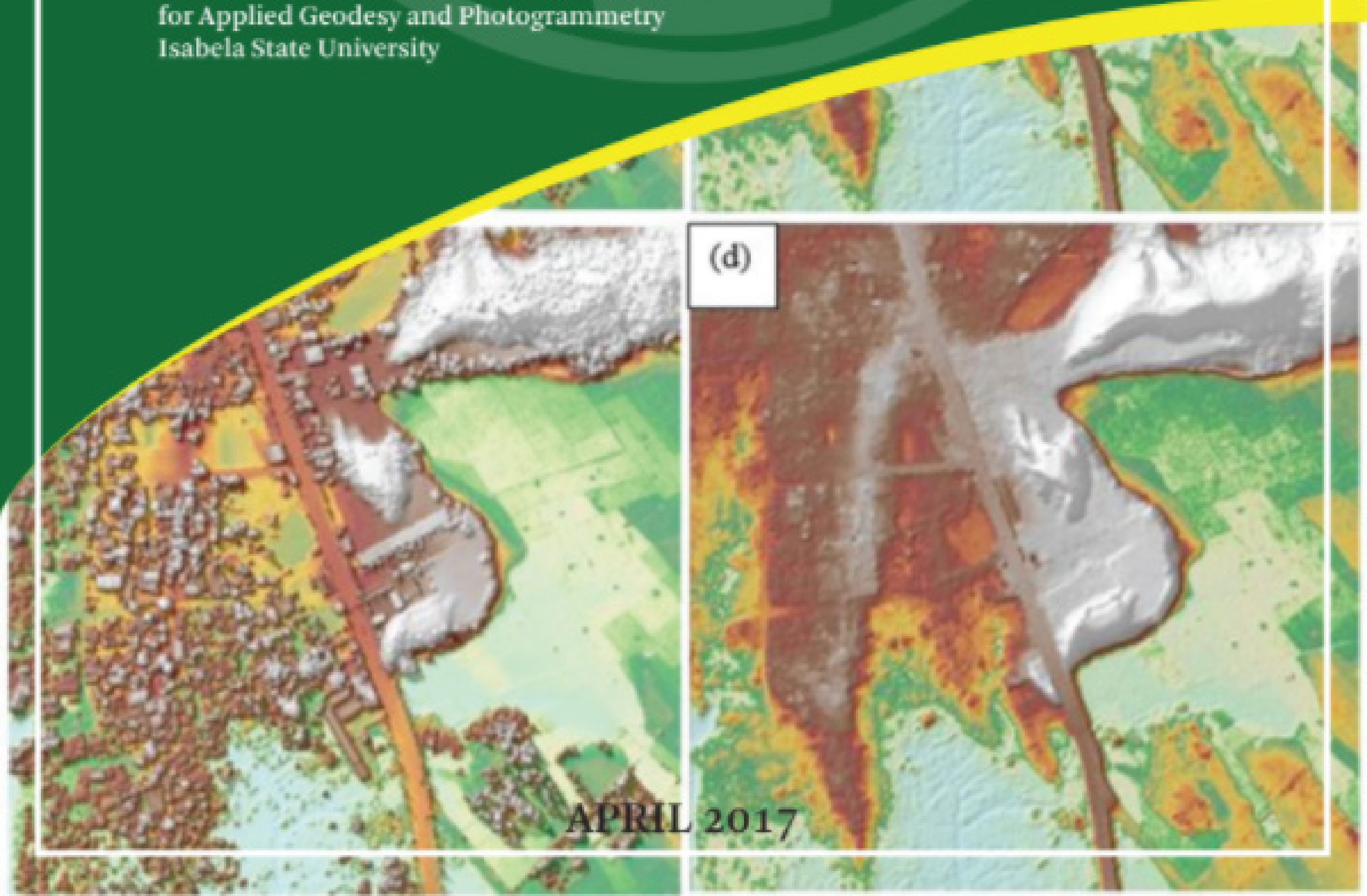
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Tangatan River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Isabela State University



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AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
ISU	Isabela State University
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PSA	Philippine Statistics Authority
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 TANGATAN RIVER

Enrico C. Paringit, Dr. Eng.,and Dr. Januel P. Floresca

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Isabela State University (ISU). The ISU was 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 ten (10) river basins in the Cagayan Valley Region. The university is located at Ilagan City in the Province of Isabela.

1.2 Overview of the Tangatan River Basin

The Tangatan River Basin (Figure 1) is a stream located in the Municipality of Santa Ana, a second-class municipality in the Province of Cagayan, Cagayan Valley, Philippines. It has an estimated terrain elevation above sea level of two (2) meters. According to the 2015 census, it has a population of 32,906 people with a density of seventy five (75) inhabitants per square kilometer or 190 inhabitants per square mile. It is situated in the Northern-Eastern most point of Luzon and includes Palaui Island. It is the home of the Cagayan Special Economic Zone and the Naval Base Camilo Osias (Naval Operating Base San Vicente).

The Municipality of Santa Ana is politically subdivided into sixteen (16) barangays: Casagan, Casambalangan, Centro (Poblacion), Diora-Zinungan, Dungeg, Kapanikian, Marede, Palawig, Parada-Batu, Patunungan, Rapuli, San Vicente, Santa Clara, Santa Cruz, Visitacion, and Tangatan. The Municipality of Santa Ana is a mix of agricultural, commercial and agricultural economy. Most of the commercial and industrial activities are done at Port Irene since the Cagayan Special Economic Zone in Casambalangan.

The main stem of the Tangatan River Basin, the Tangatan River, is among the ten (10) river systems in Cagayan Valley. According to the 2015 national census of the Philippine Statistics Authority (PSA), a total of 5,649 persons are residing within the immediate vicinity of the river, which is distributed among barangays Dungeg, Marede, Casagan, Sta. Cruz, and Tangatan in the Municipality of Sta. Ana. The economy of Cagayan Province largely rests on agriculture with rice, corn, and banana as the main crops and products (Philippine Statistics Authority, 2017).

Some of its agricultural and aquatic products are rice, corn, peanut, fish, lumber, shells, etc. Among its natural resources are limestone deposits at Bawac Mountain, coal at Carbon Mountain, Santa Clara and guano deposit in the Kapanikian Cave. Sta. Ana is 158 kilometers from Tuguegarao City. Due to its economic potentials particularly in tourism, travel businessmen who develop the island into a luxurious tourist destination continue to grow in number.

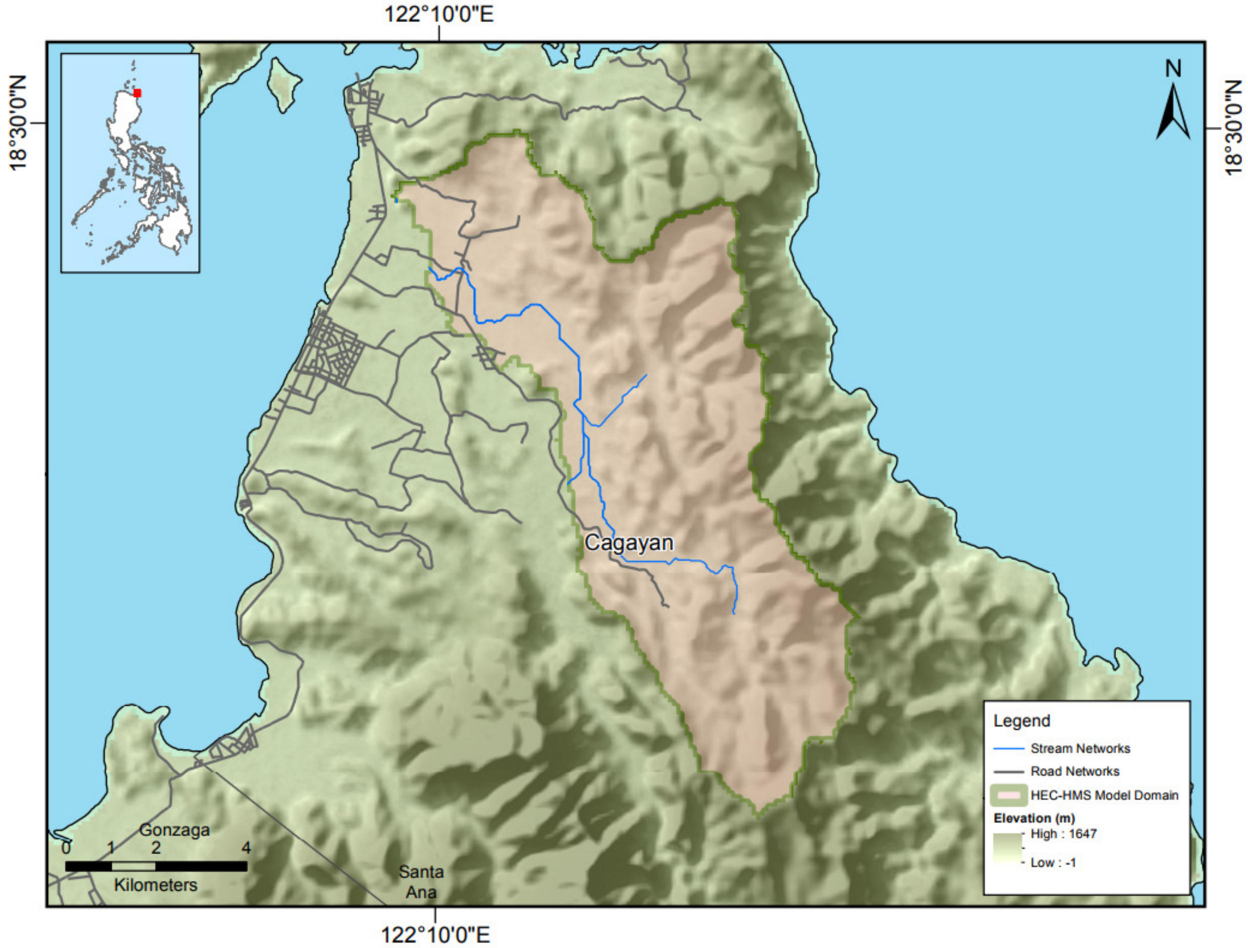

Figure 1. Map of Tangatan River Basin (in brown)

The Tangatan River Basin covers the Municipality of Sta. Ana in Cagayan. The Flood Modelling Component (FMC) of the PHIL-LiDAR 1 Program has computed that the Tangatan River Basin has a drainage area of 67 km².

On October 20, 2016, the Municipality of Sta. Ana was devastated by the Storm Typhoon Lawin with the Storm Signal Number 5. The Mahar Lagmay of Project Noah (Nationwide Operational Assessment of Hazards) urged residents of coastal areas to seek higher ground as the weather bureau expected 2- to 5-meter storm surges, particularly in the towns of Santa Ana, Bugue, Gonzaga and Aparri in the Northern part of Cagayan. Last November 17, 2016, Quibal-Nanguillatan-Baggao provincial road in Cagayan and Abusag Bridge in Baggao Town were not passable due to floods due to heavy rains brought on by the tail-end of a cold front (Visaya, 2016).

According to the disaster risk management agency, with the Lawin's cloud band of 800 kilometers, more than 10 million people across the Northern parts of Luzon were affected. Nevertheless, the areas directly in the typhoon's path were not densely populated and were well-drilled in storm preparations.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE TANGATAN 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 Tangatan Floodplain in Antique . Each flight mission has an average of twelve (12) lines which 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 1 shows the flight plans and base stations for Tangatan Floodplain.

Table 1. Parameters used in Gemini LiDAR System during Flight Acquisition

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
CAG2M	800	30	50	100	50	120	5
CAG2Q	1000	30	40	100	50	120	5
CAG2R	1000	30	40	100	50	120	5

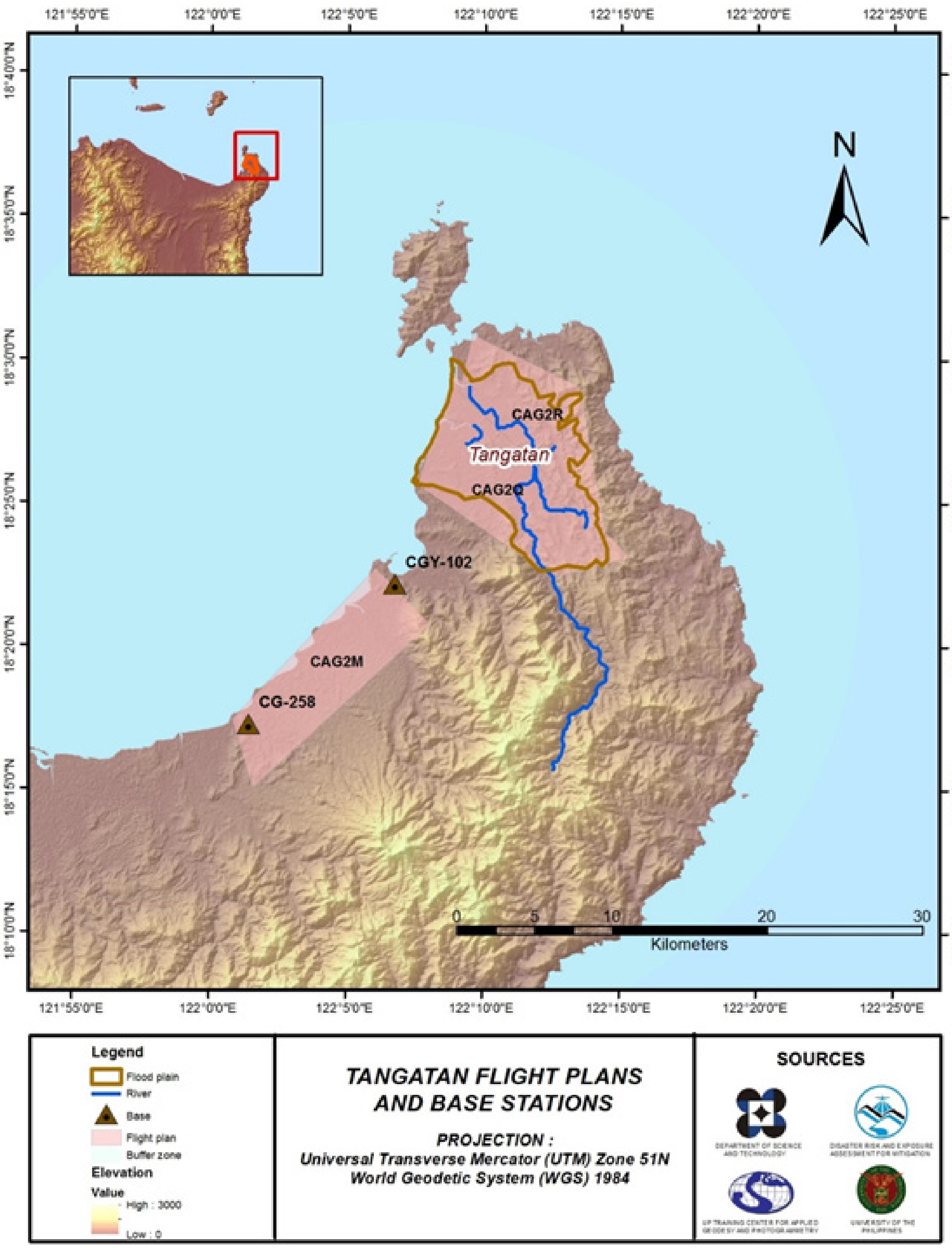

Figure 2. Flight plans and base stations for Tangatan Floodplain

2.2 Ground Base Stations

The Project Team was able to recover One (1) NAMRIA reference point: CGY-102 with second (2nd) order of accuracy. One benchmark reference point: CG-258 with second (2nd) order of accuracy. The certification for the base station is found in Annex 2. These were used as base stations during flight operations for the entire duration of the survey (April 25 to May 9, 2016). Base stations were observed using Dual Frequency GPS Receivers, TRIMBLE SPS 852 and TRIMBLE SPS 985. Flight plans and location of base stations used during the aerial LiDAR Acquisition in Tangatan Floodplain are shown in Figure 2.

Figure 3 to Figure 4 shows the recovered NAMRIA control station within the area. In addition, Tables 2 to 3 show the details about the following NAMRIA control stations and established points, Table 4 shows the list of all ground control points occupied during the acquisition together with the dates they are utilized during the survey.

Figure 3. GPS set-up over CGY-102 located about 2 meters from the south corner of the triangular island at the intersection of the national highway and the road to Port Irene at Santa Ana, Cagayan (a) NAMRIA reference point CGY-102 (b) as recovered by field team

Table 2. Details of the recovered NAMRIA horizontal control point CGY-102 used as base station for the LiDAR Acquisition

Station Name	CGY-102	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference 0f 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	18° 22' 15.98573" 122° 6' 41.74346" 22.608 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	617476.569 m 2032192.366 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	18° 22' 9.81367" 122° 6' 46.31361" 57.195 m
Grid Coordinates, Philippine Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	406145.45 m 2031351.34 m

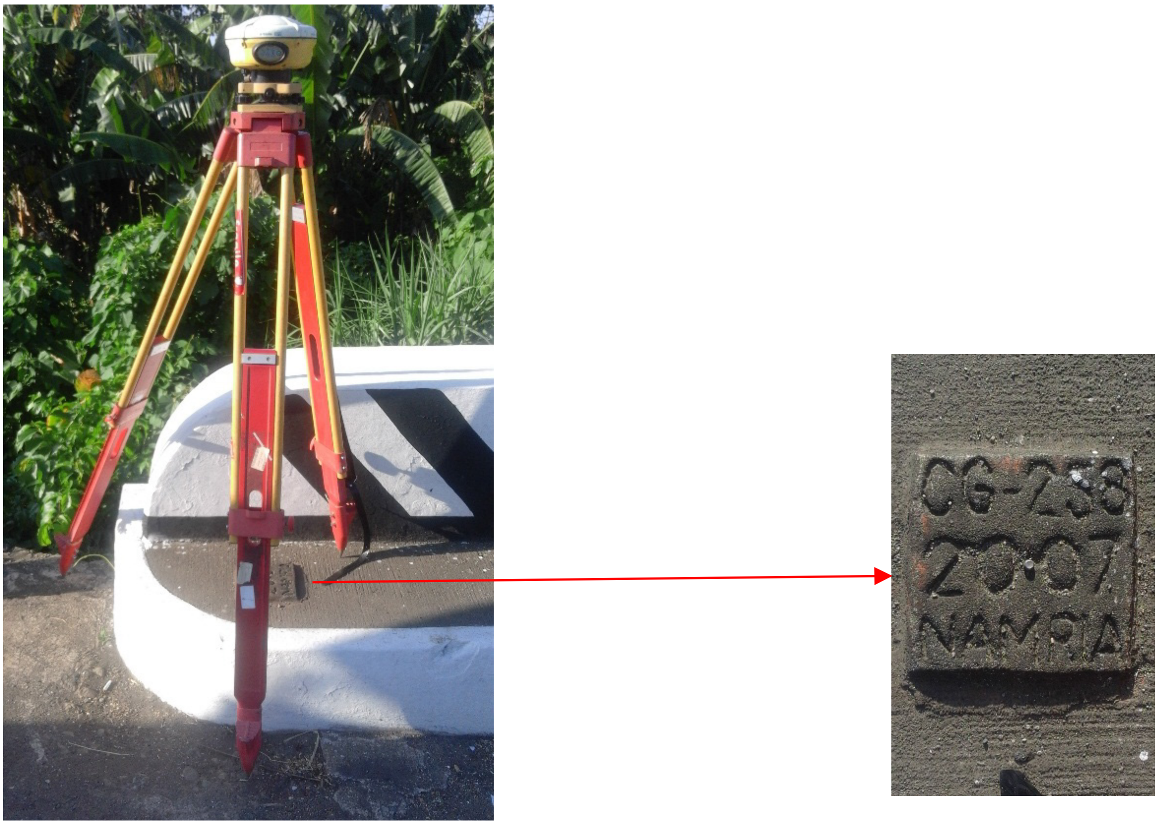

Figure 4. GPS set-up over CG-258, on a bridge near CGY-102 (a) NAMRIA reference point CG-258 (b) as recovered by field team

Table 3. Details of the recovered NAMRIA horizontal control point CG-258 used as base station for the LiDAR Acquisition.

Station Name	CG-258	
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° 11' 56.27238" North 123° 27' 47.60156" East 127.309000 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	550210.89 meters 1459605.458 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 11' 51.38974" North 123° 27' 52.59990" East 180.74900 meters

Table 4. Details of the recovered NAMRIA horizontal control point LY-199 used as base station for the LiDAR Acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
27-Aug-16	3971G	2CAG2DGH118A	CG-258 and CGY-102
3-May-16	3989G	2BLK3CAG2QSR124A	CG-258 and CGY-102
3-May-16	3991G	2BLK3CAG2MSQS124B	CG-258 and CGY-102
6-May-16	4001G	2BLK3CAG2MRS127A	CG-258 and CGY-102

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR Data Acquisition in Tangatan Floodplain, for a total of fourteen hours and fifty-eight minutes (14+58) of flying time for RP-C9122. All missions were acquired using the Gemini LiDAR System. Table 5 shows the total area of actual coverage per mission and the flying length for each mission and Table 12 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for LiDAR data acquisition in Tangatan 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
27-Aug-16	3971G	191.44	162.97	58.09	104.88	0	4	35
3-May-16	3989G	124.92	91.29	41.61	49.68	0	3	57
3-May-16	3991G	191.44	60.21	13.29	46.92	0	2	26
6-May-16	4001G	117.13	127.08	0	127.08	0	4	0
TOTAL		**191.44**	**441.55**	**112.99**	**328.56**	**0**	**14**	**58**

Table 6. Actual Parameters used during LiDAR Data Acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
2593P	850	30	40	100	50	120	5
2602G	1000	30	40	100	50	125	5
2606G	800	30	40	100	50	110	5
2610G	1000	30	40	100	50	110	5

2.4 Survey Coverage

The Tangatan Floodplain is located in the Provinces of Cagayan with majority of the floodplain situated within the Municipality of Santa Ana. 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 Tangatan Floodplain is presented in Figure 5.

Table 7. List of Municipalities and cities surveyed during Tangatan Floodplain LiDAR survey.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Cagayan	Santa Ana	437.13	223.41	51%
	Gonzaga	497.62	74.67	15%
Total		**934.75**	**298.08**	**31.89%**

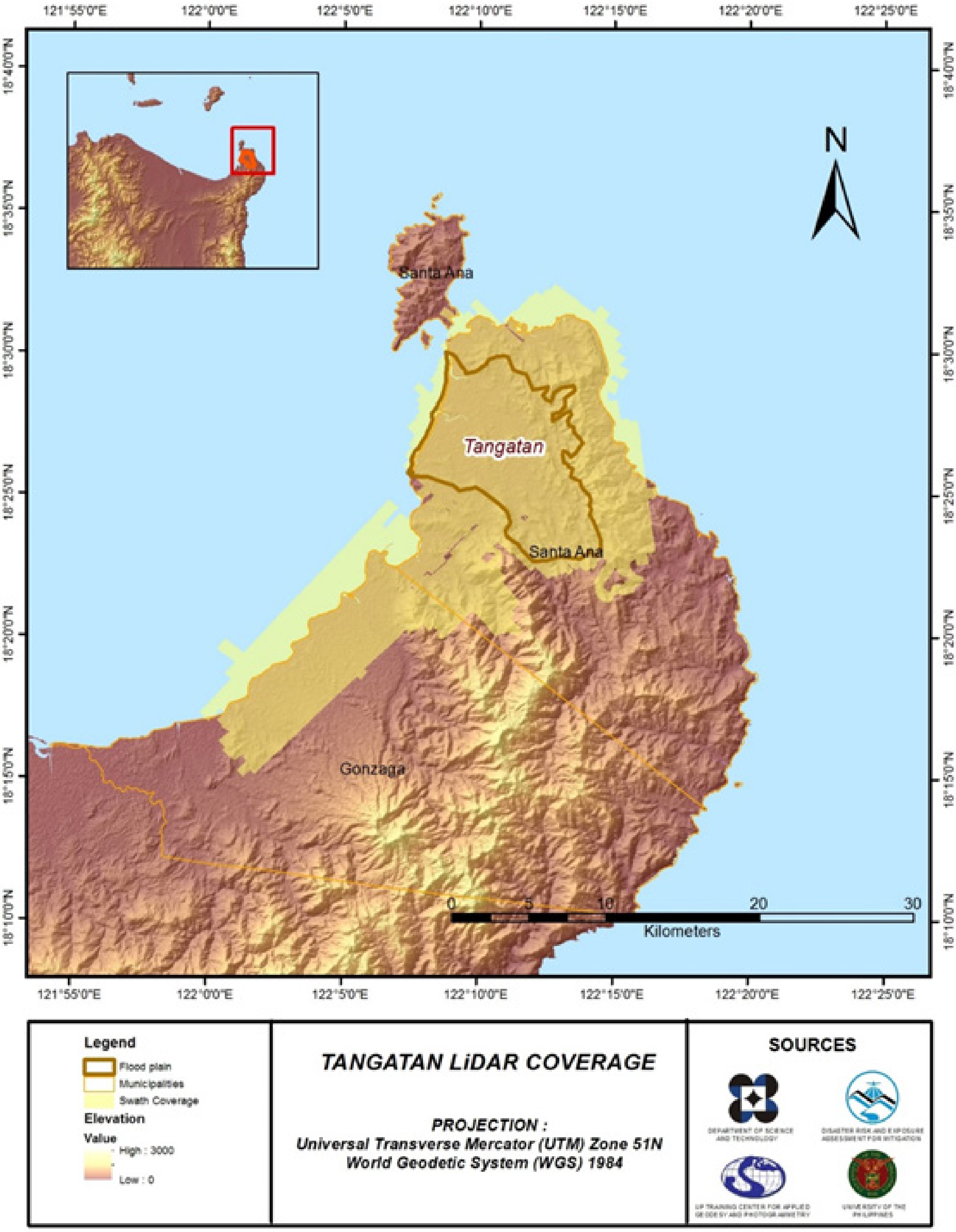

Figure 5. Actual LiDAR survey coverage for Tangatan Floodplain

CHAPTER 3: LIDAR DATA PROCESSING OF THE TANGATAN FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

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

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

These processes are summarized in the flowchart shown in Figure 6.

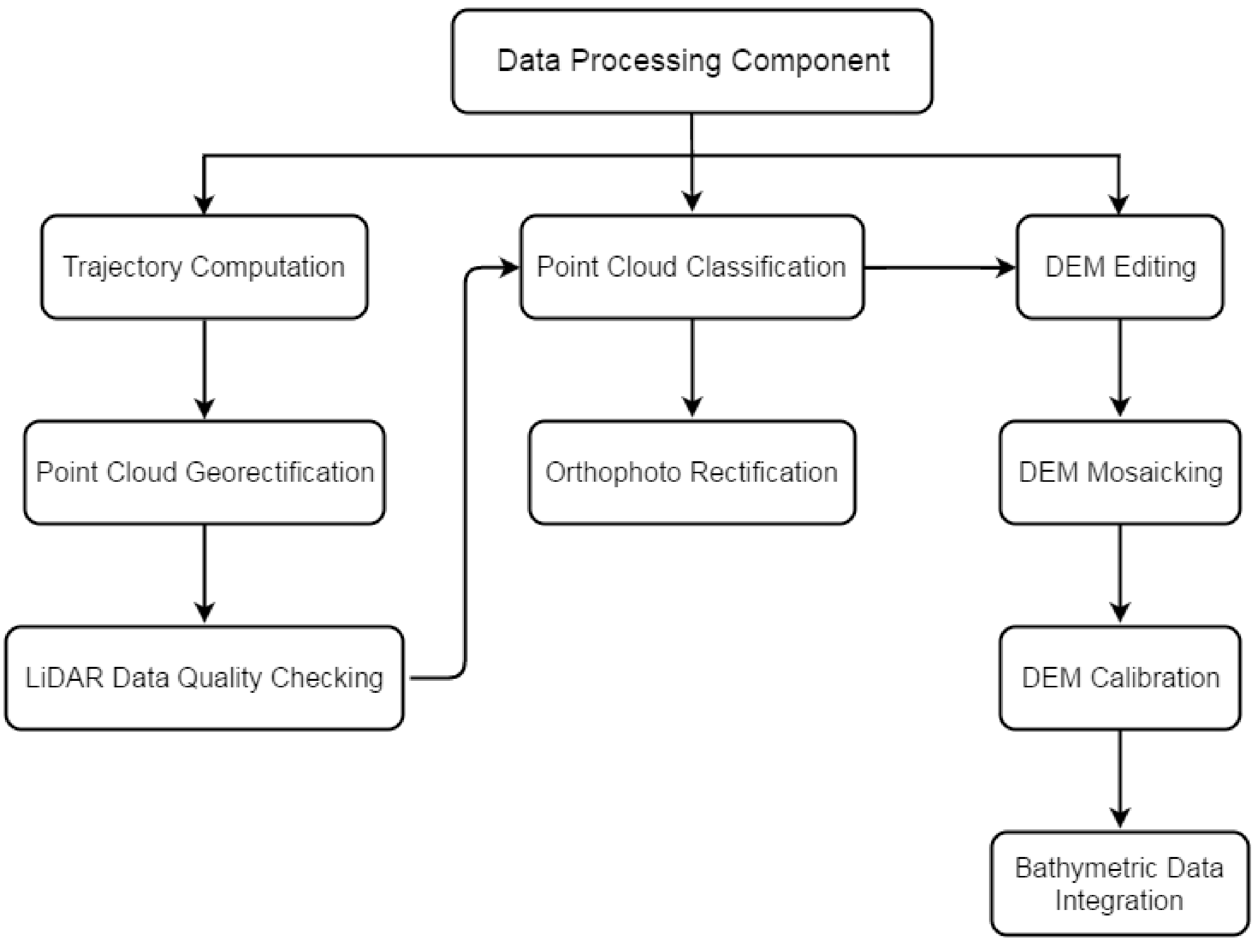


Figure 6. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

The Data transfer sheets for all the LiDAR missions for Tangatan Floodplain can be found in Annex 5. Missions flown during the survey conducted on April 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini System in Sta. Ana, Cagayan. The Data Acquisition Component (DAC) transferred a total of 62.85 Gigabytes of Range data, 0.89 Gigabytes of POS data, 48.33 Megabytes of GPS base station data, and 0 Gigabytes of raw image data to the data server on June 21, 2016. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tangatan was fully transferred on June 21, 2016, as indicated on the Data Transfer Sheets for Tangatan Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 3971G, one of the Tangatan 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 April 28, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

Figure 7. Smoothed Performance Metrics of Tangatan Flight 3971G

The time of flight was from 356,500 seconds to 363,500 seconds, which corresponds to morning of April 28, 2016. The initial spike seen in the data corresponds to the time when the aircraft was getting into position to start the acquisition, and when the POS system started 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 1.25 centimeters, the East position RMSE peaks at 1.15 centimeters, and the Down position RMSE peaks at 5.00 centimeters, which are within the prescribed accuracies described in the methodology.

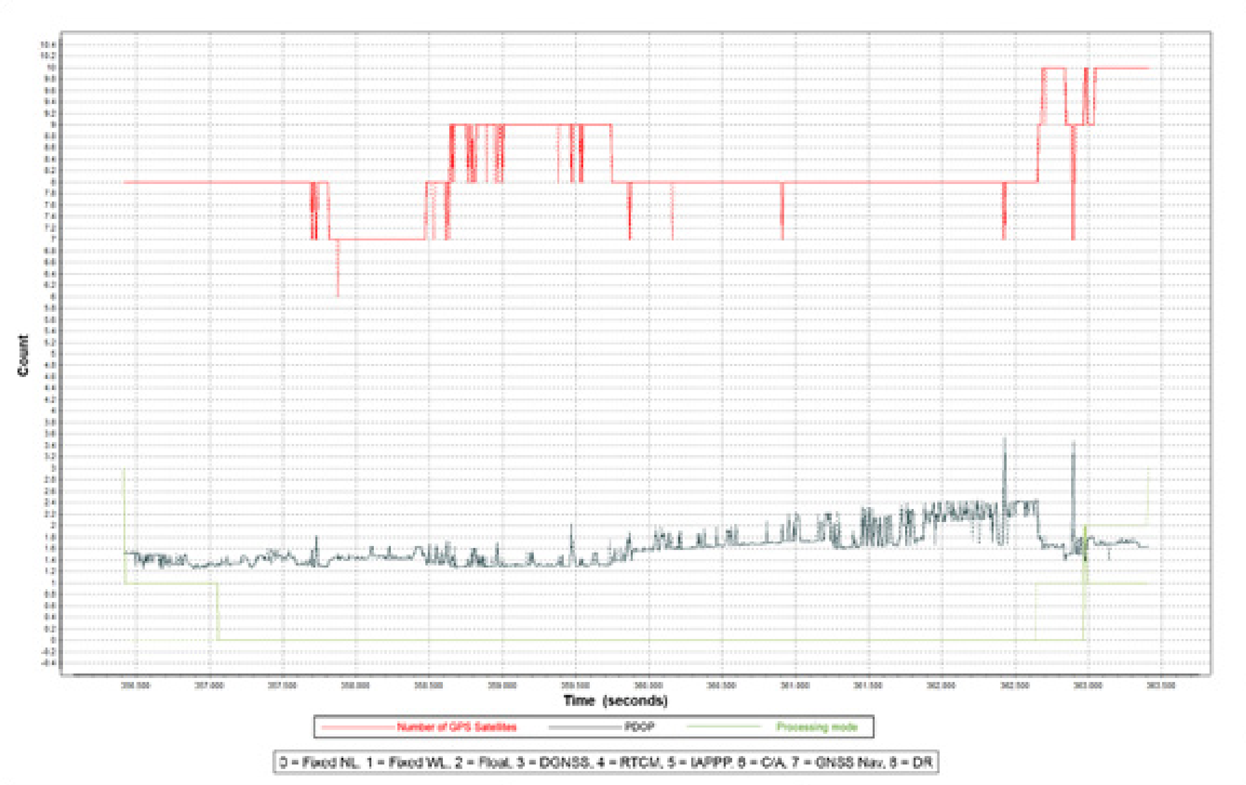


Figure 8. Solution Status Parameters of Tangatan Flight 3971G

The Solution Status parameters of flight 3971G, one of the Tangatan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go below 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3.6, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey. 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 Tangatan flights is shown in Figure 9.

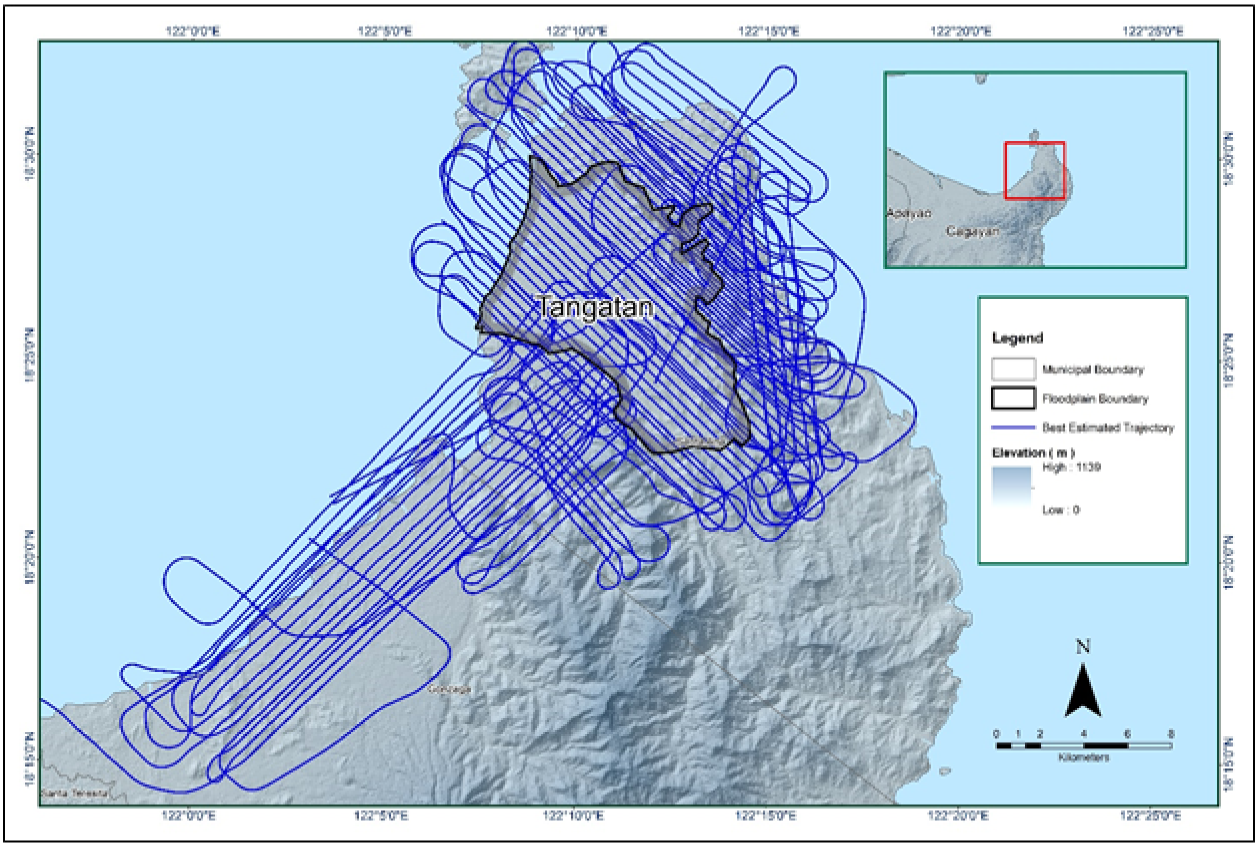


Figure 9. Best Estimated Trajectory for Tangatan Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contain 71 flight lines, with each flight line containing one channel, since the Gemini System contains only one channel. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tangatan Floodplain are given in Table 8.

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

Parameter	Acceptable Value	Value
Boresight Correction stdev)	<0.001degrees	0.000876
IMU Attitude Correction Roll and Pitch Correction stdev)	<0.001degrees	0.000809
GPS Position Z-correction stdev)	<0.01meters	0.0024

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Tangatan Floodplain is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

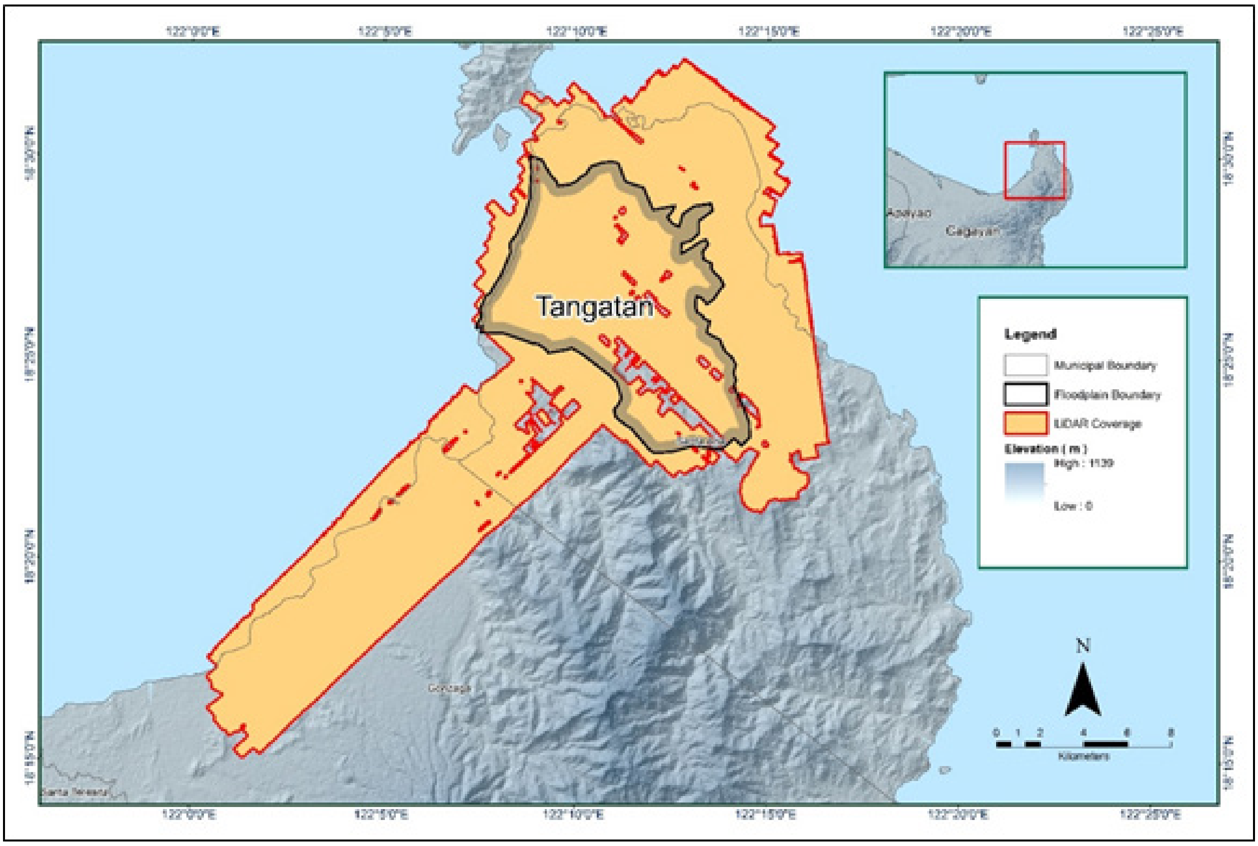


Figure 10. Boundary of the processed LiDAR data over Tangatan Floodplain

The total area covered by the Tangatan missions is 319.39 sq.km that is comprised of four (4) flight acquisitions grouped and merged into four (4) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Tangatan Floodplain

LiDAR Blocks	Flight Numbers	Area (sq. km)
Cagayan_reflights_Blk3D	4001G	25.86
Cagayan_reflights_Blk3E	4001G	31.41
Cagayan_reflights_Blk3A	3971G	107.76
	3991G	
	4001G	
Cagayan_reflights_Blk3C	3971G	154.36
	3989G	
	3991G	
TOTAL		**319.39 sq. km.**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 11. Since the Gemini System employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

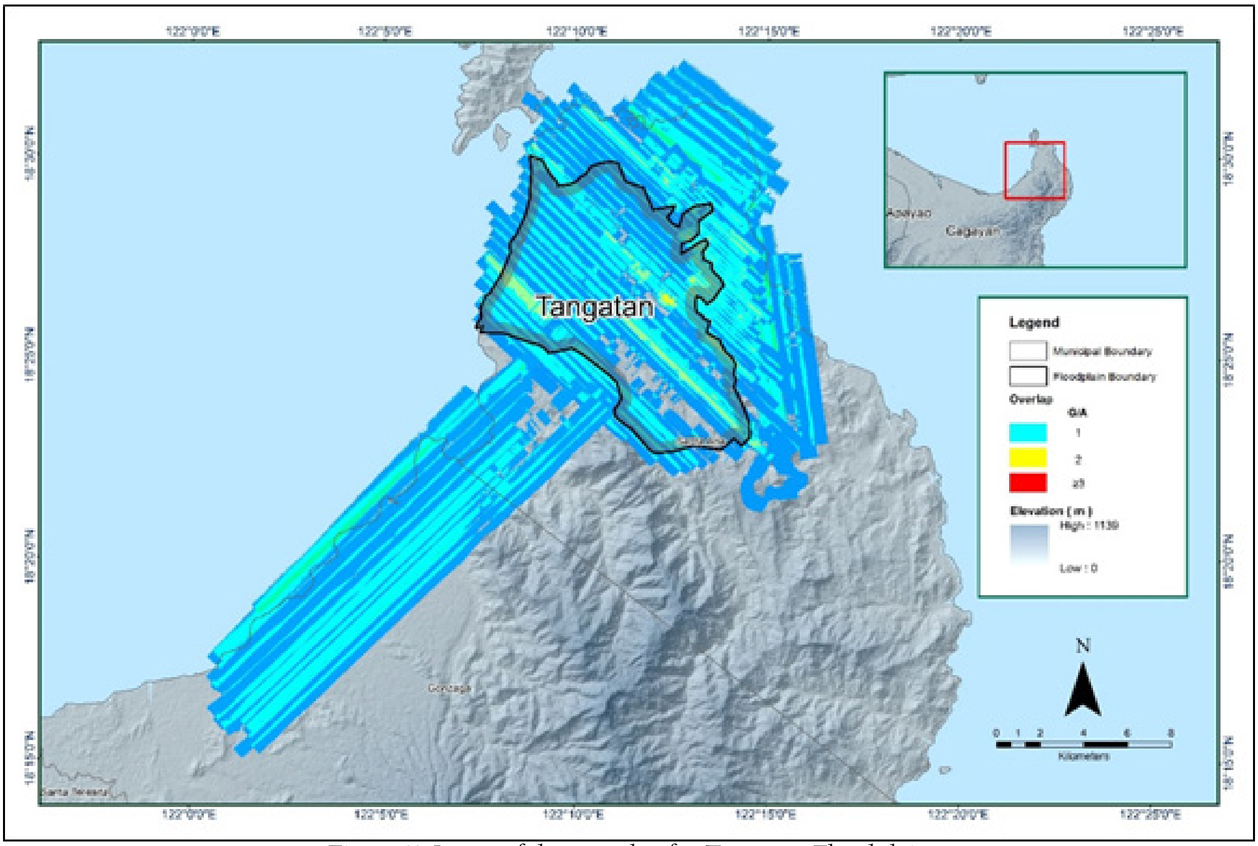


Figure 11. Image of data overlap for Tangatan Floodplain

The overlap statistics per block for the Tangatan 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 39.43% and 44.96% 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 Tangatan Floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.17 points per square meter.

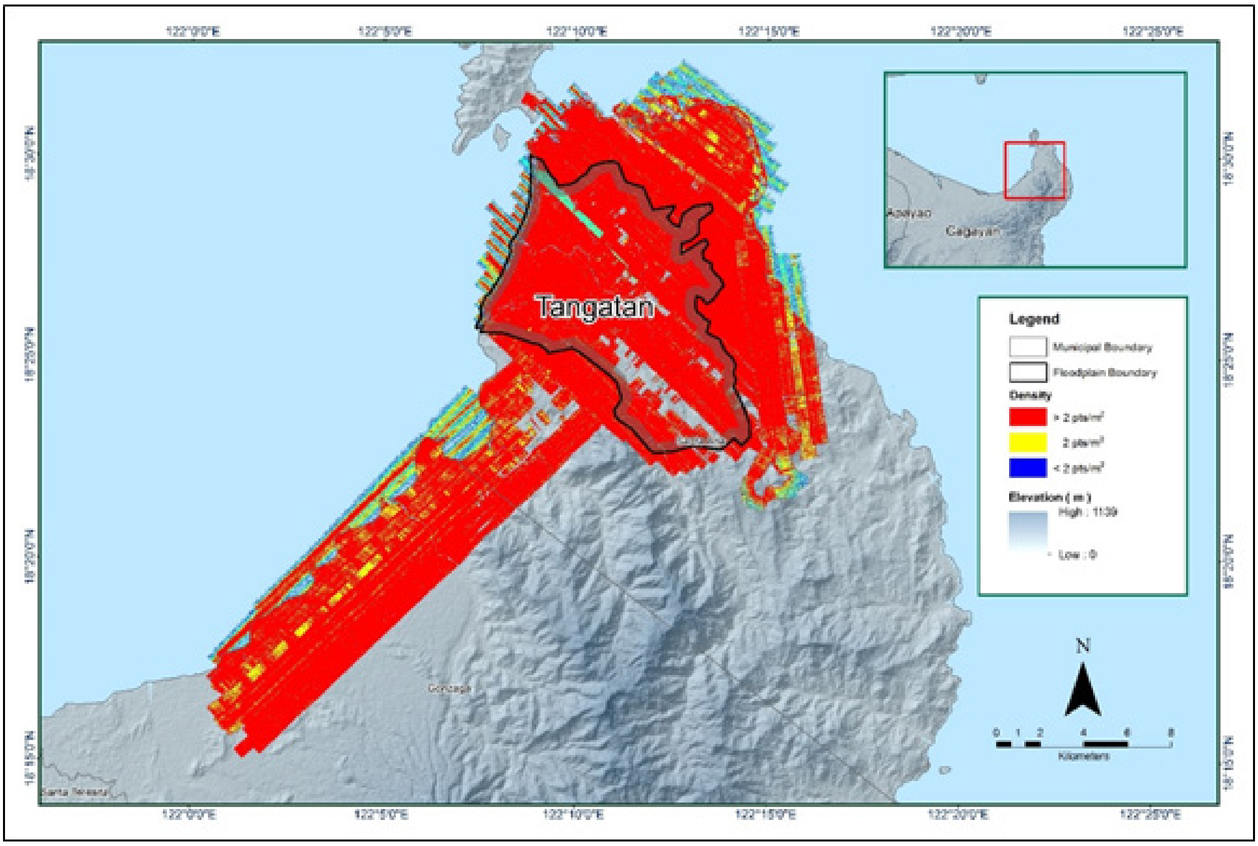


Figure 12. Pulse density map of merged LiDAR data for Tangatan Floodplain

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.

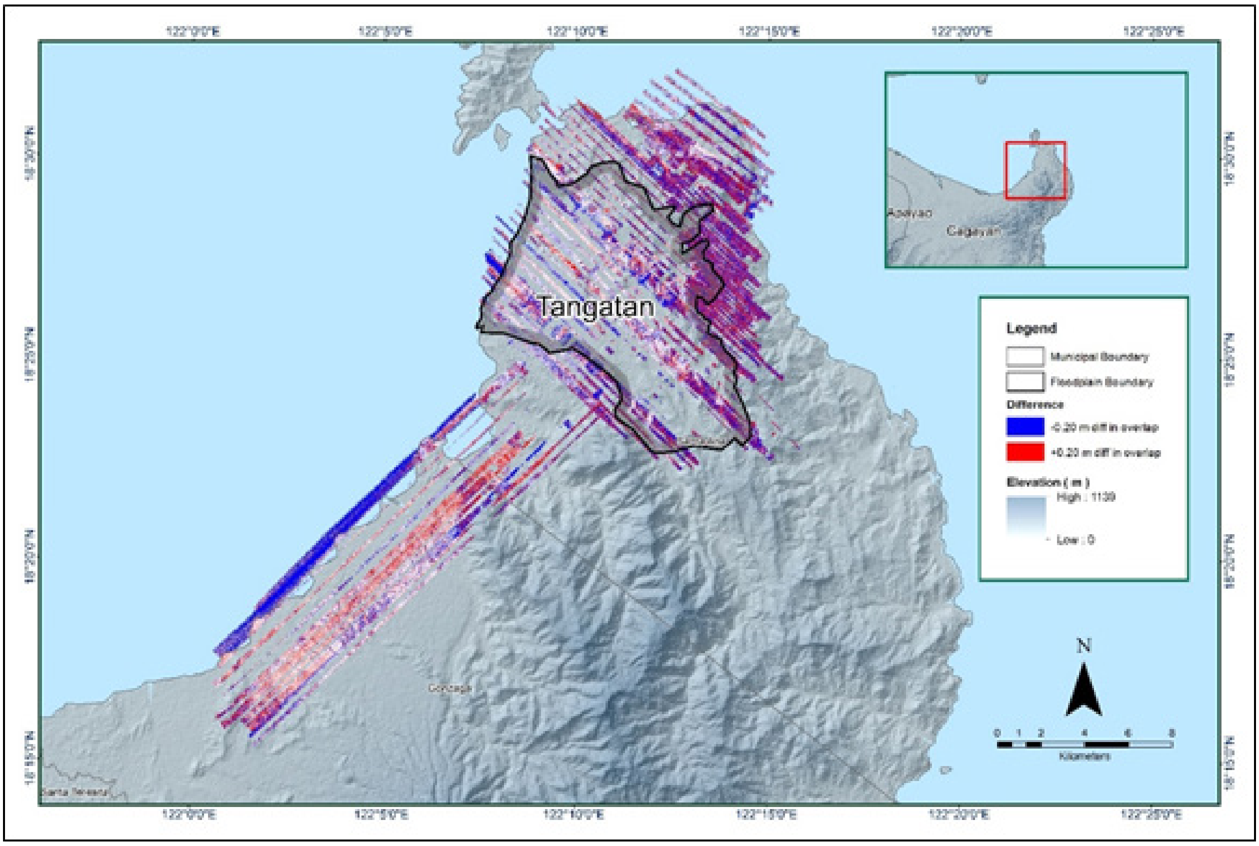


Figure 13. Elevation difference map between flight lines for Tangatan Floodplain

A screen capture of the processed LAS data from Tangatan flight 3971G loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

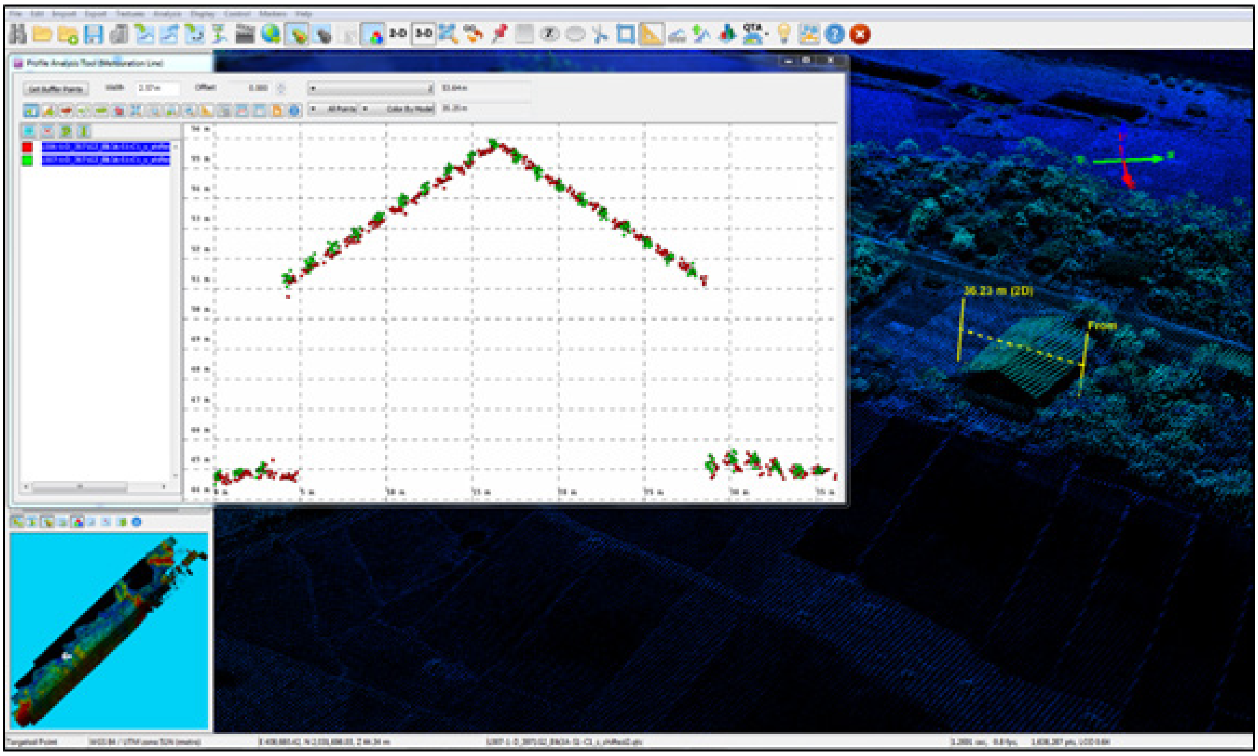


Figure 14. Quality checking for Tangatan flight 1436A using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Tangatan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	152,013,355
Low Vegetation	147,703,840
Medium Vegetation	410,163,866
High Vegetation	778,394,471
Building	13,610,705

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tangatan floodplain is shown in Figure 15. A total of 471 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 1,137.78 meters and 36.47 meters respectively.

