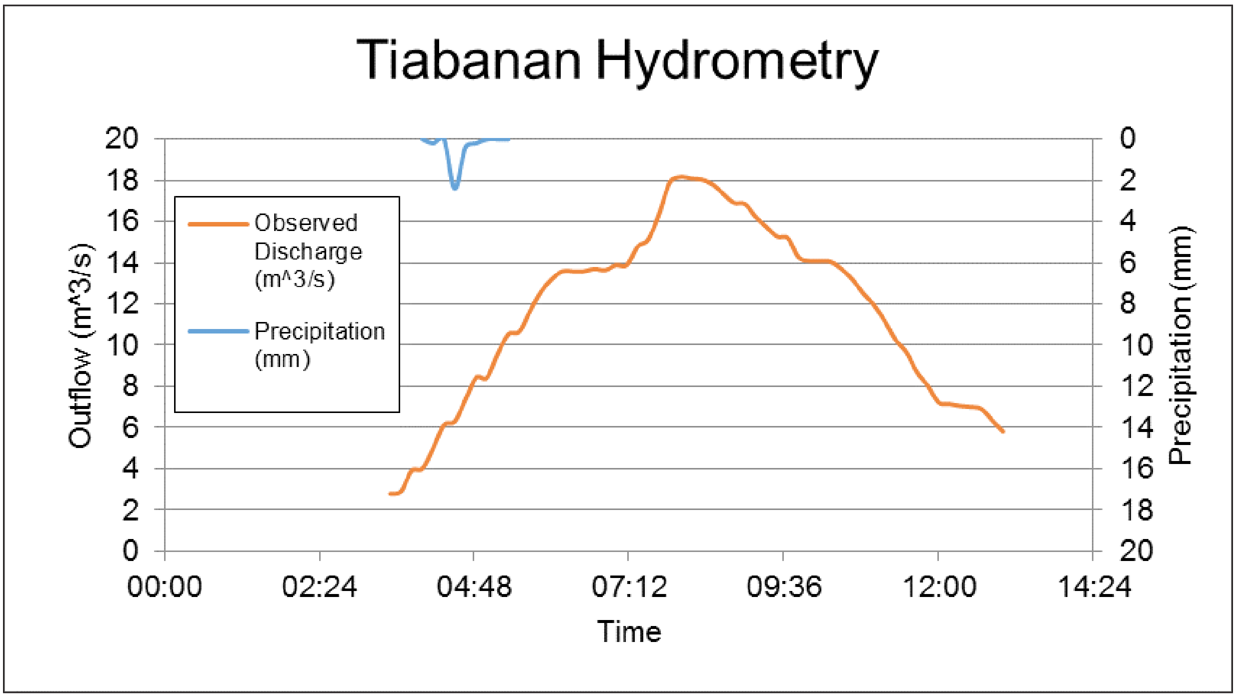

Figure 46. Rainfall and outflow data at Brgy. Bungalunan used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Dumaguete Point Gauge. This station chosen based on its proximity to the Tiabanan watershed. Tiabanan extreme values for this watershed were computed based on a 35-year record, shown in Table 25.

Table 25. RIDF values for Dumaguete Point 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	16.2	24.8	30.6	39.7	50	55.3	63.4	69.1	76
5	21.8	33.6	42.3	57.1	76.5	87.3	100	109.5	116.5
10	25.6	39.4	50	68.6	94	108.5	124.3	136.3	143.3
15	27.7	42.7	54.3	75.1	103.9	120.5	138	151.4	158.4
20	29.1	45	57.4	79.7	110.8	128.9	147.5	162	169
25	30.3	46.8	59.7	83.2	116.1	135.3	154.9	170.2	177.2
50	33.8	52.3	66.9	94	132.5	155.2	177.6	195.3	202.4
100	37.2	57.7	74.1	104.8	148.8	174.9	200.2	220.2	227.3

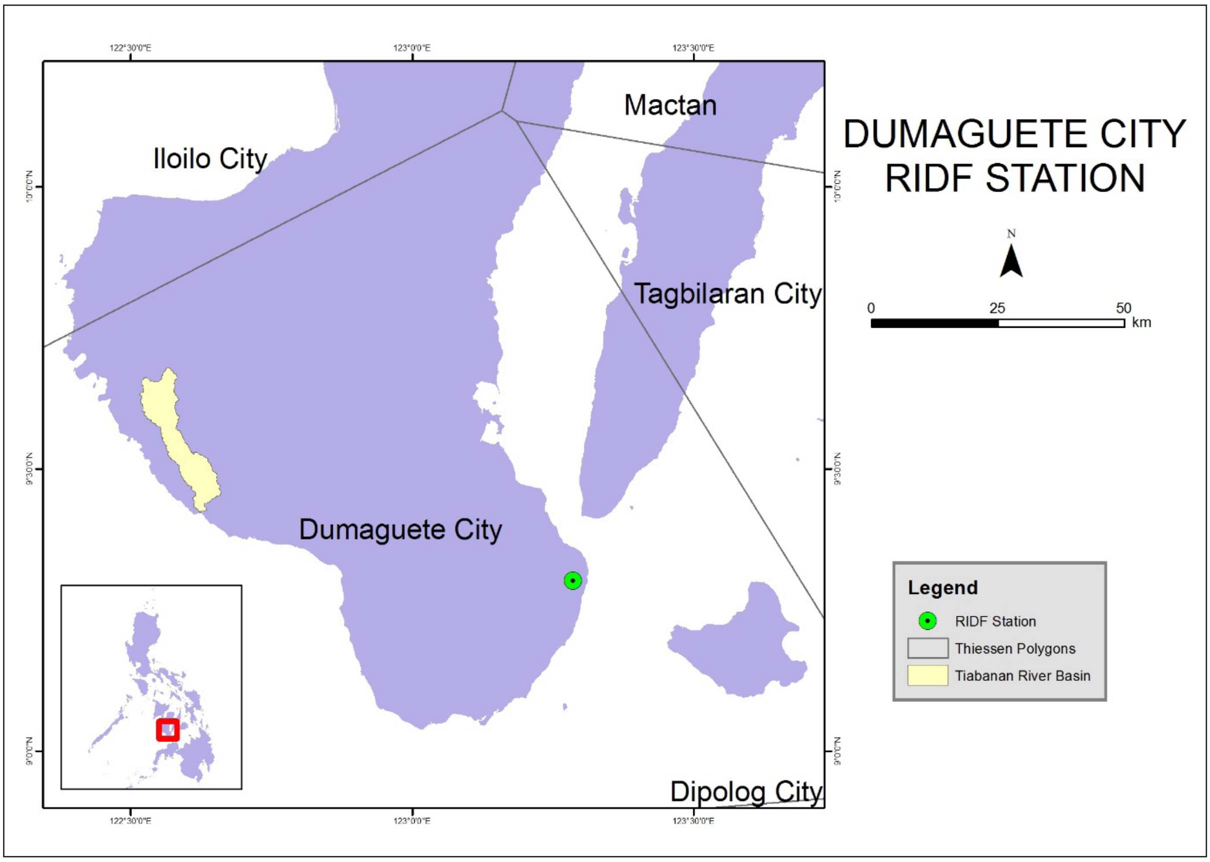

Figure 47. Location of Dumaguete Point RIDF Station relative to Tiabanan River Basin

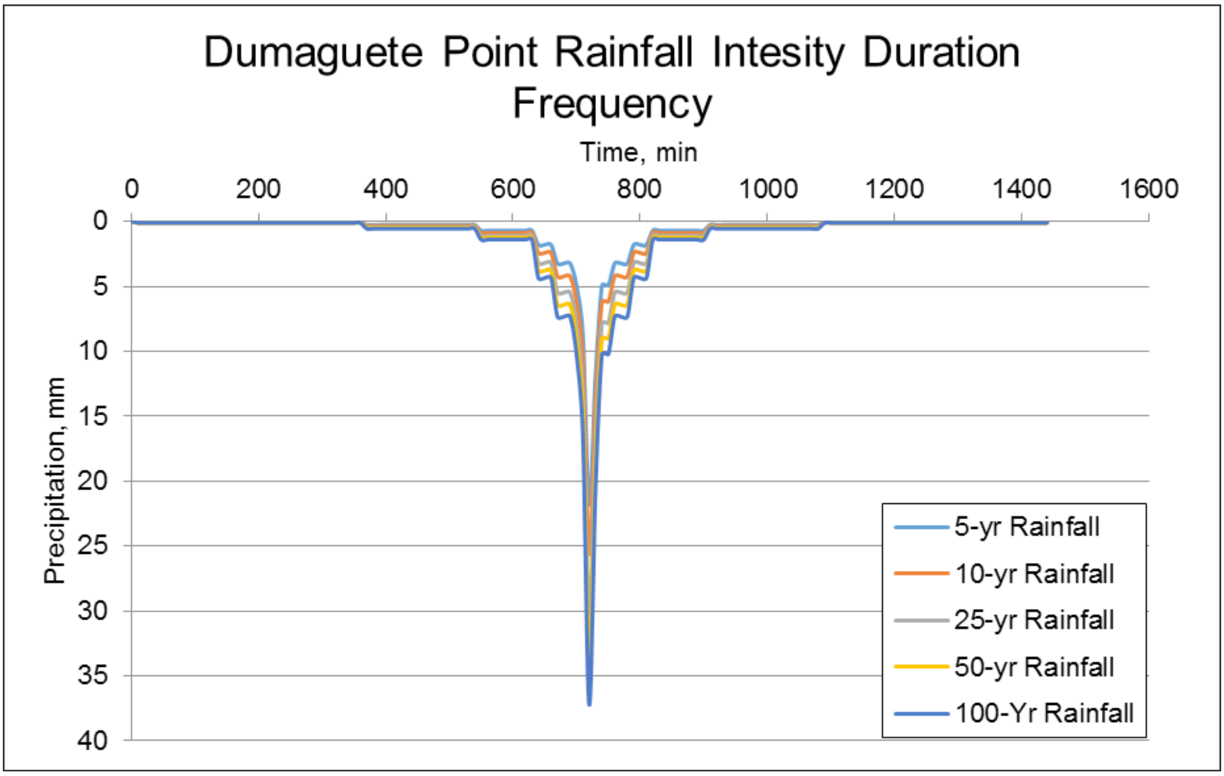

Figure 48. Synthetic storm generated for a 24-hr period rainfall for various return periods.

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 Tiabanan River Basin are shown in Figure 49 and Figure 50, respectively.

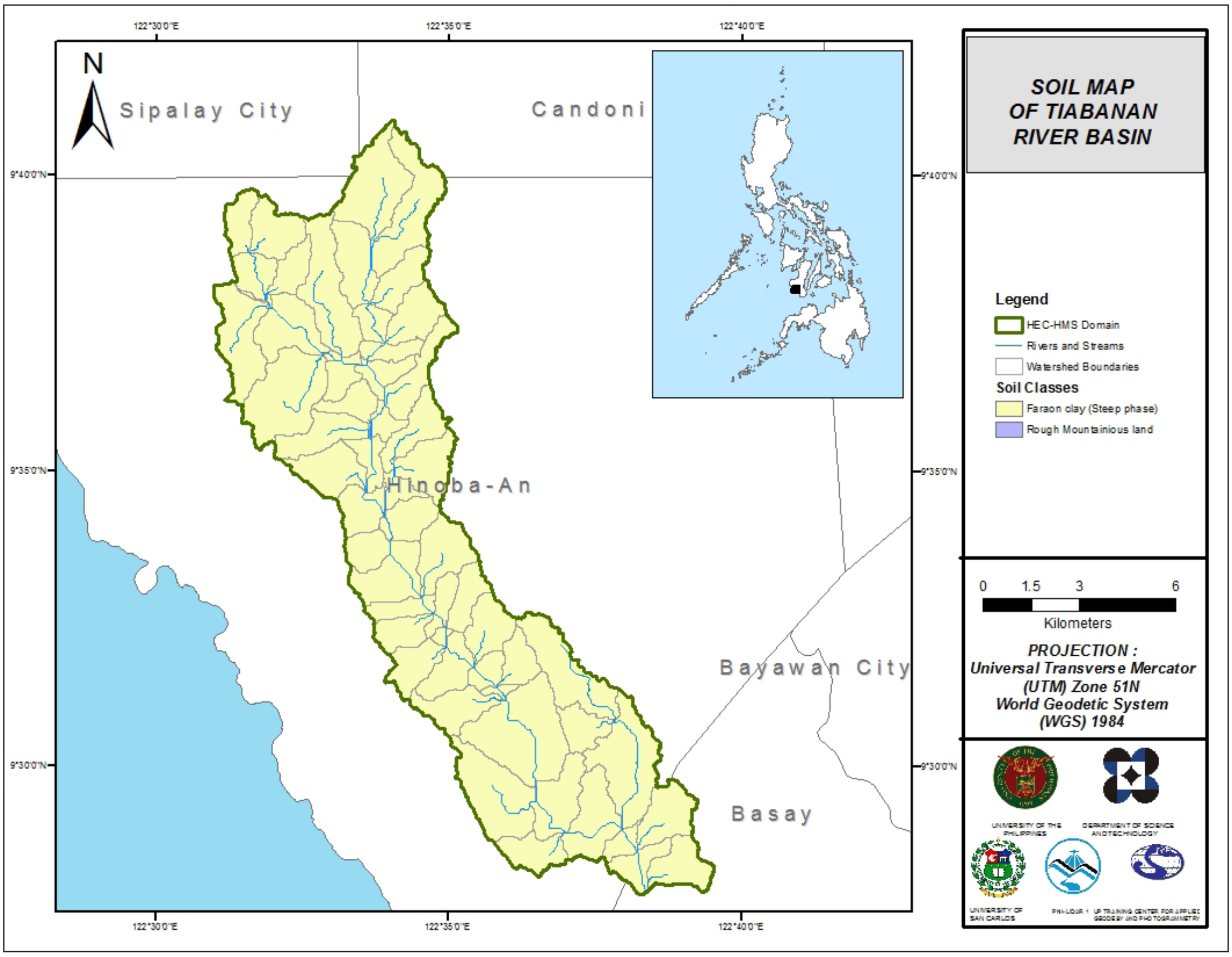

Figure 49. Soil map of the Tiabanan River Basin used for the estimation of the CN parameter. (Source: DA)

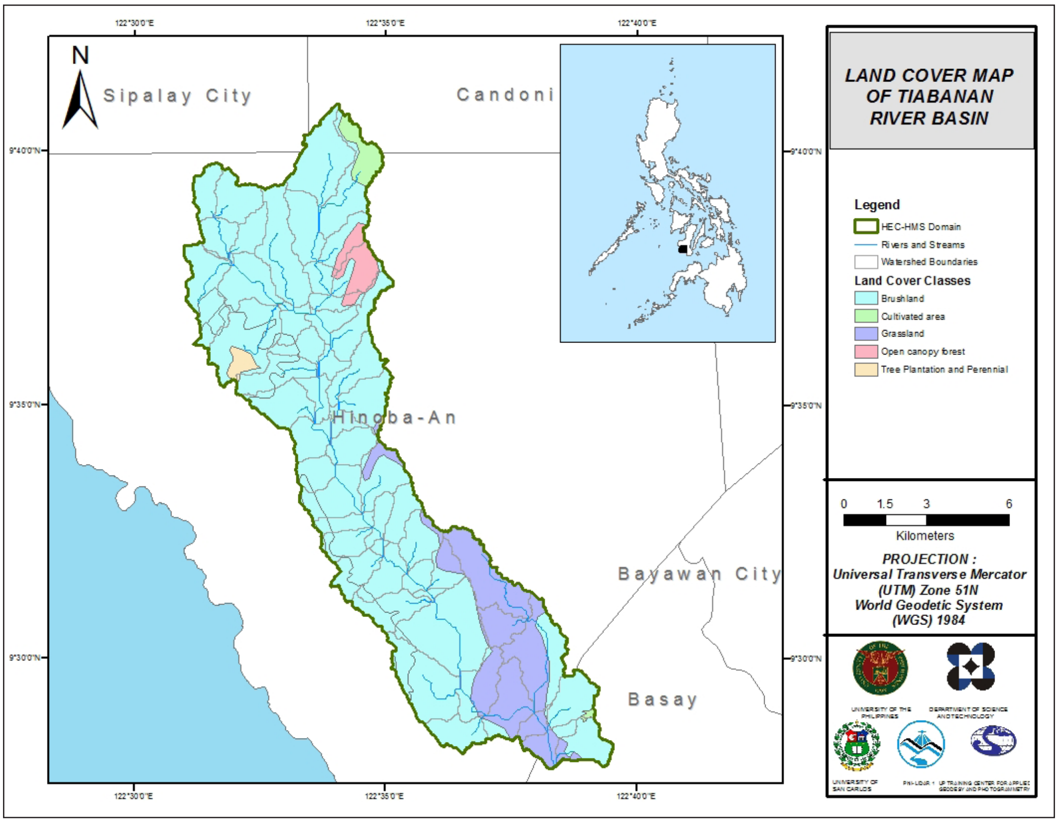

Figure 50. Land cover map of Tiabanan River Basin used for the estimation of the Curve Number (CN) and the watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

For the Tiabanan river basin, one (1) soil class was identified. The Tiabanan river basin is mostly Faraon clay (Steep phase). Moreover, five (5) land cover classes were identified. Most of the Tiabanan river basin is brushland and grassland, while a small portion is open canopy forest, cultivated area, and tree plantation and perennial land cover.

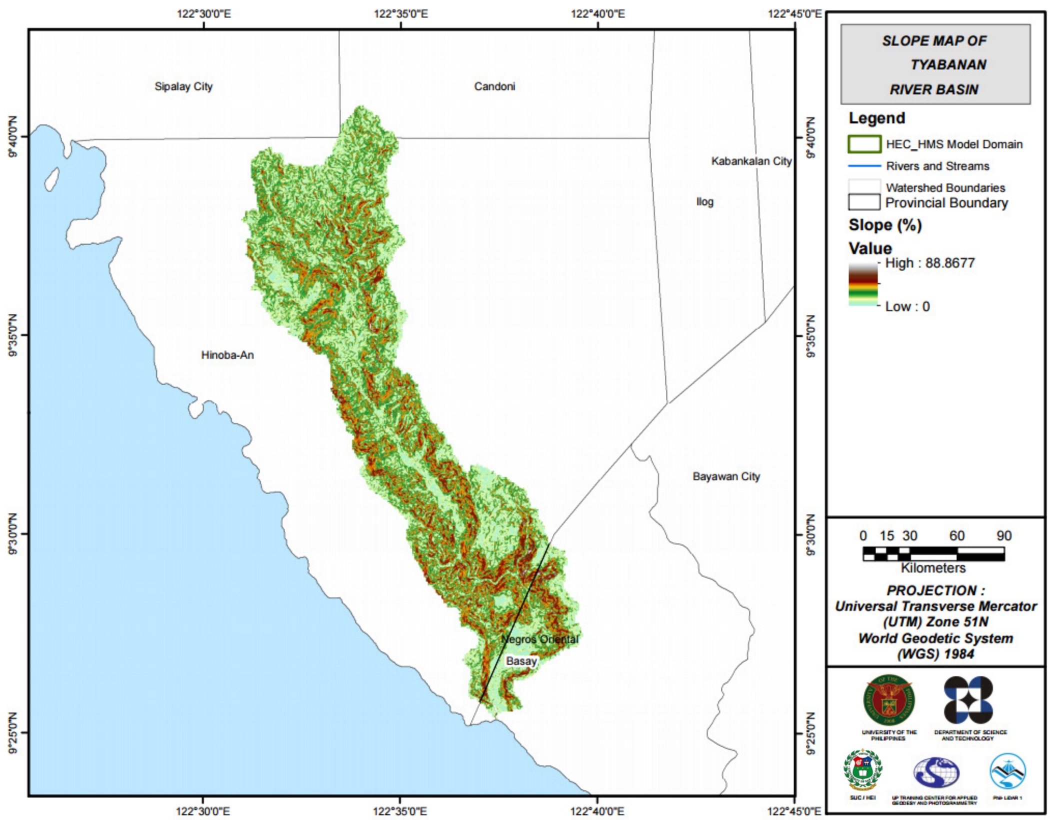

Figure 51. Slope map of Tiabanan River Basin

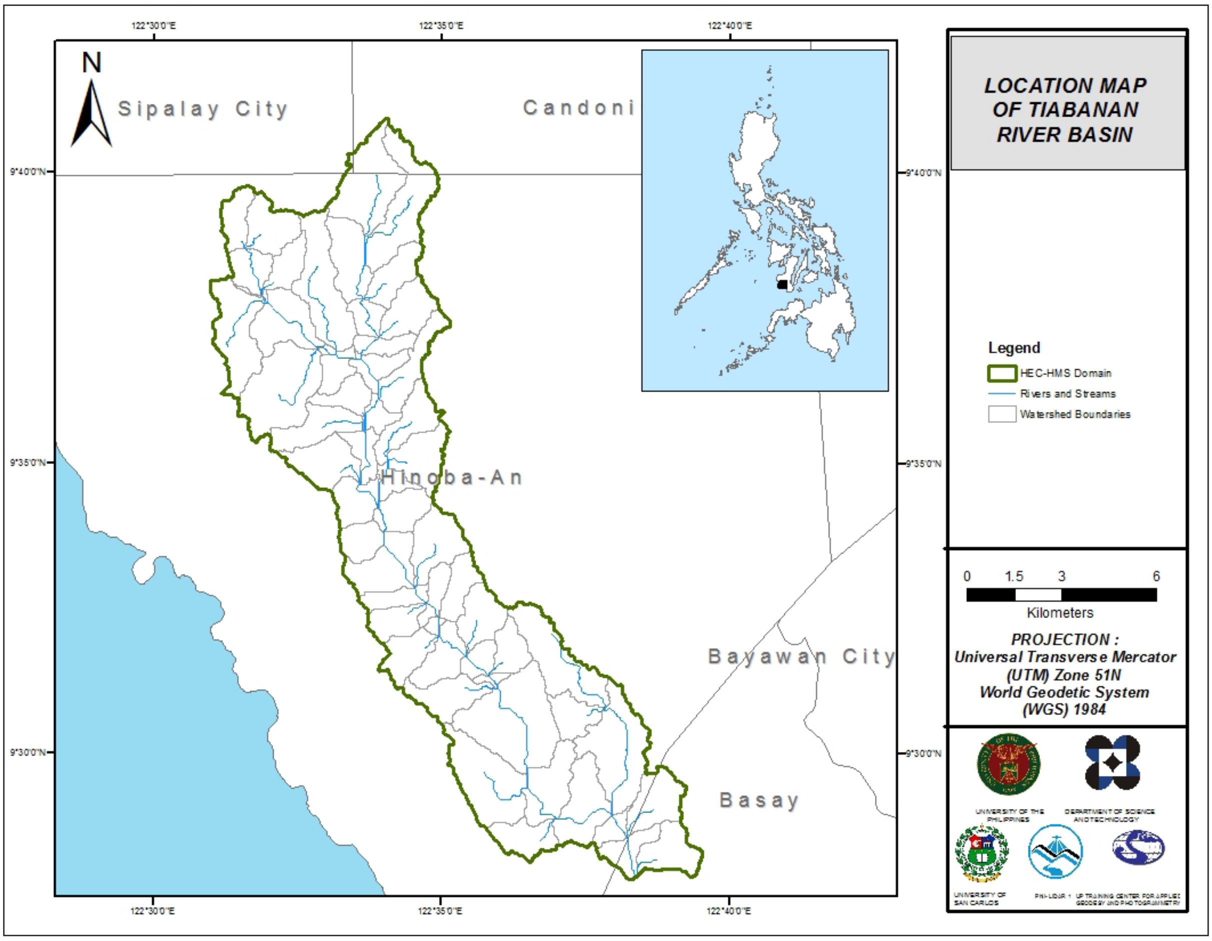

Figure 52. Stream delineation map of Tiabanan River Basin

The Tiabanan basin model comprises 59 sub basins, 28 reaches, and 28 junctions. The main outlet is outlet 1. This basin model is illustrated in Figure 53. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed rain gauge near and inside the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in the Brgy. Bungalunan, Basay.

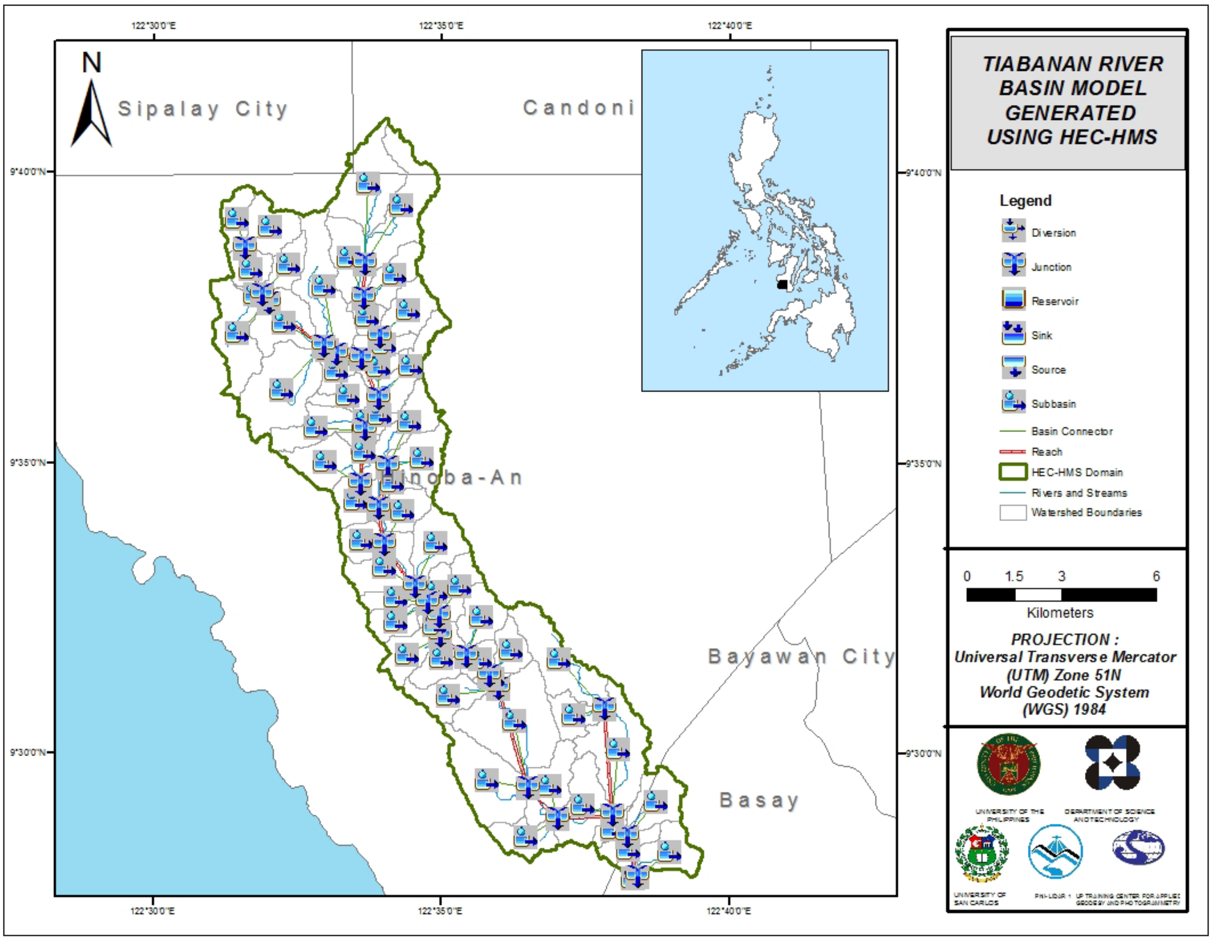

Figure 53. HEC-HMS generated Tiabanan River Basin Model.

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.

