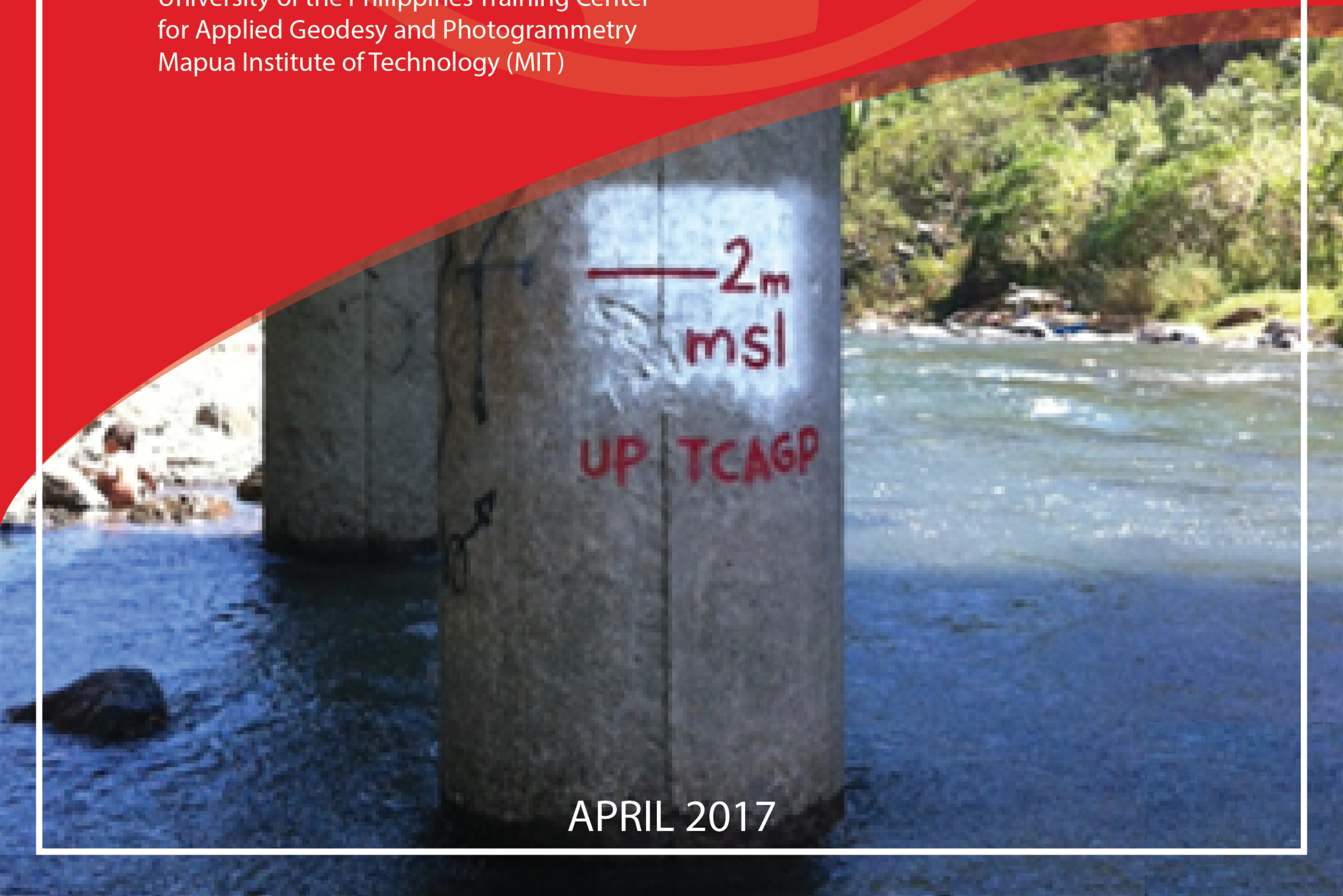
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Tignoan River

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



APRIL 2017

Published by the UP Training Center for Applied Geodesy and Photogrammetry (TCAGP)
College of Engineering
University of the Philippines – Diliman
Quezon City
1101 PHILIPPINES

This research project is supported by the Department of Science and Technology (DOST) as part of its Grants-in-Aid Program and is to be cited as:

E.C. Paringit and F.A. Uy (eds.) (2017), LiDAR Surveys and Flood Mapping of Tignoan River, Quezon City: University of the Philippines Training Center on Applied Geodesy and Photogrammetry-133pp.

For questions/queries regarding this report, contact:

Dr. Francis Aldrine A. Uy
Project Leader, Phil-LiDAR 1 Program
MAPUA Institute of Technology
City of Manila, Metro Manila 1002
E-mail: faauy@mapua.edu.ph

Enrico C. Paringit, Dr. Eng.
Program Leader, Phil-LiDAR 1 Program
University of the Philippines Diliman
Quezon City, Philippines 1101
E-mail: ecparingit@up.edu.ph

National Library of the Philippines
ISBN: 978-621-430-064-8

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

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

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND TIGNOAN RIVER

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

1.1 Background of the Phil-LiDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Mapua Institute of Technology (MIT). MIT is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 25 river basins in the Southern Tagalog Region. The university is located in Intramuros in the City of Manila.

1.2 Overview of the Tignoan River Basin

The Tignoan River Basin is located in the northern area of Quezon province. Specifically, it is situated in Real, Quezon and bounded by the municipalities of Santa Maria, Famy, and Siniloan in the province of Laguna in the west. It traverses entirely through Real and serves as one of the major sources of income for the local population. It helps stabilize industries such as tourism and agriculture and adds a vital impact on economic growth.

According to the 2015 national census of NSO, a total of 6,771 persons are residing within the immediate vicinity of the river which is distributed among three (3) barangays in the municipality of Real namely: Tanauan, Tignoan, and Malapad (NSO, 2015). Areas in the vicinity of the Tignoan River Basin such as Brgy. Tignoan and Brgy. Tanauan are classified as highly susceptible to flooding based on the 2007 Mines and Geosciences Bureau's (MGB) Geohazard Assessment Prone Areas. Its water, according to its beneficial use, is categorized as Class C by the Department of Environmental Management. It also belongs under Fishery Water for the propagation and growth of fish and other aquatic resources; Recreational Water Class II for purposes such as Boatings; and Industrial Water Supply Class I for manufacturing processes after treatment.

The river basin, due to its location, is frequently hit by typhoons. One of the most devastating typhoons that hit the area is Typhoon Rosing in 1995. Another is Typhoon Winnie in 2004 that dumped huge amount of rainfall causing flooding and landslides. The Philippines at the time was not prepared for such severe events, and, as a result, many lives and properties were lost. More recently, Quezon Province suffered flooding due to immense rain produced by Typhoon Glenda last 17th of July 2014. Typhoon Glenda put Quezon Province under the state of calamity moving families to rehabilitation. Power distribution was heavily affected causing a power down to the community.

To prevent similar outcomes from happening again, a combination of several technologies have been employed to produce flood hazard maps. The first is LiDAR data, which primarily contains elevation values. From the data, one can infer the presence and behavior of water bodies (such as rivers, streams, ponds, and lakes) and structures (such as roads, bridges, and buildings). Additionally, important information such

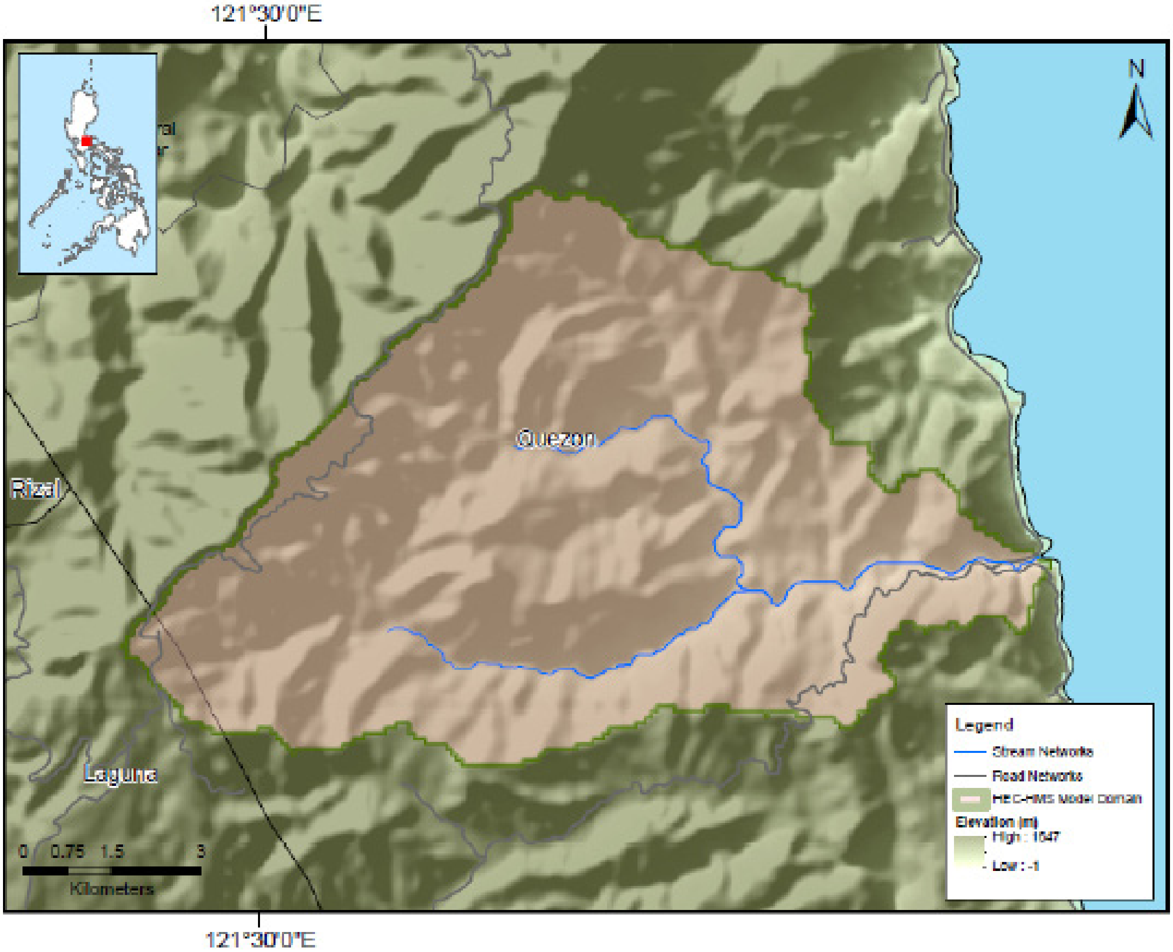


Figure 1. Map of the Tignoan River Basin (in brown)

as discharge and rainfall events gathered through fieldwork can be used as inputs to the hydrological model. The gathered data will help generate hydrographs to create the calibrated model. These generated outputs, along with LiDAR data, will then be used for the generation of a river hydraulic model. The final output for these processes will be flood hazard maps of the river basin. The generated maps can be used for urban planning and disaster risk reduction planning.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE TIGNOAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Pauline Joanne G. Arceo, Engr. Renan D. Punto

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 Tignoan Floodplain in Quezon. These missions were planned for 14 lines and ran for at most three (3) hours including take-off, landing, and turning time. The flight planning parameters for Pegasus is found in Table 1. Figure 2 shows the flight plan for Tignoan Floodplain.

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

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK18Q	1200	30	50	200	30	130	5

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

2.2 Ground Base Stations

The project team was able to recover one (1) NAMRIA ground control point: RZL-28 which is of second (2nd)-order accuracy. The project team also established one (1) ground control points BRS-1. The certifications for the base stations are found in Annex 2 while the baseline processing reports for the established point is found in Annex 3.

These points were used as base stations during flight operations for the entire duration of the survey (June 22, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 985 and TOPCON GR5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Tignoan Floodplain are shown in Figure 2.

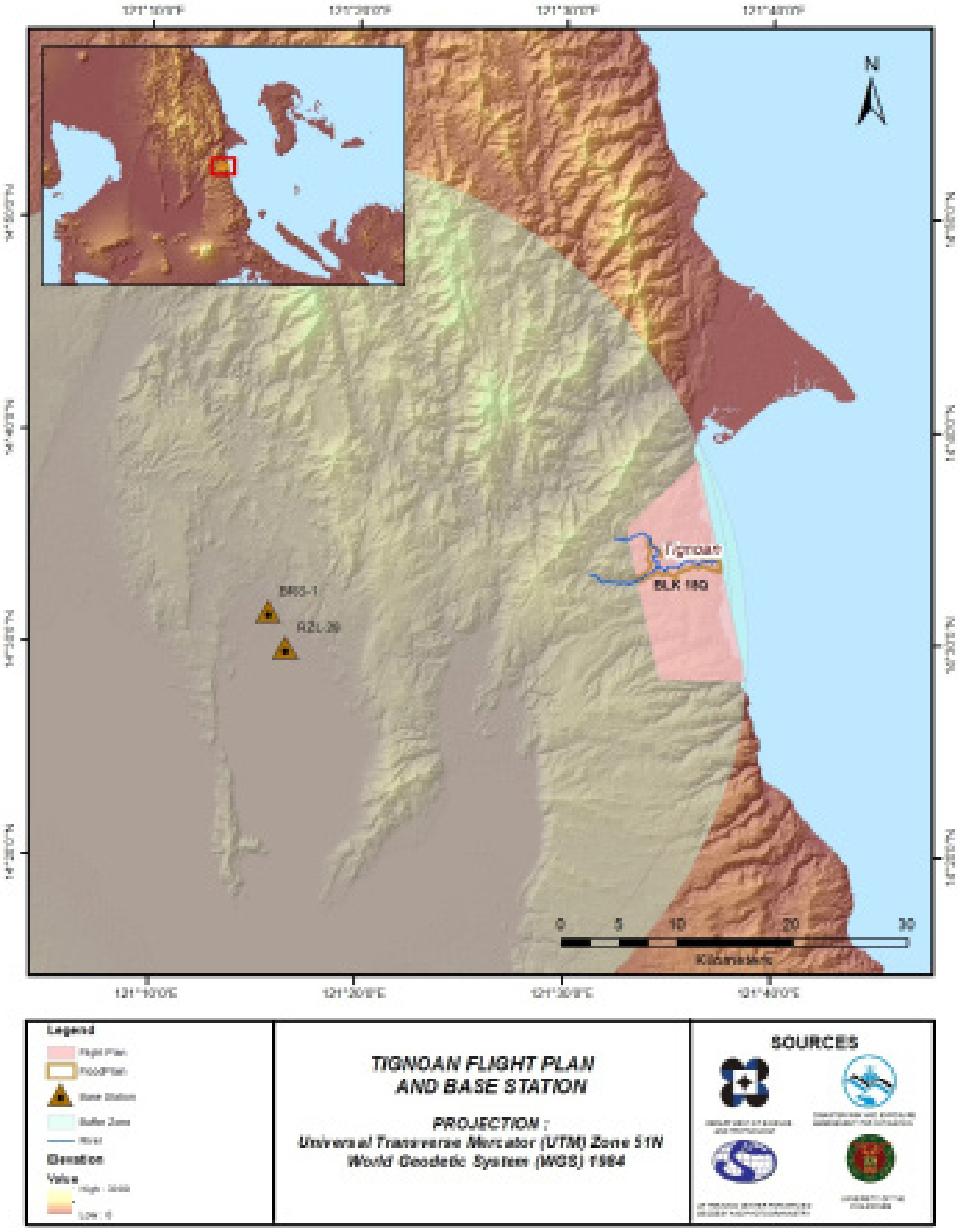


Figure 2. Flight Plan and base stations used for the Tignoan Floodplain survey.

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

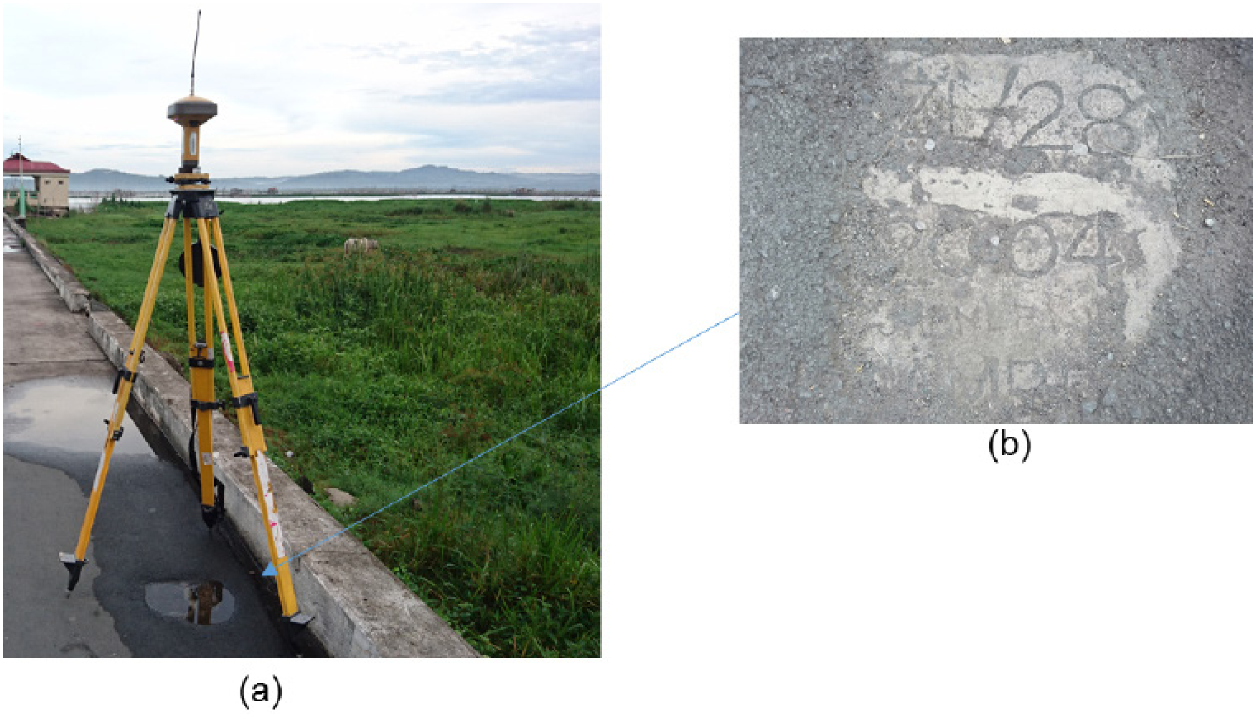


Figure 3. GPS set-up over RZL-28 near the lighthouse beside the fishport in Barangay San Isidro, Tanay, Rizal (a) and NAMRIA reference point RZL-28 (b) as recovered by the field team

Table 2. Details of the recovered NAMRIA horizontal control point RZL-28 used as base station for the LiDAR acquisition

Station Name	**RZL-28**	
Order of Accuracy	**2nd**	
Relative Error (Horizontal positioning)	**1:50,000**	
Geographic Coordinates Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	14° 29' 49.44078" North 121° 16' 32.56146" East 5.86600 meters
Grid Coordinates Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	529720.085 meters 1603180.963 meters
Geographic Coordinates World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	14°29 '44.06939" North 121°16'37.46276"East 50.37100 meters
Grid Coordinates Universal Transverse Mercator Zone 51 North (UTM 51N PRS1992)	Easting Northing	1,603,302.05 meters 314,172.78 meters

Figure 4. GPS set-up over BRS-1 as established in the rooftop of D' One Resort & Restaurant in Baras, Rizal

Table 3. Details of the established control point BRS-1 used as base station for the LiDAR acquisition

Station Name	BRS-1	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1:50,000	
Geographic Coordinates Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	14° 31' 32.82507" North 121° 15' 40.79958" East 15.361 meters
Geographic Coordinates World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	14° 31'27.44582" North 121° 15' 45.69850" East 59.750 meters
Grid Coordinates Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	312646.981 meters 1606491.077 meters

Table 4. Ground control points that were used during the LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
22 June 2016	23474P	1BLK18QO173A	BRS-1 and RZL-28

2.3 Flight Missions

One (1) mission was conducted to complete the LiDAR data acquisition in Tignoan Floodplain, for a total of three hours and seventeen minutes (3+17) of flying time for RP-C9022. The mission was acquired using the Pegasus LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight missions for the LiDAR data acquisition of the Tignoan 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
22 June 2016	23474P	121.55	146.82	10.16	136.66	NA	3	17

Table 6. Actual parameters used during the LiDAR data acquisition of the Tignoan Floodplain.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23474P	1000	60	50	200	32	130	5

2.4 Survey Coverage

Tignoan Floodplain is situated in Real, Quezon. About 36.73% of Real, Quezon was surveyed as shown in Table 7. The actual coverage of the LiDAR acquisition for Tignoan Floodplain is presented in Figure 5.

Table 8. List of municipalities and cities surveyed of the Tignoan Floodplain LiDAR acquisition.

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Quezon	Real	382.11	140.35	36.73%

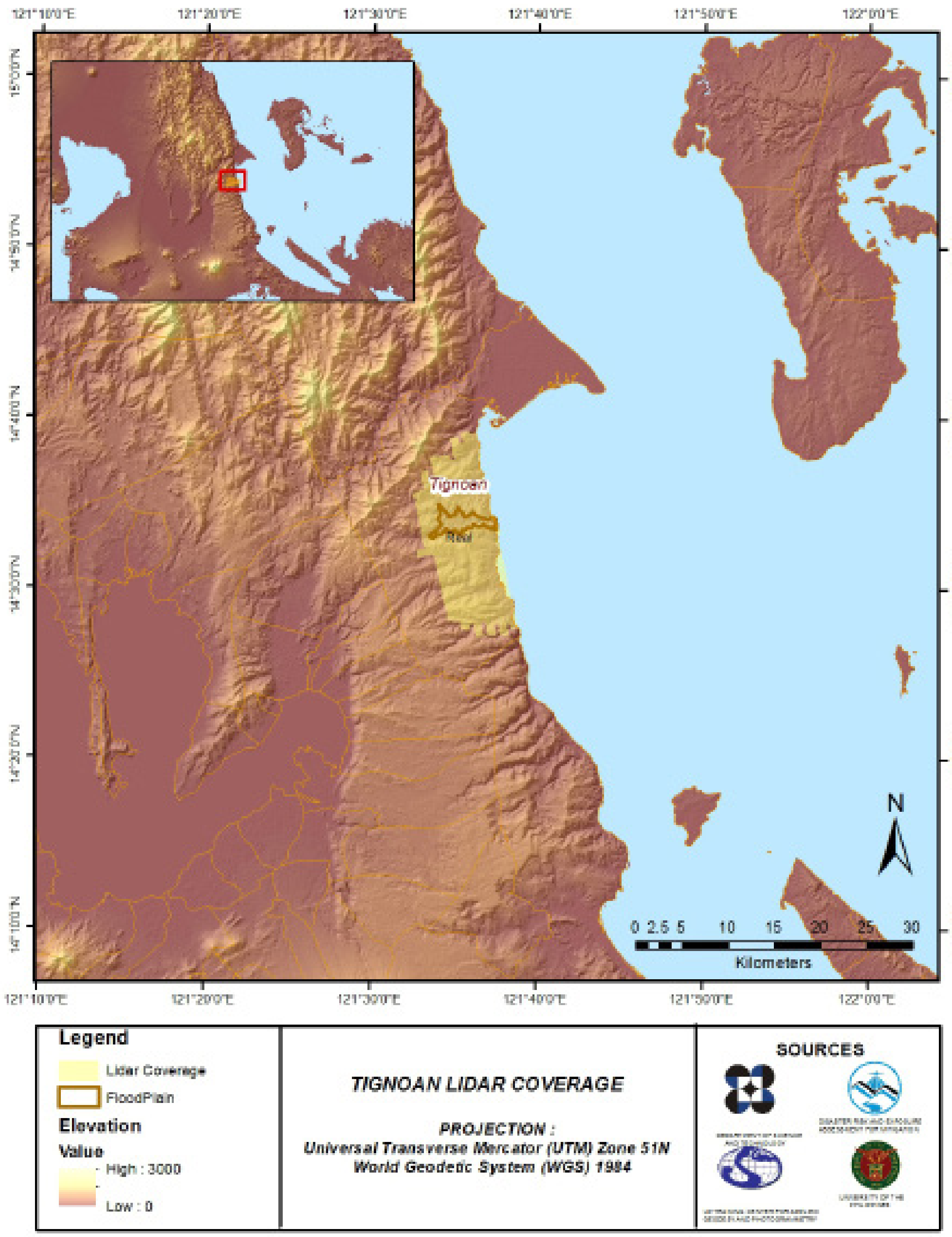


Figure 5. Actual LiDAR survey coverage of the Tignoan Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE TIGNOAN FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo, Engr. Joida F. Prieto, Engr. Melissa F. Fernandez, Engr. Ma. Ailyn L. Olanda, Engr. Sheila-Maye F. Santillan, Engr. Erica Erin E. Elazegui, Engr. Ezzo Marc C. Hibionada, and Ziarre Anne P. Mariposa

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 subject for quality checking to ensure that the required accuracies of the program, which were 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.

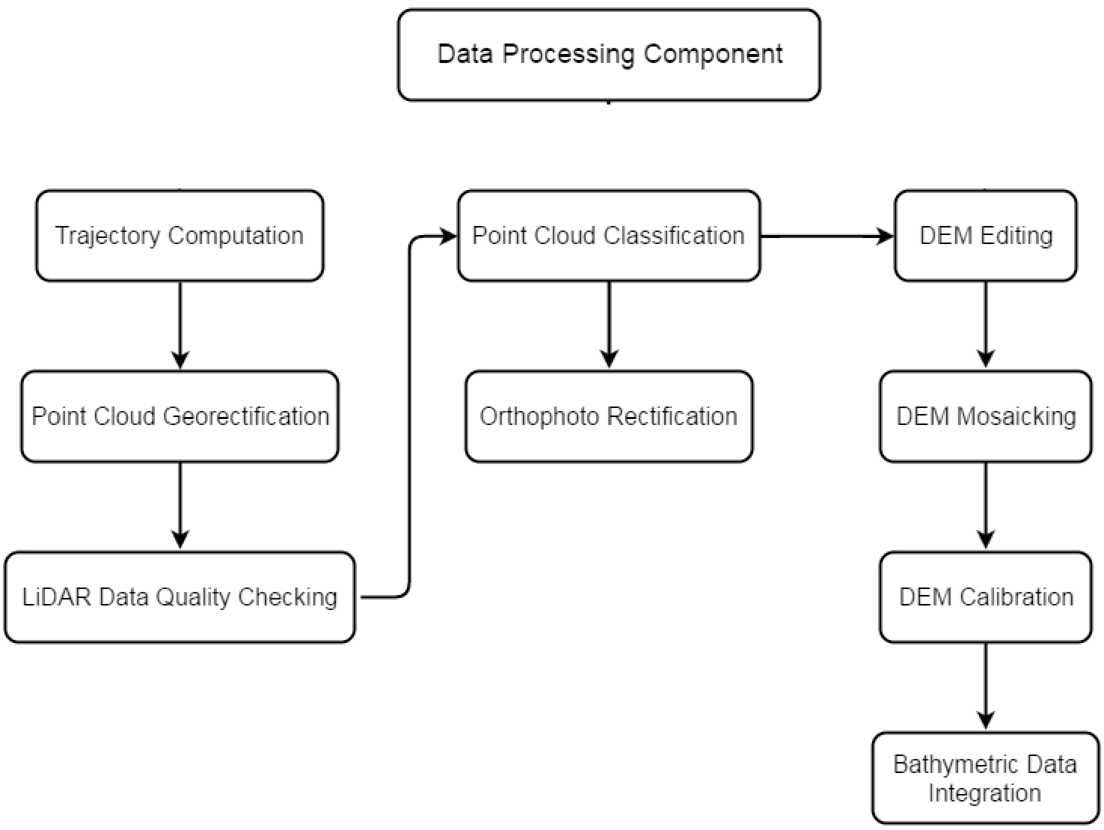


Figure 6. Schematic diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Tignoan Floodplain can be found in ANNEX 5. Missions flown during the survey conducted on June 2016 both used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus and Leica systems over Real, Quezon.

The Data Acquisition Component (DAC) transferred a total of 12.7 Gigabytes of Range data, 200 Megabytes of POS data, and 468 Megabytes of GPS base station data to the data server on July 13, 2016 for the survey. The Data Pre-Processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Tignoan was fully transferred on July 14, 2016, as indicated on the data transfer sheets for Tignoan Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 23474P, one of the Tignoan 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 June 22, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

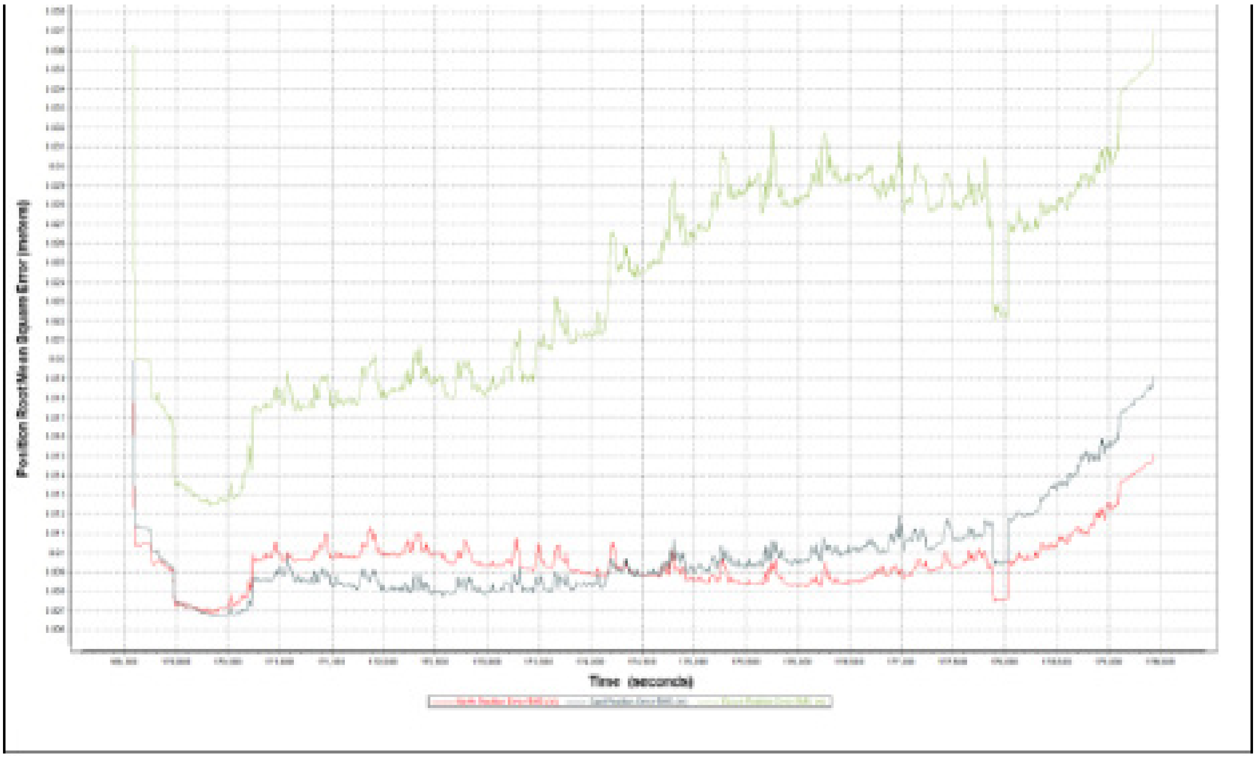


Figure 7. Smoothed Performance Metrics of Tignoan Flight 23474P

The time of flight was from 169500 seconds to 179500 seconds, which corresponds to morning of June 22, 2016. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the time 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 1.40 centimeters, the East position RMSE peaks at 1. 80 centimeters, and the Down position RMSE peaks at 3.40 centimeters, which are within the prescribed accuracies described in the methodology.

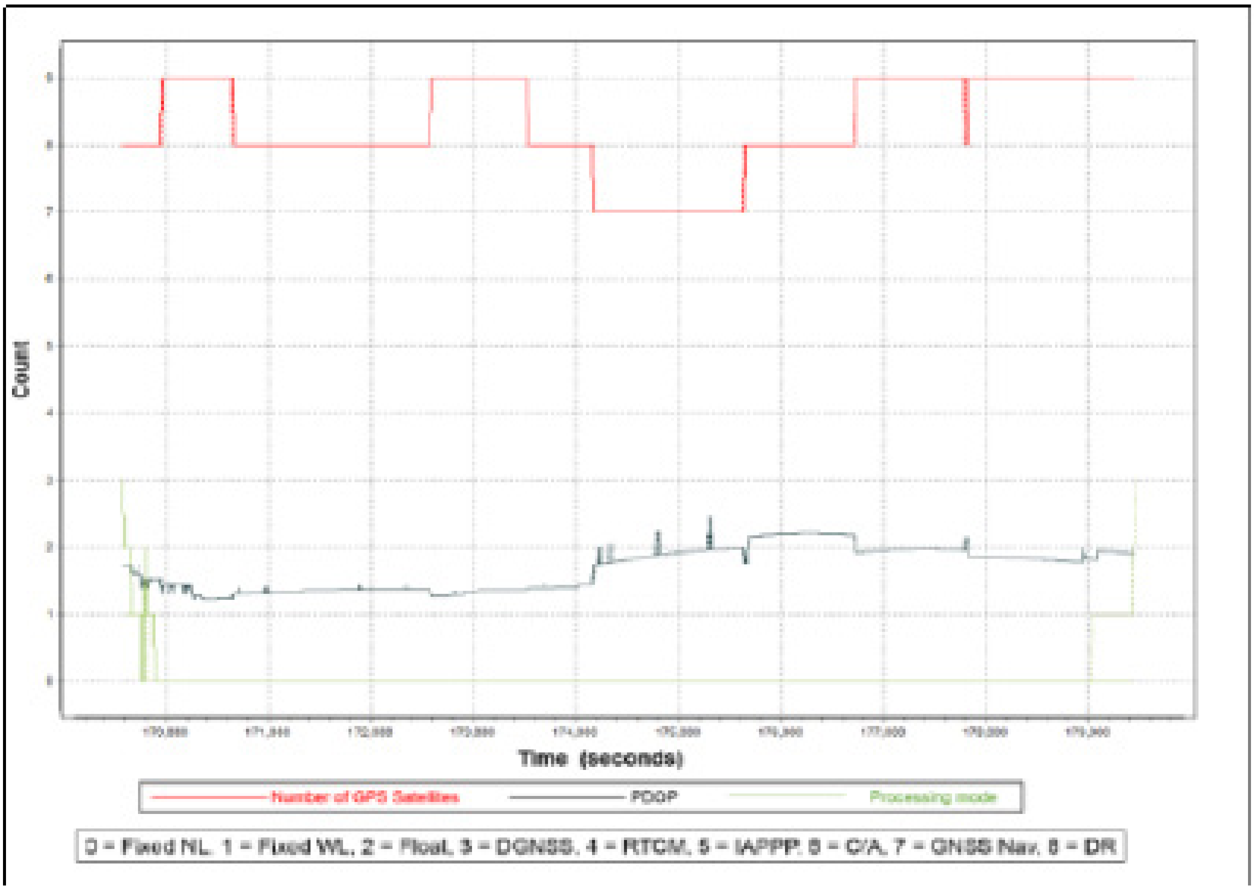


Figure 8. Solution Status Parameters of Tignoan Flight 23474P.

The Solution Status parameters of flight 23474P, one of the Tignoan flights, which are the number of GPS satellites, Positional Dilution of Precision, and the GPS processing mode used are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Tignoan flights is shown in Figure 9.

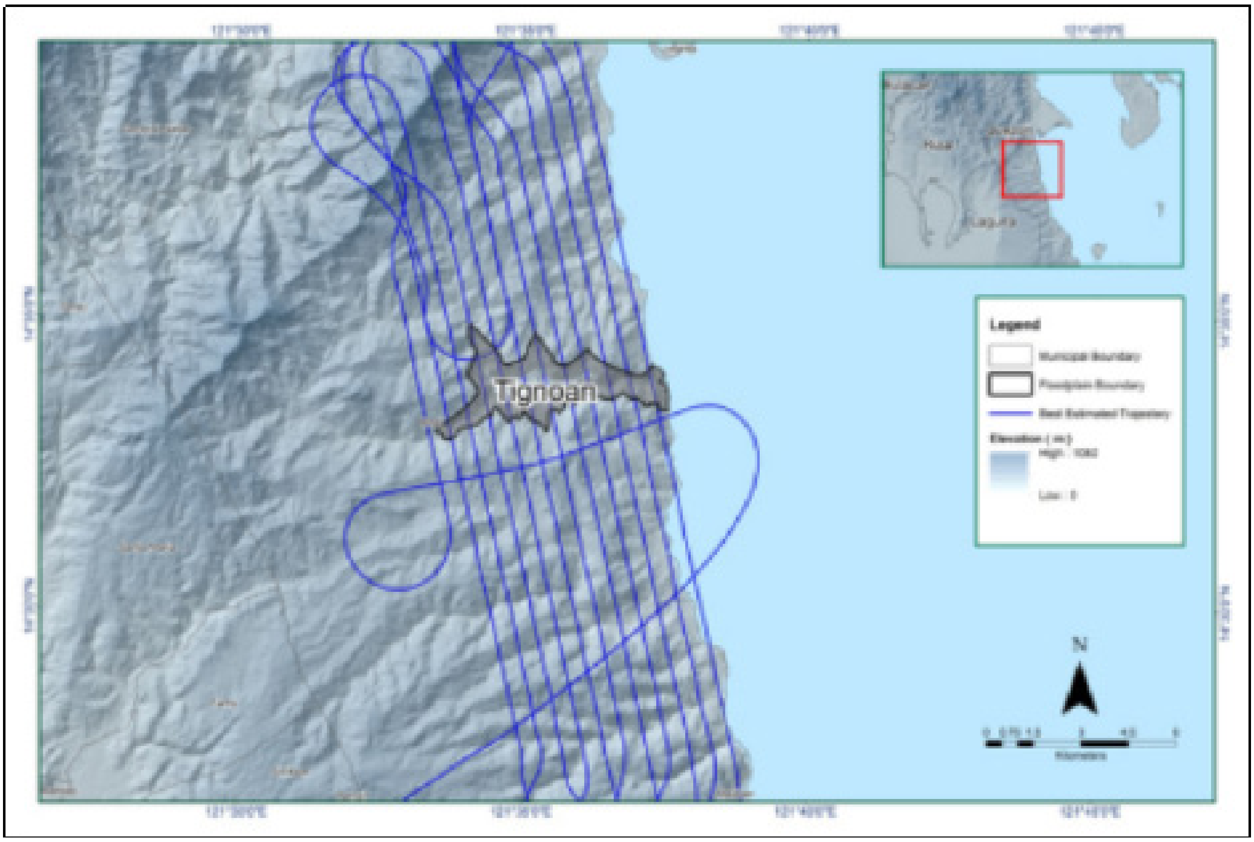


Figure 9. Best estimated trajectory of the LiDAR missions conducted over Tignoan Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 19 flight lines, with each flight line containing two channels, since the Pegasus system contains two channels.

The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Tignoan Floodplain are given in Table 8.

Table 8. Self-calibration result values for Tignoan flights

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev	<0.001degrees	0.000335
IMU Attitude Correction Roll and Pitch Correction stdev	<0.001degrees	0.000935
GPS Position Z-correction stdev	<0.01meters	0.0020

The optimum accuracy was obtained for all Tignoan flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in ANNEX 8.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Tignoan 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 Tignoan Floodplain

The total area covered by the Tignoan missions is 152.09 sq km that is comprised of one (1) flight acquisition grouped and merged into two (2) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Tignoan Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Calabarzon_reflights_Blk18Q	23474P	142.52
Calabarzon_reflights_Blk18Q_supplement	23474P	9.57
TOTAL		152.09 sq km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location, is shown in Figure 11. Since the Pegasus system employs two channels, an average value of 2 (blue) would be expected for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

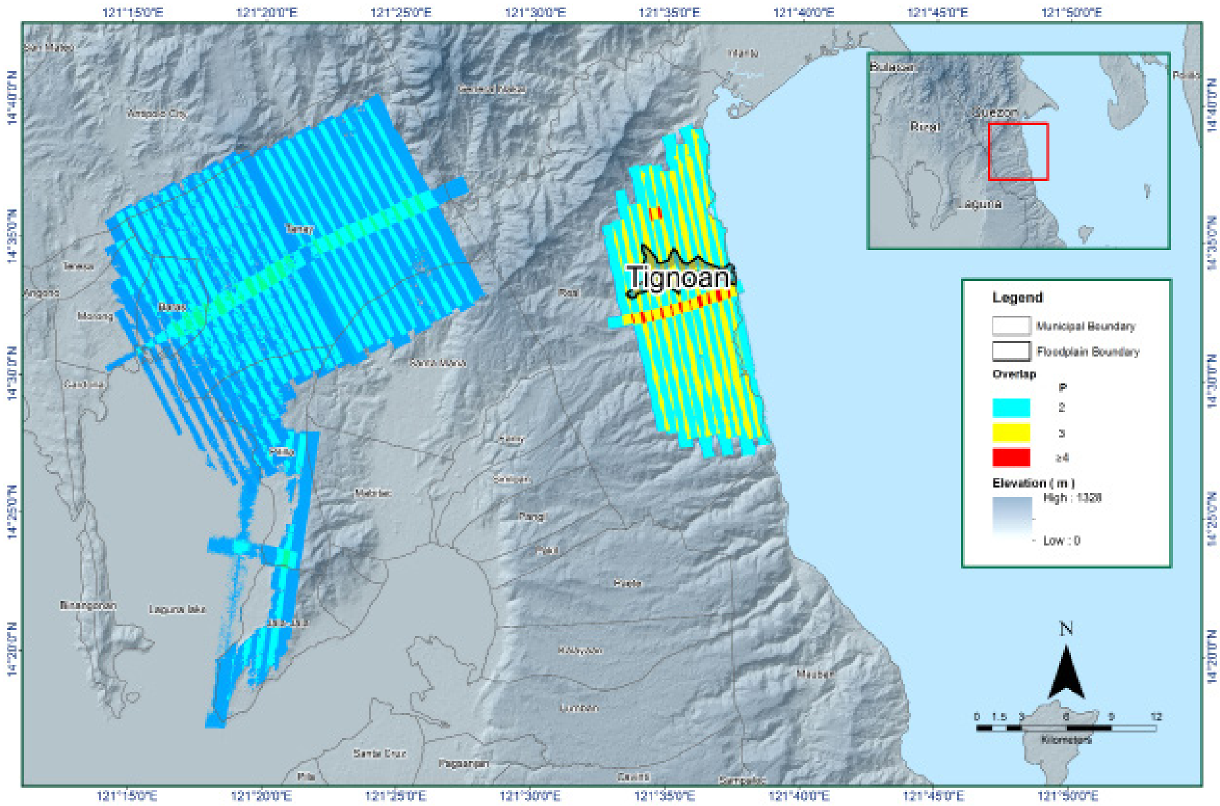


Figure 11. Image of data overlap for Tignoan Floodplain.

The overlap statistics per block for the Tignoan Floodplain can be found in Annex 8. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the maximum percent overlap is 42.49%, 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 Tignoan Floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.82 points per square meter.

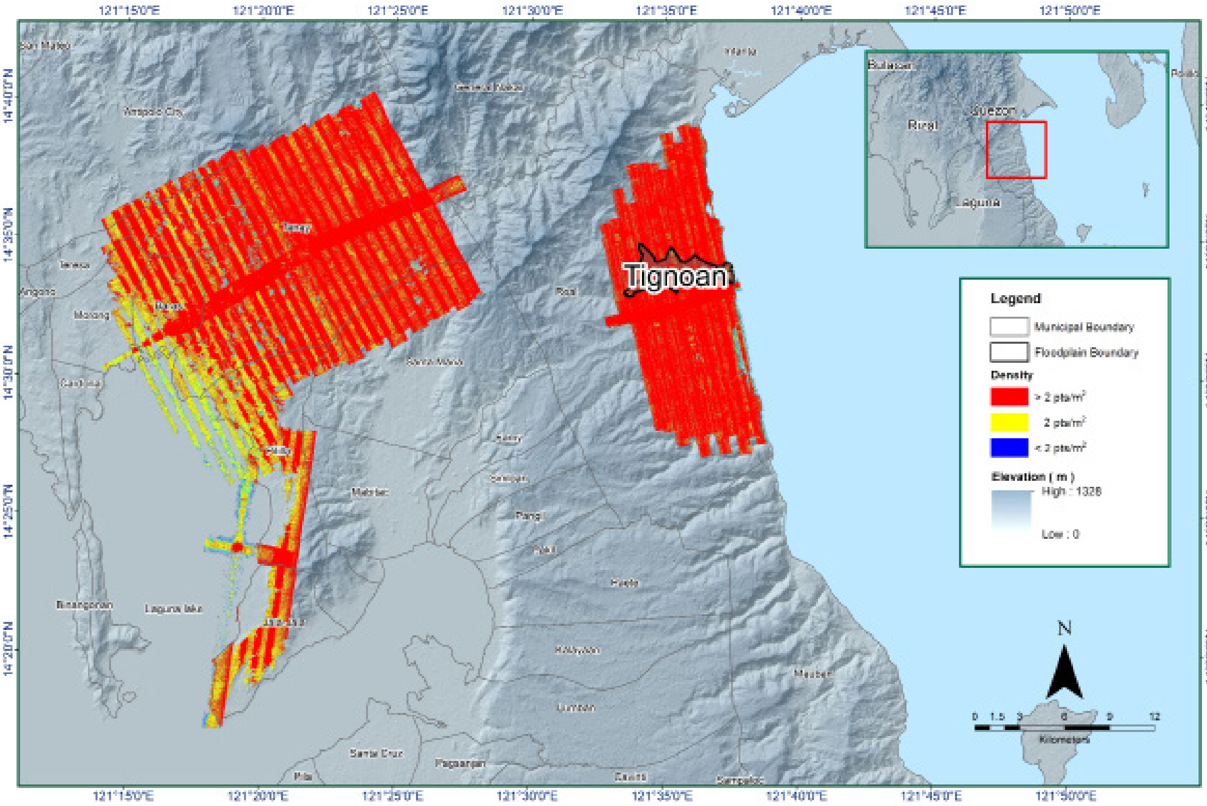


Figure 12. Pulse density map of merged LiDAR data for Tignoan Floodplain.

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 0.20 m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20 m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

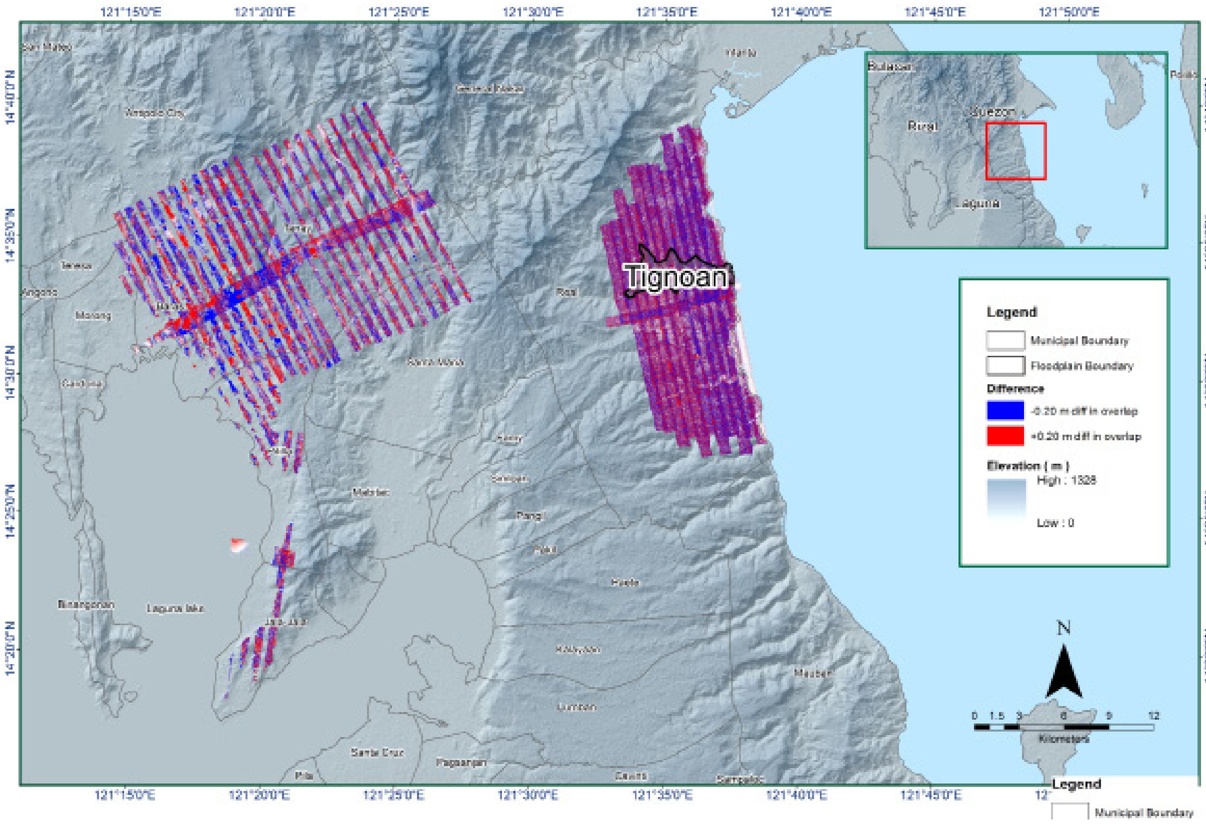


Figure 13. Elevation Difference Map between flight lines for Tignoan Floodplain Survey.

