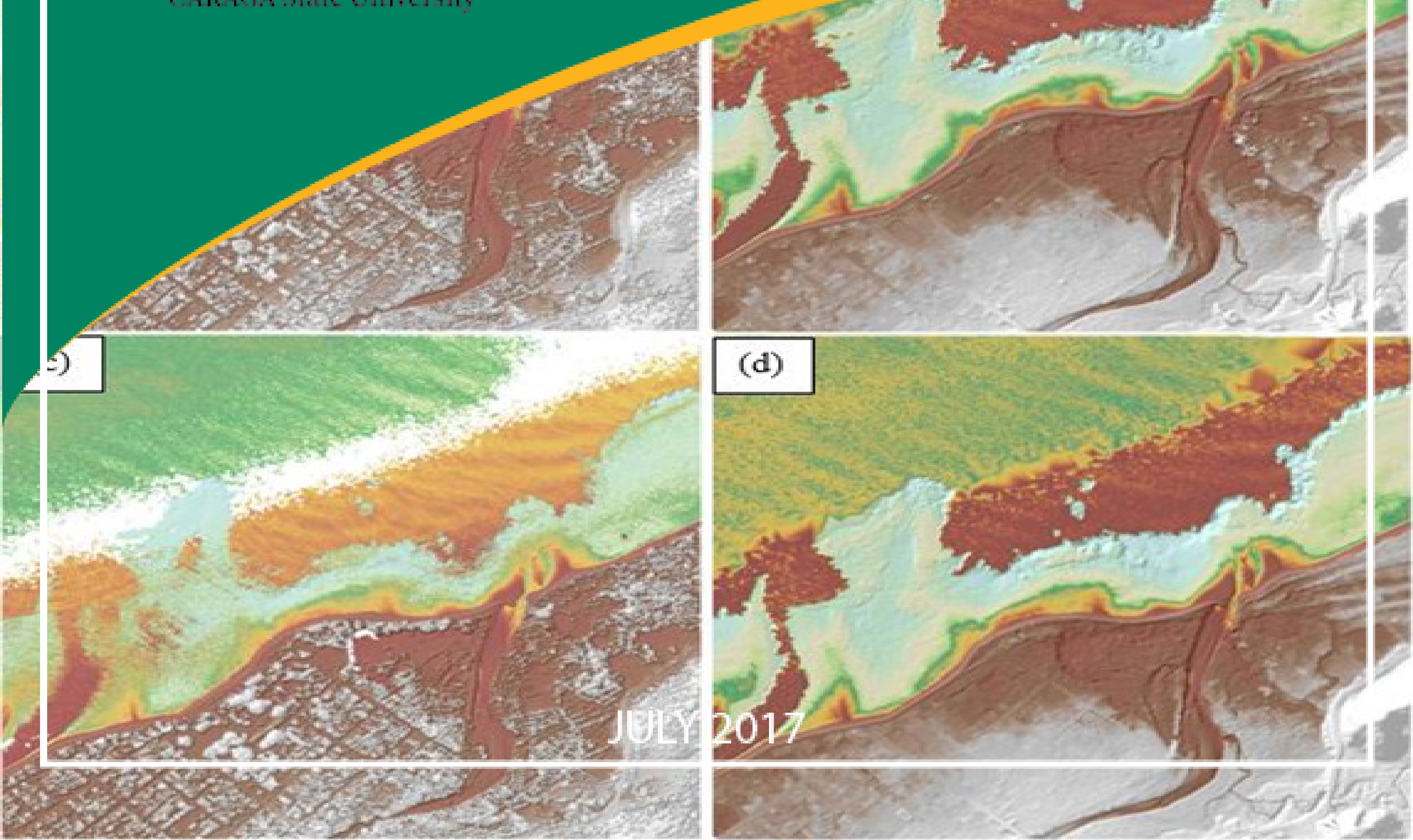
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Cantilan River

University of the Philippines Training Center for Applied Geodesy and Photogrammetry
CARAGA State University



JULY 2017

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

Report on the LiDAR Surveys and Flood Mapping of Libertad River

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

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LIST OF ACRONYMS AND ABBREVIATIONS

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

CHAPTER 1: OVERVIEW OF THE PROGRAM AND CANTILAN RIVER

1.1 Background of the Phil-LIDAR 1 Program

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

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

The implementing partner university for the Phil-LiDAR 1 Program is the Caraga State University (CSU). CSU 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 11 river basins in the Eastern Mindanao . The university is located in City in the province of.

1.2 Overview of Cantilan River Basin

The Cantilan River Basin is situated in the province of Surigao del Sur in Mindanao, Philippines. It lies generally between 125006' to 126046' east longitude and 9010' to 9019' north latitude. The river basin consists of four (4) municipalities namely; Carrascal, Cantilan, Madrid, Carmen and Lanuza. The basin covers an area of approximately 776 square kilometers, and is about 51 kilometers long and averages about 22 kilometers in width.

The Cantilan River Basin covers the municipalities of Carmen, Madrid, Cantilan, and Carascal in Surigao del Sur; the municipalities of Jabonga and Santiago and the City of Cabadbaran in Agusan del Norte; and the Municipality of Sibagat in Agusan del Sur. The DENR River Basin Control Office (RBCO) states that the Cantilan River Basin has a drainage area of 188 km² and an estimated 376 cubic meter (MCM) annual run-off (RBCO, 2015).

Its main stem, Cantilan River, is among the eleven (11) river systems in Caraga Region. According to the 2015 national census of PSA, a total of 7,426 persons reside within the immediate vicinity of the river, which is distributed among barangays Santa Cruz, Antao, and Esperanza in Carmen, Surigao del Sur and barangays San Antonio, manga, San Juan, San Vicente, San Roque, and Bagsac in Madrid, Surigao del Sur.

The Cantilan River basin has two major rivers connected to each other, the Carrascal andCarac-anRivers. Carac-anRiver can be considered the principal drainageway of the basin. It has one major tributary which is the Cantilan River that originates from the southwest portion of the basin and meets the Carac-an River at a junction near the municipality of Lanuza, Surigao del Sur. From this junction, Carac-an River flows towards Lanuza Bay at a distance of approximately 1.5 kilometers. At this portion, the river channel is wide and is navigable by motor boats for about 4 kilometers from the bay in northwest direction. Carrascal River, on the other hand, originates from northeast portion of the basin and discharges into Carrascal Bay.

The climate of the basin specifically in Cantilan is tropical which is characterized by only two seasons, a wet and a dry season. The wet season of the basin fall between the months of November until March and dry season starts between April to September .
The basin's highest point is at 1,823 meters above mean sea level situated along the mountain ridges of Barangay Libas, Municipality of Jabonga, Agusan del Norte . Based on maps published by the Bureau of Soil and Water Management-Department of Agriculture there were three types of soil in the basin namely loam, clay and silt loam in which the most abundant soil type in the basin was loam which

accounts for 66% of the basin's land area. The basin is mostly covered by open canopy forests and brush land leaving the built-up areas only covering less than 1 % of the basin.
Built-up areas and communities in the basin are concentrated in the municipalities of Cantilan and Carrascal. Municipality of Cantilan is considered as a second class municipality in the province of Surigao del Sur. In terms of population, Cantilan is more populated than Carrascal. As of the 2015 estimate, Cantilan has a population of 31,492 while Carrascal has 22,479 populations. Both municipalities belong to "CarCanMadCarLan" which is the abbreviated term for Carrascal, Cantilan, Madrid, Carmen and Lanuza. All these municipalities were once under a single municipality in Cantilan before 1990's1. The Benoni Bridge which plies the Surigao-Davao Coastal Road connects other municipalities and localities in the south to Lanuza, Surigao del Sur.
The local language in Cantilan is Cantilangnon, a northern variation of Surigaonon which is very much similar to the dialect in Surigao City, Surigao del Norte, spoken mostly in the CarCanMadCarLan municipalities . The municipality is a producer of good quality agricultural and aquamarine products, and is becoming a leading eco-tourism destination in Southeastern Philippines. CARAGA Region is notable for its wood-based economy extensive water resources, and rich mineral deposits such as gold, iron, silver, nickel, chromite, manganese, and copper. Palay, banana, and coconut are the primary crops of the region (National Nutrition Council). The people's main sources of living are fishing, farming corn cropping, logging and tourism. Cantilan Water District is the main water source of the people in the municipality, serving 14 barangays .
Province of Surigao del Sur including the municipality of Cantilan is one of areas that were affected during the onslaught of Tropical Storm "Pablo" in December 2012where an estimated 2,000 individuals living in Cantilan were affected. As reported, Typhoon Pablo intensified and entered the Philippine Area of Responsibility on December 2, 2012 and on December 3, 2012 the typhoon regained strength and headed towards the province of Surigao del Sur and finally weakened into a tropical depression as it moved towards Ilocos Norte on December 9, 2012. The incessant movement of "Pablo" and the continuous rain and strong winds that it brought along caused flooding and landslides not only in the municipality of Cantilan but also in other provinces and regions in Mindanao .

On February 1, 2017, the NDRRMC has released the 2nd General Flood Advisory for CARAGA Region with Cantilan, Toracan, Tandag, Tago, Hubo-Otieza, Hinatuan, and Bislig Rivers to be still likely affected by moderate to occasionally heavy rains and thunderstorms as per NDRRMC report(National Disaster Risk Reduction and Management Council, 2017).

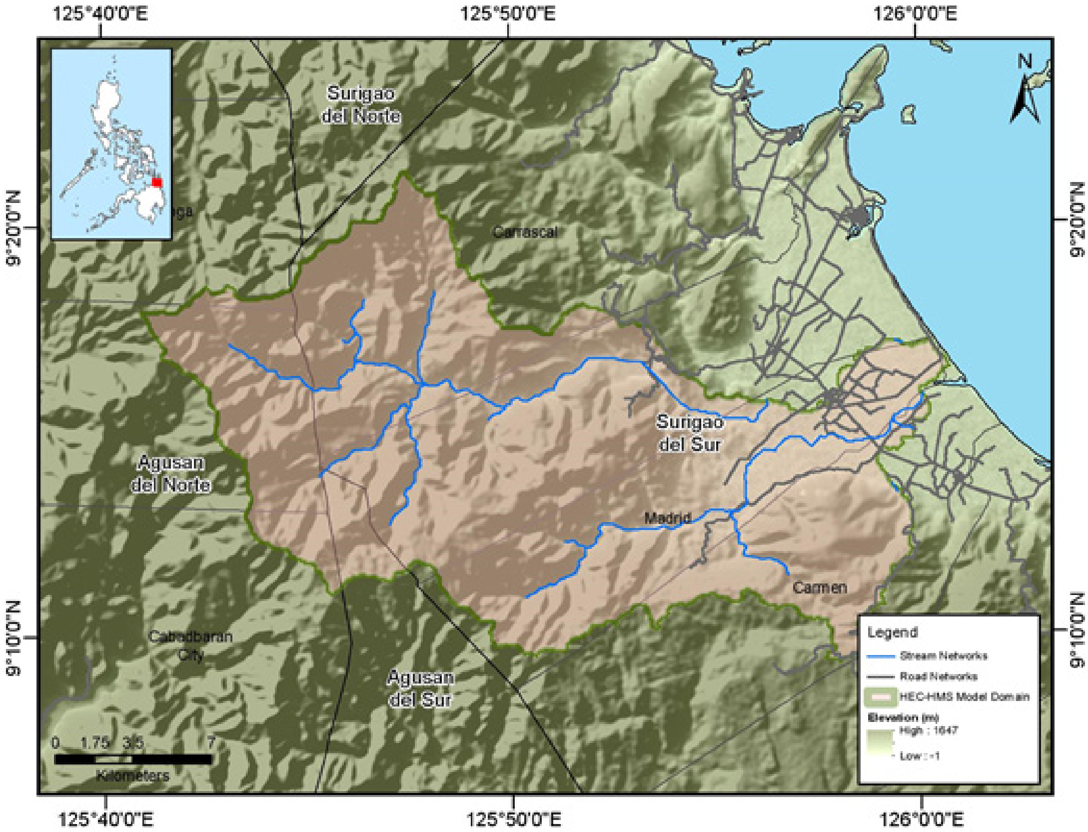

Figure 1 Map of Cantilan River

CHAPTER 2: LIDAR ACQUISITION IN CANTILAN 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).

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Cantillan Floodplain in Surigao del Sur. Each flight mission has an average of 12 lines and ran for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameter for the LiDAR system is found in Table 1. Figure 2 shows the flight plan for Cantillan Floodplain.

Table 1 Flight planning parameters for Aquarius LiDAR System.

Block Name	Flying Height (m AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK60A	600	30	18	50	45	130	5
BLK60B	600	30	18	50	45	130	5
BLK60C	600	30	18	50	45	130	5
BLK60D	600	30	18	50	45	130	5
BLK60E	600	30	18	50	45	130	5
BLK60F	600	30	18	50	45	130	5
BLK60G	600	30	18	50	45	130	5
BLK61O	600	30	18	50	45	130	5
BLK61N	600	30	18	50	45	130	5

2.2 Ground Base Stations

The project teams was able to recover three (3) NAMRIA ground control points: SRN-106, SRS-47, SRS-45, which are of second (2nd) order accuracy, and three (3) NAMRIA benchmarks, SS-101, SS-80, and SN-106. The certifications for the NAMRIA reference points are found in Annex 2. These were used as base stations during flight operations for the entire duration of the survey (July 31, 2014, September 9-10, 2014, and May 11-12, 2016). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 882, SPS852, SPS985, and Topcon GR-5. Flight plans and location of base stations used during the aerial LiDAR acquisition in Cantillan Floodplain are shown in Figure 1.

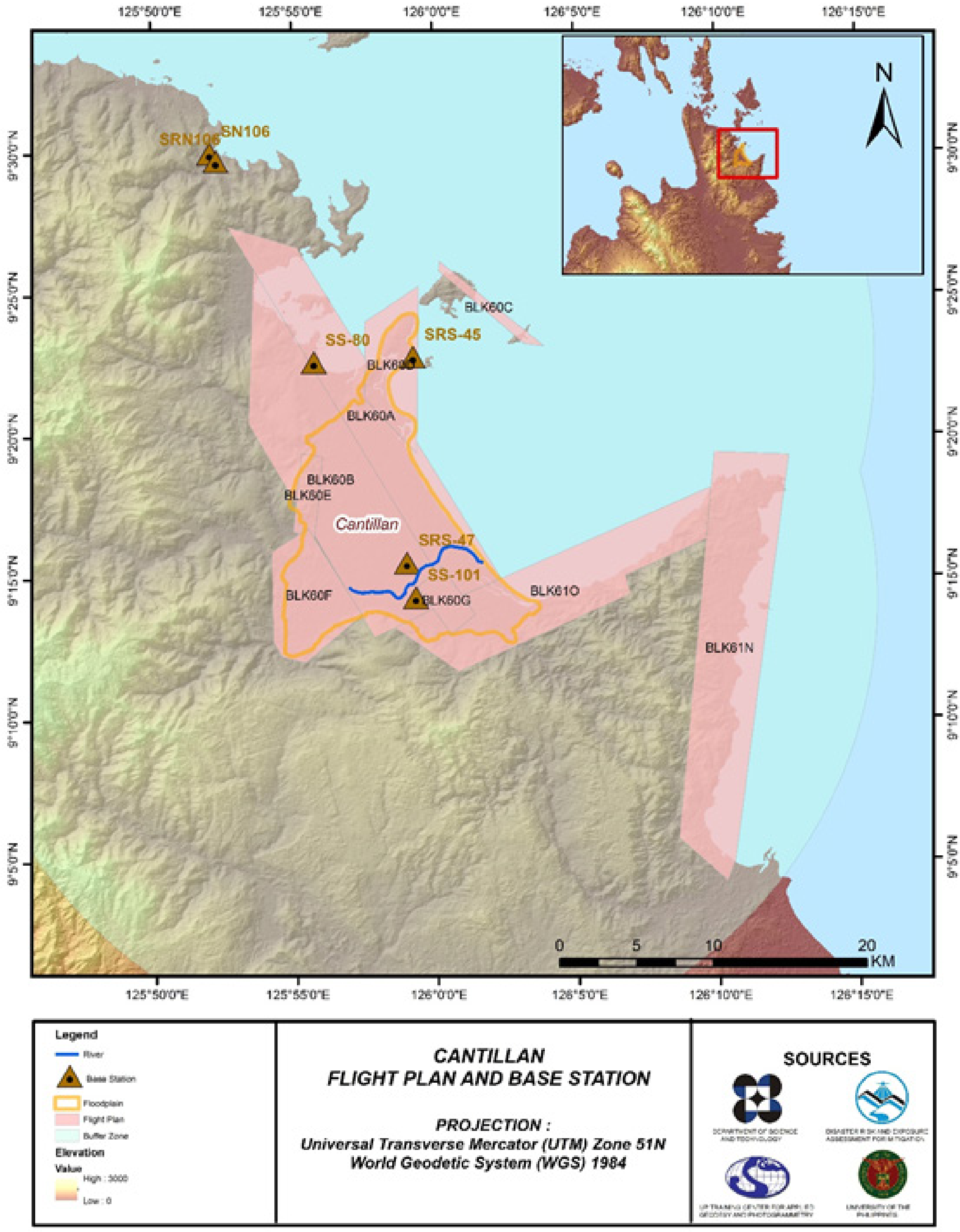


Figure 2 Flight plans and base stations for Cantilan Floodplain.

Figure 3 to 6 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 7 show the details about the following NAMRIA control stations whileTable 8 shows the list of all ground control points occupied during the acquisition together with the corresponding dates of utilization.

(b)

(a)

Figure 3 GPS set-up over SS-101 located at the first approach of Antao Bridge KM. post 1249+122.90 near a concrete electric post in Brgy. Antao, Carmen, Surigaodel Sur (a) and NAMRIA reference point SS-101 (b) as recovered by the field team.

Table 2 Details of the recovered NAMRIA vertical control point SS-101 used as base station for the LiDAR acquisition.

Station Name	SS-101	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1:50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9°14’21.88056” North 125°59’11.96188” East 8.363 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	608419.412 meters 1021764.188 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9°14’18.21639” North 125°59’17.28524”East 77.664 meters

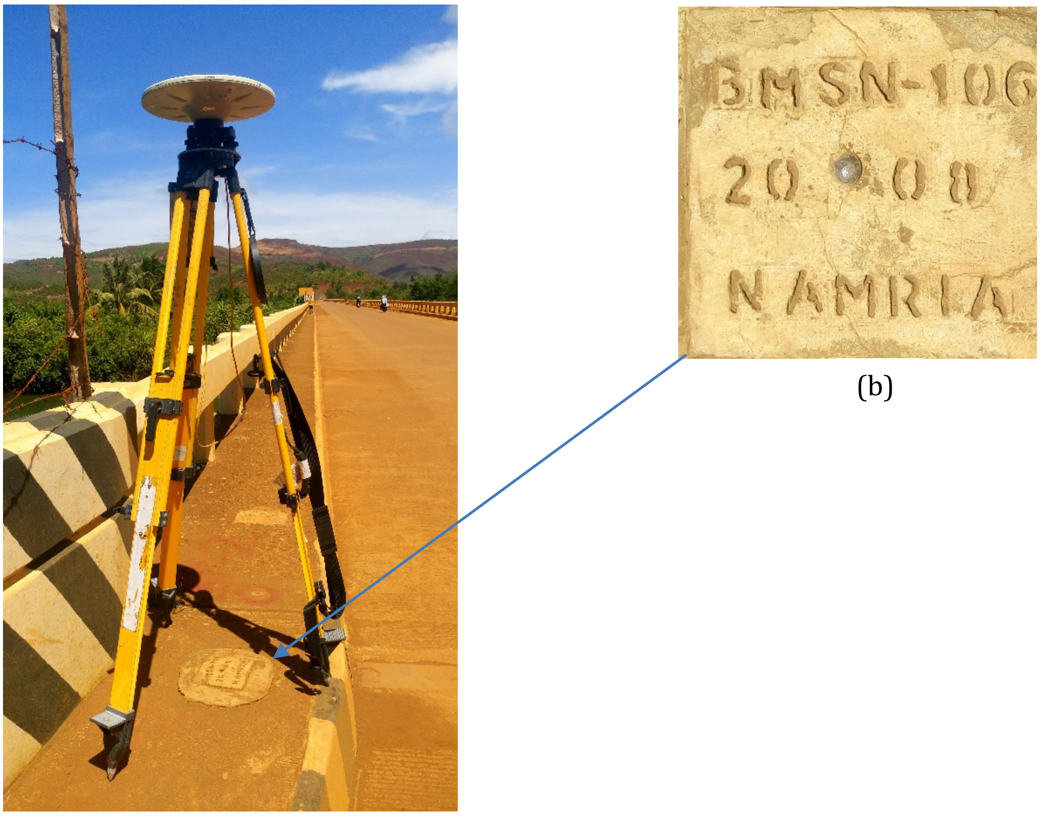
(b)

(a)

Figure 4 GPS set-up over SRS-47 located on the left side ground corner of the barangay hall about 60m from the crossing in Brgy. Manga, Madrid, Surigao del Sur (a) NAMRIA reference point SS-101 (b) as recovered by the field team

Table 3 Details of the recovered NAMRIA horizontal control point SRS-47 used as base station for the LiDAR acquisition

Station Name	SRS-47	
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° 15’ 35.53566” North 125° 58’ 53.39602” East 5.36600 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	607846.421 meters 1024025.604 meters
Geographic Coordinates, World Geodetic System 1984 Datum(WGS 84)	Latitude Longitude Ellipsoidal Height	9° 15’ 31.86566” North 125° 58’ 58.71761” East 74.61000 meters



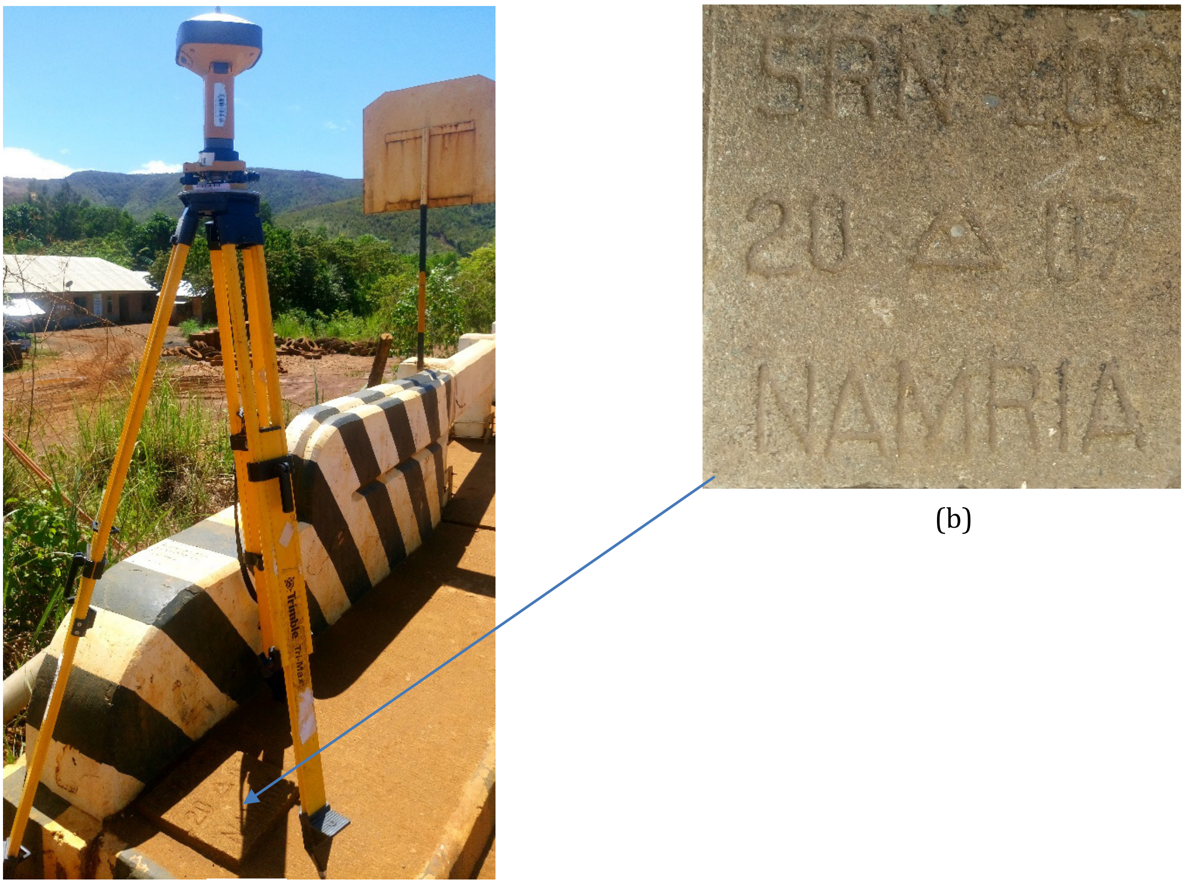
(b)

(a)

Figure 5 GPS set-up over SN-106 located on the first approach of Claver bridge going to Surigao del Sur (a) and NAMRIA reference point SN-106 (b) as recovered by the field team

Table 4 Details of the recovered NAMRIA vertical control point SN-106 used as base station for the LiDAR acquisition.

Station Name	SN-106	
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° 30’ 4.11065” 125° 51’ 58.82629” 9.622 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	595126.164 meters 1050678.175 meters
Geographic Coordinates, World Geodetic System 1984 Datum(WGS 84)	Latitude Longitude Ellipsoidal Height	9° 30’ 0.36727” North 125° 52’ 4.12753” East 78.052 meters



(b)

(a)

Figure 6 GPS set-up over SRN-106located on the last approach of Claver bridge going to Surigao del Sur (a) and NAMRIA reference point SRN-106 (b) as recovered by the field team

Table 5 Details of the recovered NAMRIA horizontal control point SN-106 used as base station for the LiDAR acquisition.

Station Name	SRN-106	
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° 29' 47.27035" North 125° 52' 12.24874" East 8.064 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	595536.884 meters 1050161.808 meters
Geographic Coordinates, World Geodetic System 1984 Datum(WGS 84)	Latitude Longitude Ellipsoidal Height	9° 29' 43.52852" North 125° 52' 17.55036" East 76.513 meters

Table 6 Details of the recovered NAMRIA vertical control point SS-80 used as base station for the LiDAR acquisition.

Station Name	SN-106	
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° 22' 40.99244" North 125° 55' 38.00994" East 4.910 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	601848.077 meters 1037081.482 meters
Geographic Coordinates, World Geodetic System 1984 Datum(WGS 84)	Latitude Longitude Ellipsoidal Height	9° 22' 37.29665" North 125° 55' 43.32154" East 73.761 meters

Table 7 Details of the recovered NAMRIA horizontal control point SRS-45 used as base station for the LiDAR acquisition.

Station Name	SN-106	
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° 22' 51.04574" North 125° 59' 14.66370" East 2.106 meters
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 5 PRS 92)	Easting Northing	608296.217 meters 1037407.601 meters
Geographic Coordinates, World Geodetic System 1984 Datum(WGS 84)	Latitude Longitude Ellipsoidal Height	9° 22' 47.34439" North 125° 59' 14.66370" East 71.096 meters

Table 8 Ground control points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
July 31, 2014	1766A	3BLK61NSO212A	SRS-47, BMSS 101
July 31, 2014	1768A	3BLK61OSB212B	SRS-47, BMSS 101
September 9, 2014	1928A	3BLK60A252B	SRS-45 BMSS 80
September 10, 2014	1930A	3BLK60AS253A	SRS-45, BMSS 80
September 10, 2014	1932A	3BLK60BS253B	SRS-45, BMSS 80
June 11, 2016	8488AC	3BLK60D132B	SN-106, SRN-106
June 12, 2016	8489AC	3BLK60EF133A	SN-106, SRN-106
June 13, 2016	8490AC	3BLK60CESG133B	SN-106, SRN-106

2.3 Flight Missions

Eight (8) missions were conducted to Cantilan Floodplain, for a total twenty-nine hours and 4 four minutes (29+04) of flying time for RP-C9022 and RP-C9322. All missions were conducted using the Aquarius LiDAR system. Table 9 shows the total area of actual coverage and the corresponding flying hours per mission while Table 10 presents the actual parameters used during the LiDAR data acquisition.

Table 7. Flight missions for LiDAR data acquisition in Libertad floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
July 31, 2014	1766A	195.53	178.60	22.64	155.96	3568	4	11
July 31, 2014	1768A	80.42	83.06	22.64	60.42	1511	4	11
September 9, 2014	1928A	201.66	76.11	39.51	36.60	1640	3	17
September 10, 2014	1930A	201.66	137.70	74.91	62.79	360	4	23
September 10, 2014	1932A	201.66	162.04	92.59	69.44	883	3	11
May 11, 2016	8488AC	27.18	35.76	15.88	19.88	1	2	41
May 12, 2016	**8489AC**	40.19	55.28	33.01	22.27	6	4	17
May 12, 2016	**8490AC**	47.92	82.05	45.27	36.77	3	2	53
TOTAL		998.86	810.59	346.46	464.14	7972	29	4

Table 10 Actual parameters used during LiDAR data acquisiton

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (KHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1766A	600	30	18	50	45	130	5
1768A	600	30	18	50	45	130	5
1928A	600	30	18	50	45	130	5
1930A	600	30	18	50	45	130	5
1932A	600	30	18	50	45	130	5
8488AC	500	30	18	50	45	130	5
8489AC	500	30	18	50	45	130	5
8490AC	500	30	18	50	45	130	5

2.4 Survey Coverage

Cantillan Floodplain is located in the province of Surigao del Sur. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 11. The actual coverage of the LiDAR acquisition for Cantilan Floodplain is presented in Figure 7.

Table 11 Area of Coverage of the LiDAR Data Acquisition in Cantilan Floodplain

Province	Municipality/City	Area of Municipality/City (km2)	Total Area Surveyed (km2)	Percentage of Area Surveyed
Surigao del Sur	Cantilan	182.83	76.23	42%
	Carrascal	317.34	69.23	22%
	Madrid	116.81	53.12	45%
	Carmen	**172.33**	**46.66**	**27%**
	Lanuza	**231.62**	**44.30**	**19%**
	Cortes	**82.48**	**38.46**	**47%**
	Tandag City	**392.39**	**17.04**	**4%**
	Libertad	**130.62**	**36.81**	**28%**

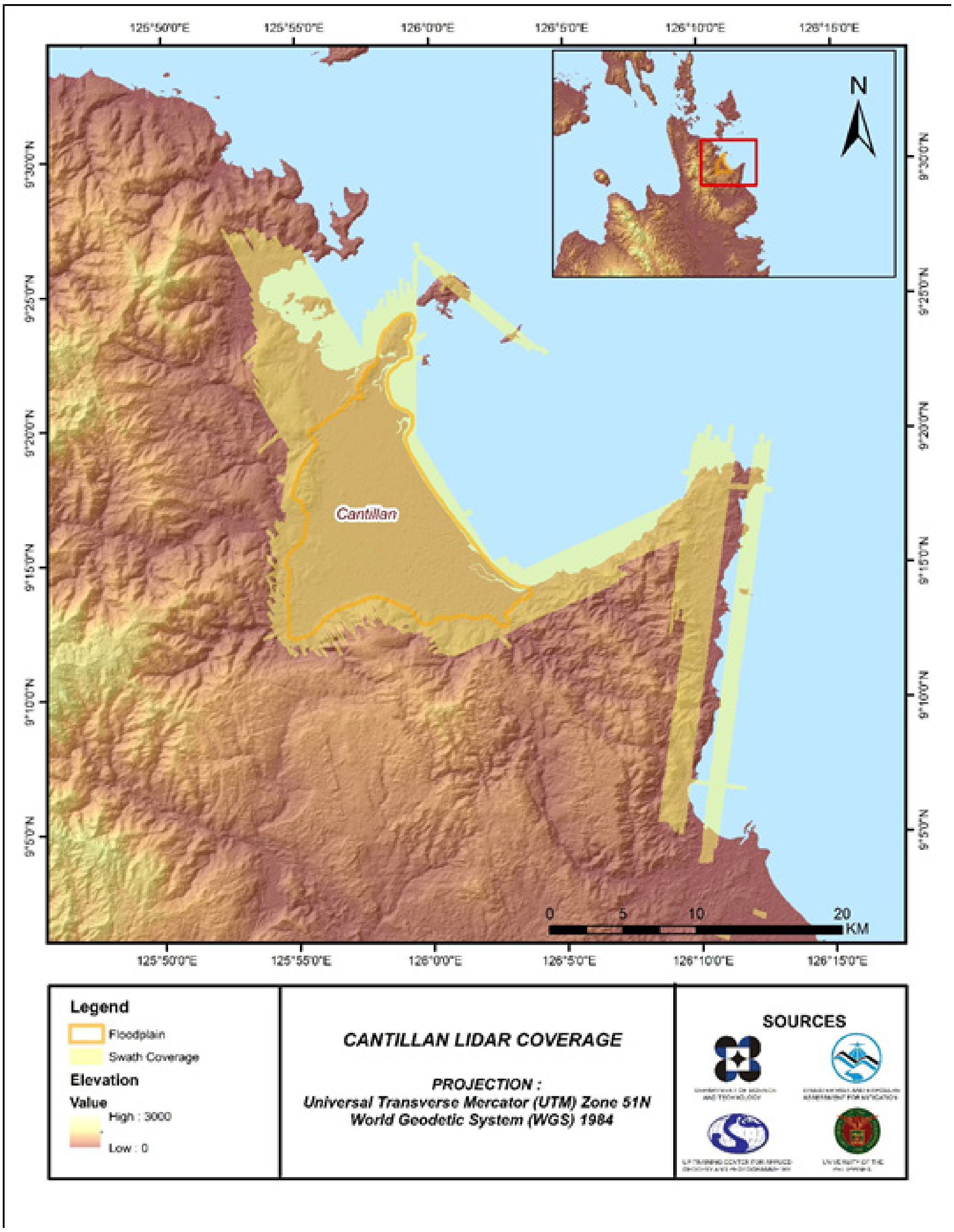


Figure 7 Actual LiDAR survey coverage for Cantillan Floodplain

CHAPTER 3: LIDAR DATA PROCESSING FOR CANTILAN 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 were checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory was done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification was performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds were subject for quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, were met. The point clouds were then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model. Using the elevation of points gathered in the field, the LiDAR-derived digital models were calibrated. Portions of the river that were barely penetrated by the LiDAR system were replaced by the actual river geometry measured from the field by the Data Validation and Bathymetry Component. LiDAR acquired temporally were then mosaicked to completely cover the target river systems in the Philippines. Orthorectification of images acquired simultaneously with the LiDAR data was done through the help of the georectified point clouds and the metadata containing the time the image was captured.

These processes are summarized in the flow chart shown in Figure 8.

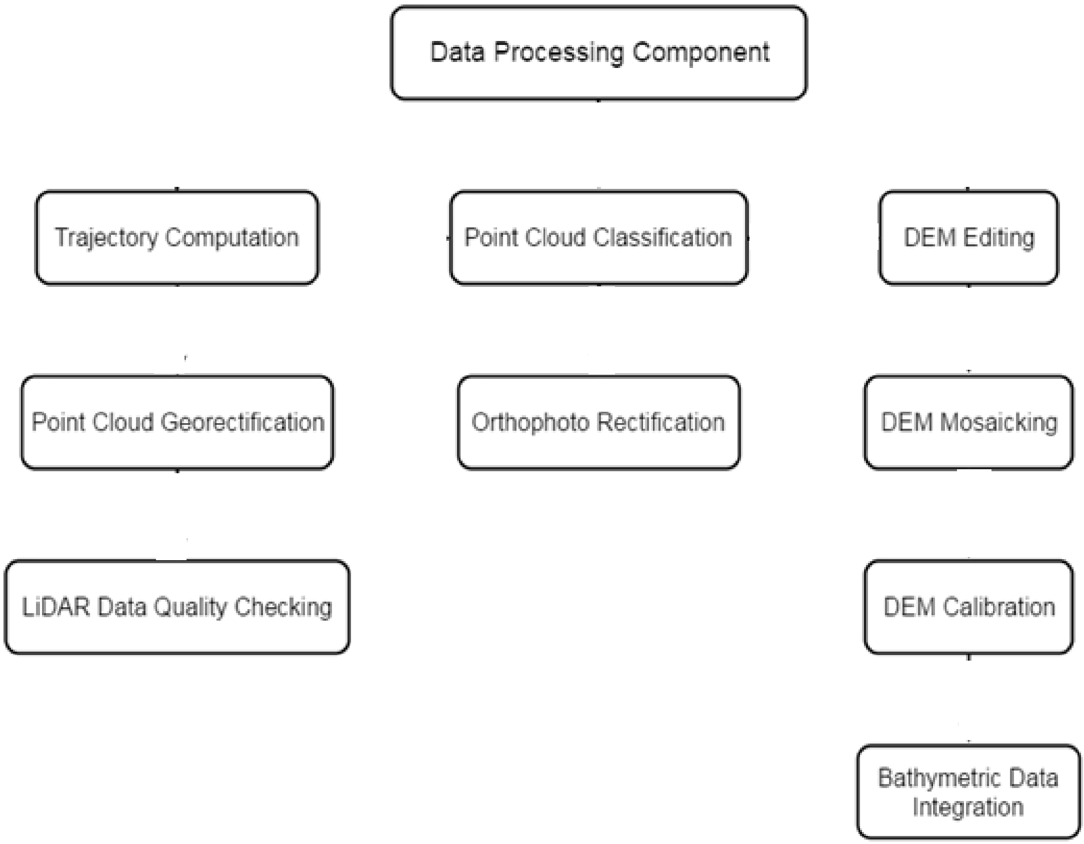


Figure 8 Schematic Diagram for Data

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Cantilan Floodplain can be found in Annex 5 Data Transfer Sheets. Missions flown during the first survey conducted on July 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Aquarius system which was also used for the succeeding surveys held on September 2014 and May 2016 over Surigao del Sur. The Data Acquisition Component (DAC) transferred a total of 63.92 Gigabytes of Range data, 1.45 Gigabytes of POS data, 260.5 Megabytes of GPS base station data, and 229.45 Gigabytes of raw image data to the data server on August 14, 2014 for the first survey, October 1, 2014 for the second survey and June 23, 2016 for the third survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Cantilan was fully transferred on June 23, 2016, as indicated on the Data Transfer Sheets for Cantilan Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 8490A, one of the Cantilan Flights, which is the North, East, and Down position RMSE values are shown in Figure 11. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on May 8, 2016 00:00AM. The y-axis is the RMSE value for that particular position.

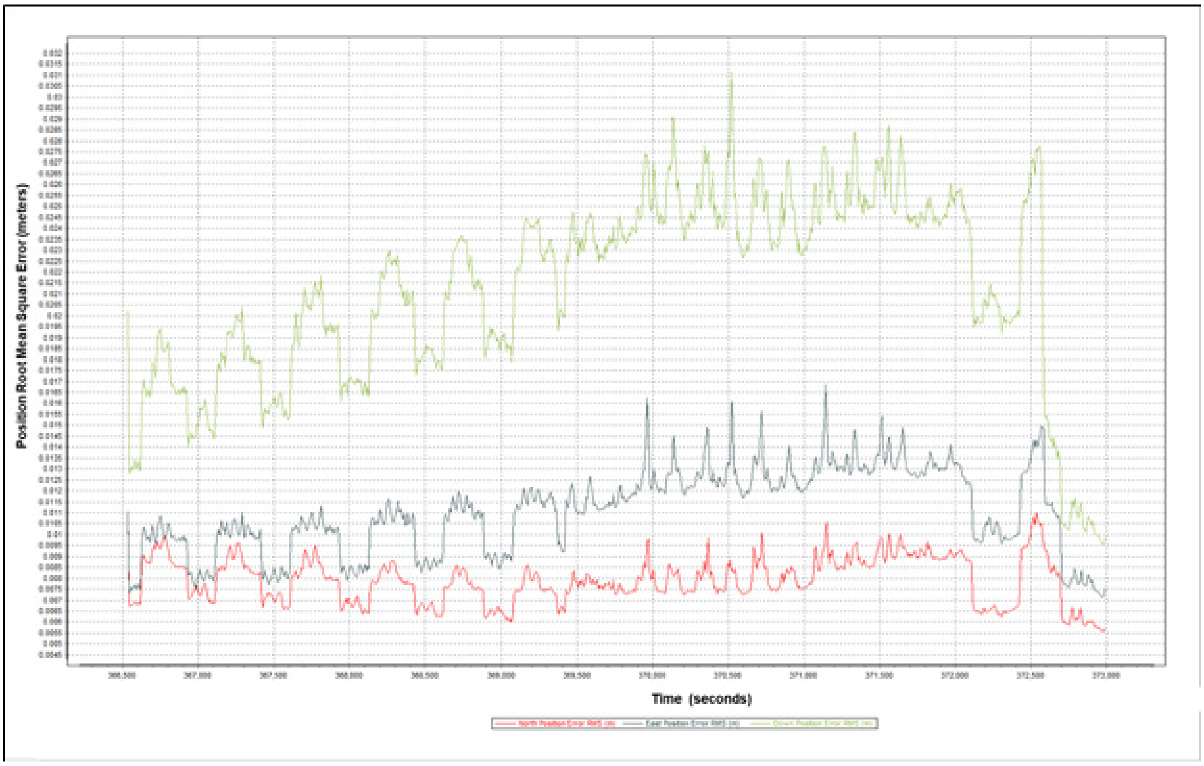


Figure 9 Smoothed Performance Metric Parameters of a Cantilan Flight 8490A

The time of flight was from 366500 seconds to 373000 seconds, which corresponds to morning of May 12, 2016.The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 11 shows that the North position RMSE peaked at 1.10 centimeters, the East position RMSE peaked at 1. 70 centimeters, and the Down position RMSE peaked at 3.10 centimeters, which are within the prescribed accuracies described in the methodology.

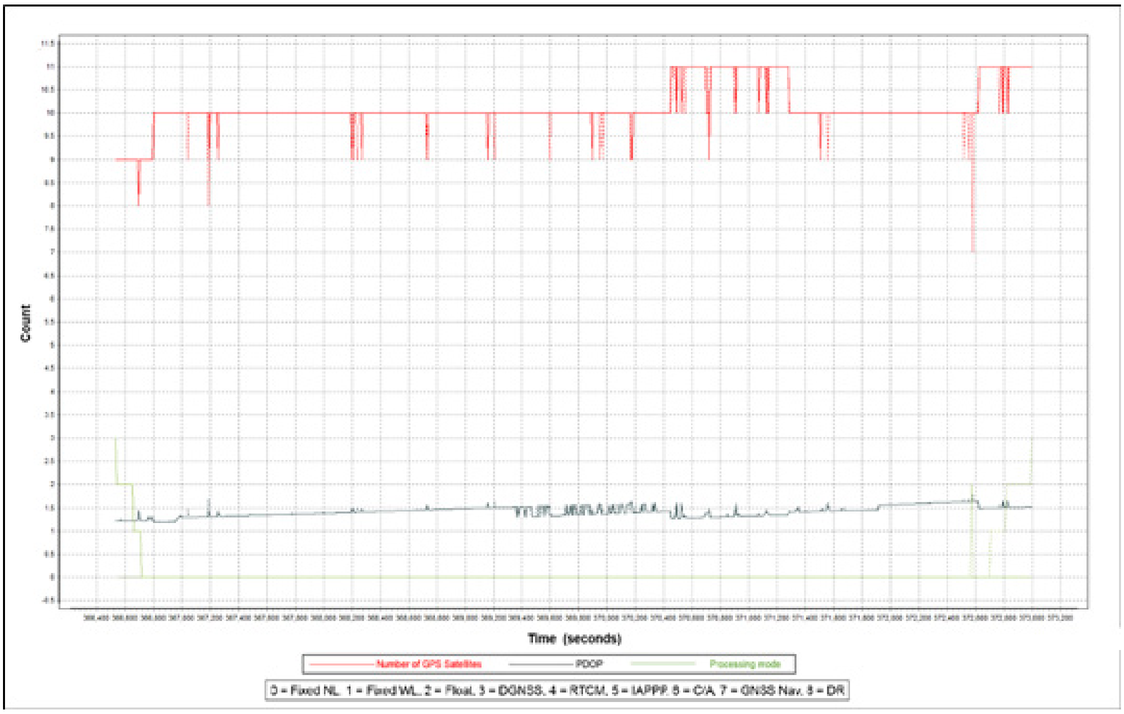


Figure 10 Solution Status Parameters of Cantilan Flight 8490A

The Solution Status parameters of flight 8490A, one of the Cantilan flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 10. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 7 and 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 Cantilan flights is shown in Figure 11.

