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

LiDAR Surveys and Flood Mapping of Catanauan River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
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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

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UPC	University of the Philippines Cebu
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry

CHAPTER 1: OVERVIEW OF THE PROGRAM AND CATANAUAN RIVER

Enrico C. Paringit, Dr. Eng., Dr. Francis Aldrine A. 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 in 2014" or Phil-LiDAR 1, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied in this report are thoroughly described in a separate publication entitled "FLOOD MAPPING OF RIVERS IN THE PHILIPPINES USING AIRBORNE LIDAR: METHODS (Paringit, et. al. 2017) available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Baguio (UPB). UPB is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 26 river basins in the Southern Tagalog Region. The university is located in the City of Manila in Metro Manila.

1.2 Overview of the Catanauan River Basin

Located at the southern part of Luzon, the Catanauan river basin flows through the first class municipalities of Catanauan and Lopez in Quezon Province. Since these municipalities are situated within the usual tracks of typhoon, they have been witnesses to the some of the strongest and disastrous typhoons- Rosing (1995), Milenyo (2006), Glenda (2014) and Nina (2016). These areas are mainly dependent on agriculture but due to their hilly, rolling and mountainous landscape, and not to discount their pristine beaches, their boosting tourism become one of the sources of income of some residents.

Given their topography and geographical location, these two municipalities are prone to several disasters. During heavy rains and typhoons, flash flood and landslides often follow. In fact, Catanauan is typically on the watch list of the National Disaster Risk Reduction Management Council (NDRRMC) during typhoons. Moreover, according to Disaster Risk Reduction Climate Change Adaptation of Quezon Province, there had been an incident of a storm surge on this municipality last October 2009 during the typhoon Santi.

Indeed, there are high risks for the people of Catanauan and Lopez to this kind of disasters. In order to reduce risks associated with flooding and heavy rains, flood hazard maps would definitely be of great help. More accurate flood maps would only be possible if there are accurate elevation data gathered using light detection and ranging (LiDAR) technology leading to the production of reliable hydrological and river models. Communities would then be properly guided in formulating plans before, during and after typhoons or even heavy rains would hit their municipalities.

The majority of Catanauan River Basin covers the Municipalities of Catanauanand parts of the Municipalities of General Luna, Lopez and Buenavista in Quezon Province. The DENR River Basin Control Office, identified the basin to has a drainage area of 122 km2 and an estimated annual run-off of 195 million cubic meter (MCM) (RBCO, 2015).

Its main stem, Catanauan River, is part of the 26 river systems in Southern Tagalog Region. According to the 2010 national census of NSO, a total of 19,056 locals are residing in the immediate vicinity of the river which are distributed among the thirteen (13) barangays in Catanauan. The municipality is known for its archeological richness, where experts have retrieved burial jars, earthenware sherds, skeletal remains, and shell middens.The archeological potential of the Catanauan significantly helped the area from being a third-class to a first-class municipality. Widespread flooding in the area is very unusual even if it is often traversed by typhoons (Catanauan Archeological and Heritage Project, 2014). The Philippine Star in December 2015 reported that Typhoon 'Nona' is the most recent typhoon that hit Catanauan, leaving with no reported evacuees and casualties. The municipality just experienced dark Christmas since power and communication lines were down for several weeks.

CHAPTER 2: LIDAR DATA ACQUISITION OF THE CATANAUAN FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuna, Engr. Gerome Hipolito, Engr. Grace B. Sinadjan, and Ms. Jonalyn S. Gonzales

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).

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Catanauan floodplain in Quezon Province. These missions were planned for 10 lines that run for at most four (4) hours including take-off, landing and turning time.

The flight planning parameters for the LiDAR system is found in Table 1. Figure 1 shows the flight plan for Catanauan floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR System.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK 21E	1000	30	50	200	30	130	5
BLK 21F	1000	30	50	200	30	130	5
BLK 21D	1000	30	50	200	30	130	5
BLK 21I	1000	30	50	200	30	130	5
BLK 21H	1000	30	50	200	30	130	5

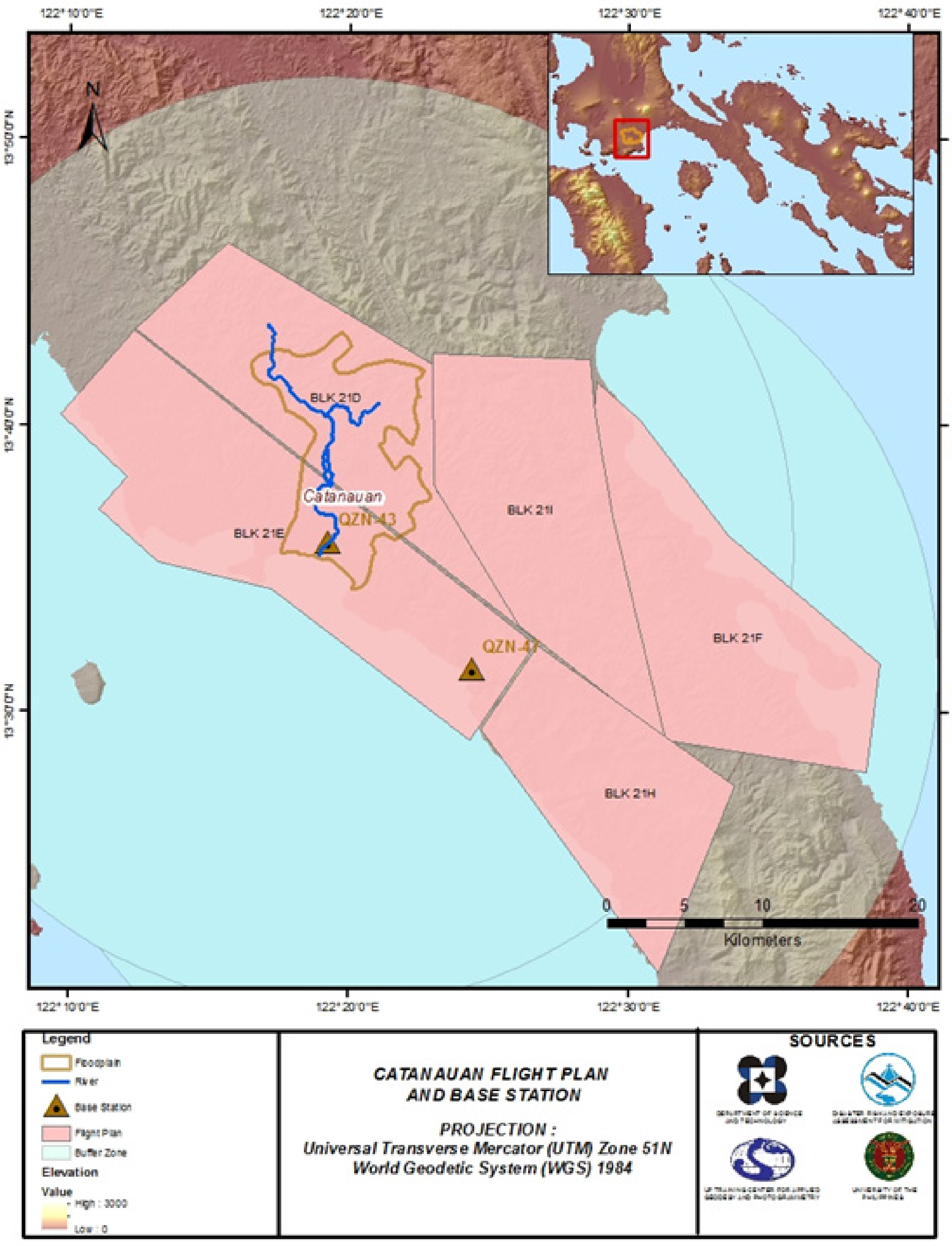


Figure 1. Flight plan and base stations used for Catanauan floodplain.

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA ground control points QZN-47 and QZN-43 which are of second (2nd) order accuracy. The certification for the base stations are found in Annex 2. These were used as base stations during flight operations for the entire duration of the survey (May 4-18, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TOPCON GR-5. Flight plans and location of base stations used during aerial LiDAR acquisition in Catanauan floodplain are shown in Figure 1.

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

Figure 2. GPS set-up over QZN-43 inside the DPWH compound of Brgy.10, Catanauan, Quezon.

Table 2. Details of the recovered NAMRIA horizontal control point QZN-43 used as base station for the LiDAR Acquisition.

Station Name	QZN-43	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 36’ 0.89019” North 122° 19’ 8.55832” East 3.53354 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	426309.396 meters 1504052.784 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 35’ 55.81611” North 122° 19’ 13.53031” East 53.08700 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	426,335.19 meters 1,503,526.34 meters

Figure 3. GPS set-up over QZN-47 on the center of Mulanay Elementary School oval, Brgy. DOS, Mulanay, Quezon.

Table 3. Details of the recovered NAMRIA horizontal control point QZN-47 used as base station for the LiDAR Acquisition.

Station Name	QZN-47	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 31’ 34.57412” North 122° 24’ 18.47045” East 5.99800 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	435605.783 meters 1495844.441 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 31’ 29.52488” North 122° 24’ 23.44821” East 55.96400 meters
Grid Coordinates, Universal Transverse Mercator Zone 52 North (UTM 52N PRS 92)	Easting Northing	435,628.32 meters 1,495,320.87 meters

Table 4. Ground control points used during LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
7 May 2016	23326P	1BLK21E128A	QZN-47 & QZN-43
10 May 2016	23334P	1BLK21F131A	QZN-47 & QZN-43
15 May 2016	23354P	1BLK21EF136A	QZN-47 & QZN-43
16 May 2016	23358P	1BLK21H137A	QZN-47 & QZN-43

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR Data Acquisition in Catanauan floodplain, for a total of seventeen hours and seven minutes (17+07) of flying time for RP-C9122. All missions were acquired using the Pegasus LiDAR system. Table 5 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 6 presents the actual parameters used during the LiDAR data acquisition.

Table 5. Flight Missions for LiDAR data acquisition in Catanauan 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
7 May 2016	23326P	884.7	206.57	38.82	167.75	NA	4	12
10 May 2016	23334P	884.7	203.67	71.87	131.8	NA	4	35
15 May 2016	23354P	884.7	191.52	3.39	188.13	NA	4	20
16 May 2016	23358P	884.7	324.59	3.31	321.28	NA	4	00
TOTAL		3538.8	464.8	38.98	415.37	NA	17	07

Table 6. Actual Parameters used during LiDAR Data Acquisition.

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (KHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23324P	1000	30	50	200	30	130	5
23334P	1000	30	50	200	30	130	5
23354	1000	30	50	200	30	130	5
23358P	1000	30	50	200	30	130	5

2.4 Survey Coverage

Catanauan floodplain is located in the province of Quezon with majority of floodplain situated within the municipality of Catanauan. The municipalities of Catanauan and General Luna are mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Catanauan floodplain is presented in Figure 4.

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

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Quezon	Catanauan	267.28	259.67	97.16%
	General Luna	119.16	104.39	87.61%
	Mulanay	262.91	225.88	85.92%
	San Narciso	241.20	89.57	37.13%
	Buenavista	157.40	34.20	21.73%
	San Francisco	320.48	16.41	5.12%
	Lopez	378.81	6.31	1.66%
Total		**1747.24**	**736.43**	**48.05%**

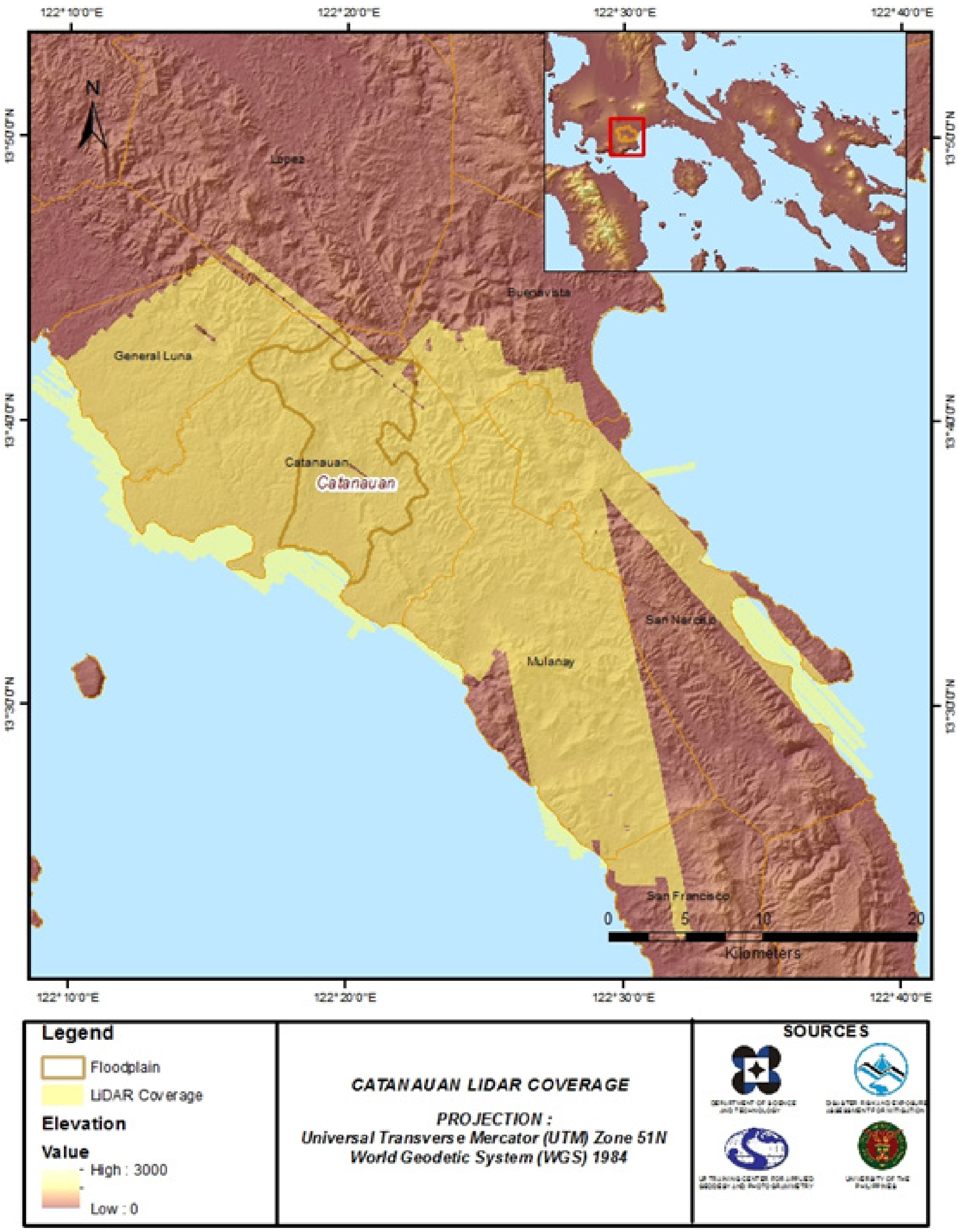


Figure 4. Actual LiDAR survey coverage for Catanauan floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE CATANAUAN 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, SEngr. Ma. Ailyn L. Olanda, Engr. Sheila-Maye F. Santillan, Engr. Merven Mattew D. Natino, 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 are checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory is done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification is performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds are subject for quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, are met. The point clouds are then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model.

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

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

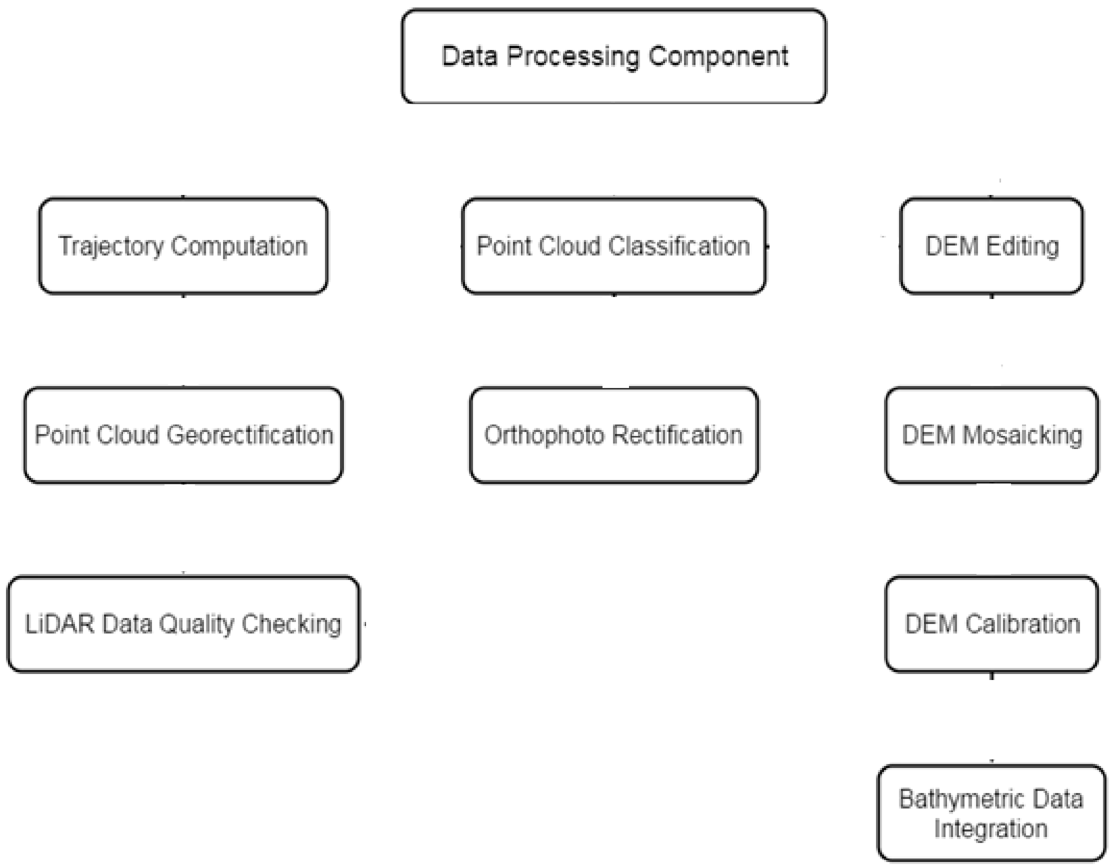


Figure 5. Schematic Diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Catanauan floodplain can be found in Annex 4. Missions flown during the survey conducted on May 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus over Catanauan, Quezon. The Data Acquisition Component (DAC) transferred a total of 123 Gigabytes of Range data, 1.08 Gigabytes of POS data, 356.2 Megabytes of GPS base station data, and 7.27 Gigabytes of raw image data to the data server on September 2016 for the survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Catanauan was fully transferred on September 6, 2016, as indicated on the Data Transfer Sheets for Catanauan floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 23326P, one of the Catanauan flights, which is the North, East, and Down position RMSE values are shown in Figure 6. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on May 07,2016 00:00AM. The y-axis is the RMSE value for that particular position.

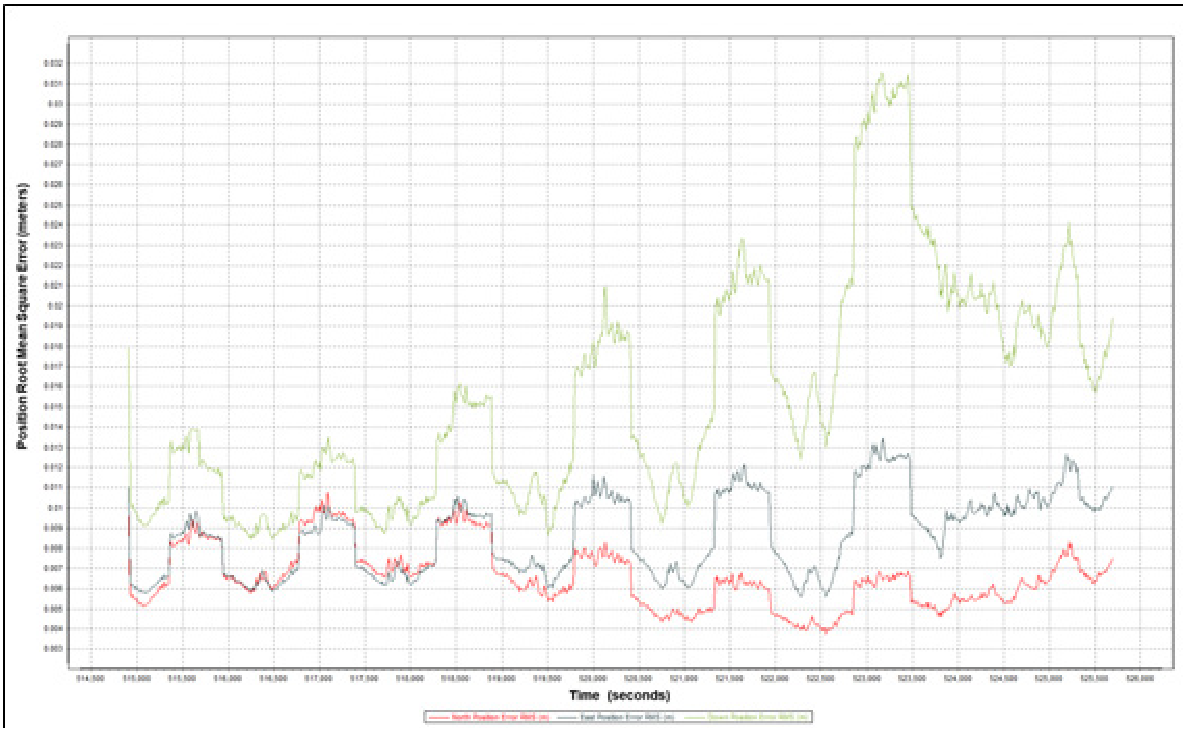


Figure 6. Smoothed Performance Metric Parameters of a Catanauan Flight 23326P.

The time of flight was from 515000 seconds to 526000 seconds, which corresponds to morning of May 07, 2016. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 6 shows that the North position RMSE peaks at 1.00 centimeters, the East position RMSE peaks at 1. 30 centimeters, and the Down position RMSE peaks at 3.20 centimeters, which are within the prescribed accuracies described in the methodology.

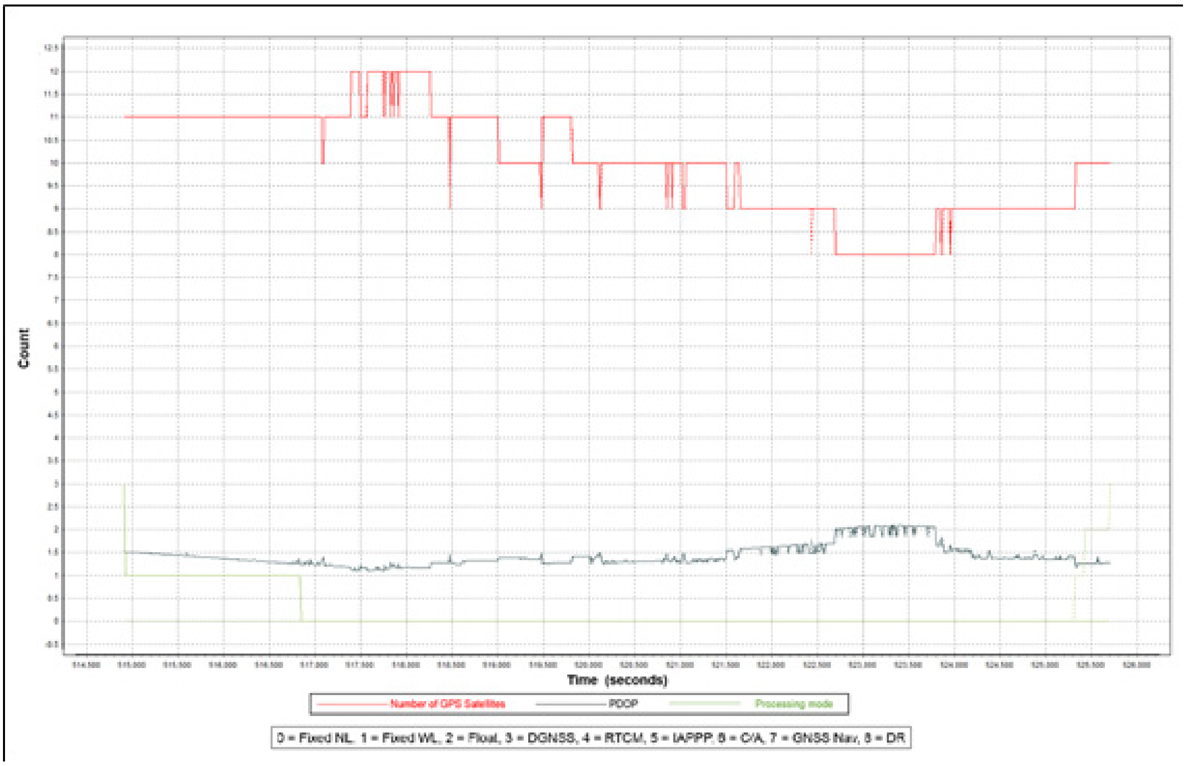


Figure 7. Solution Status Parameters of Catanauan Flight 23326P.

The Solution Status parameters of flight 23326P, one of the Catanauan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 7. The graphs indicate that the number of satellites during the acquisition did not go down to 8. Majority of the time, the number of satellites tracked was between 8 and 12. 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 Catanauan flights is shown in Figure 8.

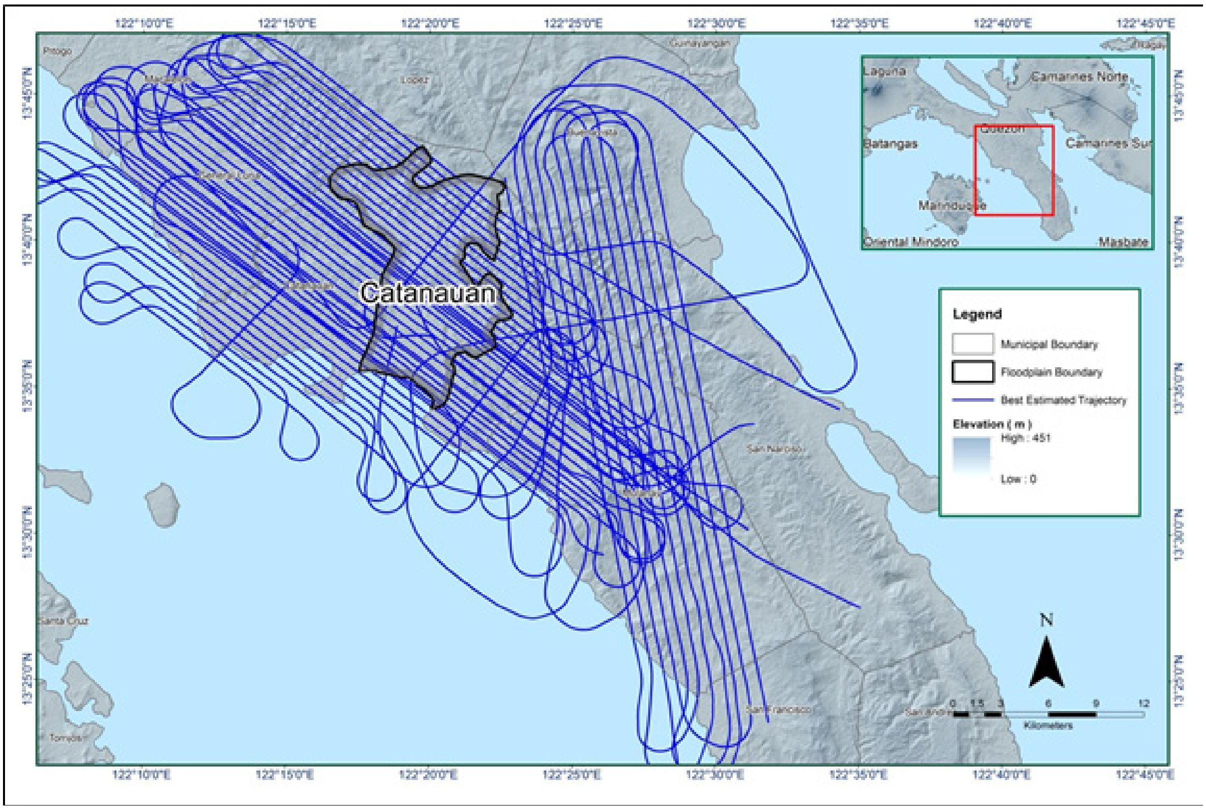


Figure 8. Best Estimated Trajectory for Catanauan floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 134 flight lines, with each flight line containing two channels, since 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 Catanauan floodplain are given in Table 8.

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

Parameter	Acceptable Value	Computed Value
Boresight Correction stdev)	<0.001degrees	0.000137
IMU Attitude Correction Roll and Pitch Corrections stdev)	<0.001degrees	0.000379
GPS Position Z-correction stdev)	<0.01meters	0.0065

The optimum accuracy is obtained for all Catanauan flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex 7. Mission Summary Reports.

3.5 LiDAR Quality Checking

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

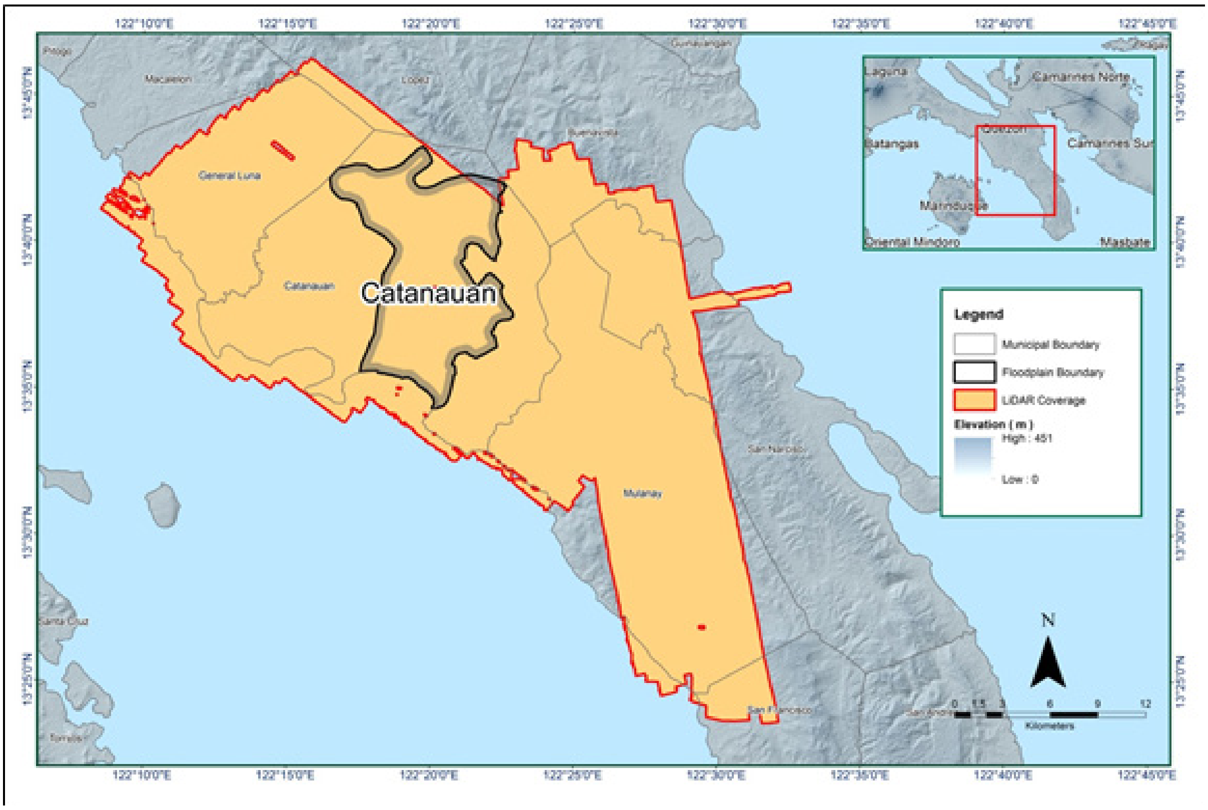


Figure 9. Boundary of the processed LiDAR data over Catanauan Floodplain.

The total area covered by the Catanauan missions is 853.40 sq.km that is comprised of four (4) flight acquisitions and four (4) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Catanauan floodplain.

LiDAR Blocks	Flight Numbers	Area (sq.km)
Bagasbas_Blk21E	23326P	202.75
Bagasbas_Blk21E_additional	23354P	124.89
Bagasbas_Blk21I	23358P	320.59
Bagasbas_Blk21D_supplement	23334P	205.17
TOTAL		**853.40 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 10. Since the Pegasus system employs two channels, we would expect an average value of 2 (blue) for areas where there is limited overlap, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines.

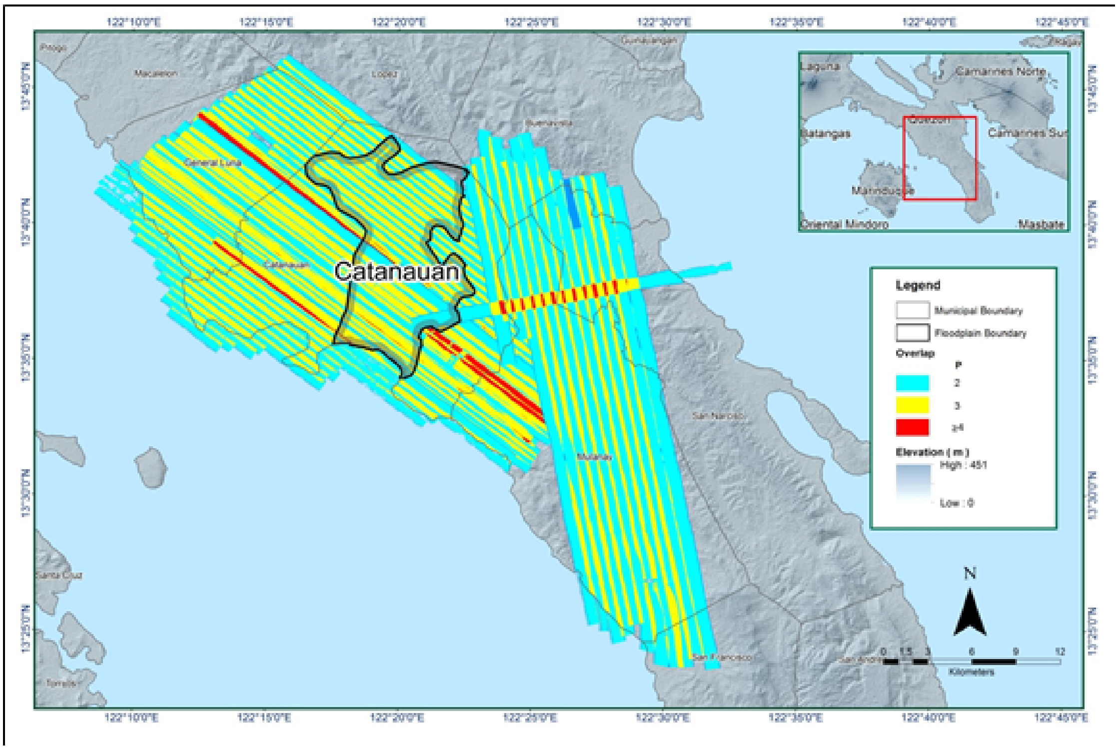


Figure 10. Image of data overlap for Catanauan floodplain.

The overlap statistics per block for the Catanauan floodplain can be found in Annex 7. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 32.49% and 57.10% respectively, which passed the 25% requirement.

The density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 11. It was determined that all LiDAR data for Catanauan floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.28 points per square meter.

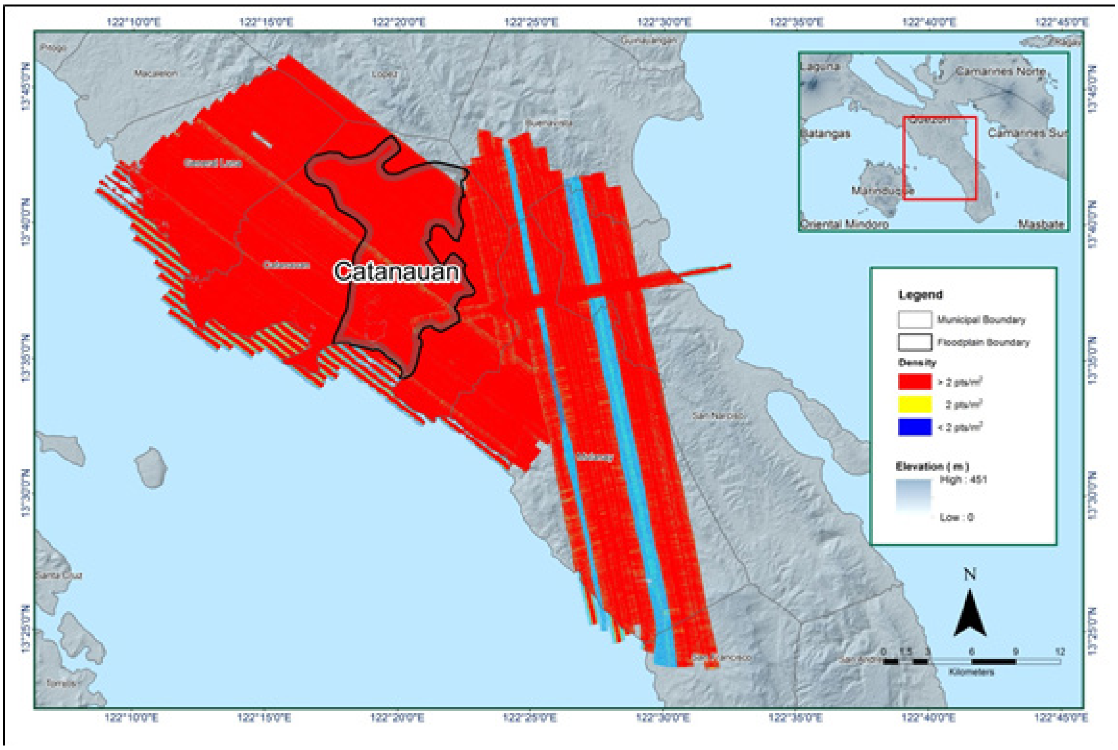


Figure 11. Density map of merged LiDAR data for Catanauan floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure B-8. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

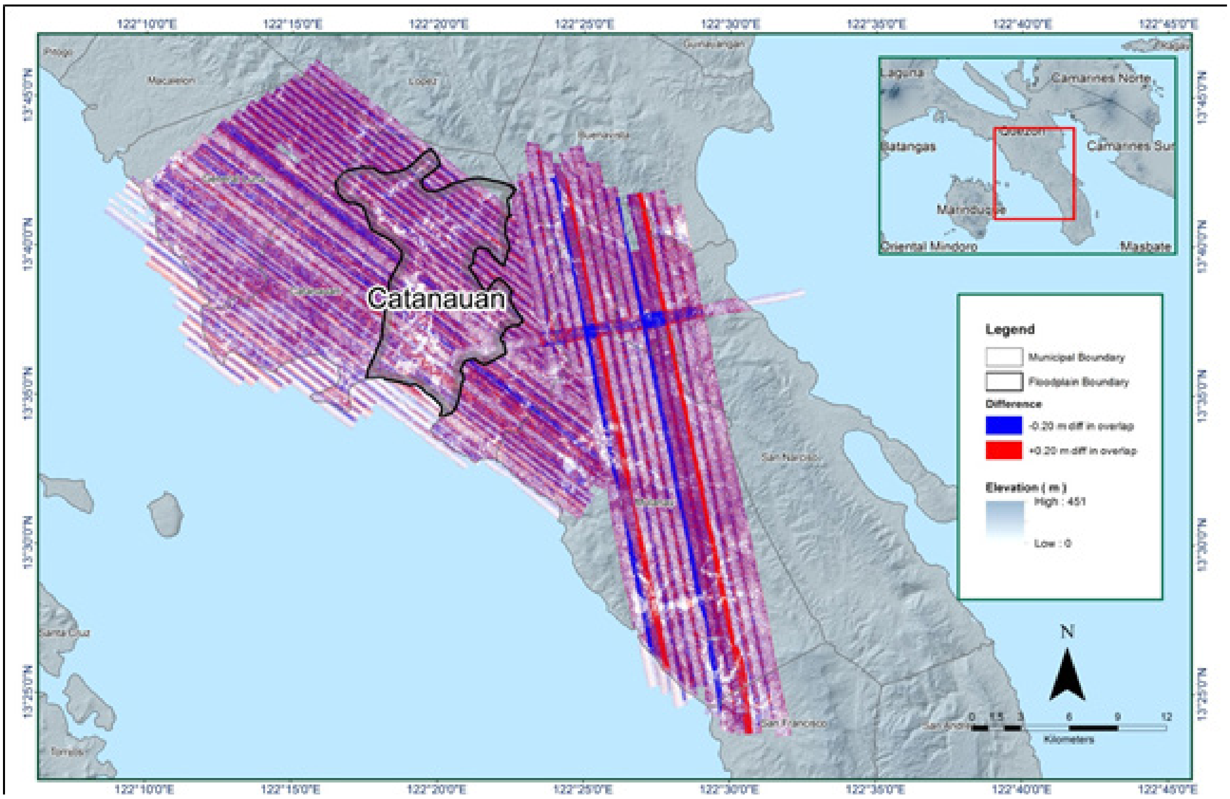


Figure 12. Elevation difference map between flight lines for Catanauan floodplain.

A screen capture of the processed LAS data from a Catanauan flight 23326P loaded in QT Modeler is shown in Figure 13. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

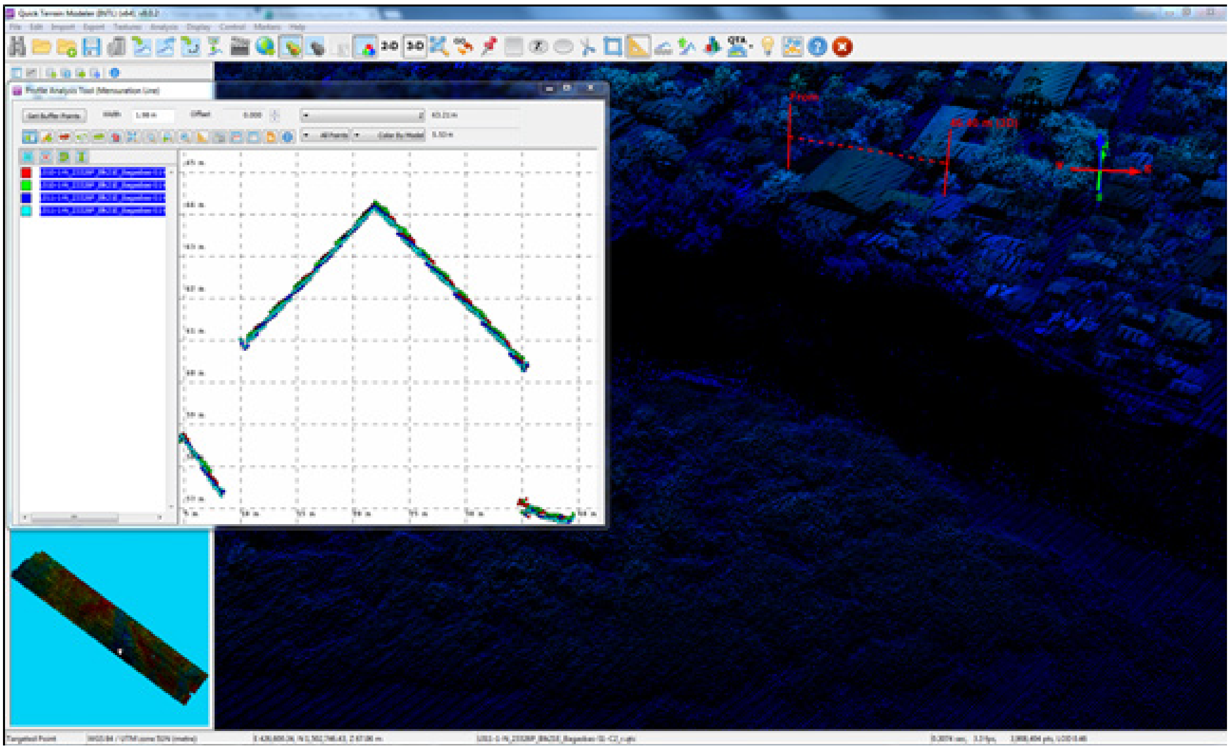


Figure 13. Quality checking for a Catanauan flight 23326P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Catanauan classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	952,112,219
Low Vegetation	739,246,312
Medium Vegetation	1,653,331,102
High Vegetation	3,959,248,246
Building	32,249,668

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Catanauan floodplain is shown in Figure 14. A total of 1,100 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 809.27 meters and 40.24 meters respectively.

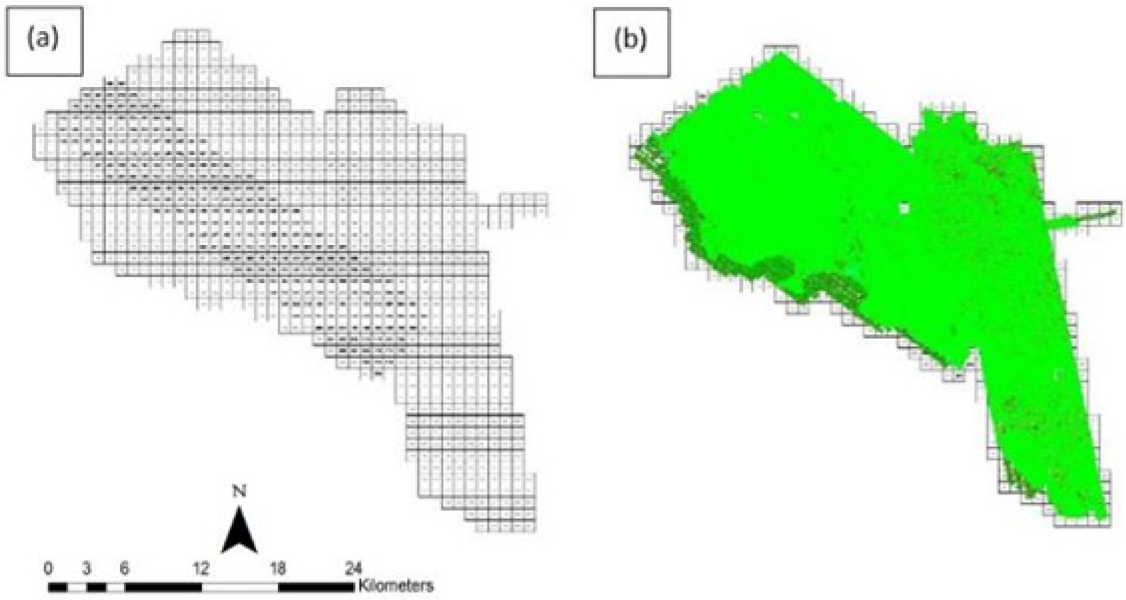


Figure 14. Tiles for Catanauan floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 15. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

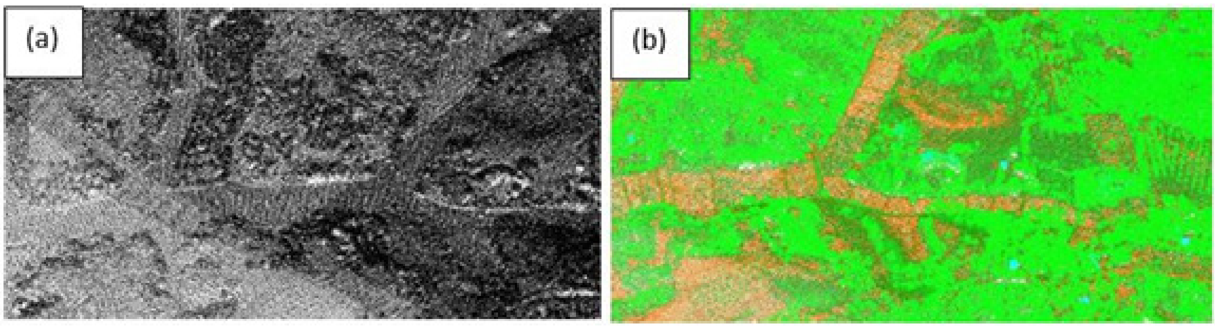


Figure 15. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 16. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

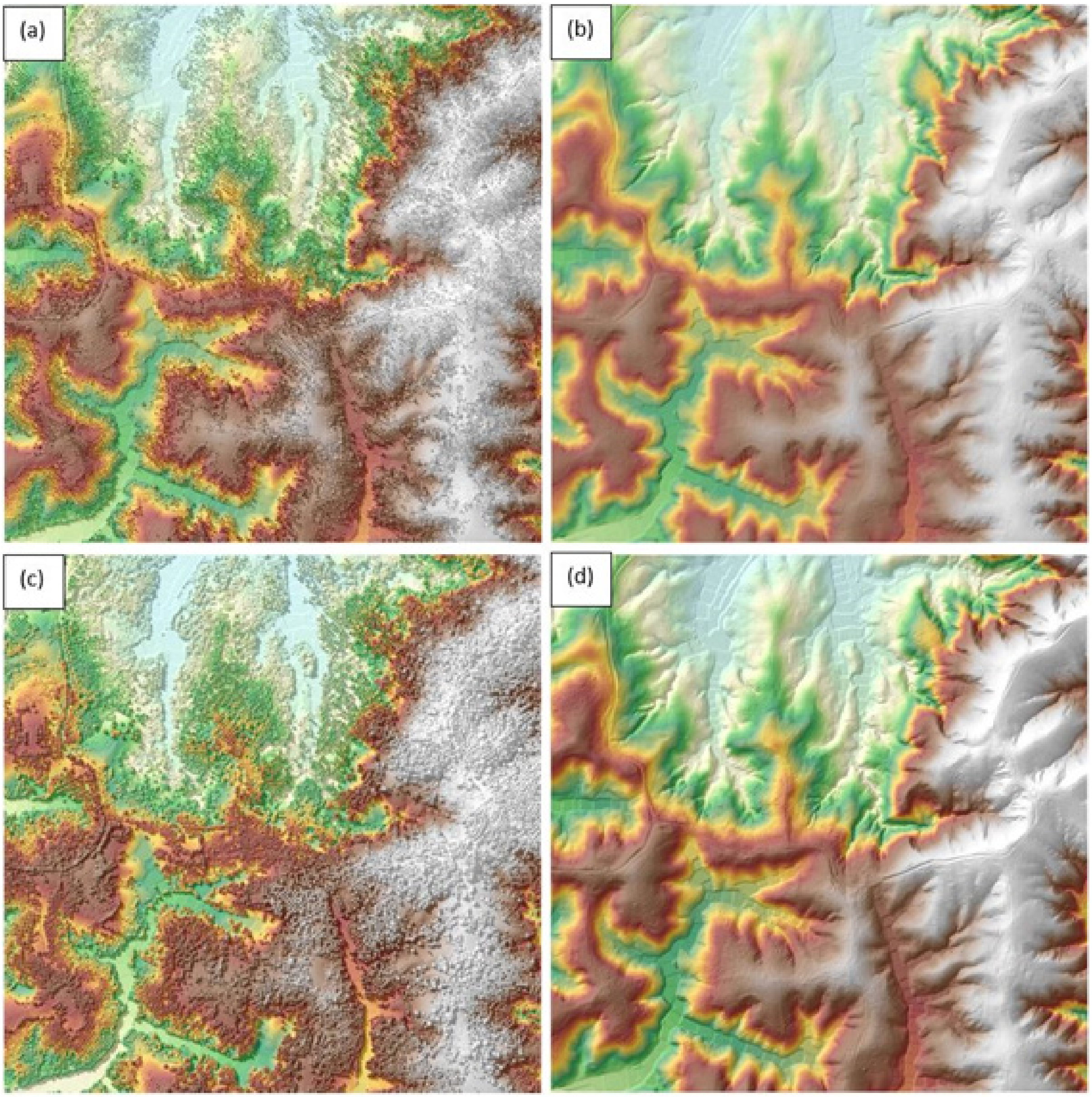


Figure 16. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Catanauan floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 71 1km by 1km tiles of the block covering the Catanauan floodplain is shown in Figure 17. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The block covering the Catanauan floodplain has a total of 36.84 sq.km orthophotogaph coverage comprised of 81 images. However, the block does not have a complete set of orthophotographs and no orthophotographs cover the area of the Catanauan floodplain. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 18.

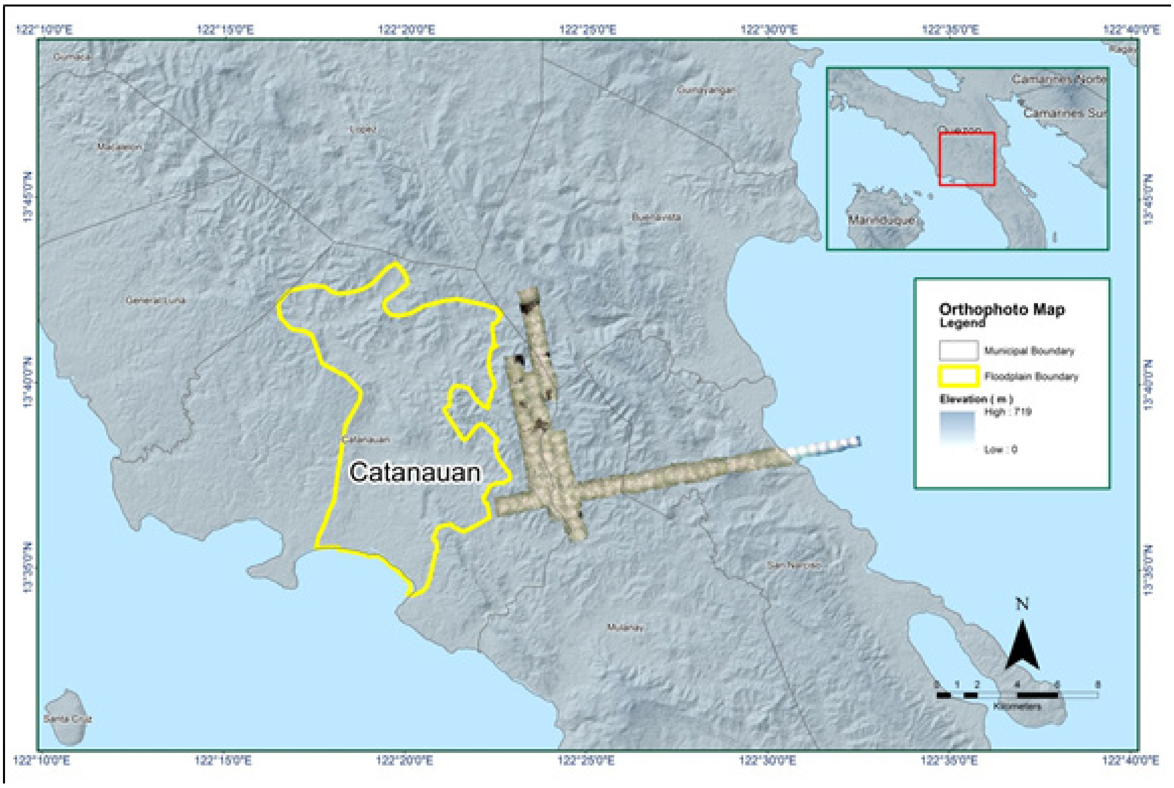


Figure 17. Available orthophotographs near Catanauan floodplain.

