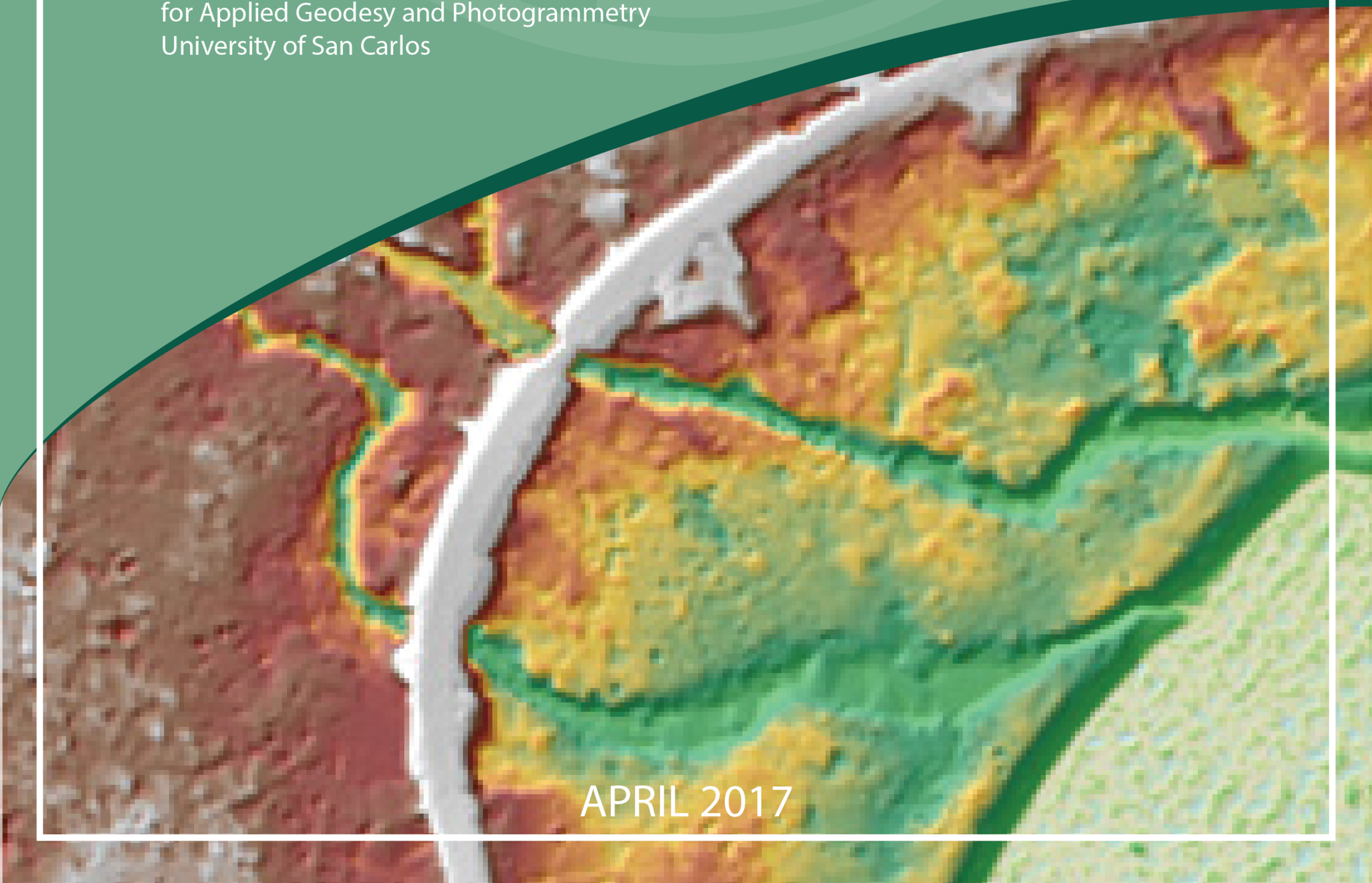
Hazard Mapping of the Philippines Using LIDAR (Phil-LIDAR 1)

LiDAR Surveys and Flood Mapping of Loboc River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of San Carlos



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LIST OF ACRONYMS AND ABBREVIATIONS

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

Enrico C. Paringit, Dr. Eng.,and Dr. Roland Emerito S. Otadoy

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 in 2014 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 methods applied in this report are thoroughly described in a separate publication entitled "FLOOD MAPPING OF RIVERS IN THE PHILIPPINES USING AIRBORNE LIDAR: METHODS" (Paringit, et. Al. 2017).

The implementing partner university for the Phil-LiDAR 1 Program is the University of San Carlos (USC). USC 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 17 river basins in the Visayas Region. The university is located in Cebu City.

1.2 Overview of the Loboc River Basin

The Loboc River Basin, located in the southwestern area of Bohol, has a catchment area of approximately 670.4 km2 based on the Flood Modelling Component database. Encompassing the Loboc River Basin are the municipalities of Loay, Lila and Loboc with a total population estimated to be 16,312, according to the 2010 Census of Population and Housing of the National Statistics Office.

Its main stem, Loboc river, is part of the 17 river systems in Visayas Region. In this area, the barangays of Candasag and Canlasid are considered to be highly susceptible to flooding and the rest of the barangays are identified to be moderately susceptible to flooding according to the 2007 Mines and Geosciences Bureau (MGB)'s Bohol Geohazard Assessment Landslide Prone Areas. The recent flooding event last December 30, 2014 in this area was due to Typhoon Seniang.

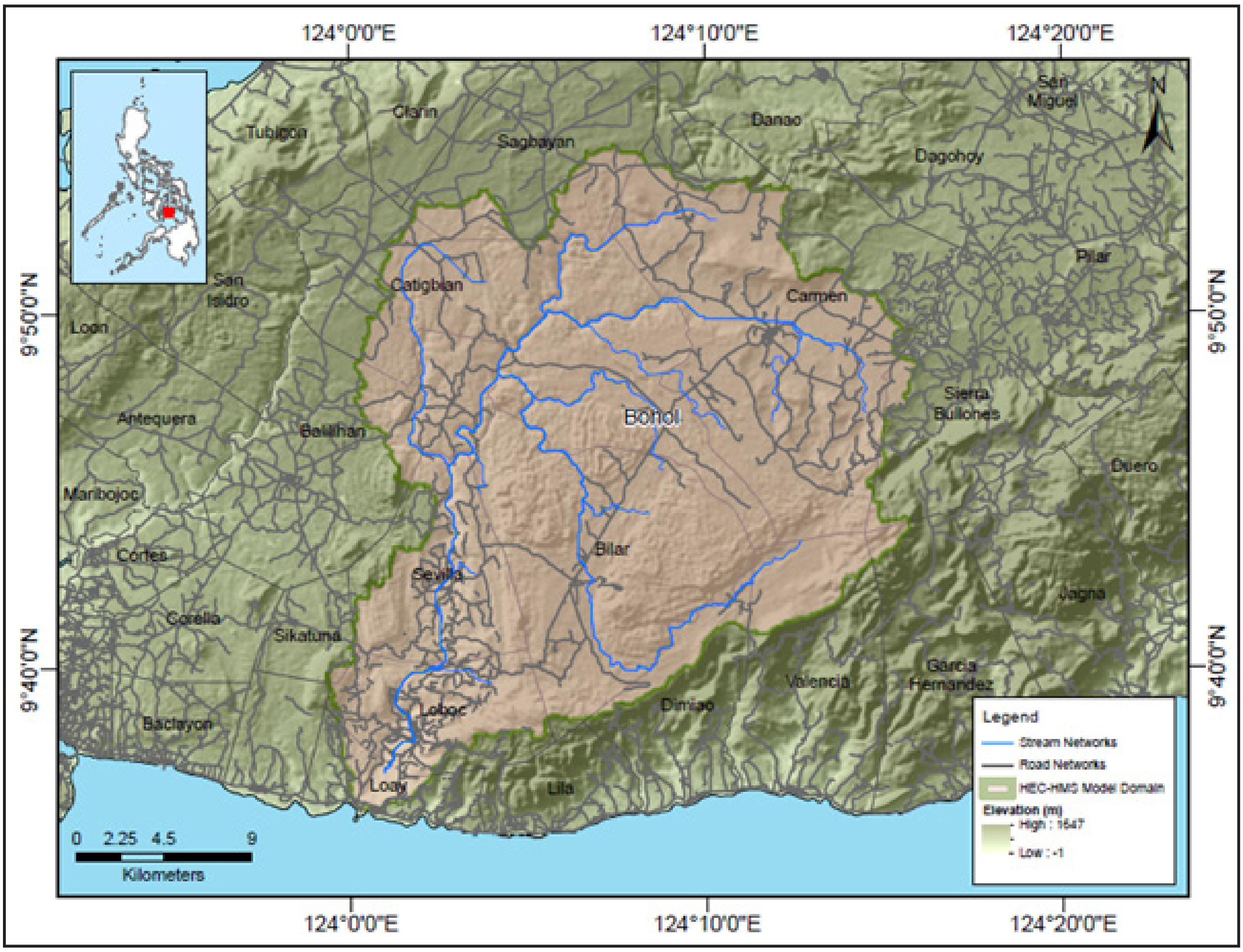

Figure 1. Map of the Loboc River Basin in brown

CHAPTER 2: LIDAR DATA ACQUISITION OF THE LOBOC 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 Loboc floodplain in Bohol. These missions were planned for 12 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system are found in Table 1. Figure 2 shows the flight plan for Loboc floodplain survey.

Table 1. Flight planning parameters for Pegasus LiDAR system.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of view (ø)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK51I	1200	25	50	200	30	130	5
BLK51K	1100	20	50	200	30	130	5
BLK51L	900,1000, 1100	20	50	200	30	130	5

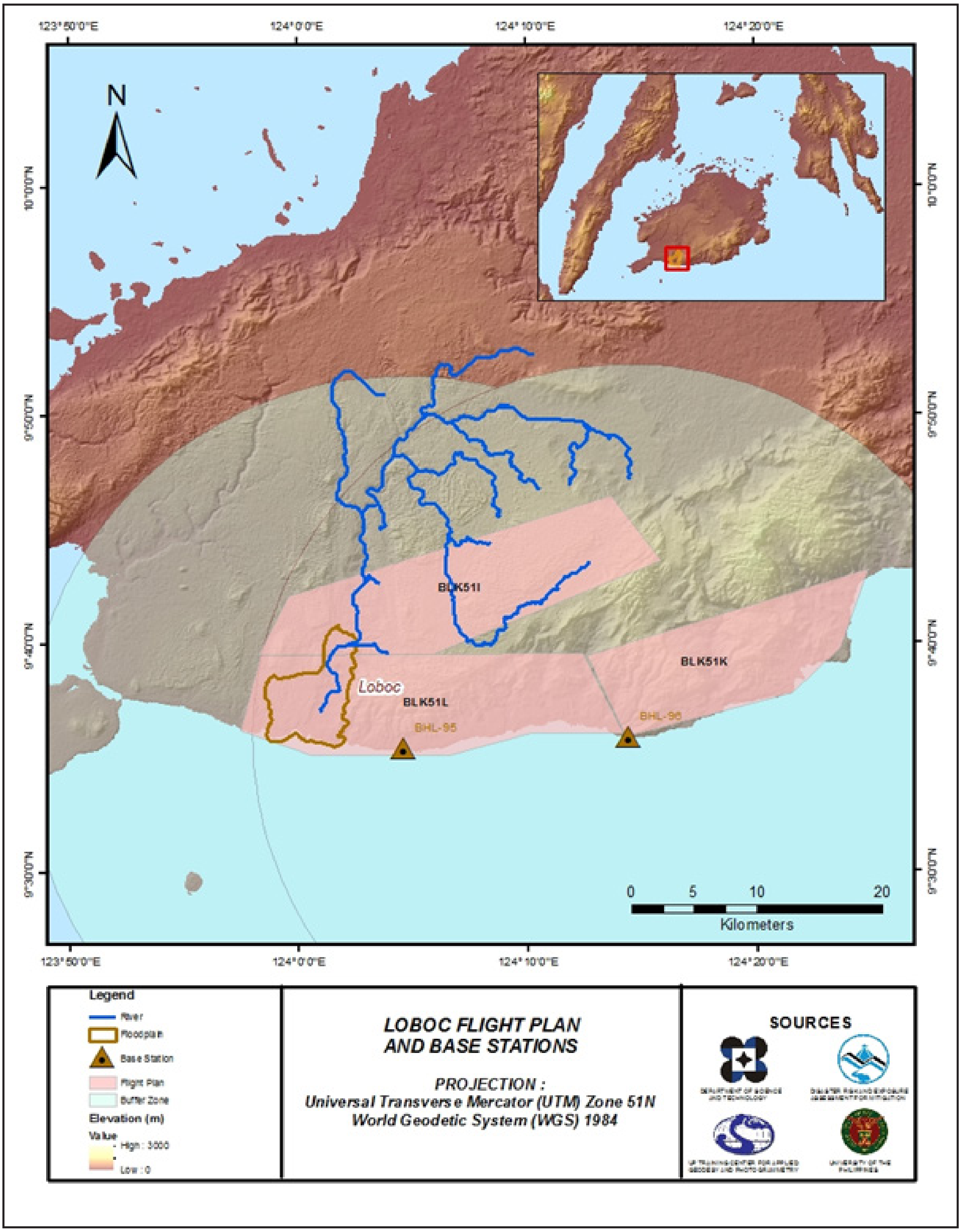
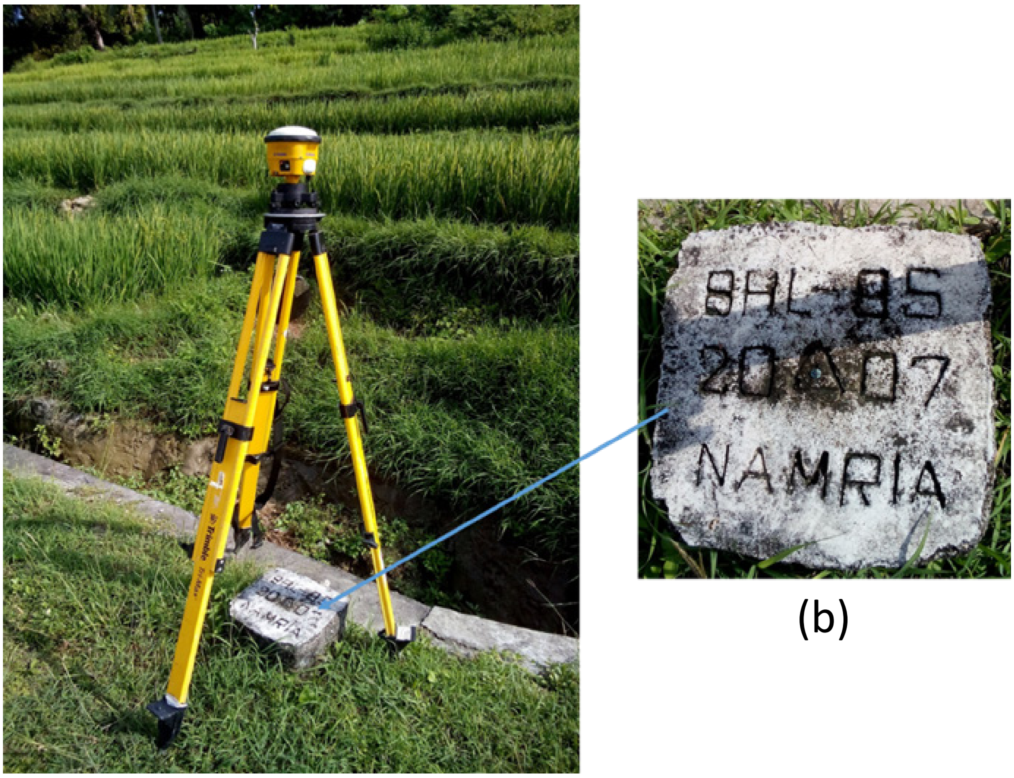


Figure 2. Flight plan and base stations used for Loboc floodplain.

2.2 Ground Base Stations

The project team was able to recover two (2) NAMRIA ground control points: BHL-95 and BHL-96 which are of second (2nd) order accuracy. However, GCPs used during the fieldwork were not certified by NAMRIA. In 2014, a new GPS network adjustment is conducted by their office to update the GCP coordinates (BHL-96) that may have been disturbed by the 2013 earthquake. The baseline processing acquired from the network adjustments performed by Data Validation and Bathymetric Component (DVBC) is found in Annex 3. The certification for the re-observed NAMRIA reference points are found in Annex 2. These were used as base stations during flight operations for the entire duration of the survey (August 26-29, 2014 and September 10-11, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882 and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Laoag floodplain are shown in Figure 2.

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

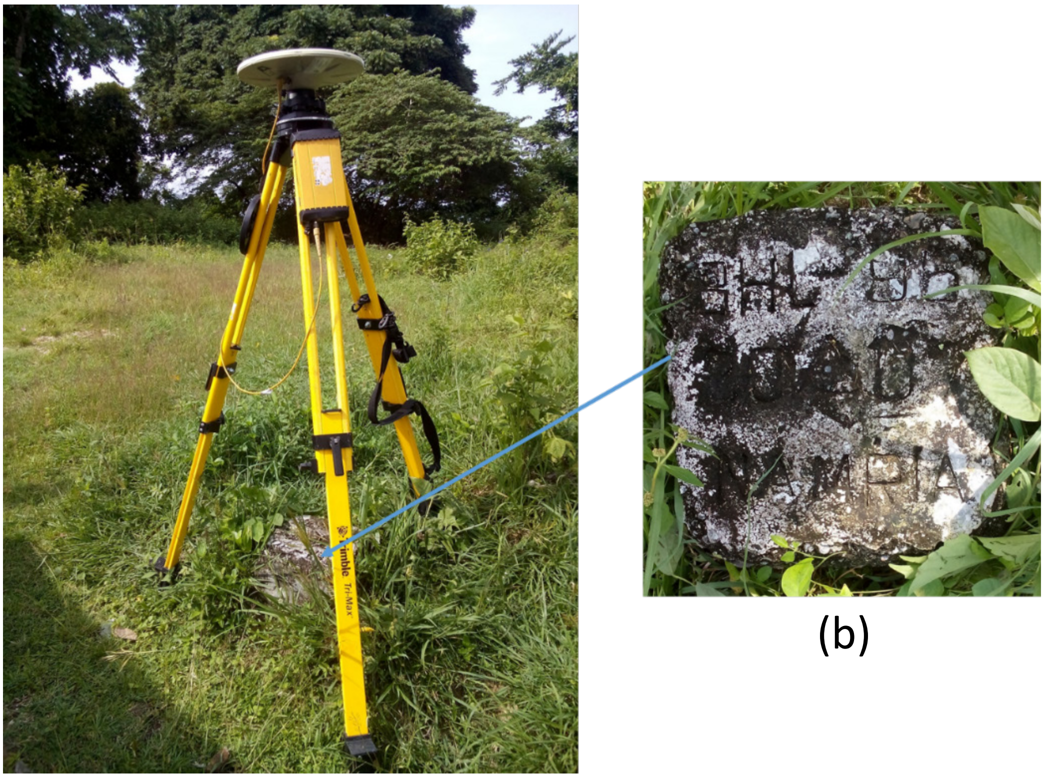


(a) (b)

Figure 3. GPS set-up over BHL-95 located at the left side of the road from Lila Town Proper, Lila, Bohol (a) and NAMRIA reference point BHL-95 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point BHL-95 used as base station for the LiDAR acquisition.

Station Name	BHL-95	
Order of Accuracy	**2nd**	
Relative Error (horizontal positioning)	**1 in 50,000**	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9° 35' 30.88081"
	Longitude	124° 4' 30.02557"
	Ellipsoidal Height	22.55200 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting	398460.059 meters
	Northing	1060734.475 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9° 35' 26.95624" North
	Longitude	124° 4' 35.33566" East
	Ellipsoidal Height	86.36200 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting	617,967.97 meters
	Northing	1,060,411.09 meters



(a) (b)

Figure 4. GPS set-up over BHL-96 located at the right side of the road from Valencia Town Proper near the Abueva Heritage Mark in Valencia, Bohol (a) and NAMRIA reference point BHL-96 (b) as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point BHL-96 used as base station for the LiDAR acquisition.

Station Name	BHL-96	
Order of Accuracy	2nd	
Relative Error (Horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 35’ 59.16579” 124° 14’ 18.58426” 23.97900 meters
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 5 PRS 92)	Easting Northing	416409.846 meters 1061559.452 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 35’ 55.25356” North 124° 14’ 23.89224” East 88.17600 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 92)	Easting Northing	635,908.05 meters 1,061,340.27 meters

Table 4. Ground Control Points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
08/26/14	1883P	1BLK51KL238A	BHL-95, BHL-96
08/27/14	1885P	1BLK51I239A	BHL-95, BHL-96
08/29/14	1895P	1BLK51K241A	BHL-95, BHL-96
09/10/15	3401P	1BLK51LS253A	BHL-95, BHL-96
09/11/15	3405P	1BLK51LS254A	BHL-95, BHL-96

2.3 Flight Missions

Five (5) missions were conducted complete the LiDAR data acquisition in Loboc floodplain, for a total of fifteen and nineteen minutes (15+19) hours for RP-C9022. All missions are 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 Loboc floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km^2)	Surveyed Area (km^2)	Area Surveyed within the Floodplain (km^2)	Area Surveyed Outside the Floodplain (km^2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
08/26/14	1883P	159.2	82.89	16.47	25.03	314	2	29
08/27/14	1885P	182.2	191	7.43	34.07	646	3	53
08/29/14	1895P	159.2	151.22	0	41.5	408	3	23
09/10/15	3401P	185.8	89.71	1.81	39.69	0	2	41
09/11/15	3405P	185.8	151.22	41.44	0.06	0	2	53
TOTAL		872.2	666.04	67.15	140.35	1368	15	19

Table 6. Actual Parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1883P	1100	20	50	200	30	130	5
1885P	1200	25	50	200	30	130	5
1895P	1100	20	50	200	30	130	5
3401P	900, 1000	20	50	200	30	130	5
3405P	900, 1000	20	50	200	30	130	5

2.4 Survey Coverage

Loboc floodplain is located in the province of Bohol with majority of the floodplain situated within the municipality of Loay and Loboc. Municipalities of Loay, Loboc and Garcia Hernandez are mostly covered by the survey. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 7. The actual coverage of the LiDAR acquisition for Loboc Floodplain is presented in Figure 5.

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

Province	Municipality/ City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Bohol	Loay	29.63	29.46	99%
	Loboc	57.4	43.6	76%
	Garcia Hernandez	100.17	73.2	73%
	Lila	32.97	21.57	65%
	Albuquerque	26.84	17.04	63%
	Sevilla	68.37	41.3	60%
	Sikatuna	21.88	12.9	59%
	Bilar	137.93	80.7	59%
	Valencia	95.28	53.57	56%
	Jagna	106.06	57.56	54%
	Corella	40.09	9.66	24%
	Dimiao	55.65	12.38	22%
	Duero	74.75	12.64	17%
	Carmen	221.41	29.33	13%
	Cortes	30.52	2.43	8%
	Batuan	90.27	6.65	7%
	Sierra Bullones	85.93	5.52	6%
	Total	**1,275.15**	**509.51**	**39.96%**

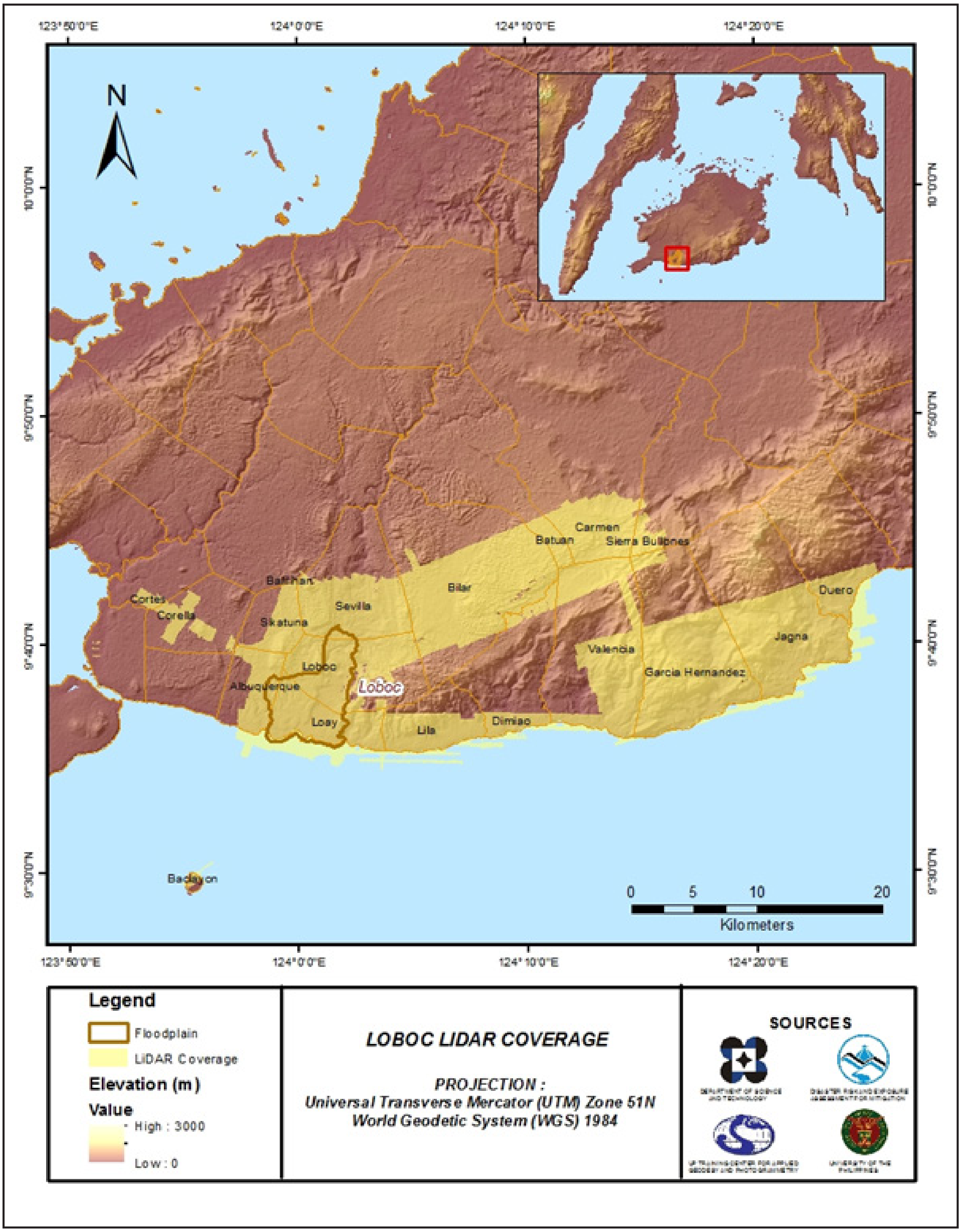


Figure 5. Actual LiDAR data acquisition for Loboc floodplain.

CHAPTER 3: LIDAR DATA PROCESSING OF THE LOBOC FLOODPLAIN

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

3.1 Overview of the LiDAR Data Pre-Processing

The data transmitted by the Data Acquisition Component 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.

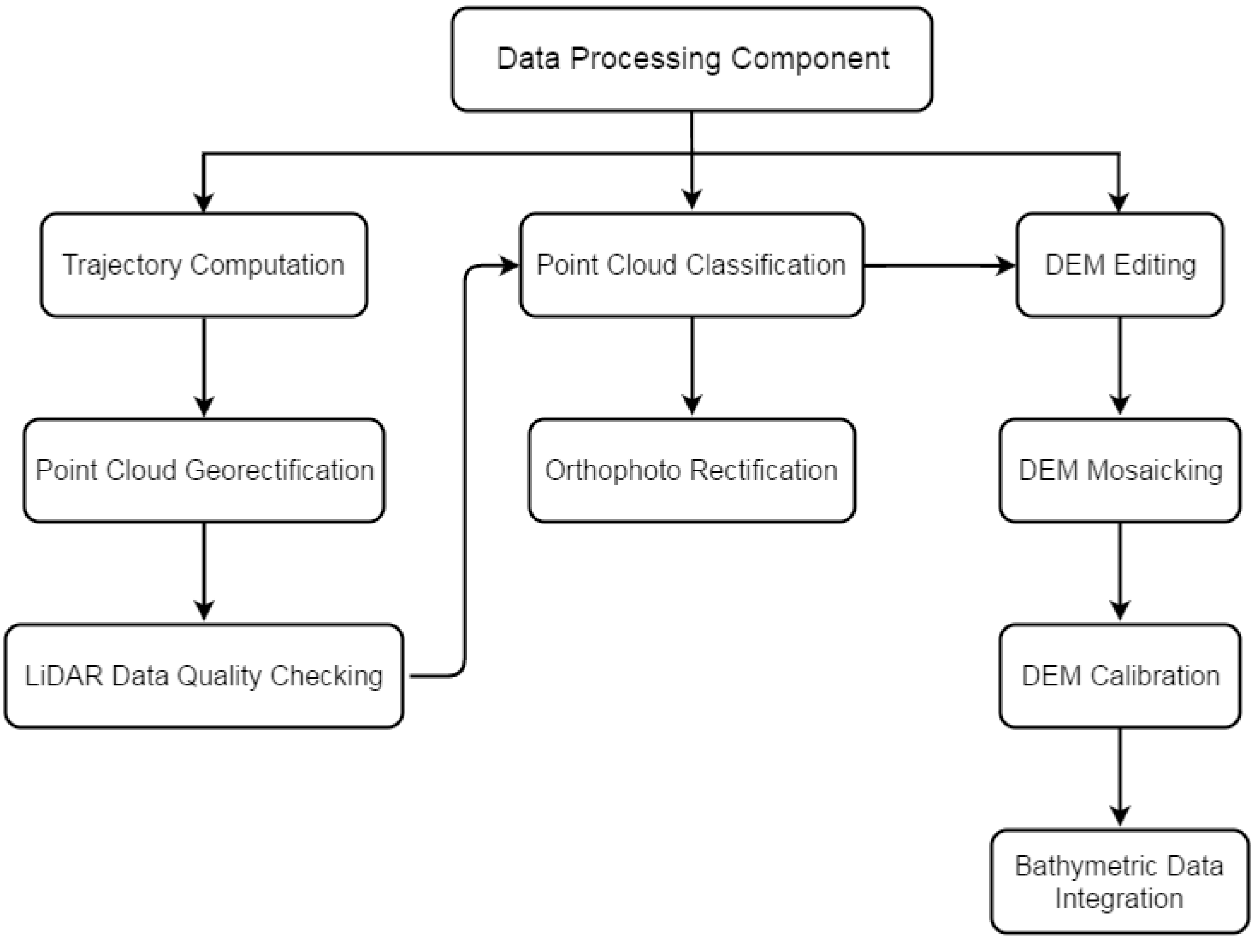

Figure 6.Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Loboc floodplain can be found in Annex 5: Data Transfer Sheets. Missions flown during the first survey conducted on August 2014 and second survey conducted on September10, 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus system over Bohol. The Data Acquisition Component (DAC) transferred a total of 102.80 Gigabytes of Range data, 9.26 Gigabytes of POS data, 44.29 Megabytes of GPS base station data, and 89.30 Gigabytes of raw image data to the data server on August 27, 2014 for the first survey and September 10, 2015 for the second survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Loboc was fully transferred on September 21, 2015, as indicated on the Data Transfer Sheets for Loboc floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 3405P, one of the Loboc 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 September 11, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

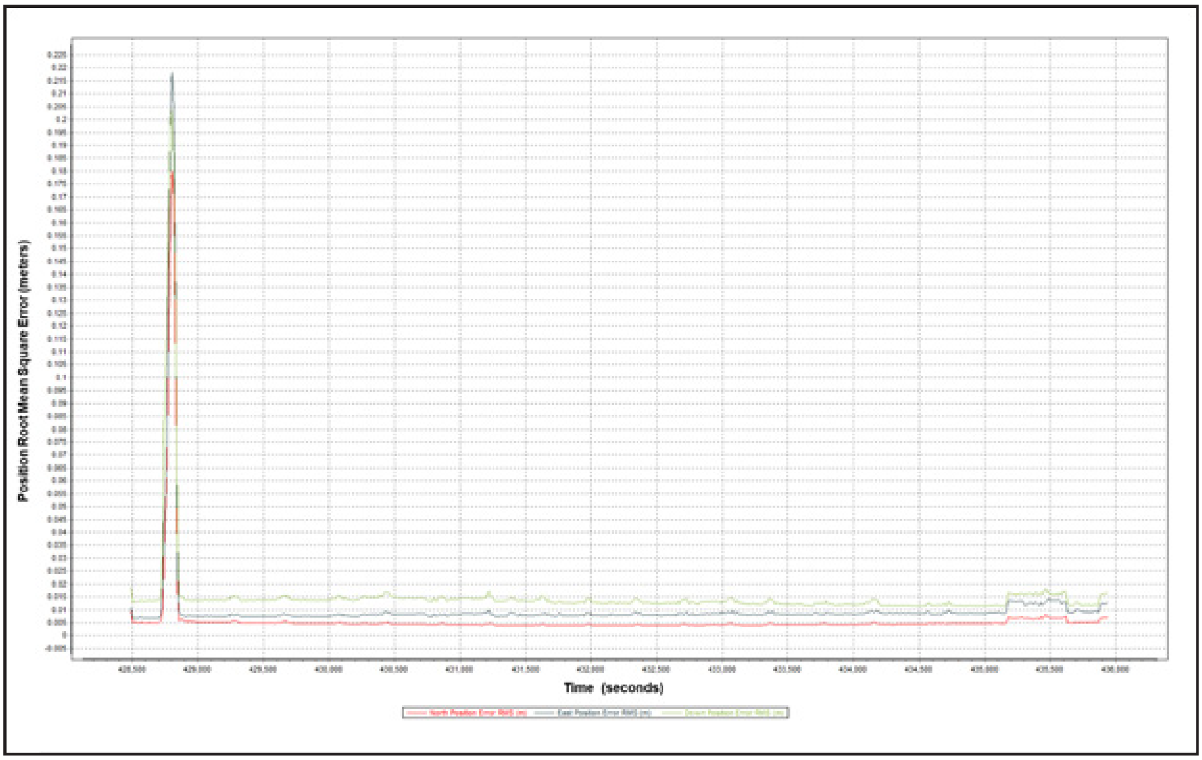

Figure 7. Smoothed Performance Metric Parameters of Loboc Flight 3405P.

The time of flight was from 428500 seconds to 436000 seconds, which corresponds to morning of September 11, 2015. 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 18.00 centimeters, the East position RMSE peaks at 22.00 centimeters, and the Down position RMSE peaks at 20.00 centimeters, which are within the prescribed accuracies described in the methodology.

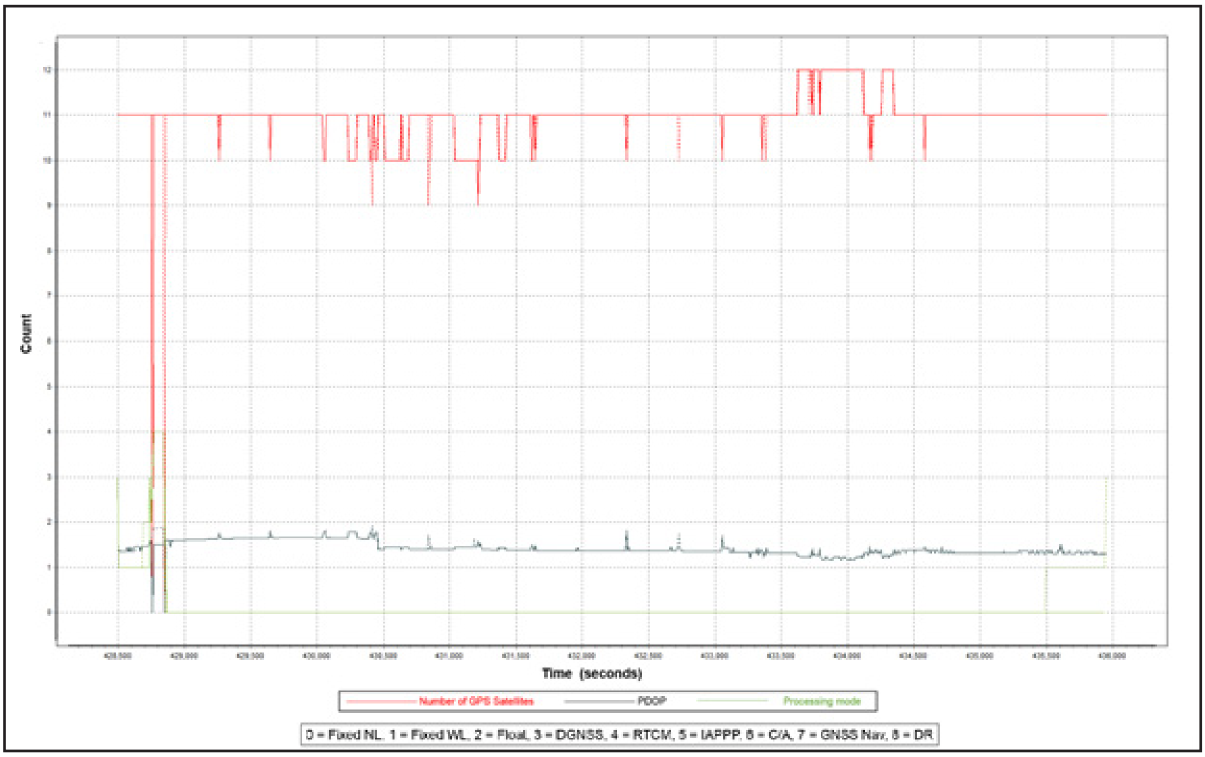

Figure 8. Solution Status Parameters of Loboc Flight 3405P.

The Solution Status parameters of flight 3405P, one of the Loboc 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 go down to 6. Majority of the time, the number of satellites tracked was between 0.5 and 11. 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 3 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 Loboc flights is shown in Figure 9.

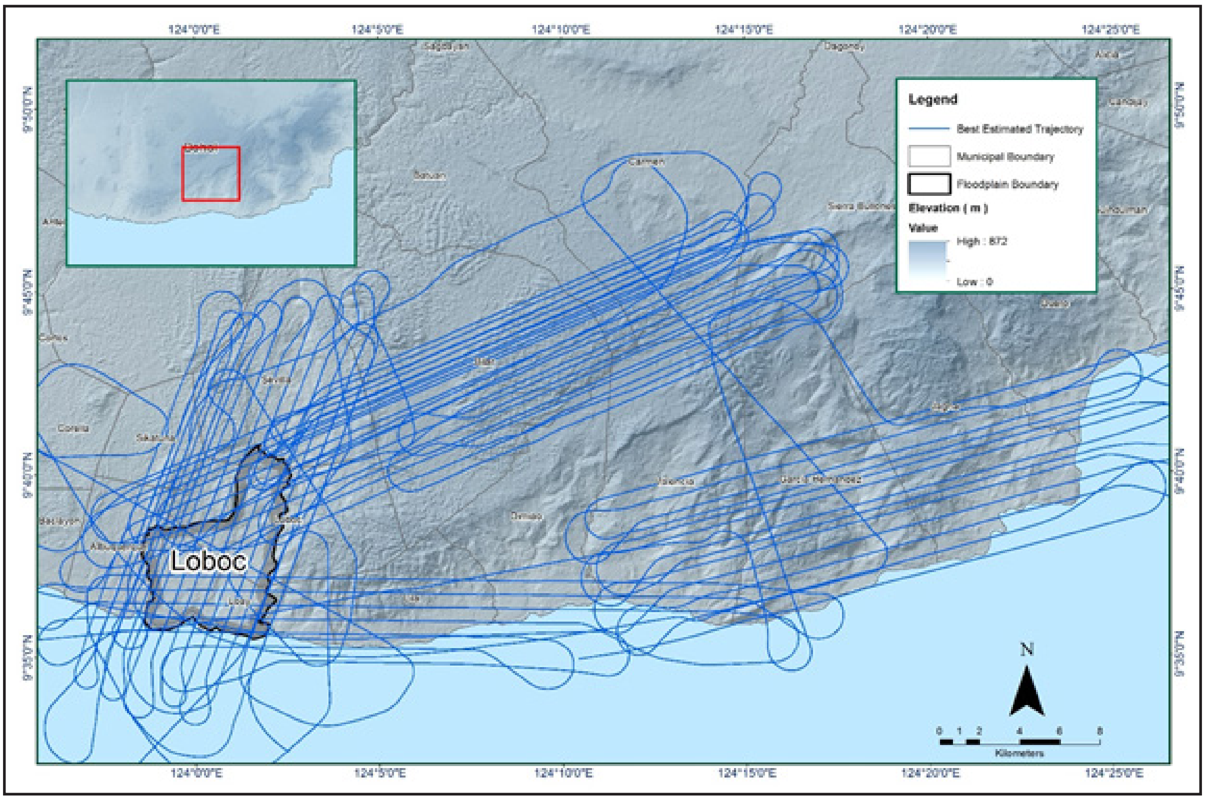

Figure 9. The best estimated trajectory of the LiDAR missions conducted over the Loboc Floodplain

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 74 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 Loboc floodplain are given in Table 8.

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

Parameter	Acceptable Value	Value
Boresight Correction stdev)	<0.001degrees	0.000238
IMU Attitude Correction Roll and Pitch Correction stdev)	<0.001degrees	0.000614
GPS Position Z-correction stdev)	<0.01meters	0.0009

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

3.5 LiDAR Data Quality Checking

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

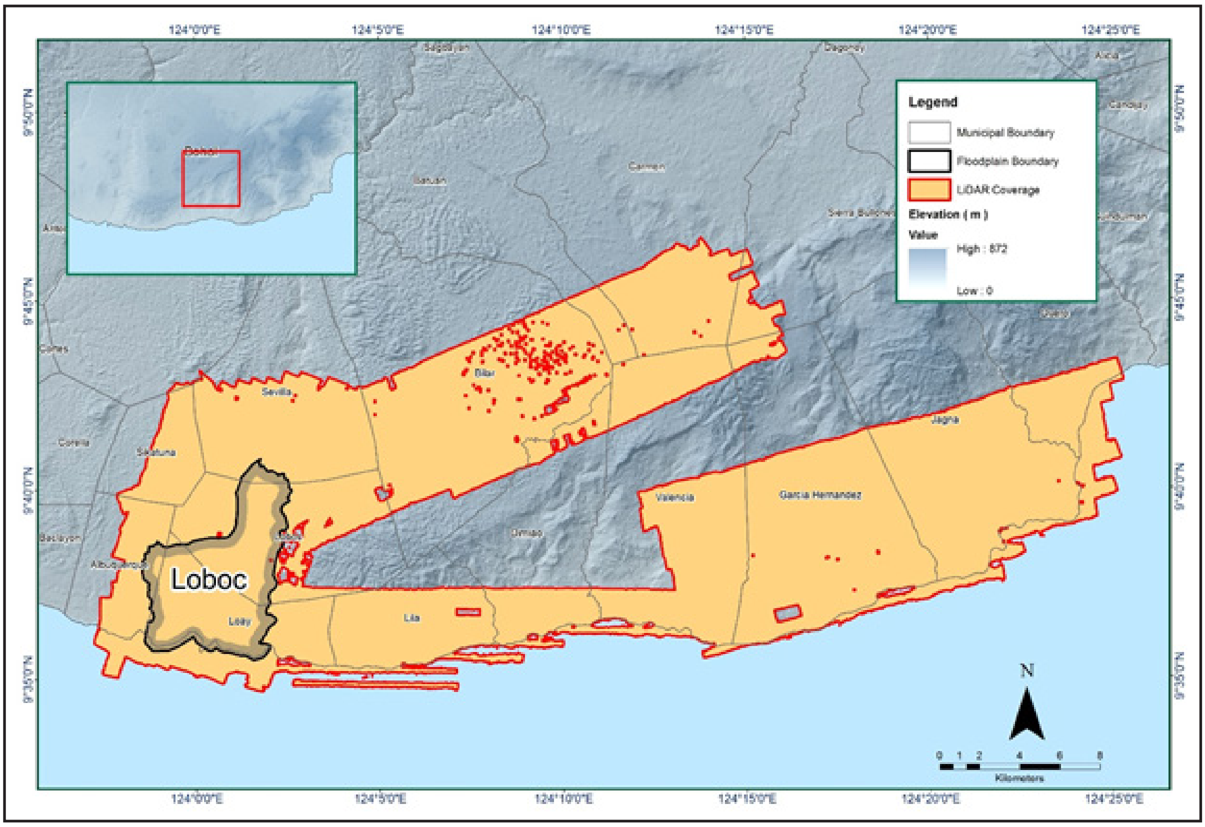

Figure 10. Boundary of the processed LiDAR data over Loboc Floodplain.

The total area covered by the Loboc missions is 611. 108 sq.km that is comprised of five (5) flight acquisitions grouped and merged into four (4) blocks as shown in Table 9.

Table 9. List of LiDAR blocks for Loboc floodplain.

