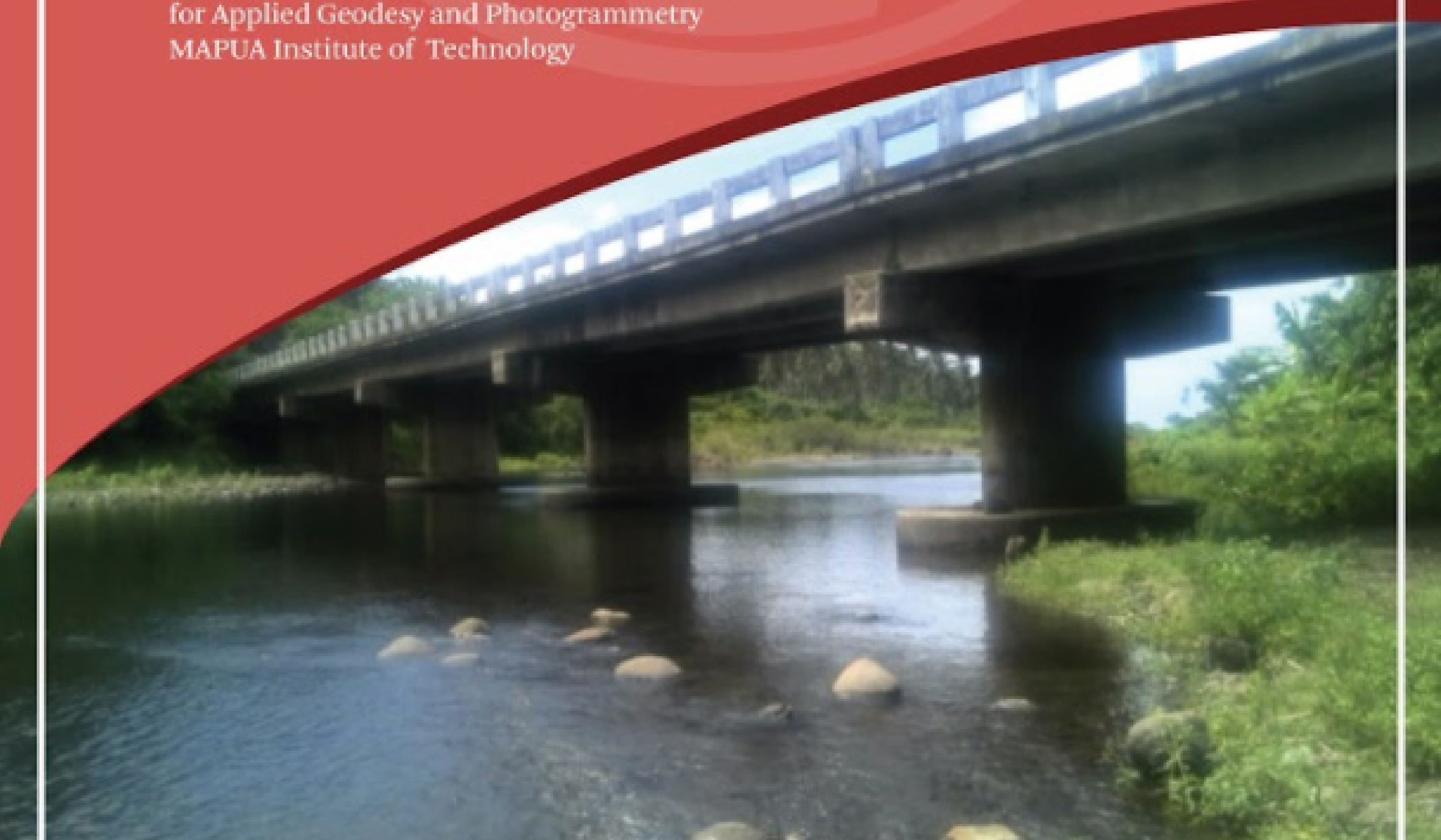
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR 1)

LiDAR Surveys and Flood Mapping of Lubayat River

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



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LIST OF ACRONYMS AND ABBREVIATIONS

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

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND LUBAYAT RIVER

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

1.1 Background of the Phil-LIDAR 1 Program

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

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

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

1.2 Overview of the Lubayat River Basin

The Lubayat River Basin is located in the northern part of Quezon province. Specifically, it is situated in the municipality of Real and is bounded by the municipalities of Tanay, Rizal and Santa Maria, Laguna to the west. The Lubayat River Basin covers portions of the Municipality of Real in Quezon Province and, Municipalities of Santa Maria, Famy, Siniloan and Pangil, in Laguna Province. The DENR River Basin Control Office identified the Lubayat River Basin to have drainage area of 56 km2 with an estimated annual run-off of 90 million cubic meter (MCM) (RBCO,2015).

Its main stem, the Lubayat River, is part of the twenty six (26) river systems in the Southern Tagalog Region. According to the 2015 national census of the Philippine Statistics Authority (PSA), a total of 2,139 persons are residing within the immediate vicinity of the river which is distributed among two (2) barangays in the municipality of Real, namely: Barangay Maunlad and Lubayat. The waters of Lubayat River cuts through Brgy. Lubayat in Real Quezon—the upstream of the river forks in Brgy. Maunlad also in the Municipality of Real. In terms of practical use, the river is categorized as Class C by the Department of Environment and Natural Resources (DENR). Its uses are for fishery (Fishery Water) for the propagation and growth of fish and other aquatic resources; Recreational Water Class II as a boating site; and Industrial Water Supply Class I used in manufacturing processes after treatment. It traverses mainly through Real, Quezon and it serves as one of the major sources of income for the communities in the area. It helps stabilize industries such as tourism and agriculture and adds a vital impact on economic growth.

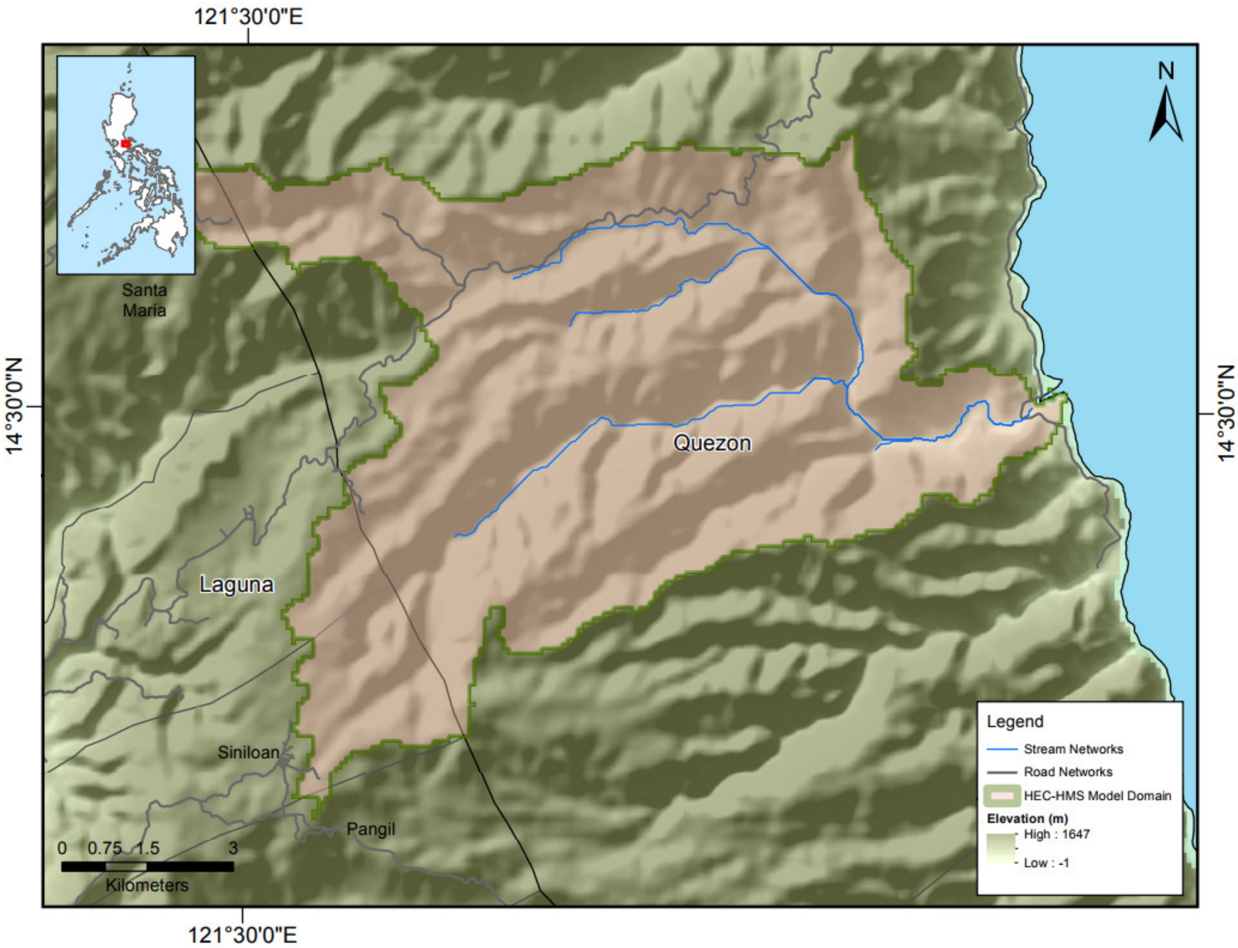

Figure 1. Map of Lubayat River Basin

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

To prevent a similar outcome from happening again, a combination of several technologies have been employed to produce flood hazard maps. The first is LiDAR data, which primarily contains elevation. From elevation values, one can infer the presence and behavior of waterbodies (such as rivers, streams, ponds, and lakes) and structures (such as roads, bridges, and buildings). Next, important data such as discharge and rainfall events gathered through fieldwork are used as inputs to the hydrological model. The gathered data is used to generate hydrographs that is used to create the calibrated model. These generated outputs, along with LiDAR data, will then be input for the river hydraulic model. The final output for these processes will be flood hazard maps of the river basin. The generated maps are used for urban planning and disaster risk reduction planning.

CHAPTER 2: LIDAR ACQUISITION IN LUBAYAT FLOODPLAIN

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

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Lubayat floodplain in Quezon. These missions were planned for 14 lines that run for at most three (3) hours including take-off, landing and turning time. The flight planning parameters for Pegasus is found in Table 1. Figure 2 shows the flight plan for Lubayat floodplain.

Table 1. Flight planning parameters for Pegasus LiDAR System.

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

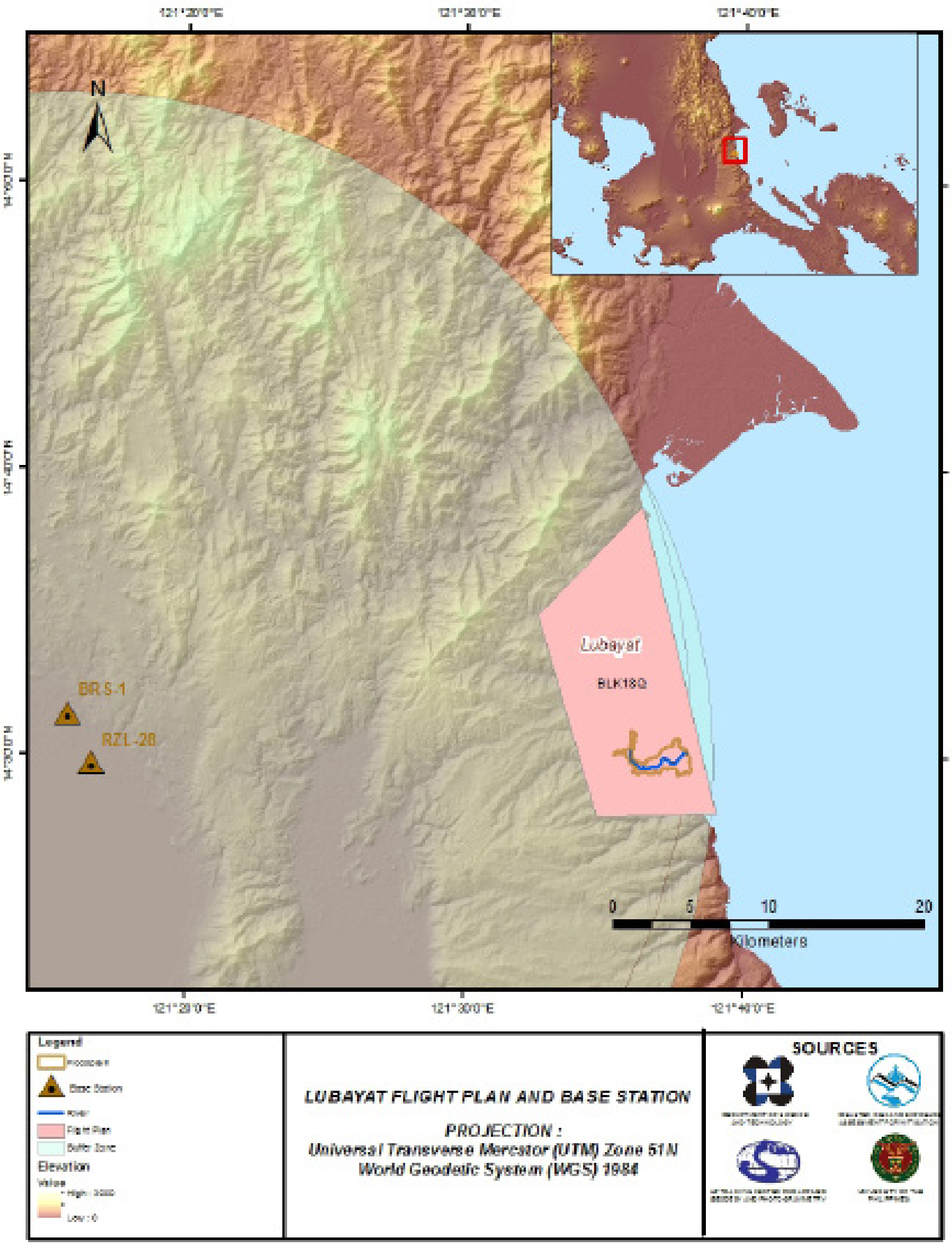

Figure 2. Flight plan and base station for Pegasus System used for Lubayat (also known as Yabahaan) Floodplain

2.2 Ground Base Station

The project team was able to recover one (1) NAMRIA ground control point: RZL-28 which is of second (2nd) order accuracy. One (1) ground control point, BRS-1, was also established. The certifications for the base stations are found in Annex 2 while the baseline processing reports for the established point is found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (June 22, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 985 and TOPCON GR5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Lubayat floodplain are shown in Figure 2. The list of team members for LiDAR data acquisition is found in Annex 4.

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

(a) (b)

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

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

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

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

Table 3. Details of the recovered NAMRIA horizontal control point BRS-1 used as base station for the LiDAR data acquisition.

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

Table 4. Ground control points used during LiDAR data acquisition

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

2.3 Flight Missions

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

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

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
21 June 2016	23474P	243.68	146.50	5.08	141.42	NA	3	17

Table 6. Actual parameters used during LiDAR data acquisition.

Flight Number	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
23474P	1000	60	50	200	32	130	5

2.4 Survey Coverage

Lubayat Floodplain is situated in Real, Quezon. About 38.34% of Real, Quezon was surveyed and is shown in Table 7. The actual coverage of the LiDAR acquisition for Lubayat floodplain is presented in Figure 5.

Table 7. Municipality Surveyed during Lubayat Floodplain LiDAR survey

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Quezon	Real	382.11	140.22	38.34%
Total		382.11	140.22	38.34%

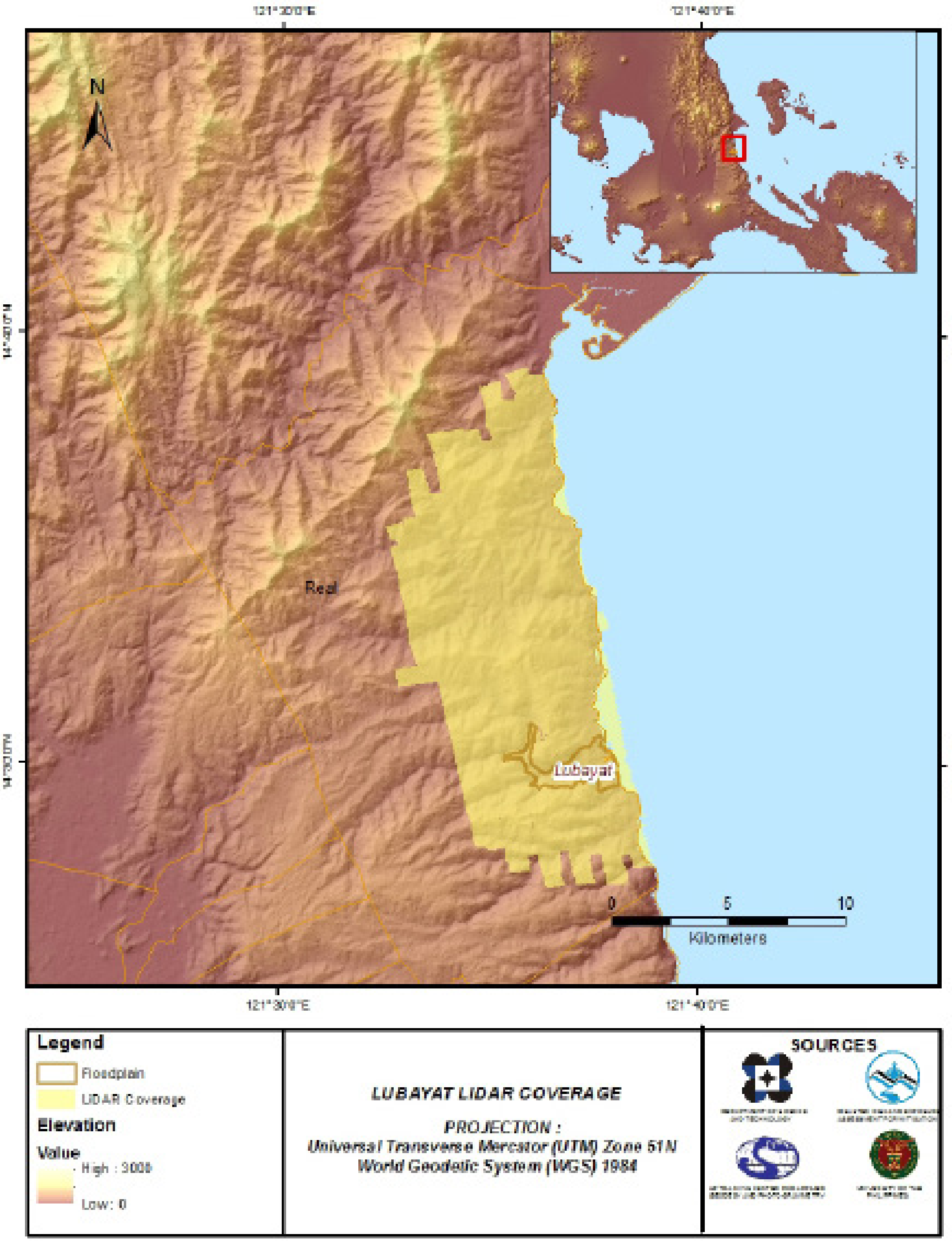

Figure 5. Actual LiDAR survey coverage for Lubayat Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR LUBAYAT FLOODPLAIN

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

3.1 Overview of LiDAR Data Pre-Processing

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

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

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

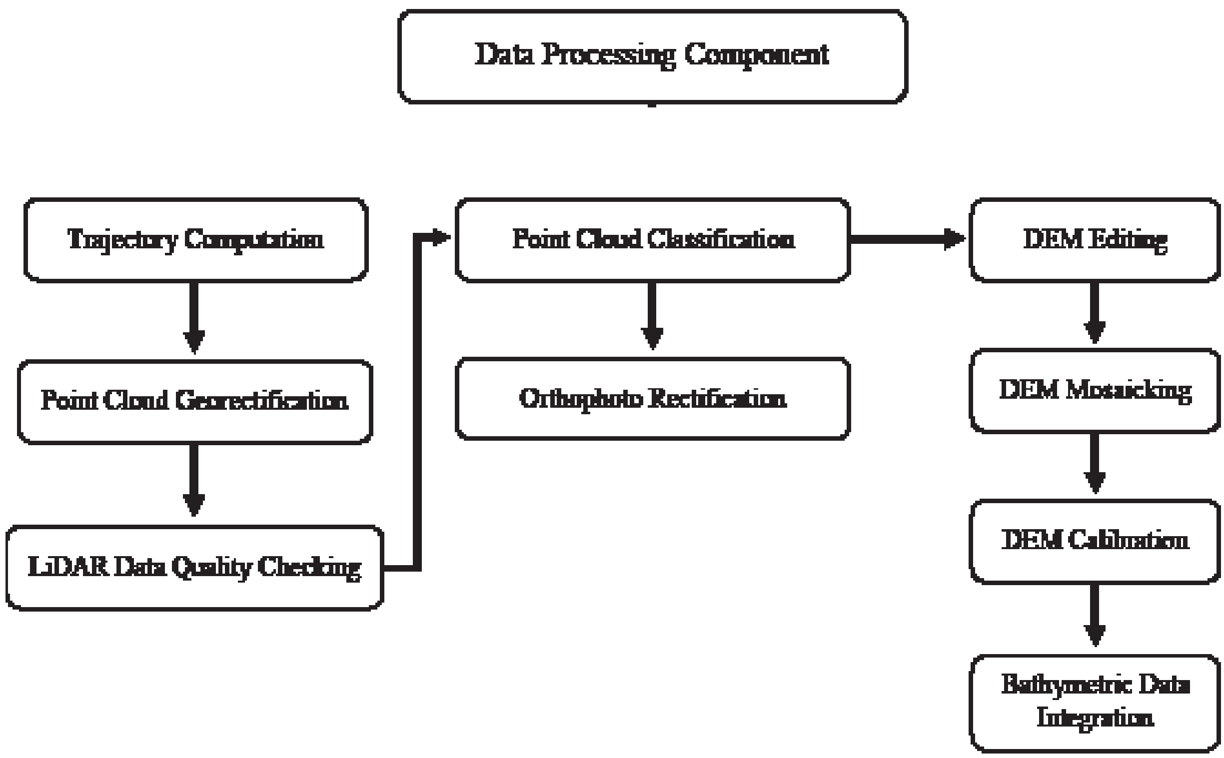


Figure 6. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Lubayat floodplain can be found in Annex 5. Missions flown during the survey conducted on June 2016 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Real, Quezon. The Data Acquisition Component (DAC) transferred a total of 12.70 Gigabytes of Range data, 200 Megabytes of POS data and 488 Megabytes of GPS base station data to the data server on July 14, 2016.

The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Lubayat was fully transferred on July 14, 2016, as indicated on the Data Transfer Sheets for Lubayat floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 23474P, one of the Lubayat flights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on June 22, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

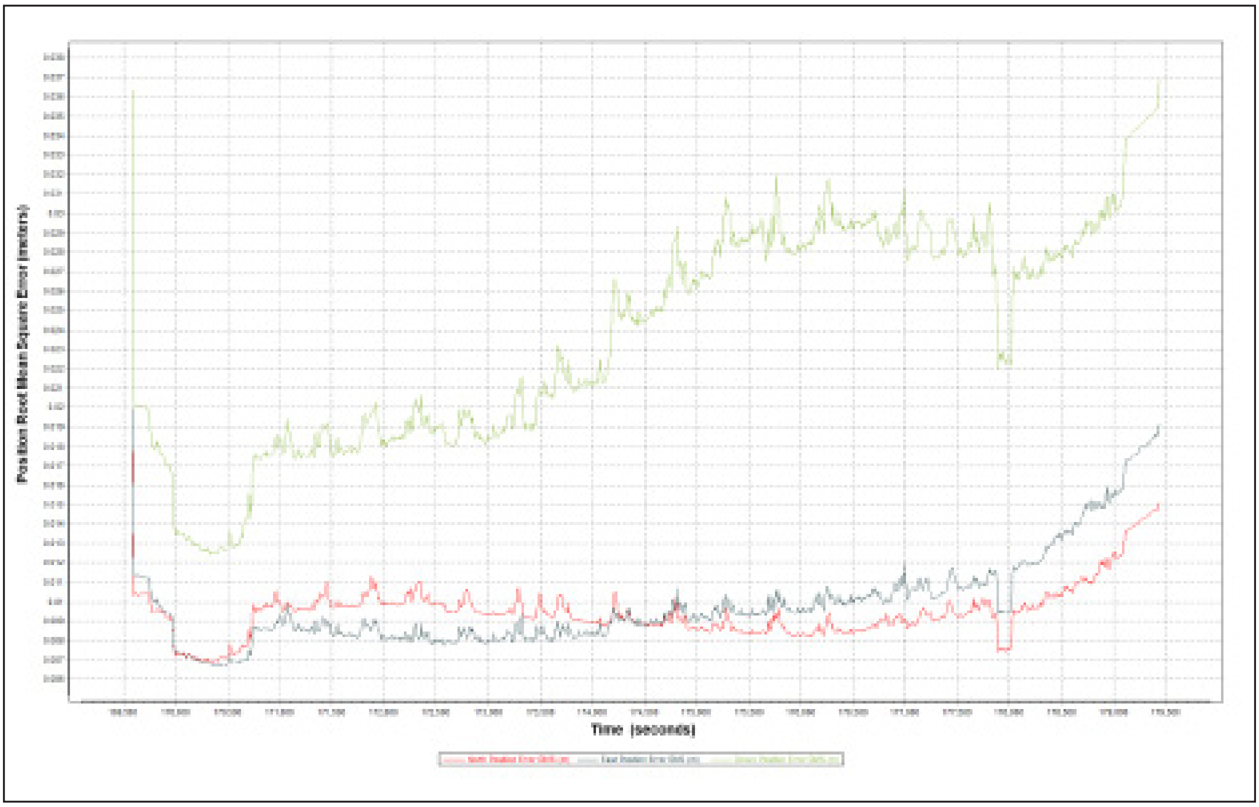


Figure 7. Smoothed Performance Metrics of Lubayat Flight 23342P.

The time of flight was from 169600 seconds to 179400 seconds, which corresponds to morning of June 22, 2016. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 7 shows that the North position RMSE peaks at 1.80 centimeters, the East position RMSE peaks at 2.00 centimeters, and the Down position RMSE peaks at 3.70 centimeters, which are within the prescribed accuracies described in the methodology.

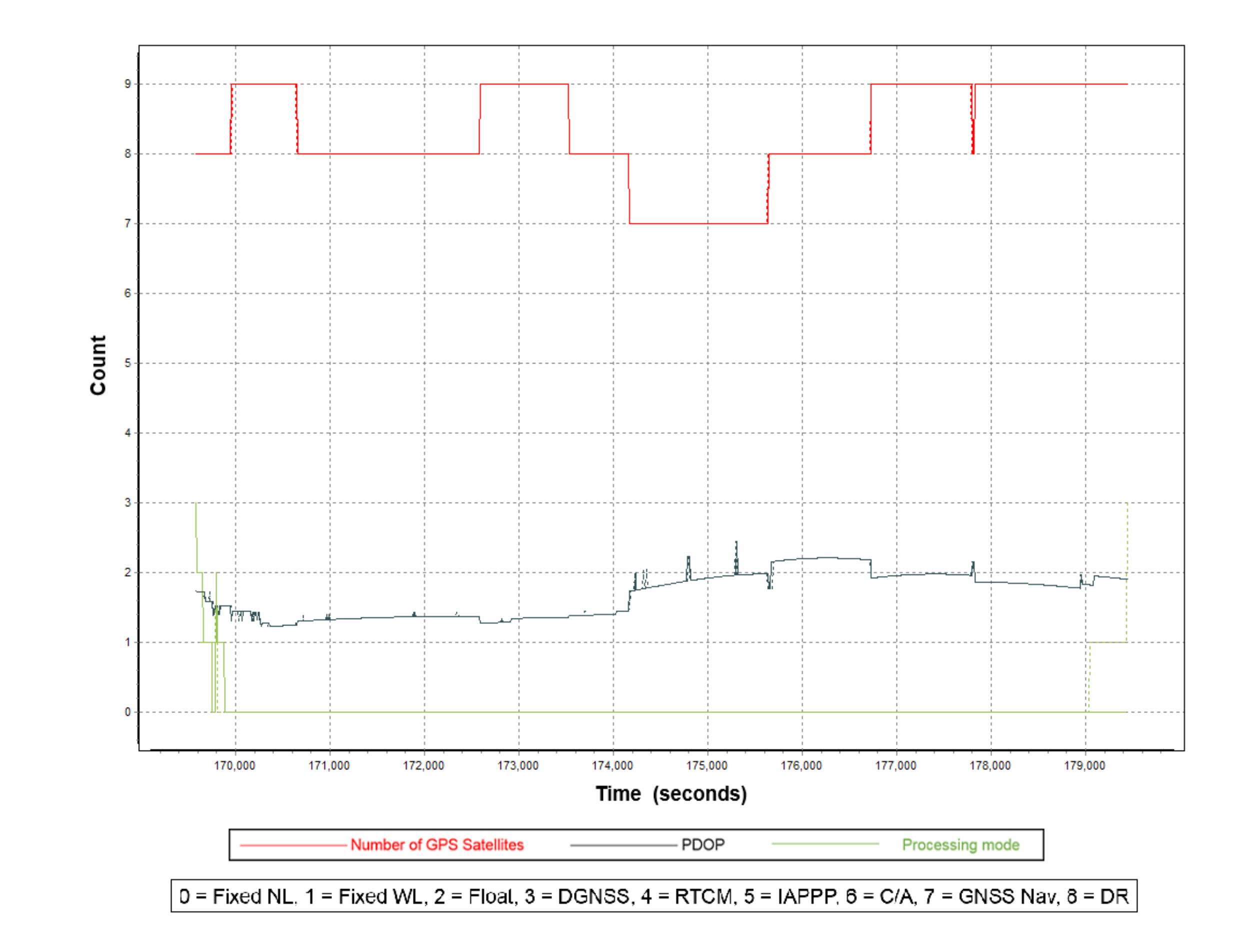


Figure 8. Solution Status Parameters of Lubayat Flight 23342P.

The Solution Status parameters of flight 23474P, one of the Lubayat flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 7 and 9. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Lubayat flights is shown in Figure 9.

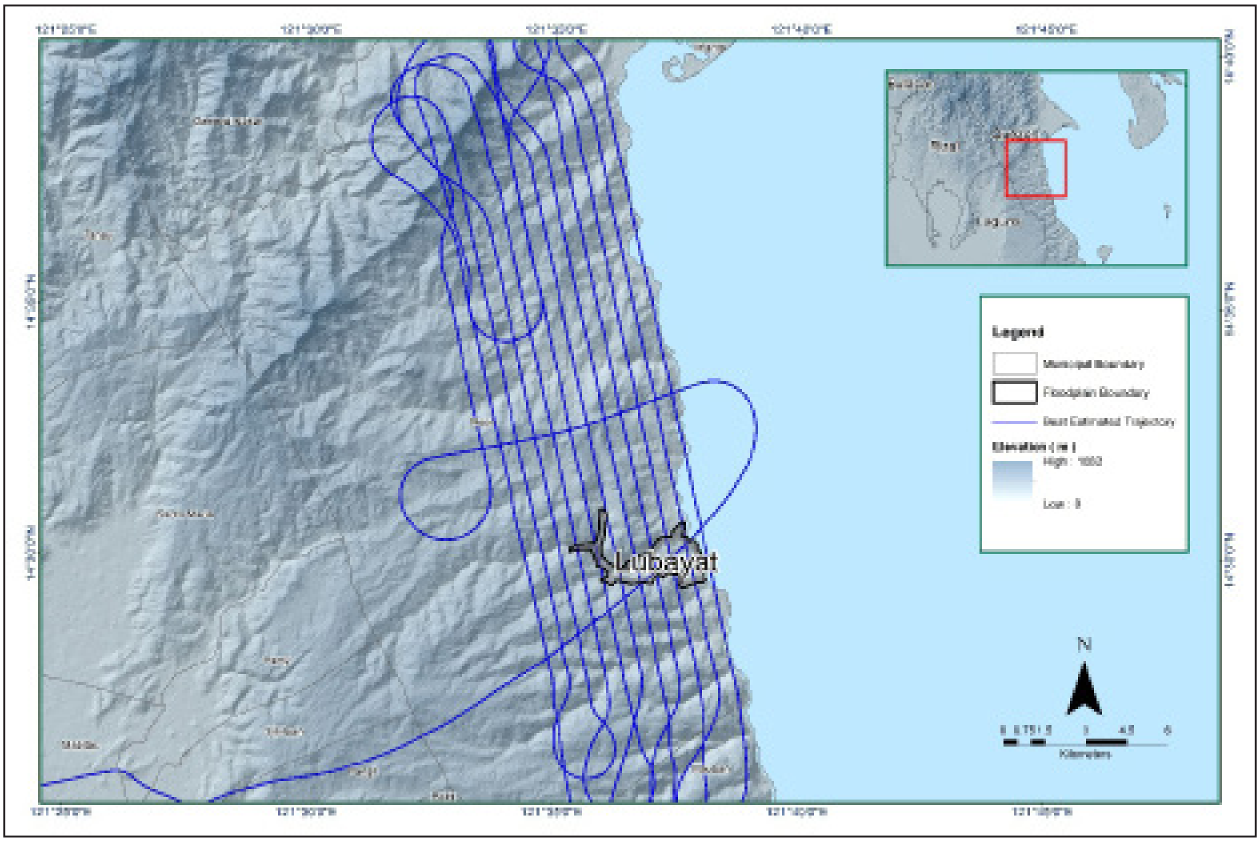


Figure 9. Best Estimated Trajectory for Lubayat Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 14 flight lines, with each flight line containing two channels, since the Pegasus system contain two channels. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Lubayat floodplain are given in Table 8.