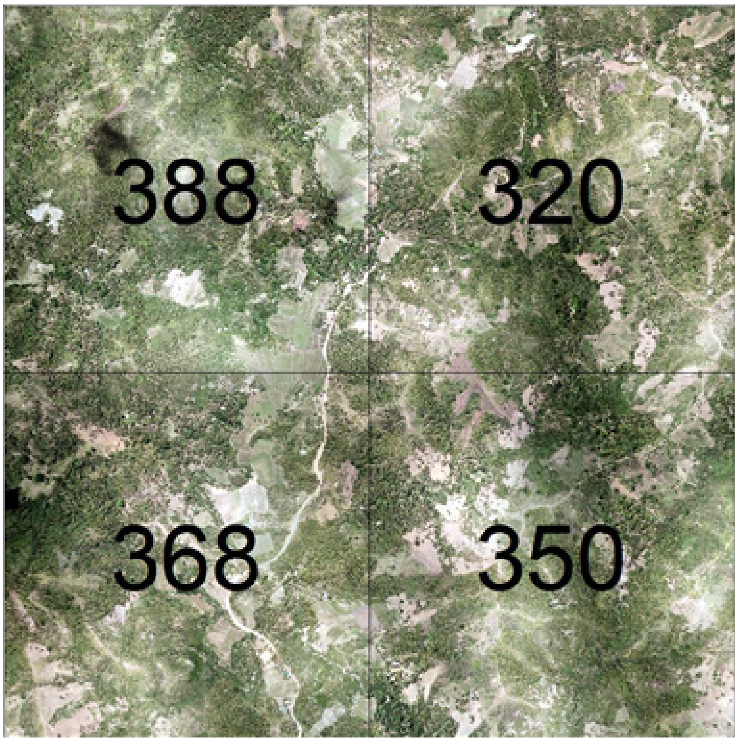


Figure 18. Sample orthophotograph tiles near Catanauan floodplain.

3.8 DEM Editing and Hydro-Correction

Four (4) mission blocks were processed for Catanauan flood plain. These blocks are composed of Bagasbas blocks with a total area of 853.4 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq. km.)
Bagasbas_Blk21D_supplement	205.17
Bagasbas_Blk21E	202.75
Bagasbas_Blk21E_additional	124.89
Bagasbas_Blk21I	320.59
TOTAL	853.40 sq.km

Portions of DTM before and after manual editing are shown in Figure 19. The bridge (Figure 19a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 19b) in order to hydrologically correct the river. Ridges (Figure 19c) have been misclassified and removed during classification process and have to be retrieved to complete the surface (Figure 19d) to allow the correct flow of water. Another example is a building that is still present in the DTM after classification (Figure 19e) and has to be removed through manual editing (Figure 19f).

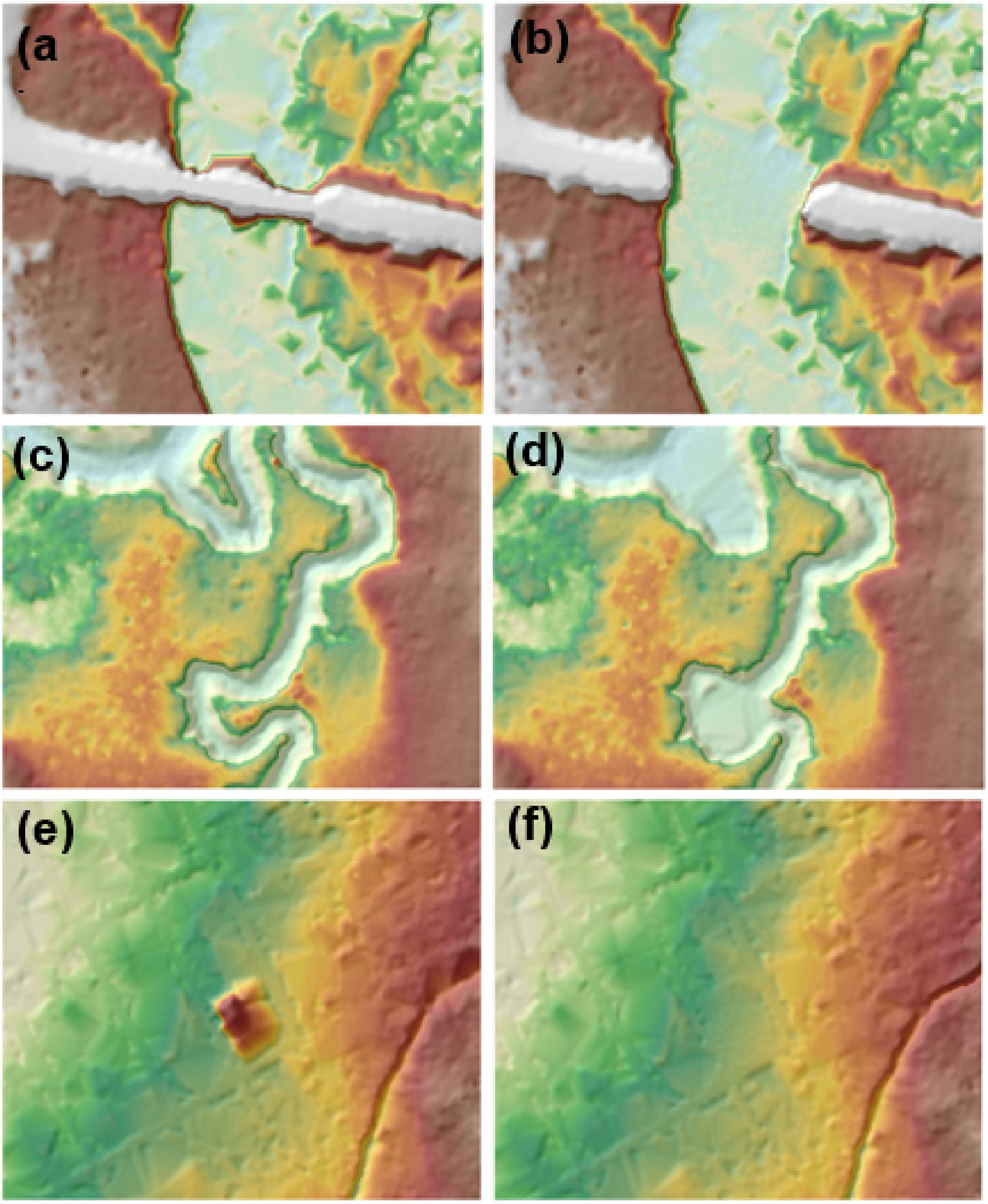


Figure 19. Portions in the DTM of Catanauan floodplain – a bridge before (a) and after (b) manual editing; ridges before (c) and after (d) data retrieval; and a building before (a) and after (b) manual editing.

3.9 Mosaicking of Blocks

Bagasbas_Blk20F was used as the reference block at the start of mosaicking because this block is the one used as a base for other floodplains covered by Bagasbas blocks. Bagasbas_Blk21D_supplement is the block closest to the reference block that covers Catanauan floodplain. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Catanauan floodplain is shown in Figure 20. It can be seen that the entire Catanauan floodplain is 98% covered by LiDAR data.

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Bagasbas_Blk21D_supplement	-1.28	0.98	0.65
Bagasbas_Blk21E	1.56	-1.30	0.50
Bagasbas_Blk21E_additional	1.08	-0.57	0.50
Bagasbas_Blk21I	-1.02	0.97	0.55

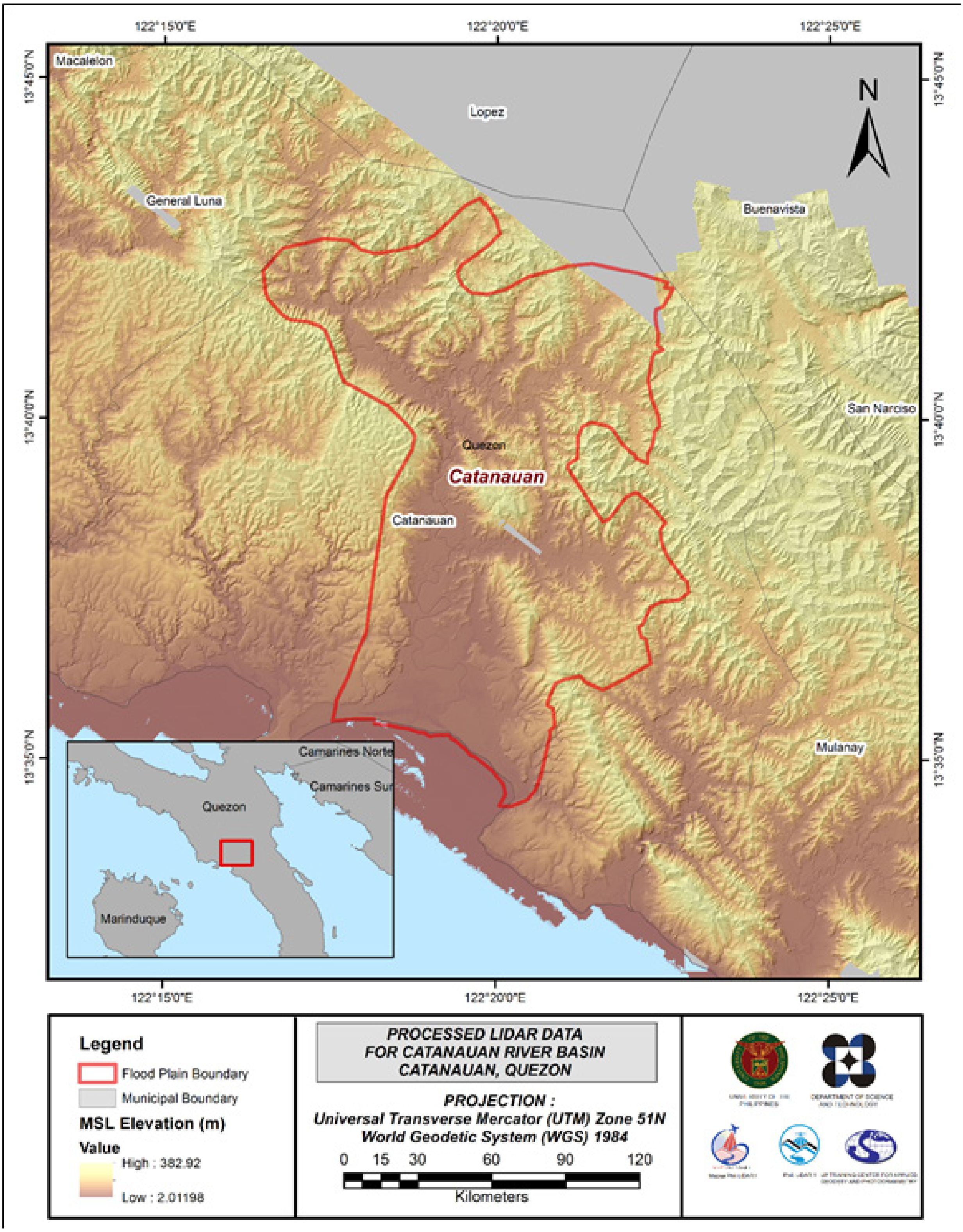


Figure 20. Map of Processed LiDAR Data for Catanauan Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Catanauan to collect points with which the LiDAR dataset is validated is shown in Figure 21. A total of 15,500 survey points were gathered for all the flood plains within the provinces of Quezon and Camarines Sur wherein the Catanauan floodplain is located. Random selection of 80% of the survey points, resulting to 12400 points, was used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR DTM and ground survey elevation values is shown in Figure 22. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 3.08 meters with a standard deviation of 0.17 meters. Calibration of the LiDAR data was done by subtracting the height difference value, 3.08 meters, to the mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between the LiDAR data and calibration data.

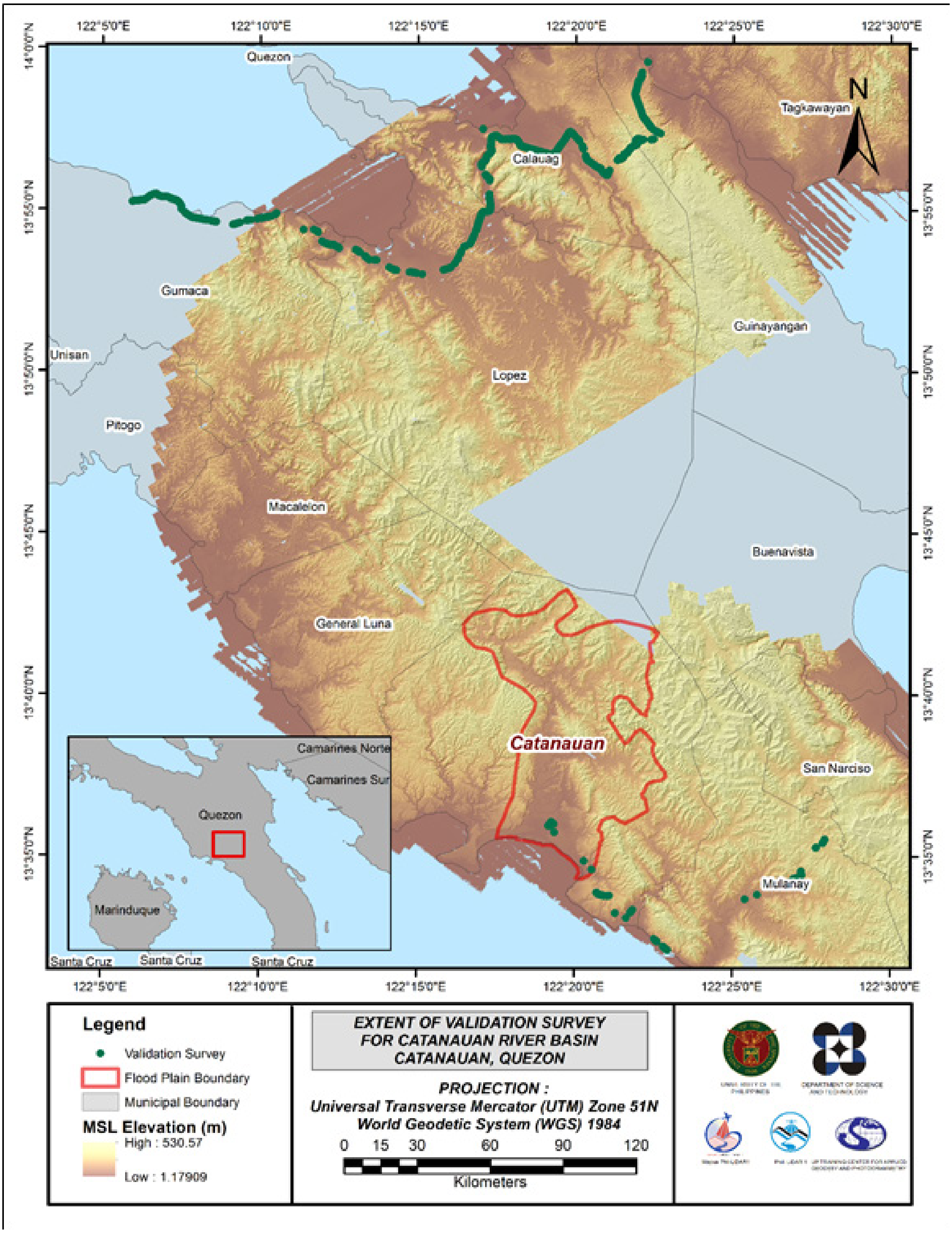


Figure 21. Map of Catanauan Flood Plain with validation survey points in green.

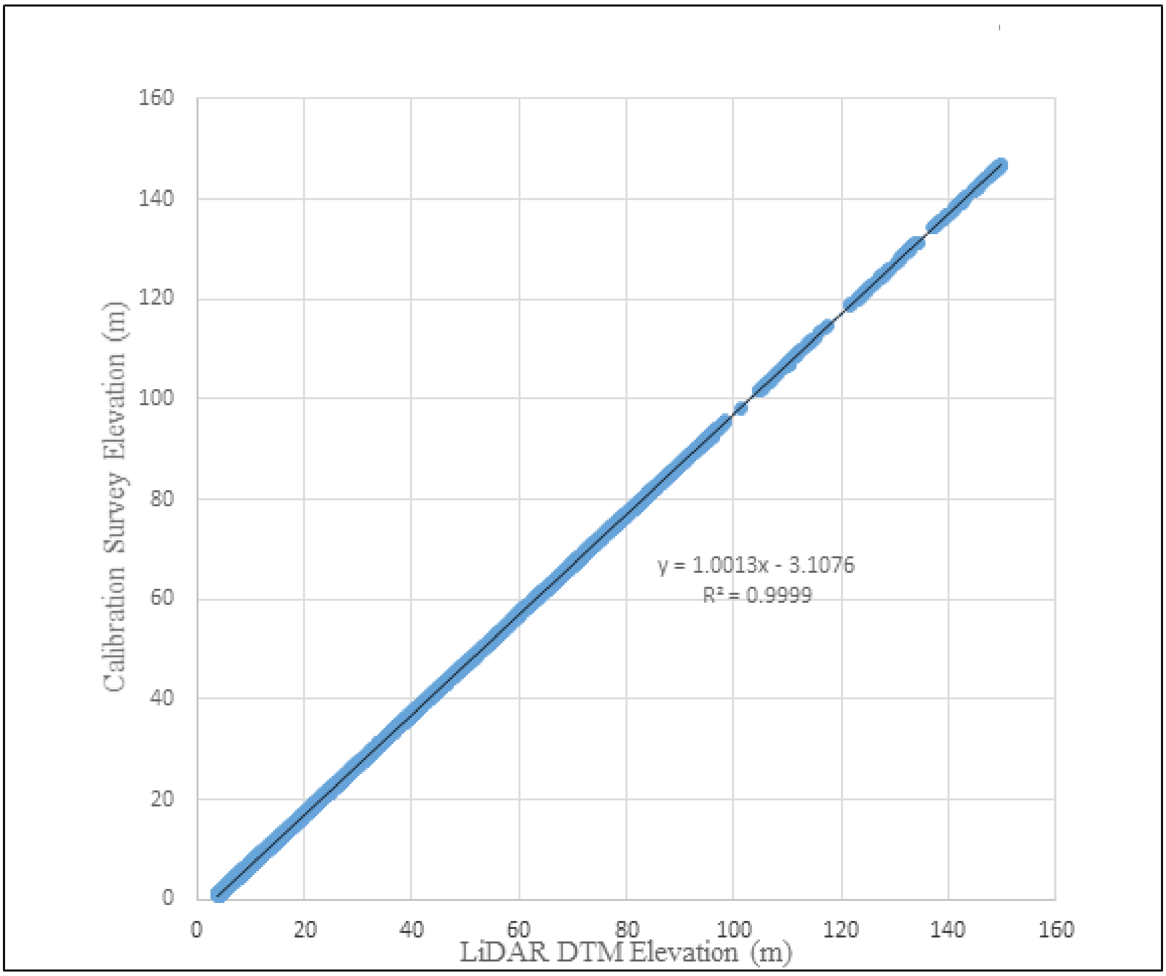


Figure 22. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

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

The remaining 20% of the total survey points that are near Catanauan flood plain, resulting to 45 points, were used for the validation of calibrated Catanauan 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 23. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.10 meters with a standard deviation of 0.08 meters, as shown in Table 14.

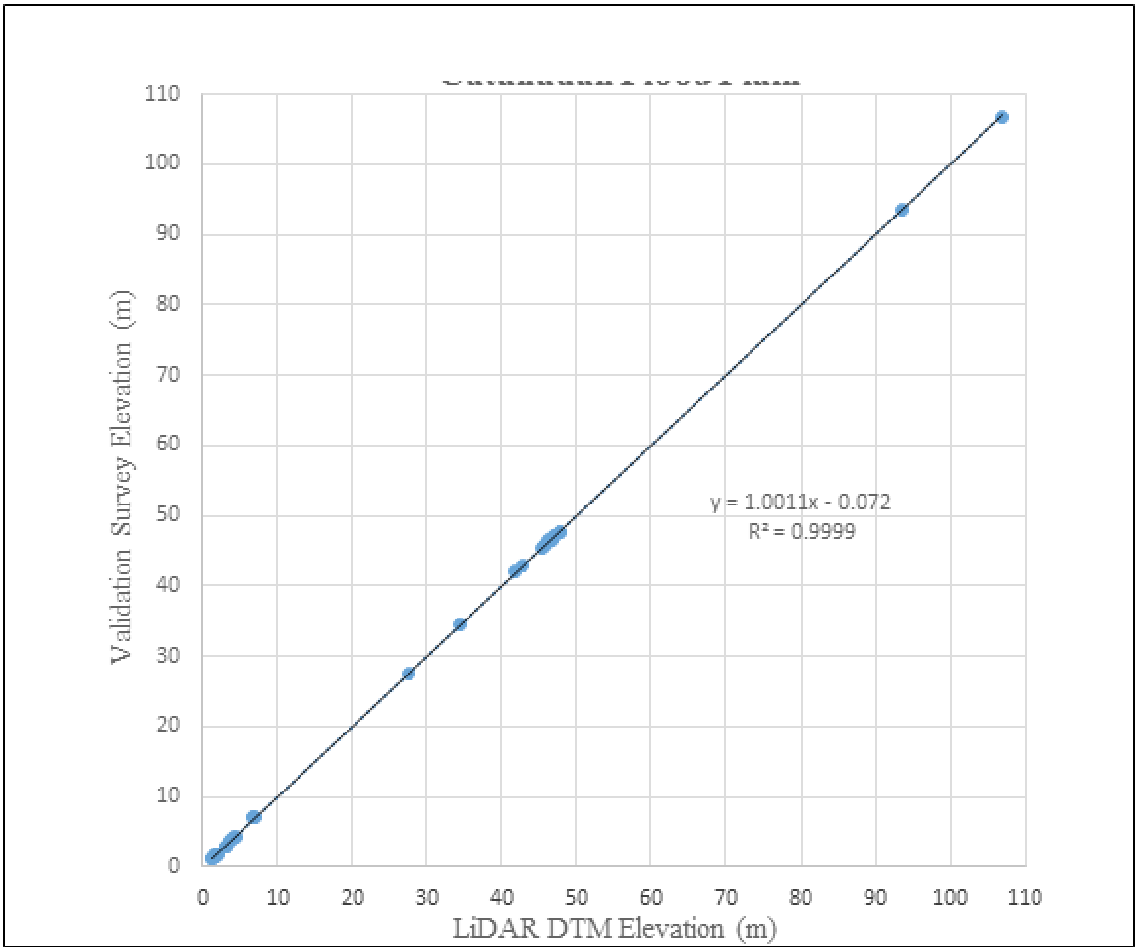


Figure 23. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.10
Standard Deviation	0.08
Average	-0.05
Minimum	-0.16
Maximum	0.13

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline data was available for Catanauan with 5,532 bathymetric survey points. The resulting raster surface produced was done by Kernel interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.32 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Catanauan integrated with the processed LiDAR DEM is shown in Figure 24.

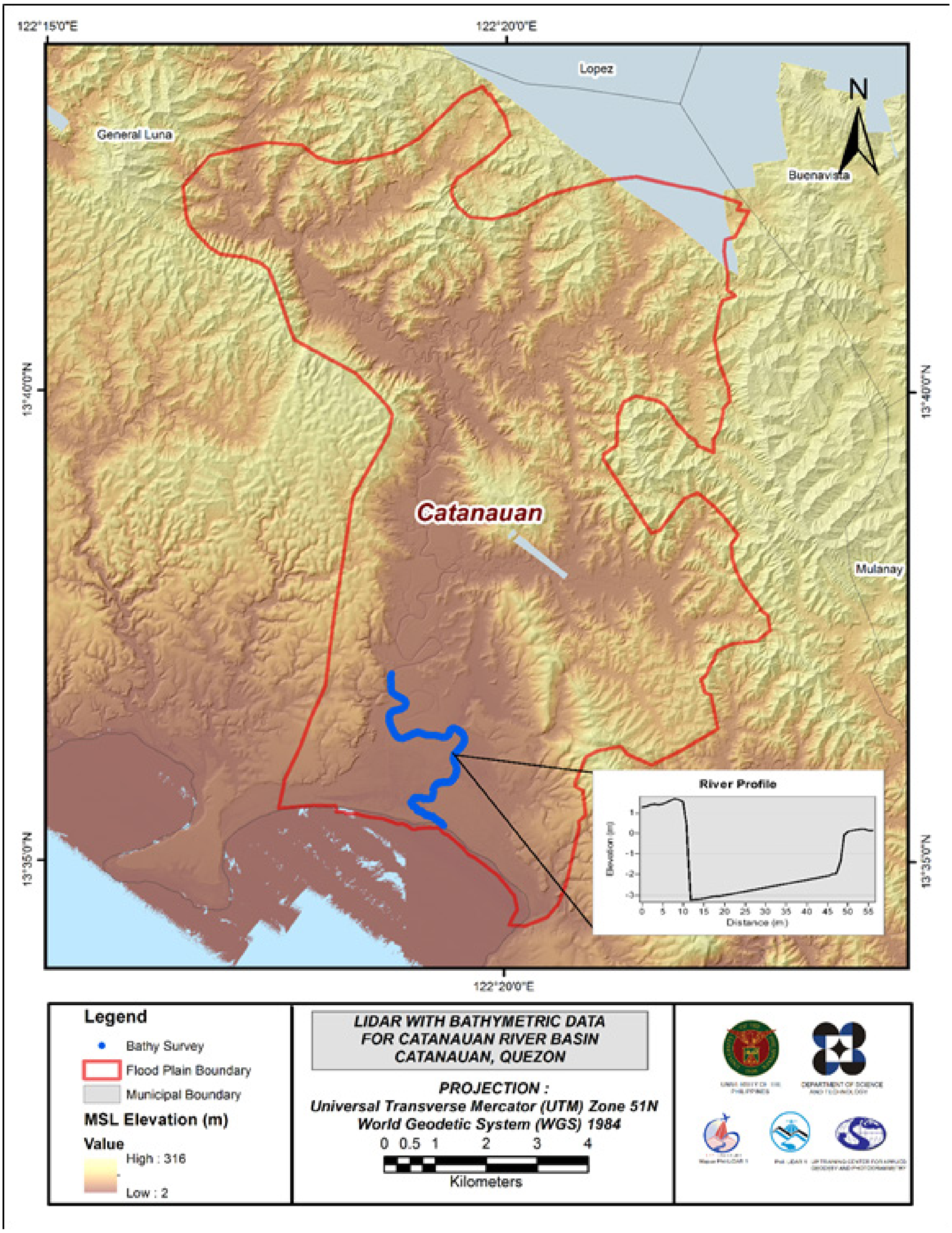


Figure 24. Map of Catanauan Flood Plain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking (QC) of Digitized Features' Boundary

Catanauan floodplain, including its 200 m buffer, has a total area of 113.36 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 1204 building features, are considered for QC. Figure 25 shows the QC blocks for Catanauan floodplain.

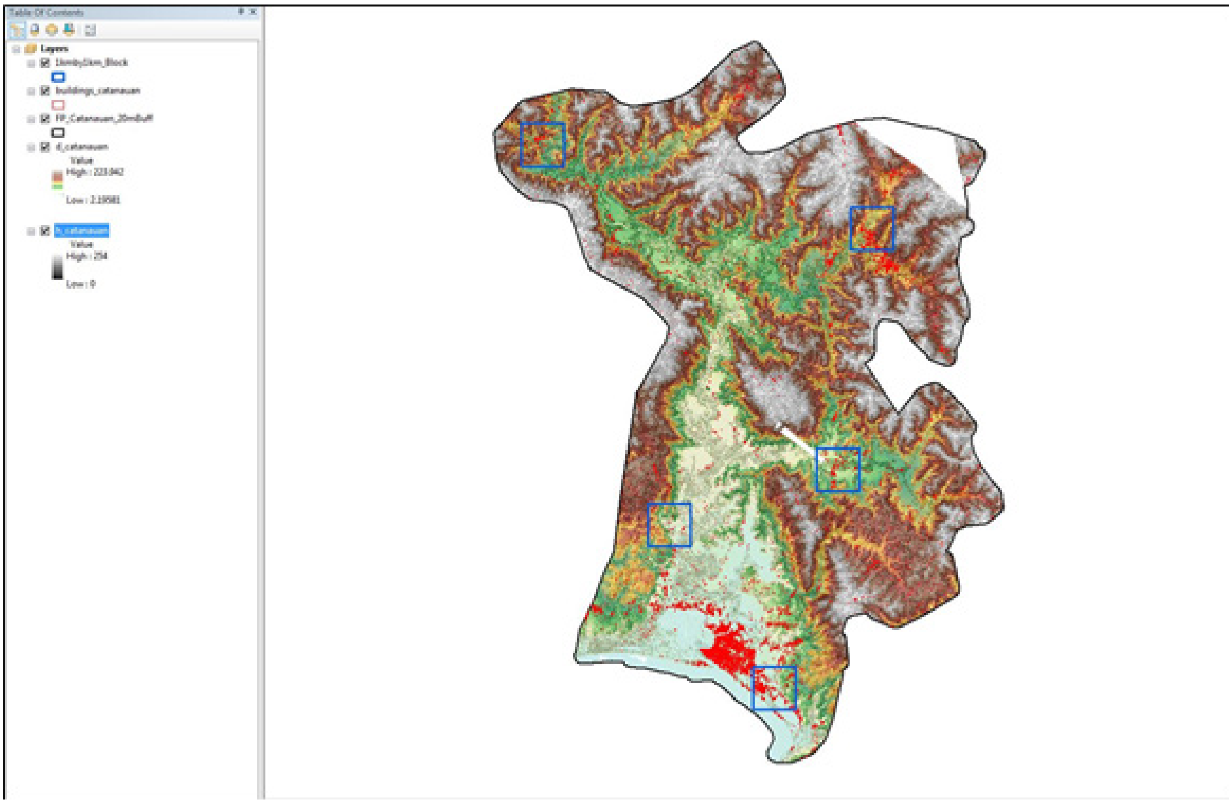


Figure 25. QC blocks for Catanauan building features.

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

Table 15. Quality Checking Ratings for Catanauan Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Catanauan	97.81	100.00	93.69	PASSED

3.12.2 Height Extraction

Height extraction was done for 8,279 building features in Catanauan floodplain. Of these building features, none was filtered out after height extraction, resulting to 8,027 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 9.90 m.

3.12.3 Feature Attribution

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

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

Table 16. Building Features Extracted for Catanauan Floodplain.

Facility Type	No. of Features
Residential	7,829
School	105
Market	1
Agricultural/Agro-Industrial Facilities	0
Medical Institutions	18
Barangay Hall	18
Military Institution	0
Sports Center/Gymnasium/Covered Court	1
Telecommunication Facilities	1
Transport Terminal	1
Warehouse	0
Power Plant/Substation	1
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	16
Bank	3
Factory	0
Gas Station	7
Fire Station	1
Other Government Offices	8
Other Commercial Establishments	17
Total	8,027

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Catanauan	68.02	32.58	0.00	31.54	0.00	132.14

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

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Catanauan	3	82	1	0	0	86

A total of 21 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 26 shows the Digital Surface Model (DSM) of Catanauan floodplain overlaid with its ground features.

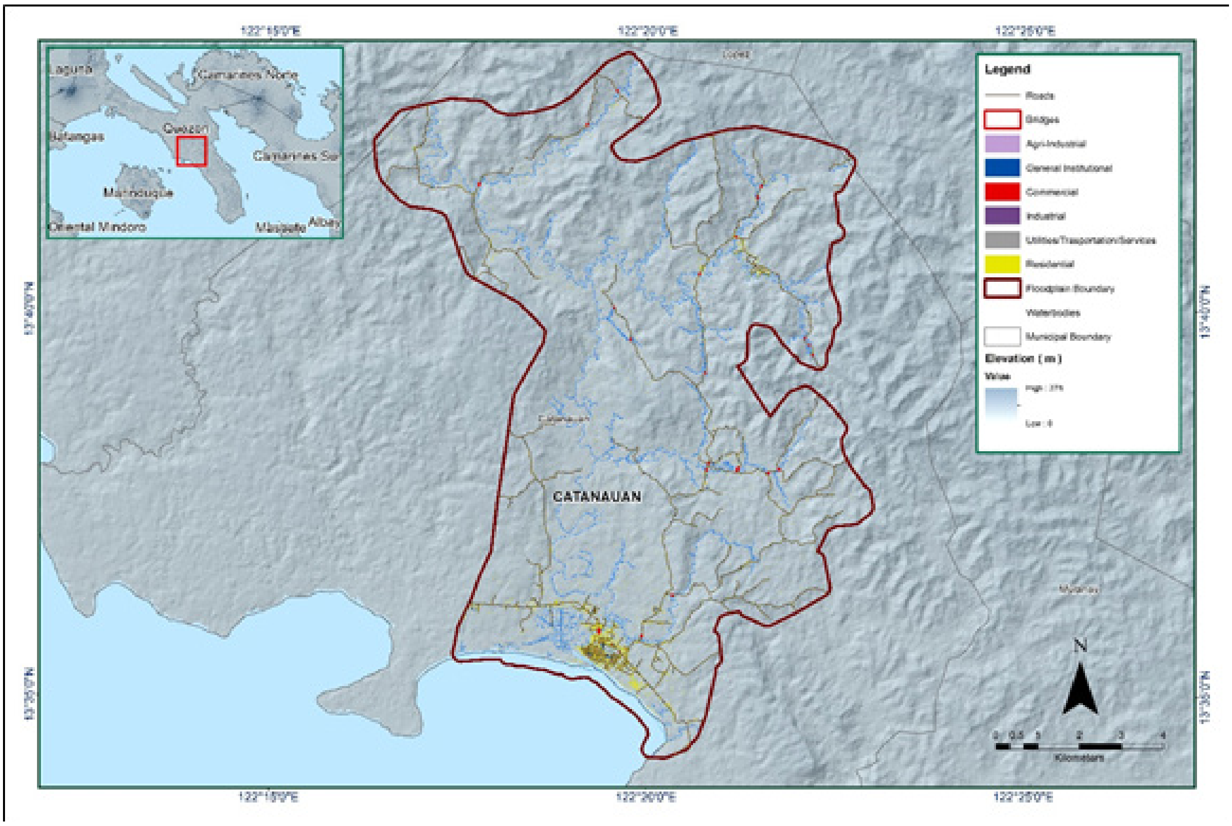


Figure 26. Extracted features for Catanauan floodplain.

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

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

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 Catanauan River on May 2-16, 2016 with the following scope of work: reconnaissance; control survey; cross-section ans as-built survey at Catanauan Bridge in Brgy. Matandang Sabang Silangan, Municipality of Catanauan; validation points acquisition of about 67 km covering the Catanauan River Basin area; and bathymetric survey from its upstream in Brgy. Canculajao, down to the mouth of the river in Barangay 8 Poblacion, both in Municipality of Catanauan, with an approximate length of 5.976 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 27).

Figure 27. Survey extent for Catanauan River Basin.

4.2 Control Survey

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

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

The summary of reference and control points and its location is summarized in Table 19 while GNSS network established is illustrated in Figure 28.

Table 19. List of reference and control points occupied for Catanauan River Survey (Source: NAMRIA, UP-TCAGP) .

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

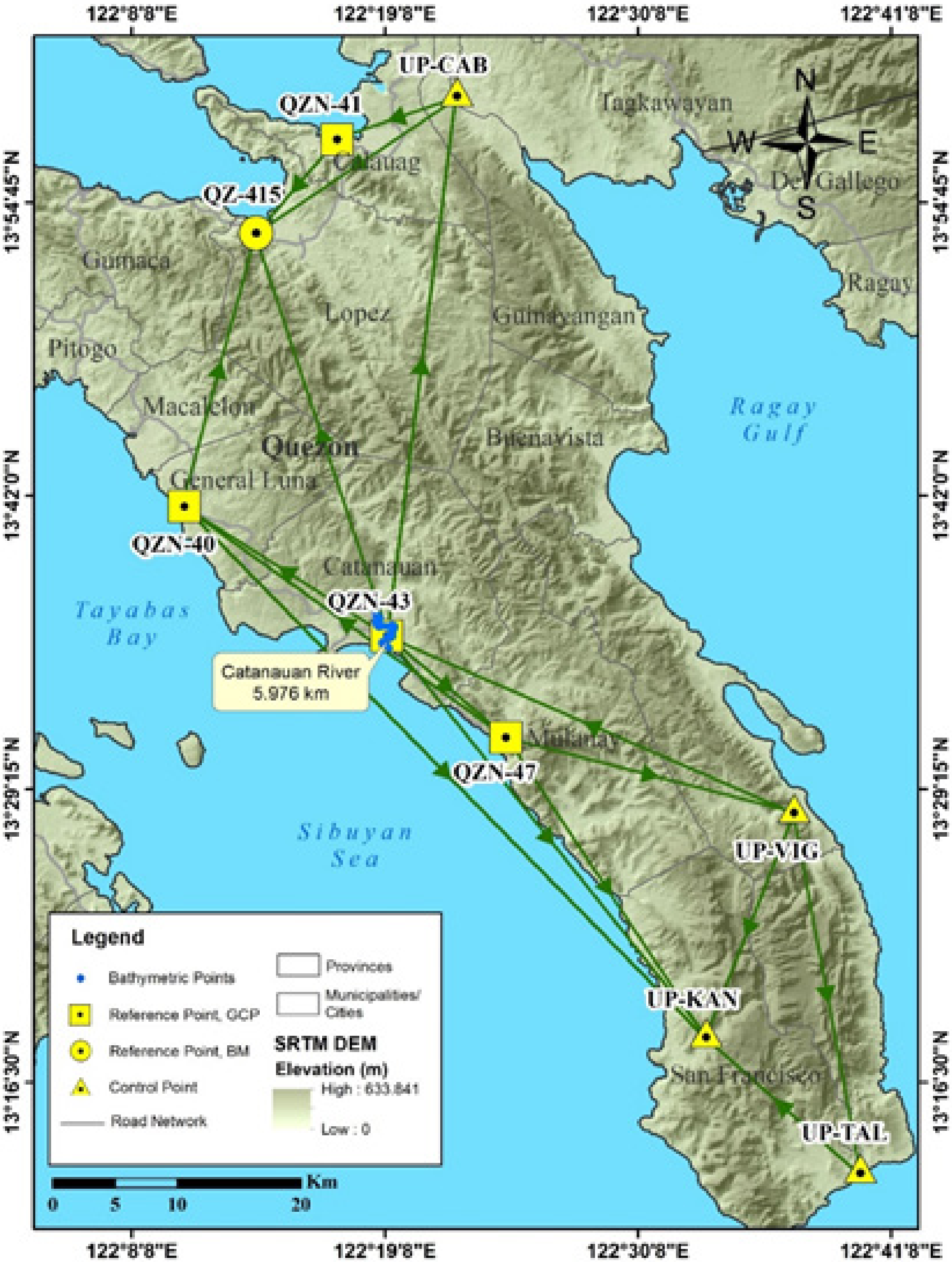


Figure 28. GNSS Network of Catanauan River field survey.

The GNSS set-ups of the reference and control points are exhibited are shown in Figure 29 to Figure 37.

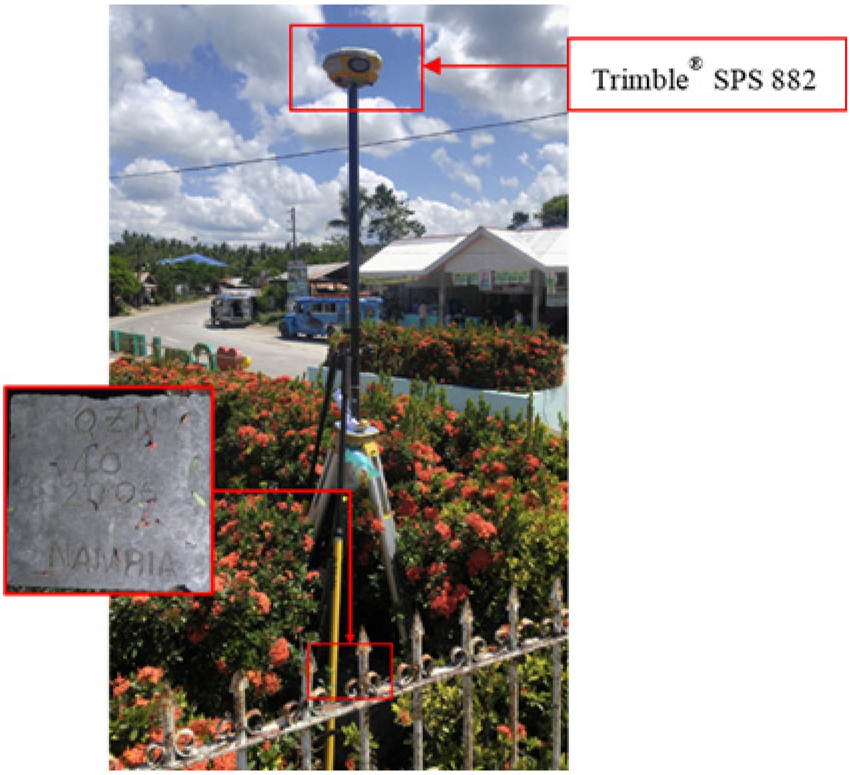


Figure 29. GNSS base set up, Trimble® SPS 882, at QZN-40, located inside a triangular plant area found at the center of a triangular island in Brgy. San Jose, Municipality of Gen. Luna, Quezon.

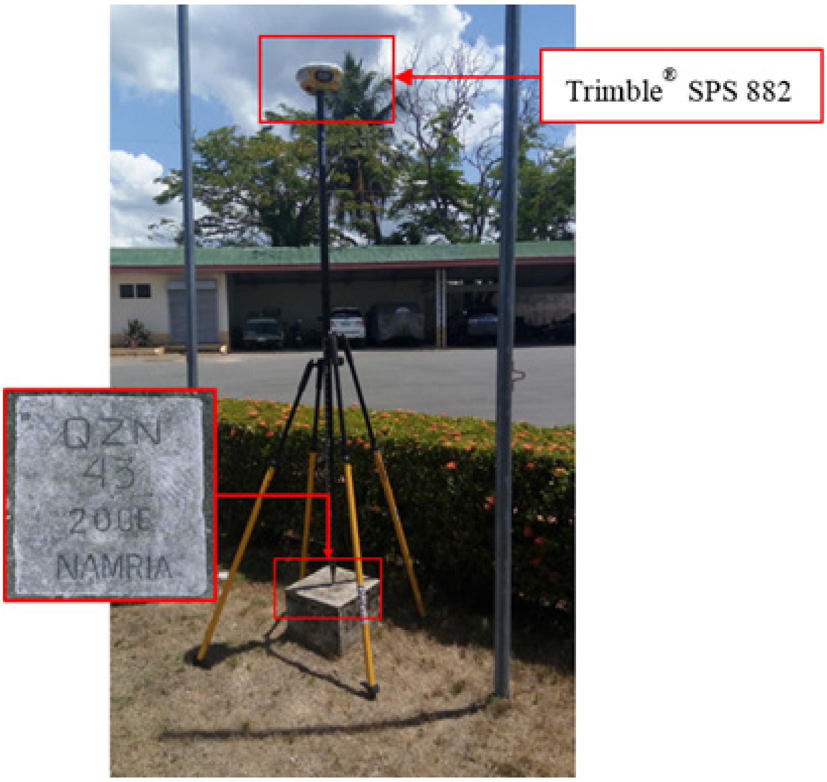


Figure 30. GNSS base set up, Trimble® SPS 882, at QZN-43, located inside the DPWH compound in Brgy. Matandang Sabang Silangan, Municipality of Catanauan, Quezon.

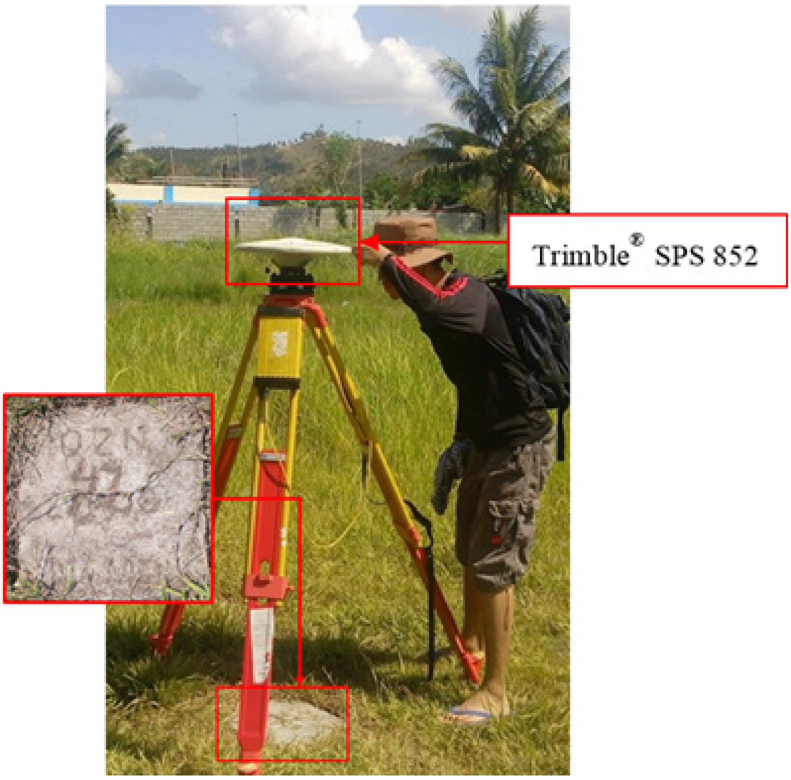


Figure 31. GNSS base set up, Trimble® SPS 852, at QZN-47, located at the back of the Principal's Office of Mulanay Elementary School in Barangay II, Municipality of Mulanay, Quezon.

Figure 32. GNSS base set up, Trimble® SPS 985, at QZ-415, located at the approach of Pansol Bridge in Brgy. Pansol, Municipality of Lopez, Quezon.

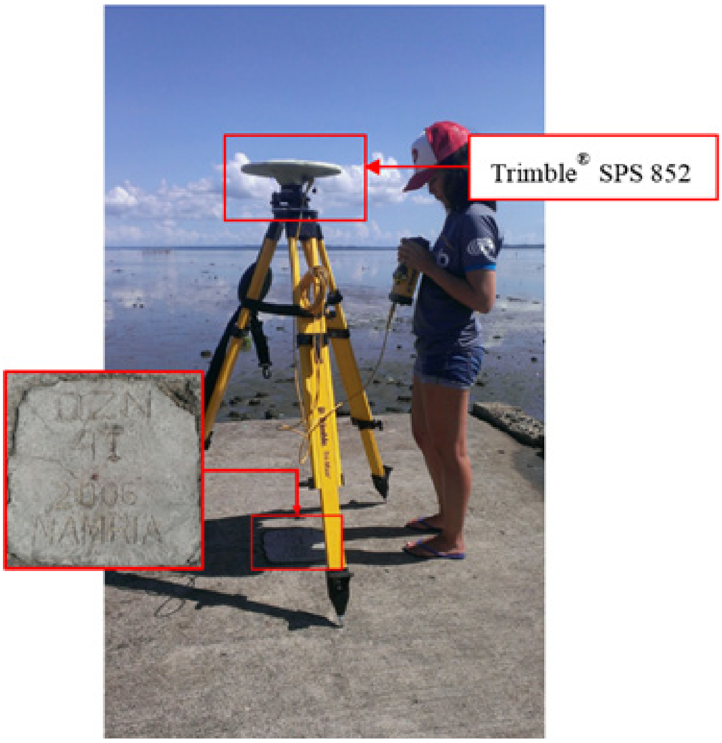


Figure 33. GNSS base set up, Trimble® SPS 852, at QZN-41, located in front of Brgy. Sabang basketball court found in Calauag Port, Barangay I, Municipality of Calauag, Quezon.

Figure 34. GNSS base set up, Trimble® SPS 882, at UP-CAB, located inside a basketball court in Brgy. Aloneros, Municipality of Guinayangan, Quezon.

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

Figure 36. GNSS base set up, Trimble® SPS 852, at UP-TAL, located at the approach of Talisay Bridge in Brgy. Pagsangahan, Municipality of San Francisco, Quezon.

Figure 37. GNSS base set up, Trimble® SPS 882, at UP-VIG, located at the approach of Vigo Bridge in Brgy. Vigo Central, Municipality of San Francisco, Quezon.

4.3 Baseline Processing

The 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 cases where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. The baseline processing result of control points in the Ogod River Basin is summarized in Table 20 as generated by TBC software.

Table 20. Validation Statistical Measures.

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
QZN-47 --- QZN-40	05-11-2016	Fixed	0.003	0.011	306°22'36"	31263.486	-19.930
QZN-47 --- QZN-43	05-11-2016	Fixed	0.003	0.013	131°16'56"	12401.416	-12.150
QZN-47 --- UP-VIG	05-11-2016	Fixed	0.003	0.012	103°58'19"	23335.323	7.791
QZN-47 --- UP-KAN	05-11-2016	Fixed	0.005	0.019	146°21'08"	28388.037	19.975
QZN-40 --- QZ-415	05-11-2016	Fixed	0.003	0.023	14°21'16"	22613.475	-0.448
UP-CAB --- QZ-415	05-04-2016	Fixed	0.004	0.025	234°09'16"	19401.067	-20.388
QZN-40 --- UP-KAN	05-11-2016	Fixed	0.011	0.027	135°49'24"	58749.581	
QZN-43 --- QZ-415	05-11-2016	Fixed	0.006	0.033	342°23'19"	33841.349	
QZN-43 --- UP-KAN	05-11-2016	Fixed	0.005	0.018	141°46'15"	40492.330	
UP-TAL --- UP-KAN	05-11-2016	Fixed	0.005	0.018	312°01'33"	16293.271	
UP-VIG --- UP-TAL	05-11-2016	Fixed	0.003	0.014	169°50'51"	29356.882	
UP-VIG --- QZN-43	05-11-2016	Fixed	0.003	0.014	293°25'54"	34821.073	
UP-VIG --- UP-KAN	05-11-2016	Fixed	0.005	0.021	201°04'03"	19280.526	
QZN-41 --- UP-CAB	05-04-2016	Fixed	0.004	0.024	247°44'12"	10141.643	
QZN-41 --- QZ-415	05-04-2016	Fixed	0.003	0.022	220°07'13"	9835.756	
QZN-40 --- QZN-43	05-11-2016	Fixed	0.003	0.014	303°07'59"	18937.828	
UP-CAB --- QZN-43	05-11-2016	Fixed	0.004	0.019	7°10'02"	43963.480	

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

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is performed using TBC. Looking at the Adjusted Grid Coordinates Table 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:

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

where:

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

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

The nine (9) control points, QZN-40, QZN-43, QZN-47, QZ-415, QZN-41, UP-CAB, UP-KAN, UP-TAL and UP-VIG were occupied and observed simultaneously to form a GNSS loop. Elevation value of QZ-415 and coordinates of points QZN-40, QZN-43 and QZN-47 were held fixed during the processing of the control points as presented in Table 21. Through these reference points, the coordinates and elevation of the

Table 21. Control Point Constraints.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
QZN-40	Global	Fixed	Fixed		
QZN-43	Global	Fixed	Fixed		
QZN-47	Global	Fixed	Fixed		
QZ-415	Grid				Fixed
Fixed = 0.000001(Meter)					

The list of adjusted grid coordinates, i.e. Northing, Easting, Elevation and computed standard errors of the control points in the network is indicated in Table 22. The fixed control points QZN-40, QZN-43 and QZN-47 have no values for grid and elevation errors, respectively.

Table 22. Adjusted Grid Coordinates

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

The network is fixed at reference points QZN-40, QZN-43, and QZN-47 with known coordinates, and QZ-415 with known elevation. As shown in Table C-4, the standard errors (xe and ye) of QZ-415 are 1.0 cm and 1.0 cm. With the mentioned equation, $\sqrt{(x_e)^2+(y_e)^2}<20$cm for horizontal and $z_e<10$ cm for the vertical; the computation for the accuracy of the reference and control points are as follows:

a.	**QZN-40**		
	horizontal accuracy	=	Fixed
	vertical accuracy	=	7.5 cm < 10 cm
b.	**QZN-43**		
	horizontal accuracy	=	Fixed
	vertical accuracy	=	7.3 cm < 10 cm
c.	**QZN-47**		
	horizontal accuracy	=	Fixed
	vertical accuracy	=	7.9 cm < 10 cm
d.	**QZ-415**		
	horizontal accuracy	=	$\surd((1.\ 0)^2 + (1.0)^2$
		=	$\surd\ (1.0 + 1.0)$
		=	1.41cm < 20 cm
	vertical accuracy	=	Fixed
e.	**QZN-41**		
	horizontal accuracy	=	$\surd((1.40)^2 + (1.40)^2$
		=	$\surd\ (1.96+ 1.96)$
		=	1.98cm < 20 cm
	vertical accuracy	=	8.2 cm < 10 cm
f.	**UP-CAB**		
	horizontal accuracy	=	$\surd((1.20)^2 + (1.30)^2$
		=	$\surd\ (1.44 + 1.69)$
		=	1.77 cm < 20 cm
	vertical accuracy	=	7.3 cm < 10 cm
g.	**UP-KAN**		
	horizontal accuracy	=	$\surd((1.20)^2 + (1.10)^2$
		=	$\surd\ (1.44 + 1.21)$
		=	1.63 cm < 20 cm
	vertical accuracy	=	8.6 cm < 10 cm
h.	**UP-TAL**		
	horizontal accuracy	=	$\surd((1.60)^2 + (1.40)^2$
		=	$\surd\ (2.56 + 1.96)$
		=	2.13 cm < 20 cm
	vertical accuracy	=	9.5 cm < 10 cm
i.	**UP-VIG**		
	horizontal accuracy	=	$\surd((1.10)^2 + (0.80)^2$
		=	$\surd\ (1.21 + 0.64)$
		=	1.36 cm < 20 cm
	vertical accuracy	=	8.3 cm < 10 cm

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

Table 23. Adjusted Geodetic Coordinates.

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

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

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

Table 24. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP).

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
QZN-40	2nd Order GCP	13°41'32.47595" N	122°10'25.77273" E	51.703	1513855.137	410660.624	2.622
QZN-43	2nd Order GCP	13°35'55.81611" N	122°19'13.53031" E	51.015	1503462.996	426485.118	1.574
QZN-47	2nd Order GCP	13°31'29.52488" N	122°24'23.44821" E	53.862	1495257.875	435778.405	4.163
QZ-415	1st Order BM	13°53'25.29589" N	122°13'32.50380" E	57.290	1535736.431	416340.495	8.613
QZN-41	Used as Marker	13°57'30.05268" N	122°17'03.60722" E	50.089	1543236.263	422699.129	1.392
UP-CAB	UP Established	13°59'35.12930" N	122°22'16.30558" E	52.023	1547052.366	432091.726	3.211
UP-KAN	UP Established	13°18'40.40211" N	122°33'06.07511" E	75.768	1471596.832	451445.231	25.095
UP-TAL	UP Established	13°12'45.55145" N	122°39'48.22322" E	55.864	1460676.916	463529.271	4.949
UP-VIG	UP Established	13°28'25.87675" N	122°36'56.35787" E	56.412	1489570.998	458401.312	6.030

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

Cross-section survey was conducted at the downstream part of Catanauan Bridge on May 6 and 12, 2016 using a GNSS receiver, Trimble® SPS 882, in PPK survey technique paired with an Ohmex™ single beam echo sounder; and a Total Station through Open Traverse Method as shown in Figure 38.

Figure 38. Cross-Section Survey for Catanauan River using GNSS receiver, Trimble® SPS 882.

The cross-sectional line length of Catanauan River is about 257.110 m with 76 cross-sectional points acquired using QZN-43 as the GNSS base station. The location map, cross section diagram, and bridge as-built form are illustrated in Figure 40 to Figure 42.

Figure 39. Water Level Marking for Catanauan River.

Water surface elevation in MSL of Catanauan River was determined using a Total Station in an Open Traverse Method on May 12, 2016 at 11:28 AM with a value of -0.486 m in MSL. This was translated onto marking on the bridge's pier as shown in Figure 39. The markings will serve as their reference for flow data gathering and depth gauge deployment for Catanauan River.