LiDAR Blocks	Flight Numbers	Area (sq. km)
Bohol_ Blk51I	1885P	187.74
Bohol_ Blk51KL_supplement	3401P	136.15
	3405P	
Bohol_ Blk51L	1883P	101.15
Bohol_ Blk51K	1895P	186.068
TOTAL		611.11sq.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 Since the Pegasus systems 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.

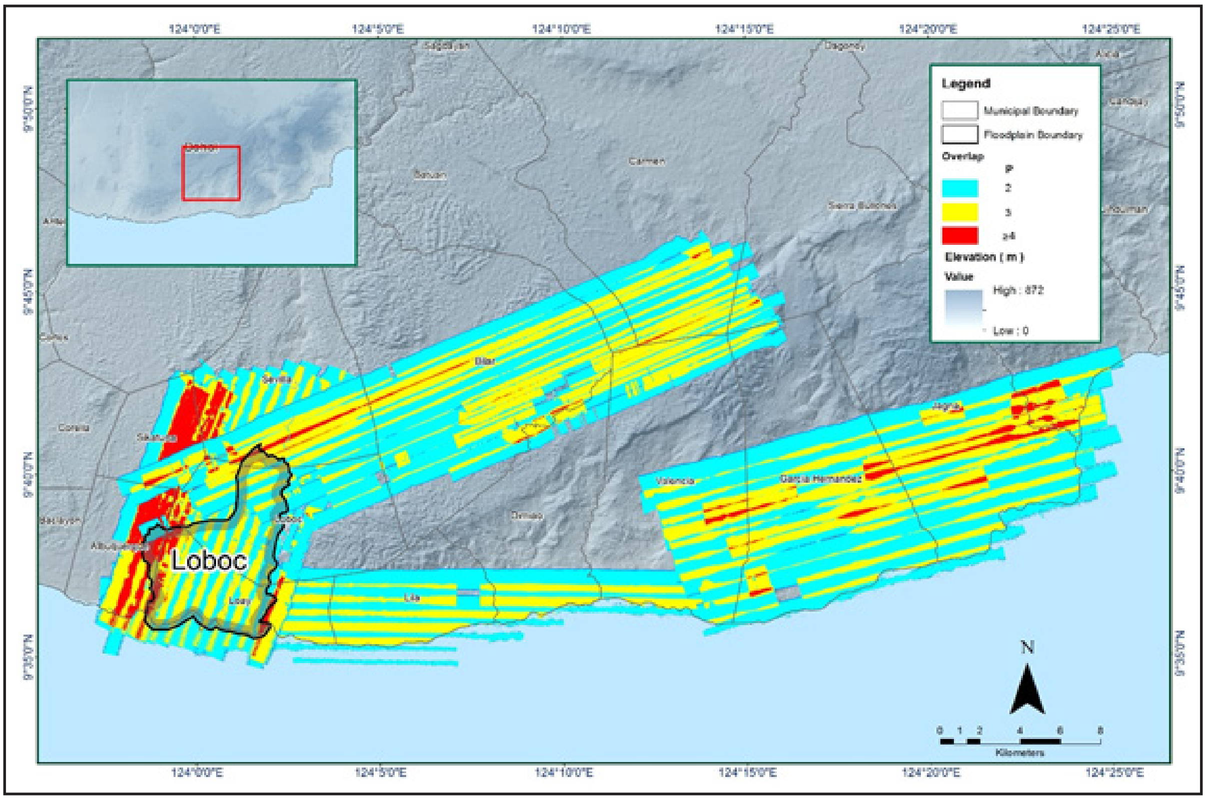

Figure 11. Image of data overlap for Loboc floodplain.

The overlap statistics per block for the Loboc 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 15.13% and 46.84% respectively.

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 Loboc floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.35 points per square meter.

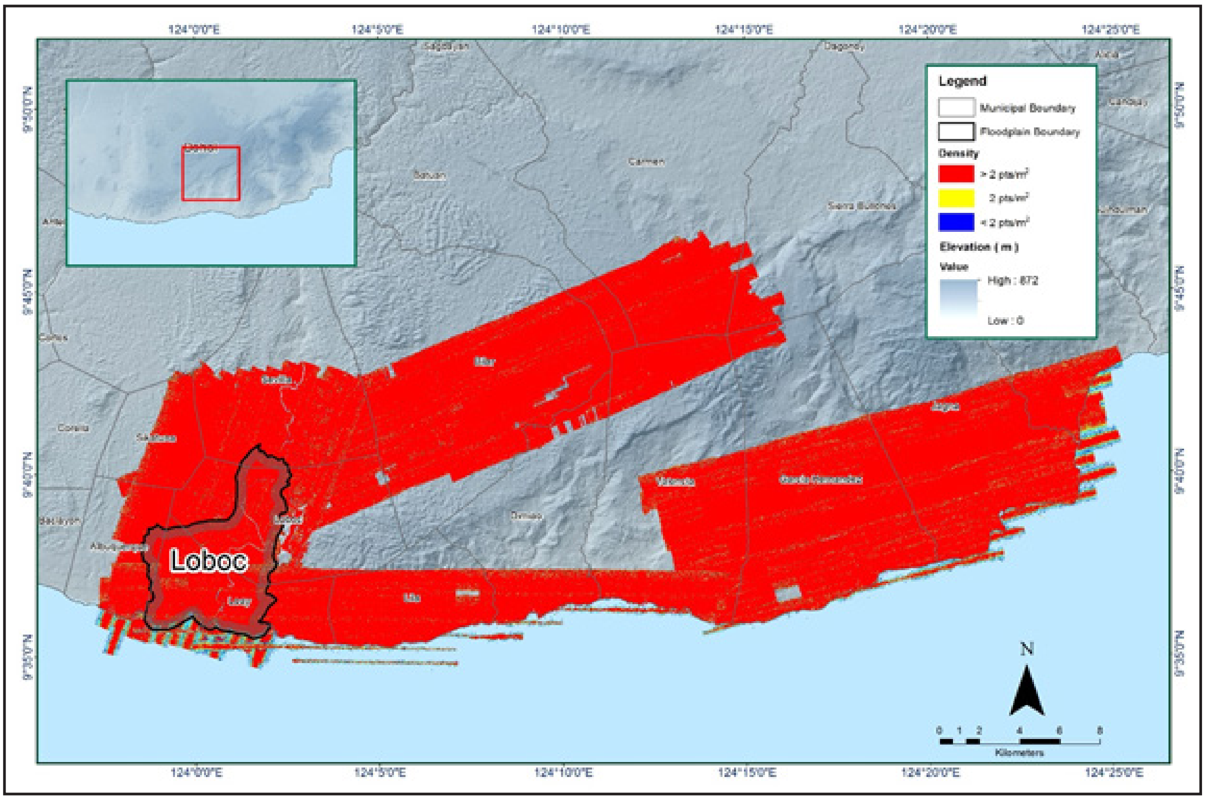

Figure 12. Pulse density map of merged LiDAR data for Loboc floodplain.

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.

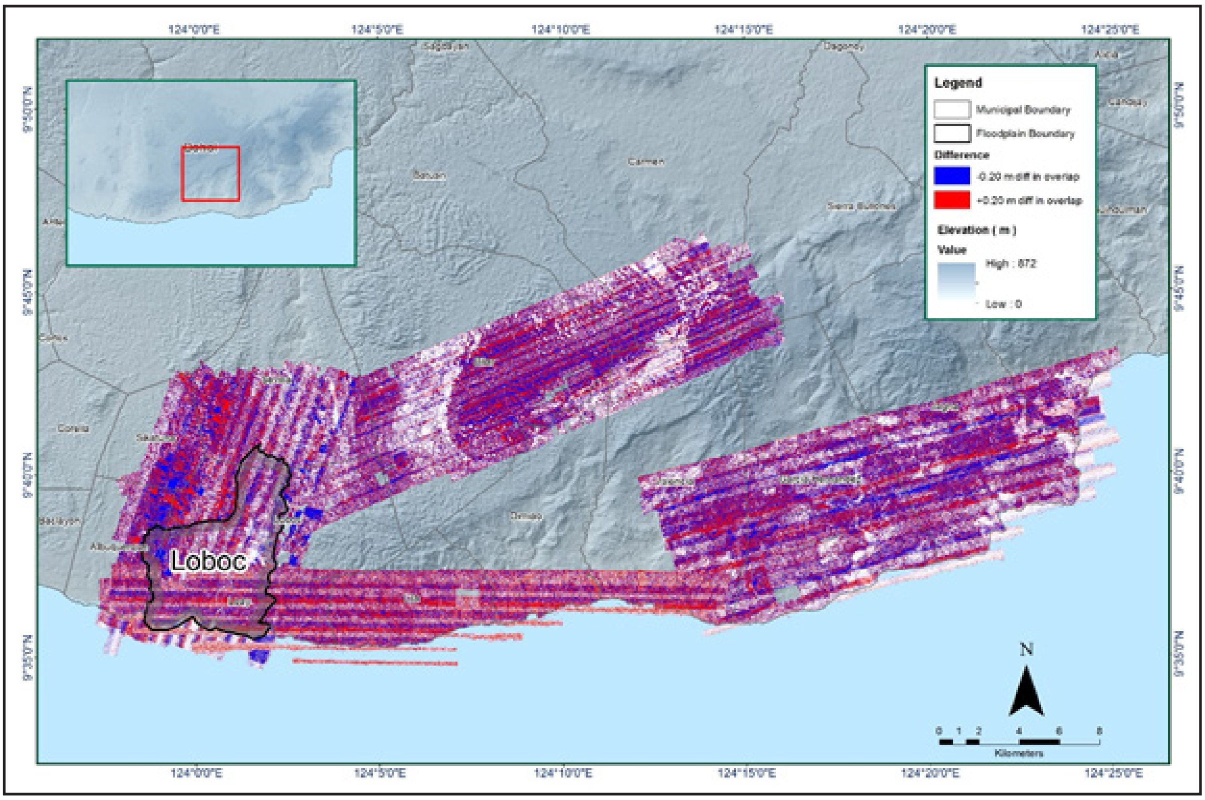

Figure 13. Elevation difference map between flight lines for Loboc floodplain.

A screen capture of the processed LAS data from a Loboc flight 3405P loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed yellow line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

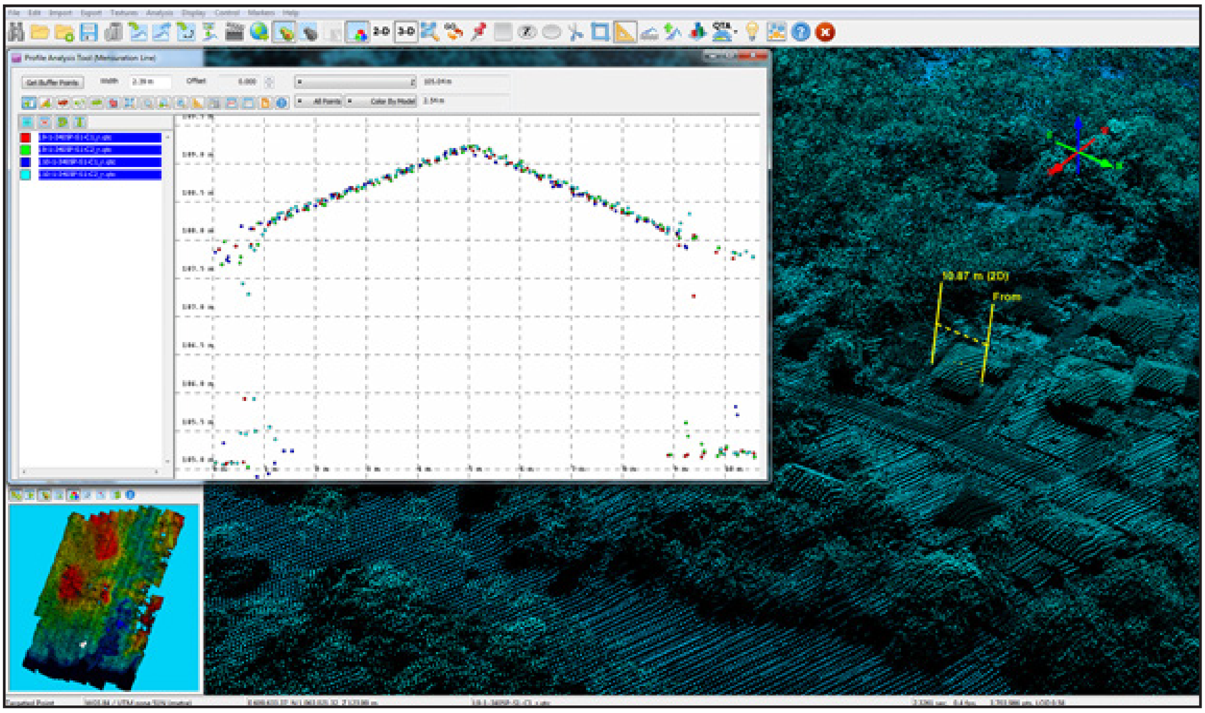

Figure 14. Quality checking for a Loboc flight 3405P using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 10. Loboc classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	140,395,374
Low Vegetation	100,704,616
Medium Vegetation	248,233,071
High Vegetation	481,224,008
Building	12,733,441

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Loboc floodplain is shown in Figure 15. A total of 813 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 786.95 meters and 62.37 meters respectively.

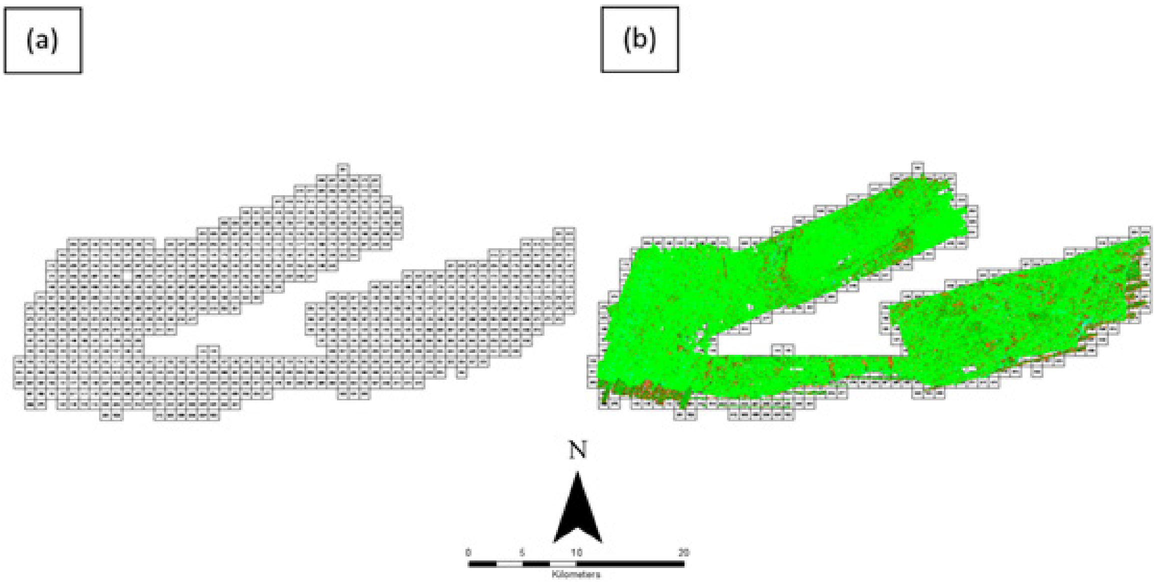

Figure 15. Tiles for Loboc floodplain (a) and classification results (b) in TerraScan.

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.

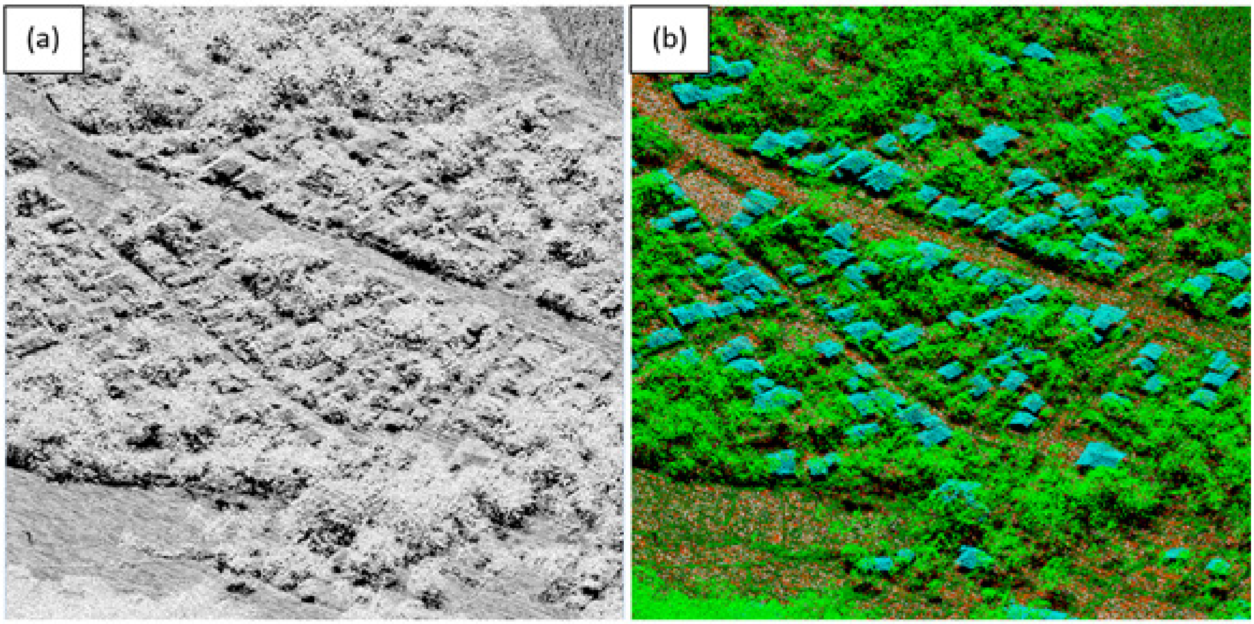

Figure 16. Point cloud before (a) and after (b) classification.

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.

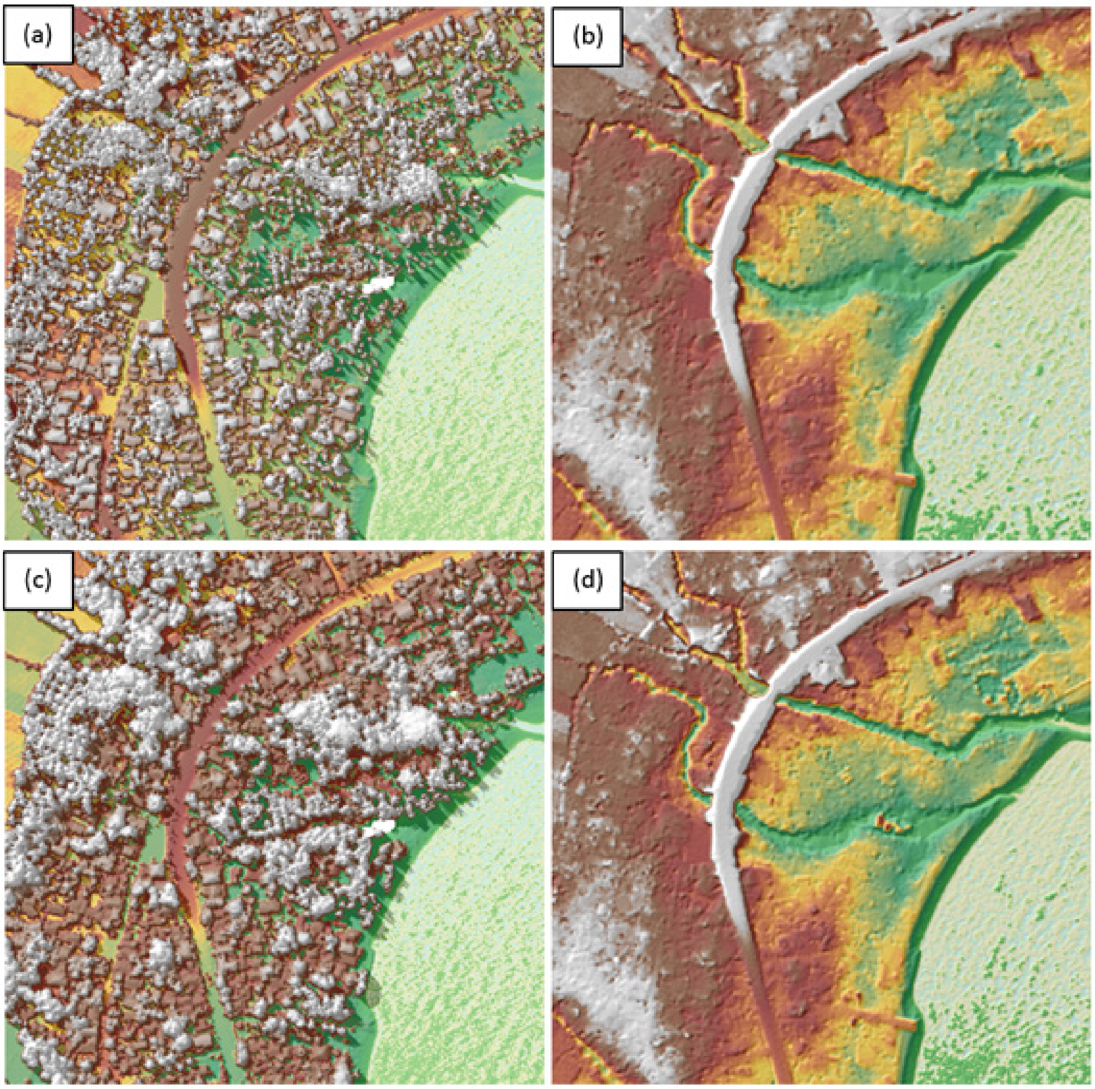

Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Loboc floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 600 1km by 1km tiles area covered by Loboc floodplain is shown in Figure 18. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Loboc floodplain survey attained a total of 460.05 km2 in orthophotogaph coverage, comprised of 1,316 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 19.

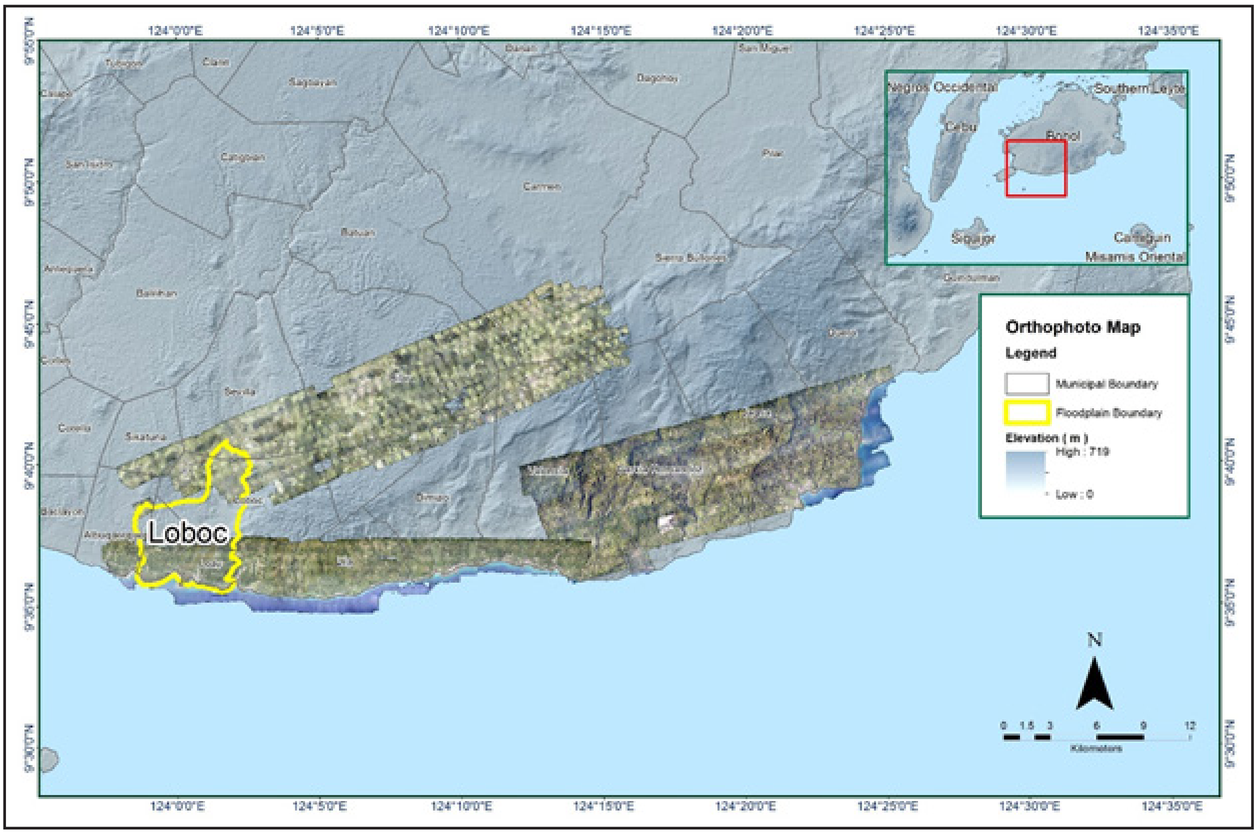

Figure 18. Loboc floodplain with available orthophotographs.

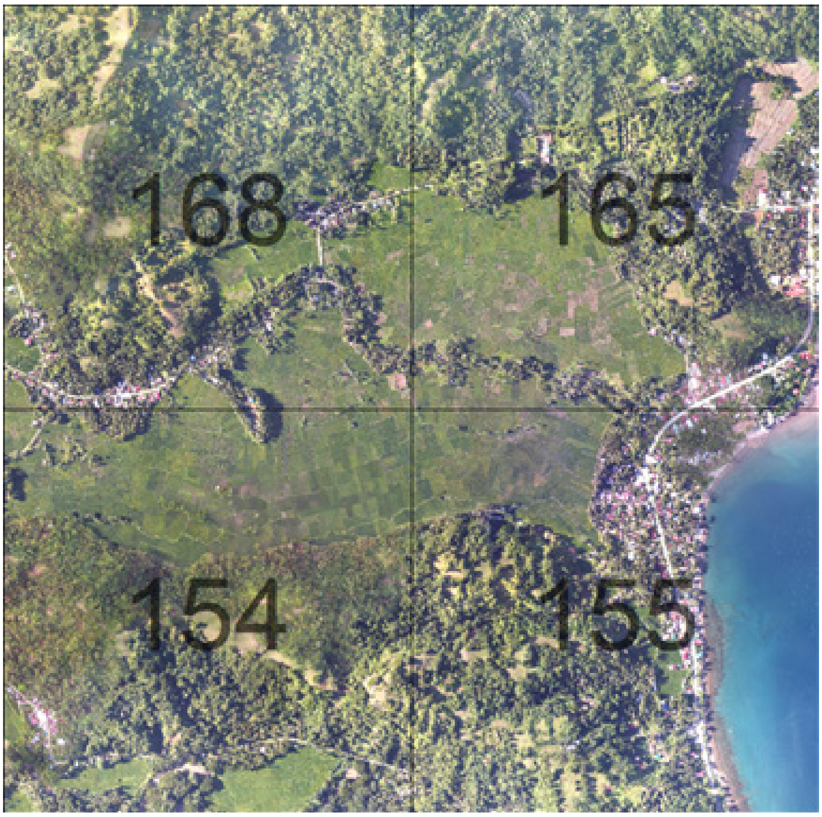

Figure 19. Sample orthophotograph tiles for Loboc floodplain.

3.8 DEM Editing and Hydro-Correction

Four (4) mission blocks were processed for Loboc flood plain. These blocks are composed of SamarLeyte and Leyte blocks with a total area of 611.11 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)
Bohol_Blk51I	187.74
Bohol_Blk51K	186.068
Bohol_Blk51L	101.15
Bohol_Blk51KL_supplement	136.15
TOTAL	**611.11 sq.km**

Portions of DTM before and after manual editing are shown in Figure 20. The bridge (Figure 20a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 20b) in order to hydrologically correct the river. The data gaps over waterbodies (Figure 20c) have been filled to complete the surface (Figure 20d).

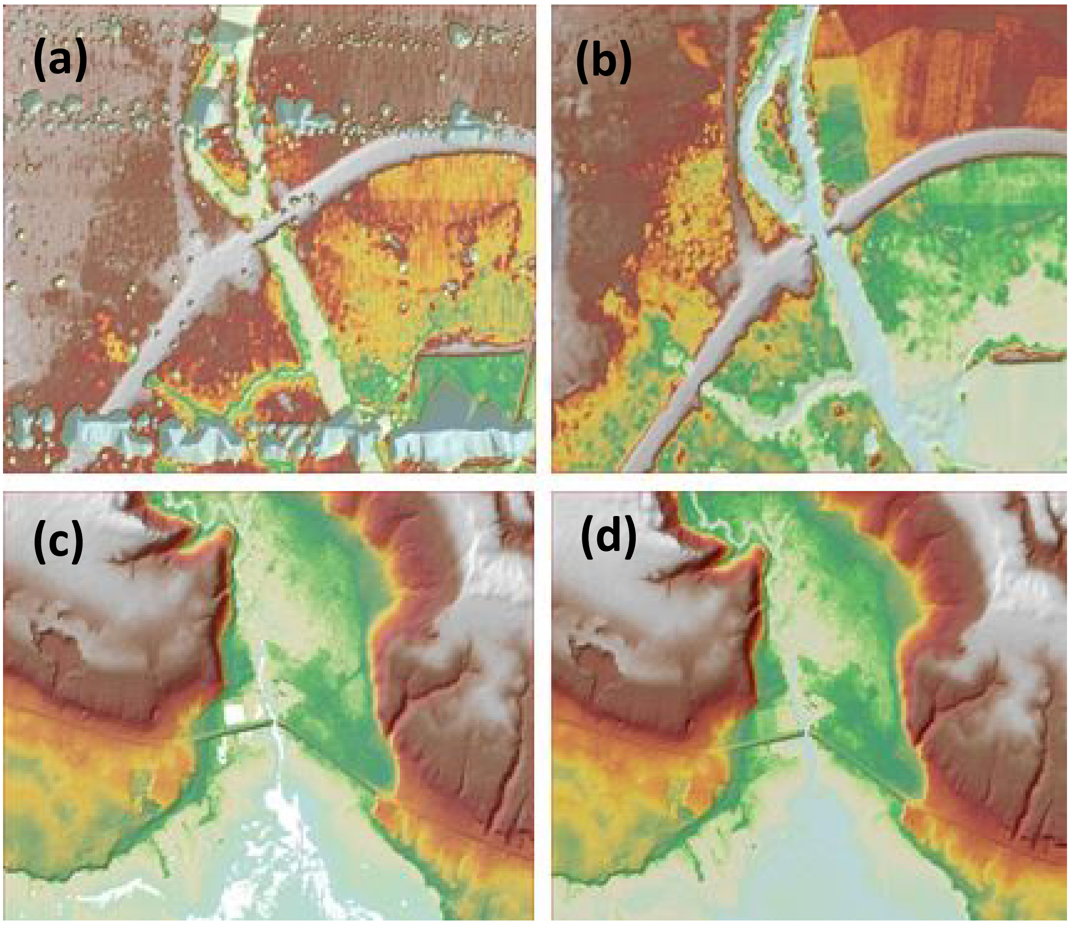

Figure 20. Portions in the DTM of Loboc floodplain – a bridge before (a) and after (b) manual editing; a water surface before (c) and after (d) filling data gaps.

3.9 Mosaicking of Blocks

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

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

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

Mission Blocks	Shift Values (meters)		
	x	y	z
Bohol_Blk51I	0.00	0.00	-1.54
Bohol_Blk51K	0.00	0.00	-1.37
Bohol_Blk51L	0.00	0.00	-1.03
Bohol_Blk51KL_supplement	0.00	0.00	-4.94

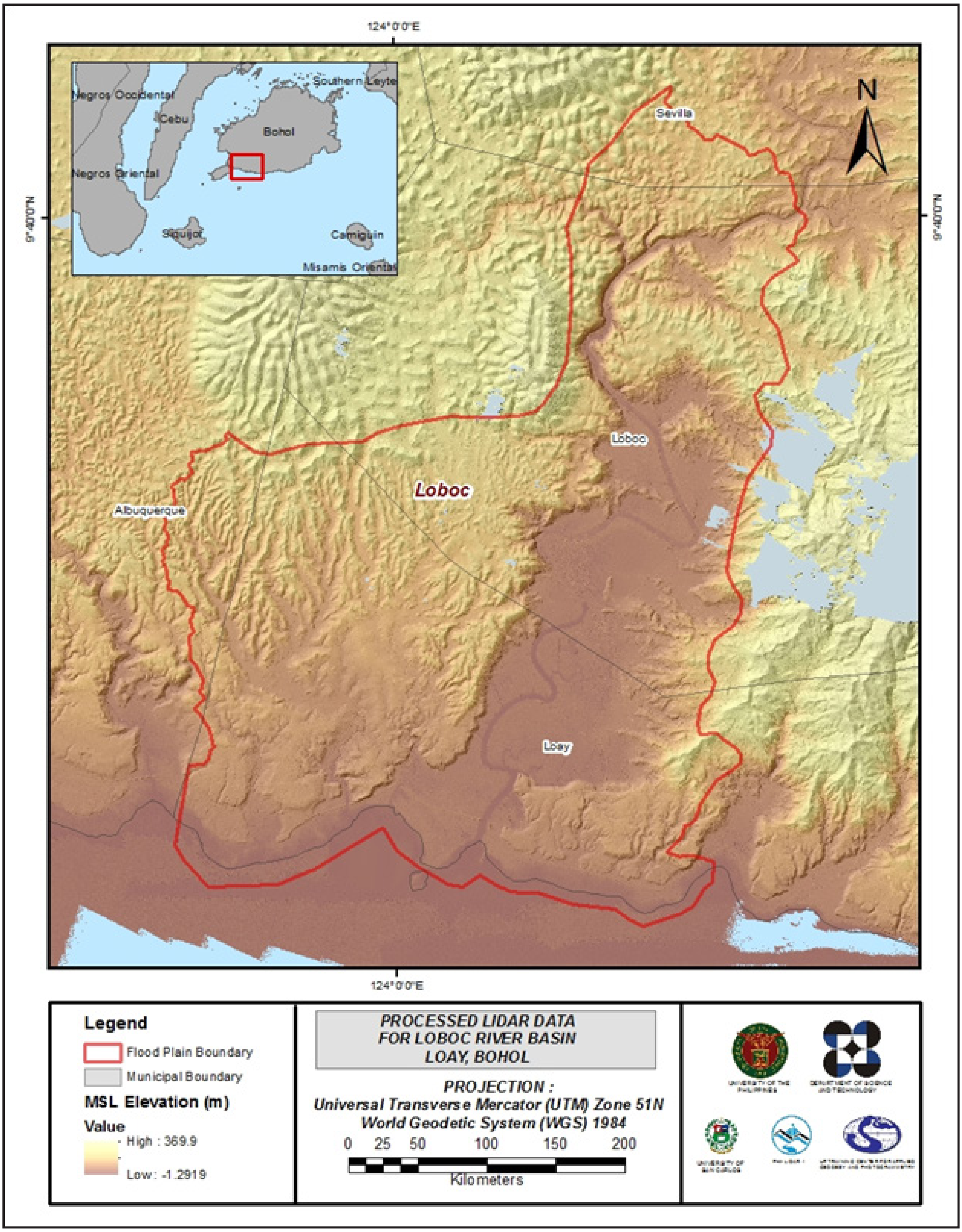

Figure 21. Map of Processed LiDAR Data for Loboc Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR DEM

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Loboc to collect points with which the LiDAR dataset is validated is shown in Figure 22. A total of 2418 survey points were gathered for calibration and validation of Loboc LiDAR data. However, the point dataset was not used for the calibration of the LiDAR data for Loboc because during the mosaicking process, each LiDAR block was referred to the calibrated Bohol DEM. Therefore, the mosaicked DEM of Loboc can already be considered as a calibrated DEM.

A good correlation between the uncalibrated Bohol LiDAR DTM and ground survey elevation values is shown in Figure 23. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration points is 1.29 meters with a standard deviation of 0.19 meters. Calibration of Bohol LiDAR data was done by subtracting the height difference value, 1.29 meters, to Bohol mosaicked LiDAR data. Table 13 shows the statistical values of the compared elevation values between Bohol LiDAR data and calibration data. These values were also applicable to the Loboc DEM.

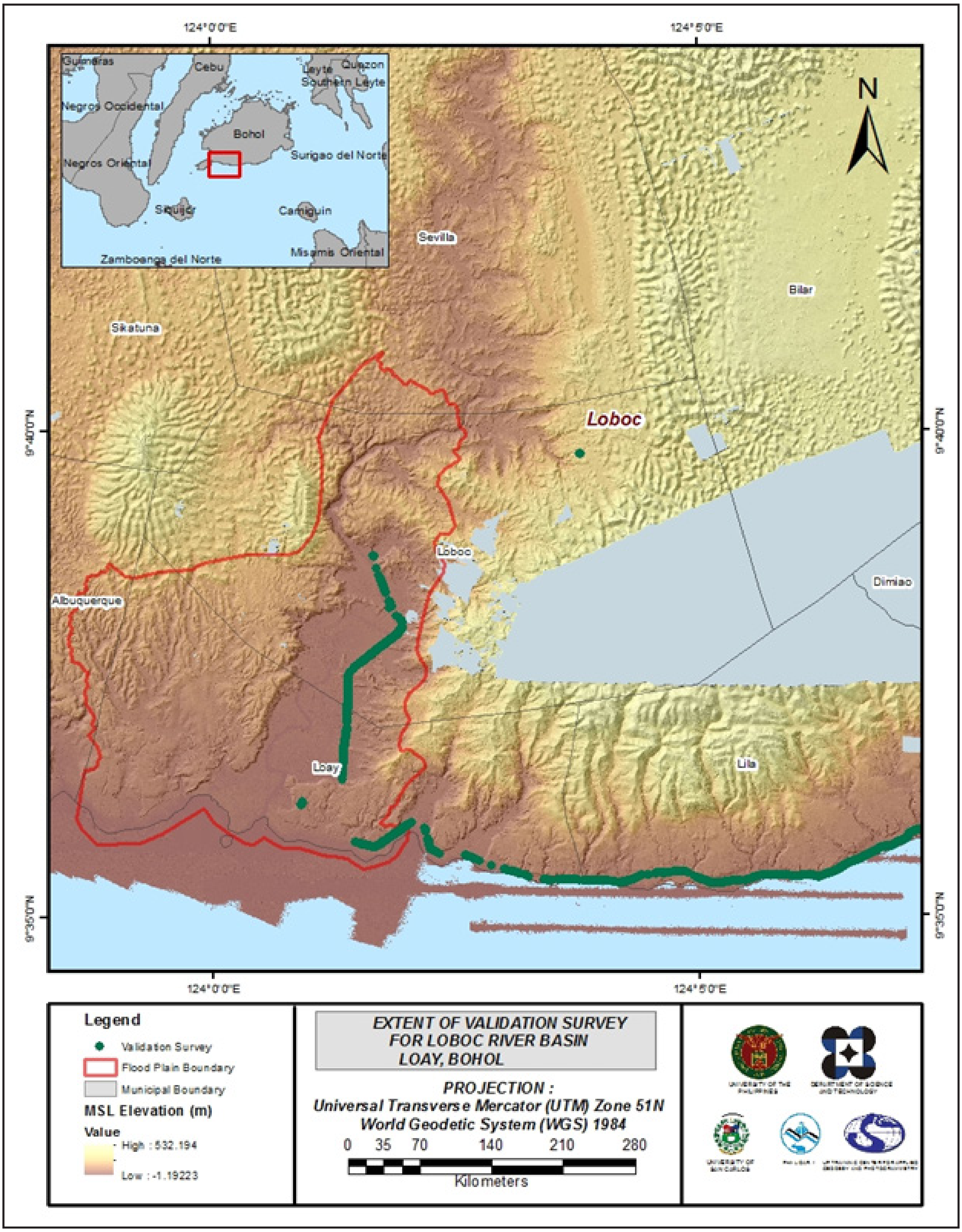

Figure 22. Map of Loboc Flood Plain with validation survey points in green.

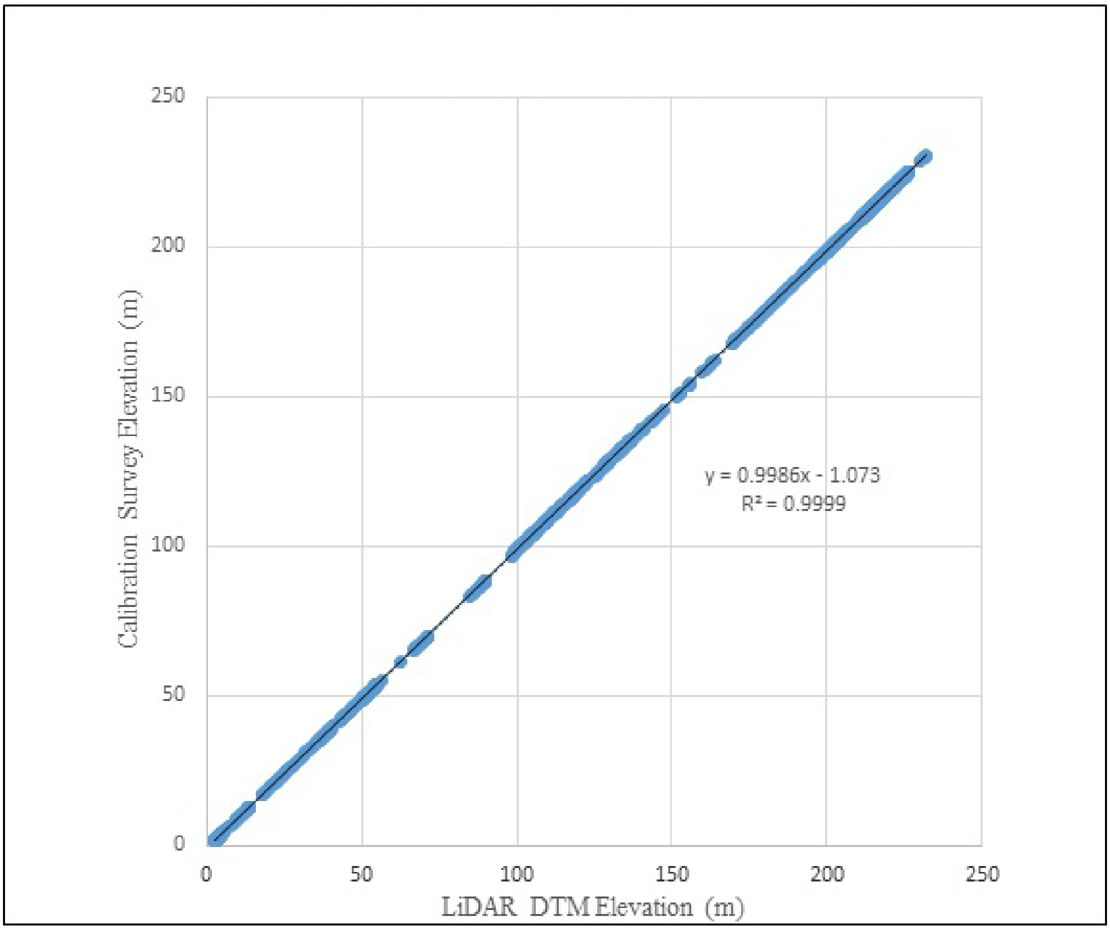

Figure 23. Correlation plot between calibration survey points and LiDAR data.

Table 13. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	1.29
Standard Deviation	0.19
Average	-1.28
Minimum	-1.65
Maximum	-0.86

All survey points were used for the validation of calibrated Loboc DTM. The good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 24. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.15 meters, as shown in Table 14.