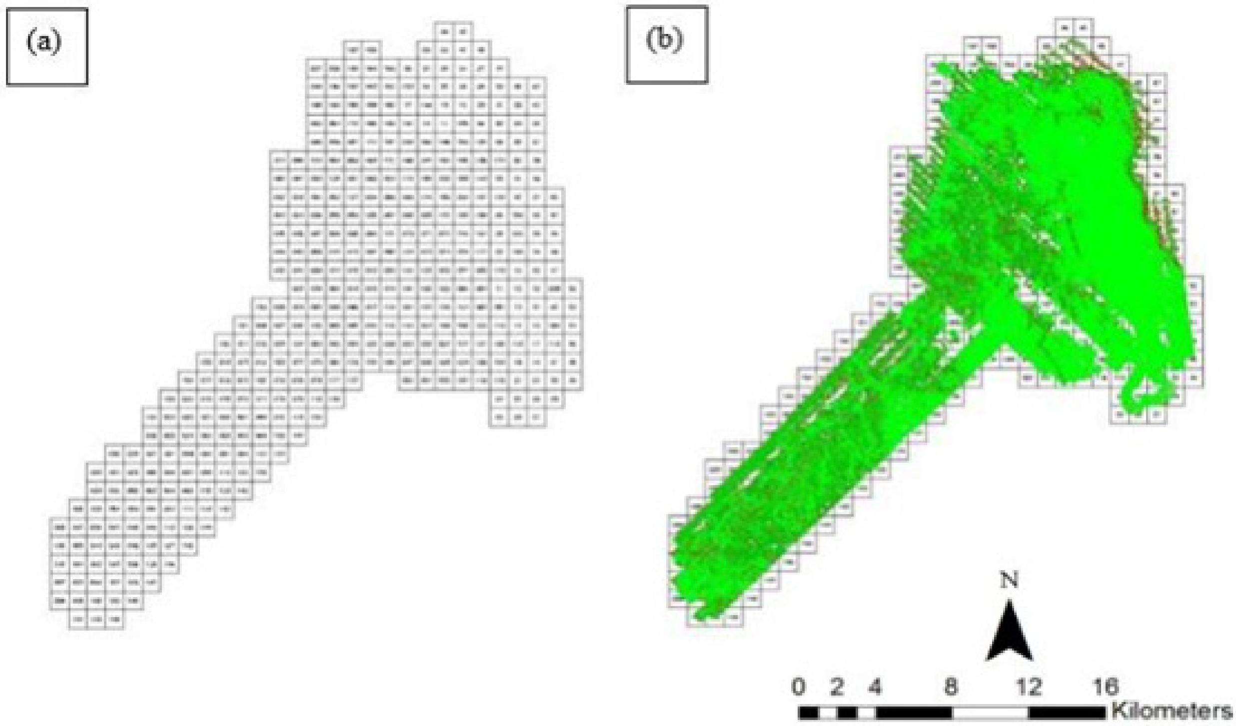


Figure 15. Tiles for Tangatan Floodplain (a) and classification results (b) in TerraScan

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.

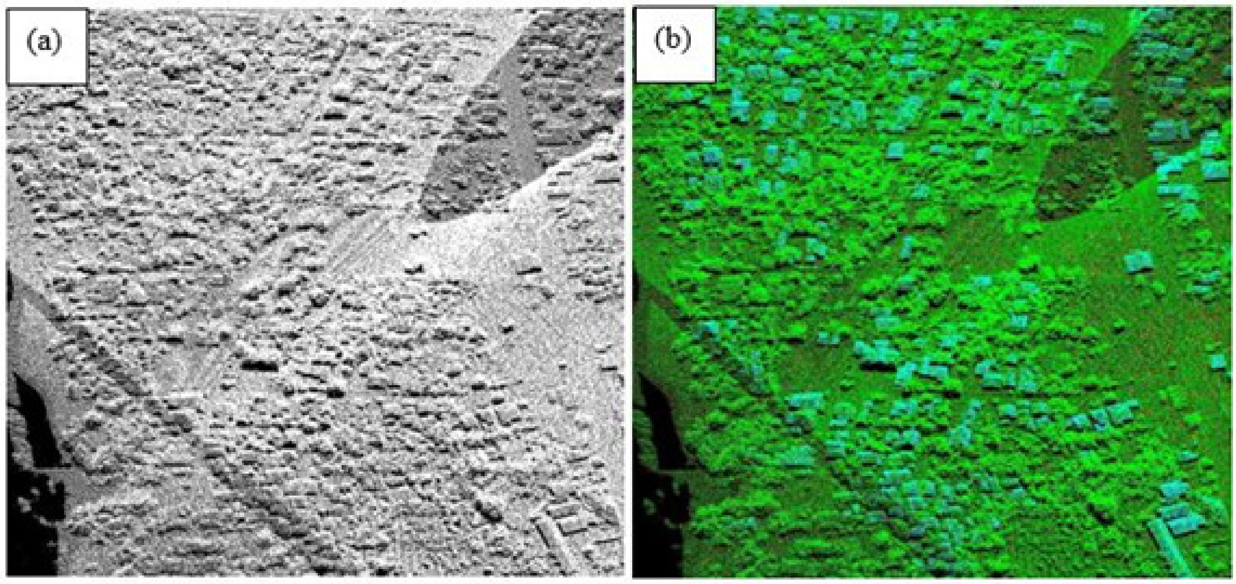


Figure 16. Point cloud before (a) and after (b) classification.

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.

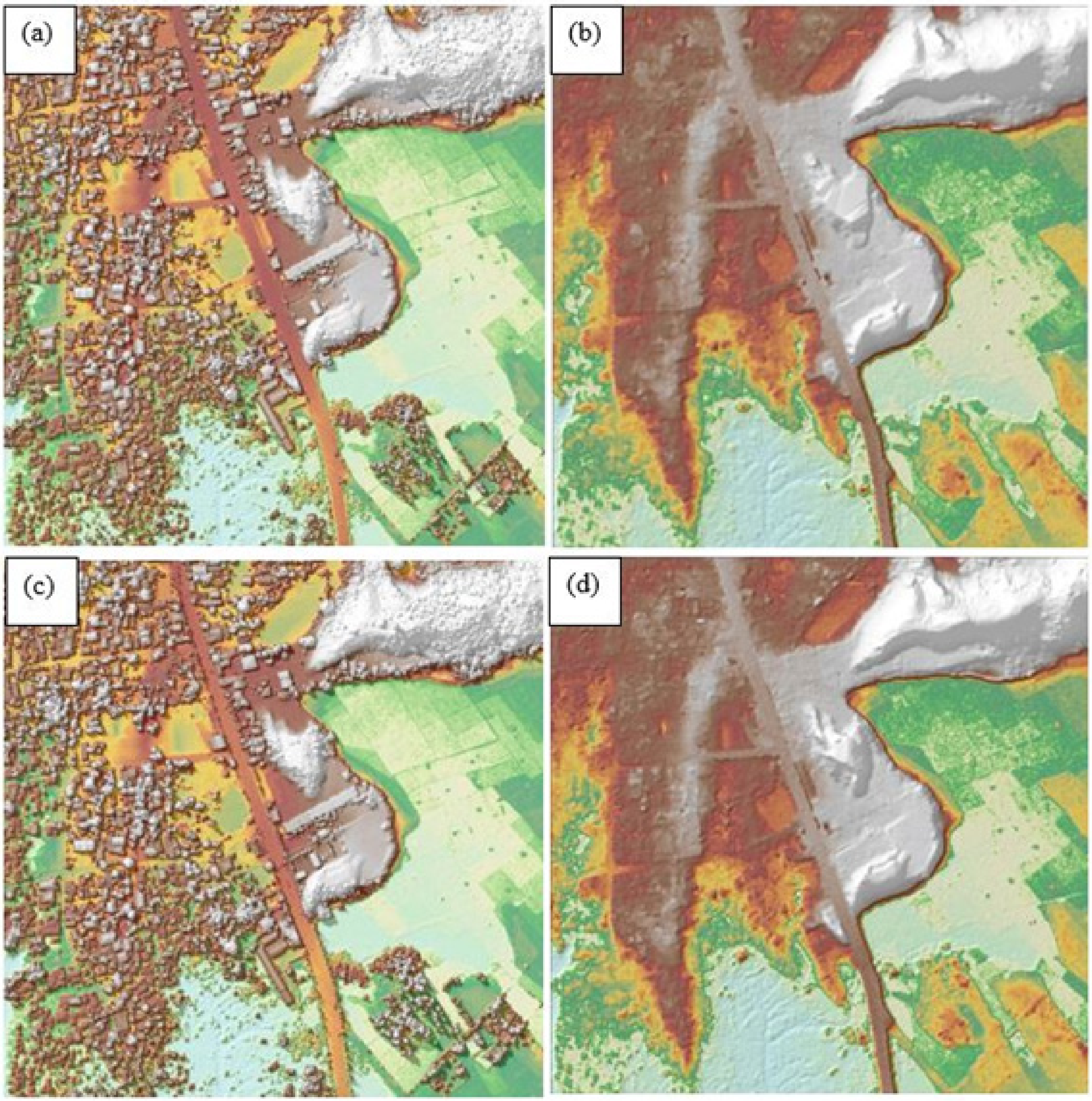


Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tangatan Floodplain

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no orthophotographs available for the Tangatan Floodplain.

3.8 DEM Editing and Hydro-Correction

Four (4) mission blocks were processed for Tangatan Floodplain. These blocks are composed of Cagayan_ reflights blocks with a total area of 320.80 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)
Cagayan_reflights_Blk3A	107.76
Cagayan_reflights_Blk3C	154.36
Cagayan_reflights_Blk3D	25.86
Cagayan_reflights_Blk3E	31.41
TOTAL	**319.39 sq.km**

Portions of DTM before and after manual editing are shown in Figure 18. A road (Figure 18a) has been misclassified and removed during classification process and has to be interpolated to complete the surface (Figure 18b) to allow the correct flow of water. An interpolated irrigation (Figure 18c) was retrieved (Figure 18d) in order to hydrologically correct the irrigation system. Another example is an interpolated ridge (Figure 18e) has to be retrieved using object retrieval to achieve the actual surface (Figure 18f). Another example is a building that is still present in the DTM after classification (Figure 18g) and has to be removed through manual editing (Figure 18h).

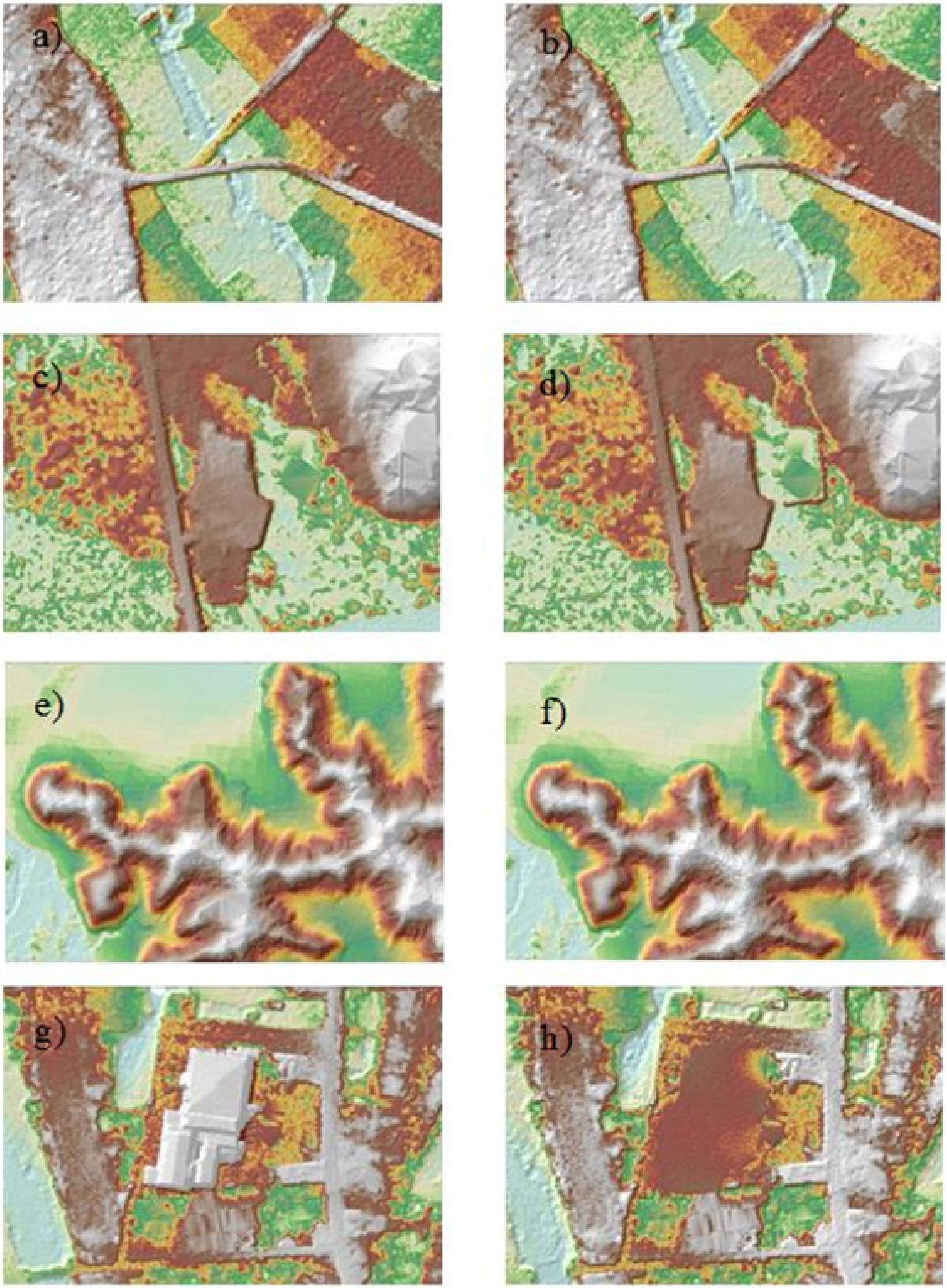


Figure 18. Portions in the DTM of Tangatan Floodplain – a bridge before (a) and after (b) manual editing; an irrigation before (c) and after (d); interpolated ridge before (e) and after (f) object retrieval; and a building before (g) and after (h) manual editing.

3.9 Mosaicking of Blocks

No assumed reference block was used in mosaicking because the identified reference for shifting was an existing Aunugay DEM which was calibrated using Cagayan DEM overlapping with the blocks to be mosaicked. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Tangatan Floodplain is shown in Figure 19. The entire Tangatan Floodplain is 91.30% covered by LiDAR data while portions with no LiDAR data were patched with the available IFSAR data.

Table 12. Shift Values of each LiDAR Block of Tangatan Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
Cagayan_reflights_Blk3A	6.32	1.18	-4.72
Cagayan_reflights_Blk3C	5.99	2.06	-4.51
Cagayan_reflights_Blk3D	6.36	1.84	-3.32
Cagayan_reflights_Blk3E	5.48	0.95	-5.01

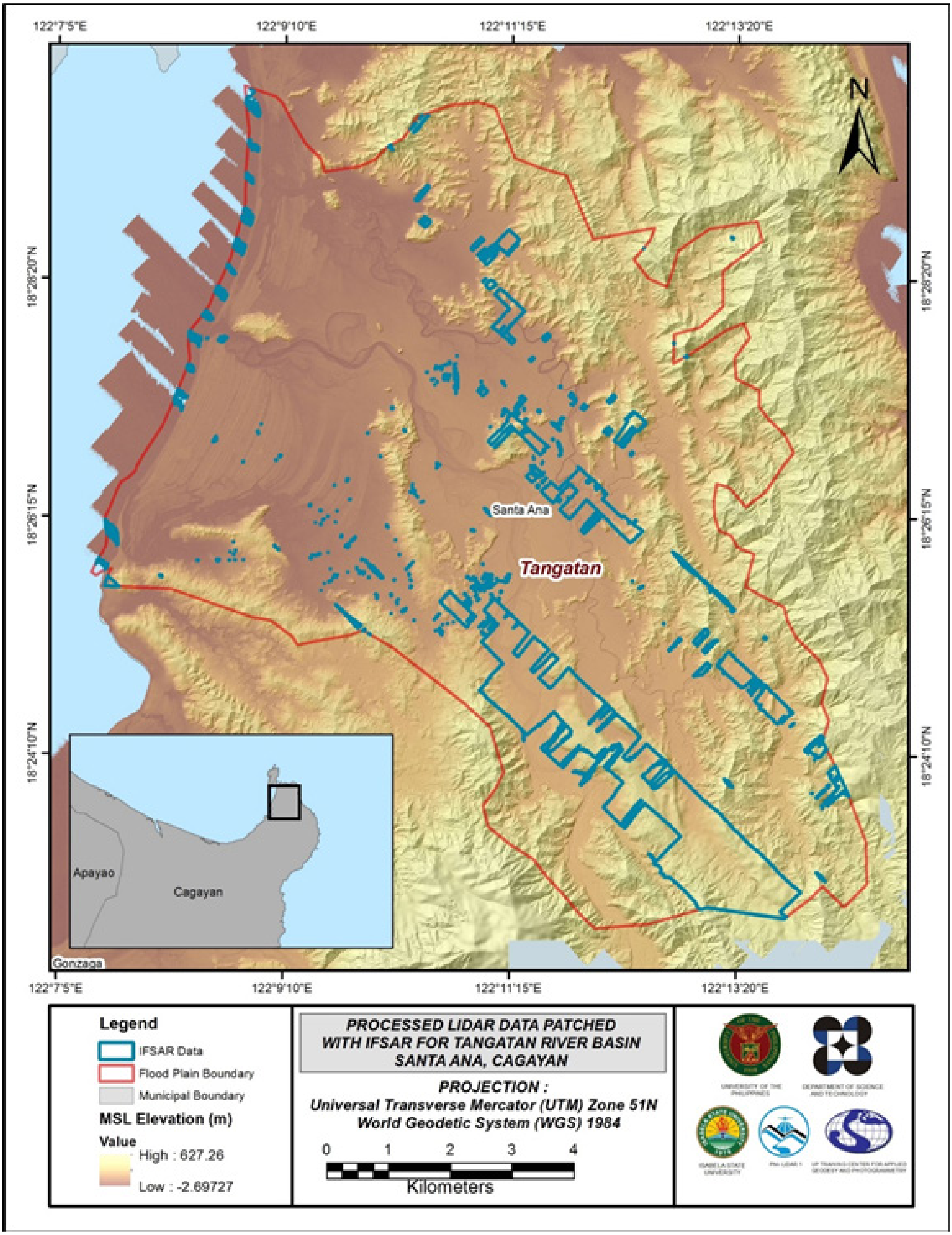


Figure 19. Map of Processed LiDAR Data for Tangatan Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Cagayan to collect points with which the LiDAR dataset was validated is shown in Figure 20. A total of 6,209 survey points were gathered for all the floodplains within Cagayan wherein the Tangatan is located. However, the point dataset was not used for the calibration of the LiDAR data for Tangatan because during the mosaicking process, each LiDAR block was referred to the calibrated Cagayan DEM. Therefore, the mosaicked DEM of Tangatan can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Cagayan LiDAR DTM and ground survey elevation values is shown in Figure 21. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 0.14 meters with a standard deviation of 0.13 meters. Calibration of Cagayan LiDAR data was done by subtracting the height difference value, 0.14 meters, to Cagayan mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between Cagayan LiDAR data and calibration data. These values were also applicable to the Tangatan DEM.

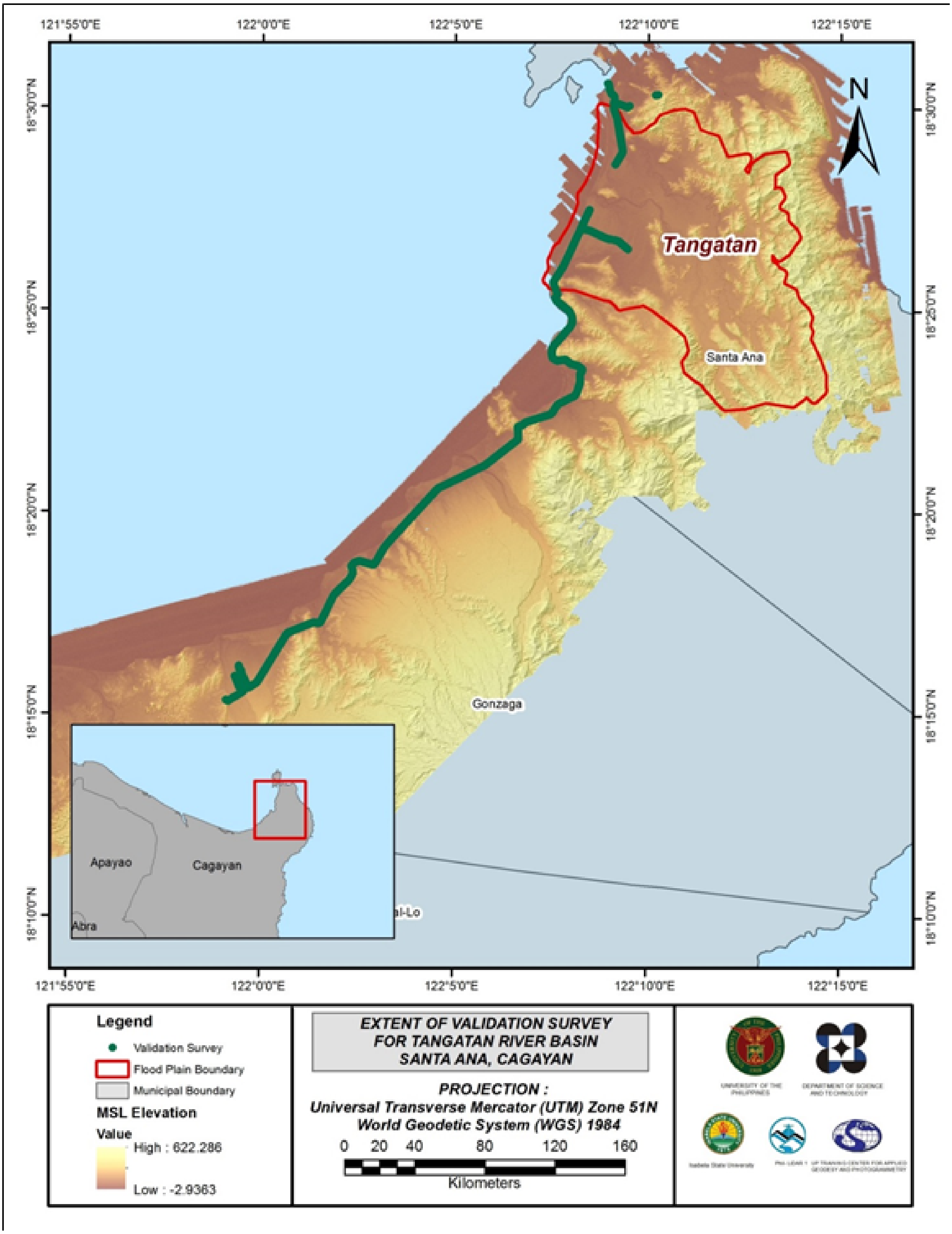


Figure 20. Map of Tangatan Floodplain with validation survey points in green

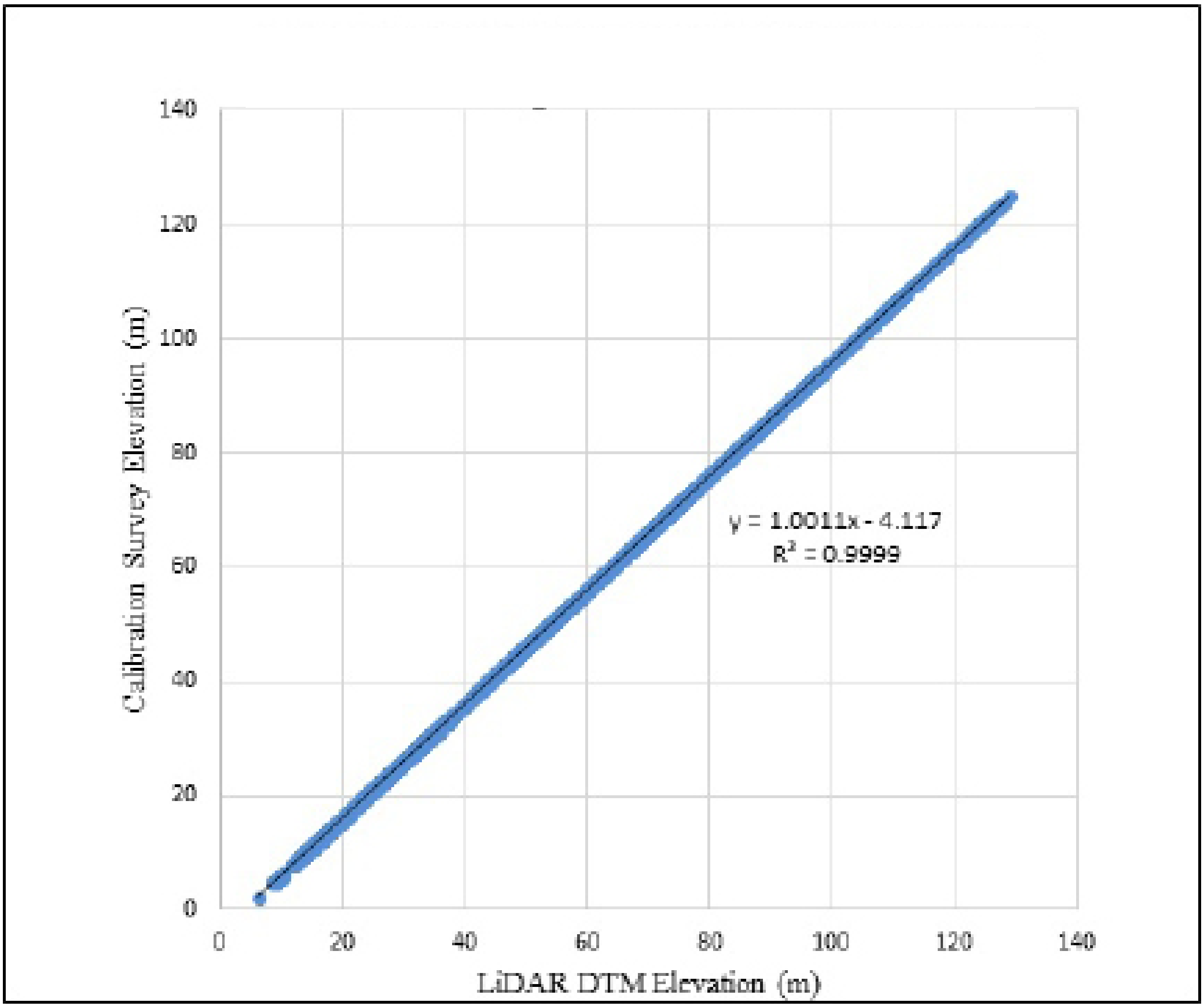


Figure 21. Correlation plot between calibration survey points and LiDAR data

Table 13. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	0.14
Standard Deviation	0.13
Average	-0.05
Minimum	-0.32
Maximum	0.22

A total of 1,074 survey points that lie within Tangatan Floodplain and were used for the validation of the calibrated Tangatan 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 0.17 meters with a standard deviation of 0.07 meters, as shown in Table 14.

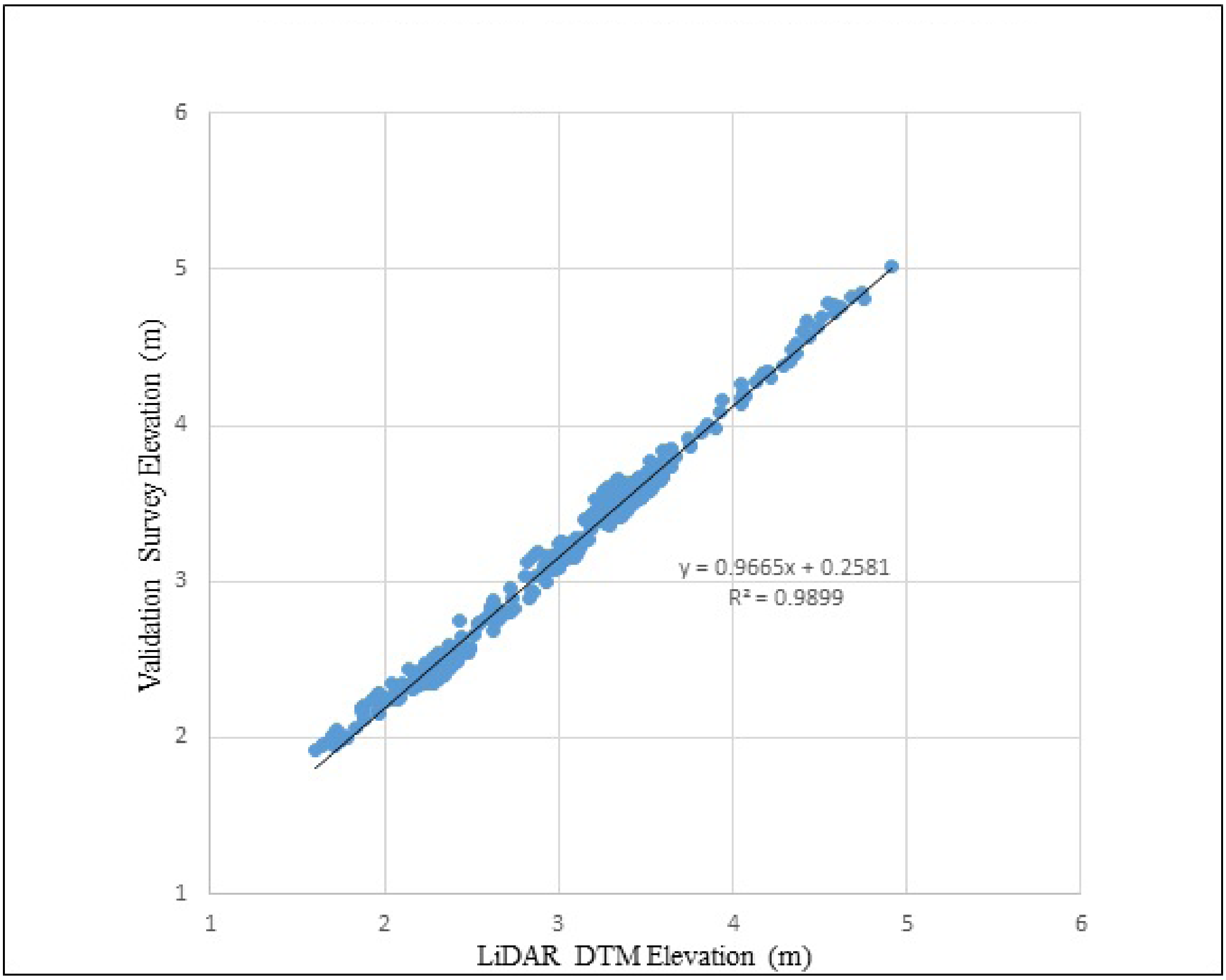


Figure 22. Correlation plot between validation survey points and LiDAR data

Table 14. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.17
Standard Deviation	0.07
Average	0.16
Minimum	0.06
Maximum	0.32

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag were available for Tangatan with 4,036 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.27 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tangatan integrated with the processed LiDAR DEM is shown in Figure 23.

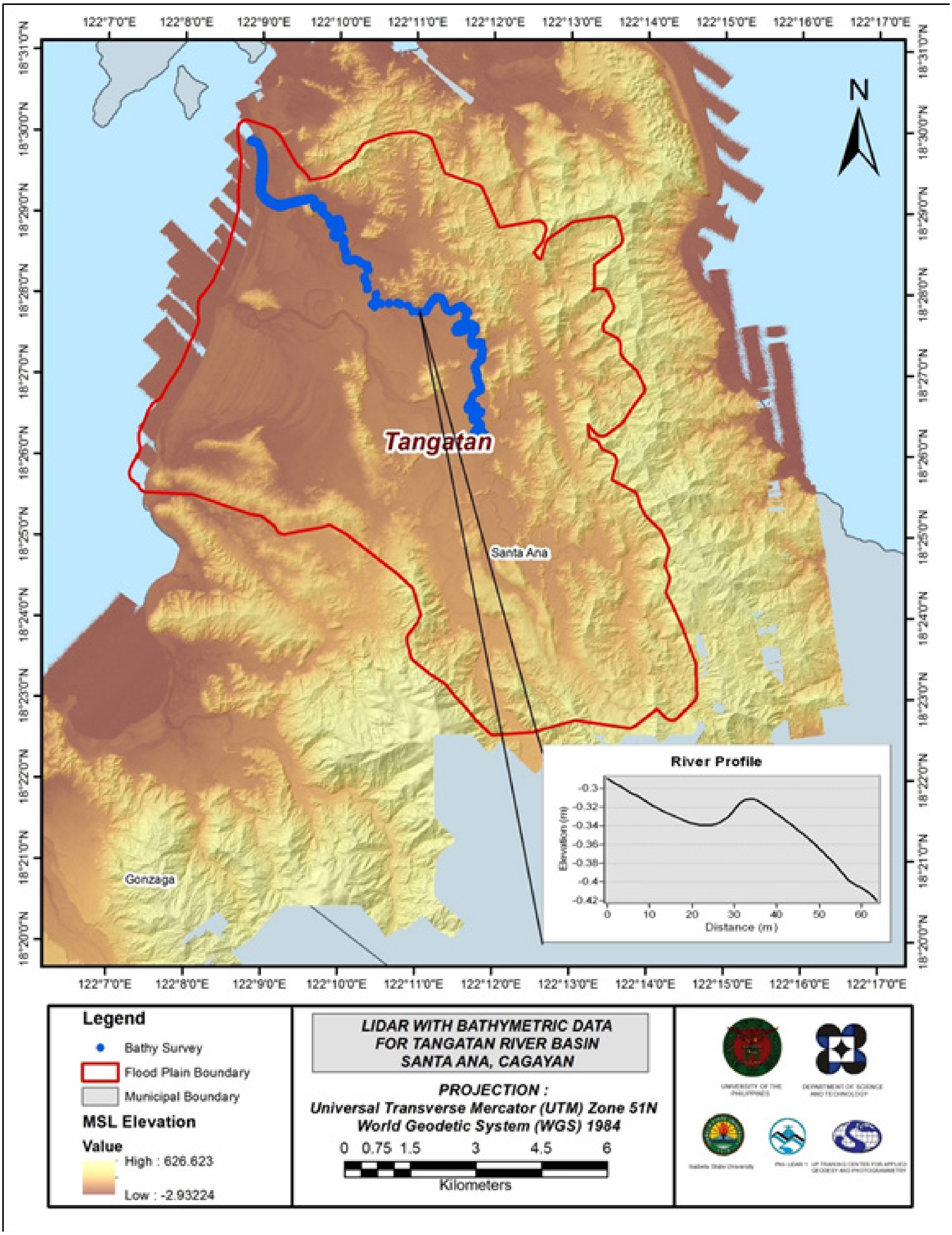


Figure 23. Map of Tangatan Floodplain with bathymetric survey points shown in blue

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

The Tangatan Floodplain, including its 200 m buffer, has a total area of 105.09 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 603 building features, are considered for QC. Figure 24 shows the QC blocks for Tangatan Floodplain.

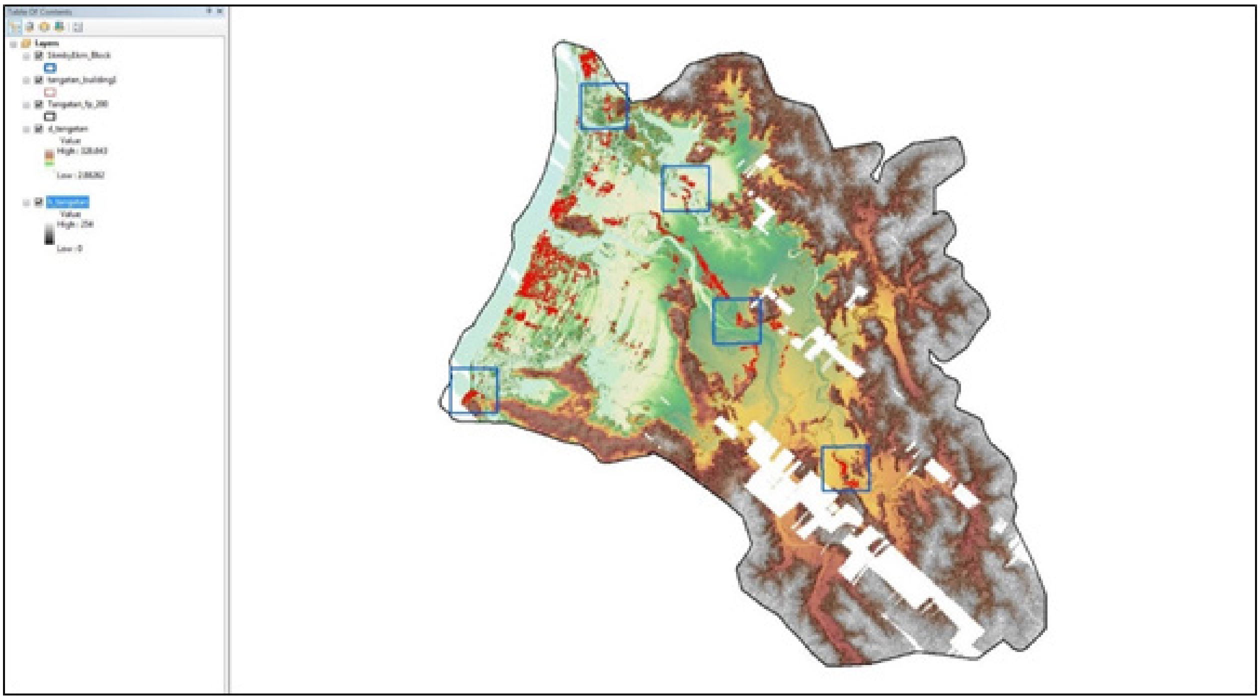


Figure 24. QC blocks for Tangatan building features

Quality checking of Tangatan building features resulted in the ratings shown in Table 16.

Table 15. Quality Checking Ratings for Tangatan Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tangatan	97.56	99.34	89.55	PASSED

3.12.2 Height Extraction

Height extraction was done for 4,911 building features in Tangatan Floodplain. Of these building features, 252 was filtered out after height extraction, resulting to 4,659 buildings with height attributes. The lowest building height is at 2.00m, while the highest building is at 4.67 m.

3.12.3 Feature Attribution

The digitized features were identified using participatory mapping. Stakeholders (barangay officials) were invited in a forum and were given maps of their respective barangays. They attributed first non-residential buildings like barangay hall, schools, churches, commercial buildings, etc. then other building left were then coded as residential. An nDSM was generated using the LiDAR DEMs to extract the heights of the buildings. A minimum height of 2 meters was used to filter out the terrain features that were digitized as buildings. Buildings that were not yet constructed during the time of LiDAR acquisition were noted as new buildings in the attribute table.

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 Tangatan Floodplain

Facility Type	No. of Features
Residential	4,331
School	104
Market	19
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	15
Barangay Hall	12
Military Institution	0
Sports Center/Gymnasium/Covered Court	2
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	1
Power Plant/Substation	4
NGO/CSO Offices	0
Police Station	2
Water Supply/Sewerage	0
Religious Institutions	15
Bank	0
Factory	0
Gas Station	5
Fire Station	2
Other Government Offices	46
Other Commercial Establishments	101
Total	**4,659**

[1] Resource Extraction for Geographic Information System (reGIS), 17 March 2015

Table 17. Total Length of Extracted Roads for Tangatan Floodplain

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tangatan	87.61	0	17.37	8.82	0	113.80

Table 18. Number of Extracted Water Bodies for Tangatan Floodplain

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Tangatan	20	0	0	0	0	20

A total of 20 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 Tangatan Floodplain overlaid with its ground features.

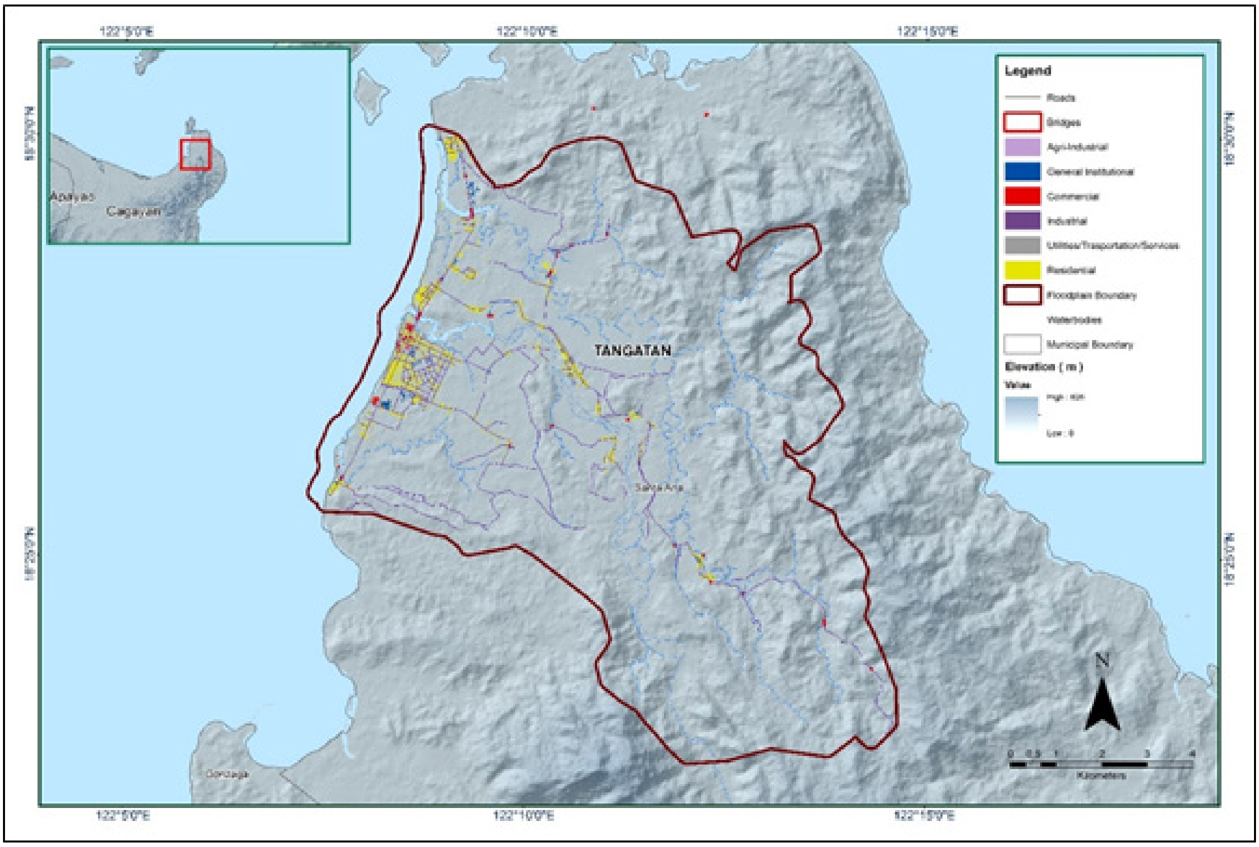


Figure 25. Extracted features for Tangatan Floodplain

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

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

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

4.1 Summary of Activities

H.O. Noveloso Surveying (HONS) conducted a field survey in Tangatan River on Jan. 19, 2017, on Jan. 23 to 24, 2017, on Jan. 27 to 28, 2017, on Feb. 7, 2017, on Feb. 9, 2017, on Mar. 17 to 18, 2017, and on Mar. 20, 2017 with the following scope: reconnaissance; control survey; cross-section and as-built survey of Casagan Hanging Bridge in Brgy. Casagan and Sta. Cruz Bridge in Brgy. Sta. Cruz, Municipality of Sta. Ana, Province of Cagayan; and bathymetric survey of the river from the upstream in Brgy. Dungeg to the mouth of the river in Brgy. Tangatan, Sta. Ana, Cagayan with an approximate length of 14.90 km. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVBC on October 11-22, 2016 and on November 30 - December 14, 2016 using an Ohmex™ Single Beam Echo Sounder and Trimble® SPS 882 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Tangatan River Basin area. The entire survey extent is illustrated in Figure 27.

4.2 Control Survey

The GNSS network used for Tangatan River is composed of one (1) loop established on December 1, 2016 occupying the following reference points: CGY-102, a second-order GCP, in Brgy. San Jose, Gonzaga, Cagayan and CG-234, a first-order BM, in Brgy. Diora-Zinungan, Sta. Ana, Cagayan.

One (1) control point was also established in the area: UP-TAN-1 in Brgy. Sta. Cruz, Sta. Ana, Cagayan.

The summary of reference and control points and its location is summarized in Table 19 while GNSS network established is illustrated in Figure 26.

Table 19. List of reference and control points used during the survey in Tangatan 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
CGY-102	2nd order, GCP	18°22'09.82839"N	122°06'46.33686"E	-	-	2007
CG-234	1st Order, BM	-	-	-	3.77	2007
UP-TAN-1	Established	-	-	-	-	10-12-2016

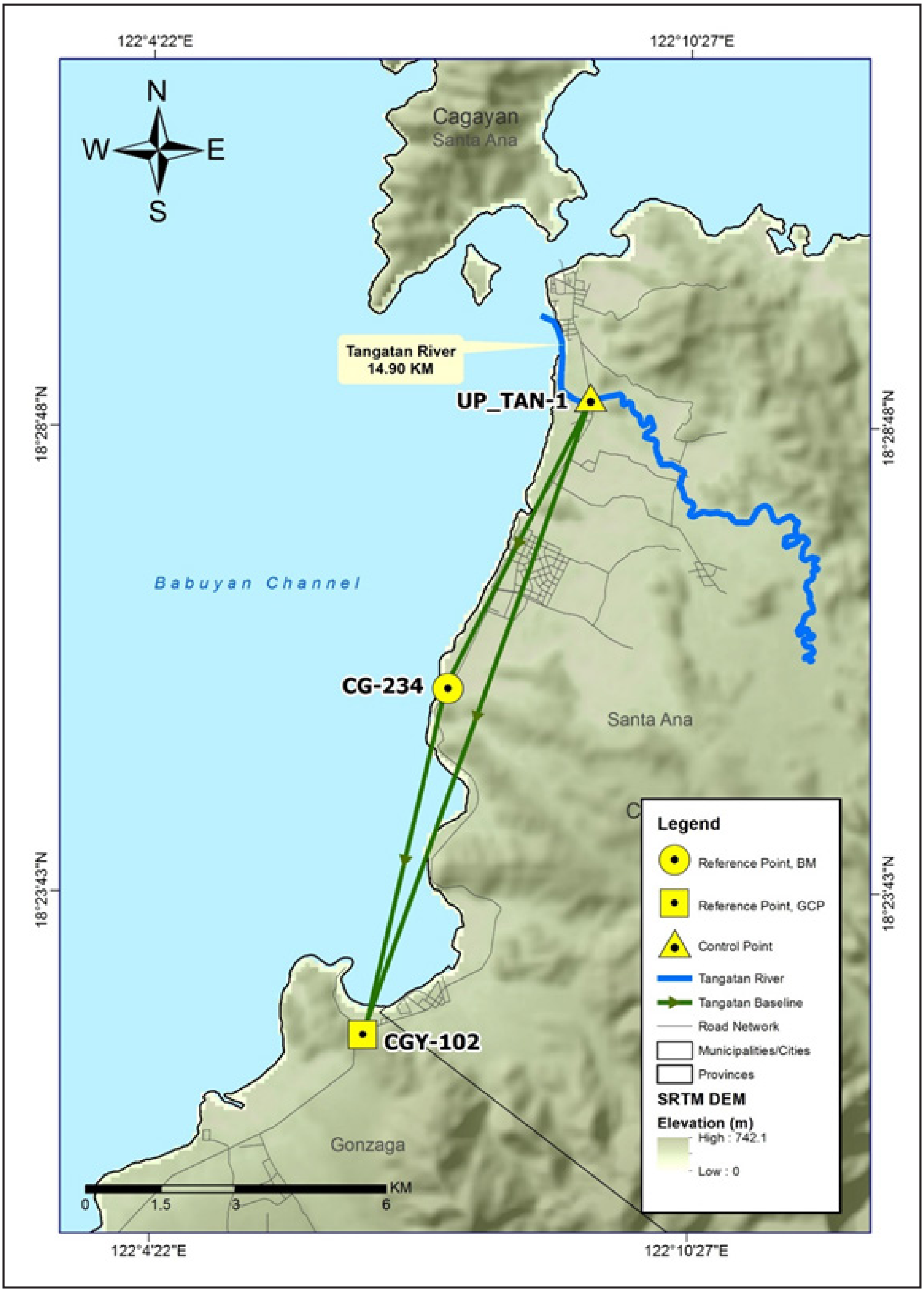


Figure 26. GNSS network for Tangatan River Survey

Table 20. List of references and control points used in Tangatan River survey in Cagayan (Source: NAMRIA and UP TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
LYT-101	2nd order, GCP	11°10'19.64869" N	125°00'43.78230" E	69.228	-	09-20-2014
LY-106	1st order, BM	-	-	68.051	4.028	2007
UP-ABG	UP Established	-	-	-	-	09-20-2014
UP-B	UP Established	-	-	-	-	09-20-2014
UP-DAG	UP Established	-	-	-	-	09-20-2014
UP-O	UP Established	-	-	-	-	09-19-2014
UP-STN	UP Established	-	-	-	-	09-11-2014
AP1	Arbitrary	-	-	-	-	09-18-2014
AP2	Arbitrary	-	-	-	-	09-20-2014

The GNSS set-ups on recovered reference points and established control points in Tangatan River are shown from Figures 27 to 29.

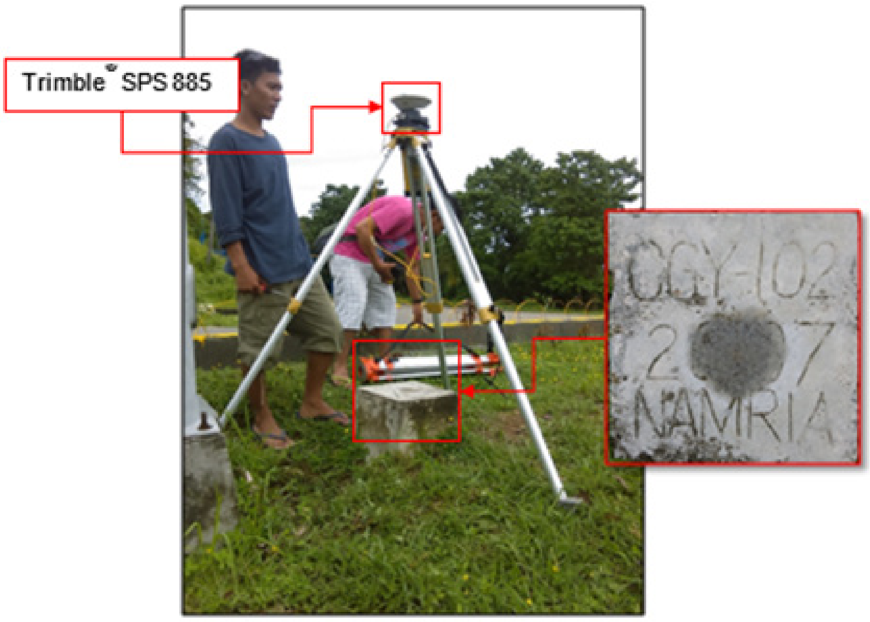


Figure 27. GNSS receiver set-up, Trimble® SPS 885, at CGY-102, located at the center island in front of the barangay marker of Brgy. Casambalangan in Brgy. San Jose, Gonzaga, Cagayan

Figure 28. GNSS receiver set-up, Trimble® SPS 885, at CG-234, located at the approach of Diora Bridge in Brgy. Diora-Zinungan, Sta. Ana, Cagayan

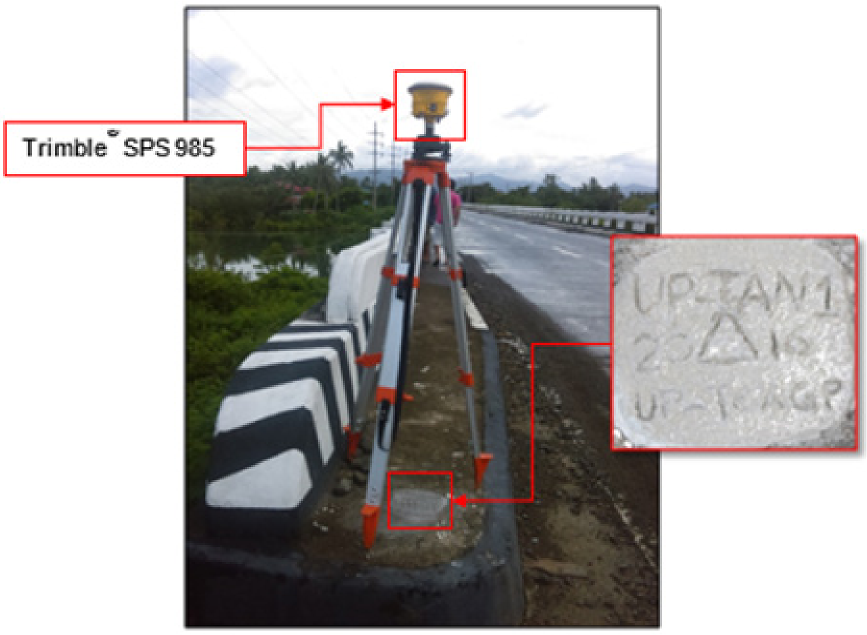


Figure 29. GNSS receiver set-up, Trimble® SPS 985, at UP-TAN-1, located at the approach of Sta. Cruz Bridge in Brgy. Sta. Cruz, Sta. Ana, Cagayan

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 Tangatan River Basin is summarized in Table 21 generated by TBC software.