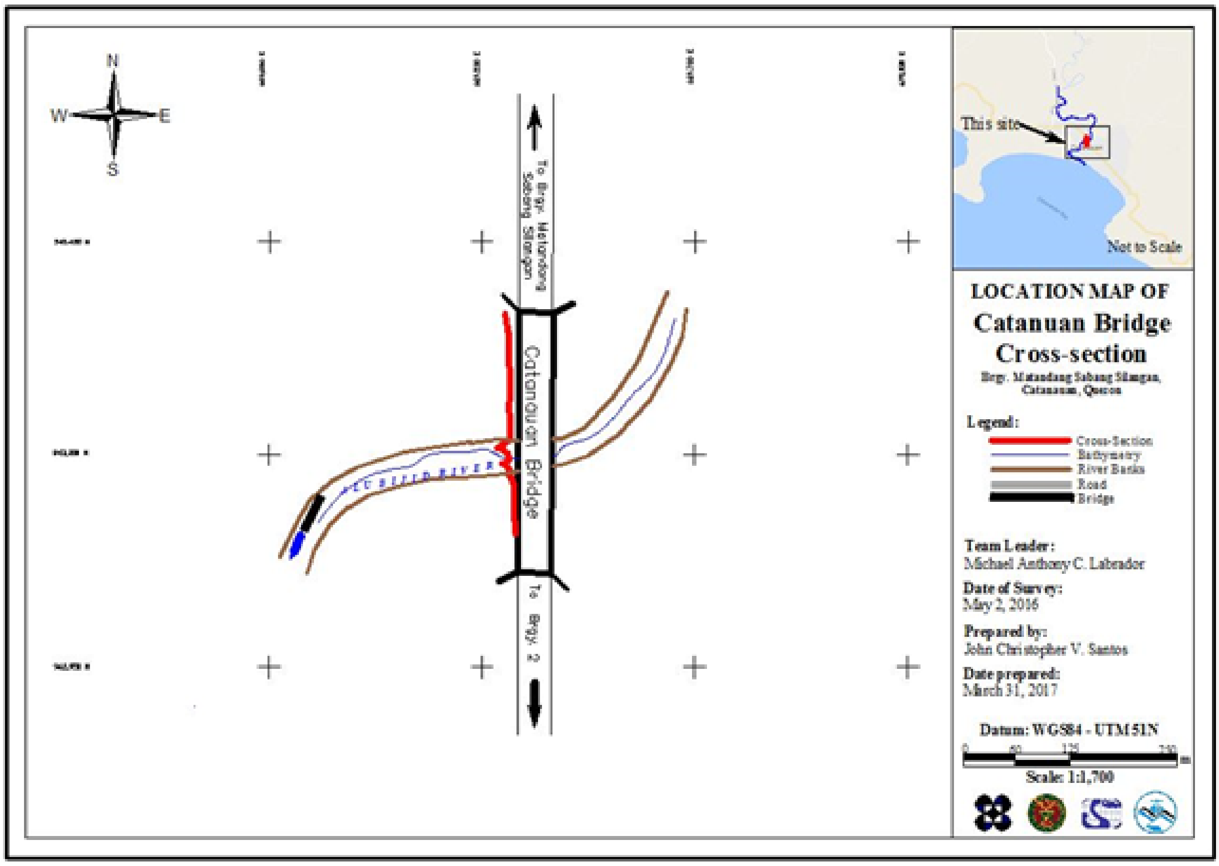


Figure 40. Catanauan bridge cross-section location map.

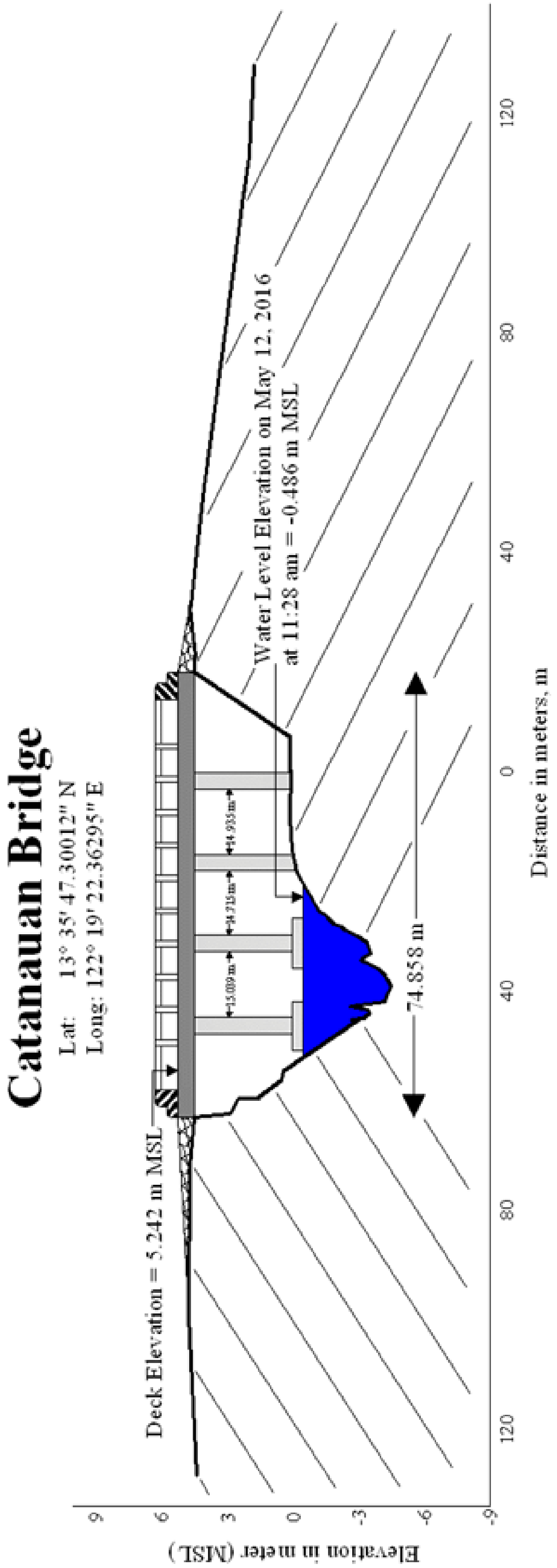
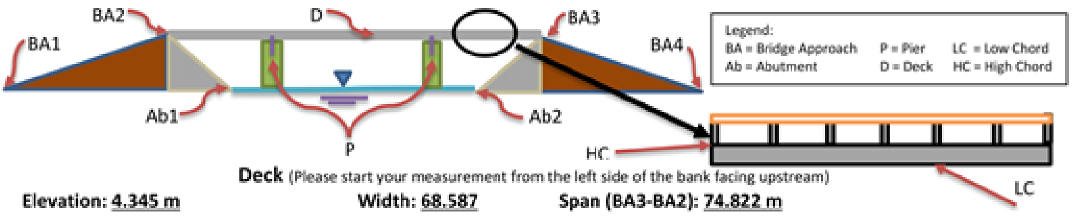


Figure 41. Catanauan Bridge Cross-section Diagram.

Bridge Data Form

Bridge Name: Catanauan Bridge	Date: May 6, 2016
River Name: Catanauan River	Time: 02:27 PM
Location (Brgy, City,Region): Brgy. Matandang Sabang Silangan, Municipality of Catanauan, Quezon	
Survey Team: Michael Labrador, Erlan Mendoza, Romalyn Boado, Mark Rojas, Marla Morris, Pauline Racoma	
Flow condition: normal	Weather Condition: fair
Latitude: 13˚35'47.30012" N	Longitude: 122˚19'22.36295" E



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

Elevation: 4.345 m   Width: 68.587   Span (BA3-BA2): 74.822 m

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

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	4.345 m	BA3	143.171 m	5.182 m
BA2	68.349 m	5.230 m	BA4	257.110 m	1.763 m

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

	Station (Distance from BA1)	Elevation
Ab1	Not available	Not available
Ab2	139.955 m	0.406 m

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

Shape: Oblong   Number of Piers: 4   Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	83.405 m	5.237 m	Not available
Pier 2	98.456 m	5.207 m	Not available
Pier 3	113.161 m	5.212 m	Not available
Pier 4	128.117	5.202	Not available

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

DREAM
Disaster Risk and Exposure Assessment for Mitigation

Figure 42. Catanauan Bridge Data Form.

Validation points acquisition survey was conducted on May 4, 5, and 6, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on the roof of the vehicle as shown in Figure 42. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was 1.895 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with QZN-41, QZN-43 and UP-CAB occupied as the GNSS base stations in the conduct of the survey.

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on May 4, 5, and 6, 2016 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on the roof of the vehicle as shown in Figure 42. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was 1.895 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with QZN-41, QZN-43 and UP-CAB occupied as the GNSS base stations in the conduct of the survey.

Figure 43. Validation points acquisition survey set up.

The survey started from Brgy. Aloneros in the Municipality of Guinayangan, going west traversing the Municipalities of Calauag, Lopez and ended in Brgy. San Diego Poblacion, Municipality of Gumaca; and from Brgy. Matandang Sabang Silangan, Municipality of Catanauan going south towards Barangay II in Municipality of Mulanay, and ended in Brgy. Anonang also in Mulaay. These routes aim to perpendicularly cut flight strips of the Data Acquisition Component. The survey gathered 5,788 points with approximate length of 67.44 km using QZN-41, QZN-43 and UP-CAB as GNSS base stations for the entire extent validation points acquisition survey as illustrated in the map in Figure 44.

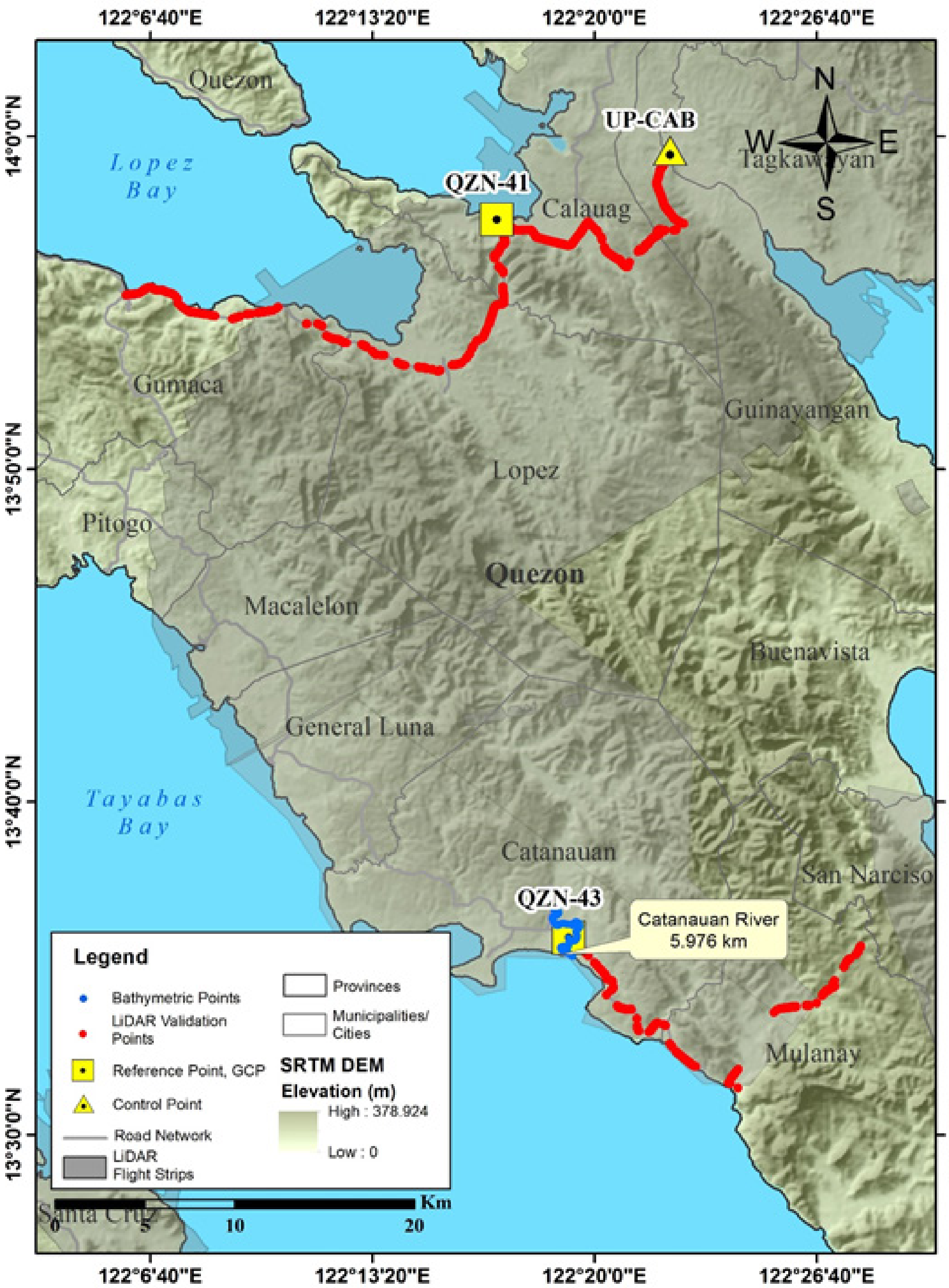


Figure 44. Validation point acquisition survey for the Catanauan River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed on May 12, 2016 using a Trimble® SPS 882 in GNSS PPK survey technique and Ohmex™ single beam echo sounder, as illustrated in Figure 45. The extent of the survey is from the upstream part of the river in Brgy. Canculajao, Municipality of Catanauan with coordinates 13°36'59.28392"N, 122°18'46.33121"E, down to the mouth of the river in Barangay 8, also in Municipality of Catanauan with coordinates 13°35'22.68522"N, 122°19'20.56894"E.

Figure 45. Bathymetry by boat set up for Catanauan River survey.

A CAD drawing was also produced to illustrate the riverbed profile of Catanauan River. As shown in Figure 47, the highest and lowest elevation has a 4-meter difference. The highest elevation observed is -1.129 m below MSL located at the downstream portion of the river in Barangay 3, while the lowest elevation observed is -5.052 m below MSL located a kilometer from its mouth in Brgy. Matandang Sabang Silangan, both in Municipality of Catanauan. The bathymetric survey gathered a total of 5,602 points covering 5.976 km of the river traversing thirteen (13) Barangays in Municipality of Catanauan.

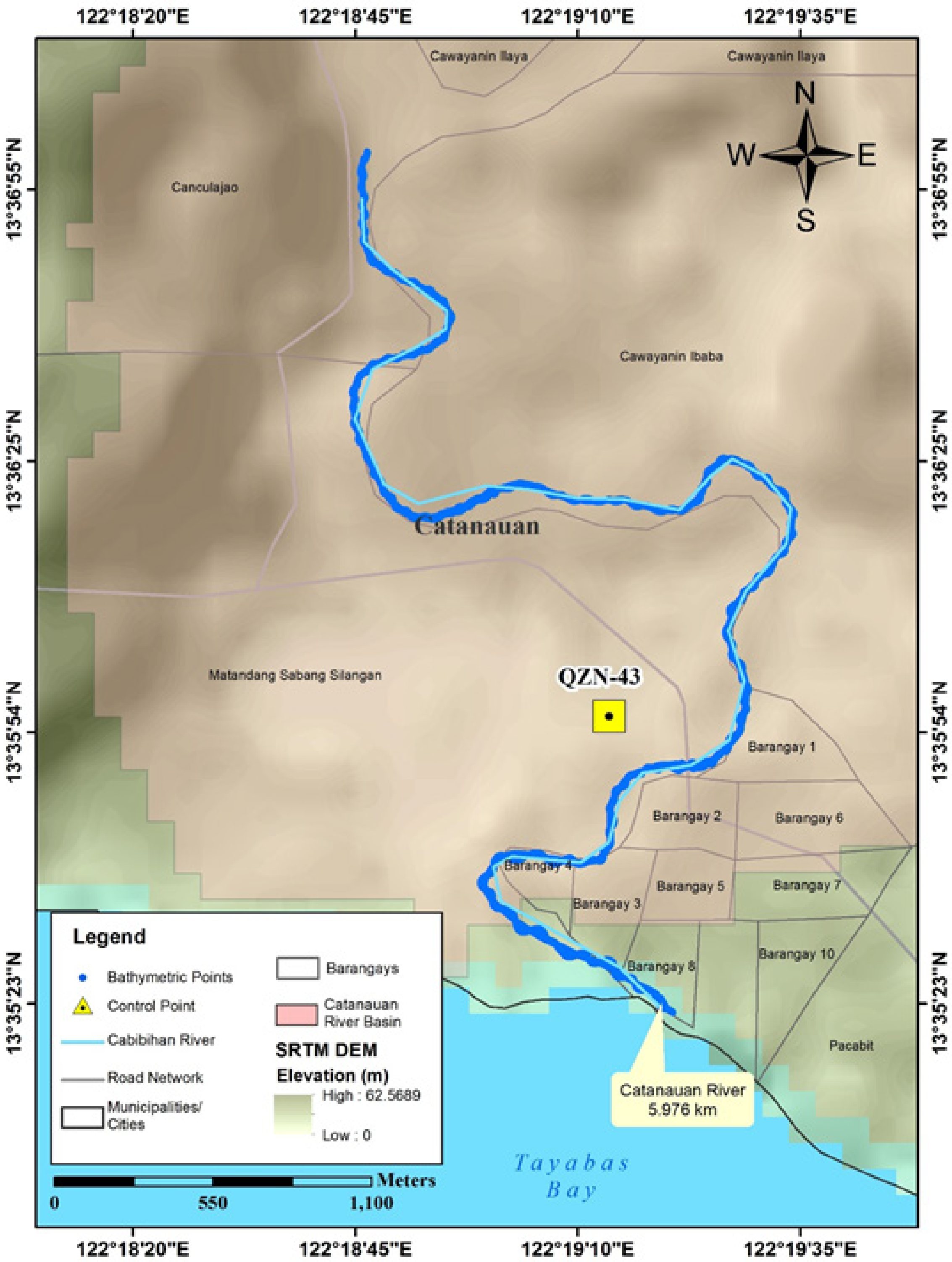


Figure 46. Bathymetric survey of Catanauan River.

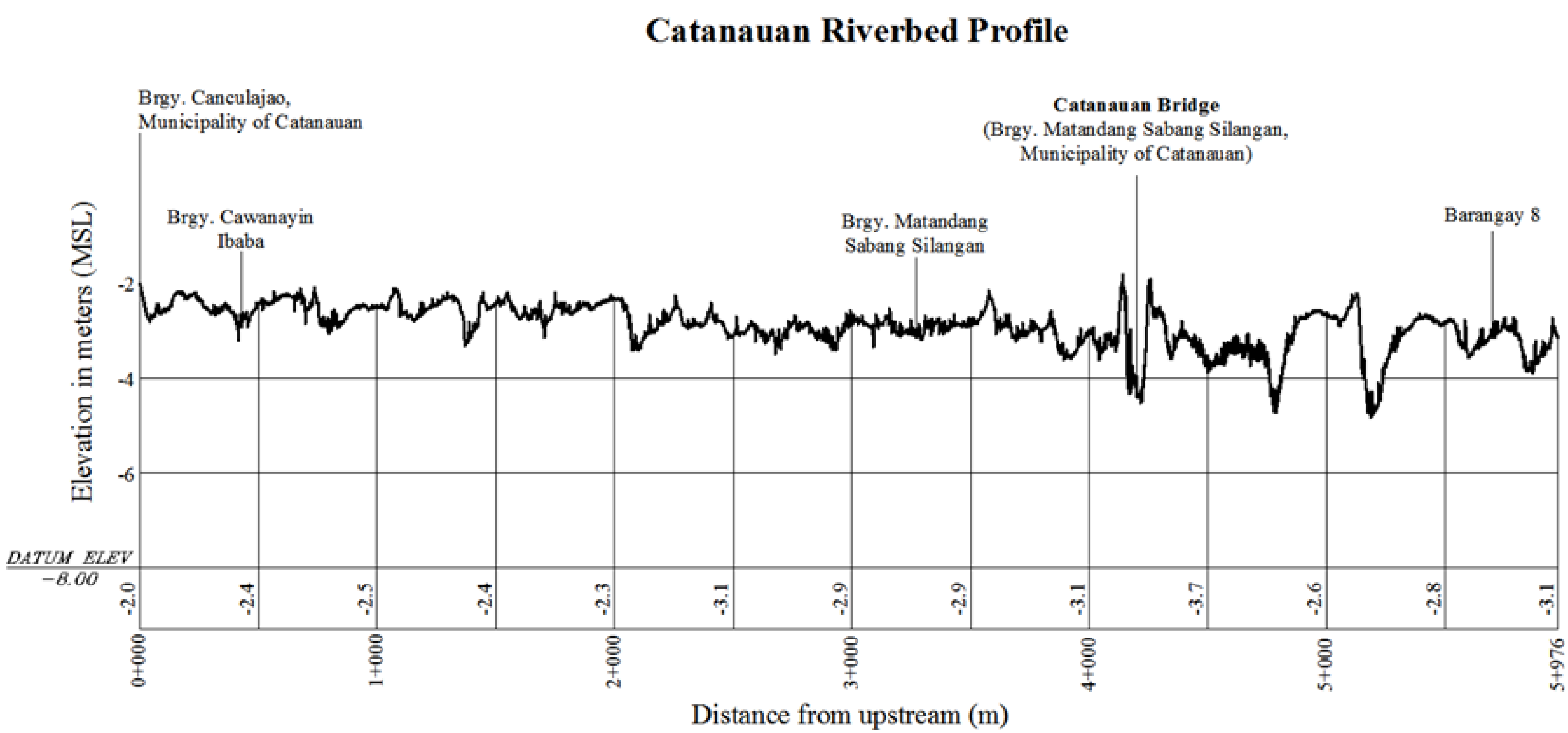


Figure 47. Riverbed profile of Catanauan River.

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, such as rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Bacarra River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from automatic rain gauges (ARG) deployed by the Mapua Institute of Technology under the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The location of the ARG is Catanauan Municipality. The location of the rain gauge is as shown in Figure 48.

The total rain from the Catanauan Municipality rain gauge is 26.4 mm. It peaked to 14 mm at 12:45 on October 5, 2016. The lag time between the peak rainfall and discharge is 14 hours and 55 minutes, as shown in Figure 51.

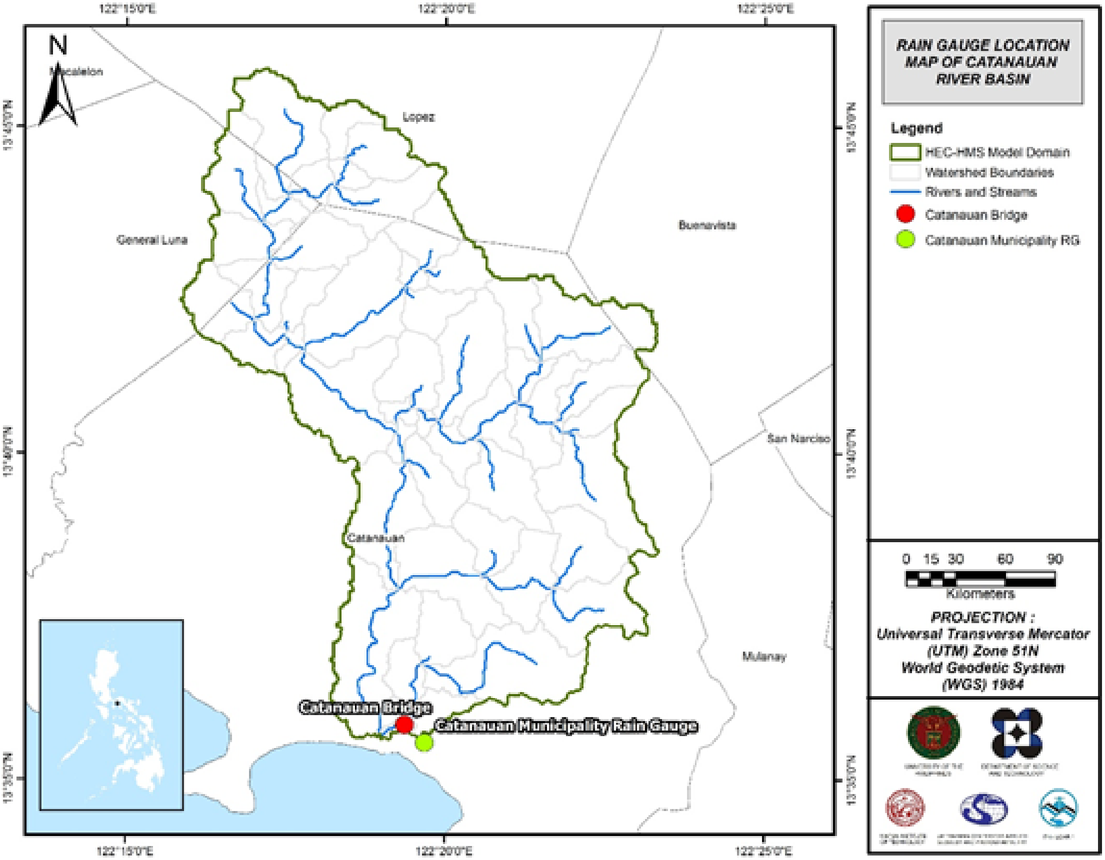


Figure 48. The location map of Catanauan HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Catanauan Bridge in Quezon Province (13˚35'47.30012"N 122˚19'22.36295"E). It gives the relationship between the observed water levels and outflow of the watershed at this location. It is expressed in the form of the following equation:

$$Q=anh$$

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

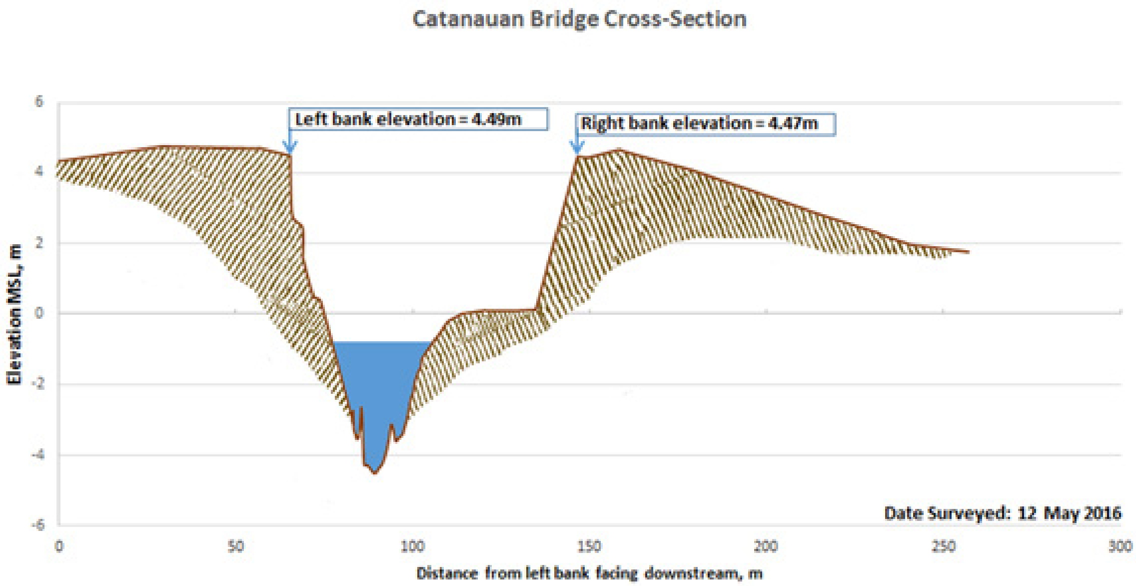


Figure 49. Cross-Section Plot of Catanauan Bridge.

For Catanauan Bridge, the rating curve is expressed y = 146.39e22.775x as shown in Figure 50.

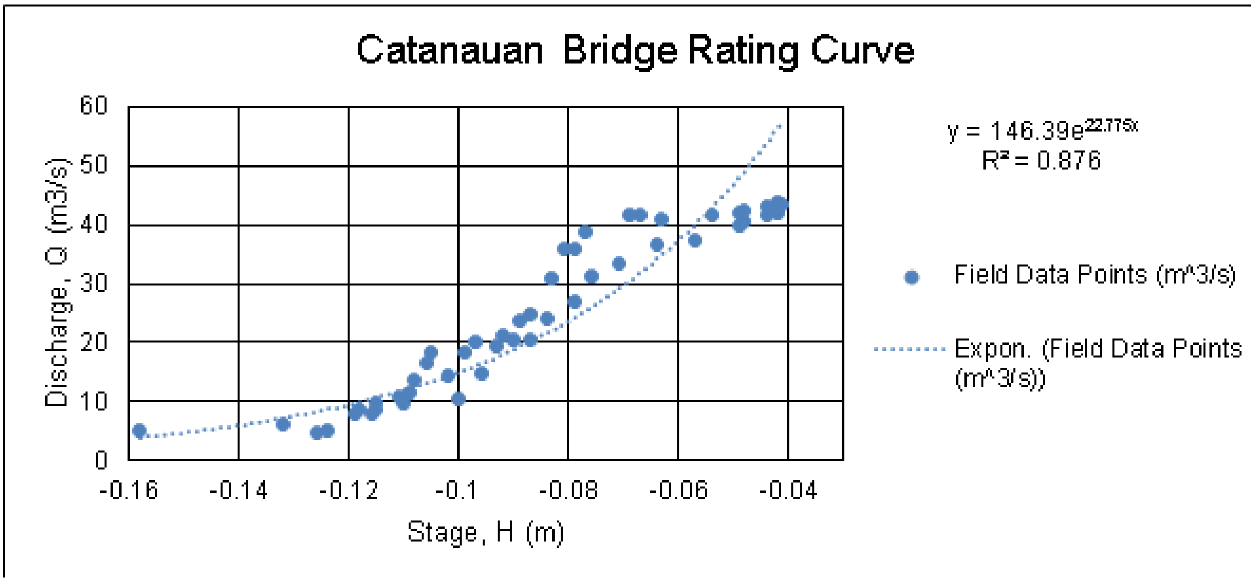


Figure 50. Rating Curve at Catanauan Bridge, Catanauan, Quezon Province.

This rating curve equation was used to compute the river outflow at Catanauan Bridge for the calibration of the HEC-HMS model shown in Figure 51. Peak discharge is 43 m3/s at 3:40, October 6, 2016.

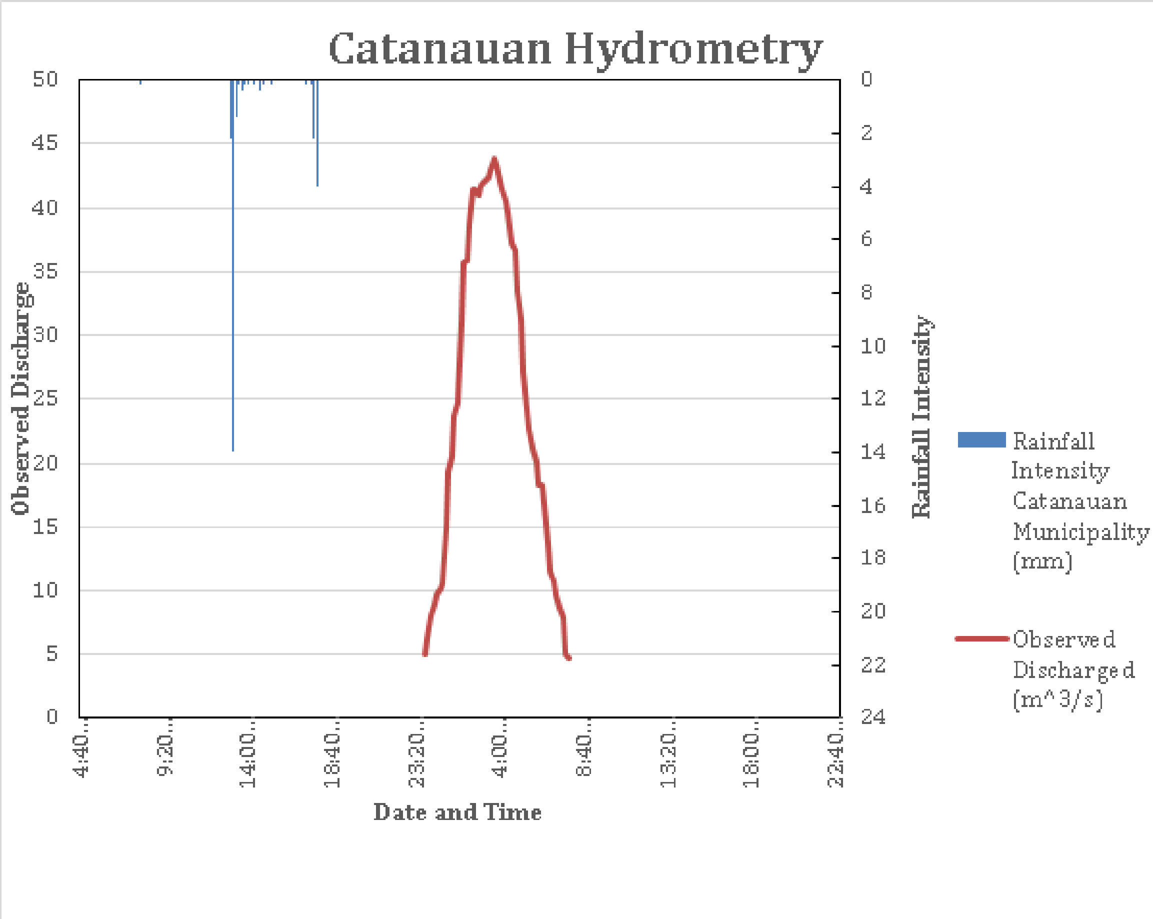


Figure 51. Rainfall and outflow data at Catanauan used for modeling.

5.2 RIDF Station

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

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

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	20.9	31.3	39.8	55.3	77	94.2	118.3	143.2	173.4
5	27.6	41.3	52.9	74.6	108.5	134.8	172.8	208.6	252
10	32.1	48	61.6	87.3	129.4	161.6	209	251.9	303.9
15	34.6	51.8	66.5	94.5	141.1	176.8	229.3	276.3	333.3
20	36.4	54.4	69.9	99.6	149.4	187.4	243.6	293.4	353.8
25	37.7	56.5	72.6	103.5	155.7	195.6	254.6	306.6	369.6
50	41.9	62.7	80.7	115.4	175.3	220.7	288.4	347.2	418.4
100	46.1	69	88.8	127.3	194.7	245.7	322	387.5	466.7

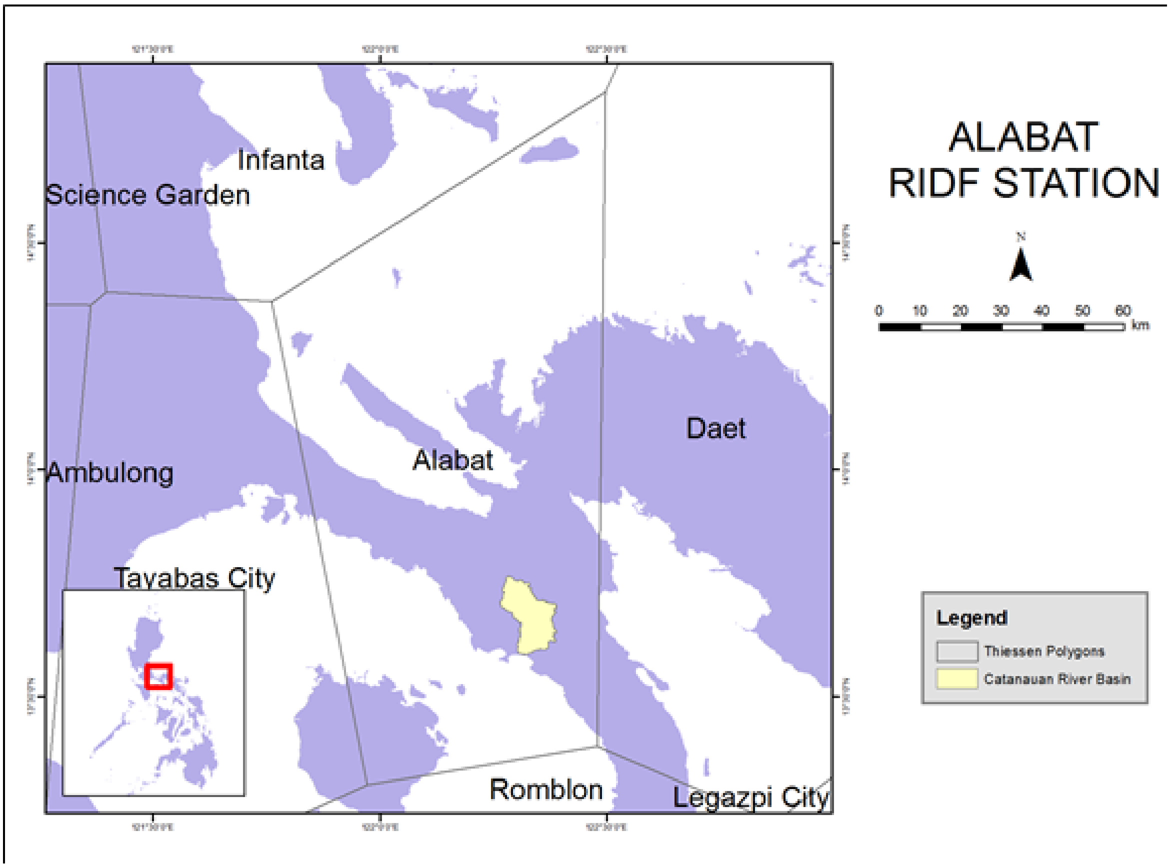


Figure 52. Alabat RIDF location relative to Catanauan River Basin.

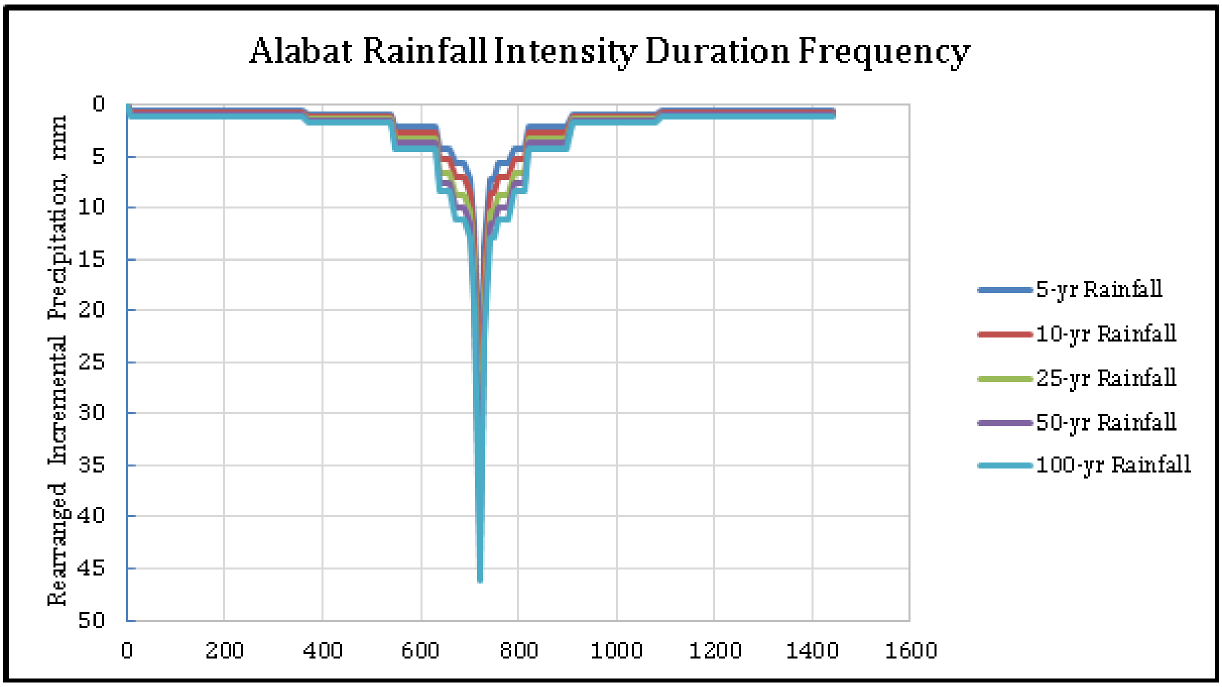


Figure 53. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was taken in 2004 by the Bureau of Soil and Water Management; this is 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 Catanauan River Basin are shown in Figures 54 and 55, respectively.

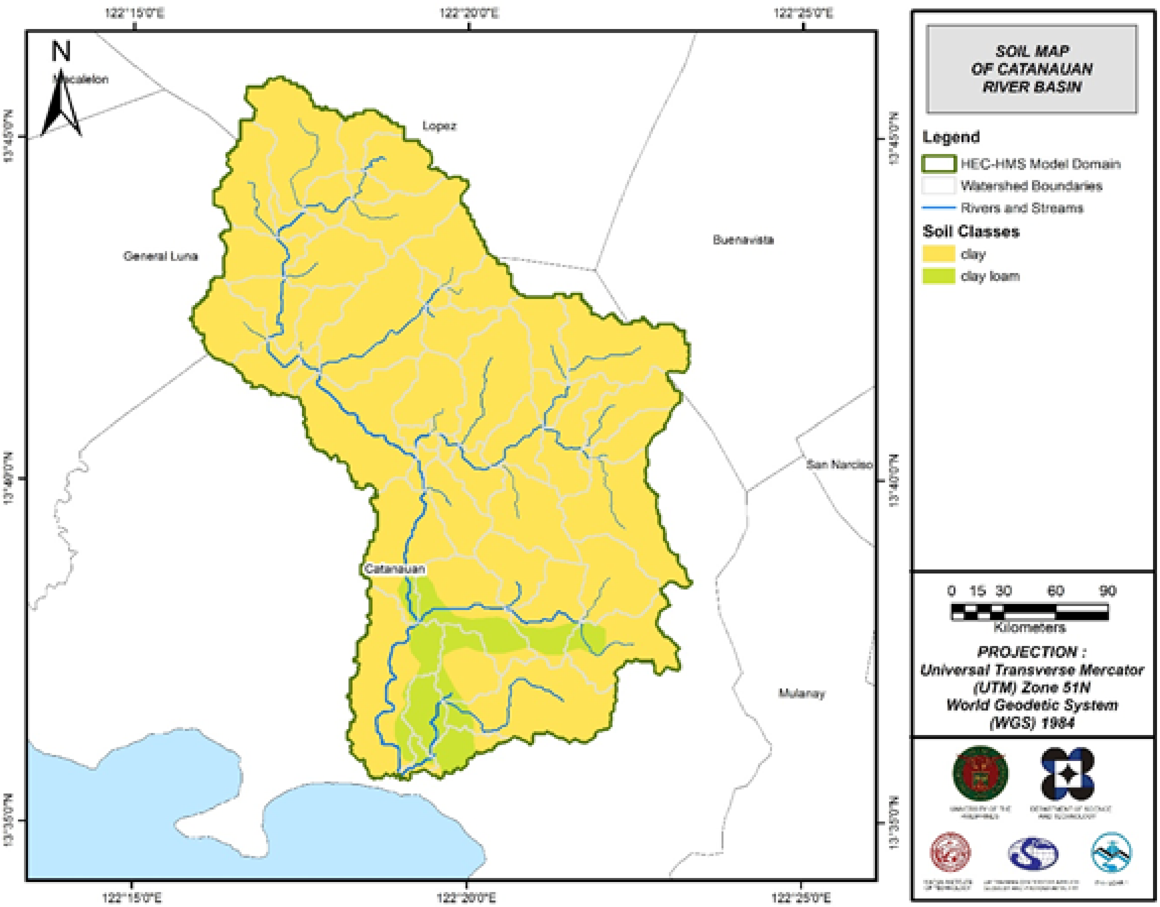


Figure 54. Soil Map of Catanauan River Basin.

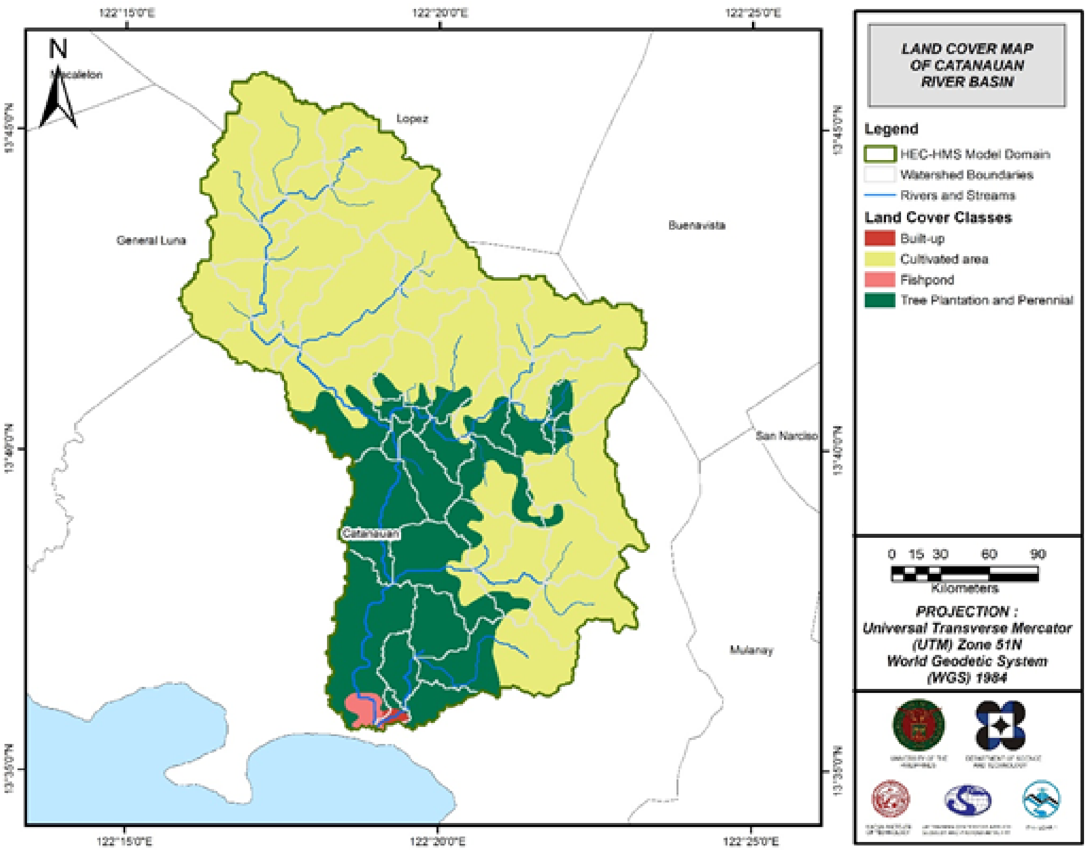


Figure 55. Land Cover Map of Catanauan River Basin

For Catanauan, the soil classes identified were clay loam and clay. The land cover types identified were built-up areas, cultivated areas, fishponds and tree plantations.

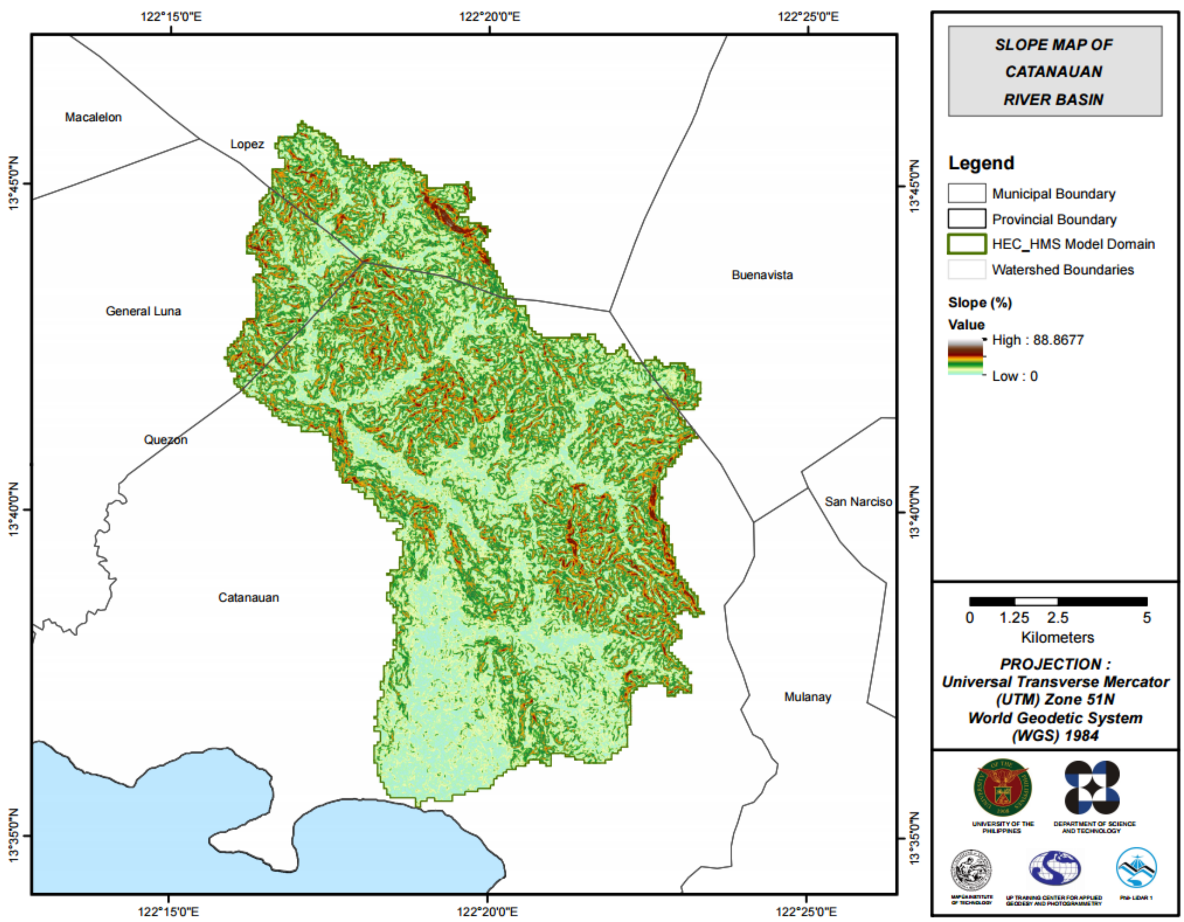


Figure 56. Slope Map of Catanauan River Basin.

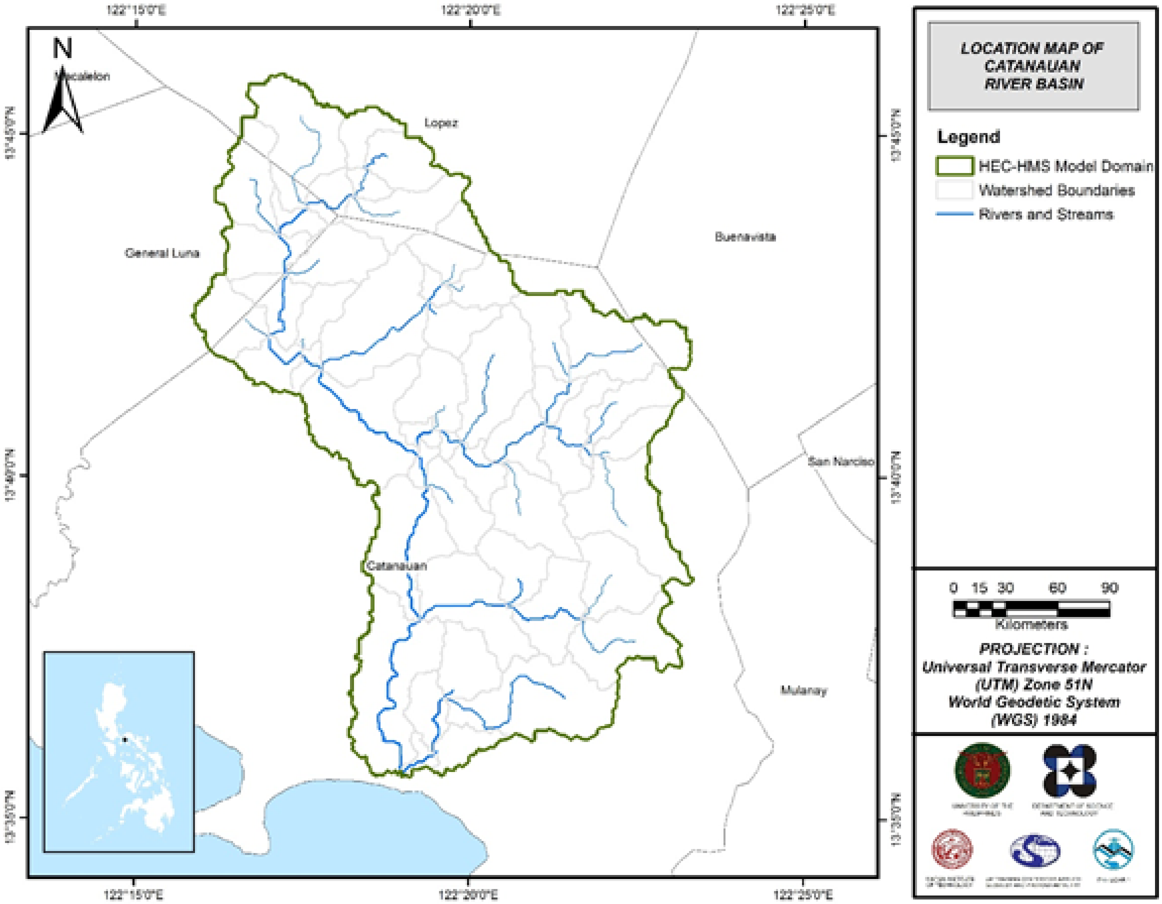


Figure 57. Stream delineation map of Catanauan river basin.

The Catanauan basin model comprises 50 sub basins, 24 reaches, and 24 junctions. The main outlet is at the southernmost part of the watershed. This basin model is illustrated in Figure 57. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed Rain Gauge near the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in the Catanauan Bridge.

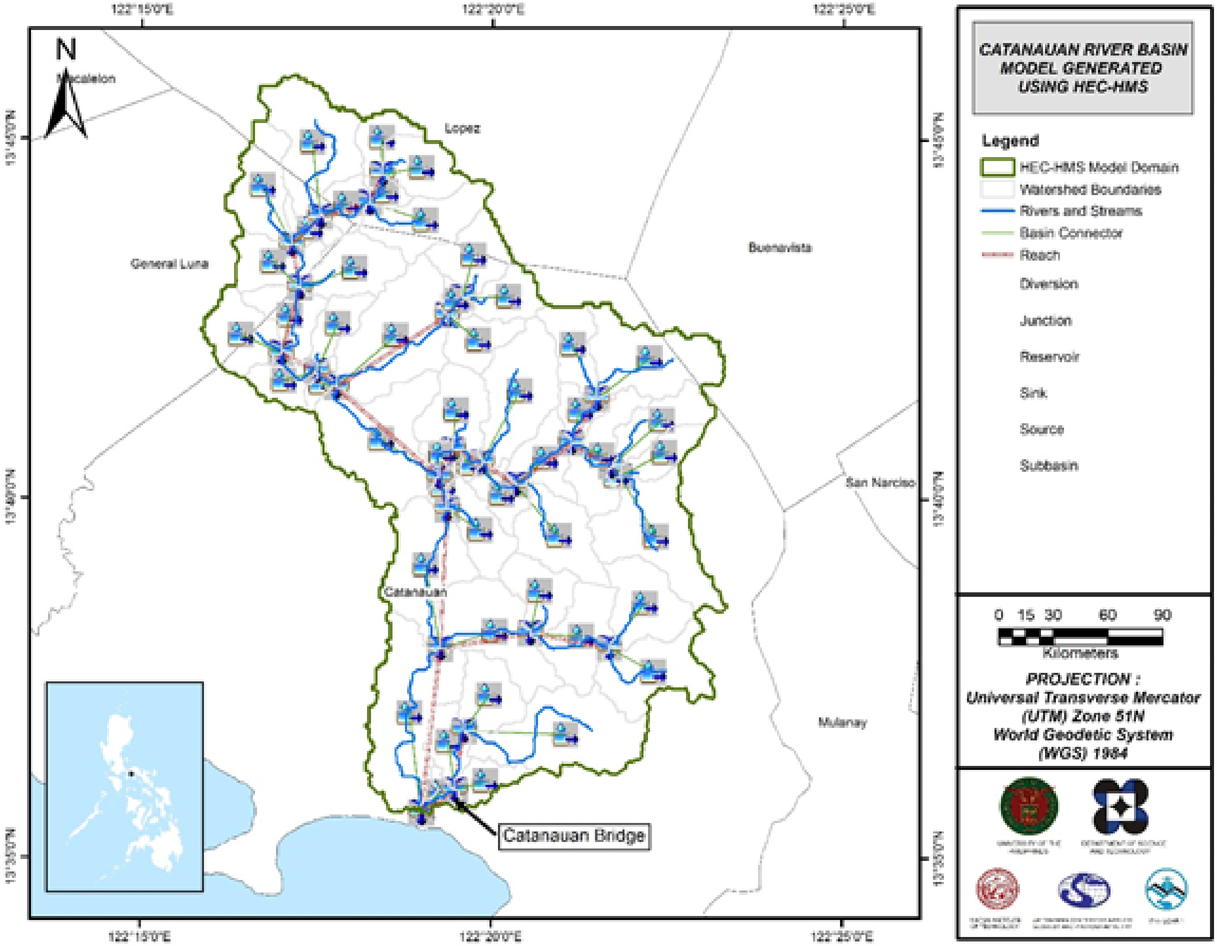


Figure 58. The Catanauan River Basin Model Domain generated using HEC-HMS.