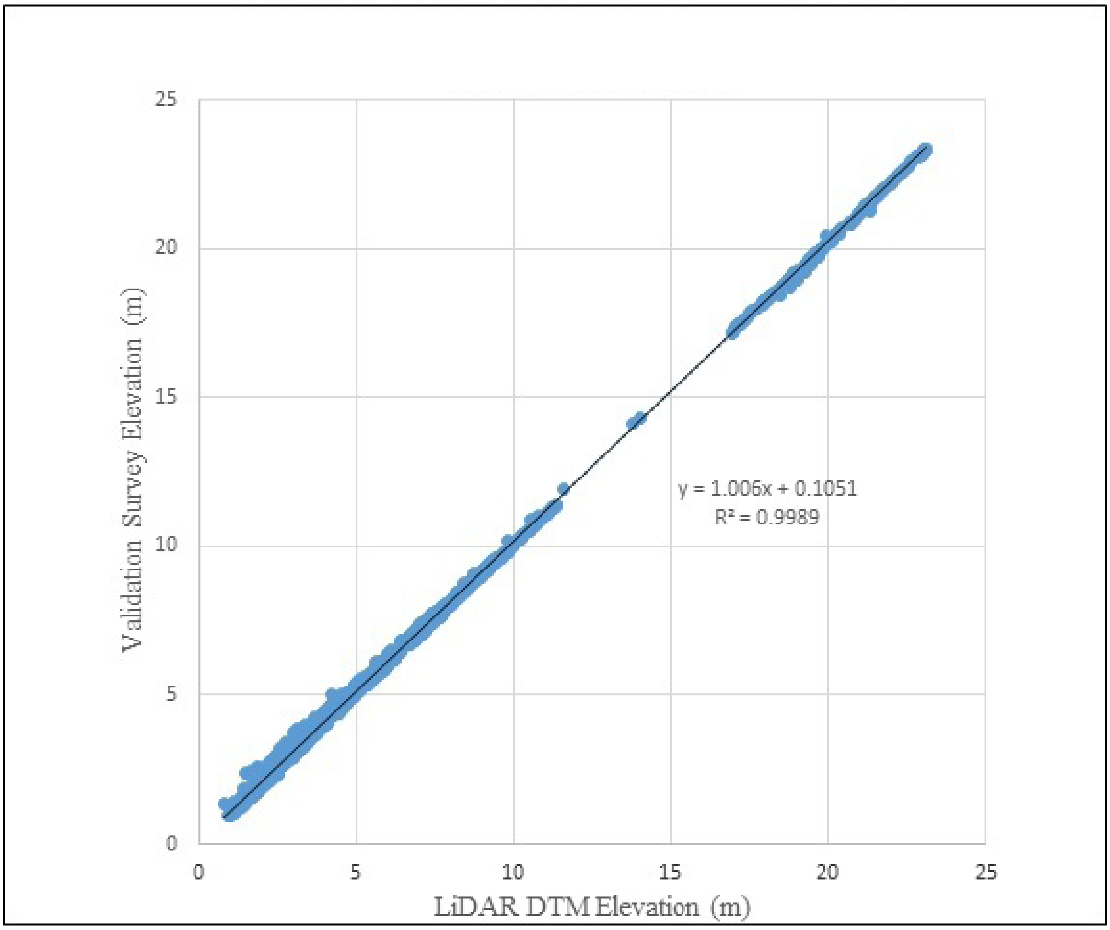

Figure 24. Correlation plot between validation survey points and LiDAR data.

Table 14. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.15
Average	0.13
Minimum	-0.16
Maximum	0.88

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, both centerline and zigzag data points were acquired for Loboc with 2,229 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.01 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Loboc integrated with the processed LiDAR DEM is shown in Figure 25.

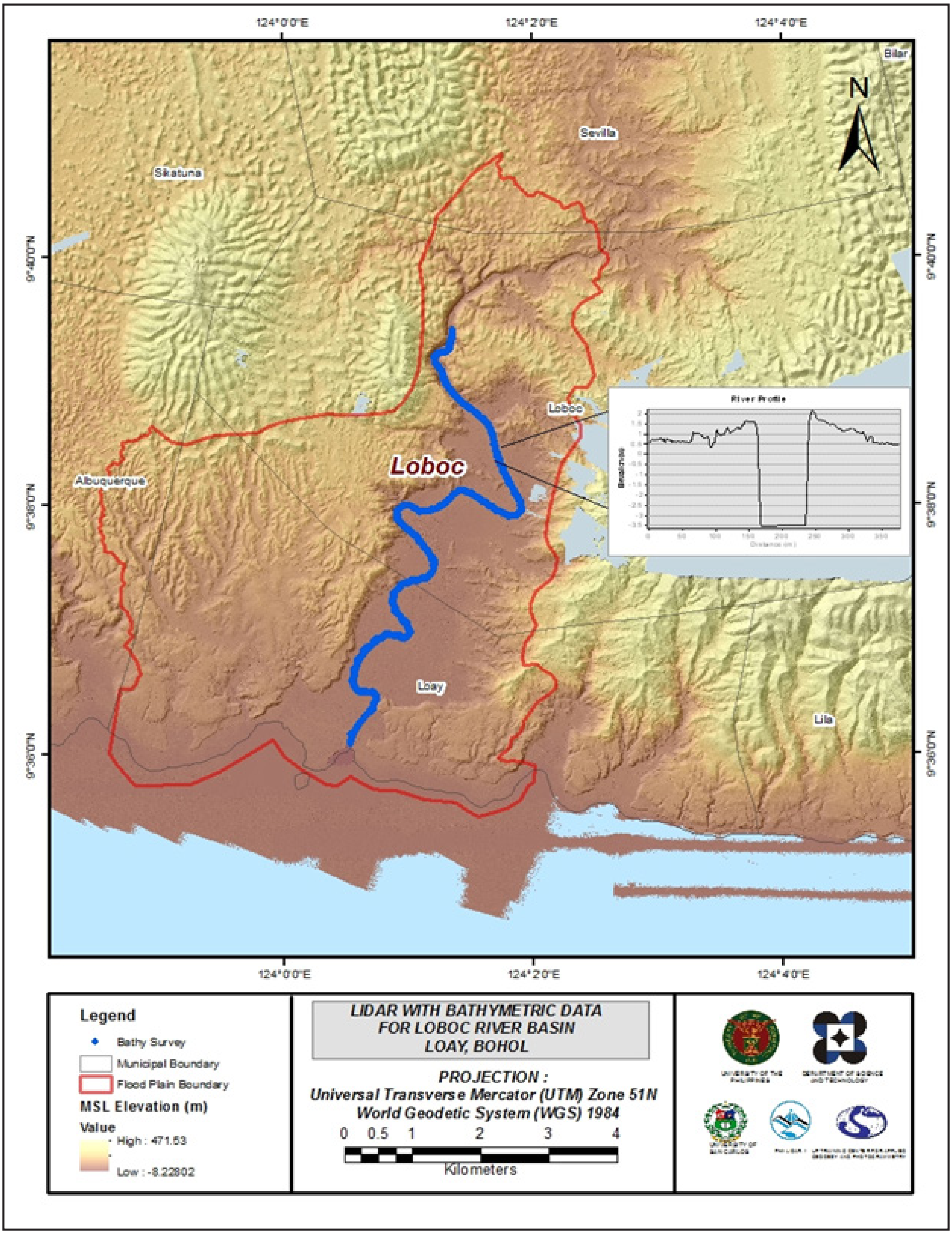

Figure 25. Map of Loboc Flood Plain with bathymetric survey points shown in blue.

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Loboc floodplain, including its 200 m buffer, has a total area of 48.36 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 691 building features, are considered for QC. Figure 26 shows the QC blocks for Loboc floodplain.

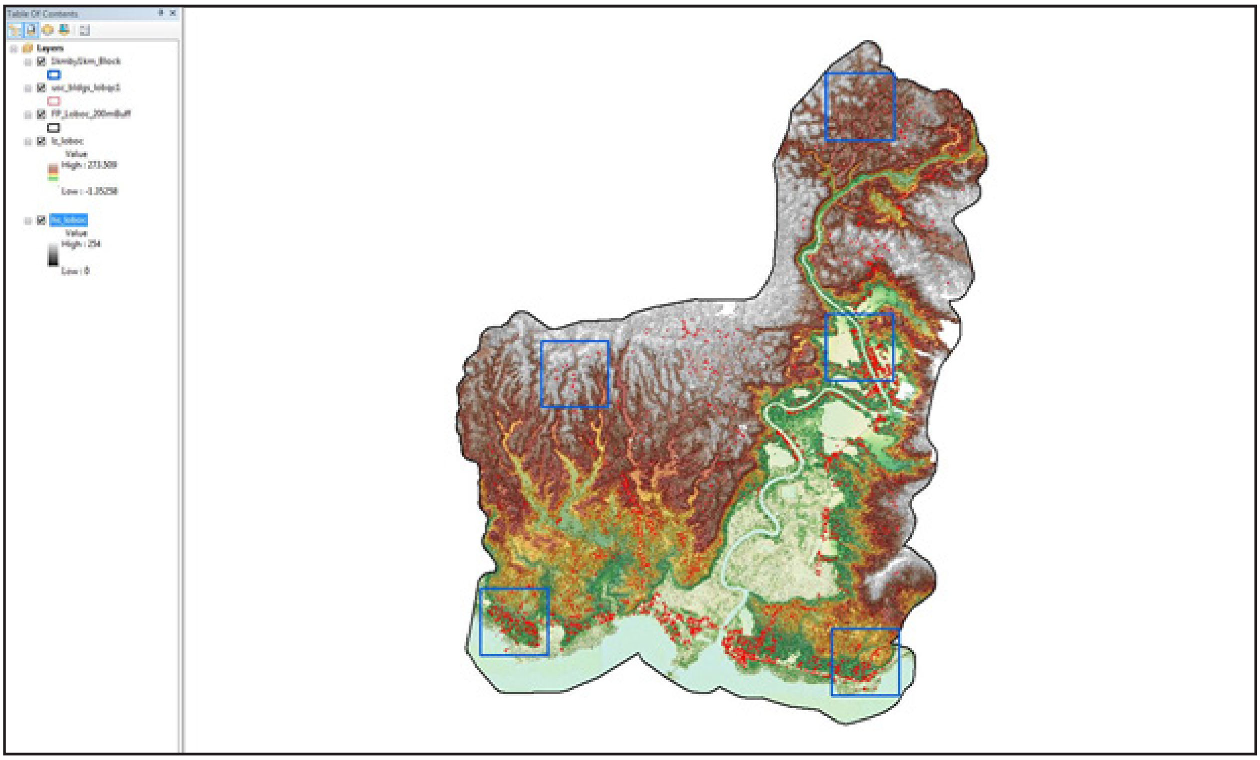

Figure 26. Blocks (in blue) of the Loboc building features which were subjected to QC

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

Table 15. Quality Checking Ratings for Loboc Building Features.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Loboc	100.00	100.00	99.87	PASSED

3.12.2 Height Extraction

Height extraction was done for 3,984 building features in Loboc floodplain. Of these building features, 40 were filtered out after height extraction, resulting to 3,944 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 13.34 m.

3.12.3 Feature Attribution

In attribution, combination of participatory mapping and actual field validation was done. Representatives from LGU were invited to assist in the determination of the features. The remaining unidentified features were then validated on the field.

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 Loboc Floodplain.

Facility Type	No. of Features
Residential	3,669
School	83
Market	12
Agricultural/Agro-Industrial Facilities	1
Medical Institutions	1
Barangay Hall	13
Military Institution	2
Sports Center/Gymnasium/Covered Court	11
Telecommunication Facilities	0
Transport Terminal	0
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	0
Water Supply/Sewerage	9
Religious Institutions	32
Bank	0
Factory	0
Gas Station	3
Fire Station	0
Other Government Offices	38
Other Commercial Establishments	70
Total	3,994

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

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/Municipal Road	Provincial Road	National Road	Others	
Loboc	89.5	5.35	14.85	7.15	0.00	116.85

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

Floodplain	Water Body Type					Total
	Rivers/Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Loboc	3	3	0	0	15	21

A total of 6 bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

3.12.4 Final Quality Checking of Extracted Features

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

Figure 27 shows the Digital Surface Model (DSM) of Loboc floodplain overlaid with its ground features.

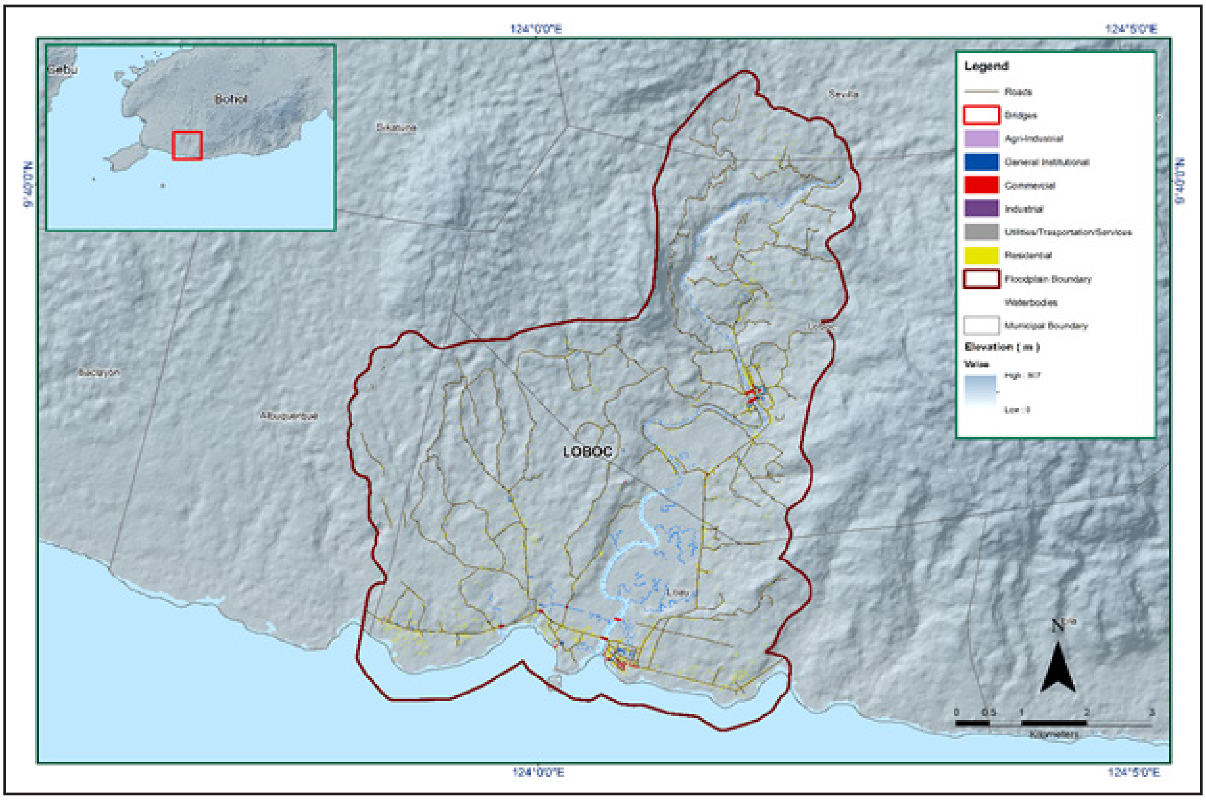

Figure 27. Extracted features for Loboc floodplain.

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

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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

A validation survey in Loboc River was conducted from June 4 to 14, 2015. The fieldwork objectives were: courtesy call to the LGU of Loboc; static survey for the establishment of control point at the approach of the bridge to be occupied as a base station for GNSS surveys; cross-section, bridge as-built and water level markings on Jumbo Bridge in Brgy. Poblacion Ondol, Municipality of Loboc; LiDAR ground validation with an estimated length of 19.69 km; and manual bathymetric survey of the river covering the municipalities of Loay and Loboc with a distance of approximately 11.67 km.

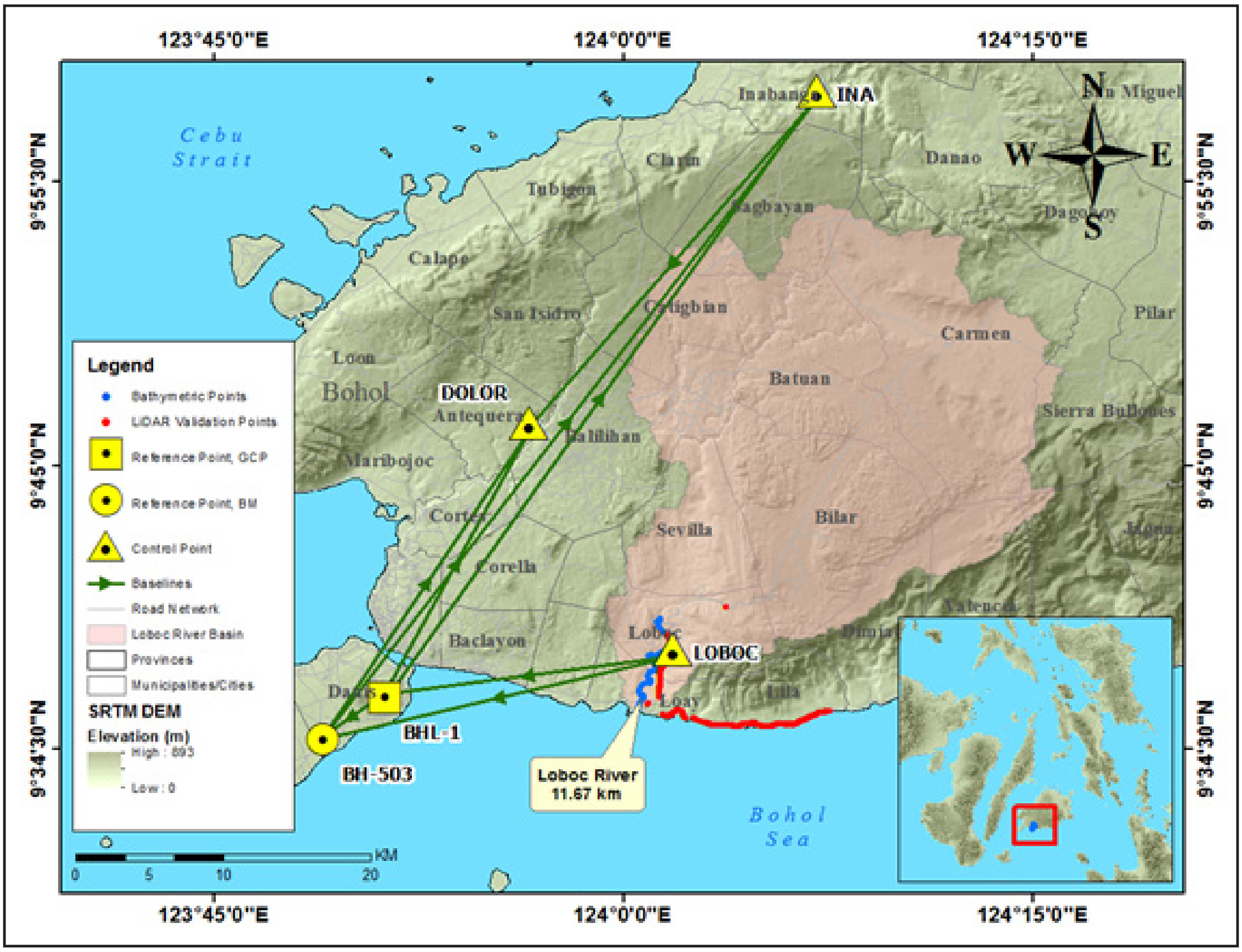


Figure 28. Extent of the bathymetric survey (blue line) in Loboc River and the LiDAR data validation survey (red)

4.2 Control Survey

The GNSS network used for Loboc River Basin is composed of three (3) loops established on June 8, 2015 occupying the following reference points: BHL-1, a first order GCP in Brgy. Catarman, Municipality of Dauis; and, BH-503, a first order BM in Brgy. Dao, Municipality of Dauis; all in the province of Bohol.

UP control points, namely: DOLOR, located in Brgy. Dolor, Municipality of Balilihan; INA, located in Brgy. Canlinte, Municipality of Inabanga; and, LOBOC, located in Brgy. Poblacion Sawang, Municipality of Loboc; all in the province of Bohol, were occupied to use as marker during the survey.

The summary of reference and control points and its location is summarized in Table 19 while the GNSS network established is illustrated in Figure 29.

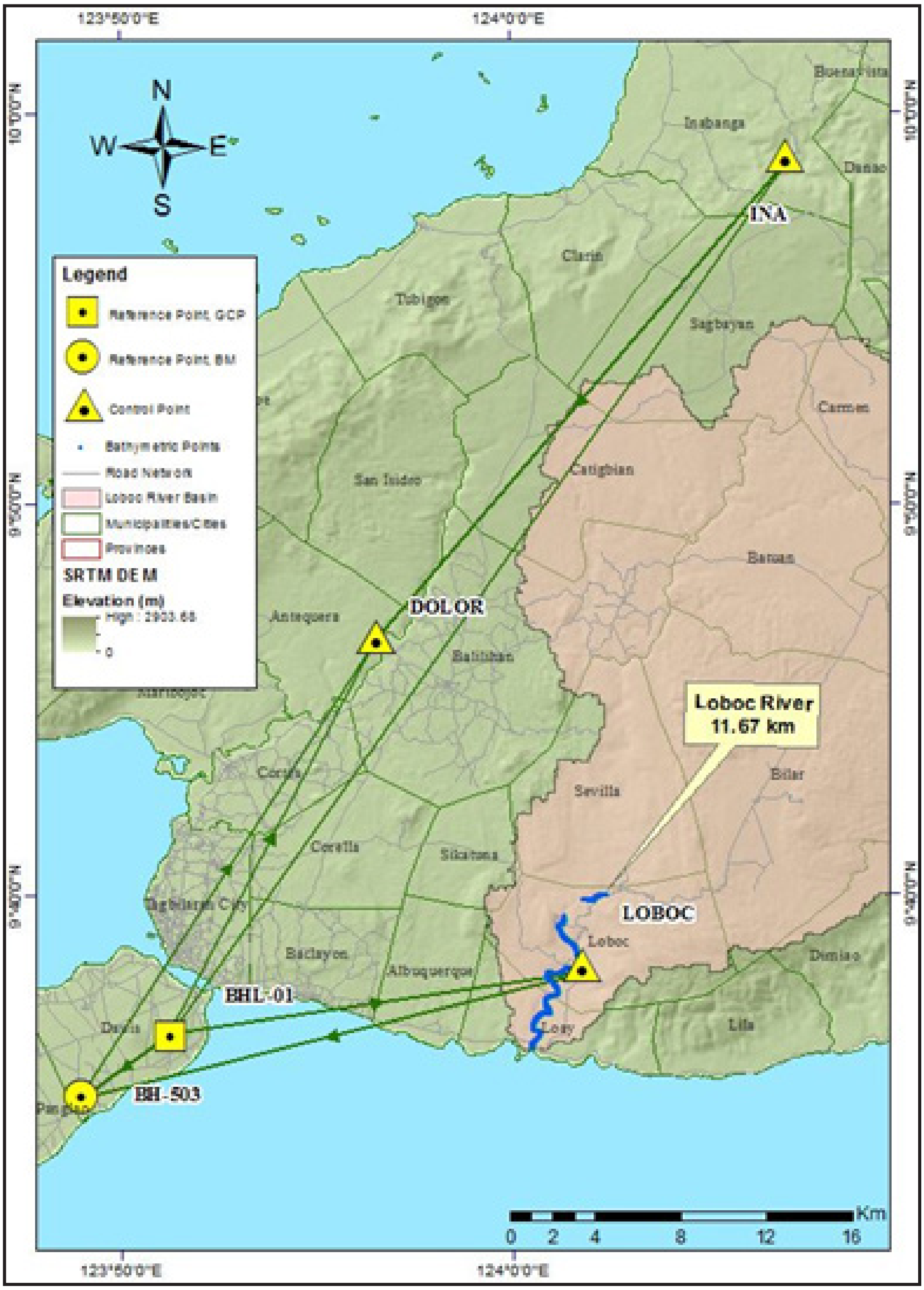


Figure 29. GNSS network covering the Loboc River.

Table 19. List of Reference and Control points occupied during Loboc River control survey (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (Meter)	Elevation in MSL (Meter)	Date Established
BHL-01	1st order, GCP	9°36'22.43560"N	123°51'15.91256”E	247.563	-	2007
BH-503	1st order, BM	-	-	85.726	22.328	2008
DOLOR	UP established	-	-	74.335	-	2015
INA	UP established	-	-	81.908	-	2015
LOBOC	UP established	-	-	73.769	-	2015

The GNSS set up on the recovered reference points and established control points are shown in Figure 30 to Figure 34.

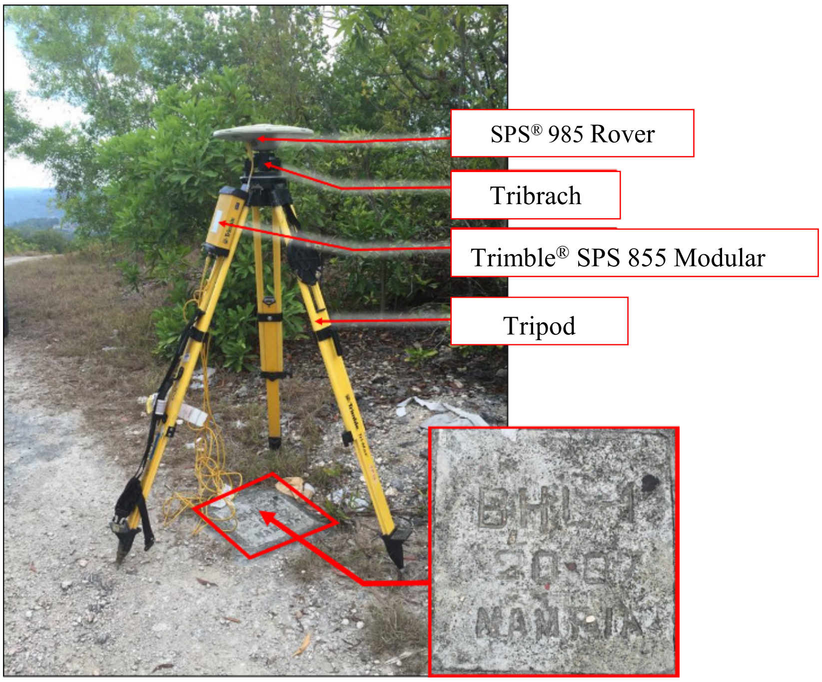


Figure 30. Trimble® SPS 985 GNSS receiver setup at BHL-01 near a telecommunication antennae in Brgy. Catarman, Municipality of Dauis, Bohol

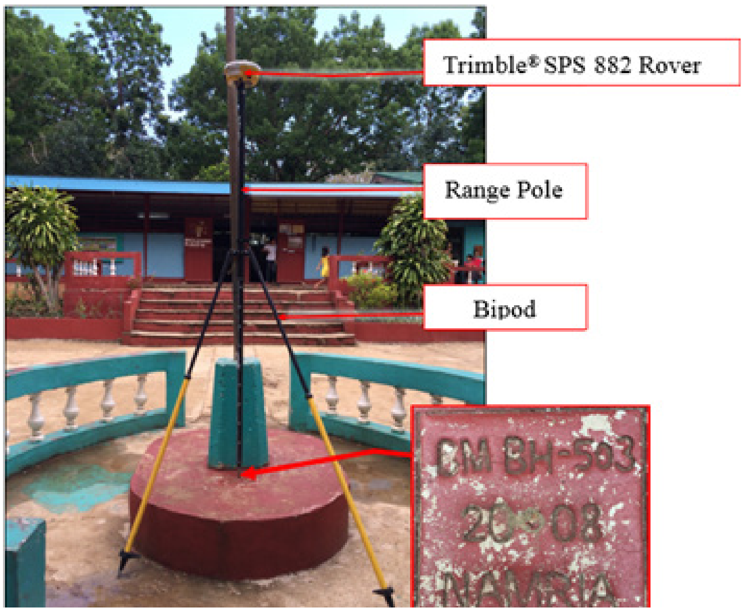


Figure 31. Trimble® SPS 882 GNSS receiver setup at BH-503 located inside the campus of Dao Elementary School, Brgy. Dao, Municipality of Dauis, Bohol

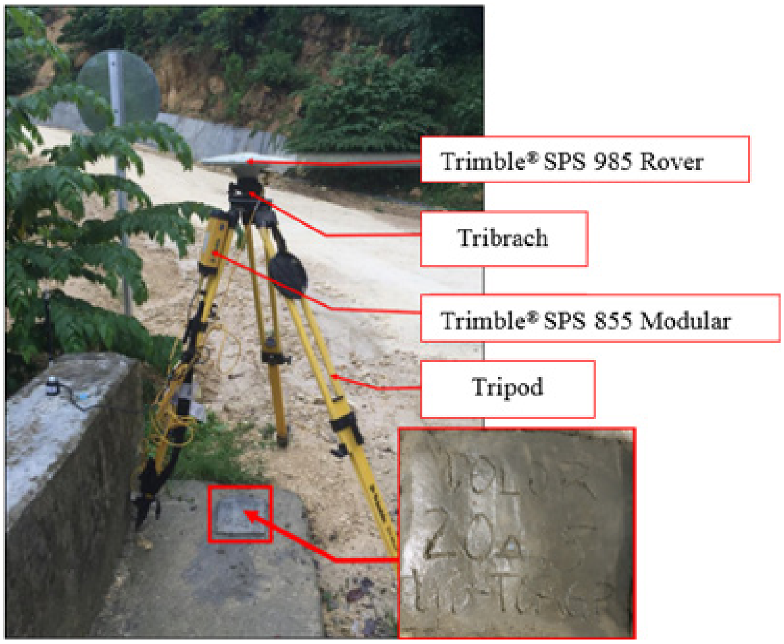


Figure 32. Trimble® SPS 985 GNSS receiver setup at control point DOLOR, located at the left most (facing downstream) Baguhan Bridge approach, across Inabanga River located in Brgy. Dorol, Municipality of Angilan, Bohol

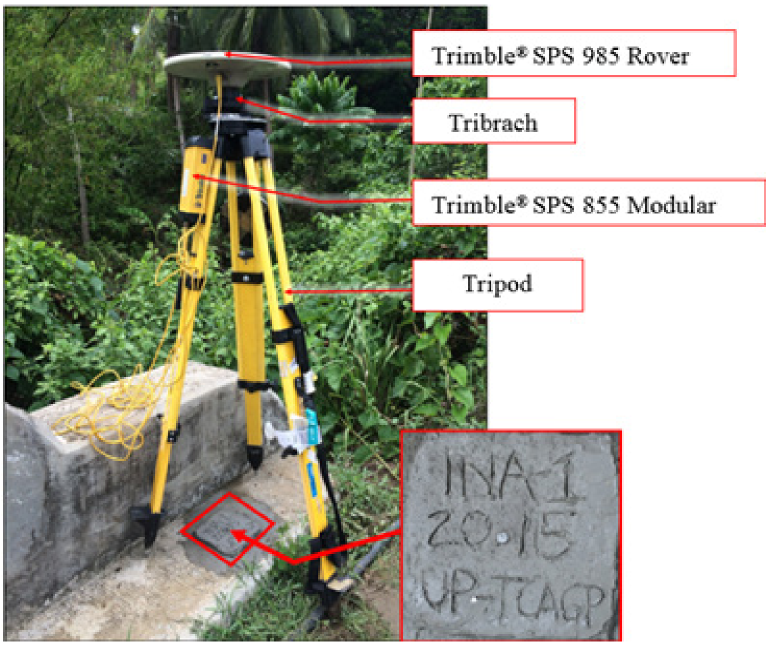


Figure 33. Trimble® SPS 985 GNSS receiver setup at INA-1 at the Inabanga Bridge approach, Brgy. Baguhan, Inabanga, Bohol

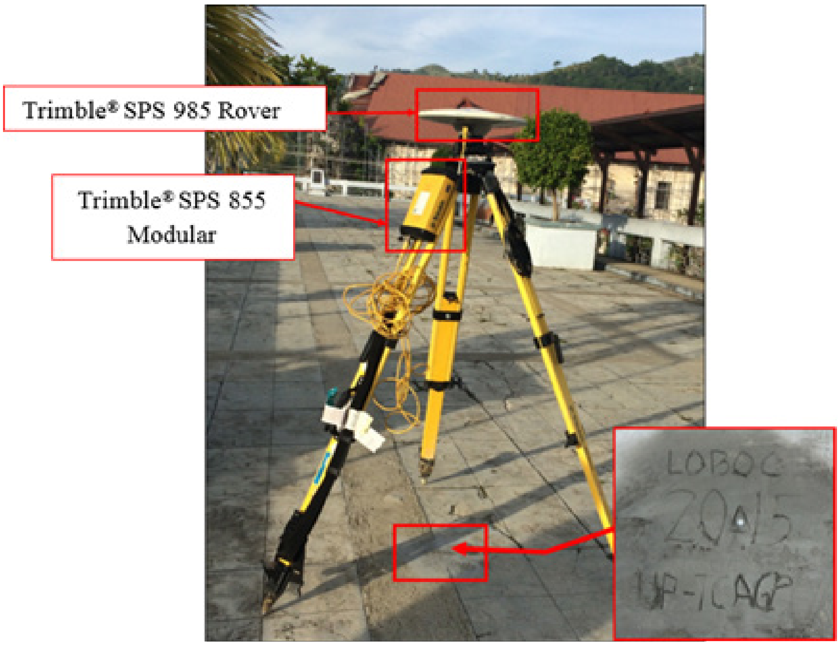


Figure 34. GPS setup of Trimble® SPS 852 on LOBOC, located on the incomplete bridge across the Loboc River near the municipality town plaza of Loboc in Brgy. Poblacion

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 used in Loboc River Basin survey is summarized in Table 20 generated by TBC software.

Table 25. Baseline Processing Summary Report for IkminRiver Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
BHL1 --- BH503	06-08-15	Fixed	0.005	0.022	235°34'43"	5045.794	-161.828
BHL1 --- DOLOR	06-08-15	Fixed	0.006	0.039	27°08'58"	21145.711	-173.237
BH503 --- DOLOR	06-08-15	Fixed	0.010	0.064	32°30'26"	25695.545	-11.413
INA --- DOLOR	06-08-15	Fixed	0.010	0.060	220°21'08"	29699.597	-7.535
BHL1 --- INA	06-08-15	Fixed	0.009	0.027	34°50'24"	50519.954	-165.707
BH503 --- INA	06-08-15	Fixed	0.013	0.043	36°41'11"	55267.714	-3.844
BHL1 --- BH503	06-08-15	Fixed	0.004	0.038	235°34'43"	5045.804	-161.825
BHL1 --- LOBOC	06-08-15	Fixed	0.004	0.027	80°13'56"	19591.794	-173.810
LOBOC --- BH503	06-08-15	Fixed	0.006	0.076	255°17'11"	24269.112	11.864

Five control points, BHL-01, BH-503 and DOLOR, INA, and LOBOC were occupied simultaneously to form a GNSS loop. All 3 baselines that formed the GNSS loop acquired fixed solutions and passed the required ±20cm and ±10cm for horizontal and vertical precisions, respectively as shown in Table 20.

4.4 Network Adjustment

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

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

where:

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

for each control point. See the Network Adjustment Report shown in Table C-3 to Table C-6 for complete details.

The five (5) control points, BHL-1, BH-503, DOLOR, INA, and, LOBOC were occupied and observed simultaneously to form a GNSS loop. Coordinates of BHL-1; and elevation value of BH-503 was 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 Constraint

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
BH503	Grid				Fixed
BHL1	Global	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. The fixed controls BHL-1 has no value for grid errors while BH-503 has no value for elevation error.

Table 22.Adjusted grid coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
BH503	589600.481	0.005	1059131.546	0.005	22.328	?	e
BHL1	593754.454	?	1061993.296	?	184.054	0.049	LL
DOLOR	603353.551	0.011	1080828.082	0.007	10.331	0.089	
INA	622503.084	0.018	1103520.295	0.011	17.794	0.093	
LOBOC	613048.755	0.007	1065364.372	0.007	9.787	0.083	

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

a. BHL-1

Horizontal Accuracy	=	Fixed
Vertical Accuracy	=	1.9 cm < 10 cm

b. BH-503

Horizontal Accuracy	=	$\sqrt{((0.5)^2 + (0.5)^2}$
	=	$\sqrt{(0.25 + 0.25)}$
	=	0.707< 20 cm
Vertical Accuracy	=	Fixed

c. DOLOR

Horizontal Accuracy	=	$\sqrt{((1.1)^2 + (0.7)^2}$
	=	$\sqrt{(1.21 + 0.49)}$
	=	1.303 < 20 cm
Vertical Accuracy	=	8.9 cm < 10 cm

d. INA

Horizontal Accuracy	=	$\sqrt{((1.8)^2 + (1.1)^2}$
	=	$\sqrt{(3.24 + 1.21)}$
	=	1.1 < 20 cm
Vertical Accuracy	=	1.993 cm < 10 cm

e. LOBOC

Horizontal Accuracy	=	$\sqrt{((0.7)^2 + (0.7)^2}$
	=	$\sqrt{(0.49 + 0.49)}$
	=	0.99< 20 cm
Vertical Accuracy	=	8.3 cm < 10 cm

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

Table 23.Adjusted geodetic coordinates

Point ID	Latitude	Longitude	Ellipsoid	Height	Constraint
BH503	N9°34'49.59212"	E123°48'59.41509"	85.726	?	e
BHL1	N9°36'22.43560"	E123°51'15.91256"	247.563	0.049	LL
DOLOR	N9°46'34.81522"	E123°56'32.52432"	74.335	0.089	
INA	N9°58'51.64572"	E124°07'03.51400"	81.908	0.093	
LOBOC	N9°38'10.45985"	E124°01'49.19123"	73.769	0.083	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 23. Based on the result of the computation, the 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-TACAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
BHL-01	1st order, GCP	9°36'22.43560"N	123°51'15.91256”E	247.563	1061993.296	593754.454	184.054
BH-503	1st order, BM	9°34'49.59212"N	123°48'59.41509"E	85.726	1059131.546	589600.481	22.328
DOLOR	UP established	9°46'34.81522"N	123°56'32.52432"E	74.335	1080828.082	603353.551	10.331
INA	UP established	9°58'51.64572"N	124°07'03.51400"E	81.908	1103520.295	622503.084	17.794
LOBOC	UP established	9°38'10.45985"N	124°01'49.19123"E	73.769	1065364.372	613048.755	9.787

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

Cross-section and as-built survey were performed on June 12, 2015 along the upstream side of Jumbo Bridge in Brgy. Poblacion Ondol, Municipality of Loboc using a GNSS receiver, Trimble® SPS 882, in PPK survey technique as shown in Figure 35.

Figure 35. Cross-section and bridge as-built survey for Jumbo Bridge, Brgy. Poblacion Ondol, Loboc Bohol.

The cross-sectional line for the Jumbo Bridge is about 124.415 m with 29 cross-sectional points. Gathered using the control point LOBOC as the GNSS base station. The location map, summary of gathered cross-section indiagram, and as-built data form for Jumbo Bridge are displayed in Figure 36 to Figure 38, respectively.

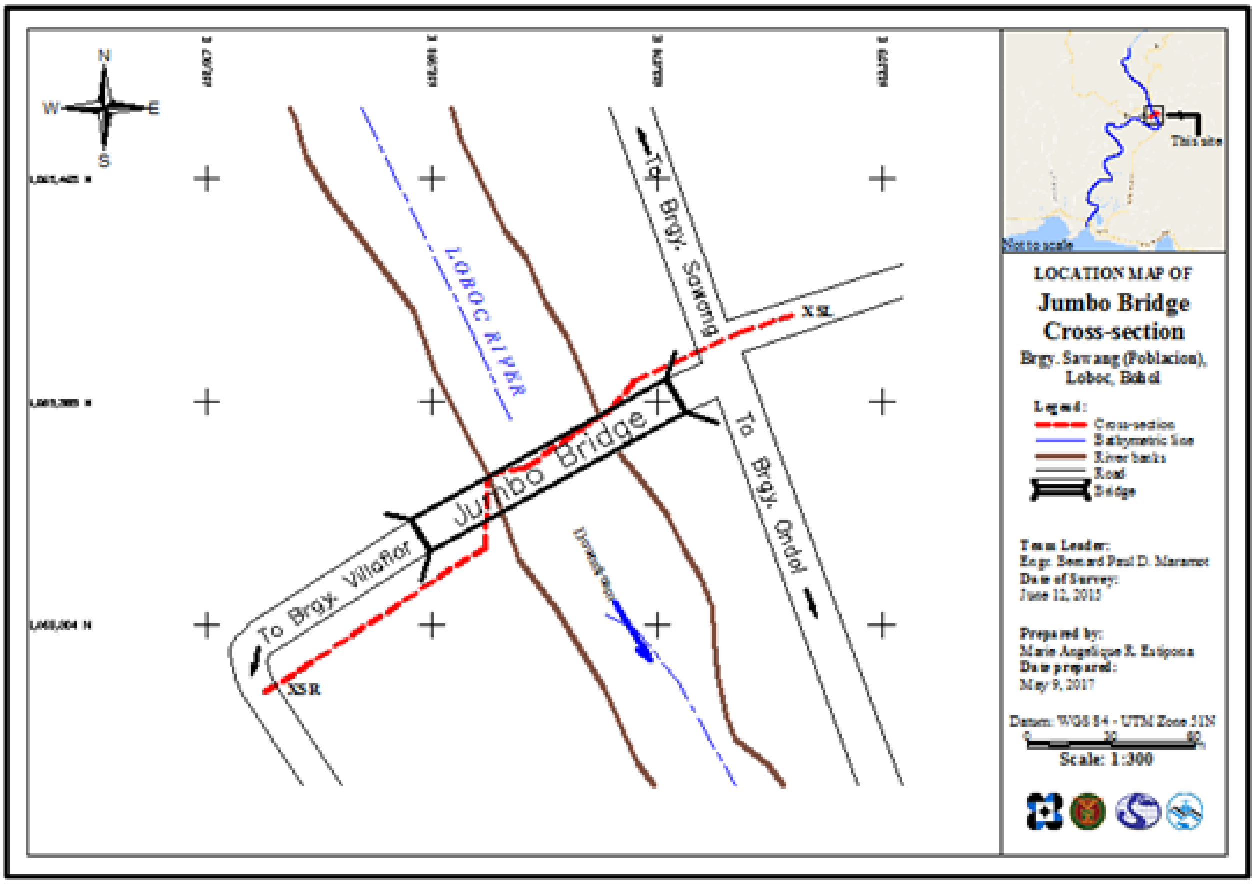


Figure 36. Jumbo Bridge cross-section location map

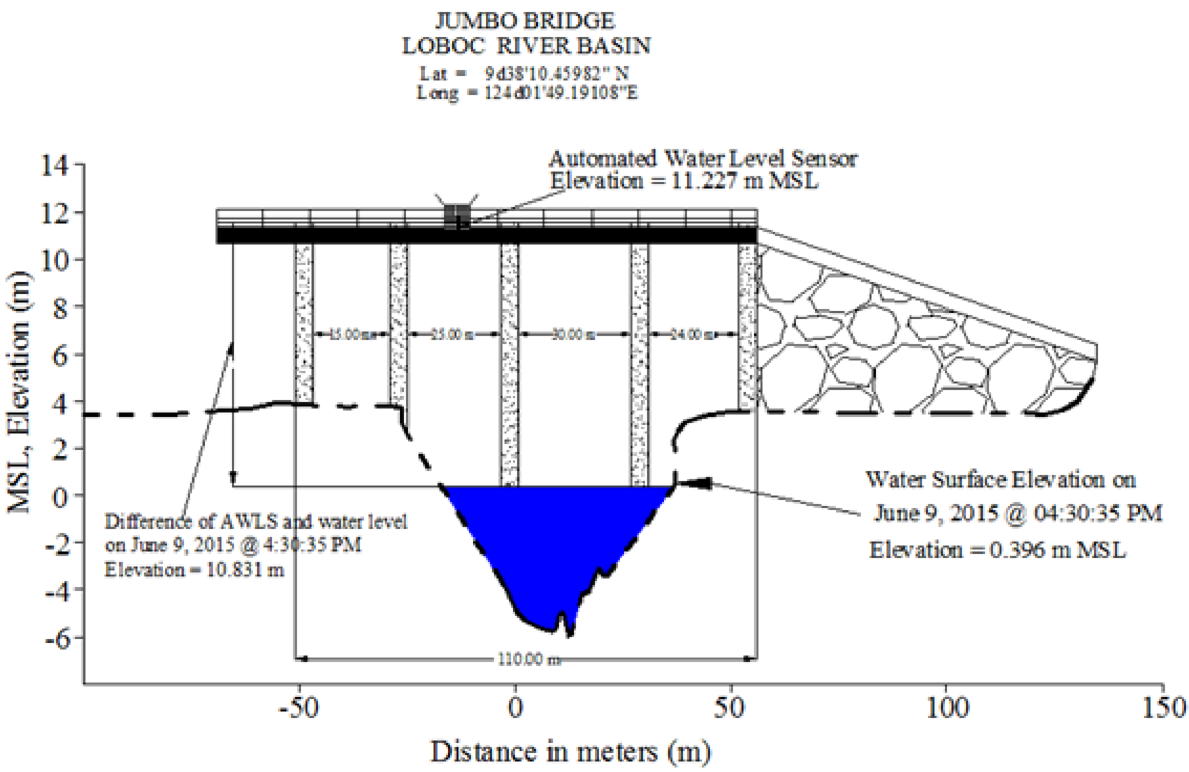


Figure 37. Jumbo Bridge cross-sectional diagram

Bridge Data Form

Bridge Name: Jumbo Bridge **Date:** June 12, 2015

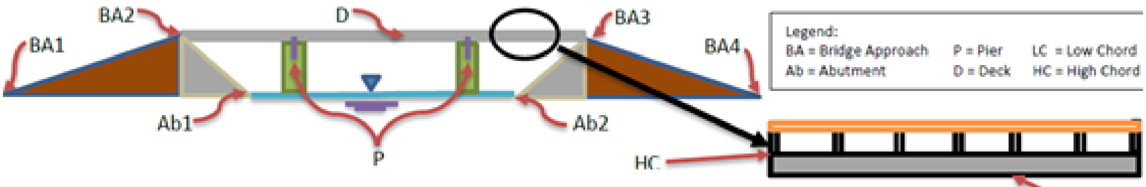
River Name: Loboc River **Time:** 11:40 A.M.

