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

LiDAR Surveys and Flood Mapping of Yabaan River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Mapua Institute of Technology

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND YABAAN RIVER

Enrico C. Paringit, Dr. Eng., Dr. Francis Aldrine Uy, and Engr. Fibor Tan

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 MAPUA Institute of Technology (MIT). MIT 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 Cavite-Batangas-Rizal-Quezon (CABARZON) Region. The university is located in the City of Manila within Metro Manila in the National Capital Region.

1.2 Overview of the Yabaan River Basin

The Yabahaan, also known as the Yabaan, River Basin is located in the southern tip of Quezon Province, which transects the municipalities of San Francisco and San Andres, respectively. The Yabaan River Basin covers Barangays Talisay, Mangero, Pansoy, and Camflora in Municipality of San Andres; and Barangays Pagsangahan, Huyon-uyon and Mabunga in Municipality of San Fracisco; all in the province of Quezon. The river basin primarily serves as a catchment basin for these areas. The Yabaan River Basin is also bounded by nearby watersheds, the Silongin River Basin in the west and the Bigol River Basin in the north. According to DENR River Basin Control Office, the Yabaan River Basin has a drainage area of 63 km2 and an estimated annual run-off of 100 million cubic meter (MCM) (RBCO, 2015) from San Andres towards the Sibuyan Sea.

Its main stem, the Yabaan River, is part of the 26 river systems in the Southern Tagalog Region. According to the 2010 national census of NSO, a total of 5,159 locals are residing in the immediate vicinity of the river which are distributed among five (5) barangays in the Municipality of Calauag namely, Bangjuruhan, Sumulong, Sumilang, Mabini and Biyan.

In terms of geography, the soil classification of the Yabaan River Basin is generally clay. Its land use is composed of 97% cultivated area and 3% brushlands. The cultivated areas are the agricultural lands that have been the main source of income of the communities in the locality. In fact, agriculture and fishing are the two primary sources of living in the area. According to the locals, majority of the agricultural land or cultivated areas are planted with coconuts, rice, citrus and vegetables (http://www.quezon.gov.ph/homepage/?info=economy, 2016). In the Yabaan River Basin, there is a thriving coconut industry.
(Nona).

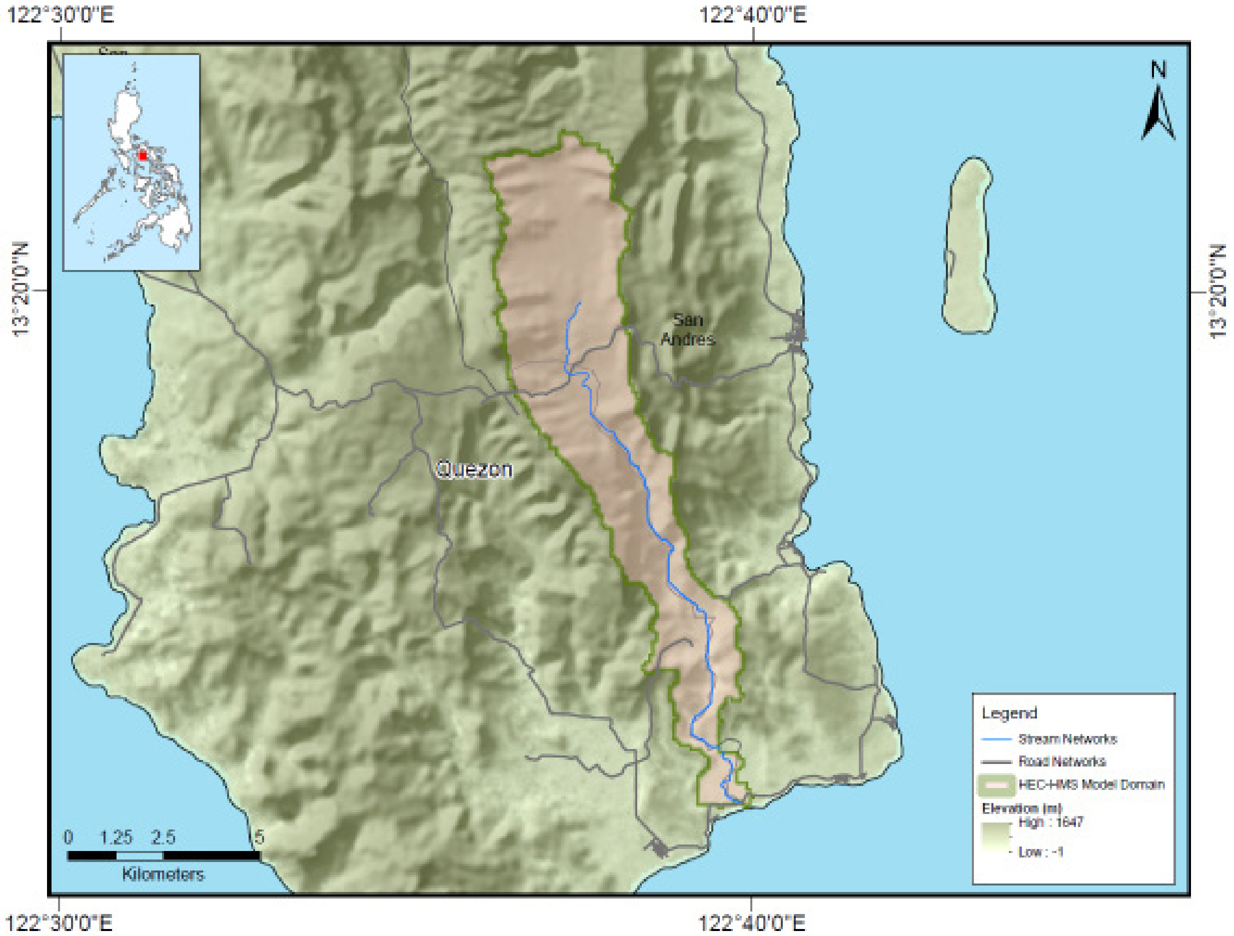

Figure 1. Map of Yabaan River Basin (in brown)

Due to the watershed's geographical location, it is frequently hit by strong typhoons, which brings severe damages to the livelihood of the residents. In the past ten years, six significant typhoons had greatly affected the low-lying areas at the mouth of the Yabaan River Basin and the surrounding municipalities. These were Typhoons Reming and Milenyo in 2006, Ondoy in 2009, Glenda and Ruby in 2014, and Nina in 2016. Typhoon "Glenda" was a significant typhhon in the area. It caused power interruption and affected more than 4,000 families on July 2014 (NDRRMC Final Report re Effects of Typhoon "Glenda" or Rammasun, 2014). Meanwhile, Typhoon Nina was the most recent typhoon to ever hit Quezon Province, and the towns of San Andres and San Francisco were among the municipalities that were strongly affected. A state of calamity was declared in the province as Nina flooded several municipalities and wiped off farmlands resulting to millions of pesos worth of damages.

Available technology provides solution to this problem. Light Detection and Ranging (LiDAR) technology is a remote sensing technology that has been recently introduced to improve disaster risk assessments and provide accurate flood mitigation planning in the country. With the aid of LiDAR digital elevation models, the country is able to develop more accurate flood mapping and modelling systems which is helpful to the local government units in their preparation for future catastrophes. In the Yabaan river basin, the fieldwork activities were very challenging because of the remote location. Nevertheless, the team was able to safely complete the work and with the aid of a hydraulic river analysis software, flood hazard maps for different return periods were produced.

CHAPTER 2: LIDAR ACQUISITION IN YABAAN FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Yabaan floodplain in Quezon. These missions were planned for 12 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 shows the flight plan for Yabaan floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR System.

Block Name	Flying Height (AGL)	Overlap (%)	Field of View	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency	Average Speed	Average Turn Time (Minutes)
BLK21G	1000	30	50	200	30	130	5
BLK21H	1000	30	50	200	30	130	5

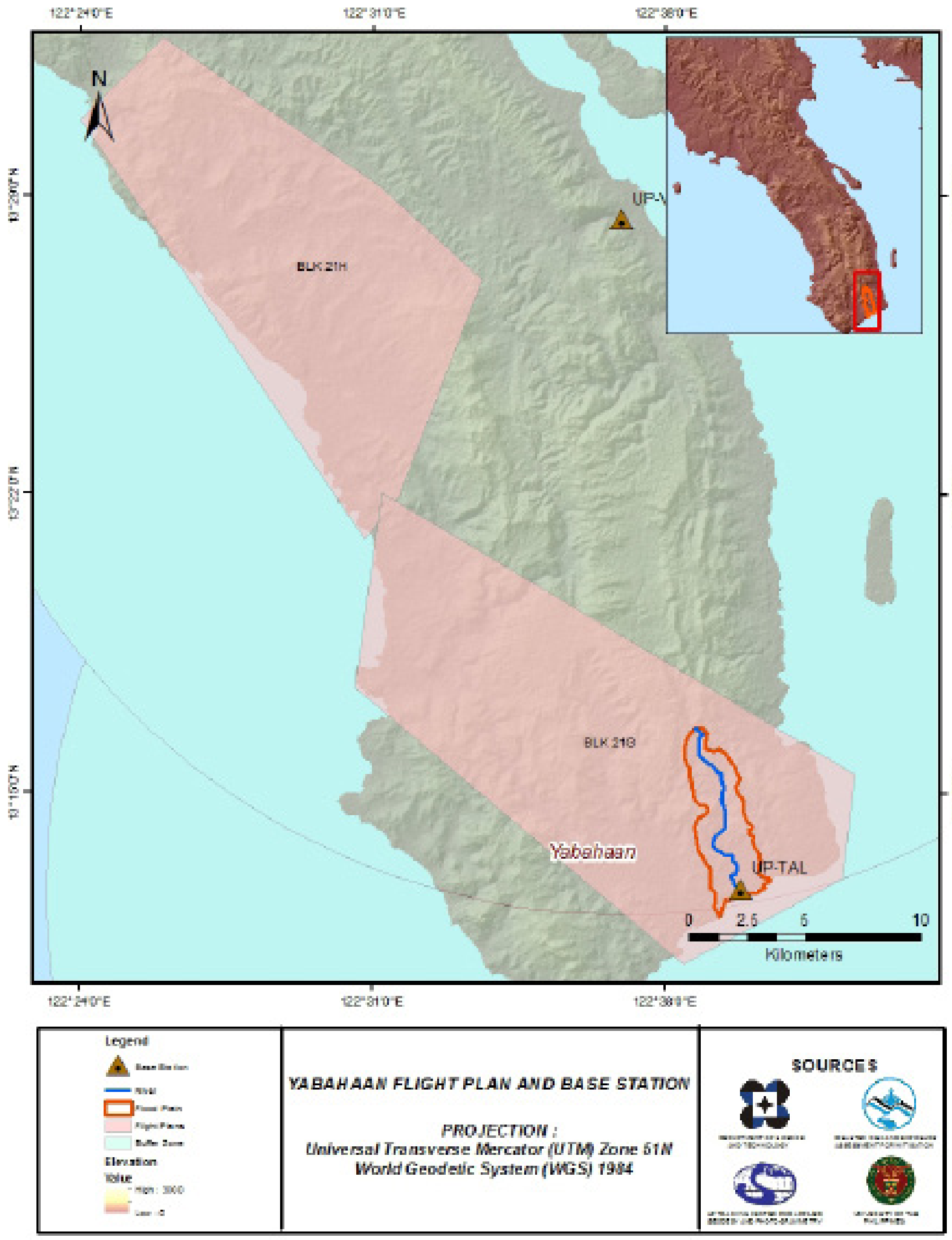

Figure 2. Flight plan and base station for Pegasus System used for Yabaan (also known as Yabahaan) Floodplain

2.2 Ground Base Station

The project team was able to establish two (2) ground control points: UP-VIG and UP-TAL. The certification for the NAMRIA reference point is found in Annex 2 while the baseline processing report for the establishment points are found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (May 12 - 13, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and Topcon GR5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Yabaan floodplain are shown in Figure 2. The list of team members for LiDAR data acquisition is found in Annex 4.

Figure 3 and Figure 4 show the established 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.

(b)

(a)

Figure 3. GPS set-up over UP-VIG at the left approach of Vigo Bridge along San Narciso-San Andres road in Brgy. Binay, San Narciso, Quezon (a) and ground control point UP-VIG (b) as established by the DVBC field team.

Table 2. Details of the established ground control point UP-VIG used as base station for the LiDAR acquisition.

Station Name	UP-VIG	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 28' 30.89562" North 122° 36' 51.38098" East 5.677 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	674799.015 meters 1490695.992 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	458401.422 meters 1489570.975 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 28' 25.87599" North 122° 36' 56.36154" East 56.297 meters

(b)

(a)

Figure 4. GPS set-up over UP-TAL at Talisay Bridge in Brgy. Pagsangahan, Municipality of San Francisco (a) and ground control point UP-TAL (b) as established by the DVBC field team.

Table 3. Details of the established ground control point UP-TAL used as base station for the LiDAR Acquisition.

Station Name	**UP-TAL**	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 12’ 55.82506” North 122° 39’ 44.45670” East 5.677 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	680162.756 meters 1461822.857 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	463529.419 meters 1460676.800 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 12’ 45.54766” North 122° 39’ 48.22813” East 55.749 meters

Table 4. Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
May 12, 2016	23342P	1BLK221G133A	UP-TAL, UP-VIG
May 13, 2016	23346P	1BLK21GS134A	UP-TAL, UP-VIG

2.3 Flight Missions

Two (2) missions were conducted to complete the LiDAR data acquisition in Yabaan floodplain, for a total of eight hours and forty one minutes (8+41) of flying time for RP-C9122. All missions were acquired using the Pegasus LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

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

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
May 12, 2016	23342P	166.15	170.33	6.29	164.04	NA	4	35
May 13, 2016	23346P	209.28	183.53	9.64	173.89	NA	4	6
TOTAL		375.43	353.86	15.93	337.93	NA	8	41

Table 6. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23342P	900	30	50	200	30	130	5
23346P	1000	30	50	200	30	130	5

2.4 Survey Coverage

Yabaan floodplain is located within the municipalities of San Andres and San Francisco in the province of Quezon. San Andres, San Francisco, and Mulanay are mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Yabaan floodplain is presented in Figure 5.

Table 7. List of municipalities and cities surveyed in Yabaan Floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Quezon	San Francisco	320.48	218.16	68.07%
	San Andres	173.7	52.51	30.23%
	Mulanay	262.91	9.56	3.64%
Total		757.09	280.23	37.01%

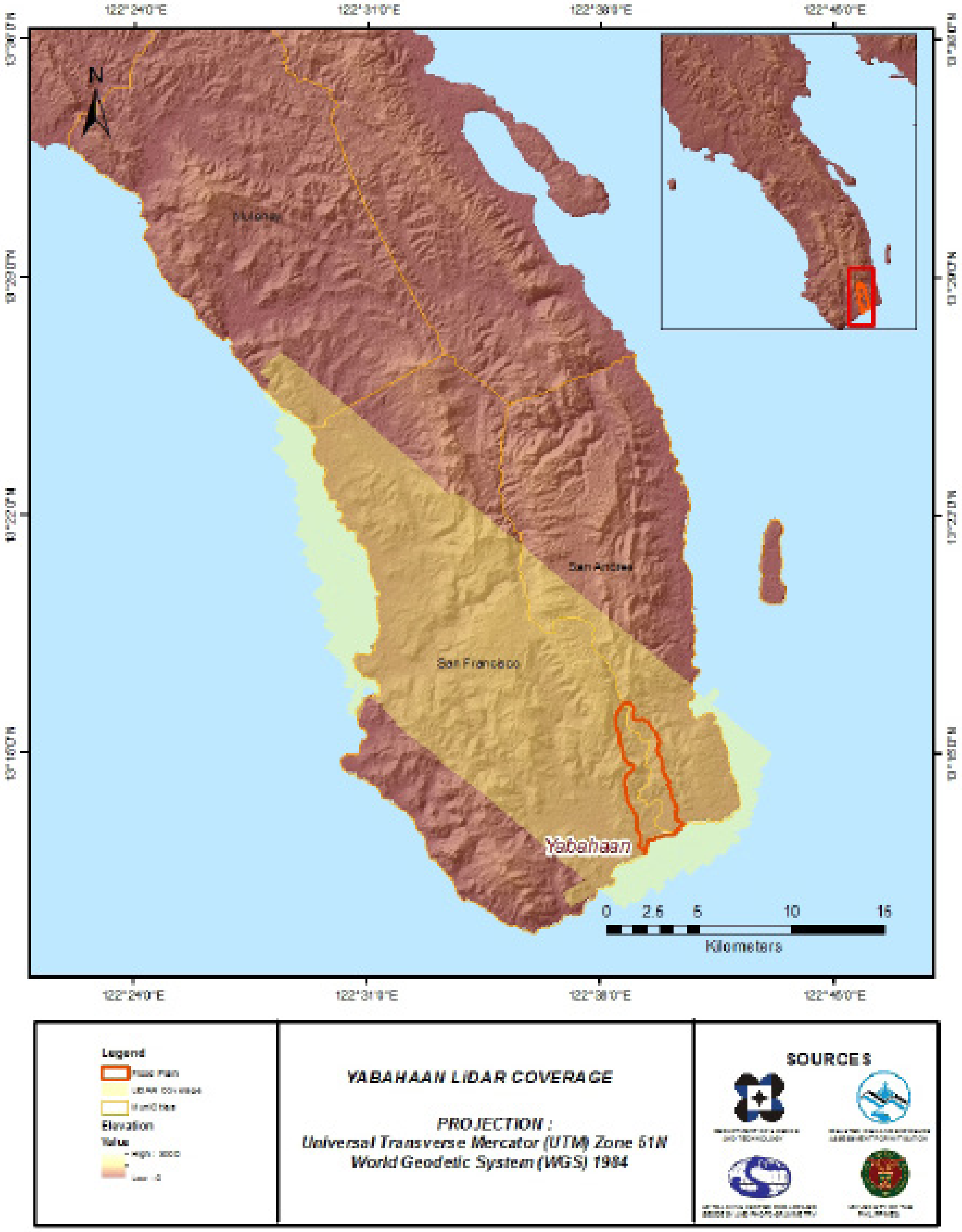

Figure 5. Actual LiDAR survey coverage for Yabaan Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR YABAAN 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 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.

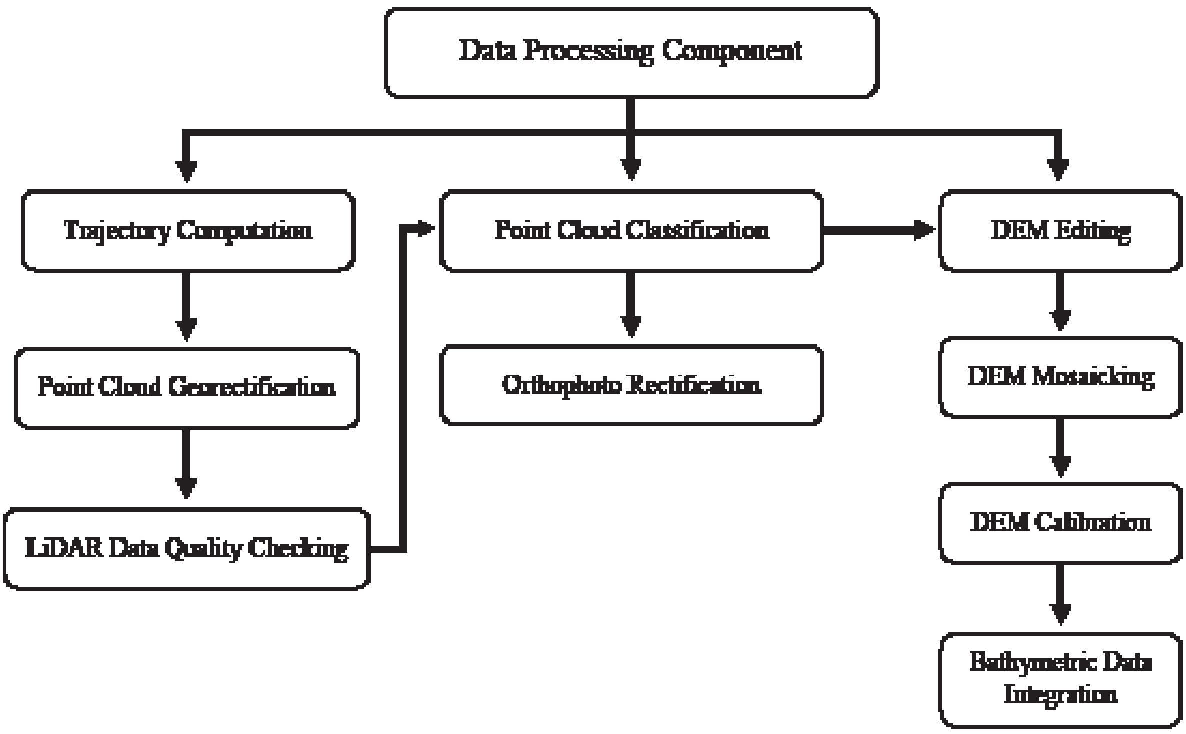

Figure 6. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Yabaan floodplain can be found in Annex 5. Missions flown during the first survey conducted on May 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over San Francisco-San Andres, Quezon.

The Data Acquisition Component (DAC) transferred a total of 66.6 Gigabytes of Range data, 0.503 Gigabytes of POS data, 301 Megabytes of GPS base station data, and 7.27 Gigabytes of raw image data to the data server on September 6, 2016. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Yabaan was fully transferred on September 6, 2016, as indicated on the Data Transfer Sheets for Yabaan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 23342P, one of the Yabaan 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 May 12, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

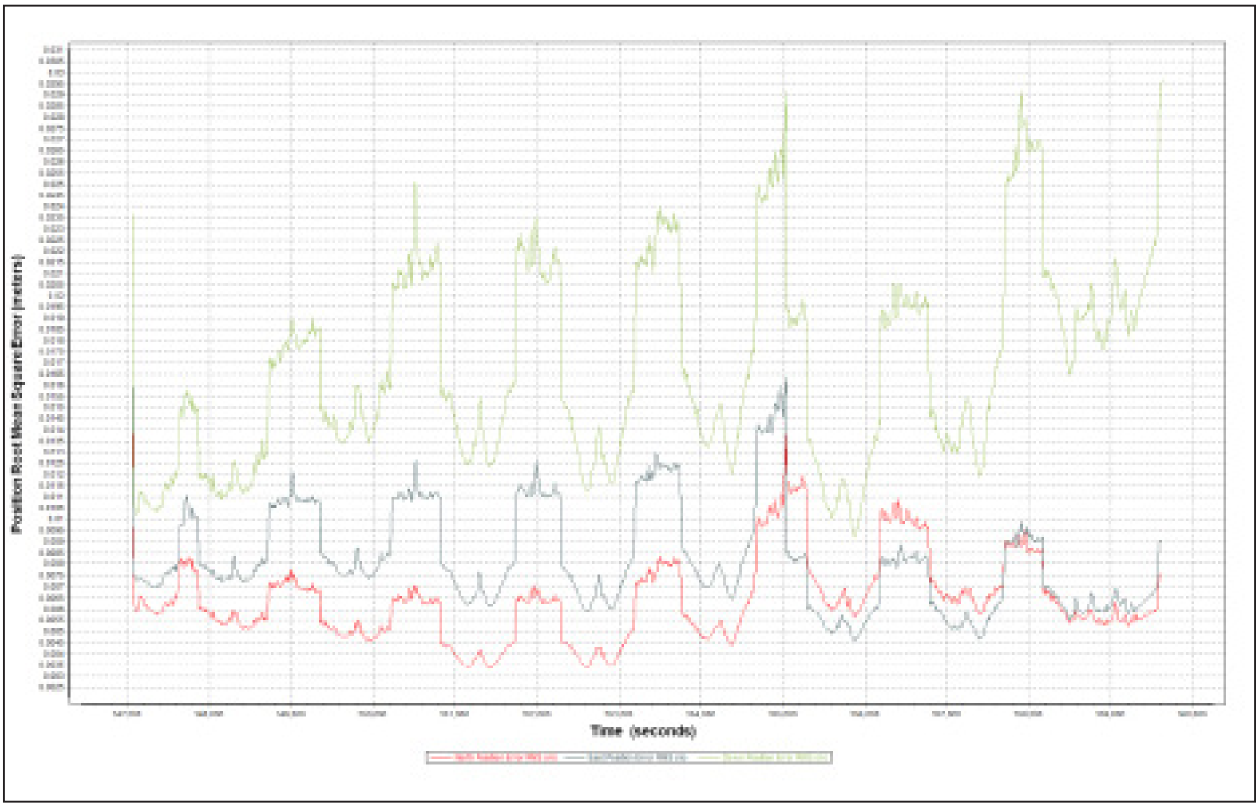

Figure 7. Smoothed Performance Metrics of Yabaan Flight 23342P.

The time of flight was from 347000 seconds to 360000 seconds, which corresponds to morning of May 12, 2016. 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 1.38 centimeters, the East position RMSE peaks at 1.64 centimeters, and the Down position RMSE peaks at 2.92 centimeters, which are within the prescribed accuracies described in the methodology.

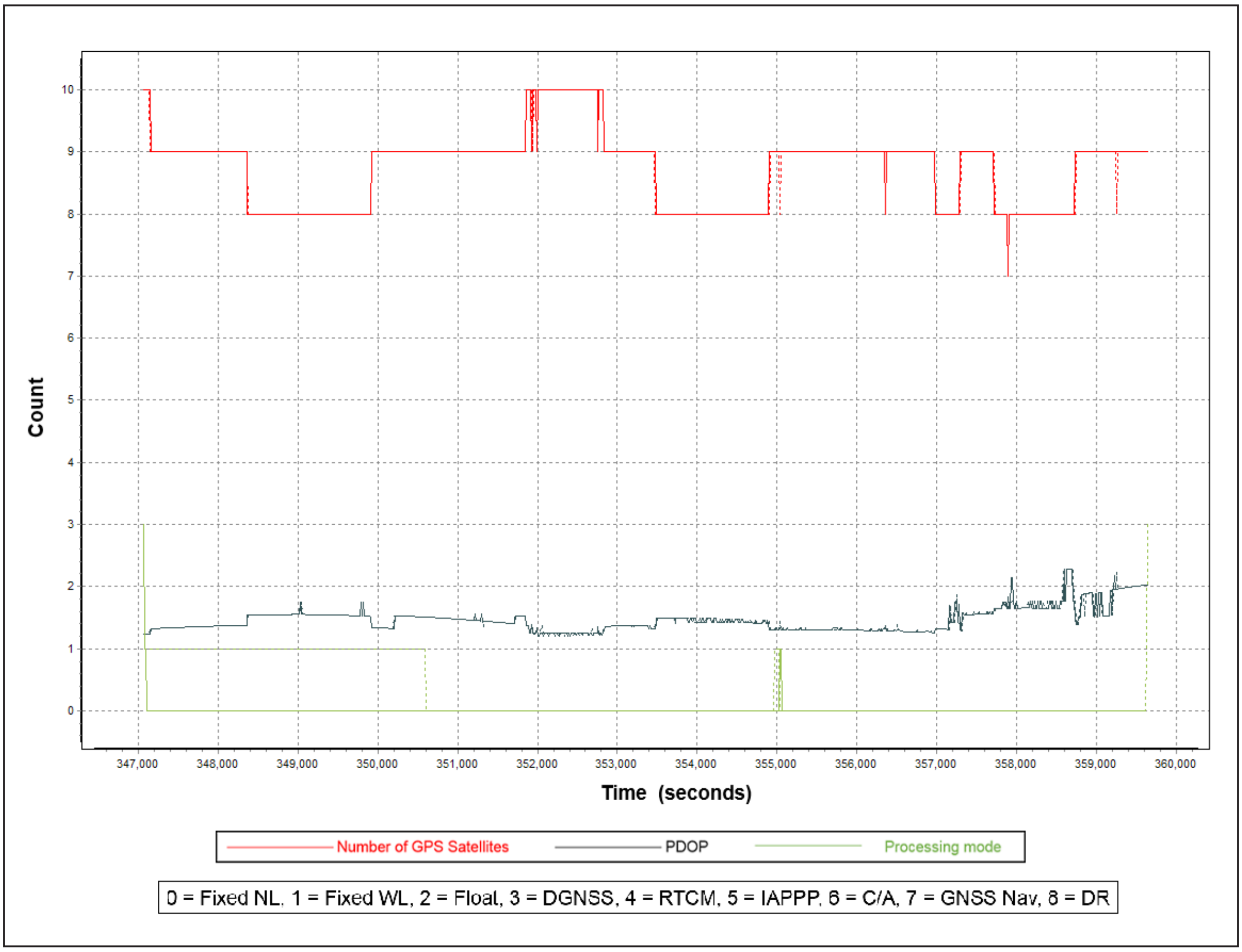

Figure 8. Solution Status Parameters of Yabaan Flight 23342P.

The Solution Status parameters of flight 23342P, one of the Yabaan flights, which indicate 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. Most of the time, the number of satellites tracked was between 7 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode remained at 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Yabaan flights is shown in Figure 9.

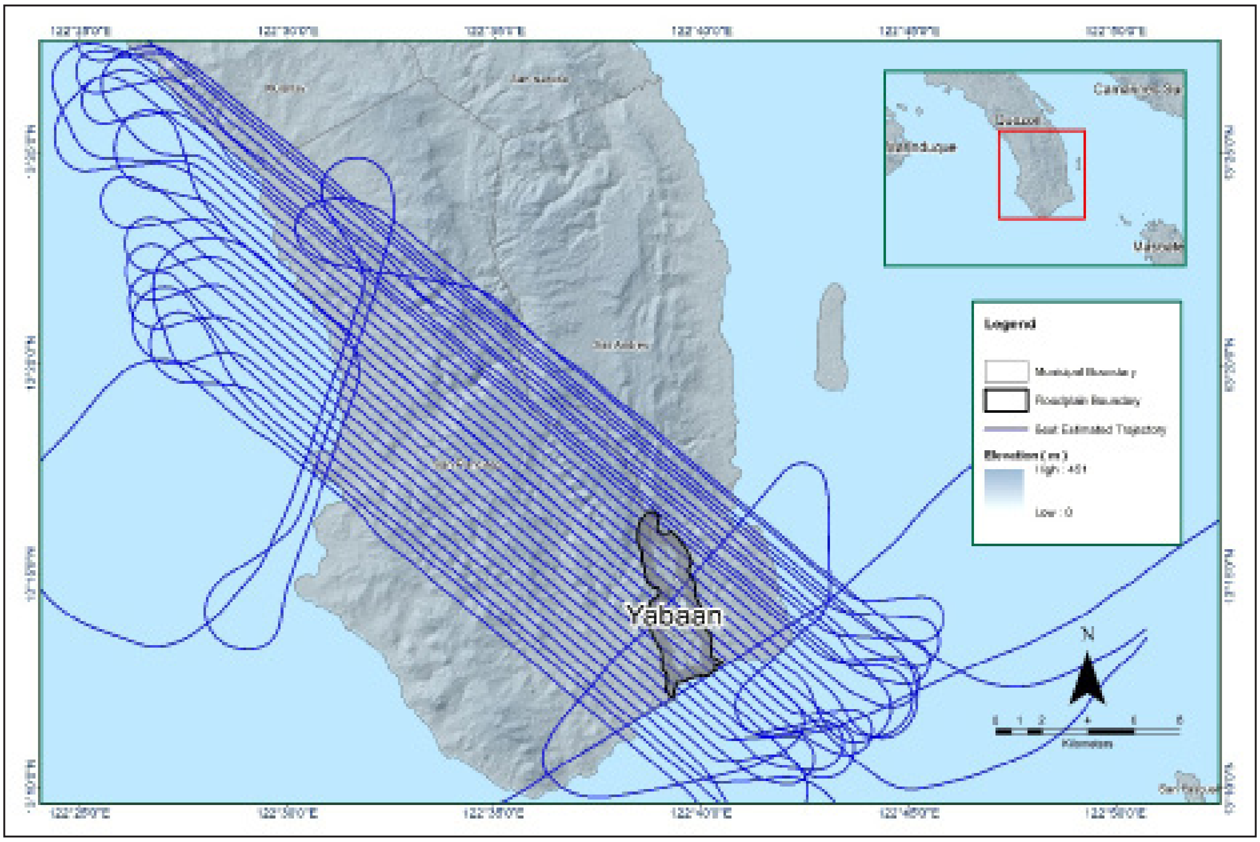

Figure 9. Best estimated trajectory for Yabaan Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 30 flight lines, with each flight line containing two channels, since the Pegasus system contains two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Yabaan floodplain are given in Table 8.

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

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	(<0.001degrees)	0.000121
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000762
GPS Position Z-correction stdev	(<0.01meters)	0.0074

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

3.5 LiDAR Data Quality Checking

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

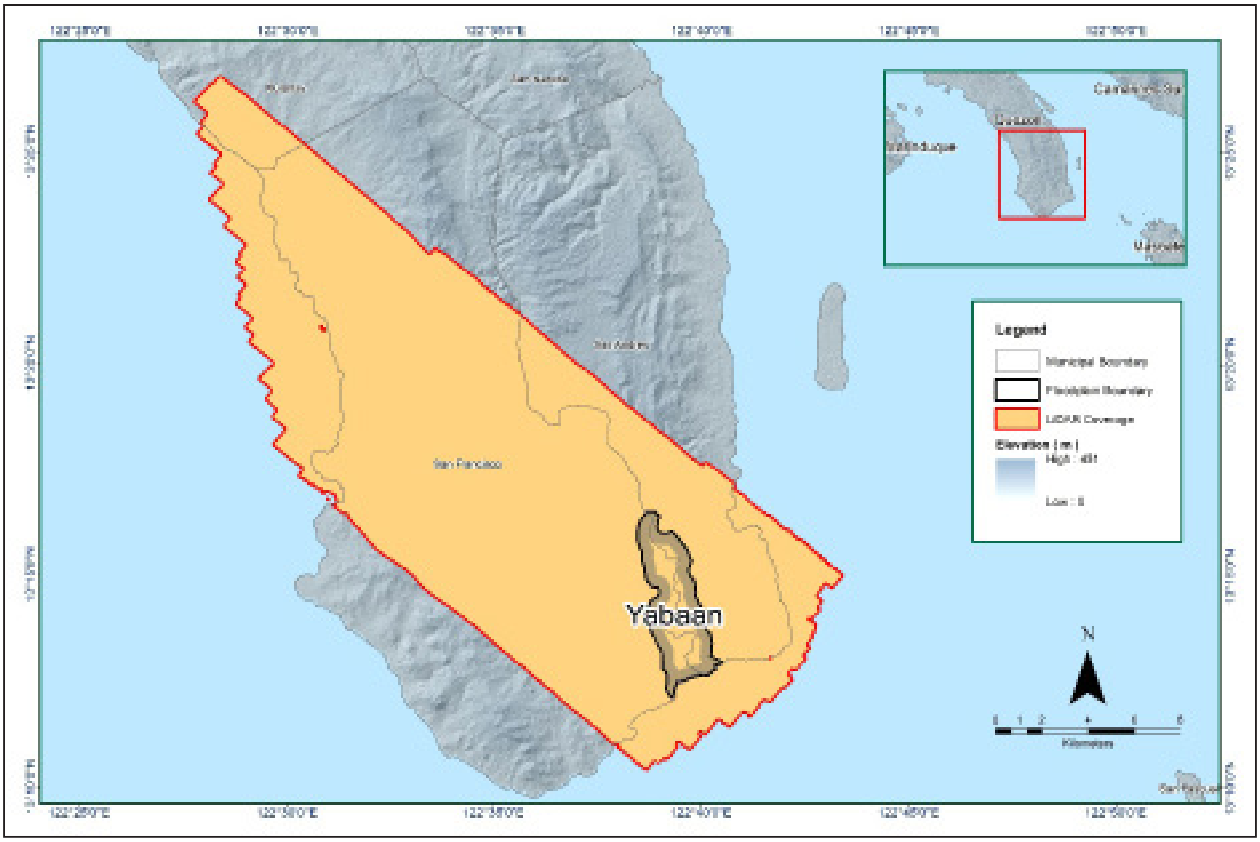

Figure 10. Boundary of the processed LiDAR data on top of a SAR Elevation Data over Yabaan Floodplain.

The total area covered by the Yabaan missions is 349.93 sq.km that is comprised of two (2) flight acquisitions grouped and merged into two (2) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Yabaan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Bagasbas_Blk21G	23346P	159.60
Bagasbas_Blk21H	23342P	190.33
TOTAL		349.93 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 Pegasus system employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

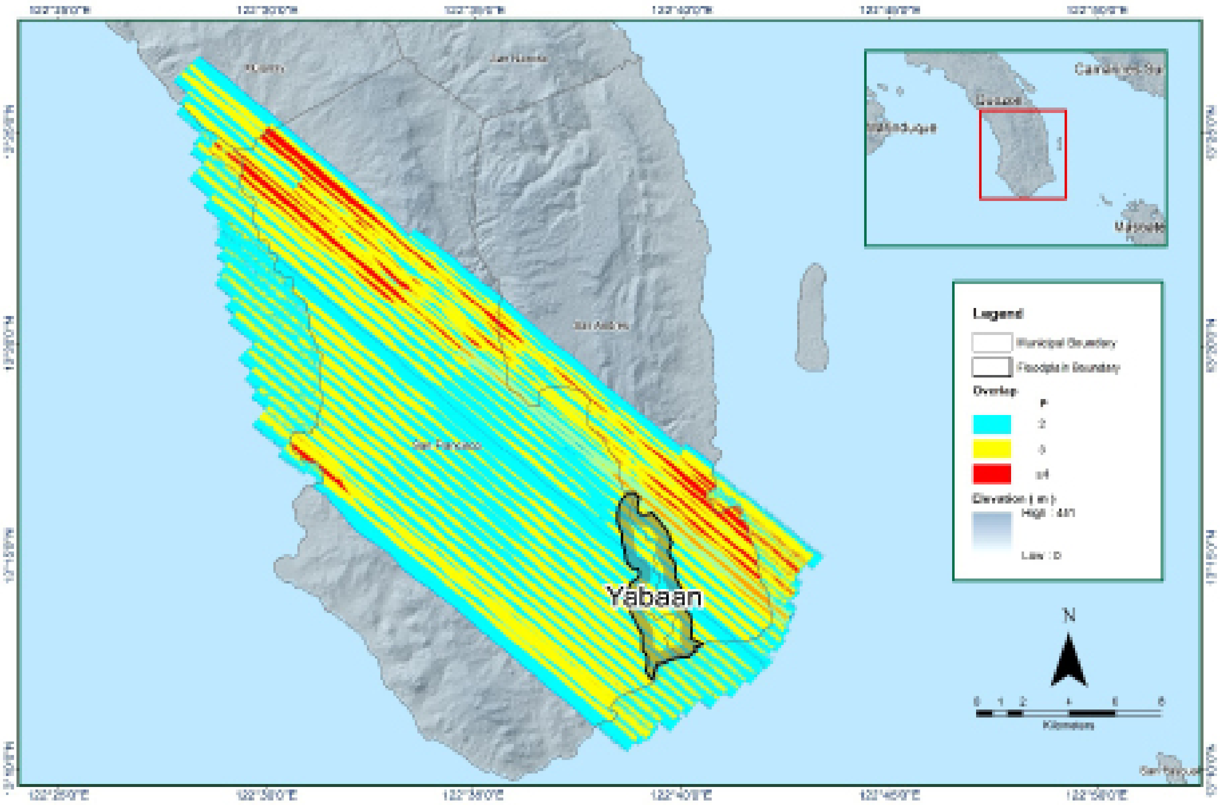

Figure 11. Image of data overlap for Yabaan Floodplain.

The overlap statistics per block for the Yabaan 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 49.23% and 62.54% 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 Yabaan floodplain satisfy the point density requirement, and the average density for the entire survey area is 5.19 points per square meter.

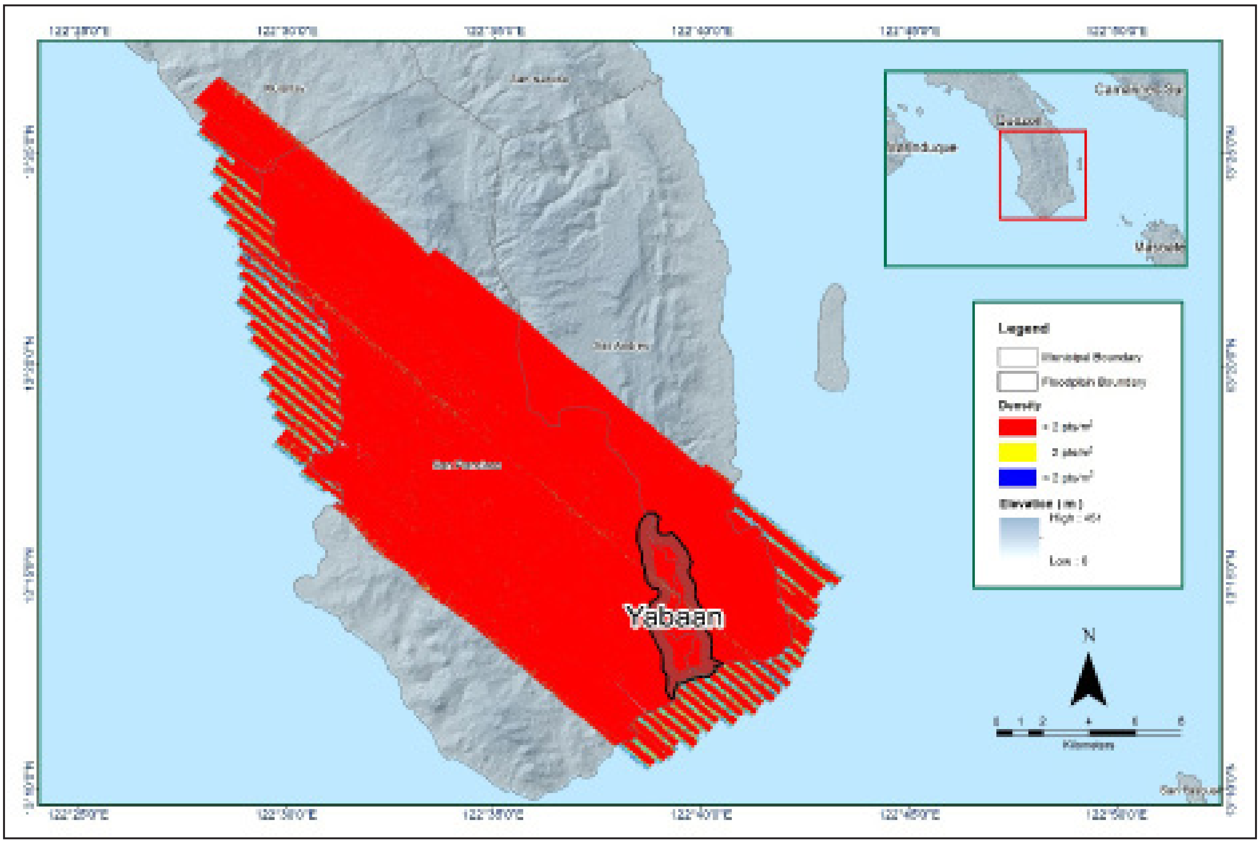

Figure 12. Pulse density map of merged LiDAR data for Yabaan Floodplain.

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.