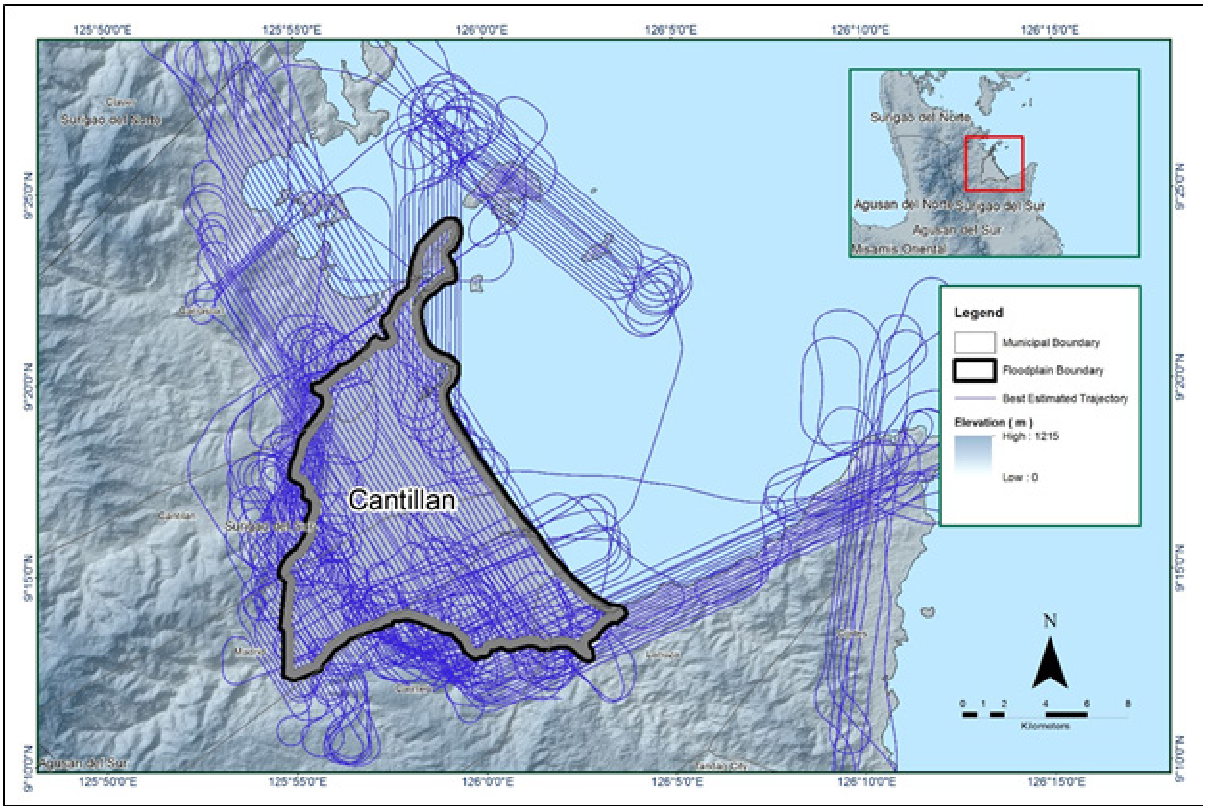


Figure 11 Best Estimated Trajectory for Cantilan Floodplain Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 188 flight lines, with each flight line containing one channel, since the Aquarius system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Cantilan Floodplain are given in Table 12.

Table 12 Self-Calibration Results values for Cantilan flights

Parameter	Acceptable Value
Boresight Correction stdev(<0.001degrees)	0.000839
IMU Attitude Correction Roll and Pitch Corrections stdev(<0.001degrees)	0.000942
GPS Position Z-correction stdev(<0.01meters)	0.0012

The optimum accuracy is obtained for all Cantilan 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 Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Cantilan Floodplain is shown in Figure 12. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

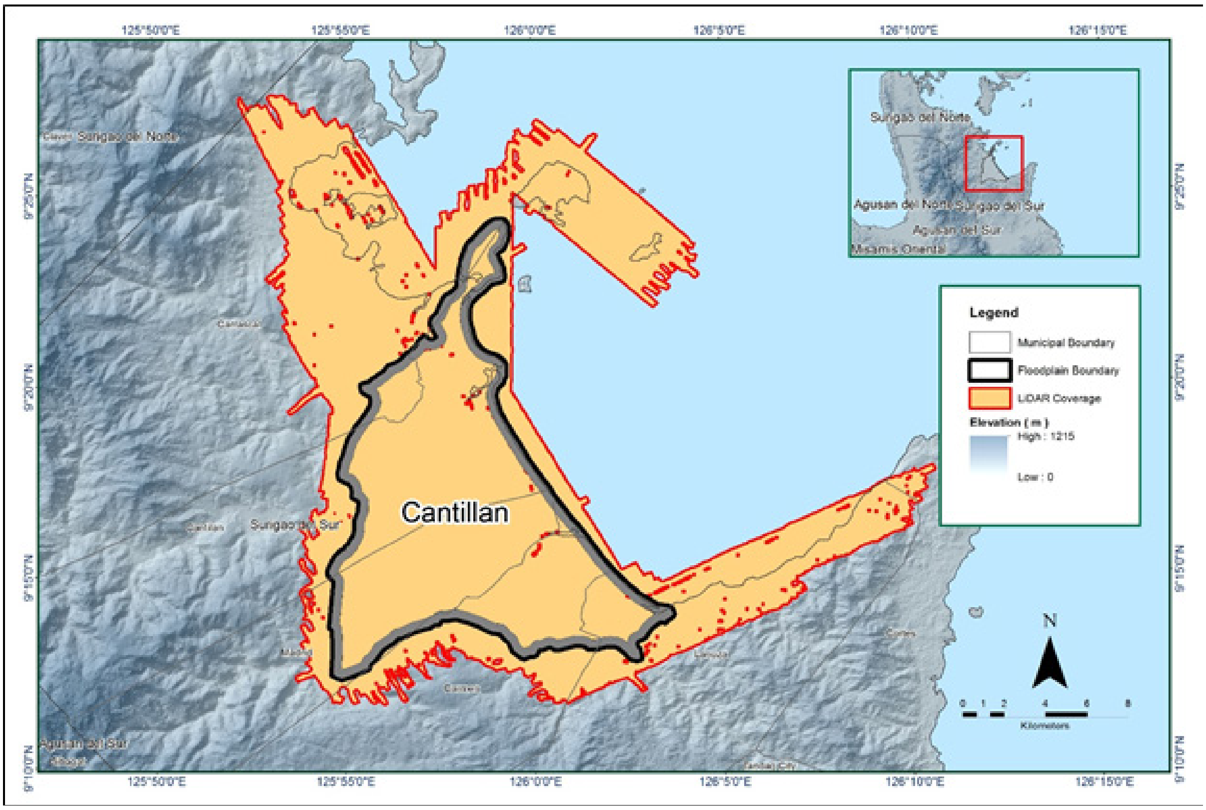


Figure 12 Boundary of the processed LiDAR data over Cantilan Floodplain

The total area covered by the Cantilan missions is 436.70 sq.km that is comprised of six (6) flight acquisitions grouped and merged into seven (7) blocks as shown in Table 13.

Table 13 List of LiDAR blocks for Cantilan Floodplain

LiDAR Blocks	Flight Numbers	Area (sq.km)
SurigaoDelSur Blk61O	1766A	79.14
	1768A	
Surigao_reflights Blk60E	8488AC	33.59
Surigao_reflights Blk60F	8490AC	34.27
Surigao_reflights Blk60G	8489AC	**16.47**
	8490AC	
Surigao_reflights Blk60H	**8489AC**	**44.52**
Surigao_reflights Blk60I	**8490AC**	**11.04**
Siargao Blk60AB	**1928A**	**217.67**
	1930A	
	1932A	
TOTAL		**436.70 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 13. Since the Aquarius system employs one channel only, an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines is expected.

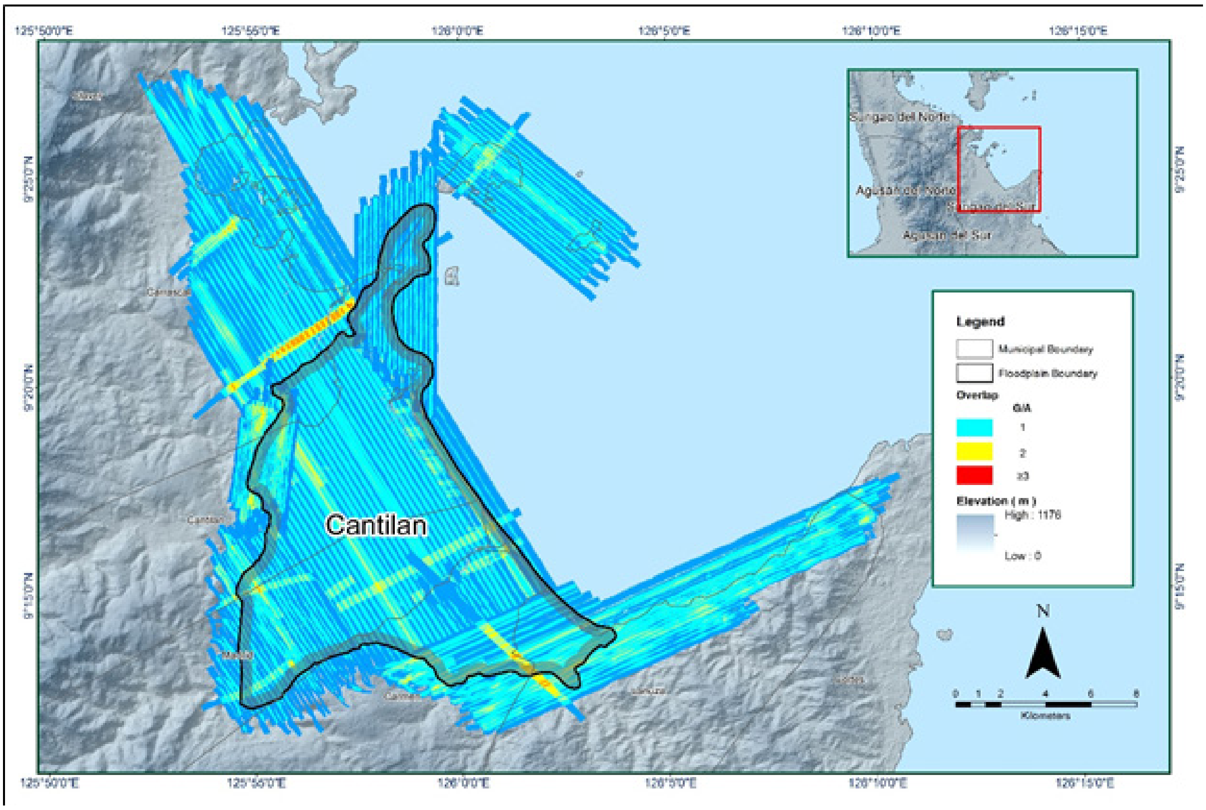


Figure 13 Image of data overlap for Cantilan Floodplain

The overlap statistics per block for the Cantilan floodplain can be found in Annex 8 Mission Summary Reports. It should be noted that one pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps were 29.41% and 62.90% respectively, which passed the 25% requirement.

The density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 14. It was determined that all LiDAR data for Cantilan Floodplain satisfy the point density requirement, and the average density for the entire survey area is 4.22 points per square meter.

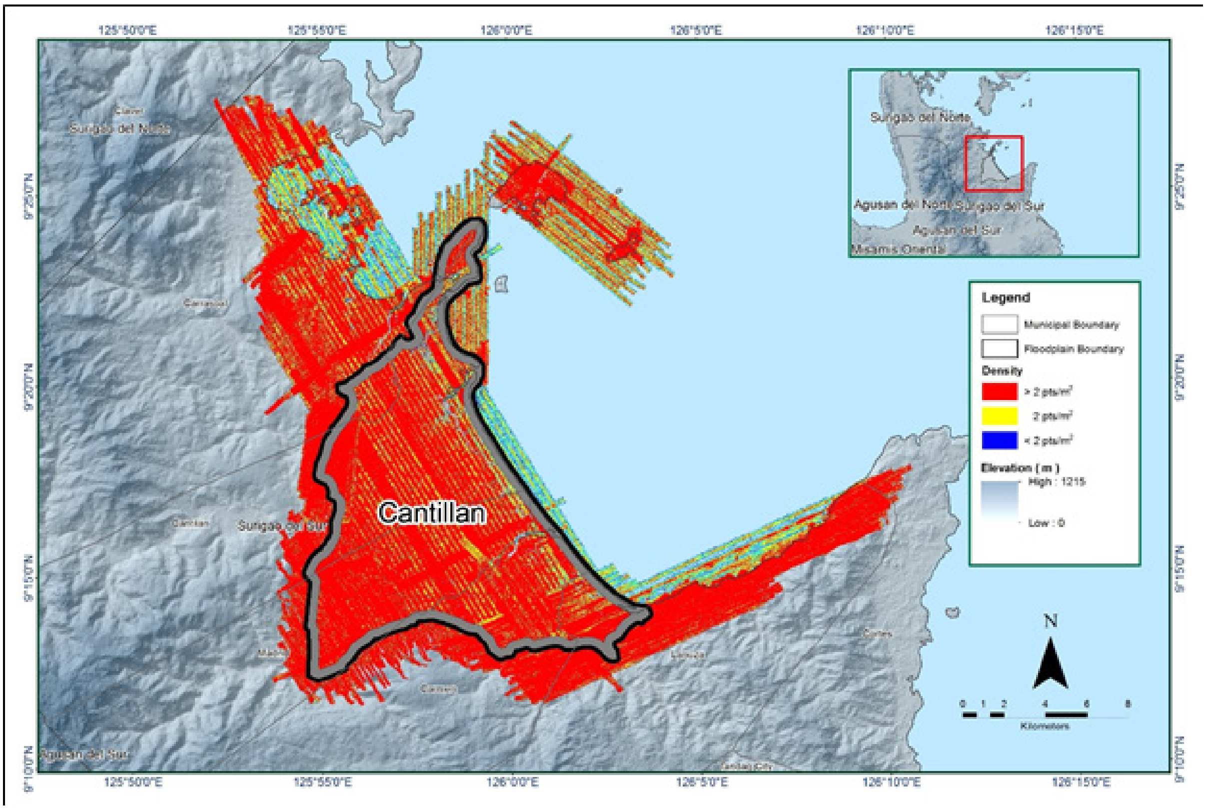


Figure 14 Density map of merged LiDAR data for Cantilan Floodplain

The elevation difference between overlaps of adjacent flight lines is shown in Figure 15. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20 m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20 m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

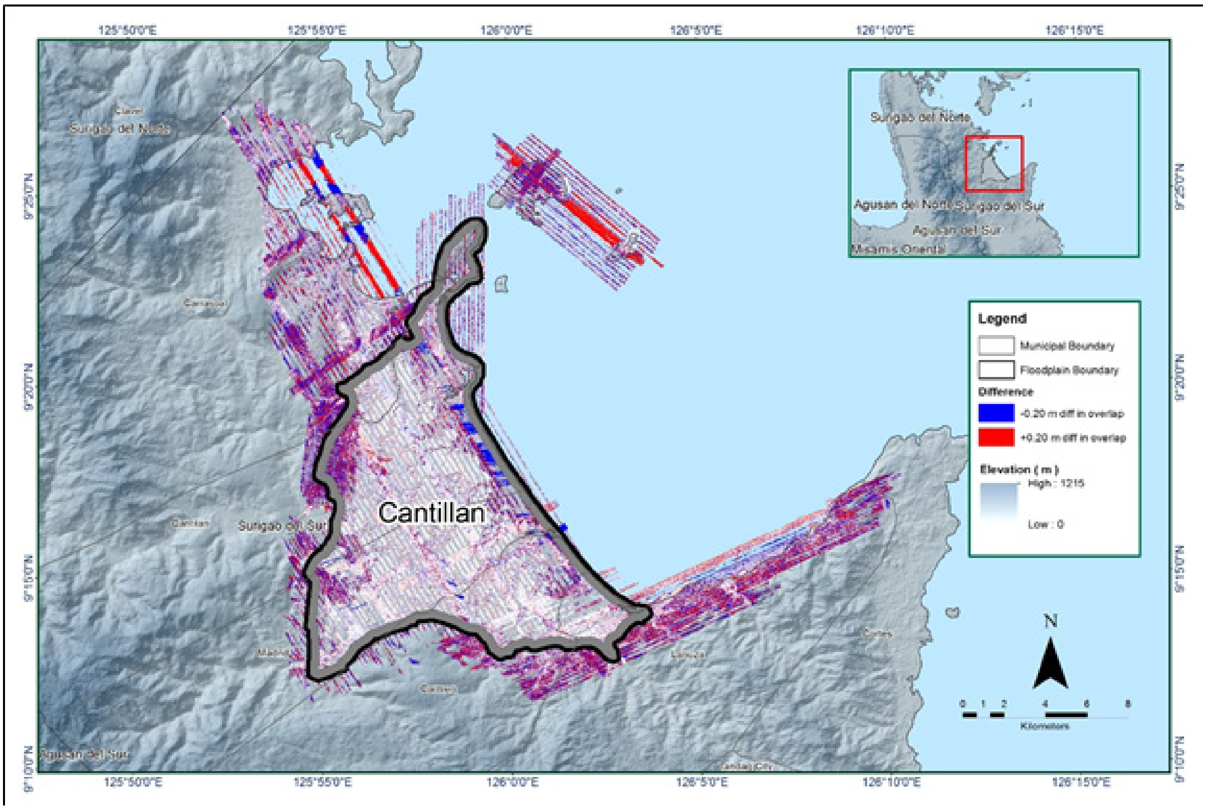


Figure 15 Elevation difference map between flight lines for Cantilan Floodplain

A screen capture of the processed LAS data from a Cantilan flight 8490A loaded in QT Modeler is shown in Figure 16. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there were differences in elevation, but the differences did 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.

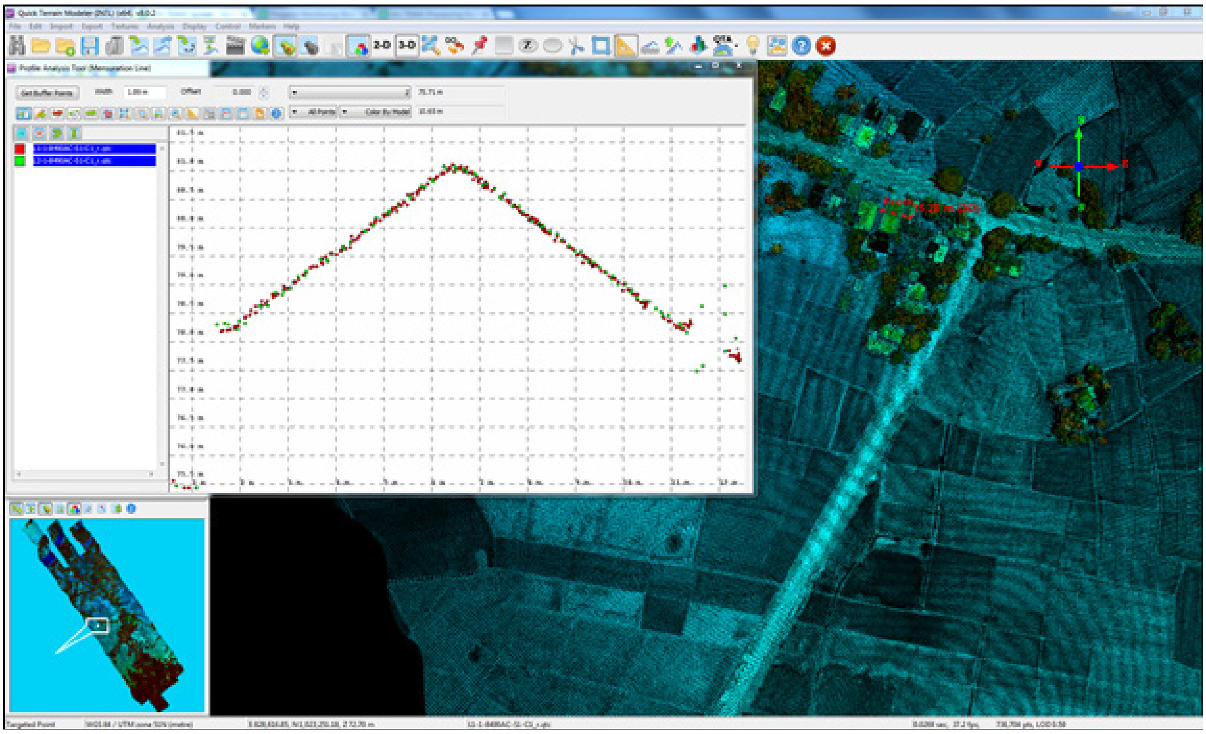


Figure 16 Quality checking for a Cantilan flight 8490A using the Profile Tool of QT Modeler

3.6 LiDAR Point Cloud Classification and Rasterization

Table 14 Cantilan classification results in TerraScan

Pertinent Class	Total Number of Points
Ground	275,566,931
Low Vegetation	290,137,517
Medium Vegetation	271,108,490
High Vegetation	646,772,119
Building	34,503,224

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Cantilan Floodplain is shown in Figure 17. A total of 648 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 14. The point cloud has a maximum and minimum height of 561.27 meters and 1.29 meters respectively.

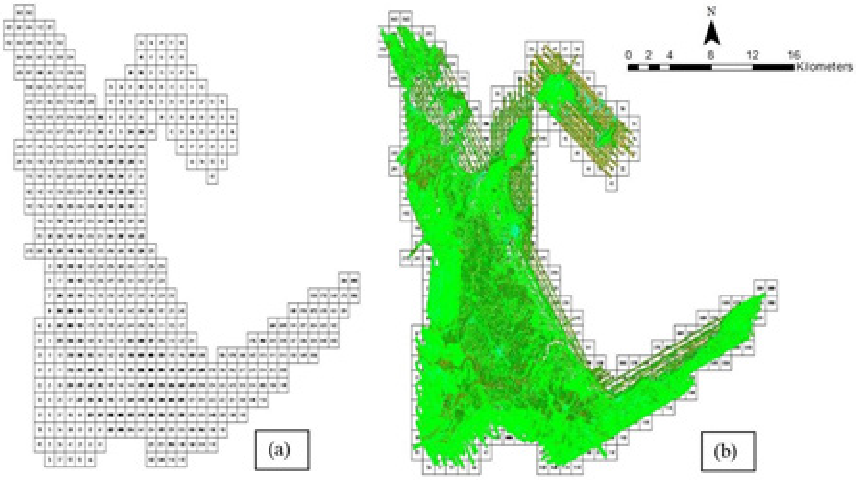


Figure 17 Tiles for Cantilan Floodplain (a) and classification results (b) in TerraScan

An isometric view of an area before and after running the classification routines is shown in Figure 18. 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.

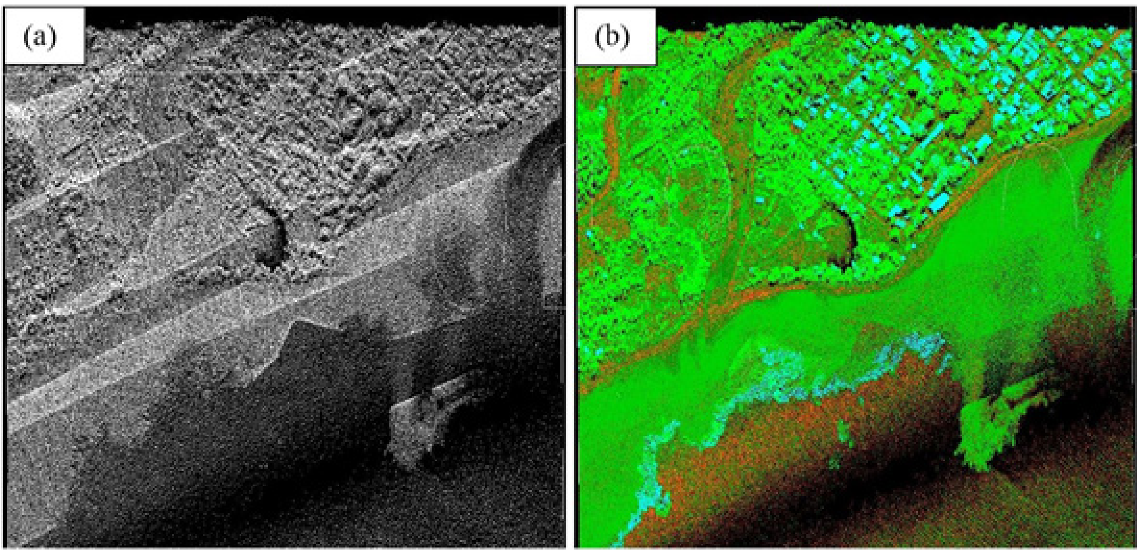


Figure 18 Point cloud before (a) and after (b) classification.

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

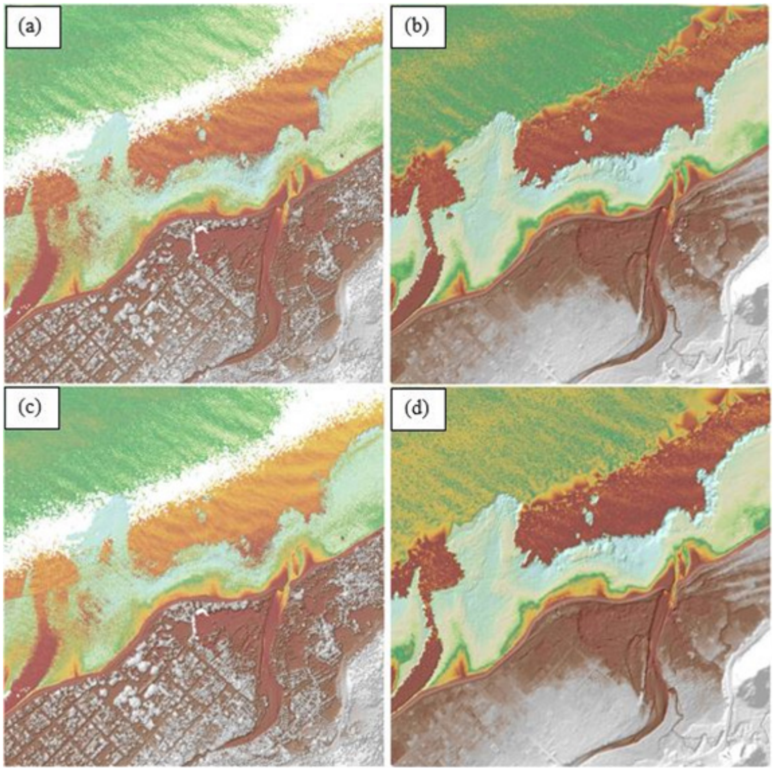


Figure 19 The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Cantilan Floodplain

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 1141 km by 1 km tiles area covered by Cantilan Floodplain is shown in Figure 20. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Cantilan Floodplain has a total 80.07 sq.km orthophotogaph coverage comprised of 1,555 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 21.

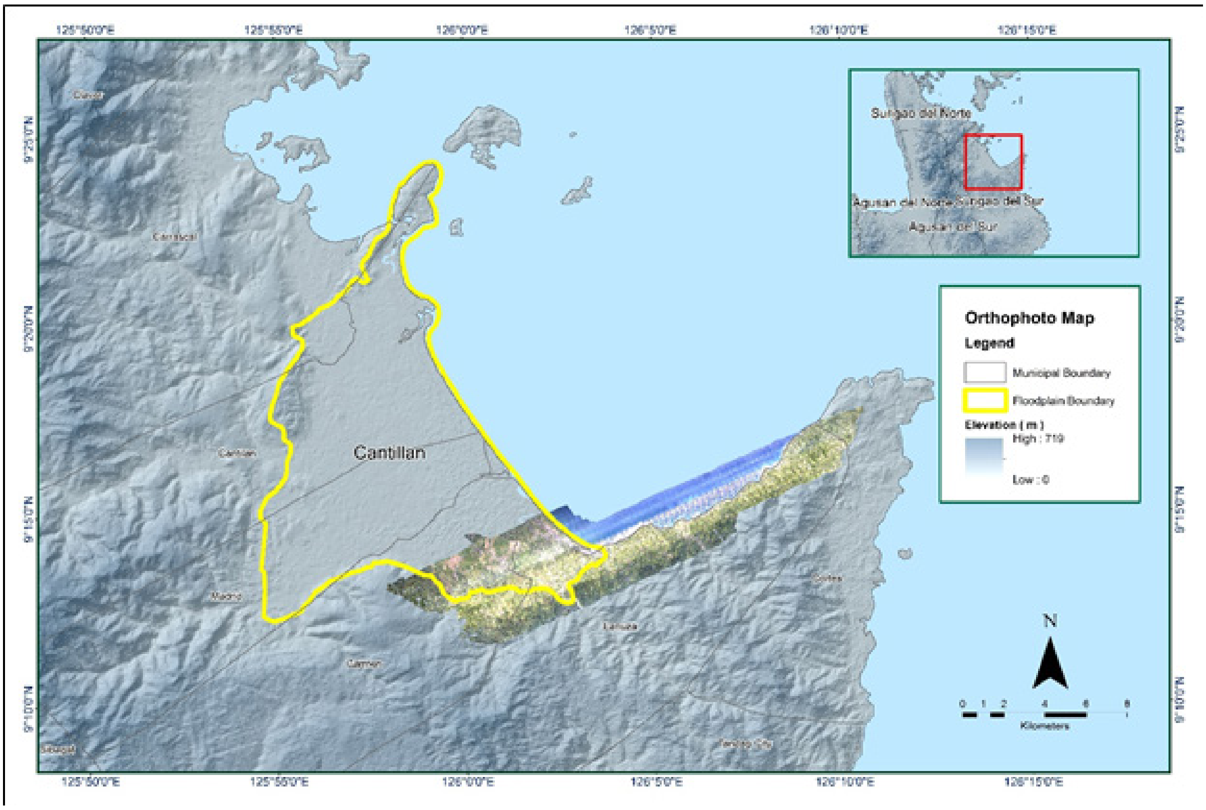


Figure 20 Cantilan Floodplain with available orthophotographs

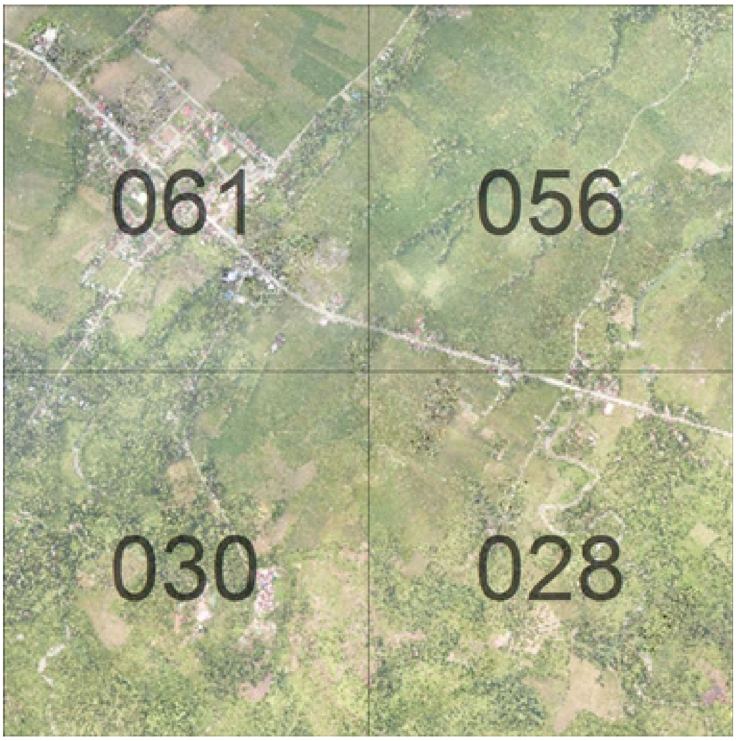


Figure 21 Sample orthophotograph tiles for Cantilan Floodplain

3.8 DEM Editing and Hydro-Correction

Seven (7) mission blocks were processed for Cantilan Floodplain. These are composed of Siargao, Surigao delSur and Surigao_reflights blocks with a total area of 436.70 square kilometers. Table 15 shows the name and corresponding area of each block in square kilometers.

Table 15 LiDAR blocks with its corresponding area

LiDAR Blocks	Area (sq. km.)
Siargao_Blk60AB	217.67
SurigaodelSur_Blk61O	79.14
Surigao_reflights_Blk60F	34.27
Surigao_reflights_Blk60G	16.467
Surigao_reflights_Blk60H	44.52
Surigao_reflights_Blk60I	11.04
Surigao_reflights_Blk60E	33.59
TOTAL	436.70 sq.km

Portions of DTM before and after manual editing are shown in Figure 22. The bridge (Figure 22a) was also considered to be an impedance to the flow of water along the river and had to be removed (Figure 22b) in order to hydrologically correct the river. The paddy field (Figure 22c) had been misclassified and removed during classification process and had to be retrieved to complete the surface (Figure 22d) to allow the correct flow of water.

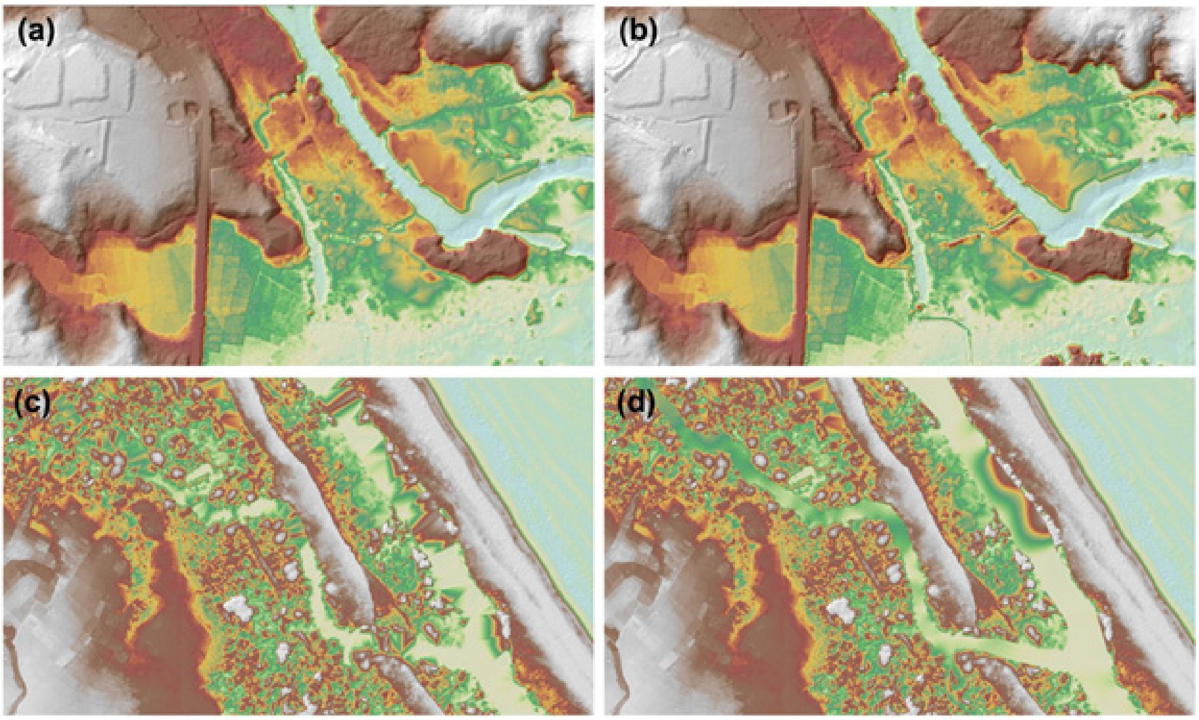


Figure 22 Portions in the DTM of Cantilan floodplain – a bridge before (a) and after (b) manual editing; and a paddy field before (c) and after (d) data retrieval

3.9 Mosaicking of Blocks

Siargao_Blk60AB was used as the reference block at the start of mosaicking because this block contained national highway in which the validation surveys passed through this road. Table 16 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Cantilan Floodplain is shown in Figure 23. It can be seen that the entire Cantilan floodplain is 99.99% covered by LiDAR data.

Table 16 Shift Values of each LiDAR Block of Cantilan Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
SurigaodelSur_Blk61O	0.00	0.00	0.08
Surigao_reflights_Blk60F	0.00	0.00	-0.13
Surigao_reflights_Blk60G	0.00	0.00	-0.15
Surigao_reflights_Blk60H	0.00	0.00	-0.23
Surigao_reflights_Blk60I	0.00	0.00	-0.14
Surigao_reflights_Blk60E	0.00	0.00	-0.13

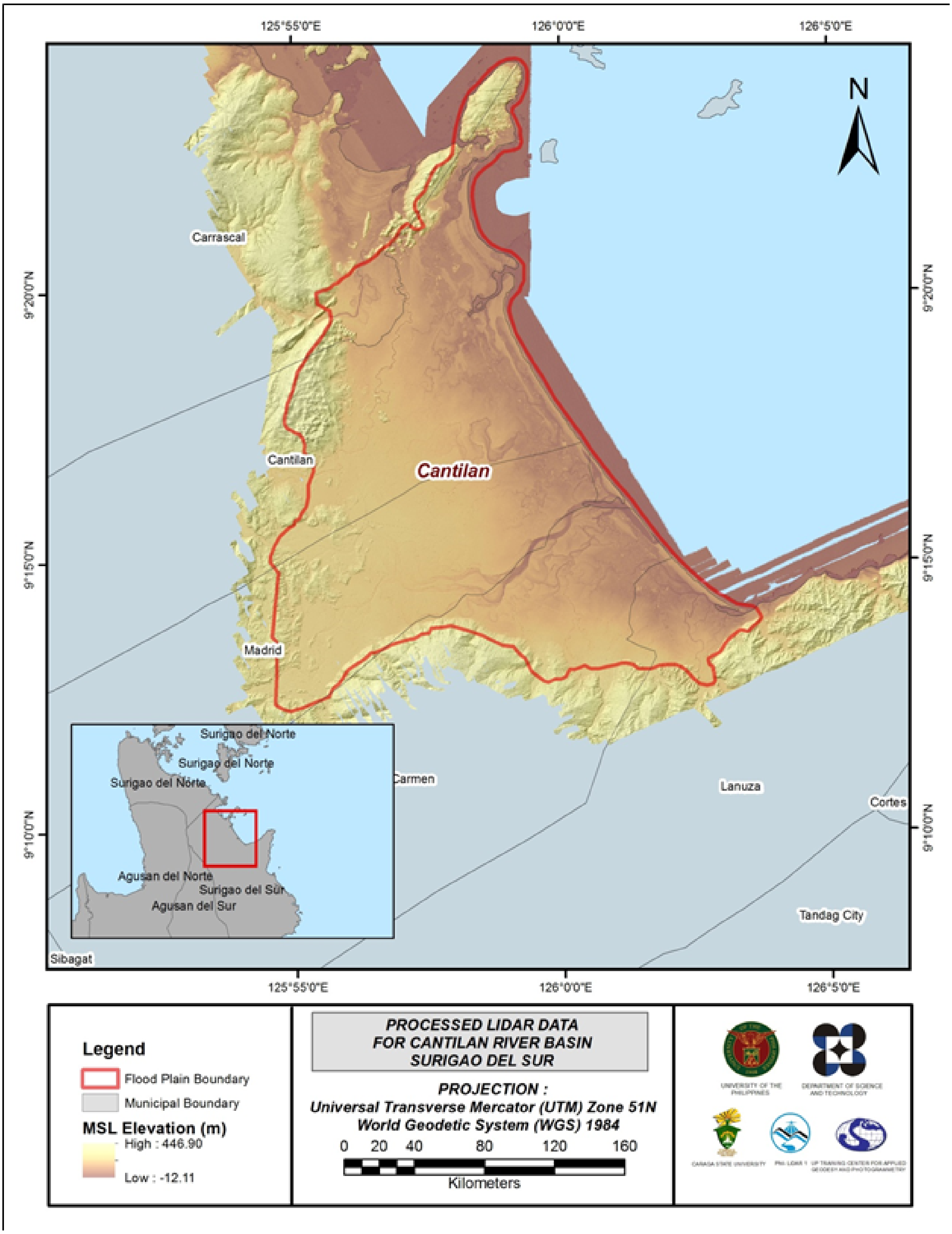


Figure 23 Map of Processed LiDAR Data for Cantilan Floodplain

3.10 Calibration and Validation of Mosaicked LiDAR DEM

CSU's Field Survey Team (FST) in coordination with the Data Validation and Bathymetry Component (DVBC) in Cantilan conducted surveys to collect points for the Lidar validation (Figure 24). A total of 11,425 survey points were used for calibration and validation of Cantilan LiDAR data. Random selection of 80% of the survey points, resulting to 9,140 points, was used for calibration. A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 25. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 0.20 meters with a standard deviation of 0.17 meters. Calibration of Cantilan LiDAR data was done by subtracting the height difference value, 0.20 meters, to Cantilan mosaicked LiDAR data. Table 17 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

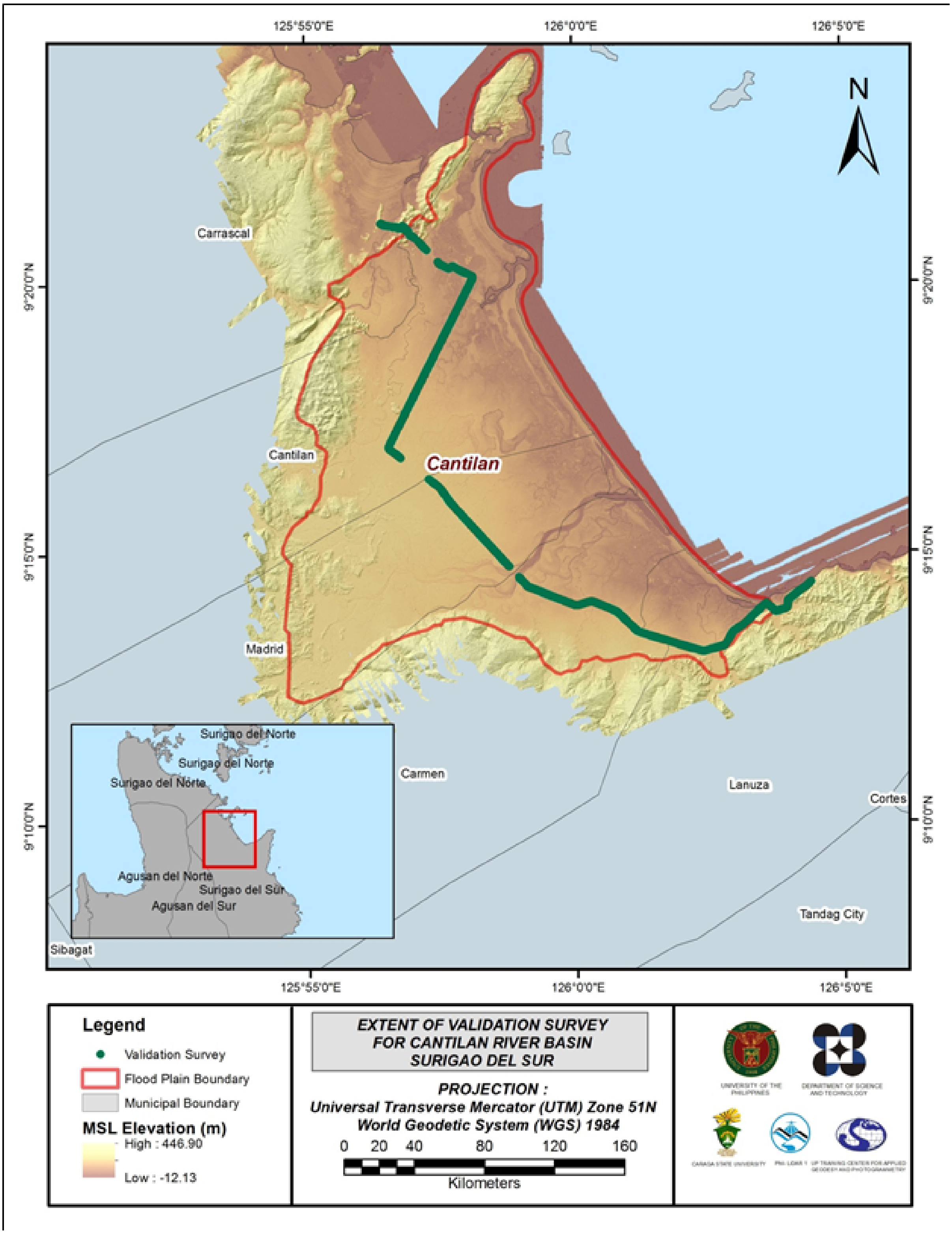
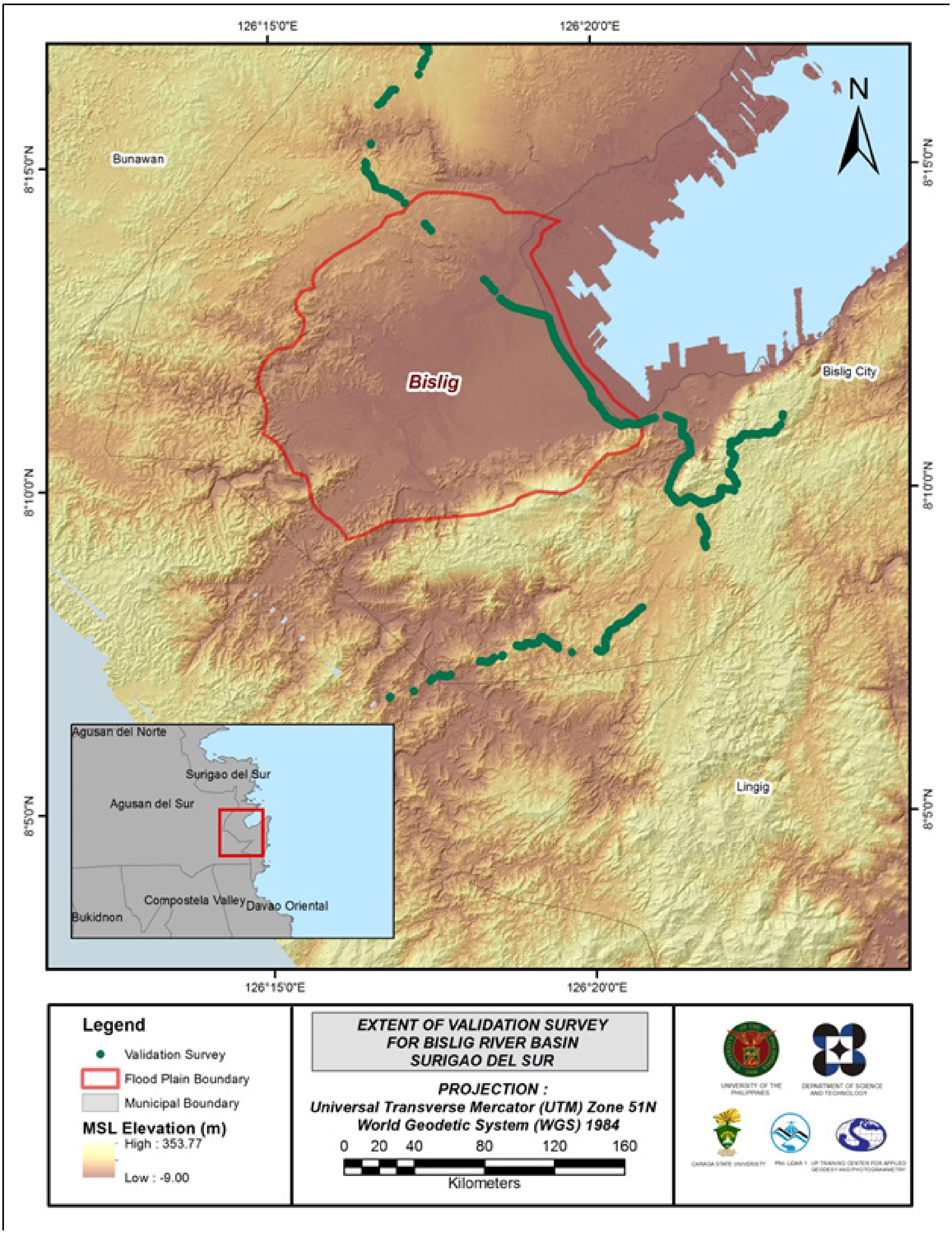


Figure 24 Map of Cantilan Floodplain with validation survey points in green


126°15'0"E
126°20'0"E
8°15'0"N
8°10'0"N
8°5'0"N
N
Bunawan
Bislig
Bislig City
Lingig
Agusan del Norte
Surigao del Sur
Agusan del Sur
Compostela Valley
Davao Oriental
Bukidnon
Legend
Validation Survey
Flood Plain Boundary
Municipal Boundary
MSL Elevation (m)
High : 353.77
Low : -9.00
EXTENT OF VALIDATION SURVEY
FOR BISLIG RIVER BASIN
SURIGAO DEL SUR
PROJECTION :
Universal Transverse Mercator (UTM) Zone 51N
World Geodetic System (WGS) 1984
0 20 40 80 120 160
Kilometers

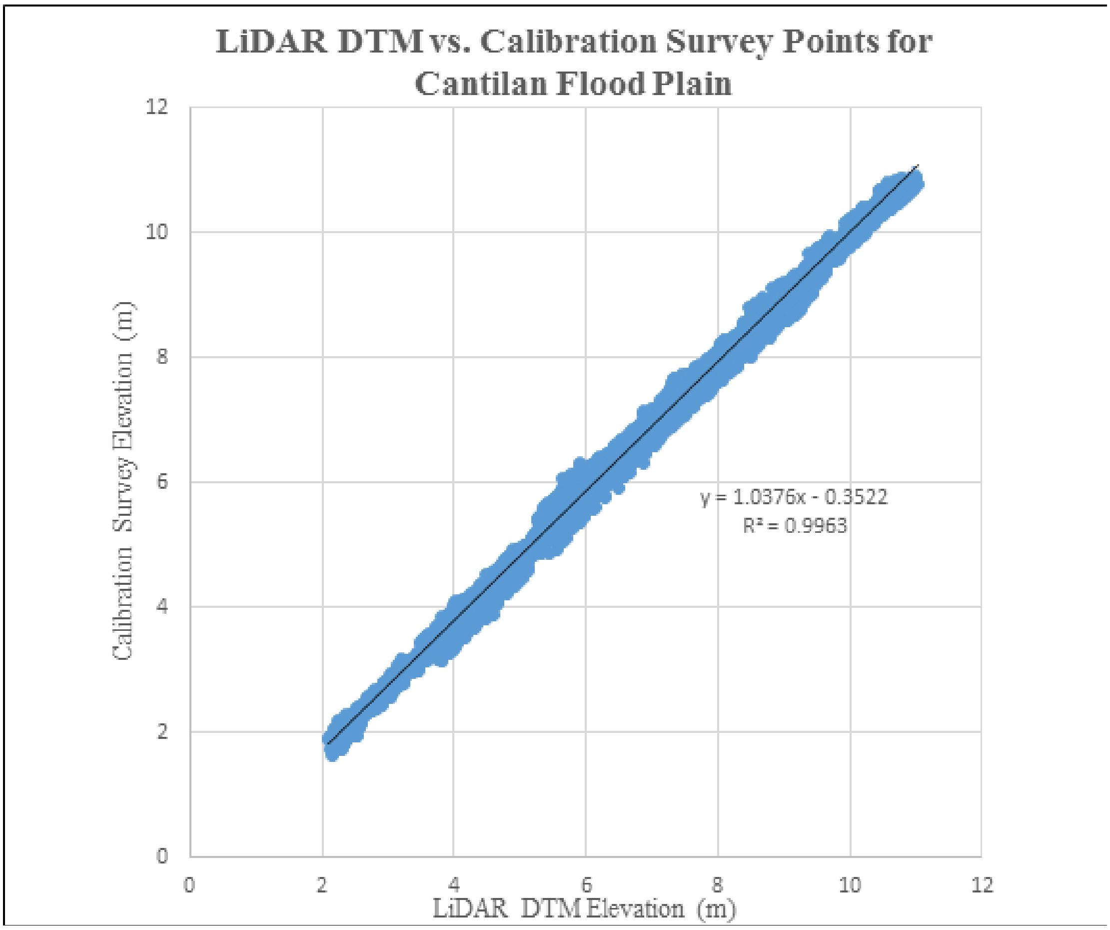


Figure 25 Correlation plot between calibration survey points and LiDAR data

Table 17 Calibration Statistical Measures

Calibration Statistical Measures	Value (meters)
Height Difference	0.20
Standard Deviation	0.17
Average	-0.11
Minimum	-0.45
Maximum	0.24

The remaining 20% of the total survey points, resulting to 2,285 points, were used for the validation of calibrated Cantilan DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 26. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.17 meters, as shown in Table 18.