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

Parameter	Acceptable Value	Value
Boresight Correction stdev	(<0.001degrees)	0.000335
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000180
GPS Position Z-correction stdev	(<0.01meters)	0.003

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

3.5 LiDAR Data Quality Checking

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

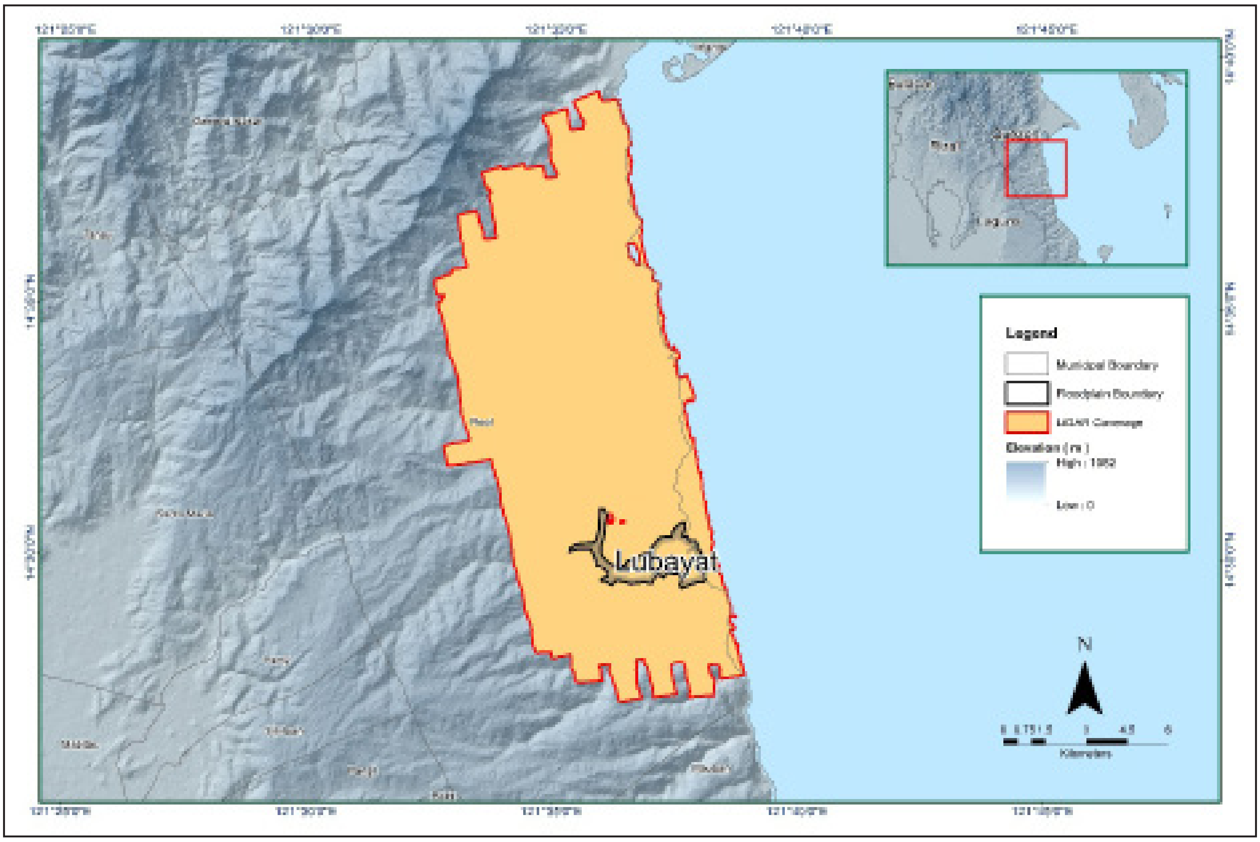


Figure 10. Boundary of the processed LiDAR data over Lubayat Floodplain

The total area covered by the Lubayat missions is 152.06 sq.km that is comprised of one (1) flight acquisition grouped and merged into two (2) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Lubayat Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
CALABARZON_reflight_Blk18Q	23474P	142.49
CALABARZON_reflight_Blk18Q_supplement	23474P	9.57
TOTAL		152.06 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 11. Since the Pegasus system 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.

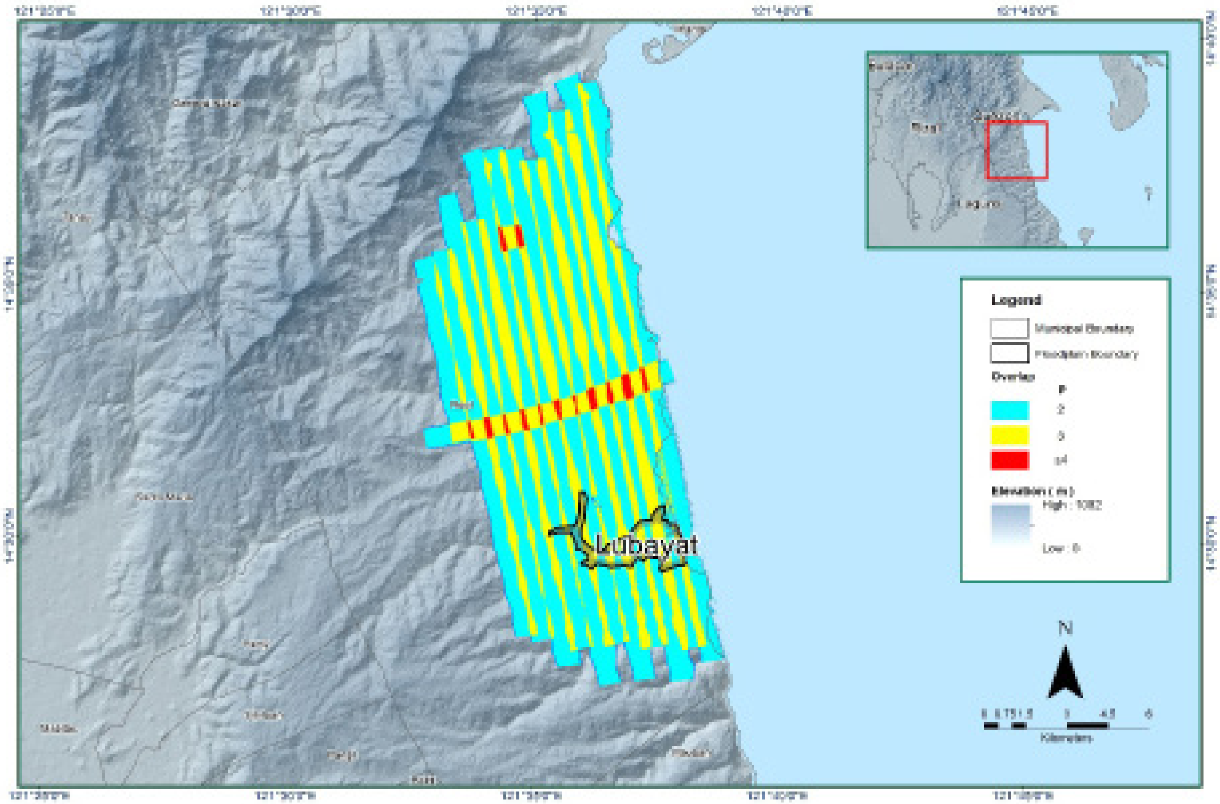


Figure 11. Image of data overlap for Lubayat floodplain.

The overlap statistics per block for the Lubayat floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 42.49%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 12. It was determined that all LiDAR data for Lubayat floodplain satisfy the point density requirement, and the average density for the entire survey area is 2.82 points per square meter.

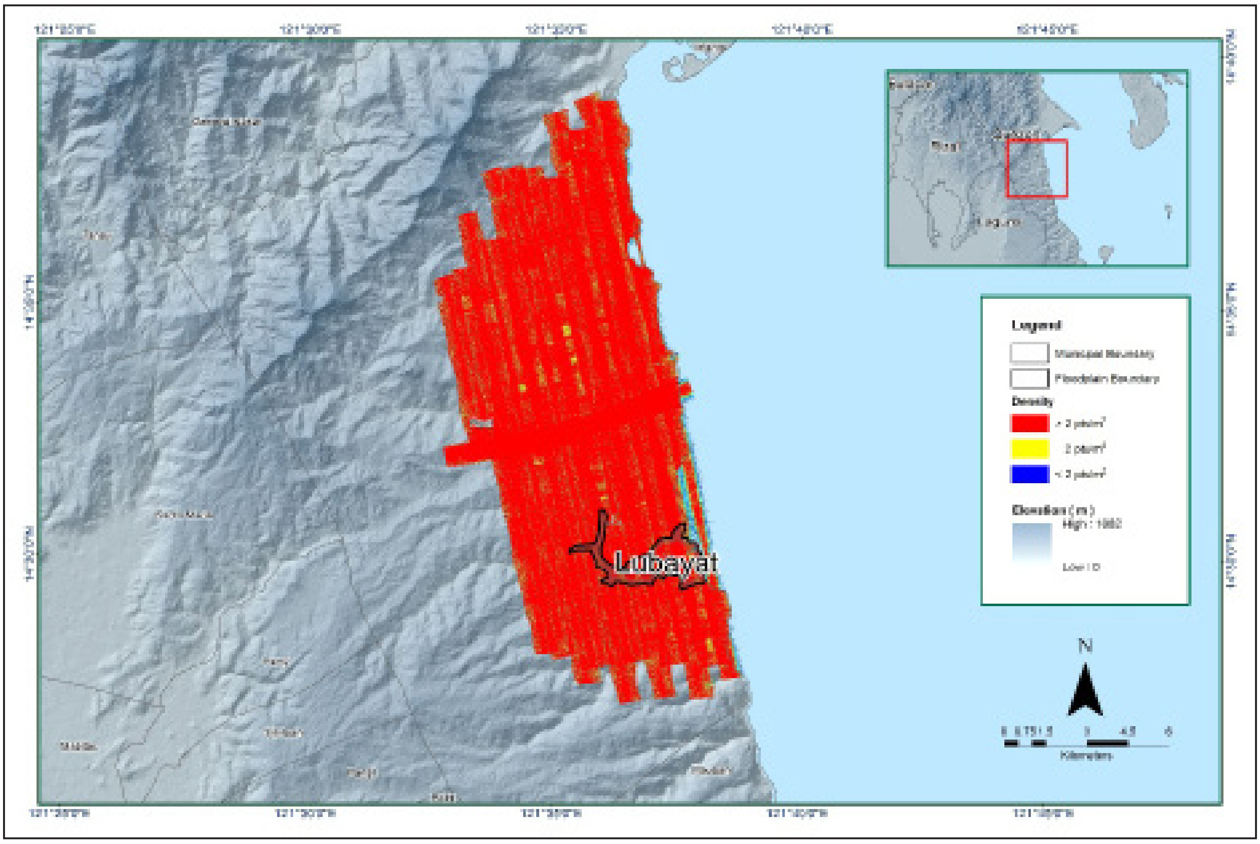


Figure 12. Pulse density map of merged LiDAR data for Lubayat Floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

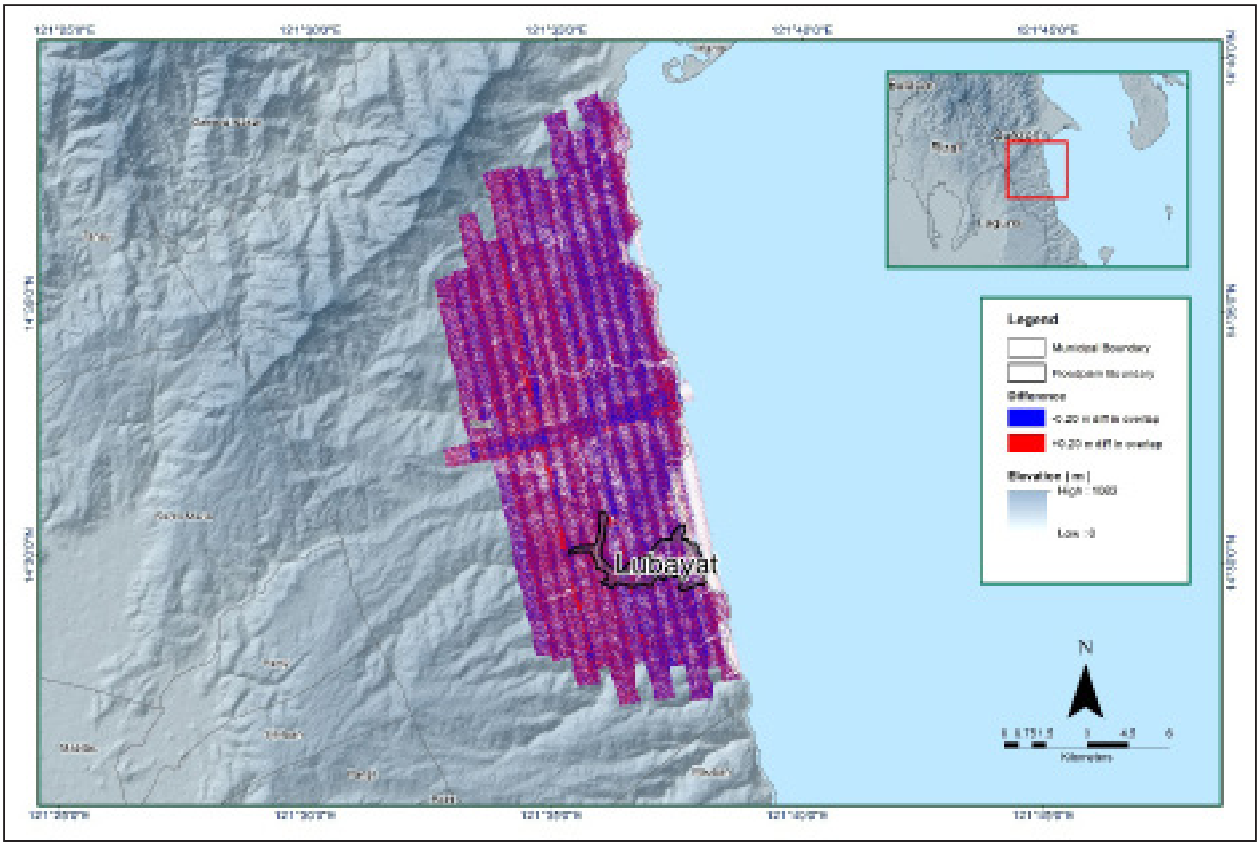


Figure 13. Elevation difference map between flight lines for Lubayat Floodplain.

A screen capture of the processed LAS data from a Lubayat flight 23474P loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

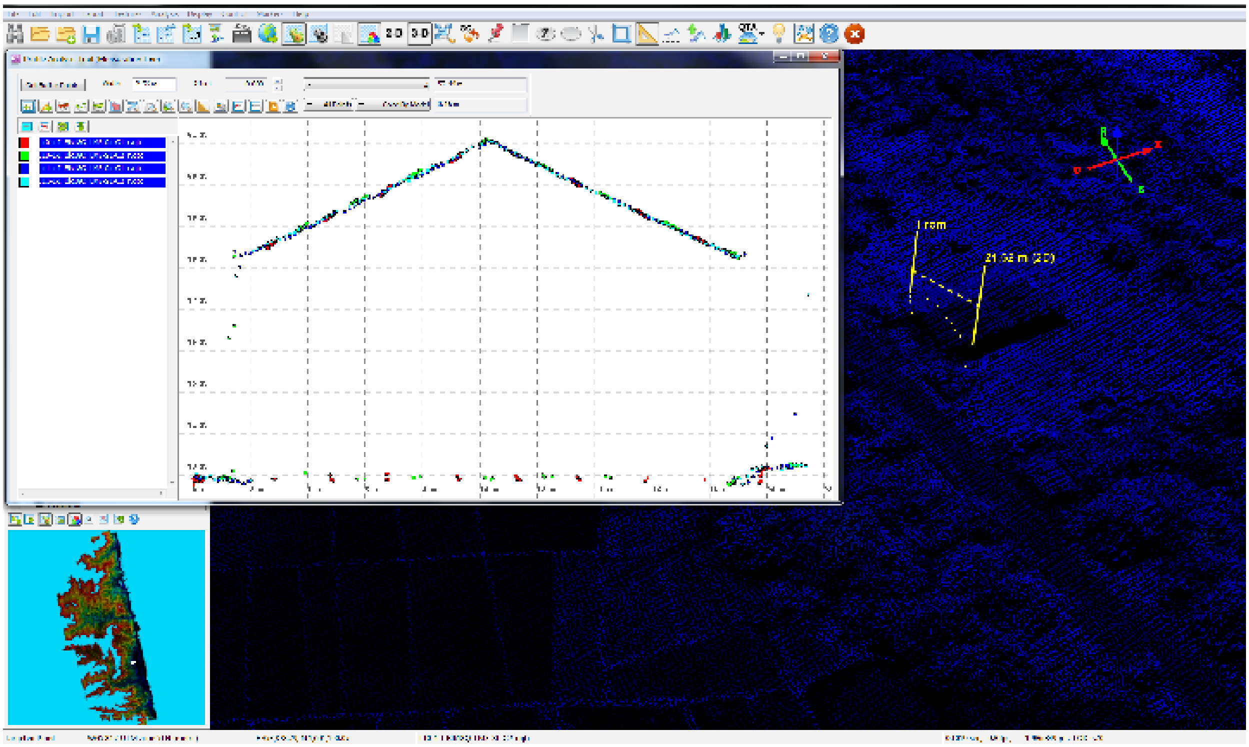


Figure 14. Quality checking for Lubayat flight 23474P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Lubayat classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	41, 354,472
Low Vegetation	12,086,308
Medium Vegetation	90,563,722
High Vegetation	527,379,966
Building	10,983,102

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Lubayat floodplain is shown in Figure 15. A total of 189 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 10. The point cloud has a maximum and minimum height of 590.20 meters and 47.79 meters respectively.

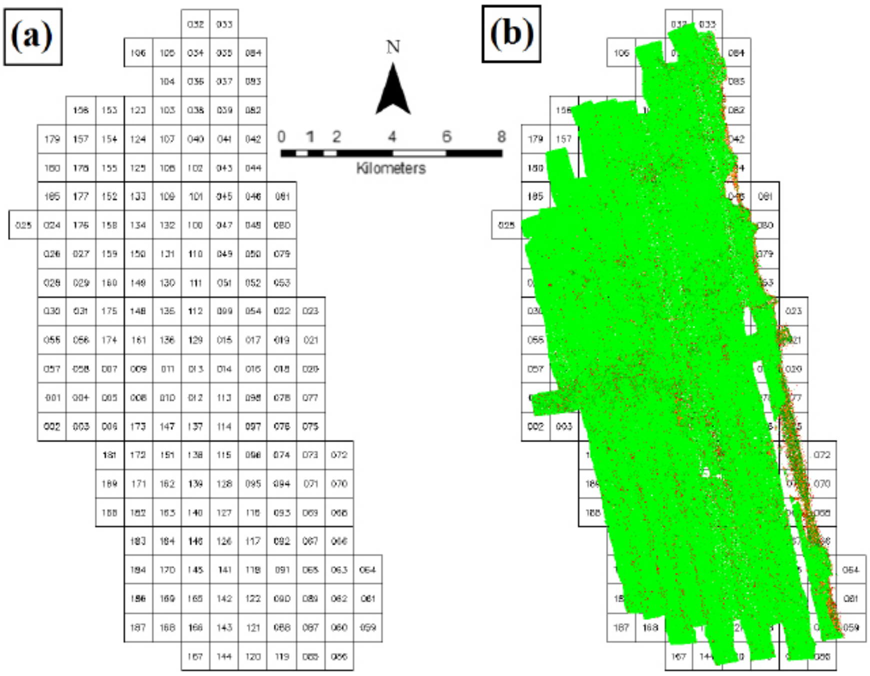


Figure 15. Tiles for Lubayat Floodplain (a) and classification results (b) in TerraScan.

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

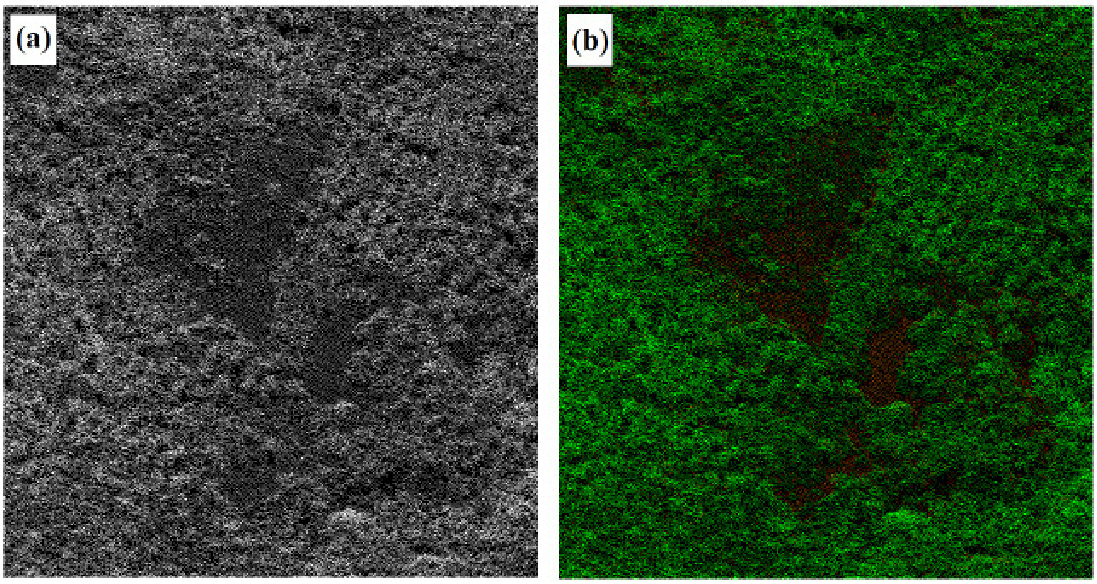


Figure 16. Point cloud before (a) and after (b) classification.

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

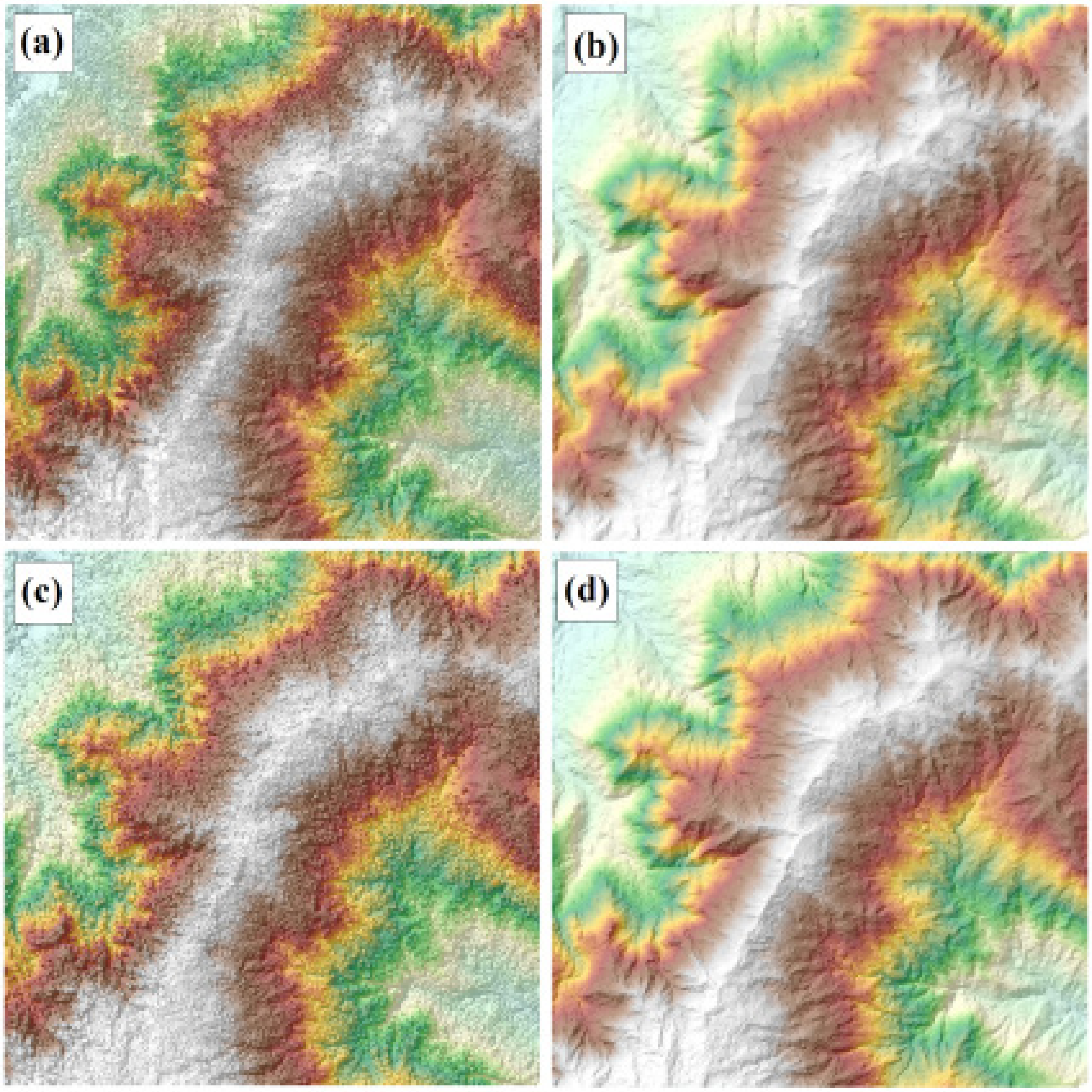


Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Lubayat Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Lubayat floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Lubayat floodplain. These blocks are composed of CALABARZON_ reflight blocks with a total area of 152.06 square kilometers. Table 11 shows the name and corresponding area of each block in square kilometers.

Table 11. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq.km)
CALABARZON_reflight_Blk18Q	142.49
CALABARZON_reflight_Blk18Q_supplement	9.57
TOTAL	152.06 sq.km

Portions of DTM before and after manual editing are shown in Figure 18. The bridge (Figure 18a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 18b) in order to hydrologically correct the river. The mountain slope (Figure 18c) has been misclassified and removed during classification process and has to be retrieved to complete the surface (Figure 18d) to allow the correct flow of water. Another example is a building that is still present in the DTM after classification (Figure 18e) and has to be removed through manual editing (Figure 18f).

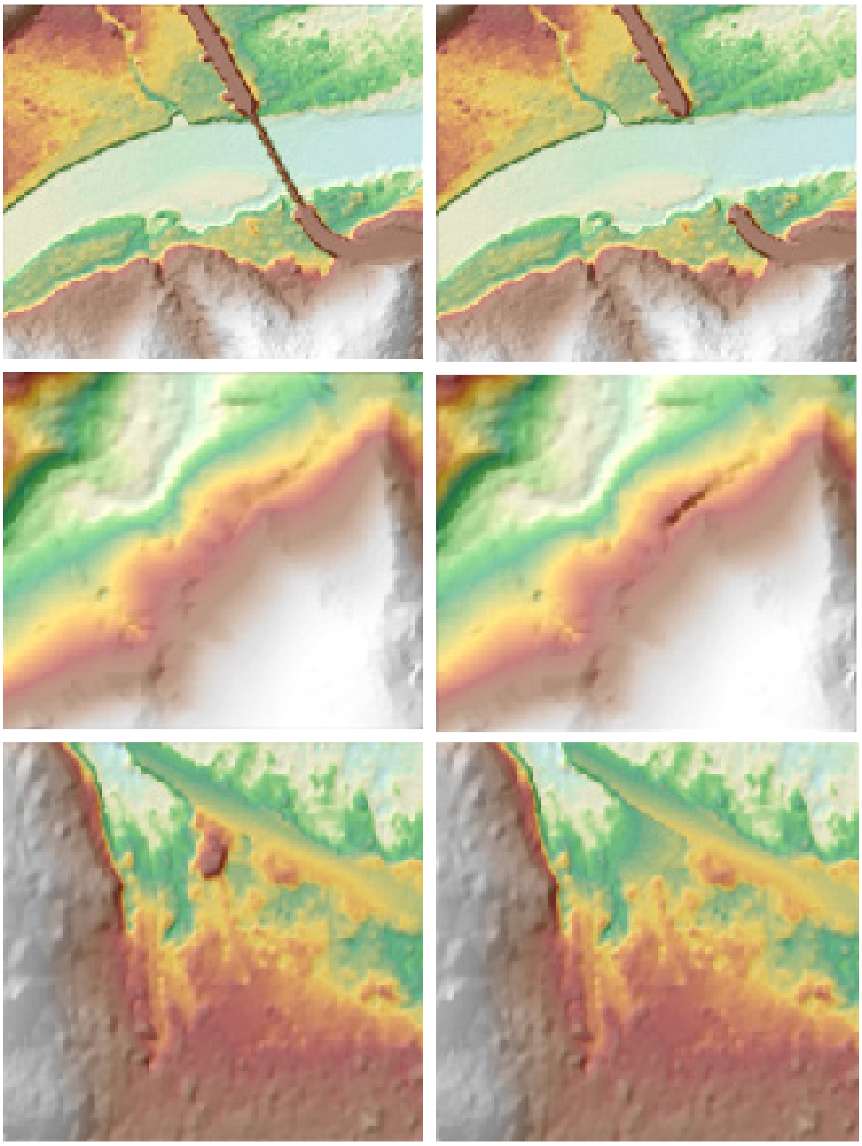


Figure 18. . Portions in the DTM of Lubayat Floodplain – a bridge before (a) and after (b) manual editing; a mountain slope before (c) and after (d) data retrieval; and a building before (a) and after (b) manual editing.

3.9 Mosaicking of Blocks

CALABARZON_reflight_Blk18Q was used as reference block at the start of mosaicking because there was no available reference DEM for shifting that overlaps with the blocks to be mosaicked. Table 12 shows the shift values applied to each LiDAR block during mosaicking.

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

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

Mission Blocks	Shift Values (meters)		
	x	y	z
CALABARZON_reflight_Blk18Q	Reference block		
CALABARZON_reflight_Blk18Q_supplement	-1.73	-1.01	+0.10

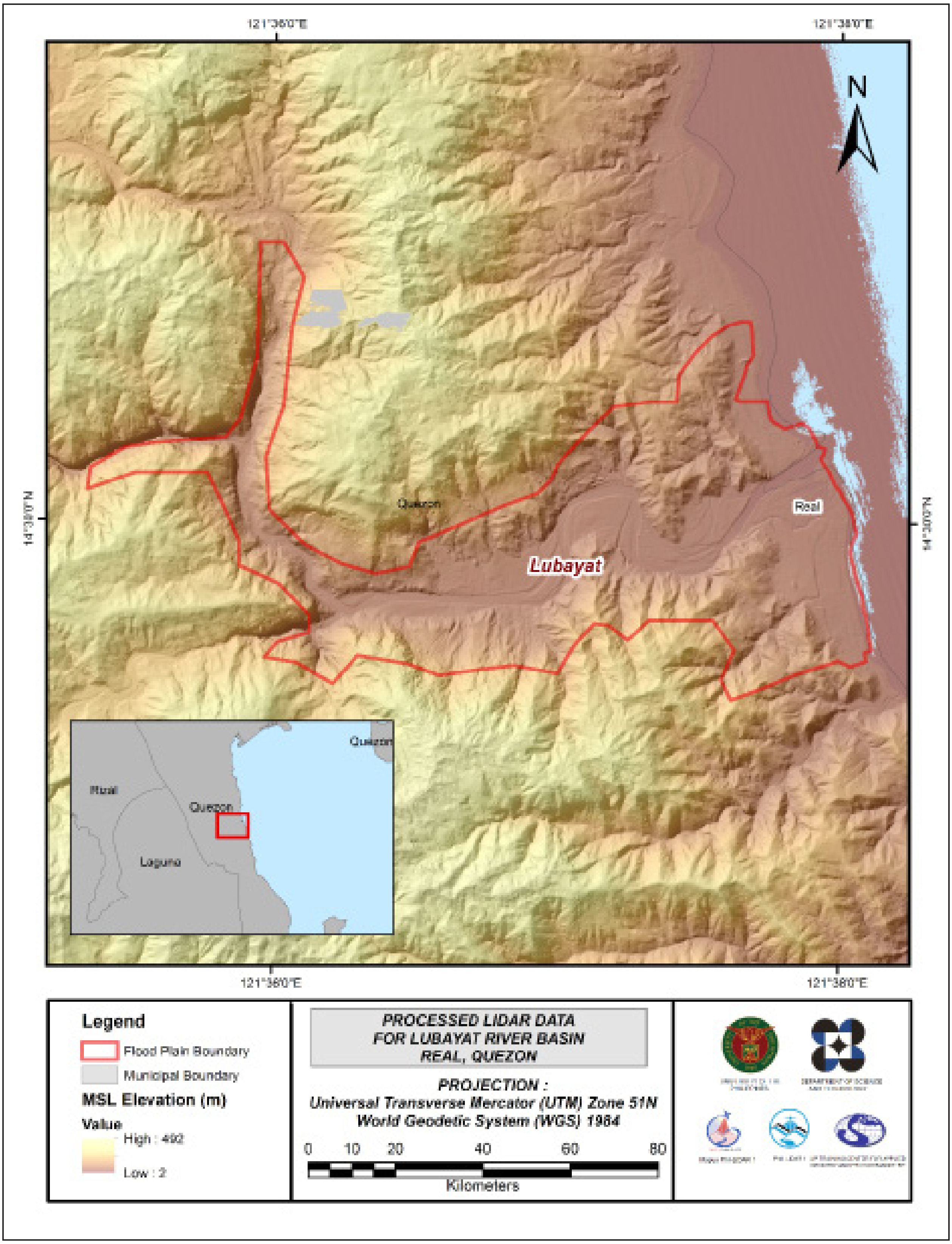


Figure 19. Map of Processed LiDAR Data for Lubayat Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Lubayat to collect points with which the LiDAR dataset is validated is shown in Figure 20. A total of 3041 survey points were used for calibration and validation of Lubayat LiDAR data. Random selection of 80% of the survey points, resulting to 2433 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 21. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 2.50 meters with a standard deviation of 0.17 meters. Calibration of Lubayat LiDAR data was done by subtracting the height difference value, 2.50 meters, to Lubayat mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

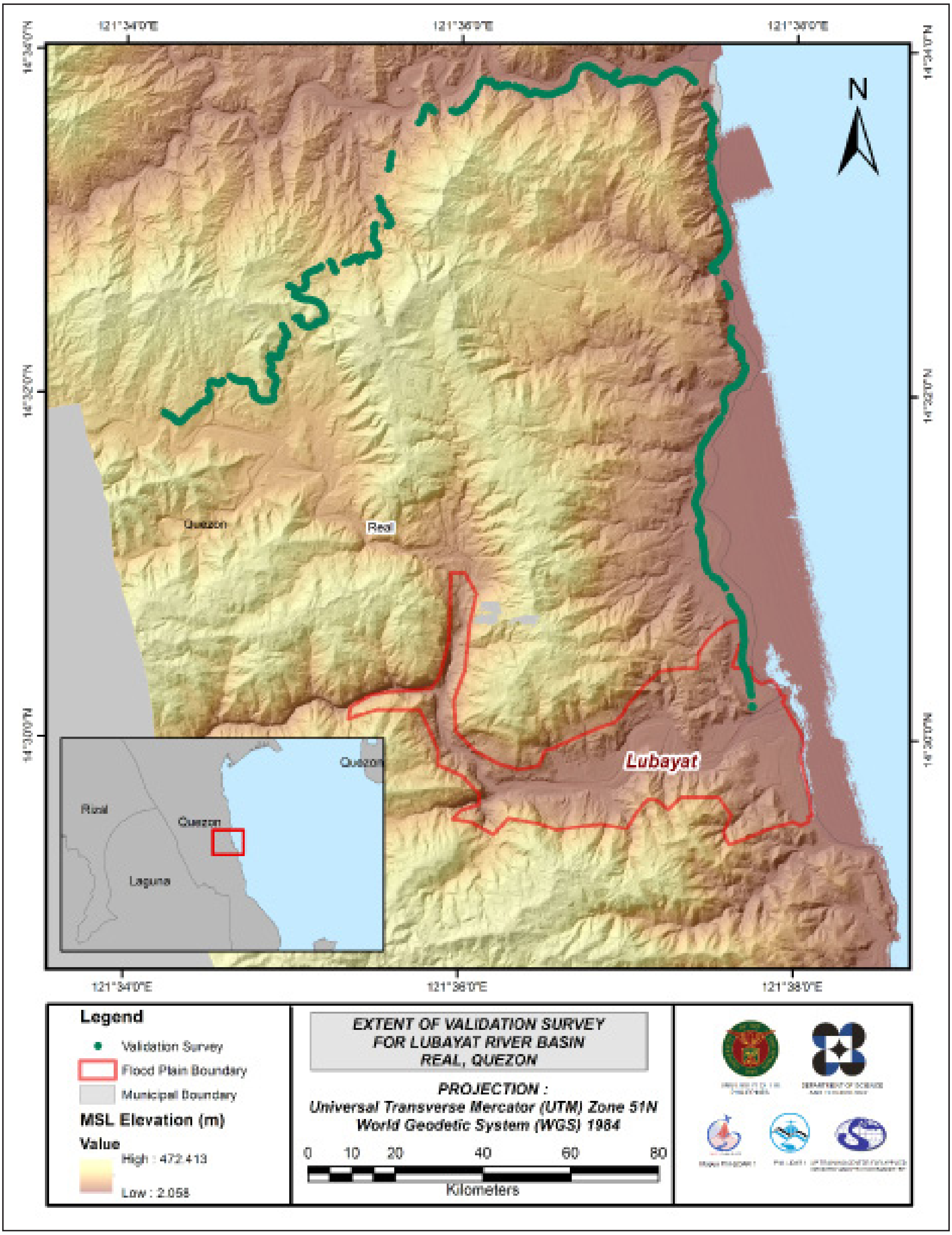


Figure 20. Map of Lubayat Flood Plain with validation survey points in green.