A screen capture of the processed LAS data from a Tignoan flight 23474P 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.

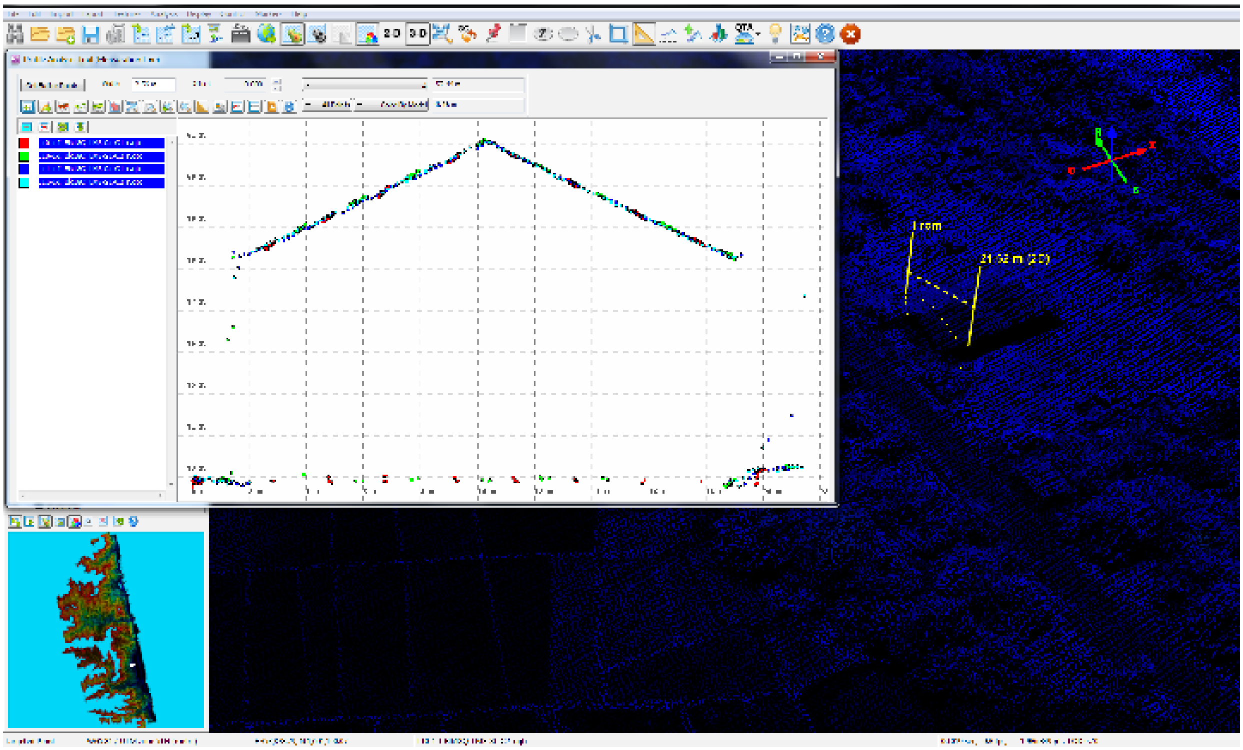


Figure 14. Quality checking for a Tignoan flight 23474P using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Tignoan classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	730,120,761
Low Vegetation	476,358,859
Medium Vegetation	658,168,041
High Vegetation	2,900,490,221
Building	33,869,042

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Tignoan Floodplain is shown in Figure 15. A total of 215 1 km by 1 km 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 590.20 meters and 47.79 meters, respectively.

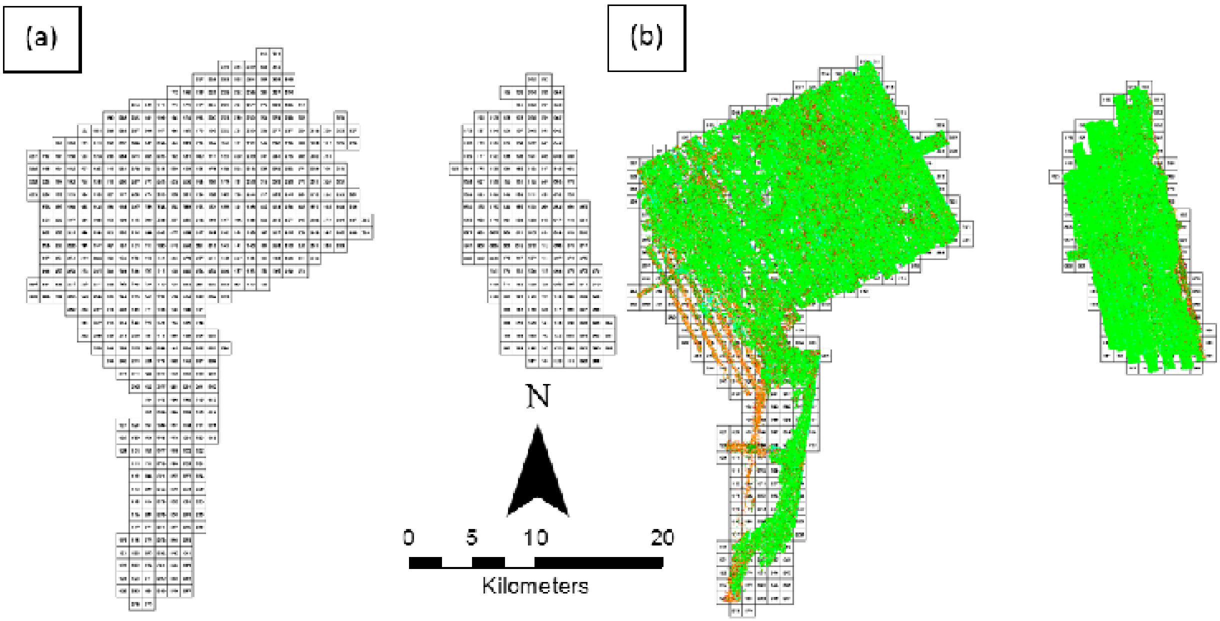


Figure 15. Tiles for Tignoan Floodplain (a) and classification results (b) in TerraScan.

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.

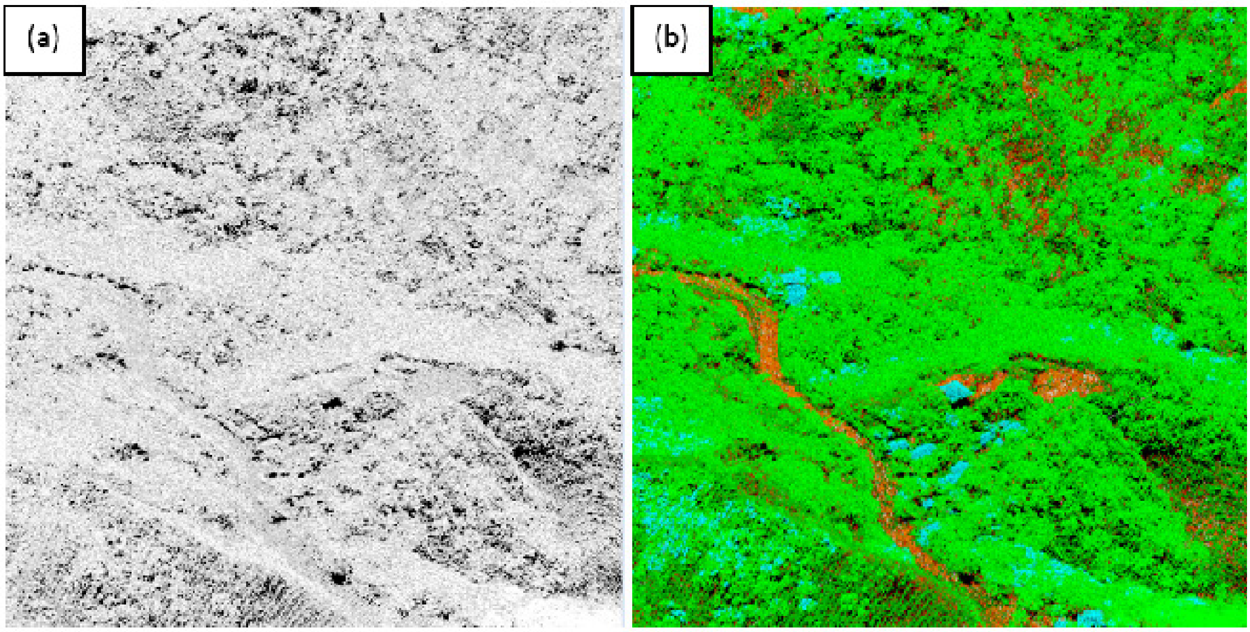


Figure 16. Point cloud before (a) and after (b) classification

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.

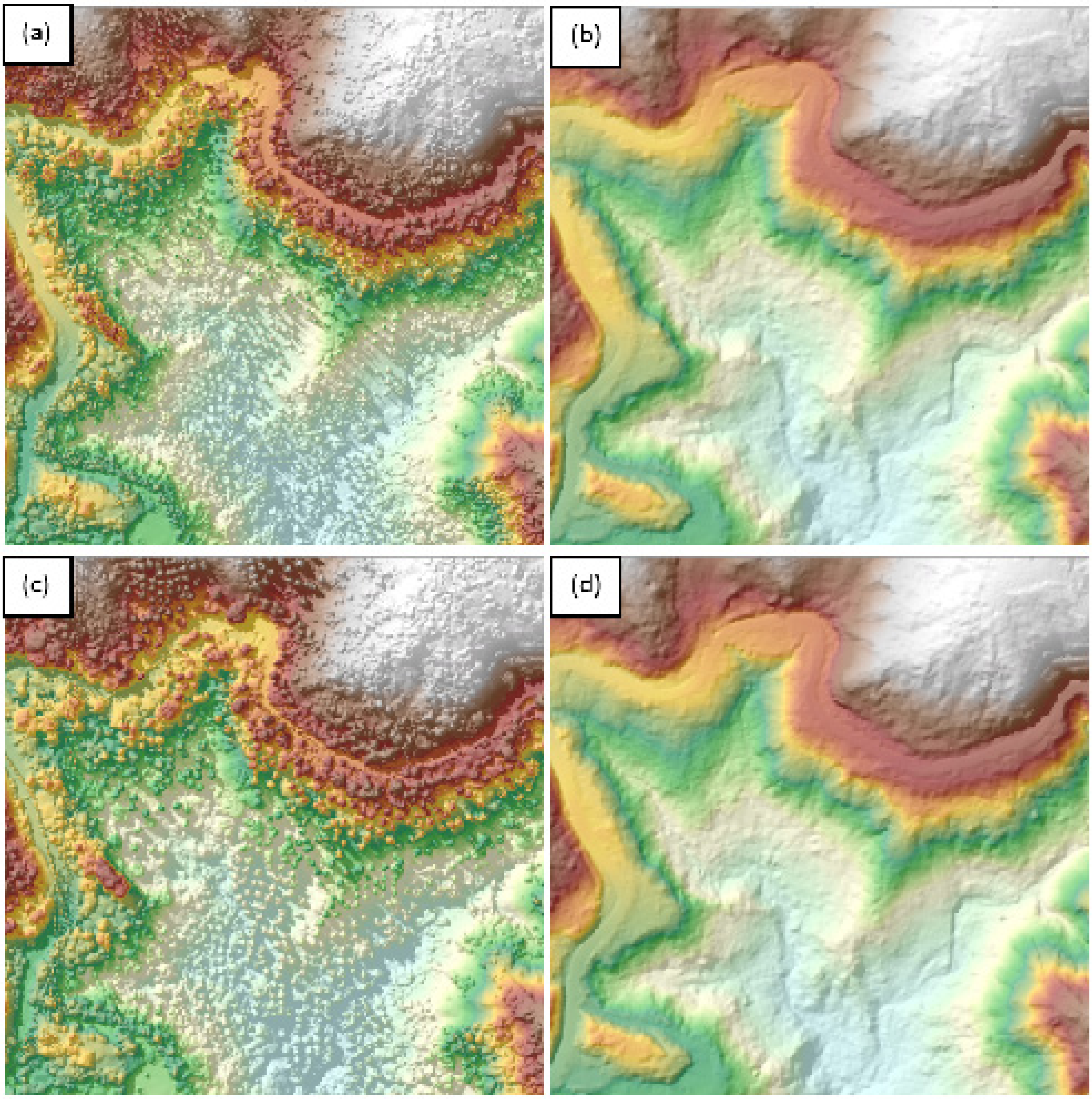


Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tignoan Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 590 1km by 1km tiles of the block covering the Tignoan floodplain is shown in Figure 18. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The block covering the Tignoan floodplain has a total of 430.77 sq.km orthophotogaph coverage comprised of 931 images. However, the block does not have a complete set of orthophotographs and no orthophotographs cover the area of the Tignoan floodplain. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 19.

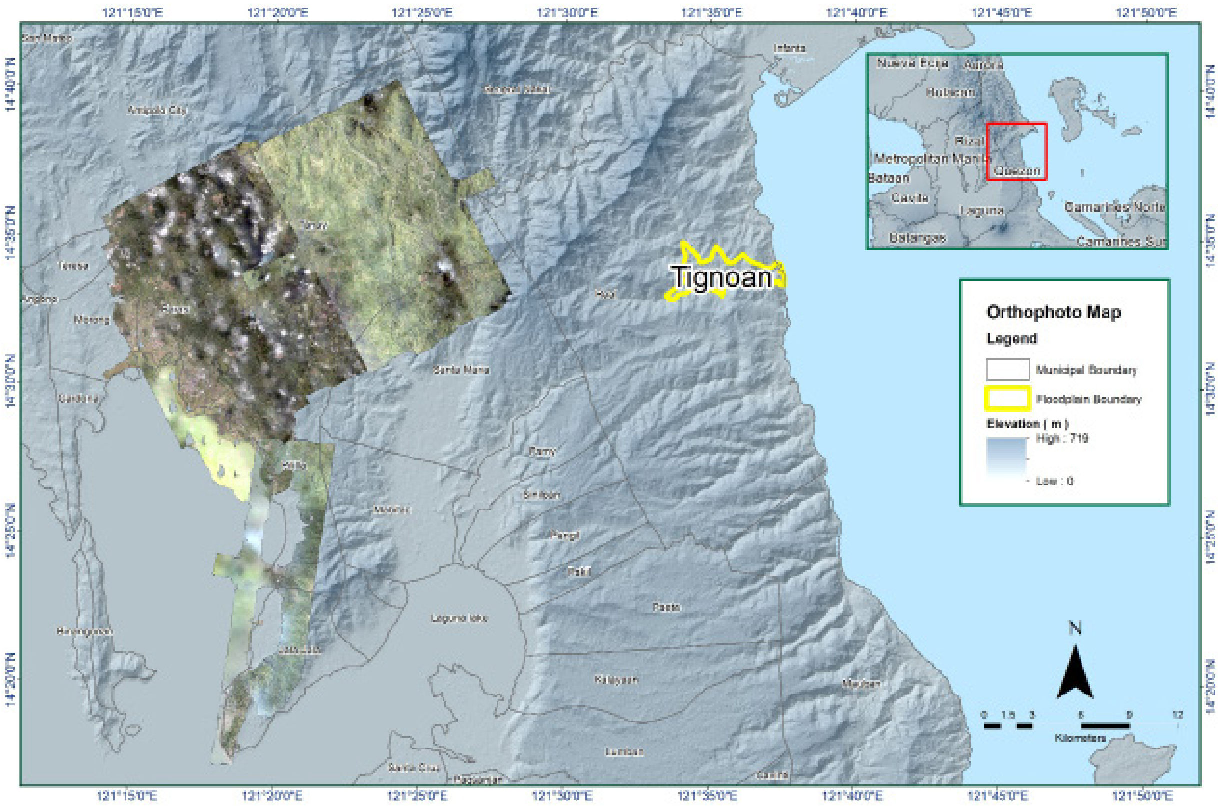


Figure 18. Available orthophotographs near Tignoan floodplain.

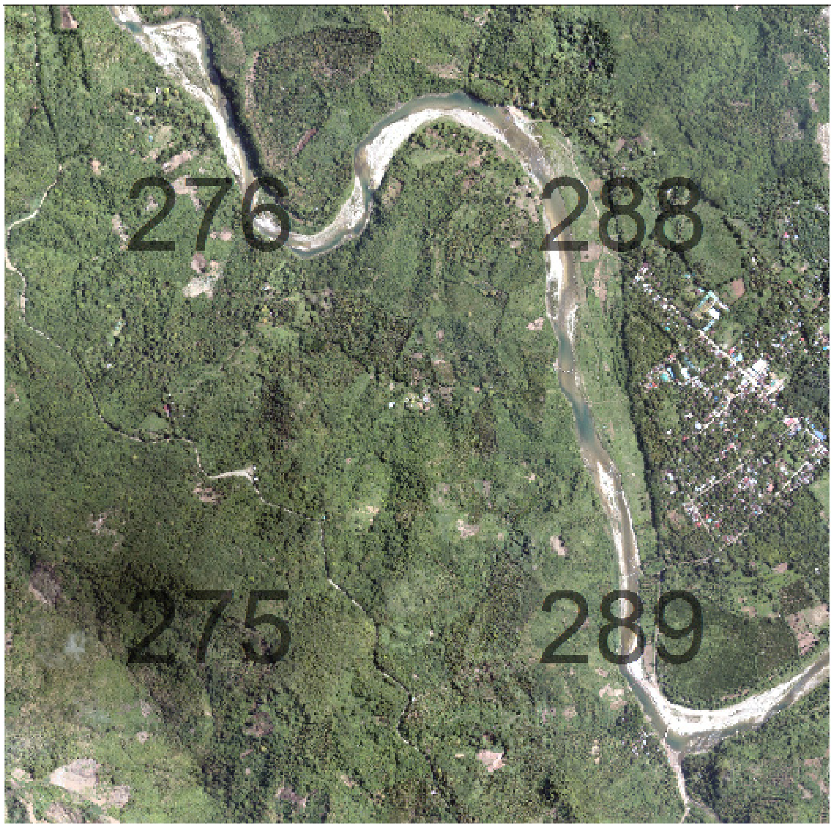


Figure 19. Sample orthophotograph tiles near Tignoan floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Tignoan Floodplain. These blocks are composed of Calabarzon_ Reflights blocks with a total area of 152.09 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding areas.

LiDAR Blocks	Area (sq.km)
Calabarzon_reflights_Blk18Q	142.52
Calabarzon_reflights_Blk18Q_supplement	9.57
TOTAL	152.09 sq km

Portions of DTM before and after manual editing are shown in Figure 18. The bridge (Figure 20a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 20b) in order to hydrologically correct the river. Some data in the mountainous areas were removed in the DTM after classification (Figure 20c) and has to be retrieved to complete the surface (Figure 20d).

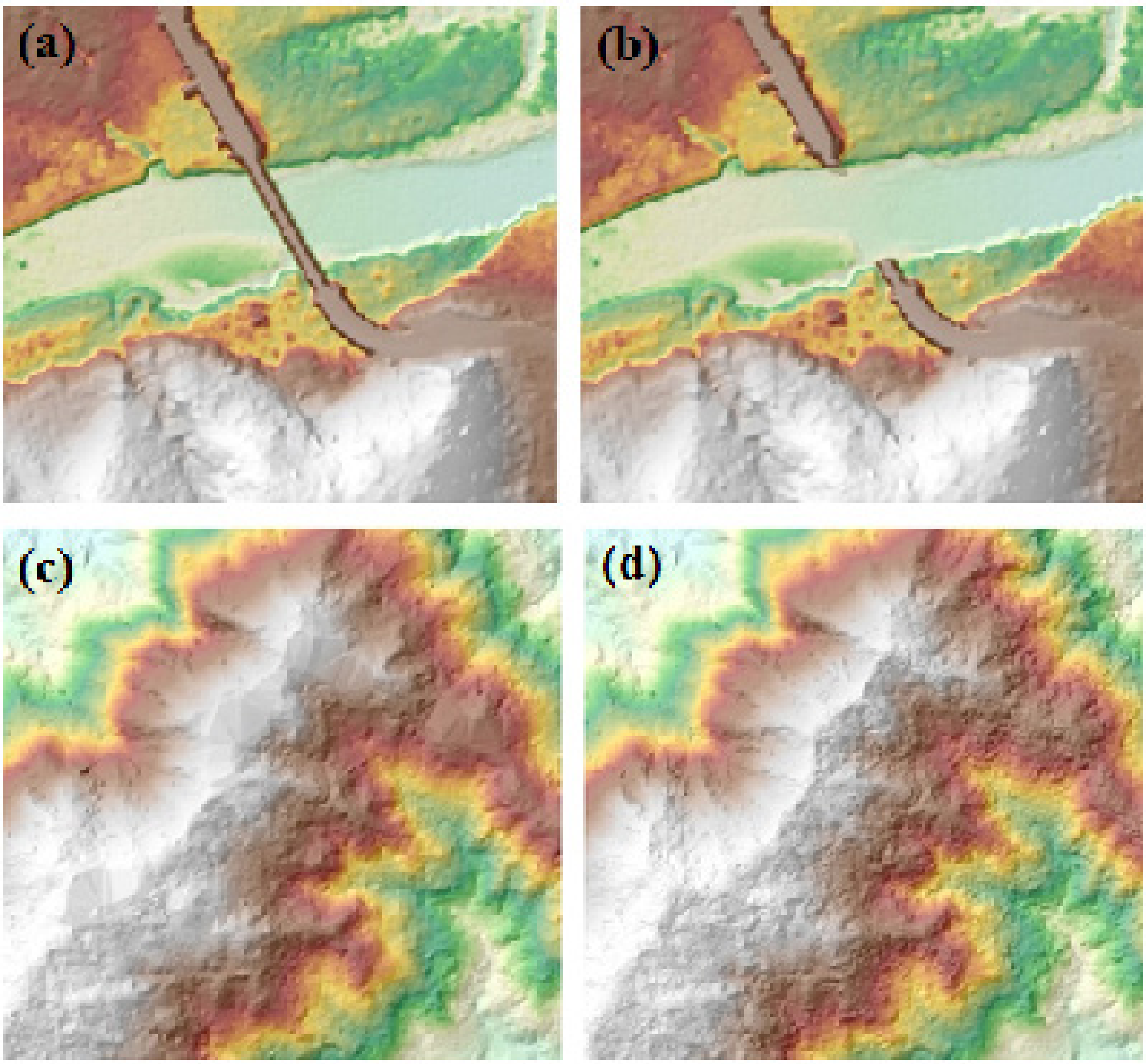


Figure 20. Production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Tignoan Floodplain

3.9 Mosaicking of Blocks

Calabarzon_reflights_Blk18Q was used as the reference block at the start of mosaicking because this is the larger block. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Tignoan Floodplain is shown in Figure 21. It can be seen that the entire Tignoan Floodplain is 100% covered by LiDAR data.

Table 12. Shift values of each LiDAR block of Tignoan Floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Calabarzon_reflights_Blk18Q	0.00	0.00	0.00
Calabarzon_reflights_Blk18Q_supplement	0.10	-1.73	-1.01

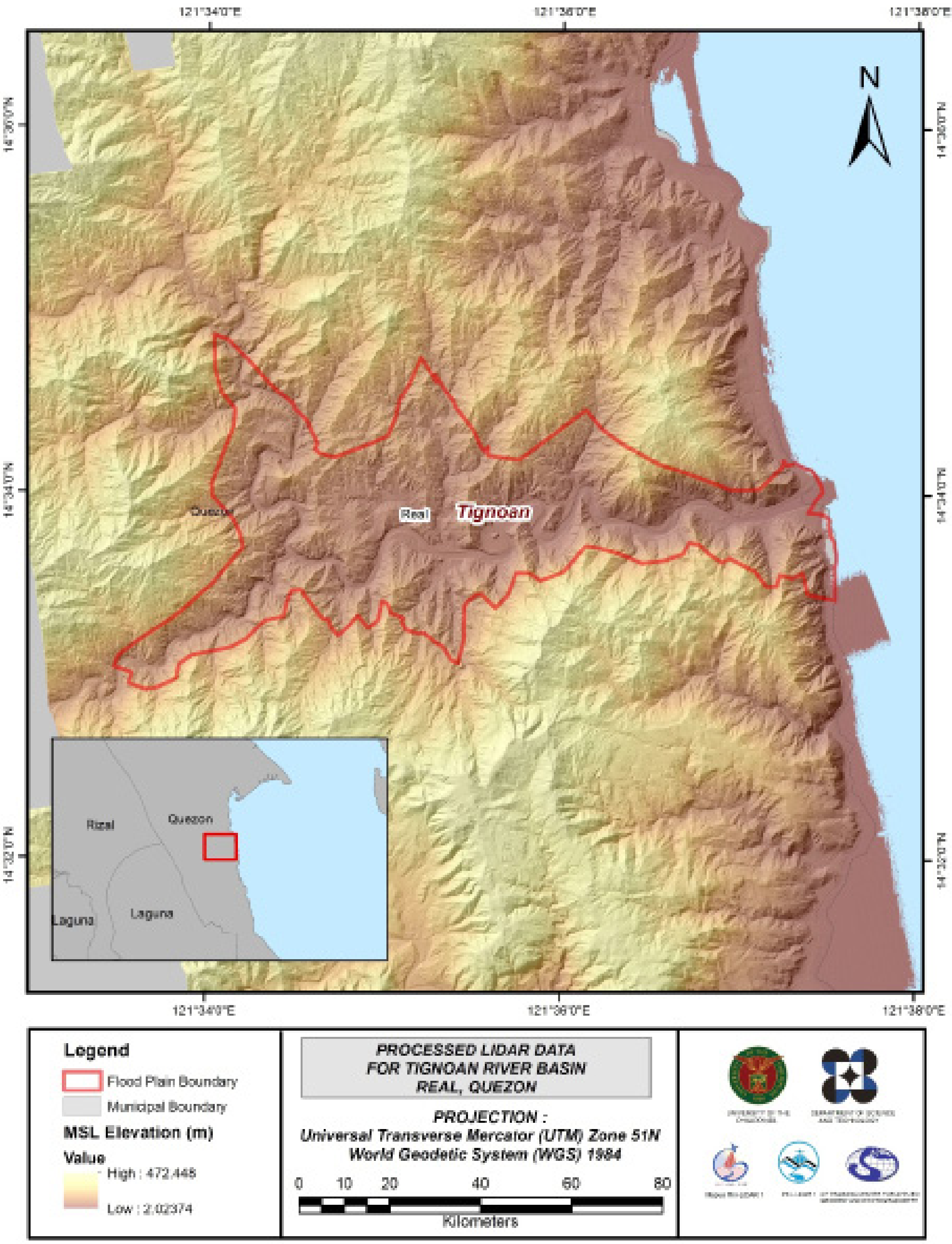


Figure 21 . Map of Processed LiDAR Data for Tignoan Floodplain.

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

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Tignoan to collect points with which the LiDAR dataset was validated is shown in Figure 22. A total of 3,041 survey points were used for calibration and validation of Tignoan LiDAR data. Eighty percent of the survey points, which were randomly selected and resulting in 2,433 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 2.50 meters with a standard deviation of 0.17 meters. Calibration of Tignoan LiDAR data was done by subtracting the height difference value, 2.50 meters, to Tignoan mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

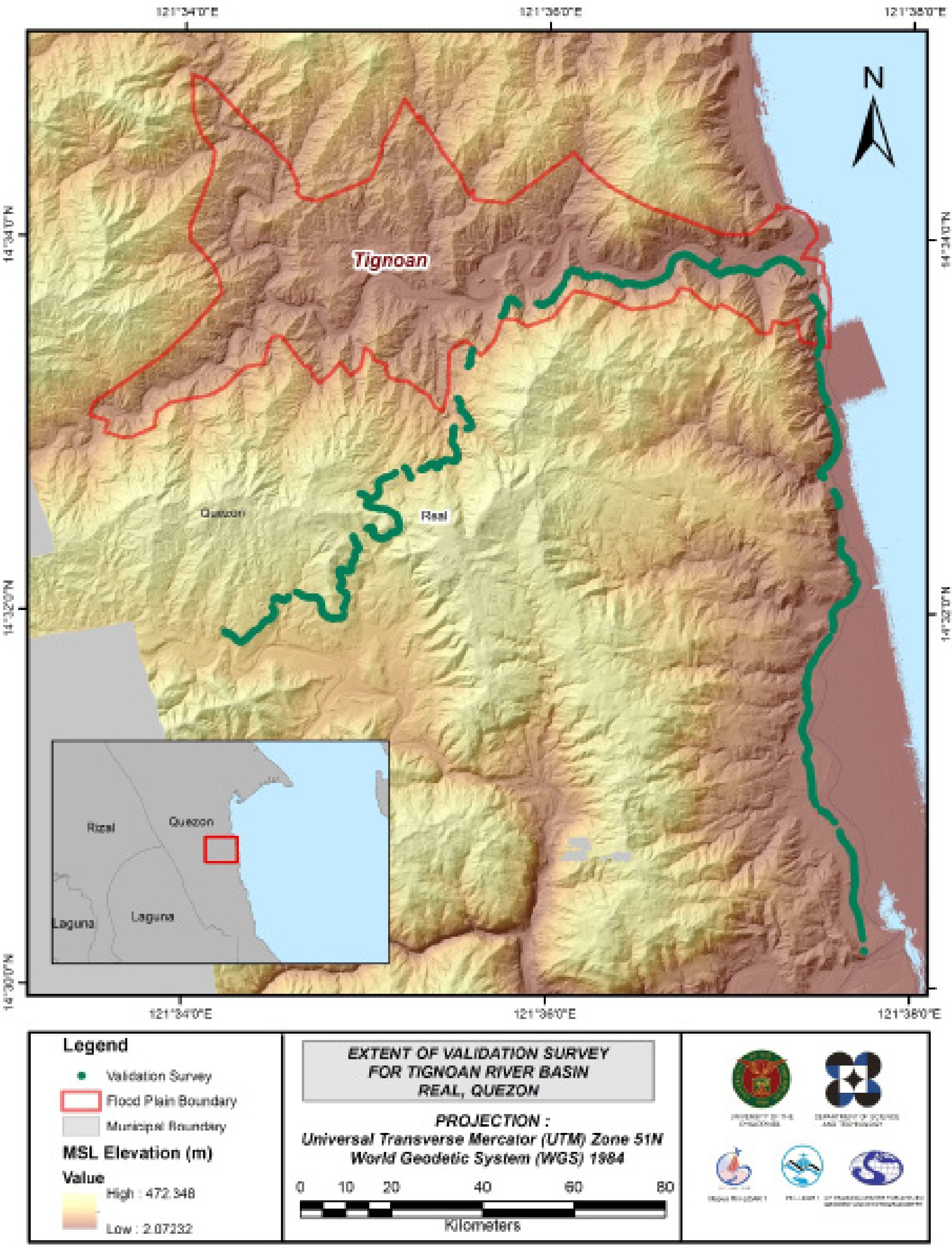


Figure 22. Map of Tignoan Floodplain with validation survey points in green.

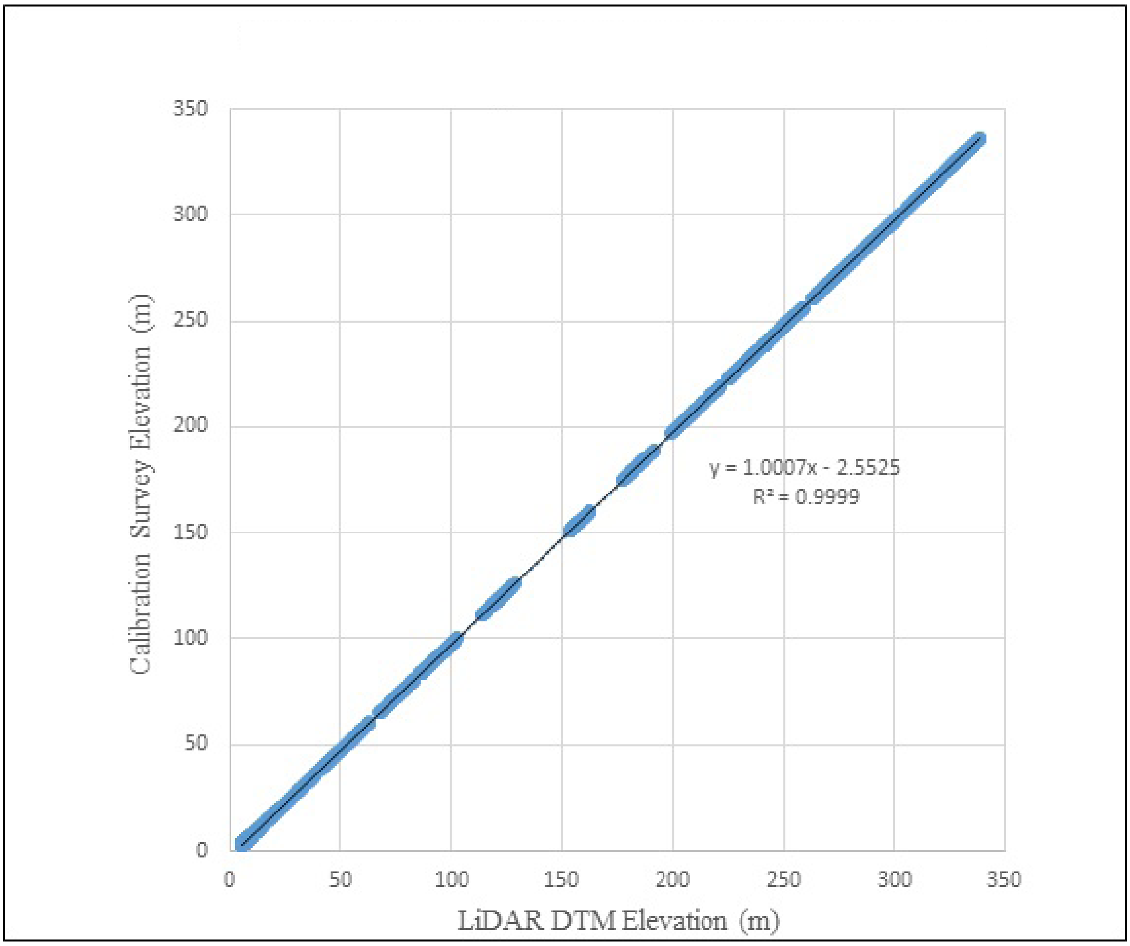


Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	2.50
Standard Deviation	0.17
Average	-2.49
Minimum	-2.14
Maximum	-2.84

The remaining 20% of the total survey points, resulting in 608 points, were used for the validation of calibrated Tignoan 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 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.14 meters with a standard deviation of 0.14 meters, as shown in Table 14.

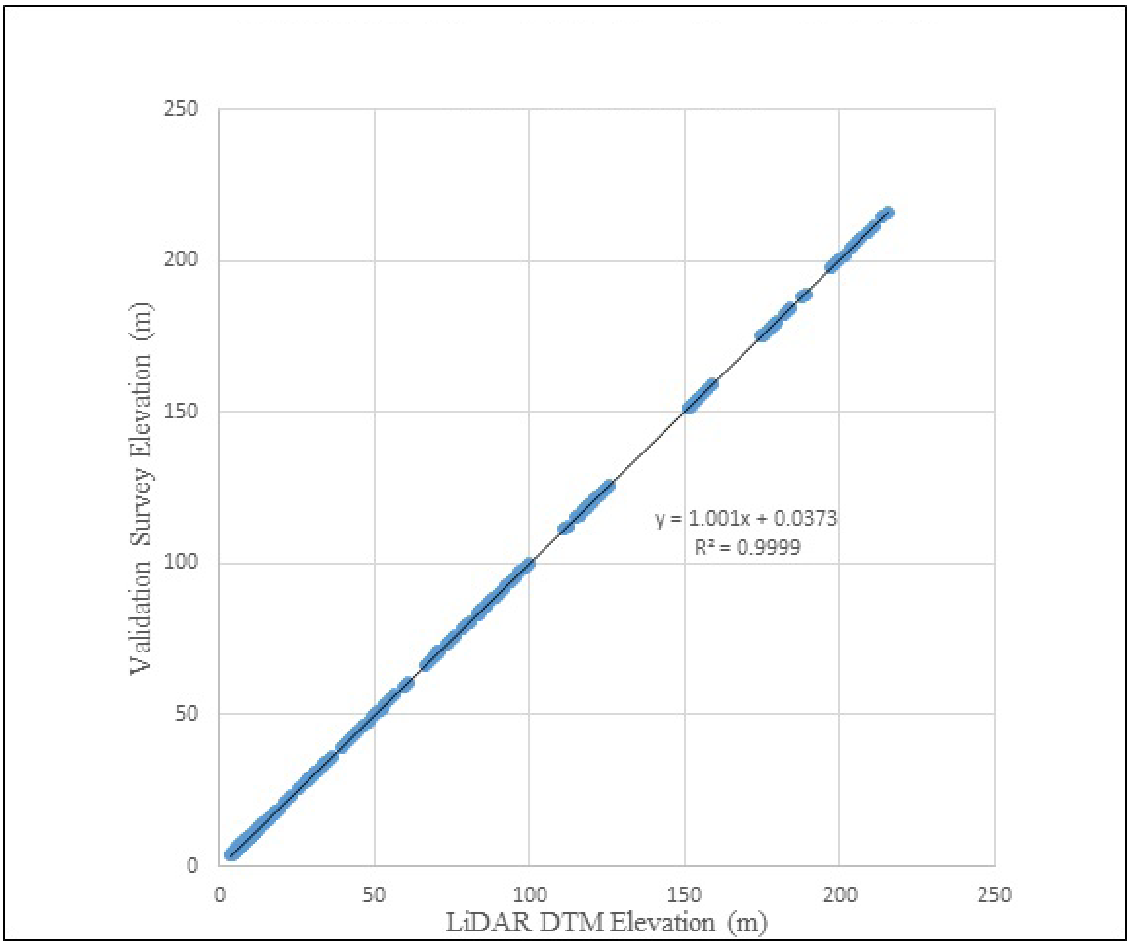


Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.14
Standard Deviation	0.11
Average	0.09
Minimum	-0.12
Maximum	0.31

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and cross-section data were available for Tignoan with 760 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barriers method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface was represented by the computed RMSE value of 0.38 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Tignoan integrated with the processed LiDAR DEM is shown in Figure 25.

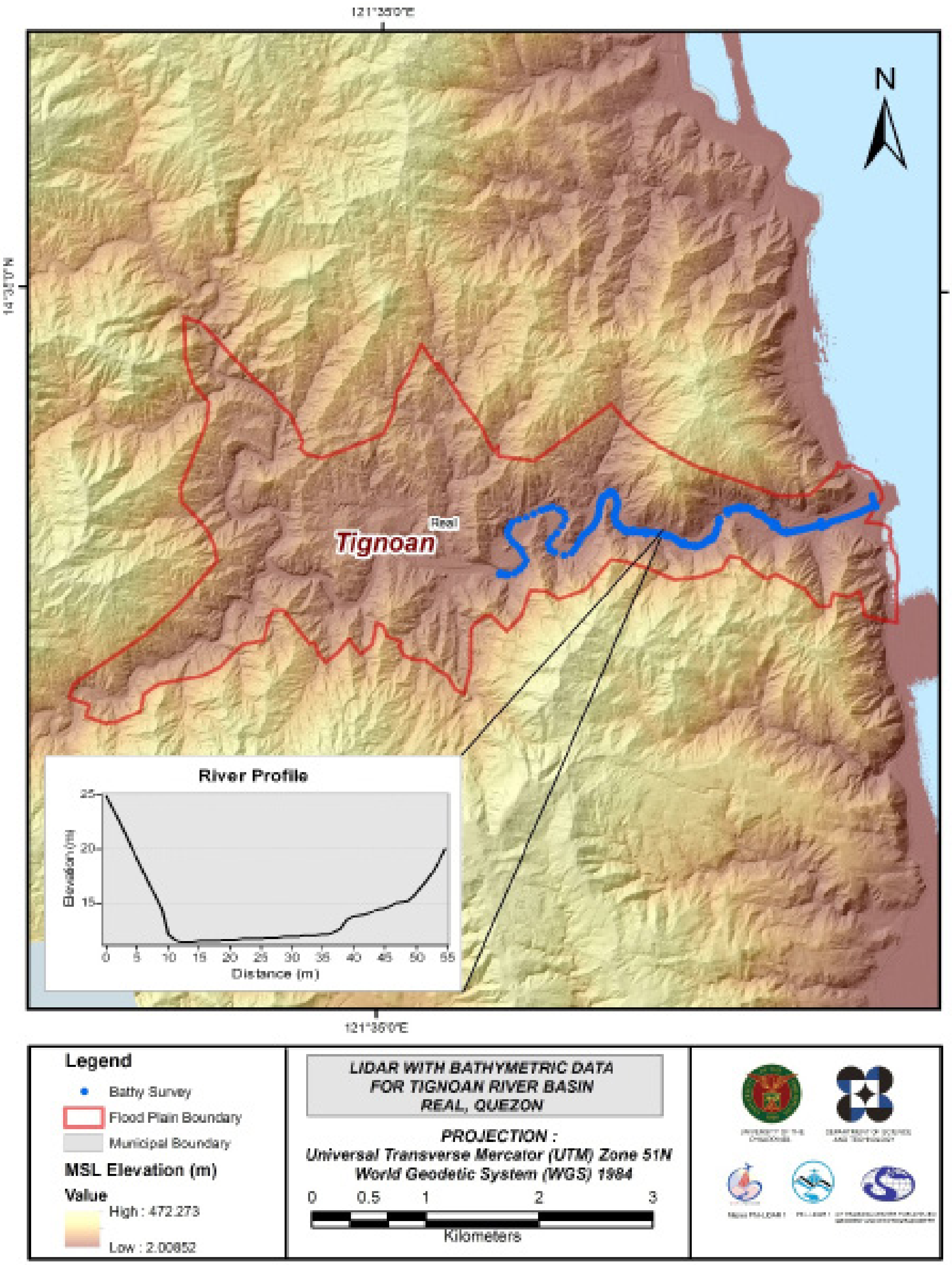


Figure 25. Map of Tignoan Floodplain with bathymetric survey points shown in blue.

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

Tignoan Floodplain, including its 200 m buffer, has a total area of 15.04 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 230 building features, are considered for QC. Figure 26 shows the QC blocks for Tignoan Floodplain.

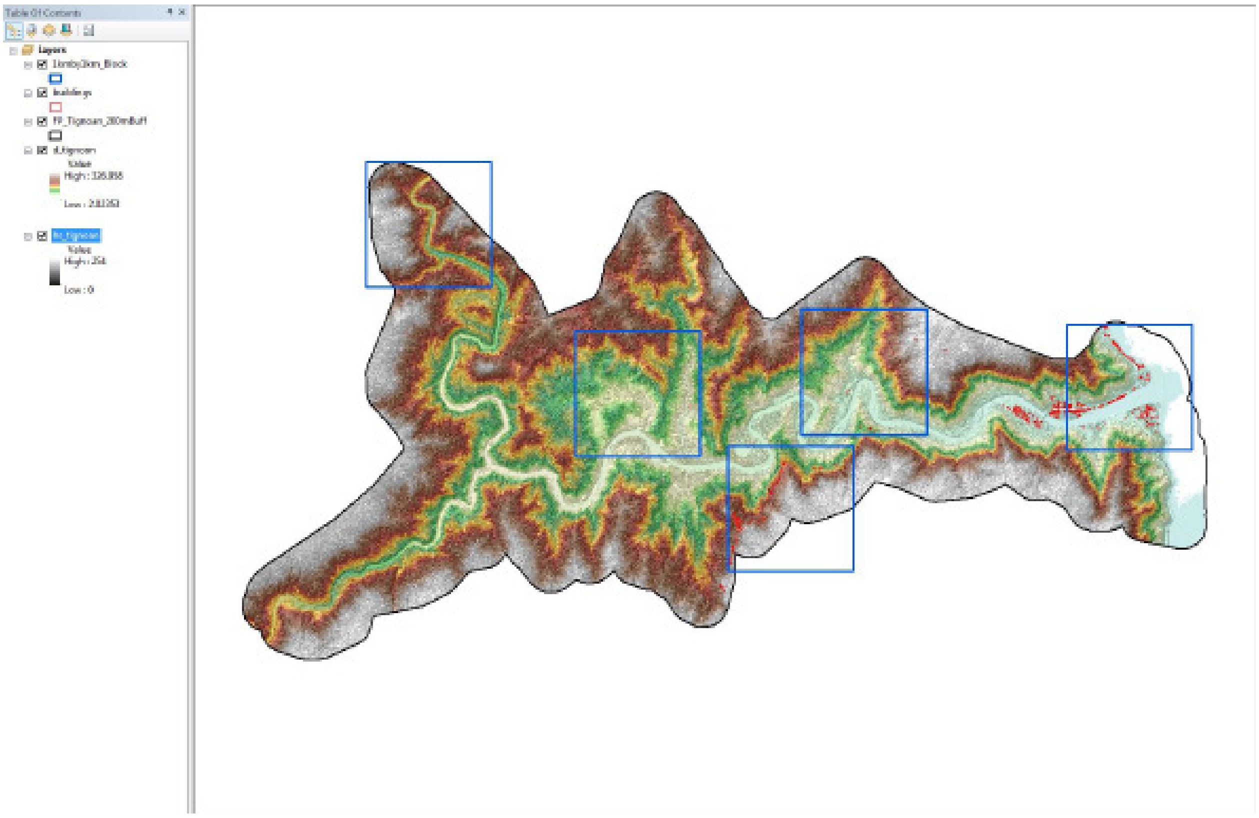


Figure 26. Blocks (in blue) of Tignoan building features that were subjected to QC

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

Table 15. Quality Checking Ratings for Tignoan Building Features

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Tignoan	99.57	100.00	92.17	PASSED

3.12.2 Height Extraction

Height extraction was done for 369 building features in Tignoan Floodplain. Of these building features, 17 were filtered out after height extraction, resulting in 352 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 6.83 m.

3.12.3 Feature Attribution

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

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 lists the number of water features extracted per type.

Table 16. Building Features Extracted for Tignoan Floodplain.

Facility Type	No. of Features
Residential	324
School	22
Market	0
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	2
Barangay Hall	1
Military Institution	0
Sports Center/Gymnasium/Covered Court	1
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	1
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	1
Total	**352**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Tignoan	0.17	2.09	5.49	0.00	0.00	7.75

Table 18 Number of Extracted Water Bodies for Tignoan Floodplain.

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Tignoan	1	1	5	0	0	7

A total of 1 bridge over small channels that are part of the river network was 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 27 shows the Digital Surface Model (DSM) of Tignoan Floodplain overlaid with its ground features.