Location (Brgy, City, Region): City Plaza, Municipality of Loboc, Bohol

Survey Team: Bernard's Team

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

Latitude: 9d38'10.45982" N **Longitude:** 124d01'49.19108" E



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

Elevation 9.993 meters **Width:** 7.21 meters **Span (BA3-BA2):**

	Station	High Chord Elevation	Low Chord Elevation
1		12.322	10.413
2			
3			
4			
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	3.387	BA3		
BA2	154.0683	9.951	BA4		

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

	Station (Distance from BA1)	Elevation
Ab1		
Ab2		

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

Shape: Rectangular Cylinders **Number of Piers:** 4 **Height of column footing:**

	Station (Distance from BA1)	Elevation	Pier Width
Pier 1	73.09736	9.848	
Pier 2	98.56153	9.912	
Pier 3	128.9378	9.915	
Pier 4	153.7854	9.968	
Pier 5			
Pier 6			

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

Figure 38. Jumbo Bridge Data Form

Figure 39. Water level markings on the post of Jumbo Bridge

Water surface elevation in MSL of Loboc River was determined using a Trimble® SPS 882 in PPK mode survey on June 9, 2015 at 4:30:35 PM. This was translated onto marking the bridge's pier using a Digital Level. The marked pier, shown in Figure 39, shall serve as a reference for flow data gathering and depth gauge deployment by the accompanying SUC, University of San Carlos, who is responsible for monitoring Loboc River.

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted on June 12, 2015 using a survey-grade GNSS Rover receiver, Trimble® SPS 882, mounted on a range pole which was attached at the side of a vehicle, as shown in Figure 40. It was secured with a cable tie to ensure that it was horizontally and vertically balanced. The antenna height was measured and recorded to be 2.330 m from the ground up to the bottom of the notch of the GNSS Rover receiver.

Figure 40. Trimble® SPS8 82 set-up for validation points acquisition survey for Loboc River

The survey was conducted using PPK technique on a continuous topography mode, which started from Brgy. Gotozon Sawang, Loboc to Malinao East, Lila, and gathered 2,420 validation points covering an approximate distance of 19.69 km. The gaps in the validation line as shown in Figure 41 were due to some difficulties in acquiring satellite signals due to the presence of obstruction such as dense canopy cover of trees along the roads.

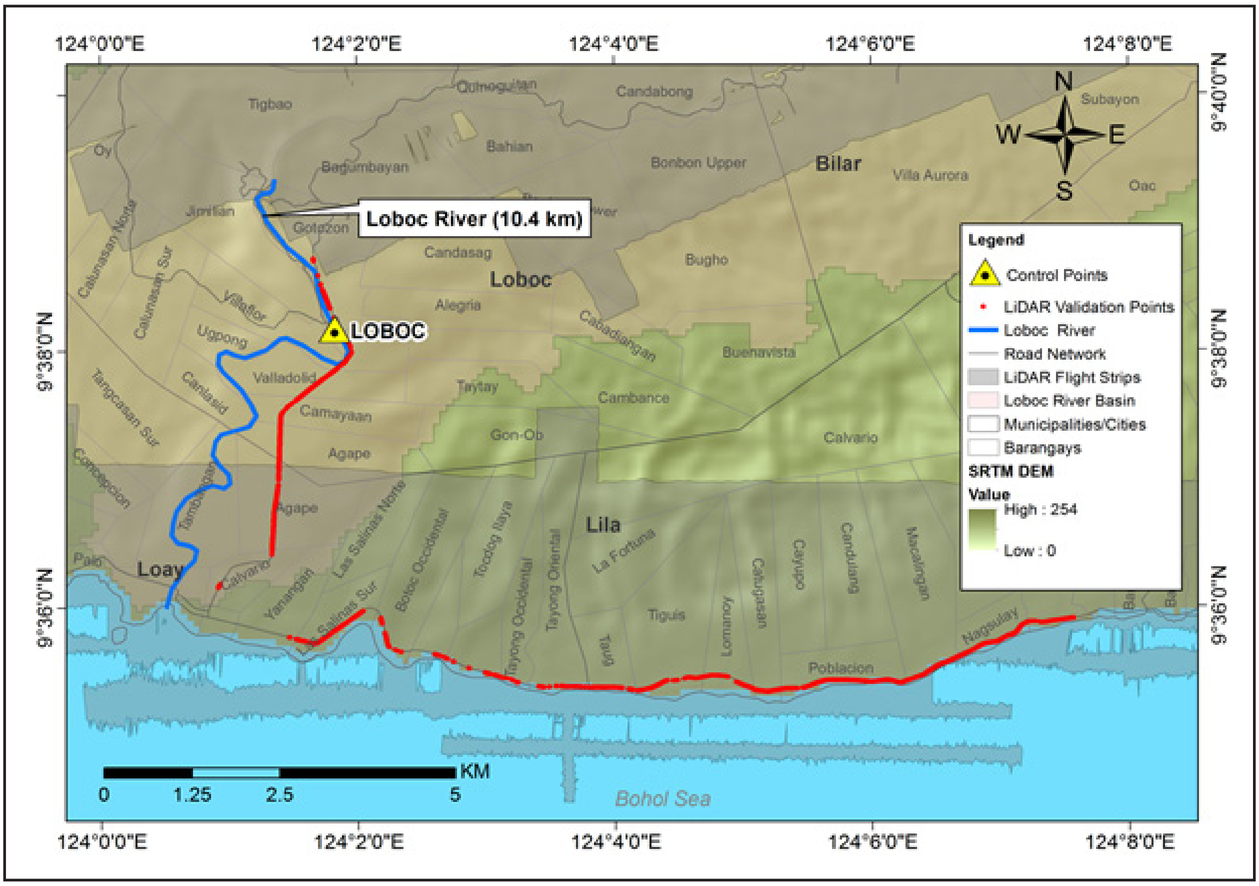


Figure 41. Validation points acquisition survey coverage for Loboc River Basin

4.7 River Bathymetric Survey

The DVBC conducted bathymetric survey on June 9, 2015, while the partner HEI, USC on September 13, 2016; using an OHMEX™ Single beam echo sounder and Trimble® SPS 882 in GNSS PPK survey technique as shown in Figure 42. The survey started from the upstream in Brgy. Tigbao, Municipality of Loboc with coordinates 9d39'58.12218" 124d02'27.07274", down to the mouth of the river in Brgy. Villalimpia, also in Municipality of Loboc with coordinates 9d36'04.66860" 124d00'31.67521". The control point LOBOC was used as the GNSS base station all throughout the bathymetric survey.

Figure 42. Bathymetric survey in Loboc River

Overall bathymetry data coverage for Loboc River is 11.67 km with 8,055 bathymetric points gathered covering 14 combined barangays of Loboc and Loay as shown in Figure 43. A CAD drawing was also produced to illustrate the riverbed profile of Loboc river. As shown in Figure 44, an elevation drop of 10.8 m in MSL was observed within the distance of approximately 11.67 km. The highest elevation observed was 22.48 m in MSL located at the upstream part of the river, while lowest elevation value observed was -9.70 below MSL located at the upstream portion of the river in Brgy. Tigbao with the vicinity of the dam.

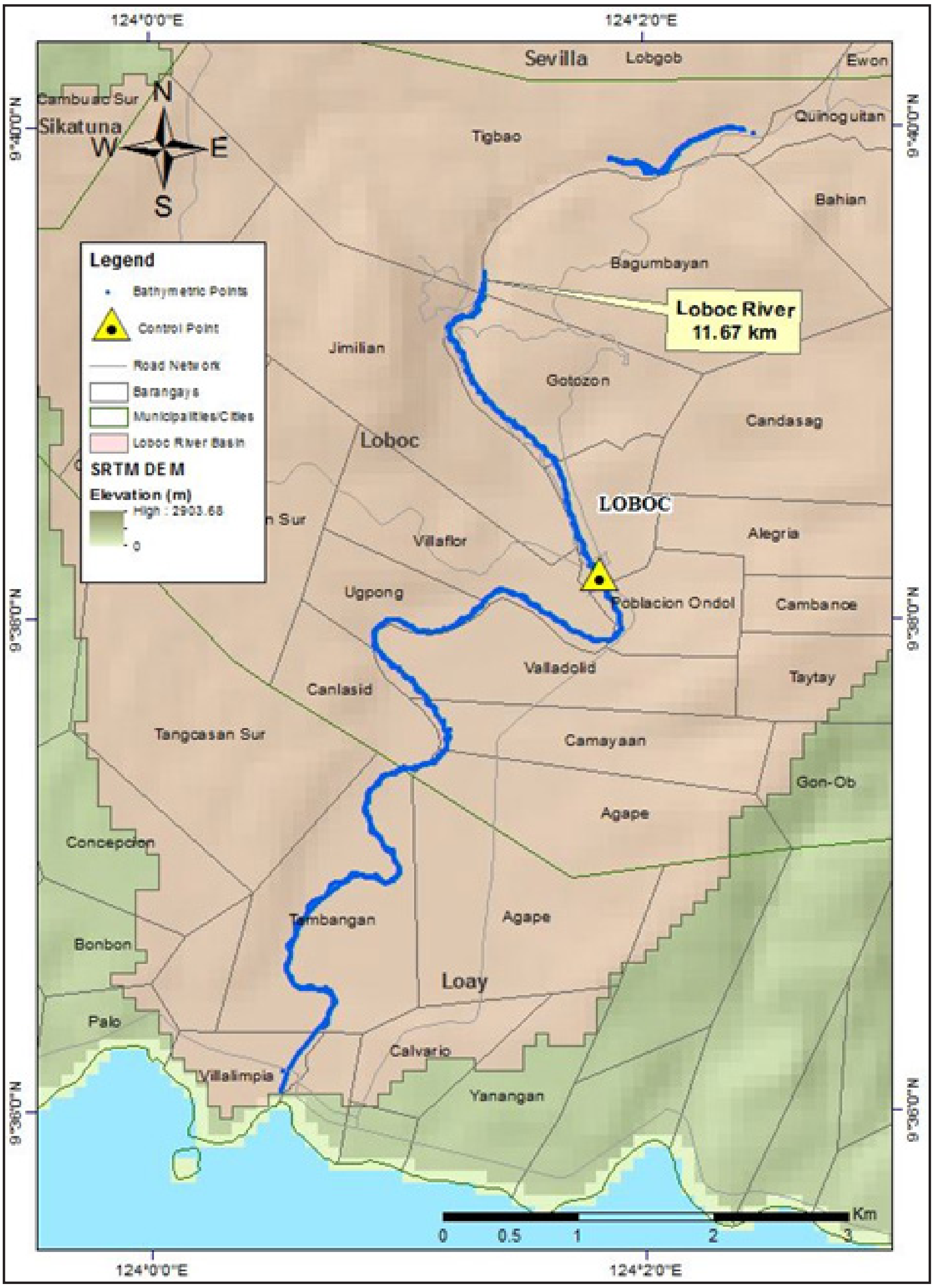


Figure 43. Bathymetric survey of Loboc River

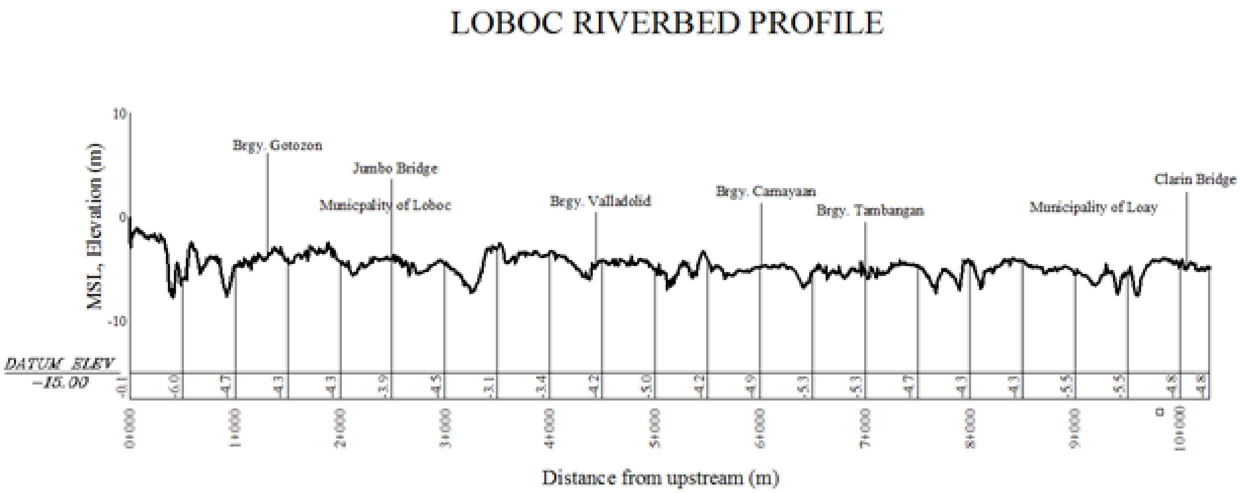


Figure 44. Riverbed profile of Loboc River

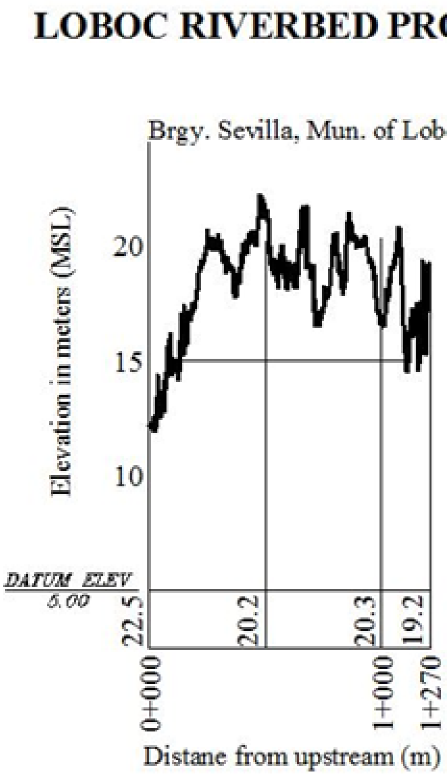


Figure 45 Riverbed profile of Loboc River

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All data that affect the hydrologic cycle of the 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 Loboc River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from a recording rain gauge installed by the USC Phil LiDAR 1. The rain gauge unit was installed in Magsaysay Bridge, Sevilla. The location of the rain gauge in the watershed is seen in Figure 46.

Total rain from the Sevilla rain gauge is 102.2 mm. It peaked to 8.2 mm on 2:15 PM of March 15, 2017.

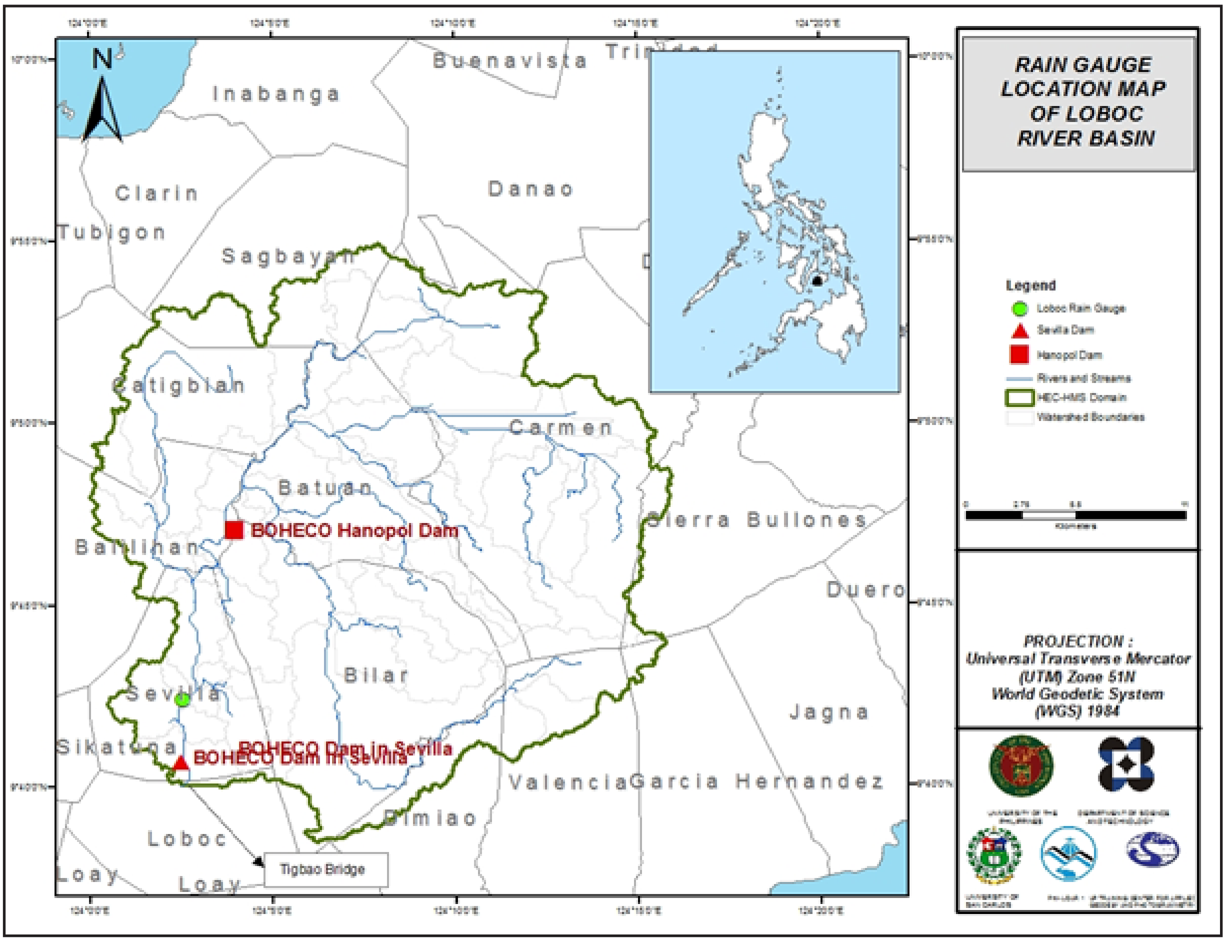


Figure 46. The location map of Loboc HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Tigbao Bridge, Loboc (9.66638°N, 124.041°E). It gives the relationship between the observed water levels and outflow of the watershed at this location.

For Tigbao Bridge, the rating curve is expressed $y=2E\text{-}10e^{2.3462x}$ as shown in Figure 47.

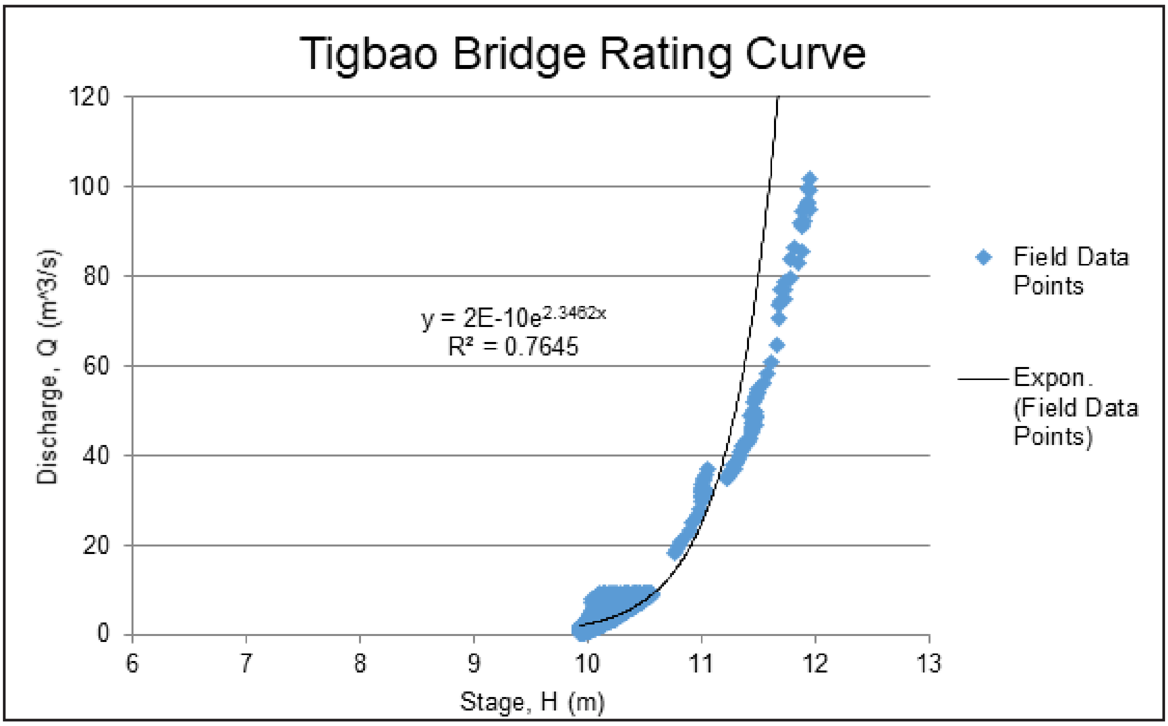


Figure 47. Rating Curve at Tigbao Bridge, Loboc, Bohol

This rating curve equation was used to compute the river outflow at Tigbao Bridge for the calibration of the HEC-HMS model shown in Figure 48. Peak discharge is 110.602 m3/s at 00:40, March 15, 2017.

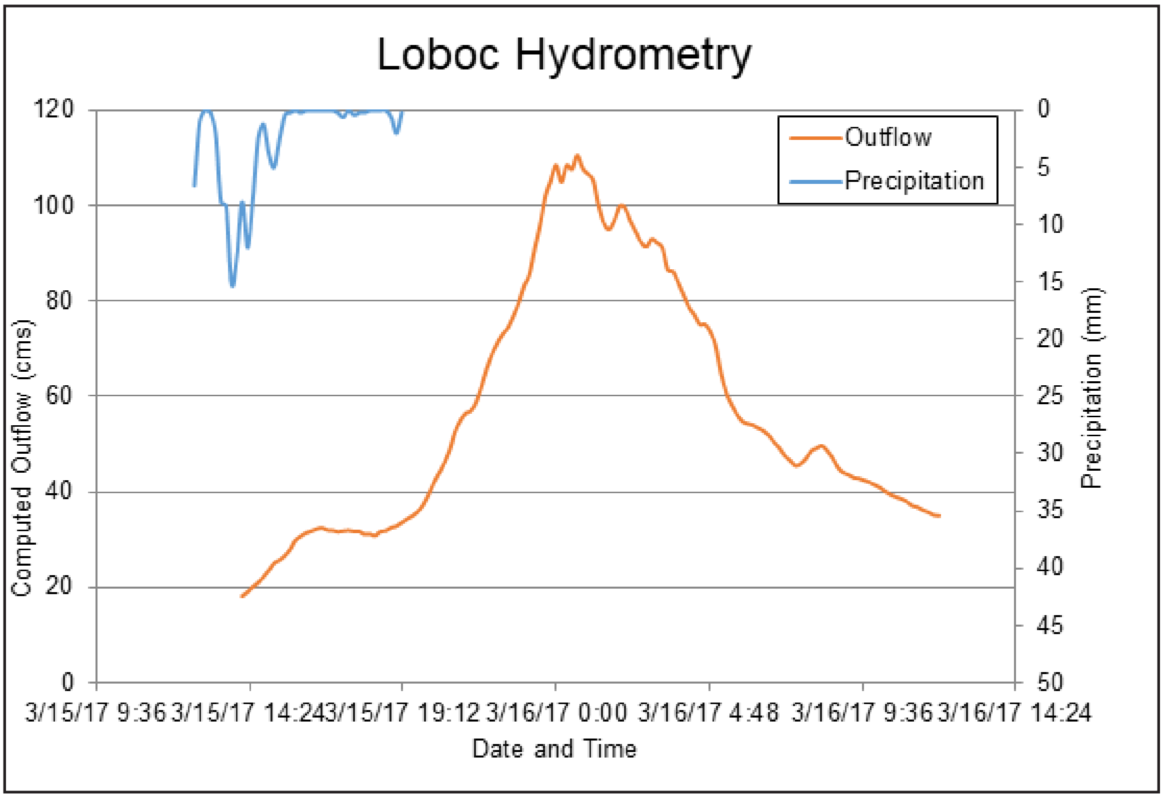


Figure 48. Rainfall and outflow data at Tigbao Bridge used for modeling.

Dams by the Bohol Electric Cooperative were found in Sevilla and Hanopol. Data on the relationship of the dams' storage, elevation and discharge were obtained. Values of the corresponding storage and discharge were computed. The length of the overflow weir of the Sevilla dam is 33 meters while that of Hanopol is 56 meters. The water is being released when the level reaches 31 meters above MSL for Sevilla and 101 meters above MSL for Hanopol.

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Tagbilaran Point Gauge. This station chosen based on its proximity to the Loboc watershed. The extreme values for this watershed were computed based on a 39-year record.

Table 25. RIDF values for Tagbilaran Point 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	14.4	21.9	26.5	34	43.7	50.4	62.6	73.8	84.1
5	23.1	35.4	41.8	54.6	65.1	76.5	95.1	108.2	121.2
10	28.8	44.3	52	68.3	79.3	93.7	116.7	131	145.7
15	32.1	49.3	57.7	76.1	87.3	103.5	128.8	143.9	159.6
20	34.3	52.8	61.7	81.5	92.9	110.3	137.3	152.9	169.3
25	36.1	55.5	64.8	85.6	97.3	115.5	143.8	159.8	176.7
50	41.5	63.8	74.4	98.5	110.6	131.7	164	181.1	199.7
100	46.8	72.1	83.8	111.2	123.8	147.7	184	202.3	222.6

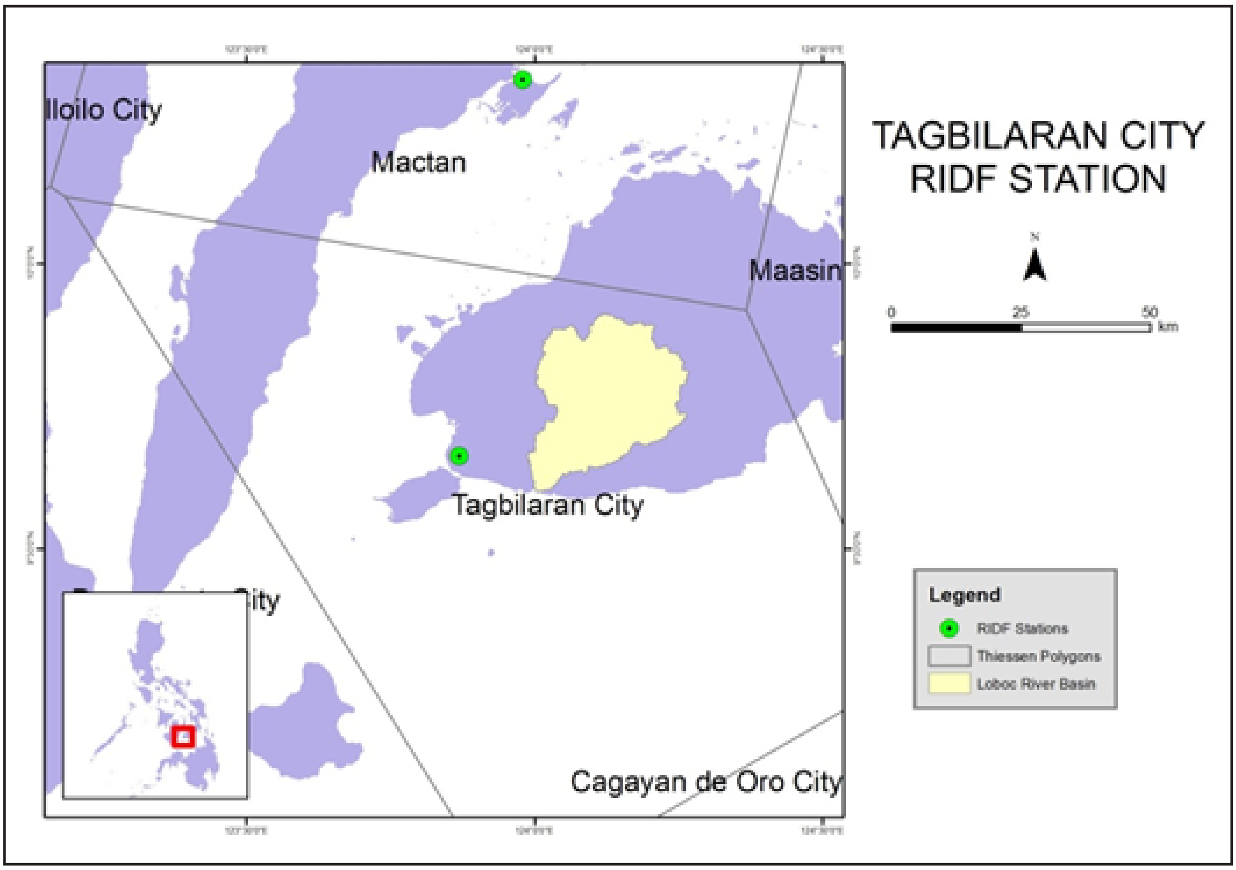


Figure 49. Tagbilaran Station relative to Loboc River Basin

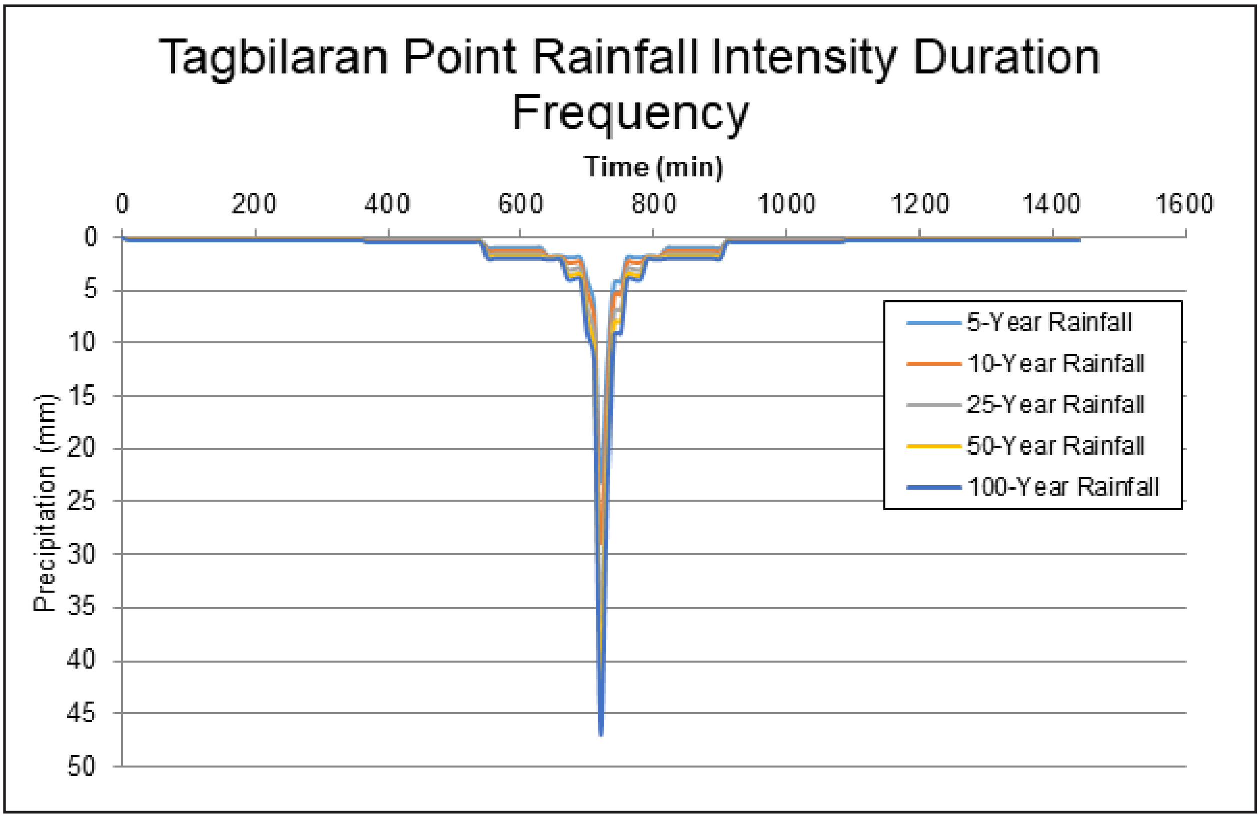


Figure 50. Synthetic storm generated for a 24-hr period rainfall for various return periods

5.3 HMS Model

The soil shapefile (dated pre-2004) was taken from the Bureau of Soils and Water Management under the Department of Agriculture. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA).

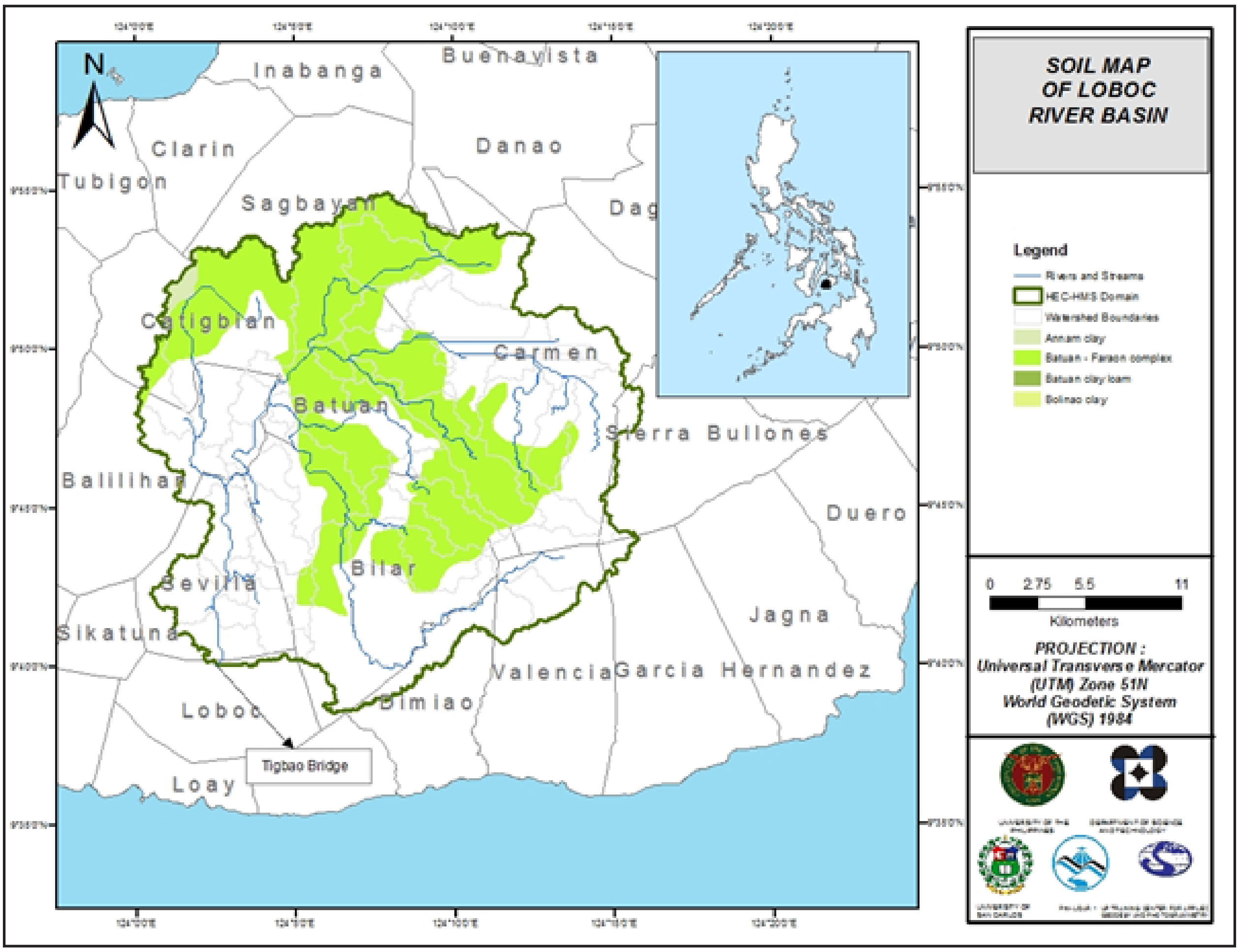


Figure 51. The soil map of the Loboc River Basin used for the estimation of the CN parameter.
(Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management – Department of Agriculture)

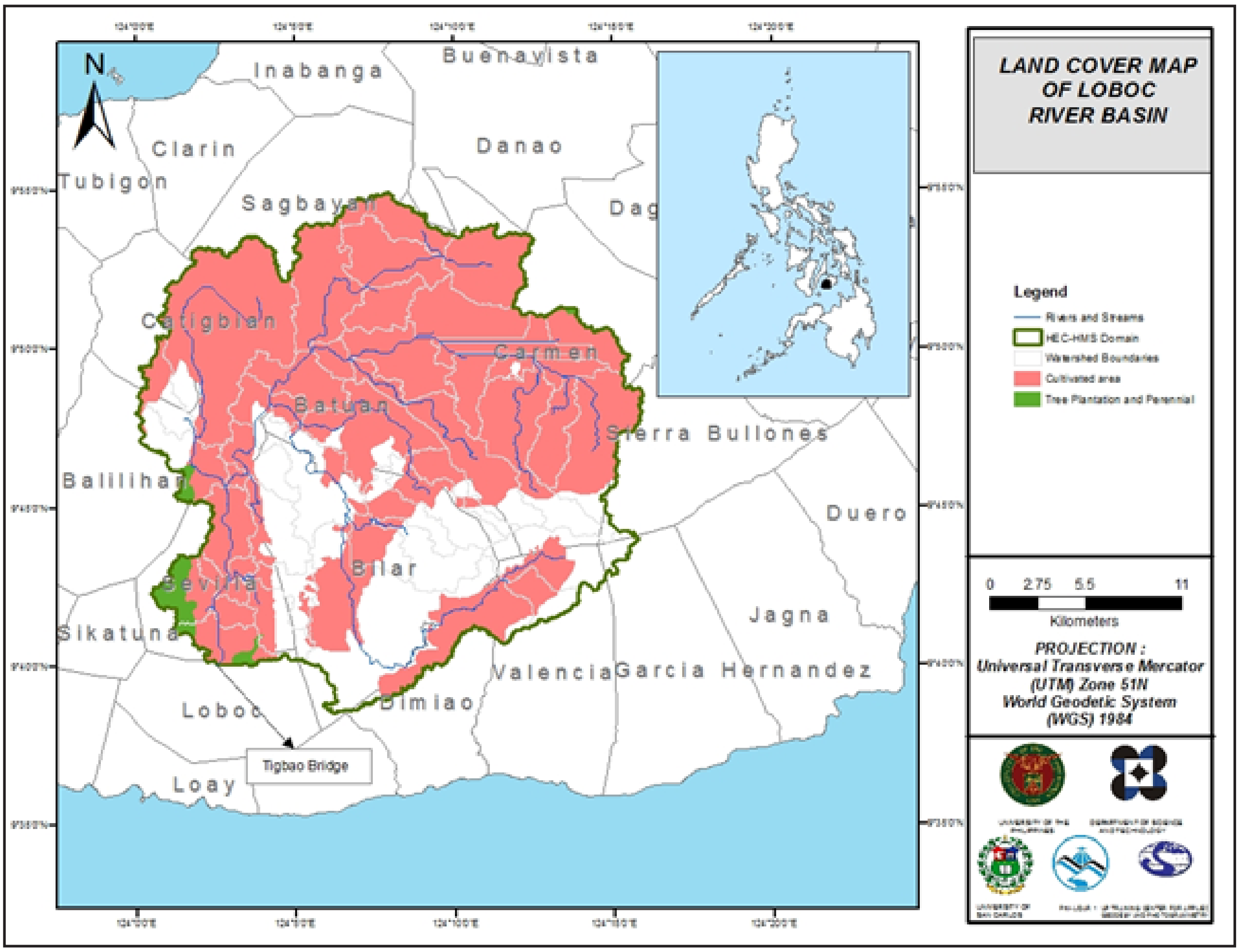


Figure 52. The land cover map of the Loboc River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source of data: National Mapping and Resource Information Authority)

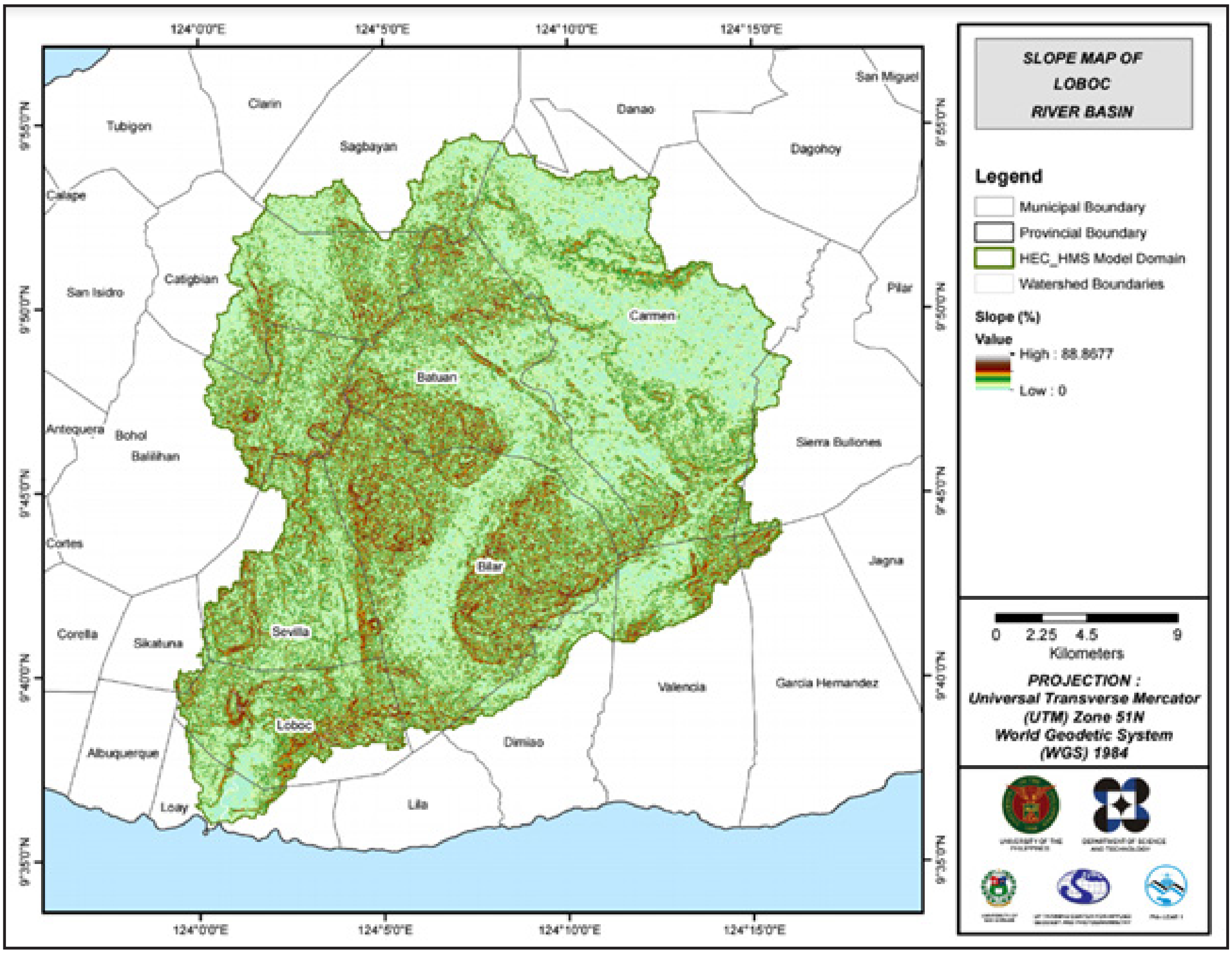


Figure 53. Slope map of the Loboc River Basin

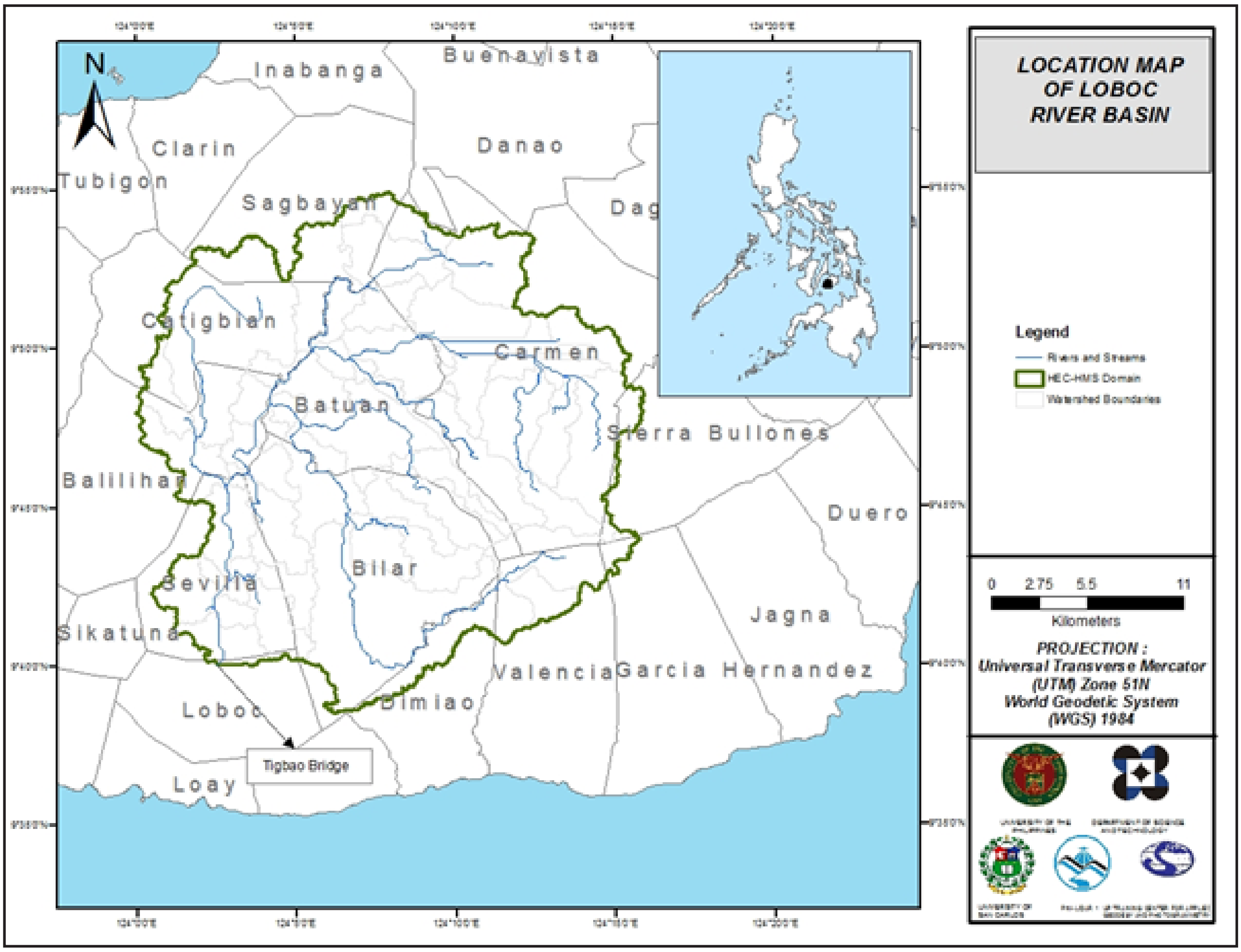


Figure 54. Location Map of Loboc River Basin relative to the Philippines

The Loboc basin model consists of 45 subbasins and 23 reaches. The catchment outlet is designated as Outlet1. Dams were modeled using the reservoir element and were labeled as Sevilla and Hanopol Dams. The basin model is presented in Figure 55. The basins were identified based on soil and land cover characteristics of the area. Precipitation from March 15, 2017 was taken from a recording rain gauge installed by USC Phil LiDAR 1. It was calibrated using the discharge data obtained from the depth gauge and currentmeter temporarily deployed in Tigbao Bridge, Loboc.