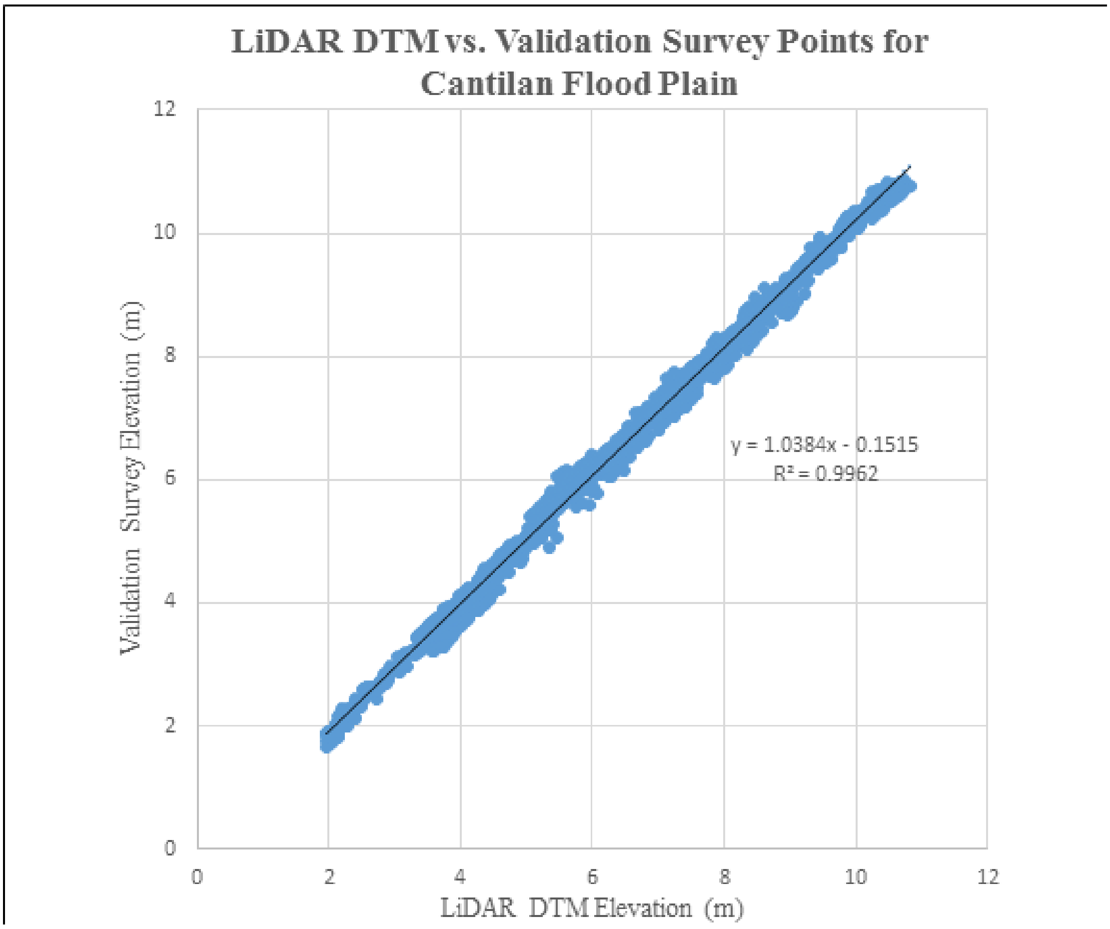


Figure 26 Correlation plot between validation survey points and LiDAR data

Table 18 Validation Statistical Measures

Validation Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.17
Average	0.09
Minimum	-0.26
Maximum	0.44

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, centerline and zigzag data were available for Cantilan with 64,167 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barriers method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.63 meters. The extent of the bathymetric survey done by the CSU's Field Survey Team (FST) in coordination with Data Validation and Bathymetry Component (DVBC) in Cantilan integrated with the processed LiDAR DEM is shown in Figure 27.

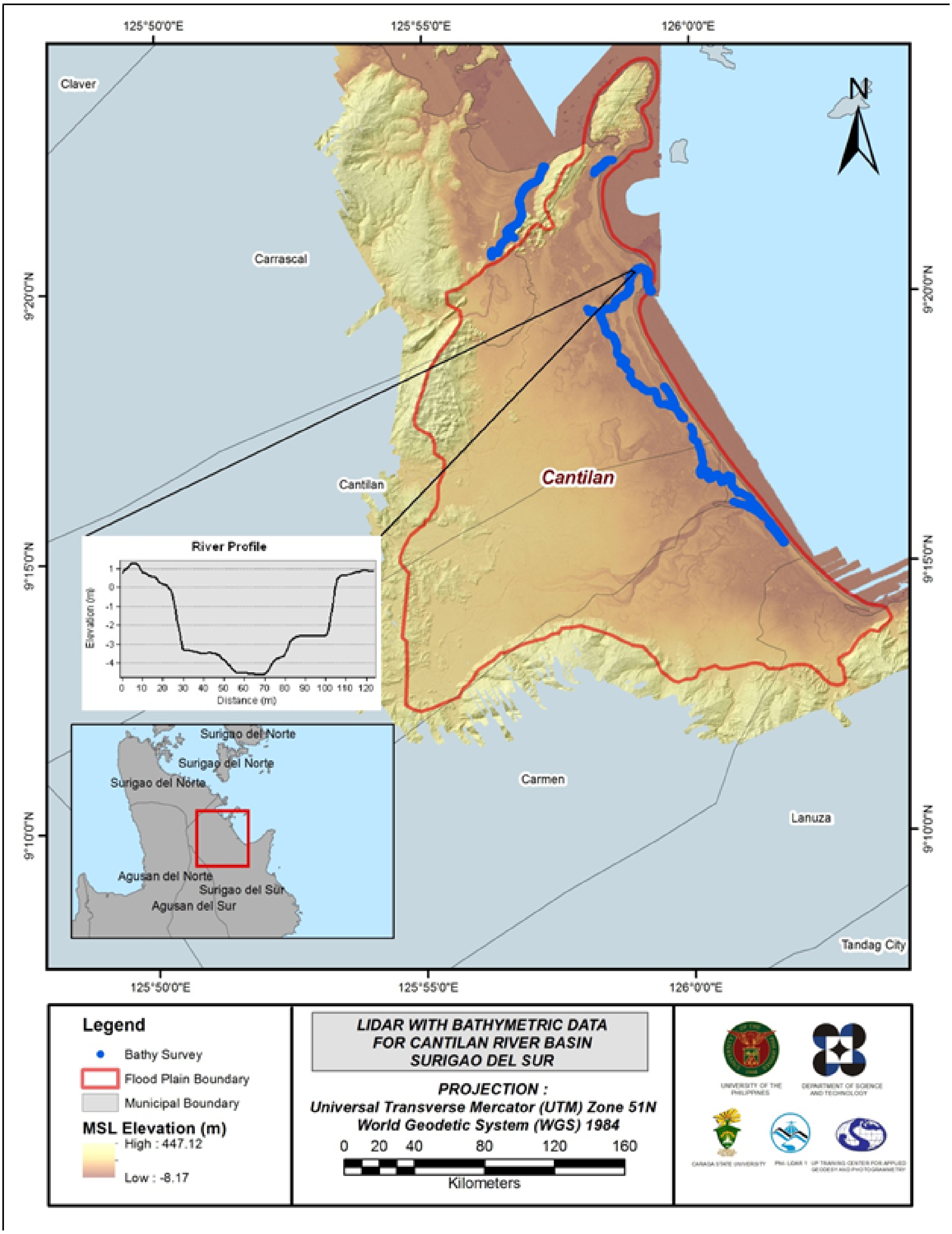


Figure 27 Map of Cantilan Floodplain with bathymetric survey points shown in blue

3.12 Feature Extraction

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

3.12.1 Quality Checking of Digitized Features' Boundary

Cantilan Foodplain, including its 200 m buffer, has a total area of 177.61 sq km. For this area, a total of 5.0 sq km, corresponding to a total of 1,863 building features, are considered for QC. Figure 28 shows the QC blocks for Cantilan Floodplain.

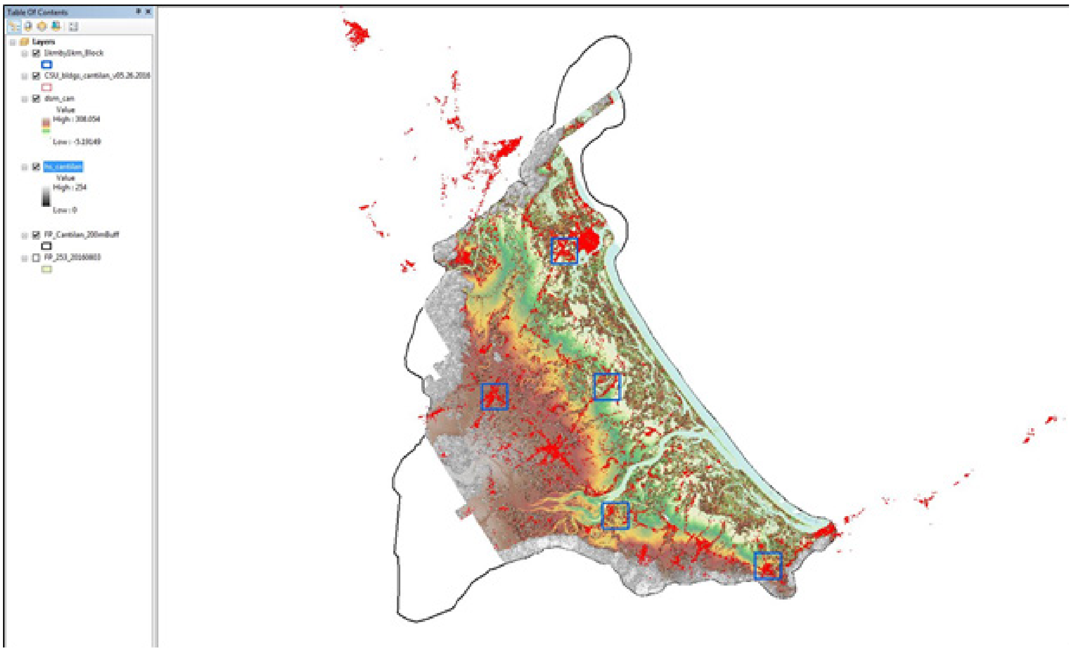


Figure 28 QC blocks for Cantilan building features.

Quality checking of Libertad building features resulted in the ratings shown in Table 17.
Quality checking of Cantilan building features resulted in the ratings shown in Table 19.

FLOODPLAIN	COMPLETENESS	CORRECTNESS	QUALITY	REMARKS
Cantilan	98.05	99.62	88.89	PASSED

3.12.2 Height Extraction

Height extraction was done for 23,350 building features in Cantilan Floodplain. Of these building features, 1,086 buildings were filtered out after height extraction, resulting to 22,264 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 6.43 m.

3.12.3 Feature Attribution

Field surveys, familiarity with the area, and free online web maps such as Wikimapia (http://wikimapia.org/) and Google Map (https://www.google.com/maps) were used to gather information such as name and type of the features within the river basin.

Table 20 summarizes the number of building features per type. On the other hand, Table 21 shows the total length of each road type, while Table 22 shows the number of water features extracted per type.

Table 20 Building Features Extracted for Cantilan Floodplain.

Facility Type	No. of Features
Residential	21,531
School	435
Market	10
Agricultural/Agro-Industrial Facilities	1
Medical Institutions	4
Barangay Hall	7
Military Institution	0
Sports Center/Gymnasium/Covered Court	46
Telecommunication Facilities	0
Transport Terminal	25
Warehouse	0
Power Plant/Substation	0
NGO/CSO Offices	0
Police Station	9
Water Supply/Sewerage	0
Religious Institutions	36
Bank	4
Factory	0
Gas Station	17
Fire Station	2
Other Government Offices	25
Other Commercial Establishments	112
Total	**3,965**

Table 21 Total Length of Extracted Roads for Cantilan Floodplain

Floodplain	Road Network Length (km)					Total
	Barangay Road	City/ Municipal Road	Provincial Road	National Road	Others	
Cantilan	88.47	49.94	199.74	33.75	0.00	371.90

Table 22 Number of Extracted Water Bodies for Cantilan Floodplain

Floodplain	Water Body Type					Total
	Rivers/ Streams	Lakes/Ponds	Sea	Dam	Fish Pen	
Cantilan	37	1	0	1	130	169

A total of 81 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 29 shows the Digital Surface Model (DSM) of Cantilan Floodplain overlaid with its ground features.

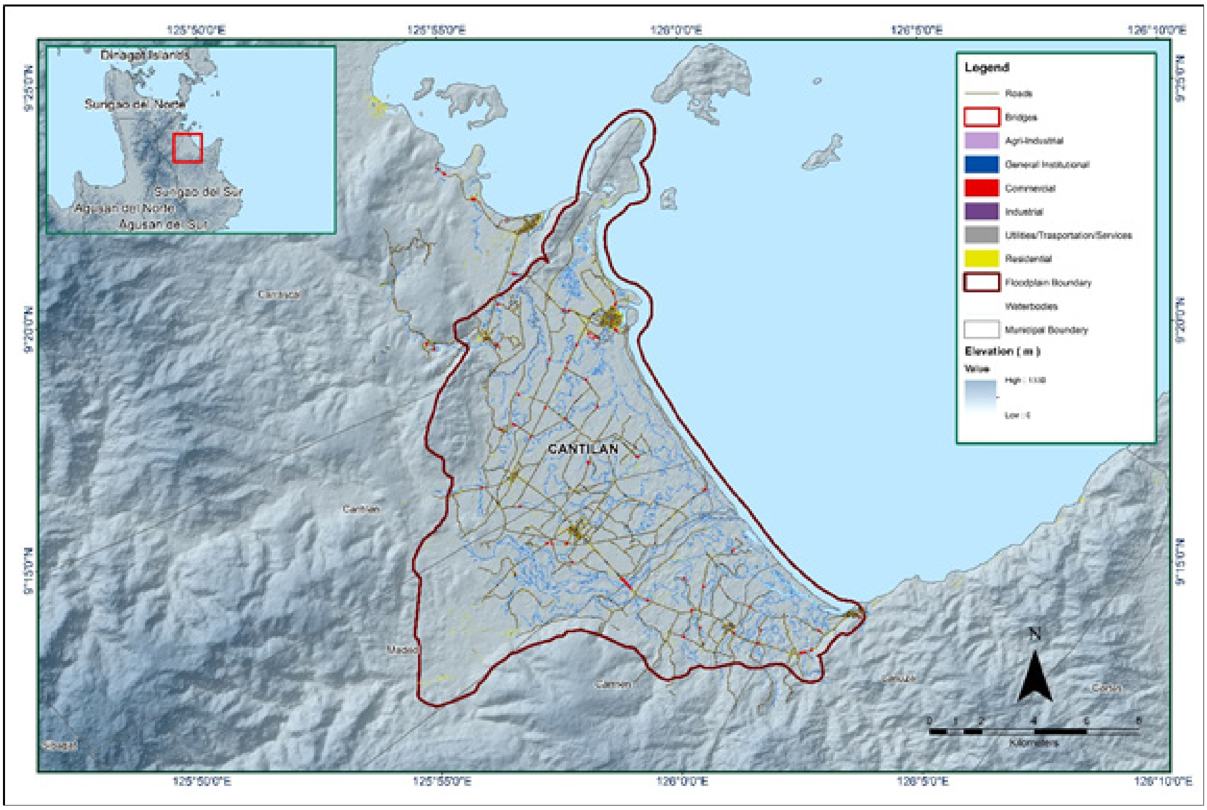


Figure 29 Extracted features for Cantilan Floodplain

Chapter 4: LiDAR Validation Survey and Measurements of Cantilan River Basin

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, Engr. Kristine Ailene B. Borromeo, Ms. Jeline M. Amante, Marie Angelique R. Estipona, Charie Mae V. Manliguez, Engr. Janina Jupiter, Vie Marie Paola M. Rivera

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 Basin Overview and Summary of Activities

AB Surveying and Development (ABSD) conducted a field survey in Cantilan River on April 4, 10 to 13, 14 and 24, 2016 and May 7, 8, and 9, 2016 with the following scope: reconnaissance; control survey; cross-section and as-built survey at Carac-An Bridge in Brgy. San Juan, Carmen, Surigao del Sur and bathymetric survey from its upstream in Brgy. Bagsac, Madrid to the mouth of the river located in Brgy. Santa Cruz, Carmen with an approximate length of 11.2 km using Hi-Target™ Echo Sounder and Horizon® Total Station. Bathymetric survey and validation points acquisition survey covering the Cantilan River Basin area were executed by CSU on June 20-24, 2016, June 27-July 1, 2016, and July 11-15, 2016 using a South Single Beam Echo Sounder and South S86T GNSS in RTK survey technique. The entire survey extent is illustrated in Figure 30.

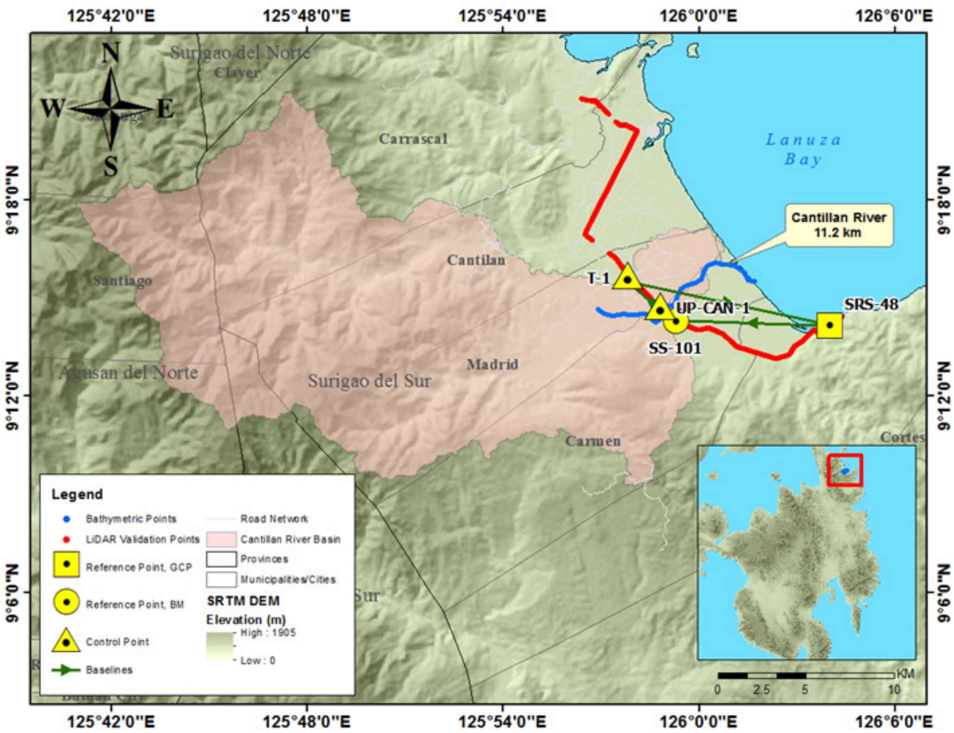


Figure 30 Cantilan River Survey Extent

4.2 Control Survey

The GNSS network used for Cantillan River is composed of one (1) loop established on June 23, 2016 occupying the following reference points: SRS-48 a second-order GCP, in Brgy. Habag, Lanuza, Surigao del Sur and SS-101, a second-order BM, in Brgy. Antao, Carmen, Surigao del Sur.
A control point established in the area by CSU was also occupied: T-1, located near the municipal hall of Madrid on Brgy. Linibuan, Madrid, Surigao del Sur.
The summary of reference and control points and its location is summarized in Table 23 while GNSS network established is illustrated in Figure 31.

Table 21. List of reference and control points used during the survey in Libertad River (Source: NAMRIA, UP-TCAGP).

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoid Height (m)	Elevation (MSL) (m)	Date of Establishment
Control Survey on December 10, 2016						
NGE-67	2nd order, GCP	10°05'32.0593"N	123°15'52.4410"E	69.290	-	2008
NE-202	1st order, BM	-	-	66.499	4.105	2008
UP-CAN	Used as Marker	-	-	-	-	January 2016

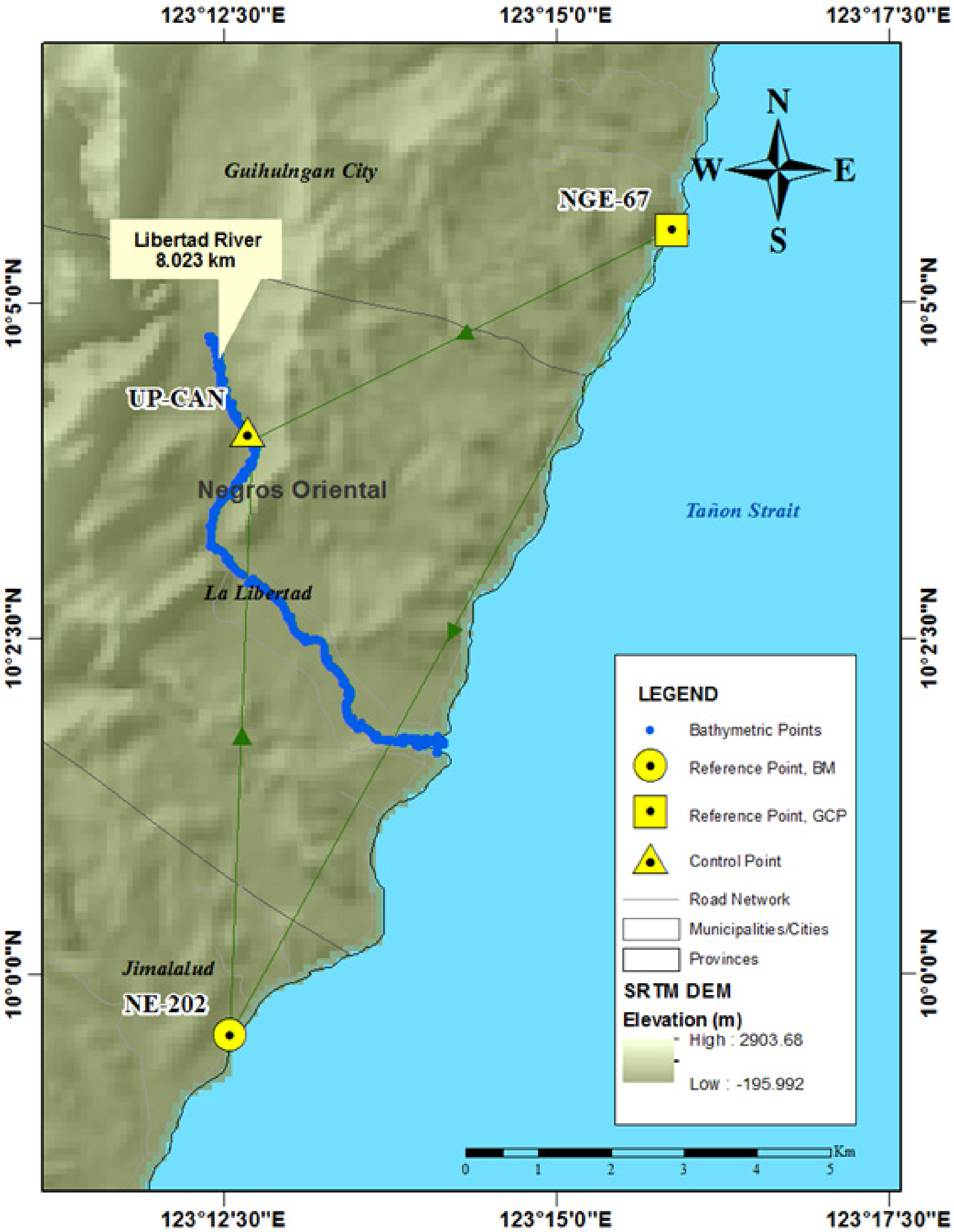


Figure 30. Libertad River Basin Control Survey Extent.

Figure 31 to Figure 33 depict the setup of the GNSS on recovered reference points and established control points in the Libertad River.

Figure 31. Trimble® SPS 852 base set-up at NGE-67 located along national road in Brgy. Mckinley, Municipality of Libertad.

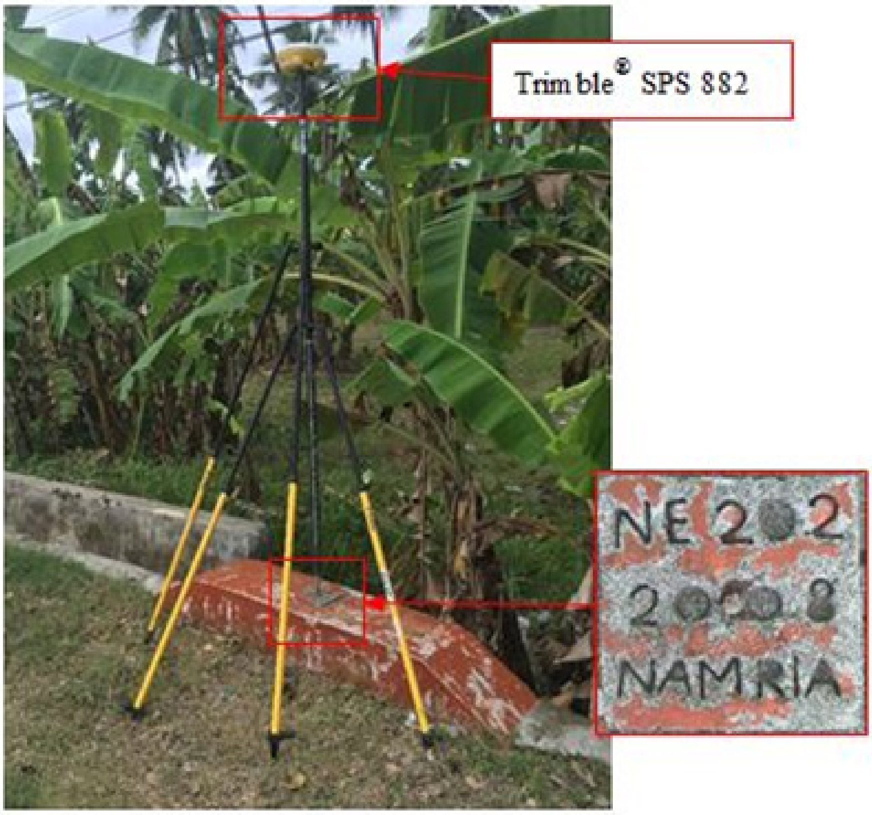


Figure 32. Trimble® SPS 882 receiver set-up at UP-CAN located at the right side of Cangabo Spillway in Brgy. Pangca, Municipality of Libertad.

Figure 33. Trimble® SPS 882 receiver set-up at UP-CAN located at the right side of Cangabo Spillway in Brgy. Pangca, Municipality of La Libertad.

4.3 Baseline Processing

The GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement respectively. In cases where one or more baselines did not meet all of these criteria, masking was performed. Masking is the removal or covering of portions of the baseline data using the same processing software. The data is then repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, a resurvey is initiated. Table 22 presents the baseline processing results of control points in the Libertad River Basin, as generated by the TBC software.

Table 22. The Baseline processing report for the Libertad River GNSS static observation survey.

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
NGE-67 --- UP-CAN (B7)	01-28, 2016	Fixed	0.006	0.027	244°43'34"	6458.846	19.529
NGE-67 --- NE-202 (B8)	01-28, 2016	Fixed	0.006	0.027	208°51'24"	12614.093	-2.801
NE-202 --- UP-CAN (B9)	01-28, 2016	Fixed	0.011	0.051	1°41'54"	8293.919	22.279

4.4 Network Adjustment

After the baseline processing procedure, the network adjustment is performed using the TBC software. 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 for each control point; or in equation form:

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

where:

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

For complete details, see the Network Adjustment Report shown in Table 23 to Table 26.

The three (3) control points, NGE-67, NE-202 and UP-CAN were occupied and observed simultaneously to form a GNSS loop. All baselines acquired fixed solutions and passed the required ±20cm and ±10cm for horizontal and vertical precisions, respectively as presented in Table 22. Through these reference points, the coordinates and elevation of the unknown control points will be computed.

Table 23. Constraints applied to the adjustment of the control points.

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
NE-202	Grid				Fixed
NGE-67	Global	Fixed	Fixed		
Fixed = 0.000001(Meter)					

Likewise, 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 24.

Table 24. Adjusted grid coordinates for the control points used in the Libertad River flood plain survey.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
NGE-67	528987.231	?	1115622.481	?	7.275	0.040	LL
NE-202	522910.723	0.007	1104574.094	0.005	4.105	?	e

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. **NGE-67**
Horizontal accuracy = Fixed
Vertical accuracy = 4.0 cm < 10 cm

b. **NE-202**
Horizontal accuracy = $\sqrt{((0.70)^2 + (0.50)^2}$
= $\sqrt{(0.49 + 0.25)}$
= 0.86 cm < 20 cm
Vertical accuracy = Fixed

c. **UP-CAN**
Horizontal accuracy = $\sqrt{((0.70)^2 + (0.50)^2}$
= $\sqrt{(0.49+ 0.25)}$
= 0.86 cm < 20 cm
Vertical accuracy = 5.0 cm < 10 cm

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

Table 25. Adjusted geodetic coordinates for control points used in the Libertad River Flood Plain validation.

Point ID	Latitude	Longitude	Ellipsoid Height (Meter)	Height Error (Meter)	Constraint
NGE-67	N10°05'32.0593"	E123°15'52.4410"	69.290	0.040	LL
NE-202	N9°59'32.4653"	E123°12'32.5537"	66.499	?	e

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 25. Based on the results of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met. The computed coordinates of the reference and control points utilized in the Libertad River GNSS Static Survey are seen in Table 26.

Table 26. The reference and control points utilized in the Libertad River Static Survey, with their corresponding locations (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
NGE-67	2nd order, GCP	10°05'32.0593"N	123°15'52.4410"E	69.290	1115622.481	528987.231	7.275
NE-202	1st order, BM	9°59'32.4653"N	123°12'32.5537"E	66.499	1104574.094	522910.723	4.105
UP-CAN	Used as marker	10°04'02.2919"N	123°12'40.6262"E	88.813	1112861.259	523151.163	26.54

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

The bridge cross-section and as-built surveys were conducted on January 29, 2016 at Cangabo Spillway in Brgy. Pangca, Municipality of La Libertad using GNSS receiver Trimble® SPS 882 in PPK survey technique as shown in Figure 36.

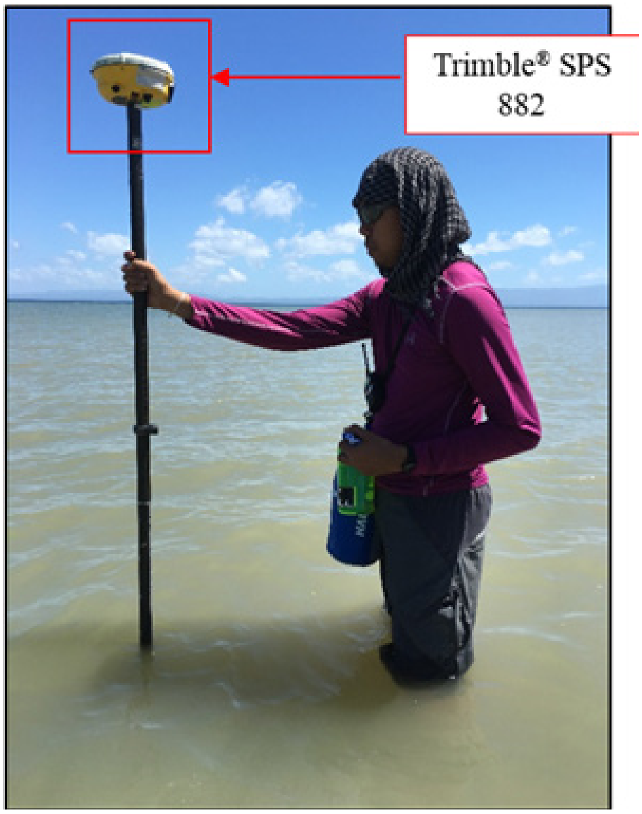


Figure 34. Cross-section survey at the Cangabo Spillway deployment site.

The length of the cross-sectional line surveyed at Cangabo Spillway is about 80.079 meters with 28 cross-sectional points acquired using the control point NGE-67 as the GNSS base station. The location map, cross-section diagram and the accomplished bridge data form for Cangabo Spillway are shown in Figure 35 and Figure 36.

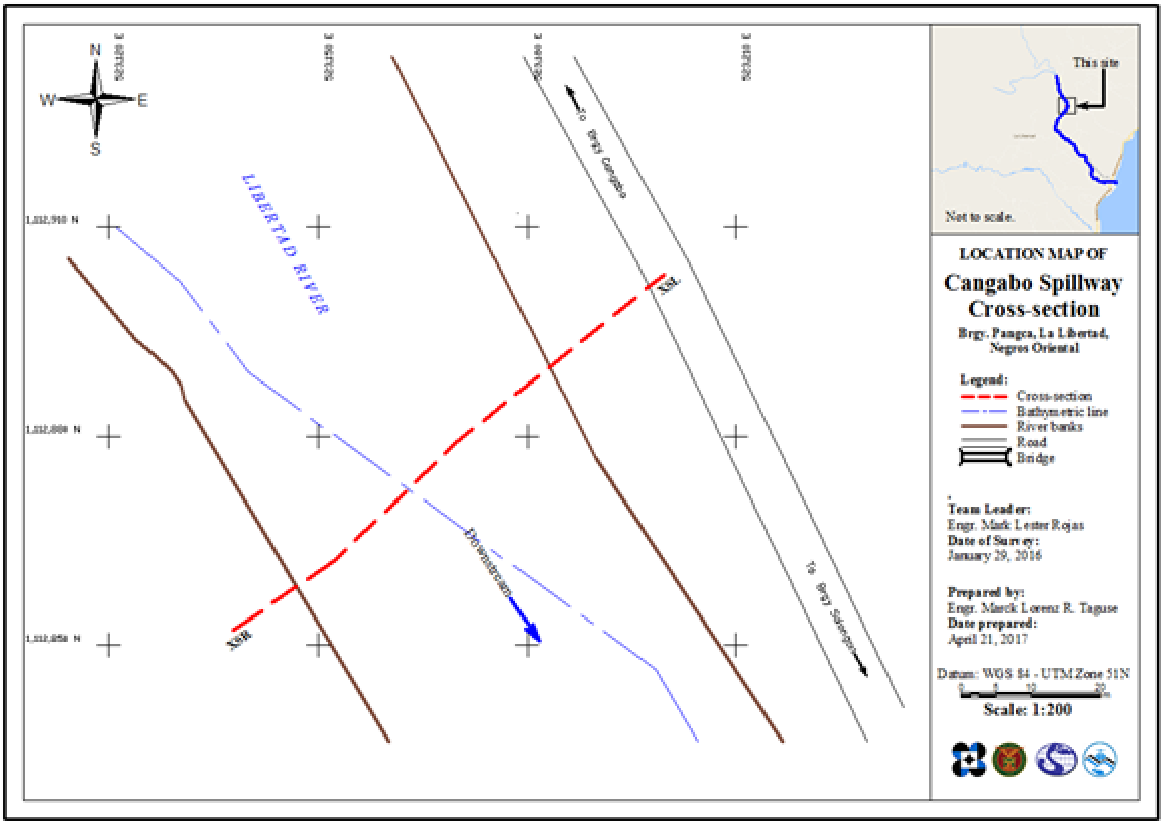


Figure 35. Location map of the Baguhan Bridge Cross Section.

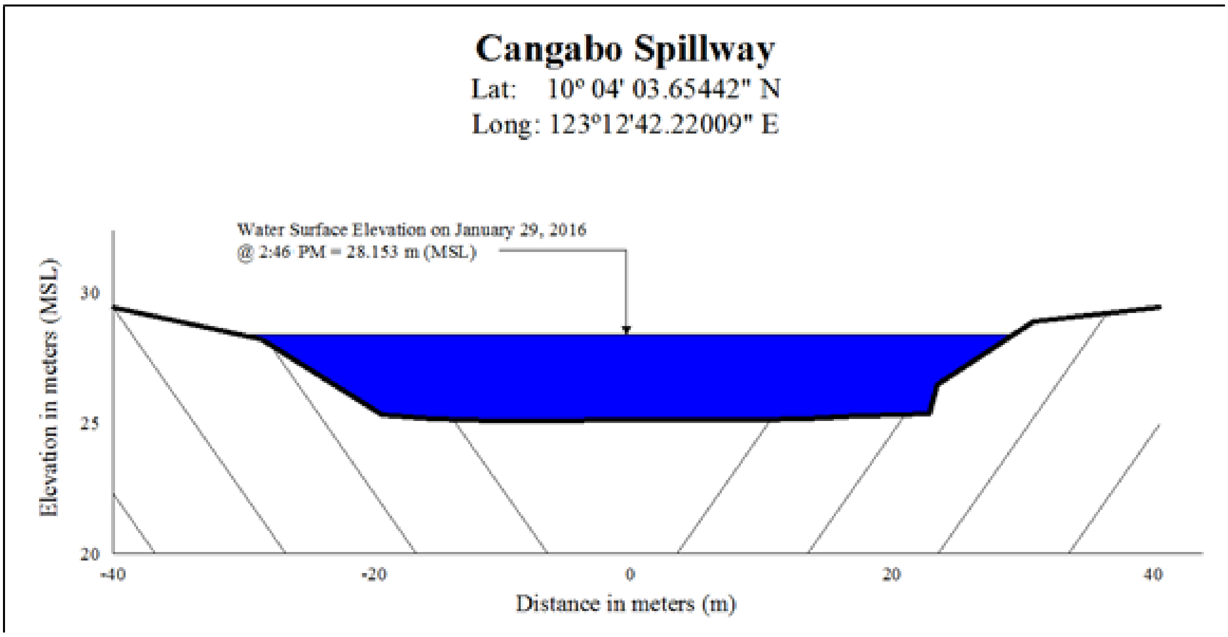


Figure 36. Deployment site, Cangabo Spillway, cross-section diagram

The water surface elevation of Libertad River was determined by a survey grade GNSS receiver Trimble® SPS 882 in PPK survey technique on January 29, 2016 at 2:46 PM with a value of 28.153 m in MSL. This was translated into marking on the bridge's pier as shown in Figure 37. It now serves as the reference for flow data gathering and depth gauge deployment of the University of San Carlos, the partner HEI responsible for the monitoring of the Libertad River.

Figure 37. Water-level markings on the post of Cangabo Spillway.

4.6 Validation Points Acquisition Survey

The validation points acquisition survey was conducted on January 28, 2016 using a survey GNSS rover receiver Trimble® SPS 882 mounted on a range pole, which was attached in front of the vehicle as shown in Figure 38. It was secured with a cable-tie to ensure that it was horizontally and vertically balanced. The antenna height was 2.24 m and measured from the ground up to the bottom of notch of the GNSS Rover receiver.

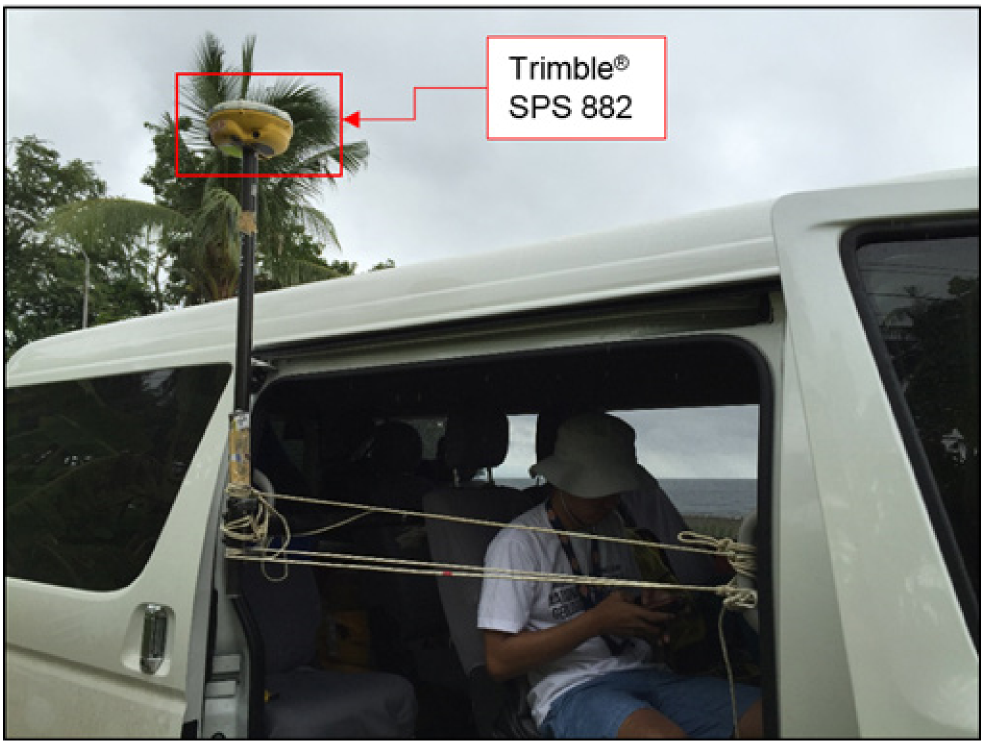


Figure 38. GNSS Receiver Trimble® SPS 882 installed on a vehicle for Ground Validation Survey.

