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

LiDAR Surveys and Flood Mapping of Lanang River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
Ateneo de Naga University

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ADNU	Ateneo De Naga University
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
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND THE LANANG RIVER

Enrico C. Paringit, Dr. Eng., Ms. Joanaviva Plopenio, and Engr. Ferdinand Bien

1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program entitled "Nationwide Hazard Mapping using LiDAR" or Phil-LiDAR 1 in 2014, supported by the Department of Science and Technology (DOST) Grant-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 described 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 Mindanao State University – Iligan Institute of Technology. MSU-IIT 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 15 river basins in the Northern Mindanao Region. The university is located in Iligan City, Lanao del Norte.

1.2 Overview of the Lanang River Basin

The Lanang river basin is under the jurisdiction of three (3) municipalities and one (1) component city. These are the two (2) first class municipalities namely Aroroy and Milagros, one (1) fourth class municipality, which is Baleno, and Masbate City. The DENR River Basin Control Office identified the basin to have a drainage area of 134 km2 and an estimated annual runoff of 181 million cubic meter (MCM) (RBCO, 2015). Aroroy has a population of 86,168 distributed in its 41 barangays, while Milagros has 57,473 in its 27 barangays, with Baleno having 26,096 in its 24 barangays and Masbate City with a population of 95,389 in its 30 barangays.

According to the modified Corona Classification of Climate in the Philippines, the area has a Type III climate. It experiences an even distribution of rainfall throughout the year except from November to April when it is relatively dry.

Lanang River empties out to a rather large inlet to the northern part of the Island of Masbate which consequently empties out to Masbate Pass. The length of Lanang River is approximately 92 km. The river basin is bound to the east by low-lying hills of not more than 800 mASL in height. Most of the hills have relatively better vegetation cover while some areas have poor vegetation cover. The river is in close proximity to the area mined by Filminera Resources Corporation. There are also several mining companies in Aroroy that produce gold and other minerals such as silver.

The basin's main stem, Lanang River, is part of the twenty-four (24) river systems in Bicol Region. According to the 2015 national census of NSO, a total of 8,851 persons are residing within the immediate vicinity of the river which is distributed among six (6) barangays in the municipality of Aroroy namely: Balawing, Cabangcalan, Lanang, Luy-a, Malubi and San Isidro (NSO, 2015).

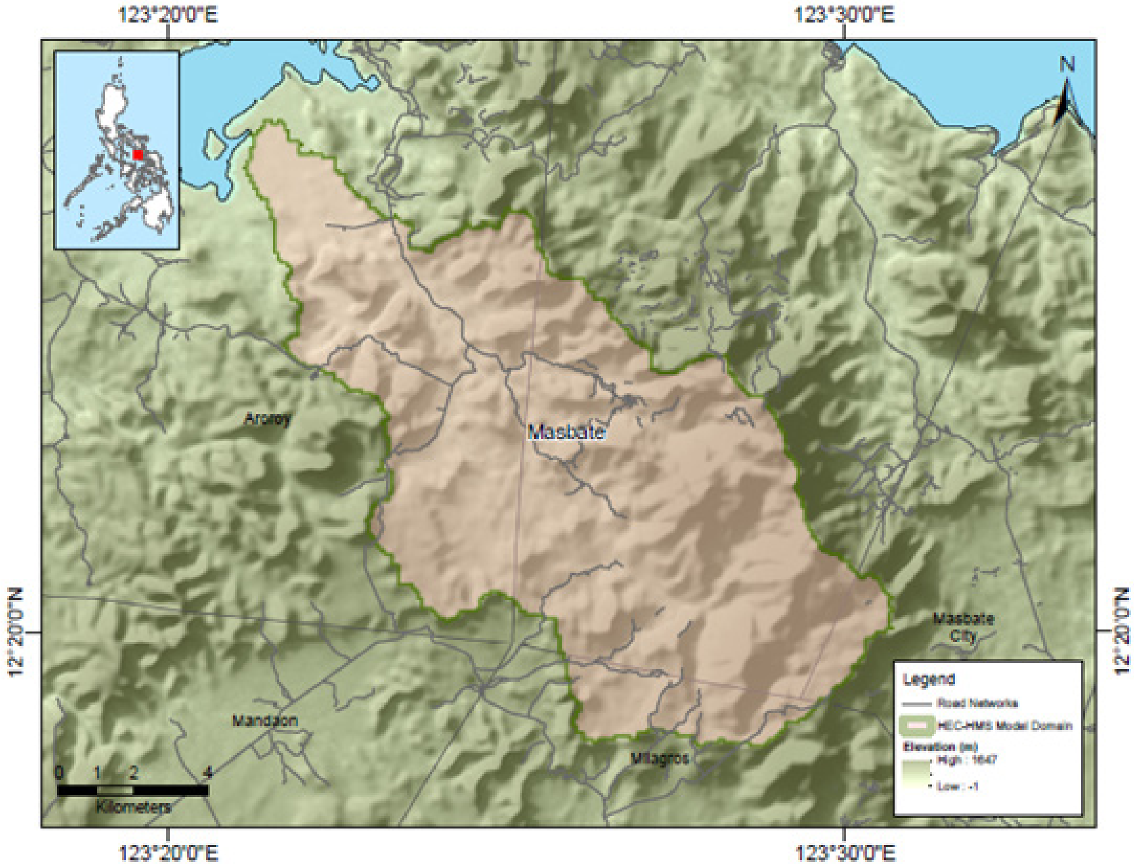


Figure 1. Map of the Lanang River Basin (in brown)

The municipality of Aroroy is known to have rich, unexploited deposits of minerals such as copper, silver, iron, manganese, copper, bauxite and gold which contributes to 60 percent of Bicol's mining receipts. Aside from mining industry, the municipality is also a top livestock producer because of their vast pasture lands for cattle swine, carabaos and goats. Their coastal communities also enjoy the benefits from their fishing grounds and the active fishing trade in their municipality (http://aroroy.masbate.gov.ph/history/, 2017). On December 2014, Typhoon Ruby, internationally known as Hagupit, entered the Philippine Area of Responsibility. Out of the 41 barangays in Aroroy, 16 barangays with 1,531 families, 8,789 individuals, were directly affected by the typhoon (http://www.ndrrmc.gov.ph/attachments/article/1356/FINAL_REPORT_re_ Effects_of_Typhoon_RUBY_(HAGUPIT)_04_-_10DEC2014.pdf, 2017).

CHAPTER 2: LIDAR DATA ACQUISITION OF THE LANANG FLOODPLAIN

Engr. Louie P. Balicanta, Engr. Christopher Cruz, Lovely Gracia Acuña, Engr. Gerome Hipolito, Ms. Sandra C. Poblete, and Engr. Grace Sinadjan

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

2.1 Flight Plans

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

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 32A	1000/1100/ 1200	25/30	50	200	30	130	5
BLK 32B	800/900/ 1000/1200	30/35	50	200	30	130	5
BLK 32C	1000/1200	30	50	200	30	130	5

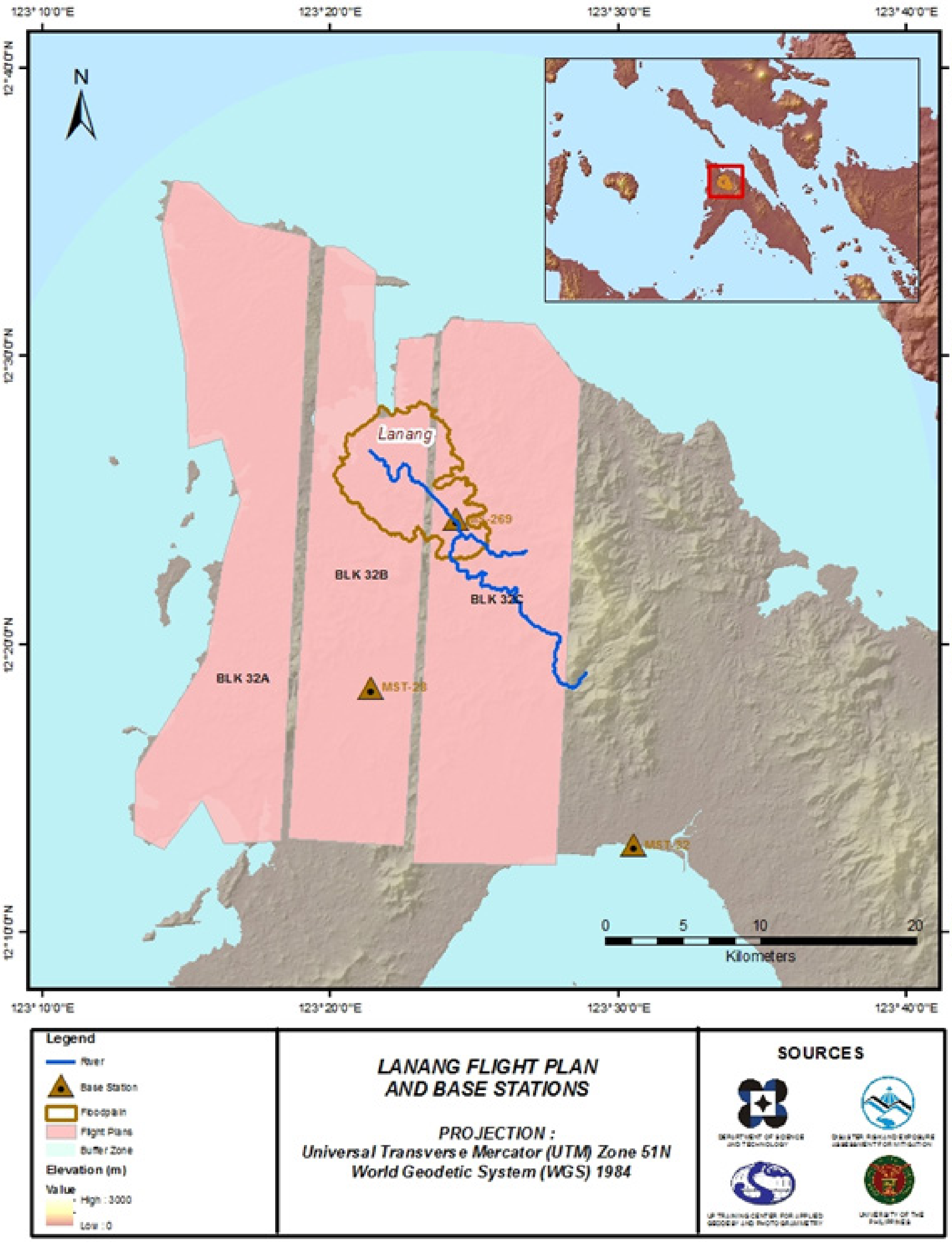


Figure 2. Flight plan and base stations used to cover Lanang Floodplain.

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA ground control points: MST-28 and MST-32 which are both of second (2nd) order accuracy. The project team also recovered one (1) benchmark, MS-269. The certification for the NAMRIA reference points are found in Annex A-2 while the baseline processing report for the benchmark is found in Annex A-3. These were used as base stations during flight operations for the entire duration of the survey (March 18 to April 11, 2014). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852 and TRIMBLE SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Lanang floodplain are shown in Figure 2.

Figure 3 to Figure 5 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 4 show the details about the following NAMRIA control stations, while Table 5 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

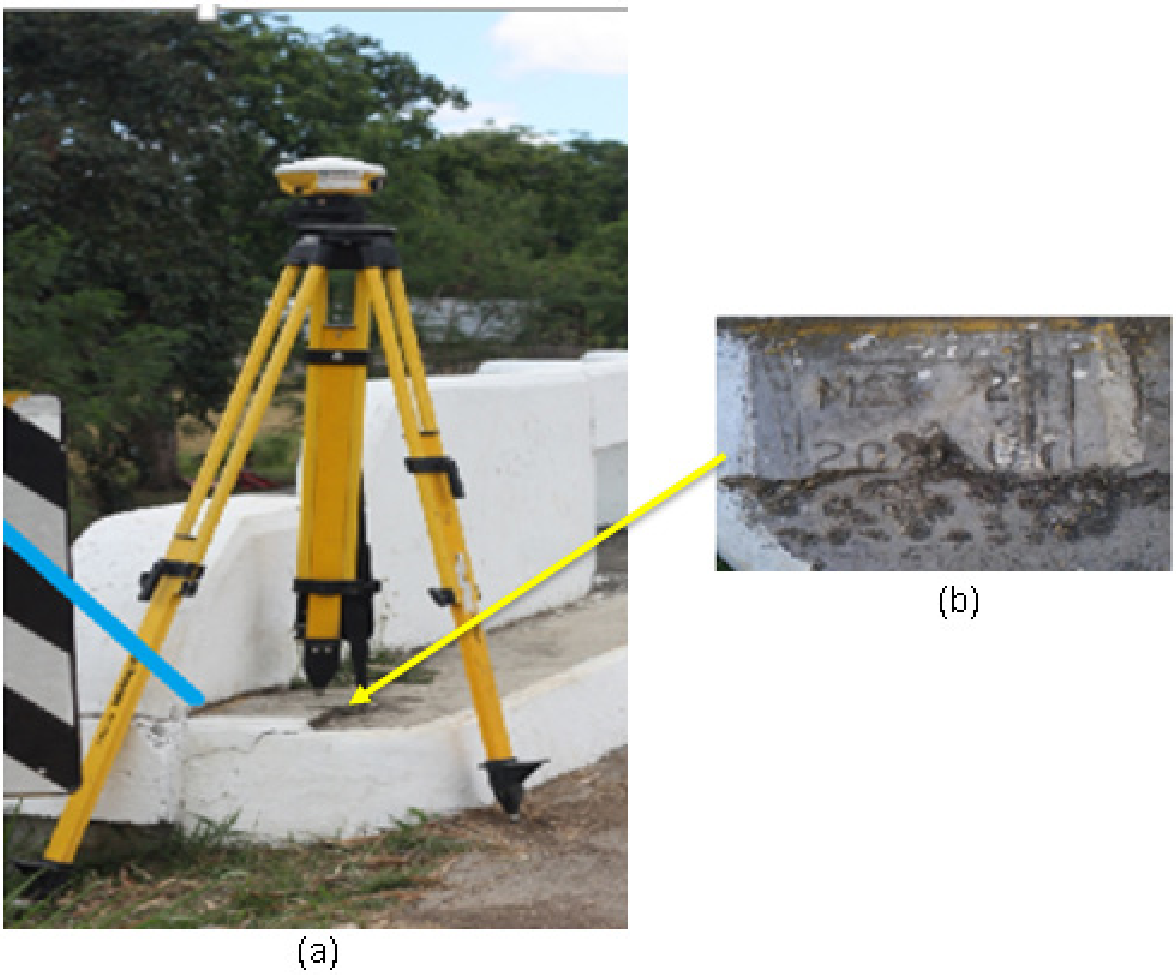


Figure 3. GPS set-up over MST-28 in Mambog Bridge, Barangay Bat-ongan, Municipality of Mandaon, Masbate (a) and NAMRIA reference point MST-28 (b) as recovered by the field team.

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

Station Name	MST-28	
Order of Accuracy	2^{nd}	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	12° 18′ 35.15371″ North
	Longitude	123° 21′ 19.21293″ East
	Ellipsoidal Height	49.128 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting	538,651.166 meters
	Northing	136,122.457 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	12° 18′ 30.47973″ North
	Longitude	123° 21′ 24.28923″ East
	Ellipsoidal Height	104.649 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	538,637.64 meters
	Northing	136,074.812 meters

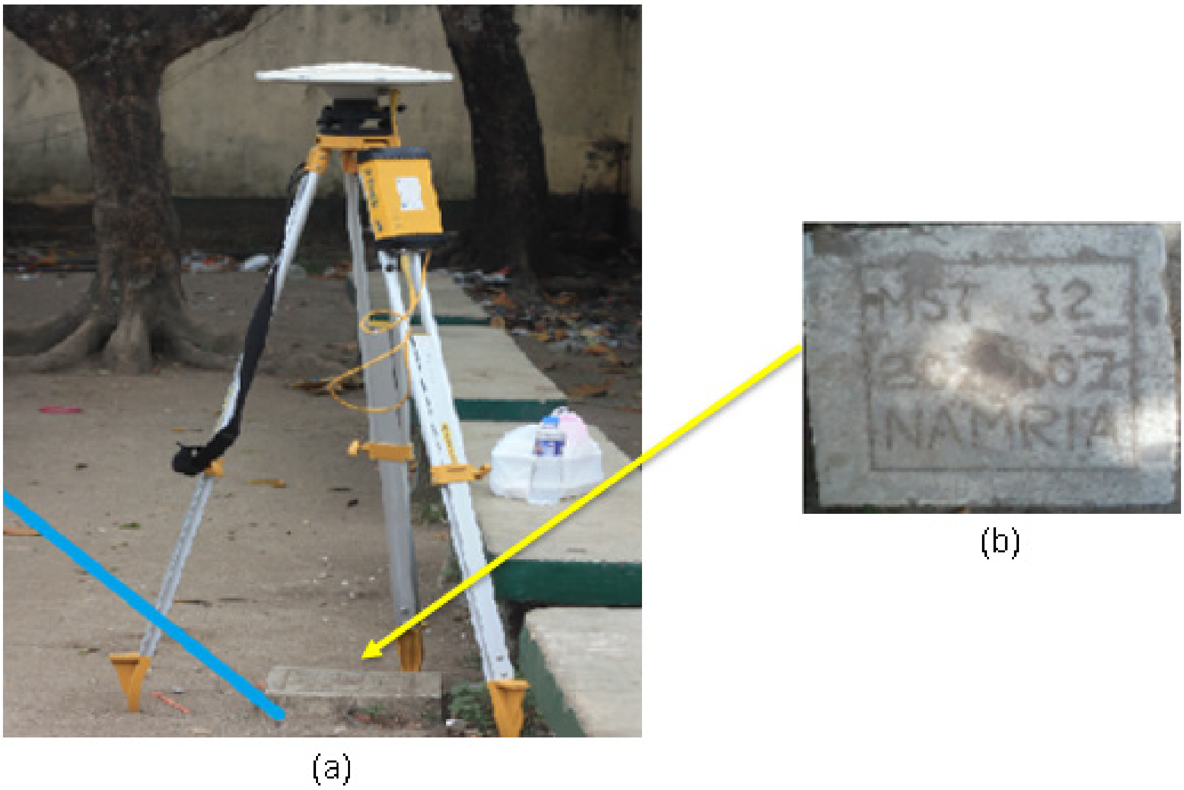
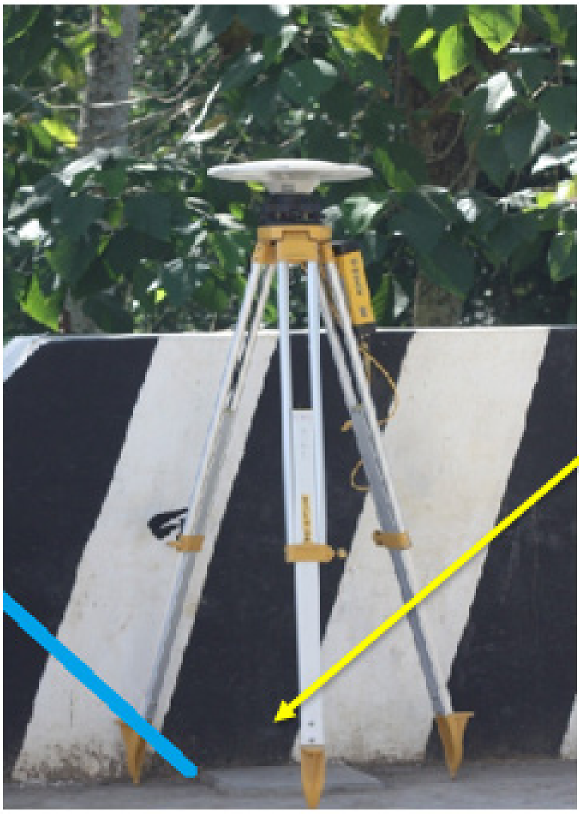


Figure 4. GPS set-up over MST-32 in Sagawsawan Bridge, Barangay Umabay Exterior, Municipality of Mobo, Masbate (a) and NAMRIA reference point MST-32 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point MST-32 used as base station for the LiDAR acquisition.

Station Name	MST-32	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	12° 13' 7.66936" North
	Longitude	123° 30' 26.72479" East
	Ellipsoidal Height	3.783 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting	555,213.396 meters
	Northing	135,118.8593 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	12° 13' 3.03064" North
	Longitude	123° 30' 31.80788" East
	Ellipsoidal Height	59.911 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	555,194.07 meters
	Northing	135,071.565 meters



(a)

(b)

Figure 5. GPS set-up over MS-269 in Luy-a Bridge in Barangay Luy-a, Municipality of Aroroy, Masbate (a) and NAMRIA reference point MS-269 (b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA benchmark MS-269 with processed coordinates used as base station for the LiDAR acquisition.

Station Name	MS-269	
Order of Accuracy	1st	
Relative Error (horizontal positioning)	1:20,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	12° 24’ 26.32173” North
	Longitude	123° 24’ 16.33349” East
	Ellipsoidal Height	27.93 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92)	Easting	543,986.60 meters
	Northing	137,202.232 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	12° 24’ 21.62786” North
	Longitude	123° 24’ 21.40082” East
	Ellipsoidal Height	83.308 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	544,123.868 meters
	Northing	190,297.142 meters

Table 5. Ground Control Points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
April 4, 2014	1303P	1BLK32A094A	MST-28; MS-269
April 4, 2014	1305P	1BLK32A094B	MST-28; MST-32
April 8, 2014	1319P	1BLK32B098A	MST-28; MS-269
April 11, 2014	1331P	1BLK32B101A	MST-28; MST-32

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Lanang floodplain, for a total of thirteen hours and thirty-two minutes (13+32) of flying time for RP-C9022. The missions were acquired using the Pegasus LiDAR system. Table 6 shows the total area of actual coverage and the corresponding flying hours per mission, while Table 7 presents the actual parameters used during the LiDAR data acquisition.

Table 6. Flight missions for LiDAR data acquisition in Lanang floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within Floodplain (km^2)	Area Surveyed Outside Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
April 4, 2014	1303P	826.23	303.74	11.46	292.28	800	3	41
April 4, 2014	1305P	272.73	237.41	0.02	237.39	326	2	59
April 8, 2014	1319P	247.35	256.23	23.84	232.39	294	4	17
April 11, 2014	1331P	247.35	128.86	28.63	100.23	460	2	35
TOTAL		1,593.66	926.24	63.95	862.29	1880	13	32

Table 7. 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)
1303P	1000/1200	30	50	200	30	130	5
1305P	1000	25	50	200	30	130	5
1319P	900	35	50	200	30	130	5
1331P	800	35	50	200	30	130	5

2.4 Survey Coverage

Lanang floodplain is located along the province of Masbate with majority of the floodplain situated within the municipality of Aroroy. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 8. The actual coverage of the LiDAR acquisition for Lanang floodplain is presented in Figure 6.

Table 8. List of municipalities and cities surveyed during Lanang floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/ City (km^2)	Total Area Surveyed (km^2)	Percentage of Area Surveyed
Masbate	Aroroy	403.62	345.77	85.67%
	Mandaon	267.43	195.2	72.99%
	Baleno	200.24	28.15	14.06%
	Milagros	530.43	69.62	13.13%
	Masbate City	192.96	3.21	1.66%
Total		1594.68	641.95	40%

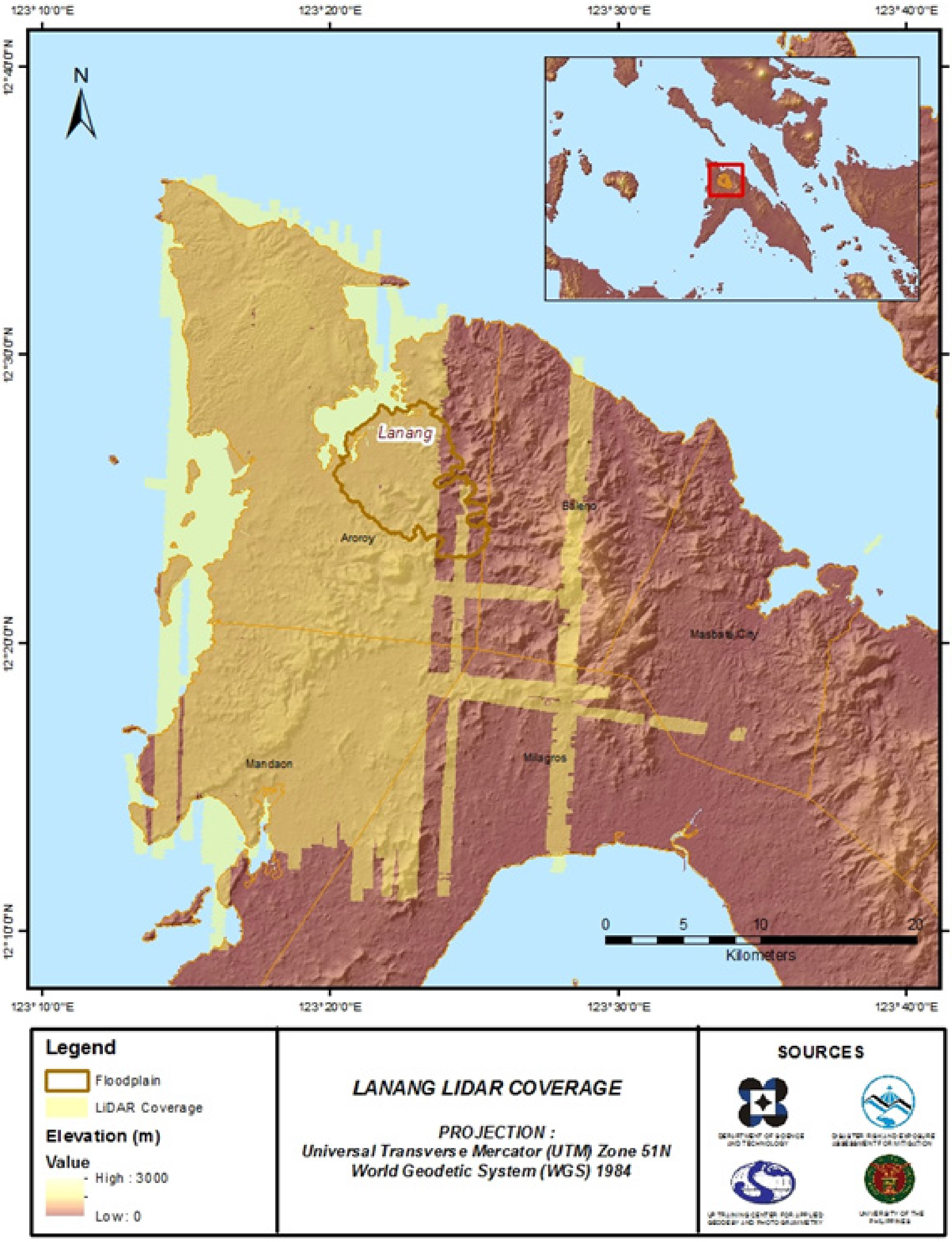


Figure 6. Actual LiDAR data acquisition of the Lanang floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE LANANG FLOODPLAIN

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Gladys Mae Apat , Engr. Harmond F. Santos , Engr. Ma. Ailyn L. Olanda, Engr. Justine Y. Francisco, Engr. Christy T. Lubiano , Jerry P. Ballori, Jaylyn L. Paterno, Engr. Ferdinand E. Bien,Richmund P. Saldo Arnulfo G. Enciso Jr.,Carlota M. Davocol,Engr. Kevin Kristian L. Penaserada, Engr. Jan Karl T. Ilarde Engr. Francis Patray P. Bolanos, Engr. Jayrik T. San Buenaventura, and Engr. Jess Andre S. Soller

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 7.

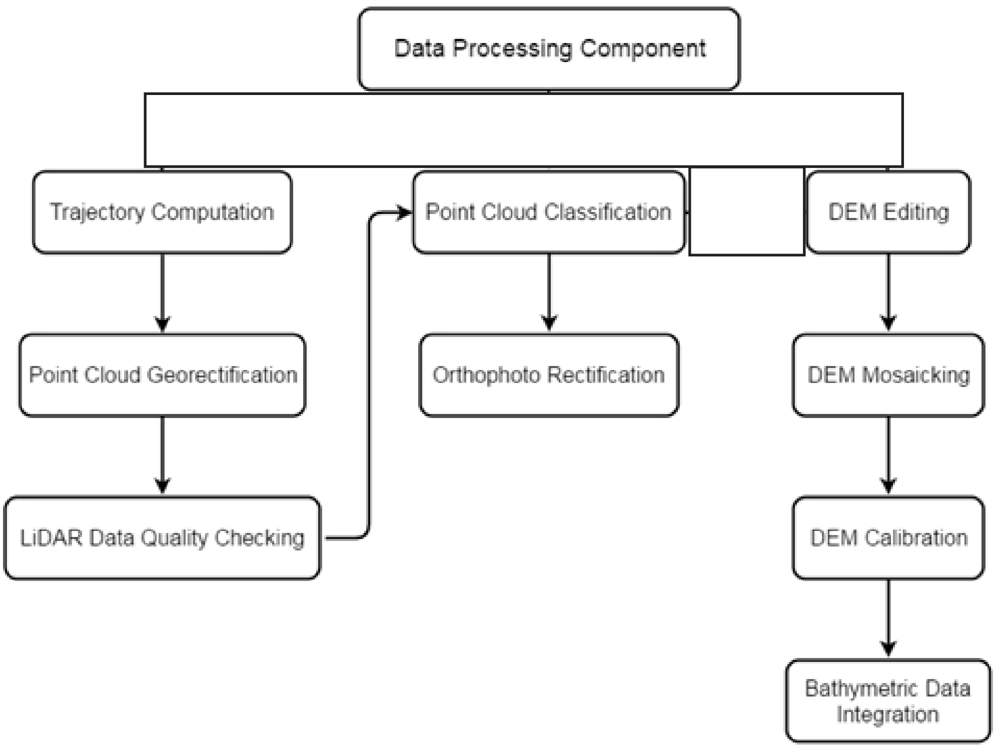


Figure 7. Schematic Diagram for Data Pre-Processing Component.

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Lanang floodplain can be found in Annex G (Data Transfer Sheets). Missions flown during the first survey conducted last April 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system while the second survey was done last February 2017 using the Leica system over Aroroy, Masbate. The Data Acquisition Component (DAC) transferred a total of 106.7 Gigabytes of Range data, 767 Megabytes of POS data, 22.38 Megabytes of GPS base station data, and 144.3 Gigabytes of Image data to the data server on April 11, 2014 for Optech LiDAR systems while a total of 3.63 Gigabytes of RawLaser data, 226 Megabytes of GNSSIMU data, 51.3 Megabytes of base station data and 19.5 Gigabytes of RCD30 raw image data were transferred on February 8, 2017 for Leica LiDAR system. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Lanang was fully transferred on February 22, 2017, as indicated on the Data Transfer Sheets for Lanang floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 1319P, one of the Lanang flights, which is the North, East, and Down position RMSE values are shown in Figure 8. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on April 8, 2014 00:00AM. The y-axis represents the RMSE value for that particular position.

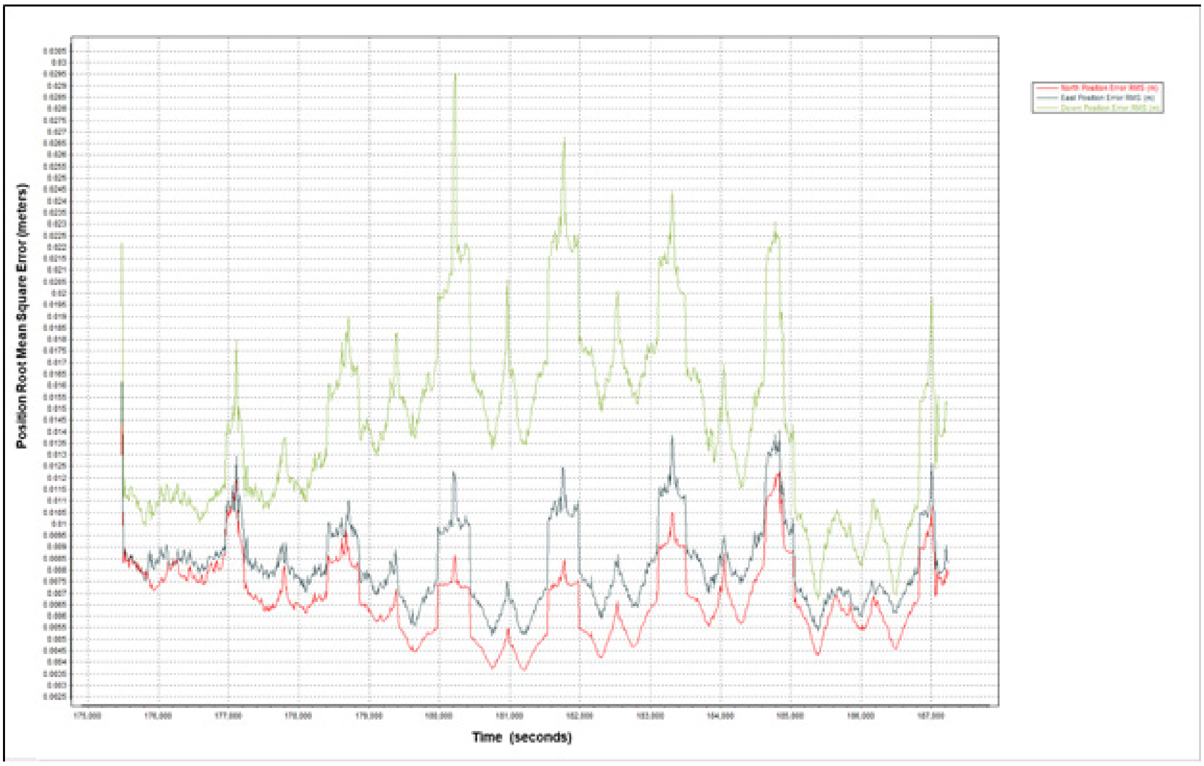


Figure 8. Smoothed Performance Metric Parameters of a Lanang Flight 1319P.

The time of flight was from 175400 seconds to 187200 seconds, which corresponds to morning of April 8, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 8 shows that the North position RMSE peaks at 1.20 centimeters, the East position RMSE peaks at 1.40 centimeters, and the Down position RMSE peaks at 2.95 centimeters, which are within the prescribed accuracies described in the methodology.

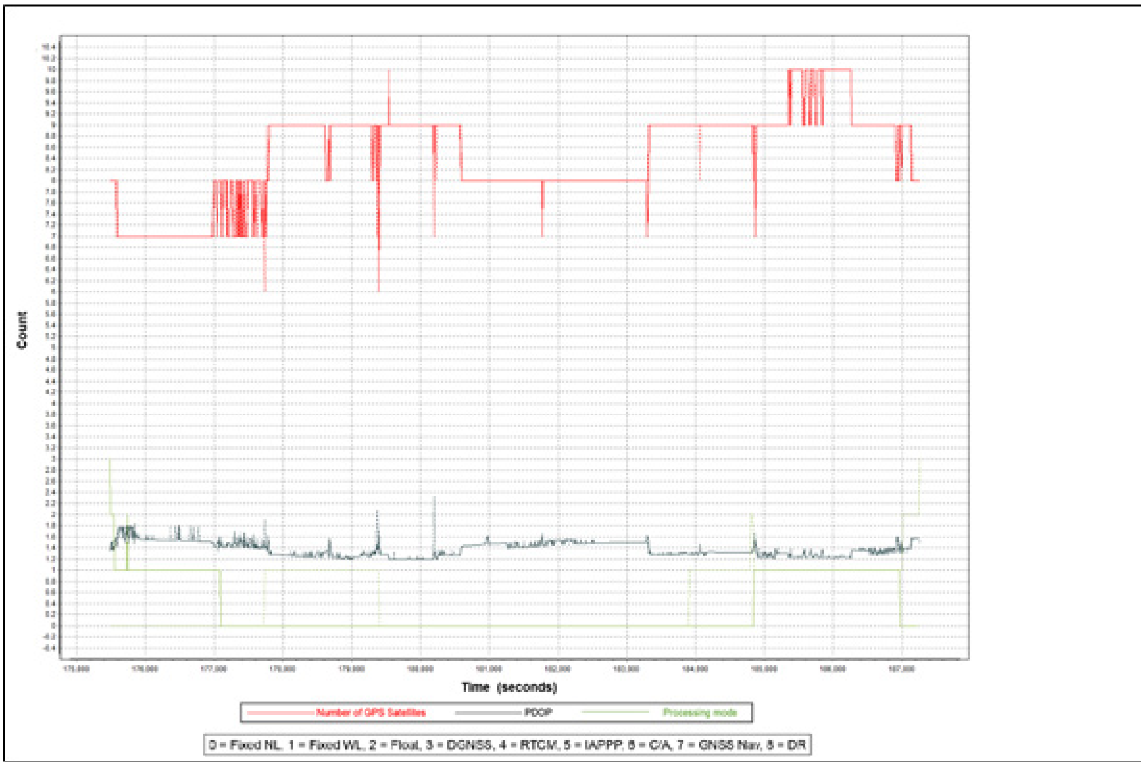


Figure 9. Solution Status Parameters of Lanang Flight 1319P.

The Solution Status parameters of flight 1319P, one of the Lanang flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 9. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 2 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 Lanang flights is shown in Figure 10.

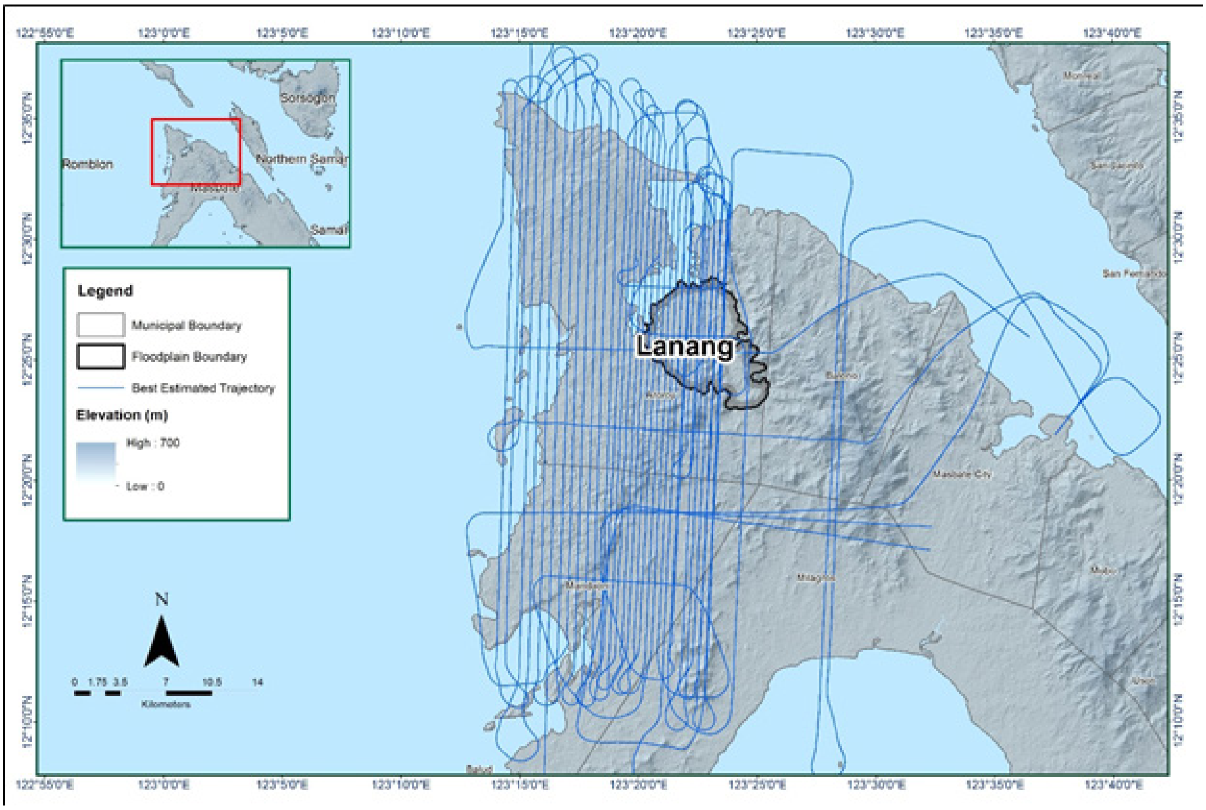


Figure 10. Best Estimated Trajectory for Lanang floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 59 flight lines, with each flight line containing two channels, since the Pegasus and Leica systems both contain two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Lanang floodplain are given in Table 9.

Table 9. Self-Calibration Results values for Lanang flights.

Parameter	Value	
Boresight Correction stdev	(<0.001degrees)	0.000416
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000422
GPS Position Z-correction stdev	(<0.01meters)	0.0061

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

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Lanang Floodplain is shown in Figure 11. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

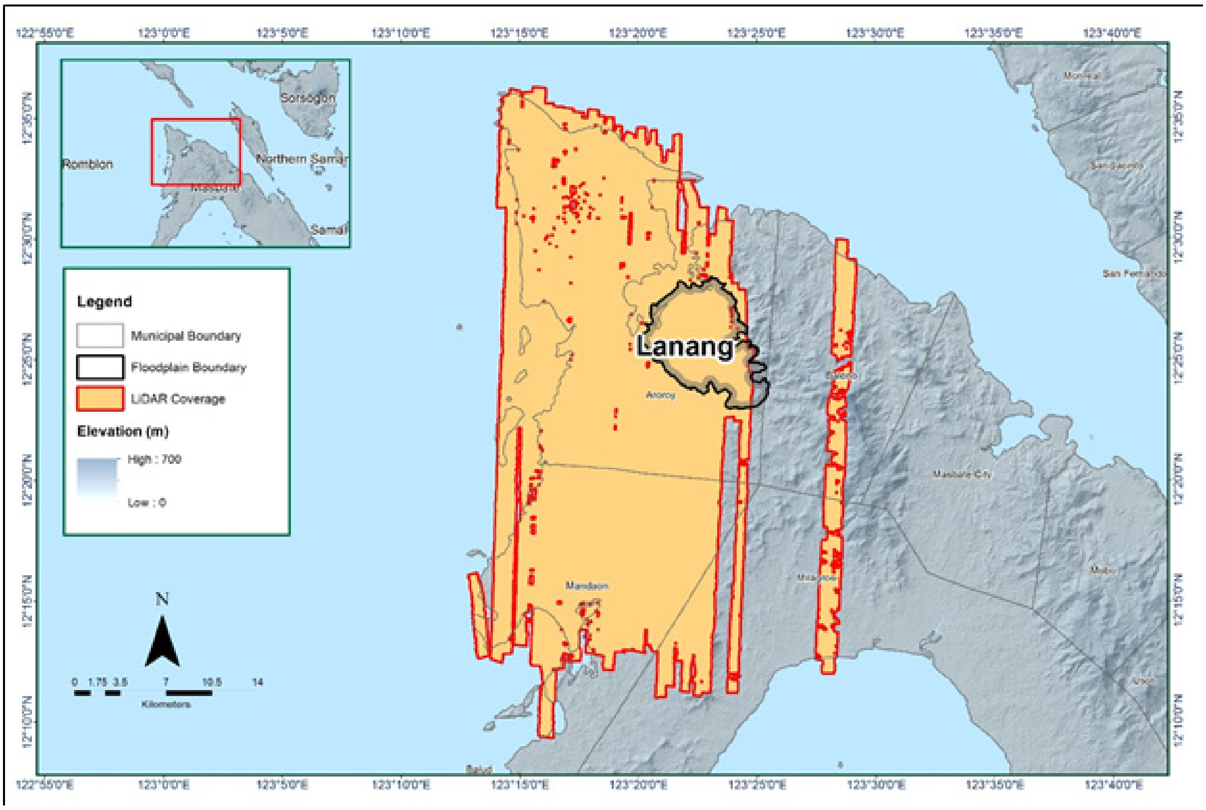


Figure 11. Boundary of the processed LiDAR data over Lanang Floodplain

The total area covered by the Lanang missions is 828.67 sq.km that is comprised of five (5) flight acquisitions grouped and merged into four (4) blocks as shown in Table 10.

Table 10. List of LiDAR blocks for Lanang floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Masbate_Blk32A	1305P	466.03
	1303P	
Masbate_Blk32A_additional	1305P	11.61
Masbate_Blk32B	1319P	324.74
	1331P	
	1303P	
Masbate_reflights_Blk32B	10337L	26.29
	TOTAL	**828.67 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 12. Since the Pegasus and Leica systems both employ 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.