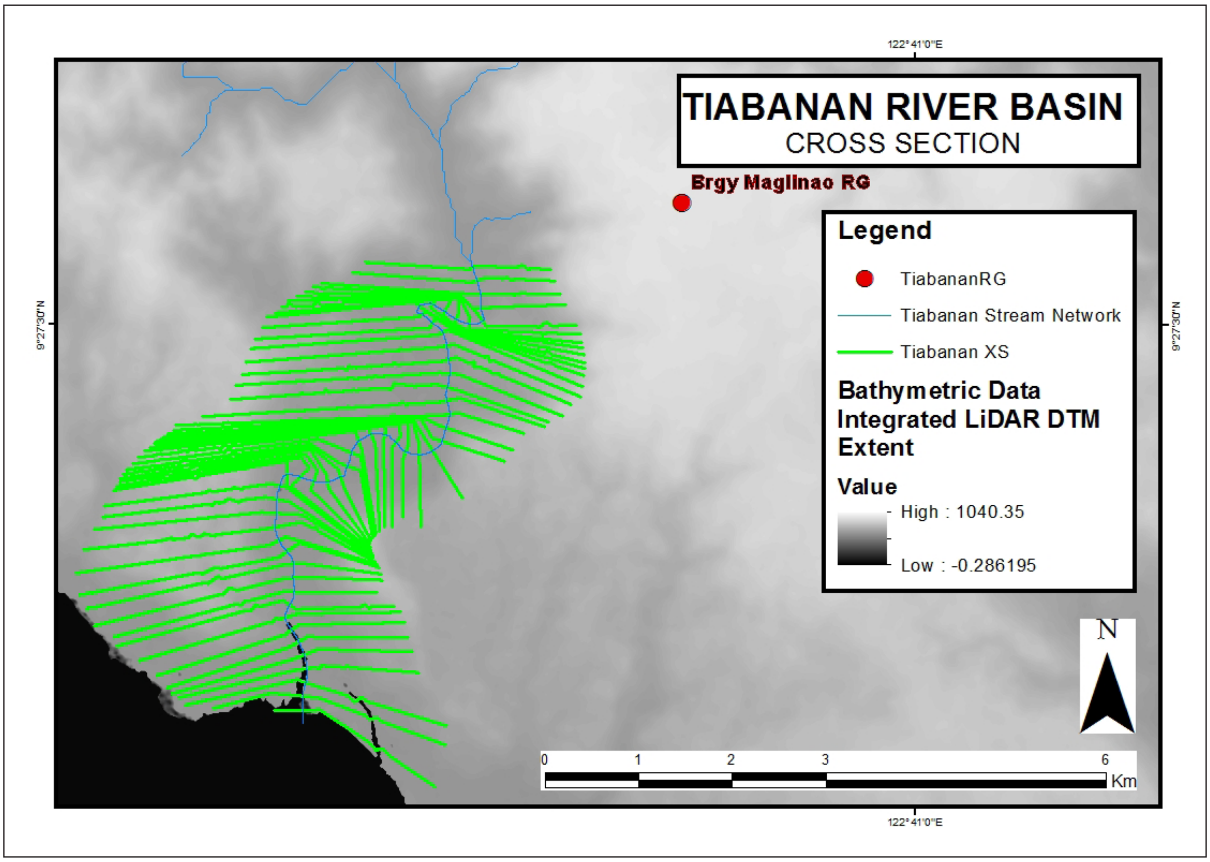

Figure 54. River cross-section of Tiabanan River generated through Arcmap HEC GeoRAS tool

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

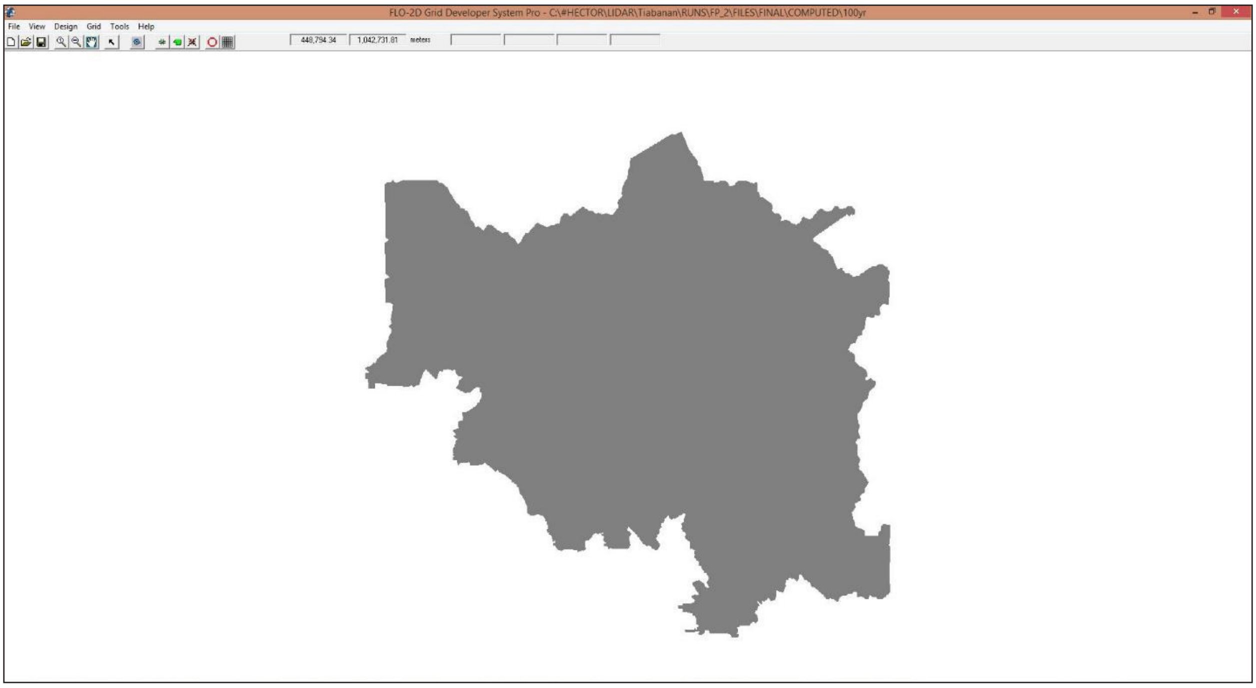

Figure 55. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 54.08398 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m^2/s.

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 60 330 400.00 m^2.

There is a total of 34 638 181.77 m^3 of water entering the model. Of this amount, 16 179 817.94 m^3 is due to rainfall while 18 458 363.83 m^3 is inflow from other areas outside the model. 4 355 312.50 m^3 of this water is lost to infiltration and interception, while 9 002 381.72 m^3 is stored by the flood plain. The rest, amounting up to 21 280 472.68 m^3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Tiabanan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 56 shows the comparison between the two discharge data.

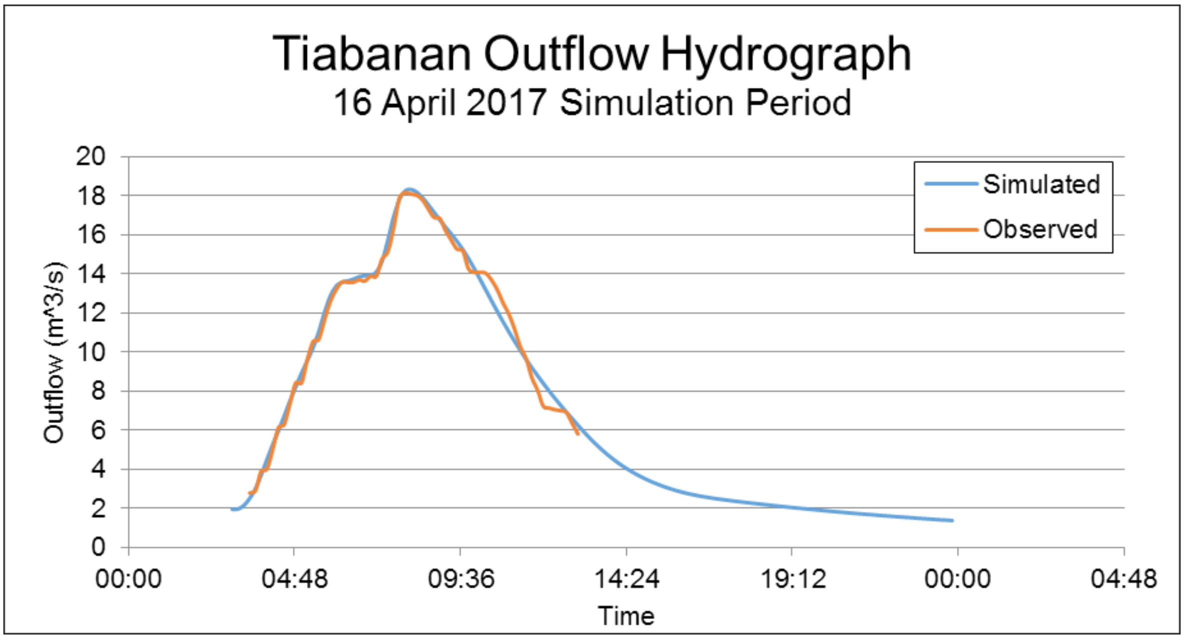

Figure 56. Outflow Hydrograph of Tiabanan produced by the HEC-HMS model compared with observed outflow.

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

Table 26. Range of calibrated values for Tiabanan Watershed

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	3.28-4.70
			Curve Number	54.16-99.00
			Impervious (%)	0
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.13-2.57
			Storage Coefficient (hr)	0.11-5.28
	Baseflow	Recession	Recession Constant	0.10-0.34
			Ratio to Peak	0.04-0.15
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	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 3.28-4.70mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 55 to 97 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area. For Tiabanan, the basin mostly consists of grasslands and the soil consists of clay and mountainous land.

Time of concentration is the travel time of runoff in a watershed. The range of calibrated values from 0.13-2.57 minutes determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.10-0.34 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher.

Manning's roughness coefficient of 0-1 corresponds to the Tiabanan river basin, which is mostly brushland and grassland, with scattered open forests and tree plantations (Brunner, 2010).

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

Accuracy measure	Value
RMSE	0.4580
r^2	0.9946
NSE	0.9887
PBIAS	-1
RSR	0.1064

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.4580

The Pearson correlation coefficient $(r^2)r^2)$ 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 0.9946.

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 0.9887.

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 -1.

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 0.1064.

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 show the Tiabanan outflow using the Dumaguete Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-, 10-, 25-, 50-, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a uniform duration of 24 hours and varying return periods.

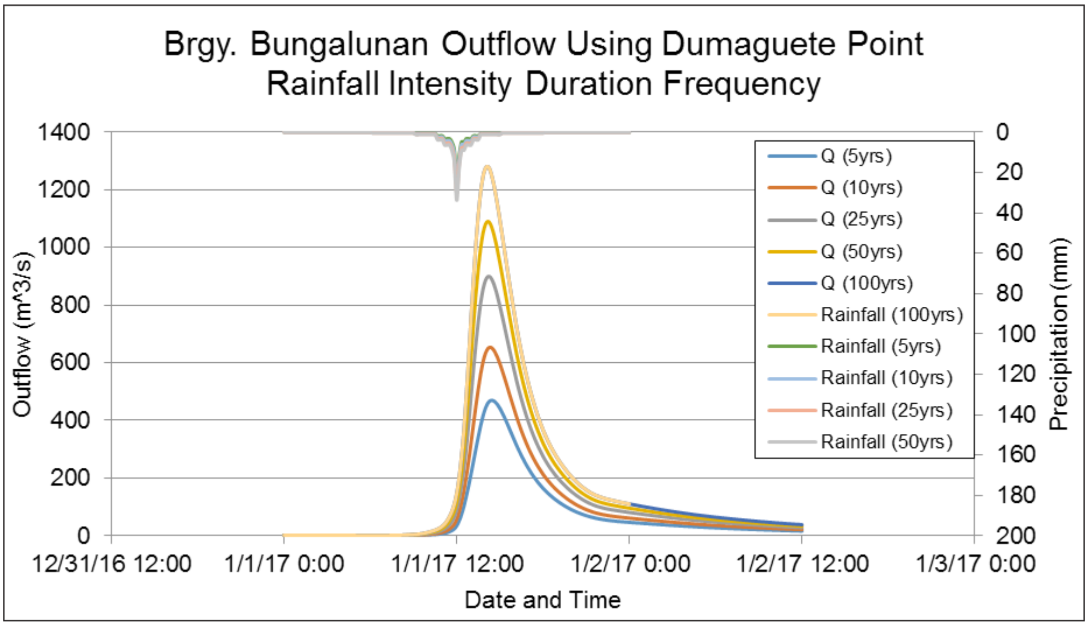

Figure 57. Outflow hydrograph at Brgy. Bungalunan, Basay generated using Dumaguete Point RIDF simulated in HEC-HMS

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

Table 28. Peak values of the Tiabanan HECHMS Model outflow using the Dumaguete RIDF

RIDF Period	Total Precipitation (mm)	Peak Rainfall (mm)	Peak Outflow $\left(\frac{m^3}{s}\right)$	Time to Peak
5-year RIDF	116.5	21.8	342.979	3 hours, 10 minutes
10-year RIDF	143.3	25.6	426.773	3 hours, 10 minutes
25-year RIDF	177.2	30.3	533.217	3 hours
50-year RIDF	202.4	33.8	612.636	3 hours
100-year RIDF	227.3	37.2	691.701	3 hours

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

The river discharge entering the floodplain is shown in Figure 58 and the peak values are summarized in Table 29.

This image is not available for this river basin.

Figure 58. Tiabanan river generated discharge using 5-, 25-, and 100-year Dumaguete City rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 29. Summary of Tiabanan river discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	643.5	17 hours, 30 minutes
25-Year	469.3	17 hours, 30 minutes
5-Year	274.3	17 hours, 30 minutes

Table 30. Validation of river discharge estimates

Discharge Point	$Q_{MED(SCS)}$, cms	$Q_{BANKFUL}$, cms	$Q_{MED(SPEC)}$, cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Tiabanan	241.384	4352.838	257.181	FALSE	TRUE

Two of the three values from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful and specific discharge methods (Table 30). The calculated values are based on theory but are supported using other discharge computation methods so they were good to use flood modeling. However, these values will need further investigation for the purpose of validation. It is therefore recommended to obtain actual values of the river discharges for higher-accuracy modeling.

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM/ Phil-LiDAR 1 website. For this publication, only a sample output map river was to be shown. The sample generated map of Tiabanan River using the calibrated event flow is shown in Figure 59.

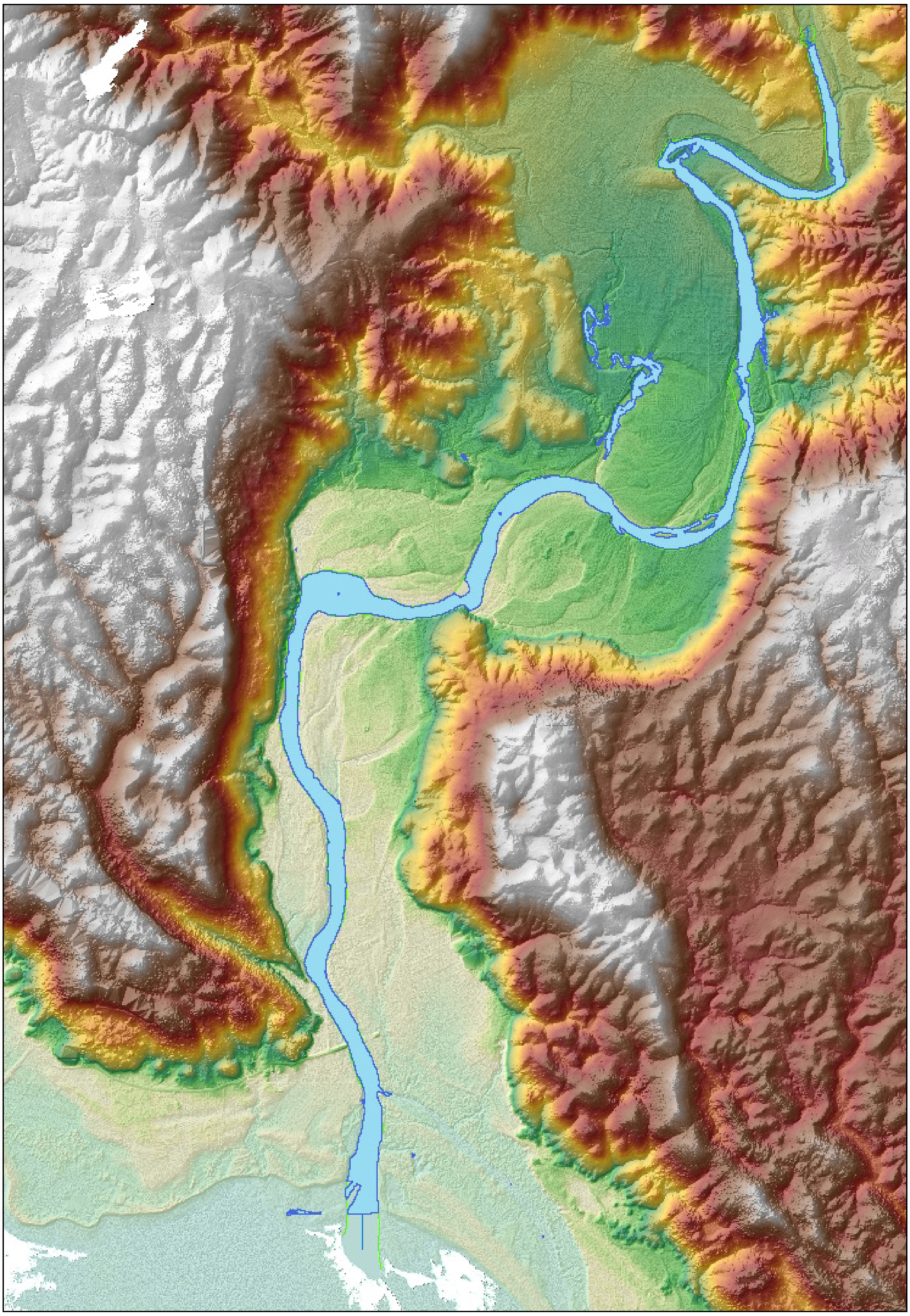

Figure 59. Sample output of Tiabanan RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. Figure 60 to Figure 65 shows the 5-, 25-, and 100-year rain return scenarios of the Tiabanan floodplain. The floodplain, with an area of ________ sq. km., covers two municipalites namely Basay and Hinoba-An. Table 31 shows the percentage of area affected by flooding per municipality.

Table 31. Municipalities affected in Tiabanan Floodplain

Municipality/ City	Total Area (sq.km.)	Area Flooded (sq. km.)	% Flooded
Basay	167.79		
Hinoba-An	401.7		

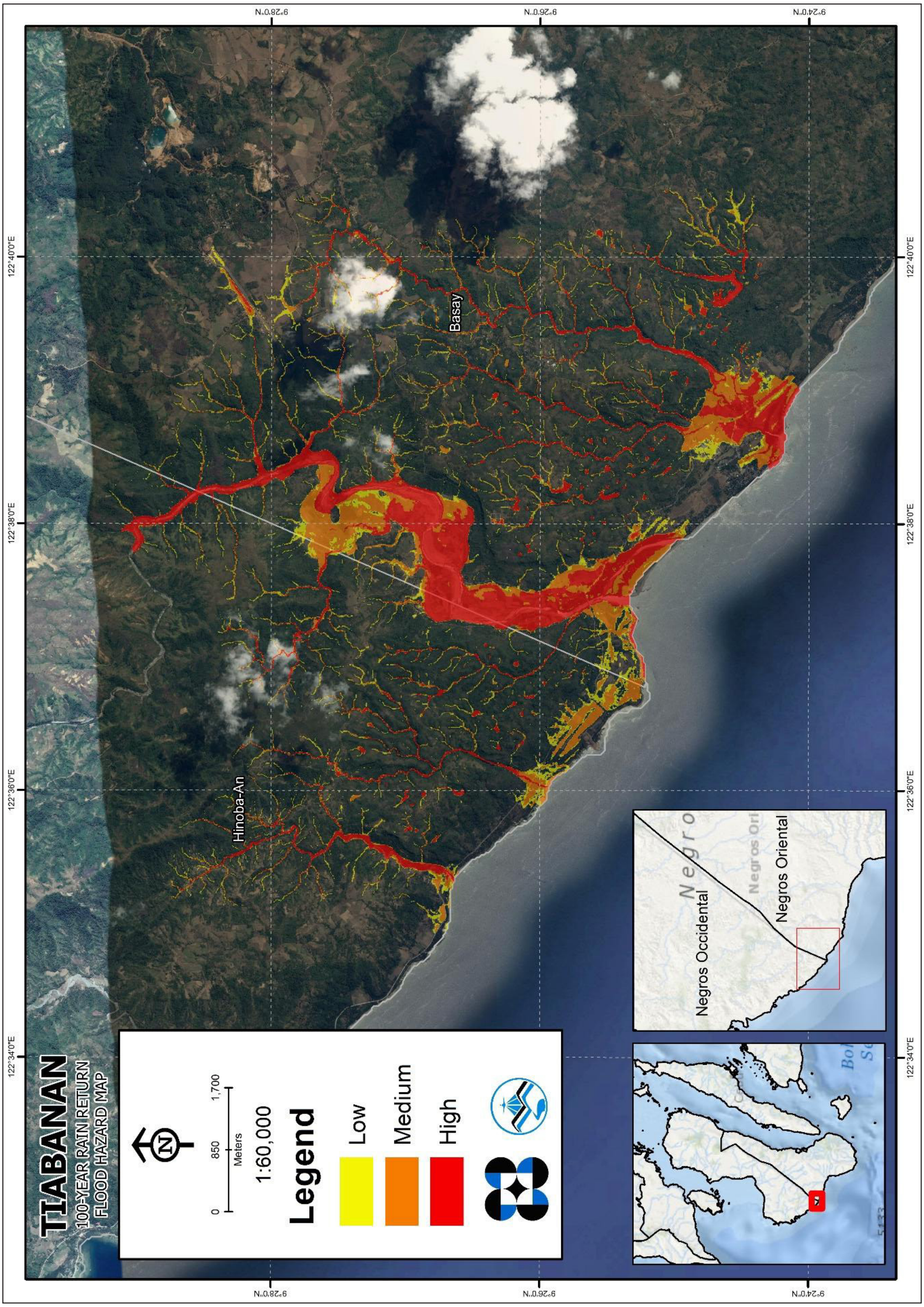

Figure 60. 100-year Flood Hazard Map for Tiabanan Floodplain overlaid on Google Earth imagery

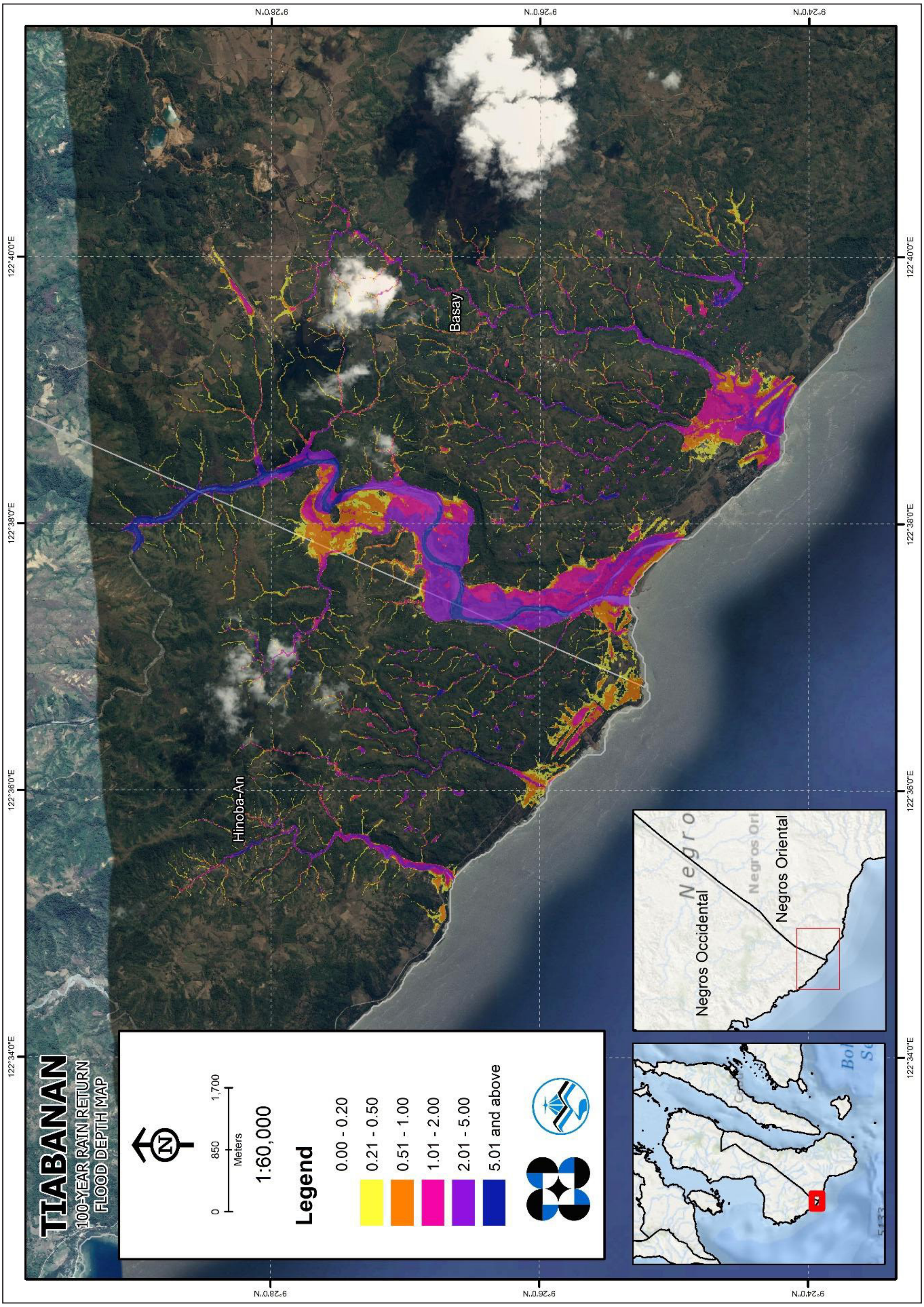

Figure 61. 100-year Flow Depth Map for Tiabanan Floodplain overlaid on Google Earth imagery