Table 21. Baseline Processing Report for Tangatan River Basin Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
UP-TAN-1 --- CGY-102	12-1-2016	Fixed	0.004	0.016	199°11'58"	13609.050	12.344
CGY-102--- CG-234	12-1-2016	Fixed	0.003	0.016	193°23'13"	7169.703	12.671
UP-TAN-1--- CG-234	12-1-2016	Fixed	0.003	0.014	205°35'16"	6516.553	-0.276

As shown in Table 21, a total of three (3) baselines were processed with coordinates of CGY-102 and elevation value of CG-234 held fixed. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

where:

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

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

The three (3) control points, CGY-102, CG-234, and UP-TAN-1, were occupied and observed simultaneously to form a GNSS loop. The coordinates of CGY-102 and elevation value of CG-234 held fixed as presented in Table 22. Through these reference points, the coordinates and elevations of the unknown control points will be computed.

Table 22. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
CG-234	Grid				Fixed
CGY-102	Global	Fixed	Fixed		
Fixed = 0.000001 (Meter)					

Table 23. Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
CG-234	407973.642	0.012	2038248.425	0.010	3.769	?	e
CGY-102	406280.704	?	2031283.618	?	15.911	0.074	LL
UP-TAN-1	410814.670	0.013	2044110.914	0.010	4.510	0.069	

With the mentioned equation, $\sqrt{((x_e)^2+(y_e)^2)}<20cm$ for horizontal and $z_e<10$ cm for the vertical; the computation for the accuracy are as follows:

a. CG-234

Horizontal Accuracy	=	√((1.2)² + (1.0)²
	=	√ (1.44 + 1.00)
	=	1.56 < 20 cm
Vertical Accuracy	=	Fixed

b. CGY-102

Horizontal Accuracy	=	Fixed
Vertical Accuracy	=	7.4 < 10 cm

c. CG-373

Horizontal Accuracy	=	√((1.3)² + (1.0)²
	=	√ (1.69 + 1.00)
	=	1.69 + 1.00
Vertical Accuracy	=	6.9 < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the three (3) occupied control points are within the required precision.

Table 24. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
CG-234	N18°25'56.68771"	E122°07'42.88274"	40.384	?	e
CGY-102	N18°22'09.82860"	E122°06'46.33709"	53.040	0.074	LL
UP-TAN-1	N18°29'07.85555"	E122°09'18.79066"	40.665	0.069	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 24. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference and control points used is indicated in Table 25.

Table 25. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
CGY-102	2nd order, GCP	18°22'09.82839"N	122°06'46.33686"E	56.475	2031283.618	406280.704	15.971
CG-234	1st Order, BM	18°25'56.68727"N	122°07'42.88284"E	43.759	2038248.425	407973.642	3.77
UP-TAN-1	Established	18°29'07.85555"	122°09'18.79066"	40.665	2044110.914	410814.67	4.51

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

Cross-section and as-built surveys were conducted on February 9, 2017 at the downstream side of Casagan Hanging Bridge in Brgy. Casagan, Sta. Ana, Cagayan as shown in Figure 30. A Sokkia™ Set CX Total Station was utilized for this survey as shown in Figure 31. The Automated Water Level System (AWLS) is located beside the foot of the bridge and its elevation was measured 3.713 m above MSL.

Figure 30. Casagan Hanging Bridge facing upstream

Figure 31. Cross-section survey of Casagan Hanging Bridge

The cross-sectional line of Casagan Hanging Bridge is about 82 m with one hundred ninety-two (192) cross-sectional points using the control points UP-TAN-5 and UP-TAN-6 as the GNSS base stations. The location map, cross-section diagram, and the bridge data form are shown from Figures 32 to 34.

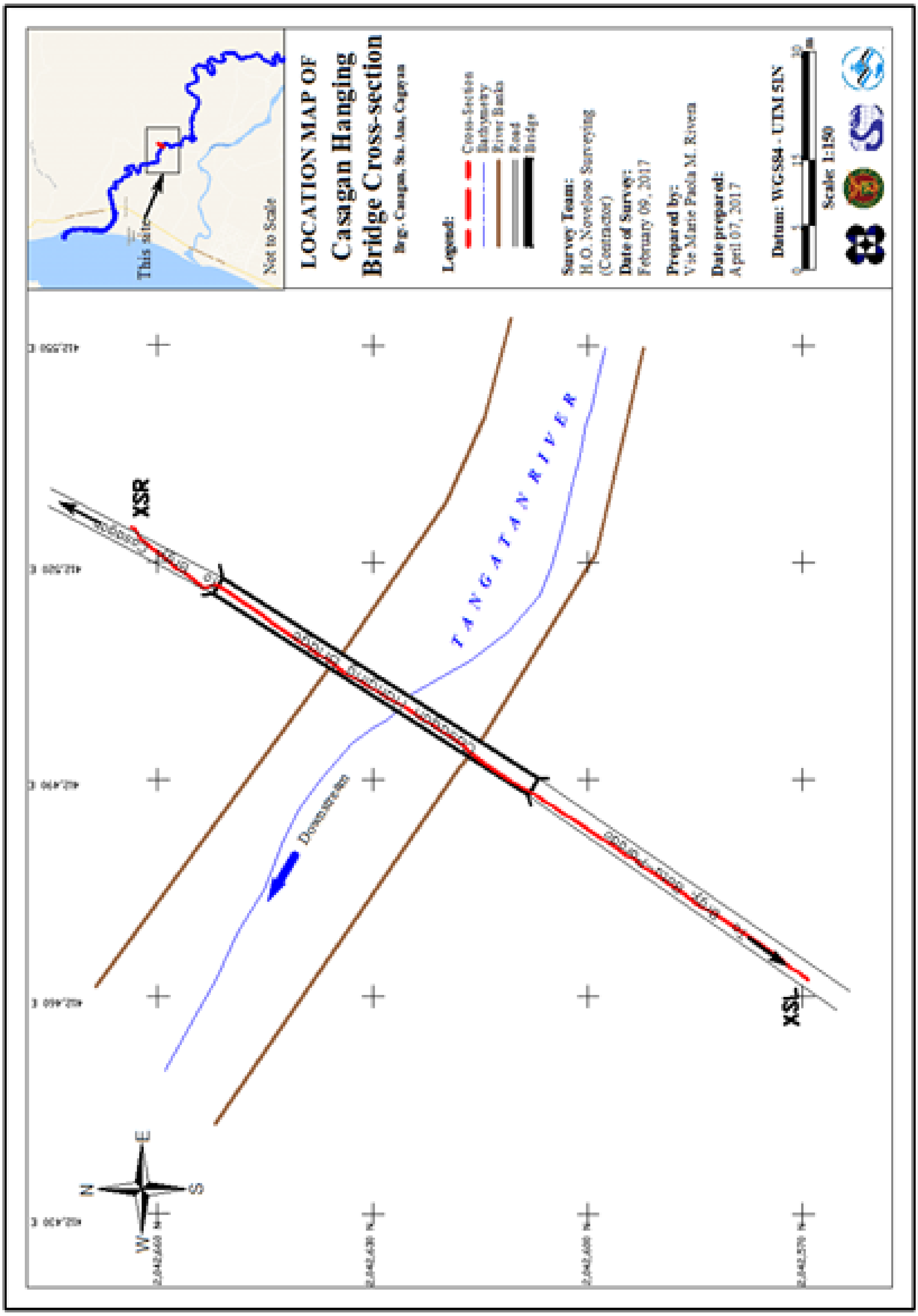


Figure 32. Location Map of Casagan Hanging Bridge Cross-Section

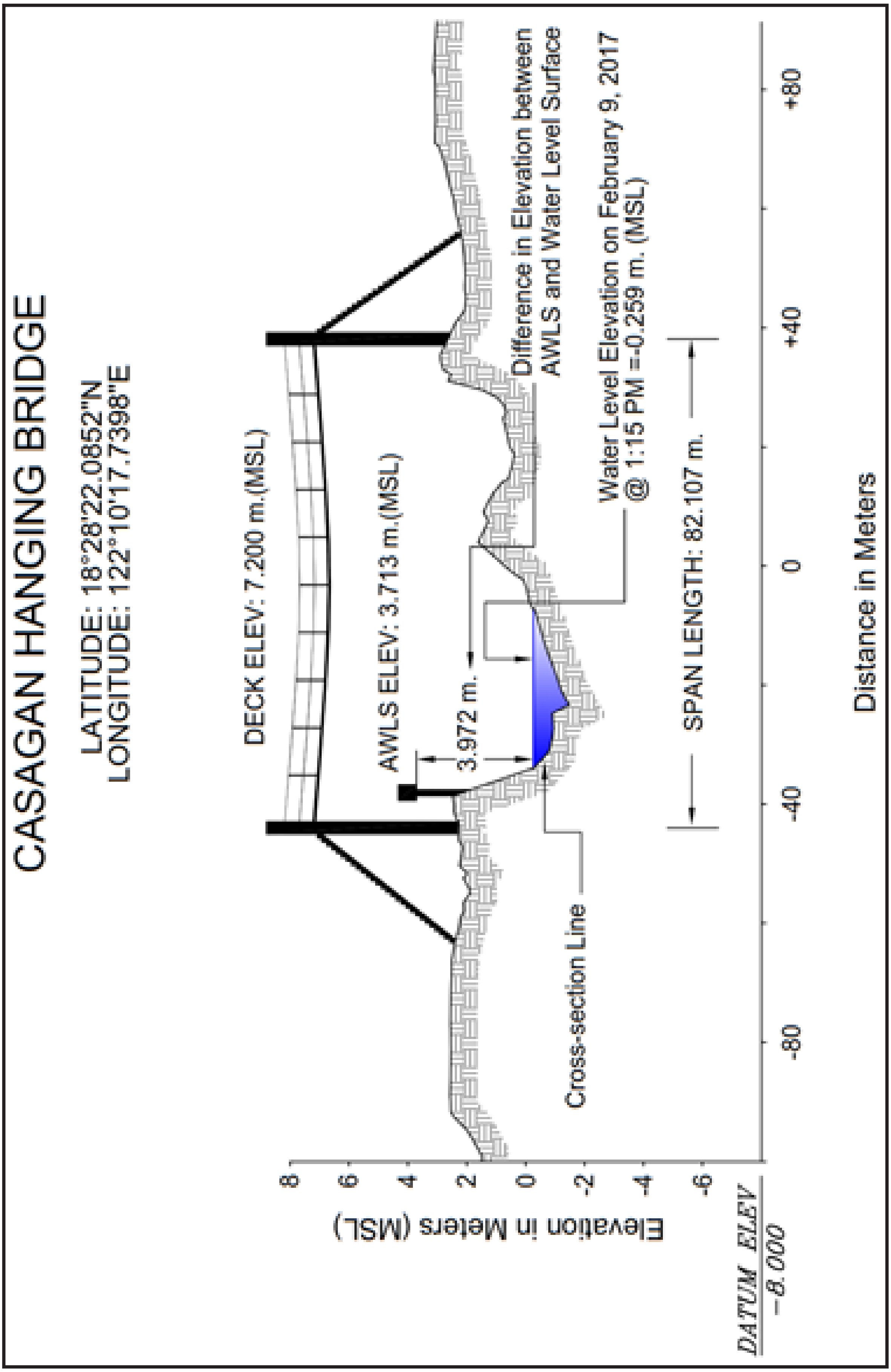


Figure 33. Casagan Bridge cross-section diagram

BRIDGE DATA FORM

Bridge Name: Casagan Hanging Bridge

River Name: Tangatan River

Location (Brgy., City, Region): Brgy. Casagan, Sta. Ana, Cagayan

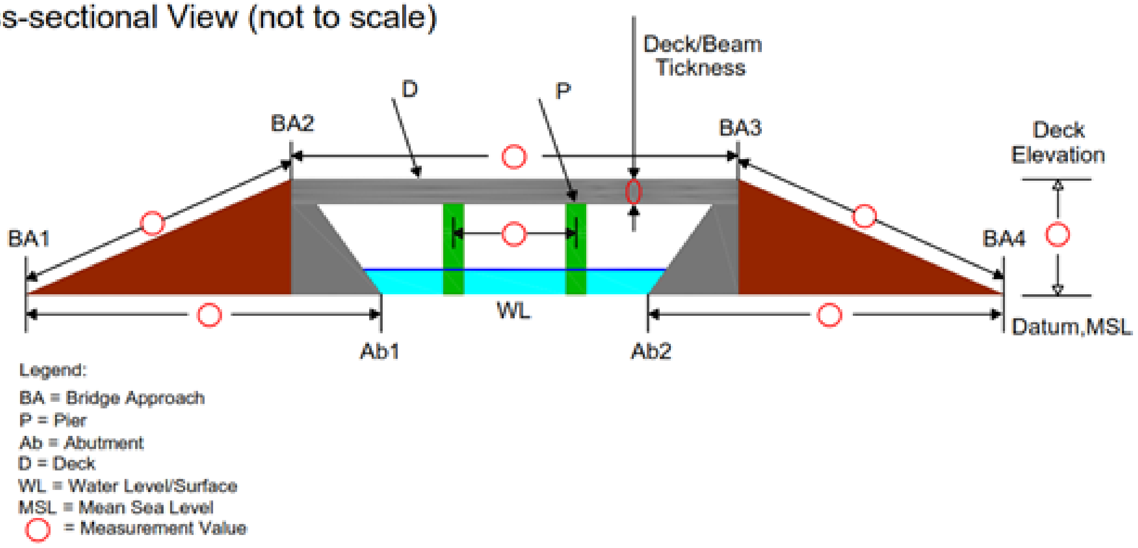
Survey Team: Jesus De Tagle, Alfie Paras, Isidro Basco, Mardy Feria, Rogelio Itorma and Myton Obaña

Date and Time: February 9, 2017 @ 1:15 pm

Flow Condition: Low Normal High

Weather Condition: Fair Rainy

Cross-sectional View (not to scale)



Line Segment	Measurement, m	Remarks
1. BA1-BA2	28.897 m.	Wood Ramp
2. BA2-BA3	82.107 m.	Wood Ramp
3. BA3-BA4	28.646 m.	Wood Ramp
4. Ab1 thickness	0.500 m.	Concrete Post
5. Ab2 thickness	0.500 m.	Concrete Post
6. Deck/Beam thickness	0.500 m.	Concrete
7. Deck Elevation	7.200 m. MSL	Concrete

Note: Observer should be facing downstream

Figure 34. Casagan Hanging Bridge Data Sheet

Cross-section and as-built surveys were conducted on February 9, 2017 at the downstream side of Sta. Cruz Bridge in Brgy. Sta. Cruz, Sta. Ana, Cagayan as shown in Figure 36. A Sokkia™ Set CX Total Station was utilized for this survey as shown in Figure 36.

Figure 35. Sta. Cruz Bridge facing upstream

Figure 36. As-built survey of Sta. Cruz Bridge

The cross-sectional line of Sta. Cruz Bridge is about 120 m with three hundred (300) cross-sectional points using the control points UP-TAN-4 as the GNSS base station. The cross-section diagram, location map, and the bridge data form are shown in Figures 37 to 39.

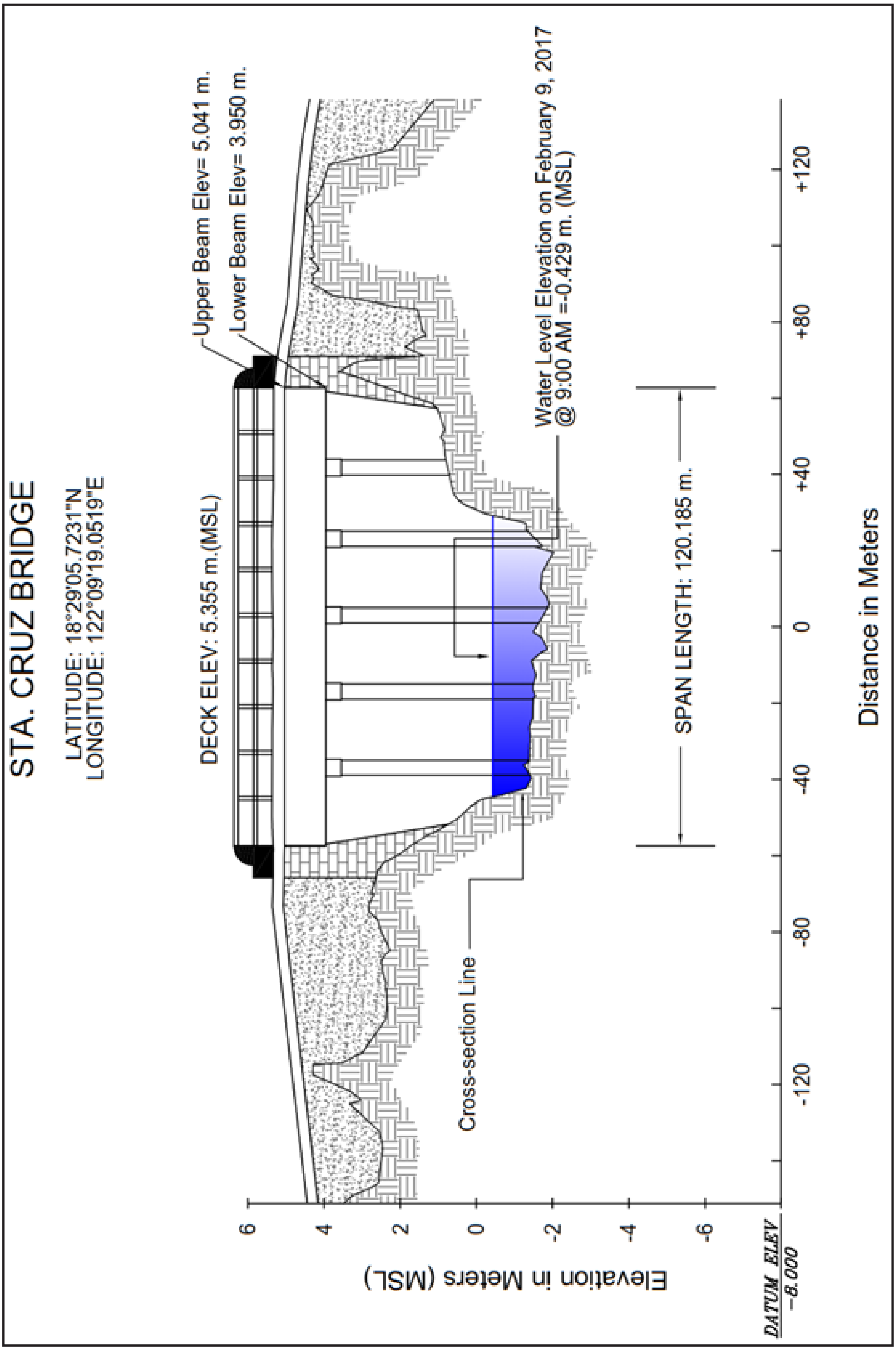


Figure 37. Sta. Cruz Bridge Cross-section Diagram

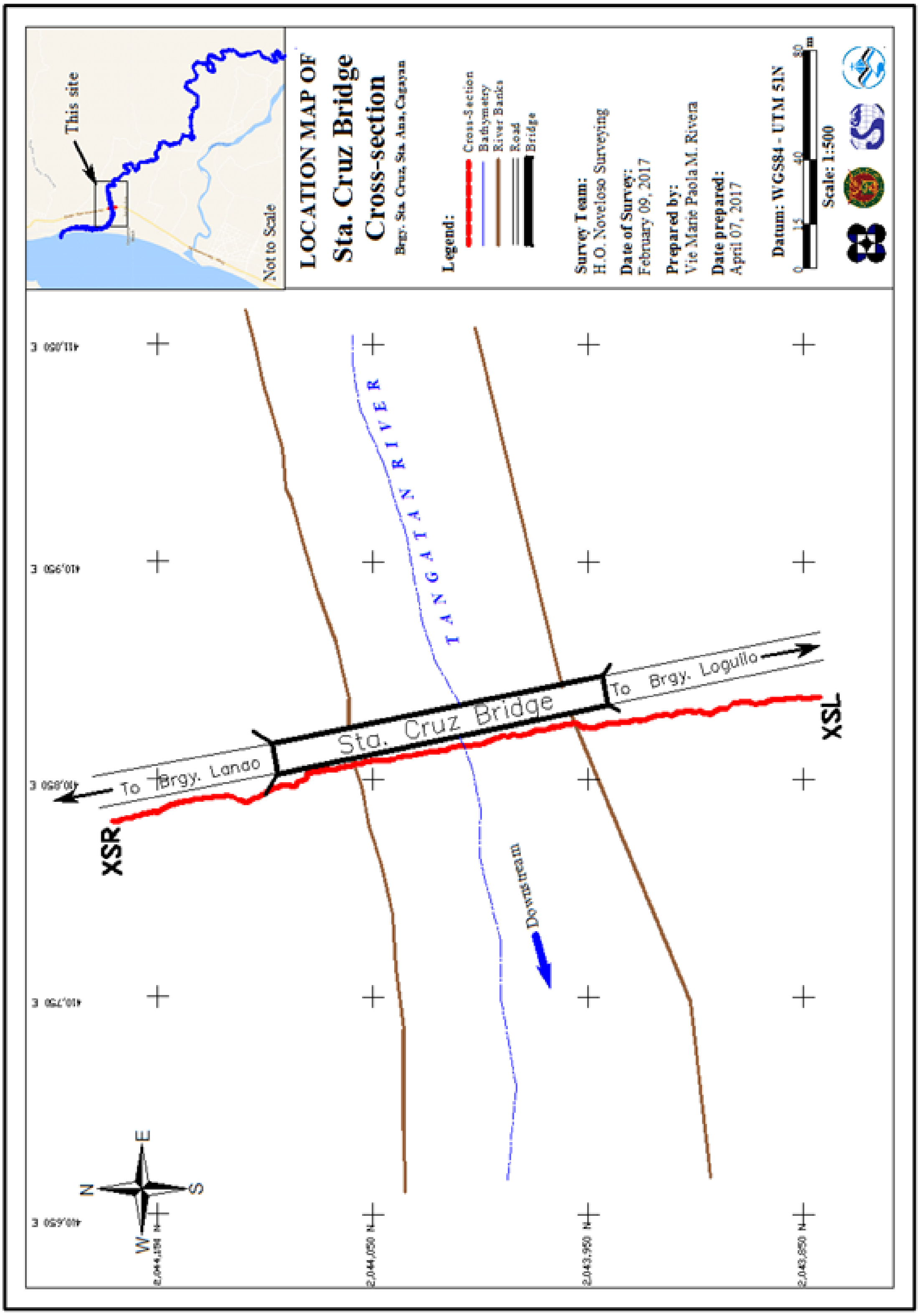


Figure 38. Location Map of Sta. Cruz Bridge Cross-Section

BRIDGE DATA FORM

Bridge Name: Sta. Cruz Bridge

River Name: Tangatan River

Location (Brgy., City, Region): Brgy. Sta. Cruz, Sta. Ana, Cagayan

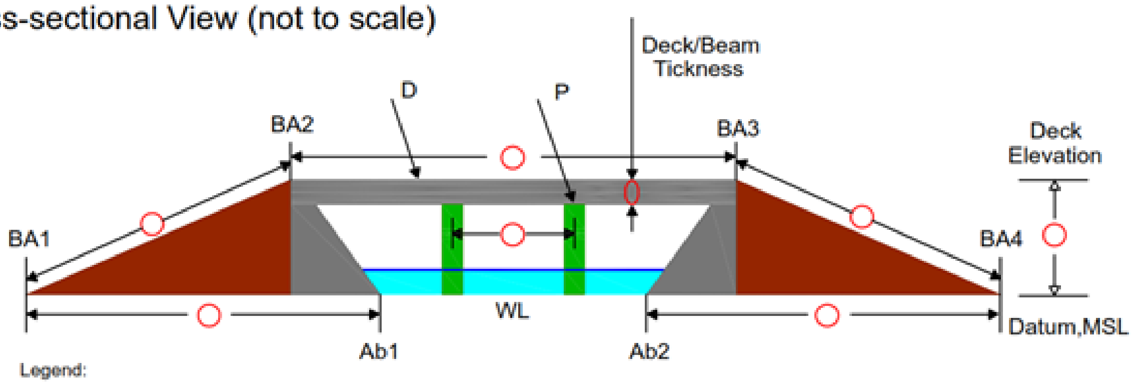
Survey Team: Jesus De Tagle, Alfie Paras, Isidro Basco, Mardy Feria, Rogelio Itorma and Myton Obaña

Date and Time: February 9, 2017 @ 9:00 am

Flow Condition: Low <u>Normal</u> High

Weather Condition: <u>Fair</u> Rainy

Cross-sectional View (not to scale)



Legend:
BA = Bridge Approach
P = Pier
Ab = Abutment
D = Deck
WL = Water Level/Surface
MSL = Mean Sea Level
○ = Measurement Value

Line Segment	Measurement, m	Remarks
1. BA1-BA2	8.337 m.	Concrete
2. BA2-BA3	120.185 m.	Concrete
3. BA3-BA4	8.281 m.	Concrete
4. BA1-Ab1	13.969 m.	Concrete
5. Ab2-BA4	13.669 m.	Concrete
6. Deck/Beam thickness	1.064 m.	Concrete
7. Deck Elevation	5.355 m. MSL	Concrete
8. P1-P2	20.000 m.	Concrete
9. P2-P3	20.000 m.	Concrete
10. P3-P4	20.000 m.	Concrete
11. P4-P5	20.000 m.	Concrete

Note: Observer should be facing downstream

Figure 39. Sta. Cruz Bridge Data Sheet

Gathering of random points for the checking of HONS's bridge cross-section and bridge points data was performed by DVBC on October 16, 2016 at Sta. Cruz Bridge using a survey grade GNSS Rover receiver attached to a 2-m pole as seen in Figure 40.

Figure 40. Gathering of random cross-section points along Sta. Cruz Bridge

Linear square correlation (R2) and RMSE analysis were performed on the two (2) datasets for the two (2) bridges. The linear square coefficient range is determined to ensure that the submitted data of the contractor is within the accuracy standard of the project which is ±20 cm and ±10 cm for horizontal and vertical, respectively. The R2 value must be within 0.85 to 1. An R2 approaching 1 signifies a strong correlation between the vertical (elevation values) of the two datasets. A computed R2 value of 0.984 was obtained by comparing the data of the contractor and DVBC for the bridge points data of Sta. Cruz Bridge; signifying a strong correlation between the two (2) datasets.

In addition to the Linear Square correlation, Root Mean Square (RMSE) analysis is also performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge points data of Sta. Cruz Bridge, a computed value of 0.839 was acquired. The computed R2 and RMSE values are within the accuracy requirement of the program.

Water surface elevation of Tangatan River was determined by a Sokkia™ Set CX Total Station on February 9, 2017 at 1:15 PM at Casagan Hanging Bridge area in Brgy. Casagan, Sta. Ana, Cagayan with a value of 0.259 m in MSL as shown in Figure 33. This was translated into marking on the bridge's riprap as shown in Figure 41.

Figure 41. Water level markings on the post of Casagan Hanging Bridge

Water surface elevation of Tangatan River was also determined by a Sokkia™ Set CX Total Station on February 9, 2017 at 9:00 AM at Sta. Cruz Bridge area in Brgy. Sta. Cruz, Sta. Ana, Cagayaan with a value of -0.429 m in MSL as shown in Figure 38. This was translated into marking on the bridge's pier as shown in Figure 42. The markings will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Tangatan River, the Isabela State University.

Figure 42. Water level marking on the pier of Sta. Cruz Bridge

4.6 Validation Points Acquisition Survey

The Validation Points Acquisition survey was conducted by DVBC on October 16, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 43. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.460 m and measured from the ground up to the bottom of the antenna mount of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with CGY-102 occupied as the GNSS base station in the conduct of the survey.

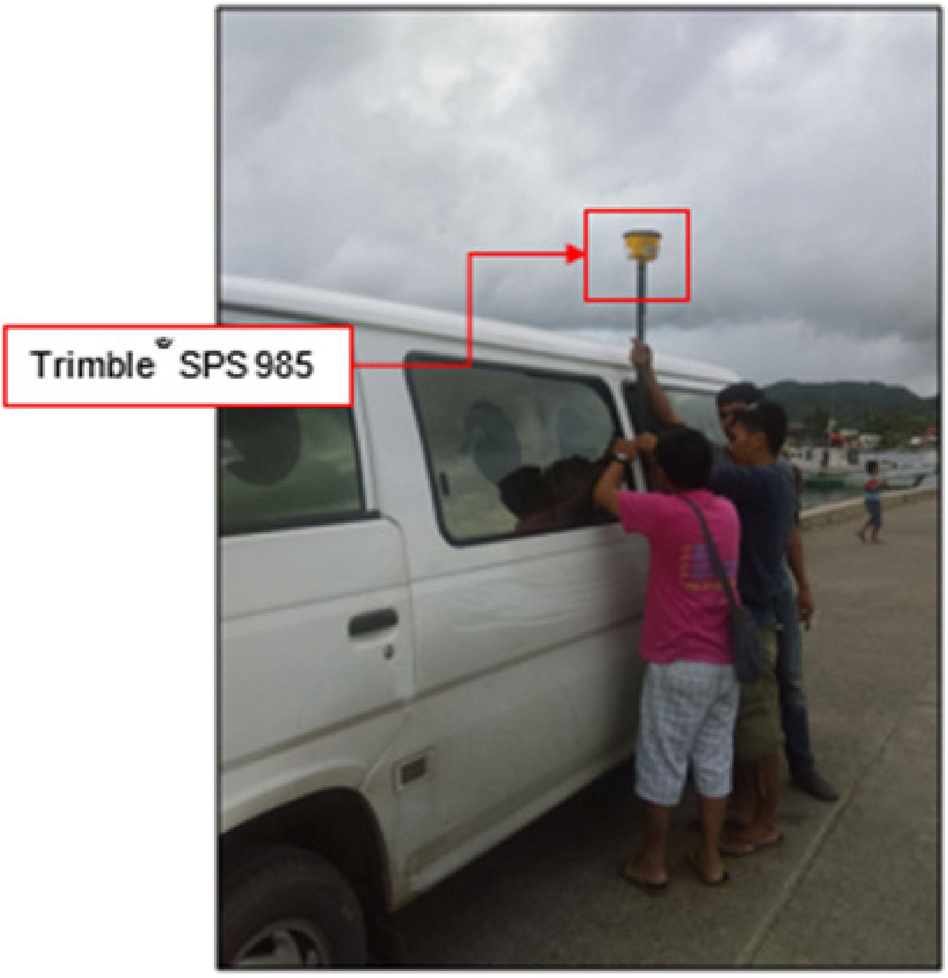


Figure 43. Validation points acquisition survey set-up for Tangatan River

The survey started from Brgy. San Jose, Gonzaga, Cagayan going northeast along the national highway, covering eight (8) barangays in Sta. Ana and ended in Brgy. San Vicente, Sta. Ana, Cagayan. The survey gathered a total of 4,378 points with approximate length of 22.71 km using CGY-102 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 44.

Figure 44. Validation points acquisition survey coverage for Tangatan River Basin

4.7 River Bathymetric Survey

The Bathymetric Survey was executed on March 17-18, 2017 using a dual frequency Hi-Target™ V30 GNSS GPS and a Hi-Target™ Single Beam Echo Sounder mounted in a motor boat as illustrated in Figure 45. The survey started in Brgy. Casagan, Sta. Ana, Province of Cagayan with coordinates 18° 28’ 20.4817” N, 122° 10’ 20.5593” E and ended at the mouth of the river in Brgy. Tangatan, also in the Municipality of Sta. Ana, with coordinates 18° 29’ 52.1270” N, 122° 08’ 52.4664” E.

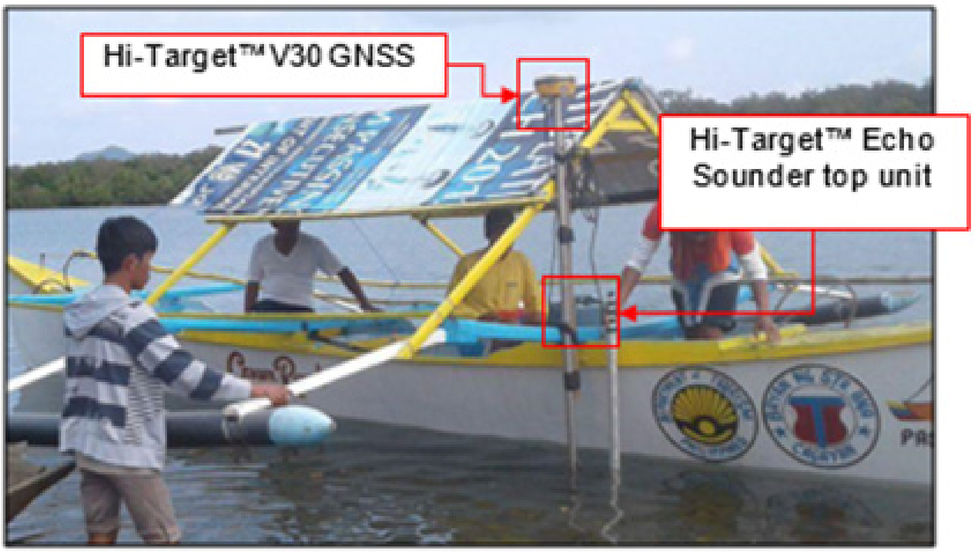


Figure 45. Bathymetric survey along Tangatan River

Manual bathymetric survey, on the other hand, was executed on Feb. 9, 2017, Mar. 17-18, 2017, and Mar. 20, 2017 using a Hi-Target™ V30 GNSS GPS as illustrated in Figure 46. The survey started in Brgy. Dungeg, Municipality of Sta. Ana, Province of Cagayan with coordinates 18° 26’ 14.2578” N, 122° 11’ 53.8700” E, traversing down the river and ended at starting point of the bathymetric survey using a boat in Brgy. Casagan, also in the Municipality of Sta. Ana. The control points UP-TAN-3, UP-TAN-5, UP-TAN-6, and UP-TAN-7 were used as GNSS base stations all throughout the entire survey.

Figure 46. Manual bathymetric survey of HONS along Tangatan River

Gathering of random points for the checking of HONS's bathymetric data was performed by DVBC on December 2, 2016 using a survey grade GNSS Rover receiver attached to a boat as seen in Figure 48. A map showing the DVBC bathymetric checking points is shown in Figure 49.

Figure 47. Gathering of random bathymetric points along Tangatan River

Linear square correlation (R2) and RMSE analysis were also performed on the two (2) datasets and a computed R2 value of 0.091 for the bathymetric data is not within the required range for R2, which is 0.85 to 1; however, its maximum value of 0.499 m did not exceed the maximum value of the difference in elevation of 0.5 m. Additionally, an RMSE value of 0.279 for the bathymetric data was obtained. Both the computed R2 and RMSE values are within the accuracy required by the program.

The bathymetric survey for Tangatan River gathered a total of 2,460 points covering 14.90 km of the river traversing barangays Dungeg, Marede, Casagan, Sta. Cruz, and Tangatan in the Municipality of Sta. Ana. A CAD drawing was also produced to illustrate the riverbed profile of Tangatan River. As shown in Figures 50 and 51, the highest and lowest elevation has a 7.63-m difference.

The highest elevation observed was 4.211 m above MSL located in Brgy. Dungeg, Sta. Ana, Cagayan while the lowest was -3.423 m below MSL located in Brgy. Sta. Cruz, Sta. Ana, Cagayan.

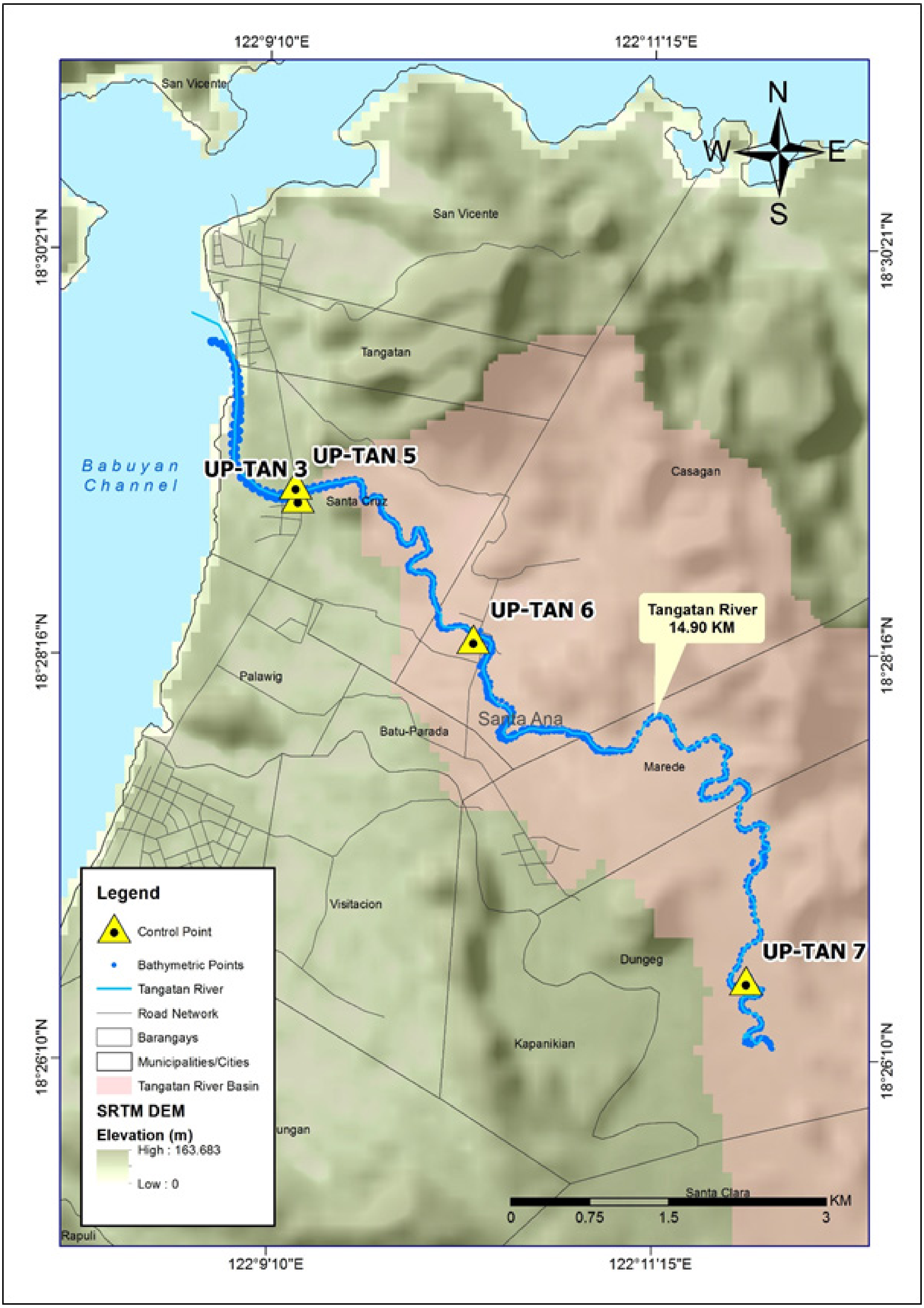


Figure 48. Bathymetric survey of Tangatan River

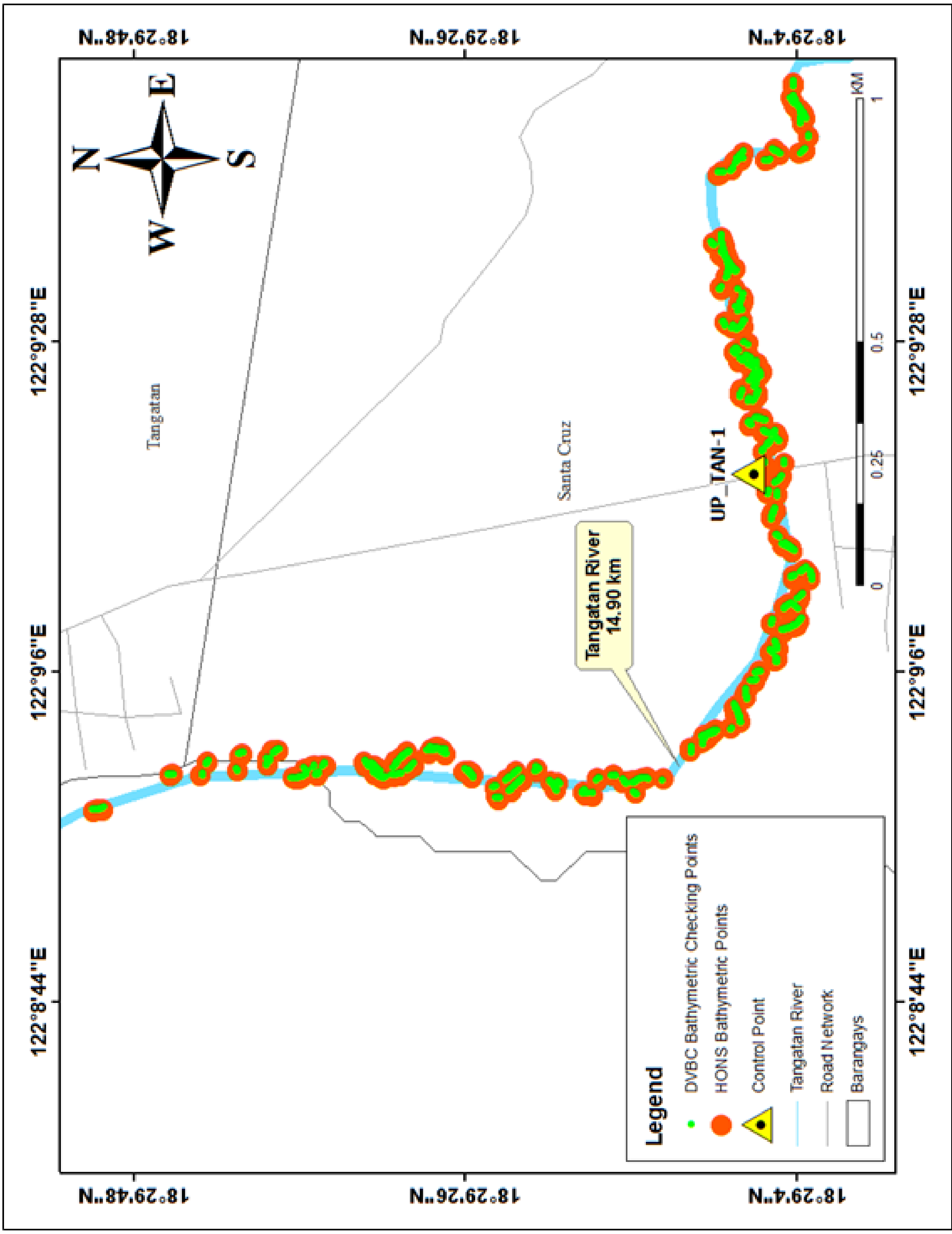


Figure 49. Quality checking points gathered along Tangatan River by DVBC

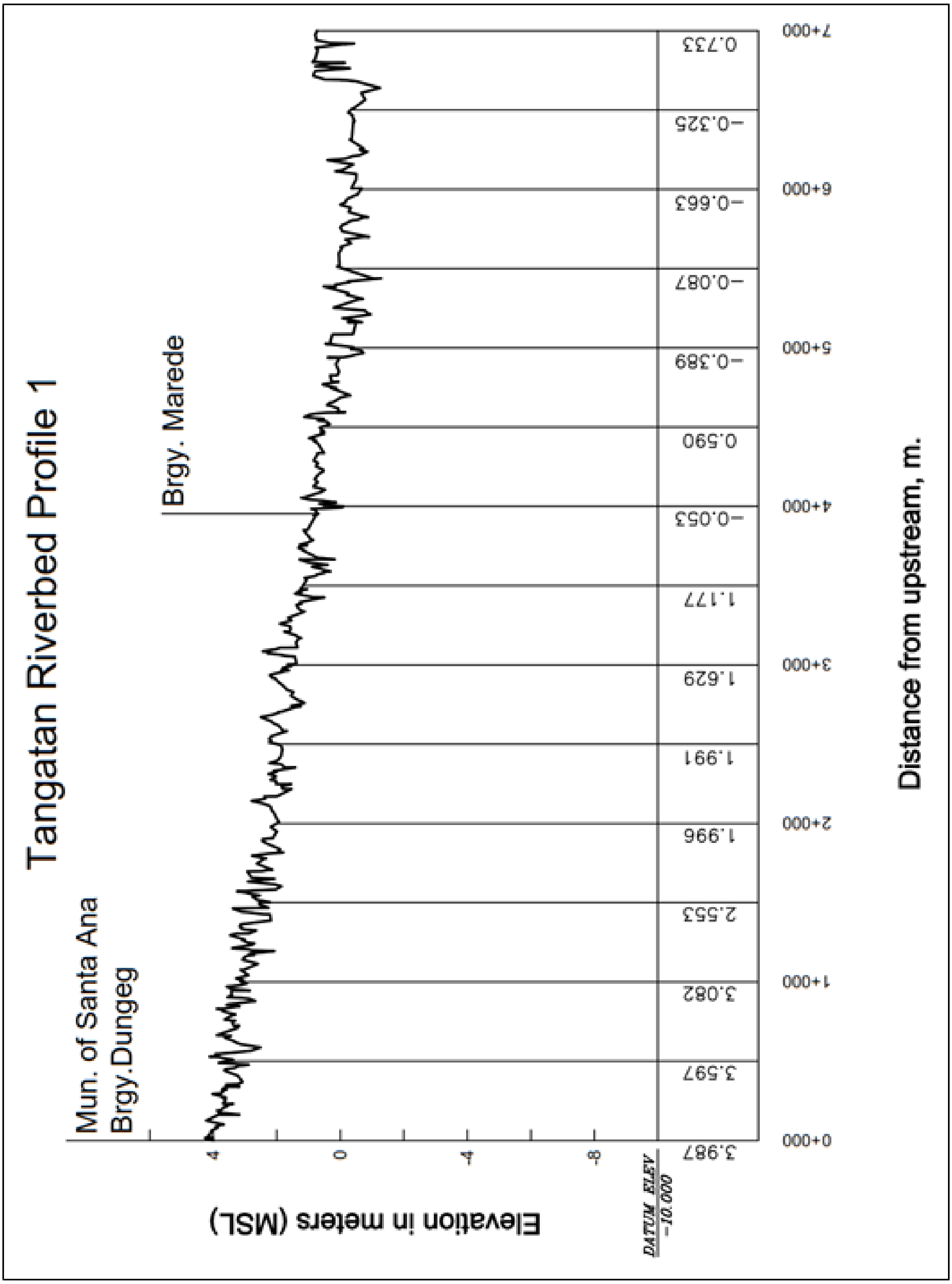


Figure 50. Tangatan Riverbed Profile 1 from Brgy. Dungeg

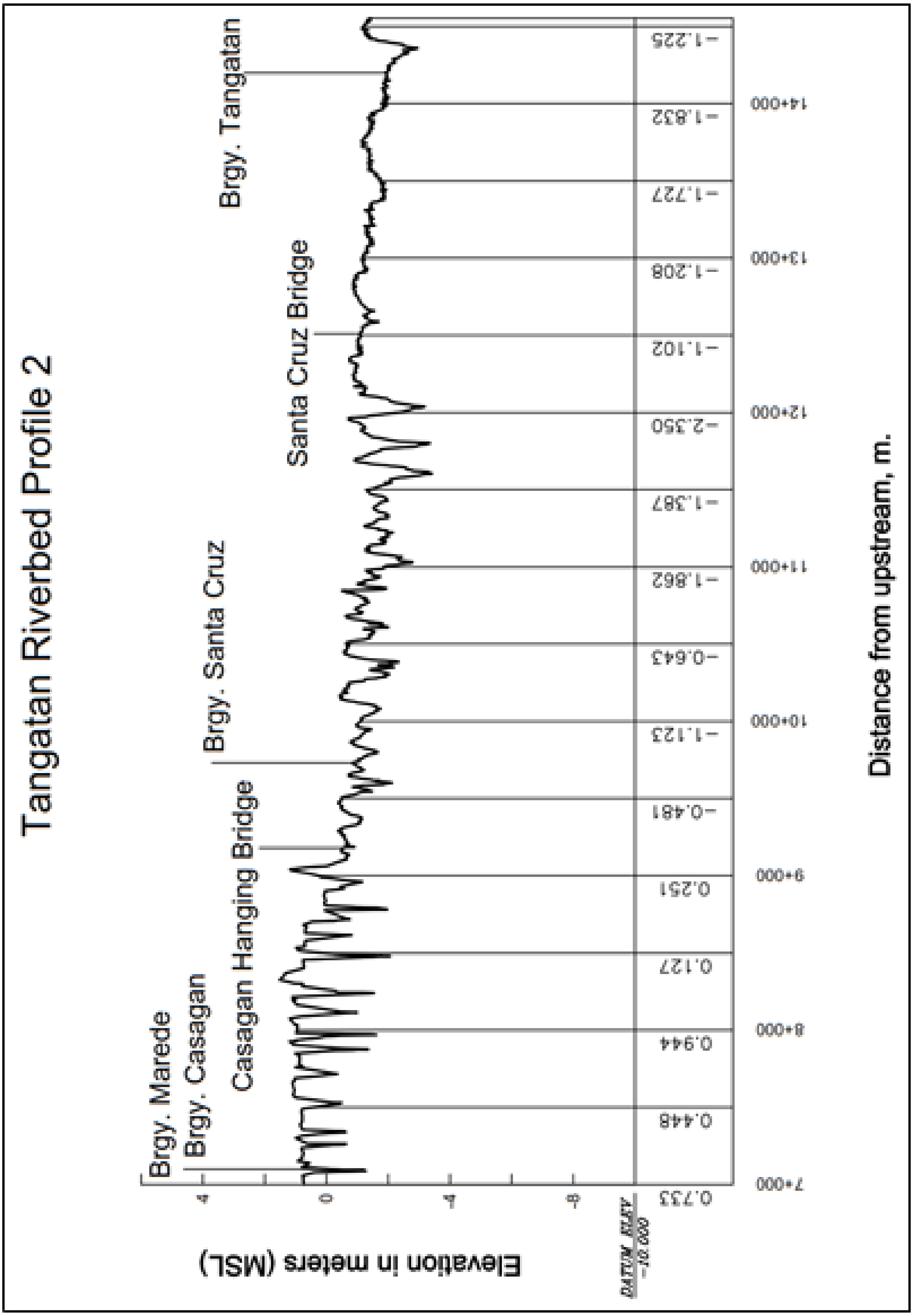


Figure 51. Tangatan Riverbed Profile 2 from Brgy. Dungeg

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, Mariel Monteclaro

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

The components and data that affect the hydrologic cycle of the river basin were monitored, collected, and analyzed. These include the rainfall, water level, and the flow in a certain period of time.

5.1.2 Precipitation

Cagayan, including the Tangatan River Basin, often experiences heavy and long term rain such as Monsoon Rain during the months of January to March. The hydrologic data collection covered the period of 22 March 2017. Hydrologic data include the river velocity, water depth and rain collected from data logging sensors (mechanical velocity meter, depth gauge and rain gauges) in specific time period. Precipitation data was taken from the Brgy. Santa Clara, Cagayan. The location of the rain gauge is seen in Figure 52.

Total rain from the Santa Clara ARG is 59 mm. It peaked to 6mm on 22 March 2017 7:30 A.M. The lag time between the peak rainfall and discharge is 7 hours and 20 minutes. The ARG for Tangatan River Basin is shown Figure 54.