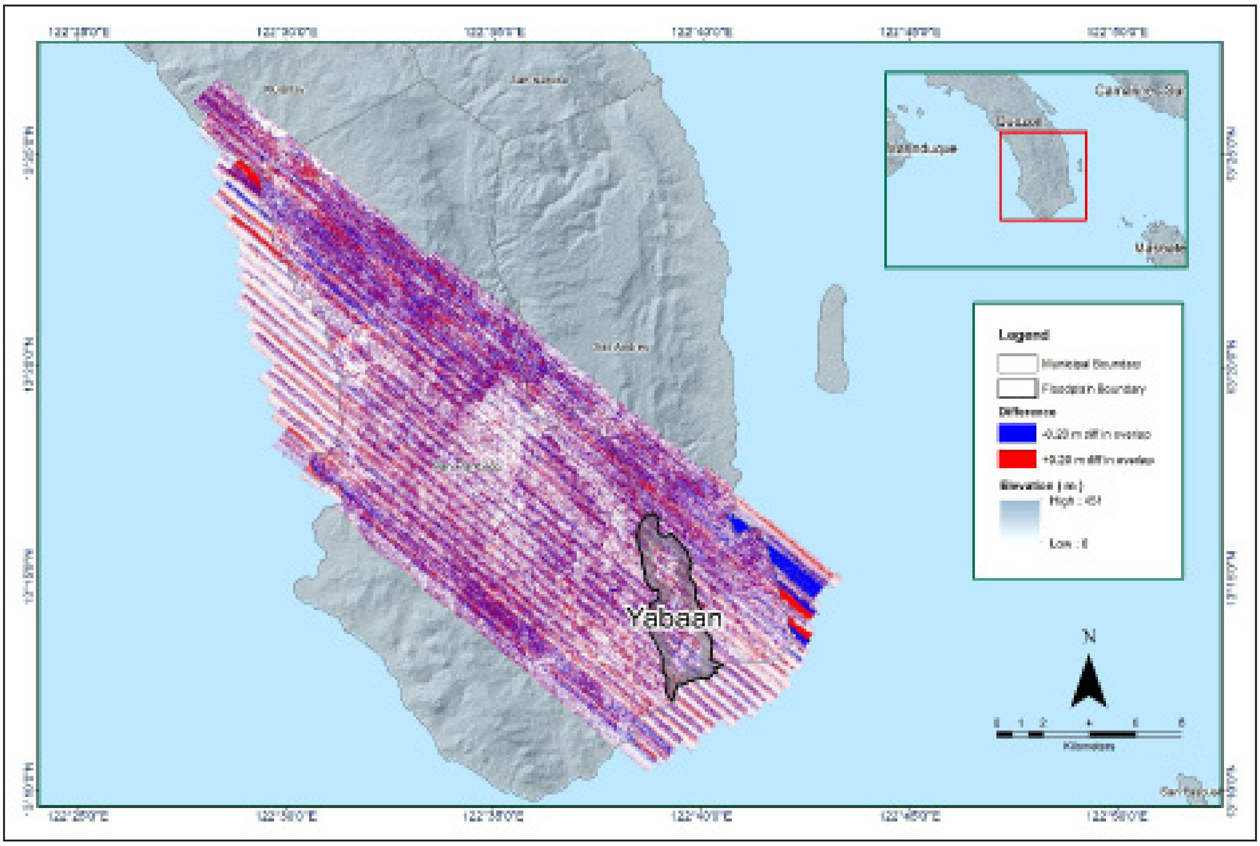

Figure 13. Elevation difference map between flight lines for Yabaan Floodplain.

A screen capture of the processed LAS data from Yabaan flight 23342P 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 satosfactory. No reprocessing was done for this LiDAR dataset.

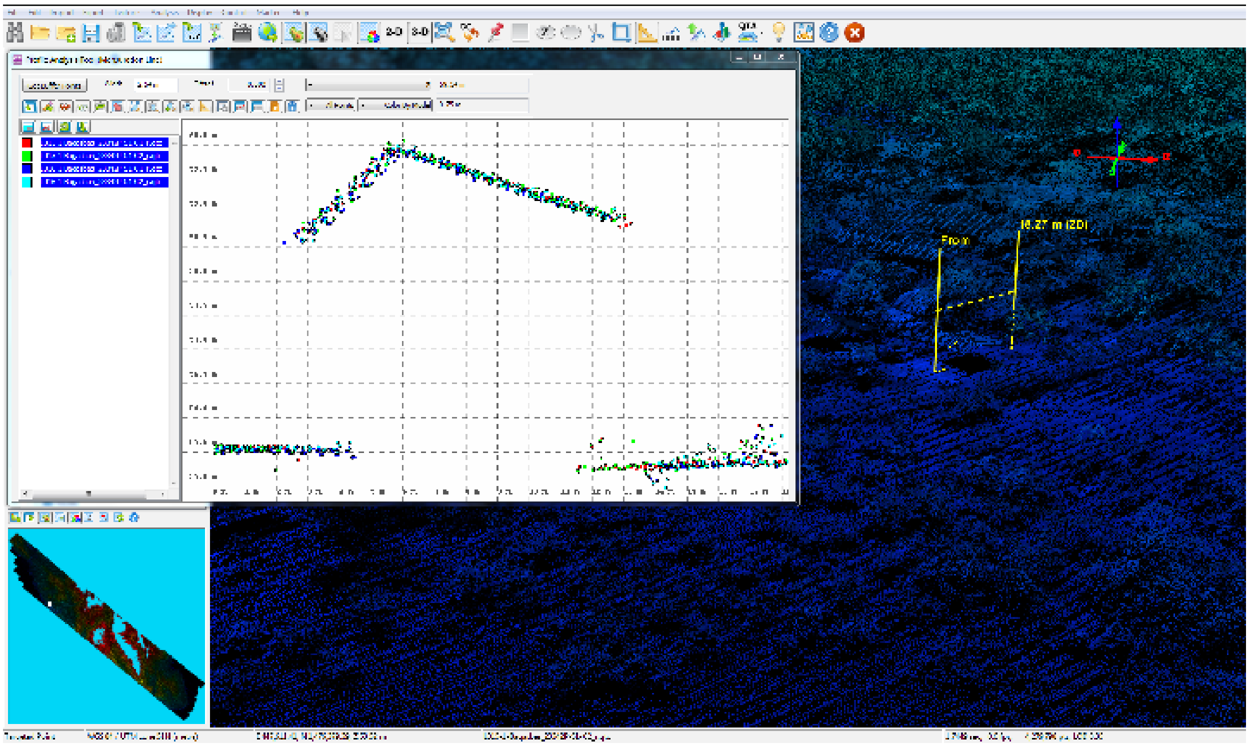

Figure 14. Quality checking for Yabaan flight 23342P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Yabaan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	595,694,730
Low Vegetation	481,122,155
Medium Vegetation	728,736,459
High Vegetation	1,646,459,899
Building	14,731,556

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Yabaan floodplain is shown in Figure 15. A total of 460 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 473.30 meters and 48.95 meters respectively.

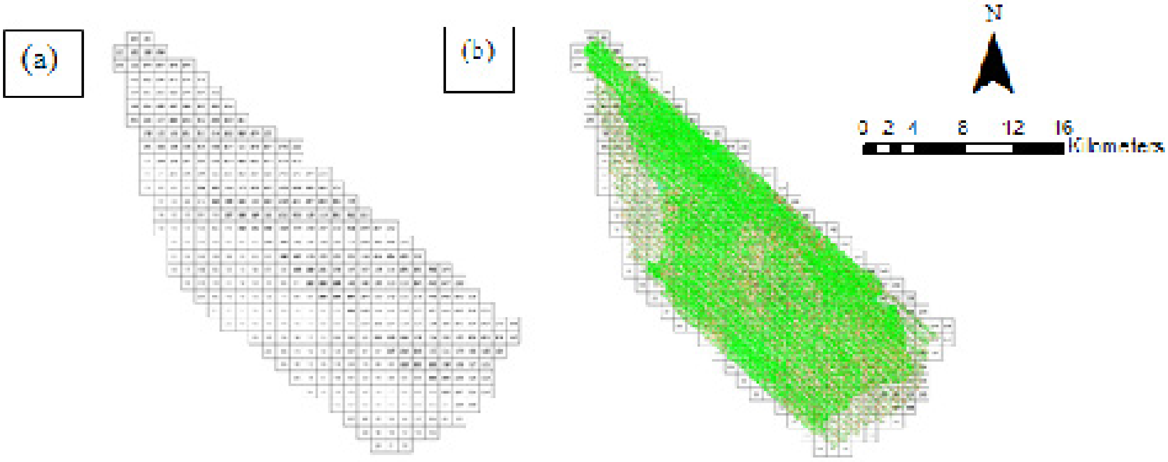

Figure 15. Tiles for Yabaan Floodplain (a) and classification results (b) in TerraScan.

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

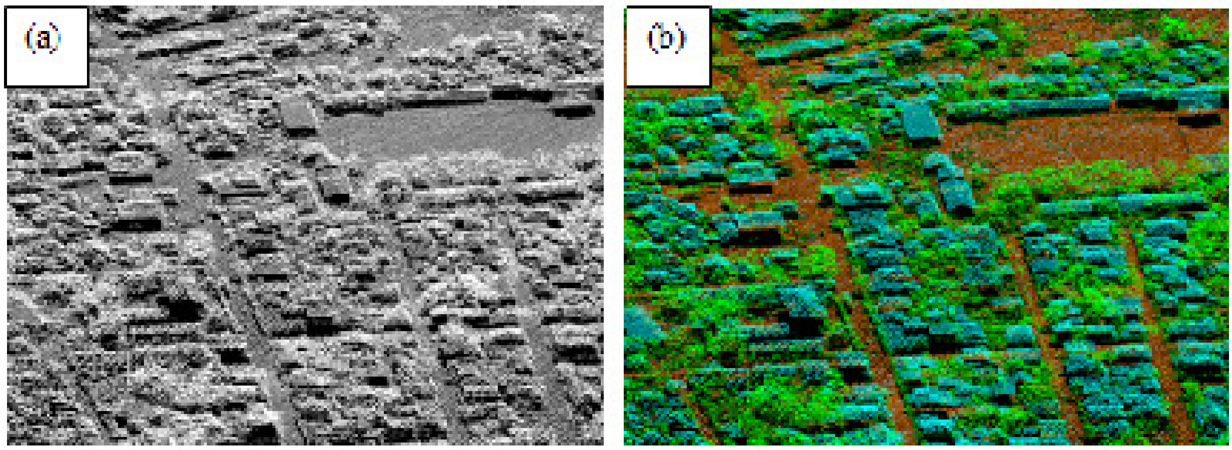

Figure 16. Point cloud before (a) and after (b) classification.

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

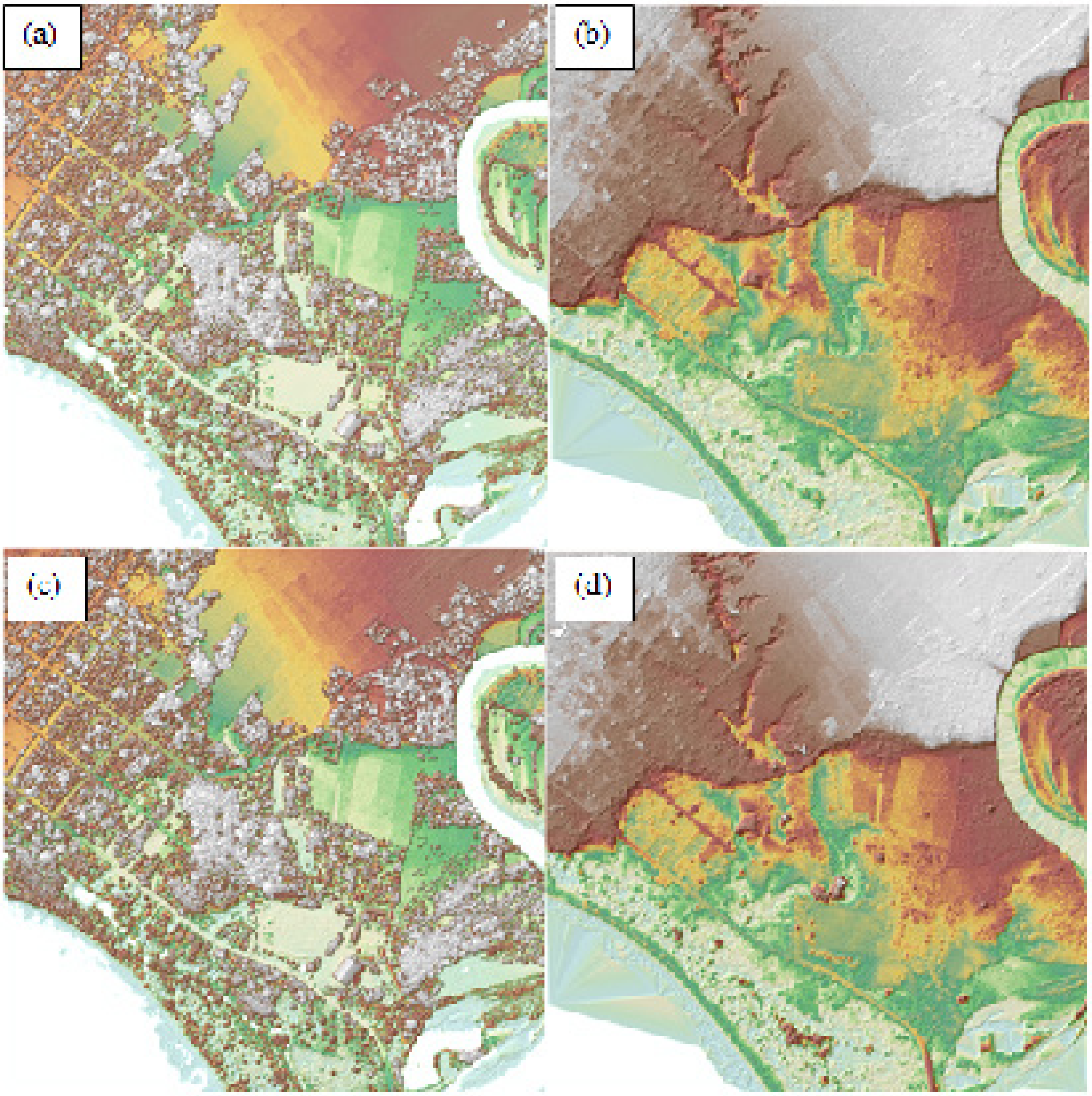

Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Yabaan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Yabaan floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Yabaan flood plain. These blocks are composed of SamarLeyte and Leyte blocks with a total area of 349.93 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)
Bagasbas_Blk21G	159.60
Bagasbas_Blk21H	190.33
TOTAL	349.93 sq.km

Portions of DTM before and after manual editing are shown in Figure 18. The bridge (Figure 18a) is 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. The point bar (Figure 18c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 18d) to allow the correct flow of water. Another example is a pit that is still present in the DTM after classification (Figure 18e) and has to be filled through manual editing (Figure 18f).

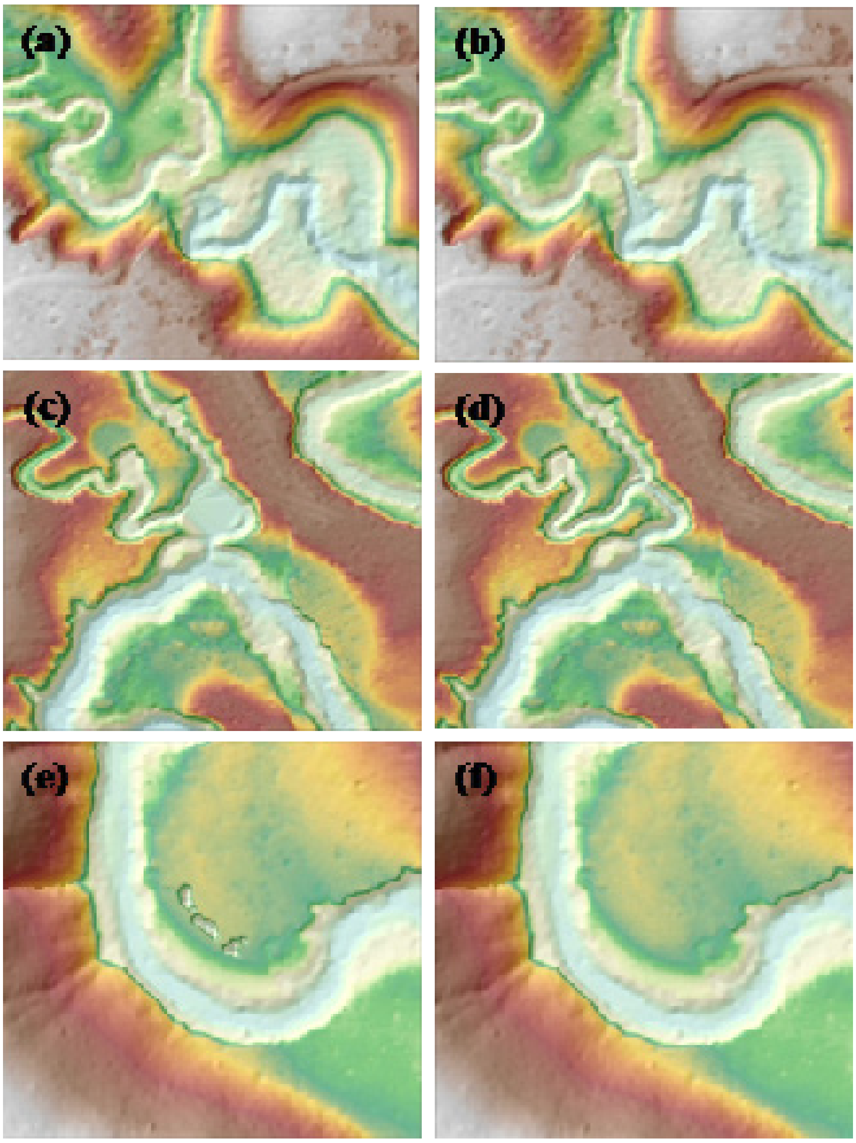

Figure 18. Portions in the DTM of Yabaan Floodplain – a bridge before (a) and after (b) manual editing; an embankment bar before (c) and after (d) data retrieval; and a pit before (e) and after (f) manual editing.

3.9 Mosaicking of Blocks

Bagasbas_Blk20F was used as the reference block at the start of mosaicking because this block is the one used as a base for other floodplains covered by Bagasbas blocks. Bagasbas_Blk21H is the block nearest from the base block that overlaps Yabaan floodplain. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

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

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Bagasbas_Blk21G	0.16	0.47	2.65
Bagasbas_Blk21H	1.23	1.39	2.60

Figure 19. Map of Processed LiDAR Data for Yabaan Flood Plain.

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 Yabaan to collect points with which the LiDAR dataset is validated is shown in Figure 20. A total of 15,500 survey points were gathered for all the flood plains within the provinces of Quezon and Camarines Sur wherein the Yabaan floodplain is located. Random selection of 80% of the survey points, resulting to 12400 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 3.08 meters with a standard deviation of 0.17 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 3.08 meters, to the mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

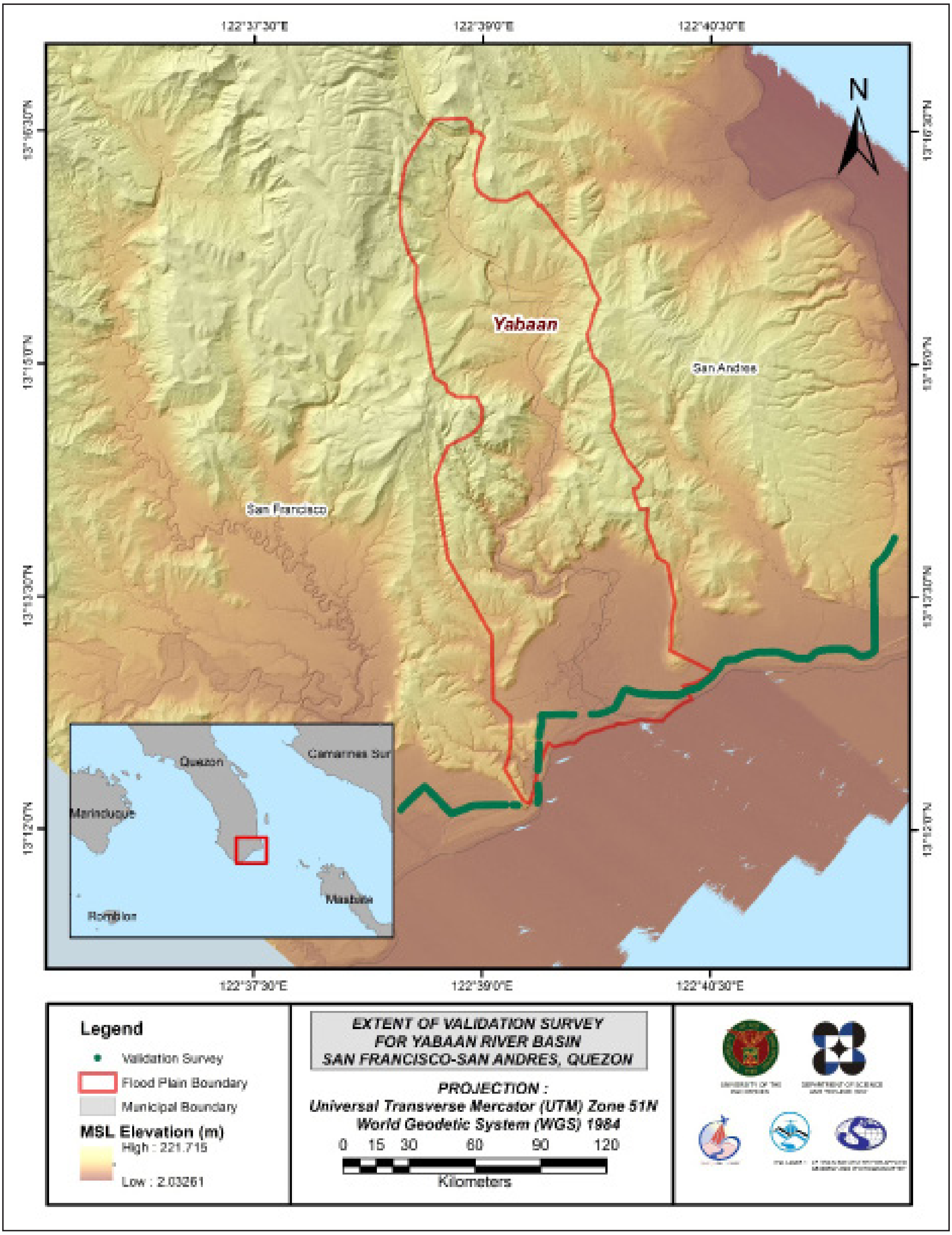

Figure 20. Map of Yabaan Flood Plain with validation survey points in green.

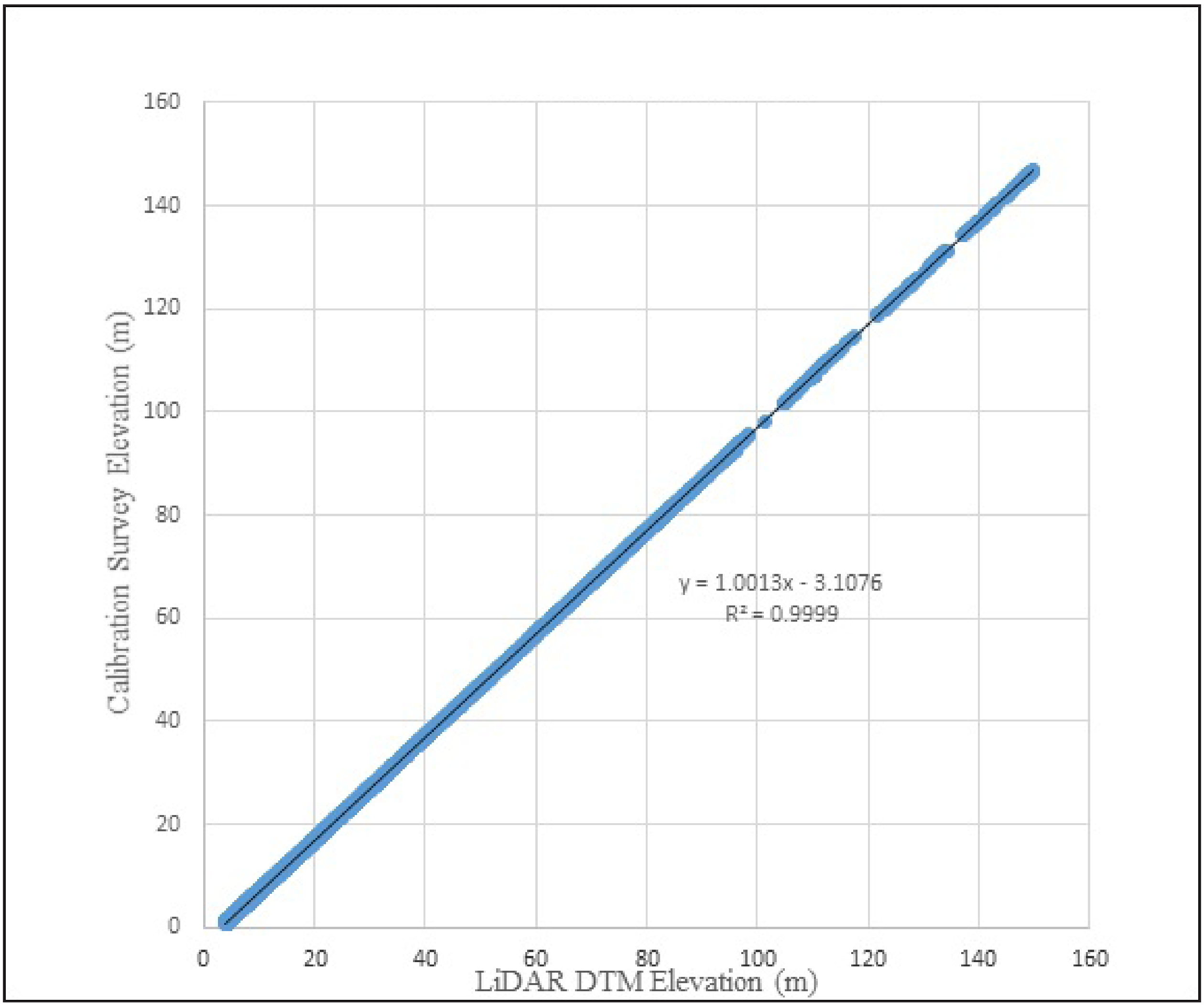

Figure 21. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	3.08
Standard Deviation	0.17
Average	-3.07
Minimum	-3.40
Maximum	-2.60

The remaining 20% of the total survey points that are near Yabaan floodplain, resulting to 247 points, were used for the validation of calibrated Yabaan 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 0.20 meters with a standard deviation of 0.05 meters, as shown in Table 14.

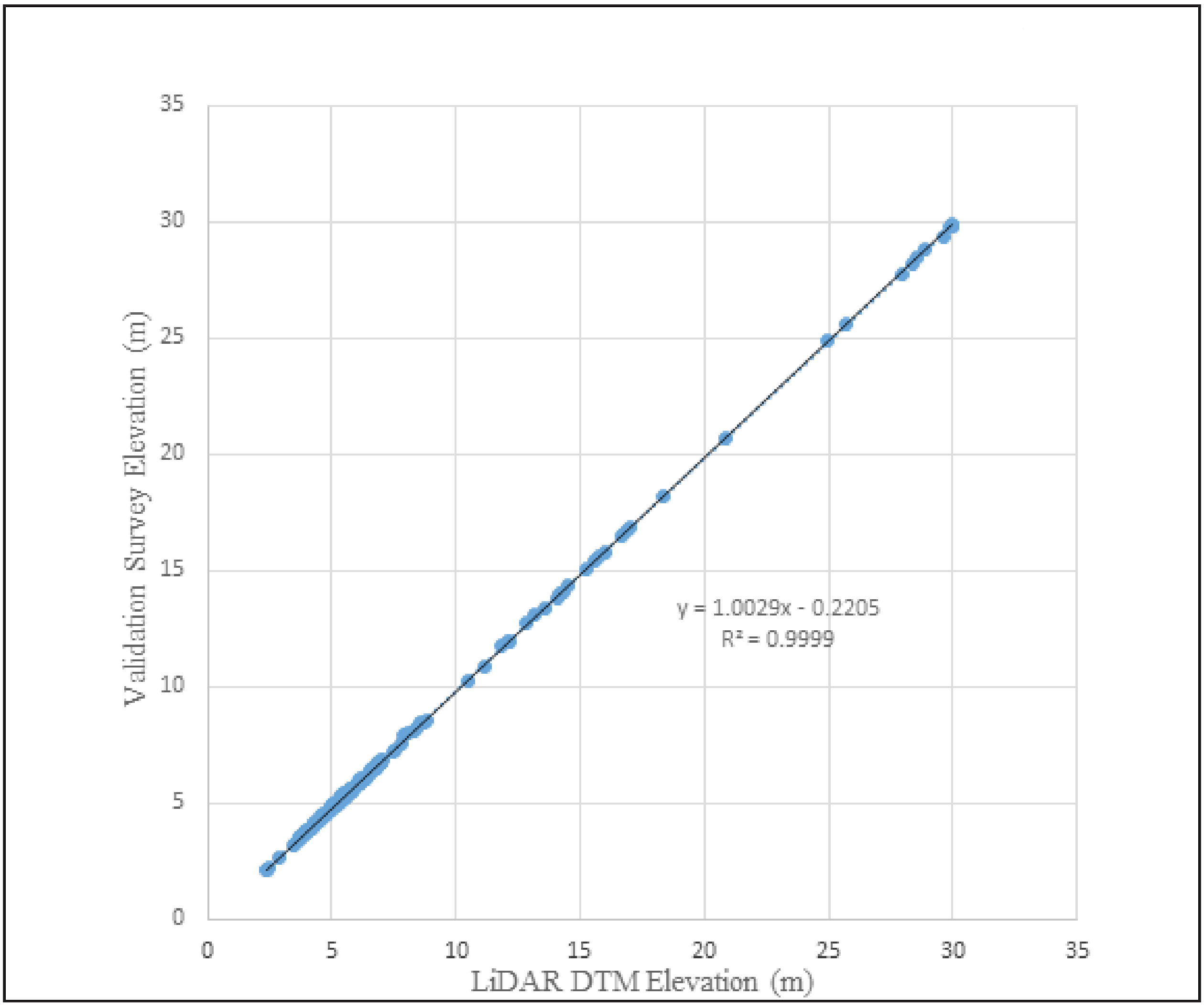

Figure 22. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.05
Average	-0.20
Minimum	-0.26
Maximum	-0.01

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Yabaan with 5440 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barriers method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.13 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Yabaan integrated with the processed LiDAR DEM is shown in Figure 23.

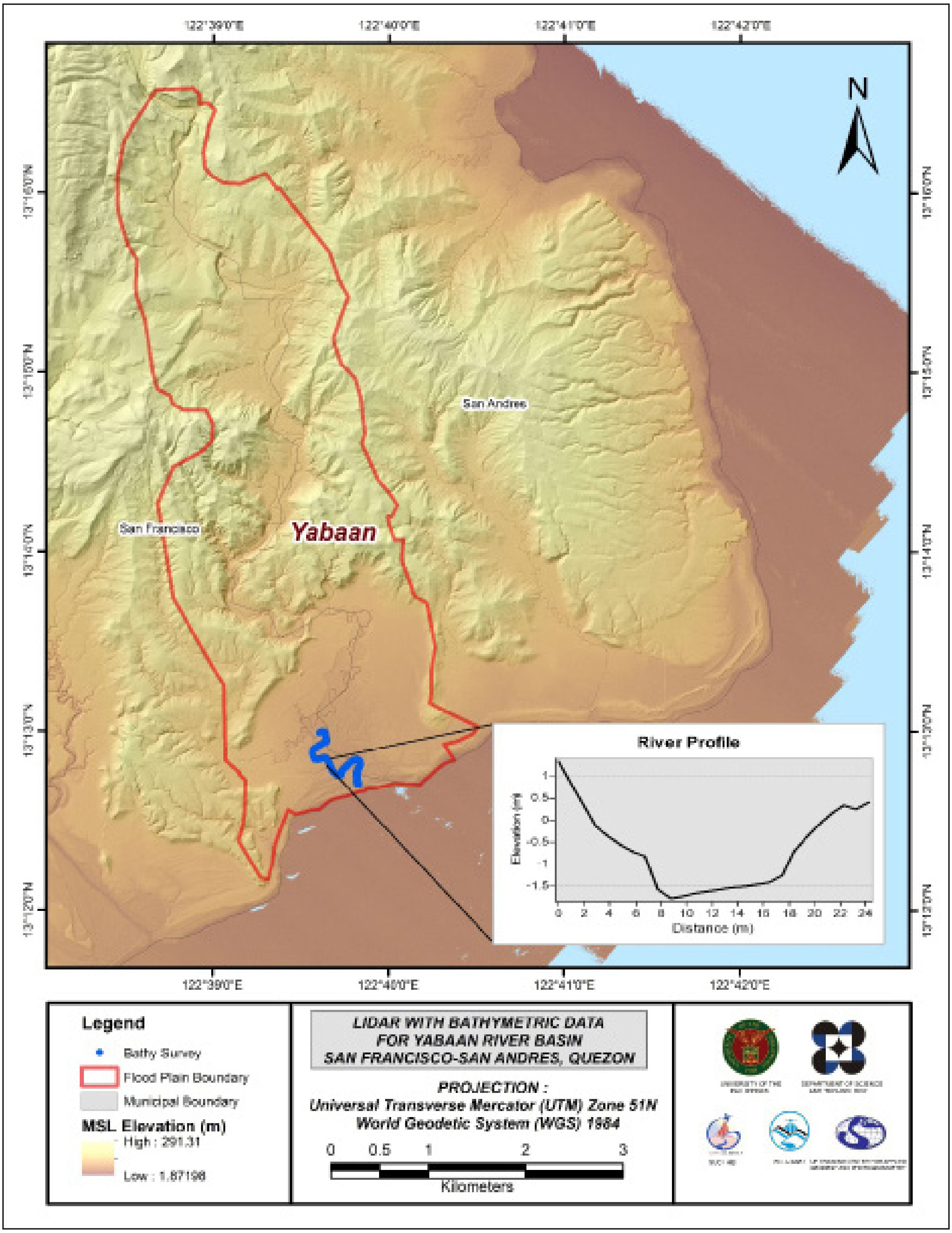

Figure 23. Map of Yabaan Floodplain with bathymetric survey points shown in blue.

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 (QC) of Digitized Features' Boundary

Yabaan floodplain, including its 200 m buffer, has a total area of 18.77 sq km. For this area, a total of 5.00 sq km, corresponding to a total of 324 building features, are considered for QC. Figure 24 shows the QC blocks for Yabaan floodplain.

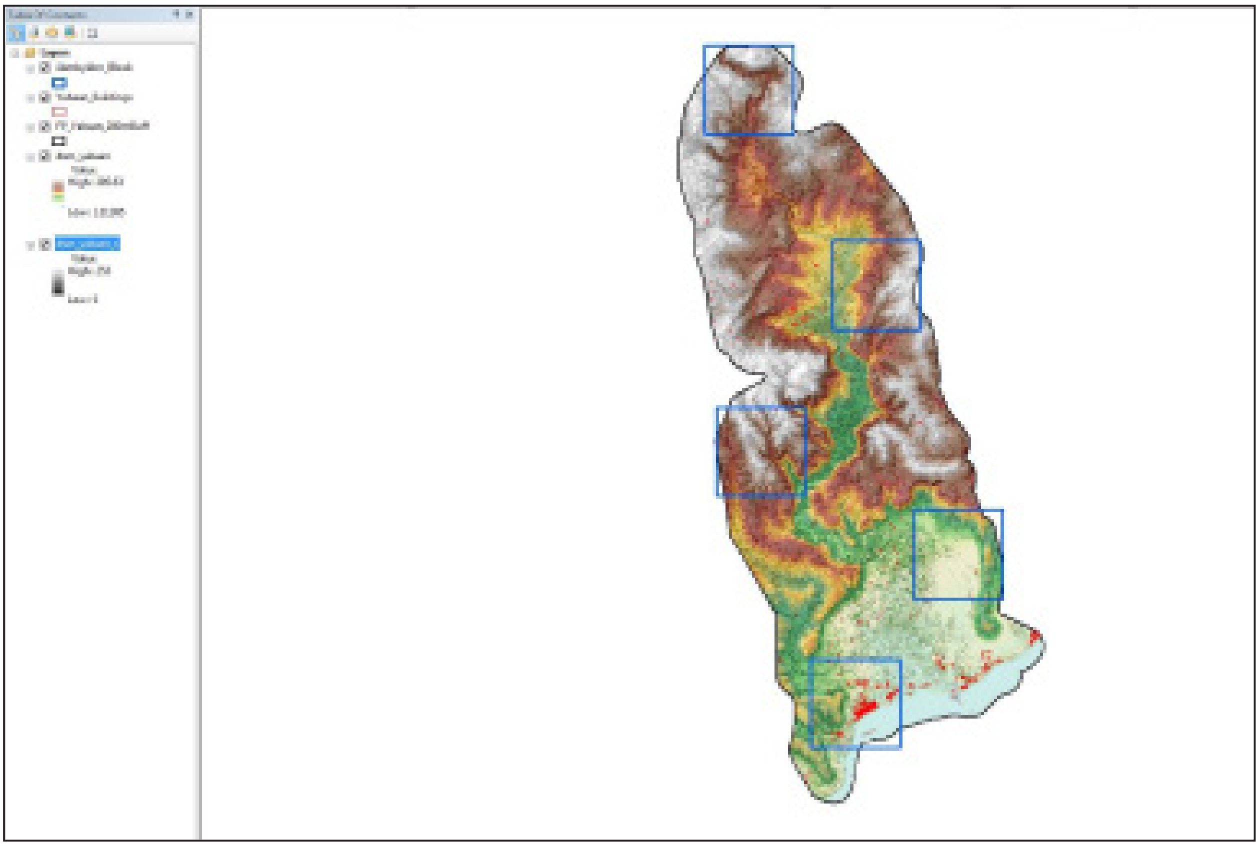

Figure 24. QC blocks for Yabaan building features.

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

Table 15. Quality Checking Ratings for Yabaan Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Yabaan	93.86	91.23	82.11	PASSED

3.12.2 Height Extraction

Height extraction was done for 733 building features in Yabaan floodplain. Of these building features, 32 were filtered out after height extraction, resulting to 701 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 8.37 m.

3.12.3 Feature Attribution

The attributes were obtained by field data gathering. GPS devices were used to determine the coordinates of important features. These points are uploaded and overlaid in ArcMap and are then integrated with the shapefiles.

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 Yabaan Floodplain.

Facility Type	No. of Features
Residential	687
School	13
Market	0
Agricultural/Agro-Industrial	0
Medical Institutions	0
Barangay Hall	0
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	0
Water Supply/Sewerage	0
Religious Institutions	1
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	0
Total	**701**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Yabaan	3.69	0.00	3.90	0.00	0.00	7.59

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

Floodplain	Water Body Type						Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	Others	
Yabaan	2	0	0	0	0	2	Yabaan

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 Yabaan floodplain overlaid with its ground features.

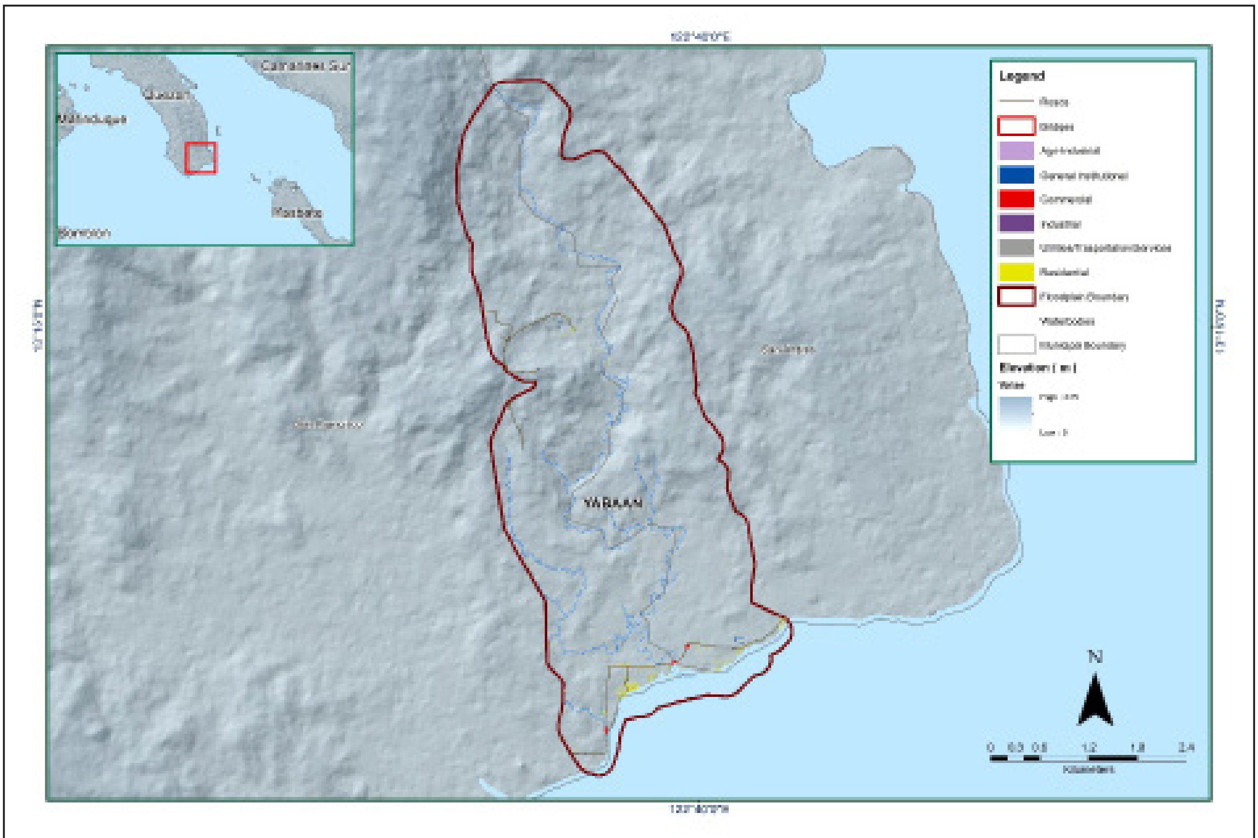

Figure 25. Extracted features for Lasang floodplain.

CHAPTER 4: DATA VALIDATION SURVEY AND MEASUREMENTS IN THE YABAAN RIVER BASIN

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Yabaan River on May 2-16, 2016 with the following scope of work: reconnaissance; control survey; cross-section ans as-built survey at Talisay Bridge in Brgy. Pagsangahan, Municipality of San Fracisco; validation points acquisition of about 8.8 km covering the Yabaan River Basin area; and bathymetric survey from its upstream to the mouth of the river both in Brgy. Pagsangahan in the Municipality of San Francisco, with an approximate length of 1.352 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 26).

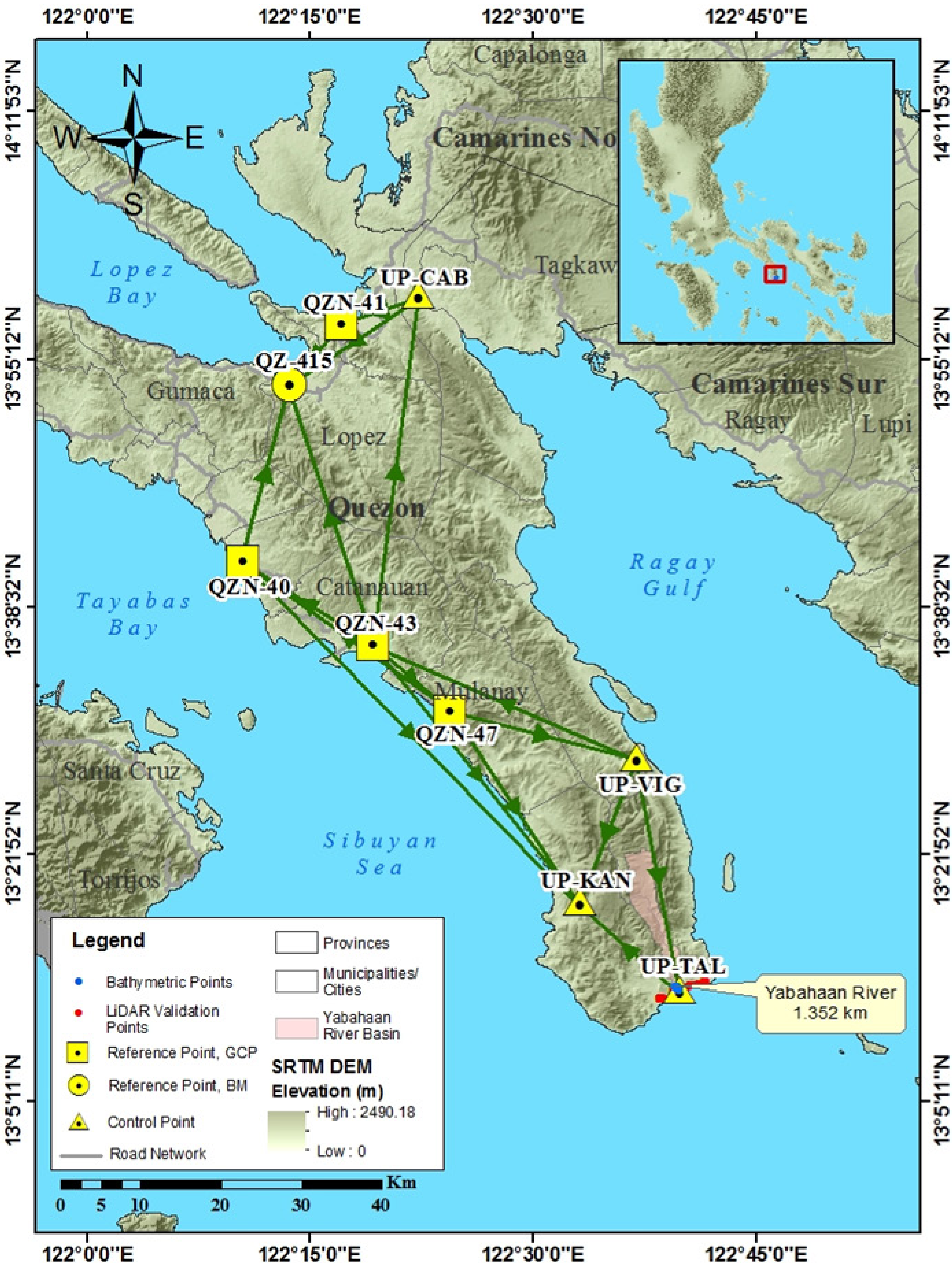


Figure 26. Yabaan (also known as Yabahaan) River Survey Extent

4.2 Control Survey

The GNSS network used for Yabaan River Basin is composed of nine (9) loops established on May 4 and 11, 2016 occupying the following reference points: QZN-40, a second-order GCP in Brgy. San Jose, Municipality of General Luna; QZN-43, a second-order GCP in Brgy. Matandang Sabang Silangan, Municipality of Catanauan; QZN-47, a second order GCP in Barangay II, Municipality of Mulanay; and QZ-415, a BM with Accuracy Class at 95% CL 8cm in Brgy. Pansol, Municipality of Lopez.