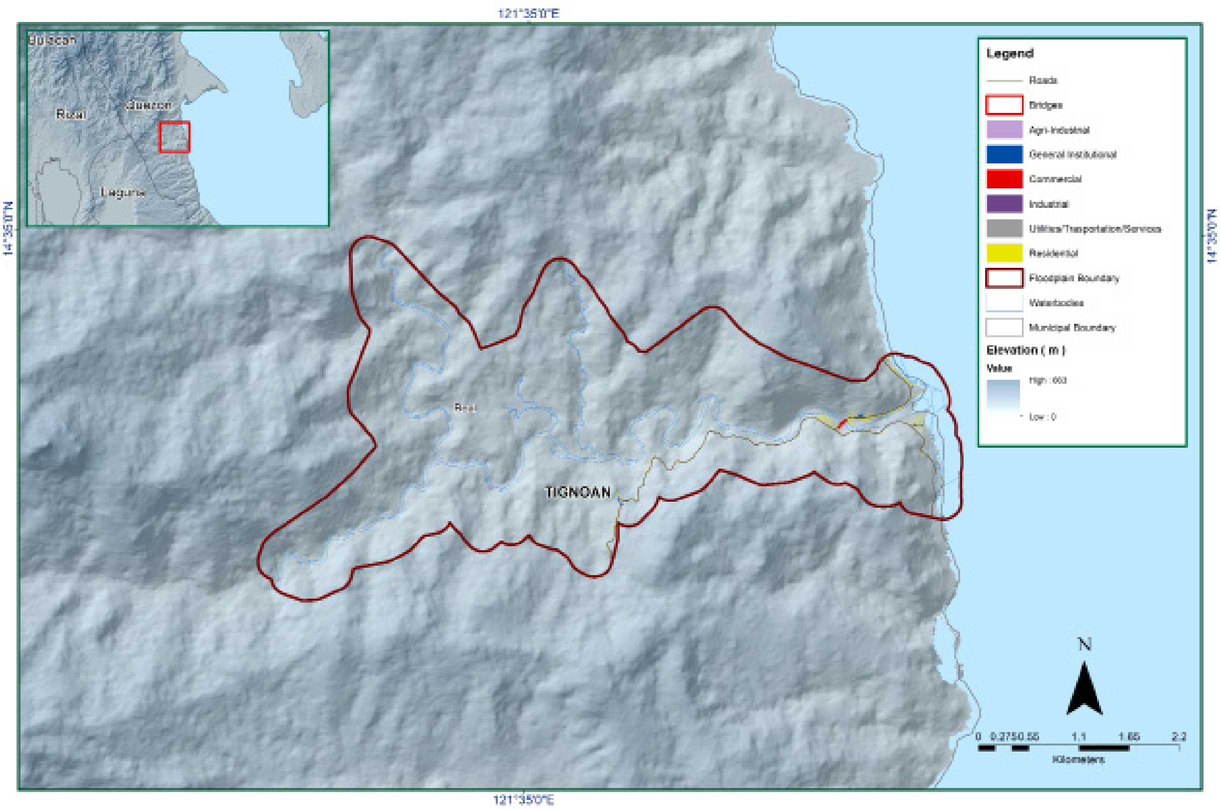


Figure 27. Extracted features for Tignoan Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Dexter T. Lozano, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, and For. Rodel C. Alberto

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Tignoan River on October 14 to 23, 2015 with the following scope of work: reconnaissance survey to determine the viability of traversing the planned routes for bathymetric survey; courtesy call to LGU Tignoan; control survey for the establishment of control point UP-LUB at Lubayat bridge approach occupied as base station for GNSS surveys; cross-section, bridge-as-built, and MSL water level marking at Tignoan Bridge in Brgy. Tignoan, Municipality of Real, Quezon; validation points data acquisition for LiDAR data with estimated distance of 18.3 km; and bathymetric survey of Tignoan River starting from the upstream from Brgy. Tanauan to Brgy. Tignoan and then to the Tignoan Bridge with an approximate length of 5km utilizing GNSS PPK survey technique, as shown in Figure 28.

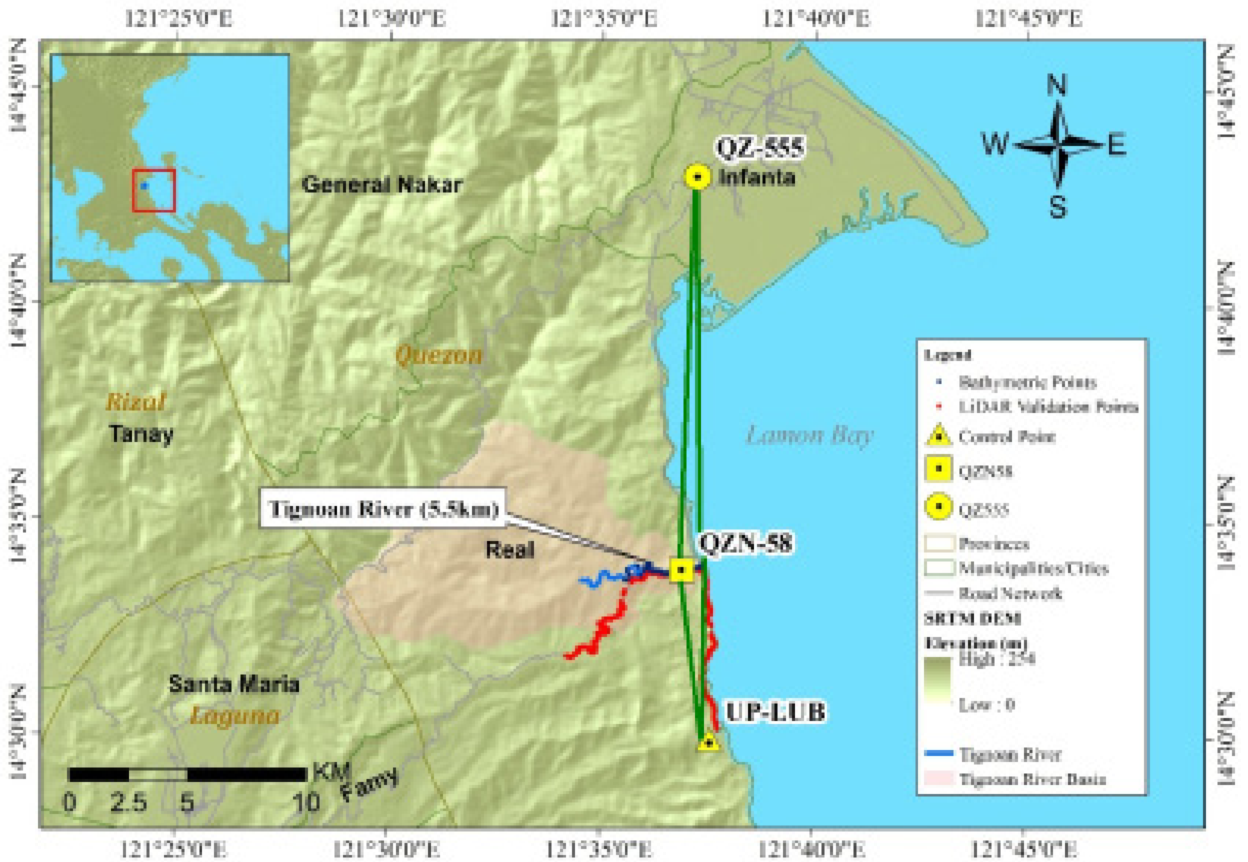


Figure 28. Extent of the bathymetric survey (in blue) in Tignoan River Basin and the LiDAR data validation survey (in red)

4.2 Control Survey

A GNSS network from Abulug River Survey was established on September 18, 2015 occupying the control points KAY-3, a second-order GCP, in Brgy. Imelda, Municipality of Pudtol; and CG-343, a first-order BM, in Brgy. Libertad, Muncipality of Abulug; both in Cagayan Province.

The GNSS network used for Tignoan River Basin is composed of four (4) loops established on June 15 and 16, 2016 occupying the following reference points: KAY-3, a second-order GCP from Abulug Survey; CG-343, a first order BM, also from Abulug Survey; and CG-373, a GCP with 95% class accuracy, in Brgy. Bangan, Municipality of Sanchez Mira.

Three (3) control points were established along the approach of bridges namely: UP-CLA, located at Cabicungan Bridge in Brgy. Dibalio, Municipality of Claveria; UP-LIN, at Linao Bridge, Brgy. Bangag-Zingag, Municipality of Aparri; and UP-PAM, at New Tignoan Bridge, Brgy. Masi, Municipality of Tignoan.

The summary of reference and control points and its location is summarized in Table 20 while the GNSS network established is illustrated in Figure 29.

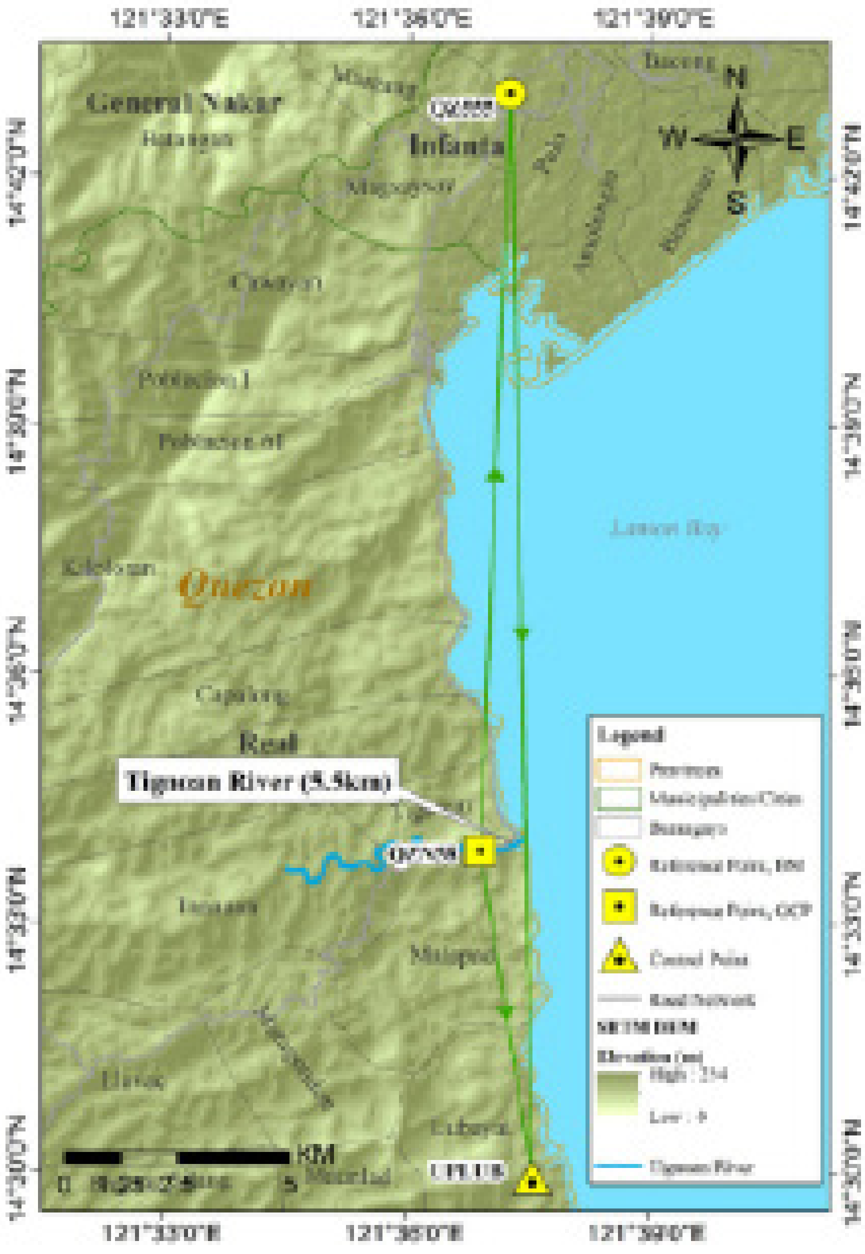


Figure 29. GNSS network of Tignoan Field Survey

Table 19. List of Reference and Control Points occupied for Tignoan River Survey
(Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
QZ-555	1st Order, BM	-	-	52.570	4.8077	
QZN-58	2nd Order, GCP	14°33'52.21121"	121°36'54.79419"	56.518	-	2007
UP-LUB	UP Established	-	-	-	-	2015

The GNSS set up for control points QZ-555, QZN-58, and UP-LUB used in the Tignoan survey are shown in Figure 30 to Figure 32, respectively.

Figure 30. GNSS base receiver set-up, Trimble® SPS 882 at QZ-555, Brgy. Gumian, Infanta, Quezon

Figure 31. GNSS base receiver set-up, Trimble® SPS 852 at QZN-58, Tignoan Bridge, along the Infanta National Road, Brgy. Tignoan, Real, Quezon

Figure 32. GNSS base receiver set-up, Trimble® SPS 882 at UP-LUB, Lubayat Bridge in Brgy. Lubayat, Municipality of Real, Quezon

4.3 Baseline Processing

GNSS baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/-20 cm and +/-10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking was 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 Tignoan River Basin is summarized in Table 20 generated TBC software.

Table 20. Baseline processing report for Tignoan River Basin static survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
QZ-555 --- UP-LUB	10-19-2015	Fixed	0.011	0.057	178°31’10”	24096.160	1.999
QZN-58 --- QZ-555	10-19-2015	Fixed	0.006	0.051	1°57’02”	16851.101	-5.270
QZN-58 --- UP-LUB	10-19-2015	Fixed	0.004	0.022	170°37’21”	7344.919	-3.313

As shown in Table 20, a total of 3 baselines were processed and all of them passed the required accuracy set by the project.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is as performed using TBC. Looking at the Adjusted Grid Coordinates (Table 23) Table C-of the TBC generated Network Adjustment Report, it is observed that the square root of the sum of the squares of x and y must be less than 20 cm and z less than 10 cm or in equation form:

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

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

The six (6) control points, KAY-3, CG-343, CG-373, UP-CLA, UP-LIN and UP-PAM were occupied and observed simultaneously to form a GNSS loop. Coordinates of KAY-3 and CG-343; and elevation values of both controls including CG-373 were held fixed during the processing of the control points as presented in Table 22. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 21. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
QZ-55	Grid				Fixed
QZN-58	Local	Fixed	Fixed	Fixed	
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e., Northing, Easting, Elevation, and computed standard errors of the control points in the network, is indicated in Table 22. All fixed control points have no values for grid and elevation errors.

Table 22. Adjusted grid coordinates for the control points used in the Tignoan River Floodplain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
QZ-555	351492.460	0.009	1627447.834	0.010	4.808	?	e
QZN-58	350816.073	?	1610612.434	?	10.028	0.093	LL
UP-LUB	351968.736	0.007	1603359.466	0.007	6.710	0.094	

The network is fixed at reference points. The list of adjusted grid coordinates of the network is shown in Table 23 .Using the equation for horizontal and   for the vertical, below is the computation for accuracy that passed the required precision:

QZN-58
Horizontal accuracy = Fixed
Vertical accuracy = 9.3 cm < 10 cm

QZ-555
Horizontal accuracy = $\sqrt{((0.9)^2 + (1.0)^2}$
= $\sqrt{(0.81+1.0)}$
= 1.4 cm < 20 cm
Vertical accuracy = Fixed

UP-LUB
Horizontal accuracy = $\sqrt{((0.7)^2 + (0.7)^2}$
= $\sqrt{(0.49+0.49)}$
= 1.0 cm < 20 cm
Vertical accuracy = 9.4 cm < 10 cm

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

Table 23. Adjusted geodetic coordinates for control points used in theTignoan River Floodplain validation.

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
QZ-555	N14°43'00.16787"	E121°37'13.96853"	50.764	?	e
QZN-58	N14°33'52.21121"	E121°36'54.79419"	56.063	0.093	LL
UP-LUB	N14°29'56.42439"	E121°37'34.76226"	52.753	0.094	

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

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

Table 24. References 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)
QZ-555	1st Order, BM	14°43'00.16787"	121°37'13.96853"	50.764	1627447.834	351492.460	4.808
QZN-58	2nd Order, GCP	14°33'52.21121"	121°36'54.79419"	56.063	1610612.434	350816.073	10.028
UP-LUB	UP Established	14°29'56.42439"	121°37'34.76226"	52.753	1603359.466	351968.736	6.710

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

Cross-section and as-built surveys for Tignoan Bridge in Brgy. Tignoan across Tignoan River in Real, Quezon were done simultaneously on October 19, 2015 using GNSS receiver Trimble® SPS 882 in PPK survey technique as shown in Figure 33.

Figure 33. New Tignoan Bridge facing downstream

A total of 33 cross-sectional points were gathered with an approximate length of 72.359 meters using QZN-58 as base station. Bridge as-built features determination was also performed to get the distance of piers and abutments from the bridge approach. The location map, cross-section diagram, and the bridge data form are shown in Figure 34 to Figure 36, respectively.

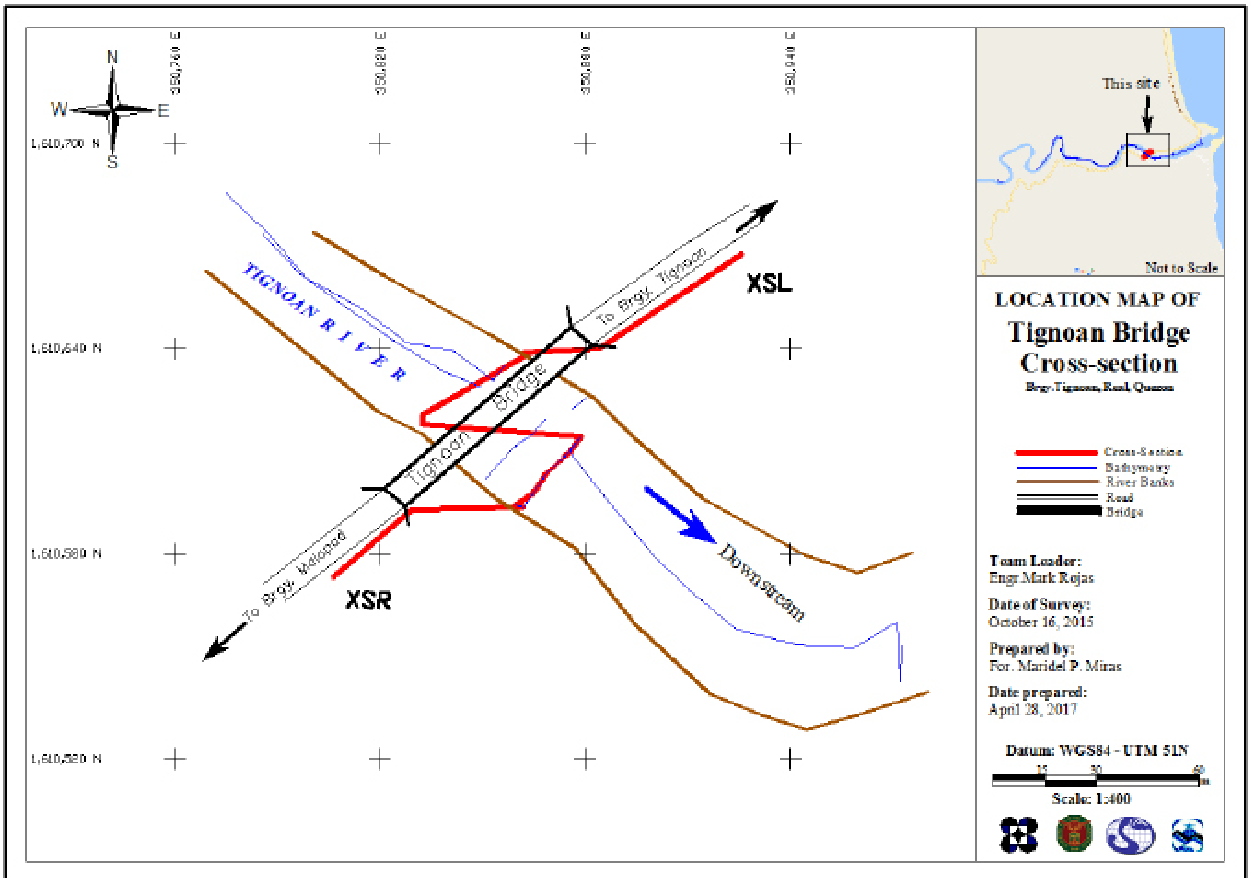


Figure 34. Tignoan bridge cross-section location map

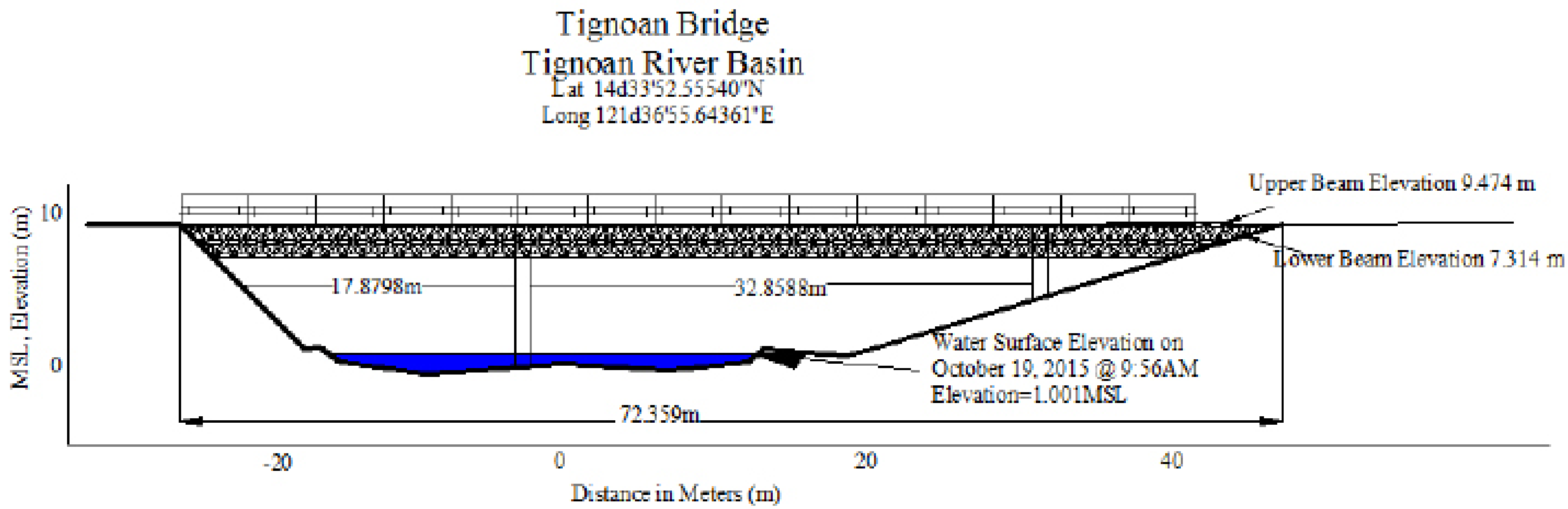


Figure 35. Tignoan Bridge cross-section diagram

Bridge Data Form

Bridge Name: TIGNOAN BRIDGE **Date:** October 22, 2015

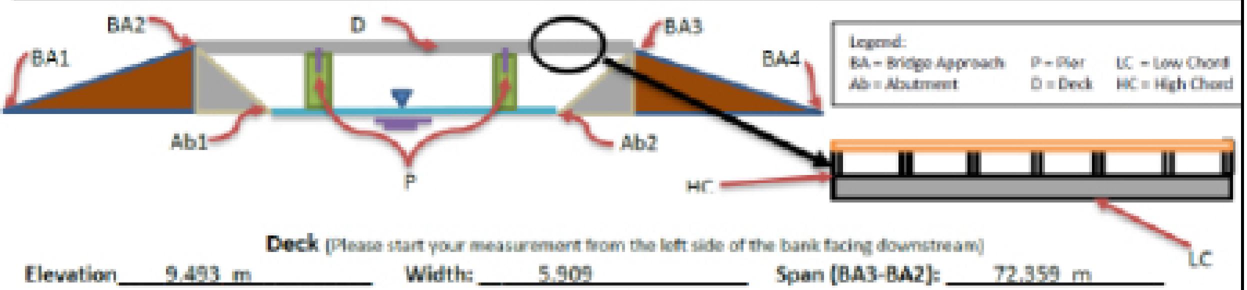
River Name: TIGNOAN RIVER BASIN **Time:** 10:00 AM

Location (Brgy, City, Region): Brgy. Tignoan, Real, Quezon

Survey Team: Mark Lester D. Rojas, Dona Rina Patricia Tajora, Edjie Abalos, April Joy Lim

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

Latitude: 14d33'54.67592" N **Longitude:** 121d36'58.44286" E



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

Elevation: 9.493 m Width: 5.909 Span (BA3-BA2): 72.359 m

	Station	High Chord Elevation	Low Chord Elevation
1	72.30077	9.474	7.314
2	85.11924	9.493	7.333
3	106.1424	9.441	7.281
4	114.7606	9.519	7.359
5	72.30077	9.474	7.314

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	9.360	BA3	122	9.502
BA2	49.84	9.502	BA4	152.2	9.538

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

	Station (Distance from BA1)	Elevation
Ab1		
Ab2		

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

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

Figure 36. Tignoan Bridge data form

Water surface elevation of Tignoan River was determined using Trimble® SPS 882 in PPK mode survey on October 19, 2015 at 9:56 AM. This was translated onto marking the bridge's pier using a digital level. The resulting water surface elevation data is 1.001 m above MSL. The markings on the bridge pier are shown in Figure 37. This shall serve as a reference for flow data gathering and depth gauge deployment of Mapua Phil-LiDAR 1.

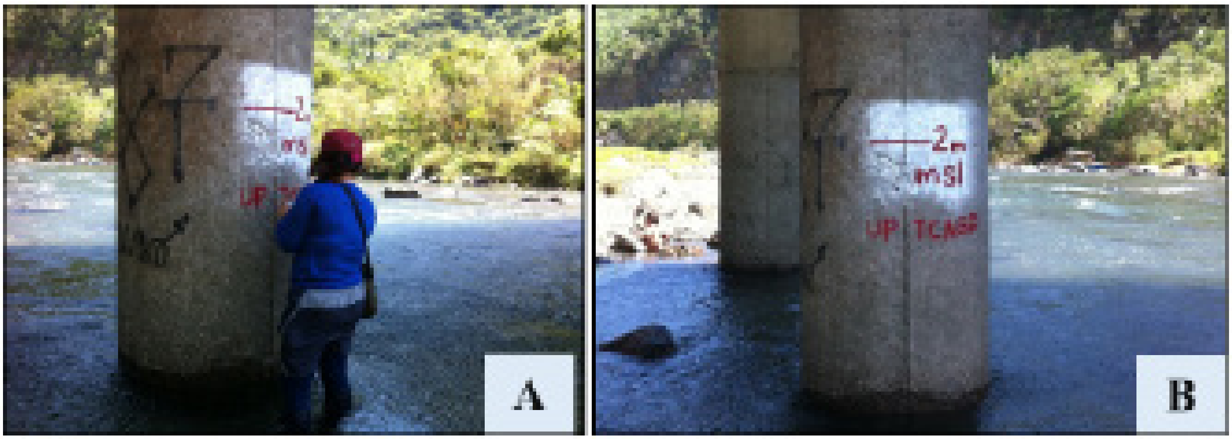


Figure 37. MSL water level markings in Tignoan Bridge's pier

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on October 17 and October 19, 2015 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a pole which was attached in front of the vehicle as seen in Figure 38. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height of 2.32 m was measured from the ground up to the bottom of the notch of the GNSS Rover receiver. The survey was conducted using PPK technique on a continuous topography mode using QZN-58 as base station.

Figure 38. Validation points acquisition set-up

Within the two (2) days of ground validation, the team covered the major roads of Maragondon, Tignoan, Malapad, and Lubayat. The survey acquired 3,040 ground validation points with an approximate length of 18.3 km presented in Figure 39.

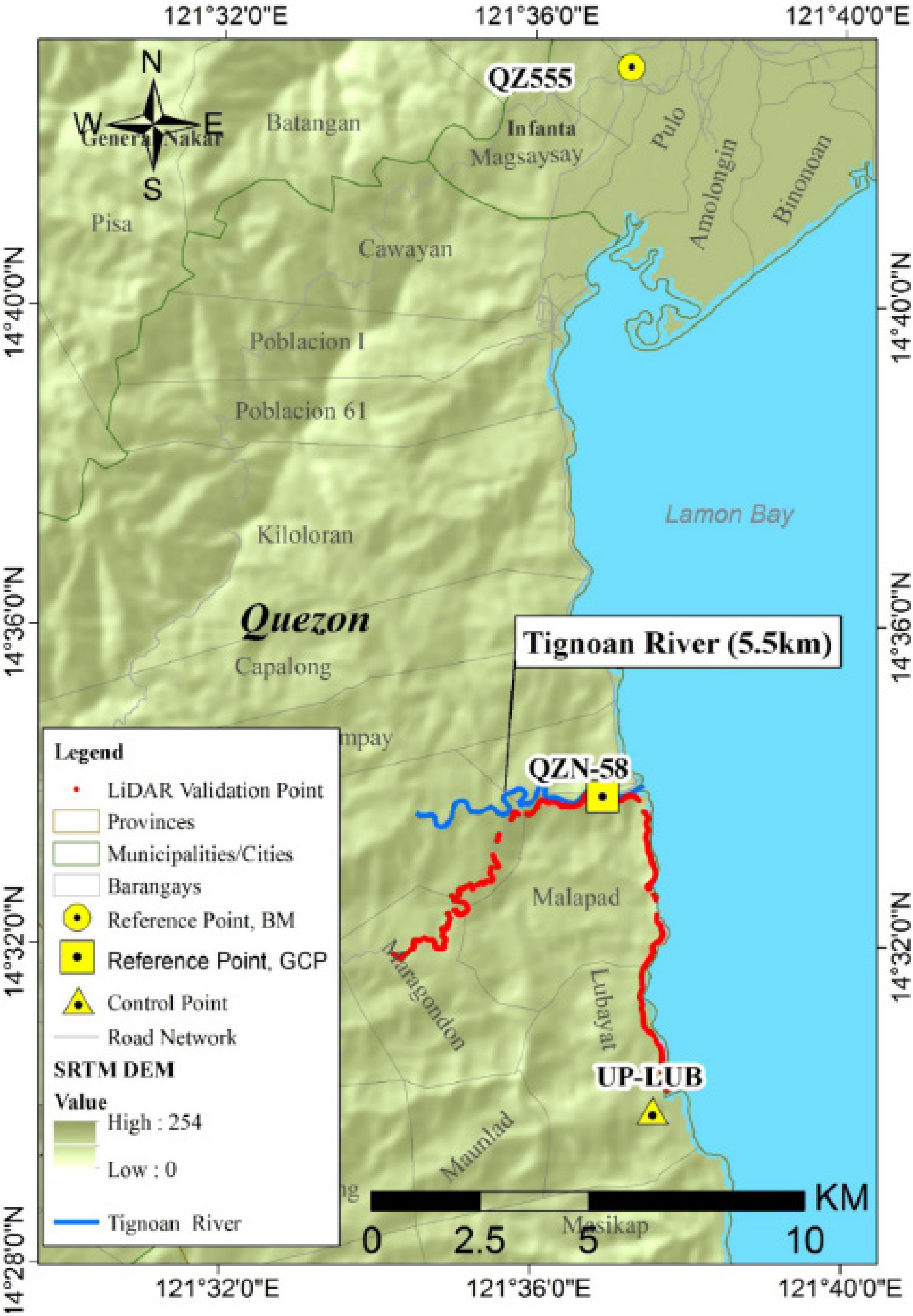


Figure 39. LiDAR ground validation survey along Quezon

4.7 River Bathymetric Survey

Bathymetric survey was conducted on October 16 and 22, 2015. The team conducted manual bathymetric survey using Trimble® SPS 882 in GNSS PPK survey technique as illustrated in Figure 40. The survey started from upstream in Brgy. Tignoan with coordinates 14°33'38.75594"N, 121°35'35.80651"E and ended down to the mouth of the river with coordinates 14°34'01.56376"N, 121°37'25.09794" E in Brgy. Tignoan, Real, Quezon as shown in Figure 41. The control point QZN-58 was used as GNSS base station all throughout the entire survey.

Figure 40. Manual bathymetric survey in Tignoan River

The bathymetric survey for Tignoan River gathered a total of 725 points with an estimated length of 4.8 km traversing Brgy. Tanauan down to the mouth of the river in Brgy. Tignoan, Real, Quezon.

About 3.2 km of the Tignoan River were not surveyed due to the difficulties encountered by the team such as slippery pathway, highly steep slope, and the typhoon causing immense rain during the survey. About 5 km of the planned 8.2 km was covered by the bathymetry survey.

Figure 41. Bathymetric points gathered from Tignoan River

A CAD drawing as shown in Figure 42 illustrates the Tignoan Riverbed profile where the highest elevation record is found in Brgy. Tanauan and the lowest is in Tignoan Bridge. An elevation drop of 32.6 meters was observed within the distance of approximately 5 km. The highest elevation is 31.926 m above MSL while the lowest is 1.441m below MSL located in Brgy. Tignoan near the mouth of the river.

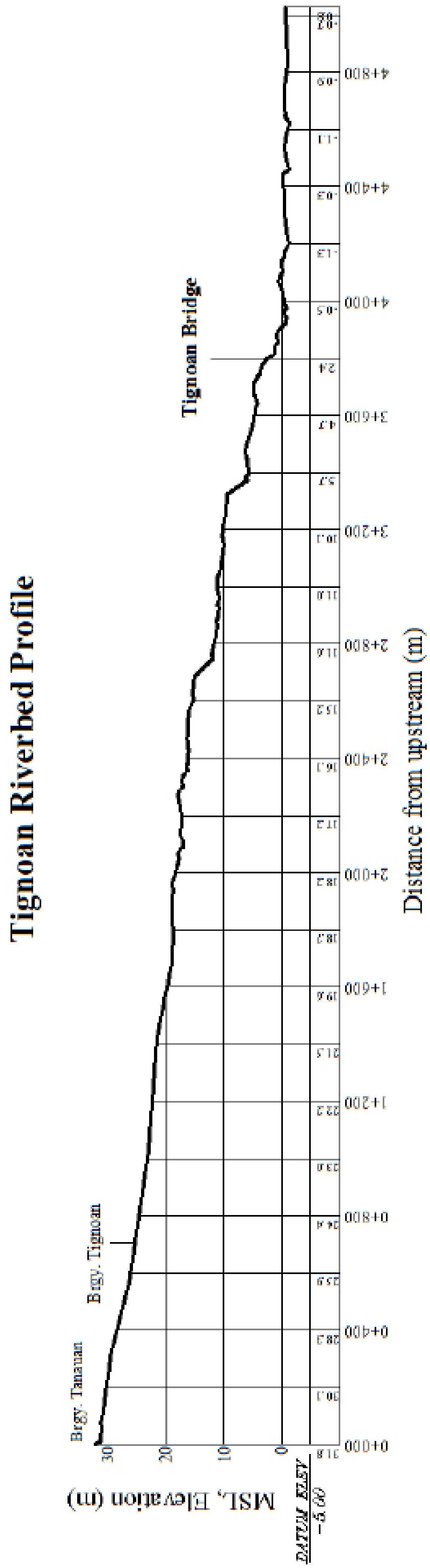


Figure 42. The Tignoan riverbed profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, and Pauline Racoma

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All components and data that affect the hydrologic cycle of the Tignoan River Basin were monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Tignoan River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) deployed by the Mapua Institute of Technology under the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) The ARG was installed Tanauan Elementary School Real, Quezon (Figure 43). The precipitation data collection started from November 11, 2016 00:10 am to November 12, 2016 at 02:55 am with a 15-minute recording interval.

The total precipitation for this event in Tanauan Elementary School ARG was 55.4 mm. It has a peak rainfall of 13.8 mm on 11 November 2016 at 21:25 pm. The lag time between the peak rainfall and discharge is 2 hours and 35 minutes.

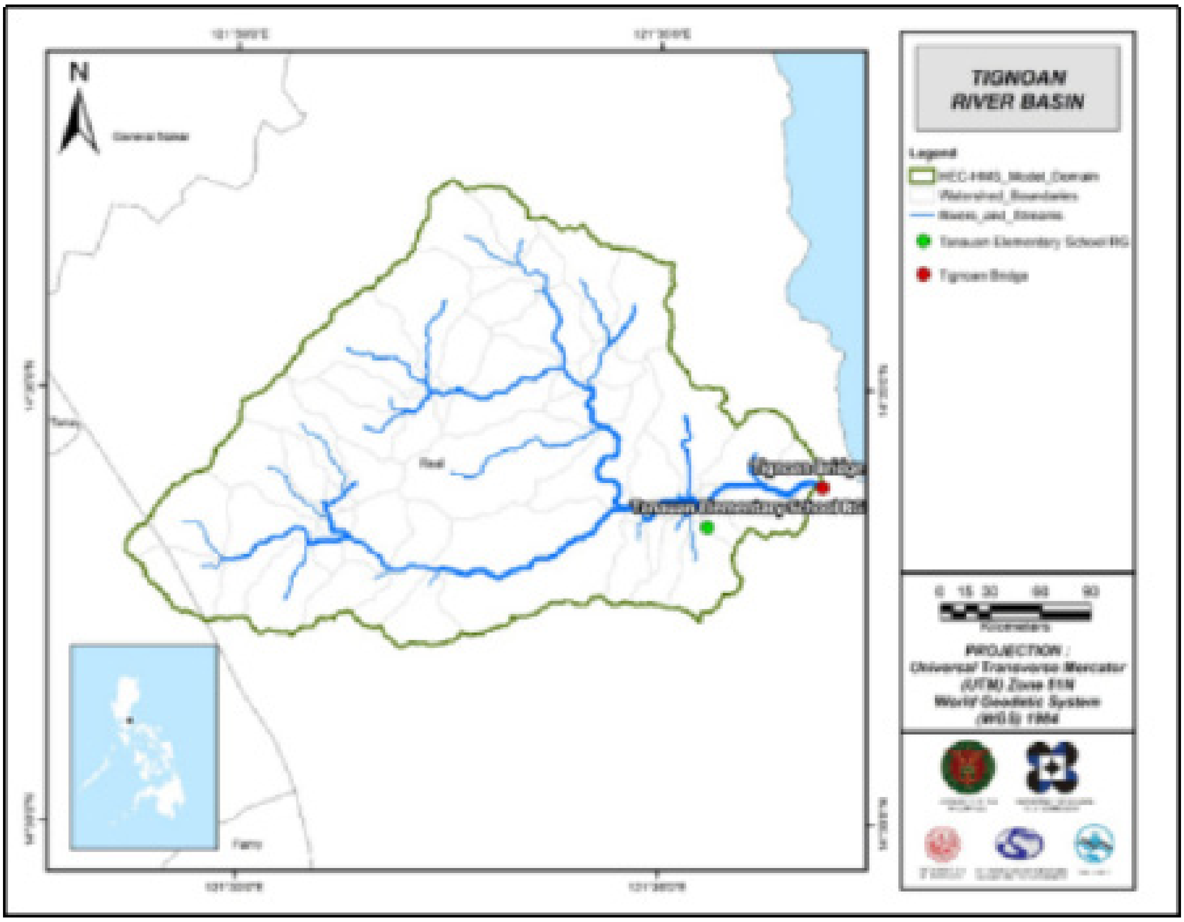


Figure 43. Location map of the Tignoan HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Tignoan Bridge, Real, Quezon (14°33'53.21"N, 121°36'56.14"E). It gives the relationship between the observed water levels from the Tignoan Bridge using depth gage and outflow of the watershed recorded using the flow meter at this location.

For Tignoan Bridge, the rating curve is expressed as Q = 3.4458e1.587h as shown in Figure 45.

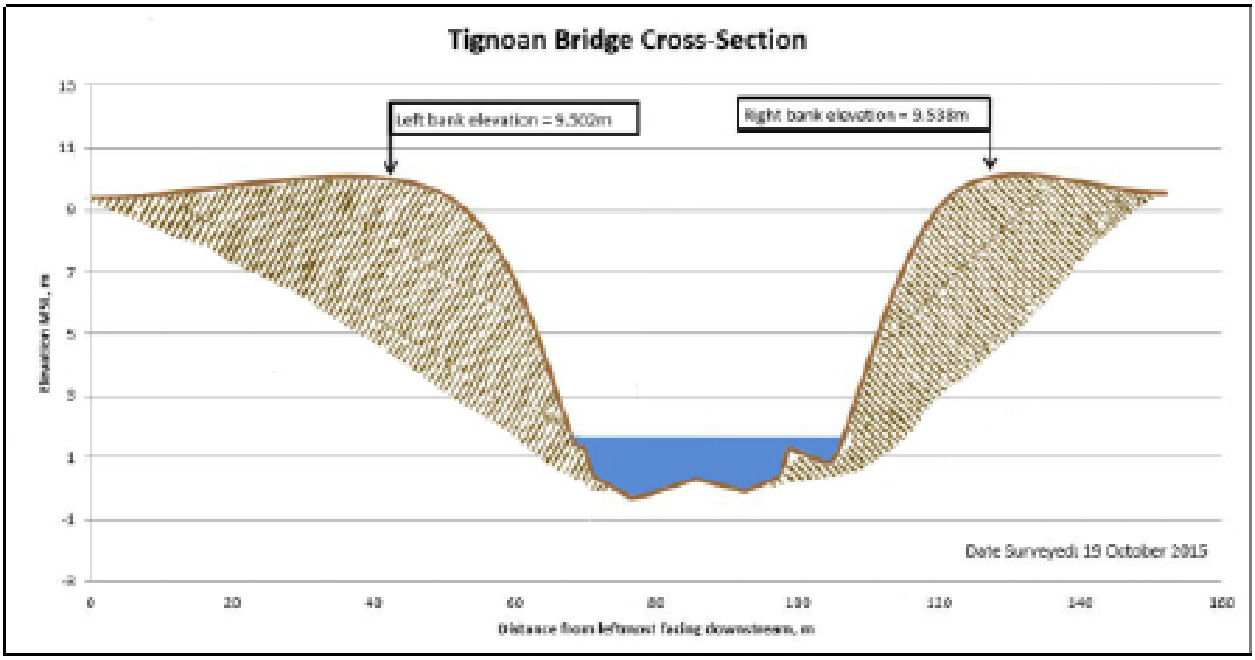


Figure 44. Cross-section plot of Tignoan Bridge

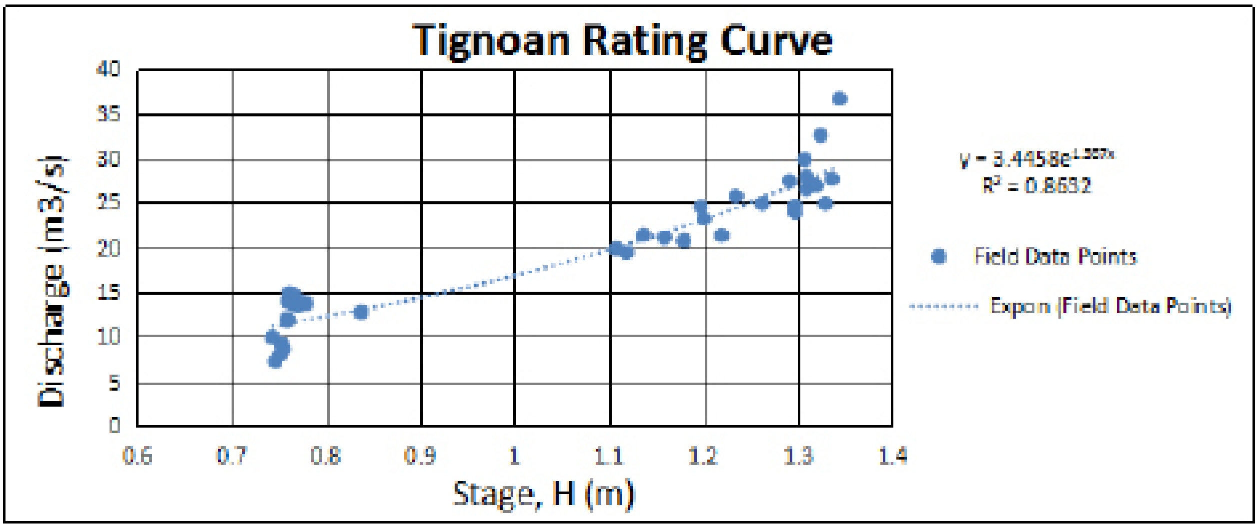


Figure 45. Rating curve at Tignoan Bridge, Real, Quezon

This rating curve equation was used to compute the river outflow at Tignoan Bridge for the calibration of the HEC-HMS model shown in Figure 53. Peak discharge is 36.66 m3/s at 00:00 AM, November 12, 2016. The Tignoan River Rating Curve measured at Tignoan Bridge is expressed as Q = 305.63e0.5029x (Figure 45).

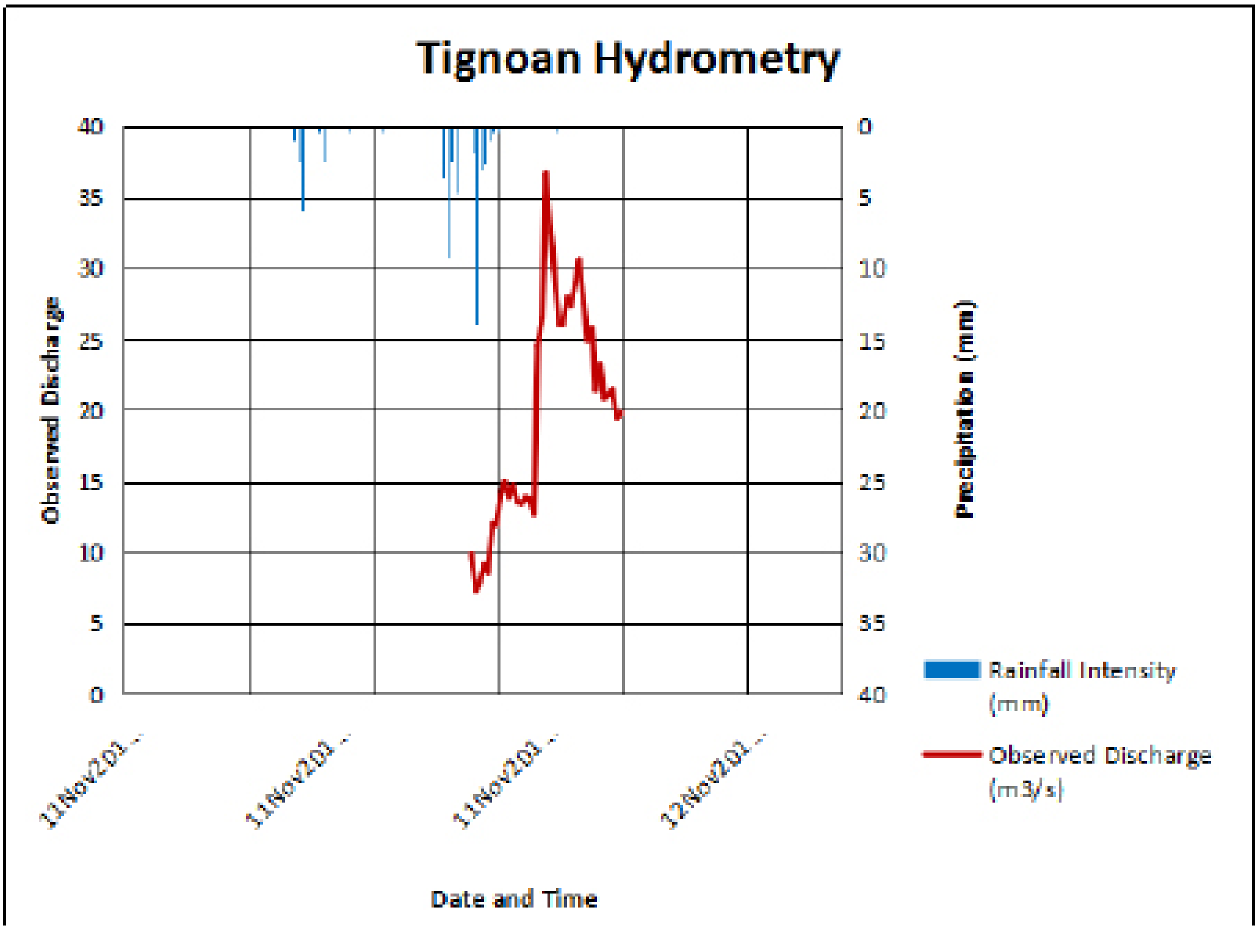


Figure 46. Rainfall and outflow data of the Tignoan River Basin used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Infanta Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time. This station is chosen based on its proximity to the Tignoan watershed. The extreme values for this watershed were computed based on a 40-year record.