The survey for the Libertad River Basin traversed the Municipalities of Tayasan, Jimalalud, La Libertad, and Guihulngan City. The route of the survey aims to traverse LiDAR flight strips perpendicularly for the basin. A total of 3,209 points with an approximate length of 24.175 km was acquired for the validation point acquisition survey as illustrated in the map in Figure 39.

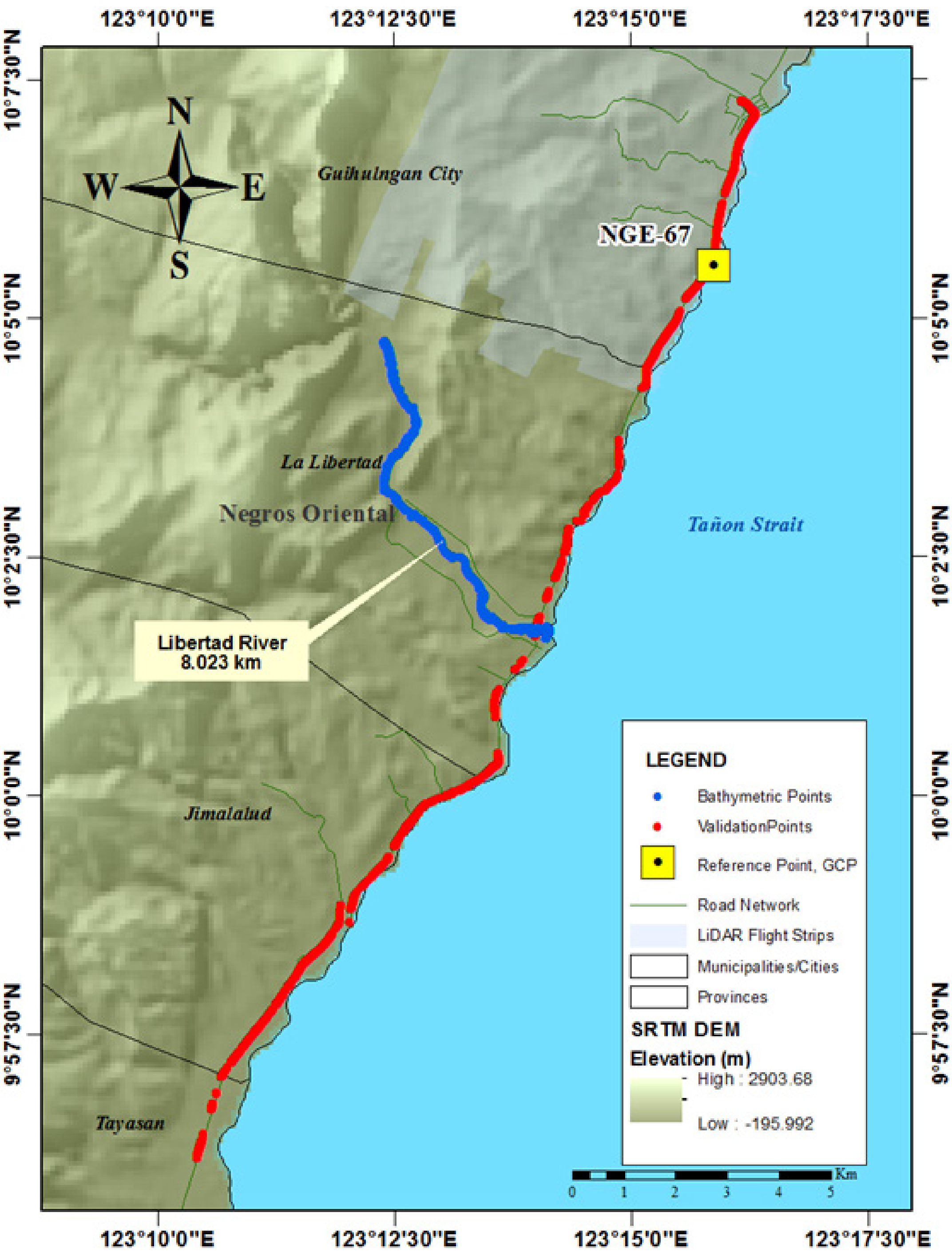


Figure 39. The extent of the LiDAR ground validation survey (in red) for Libertad River Basin.

4.7 River Bathymetric Survey

A bathymetric survey was performed on January 28 and January 30, 2016 starting from the mouth of the river in Brgy. Poblacion with coordinates 10°1'42.8580"N 123°14'9.3890"E and ended in Brgy. Cantupa with coordinates 10°1'45.7541"N 123°13'38.5444"E using Trimble® SPS 882 in GNSS PPK survey technique in continuous topo mode as shown in Figure 40.

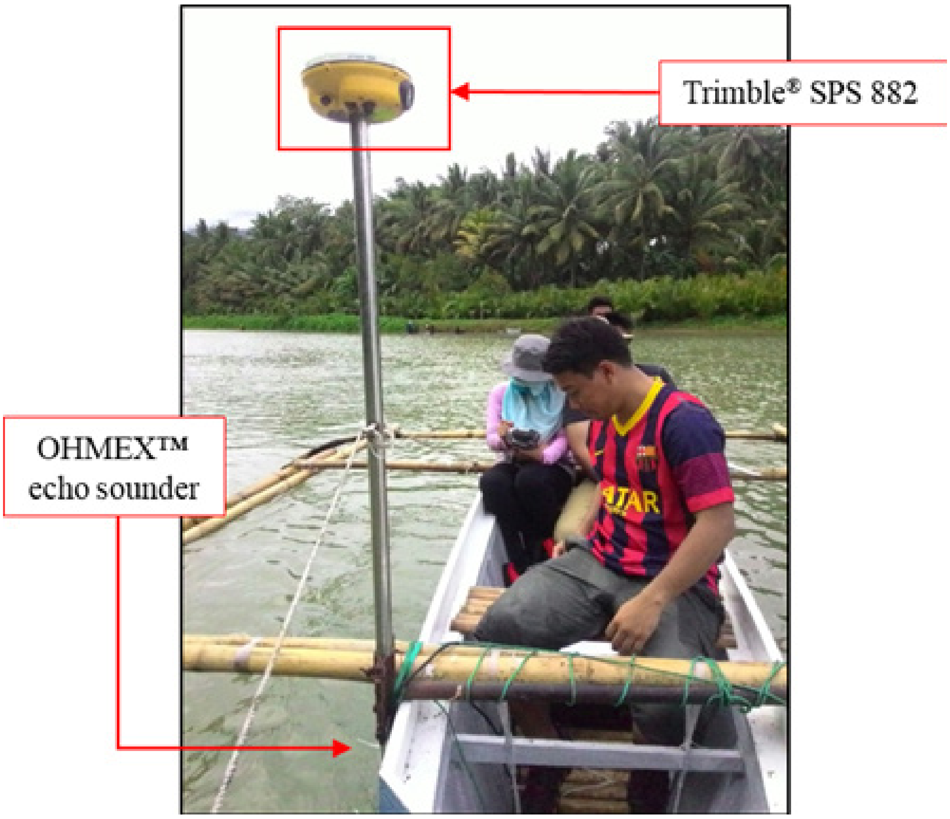


Figure 40. Set up of the bathymetric survey at Libertad River using Trimble® SPS 882 in GNSS PPK survey technique.

Manual bathymetric survey using a GNSS PPK technique was executed on January 29, 2016 starting from the upstream in Brgy. Cangabo with coordinates 10°4'45.1183"N 123°12'24.2921"E traversed the river by foot ending in Brgy. Cantupa with coordinates 10°1'45.7541"N 123°13'38.5444"E as shown in Figure 41. The control point UP-MAN was used as GNSS base station for the whole conduct of the survey.

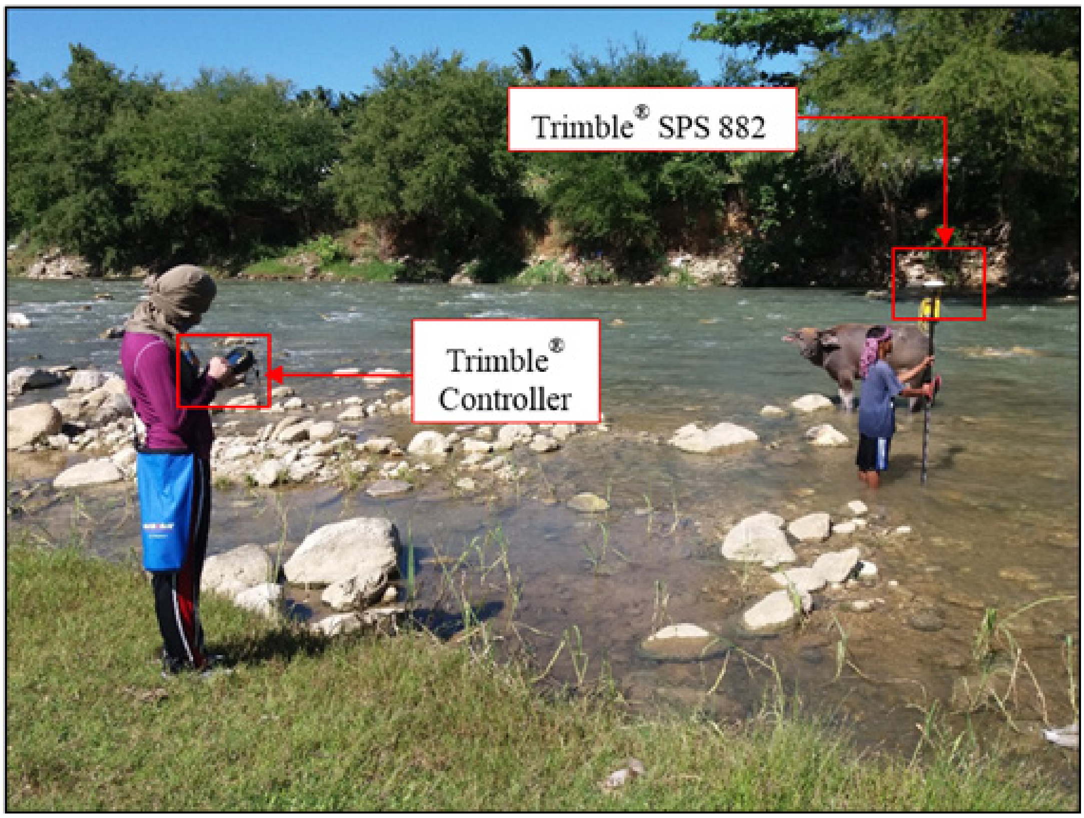


Figure 41. Manual bathymetric survey set-up for Libertad River.

Overall, the bathymetric survey for Libertad River gathered a total of 3,477 points, covering 8.023 km of the river. The extent of the bathymetric survey for the Libertad River is shown in Figure 42. To further illustrate this, a CAD drawing of the riverbed profile of the Libertad River was produced. As seen in Figure 43, the highest and lowest elevation has a 40-m difference. The highest elevation observed was 37.575 m in MSL located at Brgy. Cangabo, Libertad; while the lowest was -3.217 m below MSL located in Brgy. Poblacion also in Libertad.

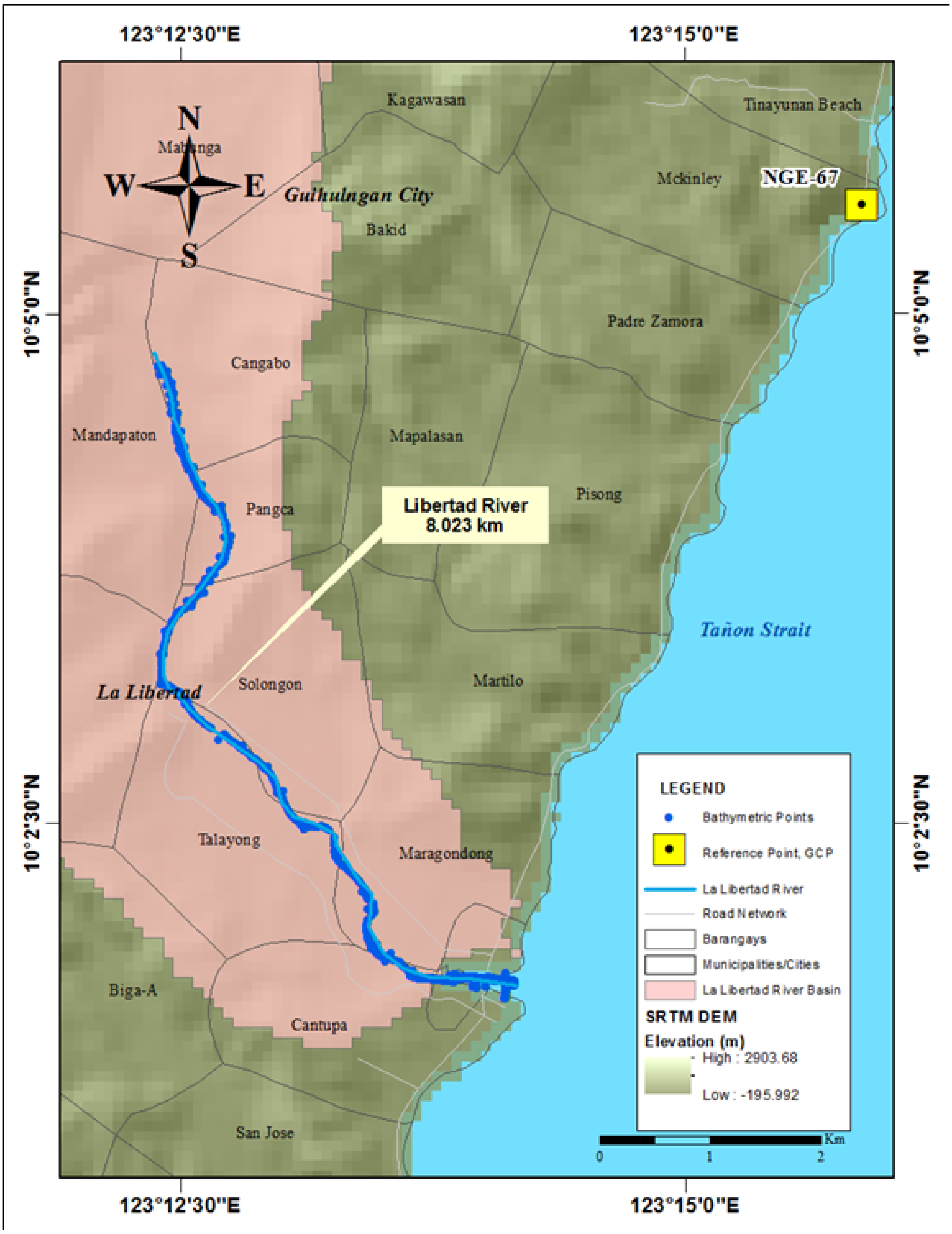


Figure 42. The extent of the Libertad River Bathymetry Survey.

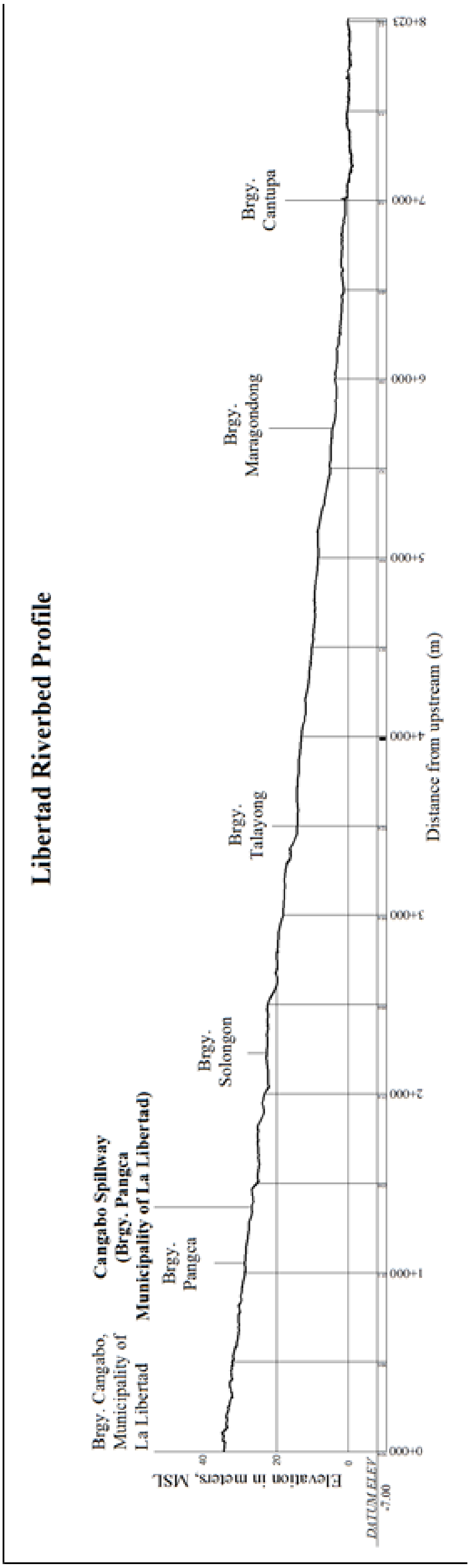


Figure 43. The Libertad Riverbed Profile.

CHAPTER 5: FLOOD MODELING AND MAPPING

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

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

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

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

5.1.2 Precipitation

Precipitation data was taken from an installed Automatic Rain Gauges (ARG) by the Department of Science and Technology - Advanced Science and Technology Institute (DOST-ASTI). They gauge station is located within the Libertad floodplain, municipality of Libertad. The total precipitation used in the calibration of the HMS model is 50.2 mm. It peaked to 6.2 mm on 23:00 on November 16, 2016. The location of this station in the watershed is illustrated in Figure 44.

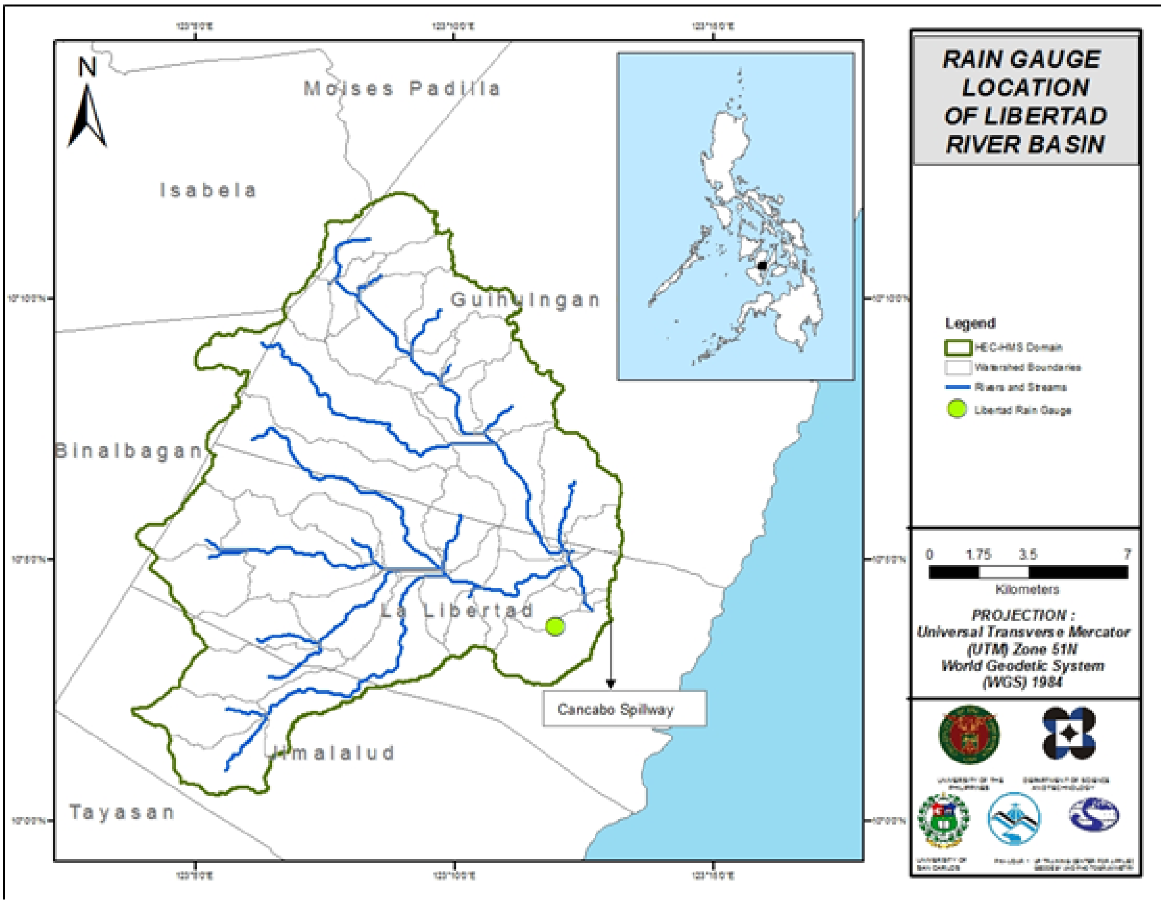


Figure 44. Location Map of the Libertad HEC-HMS model used for calibration.

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Cancabo Spillway (10.0674°N and 123.212°E). It gives the relationship between the observed water levels and outflow of the watershed at this location.

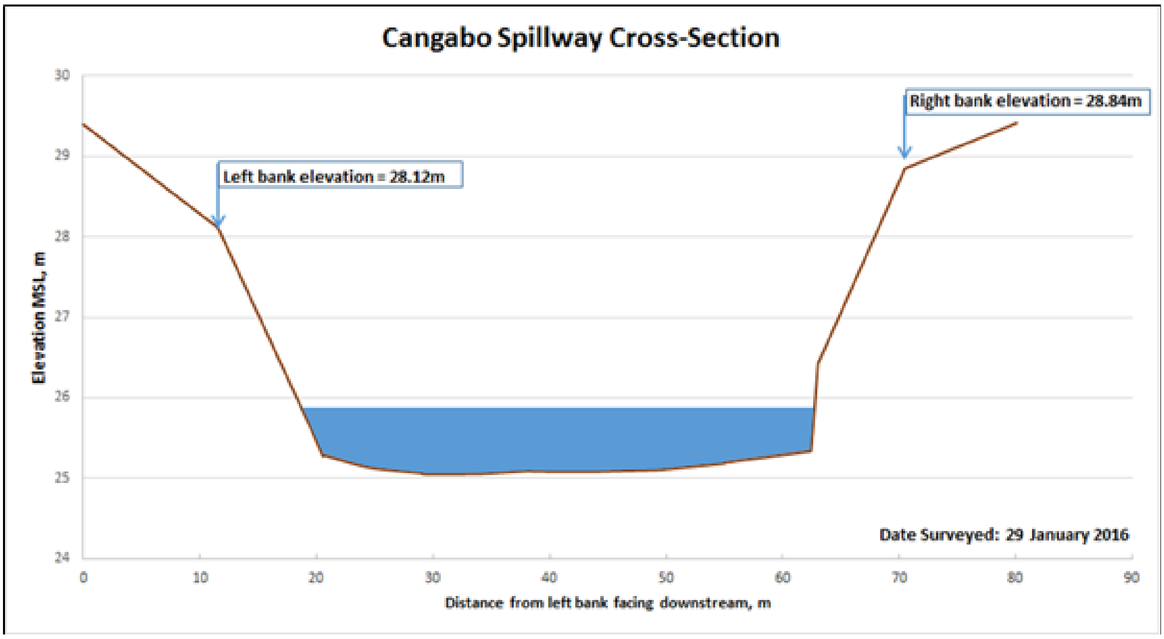


Figure 45. Cross-Section Plot of Cancabo Spillway in Libertad River.

For Libertad Bridge, the rating curve is expressed y=2E-63e^5.8381x as shown in Figure 46.

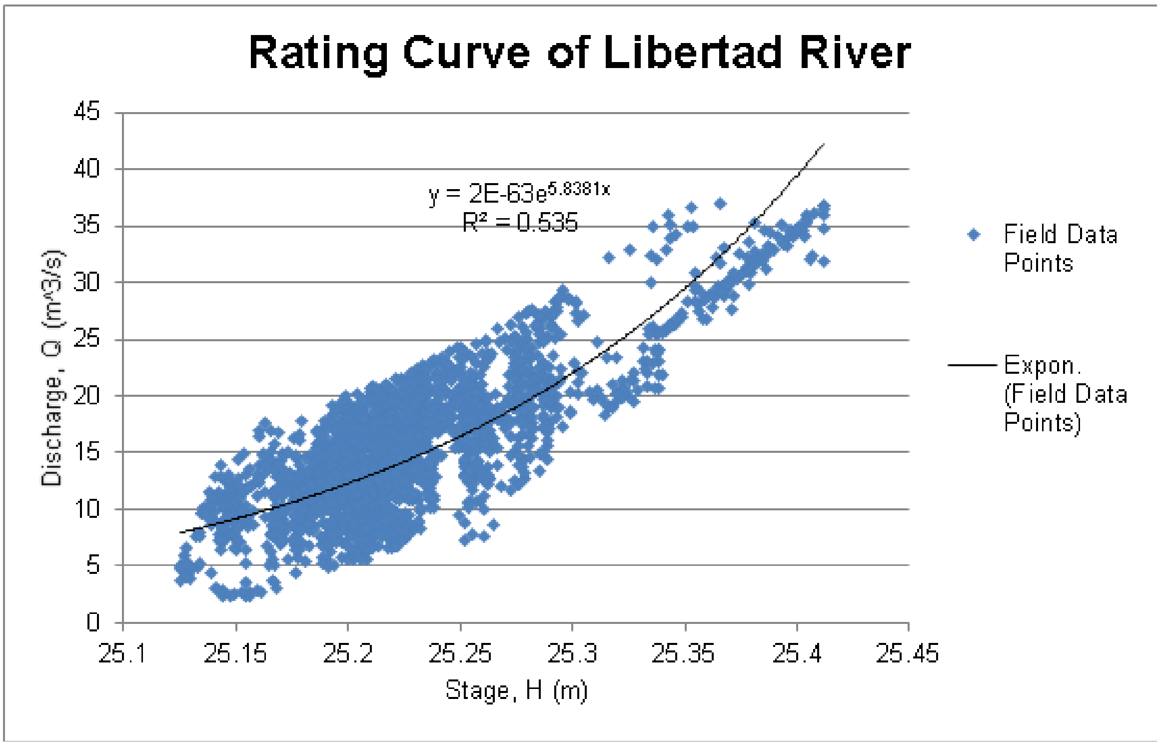


Figure 46. The rating curve at Libertad Bridge, Bohol.

This rating curve equation was used to compute the river outflow at Cancabo Spillway for the calibration of the HEC-HMS model for Libertad shown in Figure 47. The peak discharge is 37.4 m3/s at 3:25 PM, Novermber 17, 2016.

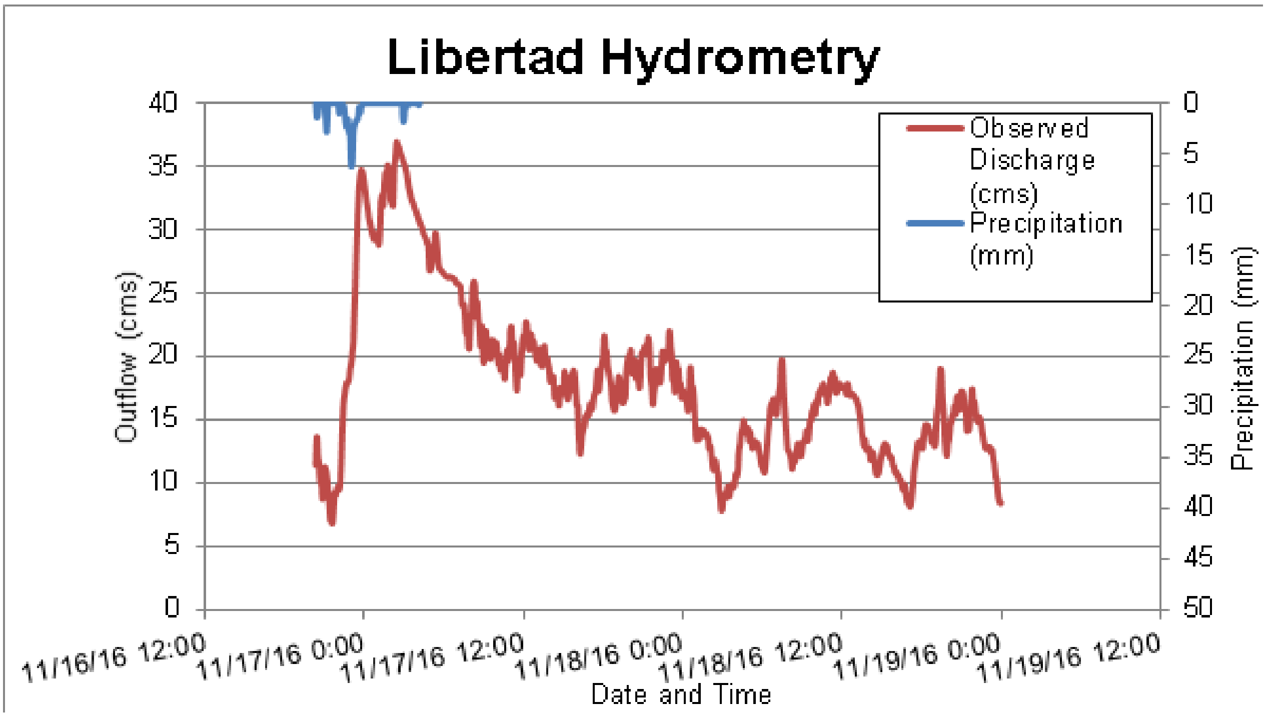


Figure 47. Rainfall and outflow data at Cancabo Spillway used for modeling.

5.2 RIDF Station

PAGASA computed the Rainfall Intensity Duration Frequency (RIDF) values for the Dumaguete Point Gauge (Table 27). The RIDF rainfall amount for 24 hours was converted into a synthetic storm by interpolating and re-arranging the values in such a way that certain peak values will be attained at a certain time (Figure 48). This station was selected based on its proximity to the Libertad watershed. The extreme values for this watershed were computed based on a 37-year record.

Table 27. RIDF values for the Libertad River Basin based on average RIDF data of Dumaguete station, as 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	16.2	24.8	30.6	39.7	50	55.3	63.4	69.1	76
5	21.8	33.6	42.3	57.1	76.5	87.3	100	109.5	116.5
10	25.6	39.4	50	68.6	94	108.5	124.3	136.3	143.3
15	27.7	42.7	54.3	75.1	103.9	120.5	138	151.4	158.4
20	29.1	45	57.4	79.7	110.8	128.9	147.5	162	169
25	30.3	46.8	59.7	83.2	116.1	135.3	154.9	170.2	177.2
50	33.8	52.3	66.9	94	132.5	155.2	177.6	195.3	202.4
100	37.2	57.7	74.1	104.8	148.8	174.9	200.2	220.2	227.3

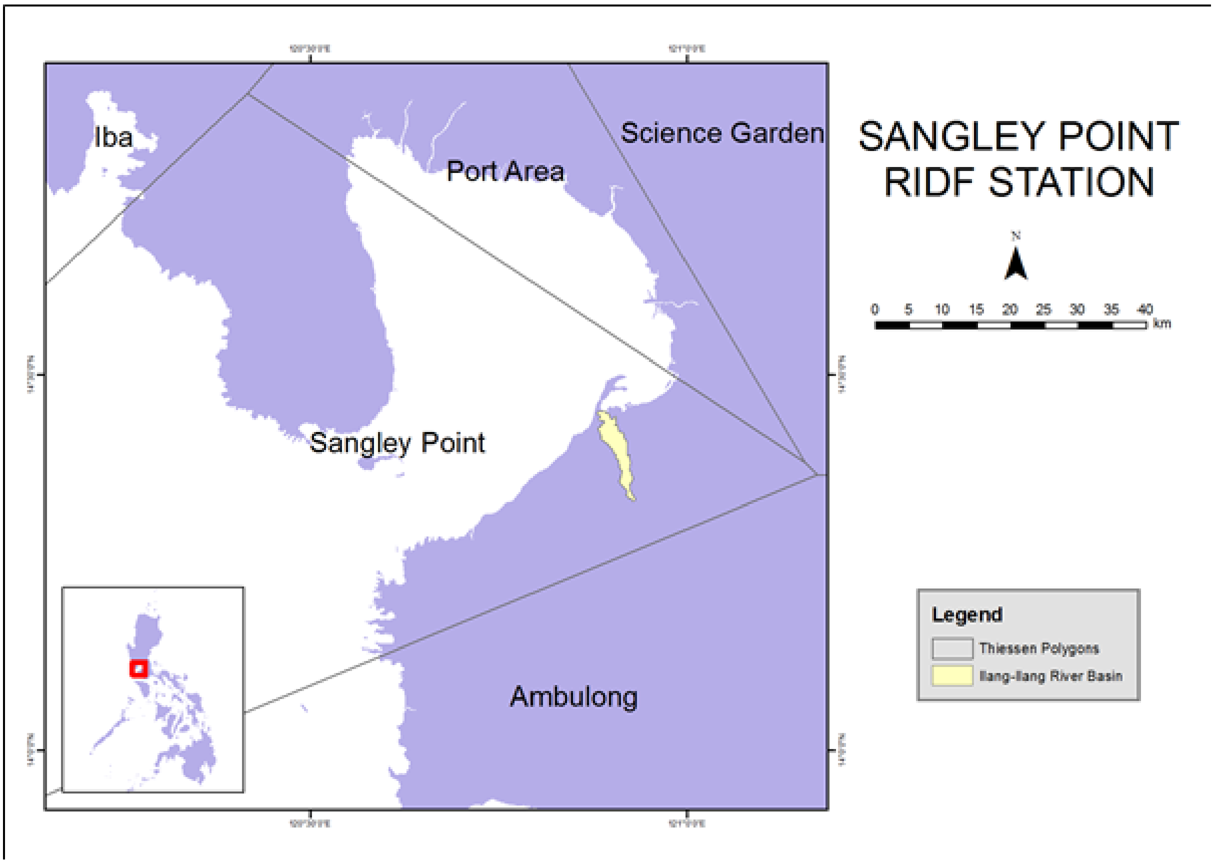


Figure 48. Dumaguete Point RIDF location relative to Libertad River.

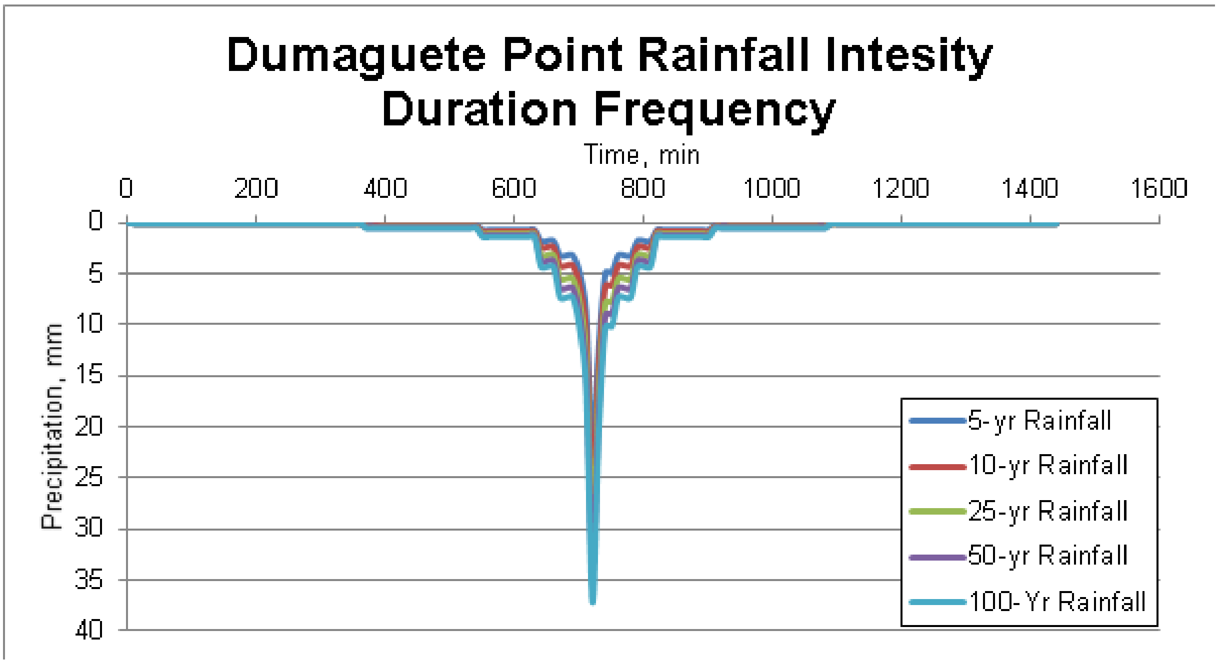


Figure 49. The synthetic storm generated for a 24-hour period rainfall for various return periods.

5.3 HMS Model

The soil dataset was taken on 2004 from the Bureau of Soils and Water Management (BSWM). It is under the Department of Agriculture (DA). The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil and land cover of the Libertad River Basin are shown in Figure 50 and Figure 51, respectively.

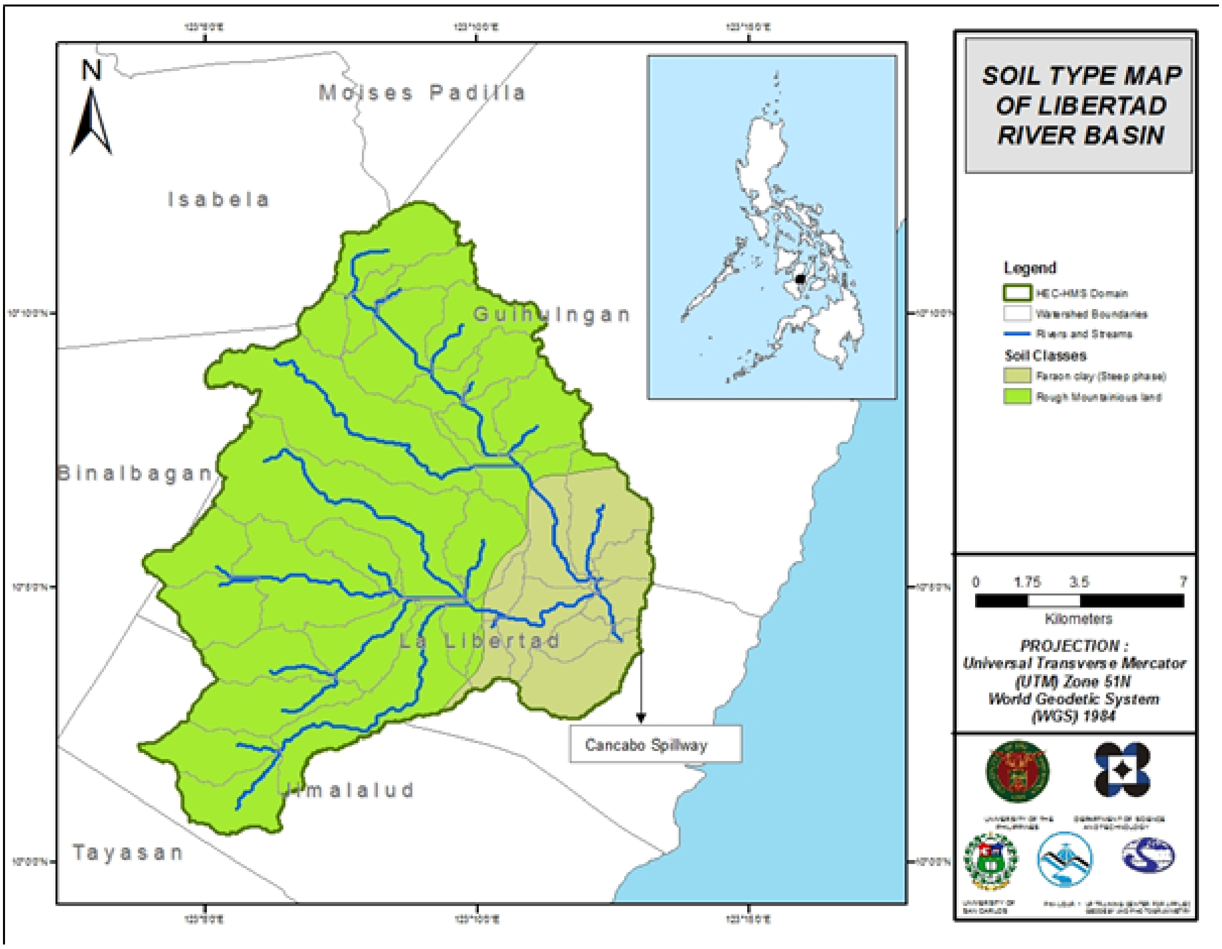


Figure 50. Soil Map of Libertad River Basin.

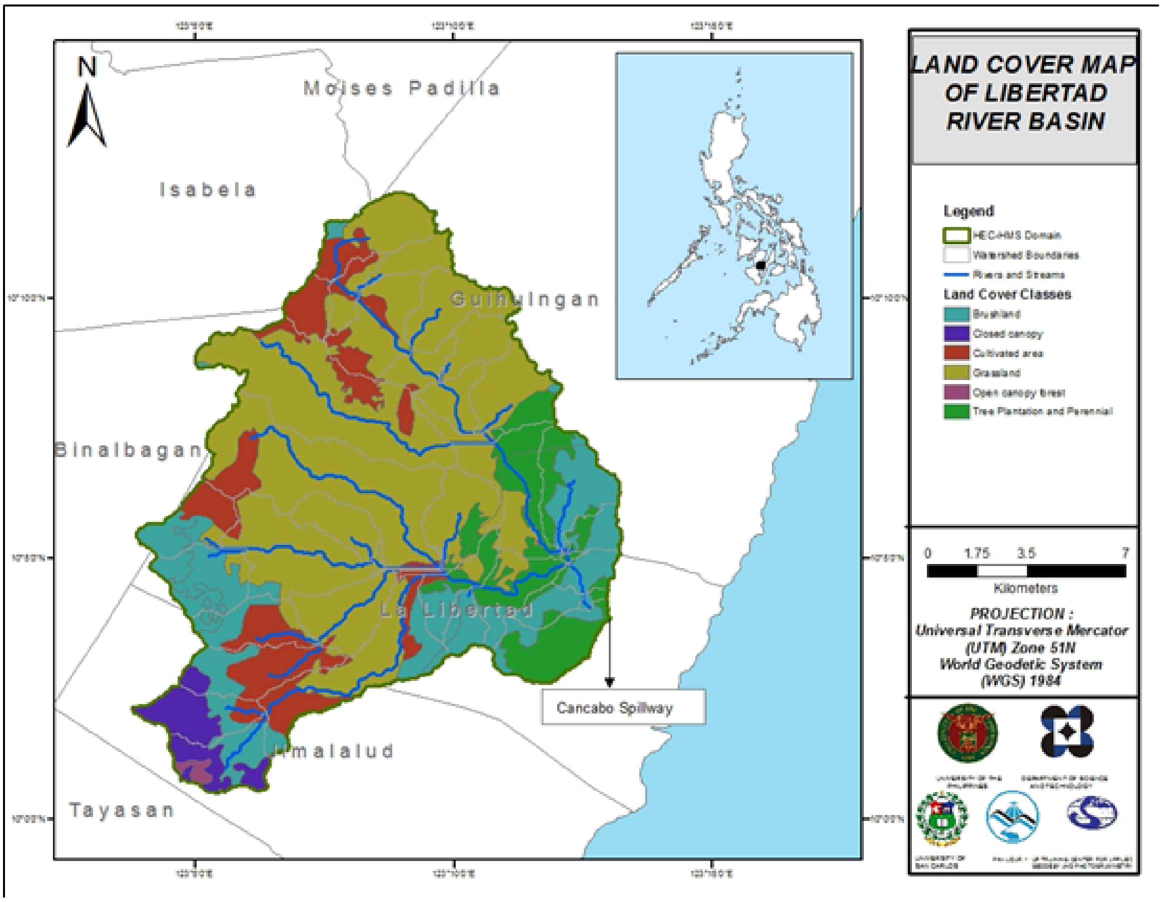


Figure 51. Land Cover Map of Libertad River Basin.