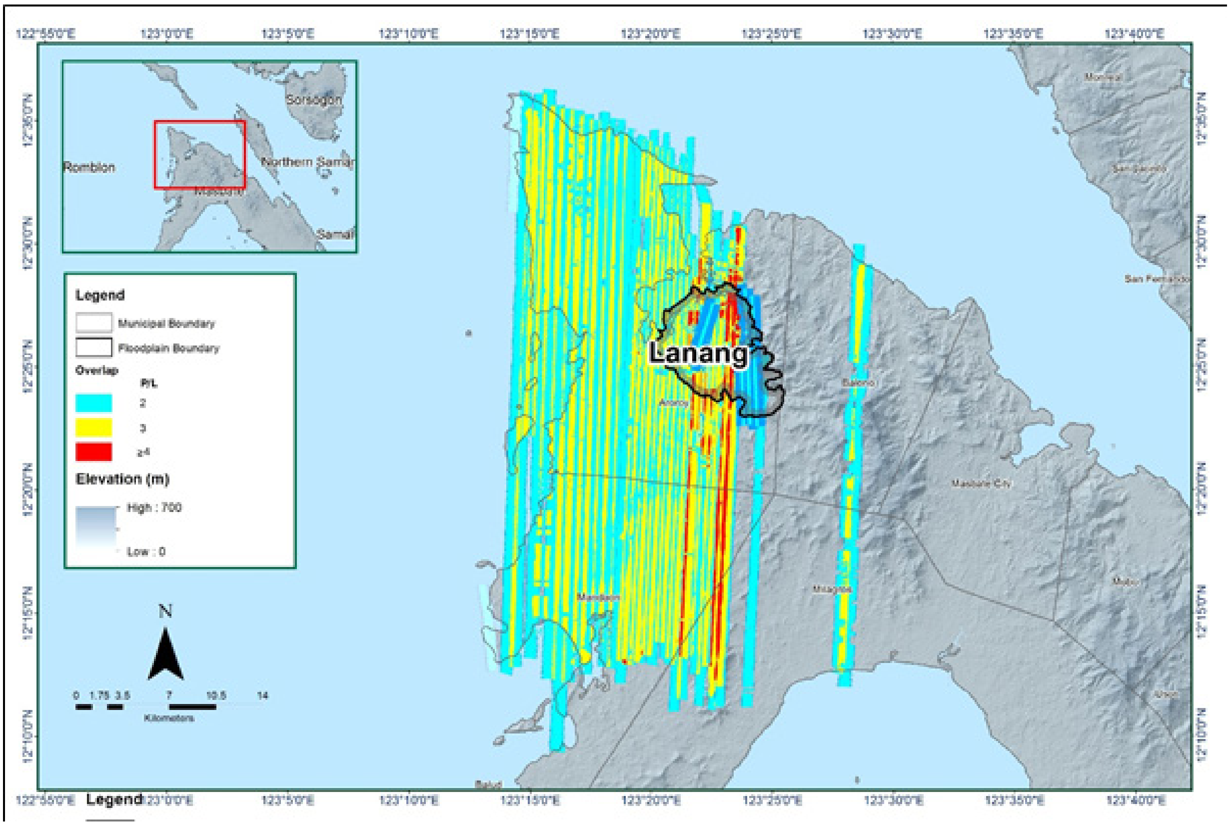


Figure 12. Image of data overlap for Lanang floodplain.

The overlap statistics per block for the Lanang floodplain can be found in Annex E. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 35.60% and 61.52% respectively, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 13. It was determined that all LiDAR data for Lanang floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.42 points per square meter.

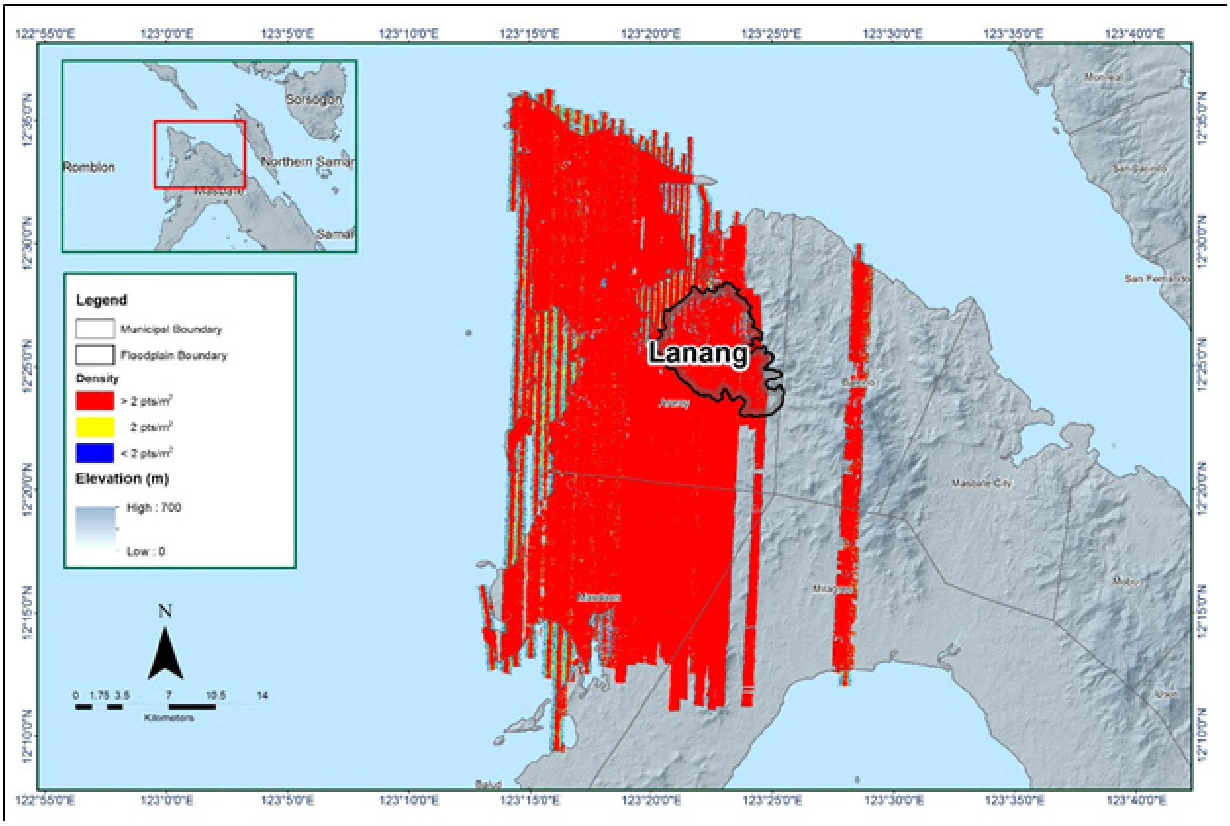


Figure 13. Pulse density map of merged LiDAR data for Lanang floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 14. 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.

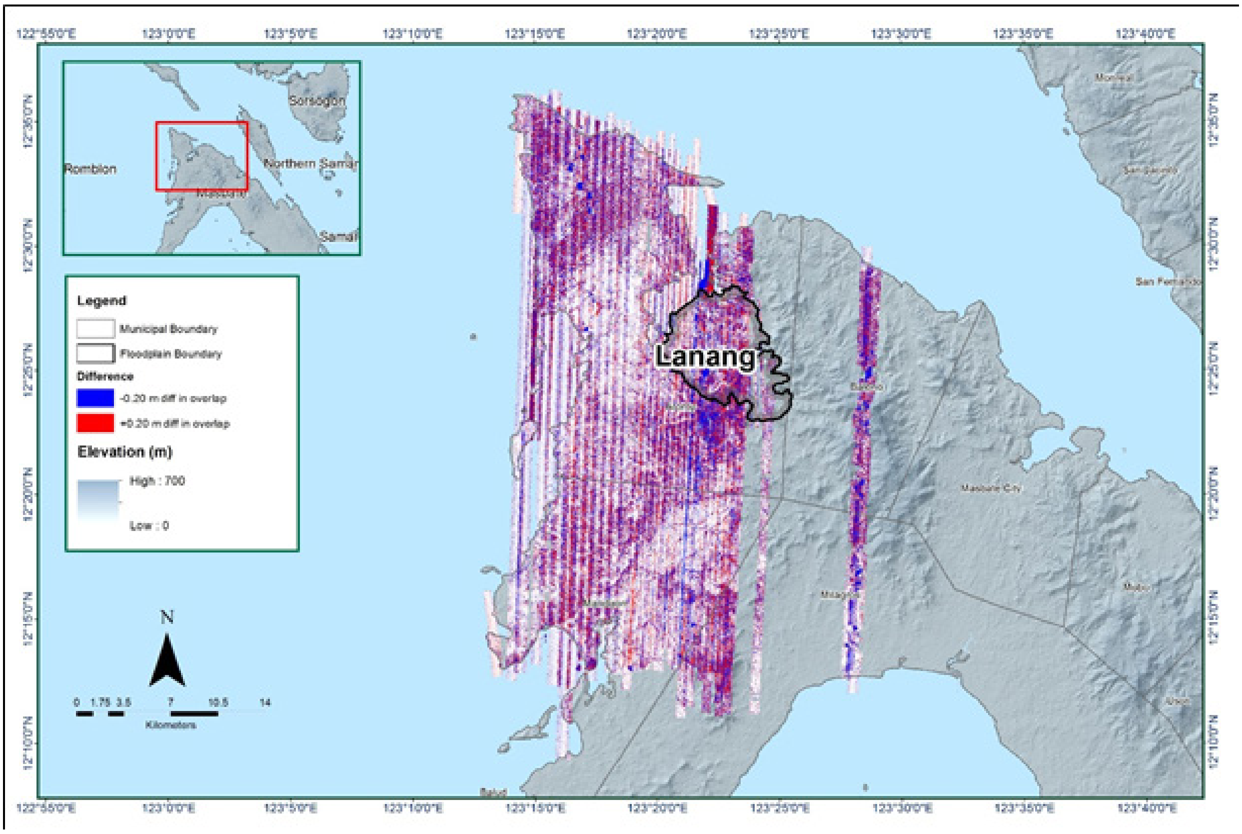


Figure 14. Elevation difference map between flight lines for Lanang floodplain.

A screen capture of the processed LAS data from a Lanang flight 1319P loaded in QT Modeler is shown in Figure 15. 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.

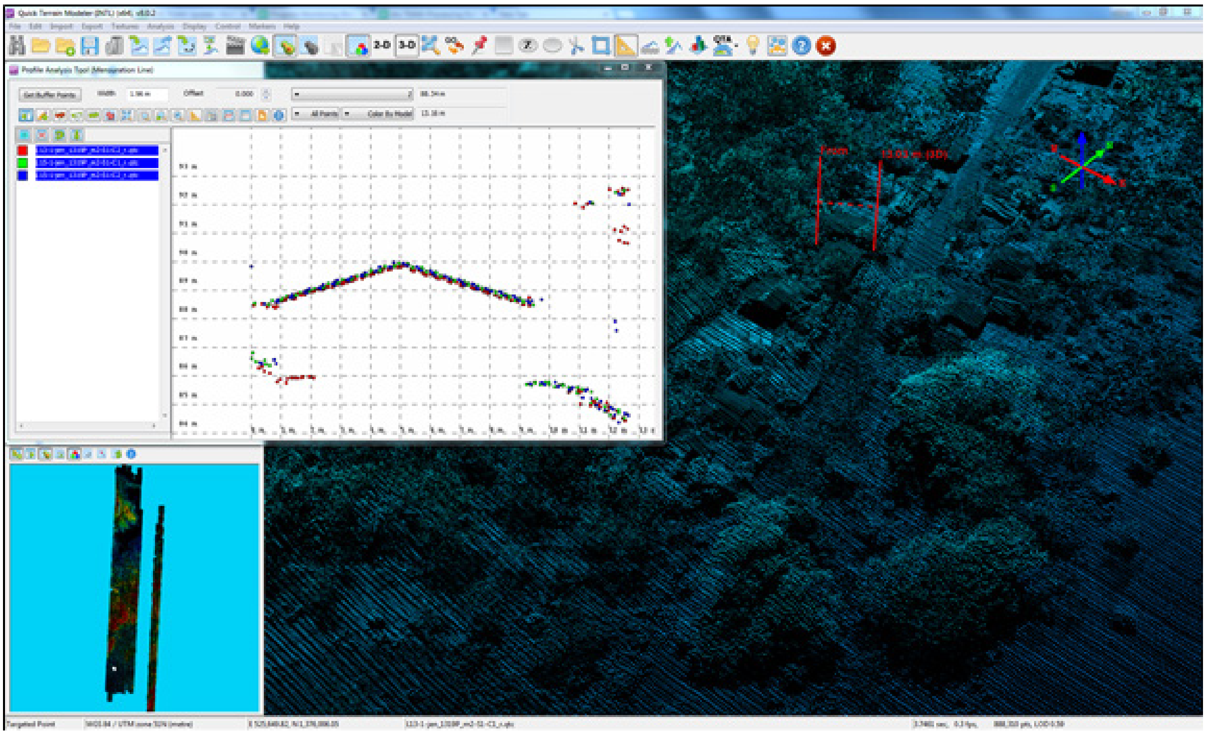


Figure 15. Quality checking for a Lanang flight 1319P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Lanang classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	600,455,011
Low Vegetation	452,670,633
Medium Vegetation	444,040,393
High Vegetation	262,953,915
Building	4,964,115

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Lanang floodplain is shown in Figure 16. A total of 1,149 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 11. The point cloud has a maximum and minimum height of 710.95 meters and 8.45 meters respectively.

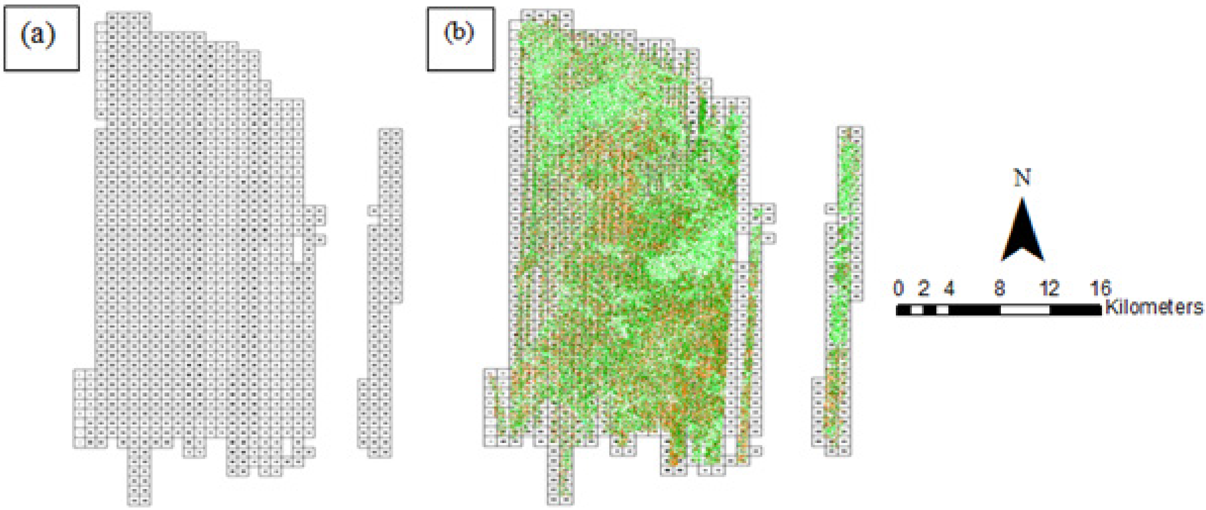


Figure 16. Tiles for Lanang floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 17. 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.

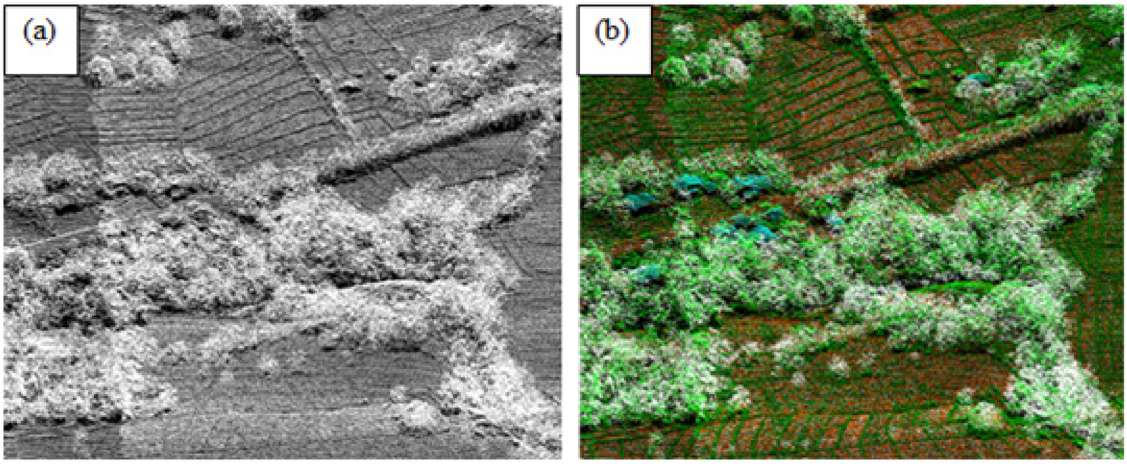


Figure 17. Point cloud before (a) and after (b) classification.

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 18. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

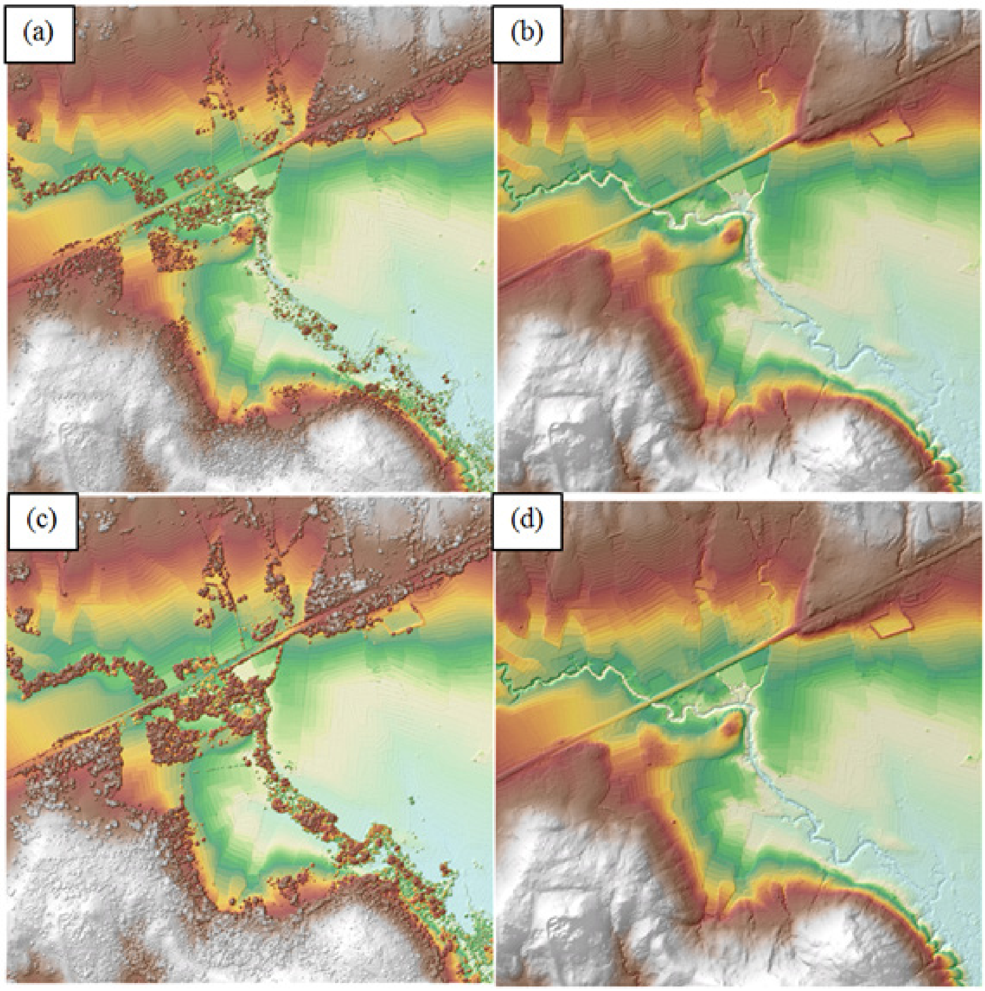


Figure 18. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Lanang floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 692 1km by 1km tiles area covered by Lanang floodplain is shown in Figure 19. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Lanang floodplain has a total of 488.60 sq.km orthophotogaph coverage comprised of 1,387 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 20.

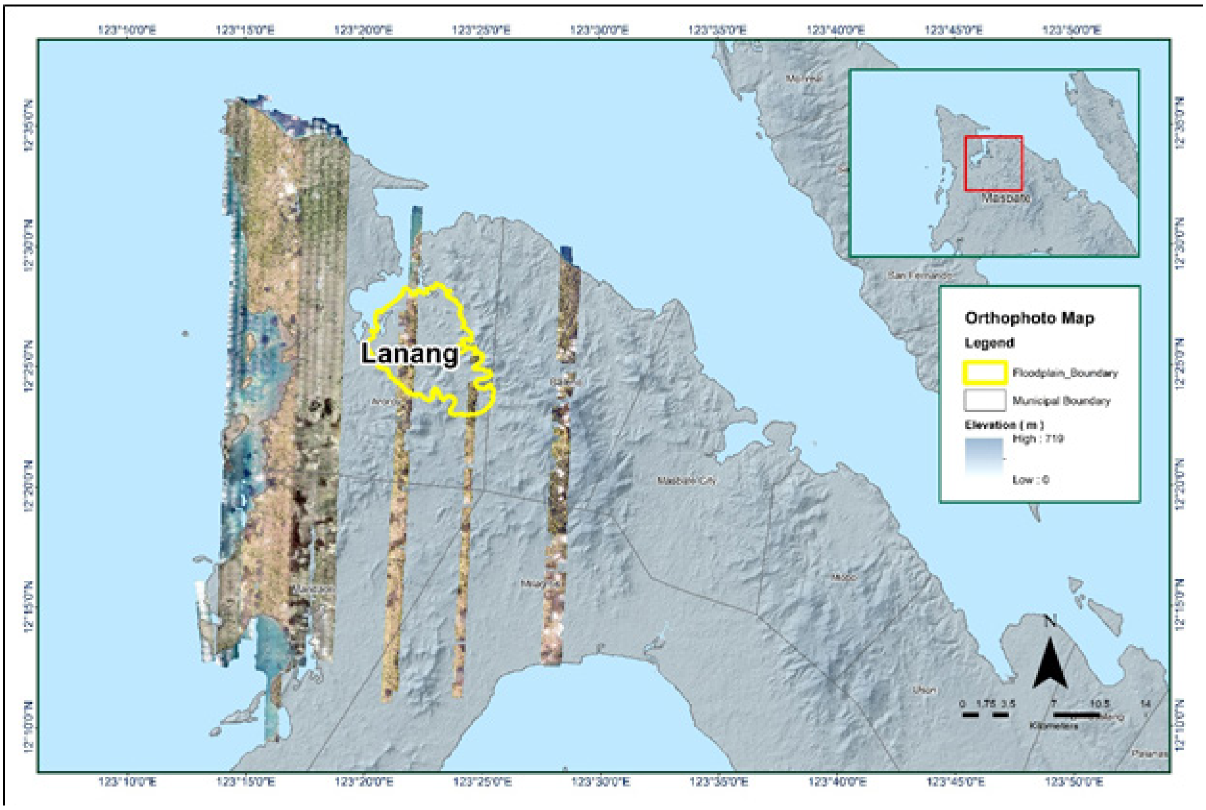


Figure 19. Lanang floodplain with available orthophotographs.

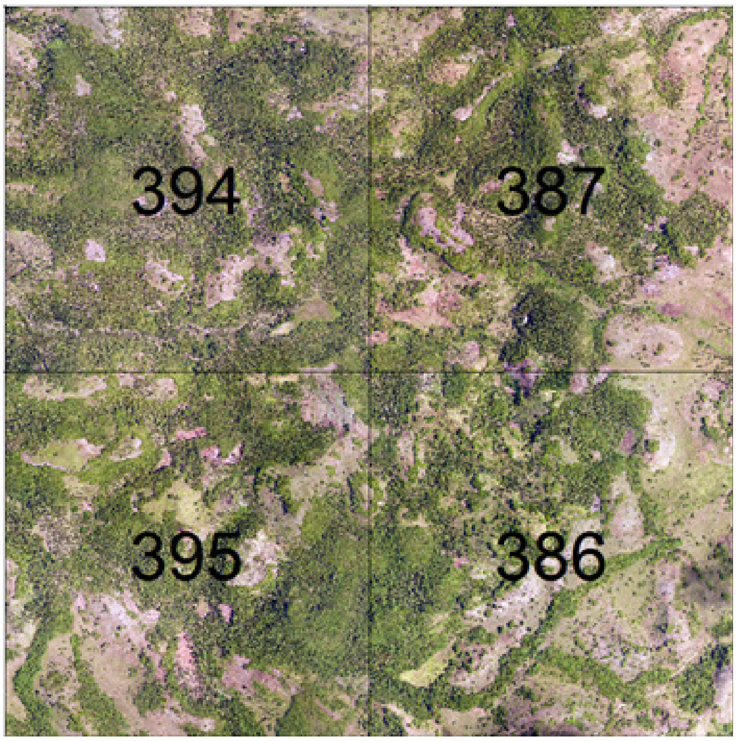


Figure 20. Sample orthophotograph tiles for Lanang floodplain.

3.8 DEM Editing and Hydro-Correction

Four (4) mission blocks were processed for Lanang flood plain. These blocks are composed of Masbate and Masbate reflights blocks with a total area of 828.67 square kilometers. Table 12 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
Masbate_Blk32A	466.03
Masbate_Blk32A_additional	11.61
Masbate_Blk32B	324.74
Masbate_reflights_Blk32B	26.29
TOTAL	**828.67 sq. km**

Portions of DTM before and after manual editing are shown in Figure 21. The bridge (Figure 21a) is considered to be an impedance to the flow of water along the river and has to be removed (Figure 21b) in order to hydrologically correct the river. An elevated area (Figure 21c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 21d) to allow the correct flow of water.

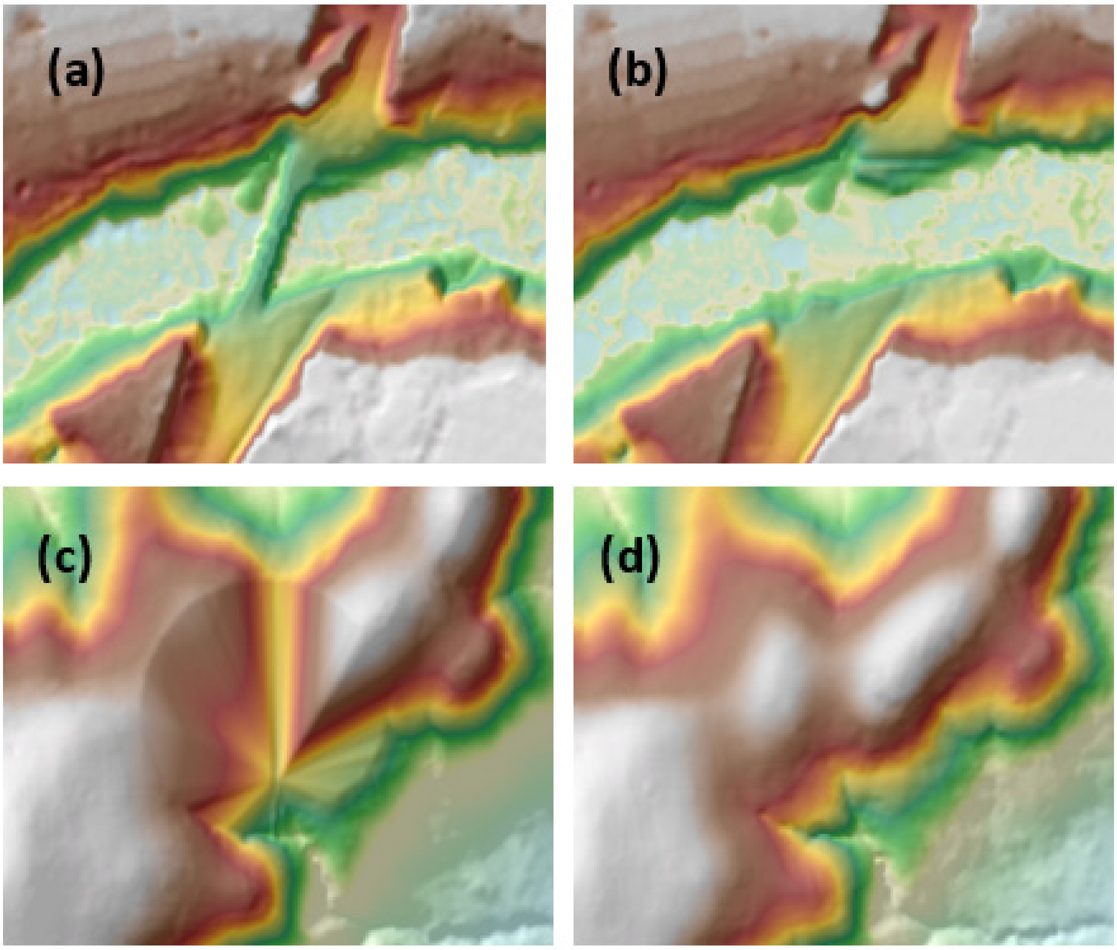


Figure 21. Portions in the DTM of Lanang floodplain – a bridge before (a) and after (b) manual editing; and an elevated area before (c) and after (d) data retrieval.

3.9 Mosaicking of Blocks

Masbate_Blk32A was used as the reference block at the start of mosaicking because it was referred to a base station with an acceptable order of accuracy. Table 13 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Lanang floodplain is shown in Figure 22. It can be seen that the entire Lanang floodplain is 93.70% covered by LiDAR data.

Table 13. Shift Values of each LiDAR Block of Lanang floodplain.

Mission Blocks	Shift Values (meters)		
	x	y	z
Masbate_Blk32A	0.00	0.00	0.00
Masbate_Blk32A_additional	0.00	0.00	0.00
Masbate_Blk32B	0.00	0.00	0.00
Masbate_reflights_Blk32B	1.50	0.50	0.08

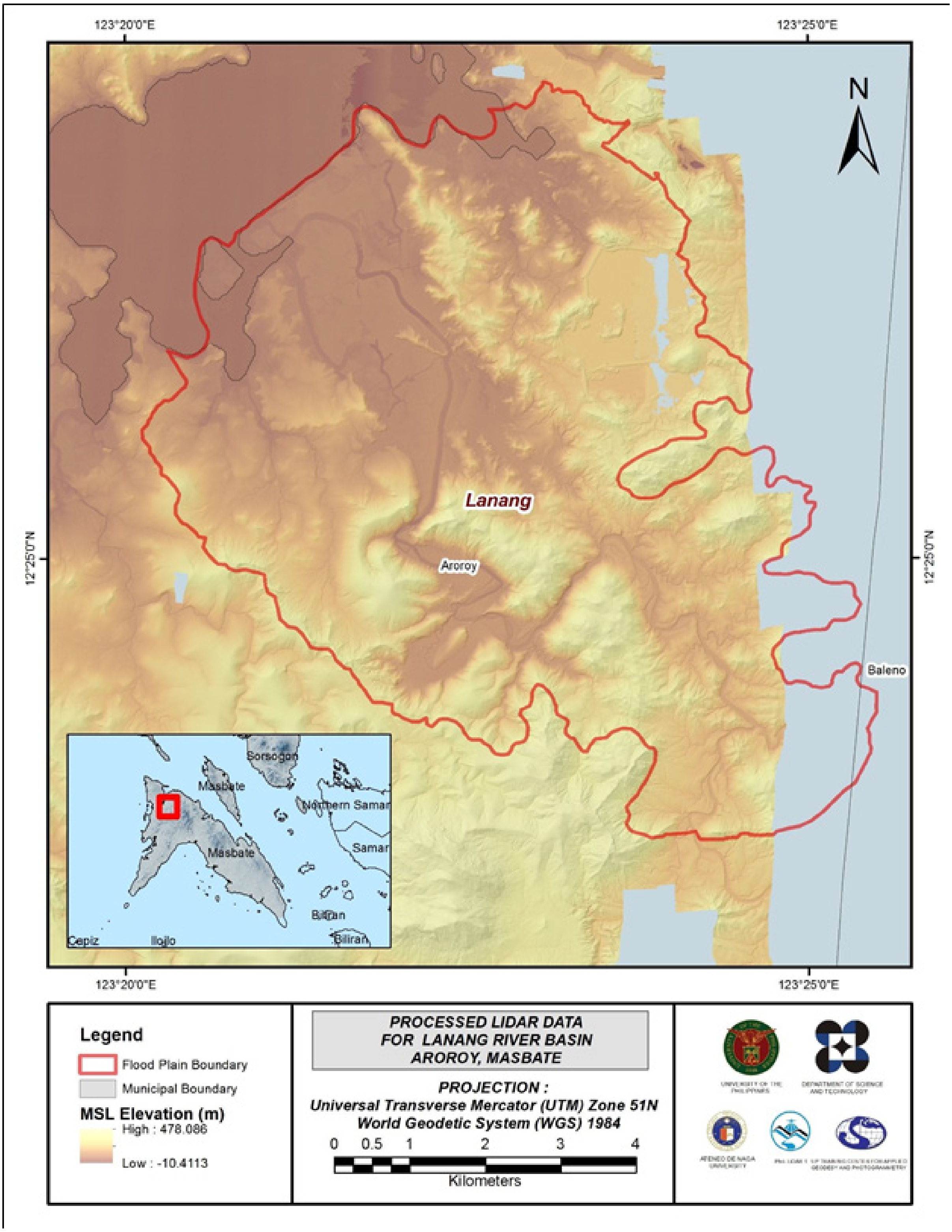


Figure 22. Map of Processed LiDAR Data for Lanang Flood Plain..

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 Lanang to collect points with which the LiDAR dataset is validated is shown in Figure 23. A total of 1,135 survey points were used for calibration and validation of Lanang LiDAR data. Random selection of 80% of the survey points, resulting to 1,087 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 24. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 5.33 meters with a standard deviation of 0.15 meters. Calibration of Lanang LiDAR data was done by subtracting the height difference value, 5.33 meters, to Lanang mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

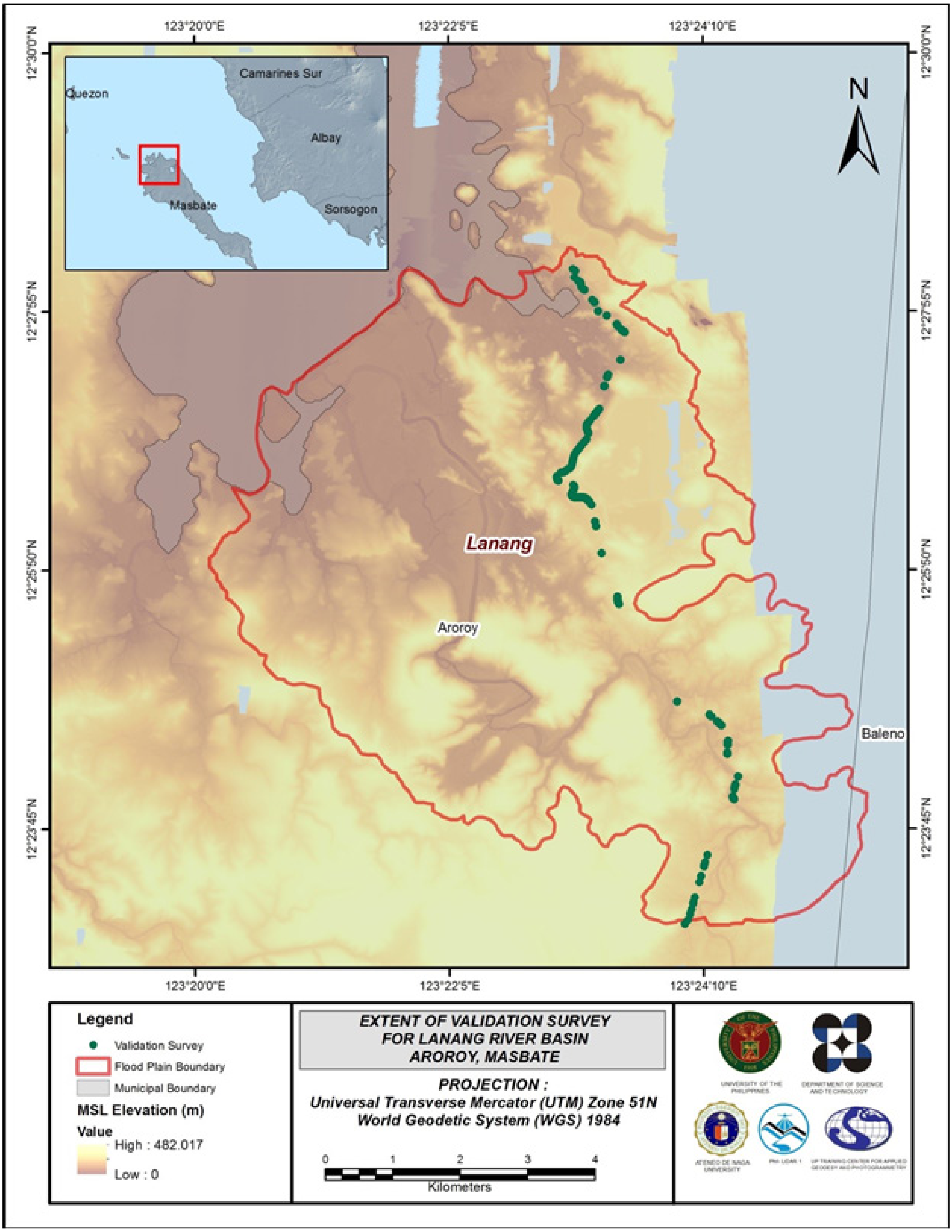


Figure 23. Map of Lanang Floodplain with validation survey points in green.

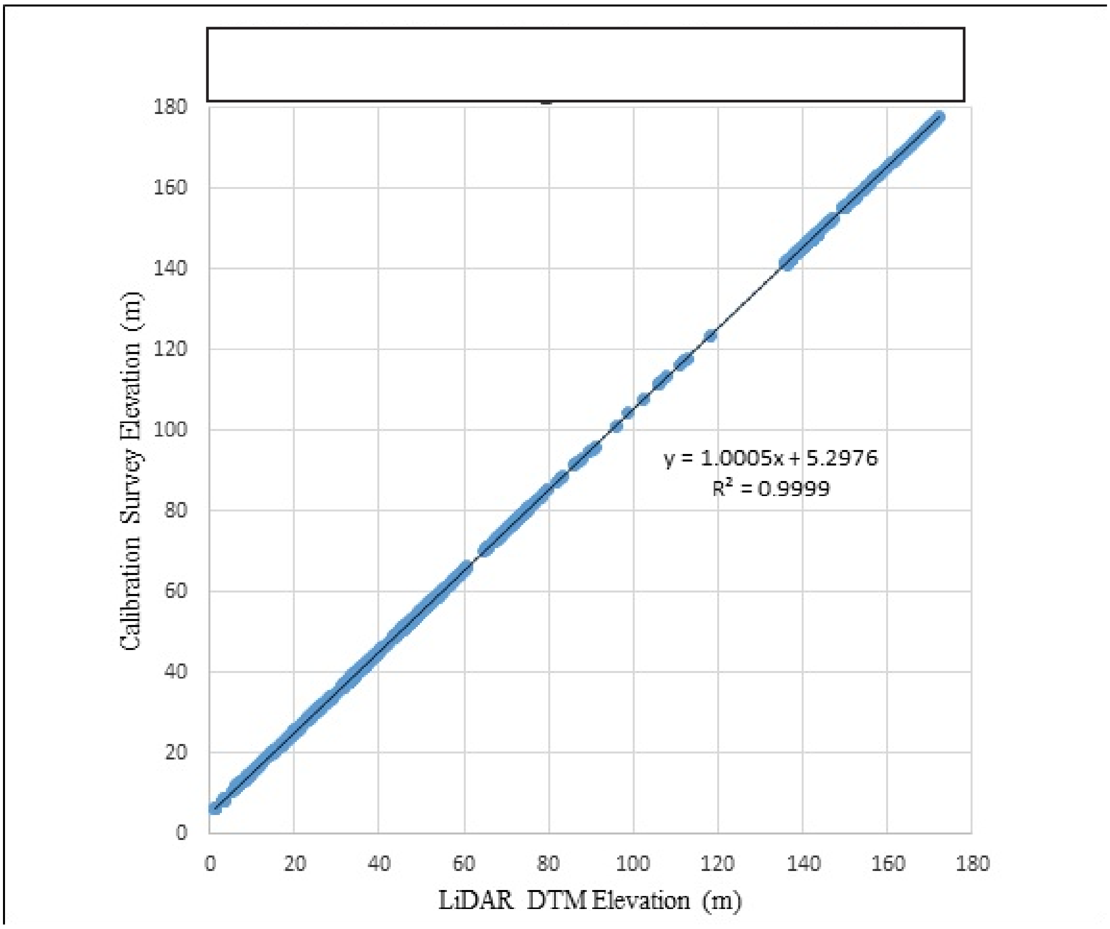


Figure 24. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	5.33
Standard Deviation	0.15
Average	-5.33
Minimum	-5.63
Maximum	-5.03

The remaining survey points that fall within the floodplain boundary, resulting to 302 points, were used for the validation of calibrated Lanang 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 25. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.16 meters with a standard deviation of 0.16 meters, as shown in Table 15.

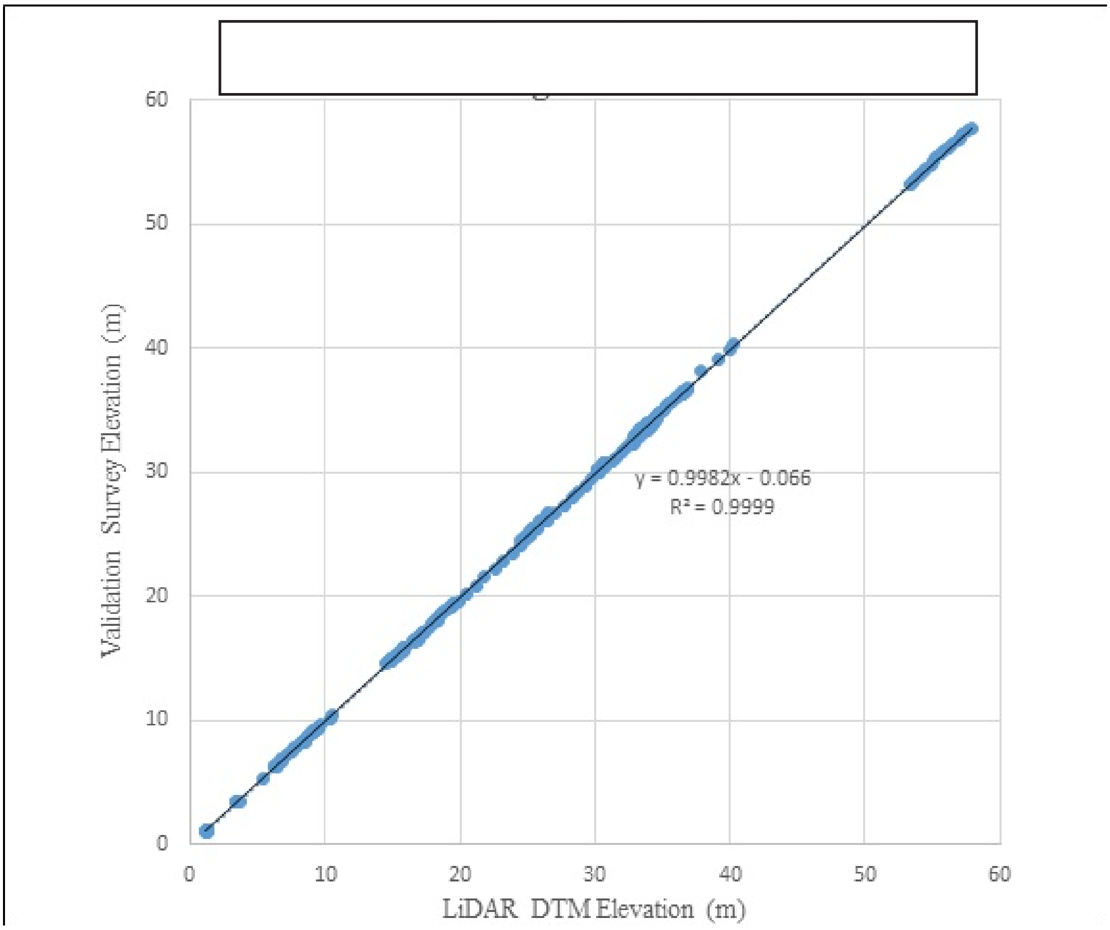


Figure 25. Correlation plot between validation survey points and LiDAR data.

Table 15. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.16
Average	0.11
Minimum	-0.25
Maximum	0.45

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data was available for Lanang with 12,264 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 0.433 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Lanang integrated with the processed LiDAR DEM is shown in Figure 26.