Table 25. RIDF values for Infanta Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	**10 mins**	**20 mins**	**30 mins**	**1 hr**	**2 hrs**	**3 hrs**	**6 hrs**	**12 hrs**	**24 hrs**
2	20.4	30.7	39.2	57	79.5	93	121.9	151.2	192.9
5	25.7	38.3	49.3	75.4	112.9	133.1	175.3	212.7	249.6
10	29.2	43.4	56	87.6	135	159.6	210.7	253.4	287.1
15	31.2	46.2	59.8	94.5	147.4	174.5	230.7	276.4	308.2
20	32.6	48.2	62.4	99.4	156.2	185	244.6	292.4	323
25	33.7	49.7	64.4	103.1	162.9	193.1	255.4	304.8	334.4
50	37	54.5	70.7	114.5	183.6	217.9	288.6	343	369.6
100	40.3	59.2	76.9	125.9	204.2	242.6	321.5	380.9	404.4

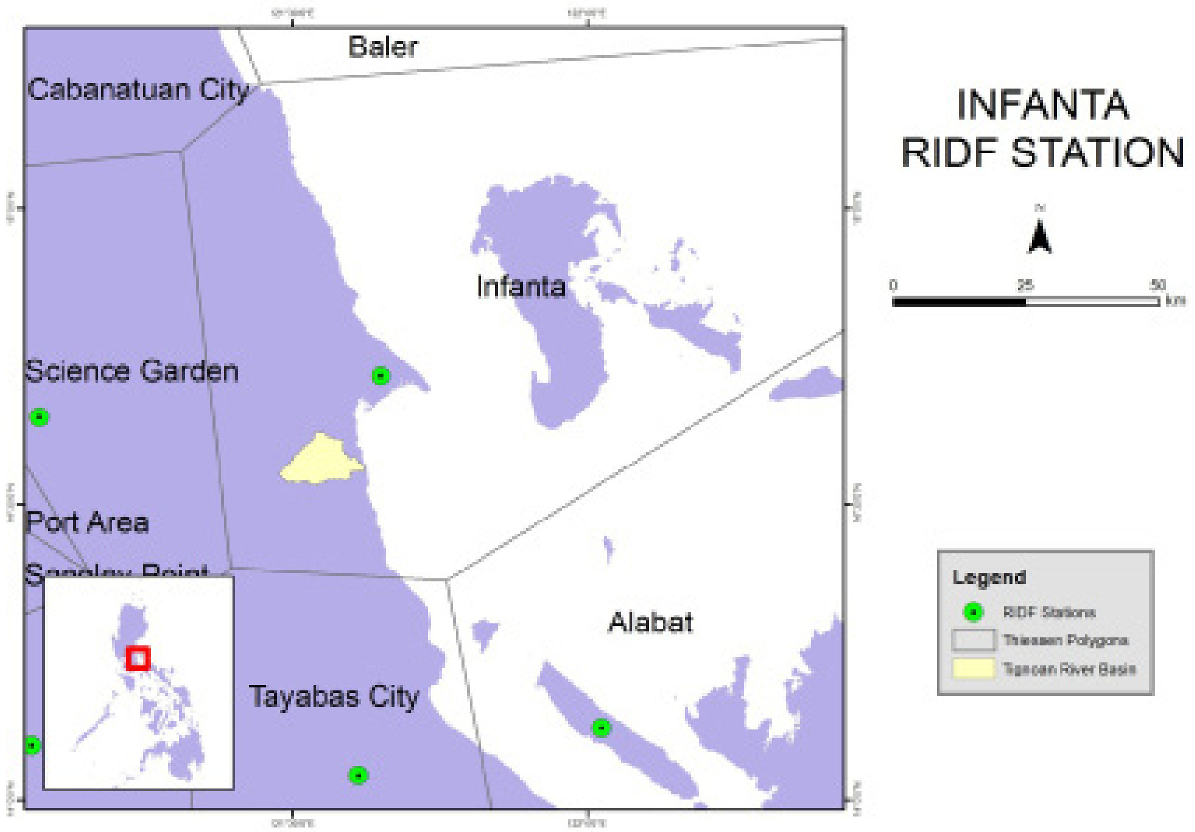


Figure 47. Infanta RIDF location relative to Tignoan River Basin

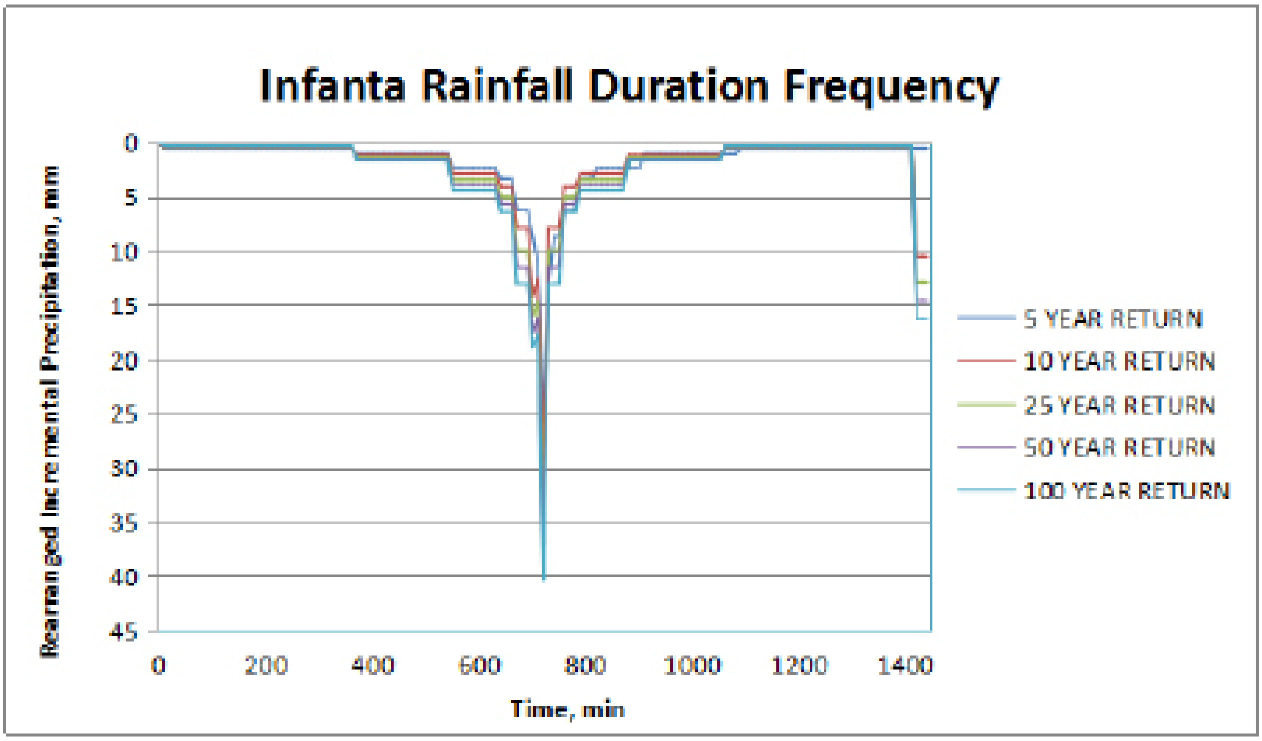


Figure 48. Synthetic storm generated for a 24-hour period rainfall for various return periods

5.3 HMS Model

The soil dataset was taken from and generated by the Bureau of Soils and Water Management (BSWM) under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Tignoan River Basin are shown in Figure 49 and Figure 50, respectively.

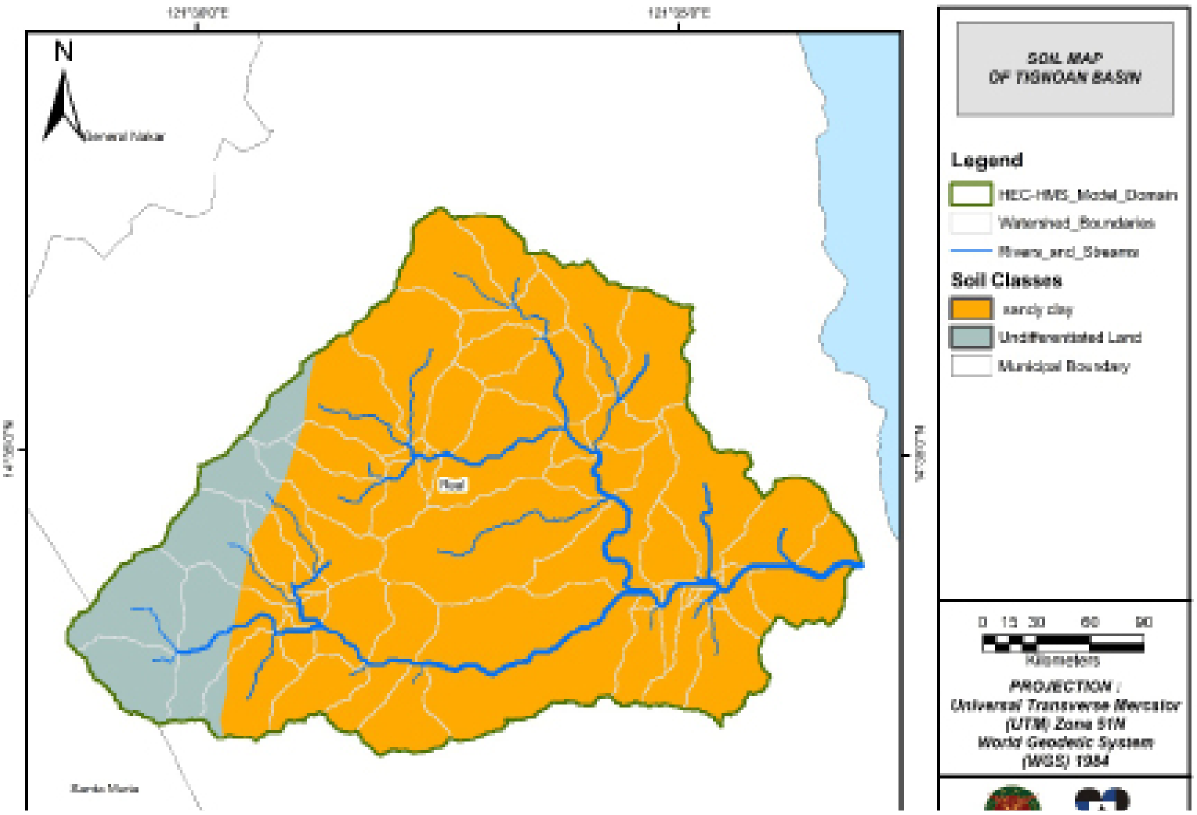


Figure 49. Soil map of Tignoan River Basin

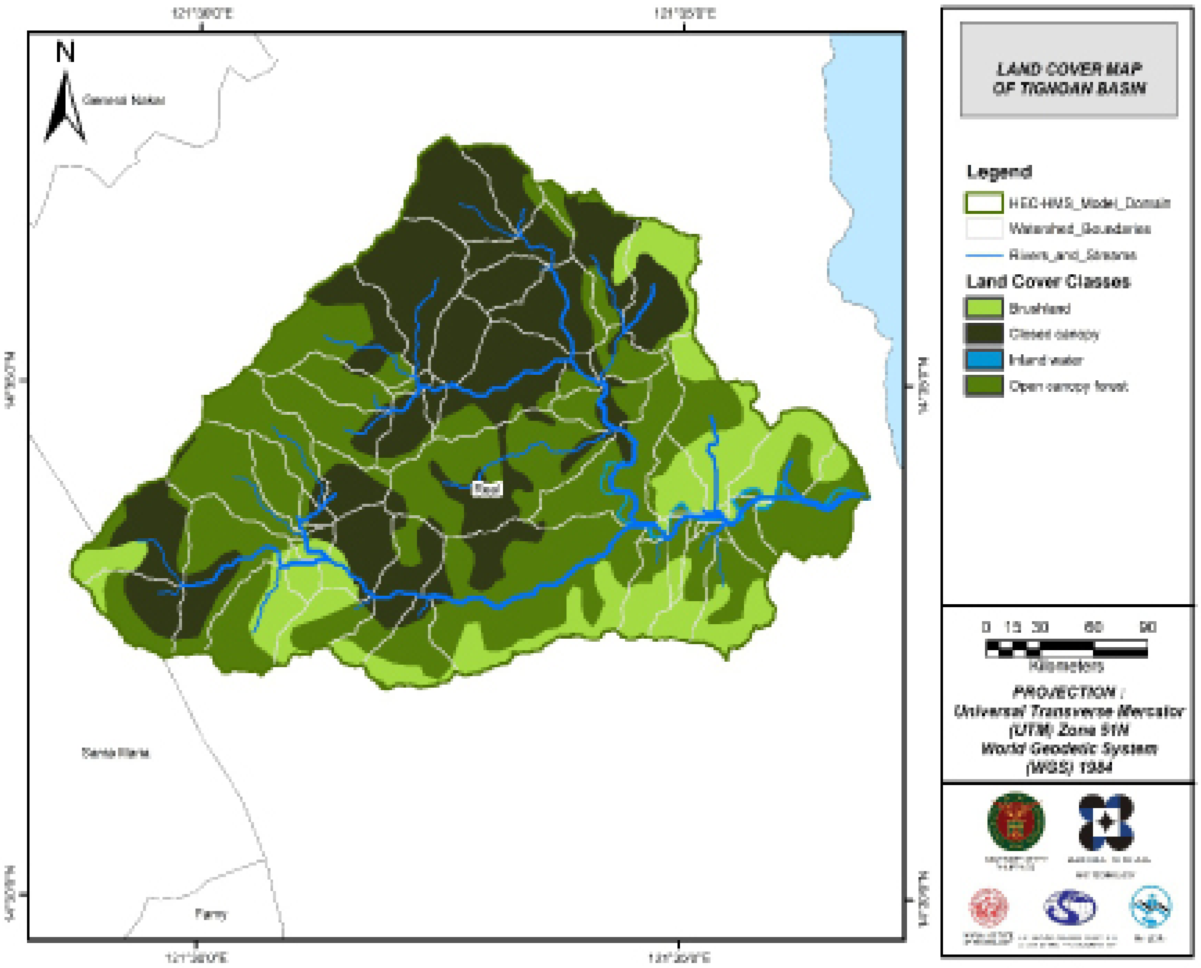


Figure 50. Land cover map of Tignoan River Basin

For Tignoan, the soil classes identified were sandy clay and undifferentiated mountain soil. The land cover types identified were brushland, inland water, and open and closed canopy forest.

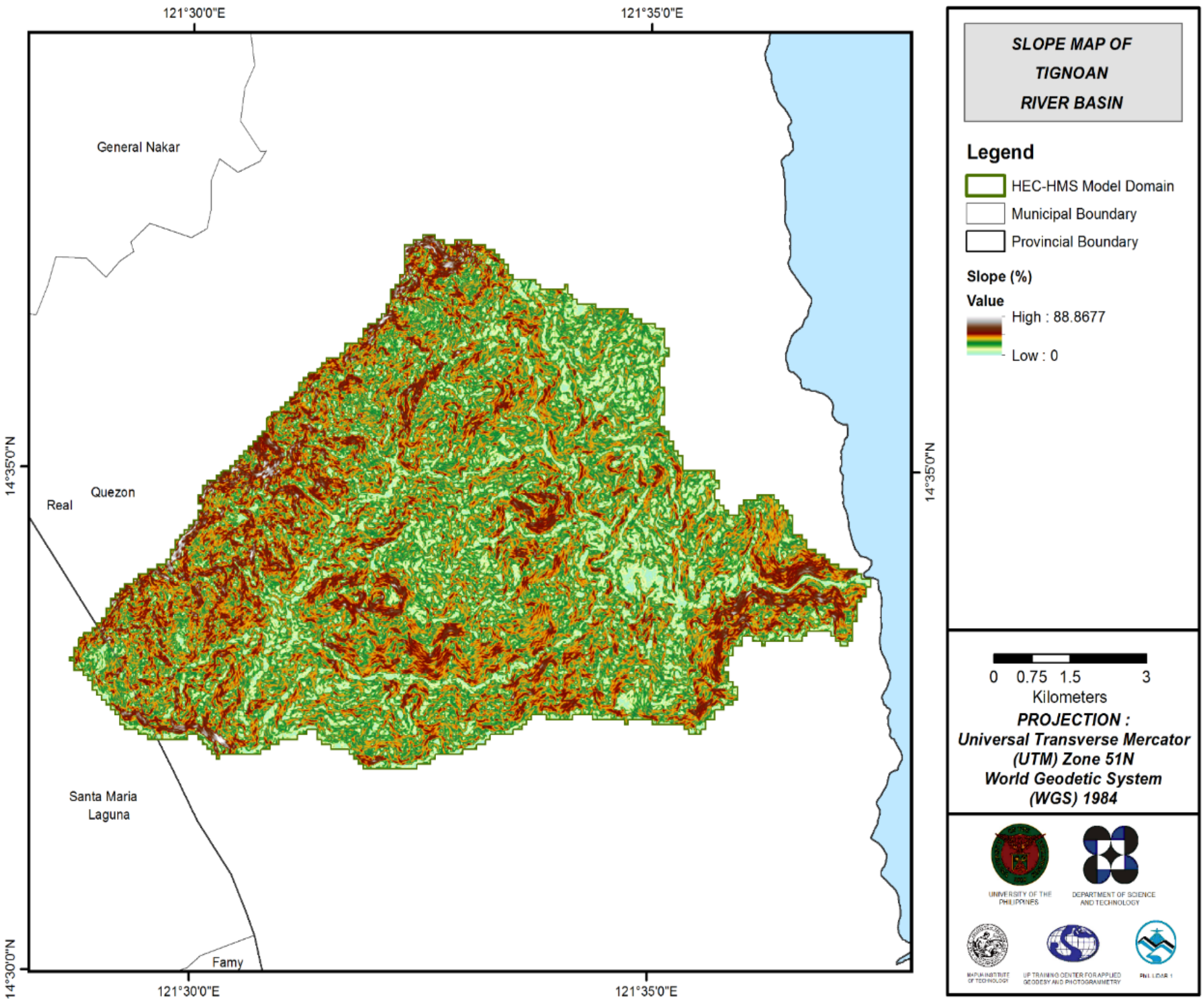


Figure 51. Slope map of Tignoan River Basin

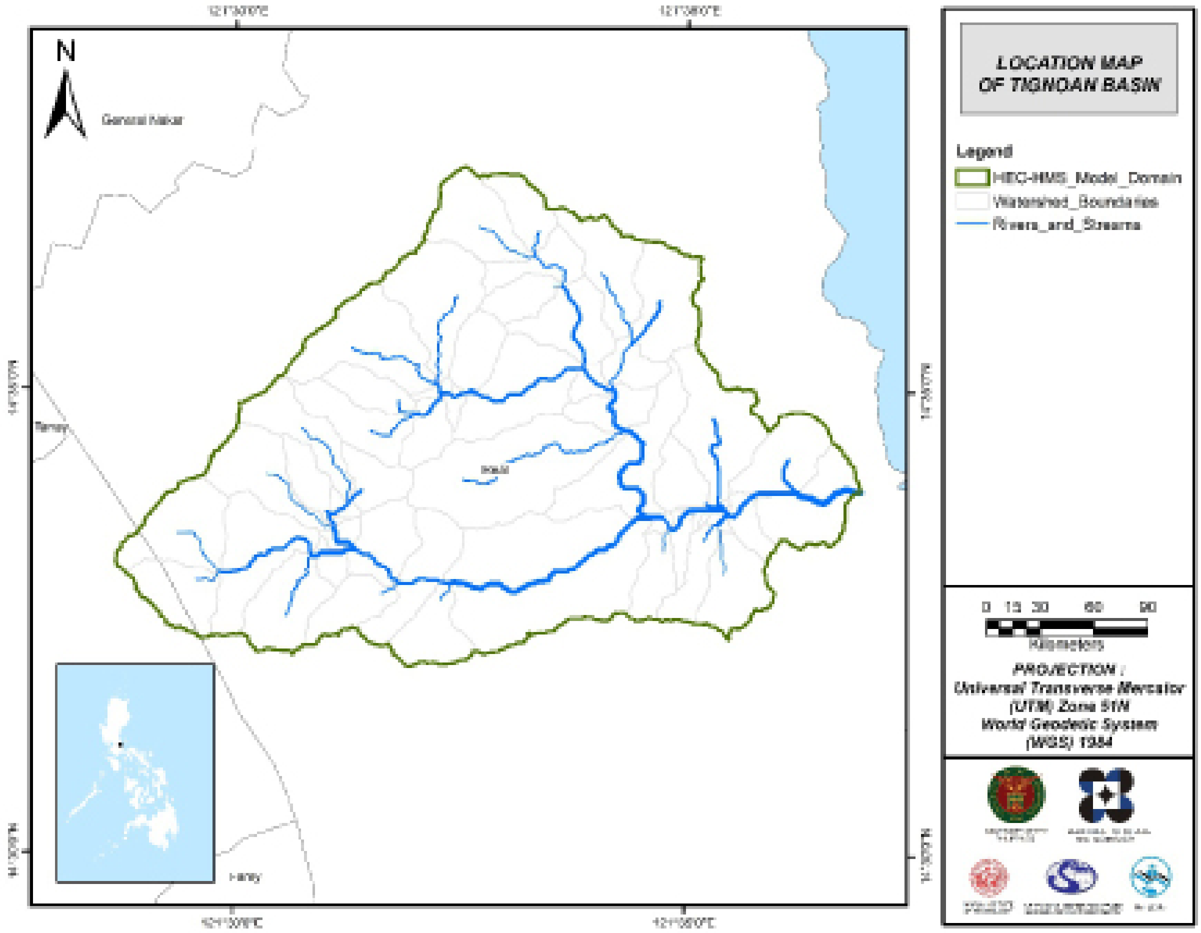


Figure 52. Stream delineation map of Tignoan River Basin

The Tignoan basin model consists of 51 subbasins, 25reaches, and 25 junctions. The main outlet is at the easternmost tip of the watershed. This basin model is illustrated in Figure 51. The basins were identified based on soil and land cover characteristics of the area. Precipitation was taken from DOST rain gauges. Finally, it was calibrated using data from the Tignoan Bridge.

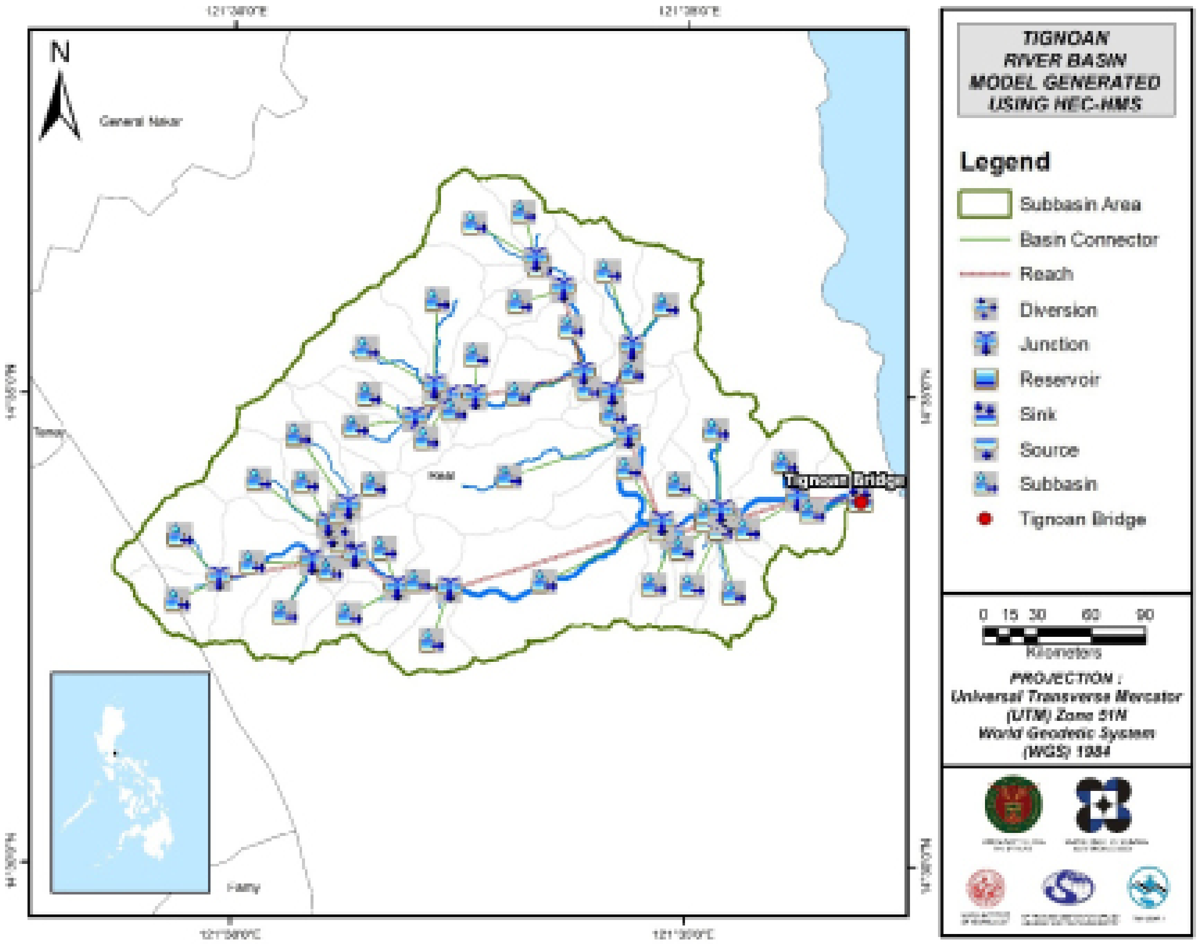


Figure 53. The Tignoan River Basin model generated using HEC-HMS

5.4 Cross-section Data

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

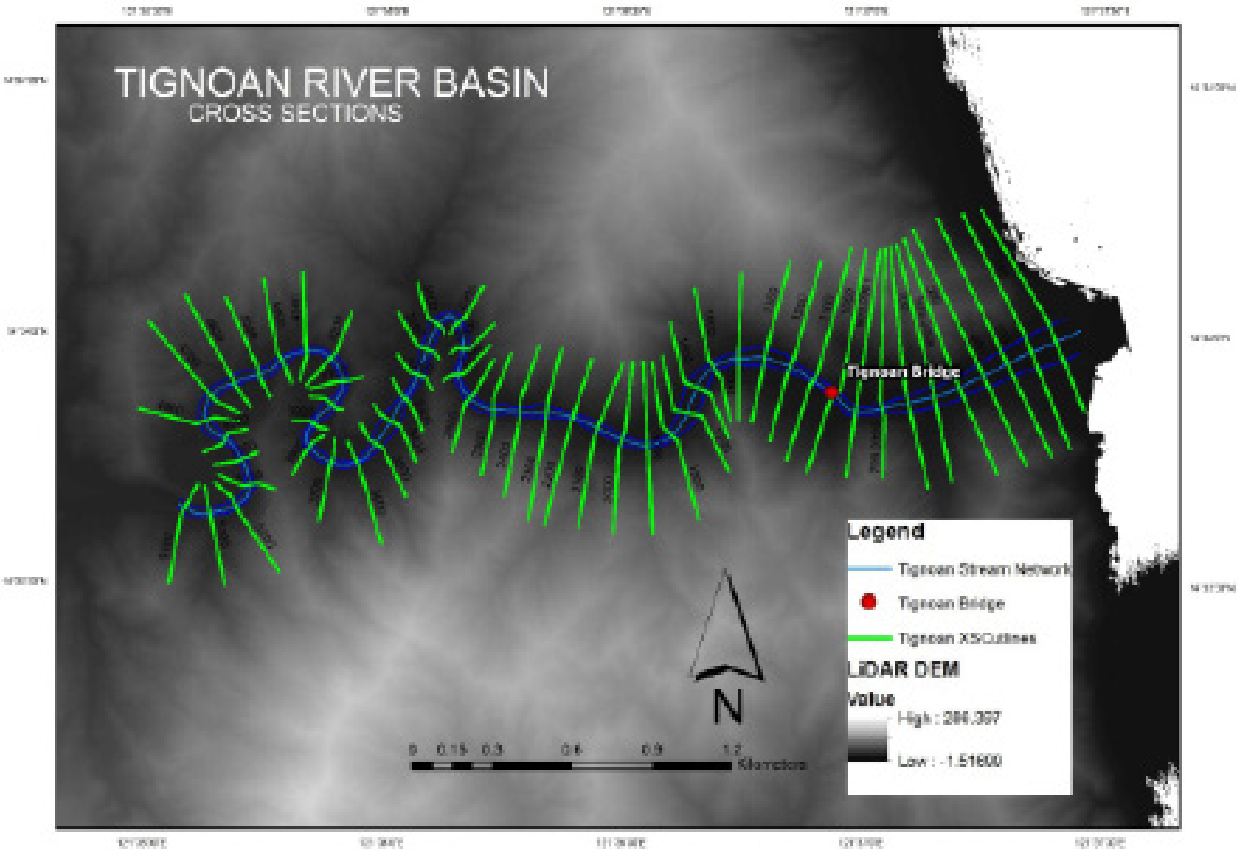


Figure 54. River cross-section of Tignoan River generated through Arcmap HEC GeoRAS tool

5.4.1 Manning's n

Manning's n is a constant value that depends on the nature of the channel and its surface. Determining the roughness coefficient of the channel is important in determining the water flow. Appropriate selection of Manning's n values is based on the land cover type of the watershed area.

A look-up table was derived to have a standardized Manning's n value for the HEC-RAS model.

Table 26. Look-up table for Manning's n values (Source: Brunner, 2010)

Land-cover Class	Corresponding Manning's *n* Class	Manning's *n*
Barren Land	Cultivated areas, no crop	0.030
Built-up Area	Concrete, float finished	0.015
Cultivated land, annual crop	Cultivated areas, mature field crops	0.040
Cultivated land, perennial crop	Cultivated areas, mature row crops	0.035
Fishpond	Excavated, earth, straight and uniform	0.018
Inland Water	Main channel, clean, straight, no rifts or deep pools	0.030
Grassland	Pasture, no brush, short grass	0.030
Mangrove Forest	Trees, heavy stand, flow into branches	0.120
Shrub land	Medium to dense brush	0.100

5.5 Flo 2D Model

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

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

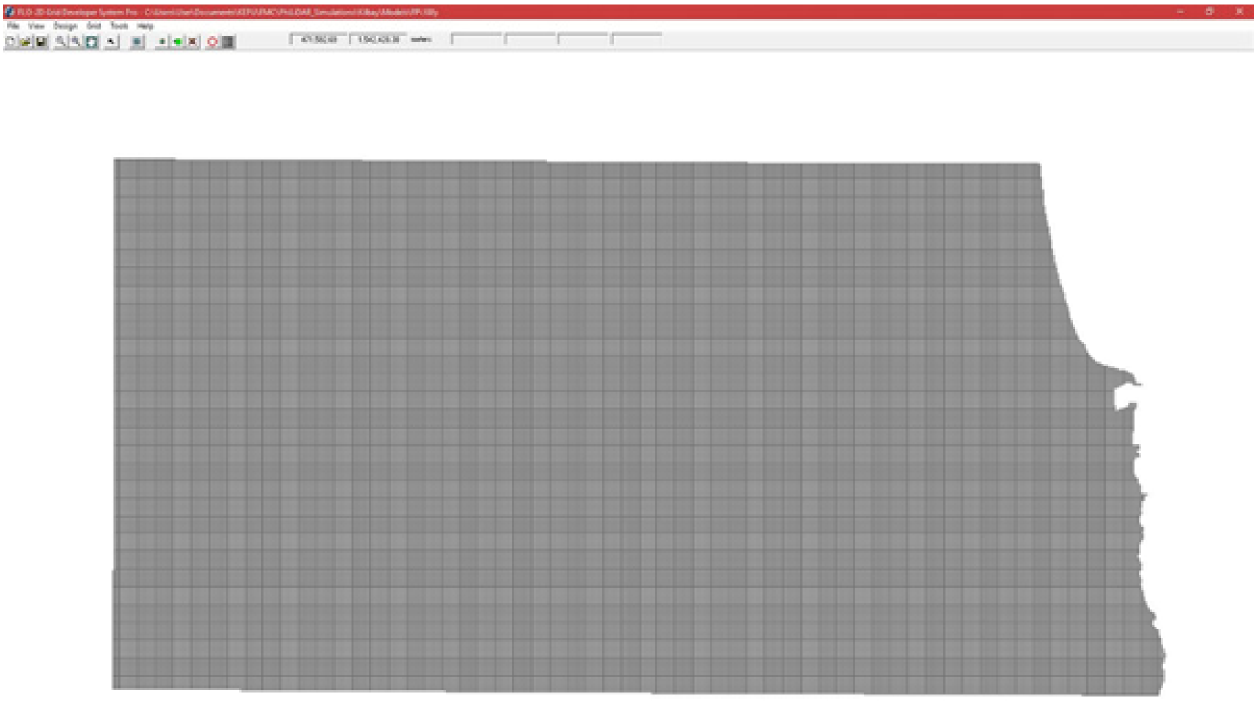


Figure 55.Screenshot of sub-catchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 79.43701 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

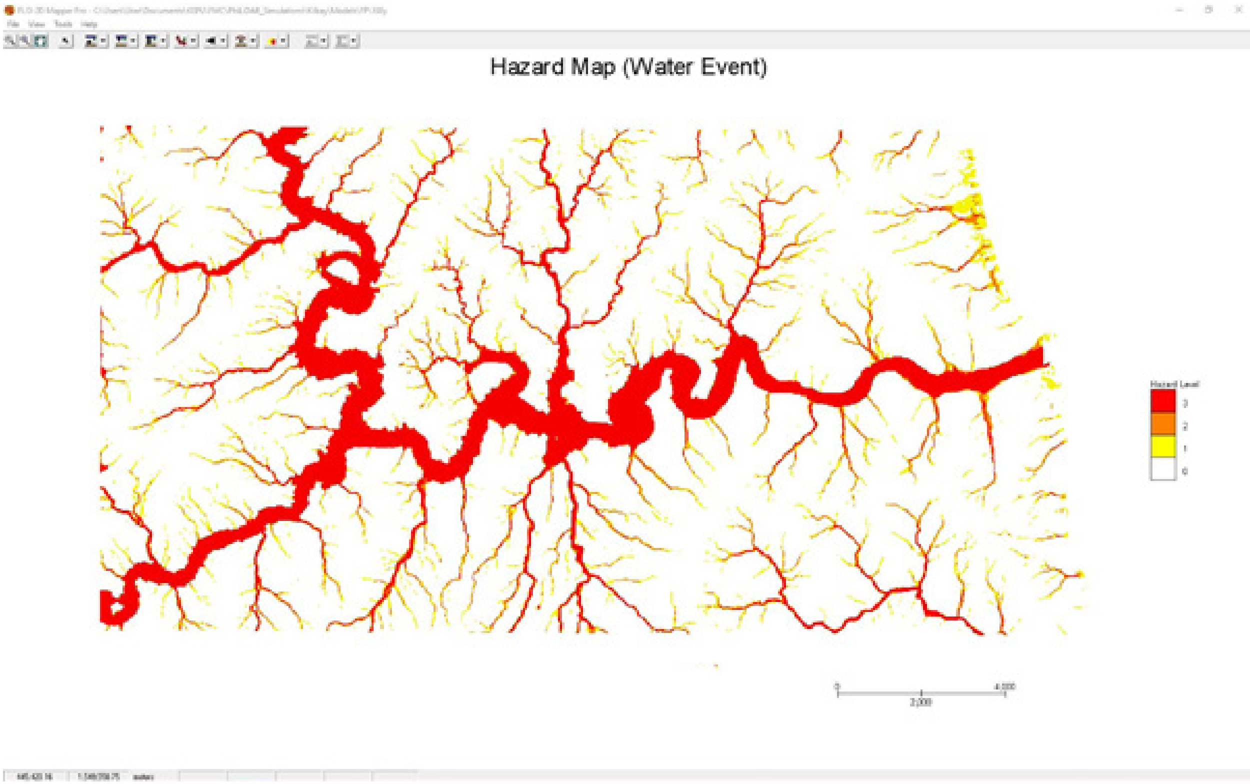


Figure 56. Generated 100-year rain return hazard map from FLO-2D Mapper

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 91488288.00 m2.

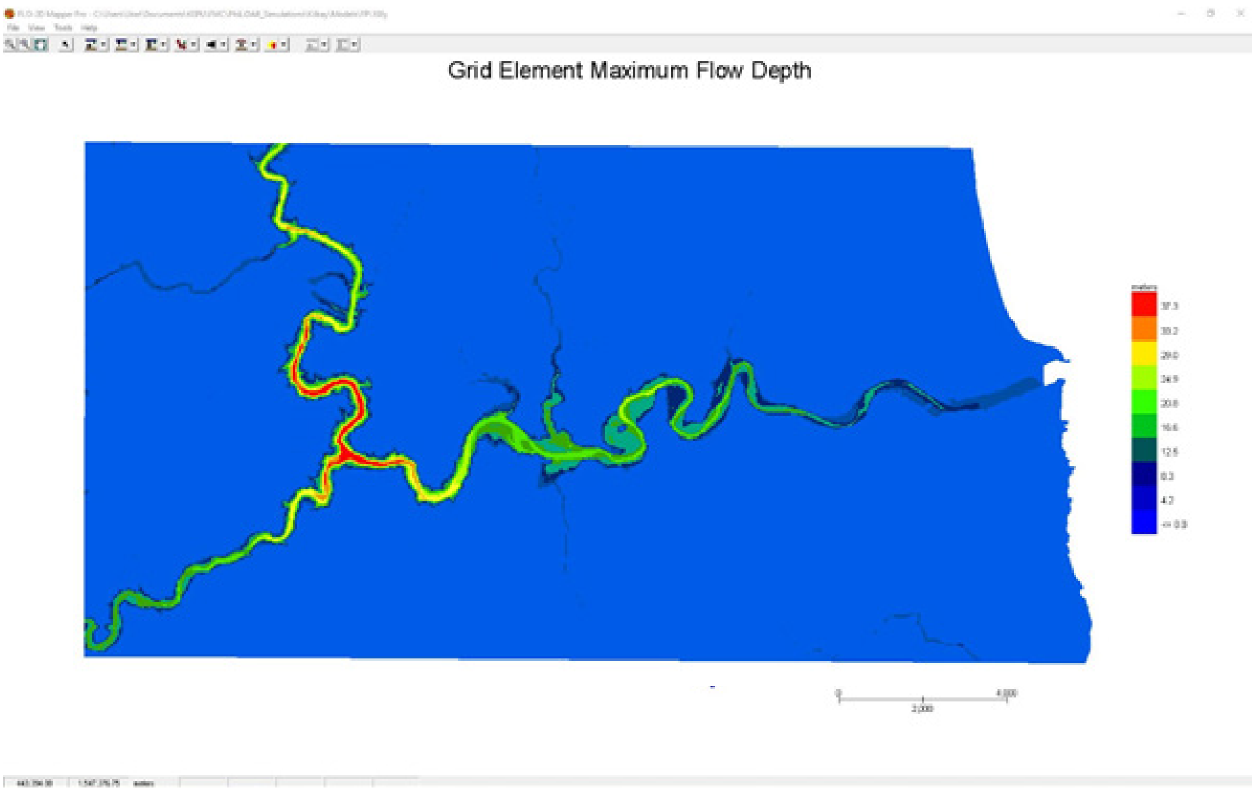


Figure 57. Generated 100-year rain return flow depth map from FLO-2D Mapper

There is a total of 51500173.31 m3 of water entering the model. Of this amount, 51500173.31 m3 is due to rainfall. 4795659.00 m3 of this water is lost to infiltration and interception, while 2908155.92 m3 is stored by the flood plain. The rest, amounting up to 43796402.36 m3, is outflow.

5.6 Results of HMS Calibration

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

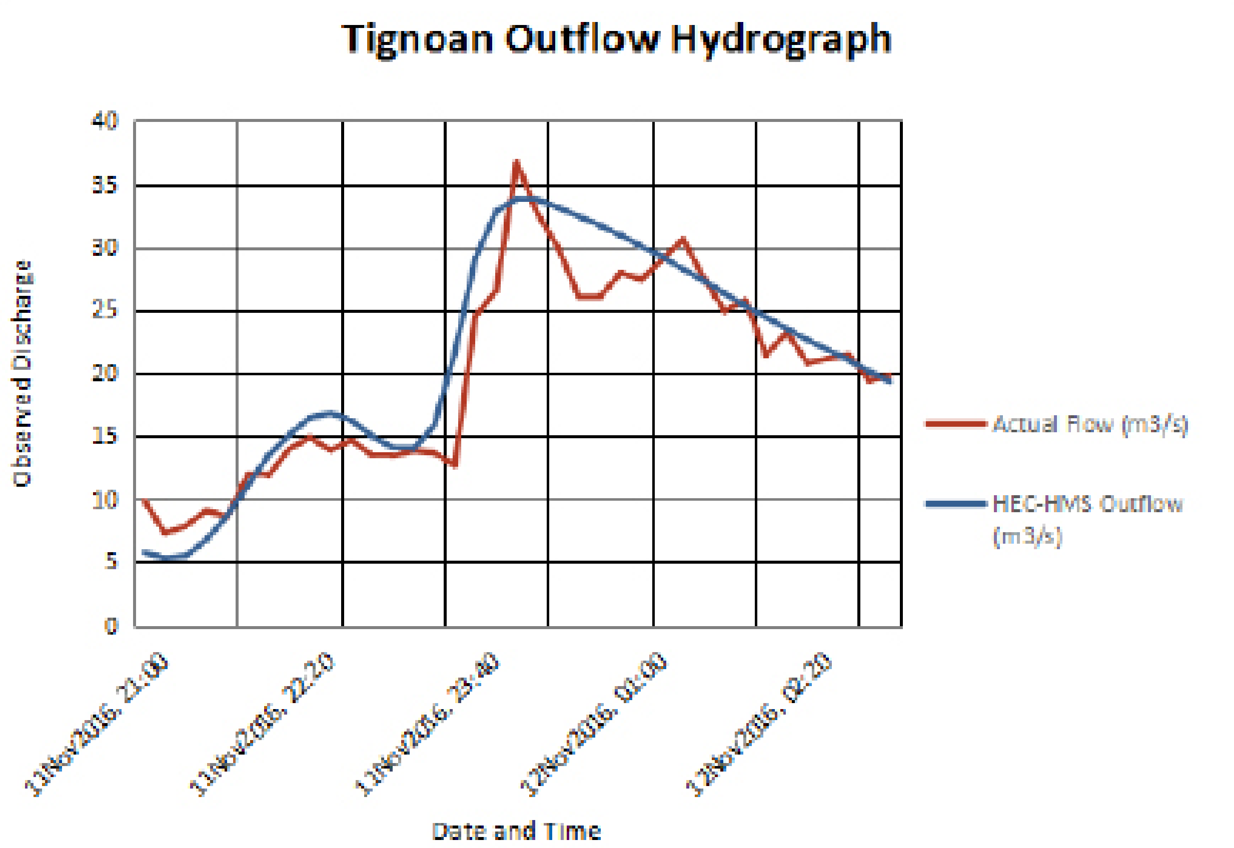


Figure 58. Outflow hydrograph of Tignoan produced by the HEC-HMS model compared with observed outflow

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 Tignoan Floodplain

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	2.18 – 44.19
			Curve Number	35.19 – 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.15 -3.38
			Storage Coefficient (hr)	0.57 – 5.26
	Baseflow	Recession	Recession Constant	0.013 – 1
			Ratio to Peak	0.35 - 1
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.04

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 2.18 mm to 44.19 mm means that there is minimal to considerable amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of values for the basin's curve number is from 35.19 to 99. For Tignoan, the soil classes identified were sandy clay and undifferentiated mountain soil. The land cover types identified were brushland, inland water, and open and closed canopy forest.

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 0.15 hours to 5.26 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. The recession constant ranges from 0.013 to 1 and the ratio to peak is from 0.35 to 1. The receding limb of the outflow hydrograph does not recede or return to its original discharge quickly.

Manning's roughness coefficient of 0.04 corresponds to the common roughness in Tignoan watershed.

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

Accuracy measure	Value
RMSE	2.97
r2	0.906
NSE	0.85
PBIAS	-5.71
RSR	0.38

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.97 (m3/s).

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. A value 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 0.906.

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 0.85.

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 -5.71.

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 0.38.

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 59) shows the Tignoan outflow using the Infanta RIDF curves in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the PAGASA data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

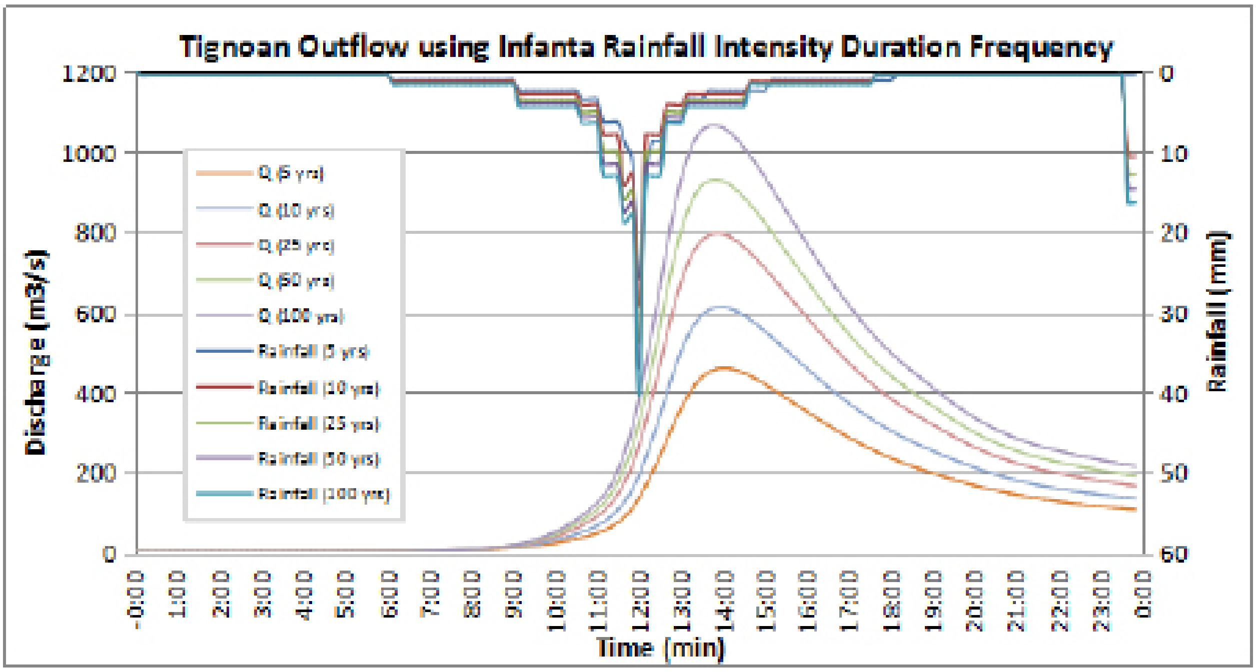


Figure 59. Outflow hydrograph at Tignoan Station generated using Infanta RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, and time to peak of the Tignoan discharge using the Infanta RIDF curves in five different return periods is shown in Table 29.

Table 29. Peak values of the Tignoan HEC-HMS Model outflow using the Infanta RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	249.6	25.70	487.4	14 hours, 0 minutes
10-Year	287.1	29.20	614.5	14 hours, 0 minutes
25-Year	334.4	33.70	762.3	13 hours, 50 minutes
50-Year	369.6	37.00	867.4	13 hours, 50 minutes
100-Year	404.4	40.30	972.2	13 hours, 50 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS flood model produced a simulated water level at every cross-section for every time step for every flood simulation created.

The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample generated map of Tignoan River using the calibrated HMS event flow with 25-year rain return scenario is shown in Figure 60.

Figure 60. Sample output of Tignoan RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10 m resolution. Figure 61 to Figure 66 show the 100-, 25-, and 5-year rain return scenarios of the Tignoan Floodplain.