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

5.4 Cross-section Data

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

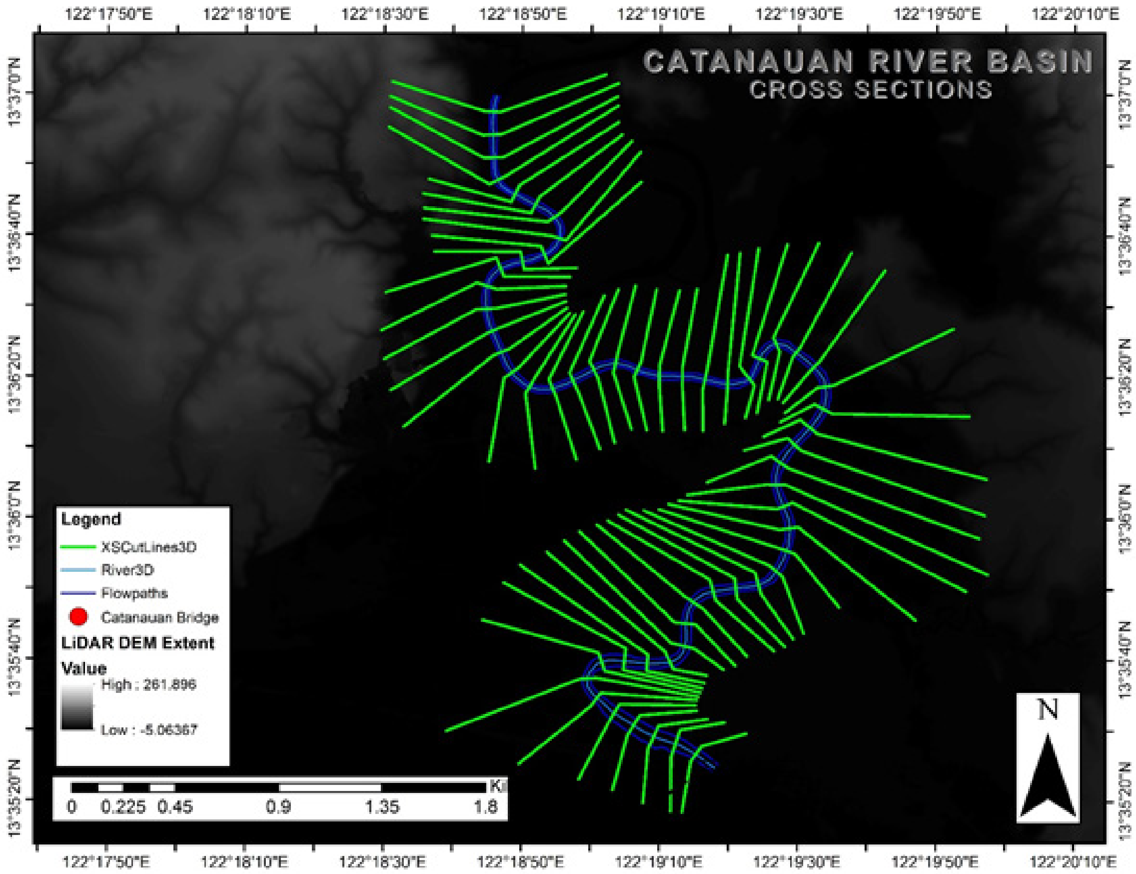


Figure 59. River cross-section of Catanauan River generated through Arcmap HEC GeoRAS tool.

Manning's n

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

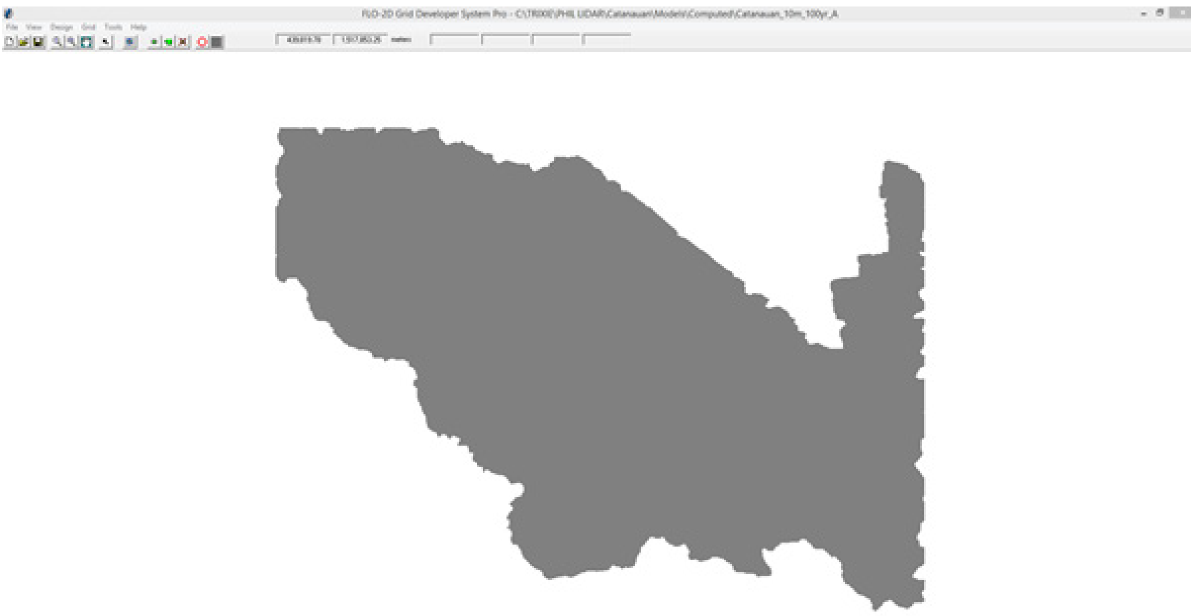


Figure 60. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro.

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 131.33838 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.

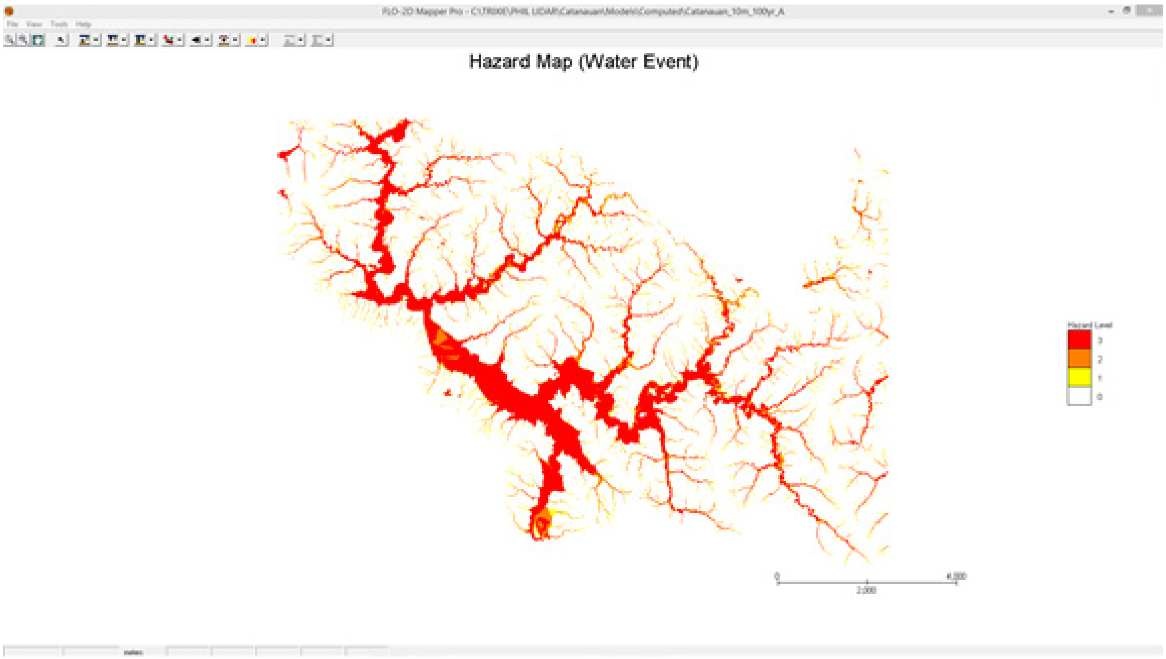


Figure 61. Generated 100-year rain return hazard map from FLO-2D Mapper.

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 84 719 136.00 m2.

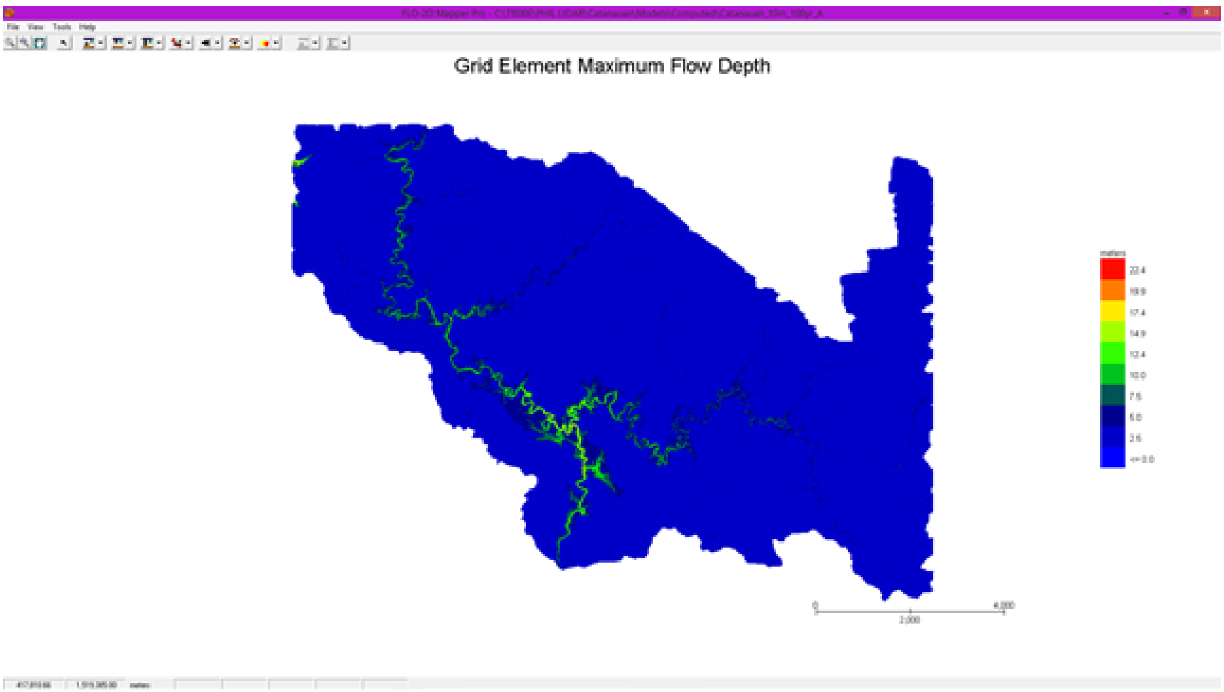


Figure 62. Generated 100-year rain return flow depth map from FLO-2D Mapper.

There is a total of 44 772 218.06 m3 of water entering the model. Of this amount, 39 745 196.86 m3 is due to rainfall while 5 027 021.20 m3 is inflow from other areas outside the model. 7 349 112.00 m3 of this water is lost to infiltration and interception, while 11 652 393.82 m3 is stored by the flood plain. The rest, amounting up to 25 770 713.15 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Catanauan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 64 shows the comparison between the two discharge data.

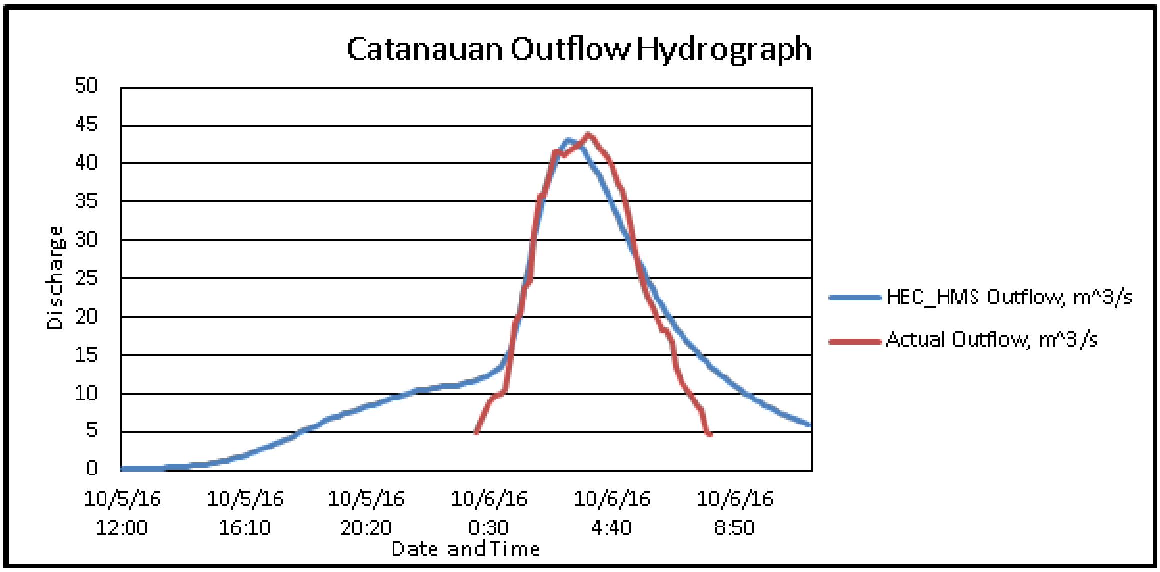


Figure 63. Outflow Hydrograph of Catanauan produced by the HEC-HMS model compared with observed outflow

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 Catanauan.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.62 – 32.75
			Curve Number	74.76 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.017 – 15.55
			Storage Coefficient (hr)	0.063 – 3.17
	Baseflow	Recession	Recession Constant	0.00043 – 0.0028
			Ratio to Peak	0.099 – 0.76
Reach	Routing	Muskingum-Cunge	Slope	0.0001 – 0.61
			Manning’s n	0.0001-1

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.62mm to 32.75mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 74.76 to 99 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Catanauan, the soil classes identified were clay loam and clay. The land cover types identified were built-up areas, cultivated areas, fishponds and tree plantations.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.017 hours to 15.55 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. Recession Constant values range from 0.00043 to 0.0028 and the Ratio to Peak ranges from 0.099 to 0.76. The receding limb of the outflow hydrograph is steep and is likely to quickly return to its original discharge.

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

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

Accuracy Measure	Value
RMSE	4
r2	0.9648
NSE	0.91
PBIAS	-5.05
RSR	0.29

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 4 m3/s.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.9648.

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 0.91.
.
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 -5.05.

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 0.29.

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

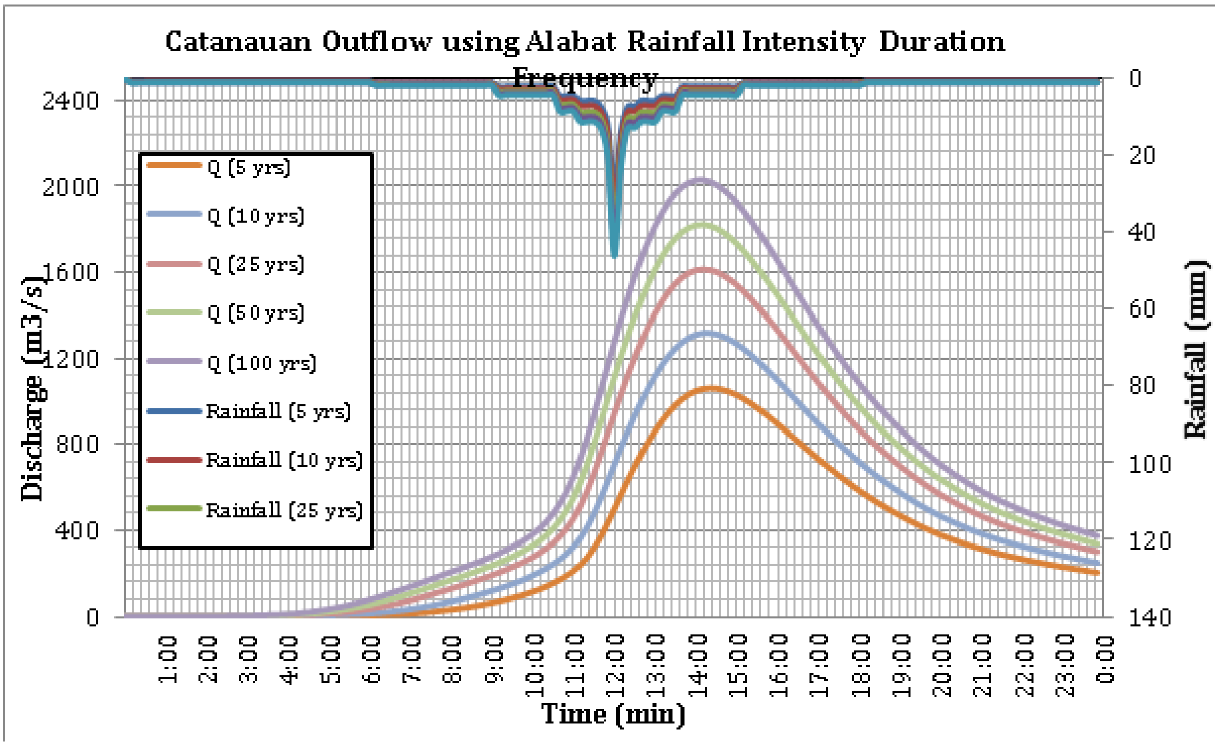


Figure 64. Outflow hydrograph at Catanauan generated using Alabat RIDF simulated in HEC-HMS.

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

Table 29. Peak values of the Catanauan HECHMS Model outflow using the Alabat RIDF.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	252	27.6	1061.2	14 hours, 20 minutes
10-Year	303.9	32.1	1317.1	14 hours, 20 minutes
25-Year	369.6	37.7	1614	14 hours, 10 minutes
50-Year	418.4	41.9	1822.4	14 hours, 10 minutes
100-Year	466.7	46.1	2027.9	14 hours, 10 minutes

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

The river discharge values for the rivers entering the floodplain are shown in Figure 62 to Figure 63 and the peak values are summarized in Table 30 to Table 32.

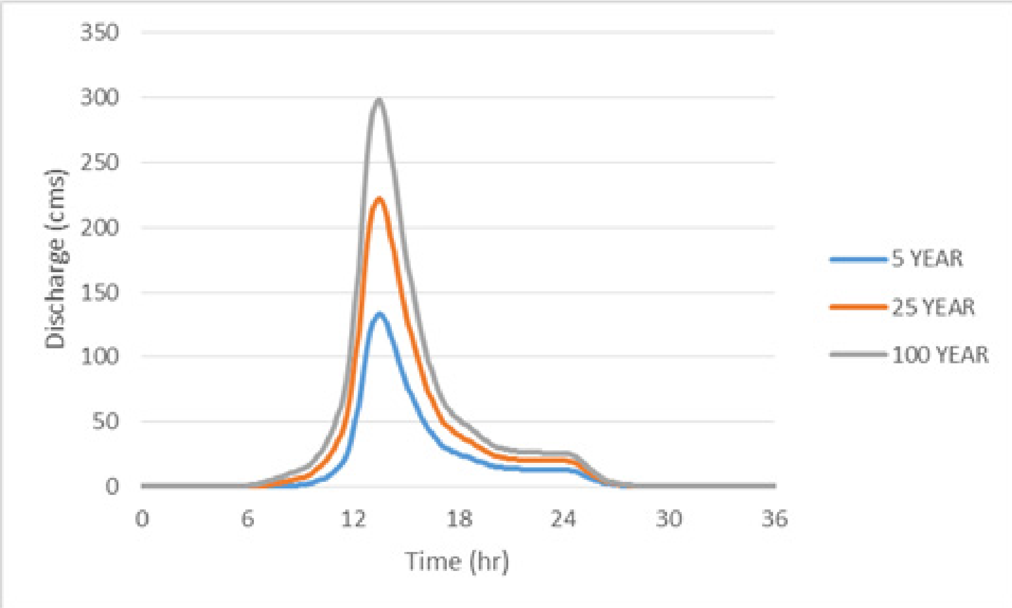


Figure 65. Catanauan river (1) generated discharge using 5-, 25-, and 100-year rainfall intensity-duration-frequency (RIDF) in HEC-HMS

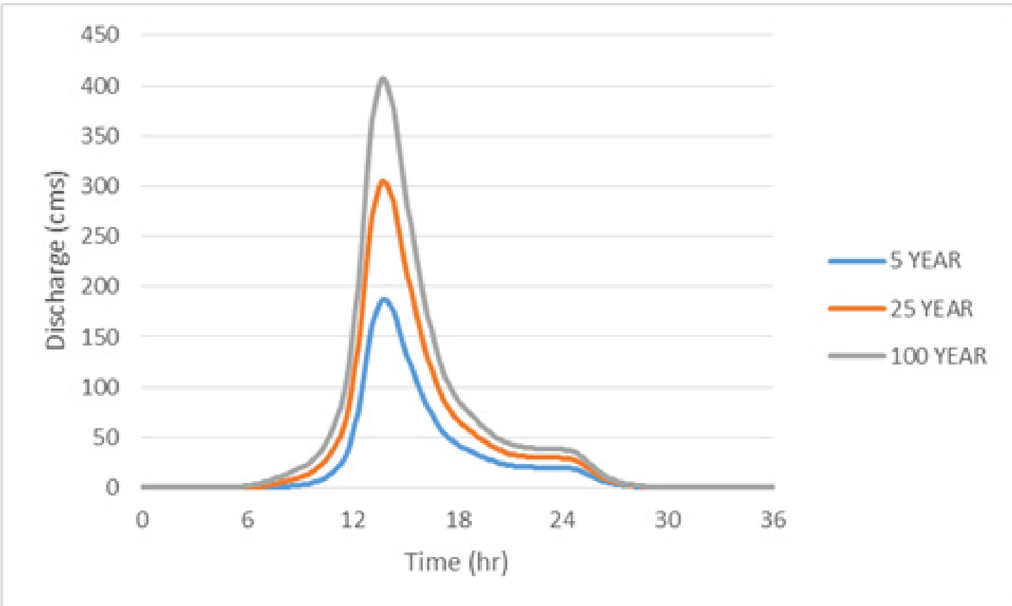


Figure 66. Catanauan river (2) generated discharge using 5-, 25-, and 100-year rainfall intensity-duration-frequency (RIDF) in HEC-HMS.

Table 30. Summary of Catanauan river (1) discharge generated in HEC-HMS.

RIDF Period	Peak discharge (cms)	Time-to-peak (minutes)
100-Year	298.2	88.19
25-Year	222.3	88.19
5-Year	133.4	88.19

Table 31. Summary of Catanauan river (2) discharge generated in HEC-HMS.

RIDF Period	Peak discharge (cms)	Time-to-peak (minutes)
100-Year	406.9	104.50
25-Year	305.2	104.50
5-Year	187.4	104.50

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

Table 32. Validation of river discharge estimates.

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Catanauan (1)	117.392	152.570	181.817	PASS	PASS
Catanauan (2)	164.912	238.931	245.912	PASS	PASS

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

5.8 River Analysis (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. For this publication, only a sample output map river was to be shown, since only the Flood Acquisition and Validation Component (MIT-FAVC) base flow was calibrated. The sample generated map of Catanauan River using the calibrated HMS base flow is shown in Figure 66.

Figure 67. Sample output of Catanauan RAS Model.

5.9 Flow Depth and Flood Hazard

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

Table 33. Municipalities affected in Catanauan floodplain.

Municipality	Total Area	Area Flooded	% Flooded
Catanauan	253.19	183.97	72.66%
Buenavista	171.22	4.00	2.33%
General Luna	100.0022	7.73	7.73%

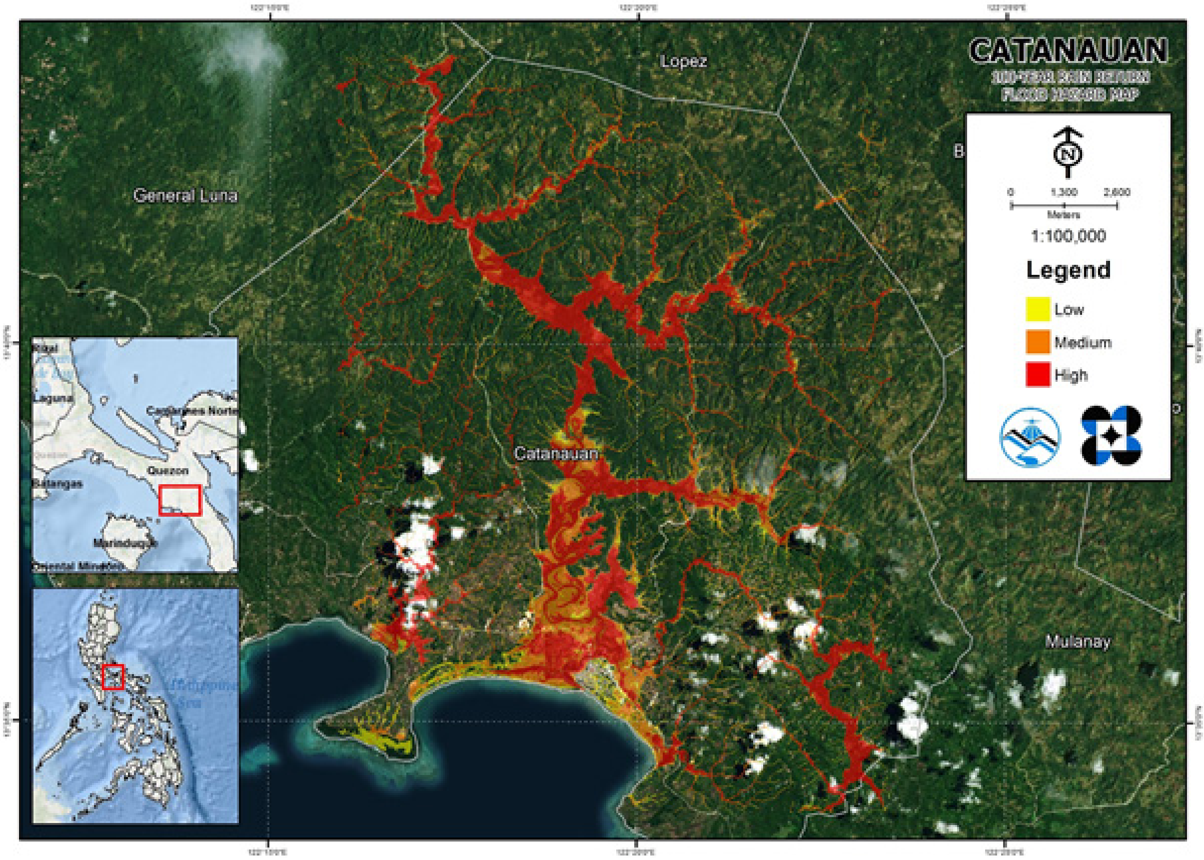


Figure 68. 100-year Rain Return Flood Hazard Map for Catanauan Floodplain.

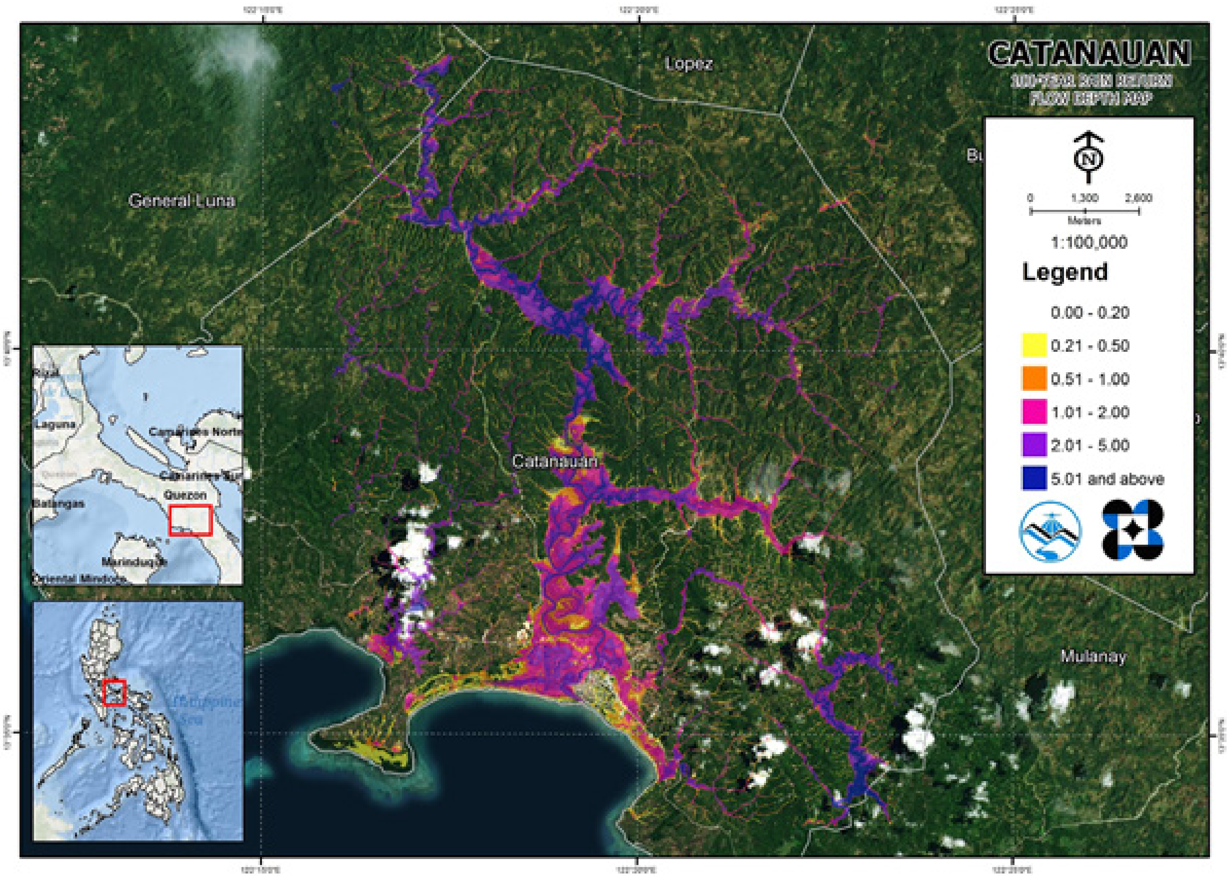


Figure 69. 100-year Rain Return Flood Depth Map for Catanauan Floodplain.

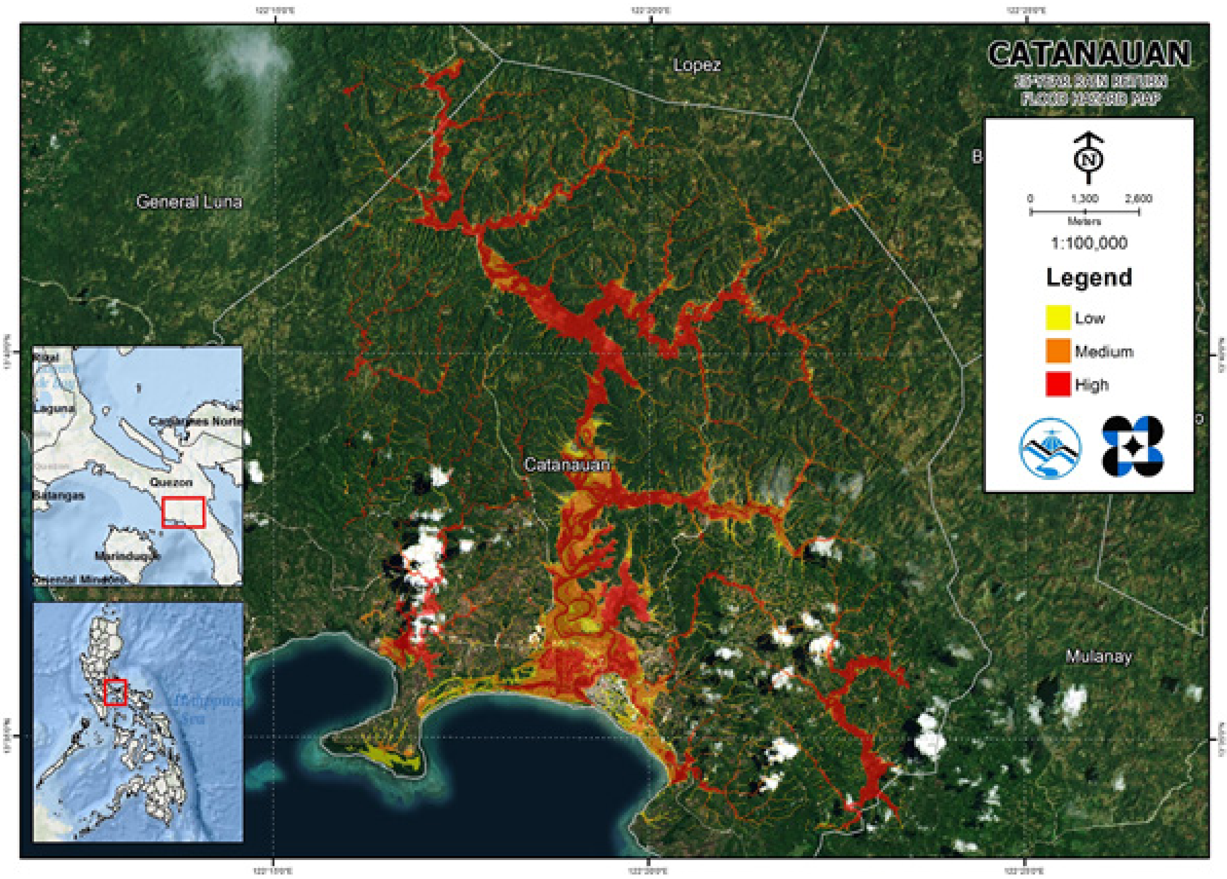


Figure 70. 25-year Rain Return Flood Hazard Map for Catanauan Floodplain.

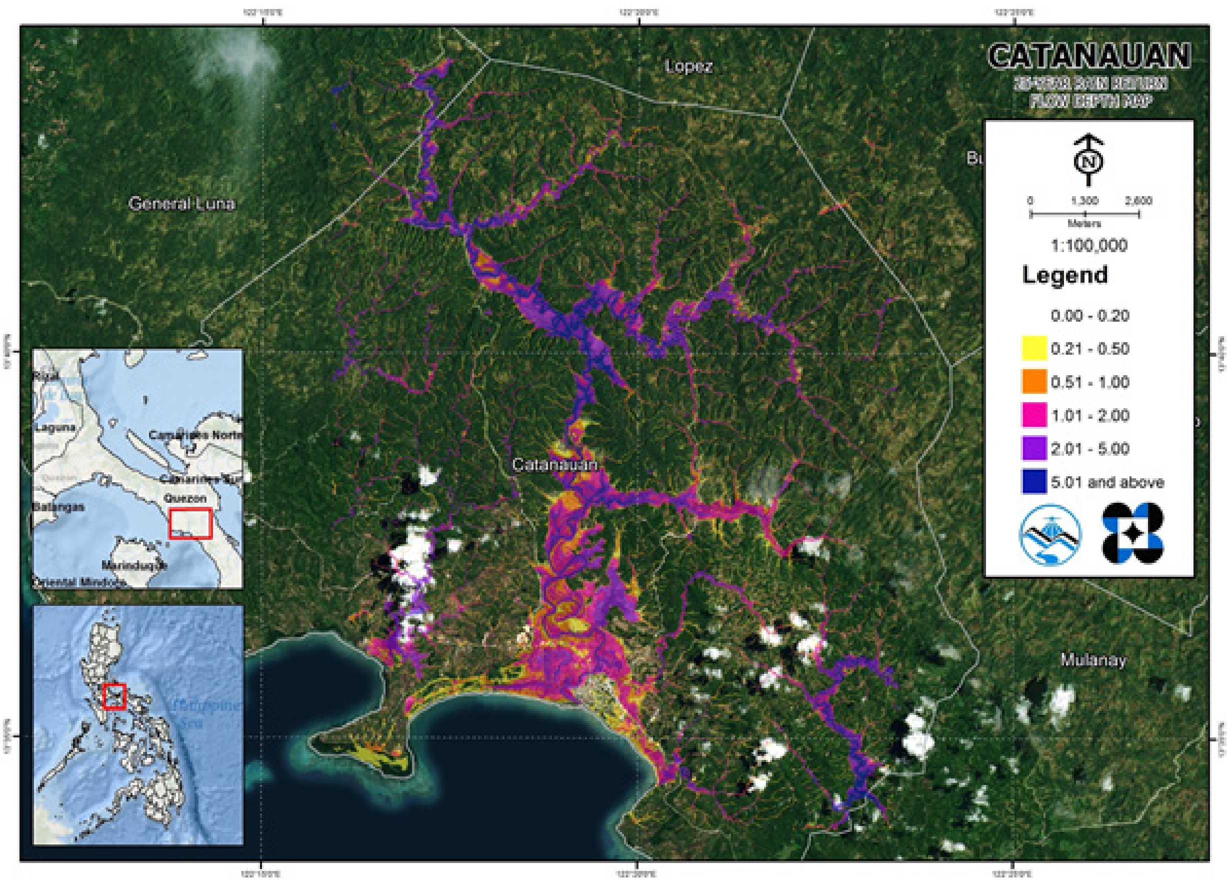


Figure 71. 25-year Rain Return Flood Depth Map for Catanauan Floodplain.

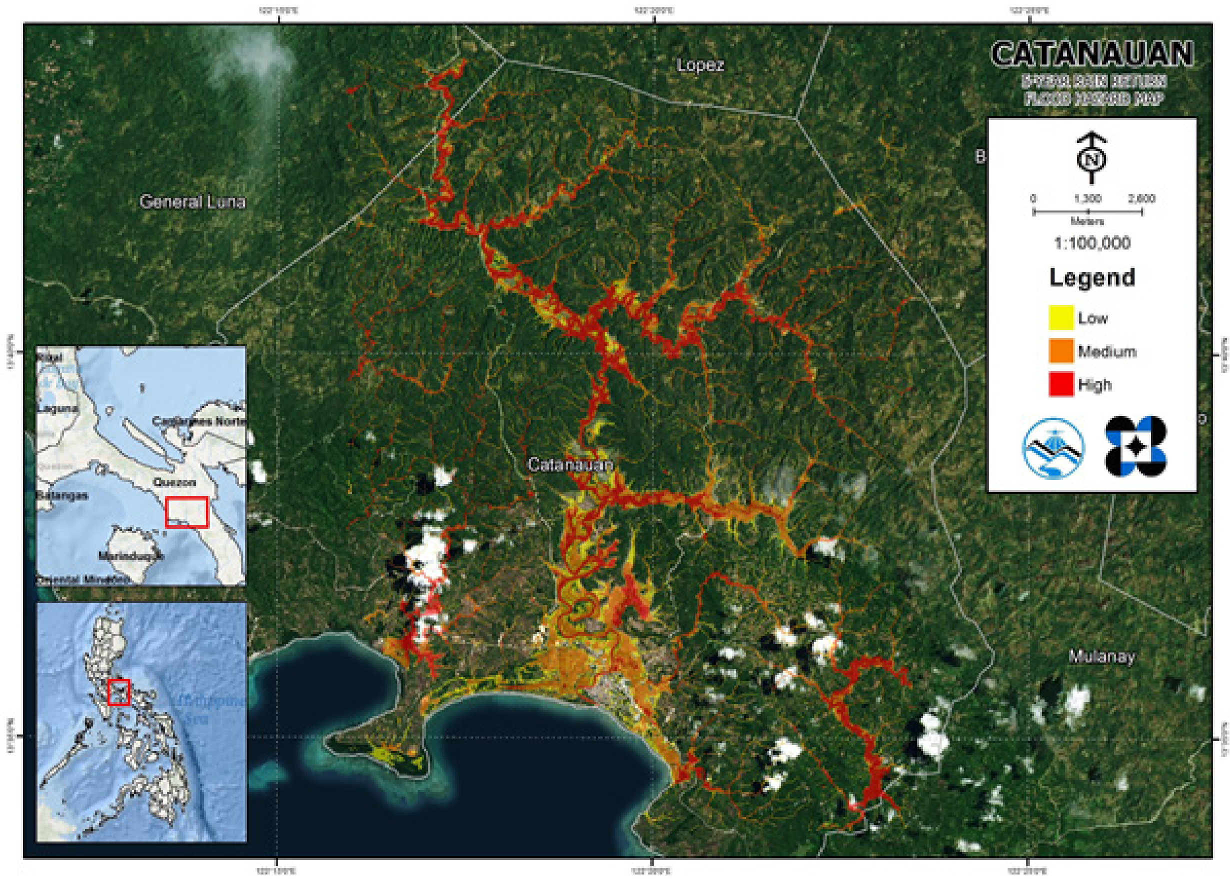


Figure 72. 5-year Rain Return Flood Hazard Map for Catanauan Floodplain.

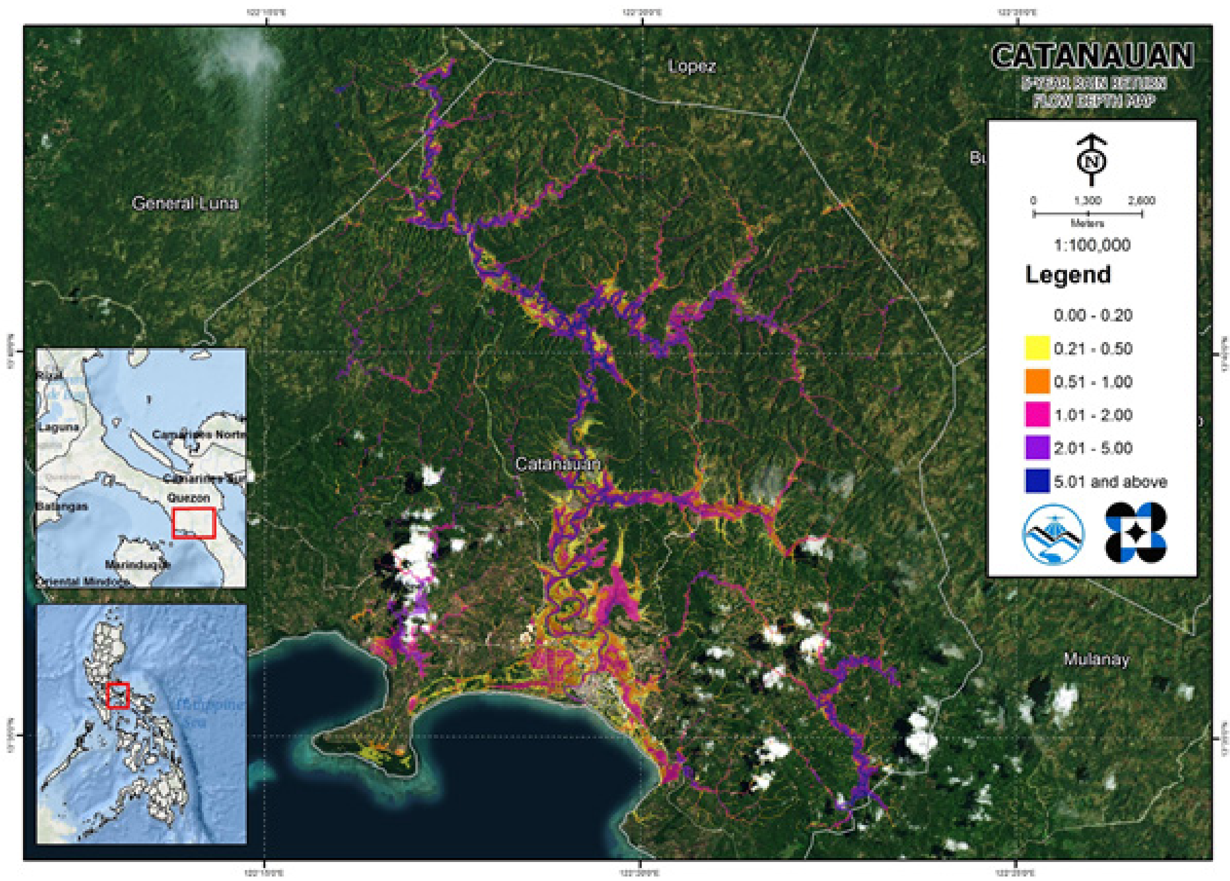


Figure 73. 5-year Rain Return Flood Depth Map for Catanauan Floodplain.

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Catanauan River Basin, grouped accordingly by municipality. For the said basin, three (3) municipalities consisting of 45 barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 60.17% of the municipality of Catanauan with an area of 253.19 sq. km. will experience flood levels of less than 0.20 meters. 3.19% of the area will experience flood levels of 0.21 to 0.50 meters while 3.18%, 3.46%, 2.15%, and 0.48% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

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

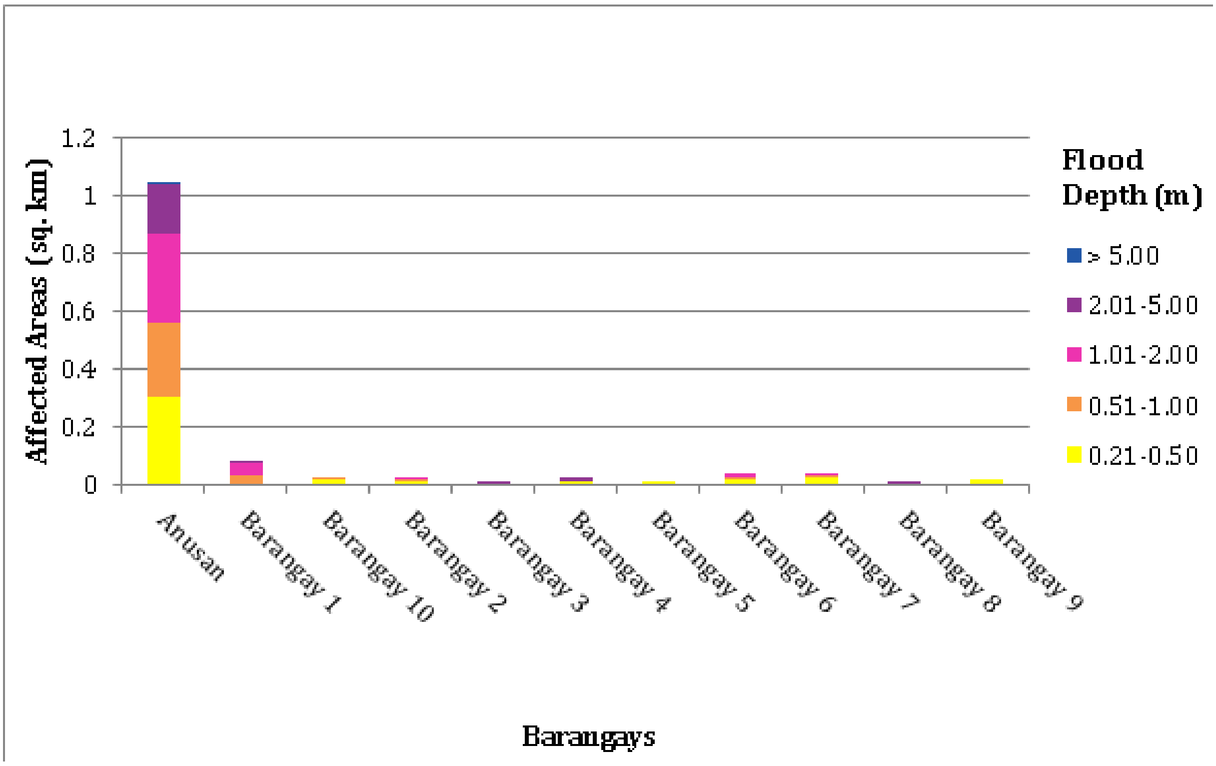
Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)						
	Anusan	Barangay 1	Barangay 10	Barangay 2	Barangay 3	Barangay 4	Barangay 5
0.03-0.20	11.53	0.024	0.086	0.073	0.08	0.022	0.058
0.21-0.50	0.3	0.0058	0.015	0.012	0.0017	0.0089	0.0097
0.51-1.00	0.26	0.027	0.0002	0.0016	0.00049	0.0015	0
1.01-2.00	0.31	0.039	0	0.000001	0.0019	0.0028	0
2.01-5.00	0.17	0.0022	0	0	0.0039	0.0093	0
> 5.00	0.0004	0	0	0	0	0	0

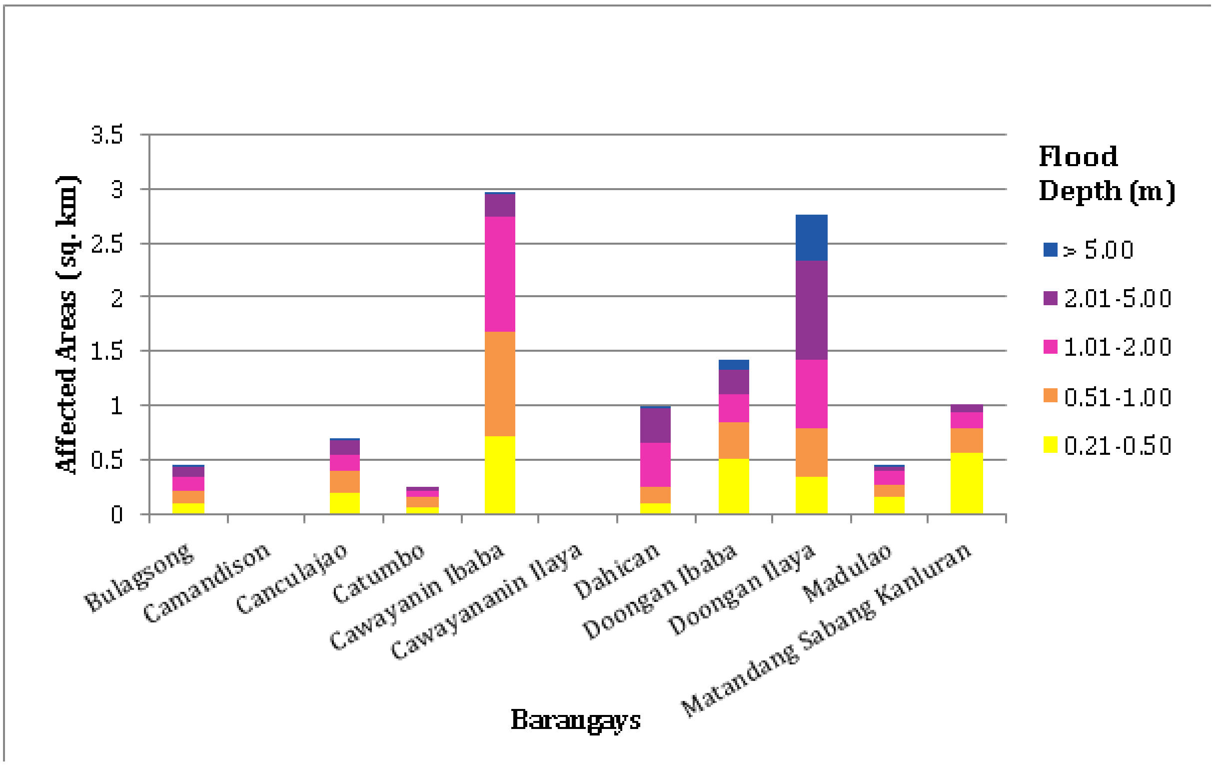
Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)						
	Barangay 6	Barangay 7	Barangay 8	Barangay 9	Bulagsong	Camandison	Canculajao
0.03-0.20	0.089	0.085	0.061	0.076	1.66	0	3.78
0.21-0.50	0.015	0.022	0.0016	0.016	0.097	0	0.2
0.51-1.00	0.012	0.0069	0.00085	0	0.12	0	0.2
1.01-2.00	0.011	0.0029	0.0015	0	0.12	0	0.15
2.01-5.00	0	0	0.00099	0	0.098	0	0.12
> 5.00	0	0	0	0	0.017	0	0.02

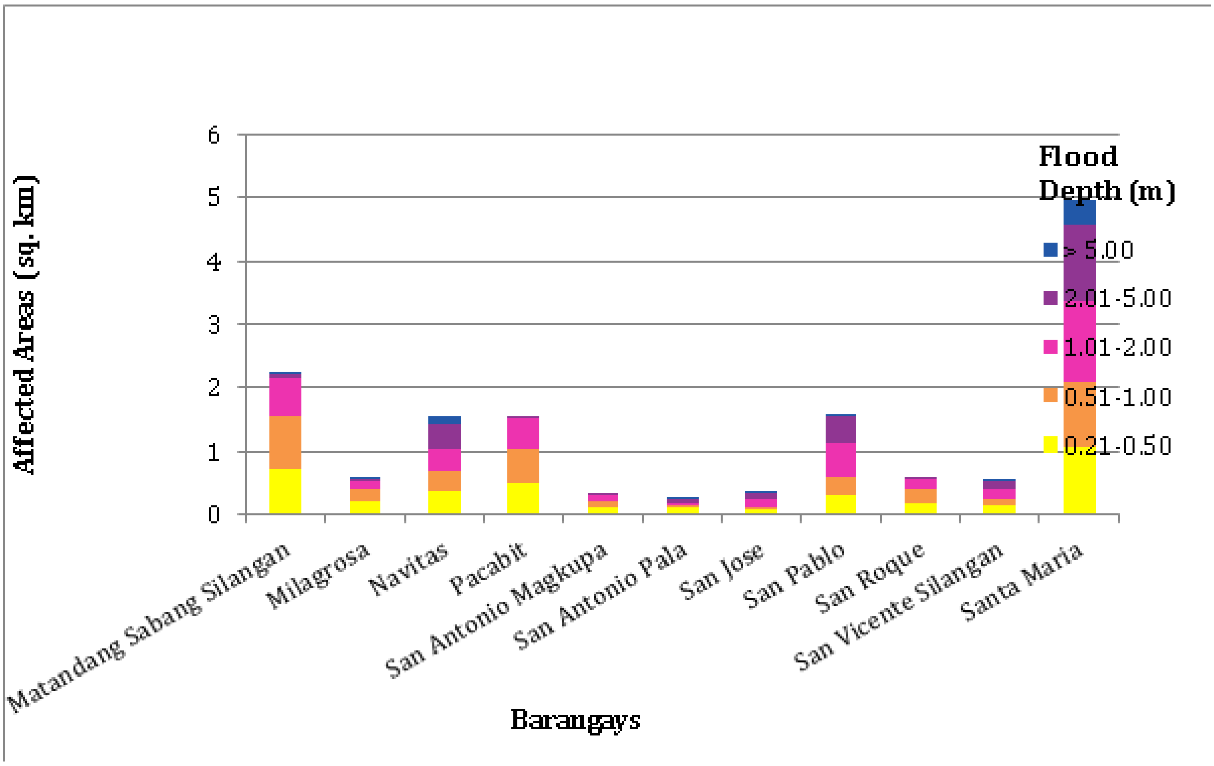
Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)					
	Catumbo	Cawayanin Ibaba	Cawayananin Ilaya	Dahican	Doongan Ibaba	Doongan Ilaya
0.03-0.20	1.32	3.93	0	2.35	7.12	4.46
0.21-0.50	0.061	0.71	0	0.1	0.51	0.35
0.51-1.00	0.095	0.97	0	0.15	0.34	0.43
1.01-2.00	0.06	1.06	0	0.4	0.25	0.65
2.01-5.00	0.036	0.21	0	0.32	0.23	0.91

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)								
	Madulao	Matandang Sabang Kanluran	Matandang Sabang Silangan	Milagrosa	Navitas	Pacabit	San Antonio Magkupa	San Antonio Pala	San Jose
0.03-0.20	4.07	3.92	2.13	6.07	6.07	5.87	4.11	2.04	2.34
0.21-0.50	0.15	0.56	0.73	0.21	0.37	0.49	0.11	0.093	0.061
0.51-1.00	0.11	0.23	0.81	0.17	0.3	0.54	0.089	0.049	0.06
1.01-2.00	0.13	0.15	0.6	0.13	0.36	0.47	0.11	0.033	0.11
2.01-5.00	0.046	0.075	0.066	0.036	0.4	0.06	0.032	0.049	0.097
> 5.00	0.0072	0	0.0033	0.0001	0.12	0	0	0.0061	0.018

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)								
	San Pablo	San Roque	San Vicente Silangan	Santa Maria	Tagabas Ibaba	Tagabas Ilaya	Tagbacan Ibaba	Tagbacan Ilaya	Tagbacan Silangan
0.03-0.20	9.25	4.08	5.02	29.66	3.06	8.91	7.28	7.89	3.41
0.21-0.50	0.29	0.16	0.13	1.08	0.082	0.28	0.28	0.38	0.12
0.51-1.00	0.31	0.24	0.12	1.02	0.075	0.24	0.28	0.63	0.15
1.01-2.00	0.54	0.17	0.14	1.27	0.15	0.27	0.24	0.56	0.26
2.01-5.00	0.39	0.026	0.13	1.22	0.1	0.097	0.019	0.12	0.36
> 5.00	0.026	0	0.017	0.37	0.0002	0.0022	0	0	0.086


Affected Areas (sq. km)
1.2
1
0.8
0.6
0.4
0.2
0
Anusan
Barangay 1
Barangay 10
Barangay 2
Barangay 3
Barangay 4
Barangay 5
Barangay 6
Barangay 7
Barangay 8
Barangay 9
Barangays
Flood Depth (m)
> 5.00
2.01-5.00
1.01-2.00
0.51-1.00
0.21-0.50


Affected Areas (sq. km)
3.5
3
2.5
2
1.5
1
0.5
0
Bulagsong
Camandison
Canculajao
Catumbo
Cawayanin Ibaba
Cawayananin Ilaya
Dahican
Doongan Ibaba
Doongan Ilaya
Madulao
Matandang Sabang Kanluran
Barangays
Flood Depth (m)
> 5.00
2.01-5.00
1.01-2.00
0.51-1.00
0.21-0.50



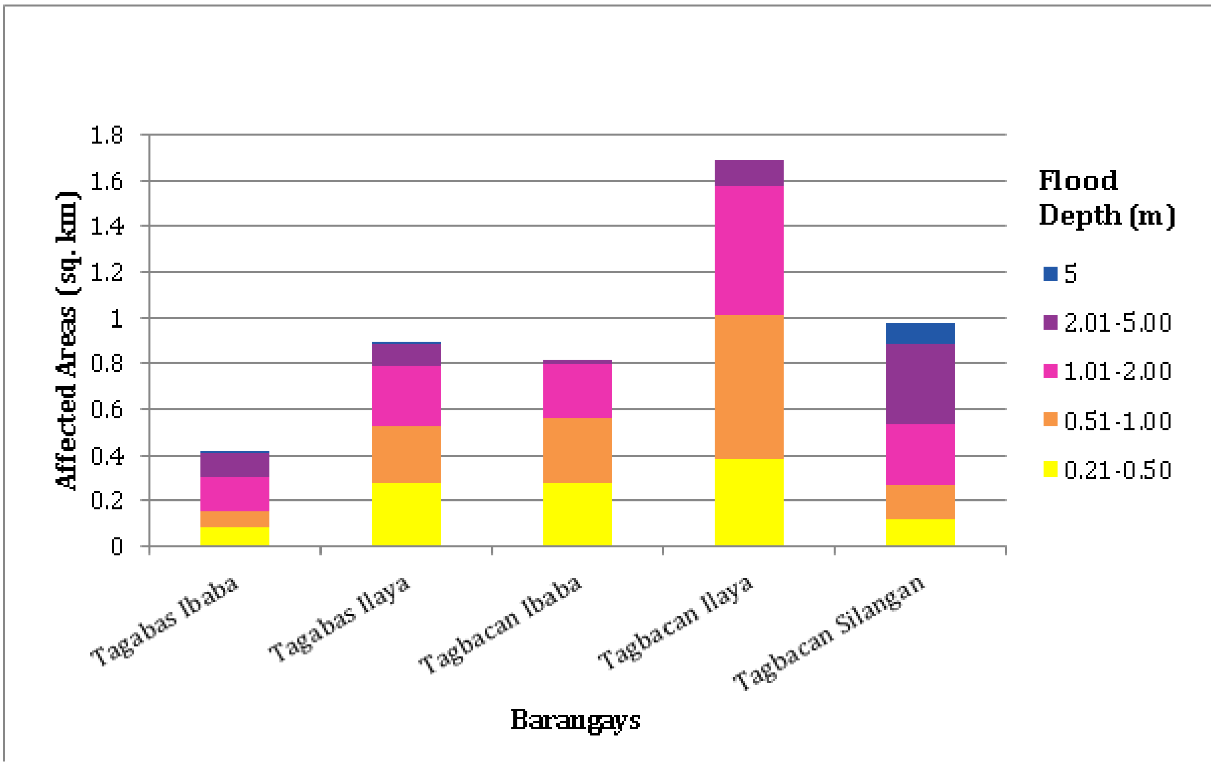


Figure 74. Affected areas in Catanauan, Quezon during a 5-Year Rainfall Return Period.