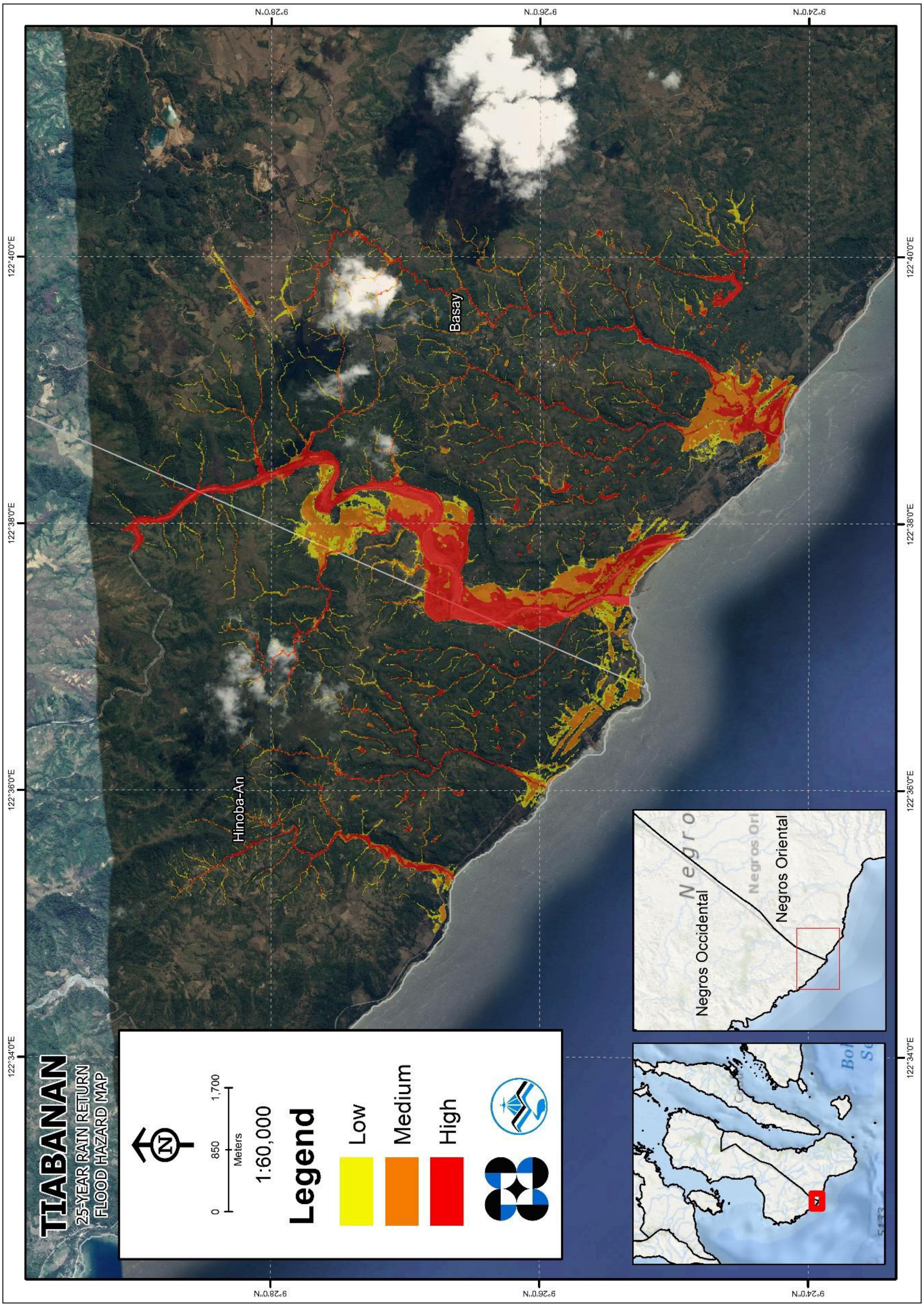

Figure 62. 25-year Flood Hazard Map for Tiabanan Floodplain overlaid on Google Earth imagery

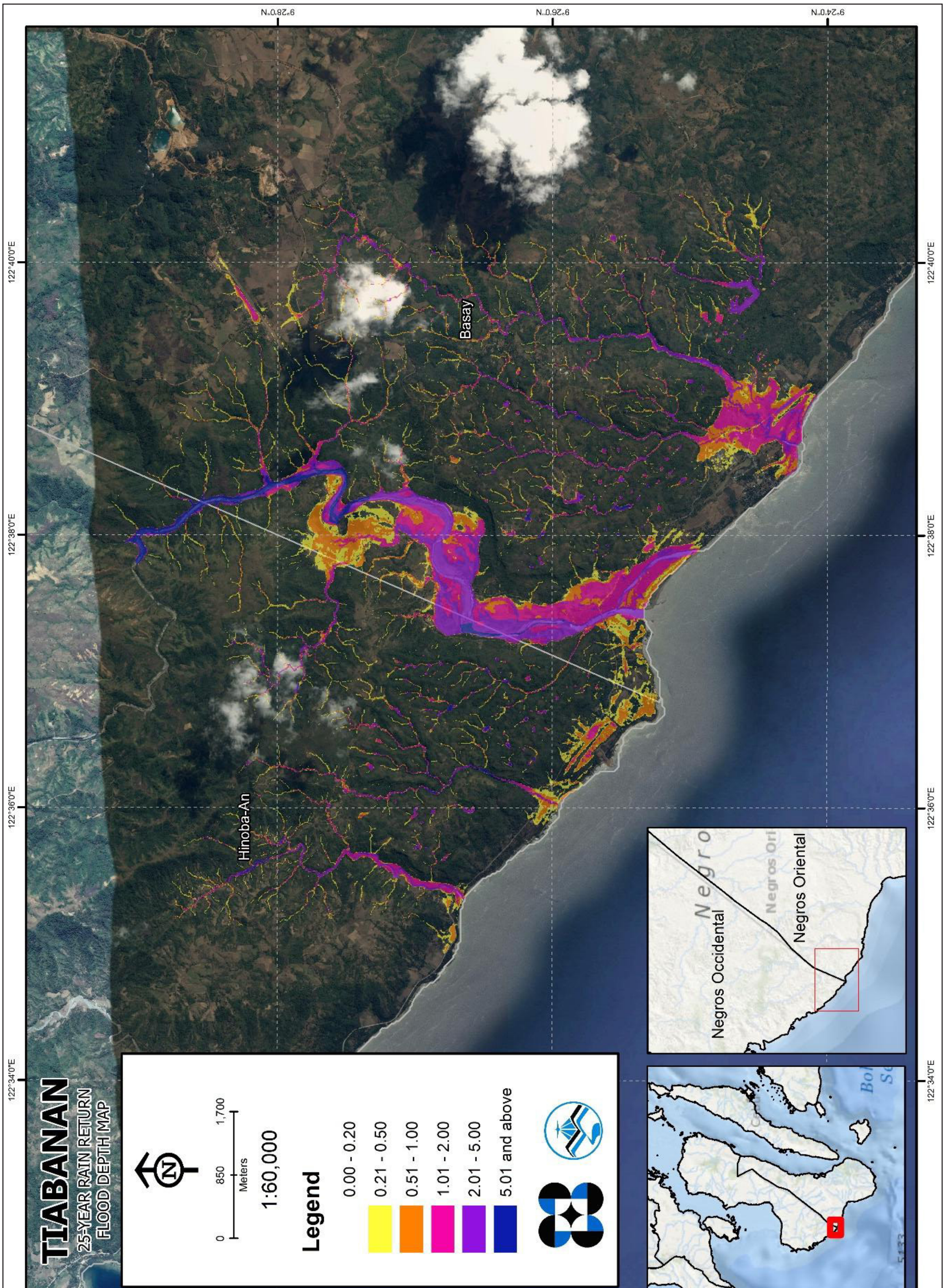

Figure 63. 25-year Flow Depth Map for Tiabanan Floodplain overlaid on Google Earth imagery

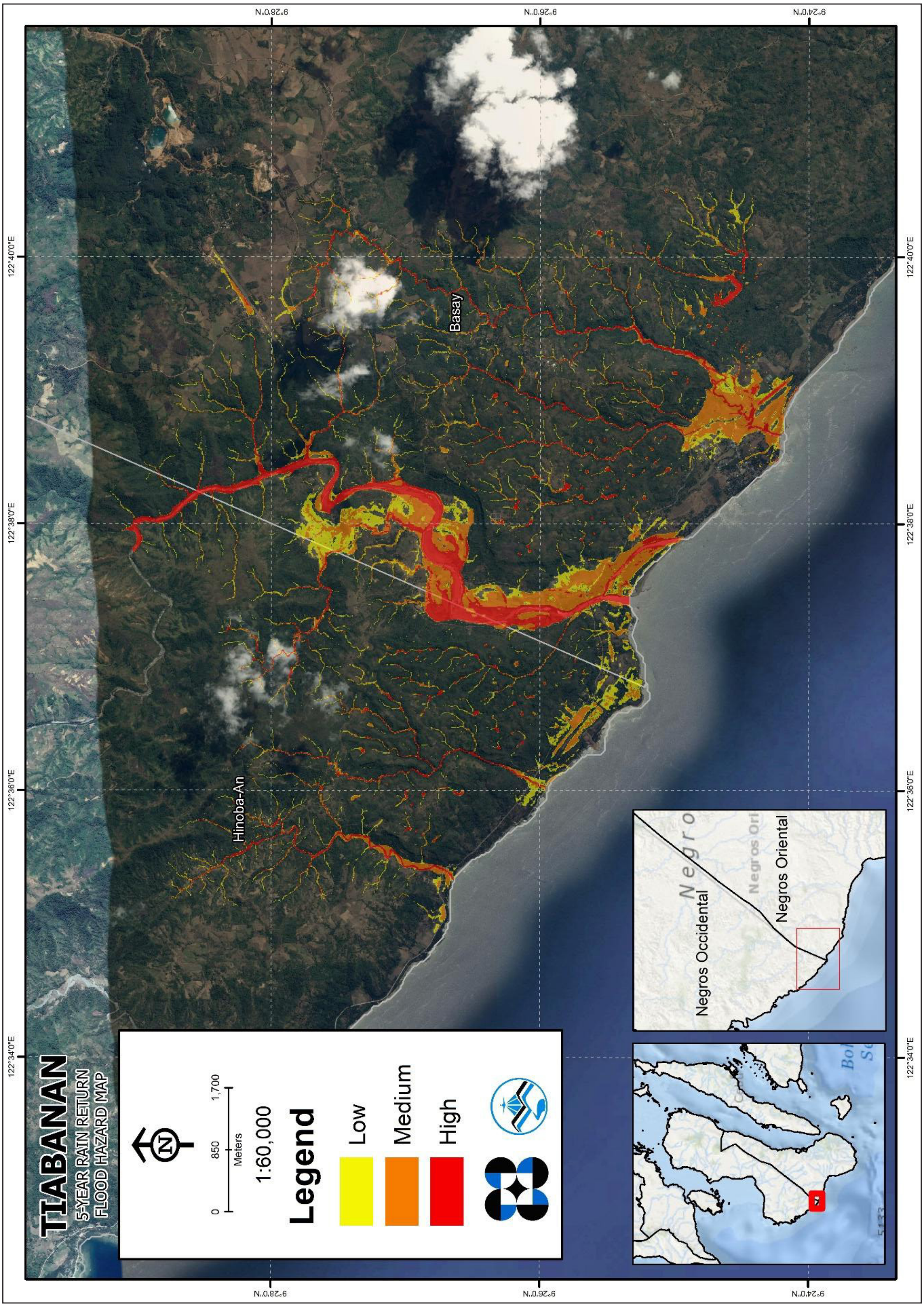

Figure 64. 5-year Flood Hazard Map for Tiabanan Floodplain overlaid on Google Earth imagery

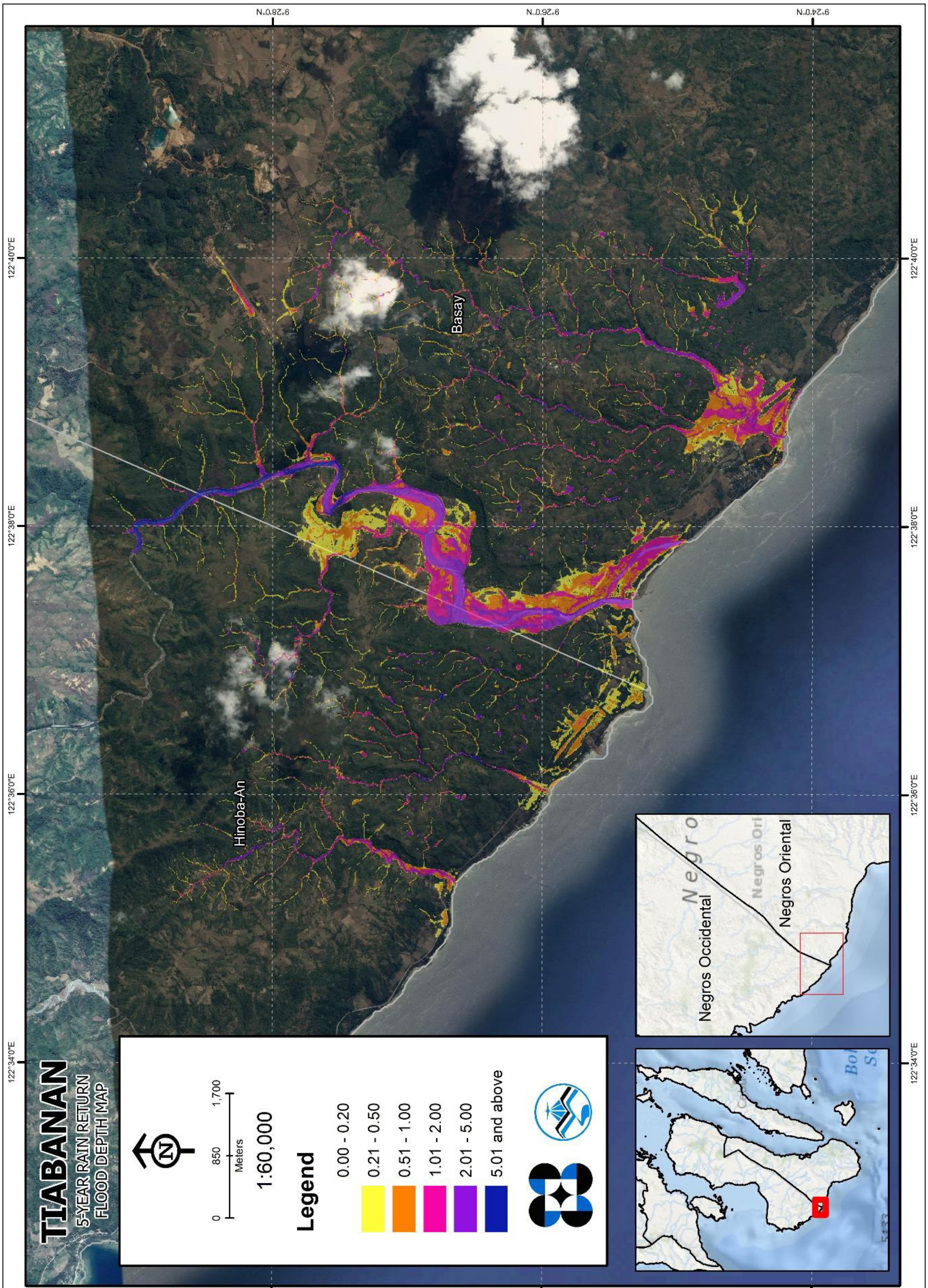

Figure 65. 5-year Flood Depth Map for Tiabanan Floodplain overlaid on Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Tiabanan river basin, grouped by municipality, are listed below. For the said basin, two (2) municipalities consisting of 8 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 17.64% of the municipality of Basay with an area of 167.79 sq. km. will experience flood levels of less 0.20 meters. 1.17% of the area will experience flood levels of 0.21 to 0.50 meters while 1.1%, 1.05%, 0.7%, and 0.08% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 32 and shown in Figure 66 are the affected areas in square kilometres by flood depth per barangay.

Table 32. Affected Areas in Basay, Negros Oriental during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Basay (in sq. km.)					
	Actin	Bal-Os	Bongalonan	Cabalayongan	Nagbo-Alao	Poblacion
0.03-0.20	4.69	5.98	12.18	0.96	0.098	5.69
0.21-0.50	0.16	0.18	1.17	0.045	0.0044	0.4
0.51-1.00	0.12	0.12	1.08	0.017	0.0002	0.53
1.01-2.00	0.071	0.11	1.04	0.012	0.000001	0.52
2.01-5.00	0.027	0.077	0.86	0.0083	0	0.2
> 5.00	0.0002	0.0035	0.12	0	0	0.0031

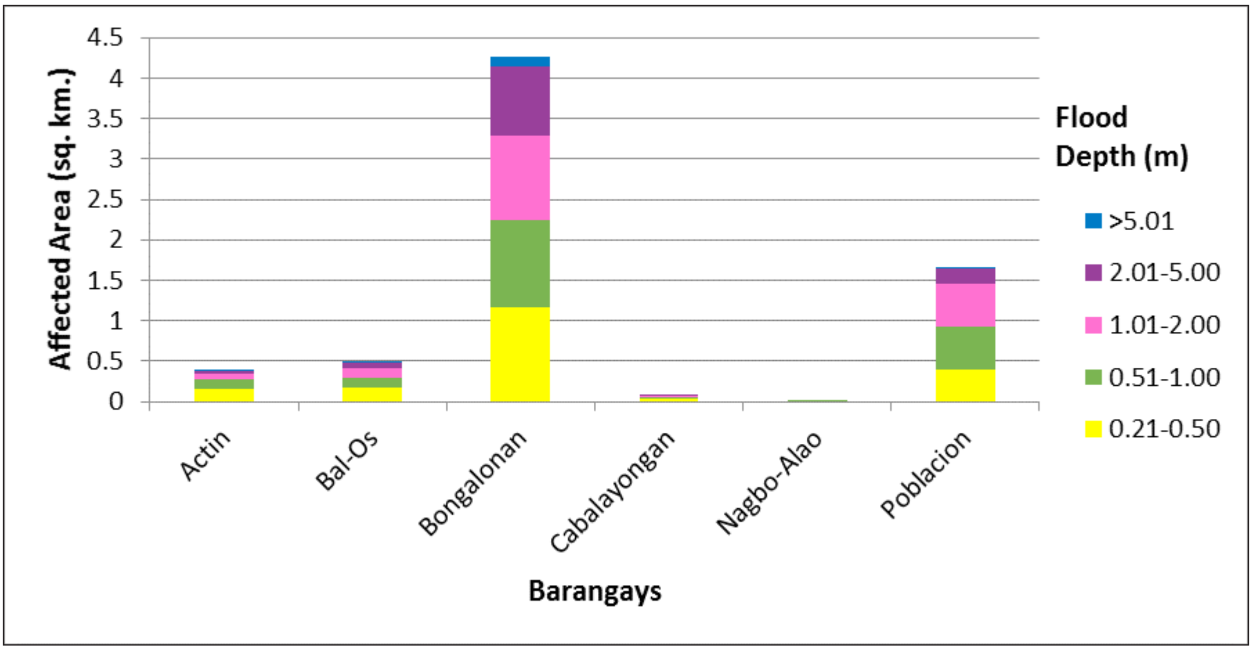

Figure 66. Affected Areas in Basay, Negros Oriental during 5-Year Rainfall Return Period

For the municipality of Hinoba-An, with an area of 401.7 sq. km., 4.91% will experieZnce flood levels of less 0.20 meters. 0.21% of the area will experience flood levels of 0.21 to 0.50 meters while 1.3%, 0.1%, 0.08%, and 0.026% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 33 and shown in Figure 67 are the affected areas in square kilometres by flood depth per barangay.

Table 33. Affected Areas in Hinoba-An, Negros Occidental during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Hinoba-An (in sq. km.)	
	Culipapa	Sangke
0.03-0.20	0.64	19.1
0.21-0.50	0.023	0.83
0.51-1.00	0.011	0.5
1.01-2.00	0.006	0.39
2.01-5.00	0.0011	0.32
> 5.00	0	0.11

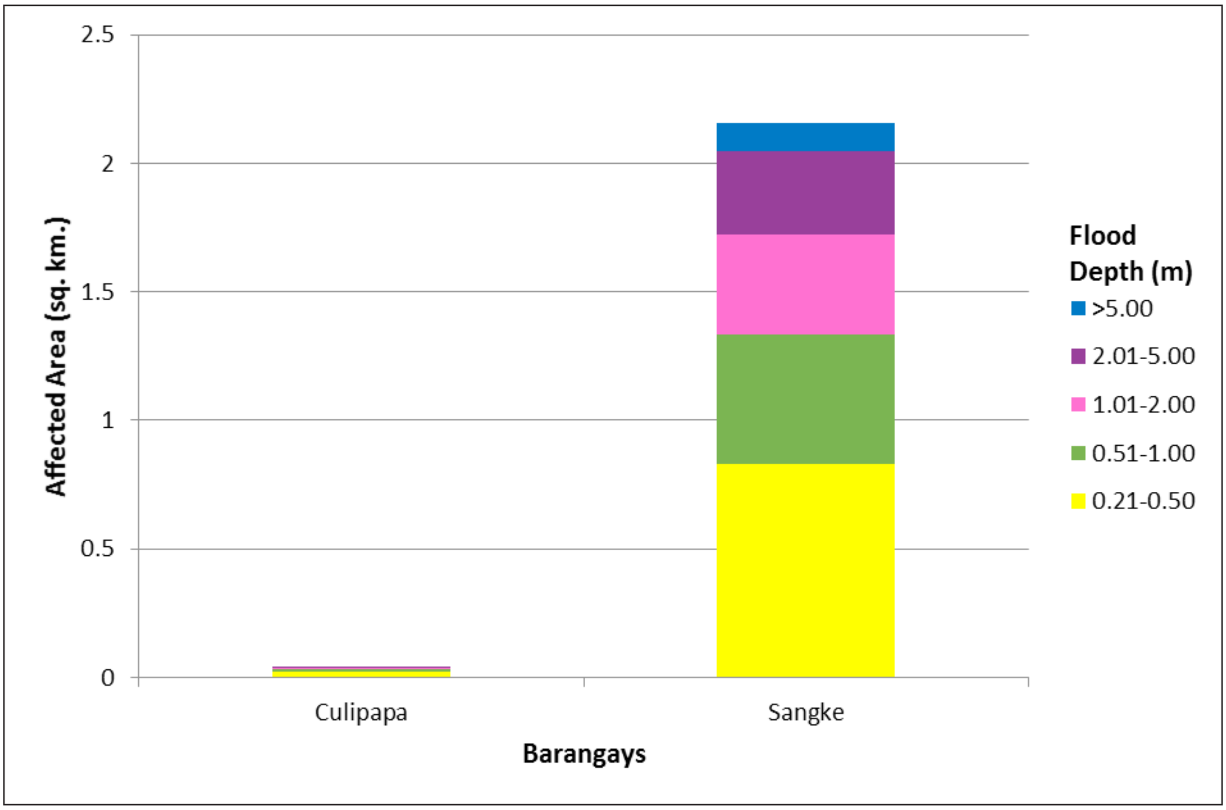

Figure 67. Affected Areas in Hinoba-An, Negros Occidental during 5-Year Rainfall Return Period

For the 25-year return period, 16.94% of the municipality of Basay with an area of 167.79 sq. km. will experience flood levels of less 0.20 meters. 1.03% of the area will experience flood levels of 0.21 to 0.50 meters while 1.04%, 1.47%, 1.12%, and 0.14% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 34 and shown in Figure 68 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected Areas in Basay, Negros Oriental during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Basay (in sq. km.)					
	Actin	**Bal-Os**	**Bongalonan**	**Cabalayongan**	**Nagbo-Alao**	**Poblacion**
0.03-0.20	4.64	5.92	11.42	0.95	0.097	5.4
0.21-0.50	0.17	0.19	0.96	0.052	0.0051	0.36
0.51-1.00	0.13	0.13	1.03	0.021	0.0005	0.44
1.01-2.00	0.084	0.12	1.49	0.015	0.000001	0.75
2.01-5.00	0.048	0.12	1.32	0.01	0	0.38
> 5.00	0.0005	0.0062	0.22	0	0	0.011

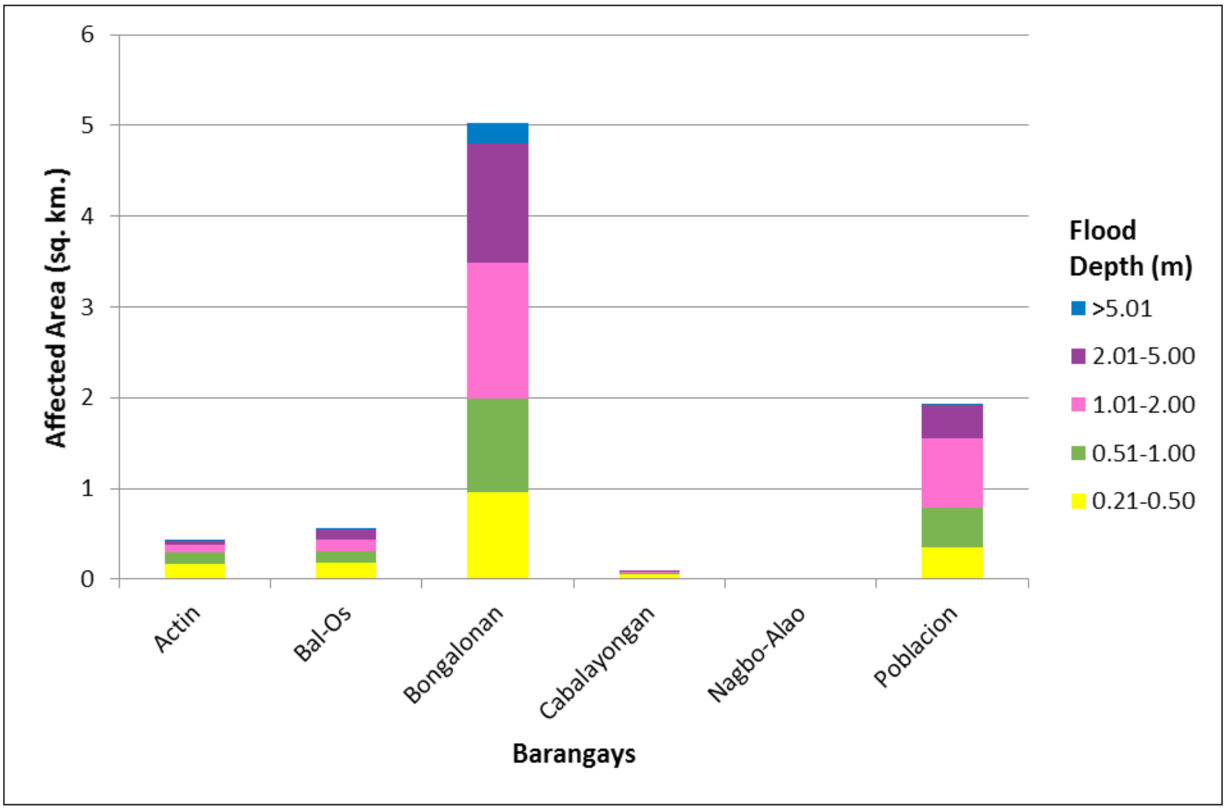

Figure 68. Affected Areas in Basay, Negros Oriental during 25-Year Rainfall Return Period

For the municipality of Hinoba-An, with an area of 401.7 sq. km., 4.82% will experience flood levels of less 0.20 meters. 0.22% of the area will experience flood levels of 0.21 to 0.50 meters while 0.15%, 0.11%, 0.11%, and 0.047% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 35 and shown in Figure 69 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected Areas in Hinoba-An, Negros Occidental during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Hinoba-An (in sq. km.)	
	Culipapa	Sangke
0.03-0.20	0.63	18.72
0.21-0.50	0.026	0.86
0.51-1.00	0.012	0.61
1.01-2.00	0.0069	0.44
2.01-5.00	0.0021	0.45
> 5.00	0	0.19

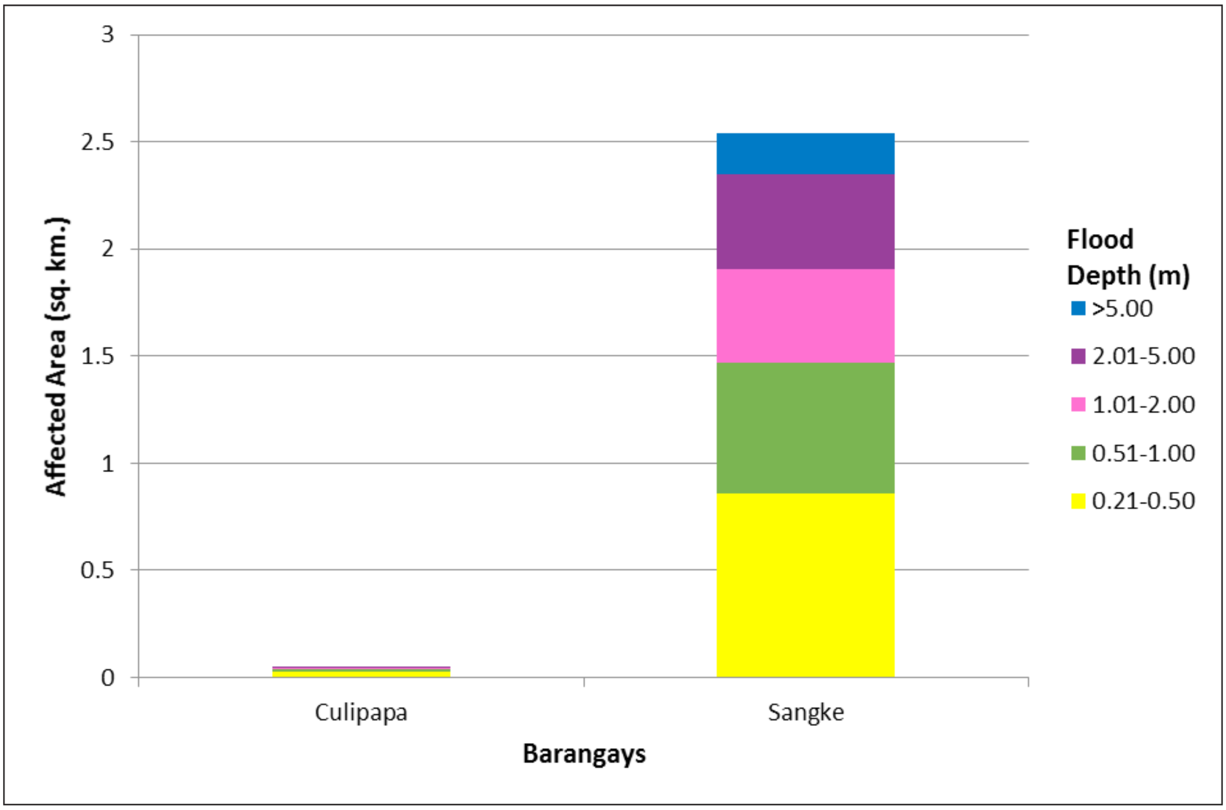

Figure 69. Affected Areas in Hinoba-An, Negros Occidental during 25-Year Rainfall Return Period

For the 100-year return period, 16.56% of the municipality of Asturias with an area of 167.79 sq. km. will experience flood levels of less 0.20 meters. 0.95% of the area will experience flood levels of 0.21 to 0.50 meters while 1%, 1.42%, 1.51%, and 0.3% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 36 and shown in Figure 70 are the affected areas in square kilometres by flood depth per barangay.