There are four (4) UP established control points located at the approach of bridges namely: UP-KAN, at Kanguinsa Bridge in Brgy. Silongin, Municipality of San Francisco; UP-TAL at Talisay Bridge in Brgy. Pagsangahan, also in the Municipality of San Francisco; and UP-VIG at Vigo Bridge in Brgy. Vigo Central, Municipality of San Narciso. The UP established control point UP-CAB is located in a residential court in Brgy. Aloneros, Municipality of Guinayangan. A NAMRIA established control point QZN-41 in Barangay I, Municipality of Calauag was 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.

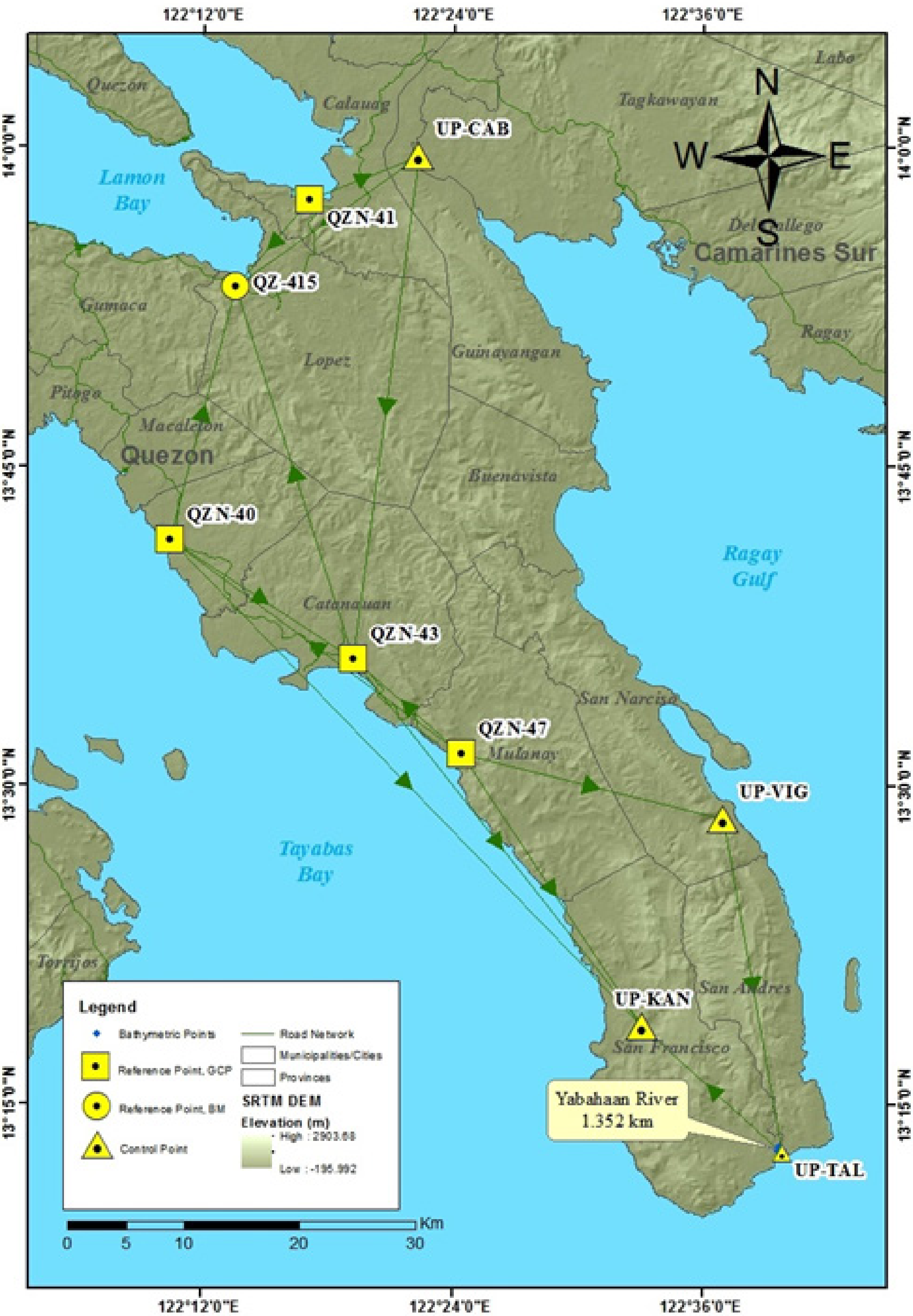


Figure 27. GNSS Network of Yabaan Field Survey

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
QZN-40	2nd Order, GCP	13°41'32.47595" N	122°10'25.77273" E	51.703	-	2006
QZN-43	2nd Order, GCP	13°35'55.81611" N	122°19'13.53031" E	51.015	-	2006
QZN-47	2nd Order, GCP	13°31'29.52488" N	122°24'23.44821" E	53.862	-	2006
QZ-415	1st order Order, BM	-	-	57.290	8.613	2007
QZN-41	Used as Marker	-	-	-	-	2006
UP-CAB	UP Established	-	-	-	-	05-04-2016
UP-KAN	UP Established	-	-	-	-	05-11-2016
UP-TAL	UP Established	-	-	-	-	05-11-2016
UP-VIG	UP Established	-	-	-	-	05-11-2016

The GNSS set-ups of the reference and control points are exhibited are shown in Figure 28 to Figure 36.

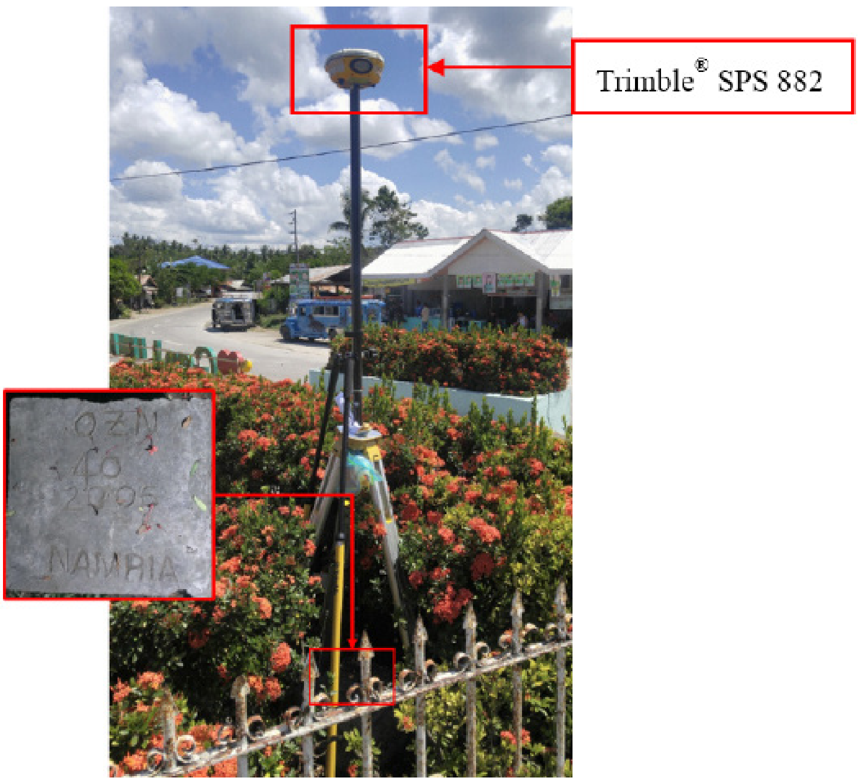


Figure 28. GNSS base set up, Trimble® SPS 882, at QZN-40, located inside a triangular plant area found at the center of a triangular island in Brgy. San Jose, Municipality of Gen. Luna, Quezon

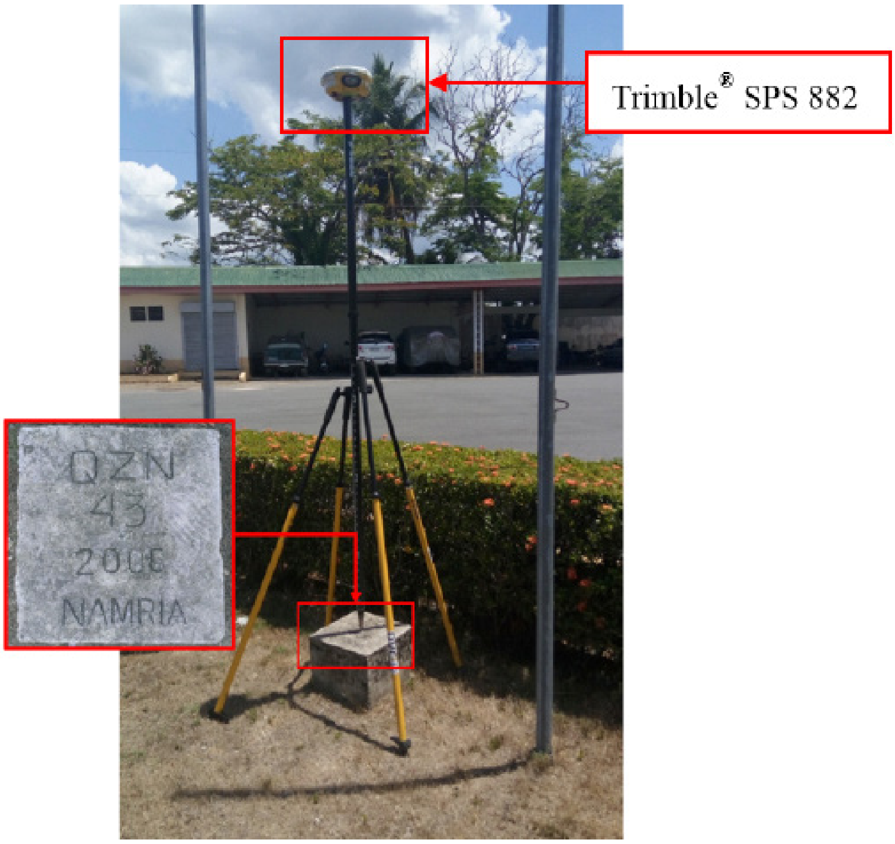


Figure 29. GNSS base set up, Trimble® SPS 882, at QZN-43, located inside the DPWH compound in Brgy. Matandang Sabang Silangan, Municipality of Catanauan, Quezon

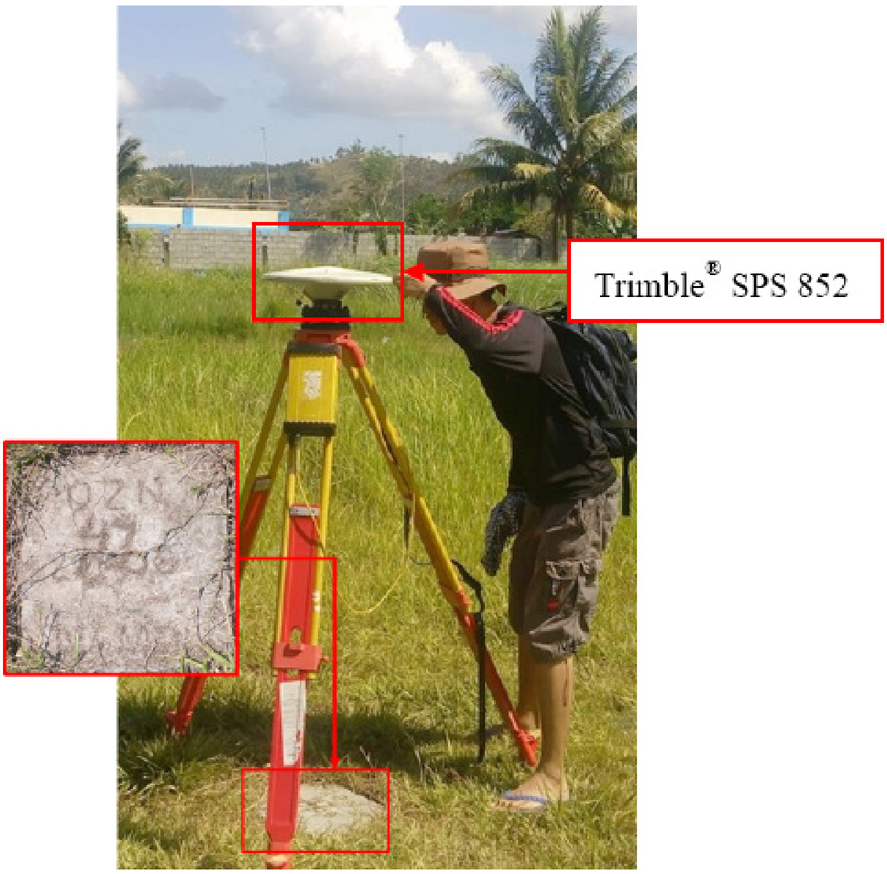


Figure 30. GNSS base set up, Trimble® SPS 852, at QZN-47, located at the back of the Principal's Office of Mulanay Elementary School in Barangay II, Municipality of Mulanay, Quezon.

Figure 31. GNSS base set up, Trimble® SPS 985, at QZ-415, located at the approach of Pansol Bridge in Brgy. Pansol, Municipality of Lopez, Quezon

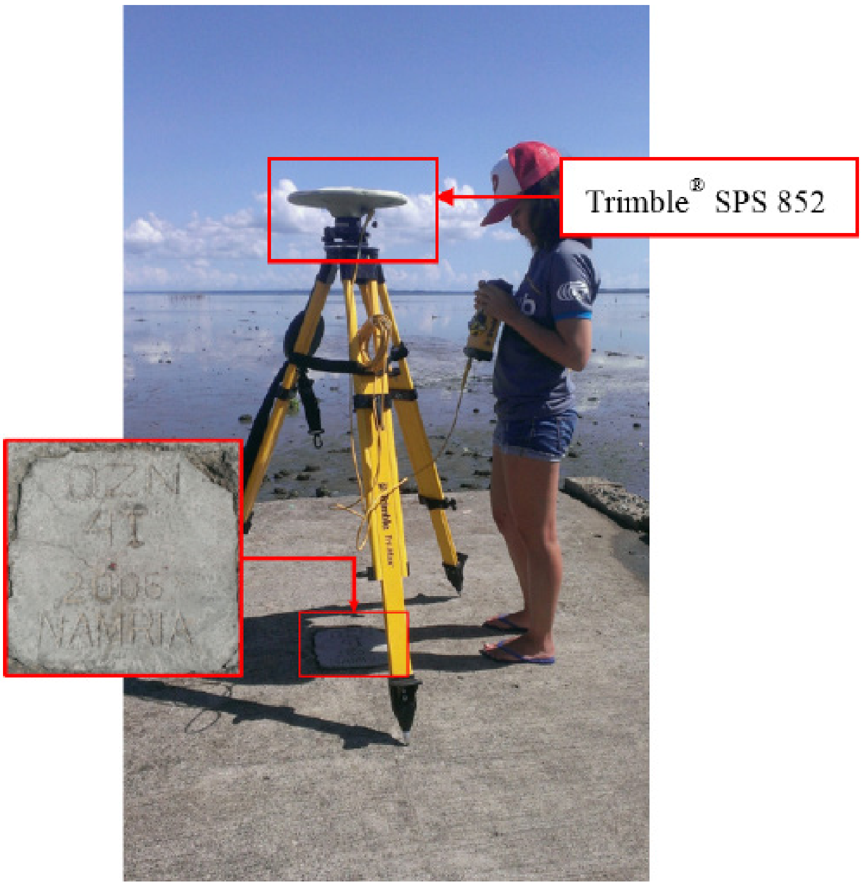


Figure 32. GNSS base set up, Trimble® SPS 852, at QZN-41, located in front of Brgy. Sabang basketball court found in Calauag Port, Barangay I, Municipality of Calauag, Quezon

Figure 33. GNSS base set up, Trimble® SPS 882, at UP-CAB, located inside a basketball court in Brgy. Aloneros, Municipality of Guinayangan, Quezon

Figure 34. GNSS base set up, Trimble® SPS 852, at UP-KAN, located at the approach of Kanguinsa Bridge in Brgy. Silongin, Municipality of San Francisco, Quezon

Figure 35. GNSS base set up, Trimble® SPS 852, at UP-TAL, located at the approach of Talisay Bridge in Brgy. Pagsangahan, Municipality of San Francisco, Quezon

Figure 36. GNSS base set up, Trimble® SPS 882, at UP-VIG, located at the approach of Vigo Bridge in Brgy. Vigo Central, Municipality of San Francisco, Quezon

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

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

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)
QZN-47 --- QZN-40	05-11-2016	Fixed	0.003	0.011	306°22'36"	31263.486
QZN-47 --- QZN-43	05-11-2016	Fixed	0.003	0.013	131°16'56"	12401.416
QZN-47 --- UP-VIG	05-11-2016	Fixed	0.003	0.012	103°58'19"	23335.323
QZN-47 --- UP-KAN	05-11-2016	Fixed	0.005	0.019	146°21'08"	28388.037
QZN-40 --- QZ-415	05-11-2016	Fixed	0.003	0.023	14°21'16"	22613.475
UP-CAB --- QZ-415	05-04-2016	Fixed	0.004	0.025	234°09'16"	19401.067
QZN-40 --- UP-KAN	05-11-2016	Fixed	0.011	0.027	135°49'24"	58749.581
QZN-43 --- QZ-415	05-11-2016	Fixed	0.006	0.033	342°23'19"	33841.349
QZN-43 --- UP-KAN	05-11-2016	Fixed	0.005	0.018	141°46'15"	40492.330
UP-TAL --- UP-KAN	05-11-2016	Fixed	0.005	0.018	312°01'33"	16293.271
UP-VIG --- UP-TAL	05-11-2016	Fixed	0.003	0.014	169°50'51"	29356.882
UP-VIG --- QZN-43	05-11-2016	Fixed	0.003	0.014	293°25'54"	34821.073
UP-VIG --- UP-KAN	05-11-2016	Fixed	0.005	0.021	201°04'03"	19280.526
QZN-41 --- UP-CAB	05-04-2016	Fixed	0.004	0.024	247°44'12"	10141.643
QZN-41 --- QZ-415	05-04-2016	Fixed	0.003	0.022	220°07'13"	9835.756
QZN-40 --- QZN-43	05-11-2016	Fixed	0.003	0.014	303°07'59"	18937.828
UP-CAB --- QZN-43	05-11-2016	Fixed	0.004	0.019	7°10'02"	43963.480

As shown in Table 20, a total of seventeen (17) baselines were processed with reference points QZN-40, QZN-43 and QZN-47 fixed for grid values; and QZ-415 held fixed for elevation. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

xe is the Easting Error,
yeis the Northing Error, and
zeis the Elevation Error

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

The nine (9) control points, QZN-40, QZN-43, QZN-47, QZ-415, QZN-41, UP-CAB, UP-KAN, UP-TAL and UP-VIG were occupied and observed simultaneously to form a GNSS loop. Elevation value of QZ-415 and coordinates of points QZN-40, QZN-43 and QZN-47 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)
QZN-40	Global	Fixed	Fixed		
QZN-43	Global	Fixed	Fixed		
QZN-47	Global	Fixed	Fixed		
QZ-415	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 points QZN-40, QZN-43, QZN-47 and QZ-415 have no values for grid and elevation errors, respectively.

Table 22. Adjusted Grid Coordinates

Point ID	Easting	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
QZN-40	410660.624	?	1513855.137	?	2.622	0.075	LL
QZN-43	426485.118	?	1503462.996	?	1.574	0.073	LL
QZN-47	435778.405	?	1495257.875	?	4.163	0.079	LL
QZ-415	416340.495	0.010	1535736.431	0.010	8.613	?	e
QZN-41	422699.129	0.014	1543236.263	0.014	1.392	0.082	
UP-CAB	432091.726	0.012	1547052.366	0.013	3.211	0.073	
UP-KAN	451445.231	0.012	1471596.832	0.011	25.095	0.086	
UP-TAL	463529.271	0.016	1460676.916	0.014	4.949	0.095	
UP-VIG	458401.312	0.010	1489570.998	0.008	6.030	0.083	

The network is fixed at reference points QZN-40, QZN-43, and QZN-47 with known coordinates, and QZ-415 with known elevation. As shown in Table 22, the standard errors (xe and ye) of QZ-415 are 1.0 cm and 1.0 cm. With the mentioned equation, $\sqrt{((x_e)^2 + (y_e)^2)}$ <20cm and $z_e < 10\ cm$ for horizontal and for the vertical, respectively; the computation for the accuracy of the reference and control points are as follows:

a. QZN-40
horizontal accuracy = Fixed
vertical accuracy = 7.5 cm < 10 cm

b. QZN-43
horizontal accuracy = Fixed
vertical accuracy = 7.3 cm < 10 cm

c. QZN-47
horizontal accuracy = Fixed
vertical accuracy = 7.9 cm < 10 cm

d. QZ-415
horizontal accuracy = √((1. 0)² + (1.0)²
= √ (1.0 + 1.0)
= 1.41cm < 20 cm
vertical accuracy = Fixed

e. QZN-41
horizontal accuracy = √((1.40)² + (1.40)²
= √ (1.96+ 1.96)
= 1.98cm < 20 cm
vertical accuracy = 8.2 cm < 10 cm

f. UP-CAB
horizontal accuracy = √((1.20)² + (1.30)²
= √ (1.44 + 1.69)
= 1.77 cm < 20 cm
vertical accuracy = 7.3 cm < 10 cm

g. UP-KAN
horizontal accuracy = √((1.20)² + (1.10)²
= √ (1.44 + 1.21)
= 1.63 cm < 20 cm
vertical accuracy = 8.6 cm < 10 cm

h. UP-TAL
horizontal accuracy = √((1.60)² + (1.40)²
= √ (2.56 + 1.96)
= 2.13 cm < 20 cm
vertical accuracy = 9.5 cm < 10 cm

i. UP-VIG
horizontal accuracy = √((1.10)² + (0.80)²
= √ (1.21 + 0.64)
= 1.36 cm < 20 cm
vertical accuracy = 8.3 cm < 10 cm

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

Table 23. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
QZN-40	N13°41'32.47595"	E122°10'25.77273"	51.703	0.075	LL
QZN-43	N13°35'55.81611"	E122°19'13.53031"	51.015	0.073	LL
QZN-47	N13°31'29.52488"	E122°24'23.44821"	53.862	0.079	LL
QZ-415	N13°53'25.29589"	E122°13'32.50380"	57.290	?	e
QZN-41	N13°57'30.05268"	E122°17'03.60722"	50.089	0.082	
UP-CAB	N13°59'35.12930"	E122°22'16.30558"	52.023	0.073	
UP-KAN	N13°18'40.40211"	E122°33'06.07511"	75.768	0.086	
UP-TAL	N13°12'45.55145"	E122°39'48.22322"	55.864	0.095	
UP-VIG	N13°28'25.87675"	E122°36'56.35787"	56.412	0.083	

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 used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)					
		Latitude	Longitude	Ellipsoidal Height (m)	Northing	Easting	BM Ortho
QZN-40	2nd Order GCP	13°41'32.47595" N	122°10'25.77273" E	51.703	1513855.137	410660.624	(m)
QZN-43	2nd Order GCP	13°35'55.81611" N	122°19'13.53031" E	51.015	1503462.996	426485.118	1.574
QZN-47	2nd Order GCP	13°31'29.52488" N	122°24'23.44821" E	53.862	1495257.875	435778.405	4.163
QZ-415	1st Order BM	13°53'25.29589" N	122°13'32.50380" E	57.290	1535736.431	416340.495	8.613
QZN-41	Used as Marker	13°57'30.05268" N	122°17'03.60722" E	50.089	1543236.263	422699.129	1.392
UP-CAB	UP Established	13°59'35.12930" N	122°22'16.30558" E	52.023	1547052.366	432091.726	3.211
UP-KAN	UP Established	13°18'40.40211" N	122°33'06.07511" E	75.768	1471596.832	451445.231	25.095
UP-TAL	UP Established	13°12'45.55145" N	122°39'48.22322" E	55.864	1460676.916	463529.271	4.949
UP-VIG	UP Established	13°28'25.87675" N	122°36'56.35787" E	56.412	1489570.998	458401.312	6.030

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

Cross-section survey was conducted at the downstream part of Talisay Bridge on May 12, 2016 using Ohmex™ single beam echo sounder and a GNSS receiver, Trimble® SPS 882, in PPK survey technique as shown in Figure 37.

Figure 37. (A) Talisay Bridge facing upstream and (B) cross-section Survey using Trimble® SPS 882 in PPK survey technique

The cross-sectional line length for Yabaan River is about 175.214 m with 118 total cross-sectional points acquired using UP-TAL as the GNSS base station. The location map, cross-section diagram, and bridge as-built form are illustrated in Figure 38 to Figure 40.

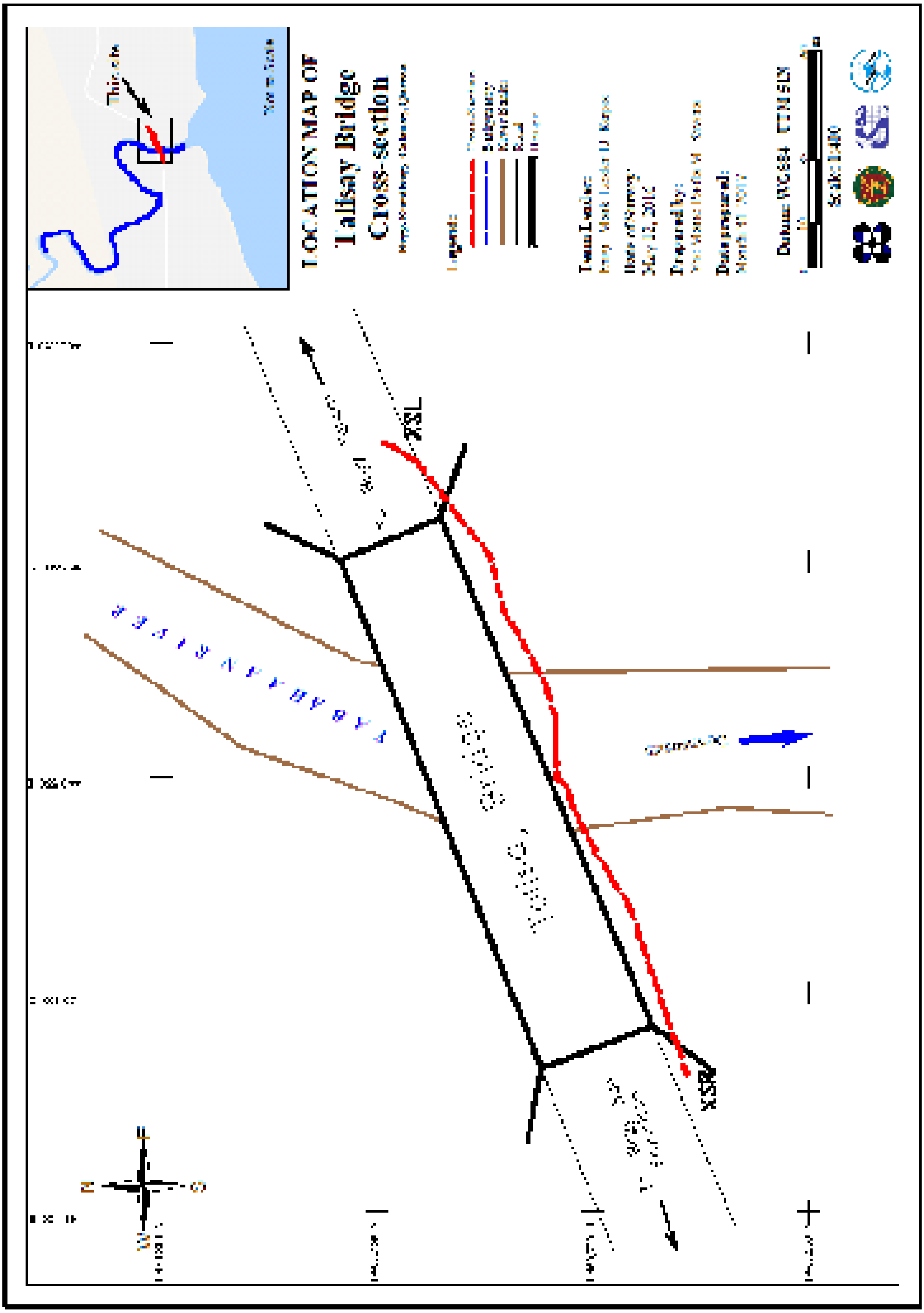


Figure 38. Location map of Talisay (also known as Yabaan) Bridge cross-section

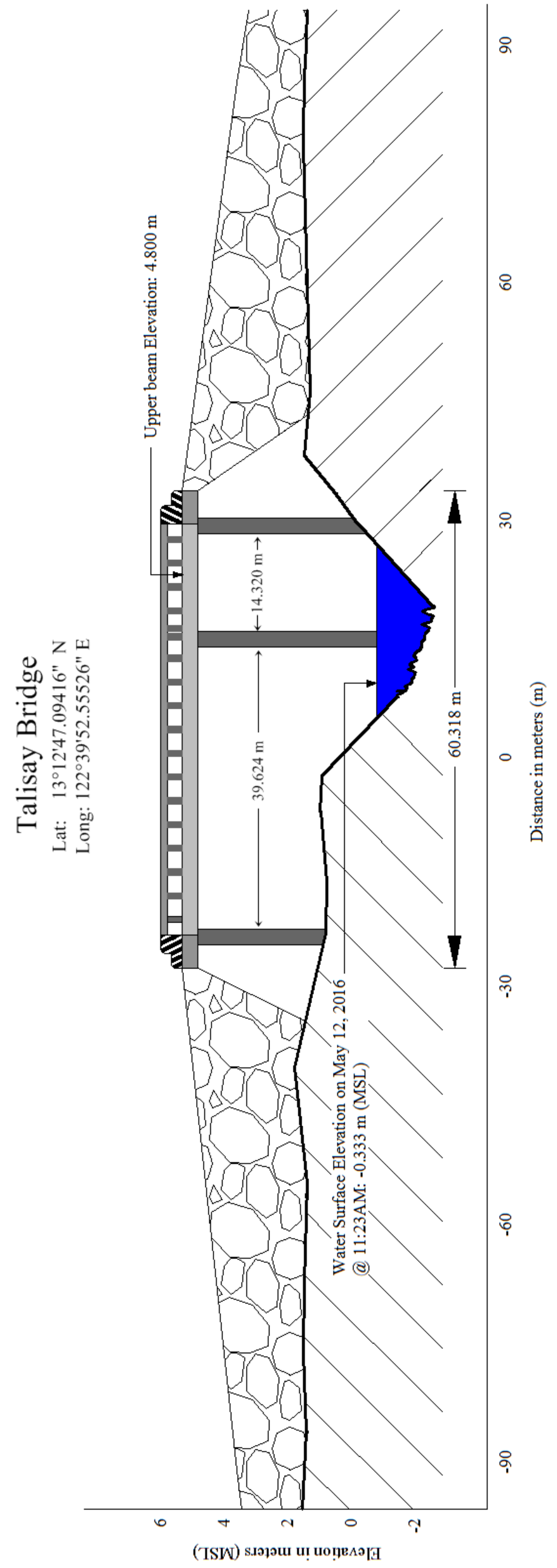


Figure 39. Talisay (also known as Yabaan) Bridge cross-section diagram

Bridge Data Form

Bridge Name: Talisay Bridge **Date: May 12, 2016**

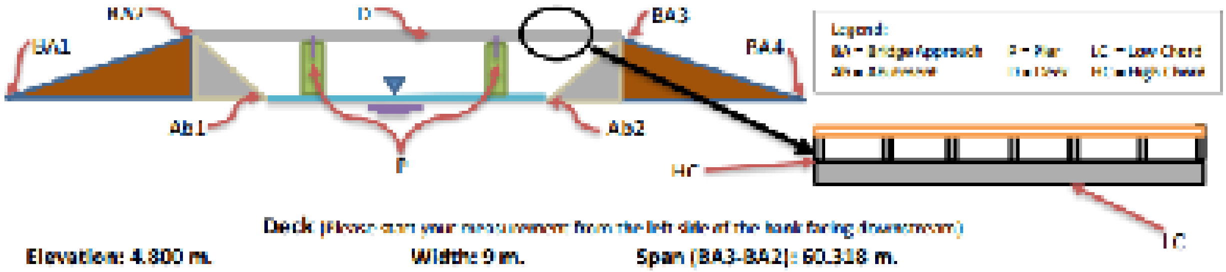
River Name: Yabahaan River **Time: 11:23 AM**

Location: Brgy. Sumilang, Municipality of Calauag, Quezon

Survey Team: Mark Rojas, Maria Morris, Pauline Racoma, Michael Labrador, Erlan Mendoza, Romalyn Dosado

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

Latitude: 13°12'47.09416"N **Longitude: 122°39'52.55526"E**



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

Elevation: 4.800 m. **Width: 9 m.** **Span (BA3-BA2): 60.318 m.**

	Station	High Chord Elevation	Low Chord Elevation
1	NA		

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	3.081	BA3	123.646	4.829
BA2	63.328	4.794	BA4	175.205	3.094

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

	Station (Distance From BA1)	Elevation
Ab1	NA	
Ab2		

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

Shape: Rectangular Number of Piers: 3 Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	66.256	4.816	
Pier 2	105.880	4.804	
Pier 3	120.201	4.828	
Pier 4			

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

Figure 40. Talisay (also known as Yabaan) Bridge Data Form

Water surface elevation in MSL of Yabaan River was determined using GNSS receiver, Trimble® SPS 882, in PPK survey technique on May 12, 2016 at 11:23 AM with a value of -0.333 m in MSL. This was translated onto marking on the Talisay bridge's pier using the same technique as shown in Figure 41. The markings will serve as their reference for flow data gathering and depth gauge deployment for Yabaan River.

Figure 41. Water-Level Marking at Talisay Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on May 12, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on the roof of the vehicle as shown in Figure 42. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was 1.87 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 UP-TAL occupied as the GNSS base stations in the conduct of the survey.

Figure 42. Validation points acquisition survey set up along Yabaan River Basin

The survey started from Brgy. Talisay in the Municipality of San Andres, going west and ended in Brgy. Pagsangahan in Municipality of San Francisco. This route aims to cut flight strips made by the Data Acquisition Team, perpendicularly. The survey gathered 1,281 points with an approximate length of 8.8 km using UP-TAL as GNSS base station for the entire extent validation points acquisition survey as illustrated in the map in Figure 43.

Figure 43. LiDAR validation points acquisition survey for Yabaan River Basin

4.3.2 Bathymetric Survey

Bathymetric survey was executed on May 12, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and an OHMEX™ single beam echo sounder as shown in Figure 44. The extent of the survey is from the upstream in Brgy. Pagsangahan, Municipality of San Francisco with coordinates 13°12'59.52872"N, 122°39'36.83627"E, and ended at the mouth of the river also in the same barangay with coordinates 13°12'42.11721"N, 122°39'49.68550"E.

Figure 44. Bathymetry by boat set up for Yabaan River survey

The bathymetric survey coverage for Yabaan river is illustrated in Figure 45. A CAD drawing was also produced to illustrate the riverbed profile of Yabaan River. As shown in Figure 46, the highest and lowest elevation has a 2.5-meter difference. The highest elevation observed is -0.374 m above MSL located at the upstream portion of the river while the lowest elevation observed is -2.926 m below MSL located near the Talisay Bridge portion of the river both in Brgy. Pagsangahan, Municipality of San Fracisco. The bathymetric survey gathered a total of 6,018 points covering 1.352 km of the river traversing Brgy. Pagsangahan in the Municipality of San Francsco, and a small portion of Brgy. Talisay in the Municipality of San Andres.

Figure 45. Bathymetric points gathered from Yabaan River

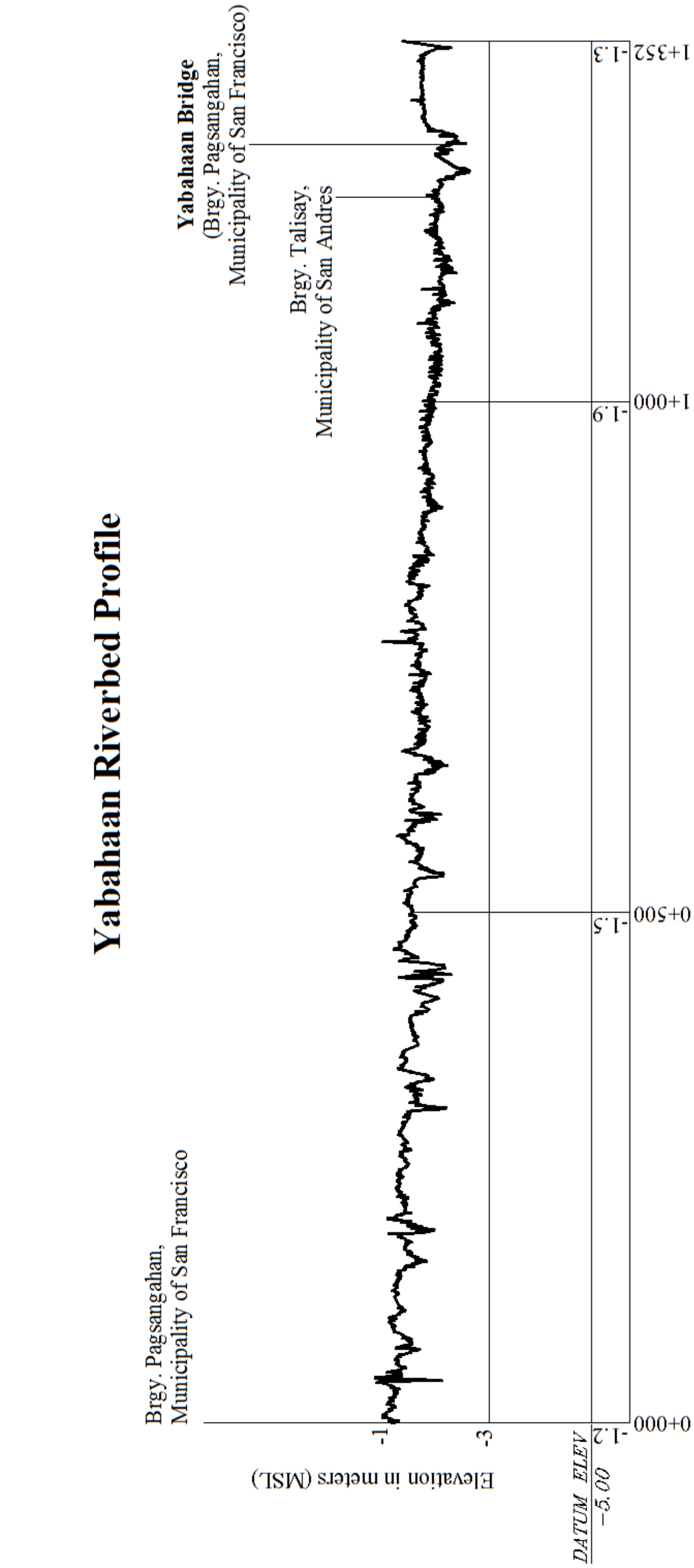


Figure 46. Yabaan riverbed profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, 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 Yabaan 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 Yabaan River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from automatic rain gauges (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The locations of the ARG are San Andres and Silongin. The location of the rain gauge is as shown in Figure 47.

The total rain from the San Andres rain gauge is 14 mm. It peaked to 3 mm at 18:50 on October 11, 2016. The lag time between the peak rainfall and discharge is 3 hours and 10 minutes, as shown in Figure 50.

For Silongin rain gauge the total rain is 8.8 mm. Peak rain of 0.8 mm at 21:00 was recorded on October 11, 2016. The lag time between the peak rainfall and discharge is 1 hour, as shown in Figure 50.

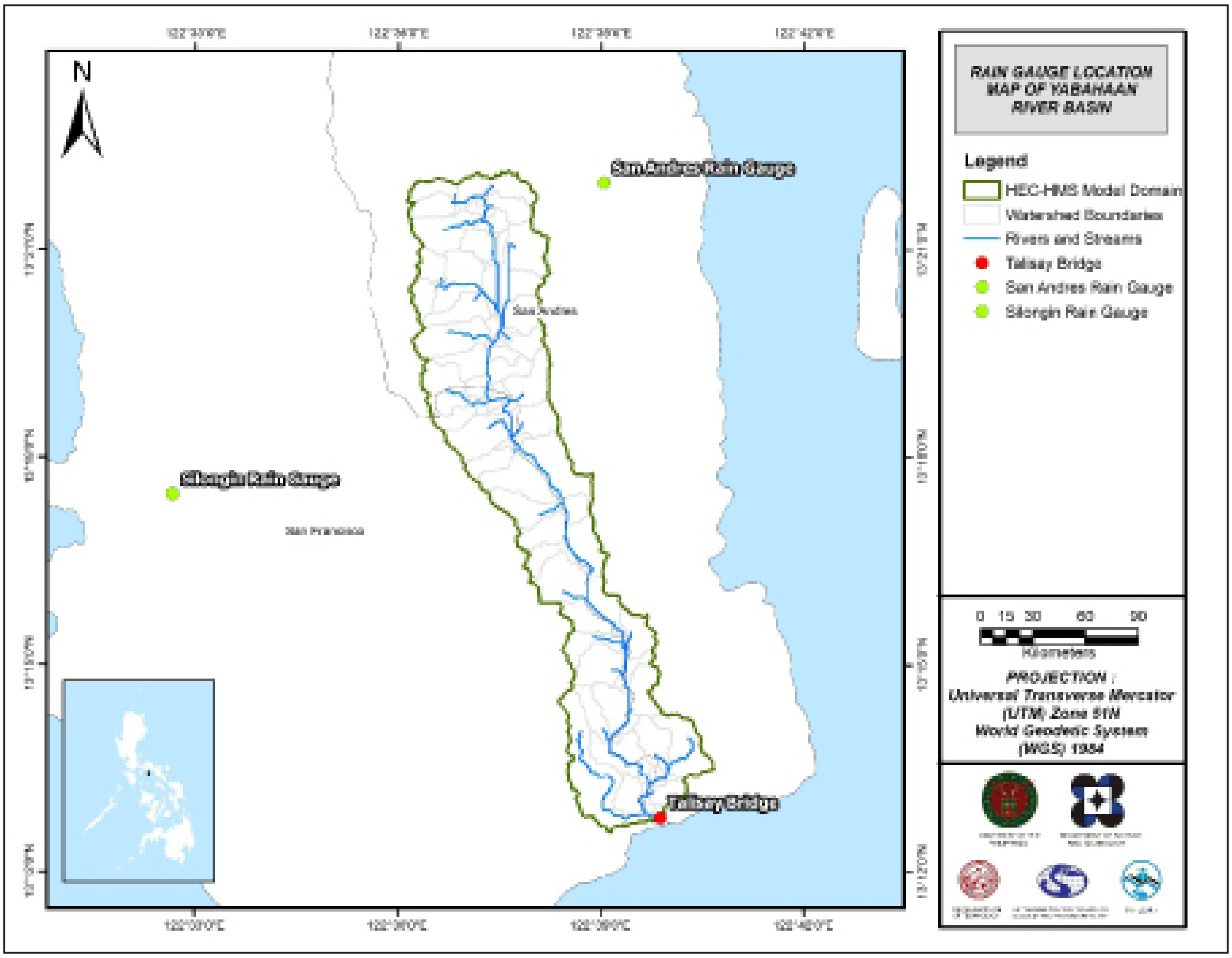


Figure 47. The location map of Yabaan HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Talisay Bridge, which is located at the boundary of San Francisco and San Andres in Quezon Province (13°12’47.09416”N 122°39’52.55526”E). It gives the relationship between the observed water levels and outflow of the watershed at this location. It is expressed in the form of the following equation:

Q=anh

where, Q : Discharge (m3/s),
h : Gauge height (reading from Talisay Bridge AWLS), and;
a and n: Constants.