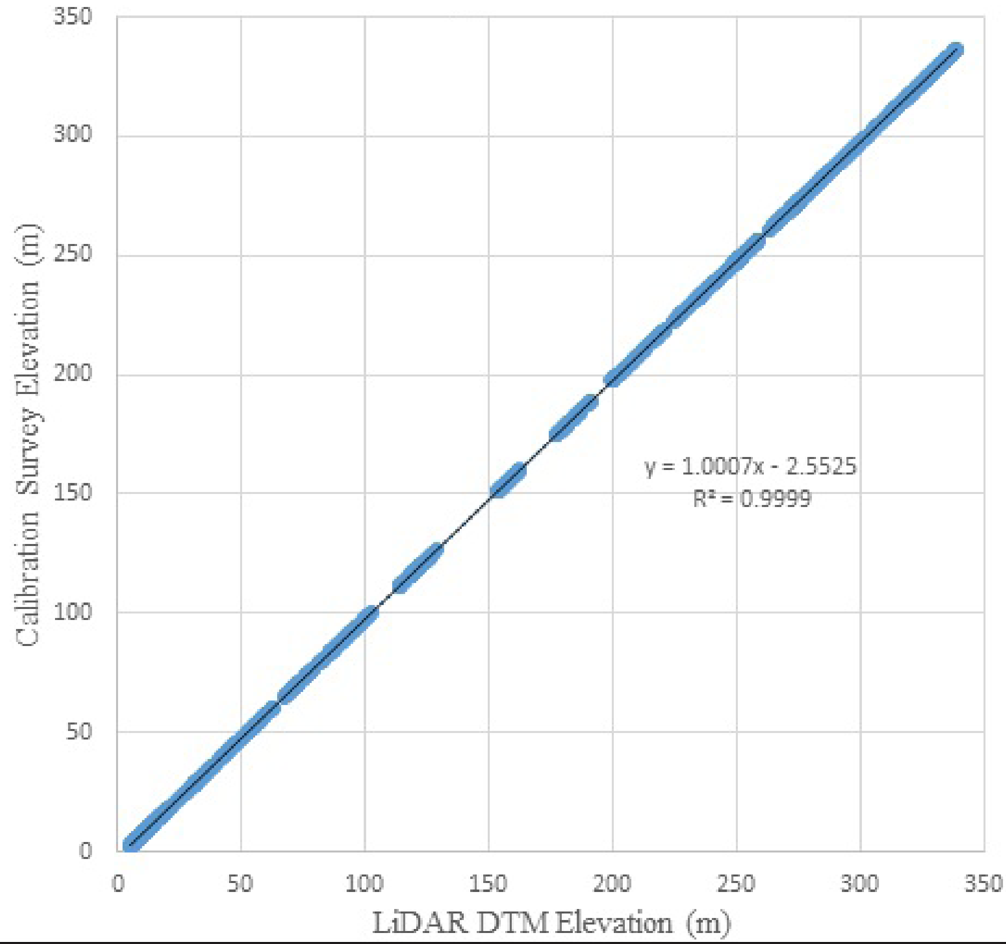


Figure 21. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

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

The remaining 20% of the total survey points, resulting to 608 points, were used for the validation of calibrated Lubayat DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 22. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.14 meters with a standard deviation of 0.14 meters, as shown in Table 14.

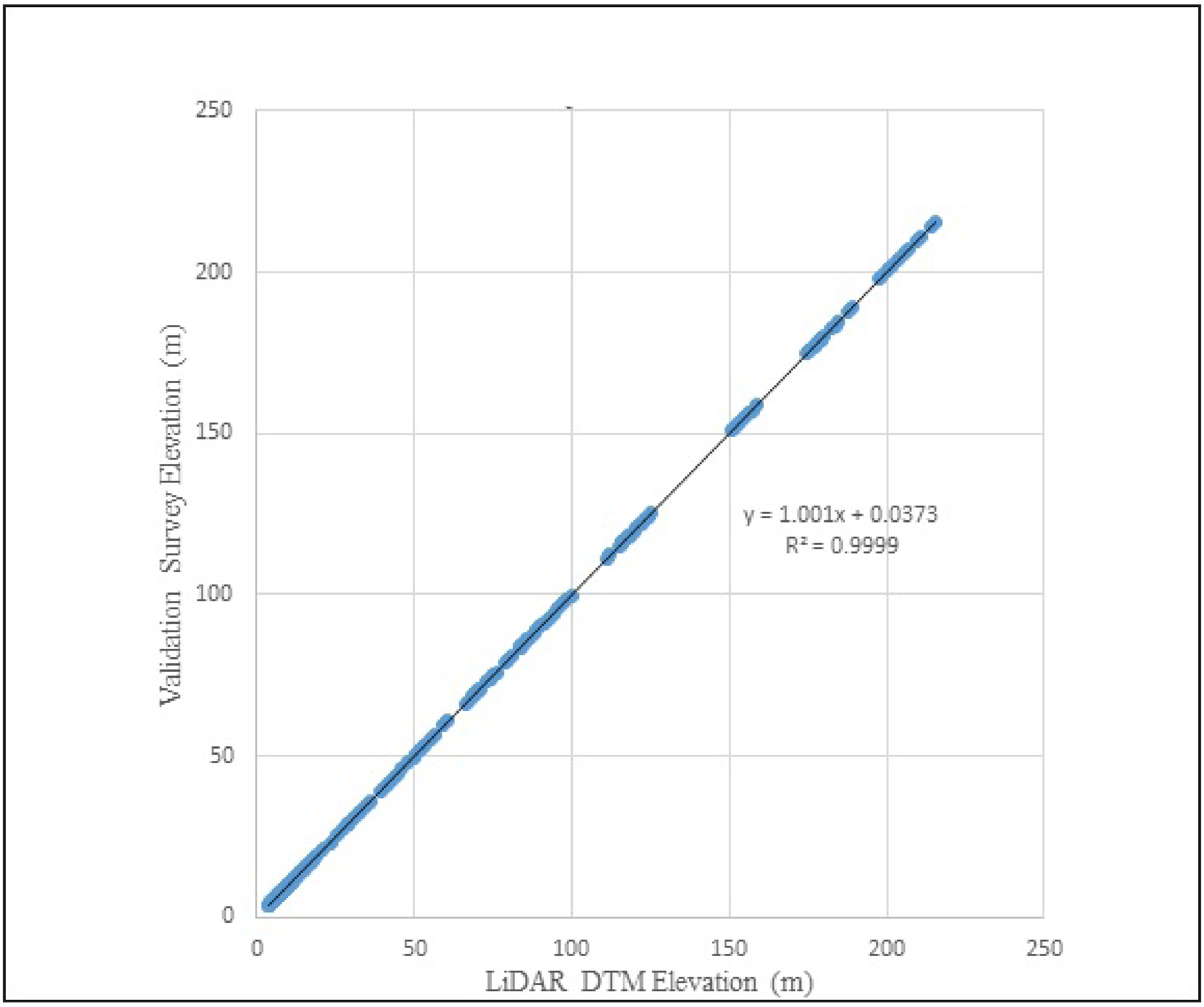


Figure 22. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

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

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, only centerline data was available for Lubayat with 791 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation (with barriers) method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.49 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Lubayat integrated with the processed LiDAR DEM is shown in Figure 23.

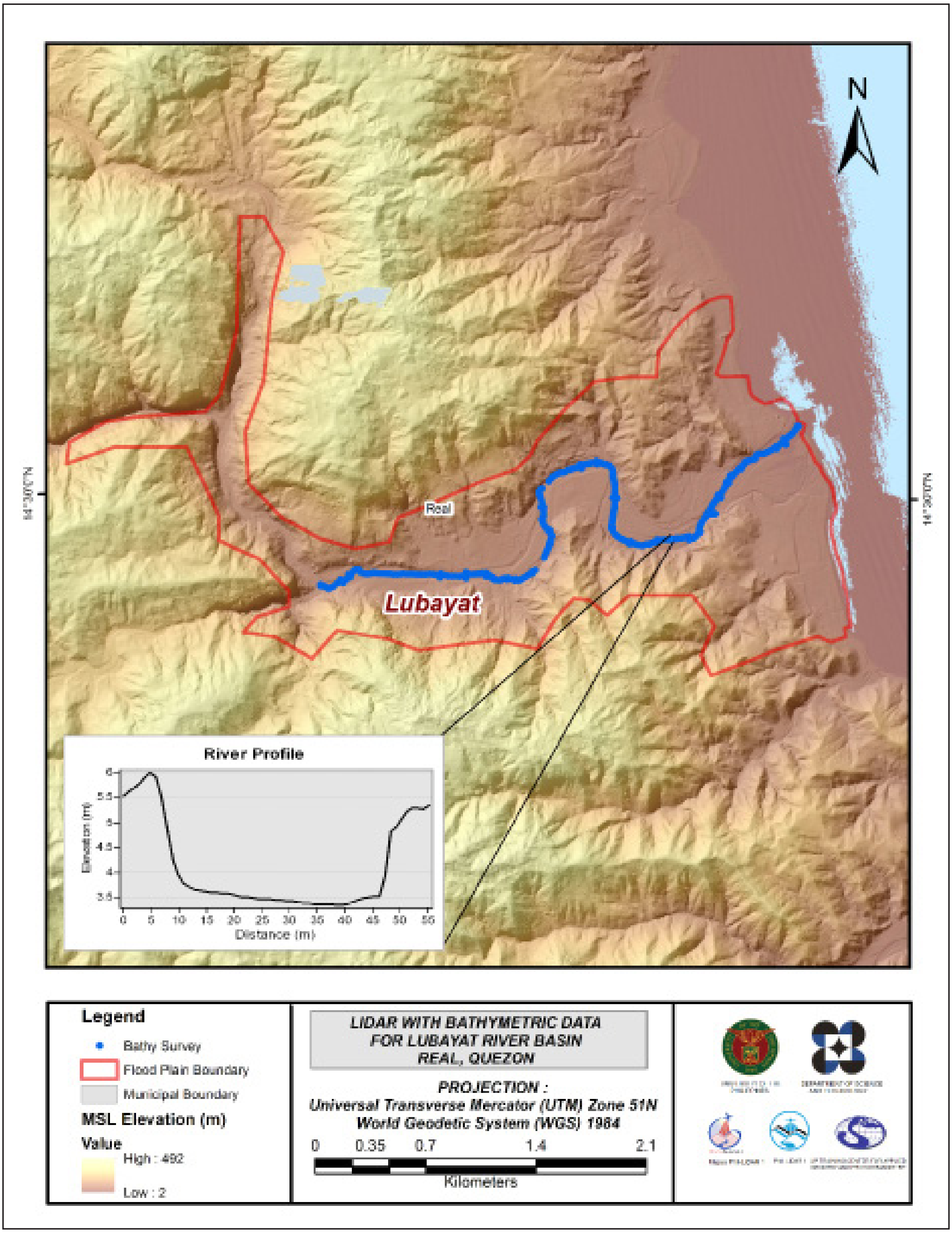


Figure 23. Map of Lubayat Floodplain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking (QC) of Digitized Features' Boundary

Lubayat floodplain, including its 200 m buffer, has a total area of 8.76 sq km. For this area, a total of 3.0 sq km, corresponding to a total of 68 building features, are considered for QC. Figure 24shows the QC blocks for Lubayat floodplain.

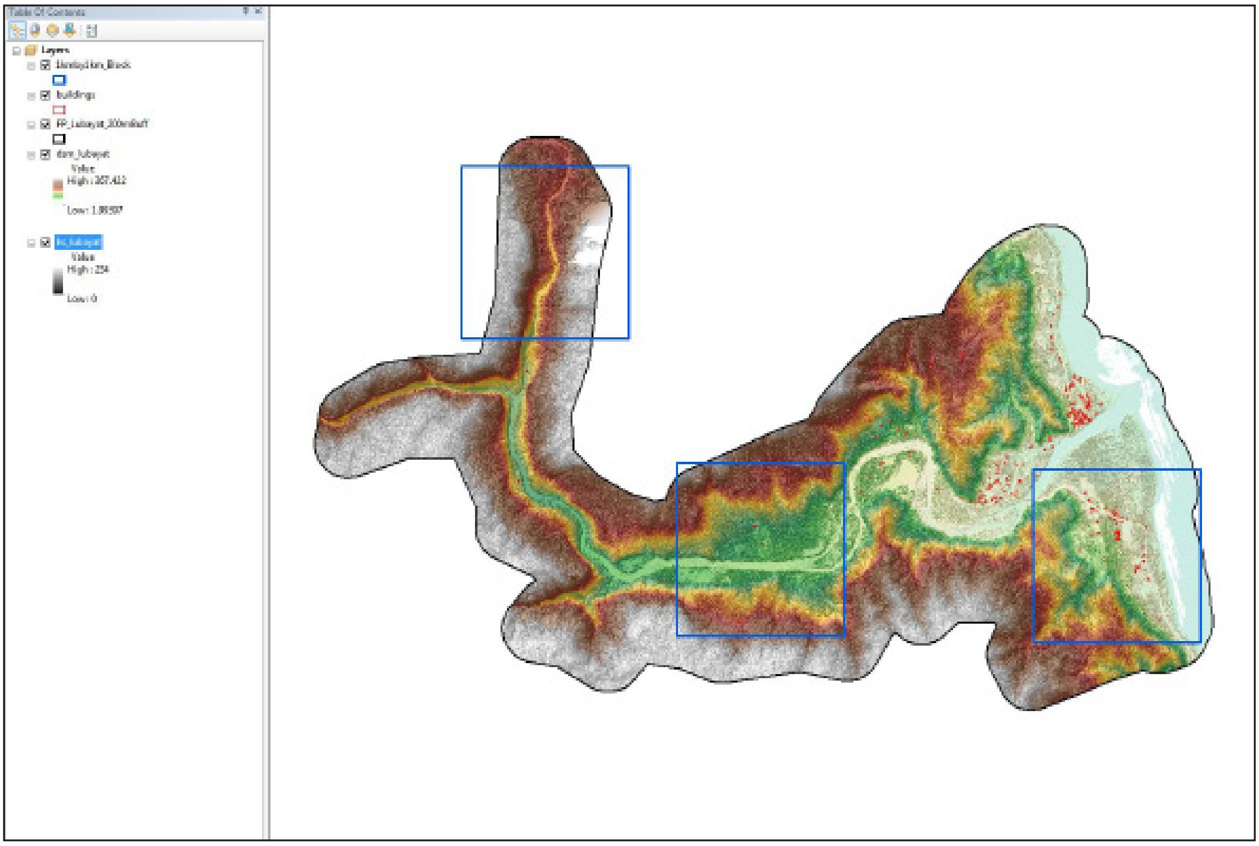


Figure 24. QC blocks for Lubayat building features.

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

Table 15. Quality Checking Ratings for Lubayat Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Lubayat	100.00	100.00	91.18	PASSED

3.12.2 Height Extraction

Height extraction was done for 244 building features in Lubayat floodplain. Of these building features, 10 were filtered out after height extraction, resulting to 234 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 7.70 m.

3.12.3 Feature Attribution

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

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

Table 16. Building Features Extracted for Lubayat Floodplain.

Facility Type	No. of Features
Residential	221
School	9
Market	0
Agricultural/Agro-Industrial	0
Medical Institutions	1
Barangay Hall	1
Military Institution	0
Sports Center/Gymnasium/Covered Court	0
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	0
Religious Institutions	2
Bank	0
Factory	0
Gas Station	0
Fire Station	0
Other Government Offices	0
Other Commercial Establishments	0
Total	**234**

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Lubayat	1.54	3.39	0.00	0.00	0.00	4.93

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

Floodplain	Water Body Type						Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	Others	
Lubayat	2	0	1	0	0	3	Lubayat

One (1) bridge over small channels that are part of the river network was also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 25 shows the Digital Surface Model (DSM) of Lubayat floodplain overlaid with its ground features.

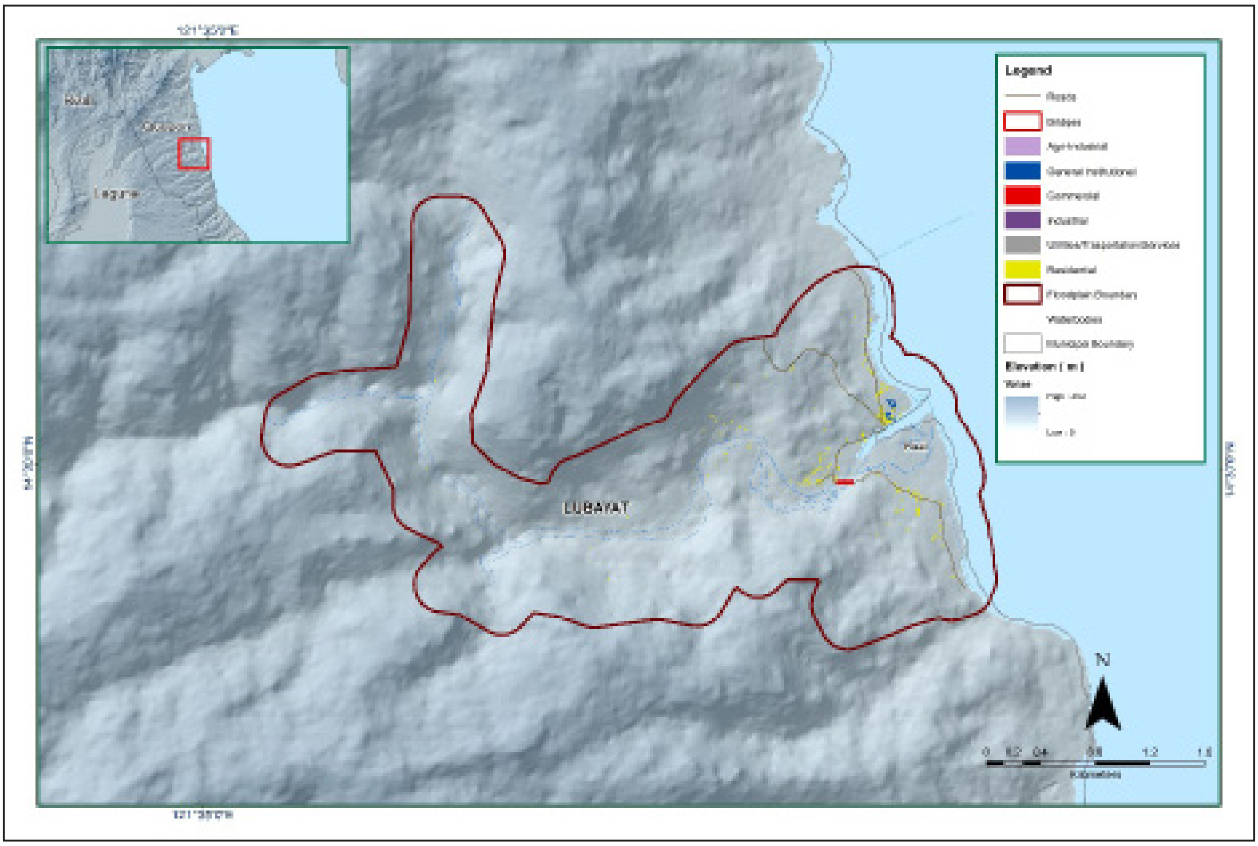


Figure 25. Extracted features for Lubayat Floodplain.

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

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Dexter T. Lozano, For. Dona Rina Patricia C. Tajora, Elaine Bennet Salvador, 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 series of surveys for Lubayat River Basin on October 14 to 23, 2015 with the following scope of work: reconnaissance of the affected site; control survey for the establishment of an accessible control point to be used in other survey types; cross-section survey, determination of bridge as-built features and water-level marking with respect to MSL on the pier of Lubayat Bridge; LiDAR ground validation points acquisition; and manual bathymetry survey using Trimble® GNSS PPK survey technique covering an estimated 5.546-km length over Brgys. Lubayat, Maunlad and Bagong Silang; as shown in Figure 26. These barangays have a total population of 2,820 based on the 2010 census of population and housing by the NSO.

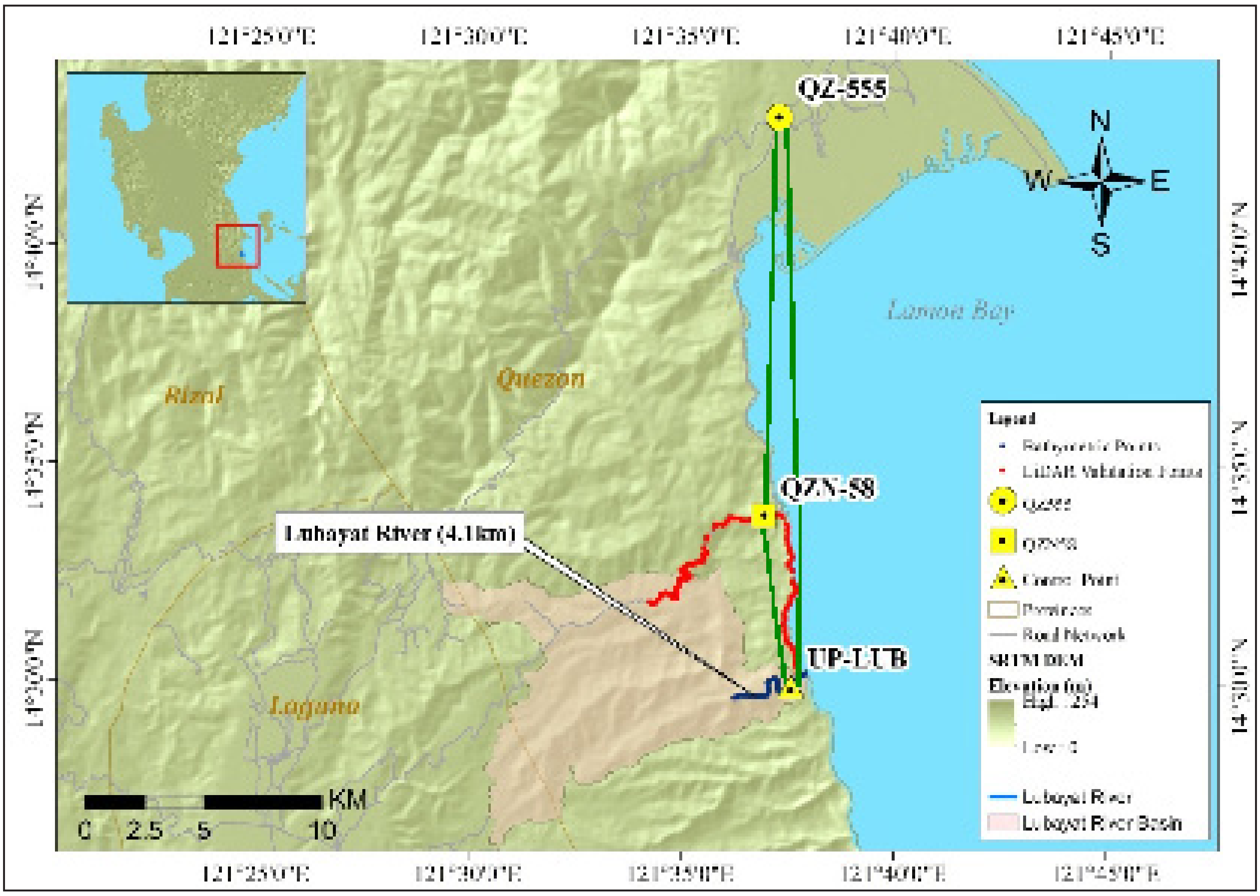


Figure 26. Lubayat River Survey Extent

4.2 Control Survey

The GNSS network used for Lubayat River Basin is composed of one (1) loop established on October 19, 2015 occupying the following reference points: QZN-58, a second-order GCP in Brgy. Tignoan, Municipality of Real; QZ-555, a first-order BM in Brgy. Gumian, Municipality of Infanta, all in Province of Quezon.

One (1) control point was established along the bridge, namely: UP-LUB, located at Lubayat Bridge in Brgy. Lubayat, Municipality of Real, Quezon.

The summary of reference and control points and its location is summarized in Table 19 while GNSS network established is illustrated in Figure 27.

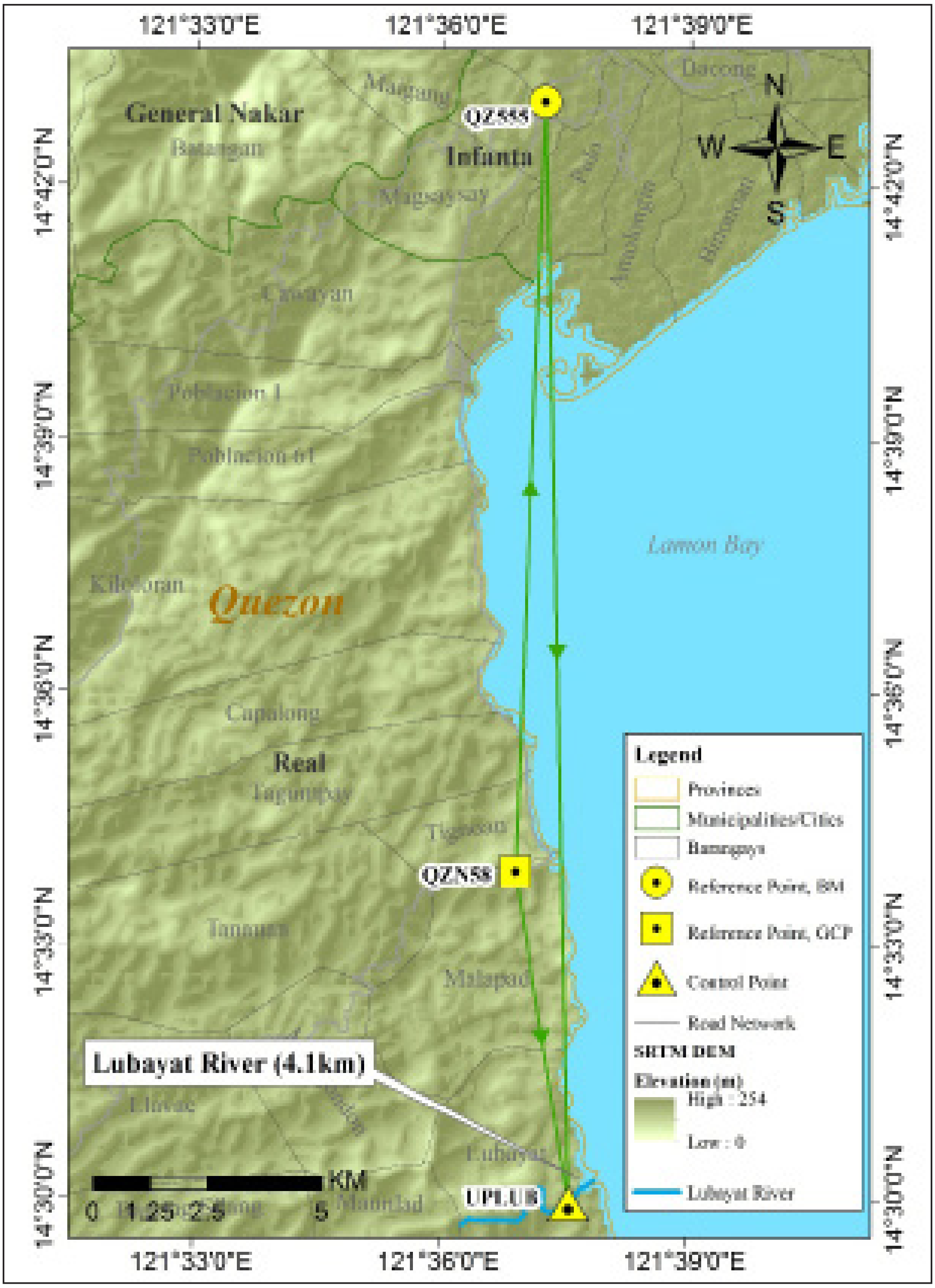


Figure 27. GNSS Network of Lubayat Field Survey

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

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

The setup of the GNSS GPS receivers on UP-LUB, QZ-555 and QZN-58 in Quezon province are shown in Figure 28, Figure 29 and Figure 30, respectively:

Figure 28. Trimble® SPS 882 GPS setup at UP-LUB at Lubayat Bridge, Brgy. Lubayat, Real, Quezon

Figure 29. Trimble® SPS 882 GPS setup at QZ-555, Brgy. Gumian, Municipality of Infanta, Quezon

Figure 30. Trimble® SPS 852 base setup at QZN-58, Brgy. Tignoan, Municipality of Real, Quezon

4.3 Baseline Processing

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

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

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

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

4.4 Network Adjustment

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

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

Where:

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

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

The three (3) control points, QZN-58, QZ-555 and UP-LUB were occupied and observed simultaneously to form a GNSS loop. Coordinates of QZN-58 and elevation values of QZ-555 were held fixed during the processing of the control points as presented in Table 21. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 21. Control Point Constraints

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

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

Table 22. Adjusted Grid Coordinates

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

The network is fixed at reference points. The list of adjusted grid coordinates of the network is shown in Table 22. Using the equation $\sqrt{((x_e)^2 + (y_e)^2)} < 20cm$ for horizontal and $z_e < 10\ cm$ for the vertical; below is the computation for accuracy that passed the required precision:

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

b. QZ-555
Horizontal accuracy = √ ((0.9) ² + (1.0) ²
= √(0.81+1.0)
= 1.4 cm < 20 cm
Vertical accuracy = Fixed

c. UP-LUB
Horizontal accuracy = √ ((0.7) ² + (0.7) ²
= √(0.49+0.49)
= 1.0 cm < 20 cm
Vertical accuracy = 9.4 cm < 10 cm

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

Table 23. Adjusted Geodetic Coordinates

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

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

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

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

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)					
		Latitude	Longitude	Ellipsoidal Height (m)	Northing	Easting	BM Ortho
QZ-555	1st Order, BM	14°43' 00.16787"	121°37' 13.96853"	50.764	1627447.834	351492.460	4.808
QZN-58	2nd Order, GCP	14°33' 52.21121"	121°36' 54.79419"	56.063	1610612.434	350816.073	10.028
UP-LUB	UP Established	14°29' 56.42439"	121°37' 34.76226"	52.753	1603359.466	351968.736	6.710

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

The cross-section survey was conducted at the downstream side of Lubayat Bridge on October 19, 2015 as shown in Figure 31. Simultaneously, the bridge as-built features of Lubayat Bridge were measured using the same setup with the base station at UP-LUB as shown in Figure 32.

Figure 31. Lubayat Bridge taken on the upstream side.