For the 5-year return period, 2.20% of the municipality of Buenavista with an area of 171.22 sq. km. will experience flood levels of less than 0.20 meters. 0.07% of the area will experience flood levels of 0.21 to 0.50 meters while 0.05%, 0.02%, 0.00%, and 0.00% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

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

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)			
	Maligaya	Masaya	Villa Magsaysay	Villa Veronica
0.03-0.20	3.04	0.1	0.36	0.26
0.21-0.50	0.099	0.0036	0.0033	0.008
0.51-1.00	0.077	0.0024	0.0021	0.0079
1.01-2.00	0.03	0.0041	0.001	0.004
2.01-5.00	0.0044	0.0011	0.00019	0.00091
> 5.00	0	0	0	0

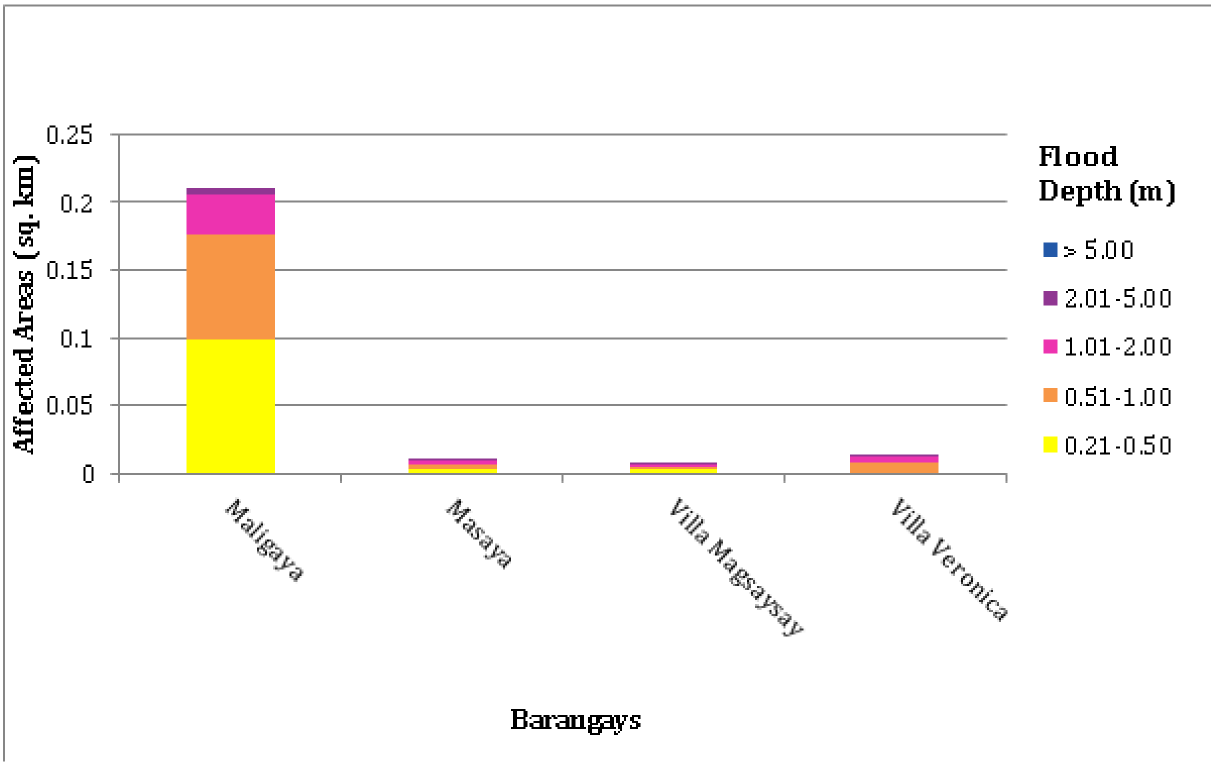


Figure 75. Areas affected by flooding in Buenavista, Quezon for a 5-Year Return Period rainfall event.

For the 5-year return period, 6.90% of the municipality of General Luna with an area of 100.0022 sq. km. will experience flood levels of less than 0.20 meters. 0.19% of the area will experience flood levels of 0.21 to 0.50 meters while 0.14%, 0.19%, 0.24%, and 0.07% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 36. Affected areas in General Luna, Quezon during a 5-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in General Luna (in sq. km.)		
	Lavides	Magsaysay	Malaya
0.03-0.20	0.33	2.81	3.76
0.21-0.50	0.0059	0.075	0.11
0.51-1.00	0.0049	0.044	0.095
1.01-2.00	0.0053	0.029	0.16
2.01-5.00	0.012	0.02	0.21
> 5.00	0.017	0.0046	0.048

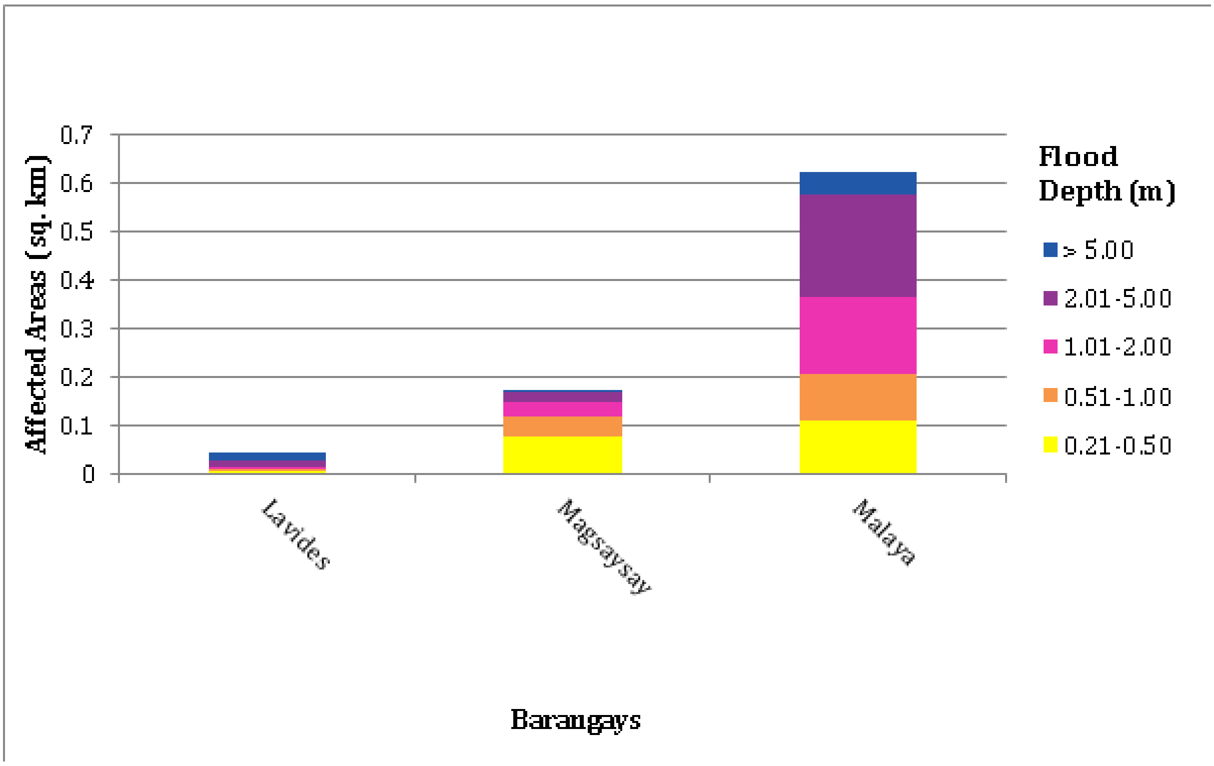


Figure 76. Affected areas in General Luna, Quezon during a 5-Year Rainfall Return Period.

For the 25-year return period, 57.76% of the municipality of Catanauan with an area of 253.19 sq. km. will experience flood levels of less than 0.20 meters. 2.87% of the area will experience flood levels of 0.21 to 0.50 meters while 2.82%, 4.35%, 3.95%, and 0.91% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

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

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)						
	Anusan	Barangay 1	Barangay 10	Barangay 2	Barangay 3	Barangay 4	Barangay 5
0.03-0.20	11.34	0.018	0.074	0.057	0.066	0.0011	0.051
0.21-0.50	0.34	0.0042	0.026	0.0073	0.0054	0.0016	0.017
0.51-1.00	0.26	0.0034	0.0009	0.0045	0.004	0.0047	0.0001
1.01-2.00	0.33	0.043	0	0.017	0.0072	0.024	0
2.01-5.00	0.3	0.028	0	0.000001	0.0047	0.012	0
> 5.00	0.0073	0.0014	0	0	0.0012	0.0016	0

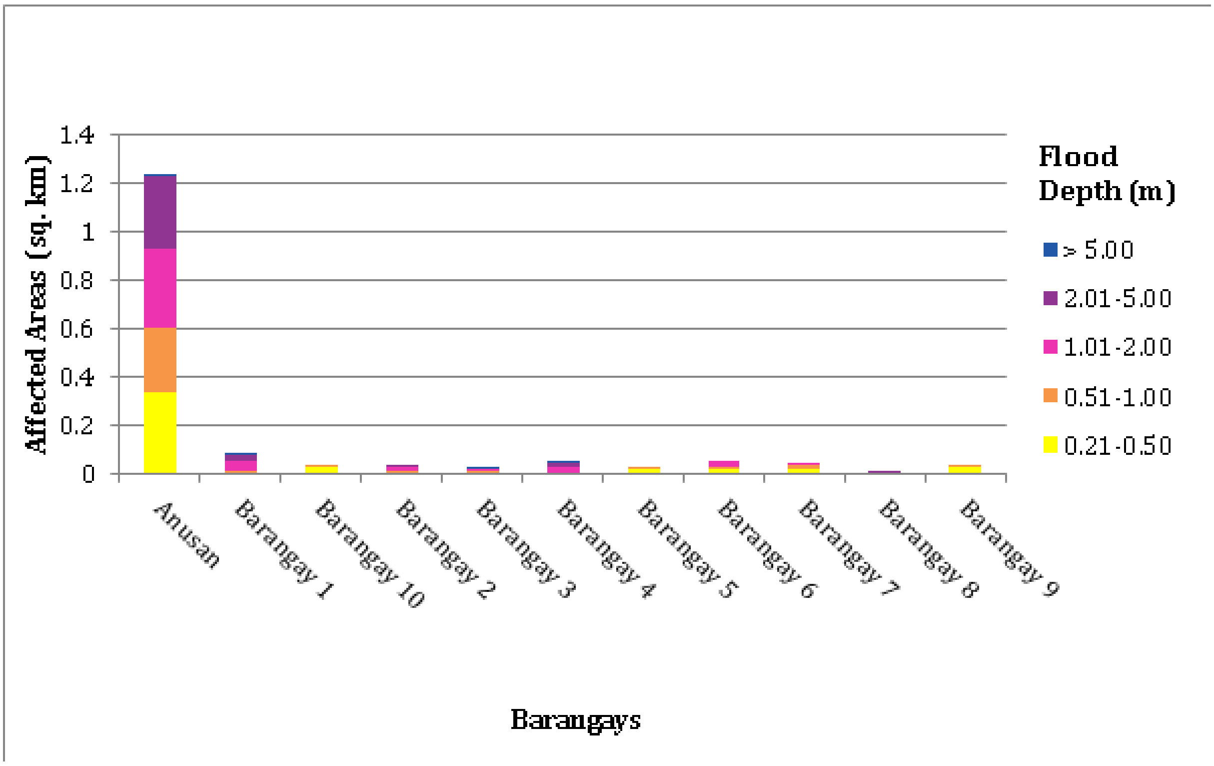
Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)						
	Barangay 6	Barangay 7	Barangay 8	Barangay 9	Bulagsong	Camandison	Canculajao
0.03-0.20	0.076	0.075	0.056	0.066	1.61	0	3.67
0.21-0.50	0.023	0.022	0.0056	0.026	0.062	0	0.14
0.51-1.00	0.0057	0.016	0.00064	0.0009	0.084	0	0.2
1.01-2.00	0.022	0.0038	0.0012	0	0.18	0	0.26
2.01-5.00	0	0	0.0027	0	0.15	0	0.17
> 5.00	0	0	0	0	0.024	0	0.032

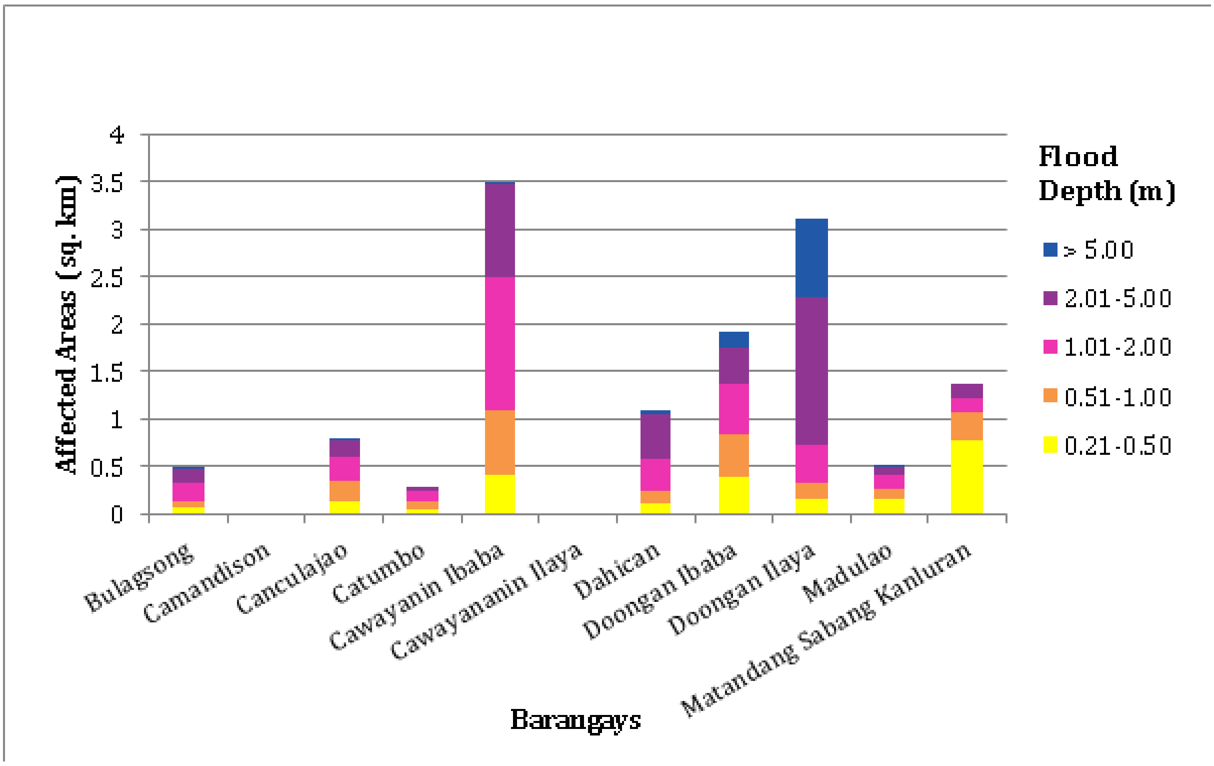
Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)					
	Catumbo	Cawayanin Ibaba	Cawayananin Ilaya	Dahican	Doongan Ibaba	Doongan Ilaya
0.03-0.20	1.28	3.4	0	2.24	6.62	4.12
0.21-0.50	0.059	0.41	0	0.11	0.39	0.16
0.51-1.00	0.083	0.68	0	0.13	0.44	0.17
1.01-2.00	0.096	1.41	0	0.35	0.55	0.4
2.01-5.00	0.049	0.97	0	0.46	0.37	1.56
> 5.00	0	0.033	0	0.035	0.17	0.82

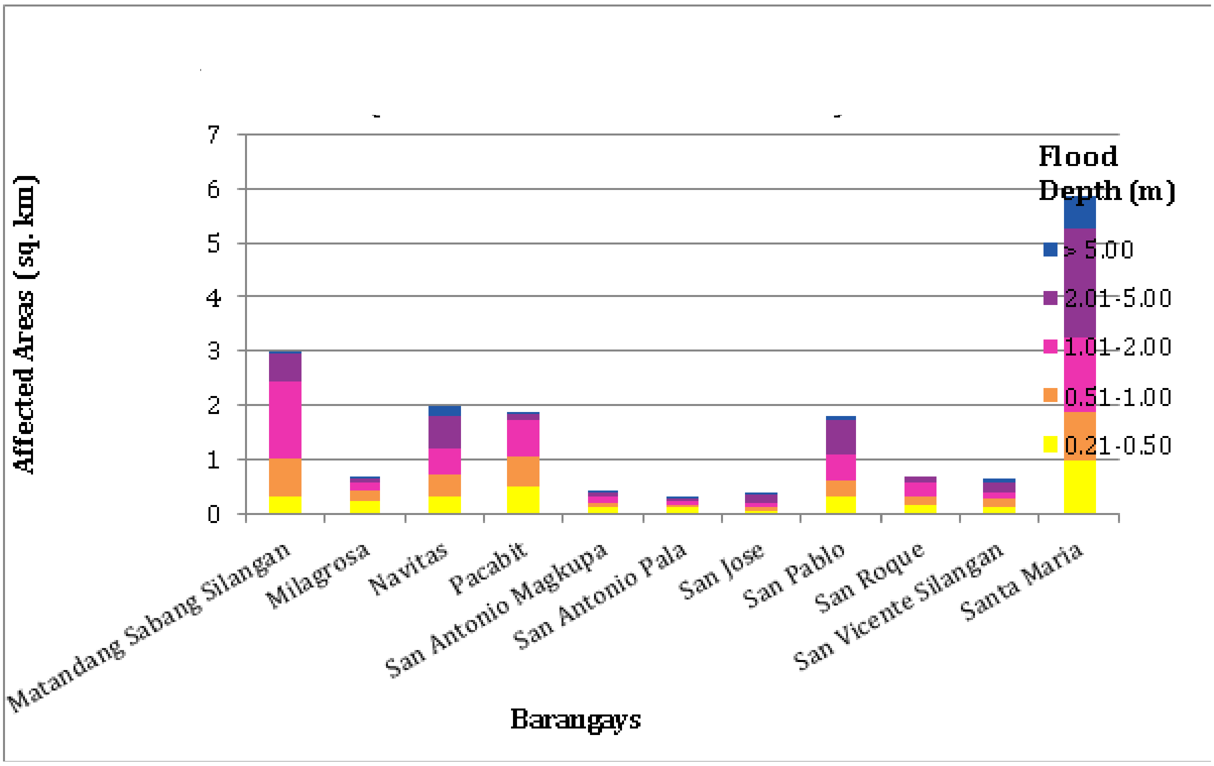
Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)					
	Madulao	Matandang Sabang Kanluran	Matandang Sabang Silangan	Milagrosa	Navitas	Pacabit
0.03-0.20	4	3.57	1.36	5.97	5.62	5.6
0.21-0.50	0.15	0.78	0.33	0.23	0.32	0.5
0.51-1.00	0.12	0.29	0.69	0.18	0.42	0.55
1.01-2.00	0.14	0.16	1.4	0.17	0.48	0.66
2.01-5.00	0.094	0.13	0.53	0.067	0.57	0.14
> 5.00	0.014	0	0.025	0.0002	0.2	0.00023

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)				
	San Antonio Magkupa	San Antonio Pala	San Jose	San Pablo	San Roque
0.03-0.20	4.04	1.99	2.3	8.99	4.01
0.21-0.50	0.12	0.12	0.069	0.32	0.15
0.51-1.00	0.091	0.059	0.049	0.28	0.18
1.01-2.00	0.12	0.042	0.078	0.5	0.25
2.01-5.00	0.07	0.053	0.15	0.64	0.091
> 5.00	0.000006	0.014	0.038	0.073	0

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)						
	San Vicente Silangan	Santa Maria	Tagabas Ibaba	Tagabas Ilaya	Tagbacan Ibaba	Tagbacan Ilaya	Tagbacan Silangan
0.03-0.20	4.93	28.77	3	8.78	7.15	7.72	3.29
0.21-0.50	0.13	0.98	0.083	0.28	0.29	0.37	0.13
0.51-1.00	0.13	0.91	0.072	0.24	0.25	0.41	0.1
1.01-2.00	0.14	1.37	0.098	0.3	0.33	0.84	0.21
2.01-5.00	0.19	1.99	0.21	0.18	0.074	0.24	0.51
> 5.00	0.046	0.6	0.0065	0.008	0	0.0023	0.15




Affected Areas (sq. km)
0
0.5
1
1.5
2
2.5
3
3.5
4
Bulagsong
Camandison
Canculajao
Catumbo
Cawayanin Ibaba
Cawayananin Ilaya
Dahican
Doongan Ibaba
Doongan Ilaya
Madulao
Matandang Sabang Kanluran
Barangays
Flood Depth (m)
> 5.00
2.01-5.00
1.01-2.00
0.51-1.00
0.21-0.50


Affected Areas (sq. km)
0
1
2
3
4
5
6
7
Matandang Sabang Silangan
Milagrosa
Navitas
Pacabit
San Antonio Magkupa
San Antonio Pala
San Jose
San Pablo
San Roque
San Vicente Silangan
Santa Maria
Barangays
Flood Depth (m)
> 5.00
2.01-5.00
1.01-2.00
0.51-1.00
0.21-0.50

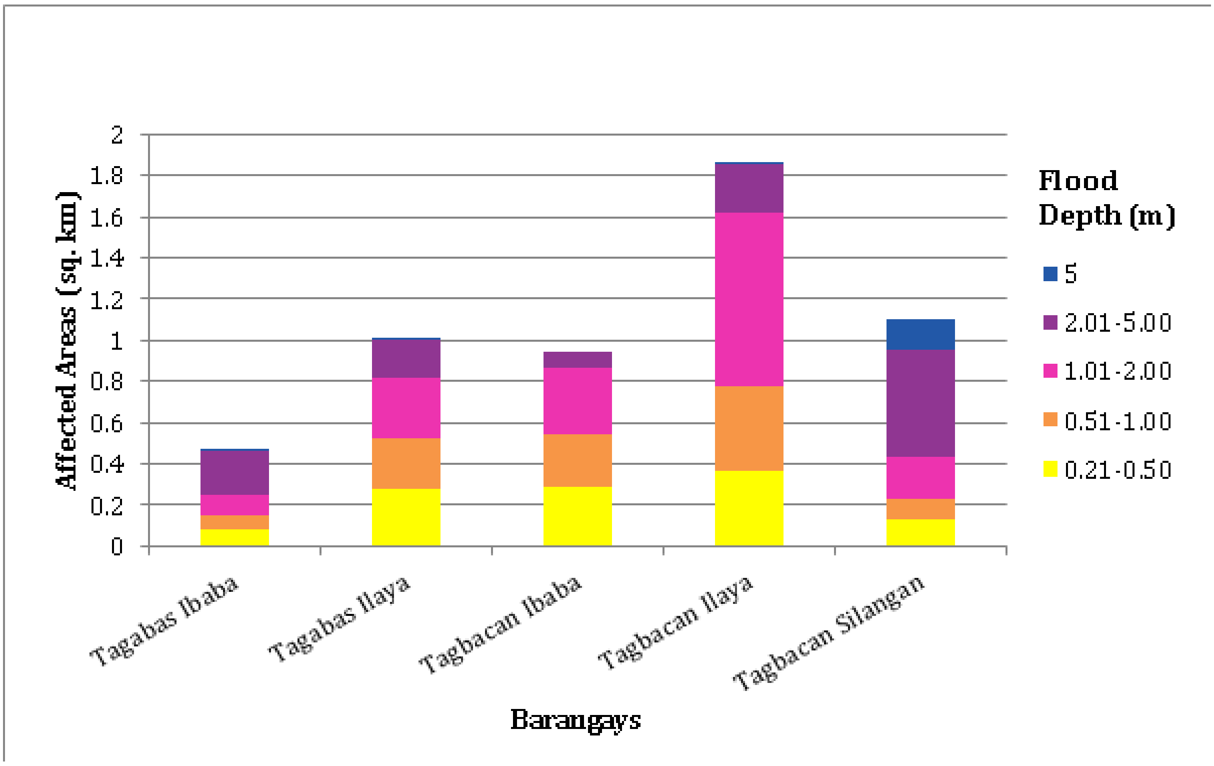


Figure 77. Affected Areas in Catanauan, Quezon during 25-Year Rainfall Return Period.

For the 25-year return period, 2.16% of the municipality of Buenavista with an area of 171.22 sq. km. will experience flood levels of less than 0.20 meters. 0.08% of the area will experience flood levels of 0.21 to 0.50 meters while 0.06%, 0.04%, 0.01%, and 0.00% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected Areas in Buenavista, Quezon during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)			
	Maligaya	Masaya	Villa Magsaysay	Villa Veronica
0.03-0.20	3	0.1	0.35	0.25
0.21-0.50	0.11	0.0043	0.0061	0.011
0.51-1.00	0.083	0.0021	0.0023	0.0079
1.01-2.00	0.052	0.004	0.0013	0.0062
2.01-5.00	0.0067	0.0022	0.00019	0.0013
> 5.00	0	0	0	0

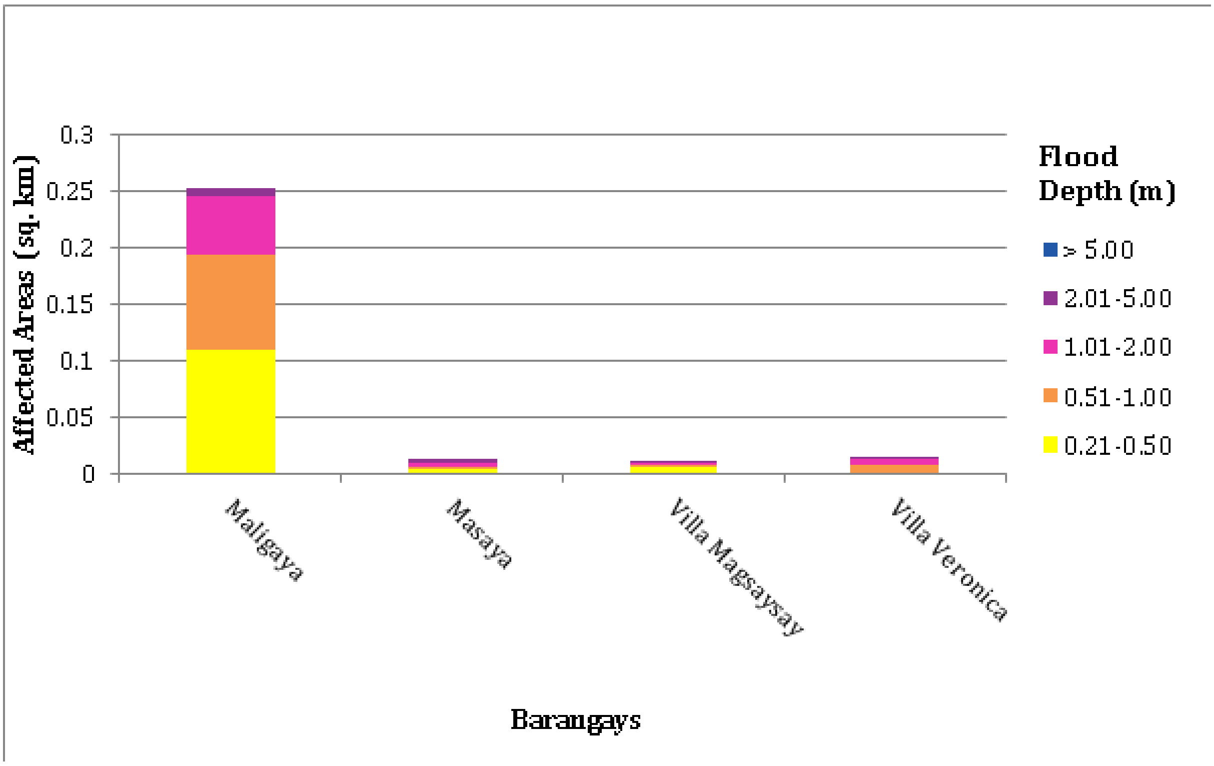


Figure 78. Affected Areas in Buenavista, Quezon during 25-Year Rainfall Return Period.

For the 25-year return period, 6.75% of the municipality of General Luna with an area of 100.0022 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 0.15%, 0.18%, 0.33%, and 0.13% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 39. Affected Areas in General Luna, Quezon during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in General Luna (in sq. km.)		
	Lavides	Magsaysay	Malaya
0.03-0.20	0.32	2.77	3.66
0.21-0.50	0.0062	0.093	0.11
0.51-1.00	0.0045	0.049	0.094
1.01-2.00	0.0055	0.036	0.14
2.01-5.00	0.01	0.029	0.29
> 5.00	0.03	0.0086	0.09

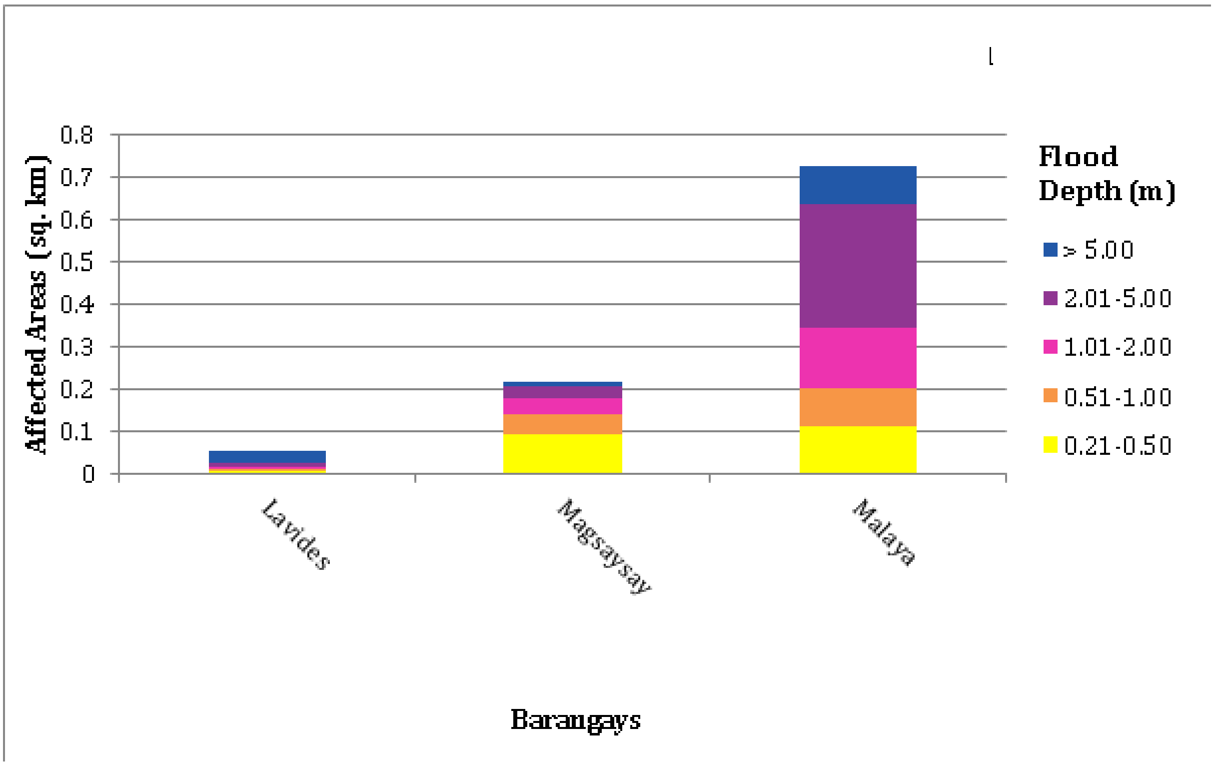


Figure 79. Affected Areas in General Luna, Quezon during 25-Year Rainfall Return Period.

For the100-year return period, 57.12% of the municipality of Catanauan with an area of 253.19 sq. km. will experience flood levels of less than 0.20 meters. 2.84% of the area will experience flood levels of 0.21 to 0.50 meters while 2.56%, 4.33%, 4.61%, and 1.20% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 40. Affected Areas in Catanauan, Quezon during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)						
	Anusan	Barangay 1	Barangay 10	Barangay 2	Barangay 3	Barangay 4	Barangay 5
0.03-0.20	11.27	0.014	0.069	0.054	0.06	0.00058	0.048
0.21-0.50	0.36	0.0061	0.031	0.0092	0.0087	0.00074	0.019
0.51-1.00	0.25	0.0029	0.0011	0.0024	0.0046	0.0039	0.0004
1.01-2.00	0.34	0.031	0	0.02	0.0081	0.021	0
2.01-5.00	0.34	0.041	0	0.00056	0.0055	0.015	0
> 5.00	0.0083	0.0015	0	0	0.0012	0.0037	0

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)						
	Barangay 6	Barangay 7	Barangay 8	Barangay 9	Bulagsong	Camandison	Canculajao
0.03-0.20	0.069	0.071	0.053	0.062	1.6	0	3.65
0.21-0.50	0.028	0.024	0.0079	0.029	0.063	0	0.13
0.51-1.00	0.0057	0.017	0.00064	0.0014	0.061	0	0.16
1.01-2.00	0.02	0.0041	0.0011	0	0.19	0	0.29
2.01-5.00	0.0038	0.0002	0.003	0	0.17	0	0.2

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)									
	Catumbo	Cawayanin Ibaba	Cawayananin Ilaya	Dahican	Doongan Ibaba	Doongan Ilaya	Madulao	Matandang Sabang Kanluran	Matandang Sabang Silangan	Milagrosa
0.03-0.20	1.27	3.33	0	2.2	6.53	4.04	3.97	3.45	1.24	5.93
0.21-0.50	0.057	0.28	0	0.11	0.37	0.15	0.15	0.85	0.28	0.24
0.51-1.00	0.081	0.56	0	0.13	0.38	0.13	0.13	0.31	0.52	0.18
1.01-2.00	0.11	1.46	0	0.31	0.63	0.3	0.14	0.17	1.39	0.19
2.01-5.00	0.056	1.25	0	0.5	0.43	1.55	0.11	0.14	0.87	0.082
> 5.00	0	0.036	0	0.081	0.21	1.06	0.017	0	0.031	0.00077

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)									
	Navitas	Pacabit	San Antonio Magkupa	San Antonio Pala	San Jose	San Pablo	San Roque	San Vicente Silangan	Santa Maria	Tagabas Ibaba
0.03-0.20	5.55	5.52	4.03	1.97	2.27	8.91	3.99	4.9	28.49	2.99
0.21-0.50	0.3	0.48	0.12	0.12	0.072	0.33	0.15	0.13	1.01	0.08
0.51-1.00	0.39	0.57	0.094	0.065	0.05	0.27	0.16	0.13	0.77	0.075
1.01-2.00	0.5	0.71	0.12	0.045	0.073	0.46	0.26	0.13	1.23	0.094
2.01-5.00	0.65	0.17	0.085	0.053	0.15	0.74	0.12	0.21	2.3	0.22
> 5.00	0.23	0.0011	0.000006	0.02	0.063	0.09	0	0.06	0.82	0.017

Affected area (sq. km.) by flood depth (in m.)	Areas of affected Barangays in Catanauan (in sq.km.)									
	Tagabas Ilaya	Tagbacan Ibaba	Tagbacan Ilaya	Tagbacan Silangan						
0.03-0.20	8.73	7.1	7.65	3.24						
0.21-0.50	0.29	0.29	0.37	0.13						
0.51-1.00	0.25	0.24	0.36	0.094						
1.01-2.00	0.3	0.35	0.9	0.15						
2.01-5.00	0.22	0.11	0.29	0.57						
> 5.00	0.012	0.0001	0.0076	0.21						

For the 25-year rainfall return period, 1.03% of the municipality of Camalig with an area of 136.54 sq. km. will experience flood levels of less than 0.20 meters. 0.03% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.03%, 0.03%, 0.02%, and 0.0007% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 41 depicts the areas affected in Camalig in square kilometers by flood depth per barangay.

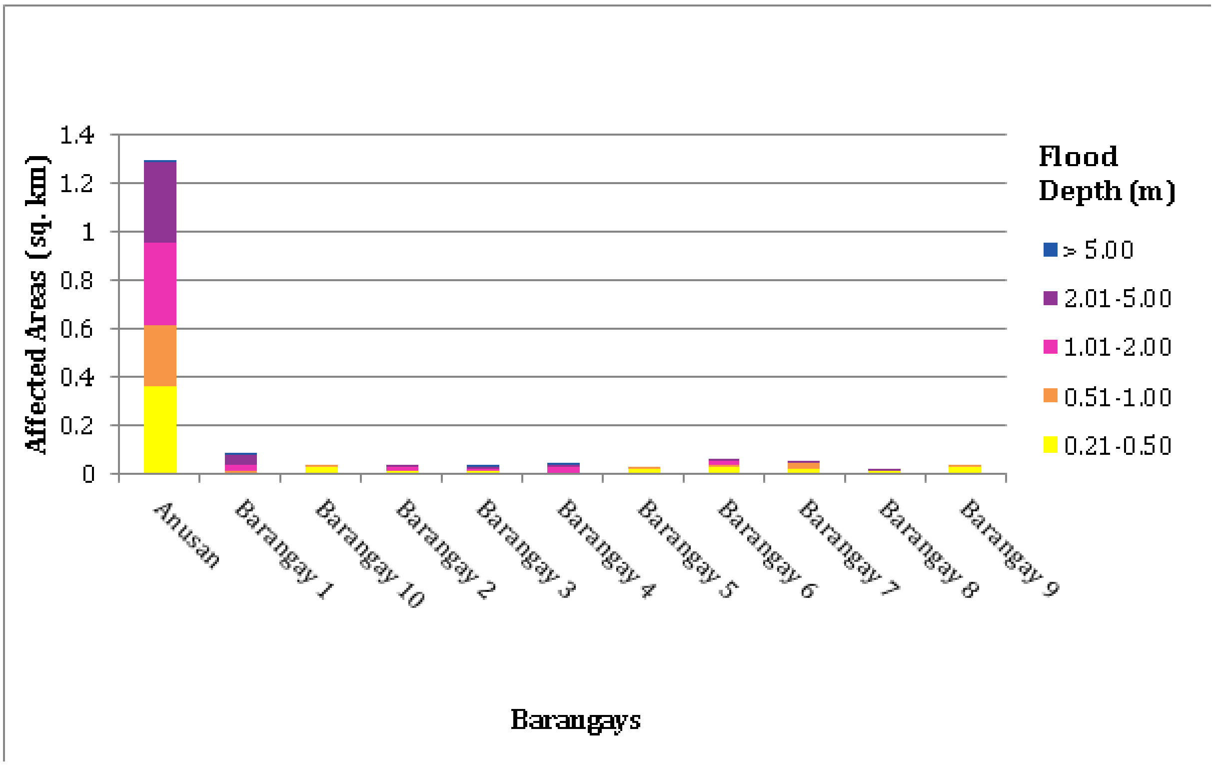
Table 41. Affected Areas in Camalig, Albay during 25-Year Rainfall Return Period.

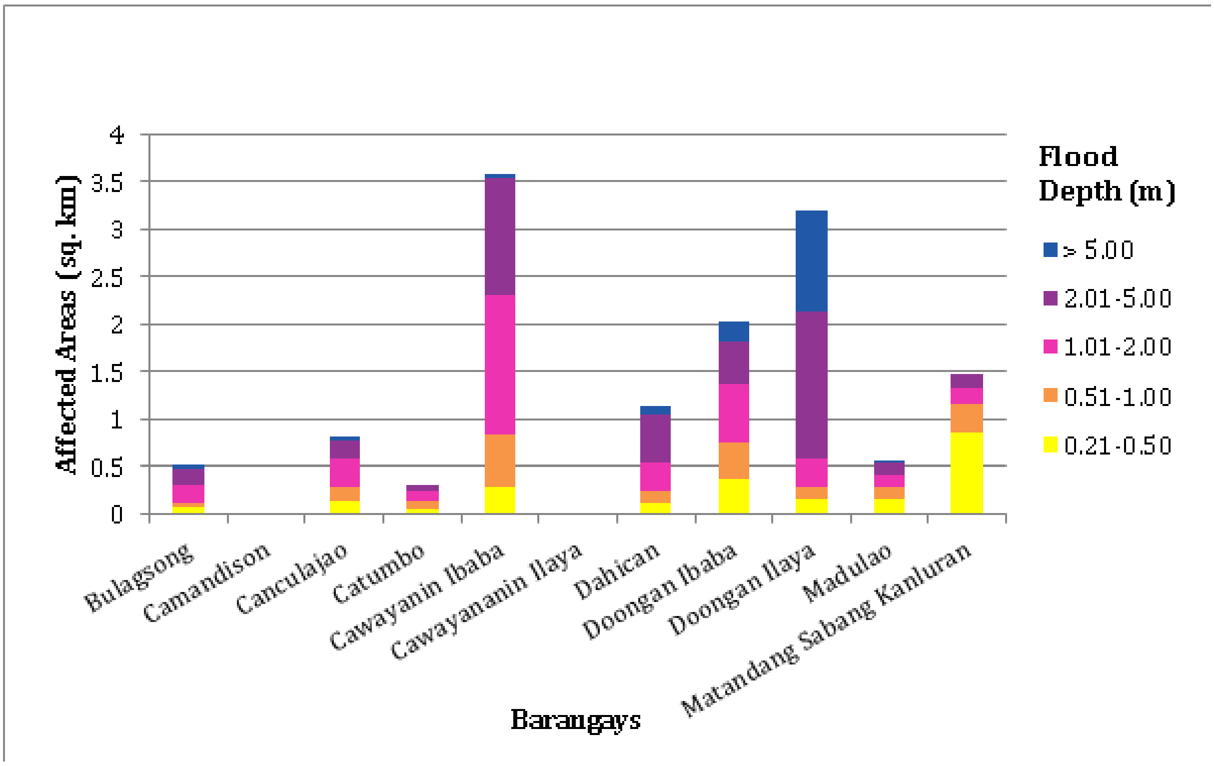
Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Camalig
	Quinartilan
0.03-0.20	1.41
0.21-0.50	0.047
0.51-1.00	0.045
1.01-2.00	0.042
2.01-5.00	0.021
> 5.00	0.00089

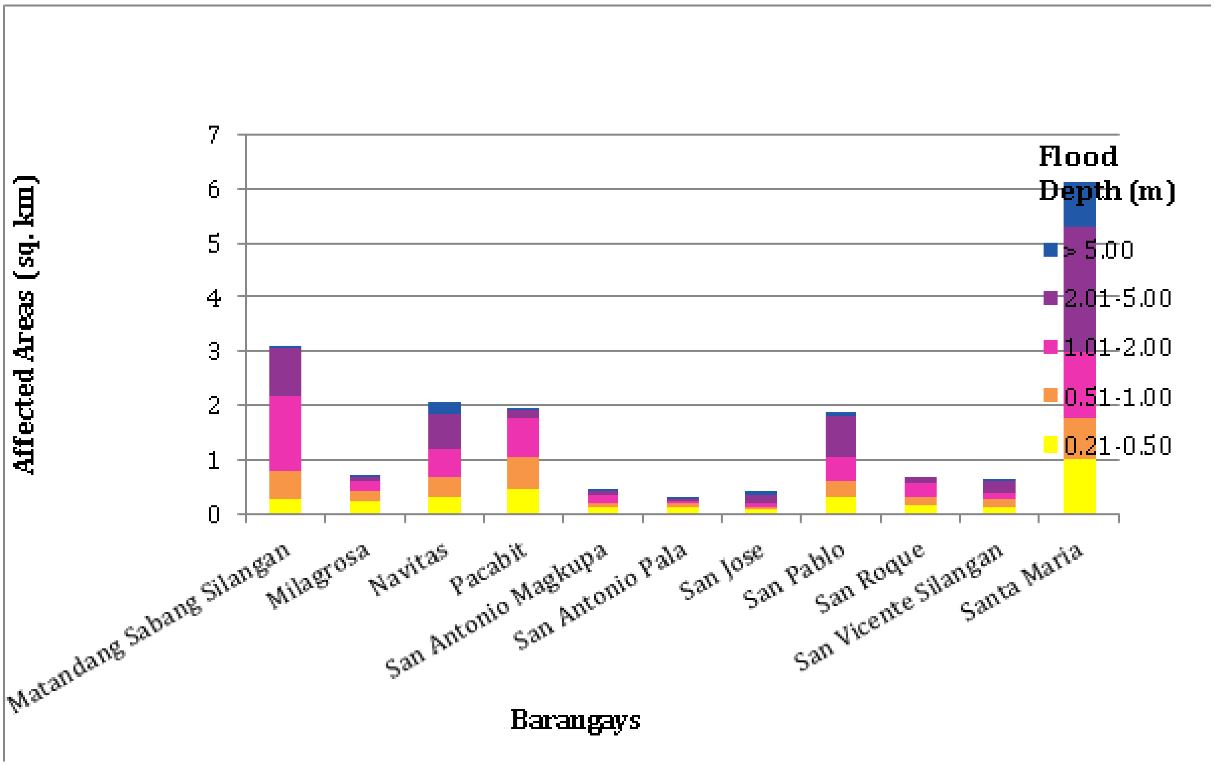
For the municipality of Guinobatan with an area of 174.07 sq. km., 0.23% will experience flood levels of less than 0.20 meters. 0.009% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.006%, 0.007%, 0.01%, and 0.02% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Table 42 depicts the areas affected in Guinobatan in square kilometers by flood depth per barangay.

Table 42. Affected Areas in Guinobatan during 25-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Guinobatan	
	Balite	Malobago
0.03-0.20	0.07	0.34
0.21-0.50	0.00084	0.014
0.51-1.00	0.00042	0.0093
1.01-2.00	0.0013	0.012
2.01-5.00	0.0028	0.015
> 5.00	0.014	0.012


Affected Areas (sq. km)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Anusan
Barangay 1
Barangay 10
Barangay 2
Barangay 3
Barangay 4
Barangay 5
Barangay 6
Barangay 7
Barangay 8
Barangay 9
Barangays
Flood Depth (m)
> 5.00
2.01-5.00
1.01-2.00
0.51-1.00
0.21-0.50


Affected Areas (sq. km)
4
3.5
3
2.5
2
1.5
1
0.5
0
Bulagsong
Camandison
Canculajao
Catumbo
Cawayanin Ibaba
Cawayananin Ilaya
Dahican
Doongan Ibaba
Doongan Ilaya
Madulao
Matandang Sabang Kanluran
Barangays
Flood Depth (m)
> 5.00
2.01-5.00
1.01-2.00
0.51-1.00
0.21-0.50



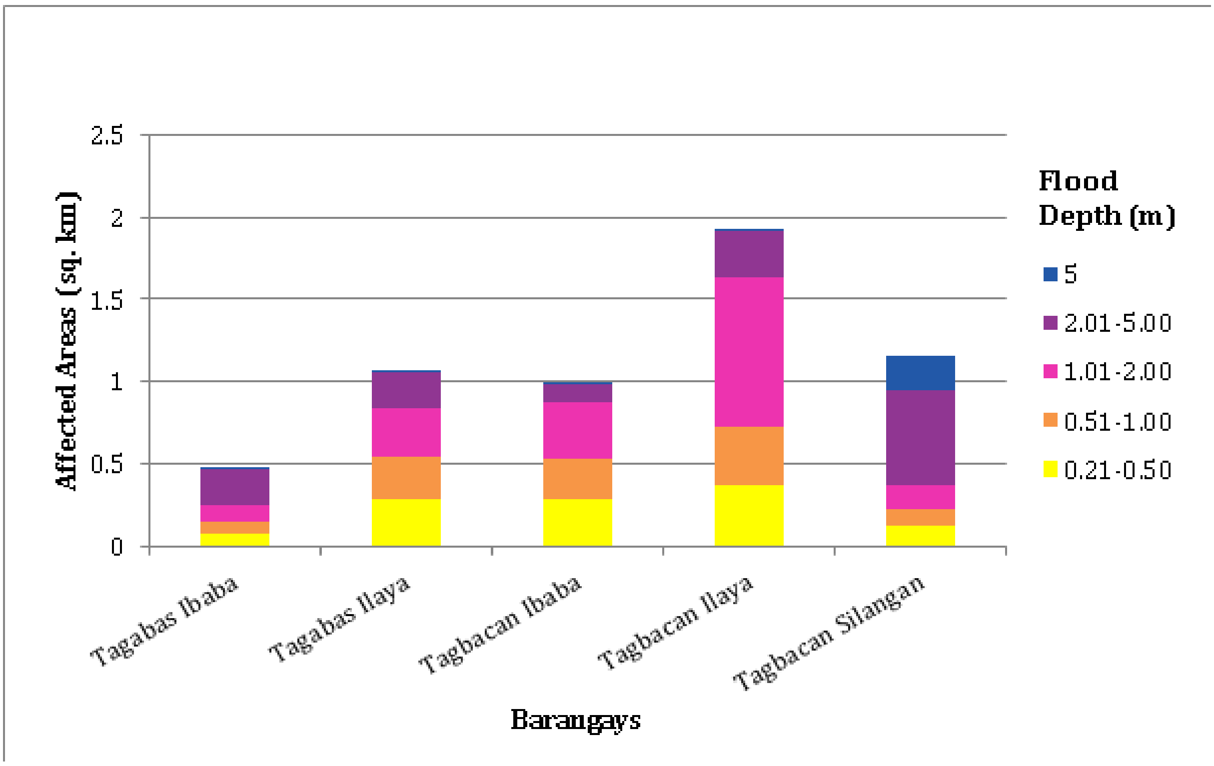


Figure 80. Affected Areas in Catanauan, Quezon during 100-Year Rainfall Return Period.