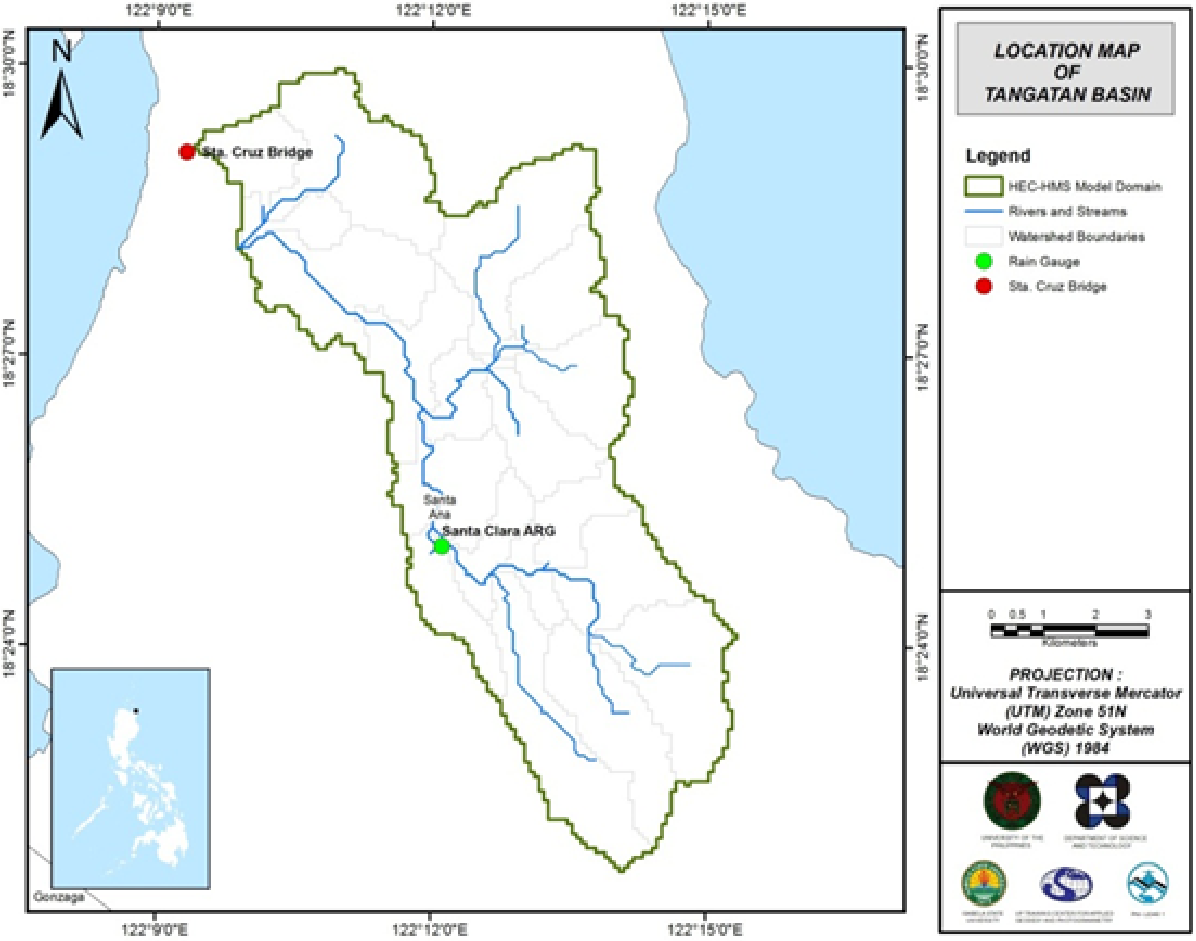


Figure 52. Location map of Tangatan HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

The Monsoon rain that occurred on 22 March 2017 contributed to a 0.768 meter water level rise with peak discharge of 56.5m3/s recorded at 12:20 PM on 22 March 2017 with accumulated rainfall 59 mm. These hydrologic data is the actual event of Tangatan River and inputted to hydrologic modeling. Hydrologic measurements were taken from Sta. Cruz Bridge, Sta. Ana, Cagayan.

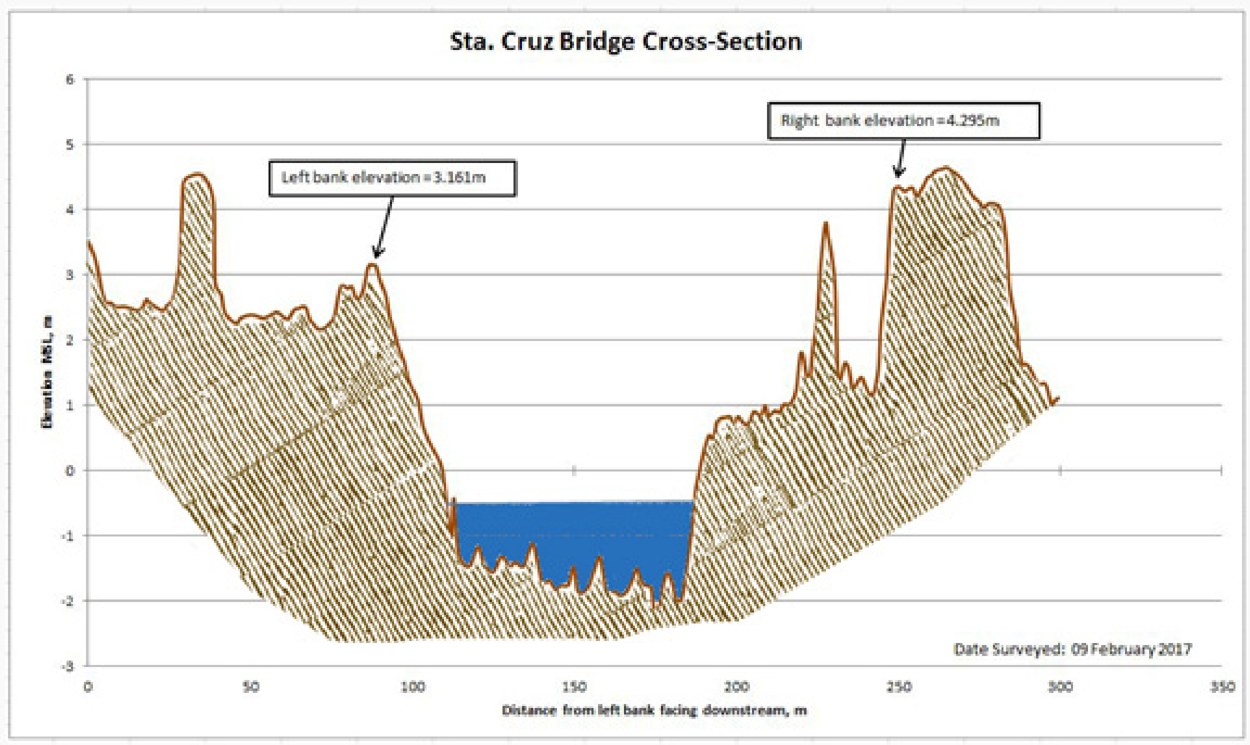


Figure 53. Cross Section Plot of Sta. Cruz Bridge

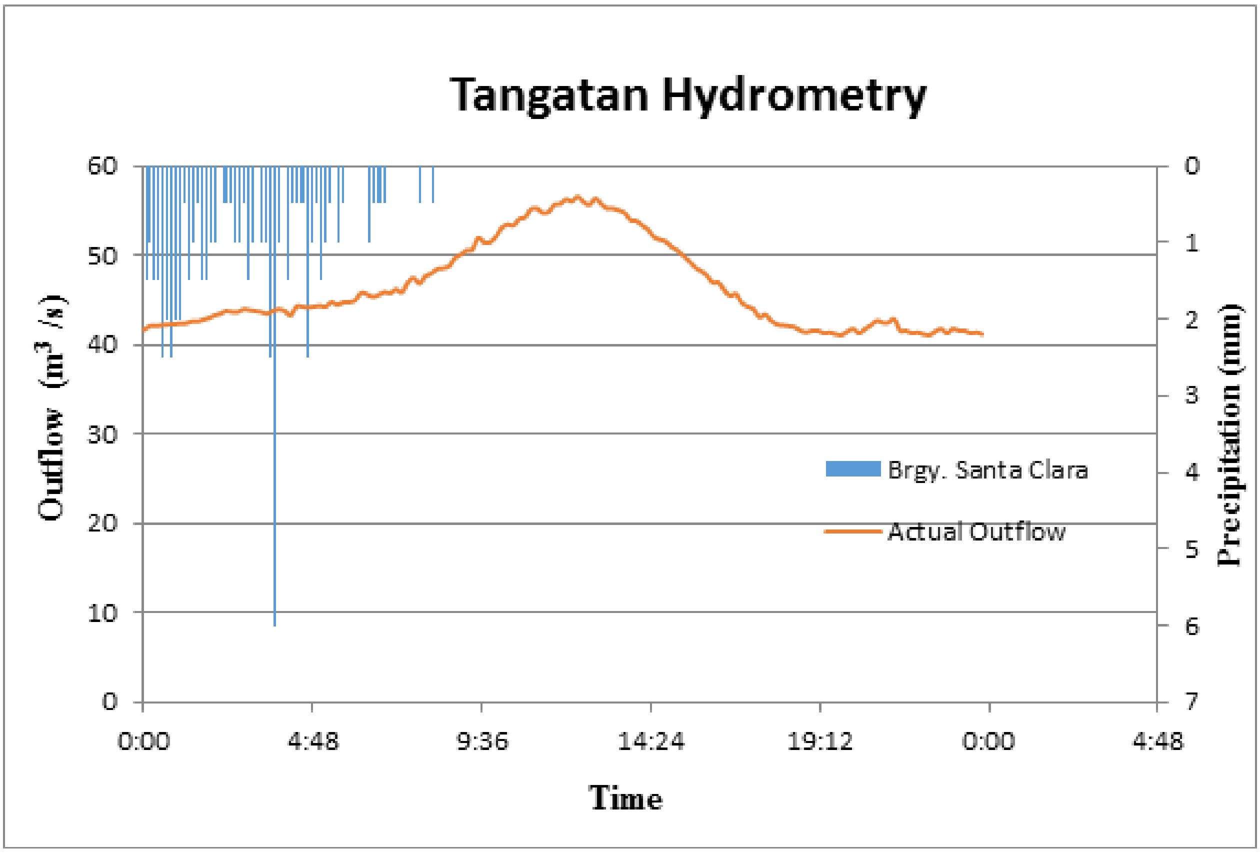


Figure 54. Rainfall and outflow data used for modeling

A rating curve was generated for the observed flow and water level. It shows the relationship of the two hydrologic data. It is expressed in the form of the following equation:

Q=anh

where,

Q : Discharge (m3/s),
h : Gauge height (reading from Sta. Cruz Bridge depth gauge sensor), and
a and n : Constants.

The Tangatan River Rating Curve measured at Sta Cruz Bridge is expressed as Q = 36.362e0.5738x (Figure 55).

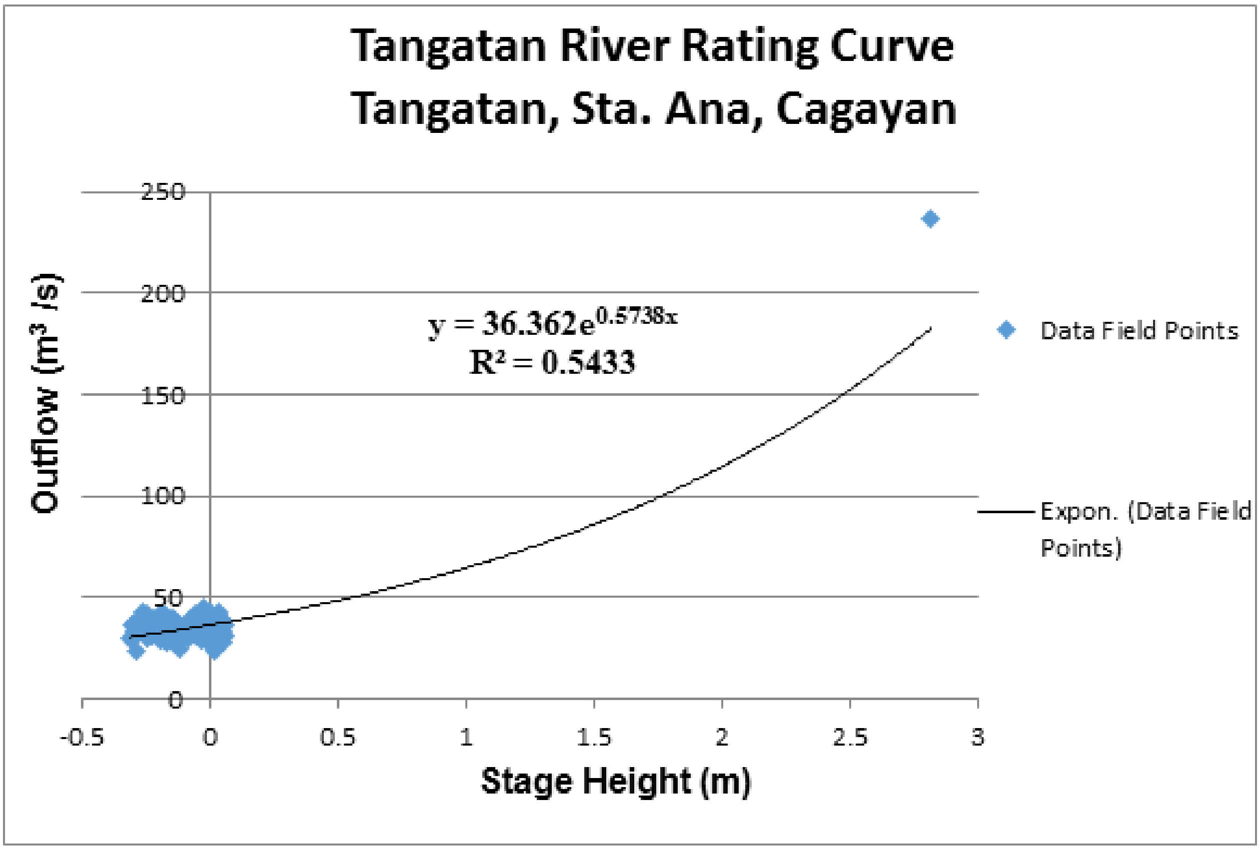


Figure 55. HQ Curve of HEC-HMS model

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed the Rainfall Intensity Duration Frequency (RIDF) values for the Aparri 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 was chosen based on its proximity to the Tangatan watershed. The extreme values for this watershed were computed based on a 47-year record.

Table 26. RIDF values for the Aparri Rain Gauge, as computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	20.1	31.4	39.4	53.3	75.6	92.2	119.4	147.7	167.9
5	28.5	44.9	55.8	78.7	110.4	137	173.6	221.2	252.5
10	34.1	53.8	66.6	95.6	133.4	166.6	209.5	269.9	308.5
15	37.2	58.8	72.7	105.1	146.5	183.4	229.7	297.4	340.2
20	39.4	62.3	77	111.8	155.6	195.1	243.9	316.6	362.3
25	41.1	65	80.3	116.9	162.6	204.1	254.8	331.4	379.3
50	46.3	73.4	90.5	132.7	184.2	231.9	288.4	377.1	431.9
100	51.4	81.7	100.6	148.4	205.6	259.5	321.7	422.4	484

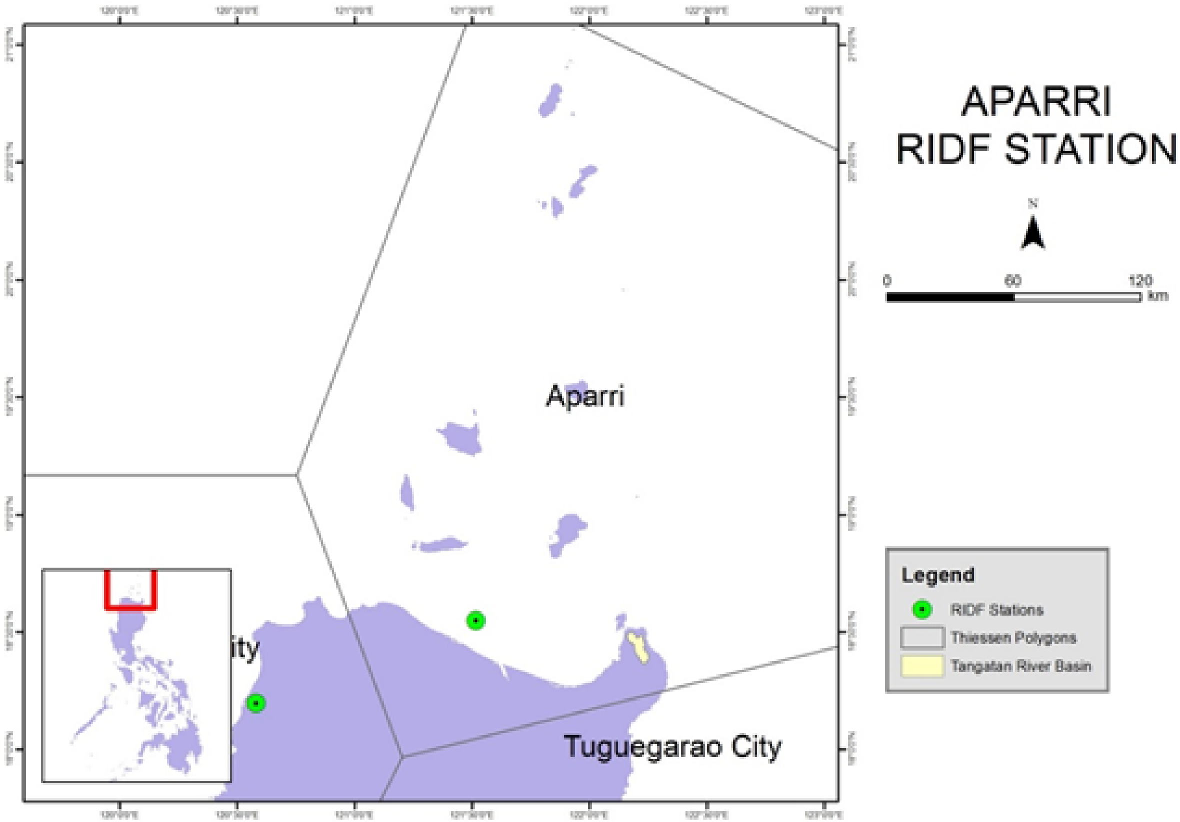


Figure 56. Location of Aparri RIDF Station relative to Tangatan River Basin

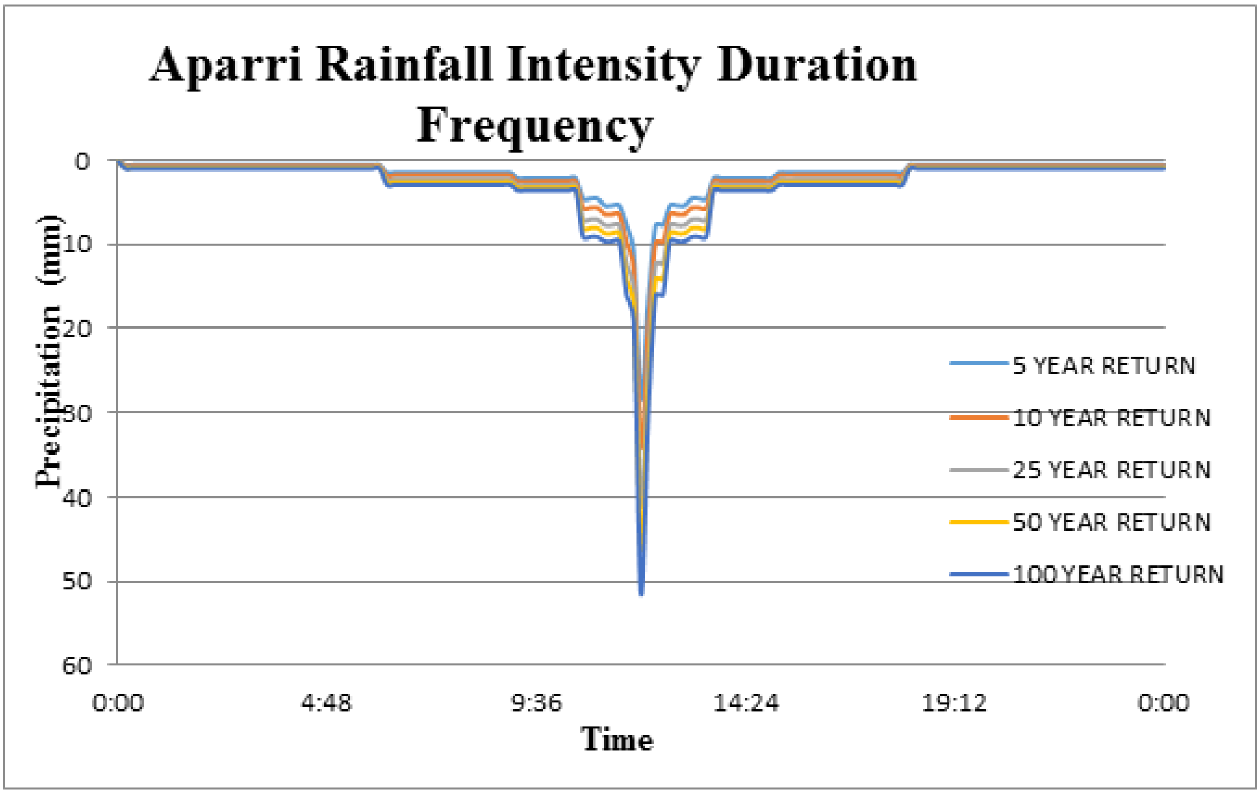


Figure 57. Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil dataset, taken in 2004, was sourced out from the Bureau of Soils under the Department of Agriculture. The land cover data, on the other hand, was taken from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Tangatan River Basin are shown in Figures 58 and 59, respectively.

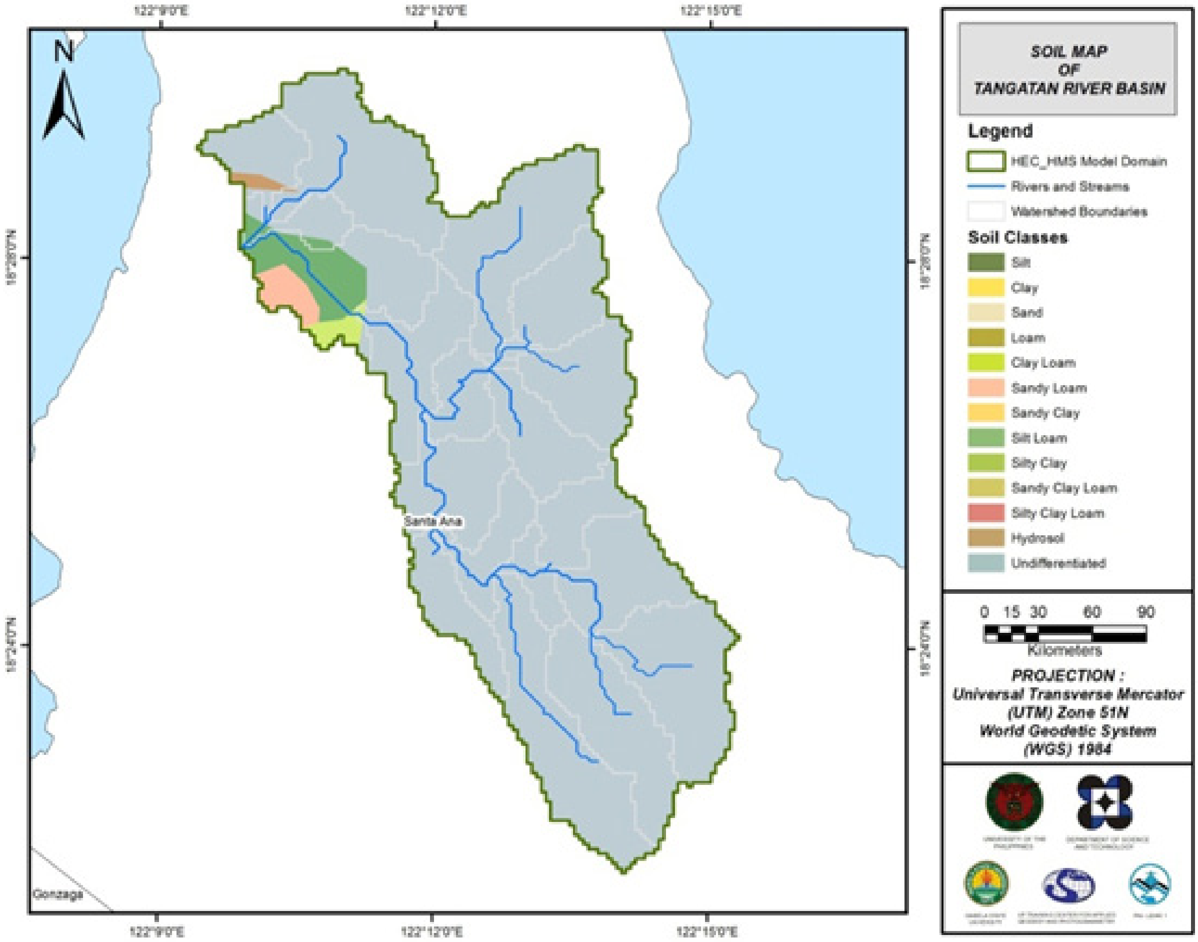


Figure 58. Soil Map of Tangatan River Basin

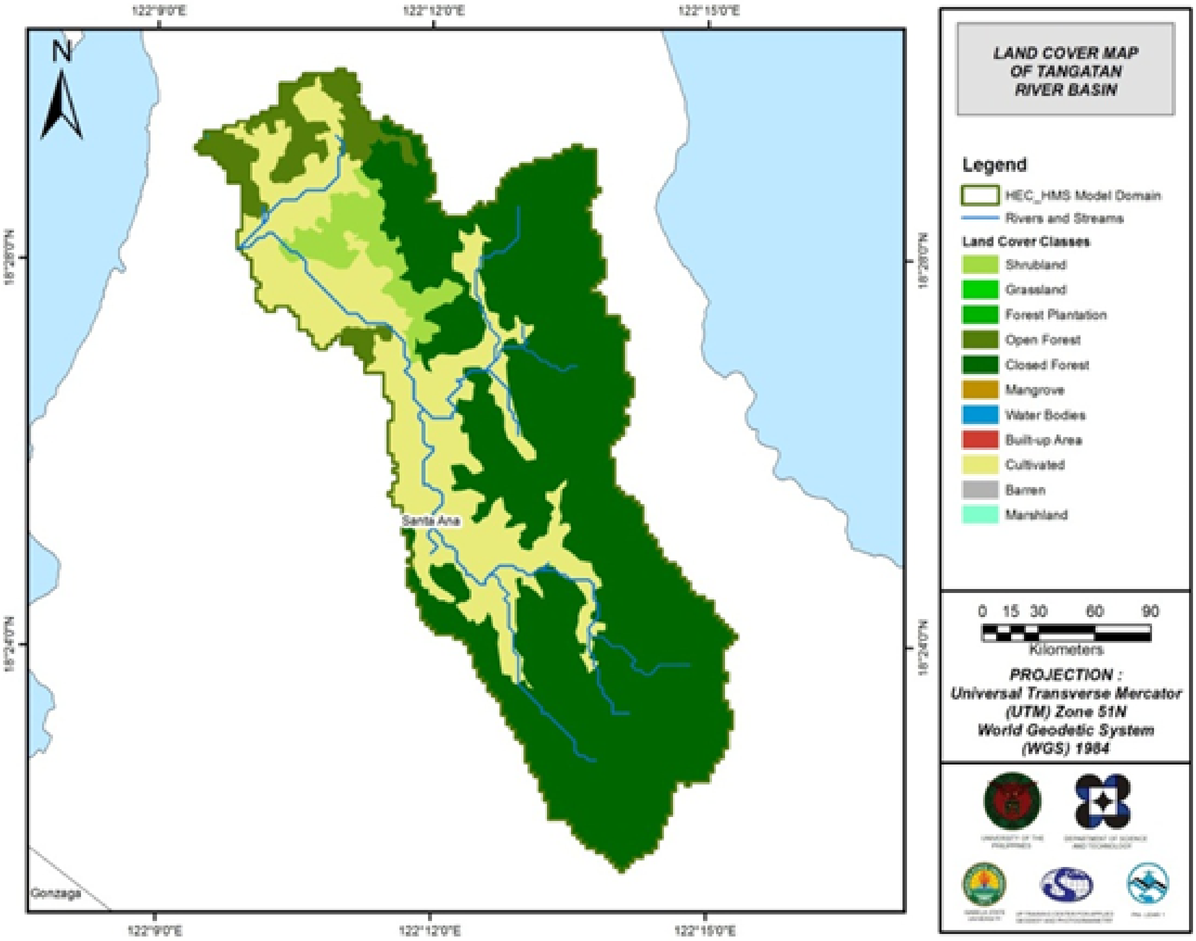


Figure 59. Land Cover Map of Tangatan River Basin

For Tangatan, five (5) soil classes were identified. These are silt, clay loam, sandy loam, hydrosol and undifferentiated soil. Moreover, four (4) land cover classes were identified. These are shrubland, open forest, closed forest, and cultivated area.

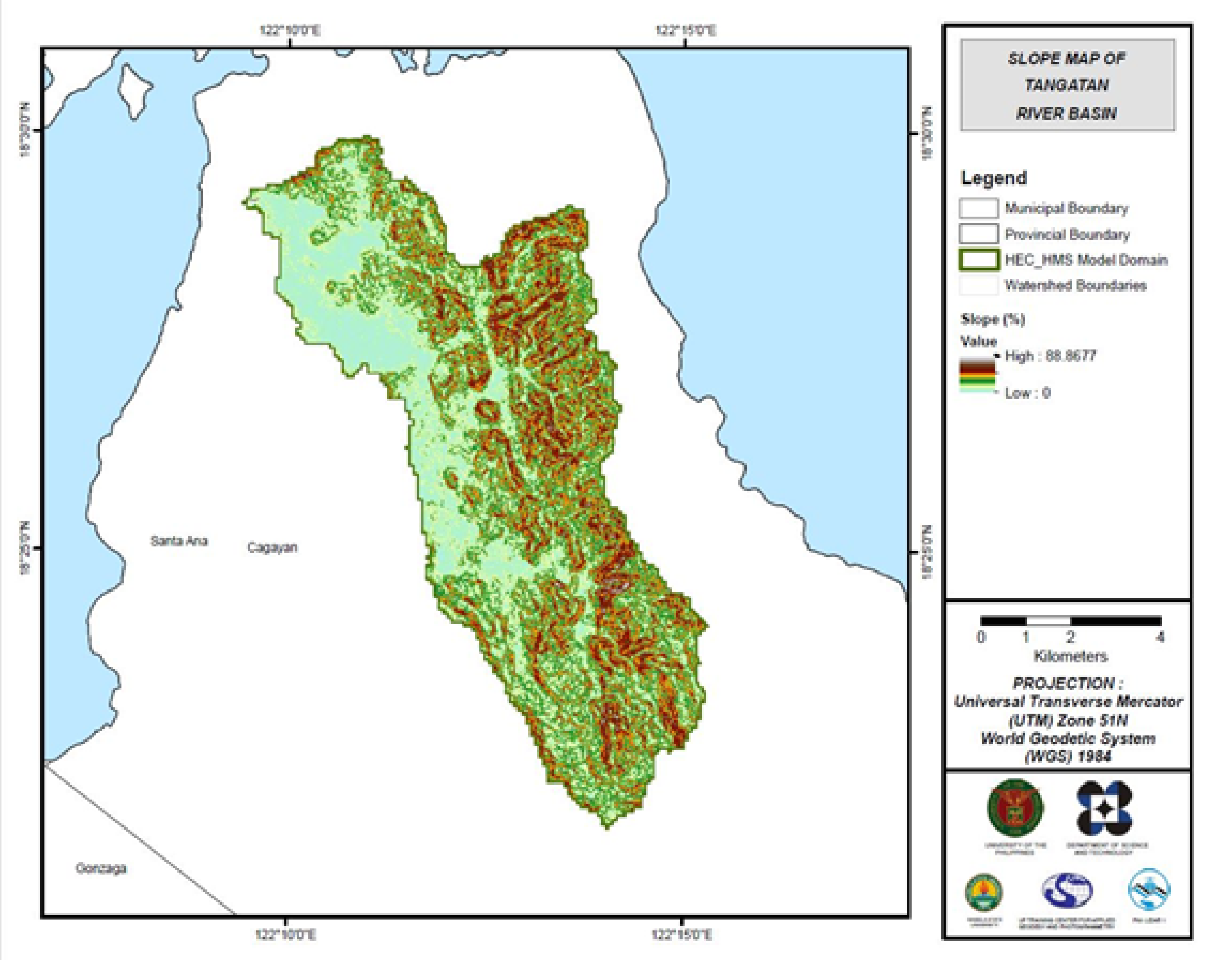


Figure 60. Slope Map of the Tangatan River Basin

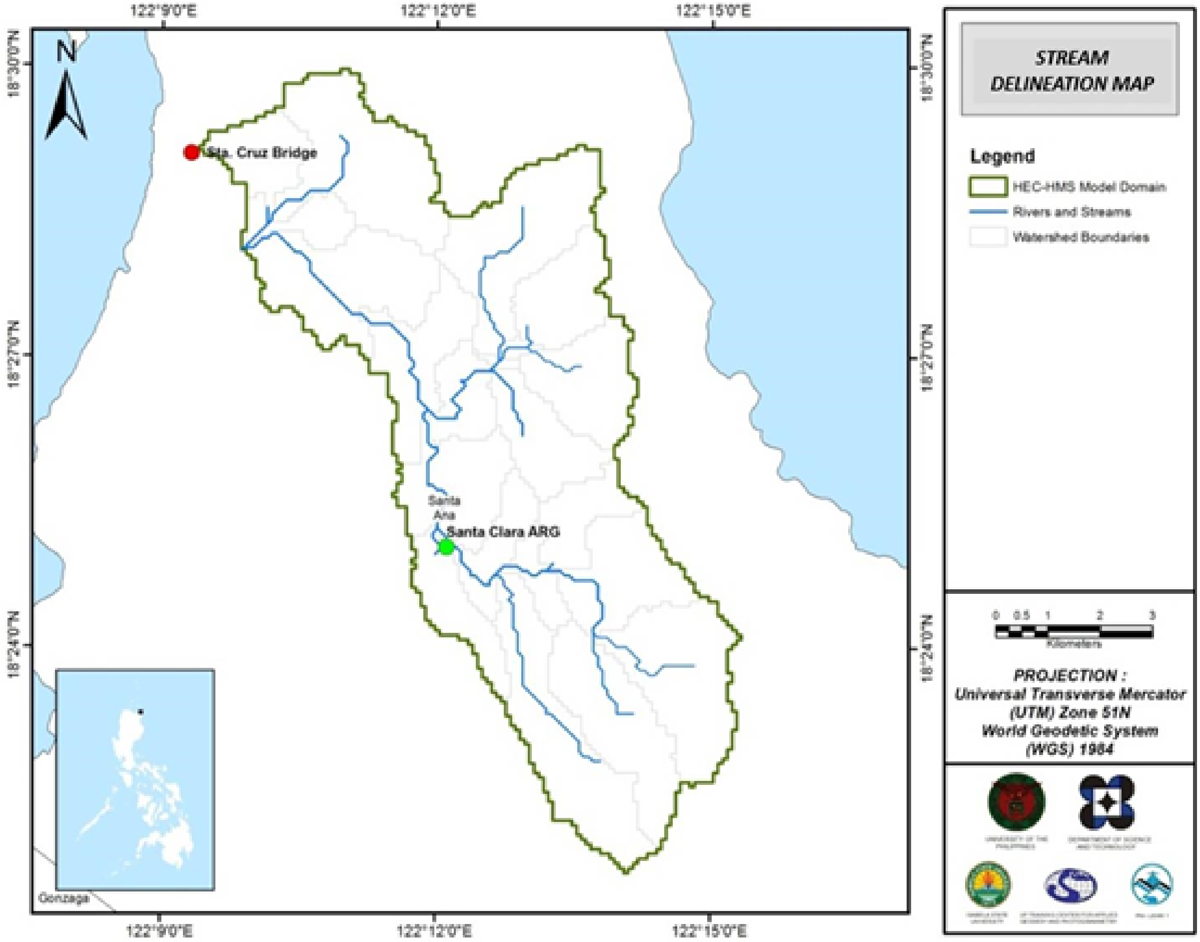


Figure 61. Stream Delineation Map of the Tangatan River Basin

A drainage system includes the basin boundary, subbasin and the stream networks of the basin. Using ArcMap 10.2 with HEC-GeoHMS version 10.2 extension, the Tangatan River centerline and SAR-DEM 10m resolution served as primary data, delineating the drainage system of the Tangatan river basin. The river centerline was digitized starting from upstream towards downstream in Google Earth (2014). Default threshold area used is 140 hectares.

Using the SAR-based DEM, the Tangatan basin was delineated and further subdivided into subbasins. The Tangatan Basin model consists of 22 subbasins, 11 reaches, and 10 junctions. The main outlet is at Outlet 1. This basin model is illustrated in Figure 62. The basins were identified based on soil and land cover characteristics of the area. Precipitation on 22 March 2017 (Monsoon Rain) was taken from the Brgy. Santa Clara ARG. Finally, it was calibrated using data from the Tangatan depth gauge sensor.

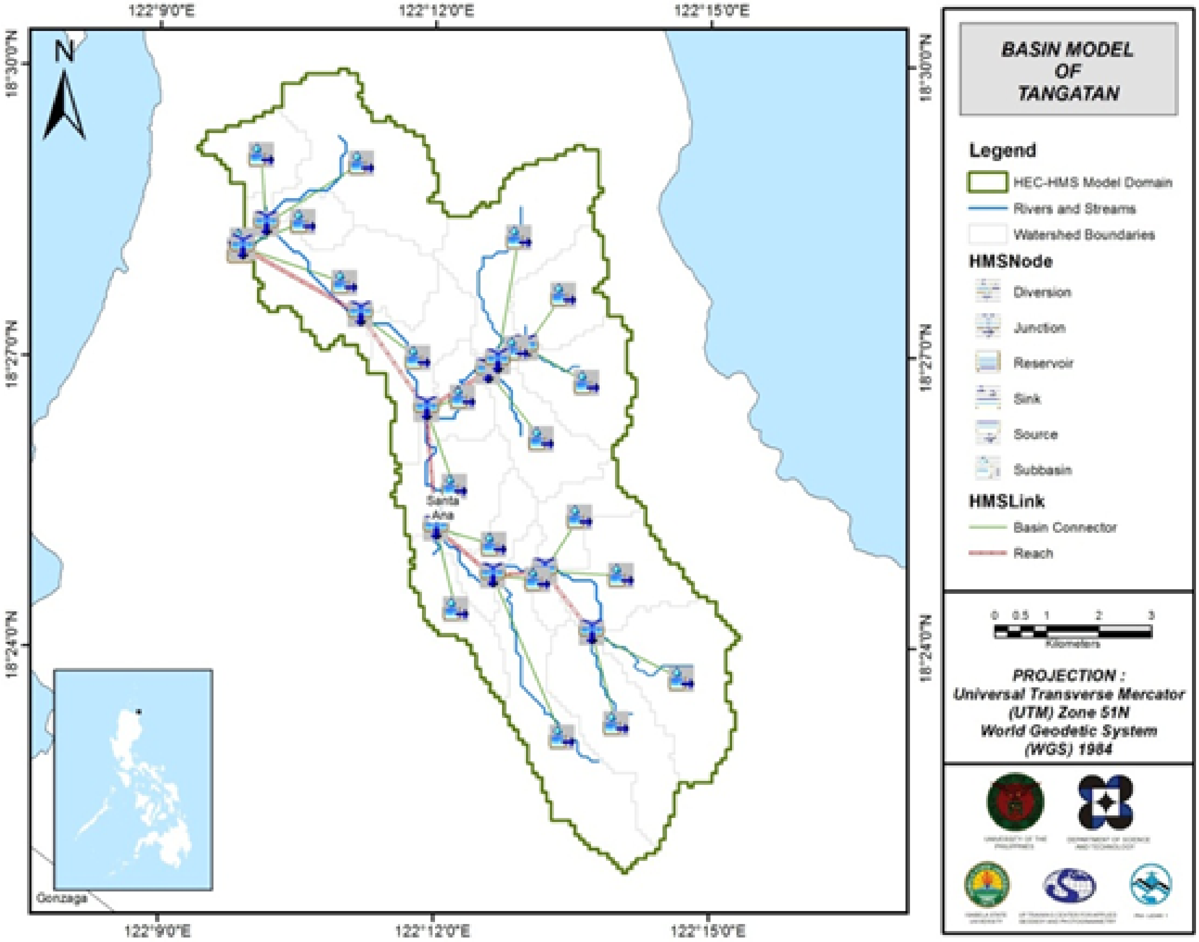


Figure 62. HEC-HMS generated Tangatan River Basin Model

5.4 Cross-section Data

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

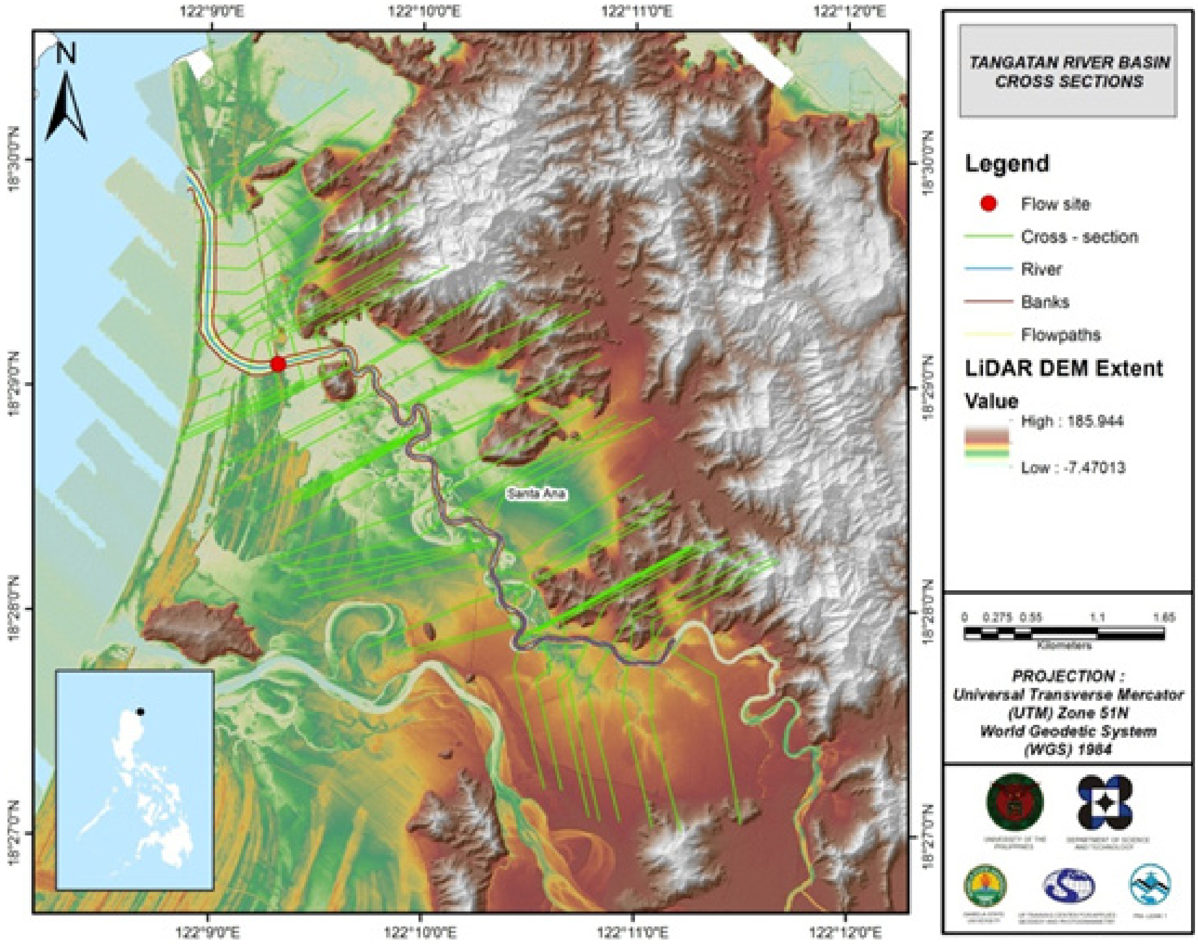


Figure 63. River cross-section of Tangatan River generated through Arcmap HEC GeoRAS tool

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 was divided into square grid elements, 10 meter by 10 meter in size. Each element was assigned with a unique grid element number which served 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 were arranged spatially to form the model, allowing the software to simulate the flow of water across the grid elements and in eight directions (north, south, east, west, northeast, northwest, southeast, southwest).

Based on the elevation and flow direction, it was seen that the water generally flows from the southeast of the model to the northwest, following the main channel. As such, boundary elements in those particular regions of the model were assigned as inflow and outflow elements respectively.

Figure 64. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation was then run through FLO-2D GDS Pro. This particular model had a computer run time of 96.46191 hours. After the simulation, FLO-2D Mapper Pro was used to transform the simulation results into spatial data showing flood hazard levels, as well as the extent and inundation of the flood. By assigning the appropriate flood depth and velocity values as Low, Medium, and High, the following food hazard map was created. Most of the default values given by FLO-2D Mapper Pro were used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) was set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) was set at 0 m2/s.

The creation of a flood hazard map from the model also automatically created a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper was not a good representation of the range of flood inundation values, so a different legend was used for the layout. In this particular model, the inundated parts covered a maximum land area of 102 842 592.00 m2.

There was a total of 128 535 709.02 m3 of water entering the model. Of this amount, 52 256 677.55 m3 was due to rainfall while 76 279 031.48 m3 was inflow from other areas outside the model. 15 800 858.00 m3 of this water was lost to infiltration and interception, while 40 272 552.26 m3 was stored by the floodplain. The rest, amounting up to 72 462 374.91 m3, was outflow.

5.6 Results of HMS Calibration

After calibrating the Tangatan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 65 shows the comparison between the two discharge data.

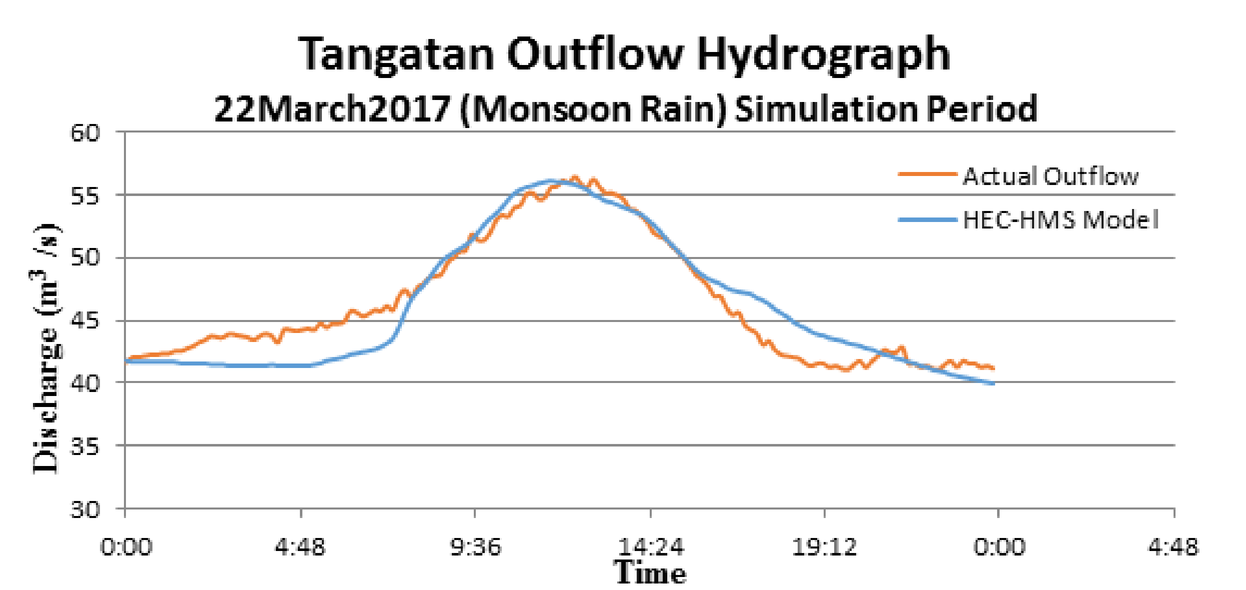


Figure 65. Outflow Hydrograph of Tangatan produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 27 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 27. Range of Calibrated Values for Tangatan

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	14.31 – 36.52
			Curve Number	67.82 - 92.92
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.22 – 5.31
			Storage Coefficient (hr)	0.50 – 8.93
	Baseflow	Recession	Recession Constant	0.55 – 1
			Ratio to Peak	0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.016 – 0.08

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 14.31mm to 36.52mm means that there is an average amount of infiltration or rainfall interception by vegetation.

The 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 for the curve number of Tangatan River Basin is 67.82 to 92.92. For Tangatan, the basin mostly consists of closed forest and cultivated areas and the soil mostly consists of undifferentiated soil.

The 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 0.22 hours to 8.93 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, while ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.55 - 1 indicates that the basin is highly unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.5 indicates a steep receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.016 - 0.08 corresponds to the common roughness in Tangatan watershed, which is determined to have scattered brush with heavy weeds (Brunner, 2010).

Table 28. Summary of the Efficiency Test of Tangatan HMS Model

Accuracy measure	Value
RMSE	0.8947
r^2	0.88
NSE	0.49
PBIAS	0.35
RSR	0.21

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 1.7 (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 0.8947.

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 0.88. A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 0.49.

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 0.35.

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

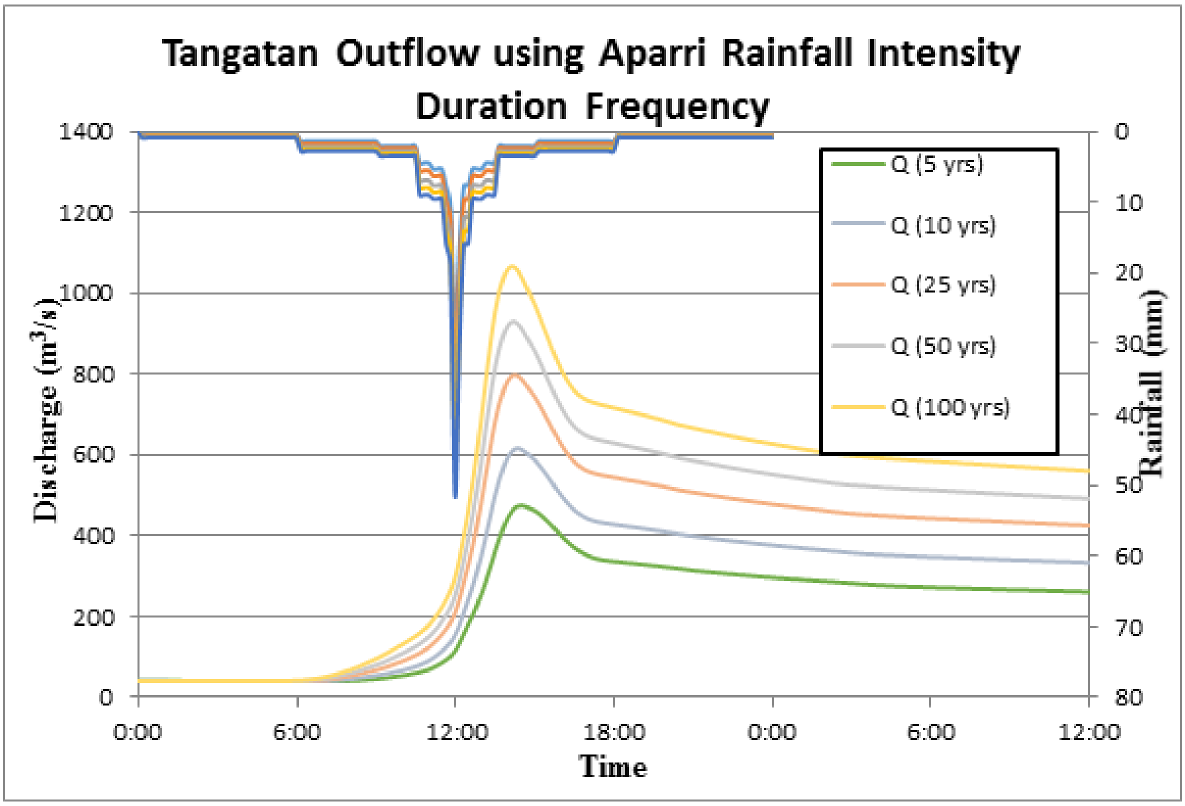


Figure 66. Outflow hydrograph at Tangatan Station generated using Maasin RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Tangatan discharge using the Aparri Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 29.

Table 29. Peak values of the Tangatan HEC-HMS Model outflow using the Aparri RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	252.5	28.5	473.1	2 hours, 30 minutes
10-Year	308.5	34.1	615.9	2 hours, 20 minutes
25-Year	379.3	41.1	796.5	2 hours,10 minutes
50-Year	431.9	46.3	930.1	2 hours, 10 minutes
100-Year	484	51.4	1064.2	2 hours, 10 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model was used in determining the flooded areas within the model. The simulated model is an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river will be shown. The sample generated map of Tangatan River using the calibrated HMS is shown in Figure 67.

Figure 67. Sample output of Tangatan RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figures 68 to 73 show the 5-, 25-, and 100-year rain return scenarios of the Tangatan Floodplain. The floodplain, with an area of 167.09 sq. km., covers two municipalities namely Gonzaga and Santa Ana. Table 30 shows the percentage of area affected by flooding per municipality.