Figure 32. Cross-section and bridge as-built survey on Lubayat Bridge

A total of twenty two (22) points were obtained using a Trimble® SPS 882 receiver covering a total length of 134.77 meters. The location map and cross-section survey are shown in Figure 33 and Figure 34, while the data encoded in the bridge as-built form is in Figure 35

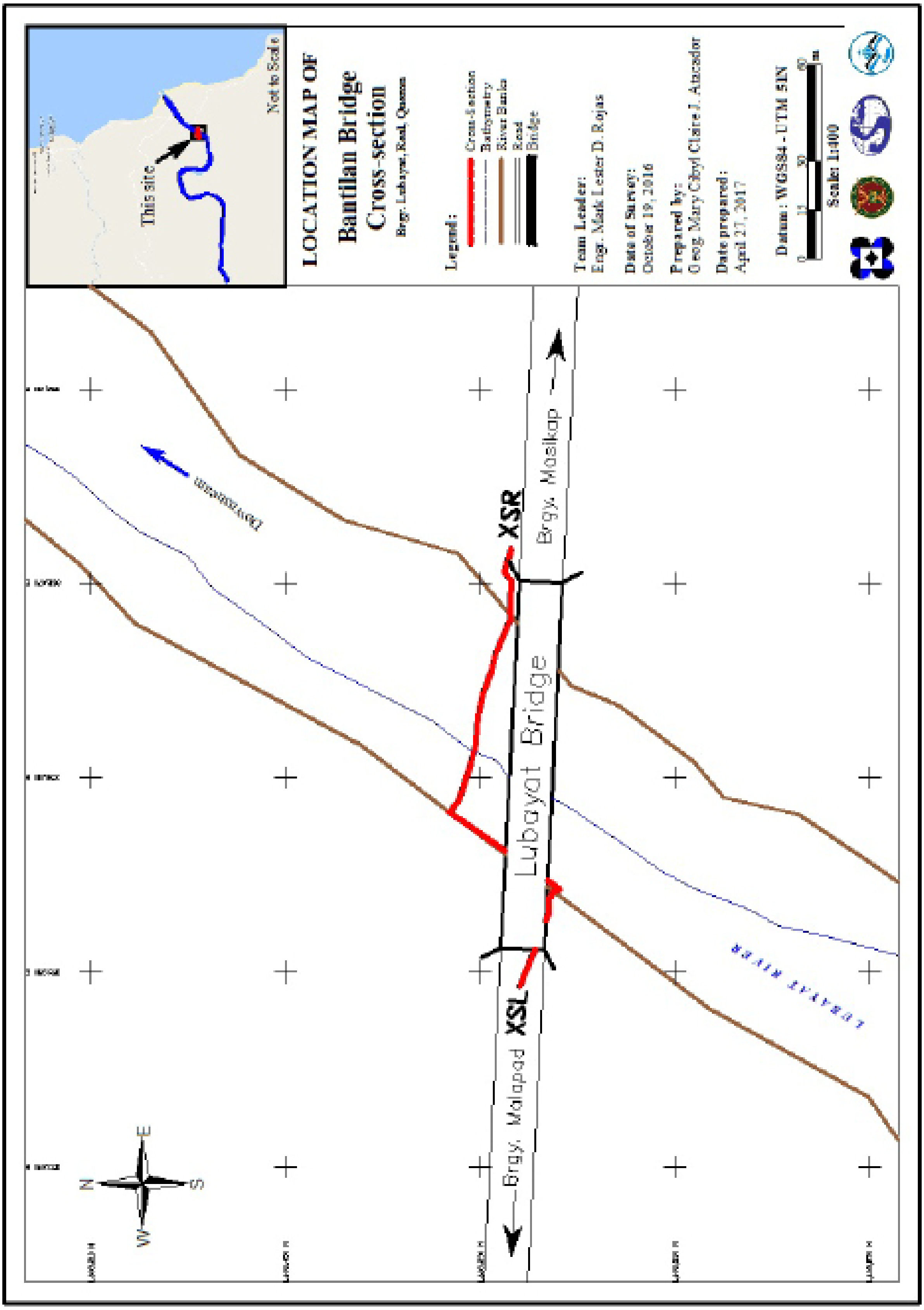


Figure 33. Location map of Lubayat Bridge cross-section

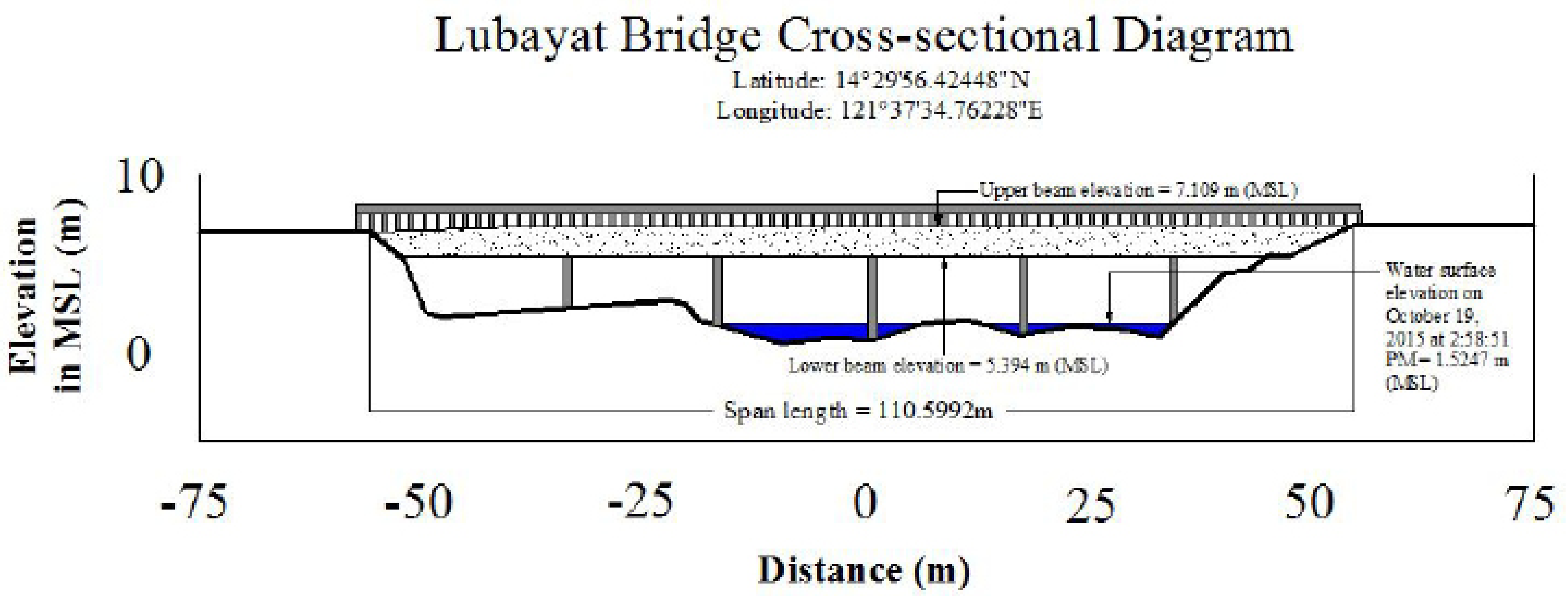


Figure 34. Talisay (also known as Yabaan) Bridge cross-section diagram

Bridge Data Form

Bridge Name: LUBAYAT BRIDGE | Date: October 19, 2015

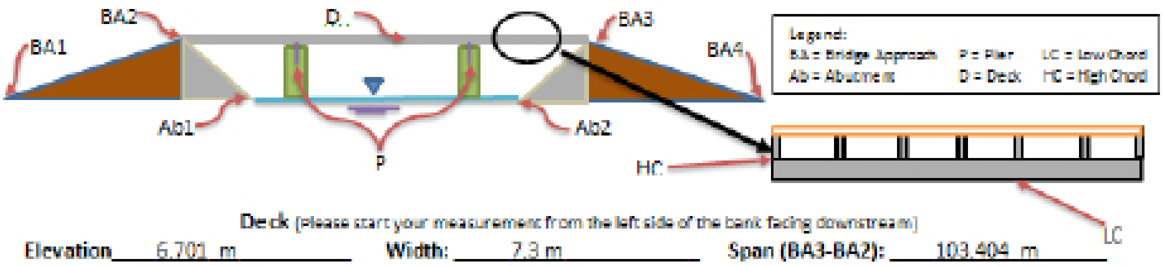
River Name: LUBAYAT RIVER BASIN | Time: 10:00 AM

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

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

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

Latitude: 14d29'56.72580"N | Longitude: 121d37'36.51850" E



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

Elevation: 6.701 m | Width: 7.3 m | Span (BA3-BA2): 103.404 m

	Station	High Chord Elevation	Low Chord Elevation
1	41.45214428	6.6857	5.313
2	75.67771472	6.7017	5.329
3	92.60915847	6.7237	5.351
4	109.5233271	6.7667	5.394
5			

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

	Station(Distance from BA1)	Elevation		Station(Distance from BA1)	Elevation
BA1	0	6.431	BA3	127.576	5.064
BA2	24.172	6.431	BA4	134.771	6.738

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

	Station (Distance from BA1)	Elevation
Ab1	30.45803442	1.9277
Ab2	122.8731353	4.2447

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

Shape: Oval | Number of Piers: 5 | Height of column footing: N/A

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	41.45214428	6.6857	0.5m
Pier 2	58.22667061	6.7017	0.5m
Pier 3	75.67771472	6.7017	0.5m
Pier 4	92.60915847	6.7237	0.5m
Pier 5	109.5233271	6.7667	0.5m

Figure 35. Lubayat Bridge Data Form

The water surface elevation measured on October 19, 2015 at 2:58:51 PM was 1.525 meters in reference to MSL. Water-level marking was done at a pier of Lubayat Bridge as shown in Figure 36. The markings on the bridge pier shall serve as the reference for the flow data gathering and depth gauge deployment of MAPUA PHIL-LIDAR 1.

Figure 36. (A) Actual water-level marking on Lubayat Bridge and (B) finished markings on the bridge pier

4.6 Validation Points Acquisition Survey

LiDAR Validation points acquisition survey was conducted on October 17 and 19, 2015 using a survey-grade GNSS rover receiver mounted on a pole attached in front of a vehicle as seen in Figure 37. It was secured with a nylon rope and cable ties to ensure that it was horizontally and vertically balanced. The antenna height of 2.32 m was measured from the ground up to the bottom of the notch of the GNSS rover receiver. The survey was conducted using PPK technique on a continuous topography mode. Within two (2) days of ground validation survey, the team covered the major roads and highways in Maragondon, Tignoan, Malapad and Lubayat.

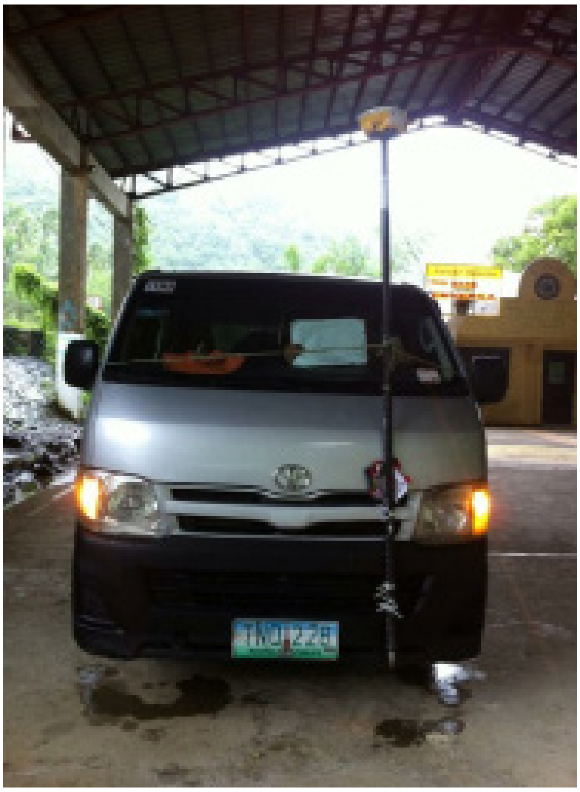


Figure 37. Validation points acquisition survey set up along Lubayat River Basin

The survey acquired 3,040 ground validation points shown in the map in Figure 38. The ground validation started from the municipality of Tignoan going to Maragondon on the first day and started from Tignoan going to Lubayat on the second day covering an approximate distance of 18.3 km.

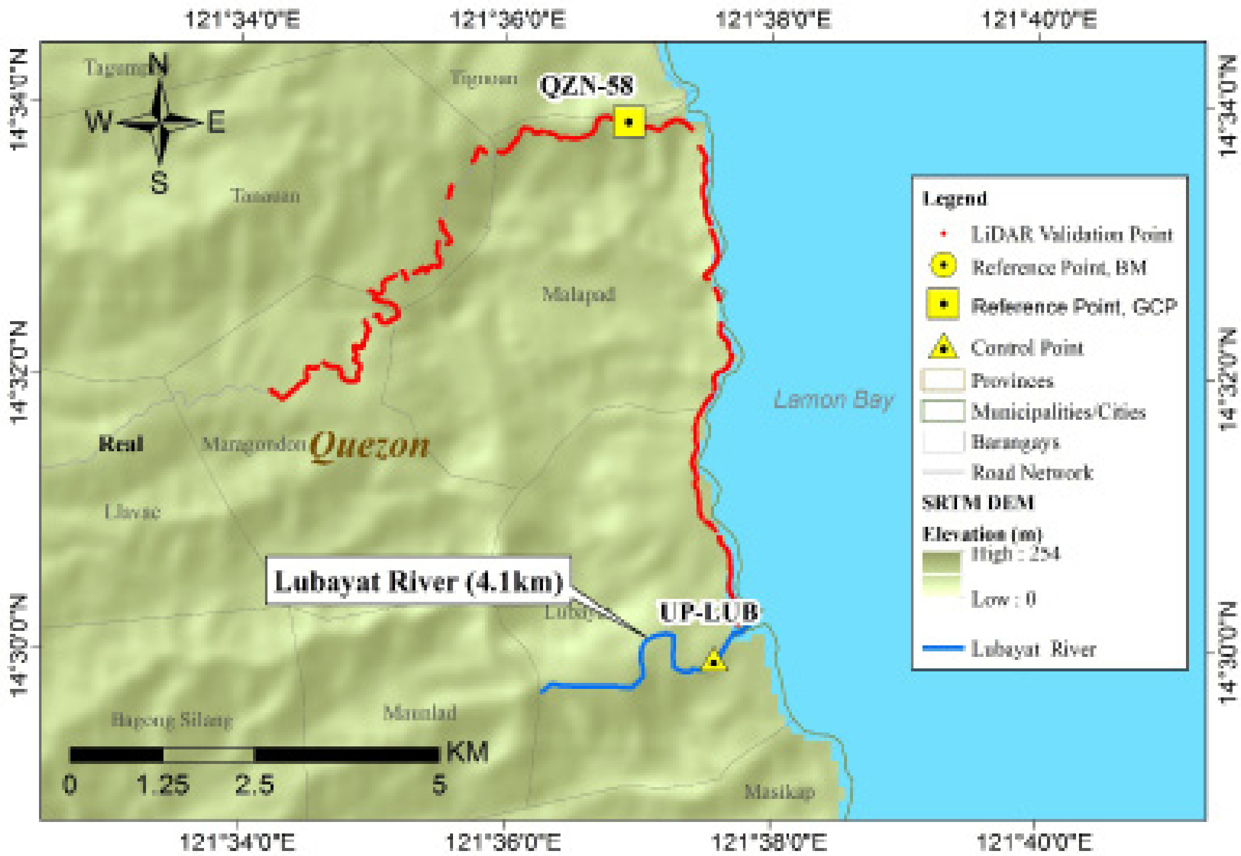


Figure 38. LiDAR validation points acquisition survey for Lubayat River Basin

4.7 Bathymetric Survey

Manual bathymetry survey was conducted on October 15, 2015 using a Trimble® SPS 882 GNSS receiver as shown in Figure 39. The survey started in Brgy. Maulad, Municipality of Real with coordinates 14°29'42.01635" 121°36'14.52554", traversed down the river by foot, and ended at the mouth of the river in Brgy. Lubayat, with coordinates 14°30'14.56948" 121°37'55.90604", also in Municipality of Real. The established point, UP-LUB, at the approach of Lubayat Bridge was used as the GNSS base station all throughout the survey.

Figure 39. Setup of manual bathymetry survey for Lubayat River using a Trimble® SPS 882 Rover

A total of 805 bathymetry points were acquired starting from Brgy. Maunlad down to the mouth of the river at Brgy. Lubayat over an approximated distance of 5.546 kilometers. The entire traverse covered for the bathymetry survey is shown in the map in Figure 40.

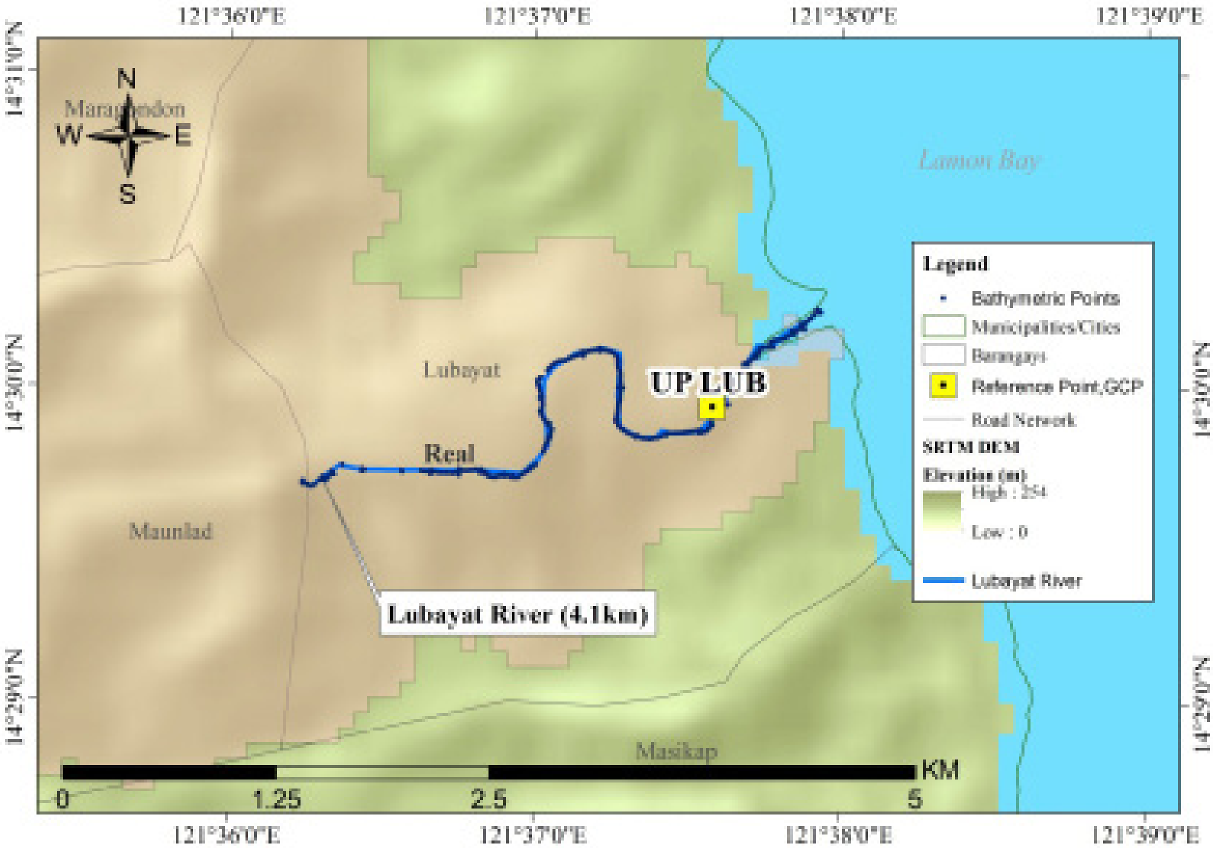


Figure 40. Bathymetric points gathered from Lubayat River

A CAD drawing was produced illustrating the Lubayat centerline riverbed profile. As shown in Figure 41, the difference in elevation from the first point and upstream in Brgy. Maunlad down to the last point in Brgy. Lubayat is 24.650 m. The highest elevation observed was 24.3457 m above MSL while the lowest point was 0.3043 m below MSL located near the mouth of the river.

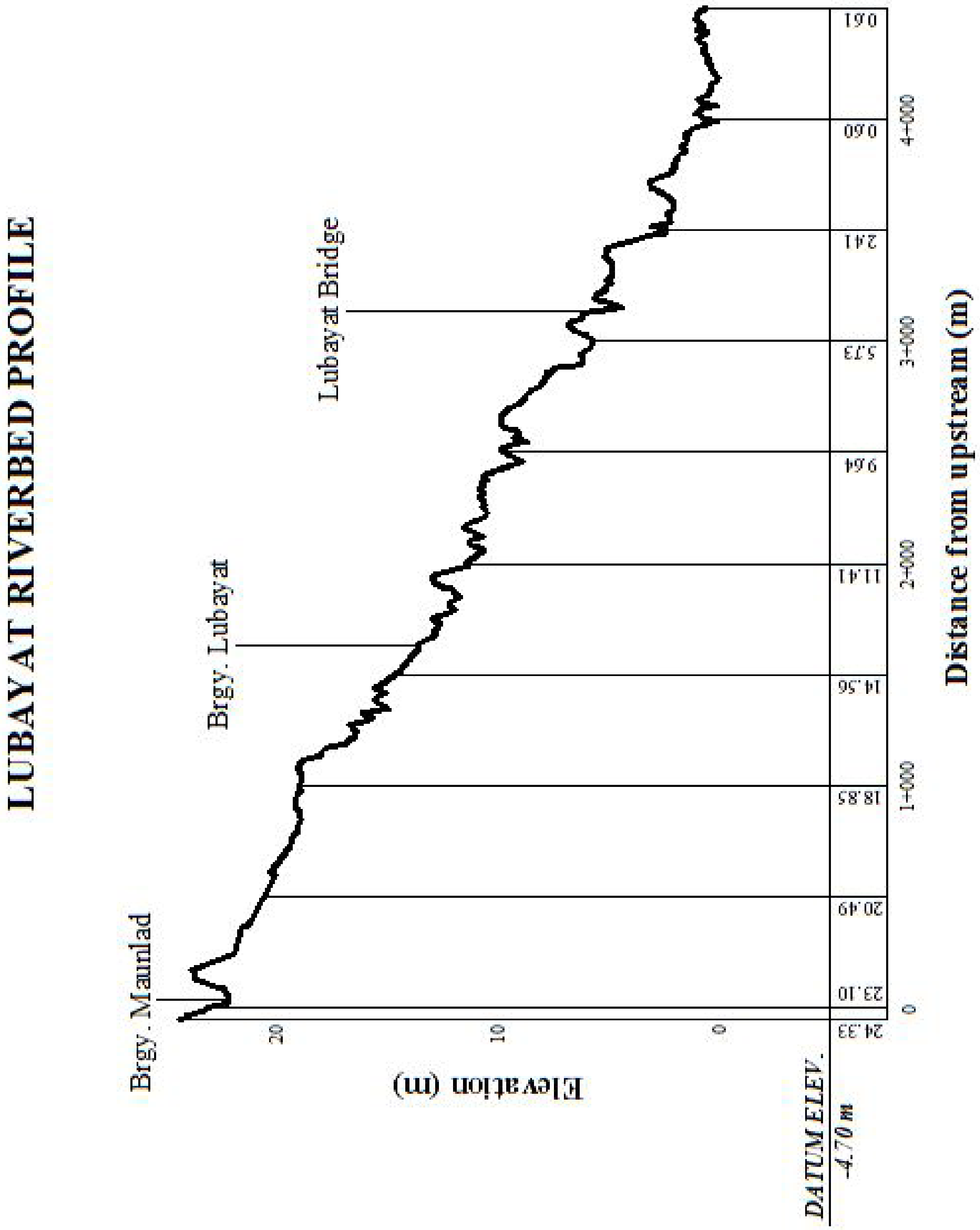


Figure 41. Lubayat riverbed profile

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data used in Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from an automatic rain gauge (ARG) deployed by the Mapua Institute of Technology under the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The ARG was installed in Llavac High School Real, Quezon (Figure 42). The precipitation data collection started from November 25, 2016 00:00 am to November 26, 2016 at 18:00 with 15 minutes recording interval.

The total precipitation for this event in Llavac High School ARG was 76.338614. It has a peak rainfall of 6.2 mm. on 25 November 2016 at 10:15 pm. The lag time between the peak rainfall and discharge is 8 hours and 35 minutes, as seen in Figure 45.

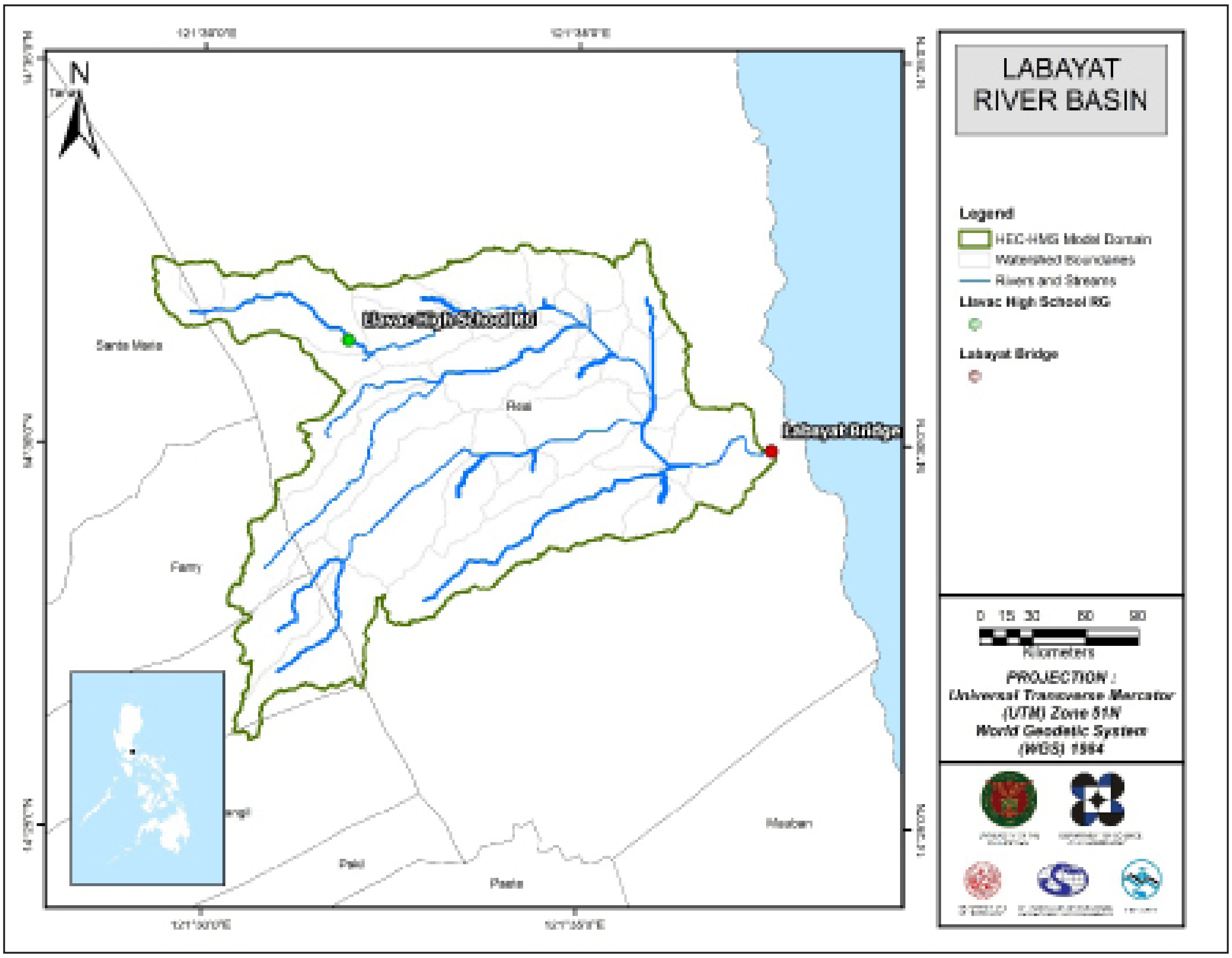


Figure 42. Location map of Lubayat HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Lubayat Bridge, Real, Quezon (14°29'56.42448"N, 121°37'34.76228"E). It gives the relationship between the observed water levels from the Lubayat Bridge using depth gage and outflow of the watershed got using the flow meter at this location.

For Lubayat Bridge, the rating curve is expressed as Q = 0.083e3.0497x as shown in Figure 44.

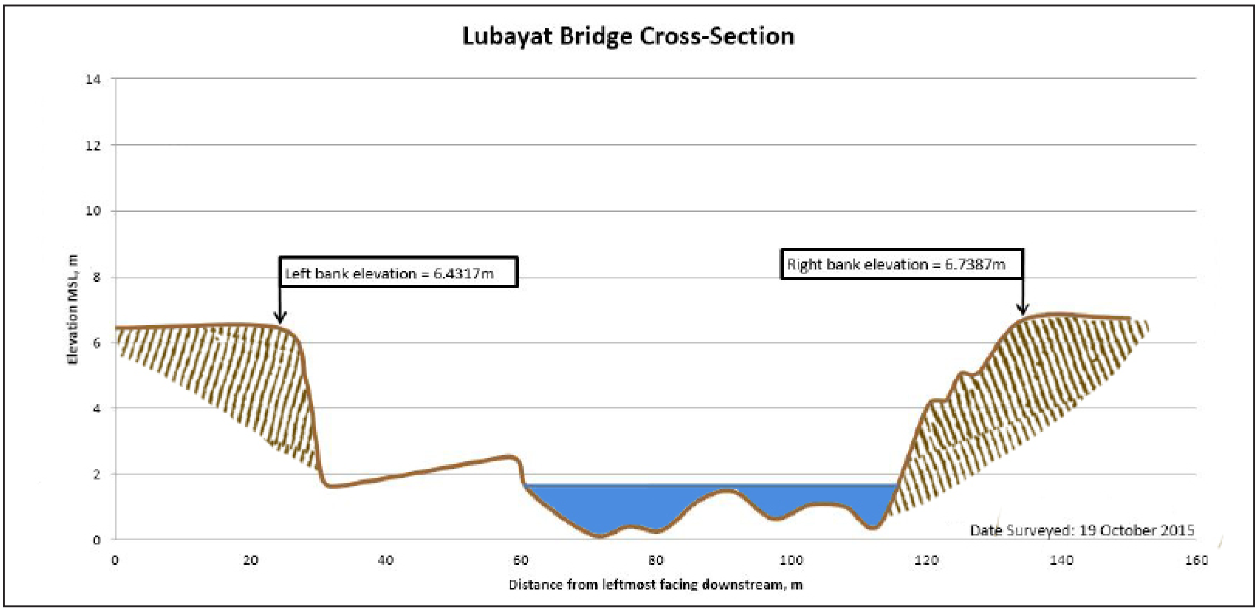


Figure 43. Cross-Section Plot of Lubayat Bridge

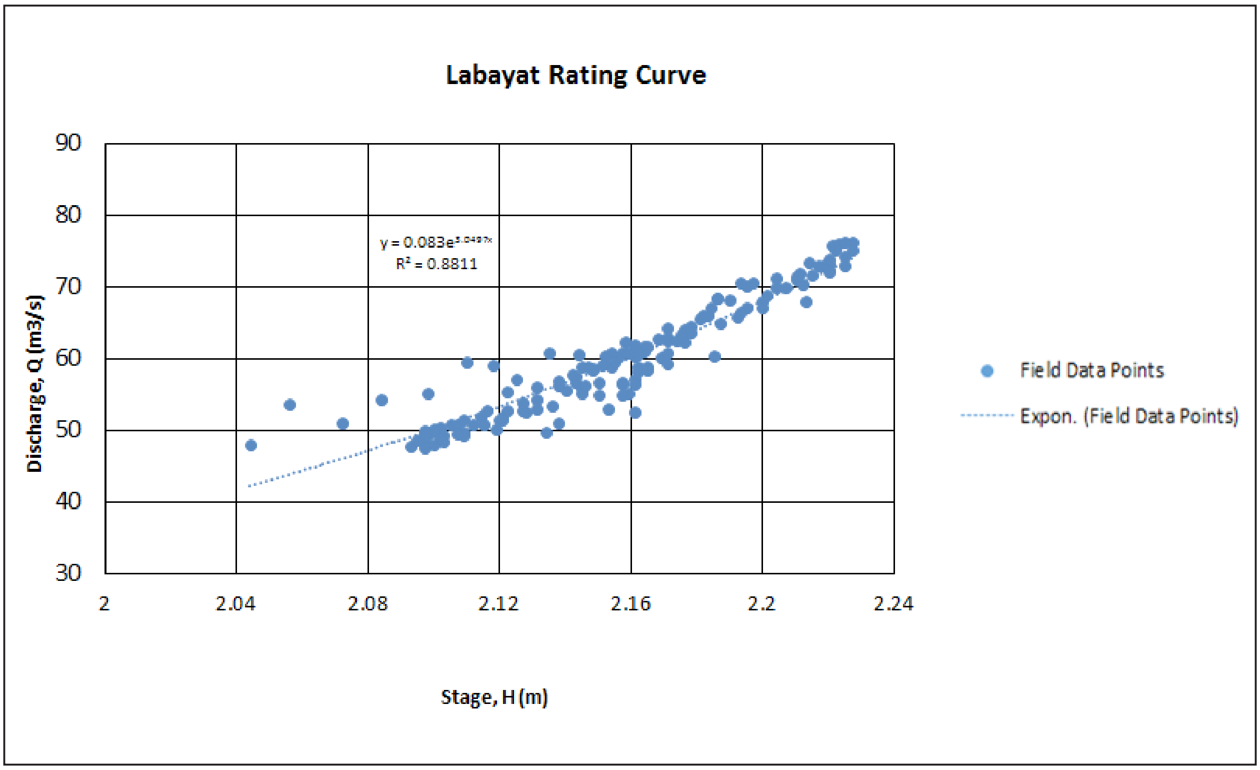


Figure 44. Rating curve at Lubayat (also known as Labayat) Bridge, Real, Quezon Province

This rating curve equation was used to compute the river outflow at Labayat Bridge or the calibration of the HEC-HMS model shown in Figure 45. Peak discharge is 76.34 cms at 6:50 AM, November 26, 2016.

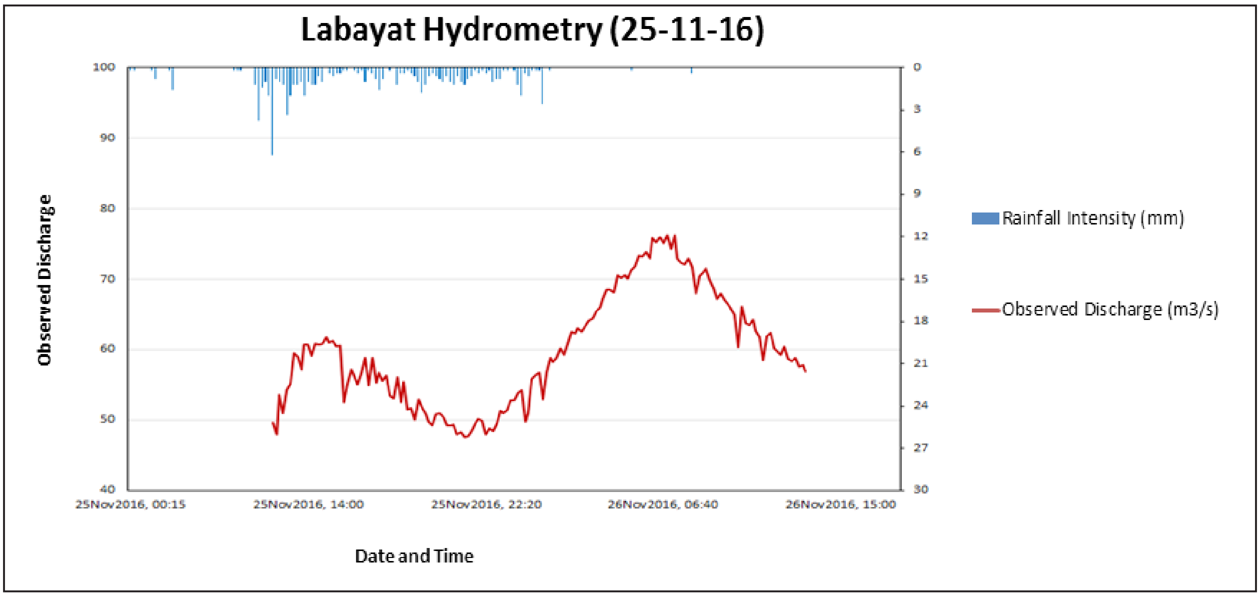


Figure 45. Rainflow and outflow data at Lubayat River used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Infanta Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the value in such a way certain peak value will be attained at a certain time. This station chosen based on its proximity to the Lubayat watershed. The extreme values for this watershed were computed based on a 40-year record, as shown in Table 25.