For the100-year return period, 2.15% of the municipality of Buenavista with an area of 171.22 sq. km. will experience flood levels of less than 0.20 meters. 0.08% of the area will experience flood levels of 0.21 to 0.50 meters while 0.06%, 0.04%, 0.01%, and 0.00% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 43. Affected Areas in Buenavista, Quezon during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Buenavista (in sq. km.)			
	Maligaya	Masaya	Villa Magsaysay	Villa Veronica
0.03-0.20	2.98	0.1	0.35	0.25
0.21-0.50	0.11	0.0044	0.0073	0.011
0.51-1.00	0.084	0.0024	0.0024	0.0084
1.01-2.00	0.062	0.0041	0.0013	0.0072
2.01-5.00	0.008	0.0026	0.00019	0.0015
> 5.00	0	0	0	0

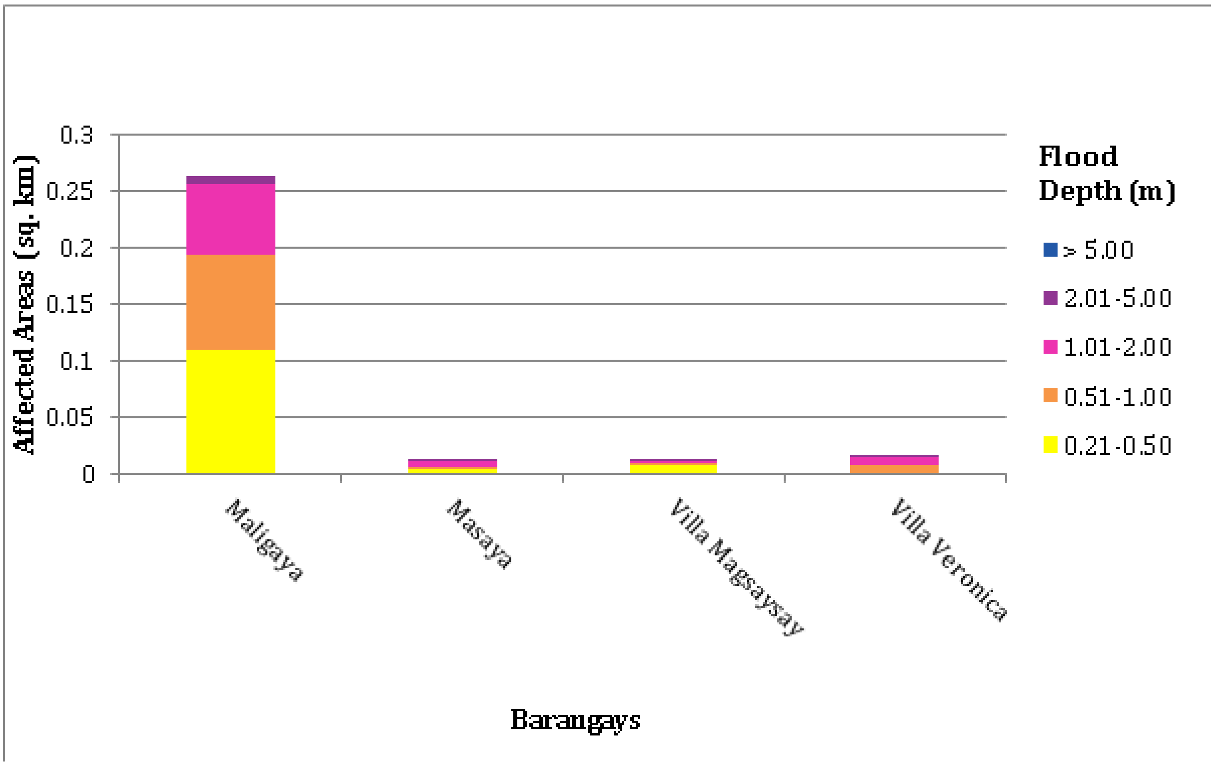


Figure 81. Affected Areas in Buenavista, Quezon during 100-Year Rainfall Return Period.

For the100-year return period, 6.68% of the municipality of General Luna with an area of 100.0022 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 0.14%, 0.16%, 0.34%, and 0.19% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in the table are the affected areas in square kilometers by flood depth per barangay.

Table 44. Affected Areas in General Luna, Quezon during 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in General Luna (in sq. km.)		
	Lavides	Magsaysay	Malaya
0.03-0.20	0.32	2.75	3.61
0.21-0.50	0.006	0.096	0.11
0.51-1.00	0.0047	0.053	0.082
1.01-2.00	0.0053	0.036	0.12
2.01-5.00	0.011	0.033	0.3
> 5.00	0.034	0.0099	0.15

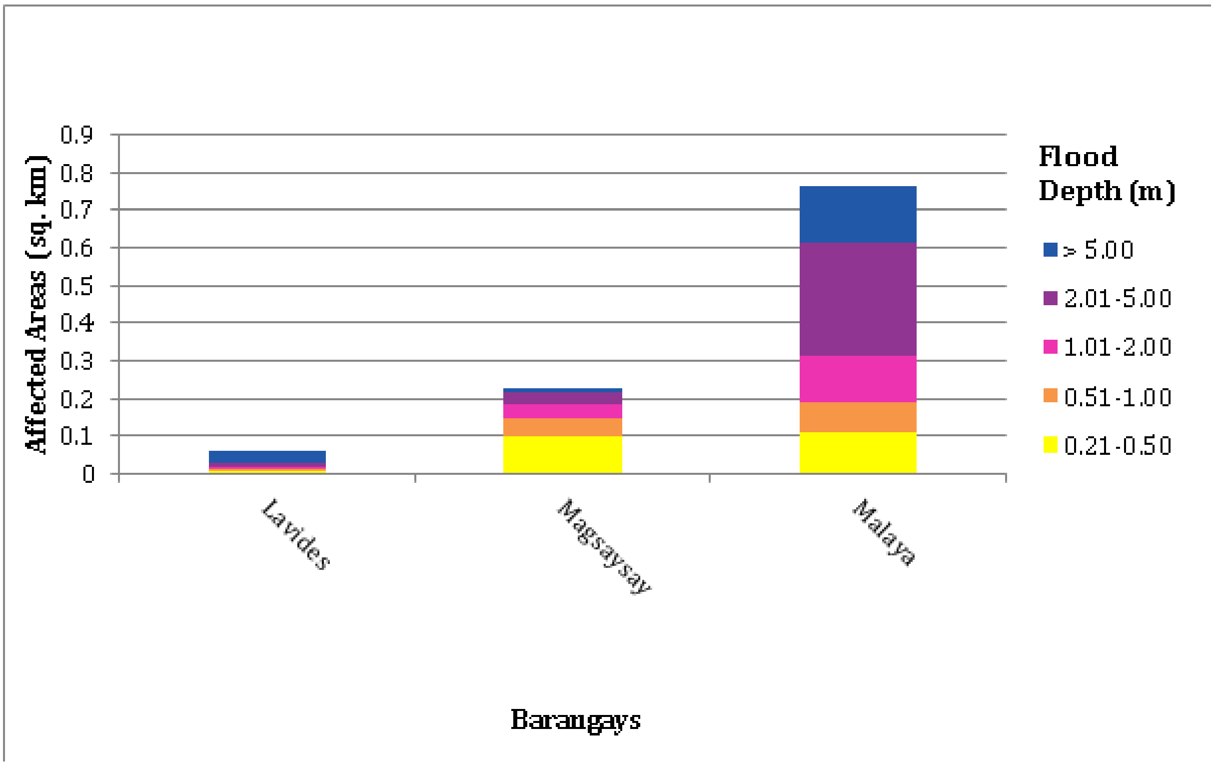


Figure 82. Affected Areas in General Luna, Quezon during 100-Year Rainfall Return Period.

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

Table 45. 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	8.99	7.86	7.79
Medium	14.53	14.083	13.060
High	12.22	20.51	23.44
Total	35.74	42.444	44.285

Of the 26 identified Education Institute in Catanauan Flood plain, four (4) schools were discovered exposed to Low-level flooding during a 5-year scenario, while three (3) schools were found exposed to Medium-level flooding in the same scenario. Tagbacan Ilaya National High School was discovered exposed to High-level flooding.

In the 25-year scenario, two (2) schools were found exposed to Low-level flooding, while five (5) schools were discovered exposed to Medium-level flooding. Four (4) schools were found exposed to high-level flooding.

For the 100-year scenario, two (2) school was discovered exposed to Low-level flooding , while two (2) schools were exposed to Medium-level flooding. In the same scenario, seven (7) schools were found exposed to High-level flooding.

Apart from this, eleven (11) Medical Institutions were identified in Catanauan Floodplain. One (1) was assessed to be exposed to low flooding for the 5-year scenario while two (2) were assessed for the same level for the 25-year scenario. Three (3) were assessed to be exposed to low flooding for the 100-year scenario.

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 gather 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 are identified for validation.

The validation personnel will then go to the specified points identified in a river basin and will gather data regarding the actual flood level in each location. Data gathering can be done through a local DRRM office to obtain maps or situation reports about the past flooding events or interview some residents with knowledge of or have had experienced flooding in a particular area.

After which, the actual data from the field will be compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 77.

The flood validation consists of 180 points randomly selected all over the Catanauan flood plain (Figure 36). Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.47m. Table 42 shows a contingency matrix of the comparison.

The flood validation consists of 564 points randomly selected all over the Bacarra flood plain Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.69 m. Table 477 shows a contingency matrix of the comparison. The validation points are found in Annex 11.

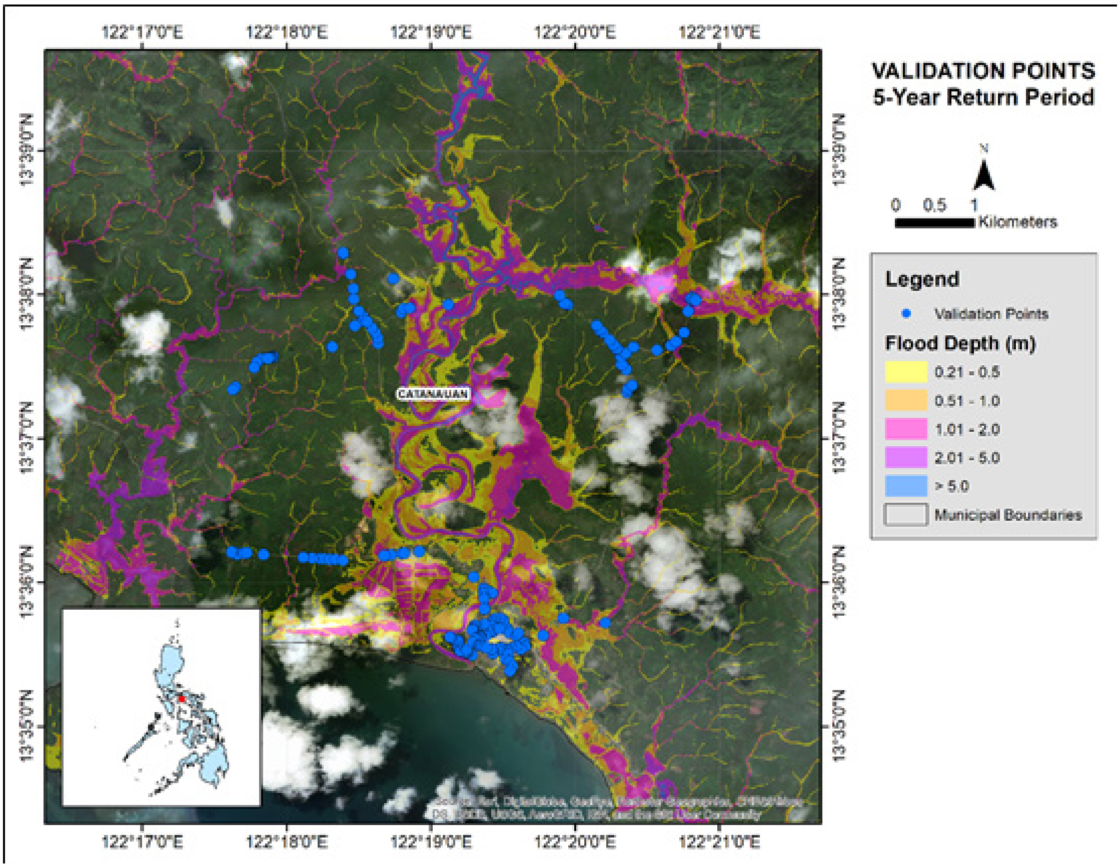


Figure 83. Validation points for 5-year Flood Depth Map of Catanauan Floodplain.

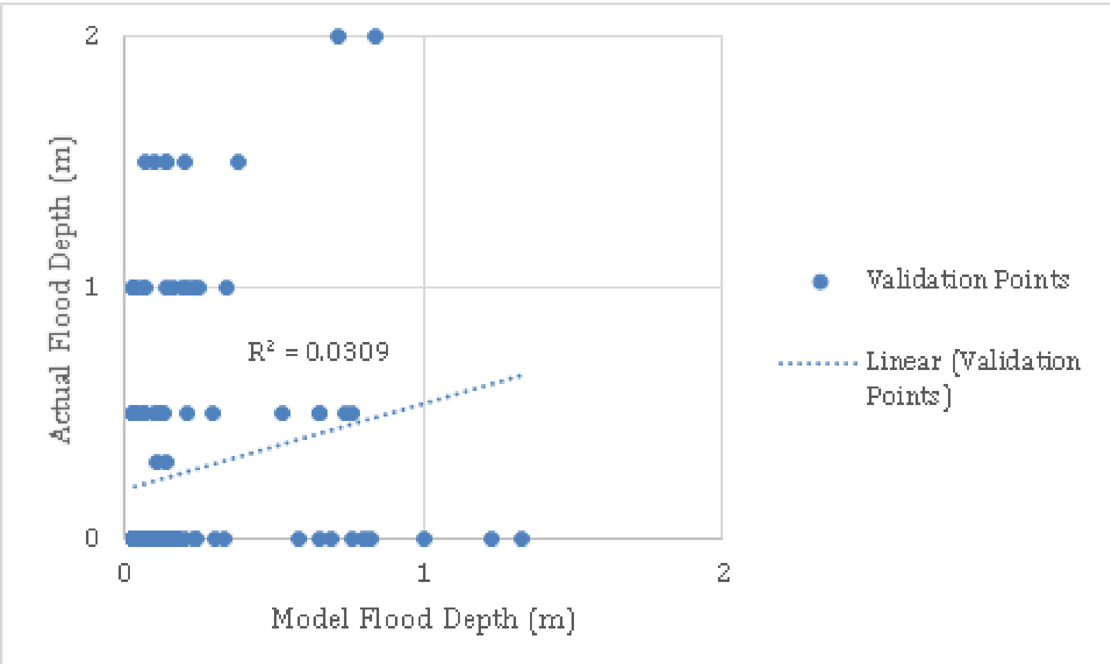


Figure 84. Flood map depth vs actual flood depth.

Table 46. Actual Flood Depth vs Simulated Flood Depth

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	113	4	7	2	0	0	126
0.21-0.50	23	2	5	0	0	0	30
0.51-1.00	12	4	0	0	0	0	16
1.01-2.00	5	1	2	0	0	0	8
2.01-5.00	0	0	0	0	0	0	0
> 5.00	0	0	0	0	0	0	0
Total	153	11	14	2	0	0	180

The overall accuracy generated by the flood model is estimated at 63.89% with 115 points correctly matching the actual flood depths. In addition, there were 34 points estimated one level above and below the correct flood depths while there were 20 points and 7 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 47 points were underestimated in the modelled flood depths of Catanauan.

Table 47. Summary of Accuracy Assessment in the Catanauan River Basin Survey

	No. of Points	%
Correct	115	63.89
Overestimated	18	10.00
Underestimated	47	26.11
Total	180	100.00

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

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

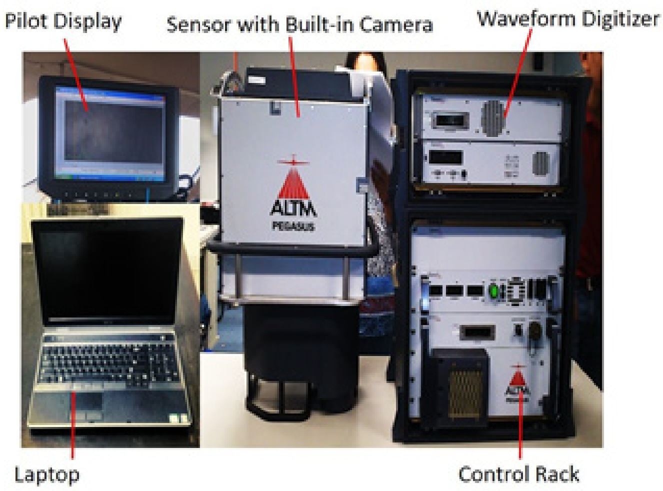
Paringit E.C, Balicanta L.P., Ang, M.O., Sarmiento, C. 2017. Flood Mapping of Rivers in the Philippines Using Airborne Lidar: Methods. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

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

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

ANNEXES

Annex 1. Technical Specifications of the Pegasus Sensor



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

Annex 2. NAMRIA Certificate of Reference Points Used in the LiDAR Survey

1. QZN-47

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

May 06, 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: **QUEZON**
Station Name: **QZN-47**
Order: **2nd**

Island: **LUZON**
Municipality: **MULANAY**
Barangay: **DOS**
MSL Elevation:

PRS92 Coordinates

Latitude: **13° 31' 34.57412"**	Longitude: **122° 24' 18.47045"**	Ellipsoidal Hgt: **5.99800 m.**

WGS84 Coordinates

Latitude: **13° 31' 29.52488"**	Longitude: **122° 24' 23.44821"**	Ellipsoidal Hgt: **55.96400 m.**

PTM / PRS92 Coordinates

Northing: **1495844.441 m.**	Easting: **435605.783 m.**	Zone: **4**

UTM / PRS92 Coordinates

Northing: **1,495,320.87**	Easting: **435,628.32**	Zone: **51**

Location Description

QZN-47
Is located on the center of Mulanay Elem. School oval. It is directly at the back of the Principal's Office with a distance of about 40 m. The Mulanay Municipal Hall is located 300 m. E of the station. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. concrete monument flushed and leveled on the ground, with inscriptions "QZN-47 2006 NAMRIA".

Requesting Party: **U.P DREAM**
Purpose: **Reference**
OR Number: **8090312 I**
T.N.: **2016-1057**

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

9 9 0 5 0 6 2 0 1 6 1 0 0 0 3 2

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

2. QZN-43

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

May 06, 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: **QUEZON**
Station Name: **QZN-43**
Order: **2nd**

Island: **LUZON** | Barangay: **10**
Municipality: **CATANAUAN** | MSL Elevation:

PRS92 Coordinates

Latitude: 13° 36' 0.89019"	Longitude: 122° 19' 8.55832"	Ellipsoidal Hgt: 3.53354 m.

WGS84 Coordinates

Latitude: 13° 35' 55.81611"	Longitude: 122° 19' 13.53031"	Ellipsoidal Hgt: 53.08700 m.

PTM / PRS92 Coordinates

Northing: 1504052.784 m.	Easting: 426309.396 m.	Zone: 4

UTM / PRS92 Coordinates

Northing: 1,503,526.34	Easting: 426,335.19	Zone: 51

Location Description

QZN-43
From Catanauan Municipal Hall, travel along the natl. highway going to rotunda, after reaching the rotunda turn right to the road going to Gen. Luna until reaching the first road going to the left. Follow that road until reaching the DPWH compound. Station is located inside the said compound about 50 m. WSW from the gate of the compound and approx. 13 m. NW from the door of the main bldg. It is situated inside the plant area, where the flagpole is located. It is 2.3 m. NE from the base of the flagpole and 1.2 m. SW from the center of the NE side of the plant area. Mark is the head of a 4 in. copper nail centered on a 30 cm. x 30 cm. concrete monument protruding 20 cm. above ground surface, with inscriptions "QZN-43 2006 NAMRIA".

Requesting Party: **U.P DREAM**
Purpose: **Reference**
OR Number: **8090312 I**
T.N.: **2016-1060**

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

9905062016100210

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

Annex 3. The Survey Team

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. LOVELYN ASUNCION	UP TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	KRISTINE JOY ANDAYA	UP-TCAGP
		JERIEL PAUL ALAMBAN	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	JASMIN DOMINGO	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. ERWIN DELOS SANTOS	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. KHALIL ANTHONY CHI	AAC

Annex 4. Data Transfer Sheet for Catanauan Floodplain Flights

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

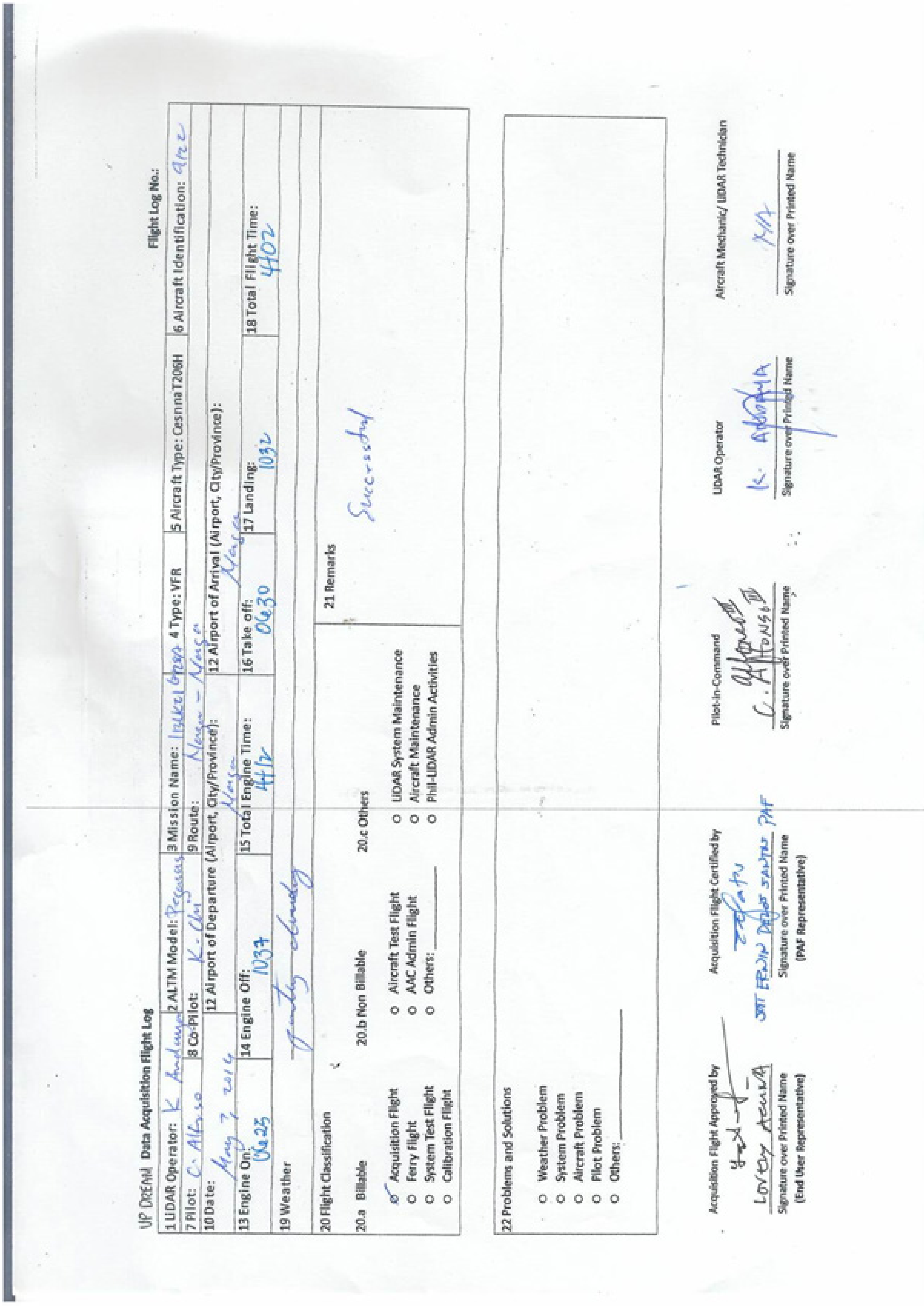
DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
5/6/2016	23324P	1BLK21F127A	PEGASUS	2.55	62.1	10.5	240	NA	NA	26.5	NA	55.5	1KB	1KB	53/70/63/5	NA	Z:\DAC\RAWDATA
5/7/2016	23326P	1BLK21E128A	PEGASUS	3.13	43.7	13.8	283	NA	NA	31	NA	81.2	1KB	1KB	74/41/185/	NA	Z:\DAC\RAWDATA
5/10/2016	23334P	1BLK21D131A	PEGASUS	3.57	48.9	13.1	301	NA	NA	36.2	NA	33	1KB	1KB	53/48/41/36/33/51/64/39/51	NA	Z:\DAC\RAWDATA
5/12/2016	23342P	1BLK21G133A	PEGASUS	3.42	38.4	15.5	290	NA	NA	35	NA	180	1KB	1KB	258	NA	Z:\DAC\RAWDATA
5/13/2016	23346P	1BLK21GS134A	PEGASUS	2.43	54.4	13	270	NA	NA	26.7	NA	134	1KB	1KB	43/176	NA	Z:\DAC\RAWDATA
5/15/2016	23354P	1BLK21EF136A	PEGASUS	1.99	93	13.1	277	NA	NA	24.2	NA	121	1KB	1KB	176	NA	Z:\DAC\RAWDATA
5/16/2016	23358P	1BLK21H137A	PEGASUS	3.21	40.1	11.7	214	7.27	NA	31.6	NA	121	1KB	1KB N/A	301	NA	Z:\DAC\RAWDATA
5/17/2016	23362P	1BLK21S138A	PEGASUS	628	55.3	7.29	178	22.4	NA	9.43	NA	98.9	1KB	1KB	228	NA	Z:\DAC\RAWDATA

Name DARRYL AUSTRIA
Position R.A.
Signature

Name AC BONGAT
Position SSRS
Signature

Annex 5. Flight Logs

1. Flight log for 23326P


UP DREAM Data Acquisition Flight Log

Flight Log No.:

1 LiDAR Operator: K. Andaya	2 ALTM Model: Pegasus	3 Mission Name: 1BLK21 G128A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: C. Alfonso	8 Co-Pilot: K. Chi	9 Route: Naga – Naga			
10 Date: May 7, 2014	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0625	14 Engine Off: 1037	15 Total Engine Time: 4+12	16 Take off: 0630	17 Landing: 1032	18 Total Flight Time: 4+02
19 Weather: partly cloudy					

20 Flight Classification

20.a Billable
- ✓ Acquisition Flight
- o Ferry Flight
- o System Test Flight
- o Calibration Flight

20.b Non Billable
- o Aircraft Test Flight
- o AAC Admin Flight
- o Others: ____

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

21 Remarks

Successful

22 Problems and Solutions
- o Weather Problem
- o System Problem
- o Aircraft Problem
- o Pilot Problem
- o Others: ____

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

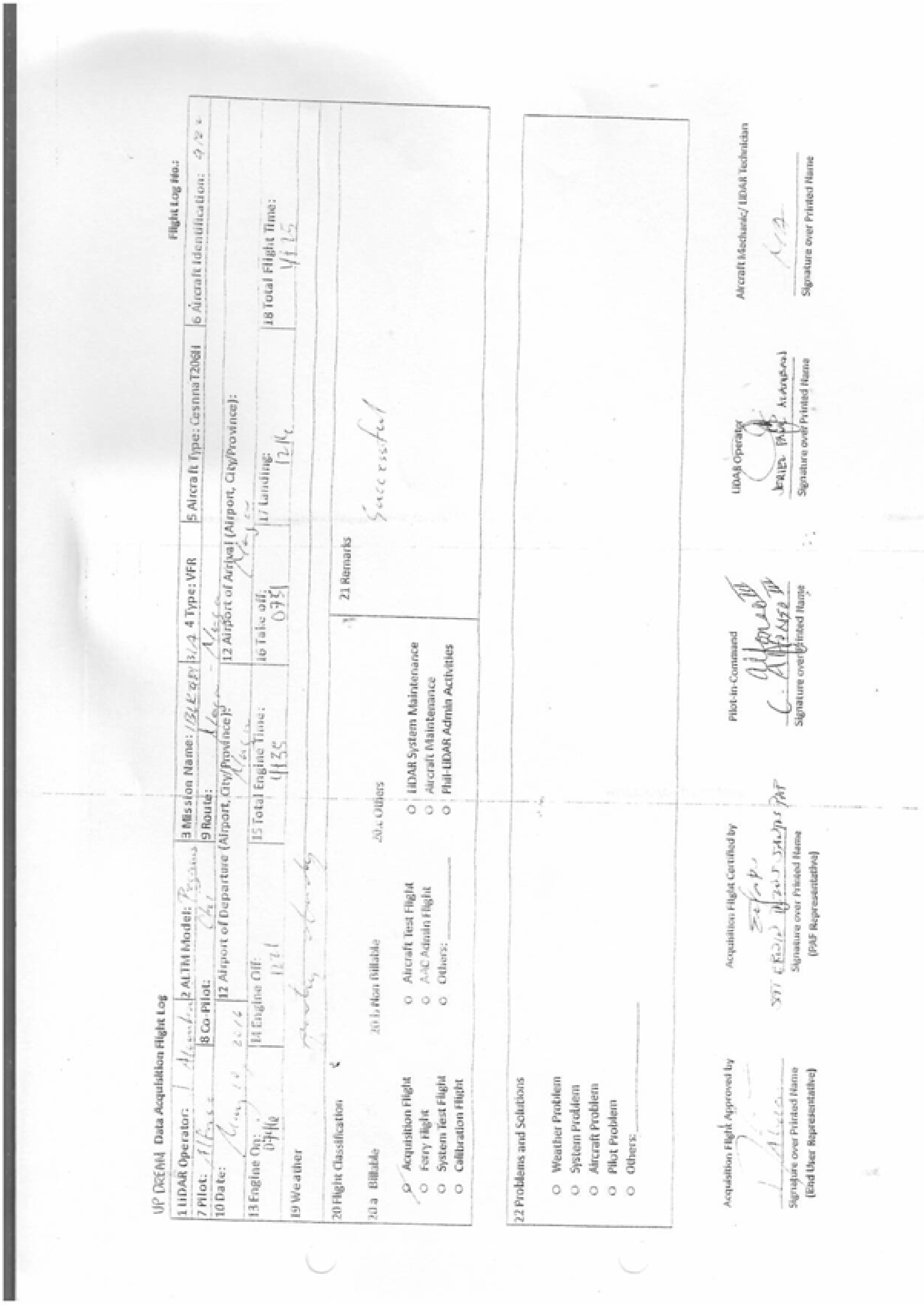
Acquisition Flight Certified by: SGT Erwin Delos Santos PAF — Signature over Printed Name (PAF Representative)

Pilot-in-Command: C. Alfonso III — Signature over Printed Name

LiDAR Operator: K. Andaya — Signature over Printed Name

Aircraft Mechanic/ LiDAR Technician: N/A — Signature over Printed Name

2. Flight log for 23334P



UP DREAM Data Acquisition Flight Log

Flight Log No.:

1 LIDAR Operator: I. Alcantara	2 ALTM Model: Pegasus	3 Mission Name: 1BLK48Y131A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: Alfonso	8 Co-Pilot: Chi	9 Route: Naga - Naga			
10 Date: May 10, 2016	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0746	14 Engine Off: 1221	15 Total Engine Time: 4135	16 Take off: 0751	17 Landing: 1216	18 Total Flight Time: 4+25
19 Weather					

20 Flight Classification

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

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

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

21 Remarks

Successful

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

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

Acquisition Flight Certified by
SSgt Erwin Santos PAF
Signature over Printed Name
(PAF Representative)

Pilot-in-Command
C. Alfonso III
Signature over Printed Name

LIDAR Operator
Jerico Alcantara
Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician
N/A
Signature over Printed Name

3. Flight Log for 23354P Mission

UP DREAM Data Acquisition Flight Log

1 LiDAR Operator: K. Andaya	2 ALTM Model: Peg	3 Mission Name: 1BLK21F136A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9122
7 Pilot: Alfonso	8 Co-Pilot: Obal	9 Route: Naga – Naga			Flight Log No.: 23354
10 Date: May 15, 2016	12 Airport of Departure (Airport, City/Province): Naga		12 Airport of Arrival (Airport, City/Province): Naga		
13 Engine On: 0800	14 Engine Off: 1220	15 Total Engine Time: 4+20	16 Take off: 0805	17 Landing: 1213	18 Total Flight Time: 4+10
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

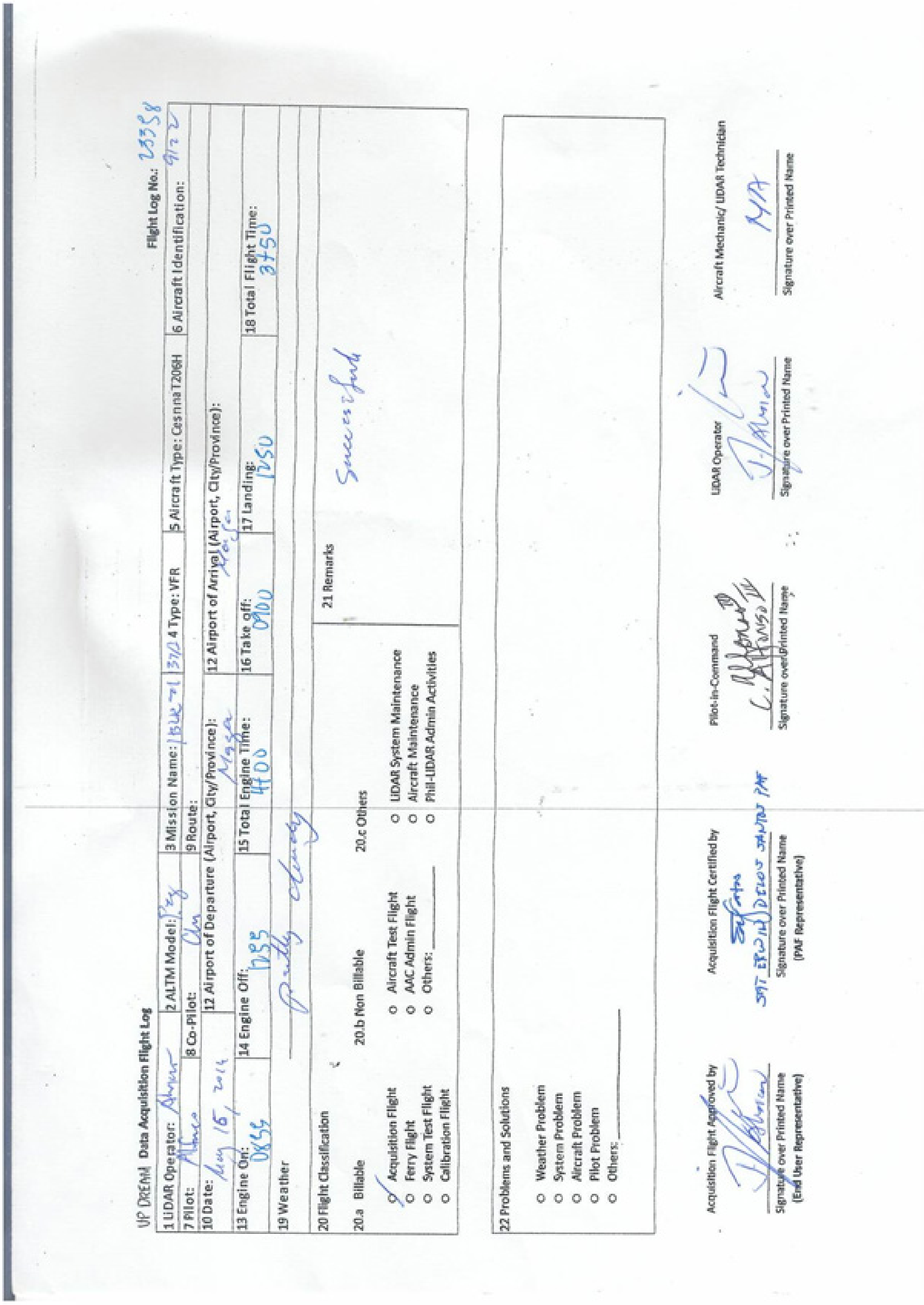
21 Remarks

Successful

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Alcovia	SGT ERWIN DELOS SANTOS PAF	C. ALFONSO III	K. ANDAYA	MA
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

4. Flight log for 23358P Mission



UP DREAM Data Acquisition Flight Log

Flight Log No.: 23358

1 LIDAR Operator: Alvaro	2 ALTM Model: Peg	3 Mission Name: 1BLK71 137A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9122
7 Pilot: Alfonso	8 Co-Pilot: Chu	9 Route:			
10 Date: May 16, 2014	12 Airport of Departure (Airport, City/Province): Masa		12 Airport of Arrival (Airport, City/Province): Masa		
13 Engine On: 0855	14 Engine Off: 1255	15 Total Engine Time: 4+00	16 Take off: 0900	17 Landing: 1250	18 Total Flight Time: 3+50
19 Weather: Partly cloudy					

20 Flight Classification

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

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

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

21 Remarks

Successful

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

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

Acquisition Flight Certified by — SGT ERWIN DELOS SANTOS PAF — Signature over Printed Name (PAF Representative)

Pilot-in-Command — C. ALFONSO III — Signature over Printed Name

LIDAR Operator — Signature over Printed Name

Aircraft Mechanic/ LIDAR Technician — Signature over Printed Name

Annex 6. Flight Status Report

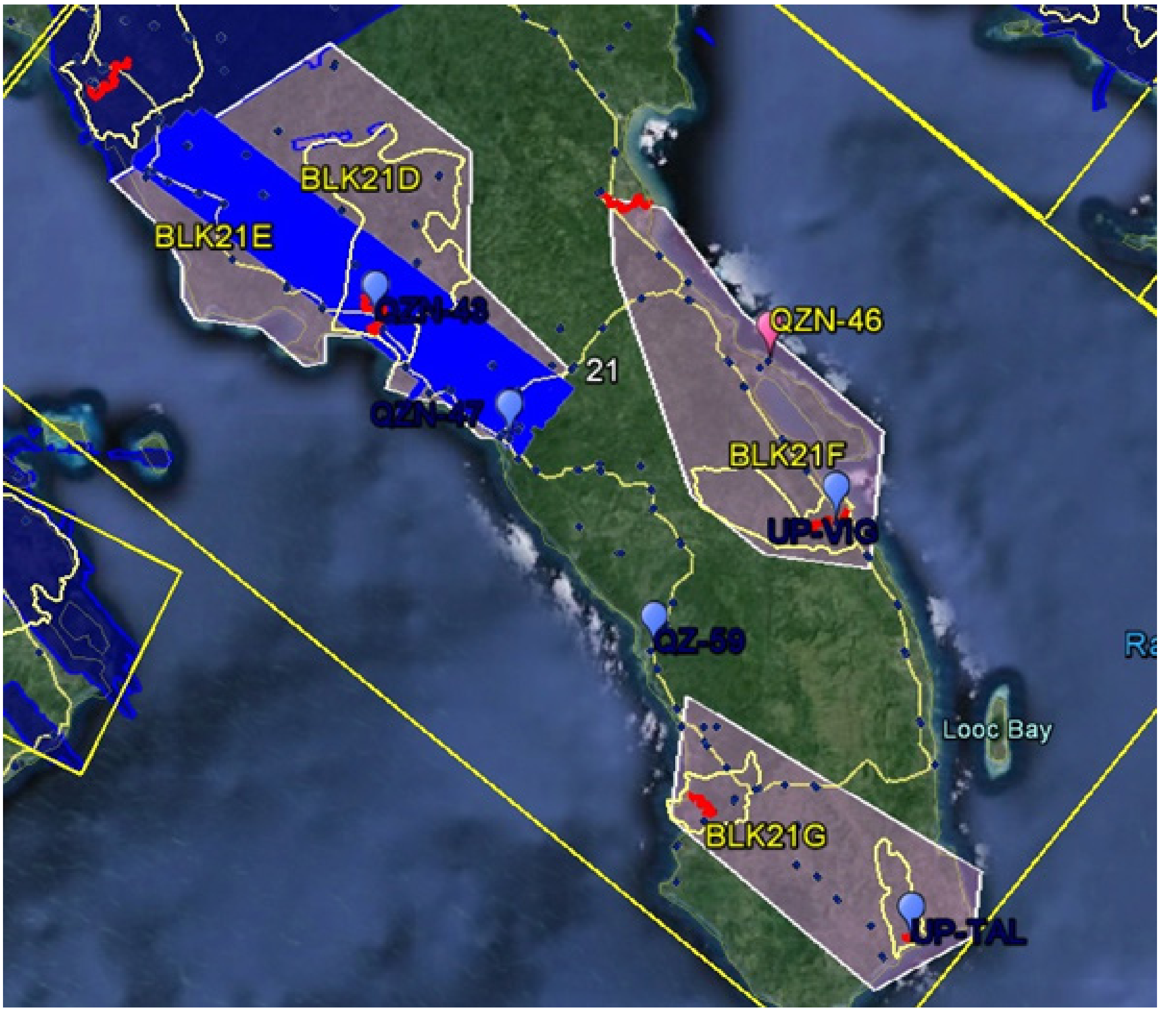
CAMARINES SUR & QUEZON
(May 7-16, 2016)

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
23326P	CATANAUAN FP	1BLK21E128A	KJ ANDAYA	May 7	SURVEYED BLK 21E; NOT COMPLETED
23334P	BLK 21D CATANAUAN FP	1BLK21F131A	K ANDAYA	MAY 10	SURVEYED BLK 21D 229.53 SQ.KM
23354P	BLK 21EF CATANAUAN AND VIGO FPs	1BLK21EF136A	K ANDAYA	MAY 15	SURVEYED BLK 21EF; 217.94 SQ.KM
23358P	BLK 21IH MULANAY	1BLK21H137A	J ALVIAR	MAY 16	SURVEYED MIDDLE PORTION, MULANAY TOWN PROPER NOT COVERED DUE TO HEAVY BUILD UP 332 SQ.KM

LAS BOUNDARIES PER FLIGHT

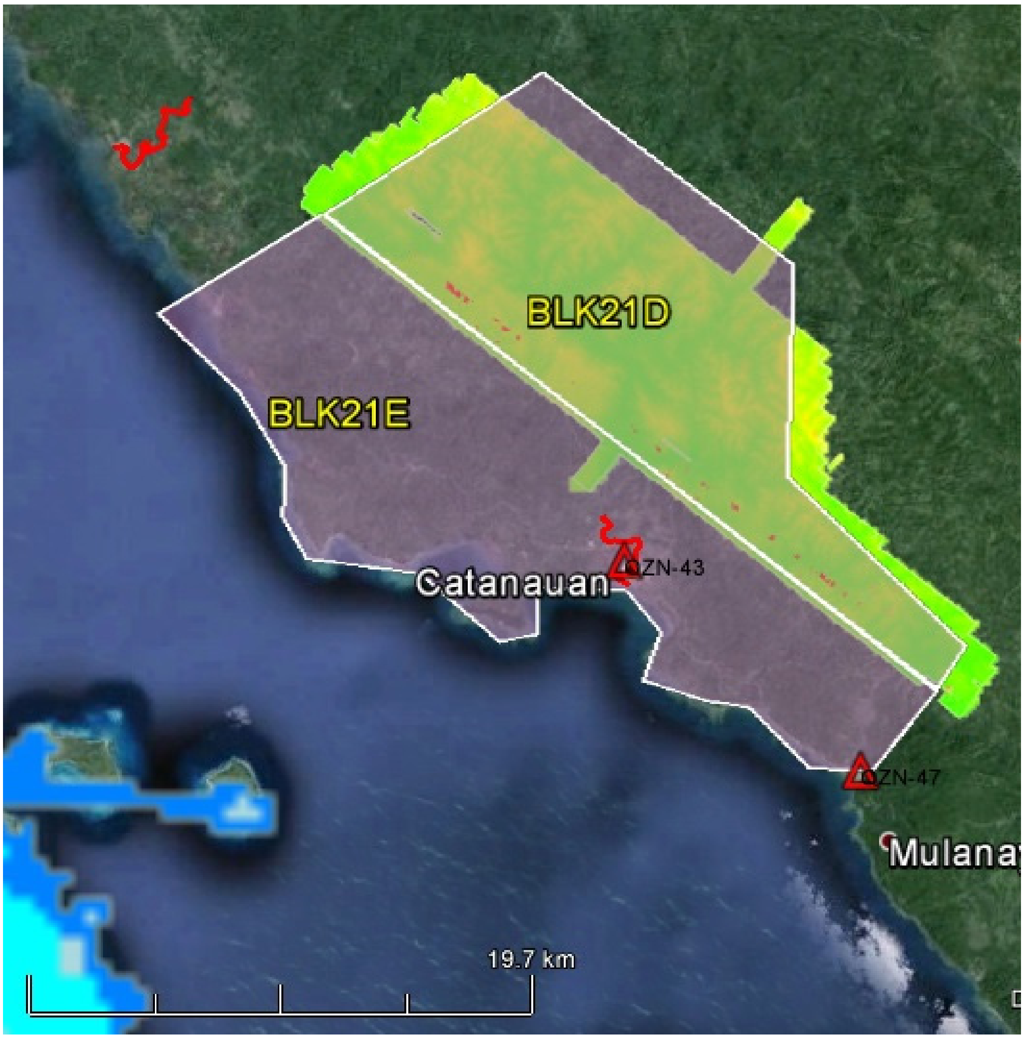
FLIGHT NO.	23326P	
AREA:	Quezon (CATANAUAN FP)	
MISSION NAME:	1BLK21E128A	
ALT: 700-1000M	SCAN FREQ: 30	SCAN ANGLE: 50
SURVEYED AREA:	205 SQ KM	

LAS



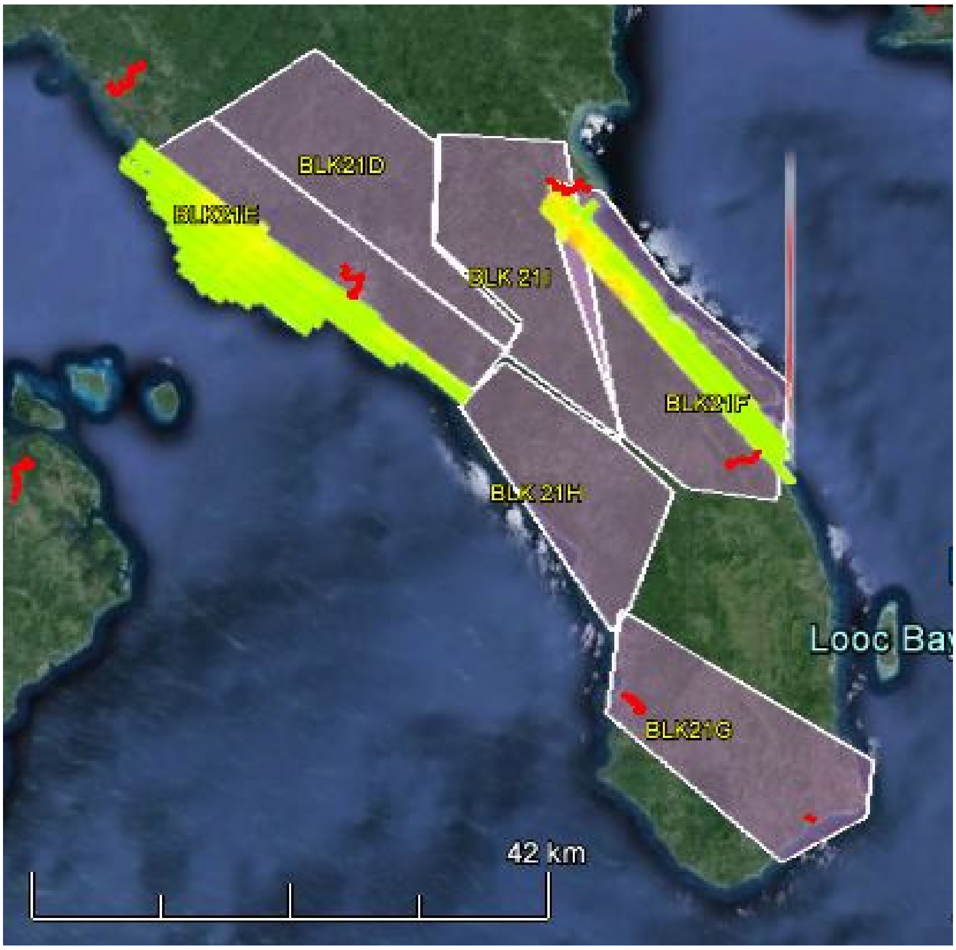
Flight No. :	23334P					
Parameters:	PRF 200	SF	30	FOV	50	

LAS



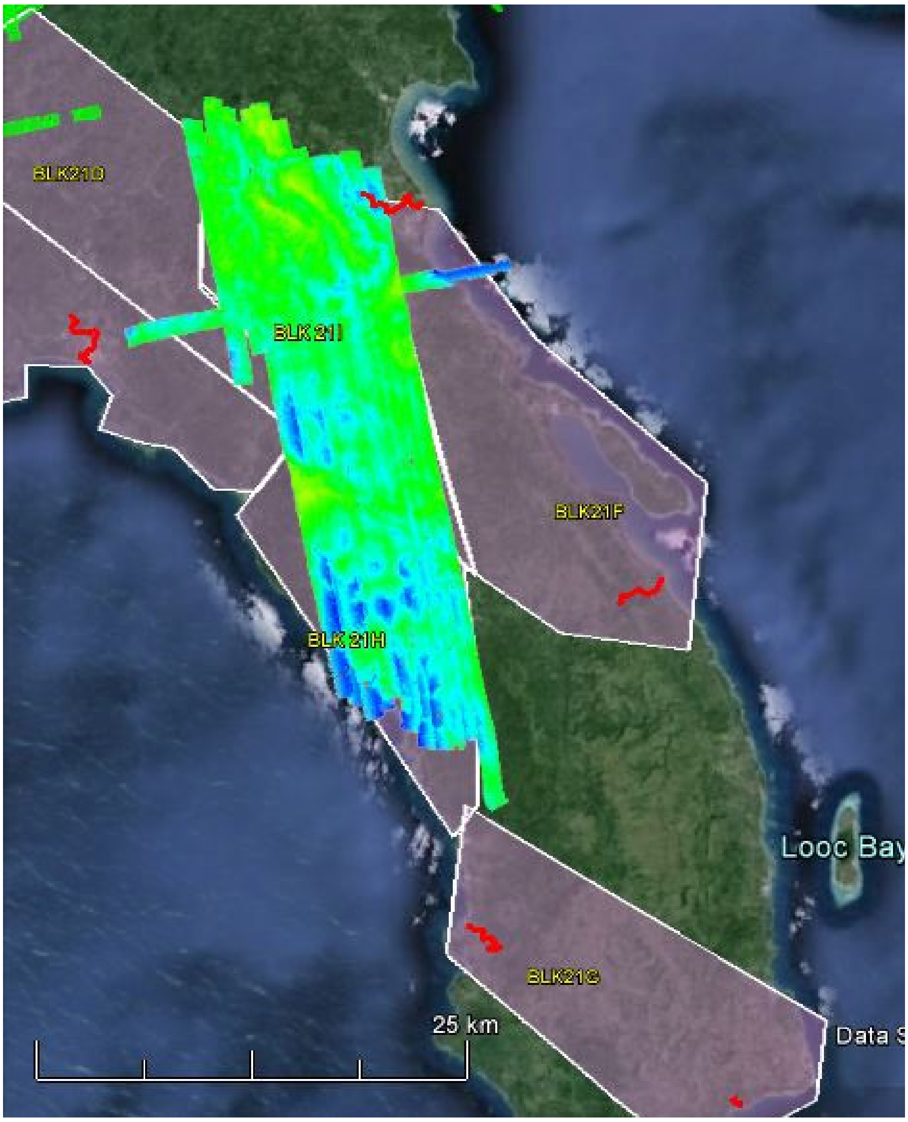
Flight No. : 23354P
Parameters: PRF 200 SF 30 FOV 50

LAS



Flight No. :	23358P				
Parameters:	PRF 200	SF	30	FOV	50

LAS



Annex 7. Mission Summary Reports

Flight Area	Bagasbas
Mission Name	**Bagasbas_Blk21D_supplement**
Inclusive Flights	23334P
Range data size	36.2 GB
POS data size	301 MB
Base data size	33 MB
Image	n/a
Transfer date	September 6, 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)	1.7
RMSE for East Position (<4.0 cm)	2.2
RMSE for Down Position (<8.0 cm)	3.3
Boresight correction stdev (<0.001deg)	0.000133
IMU attitude correction stdev (<0.001deg)	0.000924
GPS position stdev (<0.01m)	0.0019
Minimum % overlap (>25)	56.44%
Ave point cloud density per sq.m. (>2.0)	5.43
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	261
Maximum Height	326.13 m
Minimum Height	50.39 m
Classification (# of points)	
Ground	252,665,736
Low vegetation	192,816,985
Medium vegetation	526,903,435
High vegetation	1,297,279,755
Building	10,545,084
Orthophoto	No
Processed by	Engr. Angelo Carlo Bongat, Engr. Chelou Prado, Engr. Monalyne Rabino