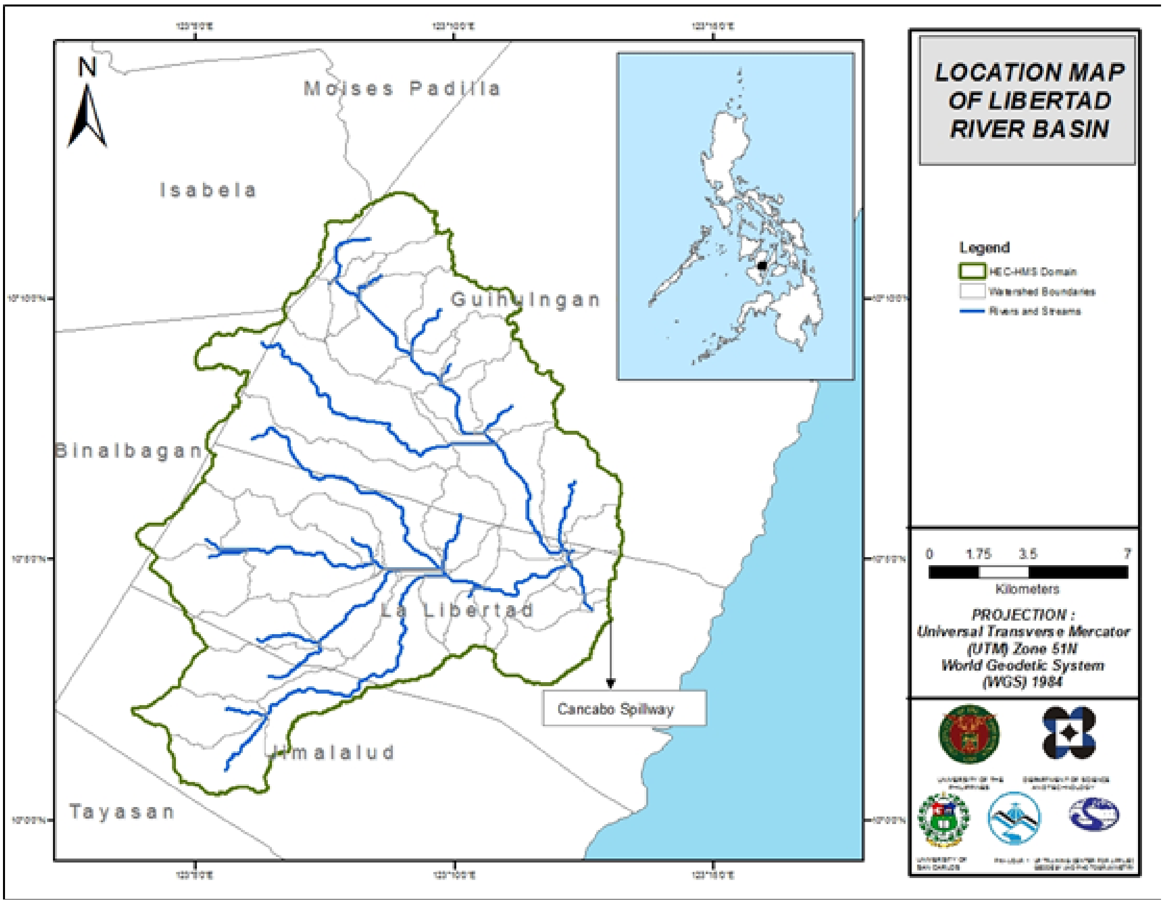


Figure 52. Stream Delineation Map of Libertad River Basin.

Using the SAR-based DEM, the Libertad basin was delineated and further subdivided into subbasins. The model consists of 49 sub basins, 19 reaches, and 19 junctions as shown in Figure 53. The main outlet is Outlet 1. The basins were identified based on soil and land cover characteristic of the area. Precipitation was taken from an installed Rain Gauge near and inside the river basin. Finally, it was calibrated using the data from actual discharge flow gathered in the Cancabo Spillway.

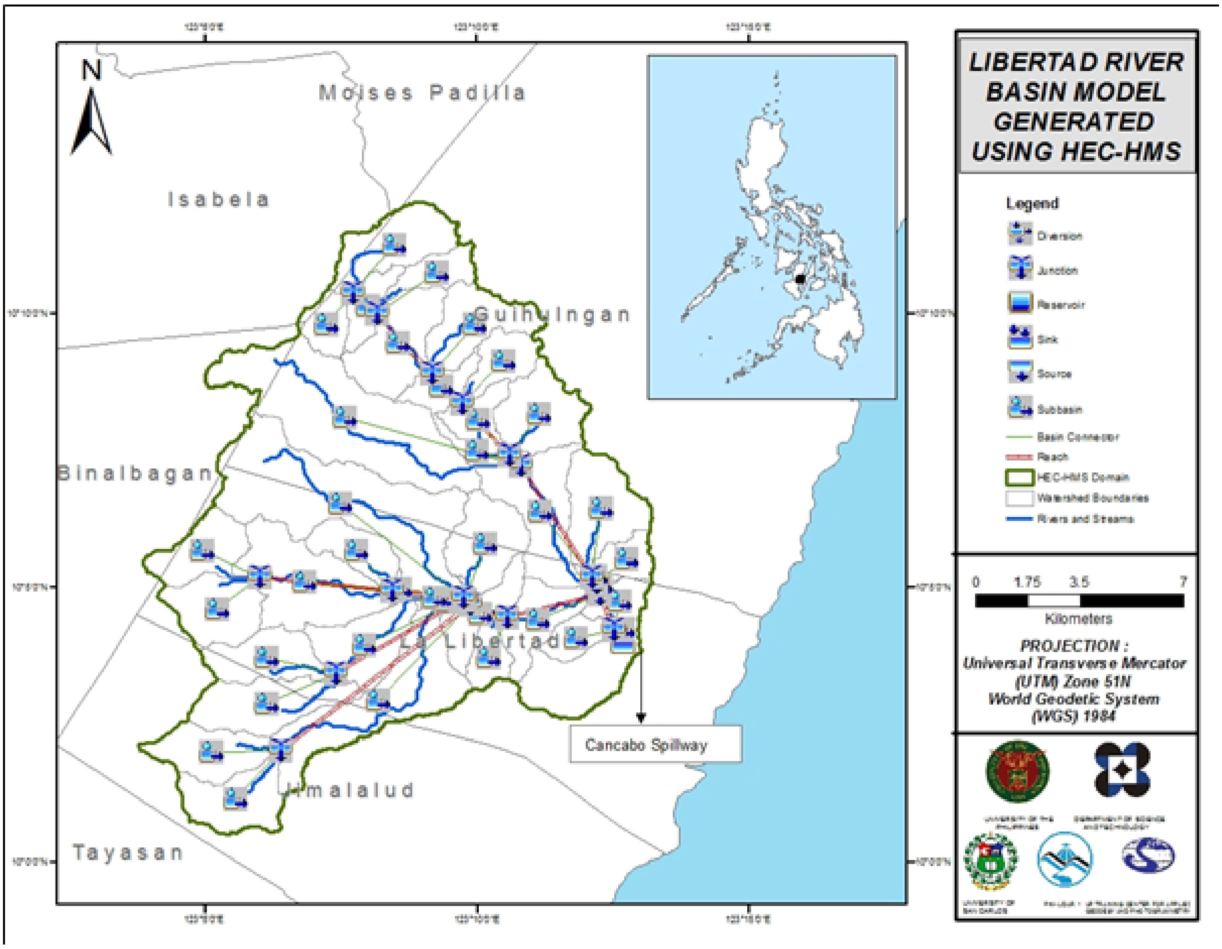


Figure 53. Libertad river basin model generated in HEC-HMS.

5.4 Cross-section Data

The 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, which was defined using the Arc GeoRAS tool and was post-processed in ArcGIS (Figure 54).

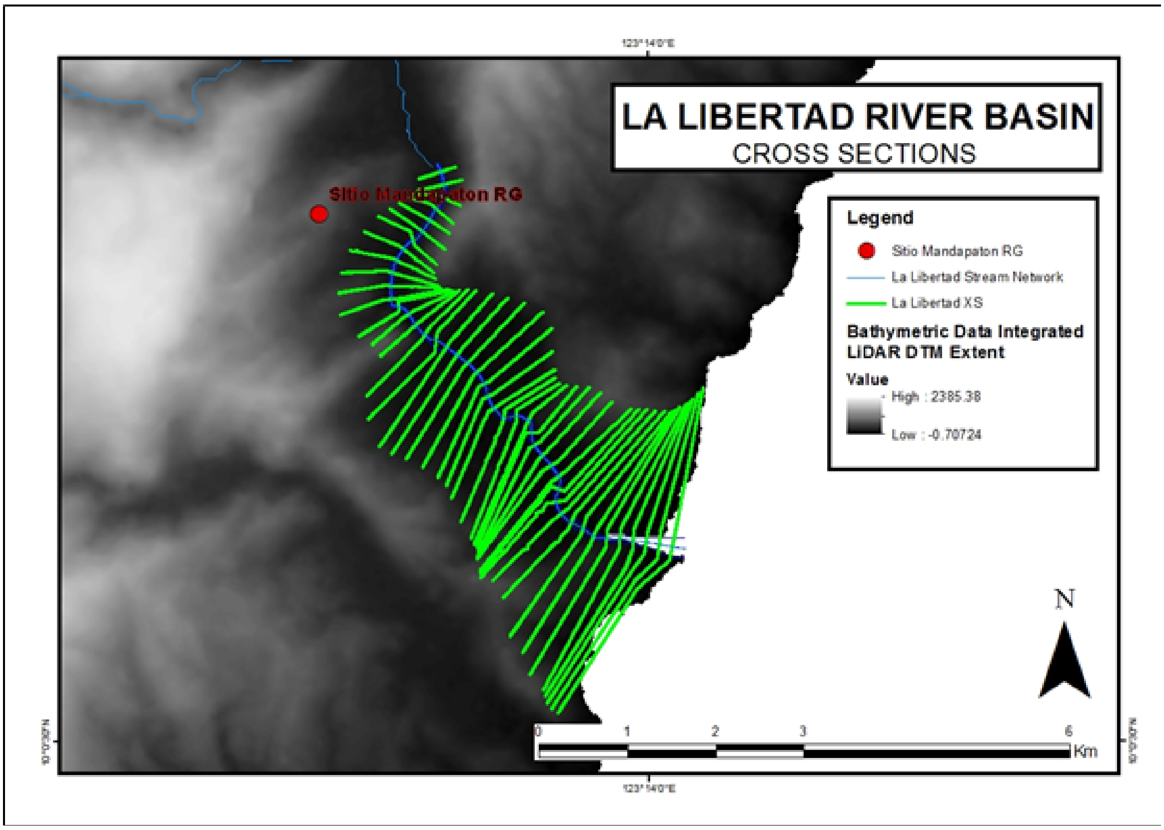


Figure 54. River cross-section of the Libertad River through the ArcMap HEC GeoRas tool.

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

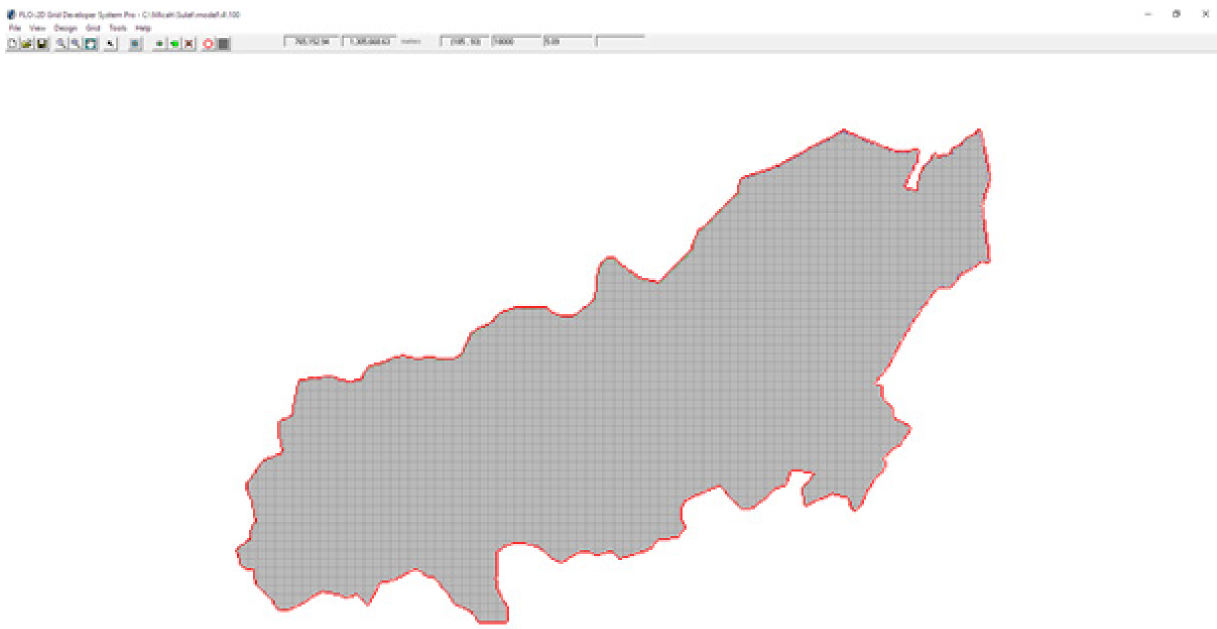


Figure 55. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid Developer System Pro (FLO-2D GDS Pro).

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 53.15430 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s. The generated hazard maps for Libertad are in Figure 58, 60, and 61.

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 20 409 100.00 m2. The generated flood depth maps for Libertad are in Figure 59, 61, and 63.

There is a total of 142 591 389.45 m3 of water entering the model. Of this amount, 8 999 786.63 m3 is due to rainfall while 133 591 602.81 m3 is inflow from other areas outside the model. 2 344 289.25 m3 of this water is lost to infiltration and interception, while 1 180 884.23 m3 is stored by the flood plain.

5.6 Results of HMS Calibration

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

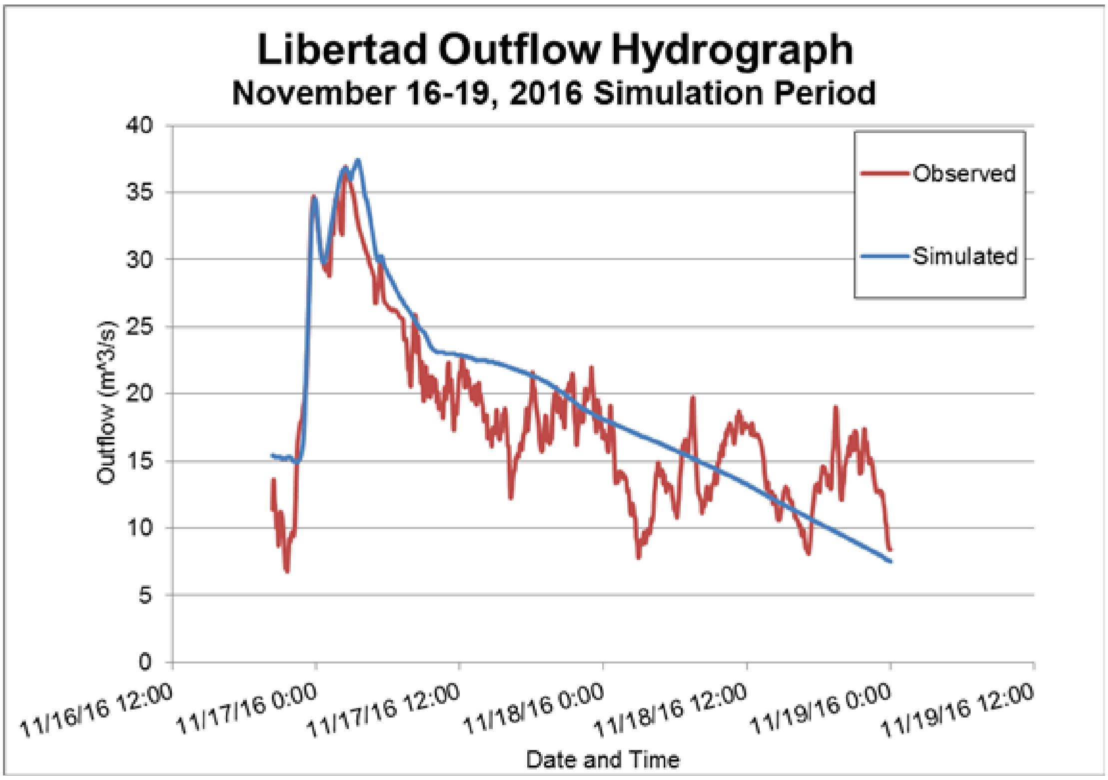


Figure 56. Outflow Hydrograph of Libertad produced by the HEC-HMS model compared with observed outflow.

Table 28 shows the adjusted ranges of values of the parameters used in calibrating the model.

Table 28. Range of calibrated values for the Libertad River Basin.

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve Number	Initial Abstraction (mm)	2.90-25.29
			Curve Number	35.18-99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0-52.46
			Storage Coefficient (hr)	0.03-5.67
	Baseflow	Recession	Recession Constant	0.15-0.76
			Ratio to Peak	0.001
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.06-0.31

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 2.90-25.29 mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 65 to 90 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area. For Libertad, since the soil consists of clay and mountainous land, the basin curve number ranges from 35.18-99.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0-52.46 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.15-0.76 indicates that the basin will to go back to its original. Ratio to peak of 0.001 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.06-0.31 corresponds to the common roughness of Philippine watersheds. Libertad river basin is covered mostly with grassland and cultivated areas.

Table 29. Summary of the Efficiency Test of the Libertad HMS Model.

Accuracy measure	Value
RMSE	3.541
r2	0.7982
NSE	0.718
PBIAS	21.67
RSR	0.531

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 3.541.

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 0.7092.

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 0.718.

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 21.67.

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 0.531.

5.7 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 57) shows the Libertad outflow using the Tagbilaran Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal increasing outflow magnitude as the rainfall intensity increases for a range of duration of 24 hours and varying return periods.

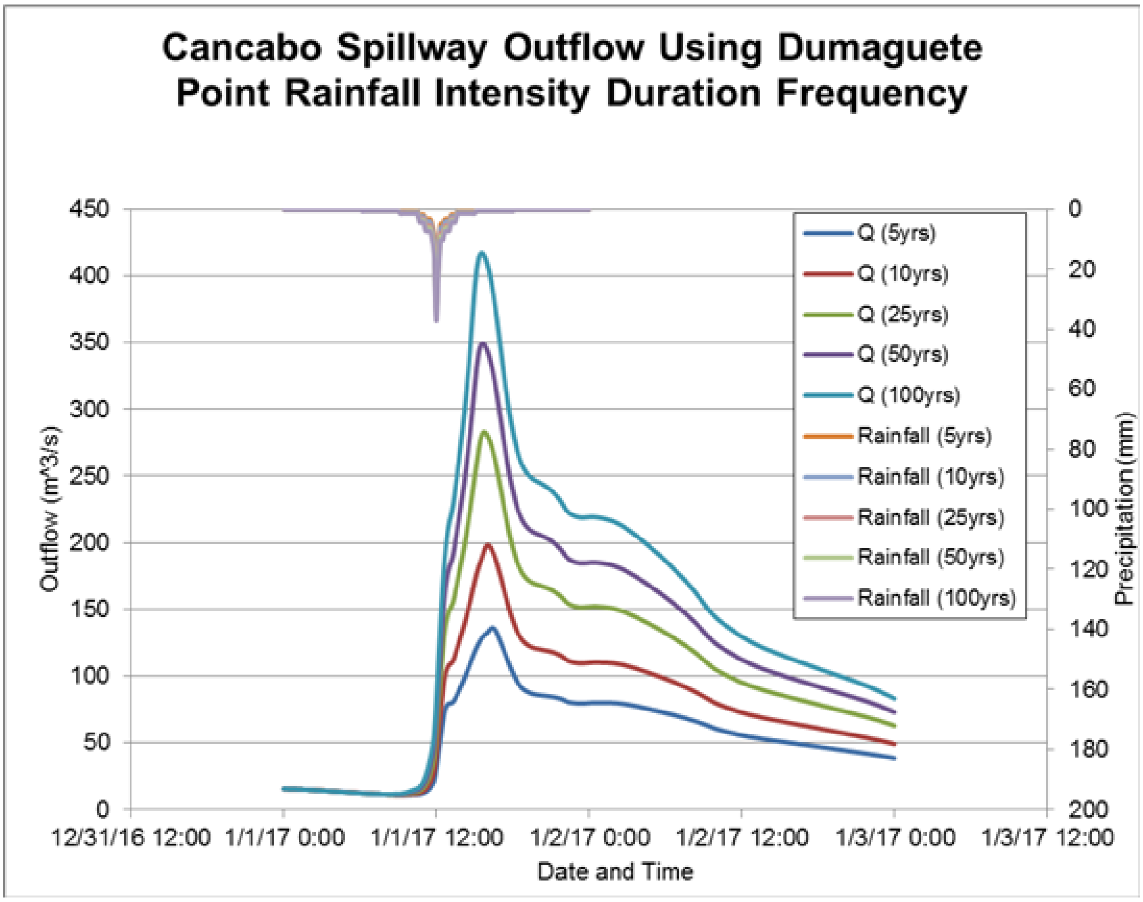


Figure 57. The Outflow hydrograph at the Cancabo Spillway, Libertad generated using the Dumagutete Point RIDF simulated in HEC-HMS.

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Libertad discharge using the Dumaguete Point Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 30.

Table 30. The peak values of the Libertad HEC-HMS Model outflow using the Dumaguete Point RIDF.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (m 3/s)	Time to Peak
5-Year	116.5	21.800	135.840	4 hour, 10 minutes
10-Year	143.3	25.600	198.056	3 hour, 50 minutes
25-Year	177.2	30.300	282.668	3 hour, 40 minutes
50-Year	202.4	33.800	349.211	3 hour, 30 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. Figure 58 shows a generated sample map of the Libertad River using the calibrated event flow.

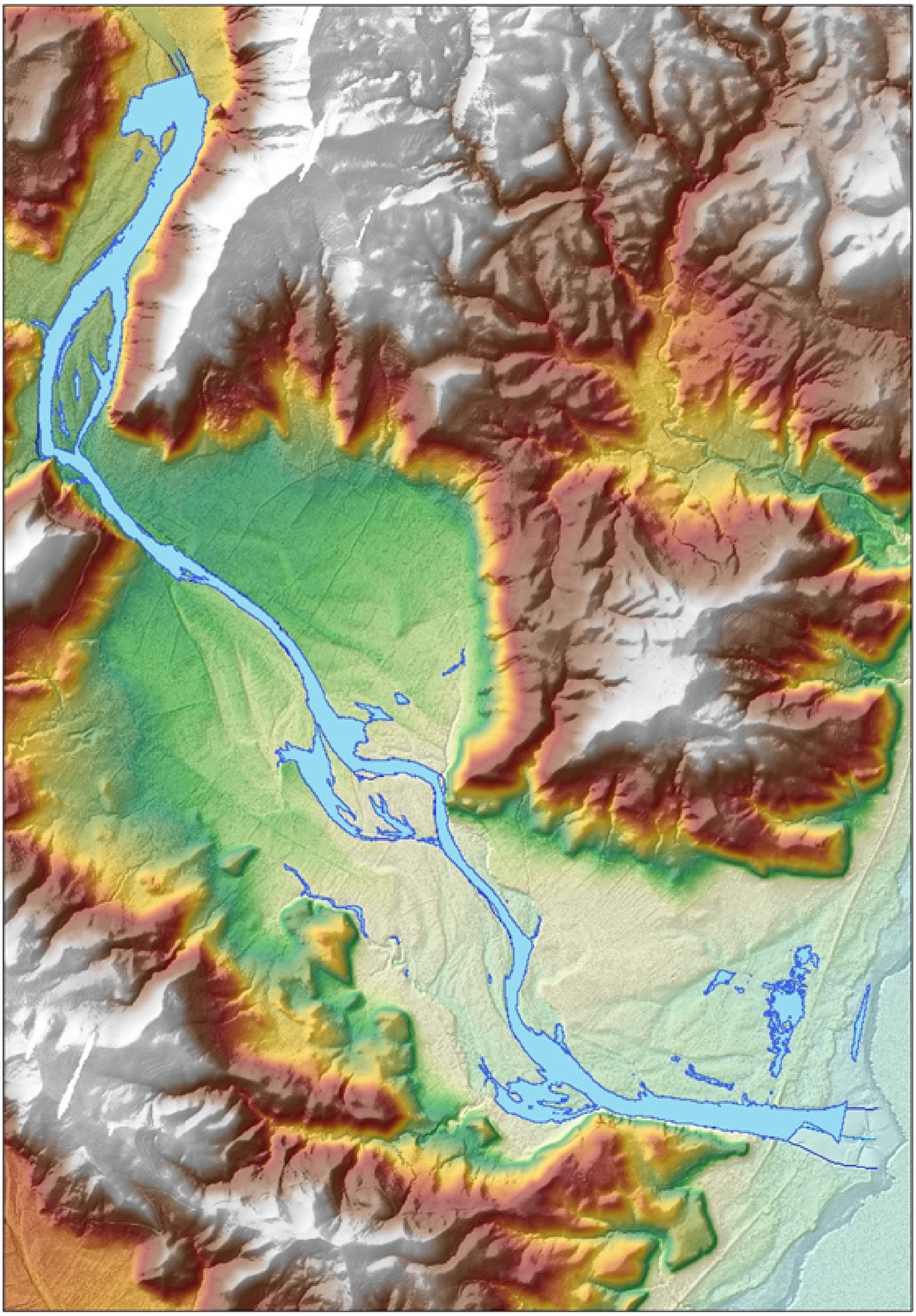


Figure 58. Sample output map of the Libertad RAS Model.

5.9 Flow Depth and Flood Hazard

The resulting hazard and flow depth maps have a 10m resolution. Figure 59 to Figure 64 shows the 5-, 25-, and 100-year rain return scenarios of the Libertad floodplain. The floodplain, with an area of 54.62 sq. km., covers three municipalites namely San Julian, Libertad, and Taft. Table 31 shows the percentage of area affected by flooding per municipality.

Table 31. Municipalities affected in Libertad floodplain.

Province	Municipality	Total Area	Area Flooded	% Flooded
San Julian	127.43	1.79	1%	23.71 %
Libertad	150.05	50.14	33%	5.65%
Taft	230.27	2.68	1%	

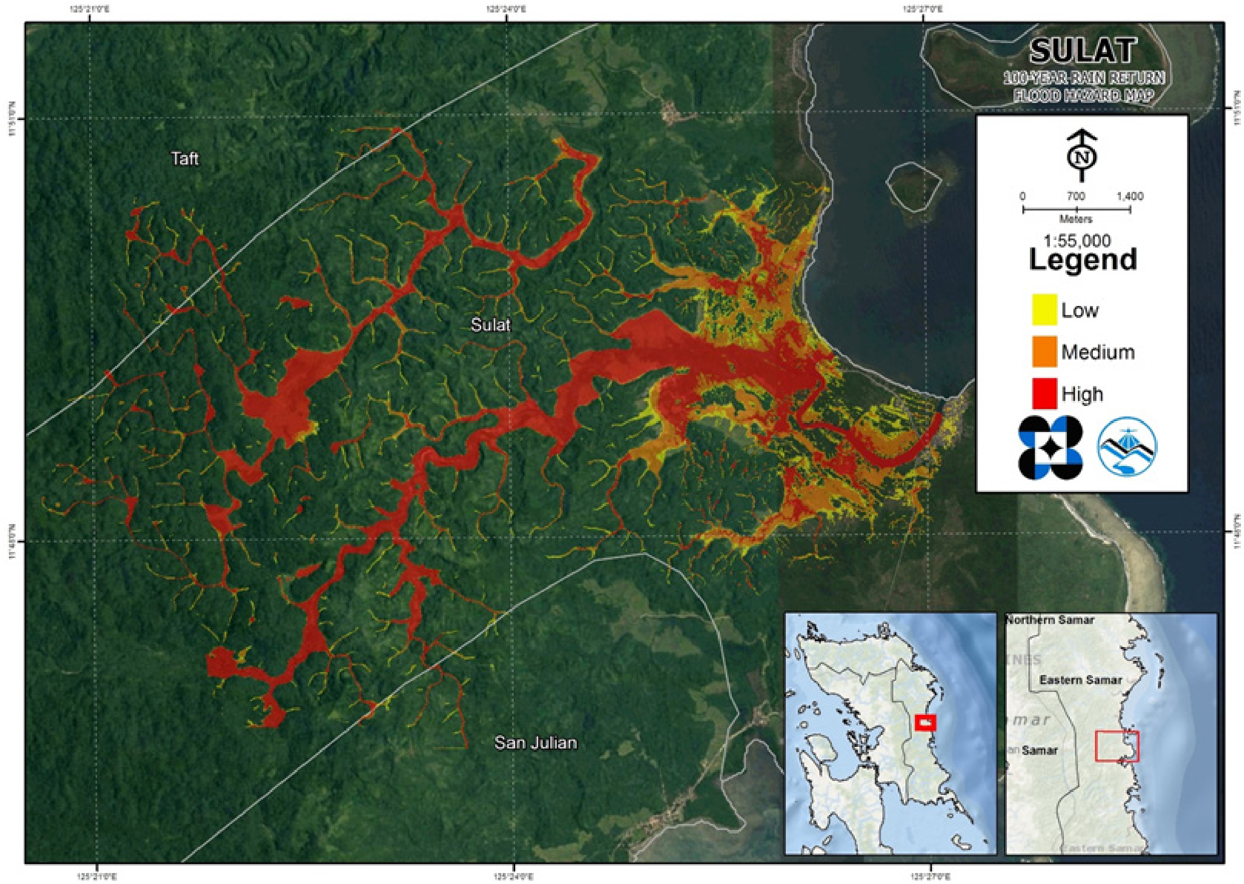


Figure 59. A 100-year Flood Hazard Map for Libertad Floodplain overlaid on Google Earth imagery.

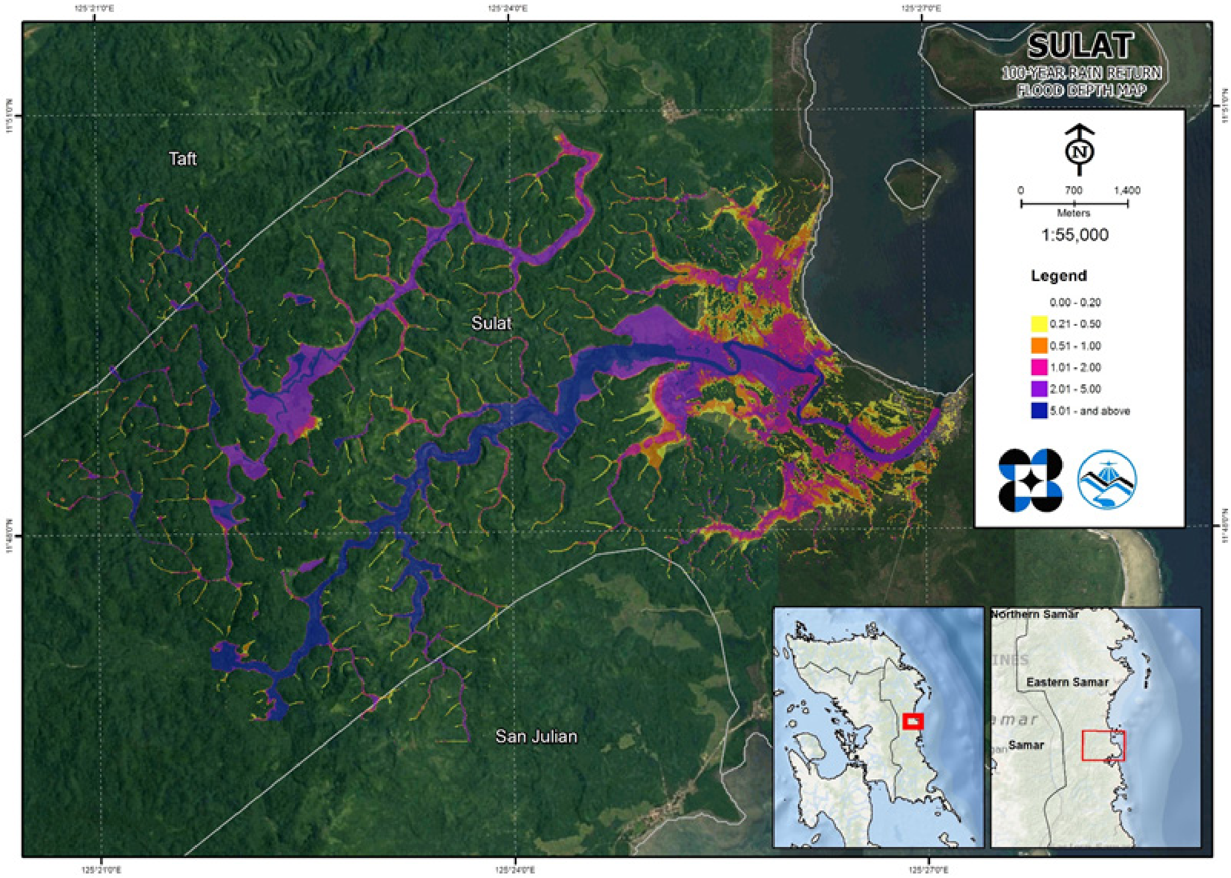


Figure 60. A 100-year Flow Depth Map for Libertad Floodplain overlaid on Google Earth imagery.

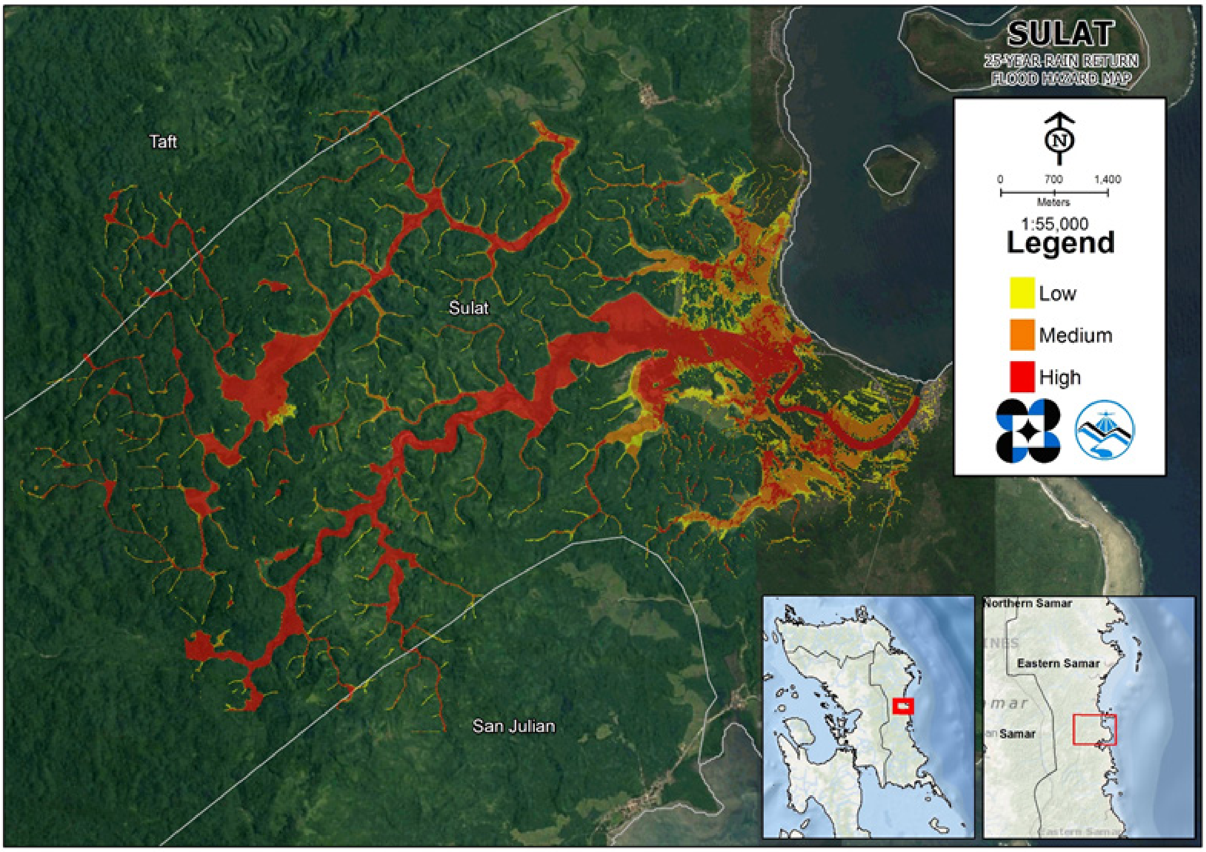


Figure 61. A 25-year Flood Hazard Map for Libertad Floodplain overlaid on Google Earth imagery.

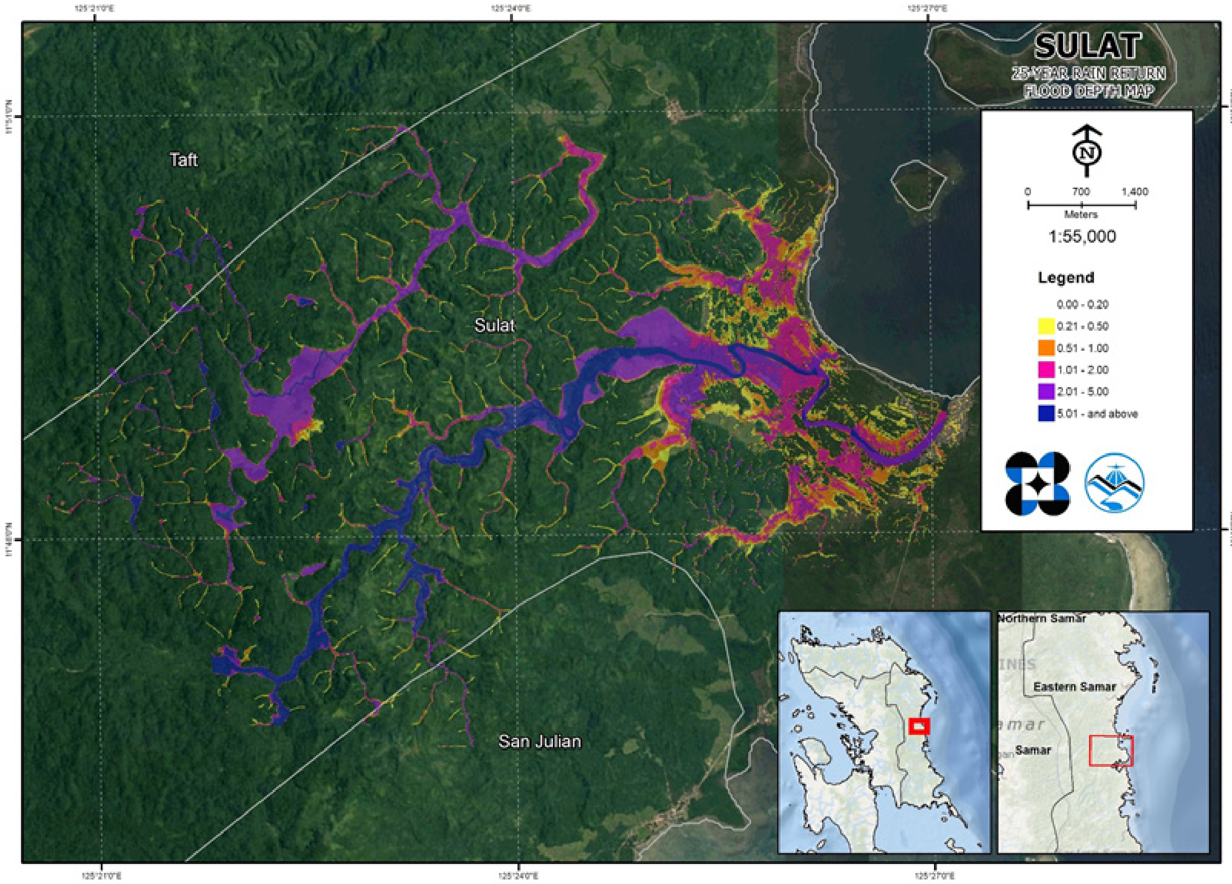


Figure 62. A 25-year Flow Depth Map for Libertad Floodplain overlaid on Google Earth imagery.

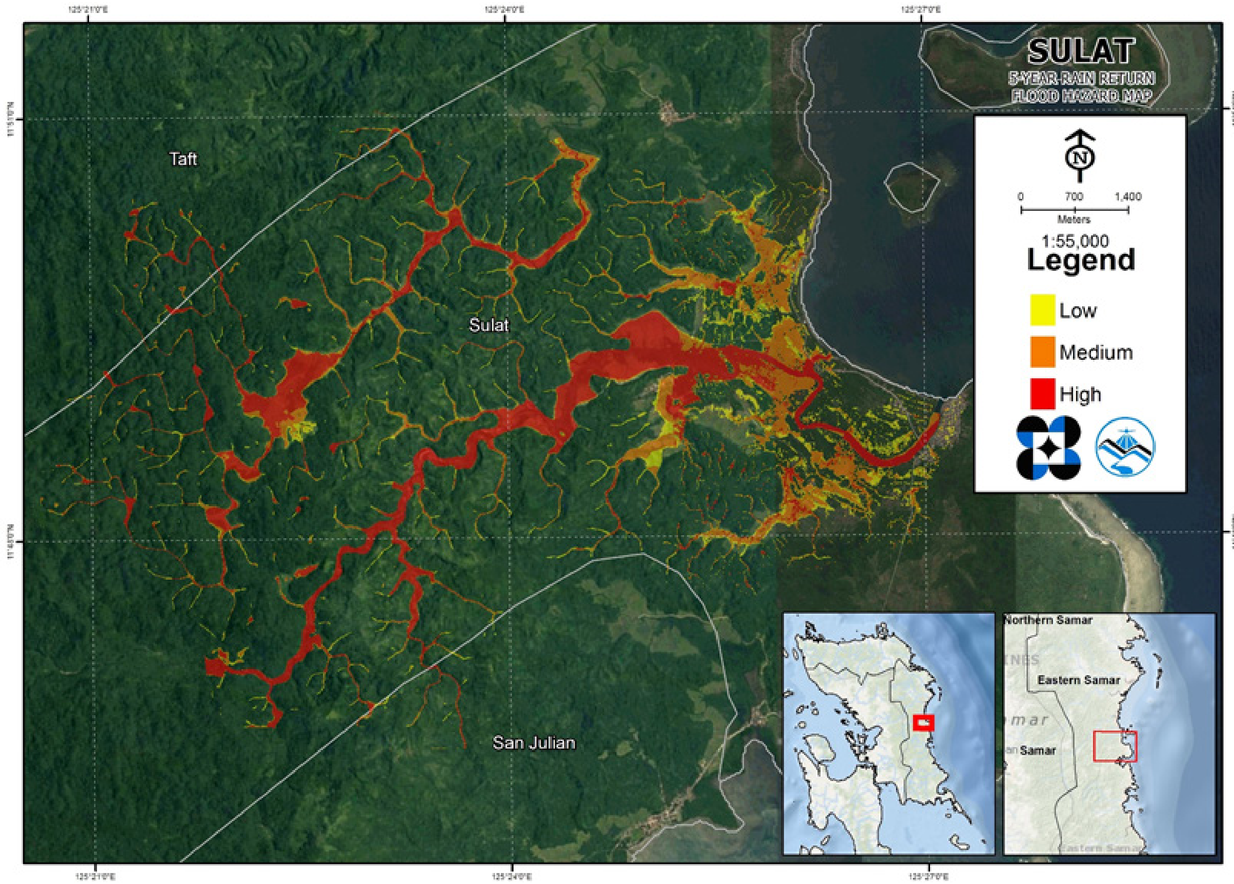


Figure 63. A 5-year Flood Hazard Map for Libertad Floodplain overlaid on Google Earth imagery.

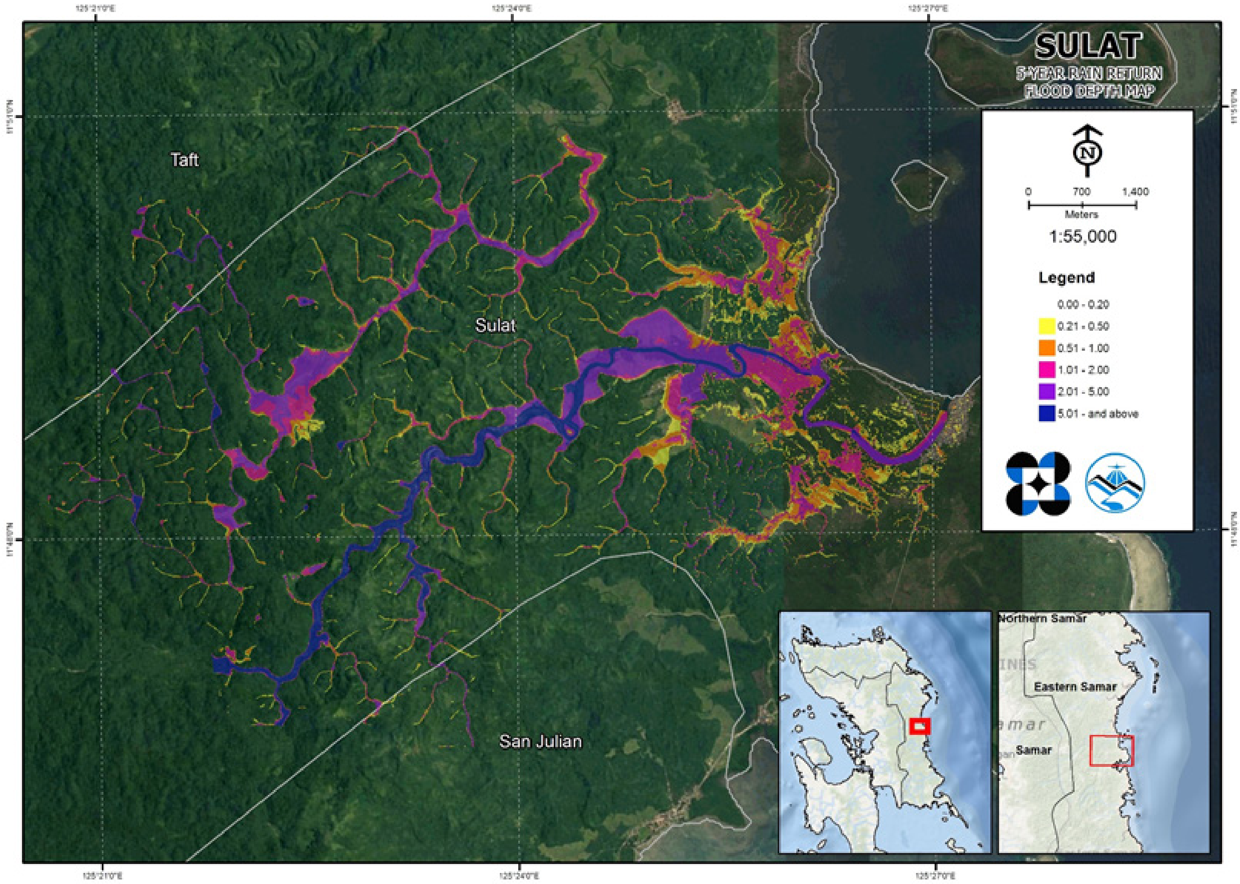


Figure 64. A 5-year Flood Depth Map for Libertad Floodplain overlaid on Google Earth imagery.