Table 25. values for Romblon Rain Gauge computed by PAGASA

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

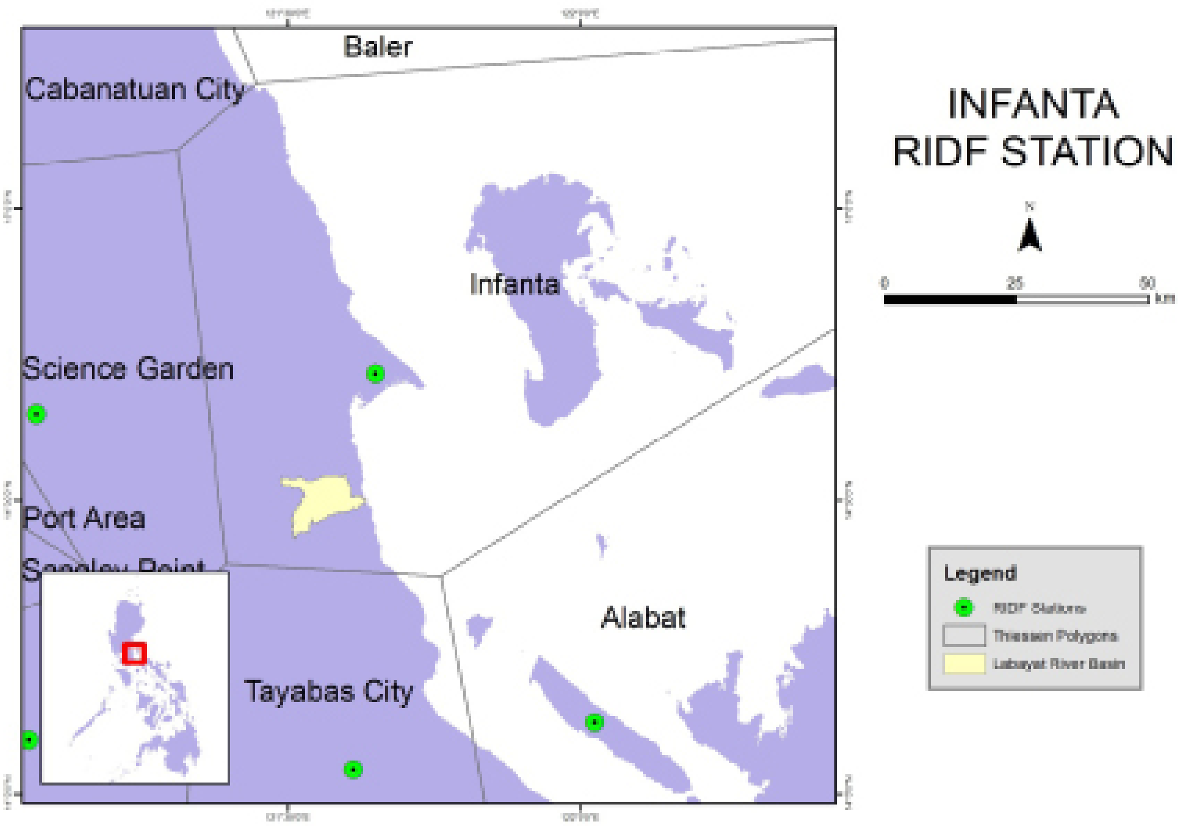


Figure 46. Infant RIDF location relative to Lubayat (also known as Labayat) River Basin

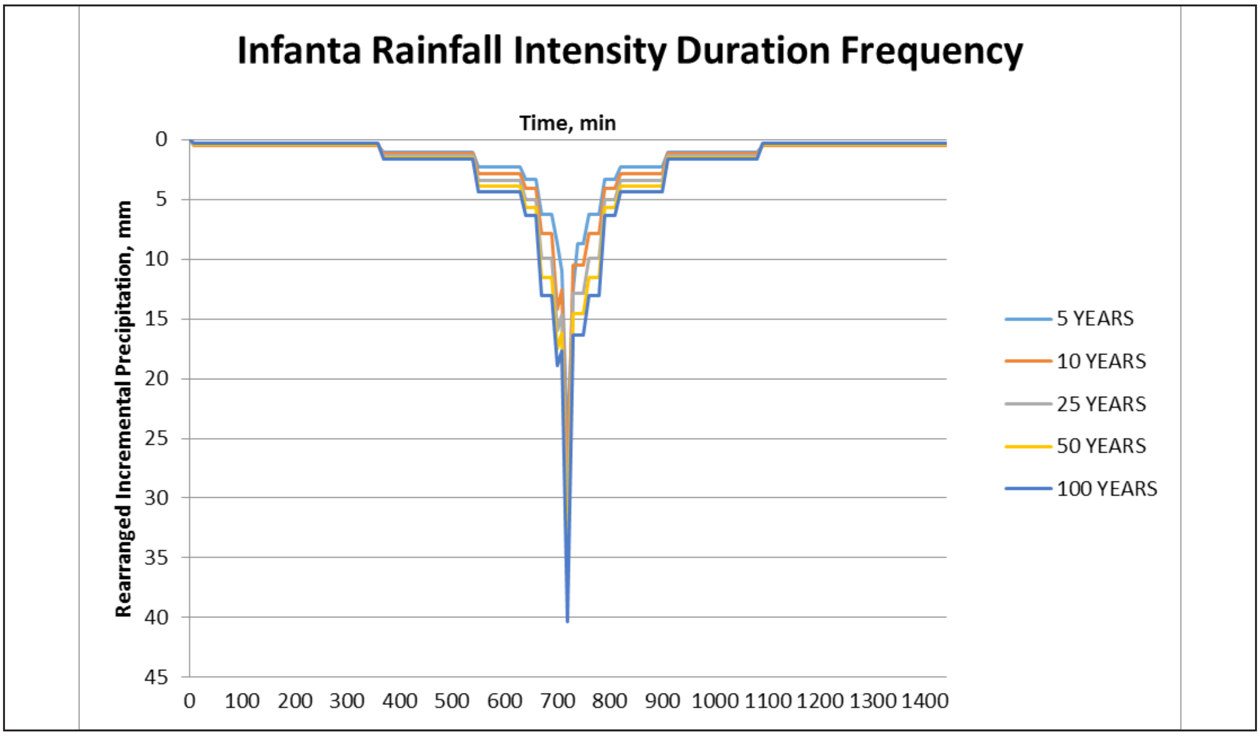


Figure 47. Synthetic storm generated for a 24-hr period rainfall for various return periods.

5.3 HMS Model

The soil dataset was generated before 2004 from the Bureau of Soil and Water Management (BSWM) under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Lubayat River Basin are shown in Figure 48 and Figure 49, respectively.

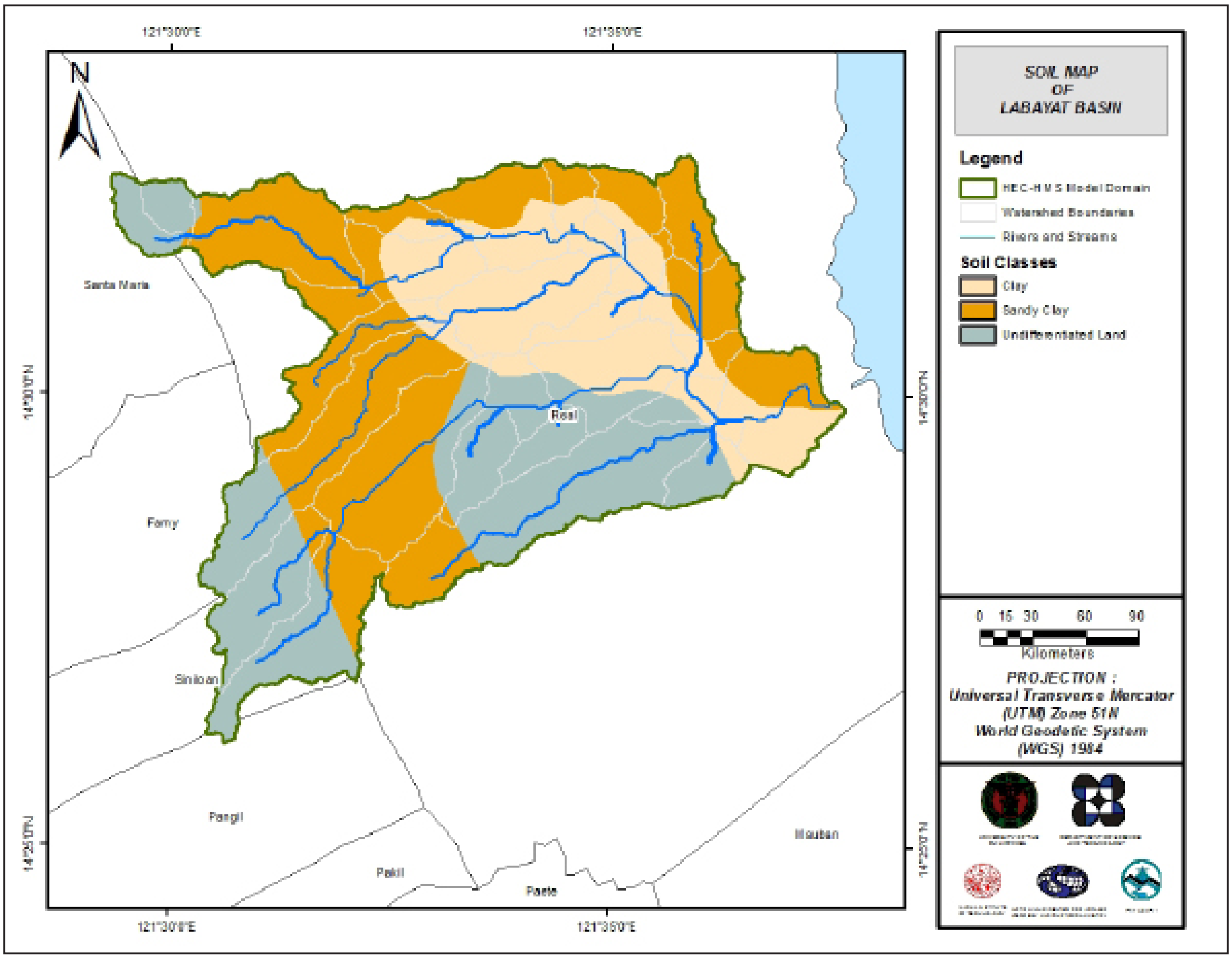


Figure 48. Soil map of the Lubayat River Basin

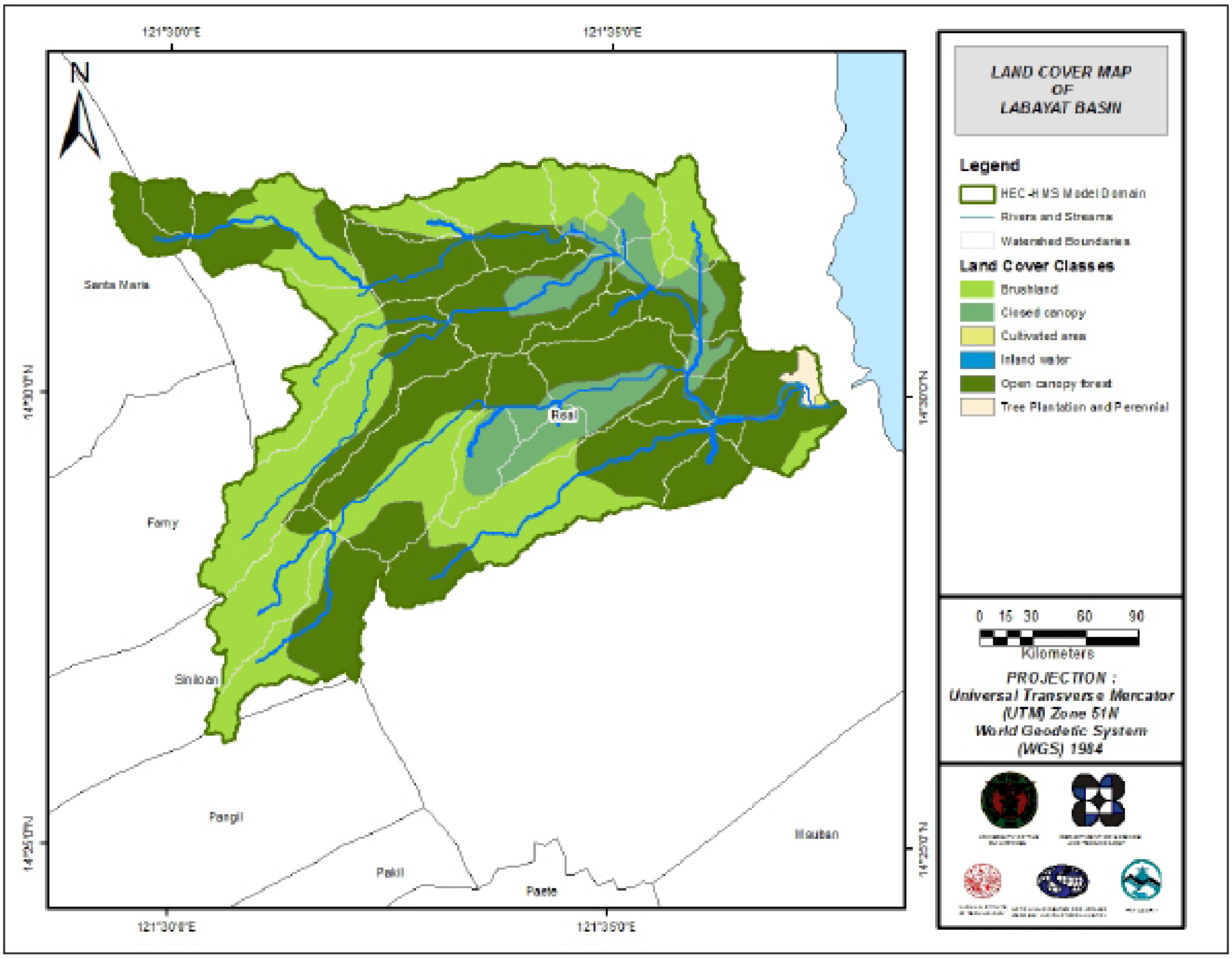


Figure 49. Land cover map of Lubayat River Basin

For Lubayat River Basin, three (3) soil classes were identified. These are clay, sandy clay and undifferentiated land. Moreover, six (6) land cover classes were identified, These are brushland, closed canopy, cultivated area, inland water, open canopy forest and tree plantation and perennial.

Figure 50. Slope map of Lubayat River Basin

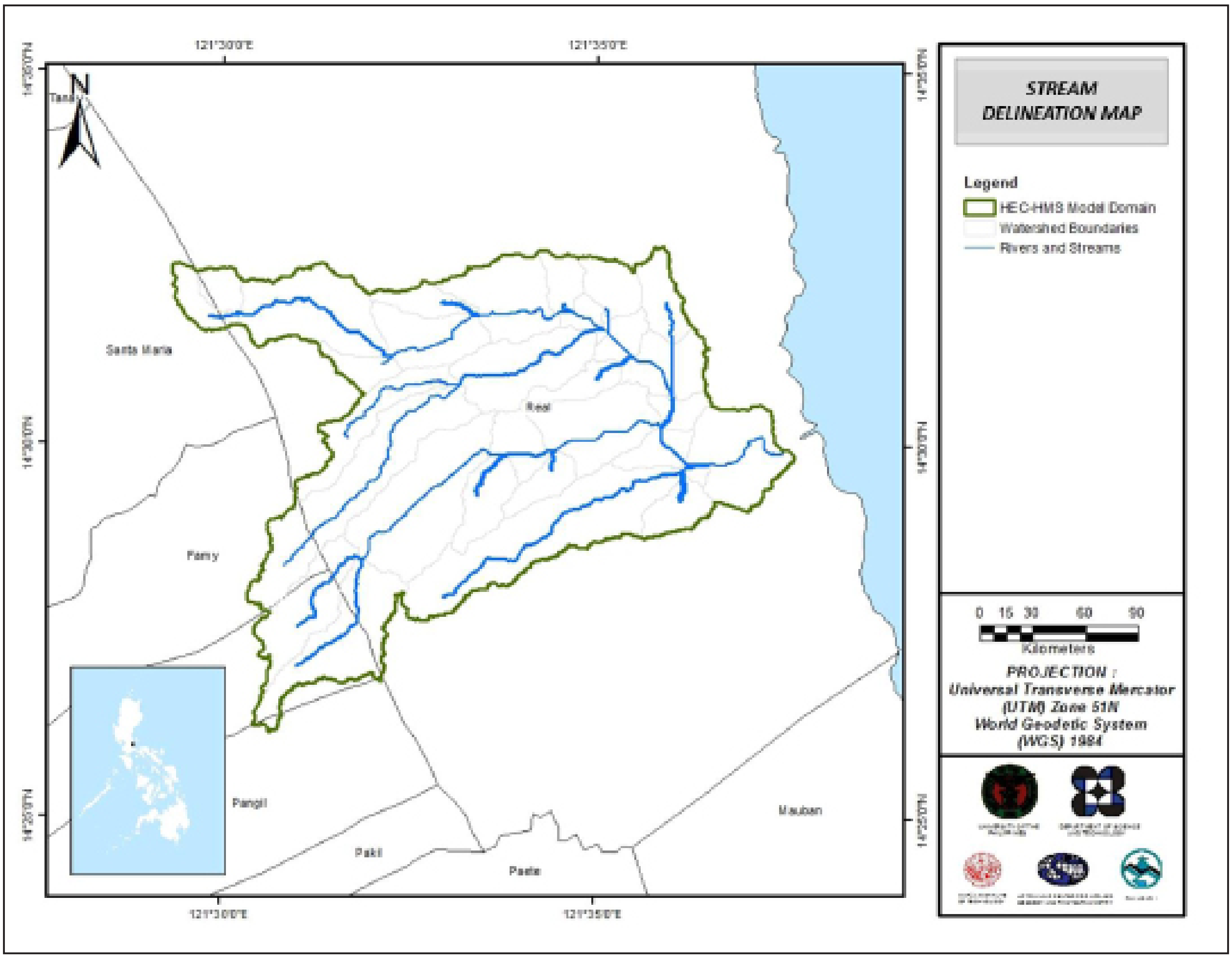


Figure 51. Stream Delineation Map of the Lubayat River Basin

The Labayat basin model consists of 33 sub basins, 16 reaches, and 16 junctions. The main outlet is at the northernmost tip of the watershed. This basin model is illustrated in Figure 52. The basins were identified based on soil and land cover characteristics of the area. Precipitation was taken from DOST rain gauges. Finally, it was calibrated using data from the Labayat Bridge.

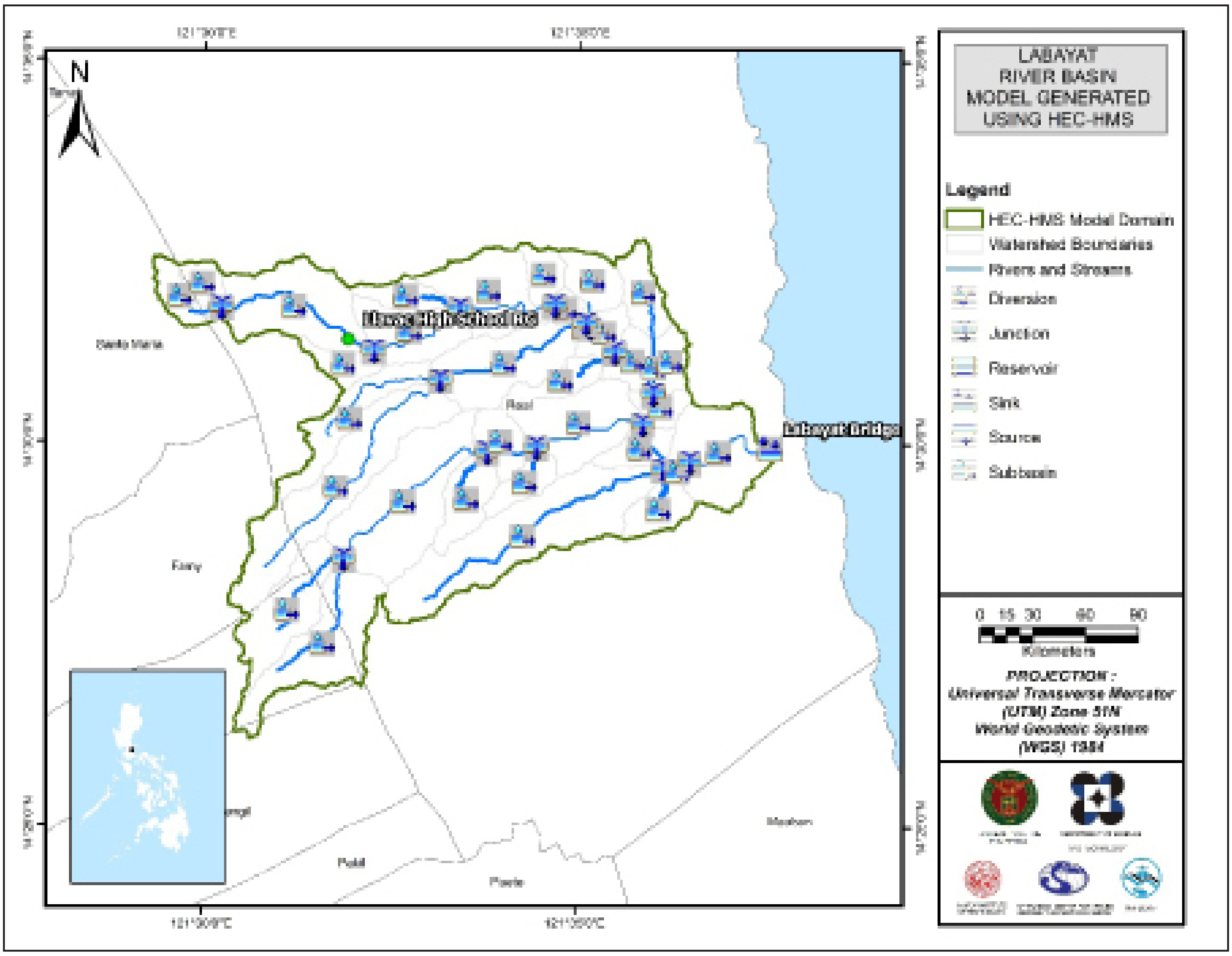


Figure 52. HEC-HMS generated Lubayat River Basin Model.

5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS. This is illustrated in Figure 53.

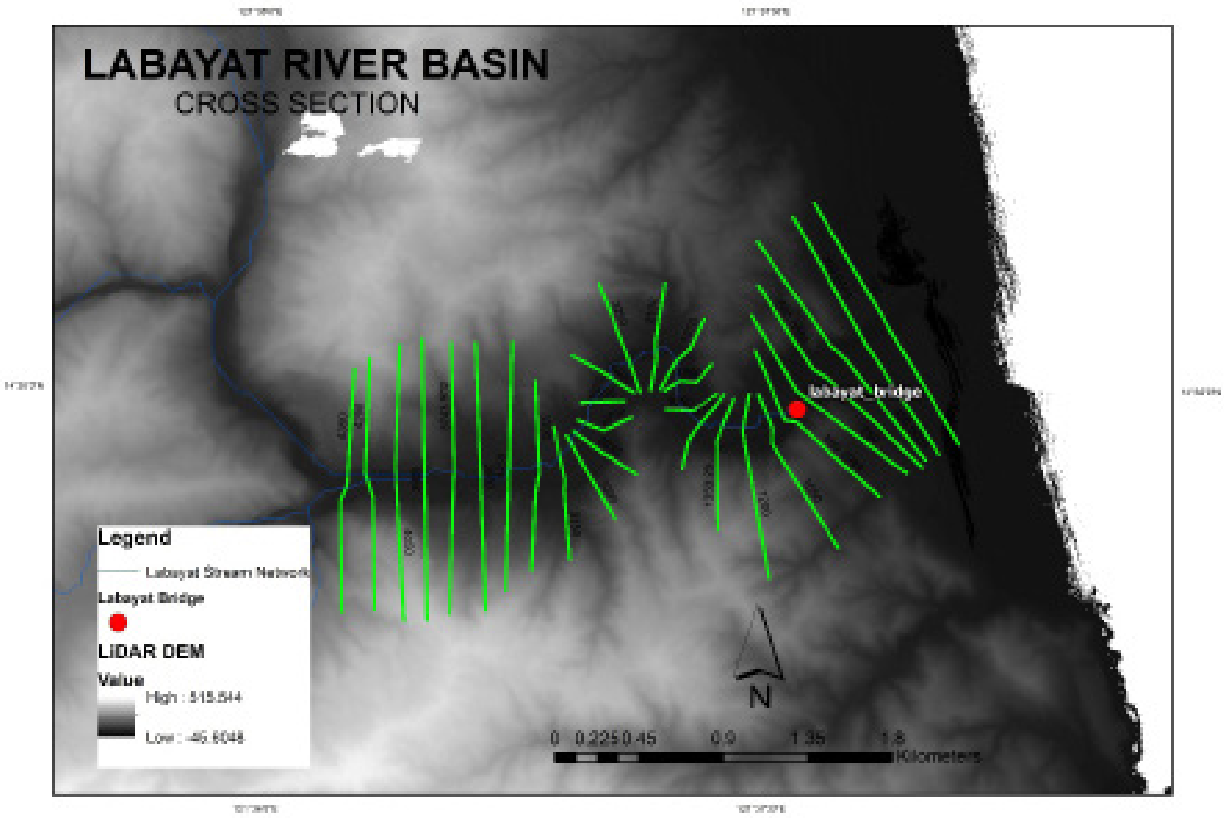


Figure 53. River cross-section of Lubayat (also known as Labayat) River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

Figure 54. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

5.6 Results of HMS Calibration

After calibrating the Labayat HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 55 shows the comparison between the two discharge data.

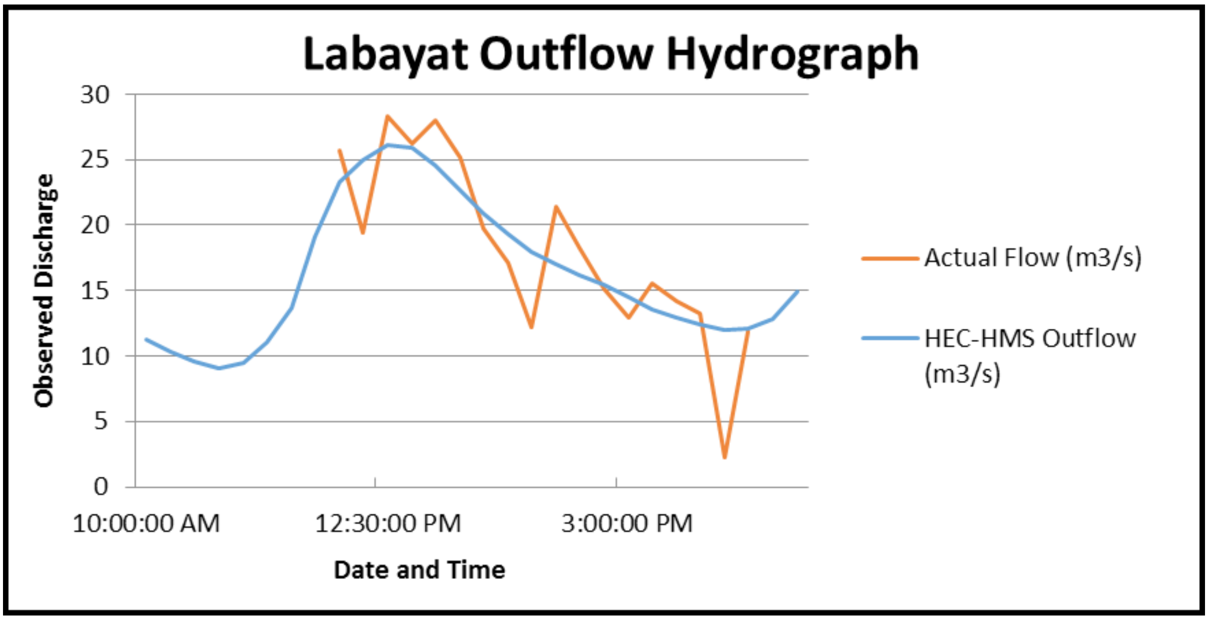


Figure 55. Outflow Hydrograph of Lubayat (also known as Labayat) River produced by the HEC-HMS model compared with observed outflow.

Enumerated in Table 26 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 26. Range of Calibrated Values for Lubayat

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.31 – 52
			Curve Number	59 – 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.14 – 14.10
			Storage Coefficient (hr)	0.08 – 20.62
	Baseflow	Recession	Recession Constant	0.02 – 1
			Ratio to Peak	0.24 – 1
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.01 – 0.46

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 0.31 mm to 52 mm signifies that there is minimal to average amount of infiltration or rainfall interception by vegetation.

The curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range for the curve number of Labayat River Basin is 59 to 99. For Labayat, the basin mostly consists of brushland and open canopy forest and the soil mostly consists of sandy clay and clay.

The time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.08 hours to 20.62 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events, while ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.02 - 1 indicates that the basin is highly unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.24 – 1 indicates a steep receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.01 - 0.46 corresponds to the common roughness in Labayat watershed, which is determined to have a light brush and trees (Brunner, 2010).

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

Accuracy measure	Value
RMSE	2.228
r2	0.9253
NSE	0.922
PBIAS	0.163
RSR	0.279

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.228 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 0.9253.

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 0.922.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 0.163.

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 0.279.

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

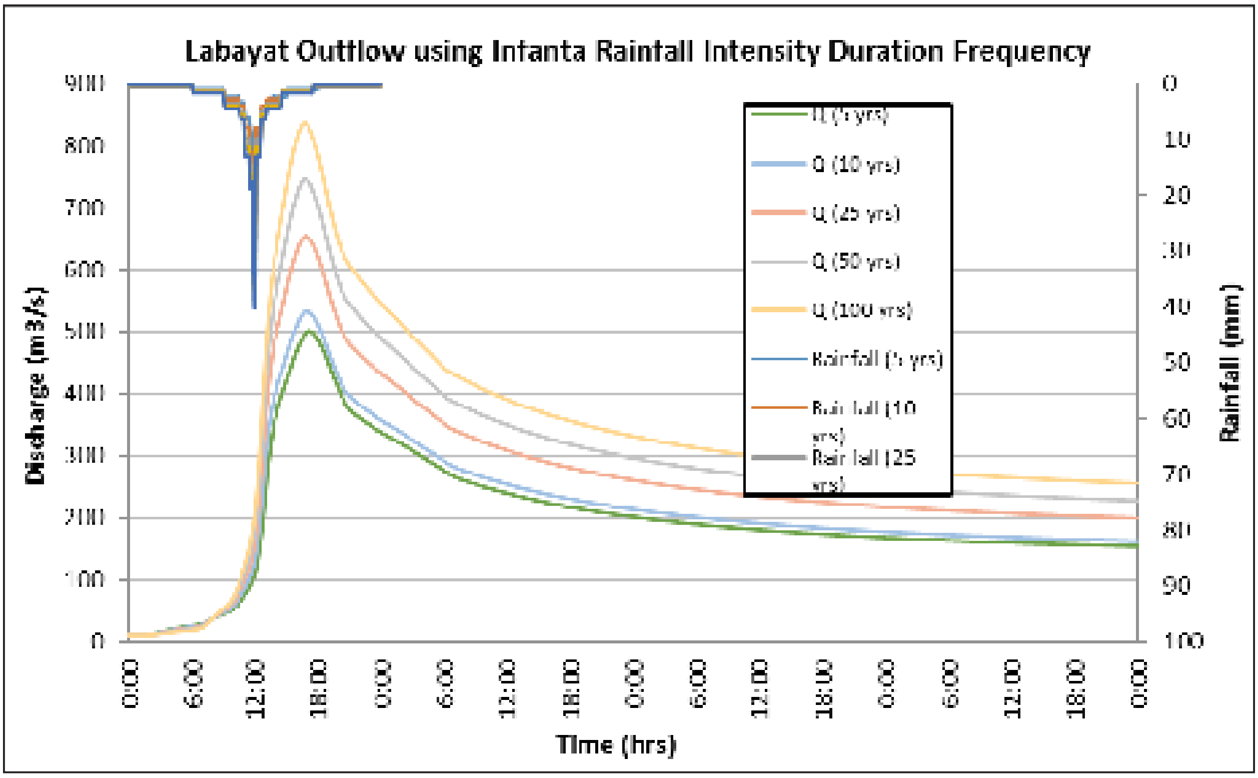


Figure 56. Outflow hydrograph at Lubayat Station generated using Infanta RIDF simulated in HEC-HMS

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

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

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	249.6	25.70	500.9	17 hours, 10 minutes
10-Year	287.1	29.20	533.4	17 hours, 00 minutes
25-Year	334.4	33.70	654.2	16 hours, 50 minutes
50-Year	369.6	37.00	745.3	16 hours, 50 minutes
100-Year	404.4	40.30	835.5	16 hours, 50 minutes

5.8 River Analysis Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown, since only the VSU-FMC base flow was calibrated. The sample generated map of Lubayat River using the calibrated HMS event flow with 25-year rain return scenario is shown in Figure 57.

Figure 57. Sample output of Lubayat RAS Model

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps have a 10m resolution. Figure 58 to Figure 63 shows the 5-, 25-, and 100-year rain return scenarios of the Labayat floodplain. The floodplain, with an area of 274.89 sq. km., covers one municipality namely Real. Table 29 shows the percentage of area affected by flooding per municipality.