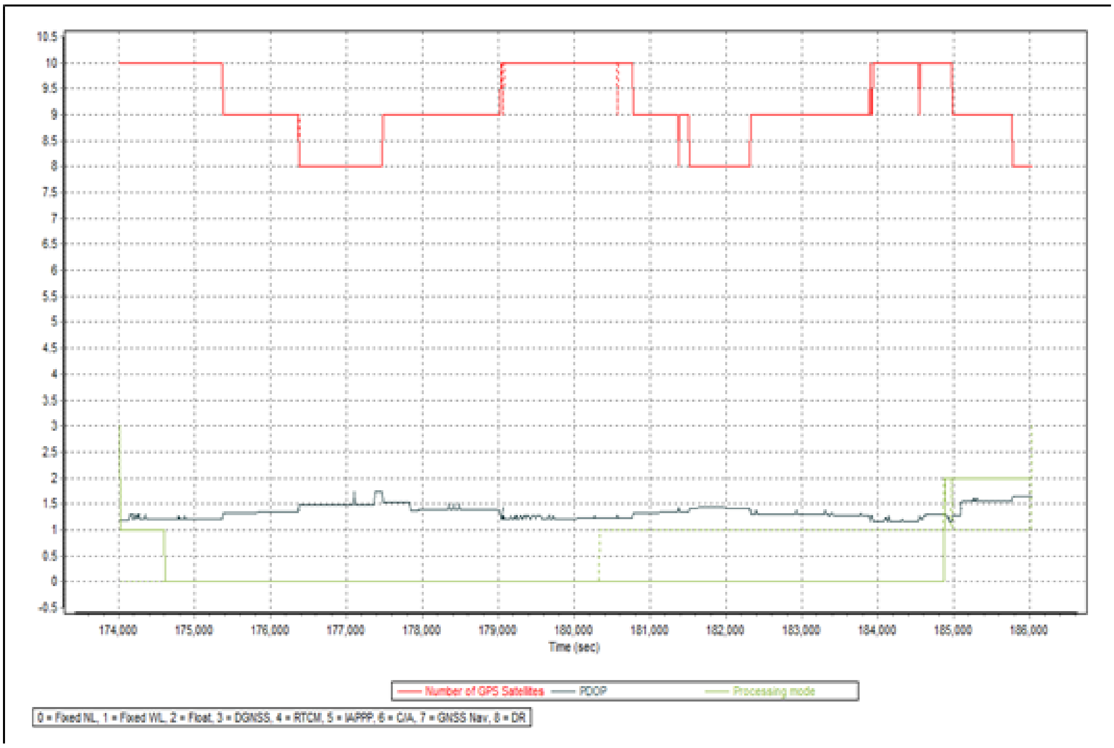


Figure 1.1.1. Solution Status

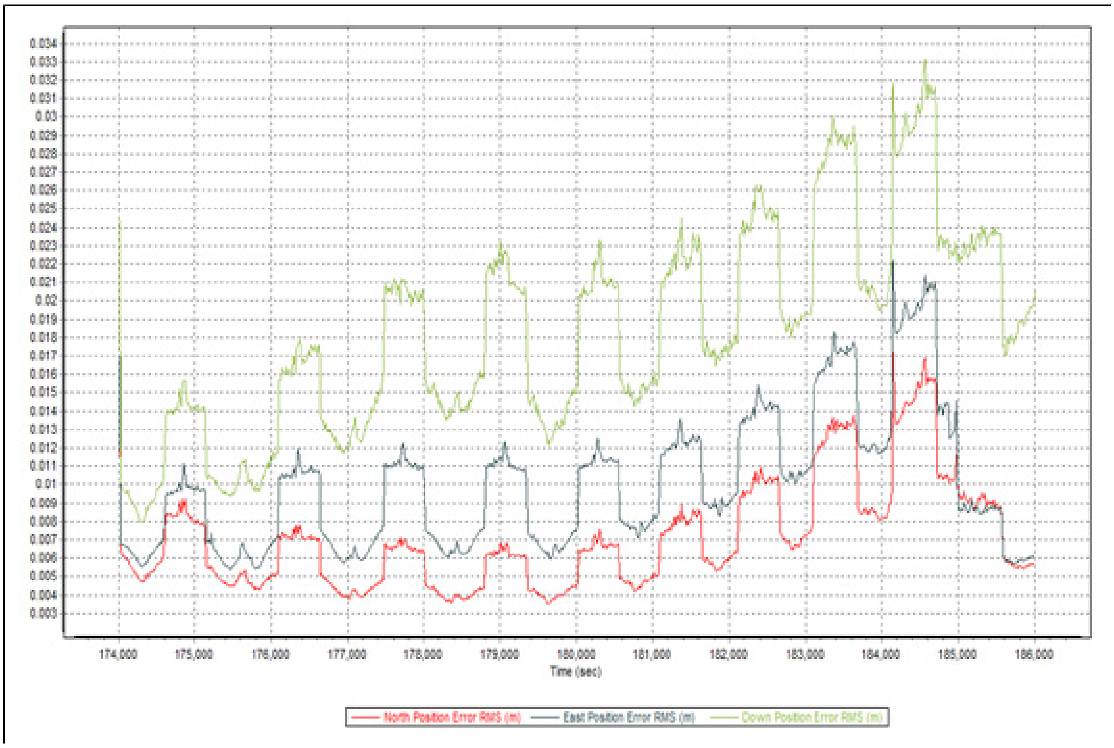


Figure 1.1.2. Smoothed Performance Metric Parameters

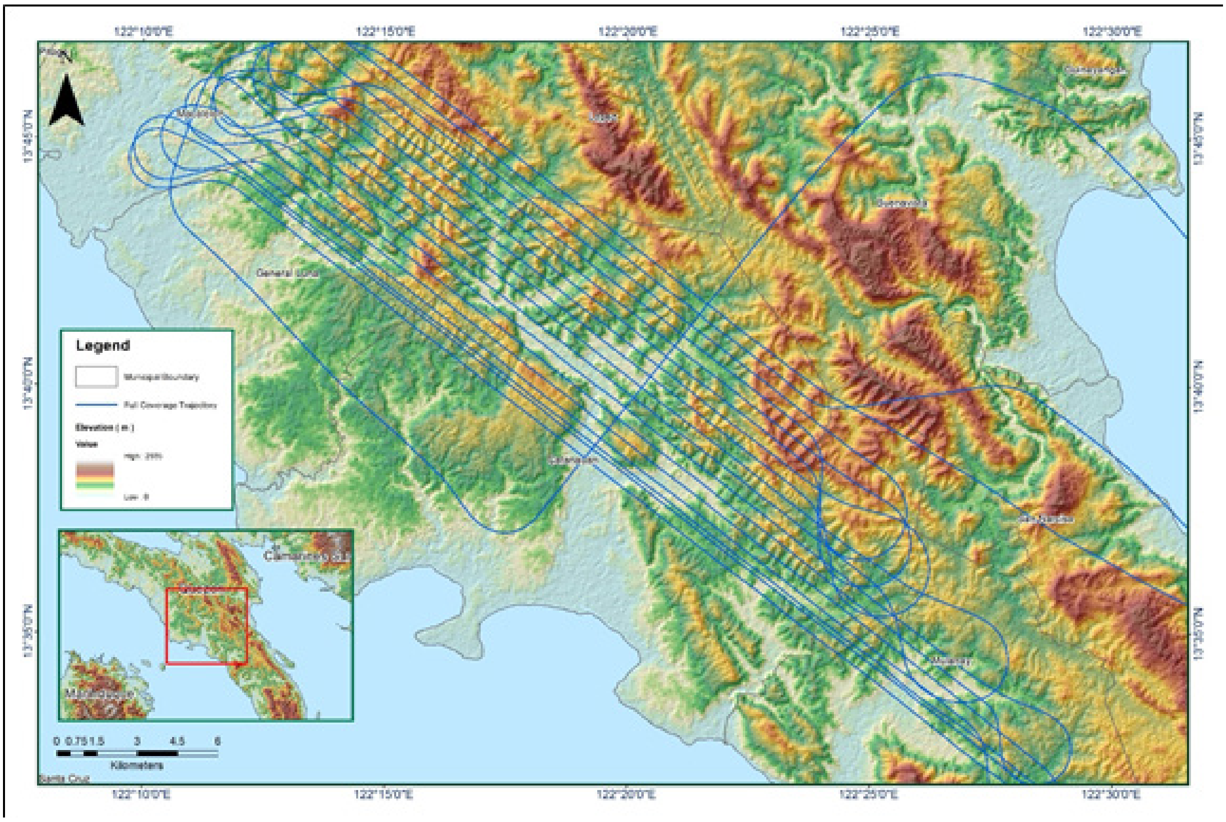


Figure 1.1.3. Best Estimated Trajectory

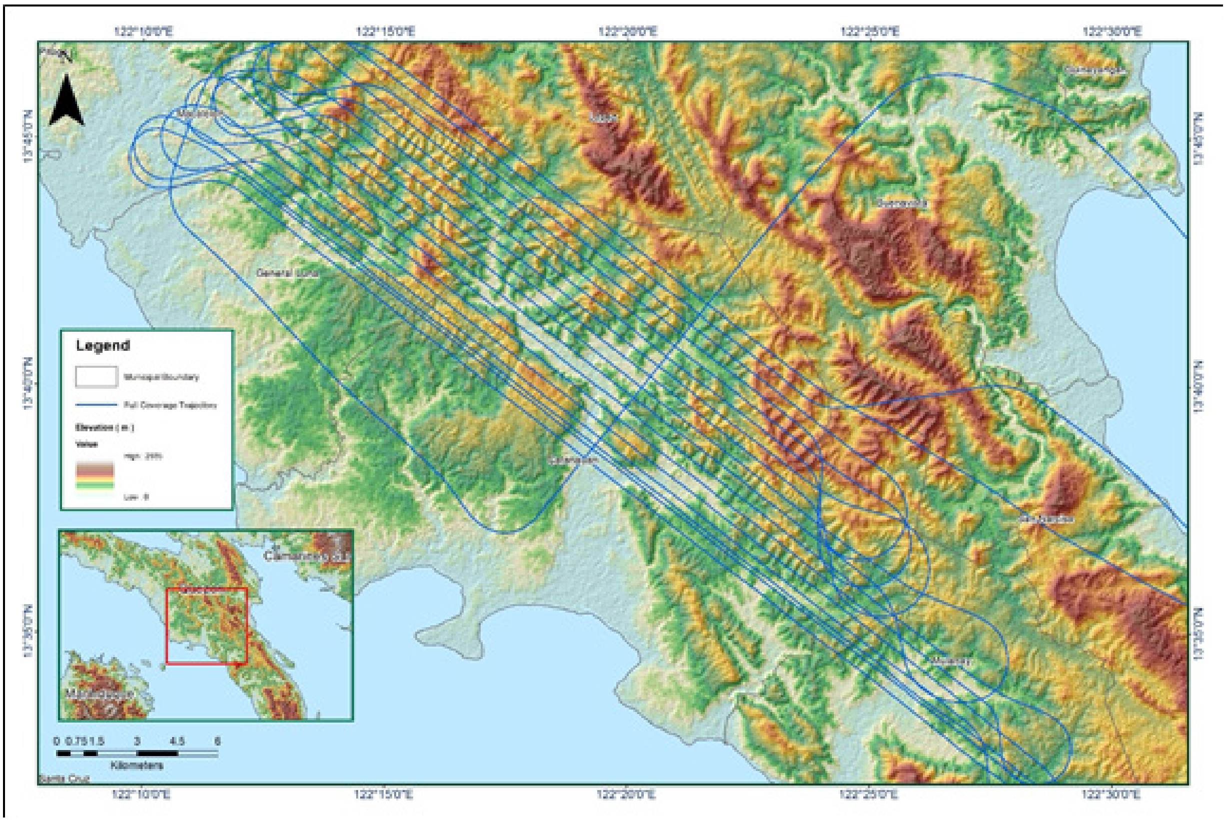


Figure 1.1.4. Coverage of LiDAR Data

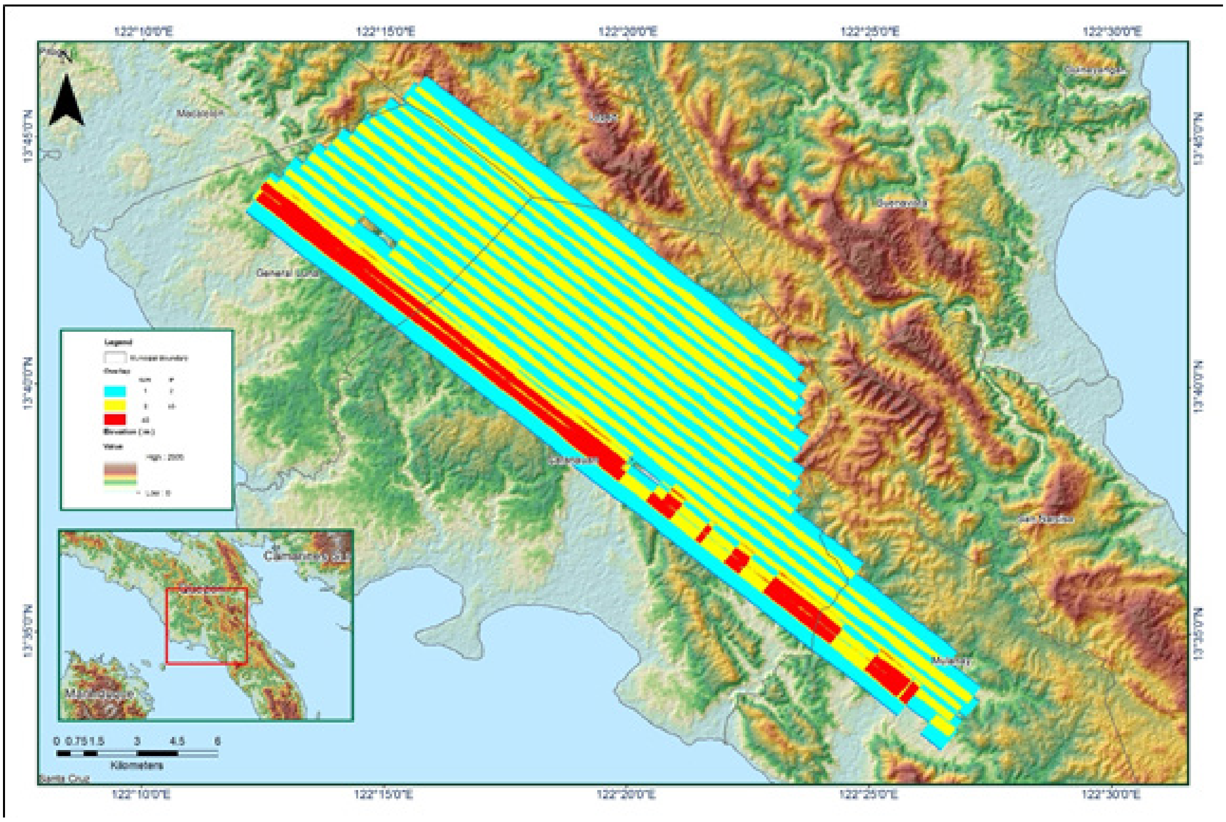


Figure 1.1.5. Image of data overlap

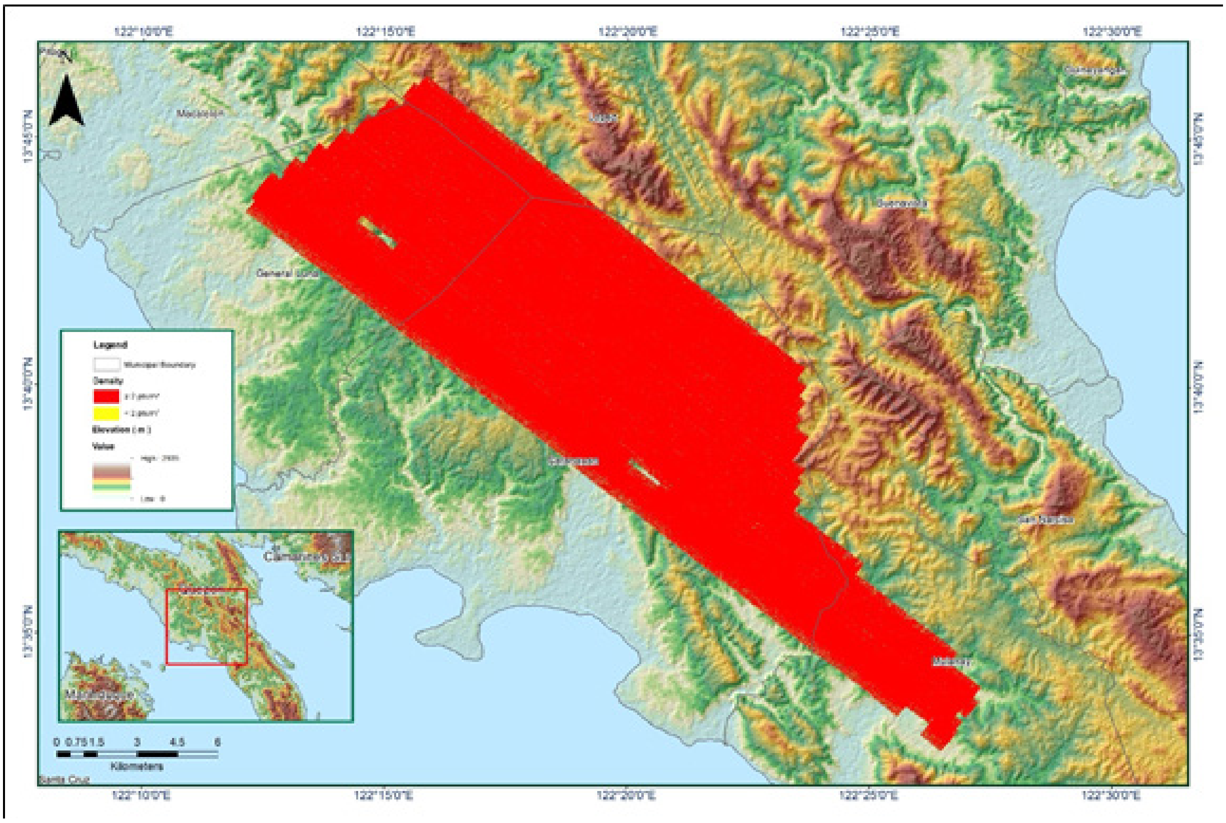


Figure 1.1.6. Density map of merged LiDAR data

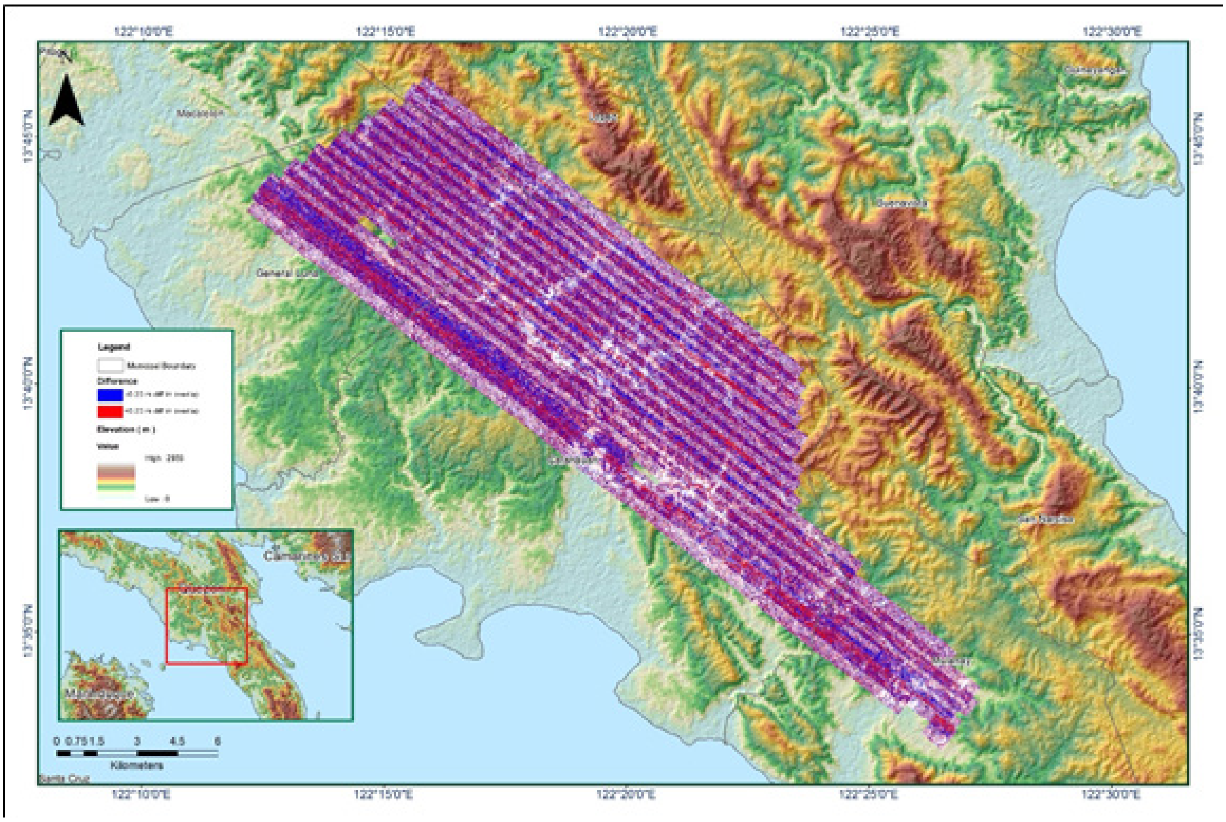


Figure 1.1.7. Elevation difference between flight line

Flight Area	**Bagasbas**
Mission Name	Bagasbas_Blk21E
Inclusive Flights	23326P
Range data size	31 GB
POS data size	283 MB
Base data size	81.2 MB
Image	n/a
Transfer date	September 6, 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)	1.0
RMSE for East Position (<4.0 cm)	1.3
RMSE for Down Position (<8.0 cm)	3.2
Boresight correction stdev (<0.001deg)	0.000137
IMU attitude correction stdev (<0.001deg)	0.000379
GPS position stdev (<0.01m)	0.0065
Minimum % overlap (>25)	57.10%
Ave point cloud density per sq.m. (>2.0)	5.44
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	259
Maximum Height	809.27 m
Minimum Height	50.28 m
Classification (# of points)	
Ground	252,534,557
Low vegetation	201,086,073
Medium vegetation	489,686,049
High vegetation	1,168,409,302
Building	12,122,577
Orthophoto	No
Processed by	Engr. Analyn Naldo, Aljon Rie Araneta, Engr. Karl Adrian Vergara

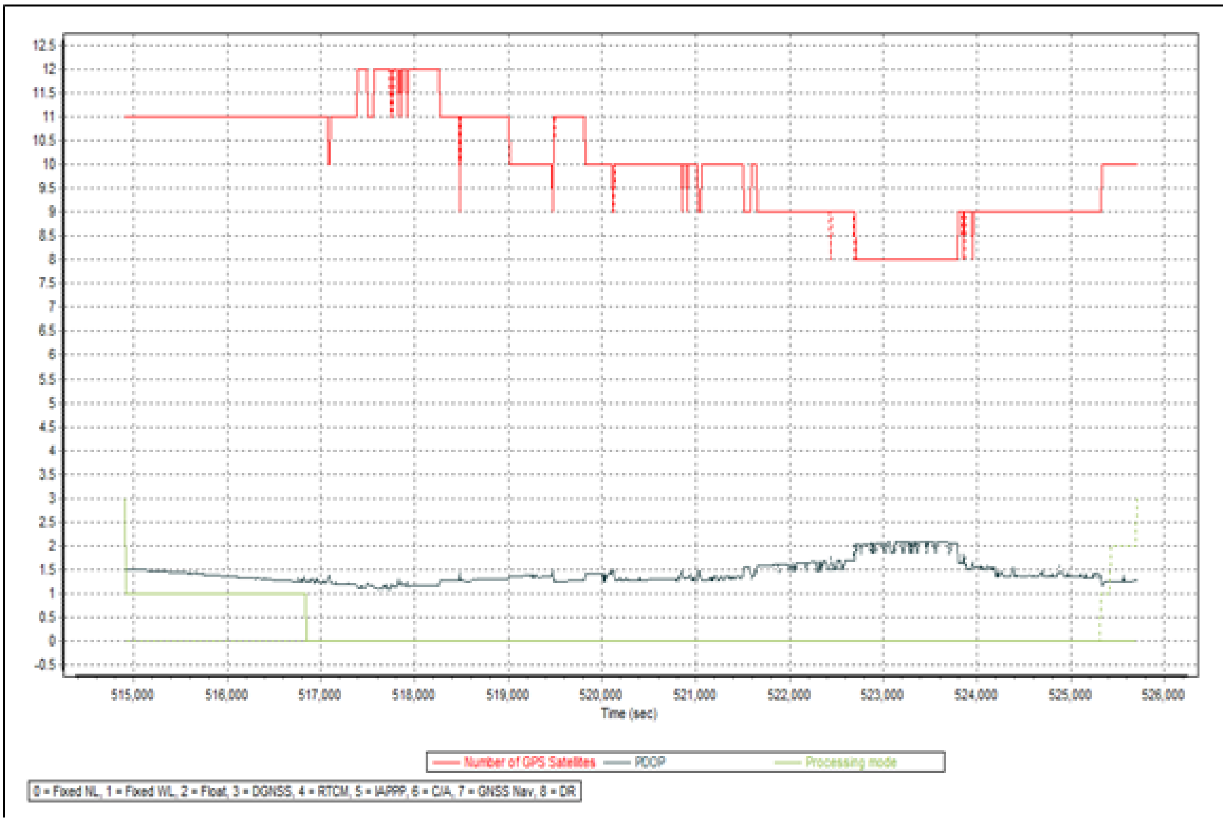


Figure 1.2.1. Solution Status

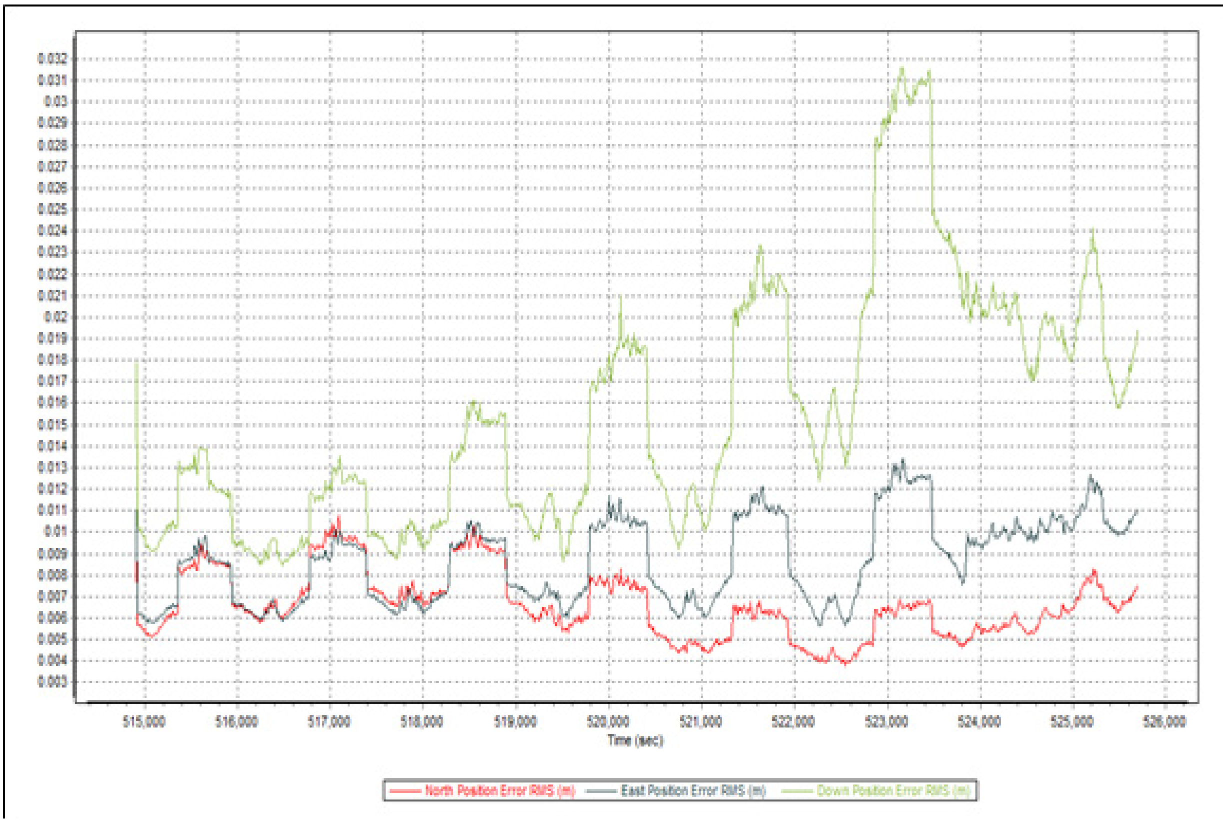


Figure 1.2.2. Smoothed Performance Metric Parameters

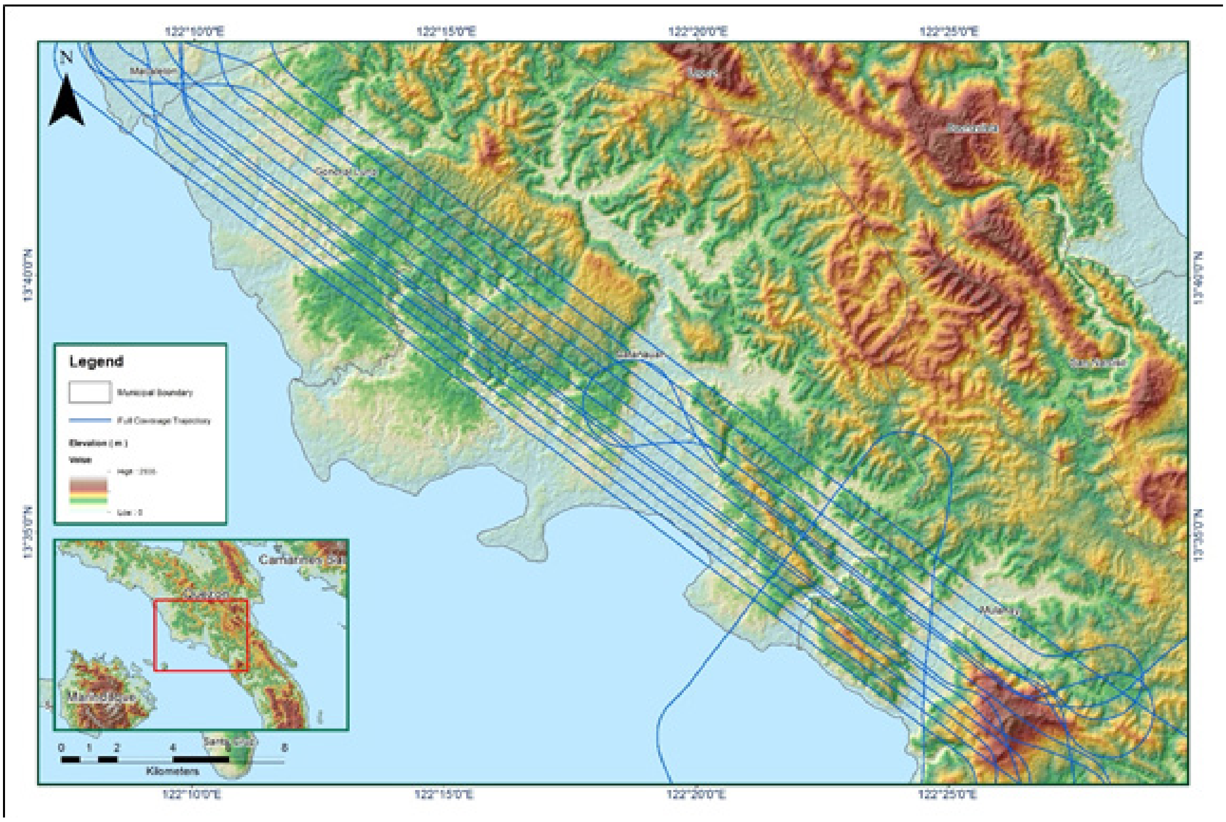


Figure 1.2.3. Best Estimated Trajectory

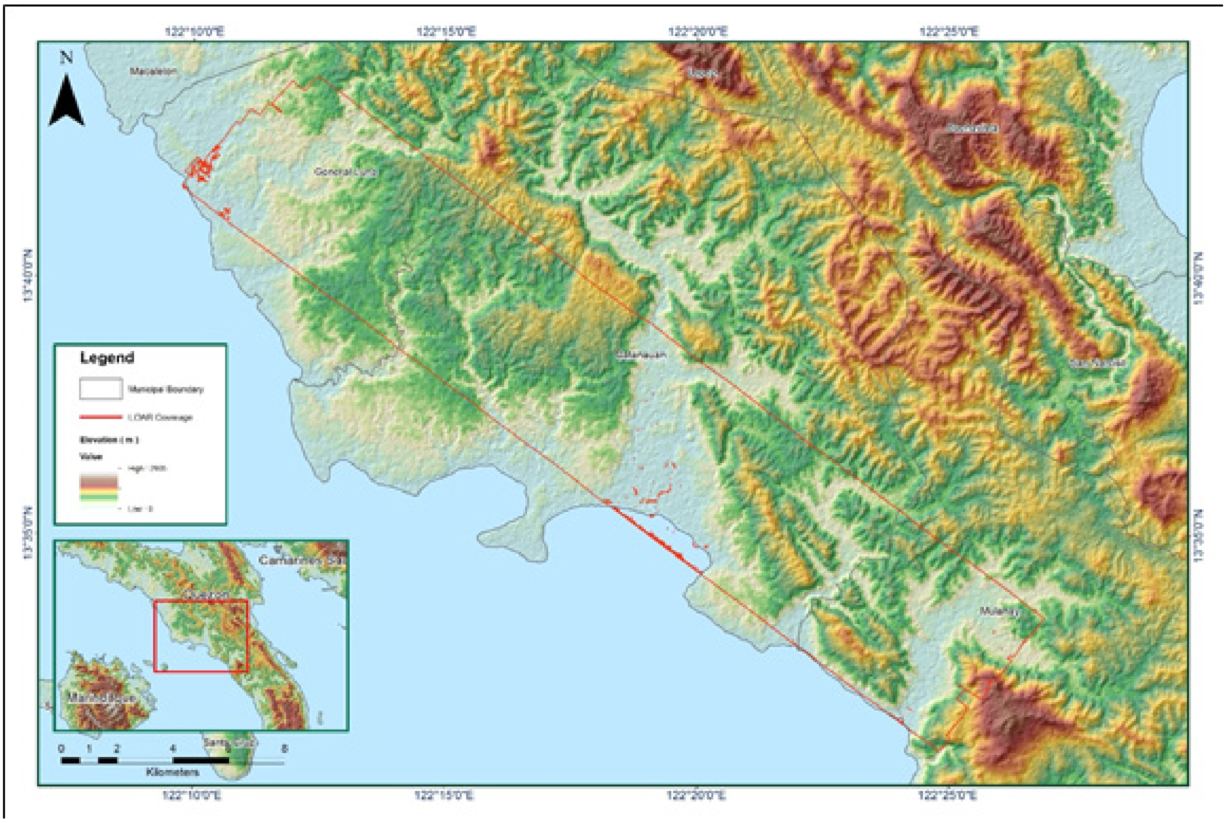


Figure 1.2.4. Coverage of LiDAR Data

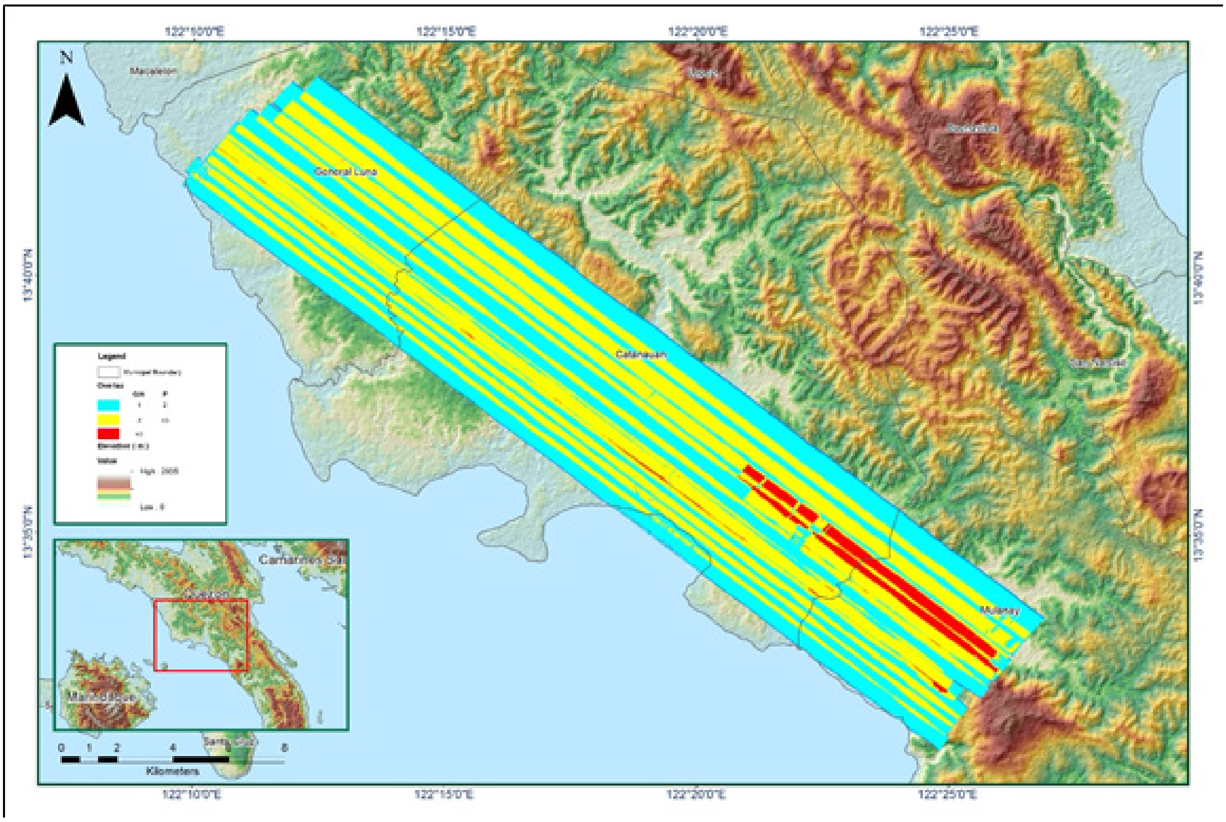


Figure 1.2.5. Image of data overlap

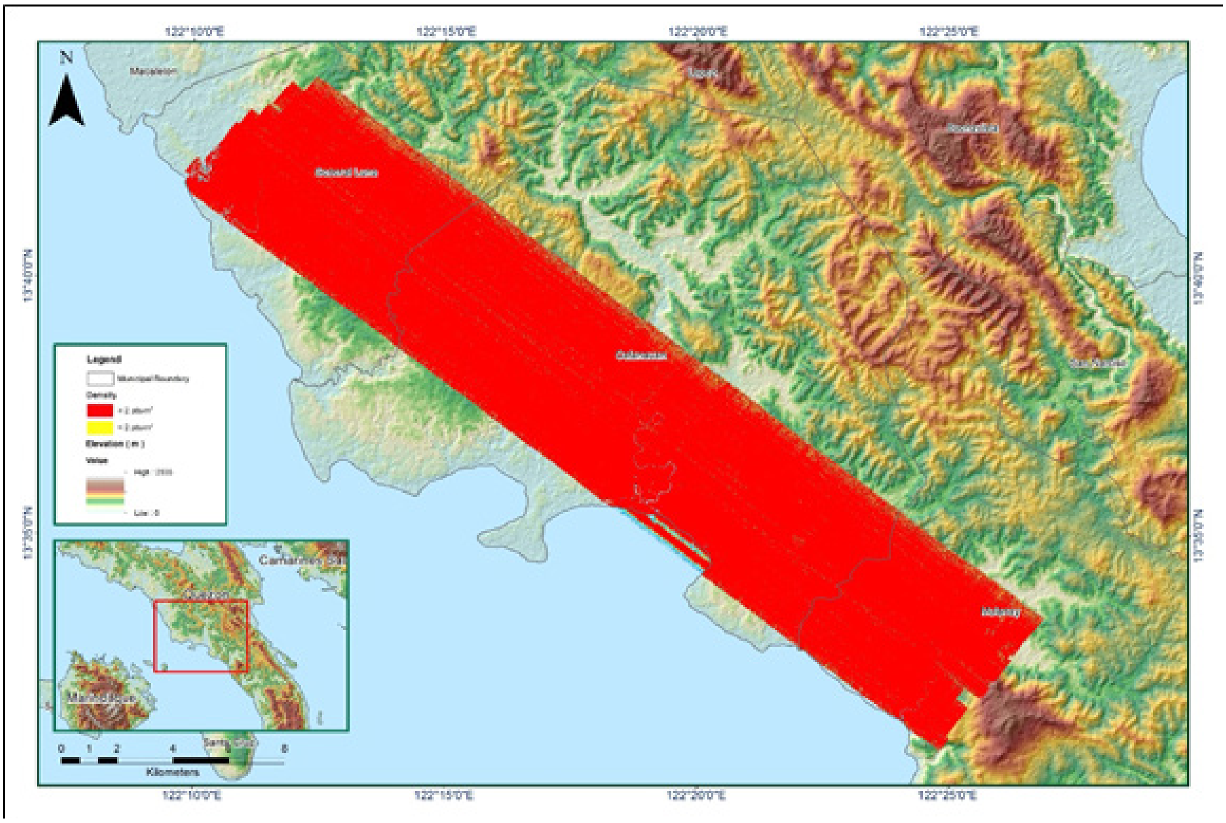


Figure 1.2.6. Density map of merged LiDAR data

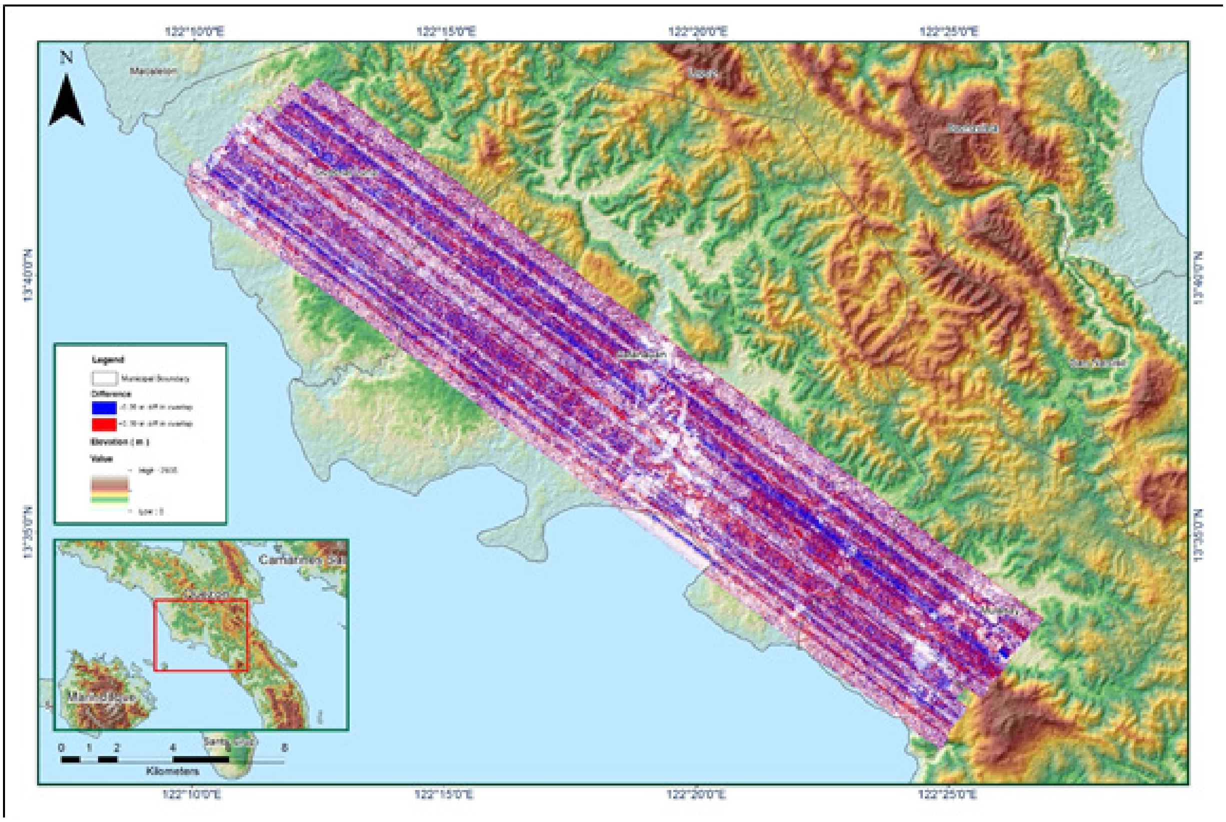


Figure 1.2.7. Elevation difference between flight line

Flight Area	**Bagasbas**
Mission Name	Bagasbas_Blk21E_additional
Inclusive Flights	23354P
Range data size	24.2 GB
POS data size	277 MB
Base data size	121 MB
Image	n/a
Transfer date	September 6, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.4
RMSE for East Position (<4.0 cm)	1.8
RMSE for Down Position (<8.0 cm)	2.9
Boresight correction stdev (<0.001deg)	0.000228
IMU attitude correction stdev (<0.001deg)	0.001445
GPS position stdev (<0.01m)	0.0072
Minimum % overlap (>25)	45.57%
Ave point cloud density per sq.m. (>2.0)	3.41
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	182
Maximum Height	186.83 m
Minimum Height	40.24 m
Classification (# of points)	
Ground	130,012,639
Low vegetation	128,457,687
Medium vegetation	170,700,536
High vegetation	333,337,303
Building	4,024,634
Orthophoto	No
Processed by	Engr. Analyn Naldo, Engr. Chelou Prado, Engr. Czarina Jean Añonuevo