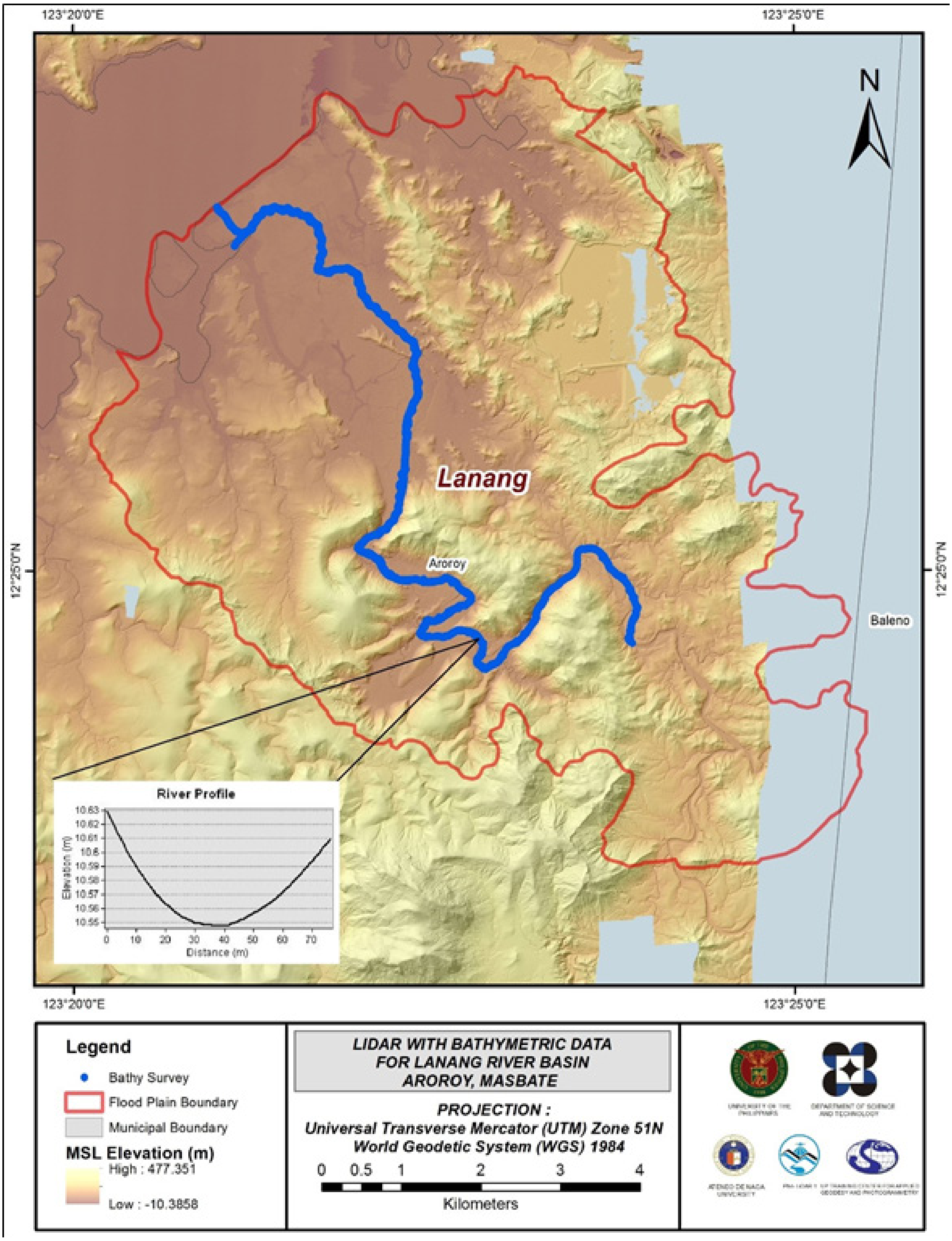


Figure 26. Map of Lanang Floodplain with bathymetric survey points in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Lanang floodplain, including its 200 m buffer, has a total area of 66.46 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 935 building features, are considered for QC. Figure 27 shows the QC blocks for Lanang floodplain.

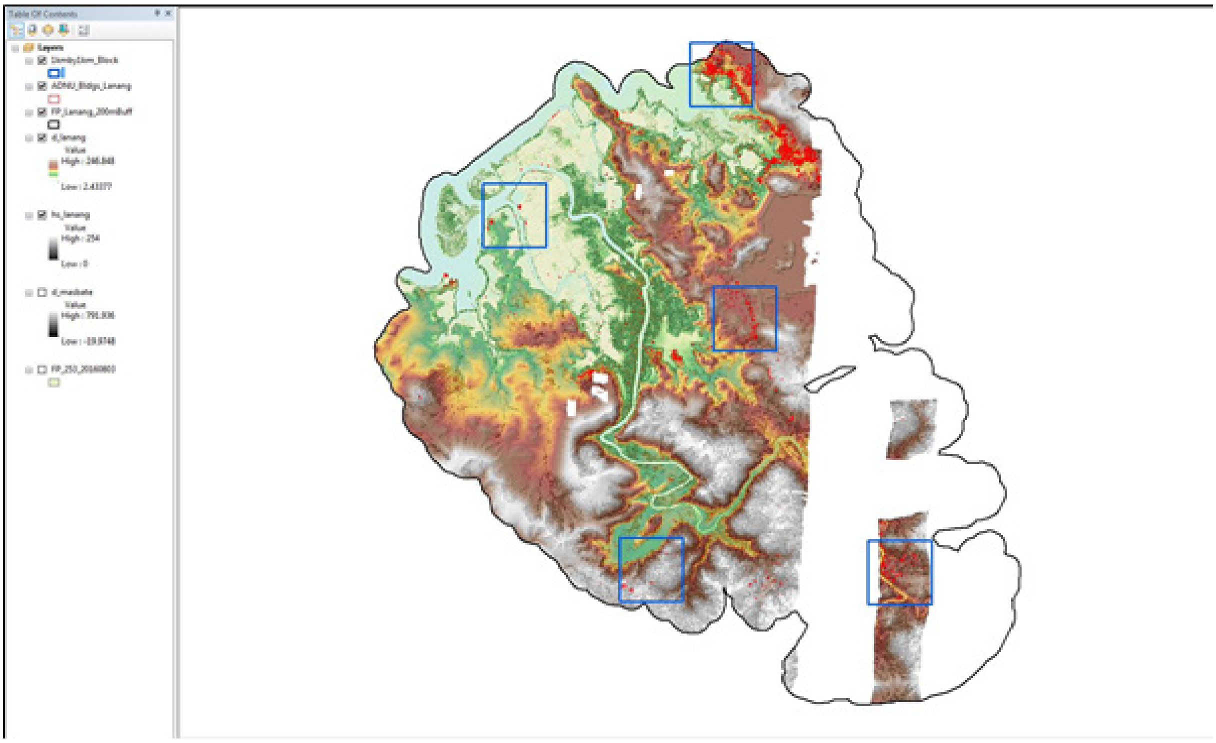


Figure 27. QC blocks for Lanang building features.

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

Table 16. Quality Checking Ratings for Lanang Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Lanang	97.61	95.94	93.48	PASSED

3.12.2 Height Extraction

Height extraction was done for 1,441 building features in Lanang floodplain. Of these building features, 2 were filtered out after height extraction, resulting to 1,439 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 4.96 m.

3.12.3 Feature Attribution

Feature Attribution was done for 1,439 building features in Lanang Floodplain with the use of participatory mapping and innovations. The approach used in participatory mapping undergoes the creation of feature extracted maps in the area and presenting spatial knowledge to the community with the premise that the local community in the area are considered experts in determining the correct attributes of the building features in the area.

The innovation used in this process is the creation of an android application called reGIS. The Resource Extraction for Geographic Information System (reGIS) (Resource Extraction for Geographic Information System (reGIS), 17 March 2015) app was developed to supplement and increase the field gathering procedures being done by the AdNU Phil-LiDAR 1. The Android application allows the user to automate some procedures in data gathering and feature attribution to further improve and accelerate the geotagging process. The app lets the user record the current GPS location together with its corresponding exposure features, code, timestamp, accuracy and additional remarks. This is all done by a few swipes with the help of the device's pre-defined list of exposure features. This effectively allows unified and standardized sets of data.

Table 17 summarizes the number of building features per type, while Table 18 shows the total length of each road type, and Table 19 shows the number of water features extracted per type.

Table 17. Building Features Extracted for Lanang Floodplain.

Facility Type	No. of Features
Residential	1,338
School	36
Market	9
Agricultural/Agro-Industrial Facilities	3
Medical Institutions	3
Barangay Hall	5
Military Institution	0
Sports Center/Gymnasium/Covered Court	1
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	2
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	2
Religious Institutions	15
Bank	0
Factory	0
Gas Station	2
Fire Station	0
Other Government Offices	5
Other Commercial Establishments	17
Demolished Building	1
Total	1,439

Table 18 Total Length of Extracted Roads for Lanang Floodplain.

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Lanang	32.02	0	0	13.30	4.08	**49.41**

Table 19. Number of Extracted Water Bodies for Lanang Floodplain.

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/ Ponds	Sea	Dam	Fish Pen	
Lanang	1	259	1	0	0	**261**

A total of 5 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 28 shows the Digital Surface Model (DSM) of Lanang floodplain overlaid with its ground features.

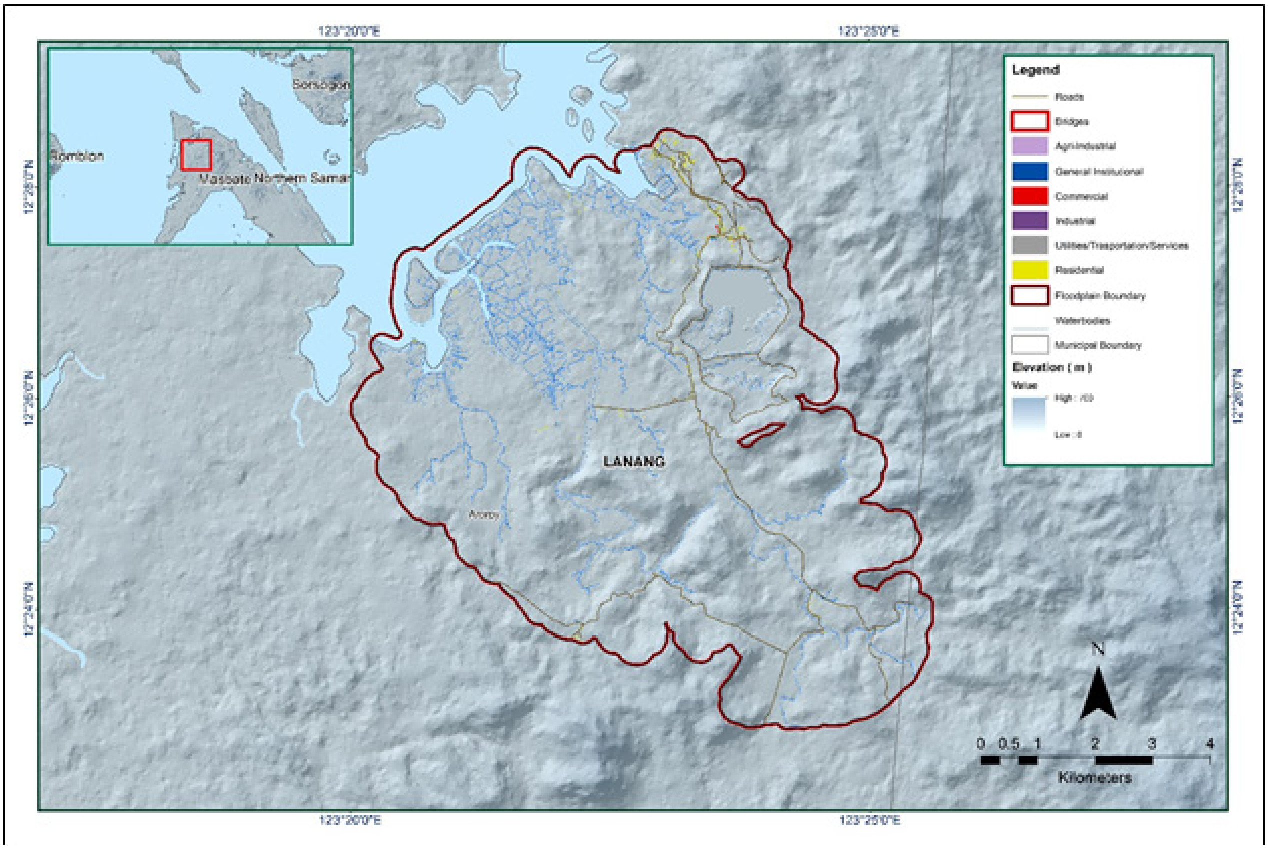


Figure 28. Extracted features for Lanang floodplain.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE LANANG 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, and For. Rodel C. Alberto

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

4.1 Summary of Activities

The Data Validation and Bathymetry Component (DVBC) conducted a field survey in Lanang River on December 3-17, 2015 for control survey and validation points acquisition survey and on February 5 – 19, 2017 with the following scope of work: reconnaissance; cross-section at Lanang Bridge in Brgy. Malubi, Aroroy, Masbate and bathymetric survey from its upstream in Brgy. Luy-a, to the mouth of the river located in Brgy. Balawing, municipality of Aroroy with an approximate length of 14.361 km using Ohmex™ single beam echo sounder and Trimble® SPS 882 GNSS PPK survey technique (Figure 29).

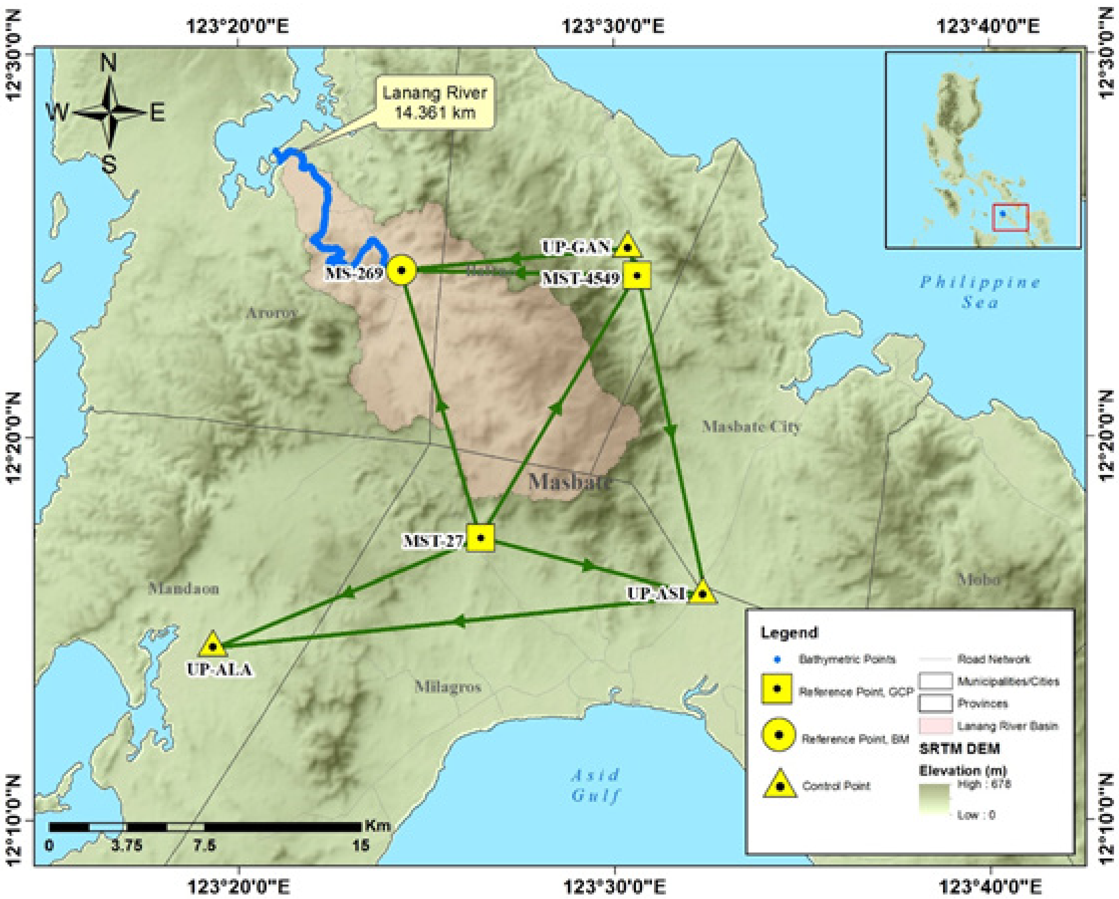


Figure 29. Extent of the bathymetric survey (in blue line) in Lanang River.

4.2 Control Survey

The GNSS network used for Lanang River Basin is composed of four (4) loops established on December 4, 5, 6 and 13, 2015 occupying the following reference points: MST-27, a second order GCP in Brgy. Matiporon, Municipality of Milagros; and MS-269, a first order benchmark in Brgy. Luy-A, Municipality of Aroroy.

Three (3) control points were established along the approach of bridges, namely: UP-ALA at Alas Bridge in Brgy. Alas, Municipality of Mandaon; UP-ASI at Asid Bridge in Brgy. Asid, Masbate City; and UP-GAN near Gangao Bridge, in Brgy. Gangao, Municipality of Baleno. The control point established by DENR, MST-4945, in Brgy. Gangao, also in Baleno was occupied to use as a marker for the network.

Three (3) control points were established along the approach of bridges, namely: UP-ALA at Alas Bridge in Brgy. Alas, Municipality of Mandaon; UP-ASI at Asid Bridge in Brgy. Asid, Masbate City; and UP-GAN near Gangao Bridge, in Brgy. Gangao, Municipality of Baleno. The control point established by DENR, MST-4945, in Brgy. Gangao, also in Baleno was occupied to use as a marker for the network.

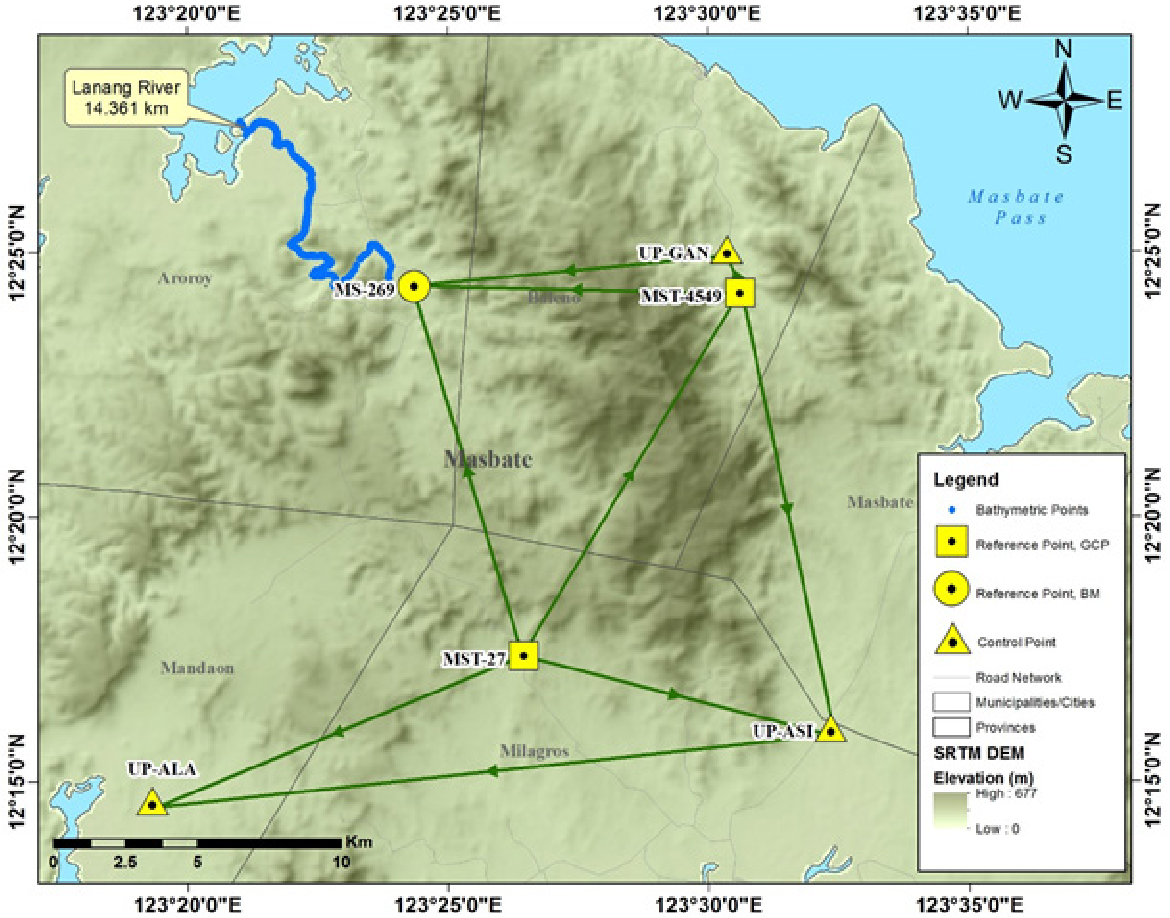


Figure 30. The GNSS Network established in the Lanang River

Table 20. List of references and control points occupied during control survey in Lanang River (Source: NAMRIA; UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84 N)				
		Latitude	Longitude	Ellipsoidal Height (m)	MSL Elevation (m)	Date Established
MST-27	2nd order, GCP	12°17'22.32360"N	123°26'26.50548"E	109.123	-	2007
MS-269	1st order, BM	-	-	82.132	27.408	2008
MST-4549	Used as Marker	-	-	-	-	07-02-16
	Used as Marker	-	-	-	-	2013
UP-ALA						
	UP Established	-	-	-	-	Dec. 12, 2015
UP-ASI						
	UP Established	-	-	-	-	Dec. 5, 2015
UP-GAN						
	UP Established	-	-	-	-	Dec. 4, 2015

The GNSS set-ups on recovered reference points and established control points in Lanang River are shown in Figure 31 to Figure 36.

Figure 31. GNSS base set up, Trimble® SPS 852 at MS-269 benchmark located at Lanang Bridge, along Central Nautical Highway in Brgy. Luy-A, Aroroy, Masbate.

Figure 32. GNSS receiver set up, Trimble® SPS 882 at MST-27, a second order GCP located at Mabuaya Bridge along Central Nautical Highway in Brgy. Matiporon, Milagros, Masbate.

Figure 33. Trimble® SPS 852 base setup at MST-4945, a DENR-established control point located at the approach of Cancahorao Bridge along Central Nautical Highway in Brgy. Gangao, Baleno, Masbate.

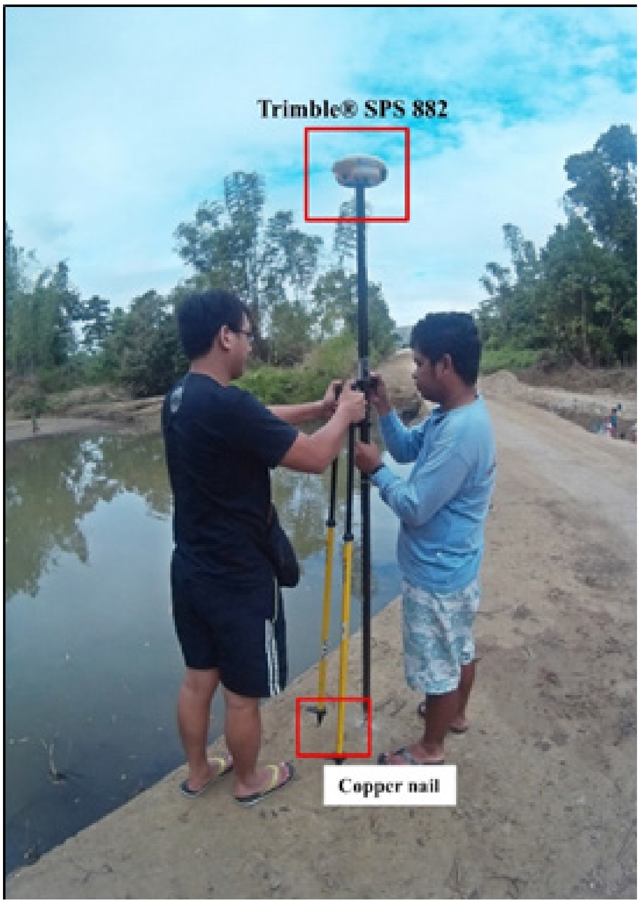


Figure 34. Trimble® SPS 882 setup at UP-ALA, an established control point located at Alas Bridge in Brgy. Alas, Mandaon, Masbate.

Figure 35. GNSS receiver setup, Trimble® SPS 882, at UP-ASI, an established control point located at Asid Bridge, along Central Nautical Highway, Brgy. Asid, Masbate City.

Figure 36. GNSS receiver setup, Trimble® SPS 882, at UP-GAN, an established control point located on the top of a riprap near Gangao Bridge, along Central Nautical Highway, Brgy. Gangao, Baleno, Masbate.

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Lanang River Basin is summarized in Table 21 generated by TBC software.

Table 21. Baseline processing summary report for Lanang River control survey.

Observation	Date of Observation	Solution Type	H.Prec. (Meter)	V.Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	Height (Meter)
UP-GAN --- MS-269	12-04-2015	Fixed	0.064	0.077	263°25'15"	10958.94	8.902
UP-ASI --- UP-ALA	12-05-2015	Fixed	0.007	0.04	263°57'41"	23763.75	-9.332
MST-4549 --- UP-ASI	12-05-2015	Fixed	0.007	0.034	168°18'59"	15487.62	-10.509
MST-4549 --- MS-269	12-05-2015	Fixed	0.013	0.019	271°18'18"	11347.5	5.154
MST-4549 --- UP-GAN	12-04-2015	Fixed	0.003	0.005	343°10'30"	1581.606	-3.725
MST-27 --- UP-ALA	12-12-2015	Fixed	0.006	0.046	248°40'43"	13874.51	-52.04
MST-27 --- UP-ASI	12-05-2015	Fixed	0.005	0.019	103°19'39"	11002.41	-42.67
MST-27 --- MS-269	12-05-2015	Fixed	0.015	0.076	343°39'18"	13427.81	-26.942
MST-4549 ---MST-27	12-05-2015	Fixed	0.006	0.023	30°55'25"	14722.42	-32.154

As shown Table 21, a total of thirteen (9) baselines were processed with reference point MST-27 held fixed for coordinate values; and, MS-269 fixed for elevation values. All of them passed the required accuracy.

4.4 Network Adjustment

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

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

Where:

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

For complete details, see the Network Adjustment Report shown in Table 22 to Table 25 for reference.

The six (6) control points, MST-27, MST-4549, MS-269. UP-ALA, UP-ASI, UP-GAN were occupied and observed simultaneously to form a GNSS loop. Coordinates of MST-27 and elevation values of MS-269 were held fixed during the processing of the control points as presented in Table 22. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 22. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
MST-27	Global	Fixed	Fixed	Fixed	
MS-269	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 23. All fixed control points have no values for grid and elevation errors.

Table 23. Adjusted grid coordinates for the control points used in the Lanang River flood plain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
MS-269	544123.788	0.018	1371483.424	0.013	27.408	?	e
MST-27	547922.386	?	1358609.337	?	53.606	0.063	LL
MST-4549	555464.635	0.009	1371246.784	0.006	21.829	0.043	
UP-ALA	535010.665	0.009	1353545.355	0.008	1.754	0.100	
UP-ASI	558628.712	0.007	1356091.508	0.006	10.476	0.069	
UP-GAN	555004.108	0.011	1372759.259	0.008	18.209	0.045	

With the mentioned equation, $\sqrt{((x\_e)^2+(y\_e)^2)}<20cm$ for horizontal and $z^e<10$ cm for the vertical; the computation for the accuracy are as follows:

a. MST-27
horizontal accuracy = Fixed
vertical accuracy = 6.3 cm < 10 cm

b. MS-269
horizontal accuracy = $\sqrt{((1.8)^2 + (1.3)^2)}$
= $\sqrt{(3.24+ 1.69)}$
= 2.2 cm < 20 cm
vertical accuracy = Fixed

c. MST-4549
horizontal accuracy = $\sqrt{((0.9)^2 + (0.6)^2)}$
= $\sqrt{(0.81 + 0.36)}$
= 1.08 cm < 20 cm
vertical accuracy = 4.30 cm < 10 cm

d. UP-ALA
horizontal accuracy = $\sqrt{((0.9)^2 + (0.8)^2)}$
= $\sqrt{(0.81 + 0.64)}$
= 1.20 cm < 20 cm
vertical accuracy = 10 cm < 10 cm

e. UP-ASI
horizontal accuracy = $\sqrt{((0.70)^2 + (0.60)^2)}$
= $\sqrt{(0.49 + 0.36)}$
= 0.92 cm < 20 cm
vertical accuracy = 6.90 cm < 10 cm

f. UP-GAN
horizontal accuracy = $\sqrt{((1.1)^2 + (0.8)^2)}$
= $\sqrt{(1.21 + 0.64)}$
= 1.36 cm < 20 cm
vertical accuracy = 4.5 cm < 10 cm

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

Table 24. Adjusted geodetic coordinates for control points used in the Lanang River Flood Plain validation.

Point ID	Latitude	Longitude	Ellipsoidal Height (Meter)	Height Error (Meter)	Constraint
MS-269	N12°24'21.62817"	E123°24'21.39816"	82.132	?	e
MST-27	N12°17'22.32360"	E123°26'26.50548"	109.123	0.063	LL
MST-4549	N12°24'13.29041"	E123°30'36.98735"	76.970	0.043	
UP-ALA	N12°14'38.06086"	E123°19'18.85903"	57.103	0.100	
UP-ASI	N12°15'59.72358"	E123°32'20.76940"	66.451	0.069	
UP-GAN	N12°25'02.55601"	E123°30'21.83023"	73.244	0.045	

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

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

Table 25. The reference and control points utilized in the Lanang River Static Survey, with their corresponding locations (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)
MST-27	2nd order, GCP	12°17'22.32360"	123°26'26.50548"	109.123	1358609.337	547922.386	53.606
MS-269	1st order, BM	12°24'21.62817"	123°24'21.39816"	82.132	1371483.424	544123.788	27.408
MST-4549	Used as Marker	12°24'13.29041"	123°30'36.98735"	76.970	1371246.784	555464.635	21.829
UP-ALA	UP Estab-lished	12°d14'38.06086"	123°19'18.85903"	57.103	1353545.355	535010.665	1.754
UP-ASI	UP Estab-lished	12°15'59.72358"	123°32'20.76940"	66.451	1356091.508	558628.712	10.476
UP-GAN	UP Estab-lished	12°25'02.55601"	123°30'21.83023"	73.244	1372759.259	555004.108	18.209

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

Cross-section and bridge as-built survey was executed on February 15 and 16, 2017 at the upstream portion of Lanang river along the downstream side of Lanang Bridge in Barangay Malubi, Aroroy, Masbate as shown in Figure 37. A survey grade GNSS receiver Trimble® SPS 883 in PPK survey technique was utilized for this survey.

Figure 37. Cross-section survey on the downstream side of Lanang Bridge

The cross-sectional line of Lanang Bridge is about 128.868 m with 28 cross-sectional points, using the control point MST-269 as GNSS base stations. The location map, cross-section diagram, and as-built data are shown in Figure 38 to Figure 40, respectively.

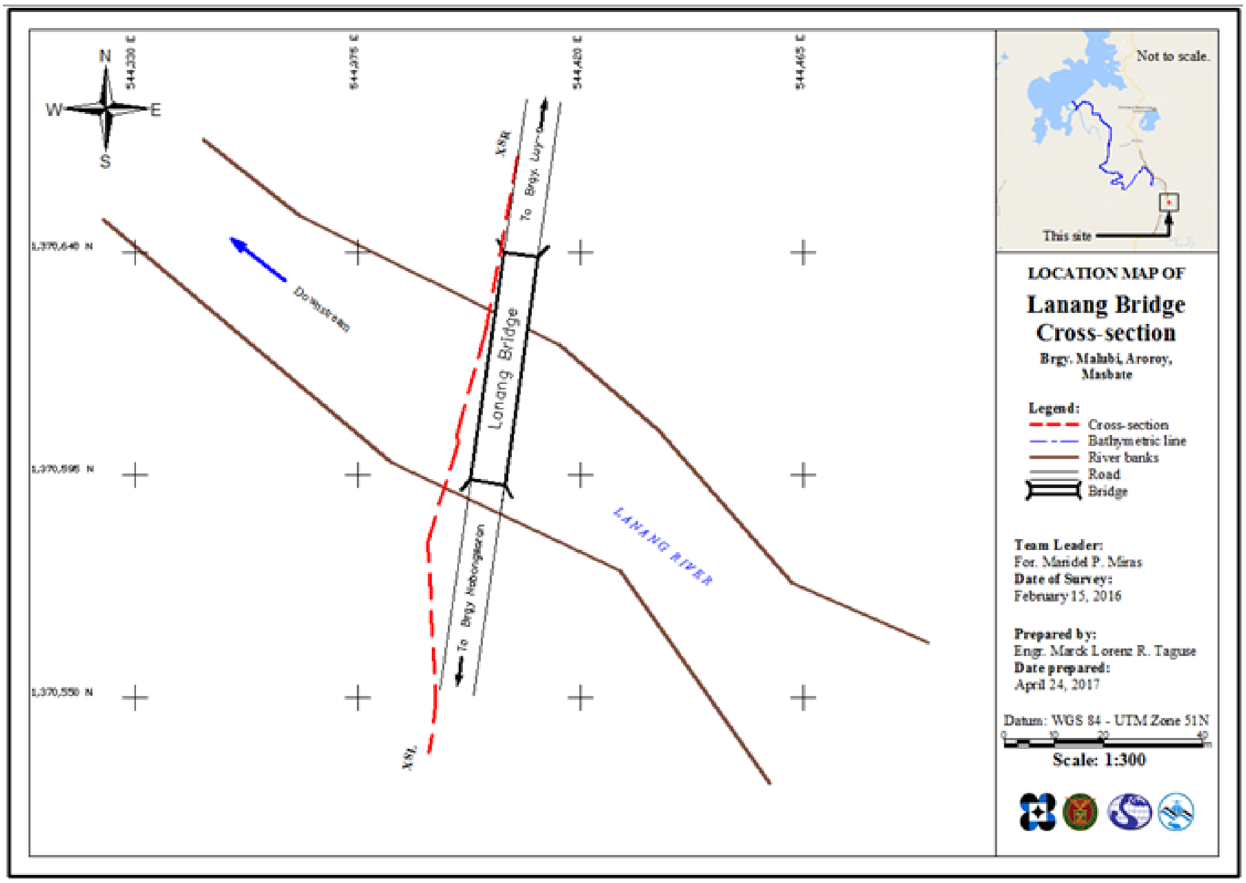


Figure 38. Location map of the Lanang Bridge cross-section survey

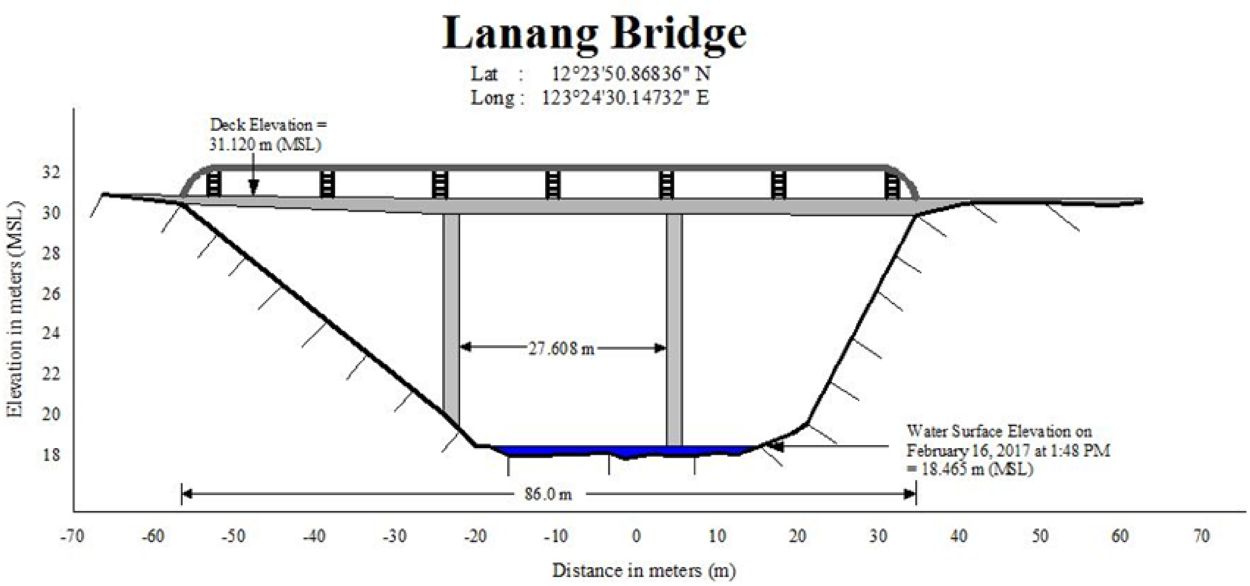


Figure 39. Lanang bridge cross-section survey drawn to scale

Bridge Data Form

Bridge Name: Lanang Bridge | Date: February 15 and 16, 2017

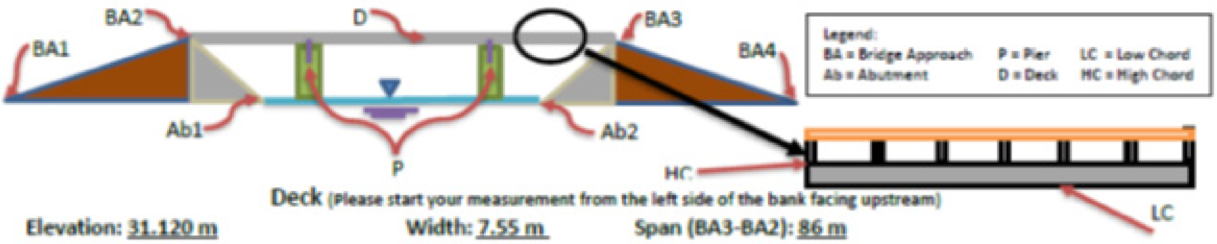
River Name: Lanang River | Time: 1:48 PM

Location (Brgy, City,Region): Brgy. Malubi, Aroroy, Masbate

Survey Team: Maridel Miras, Marla Tricia Morris, Randell Pabroquez

Flow condition: average | Weather Condition: fair

Latitude: 12°23'50.86836"N | Longitude: 123°24'30.14732"E



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

Elevation: 31.120 m   Width: 7.55 m   Span (BA3-BA2): 86 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	31.318 m	BA3	102.184 m	31.120 m
BA2	16.184 m	31.318 m	BA4	125.218 m	30.743 m

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

	Station (Distance from BA1)	Elevation
Ab1		
Ab2		

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

Shape: round   Number of Piers: 2   Height of column footing: Not available

	Station (Distance from BA1)	Elevation	Pier Diameter
Pier 1	43.200 m	31.139 m	1 m
Pier 2	70.808 m	31.115 m	1 m

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

Figure 40. Bridge As-built Form of Lanang Bridge

Water surface elevation of Lanang River was determined by a survey grade GNSS receiver Trimble® SPS 985 in PPK survey technique on February 16, 2017 at 1:48 PM at Lanang Bridge with a value of 18.465 m in MSL as shown in Figure 38. This was translated into marking on the bridge's deck as shown in Figure 41. The marking will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Lanang River, the Ateneo de Naga University.

Figure 41. Water-level markings on the abutment of Lanang Bridge.

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on December 5 to 6, 2015 using a Trimble® SPS 882 attached in front of a vehicle, as shown in Figure 42. It was secured with a nylon rope to ensure that it was horizontally and vertically balanced. The antenna height was 1.902-meter 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 MST-4549 and MST-27 as the GNSS base stations.

On December 05, validation points acquisition survey ran from Mabuaya Bridge in Brgy. Matiporon, Milagros to Brgy. Poblacion, Aroroy via Baleno in a near semi-circumferential route. The second day of this survey also started in Mabuayan Bridge going to Brgy. Poblacion in Aroroy via Mandaon, the other half of the circumferential road. This survey also covered Mandaon Road which started from Brgy. Mabatobato going southwest towards Brgy. Nailaban, both in the Municipality of Mandaon.

A total of 4,709 were gathered with approximate length of 112km using MST-4549 and MST-27 as the GNSS base stations for the entire extent validation points acquisition survey, as illustrated in the map in Figure 43.

Figure 42. The validation points acquisition survey set-up using a GNSS receiver mounted on top of the vehicle along Lanang River Basin.

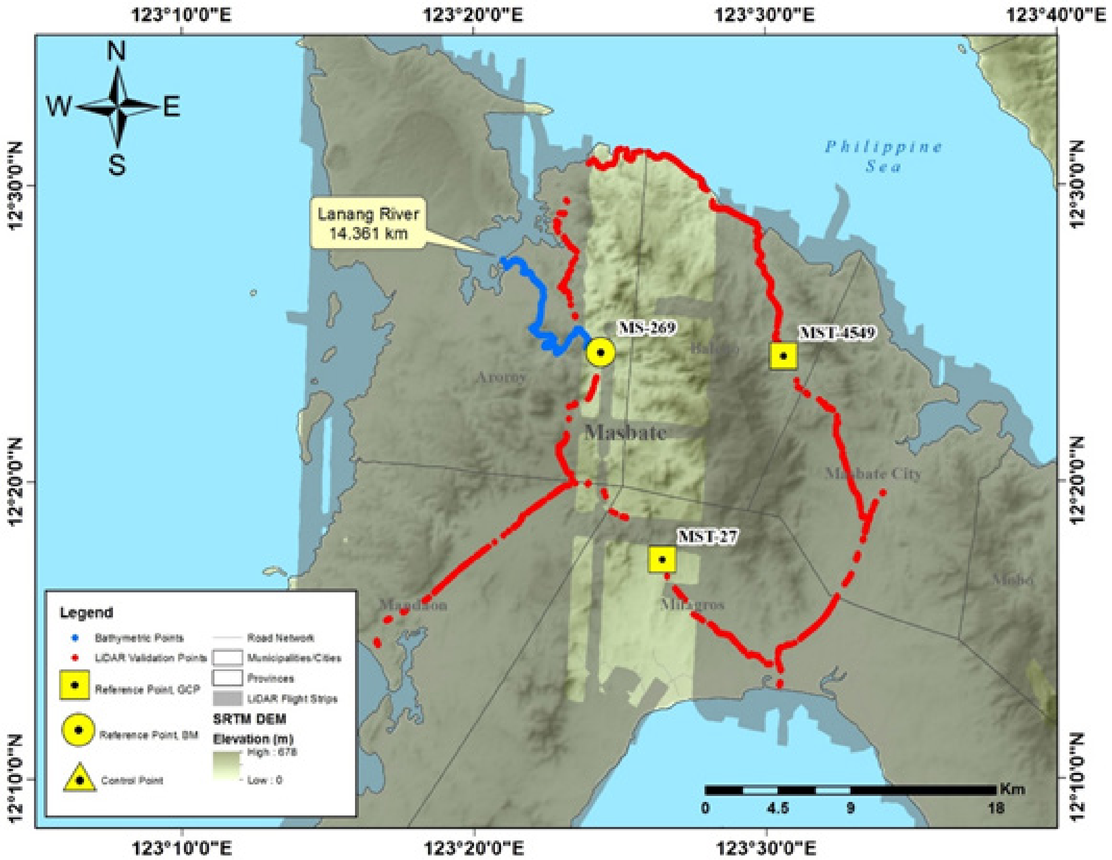


Figure 43. Extent of the LiDAR ground validation survey of the Lanang River basin

4.7 Bathymetric Survey

Bathymetric survey for Lanang River was executed on February 15, 16 and 17, 2017 using an Ohmex™ single beam echo sounder and Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode as illustrated in Figure 44. The bathymetric survey started in Brgy, Luy-A, Aroroy, Masbate with coordinates 12°14'30.27999"N, 123°23'52.67593"E, traversed down the river by boat and ended at the mouth of the river in Brgy. Balawing, Aroroy, Masbate with coordinates 12°27'28.78146"N, 123°20'59.97772"E, the control MST-269 was used as GNSS base stations all throughout the entire survey.

Figure 44. Bathymetric survey using a Trimble® SPS 882 in GNSS PPK in Lanang River

The bathymetric survey for Lanang River gathered a total of 12,422 points covering 14.361 km of the river traversing from Barangay Luy-A, Aroroy and down to Barangay Balawing, Aroroy, Masbate as shown in Figure 45.

A CAD drawing was also produced to illustrate the riverbed profile of Lanang River. As shown in Figure 46, the highest and lowest elevation has an 18.985-m difference. The highest elevation observed was 13.118 m above MSL located at the upstream part of Lanang River near the Barangay Luy-A; while the lowest was –5.867 m below MSL located in the downstream portion of the river.

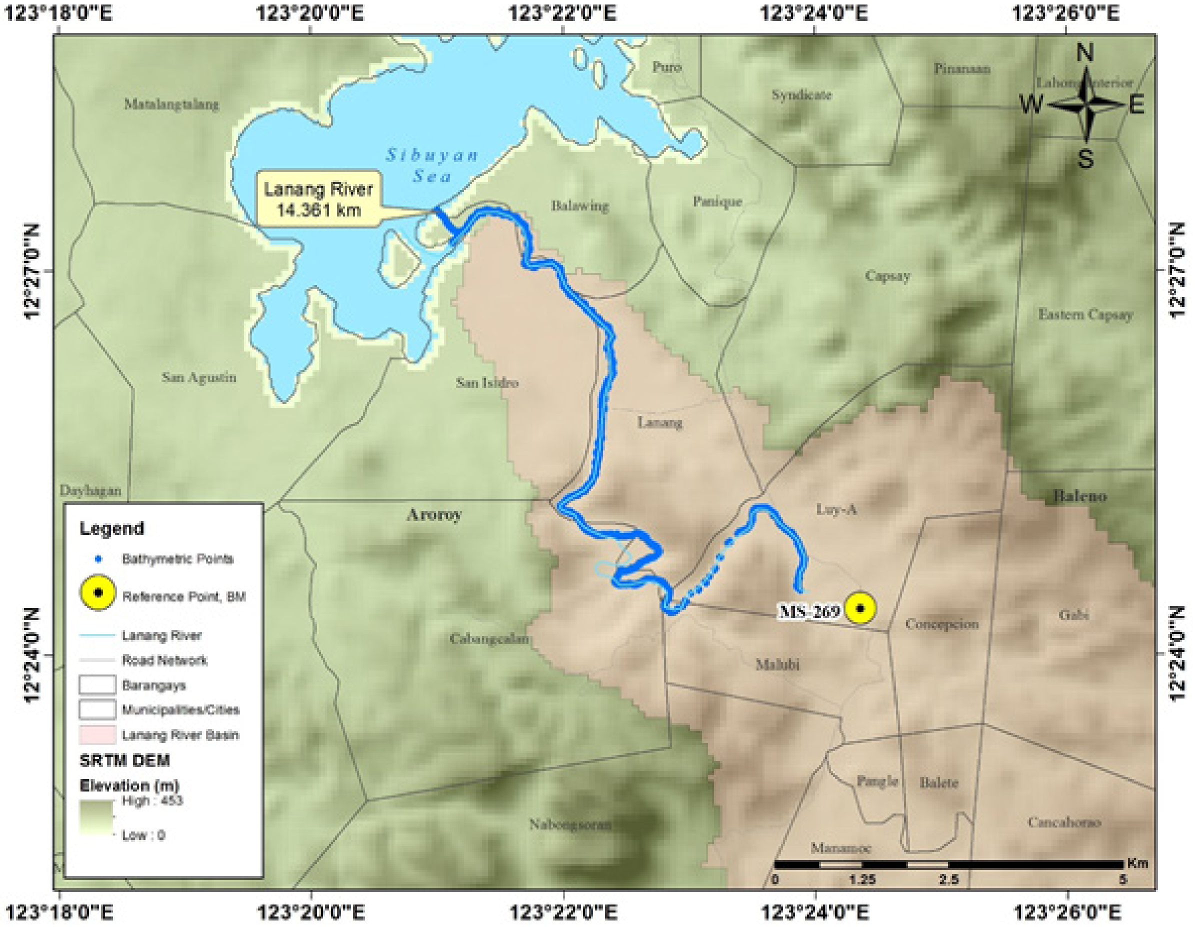


Figure 45. Extent of the Lanang River Bathymetry Survey.