Table 30. Municipalities affected in Tignoan Floodplain

Municipality	Total Area	Area Flooded	% Flooded
Real	350.69	27.79	7.92%

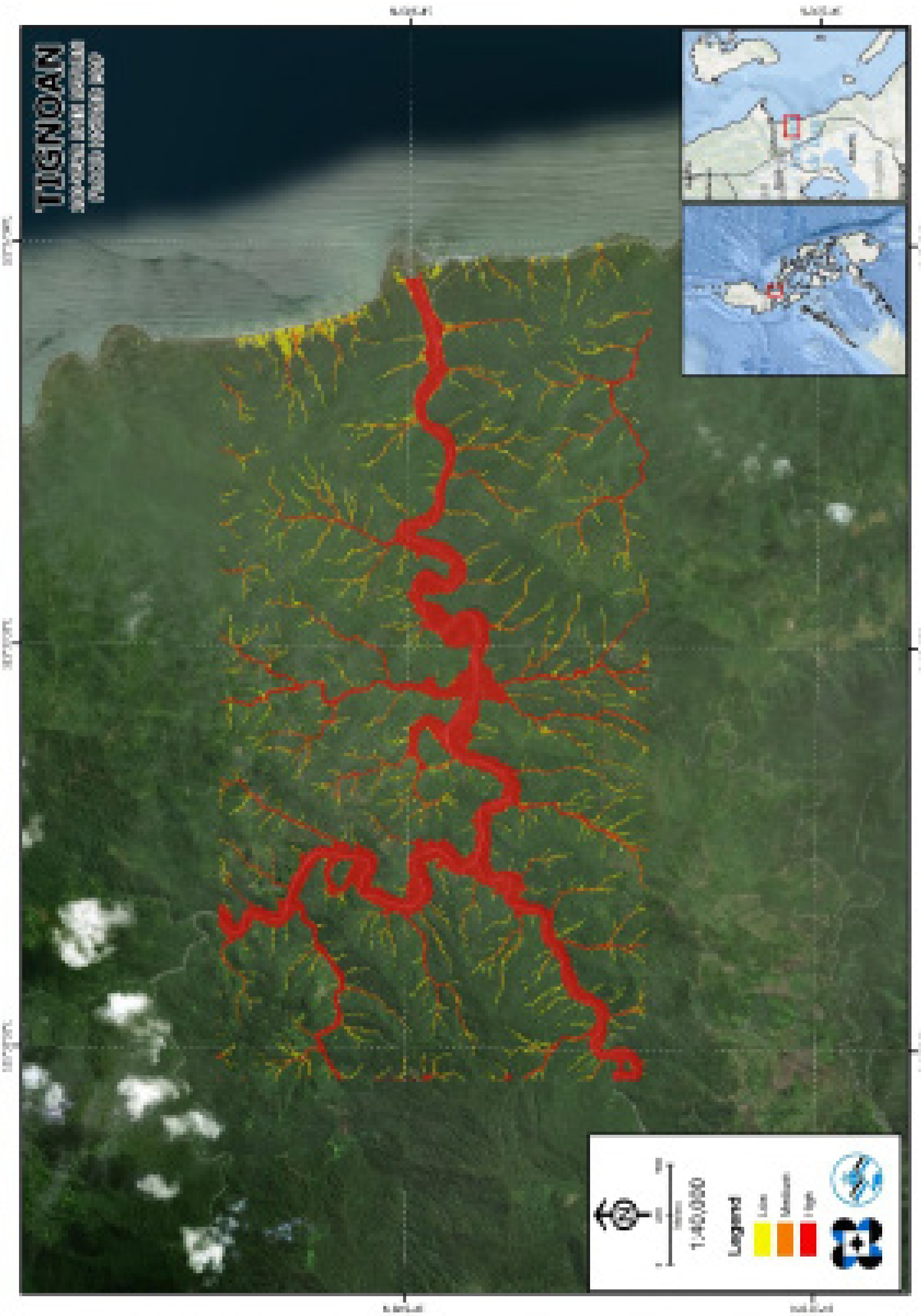


Figure 61 .100-year flood hazard map for Tignoan Floodplain

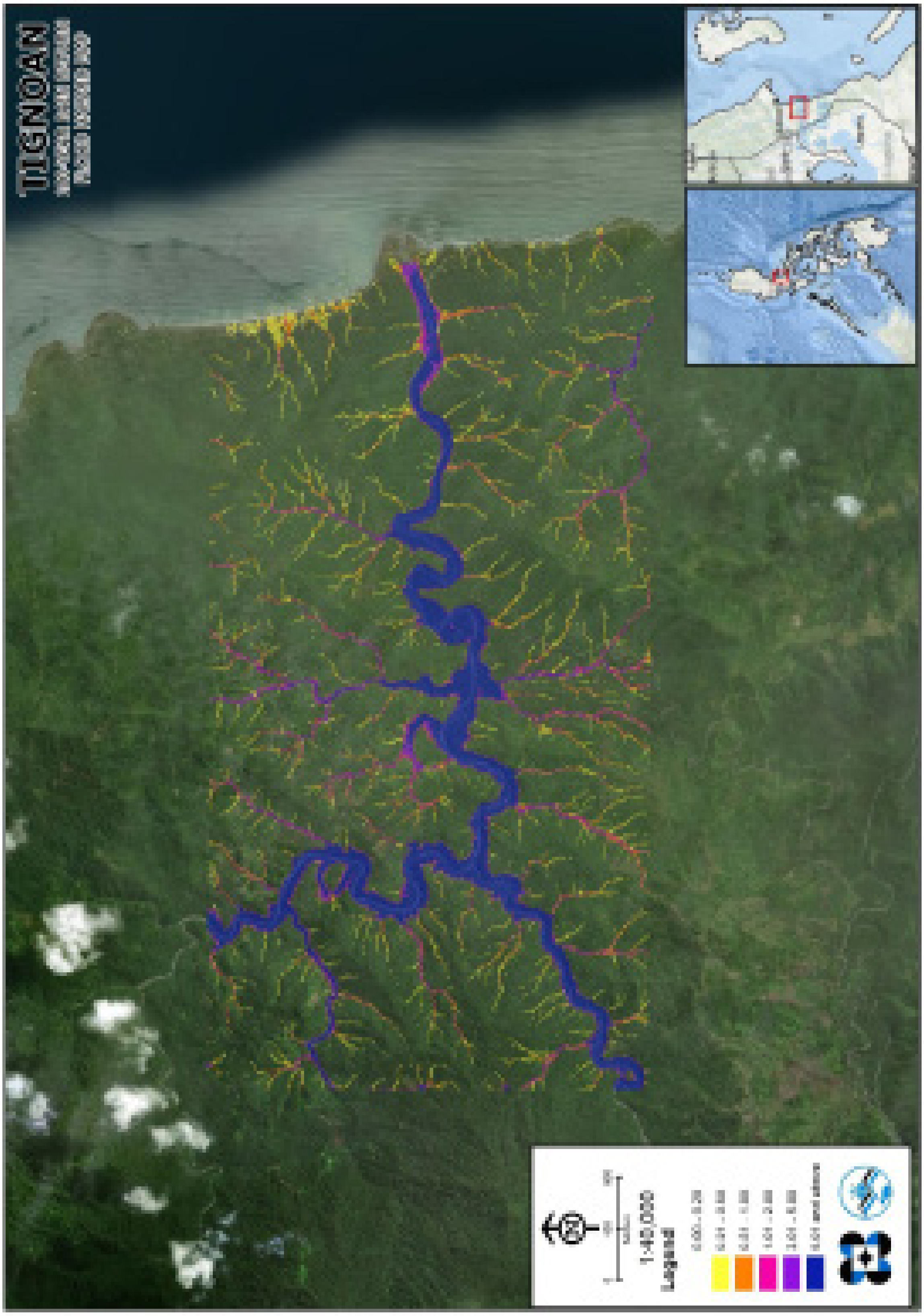


Figure 62. 100-year flow depth map for Tignoan Floodplain

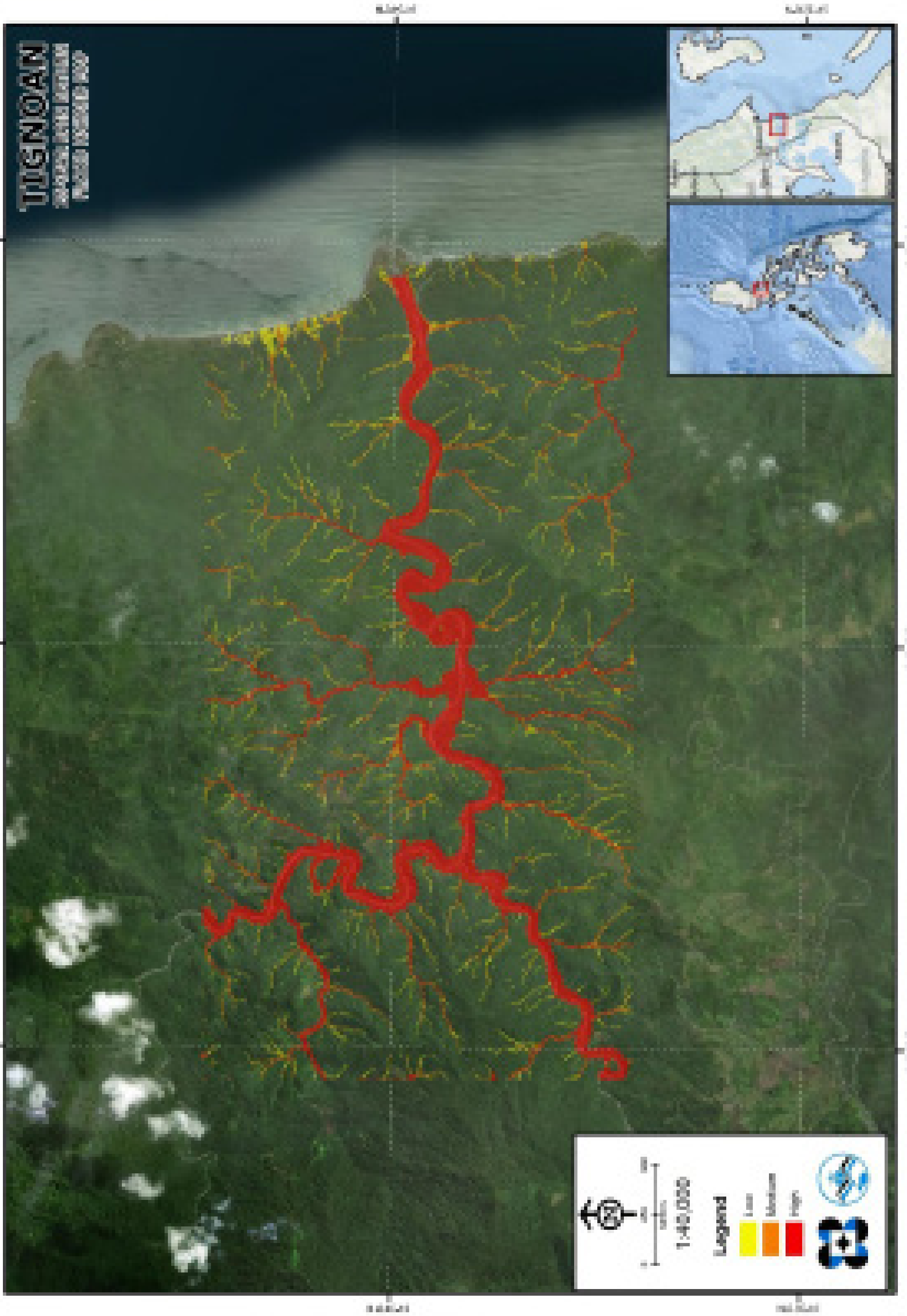


Figure 63. 25-year flood hazard map for Tignoan Floodplain

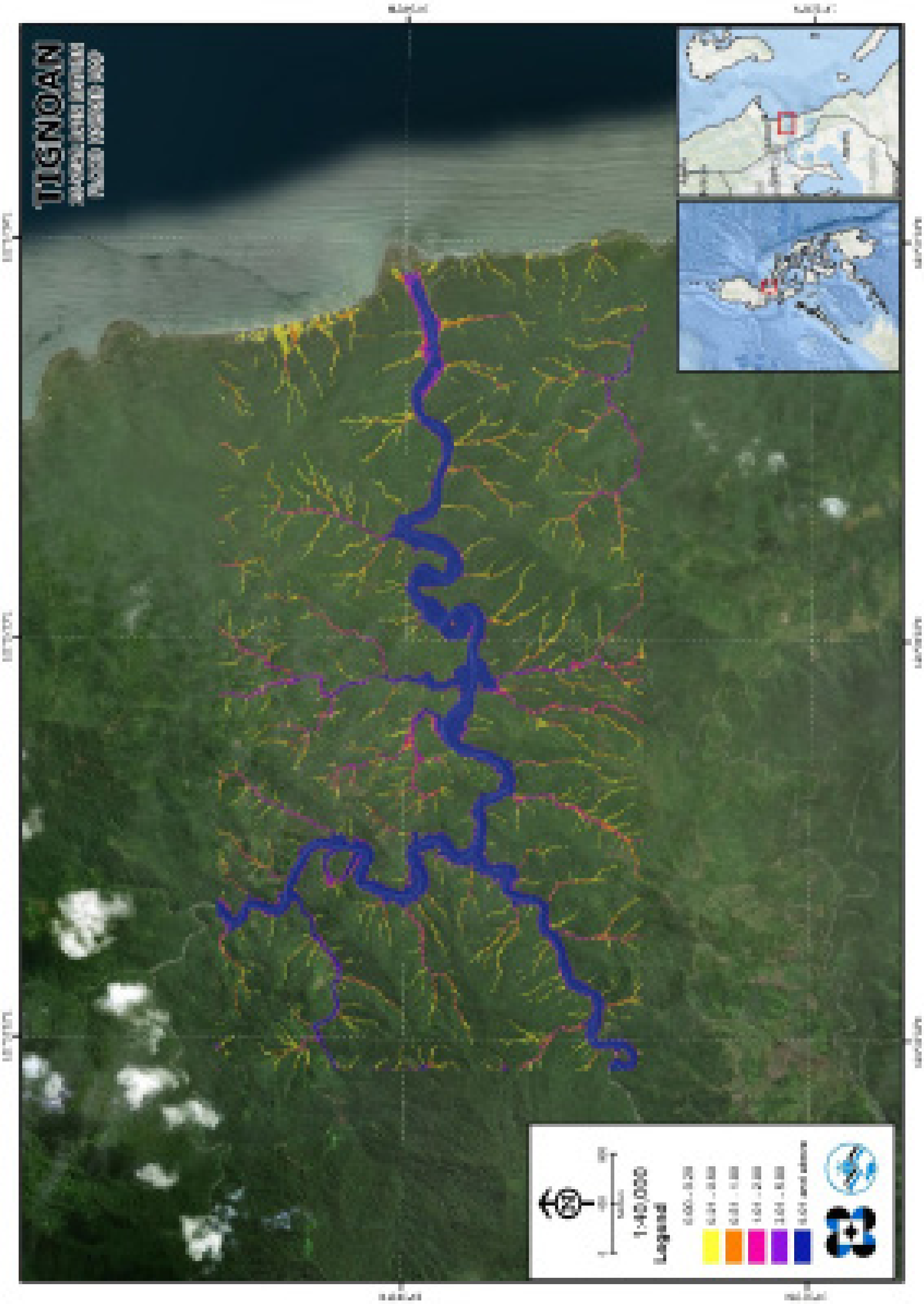


Figure 64. 25-year flow depth map for Tignoan Floodplain

Figure 65. 5-year flood hazard map for Tignoan Floodplain

Figure 66. 5-year flood depth map for Tignoan Floodplain

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Tignoan River Basin, grouped accordingly by municipality. For the said basin, one (1) municipality consisting of 4 barangay is expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 7.06% of the municipality of Real with an area of 350.69 sq km will experience flood levels of less than 0.20 meters; 0.21% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.10%, 0.08%, 0.11%, and 0.36% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 31 are the affected areas in square kilometers by flood depth per barangay.

Table 31. Affected areas in Real, Quezon during a 5-Year Rainfall Return period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Luna (in sq. km.)			
	Malapad	Tagumpay	Tanauan	Tignoan
0.03-0.20	5.58	4.54	9.8	4.85
0.21-0.50	0.16	0.11	0.3	0.15
0.51-1.00	0.066	0.066	0.18	0.045
1.01-2.00	0.048	0.052	0.15	0.036
2.01-5.00	0.099	0.081	0.17	0.043
> 5.00	0.18	0.12	0.77	0.19

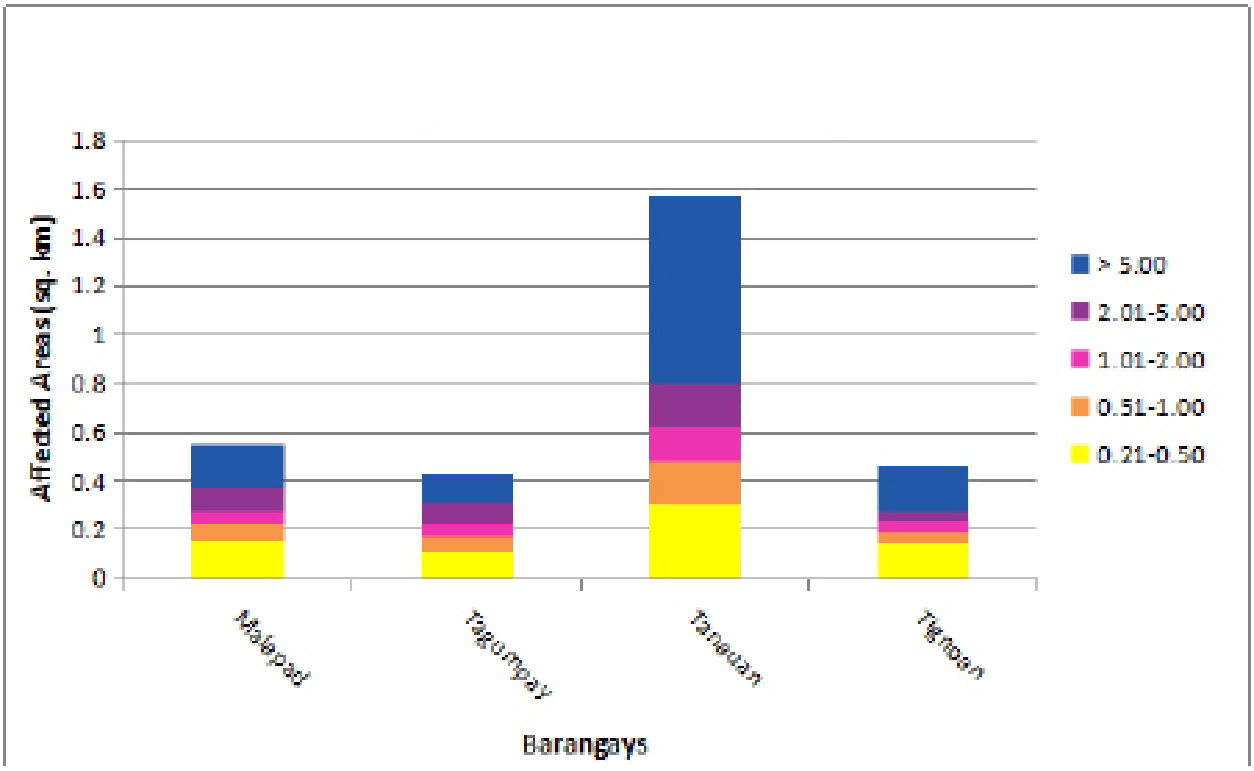


Figure 67. Affected areas in Real, Quezon during a 5-year rainfall return period

For the 25-year return period, 6.74% of the municipality of Real with an area of 350.69 sq km will experience flood levels of less than 0.20 meters; 0.30% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.14%, 0.10%, 0.14%, and 0.50% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 32 are the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected areas in Real, Quezon during a 25-Year rainfall return period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tignoan (in sq. km.)			
	Malapad	Tagumpay	Tanauan	Tignoan
0.03-0.20	5.4	4.34	9.24	4.66
0.21-0.50	0.22	0.17	0.4	0.25
0.51-1.00	0.11	0.082	0.22	0.078
1.01-2.00	0.065	0.068	0.19	0.04
2.01-5.00	0.097	0.11	0.24	0.061
> 5.00	0.24	0.2	1.09	0.23

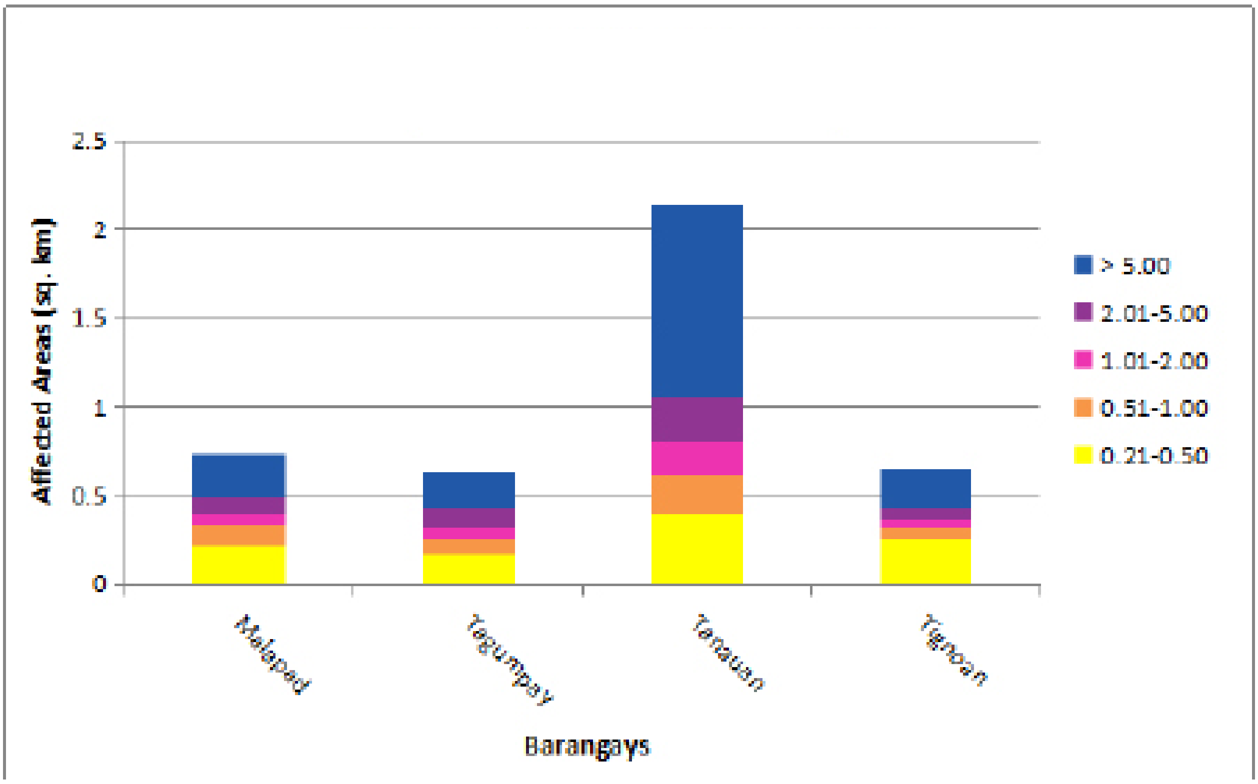


Figure 68.Affected areas in Real, Quezon during a 25-year rainfall return period

For the 100-year return period, 6.58% of the municipality of Real with an area of 350.69 sq km will experience flood levels of less than 0.20 meters; 0.33% of the area will experience flood levels of 0.21 to 0.50 meters; while 0.15%, 0.12%, 0.16%, and 0.58% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 33 are the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected areas in Real, Quezon during a 100-year rainfall return period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Tignoan (in sq. km.)			
	Malapad	Tagumpay	Tanauan	Tignoan
0.03-0.20	5.33	4.25	8.92	4.58
0.21-0.50	0.25	0.19	0.44	0.29
0.51-1.00	0.12	0.086	0.23	0.096
1.01-2.00	0.077	0.079	0.21	0.044
2.01-5.00	0.1	0.12	0.28	0.067
> 5.00	0.24	0.26	1.3	0.23

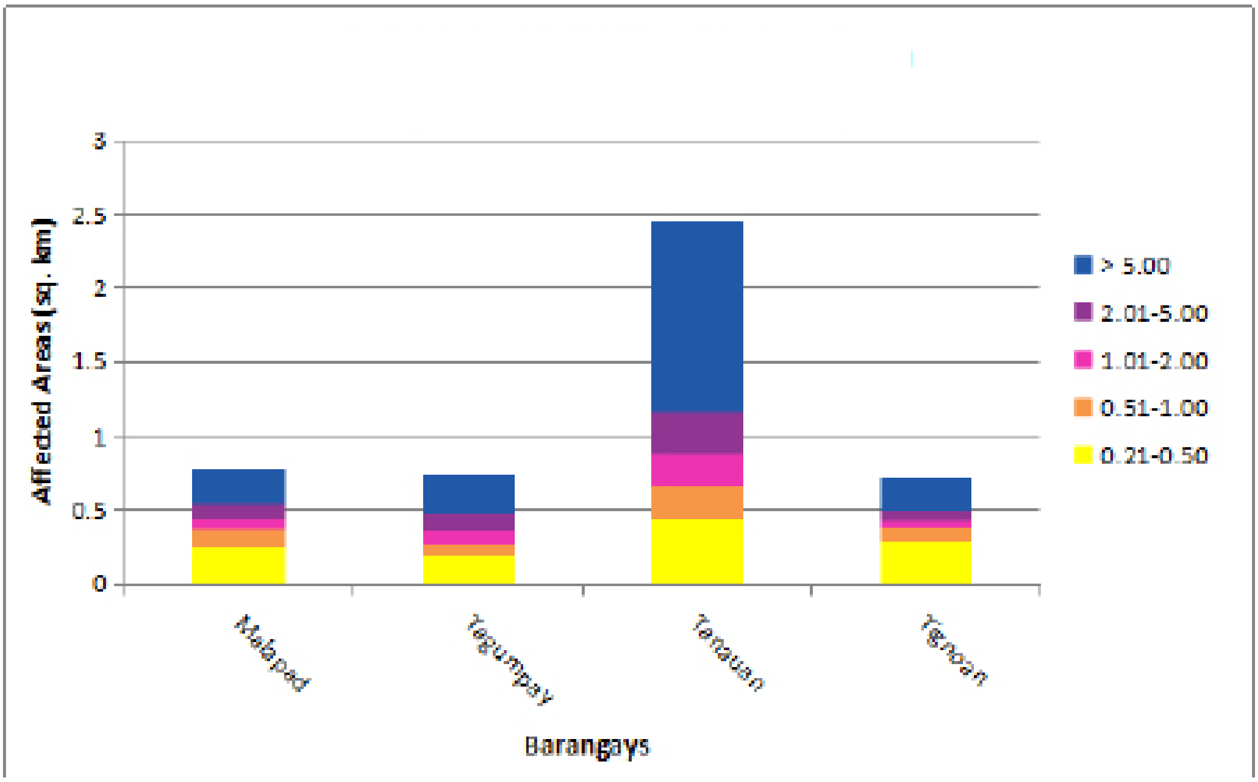


Figure 69. Affected areas in Real, Quezon during a 100-year rainfall return period

Moreover, the generated flood hazard maps for the Tignoan Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAGASA for hazard maps ("Low," "Medium," and "High"), the affected institutions were given their individual assessment for each flood hazard scenario (5-year, 25-year, and 10-year).

Table 34. 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	0.67	0.93	1.033
Medium	0.47	0.65	0.73
High	1.92	2.62	3.0084
TOTAL	**3.064**	**4.21**	**4.77**

Of the three identified educational institutions in Tignoan Floodplain, one school was discovered exposed to medium-level flooding during the 5- and 25-year scenarios.

For the 100-year scenario, the same school, Tignoan Elementary School in Barangay Malapad, Real, Quezon, was discovered exposed to high-level flooding. The complete details are found in ANNEX 12.

Apart from this, two health institutions were identified in the Tignoan Floodplain, yet only one (1) was discovered exposed to High-level flooding in all three scenarios: the Health Center in Brgy. Malapad, Real, Quezon. The complete details are found in ANNEX 13.

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 by going to a local DRRM office to obtain maps or situation reports about the past flooding events or by interviewing 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 180 points randomly selected all over the Tignoan Floodplain. It has an RMSE value of 2.929.

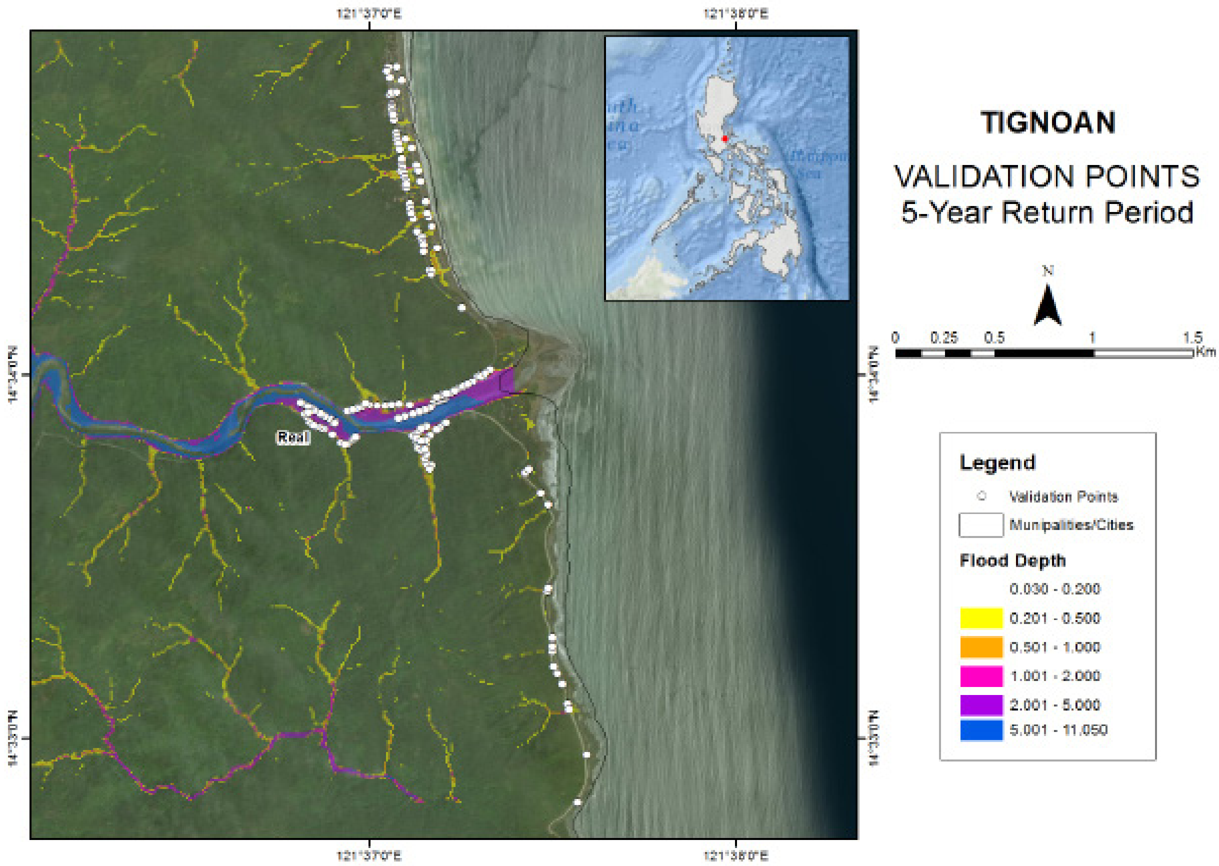


Figure 70. Flood validation points of Tignoan River Basin

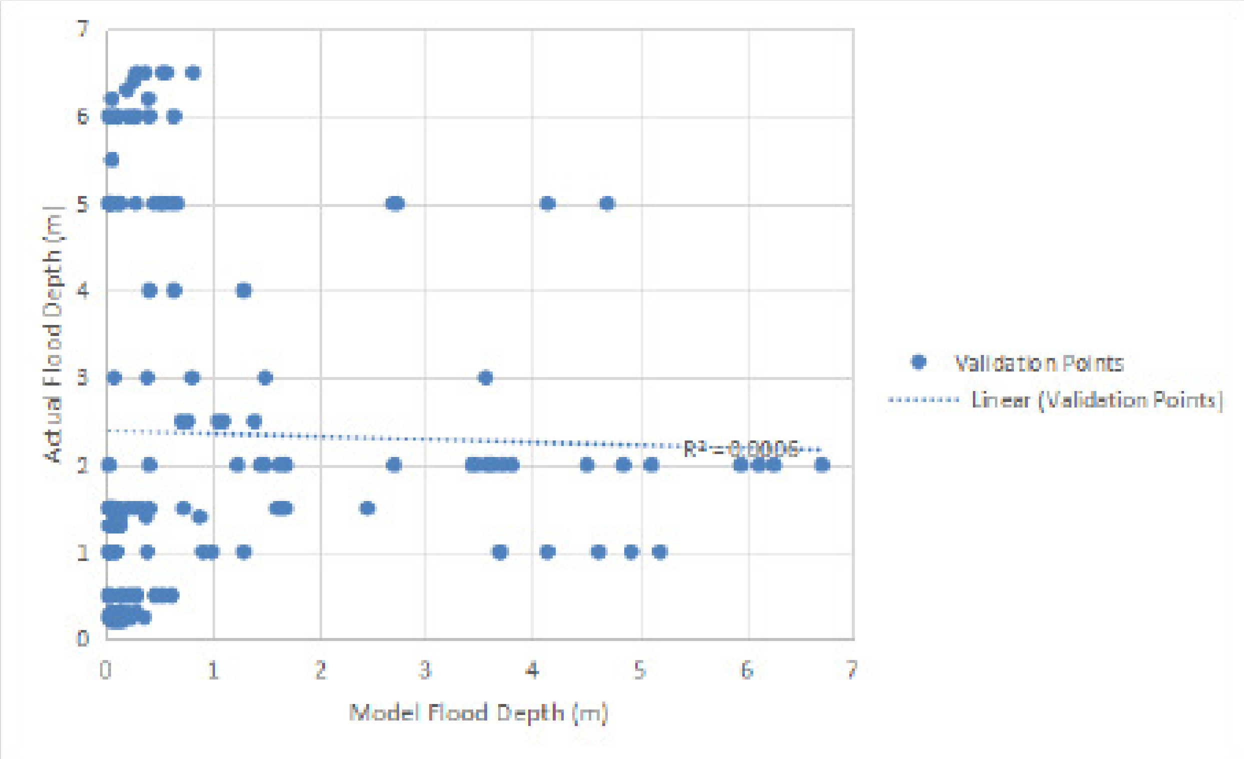


Figure 71. Flood map depth vs. actual flood depth

Table 35. Actual flood depth vs. simulated flood depth in Tignoan

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	6	0	0	0	0	0	6
0.21-0.50	25	12	2	0	0	0	39
0.51-1.00	9	1	2	1	5	1	19
1.01-2.00	23	6	2	10	11	5	57
2.01-5.00	13	4	10	5	5	0	37
> 5.00	10	8	4	0	0	0	22
Total	86	31	20	16	21	6	180

The overall accuracy generated by the flood model is estimated at 19.44% with 35 points correctly matching the actual flood depths. In addition, there were 46 points estimated one level above and below the correct flood depths while there were 35 points and 63 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 120 points were underestimated in the modeled flood depths of Tignoan.

Table 36. Summary of accuracy assessment in the Tignoan River Basin survey

	No. of Points	%
Correct	35	19.44
Overestimated	25	13.89
Underestimated	120	66.67
Total	180	100.00

REFERENCES

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

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

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

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

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

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

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

ANNEXES

Annex 1. Optech Technical Specification of the Pegasus Sensor

Table A-1.1. Parameters and Specification of Pegasus Sensor

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

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

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

1. RZL-28

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

June 14, 2016

CERTIFICATION

To whom it may concern:

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

Province: **RIZAL**
Station Name: **RZL-28**
Order: **2nd**

Island: **Luzon** Municipality: **TANAY**	Barangay: **SAN ISIDRO (POB.)** MSL Elevation:		
	PRS92 Coordinates		
Latitude: **14° 29' 49.44078"**	Longitude: **121° 16' 32.56146"**	Ellipsoidal Hgt:	**5.86600 m.**
	WGS84 Coordinates		
Latitude: **14° 29' 44.06939"**	Longitude: **121° 16' 37.46276"**	Ellipsoidal Hgt:	**50.37100 m.**
	PTM / PRS92 Coordinates		
Northing: **1603180.963 m.**	Easting: **529720.085 m.**	Zone:	**3**
	UTM / PRS92 Coordinates		
Northing: **1,603,302.05**	Easting: **314,172.78**	Zone:	**51**

Location Description

The station is located near at the light house beside fish port and approximately 300 m going to Pang-alaalng Paaralang Elementarya ng Patricio Jarin,

Mark is the head of a 4" copper nail centered and set on top of a 30 cm. x 30 cm. cement putty, with inscription "RZL-28, 2004, NAMRIA".

Requesting Party: **UP Lidar 1**
Purpose: **Reference**
OR Number: **8094772**
T.N.: **2016-1261**

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

9906142016162838

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

CIP/47C1/12/09/814

Figure A-2.1. RZL-28

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

Table A-3.1 BRS-1

BRS-1 - RZL-28 (9:25:08 AM-5:15:34 PM) (S1)	
Baseline observation:	BRS-1 --- RZL-28 (B1)
Processed:	6/23/2016 11:42:55 AM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.004 m
Vertical precision:	0.018 m
RMS:	0.006 m
Maximum PDOP:	4.149
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	6/10/2016 9:25:08 AM (Local: UTC+8hr)
Processing stop time:	6/10/2016 5:15:34 PM (Local: UTC+8hr)
Processing duration:	07:50:26
Processing interval:	1 second

From:	RZL-28				
Grid		Local		Global	
Easting	314172.786 m	Latitude	N14°29'49.44078"	Latitude	N14°29'44.06939"
Northing	1603302.052 m	Longitude	E121°16'32.56145"	Longitude	E121°16'37.46276"
Elevation	4.971 m	Height	5.866 m	Height	50.371 m

To:	BRS-1				
Grid		Local		Global	
Easting	312646.981 m	Latitude	N14°31'32.82507"	Latitude	N14°31'27.44582"
Northing	1606491.077 m	Longitude	E121°15'40.79958"	Longitude	E121°15'45.69850"
Elevation	14.362 m	Height	15.361 m	Height	59.750 m

Vector					
ΔEasting	-1525.805 m	NS Fwd Azimuth	333°59'56"	ΔX	1733.279 m
ΔNorthing	3189.025 m	Ellipsoid Dist.	3535.137 m	ΔY	131.879 m
ΔElevation	9.391 m	ΔHeight	9.496 m	ΔZ	3078.254 m

Annex 4. The LIDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D. Eng.	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader - I	ENGR. LOUIE P. BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUNA	UP-TCAGP
		ENGR. GEROME HIPOLITO	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	AUBREY MATIRA	UP TCAGP
	Research Associate (RA)	ENGR. GRACE SINADJAN	UP TCAGP
	RA	JASMIN DOMINGO	UP TCAGP
Ground Survey, Data Download and Transfer	RA	KRISTINE JOY ANDAYA	UP TCAGP
LiDAR Operation	Airborne Security	FRANK NICOLAS ILEJAY	UP TCAGP
	Pilot	TSG. CEBU	PHILIPPINE AIR FORCE (PAF)
		CAPT. MARK TANGONAN	ASIAN AEROSPACE CORP (AAC)
		CAPT. CAESAR ALFONSO II	AAC
		CAPT. DANTHONY LOGRONIO	AAC
		CAPT. CEDRIC DE ASIS	AAC

Annex 5. Data Transfer Sheet for Tignoan Floodplain

DATA TRANSFER SHEET
CALABARZON 7/13/2016

DATE	FLIGHT NO.	MISSION NAME	SENSOR	KML (swath)	Gnssimu	LogFiles	TestData	RawLaser	RawTDC	RawWFD	WebCam	RCD30 RAW IMAGES	BASE STATION(S): BASE STATION(S)	BASE STATION(S): Base Info (.txt)	SERVER LOCATION
13-Jun-16	10161L	4BLK18CF 165A	ALS 80	NA	352	134	79.7	4.65	3.89	NA	145	22	649	1KB	Z:\DAC\RAW DATA
13-Jun-16	10162L	4BLK18CF S165B	ALS 80	NA	353	96.5	21.5	8.99	7.55	NA	262	39.5	649	1KB	Z:\DAC\RAW DATA
15-Jun-16	10165L	4BLK18RN 167A	ALS 80	NA	472	130	43.8	12.7	7.2	NA	285	26.7	653	1KB	Z:\DAC\RAW DATA
15-Jun-16	10166L	4BLK18CF 167B	ALS 80	NA	251	102	124	3.42	2.66	NA	79.3	NA	653	1KB	Z:\DAC\RAW DATA
16-Jun-16	10167L	4BLK18R MNS168A	ALS 80	NA	454	134	44	13.8	8.88	NA	320	36.9	316	1KB	Z:\DAC\RAW DATA

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS: Output LAS	RAW LAS: KML (swath)	LOGS	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S): BASE STATION(S)	BASE STATION(S): Base Info (.txt)	OPERATOR LOGS (OPLOG)	FLIGHT PLAN: Actual	FLIGHT PLAN: KML	SERVER LOCATION
June 16, 2016	23462P	1BLK18CF S168A	PEGASUS	2.76	NA	10.4	225	NA	NA	25.7	NA	316	1KB	1KB	359/364/268/464/201/203	NA	Z:\DAC\RAW DATA
June 22, 2016	23474P	1BLK18Q1 73A	PEGASUS	1.22	NA	8.87	200	NA	NA	12.7	NA	468	1KB	1KB	268/464/201/203	NA	Z:\DAC\RAW DATA

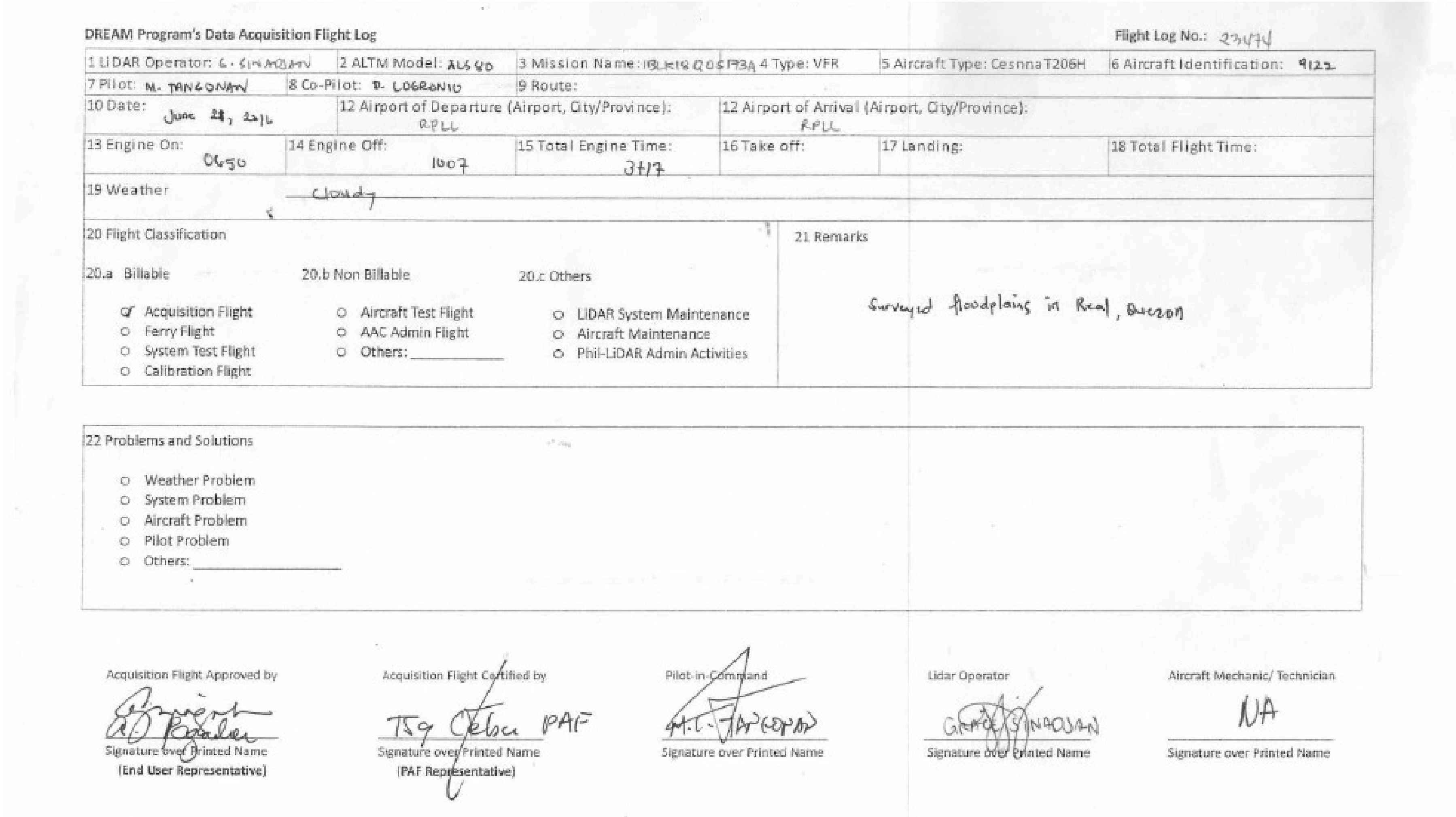
Received from
Name R. PUNTO
Position RA
Signature

Received by
Name AC Borja T
Position SSRS
Signature 7/14/16

Figure A-5.1. Data Transfer Sheet for Tignoan Floodplain

Annex 6. Flight Logs for the Flight Missions

Flight Log for 23474P



DREAM Program's Data Acquisition Flight Log

Flight Log No.: 23474

1 LiDAR Operator: G. SINADJAN	2 ALTM Model: ALS 80	3 Mission Name: 1BLK18QOS173A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: M. TANGONAN	8 Co-Pilot: D. LOGRONIO	9 Route:			
10 Date: June 21, 2016	12 Airport of Departure (Airport, City/Province): RPLL		12 Airport of Arrival (Airport, City/Province): RPLL		
13 Engine On: 0650	14 Engine Off: 1007	15 Total Engine Time: 3+17	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Cloudy					

20 Flight Classification

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

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

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

21 Remarks

Surveyed floodplains in Real, Quezon

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator	Aircraft Mechanic/ Technician
A.D. Bagalee	TSg Celsu PAF	M.C. TANGONAN	G. SINADJAN	NA
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 23474P

Annex 7. Flight Status Reports

CALABARZON
(June 22, 2016)

Table A-7.1. Flight Status Report

FLIGHT NO.	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
23474P	BLK18Q	1BLK18Q173A	G. SINADJAN J. DOMINGO	22 June 2016	Covered 14 lines over Real, Quezon