Table 30. Municipalities affected in Tangatan Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Gonzaga	497.62	0.32	0.06%
Santa Ana	437.13	166.76	38%

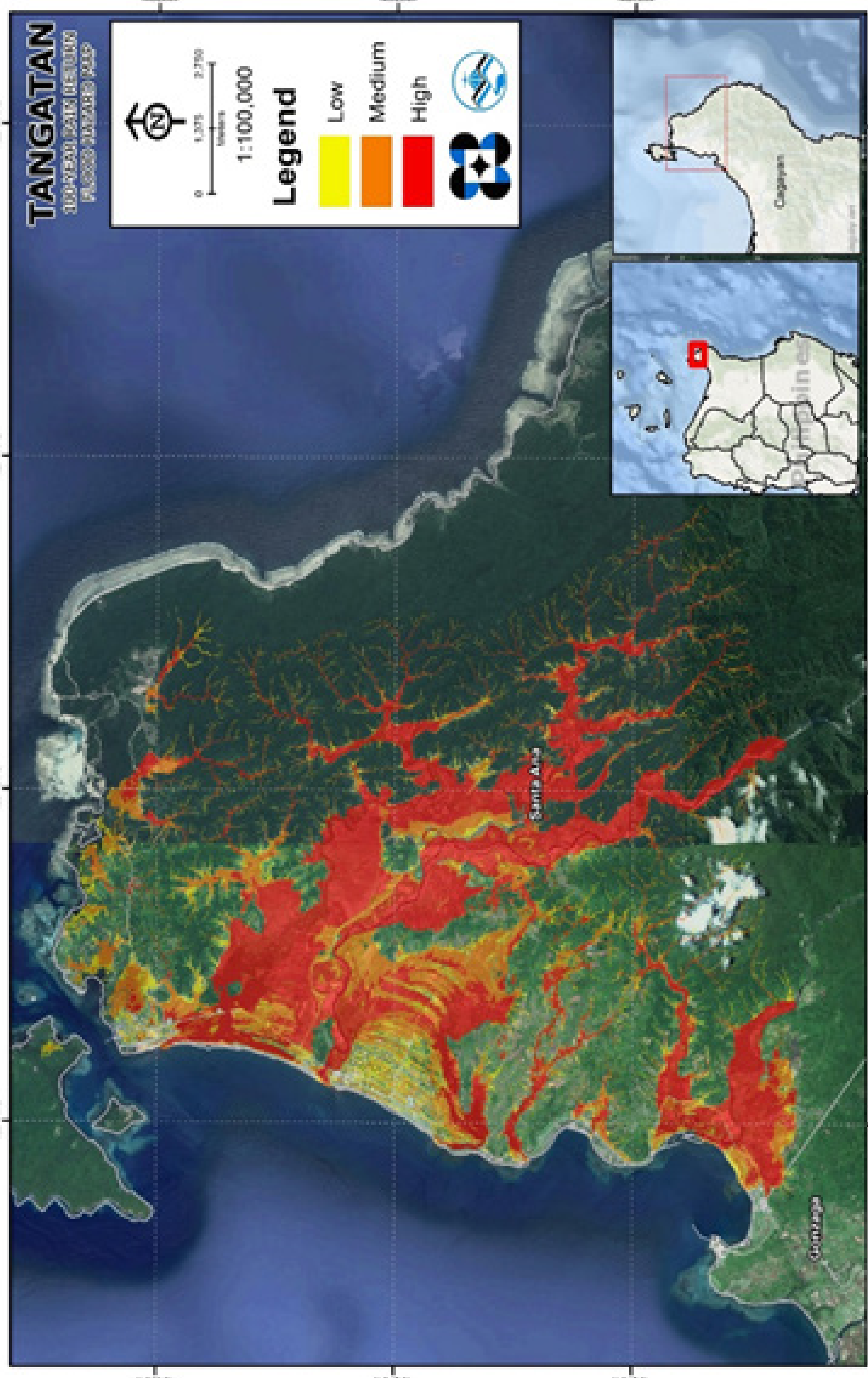


Figure 68. 100-year Flood Hazard Map for Tangatan Floodplain overlaid in Google Earth imagery

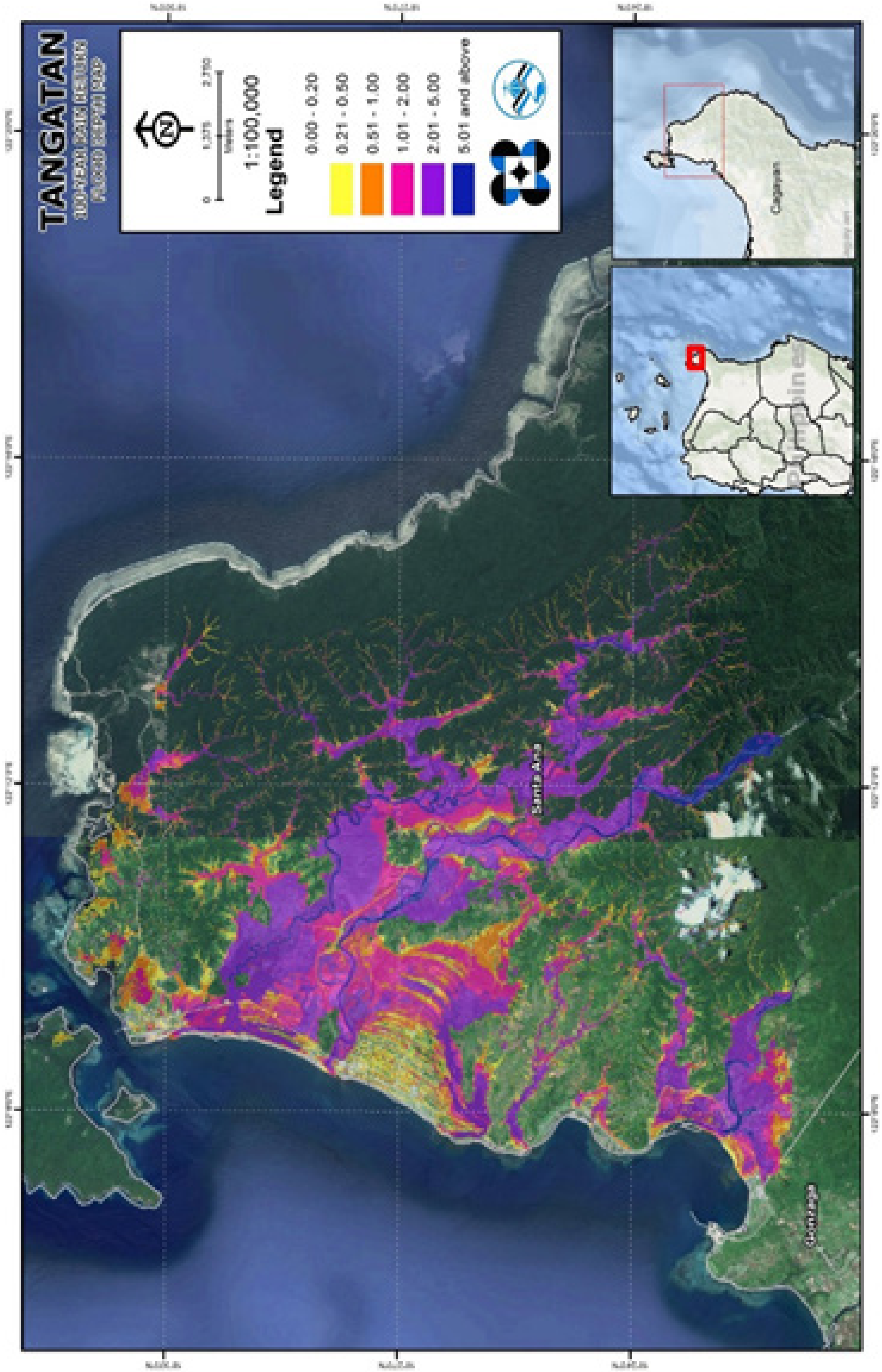


Figure 69. 100-year Flow Depth Map for Tangatan Floodplain overlaid in Google Earth imagery

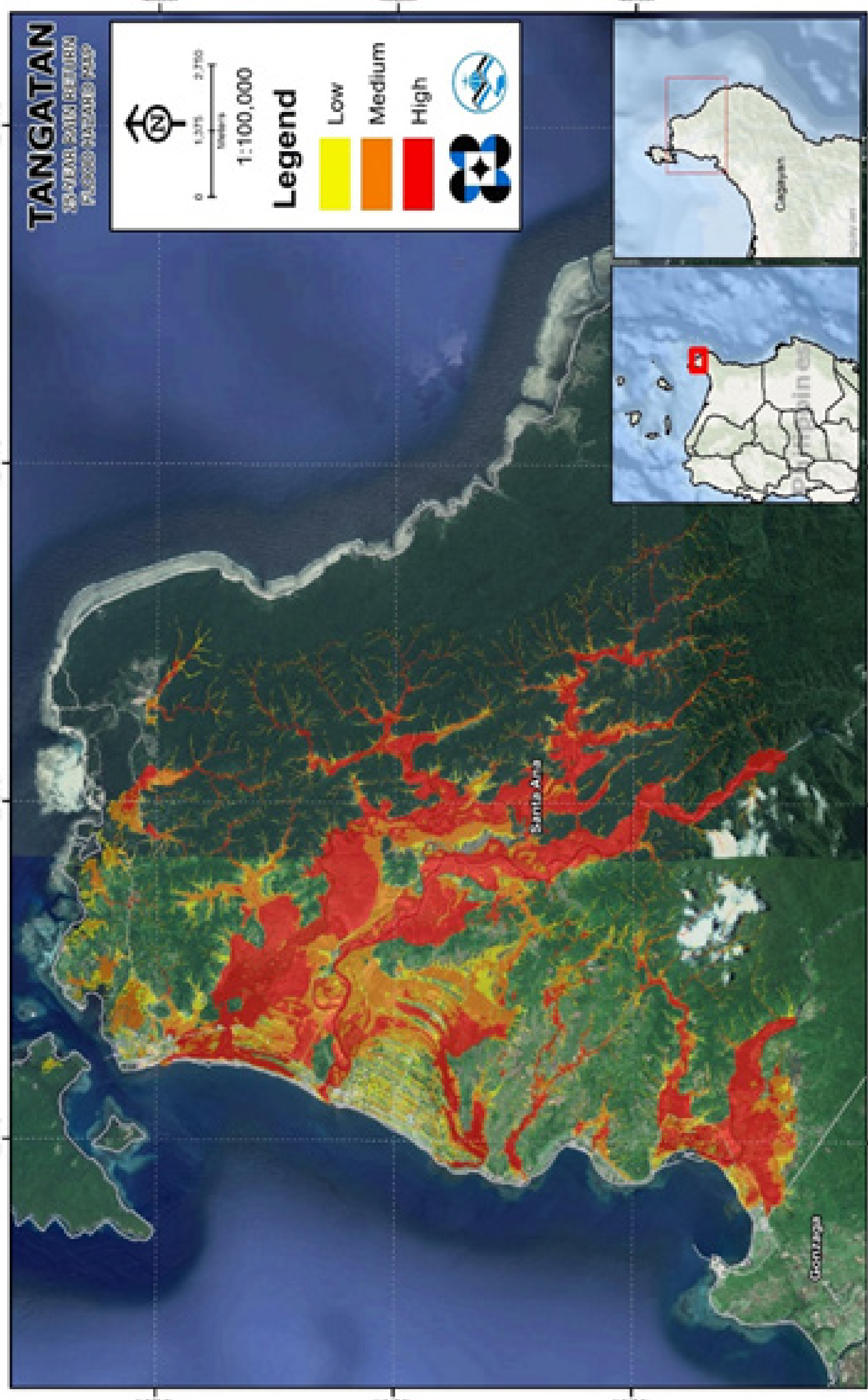


Figure 70. 25-year Flood Hazard Map for Tangatan Floodplain overlaid in Google Earth imagery

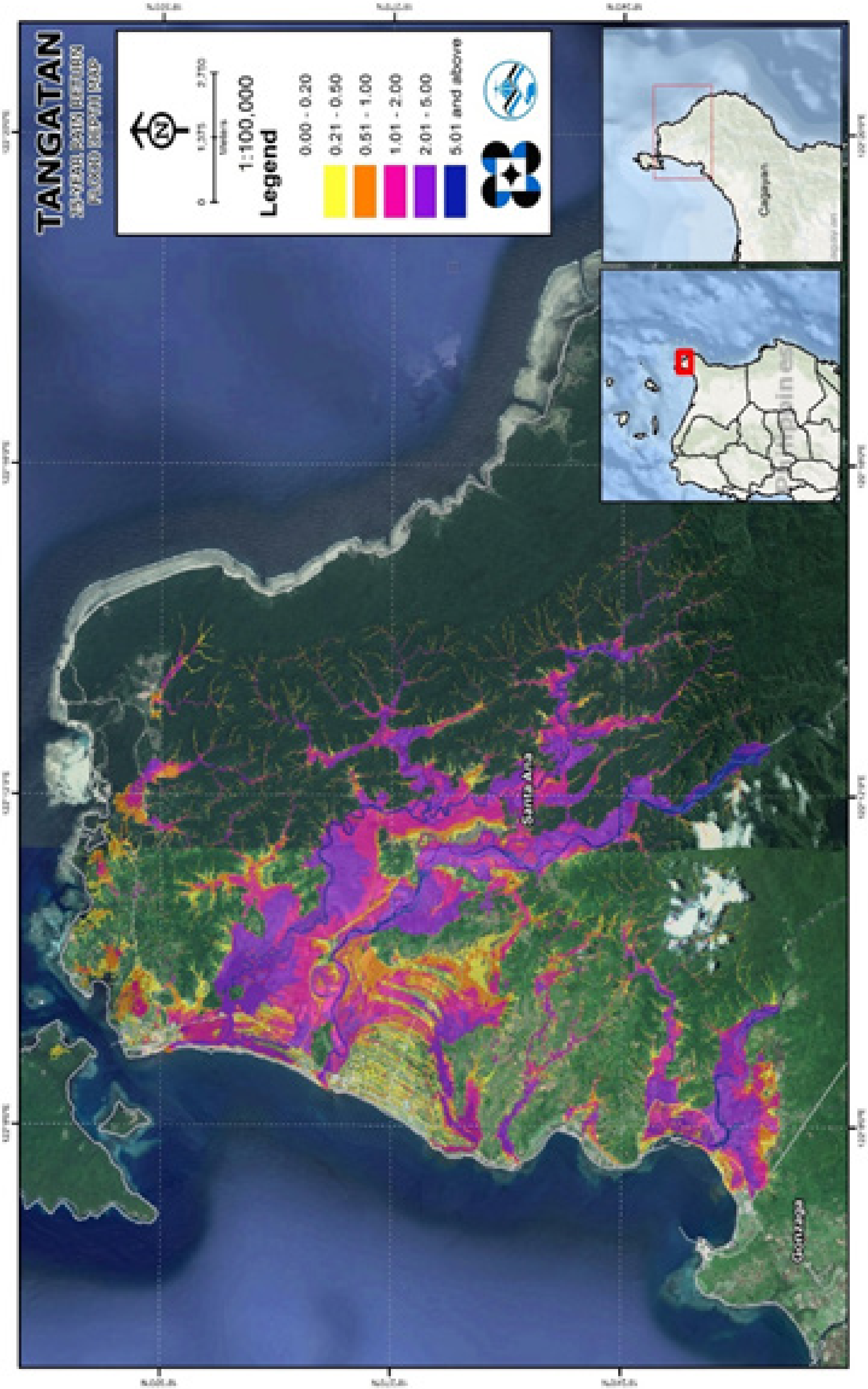


Figure 71. 25-year Flood Hazard Map for Tangatan Floodplain overlaid in Google Earth imagery

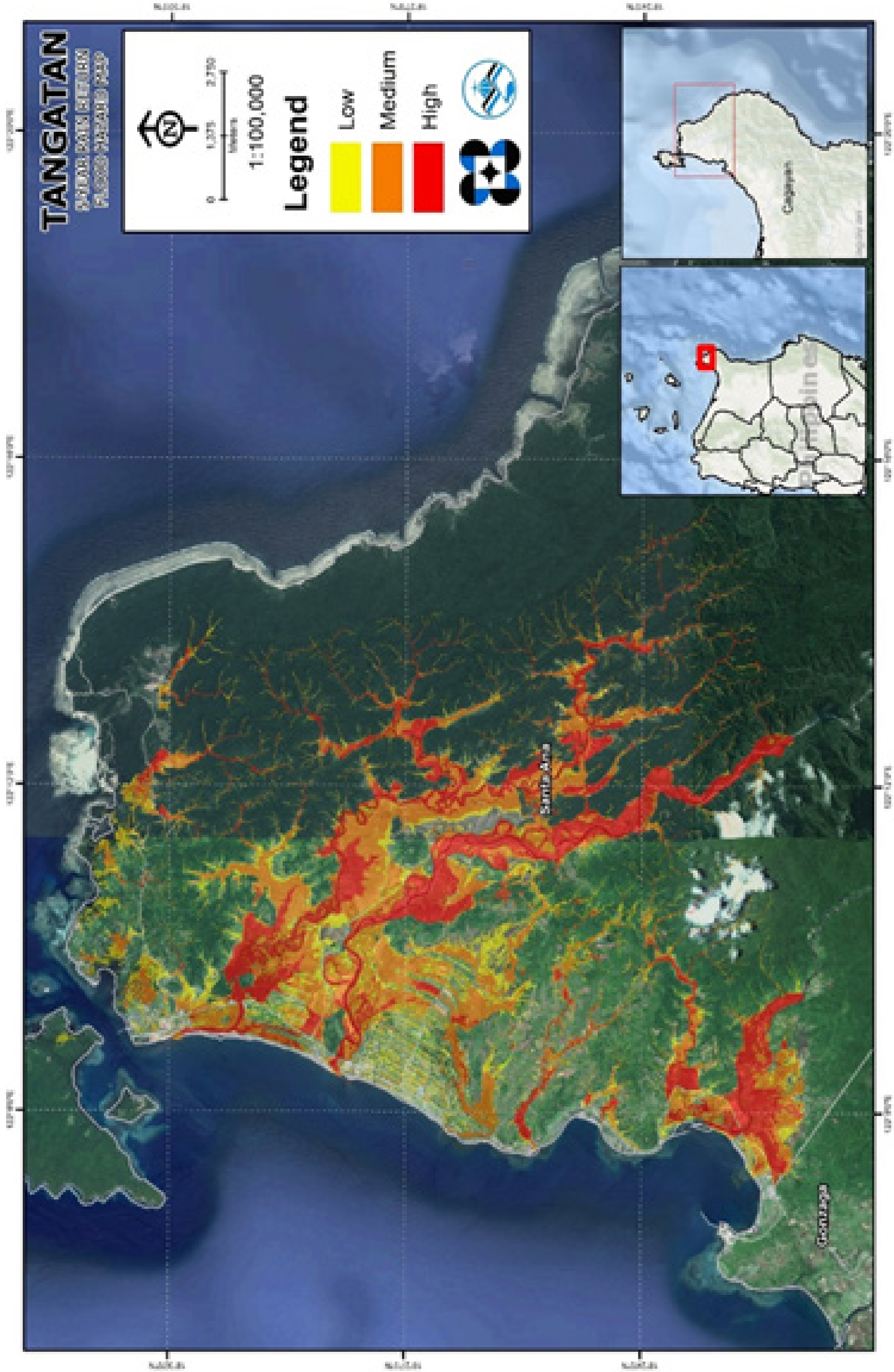


Figure 72. 5-year Flood Hazard Map for Tangatan Floodplain overlaid in Google Earth imagery

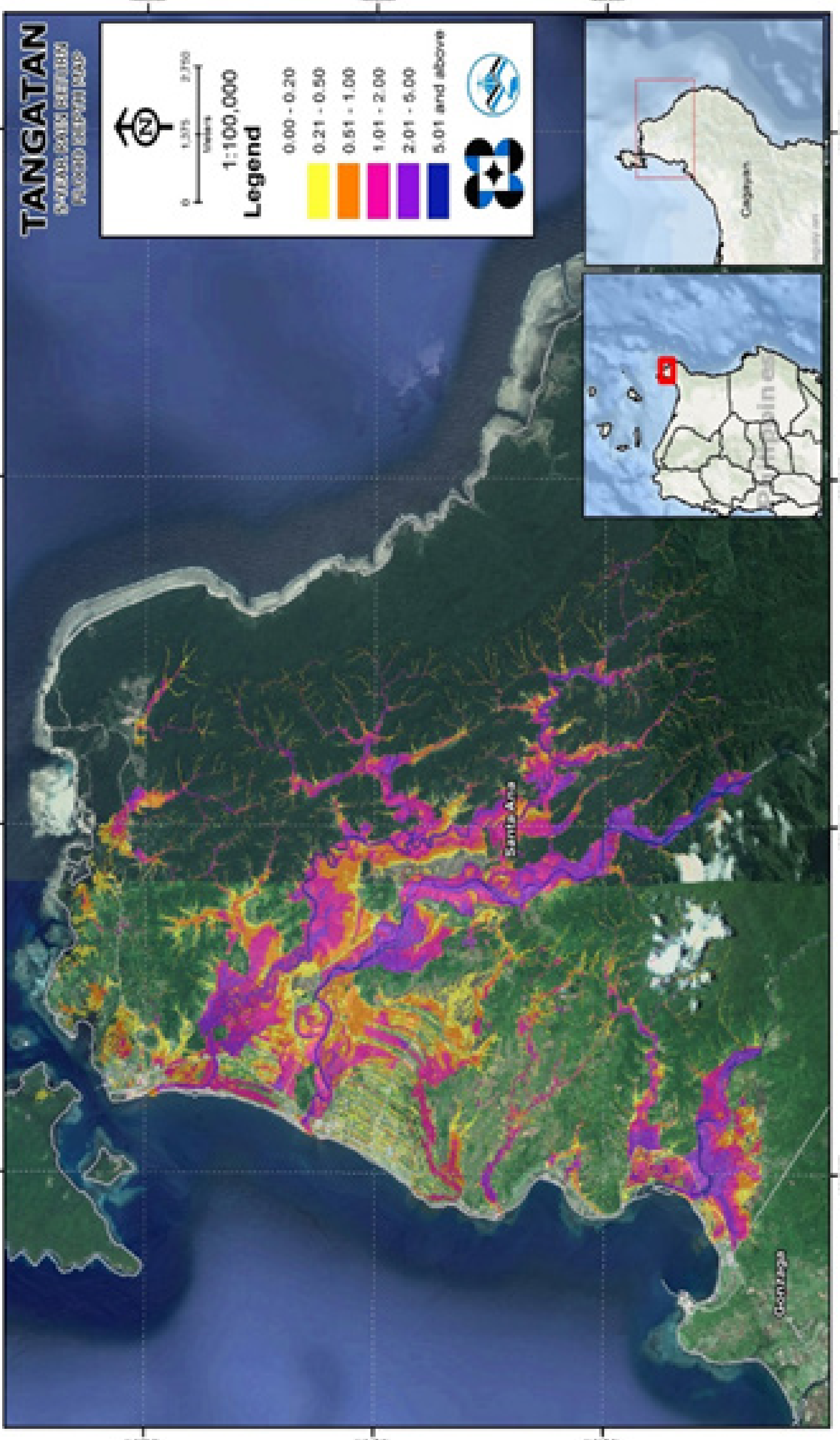


Figure 73. 5-year Flood Depth Map for TangatanFloodplain overlaid in Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Tangatan River Basin, grouped by municipality, are listed below. For the said basin, two municipalities consisting of 17 barangays are expected to experience flooding when subjected to 5-, 25-, and 100-yr rainfall return period.

For the 5-year return period, 0.06% of the Municipality of Gonzaga with an area of 497.62 sq. km. will experience flood levels of less than 0.20 meters. 0.00% of the area will experience flood levels of 0.21 to 0.50 meters while 0.00% of the area will experience flood depths of 0.51 to 1 meter. Listed in Table 31 are the affected areas in square kilometers by flood depth per barangay.

Table 31. Affected Areas in Gonzaga, Cagayan during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Gonzaga (in sq. km)
	San Jose
0.03-0.20	0.28
0.21-0.50	0.015
0.51-1.00	0.0089
1.01-2.00	0.0088
2.01-5.00	0
> 5.00	0

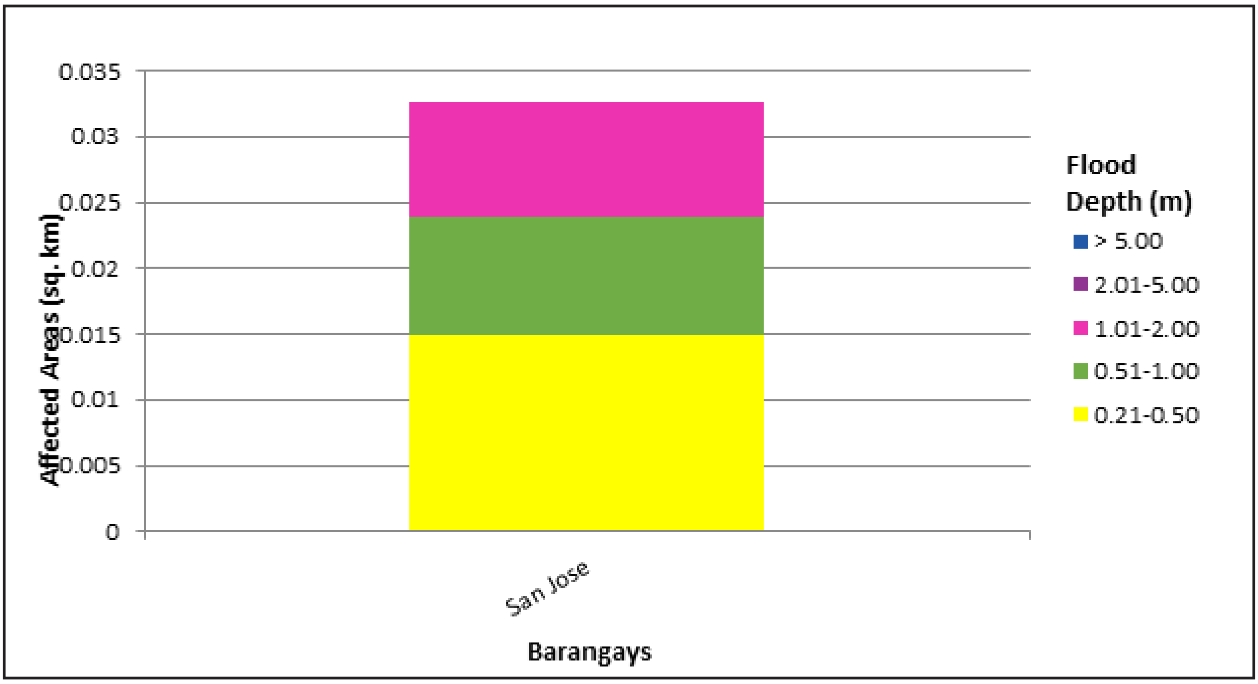


Figure 74. Affected Areas in Gonzaga, Cagayan during 5-Year Rainfall Return Period

For the 5-year return period, 25.91% of the Municipality of Santa Ana with an area of 437.13 sq. km. will experience flood levels of less than 0.20 meters. 2.58% of the area will experience flood levels of 0.21 to 0.50 meters while 3.16%, 3.89%, 2.37%, and 0.24% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Tables 32 and 33 are the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected Areas in Santa Ana, Cagayan during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Ana (in sq. km)							
	Batu-Parada	Casagan	Casambalangan	Centro	Diora-Zinungan	Dungeg	Kapanikian	Marede
0.03-0.20	0.28	15.16	1.15	2.14	7.4	12.72	1.76	5.27
0.21-0.50	0.2	1.37	0.42	0.64	1.51	0.88	0.23	0.34
0.51-1.00	0.24	1.75	0.73	0.26	1.36	1.36	0.35	1.02
1.01-2.00	0.2	1.52	1.06	0.18	1.35	2.09	0.71	1.39
2.01-5.00	0.11	0.54	1.38	0.095	0.18	1.43	0.75	0.6
> 5.00	0.015	0.02	0.14	0	0	0.17	0.021	0.14

Table 33. Affected Areas in Santa Ana, Cagayan during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Ana (in sq. km)							
	Palawig	Patunungan	Rapuli	San Vicente	Santa Clara	Santa Cruz	Tangatan	Visitacion
0.03-0.20	0.93	1.89	14.16	5.39	39.68	2.06	1.99	1.3
0.21-0.50	0.26	0.054	0.91	1.03	1.85	0.52	0.25	0.81
0.51-1.00	0.49	0.041	0.94	0.61	2.19	0.66	0.15	1.65
1.01-2.00	0.7	0.068	1.5	0.11	3.45	1.58	0.068	1.04
2.01-5.00	0.18	0.14	0.93	0.026	2.98	0.87	0.013	0.15
> 5.00	0	0.051	0.022	0.0001	0.46	0.011	0.0012	0

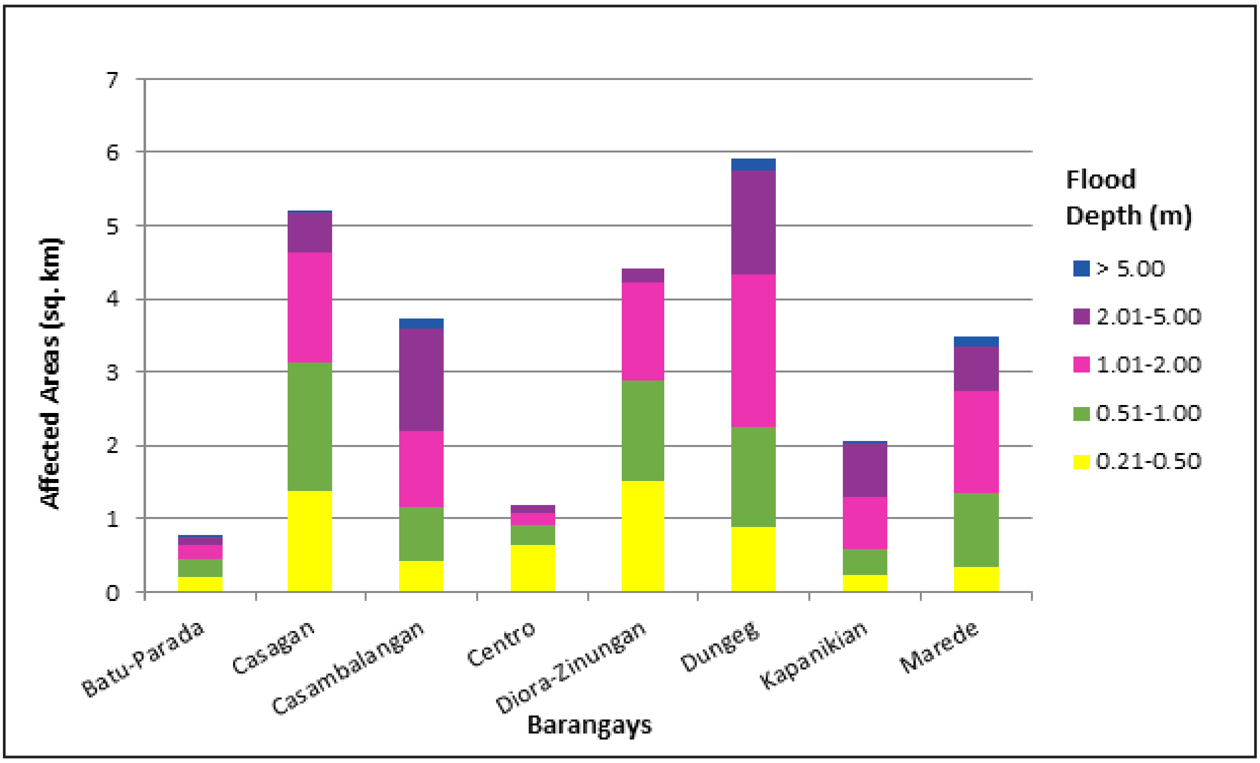


Figure 75. Affected Areas in Santa Ana, Cagayan during 5-Year Rainfall Return Period

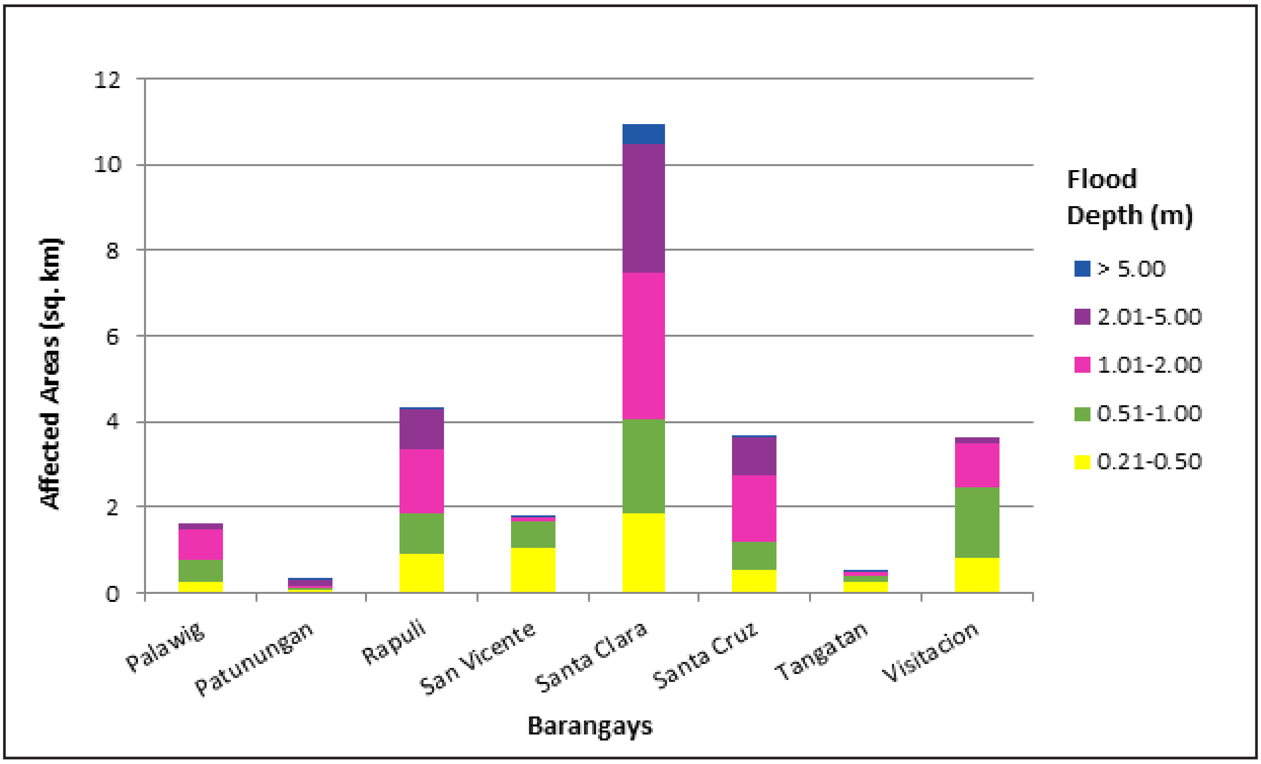


Figure 76. Affected Areas in Santa Ana, Cagayan during 5-Year Rainfall Return Period

For the 25-year return period, 0.05% of the Municipality of Gonzaga with an area of 497.62 sq. km. will experience flood levels of less than 0.20 meters. 0.00% of the area will experience flood levels of 0.21 to 0.50 meters while 0.00% of the area will experience flood depths of 0.51 to 1 meter. Listed in Table 34 are the affected areas in square kilometers by flood depth per barangay.

Table 34. Affected Areas in Gonzaga, Cagayan during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Gonzaga (in sq. km)
	San Jose
0.03-0.20	0.27
0.21-0.50	0.021
0.51-1.00	0.0074
1.01-2.00	0.014
2.01-5.00	0
> 5.00	0

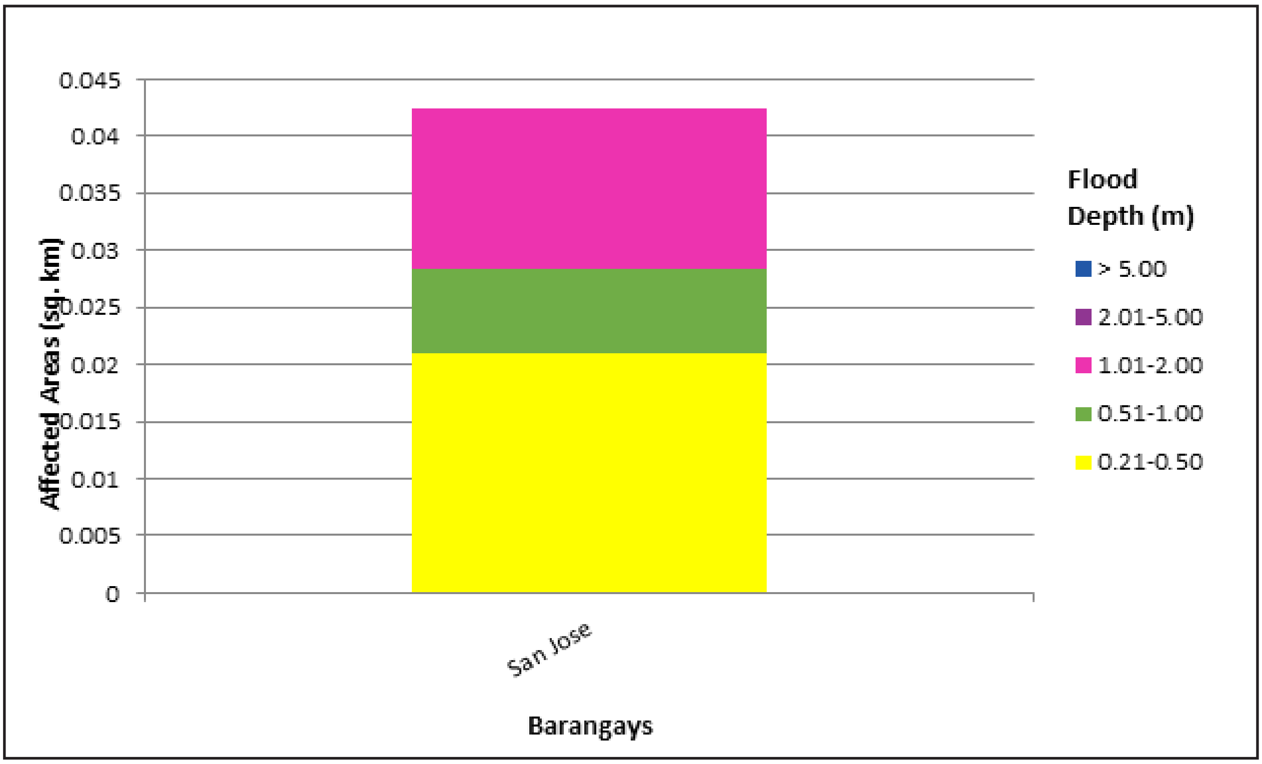


Figure 77. Affected Areas in Gonzaga, Cagayan during 25-Year Rainfall Return Period

For the 25-year return period, 24.30% of the Municipality of Santa Ana with an area of 437.13 sq. km. will experience flood levels of less than 0.20 meters. 2.12% of the area will experience flood levels of 0.21 to 0.50 meters while 2.49%, 4.24%, 4.56%, and 0.43% 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 Tables 35 and 36 are the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected Areas in Santa Ana, Cagayan during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Ana (in sq. km)							
	Batu-Parada	Casagan	Casambalangan	Centro	Diora-Zinungan	Dungeg	Kapanikian	Marede
0.03-0.20	0.11	14.57	0.91	1.76	6.23	12.06	1.58	5.13
0.21-0.50	0.086	0.9	0.29	0.81	1.17	0.69	0.13	0.2
0.51-1.00	0.21	1.26	0.58	0.39	1.28	0.84	0.14	0.28
1.01-2.00	0.47	1.94	1.09	0.21	1.81	2.41	0.6	1.13
2.01-5.00	0.15	1.62	1.79	0.15	1.3	2.36	1.32	1.82
> 5.00	0.016	0.06	0.23	0	0	0.28	0.048	0.19

Table 36. Affected Areas in Santa Ana, Cagayan during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Ana (in sq. km)							
	Palawig	Patunungan	Rapuli	San Vicente	Santa Clara	Santa Cruz	Tangatan	Visitacion
0.03-0.20	0.63	1.86	13.59	5	38.57	1.57	1.87	0.8
0.21-0.50	0.13	0.058	0.88	1.02	1.74	0.34	0.22	0.62
0.51-1.00	0.31	0.032	0.85	0.82	1.64	0.4	0.21	1.66
1.01-2.00	0.92	0.03	1.51	0.29	3.34	1.08	0.15	1.55
2.01-5.00	0.58	0.15	1.61	0.038	4.47	2.25	0.021	0.32
> 5.00	0	0.12	0.03	0.0011	0.85	0.049	0.0017	0.0003

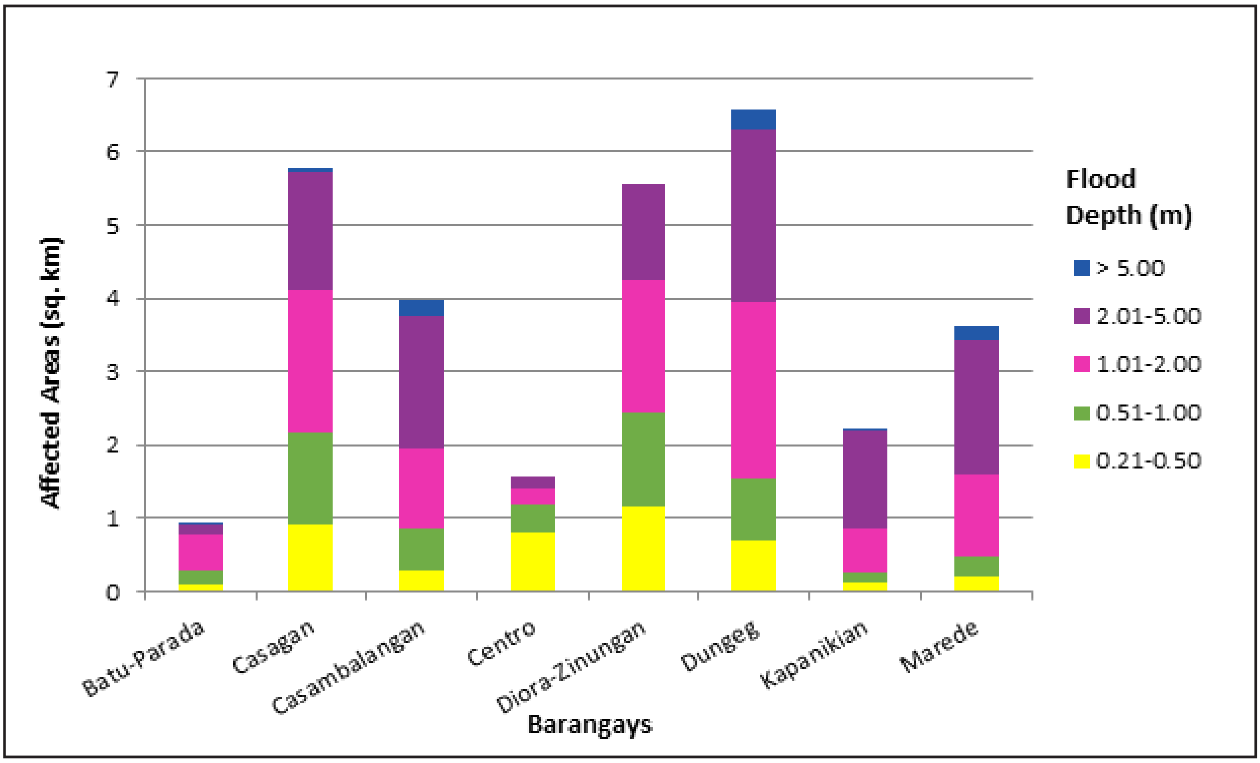


Figure 78. Affected Areas in Santa Ana, Cagayan during 25-Year Rainfall Return Period

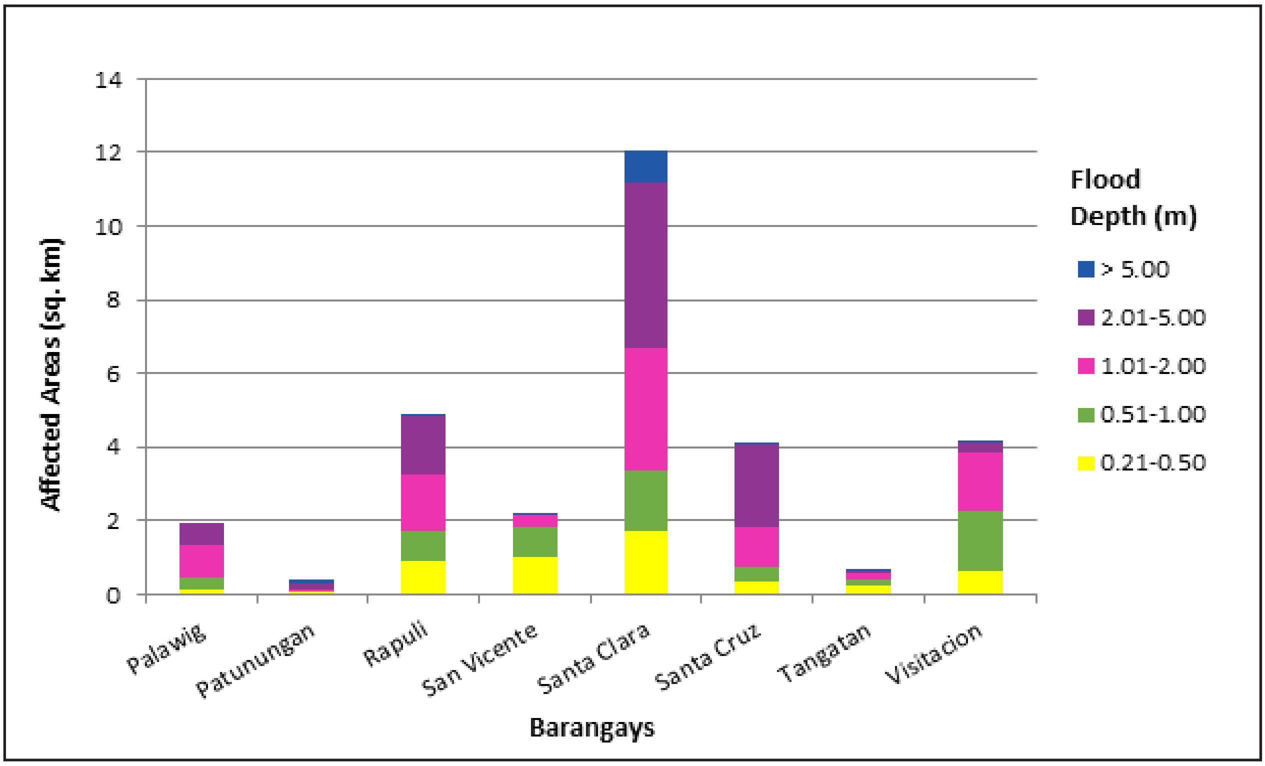


Figure 79. Affected Areas in Santa Ana, Cagayan during 25-Year Rainfall Return Period

For the 100-year return period, 0.05% of the Municipality of Gonzaga with an area of 497.62 sq. km. will experience flood levels of less than 0.20 meters. 0.00% of the area will experience flood levels of 0.21 to 0.50 meters while 0.00% of the area will experience flood depths of 0.51 to 1 meter. Listed in the Table 37 are the affected areas in square kilometers by flood depth per barangay.

Table 37. Affected Areas in Gonzaga, Cagayan during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Gonzaga (in sq. km)
	San Jose
0.03-0.20	0.27
0.21-0.50	0.021
0.51-1.00	0.0074
1.01-2.00	0.014
2.01-5.00	0
> 5.00	0

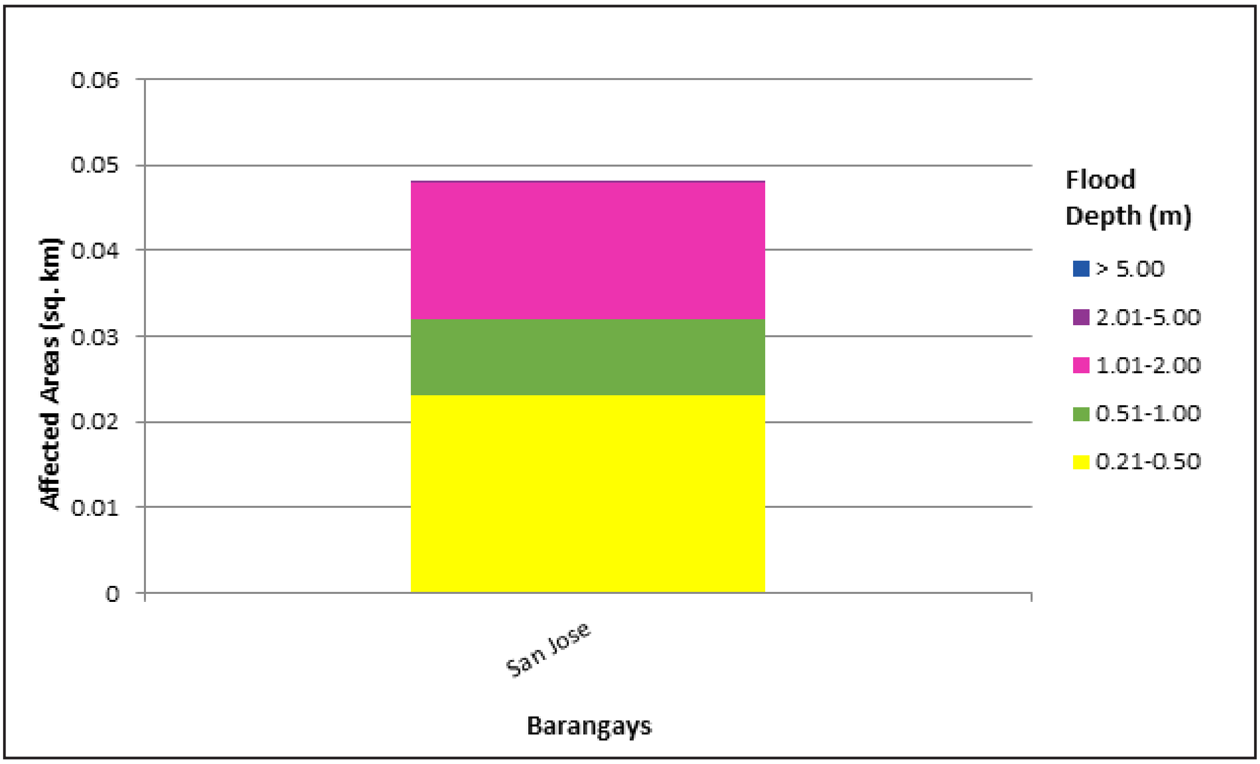


Figure 80. Affected Areas in Gonzaga, Cagayan during 100-Year Rainfall Return Period

For the 100-year return period, 23.46% of the Municipality of Santa Ana with an area of 437.13 sq. km. will experience flood levels of less than 0.20 meters. 1.88% of the area will experience flood levels of 0.21 to 0.50 meters while 2.18%, 4.01%, 6.02%, and 0.59% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the Table 38 and 39 are the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected Areas in Santa Ana, Cagayan during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Ana (in sq. km)							
	Batu-Parada	Casagan	Casambalangan	Centro	Diora-Zinungan	Dungeg	Kapanikian	Marede
0.03-0.20	0.047	14.34	0.81	1.4	5.64	11.71	1.51	5.06
0.21-0.50	0.036	0.83	0.22	0.85	0.75	0.67	0.11	0.2
0.51-1.00	0.11	1.11	0.49	0.59	1.31	0.66	0.12	0.19
1.01-2.00	0.52	1.72	1.03	0.27	1.89	2.01	0.45	0.69
2.01-5.00	0.3	2.28	2.02	0.21	2.2	3.22	1.55	2.39
> 5.00	0.023	0.084	0.31	0	0.0007	0.36	0.074	0.23

Table 39. Affected Areas in Santa Ana, Cagayan during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Santa Ana (in sq. km)							
	Palawig	Patunungan	Rapuli	San Vicente	Santa Clara	Santa Cruz	Tangatan	Visitacion
0.03-0.20	0.53	1.84	13.28	4.8	37.94	1.44	1.82	0.4
0.21-0.50	0.11	0.062	0.87	0.98	1.78	0.27	0.21	0.26
0.51-1.00	0.19	0.034	0.83	0.9	1.5	0.38	0.22	0.91
1.01-2.00	0.78	0.027	1.35	0.43	2.74	0.89	0.19	2.56
2.01-5.00	0.95	0.066	2.1	0.046	5.52	2.65	0.033	0.8
> 5.00	0.001	0.22	0.042	0.002	1.14	0.065	0.0022	0.0088

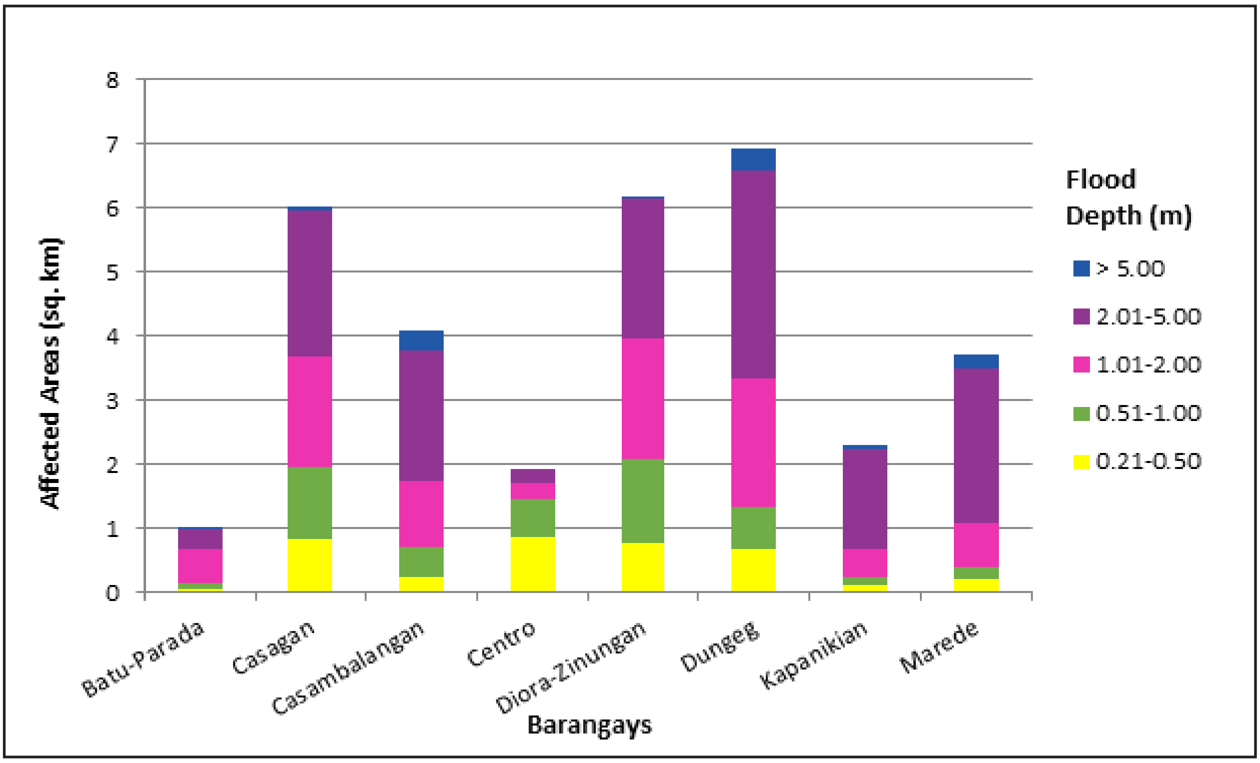


Figure 81. Affected Areas in Santa Ana, Cagayan during 100-Year Rainfall Return Period

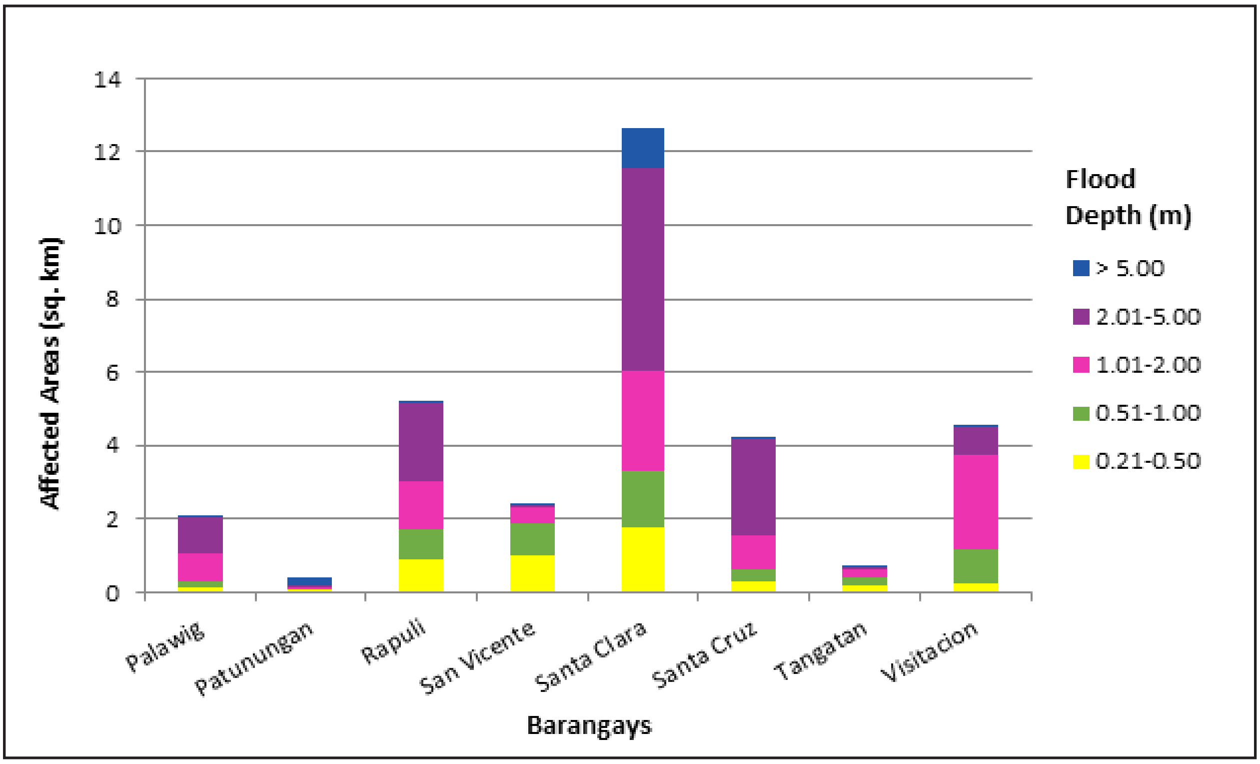


Figure 82. Affected Areas in Santa Ana, Cagayan during 100-Year Rainfall Return Period

The Brgy. San Jose is the only barangay affected in the Municipality of Gonzaga in Cagayan. The barangay is projected to experience flood in 0.06% of the municipality.