Table 29. Municipalities affected in Lubayat Floodplain

City / Municipality	Total Area	Area Flooded	% Flooded
Real	382.11	7.22	1.89%

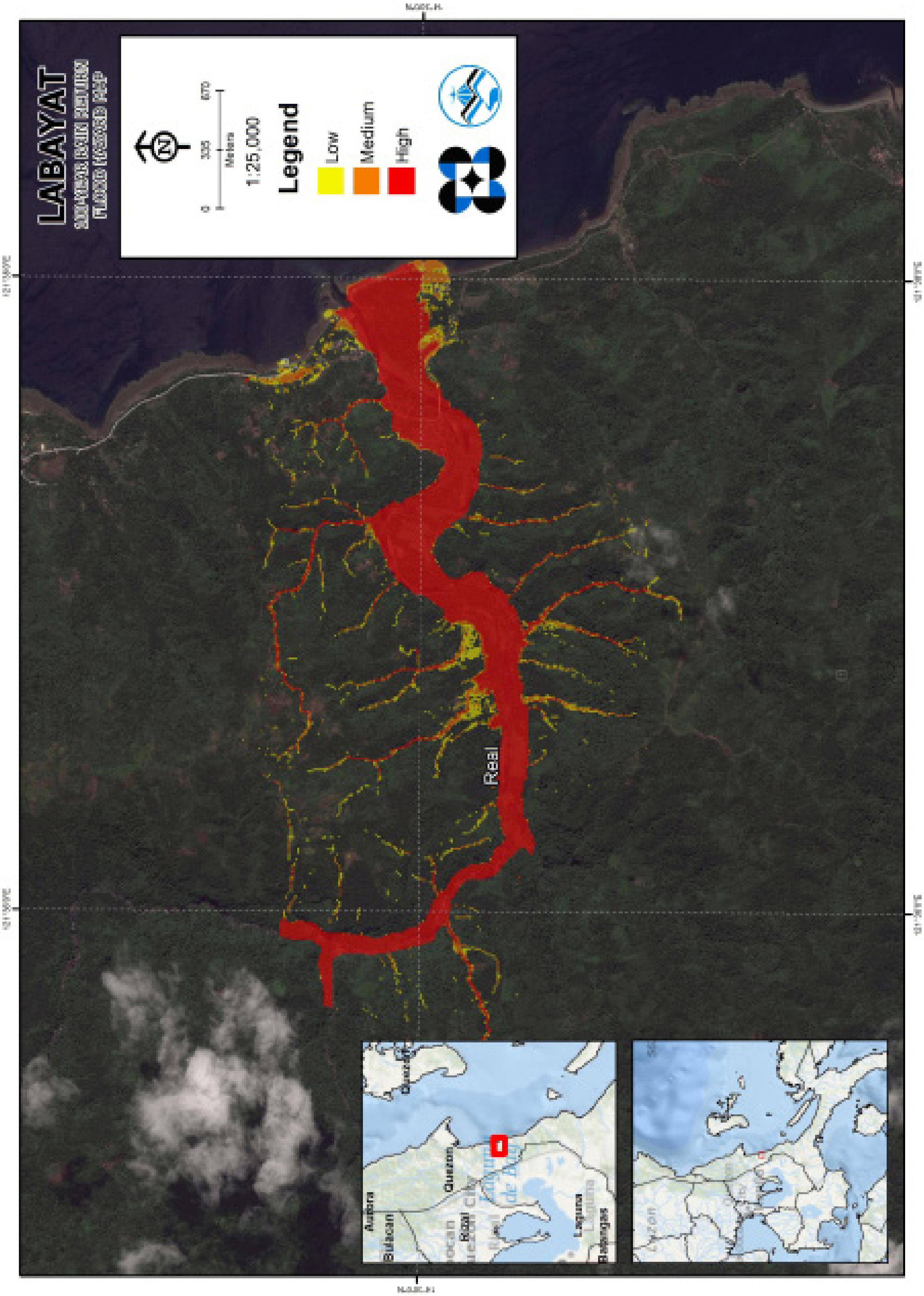


Figure 58. 100-year Flood Hazard Map for Lubayat Floodplain overlaid in Google Earth imagery

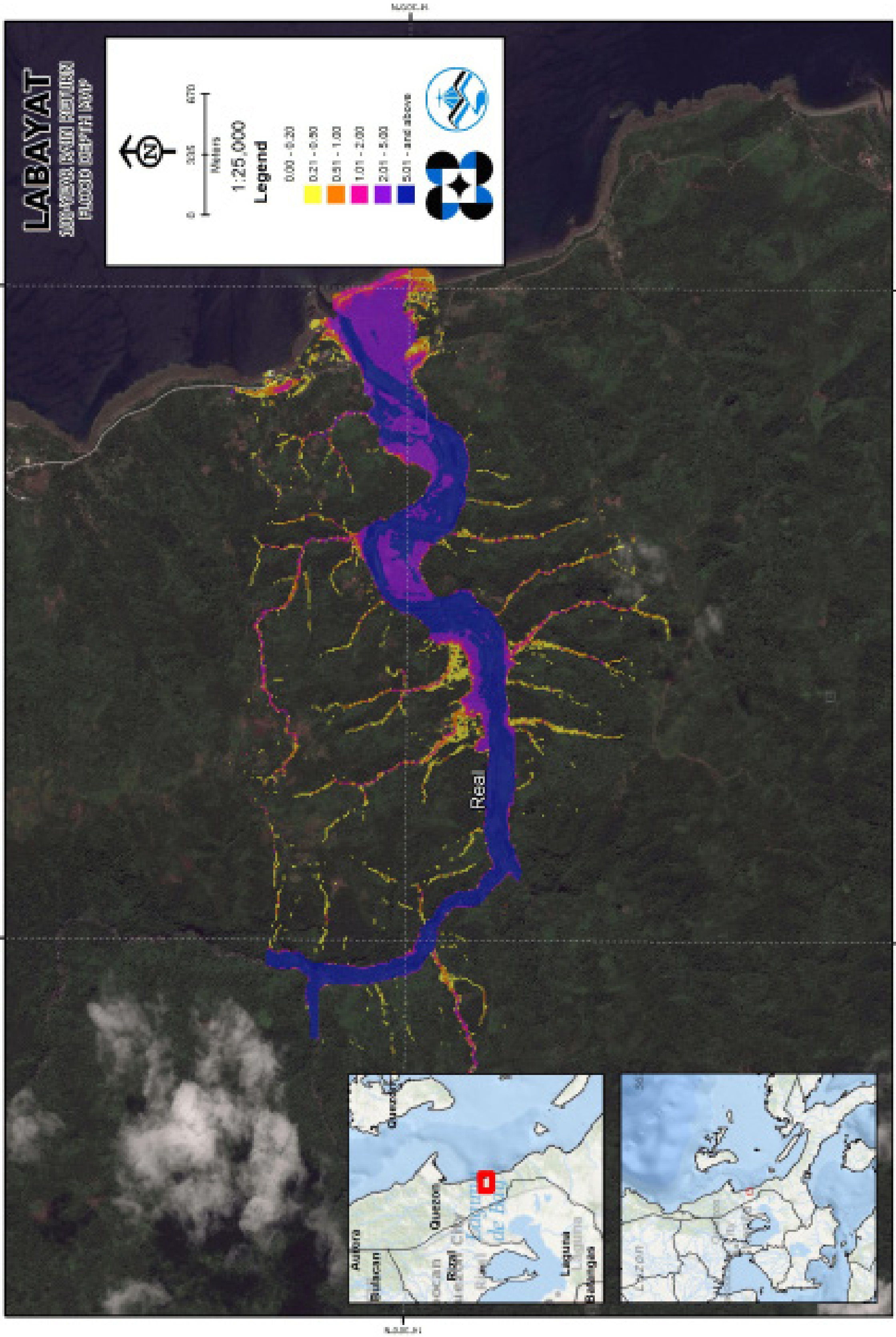


Figure 59. 100-year Flow Depth Map for Lubayat Floodplain overlaid in Google Earth imagery

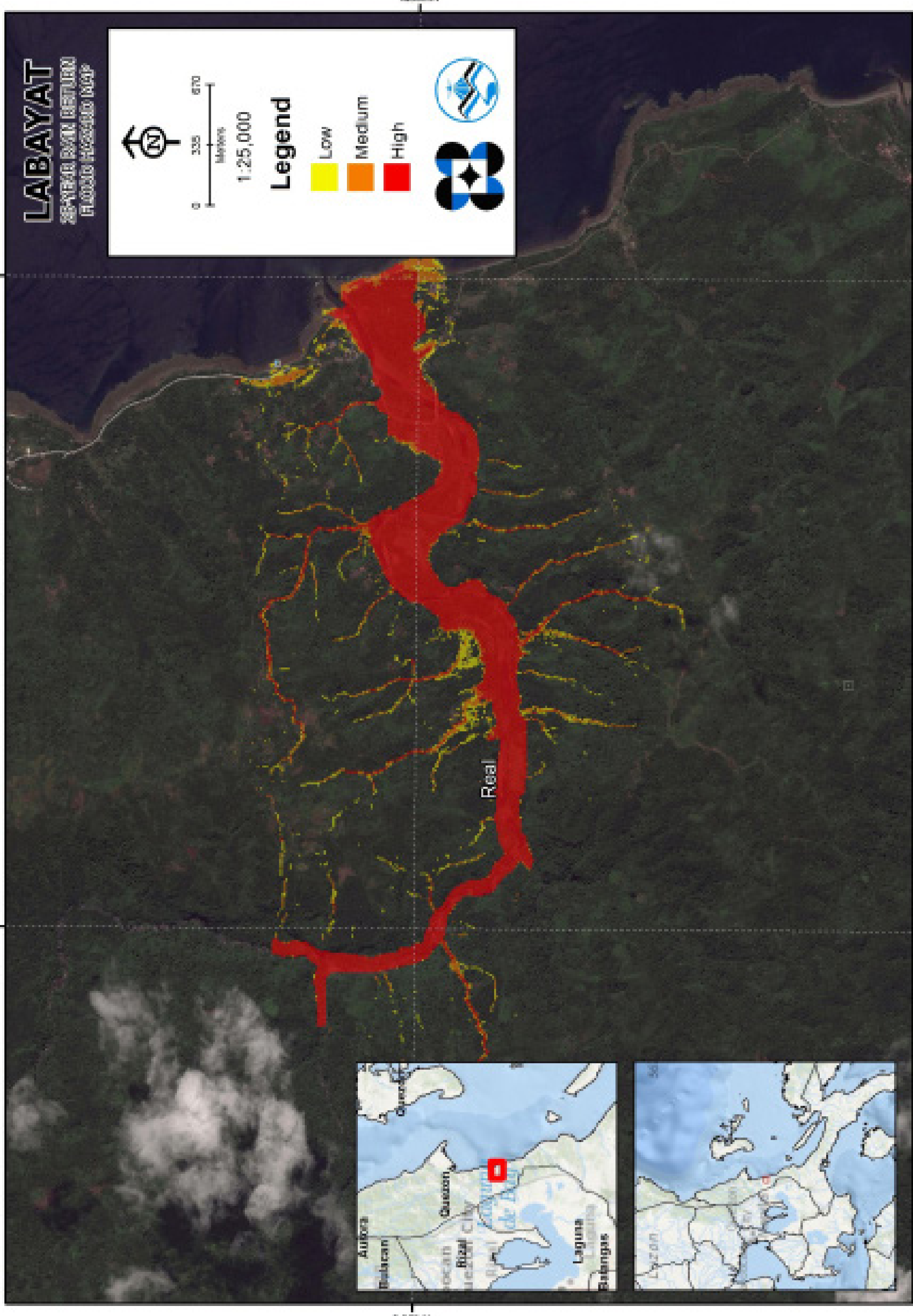


Figure 60. 25-year Flood Hazard Map for Lubayat Floodplain overlaid in Google Earth imagery

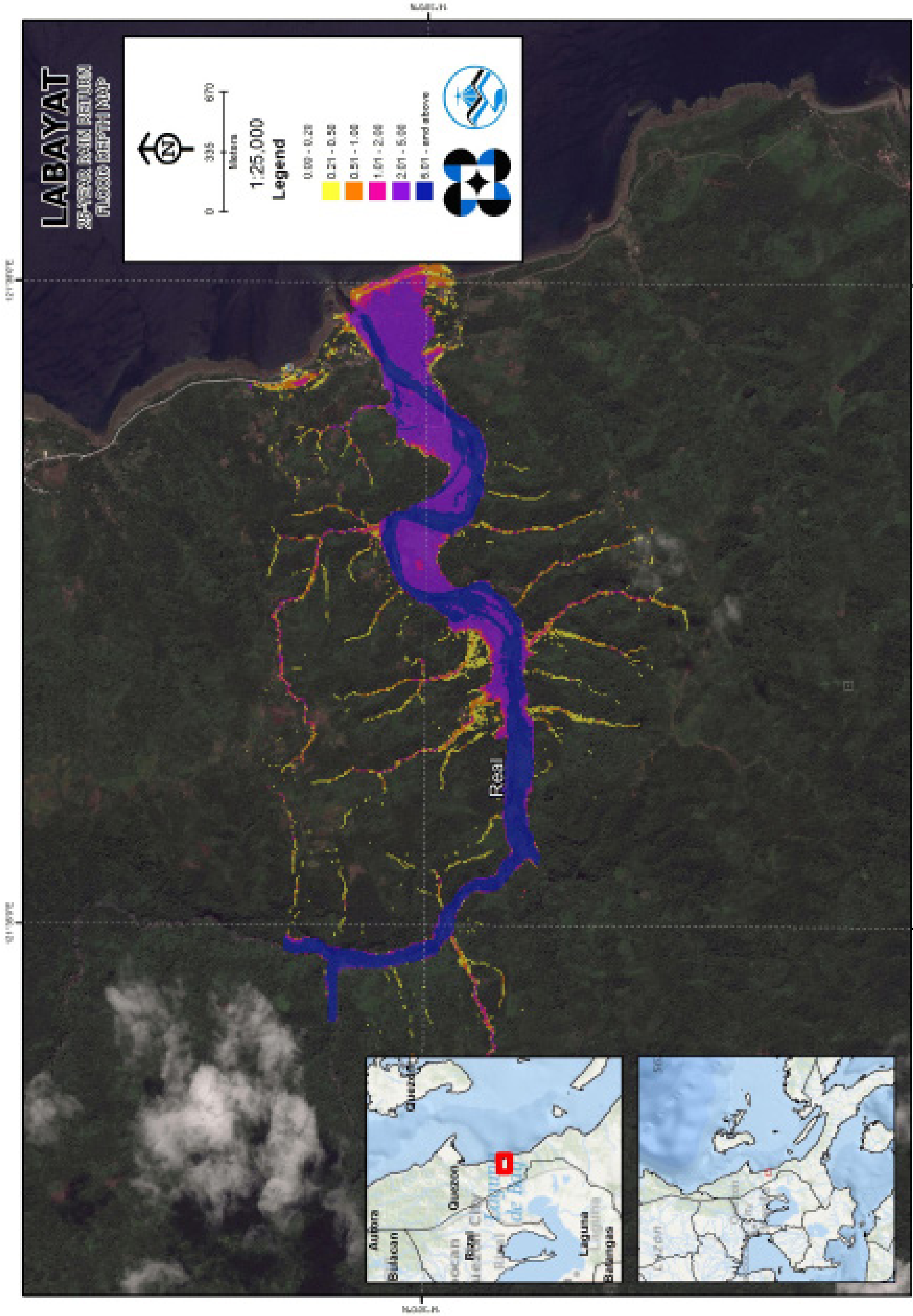


Figure 61. 25-year Flow Depth Map for Lubayat Floodplain overlaid in Google Earth imagery

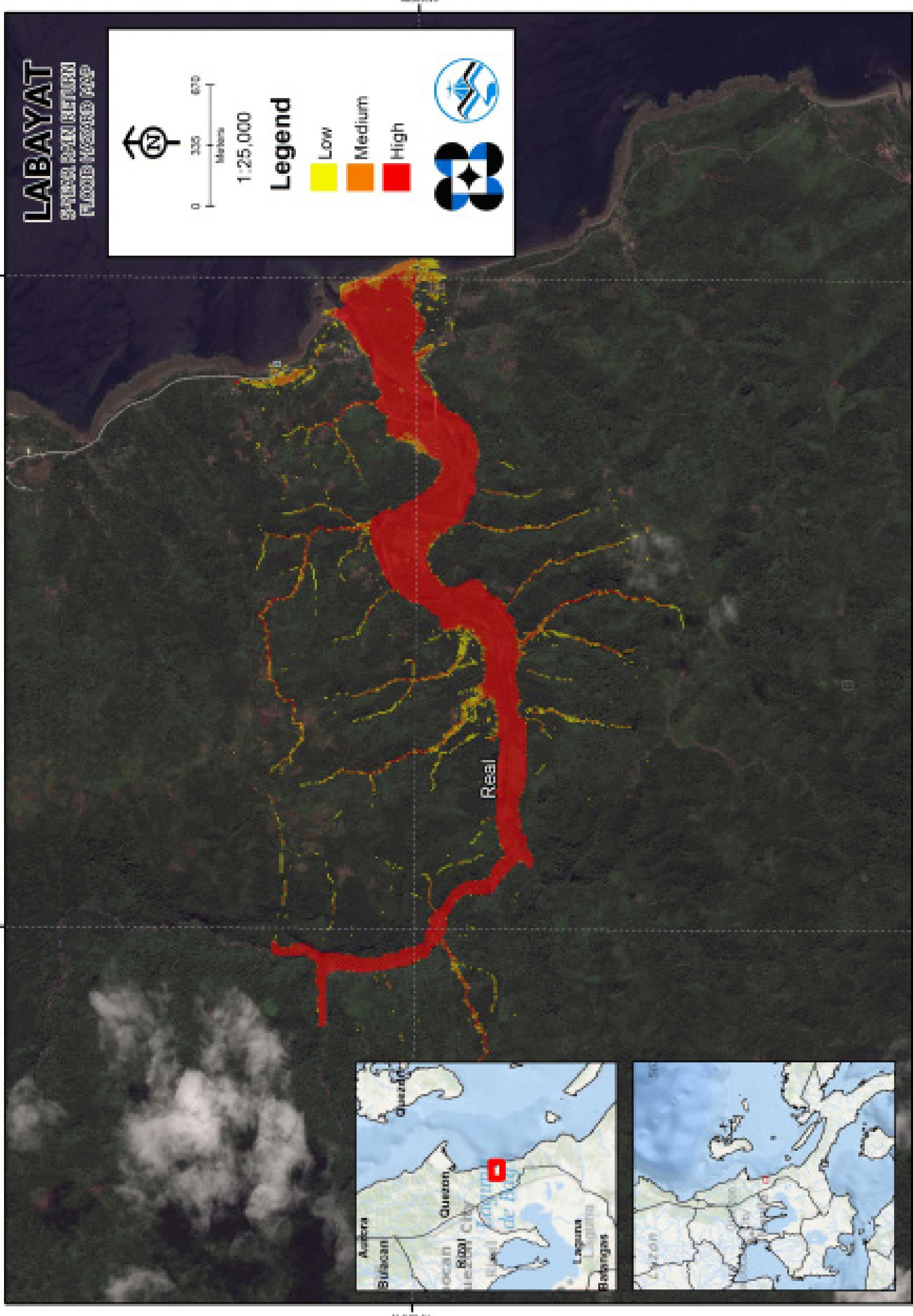


Figure 62. 5-year Flood Hazard Map for Lubayat Floodplain overlaid in Google Earth imagery

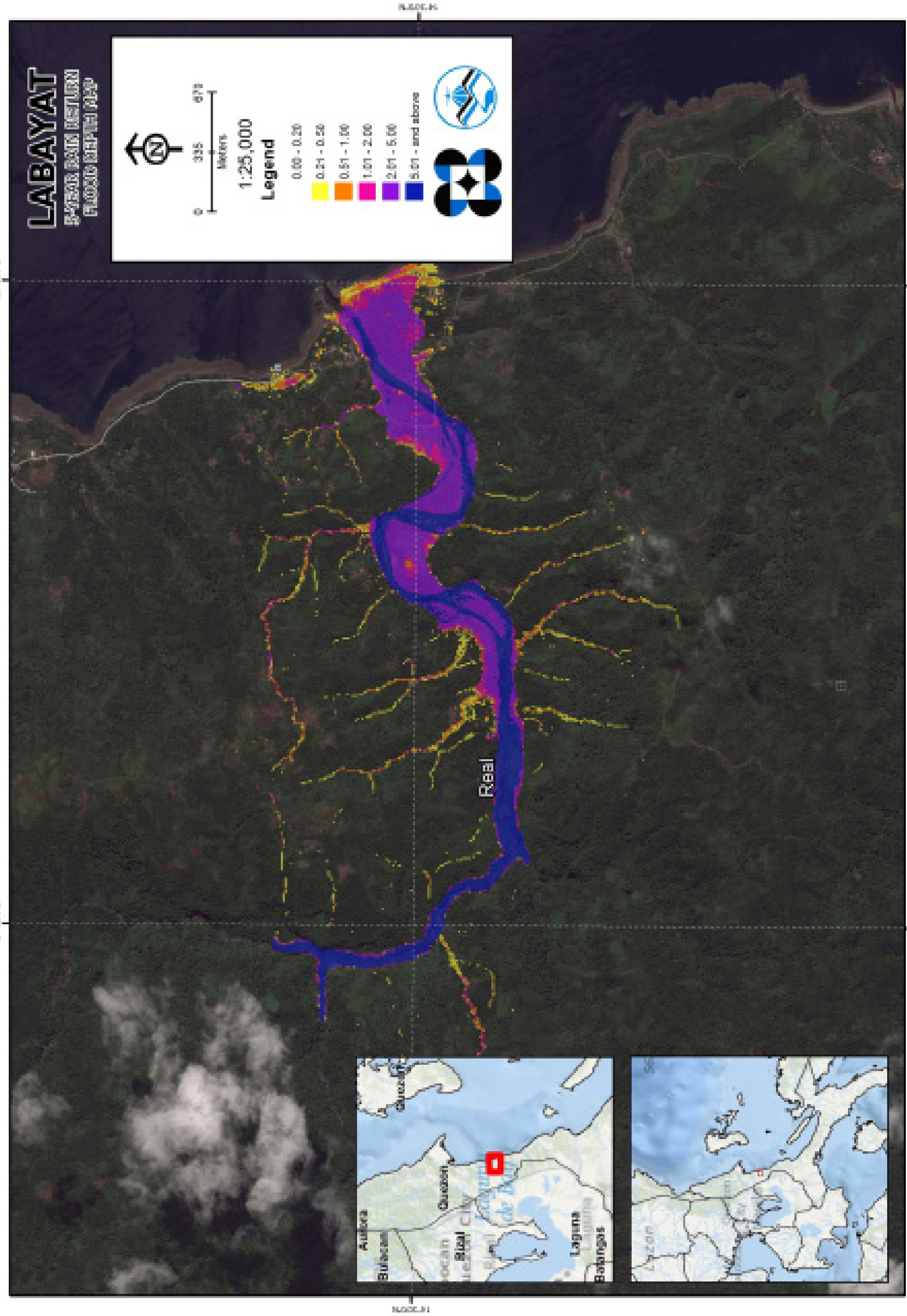


Figure 63. 5-year Flow Depth Map for Lubayat Floodplain overlaid in Google Earth imagery

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in Lubayat river basin, grouped by municipality, are listed below. For the said basin, one (1) municipality consisting of three (3) barangays are expected to experience flooding when subjected to 5-, 25-, and 100-yr rainfall return period.

For the 5-year return period, 1.54% of the municipality of Real with an area of 382.11 sq. km. will experience flood levels of less than 0.20 meters. 0.05% of the area will experience flood levels of 0.21 to 0.50 meters while 0.03% of the area will experience flood depths of 0.51 to 1 meter. Listed in Table 30 and shown in Figure 64 are the affected areas in square kilometers by flood depth per barangay.

Table 30. Affected Areas in Real, Quezon during 5-year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Real (in sq. km)		
	Lubayat	Maragondon	Maunlad
0.03-0.20	4.96	0.0009	0.94
0.21-0.50	0.16	0	0.017
0.51-1.00	0.098	0	0.0076
1.01-2.00	0.11	0	0.0099
2.01-5.00	0.47	0	0.015
> 5.00	0.3	0	0.12

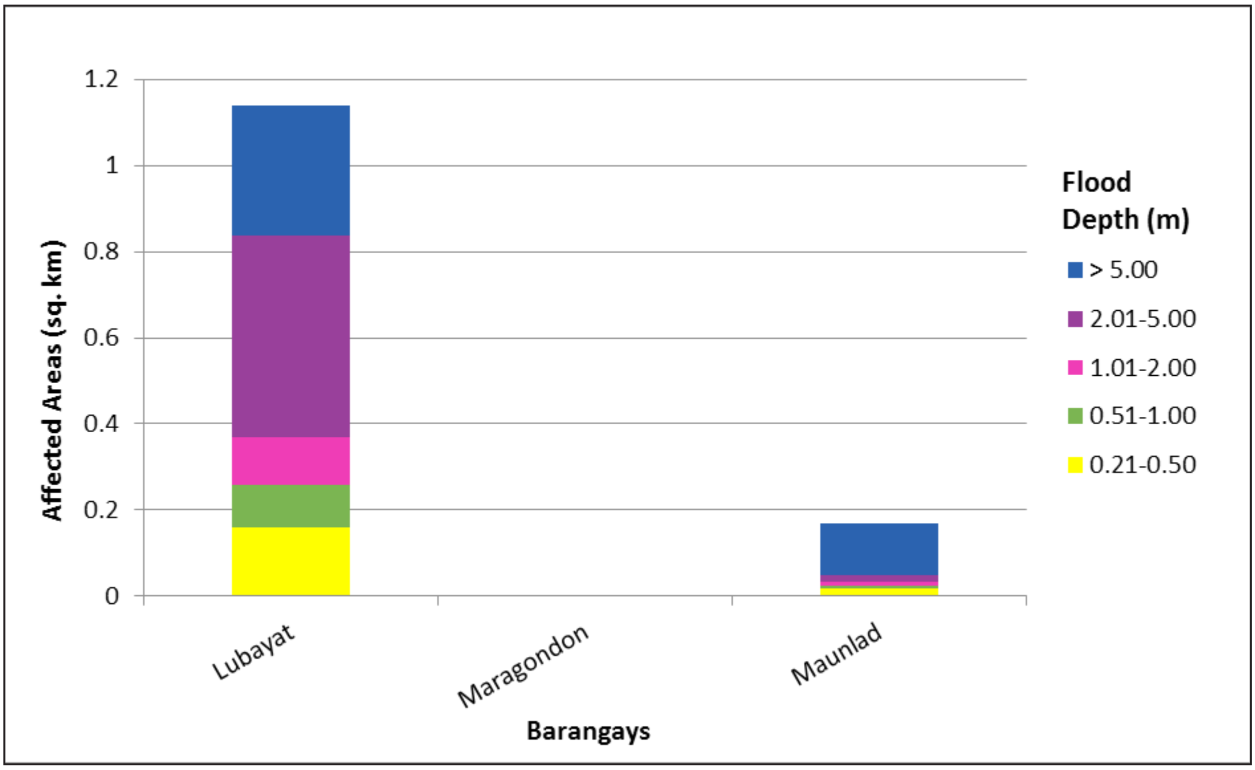


Figure 64. Affected Areas in Real, Quezon during 5-year Rainfall Return Period

For the 25-year return period, 1.51% of the municipality of Real with an area of 382.11 sq. km. will experience flood levels of less than 0.20 meters. 0.06% of the area will experience flood levels of 0.21 to 0.50 meters while 0.03%, 0.03%, 0.12%, and 0.14% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 31 and shown in Figure 65 are the affected areas in square kilometers by flood depth per barangay.

Table 31. Affected Areas in Real, Quezon during 25-year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Real (in sq. km)		
	Lubayat	Maragondon	Maunlad
0.03-0.20	4.83	0.0009	0.92
0.21-0.50	0.19	0	0.022
0.51-1.00	0.12	0	0.01
1.01-2.00	0.1	0	0.01
2.01-5.00	0.46	0	0.015
> 5.00	0.4	0	0.14

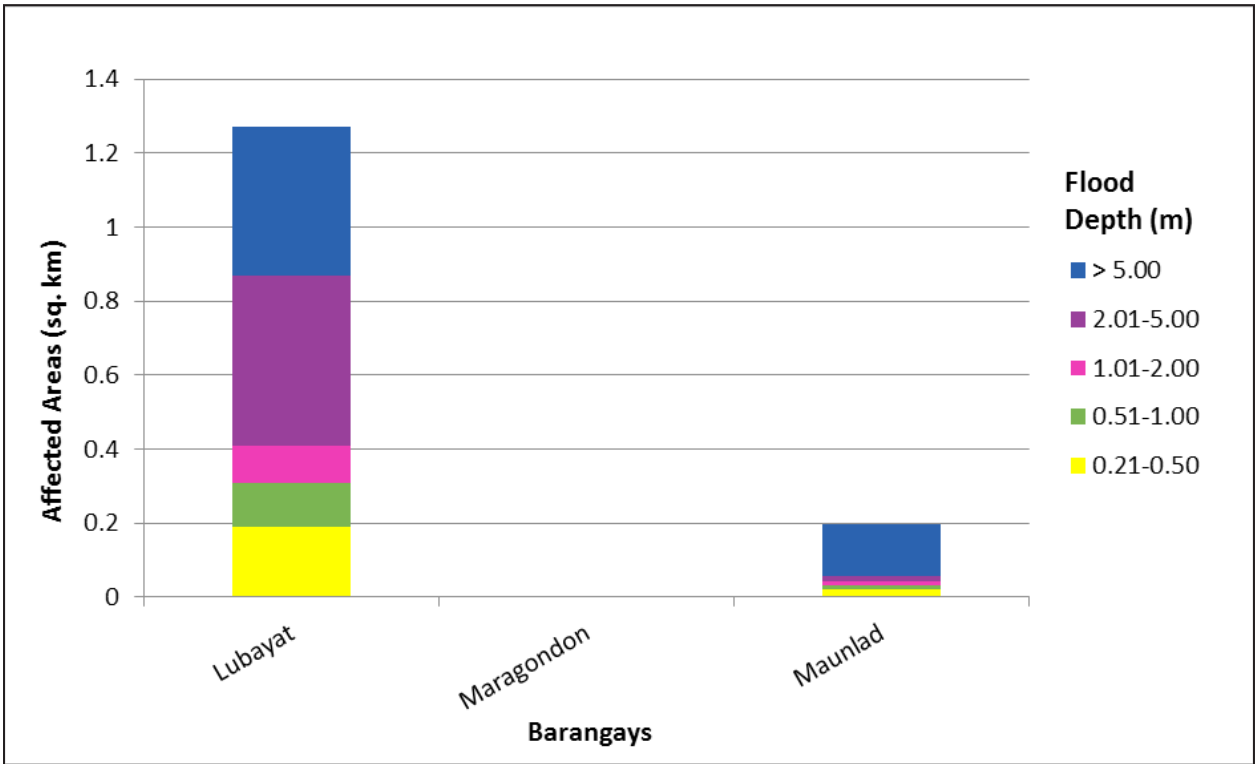


Figure 65. Affected Areas in Real, Quezon during 25-year Rainfall Return Period

For the 100-year return period, 1.48% of the municipality of Real with an area of 382.11 sq. km. will experience flood levels of less than 0.20 meters. 0.06% of the area will experience flood levels of 0.21 to 0.50 meters while 0.04%, 0.03%, 0.10%, and 0.18% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 32 and shown in Figure 66 are the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected Areas in Real, Quezon during 100-year Rainfall Return Period

Affected area (sq.km.) by flood depth (in m.)	Area of affected barangays in Real (in sq. km)		
	Lubayat	Maragondon	Maunlad
0.03-0.20	4.75	0.0009	0.9
0.21-0.50	0.22	0	0.026
0.51-1.00	0.13	0	0.011
1.01-2.00	0.11	0	0.01
2.01-5.00	0.36	0	0.017
> 5.00	0.54	0	0.15

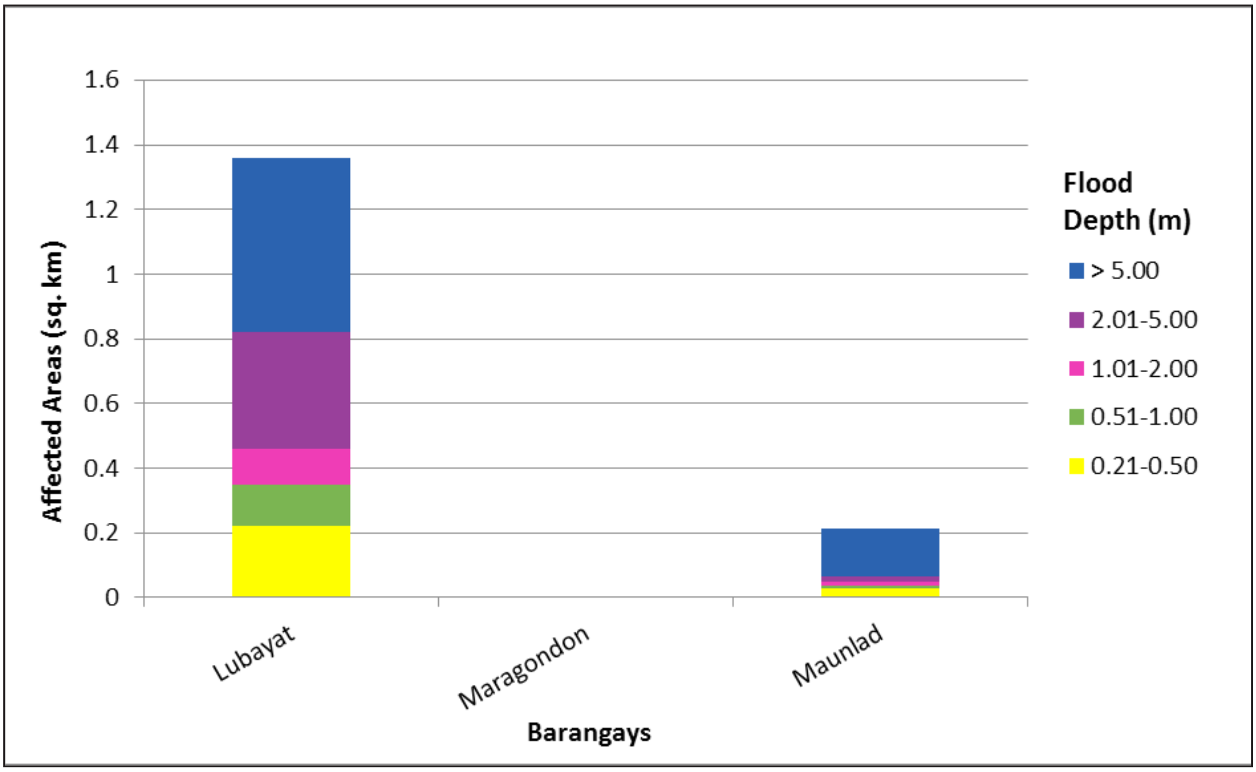


Figure 66. Affected Areas in Real, Quezon during 100-year Rainfall Return Period

Among the barangays in the municipality of Real in Quezon, Lubayat is projected to have the highest percentage of area that will experience flood levels at 1.60%. Meanwhile, Maunlad posted the second highest percentage of area that may be affected by flood depths at 0.29%.
Moreover, the generated flood hazard maps for the Labayat Floodplain were used to assess the vulnerability of the educational and medical institutions in the floodplain. Using the flood depth units of PAG-ASA for hazard maps ("Low", "Medium", and "High"), the affected institutions were given their individual assessment for each Flood Hazard Scenario (5-year, 25-year, and 10-year).

Table 33. Areas covered by each warning level with respect to the rainfall scenarios

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	0.15	0.18	0.20
Medium	0.17	0.19	0.20
High	1.05	1.15	1.23
TOTAL	1.37	1.52	1.63

Of the 2 identified educational institutions in Lubayat Floodplain, no schools were discovered exposed to any flood warning level during the 5-year scenario.

For the 25-year scenario, one (1) school was discovered exposed to low-level flooding.

For the 100-year scenario, one (1) school was discovered exposed to low-level flooding. The educational institutions affected by flooding in the Lubayat Floodplain are found in Annex 12.

Only 1 medical institution was identified in Lubayat Floodplain and was discovered exposed to low-level flooding for the 100-year scenario. The medical or health institutions affected by flooding in the Lubayat Floodplain are found in Annex 13.

5.11 Flood Validation

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

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

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

After which, the actual data from the field was compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 68.

The flood validation consists of 180 points randomly selected all over the Lubayat floodplain (Figure 67). It has an RMSE value of 2.50623. Table 34 shows a contingency matrix of the comparison.