For Talisay Bridge, the rating curve is expressed y = 54.633e8.3925x as shown in Figure 48.

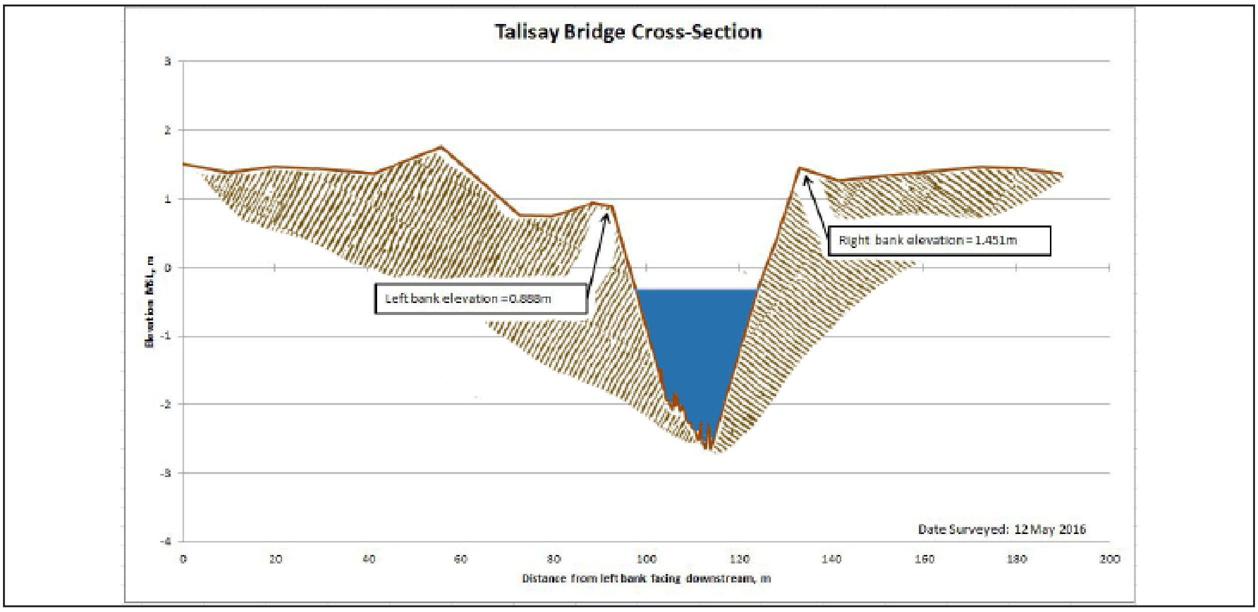


Figure 48. Cross-Section Plot of Talisay (also known as Yabaan) Bridge

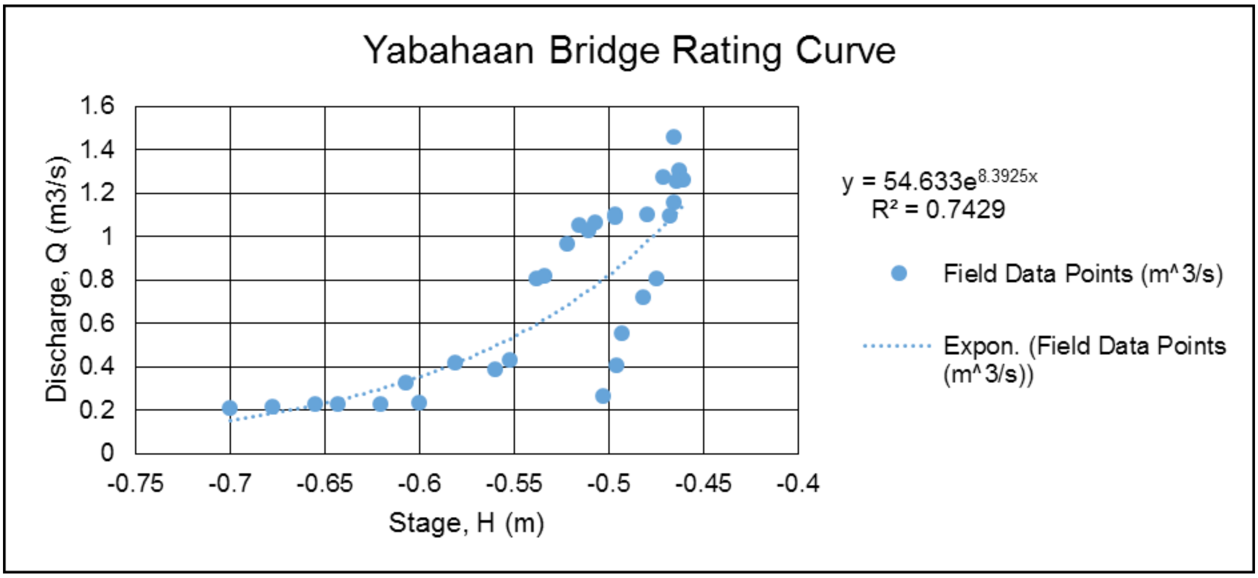


Figure 49. Rating curve at Talisay (also known as Yabaan or Yabahaan) Bridge, San Andres, Quezon Province

This rating curve equation was used to compute the river outflow at Talisay Bridge for the calibration of the HEC-HMS model shown in Figure 50. Peak discharge is 1.46 m3/s at 22:05, October 11, 2016.

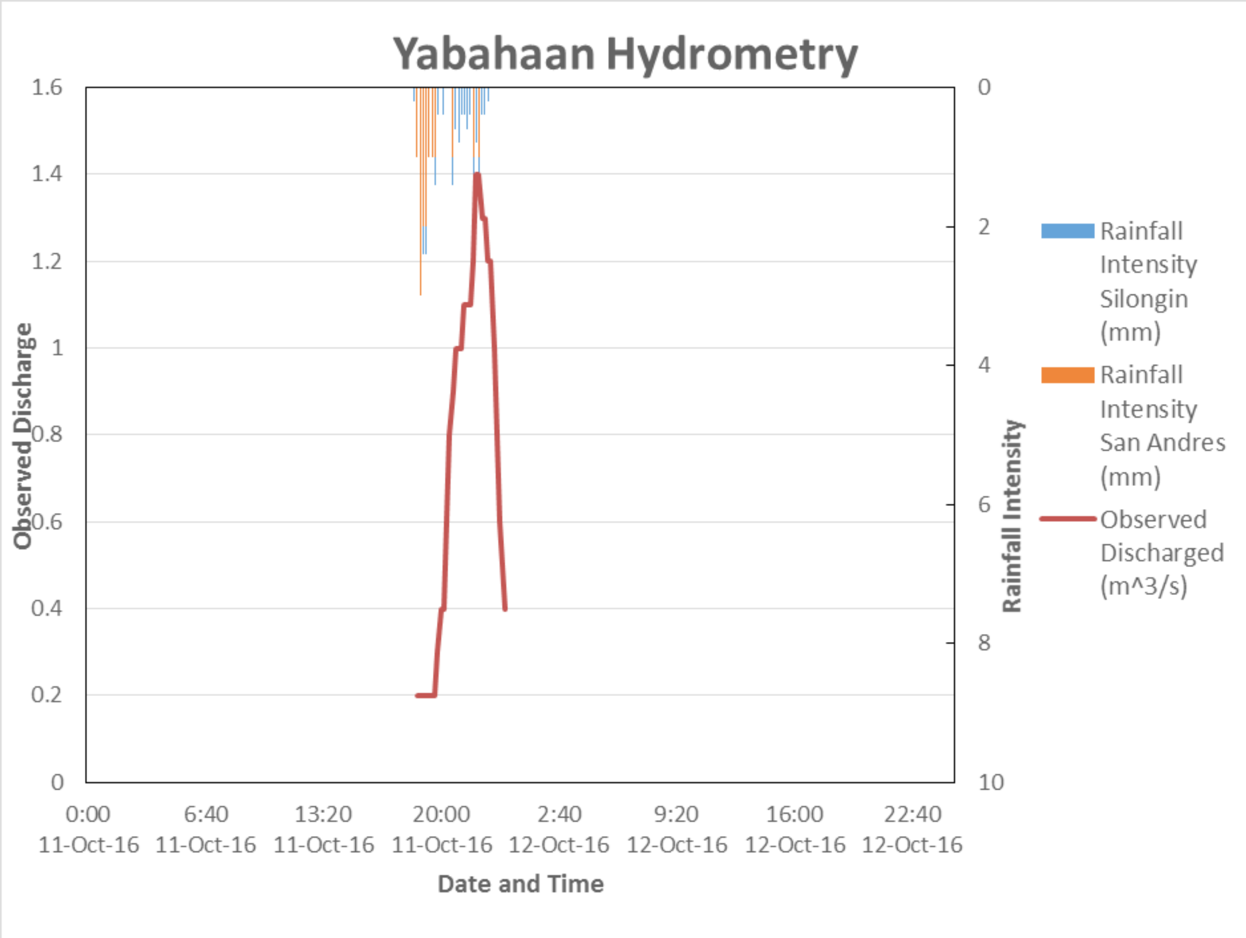


Figure 50. Rainflow and outflow data at Yabaan River used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Romblon Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station is chosen based on its proximity to the Yabahaan watershed. The extreme values for this watershed were computed based on a 48-year record, as shown in Table 25.

Table 25. values for Romblon 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	18.2	27	33.5	44.3	59.5	70.4	89.5	107	119.8
5	26	37.7	46.5	60.7	82.2	97.6	125.5	152.9	171.6
10	31.1	44.8	55	71.5	97.3	115.7	149.3	183.4	205.9
15	34	48.8	59.9	77.7	105.8	125.8	162.8	200.5	225.2
20	36	51.6	63.3	82	111.8	133	172.2	212.6	238.8
25	37.6	53.8	65.9	85.3	116.4	138.4	179.4	221.8	249.2
50	42.4	60.4	74	95.4	130.5	155.3	201.8	250.3	281.4
100	47.2	67	81.9	105.5	144.5	172.1	223.9	278.6	313.3

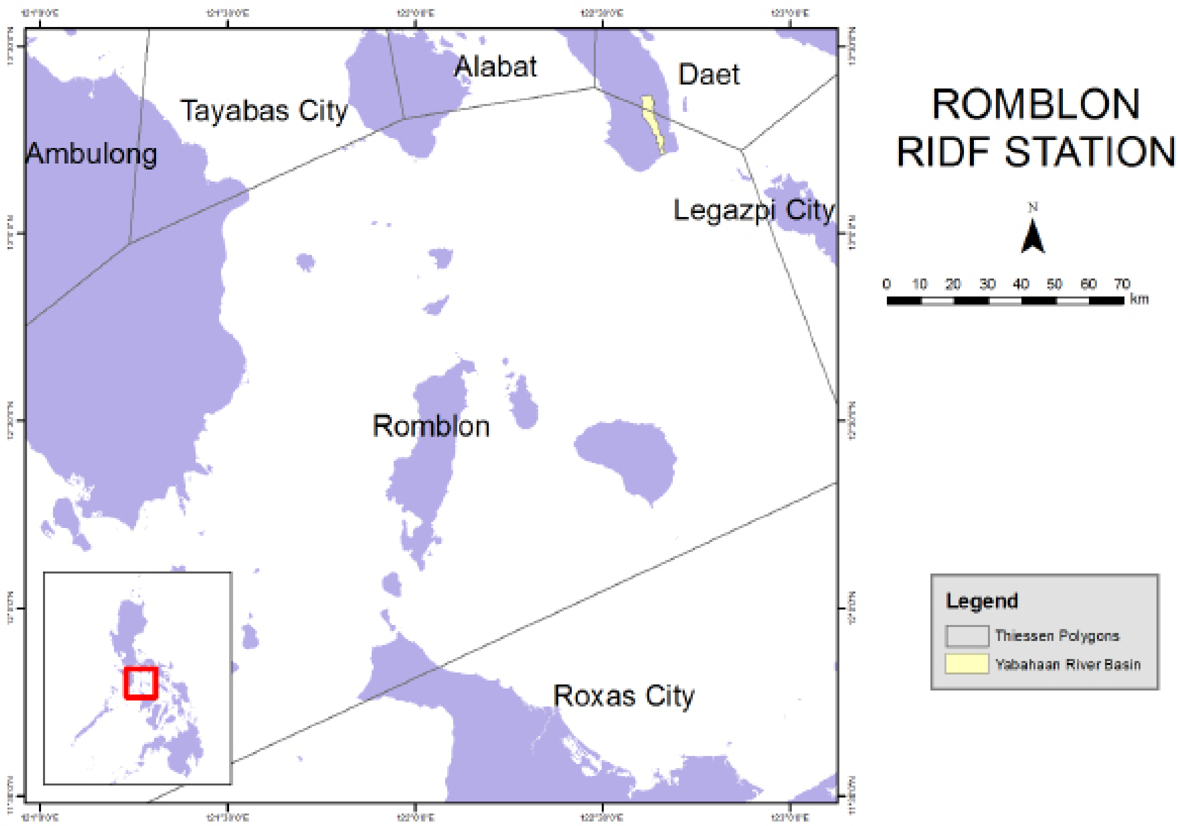


Figure 51. Romblon RIDF location relative to Yabaan River Basin

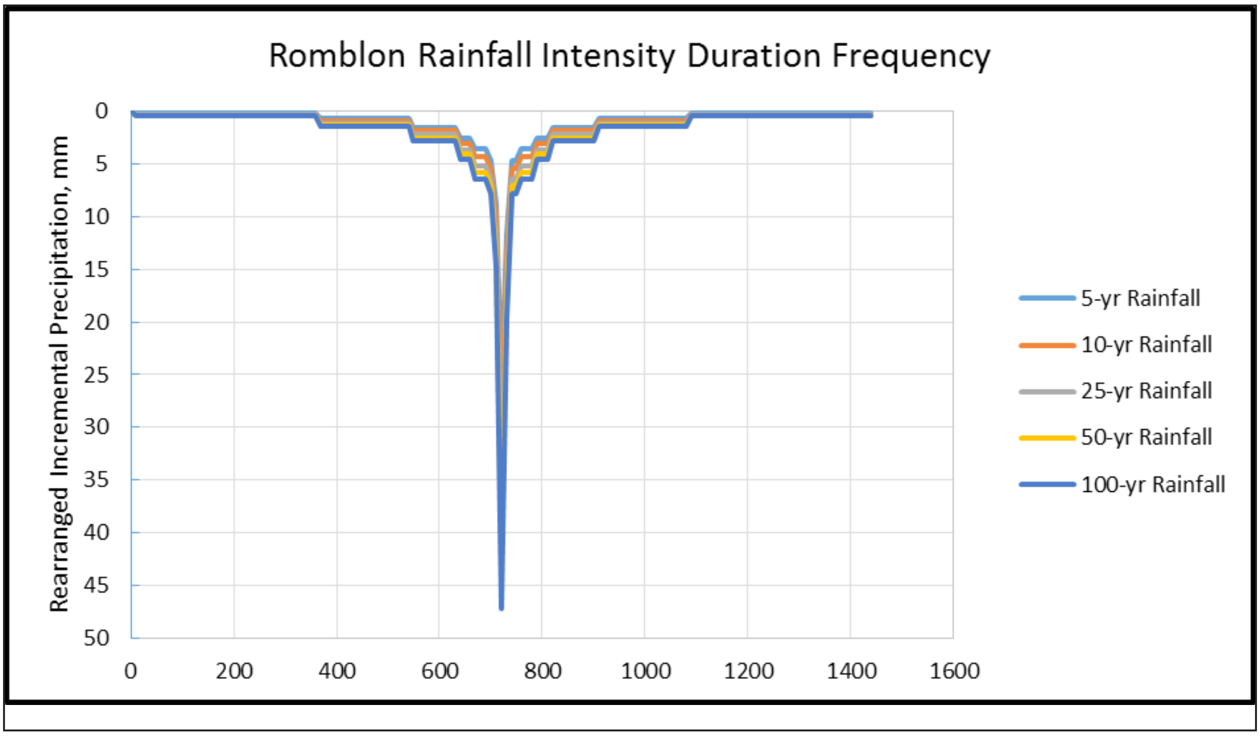


Figure 52. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 from the Bureau of Soil and Water Management (BSWM) under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Yabaan River Basin are shown in Figure 53 and Figure 54, respectively.

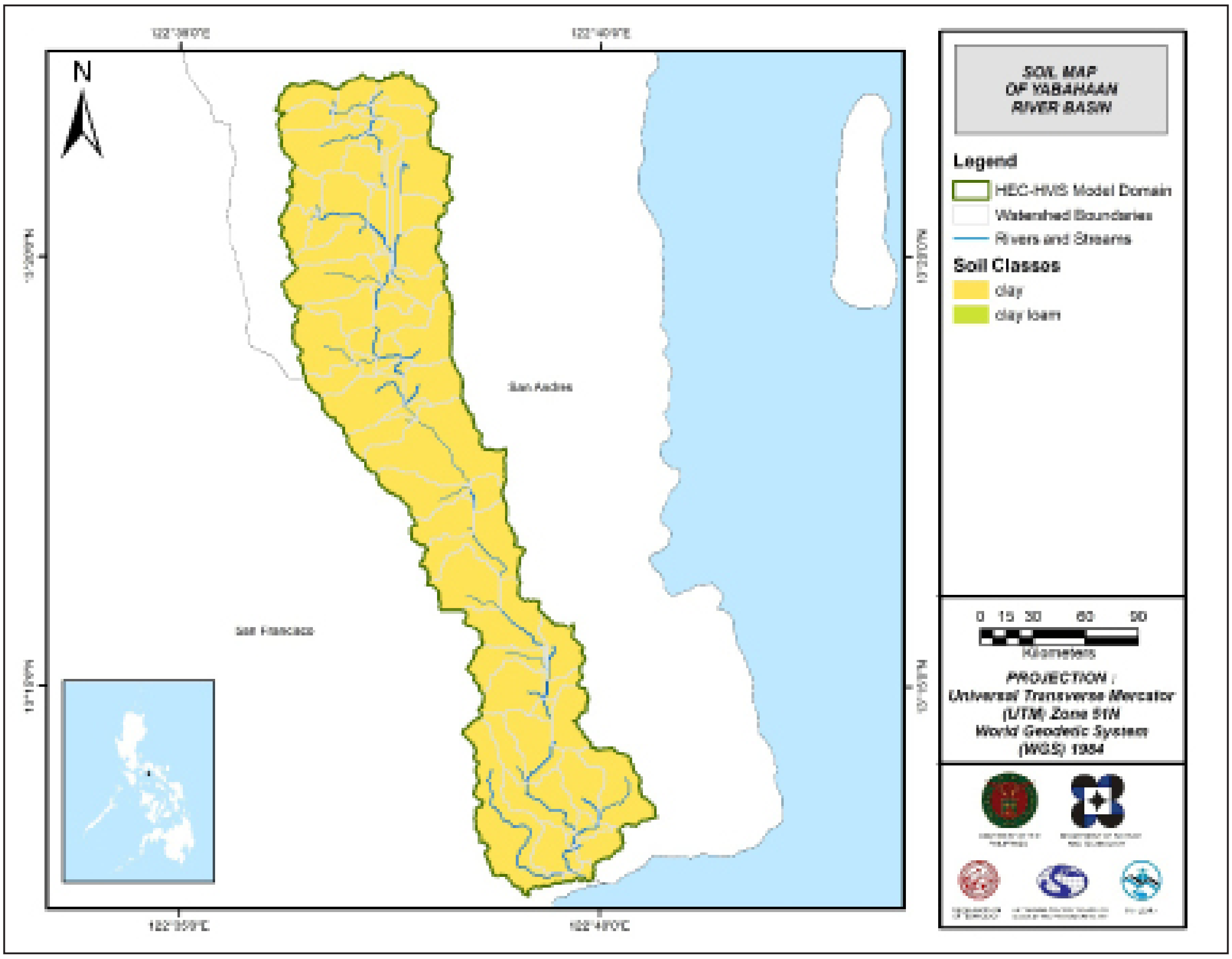


Figure 53. Soil map of the Yabaan River Basin

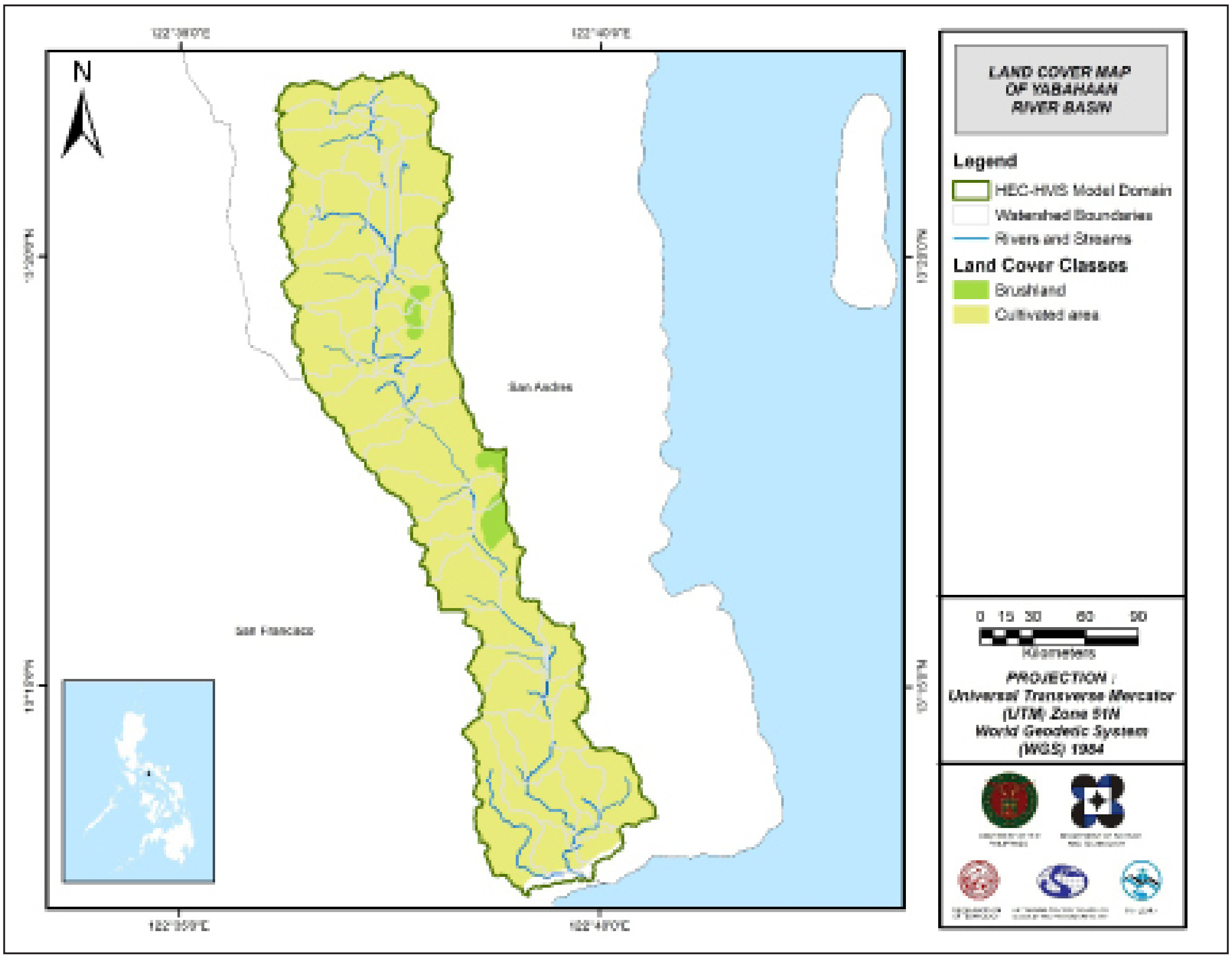


Figure 54. Land cover map of Yabaan River Basin

For the Yabaan River Basin, the two (2) soil classes identified were largely clay, with a very small portion of clay loam. The two (2) land cover types identified were mostly cultivated area, with a few patches of brushland.

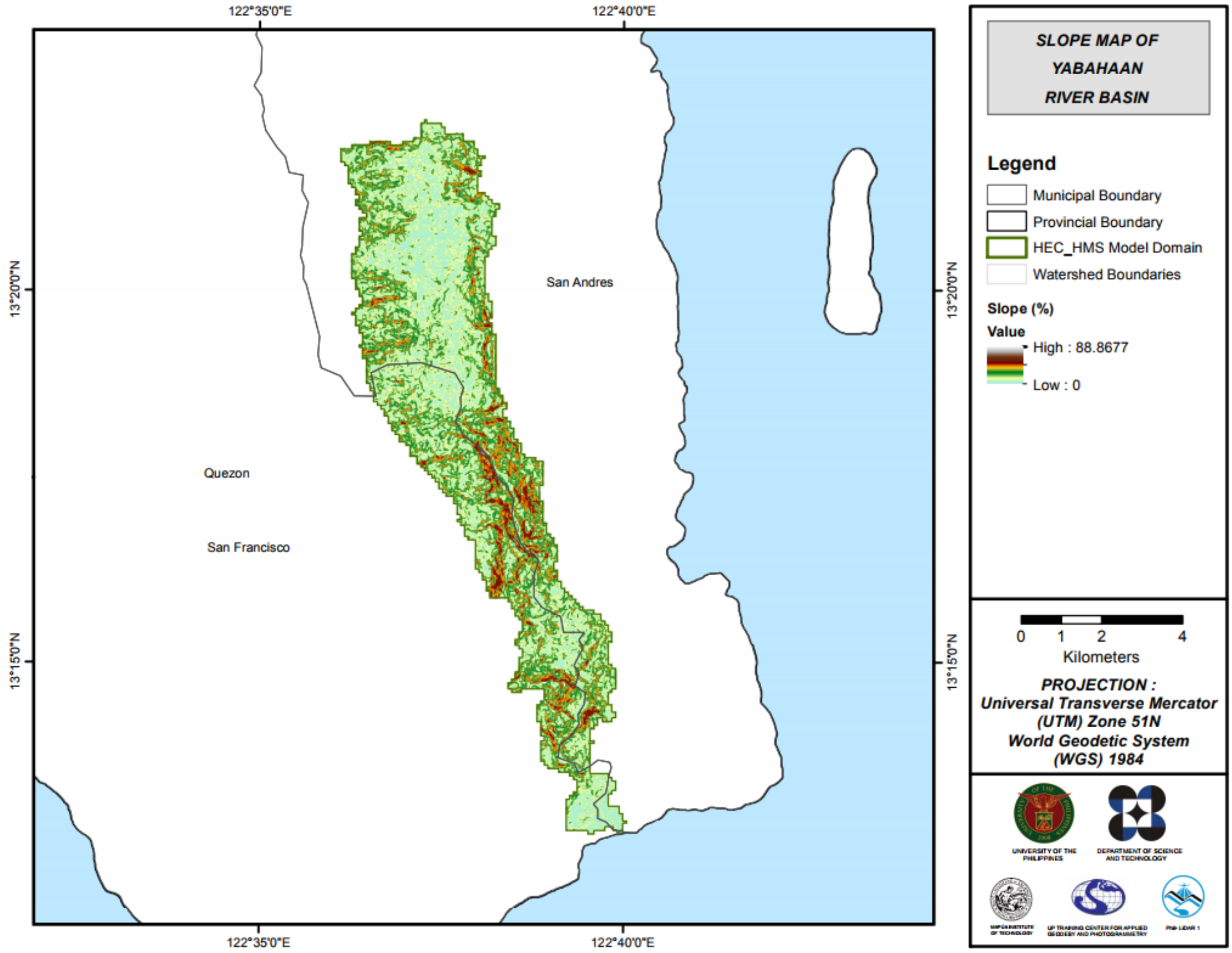


Figure 55. Slope map of Yabaan River Basin

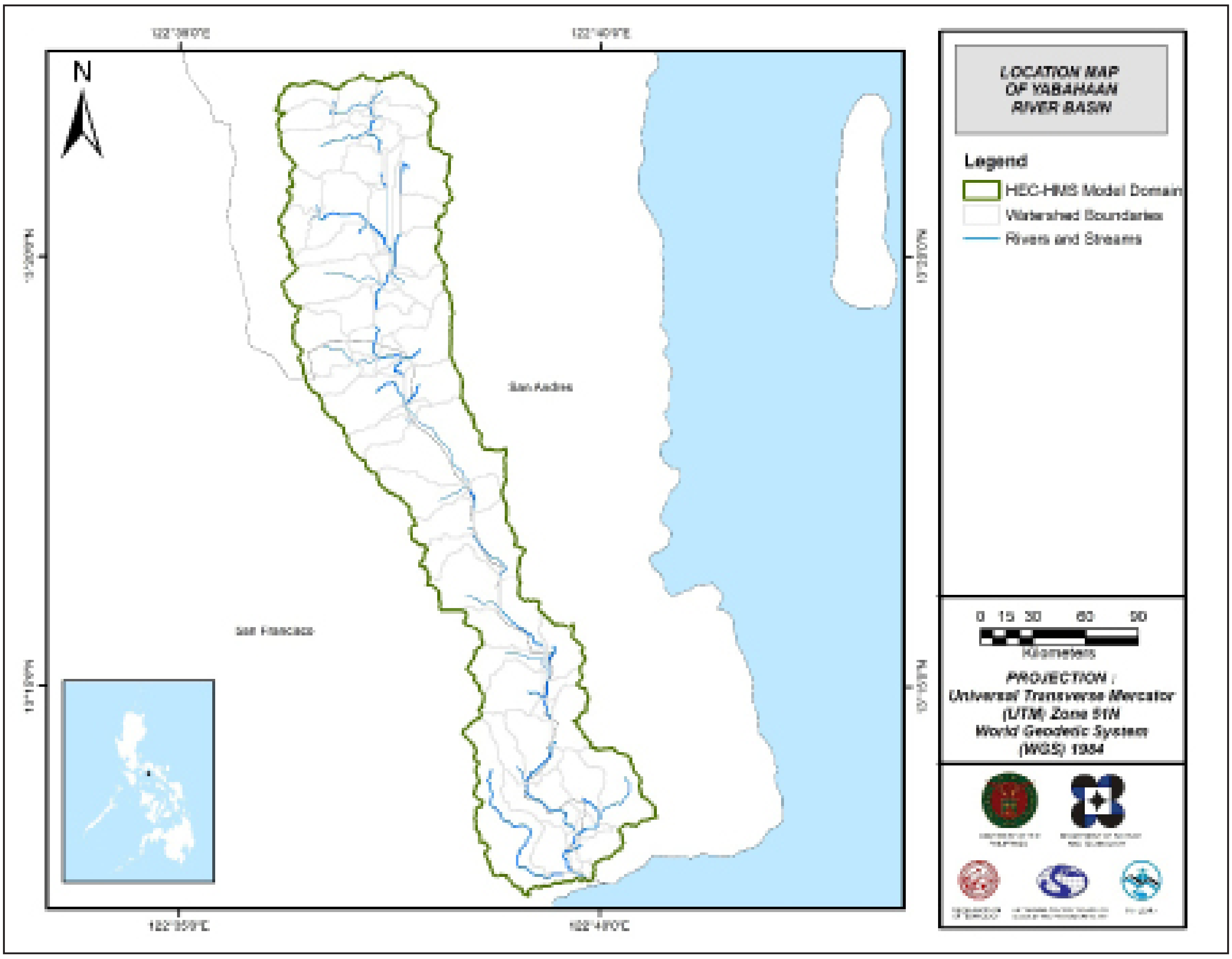


Figure 56. Stream Delineation Map of the Yabaan River Basin

The Yabaan basin model comprises 63 sub basins, 31 reaches, and 31 junctions. The main outlet is at the southernmost part of the watershed. This basin model is illustrated in Figure 57. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed Rain Gauge near the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in the Talisay Bridge.

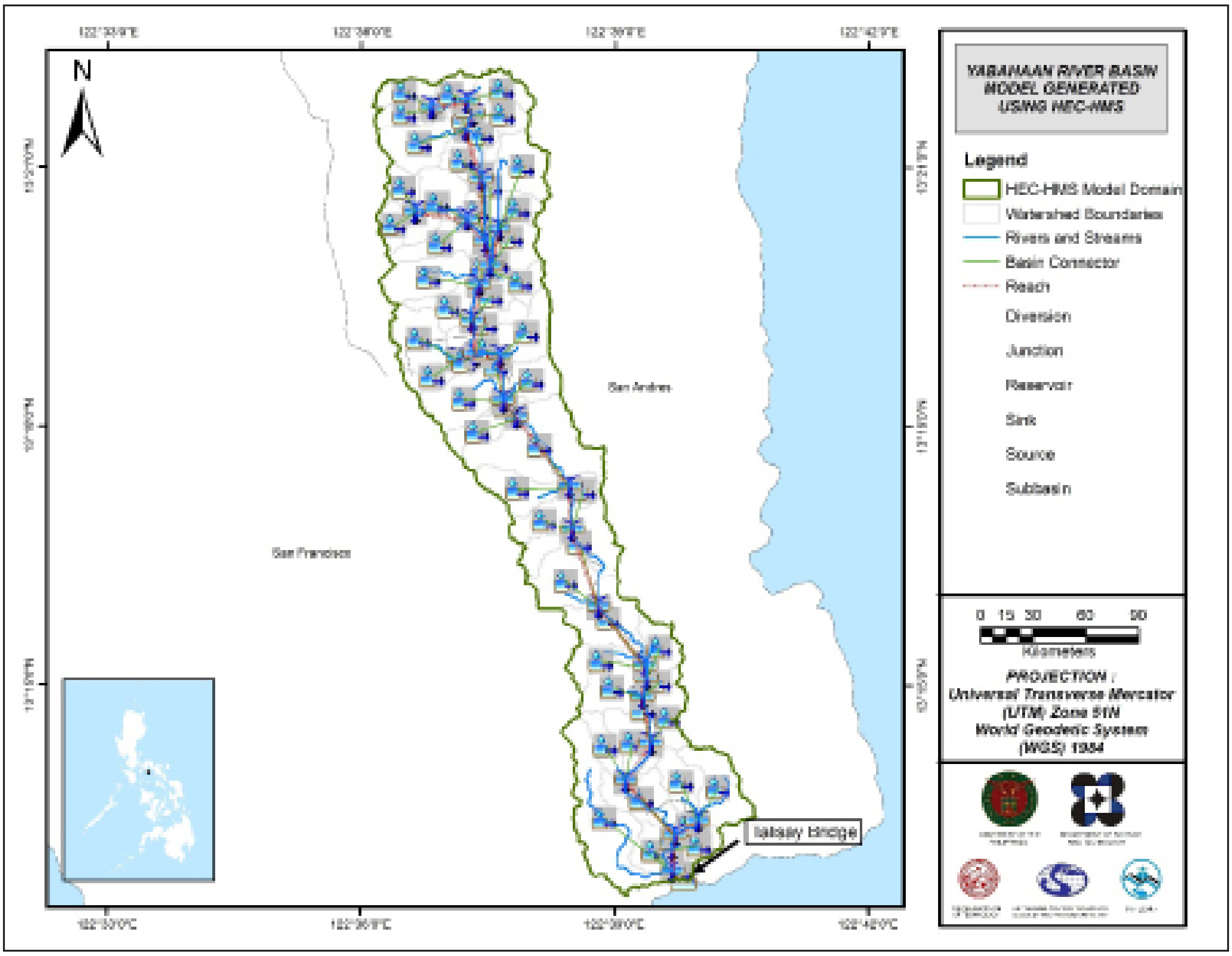


Figure 57. HEC-HMS generated Yabaan River Basin Model.

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. This is illustrated in Figure 58.

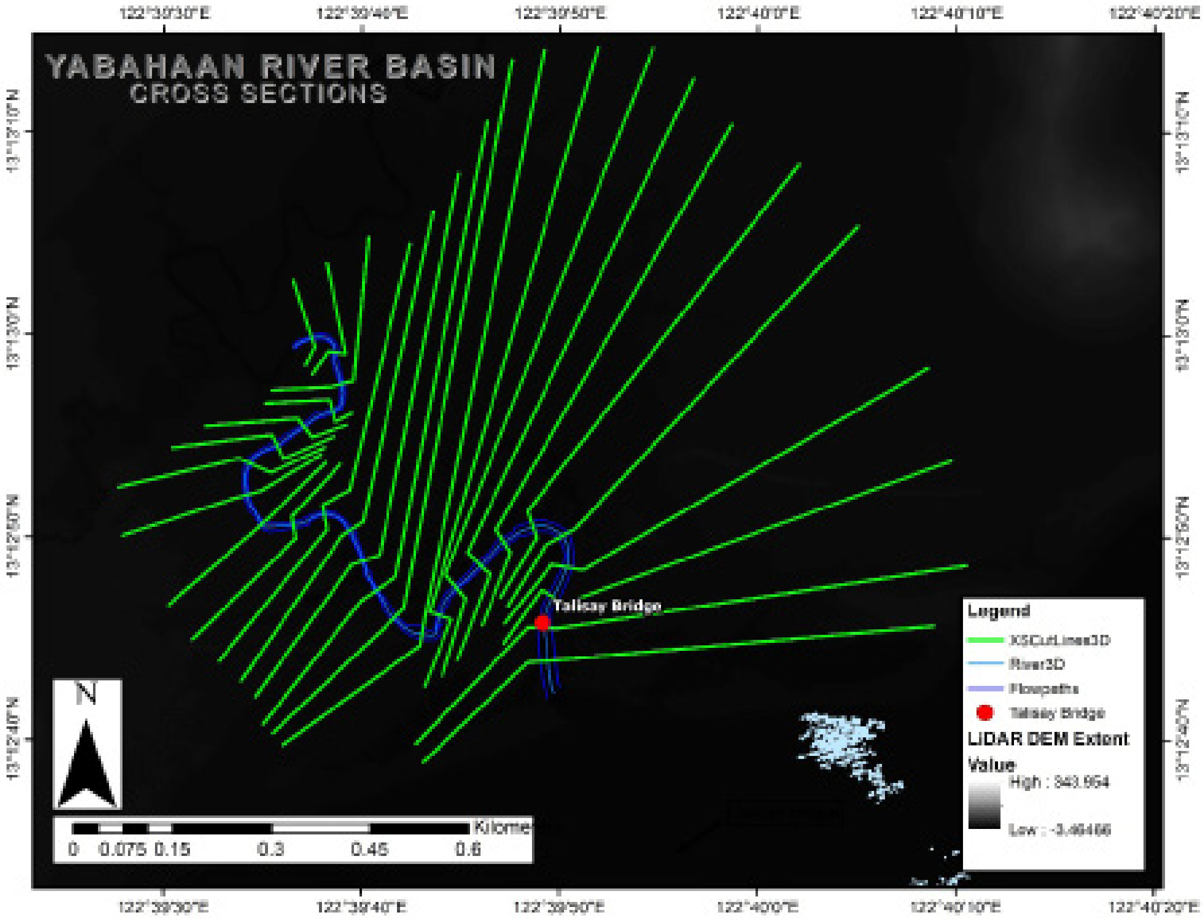


Figure 58. Figure 58. River cross-section of Yabaan (also known as Yabahaan) River generated through Arcmap HEC GeoRAS tool

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

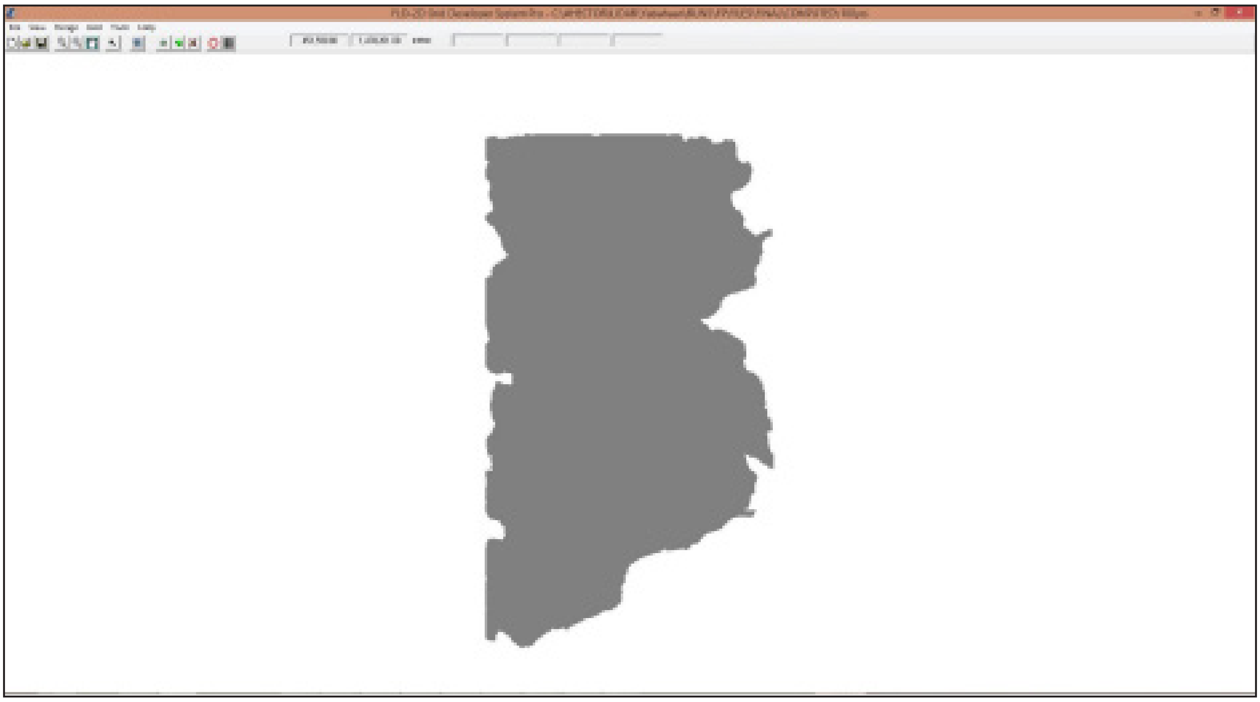


Figure 59. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 219.97021 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

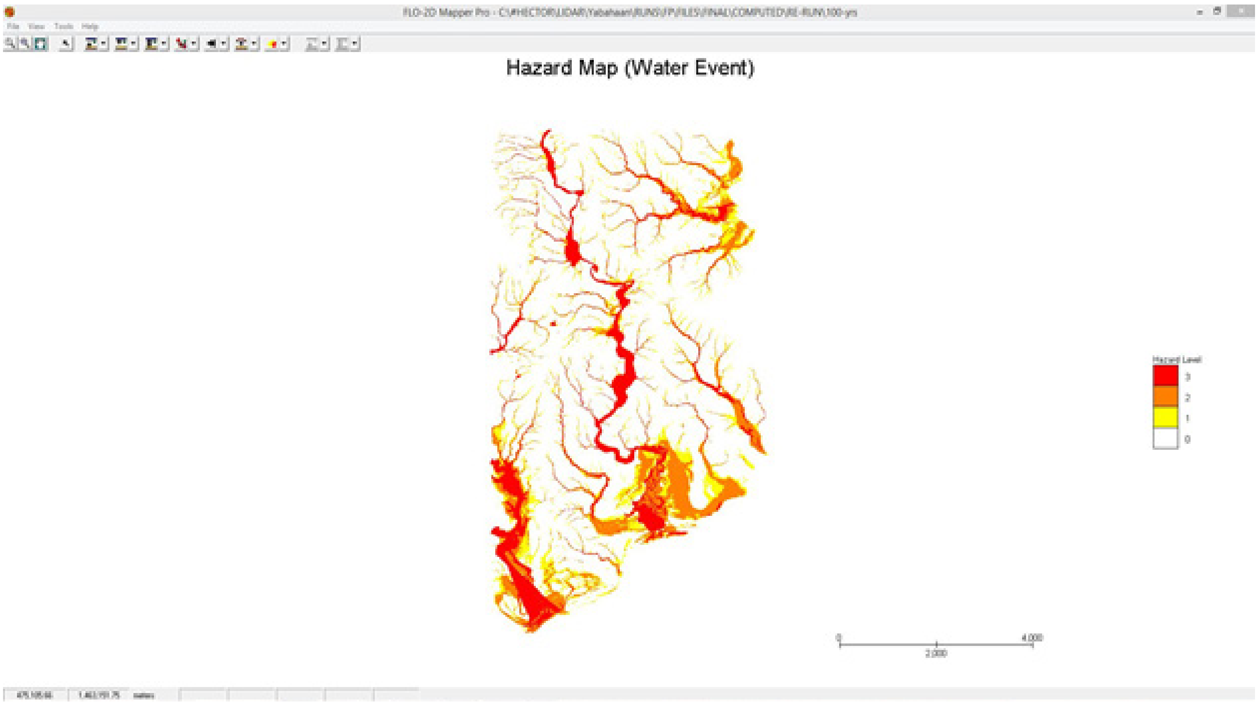


Figure 60. Generated 100-year Rain Return Hazard Map from FLO-2D Mapper

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 46 511 300.00 sq.m.