Among the barangays in the municipality of Santa Ana in Cagayan, Santa Clara is projected to have the highest percentage of area that will experience flood levels at 10.17%. Meanwhile, Casagan posted the second highest percentage of area that may be affected by flood depths at 4.09%.

Moreover, the generated flood hazard maps for the Tangatan 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	11.32	9.30	8.23
Medium	23.91	20.31	18.06
High	18.94	31.53	38.54
TOTAL	54.17	61.14	64.83

Of the 14 identified educational institutions in Tangatan Floodplain, five (5) schools were discovered exposed to Low-level flooding while five (5) schools were found exposed to Medium-level flooding, both during the 5-year scenario.

For the 25-year scenario, four (4) schools were discovered exposed to Low-level flooding while six (6) schools were found exposed to Medium-level flooding. In the same scenario, one (1) school was discovered exposed to High-level flooding.

For the 100-year scenario, three (3) schools were discovered exposed to Low-level flooding while five (5) schools were found exposed to Medium-level flooding. In the same scenario, one (3) schools were discovered exposed to High-level flooding.

Of the six (6) identified medical or health institutions in Tangatan Floodplain, two (2) medical institutions were discovered exposed to Low-level flooding.

For the 25-year scenario, two (2) health institutions were discovered exposed to Low-level flooding.

For the 100-year scenario, one (1) health institution was discovered exposed to Low-level flooding while one (1) medical institution was found exposed to Medium-level flooding.

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 to obtain maps or situation reports about the past flooding events or interview some residents with knowledge of or have had experienced flooding in a particular area.

After which, the actual data from the field were compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed.

The flood validation consists of 226 points randomly selected all over the Tangatan Floodplain. It has an RMSE value of 0.77.

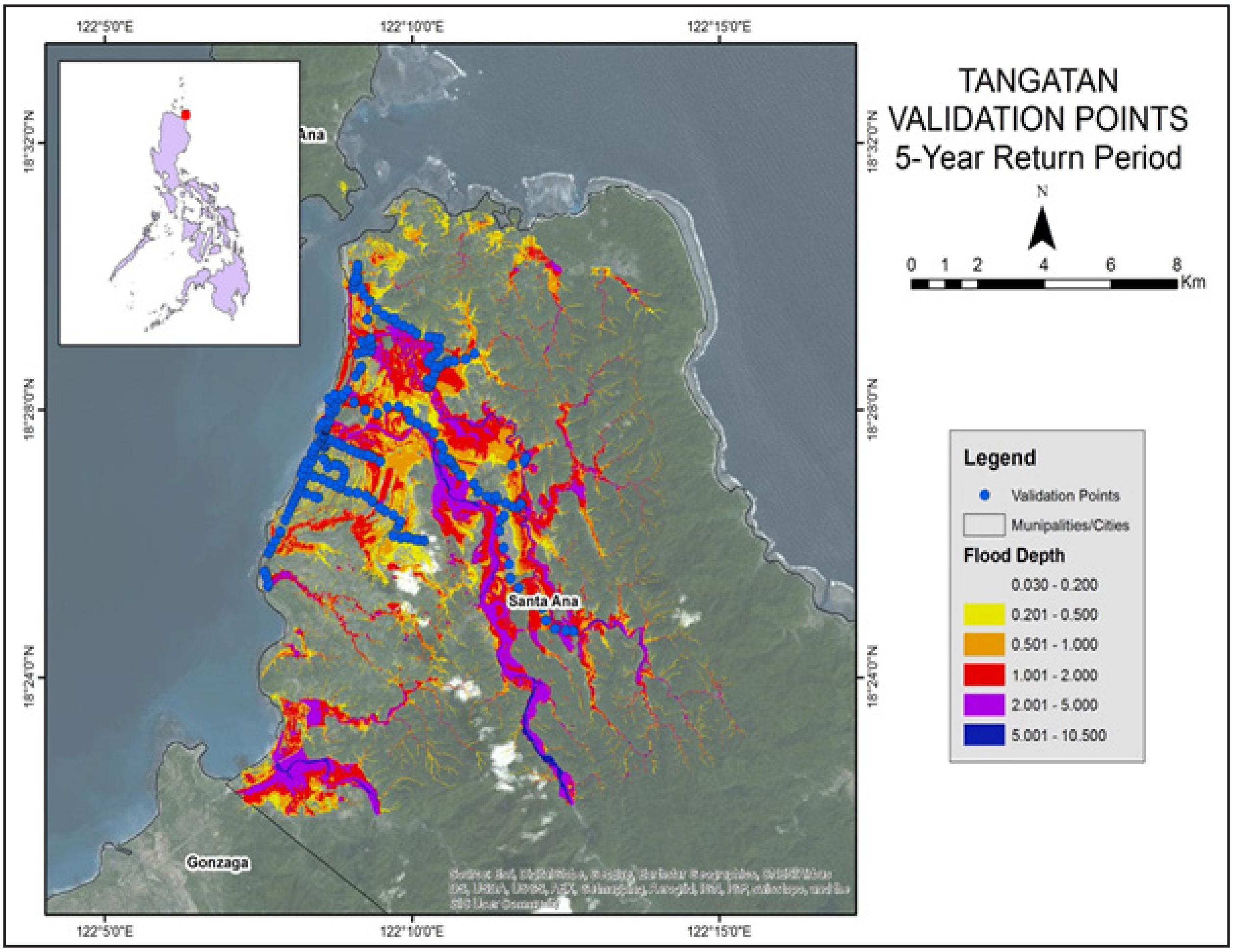


Figure 83. Tangatan Flood Validation Points

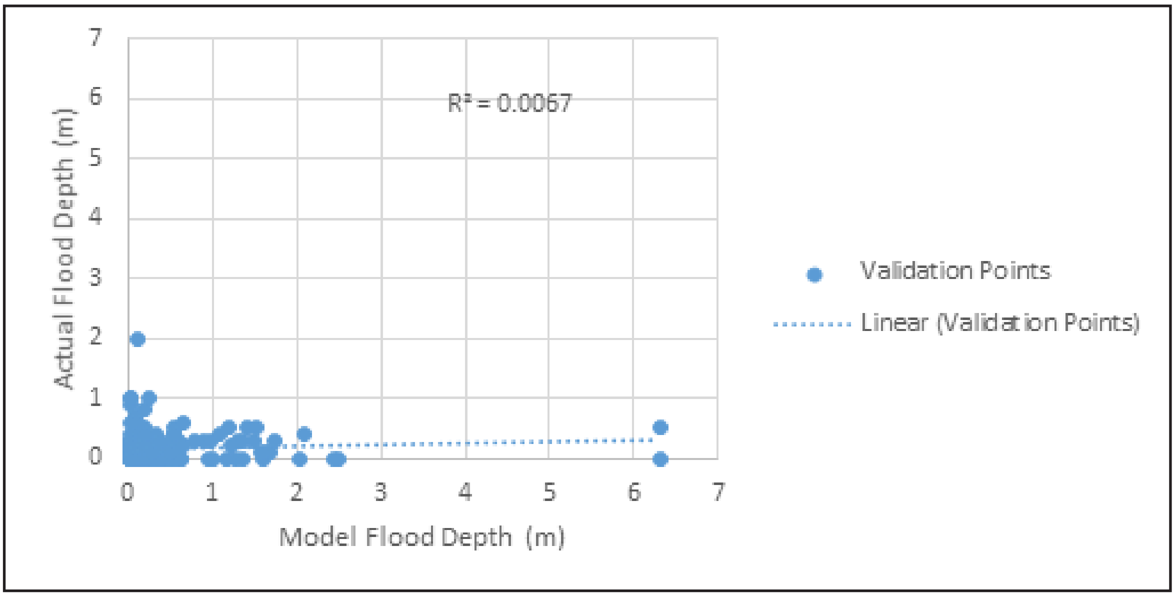


Figure 84. Model flood depth vs actual flood depth

Table 41. Actual Flood Depth vs Simulated Flood Depth in Tangatan

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	127	27	12	9	3	1	179
0.21-0.50	12	6	9	8	1	1	37
0.51-1.00	7	1	1	0	0	0	9
1.01-2.00	1	0	0	0	0	0	1
2.01-5.00	0	0	0	0	0	0	0
> 5.00	0	0	0	0	0	0	0
Total	147	34	22	17	4	2	226

The overall accuracy generated by the flood model was estimated at 59.29% with 134 points correctly matching the actual flood depths. In addition, there were 48 points estimated one level above and below the correct flood depths while there were 27 points and 16 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 21 points were underestimated in the modelled flood depths of Tangatan.

Table 42. Summary of Accuracy Assessment in Tangatan River Basin Survey.

	No. of Points	%
Correct	134	59.29
Overestimated	71	31.42
Underestimated	21	9.29
Total	226	100.00

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ANNEXES

Annex 1. Technical Specifications of the Lidar Sensor Used In The Tangatan Floodplain Survey

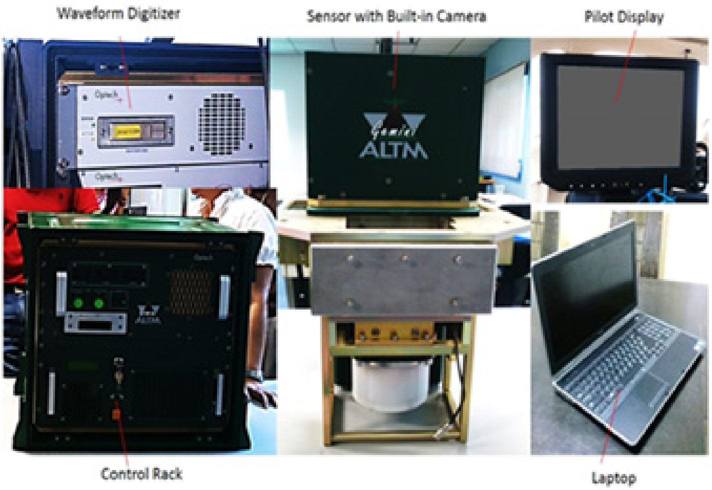
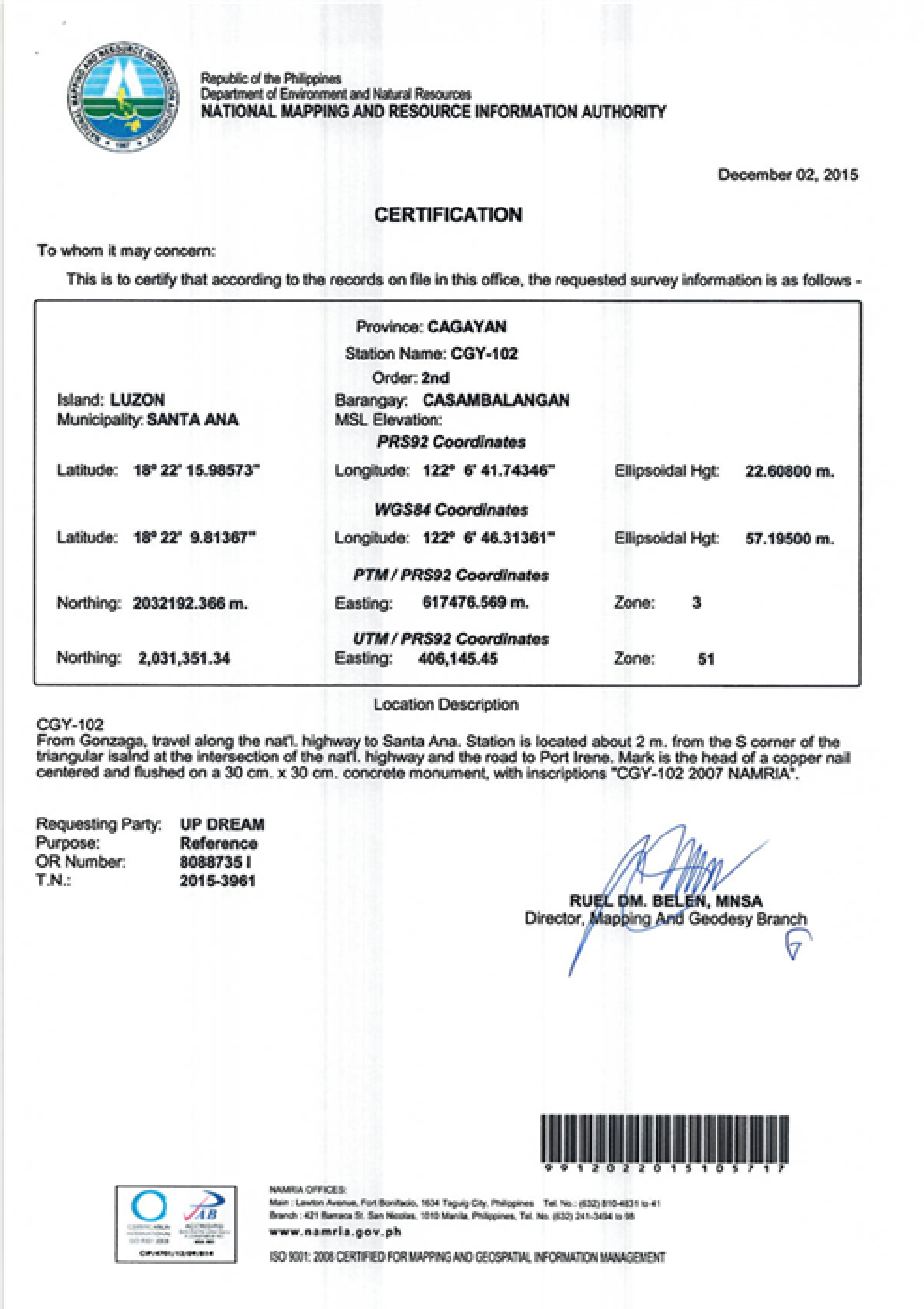


Figure A-1.1 Gemini Sensor

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

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

1. CGY-102



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

December 02, 2015

CERTIFICATION

To whom it may concern:

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

Province: CAGAYAN
Station Name: CGY-102
Order: 2nd

Island: LUZON		Barangay: CASAMBALANGAN	
Municipality: SANTA ANA		MSL Elevation:	
	PRS92 Coordinates		
Latitude: 18° 22' 15.98573"	Longitude: 122° 6' 41.74346"	Ellipsoidal Hgt:	22.60800 m.
	WGS84 Coordinates		
Latitude: 18° 22' 9.81367"	Longitude: 122° 6' 46.31361"	Ellipsoidal Hgt:	57.19500 m.
	PTM / PRS92 Coordinates		
Northing: 2032192.366 m.	Easting: 617476.569 m.	Zone:	3
	UTM / PRS92 Coordinates		
Northing: 2,031,351.34	Easting: 406,145.45	Zone:	51

Location Description

CGY-102
From Gonzaga, travel along the nat'l. highway to Santa Ana. Station is located about 2 m. from the S corner of the triangular isalnd at the intersection of the nat'l. highway and the road to Port Irene. Mark is the head of a copper nail centered and flushed on a 30 cm. x 30 cm. concrete monument, with inscriptions "CGY-102 2007 NAMRIA".

Requesting Party: UP DREAM
Purpose: Reference
OR Number: 8088735 I
T.N.: 2015-3961

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. CGY-102

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

Table A-3.1. CGY-102

Vector Components (Mark to Mark)

From:	CGY-102				
Grid		Local		Global	
Easting	406145.451 m	Latitude	N18°22'15.98572"	Latitude	N18°22'09.81367"
Northing	2031351.336 m	Longitude	E122°06'41.74346"	Longitude	E122°06'46.31361"
Elevation	20.066 m	Height	22.609 m	Height	57.195 m

To:	CG-258				
Grid		Local		Global	
Easting	396708.418 m	Latitude	N18°17'21.32897"	Latitude	N18°17'15.16762"
Northing	2022343.154 m	Longitude	E122°01'21.83970"	Longitude	E122°01'26.41723"
Elevation	9.620 m	Height	12.774 m	Height	47.419 m

Vector					
ΔEasting	-9437.033 m	NS Fwd Azimuth	226°03'09"	ΔX	6452.377 m
ΔNorthing	-9008.183 m	Ellipsoid Dist.	13049.913 m	ΔY	7393.391 m
ΔElevation	-10.445 m	ΔHeight	-9.835 m	ΔZ	-8602.642 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.005 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.007 m
σ ΔElevation	0.009 m	σ ΔHeight	0.009 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000235542		
Y	-0.0000335823	0.0000546286	
Z	-0.0000130276	0.0000212981	0.0000098327

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LIDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
Data Acquisition Component Leader	Data Component Program Leader	ENRICO C. PARINGIT	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader -I	ENGR. LOUIE P. BALICANTA	
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	
LiDAR Operation	Senior Science Research Specialist	ENGR. IRO NIEL ROXAS	
LiDAR Operation	Research Associate	SANDRA POBLETE	
	Research Associate	JONATHAN ALMALVEZ	
Ground Survey	Research Associate	DARRYL AUSTRIA	
Data Download and Transfer	Senior Science Research Specialist	SANDRA POBLETE	
LiDAR Operation	Airborne Security	SSG. JOHN ERIC CACANINDIN	PHILIPPINE AIR FORCE (PAF)
LiDAR Operation	Pilot	CAPT. JERICO JECIEL	ASIAN AEROSPACE CORPORATION (AAC)
LiDAR Operation	Co-Pilot	CAPT. JEROME MOONEY	

Annex 5. Data Transfer Sheet for Tangatan Floodplain

DATA TRANSFER SHEET
21/06/2016 TUGUEGARAO

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	
4/27/2016	3965G	2CAG2DGH118A	GEMINI	NA	367	585	251	NA	NA	28.2	NA	9.67	1KB	1KB	252	NA	Z:\DAC\RAWDATA
4/28/2016	3971G	2BLK3CAG2MQR119A	GEMINI	NA	193	559	252	NA	NA	21	NA	9.78	1KB	1KB	65.1	NA	Z:\DAC\RAWDATA
4/29/2016	3973G	2CAG2GSHS120A	GEMINI	NA	740	662	274	NA	NA	28.6	NA	9.24	1KB	1KB	506	NA	Z:\DAC\RAWDATA
4/30/2016	3977G	2CAG2FG121A	GEMINI	NA	392/99.5/404/107	767	255	NA	NA	29.4	NA	12.1	1KB	1KB	NA	NA	Z:\DAC\RAWDATA
4/30/2016	3979G	2CAG2E121B	GEMINI	NA	99.5	193	71.1	NA	NA	7.57	NA	12.1	1KB	1KB	67.2	NA	Z:\DAC\RAWDATA
5/1/2016	3981G	2CAG2I122A	GEMINI	NA	404	730	263	NA	NA	30.2	NA	8.23	1KB	1KB	23.2/20.6/276/129	NA	Z:\DAC\RAWDATA
5/1/2016	3983G	2CAG2CJ122B	GEMINI	NA	107	220	103	NA	NA	8.25	NA	8.23	1KB	1KB	72.4	NA	Z:\DAC\RAWDATA
5/3/2016	3989G	2BLK3CAG2QSR124A	GEMINI	NA	136/319	514	245	NA	NA	17.1	NA	14.6	1KB	1KB	NA	NA	Z:\DAC\RAWDATA
5/3/2016	3991G	2BLK3CAG2MNSQS124B	GEMINI	NA	204	228	143	NA	NA	8.65	NA	14.6	1KB	1KB	137	NA	Z:\DAC\RAWDATA
5/4/2016	3993G	2BLK3CAG2LMNQR125A	GEMINI	NA	435	161	244	NA	NA	21.2	NA	8.65	1KB	1KB	294	NA	Z:\DAC\RAWDATA
5/5/2016	3997G	2BLK3CAG2NO126A	GEMINI	NA	353	691	272	NA	NA	26.4	NA	13.9	1KB	1KB	239	NA	Z:\DAC\RAWDATA
5/5/2016	3999G	2CAG2P126B	GEMINI	NA	151	290	137	NA	NA	11.6	NA	13.9	1KB	1KB	102	151	Z:\DAC\RAWDATA
5/6/2016	4001G	2BLK3CAG2MRS127A	GEMINI	NA	208	459	245	NA	NA	16.1	NA	9.35	1KB	1KB	138	NA	Z:\DAC\RAWDATA
5/7/2016	4005G	2CAG2ABC128A	GEMINI	NA	316	NA	257	NA	NA	24	NA	8.88	1KB	1KB	215	NA	Z:\DAC\RAWDATA
5/8/2016	4009G	2CAG2K129A	GEMINI	NA	132	286	118	NA	NA	10	NA	5.85	1KB	1KB	114	NA	Z:\DAC\RAWDATA

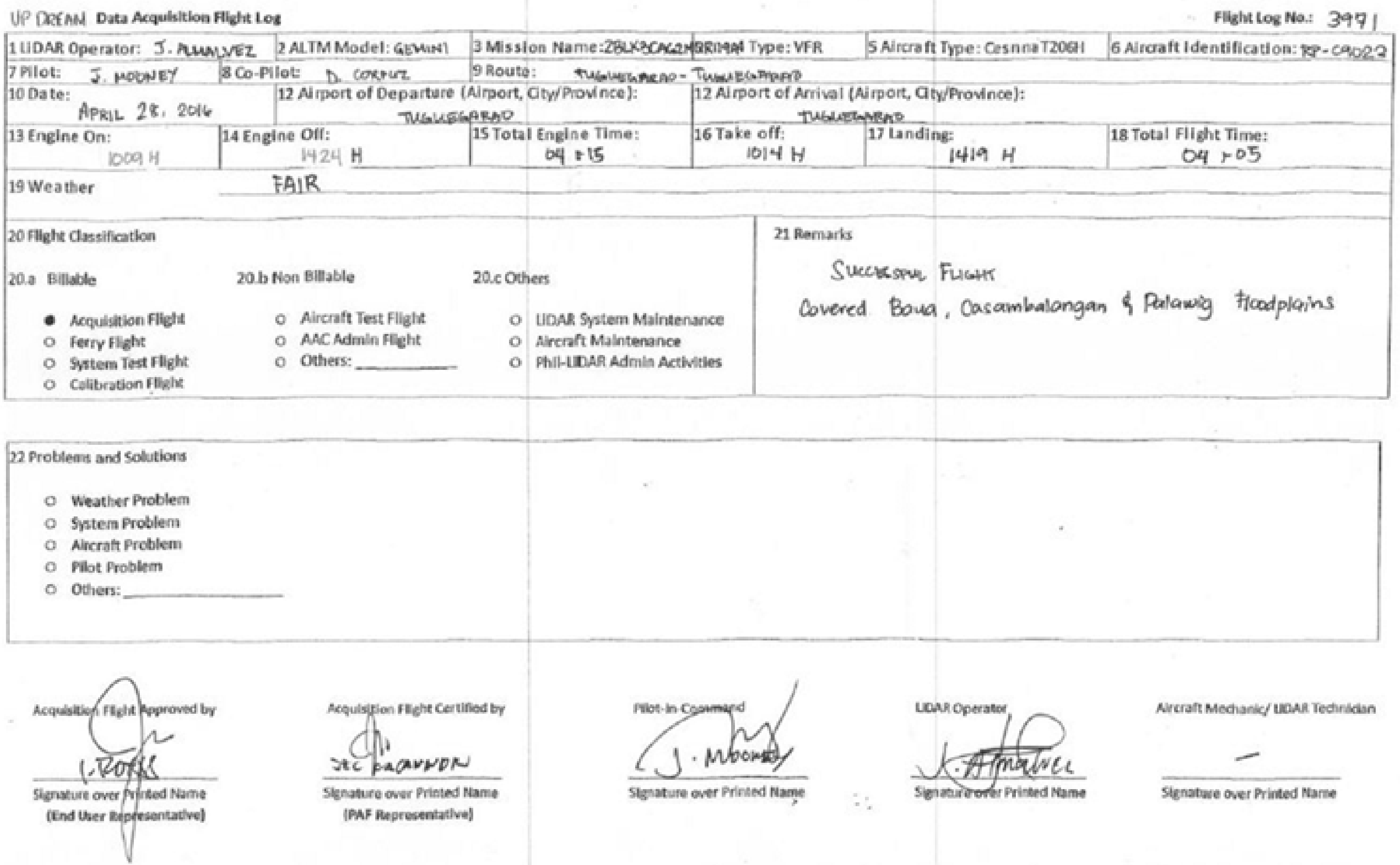
Name DARRYL AUSTRIA
Position R.A.
Signature

Name AC Bongat
Position SS RS
Signature 6/21/16

Figure A-5.1. Transfer Sheet for Tangatan Floodplain

Annex 6. Flight logs for the Tangatan Flight Missions

1. Flight Log for 3971G Mission



UP DREAM Data Acquisition Flight Log

Flight Log No.: 3971

1 LIDAR Operator: J. ALMALVEZ	2 ALTM Model: GEMINI	3 Mission Name: 2BLK3CAG2HBR119A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. MOONEY	8 Co-Pilot: D. CORPUZ	9 Route: TUGUEGARAO - TUGUEGARAO			
10 Date: APRIL 28, 2016	12 Airport of Departure (Airport, City/Province): TUGUEGARAO		12 Airport of Arrival (Airport, City/Province): TUGUEGARAO		
13 Engine On: 1009 H	14 Engine Off: 1424 H	15 Total Engine Time: 04 + 15	16 Take off: 1014 H	17 Landing: 1419 H	18 Total Flight Time: 04 + 05
19 Weather	FAIR				

20 Flight Classification

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

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

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

21 Remarks

Successful Flight

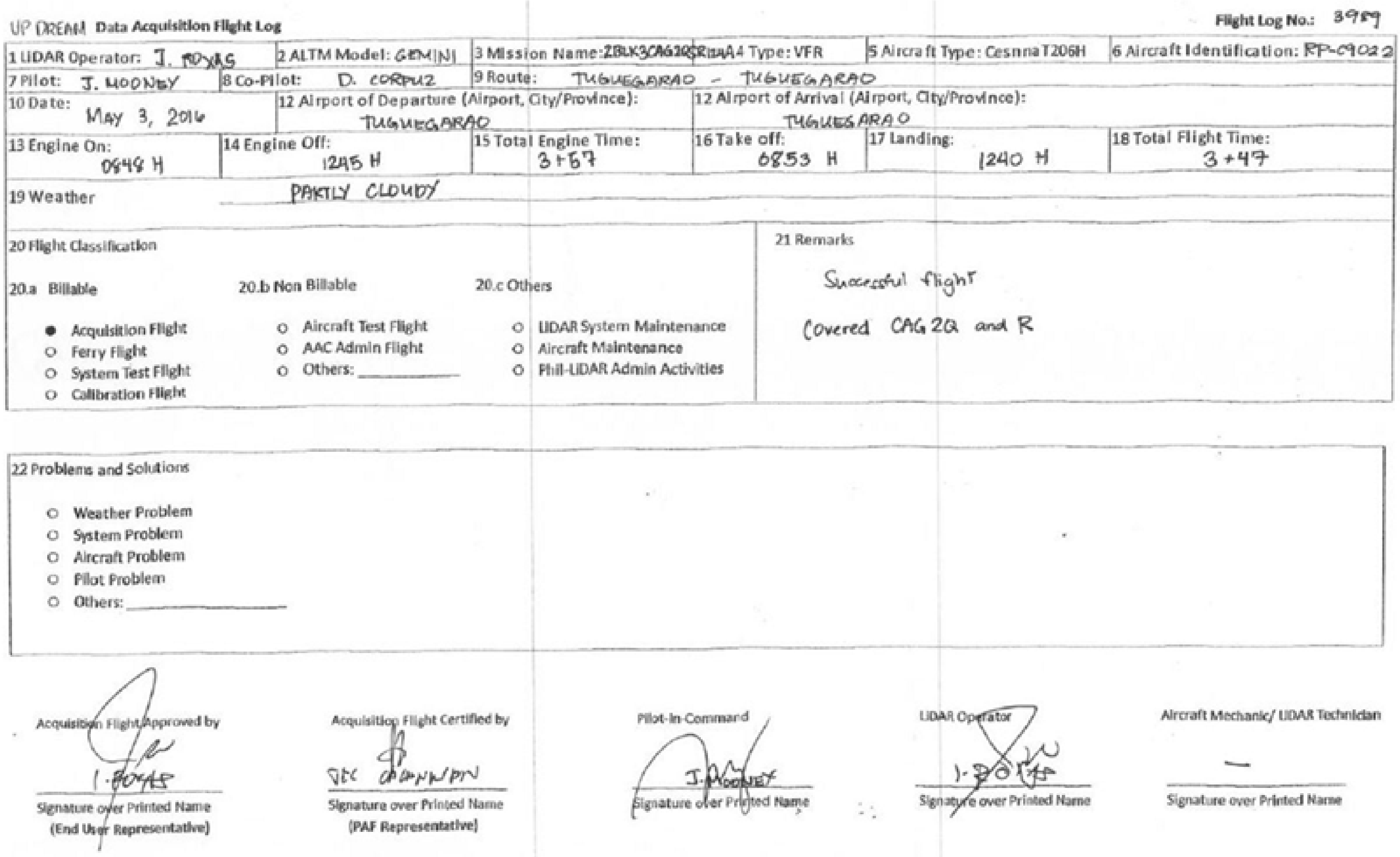
Covered Bua, Cacambalongan & Palawig floodplains

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
I. ROXAS	SEC PAGAYNON	J. MOONEY	J. ALMALVEZ	–
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.1. Flight Log for Mission 3971G

2. Flight Log for 3989G Mission


UP DREAM Data Acquisition Flight Log

Flight Log No.: 3989

1 LIDAR Operator: I. ROXAS	2 ALTM Model: GEMINI	3 Mission Name: 2BLK3CAG2QR	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. MOONEY	8 Co-Pilot: D. CORPUZ	9 Route: TUGUEGARAO - TUGUEGARAO			
10 Date: MAY 3, 2016	12 Airport of Departure (Airport, City/Province): TUGUEGARAO		12 Airport of Arrival (Airport, City/Province): TUGUEGARAO		
13 Engine On: 0848 H	14 Engine Off: 1245 H	15 Total Engine Time: 3+57	16 Take off: 0853 H	17 Landing: 1240 H	18 Total Flight Time: 3+47
19 Weather: PARTLY CLOUDY					

20 Flight Classification

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

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

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

21 Remarks

Successful flight

Covered CAG 2Q and R

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
I. ROXAS	SSC [illegible]	J. MOONEY	I. ROXAS	—
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.2. Flight Log for Mission 3989G

3. Flight Log for 3991G Mission

UP DREAM Data Acquisition Flight Log

Flight Log No.: 3991

1 LIDAR Operator: J. ALMALVEZ	2 ALTM Model: GEMINI	3 Mission Name: [illegible] 4 Type: VFR		5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. MOONEY	8 Co-Pilot: D. CORPUZ	9 Route: TUGUEGARAO - TUGUEGARAO			
10 Date: MAY 3, 2016	12 Airport of Departure (Airport, City/Province): TUGUEGARAO		12 Airport of Arrival (Airport, City/Province): TUGUEGARAO		
13 Engine On: 1334 H	14 Engine Off: 1600 H	15 Total Engine Time: 2+26	16 Take off: 1339 H	17 Landing: 1555 H	18 Total Flight Time: 2+16
19 Weather: PARTLY CLOUDY					

20 Flight Classification

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

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

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

21 Remarks

Successful flight

Covered CAG2M and C

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
[signature]	TSC [signature]	J. MOONEY	J. ALMALVEZ	—
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 3991G

4. Flight Log for 4001G Mission

UP DREAM Data Acquisition Flight Log

Flight Log No.: 4001

1 LIDAR Operator: J. ALMALVEZ	2 ALTM Model: GEMINI	3 Mission Name: 2BLK3AG[illegible]	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. MOONEY	8 Co-Pilot: D. CORPUZ	9 Route: TUGUEGARAO - TUGUEGARAO			
10 Date: MAY 6, 2016	12 Airport of Departure (Airport, City/Province): TUGUEGARAO		12 Airport of Arrival (Airport, City/Province): TUGUEGARAO		
13 Engine On: 1033 H	14 Engine Off: 1433 H	15 Total Engine Time: 4+00	16 Take off: 1038 H	17 Landing: 1428 H	18 Total Flight Time: 3+50
19 Weather: PARTLY CLOUDY					

20 Flight Classification

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

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

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

21 Remarks

Successful flight

Completed CAG2M and Gamabalangan Floodplain

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LIDAR Operator	Aircraft Mechanic/ LIDAR Technician
I. ROXAS	JBC CAPARINDON	J. MOONEY	J. Almalvez	–
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 4001G

Annex 7. Flight status reports

FLIGHT STATUS REPORT
TANGATAN
(April 25 to May 9, 2016)

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3971G	CAG2M, CAG2Q, CAG2R	2BLK3CAG2MQR119A	J. ALMALVEZ	April 28, 2016	Covered Baua, Casambalangan and Palawig Floodplains
3989G	CAG2Q, CAG2R	2BLK3CAG2QSR124A	I. ROXAS	May 3, 2016	Covered CAG2Q and R
3991G	CAG2M, CAG2Q, CAG2R	2BLK3CAG2MSQS124B	J. ALMALVEZ	May 3, 2016	Covered CAG2M and Q
4001G	CAG2M, CAG2R	2BLK3CAG2MRS127A	J. ALMALVEZ	May 6, 2016	Completed CAG2M and R

LAS BOUNDARIES PER MISSION FLIGHT

FLIGHT NO.: 3971G
AREA: CAG2M, CAG2Q, CAG2R
MISSION NAME: 2BLK3CAG2MQR119A

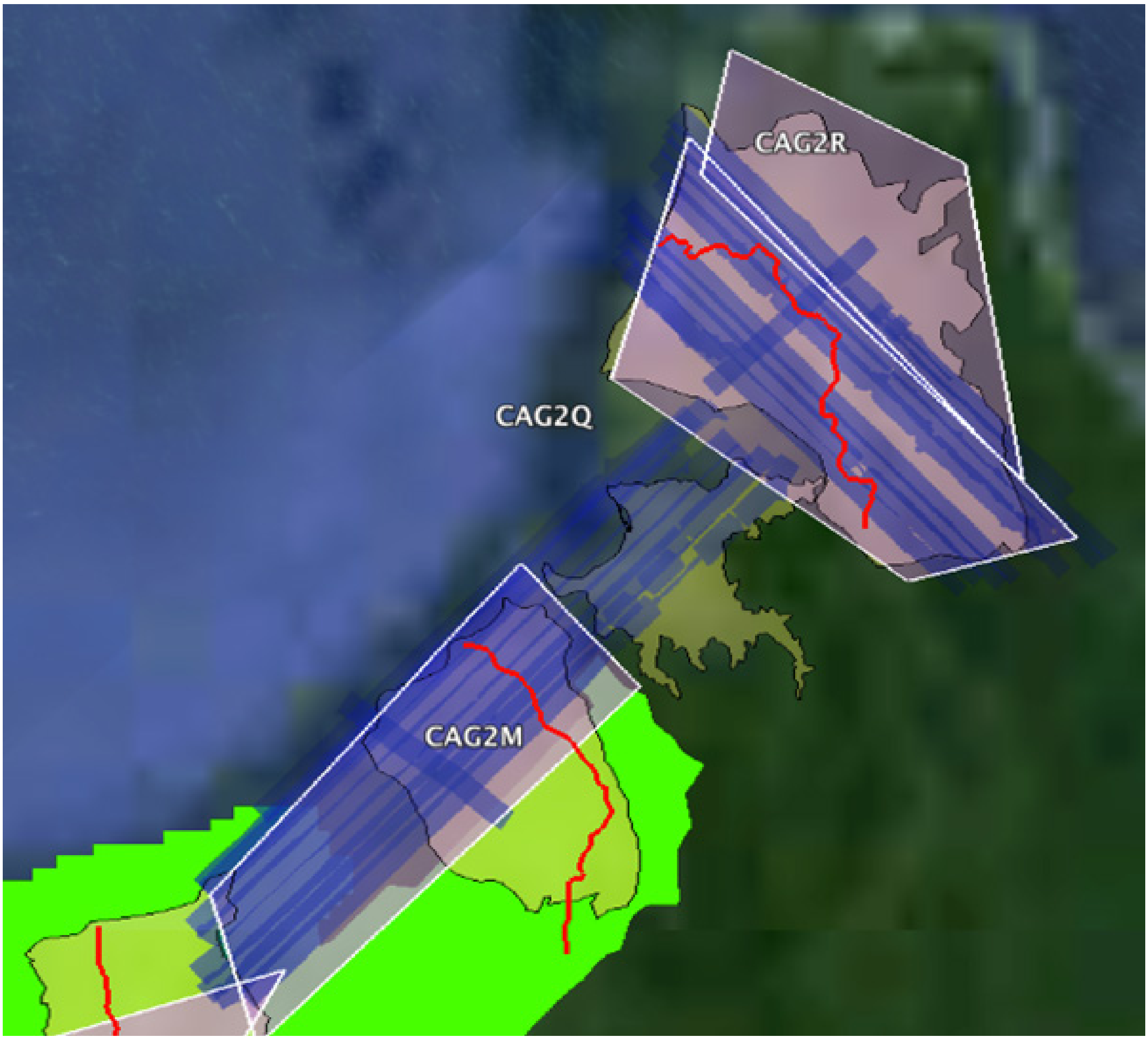


Figure A-7.3. Swath for Flight No. 3971G

FLIGHT NO.: 3989G
AREA: CAG2Q, CAG2R
MISSION NAME: 2BLK3CAG2QSR124A

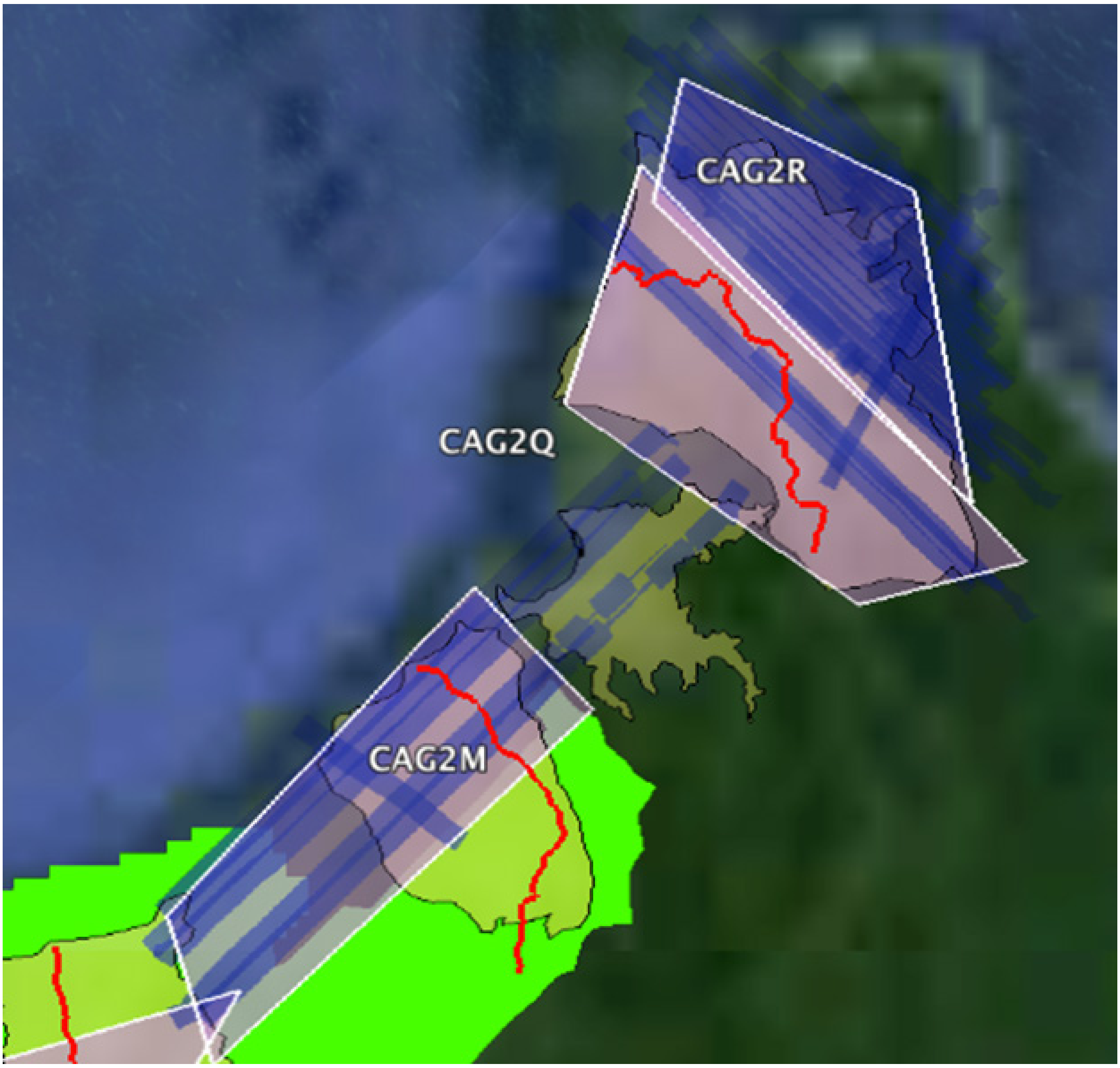


Figure A-7.3. Swath for Flight No. 3989G

FLIGHT NO.: 3991G
AREA: CAG2M, CAG2Q, CAG2R
MISSION NAME: 2BLK3CAG2MSQS124B

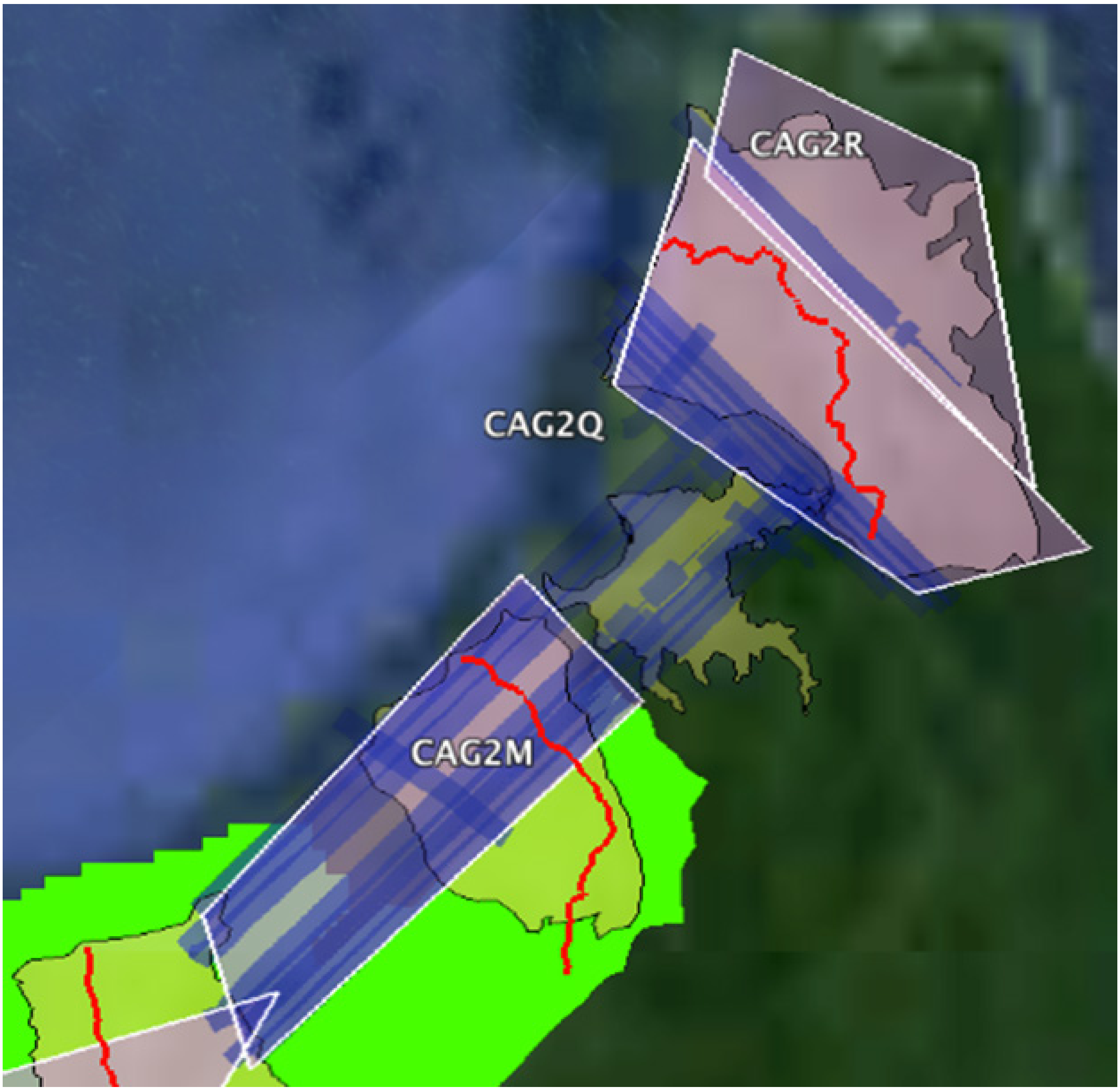


Figure A-7.4. Swath for Flight No. 3991G

FLIGHT NO.: 4001G
AREA: CAG2M, CAG2R
MISSION NAME: 2BLK3CAG2MRS127A

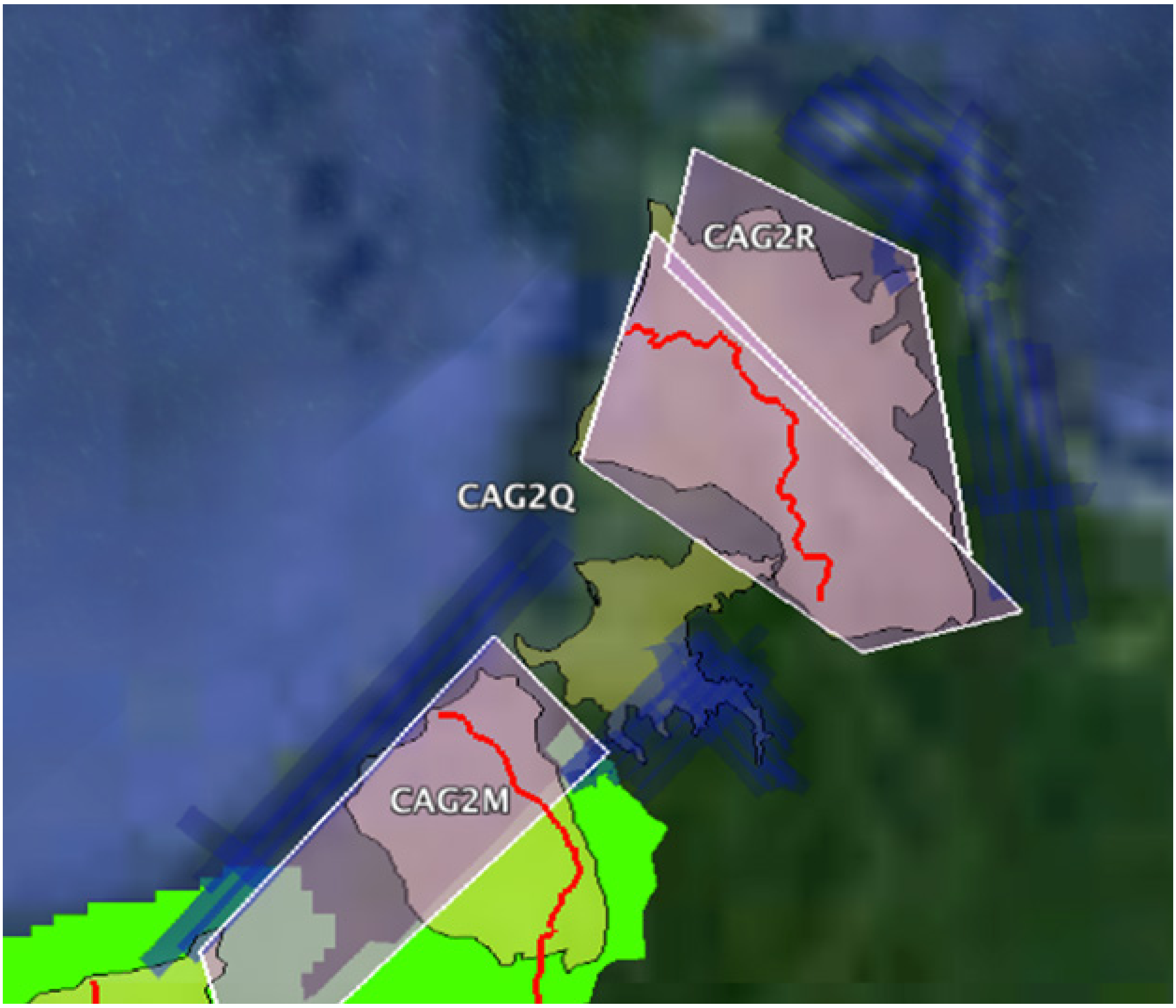


Figure A-7.5. Swath for Flight No. 4001G

Annex 8. Mission Summary Reports

Table A-8.1 Mission Summary Report of Mission Blk3A

Flight Area	Cagayan
Mission Name	Cagayan_reflights_Blk3A
Inclusive Flights	3971G, 3991G, 4001G
Range data size	45.75 GB
POS data size	640 MB
Base data size	33.73 MB
Image	NA
Transfer date	June 21, 2016
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.5
RMSE for East Position (<4.0 cm)	1.7
RMSE for Down Position (<8.0 cm)	2.4
Boresight correction stdev (<0.001deg)	0.000876
IMU attitude correction stdev (<0.001deg)	0.015089
GPS position stdev (<0.01m)	0.0024
Minimum % overlap (>25)	42.36%
Ave point cloud density per sq.m. (>2.0)	3.56
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	156
Maximum Height	526.96 m
Minimum Height	39.41 m
Classification (# of points)	
Ground	70,619,413
Low vegetation	72,372,299
Medium vegetation	199,312,514
High vegetation	122,546,677
Building	5,607,920
Orthophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. Christy Lubiano, Engr. Karl Adrian Vergara