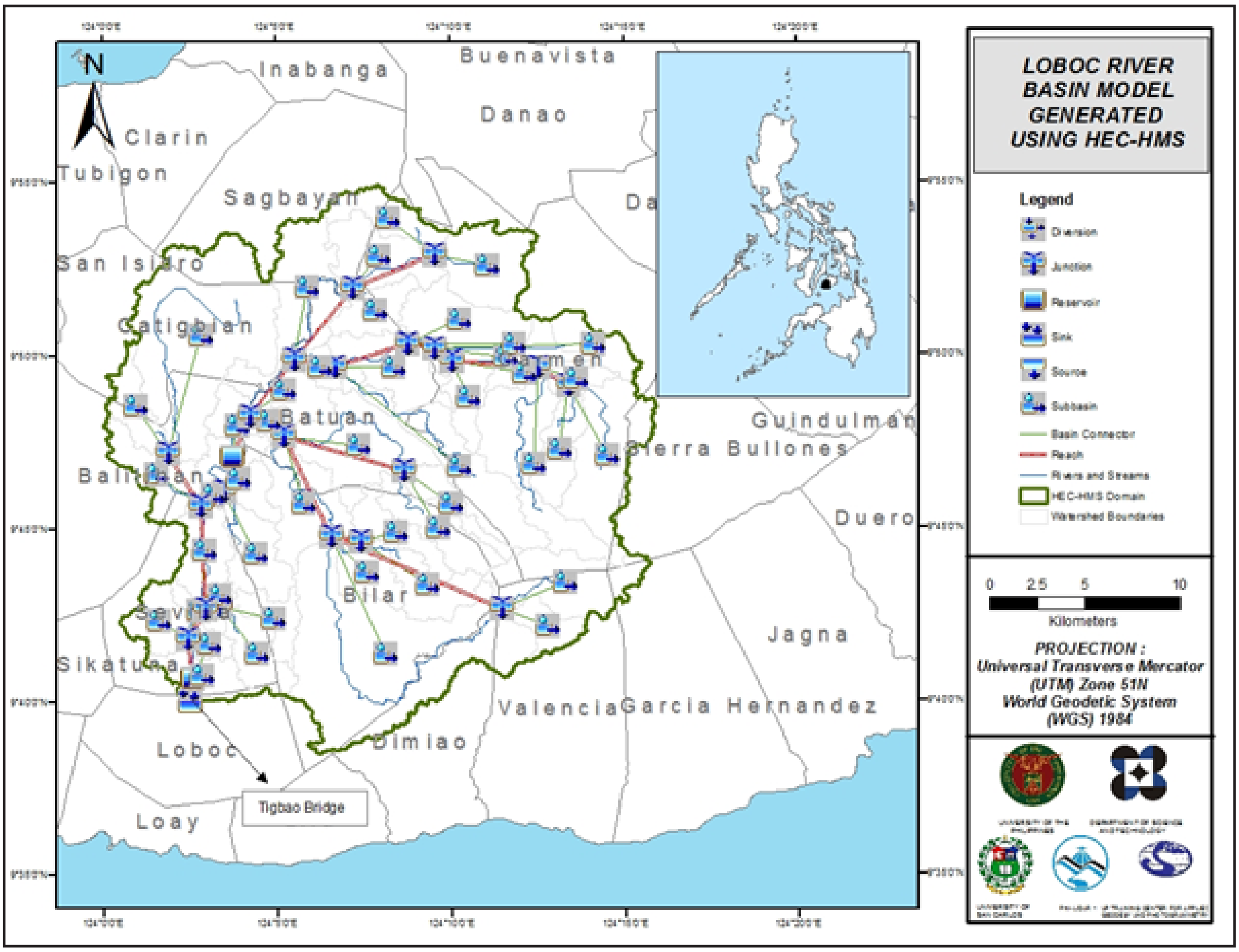


Figure 55. Stream delineation map of Loboc River Basin

5.4 Cross-section Data

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

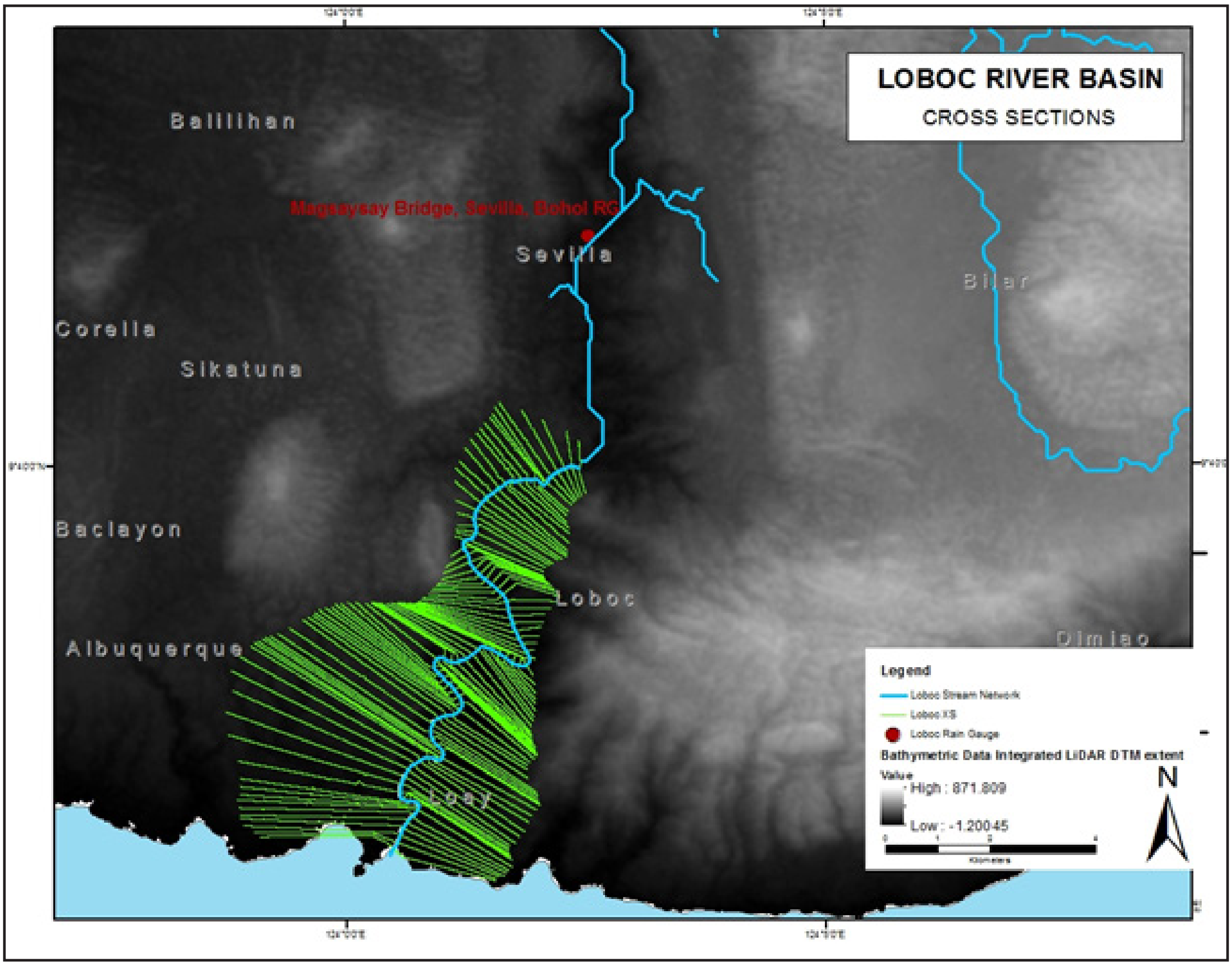


Figure 56. River cross-section of Loboc River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

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

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

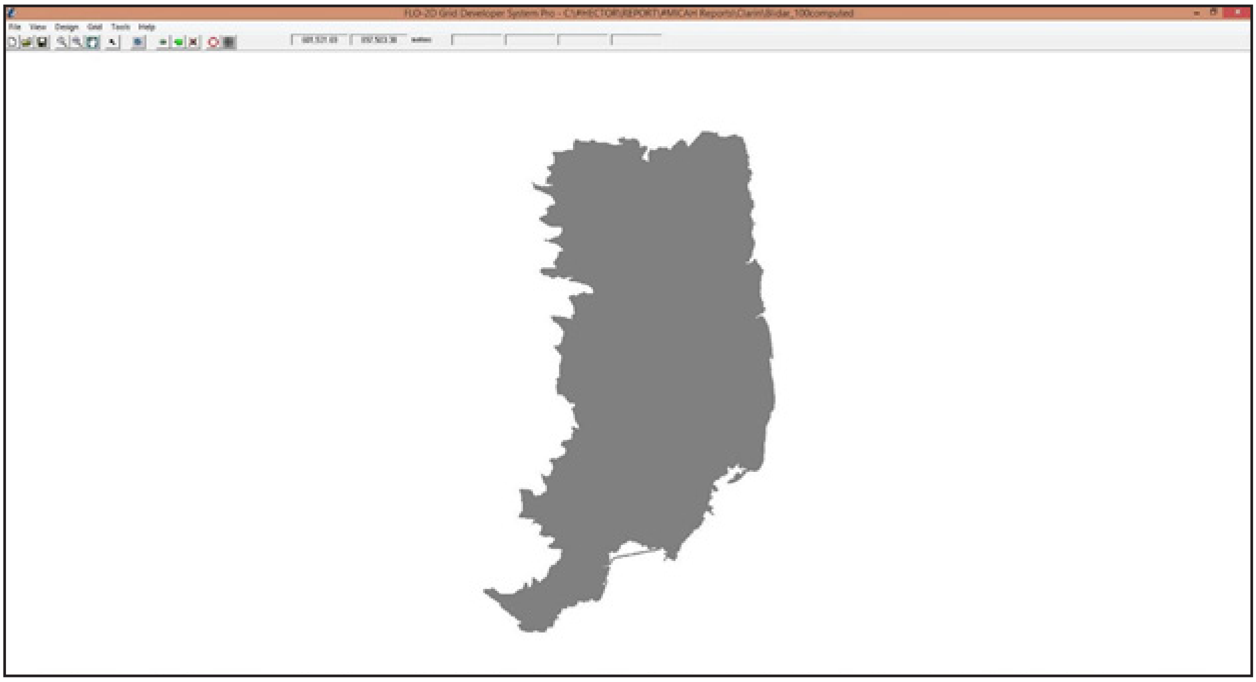


Figure 57. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 24.37769 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m^2/s.

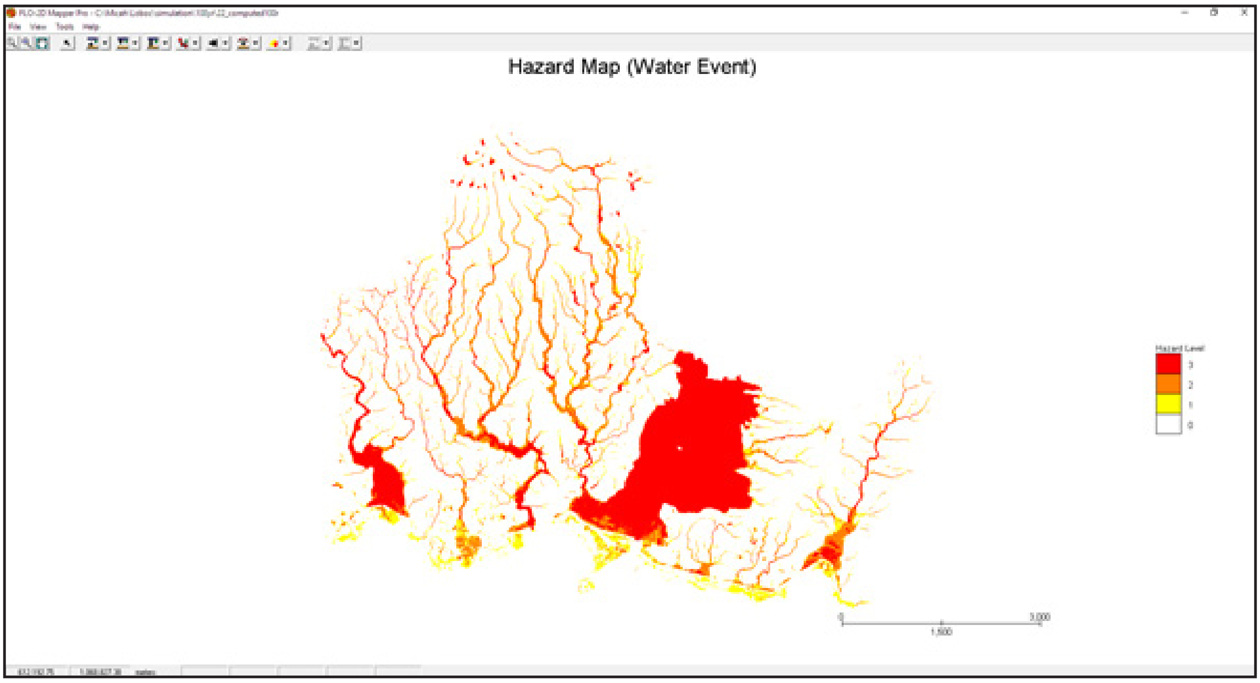


Figure 58. Generated 100-year rain return hazard map from FLO-2D Mapper

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 38 175 900.00 m^2.

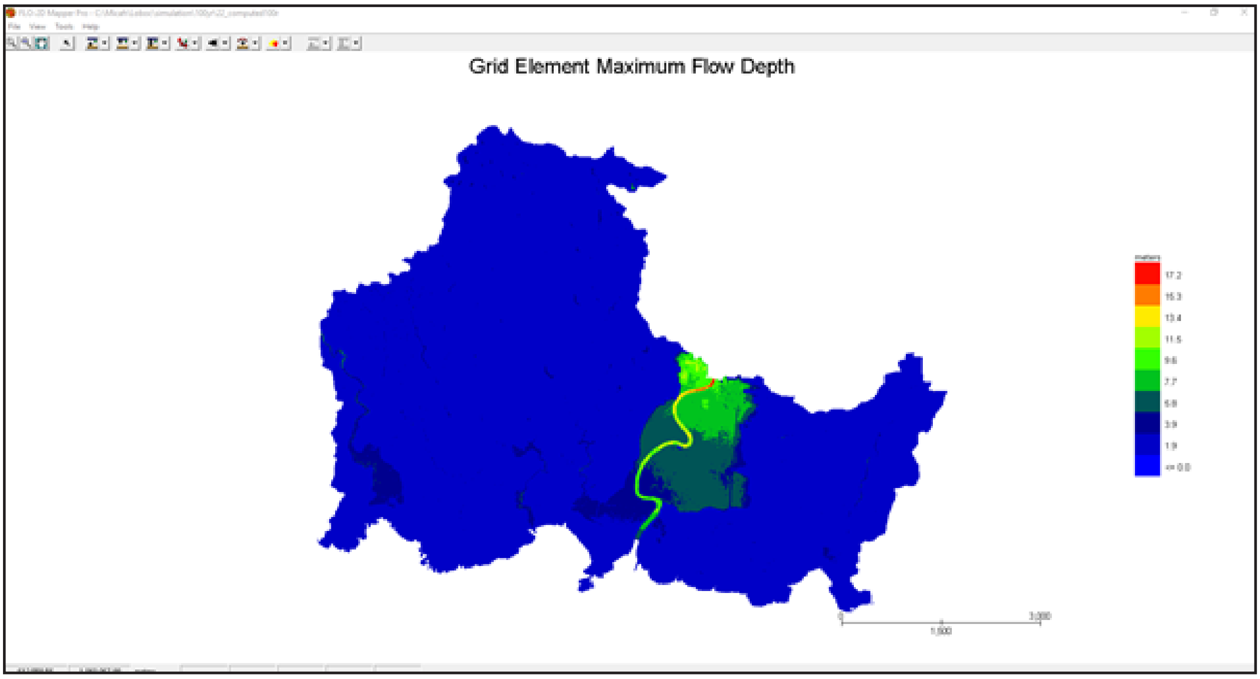


Figure 59. Generated 100-year rain return flow depth map from FLO-2D Mapper

There is a total of 79 468 633.59 m^3 of water entering the model. Of this amount, 8 124 218.73 m^3 is due to rainfall while 71 344 414.86 m^3 is inflow from other areas outside the model 3 309 884.75 m^3 of this water is lost to infiltration and interception, while 14 922 612.67 m^3 is stored by the flood plain. The rest, amounting up to 61 236 137.20 m^3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Loboc HEC-HMS river basin model, its accuracy was measured against the observed values (see Annex 9. Loboc Model Basin Parameters). Figure 60 shows the comparison between the two discharge data.

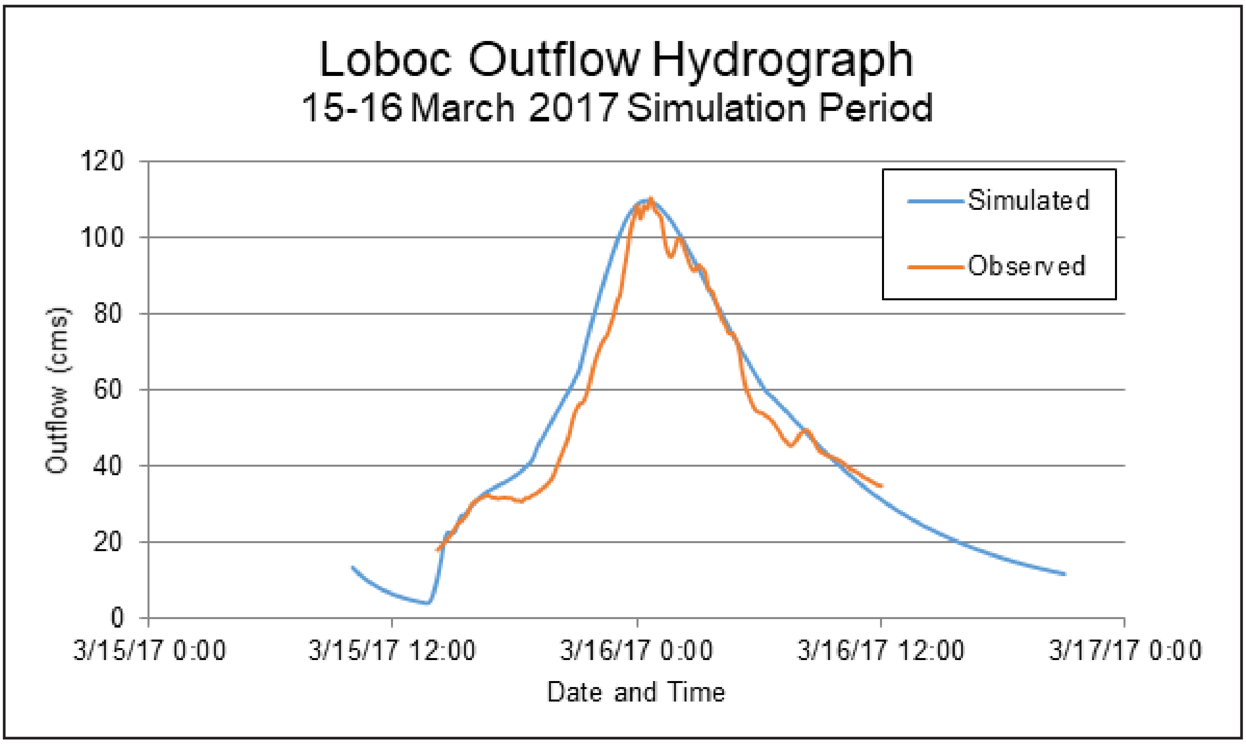


Figure 60. Outflow Hydrograph of Loboc produced by the HEC-HMS model compared with observed outflow.

Table 26. Range of Calibrated Values for Loboc

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	10.60-121.71
			Curve Number	35-99
			Impervious (%)	0-20
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.02-16.62
			Storage Coefficient (hr)	0.47-23.75
	Baseflow	Recession	Recession Constant	0-0.14
			Ratio to Peak	0-1.00
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0-0.17

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 10.60 to 121.71 mm means that there is a substantial amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 65 to 90 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012). The curve number for the Loboc river basin is 35 to 99, since its soil type is mostly clay and clay loam.

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 0.02 to 16.62 minutes determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0 to 0.14 indicates that the basin will quickly go back to its original discharge.

Manning's roughness coefficient of 0 to 0.17corresponds to the common roughness in Loboc, which is determined to be mostly cultivated areas with tree plantations and perennials (Brunner, 2010).

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

Accuracy measure	Value
RMSE	7.3351.
r^2	0.9778
NSE	0.9214
PBIAS	-8
RSR	0.2804

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 7.3351.

The Pearson correlation coefficient (r^2) 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 0.9778.

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 0.9214.

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 -8.

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 0.2804.

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 show the Loboc outflow using the Tagbilaran Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-, 10-, 25-, 50-, 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 uniform duration of 24 hours and varying return periods.

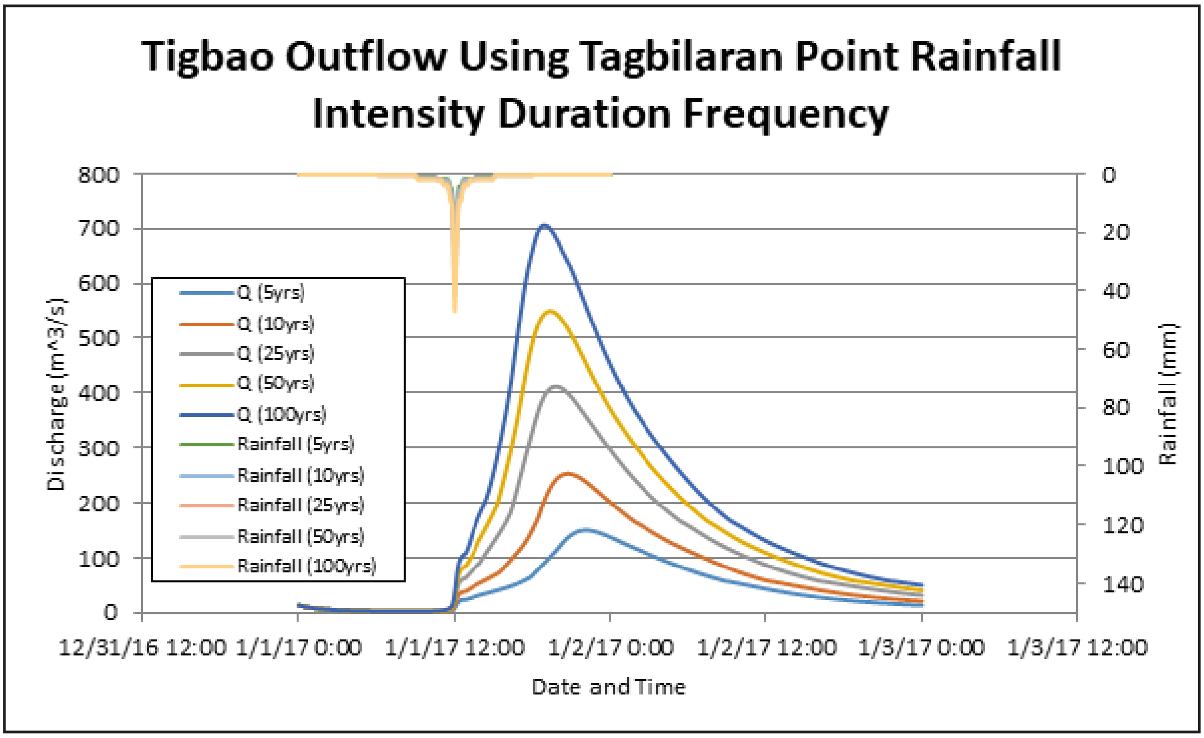


Figure 61. Outflow hydrograph at Tigbao generated using Tagbilaran PointRIDF simulated in HEC-HMS

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

Table 28. Peak values of the Loboc HECHMS Model outflow using the Tagbilaran RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m^3/s)	Time to Peak
5-year RIDF	121.2	23.100	150.491	10:10
10-year RIDF	145.7	28.800	253.218	10:10
25-year RIDF	176.7	36.100	411.926	10:10
50-year RIDF	199.7	41.500	549.643	10:10
100-year RIDF	222.6	46.800	706.159	10:10

5.7.2 Discharge Data Using Dr. Horritt's Recommended Hydrologic Method

The river discharges for the two rivers entering the floodplain are shown in Figure 62 and the peak values are summarized in Table 29 to Table 30.

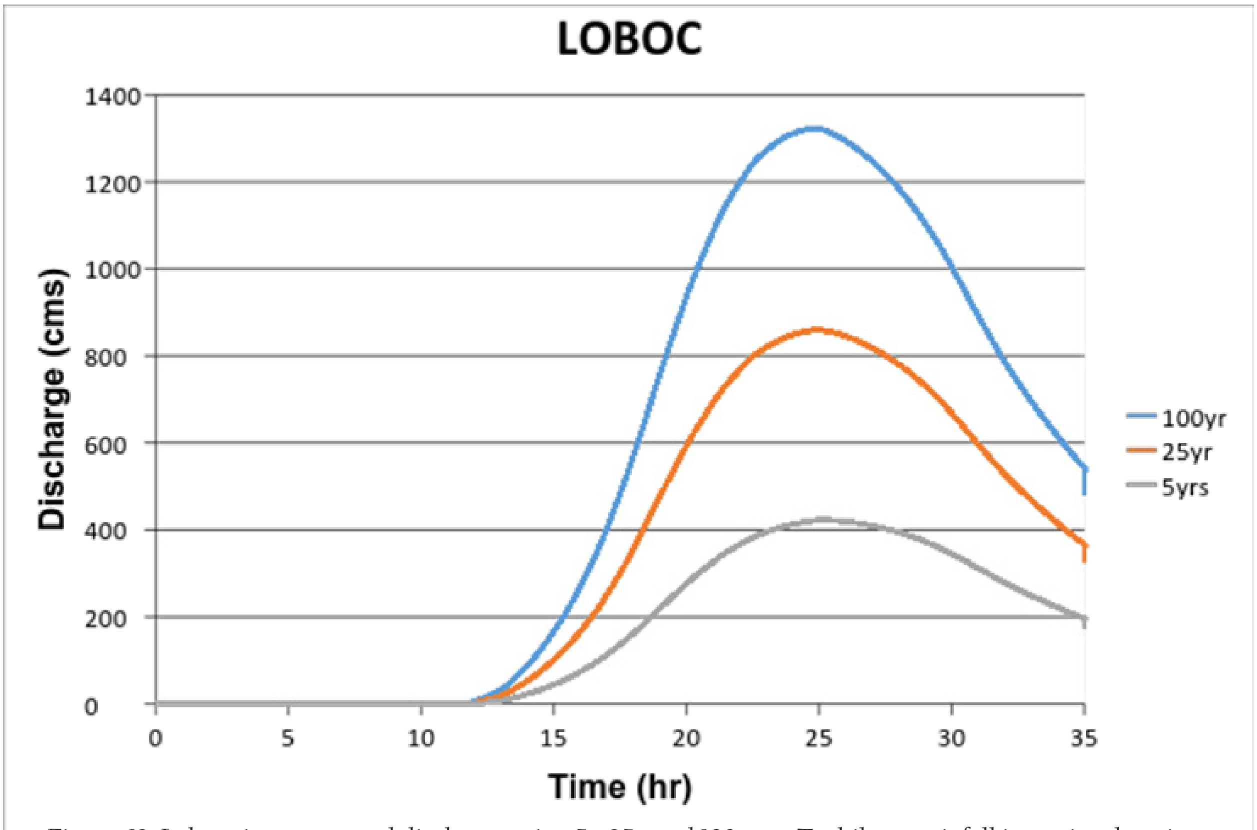


Figure 62. Loboc river generated discharge using 5-, 25-, and 100-year Tagbilaran rainfall intensity-duration-frequency (RIDF) in HEC-HMS

Table 29. Summary of Loboc river discharge generated in HEC-HMS

RIDF Period	Peak discharge (cms)	Time-to-peak
100-Year	1323.6	24 hours, 50 minutes
25-Year	859.9	24 hours, 50 minutes
5-Year	422.3	25 hours, 10 minutes

Table 30. Validation of river discharge estimates

Discharge Point	QMED(SCS), cms	QBANKFUL, cms	QMED(SPEC), cms	VALIDATION	
				Bankful Discharge	Specific Discharge
Loboc	271.128	224.133	444.630	Pass	Pass

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

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. For this publication, only a sample output map river was to be shown. The sample generated map of Loboc River using the calibrated event flow is shown in Figure 63.

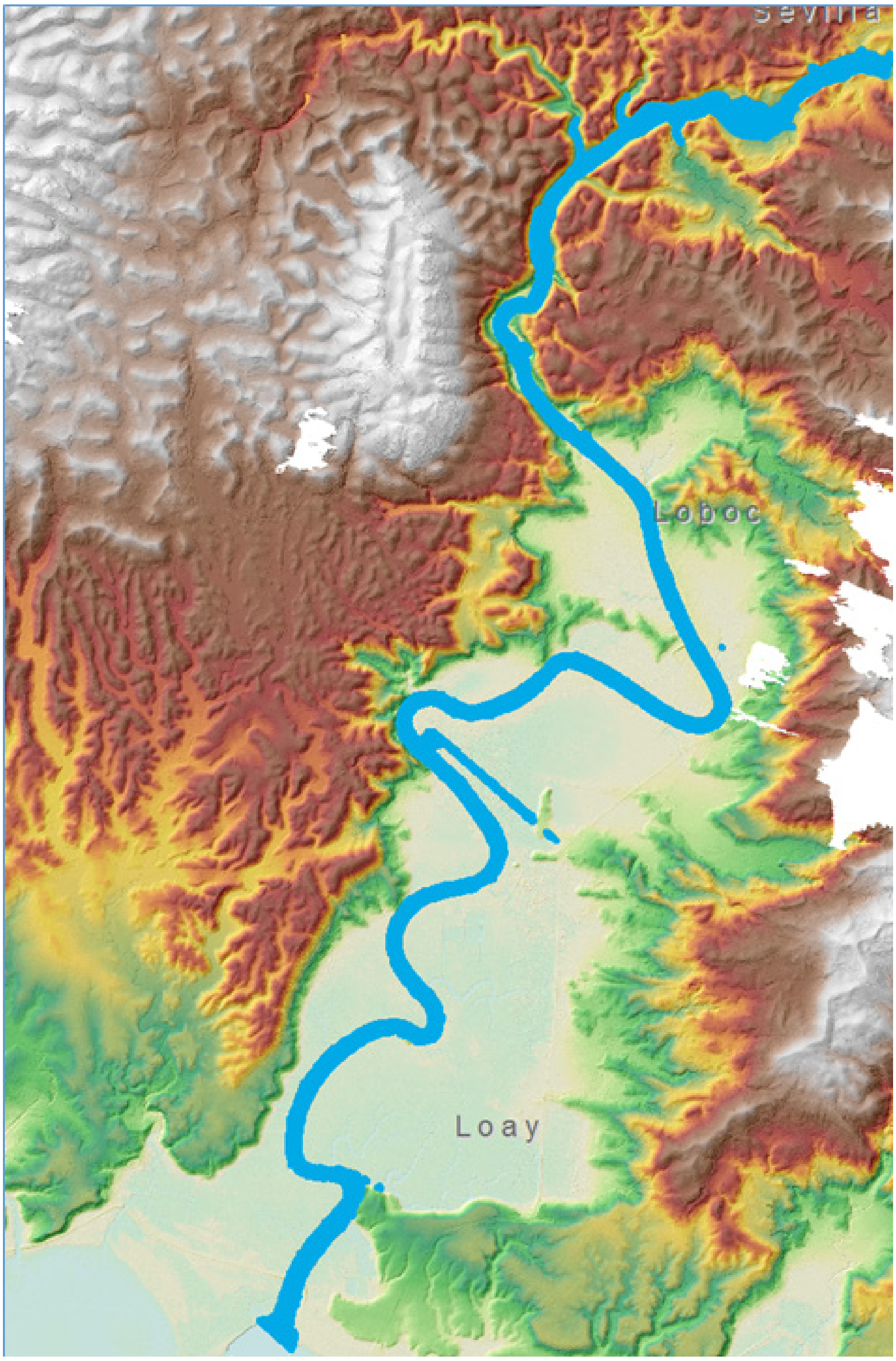


Figure 63. Sample output of Loboc RAS Model

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 64 to Figure 69 shows the 5-, 25-, and 100-year rain return scenarios of the Loboc floodplain.