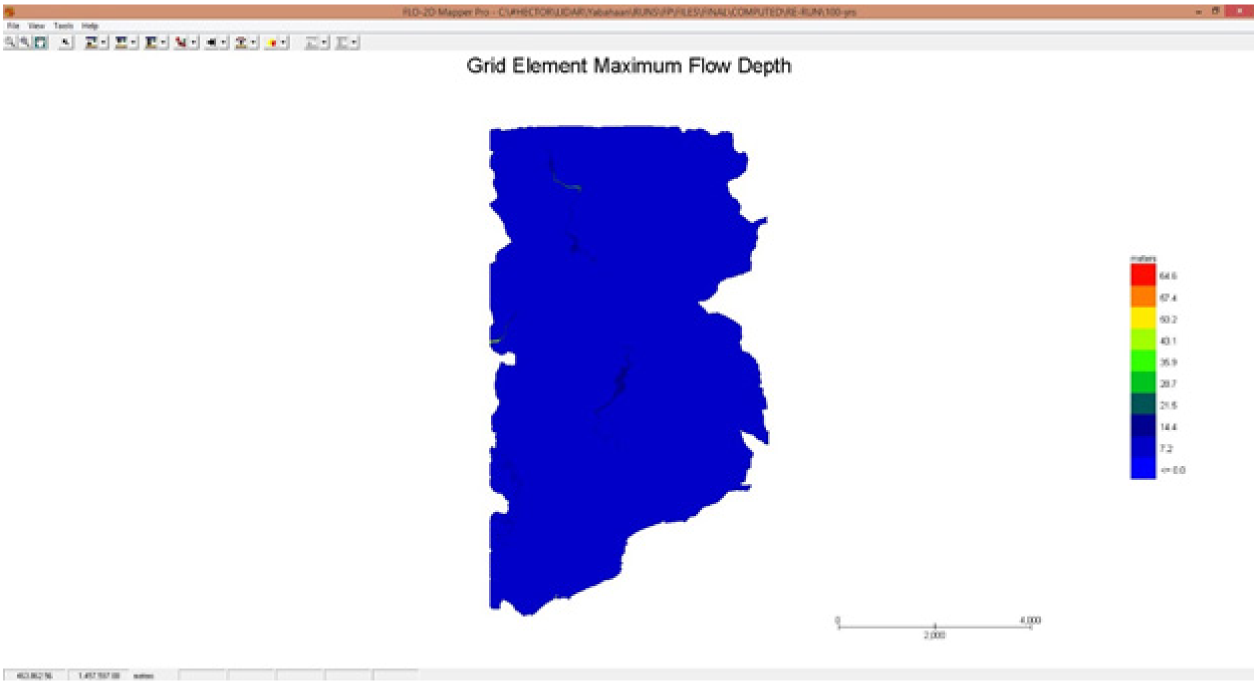


Figure 61. Generated 100-year Rain Return Flow Depth Map from FLO-2D Mapper

There is a total of 47 561 181.52 m3 of water entering the model. Of this amount, 16 909 746.76 m3 is due to rainfall while 30 651 434.76 m3 is inflow from other areas outside the model. 3 637 439.00 m3 of this water is lost to infiltration and interception, while 2 845 271.94 cu.m. is stored by the floodplain. The rest, amounting up to 41 078 444.53 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Yabaan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 62 shows the comparison between the two discharge data.

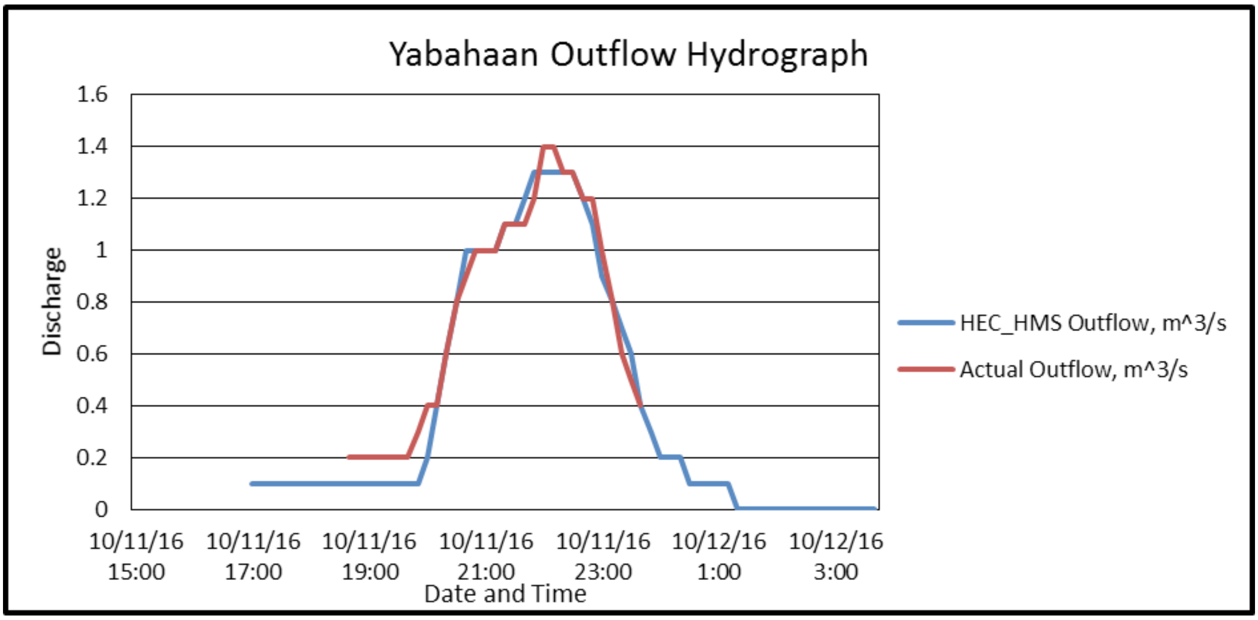


Figure 62. Outflow Hydrograph of Yabaan produced by the HEC-HMS model compared with observed outflow.

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 Yabaan

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.38 – 500
			Curve Number	43.58 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.03 – 131.83
			Storage Coefficient (hr)	0.017 – 21.29
	Baseflow	Recession	Recession Constant	0.0001 – 0.0063
			Ratio to Peak	0.0005 – 0.01
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.0006 – 0.052

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.38mm to 500mm means that there is minimal to extreme 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 43.58 to 99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Yabaan, the soil classes identified were clay loam and clay. The land cover types identified were brushland, and cultivated areas.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.017 hours to 131.83 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. The Recession Constant values in this basin range from 0.0001 to 0.0063 and the Ratio to Peak values are from 0.0005 to 0.01. These values influence the receding limb of the outflow hydrograph which is slightly likely to quickly return to its original discharge values.

Manning's roughness coefficients of 0.0006 to 0.052 corresponds to the common roughness in Yabaan watershed (Brunner, 2010).

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

Accuracy Measure	Value
RMSE	0.1
r2	0.9727
NSE	0.96
PBIAS	4.46
RSR	0.21

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.1 m3/s.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9727.

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 0.96.

.

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 4.46.

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 0.21.

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

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 63) shows the Yabahaan outflow using the Romblon Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

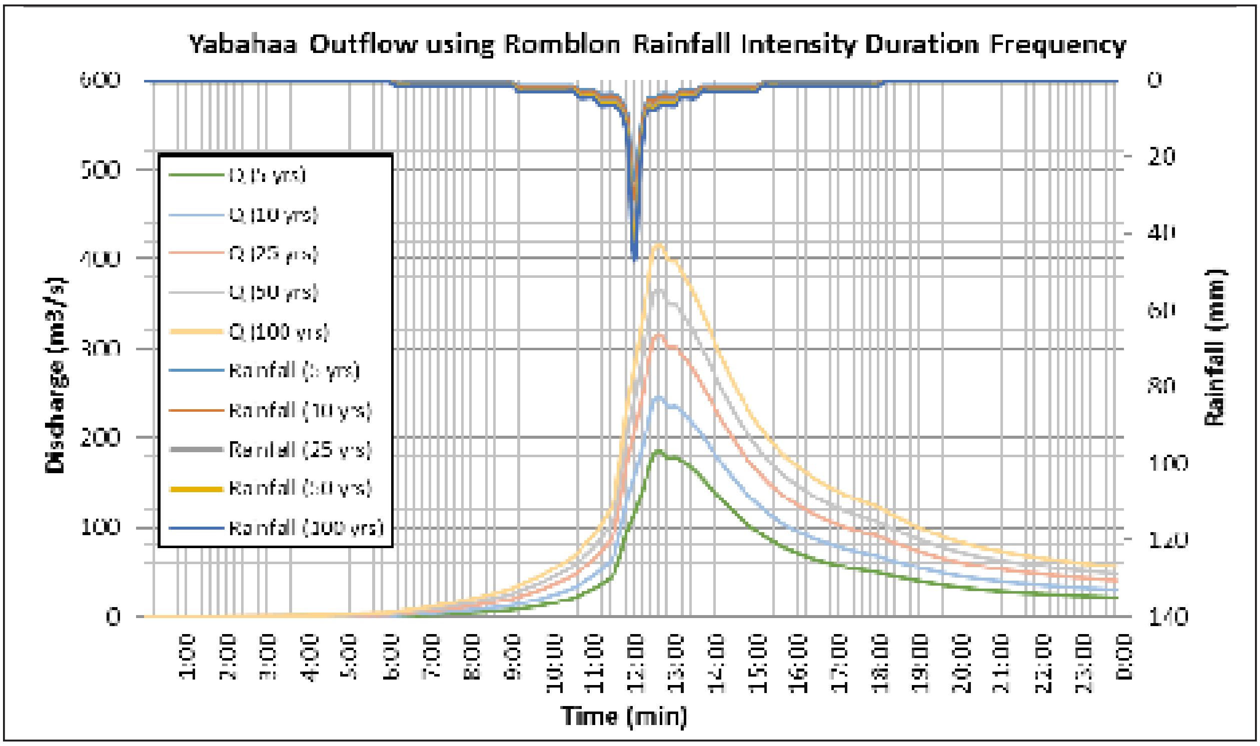


Figure 63. Outflow hydrograph at Yabaan Station generated using Romblon RIDF simulated in HEC-HMS

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

Table 28. Peak values of the Yabaan HECHMS Model outflow using the Romblon RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	171.6	26	184.9	12 hours, 40 minutes
10-Year	205.9	31.1	244.3	12 hours, 40 minutes
25-Year	249.2	37.6	314.6	12 hours, 40 minutes
50-Year	281.4	42.4	364.8	12 hours, 40 minutes
100-Year	313.3	47.2	415.4	12 hours, 40 minutes

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

The river discharge values for the nine rivers entering the floodplain are shown in Figure 11 to Figure 15 and the peak values are summarized in Table 4 to Table 6.

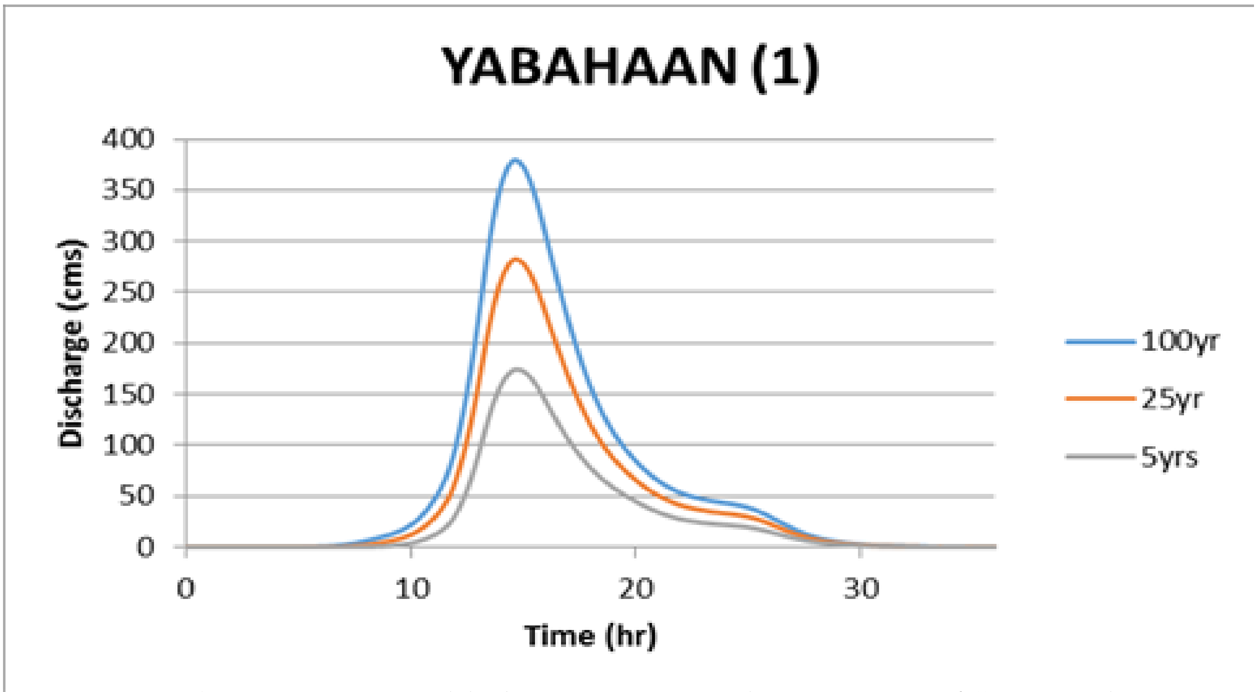


Figure 64. Yabaan river (1) generated discharge using 5-, 25-, and 100-year Daet rainfall intensity-duration-frequency (RIDF) in HEC-HMS

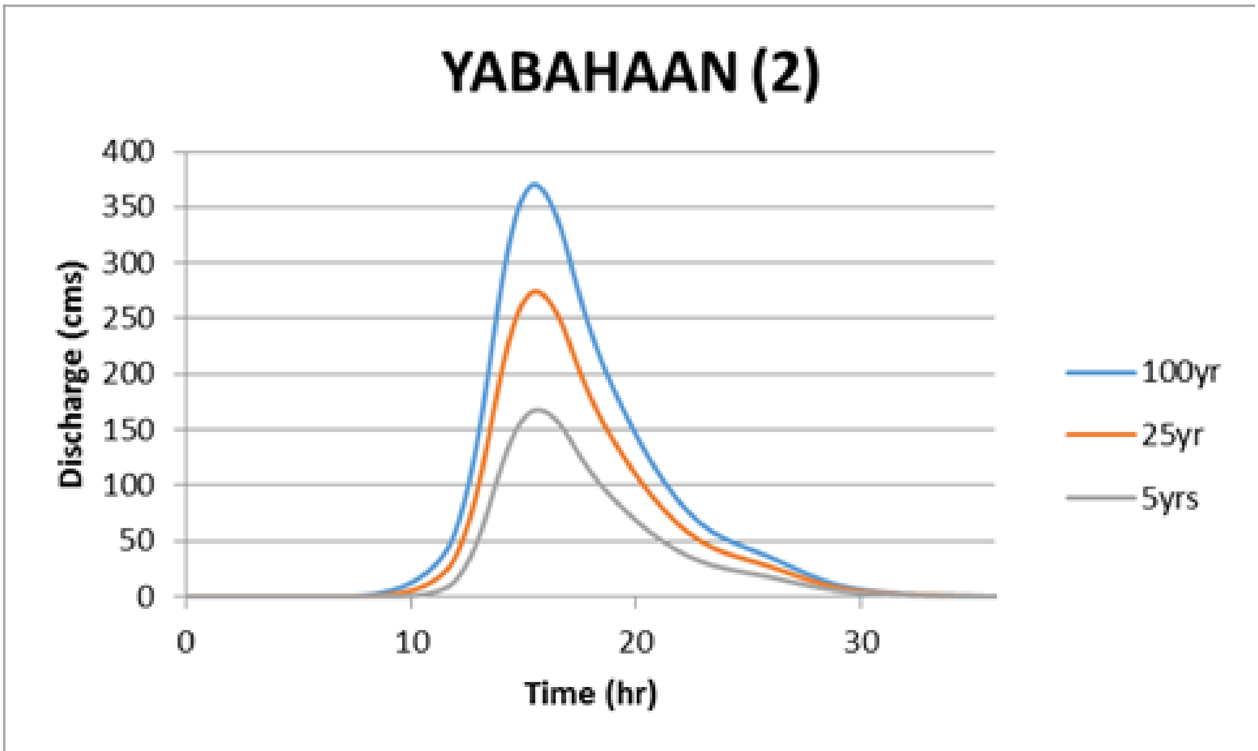


Figure 65. Yabaan river (2) generated discharge using 5-, 25-, and 100-year Daet rainfall intensity-duration-frequency (RIDF) in HEC-HMS

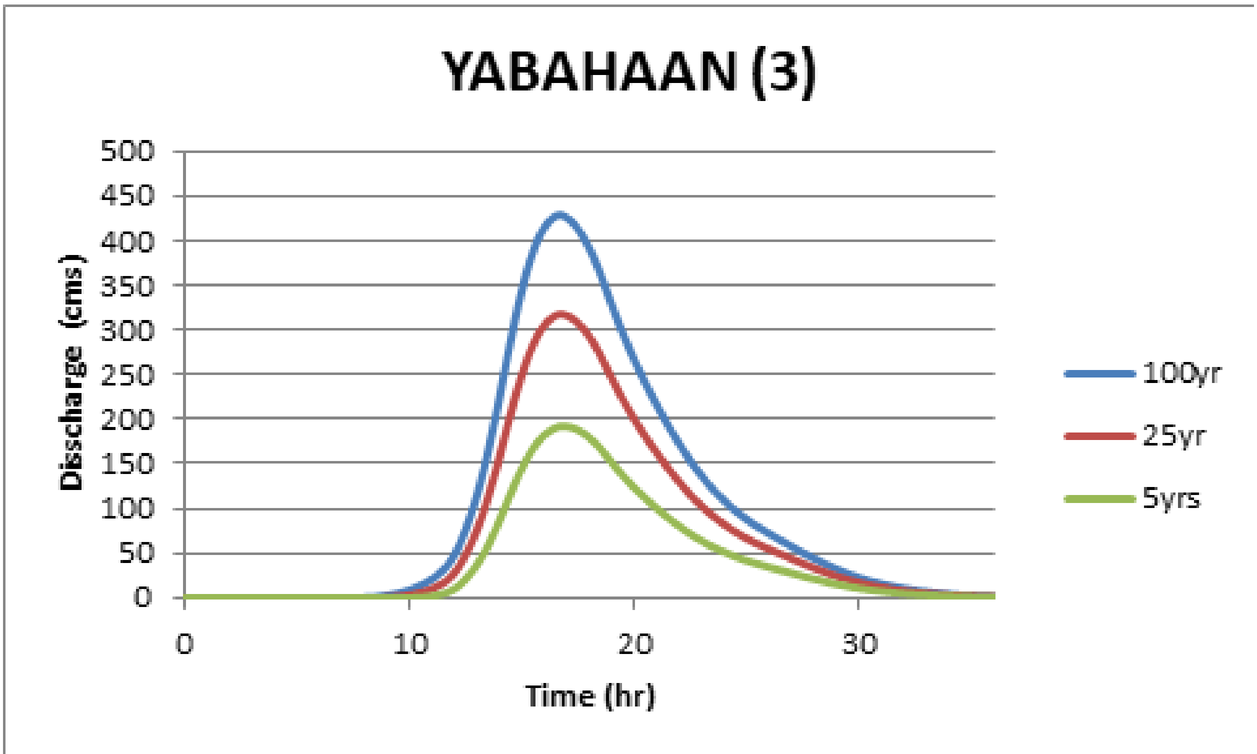


Figure 66. Yabaan river (3) generated discharge using 5-, 25-, and 100-year Daet rainfall intensity-duration-frequency (RIDF) in HEC-HMS

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

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	379.6	14 hours, 40 minutes
25-Year	282.4	14 hours, 40 minutes
5-Year	174.2	14 hours, 40 minutes

Table 30. Summary of Yabaan river (2) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	370.6	15 hours, 30 minutes
25-Year	274.3	15 hours, 30 minutes
5-Year	167.9	15 hours, 40 minutes

Table 31. Summary of Yabaan river (3) discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	428.9	16 hours, 40 minutes
25-Year	317	16 hours, 40 minutes
5-Year	96.75	16 hours, 50 minutes

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 32.

Table 32. Validation of river discharge estimates

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Yabahaan (1)	153.296	240.230	283.128	PASS	PASS
Yabahaan (2)	147.752	1228.097	314.080	FAIL	FAIL
Yabahaan (3)	85.140	627.078	394.056	FAIL	FAIL

Only one from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful and specific discharge methods. The other two estimates were not able to satisfy the specific discharge and the bankful discharge method. The passing values are based on theory but are supported using other discharge computation methods so they were good to use flood modeling while the other two values will need further calculations. 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 website. The sample map of Yabaan River using the HMS base flow is shown on Figure 67 below.

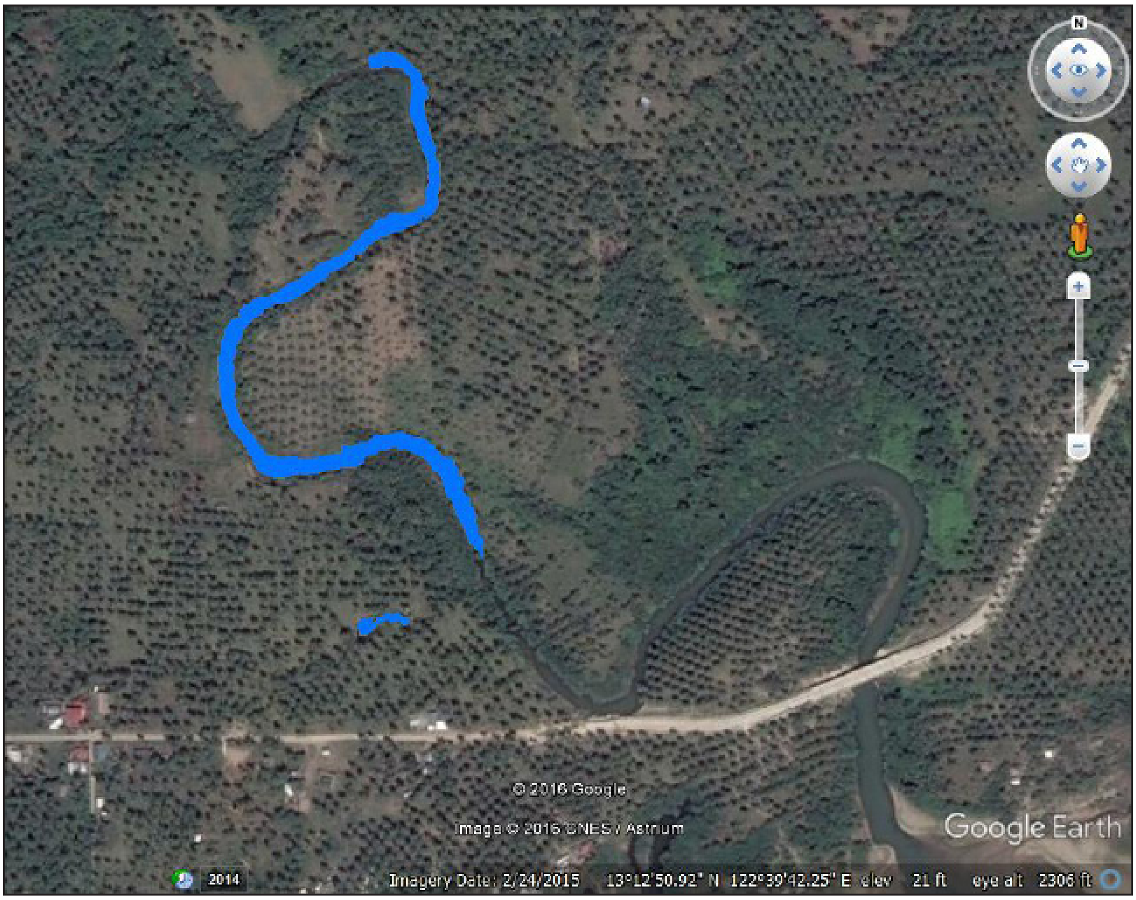


Figure 67. Sample output of Yabaan RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. Figure 68 to Figure 73 shows the 5-, 25-, and 100-year rain return scenarios of the Yabaan floodplain.

Table 33. Municipalities affected in Yabaan floodplain

City / Municipality	Total Area	Area Flooded	% Flooded
San Andres	173.7	23.16	13.33%
San Francisco	320.48	23.075	4.78%

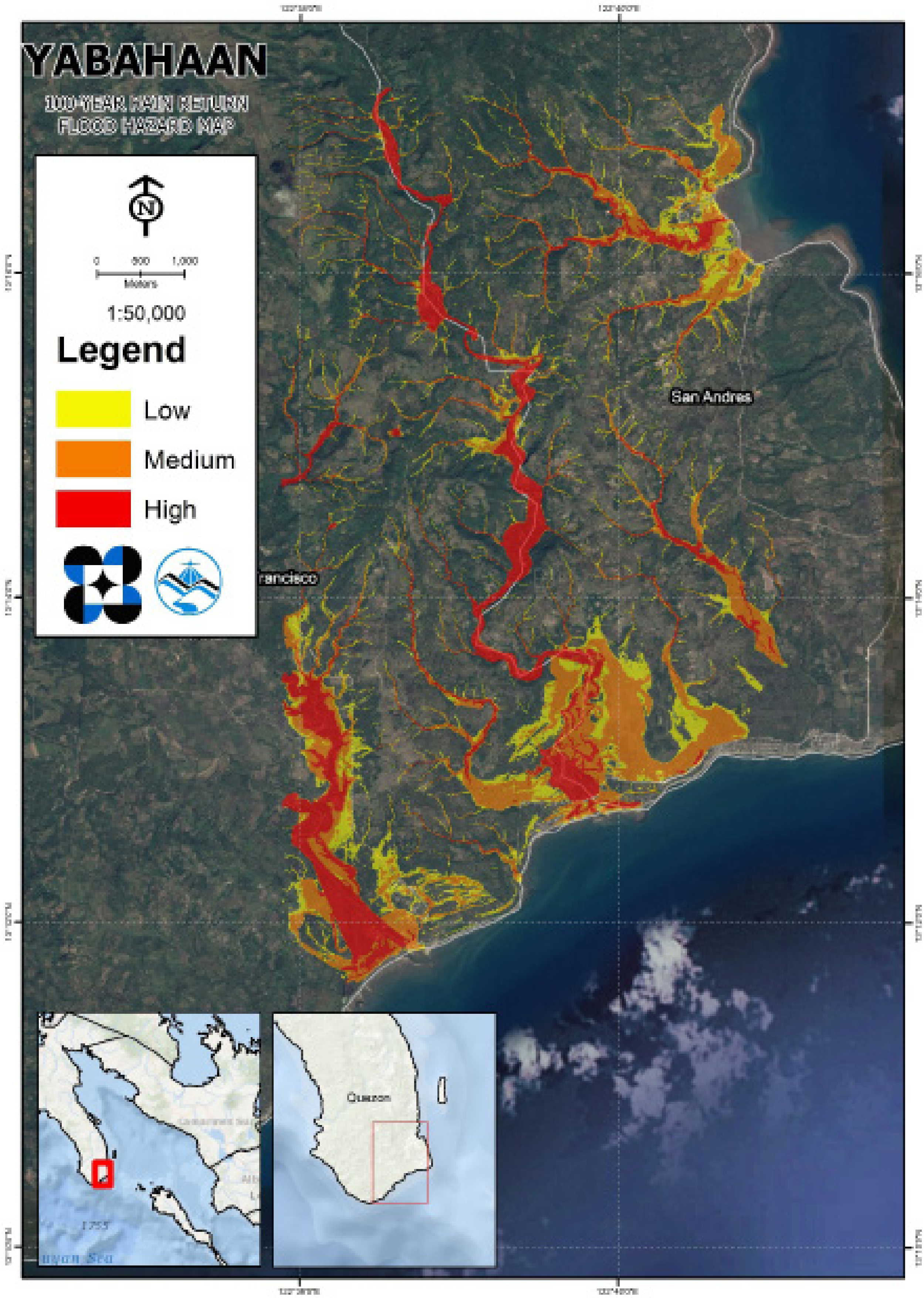


Figure 68. 100-year Flood Hazard Map for Yabaan Floodplain overlaid in Google Earth imagery

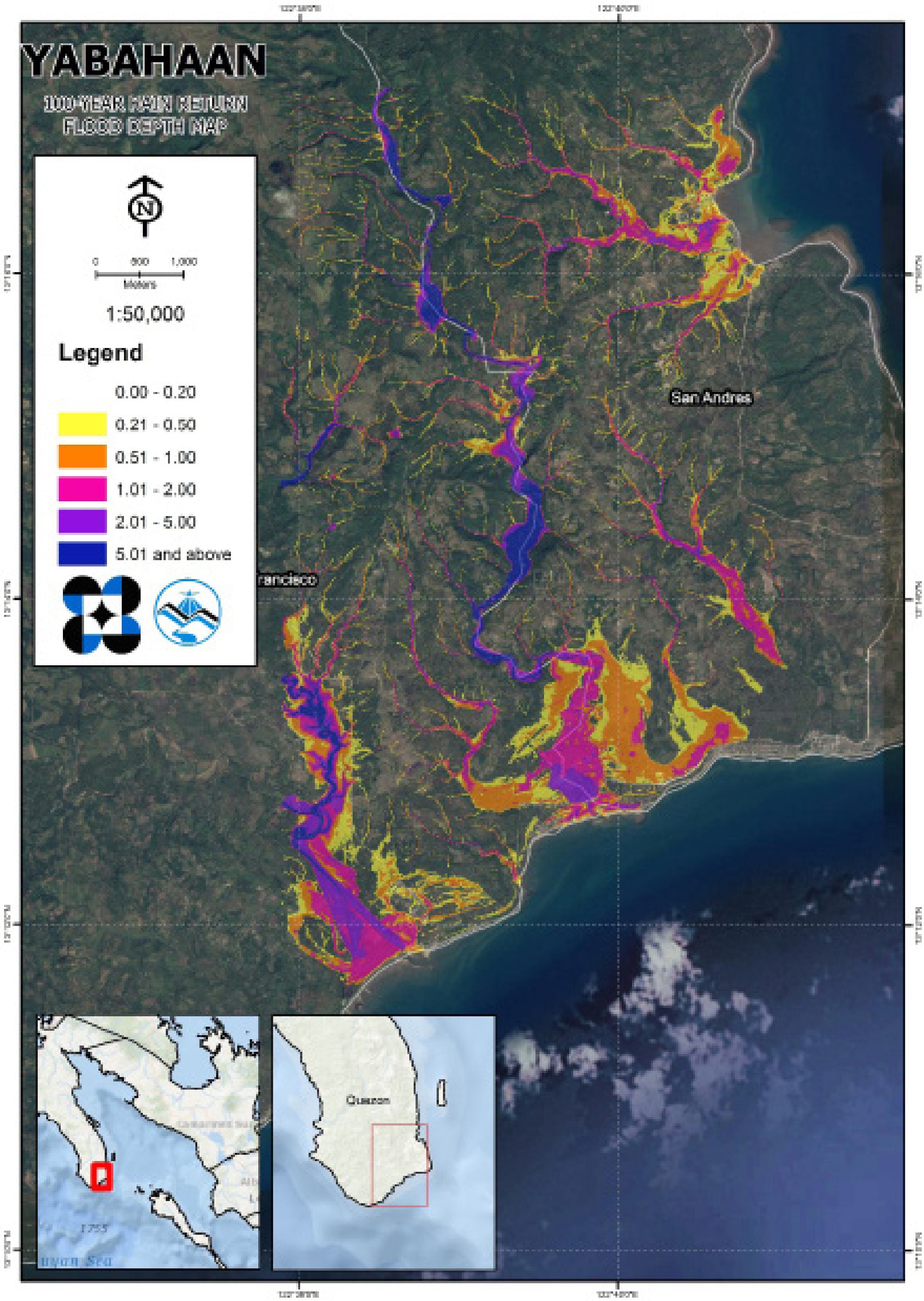


Figure 69. 100-year Flow Depth Map for Yabaan Floodplain overlaid in Google Earth imagery

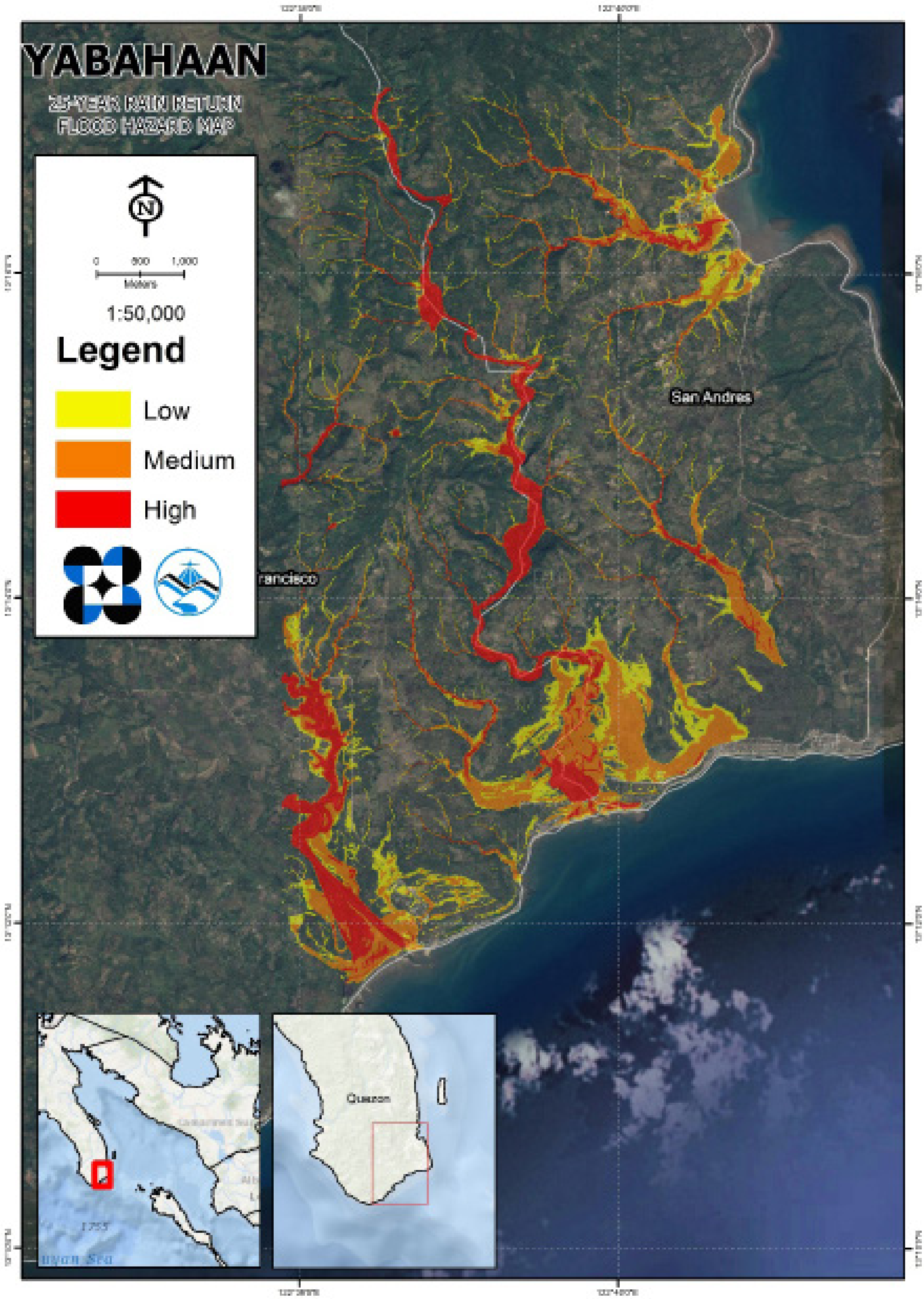


Figure 70. 25-year Flood Hazard Map for Yabaan Floodplain overlaid in Google Earth imagery

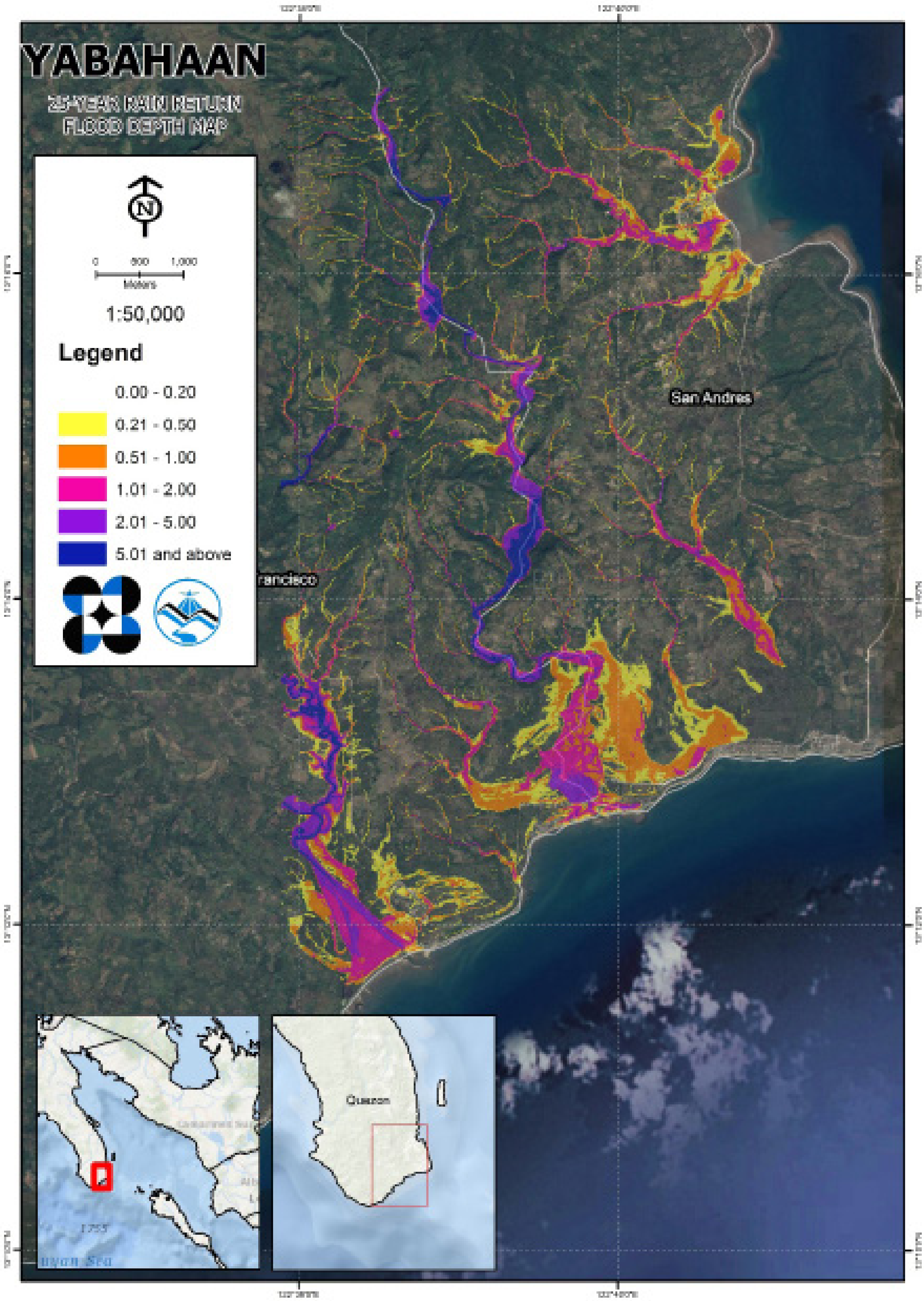


Figure 71. 25-year Flow Depth Map for Yabaan Floodplain overlaid in Google Earth imagery

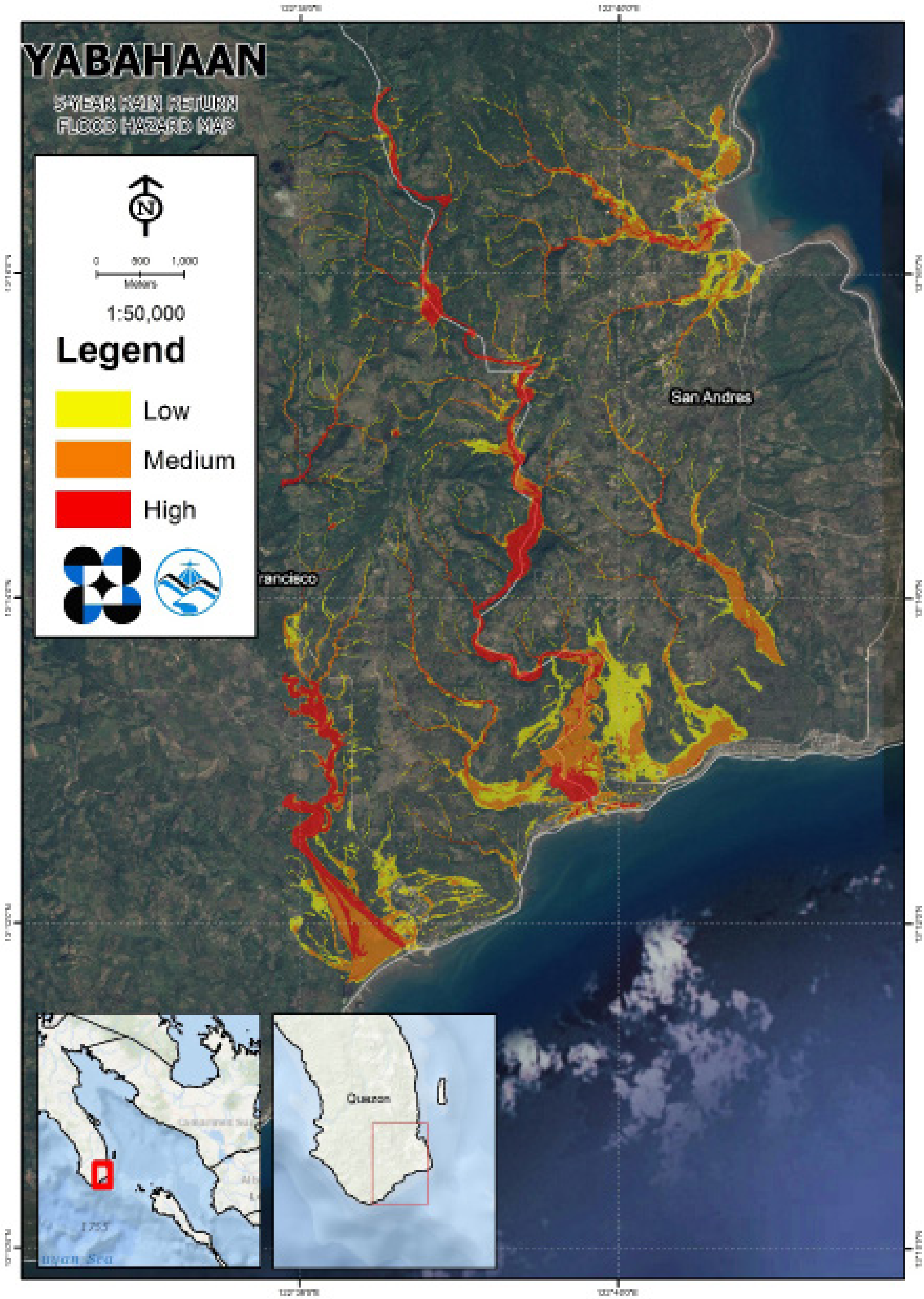


Figure 72. 5-year Flood Hazard Map for Yabaan Floodplain overlaid in Google Earth imagery

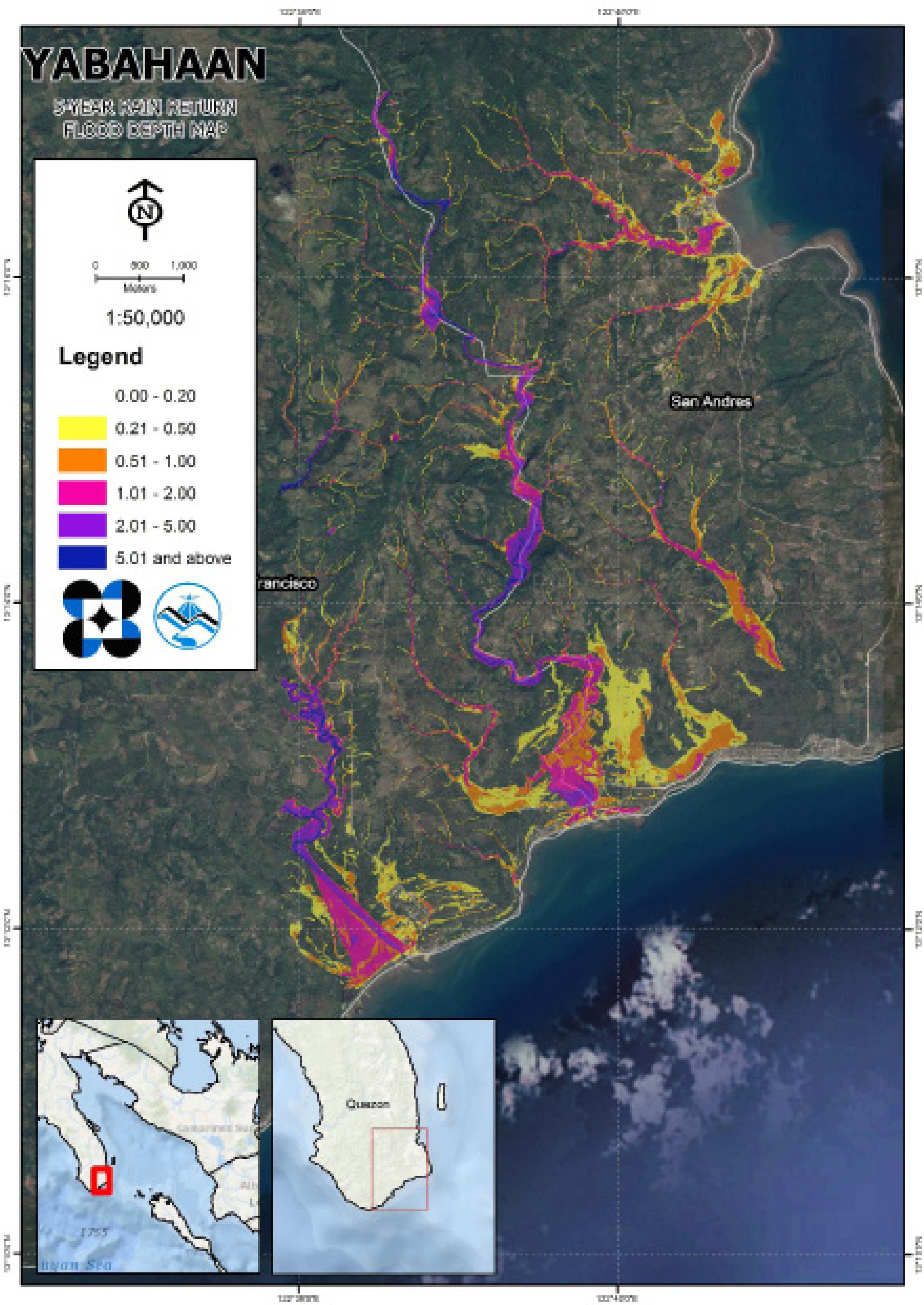


Figure 73. 5-year Flow Depth Map for Yabaan Floodplain overlaid in Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

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

For the 5-year return period, 10.44% of the municipality of San Andres with an area of 173.7 sq. km. will experience flood levels of less than 0.20 meters. 0.64% of the area will experience flood levels of 0.21 to 0.50 meters while 0.57%, 0.93%, 0.65%, and 0.11% 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 74 are the affected areas in square kilometers by flood depth per barangay.