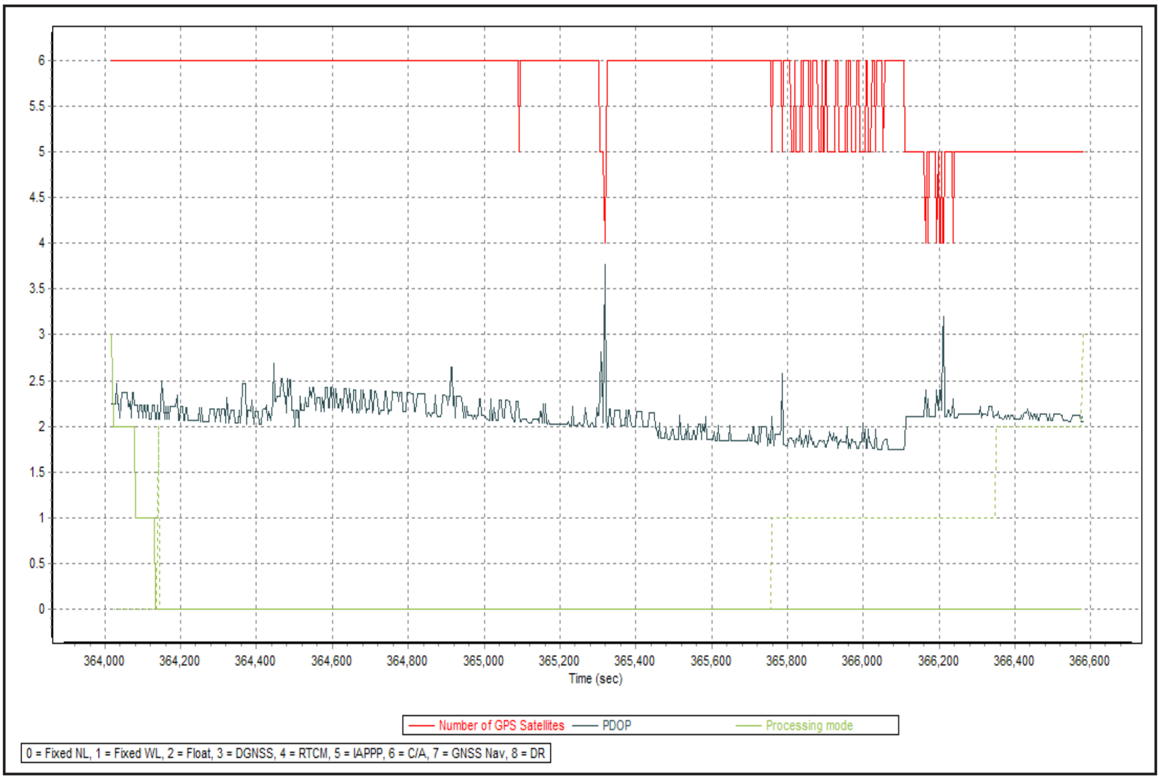


Figure 1.1.1. Solution Status

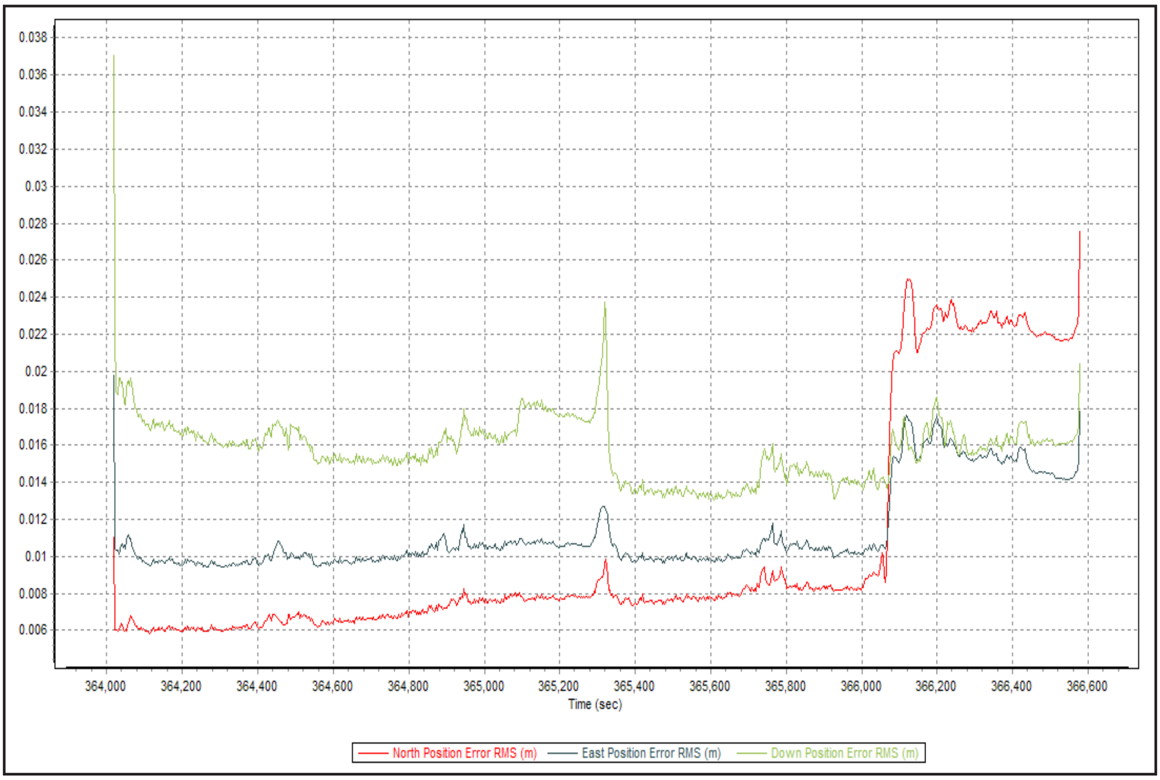


Figure 1.1.2. Smoothed Performance Metric Parameters

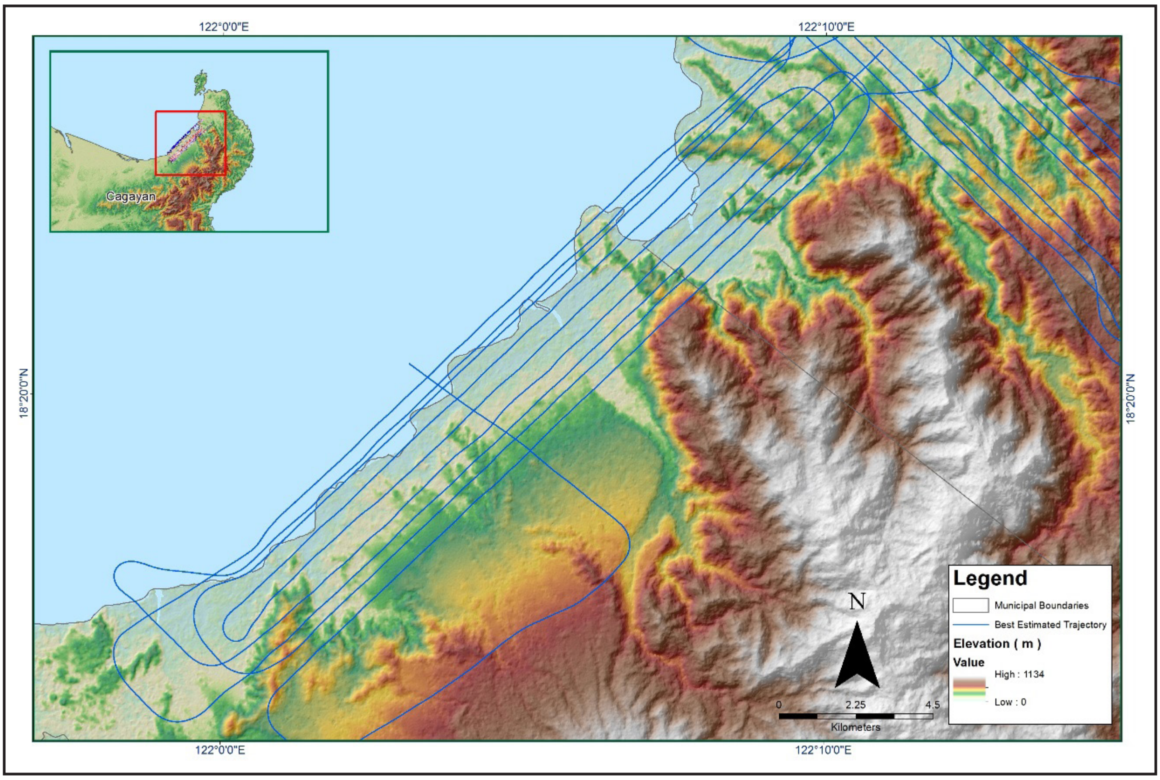


Figure 1.1.3. Best Estimated Trajectory

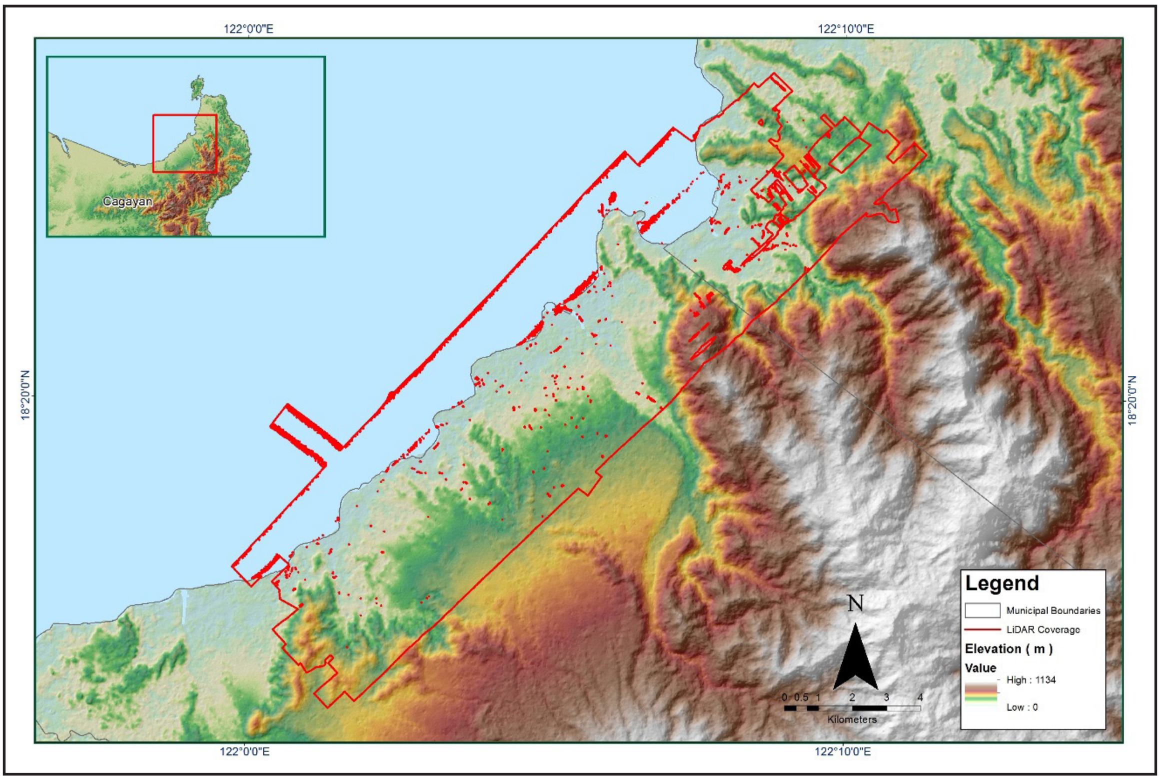


Figure 1.1.4. Coverage of LiDAR Data

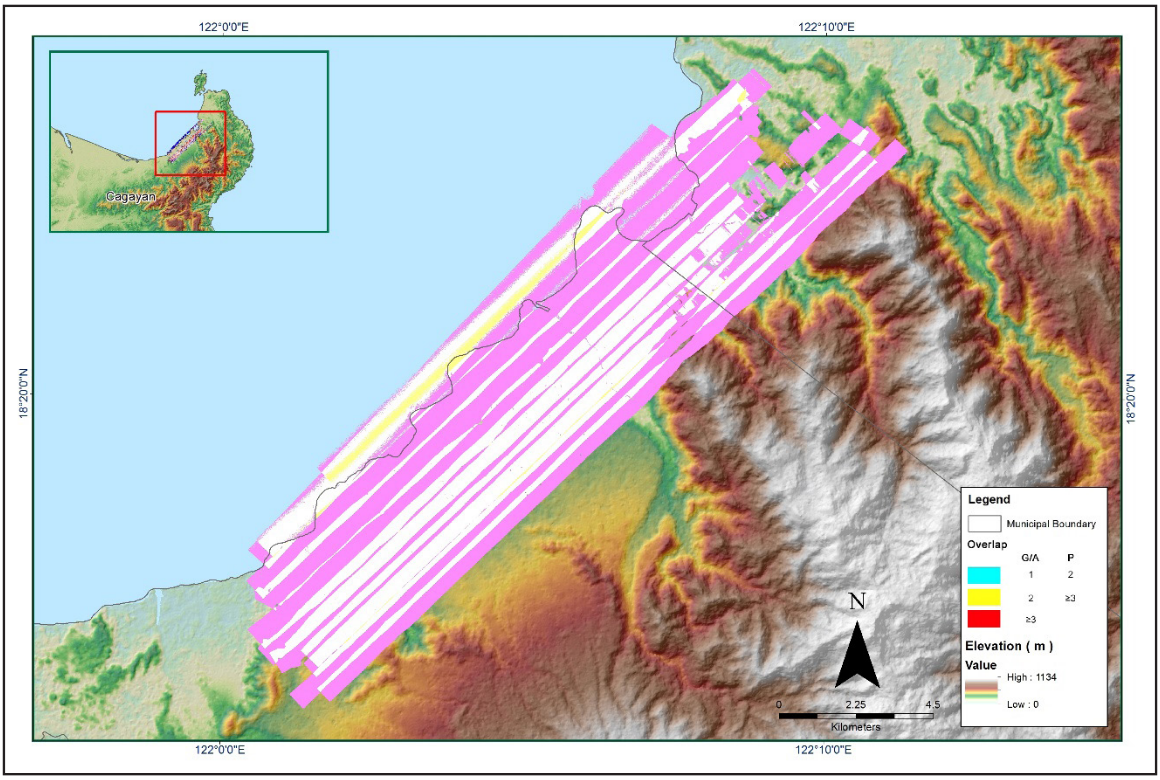


Figure 1.1.5. Image of data overlap

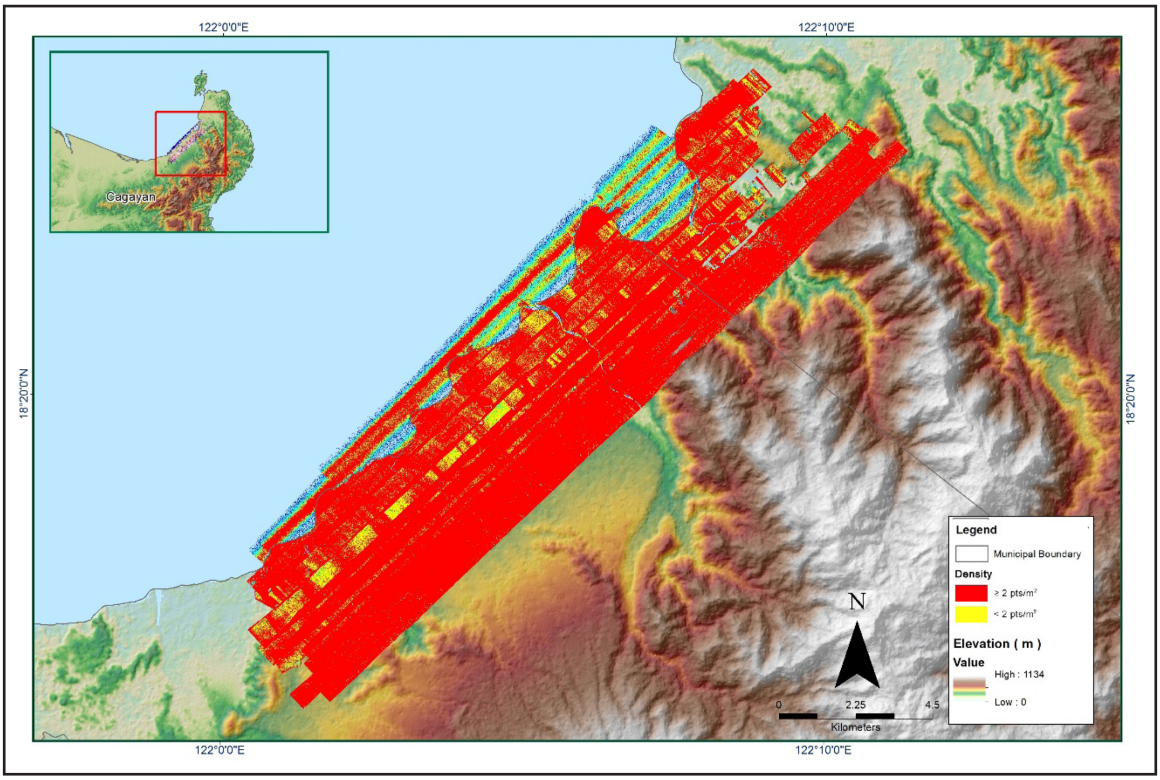


Figure 1.1.6. Density map of merged LiDAR data

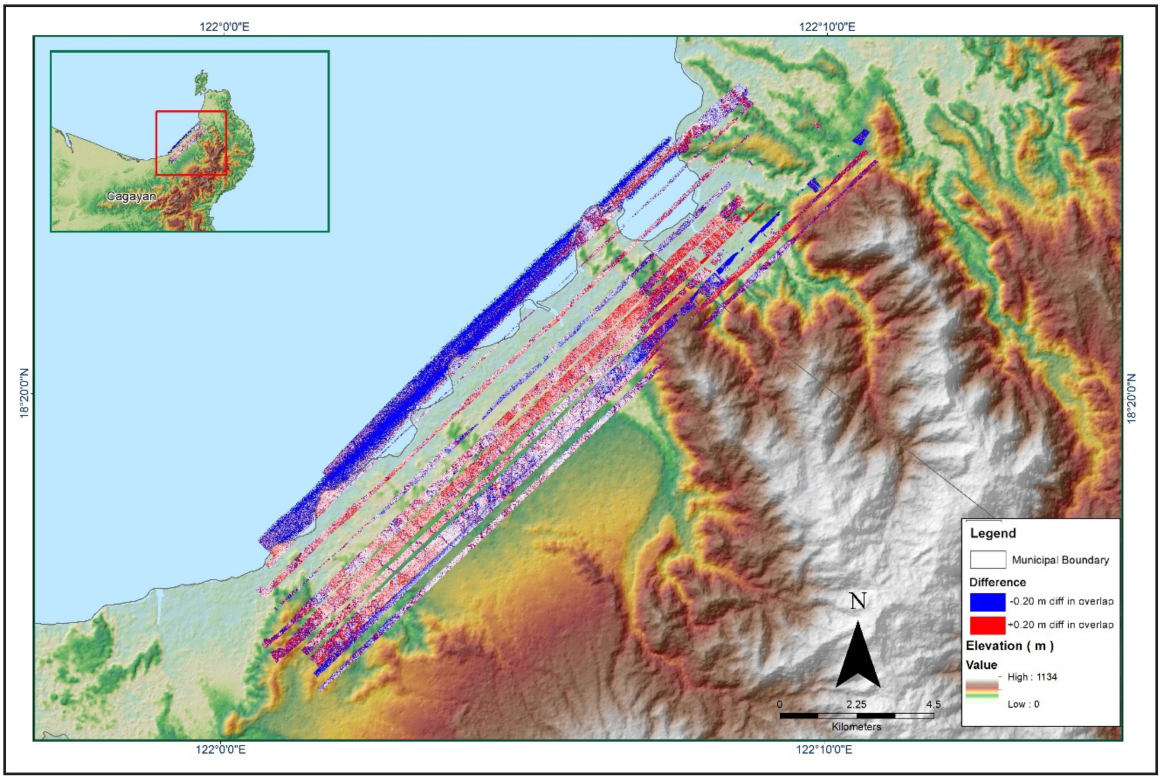


Figure 1.1.7. Elevation difference between flight lines

Table A-8.2 Mission Summary Report of Mission Blk3C

Flight Area	**Cagayan**
Mission Name	**Cagayan_reflights_Blk3C**
Inclusive Flights	3991G, 3971G, 3989G
Range data size	46.75 GB
POS data size	640 MB
Base data size	38.98 MB
Image	NA
Transfer date	June 21, 2016
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)	1.5
RMSE for Down Position (<8.0 cm)	3.0
Boresight correction stdev (<0.001deg)	0.000342
IMU attitude correction stdev (<0.001deg)	0.000718
GPS position stdev (<0.01m)	0.0014
Minimum % overlap (>25)	44.96%
Ave point cloud density per sq.m. (>2.0)	5.54
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	211
Maximum Height	801.02 m
Minimum Height	37.68 m
Classification (# of points)	
Ground	64,955,431
Low vegetation	70,520,039
Medium vegetation	182,653,450
High vegetation	495,888,734
Building	7,863,830
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Harmond Santos, Engr. Gladys Mae Apat

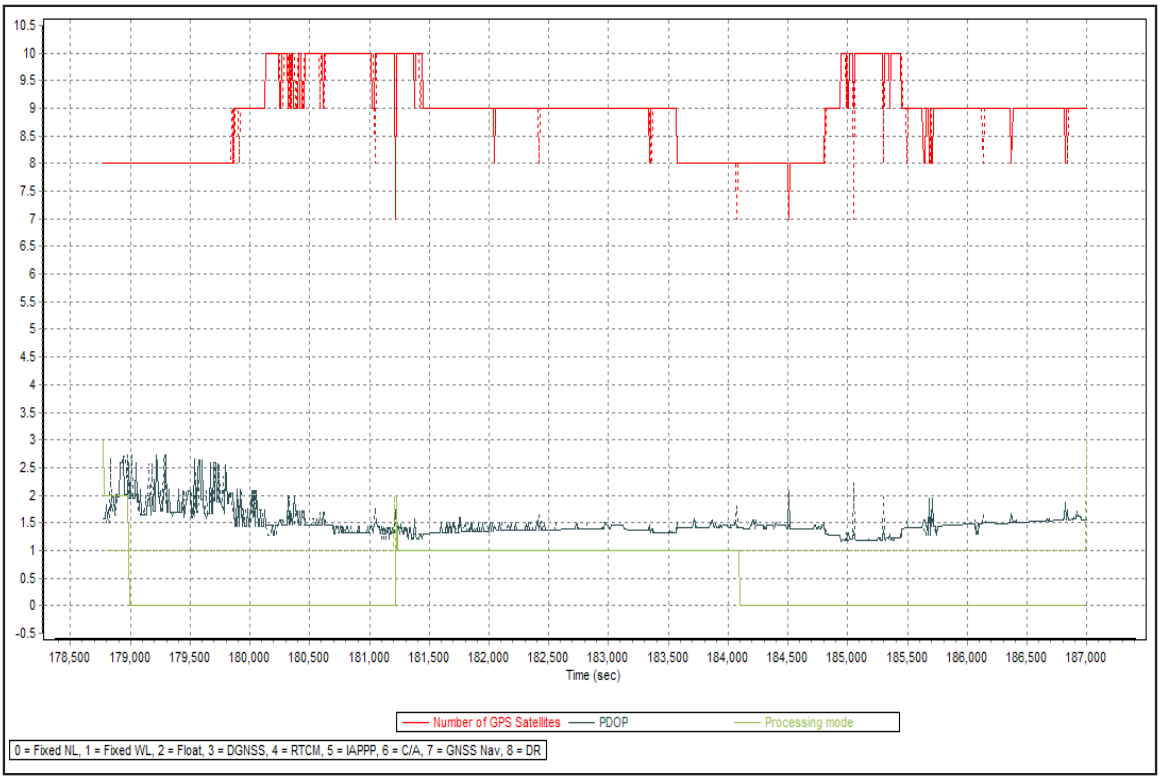


Figure 1.2.1. Solution Status

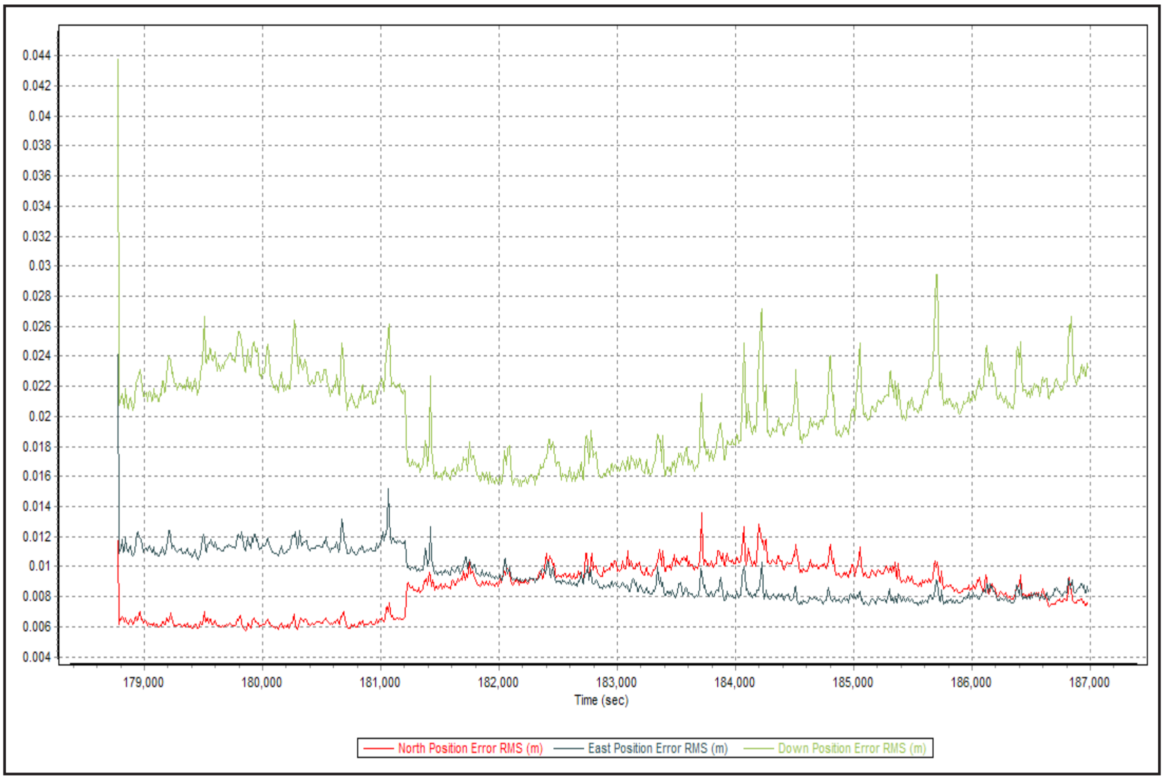


Figure 1.2.2. Smoothed Performance Metric Parameters

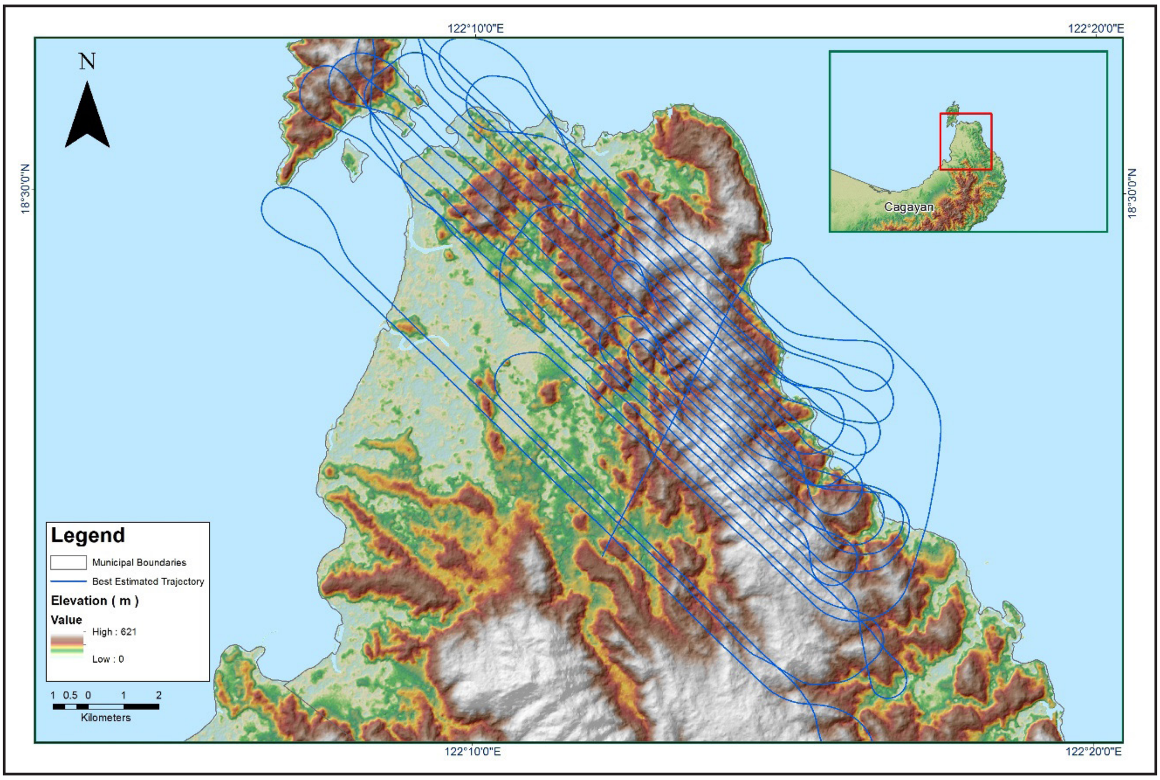


Figure 1.2.3. Best Estimated Trajectory

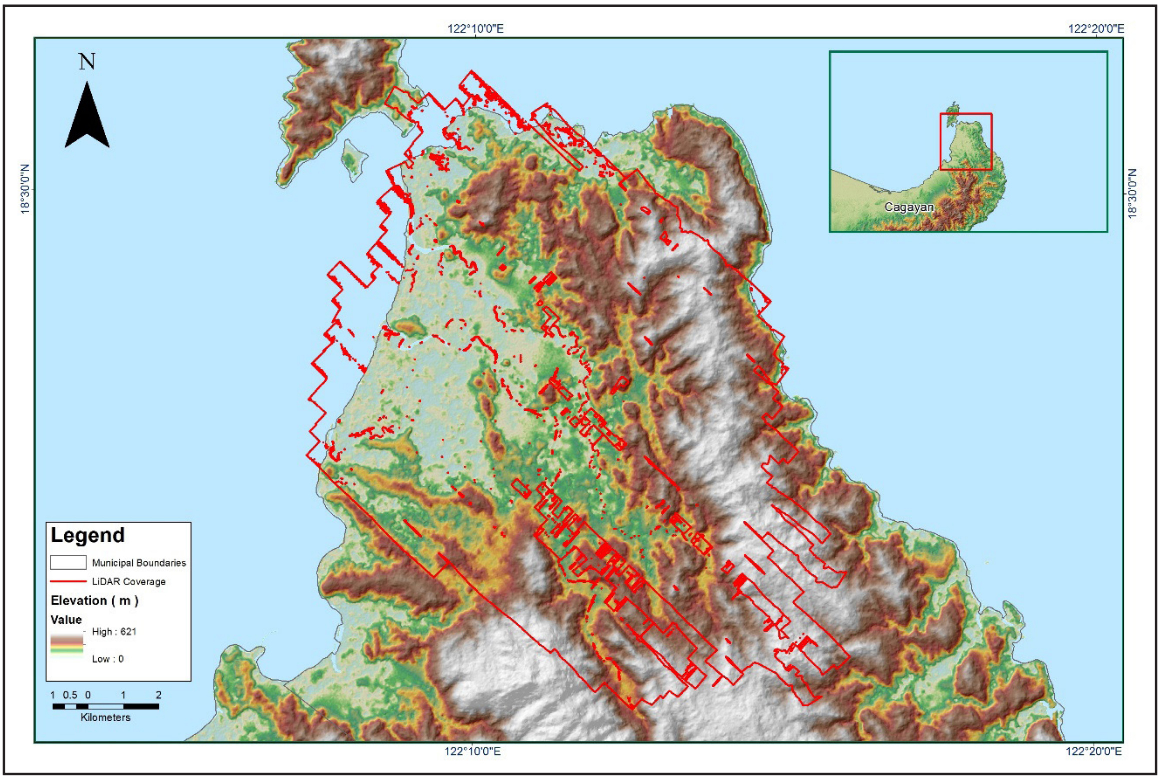


Figure 1.2.4. Coverage of LiDAR Data

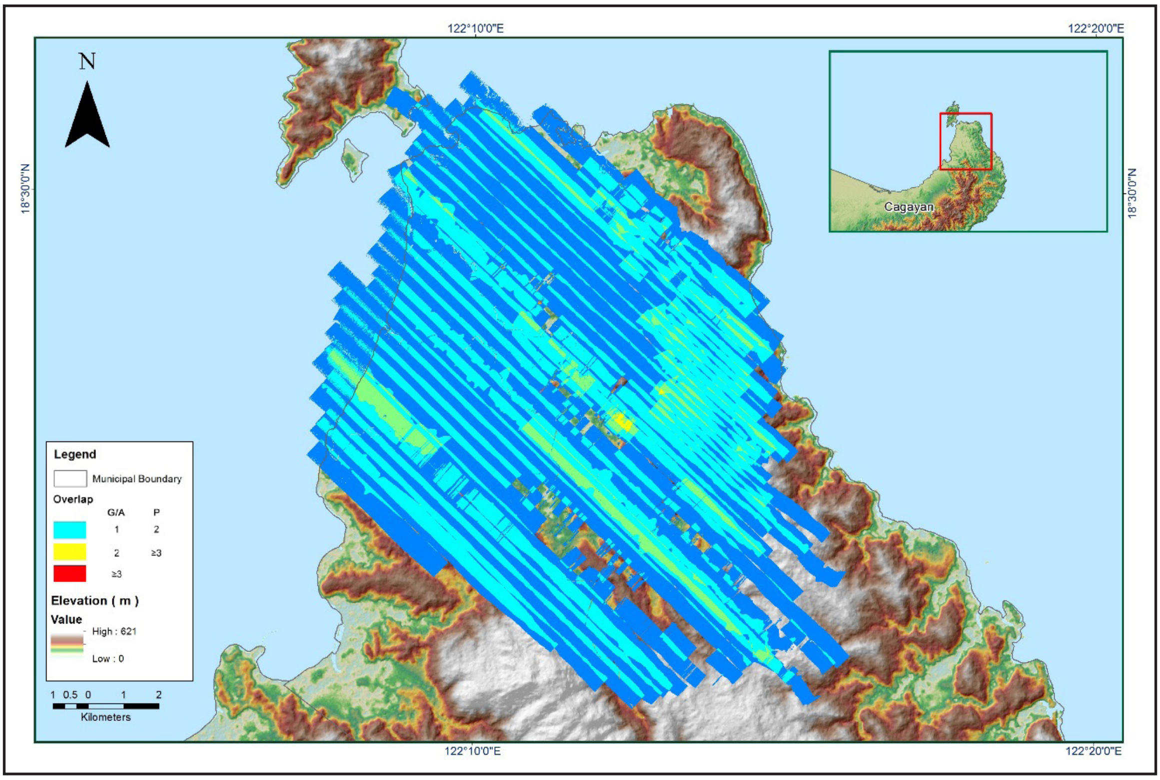


Figure 1.2.5. Image of data overlap

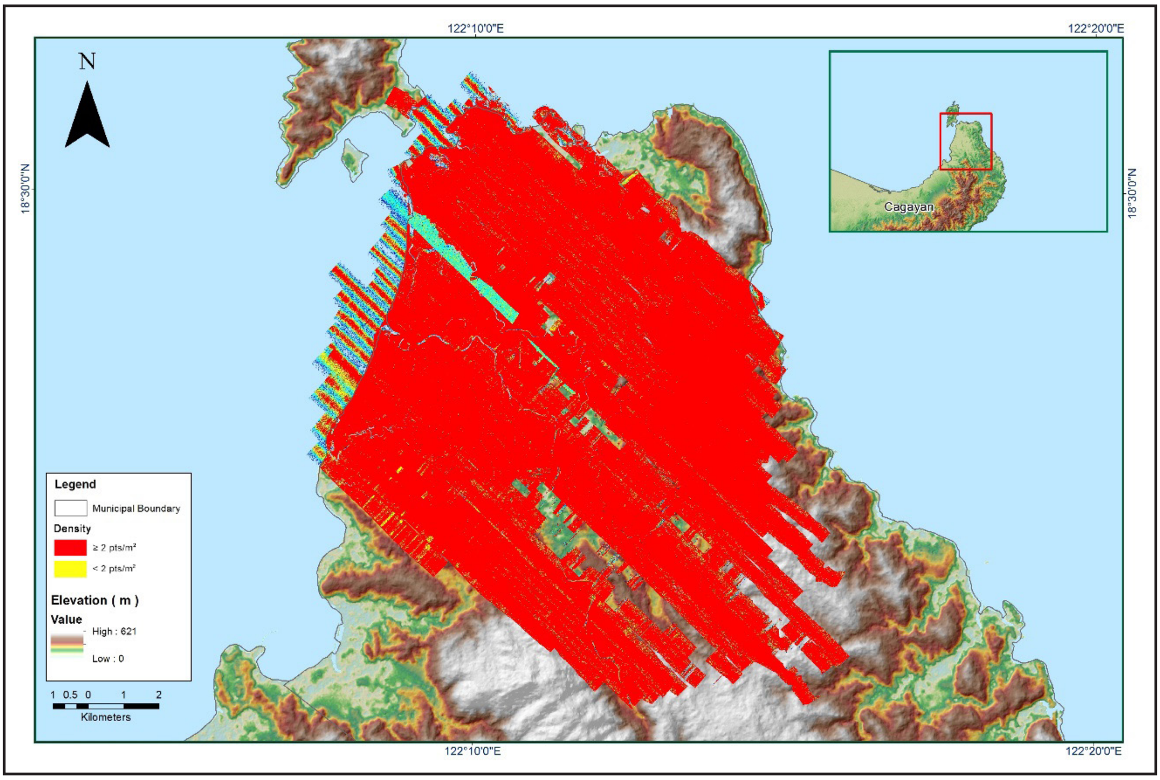


Figure 1.2.6. Density map of merged LiDAR data

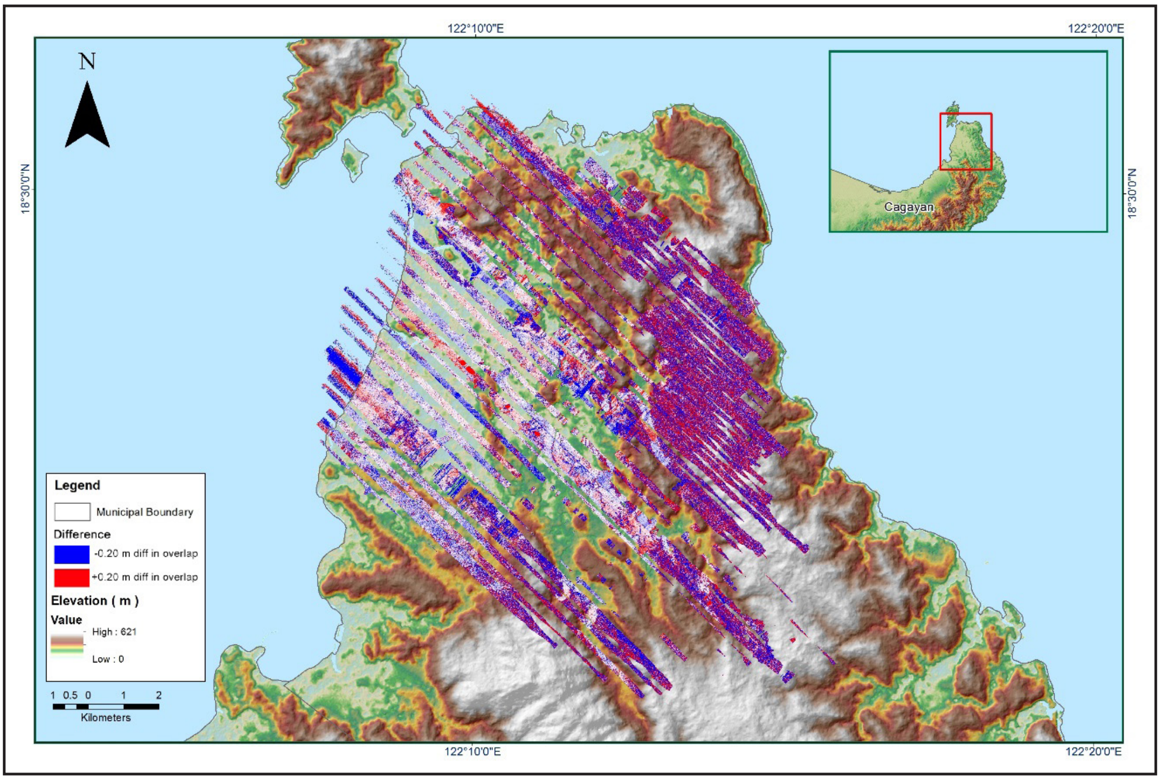


Figure 1.2.7. Elevation difference between flight lines

Table A-8.3 Mission Summary Report of Mission Blk3D

Flight Area	Cagayan
Mission Name	**Cagayan_reflights_Blk3D**
Inclusive Flights	4001G
Range data size	16.1 GB
POS data size	245 MB
Base data size	9.35 MB
Image	NA
Transfer date	June 21, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.0
RMSE for East Position (<4.0 cm)	1.1
RMSE for Down Position (<8.0 cm)	4.0
Boresight correction stdev (<0.001deg)	0.001846
IMU attitude correction stdev (<0.001deg)	0.0027
GPS position stdev (<0.01m)	0.007490
Minimum % overlap (>25)	40.87%
Ave point cloud density per sq.m. (>2.0)	3.10
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	48
Maximum Height	384.55 m
Minimum Height	36.47 m
Classification (# of points)	
Ground	9,410,752
Low vegetation	3,773,495
Medium vegetation	18,571,059
High vegetation	4,495,3057
Building	60,141
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Harmond Santos, Engr. Gladys Mae Apat