Table 36. Affected Areas in Basay, Negros Oriental during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Basay (in sq. km.)					
	Actin	Bal-Os	Bongalonan	Cabalayongan	Nagbo-Alao	Poblacion
0.03-0.20	4.6	5.87	11.08	0.94	0.096	5.2
0.21-0.50	0.17	0.2	0.79	0.06	0.0062	0.37
0.51-1.00	0.13	0.13	1.02	0.022	0.0006	0.38
1.01-2.00	0.093	0.12	1.42	0.017	0.000001	0.74
2.01-5.00	0.067	0.14	1.71	0.011	0	0.61
> 5.00	0.0006	0.011	0.45	0.0009	0	0.035

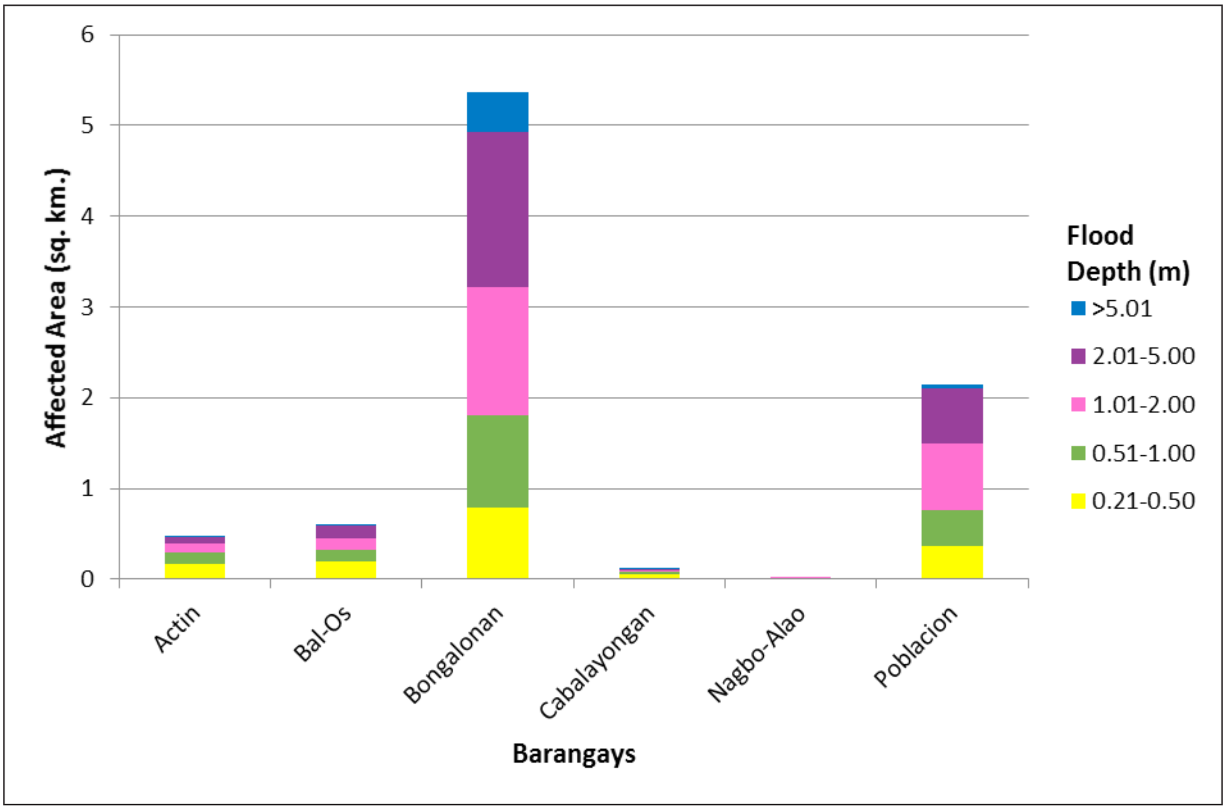

Figure 70. Affected Areas in Basay, Negros Oriental during 100-Year Rainfall Return Period

For the municipality of Hinoba-An, with an area of 401.7 sq. km., 4.75% will experience flood levels of less 0.20 meters. 0.23% of the area will experience flood levels of 0.21 to 0.50 meters while 0.17%, 0.12%, 0.13%, and 0.06% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 37 and shown in Figure 71 are the affected areas in square kilometres by flood depth per barangay.

Table 37. Affected Areas in Hinoba-An, Negros Occidental during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Hinoba-An (in sq. km.)	
	Culipapa	Sangke
0.03-0.20	0.63	18.45
0.21-0.50	0.027	0.88
0.51-1.00	0.013	0.68
1.01-2.00	0.0075	0.47
2.01-5.00	0.0027	0.53
> 5.00	0	0.25

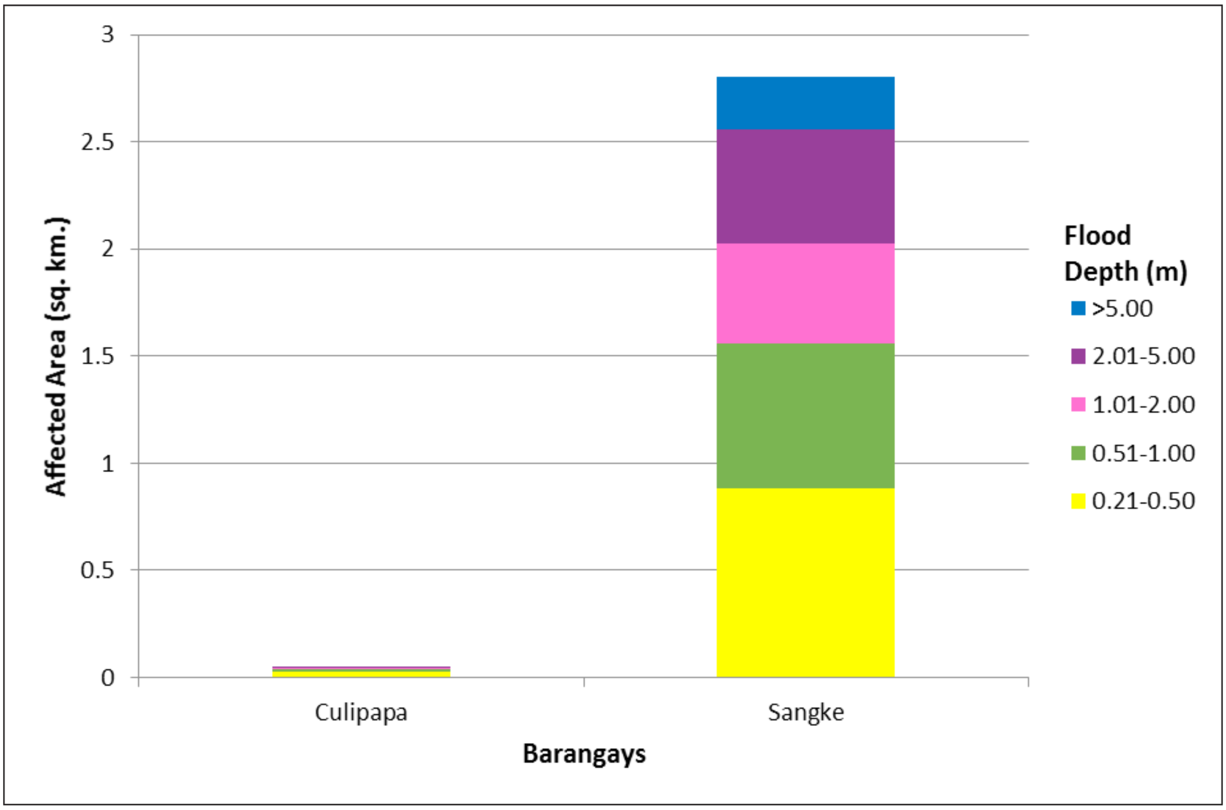

Figure 71. Affected Areas in Hinoba-An, Negros Occidental during 100-Year Rainfall Return Period

Among the barangays in the municipality of Basay, Poblacion is projected to have the highest percentage of area that will experience flood levels at 4.37%. Meanwhile, Bal-Os posted the second highest percentage of area that may be affected by flood depths at 3.86%.

Among the barangays in the municipality of Hinoba-An, Sangke is projected to have the highest percentage of area that will experience flood levels at 5.29%. Meanwhile, Culipapa posted the second highest percentage of area that may be affected by flood depths at 0.17%.

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

Table 38. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	2.78	2.57	2.44
Medium	3.69	3.86	3.76
High	2.72	4.33	5.46
TOTAL	9.19	10.76	11.66

Of the 4 identified education institutions in the Tiabanan Flood plain, 2 schools were assessed to be exposed to Low level flooding during a 5 year scenario. In the 25 year scenario, 1 school was assessed to be exposed to low level flooding, while 1 school was assessed to be exposed to medium level flooding in the same scenario. In the 100 year scenario, 2 schools were assessed to be exposed to low level flooding, while 1 school was assessed to be exposed to medium level flooding in the same scenario.

No medical institutions were identified to be exposed to flooding in the Tiabanan floodplain.

5.11 Flood Validation

Survey was done along the floodplain of Tiabanan River to validate the generated flood maps. The team gathered secondary data regarding flood occurrence in the area. Ground validation points were acquired as well as the other necessary details like date of occurrence, name of typhoon and actual flood depth.

During validation conducted last December 8 to 9, 2016, the team was assisted by the local Disaster Risk Reduction and Management representative from the Municipality of Basay. Residents along the floodplain were interviewed of the historical flood events they experiences.

Actual flood depth acquired from the ground validation were then computed and compared to the flood depth simulated by the model. An RMSE value of 1.27 was obtained.

[PLACEHOLDER FOR FIGURE 72]

Figure 72. Tiabanan River Basin Flood Validation Points

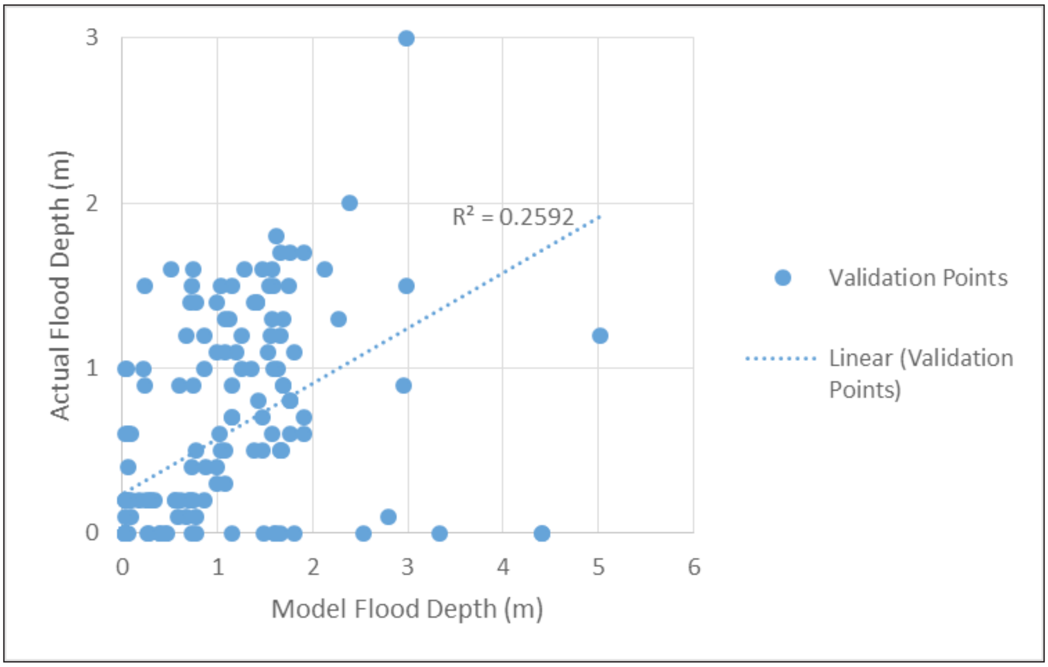

Figure 73. Flood map depth vs. actual flood depth

Table 39. Table 39. Actual flood vs simulated flood depth of Tiabanan 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	69	10	12	6	5	0	102
0.21-0.50	1	0	5	8	0	0	14
0.51-1.00	6	2	3	18	1	0	30
1.01-2.00	0	1	9	26	4	1	41
2.01-5.00	0	0	0	0	1	0	1
> 5.00	0	0	0	0	0	0	0
Total	76	13	29	58	11	1	188

The overall accuracy generated by the flood model is estimated at 52.66% with 99 points correctly matching the actual flood depths. In addition, there were 47 points estimated one level above and below the correct flood depths while there were 29 points and 11 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 19 points were underestimated in the modelled flood depths of Tiabanan. The summary of the accuracy assessment is presented in Table 40.

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

	No. of Points	%
Correct	99	**52.66**
Overestimated	70	**37.23**
Underestimated	19	**10.11**
Total	188	**100.00**

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

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

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

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

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

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

ANNEXES

Annex 1. Optech Technical Specification of the Gemini Sensor

Figure A-1.1 Gemini Sensor

Table A-1.1 Parameters and Specifications of the Gemini Sensor

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

Annex 2. NAMRIA Certificates of Reference Points Used

1. NGE-94

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

October 30, 2014

CERTIFICATION

To whom it may concern:

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

Province: **NEGROS ORIENTAL**
Station Name: **NGE-94**
Order: **2nd**

Island: **VISAYAS**
Municipality: **BASAY**
Barangay: **BAL-OS**
MSL Elevation:

PRS92 Coordinates

Latitude: **9° 25' 41.58333"**	Longitude: **122° 37' 17.78349"**	Ellipsoidal Hgt: **8.56700 m.**

WGS84 Coordinates

Latitude: **9° 25' 37.57296"**	Longitude: **122° 37' 23.11929"**	Ellipsoidal Hgt: **69.14100 m.**

PTM / PRS92 Coordinates

Northing: **1042517.096 m.**	Easting: **458444.003 m.**	Zone: **4**

UTM / PRS92 Coordinates

Northing: **1,042,152.20**	Easting: **458,458.55**	Zone: **51**

Location Description

NGE-94
The station is located on the SE of south approach of the Tiabanan's bridge wingwall sidewalk. It is about 6.4 km from the provincial boundary of Negros Oriental & Occidental, along the Sipalay-Dumaguete national road. Mark is the head of a 4" copper nail drilled and grouted at the center of a 30 x 30 cm. cement putty embedded on the concrete pavement of the bridge sidewalk with inscriptions "NGE-94; 2007; NAMRIA".

Requesting Party: **PHIL-LIDAR I**
Purpose: **Reference**
OR Number: **8075910 I**
T.N.: **2014-2594**

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

9 9 1 0 3 0 2 0 1 4 1 3 5 0 2 8

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

CIP/4701/12/09/814

Figure A-2.1 NGE-94

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

1. NE-08

Vector Components (Mark to Mark)

From:	NGE-94				
Grid		Local		Global	
Easting	458458.548 m	Latitude	N9°25'41.58333"	Latitude	N9°25'37.57296"
Northing	1042152.197 m	Longitude	E122°37'17.78349"	Longitude	E122°37'23.11929"
Elevation	7.540 m	Height	8.568 m	Height	69.141 m

To:	NE-08				
Grid		Local		Global	
Easting	459762.045 m	Latitude	N9°25'12.20140"	Latitude	N9°25'08.19418"
Northing	1041248.495 m	Longitude	E122°38'00.55785"	Longitude	E122°38'05.89430"
Elevation	7.528 m	Height	8.582 m	Height	69.203 m

Vector					
ΔEasting	1303.497 m	NS Fwd Azimuth	124°40'16"	ΔX	-1178.739 m
ΔNorthing	-903.702 m	Ellipsoid Dist.	1586.723 m	ΔY	-579.131 m
ΔElevation	-0.012 m	ΔHeight	0.015 m	ΔZ	-890.435 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.002 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.002 m
σ ΔElevation	0.002 m	σ ΔHeight	0.002 m	σ ΔZ	0.001 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000031768		
Y	-0.0000000334	0.0000038050	
Z	0.0000000263	0.0000006991	0.0000005522

Figure A-2.1 NE-08

Annex 4. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
LiDAR Operation	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
		ENGR. GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	MA. VERLINA TONGA	UP-TCAGP
		MA. REMEDIOS VILLANUEVA	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JONATHAN ALMALVEZ	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. RAYMUND DOMINE	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. RAUL CZ SAMAR II	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. JOHN BRYAN DONGUINES	AAC
		CAPT. NEIL ACHILLES AGAWIN	AAC

Annex 5. Data Transfer Sheets

DATA TRANSFER SHEET
DUMAGUETE (11/06/2014)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	POS (MB)	RAW IMAGES / CASI	MISSION LOG FILE / CASI LOGS	RANGE (GB)	DIGITIZER (GB)	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION/S	BASE INFO (.txt)		ACTUAL	KML	
6-Oct-14	7538	2BLK54BS279A	GEMINI-CASI	N/A	64.3 KB	136 KB	109	N/A	N/A	5.59	N/A	3.61	1 KB	1 KB	4 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
7-Oct-14	7540	2BLK55AS53KS280A	GEMINI-CASI	N/A	157 KB	299 KB	208	N/A	N/A	13.1	N/A	4.94	1 KB	1 KB	116 KB	6.76 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
17-Oct-14	7560	2BLK55A290A	GEMINI-CASI	N/A	257 KB	N/A	221	N/A	N/A	19.6	N/A	5.34	1 KB	1 KB	366 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
18-Oct-14	7562	2BLK53I291A	GEMINI-CASI	N/A	302 KB	511 KB	248	N/A	N/A	24.1	N/A	6.49	1 KB	1 KB	236	7.6 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
20-Oct-14	7566	2BLK53JK293A	GEMINI-CASI	17.1 GB	293 KB	827 KB	210	70.5 GB	118 KB	19	N/A	6.05	1 KB	1 KB	372 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
21-Oct-14	7568	2BLK53KS294A	GEMINI-CASI	7.4 GB	265 KB	224 KB	192	21 GB	101 KB	9.89	N/A	6.01	1 KB	1 KB	198 KB	20.3 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
22-Oct-14	7570	2BLK53H295A	GEMINI-CASI	18 GB	242 KB	416 KB	246	75.5	106 KB	21.5	N/A	6.57	1 KB	1 KB	352 KB	7.84 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
24-Oct-14	7574	2BLK53I297A	GEMINI-CASI	18.2 GB	490 KB	433 KB	258	N/A	N/A	20.2	N/A	5.78	1 KB	1 KB	351 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
25-Oct-14	7576	2BLK53H298A	GEMINI-CASI	14.6 GB	208 KB	354 KB	228	N/A	N/A	17.1	N/A	4.91	1 KB	1 KB	151 KB	8.55 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
26-Oct-14	7578	2BLK53HSGF299A	GEMINI-CASI	6.74 GB	426 KB	411 KB	259	N/A	N/A	18.1	N/A	6.18	1 KB	1 KB	672 KB	16.4 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
27-Oct-14	7580	2BLK56ESBLK53FS300A	GEMINI-CASI	2.30 GB	122 KB	240 KB	229	N/A	N/A	10.9	N/A	5.16	1 KB	1 KB	141 KB	7.89 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
28-Oct-14	7582	2BLK56BSES301A	GEMINI-CASI	12.7 GB	272 KB	344 KB	165	7.62 GB	63.1 KB	16.7	N/A	8.47	1 KB	1 KB	193 KB	N/A	\\aquinas.lan.dream.upd.edu.ph\RAWDATA
28-Oct-14	7583	2BLK56ABS301B	GEMINI-CASI	N/A	82.1 KB	307 KB	145	N/A	N/A	9.86	N/A	8.47	1 KB	1 KB	N/A	11.8 KB	\\aquinas.lan.dream.upd.edu.ph\RAWDATA

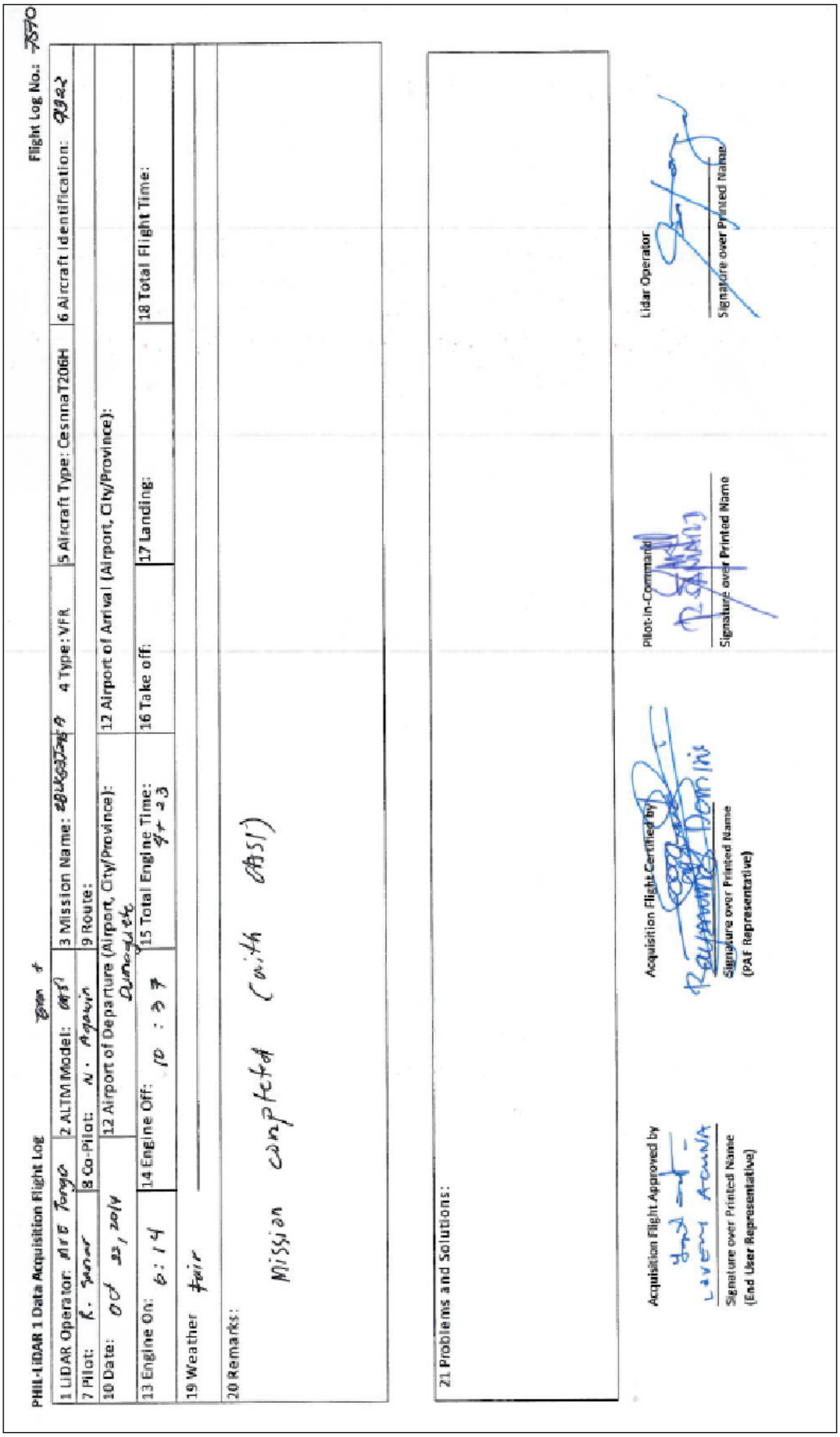
RECEIVED FROM:
NAME: C. Joaquin
POSITION:
SIGNATURE:

RECEIVED BY:
NAME: JOIDA PRIETO
POSITION: SSRS
SIGNATURE:
DATE: NOV/06/2014

Figure A-5.1 Data Transfer Sheet for Tiabanan Floodplain Flight - A

Annex 6. Flight Logs

1. Flight Log for 2BLK53H295A Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7570

1 LiDAR Operator: ARE Tongo	2 ALTM Model: Gem 7	3 Mission Name: 2BLK53H295A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9322
7 Pilot: R. Samar	8 Co-Pilot: N. Agawin	9 Route:			
10 Date: Oct 22, 2014	12 Airport of Departure (Airport, City/Province): Dumaguete		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 6:14	14 Engine Off: 10:37	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: fair					

20 Remarks:

Mission completed (with GAS1)

21 Problems and Solutions:

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

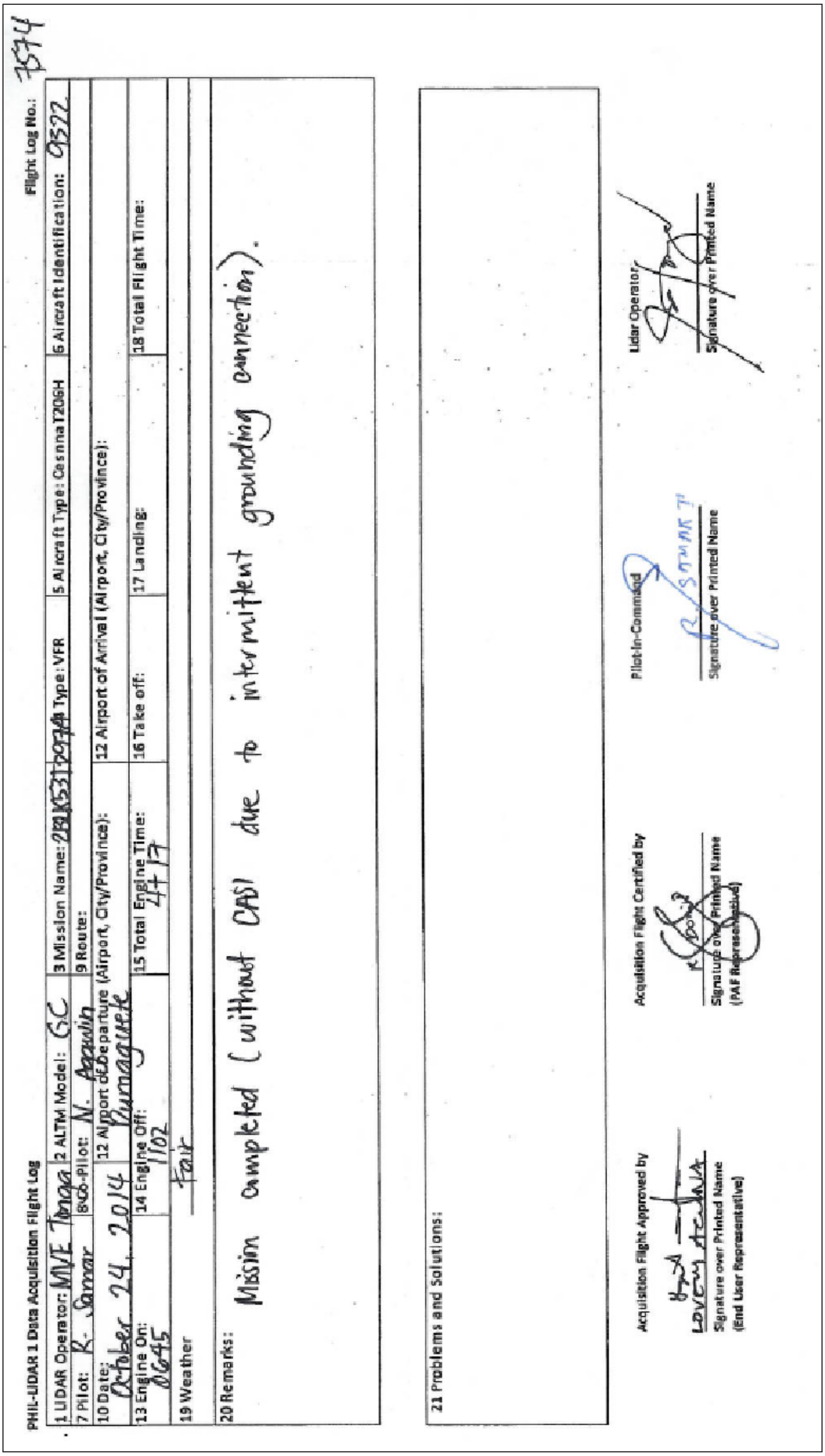
Acquisition Flight Certified by: Raymond Dominis — Signature over Printed Name (PAF Representative)

Pilot-in-Command: R. Samar — Signature over Printed Name

Lidar Operator: Signature over Printed Name

Figure A-6.1 Flight Log for 2BLK53H295A Mission

2. Flight Log for 2BLK53G297A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7574

1 LiDAR Operator: MVE Tonga	2 ALTM Model: GC	3 Mission Name: 2BLK53G297A	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: 9322
7 Pilot: R. Samar	8 Co-Pilot: N. Aguilin	9 Route:			
10 Date: October 24, 2014	12 Airport of Departure (Airport, City/Province): Dumaguete		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 0645	14 Engine Off: 1102	15 Total Engine Time: 4+17	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Fair					

20 Remarks:

Mission completed (without CASI due to intermittent grounding connection).