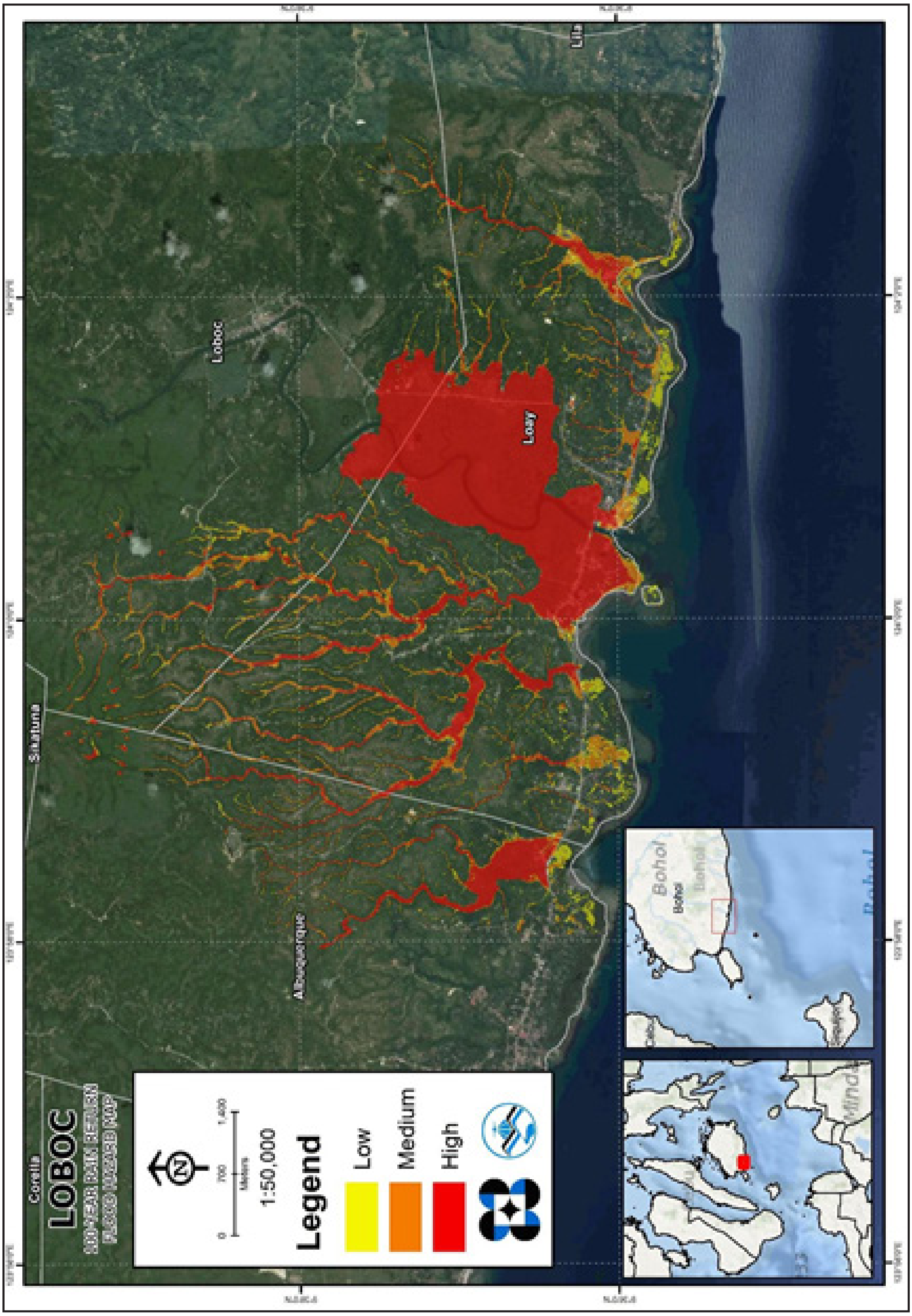


Figure 64. 100-year Hazard Map for Loboc Floodplain

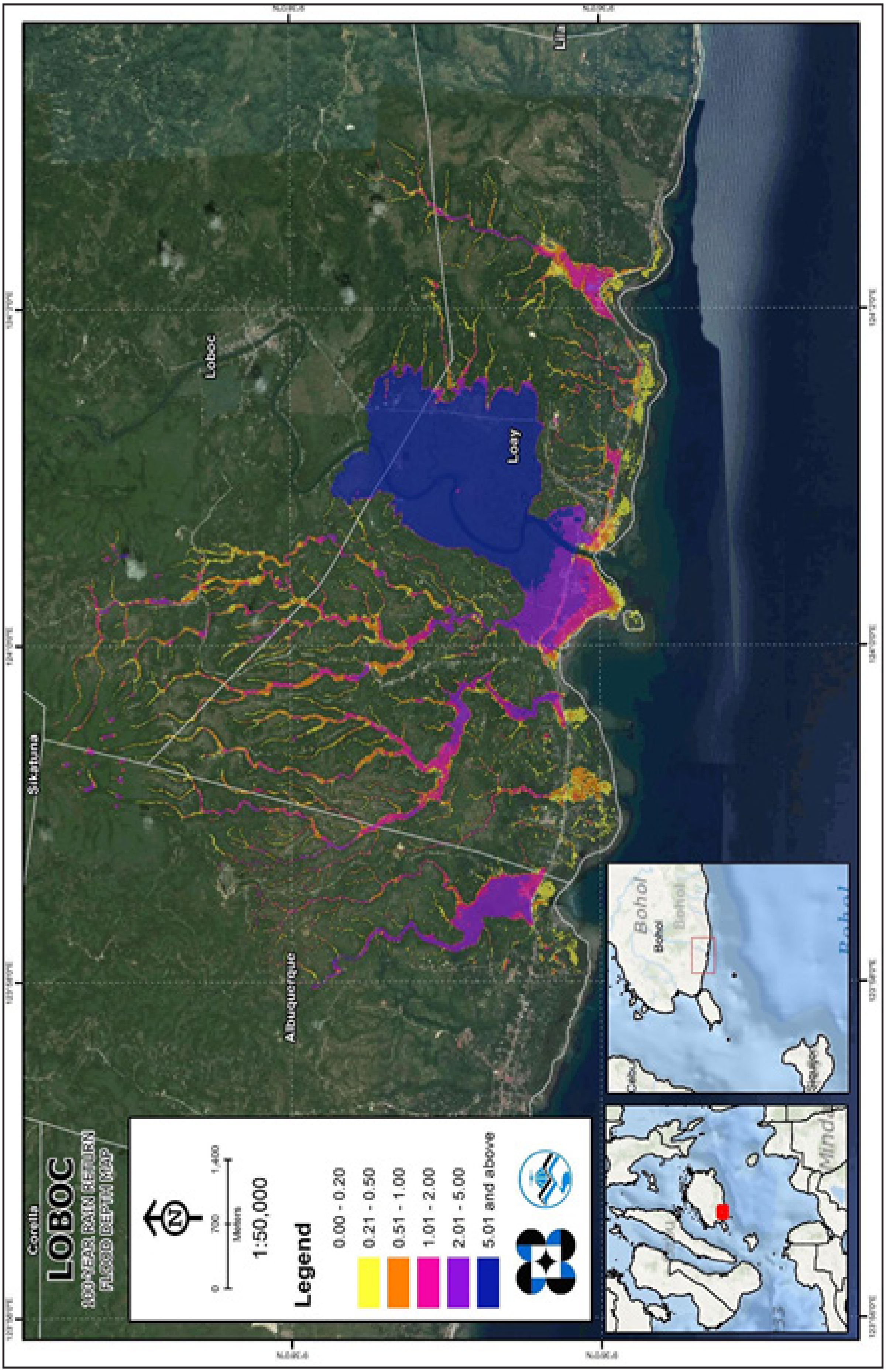


Figure 65. 100-year Flow Depth Map for Loboc Floodplain

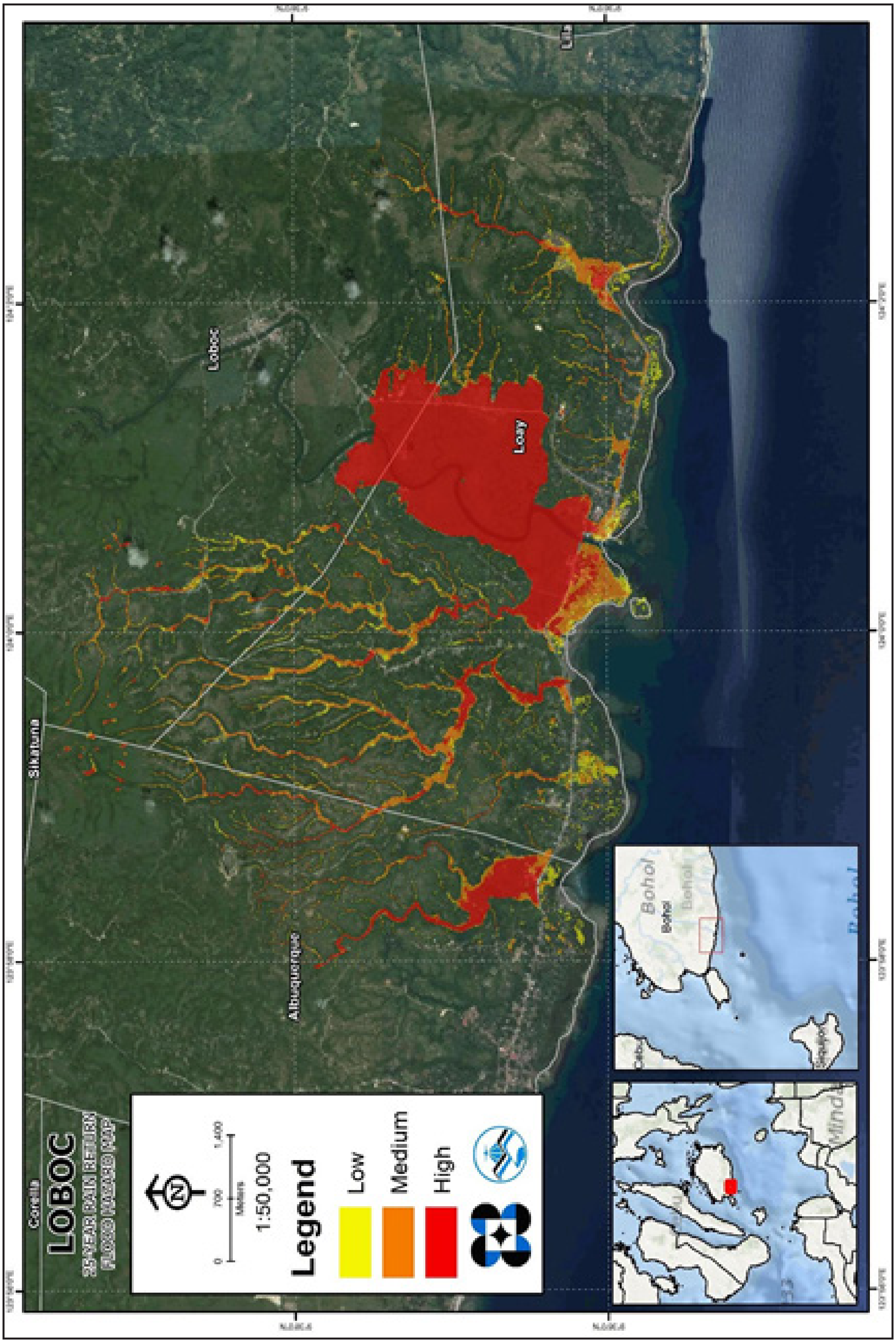


Figure 66. 25-year Hazard Map for Loboc Floodplain

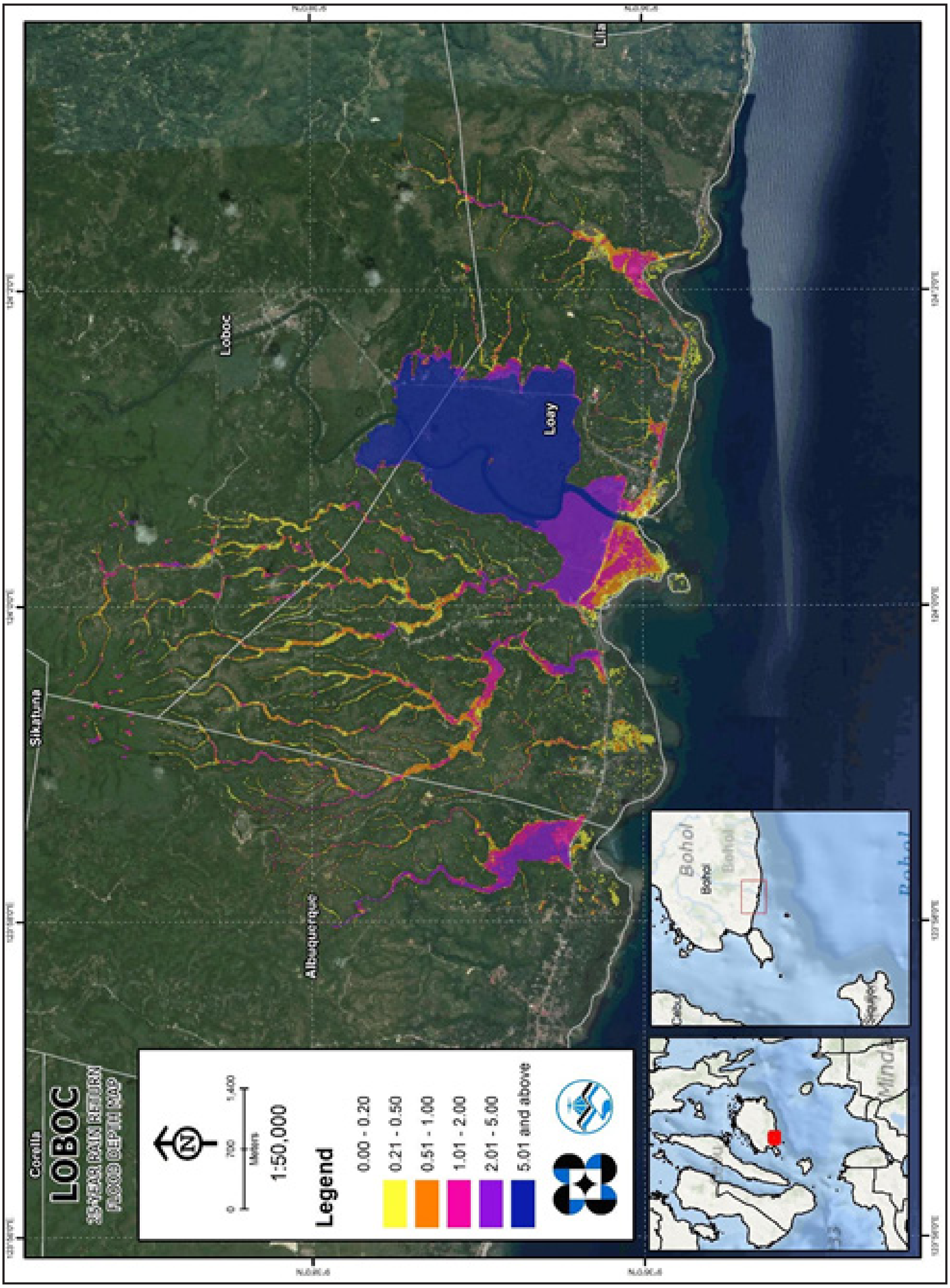


Figure 67. 25-year Flow Depth Map for Loboc Floodplain

Figure 68. 5-year Hazard Map for Loboc Floodplain

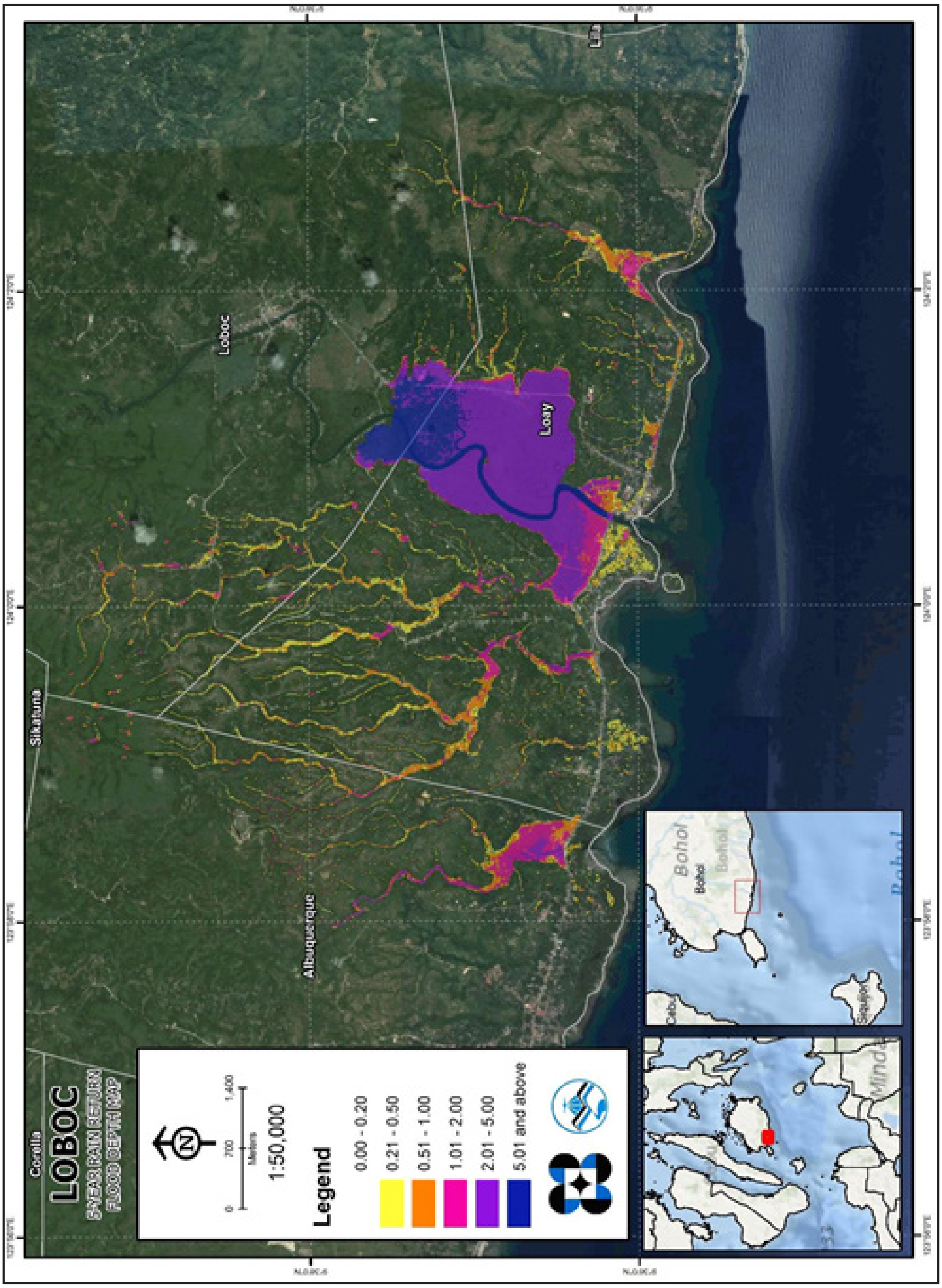


Figure 69. 5-year Flow Depth Map for Loboc Floodplain

5.10 Inventory of Areas Exposed to Flooding

Affected barangays in the Loboc river basin, grouped by municipality, are listed below. For the said basin, three municipalities consisting of 34 barangays are expected to experience flooding when subjected to 5-yr rainfall return period. The list of educational and health institutions affected by flooding in the Loboc floodplain can be found in Annex 12 and 13, respectively.

For the 5-year return period, 24.84% of the municipality of Albuquerque with an area of 25.5 sq. km. will experience flood levels of less 0.20 meters. 0.76% of the area will experience flood levels of 0.21 to 0.50 meters while 0.96%, 1.25%, 0.32, and 0.0004% 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 29 are the affected areas in square kilometres by flood depth per barangay.

Table 31. Affected Areas in Albuquerque, Bohol during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Albuquerque (in sq. km.)		
	Allangigan Primero	Cubcubboot	Palacapac
0.03-0.20	3.01	0.97	2.36
0.21-0.50	0.082	0.029	0.083
0.51-1.00	0.084	0.012	0.15
1.01-2.00	0.044	0.0096	0.27
2.01-5.00	0.0056	0.0018	0.075
> 5.00	0	0	0.0001

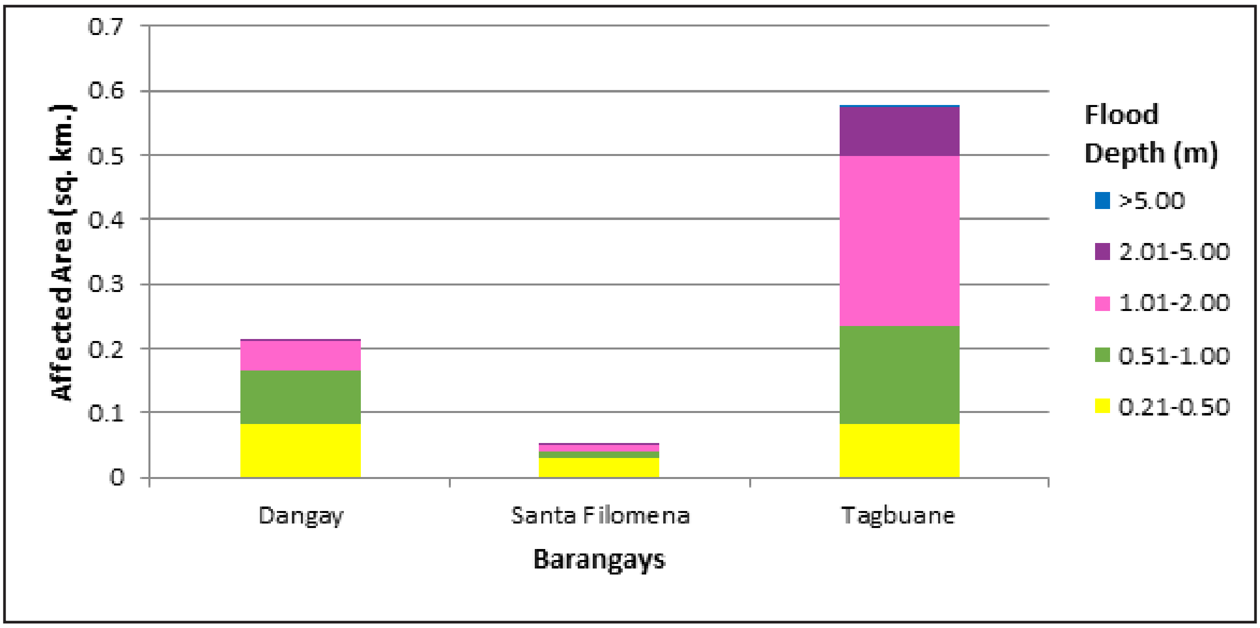


Figure 70. Affected Areas in Albuquerque, Bohol during 5-Year Rainfall Return Period

For the municipality of Loay, with an area of 26.06 sq. km., 68.75% will experience flood levels of less 0.20 meters. 3.89% of the area will experience flood levels of 0.21 to 0.50 meters while 2.91%, 2.32%, 9.54%, and 1.89% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Tables 30-31 are the affected areas in square kilometres by flood depth per barangay.

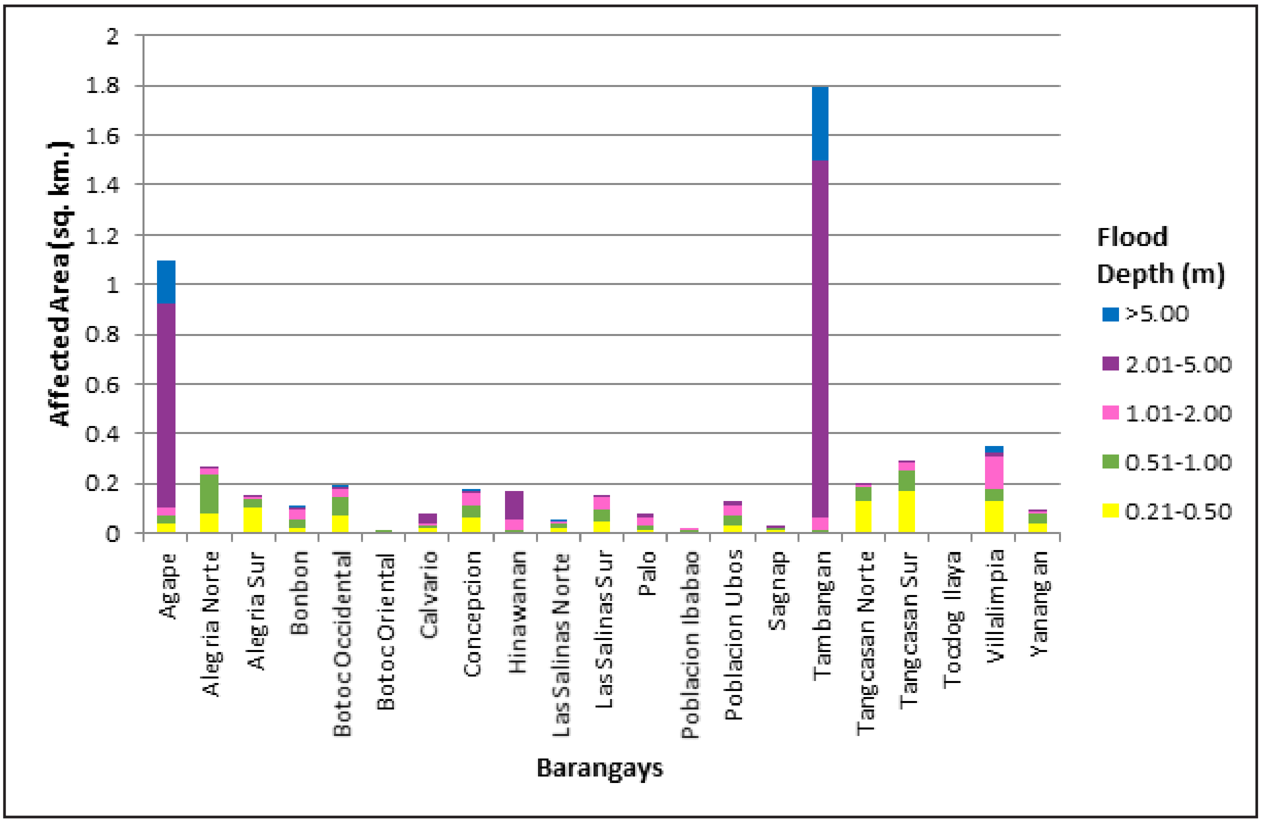


Figure 71. Affected Areas in Loay, Bohol during 5-Year Rainfall Return Period

Table 32. Affected Areas in Loay, Bohol during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loay (in sq. km.)										
	Agape	Alegria Norte	Alegria Sur	Bonbon	Botoc Occidental	Botoc Ori-ental	Calvario	Concepcion	Hinawanan	Las Salinas Norte	Las Salinas Sur
0.03-0.20	0.85	1.43	1.49	0.62	1.45	0.029	0.65	1.22	0.23	1.2	0.71
0.21-0.50	0.042	0.082	0.1	0.021	0.067	0.0019	0.018	0.064	0.0053	0.026	0.043
0.51-1.00	0.027	0.15	0.034	0.03	0.076	0.0005	0.0085	0.051	0.0087	0.0098	0.056
1.01-2.00	0.037	0.023	0.0056	0.043	0.038	0	0.011	0.044	0.043	0.007	0.05
2.01-5.00	0.82	0.00076	0.0011	0.01	0.006	0	0.044	0.01	0.11	0.0012	0.0001
> 5.00	0.18	0	0	0.00004	0.000012	0	0	0.00006	0	0.000088	0

Table 33. Affected Areas in Loay, Bohol during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loay (in sq. km.)									
	Palo	Poblacion Ibabao	Poblacion Ubos	Sagnap	Tambangan	Tangcasan Norte	Tangcasan Sur	Tocdog Ilaya	Villalimpia	Yanangan
0.03-0.20	0.44	0.18	0.2	0.62	0.33	2.29	2.62	0.0053	0.28	1.07
0.21-0.50	0.015	0.0057	0.031	0.014	0.0046	0.13	0.17	0	0.13	0.041
0.51-1.00	0.018	0.0059	0.037	0.0047	0.0089	0.059	0.086	0	0.045	0.038
1.01-2.00	0.028	0.0035	0.044	0.0015	0.05	0.0067	0.028	0	0.13	0.0084
2.01-5.00	0.015	0	0.017	0.0002	1.43	0.0008	0.003	0	0.018	0.0003
> 5.00	0	0	0	0	0.29	0	0	0	0.022	0

For the municipality of Loboc, with an area of 57.85 sq. km., 11.47% will experience flood levels of less 0.20 meters. 0.43% of the area will experience flood levels of 0.21 to 0.50 meters while 0.21%, 0.13%, 0.3%, and 0.73% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 32 are the affected areas in square kilometres by flood depth per barangay.

Table 34. Affected Areas in Loboc, Bohol during 5-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loboc (in sq. km.)									
	Agape	Calunasan Norte	Calunasan Sur	Camayaan	Canlasid	Gon-Ob	Jimilian	Oy	Taytay	Valladolid
0.03-0.20	0.92	1.33	1.36	0.048	0.37	0.73	0.32	1.5	0.061	0
0.21-0.50	0.025	0.045	0.1	0.00096	0.013	0.019	0.0047	0.042	0.0005	0
0.51-1.00	0.015	0.034	0.036	0.0021	0.0086	0.0083	0.004	0.016	0.0001	0
1.01-2.00	0.015	0.014	0.013	0.0059	0.0088	0.0027	0.0048	0.0086	0.0001	0
2.01-5.00	0.12	0.0023	0.0024	0.016	0.024	0.0007	0.0018	0.0008	0	0
> 5.00	0.2	0	0	0.032	0.19	0	0	0	0	0.000088

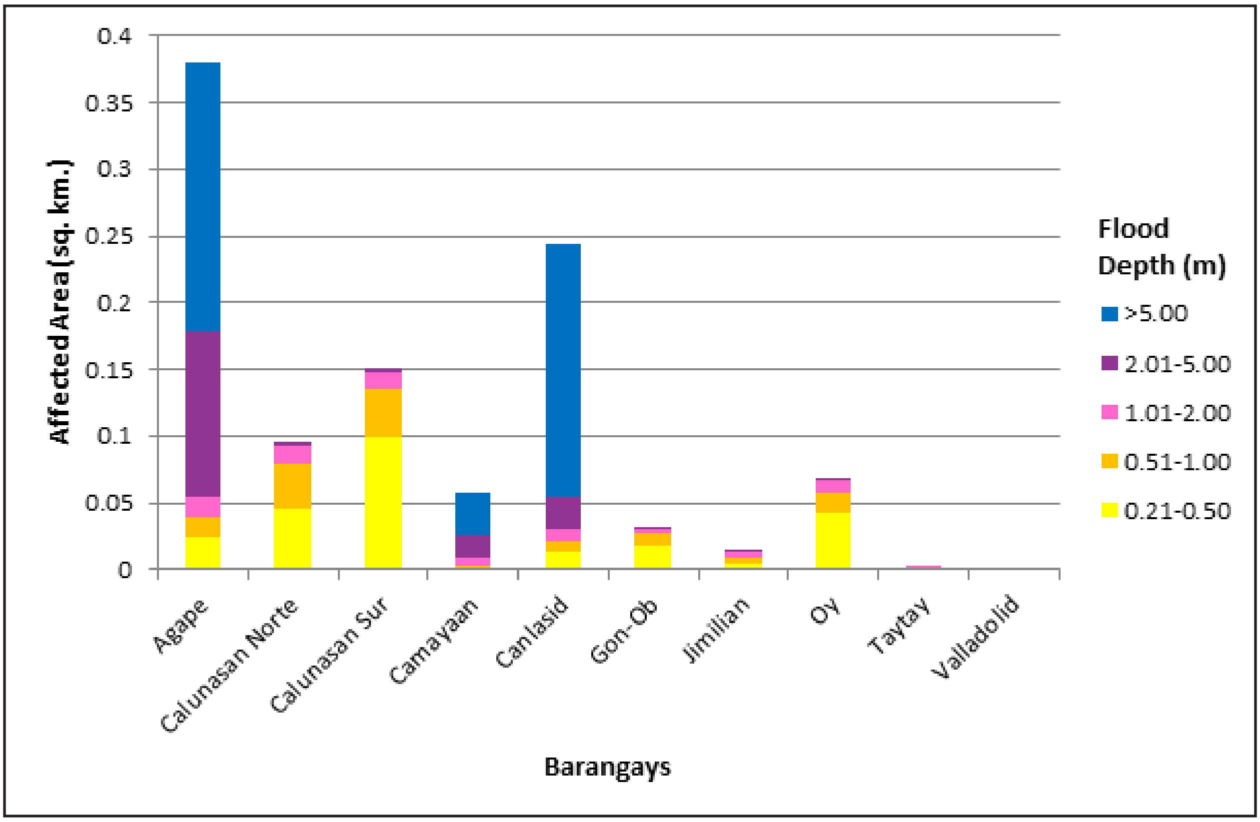


Figure 72. Affected Areas in Loboc, Bohol during 5-Year Rainfall Return Period

For the 25-year return period, 24.13% of the municipality of Albuquerque with an area of 25.5 sq. km. will experience flood levels of less 0.20 meters. 0.84% of the area will experience flood levels of 0.21 to 0.50 meters while 0.66%, 1.24%, 1.25, and 0.013% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 33 are the affected areas in square kilometres by flood depth per barangay.

Table 35. Affected Areas in Albuquerque, Bohol during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Albuquerque (in sq. km.)		
	Allangigan Primero	Cubcubboot	Palacapac
0.03-0.20	2.96	0.95	2.26
0.21-0.50	0.082	0.044	0.089
0.51-1.00	0.077	0.014	0.077
1.01-2.00	0.084	0.011	0.22
2.01-5.00	0.024	0.008	0.29
> 5.00	0.00043	0	0.003

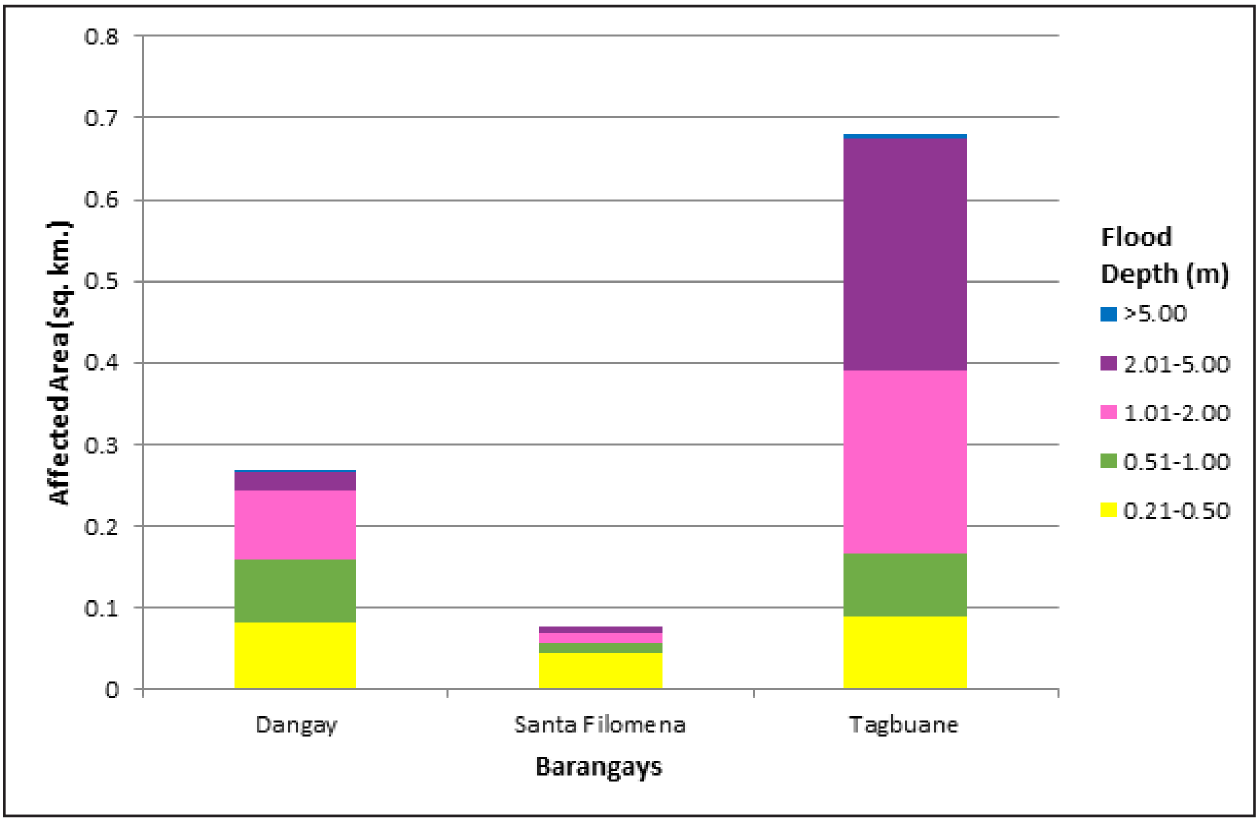


Figure 73. Affected Areas in Albuquerque, Bohol during 25-Year Rainfall Return Period

For the municipality of Loay, with an area of 26.06 sq. km., 64.89% will experience flood levels of less 0.20 meters. 4.08% of the area will experience flood levels of 0.21 to 0.50 meters while 3.82%, 2.96%, 3.71%, and 9.83% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Tables 34-35 are the affected areas in square kilometres by flood depth per barangay.

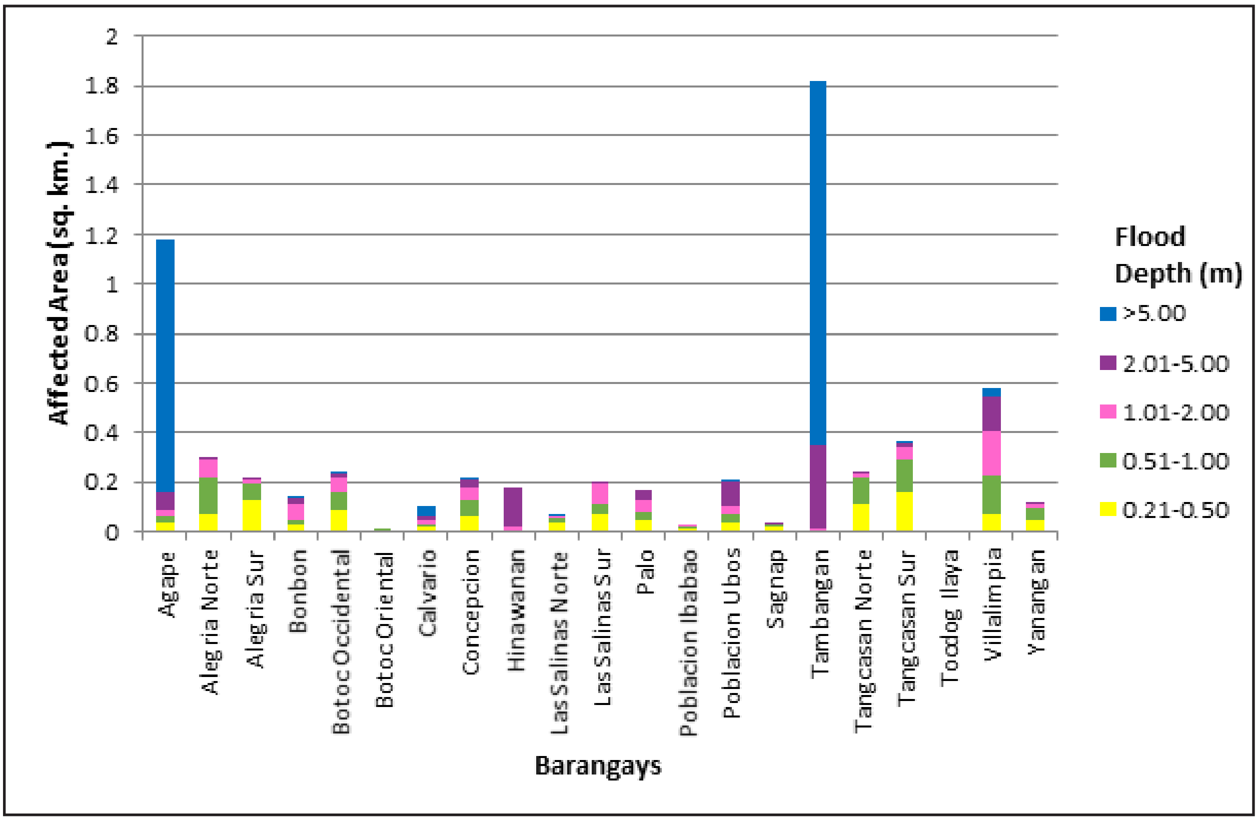


Figure 74. Affected Areas in Loay, Bohol during 25-Year Rainfall Return Period

Table 36. Affected Areas in Loay, Bohol during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loay (in sq. km.)										
	Agape	Alegria Norte	Alegria Sur	Bonbon	Botoc Occidental	Botoc Ori-ental	Calvario	Concepcion	Hinawanan	Las Salinas Norte	Las Salinas Sur
0.03-0.20	0.76	1.39	1.43	0.59	1.4	0.029	0.63	1.18	0.22	1.18	0.67
0.21-0.50	0.037	0.073	0.13	0.027	0.09	0.0023	0.021	0.064	0.0046	0.037	0.068
0.51-1.00	0.023	0.14	0.065	0.023	0.072	0.00053	0.012	0.064	0.0046	0.016	0.042
1.01-2.00	0.028	0.076	0.016	0.059	0.057	0	0.009	0.052	0.013	0.0097	0.081
2.01-5.00	0.072	0.0013	0.0016	0.028	0.014	0	0.018	0.033	0.15	0.0039	0.0017
> 5.00	1.02	0	0	0.00004	0.000012	0	0.046	0.00046	0	0.00049	0

Table 37. Affected Areas in Loay, Bohol during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loay (in sq. km.)									
	Palo	Poblacion Ibabao	Poblacion Ubos	Sagnap	Tambangan	Tangcasan Norte	Tangcasan Sur	Tocdog Ilaya	Villalimpia	Yanangan
0.03-0.20	0.35	0.17	0.13	0.6	0.31	2.24	2.54	0.0053	0.051	1.04
0.21-0.50	0.044	0.013	0.039	0.022	0.0038	0.11	0.16	0	0.074	0.05
0.51-1.00	0.037	0.0072	0.03	0.0079	0.0049	0.11	0.13	0	0.16	0.046
1.01-2.00	0.052	0.007	0.033	0.0045	0.0083	0.023	0.049	0	0.17	0.02
2.01-5.00	0.038	0	0.1	0.0004	0.33	0.002	0.015	0	0.15	0.0006
> 5.00	0	0	0.000008	0	1.46	0	0.0029	0	0.028	0

For the municipality of Loboc, with an area of 57.85 sq. km., 11.04% will experience flood levels of less 0.20 meters. 0.47% of the area will experience flood levels of 0.21 to 0.50 meters while 0.30%, 0.21%, 0.12%, and 1.11% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 36 are the affected areas in square kilometres by flood depth per barangay.

Table 38. Affected Areas in Loboc, Bohol during 25-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loboc (in sq. km.)									
	Agape	Calunasan Norte	Calunasan Sur	Camayaan	Canlasid	Gon-Ob	Jimilian	Oy	Taytay	Valladolid
0.03-0.20	0.85	1.31	1.3	0.032	0.33	0.72	0.31	1.47	0.06	0
0.21-0.50	0.028	0.041	0.12	0.0009	0.014	0.02	0.0046	0.041	0.0009	0
0.51-1.00	0.019	0.037	0.054	0.0019	0.011	0.015	0.0049	0.032	0.0006	0
1.01-2.00	0.02	0.032	0.03	0.0026	0.0098	0.0072	0.007	0.014	0.0001	0
2.01-5.00	0.034	0.0075	0.0053	0.0062	0.012	0.0008	0.0028	0.0035	0.0001	0
> 5.00	0.35	0	0	0.061	0.23	0.0001	0.001	0	0	0.000088

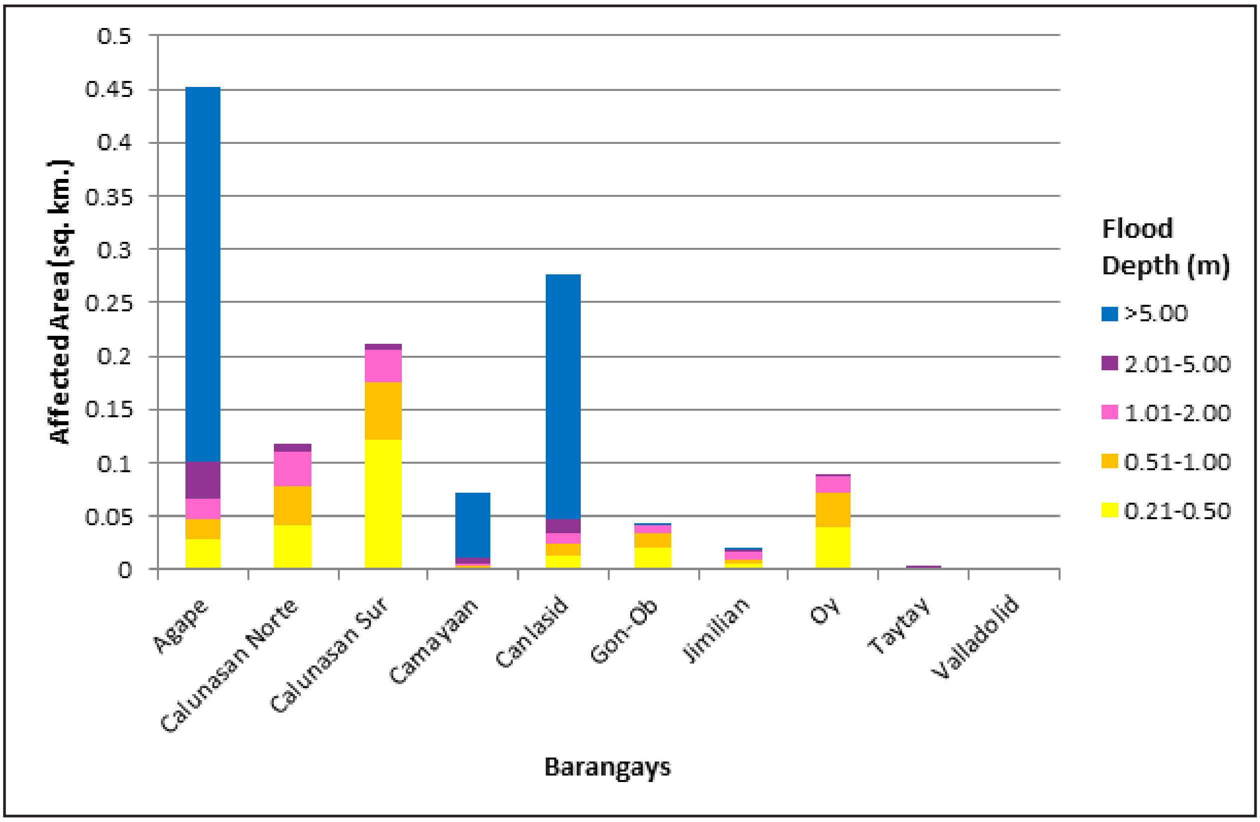


Figure 75. Affected Areas in Loboc, Bohol during 25-Year Rainfall Return Period

For the 100-year return period, 23.63% of the municipality of Albuquerque with an area of 25.5 sq. km. will experience flood levels of less 0.20 meters. 0.92% of the area will experience flood levels of 0.21 to 0.50 meters while 0.65%, 1.12%, 1.8, and 0.024% 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 37 are the affected areas in square kilometres by flood depth per barangay.

Table 39. Affected Areas in Albuquerque, Bohol during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Albuquerque (in sq. km.)		
	Allangigan Primero	Cubcubboot	Palacapac
0.03-0.20	2.91	0.93	2.2
0.21-0.50	0.077	0.061	0.098
0.51-1.00	0.078	0.017	0.071
1.01-2.00	0.098	0.014	0.17
2.01-5.00	0.055	0.0094	0.39
> 5.00	0.00083	0	0.0053

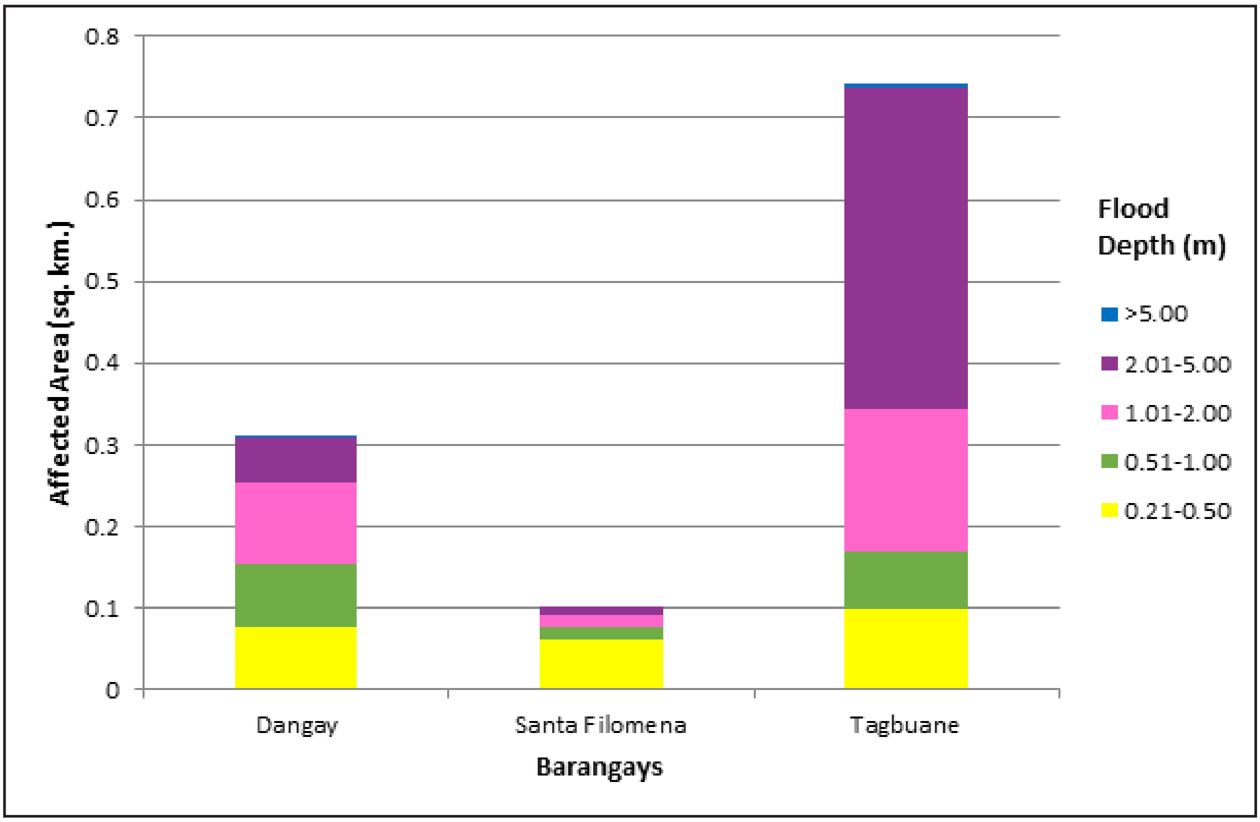


Figure 76. Affected Areas in Albuquerque, Bohol during 100-Year Rainfall Return Period

For the municipality of Loay, with an area of 26.06 sq. km., 61.94% will experience flood levels of less 0.20 meters. 4.1% of the area will experience flood levels of 0.21 to 0.50 meters while 3.64%, 4.13%, 3.86%, and 11.62% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Tables 38-39 are the affected areas in square kilometres by flood depth per barangay.