SWATH PER FLIGHT MISSION

FLIGHT NO.: 2842P
AREA: BLK2B
MISSION NAME: 1BLK2B316A
ALT: 850 m SCAN FREQ: 30 SCAN ANGLE: 25
SURVEYED AREA: 136.73 km2

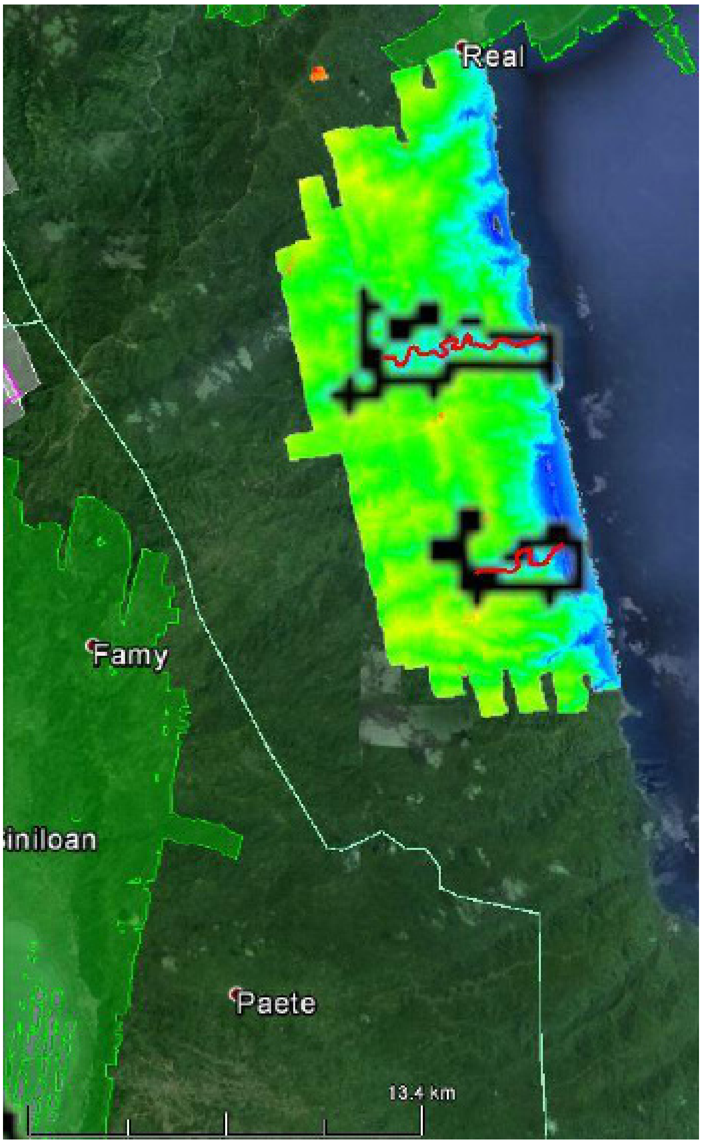


Figure A-7.1. Swath for Flight No. 2842P

Annex 8. Mission Summary Reports

Table A-8.1 Mission Summary Report for Calabarzon_Reflights_Blk18Q

Flight Area	CALABARZON
Mission Name	Calabarzon_Reflights_Blk18Q
Inclusive Flights	23474P
Range data size	12.7 GB
POS data size	200 MB
Base data size	468 MB
Image	n/a
Transfer date	July 14, 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)	1.1
RMSE for East Position (<4.0 cm)	1.6
RMSE for Down Position (<8.0 cm)	3.2
Boresight correction stdev (<0.001deg)	0.000335
IMU attitude correction stdev (<0.001deg)	0.001170
GPS position stdev (<0.01m)	0.0020
Minimum % overlap (>25)	42.49%
Ave point cloud density per sq.m. (>2.0)	2.82
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	189
Maximum Height	590.20
Minimum Height	47.79
Classification (# of points)	
Ground	41,354,472
Low vegetation	12,086,308
Medium vegetation	90,563,722
High vegetation	527,379,966
Building	10,983,102
Orthophoto	No
Processed by	Engr. Irish Cortez, Engr. Melanie Hingpit, Engr. Czarinajean Añonuevo

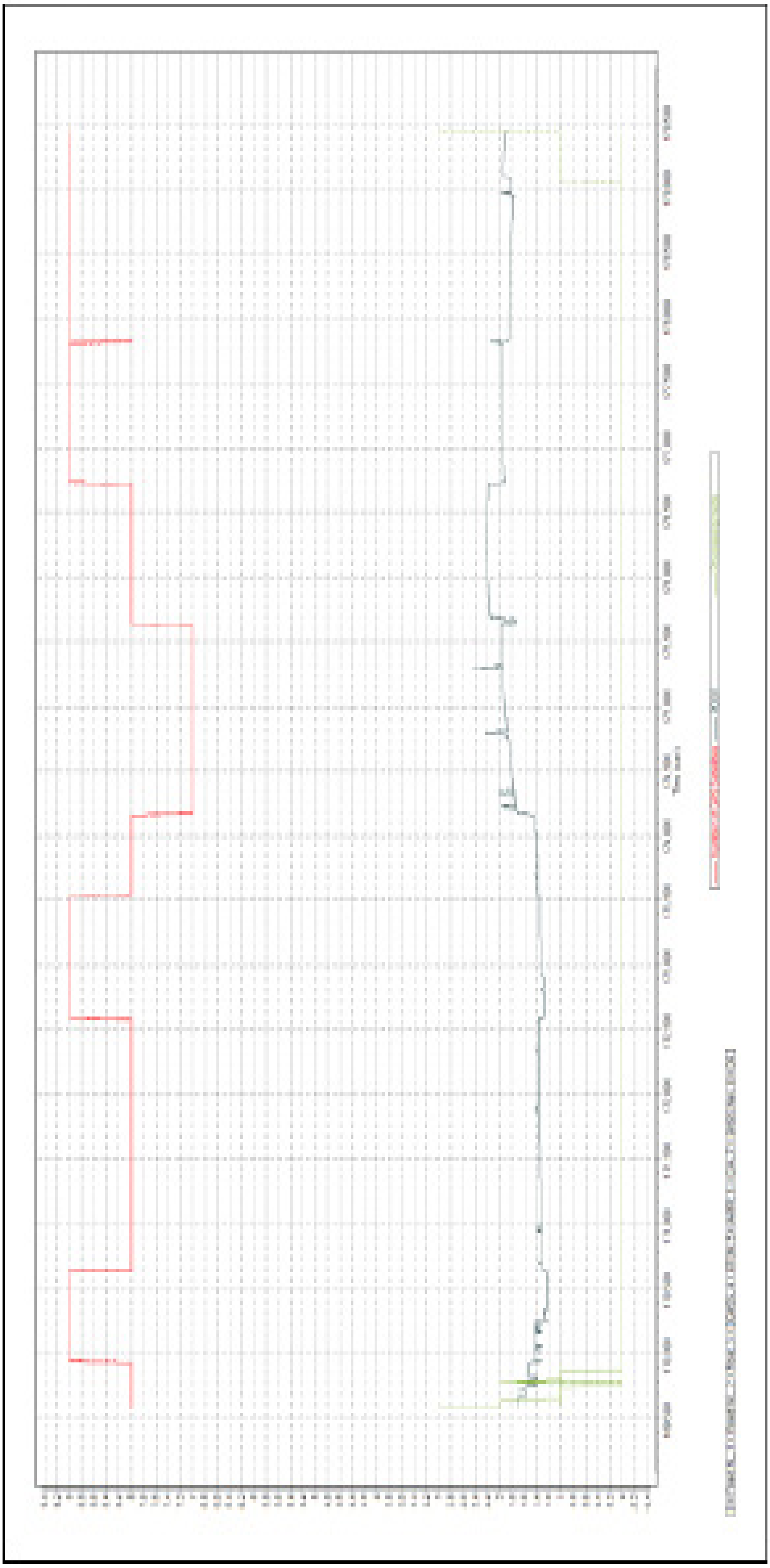


Figure A-8.1. Solution Status

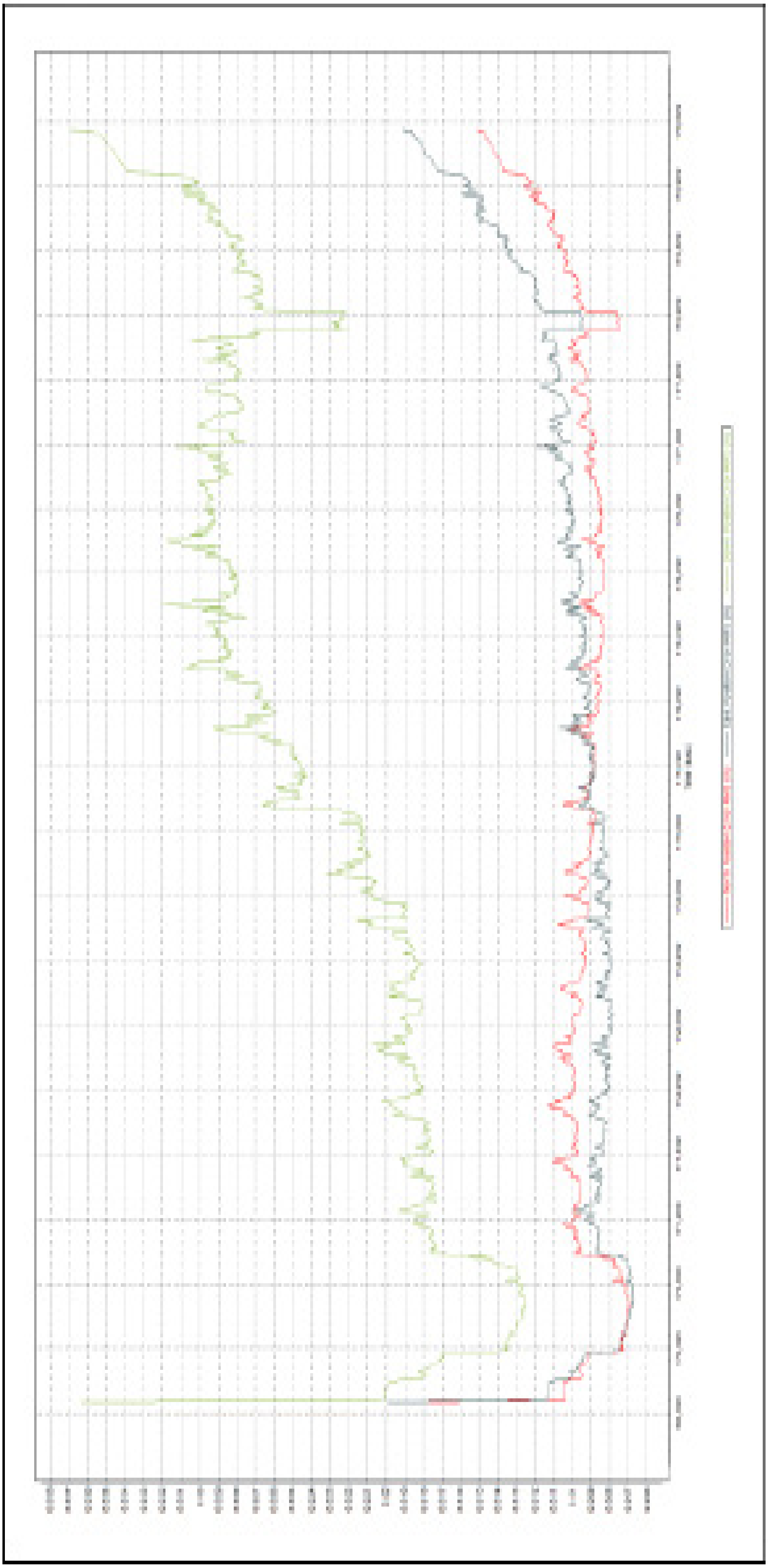


Figure A-8.2. Smoothed Performance Metric Parameters

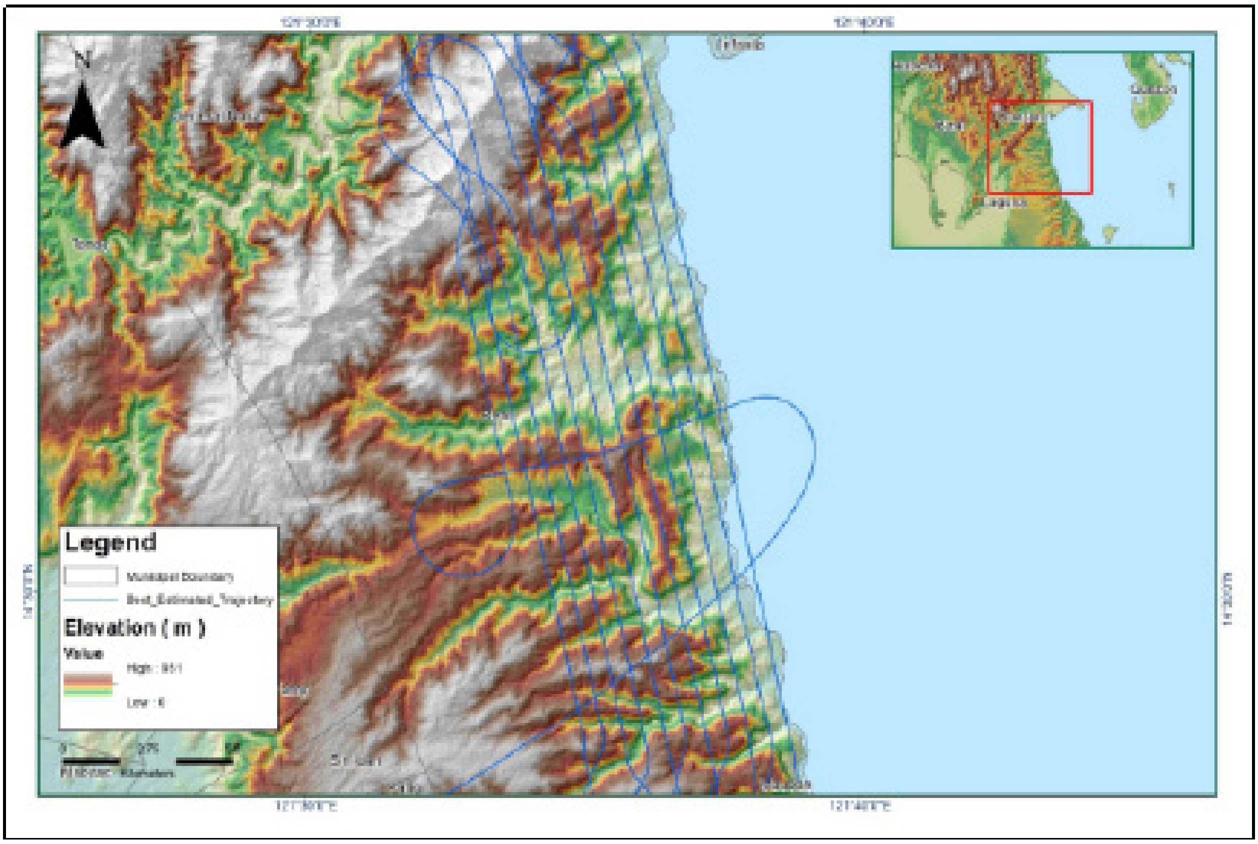


Figure A-8.3. Best Estimated Trajectory

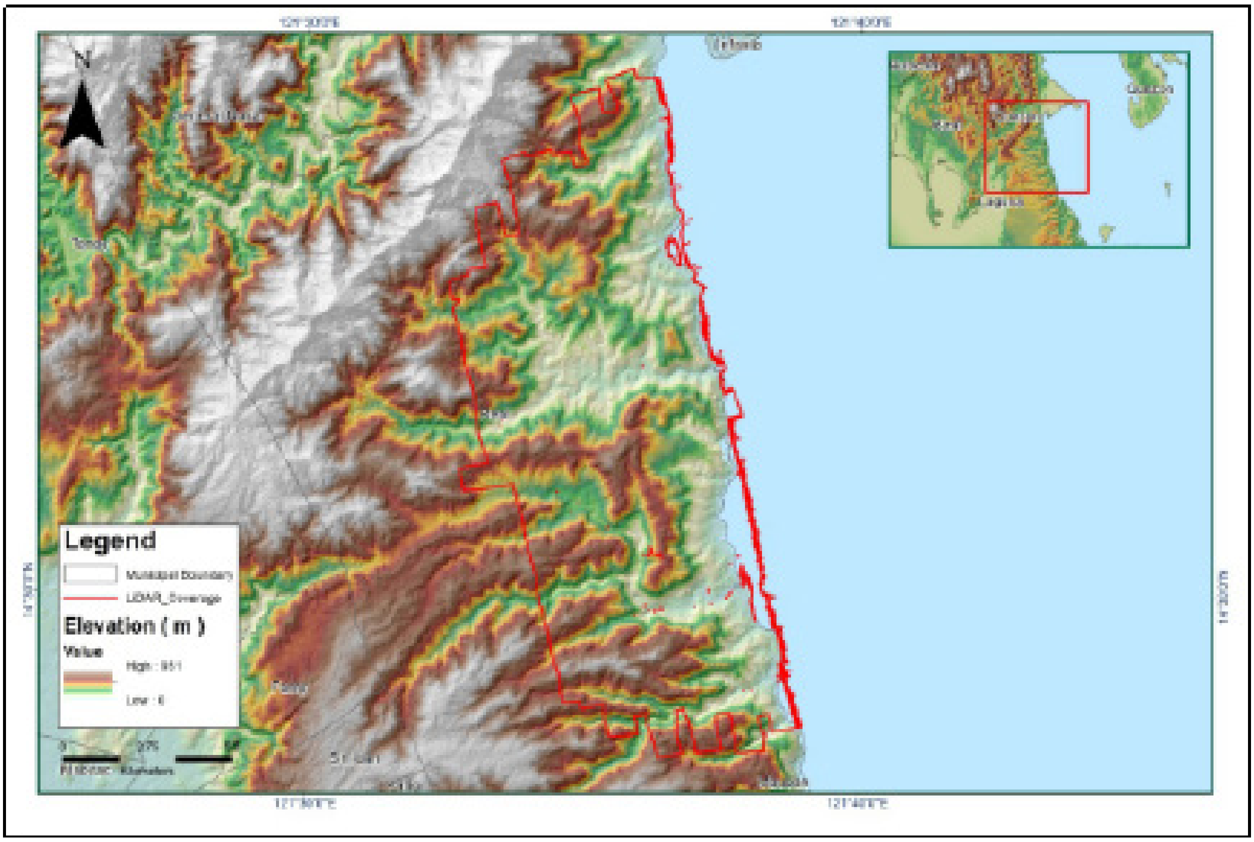


Figure A-8.4. Coverage of LiDAR Data

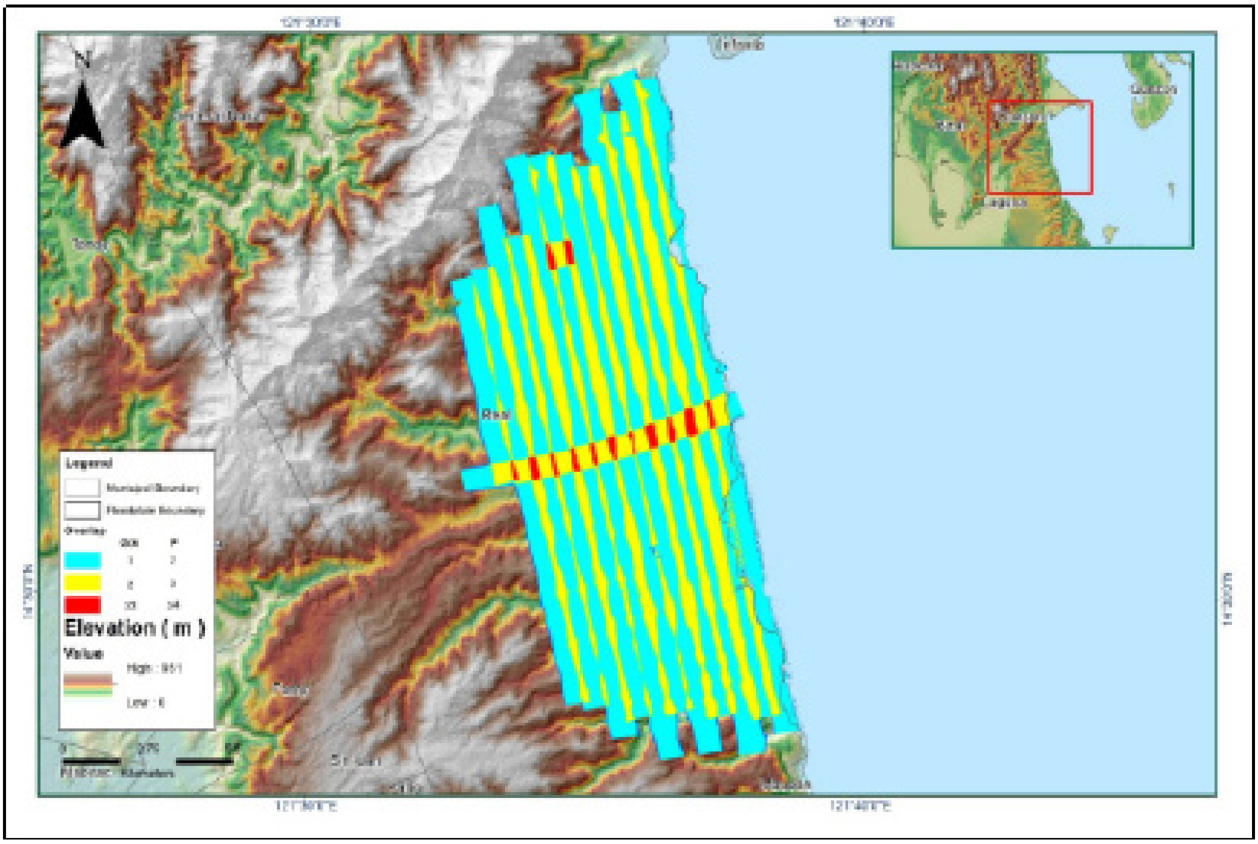


Figure A-8.5. Image of data overlap

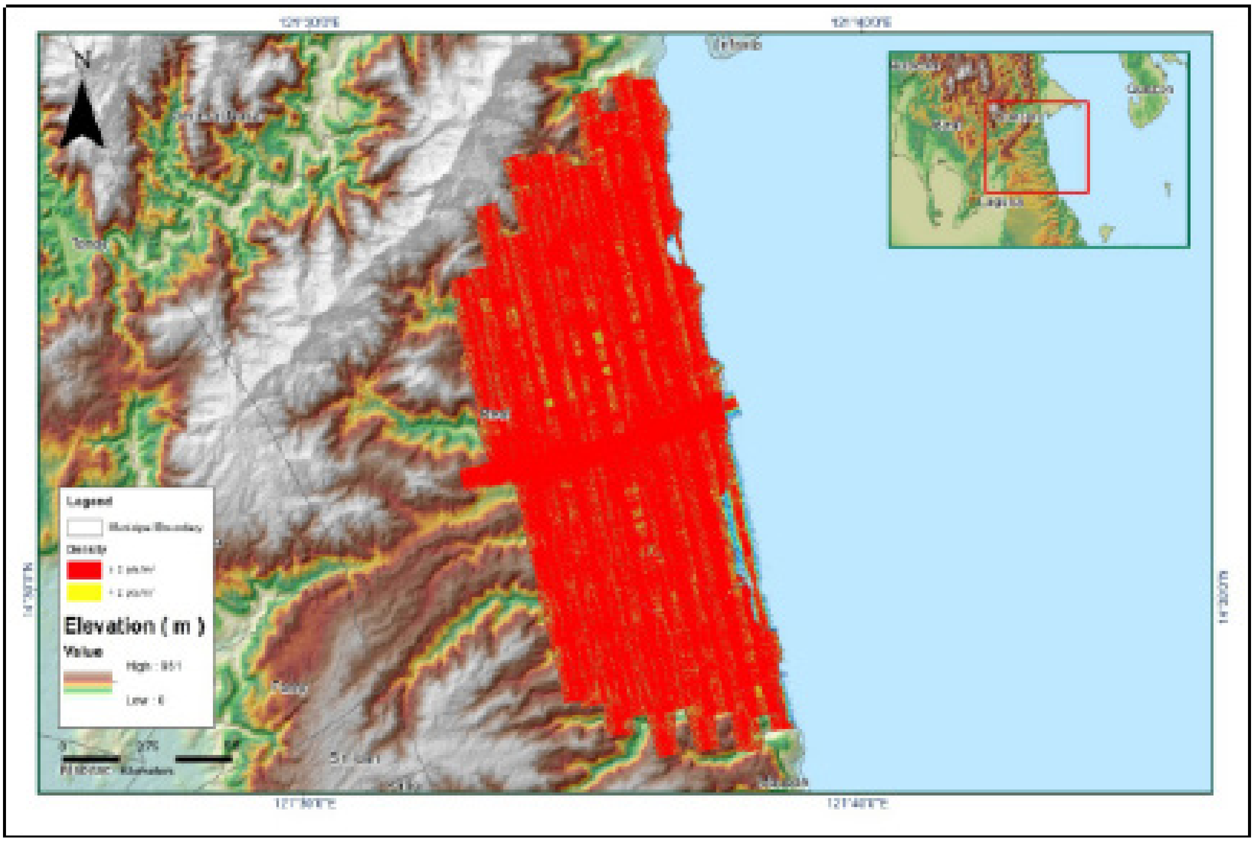


Figure A-8.6. Density map of merged LiDAR data

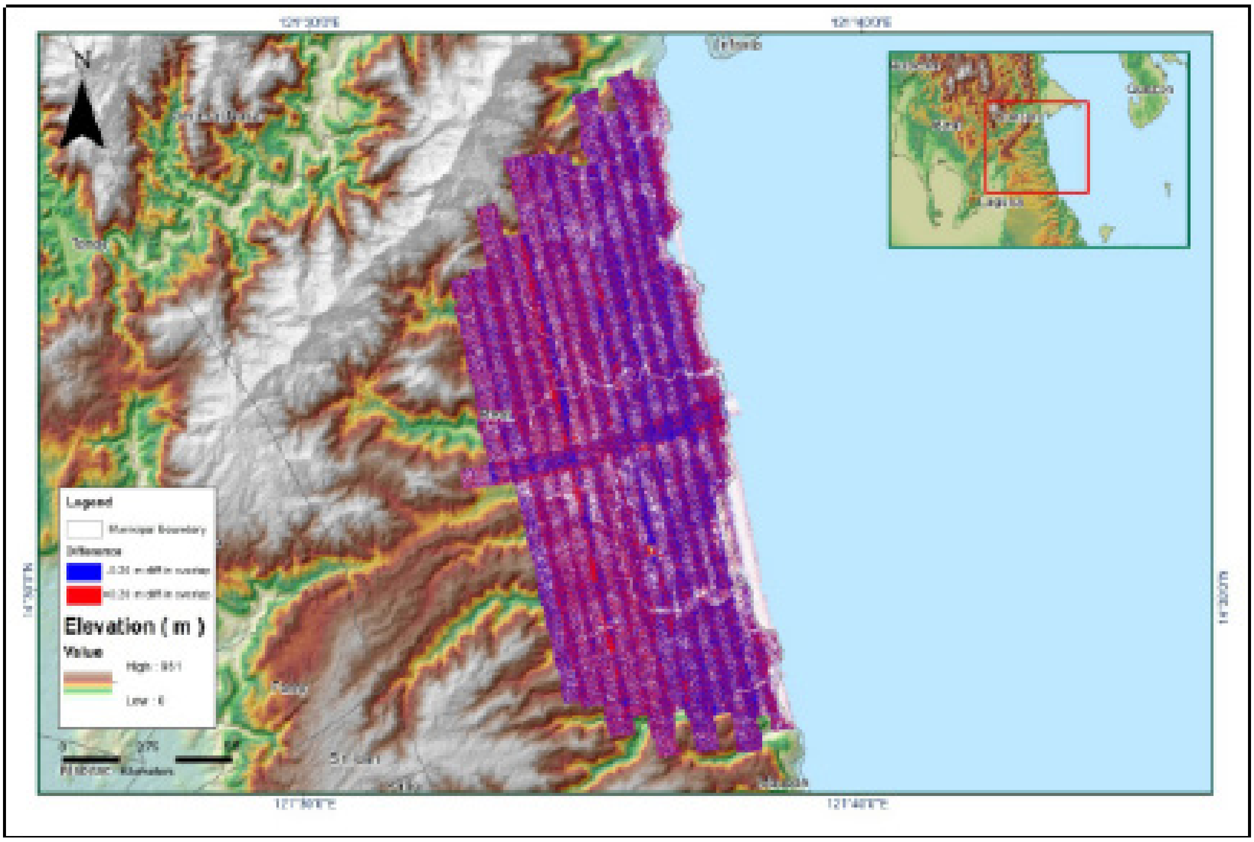


Figure A-8.7. Elevation difference between flight lines

Table A-8.2 Mission Summary Report for Calabarzon_Reflights_Blk18Q_Supplement

Flight Area	Calabarzon_Reflights
Mission Name	Calabarzon_Reflights_Blk18Q_Supplement
Inclusive Flights	23474P
Range data size	12.7 GB
POS data size	200 MB
Base data size	468 MB
Image	n/a
Transfer date	July 14, 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)	1.1
RMSE for East Position (<4.0 cm)	1.6
RMSE for Down Position (<8.0 cm)	3.2
Boresight correction stdev (<0.001deg)	0.000335
IMU attitude correction stdev (<0.001deg)	0.001170
GPS position stdev (<0.01m)	0.0020
Minimum % overlap (>25)	55.48%
Ave point cloud density per sq.m. (>2.0)	2.50
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	26
Maximum Height	350.18 m
Minimum Height	47.79 m
Classification (# of points)	
Ground	5,436,252
Low vegetation	1,865,835
Medium vegetation	7,144,399
High vegetation	33,665,181
Building	895,541
Orthophoto	No
Processed by	Engr. Irish Cortez, Engr. Melanie Hingpit, Engr. Monalye Rabino

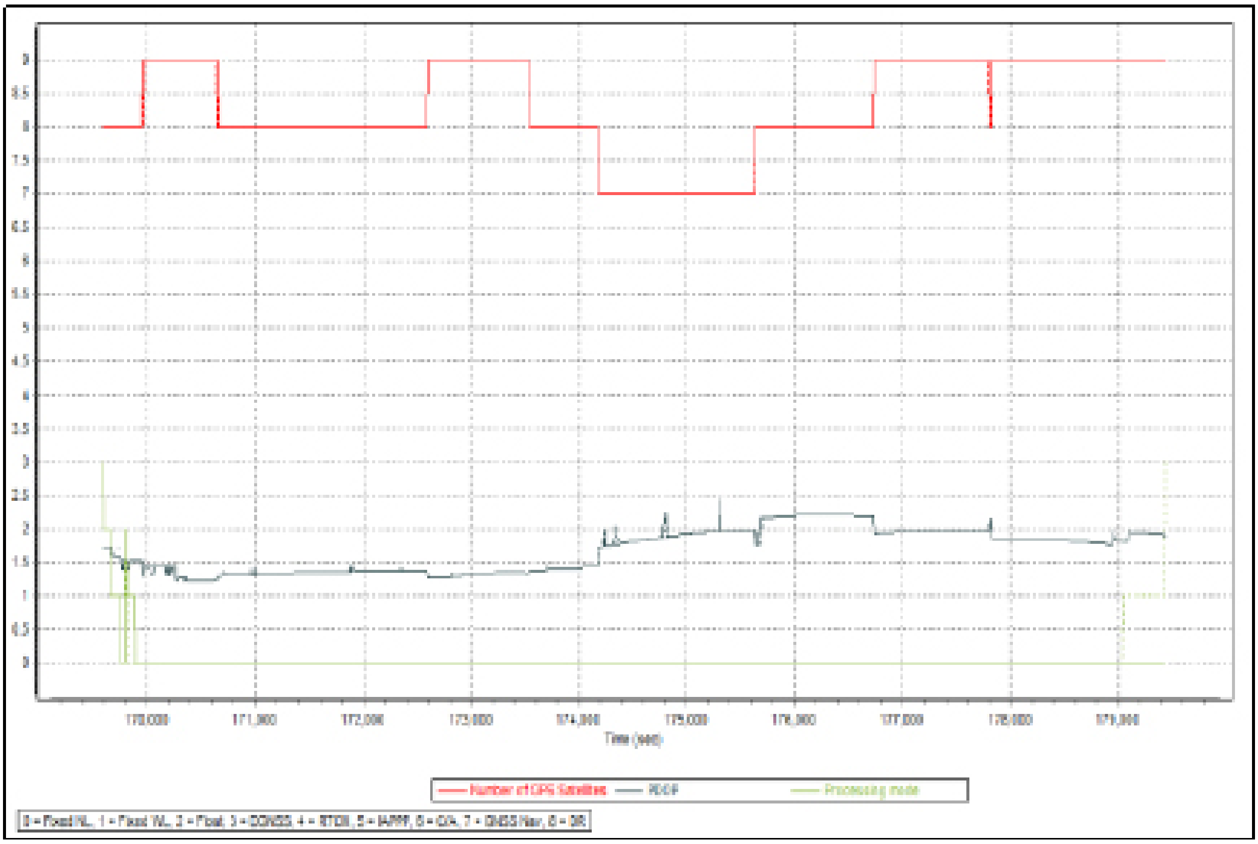


Figure A-8.8. Solution Status

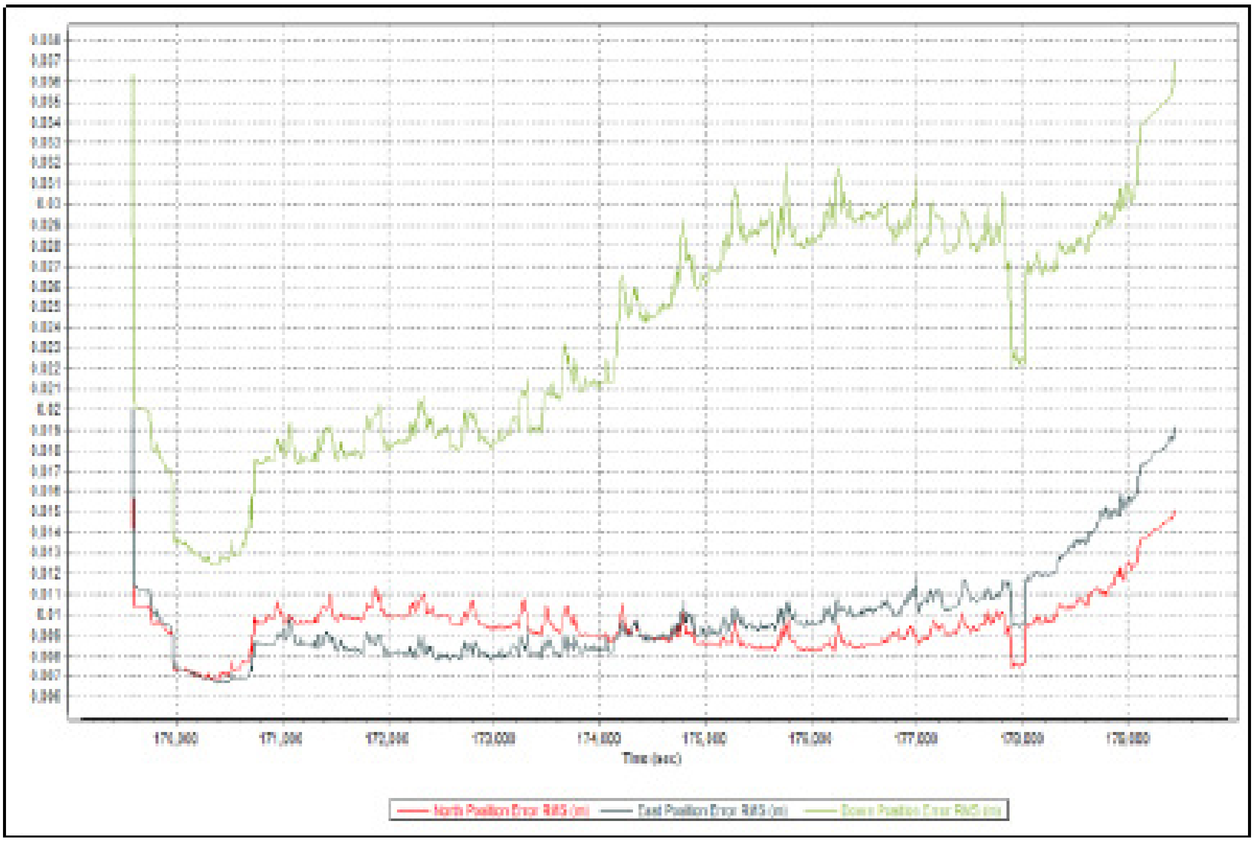


Figure A-8.9. Smoothed Performance Metric Parameters

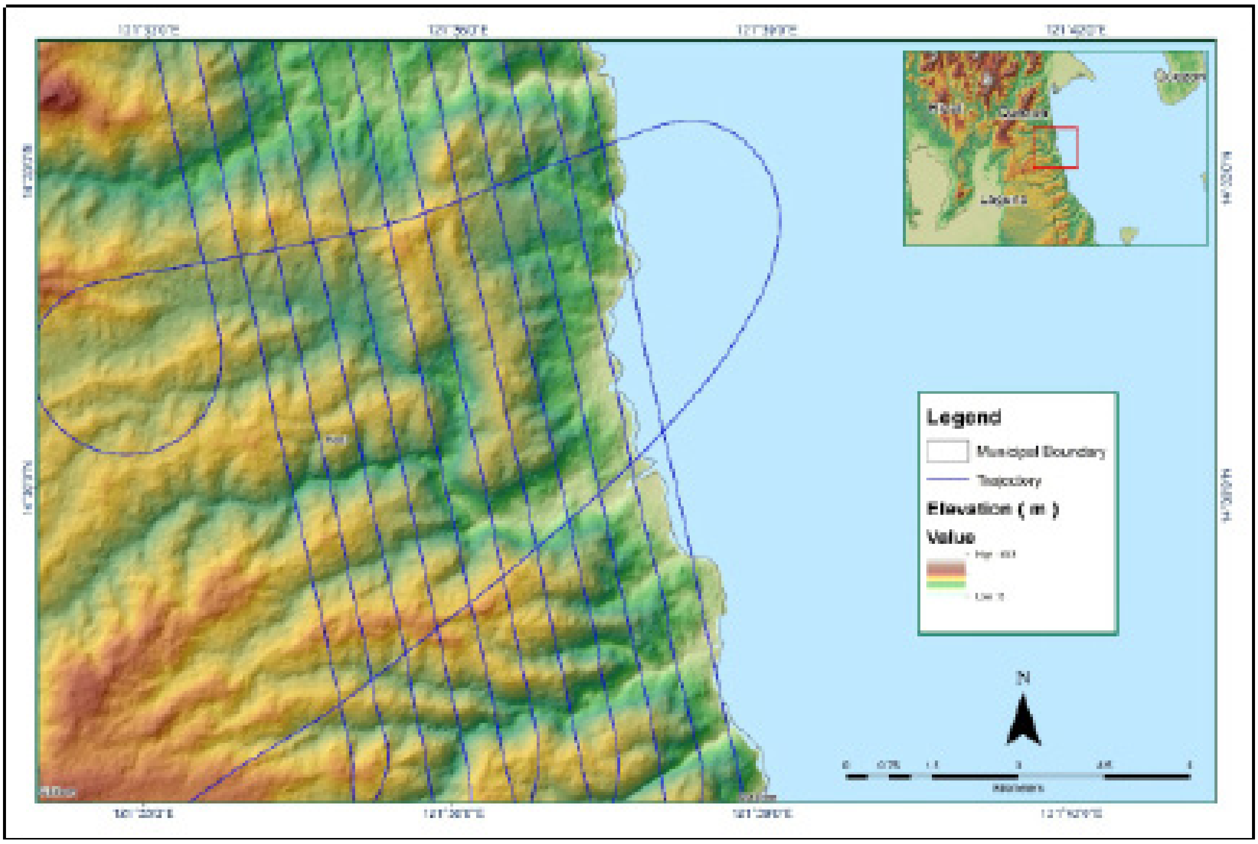


Figure A-8.10. Best Estimated Trajectory

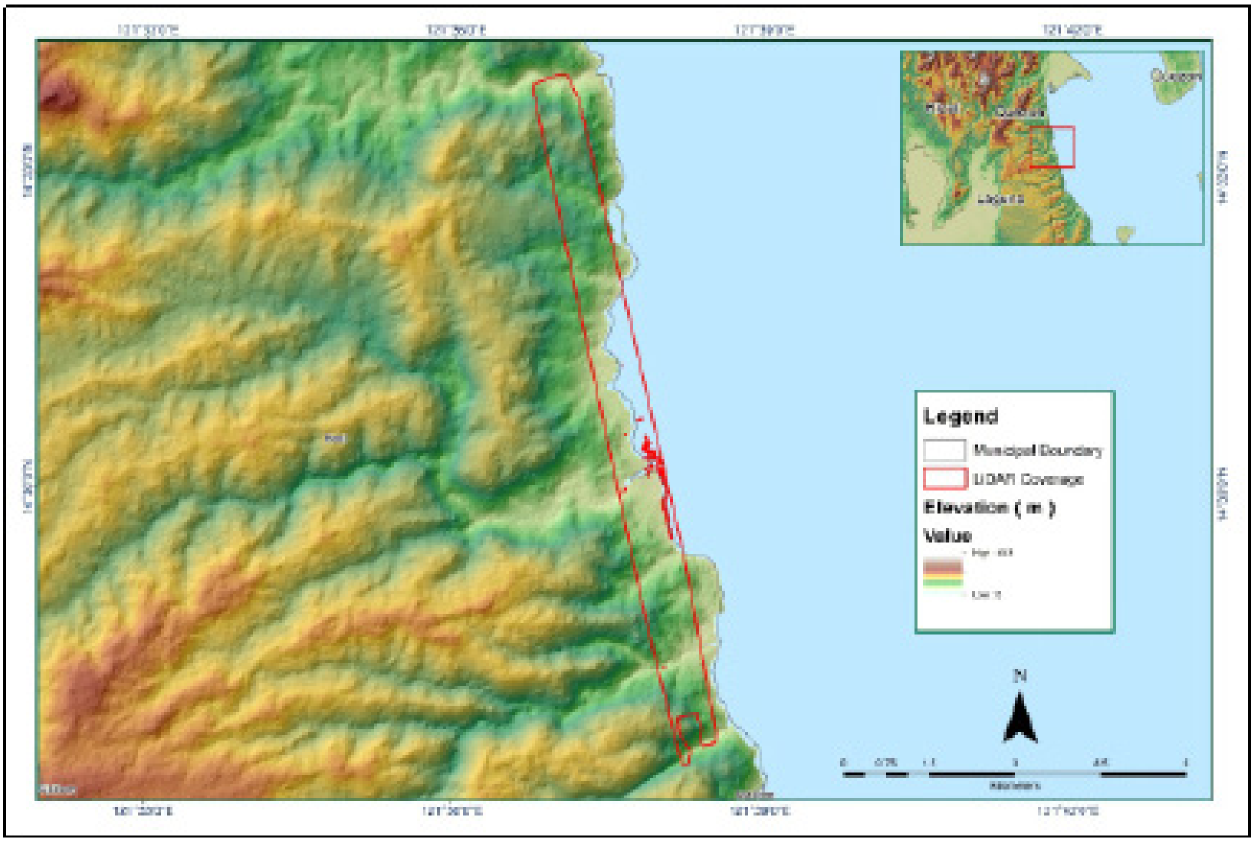


Figure A-8.11. Coverage of LiDAR Data

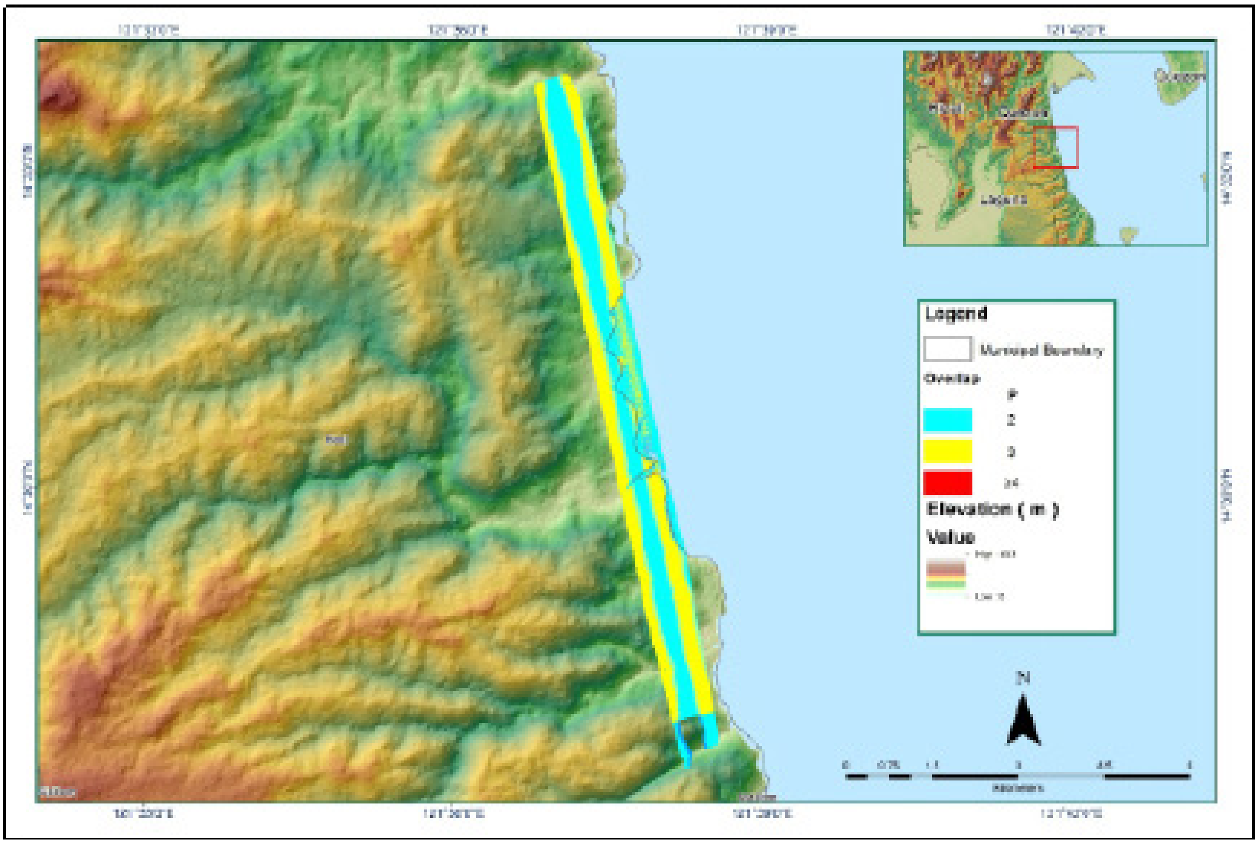


Figure A-8.12. Image of data overlap

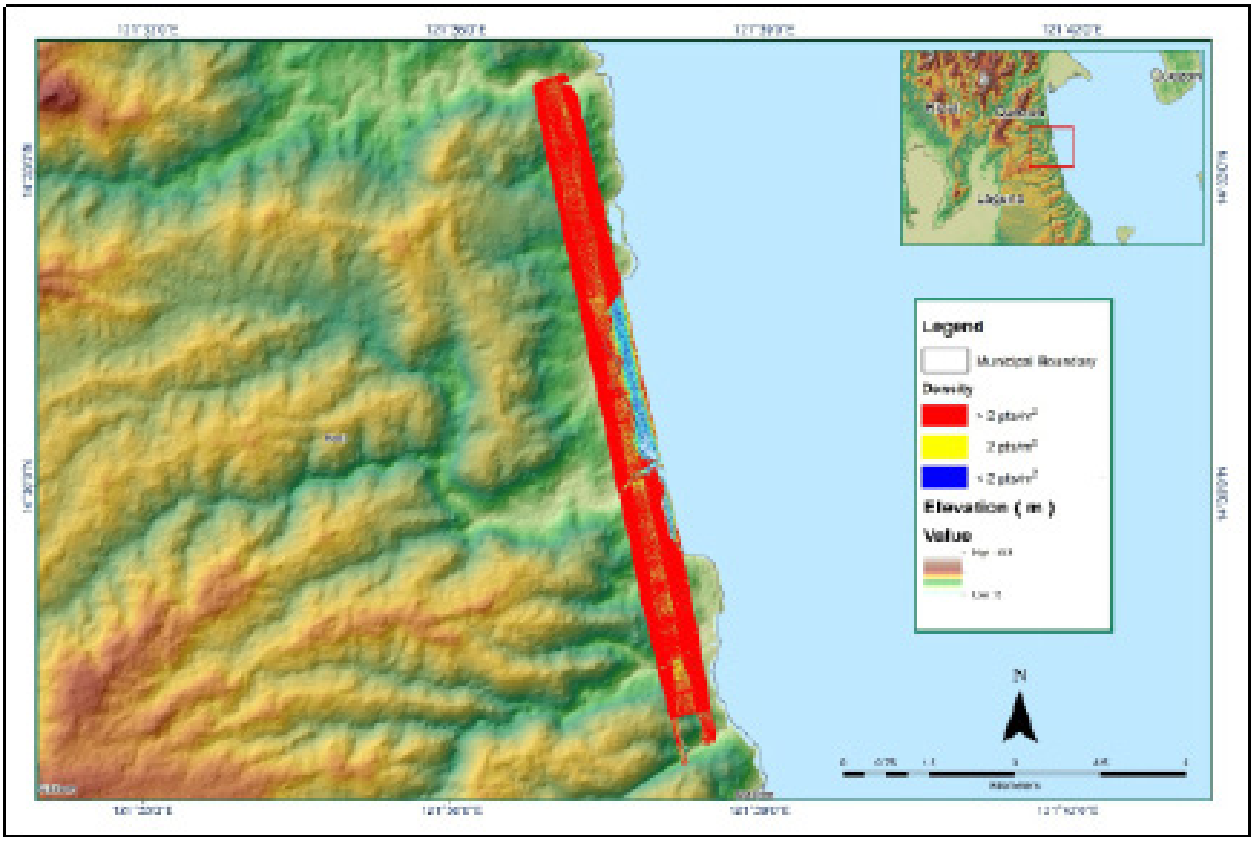


Figure A-8.13. Density map of merged LiDAR data

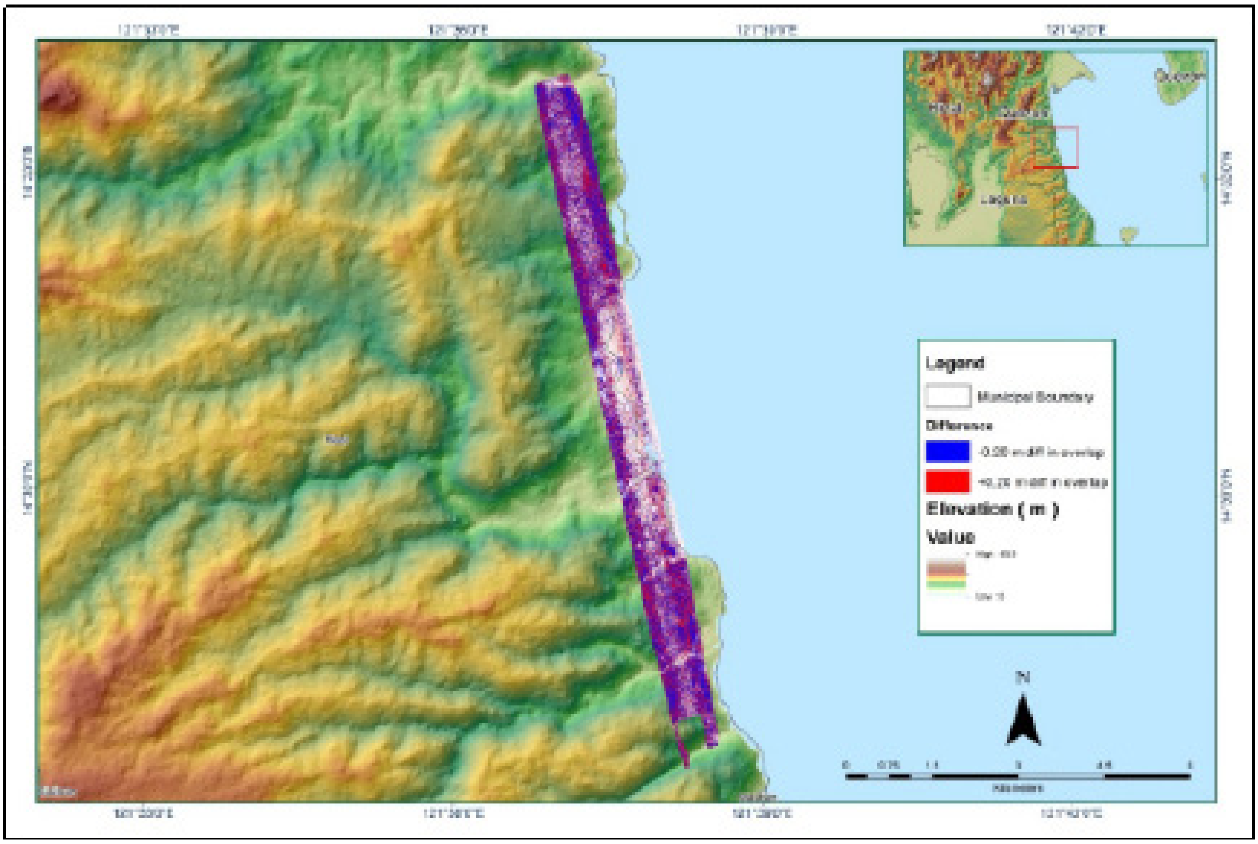


Figure A-8.14. Elevation difference between flight lines

Table A-8.3 Mission Summary Report for Blk18N

Flight Area	Calabarzon_Reflights
Mission Name	Blk18N
Inclusive Flights	10167L
RawLaser	13.8 GB
GnssImu	454 MB
Image	36.9 GB
Transfer date	7/13/2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Combined Separation (-0.1 up to 0.1)	No
Estimated Position Accuracy (in cm)	
Estimated Standard Devation for North Position (<4.0 cm)	0.45
Estimated Standard Devation for East Position (<4.0 cm)	0.46
Estimated Standard Devation for Height Position (<8.0 cm)	1.20
Minimum % overlap (>25)	33.32%
Ave point cloud density per sq.m. (>2.0)	2.17
Elevation difference between strips (<0.20 m)	
Number of 1km x 1km blocks	340
Maximum Height	771.64 m
Minimum Height	47.25 m
Classification (# of points)	
Ground	100,419,191
Low vegetation	32,772,585
Medium vegetation	226,212,330
High vegetation	518,198,243
Building	22,738,410
Orthophoto	Yes
Processed by	Engr. Don Matthew Banatin, Engr. Harmond Santos, Engr. Gladys Mae Apat