21 Problems and Solutions:

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

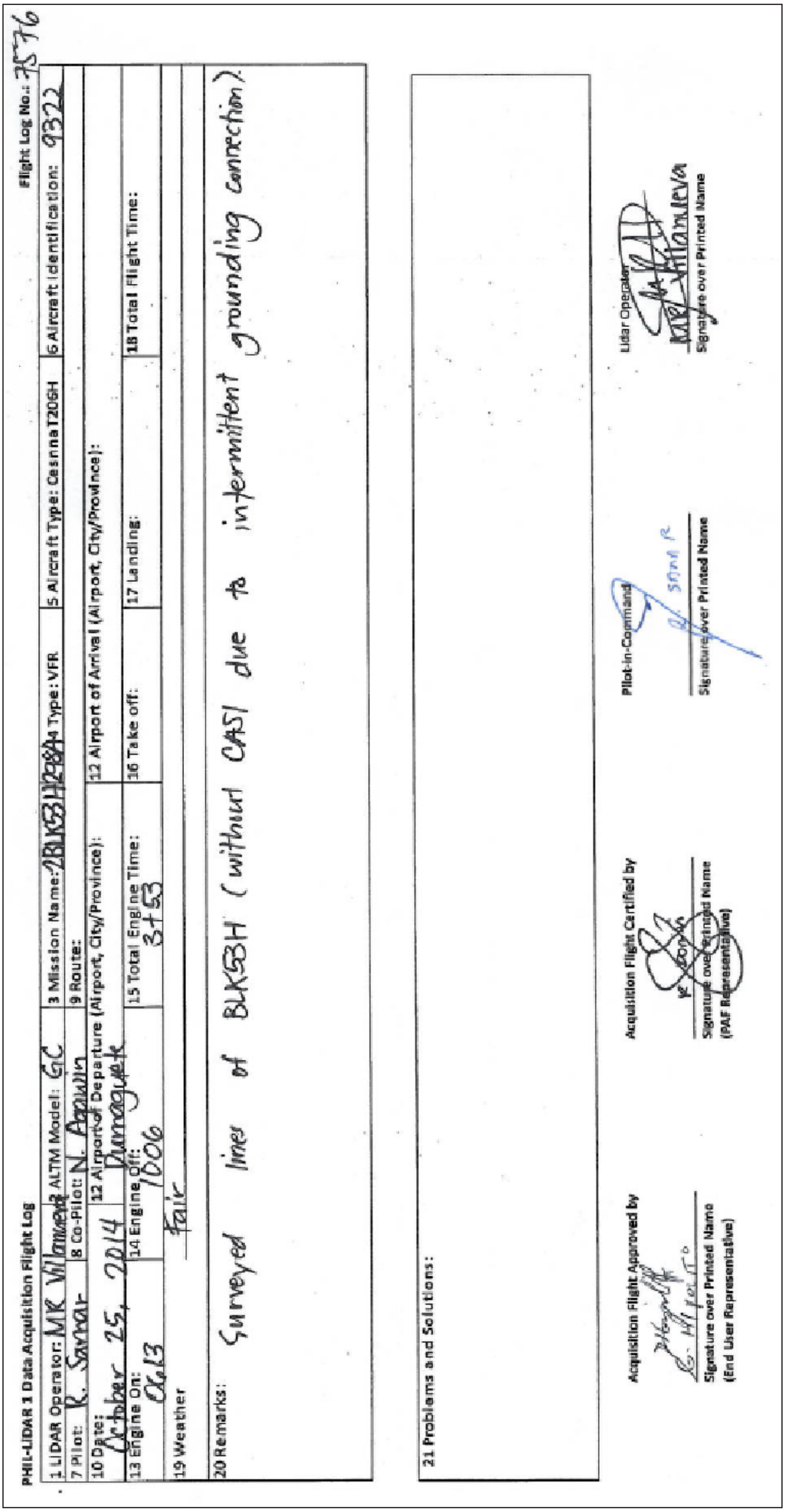
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Figure A-6.2 Flight Log for 2BLK53G297A Mission

3. Flight Log for 2BLK53F298A Mission


PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7576

1 LIDAR Operator: MK Villanueva	2 ALTM Model: GC	3 Mission Name: 2BLK53H298A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: R. Samar	8 Co-Pilot: N. Aquino	9 Route:			
10 Date: October 25, 2014	12 Airport of Departure (Airport, City/Province): Dumaguete		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 0613	14 Engine Off: 1006	15 Total Engine Time: 3+53	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Fair					

20 Remarks: Surveyed lines of BLK53H (without CASI due to intermittent grounding connection).

21 Problems and Solutions:

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

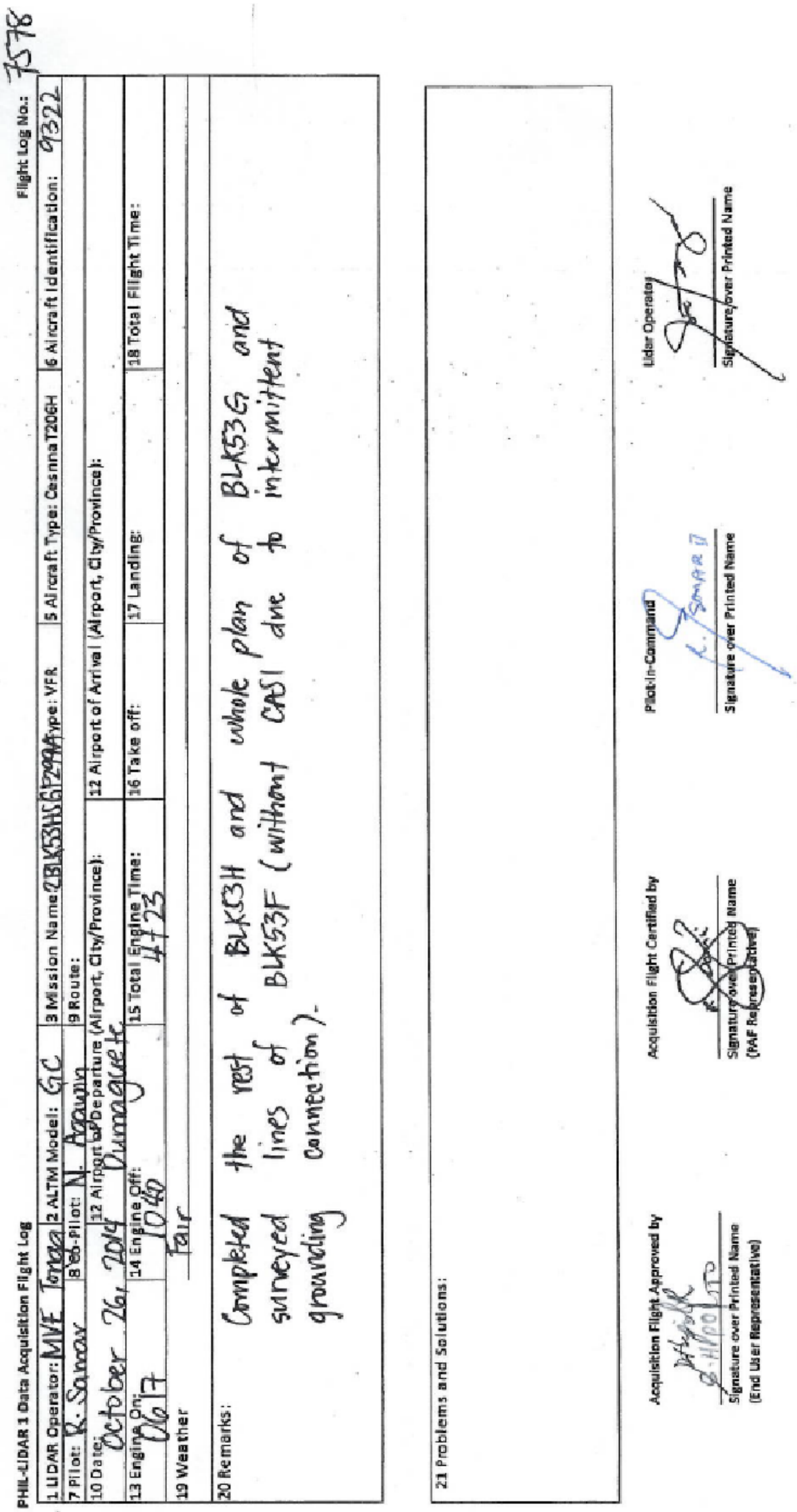
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — MK Villanueva — Signature over Printed Name

Figure A-6.3 Flight Log for 2BLK53F298A Mission

4. Flight Log for 2BLK53DEFS299A Mission



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 7578

1 LiDAR Operator: MVE Tonga	2 ALTM Model: GC	3 Mission Name: 2BLK53HSG1299A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: R. Samar	8 Co-Pilot: N. Aguirin	9 Route:			
10 Date: October 26, 2014	12 Airport of Departure (Airport, City/Province): Dumaguete		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 0617	14 Engine Off: 1040	15 Total Engine Time: 4+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Fair					
20 Remarks: Completed the rest of BLK53H and whole plan of BLK53G and surveyed lines of BLK53F (without CASI due to intermittent grounding connection).					

21 Problems and Solutions:

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

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

Pilot-in-Command: R. Samar II — Signature over Printed Name

Lidar Operator: Signature over Printed Name

Figure A-6.4 Flight Log for 2BLK53DEFS299A Mission

Annex 7. Flight Status Report

NEGROS OCCIDENTAL-NEGROS ORIENTAL

(September 24 to October 6, 2014)

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
7570G	BLK 53H	2BLK53H295A	MVE Tonga	October 22, 2014	Mission completed (with CASI)
7574G	BLK 53G	2BLK53G297A	MVE Tonga	October 24, 2014	Mission completed (without CASI due to intermittent grounding connection)
7576G	BLK 53F	2BLK53F298A	MR Villanueva	October 25, 2014	Surveyed lines of BLK53F (without CASI due to intermittent grounding connection)
7578G	BLK 53D; 53E; 53F	2BLK53DEFS299A	MVE Tonga	October 26, 2014	Completed the rest of BLK53F and whole plan of BLK53E and surveyed lines of BLK53F (without CASI due to intermittent grounding connection)

LAS BOUNDARIES PER FLIGHT

LAS

Flight No.:	7570G		
Area:	BLK 53H		
Mission Name:	2BLK53H295A		
Parameters:	Altitude: 1000 m;	Scan Frequency: 50 Hz;	
Scan Angle:	20 deg;	Overlap: 60%	

LAS

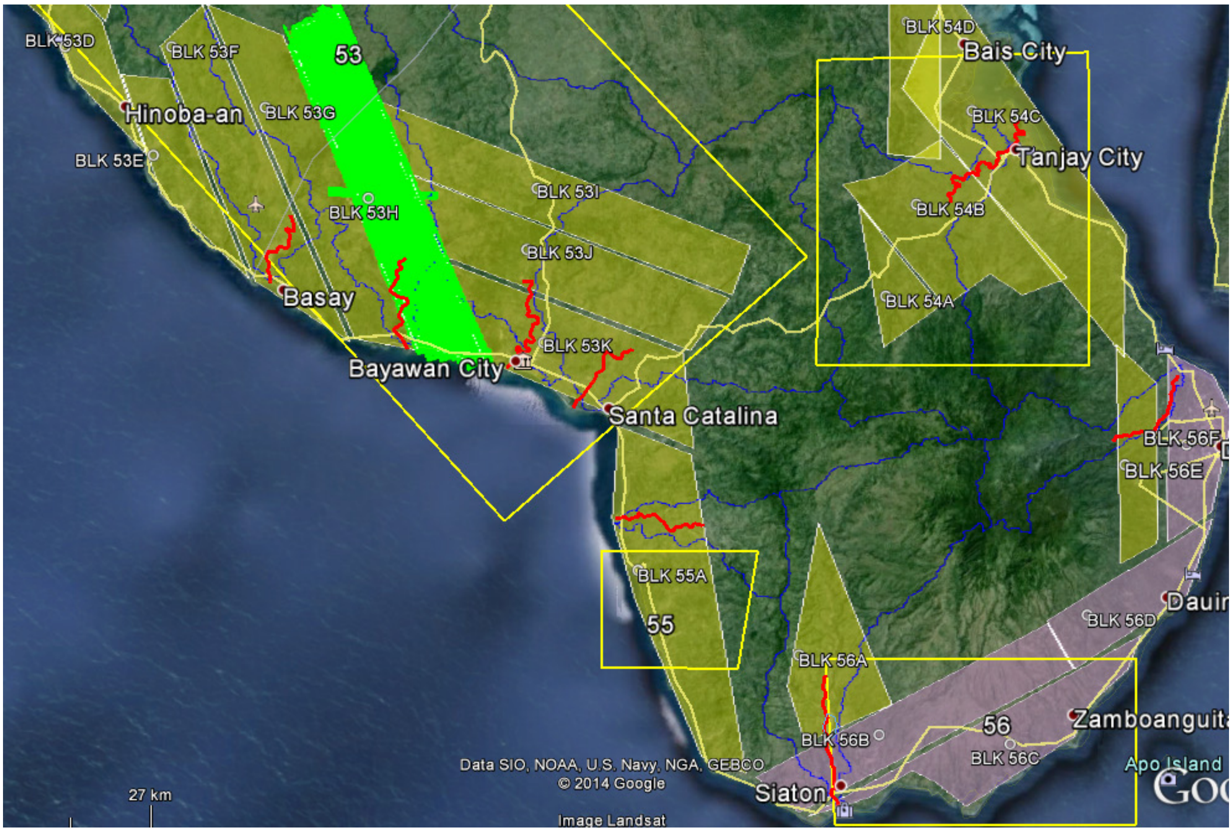


Figure A-7.1 Swath for Flight No. 7570G

Flight No.: 7574G
Area: BLK 53G
Mission Name: 2BLK53G297A
Parameters: Altitude: 1000 m; Scan Frequency: 50 Hz;
Scan Angle: 20 deg; Overlap: 60%

LAS

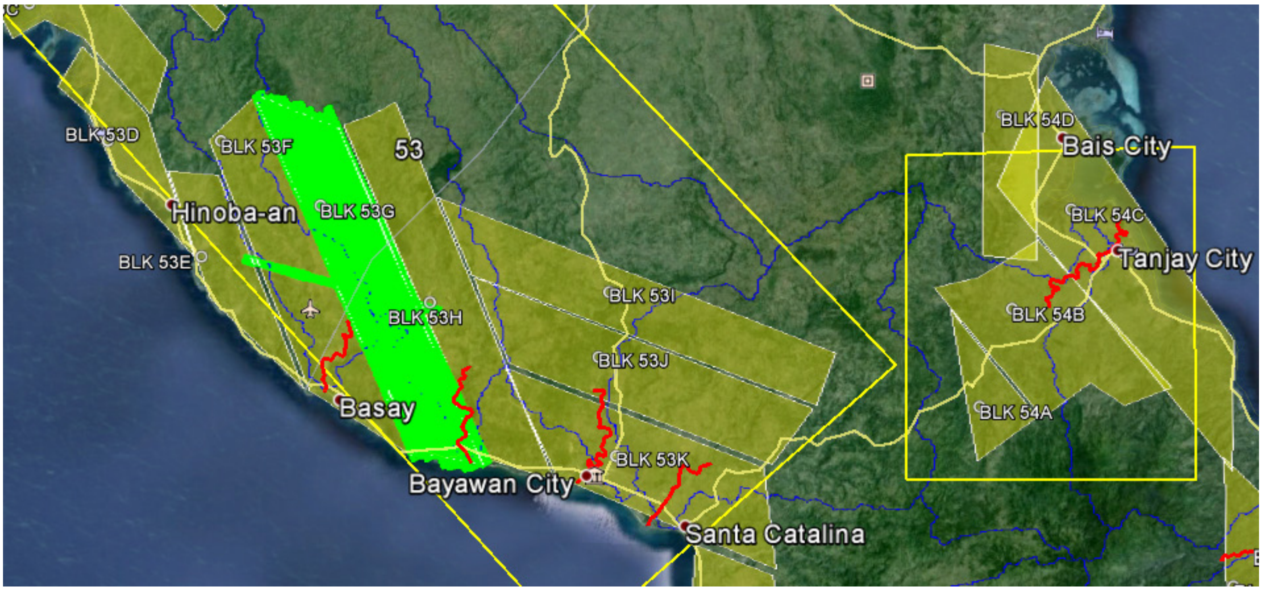


Figure A-7.2 Swath for Flight No. 7574G

Flight No.:	7576G		
Area:	BLK 53F		
Mission Name:	2BLK53F298A		
Parameters:	Altitude: 1000 m;	Scan Frequency: 50 Hz;	
Scan Angle:	20 deg;	Overlap: 60%	

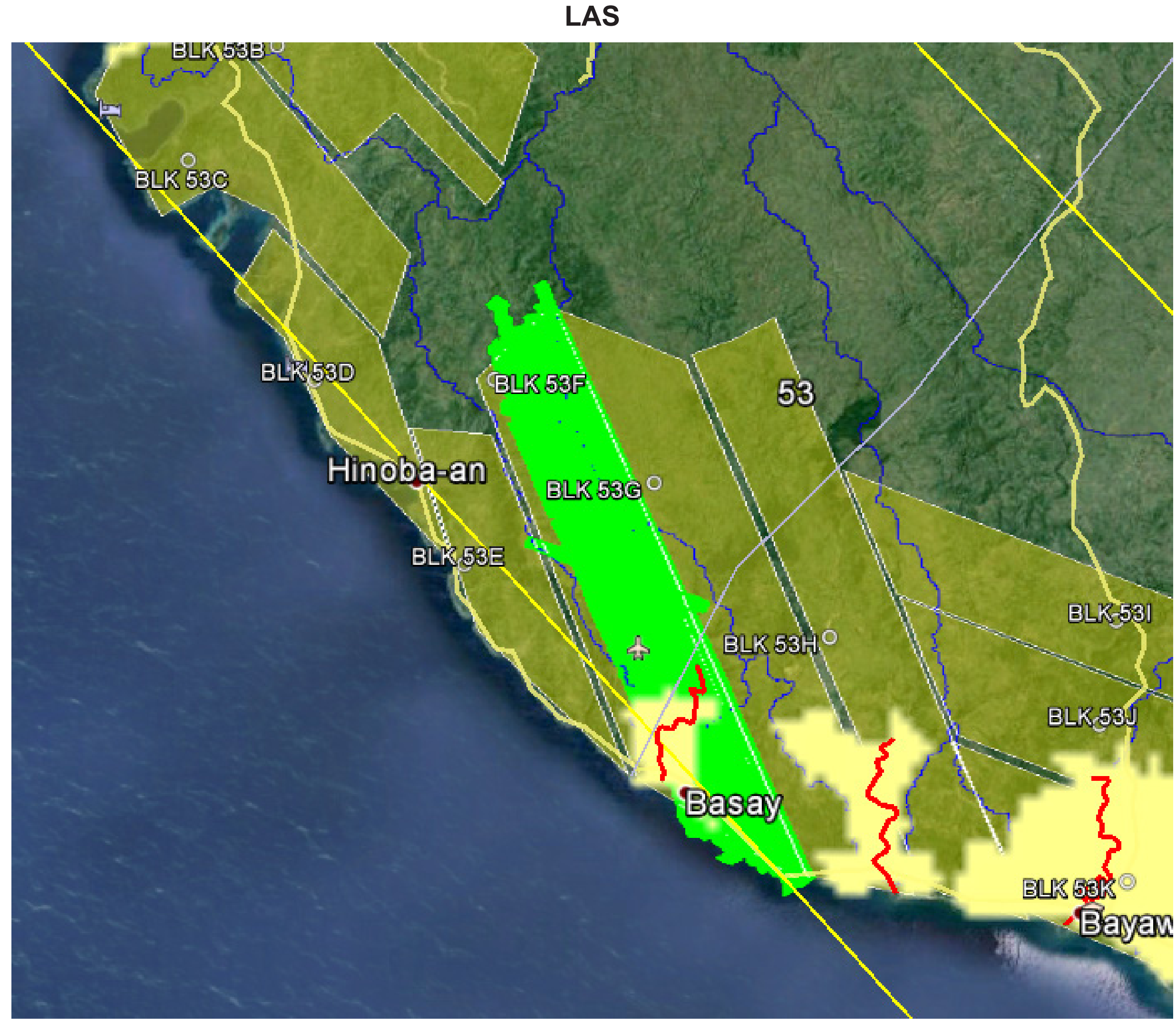


Figure A-7.3 Swath for Flight No. 7576G

Flight No.: 7578G
Area: BLK 53D, BLK 53E, BLK 53F
Mission Name: 2BLK53DEFS299A
Parameters: Altitude: 1000 m; Scan Frequency: 50 Hz;
Scan Angle: 20 deg; Overlap: 60%

LAS

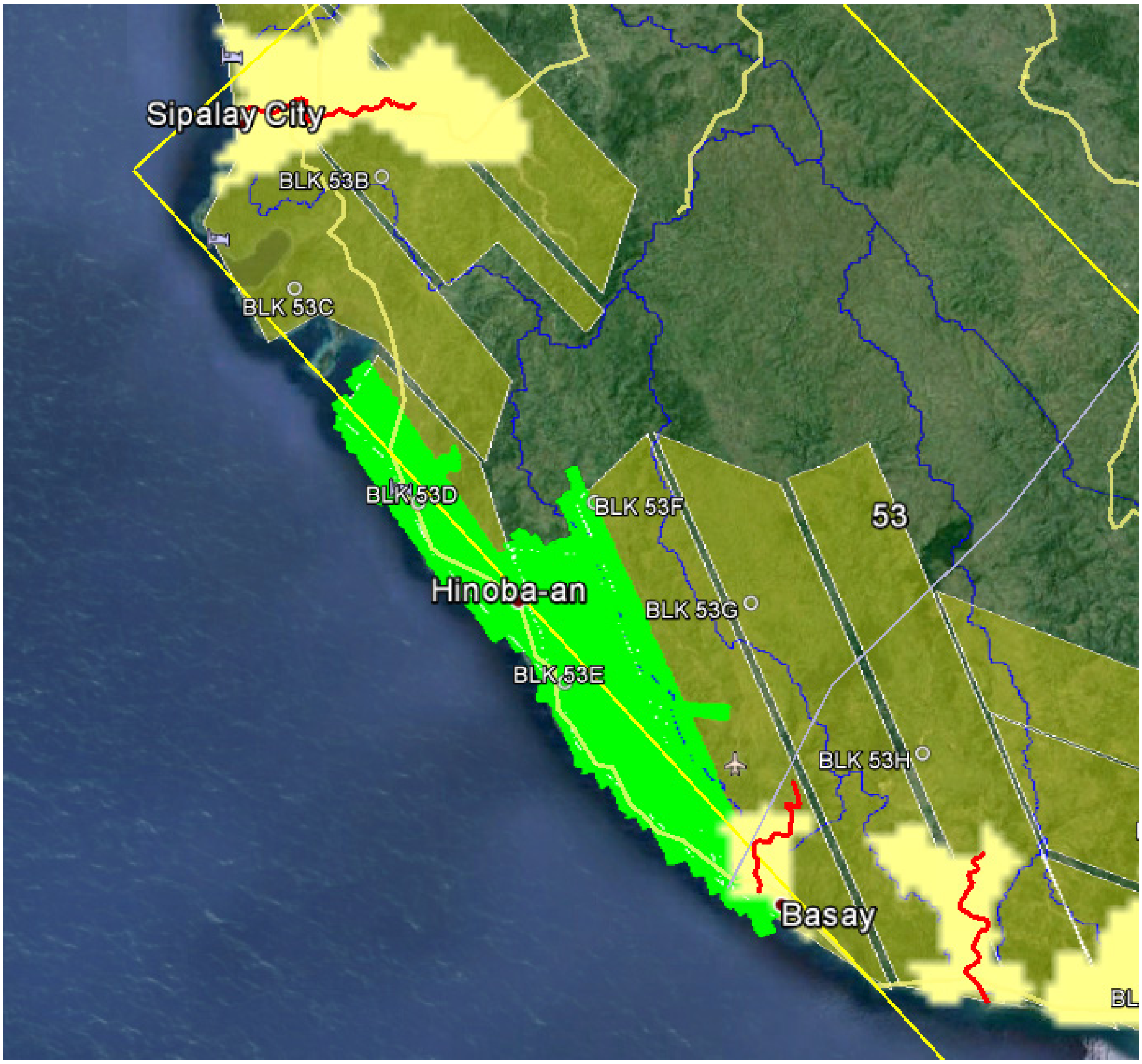


Figure A-7.4 Swath for Flight No. 7578G

Annex 8. Mission Summary Report

Table A-8.1 Mission Summary Report for Mission Blk53I

Flight Area	Dumaguete
Mission Name	**Blk53I**
Inclusive Flights	7562G, 7574G
Range data size	44.3 GB
Base data size	12.27 MB
POS	506 MB
Image	NA
Transfer date	
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)	2.6
RMSE for East Position (<4.0 cm)	2.1
RMSE for Down Position (<8.0 cm)	3.7
Boresight correction stdev (<0.001deg)	0.000167
IMU attitude correction stdev (<0.001deg)	0.000962
GPS position stdev (<0.01m)	0.0024
Minimum % overlap (>25)	36.98%
Ave point cloud density per sq.m. (>2.0)	4.22
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	419
Maximum Height	583.91 m
Minimum Height	61.34 m
Classification (# of points)	
Ground	142,510,622
Low vegetation	138,131,902
Medium vegetation	387,773,870
High vegetation	480,080,109
Building	9,091,742
Orthophoto	No
Processed by	Engr. Irish Cortez, Engr. Edgardo Gubatanga Jr., Engr. Jeffrey Delica