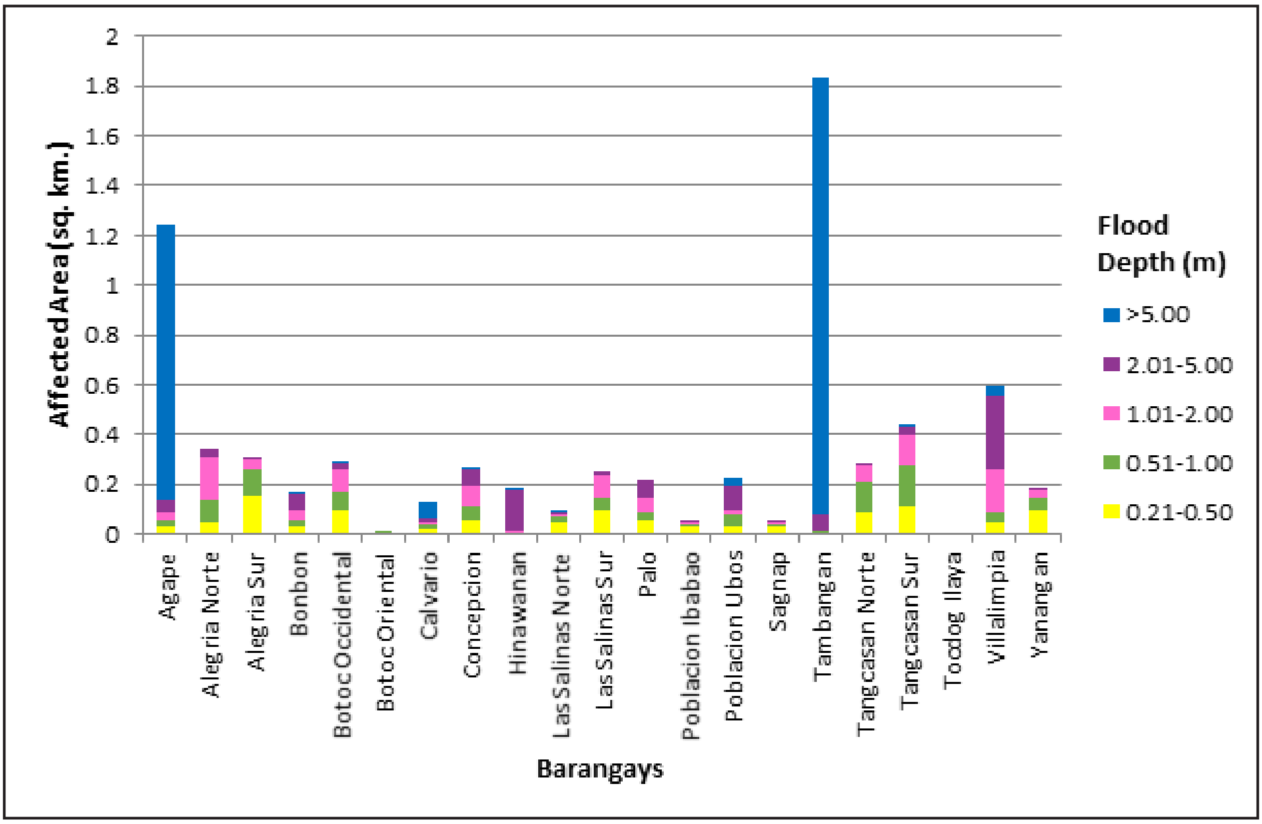


Figure 77. Affected Areas in Loay, Bohol during 100-Year Rainfall Return Period

Table 40. Affected Areas in Loay, Bohol during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loay (in sq. km.)										
	Agape	Alegria Norte	Alegria Sur	Bonbon	Botoc Occidental	Botoc Ori-ental	Calvario	Concepcion	Hinawanan	Las Salinas Norte	Las Salinas Sur
0.03-0.20	0.7	1.34	1.33	0.56	1.35	0.028	0.61	1.13	0.21	1.16	0.61
0.21-0.50	0.034	0.048	0.15	0.027	0.097	0.0029	0.021	0.052	0.006	0.048	0.098
0.51-1.00	0.023	0.086	0.11	0.025	0.069	0.00094	0.018	0.062	0.0033	0.021	0.049
1.01-2.00	0.028	0.17	0.036	0.041	0.098	0	0.011	0.079	0.0071	0.012	0.088
2.01-5.00	0.05	0.04	0.0035	0.067	0.022	0	0.014	0.065	0.16	0.0063	0.012
> 5.00	1.11	0	0	0.0011	0.00041	0	0.062	0.0016	0.0039	0.00059	0

Table 41. Affected Areas in Loay, Bohol during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loay (in sq. km.)									
	Palo	Poblacion Ibabao	Poblacion Ubos	Sagnap	Tambangan	Tangcasan Norte	Tangcasan Sur	Tocdog Ilaya	Villalimpia	Yanangan
0.03-0.20	0.3	0.15	0.1	0.59	0.29	2.2	2.46	0.0053	0.03	0.98
0.21-0.50	0.051	0.034	0.032	0.031	0.0056	0.084	0.11	0	0.043	0.093
0.51-1.00	0.033	0.0079	0.045	0.01	0.0041	0.12	0.17	0	0.042	0.048
1.01-2.00	0.059	0.008	0.017	0.0064	0.0068	0.068	0.13	0	0.17	0.036
2.01-5.00	0.075	0.000079	0.096	0.00078	0.066	0.0044	0.025	0	0.29	0.0018
> 5.00	0	0	0.038	0	1.75	0	0.01	0	0.045	0

For the municipality of Loboc, with an area of 57.85 sq. km., 10.7% will experience flood levels of less 0.20 meters. 0.45% of the area will experience flood levels of 0.21 to 0.50 meters while 0.42%, 0.27%, 0.15%, and 1.28% 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 are the affected areas in square kilometres by flood depth per barangay.

Table 42. Affected Areas in Loboc, Bohol during 100-Year Rainfall Return Period

Affected area (sq. km.) by flood depth (in m.)	Area of affected barangays in Loboc (in sq. km.)									
	Agape	Calunasan Norte	Calunasan Sur	Camayaan	Canlasid	Gon-Ob	Jimilian	Oy	Taytay	Valladolid
0.03-0.20	0.79	1.28	1.24	0.024	0.31	0.71	0.31	1.45	0.059	0
0.21-0.50	0.033	0.038	0.099	0.0008	0.01	0.024	0.0053	0.05	0.001	0
0.51-1.00	0.019	0.046	0.11	0.00055	0.01	0.017	0.0052	0.035	0.0003	0
1.01-2.00	0.015	0.037	0.048	0.0014	0.014	0.0093	0.0078	0.023	0.0005	0
2.01-5.00	0.027	0.019	0.011	0.0041	0.012	0.0023	0.0038	0.0061	0.0001	0
> 5.00	0.41	0	0	0.075	0.25	0.0001	0.0019	0.0001	0	0.000088

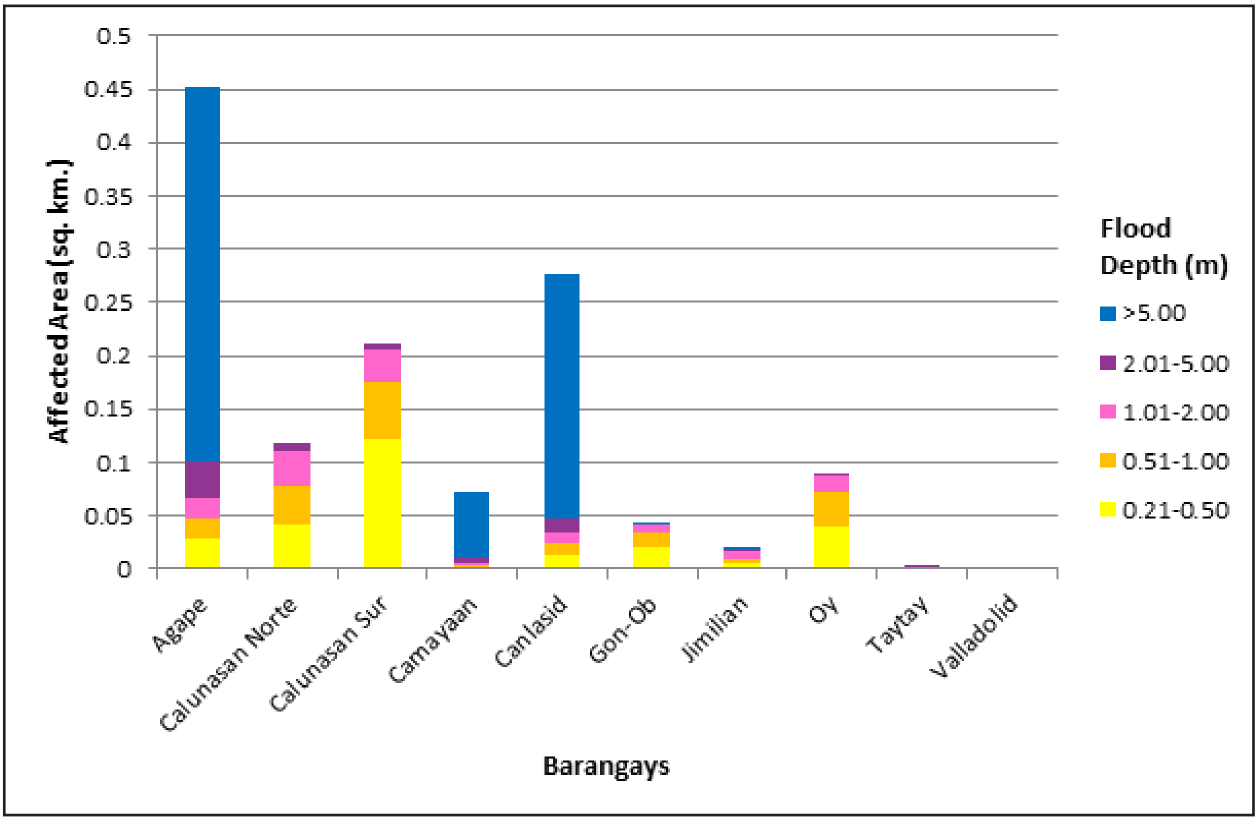


Figure 78. Affected Areas in Loboc, Bohol during 100-Year Rainfall Return Period

Among the barangays in the municipality of Albuquerque, Dangay is projected to have the highest percentage of area that will experience flood levels at 12.62%. Meanwhile, Tagbuane posted the second highest percentage of area that may be affected by flood depths at 11.5%.

Among the barangays in the municipality of Loay, Tangcasan Sur is projected to have the highest percentage of area that will experience flood levels at 11.13%. Meanwhile, Tangcasan Norte posted the second highest percentage of area that may be affected by flood depths at 9.53%.

Among the barangays in the municipality of Loboc, Oy is projected to have the highest percentage of area that will experience flood levels at 2.7%. Meanwhile, Calunasan Sur posted the second highest percentage of area that may be affected by flood depths at 2.61%.

Moreover, the generated flood hazard maps for the Loboc 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 yr, 25 yr, and 100 yr).

Table 43. Area covered by each warning level with respect to the rainfall scenario

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	1.33	1.22	1.19
Medium	1.82	2.18	1.93
High	4.18	5.37	6.74
TOTAL	**7.33**	**8.77**	**9.86**

Of the 16 identified Education Institutions in the Loboc Flood plain, 1 school was assessed to be exposed to medium level flooding during a 5 year scenario, while 1 school was assessed to be exposed to high level flooding in the same scenario. In the 25 year scenario, 3 schools were assessed to be exposed to medium level flooding, while 1 school was assessed to be exposed to high level flooding in the same scenario. In the 100 year scenario, 1 school was assessed to be exposed to medium level flooding, while 3 schools were assessed to be exposed to high level flooding in the same scenario. See Annex 12 for a detailed enumeration of schools in the Loboc floodplain.

One Medical Institution was identified in the Loboc Flood Plain, and it was assessed to be exposed to high level flooding in all of the three flooding scenarios (5yr, 25yr, and 100yr). See Annex 13 for a detailed enumeration of hospitals and clinics in the Loboc floodplain.

5.11 Flood Validation

A survey was done along the floodplain of Loboc River to validate the generated flood maps. The team gathered secondary data regarding flood occurrence in the area. Ground validation points were acquired as well as the other necessary details like date of occurrence, name of typhoon and actual flood depth.

During validation survey conducted last April 6 – 8, 2017, the team was assisted by the local Disaster Risk Reduction and Management representatives from the Municipalities of Loboc and Loay. Residents along the floodplain were interviewed of the historical flood events they experiences.

Actual flood depth acquired from the ground validation were then computed and compared to the flood depth simulated by the model. An RMSE value of 8.25 meters was obtained. The validation points are found in Annex 11.

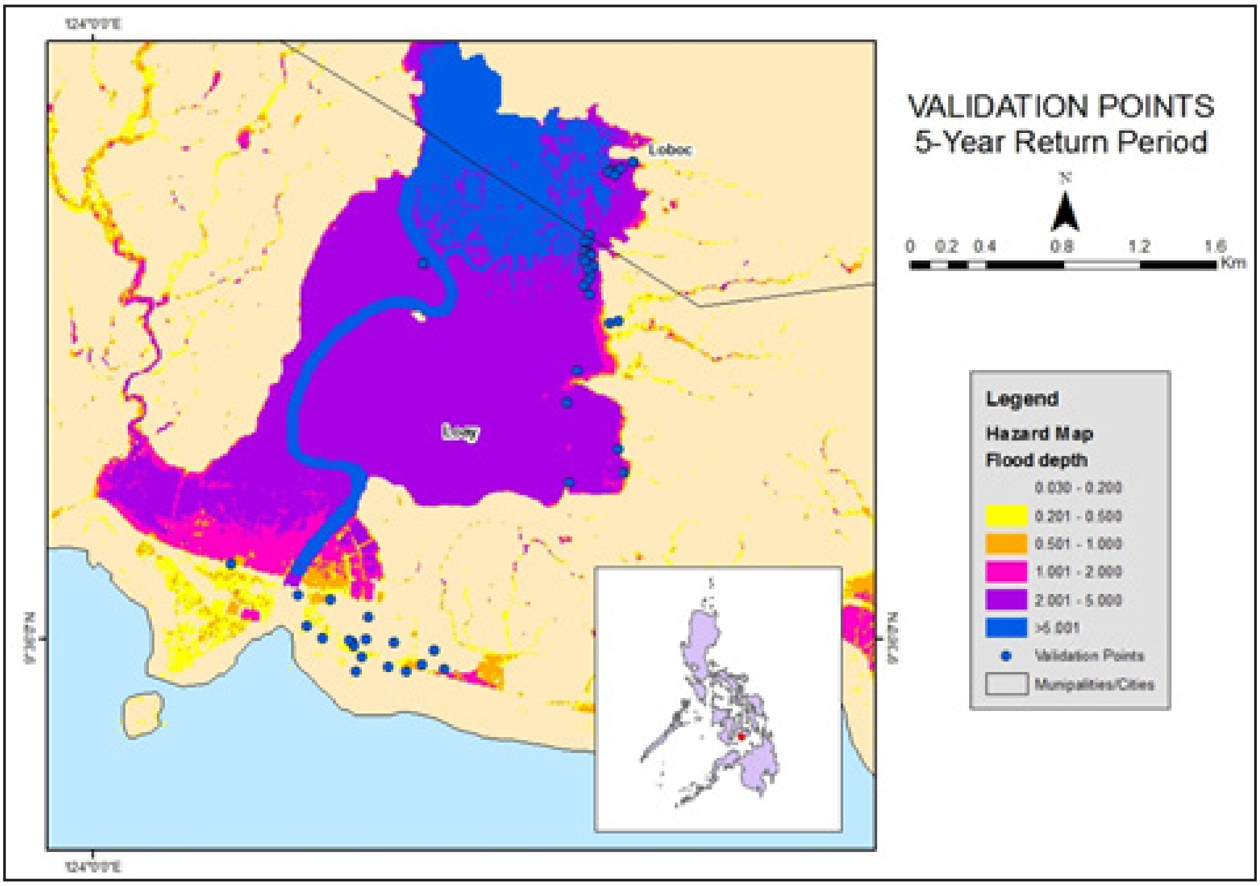


Figure 79. Validation Points for a 5-yr Flood Depth Map of the Loboc Floodplain

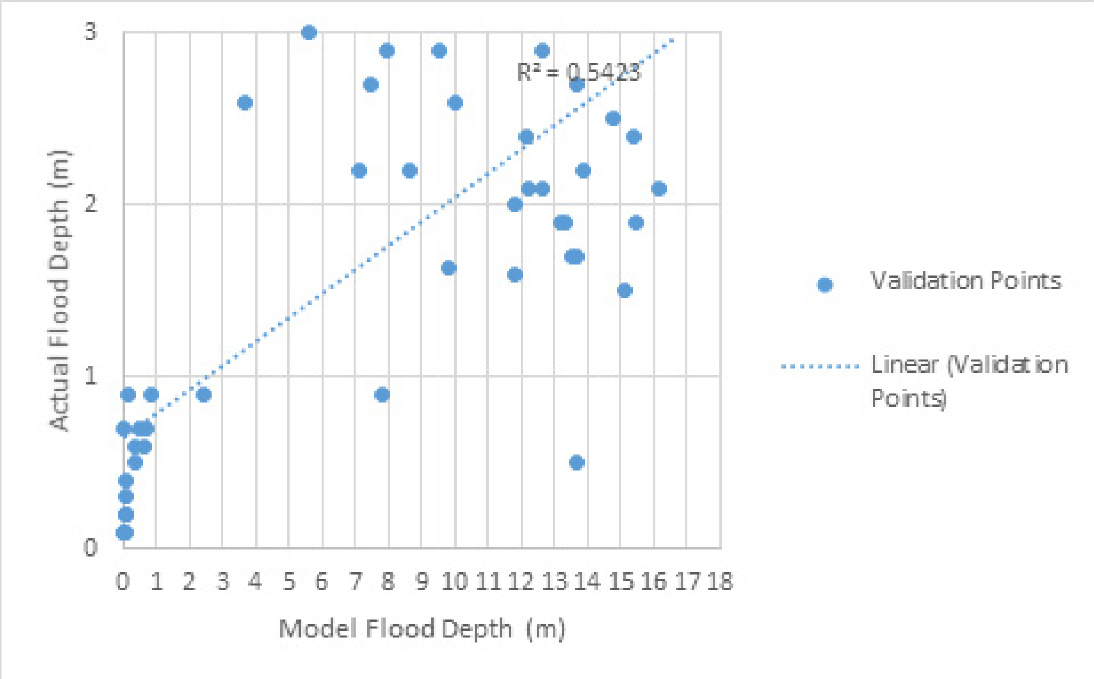


Figure 80. Flood map depth vs actual flood depth

Table 44. Actual flood vs simulated flood depth at differnent levels in the Loboc 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	6	0	0	0	0	0	6
0.21-0.50	2	1	0	0	0	1	4
0.51-1.00	2	1	4	0	1	1	9
1.01-2.00	0	0	0	0	0	9	9
2.01-5.00	0	0	0	0	1	23	24
> 5.00	0	0	0	0	0	0	0
Total	10	2	4	0	2	34	52

The overall accuracy generated by the flood model is estimated at 23.08% with 12 points correctly matching the actual flood depths. In addition, there were 25 points estimated one level above and below the correct flood depths while there were 12 points and 2 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 5 points were underestimated in the modelled flood depths of Loboc.

Table 45. Summary of the Accuracy Assessment in the Loboc River Basin Survey

	No. of Points	%
Correct	12	23.08
Overestimated	35	67.31
Underestimated	5	9.62
Total	52	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

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

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

Paringit, E.C., Balicanta, L.P., Ang, M.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

ANNEXES

ANNEX 1. Technical Specifications of the LiDAR Sensors used in the Loboc Floodplain Survey

Table A-1.1. Parameters and Specification of Sensors used in the Loboc Floodplain survey

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 footprint
5 Dependent on system configuration

ANNEX 2. NAMRIA Certification of Reference Points Used in the Loboc Floodplain Survey

Table A-2.1 NAMRIA Certification of Reference Points used in the Loboc Floodplain Survey

1. BHL-95

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

September 21, 2015

CERTIFICATION

To whom it may concern:

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

Province: **BOHOL**
Station Name: **BHL-95**
Order: **2nd**

Island: **VISAYAS**		Barangay: **TIGUIS**	
Municipality: **LILA**		MSL Elevation:	

PRS92 Coordinates

Latitude:	**9° 35' 30.88081"**	Longitude:	**124° 4' 30.02557"**	Ellipsoidal Hgt:	**22.55200 m.**

WGS84 Coordinates

Latitude:	**9° 35' 26.95624"**	Longitude:	**124° 4' 35.33566"**	Ellipsoidal Hgt:	**86.36200 m.**

PTM / PRS92 Coordinates

Northing:	**1060734.475 m.**	Easting:	**398460.059 m.**	Zone:	**5**

UTM / PRS92 Coordinates

Northing:	**1,060,411.09**	Easting:	**617,967.97**	Zone:	**51**

Location Description

BHL-95

From Loay Town travel NE to Lila, Bohol about 2.5 Km. from Lila Proper on the left side of the road. Mark is the head of a 3 in. copper nail embedded on a concrete monument 30 cm x 30 cm x 1.20 cm set to the ground 0.20 cm above ground level with inscritions, BHL-95, 2007, NAMRIA". Ref. no. 1 Electric post about 30 m SW; Ref. no. 2 Molave Tree near concrete post about 25 m NW; Station is about 60 m to the corner of Brgy. Tiguis on the NE.

recomputed 3/19/2014

Requesting Party:	**UP-DREAM**
Purpose:	**Reference**
OR Number:	**8087355 I**
T.N.:	**2015-2817**

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

9 9 0 9 2 1 2 0 1 5 1 2 4 1 3 1

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. BHL-95

2. BHL-96

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

September 21, 2015

CERTIFICATION

To whom it may concern:

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

	Province: **BOHOL**	
	Station Name: **BHL-96**	
	Order: **2nd**	
Island: **VISAYAS**	Barangay: **ANAS**	
Municipality: **VALENCIA**	MSL Elevation:	
	PRS92 Coordinates	
Latitude: **9° 35' 59.16579"**	Longitude: **124° 14' 18.58426"**	Ellipsoidal Hgt: **23.97900 m.**
	WGS84 Coordinates	
Latitude: **9° 35' 55.25356"**	Longitude: **124° 14' 23.89224"**	Ellipsoidal Hgt: **88.17600 m.**
	PTM / PRS92 Coordinates	
Northing: **1061559.452 m.**	Easting: **416409.846 m.**	Zone: **5**
	UTM / PRS92 Coordinates	
Northing: **1,061,340.27**	Easting: **635,908.05**	Zone: **51**

Location Description

BHL-96

From Valencia Town Proper go NE towards Garcia Hernandez at the last barrio of Valencia Sitio Tungon Brgy. Anas about 3 Km. from Valencia Proper on NW right side of the nat'l road. Mark is the head of a 3 in. copper nail embedded on a concrete monument 30 cm x 30 cm x 1.20 cm set to the ground by 1.0 m and 0.20 cm above the ground level with inscriptions, "BHL-96, 2007, NAMRIA". Ref. no. 1 Electric post 25 m NE; Ref. no. 2 Abueva Heritage Marked about 45 m NW.

Requesting Party: **UP-DREAM**
Purpose: **Reference**
OR Number: **8087355 I**
T.N.: **2015-2818**

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

9 9 0 9 2 1 2 0 1 5 1 2 4 1 4 6

CP/4701/12/09/814

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph
ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2. BHL-96

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

Table A-3.1. Baseline Processing Reports of Control Points used in the LiDAR Survey

1. BHL-96

Table A-3.1. BHL-96

Project Information		Coordinate System	
Name:		Name:	UTM
Size:		Datum:	PRS 92
Modified:	10/12/2012 4:40:11 PM (UTC:-6)	Zone:	51 North (123E)
Time zone:	Mountain Standard Time	Geoid:	EGMPH
Reference number:		Vertical datum:	
Description:			

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
BHL-95 --- BHL-96 (B1)	BHL-95	BHL-96	Fixed	0.007	0.028	87°12'52"	17967.841	1.445
BHL-95 --- BHL-96 (B2)	BHL-95	BHL-96	Fixed	0.008	0.025	87°12'51"	17967.733	1.458

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

BHL-95 - BHL-96 (3:24:12 PM-5:33:45 PM) (S1)

Baseline observation:	BHL-95 --- BHL-96 (B1)
Processed:	9/7/2014 8:02:29 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.007 m
Vertical precision:	0.028 m
RMS:	0.004 m
Maximum PDOP:	5.964
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	8/26/2014 3:24:27 PM (Local: UTC+8hr)
Processing stop time:	8/26/2014 5:33:45 PM (Local: UTC+8hr)
Processing duration:	02:09:18
Processing interval:	1 second

2. BHL-95

Table A-3.2. BHL-95

Vector Components (Mark to Mark)

From:	BHL-95				
Grid		Local		Global	
Easting	617967.834 m	Latitude	N9°35'30.95701"	Latitude	N9°35'27.03243"
Northing	1060413.425 m	Longitude	E124°04'30.02141"	Longitude	E124°04'35.33150"
Elevation	19.099 m	Height	18.988 m	Height	82.798 m

To:	BHL-96				
Grid		Local		Global	
Easting	635908.032 m	Latitude	N9°35'59.24046"	Latitude	N9°35'55.32822"
Northing	1061342.560 m	Longitude	E124°14'18.58410"	Longitude	E124°14'23.89209"
Elevation	21.036 m	Height	20.433 m	Height	84.630 m

Vector					
ΔEasting	17940.199 m	NS Fwd Azimuth	87°12'52"	ΔX	-14770.477 m
ΔNorthing	929.135 m	Ellipsoid Dist.	17967.841 m	ΔY	-10195.201 m
ΔElevation	1.937 m	ΔHeight	1.445 m	ΔZ	857.505 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.008 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.012 m
σ ΔElevation	0.014 m	σ ΔHeight	0.014 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000718223		
Y	-0.0000926247	0.0001333969	
Z	-0.0000152817	0.0000253463	0.0000091765

Occupations

	From	To
Point ID:	BHL-95	BHL-96
Data file:	C:\Users\Francis\Documents\Business Center - HCE\Unnamed\BHL-95 08-26-2014.T02	C:\Users\Francis\Documents\Business Center - HCE\Unnamed\BHL-96 08-26-2014.T02
Receiver type:	SPS852	SPS882
Receiver serial number:	5217K84538	5205482305
Antenna type:	Zephyr Geodetic 2	R8 GNSS/SPS88x Internal
Antenna serial number:	--------	2305
Antenna height (measured):	1.292 m	1.412 m
Antenna method:	Bottom of notch	Center of bumper

Tracking Summary

ANNEX 4. The LIDAR Survey Team Composition

Table A-4.1. The LIDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader - I	ENGR. CZAR JAKIRI SARMIENTO	
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	
LiDAR Operation	Senior Science Research Specialist	JASMINE ALVIAR	
	Research Associate	ENGR. IRO NIEL ROXAS	
		KRISTINE JOY ANDAYA	
Ground Survey		ENGR. MA. KATRINA RANESES	
LiDAR Operation	Airborne Security	SSG. MICHAEL BERONILLA	PHILIPPINE AIR FORCE (PAF)
	Pilot	CAPT. CESAR ALFONSO III	ASIAN AEROSPACE CORPORATION (AAC)
	Co-Pilot	CAPT. RANDY LAGCO	

ANNEX 5. Data Transfer Sheet for Loboc Floodplain

Table A-5.1. Data Transfer Sheet for Loboc Floodplain

DATA TRANSFER SHEET
09/09/2014(BOHOL ready)

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	
1867P	1BLK51M234	Pegasus	1.43	1.95	6.34	188	25	195	16.3	NA	10.8	1KB	1KB	262	NA	Z:\DAC\RAWDATA
1871P	1BLK51H235	Pegasus	3.8	4.06	9.09	222	52.8	402	36.7	NA	7.77	1KB	1KB	36	NA	Z:\DAC\RAWDATA
1883P	1BLK51L238A	Pegasus	972	1.13	5.69	145	18.3	159	11.6	NA	4.48	1KB	1KB	454	NA	Z:\DAC\RAWDATA
1885P	1BLK51I239A	Pegasus	3.16	3.43	8.98	236	44.1	325	32.5	NA	11.8	1KB	1KB	104	NA	Z:\DAC\RAWDATA
1895P	1BLK51K241A	Pegasus	2.05	2.50	7.51	204	26.9	207	21.9	NA	10.9	1KB	1KB	93.5	NA	Z:\DAC\RAWDATA

Received from

Name C JOAQUIN / 9/9/14
Position RA
Signature [signature]

Received by

Name JUDA PRIETO 9/12/14
Position SSRS
Signature [signature]

Figure A-5.1. Transfer Sheet for Loboc Floodplain - A

DATA TRANSFER SHEET
bohol 9/17/15

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	
10-Sep	3401P	1BLK51LS253A	pegasus	1.7	657/318	7.44	163	na	na	17.4	na	10.2	1KB	1KB	38/55/25	na	Z:\DAC\RAW DATA
11-Sep	3405P	1BLK51LS254A	pegasus	1.87	2606/367	8.31	176	na	na	19.4	na	6.91	1KB	1KB	38/55/25	na	Z:\DAC\RAW DATA
12-Sep	3409P	1BLK51B255A	pegasus	1.6	525/635	14.1	302	na	na	32.8	na	15.7	1KB	1KB	42	na	Z:\DAC\RAW DATA
12-Sep	3411P	1BLK51C255B	pegasus	1.24	1826/263	5.78	151	na	na	12.9	na	15.7	1KB	1KB	na	na	Z:\DAC\RAW DATA

Received from

Name
Position
Signature 9/17/15

Received by

Name AC Bongat
Position SSRS
Signature 9/21/15

Figure A-5.2. Transfer Sheet for Loboc Floodplain - B

ANNEX 6. Flight logs for the Flight Missions

Table A-6.1. Flight Logs for the Flight Missions

1. Flight Log for Mission 1BLK51I239A

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 1883P

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Peg	3 Mission Name: 1BLK51L238A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: K. Andrews	9 Route: Bohol			
10 Date: August 26, 2014	12 Airport of Departure (Airport, City/Province): Bohol		12 Airport of Arrival (Airport, City/Province): Bohol		
13 Engine On: 1507H	14 Engine Off: 1736H	15 Total Engine Time: 2+29	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Cloudy				

20 Remarks:

Data acquired on BLK51L at 1200m; Only half of survey areas completed due to cloud buildup.

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
G. Hipolito		Cesar Alfonso III	Grace Sinadjan
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.1. Flight Log for Mission 1BLK51I239A

2. Flight Log for Mission 1BLK51I239A

PHIL-LiDAR 1 Data Acquisition Flight Log

Flight Log No.: 1885P

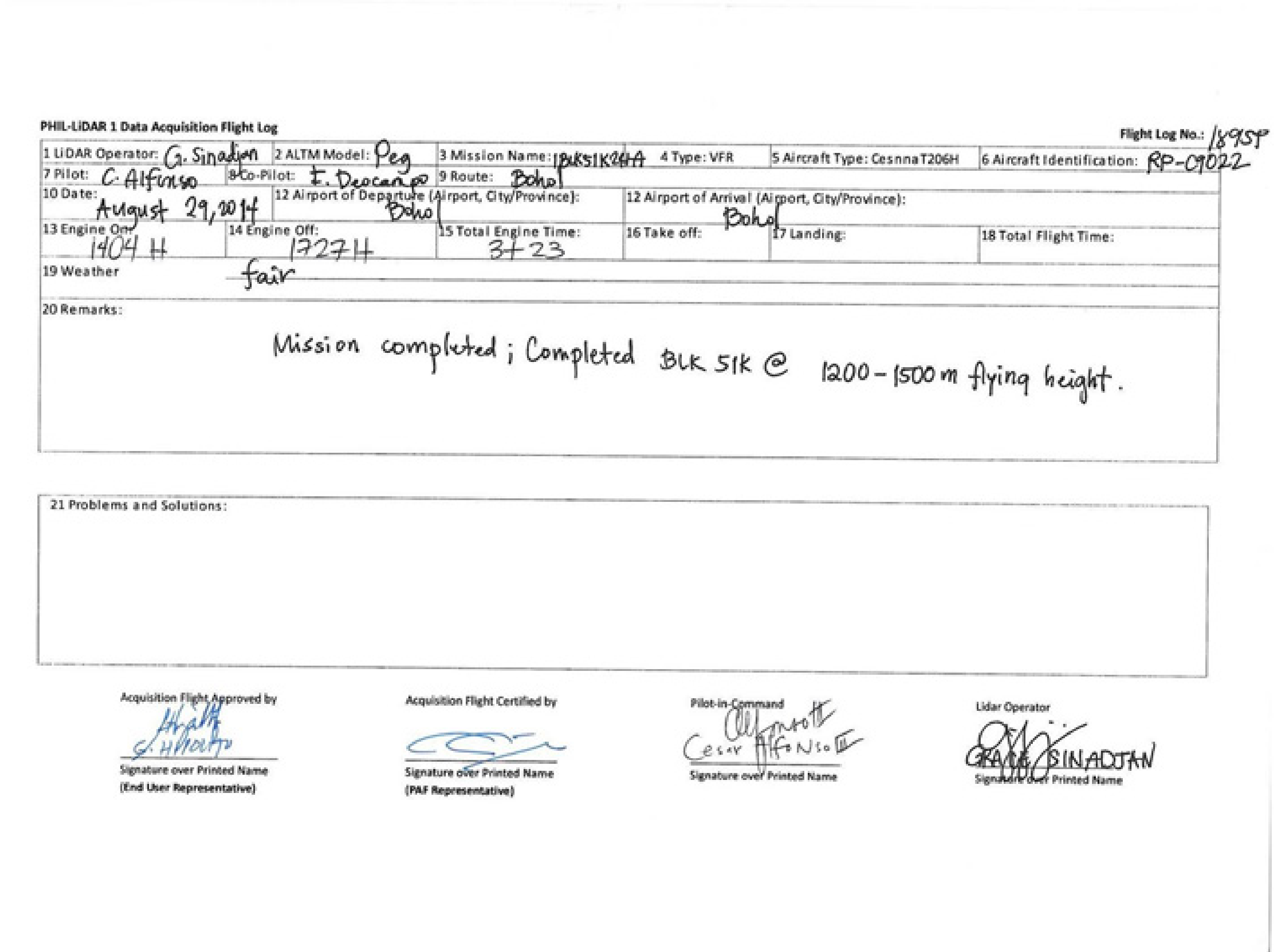
1 LiDAR Operator: I. Roxas	2 ALTM Model: Peg	3 Mission Name: 1BLK51I239A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification:
7 Pilot: C. Alfonso	8 Co-Pilot: K. Andrews	9 Route: Bohol			
10 Date: August 27, 2014	12 Airport of Departure (Airport, City/Province): Bohol		12 Airport of Arrival (Airport, City/Province): Bohol		
13 Engine On: 0934H	14 Engine Off: 1327H	15 Total Engine Time: 3+53	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	Cloudy				
20 Remarks:					

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
G. H Molito		Cesar Alfonso III	Iro Roxas
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.2. Flight Log for Mission 1BLK51I239A

3. Flight Log for Mission 1BLK51K241A



PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 1895P

1 LiDAR Operator: G. Sinadjan	2 ALTM Model: Peg	3 Mission Name: 1BLK51K241A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: C. Alfonso	8 Co-Pilot: F. Deocampo	9 Route: Bohol			
10 Date: August 29, 2014	12 Airport of Departure (Airport, City/Province): Bohol		12 Airport of Arrival (Airport, City/Province): Bohol		
13 Engine On: 1404 H	14 Engine Off: 1727 H	15 Total Engine Time: 3+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: fair					

20 Remarks:

Mission completed; Completed BLK 51K @ 1200-1500 m flying height.

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
C. Alfonso		Cesar Alfonso III	Grace Sinadjan
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 1BLK51K241A

4. Flight Log for Mission 1BLK51LS253A

PHIL-LIDAR 1 Data Acquisition Flight Log

Flight Log No.: 3401P

1 LiDAR Operator: T. Rosos	2 ALTM Model: Peg	3 Mission Name: 1BLK51LS253A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RPC9022
7 Pilot: C. Alfonso	8 Co-Pilot: R. Lasco	9 Route: Tagbilaran – Tagbilaran			
10 Date: Sept 10, 2015	12 Airport of Departure (Airport, City/Province): Tagbilaran		12 Airport of Arrival (Airport, City/Province): Tagbilaran		
13 Engine On:	14 Engine Off:	15 Total Engine Time: 2+41	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: partly cloudy					

20 Flight Classification

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

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

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

21 Remarks

Surveyed BLK 51LS

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

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	LiDAR Operator	Aircraft Mechanic/ LiDAR Technician
J. Alviar	B. Bayrinia	C. Alfonso III		
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name	Signature over Printed Name

Figure A-6.3. Flight Log for Mission 1BLK51K241A

ANNEX 7. Flight status reports

FLIGHT STATUS REPORT
BOHOL
Table A-7.1. Flight Status Report

FLIGHT NO.	MISSION NAME	AREA NAME	AREA SURVEYED (sq km)	OPERATOR	DATE FLOWN	REMARKS
1883P	1BLK51L238A	BLK51L	84.253	G. SINADJAN	AUG 26	Data acquired on Blk 51L at 1200m; Only half of survey area completed due to cloud buildup
1885P	1BLK51I239A	BLK51I	198.521	I.ROXAS	AUG 27	Surveyed BLK51I; Voids due to low clouds
1895P	1BLK51K241A	BLK51K	191.98	G. SINADJAN	AUG 29	Mission completed; Completed blk 51K at 1200-1500m flying height
3401P	1BLK51LS253A	BLK 51KS VOIDS	89.71	I.ROXAS	SEPT10	Surveyed blk 51ks; voids due to clouds; 1000m alt; abnormal avposview termination; digi hd writing error
3405P	1BLK51LS254A	BLK 51LS LOBOC FP	135.67	KJ ANDAYA	SEPT 11	Surveyed blk 51ls loboc fp; voids due to clouds; abnormal avposview termination; digi hd writing error; 1100m alt

Flight No. : 1883P
Area: BLK51L
Mission Name: 1BLK51L238A
Parameters: PRF 200kHz SF 30Hz FOV 50⁰

Figure A-7.1. Swath for Flight No. 1883P

Flight No. : 1885P
Area: BLK51I
Mission Name: BLK51I239A
Parameters: PRF 200kHz SF 30Hz FOV 50⁰

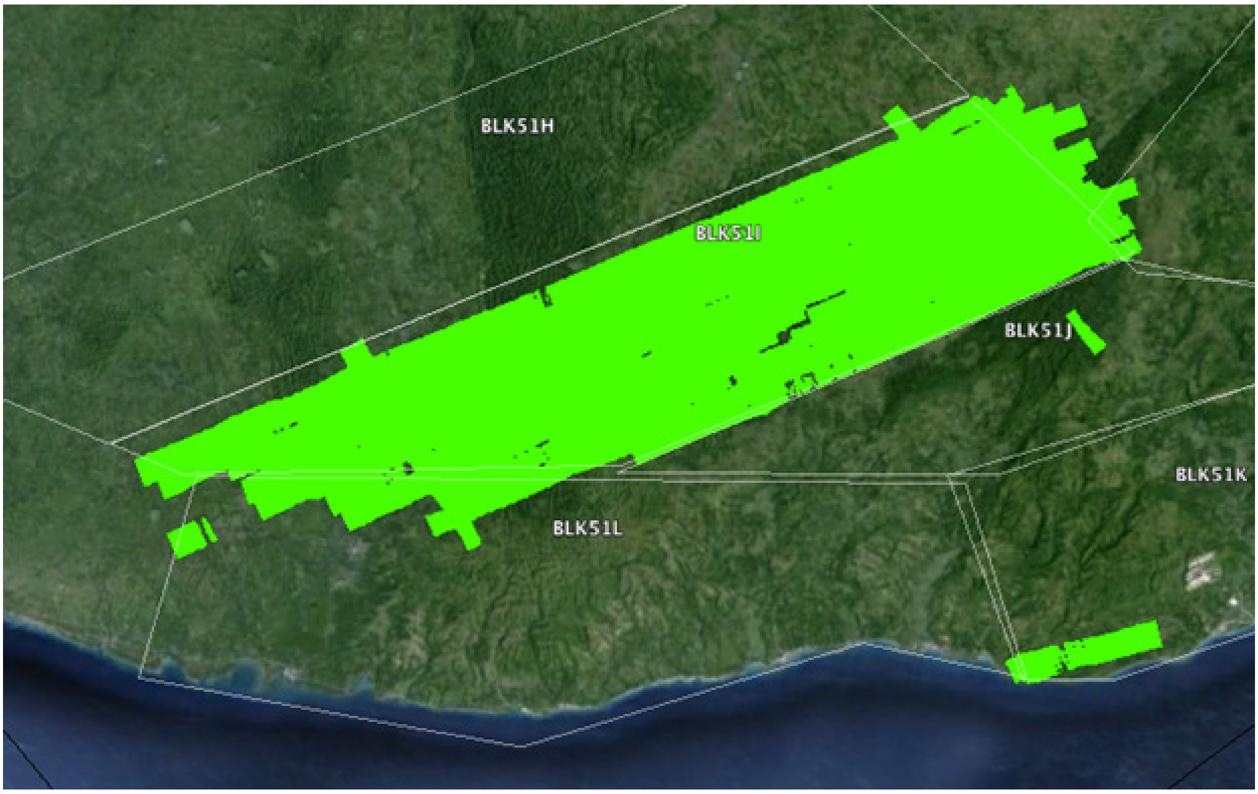


Figure A-7.2. Swath for Flight No. 1885P

Flight No. :	1895P
Area:	BLK51K
Mission Name:	1BLK51K241A
Parameters:	PRF 200kHz SF 30Hz FOV 50θ

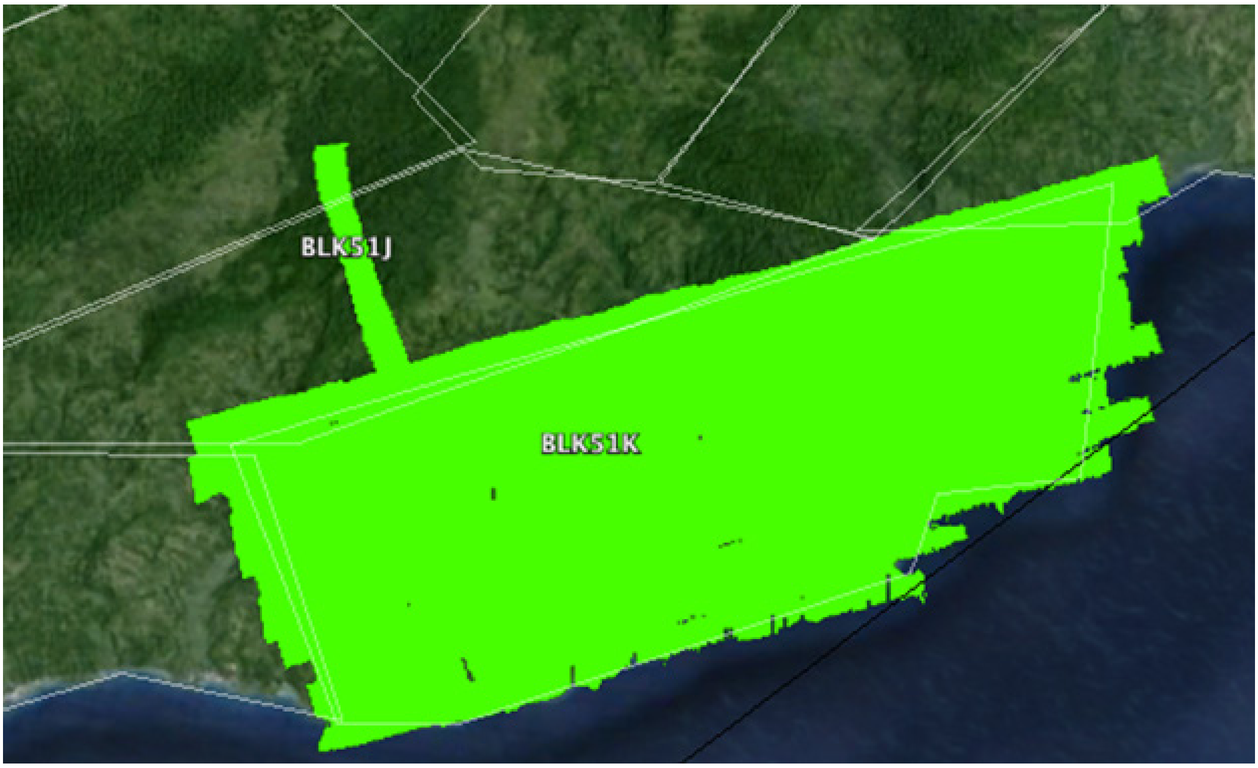


Figure A-7.3. Swath for Flight No. 1895P

Flight No. :	3401P
Area:	BLK 51KS VOIDS
Mission Name:	1BLK51LS253A
Parameters:	PRF 200kHz SF 30Hz FOV 50⁰

LAS/SWATH

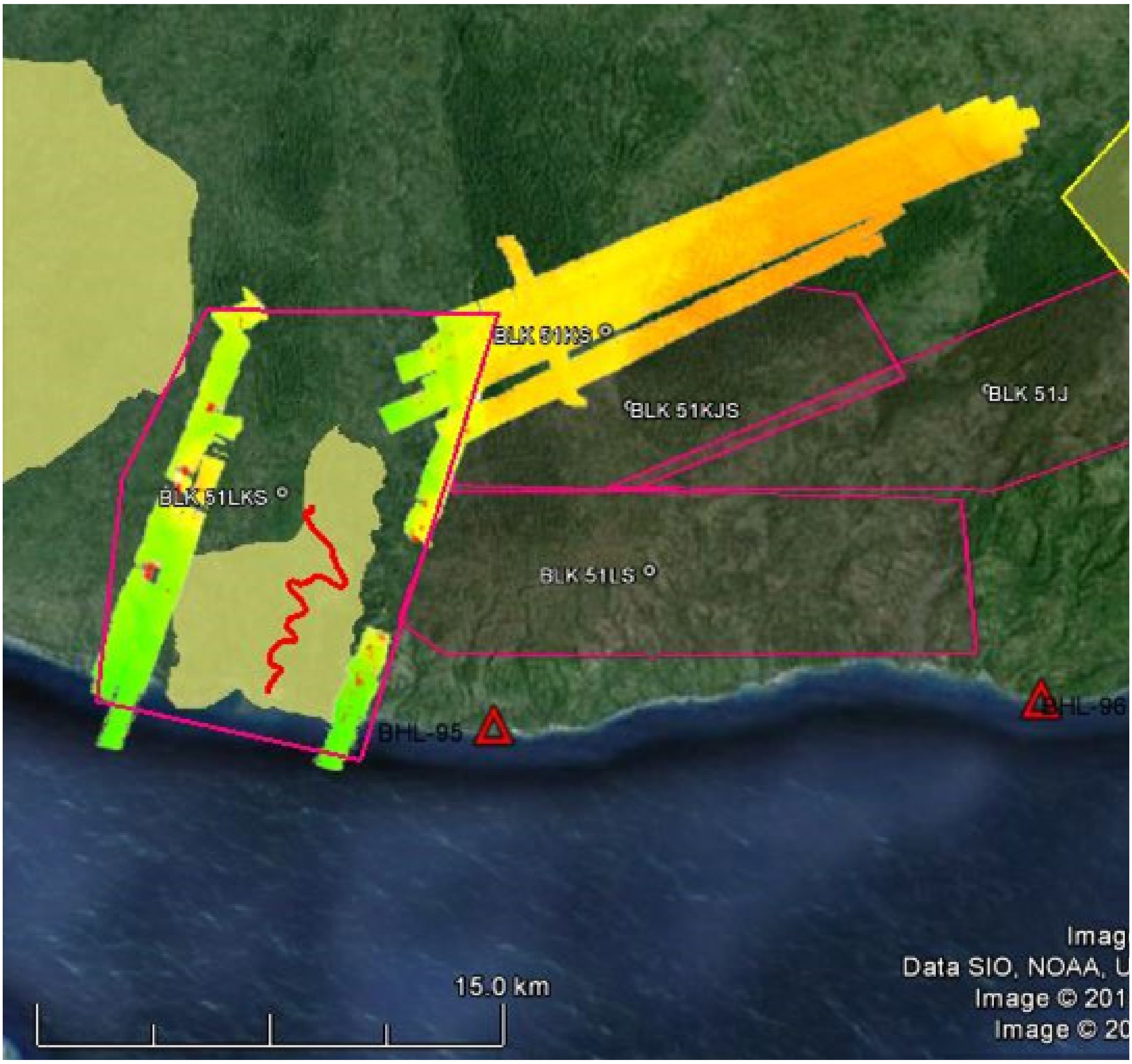


Figure A-7.4. Swath for Flight No. 3401P

Flight No. :	3405P
Area:	BLK 51LS LOBOC FP
Mission Name:	1BLK51LS254A
Parameters:	PRF 200kHz SF 30Hz FOV 50θ