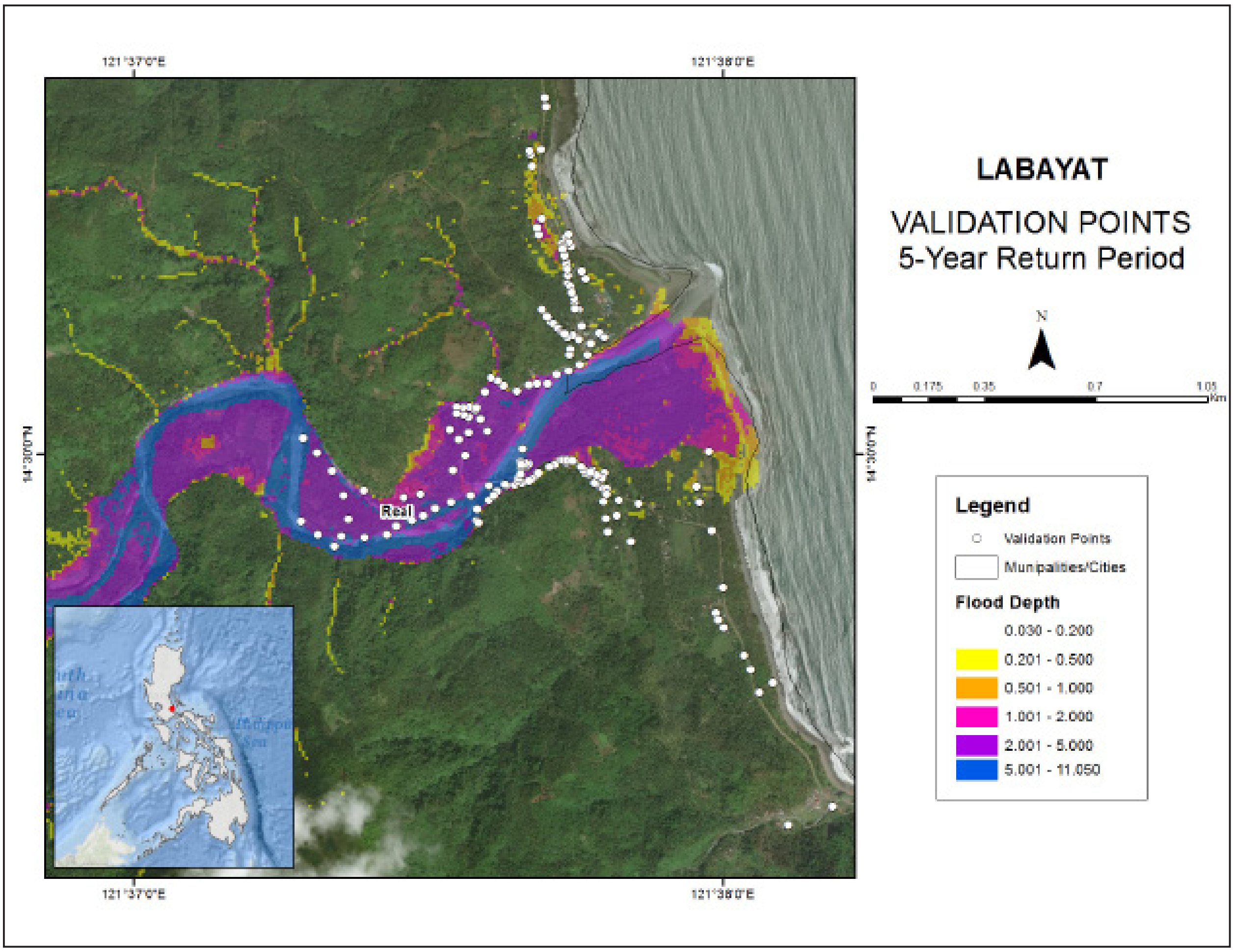


Figure 67. Validation points for 5-year Flood Depth Map of Lubayat (also known as Labayat) Floodplain

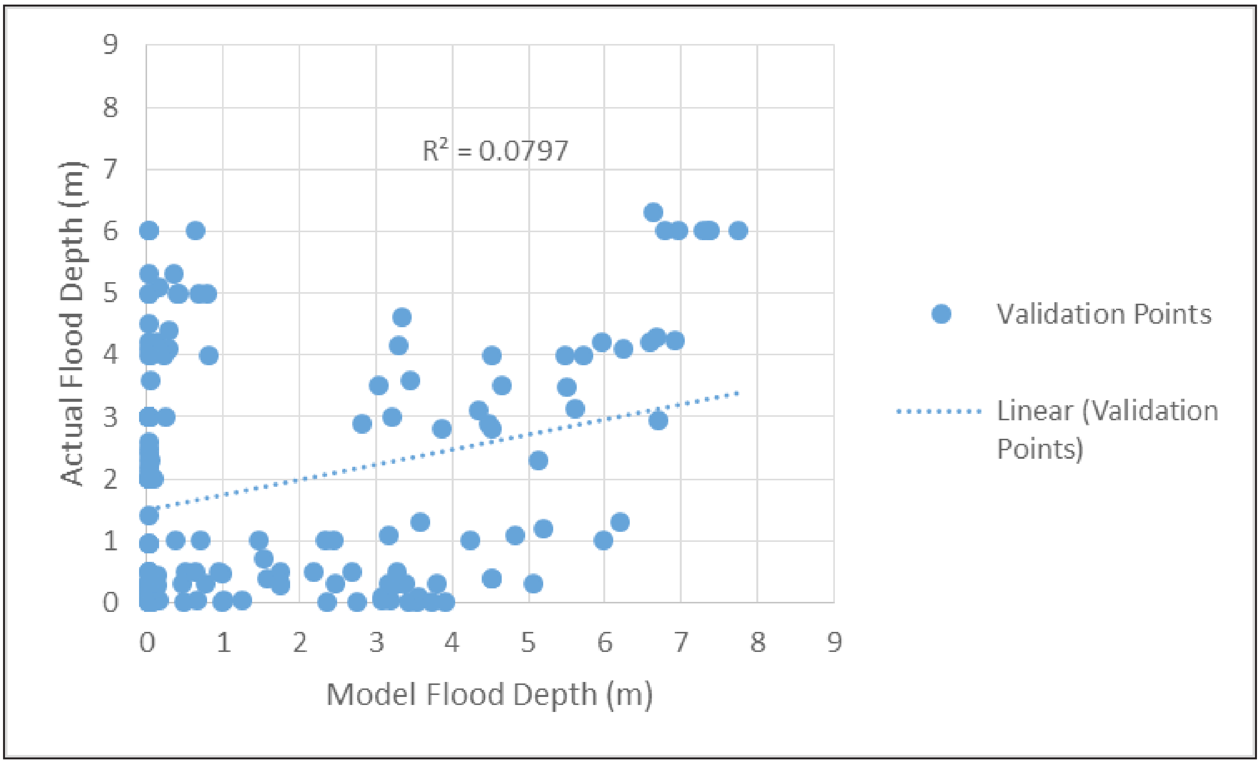


Figure 68. Flood map depth vs. actual flood depth

Table 34. Actual flood vs simulated flood depth at different levels in the Lubayat River Basin.

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	**0.21-0.50**	**0.51-1.00**	**1.01-2.00**	**2.01-5.00**	**> 5.00**	**Total**
0-0.20	28	1	2	2	10	0	43
0.21-0.50	14	1	5	4	12	1	37
0.51-1.00	3	1	1	2	3	1	11
1.01-2.00	10	0	0	0	3	2	15
2.01-5.00	29	6	3	0	12	11	61
> 5.00	4	1	1	0	0	7	13
Total	88	10	12	8	40	22	180

The overall accuracy generated by the flood model was estimated at 27.22% with 49 points correctly matching the actual flood depths. In addition, there were 36 points estimated one level above and below the correct flood depths while there were 17 points and 77 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 72 points were underestimated in the modelled flood depths of Lubayat. Table 35 depicts the summary of the Accuracy Assessment in the Lubayat River Basin Survey.

Table 35. Summary of the Accuracy Assessment in the Lubayat River Basin Survey

	No. of Points	**%**
Correct	49	27.22
Overestimated	59	32.78
Underestimated	72	40.00
Total	180	100.00

REFERENCES

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

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

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

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

Paringit, E.C., Balicanta, L.P., Ang, M.C., Lagmay, A.F., 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.J.S., Paringit E.C., et al. 2014. DREAM Data Aquisition Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry

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

Annex 1. Optech Technical Specification of the Sensor

1. PEGASUS SENSOR

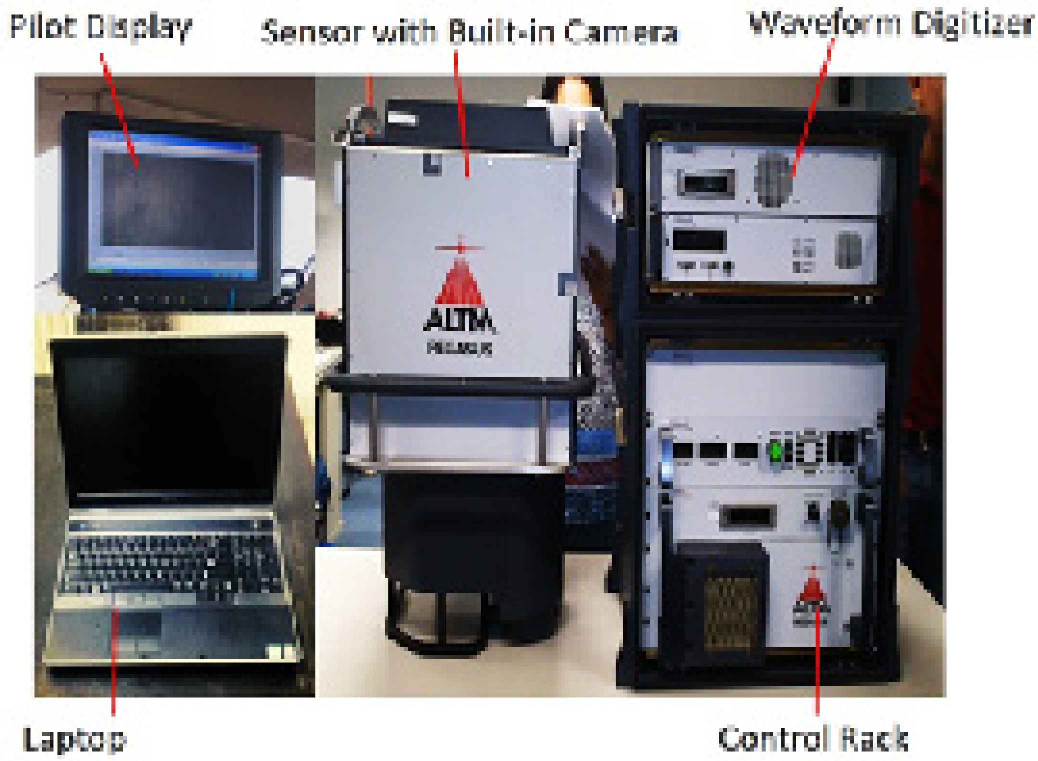


Figure A-1.1 Pegasus Sensor

2. PARAMETERS AND SPECIFICATIONS OF THE PEGASUS SENSOR

Table A-1.1 Parameters and Specifications of the Pegasus Sensor

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

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

Annex 2. NAMRIA Certificates of Reference Points Used

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

June 14, 2016

CERTIFICATION

To whom it may concern:

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

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

Island: **Luzon**
Municipality: **TANAY**
Barangay: **SAN ISIDRO (POB.)**
MSL Elevation:

PRS92 Coordinates

Latitude:	14° 29' 49.44078"	Longitude:	121° 16' 32.56146"	Ellipsoidal Hgt:	5.86600 m.

WGS84 Coordinates

Latitude:	14° 29' 44.06939"	Longitude:	121° 16' 37.46276"	Ellipsoidal Hgt:	50.37100 m.

PTM / PRS92 Coordinates

Northing:	1603180.963 m.	Easting:	529720.085 m.	Zone:	3

UTM / PRS92 Coordinates

Northing:	1,603,302.05	Easting:	314,172.78	Zone:	51

Location Description

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

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

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

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

9906142016162838

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1 RZL-28

Annex 3. Baseline Processing Report of Reference Points Used

1. UP-TAL and UP-VIG

Processing Summary

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

1

Figure A-3.1 Baseline Processing Report - A

Vector Components (Mark to Mark)

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

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

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

Standard Errors

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

Aposteriori Covariance Matrix (Meter²)

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

Figure A-3.2 Baseline Processing Report - B

Annex 4. The LiDAR Survey Team Composition

Figure A-4.1 LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

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

Annex 5. Data Transfer Sheet For Lubayat Floodplain

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

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

Name: DARRYL AUSTRIA
Position: R.A.
Signature: [signature]

Name: AC Bongat
Position: SSRS
Signature: [signature]