5.10 Inventory of Areas Exposed to Flooding

Listed below are the affected barangays in the Libertad River Basin, grouped accordingly by municipality. For the said basin, three municipalities consisting of 22 barangays are expected to experience flooding when subjected to 5-yr rainfall return period.

For the 5-year return period, 1.69% of the city of Guihulngan with an area of 374.66 sq. km. will experience flood levels of less 0.20 meters. 0.09% of the area will experience flood levels of 0.21 to 0.50 meters while 0.05%, 0.03%, 0.02, and 0.005% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Listed in Table 32 are the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected Areas in Guihulngan City, Negros Oriental during 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Guihulngan City (in sq. km.)			
	Bakid	Kagawasan	Mckinley	Padre Zamora
0.03-0.20	2.47	0.44	1.17	2.27
0.21-0.50	0.11	0.018	0.085	0.14
0.51-1.00	0.043	0.0036	0.043	0.096
1.01-2.00	0.028	0.00074	0.019	0.081
2.01-5.00	0.032	0.0005	0.012	0.046
> 5.00	0.0016	0	0.0085	0.01

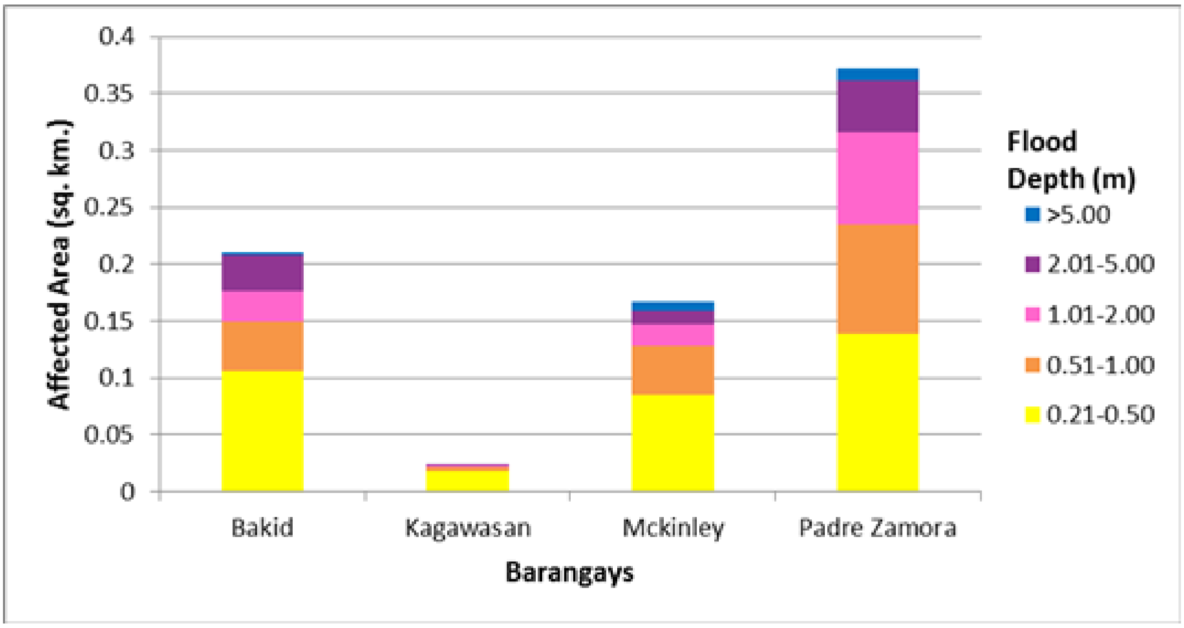


Figure 65. Affected Areas in Guihulngan City, Negros Oriental during 5-Year Rainfall Return Period.

For the municipality of Jimalalud, with an area of 154.7 sq. km., 1.65% will experience flood levels of less 0.20 meters. 0.07% of the area will experience flood levels of 0.21 to 0.50 meters while 0.034%, 0.027%, 0.026%, and 0.006% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Listed in Table 33 are the affected areas in square kilometers by flood depth per barangay.

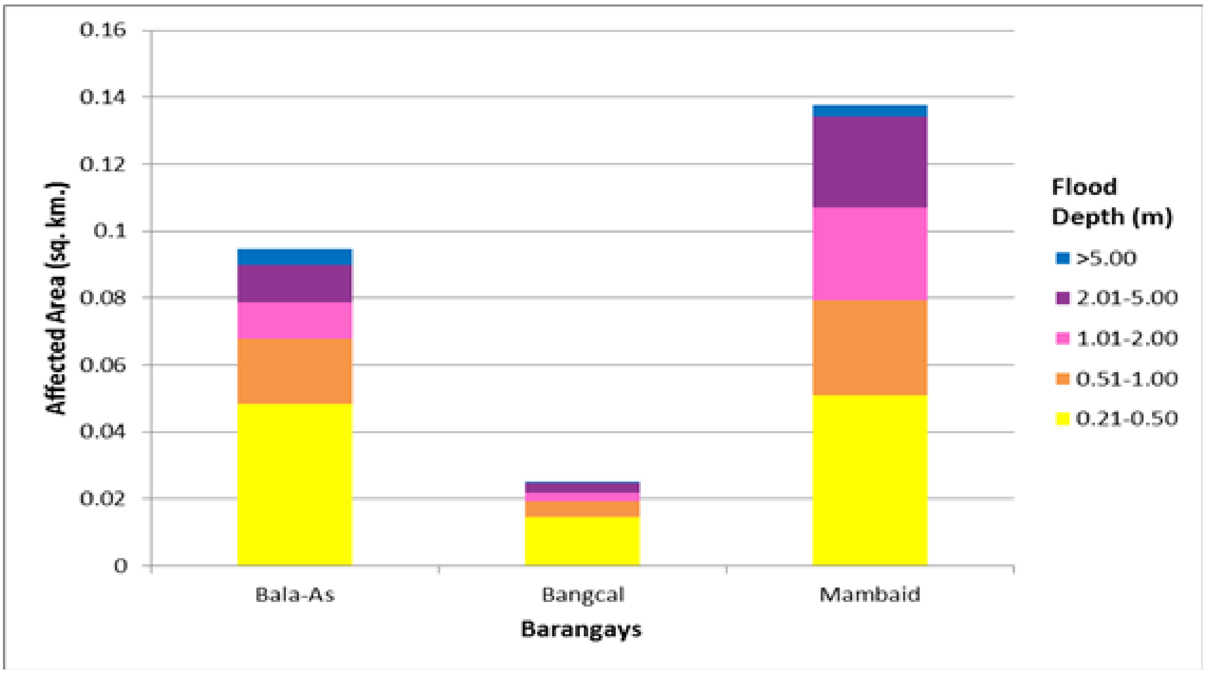


Figure 66. Affected Areas in Jimalalud, Negros Oriental during 5-Year Rainfall Return Period.

For the municipality of La Libertad, with an area of 151.4 sq. km., 17.61% will experience flood levels of less 0.20 meters. 1.8% of the area will experience flood levels of 0.21 to 0.50 meters while 1.27%, 1.23%, 1.78%, and 0.32% 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 34 are the affected areas in square kilometers by flood depth per barangay.

Table 33. Affected Areas in Jimalalud, Negros Oriental during 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Jimalalud (in sq. km.)		
	Bala-As	Bangcal	Mambaid
0.03-0.20	1.13	0.27	1.15
0.21-0.50	0.048	0.015	0.051
0.51-1.00	0.019	0.0048	0.029
1.01-2.00	0.011	0.0026	0.028
2.01-5.00	0.011	0.0026	0.027
> 5.00	0.0049	0.0004	0.0033

Table 34. Affected Areas in La Libertad, Negros Oriental during 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in La Libertad (in sq. km.)					
	Biga-A	Cangabo	Cantupa	Mandapaton	Manghulyawon	Mapalasan
0.03-0.20	2.64	1.67	2.17	0.89	1.8	2.44
0.21-0.50	0.21	0.093	0.13	0.068	0.1	0.1
0.51-1.00	0.19	0.046	0.072	0.084	0.064	0.064
1.01-2.00	0.17	0.028	0.092	0.081	0.041	0.047
2.01-5.00	0.11	0.035	0.31	0.034	0.031	0.041

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in La Libertad (in sq. km.)					
	Maragondong	Martilo	Pangca	Pisong	Poblacion North	Poblacion South
0.03-0.20	1.74	2.62	1.07	3.76	0	0.12
0.21-0.50	0.24	0.18	0.04	0.29	0	0.015
0.51-1.00	0.11	0.13	0.025	0.25	0.00003	0.0043
1.01-2.00	0.15	0.12	0.14	0.17	0.0019	0.0062
2.01-5.00	0.55	0.12	0.14	0.19	0.28	0.014

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in La Libertad (in sq. km.)					
	San Jose	Solongon	Talayong			
0.03-0.20	2.04	1.97	1.72			
0.21-0.50	0.35	0.49	0.41			
0.51-1.00	0.28	0.28	0.31			
1.01-2.00	0.36	0.18	0.29			
2.01-5.00	0.25	0.24	0.35			

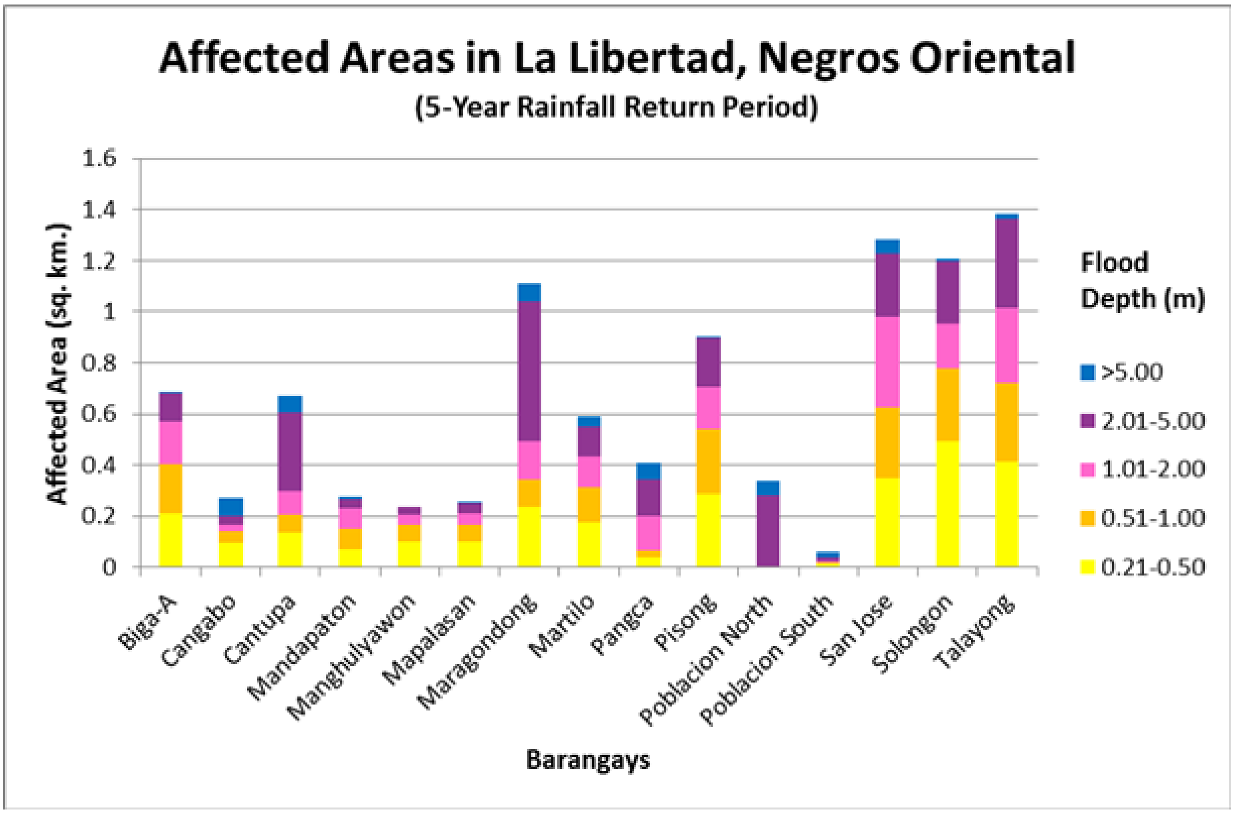


Figure 67. Affected Areas in La Libertad, Negros Oriental during 5-Year Rainfall Return Period.

For the 25-year return period, 1.66% of the city of Guihulngan with an area of 374.66 sq. km. will experience flood levels of less 0.20 meters. 0.10% of the area will experience flood levels of 0.21 to 0.50 meters while 0.058%, 0.035%, 0.038, and 0.01% 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 35 are the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected Areas in Guihulngan City, Negros Oriental during 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Guihulngan City (in sq. km.)			
	Bakid	Kagawasan	Mckinley	Padre Zamora
0.03-0.20	2.44	0.43	1.14	2.21
0.21-0.50	0.12	0.023	0.09	0.14
0.51-1.00	0.049	0.0057	0.053	0.11
1.01-2.00	0.029	0.0011	0.024	0.077
2.01-5.00	0.039	0.00094	0.017	0.084

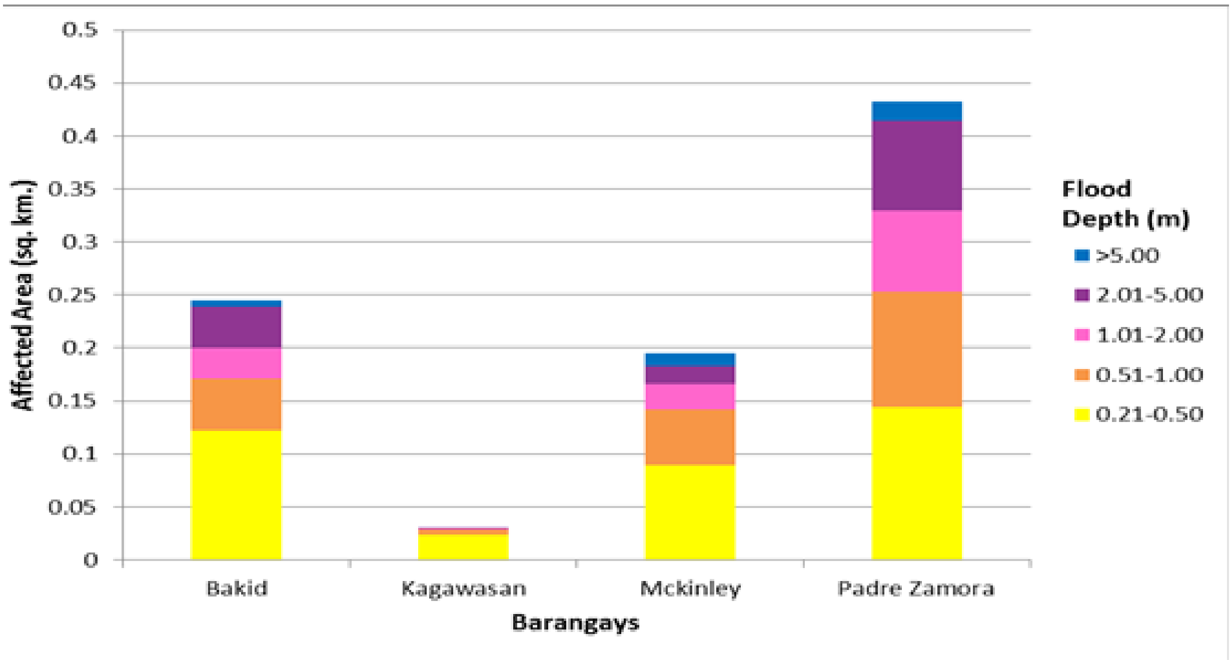


Figure 68. Affected Areas in Guihulngan City, Negros Oriental during 25-Year Rainfall Return Period.

For the municipality of Jimalalud, with an area of 154.7 sq. km., 1.6% will experience flood levels of less 0.20 meters. 0.1% of the area will experience flood levels of 0.21 to 0.50 meters while 0.036%, 0.032%, 0.042%, 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 36 are the affected areas in square kilometers by flood depth per barangay.

Table 36. Affected Areas in Jimalalud, Negros Oriental during 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Jimalalud (in sq. km.)		
	Bala-As	Bangcal	Mambaid
0.03-0.20	1.1	0.27	1.1
0.21-0.50	0.06	0.016	0.074
0.51-1.00	0.023	0.0076	0.026
1.01-2.00	0.014	0.0029	0.033
2.01-5.00	0.013	0.0037	0.048

Figure 69. Affected Areas in Jimalalud, Negros Oriental during 25-Year Rainfall Return Period.

For the municipality of La Libertad, with an area of 151.4 sq. km., 17.61% will experience flood levels of less 0.20 meters. 1.8% of the area will experience flood levels of 0.21 to 0.50 meters while 1.27%, 1.23%, 1.78%, and 0.32% 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 kilometers by flood depth per barangay.

Table 37. Affected Areas in La Libertad, Negros Oriental during 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in La Libertad (in sq. km.)							
	Biga-A	Cangabo	Cantupa	Mandapaton	Manghulyawon	Mapalasan	Maragondong	Martilo
0.03-0.20	2.56	1.64	2.09	0.86	1.76	2.4	1.55	2.51
0.21-0.50	0.19	0.099	0.13	0.057	0.11	0.11	0.18	0.17
0.51-1.00	0.15	0.051	0.067	0.04	0.058	0.067	0.085	0.14
1.01-2.00	0.26	0.039	0.087	0.1	0.056	0.054	0.18	0.14
2.01-5.00	0.16	0.04	0.2	0.087	0.042	0.055	0.57	0.19

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in La Libertad (in sq. km.)							
	Pangca	Pisong	Poblacion North	Poblacion South	San Jose	Solongon	Talayong	
0.03-0.20	1.05	3.62	0	0.11	1.85	1.79	1.53	
0.21-0.50	0.041	0.27	0	0.0067	0.32	0.3	0.35	
0.51-1.00	0.019	0.25	0	0.006	0.28	0.41	0.35	
1.01-2.00	0.039	0.2	0	0.01	0.36	0.29	0.31	
2.01-5.00	0.25	0.24	0.018	0.017	0.39	0.34	0.49	

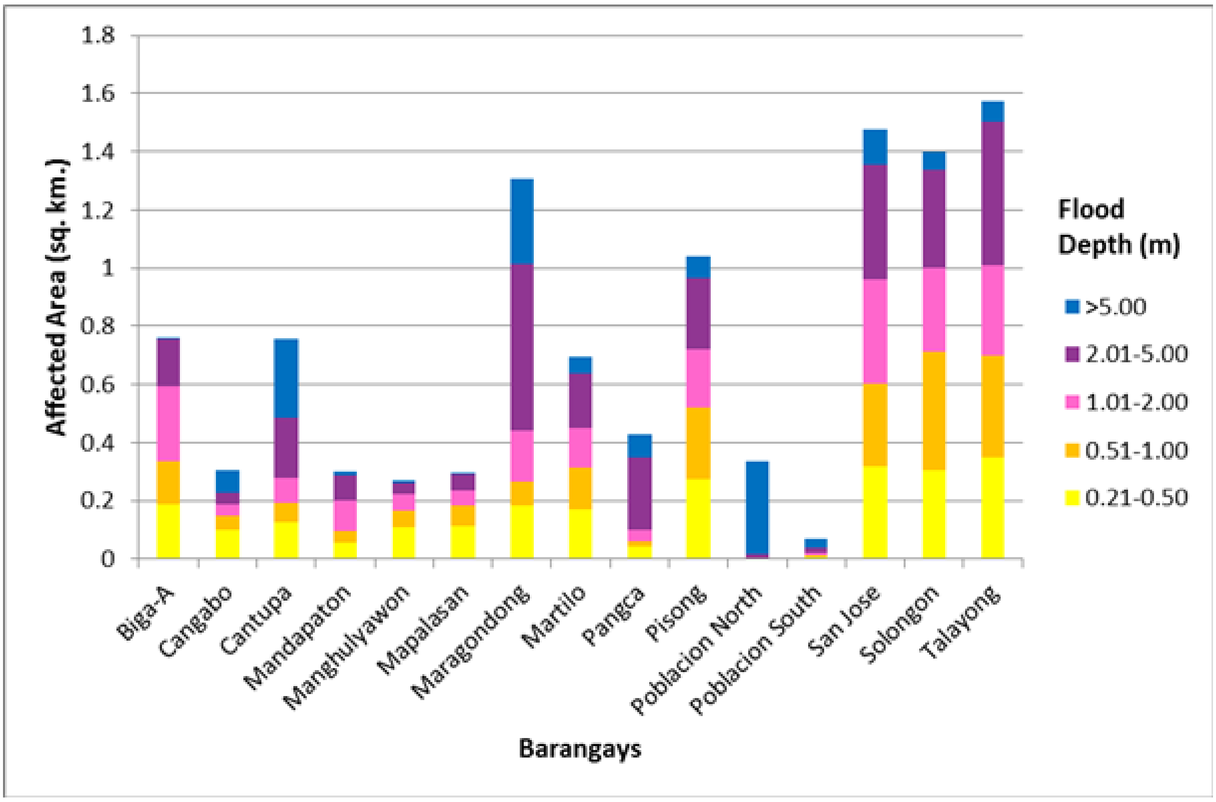


Figure 70. Affected Areas in La Libertad, Negros Oriental during 25-Year Rainfall Return Period.

For the 100-year return period, 1.63% of the city of Guihulngan with an area of 374.66 sq. km. will experience flood levels of less 0.20 meters. 0.11% of the area will experience flood levels of 0.21 to 0.50 meters while 0.06%, 0.04%, 0.044, and 0.014% 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 38 are the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected Areas in Guihulngan City, Negros Oriental during 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Guihulngan City (in sq. km.)			
	Bakid	Kagawasan	Mckinley	Padre Zamora
0.03-0.20	2.41	0.42	1.12	2.16
0.21-0.50	0.14	0.028	0.091	0.15
0.51-1.00	0.055	0.0074	0.06	0.11
1.01-2.00	0.03	0.0014	0.031	0.086
2.01-5.00	0.042	0.00094	0.022	0.1

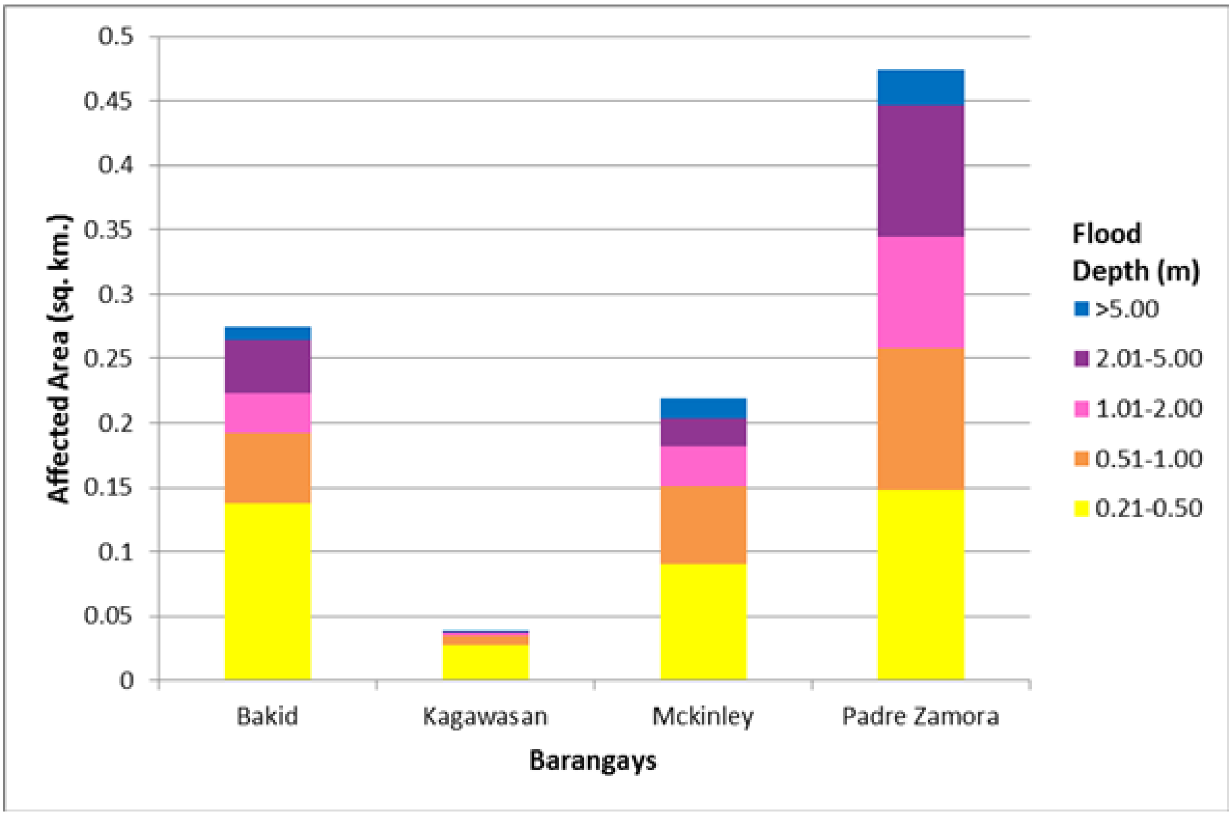


Figure 71. Affected Areas in Guihulngan City, Negros Oriental during 100-Year Rainfall Return Period.

For the municipality of Jimalalud, with an area of 154.7 sq. km., 1.55% will experience flood levels of less 0.20 meters. 0.12% of the area will experience flood levels of 0.21 to 0.50 meters while 0.041%, 0.034%, 0.052%, and 0.019% 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 39 are the affected areas in square kilometers by flood depth per barangay.

Table 39. Affected Areas in Jimalalud, Negros Oriental during 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in Jimalalud (in sq. km.)		
	Bala-As	Bangcal	Mambaid
0.03-0.20	1.09	0.26	1.05
0.21-0.50	0.067	0.017	0.098
0.51-1.00	0.026	0.0094	0.028
1.01-2.00	0.016	0.0034	0.033
2.01-5.00	0.014	0.0042	0.062

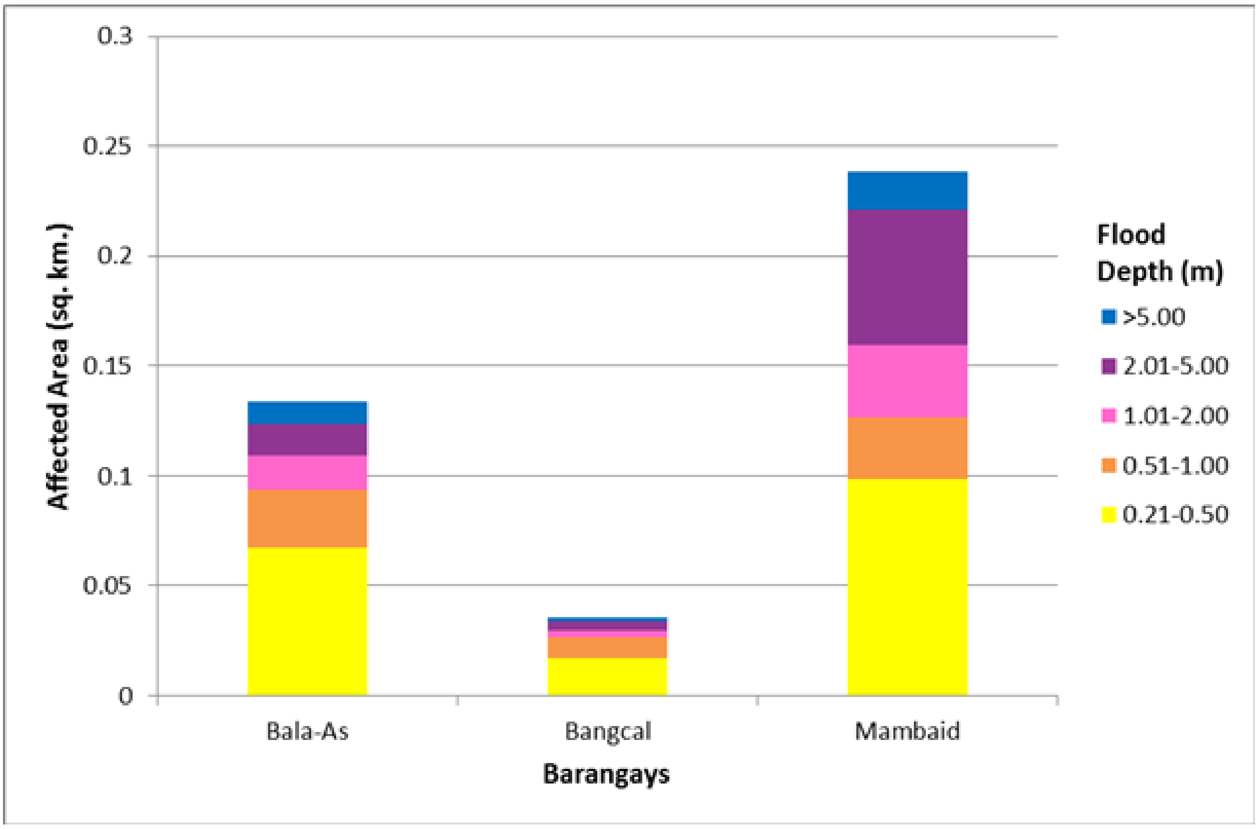


Figure 72. Affected Areas in Jimalalud, Negros Oriental during 100-Year Rainfall Return Period.

For the municipality of La Libertad, with an area of 151.4 sq. km., 16.3% will experience flood levels of less 0.20 meters. 1.47% of the area will experience flood levels of 0.21 to 0.50 meters while 1.15%, 1.48%, 2.26%, and 1.35% 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 40 are the affected areas in square kilometers by flood depth per barangay.

Table 40. Affected Areas in La Libertad, Negros Oriental during 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in La Libertad (in sq. km.)							
	Biga-A	Cangabo	Cantupa	Mandapaton	Manghulyawon	Mapalasan	Maragondong	Martilo
0.03-0.20	2.52	1.61	2.04	0.85	1.74	2.37	1.48	2.46
0.21-0.50	0.18	0.11	0.13	0.062	0.12	0.12	0.14	0.16
0.51-1.00	0.12	0.048	0.065	0.034	0.058	0.071	0.08	0.12
1.01-2.00	0.28	0.044	0.073	0.073	0.05	0.057	0.1	0.17
2.01-5.00	0.22	0.05	0.18	0.13	0.062	0.067	0.51	0.21

Affected Area (sq. km.) by flood depth (in m.)	Area of affected barangays in La Libertad (in sq. km.)							
	Pangca	Pisong	Poblacion North	Poblacion South	San Jose	Solongon	Talayong	
0.03-0.20	1.04	3.54	0	0.1	1.75	1.73	1.43	
0.21-0.50	0.044	0.28	0	0.0057	0.3	0.23	0.34	
0.51-1.00	0.018	0.23	0	0.0056	0.27	0.32	0.3	
1.01-2.00	0.028	0.23	0	0.0065	0.34	0.45	0.34	
2.01-5.00	0.26	0.28	0.0021	0.023	0.48	0.36	0.58	

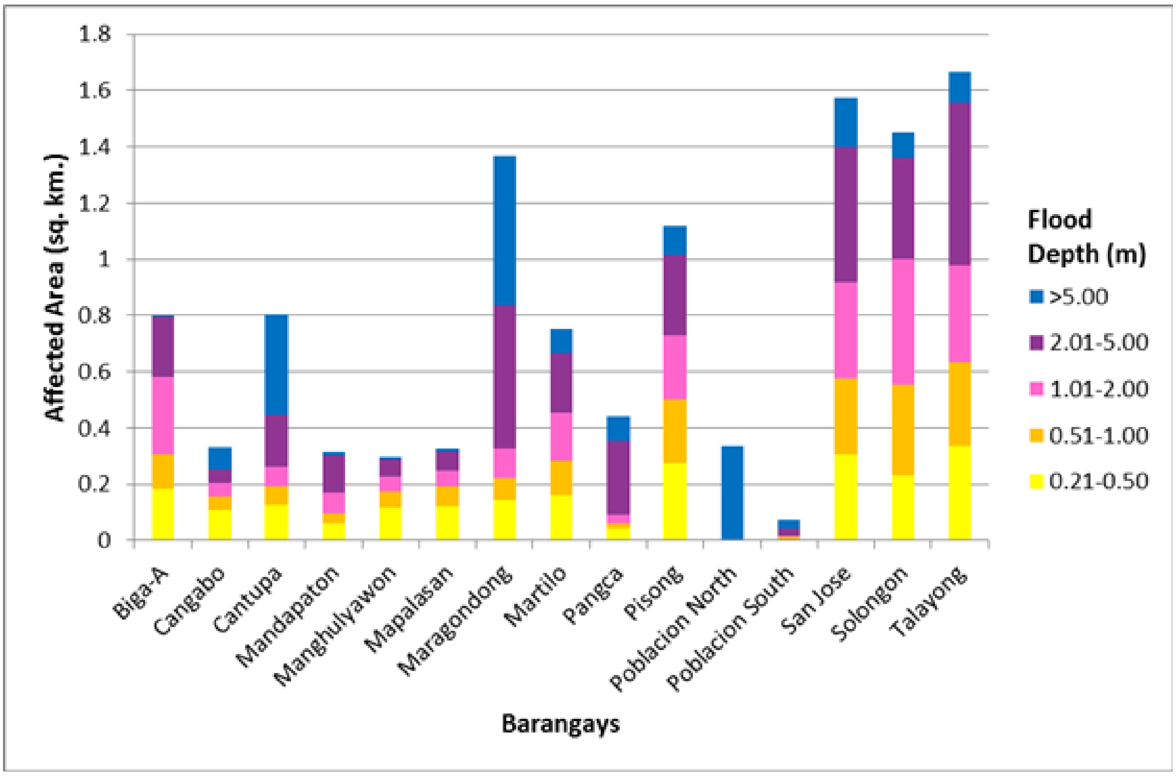


Figure 73. Affected Areas in La Libertad, Negros Oriental during 100-Year Rainfall Return Period.

Among the barangays in the city of Guihulngan, Bakid is projected to have the highest percentage of area that will experience flood levels at 0.72%. Meanwhile, Padre Zamora posted the second highest percentage of area that may be affected by flood depths at 0.70%.

Among the barangays in the municipality of Jimalalud, Mambaid is projected to have the highest percentage of area that will experience flood levels at 0.84%. Meanwhile, Bala-As posted the second highest percentage of area that may be affected by flood depths at 0.79%.

Among the barangays in the municipality of La Libertad, San Jose is projected to have the highest percentage of area that will experience flood levels at 2.2%. Meanwhile, Biga-A posted the second highest percentage of area that may be affected by flood depths at 2.19%.

Moreover, the generated flood hazard maps for the Libertad 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 41. Area covered by each warning level with respect to the rainfall scenarios.

Warning Level	Area Covered in sq. km.		
	5 year	25 year	100 year
Low	3.23	2.90	2.84
Medium	3.23	3.50	3.35
High	4.45	6.04	7.07

No Educational institutions were identified to be exposed to any of the flooding scenarios in the Libertad Flood Plain.

Of the 3 identified Medical Institutions in the Libertad Flood Plain, 1 medical institution was assessed to be exposed to medium level flooding during a 5 year scenario, while 2 medical institutions were assessed to be exposed to high level flooding in the same scenario. In the 25 and 100 year scenarios, 3 medical institutions were assessed to be exposed to high level. See Annex 12 for a detailed enumeration of hospitals and clinics in the Libertad floodplain.

5.11 Flood Validation

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

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

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

The actual data from the field were compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on the results of the flood map. The points in the flood map versus its corresponding validation depths are shown in Figure 75.

Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 4.62 m. Table 42 shows a contingency matrix of the comparison. The validation points are found in Annex 11.

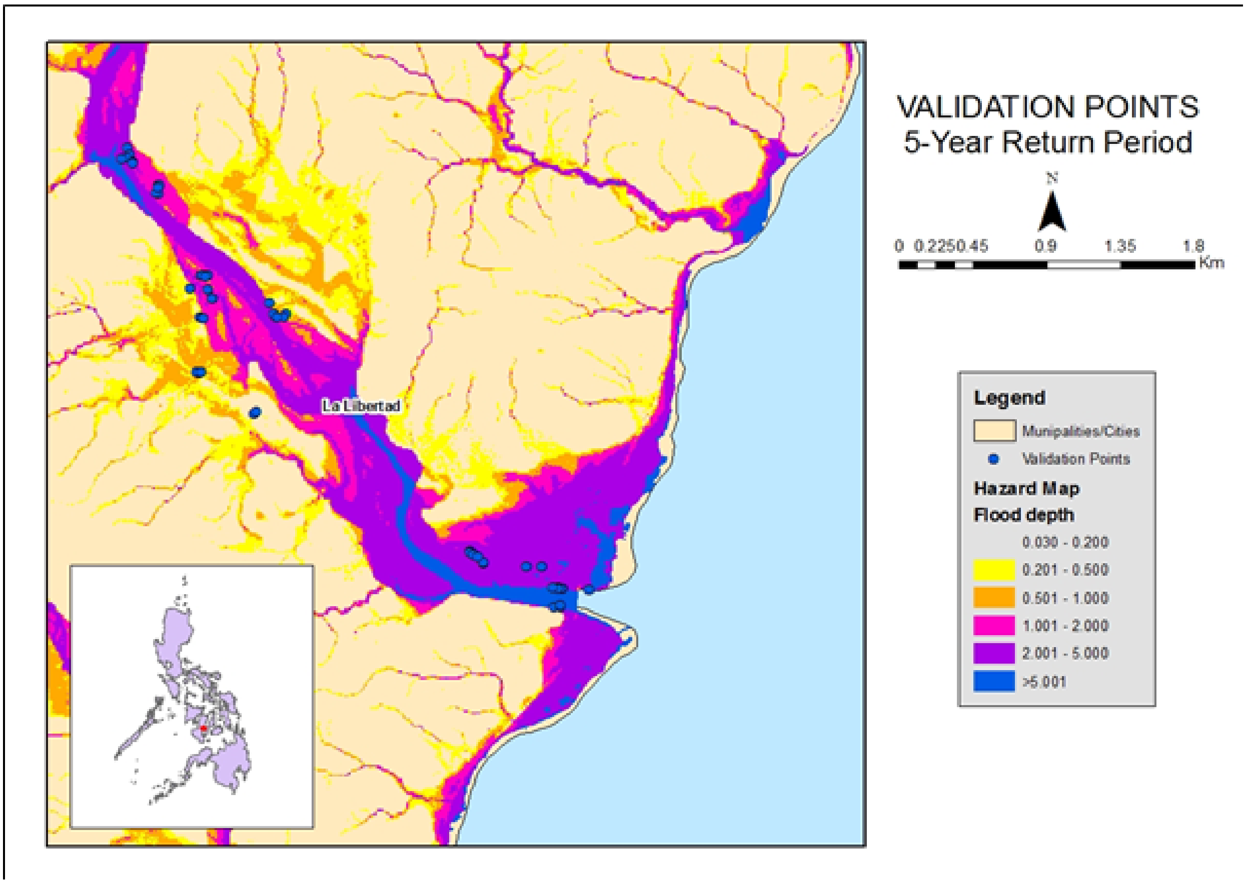


Figure 74. Validation points for a 5-year Flood Depth Map of the Libertad Flood Plain.

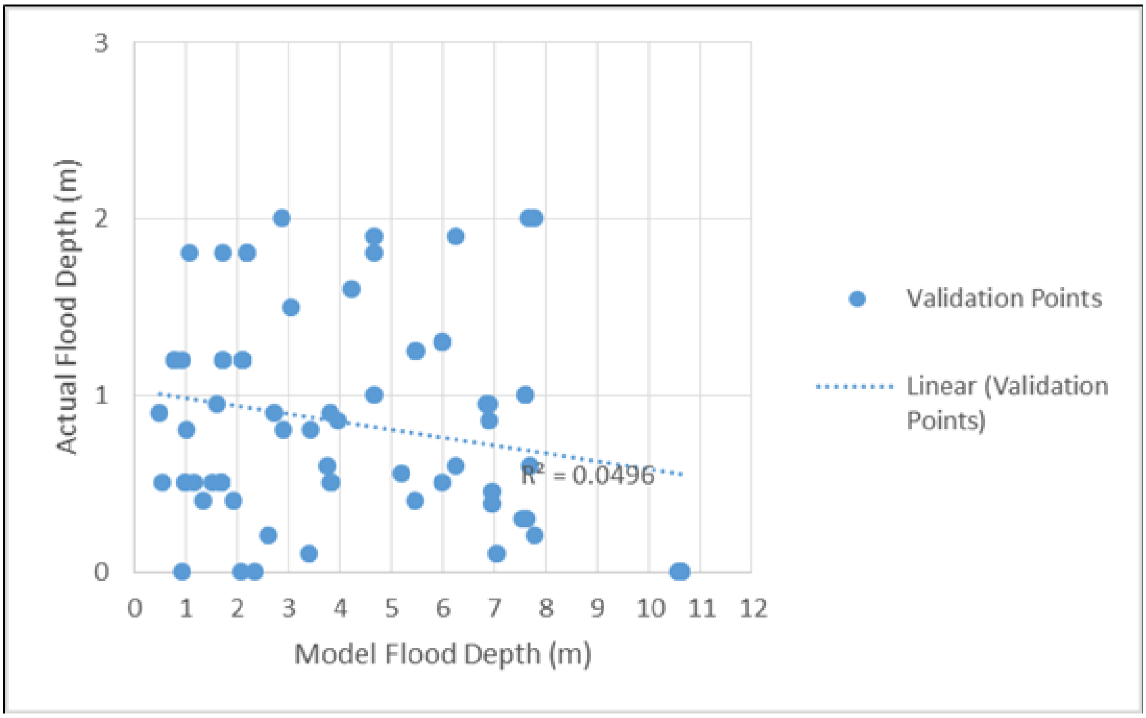


Figure 75. Flood Map depth versus Actual Flood Depth.

Table 42. Actual Flood Depth versus Simulated Flood Depth at different levels in the Libertad River Basin.

LIBERTAD BASIN		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
Actual Flood Depth (m)	0-0.20	0	0	1	0	4	7	12
	0.21-0.50	0	0	3	7	2	6	18
	0.51-1.00	0	0	1	2	7	9	19
	1.01-2.00	0	0	3	4	11	7	25
	2.01-5.00	0	0	0	0	0	0	0
	> 5.00	0	0	0	0	0	0	0
	Total	0	0	8	13	24	29	74

On the whole, the overall accuracy generated by the flood model is estimated at 6.76% with 5 points correctly matching the actual flood depths. In addition, there were 19 points estimated one level above and below the correct flood depths while there were 22 points and 28 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 14 points were underestimated in the modelled flood depths of Libertad. Table 43 depicts the summary of the Accuracy Assessment in the Libertad River Basin Flood Depth Map.

Table 43. Summary of the Accuracy Assessment in the Libertad River Basin Survey.