Table 34. Affected areas in San Andres, Quezon during a 5-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Andres (in sq. km)		
	Mangero	Pansoy	Talisay
0.03-0.20	12.22	4.13	1.78
0.21-0.50	0.73	0.13	0.26
0.51-1.00	0.57	0.081	0.34
1.01-2.00	0.68	0.059	0.87
2.01-5.00	0.32	0.051	0.75
> 5.00	0.035	0.038	0.11

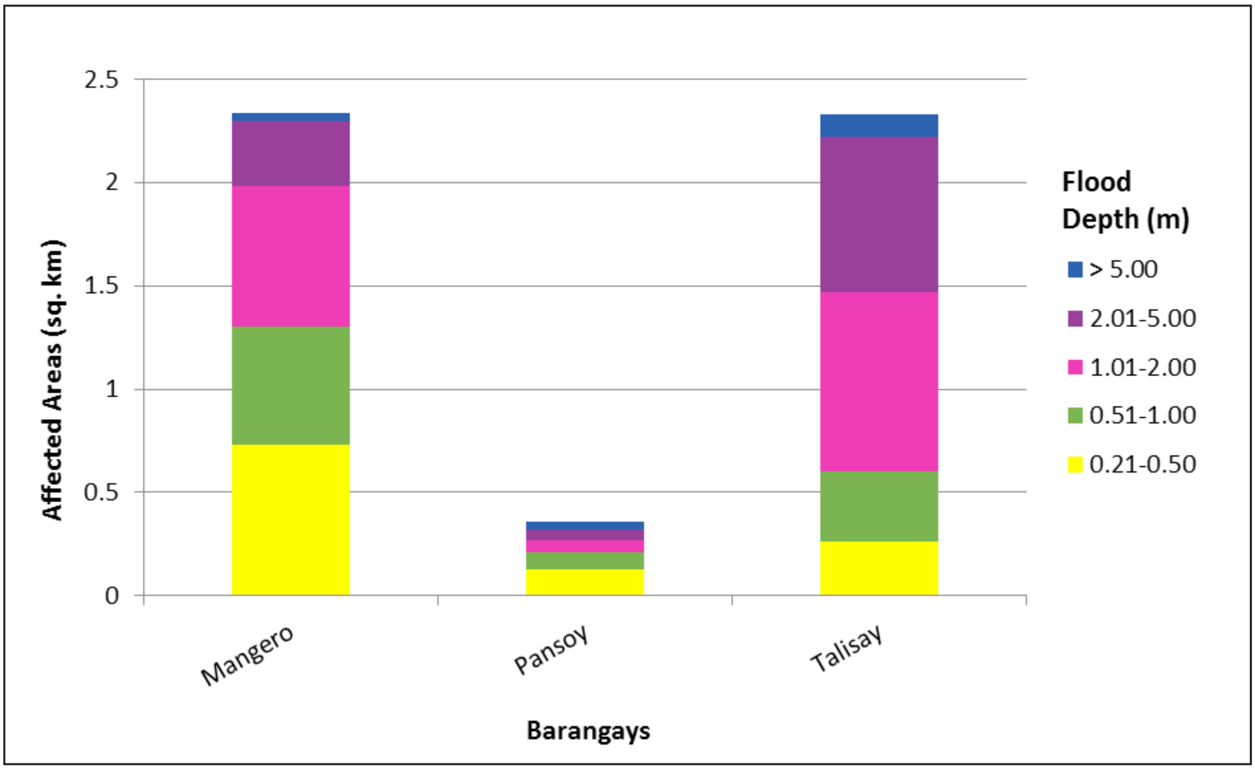


Figure 74. Affected areas in San Andres, Quezon during a 5-Year Rainfall Return Period.

For the 5-year return period, 5.36% of the municipality of San Francisco with an area of 320.48 sq. km. will experience flood levels of less than 0.20 meters. 0.32% of the area will experience flood levels of 0.21 to 0.50 meters while 0.28%, 0.37%, 0.55%, and 0.33% 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 75 are the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected areas in San Francisco, Quezon during a 5-Year Rainfall Return Period.

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Francisco (in sq. km)	
	Huyon-Uyon	Pagsangahan
0.03-0.20	3.6	13.57
0.21-0.50	0.13	0.88
0.51-1.00	0.065	0.83
1.01-2.00	0.03	1.15
2.01-5.00	0.012	1.76
> 5.00	0.003	1.04

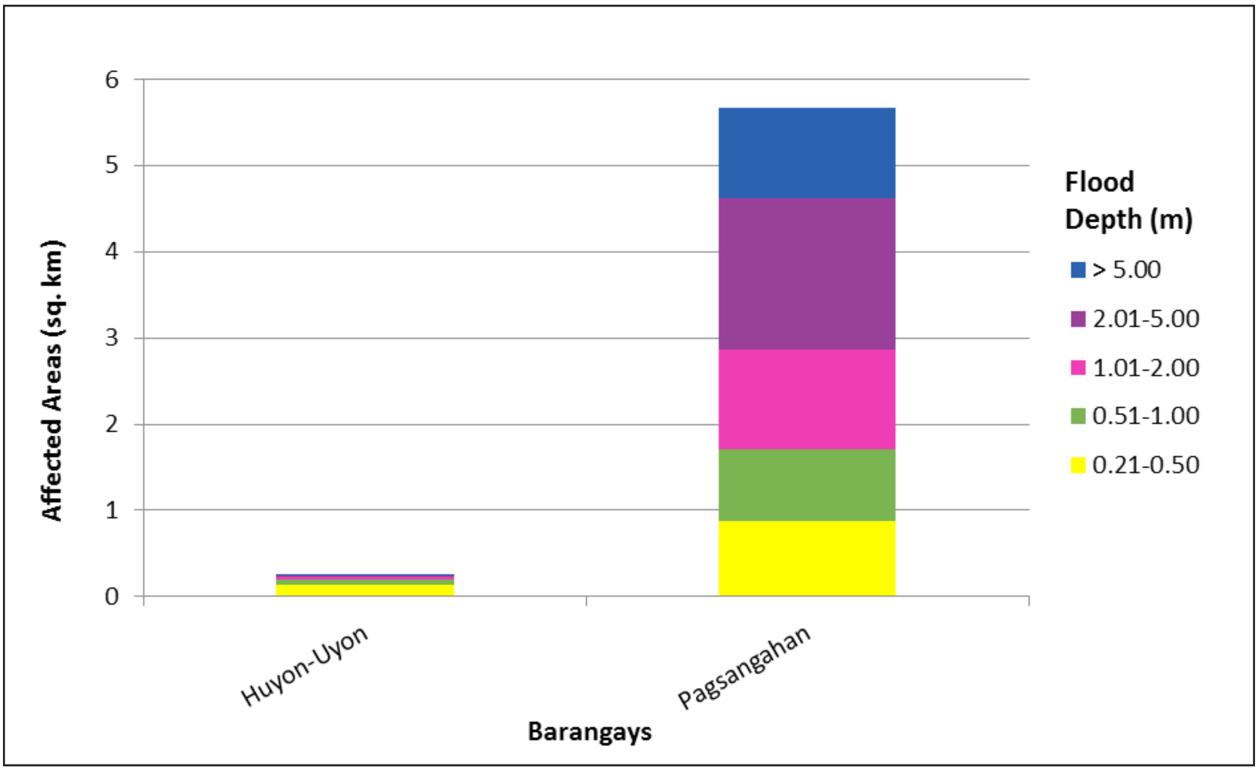


Figure 75. Areas affected by flooding in San Francisco, Quezon for a 5-Year Return Period rainfall event.

For the 25-year return period, 9.99% of the municipality of San Andres with an area of 173.7 sq. km. will experience flood levels of less than 0.20 meters. 0.62% of the area will experience flood levels of 0.21 to 0.50 meters while 0.45%, 0.58%, 1.32%, and 0.36% 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 76 are the affected areas in square kilometers by flood depth per barangay.

Table 36. Affected areas in San Andres, Quezon during a 25-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Andres (in sq. km)		
	Mangero	Pansoy	Talisay
0.03-0.20	11.76	4.05	1.55
0.21-0.50	0.77	0.15	0.15
0.51-1.00	0.56	0.086	0.14
1.01-2.00	0.68	0.074	0.26
2.01-5.00	0.64	0.069	1.59
> 5.00	0.14	0.064	0.42

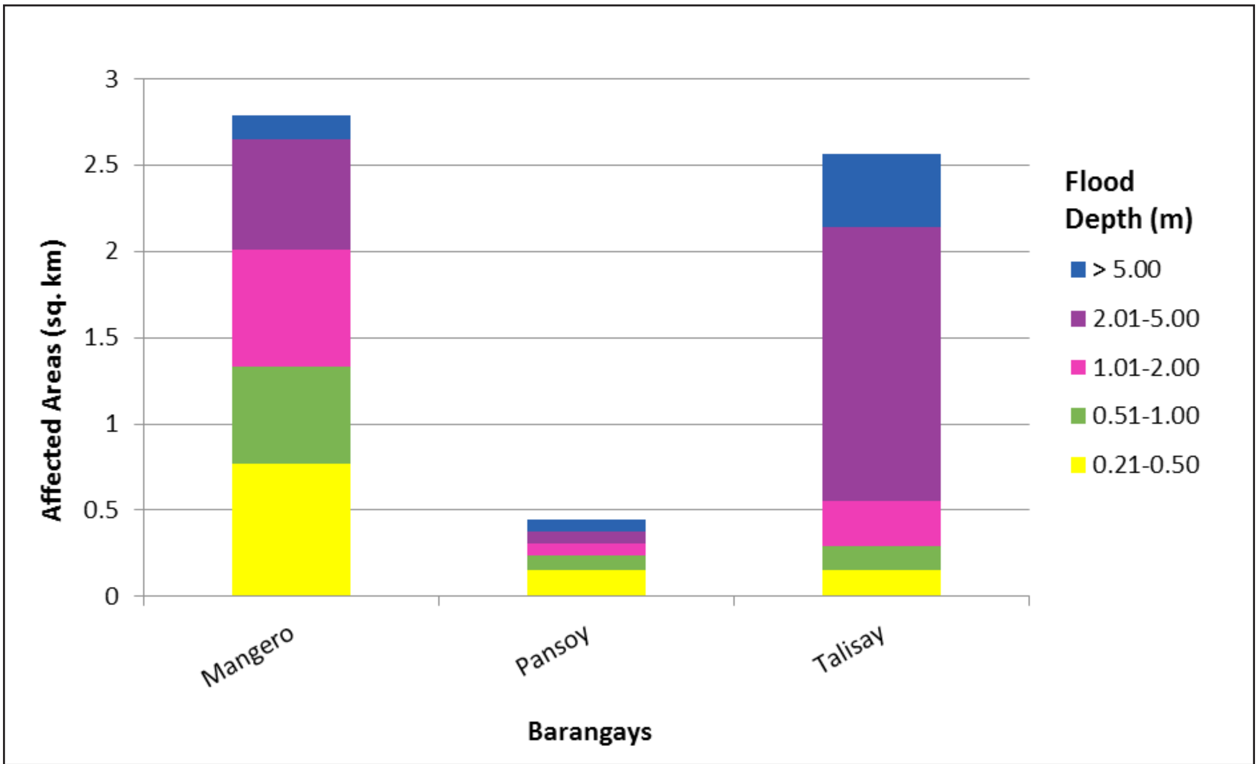


Figure 76. Affected Areas in San Andres, Quezon during 25-Year Rainfall Return Period

For the 25-year return period, 4.97% of the municipality of San Francisco with an area of 320.48 sq. km. will experience flood levels of less than 0.20 meters. 0.30% of the area will experience flood levels of 0.21 to 0.50 meters while 0.26%, 0.30%, 0.76%, and 0.60% 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 77 are the affected areas in square kilometers by flood depth per barangay.

Table 37. Affected Areas in San Francisco, Quezon during 25-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Francisco (in sq. km)	
	Huyon-Uyon	Pagsangahan
0.03-0.20	3.55	12.38
0.21-0.50	0.14	0.82
0.51-1.00	0.076	0.75
1.01-2.00	0.042	0.93
2.01-5.00	0.018	2.43
> 5.00	0.0037	1.92

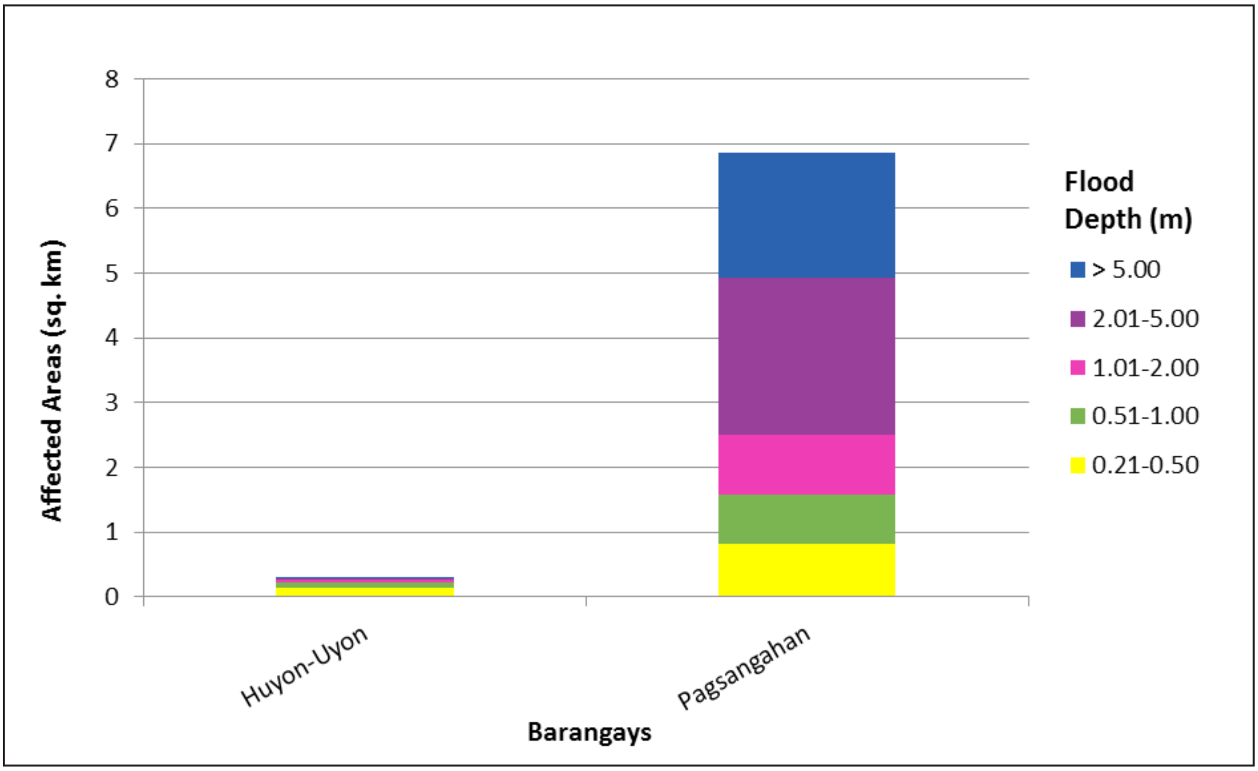


Figure 77. Affected Areas in San Francisco, Quezon during 25-Year Rainfall Return Period

For the 100-year return period, 9.74% of the municipality of San Andres with an area of 173.7 sq. km. will experience flood levels of less than 0.20 meters. 0.63% of the area will experience flood levels of 0.21 to 0.50 meters while 0.45%, 0.50%, 1.36%, and 0.66% 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 38 and shown in Figure 78 are the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected Areas in San Andres, Quezon during 100-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Andres (in sq. km)		
	Mangero	Pansoy	Talisay
0.03-0.20	11.47	3.99	1.46
0.21-0.50	0.79	0.17	0.13
0.51-1.00	0.57	0.091	0.12
1.01-2.00	0.65	0.08	0.13
2.01-5.00	0.83	0.07	1.46
> 5.00	0.25	0.091	0.81

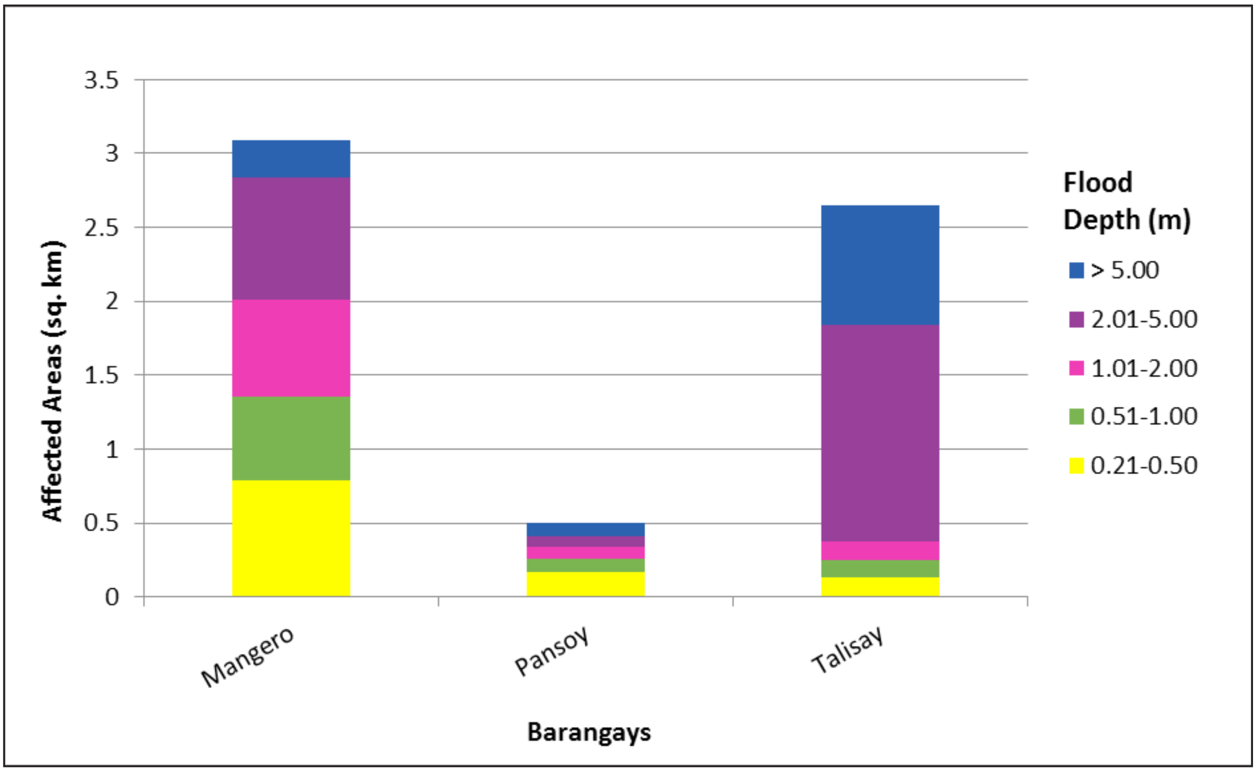


Figure 78. Affected Areas in San Andres, Quezon during 100-Year Rainfall Return Period

For the 100-year return period, 4.78% of the municipality of San Francisco with an area of 320.48 sq. km. will experience flood levels of less than 0.20 meters. 0.28% of the area will experience flood levels of 0.21 to 0.50 meters while 0.26%, 0.26%, 0.76%, and 0.86% 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 39 and shown in Figure 79 are the affected areas in square kilometers by flood depth per barangay.

Table 39. Affected Areas in San Francisco, Quezon during 100-Year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in San Francisco (in sq. km)	
	Huyon-Uyon	Pagsangahan
0.03-0.20	3.55	12.38
0.21-0.50	0.14	0.82
0.51-1.00	0.076	0.75
1.01-2.00	0.042	0.93
2.01-5.00	0.018	2.43
> 5.00	0.0037	1.92

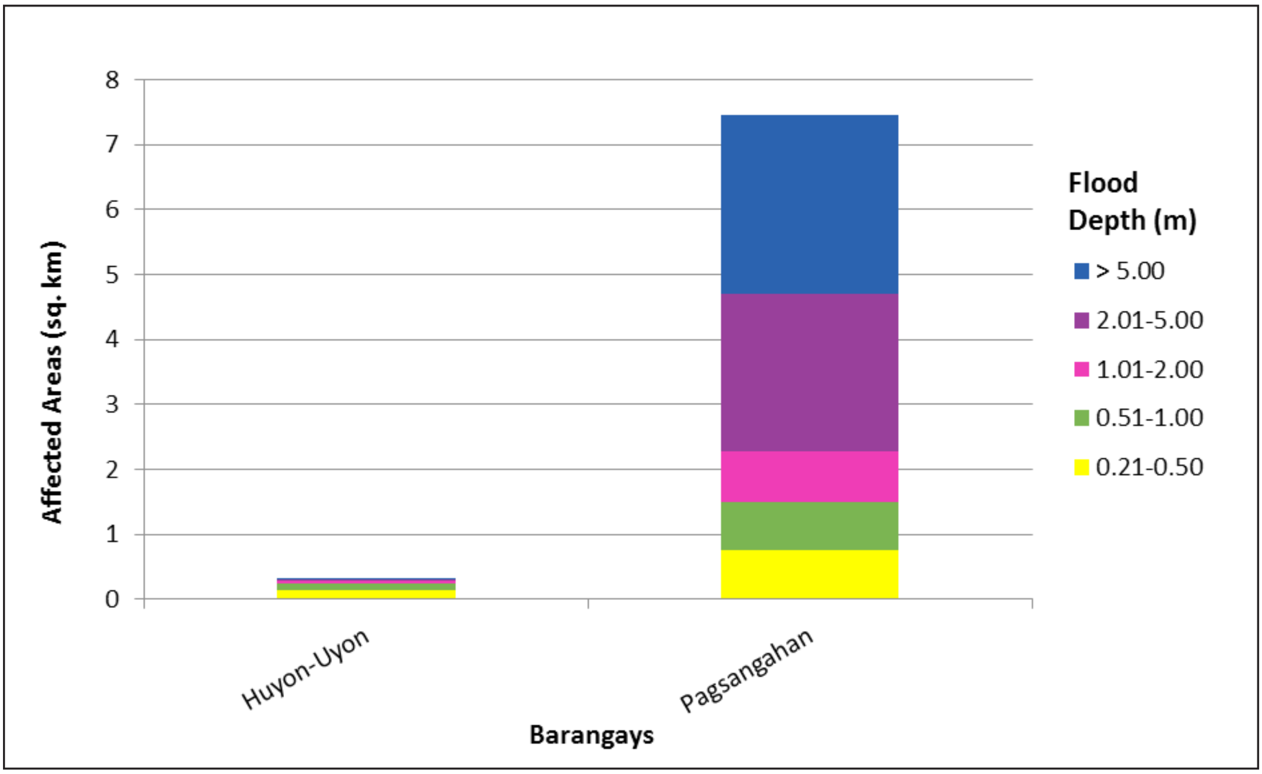


Figure 79. Affected Areas in San Francisco, Quezon during 100-Year Rainfall Return Period

Moreover, the generated flood hazard maps for the Yabaan 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-year, 25-year, and 10-year).

Table 40. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	2.15	2.034	2.00
Medium	3.36	2.60	2.42
High	5.58	8.45	9.74
TOTAL	11.091	13.084	14.16

Of the 2 educational institutions assessed, Talisay National High School in Talisay, San Andres, Quezon was exposed to High Flood Levels for all Return Periods. The educational institutions affected by flooding in the Yabaan floodplain are shown in Annex 12.

No medical institutions were assessed to be exposed to flooding in the Yabaan floodplain.

5.11 Flood Validation

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

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

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

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 81.

The flood validation consists of 180 points randomly selected all over the Yabaan floodplain (Figure 80). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 1.12m. Table 41 shows a contingency matrix of the comparison.

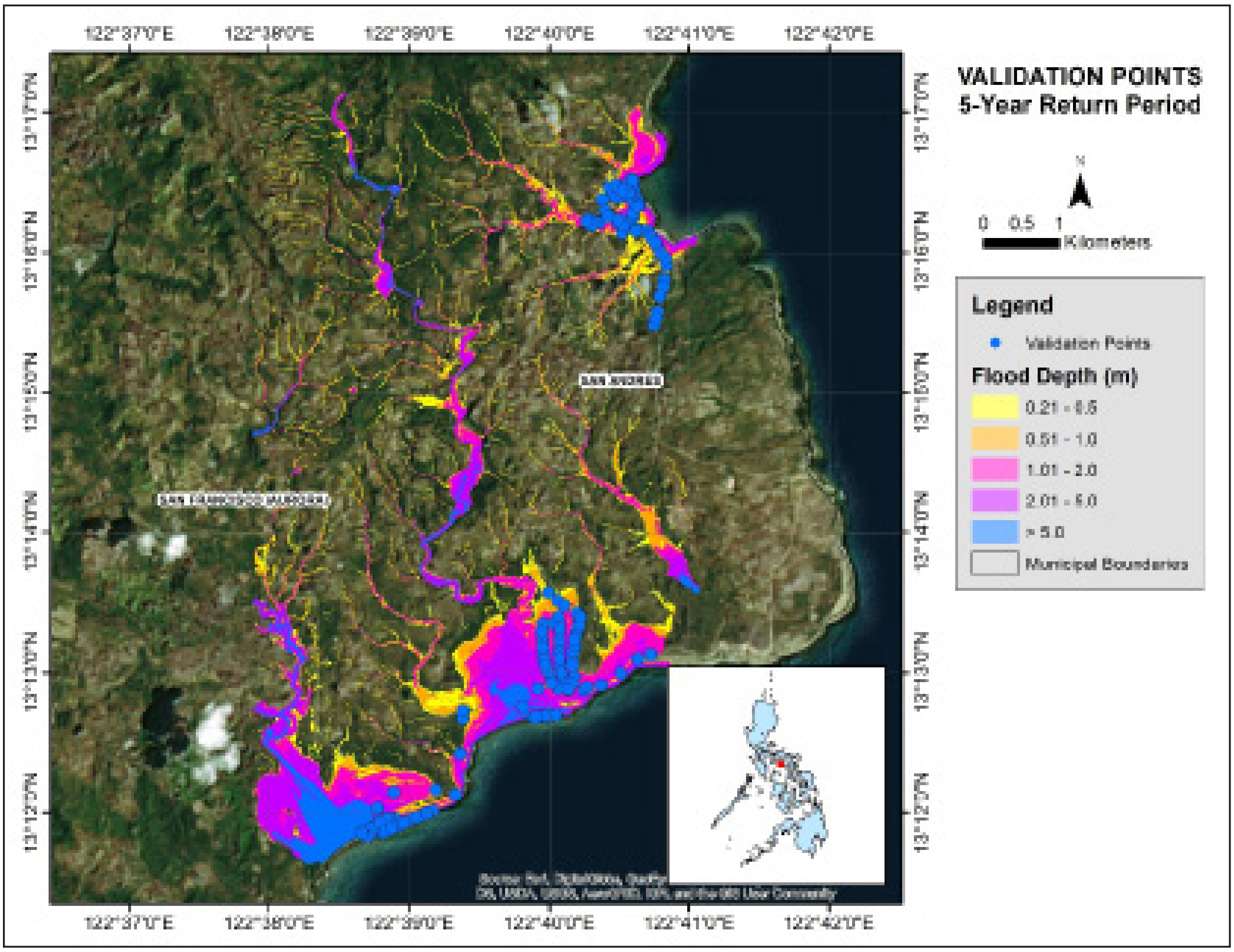


Figure 80. Validation points for 5-year Flood Depth Map of Yabaan Floodplain

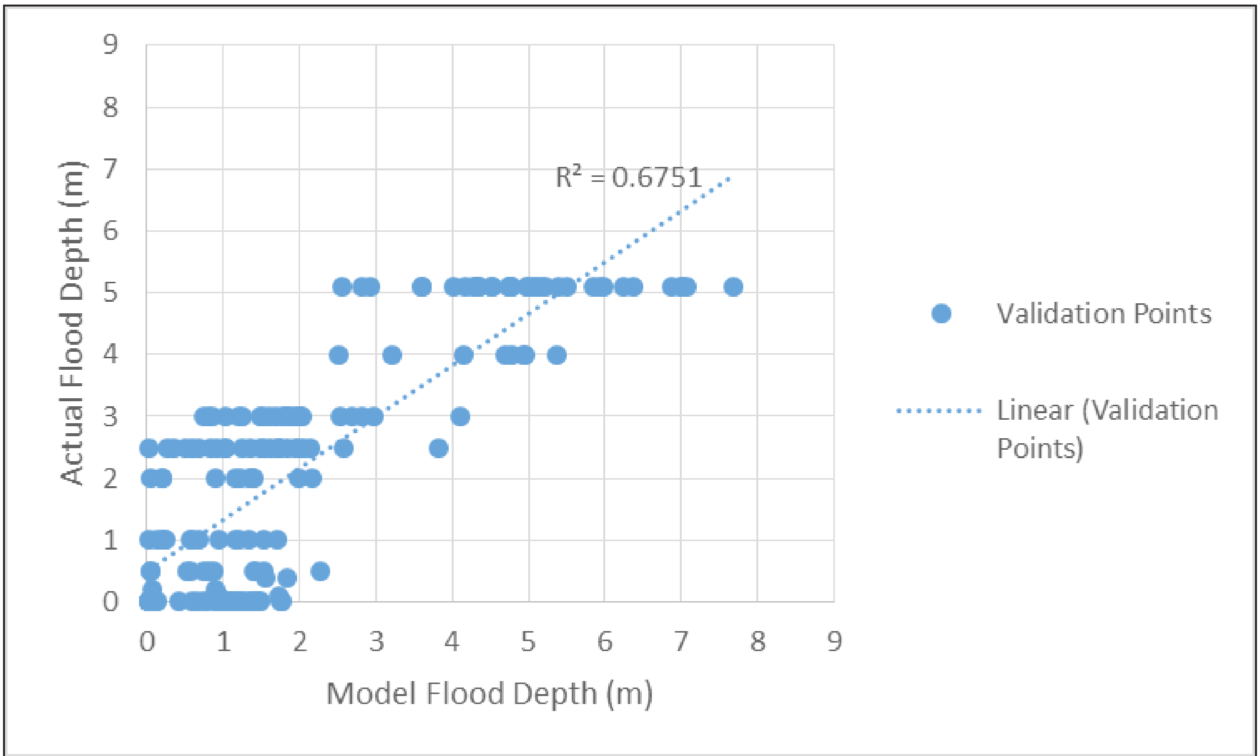


Figure 81. Flood map depth vs. actual flood depth

Table 41. Actual flood vs simulated flood depth at different levels in the Yabaan 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	16	1	11	19	0	0	47
0.21-0.50	2	0	5	5	1	0	13
0.51-1.00	3	2	4	5	0	0	14
1.01-2.00	3	0	1	7	1	0	12
2.01-5.00	1	3	7	27	19	1	58
> 5.00	0	0	0	0	20	16	36
Total	25	6	28	63	41	17	180

The overall accuracy generated by the flood model is estimated at 34.44% with 62 points correctly matching the actual flood depths. In addition, there were 63 points estimated one level above and below the correct flood depths while there were 26 points and 27 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 69 points were underestimated in the modelled flood depths of the Yabaan River Basin.

Table 42. Summary of the Accuracy Assessment in the Yabaan River Basin Survey

	No. of Points	%
Correct	62	34.44
Overestimated	49	27.22
Underestimated	69	38.33
Total	180	100.00

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Sarmiento C.J.S., Paringit E.C., et al. 2014. DREAM Data Aquisition 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

Annex 1. Optech Technical Specification of the Sensor

1. PEGASUS SENSOR

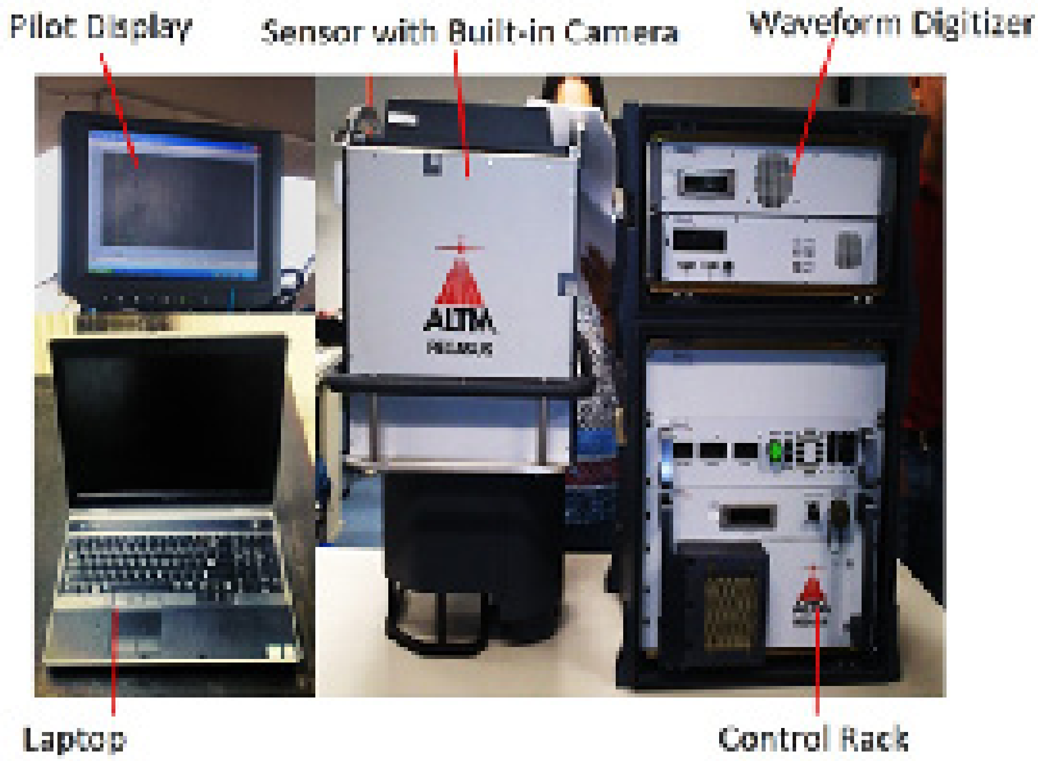


Figure A-1.1 Pegasus Sensor

2. PARAMETERS AND SPECIFICATIONS OF THE PEGASUS SENSOR

Table A-1.1 Parameters and Specifications of the Pegasus Sensor

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

1. Target reflectivity ≥20%
2. Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility
3. Angle of incidence ≤20˚
4. Target size ≥ laser footprint5 Dependent on system configuration

Annex 2. NAMRIA Certificates of Reference Points Used

Established ground control points were used for this floodplain, thus NAMRIA certificates of reference points used are not available for the Yabaan river basin.

Annex 3. Baseline Processing Report of Reference Points Used

Table A-3.1. UP-TAL and UP-VIG

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
QZN-47 --- QZN-40 (B31)	QZN-47	QZN-40	Fixed	0.003	0.011	306°22'36"	31263.486	-2.177
QZN-47 --- QZN-43 (B27)	QZN-43	QZN-47	Fixed	0.003	0.013	131°16'56"	12401.416	2.822
QZN-47 --- UP-VIG (B23)	QZN-47	UP-VIG	Fixed	0.003	0.012	103°58'19"	23335.323	2.557
QZN-47 --- UP-KAN (B36)	QZN-47	UP-KAN	Fixed	0.005	0.019	146°21'08"	28388.037	21.906
QZN-40 --- QZ-415 (B14)	QZN-40	QZ-415	Fixed	0.003	0.023	14°21'16"	22613.475	5.492
UP-CAB --- QZ-415 (B15)	UP-CAB	QZ-415	Fixed	0.004	0.025	234°09'16"	19401.067	5.290
QZN-40 --- UP-KAN (B33)	QZN-40	UP-KAN	Fixed	0.011	0.027	135°49'24"	58749.581	24.083
QZN-43 --- QZ-415 (B20)	QZN-43	QZ-415	Fixed	0.006	0.033	342°23'19"	33841.349	6.326
QZN-43 --- UP-KAN (B34)	QZN-43	UP-KAN	Fixed	0.005	0.018	141°46'15"	40492.330	24.748
UP-TAL --- UP-KAN (B35)	UP-TAL	UP-KAN	Fixed	0.005	0.018	312°01'33"	16293.271	19.903
UP-VIG --- UP-TAL (B25)	UP-VIG	UP-TAL	Fixed	0.003	0.014	169°50'51"	29356.882	-0.547
UP-VIG --- QZN-43 (B28)	UP-VIG	QZN-43	Fixed	0.003	0.014	293°25'54"	34821.073	-5.389
UP-VIG --- UP-KAN (B37)	UP-VIG	UP-KAN	Fixed	0.005	0.021	201°04'03"	19280.526	19.353
QZN-41 --- UP-CAB (B18)	UP-CAB	QZN-41	Fixed	0.004	0.024	247°44'12"	10141.643	-1.873
QZN-41 --- QZ-415 (B16)	QZN-41	QZ-415	Fixed	0.003	0.022	220°07'13"	9835.756	7.245
QZN-40 --- QZN-43 (B29)	QZN-43	QZN-40	Fixed	0.003	0.014	303°07'59"	18937.828	0.672
UP-CAB --- QZN-43 (B22)	QZN-43	UP-CAB	Fixed	0.004	0.019	7°10'02"	43963.480	1.070

1

Table A-3.2. MRE-11

Vector Components (Mark to Mark)

From:	UP-VIG				
Grid		Local		Global	
Easting	458401.422 m	Latitude	N13°28'25.87599"	Latitude	N13°28'25.87599"
Northing	1489570.975 m	Longitude	E122°36'56.36154"	Longitude	E122°36'56.36154"
Elevation	5.915 m	Height	56.297 m	Height	56.297 m

To:	UP-TAL				
Grid		Local		Global	
Easting	463529.419 m	Latitude	N13°12'45.54766"	Latitude	N13°12'45.54766"
Northing	1460676.800 m	Longitude	E122°39'48.22813"	Longitude	E122°39'48.22813"
Elevation	4.834 m	Height	55.749 m	Height	55.749 m

Vector					
ΔEasting	5127.997 m	NS Fwd Azimuth	169°50'51"	ΔX	-7951.962 m
ΔNorthing	-28894.175 m	Ellipsoid Dist.	29356.882 m	ΔY	2826.041 m
ΔElevation	-1.081 m	ΔHeight	-0.547 m	ΔZ	-28117.966 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.004 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.006 m
σ ΔElevation	0.007 m	σ ΔHeight	0.007 m	σ ΔZ	0.002 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000147120		
Y	-0.0000202520	0.0000324907	
Z	-0.0000059864	0.0000096550	0.0000038376

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	JERIEL PAUL ALAMBAN	UP-TCAGP
	RA	KRISTINE JOY ANDAYA	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JASMINE DOMINGO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. ERWIN DELOS SANTOS	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. KHALIL CHI	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. CESAR ALFONSO III	AAC

Annex 5. Data Transfer Sheet For Yabaan Floodplain

DATA TRANSFER SHEET
09/06/2016 ~~NAGA B~~ Bagonbors

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
5/6/2016	23324P	1BLK21F127A	PEGASUS	2.55	62.1	10.5	240	NA	NA	26.5	NA	55.5	1KB	1KB	53/70/63/5	NA	Z:\DAC\RAWDATA
5/7/2016	23326P	1BLK21E128A	PEGASUS	3.13	43.7	13.8	283	NA	NA	31	NA	81.2	1KB	1KB	74/41/185/	NA	Z:\DAC\RAWDATA
5/10/2016	23334P	1BLK21D131A	PEGASUS	3.57	48.9	13.1	301	NA	NA	36.2	NA	33	1KB	1KB	53/48/41/36/33/51/64/39/51	NA	Z:\DAC\RAWDATA
5/12/2016	23342P	1BLK21G133A	PEGASUS	3.42	38.4	15.5	290	NA	NA	35	NA	180	1KB	1KB	258	NA	Z:\DAC\RAWDATA
5/13/2016	23346P	1BLK21GS134A	PEGASUS	2.43	54.4	13	270	NA	NA	26.7	NA	134	1KB	1KB	43/176	NA	Z:\DAC\RAWDATA
5/15/2016	23354P	1BLK21EF136A	PEGASUS	1.99	98	13.1	277	NA	NA	24.2	NA	121	1KB	1KB	176	NA	Z:\DAC\RAWDATA
5/16/2016	23358P	1BLK21H137A	PEGASUS	3.21	40.1	11.7	214	7.27	NA	31.6	NA	121	1KB	1KB N/A	301	NA	Z:\DAC\RAWDATA
5/17/2016	23362P	1BLK21S138A	PEGASUS	628	55.3	7.29	178	22.4	NA	9.43	NA	98.9	1KB	1KB	228	NA	Z:\DAC\RAWDATA