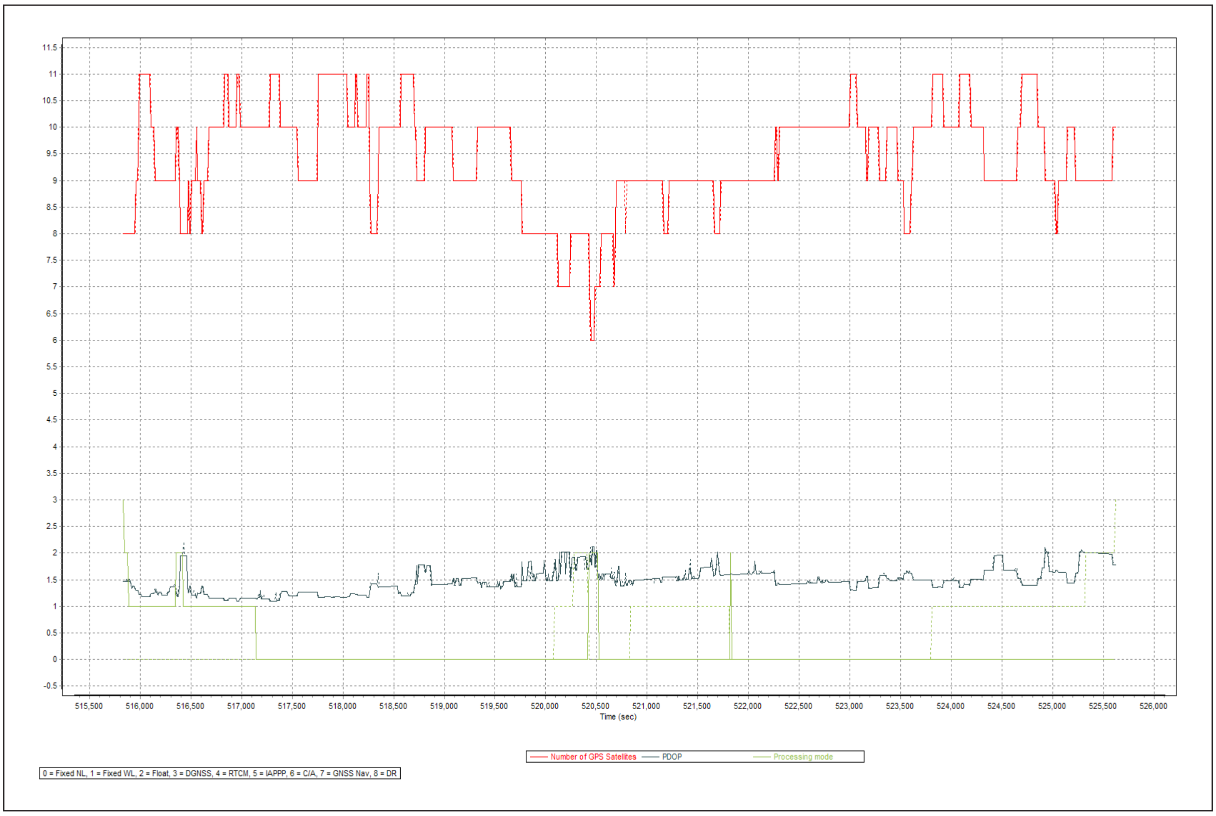


Figure A-8.1 Solution Status

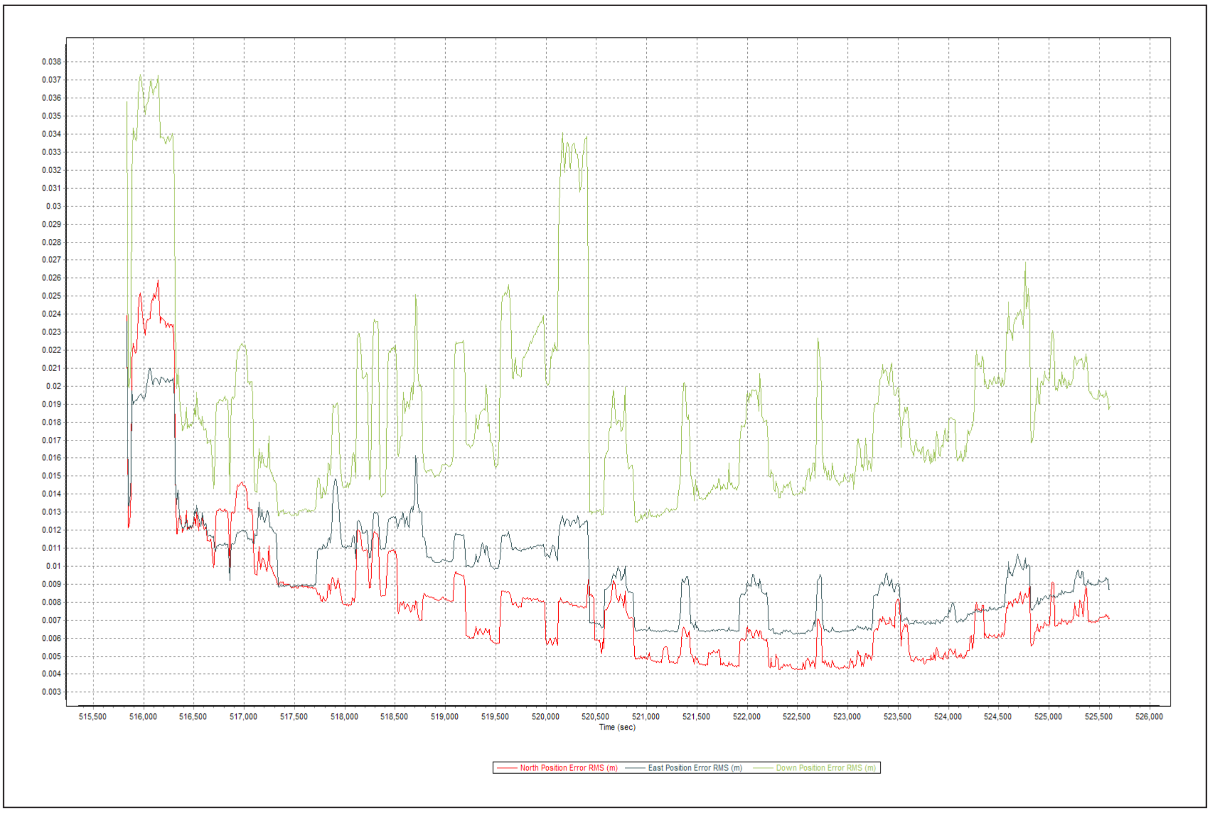


Figure A-8.2 Smoothed Performance Metrics Parameters

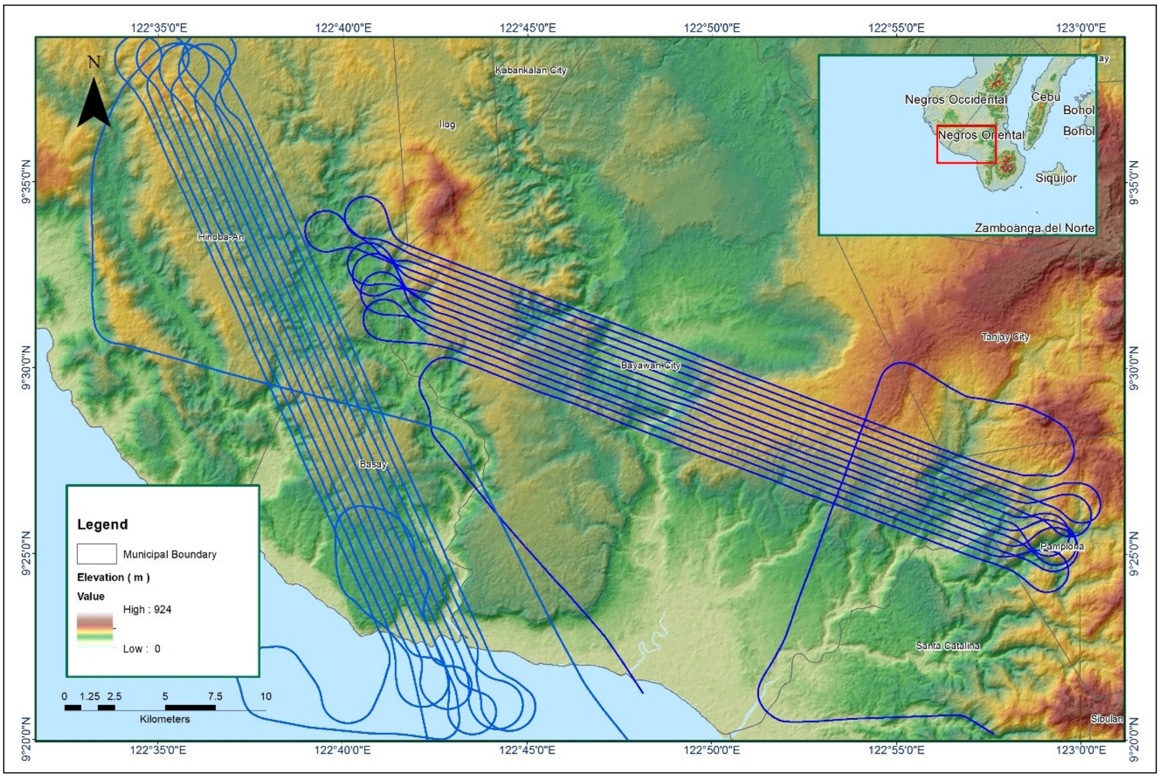


Figure A-8.3 Best Estimated Trajectory

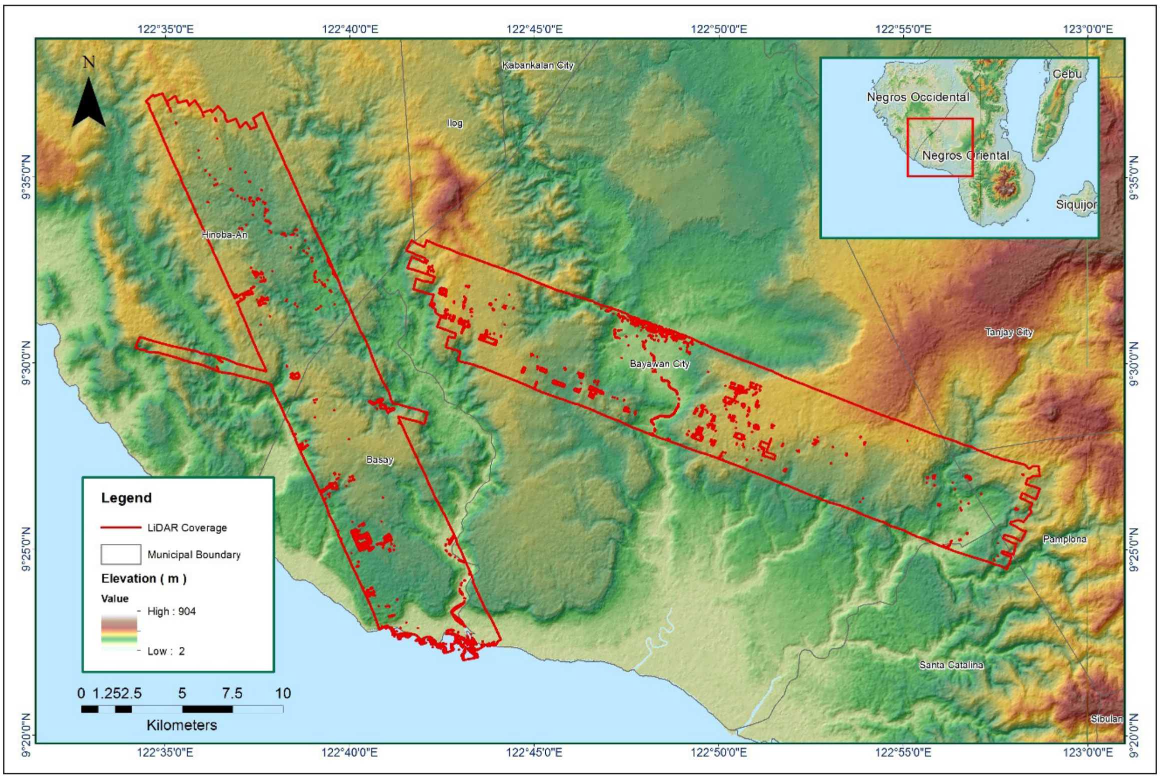


Figure A-8.4. Coverage of LiDAR data

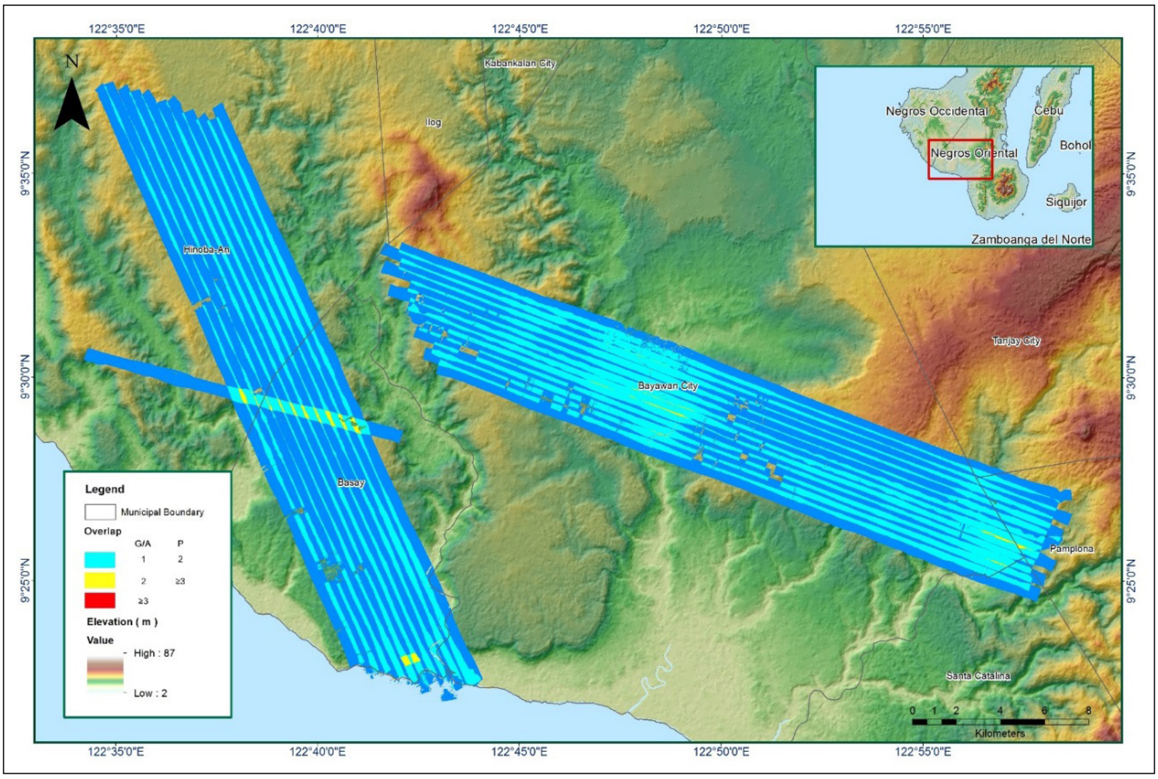


Figure A-8.5. Image of data overlap

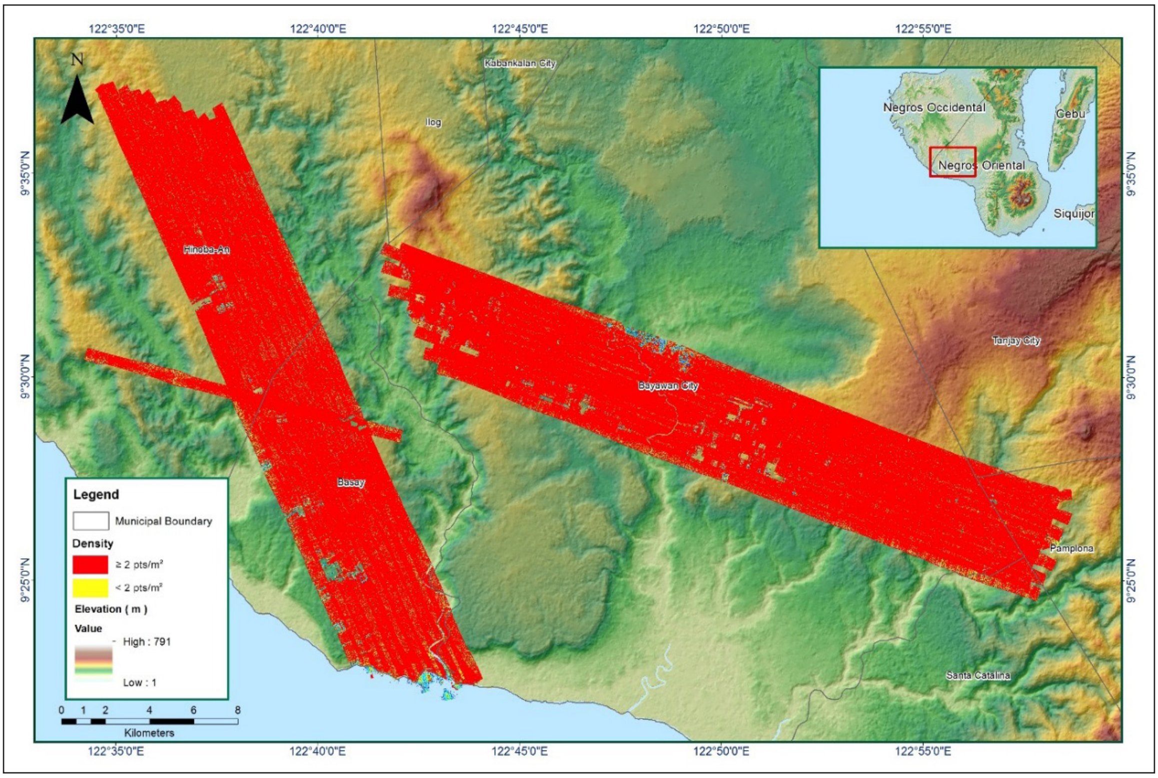


Figure A-8.6 Density of merged LiDAR data

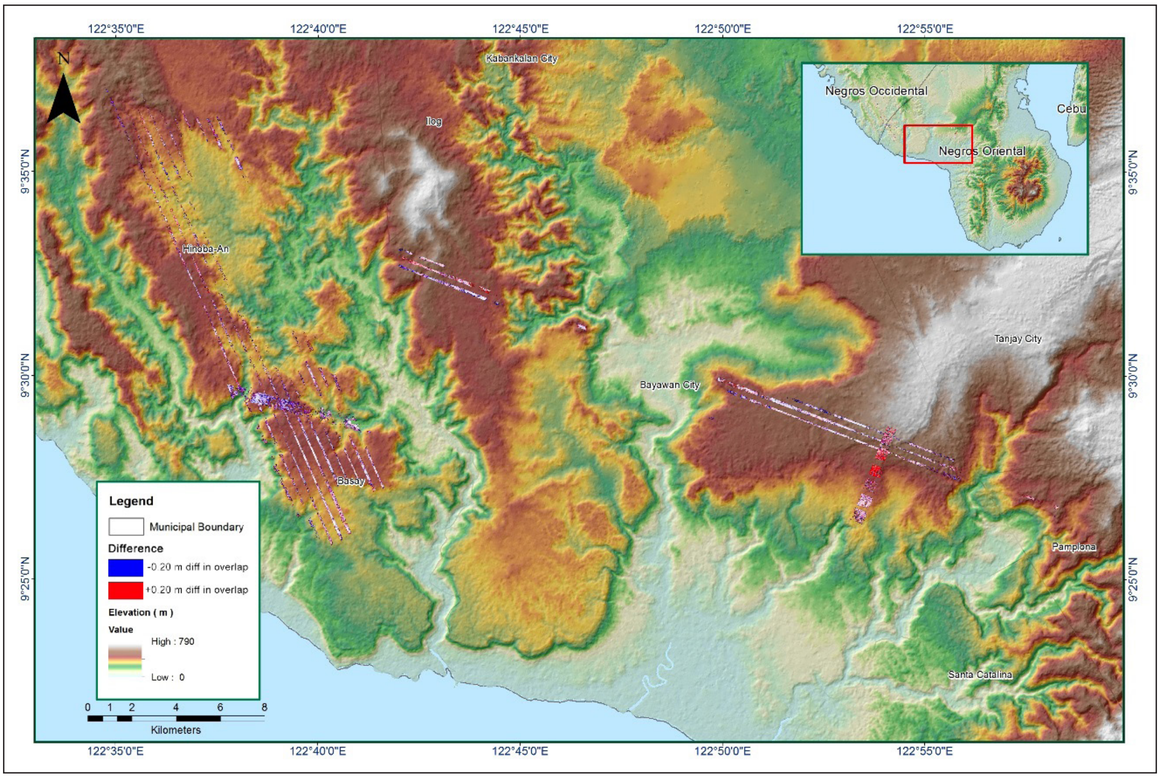


Figure A-8.7. Elevation difference between flight lines

Table A-8.2 Mission Summary Report for Mission Blk53H

Flight Area	Dumaguete
Mission Name	**Blk53H**
Inclusive Flights	7570G,7576G,7578G
Range data size	56.7 GB
Base data size	17.66 MB
POS	733 MB
Image	NA
Transfer date	
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)	0.095
RMSE for East Position (<4.0 cm)	1.25
RMSE for Down Position (<8.0 cm)	2.4
Boresight correction stdev (<0.001deg)	0.000168
IMU attitude correction stdev (<0.001deg)	0.000941
GPS position stdev (<0.01m)	0.0163
Minimum % overlap (>25)	42.05%

Ave point cloud density per sq.m. (>2.0)	4.00
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	513
Maximum Height	566.13 m
Minimum Height	60.29
Classification (# of points)	
Ground	160,627,756
Low vegetation	155,917,160
Medium vegetation	429,917,645
High vegetation	622,384,647
Building	15,103,346
Orthophoto	No
Processed by	Engr. Jennifer Saguran, Engr. Velina Angela Bemida, Engr. Jeffrey Delica