	No. of Points	%
Correct	5	6.76
Overestimated	66	89.19
Underestimated	3	4.05
Total	74	100.00

REFERENCES

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

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

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

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

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

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

ANNEXES

Annex 1. Technical Specifications of the LIDAR Sensors used in the Libertad Floodplain Survey

1. PEGASUS SENSOR

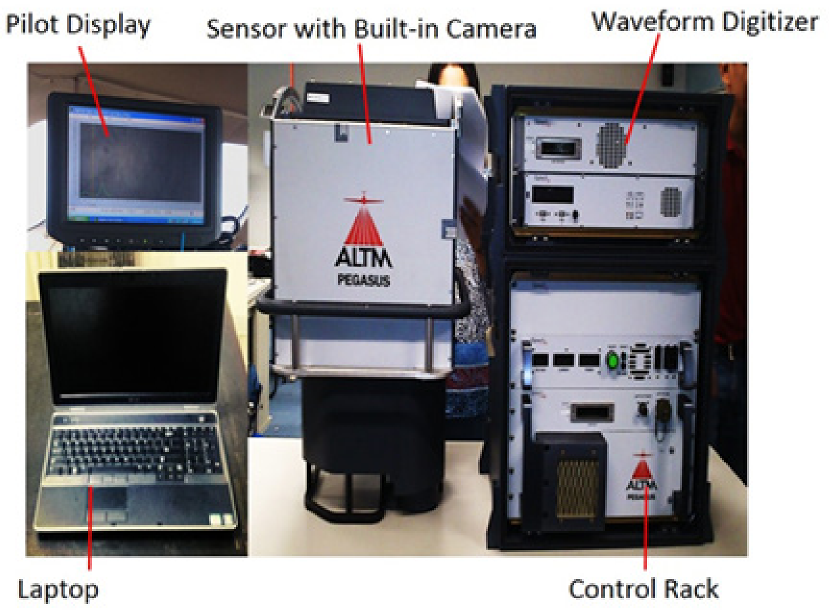


Table A-1.1 Parameters and Specifications of Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM); 220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
Operating temperature	-10˚C to +35˚C (with inLibertading jacket)
Relative humidity	0-95% no-condensing

2. AQUARIUS SENSOR

Figure A-1.2 Aquarius Sensor

Table A-1.2 Parameters and Specifications of Aquarius Sensor

Parameter	Specification
Operational altitude	300-600 m AGL
Laser pulse repetition rate	33, 50. 70 kHz
Scan rate	0-70 Hz
Scan half-angle	0 to ± 25 °
Laser footprint on water surface	30-60 cm
Depth range	0 to > 10 m (for k < 0.1/m)
Topographic mode	
Operational altitude	300-2500
Range Capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	12-bit dynamic measurement range
Position and orientation system	POS AVTM 510 (OEM) includes embedded 72-channel GNSS receiver (GPS and GLONASS)
Data Storage	Ruggedized removable SSD hard disk (SATA III)
Power	28 V, 900 W, 35 A
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitiz-er (optional)
Dimensions and weight	Sensor:250 x 430 x 320 mm; 30 kg; Control rack: 591 x 485 x 578 mm; 53 kg
Operating temperature	0-35°C
Relative humidity	0-95% no-condensing

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

1. NGW-87

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

May 09, 2014

CERTIFICATION

To whom it may concern:

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

Province: **NEGROS OCCIDENTAL**
Station Name: **NGW-87**
Order: **2nd**

Island: **VISAYAS**
Municipality: **LA CASTELLANA**
Barangay: **BALUCANAG**

	PRS92 Coordinates	
Latitude: **10° 20' 32.34942"**	Longitude: **123° 8' 53.05808"**	Ellipsoidal Hgt: **333.32600 m.**
	WGS84 Coordinates	
Latitude: **10° 20' 28.15138"**	Longitude: **123° 8' 58.30851"**	Ellipsoidal Hgt: **393.14800 m.**
	PTM Coordinates	
Northing: **1143593.27 m.**	Easting: **516216.608 m.**	Zone: **4**
	UTM Coordinates	
Northing: **1,143,192.99**	Easting: **516,210.93**	Zone: **51**

Location Description

NGW-87
The station is at the SE side of Moises Padilla-Canlaon road. Mark is the head of a 4" copper nail drilled and grouted at the center of a 30 x 30 cm. cement putty embedded on top of the headwall with inscriptions "NGW-87; 2007; NAMRIA". The station is on the SE side of the road, NE of the wooden electric post.

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8796117 A**
T.N.: **2014-1071**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1. NGW-87

2. NGW-71

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

May 02, 2016

CERTIFICATION

To whom it may concern:

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

Province: **NEGROS OCCIDENTAL**
Station Name: **NGW-71**
Order: **2nd**

Island:	**VISAYAS**	Barangay:	**HIGALAMAN**		
Municipality:	**SAN CARLOS CITY**	MSL Elevation:			
		PRS92 Coordinates			
Latitude:	**10° 28' 7.24860"**	Longitude:	**123° 23' 9.39223"**	Ellipsoidal Hgt:	**6.95200 m.**
		WGS84 Coordinates			
Latitude:	**10° 28' 3.03883"**	Longitude:	**123° 23' 14.62992"**	Ellipsoidal Hgt:	**67.06800 m.**
		PTM / PRS92 Coordinates			
Northing:	**1157590.664 m.**	Easting:	**542251.123 m.**	Zone:	**4**
		UTM / PRS92 Coordinates			
Northing:	**1,157,185.49**	Easting:	**542,236.34**	Zone:	**51**

Location Description

NGW-71
Station is located on the SW end of Higalaman Bridge at KM 148+364.5 of C.L. Ledesma Sr. Avenue (National Highway) and is about 2.1 km NE of Guadalupe Elementary School. Mark is the head of a 4 inch copper nail drilled and grouted at the center of a 30cm x 30cm cement putty embedded on top of the concrete sidewalk with inscriptions "NGW-71, 2007, NAMRIA".

Requesting Party:	**Merlin Fernando**
Purpose:	**Reference**
OR Number:	**3943035 I**
T.N.:	**2016-1023**

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

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

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.2 NGW-71

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

1. BM-105

Table A-3.1. BM-105

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
NGW-71 --- BM-105 (B2)	NGW-71	BM-105	Fixed	0.005	0.021	199°27'15"	35093.173	1.217
NGW-71 --- BM-105 (B1)	NGW-71	BM-105	Fixed	0.007	0.018	199°27'15"	35093.176	1.255

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

From:	NGW-71				
Grid		Local		Global	
Easting	542236.335 m	Latitude	N10°28'07.24860"	Latitude	N10°28'03.03883"
Northing	1157185.487 m	Longitude	E123°23'09.39223"	Longitude	E123°23'14.62992"
Elevation	5.212 m	Height	6.952 m	Height	67.068 m

To:	BM-105				
Grid		Local		Global	
Easting	530592.956 m	Latitude	N10°10'10.15714"	Latitude	N10°10'06.01438"
Northing	1124094.428 m	Longitude	E123°16'45.42883"	Longitude	E123°16'50.69386"
Elevation	6.800 m	Height	8.169 m	Height	68.712 m

Vector					
ΔEasting	-11643.379 m	NS Fwd Azimuth	199°27'15"	ΔX	6501.694 m
ΔNorthing	-33091.059 m	Ellipsoid Dist.	35093.173 m	ΔY	11372.505 m
ΔElevation	1.588 m	ΔHeight	1.217 m	ΔZ	-32556.444 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.006 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.009 m
σ ΔElevation	0.011 m	σ ΔHeight	0.011 m	σ ΔZ	0.002 m

2. BM-107

Table A-3.2. BM-107

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
BM-107 --- BM-105 (B2)	BM-105	BM-107	Fixed	0.004	0.010	15°21'48"	1705.117	-3.174
BM-105 --- BM-107 (B1)	BM-105	BM-107	Fixed	0.005	0.010	15°21'46"	1705.127	-3.150

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

Vector Components (Mark to Mark)

From:	BM-105				
Grid		Local		Global	
Easting	530592.944 m	Latitude	N10°10'10.15725"	Latitude	N10°10'06.01449"
Northing	1124094.431 m	Longitude	E123°16'45.42846"	Longitude	E123°16'50.69348"
Elevation	6.821 m	Height	8.190 m	Height	68.734 m

To:	BM-107				
Grid		Local		Global	
Easting	531043.102 m	Latitude	N10°11'03.67387"	Latitude	N10°10'59.52767"
Northing	1125738.367 m	Longitude	E123°17'00.26984"	Longitude	E123°17'05.53352"
Elevation	3.639 m	Height	5.017 m	Height	65.536 m

Vector					
ΔEasting	450.157 m	NS Fwd Azimuth	15°21'48"	ΔX	-216.491 m
ΔNorthing	1643.936 m	Ellipsoid Dist.	1705.117 m	ΔY	-493.353 m
ΔElevation	-3.182 m	ΔHeight	-3.174 m	ΔZ	1617.767 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.003 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.004 m
σ ΔElevation	0.005 m	σ ΔHeight	0.005 m	σ ΔZ	0.002 m

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. CZAR JAKIRI S. SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	
		LOVELYN ASUNCION	
LiDAR Operation	Senior Science Research Specialist (SSRS)	ENGR. CHRISTOPHER JOAQUIN	UP-TCAGP
	Senior Science Research Specialist (SSRS)	JASMINE ALVIAR	UP-TCAGP
	Research Associate (RA)	GRACE SINADJAN	UP-TCAGP
		FOR. VERLINA TONGA	
		JONALYN GONZALES	
Ground Survey	RA	LANCE KERWIN CINCO	UP-TCAGP
		ENGR. KENNETH QUISADO	
LiDAR Operation	Airborne Security	SSG. LEE JAY PUNZALAN	PILIPPINE AIR FORCE (PAF)
		SSG. RAYMUND DOMINIE	
LiDAR Operation	Pilot	CAPT. JEFFREY JEREMY ALAJAR	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. JERICO JECIEL	
		CAPT. BRYAN DONGUINES	
		CAPT. RANDY LAGCO	

Annex 5. Data Transfer Sheet for Libertad Floodplain

DATA TRANSFER SHEET
5/19/2014(Bacolod Ready)

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	
4/29/2014	1403P	1BLK44DE119A	PEGASUS	2.89GB	2078KB	13.3	550	54.5	431	57.1	NA	7.14MB	1KB	1KB	92/75/52/56	NA	Z:\Airborne_Raw\1403P
5/1/2014	1411P	1BLK44D121A	PEGASUS	NA	88KB	10.9	221	31.5	264	26.5	NA	6.74MB	1KB	1KB	82/69/56	NA	Z:\Airborne_Raw\1411P
5/2/2014	1415P	1BLK44H122A	PEGASUS	3.27GB	2121KB	14.1	266	40.3	346	32.8	NA	7.32MB	1KB	1KB	37/38/46	NA	Z:\Airborne_Raw\1415P
5/5/2014	1427P	1BLK45E125A	PEGASUS	2.73GB	661KB	10.6	219	NA	NA	25.7	NA	6.12	1KB	1KB	30.9	NA	Z:\Airborne_Raw\1427P
5/6/2014	1431P	1BLK44GHS126A	PEGASUS	3.11	1612KB	13	254	51.3	370	29.2	NA	14.4	1KB	1KB	144/137/110	NA	Z:\Airborne_Raw\1431P
5/6/2014	1433P	1BLK44FGS126B	PEGASUS	3.04	1662	12.8	271	59	495	27.8	NA	14.4	1KB	1KB	144/137/110	NA	Z:\Airborne_Raw\1433P
5/7/2014	1435P	1BLK44DS127A	PEGASUS	2.94	712	14	285	NA	NA	19.6	NA	7.14	1KB	1KB	114	NA	Z:\Airborne_Raw\1435P
5/10/2014	1447P	1BLK45FG130A	PEGASUS	3.45	1382	14.4	294	NA	NA	32.5	NA	6.21	1KB	1KB	43	NA	Z:\Airborne_Raw\1447P
5/11/2014	1451P	1BLK45S132A	PEGASUS	2.42	500	11.5	243	NA	NA	27.2	NA	11.4	1KB	1KB	53	NA	Z:\Airborne_Raw\1451P
5/11/2014	1453P	1BLK45DFGS133A	PEGASUS	1.8	581	7.34	170	21.5	171	16.6	NA	11.4	1KB	1KB	49.3	NA	Z:\Airborne_Raw\1453P
5/12/2014	1455P	1IHLS134A	PEGASUS	3.06	530	13.2	298	NA	NA	26.3	NA	8.9	1KB	1KB	81/82/33/23	NA	Z:\Airborne_Raw\1455P
5/13/2014	1459P	1IHLS136A	PEGASUS	3.23	577	14.6	287	NA	NA	31.1	NA	7.18	1KB	1KB	88	NA	Z:\Airborne_Raw\1459P
5/14/2014	1463P	1IHLX137A	PEGASUS	782MB	249	5.69	148	NA	NA	6.26	NA	6.42	1KB	1KB	119	NA	Z:\Airborne_Raw\1463P

Received from
Name C - Jeremy(?)
Position RA
Signature

Received by
Name JOIDA F. PRIETO
Position SSRS
Signature 5/26/2014

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

DATA TRANSFER SHEET
BACOLOD 5/18/2016

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	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	
April 22,2016	8453AC	3BLK44AS113A	AQUA/CASI	NA	343	769	246	NA	NA	13.9	101	99.1	1KB	1KB	6	14	Z:\DAC\RAW DATA
April 23,2016	8455AC	3BLK44AS114A	AQUA/CASI	NA	247	663	233	38.5	43	10.2	85.3	91	1KB	1KB	20	30	Z:\DAC\RAW DATA
April 24,2016	8457AC	3BLK44EDS115A	AQUA/CASI	NA	197	544	222	39.6	221	8.64	66.9	94	1KB	1KB	40	22	Z:\DAC\RAW DATA
April 25,2016	8459AC	3BLK44IJS116A	AQUA/CASI	NA	240	603	262	43.4	248	10.3	66.5	100	1KB	1KB	18	38	Z:\DAC\RAW DATA
April 26,2016	8462AC	3BLK46AS117B	AQUA/CASI	NA	194	502	229	37.4	187	8.59	67.4	107	1KB	1KB	8	20	Z:\DAC\RAW DATA
April 27,2016	8464AC	3BLK46AS118B	AQUA/CASI	NA	81	209	143	9.78	3.23	4	23.9	158	1KB	1KB	8	20	Z:\DAC\RAW DATA
May 1,2016	8471AC	3BLK44FGHS122A	AQUA/CASI	NA	191	541	241	45.3	263	8.33	139	90.5	1KB	1KB	10	22	Z:\DAC\RAW DATA
May 2,2016	8473AC	3BLK46AS123A	AQUA/CASI	NA	88	320	206	5.45	3.7	4.59	55.3	64.6	1KB	NA	16	22	Z:\DAC\RAW DATA

Received from

Name R. PUNTO
Position RA
Signature

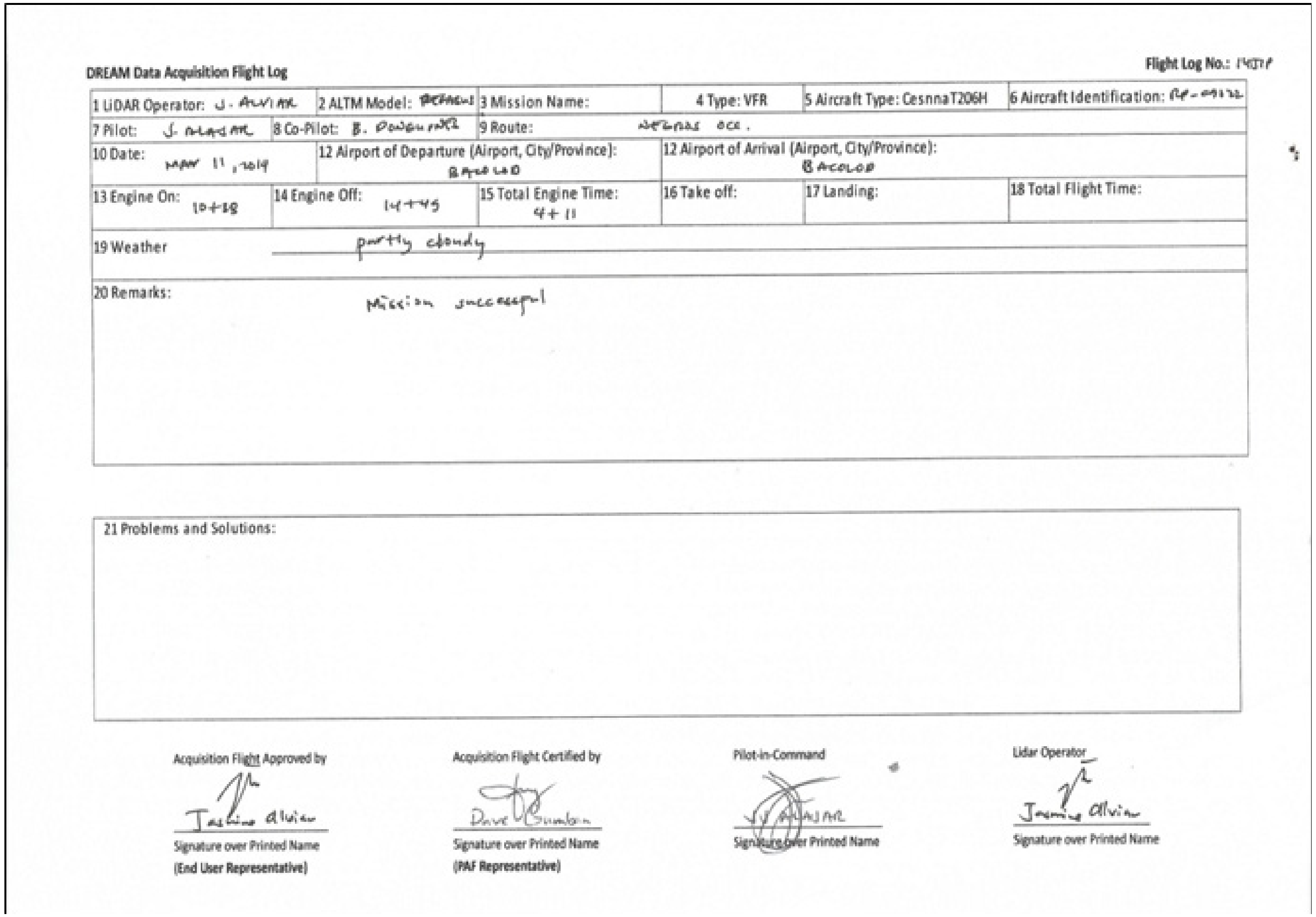
Received by

Name AC Bongat
Position SSRS
Signature 5/20/16

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

Annex 6. Flight logs for the flight missions

1. Flight Log for 1451P Mission


DREAM Data Acquisition Flight Log

Flight Log No.:

1 LiDAR Operator:	2 ALTM Model:	3 Mission Name:	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification:
7 Pilot:	8 Co-Pilot:	9 Route:			
10 Date: May 11, 2014		12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):	
13 Engine On: 10+18	14 Engine Off: 14+45	15 Total Engine Time: 4+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	partly cloudy				
20 Remarks:	Mission successful				

21 Problems and Solutions:

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

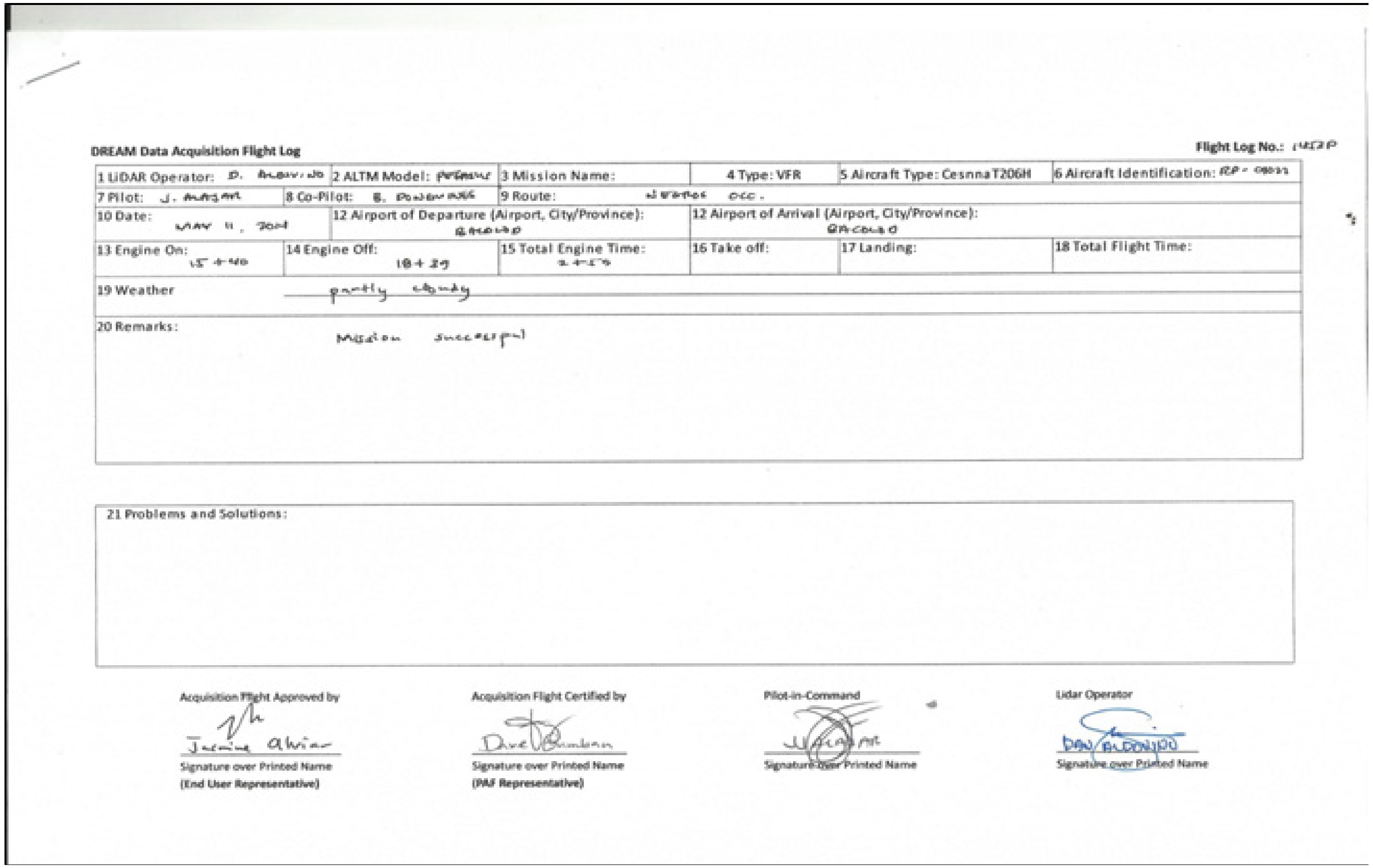
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Figure A-6.1. Flight Log for Mission 1451P

2. Flight Log for 1453P Mission



DREAM Data Acquisition Flight Log

Flight Log No.: 1453P

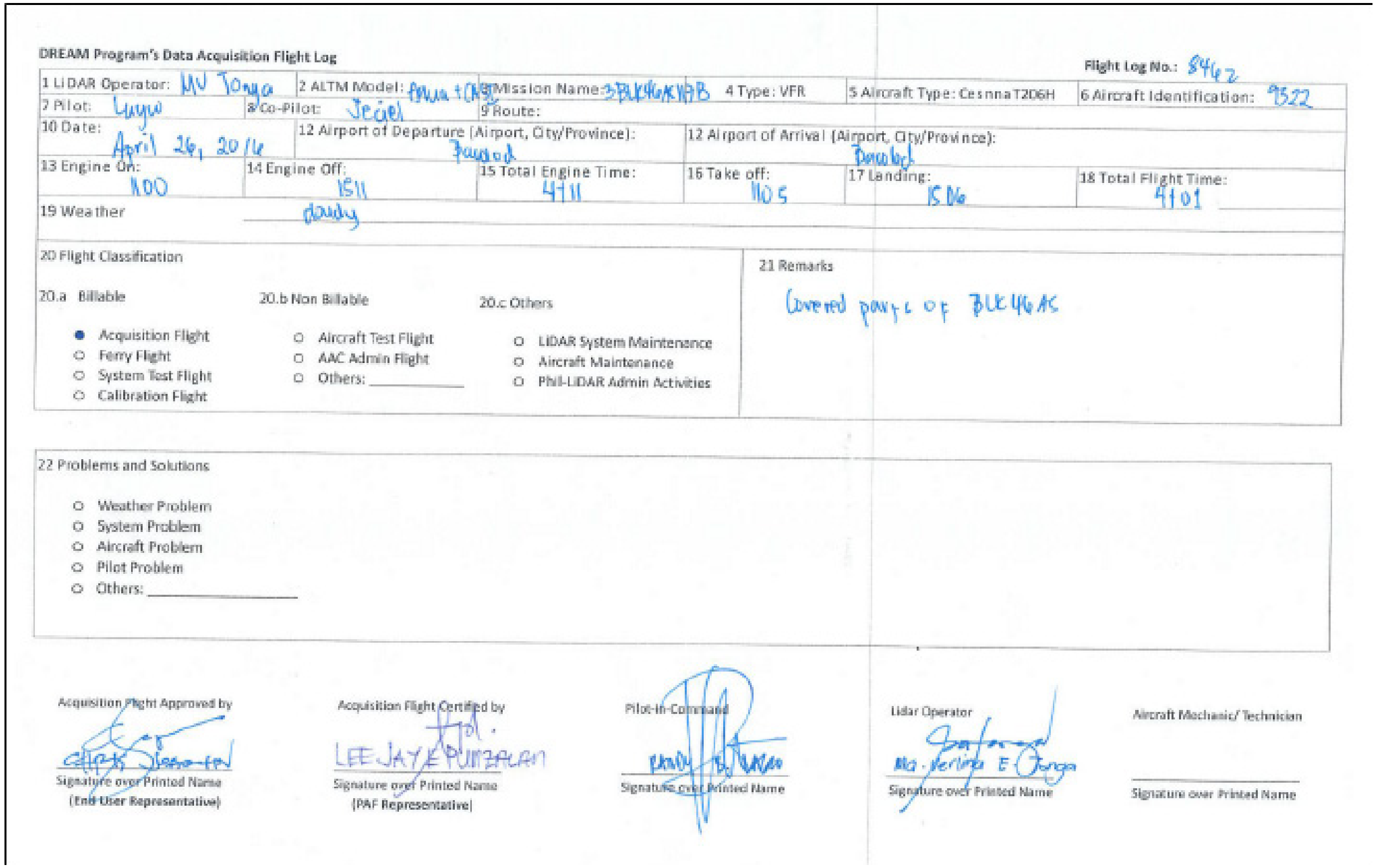
1 LiDAR Operator: D. Alcovino	2 ALTM Model: Pegasus	3 Mission Name:	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: RP-C9022
7 Pilot: J. Alajar	8 Co-Pilot:	9 Route:			
10 Date: May 11, 2014	12 Airport of Departure (Airport, City/Province): Bacolod		12 Airport of Arrival (Airport, City/Province): Bacolod		
13 Engine On: 15+40	14 Engine Off: 18+29	15 Total Engine Time:	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	partly cloudy				
20 Remarks:	Mission successful				

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Jasmine Alviar	Dave Bumbun	J. Alajar	Dan Alcovino
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 1453P

3. Flight Log for 8462AC Mission



DREAM Program's Data Acquisition Flight Log

Flight Log No.: 8462

1 LiDAR Operator: MV Tonga	2 ALTM Model: Pegasus	3 Mission Name: 3BLK46AKVB	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: Laya	8 Co-Pilot: Jeciel	9 Route:			
10 Date: April 26, 2016	12 Airport of Departure (Airport, City/Province): Butuan		12 Airport of Arrival (Airport, City/Province): Butuan		
13 Engine On: 1100	14 Engine Off: 1511	15 Total Engine Time: 4+11	16 Take off: 1105	17 Landing: 1506	18 Total Flight Time: 4+01
19 Weather: cloudy					

20 Flight Classification

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

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

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

21 Remarks

Covered parts of BLK46AS

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

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

Acquisition Flight Certified by: LEE JAY E PUNZALAN, Signature over Printed Name (PAF Representative)

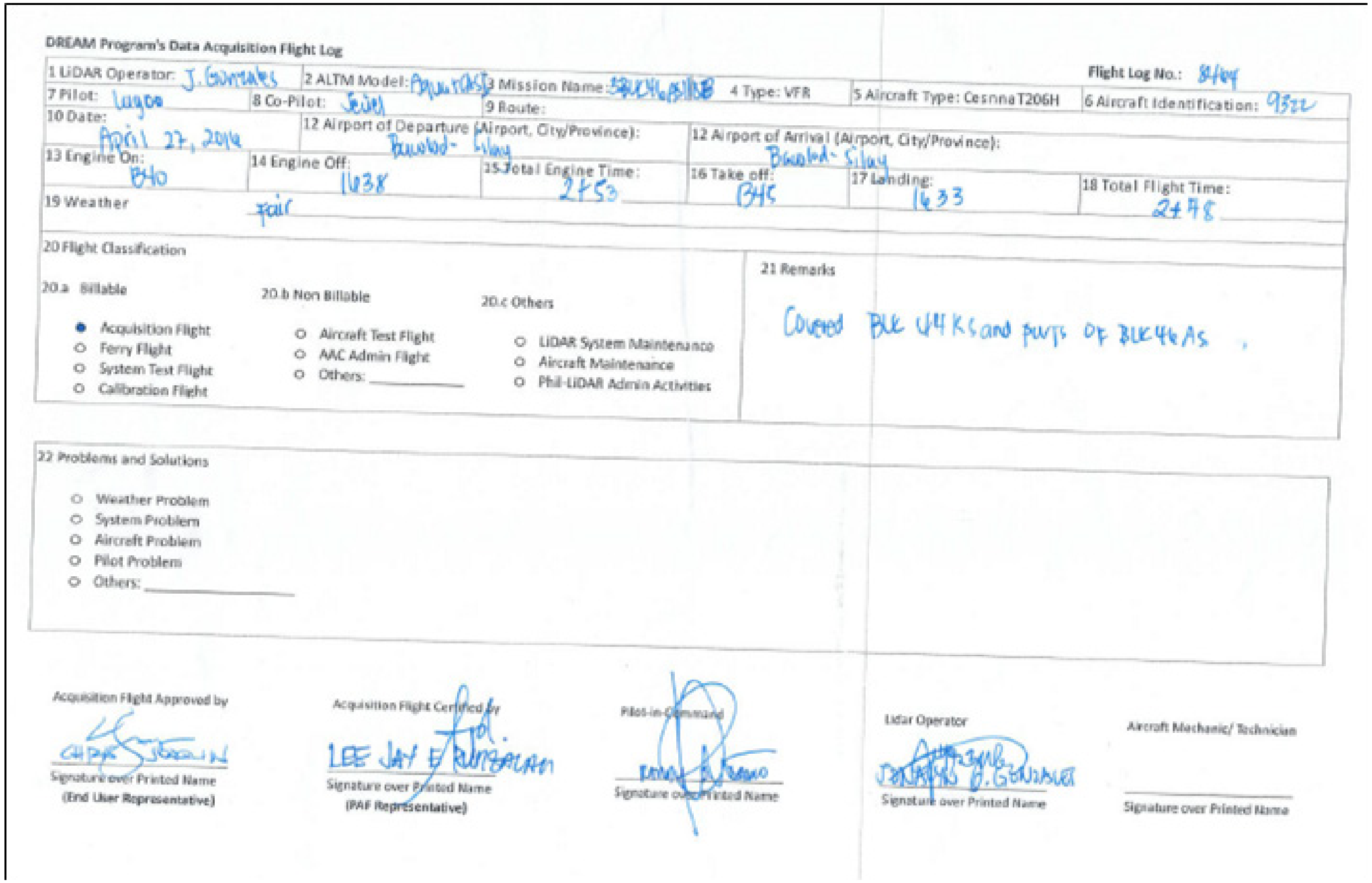
Pilot-in-Command: Signature over Printed Name

Lidar Operator: Ma. Verlina E. Tonga, Signature over Printed Name

Aircraft Mechanic/ Technician: Signature over Printed Name

Figure A-6.3. Flight Log for Mission 8462AC

4. Flight Log for 8464AC Mission


DREAM Program's Data Acquisition Flight Log

Flight Log No.: 8464

1 LiDAR Operator: J. Gonzales	2 ALTM Model: Pegasus	3 Mission Name:	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: Lugoo	8 Co-Pilot: Seval	9 Route:			
10 Date: April 27, 2014	12 Airport of Departure (Airport, City/Province): Bacolod - Silay		12 Airport of Arrival (Airport, City/Province): Bacolod - Silay		
13 Engine On: 1340	14 Engine Off: 1638	15 Total Engine Time: 2+53	16 Take off: 1345	17 Landing: 1633	18 Total Flight Time: 2+48
19 Weather: fair					

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

Covered BLK 44Ks and parts of BLK46As.

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

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

Acquisition Flight Certified by: LEE JAY E. [illegible] Signature over Printed Name (PAF Representative)

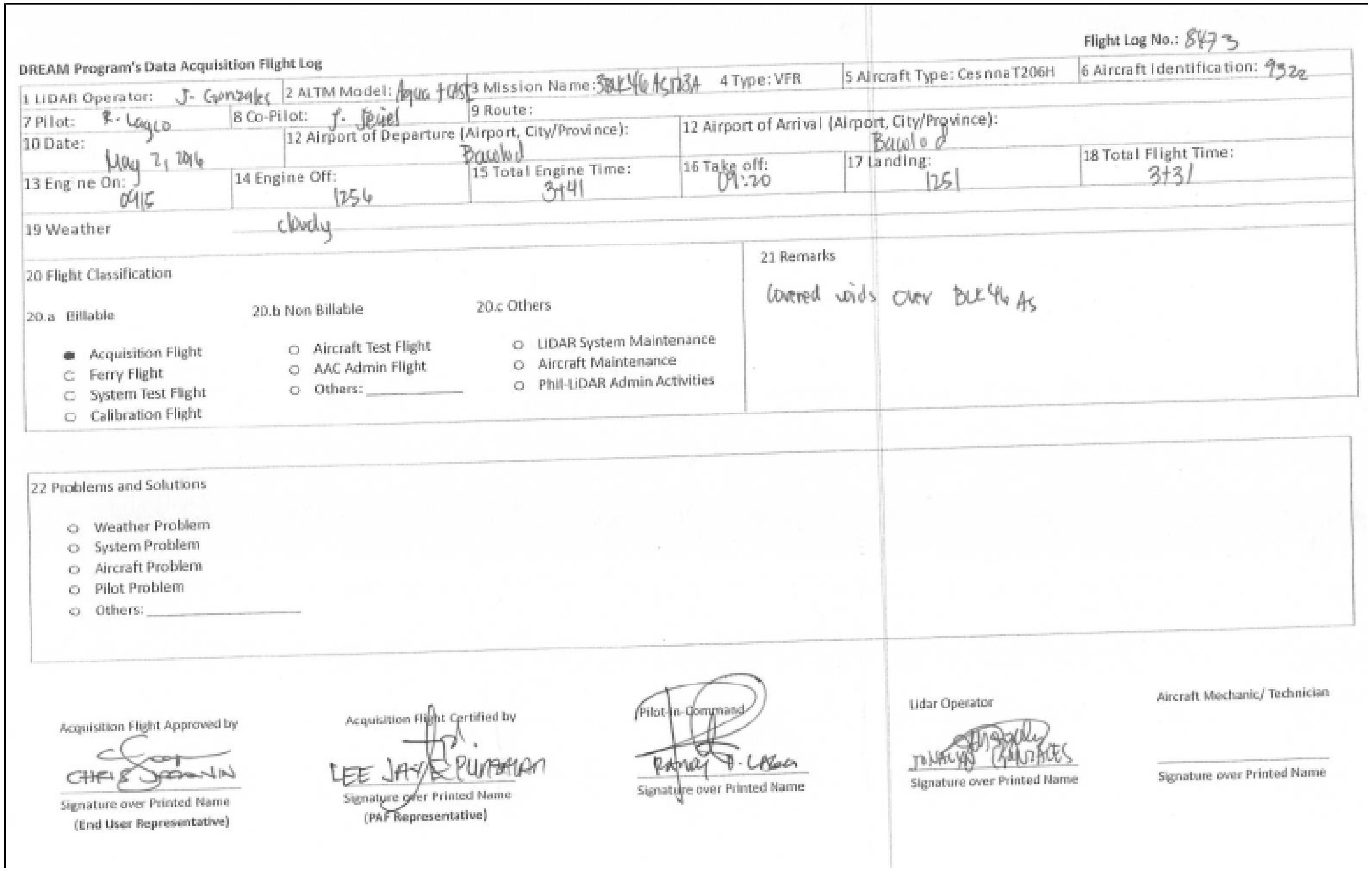
Pilot-in-Command: Signature over Printed Name

Lidar Operator: Signature over Printed Name

Aircraft Mechanic/ Technician: Signature over Printed Name

Figure A-6.4. Flight Log for Mission 8464AC

5. Flight Log for 8473AC Mission



Flight Log No.: 8473

DREAM Program's Data Acquisition Flight Log

1 LiDAR Operator: J. Gonzales	2 ALTM Model: Aqua	3 Mission Name: 3BLK46AS133A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9322
7 Pilot: R. Lagco	8 Co-Pilot: J. Jeciel	9 Route:			
10 Date: May 21, 2016	12 Airport of Departure (Airport, City/Province): Bacolod		12 Airport of Arrival (Airport, City/Province): Bacolod		
13 Engine On: 0915	14 Engine Off: 1256	15 Total Engine Time: 3+41	16 Take off: 09:20	17 Landing: 1251	18 Total Flight Time: 3+31
19 Weather: cloudy					

20 Flight Classification

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

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

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

21 Remarks

Covered voids over BLK46As

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

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

Acquisition Flight Certified by: Lee Jay E. Punzalan — Signature over Printed Name (PAF Representative)

Pilot-in-Command: Rodney F. Lagco — Signature over Printed Name

Lidar Operator: J. Gonzales — Signature over Printed Name

Aircraft Mechanic/ Technician: ____________ Signature over Printed Name

Figure A-6.5. Flight Log for Mission 8473AC

Annex 7. Flight status reports

Table A-7.1. Flight Status Report

Negros Occidental
May 11, 2014 and April 26 to May 2, 2016

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
1451P	BLK 46A	1BLK46A131A	J. Alviar	May 11	Surveyed half of BLK 46A
1453P	BLK 46A	1BLK46AS131B	D. Aldovino	May 11	Surveyed remaining half of BLK 46A
8462AC	BLK46AS	3BLK46As117B	V. Tonga	APR 26	Surveyed parts of Blk46As
8464AC	BLK46AS	3BLK46AS118B	J. Gonzales	APR 27	Surveyed parts of Blk46As
8473AC	BLK46AS	3BLK46AS123A	J. Gonzales	MAY 02	Surveyed Blk46As

SWATH PER FLIGHT MISSION

Flight No. :	1451P
Area:	BLK 46A
Mission Name:	1BLK46A131A
Area Surveyed:	186.25 sq.km.

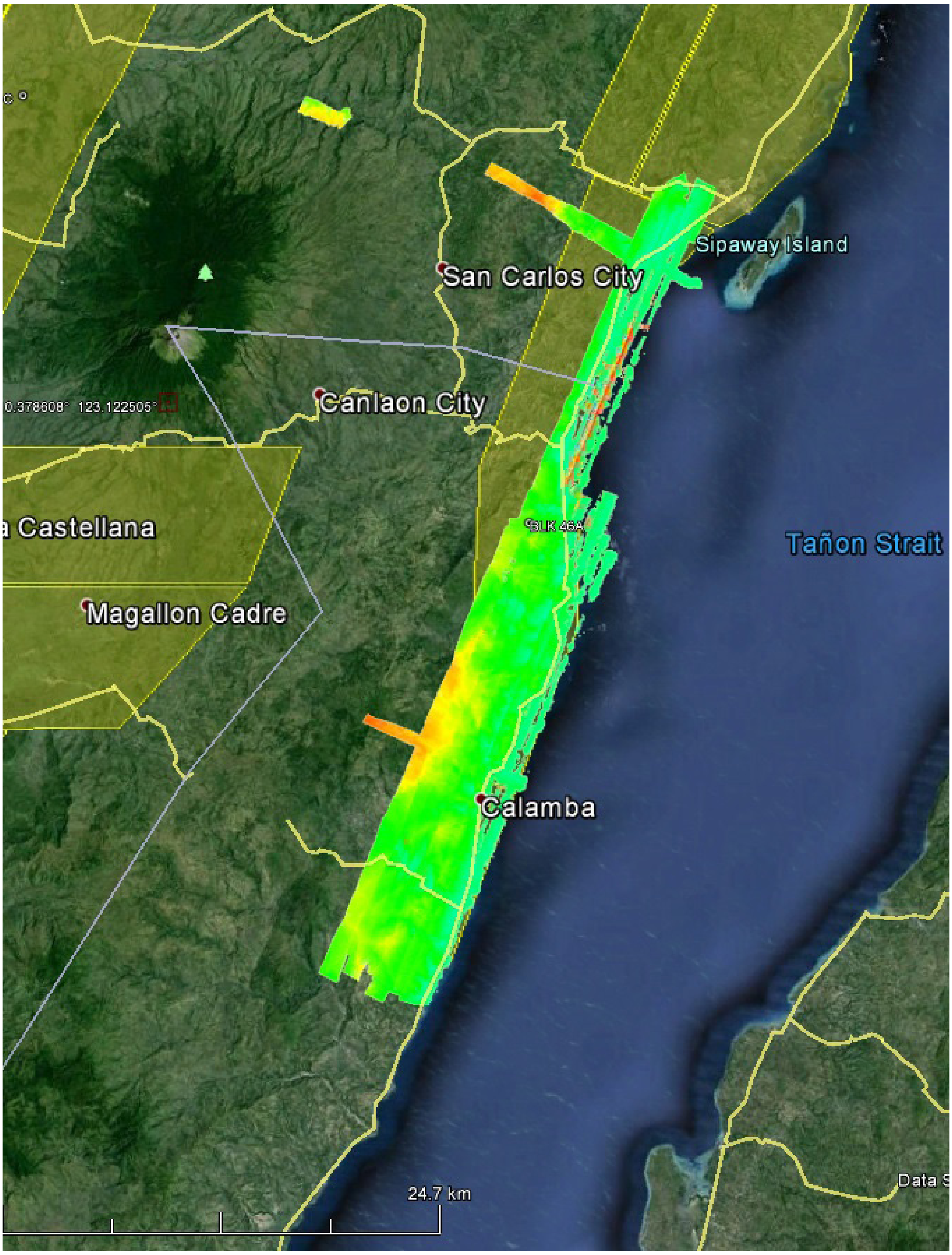


Figure A-7.1. Swath for Flight No. 1415P

Flight No. :	1453P
Area:	BLK 46A
Mission Name:	1BLK46AS131B
Area Surveyed:	183.49 sq.km.