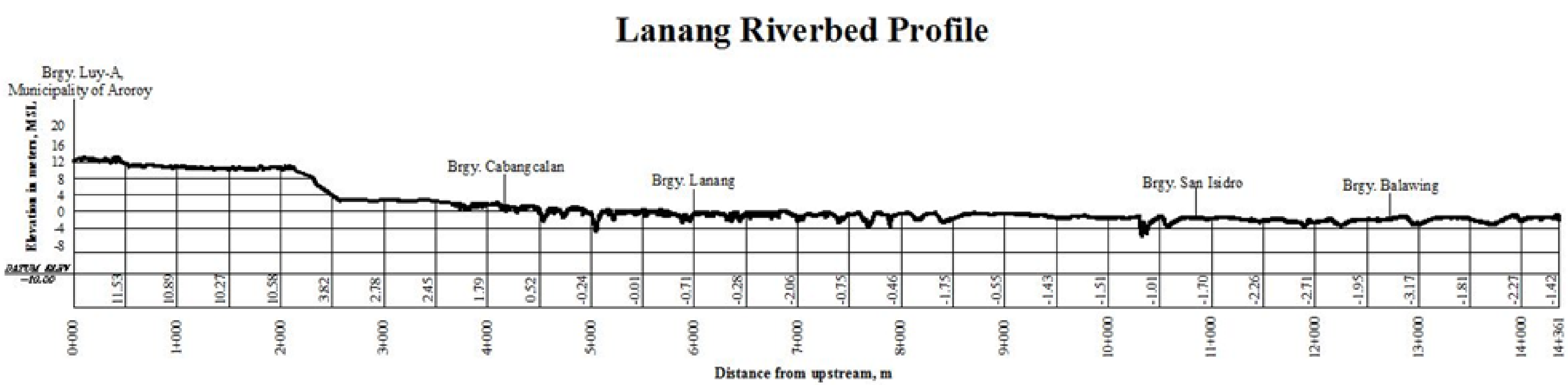


Figure 46. The Lanang Riverbed profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, Gianni Sumajit, Engr. Ferdinand E. Bien, Daniel S. Baer Jr., Engr. Mary Ruth A. Bongon, Mark D. Delloro, Sarah Mae F. Fulleros, Berlin Phil V. Garciano,Engr. Julius Hector S. Manchete, Ernesto F. Razal Jr., Engr. Lech Fidel C. Pante John Paul B. Obina, Aaron P. San Andres,Rox Harvey DP. Rosales, Engr. Mark A. Sta. Isabel, Engr. Juan Paulo B. Besa

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

5.1.2 Precipitation

Precipitation data was taken from the Portable Automatic Rain Gauge (ARG) deployed by ADNU Flood Modeling Component (FMC). The ARG was specifically installed in Brgy. Aroroy (Figure 47). The precipitation data collection started from January 21, 2017 at 3:30 PM to January 22, 2017 at 3:30 PM with a 10-minute recording interval.

The total precipitation for this event in Brgy. Aroroy rain gauge is 24.4mm. It has a peak rainfall of 2.2mm on January 22, 2017 at 1:10 AM. The lag time between the peak rainfall and discharge is 2 hours and 30 minutes.

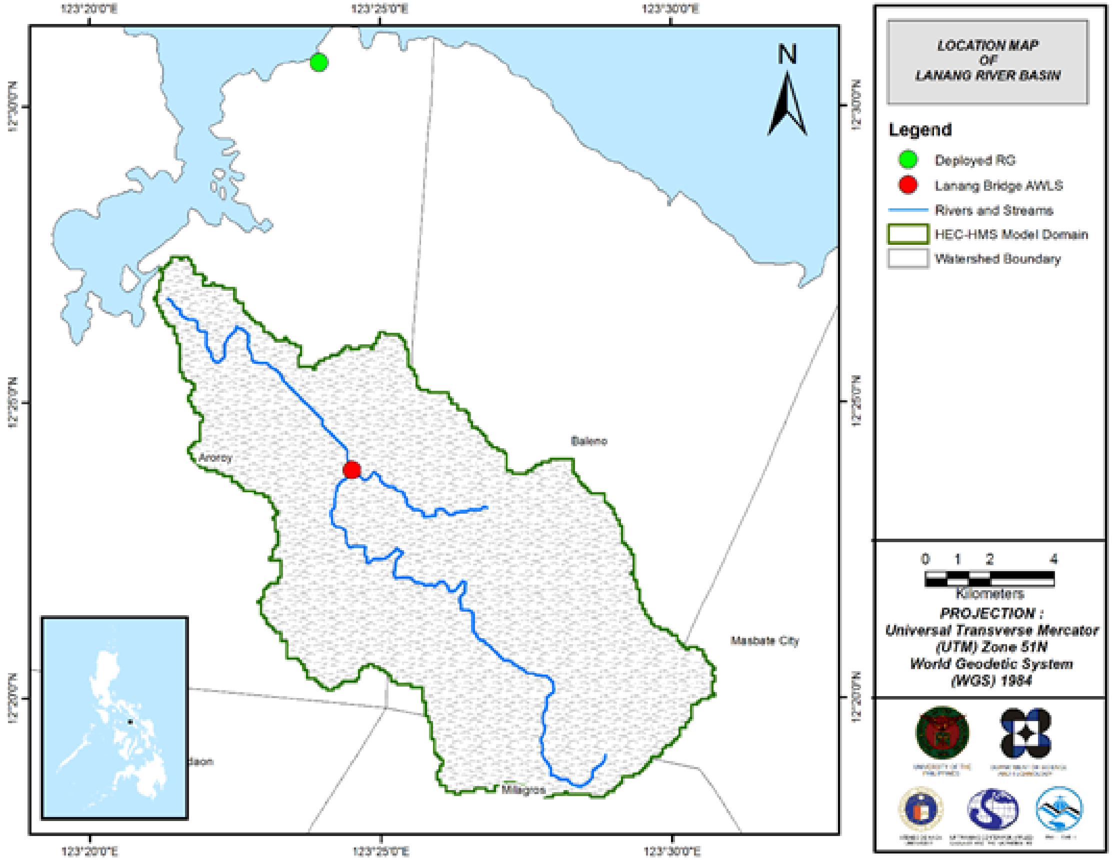


Figure 47. The location map of Lanang HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was computed based on the prevailing cross-section of the Lanang Bridge, Lanang, Masbate City (12°23’51.3”N, 123°24’30.3”E) shown in Figure 48. For the Lanang Bridge, the rating curve is expressed as Q = 0.0082e0.4254h as shown in Figure 49.

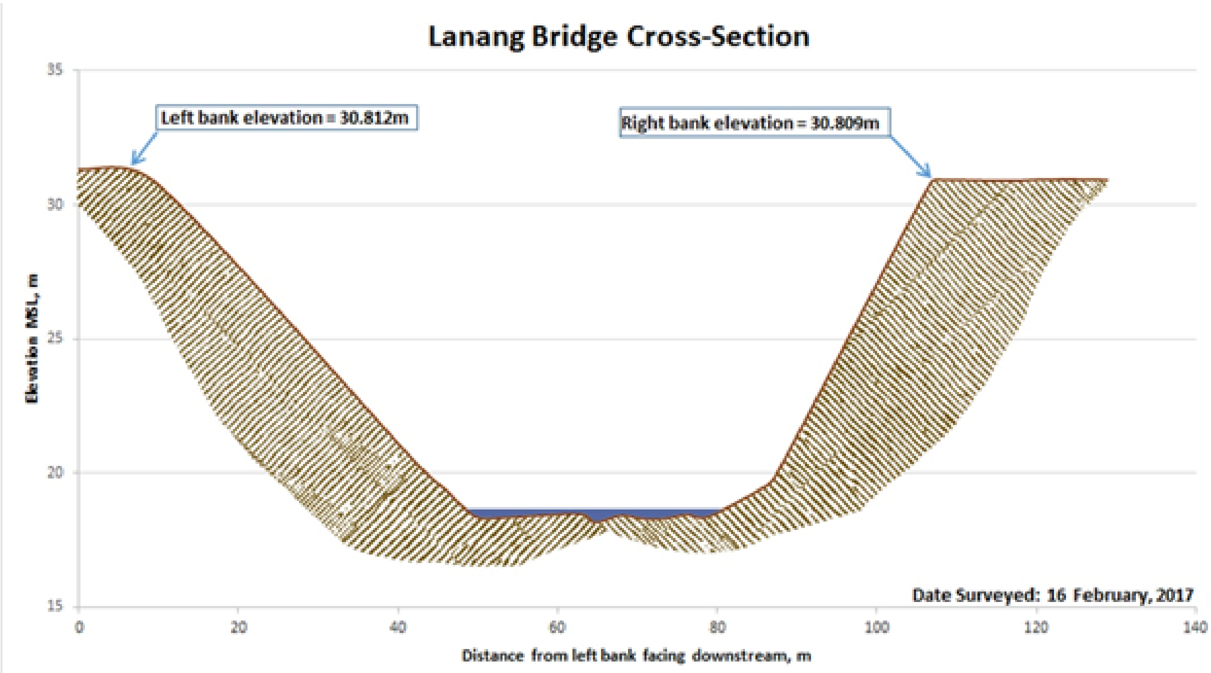


Figure 48. Cross-Section Plot of Lanang Bridge

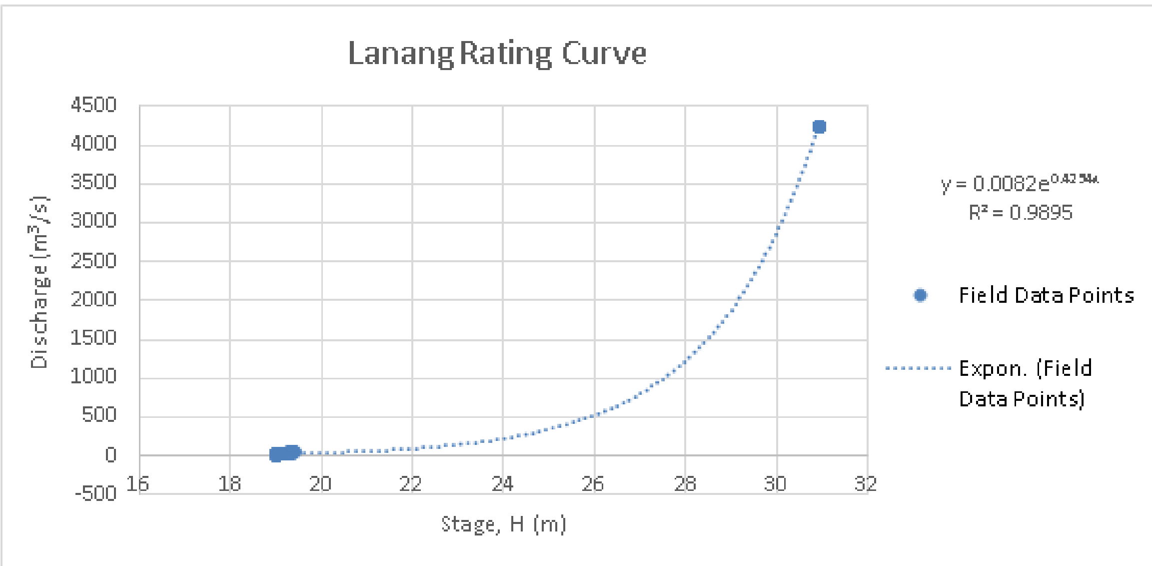


Figure 49. Rating Curve at Lanang Bridge, Masbate City.

This rating curve equation was used to compute the river outflow at Lanang Bridge for the calibration of the HEC-HMS model shown in Figure 50. The total rainfall for this event is 24.4mm and the peak discharge is 64.65m3/s at 3:40 AM, January 22, 2017.

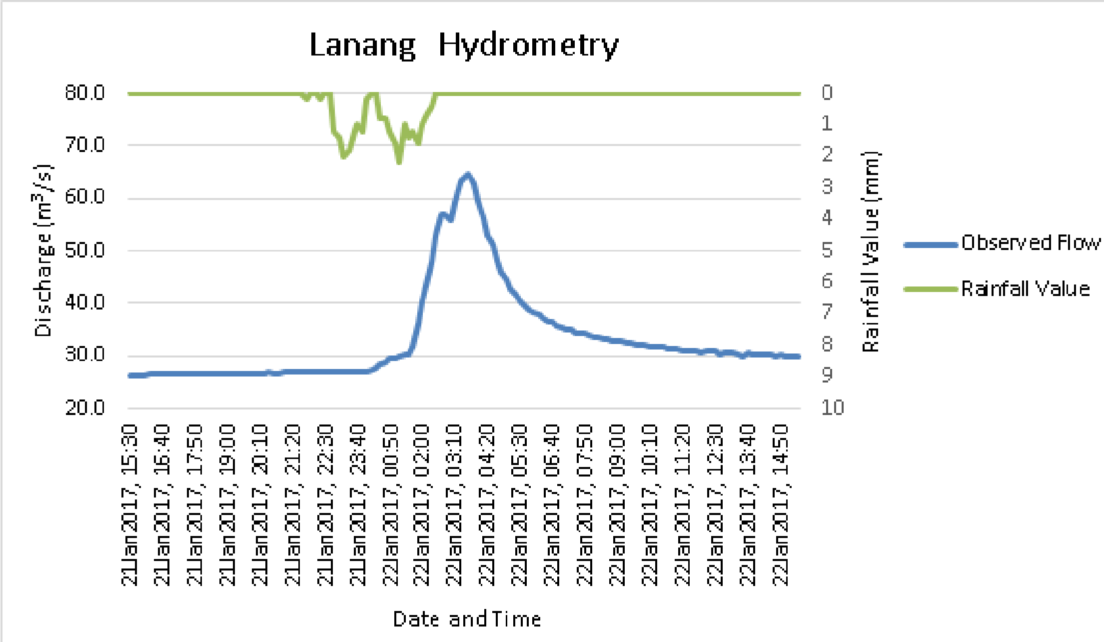


Figure 50. Rainfall and outflow data of the Lanang River Basin, which was used for modeling

5.2 RIDF Station

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Legazpi RIDF (Figure 51). The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time (Figure 52). This station was chosen based on its proximity to the Lanang watershed. The extreme values for this watershed were computed based on a 26-year record shown in Table 26.

Table 26. RIDF values for Lanang Rain Gauge, as computed by PAG-ASA.

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	21	31.9	39.6	53.4	74.5	89.3	119.2	145.5	176.4
5	29.1	43.8	54.5	76.7	113.4	138.5	189.8	228.7	260.5
10	34.5	51.6	64.3	92.2	139.1	171.1	236.6	283.8	316.1
15	37.5	56	69.8	100.9	153.6	189.4	263	314.8	347.5
20	39.6	59.1	73.7	107	163.7	202.3	281.5	336.6	369.5
25	41.3	61.5	76.7	111.7	171.6	212.2	295.7	353.4	386.4
50	46.3	68.9	85.9	126.2	195.7	242.7	339.6	405	438.6
100	51.3	76.2	95.1	140.5	219.6	273.1	383.1	456.2	490.3

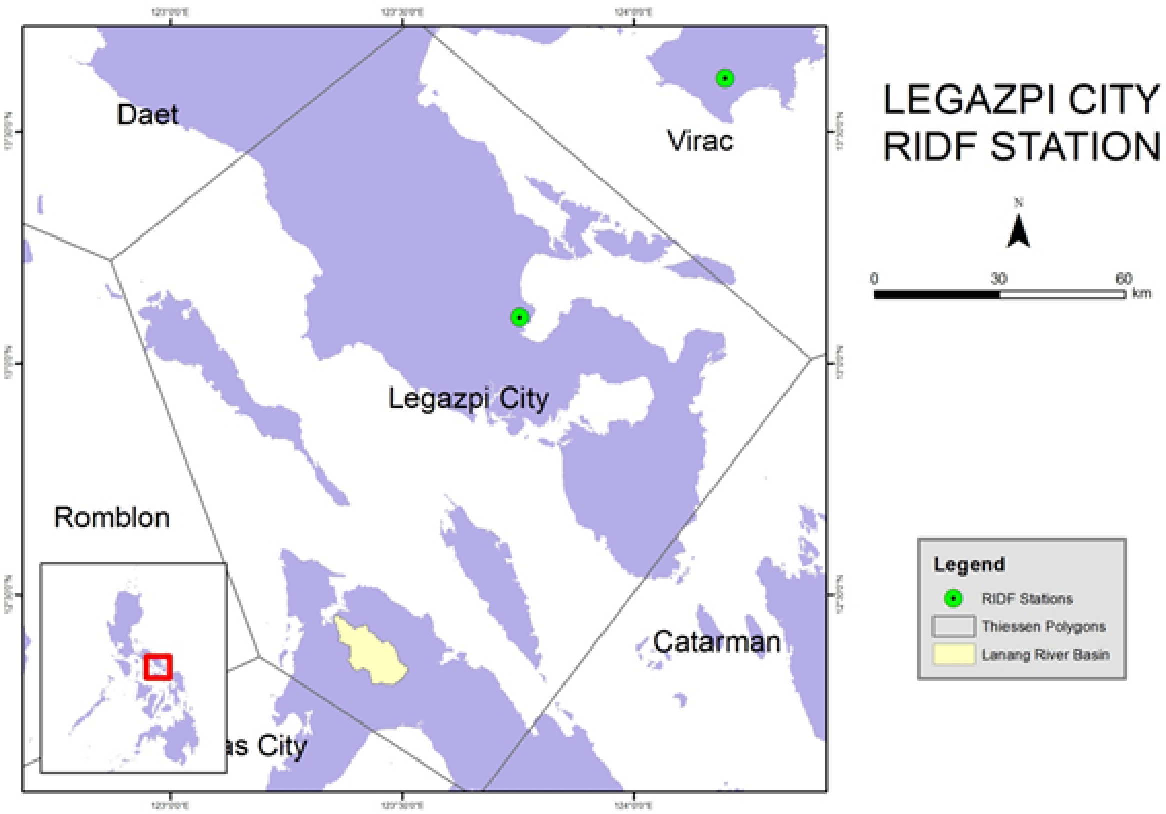


Figure 51. Location of Legazpi City RIDF station relative to the Lanang River Basin.

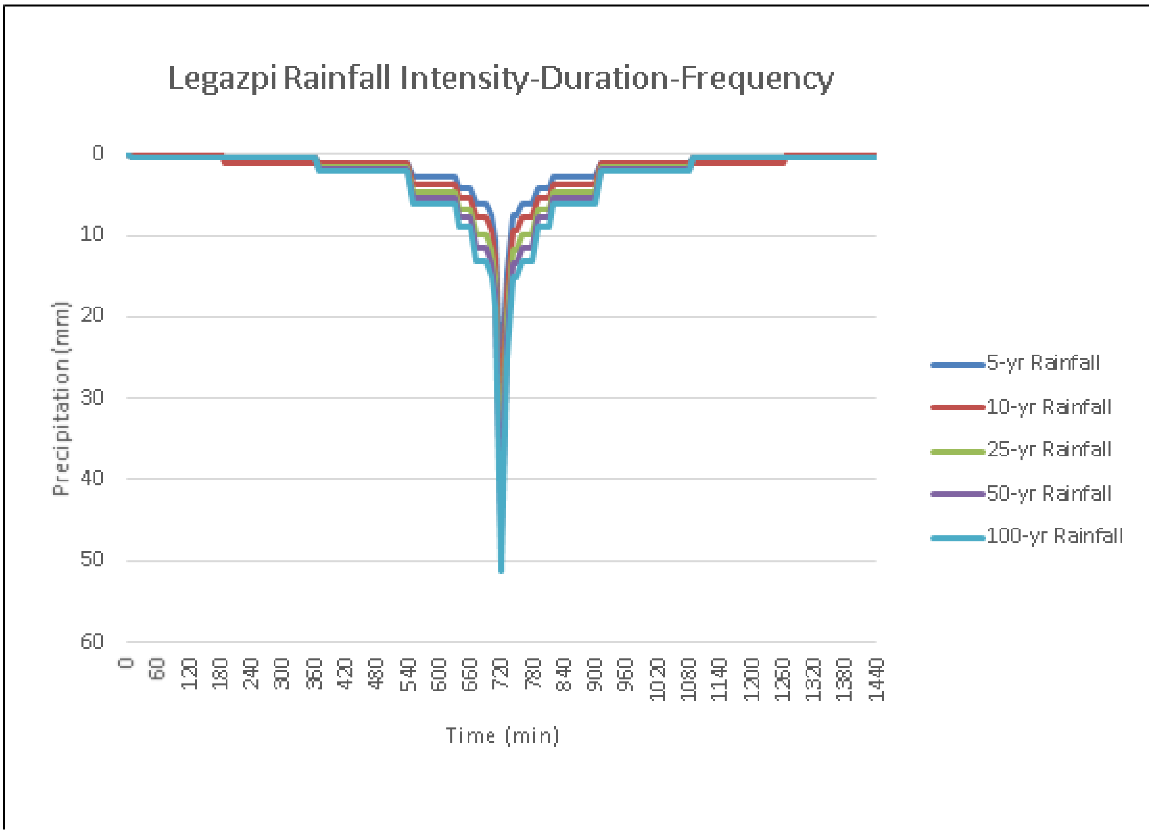


Figure 52. Synthetic storm generated for a 24-hour period rainfall for various return periods

5.3 HMS Model

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

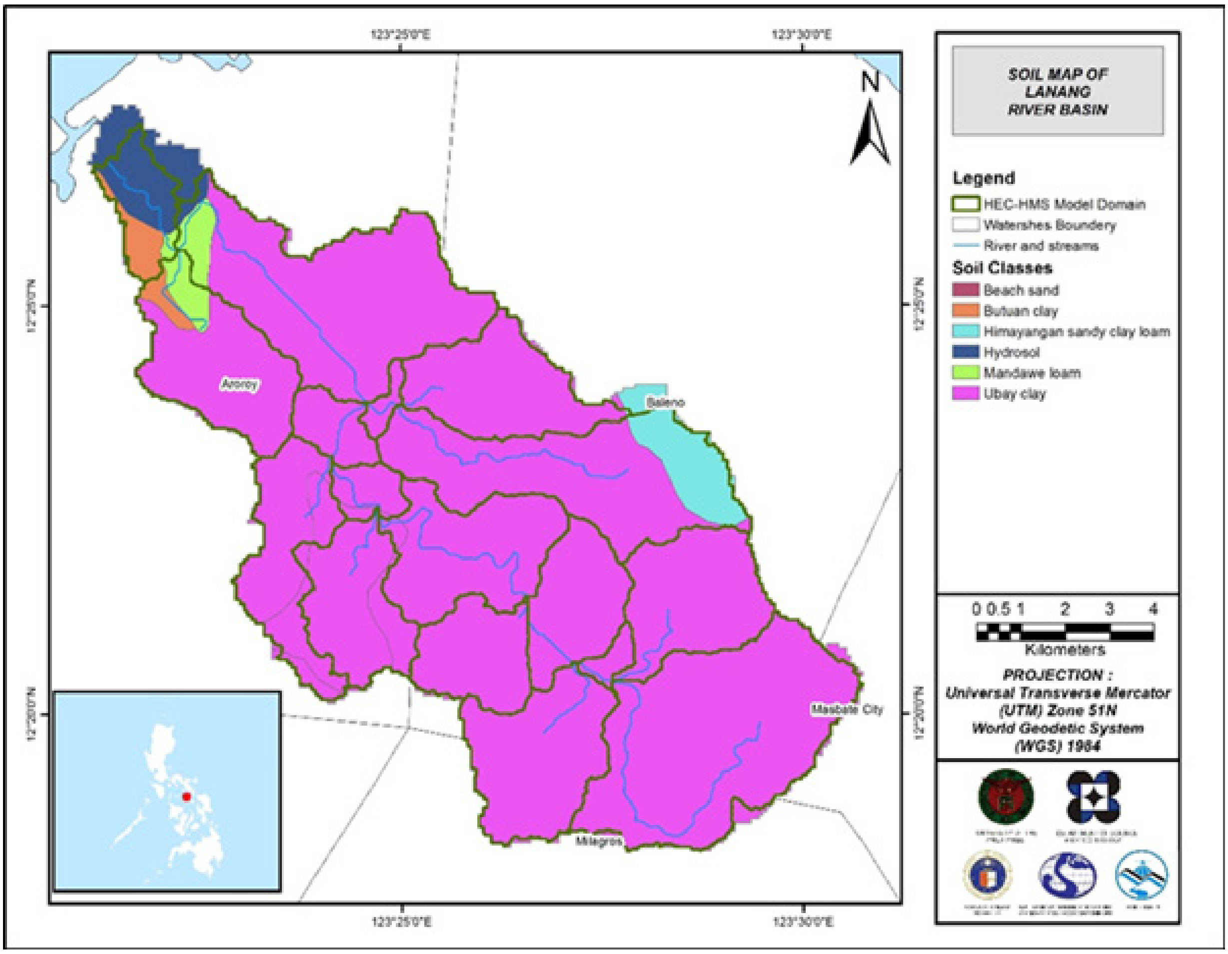


Figure 53. Soil map of Lanang River Basin

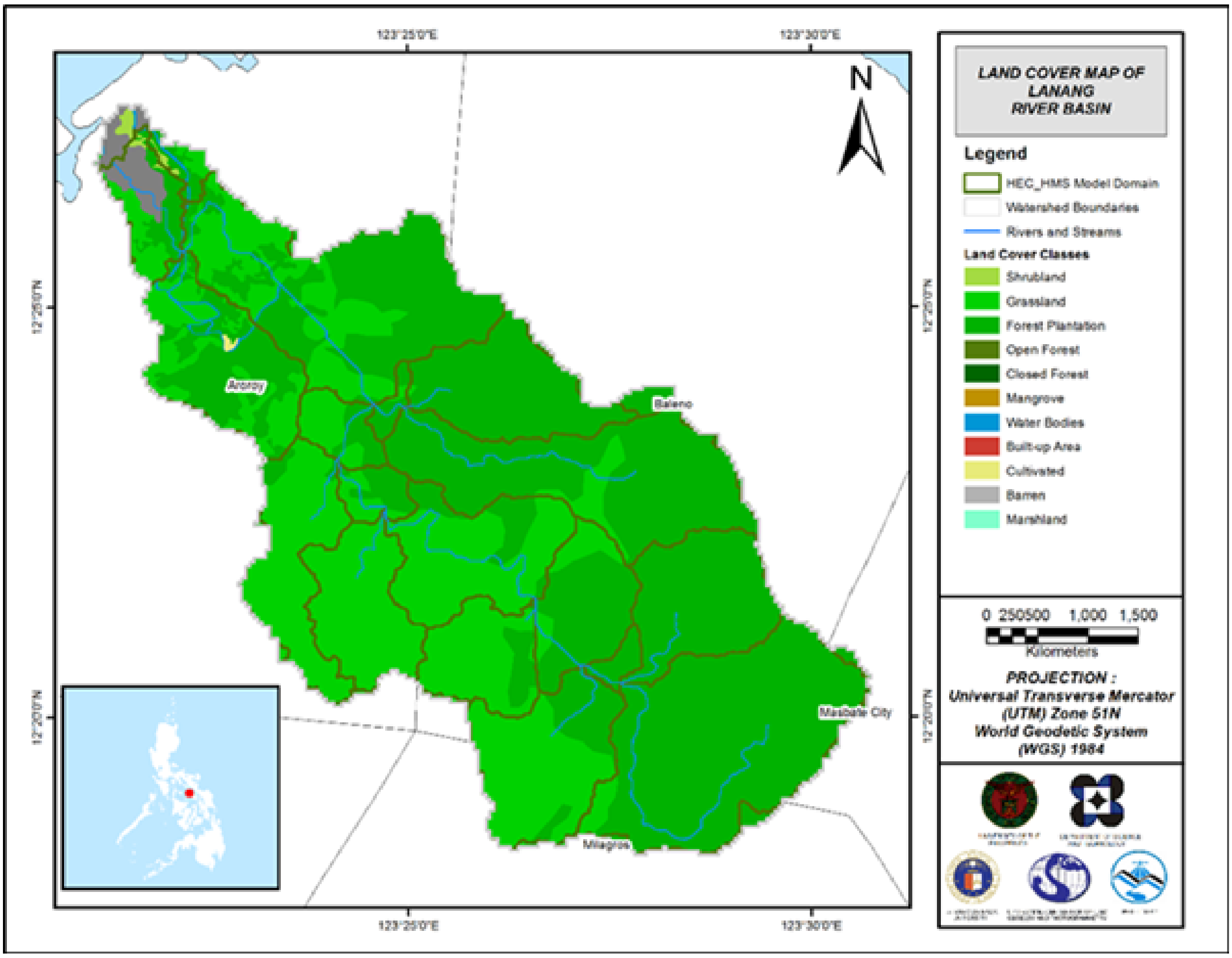


Figure 54. Land cover map of Lanang River Basin.

For Lanang, six soil classes were identified. These are Butuan clay, Himayangan sandy clay loam, Mandawe loam, Ubay clay, beach sand, and hydrosol. Moreover, five land cover classes were identified. These are grassland, forest plantation, shrubland, cultivated, and barren areas.

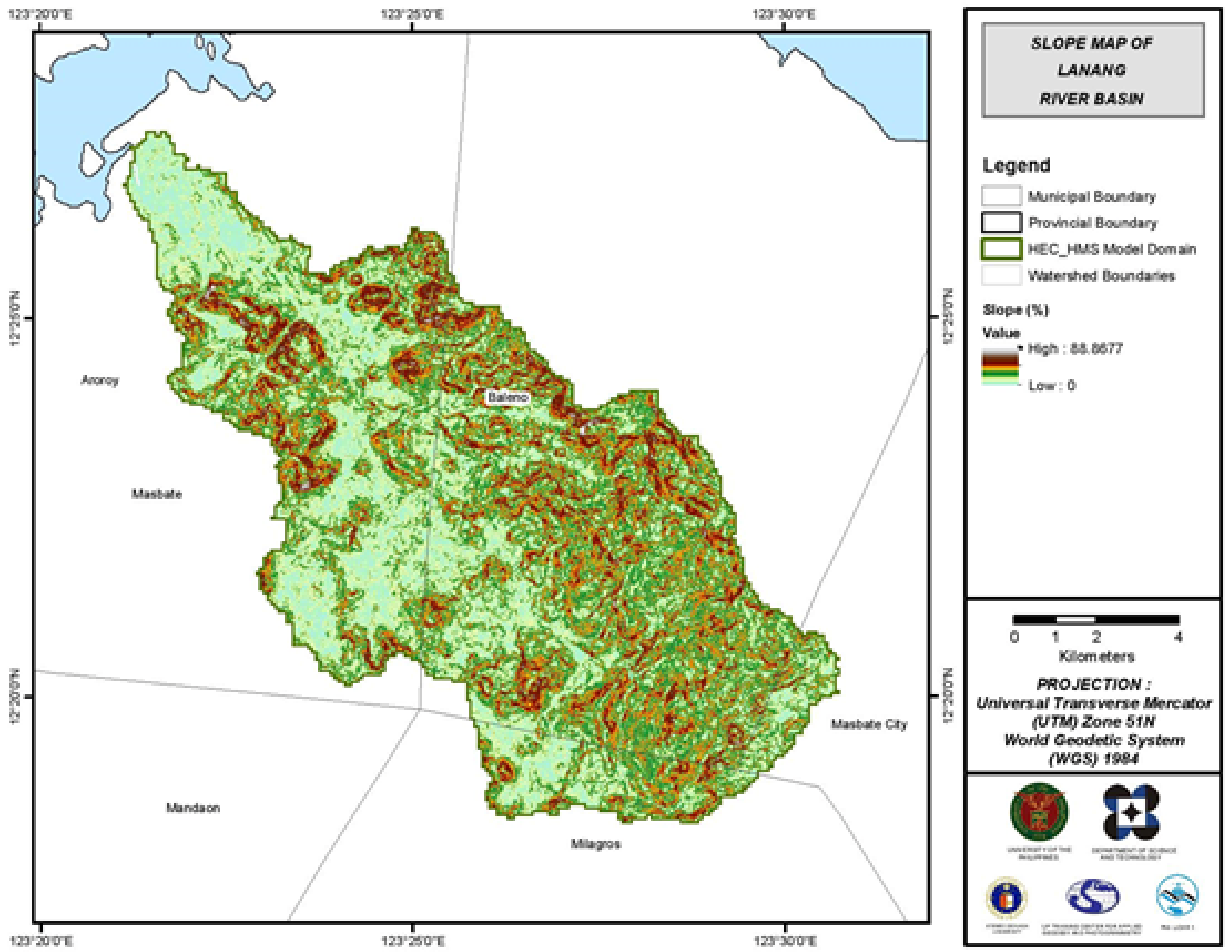


Figure 55. Slope map of Lanang River Basin.

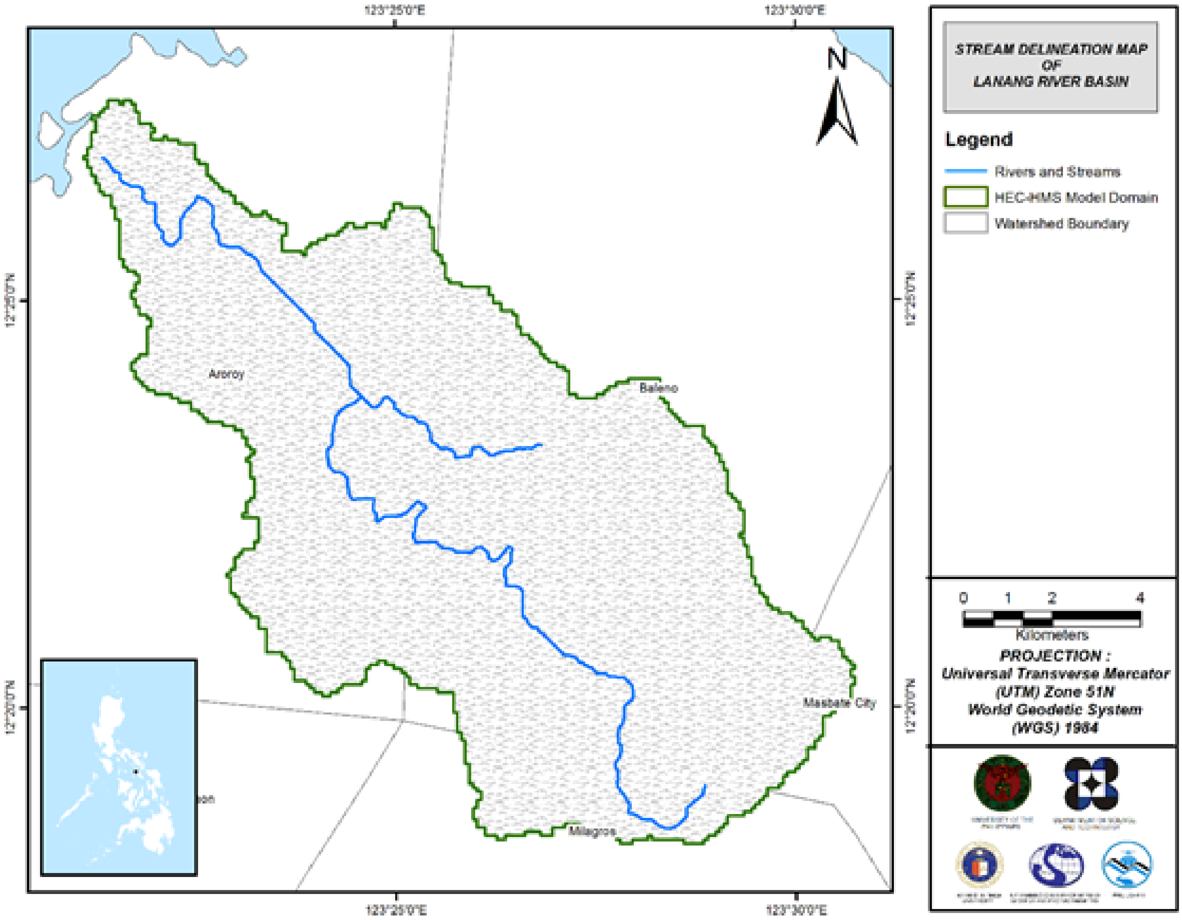


Figure 56. Stream delineation map of Lanang River Basin.

Using the SAR-based DEM, the Lanang basin was delineated and further divided into subbasins. The model consists of 17 sub basins, 8 reaches, and 8 junctions, as shown in Figure 57. The main outlet is Lanang Bridge.

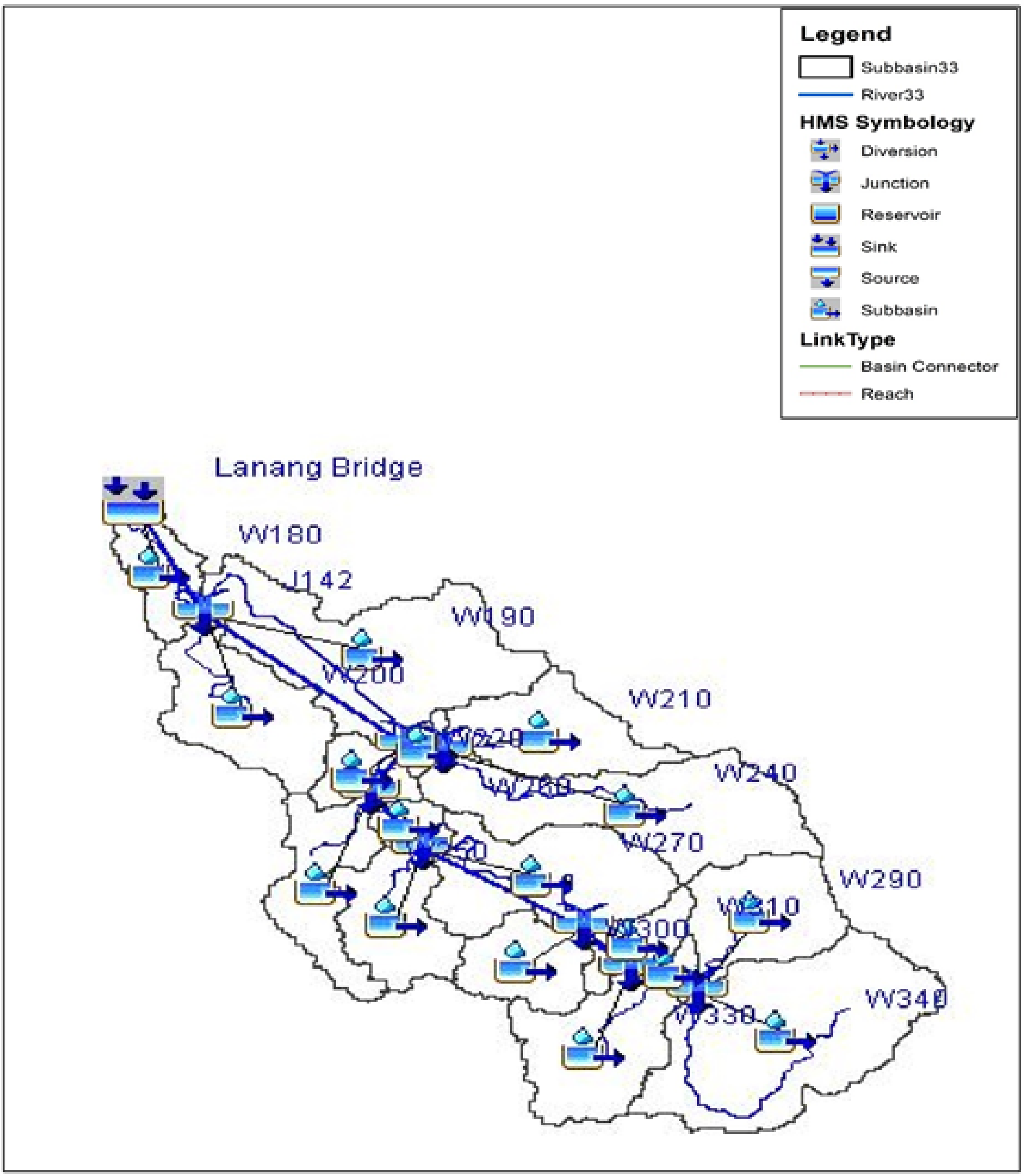


Figure 57. The Lanang Hydrologic Model generated in HEC-HMS

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 58).

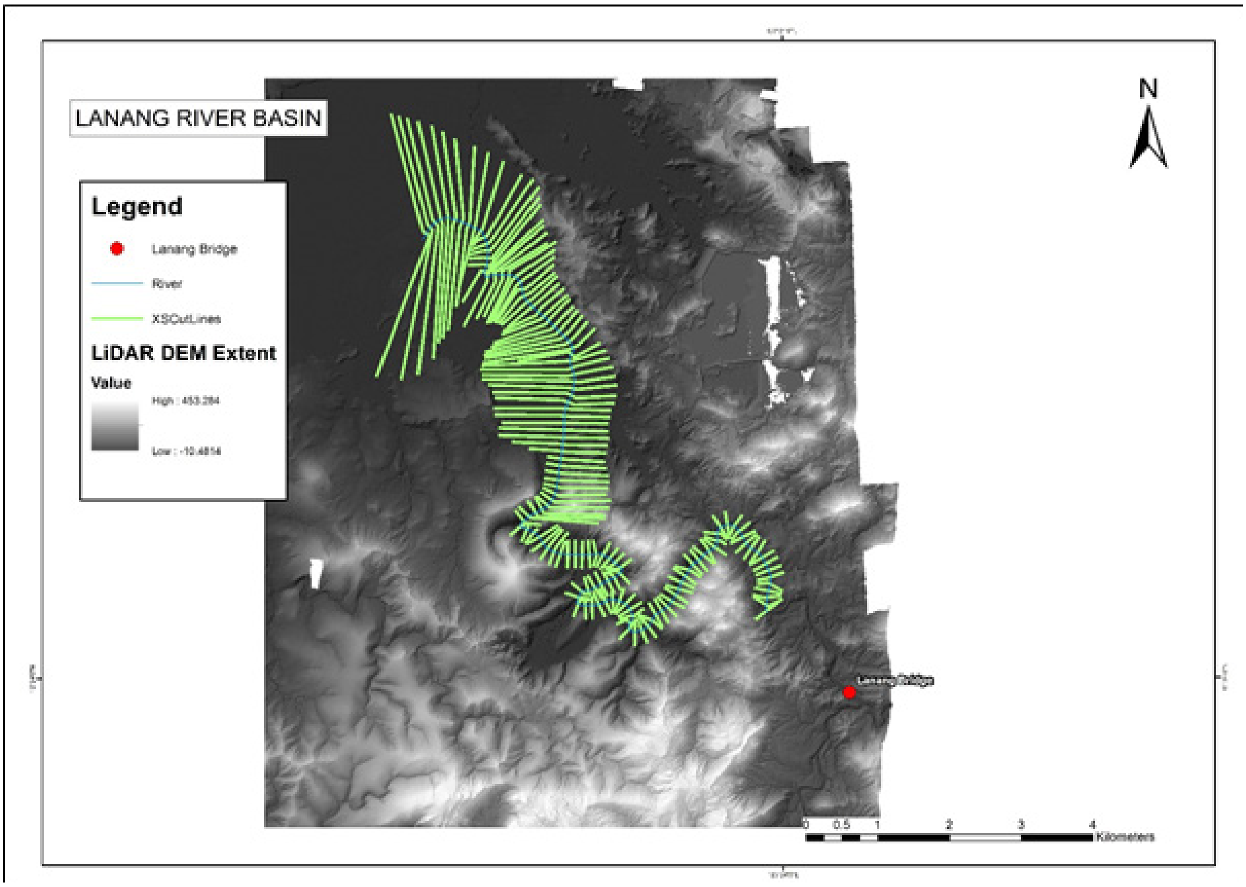


Figure 58. River cross-section of Lanang River through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

Based on the elevation and flow direction, it is seen that the water will generally flow from the south of the model to the northeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively (see Figure 59).

Figure 59. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro)

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 121.04468 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 0m2/s. The generated hazard maps for Lanang are in Figures 64, 66 and 68.

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 71,400,672.00 m2. The generated flood depth maps for Lanang are in Figures 65, 67 and 69.

There is a total of 29,787,396.56m3 of water entering the model. Of this amount, 16,472,858.86 m3 is due to rainfall while 1,331,4537.71 m3 is inflow from other areas outside the model. 5,753,252.00m3 of this water is lost to infiltration and interception, while 14,791,865.92 m3 is stored by the flood plain. The rest, amounting up to 9,242,265.39 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Lanang HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 60 shows the comparison between the two discharge data.