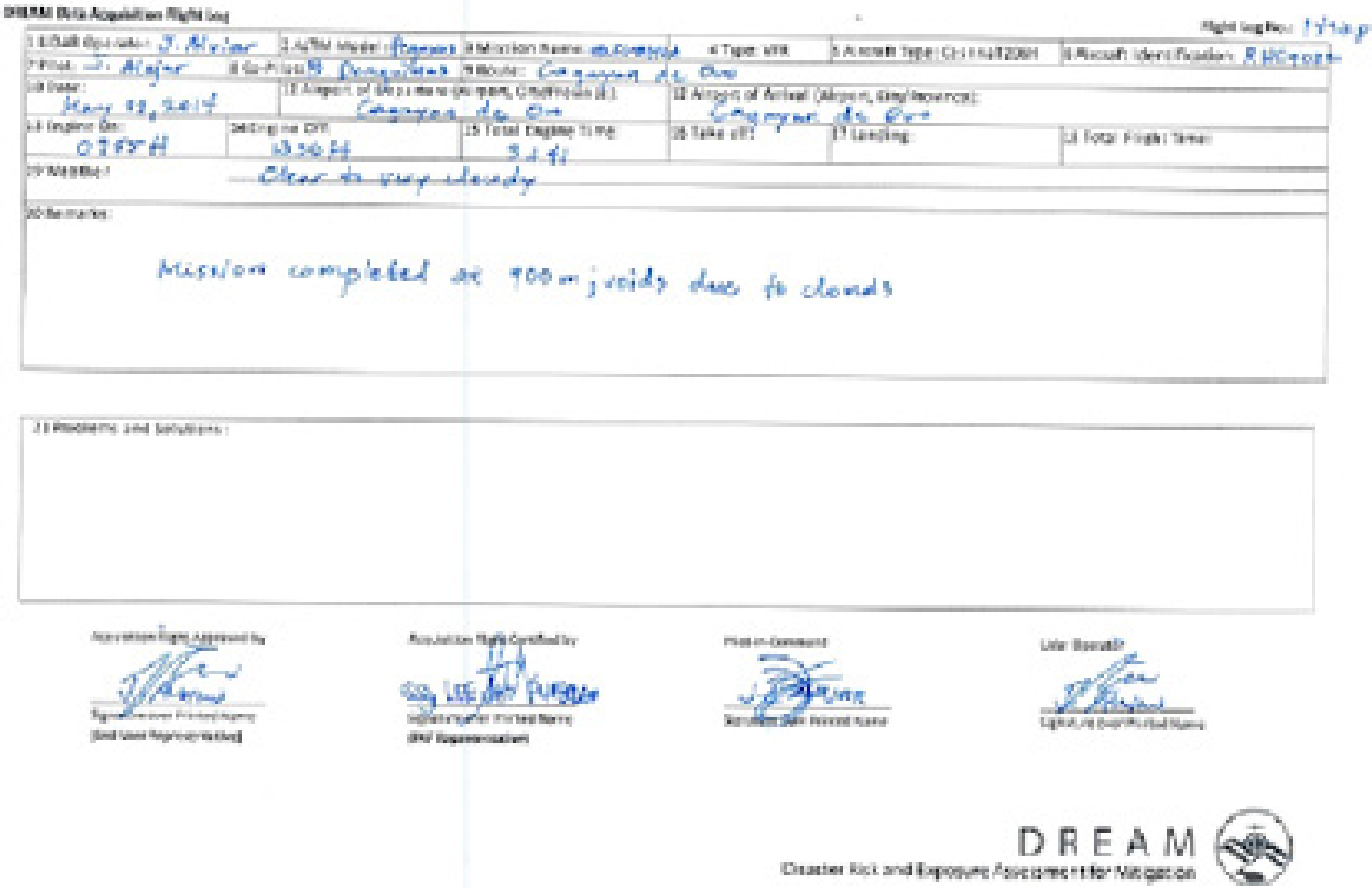
Name DARRYL AUSTRIA
Position R.A.
Signature

Name AC Bongat
Position SSRS
Signature

Figure A-5.1. Data Transfer Sheet for Yabaan Floodplain - A

Annex 6. Flight Logs

1. Flight Log for 1497P Mission



DREAM Data Acquisition Flight Log

1 LiDAR Operator: J. Alviar
7 Pilot: J. Alejar
10 Date: May 18, 2014
12 Airport of Departure: Cagayan de Oro
12 Airport of Arrival: Cagayan de Oro
13 Engine On: 0755H
14 Engine Off: 1130H
15 Total Engine Time: 3+41
16 Take off:
17 Landing:
18 Total Flight Time:
19 Weather: Clear to very cloudy
20 Remarks:

Mission completed at 900m; voids due to clouds

21 Problems and Solutions:

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure A-6.1. Flight Log for Mission 1497P

Annex 7. Flight Status

FLIGHT STATUS REPORT
QUEZON
(May 12 – 13, 2016)

Table A-7.1. Flight Status Report

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
23342P	BLK 21G YABAHAAN AND YABAHAAN FPs	1BLK221G133A	K ANDAYA	MAY 12, 2016	SURVEYED BLK 21G
23346P	BLK 21G YABAHAAN AND YABAHAAN FPs	1BLK21GS134A	K ANFAYA	MAY 13, 2016	SURVEYED BLK 21G

LAS BOUNDARIES PER FLIGHT

Flight No. :	23342P			
Area:	BLK21GH			
Parameters:	PRF:	200 kHz;	Scan Frequency:	30Hz
	Scan Angle:	25 deg;	Overlap:	30%

LAS/SWATH

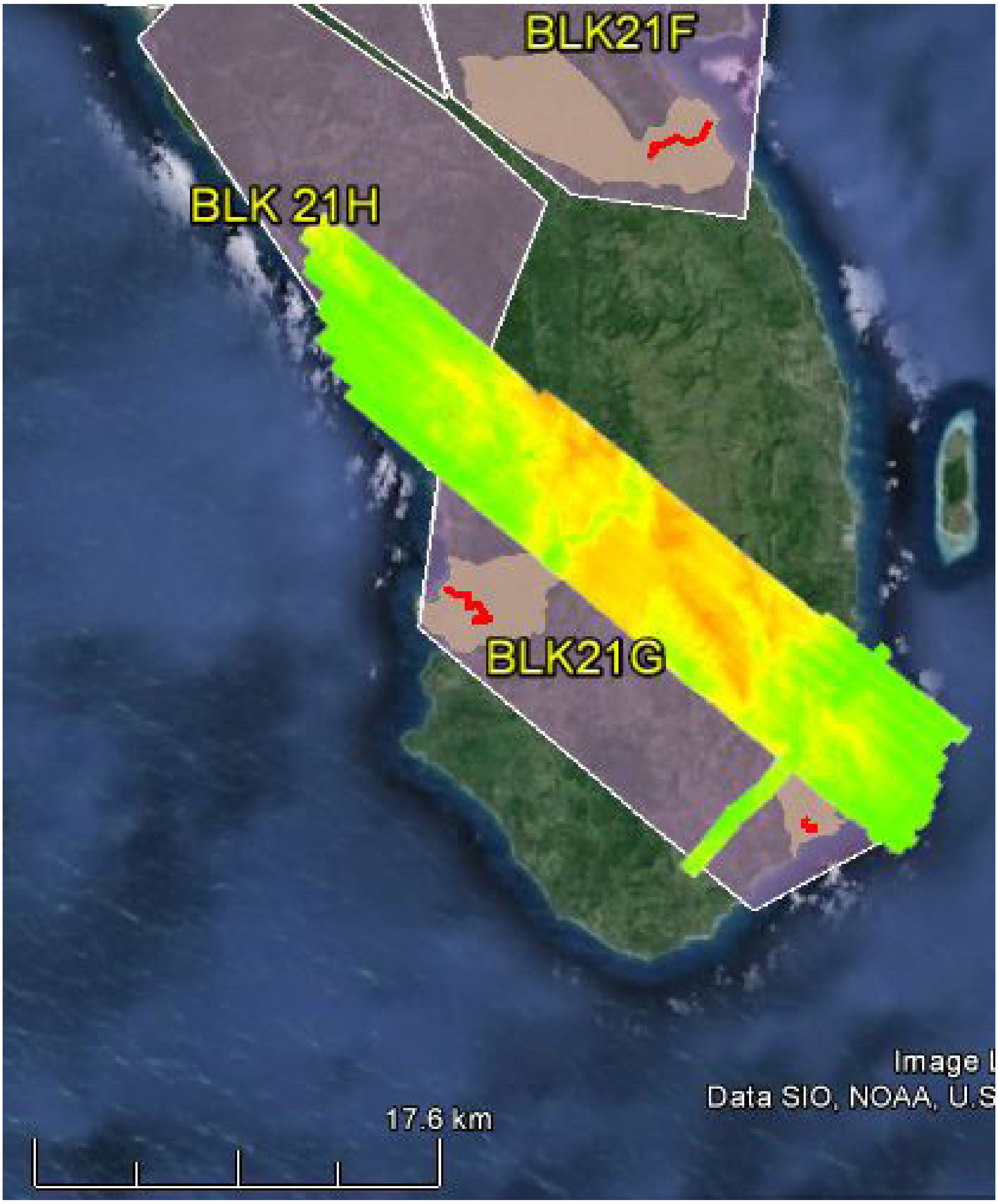


Figure A-7.1. Swath for Flight No. 23342P

Flight No. :	23346P			
Area:	BLK21GH			
Parameters:	PRF:	200 kHz;	Scan Frequency:	30Hz
	Scan Angle:	25 deg;	Overlap:	30%

LAS/SWATH

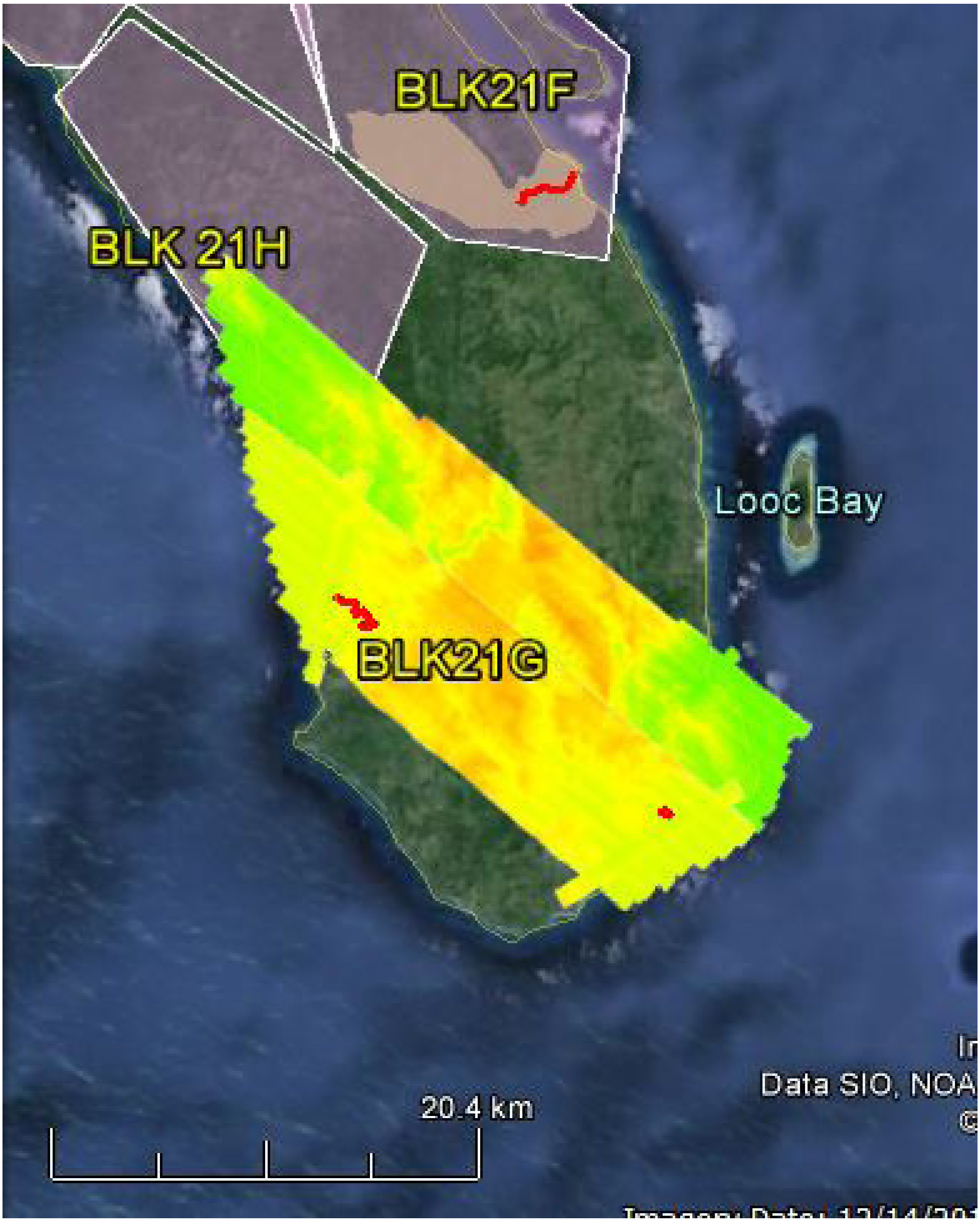


Figure A-7.2. Swath for Flight No. 23346P

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Blk21G

Flight Area	Davao Oriental
Mission Name	Blk21G
Inclusive Flights	23346P
Range data size	26.7 GB
POS data size	270 MB
Base data size	134 MB
Image	n/a
Transfer date	-
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.1
RMSE for East Position (<4.0 cm)	1.3
RMSE for Down Position (<8.0 cm)	2.1
Boresight correction stdev (<0.001deg)	0.000103
IMU attitude correction stdev (<0.001deg)	0.000268
GPS position stdev (<0.01m)	0.0061
Minimum % overlap (>25)	49.23%
Ave point cloud density per sq.m. (>2.0)	4.32
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	209
Maximum Height	348.62
Minimum Height	49.18
Classification (# of points)	
Ground	265274506
Low vegetation	205322997
Medium vegetation	245788005
High vegetation	582076822
Building	4268406
Orthophoto	
Processed by	Engr. Jommer Medina, Engr. Jovelle Anjeanette Canlas, Engr. Elainne Lopez

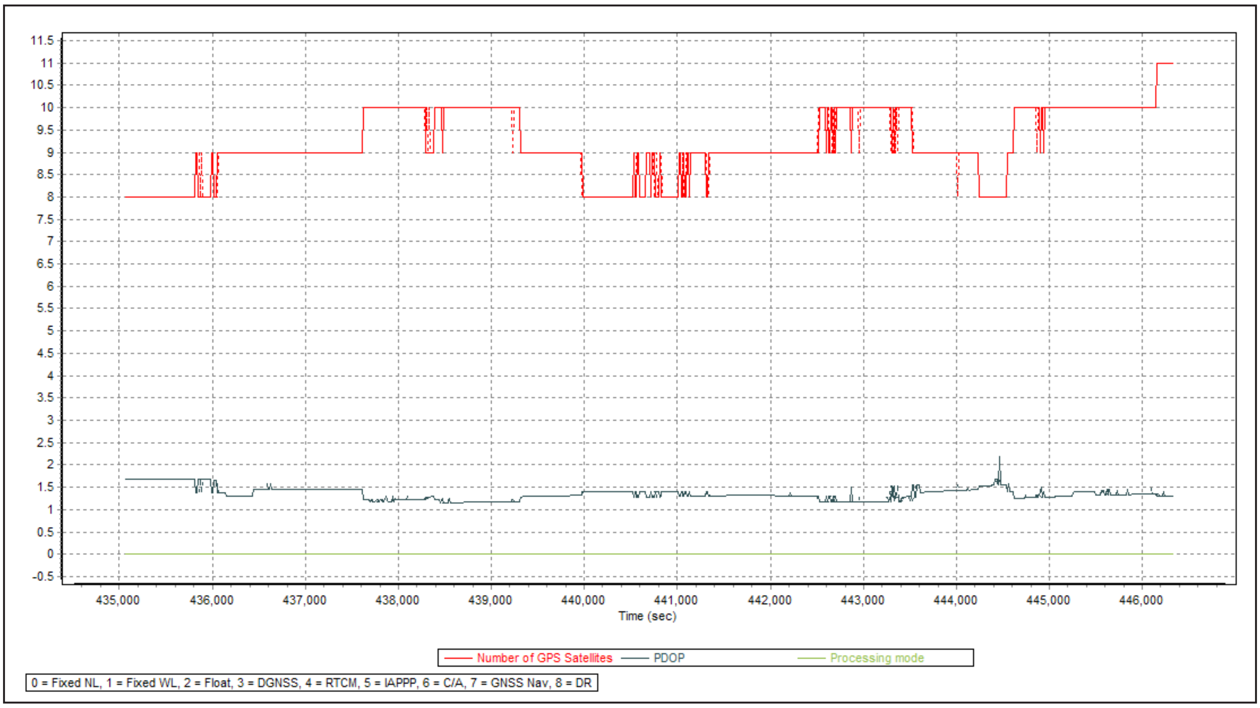


Figure A-8.1. Solution Status

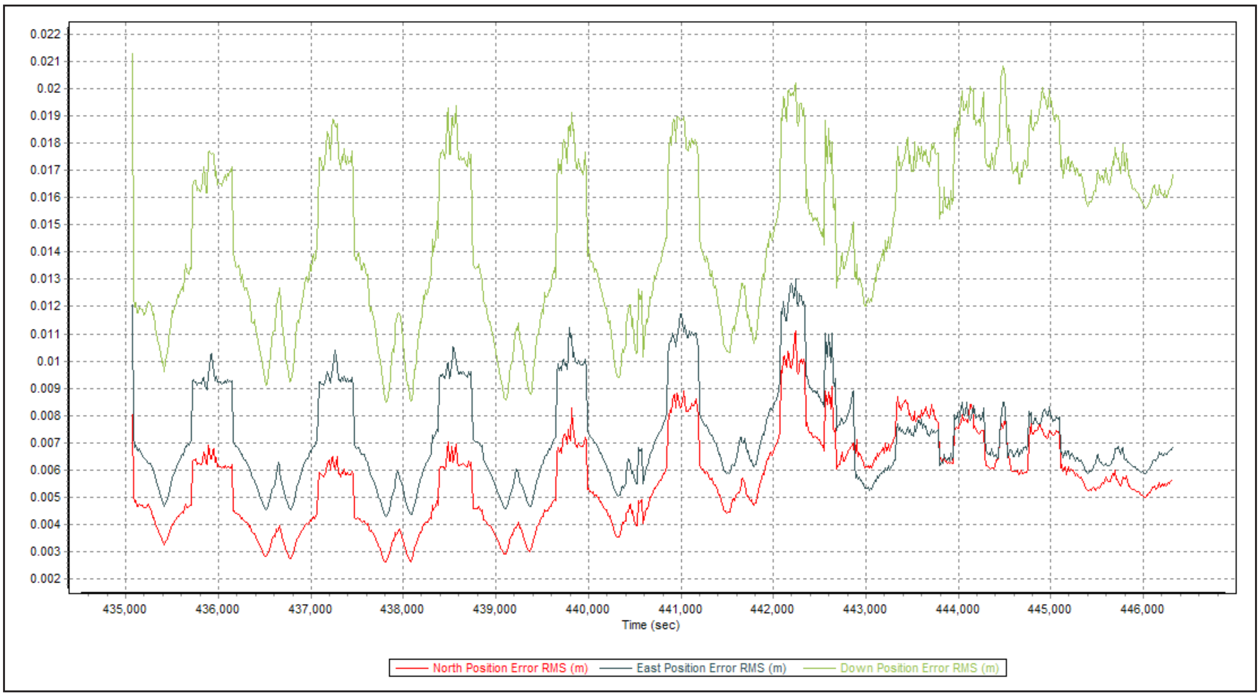


Figure A-8.2. Smoothed Performance Metric Parameters

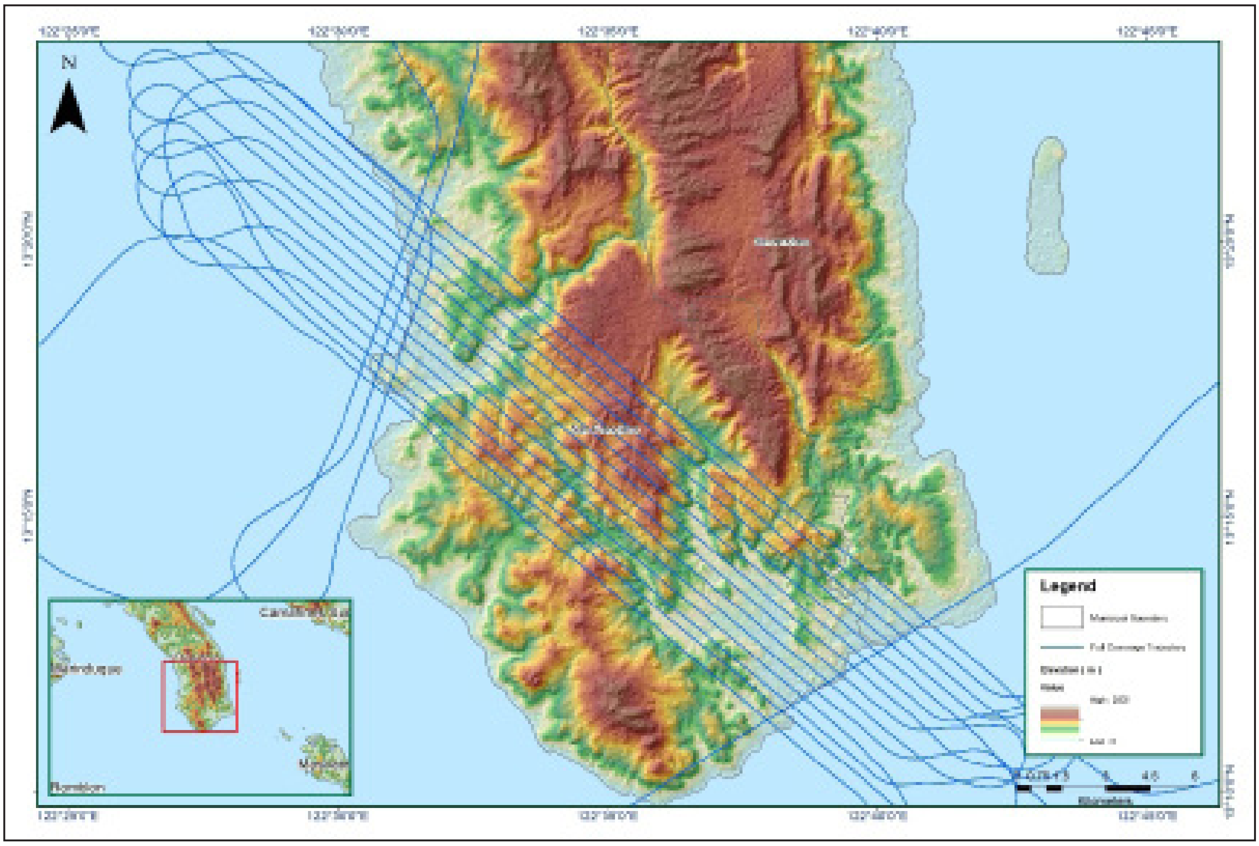


Figure A-8.3. Best Estimated Trajectory

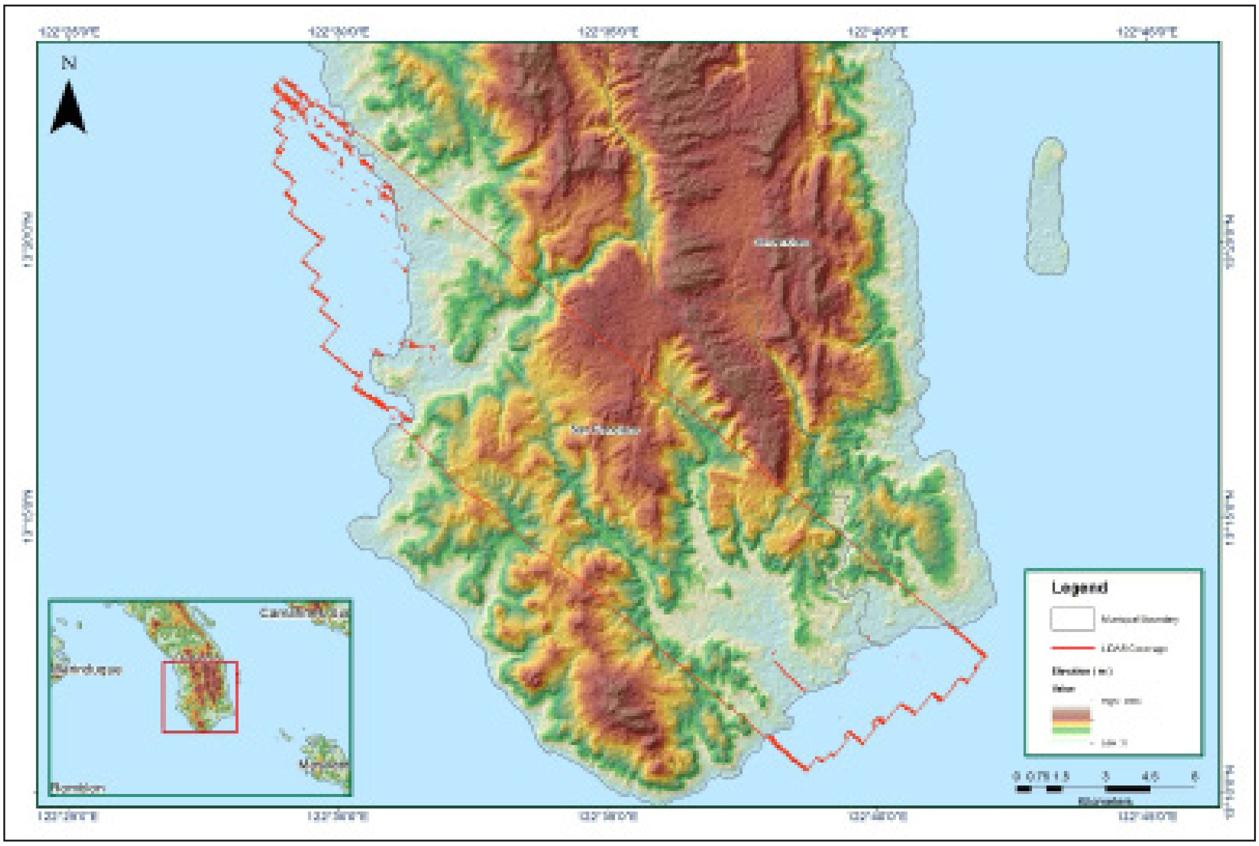


Figure A-8.4. Coverage of LiDAR data

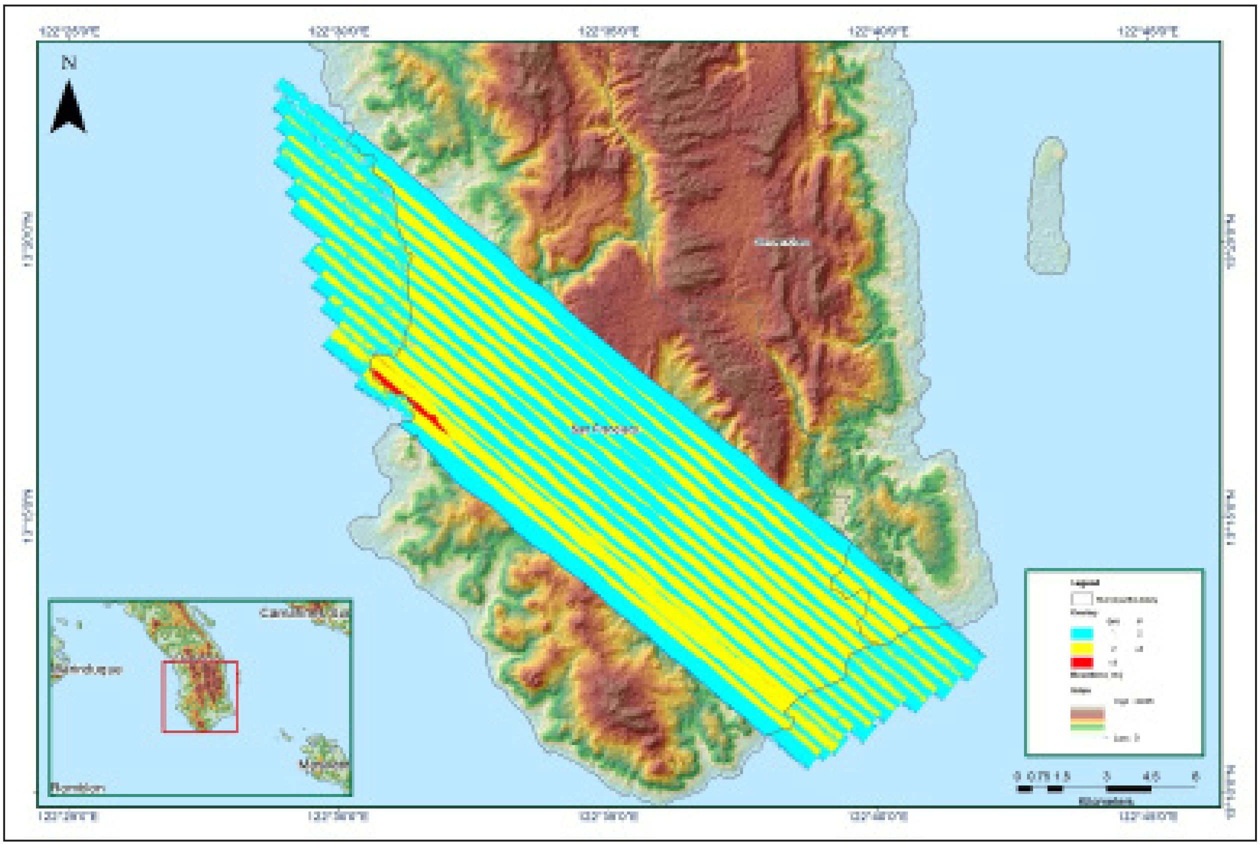


Figure A-8.5. Image of data overlap

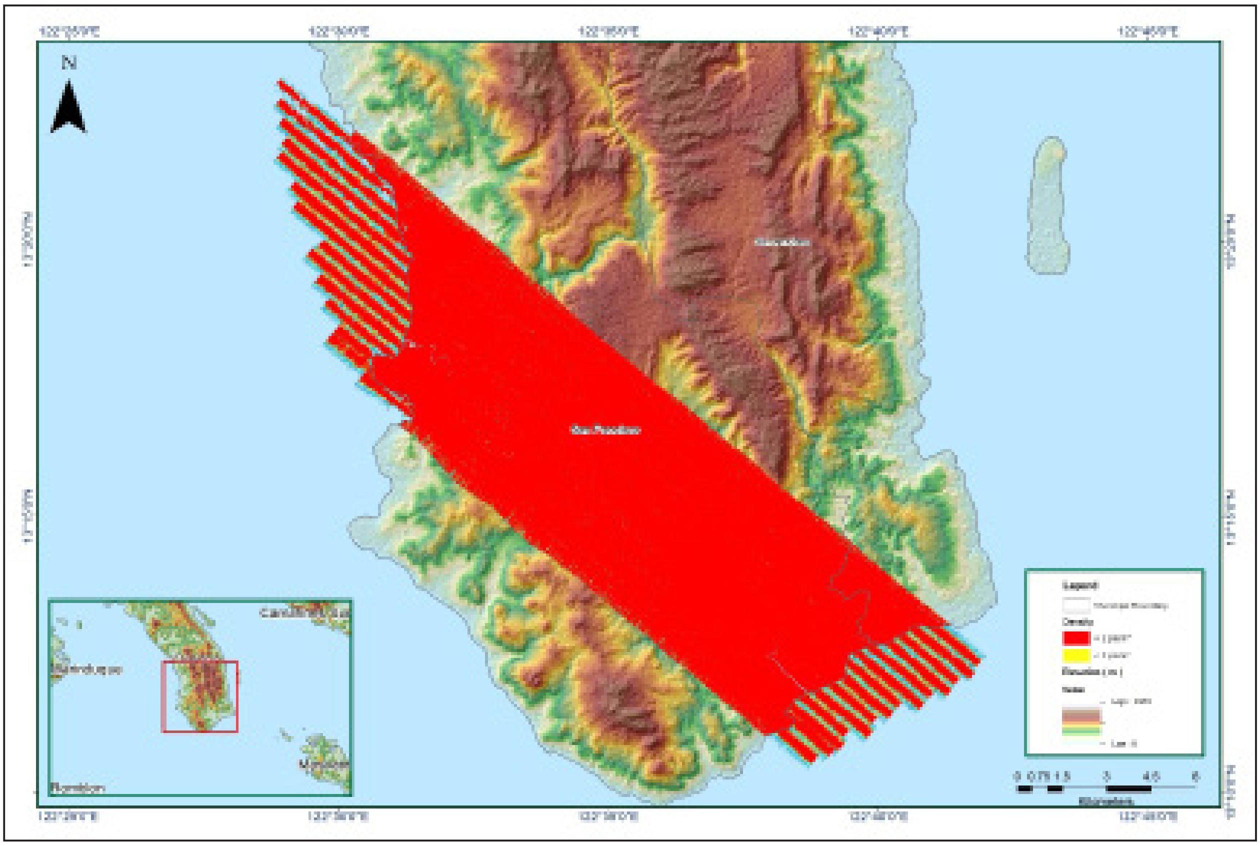


Figure A-8.6. Density map of merged LiDAR data

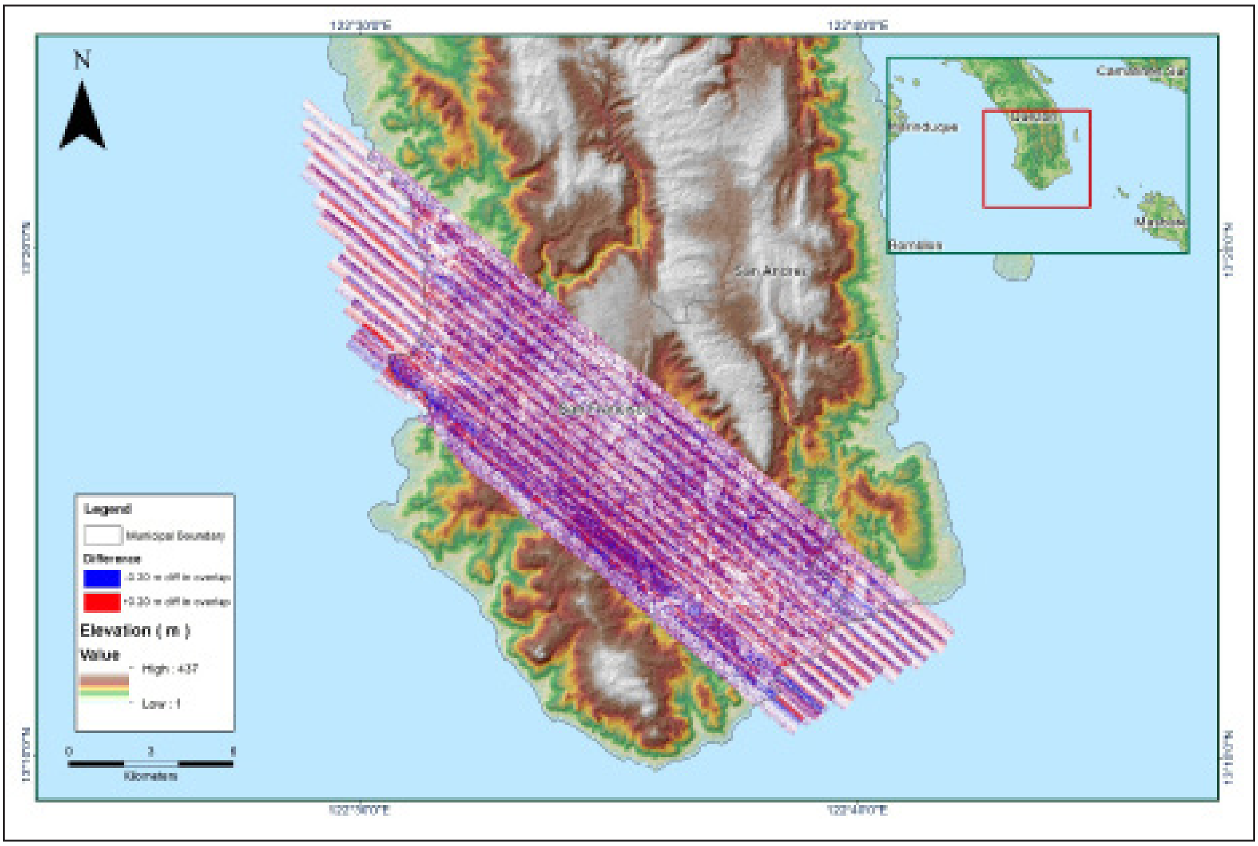


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Blk21H

Flight Area	Davao Oriental
Mission Name	Blk21H
Inclusive Flights	23342P
Range data size	35 GB
POS data size	290 MB
Base data size	180 MB
Image	n/a
Transfer date	-
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.4
RMSE for East Position (<4.0 cm)	1.6
RMSE for Down Position (<8.0 cm)	2.9
Boresight correction stdev (<0.001deg)	0.000121
IMU attitude correction stdev (<0.001deg)	0.000762
GPS position stdev (<0.01m)	0.0074
Minimum % overlap (>25)	62.54%
Ave point cloud density per sq.m. (>2.0)	6.06
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	251
Maximum Height	473.30 m
Minimum Height	48.95 m
Classification (# of points)	
Ground	330,456,714
Low vegetation	275,861,681
Medium vegetation	482,884,623
High vegetation	1,064,480,938
Building	10,367,950
Orthophoto	No
Processed by	Engr. Jennifer Saguran, Engr. Melanie Hingpit, Alex John Escobido