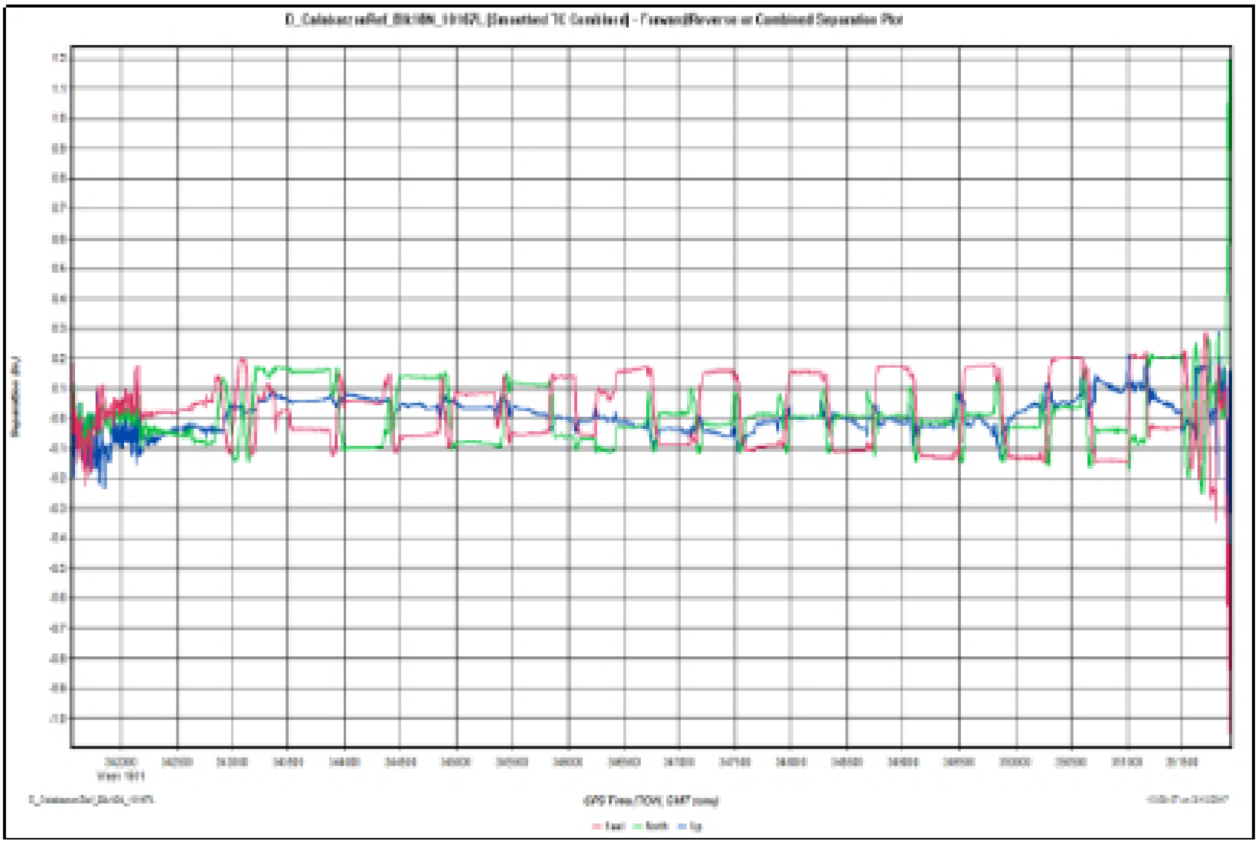


Figure A-8.15 Combined Separation

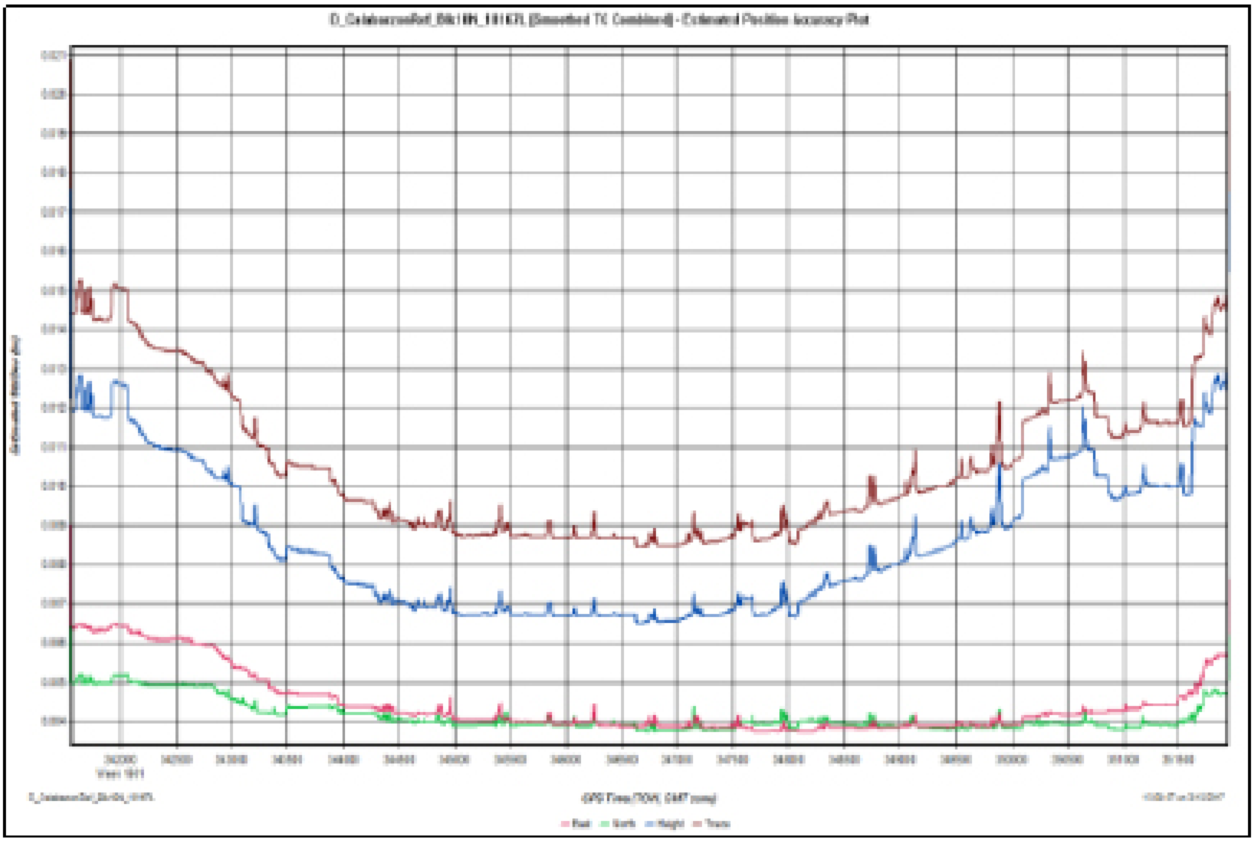


Figure A-8.16 Estimated Position of Accuracy

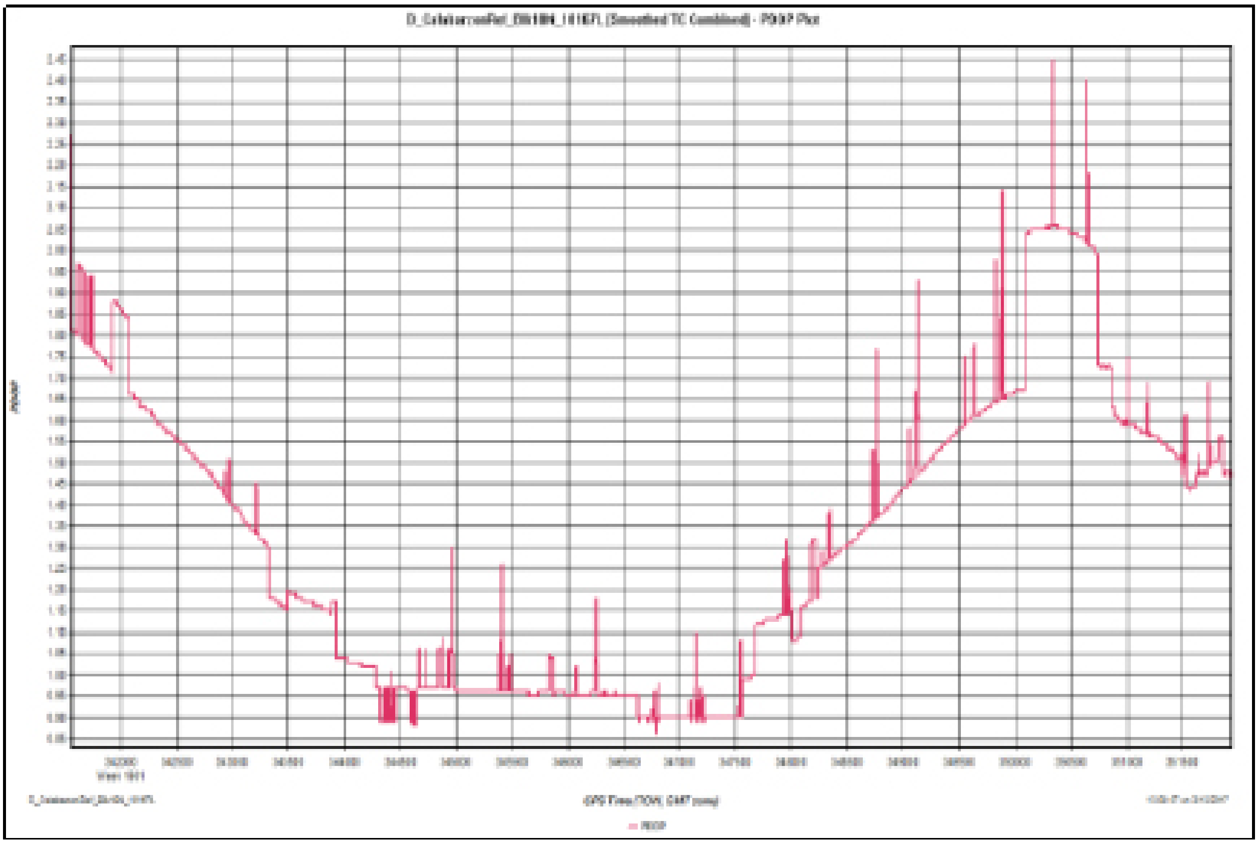


Figure A-8.17 PDOP

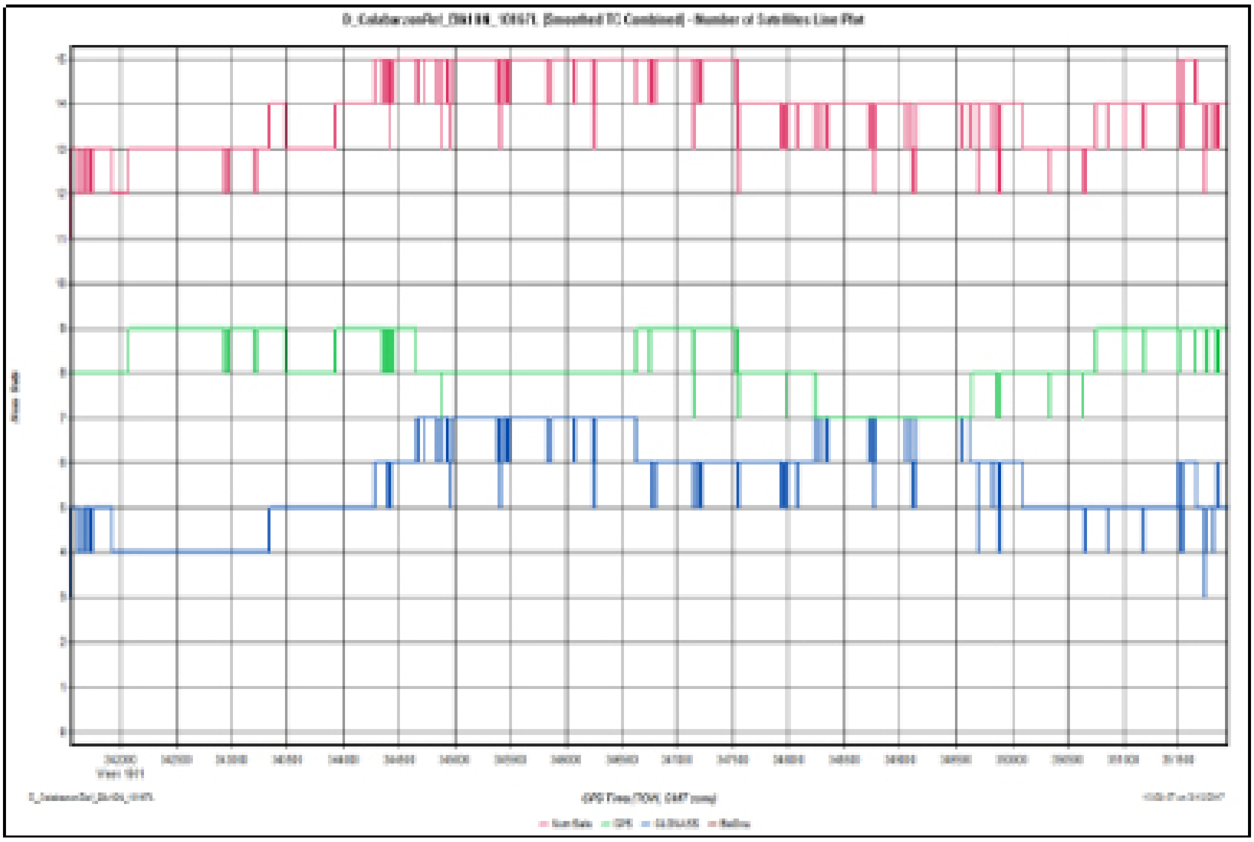


Figure A-8.18 Number of Satellites

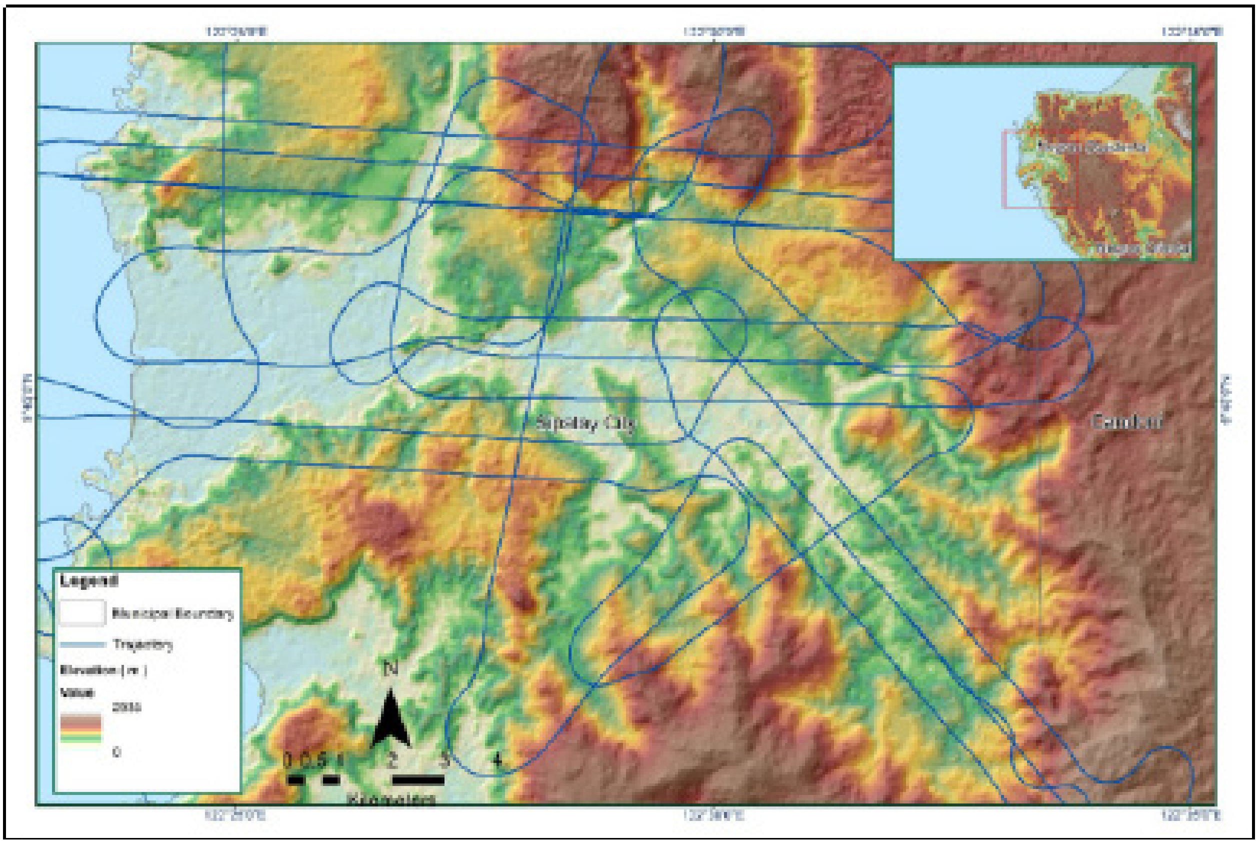


Figure A-8.19 Best Estimated Trajectory

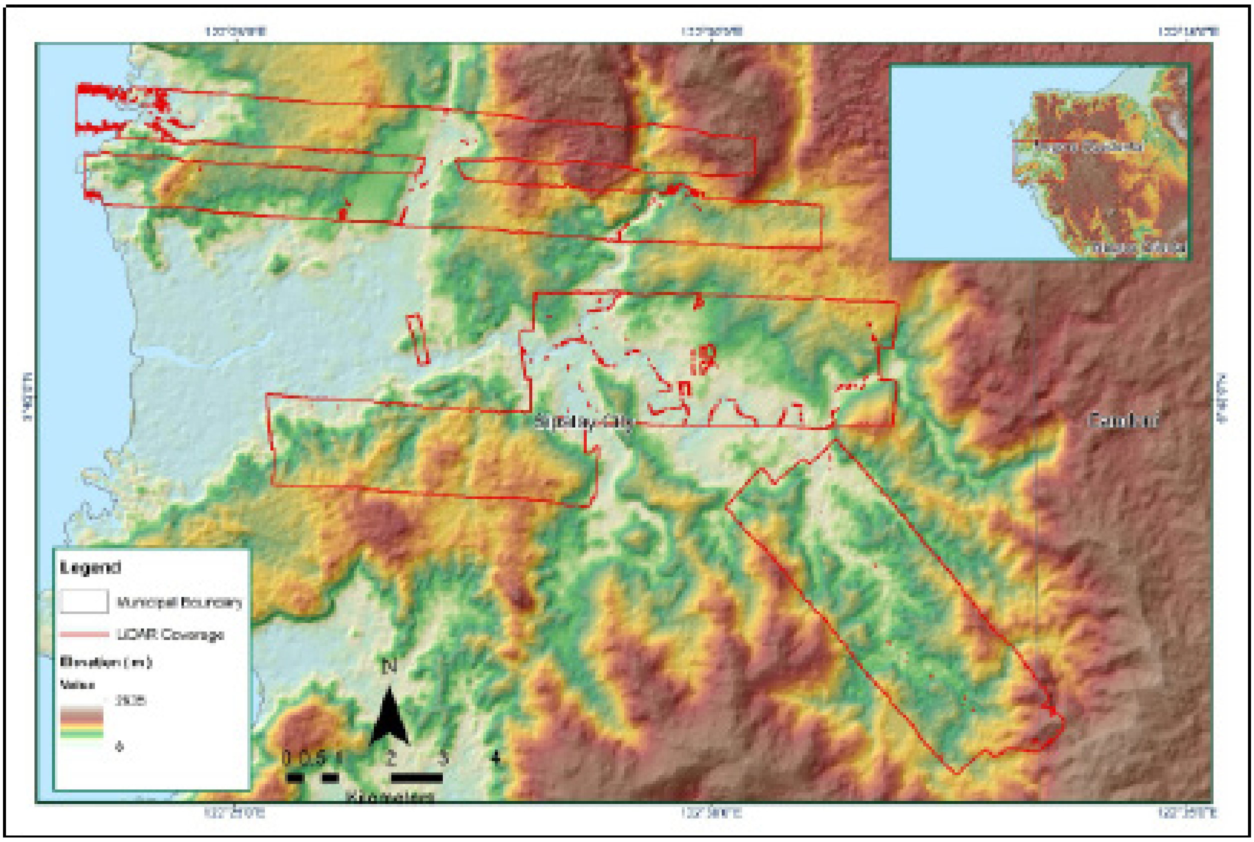


Figure A-8.20 Coverage of LiDAR data

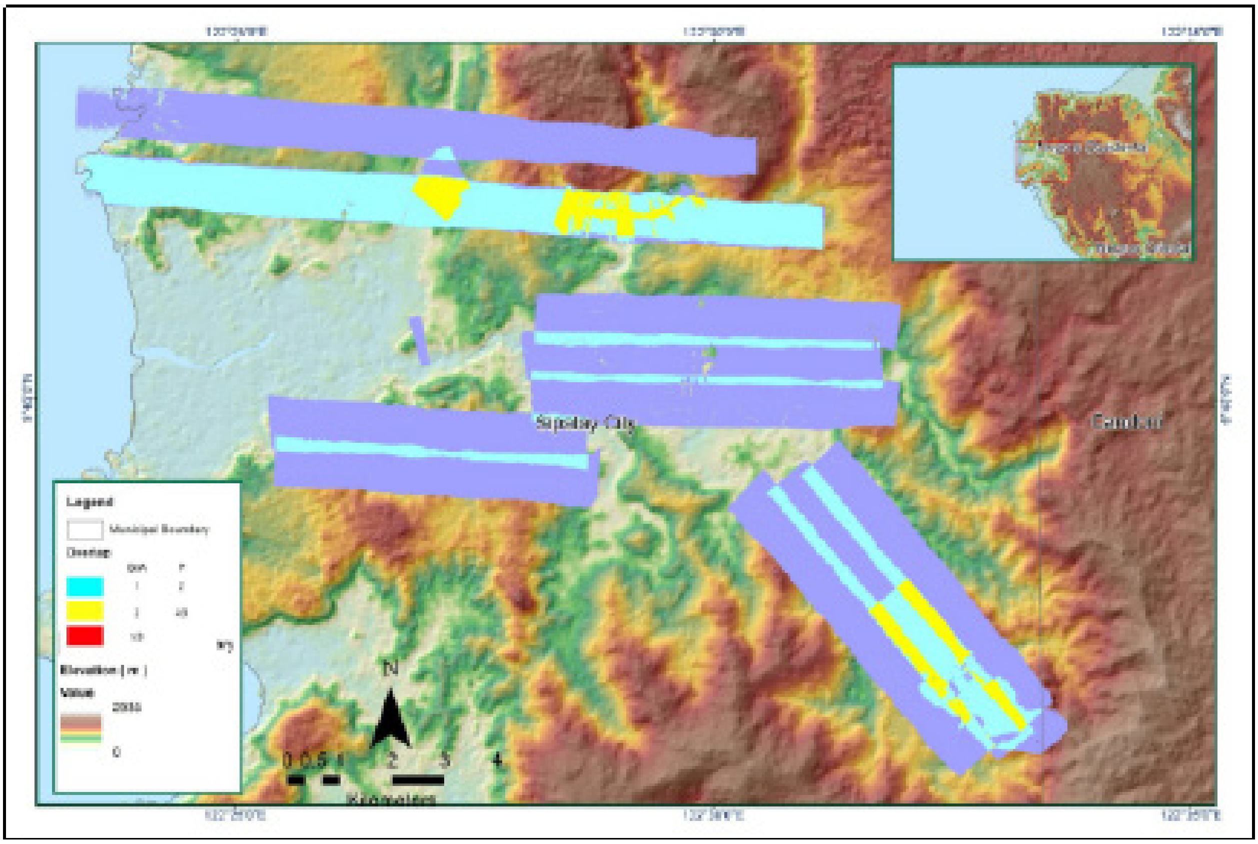


Figure A-8.21 Image of data overlap

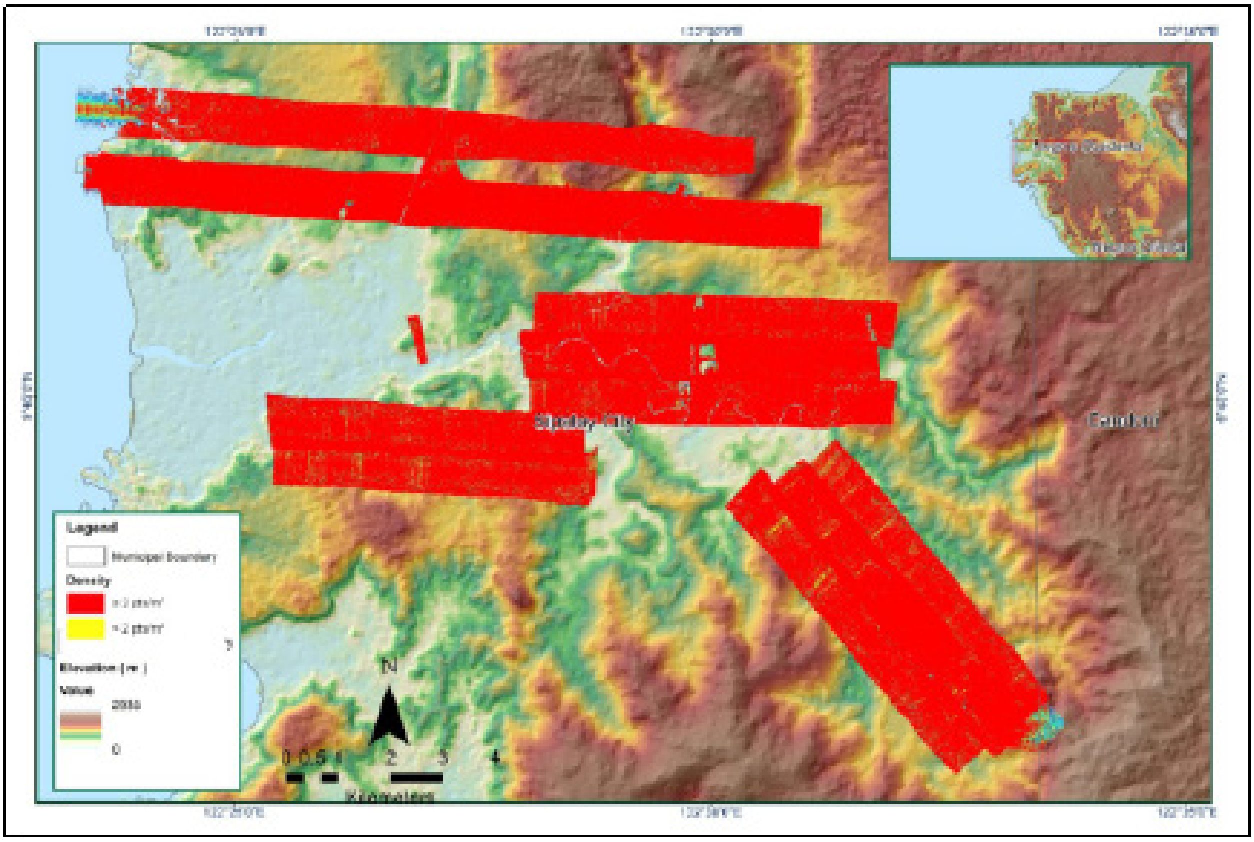


Figure A-8.22 Density map of merged LiDAR data

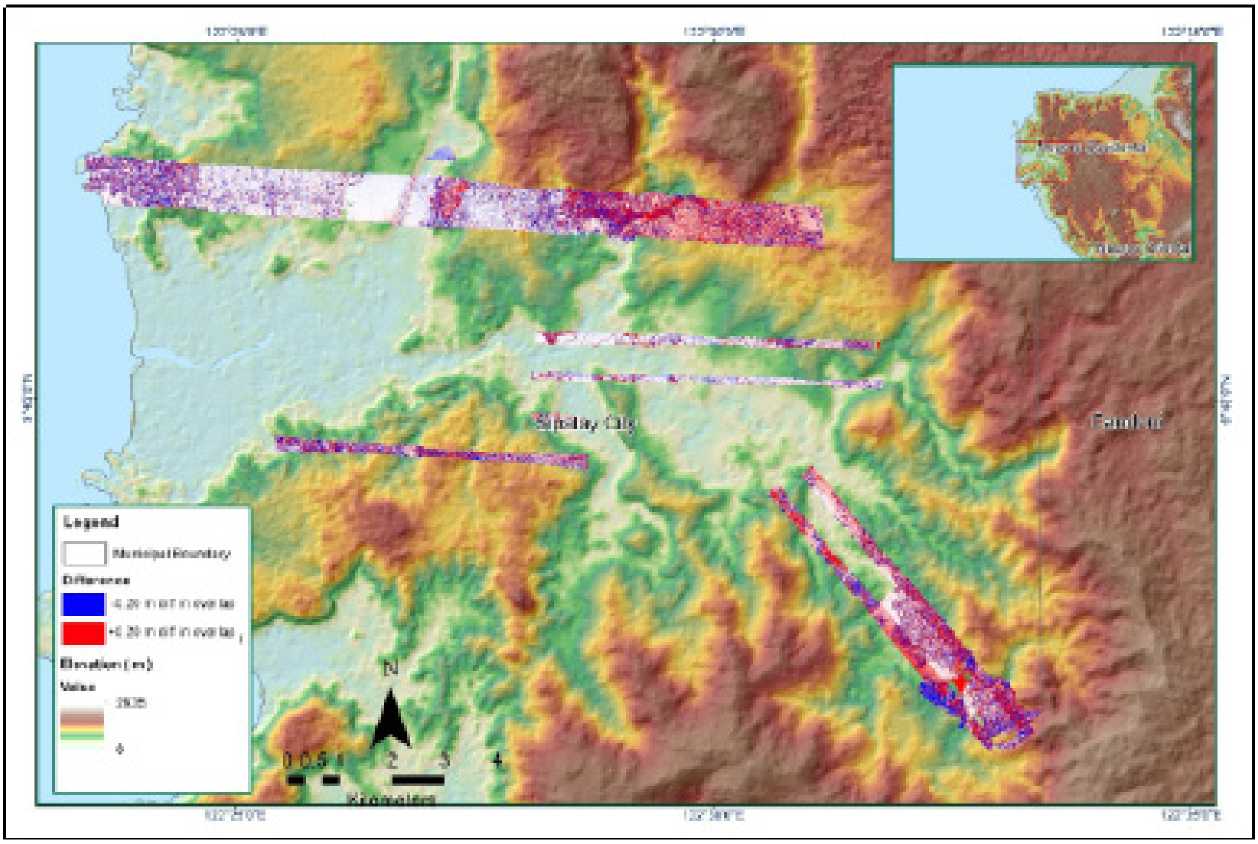


Figure A-8.23 Elevation difference between flight lines

Table A-8.4 Mission Summary Report for Blk18N_Supplement

Flight Area	Calabarzon Reflights
Mission Name	Blk18N_Supplement
Inclusive Flights	10165L
RawLaser	12.7 GB
GnssImu	472 MB
Image	26.7 GB
Transfer date	7/13/2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Combined Separation (-0.1 up to 0.1)	Yes
Estimated Position Accuracy (in cm)	
Estimated Standard Devation for North Position (<4.0 cm)	0.47
Estimated Standard Devation for East Position (<4.0 cm)	0.50
Estimated Standard Devation for Height Position (<8.0 cm)	1.05
Minimum % overlap (>25)	
Ave point cloud density per sq.m. (>2.0)	1.95
Elevation difference between strips (<0.20 m)	
Number of 1km x 1km blocks	269
Maximum Height	924.97 m
Minimum Height	47.20 m
Classification (# of points)	
Ground	114,228,548
Low vegetation	36,586,146
Medium vegetation	161,050,400
High vegetation	366,252,159
Building	18,126,699
Orthophoto	Yes
Processed by	Engr. Regis Guhiting, Engr. Harmond Santos, Engr. Gladys Mae Apat