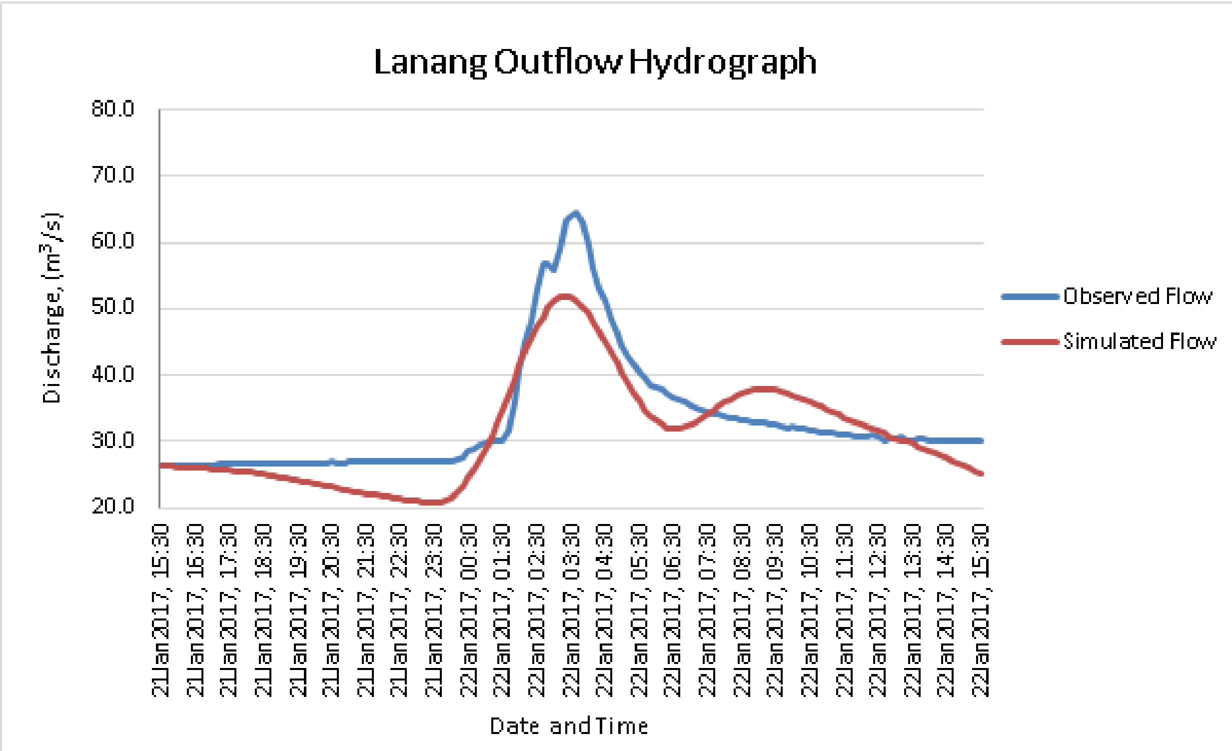


Figure 60. Outflow hydrograph of Lanang River Basin produced by the HEC-HMS model compared with observed outflow.

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 the Lanang River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.001-29
			Curve Number	35-99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.02-0.2
			Storage Coefficient (hr)	0.02-0.08
	Baseflow	Recession	Recession Constant	0.00001
			Ratio to Peak	0.01-1
Reach	Routing	Muskingum-Cunge	Slope	0.0002-0.02
			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 0.001mm to 29mm 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 35-99 for curve number is wider than the advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). For Lanang, the basin mostly consists of grassland and the soil consists of Ubay clay, Himayangan sandy clay loam, and hydrosol.

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 0.02 hours to 0.2 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. For Lanang, it will take at least 11 hours from the peak discharge to go back to the initial discharge.

Manning's roughness coefficient of 0.21 corresponds to the common roughness of Lanang watersheds, which is determined to be shrubland with medium to dense brush (Brunner, 2010).

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

Accuracy Measure	Value
RMSE	4.36
r2	0.82
NSE	0.77
PBIAS	5.64
RSR	0.47

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was computed as 4.36 (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 0.82.

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 0.77.

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 5.64.

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 0.47.

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 61) shows the Lanang outflow using the synthetic storm events using the Legazpi Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods from 910.1m3/s in a 5-year return period to 2060.1m3/s in a 100-year return period.

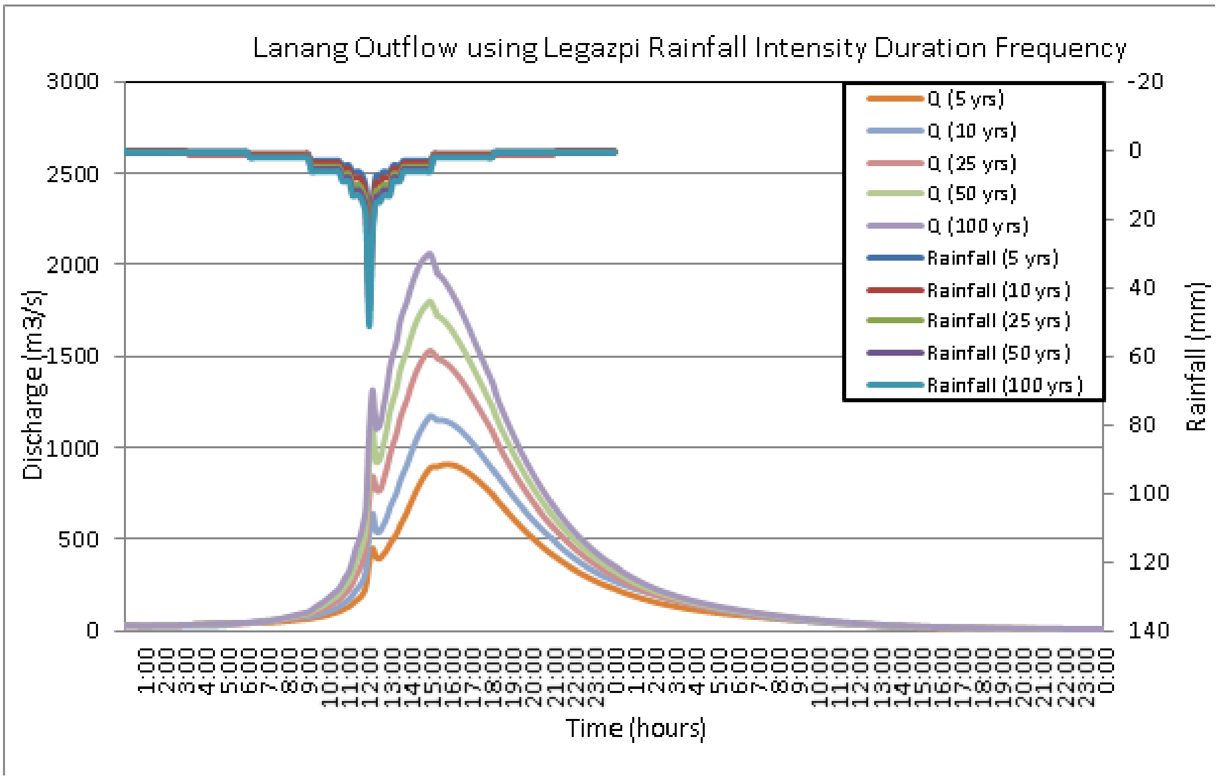


Figure 61. Outflow hydrograph at Lanang station generated using Legazpi RIDF simulated in HEC-HMS

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

Table 29. Peak values of the Lanang HECHMS Model outflow using the Legazpi RIDF values.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	260.50	29.1	910.1	3 hours, 50 minutes
10-Year	316.10	34.5	1174.1	3 hours
25-Year	386.40	41.3	1532	3 hours
50-Year	438.40	46.3	1800.4	3 hours
100-Year	490.30	51.3	2060.1	4 hours

5.7.2 Discharge Values using Dr. Horritt's Recommended Hydrological Method

The river discharge values for the nine river entering the floodplain are shown in Figure 62 and the peak values are summarized in Table 30.

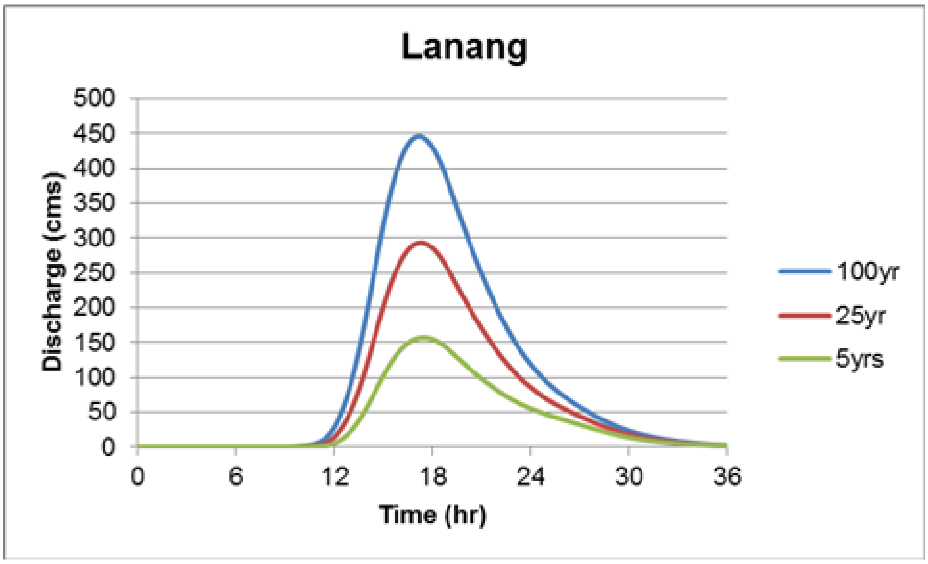


Figure 62. Lanang river generated discharge using 5-, 25-, and 100-year Legazpi rainfall intensity-duration-frequency (RIDF) in HEC-HMS.

Table 30. Summary of Lanang river discharge generated in HEC-HMS.

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	446.1	279.16 minutes
25-Year	293.4	279.16 minutes
5-Year	157.2	279.16 minutes

The comparison of the discharge results using Dr. Horritt's recommended hydrological method against the bankful and specific discharge estimates is shown in Table 31.

Table 31. Validation of river discharge estimates.

Discharge Point	$Q_{MED(SCS)}$, cms	$Q_{BANKFUL}$, cms	$Q_{MED(SPEC)}$, cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Lanang	138.336	100.625	649.244	PASS	FAIL

The results from the HEC-HMS river discharge estimates were able to satisfy the conditions for validation using the bankful discharge methods. The passing values are based on theory but are supported using other discharge computation methods so they were good to use flood modeling. 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 ADNU-DVC base flow was calibrated. The sample generated map of Lanang River using the calibrated HMS base flow is shown in Figure 63.

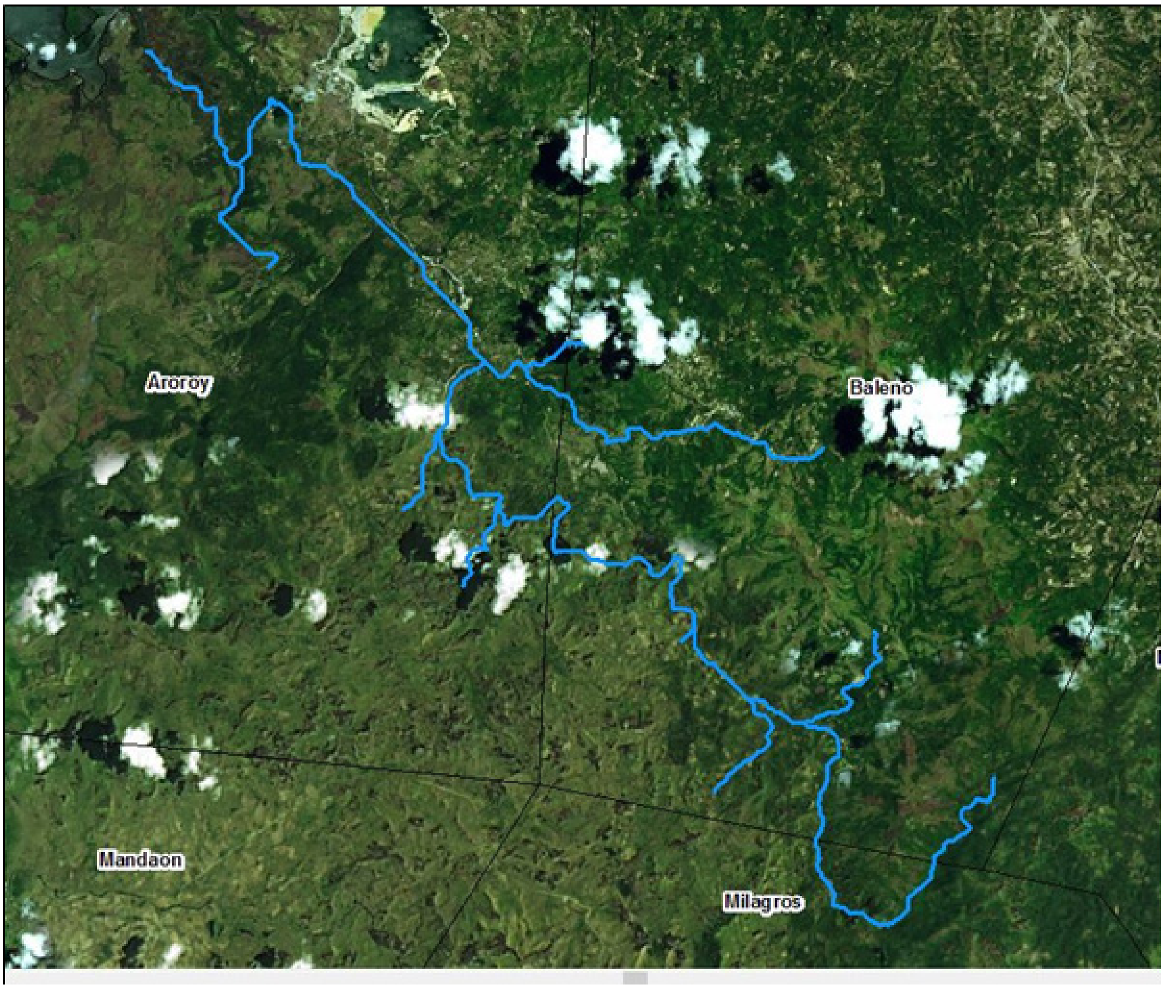


Figure 63. Sample output map of the Lanang RAS Model.

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figures 64 to 69 show the the 5-, 25-, and 100-year rain return scenarios of the Lanang flood plain. The flood plain, with an area of 71.46km2, covers one (1) municipality, namely Aroroy. Table 32 shows the percentage of area affected by flooding in the municipality.

Table 32. Municipalities affected in Lanang floodplain.

Municipality	Total Area (km2)	Area Flooded (km2)	% Flooded
Aroroy	403.62	73.43	18.19

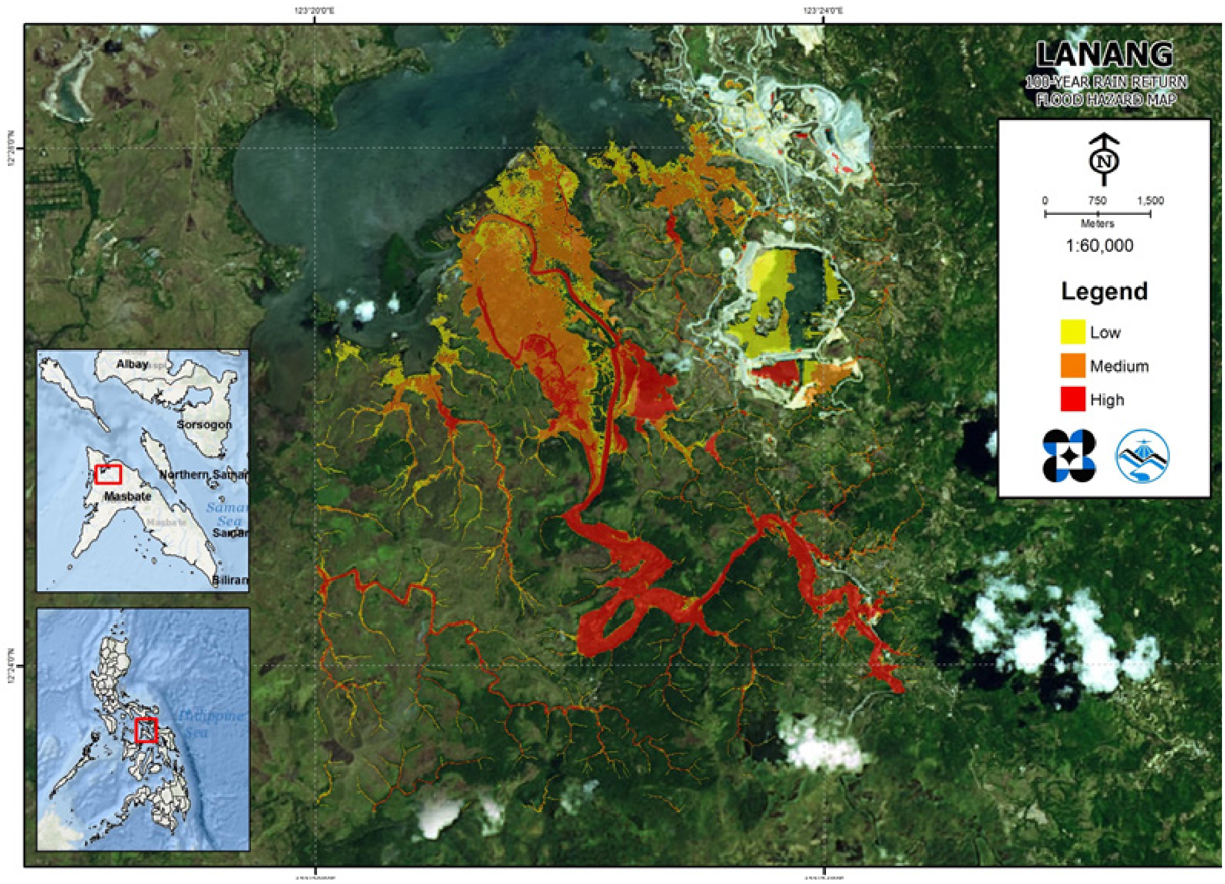


Figure 64. 100-year flood hazard map for the Lanang flood plain overlaid on Google Earth imagery

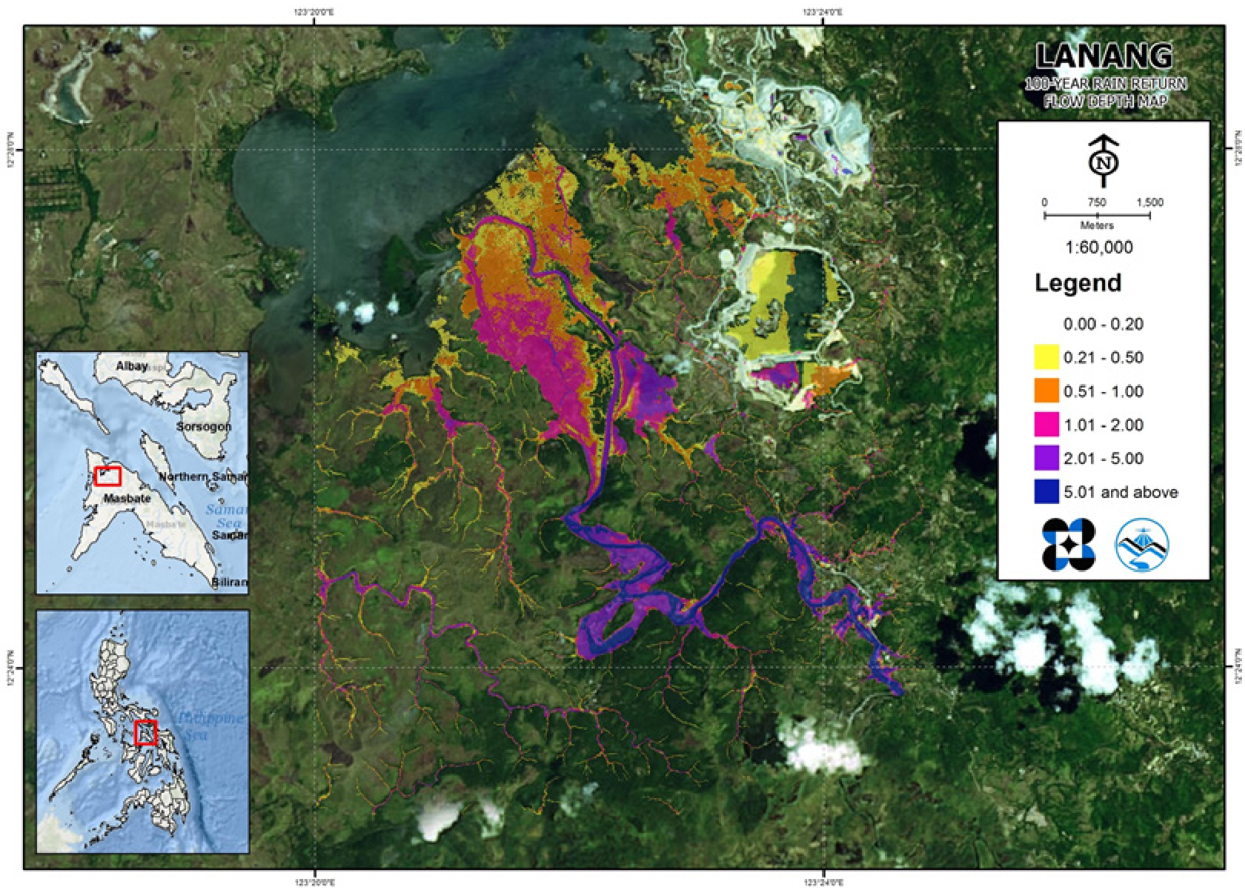


Figure 65. 100-year flow depth map for the Lanang flood plain overlaid on Google Earth imagery.

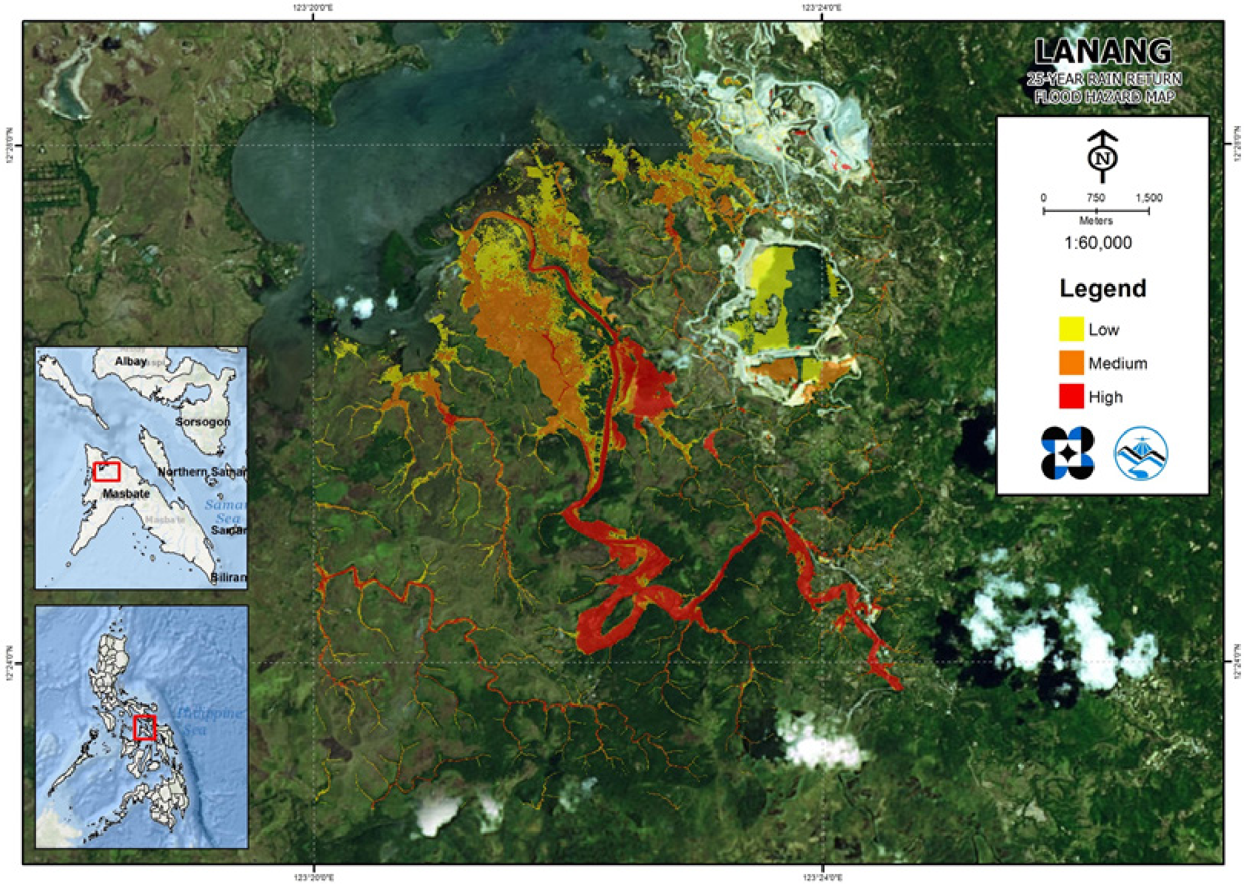


Figure 66. 25-year flood hazard map for the Lanang flood plain overlaid on Google Earth imagery.

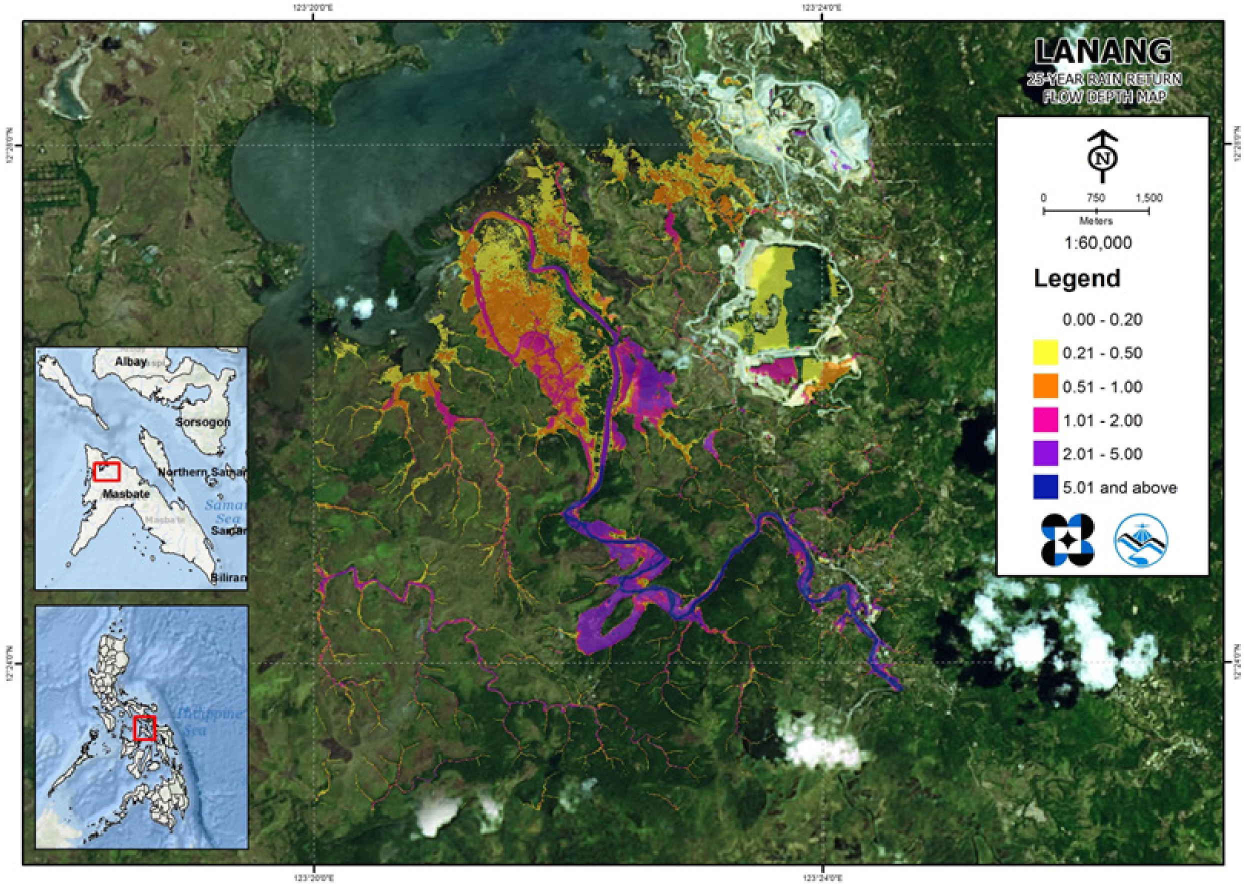


Figure 67. 25-year flow depth map for the Lanang flood plain overlaid on Google Earth imagery.

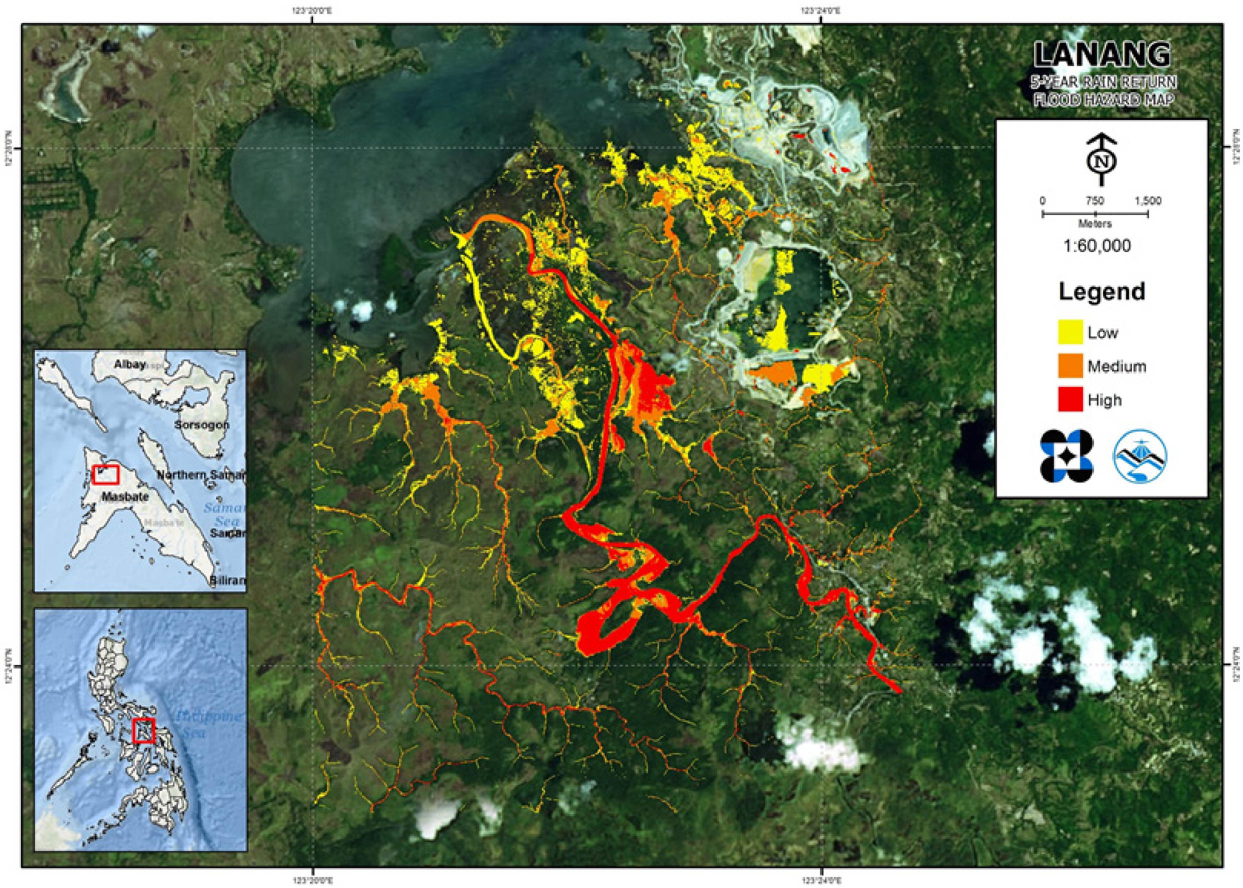


Figure 68. 5-year flood hazard map for the Lanang flood plain overlaid on Google Earth imagery.

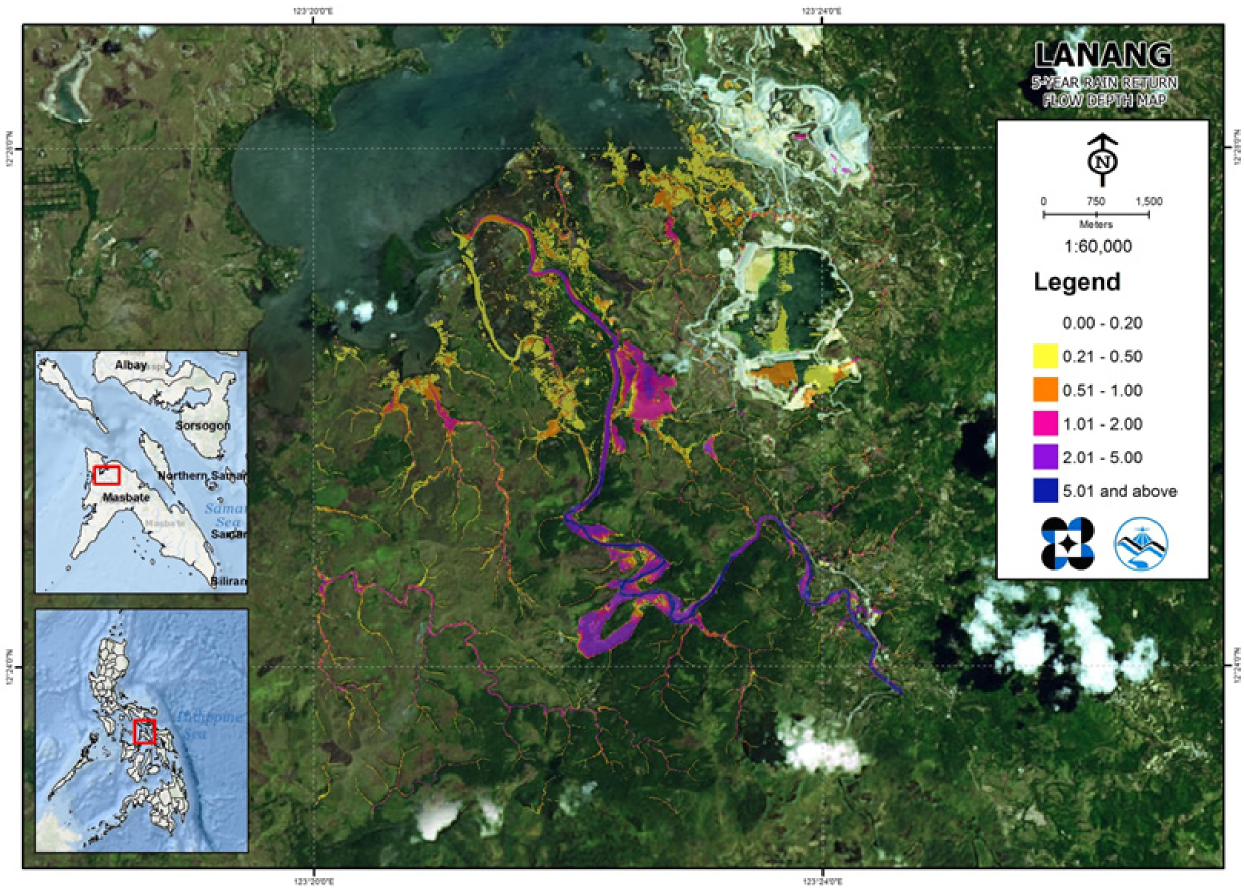


Figure 69. 5-year flow depth map for the Lanang flood plain overlaid on Google Earth imagery .

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Lanang River Basin, grouped accordingly by municipality, are listed below. For the said basin, one (1) municipality consisting of 14 barangays are expected to experience flooding when subjected to the three rainfall return period scenarios.

For the 5-year rainfall return period, 15.48% of the municipality of Aroroy with an area of 403.62 sq. km. will experience flood levels of less than 0.20 meters. The 0.94% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.46%, 0.37%, 0.83%, and 0.11% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and greater than 5 meters, respectively. Figure 70 depicts the areas affected in Aroroy in square kilometers by flood depth per barangay.

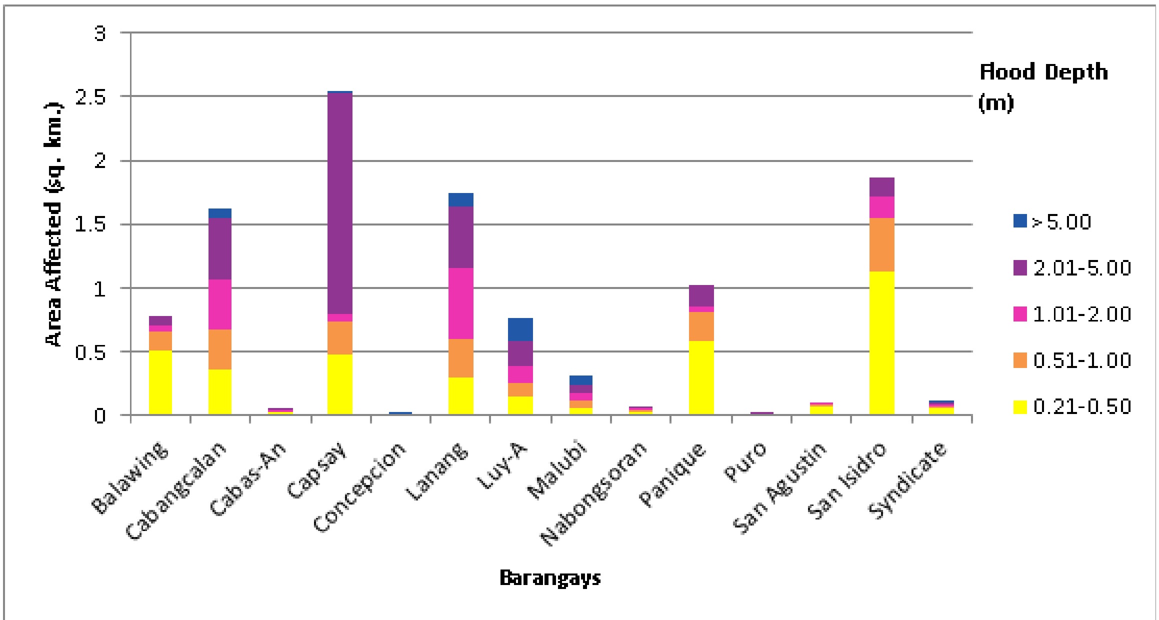


Figure 70. Affected Areas in Aroroy, Masbate during the 5-Year Rainfall Return Period

Table 33. Affected Areas in Aroroy, Masbate during the 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Aroroy (in sq. km.)						
	Balawing	Cabangcalan	Cabas-An	Capsay	Concepcion	Lanang	Luy-A
0.03-0.20	3.72	16.72	0.89	6.48	0.42	6.62	6.23
0.21-0.50	0.51	0.36	0.023	0.48	0.0078	0.31	0.15
0.51-1.00	0.14	0.31	0.0098	0.25	0.0042	0.29	0.11
1.01-2.00	0.057	0.39	0.0049	0.059	0.0013	0.56	0.13
2.01-5.00	0.074	0.48	0.0018	1.73	0.00097	0.48	0.21
> 5.00	0	0.076	0	0.00042	0.0012	0.1	0.18

	Malubi	Nabongsoran	Panique	Puro	San Agustin	San Isidro	Syndicate
0.03-0.20	2.74	3.13	3.28	0.22	1.32	9.21	1.51
0.21-0.50	0.059	0.032	0.58	0.0087	0.079	1.13	0.052
0.51-1.00	0.064	0.016	0.22	0.0022	0.0073	0.42	0.017
1.01-2.00	0.059	0.0092	0.055	0.0002	0.0008	0.16	0.02
2.01-5.00	0.057	0.0023	0.17	0.0001	0	0.15	0.011
> 5.00	0.069	0	0	0	0	0	0.00098

For the 25-year rainfall return period, 14.45% of the municipality of Aroroy with an area of 403.62 sq. km. will experience flood levels of less than 0.20 meters. 1.14% of the area will experience flood levels of 0.21 to 0.50 meters, while 0.9%, 0.54%, 1%, and 0.16% 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. Figure 71 depicts the areas affected in Aroroy in square kilometers by flood depth per barangay.

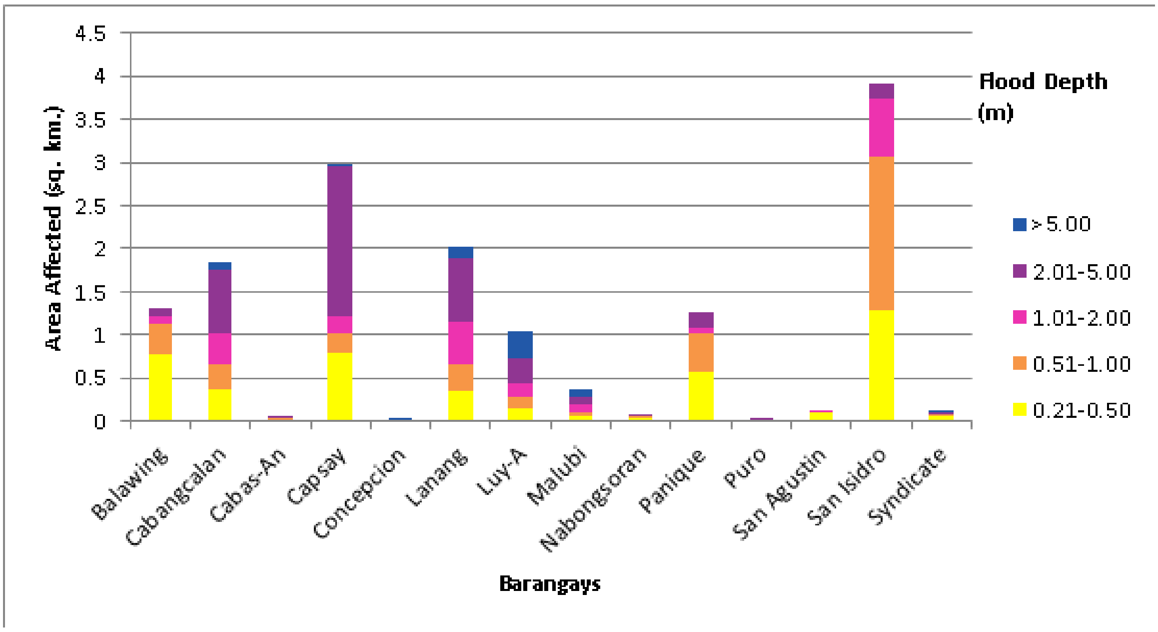


Figure 71. Affected Areas in Aroroy, Masbate during the 25-Year Rainfall Return Period

Table 34. Affected Areas in Aroroy, Masbate during the 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Aroroy (in sq. km.)						
	Balawing	Cabangcalan	Cabas-An	Capsay	Concepcion	Lanang	Luy-A
0.03-0.20	3.2	16.5	0.89	6.05	0.42	6.32	5.96
0.21-0.50	0.77	0.37	0.025	0.8	0.0094	0.35	0.15
0.51-1.00	0.37	0.3	0.012	0.22	0.0043	0.3	0.13
1.01-2.00	0.091	0.37	0.0054	0.21	0.0025	0.5	0.16
2.01-5.00	0.075	0.73	0.0025	1.74	0.0011	0.74	0.28
> 5.00	0	0.097	0	0.00052	0.0016	0.14	0.31

	Malubi	Nabongsoran	Panique	Puro	San Agustin	San Isidro	Syndicate
0.03-0.20	2.67	3.12	3.04	0.21	1.29	7.16	1.49
0.21-0.50	0.059	0.037	0.57	0.013	0.1	1.29	0.061
0.51-1.00	0.055	0.018	0.44	0.0023	0.0098	1.77	0.02
1.01-2.00	0.071	0.011	0.085	0.0001	0.0008	0.68	0.011
2.01-5.00	0.098	0.0031	0.17	0.0002	0	0.17	0.024
> 5.00	0.096	0	0	0	0	0	0.0039

For the 100-year rainfall return period, 13.91% of the municipality of Aroroy with an area of 403.62 sq. km. will experience flood levels of less than 0.20 meters. 1.07% of the area will experience flood levels of 0.21 to 0.50 meters, while 1.03%, 0.83%, 1.06%, and 0.27% 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. Figure 72 depicts the areas affected in Aroroy in square kilometers by flood depth per barangay.