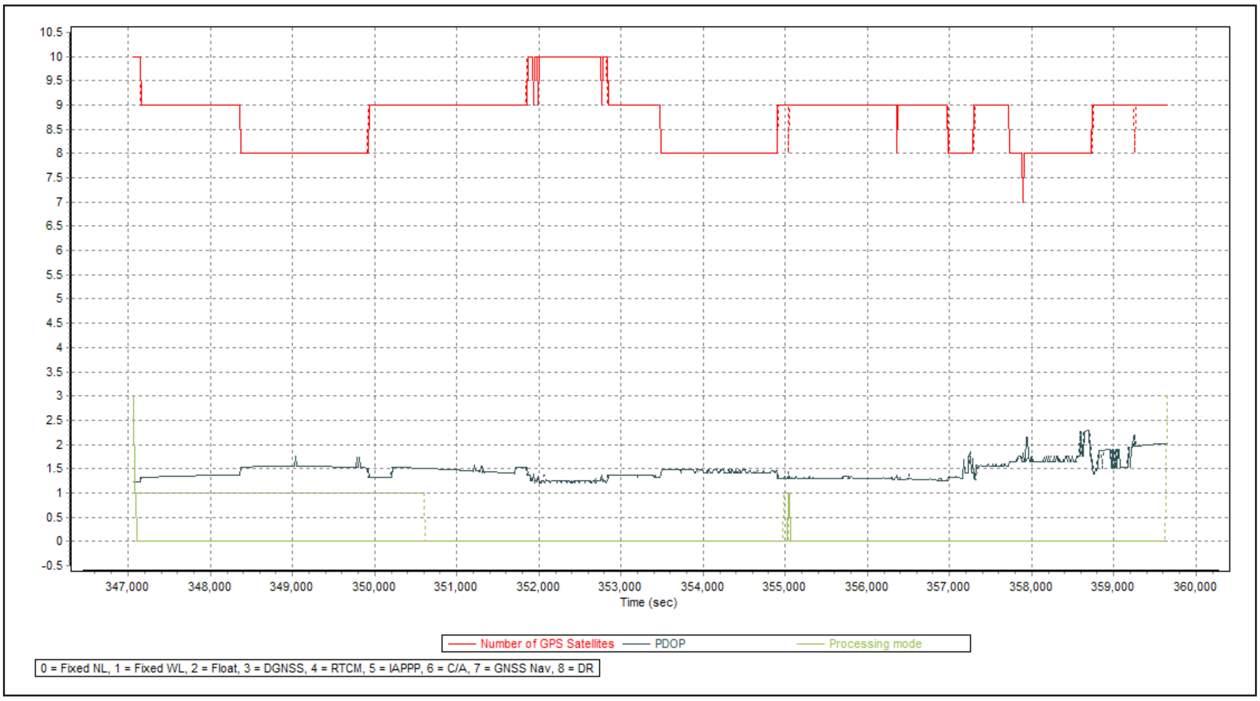


Figure A-8.8. Solution Status

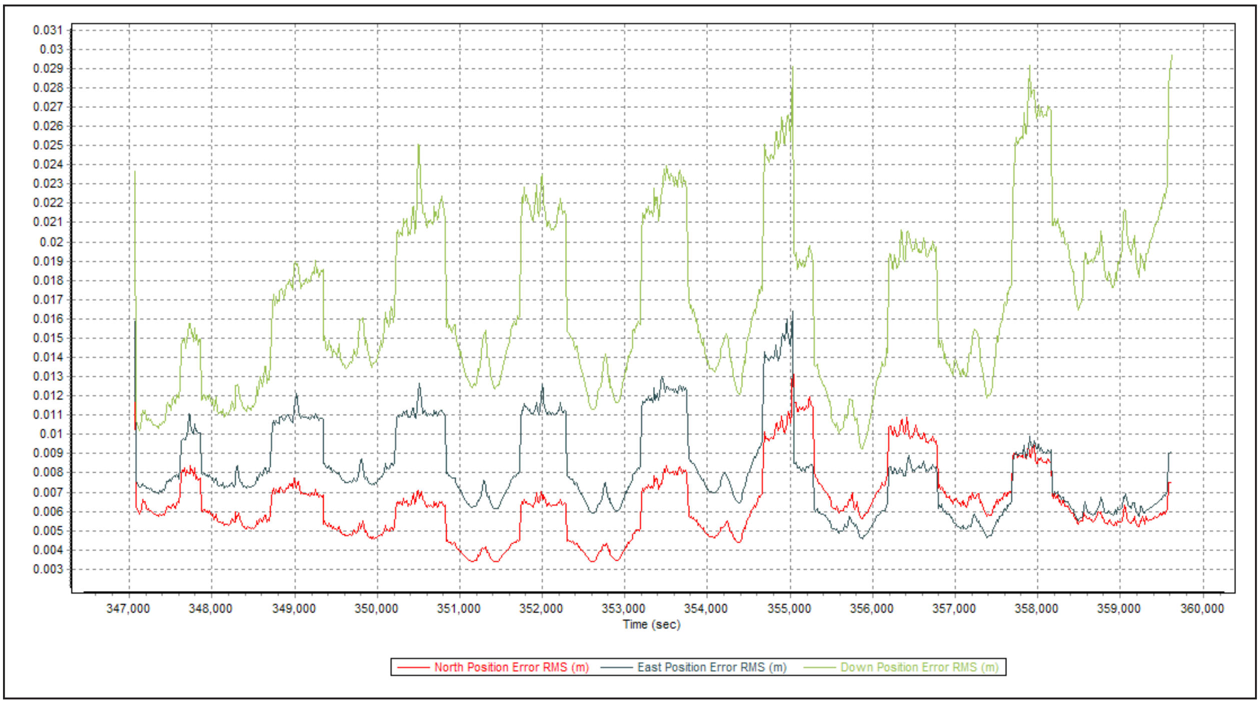


Figure A-8.9. Smoothed Performance Metric Parameters

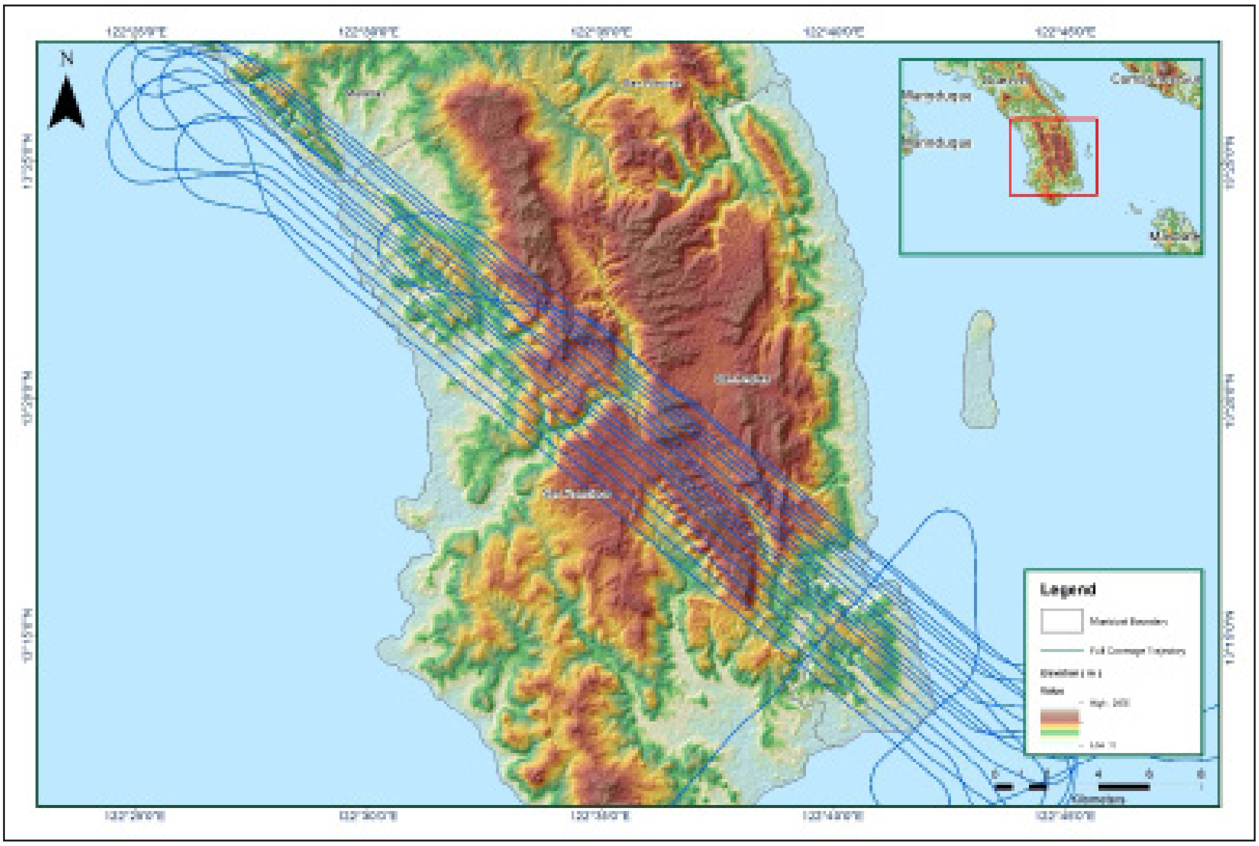


Figure A-8.10. Best Estimated Trajectory

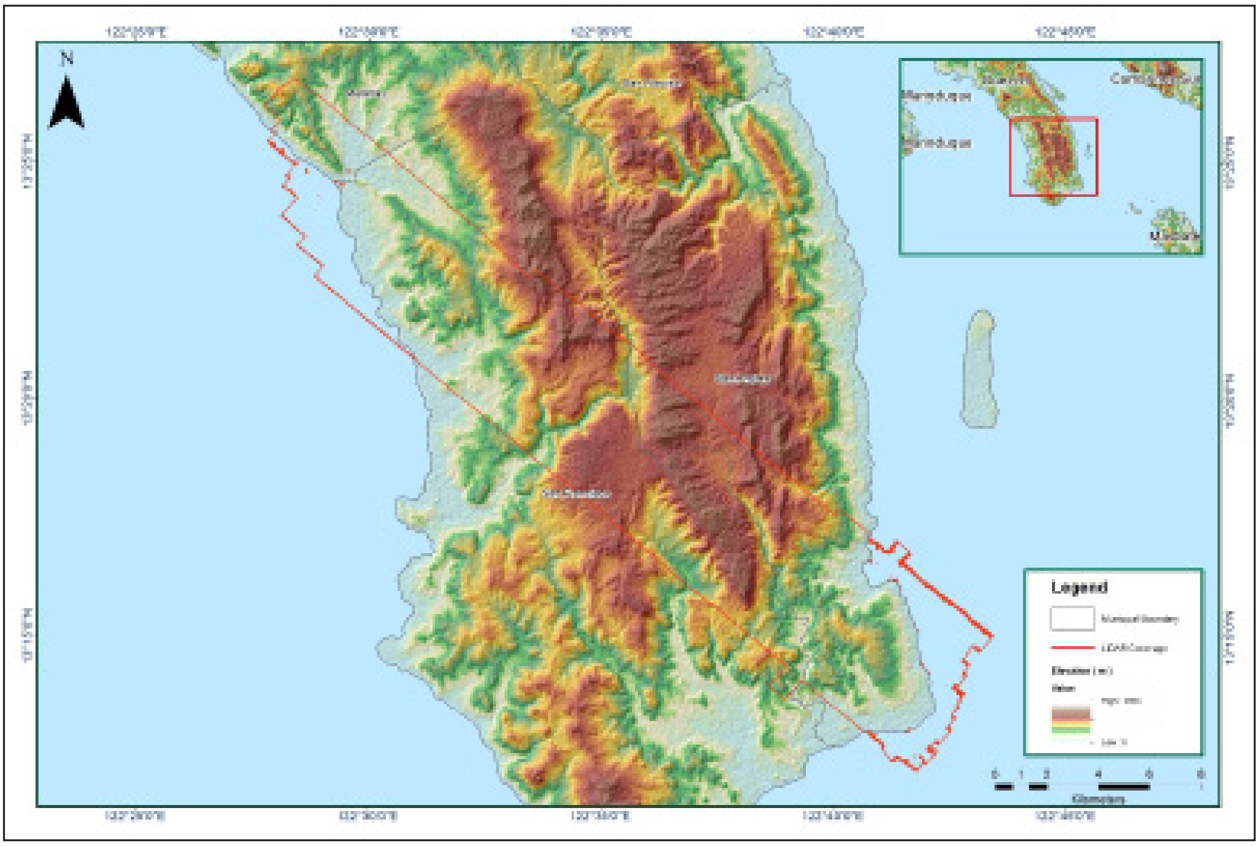


Figure A-8.11. Coverage of LiDAR data

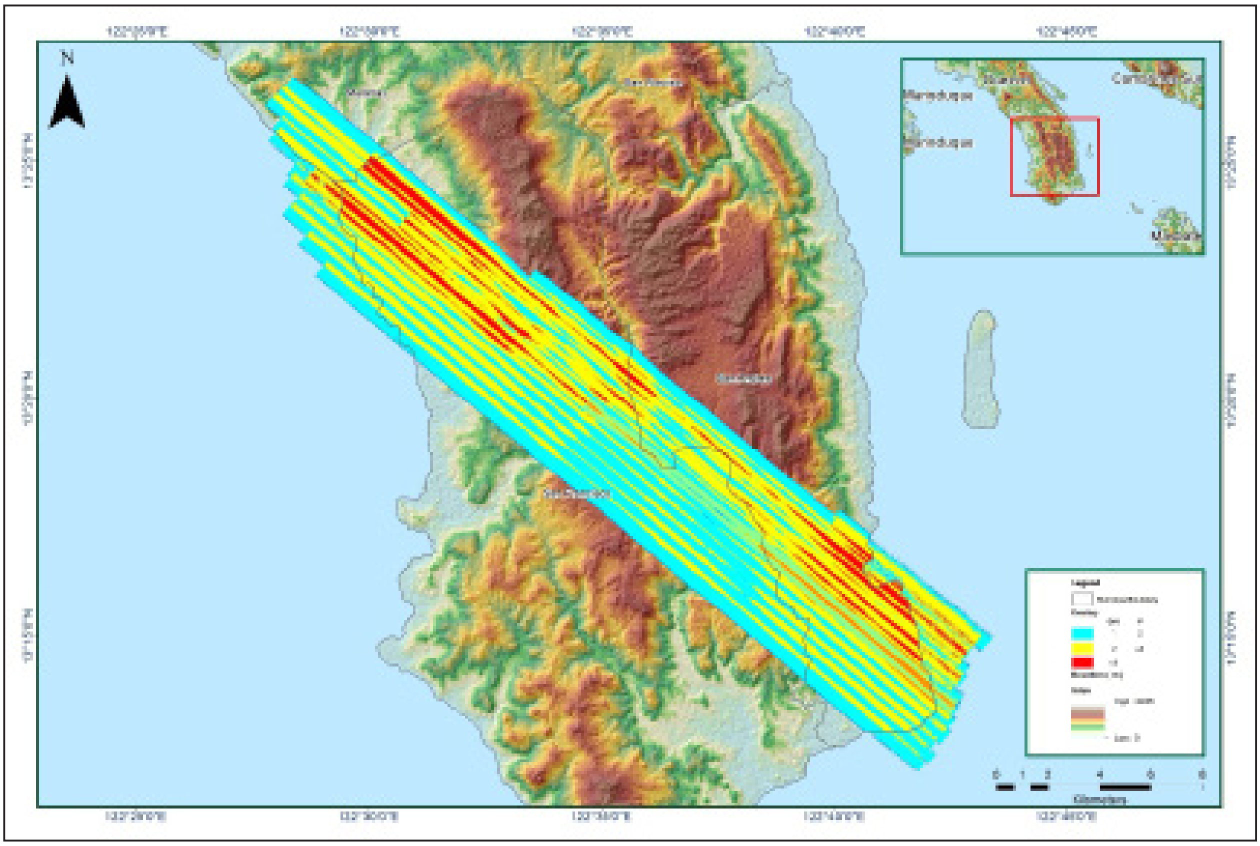


Figure A-8.12. Image of data overlap

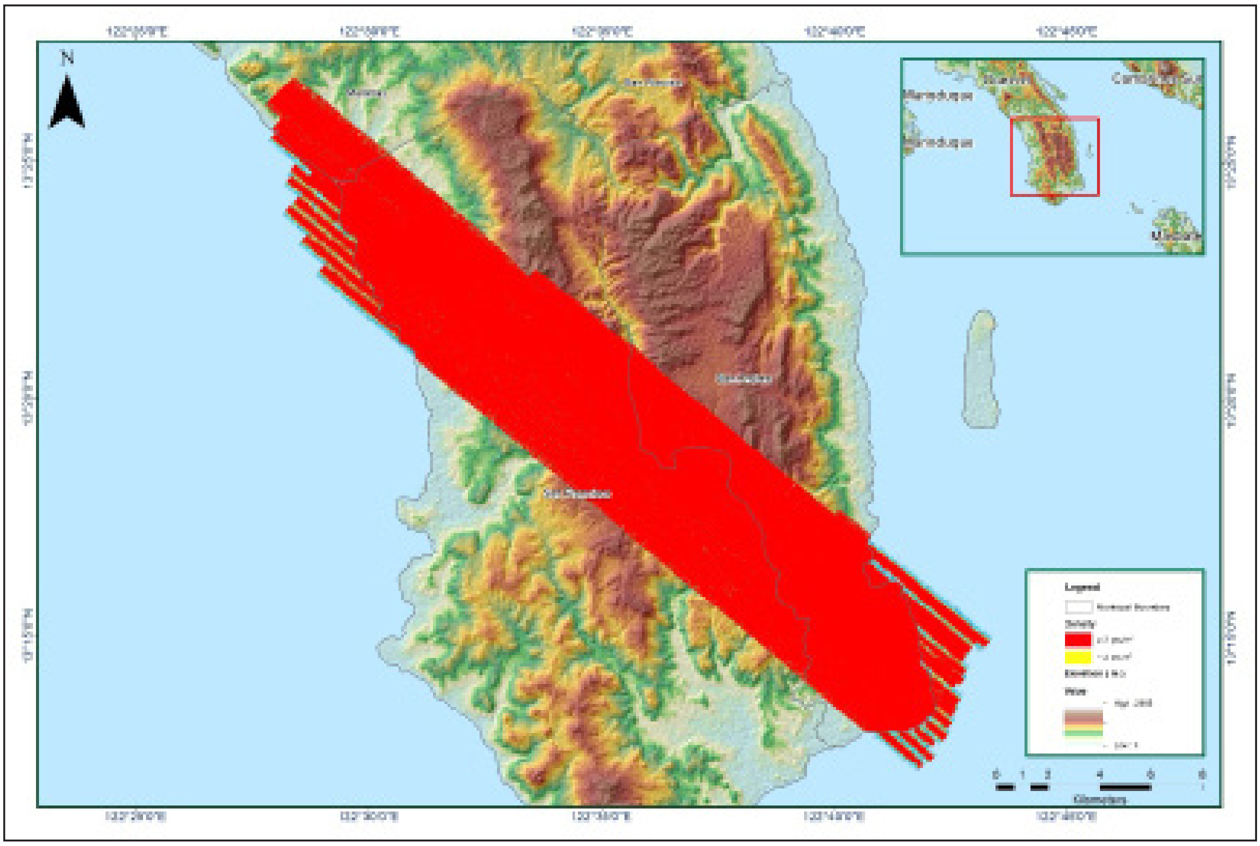


Figure A-8.13. Density map of merged LiDAR data

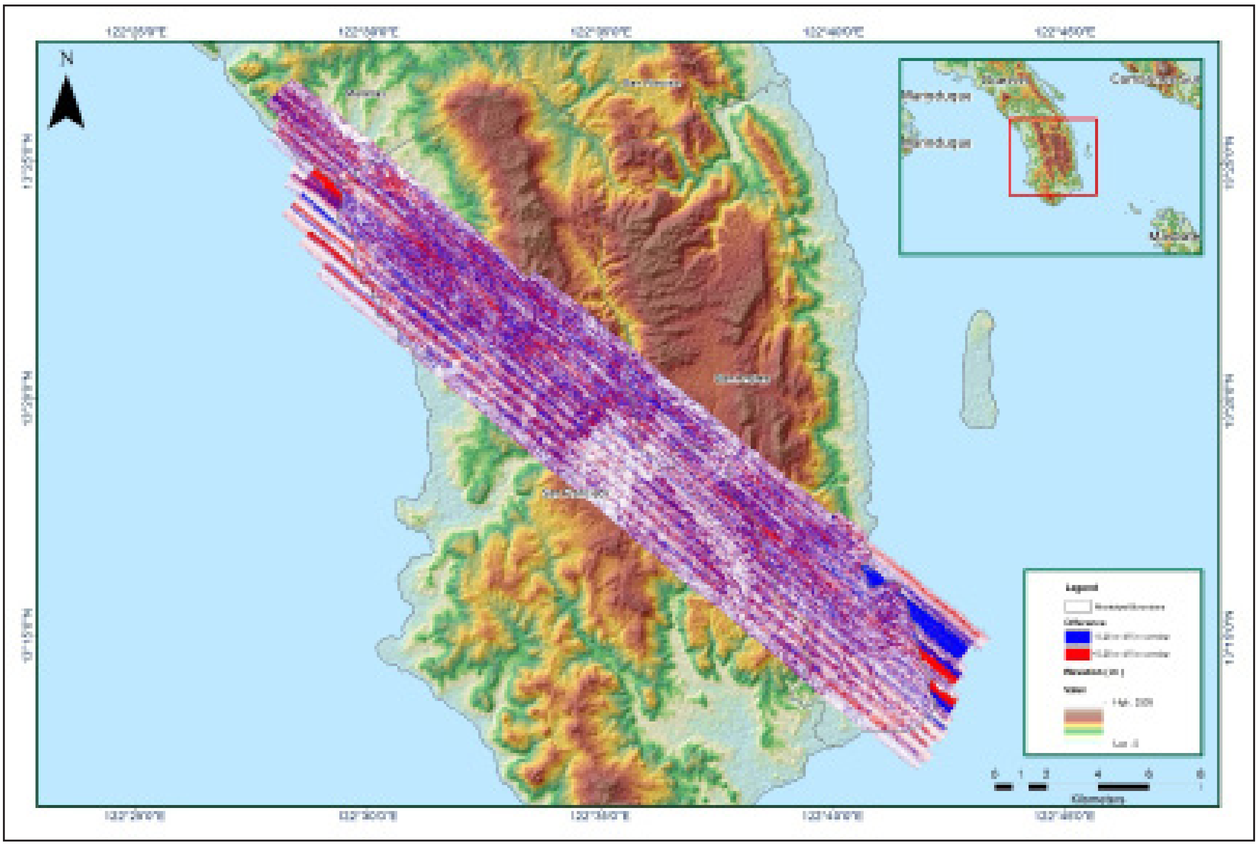


Figure A-8.14. Elevation difference between flight lines

Annex 9. Yabaan Model Basin Parameters

Table A-9.1. Yabaan Model Basin Parameters

Sub-basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W1000	19.278	94.05	0	0.03	13.553	Discharge	5.31E-04	1.00E-04	Ratio to Peak	0.0045
W1010	12.984	94.05	0	1.3623	6.2473	Discharge	1.74E-03	1.00E-04	Ratio to Peak	0.0023
W1020	39.721	50.218	0	27.954	3.5547	Discharge	8.79E-03	1.00E-04	Ratio to Peak	0.0033
W1030	61.156	50.126	0	7.11	5.7197	Discharge	2.97E-03	1.00E-04	Ratio to Peak	0.0063
W1040	20.782	80.835	0	131.83	0.9804	Discharge	1.21E-03	1.00E-04	Ratio to Peak	0.002
W1050	26.788	50.355	0	1.5462	0.0167	Discharge	2.38E-03	1.00E-04	Ratio to Peak	0.0005
W1060	37.839	94.032	0	2.7248	5.5611	Discharge	4.59E-03	1.00E-04	Ratio to Peak	0.005
W1070	19.059	50.126	0	2.0032	6.0559	Discharge	3.97E-03	1.00E-04	Ratio to Peak	0.005
W1080	104.84	50.126	0	118.1	4.3917	Discharge	4.28E-03	1.00E-04	Ratio to Peak	0.0042
W1090	47.787	50.689	0	5.1291	6.1281	Discharge	2.23E-03	1.00E-04	Ratio to Peak	0.003
W1100	18.717	65.594	0	1.8617	7.5129	Discharge	2.10E-03	1.00E-04	Ratio to Peak	0.0045
W1110	19.621	50.126	0	2.1467	5.8124	Discharge	6.77E-05	1.00E-04	Ratio to Peak	0.0045
W1120	19.265	49.955	0	3.4342	6.8603	Discharge	7.77E-04	1.00E-04	Ratio to Peak	0.0045
W1130	18.403	51.033	0	2.5843	7.0102	Discharge	3.13E-03	1.00E-04	Ratio to Peak	0.0045
W1140	18.491	50.247	0	2.5871	5.9777	Discharge	4.79E-04	1.00E-04	Ratio to Peak	0.0045
W1150	28.453	50.643	0	2.2588	6.2753	Discharge	2.38E-03	1.00E-04	Ratio to Peak	0.0045
W1160	23.951	43.576	0	2.9914	8.5375	Discharge	3.00E-03	1.00E-04	Ratio to Peak	0.0045
W1170	18.777	50.386	0	2.1575	6.7275	Discharge	1.74E-03	1.00E-04	Ratio to Peak	0.0045
W1180	37.565	52.861	0	15.771	8.8558	Discharge	4.12E-03	1.00E-04	Ratio to Peak	0.003
W1190	19.249	50.389	0	3.7116	6.2749	Discharge	3.53E-03	1.00E-04	Ratio to Peak	0.0045
W1200	22.121	50.126	0	4.3727	1.7784	Discharge	2.51E-03	1.00E-04	Ratio to Peak	0.0068

Sub-basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W1210	19.299	51.278	0	9.1516	6.819	Discharge	7.00E-04	1.00E-04	Ratio to Peak	0.0045
W1220	3.8134	85.625	0	0.1664	0.0731	Discharge	8.05E-03	1.00E-04	Ratio to Peak	0.0017
W1230	29.055	92.118	0	2.3697	6.2643	Discharge	1.80E-04	1.00E-04	Ratio to Peak	0.005
W1240	29.068	92.725	0	2.6435	6.378	Discharge	1.40E-03	1.00E-04	Ratio to Peak	0.0045
W1250	0.8474	77.342	0	0.1457	0.0742	Discharge	2.09E-03	1.00E-04	Ratio to Peak	0.0046
W1260	3.236	52.302	0	0.1735	0.05	Discharge	4.78E-04	1.00E-04	Ratio to Peak	0.0013
W640	15.5	52.138	0	1.1253	0.9746	Discharge	1.89E-03	1.00E-04	Ratio to Peak	0.0045
W650	15.5	94.05	0	1.3436	0.6459	Discharge	1.45E-03	1.00E-04	Ratio to Peak	0.0045
W660	15.5	76.618	0	0.8904	0.3344	Discharge	1.62E-03	1.00E-04	Ratio to Peak	0.0045
W670	15.5	92.996	0	0.4611	0.871	Discharge	1.59E-04	1.00E-04	Ratio to Peak	0.0045
W680	15.5	60.065	0	1.2009	0.6024	Discharge	1.64E-03	1.00E-04	Ratio to Peak	0.0045
W690	15.5	93.911	0	0.8305	0.7301	Discharge	1.63E-03	1.00E-04	Ratio to Peak	0.0045
W700	15.5	91.032	0	1.0065	1.055	Discharge	5.10E-04	1.00E-04	Ratio to Peak	0.0045
W710	15.5	94.05	0	1.4545	0.7899	Discharge	1.05E-03	1.00E-04	Ratio to Peak	0.0045
W720	15.5	91.897	0	1.6334	1.967	Discharge	3.67E-03	1.00E-04	Ratio to Peak	0.0045
W730	3.0023	90.284	0	2.3146	0.0167	Discharge	3.32E-03	1.00E-04	Ratio to Peak	0.0022
W740	15.5	94.05	0	1.2054	2.2213	Discharge	1.53E-03	1.00E-04	Ratio to Peak	0.0045
W750	0.7687	82.397	0	0.03	0.066	Discharge	3.01E-04	1.00E-04	Ratio to Peak	0.0056
W760	15.5	94.05	0	0.8059	0.05	Discharge	1.52E-03	1.00E-04	Ratio to Peak	0.0045
W770	500	94.05	0	1.179	0.3546	Discharge	3.79E-03	1.00E-04	Ratio to Peak	0.0044
W780	15.5	63.996	0	0.7482	0.929	Discharge	1.48E-03	1.00E-04	Ratio to Peak	0.0045
W790	0.3776	89.601	0	0.03	0.1149	Discharge	2.47E-03	1.00E-04	Ratio to Peak	0.0079
W800	0.9819	97.037	0	2.4042	0.4159	Discharge	1.18E-03	1.00E-04	Ratio to Peak	0.0083
W810	9.1843	98.276	0	0.7888	0.7305	Discharge	1.59E-03	1.00E-04	Ratio to Peak	0.01

Sub-basin	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W820	10.326	99	0	0.9897	0.0167	Discharge	2.98E-03	1.00E-04	Ratio to Peak	0.0037
W830	8.7235	99	0	0.7587	0.5988	Discharge	9.70E-04	1.00E-04	Ratio to Peak	0.0045
W840	19.249	85.206	0	0.03	0.9016	Discharge	2.64E-04	1.00E-04	Ratio to Peak	0.008
W850	17.159	74.3	0	0.6189	0.0167	Discharge	4.10E-03	1.00E-04	Ratio to Peak	0.004
W860	94.742	94.05	0	1.5242	1.4138	Discharge	6.27E-04	1.00E-04	Ratio to Peak	0.0045
W870	26.191	57.712	0	1.8571	1.1449	Discharge	1.64E-03	1.00E-04	Ratio to Peak	0.0068
W880	28.972	86.457	0	1.1135	0.6925	Discharge	9.01E-04	1.00E-04	Ratio to Peak	0.01
W890	17.505	59.185	0	1.9143	0.7775	Discharge	2.02E-03	1.00E-04	Ratio to Peak	0.0064
W900	17.684	89.839	0	1.3912	0.7434	Discharge	0.0025278	1.00E-04	Ratio to Peak	0.0042
W910	6.3134	44.523	0	2.1012	0.5263	Discharge	3.67E-03	1.00E-04	Ratio to Peak	0.0096
W920	24.257	65.835	0	0.5876	0.3405	Discharge	0.0031096	1.00E-04	Ratio to Peak	0.0063
W930	20.133	65.835	0	1.3684	1.663	Discharge	7.56E-04	1.00E-04	Ratio to Peak	0.005
W940	15.035	58.889	0	6.3148	1.913	Discharge	0.00044955	1.00E-04	Ratio to Peak	0.0045
W950	28.098	58.889	0	3.1993	21.286	Discharge	4.68E-04	1.00E-04	Ratio to Peak	0.0045
W960	34.087	56.841	0	0.4847	0.6656	Discharge	0.0014285	1.00E-04	Ratio to Peak	0.0066
W970	74.268	59.185	0	3.7364	7.5294	Discharge	4.04E-03	1.00E-04	Ratio to Peak	0.0045
W980	15.018	65.835	0	2.3362	0.0612	Discharge	0.0025869	1.00E-04	Ratio to Peak	0.0076
W990	29.315	57.712	0	0.0844	0.0766	Discharge	5.40E-07	1.00E-04	Ratio to Peak	0.0045

Annex 10. Yabaan Model Reach Parameters

Table A-10.1. Yabaan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	1315.3	0.00924	0.00185	Trapezoid	10	0.5
R130	Automatic Fixed Interval	1364.7	0.00534	0.01154	Trapezoid	10	0.5
R170	Automatic Fixed Interval	637.4	0.00058	0.00119	Trapezoid	10	0.5
R180	Automatic Fixed Interval	1363.1	0.00249	0.00907	Trapezoid	10	0.5
R190	Automatic Fixed Interval	555.56	0.00595	0.00326	Trapezoid	10	0.5
R200	Automatic Fixed Interval	844.56	0.00247	0.00729	Trapezoid	10	0.5
R210	Automatic Fixed Interval	84.853	0.02246	0.0008	Trapezoid	10	0.5
R240	Automatic Fixed Interval	424.56	0.01244	0.00143	Trapezoid	10	0.5
R260	Automatic Fixed Interval	837.99	0.00034	0.00277	Trapezoid	10	0.5
R270	Automatic Fixed Interval	844.26	0.01301	0.00141	Trapezoid	10	0.5
R280	Automatic Fixed Interval	605.56	0.00124	0.00126	Trapezoid	10	0.5
R310	Automatic Fixed Interval	492.84	0.02803	0.0099	Trapezoid	10	0.5
R340	Automatic Fixed Interval	1173.6	0.00402	0.00087	Trapezoid	10	0.5
R350	Automatic Fixed Interval	14.142	0.01211	0.00859	Trapezoid	10	0.5
R370	Automatic Fixed Interval	477.7	3.65E-02	0.00405	Trapezoid	10	0.5
R390	Automatic Fixed Interval	2116.2	0.0326	0.00438	Trapezoid	10	0.5
R40	Automatic Fixed Interval	878.41	0.0155	0.0006	Trapezoid	10	0.5
R420	Automatic Fixed Interval	971.42	0.00062	0.00274	Trapezoid	10	0.5
R440	Automatic Fixed Interval	2057.5	0.02712	0.00259	Trapezoid	10	0.5
R460	Automatic Fixed Interval	1838.9	0.01163	0.00151	Trapezoid	10	0.5

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R470	Automatic Fixed Interval	292.43	0.00667	0.00788	Trapezoid	10	0.5
R50	Automatic Fixed Interval	329.71	0.01391	0.0019	Trapezoid	10	0.5
R500	Automatic Fixed Interval	433.14	0.00023	0.00507	Trapezoid	10	0.5
R510	Automatic Fixed Interval	1060.4	0.00654	0.00183	Trapezoid	10	0.5
R540	Automatic Fixed Interval	1054.7	0.00297	0.00403	Trapezoid	10	0.5
R570	Automatic Fixed Interval	1968.5	0.00896	0.00123	Trapezoid	10	0.5
R580	Automatic Fixed Interval	663.55	0.00379	0.05178	Trapezoid	10	0.5
R590	Automatic Fixed Interval	310.71	0.00362	0.00596	Trapezoid	10	0.5
R610	Automatic Fixed Interval	750.12	0.00215	0.00306	Trapezoid	10	0.5
R630	Automatic Fixed Interval	364.71	0.016	0.00616	Trapezoid	10	0.5
R70	Automatic Fixed Interval	383.85	0.00052	0.00196	Trapezoid	10	0.5

Annex 11. Yabaan Field Validation Data

Table A-11.1. Yabaan Field Validation Data

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	13.198694	122.646315	0.95	0.1	-0.850	Sisang/November 23,1987	5 -Year
2	13.273997	122.675415	1.73	0.1	-1.630	Sisang/November 23,1987	5 -Year
3	13.199075	122.646514	0.91	0.2	-0.710	Sisang/November 23,1987	5 -Year
4	13.273786	122.676417	1.55	0.4	-1.150	Sisang/November 23,1987	5 -Year
5	13.274531	122.675843	1.83	0.4	-1.430	Sisang/November 23,1987	5 -Year
6	13.27447	122.676	0.82	0.5	-0.320	Sisang/November 23,1987	5 -Year
7	13.274105	122.676056	1.42	0.5	-0.920	Sisang/November 23,1987	5 -Year
8	13.27391	122.676121	1.41	0.5	-0.910	Sisang/November 23,1987	5 -Year
9	13.269206	122.677048	1.38	0	-1.380	Sisang/November 23,1987	5 -Year
10	13.26922	122.678296	0.15	0	-0.150	Sisang/November 23,1987	5 -Year
11	13.268428	122.678864	0.76	0	-0.760	Sisang/November 23,1987	5 -Year
12	13.267647	122.679385	1.45	0	-1.450	Sisang/November 23,1987	5 -Year
13	13.266643	122.679973	0.91	0	-0.910	Sisang/November 23,1987	5 -Year
14	13.265175	122.680636	0.06	0	-0.060	Sisang/November 23,1987	5 -Year
15	13.263387	122.680387	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
16	13.262518	122.68026	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
17	13.261424	122.679874	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
18	13.259641	122.679596	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
19	13.27385	122.676617	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
20	13.258933	122.679439	1.75	0	-1.750	Sisang/November 23,1987	5 -Year
21	13.258391	122.679307	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
22	13.258011	122.679216	0.03	0	-0.030	Sisang/November 23,1987	5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
23	13.274141	122.675596	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
24	13.2747	122.674653	1.23	0	-1.230	Sisang/November 23,1987	5 -Year
25	13.218805	122.67881	0.8	0	-0.800	Sisang/November 23,1987	5 -Year
26	13.218302	122.677299	1.45	0	-1.450	Sisang/November 23,1987	5 -Year
27	13.274415	122.673788	0.93	0	-0.930	Sisang/November 23,1987	5 -Year
28	13.216631	122.67526	0.59	0	-0.590	Sisang/November 23,1987	5 -Year
29	13.215126	122.672824	0.94	0	-0.940	Sisang/November 23,1987	5 -Year
30	13.214501	122.670812	0.92	0	-0.920	Sisang/November 23,1987	5 -Year
31	13.214871	122.671184	1.78	0	-1.780	Sisang/November 23,1987	5 -Year
32	13.214677	122.667753	1.46	0	-1.460	Sisang/November 23,1987	5 -Year
33	13.214698	122.665306	1.1	0	-1.100	Sisang/November 23,1987	5 -Year
34	13.212107	122.656462	0.43	0	-0.430	Sisang/November 23,1987	5 -Year
35	13.21127	122.656452	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
36	13.206967	122.656144	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
37	13.20217	122.655555	0.66	0	-0.660	Sisang/November 23,1987	5 -Year
38	13.202727	122.653164	1.15	0	-1.150	Sisang/November 23,1987	5 -Year
39	13.202414	122.648256	1	0	-1.000	Sisang/November 23,1987	5 -Year
40	13.200498	122.646219	1.5	0	-1.500	Sisang/November 23,1987	5 -Year
41	13.273017	122.672971	1.05	0	-1.050	Sisang/November 23,1987	5 -Year
42	13.199249	122.648309	0.12	0	-0.120	Sisang/November 23,1987	5 -Year
43	13.199299	122.647563	1.17	0	-1.170	Sisang/November 23,1987	5 -Year
44	13.199206	122.647365	1.35	0	-1.350	Sisang/November 23,1987	5 -Year
45	13.199062	122.647121	1.3	0	-1.300	Sisang/November 23,1987	5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
46	13.198678	122.647205	1.07	0	-1.070	Sisang/November 23,1987	5 -Year
47	13.198831	122.646568	1.13	0	-1.130	Sisang/November 23,1987	5 -Year
48	13.198802	122.646473	1.4	0	-1.400	Sisang/November 23,1987	5 -Year
49	13.198263	122.645977	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
50	13.274531	122.675618	0.03	0	-0.030	Sisang/November 23,1987	5 -Year
51	13.273741	122.676223	1.23	0	-1.230	Sisang/November 23,1987	5 -Year
52	13.274211	122.676035	1.54	1	-0.540	Sisang/November 23,1987	5 -Year
53	13.273881	122.676741	1.17	1	-0.170	Sisang/November 23,1987	5 -Year
54	13.274816	122.676721	1.38	2	0.620	Sisang/November 23,1987	5 -Year
55	13.274216	122.676812	2.54	3	0.460	Sisang/November 23,1987	5 -Year
56	13.274396	122.676752	2.68	3	0.320	Sisang/November 23,1987	5 -Year
57	13.212608	122.663505	2.98	3	0.020	Sisang/November 23,1987	5 -Year
58	13.211415	122.665347	1.97	3	1.030	Sisang/November 23,1987	5 -Year
59	13.272483	122.677466	4.1	3	-1.100	Sisang/November 23,1987	5 -Year
60	13.274004	122.676892	2.83	3	0.170	Sisang/November 23,1987	5 -Year
61	13.211429	122.665652	3.21	4	0.790	Sisang/November 23,1987	5 -Year
62	13.211635	122.66749	4.78	4	-0.780	Sisang/November 23,1987	5 -Year
63	13.198239	122.645727	4.16	4	-0.160	Sisang/November 23,1987	5 -Year
64	13.197996	122.646657	4.7	4	-0.700	Sisang/November 23,1987	5 -Year
65	13.197607	122.646886	4.93	4	-0.930	Sisang/November 23,1987	5 -Year
66	13.198793	122.64942	5.37	4	-1.370	Sisang/November 23,1987	5 -Year
67	13.272178	122.677311	4.96	4	-0.960	Sisang/November 23,1987	5 -Year
68	13.211367	122.664856	2.52	4	1.480	Sisang/November 23,1987	5 -Year

Table 43. Table A-11.3. Yabaan Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
69	13.275343	122.676559	7	5.1	-1.900	Sisang/November 23,1987	5 -Year
70	13.211371	122.665079	6.88	5.1	-1.780	Sisang/November 23,1987	5 -Year
71	13.211427	122.666057	7.01	5.1	-1.910	Sisang/November 23,1987	5 -Year
72	13.211467	122.666292	4.51	5.1	0.590	Sisang/November 23,1987	5 -Year
73	13.211505	122.666622	4.33	5.1	0.770	Sisang/November 23,1987	5 -Year
74	13.211504	122.666868	4.35	5.1	0.750	Sisang/November 23,1987	5 -Year
75	13.275298	122.676502	4.27	5.1	0.830	Sisang/November 23,1987	5 -Year
76	13.211607	122.667335	4.35	5.1	0.750	Sisang/November 23,1987	5 -Year
77	13.198123	122.645568	4.18	5.1	0.920	Sisang/November 23,1987	5 -Year
78	13.1978	122.64541	5.85	5.1	-0.750	Sisang/November 23,1987	5 -Year
79	13.197378	122.645312	5.99	5.1	-0.890	Sisang/November 23,1987	5 -Year
80	13.197257	122.645048	6.24	5.1	-1.140	Sisang/November 23,1987	5 -Year
81	13.197404	122.644654	5.93	5.1	-0.830	Sisang/November 23,1987	5 -Year
82	13.197497	122.6444	6.37	5.1	-1.270	Sisang/November 23,1987	5 -Year
83	13.197697	122.644498	7.68	5.1	-2.580	Sisang/November 23,1987	5 -Year
84	13.197733	122.647151	7.07	5.1	-1.970	Sisang/November 23,1987	5 -Year
85	13.273585	122.676984	5.5	5.1	-0.400	Sisang/November 23,1987	5 -Year
86	13.198089	122.647946	2.93	5.1	2.170	Sisang/November 23,1987	5 -Year
87	13.198224	122.648263	5.21	5.1	-0.110	Sisang/November 23,1987	5 -Year
88	13.198442	122.648718	5.39	5.1	-0.290	Sisang/November 23,1987	5 -Year
89	13.198554	122.648936	5.17	5.1	-0.070	Sisang/November 23,1987	5 -Year
90	13.198711	122.649254	5.06	5.1	0.040	Sisang/November 23,1987	5 -Year
91	13.198944	122.649717	5.1	5.1	0.000	Sisang/November 23,1987	5 -Year

Table 44. Table A-11.4

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
92	13.198993	122.649921	4.77	5.1	0.330	Sisang/November 23,1987	5 -Year
93	13.199209	122.650378	4.78	5.1	0.320	Sisang/November 23,1987	5 -Year
94	13.199443	122.65098	4.73	5.1	0.370	Sisang/November 23,1987	5 -Year
95	13.199695	122.651579	4.76	5.1	0.340	Sisang/November 23,1987	5 -Year
96	13.273	122.677231	4.52	5.1	0.580	Sisang/November 23,1987	5 -Year
97	13.199885	122.65206	3.61	5.1	1.490	Sisang/November 23,1987	5 -Year
98	13.200076	122.652428	4.97	5.1	0.130	Sisang/November 23,1987	5 -Year
99	13.200207	122.652827	4.01	5.1	1.090	Sisang/November 23,1987	5 -Year
100	13.199913	122.652	4.32	5.1	0.780	Sisang/November 23,1987	5 -Year
101	13.272744	122.67739	4.99	5.1	0.110	Sisang/November 23,1987	5 -Year
102	13.272238	122.677428	3.6	5.1	1.500	Sisang/November 23,1987	5 -Year
103	13.272176	122.677244	2.82	5.1	2.280	Sisang/November 23,1987	5 -Year
104	13.275238	122.676701	2.55	5.1	2.550	Sisang/November 23,1987	5 -Year
105	13.273322	122.674429	0.07	0.2	0.130	Sisang/November 23,1987	5 -Year
106	13.270327	122.67644	0.06	0.5	0.440	Sisang/November 23,1987	5 -Year
107	13.270758	122.676738	0.58	0.5	-0.080	Sisang/November 23,1987	5 -Year
108	13.27162	122.673266	0.74	0.5	-0.240	Sisang/November 23,1987	5 -Year
109	13.270607	122.671501	0.06	0.5	0.440	Sisang/November 23,1987	5 -Year
110	13.269071	122.678541	0.53	0.5	-0.030	Sisang/November 23,1987	5 -Year
111	13.270913	122.673686	0.89	0.5	-0.390	Sisang/November 23,1987	5 -Year
112	13.268942	122.675383	0.2	1	0.800	Sisang/November 23,1987	5 -Year
113	13.269237	122.677183	0.03	1	0.970	Sisang/November 23,1987	5 -Year
114	13.269289	122.677616	0.13	1	0.870	Sisang/November 23,1987	5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
115	13.272881	122.676814	0.25	1	0.750	Sisang/November 23,1987	5 -Year
116	13.273393	122.676075	1.71	1	-0.710	Sisang/November 23,1987	5 -Year
117	13.27329	122.675348	1.21	1	-0.210	Sisang/November 23,1987	5 -Year
118	13.273249	122.675163	0.94	1	0.060	Sisang/November 23,1987	5 -Year
119	13.270103	122.671868	0.57	1	0.430	Sisang/November 23,1987	5 -Year
120	13.270545	122.671774	0.59	1	0.410	Sisang/November 23,1987	5 -Year
121	13.27059	122.671203	0.22	1	0.780	Sisang/November 23,1987	5 -Year
122	13.270156	122.672587	0.68	1	0.320	Sisang/November 23,1987	5 -Year
123	13.270559	122.674719	1.33	1	-0.330	Sisang/November 23,1987	5 -Year
124	13.271943	122.676905	2.15	2.5	0.350	Sisang/November 23,1987	5 -Year
125	13.269857	122.671733	3.83	2.5	-1.330	Sisang/November 23,1987	5 -Year
126	13.266929	122.679823	2.57	2.5	-0.070	Sisang/November 23,1987	5 -Year
127	13.27045	122.674867	0.03	2.5	2.470	Sisang/November 23,1987	5 -Year
128	13.270176	122.675838	0.2	2	1.800	Sisang/November 23,1987	5 -Year
129	13.270082	122.67481	1.36	2	0.640	Sisang/November 23,1987	5 -Year
130	13.269924	122.67526	0.06	2	1.940	Sisang/November 23,1987	5 -Year
131	13.269789	122.675813	1.16	2	0.840	Sisang/November 23,1987	5 -Year
132	13.269834	122.676318	1.23	2	0.770	Sisang/November 23,1987	5 -Year
133	13.271267	122.676704	0.91	2	1.090	Sisang/November 23,1987	5 -Year
134	13.270224	122.672157	1.4	2	0.600	Sisang/November 23,1987	5 -Year
135	13.265982	122.680522	1.35	2	0.650	Sisang/November 23,1987	5 -Year
136	13.270459	122.67536	0.2	2	1.800	Sisang/November 23,1987	5 -Year
137	13.270372	122.671165	1.21	3	1.790	Sisang/November 23,1987	5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
138	13.267847	122.679315	1.51	3	1.490	Sisang/November 23,1987	5 -Year
139	13.269822	122.675507	1.03	3	1.970	Sisang/November 23,1987	5 -Year
140	13.217469	122.667968	1.54	0.5	-1.040	Sisang/November 23,1987	5 -Year
141	13.214629	122.668892	2.27	0.5	-1.770	Sisang/November 23,1987	5 -Year
142	13.220458	122.665838	1.53	2.5	0.970	Sisang/November 23,1987	5 -Year
143	13.221382	122.669977	1.73	2.5	0.770	Sisang/November 23,1987	5 -Year
144	13.221948	122.67017	1.04	2.5	1.460	Sisang/November 23,1987	5 -Year
145	13.222267	122.670241	0.5	2.5	2.000	Sisang/November 23,1987	5 -Year
146	13.222919	122.6703	0.93	2.5	1.570	Sisang/November 23,1987	5 -Year
147	13.223773	122.670019	0.59	2.5	1.910	Sisang/November 23,1987	5 -Year
148	13.223269	122.670401	0.27	2.5	2.230	Sisang/November 23,1987	5 -Year
149	13.22467	122.668474	0.84	2.5	1.660	Sisang/November 23,1987	5 -Year
150	13.225176	122.667705	1.03	2.5	1.470	Sisang/November 23,1987	5 -Year
151	13.218274	122.667899	0.68	2.5	1.820	Sisang/November 23,1987	5 -Year
152	13.226156	122.666538	1.94	2.5	0.560	Sisang/November 23,1987	5 -Year
153	13.223334	122.667782	0.35	2.5	2.150	Sisang/November 23,1987	5 -Year
154	13.22179	122.667914	1.25	2.5	1.250	Sisang/November 23,1987	5 -Year
155	13.218983	122.667833	1.72	2.5	0.780	Sisang/November 23,1987	5 -Year
156	13.219696	122.667871	2.05	2.5	0.450	Sisang/November 23,1987	5 -Year
157	13.220471	122.66789	1.99	2.5	0.510	Sisang/November 23,1987	5 -Year
158	13.221387	122.6679	1.85	2.5	0.650	Sisang/November 23,1987	5 -Year
159	13.222461	122.667916	1.74	2.5	0.760	Sisang/November 23,1987	5 -Year
160	13.222479	122.666993	1.62	2.5	0.880	Sisang/November 23,1987	5 -Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
161	13.222484	122.665949	1.5	2.5	1.000	Sisang/November 23,1987	5 -Year
162	13.216637	122.668123	1.35	2.5	1.150	Sisang/November 23,1987	5 -Year
163	13.215997	122.668463	2	2	0.000	Sisang/November 23,1987	5 -Year
164	13.215332	122.668619	2.16	2	-0.160	Sisang/November 23,1987	5 -Year
165	13.215331	122.669471	1.77	3	1.230	Sisang/November 23,1987	5 -Year
166	13.216133	122.669708	1.82	3	1.180	Sisang/November 23,1987	5 -Year
167	13.217478	122.669493	1.68	3	1.320	Sisang/November 23,1987	5 -Year
168	13.218084	122.66952	2.03	3	0.970	Sisang/November 23,1987	5 -Year
169	13.219085	122.669567	1.87	3	1.130	Sisang/November 23,1987	5 -Year
170	13.219782	122.66978	0.82	3	2.180	Sisang/November 23,1987	5 -Year
171	13.220585	122.669706	0.74	3	2.260	Sisang/November 23,1987	5 -Year
172	13.219564	122.665901	0.86	3	2.140	Sisang/November 23,1987	5 -Year
173	13.218728	122.665973	2.01	3	0.990	Sisang/November 23,1987	5 -Year
174	13.218142	122.666061	2.01	3	0.990	Sisang/November 23,1987	5 -Year
175	13.217571	122.666143	1.59	3	1.410	Sisang/November 23,1987	5 -Year
176	13.216845	122.666461	1.84	3	1.160	Sisang/November 23,1987	5 -Year
177	13.216163	122.666783	1.93	3	1.070	Sisang/November 23,1987	5 -Year
178	13.215353	122.666941	1.48	3	1.520	Sisang/November 23,1987	5 -Year
179	13.214515	122.668995	1.83	3	1.170	Sisang/November 23,1987	5 -Year
180	13.221407	122.665765	1.24	3	1.760	Sisang/November 23,1987	5 -Year

RMSE: 1.121563

Annex 12. Educational Institutions Affected in Yabaan Floodplain

Table A-12.1. Educational Institutions Affected in Yabaan Floodplain

QUEZON				
SAN ANDRES				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
TALISAY NATIONAL HIGH SCHOOL	Talisay	High	High	High
CUMBAHAN ELEM SCHOOL	Pagsangahan	None	None	None

Annex 13. Health Institutions Affected by Flooding in Yabaan Floodplain

There are no medical or health institutions assessed to be exposed to flooding in the Yabaan floodplain.