Figure A-5.1 Data Transfer Sheet for Lubayat Floodplain - A

Annex 6. Flight Logs

1. Flight Log for 1497P Mission

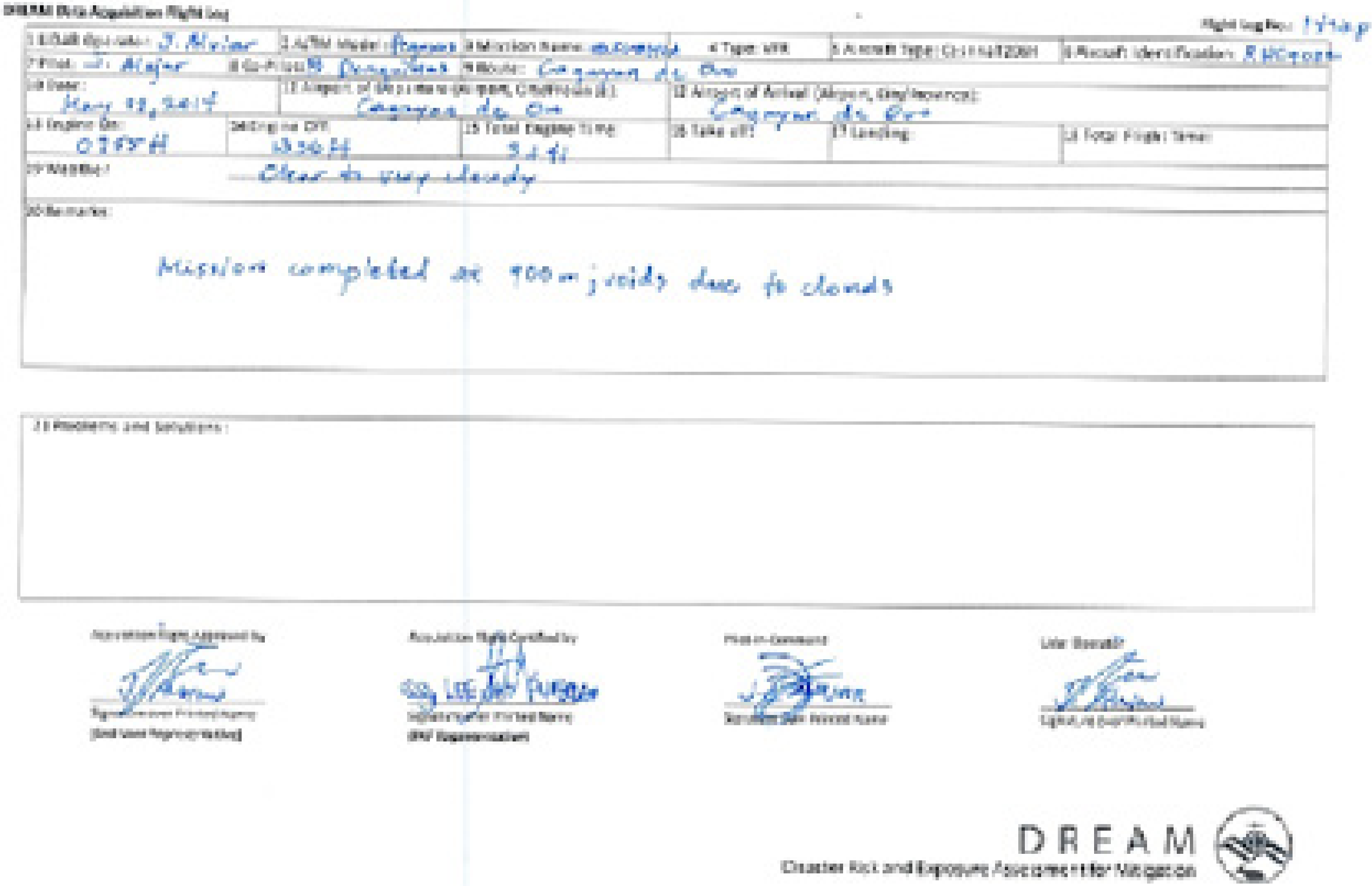


Figure A-6.1 Flight Log for Mission 1497P

Annex 7. Flight Status

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

Table A-7.1 Flight Status Report

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

LAS BOUNDARIES PER FLIGHT

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

LAS/SWATH

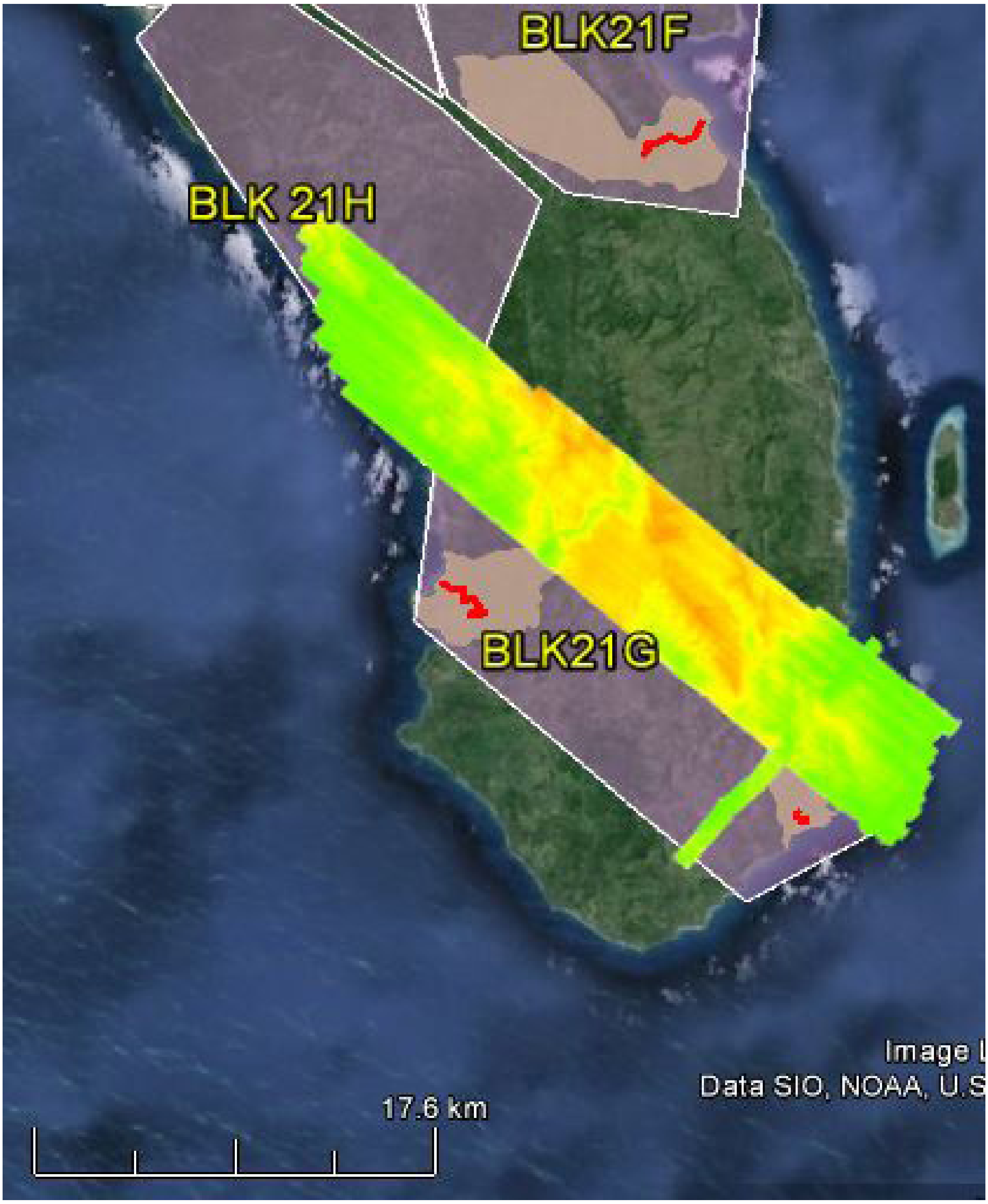


Figure A-7.1 Swath for Flight No. 23342P

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

LAS/SWATH

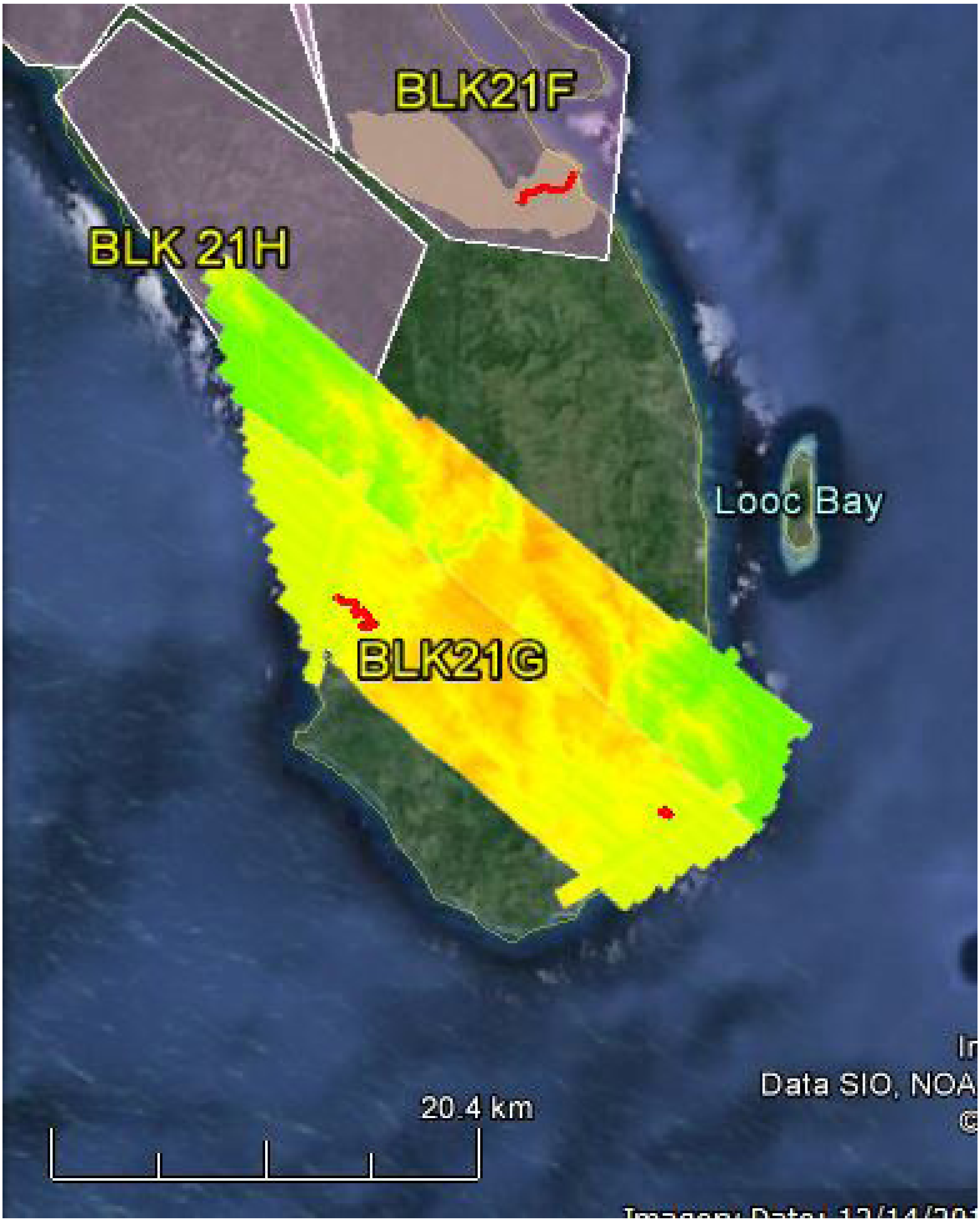


Figure A-7.2 Swath for Flight No. 23346P

Annex 8. Mission Summary Reports

Table A-8.1 Mission Summary Report for Blk21G

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

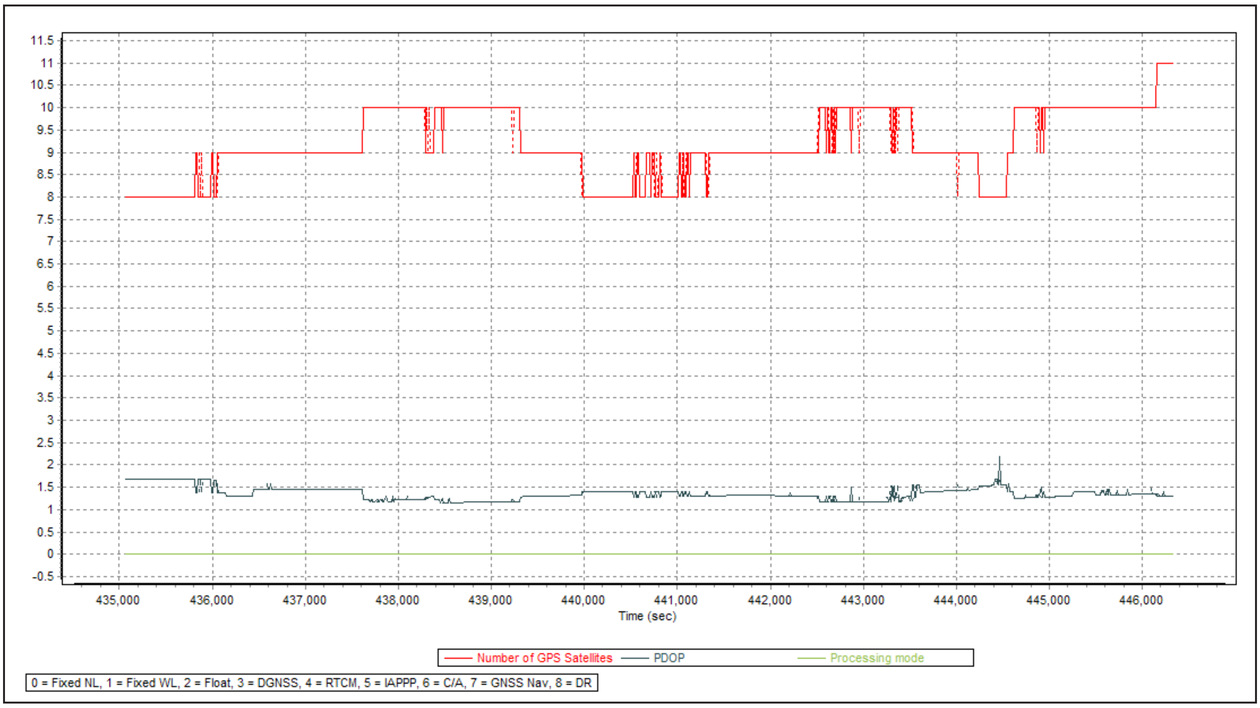


Figure A-8.1. Solution Status

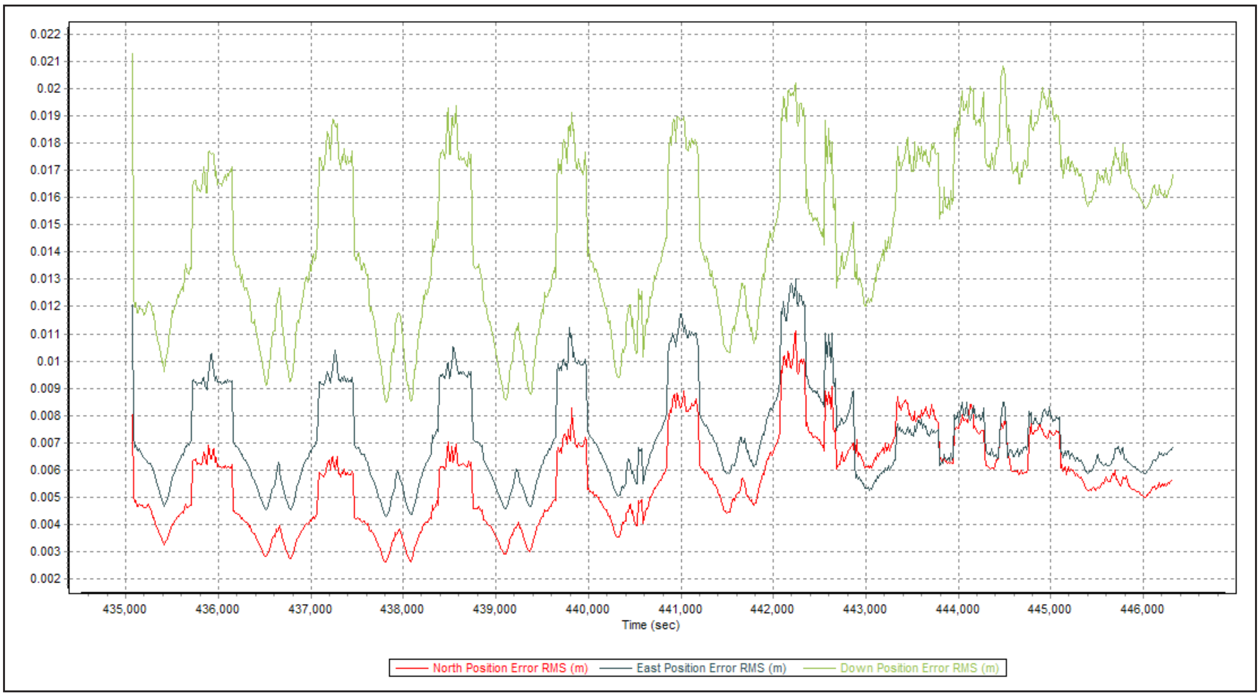


Figure A-8.2. Smoothed Performance Metric Parameters

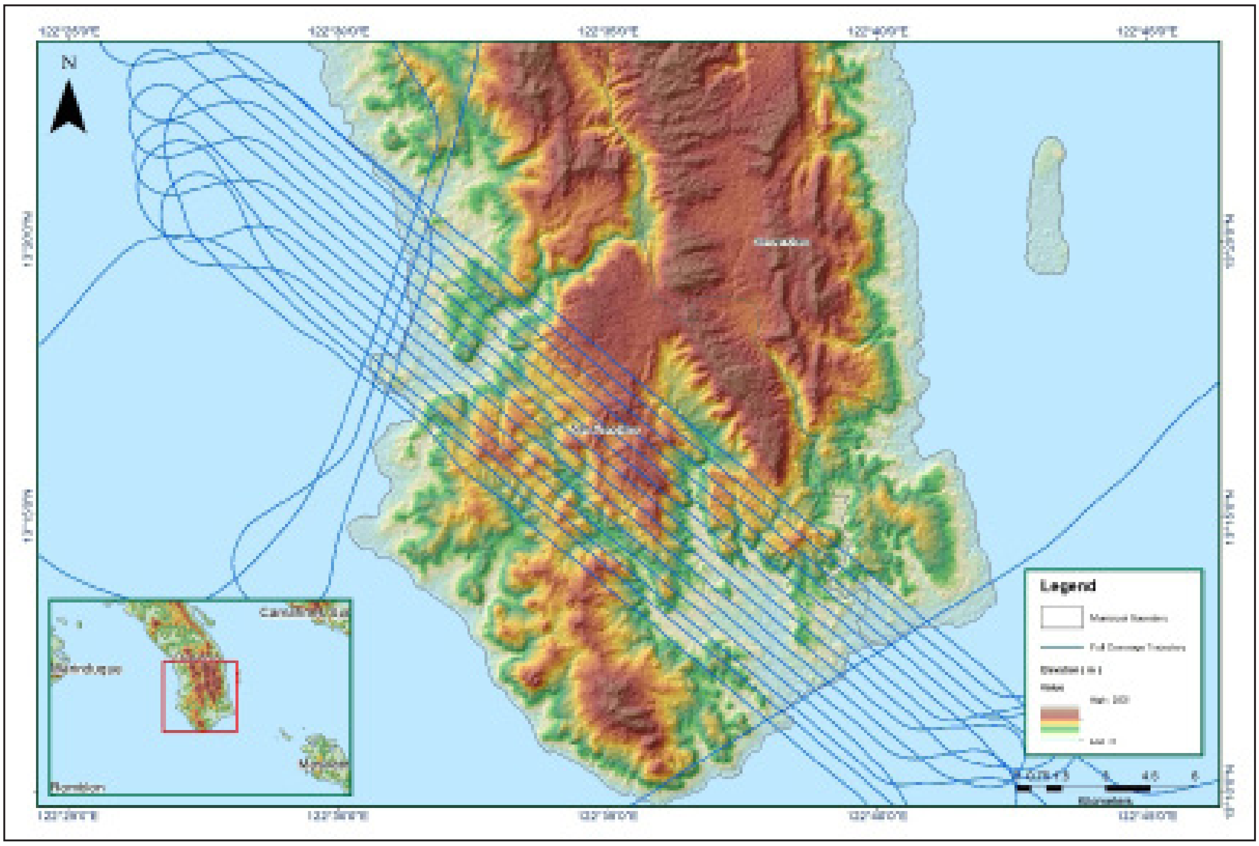


Figure A-8.3. Best Estimated Trajectory

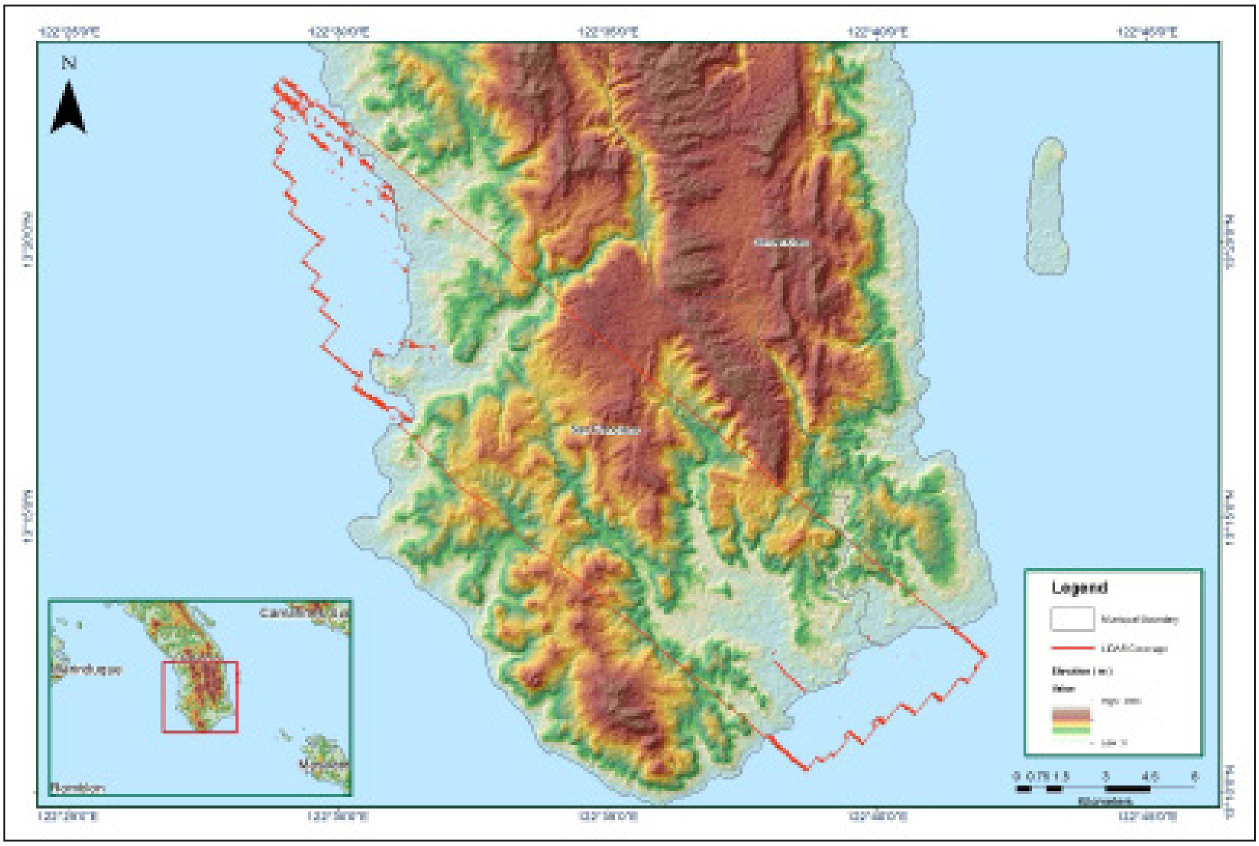


Figure A-8.4. Coverage of LiDAR data

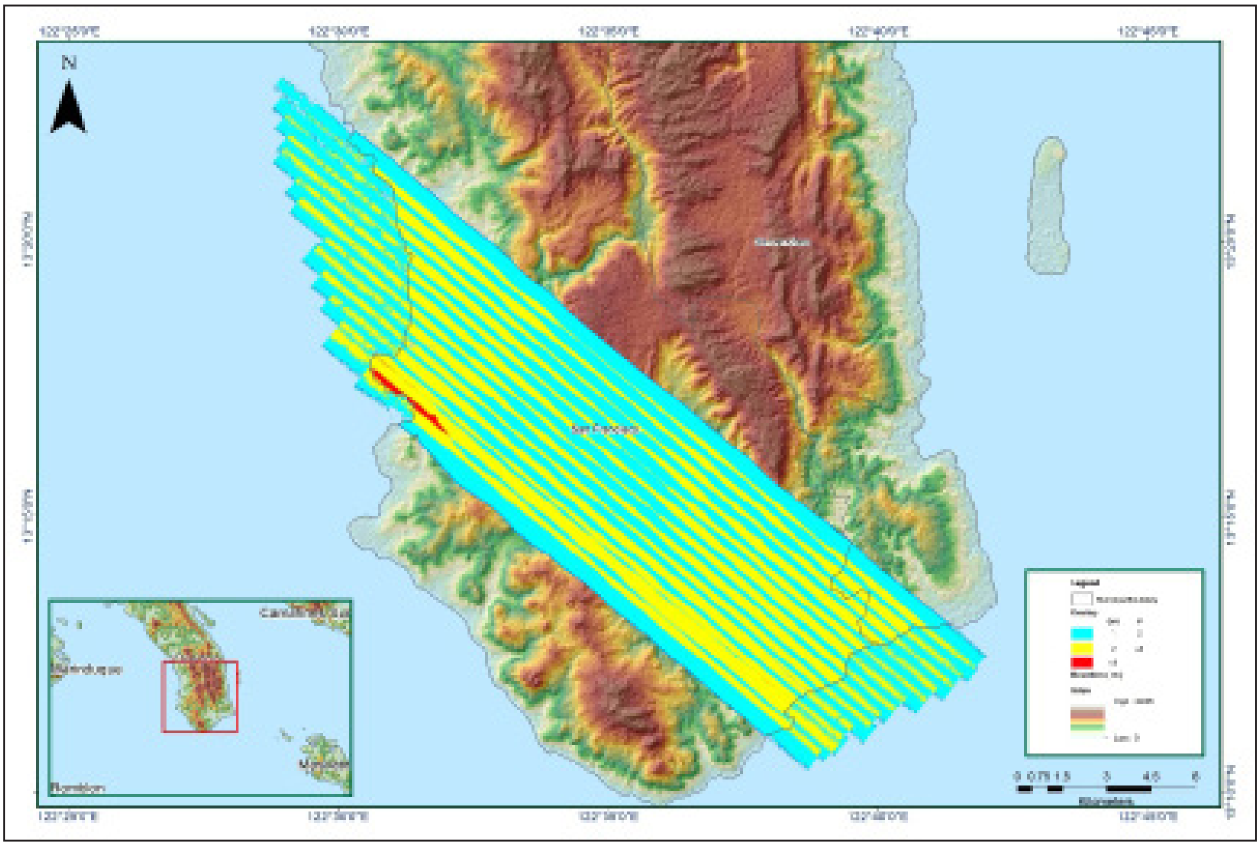


Figure A-8.5. Image of data overlap

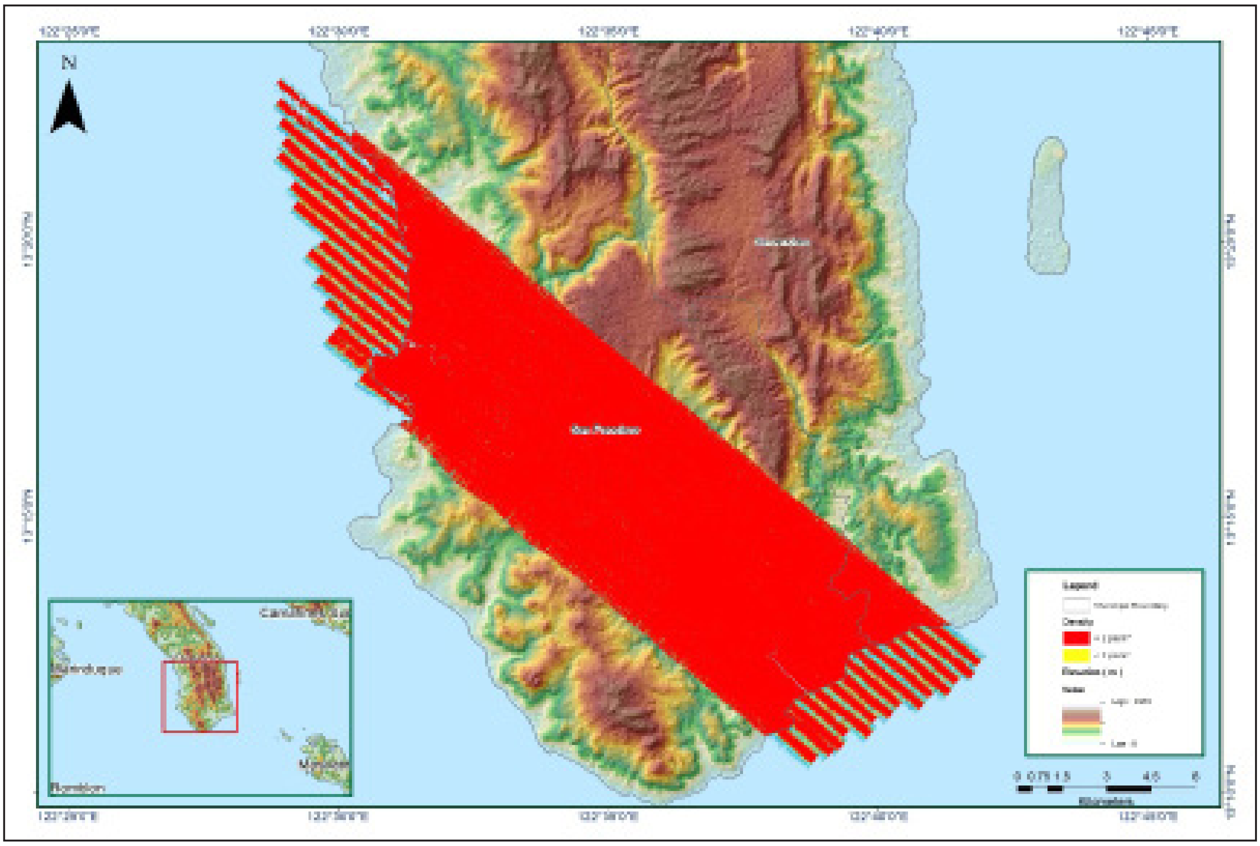


Figure A-8.6. Density map of merged LiDAR data

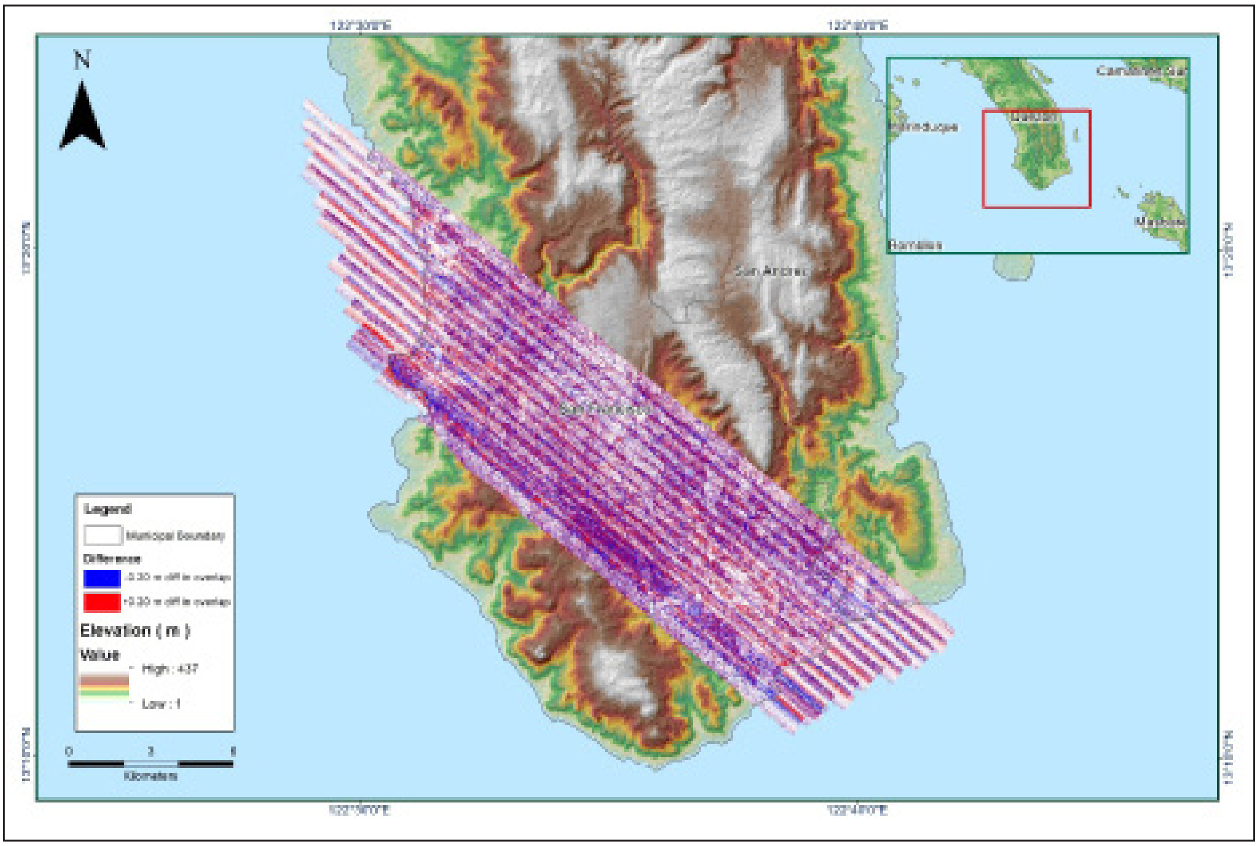


Figure A-8.7. Elevation difference between flight lines

Table A-8.2 Mission Summary Report for Blk21H

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

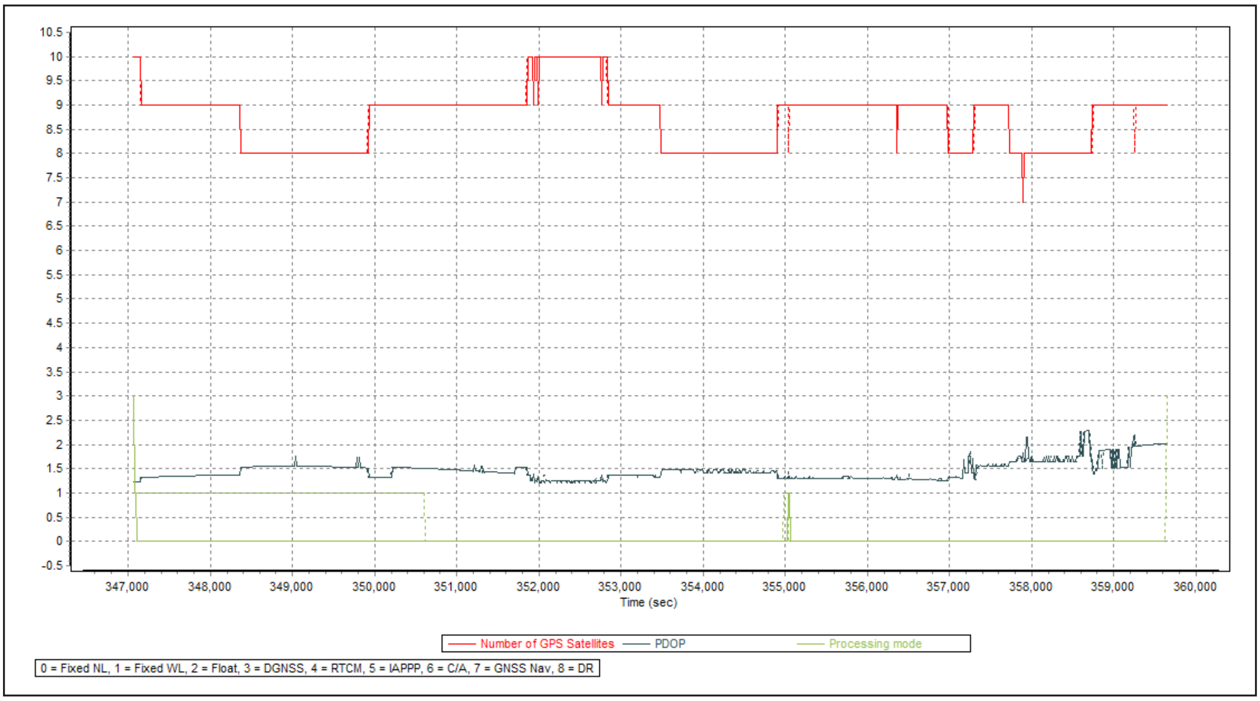


Figure A-8.8. Solution Status

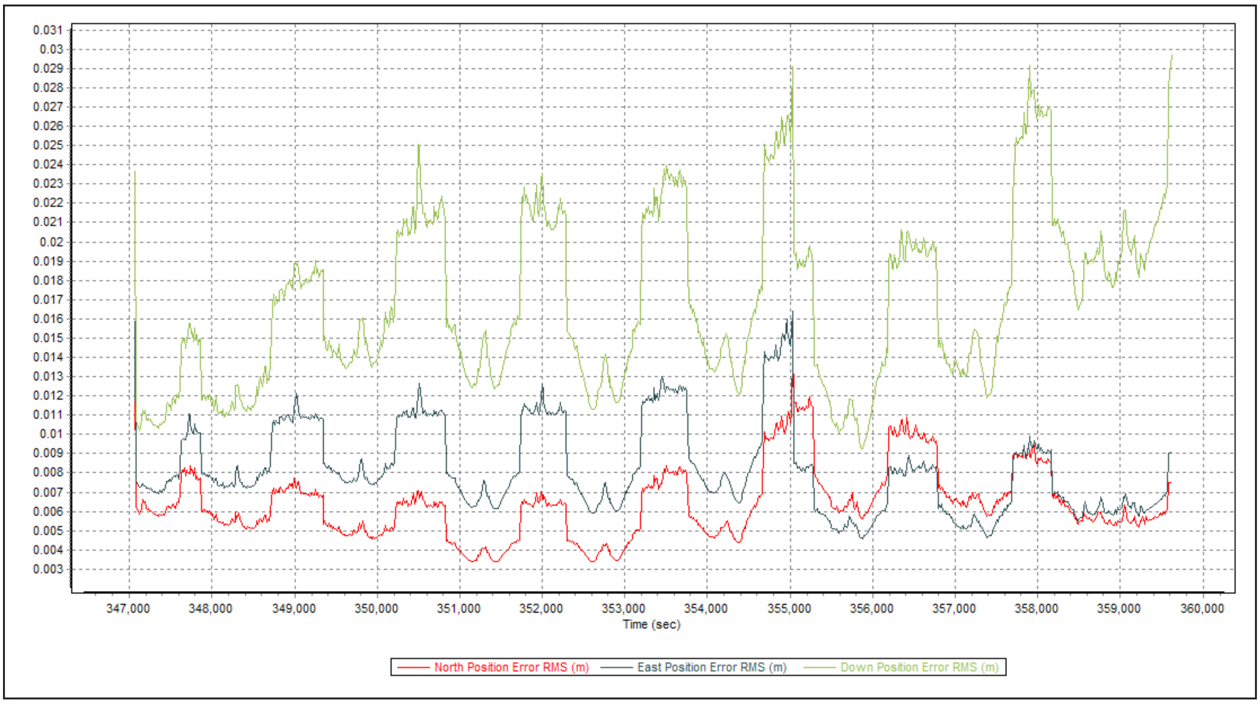


Figure A-8.9. Smoothed Performance Metric Parameters

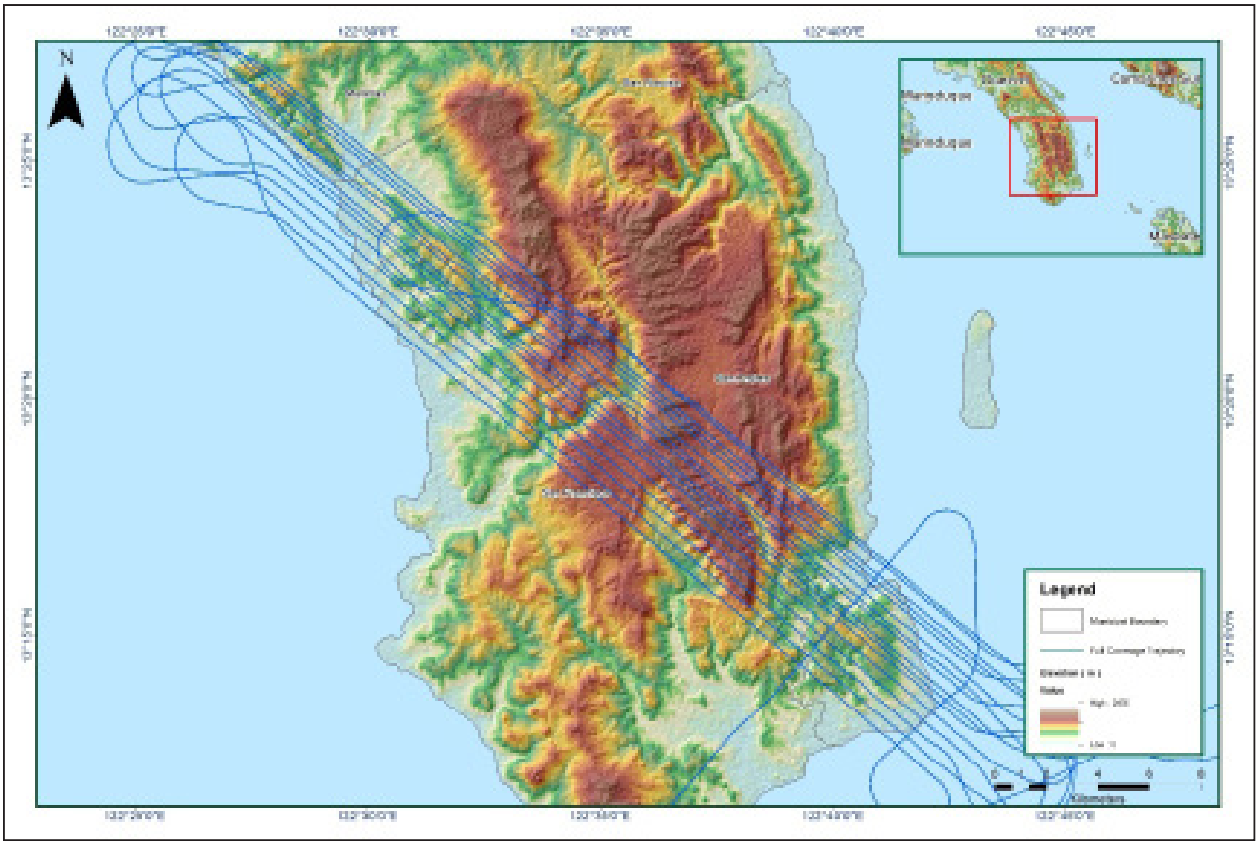


Figure A-8.10. Best Estimated Trajectory

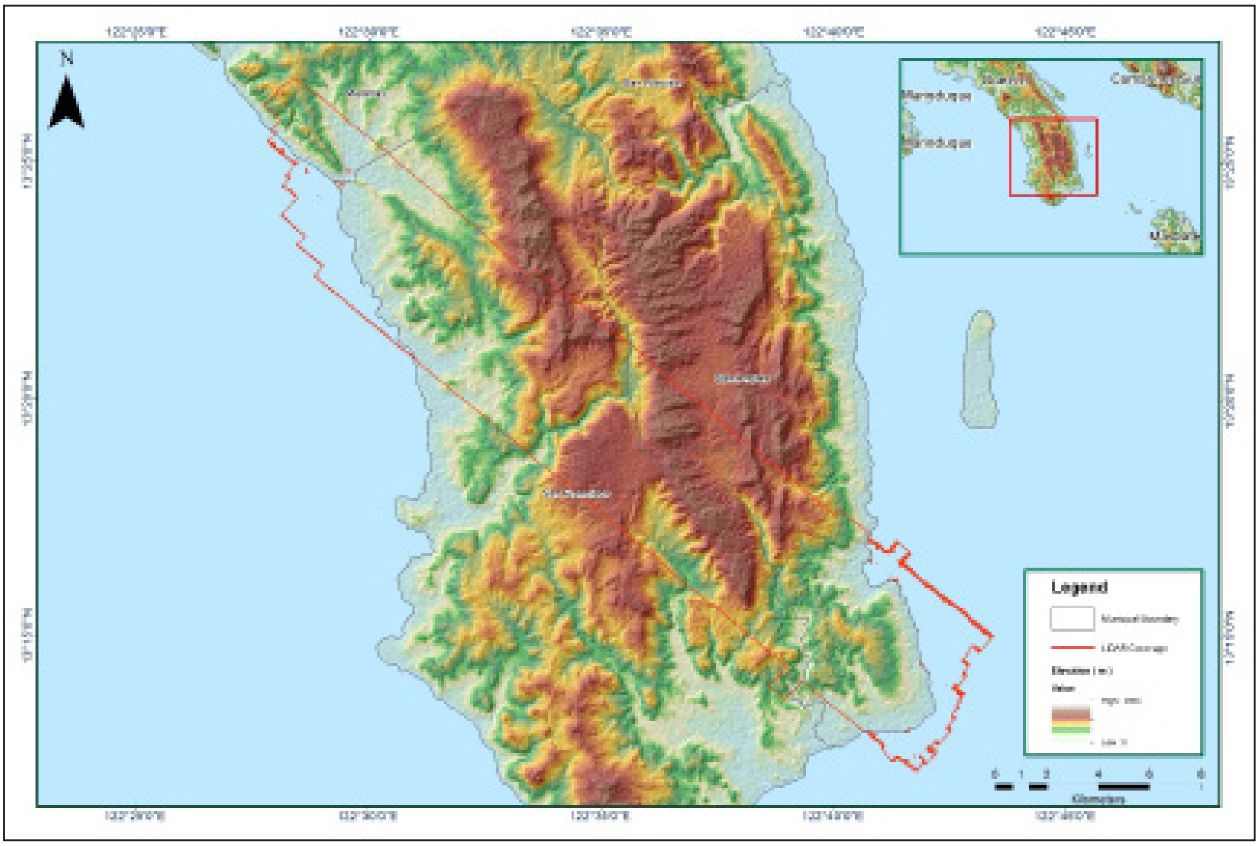


Figure A-8.11. Coverage of LiDAR data

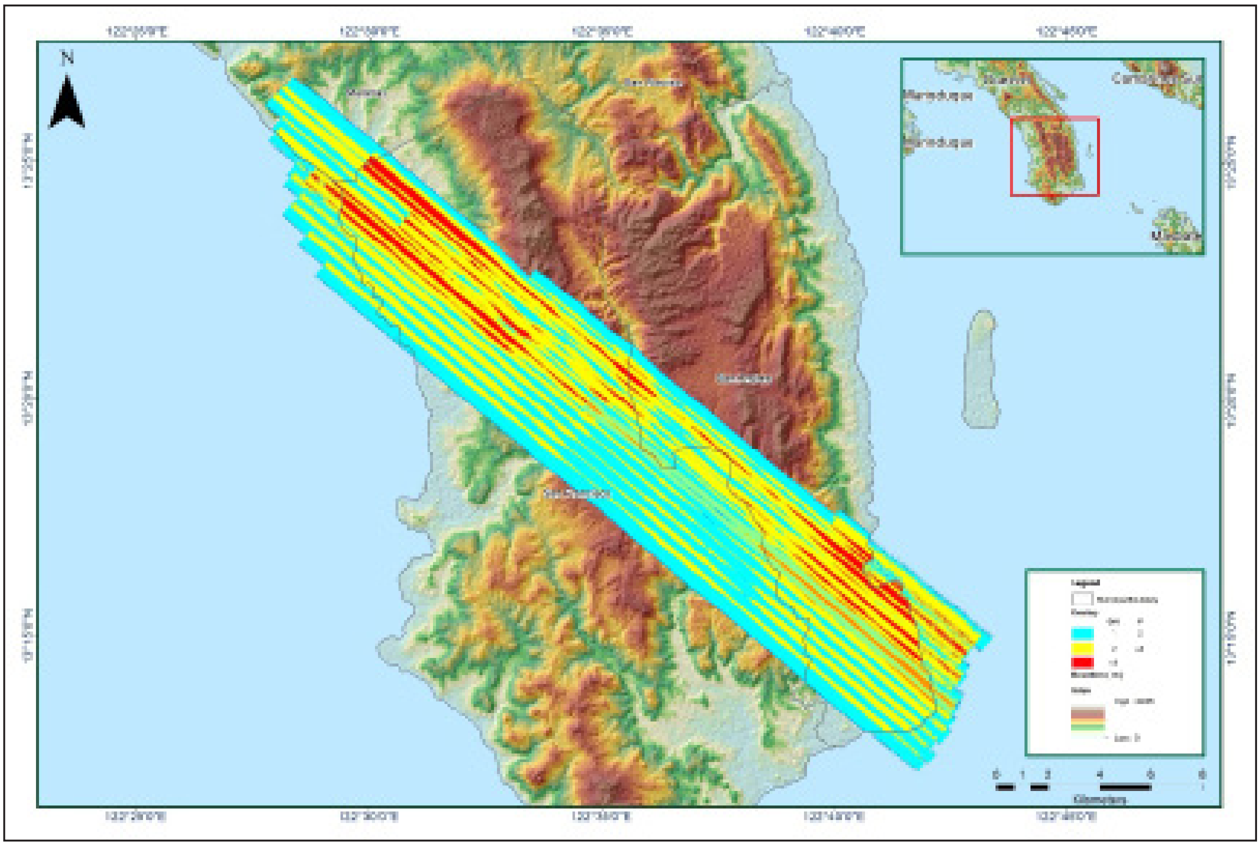


Figure A-8.12. Image of data overlap

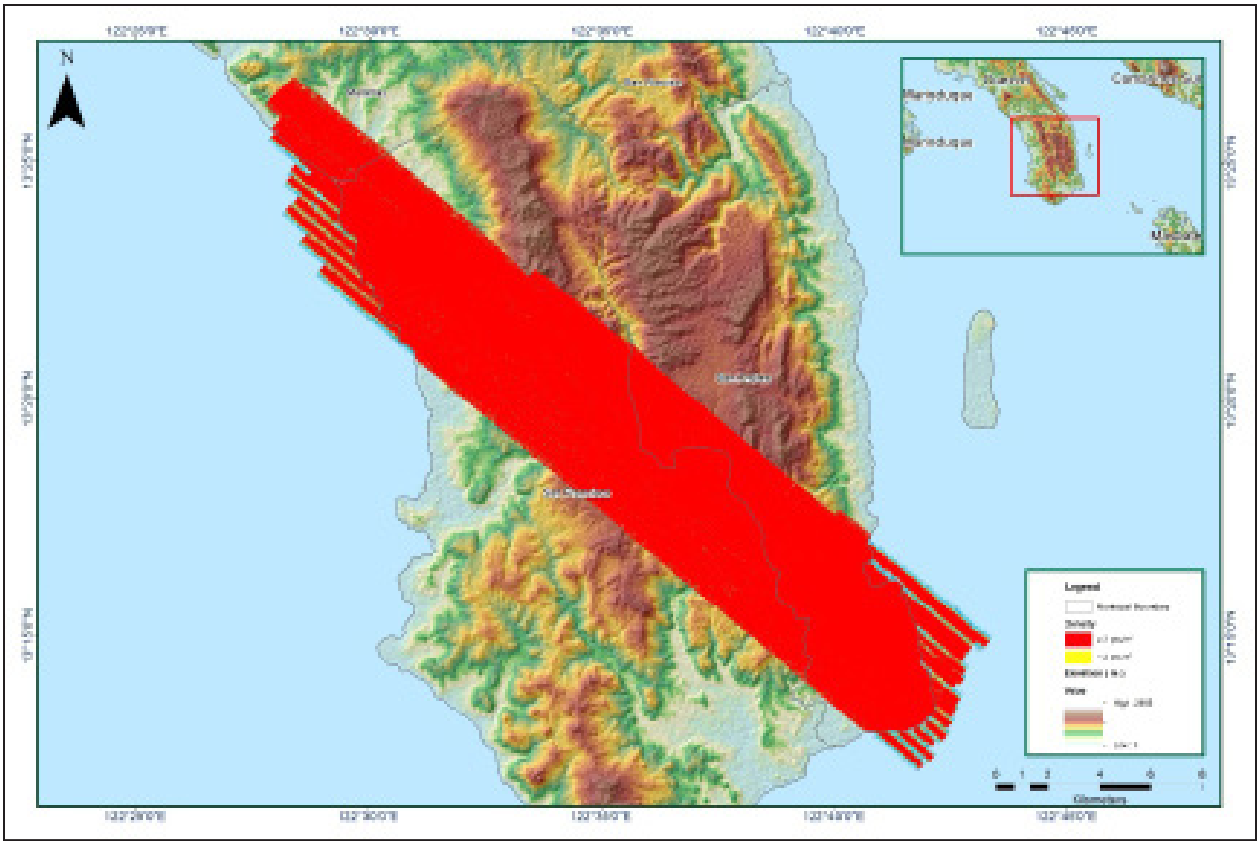


Figure A-8.13. Density map of merged LiDAR data

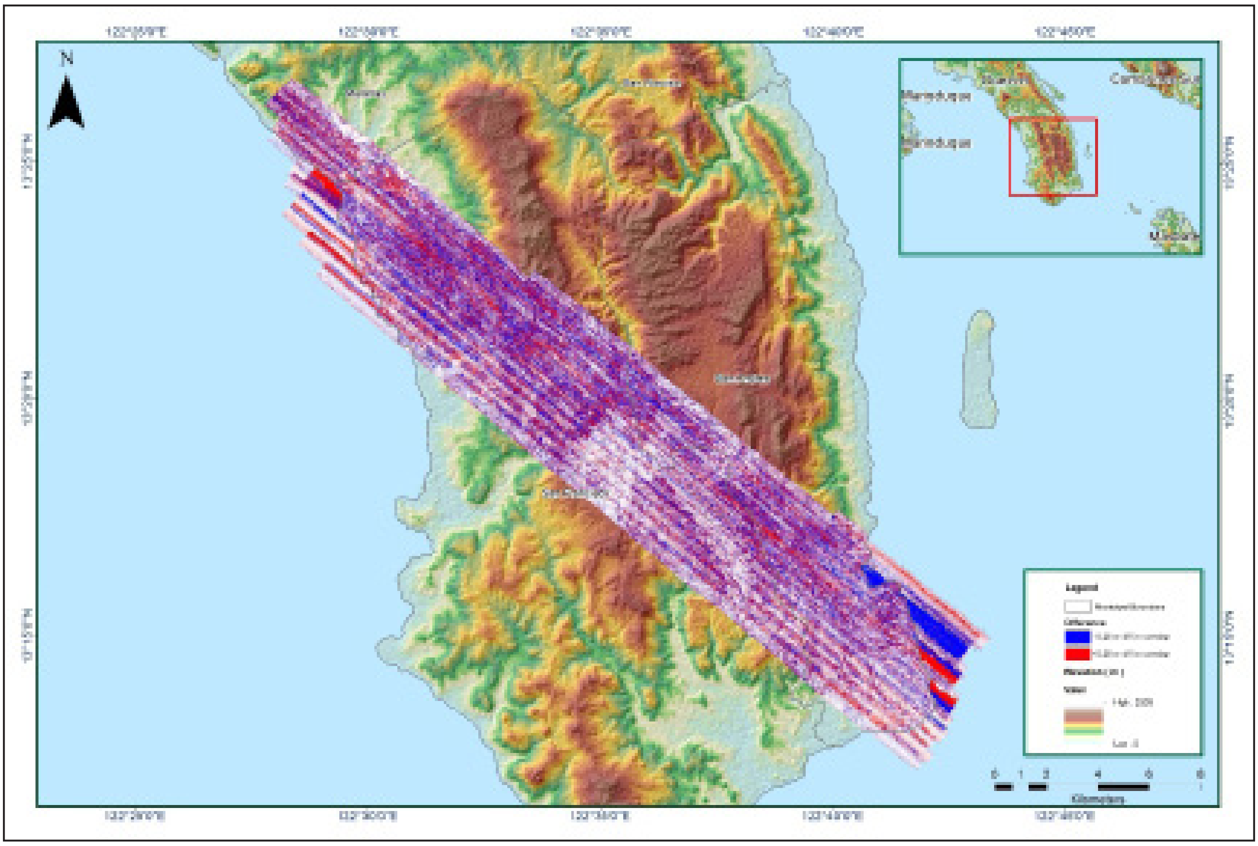


Figure A-8.14. Elevation difference between flight lines

Annex 9. Lubayat Model Basin Parameters

Table A-9.1 Lubayat Model Basin Parameters

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

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

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

Annex 10. Lubayat Model Reach Parameters

Table A-10.1 Lubayat Model Reach Parameters

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

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

Annex 11. Lubayat Field Validation Data

Table A-11.1 Lubayat Field Validation Data

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

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

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

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

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

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

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

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

RMSE: 1.121563

Annex 12. Educational Institutions Affected in Lubayat Floodplain

Table A-12.1 Educational Institutions in San Andres, Quezon Affected by Flooding in the Lubayat Floodplain

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

Annex 13. Health Institutions Affected by Flooding in Lubayat Floodplain

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