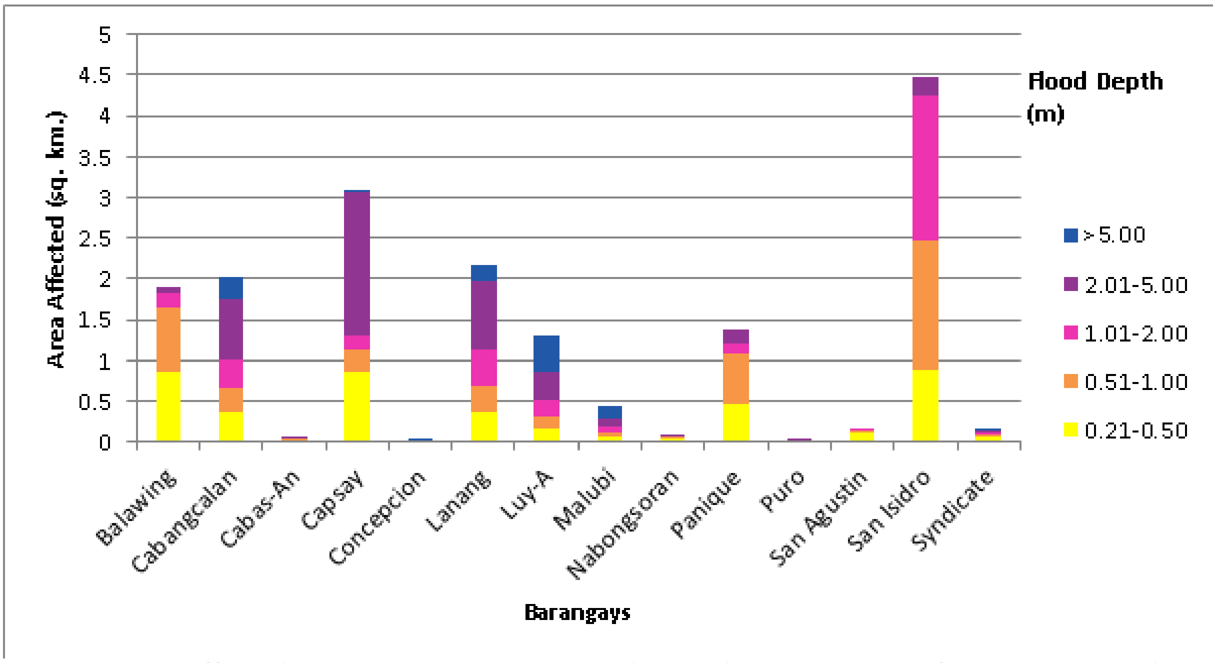


Figure 72. Affected Areas in Aroroy, Masbate during the 100-Year Rainfall Return Period.

Table 35. Affected Areas in Aroroy, Masbate during the 100-Year Rainfall Return Period.

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Aroroy (in sq. km.)						
	Balawing	Cabangcalan	Cabas-An	Capsay	Concepcion	Lanang	Luy-A
0.03-0.20	2.6	16.32	0.88	5.88	0.41	6.19	5.7
0.21-0.50	0.85	0.37	0.026	0.86	0.0099	0.37	0.16
0.51-1.00	0.81	0.29	0.015	0.28	0.0062	0.31	0.15
1.01-2.00	0.16	0.35	0.0069	0.17	0.004	0.46	0.2
2.01-5.00	0.075	0.74	0.0031	1.75	0.0033	0.83	0.35
> 5.00	0	0.28	0	0.0027	0.0019	0.19	0.45

	Malubi	Nabongsoran	Panique	Puro	San Agustin	San Isidro	Syndicate
0.03-0.20	2.61	3.11	2.92	0.21	1.26	6.59	1.46
0.21-0.50	0.061	0.044	0.47	0.016	0.13	0.89	0.075
0.51-1.00	0.053	0.02	0.61	0.0024	0.013	1.59	0.026
1.01-2.00	0.071	0.012	0.13	0.0006	0.0011	1.77	0.01
2.01-5.00	0.1	0.0038	0.17	0.0002	0	0.23	0.026
> 5.00	0.15	0	0	0	0	0	0.0094

Among the barangays in the municipality of Aroroy, Cabangcalan is projected to have the highest percentage of area that will experience flood levels at 4.55%. Meanwhile, San Isidro posted the second highest percentage of area that may be affected by flood depths at 2.74%.

Moreover, the generated flood hazard maps for the Lanang flood plain were used to assess the vulnerability of the educational and medical institutions in the flood plain. Using the flood depth units of PAG-ASA for hazard maps – "Low", "Medium", and "High" – the affected institutions were given their individual assessment for each Flood Hazard Scenario (5 yr, 25 yr, 100 yr) as shown in Table 33.

Table 36. Area covered by each warning level with respect to rainfall scenario

Warning Level	Area Covered in sq. km.		
	5-year	25-year	100-year
Low	4.02	4.73	4.35
Medium	2.75	5.16	6.37
High	4.5	5.49	6.64
Total	**11.27**	**15.38**	**17.36**

Of the 9 identified Educational Institutions in Lanang flood plain, four (4) were assessed to be exposed to low, while none was assessed to be exposed to both medium and high level flooding during the 5-year scenario. In the 25-year scenario, three (3) were assessed to be exposed to low, one (1) to medium, and none to high level flooding. In the 100-year scenario, two (2) were assessed to be exposed to low, two (2) to medium, and none to high level flooding.

Of the 3 identified Medical Institutions in Lanang flood plain, none was assessed to be exposed to any level of flooding during any rain return period scenario.

5.11 Flood Validation

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

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

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

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

The flood validation consists of 213 points randomly selected all over the Lanang floodplain. It has an RMSE value shown in Figure 73.

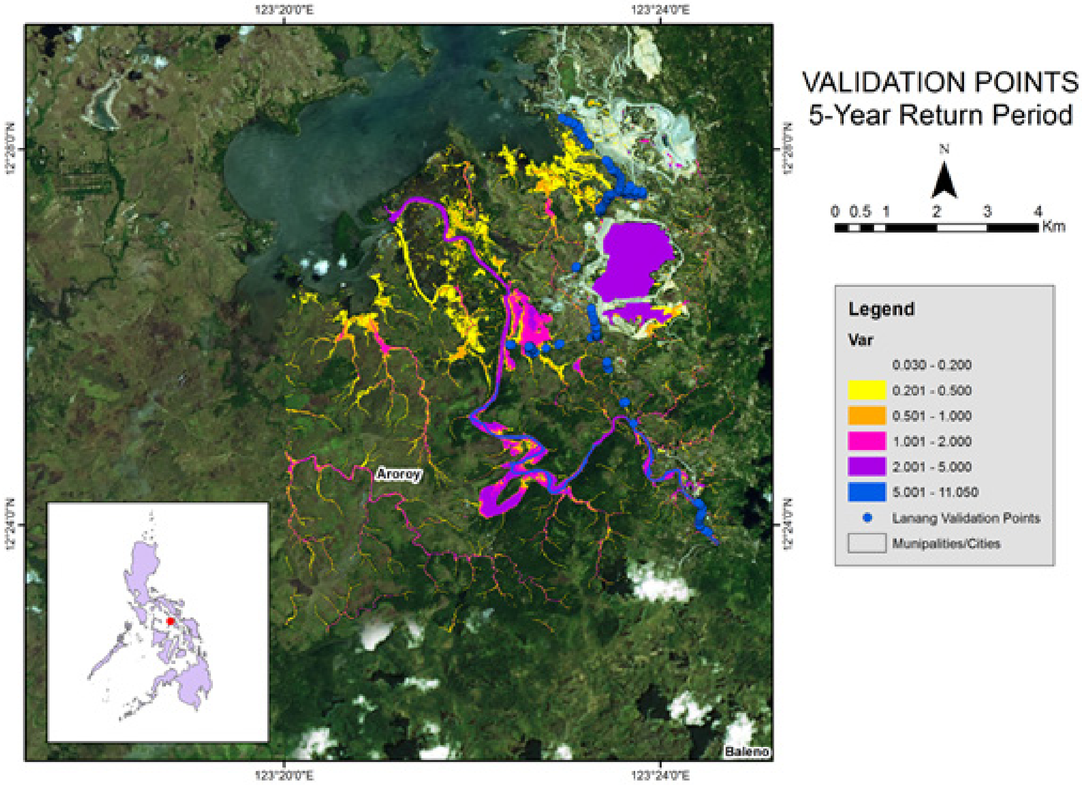


Figure 73. Validation points for the 5-Year Flood Depth Map of the Lanang Floodplain

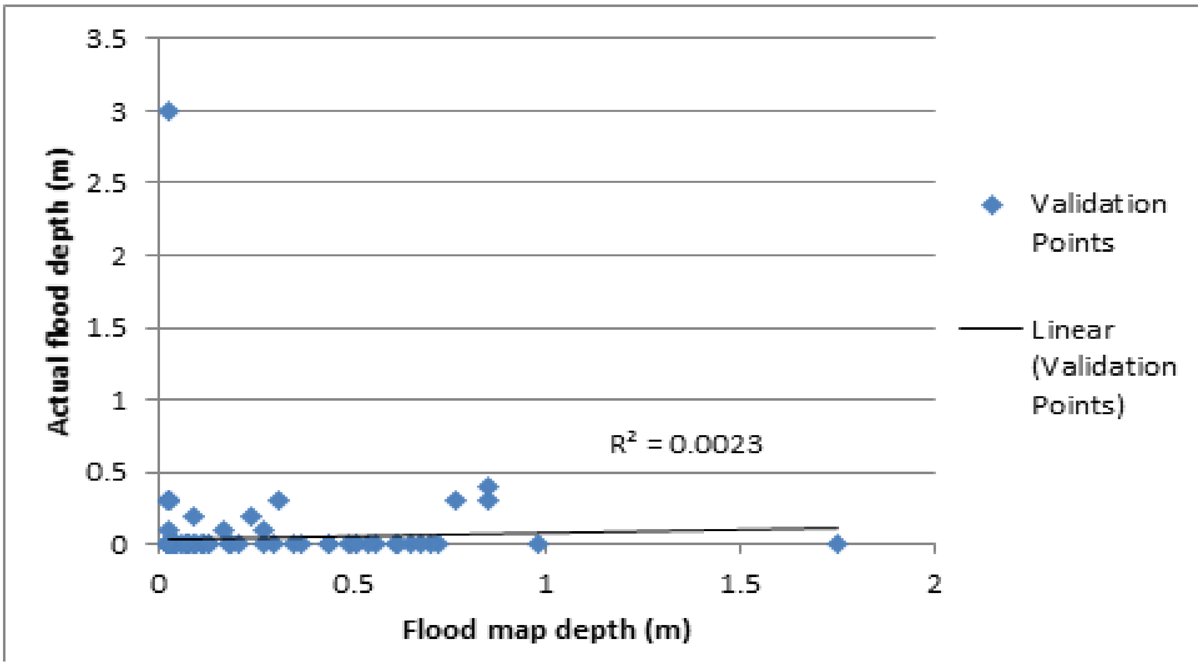


Figure 74. Flood depth map vs. Actual flood depth.

Table 37. Actual flood vs. Simulated flood depth in the Lanang River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	180	10	11	1	0	0	202
0-0.20	6	1	3	0	0	0	10
0.21-0.50	0	0	0	0	0	0	0
0.51-1.00	0	0	0	0	0	0	0
1.01-2.00	1	0	0	0	0	0	1
2.01-5.00	0	0	0	0	0	0	0
> 5.00	187	11	14	1	0	0	213
Total	54	33	38	10	0	0	135

On the whole, the overall accuracy generated by the flood model is estimated at 84.98%, with 181 points correctly matching the actual flood depths. In addition, there were 19 points estimated one level above and below the correct flood depths, 11 points estimated two levels above and below, and 2 points estimated three or more levels above and below the correct flood depths. A total of 25 points were overestimated while a total of 7 points were underestimated in the modelled flood depths of Lanang. Table35 depicts the summary of the accuracy assessment in the Lanang River Basin survey.

Table 38. The Summary of Accuracy Assessment in the Lanang River Basin Survey.

LANANG	No. of Points	%
Correct	50	**37.04**
Overestimated	29	21.48
Underestimated	56	41.48
Total	135	100

REFERENCES

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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 LiDAR Sensors used in the Lanang Floodplain Survey

Parameters and Specifications of the OPTECH 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, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
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)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	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% no-condensing

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

1. MST-28

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

Province: **MASBATE**
Station Name: **MST-28**
Order: **2nd**

Island: **LUZON**		Barangay: **BAT-ONGAN**
Municipality: **MANDAON**		
	PRS92 Coordinates	
Latitude: **12° 18' 35.15371"**	Longitude: **123° 21' 19.21293"**	Ellipsoidal Hgt: **49.12800 m.**
	WGS84 Coordinates	
Latitude: **12° 18' 30.47973"**	Longitude: **123° 21' 24.28923"**	Ellipsoidal Hgt: **104.64900 m.**
	PTM Coordinates	
Northing: **1361224.57 m.**	Easting: **538651.166 m.**	Zone: **4**
	UTM Coordinates	
Northing: **1,360,748.12**	Easting: **538,637.64**	Zone: **51**

Location Description

MST-28
From Masbate City Proper, travel for about 50.6 km. along the Nat'l. Highway going to Mambog Bridge at Brgy. Bat-ongan, Mandaon Town. Station is located at the right side wing of the said bridge. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete block protruding 0.05 m. above the ground surface, with inscriptions "MST-28 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-829**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1 MST-28

2. MST-32

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

April 10, 2014

CERTIFICATION

To whom it may concern:

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

Province: **MASBATE**
Station Name: **MST-32**
Order: **2nd**

Island:	**LUZON**			Barangay:	
Municipality:	**MILAGROS**				
		PRS92 Coordinates			
Latitude:	**12° 13' 7.66936"**	Longitude:	**123° 30' 26.72479"**	Ellipsoidal Hgt:	**3.78300 m.**
		WGS84 Coordinates			
Latitude:	**12° 13' 3.03064"**	Longitude:	**123° 30' 31.80788"**	Ellipsoidal Hgt:	**59.91100 m.**
		PTM Coordinates			
Northing:	**1351188.593 m.**	Easting:	**555213.396 m.**	Zone:	**4**
		UTM Coordinates			
Northing:	**1,350,715.65**	Easting:	**555,194.07**	Zone:	**51**

Location Description

MST-32
From Masbate City Proper, travel for about 26 km. along the Nat'l. Highway going to Pob. Milagros. Station is located at the compound of the Milagros Mun. Hall, 30 m. NW, 2 m. E of the concrete fence, 5 m. SW of the basketball court and 10 m. W of the volleyball court. Mark is the head of a 4 in. copper nail centered on a triangle on a 0.3 m. x 0.3 m. concrete, with inscriptions "MST-32 2007 NAMRIA".

Requesting Party: **UP-DREAM**
Pupose: **Reference**
OR Number: **8795949 A**
T.N.: **2014-838**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2 MST-32

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

Table A-3.1 MS-269

MS-269 - MST-28 (6:36:44 AM-10:31:44 AM) (S1)

Baseline observation:	MS-269 --- MST-28 (B1)
Processed:	5/13/2014 3:15:01 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.009 m
Vertical precision:	0.024 m
RMS:	0.004 m
Maximum PDOP:	2.923
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	4/4/2014 6:37:04 AM (Local: UTC+8hr)
Processing stop time:	4/4/2014 10:31:44 AM (Local: UTC+8hr)
Processing duration:	03:54:40
Processing interval:	5 seconds

Vector Components (Mark to Mark)

From:	MST-28				
Grid		Local		Global	
Easting	538790.668 m	Latitude	N12°18'30.47973"	Latitude	N12°18'30.47973"
Northing	1360689.389 m	Longitude	E123°21'24.28923"	Longitude	E123°21'24.28923"
Elevation	49.498 m	Height	104.649 m	Height	104.649 m

To:	MS-269				
Grid		Local		Global	
Easting	544123.868 m	Latitude	N12°24'21.62786"	Latitude	N12°24'21.62786"
Northing	1371483.415 m	Longitude	E123°24'21.40082"	Longitude	E123°24'21.40082"
Elevation	28.584 m	Height	83.308 m	Height	83.308 m

Vector					
ΔEasting	5333.200 m	NS Fwd Azimuth	26°22'11"	ΔX	-3185.907 m
ΔNorthing	10794.025 m	Ellipsoid Dist.	12044.246 m	ΔY	-4889.699 m
ΔElevation	-20.914 m	ΔHeight	-21.341 m	ΔZ	10536.100 m

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
LiDAR Operation	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP
FIELD TEAM			
LiDAR Operation	Senior Science Research Specialist (SSRS)	ENGR. GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	MARY CATHERINE ELIZABETH BALIGUAS	UP-TCAGP
		ENGR. IRO NIEL ROXAS	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	ENGR. GRACE SINADJAN	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. MARLON TORRE	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. MARK TANGONAN	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. JEFFREY ALAJAR	AAC
		CAPT. JOHN BRYAN DONGUINES	AAC

Annex 5. Data Transfer Sheet for Lanang Floodplain

DATA TRANSFER SHEET
4/22/2014(MASBATE)

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS (mb)	POS (mb)	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
4/1/2014	1291P	1BLK32KL091A	PEGASUS	2.91	3.36	9.99	256	43.6	332	29.8	NA	7.81	1KB	602	376	NA	Z:\Airborne_Raw\1291P
4/1/2014	1293P	1BLK32H091B	PEGASUS	1.75	1.46	3.86	115	24.7	213	15.6	NA	7.81	1KB	221	68.5	NA	Z:\Airborne_Raw\1293P
4/2/2014	1295P	1BLK32E092A	PEGASUS	2.93	3.42	8.9	225	54.2	404	29.2	NA	867KB	1KB	512	137	NA	Z:\Airborne_Raw\1295P
4/3/2014	1299P	1BLK32FG093A	PEGASUS	2.68	3.23	8.65	232	33.4	267	26.8	NA	7.59	1KB	358	113	NA	Z:\Airborne_Raw\1299P
4/3/2014	1301P	1BLK32F093B	PEGASUS	1.95	2.42	5.95	149	44.6	352	19.6	NA	7.59	1KB	538	201	NA	Z:\Airborne_Raw\1301P
4/4/2014	1303P	1BLK32A094A	PEGASUS	2.77	3.48	2.99	218	52.5	404	29.4	NA	6.67	1KB	694	186	NA	Z:\Airborne_Raw\1303P
4/4/2014	1305P	1BLK32A094B	PEGASUS	2.41	2.85	6.88	161	44.3	324	23.3	NA	6.67	1KB	400	2.41	NA	Z:\Airborne_Raw\1305P
4/5/2014	1307P	1BLK32DG095A	PEGASUS	3.84	4.48	4.12	271	67.2	514	37.7	NA	6.49	1KB	523	270	NA	Z:\Airborne_Raw\1307P
4/8/2014	1319P	1BLK32B098A	PEGASUS	3.66	4.32	9.93	254	17.7	526	36.2	NA	4.95	1KB	731	382	NA	Z:\Airborne_Raw\1319P
4/10/2014	1327P	1BLK32D100A	PEGASUS	2.16	2.47	6.99	175	37	277	21.7	NA	5.27	1KB	747	243	NA	Z:\Airborne_Raw\1327P
4/11/2014	1331P	1BLK32B101A	PEGASUS	1.76	1.9	5.09	134	29.8	232	17.8	NA	4.09	1KB	574	316	NA	Z:\Airborne_Raw\1331P

Received from

Name: CARLS JOTRAYIN
Position: RA
Signature: [signature] 4/23/14

Received by

Name: JOIDA F. PRIETO
Position: SSRS
Signature: [signature] 4/23/14

Figure A-5.1. Data Transfer Sheet for Lanang Foodplain

Annex 6. Flight Logs for the Flight Missions

1. Flight Log for 1BLK32A094A Mission

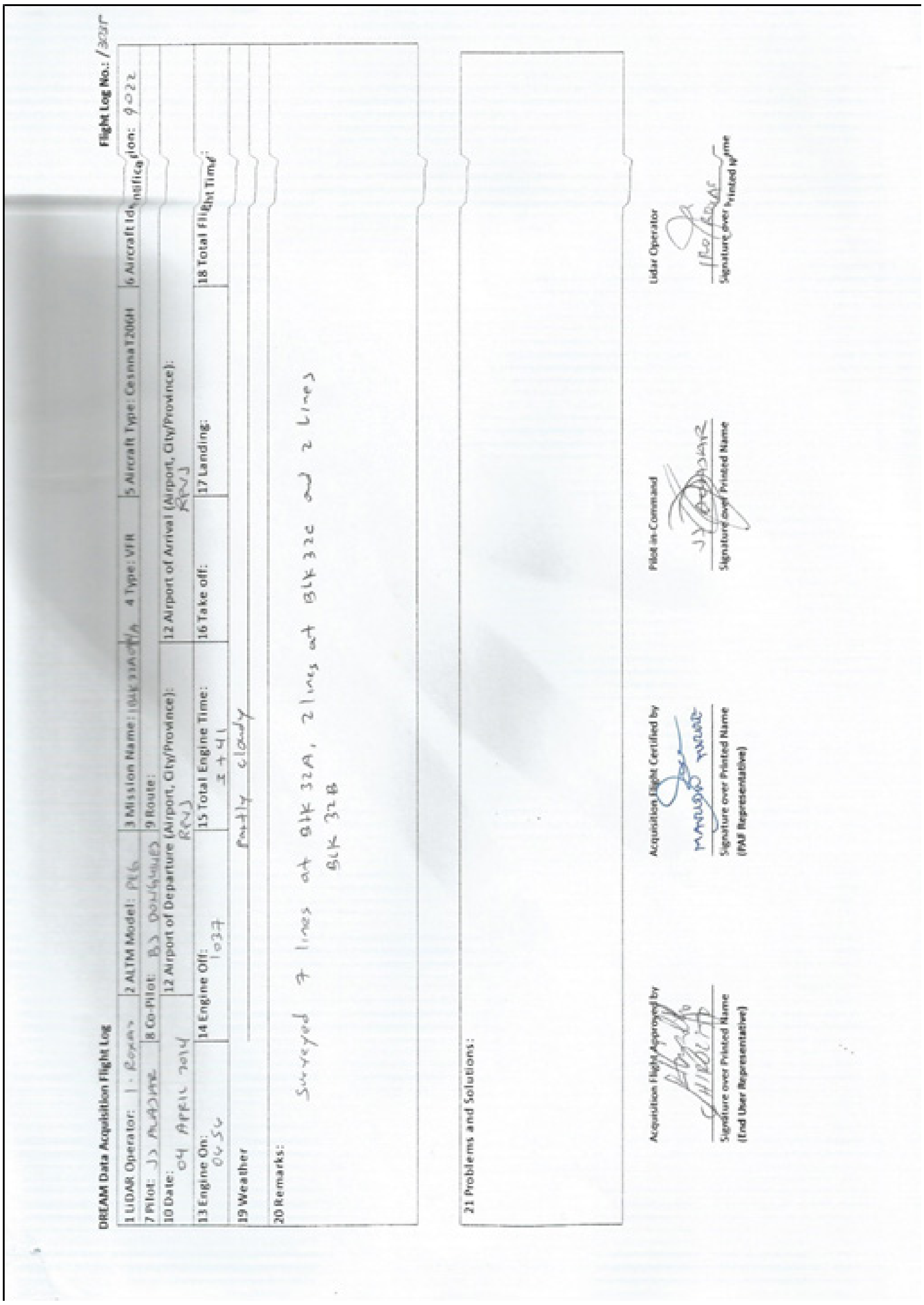
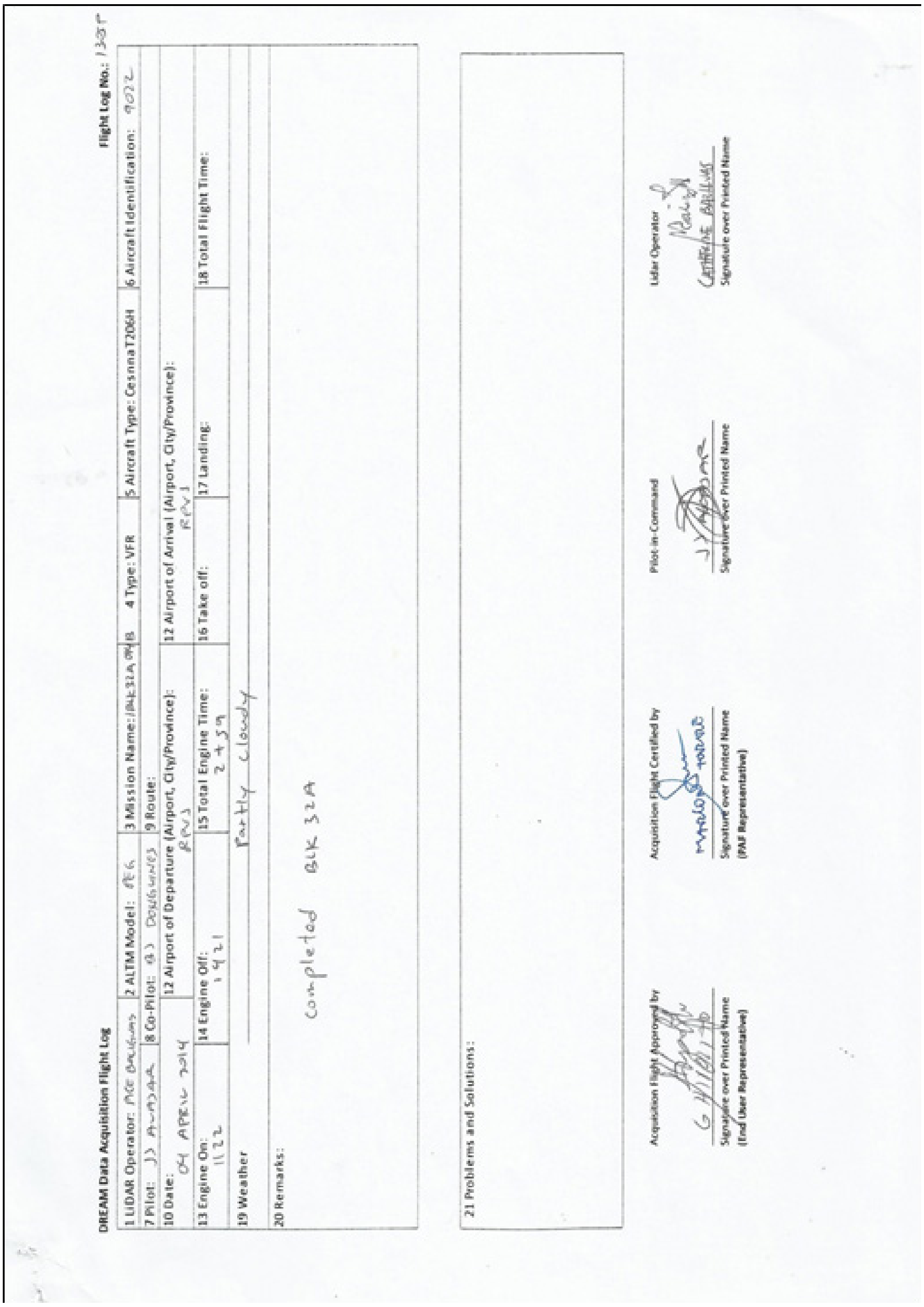


Figure A-6.1. Flight Log for 1BLK32A094A Mission

2. Flight Log for 1BLK32A094B Mission



DREAM Data Acquisition Flight Log

Flight Log No.:

1 LiDAR Operator:	2 ALTM Model: PEG	3 Mission Name: 1BLK32A094B	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot:	8 Co-Pilot:	9 Route:			
10 Date: 04 APRIL 2014	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 1122	14 Engine Off: 1421	15 Total Engine Time: 2+59	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Partly cloudy					
20 Remarks: completed BLK 32A					

21 Problems and Solutions:

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

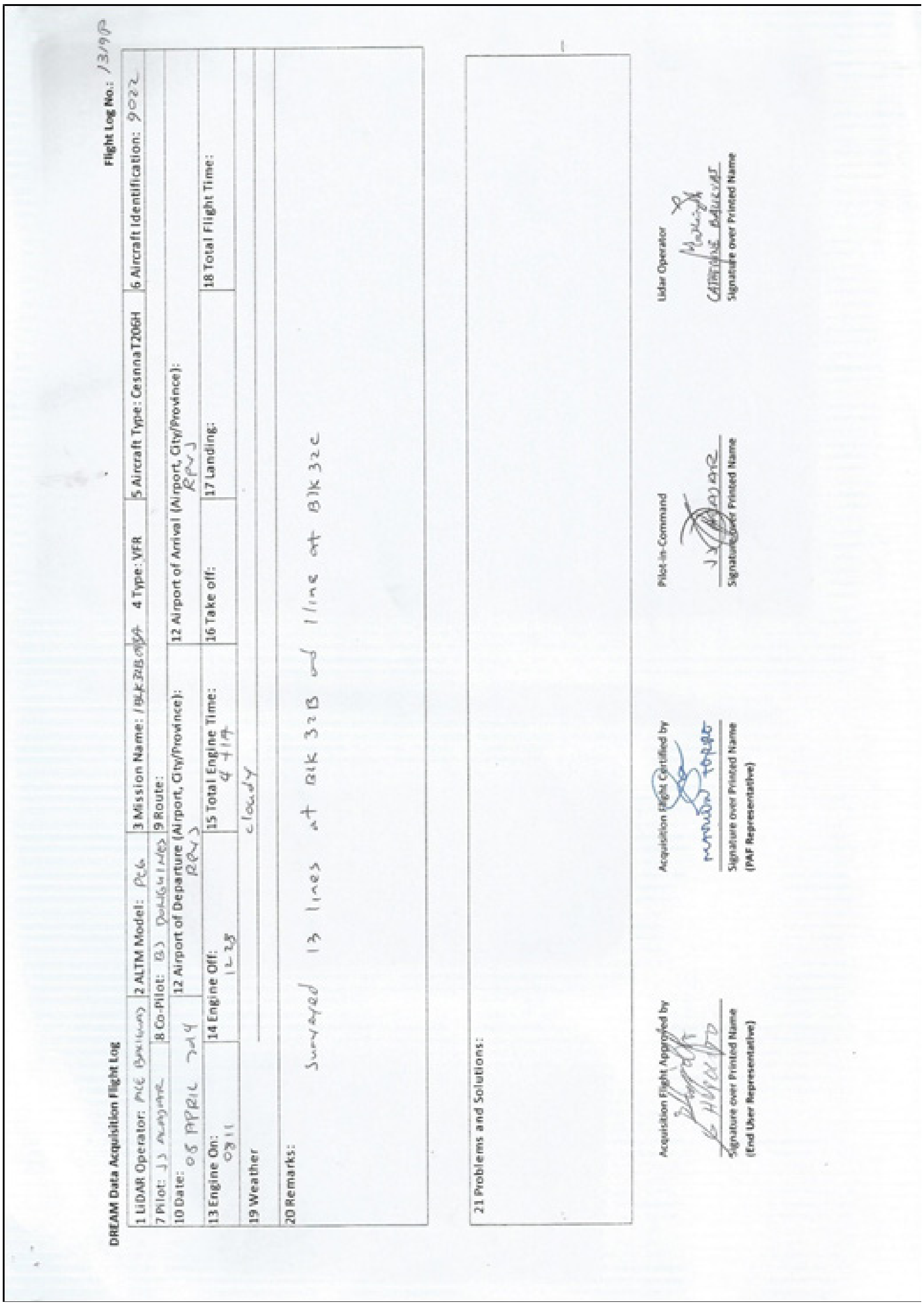
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Figure A-6.2. Flight Log for 1BLK32A094B Mission

3. Flight Log for 1BLK32B098A Mission


DREAM Data Acquisition Flight Log

Flight Log No.: 1319P

1 LiDAR Operator: MCE Balicuas	2 ALTM Model: Pc6	3 Mission Name: 1BLK32B098A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: JJ Alajar	8 Co-Pilot: BJ Dongiuines	9 Route:			
10 Date: 08 APRIL 2014	12 Airport of Departure (Airport, City/Province): RPVJ		12 Airport of Arrival (Airport, City/Province): RPVJ		
13 Engine On: 0811	14 Engine Off: 1228	15 Total Engine Time: 4+17	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	cloudy				

20 Remarks:

Surveyed 13 lines at BLK 32B and 1 line at BLK 32C

21 Problems and Solutions:

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

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

Pilot-in-Command — JJ Alajar — Signature over Printed Name

Lidar Operator — Catherine Balicuas — Signature over Printed Name

Figure A-6.3. Flight Log for 1BLK32B098A Mission

4. Flight Log for 1BLK32B101A Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 1331P

1 LIDAR Operator: PGE Dahlungas	2 ALTM Model: Peg	3 Mission Name: 1BLK32B101A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: JJ Ardiente	8 Co-Pilot: JS Dohlungas	9 Route:			
10 Date: 11 April 2016	12 Airport of Departure (Airport, City/Province): Revs		12 Airport of Arrival (Airport, City/Province): Revs		
13 Engine On: 0701	14 Engine Off: 0936	15 Total Engine Time: 2+35	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Cloudy				

20 Remarks:

Surveyed 5 lines at BLK 32B and covered voids within the area

21 Problems and Solutions:

Acquisition Flight Approved by

Signature over Printed Name
(End User Representative)

Acquisition Flight Certified by

Signature over Printed Name
(PAF Representative)

Pilot-in-Command

JJ Ardiente

Signature over Printed Name

Lidar Operator

Signature over Printed Name

Figure A-6.4. Flight Log for 1BLK32B101A Mission

Annex 7. Flight Status Reports

Table A-7.1. Flight Status Report

MASBATE

March 18 to April 11, 2014

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1303P	BLK 32A; 32B; 32C	1BLK32A094A	IN Roxas	April 4, 2014	Surveyed BLK32A, BLK32B and BLK32C
1305P	BLK 32A	1BLK32A094B	MCE Baliguas	April 4, 2014	Completed BLK32A
1319P	BLK 32B	1BLK32B098A	MCE Baliguas	April 8, 2014	Surveyed 5 lines at BLK32B and covered voids within the area
1331P	BLK 32B	1BLK32B101A	MCE Baliguas	April 11, 2014	Surveyed 5 lines at BLK32B and covered voids within the area

LAS BOUNDARIES PER FLIGHT

Flight No.: 1303P
Area: BLK 32A, BLK 32B, BLK 32C
Mission Name: 1BLK32A094A
Parameters: Altitude: 1000/1200 m; Scan Frequency: 30 Hz;
Scan Angle: 25 deg; Overlap: 30%

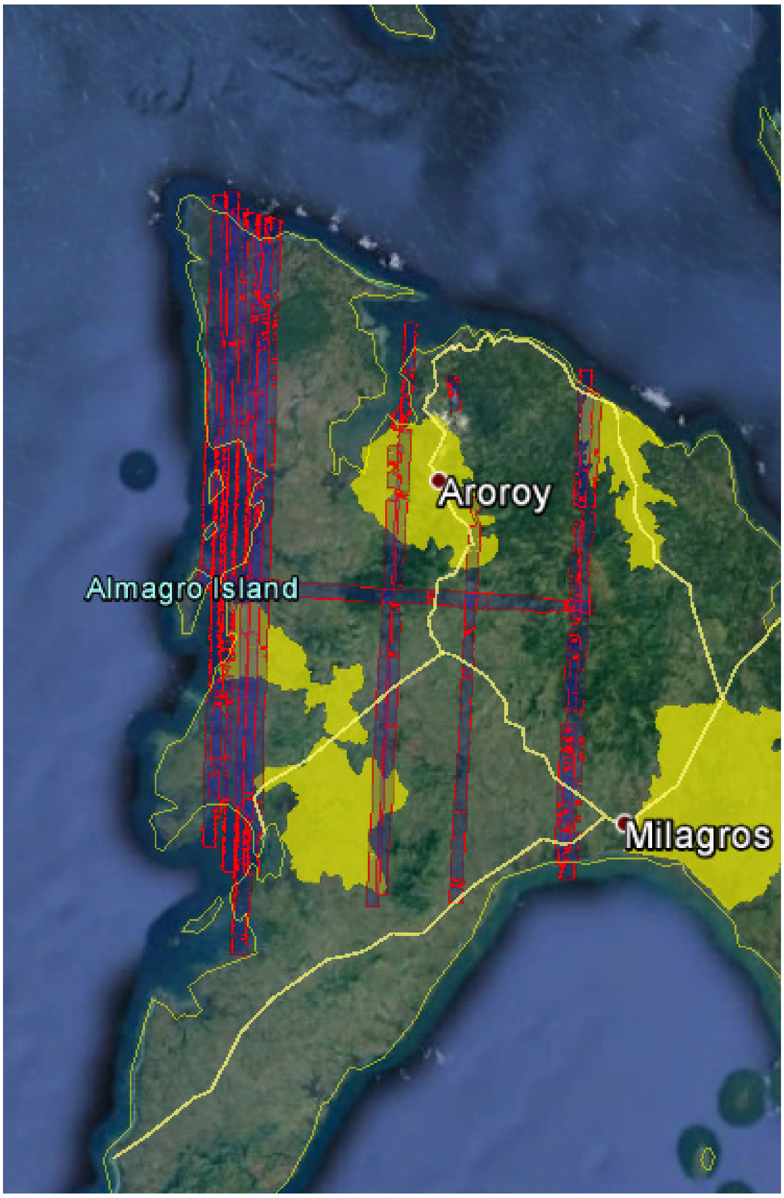


Figure A-7.1. Flight Log for Mission 1303P

Flight No.: 1305P
Area: BLK 32A
Mission Name: 1BLK32A094B
Parameters: Altitude: 1100 m; Scan Frequency: 30 Hz;
Scan Angle: 25 deg; Overlap: 25%

LAS

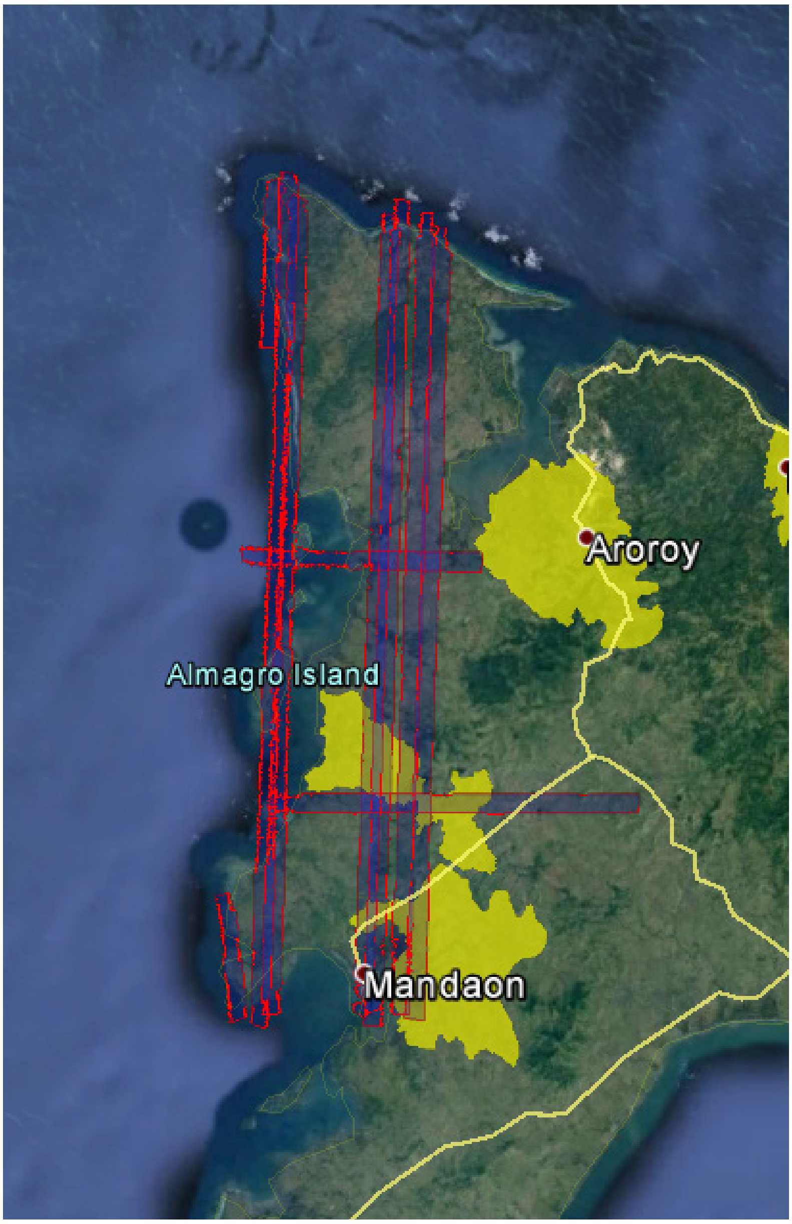


Figure A-7.2. Flight Log for Mission 1305P

Flight No.: 1319P
Area: BLK 32B
Mission Name: 1BLK32B098A
Parameters: Altitude: 900 m; Scan Frequency: 30 Hz;
Scan Angle: 25 deg; Overlap: 35%

LAS

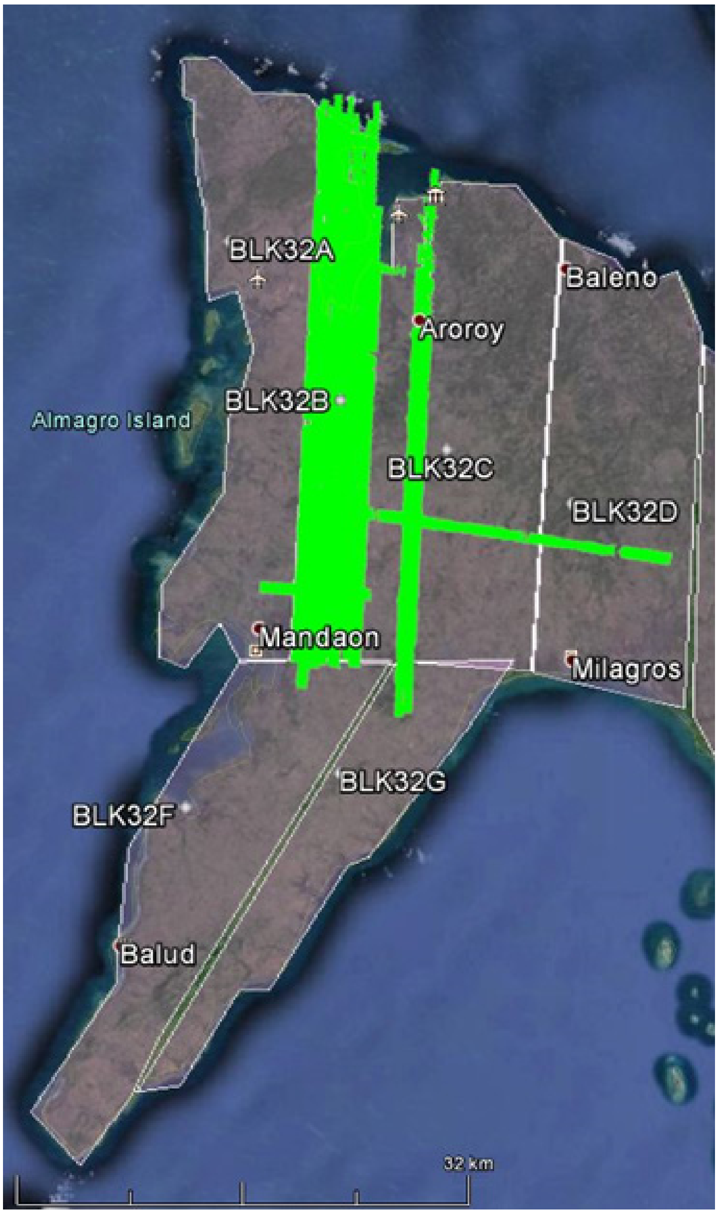


Figure A-7.3. Flight Log for Mission1319P

Flight No.: 1331P
Area: BLK 32B
Mission Name: 1BLK32B101A
Parameters: Altitude: 800 m; Scan Frequency: 30 Hz;
Scan Angle: 25 deg; Overlap: 35%

LAS

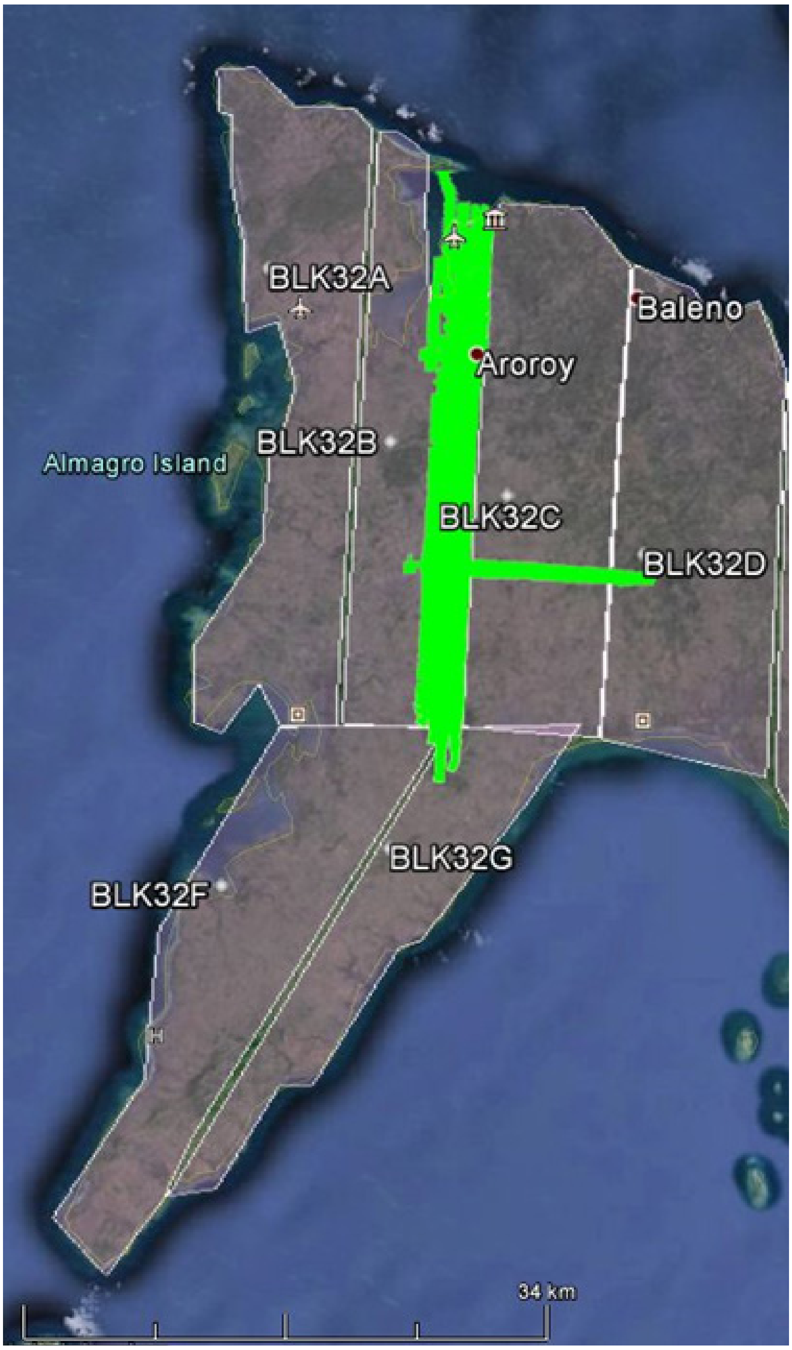


Figure A-7.4. Flight Log for Mission 1331P

Annex 8. Mission Summary Reports

Table A-8.1. **Blk 76O**

Flight Area	Pagadian
Mission Name	**Blk 76O**
Inclusive Flights	23096P
Range data size	7.07 GB
POS data size	164.2 MB
Base data size	90.32 MB
Image	n/a
Transfer date	March 01, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.7
RMSE for Down Position (<8.0 cm)	3.0
Boresight correction stdev (<0.001deg)	0.000290
IMU attitude correction stdev (<0.001deg)	0.002830
GPS position stdev (<0.01m)	0.0022
Minimum % overlap (>25)	21.83
Ave point cloud density per sq.m. (>2.0)	4.05
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	87
Maximum Height	355.86 m
Minimum Height	67.90 m
Classification (# of points)	
Ground	58,381,992
Low vegetation	43,493,419
Medium vegetation	47,030,745
High vegetation	157,370,432
Building	4,864,208
Orthophoto	Yes
Processed by	Engr. Angelo Carlo Bongat, Engr. Merven Matthew Natino, Engr. Melissa Fernandez