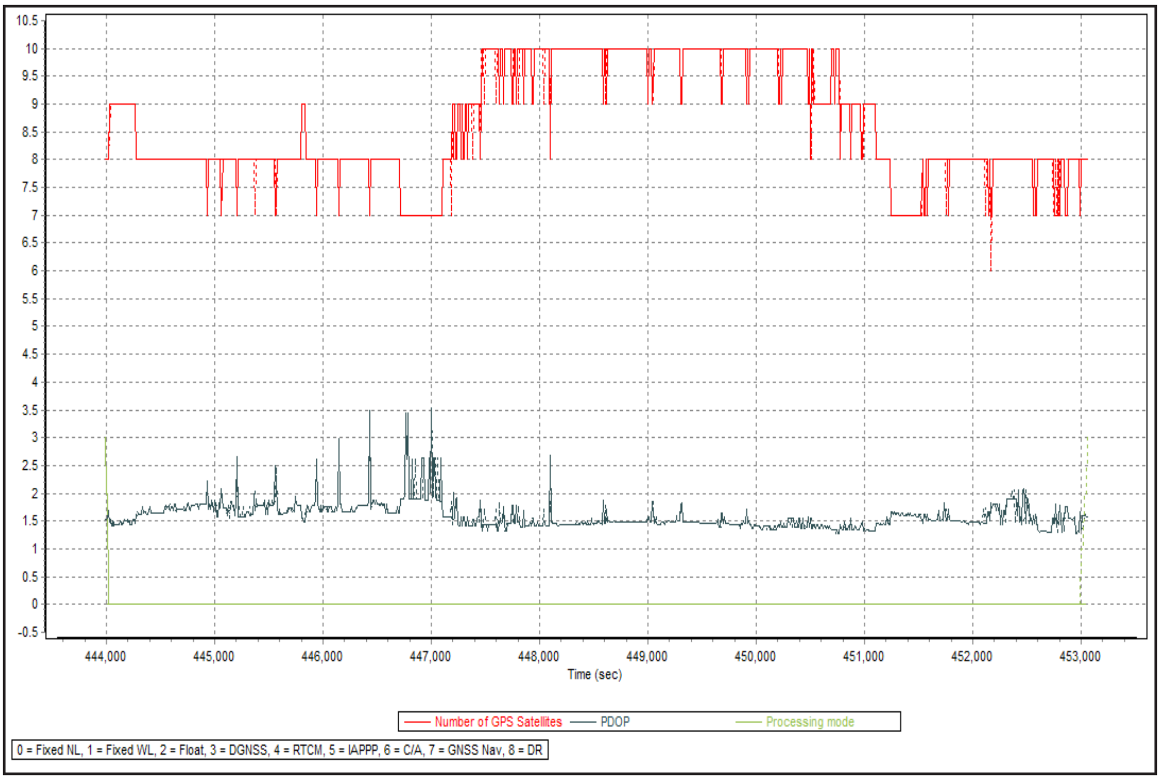


Figure 1.3.1. Solution Status

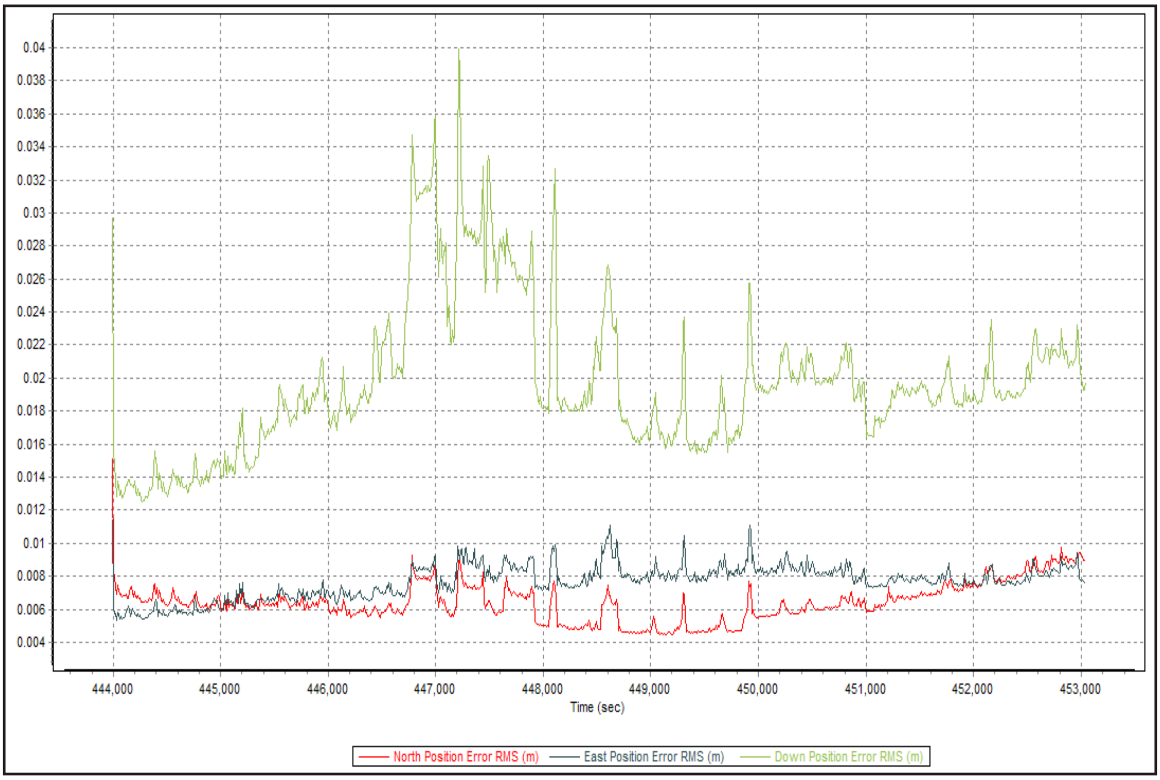


Figure 1.3.2. Smoothed Performance Metric Parameters

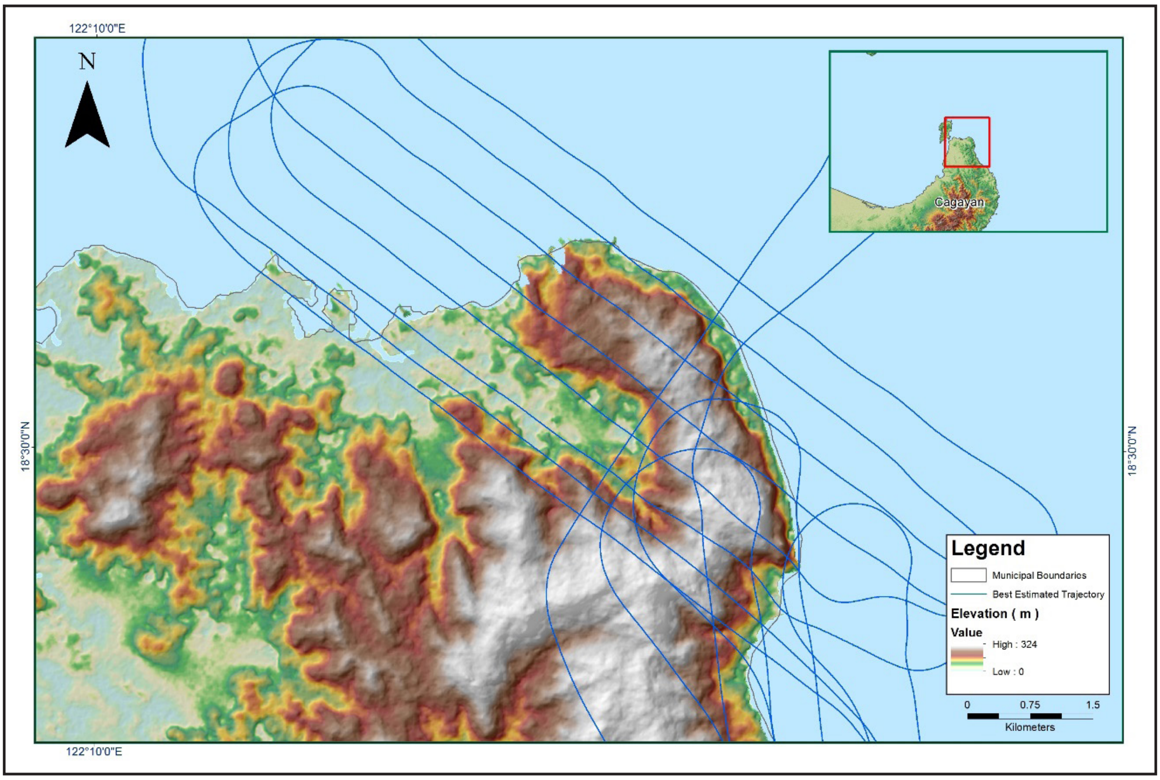


Figure 1.3.3. Best Estimated Trajectory

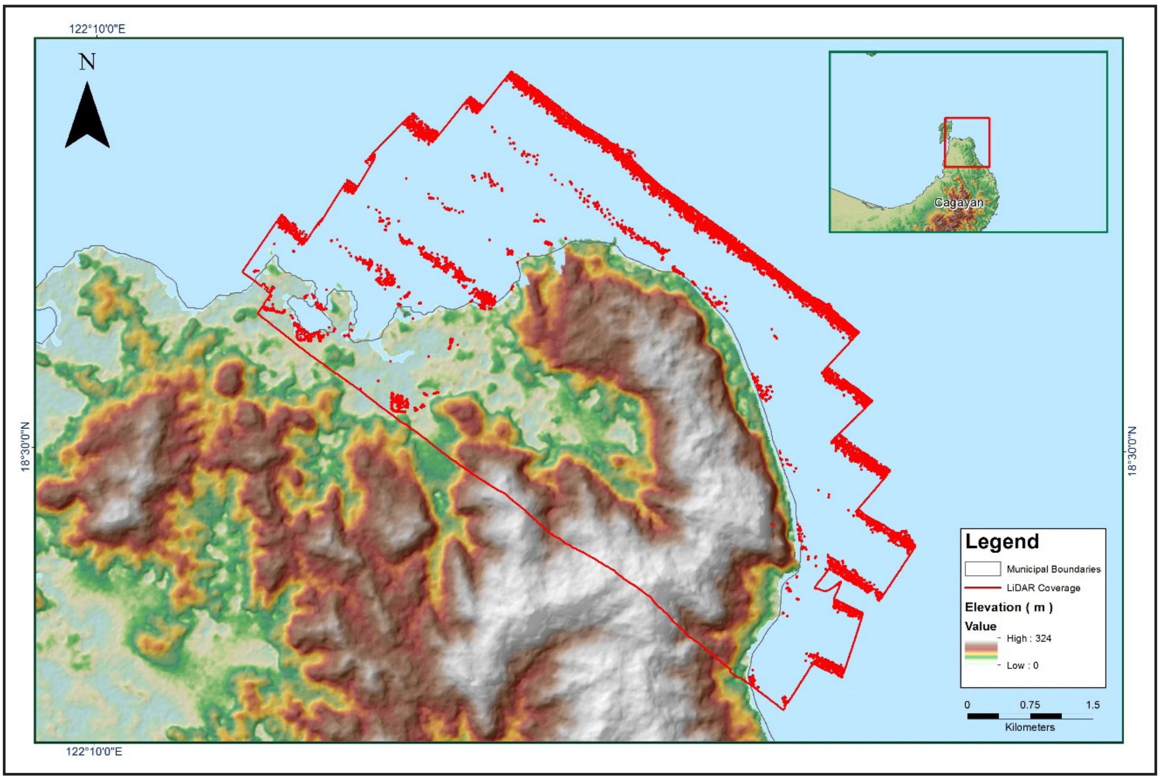


Figure 1.3.4. Coverage of LiDAR Data

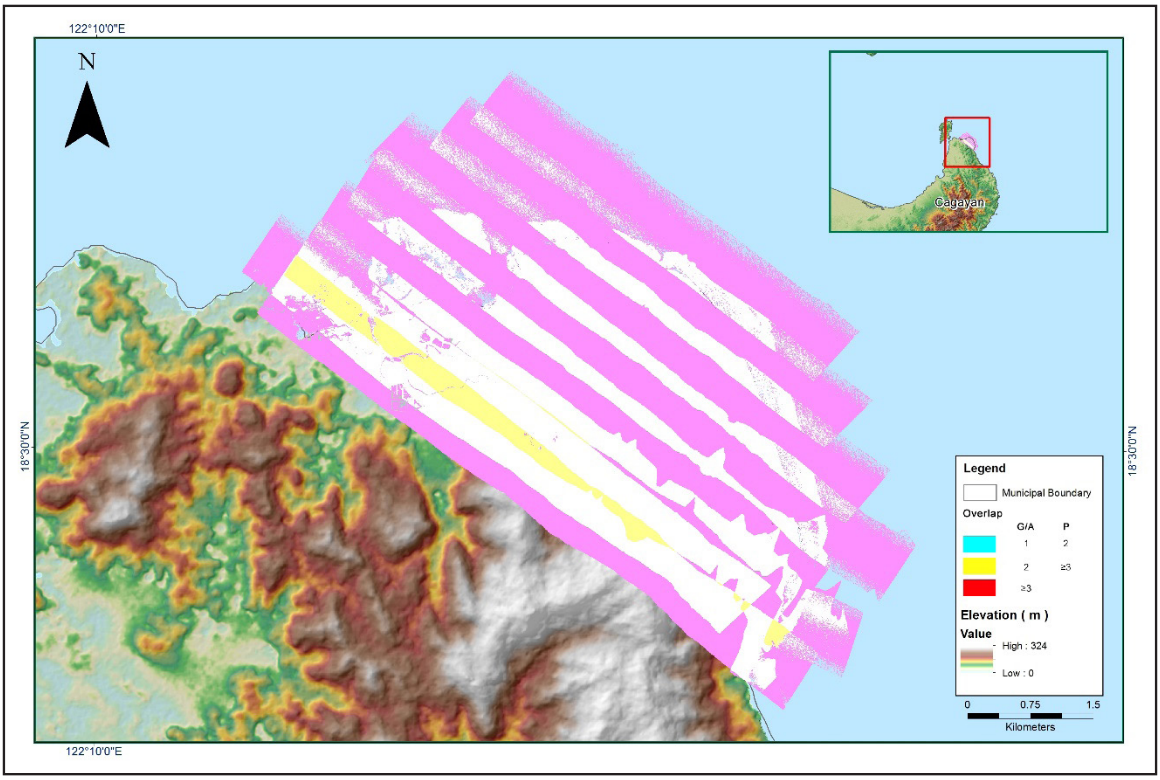


Figure 1.3.5. Image of data overlap

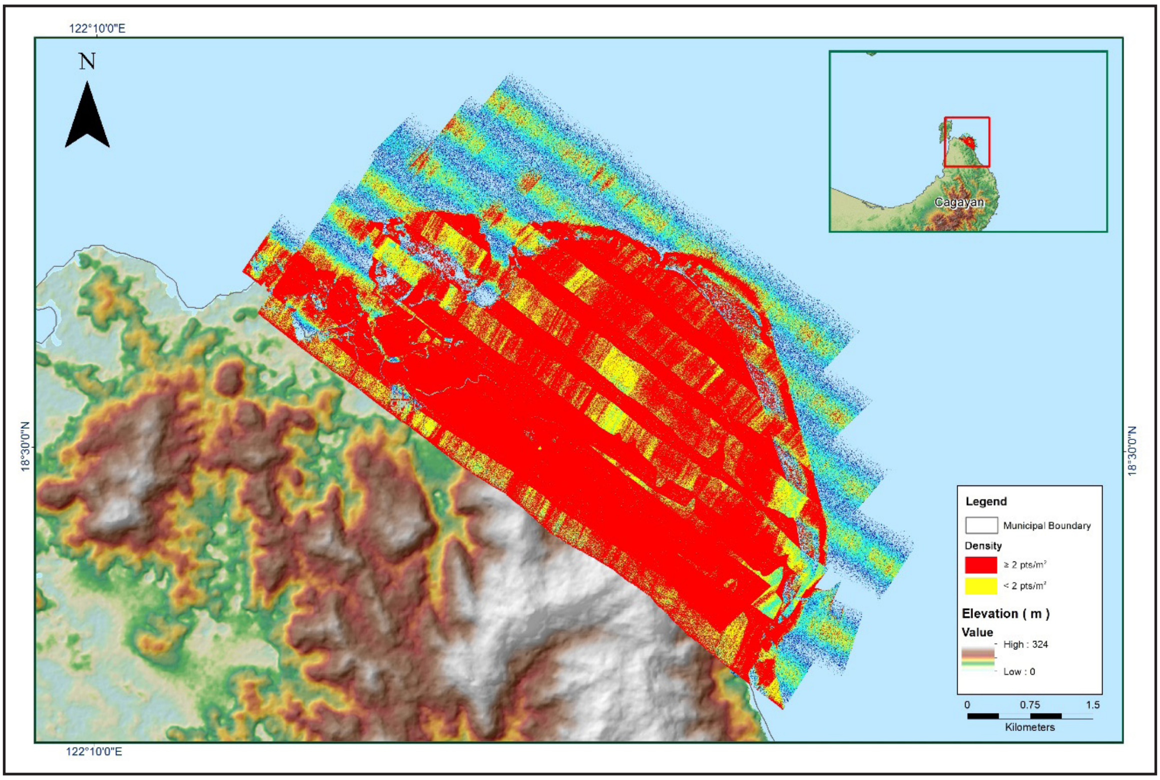


Figure 1.3.6. Density map of merged LiDAR data

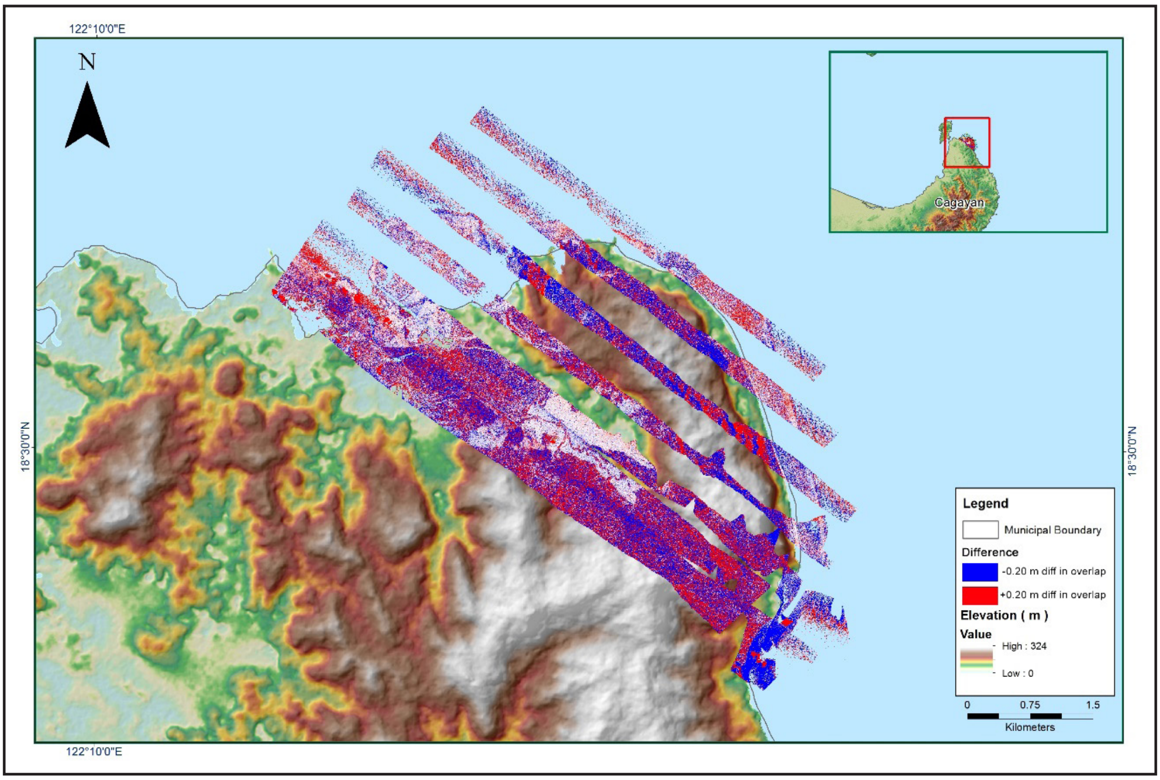


Figure 1.3.7. Elevation difference between flight lines

Table A-8.4 Mission Summary Report of Mission Blk3E

Flight Area	Cagayan
Mission Name	**Cagayan_reflights_Blk3E**
Inclusive Flights	4001G
Range data size	16.1 GB
POS data size	245 MB
Base data size	9.35 MB
Image	NA
Transfer date	June 21, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.0
RMSE for East Position (<4.0 cm)	1.1
RMSE for Down Position (<8.0 cm)	4.0
Boresight correction stdev (<0.001deg)	0.042939
IMU attitude correction stdev (<0.001deg)	0.015915
GPS position stdev (<0.01m)	0.0028
Minimum % overlap (>25)	39.43%
Ave point cloud density per sq.m. (>2.0)	4.48
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	56
Maximum Height	1137.78 m
Minimum Height	36.97 m
Classification (# of points)	
Ground	7,027,759
Low vegetation	1,038,007
Medium vegetation	9,626,843
High vegetation	115,006,003
Building	78,814
Orthophoto	No
Processed by	Engr. Regis Guhiting, Engr. Harmond Santos, Engr. Gladys Mae Apat

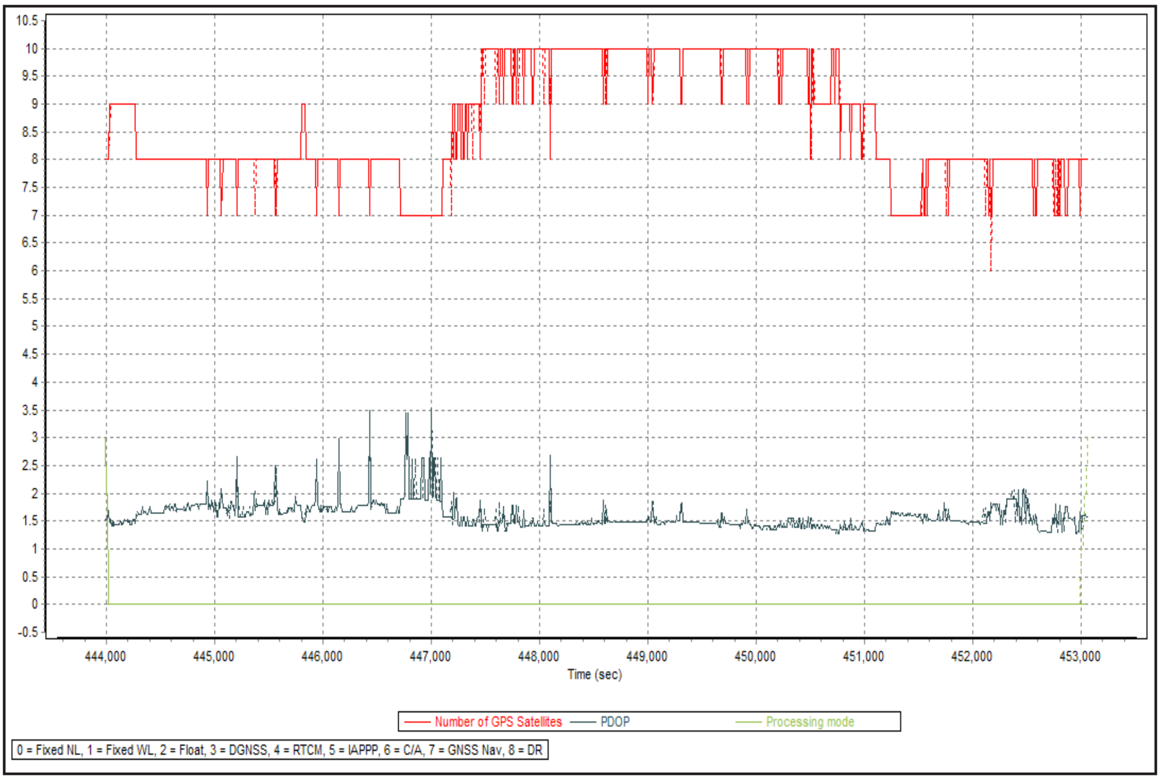


Figure 1.4.1. Solution Status

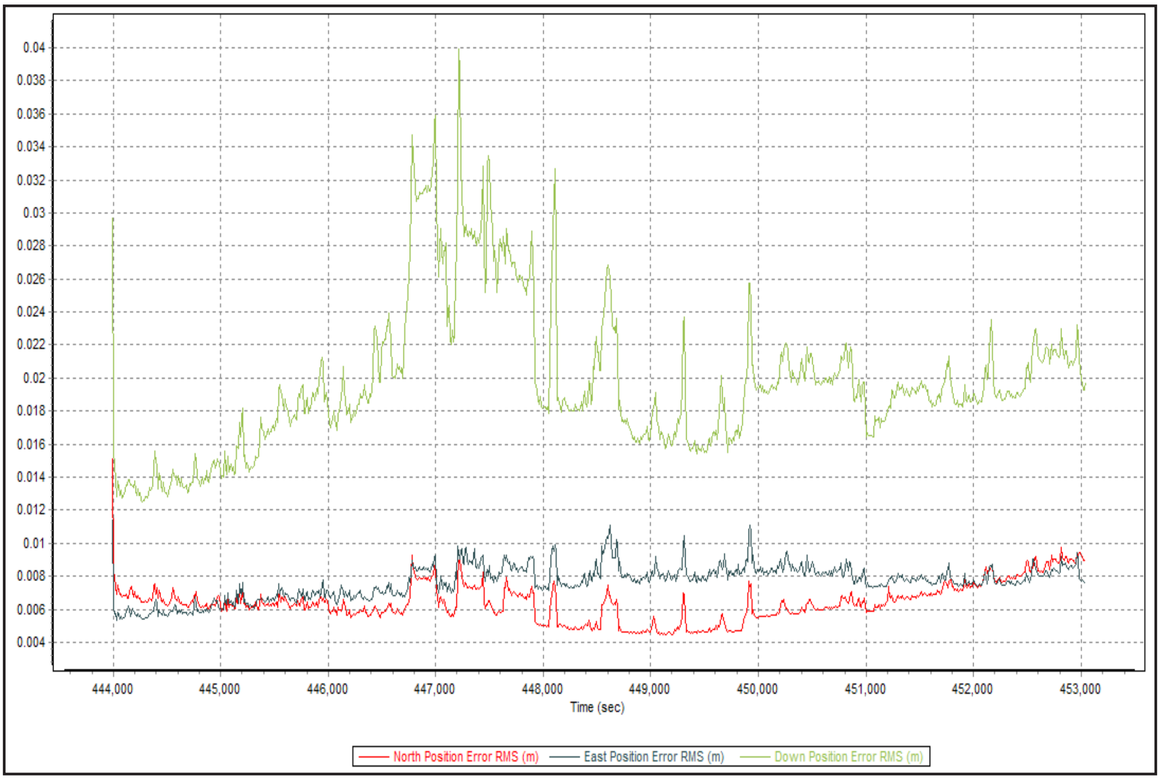


Figure 1.4.2. Smoothed Performance Metric Parameters

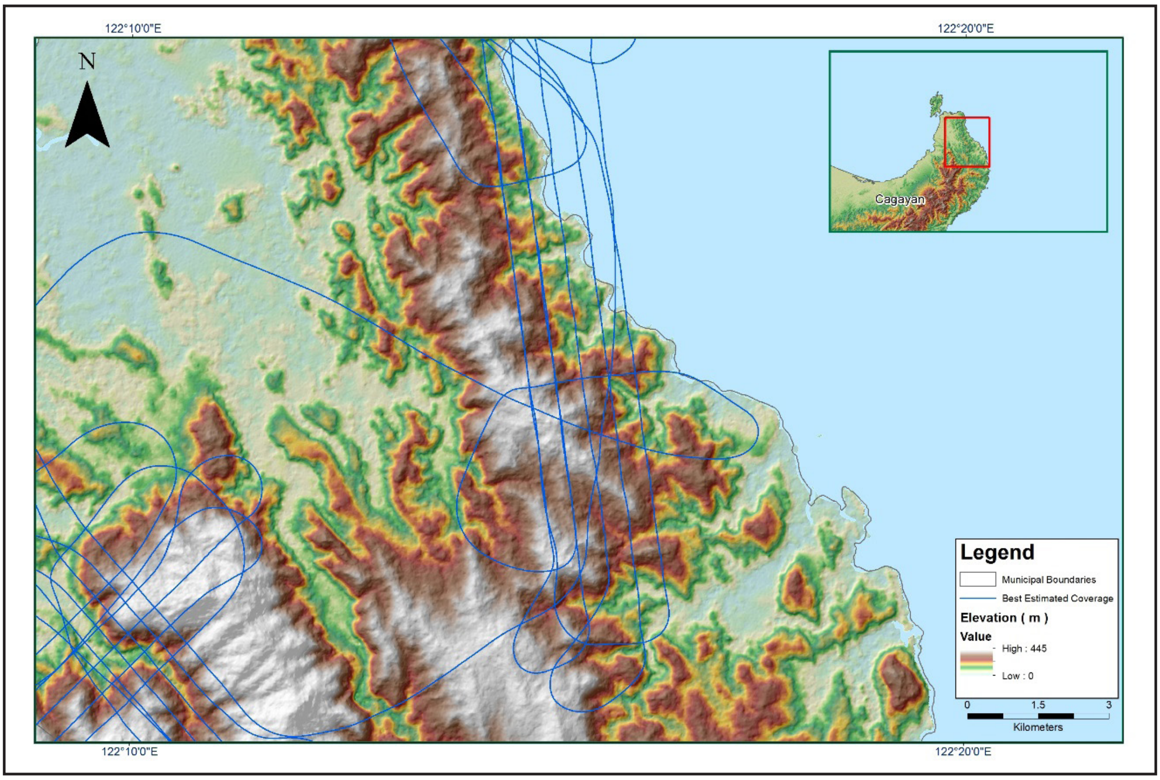


Figure 1.4.3. Best Estimated Trajectory

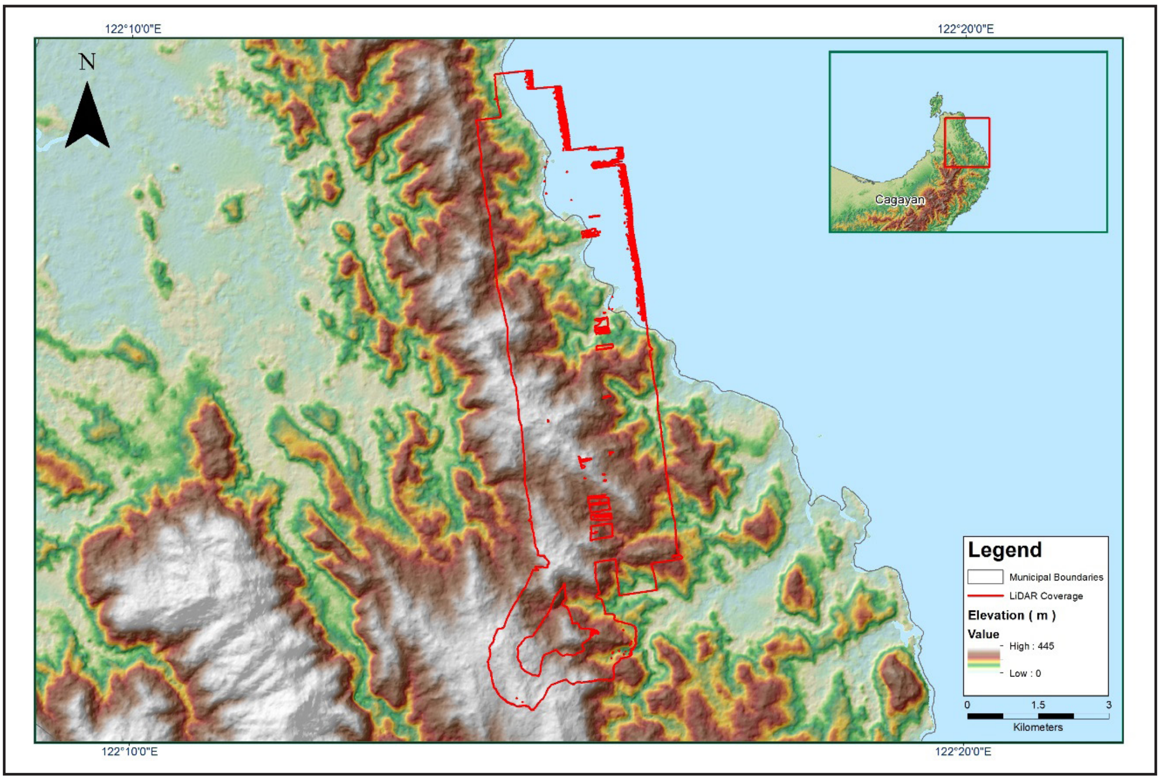


Figure 1.4.4. Coverage of LiDAR Data

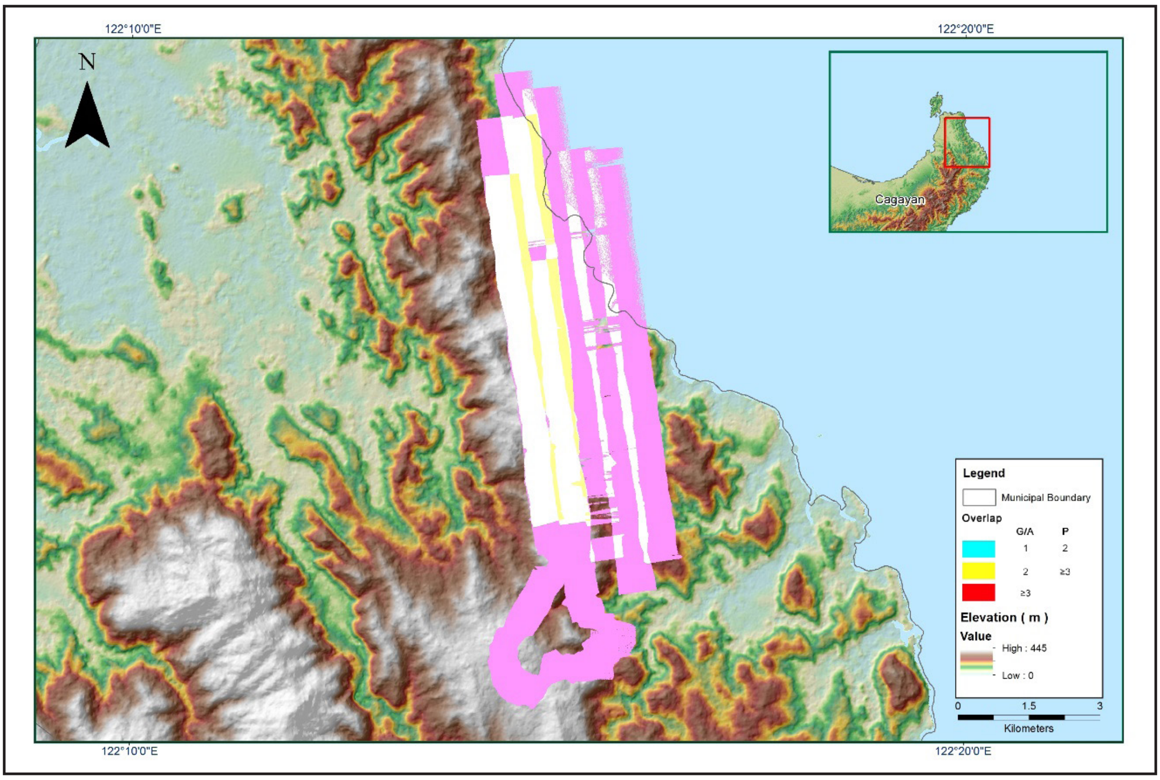


Figure 1.4.5. Image of data overlap

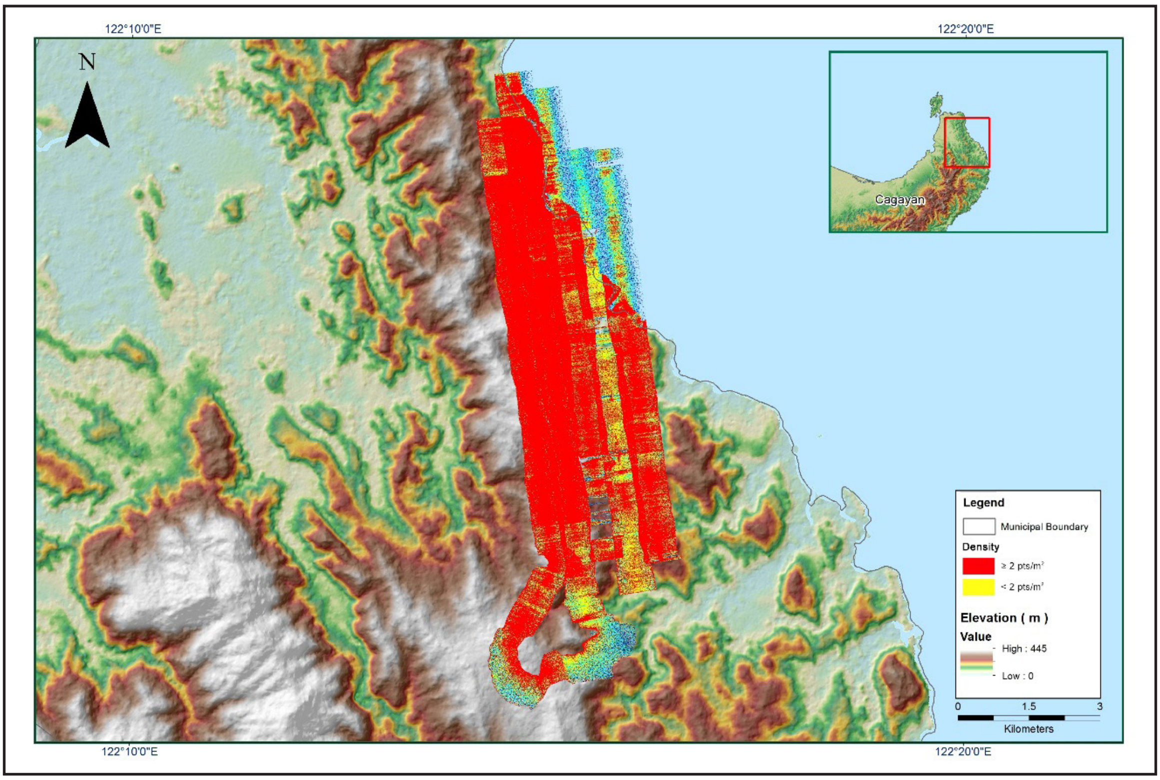


Figure 1.4.6. Density map of merged LiDAR data

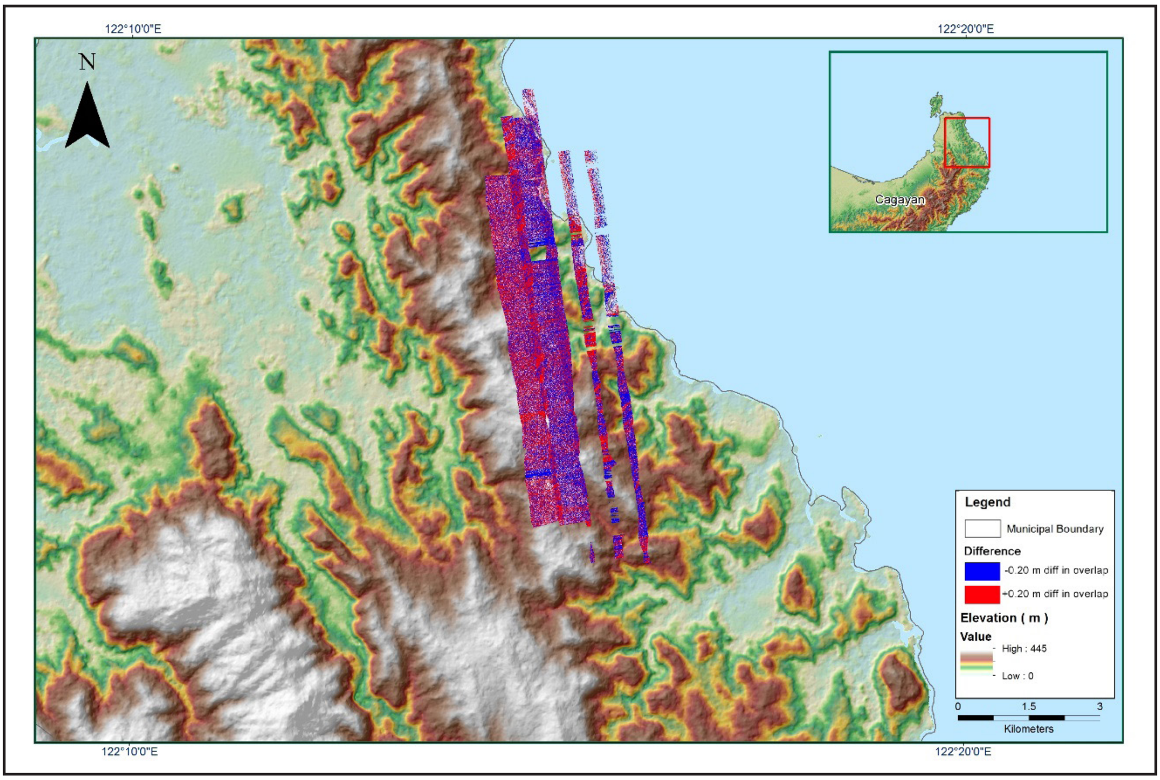


Figure 1.4.7. Elevation difference between flight lines

Annex 9. Tangatan Model Basin Parameters

Table A-9.1. Tangatan Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W230	23.656	80.401	0.0	1.50623	0.605891	Discharge	1.3830	0.86397	Ratio to Peak	0.5
W240	33.922	70.036	0.0	2.88728	7.25406	Discharge	3.6580	0.84194	Ratio to Peak	0.5
W250	16.660	89.417	0.0	0.483912	0.725582	Discharge	0.83684	0.86614	Ratio to Peak	0.5
W270	26.547	78.656	0.0	2.1839	1.6201	Discharge	0.0200440	0.85	Ratio to Peak	0.5
W280	36.434	67.895	0.0	1.42769	1.42065	Discharge	1.7689	0.84031	Ratio to Peak	0.5
W290	14.312	92.9152	0.0	0.225687	0.82005	Discharge	0.12528	0.86682	Ratio to Peak	0.5
W300	20.488	84.248	0.0	0.303149	0.497695	Discharge	0.0901981	0.8669	Ratio to Peak	0.5
W310	36.525	67.819	0.0	1.36664	0.927179	Discharge	2.1497	0.84989	Ratio to Peak	0.5
W320	18.650	86.653	0.0	1.094434	1.11804	Discharge	1.1175	1	Ratio to Peak	0.5
W330	29.680	73.977	0.0	1.6082	1.5169	Discharge	1.7789	0.85869	Ratio to Peak	0.5
W340	15.8890038	90.536	0.0	2.08769	1.29316	Discharge	2.2199	0.81988	Ratio to Peak	0.5
W350	27.520	76.158	0.0	2.40559	1.09538	Discharge	1.4281	0.86066	Ratio to Peak	0.5
W360	30.339	73.336	0.0	1.20252	1.057056	Discharge	1.2628	0.80355	Ratio to Peak	0.5
W370	19.761	85.183	0.0	2.75429	0.846417	Discharge	0.67649	0.86656	Ratio to Peak	0.5
W380	32.213	71.572	0.0	1.29283	0.977977	Discharge	2.2950	0.82263	Ratio to Peak	0.5
W390	20.770	83.89	0.0	1.50678	1.70929	Discharge	1.2227	0.54673	Ratio to Peak	0.5
W220	27.701	75.9706399	0.0	2.52549	3.84472	Discharge	3.9938	0.86474	Ratio to Peak	0.5
W400	31.118	72.592	0.0	2.85318	0.887612	Discharge	3.7633	0.86034	Ratio to Peak	0.5
W410	36.245	68.051	0.0	1.3211	7.28156	Discharge	2.9565	0.82223	Ratio to Peak	0.5
W420	36.489	67.849	0.0	0.917664	7.43523	Discharge	3.3774	0.85019	Ratio to Peak	0.5
W440	24.194	79.782	0.0	1.54253	0.742984	Discharge	3.4576	0.86401	Ratio to Peak	0.5
W450	22.379	81.908	0.0	5.30772	8.93211	Discharge	2.1898	0.86463	Ratio to Peak	0.5

Annex 10. Tangatan Model Reach Parameters

Table A-10.1. Tangatan 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	3119.9	0.001	0.022598	Trapezoid	79.08415	0.1617
R110	Automatic Fixed Interval	2223.5	0.0026984	0.0377772	Trapezoid	79.08415	0.1617
R130	Automatic Fixed Interval	2872.9	0.0010442	0.0254314	Trapezoid	79.08415	0.1617
R160	Automatic Fixed Interval	1183.6	0.0033797	0.084375	Trapezoid	79.08415	0.1617
R170	Automatic Fixed Interval	1876.9	0.0015984	0.0338175	Trapezoid	79.08415	0.1617
R180	Automatic Fixed Interval	2126.5	0.0047025	0.0847937	Trapezoid	79.08415	0.1617
R30	Automatic Fixed Interval	64.027	0.0156185	0.025	Trapezoid	79.08415	0.1617
R40	Automatic Fixed Interval	640.27	0.001	0.0156865	Trapezoid	79.08415	0.1617
R460	Automatic Fixed Interval	2623.2	0.0019061	0.0230592	Trapezoid	79.08415	0.1617
R70	Automatic Fixed Interval	708.84	0.0112860	0.056579	Trapezoid	79.08415	0.1617
R80	Automatic Fixed Interval	256.11	0.001	0.0243406	Trapezoid	79.08415	0.1617

Annex 11. Tangatan Field Validation Points

Table A-11. Tangatan Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
1	18.41135	122.21031	1.610	0.00	-1.61		5 Yr	100
2	18.41160	122.20828	2.050	0.00	-2.05		5 Yr	100
3	18.41201	122.20530	1.630	0.10	-1.53	TS Tasing/ October 1989	5 Yr	100
4	18.41418	122.20277	0.430	0.20	-0.23	TS Tasing/ October 1989	5 Yr	100
5	18.41721	122.20191	0.610	0.30	-0.31	TS Tasing/ October 1989	5 Yr	100
6	18.41915	122.19790	0.200	0.80	0.60	TS Tasing/ October 1989	5 Yr	100
7	18.42222	122.19534	0.060	0.00	-0.06		5 Yr	100
8	18.42277	122.12742	0.030	0.00	-0.03		5 Yr	100
9	18.42341	122.12767	1.290	0.00	-1.29		5 Yr	100
10	18.42462	122.19319	0.030	0.00	-0.03		5 Yr	100
11	18.42504	122.12717	0.060	0.00	-0.06		5 Yr	100
12	18.42628	122.12655	0.060	0.00	-0.06		5 Yr	100
13	18.42811	122.19287	0.100	0.30	0.20	TS Tasing/ October 1989	5 Yr	100
14	18.43113	122.12771	0.030	0.00	-0.03		5 Yr	100
15	18.43224	122.19130	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
16	18.43226	122.12844	0.950	0.00	-0.95		5 Yr	100
17	18.43405	122.16976	0.080	0.00	-0.08		5 Yr	100
18	18.43392	122.12951	0.050	0.00	-0.05		5 Yr	100
19	18.43414	122.16849	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
20	18.43425	122.16763	0.220	0.10	-0.12	TS Tasing/ October 1989	5 Yr	100
21	18.43464	122.16585	0.090	0.10	0.01	TS Tasing/ October 1989	5 Yr	100
22	18.43465	122.16367	0.170	0.10	-0.07	TS Tasing/ October 1989	5 Yr	100
23	18.43498	122.16502	0.340	0.10	-0.24	TS Tasing/ October 1989	5 Yr	100
24	18.43512	122.16161	0.060	0.10	0.04	TS Tasing/ October 1989	5 Yr	100
25	18.43593	122.13080	0.030	0.00	-0.03		5 Yr	100
26	18.43645	122.19018	1.220	0.20	-1.02	TS Tasing/ October 1989	5 Yr	100
27	18.43631	122.13092	0.040	0.00	-0.04		5 Yr	100
28	18.43767	122.16305	0.370	0.10	-0.27	TS Tasing/ October 1989	5 Yr	100
29	18.43888	122.16345	0.110	0.00	-0.11		5 Yr	100

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
30	18.43909	122.19049	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
31	18.43910	122.13226	0.030	0.00	-0.03		5 Yr	100
32	18.44015	122.19152	0.030	0.30	0.27	TS Tasing/ October 1989	5 Yr	100
33	18.44032	122.16161	0.180	0.00	-0.18		5 Yr	100
34	18.44079	122.13313	0.030	0.00	-0.03		5 Yr	100
35	18.44144	122.15926	0.420	0.00	-0.42		5 Yr	100
36	18.44229	122.19495	1.520	0.50	-1.02	TS Tasing/ October 1989	5 Yr	100
37	18.44207	122.13369	0.030	0.00	-0.03		5 Yr	100
38	18.44230	122.15788	0.030	0.00	-0.03		5 Yr	100
39	18.44257	122.19382	1.100	0.40	-0.70	TS Tasing/ October 1989	5 Yr	100
40	18.44324	122.19602	6.310	0.50	-5.81	TS Tasing/ October 1989	5 Yr	100
41	18.44326	122.19603	6.310	0.00	-6.31		5 Yr	100
42	18.44343	122.19201	0.030	0.40	0.37	TS Tasing/ October 1989	5 Yr	100
43	18.44339	122.13439	0.160	0.00	-0.16		5 Yr	100
44	18.44388	122.15588	0.090	0.00	-0.09		5 Yr	100
45	18.44394	122.15577	0.060	0.00	-0.06		5 Yr	100
46	18.44425	122.18951	0.030	0.90	0.87	TS Tasing/ October 1989	5 Yr	100
47	18.44429	122.18831	0.080	0.70	0.62	TS Tasing/ October 1989	5 Yr	100
48	18.44414	122.13472	0.240	0.00	-0.24		5 Yr	100
49	18.44485	122.18876	0.050	0.00	-0.05		5 Yr	100
50	18.44486	122.14113	0.030	0.00	-0.03		5 Yr	100
51	18.44508	122.18691	0.030	0.30	0.27	TS Tasing/ October 1989	5 Yr	100
52	18.44515	122.18928	0.220	0.00	-0.22		5 Yr	100
53	18.44509	122.14008	0.410	0.00	-0.41		5 Yr	100
54	18.44511	122.13517	0.030	0.00	-0.03		5 Yr	100
55	18.44526	122.15412	0.480	0.00	-0.48		5 Yr	100
56	18.44582	122.13796	0.030	0.00	-0.03		5 Yr	100
57	18.44589	122.13555	0.240	0.00	-0.24		5 Yr	100
58	18.44598	122.15176	0.270	0.00	-0.27		5 Yr	100
59	18.44630	122.18449	0.100	0.00	-0.10		5 Yr	
60	18.44626	122.13653	0.060	0.00	-0.06		5 Yr	
61	18.44638	122.14928	0.030	0.00	-0.03		5 Yr	
62	18.44702	122.13607	0.050	0.00	-0.05		5 Yr	
63	18.44726	122.14713	0.030	0.00	-0.03		5 Yr	

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
64	18.44738	122.14701	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
65	18.44788	122.14572	0.210	0.10	-0.11	TS Tasing/ October 1989	5 Yr	100
66	18.44787	122.13657	0.030	0.00	-0.03		5 Yr	100
67	18.44826	122.18327	0.030	0.00	-0.03		5 Yr	100
68	18.44854	122.13684	0.030	0.00	-0.03		5 Yr	100
69	18.44862	122.14404	0.100	0.10	0.00	TS Tasing/ October 1989	5 Yr	100
70	18.44876	122.14766	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
71	18.44946	122.14225	0.100	0.10	0.00	TS Tasing/ October 1989	5 Yr	100
72	18.44975	122.13742	0.200	0.00	-0.20		5 Yr	100
73	18.45007	122.14005	0.290	0.00	-0.29		5 Yr	100
74	18.45020	122.14842	0.050	0.20	0.15	TS Tasing/ October 1989	5 Yr	100
75	18.45036	122.17991	0.330	0.40	0.07	TS Tasing/ October 1989	5 Yr	100
76	18.45040	122.13786	0.030	0.00	-0.03		5 Yr	100
77	18.45077	122.13674	0.070	0.10	0.03	TS Tasing/ October 1989	5 Yr	100
78	18.45157	122.14828	0.030	0.30	0.27	TS Tasing/ October 1989	5 Yr	100
79	18.45206	122.17833	0.540	0.00	-0.54		5 Yr	100
80	18.45194	122.13852	0.030	0.00	-0.03		5 Yr	100
81	18.45224	122.13731	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
82	18.45235	122.14374	0.110	0.20	0.09	TS Tasing/ October 1989	5 Yr	100
83	18.45273	122.14695	0.040	0.10	0.06	TS Tasing/ October 1989	5 Yr	100
84	18.45297	122.19362	1.210	0.50	-0.71	TS Tasing/ October 1989	5 Yr	100
85	18.45303	122.17755	0.640	0.00	-0.64		5 Yr	100
86	18.45295	122.14581	0.330	0.20	-0.13	TS Tasing/ October 1989	5 Yr	100
87	18.45357	122.17713	0.570	0.00	-0.57		5 Yr	100
88	18.45379	122.19688	1.410	0.50	-0.91	TS Tasing/ October 1989	5 Yr	100
89	18.45375	122.17716	0.600	0.20	-0.40	TS Tasing/ October 1989	5 Yr	100
90	18.45365	122.13804	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
91	18.45372	122.13937	0.030	0.00	-0.03		5 Yr	100
92	18.45386	122.15804	0.340	0.30	-0.04	TS Tasing/ October 1989	5 Yr	100

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
93	18.45386	122.14319	0.200	0.00	-0.20		5 Yr	100
94	18.45407	122.17529	1.490	0.30	-1.19	TS Tasing/ October 1989	5 Yr	100
95	18.45428	122.17660	0.800	0.30	-0.50	TS Tasing/ October 1989	5 Yr	100
96	18.45462	122.19740	2.100	0.40	-1.70	TS Tasing/ October 1989	5 Yr	100
97	18.45449	122.14251	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
98	18.45485	122.15591	0.910	0.30	-0.61	TS Tasing/ October 1989	5 Yr	100
99	18.45520	122.17502	0.970	0.30	-0.67	TS Tasing/ October 1989	5 Yr	100
100	18.45520	122.14008	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
101	18.45534	122.15389	1.740	0.30	-1.44	TS Tasing/ October 1989	5 Yr	100
102	18.45535	122.15468	1.310	0.30	-1.01	TS Tasing/ October 1989	5 Yr	100
103	18.45569	122.15233	0.560	0.00	-0.56		5 Yr	100
104	18.45585	122.13945	0.120	0.20	0.08	TS Tasing/ October 1989	5 Yr	100
105	18.45614	122.15132	0.520	0.00	-0.52		5 Yr	100
106	18.45650	122.13986	0.440	0.10	-0.34	TS Tasing/ October 1989	5 Yr	100
107	18.45668	122.15001	0.220	0.00	-0.22		5 Yr	100
108	18.45693	122.17515	0.390	0.00	-0.39		5 Yr	100
109	18.45729	122.14292	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
110	18.45730	122.14107	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
111	18.45756	122.14796	0.030	0.00	-0.03		5 Yr	100
112	18.45756	122.14033	0.550	0.40	-0.15	TS Tasing/ October 1989	5 Yr	100
113	18.45769	122.14281	0.040	0.00	-0.04		5 Yr	100
114	18.45794	122.17442	0.390	0.00	-0.39		5 Yr	100
115	18.45787	122.14727	0.030	0.00	-0.03		5 Yr	100
116	18.45796	122.14285	0.060	0.00	-0.06		5 Yr	100
117	18.45825	122.14304	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
118	18.45832	122.14629	0.030	0.00	-0.03		5 Yr	100
119	18.45870	122.14254	0.030	0.00	-0.03		5 Yr	100
120	18.45875	122.14176	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
121	18.45898	122.14475	0.100	0.00	-0.10		5 Yr	100

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
122	18.45916	122.14198	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
123	18.45938	122.14383	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
124	18.45949	122.14227	0.030	0.00	-0.03		5 Yr	100
125	18.45955	122.14217	0.030	0.00	-0.03		5 Yr	100
126	18.45986	122.14267	0.060	0.10	0.04	TS Tasing/ October 1989	5 Yr	100
127	18.46020	122.14247	0.030	0.00	-0.03		5 Yr	100
128	18.46037	122.14253	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
129	18.46080	122.17256	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
130	18.46111	122.14283	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
131	18.46160	122.14306	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
132	18.46166	122.14309	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
133	18.46175	122.14149	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
134	18.46182	122.14291	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
135	18.46186	122.14307	0.030	0.00	-0.03		5 Yr	100
136	18.46207	122.14298	0.040	0.20	0.16	TS Tasing/ October 1989	5 Yr	100
137	18.46211	122.14330	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
138	18.46225	122.17054	0.030	0.00	-0.03		5 Yr	100
139	18.46223	122.14296	0.080	0.20	0.12	TS Tasing/ October 1989	5 Yr	100
140	18.46252	122.14236	0.210	0.20	-0.01	TS Tasing/ October 1989	5 Yr	100
141	18.46273	122.14358	0.030	0.20	0.17	TS Tasing/ October 1989	5 Yr	100
142	18.46274	122.14181	0.030	0.30	0.27	TS Tasing/ October 1989	5 Yr	100
143	18.46330	122.16809	0.030	0.10	0.07	TS Tasing/ October 1989	5 Yr	100
144	18.46339	122.14387	0.030	0.30	0.27	TS Tasing/ October 1989	5 Yr	100
145	18.46349	122.14244	0.270	0.00	-0.27		5 Yr	100
146	18.46396	122.14414	2.490	0.00	-2.49		5 Yr	100
147	18.46417	122.16612	0.030	0.00	-0.03		5yr	100
148	18.46519	122.14436	0.030	0.30	0.27	TS Tasing/ October 1989	5yr	100

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
149	18.46569	122.15716	0.030	0.20	0.17	TS Tasing/ October 1989	5yr	100
150	18.46581	122.14427	0.540	0.50	-0.04	TS Tasing/ October 1989	5yr	100
151	18.46611	122.14540	0.030	0.00	-0.03		5yr	100
152	18.46625	122.16541	0.030	0.30	0.27	TS Tasing/ October 1989	5yr	100
153	18.46644	122.14443	0.110	0.20	0.09	TS Tasing/ October 1989	5yr	100
154	18.46665	122.15396	0.570	0.10	-0.47	TS Tasing/ October 1989	5yr	100
155	18.46699	122.14599	0.030	0.10	0.07	TS Tasing/ October 1989	5yr	100
156	18.46728	122.16003	0.560	0.10	-0.46	TS Tasing/ October 1989	5yr	100
157	18.46741	122.16306	0.120	0.40	0.28	TS Tasing/ October 1989	5yr	100
158	18.46742	122.14523	0.100	0.10	0.00	TS Tasing/ October 1989	5yr	100
159	18.46833	122.14555	0.040	0.00	-0.04		5yr	100
160	18.46842	122.15093	1.700	0.10	-1.60	TS Tasing/ October 1989	5yr	100
161	18.4689	122.14451	0.030	0.10	0.07	TS Tasing/ October 1989	5yr	100
162	18.46915	122.14735	0.030	0.00	-0.03		5yr	100
163	18.4693	122.14403	0.030	0.20	0.17	TS Tasing/ October 1989	5yr	100
164	18.46959	122.14657	0.030	0.10	0.07	TS Tasing/ October 1989	5yr	100
165	18.46997	122.14805	0.160	0.10	-0.06	TS Tasing/ October 1989	5yr	100
166	18.47026	122.14773	0.030	0.10	0.07	TS Tasing/ October 1989	5yr	100
167	18.47032	122.14557	0.550	0.40	-0.15	TS Tasing/ October 1989	5yr	100
168	18.47169	122.14913	1.350	0.30	-1.05	TS Tasing/ October 1989	5yr	100
169	18.47232	122.17114	1.010	0.00	-1.01		5yr	100
170	18.47239	122.17136	1.360	0.00	-1.36		5yr	100
171	18.47316	122.17181	0.130	2.00	1.87	TS Tasing/ October 1989	5yr	100
172	18.47338	122.1719	0.030	1.00	0.97	TS Tasing/ October 1989	5yr	100
173	18.47388	122.17198	0.490	0.20	-0.29	TS Tasing/ October 1989	5yr	100
174	18.47397	122.17213	0.190	0.50	0.31	TS Tasing/ October 1989	5yr	100

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
175	18.47425	122.1709	0.250	0.30	0.05	TS Tasing/ October 1989	5yr	100
176	18.47518	122.1514	0.030	0.00	-0.03		5yr	100
177	18.47573	122.17283	1.590	0.10	-1.49	TS Tasing/ October 1989	5yr	100
178	18.4767	122.15246	0.030	0.00	-0.03		5yr	100
179	18.47737	122.17334	0.030	1.00	0.97	TS Tasing/ October 1989	5yr	100
180	18.47734	122.15282	0.030	0.00	-0.03		5yr	100
181	18.47752	122.17413	0.040	0.00	-0.04		5yr	100
182	18.47758	122.17262	0.040	0.00	-0.04		5yr	100
183	18.47852	122.17594	0.030	0.30	0.27	TS Tasing/ October 1989	5yr	100
184	18.47865	122.17671	0.570	0.30	-0.27	TS Tasing/ October 1989	5yr	100
185	18.4787	122.17108	0.550	0.00	-0.55		5yr	100
186	18.47888	122.17825	0.620	0.00	-0.62		5yr	100
187	18.47929	122.18116	1.180	0.00	-1.18		5yr	100
188	18.47994	122.17189	0.040	0.00	-0.04		5yr	100
189	18.4807	122.1731	0.490	0.10	-0.39	TS Tasing/ October 1989	5yr	100
190	18.48078	122.18345	0.670	0.20	-0.47	TS Tasing/ October 1989	5yr	100
191	18.48075	122.15185	0.540	0.40	-0.14	TS Tasing/ October 1989	5yr	100
192	18.48117	122.15328	0.240	0.30	0.06	TS Tasing/ October 1989	5yr	100
193	18.48119	122.15512	0.210	0.10	-0.11	TS Tasing/ October 1989	5yr	100
194	18.48138	122.15532	0.260	1.00	0.74	1978 Typhoon	5yr	100
195	18.48158	122.15374	0.200	0.20	0.00	TS Tasing/ October 1989	5yr	100
196	18.4818	122.17404	0.030	0.00	-0.03		5yr	100
197	18.48296	122.1738	0.300	0.10	-0.20	TS Tasing/ October 1989	5yr	100
198	18.48292	122.15567	0.030	0.20	0.17	TS Tasing/ October 1989	5yr	100
199	18.483	122.15386	0.400	0.30	-0.10	TS Tasing/ October 1989	5yr	100
200	18.48304	122.15536	0.060	0.00	-0.06		5yr	100
201	18.48366	122.1531	0.660	0.60	-0.06	TS Tasing/ October 1989	5yr	100
202	18.48387	122.15473	0.040	0.20	0.16	TS Tasing/ October 1989	5yr	
203	18.48444	122.17434	0.210	0.00	-0.21		5yr	
204	18.48446	122.15537	2.450	0.00	-2.45		5yr	

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
205	18.48468	122.17287	0.030	0.00	-0.03		5yr	100
206	18.48486	122.17124	0.04	0.00	-0.04		5yr	100
207	18.48561	122.16791	0.03	0.00	-0.03		5yr	100
208	18.48684	122.16628	0.05	0.10	0.05	TS Tasing/ October 1989	5yr	100
209	18.48761	122.16428	0.03	0.00	-0.03		5yr	100
210	18.48837	122.16253	0.06	0.00	-0.06		5yr	100
211	18.48929	122.15454	0.03	0.00	-0.03		5yr	100
212	18.4894	122.16069	0.37	0.00	-0.37		5yr	100
213	18.48943	122.16184	0.03	0.20	0.17	TS Tasing/ October 1989	5yr	100
214	18.49028	122.15903	0.03	0.20	0.17	TS Tasing/ October 1989	5yr	100
215	18.49175	122.15699	0.21	0.40	0.19	TS Tasing/ October 1989	5yr	100
216	18.4937	122.15511	0.13	0.60	0.47	TS Tasing/ October 1989	5yr	100
217	18.49534	122.15361	0.03	0.60	0.57	TS Tasing/ October 1989	5yr	100
218	18.49685	122.15082	0.27	0.10	-0.17	TS Tasing/ October 1989	5yr	100
219	18.49696	122.15286	0.14	0.00	-0.14		5yr	100
220	18.49776	122.15085	0.09	0.10	0.01	TS Tasing/ October 1989	5yr	100
221	18.49854	122.1509	0.09	0.00	-0.09		5yr	100
222	18.49878	122.15119	0.03	0.00	-0.03		5yr	100
223	18.49938	122.15194	0.03	0.00	-0.03		5yr	100
224	18.49974	122.15142	0.03	0.00	-0.03		5yr	100
225	18.50169	122.15177	0.03	0.00	-0.03		5yr	100
226	18.50274	122.15191	0.03	0.00	-0.03		5yr	100

Annex 12. Educational Institutions Affected by Flooding in Tangatan Floodplain

Table A-12.1 Educational Institutions in Loay, Bohol Affected by flooding in Tangatan Floodplain

Cagayan				
Santa Ana				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
CASAGAN ELEMENTARY SCHOOL	Casagan	Medium	High	High
DAY CARE CENTER	Centro	Medium	Medium	Medium
STA ANA CENTRAL SCHOOL	Centro	Low	Low	Medium
STA. ANA FISHERY HIGH SCHOOL	Centro		Low	Low
THE PROMISED LAND CHRISTIAN SCHOOL	Centro			
DUNGEG DAY CARE CENTER	Dungeg			
DUNGEG ELEMENTARY SCHOOL	Dungeg	Low	Low	Low
MAREDE ELEMENARY SCHOOL	Marede	Medium	Medium	Medium
PALAWIG DAY CARE CENTER	Palawig	Low	Low	Low
PALAWIG ELEMENTARY SCHOOL	Palawig	Medium	Medium	High
STA. CLARA ELEMENTARY SCHOOL	Santa Clara	Low	Medium	High
ST. ANTHONY COLLEGE	Santa Cruz	Medium	Medium	Medium
TANGATAN ELEMENTARY SCHOOL	Tangatan			
VISITACION ELEMENTARY SCHOOL	Visitacion	Low	Medium	Medium

Annex 13. Health Institutions affected by flooding in Tangatan Floodplain

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

Cagayan				
Santa Ana				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
MAIN HEALTH CENTER	Centro			
STA. ANA MUNICIPAL HOSPITAL	Centro	Low	Low	Low
BARANGAY HEALTH CENTER	Dungeg			
PALAWIG HEALTH CARE CENTER	Palawig	Low	Low	Medium
MEMORIAL FOUNDATION HOSPITAL	Santa Cruz			
BARANGAY HEALTH CENTER	Tangatan			