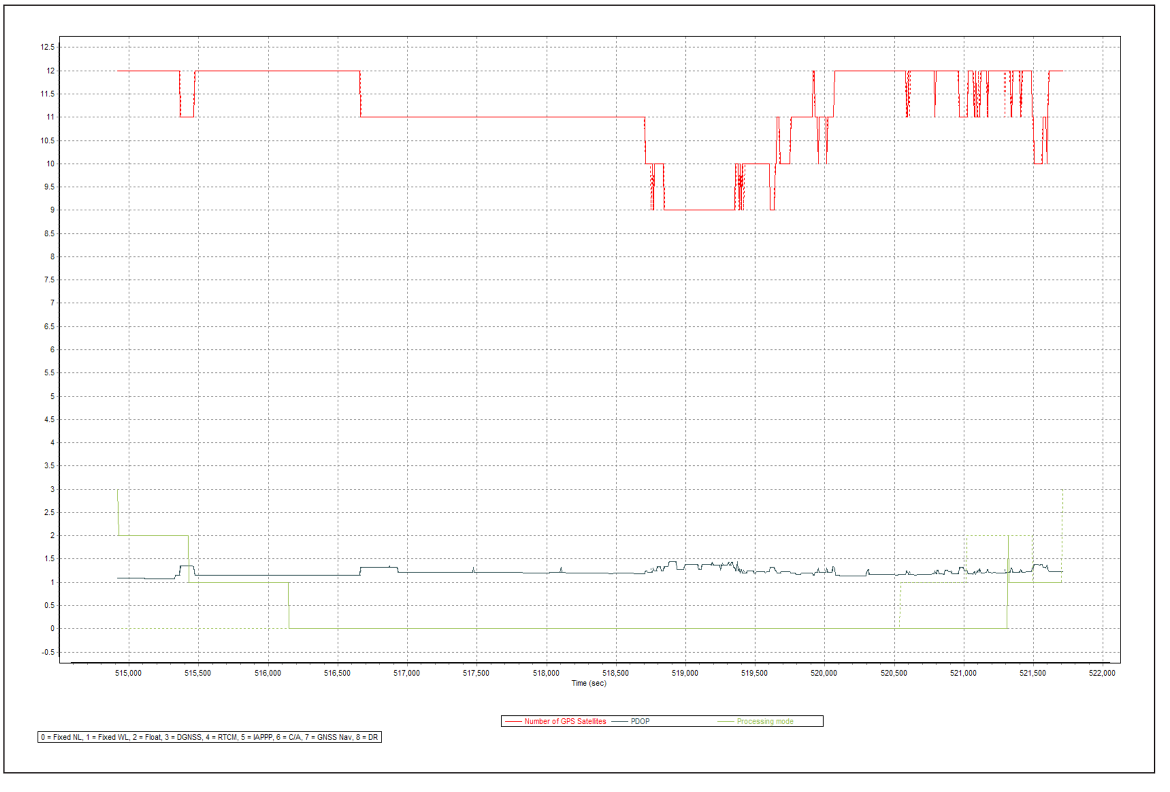


Figure A-8.8. Solution Status

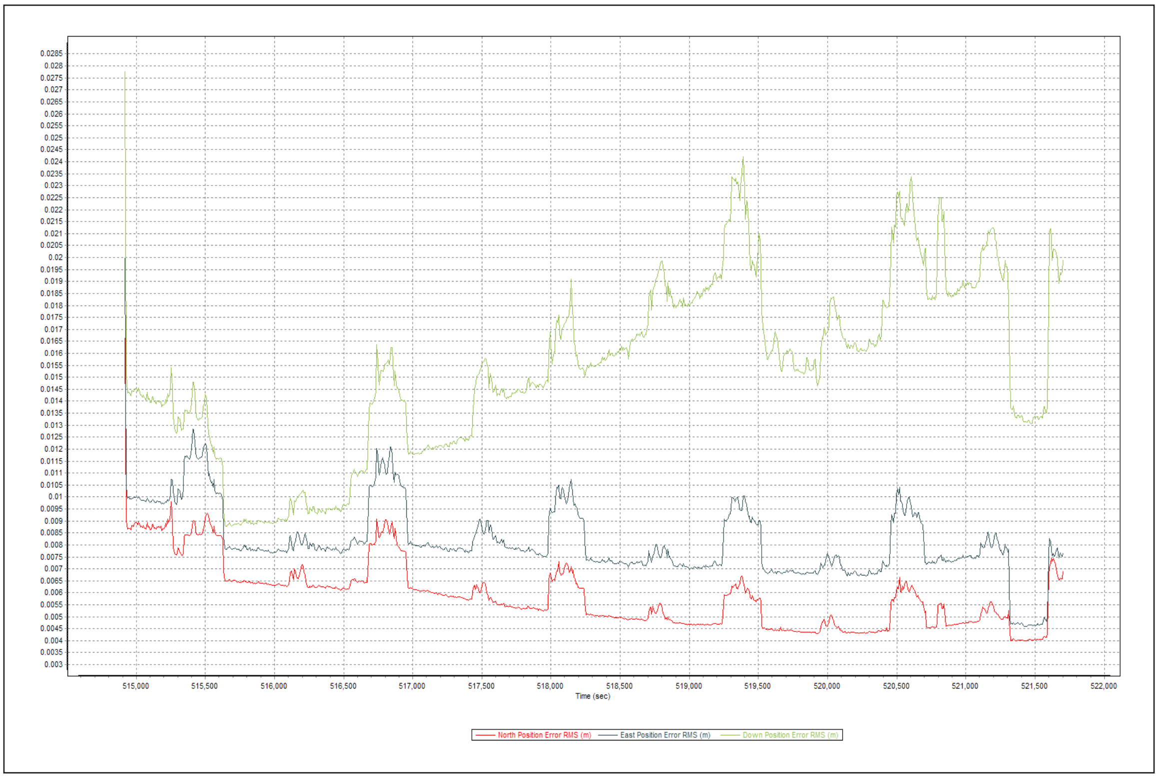


Figure A-8.9. Smoothed Performance Metrics Parameters

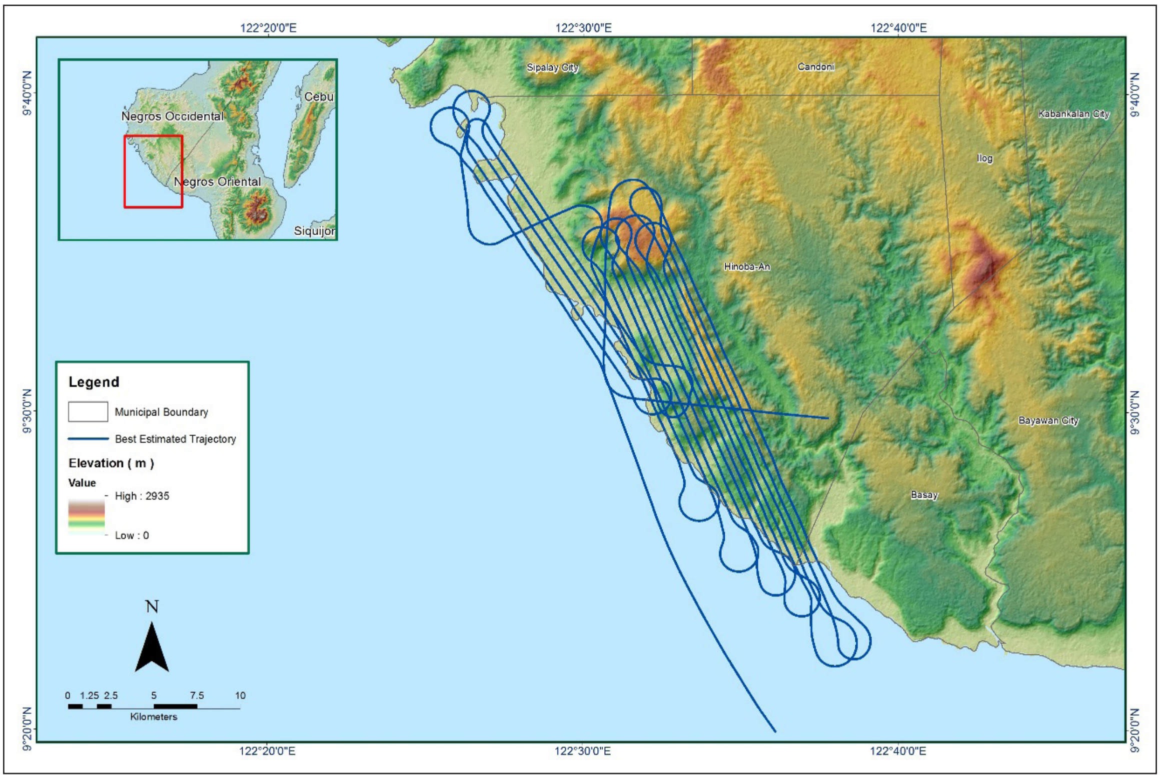


Figure A-8.10. Best Estimated Trajectory

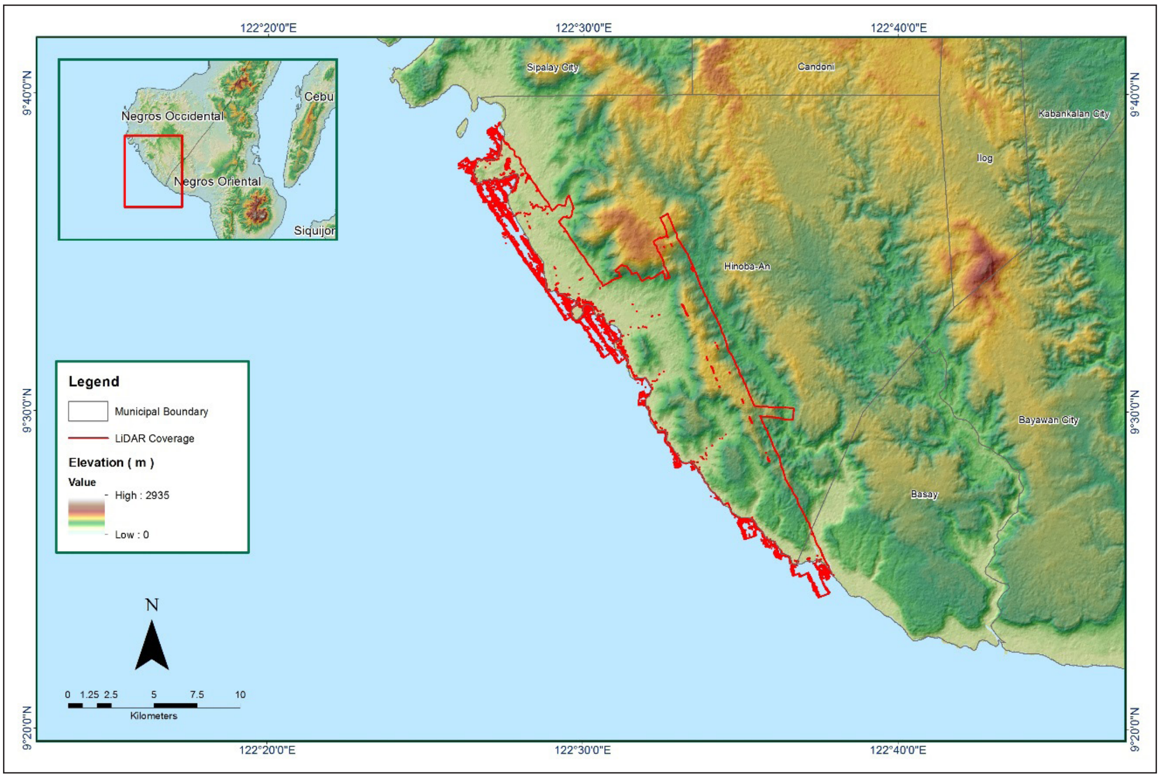


Figure A-8.11. Coverage of LiDAR data

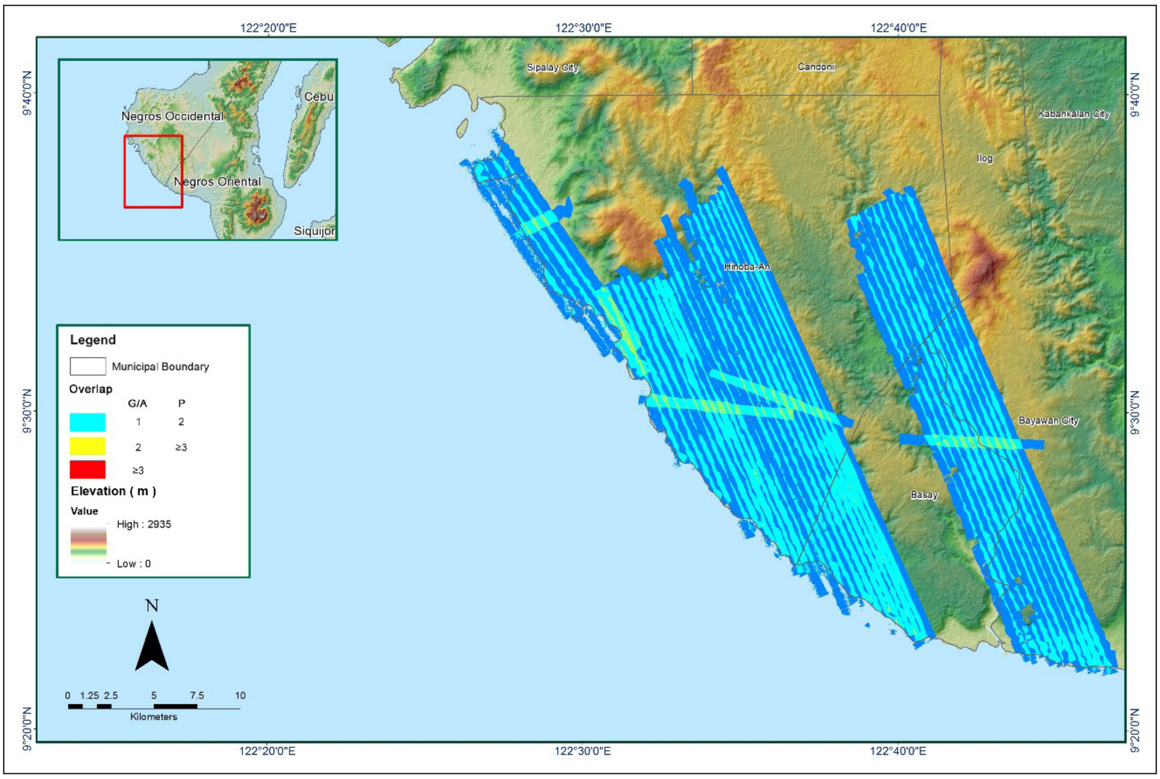


Figure A-8.12. Image of data overlap

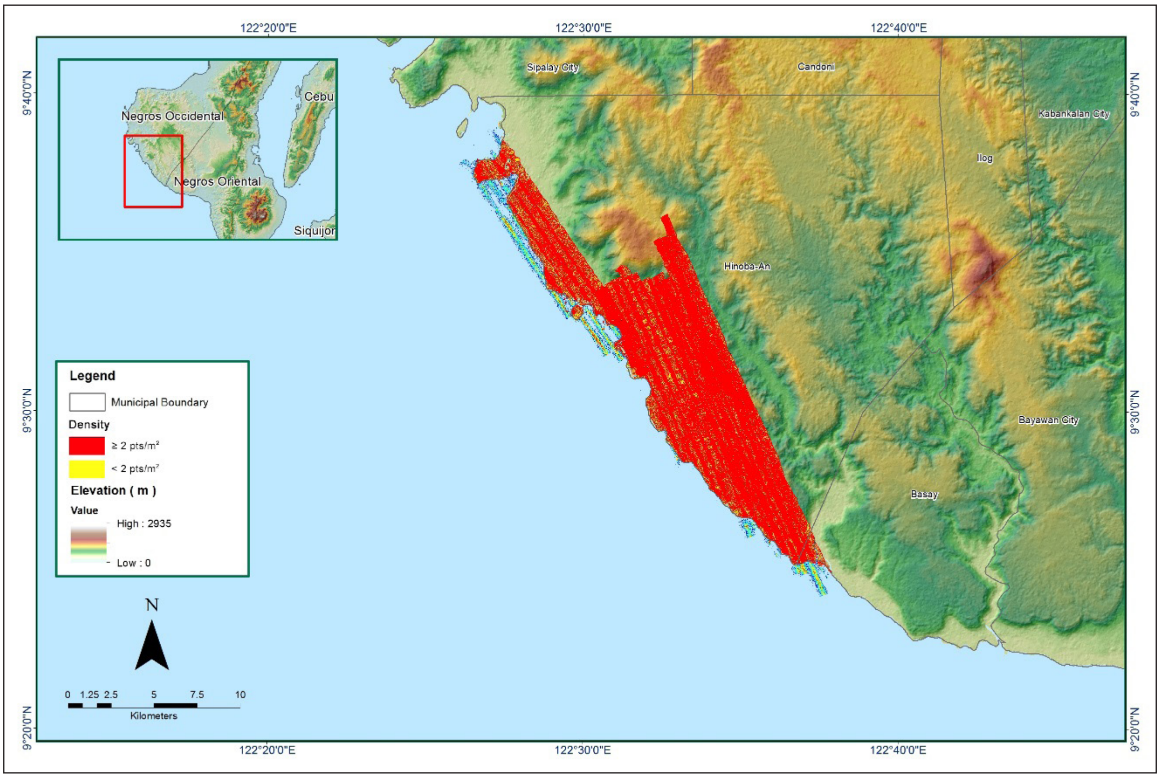


Figure A-8.13. Density of merged LiDAR data

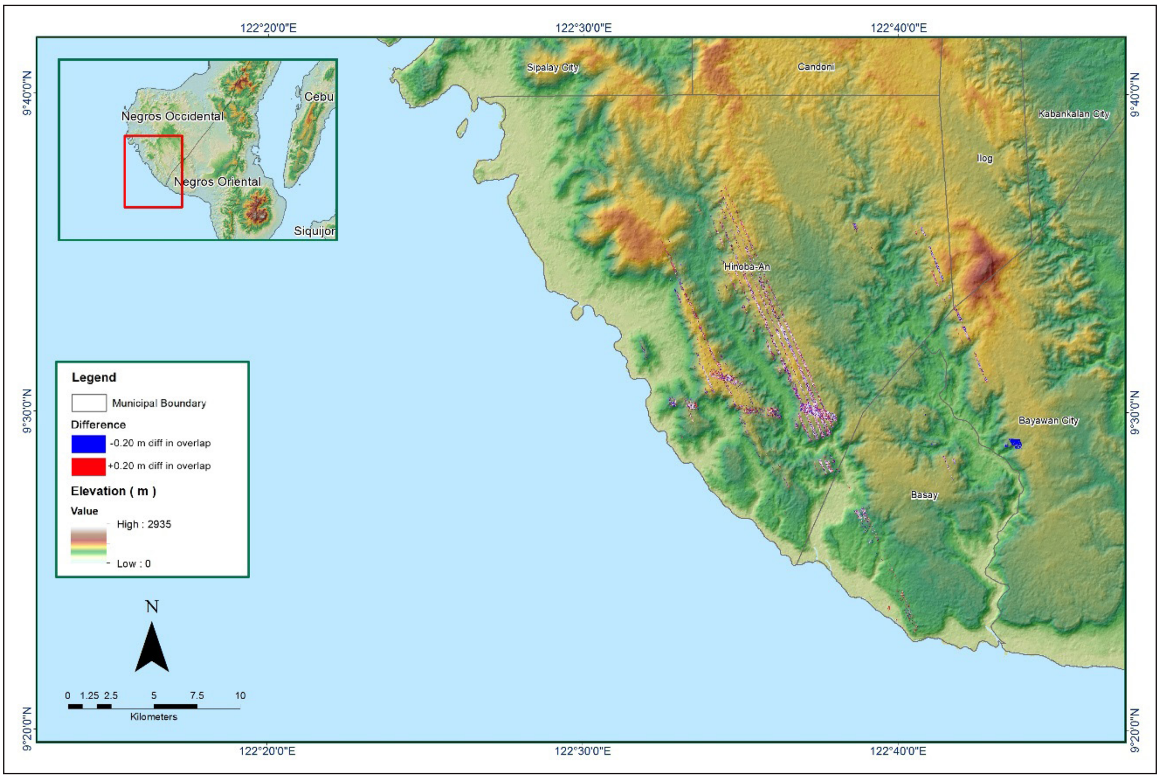


Figure A-8.14. Elevation difference between flight lines

Table A-8.3 Mission Summary Report for Mission Blk53FG

Flight Area	Dumaguete
Mission Name	**Blk53FG**
Inclusive Flights	7578G
Range data size	18.1 GB
Base data size	6.18 MB
POS	259 MB
Image	NA
Transfer date	
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.3
RMSE for East Position (<4.0 cm)	1.9
RMSE for Down Position (<8.0 cm)	2.9
Boresight correction stdev (<0.001deg)	0.000219
IMU attitude correction stdev (<0.001deg)	0.000894
GPS position stdev (<0.01m)	0.0065
Minimum % overlap (>25)	38.20%
Ave point cloud density per sq.m. (>2.0)	3.48
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	188
Maximum Height	565.94 m
Minimum Height	60.27 m
Classification (# of points)	
Ground	51,490,355
Low vegetation	51,920,120
Medium vegetation	111,909,958
High vegetation	185,584,750
Building	1,618,340
Orthophoto	No
Processed by	Engr. Carlyn Ann Ibanez, Engr. Melanie Hingpit, Jovy Narisma