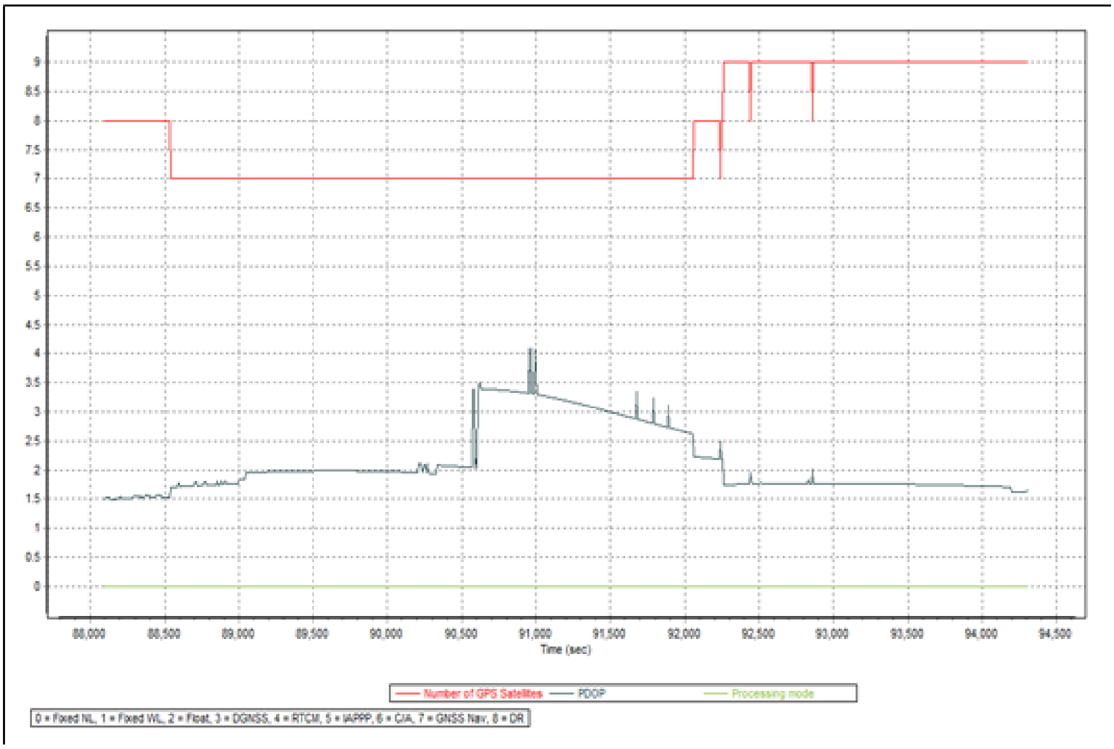


Figure A-8.1. Solution Status

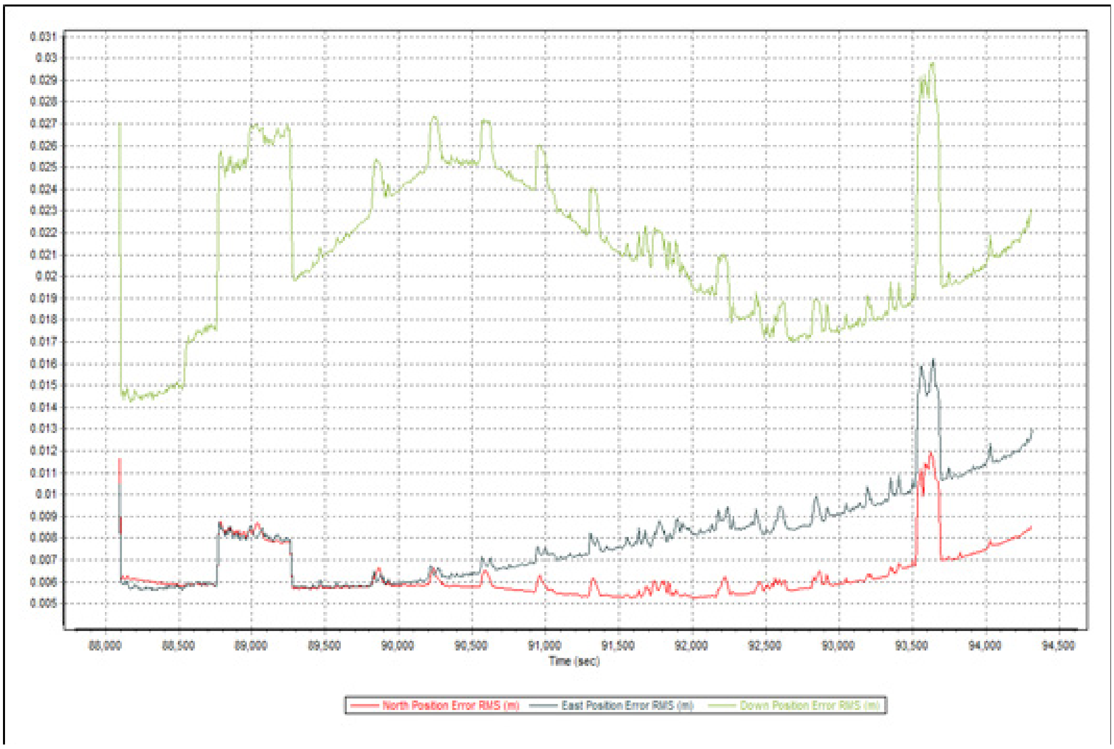


Figure A-8.2. Smoothed Performance Metric Parameters

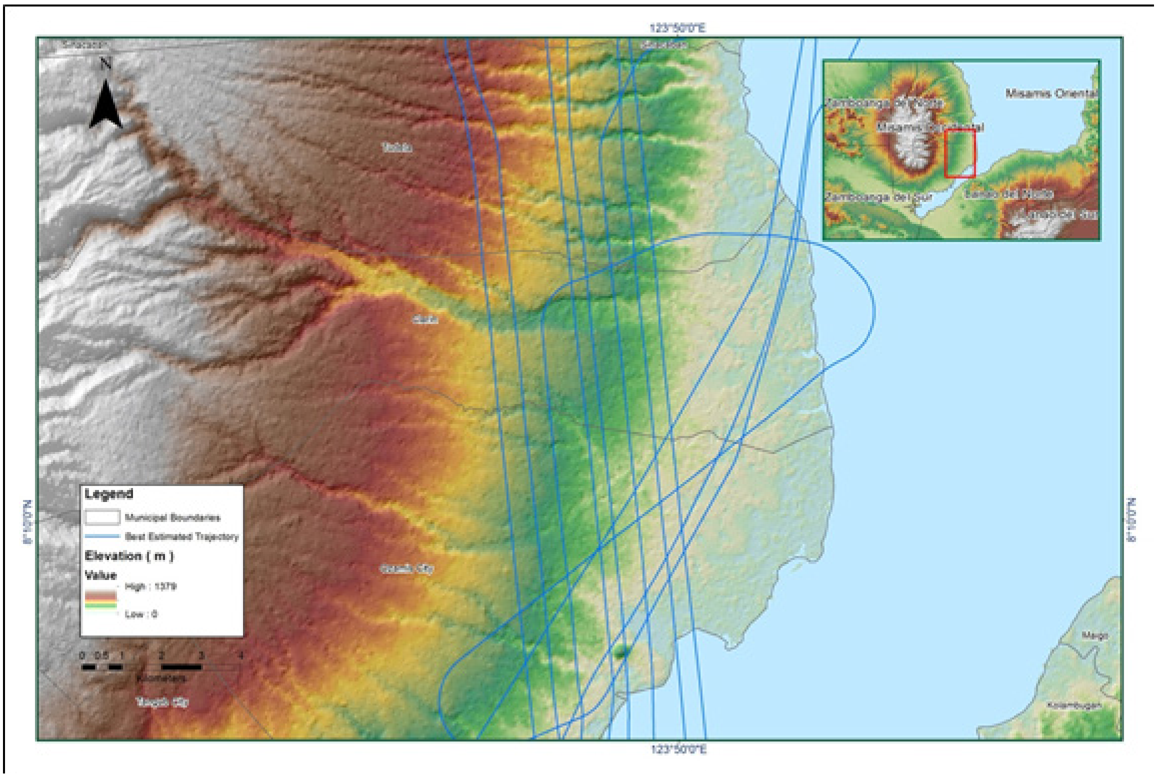


Figure A-8.3. Best Estimated Trajectory

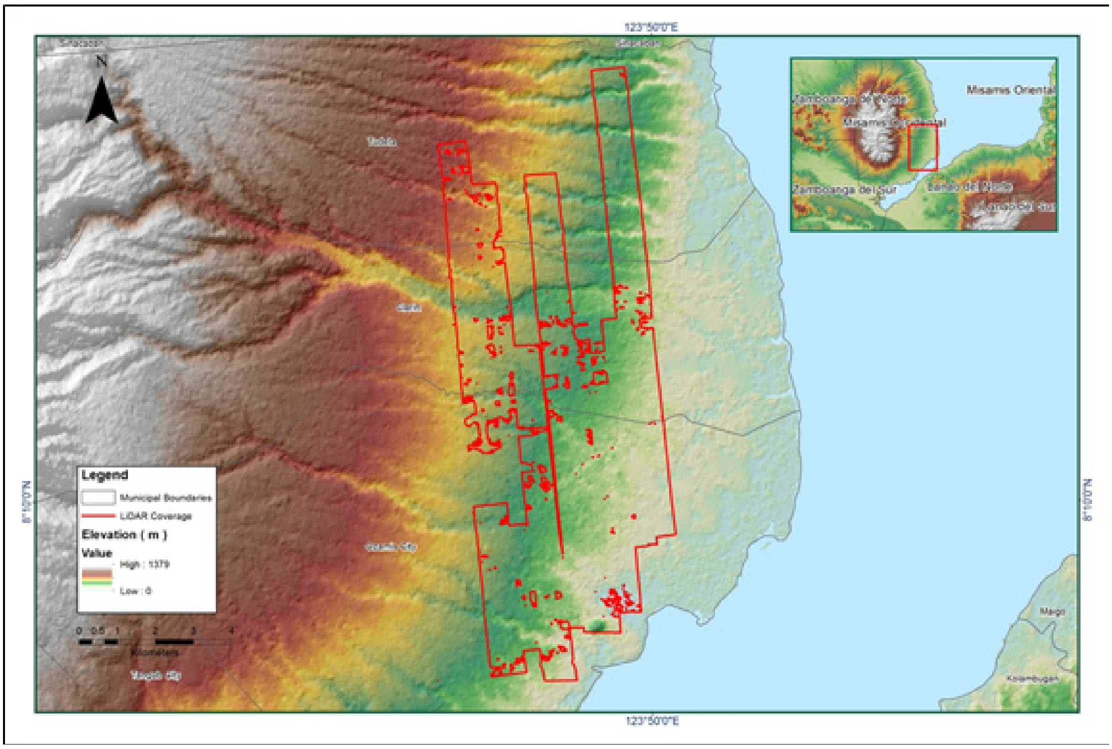


Figure A-8.4. Coverage of LiDAR Data

Table A-8.2. Blk 76O_Supplement

Flight Area	**Pagadian**
Mission Name	Blk 76O_Supplement
Inclusive Flights	23116P
Range data size	24.4 GB
POS data size	294 MB
Base data size	63.8 MB
Image	n/a
Transfer date	March 10, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.2
RMSE for East Position (<4.0 cm)	1.0
RMSE for Down Position (<8.0 cm)	3.5
Boresight correction stdev (<0.001deg)	0.000269
IMU attitude correction stdev (<0.001deg)	0.000354
GPS position stdev (<0.01m)	0.0009
Minimum % overlap (>25)	40.81
Ave point cloud density per sq.m. (>2.0)	4.53
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	50
Maximum Height	285.79 m
Minimum Height	73.96 m
Classification (# of points)	
Ground	50,283,577
Low vegetation	45,189,706
Medium vegetation	43,272,105
High vegetation	148,620,455
Building	3,336,066
Orthophoto	No
Processed by	Engr. Shiela-Maye Santillan, Aljon Rae Araneta, Marie Denise Bueno

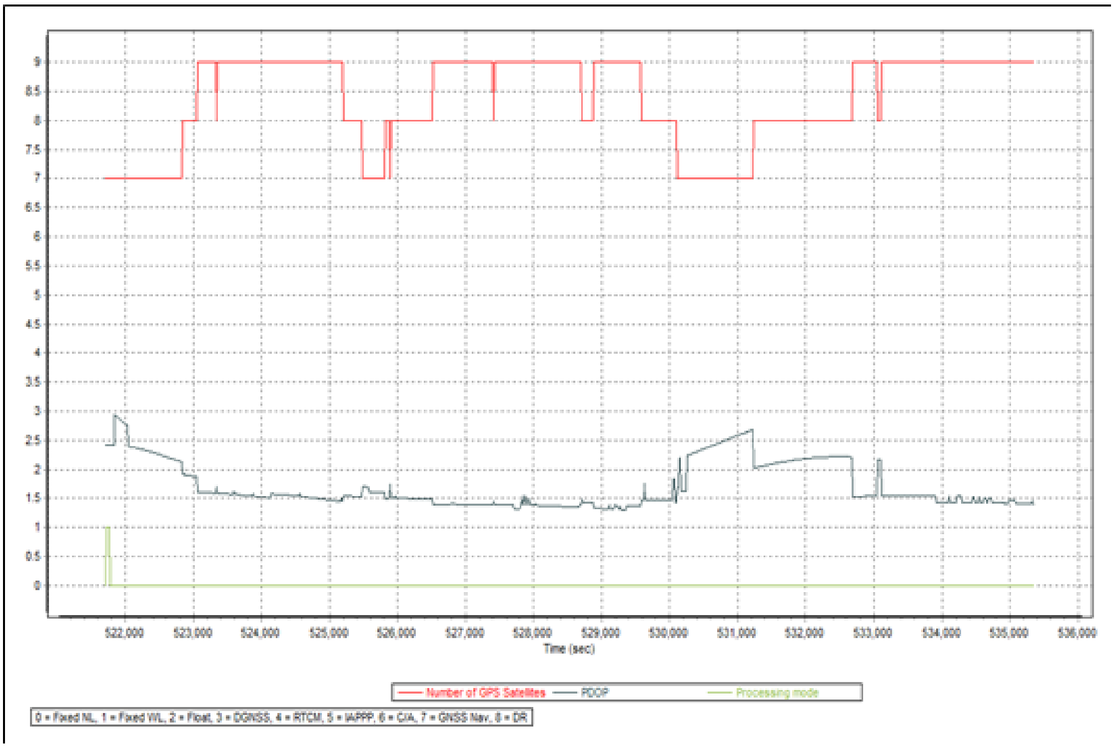


Figure A-8.5. Solution Status

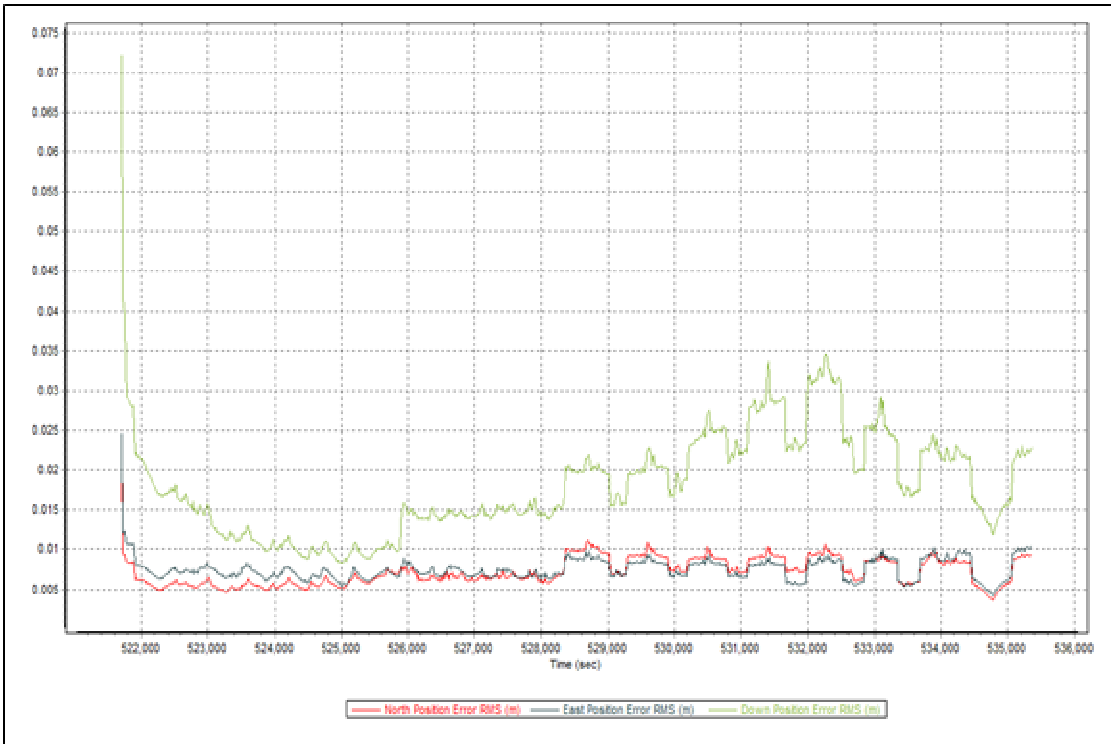


Figure A-8.6. Smoothed Performance Metric Parameters

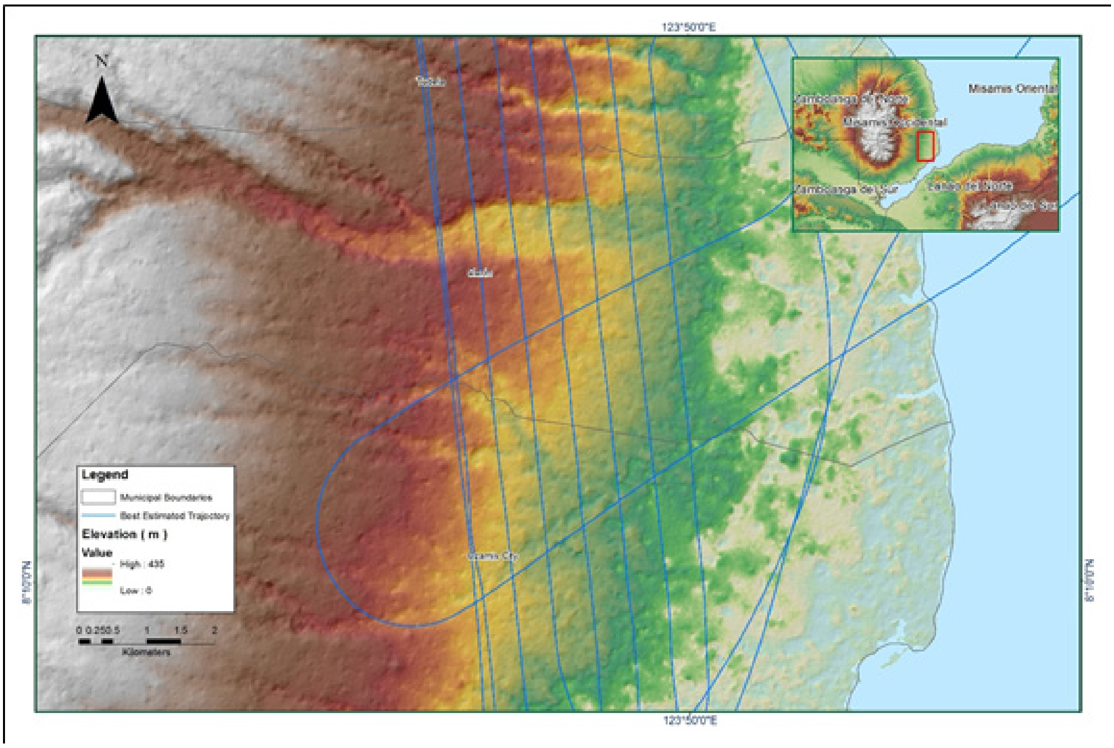


Figure A-8.7. Best Estimated Trajectory

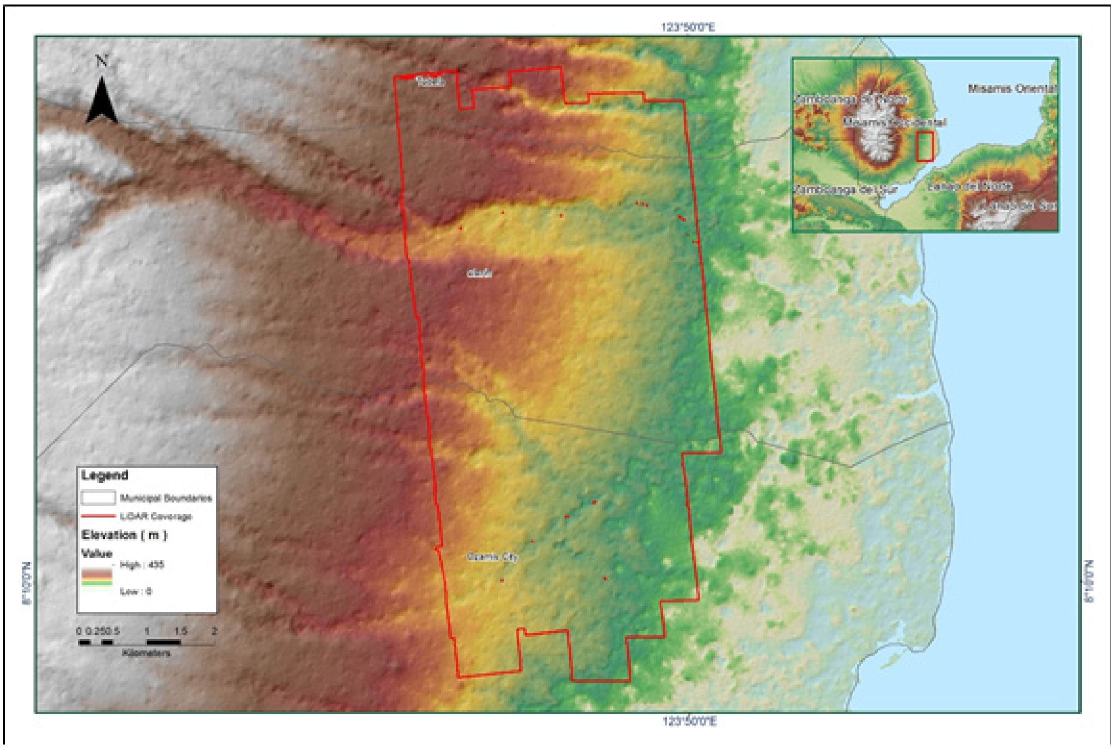


Figure A-8.9. Coverage of LiDAR Data

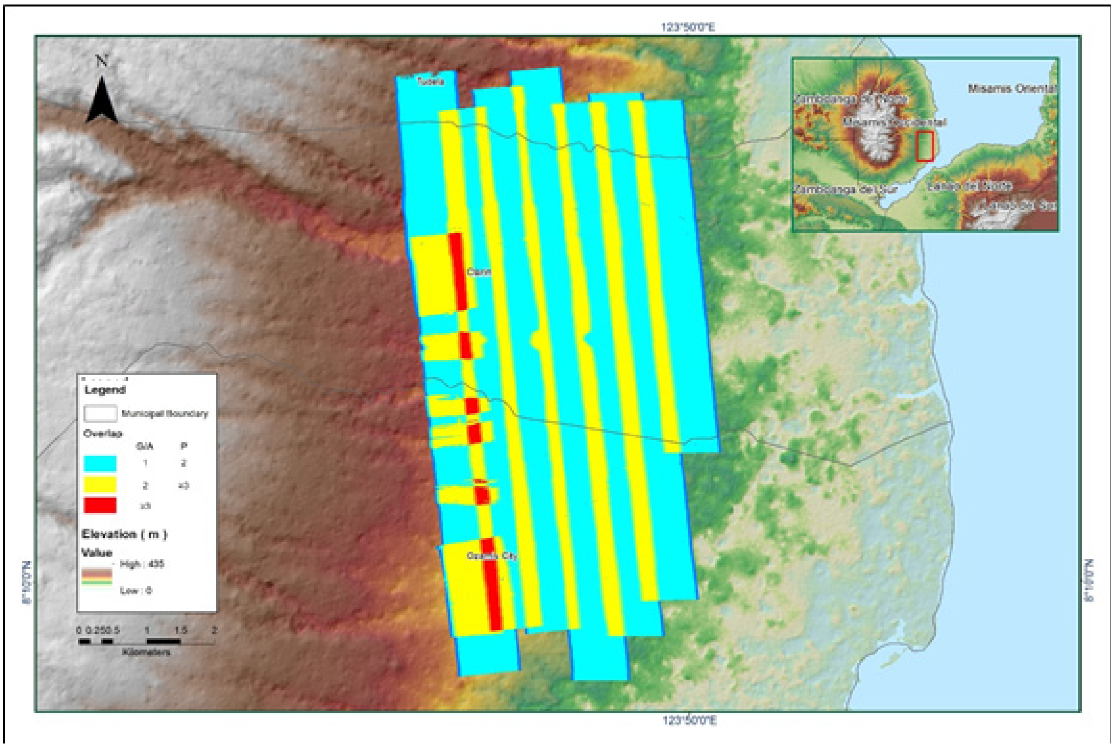


Figure A-8.10. Image of data overlap

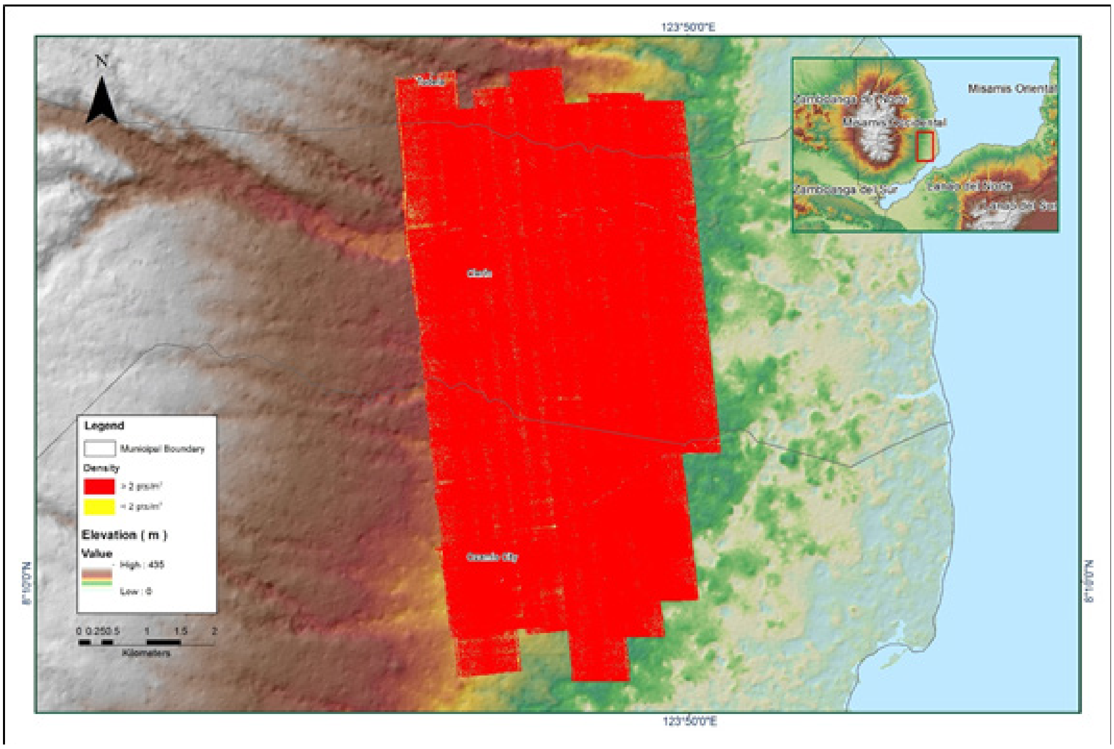


Figure A-8.11. Density map of merged LiDAR data

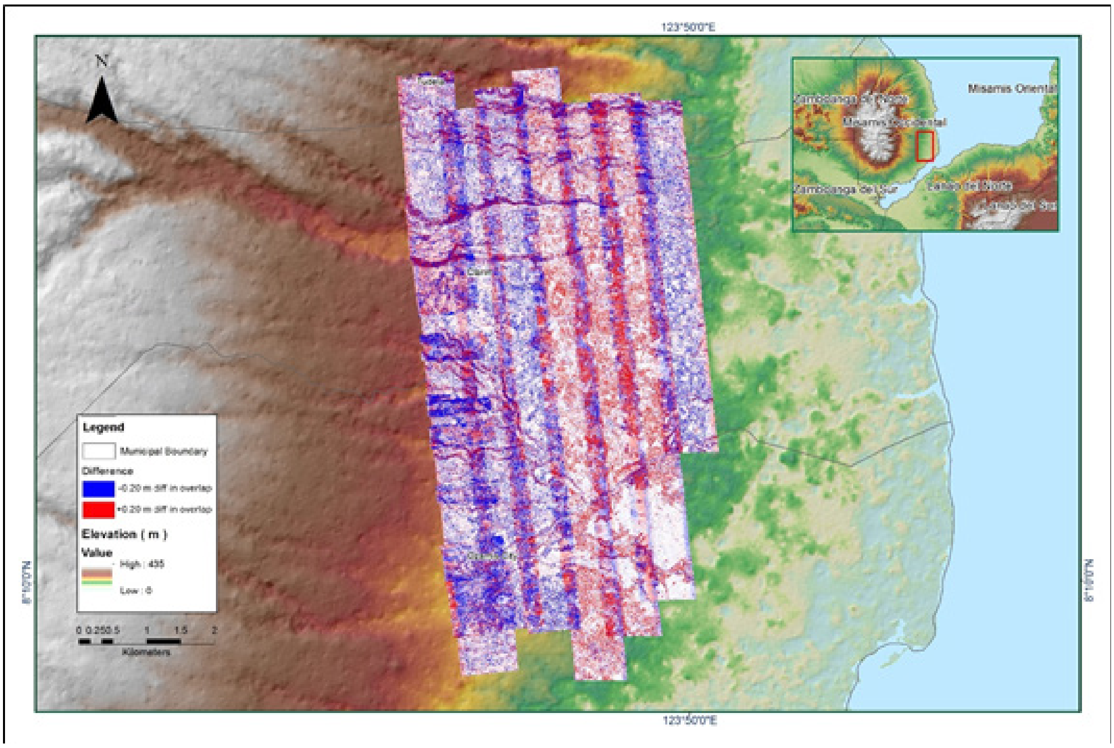


Figure A-8.12. Elevation difference between flight lines

Table A-8.2. Blk69F

Flight Area	Dipolog
Mission Name	Blk69F
Inclusive Flights	2133P,2135P,2181P
Range data size	43.4 GB
POS	501.6 MB
Image	79.8 GB
Transfer date	November 19, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	1.16
RMSE for East Position (<4.0 cm)	1.04
RMSE for Down Position (<8.0 cm)	1.85
Boresight correction stdev (<0.001deg)	0.000253
IMU attitude correction stdev (<0.001deg)	0.001628
GPS position stdev (<0.01m)	0.0059
Minimum % overlap (>25)	46.32%
Ave point cloud density per sq.m. (>2.0)	4.58
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	308
Maximum Height	420.83 m
Minimum Height	53.91 m
Classification (# of points)	
Ground	252,809,434
Low vegetation	288,314,909
Medium vegetation	302,935,924
High vegetation	361,519,536
Building	32,102,903
Orthophoto	Yes