LAS/SWATH

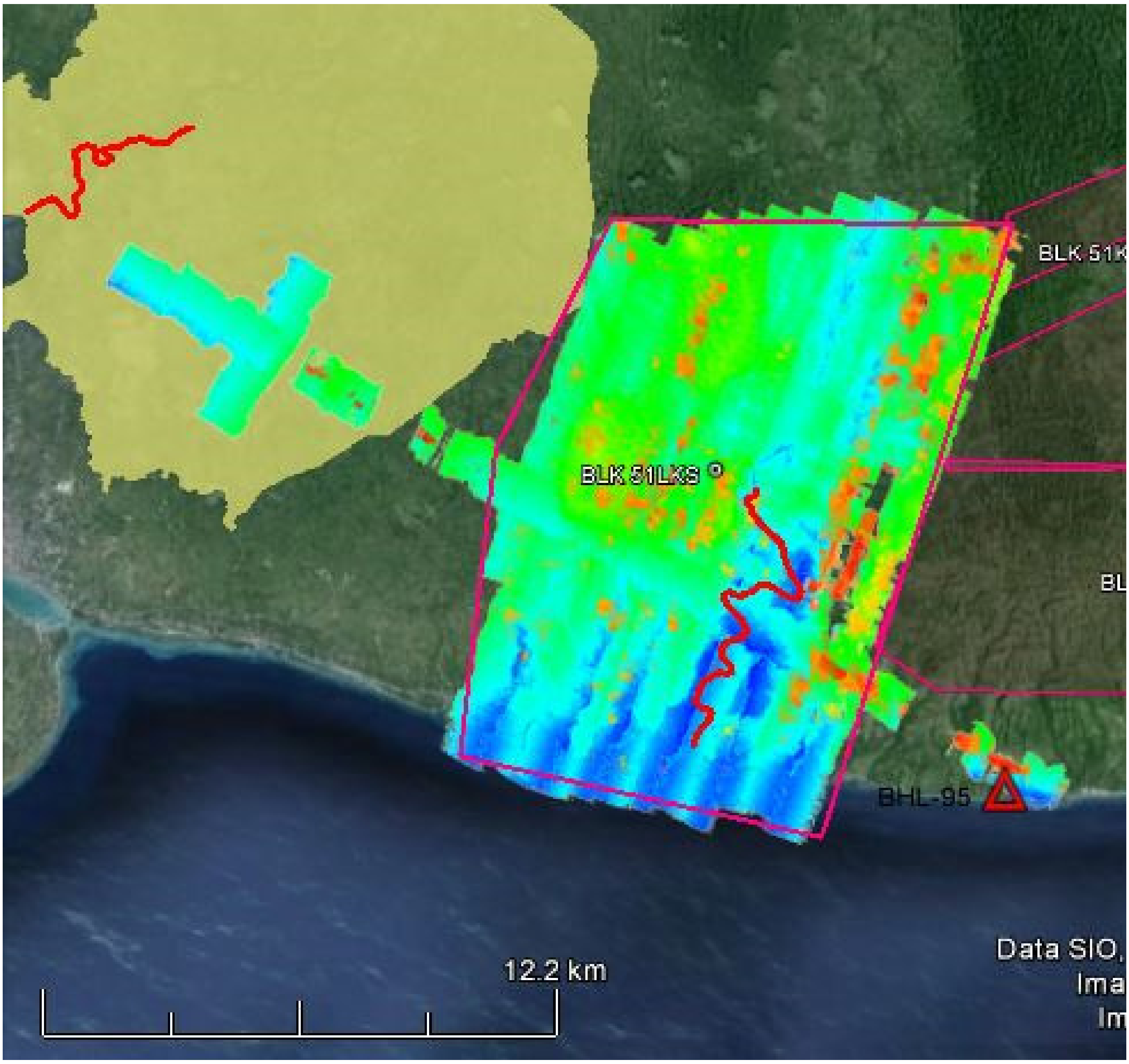


Figure A-7.5. Swath for Flight No. 3405P

ANNEX 8. Mission Summary Reports

Table A-8.1. Missions Summary Reports

Flight Area	Ilocos
Mission Name	Blk06_A
Inclusive Flights	7104GC, 7105GC
Range data size	42.6GB
Base data size	24.9 MB
POS	460MB
Image	N/A
Transfer date	April 22, 2014
Solution Status	
Number of Satellites (>6)	No
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.7
RMSE for East Position (<4.0 cm)	3.3
RMSE for Down Position (<8.0 cm)	3.3
Boresight correction stdev (<0.001deg)	0.000184
IMU attitude correction stdev (<0.001deg)	0.000642
GPS position stdev (<0.01m)	0.0064
Minimum % overlap (>25)	37.38%
Ave point cloud density per sq.m. (>2.0)	3.43
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	419
Maximum Height	614.2m
Minimum Height	39.17m
Classification (# of points)	
Ground	167,502,975
Low vegetation	193,929,105
Medium vegetation	261,271,939
High vegetation	401,795,646
Building	13,519,422
Orthophoto	NO
Processed by	Engr. Kenneth Solidum, Engr. Abigail Ching, Engr. Harmond Santos, Engr. Melissa Fernandez

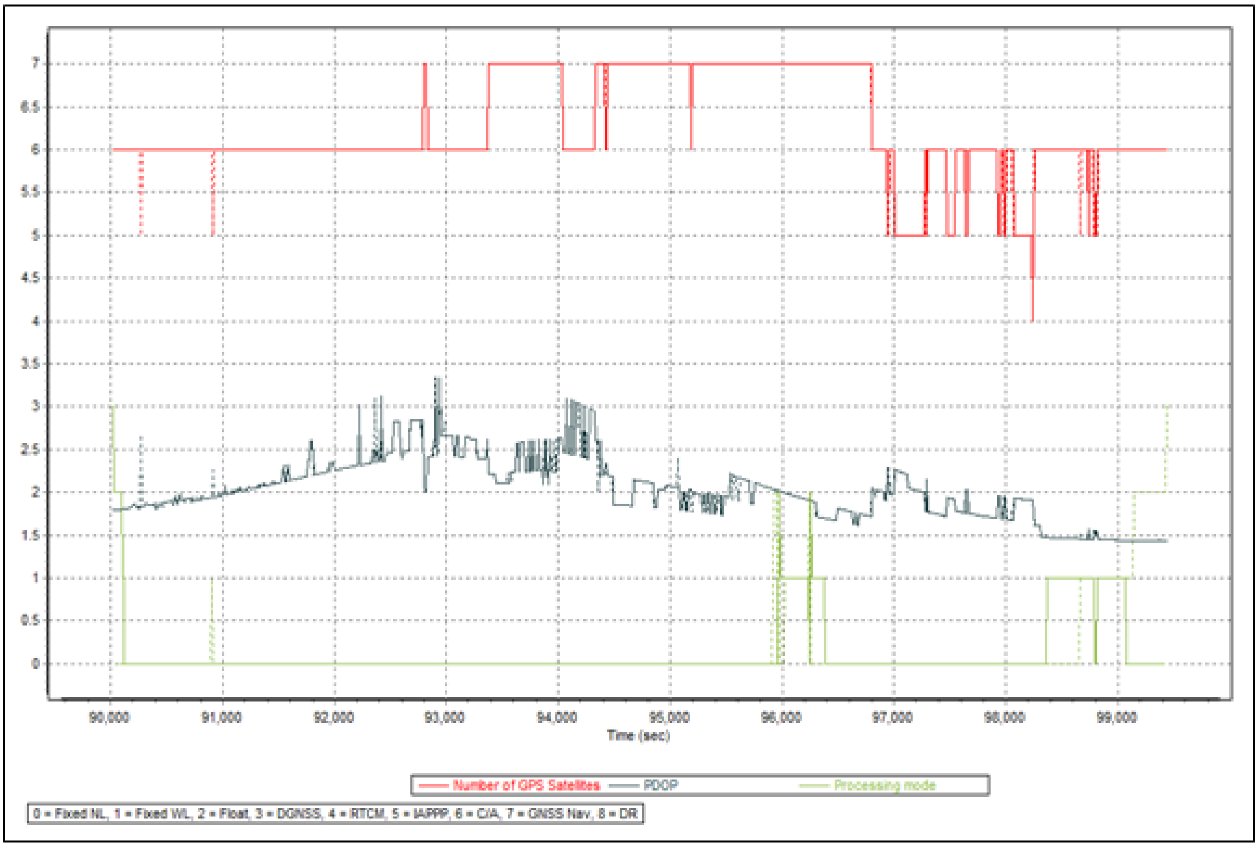


Figure A-8.1. Solution Status

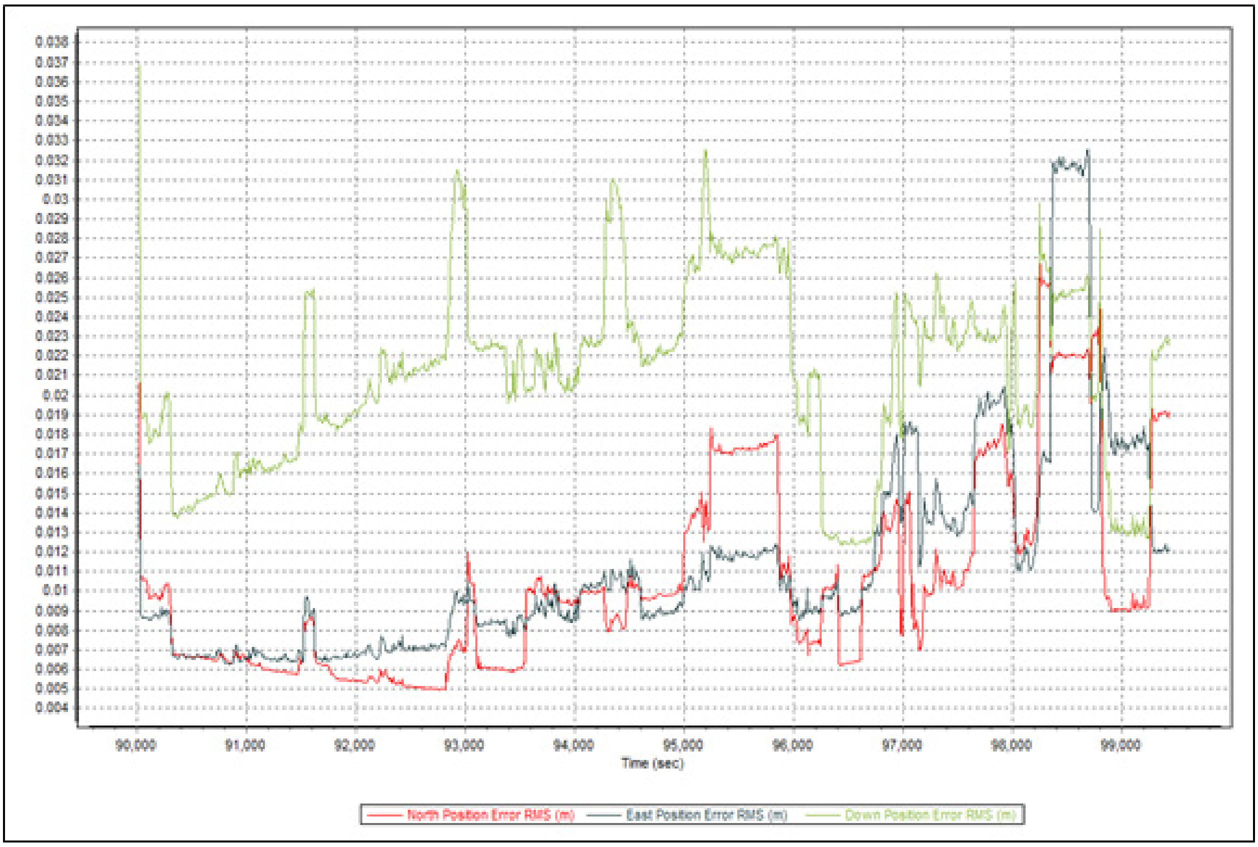


Figure A-8.2. Smoothed Performance Metrics Parameters

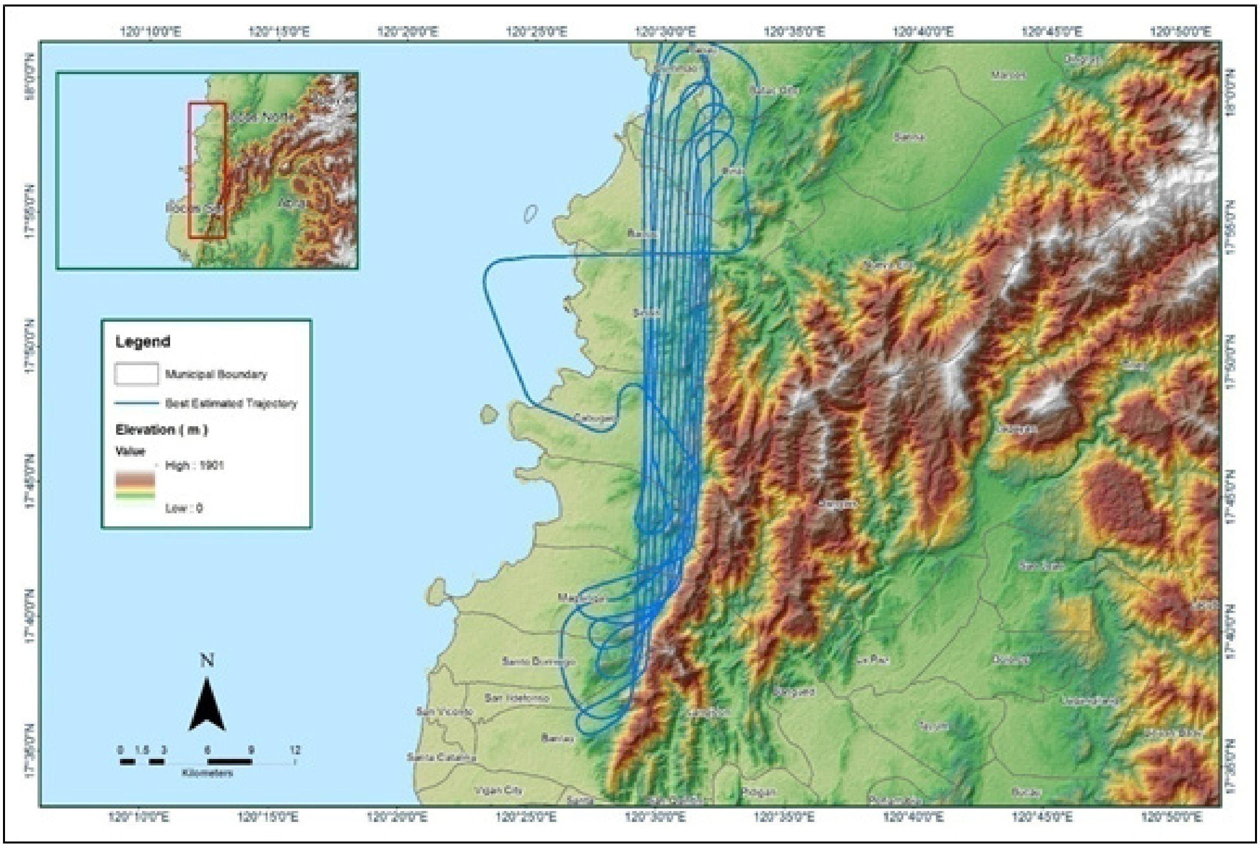


Figure A-8.3. Best Estimated Trajectory

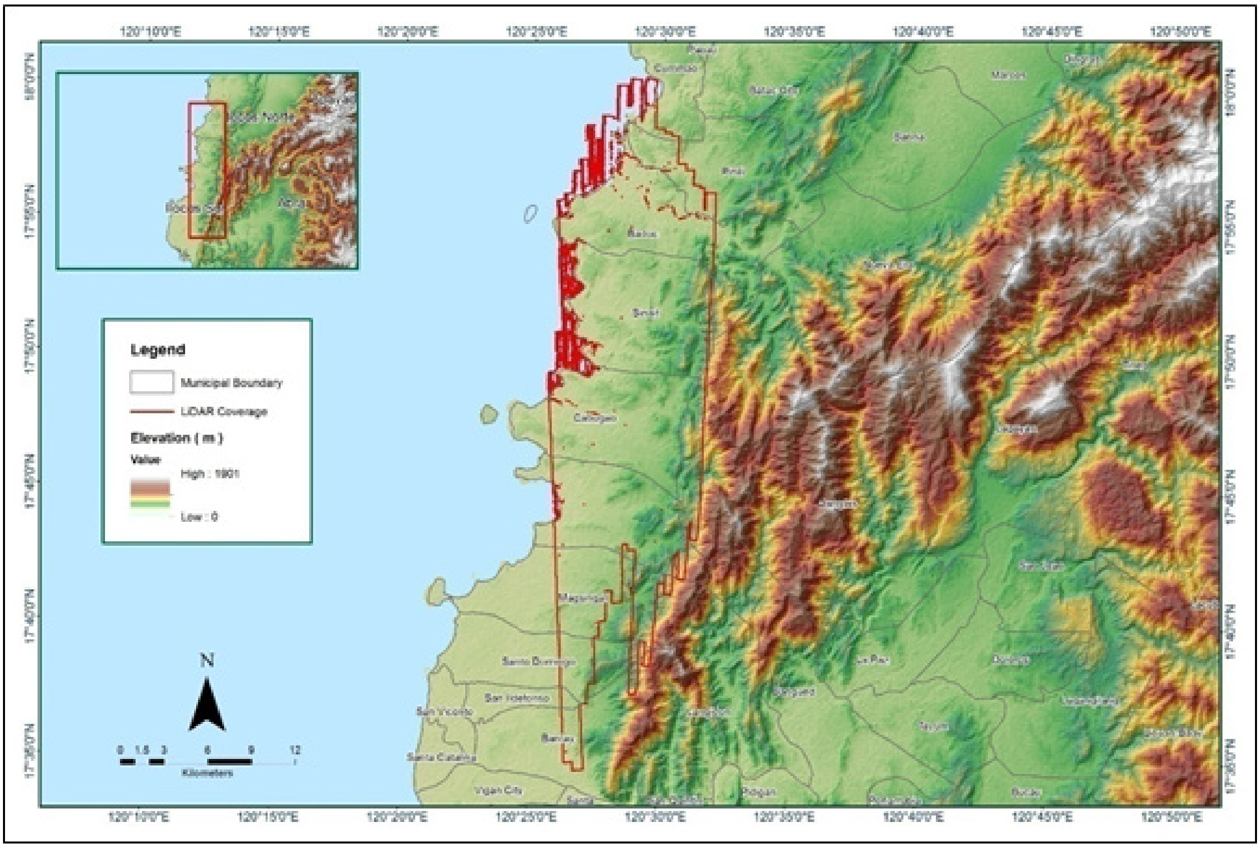


Figure A-8.4. Coverage of LiDAR data

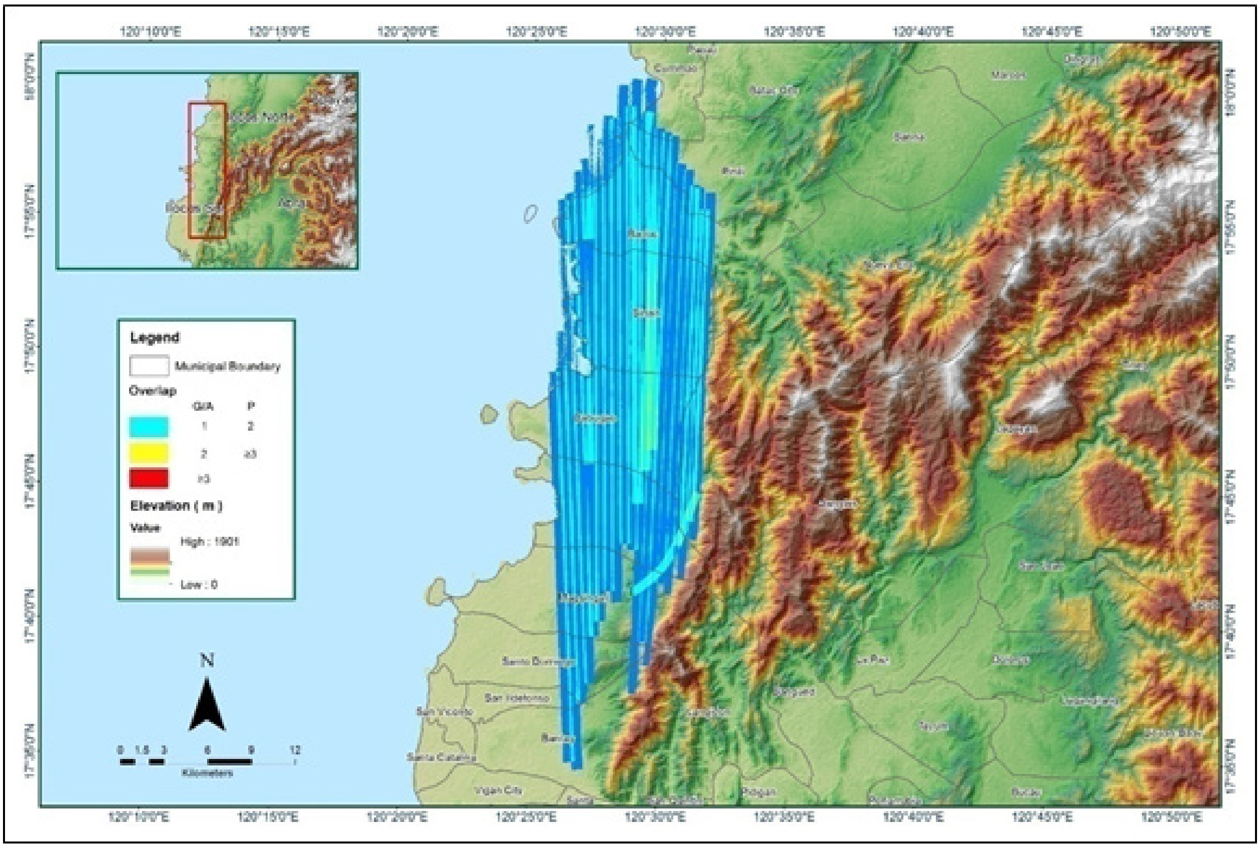


Figure A-8.5. Image of Data Overlap

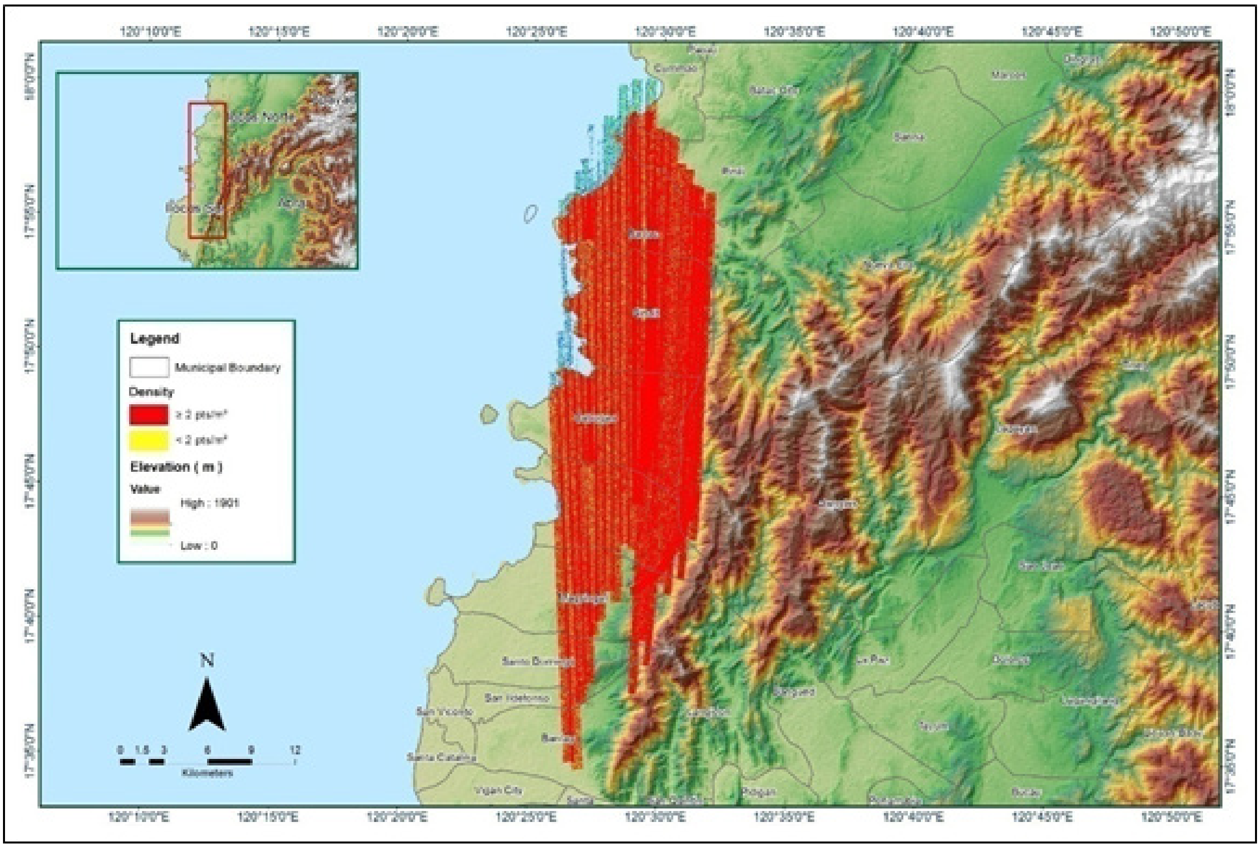


Figure A-8.6.Density map of merged LiDAR data

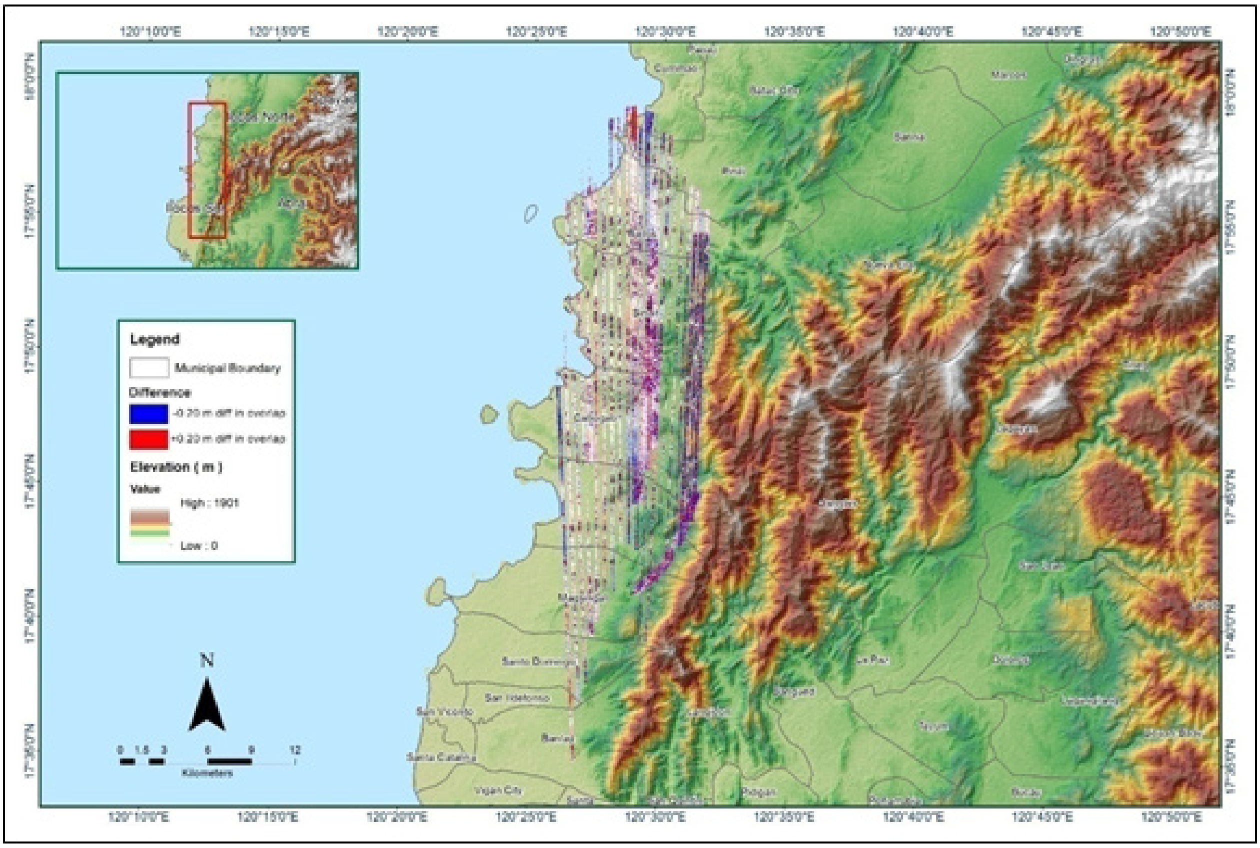


Figure A-8.7. Elevation difference between flight lines

ANNEX 9. Loboc Model Basin Parameters

Table A-9.1. Loboc Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W440	55.455	35.176	0	5.74974	5.5757	Discharge	0.0392564	6.65E-05	Ratio to Peak	0.9
W450	44.392	35.37	5	1.7873	7.3924	Discharge	0.0618306	0.00022601	Ratio to Peak	0.0774331
W460	39.646	50.118	10	3.4115	2.6122	Discharge	0.0463778	0.000988242	Ratio to Peak	0.99002
W470	43.234	35.494	0	5.3359	3.6514	Discharge	0.12456	9.93E-05	Ratio to Peak	0
W480	110.41	35.176	0	0.99054	3.1811	Discharge	0.0498632	4.42E-05	Ratio to Peak	1
W490	43.853	35.175	0	0.0166667	10.018	Discharge	0.34178	0.0394925	Ratio to Peak	0.79355
W500	53.67	36.575	0	4.1638	8.6216	Discharge	0.0914393	0.0120773	Ratio to Peak	0.42685
W510	55.363	35.045	0	3.65	10.199	Discharge	0.0939168	0.000770756	Ratio to Peak	0.25972
W520	35.111	94.836	0	1.4292	8.5296	Discharge	0.0123087	0.0024483	Ratio to Peak	0.61398
W530	33.606	99	20	5.7738	4.1598	Discharge	0.0462545	0.0025072	Ratio to Peak	0.16029
W540	19.006	36.697	0	5.0193	0.6033	Discharge	0.036783	0.0011618	Ratio to Peak	0
W550	58.573	35.176	0	1.370455	5.2984	Discharge	0.0216909	0.0017489	Ratio to Peak	0.36582
W560	45.28	35.006	0	2.2985	3.3573	Discharge	0.0674305	0.0081707	Ratio to Peak	0.34551
W570	61.696	93.306	5	2.2984	7.5187	Discharge	0.0238665	0.0017508	Ratio to Peak	0.9
W580	38.336	55.092	0	3.8573	3.5701	Discharge	0.044916	0.0035989	Ratio to Peak	1
W590	87.696	40.007	0	2.279	15.686	Discharge	0.0686733	0.0025105	Ratio to Peak	0.9
W600	10.598	46.217	10	3.4244	1.2194	Discharge	0.0156932	0.0039403	Ratio to Peak	0.0145369
W610	33.826	37.727	0	1.5029	3.8941305	Discharge	0.06758	0.0011561	Ratio to Peak	0.995
W620	83.889	92.376	10	3.315	23.754	Discharge	0.0922246	0.0017076	Ratio to Peak	0.9
W630	69.852	35.175	0	0.18052	9.0243	Discharge	0.14118	0.0024483	Ratio to Peak	0.9
W650	42.694	67.686	10	2.8515	6.0887	Discharge	0.0183597	0.0176534	Ratio to Peak	0.78478
W660	15.188	69.0438	0	2.9109	3.4672	Discharge	0.0280822	0.0136277	Ratio to Peak	0.17918

W670	53.079	35.176	0	0.93691	6.2953	Discharge	0.0473202	0.0441369	Ratio to Peak	0.15975
W680	86.177	40.483	0	2.3961	8.4975	Discharge	0.10751	0.0016655	Ratio to Peak	0.9
W690	121.71	70.73	10	3.3203	19.513	Discharge	0.0284913	0.0015295	Ratio to Peak	0.9
W700	65.365	35.176	0	8.5983	4.2507	Discharge	0.0741827	0.0432819	Ratio to Peak	0.2507
W710	35.743	35.176	0	2.9289	6.1435	Discharge	0.0078271	0.0287072	Ratio to Peak	0.14369
W720	36.142	35.174	0	9.4534	1.4004	Discharge	0.0724888	0.0129601	Ratio to Peak	0.0233677
W730	110.41	39.299	0	16.615	13.779	Discharge	0.0513445	0.0154238	Ratio to Peak	0.9
W740	31.053	35.176	0	0.16867	2.8861	Discharge	0.063285	0.0769979	Ratio to Peak	0.65503
W750	120.37	56.714	0	0.8633	6.8939	Discharge	0.0350743	0.0090388	Ratio to Peak	0.90326
W760	70.87	35.176	0	6.6447	0.47294	Discharge	0.0519382	0.0015684	Ratio to Peak	0.0045008
W770	16.427	44.283	0	2.443665	22.812	Discharge	0.0306959	0.0205371	Ratio to Peak	0.29575
W780	55.434	35.576	0	3.6001	2.3844	Discharge	0.0571555	0.0077006	Ratio to Peak	0.11996
W790	47.144	35.176	0	0.16232	5.9711	Discharge	0.041637	0.0250125	Ratio to Peak	0.52096
W800	12.546	39.301	0	0.16752	3.4386	Discharge	0.0101599	0.0271602	Ratio to Peak	0.19979
W810	61.137	35.175	0	1.6039	21.51	Discharge	0.42339	0.0076354	Ratio to Peak	0.9
W820	11.771	35.204	0	4.7257	0.89131	Discharge	0.0177666	0.0132863	Ratio to Peak	0.0333599
W830	37.671	35.176	0	0.14605	3.8687	Discharge	0.0580944	0.0448355	Ratio to Peak	0.45829
W840	25.541	38.672	0	0.14621	2.4777	Discharge	0.0203296	0.0429185	Ratio to Peak	0.21197
W850	39.701	35.176	0	0.16529	6.8427	Discharge	0.0517551	0.02789	Ratio to Peak	0.56284
W910	48.296	35.176	0	8.9128	7.9098	Discharge	0.0565167	0.13887	Ratio to Peak	0.38981
W920	40.88	35.334	0	4.387785	2.7136	Discharge	0.0440514	0.0399213	Ratio to Peak	0.75179
W960	26.082	41.57	0	0.2377	0.77395	Discharge	0.0547452	0.0784717	Ratio to Peak	0.85304
W970	35.513	35.176	0	0.14414	4.8247	Discharge	0.0192989	0.0451495	Ratio to Peak	0.0477064

ANNEX 10. Loboc Model Reach Parameters

Table A-10.1. Ikmin Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R110	Automatic Fixed Interval	4668.4	0.000856967	0.0203649	Trapezoid	30	1
R120	Automatic Fixed Interval	4617.2	0.00087178	0.17295	Trapezoid	30	1
R130	Automatic Fixed Interval	2791.5	0.0076488	0.043602	Trapezoid	30	1
R140	Automatic Fixed Interval	2034.2	0.0047637	0.008955	Trapezoid	30	1
R150	Automatic Fixed Interval	4526.3	0.0013428	0.036198	Trapezoid	30	1
R170	Automatic Fixed Interval	2485.2	0.0087735	0.0491541	Trapezoid	30	1
R210	Automatic Fixed Interval	10953	0.0112372	0.0431784	Trapezoid	30	1
R240	Automatic Fixed Interval	3639.6	0.0175104	0.0279148	Trapezoid	30	1
R250	Automatic Fixed Interval	4481.6	0.0095718	0.000336075	Trapezoid	30	1
R260	Automatic Fixed Interval	1687.5	0.0037345	0.0399368	Trapezoid	30	1
R290	Automatic Fixed Interval	8867.2	0.012237	0.0309434	Trapezoid	30	1
R30	Automatic Fixed Interval	5118	0.000613982	0.0112264	Trapezoid	30	1
R320	Automatic Fixed Interval	2455.9	0.000781464	0.1313128	Trapezoid	30	1
R360	Automatic Fixed Interval	6228.3	0.004604	0.0110676	Trapezoid	30	1
R370	Automatic Fixed Interval	1499.9	0.0291676	0.0010675	Trapezoid	30	1
R400	Automatic Fixed Interval	1958.7	0.0062065	0.000358736	Trapezoid	30	1
R420	Automatic Fixed Interval	1489.4	0.011072	0.0001	Trapezoid	30	1
R430	Automatic Fixed Interval	22288	0.0041508	0.0241179	Trapezoid	30	1
R60	Automatic Fixed Interval	1511.1	0.0039706	0.13928	Trapezoid	30	1
R80	Automatic Fixed Interval	8364.5	0.0073538	0.0048629	Trapezoid	30	1
R90	Automatic Fixed Interval	1181.7	0.0097163	0.0739851	Trapezoid	30	1
R930	Automatic Fixed Interval	2571.1	0.0070727	0.0327241	Trapezoid	30	1
R990	Automatic Fixed Interval	2205	0.0071414	0.000228622	Trapezoid	30	1

ANNEX 11. Loboc Field Validation Points

Table A-11. Loboc Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation points (m)	Error (m)	Event/Date		Return Period of Event
	Lat	Long						
1	124.009632	9.602072	0.18	0.9	0.5184	Seniang	12/29/2014	100
2	124.006458	9.603559	2.44	0.9	2.3716	Seniang	12/30/2014	100
3	124.022321	9.607445	9.78	1.64	66.2596	Seniang	12/30/2014	100
4	124.015501	9.617812	11.83	2	96.6289	Seniang	12/30/2014	100
5	124.015501	9.617812	11.83	1.6	104.6529	Seniang	12/29/2014	100
6	124.022291	124.022291	8.64	2.2	41.4736	Louise (Ining)	11/19-20/1964	100
7	124.0243464	9.622245089	16.17	2.1	197.9649	Seniang	12/29/2014	100
8	124.0243769	9.62208324	15.47	1.9	184.1449	Seniang	12/29/2014	100
9	124.0241484	9.622127691	16.26	3.5	162.8176	Seniang	12/29/2014	100
10	124.0241484	9.622127691	16.5	4.2	151.29	Seniang	12/29/2014	100
11	124.0244776	9.621996932	15.39	2.4	168.7401	Seniang	12/29/2014	100
12	124.0247434	9.622272935	15.1	1.5	184.96	Seniang	12/29/2014	100
13	124.0253345	9.622603893	7.79	0.9	47.4721	Seniang	12/29/2014	100
14	124.0253345	9.622603893	7.98	2.9	25.8064	Seniang	12/29/2014	100
15	124.0253345	9.622603893	12.14	2.4	94.8676	Seniang	12/29/2014	100
16	124.0253345	9.622603893	12.23	2.1	102.6169	Seniang	12/29/2014	100
17	124.0232749	9.61916558	15.51	3.9	134.7921	Seniang	12/29/2014	100
18	124.0232346	9.618861343	14.75	2.5	150.0625	Seniang	12/29/2014	100
19	124.0230574	9.618849234	14.16	3.1	122.3236	Seniang	12/29/2014	100
20	124.0230642	9.618378323	13.17	1.9	127.0129	Seniang	12/29/2014	100
21	124.023341	9.618243338	13.65	1.7	142.8025	Seniang	12/29/2014	100
22	124.0234029	9.618229162	13.65	0.5	172.9225	Seniang	12/29/2014	100
23	124.0230251	9.618061449	13.69	2.7	120.7801	Seniang	12/29/2014	100
24	124.0230519	9.617884688	12.66	2.1	111.5136	Seniang	12/29/2014	100
25	124.0234857	9.617679926	13.35	1.9	131.1025	Seniang	12/29/2014	100
26	124.0232403	9.617513177	13.88	2.2	136.4224	Seniang	12/29/2014	100
27	124.0233072	9.617206118	13.56	1.7	140.6596	Seniang	12/29/2014	100
28	124.0232035	9.616984762	12.56	3.5	82.0836	Seniang	12/29/2014	100
29	124.0229934	9.616754532	12.64	2.9	94.8676	Seniang	12/29/2014	100
30	124.0232791	9.616321845	11.04	3.7	53.8756	Seniang	12/29/2014	100
31	124.0246352	9.615082408	5.61	3	6.8121	Seniang	12/29/2014	100
32	124.0242361	9.614970167	7.45	2.7	22.5625	Seniang	12/29/2014	100
33	124.0227059	9.612701124	9.56	2.9	44.3556	Seniang	12/29/2014	100
34	124.0222579	9.611223735	9.99	2.6	54.6121	Seniang	12/29/2014	100
35	124.0246526	9.609019155	7.14	2.2	24.4036	Seniang	12/29/2014	100
36	124.0248924	9.607931183	8.61	3.3	28.1961	Seniang	12/29/2014	100
37	124.0111475	9.601872481	3.68	2.6	1.1664	Seniang	12/29/2014	100
38	124.0129314	9.601058835	0.1	0.2	0.01	Seniang	12/29/2014	100

39	124.0138757	9.598705952	0.05	0.1	0.0025	Seniang	12/29/2014	100
40	124.0146947	9.598471455	0.06	0.3	0.0576	Seniang	12/29/2014	100
41	124.0164989	9.598576708	0.06	0.2	0.0196	Seniang	12/29/2014	100
42	124.0123253	9.598503181	0.34	0.5	0.0256	Seniang	12/29/2014	100
43	124.01258	9.599180063	0.39	0.6	0.0441	Seniang	12/29/2014	100
44	124.0128274	9.600010102	0.1	0.4	0.09	Seniang	12/29/2014	100
45	124.0121885	9.599872234	0.03	0.1	0.0049	Seniang	12/29/2014	100
46	124.0122169	9.599686473	0.51	0.7	0.0361	Seniang	12/29/2014	100
47	124.0120133	9.599974199	0.04	0.7	0.4356	Seniang	12/29/2014	100
48	124.0107812	9.600074658	0.62	0.6	0.0004	Seniang	12/29/2014	100
49	124.0100422	9.600654903	0.88	0.9	0.0004	Seniang	12/29/2014	100
50	124.0141225	9.599830395	0.06	0.2	0.0196	Seniang	12/29/2014	100
51	124.0154527	9.598821541	0.74	0.7	0.0016	Seniang	12/29/2014	100
52	124.0160188	9.599477886	0.06	0.1	0.0016	Seniang	12/29/2014	100

ANNEX 12. Educational Institutions Affected by flooding in Loboc Floodplain

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

Bohol				
Loay				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Commodore Heracle J. Alano Memorial Elem. School	Alegria Sur			
Concepcion Elementary School	Bonbon			
Sen. President Pro-Tempore Jose A. Clarin Elem Sch	Calvario			
Tangcasan Elementary School	Concepcion			
Blessed Harvest Time Institute	Palo	High	High	High
Sen. President Pro-Tempore Jose A. Clarin Elem Sch	Poblacion Ibabao			
Holy Trinity Academy	Poblacion Ubos			
Sen. President Pro-Tempore Jose A. Clarin Elem Sch	Poblacion Ubos			
Villalimpia Day Care Center	Villalimpia		Medium	High
Villialimpia Elementary School	Villalimpia		Medium	High

Table A-12.2 Educational Institutions in Loboc, Bohol Affected by flooding in Loboc Floodplain

Bohol				
Loay				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Camaya-an Elementary School	Agape			
Calunasan Norte Day Care Center	Calunasan Sur			
Calunasan Norte Elementary School	Calunasan Sur	Medium	Medium	Medium
Camaya-an Elementary School	Camayaan			
Calunasan Sur Day Care Center	Canlasid			
Calunasan Sur Elementary School	Canlasid			

ANNEX 13. Health Institutions affected by flooding in Loboc Floodplain

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

Bohol				
Loboc				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Primary Hospital	Agape	High	High	High