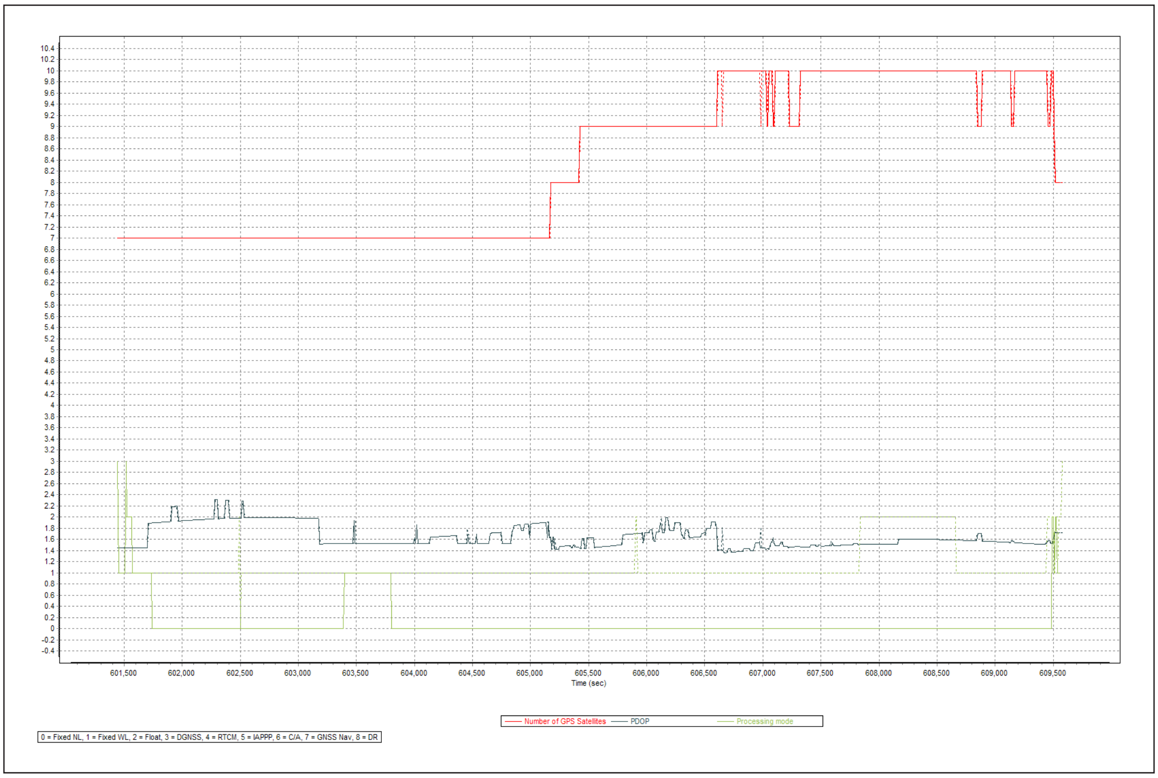


Figure A-8.15. Solution Status

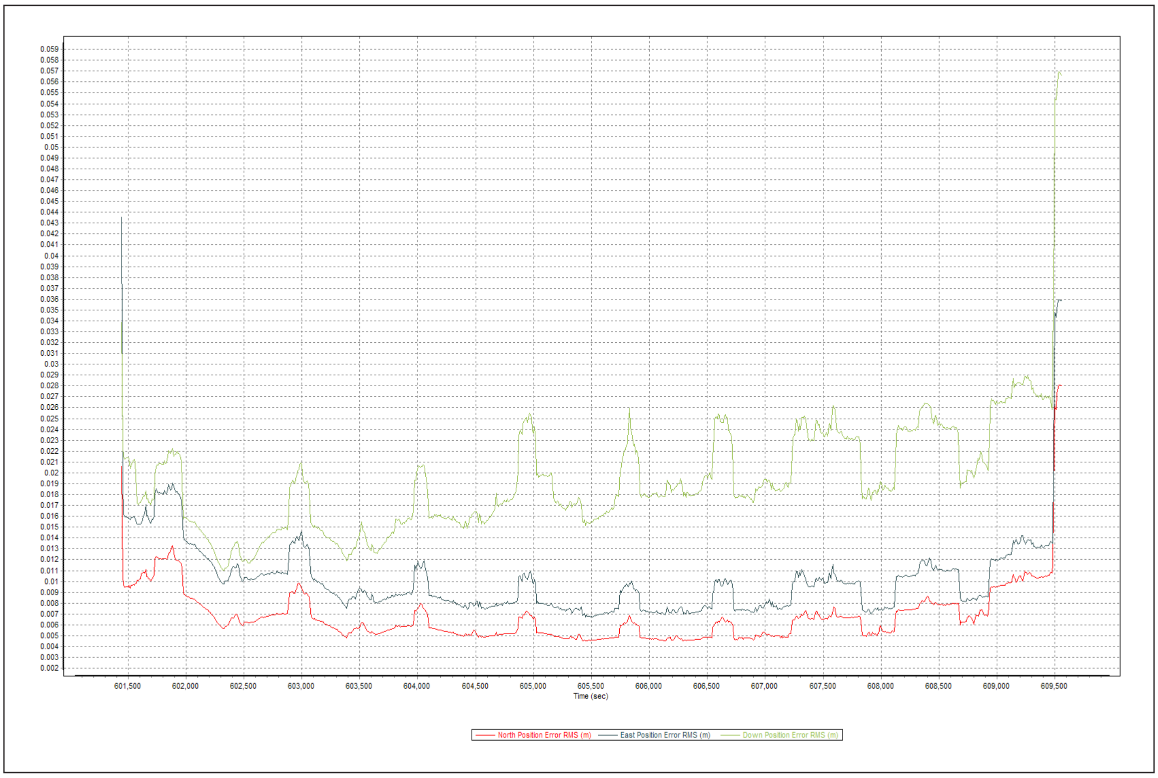


Figure A-8.16. Smoothed Performance Metrics Parameters

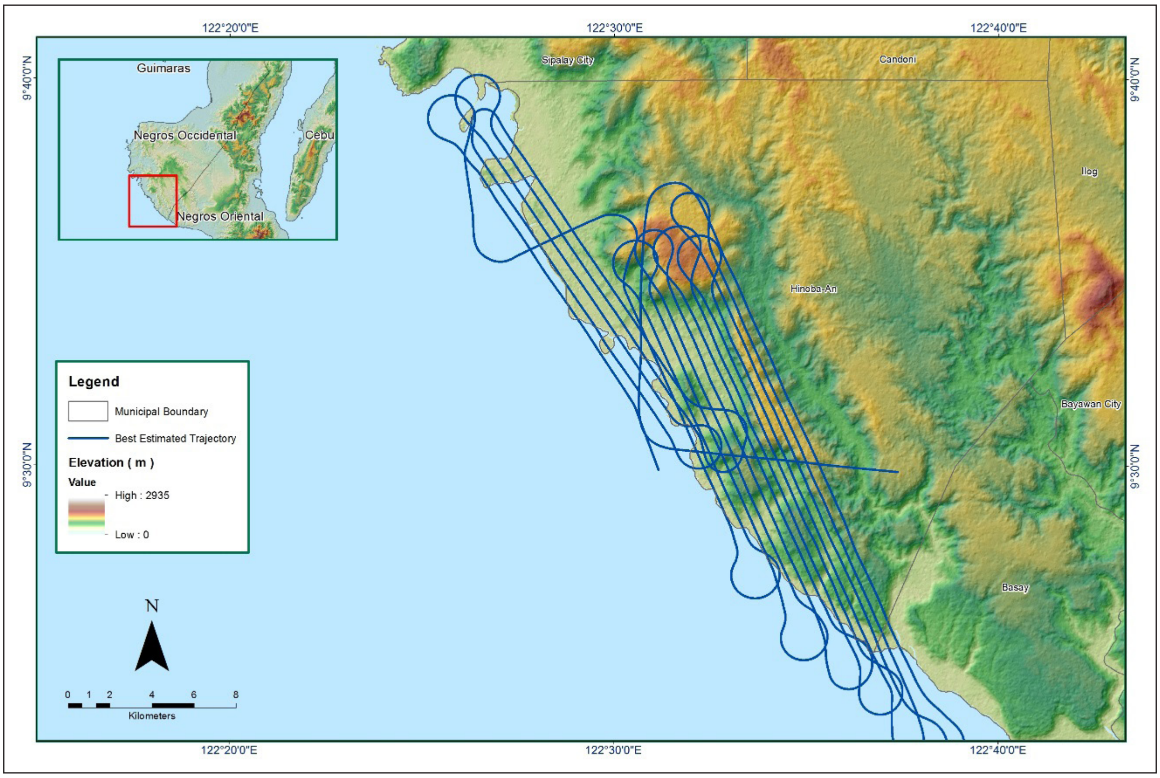


Figure A-8.17. Best Estimated Trajectory

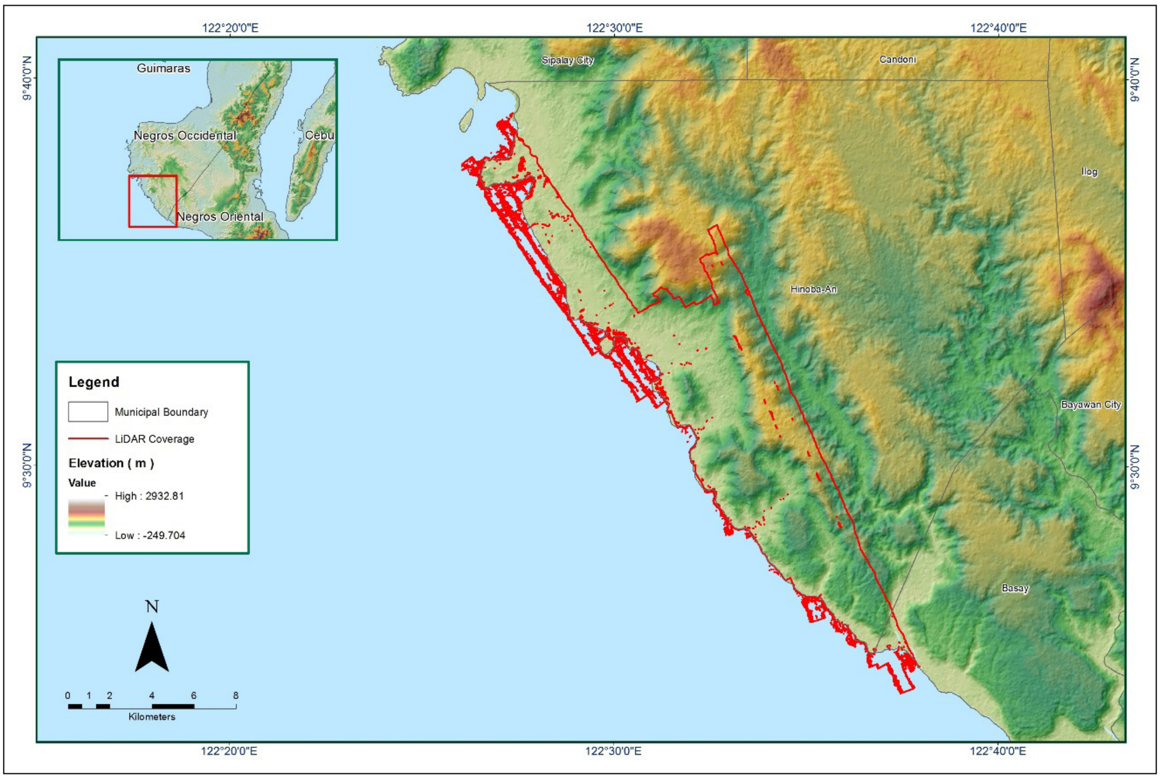


Figure A-8.18. Coverage of LiDAR data

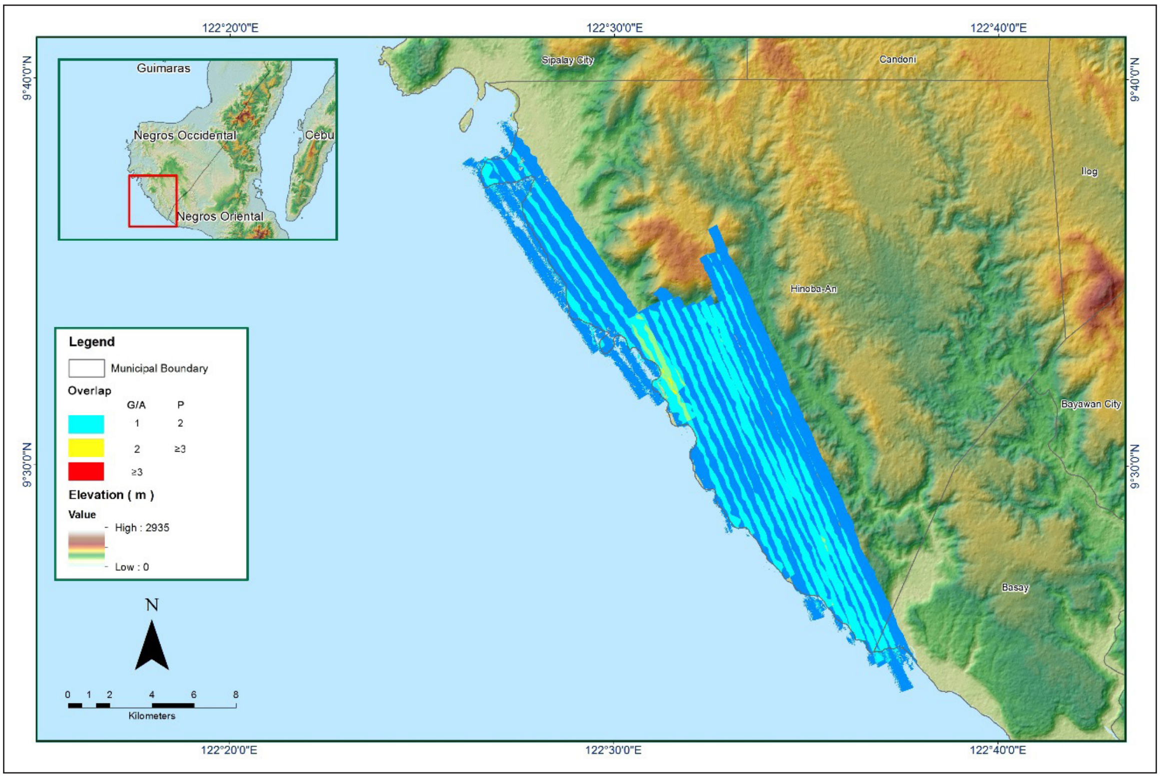


Figure A-8.19. Image of data overlap

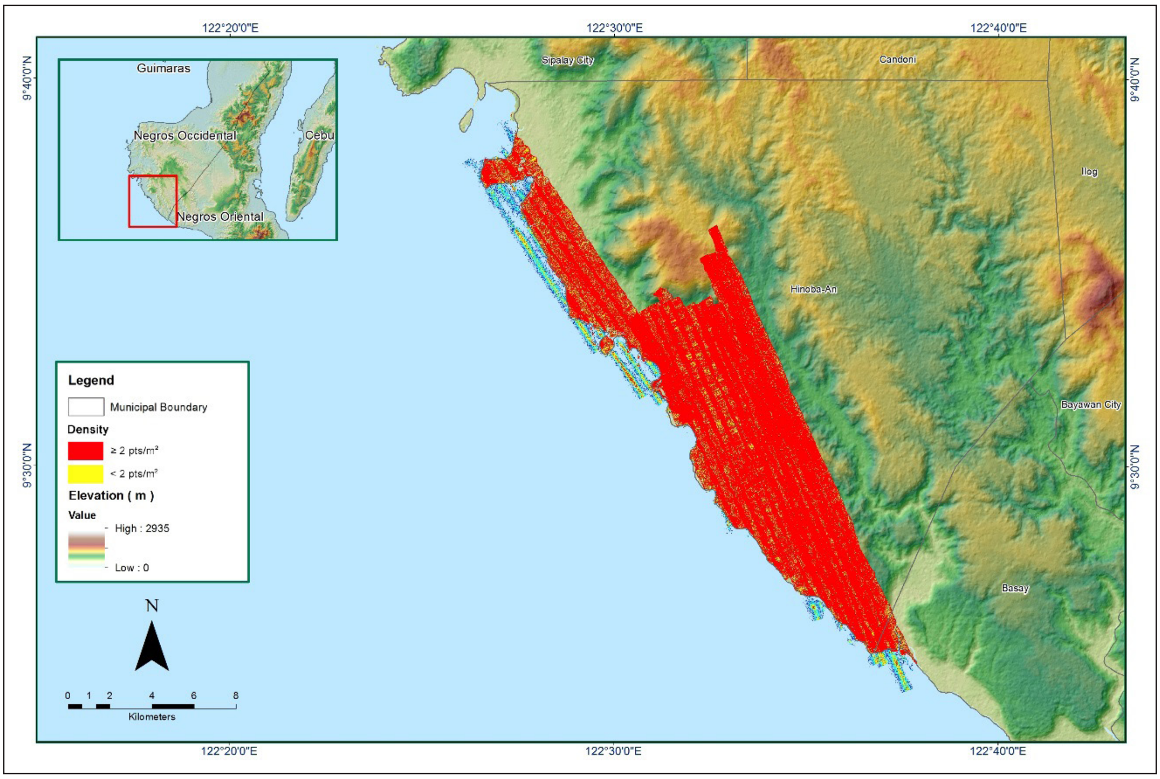


Figure A-8.20. Density of merged LiDAR data

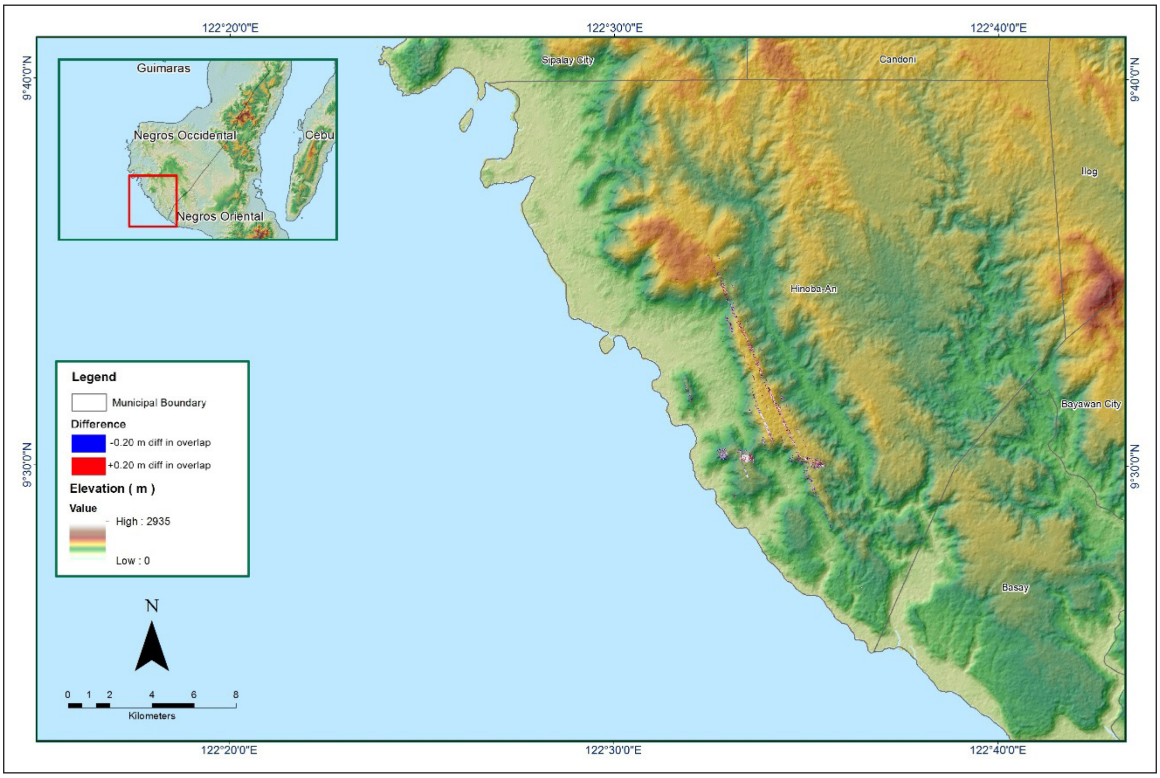


Figure A-8.21. Elevation difference between flight lines

Annex 9. Tiabanan Model Basin Parameters

Table A-9.1 Tiabanan Model Basin Parameters

Basin Number	SCS Curve Number Loss Model			Clark Transform Model		Recession Constant Baseflow Model				
	Initial Abstraction	Curve Number	Impervious	Time of Concentration	Storage Coefficient	Initial Type	Initial Discharge	Recession Constant	Threshold Type	Ratio to Peak
W1000	4.6973	96.951	0	0.3789208	0.11167	Discharge	0.0039928	0.10298	Ratio to Peak	0.0984401
W1010	4.5255	73.544	0	0.9687487	2.2161	Discharge	0.0337421	0.10299	Ratio to Peak	0.0663308
W1020	4.6973	71.343	0	0.8726023	0.83447	Discharge	0.029243	0.10298	Ratio to Peak	0.10126
W1030	4.6973	69.194	0	0.7633027	0.22713	Discharge	0.0313016	0.10298	Ratio to Peak	0.10048
W1040	4.6973	67.933	0	0.980476	0.29654	Discharge	0.0154452	0.15372	Ratio to Peak	0.15103
W1050	4.1364	77.52	0	0.8100858	2.7978	Discharge	0.0231088	0.10298	Ratio to Peak	0.1
W1060	3.5833	80.281	0	2.06998	5.2767	Discharge	0.0668737	0.10299	Ratio to Peak	0.1
W1070	4.6973	63.873	0	0.1572079	0.35021	Discharge	0.0047445	0.10298	Ratio to Peak	0.10148
W1080	4.6973	74.231	0	1.350337	2.0893	Discharge	0.0355859	0.10298	Ratio to Peak	0.0653333
W1090	4.6727	73.647	0	1.964347	2.0839	Discharge	0.1076	0.15373	Ratio to Peak	0.0941192
W1100	3.9586	76.74	0	2.093551	2.1968	Discharge	0.0818096	0.10299	Ratio to Peak	0.0941192
W1110	3.5821	77.702	0	1.166328	1.9446	Discharge	0.0255324	0.15363	Ratio to Peak	0.0444444
W1120	4.6973	71.024	0	1.585368	1.6493	Discharge	0.0741292	0.15368	Ratio to Peak	0.0640267
W1130	3.9808	77.251	0	1.017627	1.0902	Discharge	0.043725	0.15372	Ratio to Peak	0.15148
W1140	3.7074	78.271	0	0.8828552	0.78382	Discharge	0.050169	0.10298	Ratio to Peak	0.0989162
W1150	4.5164	74.924	0	0.9667796	0.65214	Discharge	0.039117	0.10298	Ratio to Peak	0.14727
W1160	3.6458	85.058	0	0.4883174	0.50675	Discharge	0.0125814	0.10298	Ratio to Peak	0.0979564
W1170	4.6907	72.076	0	0.982028	0.71396	Discharge	0.0299256	0.10298	Ratio to Peak	0.0984778
W1180	3.8455	78.584	0	0.3006806	1.033	Discharge	0.0228143	0.10299	Ratio to Peak	0.14772
W1190	4.4552	75.291	0	0.9253703	0.72335	Discharge	0.0352622	0.10299	Ratio to Peak	0.0989463
W1200	3.5821	99	0	0.1287578	0.11474	Discharge	0.0001411	0.10298	Ratio to Peak	0.0989766
W620	4.6973	81.32	0	2.573119	1.5002	Discharge	0.0709754	0.15372	Ratio to Peak	0.086436
W630	3.2837	77.263	0	2.499981	1.4899	Discharge	0.0707959	0.22921	Ratio to Peak	0.0663333
W640	4.6973	87.374	0	1.013553	1.1939	Discharge	0.0361657	0.33916	Ratio to Peak	0.1
W650	4.6973	70.124	0	1.211918	0.85361	Discharge	0.0227836	0.15222	Ratio to Peak	0.0444444
W660	4.6973	54.156	0	1.338212	1.2177	Discharge	0.0231594	0.10198	Ratio to Peak	0.1
W670	4.6973	65.463	0	0.8331912	1.4709	Discharge	0.0416112	0.15338	Ratio to Peak	0.0955598
W680	4.6973	74.232	0	2.563225	1.524	Discharge	0.0712684	0.10285	Ratio to Peak	0.0666667
W690	4.6973	71.866	0	1.132378	1.6443	Discharge	0.0218571	0.10247	Ratio to Peak	0.1

W700	4.1902	74.079	0	0.7374716	1.7132	Discharge	0.0301389	0.15372	Ratio to Peak	0.0663333
W710	4.6973	63.563	0	1.753372	0.23452	Discharge	0.0020984	0.10298	Ratio to Peak	0.10149
W720	4.6312	69.083	0	0.3056567	1.0711	Discharge	0.0157152	0.10298	Ratio to Peak	0.0588
W730	4.6973	72.203	0	1.548508	1.4377	Discharge	0.0609128	0.15222	Ratio to Peak	0.1
W740	3.7214	78.033	0	0.8044404	1.288	Discharge	0.0343557	0.10198	Ratio to Peak	0.0974392
W750	4.6973	68.466	0	0.7950799	1.2943	Discharge	0.0476166	0.10195	Ratio to Peak	0.098
W760	4.3607	75.017	0	0.7154623	0.55949	Discharge	0.0161432	0.15167	Ratio to Peak	0.10067
W770	4.3701	74.946	0	1.56267	1.545	Discharge	0.0841658	0.10192	Ratio to Peak	0.147
W780	4.6973	91.03	0	0.4815662	0.31971	Discharge	0.0021337	0.10197	Ratio to Peak	0.10099
W790	4.6973	69.108	0	0.7758739	0.79189	Discharge	0.0179977	0.10197	Ratio to Peak	0.06
W800	4.6973	81.825	0	0.7685989	1.8003	Discharge	0.0198446	0.10199	Ratio to Peak	0.06
W810	4.6556	72.607	0	1.406597	1.9626	Discharge	0.0361964	0.15223	Ratio to Peak	0.1
W820	4.6973	72.496	0	0.6784762	0.72503	Discharge	0.0121365	0.10197	Ratio to Peak	0.15075
W830	4.6973	72.456	0	1.025387	0.9196	Discharge	0.0208831	0.10197	Ratio to Peak	0.0653333
W840	4.664	74.173	0	1.310567	1.9673	Discharge	0.0379037	0.10199	Ratio to Peak	0.098
W850	4.6973	73.471	0	1.353829	1.3769	Discharge	0.035365	0.10198	Ratio to Peak	0.06
W860	4.6973	99	0	0.5555675	1.886	Discharge	0.0002853	0.10199	Ratio to Peak	0.0653333
W870	4.6973	73.21	0	1.14072	1.1604	Discharge	0.0183735	0.10199	Ratio to Peak	0.0882
W880	4.6492	73.952	0	1.101629	1.6926	Discharge	0.0391293	0.10198	Ratio to Peak	0.098
W890	4.6973	73.258	0	1.15915	1.1828	Discharge	0.0408442	0.10199	Ratio to Peak	0.098
W900	4.6973	80.733	0	0.8824381	1.3334	Discharge	0.0128621	0.10199	Ratio to Peak	0.0974757
W910	4.6973	72.88	0	0.8671509	0.89364	Discharge	0.0286187	0.10197	Ratio to Peak	0.15
W920	4.6906	71.201	0	1.872876	1.2609	Discharge	0.0288718	0.10198	Ratio to Peak	0.0653333
W930	4.4003	72.795	0	1.101047	1.1367	Discharge	0.0434166	0.10197	Ratio to Peak	0.099956
W940	4.6973	74.046	0	0.697915	0.71692	Discharge	0.0220489	0.15222	Ratio to Peak	0.15075
W950	4.6973	72.877	0	1.198823	1.209	Discharge	0.0457283	0.10199	Ratio to Peak	0.0444444
W960	4.6973	72.336	0	0.3918315	0.94361	Discharge	0.0178597	0.10189	Ratio to Peak	0.101
W970	4.6973	73.529	0	0.6775838	0.75316	Discharge	0.0237853	0.10193	Ratio to Peak	0.10099
W980	4.6973	72.509	0	0.7771834	0.85548	Discharge	0.0164408	0.15221	Ratio to Peak	0.101
W990	4.6845	73.68	0	0.775127	0.80689	Discharge	0.0246688	0.10197	Ratio to Peak	0.10099

Annex 10. Tiabanan Model Reach Parameters

Table A-10.1 Tiabanan Model Reach Parameters

Reach Number	Muskingum Cunge Routing Model						
	Time Step Method	Length	Slope	Manning's n	Shape	Width	Side Slope
R110	Automatic Fixed Interval	358.7	0.0332134	0.83244	Trapezoid	15	1
R120	Automatic Fixed Interval	1643.1	0.0267962	0.0025647	Trapezoid	15	1
R140	Automatic Fixed Interval	2522.9	0.0122548	0.11652	Trapezoid	15	1
R160	Automatic Fixed Interval	521.13	0.0033493	0.0282599	Trapezoid	15	1
R180	Automatic Fixed Interval	892.13	0.0066089	0.0405977	Trapezoid	15	1
R190	Automatic Fixed Interval	998.11	0.0242614	0.0037296	Trapezoid	15	1
R200	Automatic Fixed Interval	1497.8	0.0040861	0.0155194	Trapezoid	15	1
R240	Automatic Fixed Interval	1199.1	0.0081557	0.0390123	Trapezoid	15	1
R260	Automatic Fixed Interval	42.426	0.00001	0.20177	Trapezoid	15	1
R300	Automatic Fixed Interval	1965.7	0.0050267	0.0380126	Trapezoid	15	1
R310	Automatic Fixed Interval	1288.8	0.0049764	0.0454329	Trapezoid	15	1
R320	Automatic Fixed Interval	1421.8	0.0073274	0.0706337	Trapezoid	15	1
R340	Automatic Fixed Interval	1291.8	0.0078225	0.0552344	Trapezoid	15	1
R350	Automatic Fixed Interval	1743.5	0.0048327	0.0394761	Trapezoid	15	1
R370	Automatic Fixed Interval	726.69	0.0086391	0.12134	Trapezoid	15	1
R390	Automatic Fixed Interval	624.26	0.0051475	0.0595121	Trapezoid	15	1
R410	Automatic Fixed Interval	656.57	0.0064083	0.0524522	Trapezoid	15	1
R430	Automatic Fixed Interval	1212.7	0.0032318	0.0358372	Trapezoid	15	1
R450	Automatic Fixed Interval	974.39	0.0057777	0.0372928	Trapezoid	15	1
R470	Automatic Fixed Interval	555.27	0.0123021	0.0275404	Trapezoid	15	1
R510	Automatic Fixed Interval	3932.8	0.0027021	0.0276428	Trapezoid	15	1
R530	Automatic Fixed Interval	4261.2	0.0439737	0.0081605	Trapezoid	15	1
R540	Automatic Fixed Interval	1656.8	0.0128901	0.0478636	Trapezoid	15	1
R550	Automatic Fixed Interval	2101.1	0.0070056	0.0371769	Trapezoid	15	1
R560	Automatic Fixed Interval	868.82	0.0266025	0.22973	Trapezoid	15	1
R590	Automatic Fixed Interval	7.0711	0.063317	1	Trapezoid	15	1
R600	Automatic Fixed Interval	1406.7	0.0049334	0.0508041	Trapezoid	15	1
R70	Automatic Fixed Interval	1756.8	0.0228097	0.0515581	Trapezoid	15	1
R90	Automatic Fixed Interval	1392.3	0.0475968	0.00342	Trapezoid	15	1

Annex 11. Tiabanan Flood Validation Data

Table A-11.1 Tiabanan Flood Validation Data

Point Number	Valdiation Coordinates		Model Var (m)	Validation Points (m)	Error	Event / Date	Return Period of Event
	Longitude	Latitude					
1	122.64061	9.464614	5.02	1.2	14.59	Ruping	100-Year
2	122.64065	9.464622	2.96	0.9	4.244	Ramil	100-Year
3	122.63979	9.464512	2.79	0.1	7.236	Ramil	100-Year
4	122.63868	9.460557	1.25	1.2	0.003	Ramil	100-Year
5	122.63869	9.460552	1.25	1	0.063	Ruping	100-Year
6	122.63869	9.460545	0.88	0.4	0.23	Sendong	100-Year
7	122.63957	9.459041	1.29	1.6	0.096	Ramil	100-Year
8	122.63956	9.458941	1.49	0	2.22	Ruping	100-Year
9	122.63953	9.458901	4.41	0	19.45	Sendong	100-Year
10	122.63952	9.458914	4.41	0	19.45	Yolanda	100-Year
11	122.63932	9.45919	1.63	1.0	0.397	Ramil	100-Year
12	122.63846	9.459756	0.73	0.4	0.109	Ramil	100-Year
13	122.63846	9.459773	0.73	1.5	0.593	Nanang	100-Year
14	122.63843	9.459759	1.43	0.8	0.397	Ruping	100-Year
15	122.63824	9.459961	1	1.1	0.01	Ramil	100-Year
16	122.63823	9.459969	1	1.4	0.16	Ruping	100-Year
17	122.63823	9.459962	1	0.4	0.36	Sendong	100-Year
18	122.63824	9.459951	1	0.3	0.49	Yolanda	100-Year
19	122.63782	9.460228	1.15	0.9	0.062	Ramil	100-Year
20	122.63781	9.460247	1.15	0.7	0.203	Ruping	100-Year
21	122.63783	9.460251	1.15	0	1.323	Lawin	100-Year
22	122.63477	9.461089	0.72	1.4	0.462	Ramil	100-Year
23	122.63477	9.461076	0.56	0.2	0.13	Ruping	100-Year
24	122.63488	9.46099	0.73	0	0.533	Unsang	100-Year
25	122.63464	9.460915	0.67	1.2	0.281	Ramil	100-Year
26	122.63464	9.460925	0.67	0.1	0.325	Ruping	100-Year
27	122.63456	9.460732	0.75	1.6	0.723	Ramil	100-Year
28	122.63458	9.460692	0.74	0.9	0.026	Ruping	100-Year
29	122.63306	9.458982	0.87	1.2	0.109	Ramil	100-Year
30	122.63303	9.458999	0.87	1.0	0.017	Seniang	100-Year
31	122.63357	9.458377	0.23	1	0.593	Ramil	100-Year
32	122.62039	9.435252	1.91	1.7	0.044	Ramil	100-Year
33	122.62038	9.435251	1.91	0.7	1.464	Ruping	100-Year
34	122.62039	9.435278	1.91	0.6	1.716	Seniang	100-Year
35	122.62042	9.43532	1.76	0.6	1.346	Unsang	100-Year
36	122.62055	9.434569	2.39	2	0.152	Ramil	100-Year
37	122.62035	9.433688	2.98	3	4E-04	Ramil	100-Year
38	122.62037	9.433696	2.98	1.5	2.19	Seniang	100-Year
39	122.62046	9.433197	1.59	1.5	0.008	Ramil	100-Year
40	122.62044	9.433203	1.59	1.0	0.348	Seniang	100-Year
41	122.62061	9.433076	3.33	0	11.09	Lawin	100-Year
42	122.62046	9.43258	1.16	1.5	0.116	Ramil	100-Year
43	122.62046	9.432578	1.19	1.1	0.008	Ruping	100-Year
44	122.6205	9.432589	1.16	0.7	0.212	Seniang	100-Year
45	122.62054	9.432606	2.53	0	6.401	Lawin	100-Year

46	122.62045	9.432482	0.52	1.6	1.166	Yolanda	100-Year
47	122.62189	9.429144	1.38	1.4	4E-04	Ramil	100-Year
48	122.62189	9.429145	0.78	1.4	0.384	Ruping	100-Year
49	122.62188	9.42918	1.38	0.5	0.774	Seniang	100-Year
50	122.62189	9.429172	0.78	0.5	0.078	Unsang	100-Year
51	122.62201	9.428896	1.08	1.1	4E-04	Ramil	100-Year
52	122.622	9.428897	1.08	0.3	0.608	Ruping	100-Year
53	122.622	9.428736	1.36	1	0.13	Ramil	100-Year
54	122.62189	9.428798	1.54	1.5	0.002	Ramil	100-Year
55	122.62221	9.428864	1.61	0	2.592	Unsang	100-Year
56	122.6222	9.428863	1.61	0	2.592	Seniang	100-Year
57	122.62336	9.427205	4.21		17.72	Ramil	100-Year
58	122.62308	9.426864	1.48	1.6	0.014	Ramil	100-Year
59	122.62308	9.426886	1.13	1.3	0.029	Unsang	100-Year
60	122.62309	9.426875	1.48	0.5	0.96	Ruping	100-Year
61	122.6231	9.426872	1.48	0.7	0.608	Seniang	100-Year
62	122.62308	9.425988	1.08	1.3	0.048	Ramil	100-Year
63	122.62308	9.425985	1.04	1.5	0.212	Ruping	100-Year
64	122.62309	9.425966	1.08	0.5	0.336	Seniang	100-Year
65	122.62307	9.425984	1.04	0.5	0.292	Yolanda	100-Year
66	122.6239	9.427322	1.62	1.8	0.032	Ramil	100-Year
67	122.62389	9.427321	2.12	1.6	0.27	Ruping	100-Year
68	122.6239	9.427369	1.56	1.2	0.13	Unsang	100-Year
69	122.62421	9.427455	0.24	1.5	1.588	Ramil	100-Year
70	122.62421	9.427445	0.24	0.9	0.436	Unsang	100-Year
71	122.62457	9.434142	1.81	1.1	0.504	Ramil	100-Year
72	122.62455	9.434114	1.68	0.5	1.392	Ruping	100-Year
73	122.62456	9.434127	1.81	0	3.276	Unsang	100-Year
74	122.62429	9.43217	1.58	1.6	4E-04	Ramil	100-Year
75	122.62428	9.432144	1.58	0.6	0.96	Seniang	100-Year
76	122.6243	9.432142	1.58	1.3	0.078	Ruping	100-Year
77	122.62427	9.432108	1.53	1.1	0.185	Yolanda	100-Year
78	122.62439	9.431635	1.66	1.7	0.002	Ramil	100-Year
79	122.6244	9.43164	1.66	1.2	0.212	Ruping	100-Year
80	122.6244	9.431643	1.66	0.5	1.346	Seniang	100-Year
81	122.6244	9.431635	1.66	0.5	1.346	Unsang	100-Year
82	122.62439	9.431649	1.66	0	2.756	Yolanda	100-Year
83	122.62438	9.430985	1.77	1.7	0.005	Ramil	100-Year
84	122.62437	9.430979	1.77	0.8	0.941	Seniang	100-Year
85	122.62436	9.430984	1.77	0.8	0.941	Unsang	100-Year
86	122.6243	9.430793	1.75	1.5	0.063	Ramil	100-Year
87	122.62433	9.430722	1.69	1.3	0.152	Ruping	100-Year
88	122.62431	9.430736	1.69	0.9	0.624	Unsang	100-Year
89	122.6243	9.430751	1.69	0.9	0.624	Seniang	100-Year
90	122.62432	9.430469	1.41	1.4	1E-04	Ramil	100-Year
91	122.62433	9.430491	1.41	1.4	1E-04	Ruping	100-Year

Annex 12. Educational Institutions Affected in Tiabanan Floodplain

Table A-12.1 Educational Institutions in Basay, Negros Oriental Affected by Flooding in Tiabanan Floodplain

Negros Oriental				
Basay				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Bal-os National HIgh School	Bongalonan			Low
Monsale Elementary School	Bongalonan	Low	Medium	Medium
Tiabanan Valley Elementary School	Bongalonan			

Table A-12.2 Educational Institutions in Hinoba-An, Negros Occidental Affected by Flooding in Tiabanan Floodplain

Negros Occidental				
Hinoba-An				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Bongalonan Elementary School	Sangke	Low	Low	Low

Annex 13. Health Institutions Affected in Tiabanan Floodplain

There are no health institutions affected by flooding in the Tiabanan floodplain.