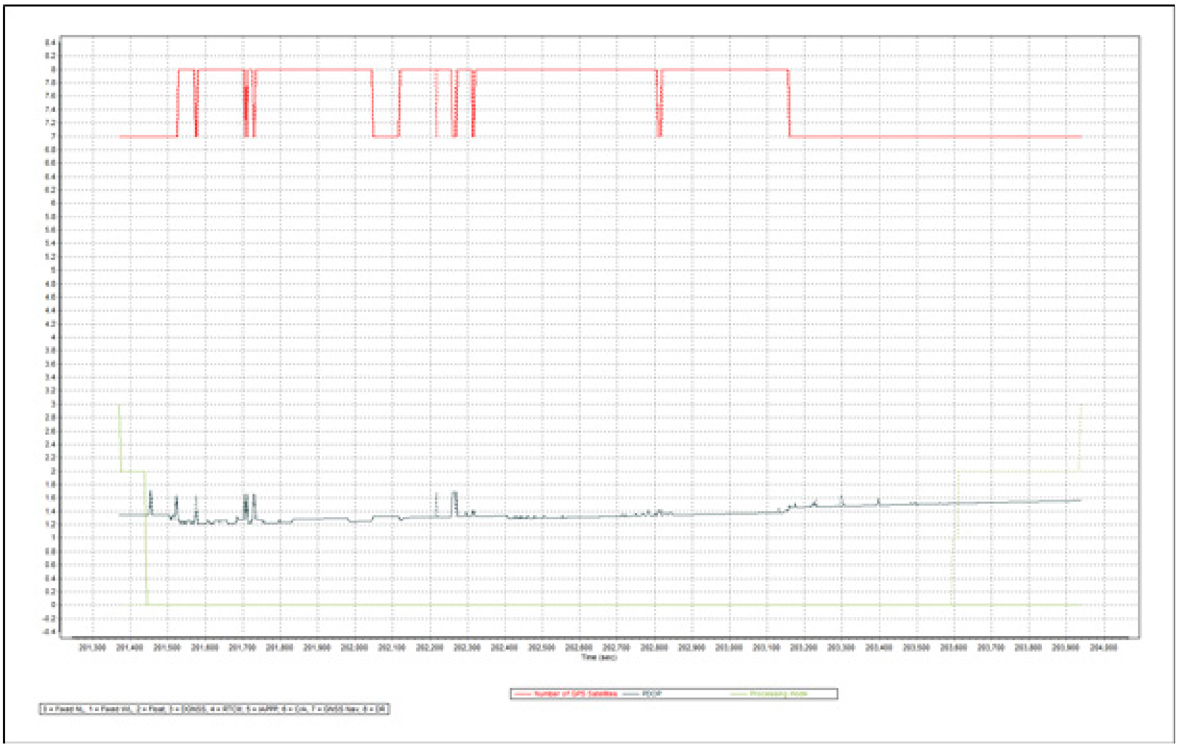


Figure A-8.13. Solution Status

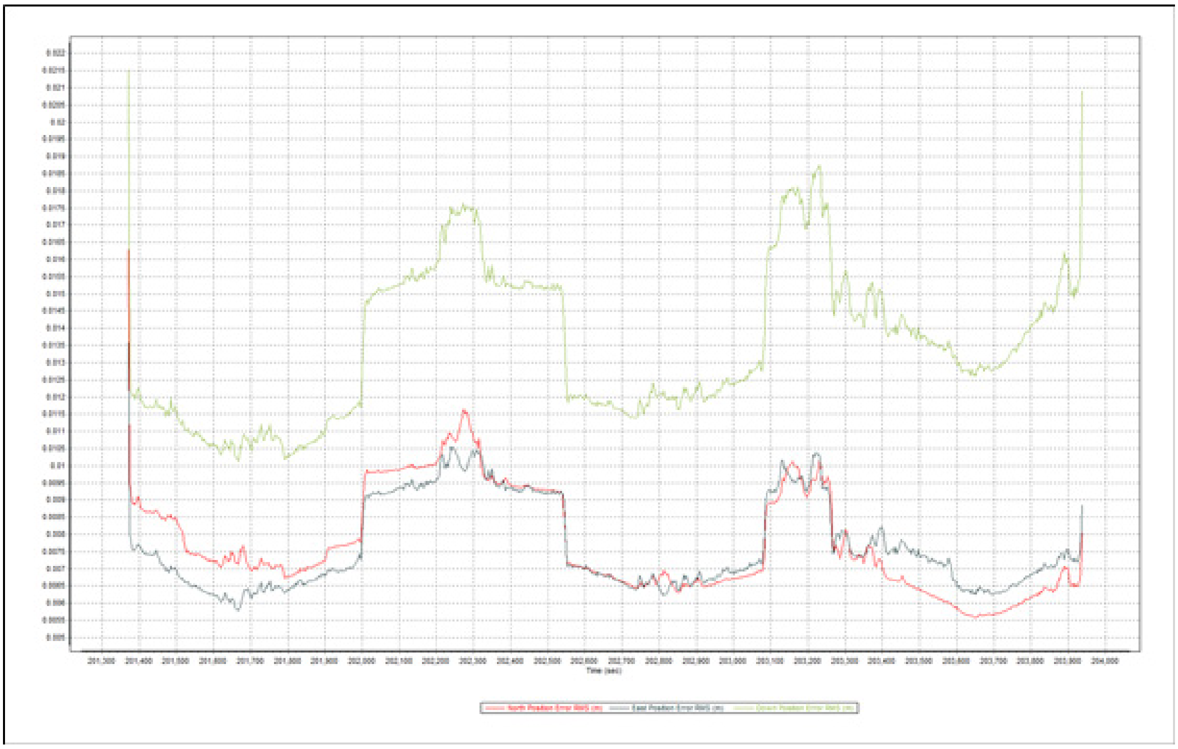


Figure A-8.13. Smoothed Performance Metric Parameters

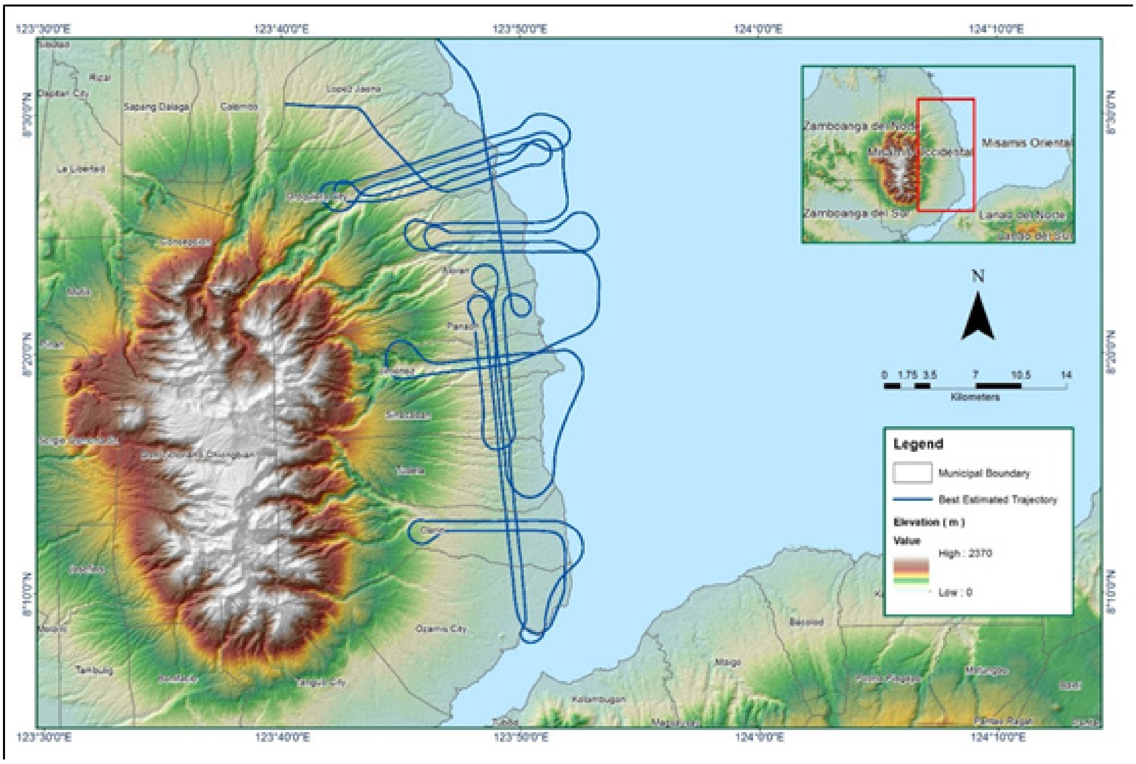


Figure A-8.14. Best Estimated Trajectory

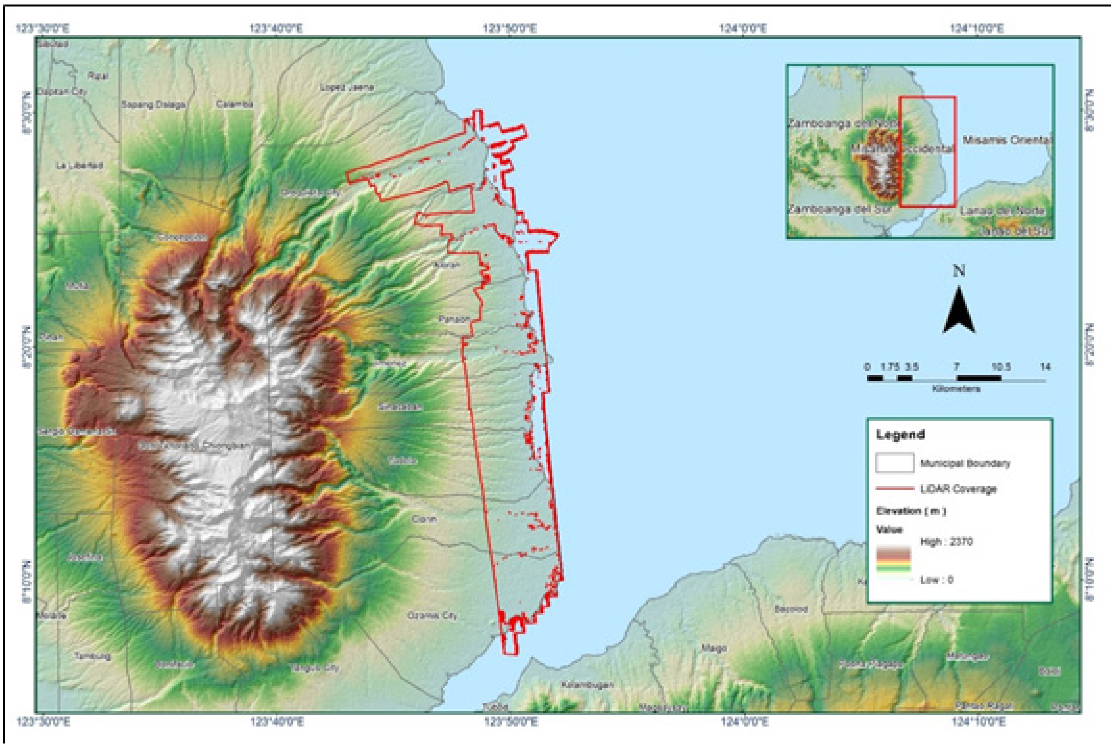


Figure A-8.15. Coverage of LiDAR data

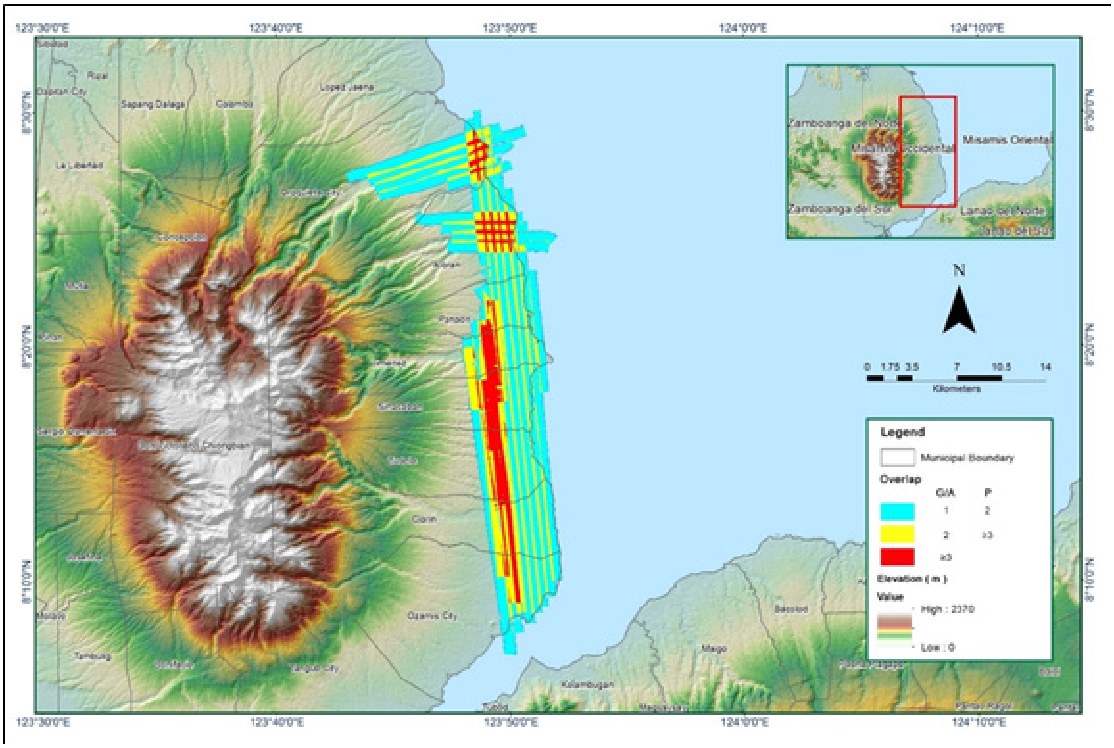


Figure A-8.16. Image of data overlap

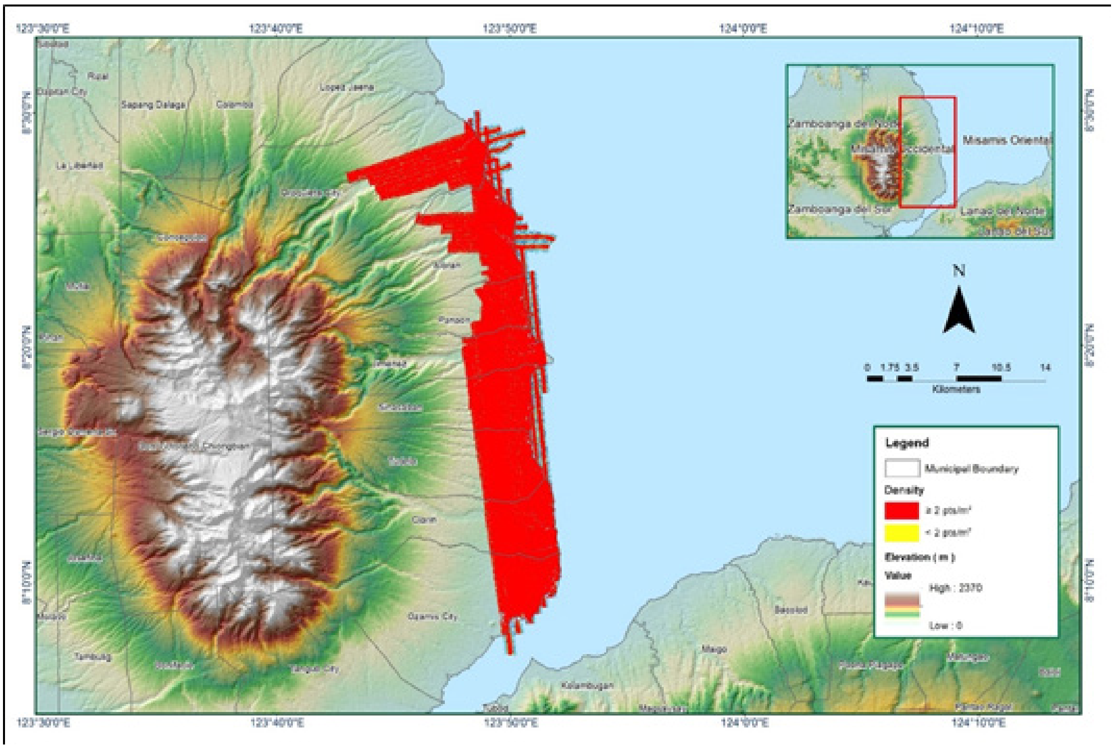


Figure A-8.17. Density map of merged LiDAR data

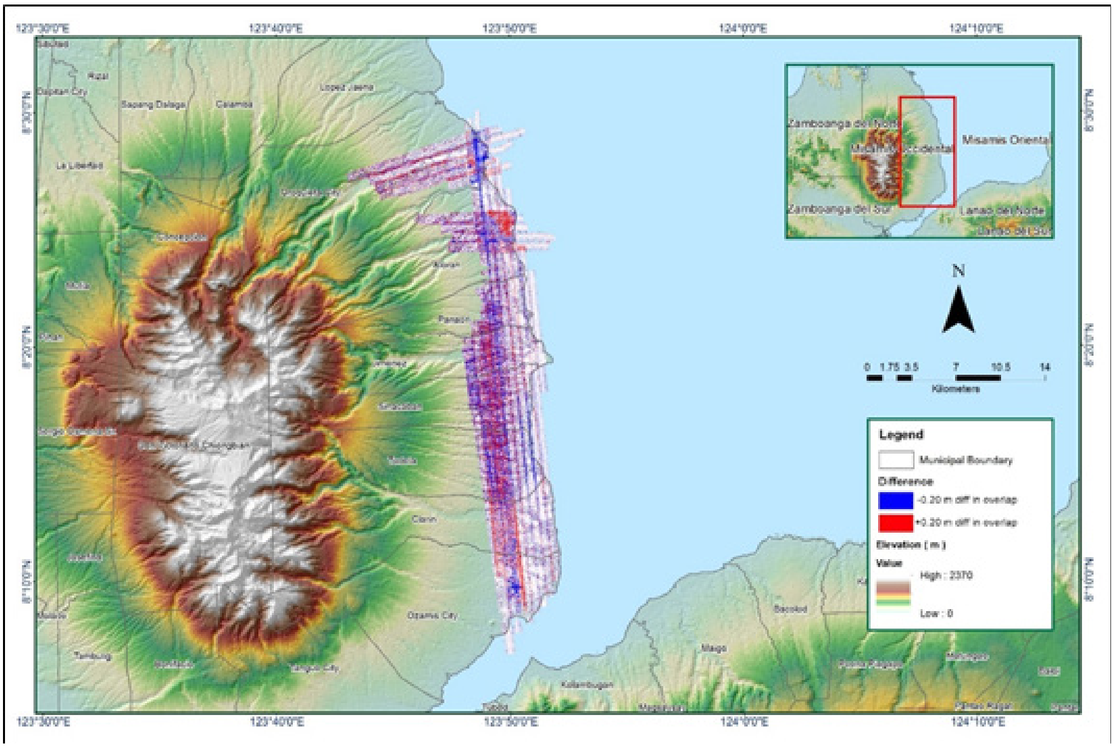


Figure A-8.18 Elevation difference between flight lines

Table A-8.3. Blk71Extension

Flight Area	Northern Mindanao
Mission Name	Blk71Extension
Inclusive Flights	1665P, 1673P, 1677P
Range data size	27.06 GB
POS	500 MB
Image	33.6 GB
Transfer date	August 6, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	3.0
RMSE for East Position (<4.0 cm)	4.0
RMSE for Down Position (<8.0 cm)	5.0
Boresight correction stdev (<0.001deg)	0.000243
IMU attitude correction stdev (<0.001deg)	0.001298
GPS position stdev (<0.01m)	0.0076
Minimum % overlap (>25)	27.83%
Ave point cloud density per sq.m. (>2.0)	2.41
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	243
Maximum Height	868.76 m
Minimum Height	63.2 m
Classification (# of points)	
Ground	107,907,148
Low vegetation	96,229,157
Medium vegetation	96,176,102
High vegetation	80,601,347
Building	17,253,174
Orthophoto	Yes

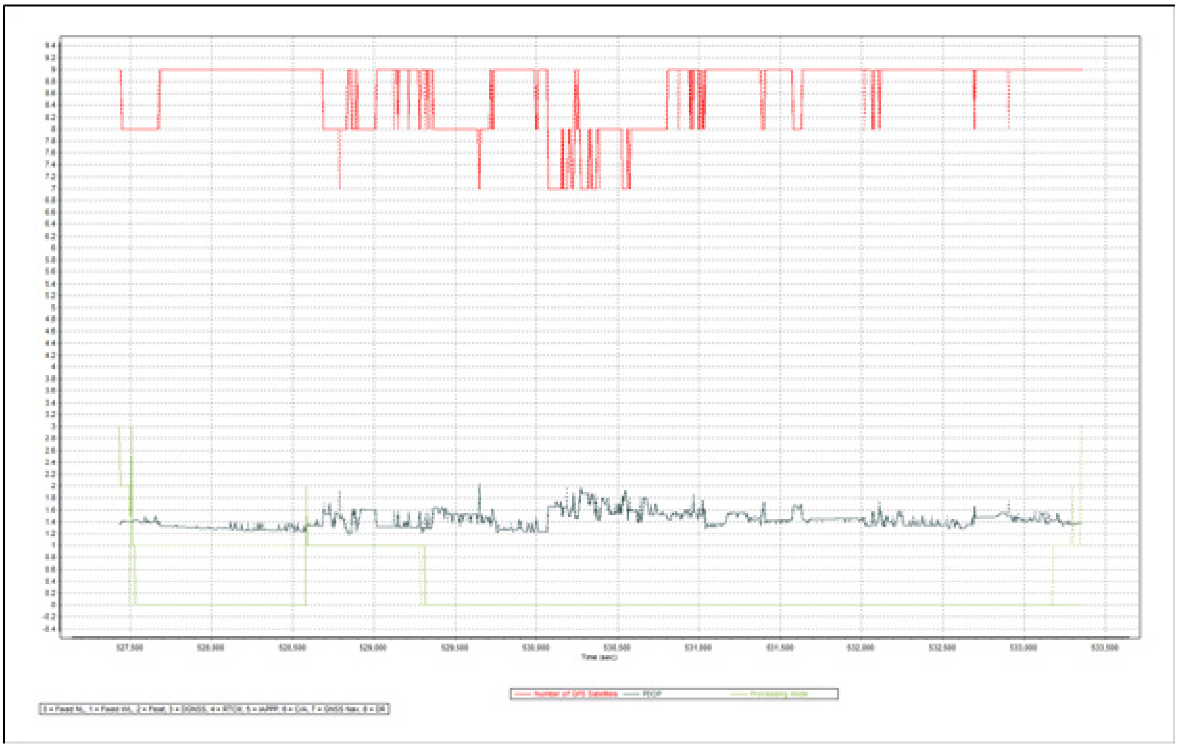


Figure A-8.20. Solution Status

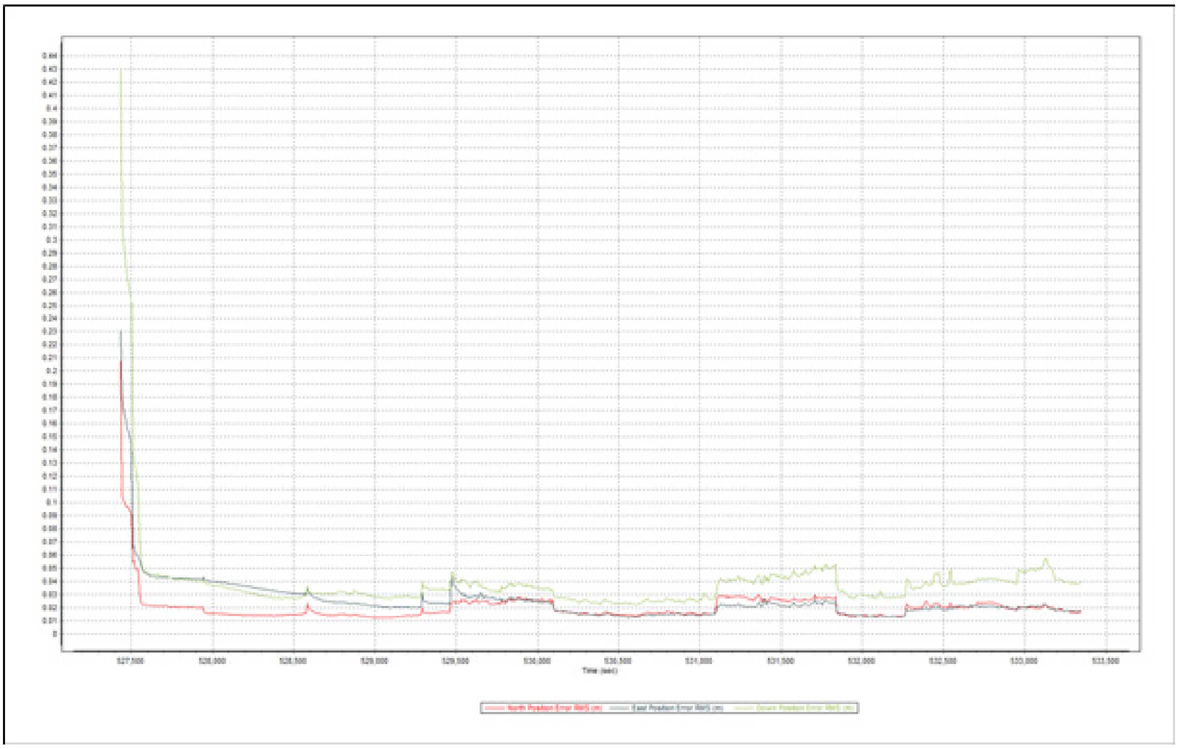


Figure A-8.21. Smoothed Performance Metric Parameters

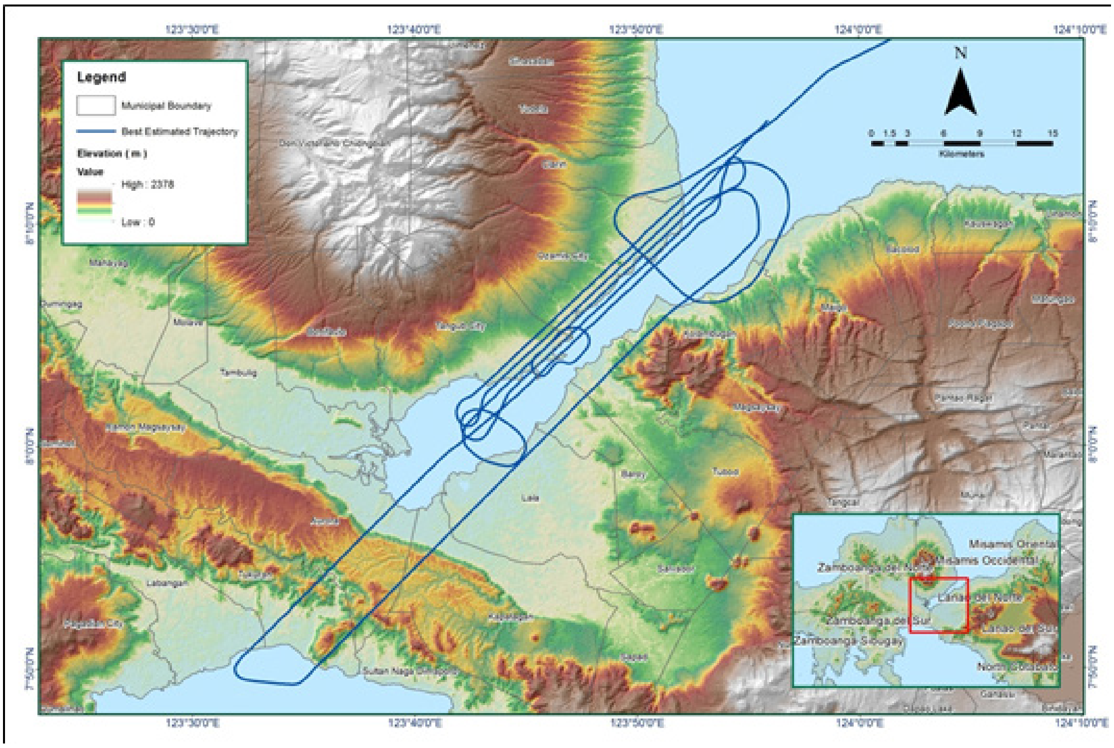


Figure A-8.22. Best Estimated Trajectory

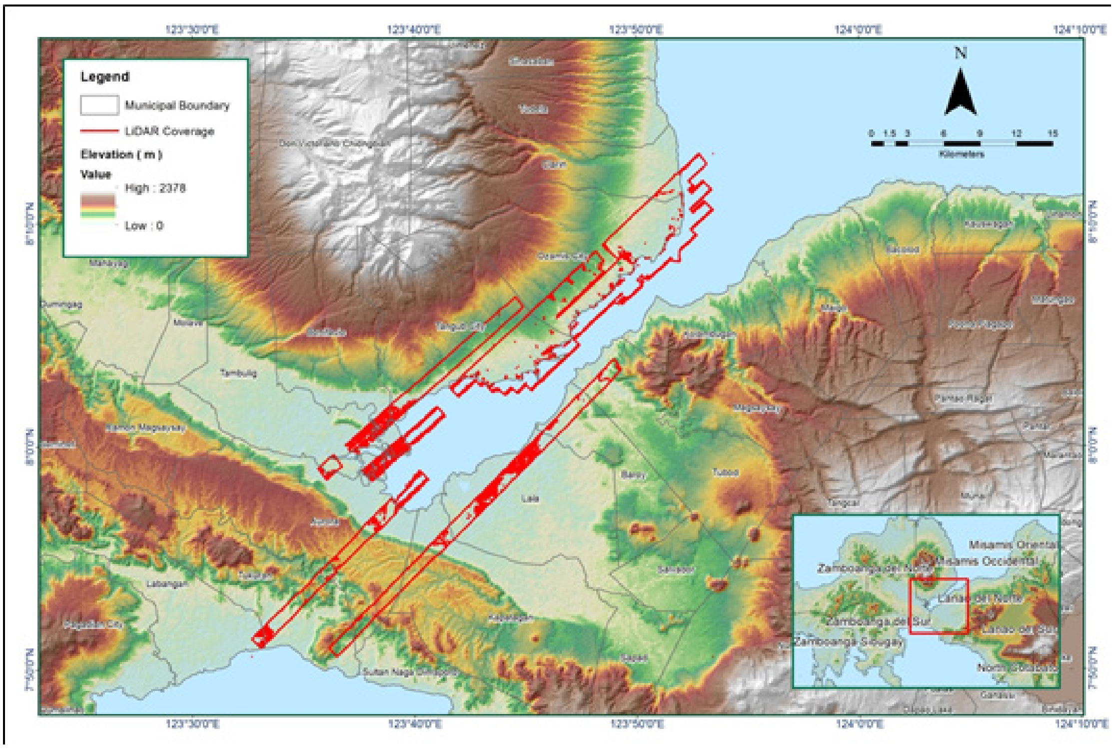


Figure A-8.23. Coverage of LiDAR data

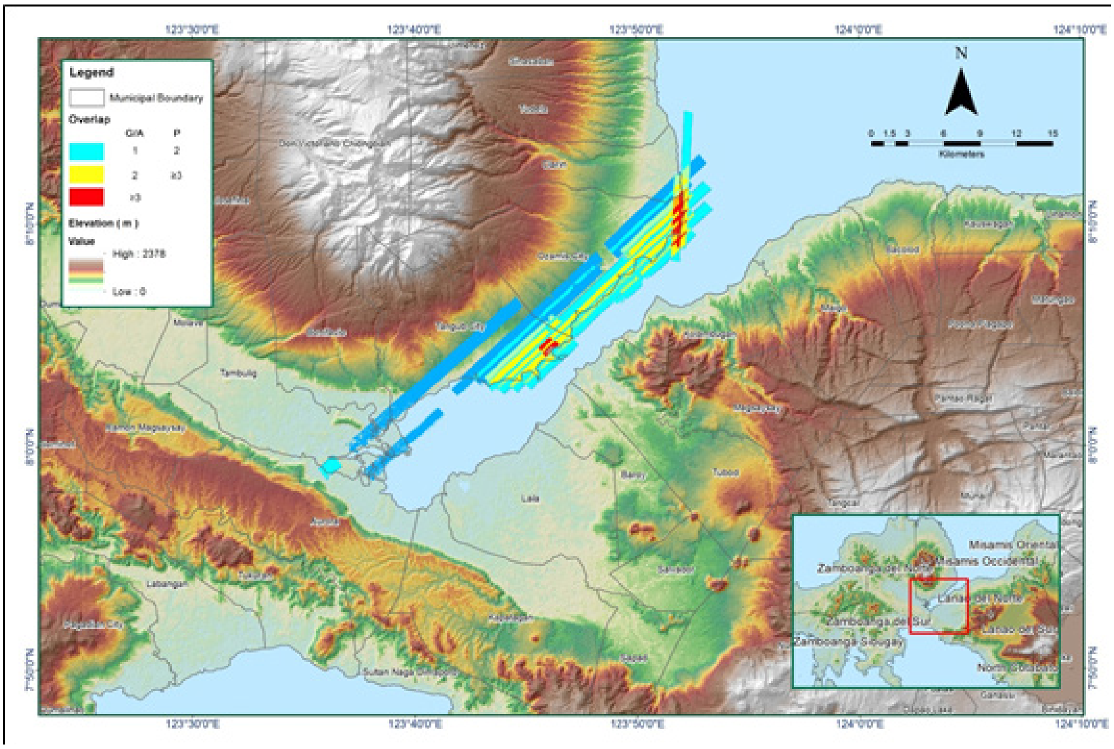


Figure A-8.24. Image of data overlap

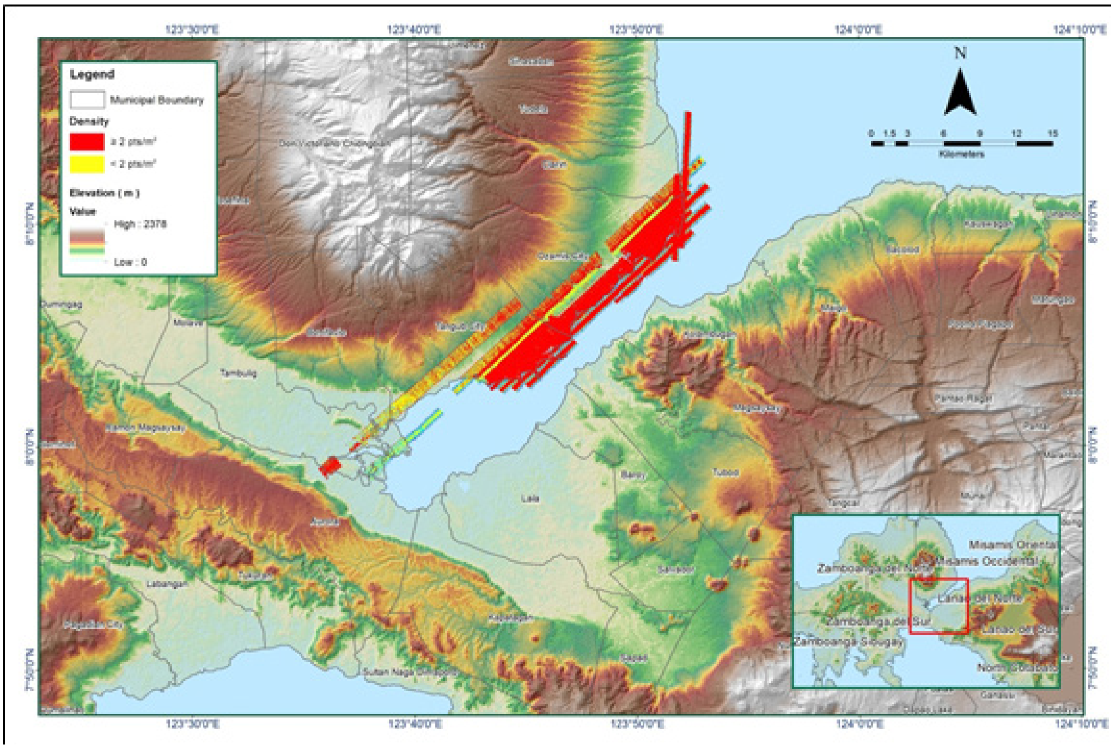


Figure A-8.25. Density map of merged LiDAR data

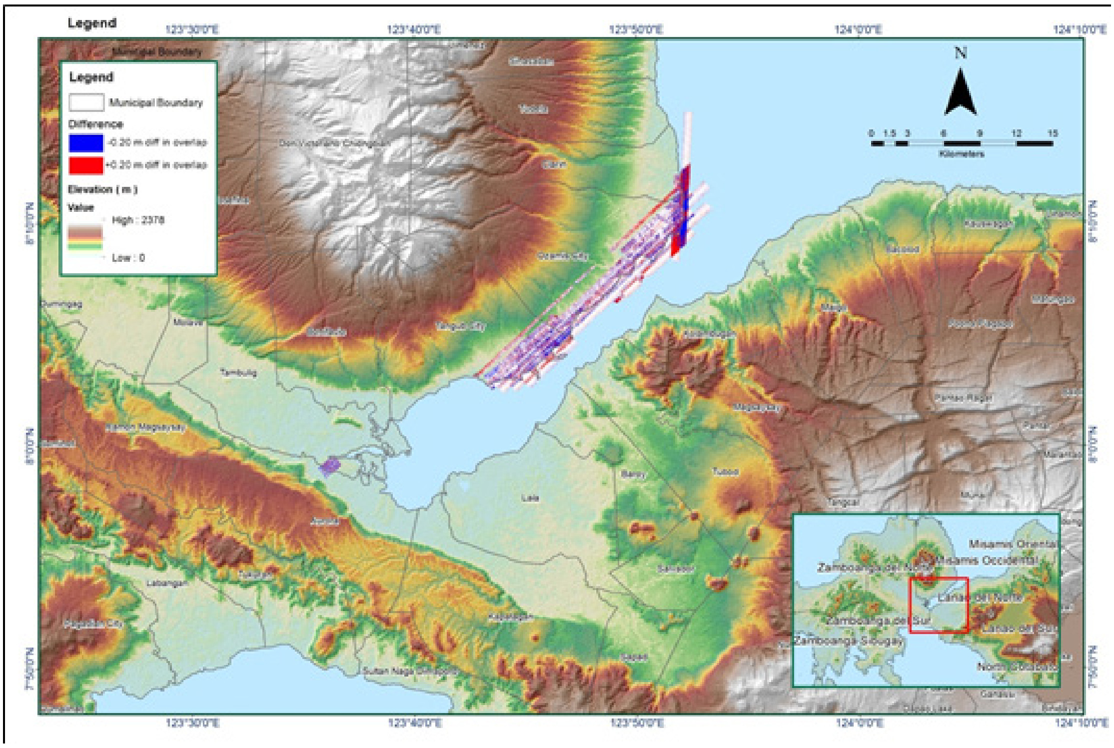


Figure A-8.26. Elevation difference between flight lines

Annex 9. Lanang Model Basin Parameters

Table A-9.1. Lanang Model Basin Parameters

Basin Number	Curve Number Loss			Clark Unit Hydrograph Transform		Recession Base flow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Dis-charge (m3/s)	Recession Constant	Threshold Type	Ratio to Peak
W180	16.631	61.541	0	0.01667	0.06925	Discharge	0.843	0.00001	Ratio to Peak	0.01807
W190	0.00325	99	0	0.01667	0.05956	Discharge	3.5577	0.00001	Ratio to Peak	0.01495
W200	0.11889	99	0	0.16523	0.01667	Discharge	1.8961	0.00001	Ratio to Peak	0.01996
W210	25.571	54.405	0	0.01667	11.103	Discharge	1.5914	0.00001	Ratio to Peak	0.01565
W220	70.774	99	0	0.14903	0.01667	Discharge	0.5984	0.00001	Ratio to Peak	0.61996
W230	0.00101	99	0	0.15475	0.08321	Discharge	0.1561	0.00001	Ratio to Peak	0.01691
W240	1.2123	98.938	0	0.01667	0.08214	Discharge	3.0396	0.00001	Ratio to Peak	1
W250	29.179	97.951	0	0.01667	0.01667	Discharge	1.3643	0.00001	Ratio to Peak	0.01843
W260	0.0172	99	0	0.14686	0.01667	Discharge	0.3611	0.00001	Ratio to Peak	0.01714
W270	22.004	99	0	0.14605	0.01667	Discharge	2.321	0.00001	Ratio to Peak	0.07923
W280	0.0023	99	0	0.14582	0.01667	Discharge	1.3477	0.00001	Ratio to Peak	0.01987

W290	0.02652	70.008	0	0.16529	0.07983	Discharge	1.6206	0.00001	Ratio to Peak	0.01852
W300	0.03358	59.658	0	0.12604	0.05962	Discharge	1.0604	0.00001	Ratio to Peak	0.65026
W310	0.00105	90.659	0	0.01667	0.08102	Discharge	0.6371	0.00001	Ratio to Peak	0.02671
W320	0.00341	99	0	0.14269	0.08055	Discharge	0.1909	0.00001	Ratio to Peak	0.04132
W330	0.00172	35.381	0	0.16662	0.07488	Discharge	1.8119	0.00001	Ratio to Peak	0.08604
W340	2.19	89.614	0	0.01667	0.08323	Discharge	4.0027	0.00001	Ratio to Peak	0.02294

Annex 10. Lanang Model Reach Parameters

Table A-10.1. Lanang Model Reach Parameters

Muskingum-Cunge Channel Routing							
Reach Number	Time Step Method	Length (m)	Slope (m/m)	Manning's n	Shape	Width (m)	Side Slope
R10	Automatic Fixed Interval	5571.1	0.00137	0.21159	Trapezoid	39.299	1
R30	Automatic Fixed Interval	9760.1	0.00263	0.19766	Trapezoid	39.299	1
R50	Automatic Fixed Interval	1304.6	0.00015	0.17341	Trapezoid	39.299	1
R60	Automatic Fixed Interval	1951.8	0.00416	1	Trapezoid	39.299	1
R80	Automatic Fixed Interval	2692.8	0.00416	0.0001	Trapezoid	39.299	1
R110	Automatic Fixed Interval	7785.2	0.00319	0.07466	Trapezoid	39.299	1
R130	Automatic Fixed Interval	2062	0.00444	0.06709	Trapezoid	39.299	1
R140	Automatic Fixed Interval	1974	0.01528	0.16707	Trapezoid	39.299	1

Annex 11. Lanang Field Validation Points

Table A-11.1. Lanang Field Validation Points

Point Number	Validation Coordinates (in WGS84)		Model Var (m)	Validation Points (m)	Error	Event/ Date	Rain Return/ Scenario
	Lat	Long					
1	12.39868833	123.408505	0.03	0	0.03		5-Year
2	12.39874833	123.408345	0.03	0	0.03		5-Year
3	12.39908167	123.4077683	0.03	0	0.03		5-Year
4	12.39976667	123.407025	0.03	0	0.03		5-Year
5	12.39977333	123.4069133	0.03	0	0.03		5-Year
6	12.39990333	123.4068017	0.08	0	0.08		5-Year
7	12.40002333	123.4068617	0.49	0	0.49		5-Year
8	12.40059667	123.4067633	0.13	0	0.13		5-Year
9	12.40075167	123.4068	0.03	0	0.03		5-Year
10	12.400825	123.406885	0.03	0	0.03		5-Year
11	12.40112333	123.4069433	0.03	0	0.03		5-Year
12	12.40113333	123.4068867	0.72	0	0.72		5-Year
13	12.40125833	123.4070033	0.03	0	0.03		5-Year
14	12.40150167	123.4070383	0.03	0	0.03		5-Year
15	12.40155167	123.4070133	0.03	0	0.03		5-Year
16	12.401845	123.4071533	0.03	0	0.03		5-Year
17	12.40224	123.40735	0.03	0	0.03		5-Year
18	12.40303333	123.4073933	0.03	0	0.03		5-Year
19	12.40346167	123.40704	0.03	0	0.03		5-Year
20	12.40351667	123.4069917	1.75	0	1.75		5-Year
21	12.40368833	123.4069317	0.03	0	0.03		5-Year
22	12.40391667	123.406655	0.04	0	0.04		5-Year
23	12.41797667	123.395185	0.03	0	0.03		5-Year
25	12.421555	123.3934533	0.04	0	0.04		5-Year
24	12.42175833	123.3934067	0.09	0	0.09		5-Year
26	12.42176667	123.3937833	0.03	0	0.03		5-Year
27	12.42762167	123.390775	0.03	0	0.03		5-Year
28	12.42804667	123.390515	0.18	0	0.18		5-Year
29	12.428445	123.390465	0.03	0	0.03		5-Year
30	12.42854	123.3905067	0.03	0	0.03		5-Year
31	12.42867167	123.3904117	0.08	0	0.08		5-Year
32	12.428765	123.390505	0.03	0	0.03		5-Year
33	12.42896167	123.3905633	0.08	0	0.08		5-Year
46	12.43038667	123.37731	0.03	0	0.03		5-Year
47	12.43054167	123.3774717	0.03	0	0.03		5-Year
45	12.43061333	123.3769733	0.03	0	0.03		5-Year
48	12.430645	123.3777783	0.03	0	0.03		5-Year
43	12.43069167	123.3766967	0.03	0	0.03		5-Year
44	12.43072	123.376765	0.03	0	0.03		5-Year

49	12.431005	123.377315	0.03	0	0.03		5-Year
51	12.43105833	123.3772533	0.03	0	0.03		5-Year
50	12.43111333	123.3772767	0.03	0	0.03		5-Year
42	12.43118167	123.376725	0.03	0	0.03		5-Year
41	12.43123333	123.3767017	0.03	0	0.03		5-Year
52	12.431275	123.37723	0.03	0.3	-0.27		5-Year
40	12.431345	123.3769717	0.03	0	0.03		5-Year
57	12.43139667	123.3797333	0.03	0	0.03		5-Year
38	12.43145833	123.3765467	0.85	0.3	0.55	TS Linda	5-Year
37	12.43150667	123.3765783	0.85	0.4	0.45	TS Linda	5-Year
39	12.43155167	123.3768717	0.03	0.1	-0.07	TS Linda	5-Year
53	12.43159	123.3770367	0.03	0.3	-0.27		5-Year
54	12.431625	123.3770333	0.77	0.3	0.47	TS Linda	5-Year
55	12.43164	123.3768683	0.03	0.3	-0.27	TS Linda	5-Year
36	12.43167833	123.3767017	0.03	0.3	-0.27	TS Linda	5-Year
56	12.431685	123.3766467	0.31	0.3	0.01	TS Linda	5-Year
35	12.43193667	123.373605	0.03	0.3	-0.27		5-Year
58	12.43193	123.3818633	0.03	0	0.03		5-Year
34	12.43200167	123.3732233	0.03	0.3	-0.27		5-Year
59	12.43215833	123.3821933	0.03	0	0.03		5-Year
60	12.43317167	123.3876733	0.03	0	0.03		5-Year
63	12.43333167	123.388695	0.03	0	0.03		5-Year
61	12.43336167	123.3880367	0.03	0	0.03		5-Year
62	12.43338	123.3885433	0.03	0	0.03		5-Year
65	12.43342333	123.3886233	0.03	0	0.03		5-Year
64	12.433435	123.3886733	0.03	0	0.03		5-Year
66	12.433555	123.3887	0.03	0	0.03		5-Year
68	12.433695	123.3886267	0.03	0	0.03		5-Year
67	12.433705	123.38863	0.03	0	0.03		5-Year
69	12.43381333	123.3886183	0.03	0	0.03		5-Year
70	12.43393333	123.3886133	0.03	0	0.03		5-Year
71	12.4343	123.3885433	0.03	0	0.03		5-Year
72	12.43478667	123.388475	0.03	0	0.03		5-Year
73	12.43502333	123.3884367	0.03	0	0.03		5-Year
75	12.43510333	123.3883933	0.03	0	0.03		5-Year
74	12.435155	123.3886083	0.03	0	0.03		5-Year
76	12.43607	123.38822	0.03	0	0.03		5-Year
77	12.43610333	123.3882117	0.03	0	0.03		5-Year
78	12.43628833	123.38813	0.03	0	0.03		5-Year
79	12.436745	123.388085	0.03	0	0.03		5-Year
80	12.43723833	123.3879283	0.03	0	0.03		5-Year
81	12.43769833	123.3878317	0.03	0	0.03		5-Year
82	12.437725	123.3879	0.05	0	0.05		5-Year
83	12.43837	123.3877317	0.03	0	0.03		5-Year
85	12.44566167	123.3849383	0.03	0	0.03		5-Year

84	12.44584833	123.3850817	0.03	0	0.03		5-Year
87	12.455375	123.3893117	0.7	0	0.7		5-Year
88	12.45543667	123.389315	0.03	0	0.03		5-Year
89	12.45545833	123.389405	0.03	0	0.03		5-Year
91	12.45558833	123.3893517	0.03	0	0.03		5-Year
86	12.45561333	123.3893883	0.03	0	0.03		5-Year
90	12.45564	123.3892517	0.03	0	0.03		5-Year
92	12.45577667	123.3894817	0.03	0	0.03		5-Year
97	12.45584667	123.389475	0.03	0	0.03		5-Year
93	12.45589	123.3892417	0.24	0.2	0.04		5-Year
94	12.45596833	123.389065	0.09	0.2	-0.11		5-Year
98	12.456025	123.3895467	0.03	0	0.03		5-Year
95	12.45608167	123.3892383	0.27	0.1	0.17		5-Year
99	12.45627167	123.3895783	0.03	0	0.03		5-Year
96	12.45633	123.3893167	0.17	0.1	0.07		5-Year
100	12.45644167	123.3896617	0.03	0	0.03		5-Year
101	12.45677667	123.3898033	0.04	0	0.04		5-Year
102	12.45698833	123.3899133	0.03	0	0.03		5-Year
103	12.457285	123.3901783	0.06	0	0.06		5-Year
105	12.457285	123.3903967	0.07	0	0.07		5-Year
104	12.45734	123.39026	0.05	0	0.05		5-Year
106	12.457505	123.3903867	0.03	0	0.03		5-Year
107	12.45757667	123.3905383	0.65	0	0.65		5-Year
109	12.45773167	123.3906117	0.44	0	0.44		5-Year
108	12.45775333	123.3905467	0.44	0	0.44		5-Year
110	12.45785833	123.39063	0.61	0	0.61		5-Year
112	12.45793167	123.3906217	0.62	0	0.62		5-Year
111	12.45794167	123.3906317	0.51	0	0.51		5-Year
113	12.45801167	123.3906083	0.56	0	0.56		5-Year
121	12.45831667	123.391185	0.68	0	0.68		5-Year
120	12.458335	123.3911533	0.98	0	0.98		5-Year
115	12.45837167	123.3907517	0.07	0	0.07		5-Year
114	12.45837667	123.3907633	0.07	0	0.07		5-Year
143	12.45837	123.39549	0.03	0	0.03		5-Year
116	12.458385	123.3907483	0.07	0	0.07		5-Year
142	12.45842667	123.3954367	0.03	0	0.03		5-Year
144	12.45845833	123.3949783	0.03	0	0.03		5-Year
119	12.45847667	123.3908533	0.12	0	0.12		5-Year
145	12.45848167	123.394795	0.03	0	0.03		5-Year
141	12.458495	123.395675	0.03	0	0.03		5-Year
132	12.4585	123.3968467	0.03	0	0.03		5-Year
147	12.45851167	123.394465	0.03	0	0.03		5-Year
148	12.45852833	123.3942417	0.03	0	0.03		5-Year
146	12.45852833	123.3946133	0.03	0	0.03		5-Year
117	12.45854667	123.390655	0.54	0	0.54		5-Year

125	12.45855833	123.39114	0.03	0	0.03		5-Year
118	12.45856	123.3908433	0.19	0	0.19		5-Year
150	12.45855833	123.3941217	0.03	0	0.03		5-Year
140	12.45855833	123.3957133	0.03	0	0.03		5-Year
149	12.45856667	123.3941167	0.03	0	0.03		5-Year
151	12.45861167	123.393825	0.03	0	0.03		5-Year
152	12.45862167	123.3937517	0.03	0	0.03		5-Year
122	12.45864	123.3911367	0.03	0	0.03		5-Year
153	12.458645	123.393725	0.03	0	0.03		5-Year
133	12.45865167	123.3968183	0.07	0	0.07		5-Year
124	12.45866	123.3911783	0.03	0	0.03		5-Year
134	12.45866833	123.3966667	0.51	0	0.51		5-Year
126	12.45868833	123.3914067	0.03	0	0.03		5-Year
123	12.45869167	123.3911867	0.03	0	0.03		5-Year
138	12.45871833	123.39625	0.03	0	0.03		5-Year
139	12.45872667	123.3961833	0.03	0	0.03		5-Year
127	12.45877333	123.3916317	0.03	0	0.03		5-Year
128	12.458795	123.391625	0.03	0	0.03		5-Year
129	12.45880833	123.3920417	0.03	0	0.03		5-Year
135	12.45880667	123.396535	0.03	0	0.03		5-Year
169	12.45883667	123.3955667	0.03	0	0.03		5-Year
130	12.45884333	123.3923683	0.03	0	0.03		5-Year
131	12.45886	123.3925033	0.03	0	0.03		5-Year
154	12.45886833	123.3935833	0.03	0	0.03		5-Year
168	12.45895	123.39551	0.03	0	0.03		5-Year
156	12.45896667	123.393395	0.35	0	0.35		5-Year
155	12.458995	123.3933433	0.11	0	0.11		5-Year
136	12.45900667	123.3966217	0.03	0	0.03		5-Year
171	12.45907333	123.3931983	0.03	0	0.03		5-Year
170	12.45908	123.3932167	0.03	0	0.03		5-Year
172	12.45911333	123.3928183	0.03	0	0.03		5-Year
167	12.45913667	123.39549	0.03	0	0.03		5-Year
157	12.45914333	123.393295	0.03	0	0.03		5-Year
173	12.459145	123.3928017	0.03	0	0.03		5-Year
158	12.45921	123.3934	0.03	0	0.03		5-Year
166	12.45922167	123.395465	0.08	0	0.08		5-Year
159	12.459245	123.3935767	0.3	0	0.3		5-Year
137	12.45925167	123.396705	0.03	0	0.03		5-Year
160	12.45928	123.3936783	0.03	0	0.03		5-Year
174	12.45933167	123.39265	0.03	0	0.03		5-Year
161	12.45934167	123.39385	0.27	0	0.27		5-Year
165	12.45934667	123.395505	0.03	0	0.03		5-Year
162	12.45940167	123.393995	0.03	0	0.03		5-Year
175	12.45944667	123.3926617	0.03	0	0.03		5-Year
163	12.45963167	123.3943267	0.37	0	0.37		5-Year

176	12.45975	123.3927633	0.04	0	0.04		5-Year
177	12.45979167	123.3927333	0.1	0	0.1		5-Year
164	12.46011333	123.3946083	0.03	0	0.03		5-Year
178	12.46028167	123.3928633	0.04	0	0.04		5-Year
179	12.46067667	123.3929333	0.21	0	0.21		5-Year
180	12.460895	123.39291	0.03	0	0.03		5-Year
181	12.461255	123.3929217	0.03	0	0.03		5-Year
182	12.46143667	123.392915	0.03	0	0.03		5-Year
183	12.46186	123.3928567	0.03	0	0.03		5-Year
184	12.462045	123.3926217	0.03	0	0.03		5-Year
185	12.46217333	123.3924833	0.03	0	0.03		5-Year
186	12.46238833	123.39226	0.03	0	0.03		5-Year
187	12.46242	123.3921633	0.03	0	0.03		5-Year
188	12.46260833	123.391895	0.03	0	0.03		5-Year
189	12.462675	123.39197	0.07	0	0.07		5-Year
191	12.46270667	123.3917817	0.03	0	0.03		5-Year
190	12.46276667	123.3920983	0.03	3	-2.97		5-Year
192	12.46279833	123.391655	0.03	0	0.03		5-Year
193	12.46287833	123.3916617	0.03	0	0.03		5-Year
194	12.462945	123.3915317	0.03	0	0.03		5-Year
195	12.46312833	123.391305	0.03	0	0.03		5-Year
196	12.46384	123.3909683	0.03	0	0.03		5-Year
197	12.46397667	123.390865	0.12	0	0.12		5-Year
198	12.46434833	123.3907467	0.03	0	0.03		5-Year
199	12.46462	123.390325	0.03	0	0.03		5-Year
200	12.46736833	123.3872467	0.03	0	0.03		5-Year
201	12.46756333	123.3870917	0.04	0	0.04		5-Year
202	12.46824667	123.3865583	0.03	0	0.03		5-Year
203	12.46872	123.38613	0.03	0	0.03		5-Year
204	12.46914333	123.386185	0.09	0	0.09		5-Year
205	12.46955167	123.3855533	0.03	0	0.03		5-Year
206	12.469885	123.38525	0.03	0	0.03		5-Year
207	12.47024833	123.3855967	0.05	0	0.05		5-Year
208	12.47064833	123.385455	0.03	0	0.03		5-Year
210	12.471155	123.3845283	0.13	0	0.13		5-Year
209	12.47124333	123.3845733	0.03	0	0.03		5-Year
212	12.471575	123.3835033	0.03	0	0.03		5-Year
211	12.47167667	123.38364	0.03	0	0.03		5-Year
213	12.47220667	123.3825783	0.07	0	0.07		5-Year

ANNEX 12. Educational Institutions Affected by flooding in Lanang Floodplain

Table A-12.1. Educational Institutions affected by flooding in Lanang Floodplain

Masbate				
Aroroy				
Name	Barangay	Rainfall Scenario		
		5-YR	25-YR	100-YR
Cabangcalan Day Care	Cabangcalan			
Cabangcalan Elementary School	Cabangcalan			
Day Care	Lanang	Low	Medium	Medium
Lanang elem School	Lanang			
Brbm Elem Sc	Panique	Low	Low	Medium
Daycare Center	Panique			
Panique DayCare	Panique	Low	Low	Low
Panique National High School	Panique	Low	Low	Low
San Isidro Elementary School	San Isidro			

ANNEX 13. Health Institutions Affected by flooding in Lanang Floodplain

Table A-12.1. Health Institutions affected by flooding in Lanang Floodplain

Masbate				
Aroroy				
Name	Barangay	Rainfall Scenario		
		5-YR	25-YR	100-YR
Cabangcalan Health Center	Cabangcalan			
HealthCare Center	Panique			
Health Center	San Isidro			