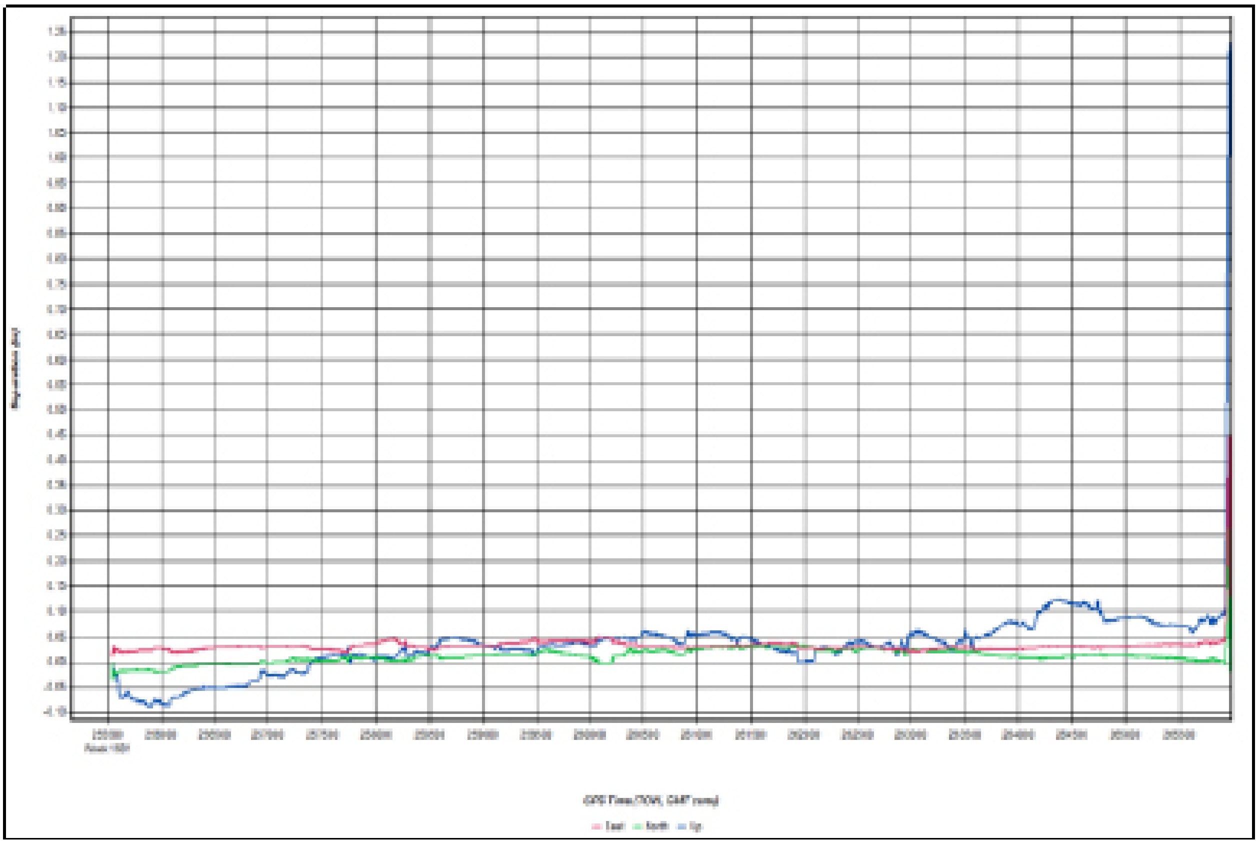


Figure A-8.24 Combined Separation

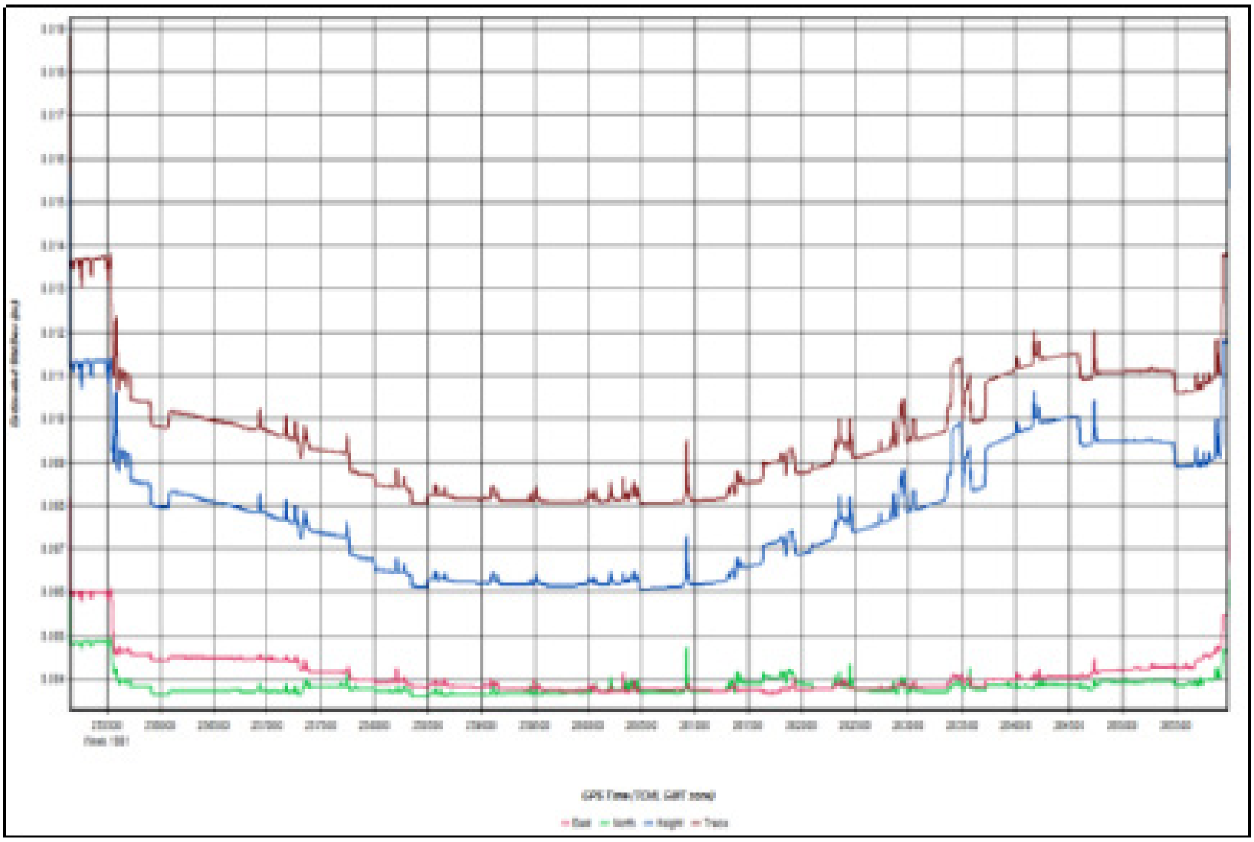


Figure A-8.25 Estimated Position of Accuracy

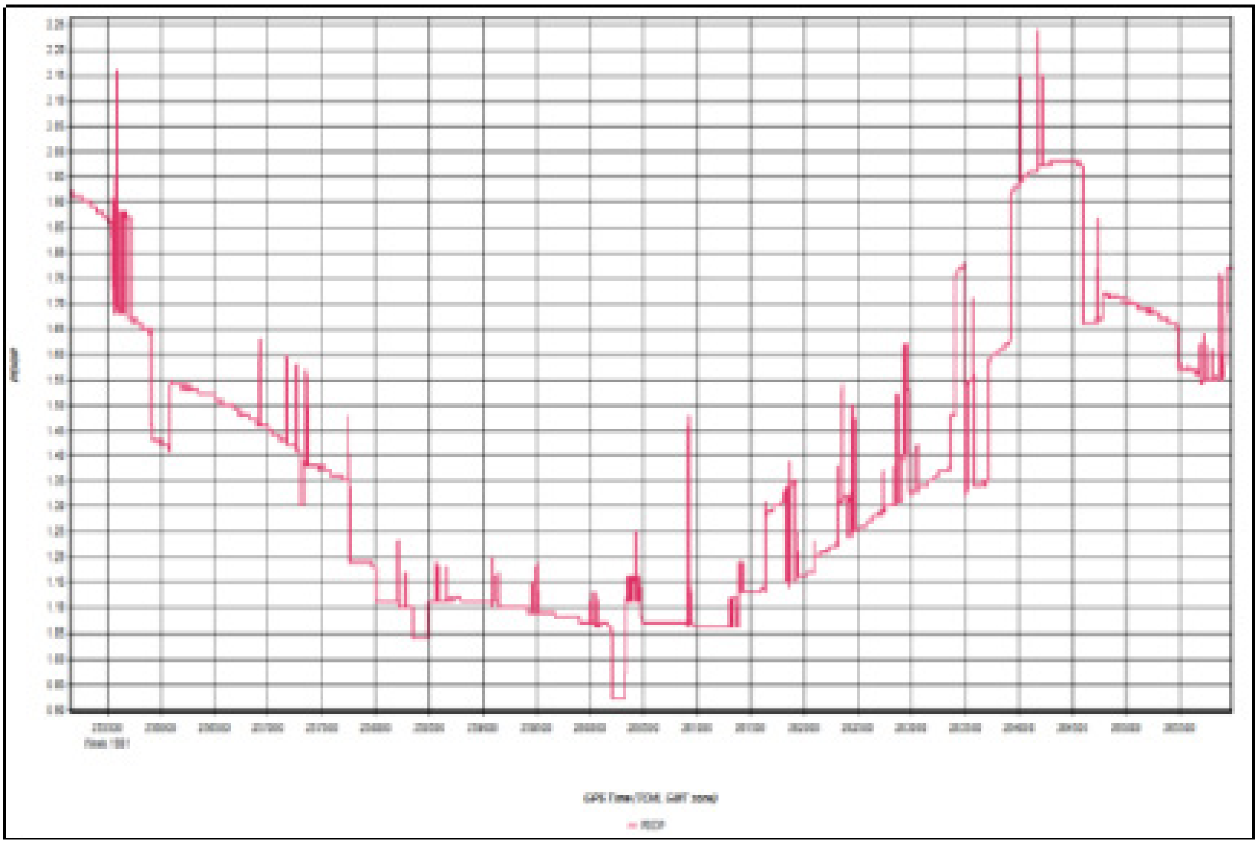


Figure A-8.26 PDOP

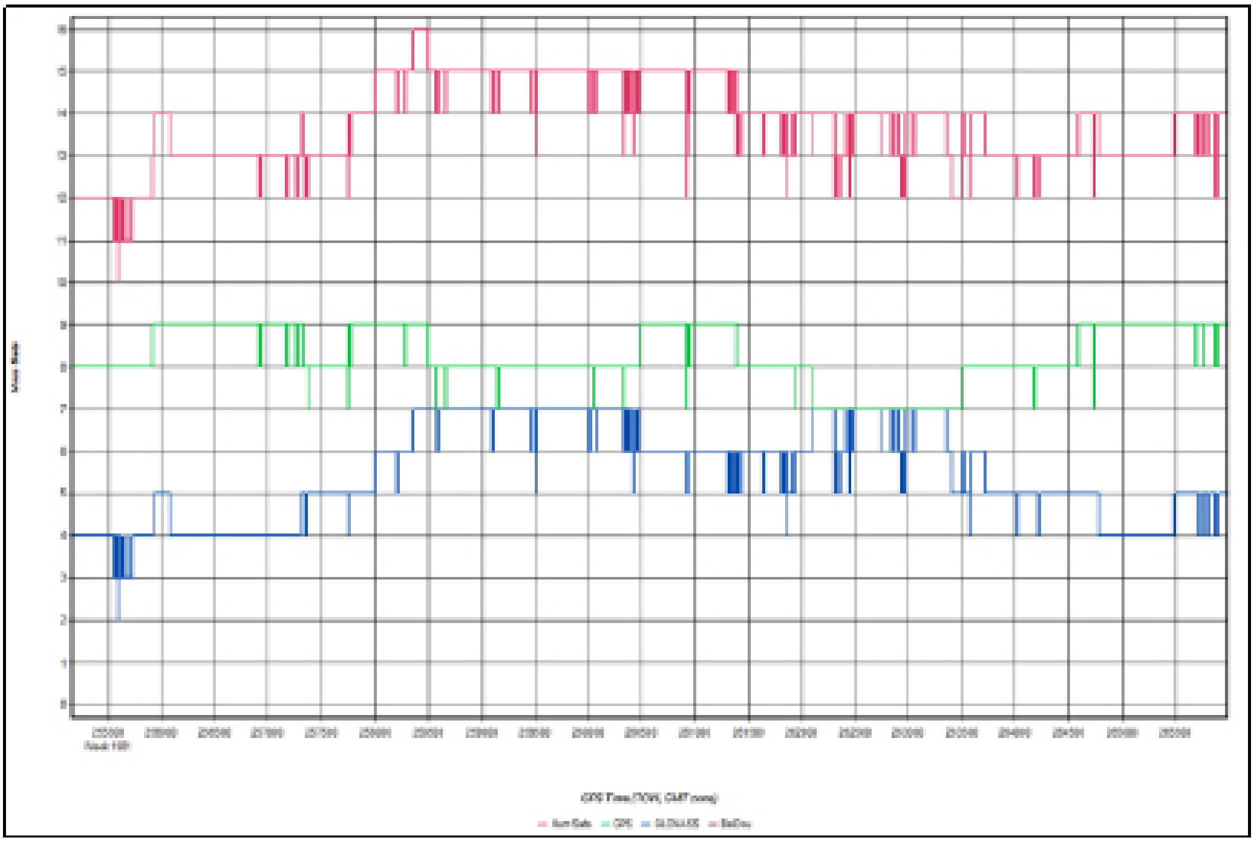


Figure A-8.27 Number of Satellites

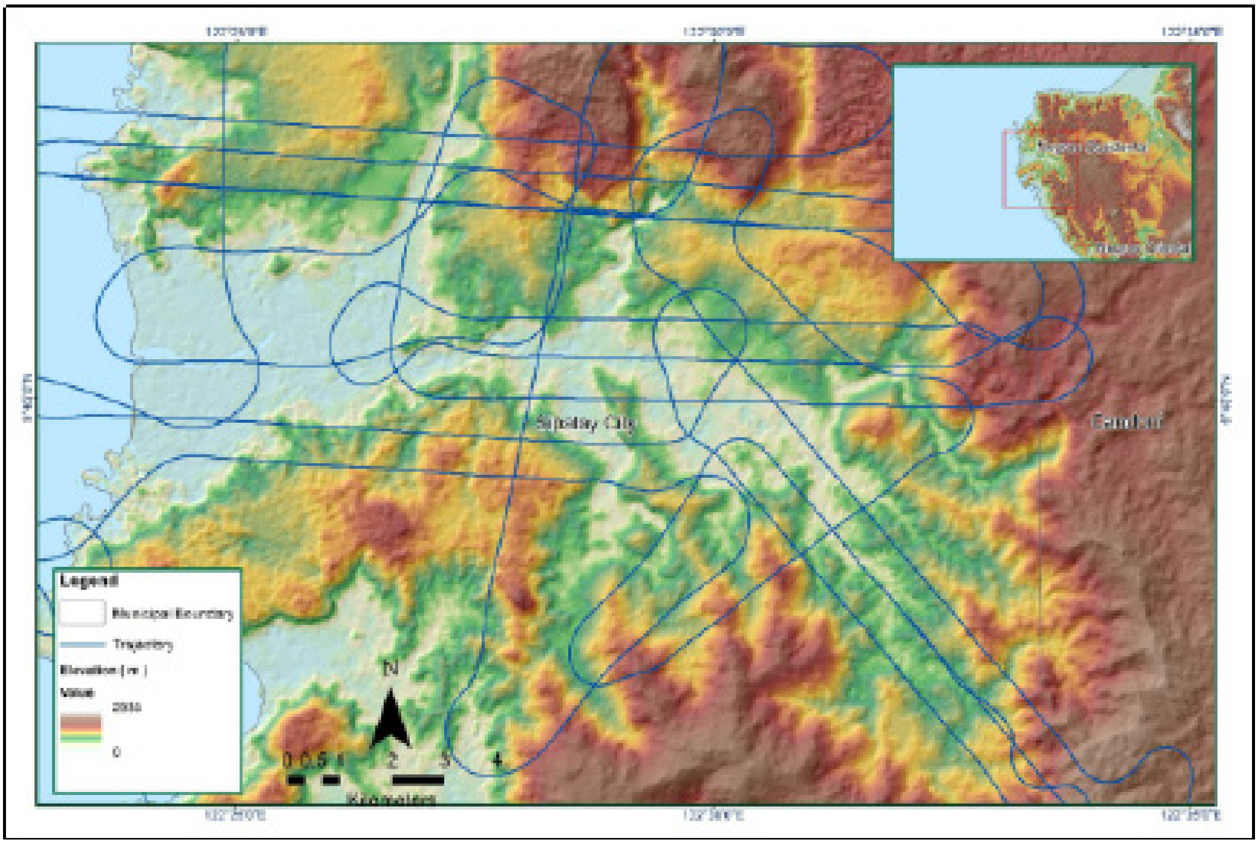


Figure A-8.28 Best Estimated Trajectory

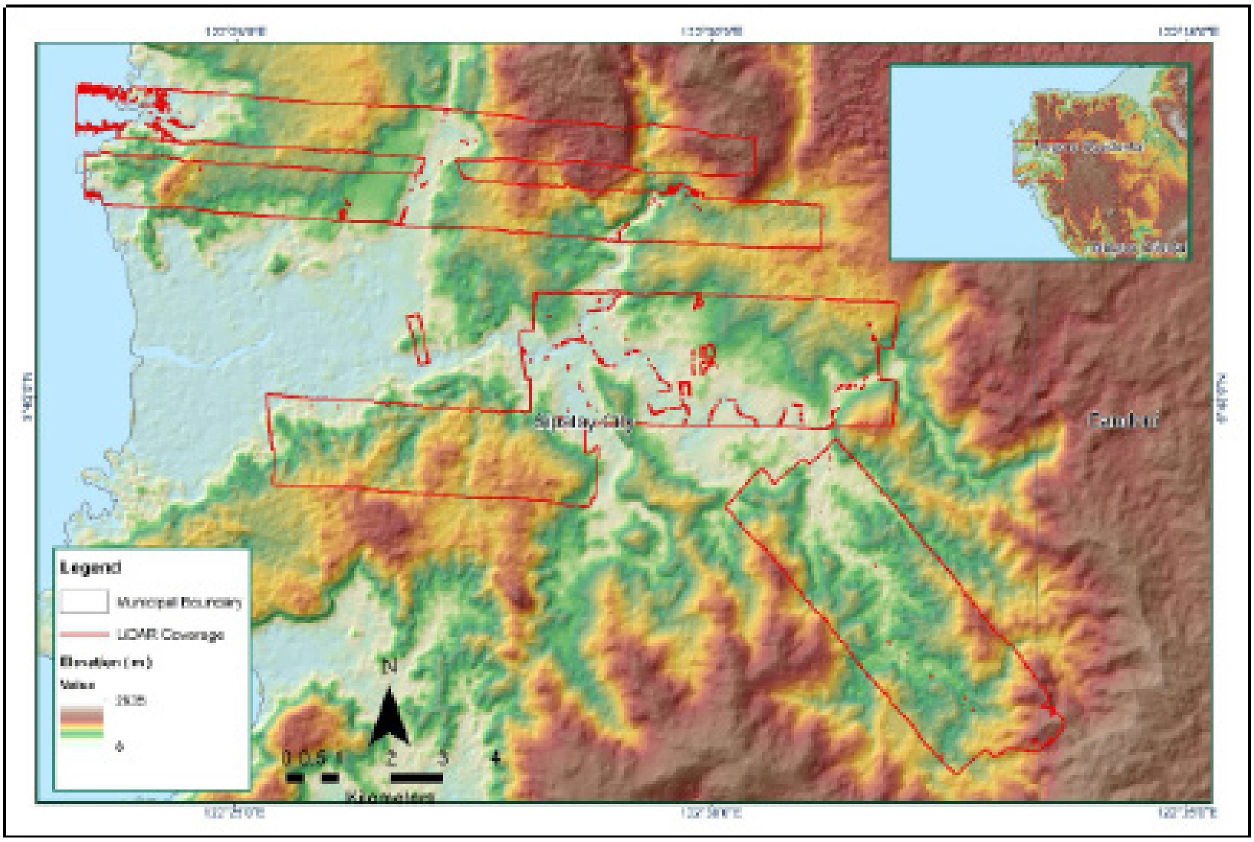


Figure A-8.29 Coverage of LiDAR data

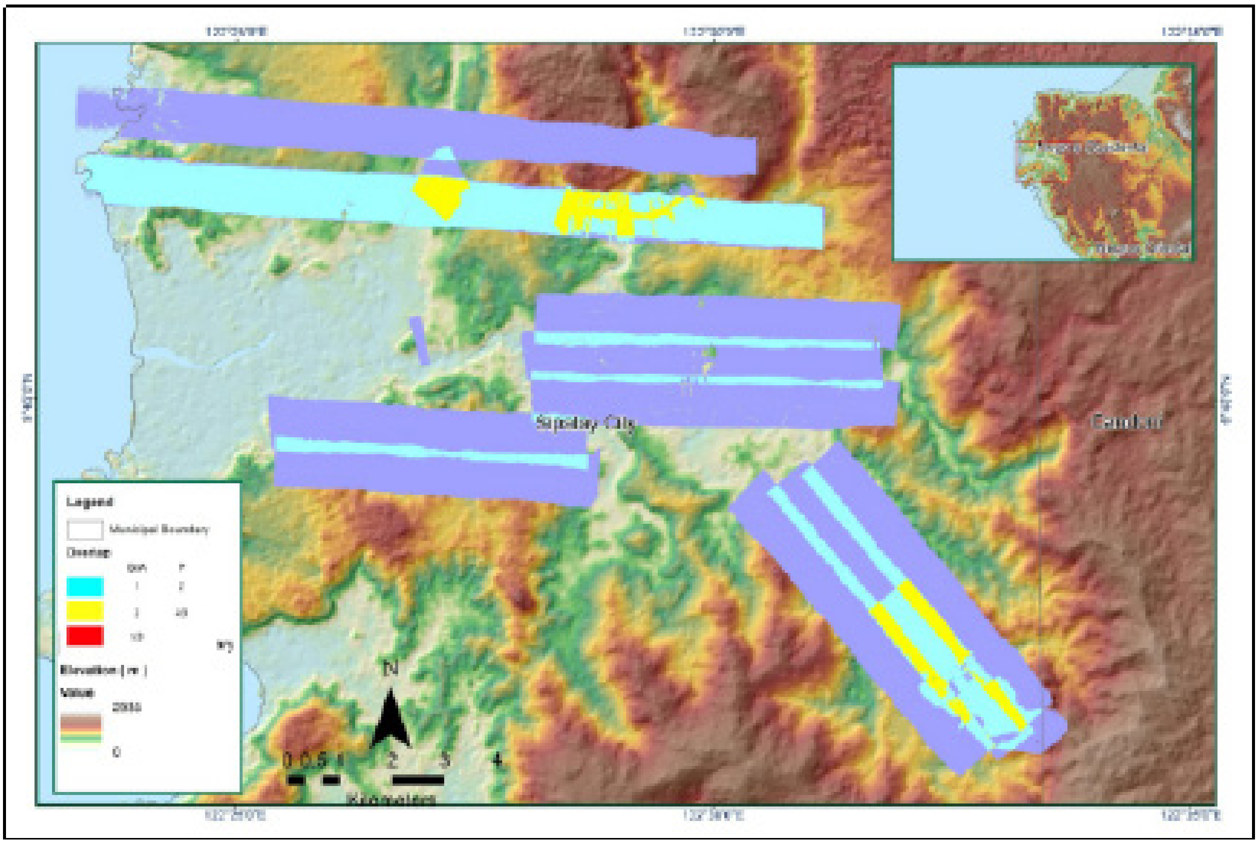


Figure A-8.30 Image of data overlap

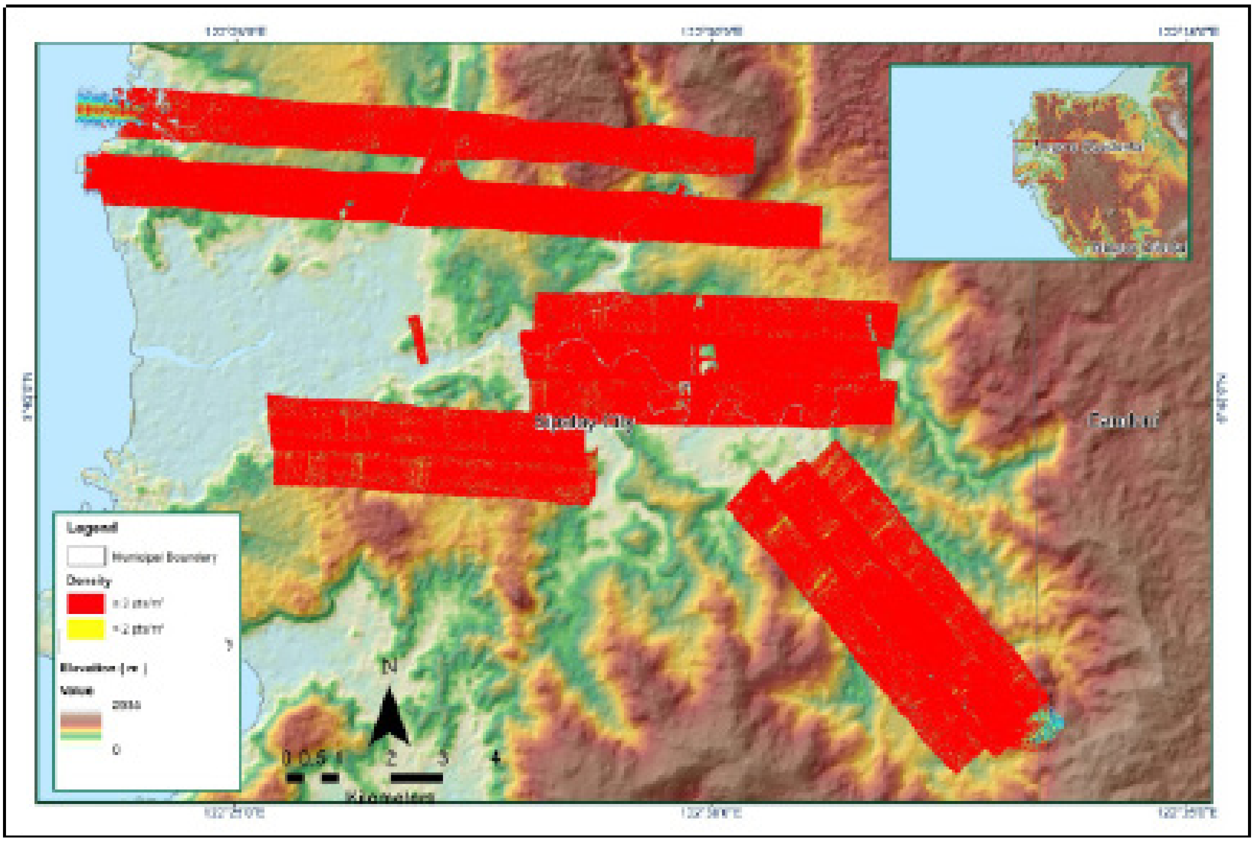


Figure A-8.31 Density map of merged LiDAR data

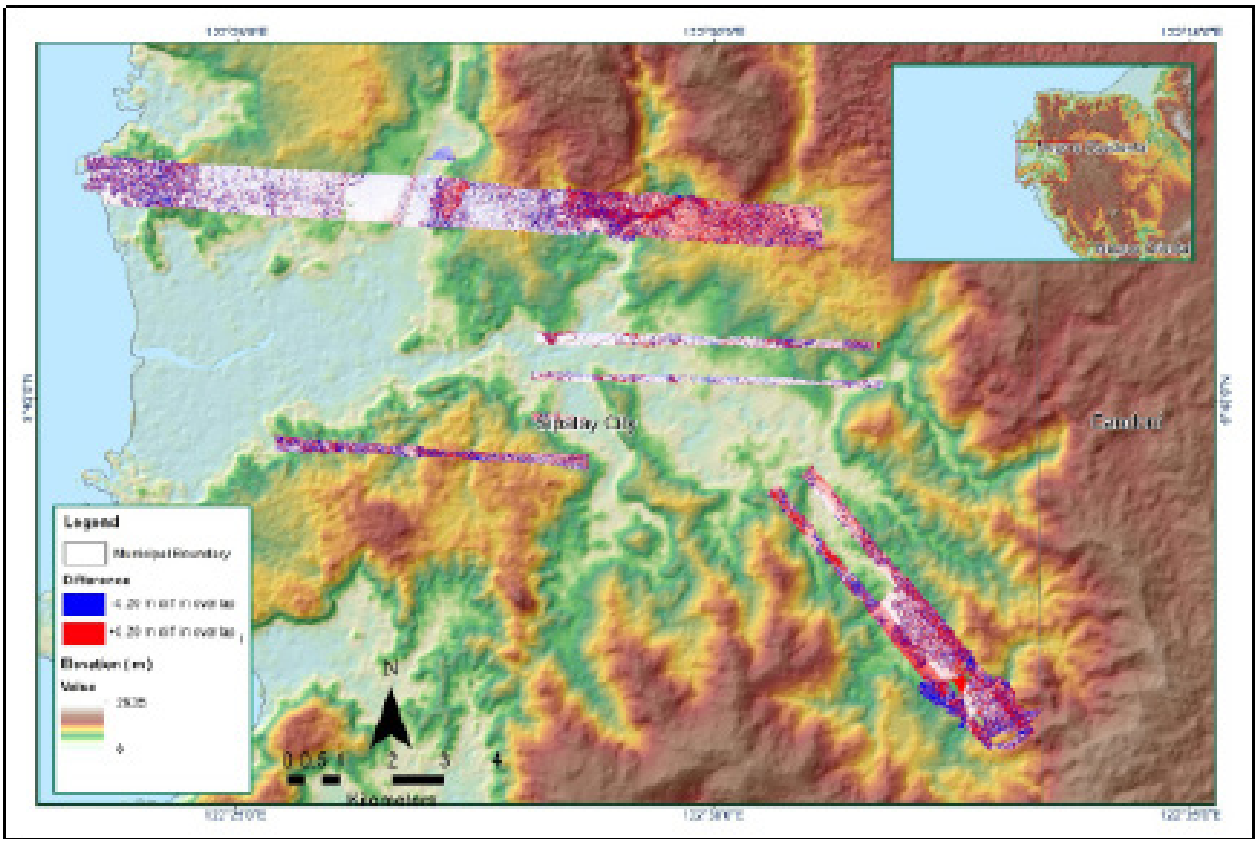


Figure A-8.32 Elevation difference between flight lines

Annex 9. Tignoan Model Basin Parameters

Table A-9.1. Tignoan 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
W1000	17.48439	64.117	0.0	1.043	1.85	Discharge	0.0306471	0.0438642	Ratio to Peak	0.30449
W1010	11.41938	40.132	0.0	0.79385	1.0547	Discharge	0.0194887	0.0371645	Ratio to Peak	0.2
W1020	10.36476	88.24	0.0	0.5664	2.9136	Discharge	0.0224999	0.0938519	Ratio to Peak	0.2
W520	12.52881	77.574	0.0	0.56334	3.6063	Discharge	0.0170944	0.0982189	Ratio to Peak	0.20401
W530	15.37893	52.235	0.0	0.59627	1.7041	Discharge	0.0326882	0.12238	Ratio to Peak	0.2
W540	12.019455	60.284	0.0	0.72411	2.56	Discharge	0.0176767	0.221	Ratio to Peak	0.19289
W550	9.46701	35.41	0.0	1.6242	2.8529	Discharge	0.0318997	0.31833	Ratio to Peak	0.20399
W560	10.54998	63.922	0.0	0.79661	0.33874	Discharge	0.0141134	0.32485	Ratio to Peak	0.2
W570	16.24077	55.107	0.0	0.70283	2.8063	Discharge	0.0291826	0.15073	Ratio to Peak	0.2
W580	10.798515	68.485	0.0	0.8283	2.2724	Discharge	0.0464024	0.3265	Ratio to Peak	0.18811
W590	11.431665	51.703	0.0	0.87667	2.3016	Discharge	0.0367056	0.66667	Ratio to Peak	0.18335
W600	22.17915	58.298	0.0	0.78852	0.4133	Discharge	0.0128853	0.0906533	Ratio to Peak	0.31061
W610	13.075965	60.918	0.0	0.6222	2.0538	Discharge	0.0499657	0.33697	Ratio to Peak	0.2
W620	16.644285	56.97	0.0	1.1204	2.6069	Discharge	0.0449782	0.34666	Ratio to Peak	0.19208
W630	10.781505	55.366	0.0	0.38853	3.872	Discharge	0.0059316	0.34142	Ratio to Peak	0.2
W640	13.95954	75.99	0.0	0.25908	0.18665	Discharge	0.0025615	0.15477	Ratio to Peak	0.2
W650	9.98109	67.008	0.0	0.83084	4.0304	Discharge	0.0167600	0.12734	Ratio to Peak	0.68912
W660	15.86466	59.653	0.0	0.56793	1.5793	Discharge	0.0177964	0.46668	Ratio to Peak	0.1325
W670	11.800215	79.519	0.0	0.51827	0.2987	Discharge	0.0033658	0.31043	Ratio to Peak	0.46356
W680	11.81628	61.568	0.0	0.56061	1.5164	Discharge	0.0142374	0.14502	Ratio to Peak	0.19801
W690	9.460395	65.374	0.0	0.52111	2.16	Discharge	0.0155434	0.21316	Ratio to Peak	1
W700	16.914555	59.462	0.0	0.7869	1.9374	Discharge	0.0271112	0.15335	Ratio to Peak	0.2
W710	16.065945	57.152	0.0	1.8358	5.2558	Discharge	0.0463375	0.10223	Ratio to Peak	0.2

W720	9.777915	50.586	0.0	1.381	2.8089	Discharge	0.0827620	0.0684844	Ratio to Peak	0.2
W730	6.210918	76.173	0.0	1.4918	3.5121	Discharge	0.0462106	0.0463156	Ratio to Peak	0.17139
W740	11.144385	60.567	0.0	3.3774	1.6155	Discharge	0.0273980	0.061614	Ratio to Peak	0.17845
W750	11.14533	64.851	0.0	0.66214	0.13052	Discharge	0.0195795	0.0298239	Ratio to Peak	0.17716
W760	8.394435	64.237	0.0	0.4783	0.0967263	Discharge	0.0246981	0.0438412	Ratio to Peak	0.18447
W770	7.6296465	66.497	0.0	0.69228	0.0674726	Discharge	0.0309123	0.0131195	Ratio to Peak	0.196
W780	14.822325	78.251	0.0	0.18209	2.6286	Discharge	0.0163275	0.13509	Ratio to Peak	0.18447
W790	14.654115	53.522	0.0	0.26873	0.0905158	Discharge	0.0035907	0.31649	Ratio to Peak	0.0592593
W800	35.463015	35.193	0.0	0.72975	0.15105	Discharge	0.0164875	0.17971	Ratio to Peak	0.0348444
W810	27.73575	47.07	0.0	0.88606	0.0829401	Discharge	0.0011863	0.18622	Ratio to Peak	0.0803485
W820	3.9294045	99	0.0	0.71863	0.14385	Discharge	0.0070113	0.52225	Ratio to Peak	0.19208
W830	11.43261	99	0.0	0.20961	0.0590071	Discharge	0.0017139	0.0355392	Ratio to Peak	0.17015
W840	20.1852	98.418	0.0	0.34891	3.5644	Discharge	0.0132341	0.041088	Ratio to Peak	0.19208
W850	10.82025	59.297	0.0	0.19261	0.0869513	Discharge	0.0017254	0.0924587	Ratio to Peak	0.17716
W860	14.66262	57.449	0.0	1.6598	3.7163	Discharge	0.11894	0.2069	Ratio to Peak	0.18078
W870	2.918727	99	0.0	0.46621	0.0569106	Discharge	0.0020599	0.17888	Ratio to Peak	0.0836615
W880	20.063295	80.226	0.0	0.14905	0.0635693	Discharge	.000771186	0.13047	Ratio to Peak	0.18078
W890	2.178792	37.262	0.0	0.50261	0.21083	Discharge	0.0157668	0.5225	Ratio to Peak	0.18078
W900	6.459453	39.176	0.0	0.58031	0.2013	Discharge	0.0283696	0.10222	Ratio to Peak	0.31041
W910	21.46662	56.702	0.0	1.794	1.4636	Discharge	0.0334464	0.26506	Ratio to Peak	0.12806
W920	16.93818	81.178	0.0	0.382	0.15411	Discharge	0.0049255	0.34632	Ratio to Peak	0.18372
W930	3.0316545	46.488	0.0	0.57435	0.1424	Discharge	0.0160118	1	Ratio to Peak	1
W940	26.398575	75.795	0.0	2.2003	0.5396	Discharge	0.0386545	0.064159	Ratio to Peak	0.18912
W950	24.01812	84.551	0.0	2.3338	1.514	Discharge	0.0431504	0.12542	Ratio to Peak	0.18447
W960	11.43639	56.289	0.0	0.46041	0.25212	Discharge	0.0066279	0.13588	Ratio to Peak	0.20399
W970	8.2902015	55.244	0.0	0.69626	1.2706	Discharge	0.0245958	0.0870671	Ratio to Peak	0.2
W980	18.8433	89.168	0.0	0.40321	2.8446	Discharge	0.0321102	0.37736	Ratio to Peak	0.2
W990	44.187255	38.536	0.0	1.0433	1.1684	Discharge	0.0266240	0.0651351	Ratio to Peak	0.69504

Annex 10. Tignoan Model Reach Parameters

Table A-10.1. Tignoan Model Reach Parameters

	Muskingum Cunge Channel Routing						
	Reach Number	Muskingum Cunge Channel Routing	Slope	Manning's n	Shape	Width	Side Slope
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R100	Automatic Fixed Interval	1157.1	0.0762243	0.04	Trapezoid	28	0.5
R110	Automatic Fixed Interval	796.69	0.0266814	0.04	Trapezoid	28	0.5
R130	Automatic Fixed Interval	437.28	0.0354605	0.04	Trapezoid	28	0.5
R140	Automatic Fixed Interval	579.71	0.0289820	0.04	Trapezoid	28	0.5
R150	Automatic Fixed Interval	2585.2	0.0261333	0.04	Trapezoid	28	0.5
R170	Automatic Fixed Interval	976.69	0.0421822	0.04	Trapezoid	28	0.5
R180	Automatic Fixed Interval	1195.7	0.0147258	0.04	Trapezoid	28	0.5
R240	Automatic Fixed Interval	2130.8	0.0038119	0.04	Trapezoid	28	0.5
R270	Automatic Fixed Interval	98.995	0.004	0.04	Trapezoid	28	0.5
R280	Automatic Fixed Interval	141.42	0.004	0.04	Trapezoid	28	0.5
R290	Automatic Fixed Interval	2728.1	0.0148073	0.04	Trapezoid	28	0.5
R300	Automatic Fixed Interval	2987.6	0.0115979	0.04	Trapezoid	28	0.5
R320	Automatic Fixed Interval	595.27	0.0472148	0.04	Trapezoid	28	0.5
R330	Automatic Fixed Interval	298.70	0.004	0.04	Trapezoid	28	0.5
R350	Automatic Fixed Interval	257.28	0.0477072	0.04	Trapezoid	28	0.5
R360	Automatic Fixed Interval	352.84	0.0333841	0.04	Trapezoid	28	0.5
R370	Automatic Fixed Interval	1244.3	0.0041259	0.04	Trapezoid	28	0.5
R390	Automatic Fixed Interval	716.98	0.0196520	0.04	Trapezoid	28	0.5
R40	Automatic Fixed Interval	1115.7	0.0815806	0.04	Trapezoid	28	0.5

R410	Automatic Fixed Interval	899.71	0.0087369	0.04	Trapezoid	28	0.5
R430	Automatic Fixed Interval	2510.7	0.0458811	0.04	Trapezoid	28	0.5
R460	Automatic Fixed Interval	1226.4	0.0373412	0.04	Trapezoid	28	0.5
R470	Automatic Fixed Interval	1148.7	0.0254538	0.04	Trapezoid	28	0.5
R480	Automatic Fixed Interval	5089.0	0.0204656	0.04	Trapezoid	28	0.5
R70	Automatic Fixed Interval	1971.7	0.0452980	0.04	Trapezoid	28	0.5

Annex 11. Tignoan Field Validation Points

Table A-11.1.Tignoan Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	14.553287	121.625073	0.03	0.5	0.470	Winnie Nov.30,2004	5 -Year
2	14.552946	121.625219	0.05	0.5	0.450	Winnie Nov.30,2004	5 -Year
3	14.552468	121.62547	0.03	0.5	0.470	Winnie Nov.30,2004	5 -Year
4	14.551553	121.625698	0.03	0.5	0.470	Winnie Nov.30,2004	5 -Year
5	14.55132	121.625738	0.18	0.5	0.320	Winnie Nov.30,2004	5 -Year
6	14.549243	121.626554	0.04	0.5	0.460	Winnie Nov.30,2004	5 -Year
7	14.547057	121.626137	0.03	0.5	0.470	Winnie Nov.30,2004	5 -Year
8	14.564394	121.620076	0.04	0.5	0.460	Winnie Nov.30,2004	5 -Year
9	14.563887	121.619469	0.06	1.3	1.240	Winnie Nov.30,2004	5 -Year
10	14.56215	121.62378	0.03	1.3	1.270	Winnie Nov.30,2004	5 -Year
11	14.561212	121.624491	0.09	1.3	1.210	Winnie Nov.30,2004	5 -Year
12	14.556927	121.624844	0.05	1.3	1.250	Winnie Nov.30,2004	5 -Year
13	14.556726	121.624773	0.13	1.3	1.170	Winnie Nov.30,2004	5 -Year
14	14.553961	121.625019	0.09	1.3	1.210	Winnie Nov.30,2004	5 -Year
15	14.563456	121.619236	0.14	1.3	1.160	Winnie Nov.30,2004	5 -Year
16	14.562631	121.619245	0.38	1.4	1.020	Winnie Nov.30,2004	5 -Year
17	14.562513	121.619322	0.14	1.4	1.260	Winnie Nov.30,2004	5 -Year
18	14.556866	121.6248	0.09	1.4	1.310	Winnie Nov.30,2004	5 -Year
19	14.563246	121.619048	0.88	1.4	0.520	Winnie Nov.30,2004	5 -Year
20	14.554595	121.624993	0.03	1.5	1.470	Winnie Nov.30,2004	5 -Year
21	14.554175	121.625013	0.07	1.5	1.430	Winnie Nov.30,2004	5 -Year
22	14.563155	121.619206	0.21	1.5	1.290	Winnie Nov.30,2004	5 -Year
23	14.562817	121.619205	0.33	1.5	1.170	Winnie Nov.30,2004	5 -Year

24	14.562483	121.619512	0.07	1.5	1.430	Winnie Nov.30,2004	5 -Year
25	14.563652	121.61923	0.27	1.5	1.230	Winnie Nov.30,2004	5 -Year
26	14.564244	121.619883	0.03	1.5	1.470	Winnie Nov.30,2004	5 -Year
27	14.564469	121.620188	0.04	1.5	1.460	Winnie Nov.30,2004	5 -Year
28	14.562312	121.623924	0.03	1.5	1.470	Winnie Nov.30,2004	5 -Year
29	14.5607	121.624816	0.03	1.5	1.470	Winnie Nov.30,2004	5 -Year
30	14.563497	121.615688	0.08	1.5	1.420	Winnie Nov.30,2004	5 -Year
31	14.562313	121.61944	0.06	1	0.940	Winnie Nov.30,2004	5 -Year
32	14.564137	121.619757	0.03	1	0.970	Winnie Nov.30,2004	5 -Year
33	14.563045	121.619277	0.1	1	0.900	Winnie Nov.30,2004	5 -Year
34	14.565064	121.619252	3.72	2	-1.720	Winnie Nov.30,2004	5 -Year
35	14.564976	121.619005	3.8099999	2	-1.810	Winnie Nov.30,2004	5 -Year
36	14.565175	121.616344	0.41	2	1.590	Winnie Nov.30,2004	5 -Year
37	14.564997	121.615687	0.03	2	1.970	Winnie Nov.30,2004	5 -Year
38	14.56442	121.615044	3.5999999	2	-1.600	Winnie Nov.30,2004	5 -Year
39	14.564535	121.615043	5.9499998	2	-3.950	Winnie Nov.30,2004	5 -Year
40	14.564619	121.614914	6.71	2	-4.710	Winnie Nov.30,2004	5 -Year
41	14.564766	121.614658	6.2600002	2	-4.260	Winnie Nov.30,2004	5 -Year
42	14.564862	121.614465	6.1199999	2	-4.120	Winnie Nov.30,2004	5 -Year
43	14.565585	121.620108	1.62	2	0.380	Winnie Nov.30,2004	5 -Year
44	14.565023	121.614192	4.8499999	2	-2.850	Winnie Nov.30,2004	5 -Year
45	14.565168	121.613969	5.1100001	2	-3.110	Winnie Nov.30,2004	5 -Year
46	14.565287	121.613742	3.4300001	2	-1.430	Winnie Nov.30,2004	5 -Year
47	14.565382	121.613568	3.5699999	2	-1.570	Winnie Nov.30,2004	5 -Year
48	14.563924	121.615013	1.67	2	0.330	Winnie Nov.30,2004	5 -Year
49	14.565536	121.619967	1.49	2	0.510	Winnie Nov.30,2004	5 -Year
50	14.565487	121.619849	1.6799999	2	0.320	Winnie Nov.30,2004	5 -Year
51	14.565445	121.619757	1.45	2	0.550	Winnie Nov.30,2004	5 -Year

52	14.565389	121.619609	2.7	2	-0.700	Winnie Nov.30,2004	5 -Year
53	14.565329	121.619555	3.47	2	-1.470	Winnie Nov.30,2004	5 -Year
54	14.565204	121.619516	4.5100002	2	-2.510	Winnie Nov.30,2004	5 -Year
55	14.565117	121.619415	3.6300001	2	-1.630	Winnie Nov.30,2004	5 -Year
56	14.565651	121.620063	1.23	2	0.770	Winnie Nov.30,2004	5 -Year
57	14.580303	121.617601	0.06	5.5	5.440	Winnie Nov.30,2004	5 -Year
58	14.563612	121.618798	0.51	5	4.490	Winnie Nov.30,2004	5 -Year
59	14.563363	121.618891	0.59	5	4.410	Winnie Nov.30,2004	5 -Year
60	14.56328	121.6189	0.62	5	4.380	Winnie Nov.30,2004	5 -Year
61	14.563159	121.619081	0.67	5	4.330	Winnie Nov.30,2004	5 -Year
62	14.563229	121.619192	0.28	5	4.720	Winnie Nov.30,2004	5 -Year
63	14.580734	121.617537	0.06	5	4.940	Winnie Nov.30,2004	5 -Year
64	14.580594	121.617477	0.11	5	4.890	Winnie Nov.30,2004	5 -Year
65	14.579485	121.617605	0.06	5	4.940	Winnie Nov.30,2004	5 -Year
66	14.57947	121.617687	0.07	5	4.930	Winnie Nov.30,2004	5 -Year
67	14.566262	121.621149	0.06	5	4.940	Winnie Nov.30,2004	5 -Year
68	14.579596	121.617723	0.04	5	4.960	Winnie Nov.30,2004	5 -Year
69	14.579611	121.61793	0.12	5	4.880	Winnie Nov.30,2004	5 -Year
70	14.580145	121.61817	0.14	5	4.860	Winnie Nov.30,2004	5 -Year
71	14.580775	121.617934	0.03	5	4.970	Winnie Nov.30,2004	5 -Year
72	14.566015	121.620731	0.56	5	4.440	Winnie Nov.30,2004	5 -Year
73	14.565896	121.620491	0.03	5	4.970	Winnie Nov.30,2004	5 -Year
74	14.565722	121.620012	0.03	5	4.970	Winnie Nov.30,2004	5 -Year
75	14.565676	121.619791	0.03	5	4.970	Winnie Nov.30,2004	5 -Year
76	14.5652	121.613899	4.1399999	5	0.860	Winnie Nov.30,2004	5 -Year
77	14.564502	121.615157	2.73	5	2.270	Winnie Nov.30,2004	5 -Year
78	14.563539	121.615416	0.45	5	4.550	Winnie Nov.30,2004	5 -Year
79	14.566396	121.621379	0.4	6.2	5.800	Winnie Nov.30,2004	5 -Year

80	14.573436	121.619542	0.06	6.2	6.140	Winnie Nov.30,2004	5 -Year
81	14.57389	121.619387	0.2	6.3	6.100	Winnie Nov.30,2004	5 -Year
82	14.571334	121.61946	0.26	6.4	6.140	Winnie Nov.30,2004	5 -Year
83	14.57249	121.619801	0.29	6.5	6.210	Winnie Nov.30,2004	5 -Year
84	14.566331	121.621261	0.57	6.5	5.930	Winnie Nov.30,2004	5 -Year
85	14.565835	121.620388	0.53	6.5	5.970	Winnie Nov.30,2004	5 -Year
86	14.565785	121.620207	0.82	6.5	5.680	Winnie Nov.30,2004	5 -Year
87	14.574075	121.619293	0.37	6.5	6.130	Winnie Nov.30,2004	5 -Year
88	14.574573	121.619223	0.05	6	5.950	Winnie Nov.30,2004	5 -Year
89	14.566568	121.62159	0.03	6	5.970	Winnie Nov.30,2004	5 -Year
90	14.56666	121.621774	0.03	6	5.970	Winnie Nov.30,2004	5 -Year
91	14.566122	121.620944	0.64	6	5.360	Winnie Nov.30,2004	5 -Year
92	14.577448	121.6179	0.11	6	5.890	Winnie Nov.30,2004	5 -Year
93	14.577055	121.618631	0.26	6	5.740	Winnie Nov.30,2004	5 -Year
94	14.577457	121.618317	0.28	6	5.720	Winnie Nov.30,2004	5 -Year
95	14.578348	121.617815	0.11	6	5.890	Winnie Nov.30,2004	5 -Year
96	14.576253	121.618813	0.21	6	5.790	Winnie Nov.30,2004	5 -Year
97	14.57601	121.618901	0.41	6	5.590	Winnie Nov.30,2004	5 -Year
98	14.575518	121.619008	0.1	6	5.900	Winnie Nov.30,2004	5 -Year
99	14.578782	121.617771	0.1	6	5.900	Winnie Nov.30,2004	5 -Year
100	14.573887	121.618653	0.2	0.25	0.050	Winnie Nov.30,2004	5 -Year
101	14.569708	121.6209	0.04	0.25	0.210	Winnie Nov.30,2004	5 -Year
102	14.566908	121.622192	0.03	0.25	0.220	Winnie Nov.30,2004	5 -Year
103	14.573009	121.619109	0.36	0.25	-0.110	Winnie Nov.30,2004	5 -Year
104	14.572971	121.619034	0.21	0.25	0.040	Winnie Nov.30,2004	5 -Year
105	14.572772	121.619093	0.06	0.25	0.190	Winnie Nov.30,2004	5 -Year
106	14.572614	121.619138	0.03	0.25	0.220	Winnie Nov.30,2004	5 -Year
107	14.572303	121.619141	0.1	0.25	0.150	Winnie Nov.30,2004	5 -Year

108	14.571459	121.619435	0.14	0.25	0.110	Winnie Nov.30,2004	5 -Year
109	14.571448	121.619523	0.25	0.25	0.000	Winnie Nov.30,2004	5 -Year
110	14.571245	121.61949	0.24	0.25	0.010	Winnie Nov.30,2004	5 -Year
111	14.573231	121.618843	0.1	0.25	0.150	Winnie Nov.30,2004	5 -Year
112	14.579073	121.617703	0.07	0.2	0.130	Winnie Nov.30,2004	5 -Year
113	14.579029	121.617701	0.09	0.2	0.110	Winnie Nov.30,2004	5 -Year
114	14.57896	121.617712	0.12	0.2	0.080	Winnie Nov.30,2004	5 -Year
115	14.57883	121.617724	0.13	0.2	0.070	Winnie Nov.30,2004	5 -Year
116	14.578677	121.617747	0.15	0.2	0.050	Winnie Nov.30,2004	5 -Year
117	14.578569	121.617766	0.06	0.2	0.140	Winnie Nov.30,2004	5 -Year
118	14.573809	121.61867	0.29	0.3	0.010	Winnie Nov.30,2004	5 -Year
119	14.577746	121.617897	0.05	0.3	0.250	Winnie Nov.30,2004	5 -Year
120	14.577607	121.617924	0.06	0.3	0.240	Winnie Nov.30,2004	5 -Year
121	14.577412	121.617966	0.13	0.3	0.170	Winnie Nov.30,2004	5 -Year
122	14.57724	121.618005	0.21	0.3	0.090	Winnie Nov.30,2004	5 -Year
123	14.576978	121.618062	0.2	0.3	0.100	Winnie Nov.30,2004	5 -Year
124	14.574471	121.618513	0.14	0.3	0.160	Winnie Nov.30,2004	5 -Year
125	14.574259	121.61854	0.08	0.3	0.220	Winnie Nov.30,2004	5 -Year
126	14.574053	121.618583	0.07	0.3	0.230	Winnie Nov.30,2004	5 -Year
127	14.575225	121.618368	0.14	0.5	0.360	Winnie Nov.30,2004	5 -Year
128	14.576422	121.618173	0.16	0.5	0.340	Winnie Nov.30,2004	5 -Year
129	14.576299	121.618172	0.29	0.5	0.210	Winnie Nov.30,2004	5 -Year
130	14.576172	121.618205	0.62	0.5	-0.120	Winnie Nov.30,2004	5 -Year
131	14.575978	121.618147	0.53	0.5	-0.030	Winnie Nov.30,2004	5 -Year
132	14.575899	121.618277	0.45	0.5	0.050	Winnie Nov.30,2004	5 -Year
133	14.575728	121.618289	0.46	0.5	0.040	Winnie Nov.30,2004	5 -Year
134	14.575566	121.618349	0.28	0.5	0.220	Winnie Nov.30,2004	5 -Year
135	14.575408	121.618354	0.23	0.5	0.270	Winnie Nov.30,2004	5 -Year

136	14.576545	121.618149	0.29	0.5	0.210	Winnie Nov.30,2004	5 -Year
137	14.564173	121.614627	1.64	1.5	-0.140	Winnie Nov.30,2004	5 -Year
138	14.5642	121.614513	1.6799999	1.5	-0.180	Winnie Nov.30,2004	5 -Year
139	14.56428	121.614363	1.62	1.5	-0.120	Winnie Nov.30,2004	5 -Year
140	14.564259	121.614257	1.6	1.5	-0.100	Winnie Nov.30,2004	5 -Year
141	14.56524	121.617419	0.04	1.5	1.460	Winnie Nov.30,2004	5 -Year
142	14.565257	121.617025	0.41	1.5	1.090	Winnie Nov.30,2004	5 -Year
143	14.565265	121.616681	0.06	1.5	1.440	Winnie Nov.30,2004	5 -Year
144	14.565355	121.616502	0.13	1.5	1.370	Winnie Nov.30,2004	5 -Year
145	14.565128	121.616125	0.73	1.5	0.770	Winnie Nov.30,2004	5 -Year
146	14.565049	121.615933	0.03	1.5	1.470	Winnie Nov.30,2004	5 -Year
147	14.564428	121.615103	2.45	1.5	-0.950	Winnie Nov.30,2004	5 -Year
148	14.56527	121.617697	0.06	1.5	1.440	Winnie Nov.30,2004	5 -Year
149	14.565642	121.619755	0.03	1	0.970	Winnie Nov.30,2004	5 -Year
150	14.565138	121.619455	3.7	1	-2.700	Winnie Nov.30,2004	5 -Year
151	14.565042	121.619189	3.6900001	1	-2.690	Winnie Nov.30,2004	5 -Year
152	14.564957	121.618933	4.1399999	1	-3.140	Winnie Nov.30,2004	5 -Year
153	14.564869	121.618638	5.1900001	1	-4.190	Winnie Nov.30,2004	5 -Year
154	14.564767	121.618303	4.6199999	1	-3.620	Winnie Nov.30,2004	5 -Year
155	14.564667	121.617996	4.9200001	1	-3.920	Winnie Nov.30,2004	5 -Year
156	14.565274	121.61852	0.91	1	0.090	Winnie Nov.30,2004	5 -Year
157	14.566656	121.621867	0.04	1	0.960	Winnie Nov.30,2004	5 -Year
158	14.565301	121.618045	0.09	1	0.910	Winnie Nov.30,2004	5 -Year
159	14.566573	121.62189	0.05	1	0.950	Winnie Nov.30,2004	5 -Year
160	14.566587	121.621755	0.03	1	0.970	Winnie Nov.30,2004	5 -Year
161	14.566335	121.621358	1.29	1	-0.290	Winnie Nov.30,2004	5 -Year
162	14.566223	121.621148	0.99	1	0.010	Winnie Nov.30,2004	5 -Year
163	14.565926	121.620573	0.39	1	0.610	Winnie Nov.30,2004	5 -Year

164	14.566737	121.621954	0.03	1	0.970	Winnie Nov.30,2004	5 -Year
165	14.564425	121.614042	1.05	2.5	1.450	Winnie Nov.30,2004	5 -Year
166	14.564497	121.613959	0.77	2.5	1.730	Winnie Nov.30,2004	5 -Year
167	14.564747	121.613804	1.1	2.5	1.400	Winnie Nov.30,2004	5 -Year
168	14.564844	121.613755	0.71	2.5	1.790	Winnie Nov.30,2004	5 -Year
169	14.564345	121.614149	1.39	2.5	1.110	Winnie Nov.30,2004	5 -Year
170	14.563465	121.615585	0.39	3	2.610	Winnie Nov.30,2004	5 -Year
171	14.563704	121.615944	0.81	3	2.190	Winnie Nov.30,2004	5 -Year
172	14.563801	121.616041	1.49	3	1.510	Winnie Nov.30,2004	5 -Year
173	14.563856	121.618655	0.08	3	2.920	Winnie Nov.30,2004	5 -Year
174	14.564936	121.613909	3.5599999	3	-0.560	Winnie Nov.30,2004	5 -Year
175	14.563986	121.618827	0.64	4	3.360	Winnie Nov.30,2004	5 -Year
176	14.564044	121.618938	1.29	4	2.710	Winnie Nov.30,2004	5 -Year
177	14.563747	121.618824	0.41	4	3.590	Winnie Nov.30,2004	5 -Year
178	14.56432	121.619265	4.6999998	5	0.300	Winnie Nov.30,2004	5 -Year
179	14.563624	121.619038	0.52	5	4.480	Winnie Nov.30,2004	5 -Year
180	14.5642	121.619049	2.6900001	5	2.310	Winnie Nov.30,2004	5 -Year

Annex 12. Educational Institutions affected by flooding in Tignoan Floodplain

Table A-12.1. Educational Institutions in Real, Quezon affected by flooding in the Tignoan Floodplain

Quezon				
Real				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Tignoan Elementary School	Malapad	Medium	Medium	High
Tanauan Day Care Center	Tanauan			
Tanauan Elementary School	Tanauan			

Annex 13. Health Institutions affected by flooding in Tignoan Floodplain

Table A-13.1. Health Institutions in Real, Quezon affected by flooding in the Tignoan Floodplain

Quezon				
Real				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Health Center	Malapad	High	High	High
Health Center	Tanauan			