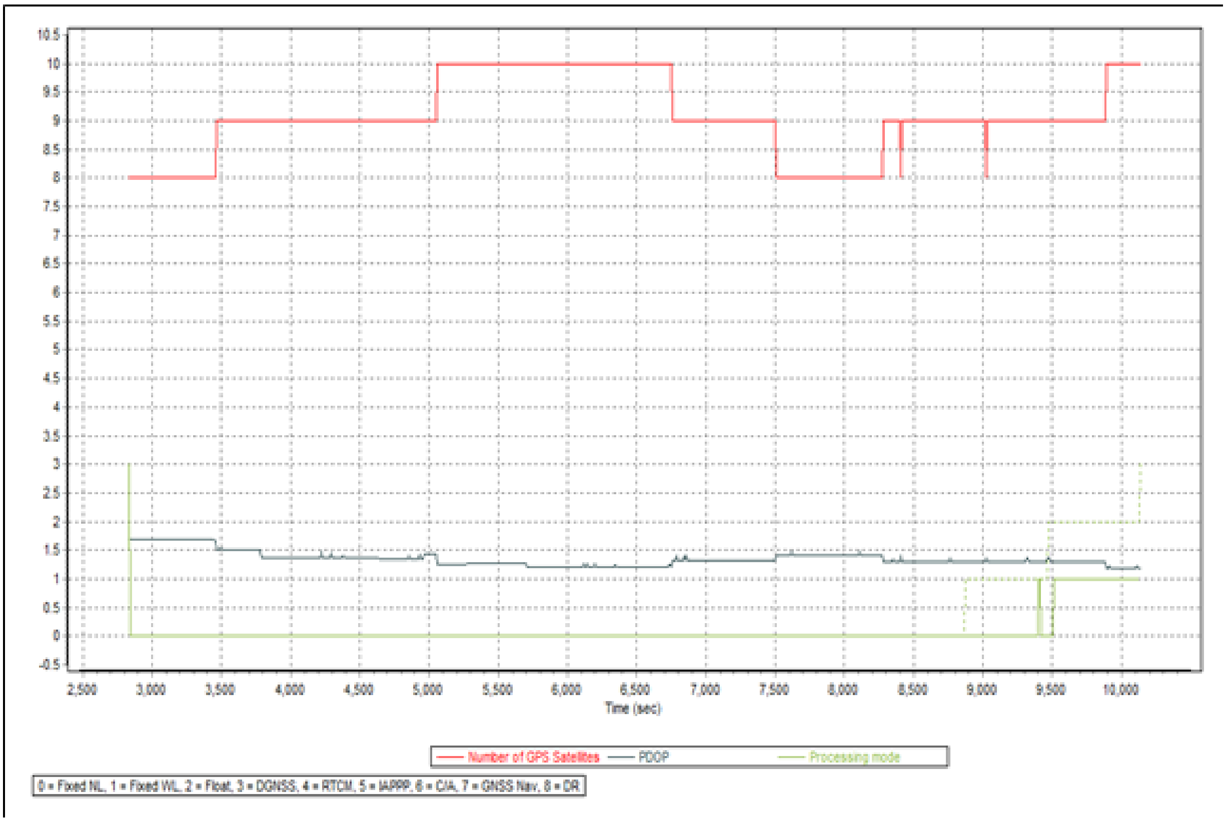


Figure 1.3.1. Solution Status

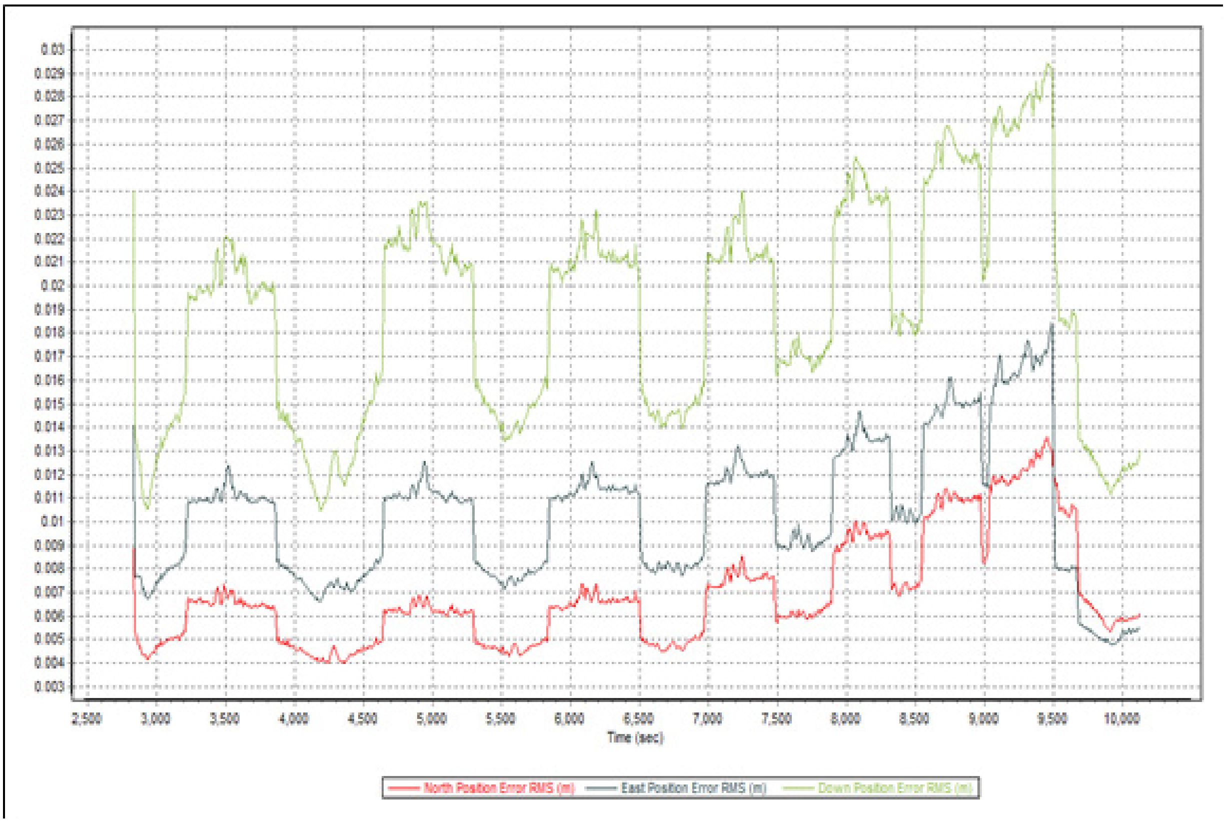


Figure 1.3.2. Smoothed Performance Metric Parameters

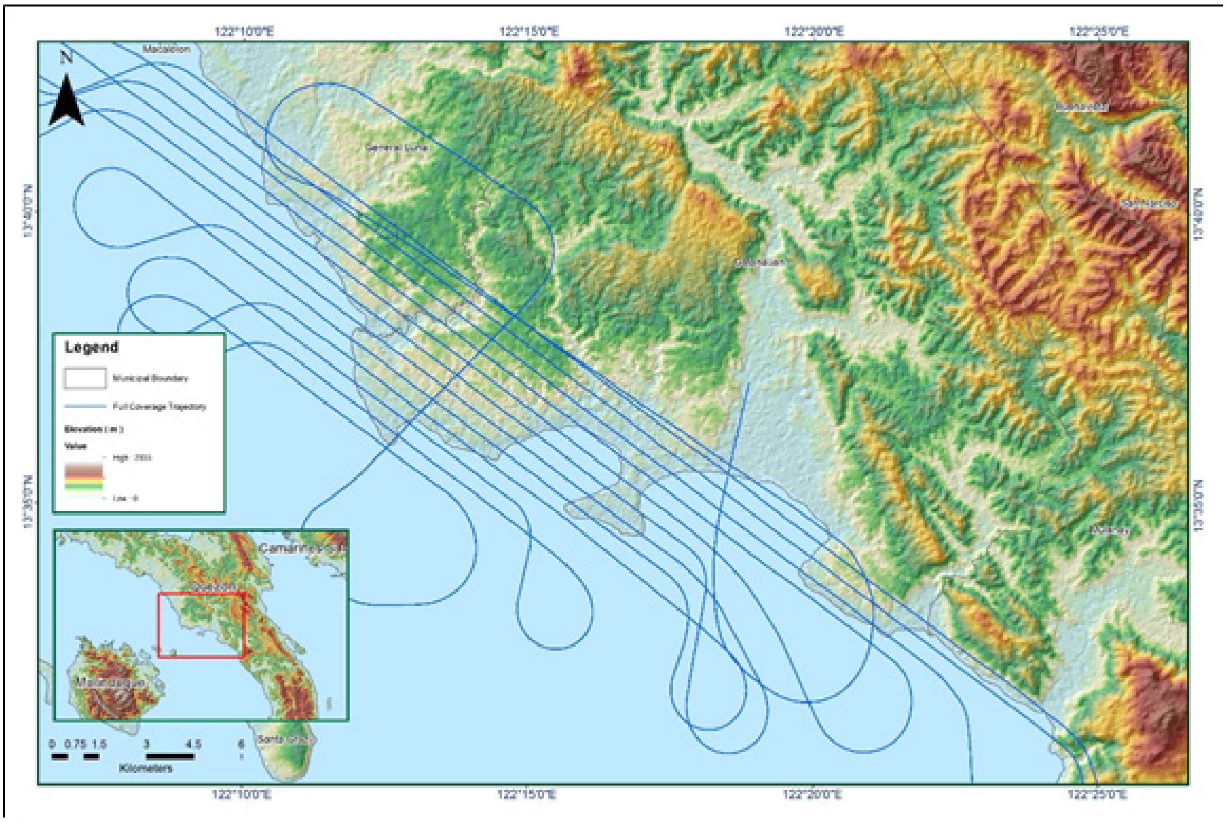


Figure 1.3.3. Best Estimated Trajectory

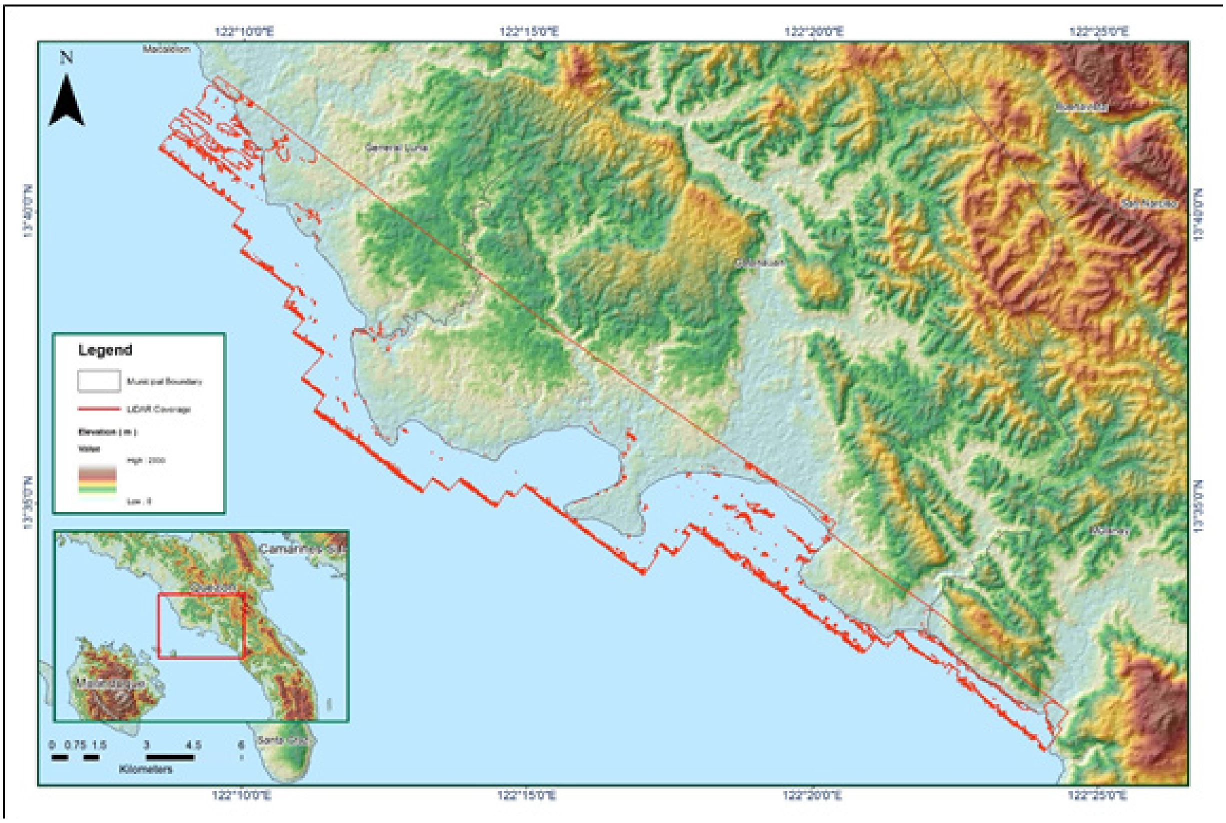


Figure 1.3.4. Coverage of LiDAR Data

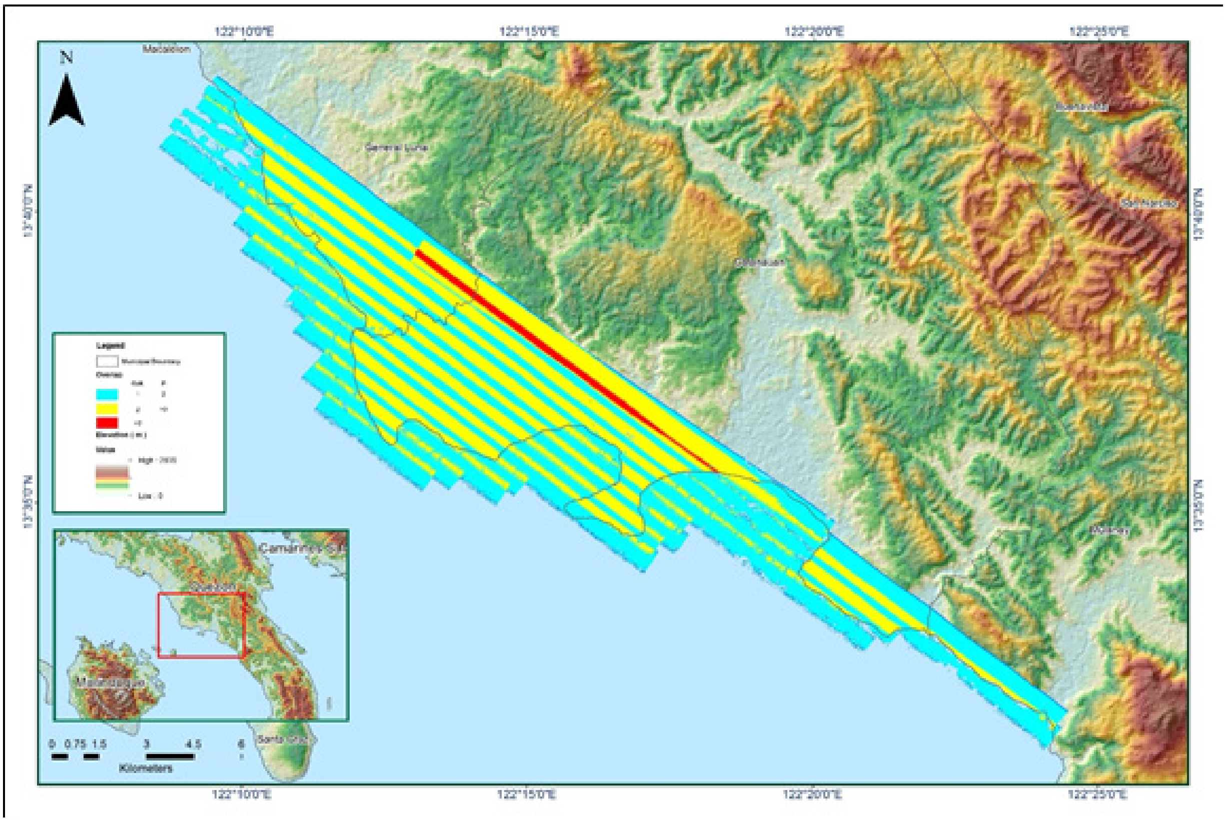


Figure 1.3.5. Image of data overlap

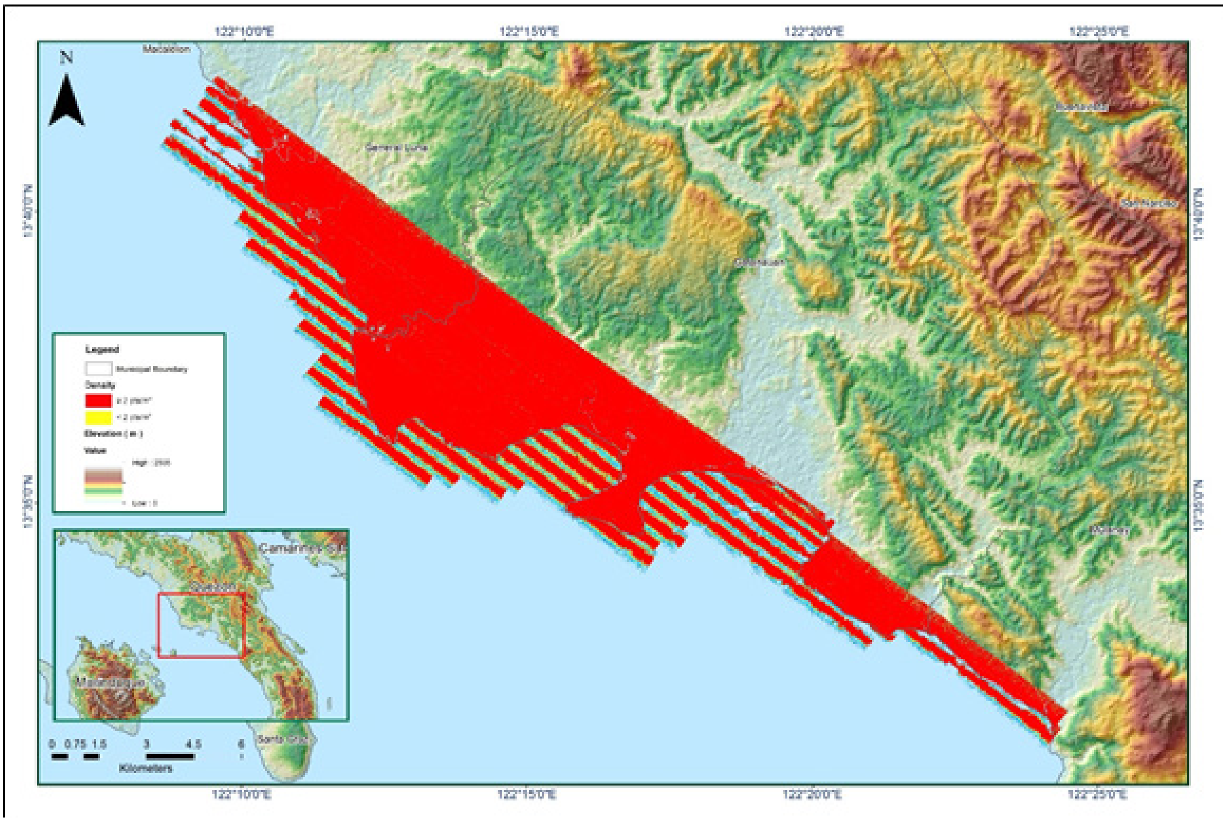


Figure 1.3.6. Density map of merged LiDAR data

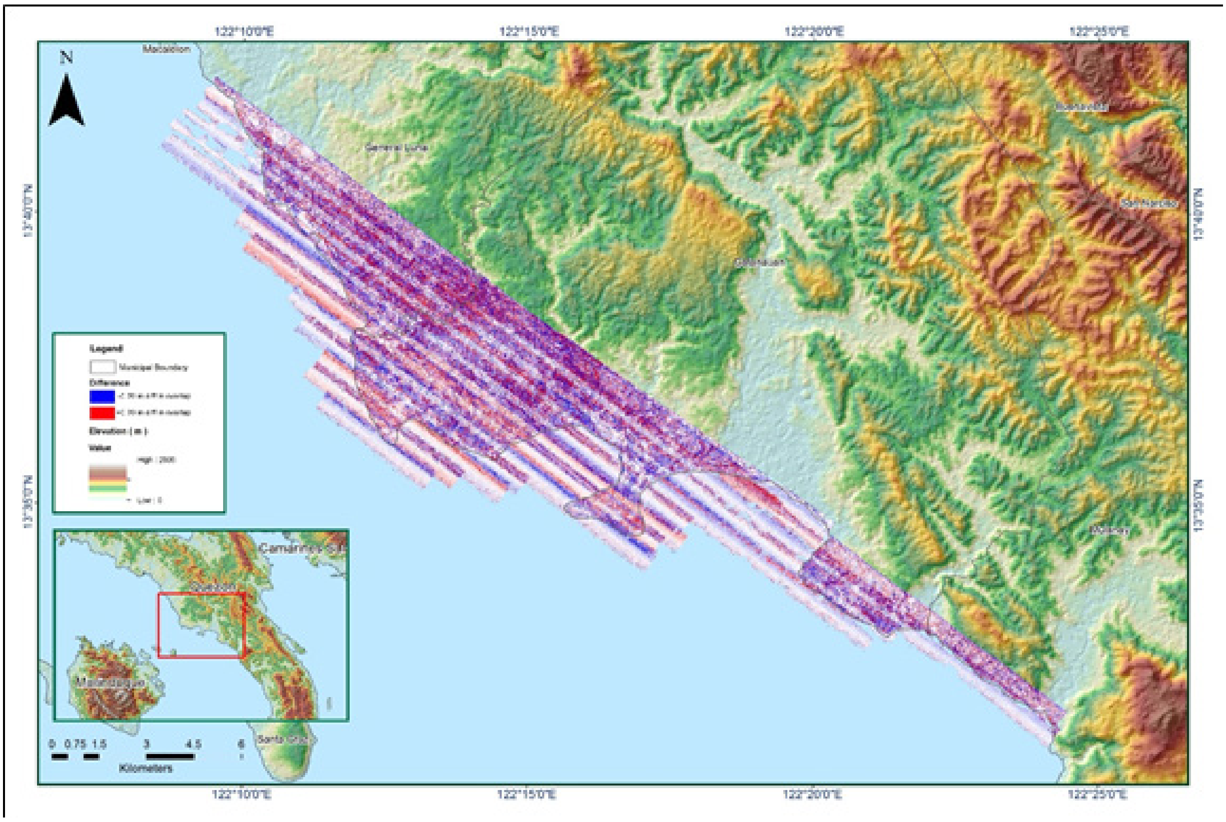


Figure 1.3.7. Elevation difference between flight line

Flight Area	Bagasbas
Mission Name	Bagasbas_Blk21I
Inclusive Flights	23358P
Range data size	31.6 GB
POS data size	214 MB
Base data size	121 MB
Image	n/a
Transfer date	September 6, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.8
RMSE for Down Position (<8.0 cm)	42
Boresight correction stdev (<0.001deg)	0.000090
IMU attitude correction stdev (<0.001deg)	0.000237
GPS position stdev (<0.01m)	0.0007
Minimum % overlap (>25)	-
Ave point cloud density per sq.m. (>2.0)	-
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	398
Maximum Height	459.14 m
Minimum Height	50.7 m
Classification (# of points)	
Ground	316,899,287
Low vegetation	216,885,567
Medium vegetation	466,041,082
High vegetation	1,160,221,886
Building	5,557,373
Orthophoto	Yes
Processed by	Engr. Don Matthew Banatin, Engr. Erica Erin Elazegui, Engr. Melissa Fernandez

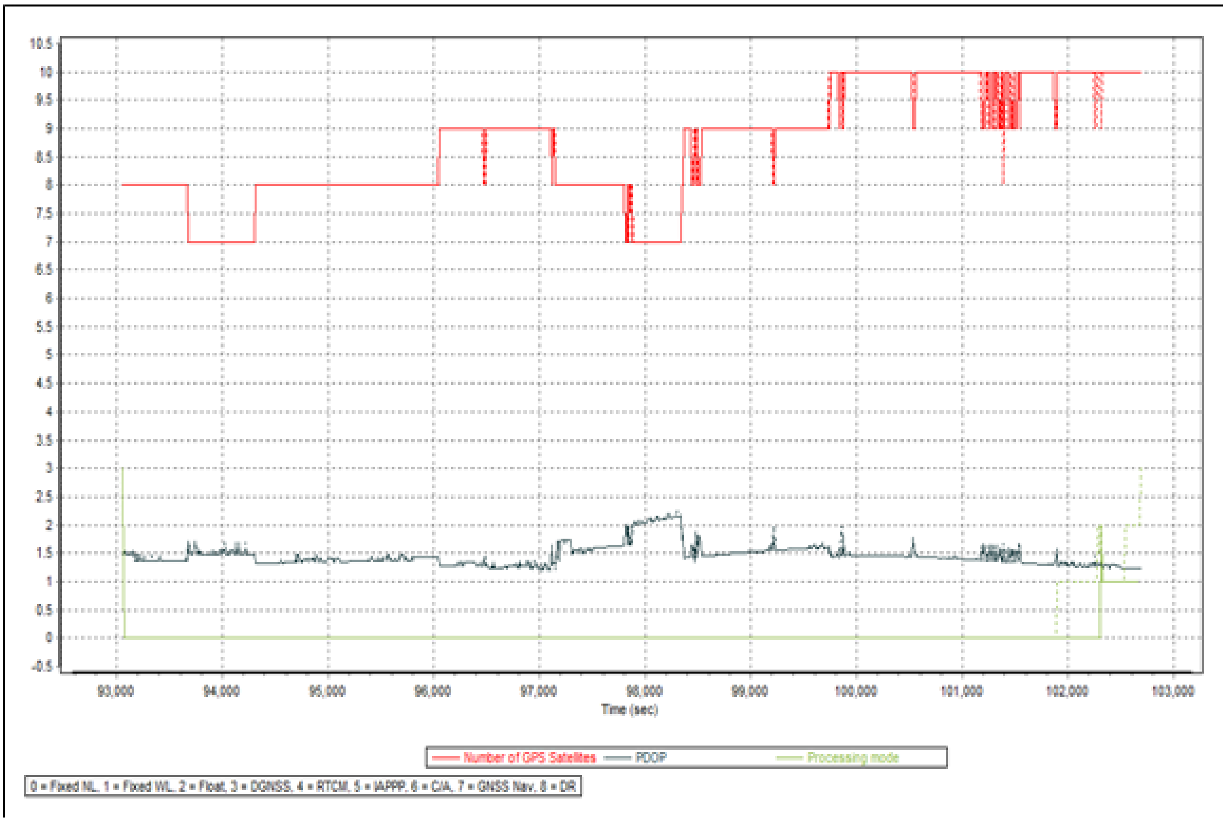


Figure 1.4.1. Solution Status

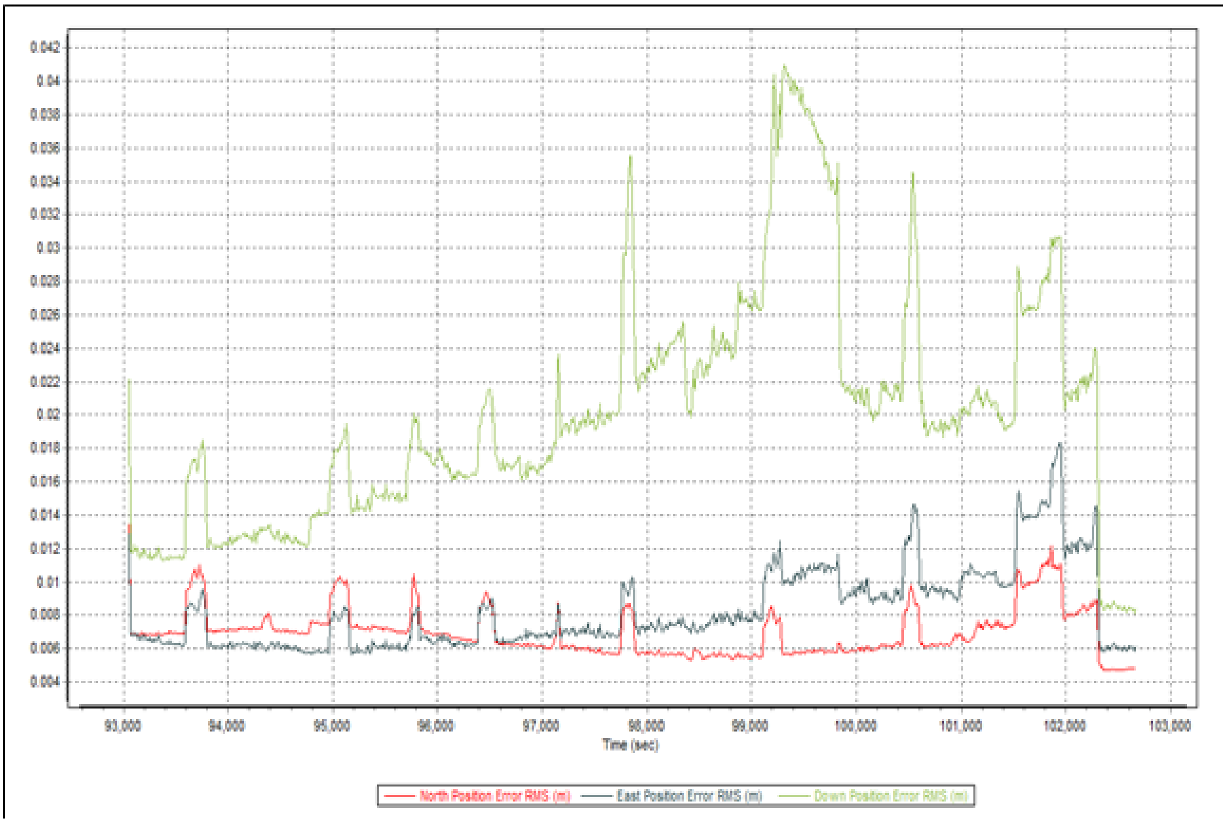


Figure 1.4.2. Smoothed Performance Metric Parameters

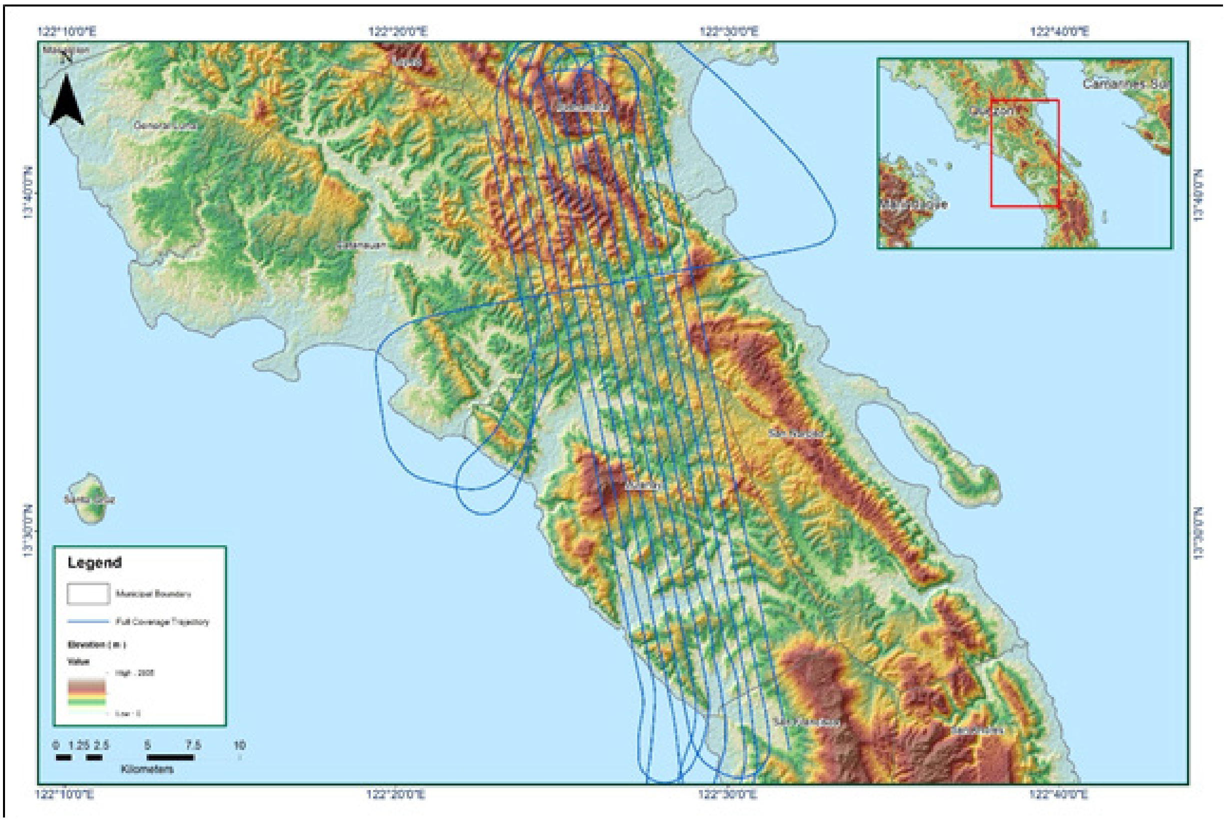


Figure 1.4.3. Best Estimated Trajectory

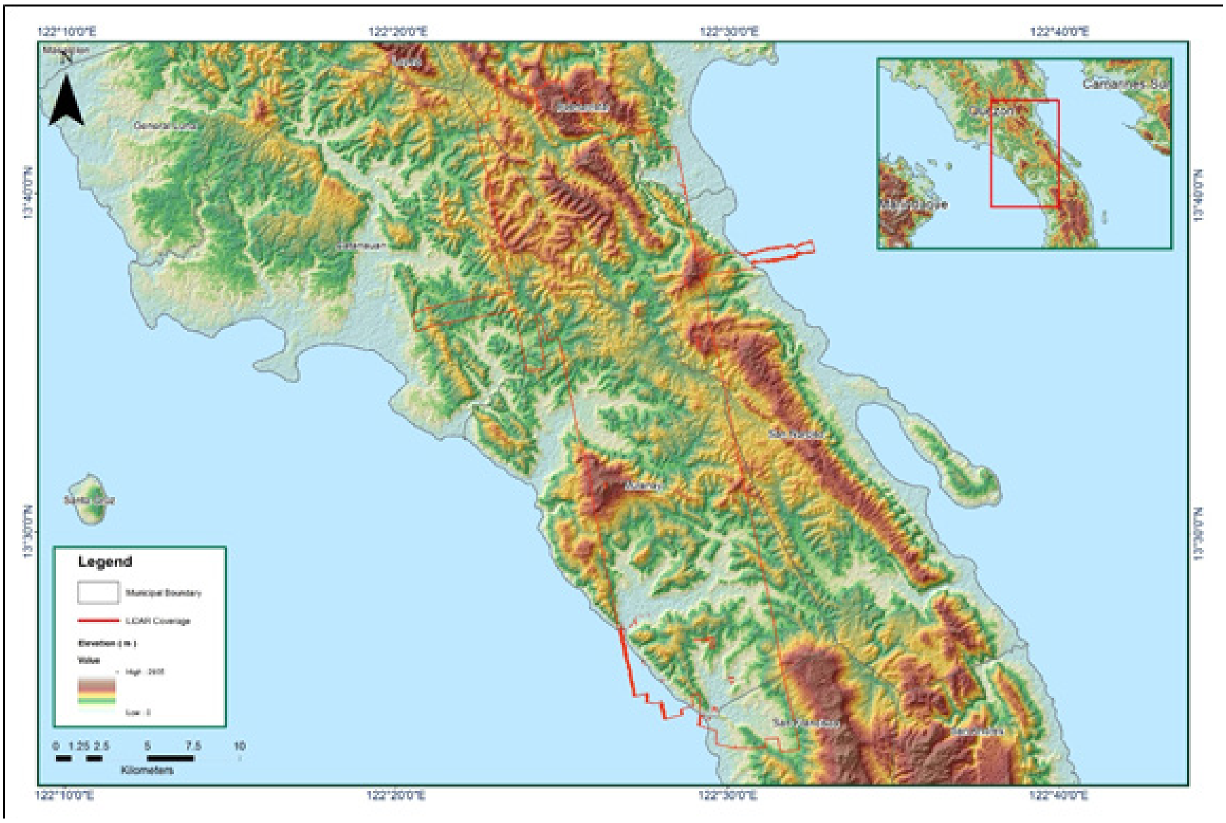


Figure 1.4.4. Coverage of LiDAR Data

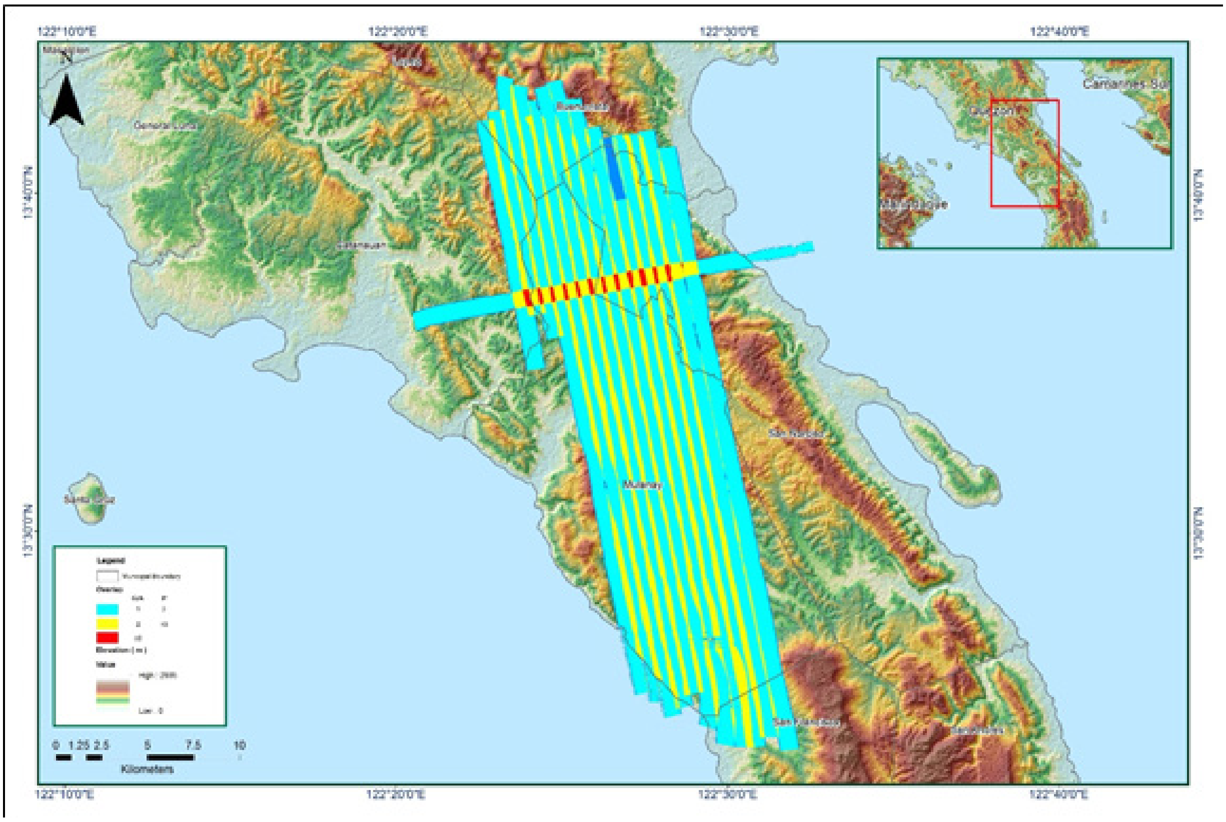


Figure 1.4.5. Image of data overlap

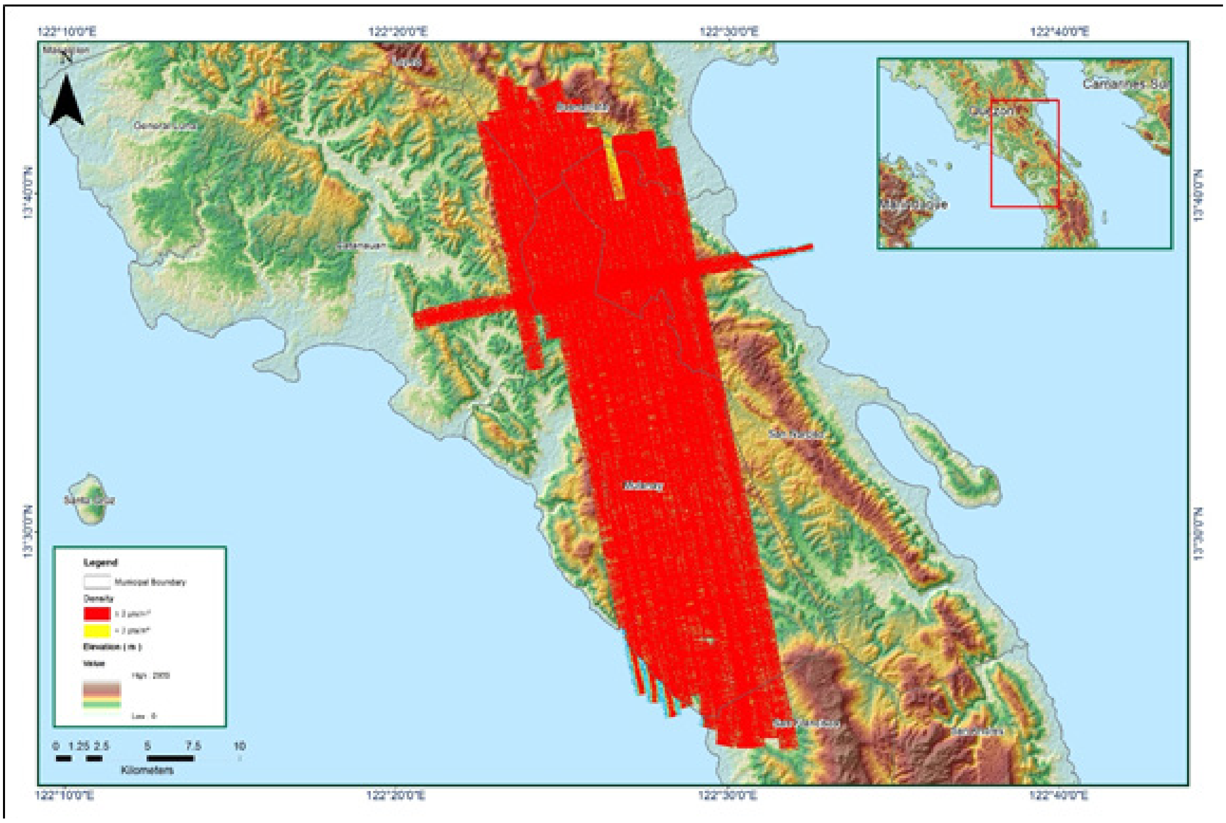


Figure 1.4.6. Density map of merged LiDAR data

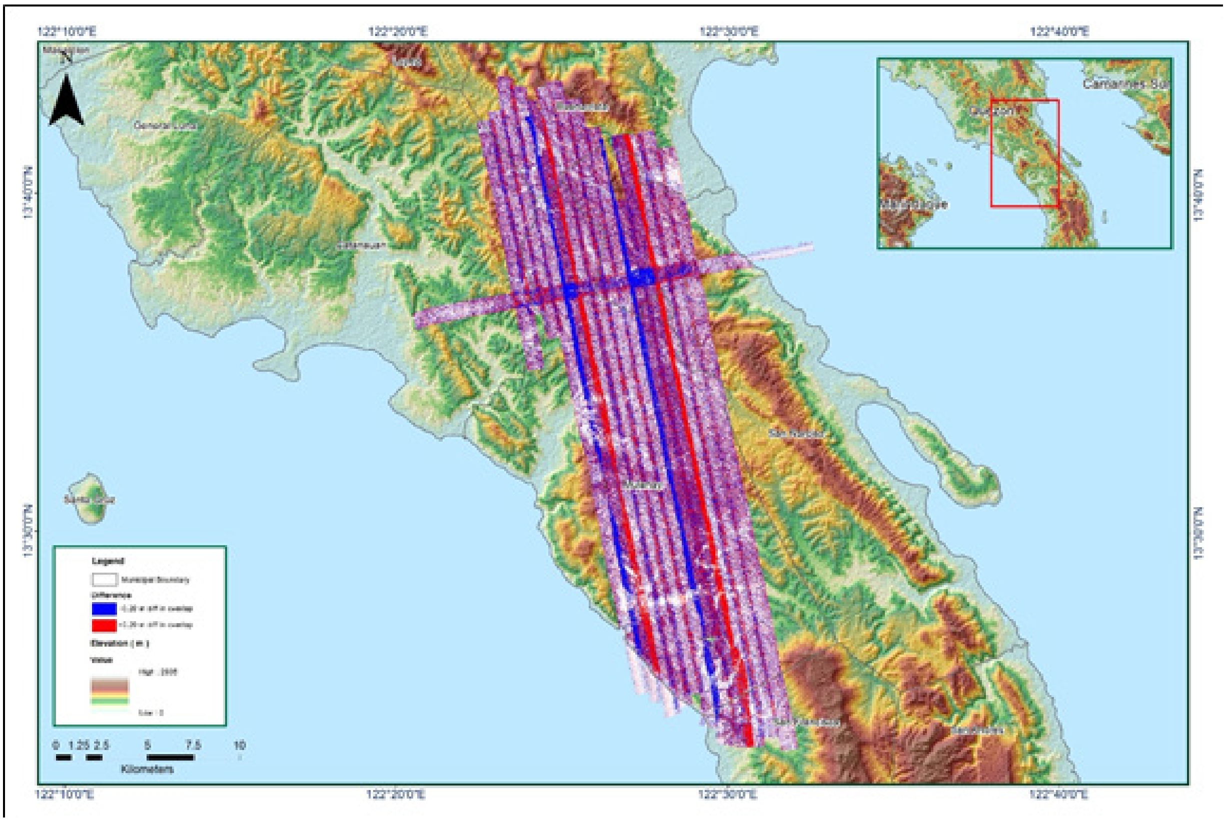


Figure 1.4.7. Elevation difference between flight line

ANNEX 8. Catanauan 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	14.114	98.199	0	9.0886	1.9436	Discharge	1.99E-6	1.0E-5	Ratio to Peak	0.0987654
W1010	28.435	99	0	11.163	0.0831579	Discharge	9.48E-4	1.0E-5	Ratio to Peak	0.5
W520	17.138	99	0	2.572	0.17648	Discharge	0.00264	1.0E-5	Ratio to Peak	0.0987654
W530	8.6677	98.245	0	0.39818	0.0663329	Discharge	0.0030	8.73115E-5	Ratio to Peak	0.14815
W540	13.479	99	0	0.59371	0.0827548	Discharge	0.00477	1.7512E-5	Ratio to Peak	0.14519
W550	9.085	98.919	0	0.0166667	0.0810067	Discharge	0.0124	1.75121E-5	Ratio to Peak	0.14519
W560	17.628	99	0	3.3967	0.29406	Discharge	0.00767	1.0E-5	Ratio to Peak	0.0987654
W570	14.191	98.826	0	0.30142	0.12747	Discharge	0.0141	.000267802	Ratio to Peak	0.50734
W580	17.616	99	0	2.2023	1.5744	Discharge	0.00634	.000342049	Ratio to Peak	0.65729
W590	0.78463	99	0	8.3562	0.39173	Discharge	0.00938	3.88065E-5	Ratio to Peak	0.21342
W600	13.786	94.349	0	3.6876	1.1586	Discharge	0.00452	.000421882	Ratio to Peak	0.57986

W610	17.591	99	0	3.8598	0.4558	Discharge	0.00649	1.0E-5	Ratio to Peak	0.0987654
W620	31.21	99	0	0.0166667	0.0634113	Discharge	0.00964	1.70786E-5	Ratio to Peak	0.21778
W630	19.47	99	0	4.7296	0.99624	Discharge	0.00439	1.0E-5	Ratio to Peak	0.0987654
W640	18.182	99	0	3.9485	0.33026	Discharge	0.00673	1.1618E-5	Ratio to Peak	0.0987654
W650	17.759	99	0	2.707	0.14261	Discharge	0.00284	1.16178E-5	Ratio to Peak	0.21659
W660	31.333	99	0	6.0686	1.0579	Discharge	0.0107	1.0E-5	Ratio to Peak	0.0987654
W670	17.988	99	0	3.8142	0.54192	Discharge	9.53E-4	1.16178E-5	Ratio to Peak	0.14519
W680	18.564	97.671	0	3.9238	2.3633	Discharge	0.0029	3.97904E-5	Ratio to Peak	0.50992
W690	18.445	99	0	6.1682	0.85695	Discharge	3.34E-4	1.0E-5	Ratio to Peak	0.50991
W700	18.542	99	0	0.64281	0.23637	Discharge	0.00558	.000284222	Ratio to Peak	0.57224
W710	18.336	99	0	3.5446	0.4007	Discharge	6.03E-4	1.0E-5	Ratio to Peak	0.0987654
W720	18.792	99	0	6.6283	0.40706	Discharge	0.00105	8.09459E-5	Ratio to Peak	0.50987
W730	1.6079	80.856	0	6.0976	0.6803	Discharge	0.00415	3.8786E-5	Ratio to Peak	0.50435
W740	31.677	99	0	5.6629	0.58371	Discharge	0.0128	1.04049E-5	Ratio to Peak	0.0987654
W750	18.583	99	0	5.1565	0.686	Discharge	0.00536	1.0E-5	Ratio to Peak	0.0987654
W760	18.446	99	0	4.3563	0.36818	Discharge	0.00436	1.13298E-5	Ratio to Peak	0.0987654

W770	4.9842	99	0	7.2094	1.8906	Discharge	0.00227	1.0E-5	Ratio to Peak	0.0987654
W780	13.365	94.804	0	7.8865	1.9332	Discharge	0.00111	1.0E-5	Ratio to Peak	0.14519
W790	18.617	99	0	6.1152	0.90671	Discharge	0.00934	1.0E-5	Ratio to Peak	0.0987654
W800	16.639	99	0	7.573	1.8566	Discharge	0.00307	1.0E-5	Ratio to Peak	0.14519
W810	27.556	99	0	6.8068	2.0907	Discharge	0.00974	1.0E-5	Ratio to Peak	0.5
W820	30.362	84.493	0	4.1584	0.54332	Discharge	0.00408	1.0E-5	Ratio to Peak	0.5
W830	18.295	99	0	4.4741	0.5105	Discharge	0.00285	1.0E-5	Ratio to Peak	0.50742
W840	7.5101	85.414	0	2.4947	0.72825	Discharge	0.0053	.000432721	Ratio to Peak	0.56933
W850	32.749	99	0	2.4605	3.1742	Discharge	0.00354	1.0E-5	Ratio to Peak	0.5
W860	18.311	99	0	4.369	0.43091	Discharge	0.0124	1.0E-5	Ratio to Peak	0.0987654
W870	18.632	99	0	6.6035	1.5047	Discharge	0.00334	1.0E-5	Ratio to Peak	0.0987654
W880	18.646	99	0	6.1792	0.96876	Discharge	0.00109	1.0E-5	Ratio to Peak	0.0987654
W890	18.966	99	0	7.8767	1.8379	Discharge	0.00416	1.0E-5	Ratio to Peak	0.0987654
W900	11.972	95.266	0	8.7059	1.8636	Discharge	0.00486	1.0E-5	Ratio to Peak	0.14519
W910	18.658	99	0	5.6074	0.52505	Discharge	0.00556	8.95217E-5	Ratio to Peak	0.21342
W920	18.749	99	0	6.9509	1.418	Discharge	0.00446	1.0E-5	Ratio to Peak	0.14519

W930	4.3089	74.756	0	15.548	1.8629	Discharge	0.00651	1.0E-5	Ratio to Peak	0.0987654
W940	18.922	99	0	6.4859	1.8756	Discharge	0.00172	1.0E-5	Ratio to Peak	0.14519
W950	8.9934	96.381	0	9.6097	2.1409	Discharge	0.00243	1.0E-5	Ratio to Peak	0.5
W960	18.965	99	0	5.5138	0.79344	Discharge	0.00615	.000183976	Ratio to Peak	0.31373
W970	0.6194	98.426	0	15.102	1.7418	Discharge	0.00131	2.51561E-5	Ratio to Peak	0.5
W980	19.465	99	0	8.6943	0.97904	Discharge	0.0026	3.78072E-5	Ratio to Peak	0.75719
W990	14.26	99	0	9.2419	1.9222	Discharge	0.00456	3.59894E-5	Ratio to Peak	0.14519

ANNEX 9. Catanauan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R130	Automatic Fixed Interval	631.54	0.0060994	0.40164	Trapezoid	30	0.5
R160	Automatic Fixed Interval	2268.8	0.0032465	0.24009	Trapezoid	30	0.5
R180	Automatic Fixed Interval	1473.1	0.0031207	0.25003	Trapezoid	30	0.5
R190	Automatic Fixed Interval	760.12	0.0035363	0.25978	Trapezoid	30	0.5
R200	Automatic Fixed Interval	3981.7	0.0071668	0.1181	Trapezoid	30	0.5
R230	Automatic Fixed Interval	1641.2	0.0076091	0.30285	Trapezoid	30	0.5
R250	Automatic Fixed Interval	973.55	0.00501	0.47978	Trapezoid	30	0.5
R270	Automatic Fixed Interval	1538.1	0.0071148	0.1047	Trapezoid	30	0.5
R290	Automatic Fixed Interval	352.84	0.0082639	0.0001	Trapezoid	30	0.5
R30	Automatic Fixed Interval	1085.7	0.0118742	0.0001	Trapezoid	30	0.5
R310	Automatic Fixed Interval	4109.0	0.00201	0.0761089	Trapezoid	30	0.5
R320	Automatic Fixed Interval	1011.1	0.0012744	0.0335277	Trapezoid	30	0.5
R330	Automatic Fixed Interval	2083.1	0.0068351	0.14128	Trapezoid	30	0.5
R340	Automatic Fixed Interval	1303.7	0.0035498	0.0870877	Trapezoid	30	0.5
R350	Automatic Fixed Interval	916.98	0.0012359	0.0406085	Trapezoid	30	0.5
R410	Automatic Fixed Interval	4155.8	0.0013484	0.0304431	Trapezoid	30	0.5
R420	Automatic Fixed Interval	2610.2	0.0027312	0.13337	Trapezoid	30	0.5
R430	Automatic Fixed Interval	2607.6	0.0034584	0.0506363	Trapezoid	30	0.5
R470	Automatic Fixed Interval	1796.8	0.001176	0.0302935	Trapezoid	30	0.5
R490	Automatic Fixed Interval	6062.4	0.0022965	0.0252739	Trapezoid	30	0.5
R50	Automatic Fixed Interval	1776.8	0.0076826	0.60719	Trapezoid	30	0.5
R500	Automatic Fixed Interval	1147.8	0.0020796	0.0614263	Trapezoid	30	0.5
R80	Automatic Fixed Interval	1127.8	0.0013694	0.16217	Trapezoid	30	0.5
R90	Automatic Fixed Interval	1361.2	0.0053544	0.0980694	Trapezoid	30	0.5

ANNEX 10. Catanauan Model Reach Parameters

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event/Date	Rain Return / Scenario
	Lat	Long					
1	13.60062	122.321635	0.03	1	0.970	Rosing/ November 7 1995	5 -Year
2	13.599267	122.322807	0.03	1	0.970	Rosing/ November 7 1995	5 -Year
3	13.599151	122.323039	0.65	0.5	-0.150	Rosing/ November 7 1995	5 -Year
4	13.598952	122.323437	0.65	0.5	-0.150	Rosing/ November 7 1995	5 -Year
5	13.603106	122.311385	0.76	0.5	-0.260	Rosing/ November 7 1995	5 -Year
6	13.598735	122.323779	0.53	0.5	-0.030	Rosing/ November 7 1995	5 -Year
7	13.598651	122.322802	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
8	13.598198	122.322825	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
9	13.59807	122.322834	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
10	13.596924	122.322874	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
11	13.6032	122.312068	0.18	0	-0.180	Rosing/ November 7 1995	5 -Year
12	13.603347	122.313338	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
13	13.603374	122.313615	0.04	0	-0.040	Rosing/ November 7 1995	5 -Year
14	13.603587	122.315358	0.71	2	1.290	Rosing/ November 7 1995	5 -Year
15	13.603101	122.311301	0.38	1.5	1.120	Rosing/ November 7 1995	5 -Year
16	13.635166	122.312312	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
17	13.635677	122.307464	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
18	13.638035	122.306643	0.09	0	-0.090	Rosing/ November 7 1995	5 -Year
19	13.63818	122.306574	0.06	0	-0.060	Rosing/ November 7 1995	5 -Year
20	13.631232	122.313242	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
21	13.631677	122.313476	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
22	13.631764	122.314215	1	0	-1.000	Rosing/ November 7 1995	5 -Year
23	13.632157	122.31868	0.65	0	-0.650	Rosing/ November 7 1995	5 -Year
24	13.630281	122.308807	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
25	13.627651	122.310645	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
26	13.629728	122.307907	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
27	13.627292	122.305326	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
28	13.628337	122.310593	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
29	13.628994	122.310302	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
30	13.629488	122.309896	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
31	13.630761	122.308891	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
32	13.631389	122.308405	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
33	13.632788	122.307796	0.05	0	-0.050	Rosing/ November 7 1995	5 -Year
34	13.633995	122.307786	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
35	13.630202	122.309347	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
36	13.625907	122.297365	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
37	13.625821	122.297033	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
38	13.625507	122.296585	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
39	13.624871	122.29627	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
40	13.622662	122.294068	0.04	0	-0.040	Rosing/ November 7 1995	5 -Year
41	13.622328	122.2938	0.16	0	-0.160	Rosing/ November 7 1995	5 -Year
42	13.626162	122.298407	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year

43	13.626124	122.298502	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
44	13.626025	122.298435	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
45	13.62605	122.298213	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
46	13.626025	122.298134	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
47	13.626003	122.298082	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
48	13.625974	122.297943	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
49	13.625935	122.297827	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
50	13.602853	122.303004	0.09	0	-0.090	Rosing/ November 7 1995	5 -Year
51	13.602778	122.303955	0.07	0	-0.070	Rosing/ November 7 1995	5 -Year
52	13.602744	122.304422	0.12	0	-0.120	Rosing/ November 7 1995	5 -Year
53	13.6027	122.305058	0.06	0	-0.060	Rosing/ November 7 1995	5 -Year
54	13.602664	122.305676	0.24	0	-0.240	Rosing/ November 7 1995	5 -Year
55	13.602583	122.306518	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
56	13.603451	122.294001	0.05	0	-0.050	Rosing/ November 7 1995	5 -Year
57	13.603293	122.294111	0.58	0	-0.580	Rosing/ November 7 1995	5 -Year
58	13.603248	122.294286	0.33	0	-0.330	Rosing/ November 7 1995	5 -Year
59	13.60337	122.295081	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
60	13.603419	122.295427	0.04	0	-0.040	Rosing/ November 7 1995	5 -Year
61	13.603238	122.297375	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
62	13.60293	122.301987	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
63	13.603492	122.293656	0.04	0	-0.040	Rosing/ November 7 1995	5 -Year
64	13.59532	122.336888	0.74	0.5	-0.240	Rosing/ November 7 1995	5 -Year
65	13.595873	122.332024	0.29	0.5	0.210	Rosing/ November 7 1995	5 -Year
66	13.59385	122.329668	0.84	2	1.160	Rosing/ November 7 1995	5 -Year
67	13.594577	122.325529	0.14	1.5	1.360	Rosing/ November 7 1995	5 -Year
68	13.594612	122.325124	0.14	1.5	1.360	Rosing/ November 7 1995	5 -Year
69	13.594896	122.325261	0.2	1.5	1.300	Rosing/ November 7 1995	5 -Year
70	13.595643	122.32505	0.1	1.5	1.400	Rosing/ November 7 1995	5 -Year
71	13.595829	122.324676	0.07	1.5	1.430	Rosing/ November 7 1995	5 -Year
72	13.595817	122.324159	0.11	0.3	0.190	Rosing/ November 7 1995	5 -Year
73	13.595564	122.323868	0.14	0.3	0.160	Rosing/ November 7 1995	5 -Year
74	13.595292	122.323725	0.13	0.5	0.370	Rosing/ November 7 1995	5 -Year
75	13.594995	122.323688	0.12	0.5	0.380	Rosing/ November 7 1995	5 -Year
76	13.594936	122.323715	0.1	0.5	0.400	Rosing/ November 7 1995	5 -Year
77	13.595172	122.322875	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
78	13.594276	122.32381	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
79	13.594318	122.323876	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
80	13.594458	122.323937	0.12	0.5	0.380	Rosing/ November 7 1995	5 -Year
81	13.594703	122.324426	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
82	13.594613	122.32467	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
83	13.594166	122.325773	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
84	13.593827	122.326584	0.06	0.5	0.440	Rosing/ November 7 1995	5 -Year
85	13.594123	122.326817	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
86	13.592981	122.327466	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
87	13.592997	122.327487	0.07	0.5	0.430	Rosing/ November 7 1995	5 -Year
88	13.59255	122.32756	0.06	0.5	0.440	Rosing/ November 7 1995	5 -Year

89	13.592265	122.327059	0.11	0.5	0.390	Rosing/ November 7 1995	5 -Year
90	13.592558	122.326526	0.21	0.5	0.290	Rosing/ November 7 1995	5 -Year
91	13.592375	122.32596	0.03	0.5	0.470	Rosing/ November 7 1995	5 -Year
92	13.592147	122.325596	0.19	1	0.810	Rosing/ November 7 1995	5 -Year
93	13.592274	122.325301	0.03	1	0.970	Rosing/ November 7 1995	5 -Year
94	13.592345	122.32502	0.03	1	0.970	Rosing/ November 7 1995	5 -Year
95	13.592434	122.324734	0.07	1	0.930	Rosing/ November 7 1995	5 -Year
96	13.592364	122.324592	0.16	1	0.840	Rosing/ November 7 1995	5 -Year
97	13.592099	122.324458	0.25	1	0.750	Rosing/ November 7 1995	5 -Year
98	13.59192	122.32393	0.03	1	0.970	Rosing/ November 7 1995	5 -Year
99	13.591739	122.323823	0.03	1	0.970	Rosing/ November 7 1995	5 -Year
100	13.592268	122.323734	0.23	1	0.770	Rosing/ November 7 1995	5 -Year
101	13.591669	122.325593	0.14	1	0.860	Rosing/ November 7 1995	5 -Year
102	13.591095	122.325317	0.21	1	0.790	Rosing/ November 7 1995	5 -Year
103	13.590804	122.325762	0.06	1	0.940	Rosing/ November 7 1995	5 -Year
104	13.590284	122.32611	0.34	1	0.660	Rosing/ November 7 1995	5 -Year
105	13.58977	122.325832	0.03	1	0.970	Rosing/ November 7 1995	5 -Year
106	13.593806	122.322991	0.17	0	-0.170	Rosing/ November 7 1995	5 -Year
107	13.591559	122.321438	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
108	13.591809	122.320896	0.11	0	-0.110	Rosing/ November 7 1995	5 -Year
109	13.591817	122.32088	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
110	13.591818	122.320747	0.04	0	-0.040	Rosing/ November 7 1995	5 -Year
111	13.591871	122.320616	0.1	0	-0.100	Rosing/ November 7 1995	5 -Year
112	13.591888	122.320542	0.2	0	-0.200	Rosing/ November 7 1995	5 -Year
113	13.591896	122.320507	0.15	0	-0.150	Rosing/ November 7 1995	5 -Year
114	13.591945	122.320524	0.17	0	-0.170	Rosing/ November 7 1995	5 -Year
115	13.591928	122.320618	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
116	13.594791	122.321929	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
117	13.594765	122.321893	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
118	13.594761	122.32191	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
119	13.594936	122.321963	0.05	0	-0.050	Rosing/ November 7 1995	5 -Year
120	13.595004	122.32169	0.04	0	-0.040	Rosing/ November 7 1995	5 -Year
121	13.594747	122.321573	0.04	0	-0.040	Rosing/ November 7 1995	5 -Year
122	13.594582	122.321525	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
123	13.594484	122.321469	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
124	13.592088	122.320067	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
125	13.592114	122.319915	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
126	13.592175	122.319867	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
127	13.592166	122.319878	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
128	13.592111	122.319999	0.05	0	-0.050	Rosing/ November 7 1995	5 -Year
129	13.592062	122.320081	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
130	13.592227	122.320791	0.06	0	-0.060	Rosing/ November 7 1995	5 -Year
131	13.592815	122.319742	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
132	13.593013	122.319827	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
133	13.593254	122.319789	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
134	13.593346	122.31951	0.05	0	-0.050	Rosing/ November 7 1995	5 -Year

135	13.593477	122.319191	0.07	0	-0.070	Rosing/ November 7 1995	5 -Year
136	13.622023	122.33931	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
137	13.593575	122.318925	0.07	0	-0.070	Rosing/ November 7 1995	5 -Year
138	13.622438	122.339464	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
139	13.593638	122.318858	0.05	0	-0.050	Rosing/ November 7 1995	5 -Year
140	13.622859	122.3399	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
141	13.624624	122.339199	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
142	13.593825	122.322456	0.15	0	-0.150	Rosing/ November 7 1995	5 -Year
143	13.625227	122.338733	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
144	13.593702	122.322388	0.09	0	-0.090	Rosing/ November 7 1995	5 -Year
145	13.626146	122.33867	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
146	13.59366	122.322336	0.23	0	-0.230	Rosing/ November 7 1995	5 -Year
147	13.626536	122.339185	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
148	13.62724	122.340074	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
149	13.626879	122.342779	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
150	13.627426	122.344428	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
151	13.59361	122.322348	0.16	0	-0.160	Rosing/ November 7 1995	5 -Year
152	13.627908	122.344996	0.3	0	-0.300	Rosing/ November 7 1995	5 -Year
153	13.628956	122.345908	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
154	13.593376	122.322155	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
155	13.631368	122.346356	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
156	13.593393	122.322063	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
157	13.632714	122.346703	0.82	0	-0.820	Rosing/ November 7 1995	5 -Year
158	13.593465	122.32177	0.18	0	-0.180	Rosing/ November 7 1995	5 -Year
159	13.633014	122.346861	0.76	0	-0.760	Rosing/ November 7 1995	5 -Year
160	13.593062	122.321546	0.14	0	-0.140	Rosing/ November 7 1995	5 -Year
161	13.632867	122.346682	0.69	0	-0.690	Rosing/ November 7 1995	5 -Year
162	13.592667	122.322209	0.12	0	-0.120	Rosing/ November 7 1995	5 -Year
163	13.632849	122.346791	0.8	0	-0.800	Rosing/ November 7 1995	5 -Year
164	13.592686	122.322358	0.09	0	-0.090	Rosing/ November 7 1995	5 -Year
165	13.632766	122.347126	1.33	0	-1.330	Rosing/ November 7 1995	5 -Year
166	13.592595	122.322524	0.16	0	-0.160	Rosing/ November 7 1995	5 -Year
167	13.632629	122.347259	1.23	0	-1.230	Rosing/ November 7 1995	5 -Year
168	13.592515	122.322801	0.13	0	-0.130	Rosing/ November 7 1995	5 -Year
169	13.627018	122.338195	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
170	13.59241	122.323105	0.05	0	-0.050	Rosing/ November 7 1995	5 -Year
171	13.627108	122.338122	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
172	13.627555	122.337816	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
173	13.628109	122.337401	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
174	13.62895	122.336582	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
175	13.629279	122.336199	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
176	13.629755	122.335872	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
177	13.632101	122.332508	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
178	13.632224	122.332406	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
179	13.632315	122.332145	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year
180	13.633225	122.331602	0.03	0	-0.030	Rosing/ November 7 1995	5 -Year

ANNEX 11. Educational Institutions Affected in Catanauan Flood Plain

Catanauan				
Barangay	Building	Rainfall Scenario		
		5-year	25-year	100-year
Barangay 10	Advance Technical Training Center Inc.	None	None	None
Doongan Ibaba	Day Care Center	Low	Medi-um	High
Cawayanin Ilaya	Day Care Center	None	None	None
Barangay 2	Day Care Center	None	None	None
Barangay 3	Day Care Center	None	None	None
Barangay 3	Day Care Center	None	Medi-um	High
Santa Maria	Day Care Center	None	None	None
Tagbacan Ibaba	Day Care Center	None	None	None
Santa Maria	Day Care Center	None	None	None
Cawayanin Ibaba	Day Care Center	Medium	High	High
Tagbacan Ilaya	Day Care Center	Medium	High	High
Barangay 7	Don Abadilla Elementary School	Low	Low	Low
Doongan Ilaya	Doongan Ibaba Elementary School	Medium	High	High
Santa Maria	Doongan Ilaya Elementary School	Low	Medi-um	Medium
Barangay 6	Learning Center	None	None	None
Barangay 2	M.S. Envarga University Foundation Catanauan Inc.	None	None	None
Matandang Sabang Kanluran	Matandang Sabang Silangan National High Schhol	None	None	None
Barangay 2	Paaralang Sentral ng Catanauan	Low	Low	Low
Barangay 3	Parochial School	None	None	None
San Pablo	San Roque Elementary School	None	Medi-um	Medium
Barangay 3	Southern Luzon Academy High School	None	None	None
Barangay 6	St. Benedict Play House	None	None	None
Santa Maria	Sta. Maria Elementary School	None	Medi-um	High
Cawayanin Ibaba	Tagbacan Ibaba Elementary School	None	None	None
Tagbacan Ilaya	Tagbacan Ilaya Elementary School	None	None	None
Tagbacan Ilaya	Tagbacan Ilaya National High School	High	High	High

ANNEX 12. Medical Institutions Affected in Catanauan Flood Plain

Catanauan				
Barangay	Building	Rainfall Scenario		
		5-year	25-year	100-year
Barangay 10	Bondoc Peninsula District Hospital	Low	Low	Low
Barangay 2	Health Center	None	None	None
Barangay 3	Health Center	None	None	None
Barangay 5	Health Center	None	None	None
Santa Maria	Health Center	None	None	None
Milagrosa	Health Center	None	Low	Low
San Pablo	Health Center	None	None	None
Barangay 10	Holy Family Clinic	None	None	Low
Barangay 9	Paanakan	None	None	None
Barangay 10	Specialty Clinic of Sta. Teresita	None	None	None
Barangay 5	YB DOTS Clininc/ Birthing Home Station	None	None	None