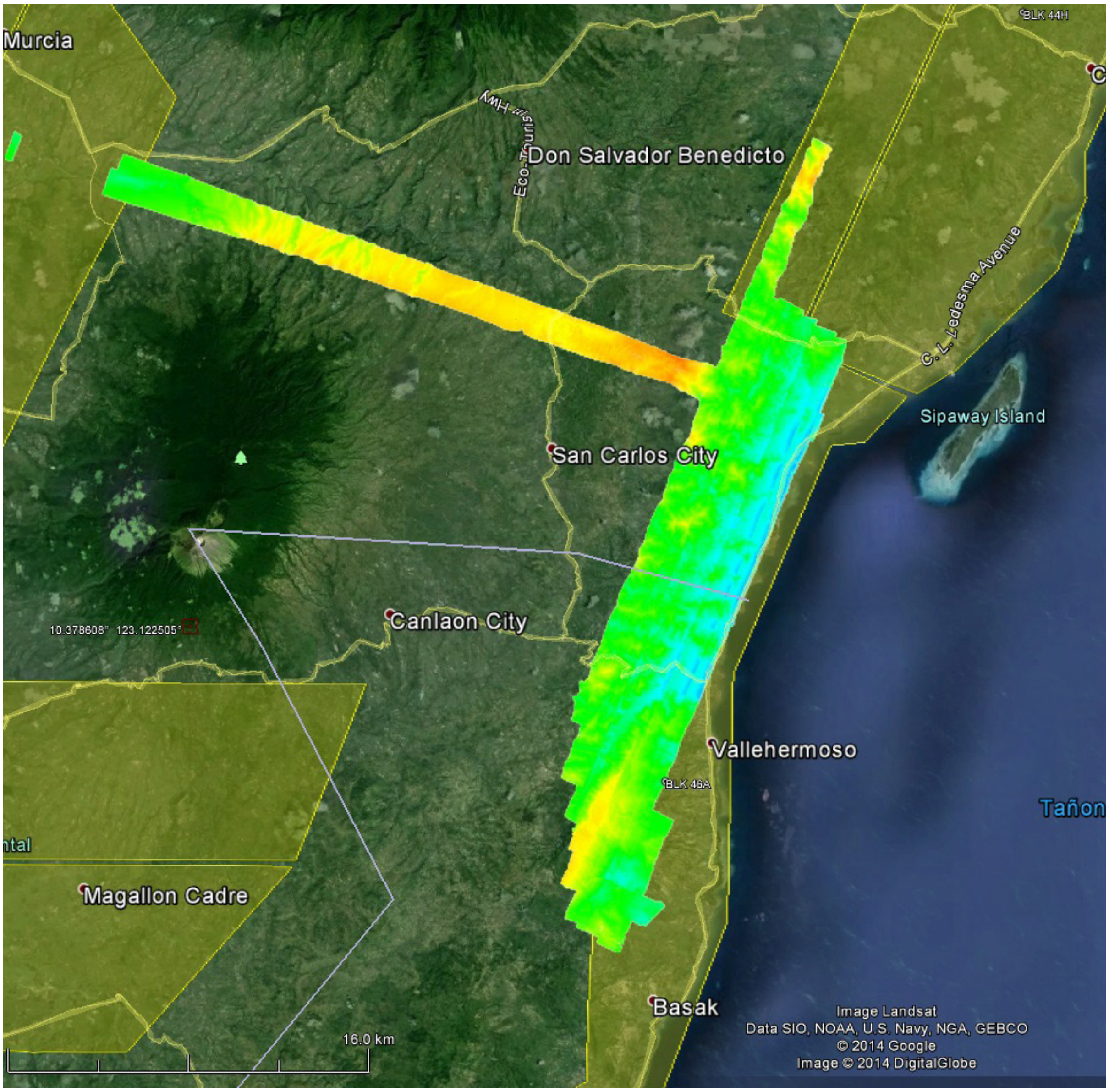


Figure A-7.2. Swath for Flight No. 1453P

Flight No. :	8462AC
Area:	BLK46AS,BLK46KS
Mission Name:	3BLK46As117B
Altitude:	500m
Scan Frequency:	45
Scan Angle:	18
Overlap:	55 %
PRF:	50kHz
Area Surveyed:	53 sq km

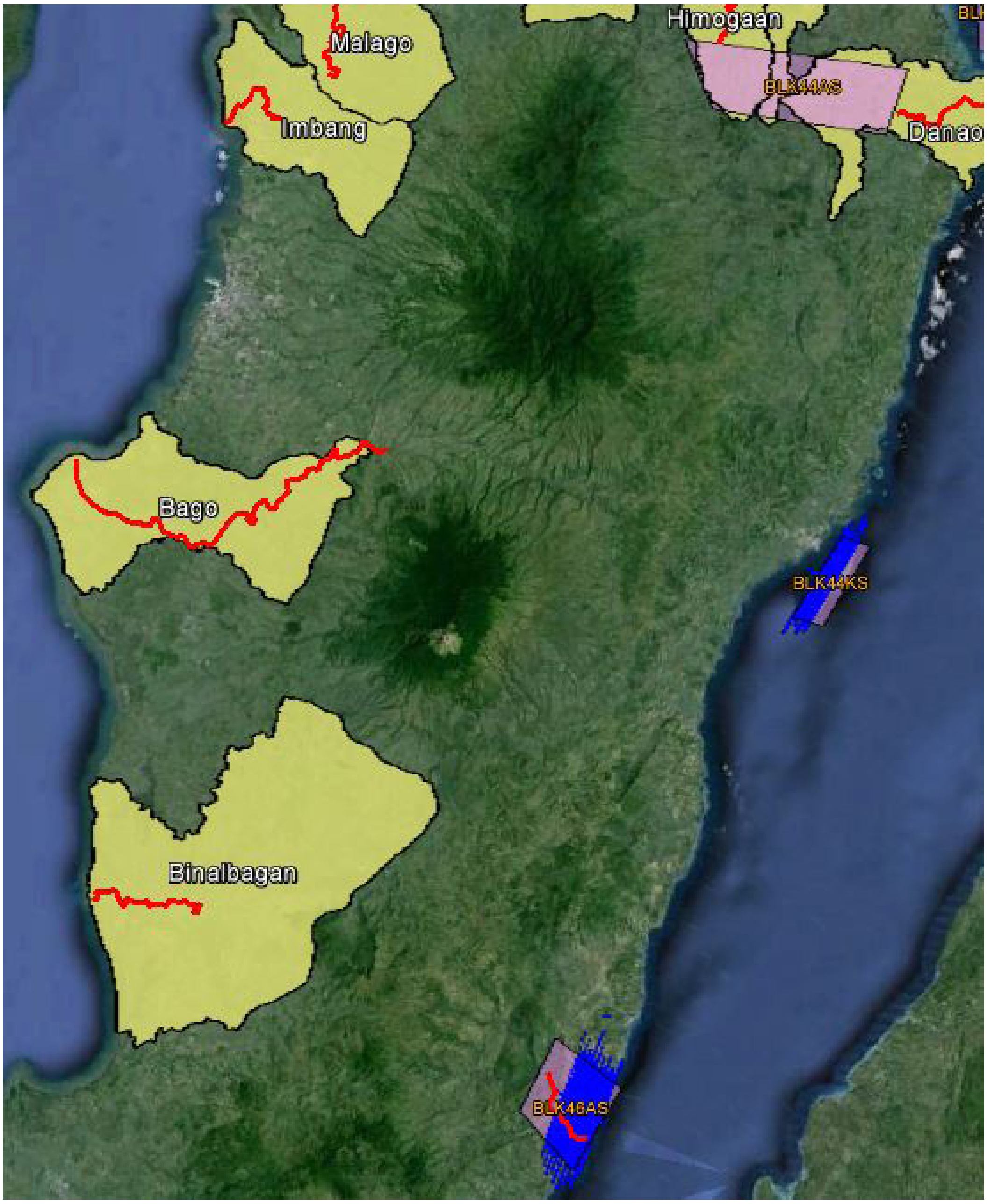


Figure A-7.3. Swath for Flight No. 8462AC

Flight No. :	8464AC
Area:	BLK46AS,BLK44KS
Mission Name:	3BLK46AS118B
Altitude:	500m
Scan Frequency:	50
Scan Angle:	20
Overlap:	25-40%
PRF:	50kHz
Area Surveyed:	19 sq km

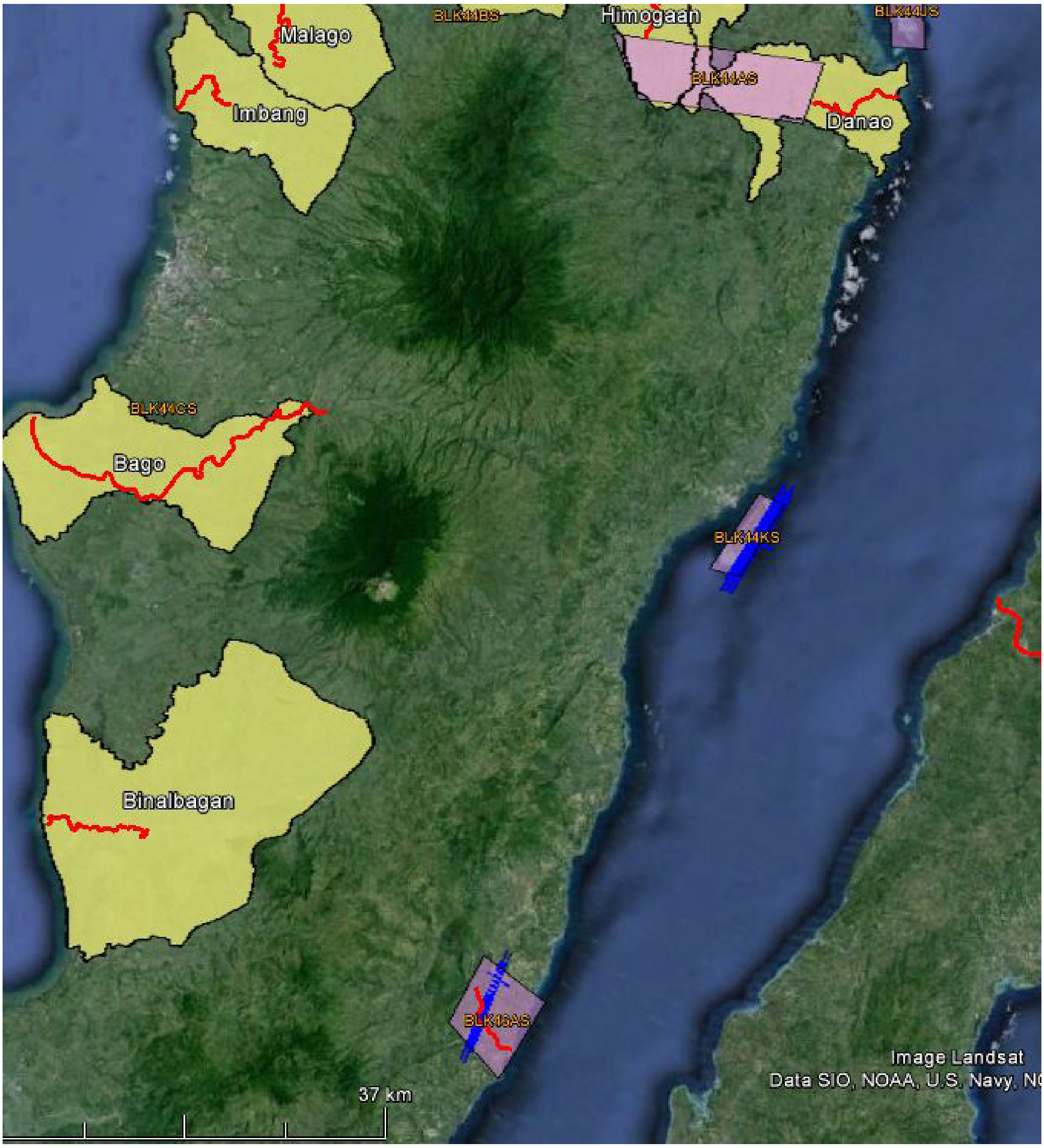


Figure A-7.4. Swath for Flight No. 8464AC

Flight No. :	8473AC
Area:	BLK46AS
Mission Name:	3BLK46AS123A
Altitude:	500m
Scan Frequency:	45
Scan Angle:	18
Overlap:	30%
PRF:	50kHz
Area Surveyed:	22 sq km

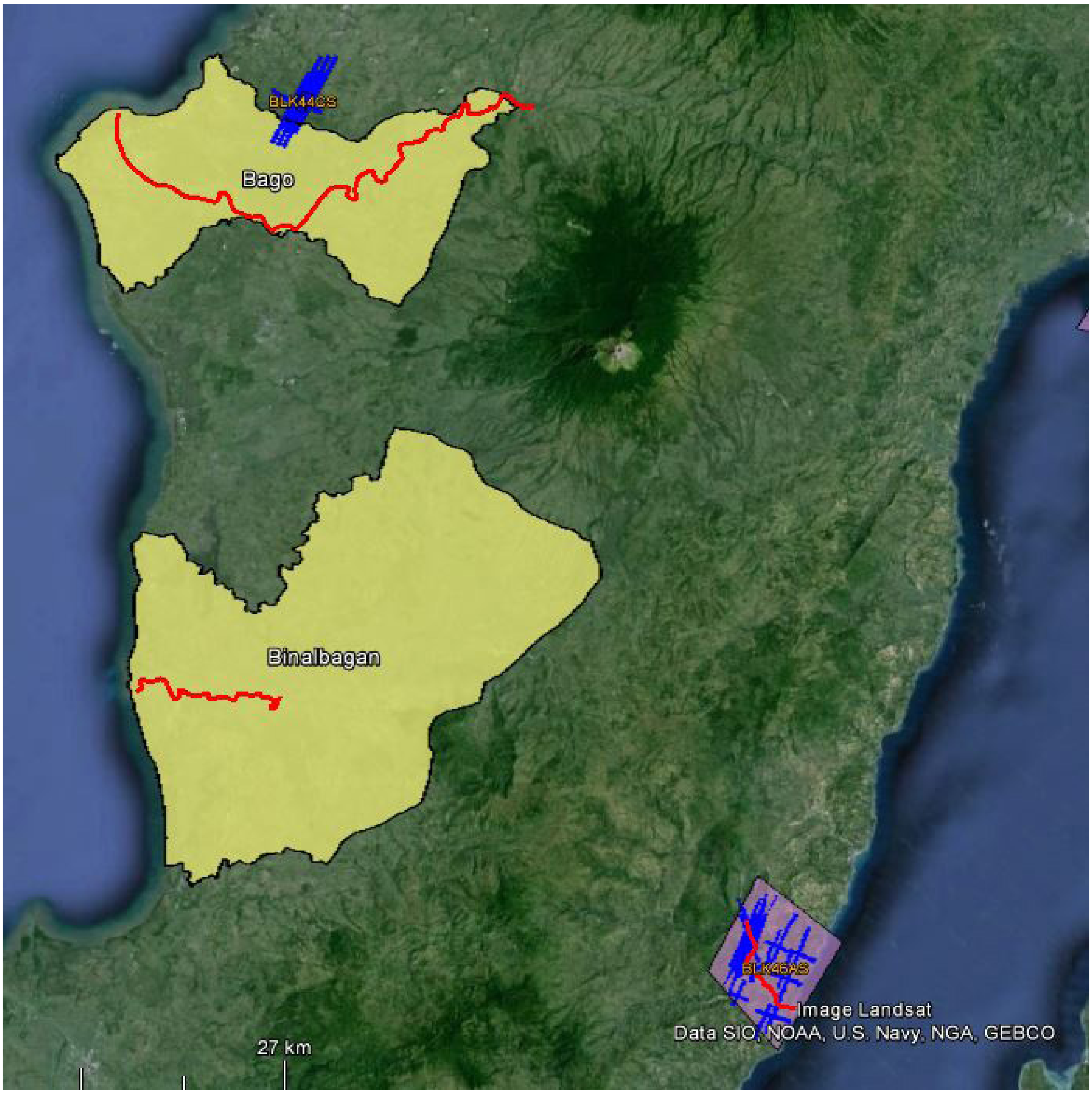


Figure A-7.5. Swath for Flight No. 8473AC

ANNEX 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk64A

Flight Area	Negros
Mission Name	Blk46A
Inclusive Flights	1451P, 1453P
Range data size	43.8 GB
POS	413 MB
Image	21.5 GB
Transfer date	May 26, 2014
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.93
RMSE for East Position (<4.0 cm)	1.15
RMSE for Down Position (<8.0 cm)	2.28
Boresight correction stdev (<0.001deg)	0.000266
IMU attitude correction stdev (<0.001deg)	0.001576
GPS position stdev (<0.01m)	0.0092
Minimum % overlap (>25)	57.62%
Ave point cloud density per sq.m. (>2.0)	6.28
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	436
Maximum Height	61.30
Minimum Height	750.91
Classification (# of points)	
Ground	346,965,657
Low vegetation	284,586,296
Medium vegetation	504,136,177
High vegetation	250,658,066
Building	7,285,413
Orthophoto	Yes
Processed by:	Engr. Jennifer Saguran, Engr. Mark Joshua Salvacion, Engr. Gladys Mae Apat

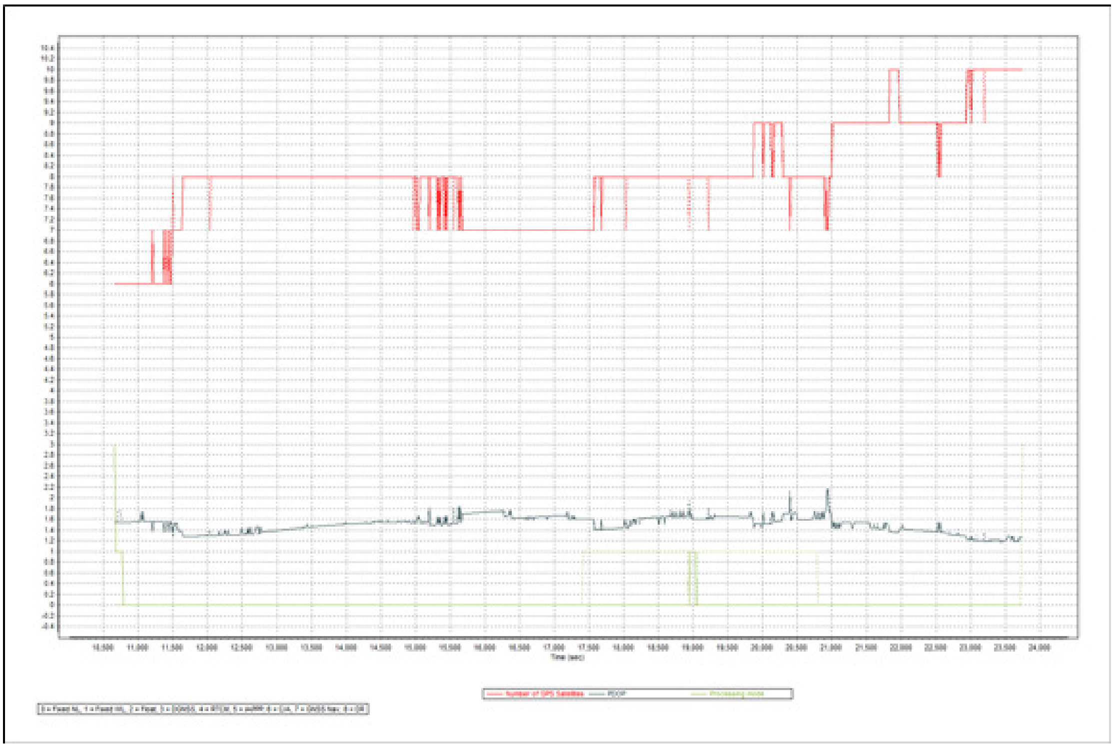


Figure A-8.1 Solution Status

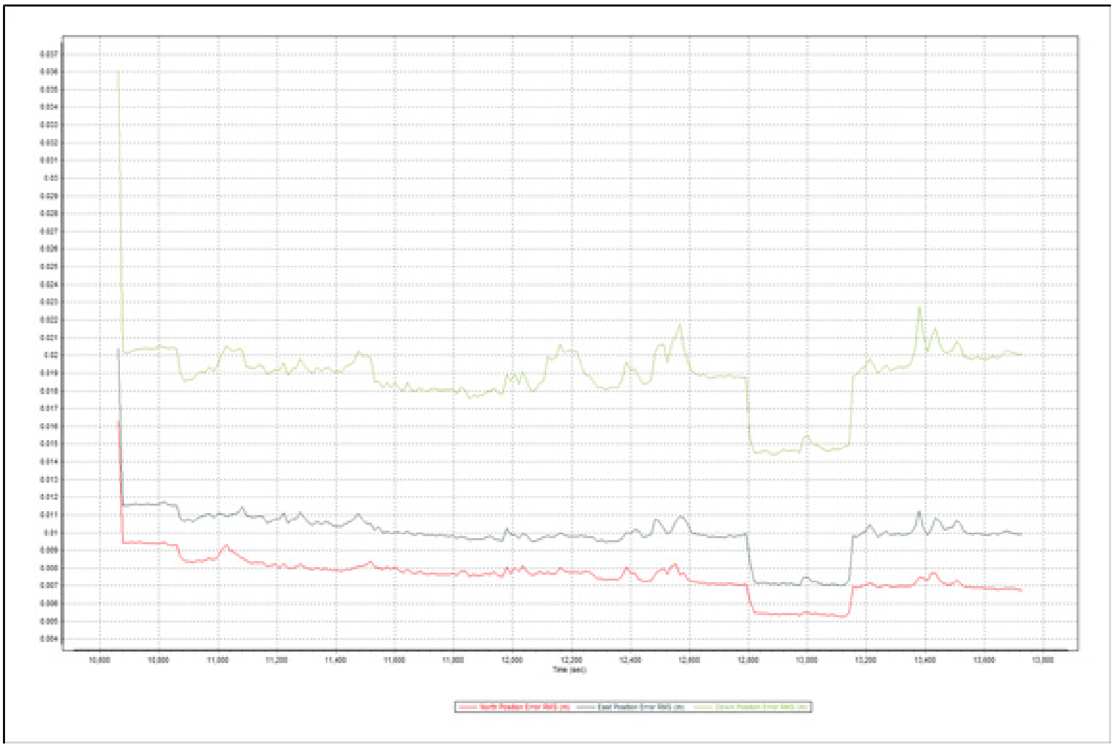


Figure A-8.2. Smoothed Performance Metric Parameters

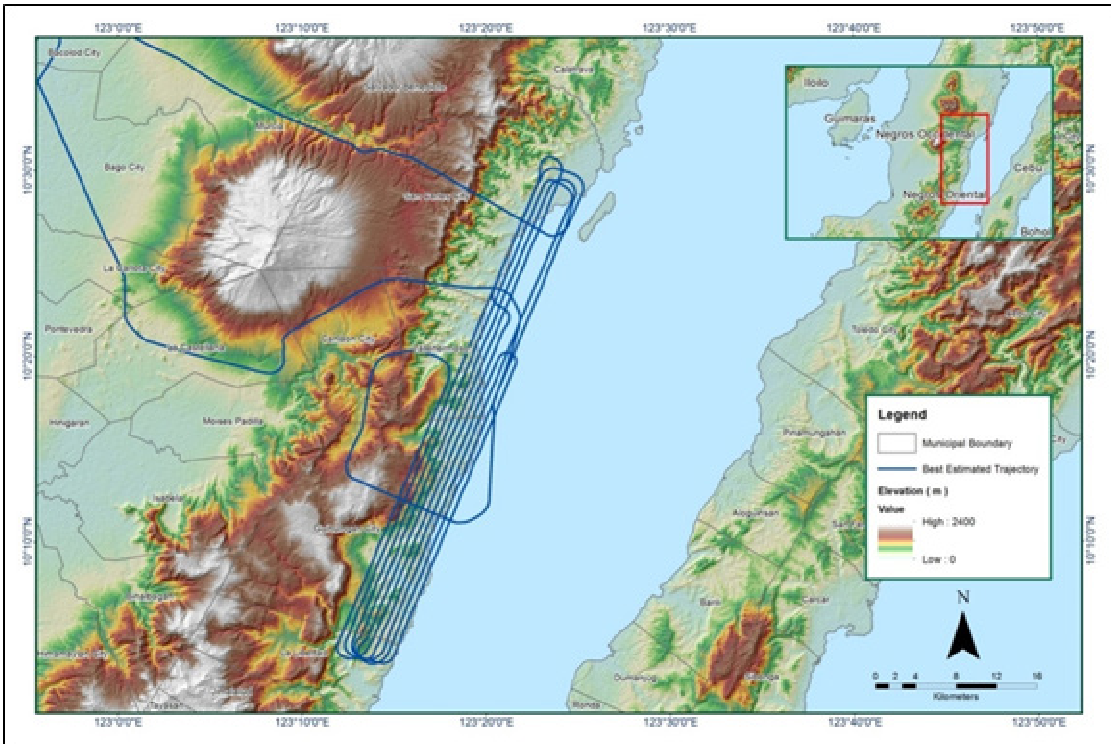


Figure A-8.3. Best Estimated Trajectory

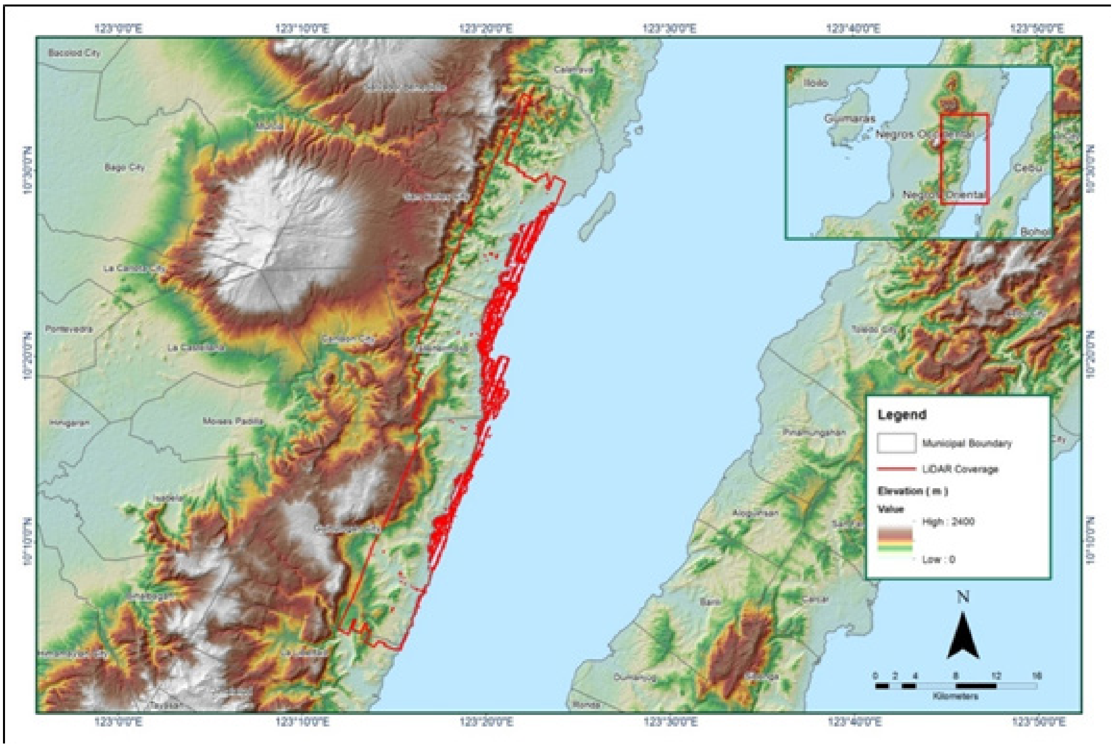


Figure A-8.4. Coverage of LiDAR data

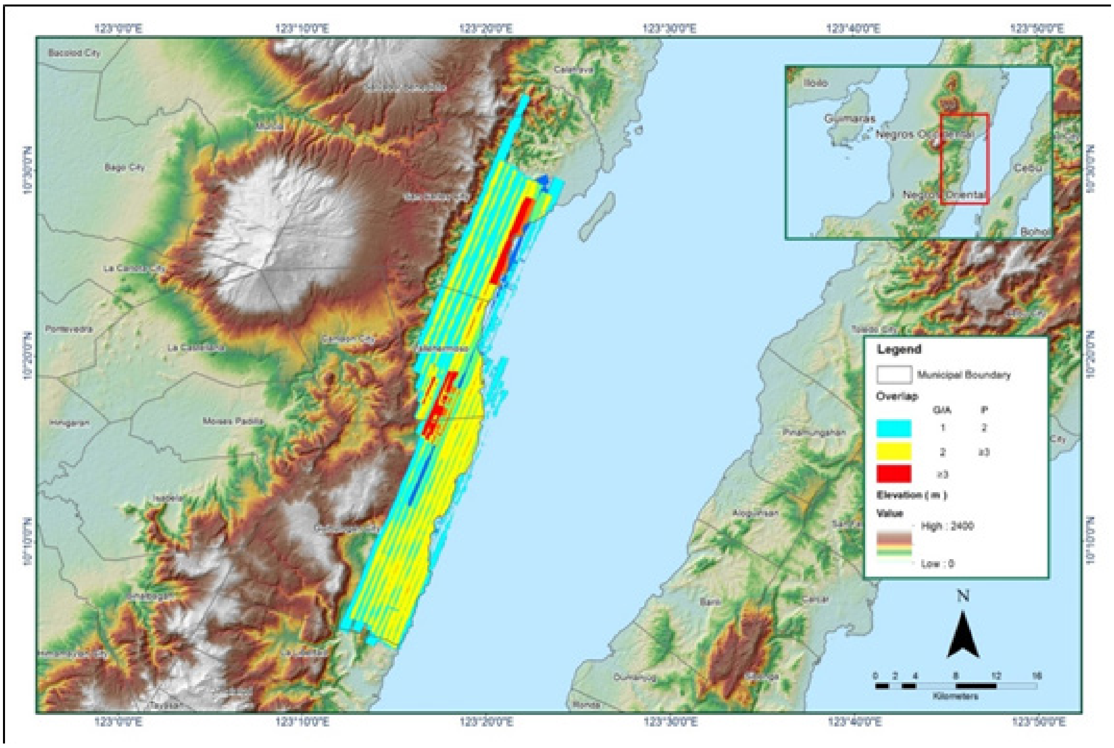


Figure A-8.5. Image of data overlap

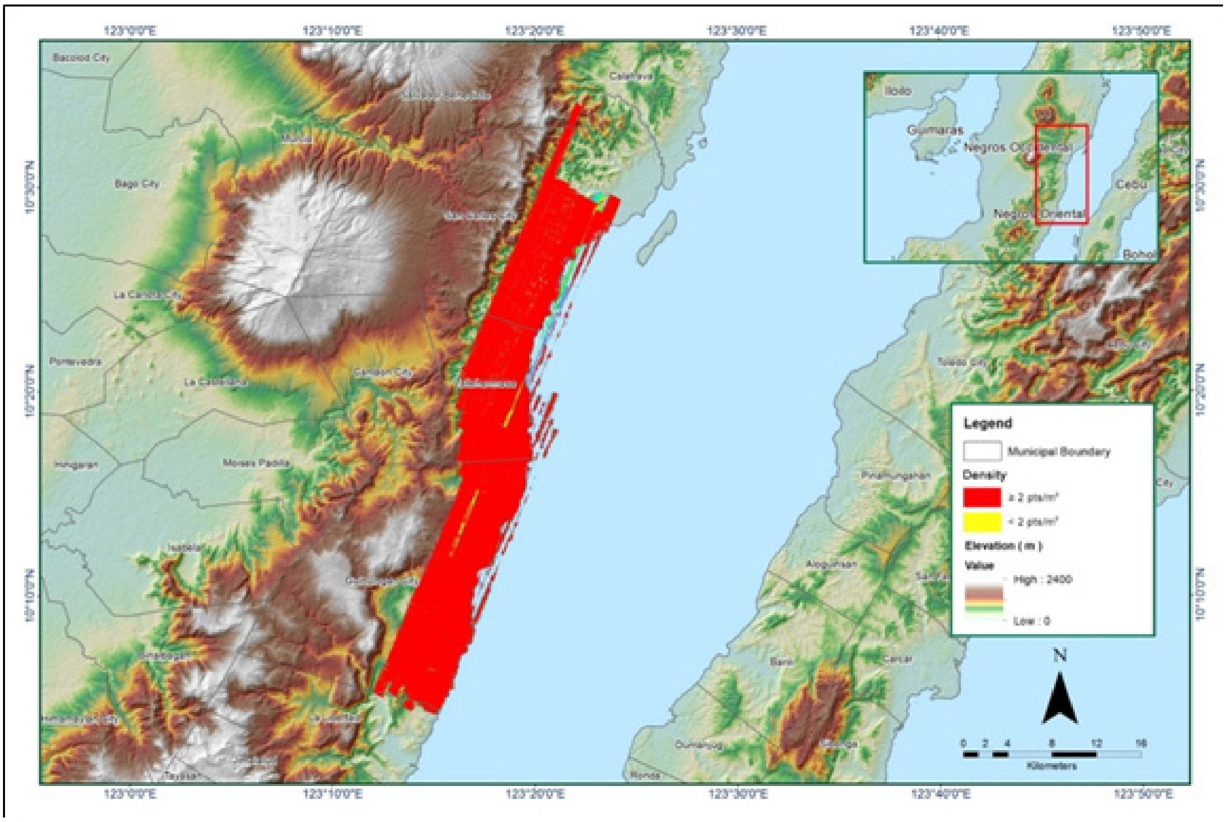


Figure A-8.6. Density map of merged LiDAR data

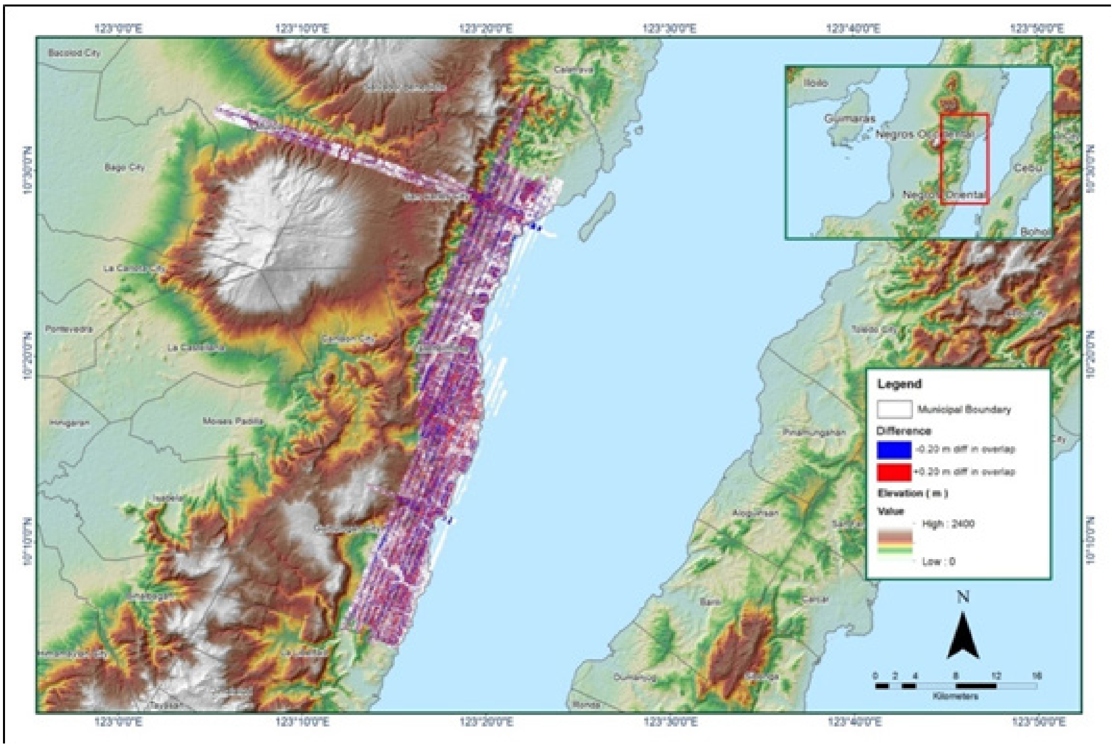


Figure A-8.7. Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk46A

Flight Area	Bacolod
Mission Name	Block 46A
Inclusive Flights	8462AC, 8464AC, 8473AC
Range data size	8.59 GB
POS data size	229 MB
Base data size	158
Image	37.4
Transfer date	May 20, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	No
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	4.702
RMSE for East Position (<4.0 cm)	4.120
RMSE for Down Position (<8.0 cm)	9.98
Boresight correction stdev (<0.001deg)	0.000219
IMU attitude correction stdev (<0.001deg)	0.003368
GPS position stdev (<0.01m)	0.0019
Minimum % overlap (>25)	35.19
Ave point cloud density per sq.m. (>2.0)	4.96
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	82
Maximum Height	515.79
Minimum Height	52.78
Classification (# of points)	
Ground	65,017,829
Low vegetation	45,666,863
Medium vegetation	41,070,217
High vegetation	89,270,904
Building	2,636,013
Orthophoto	None
Processed by:	Engr. Sheila-Maye Santillan, Engr. Ma. Joanne Balaga, Maria Tamsyn Malabanan

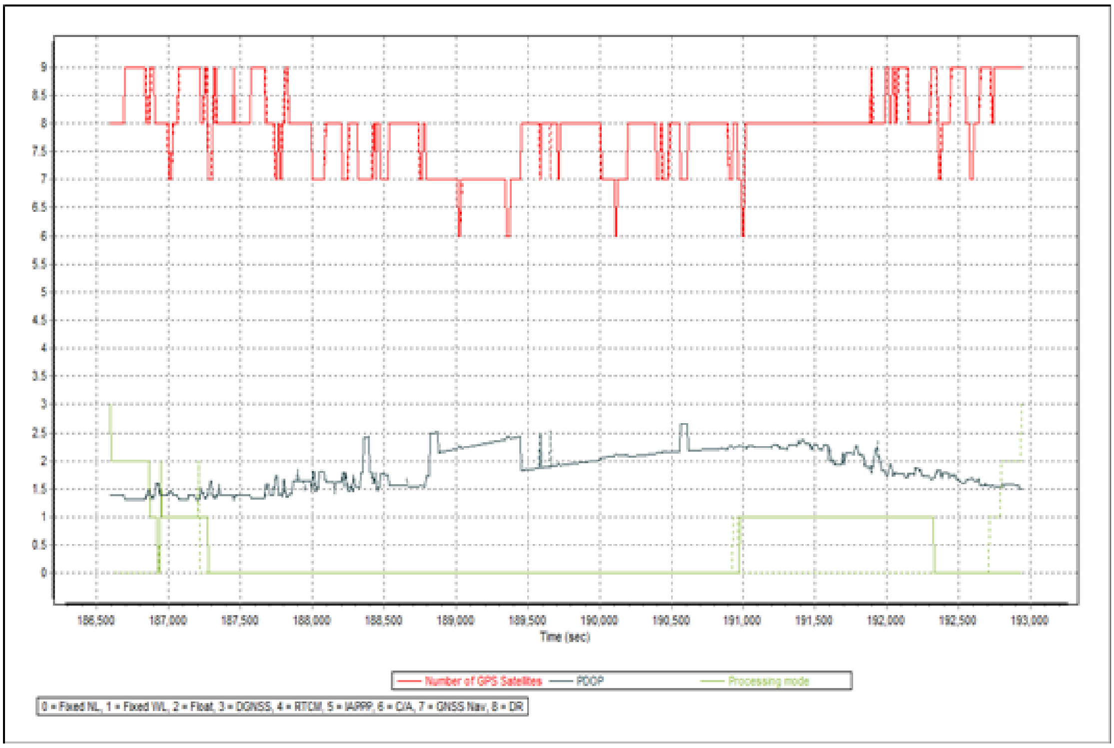


Figure A-8.8. Solution Status

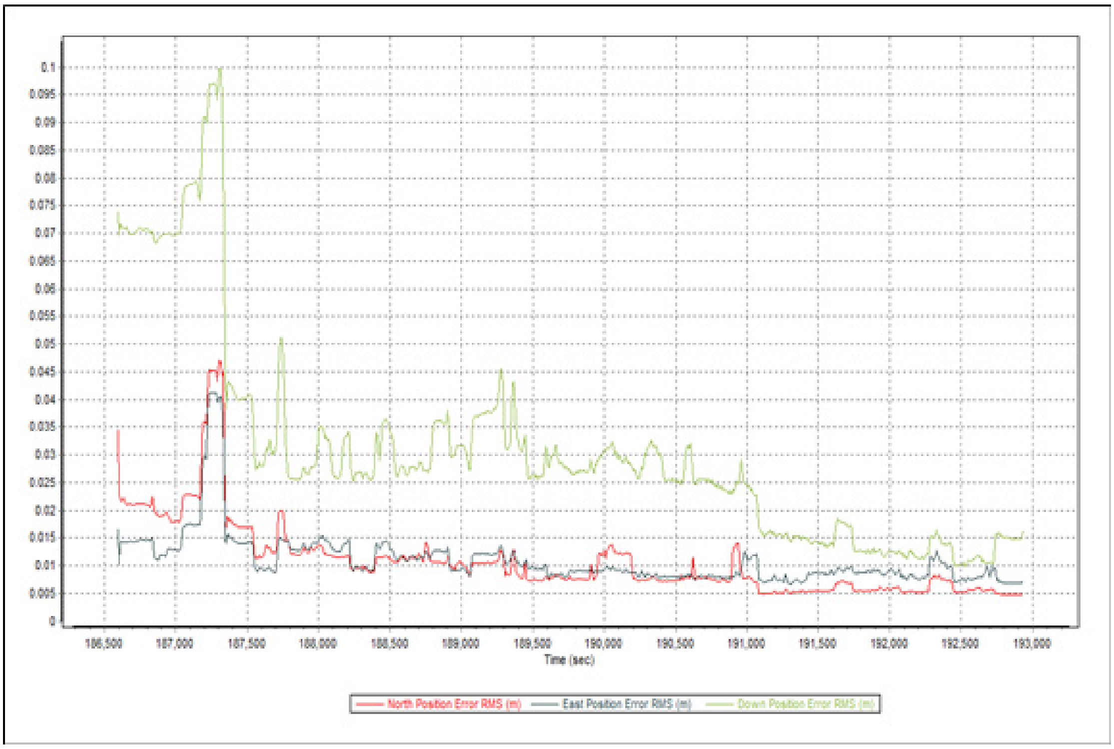


Figure A-8.9. Smoothed Performance Metric Parameters

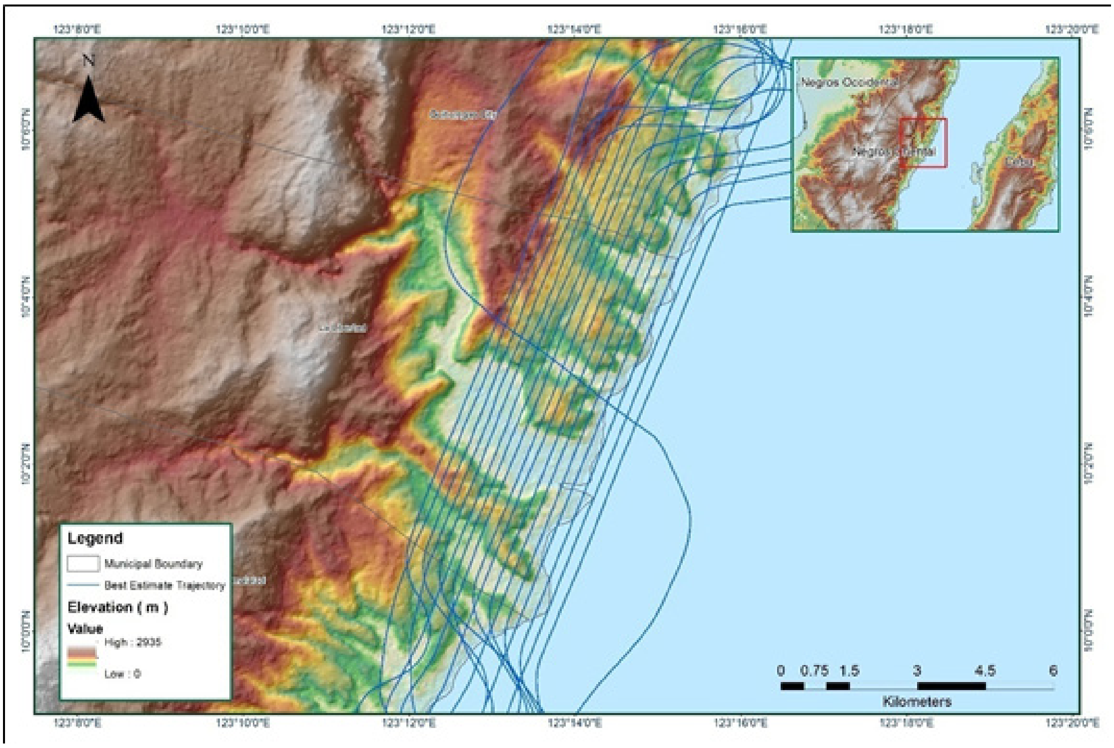


Figure A-8.10. Best Estimated Trajectory

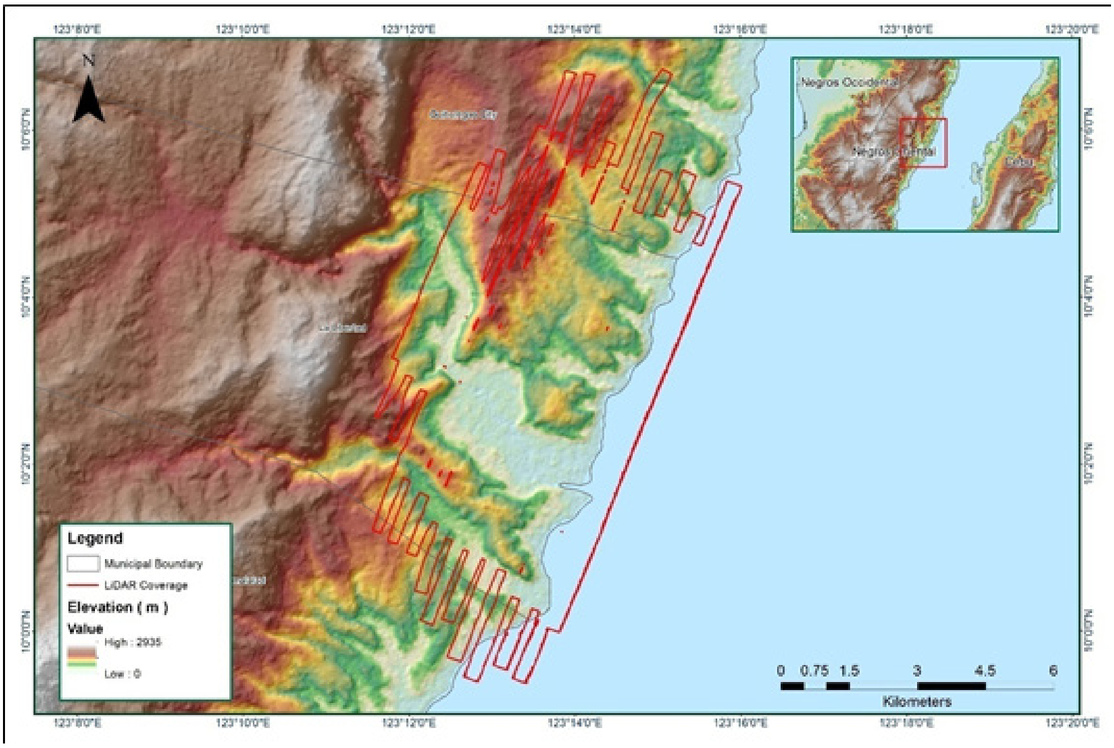


Figure A-8.11. Coverage of LiDAR data

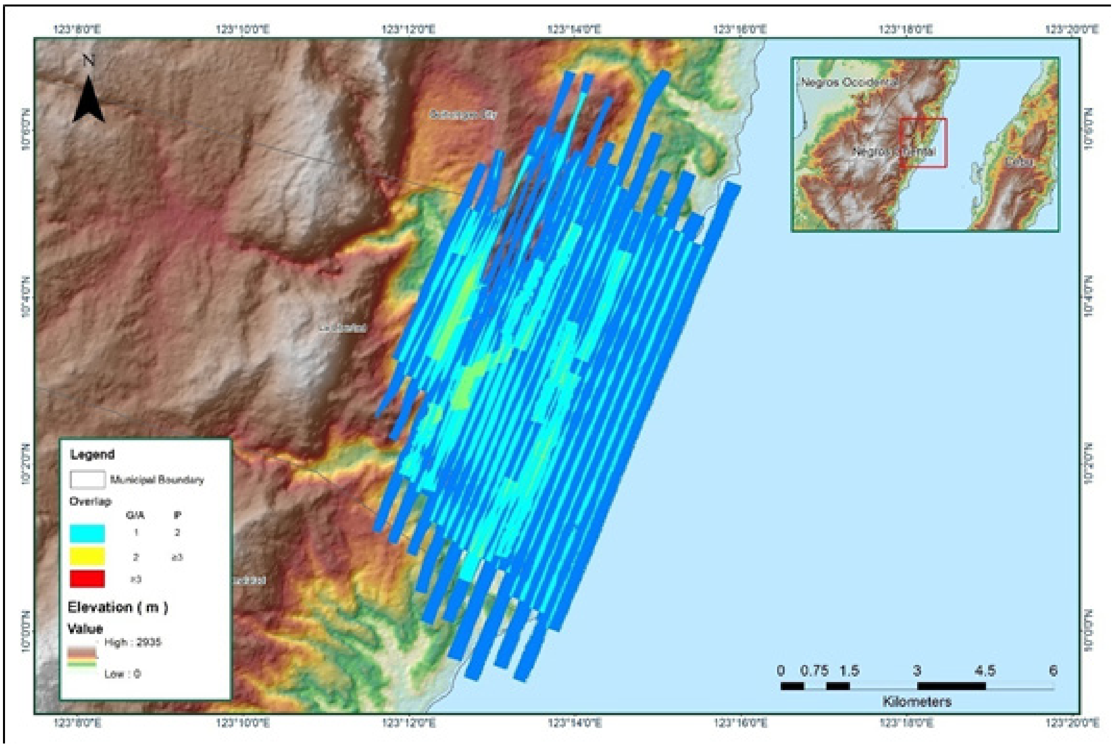


Figure A-8.12. Image of data overlap

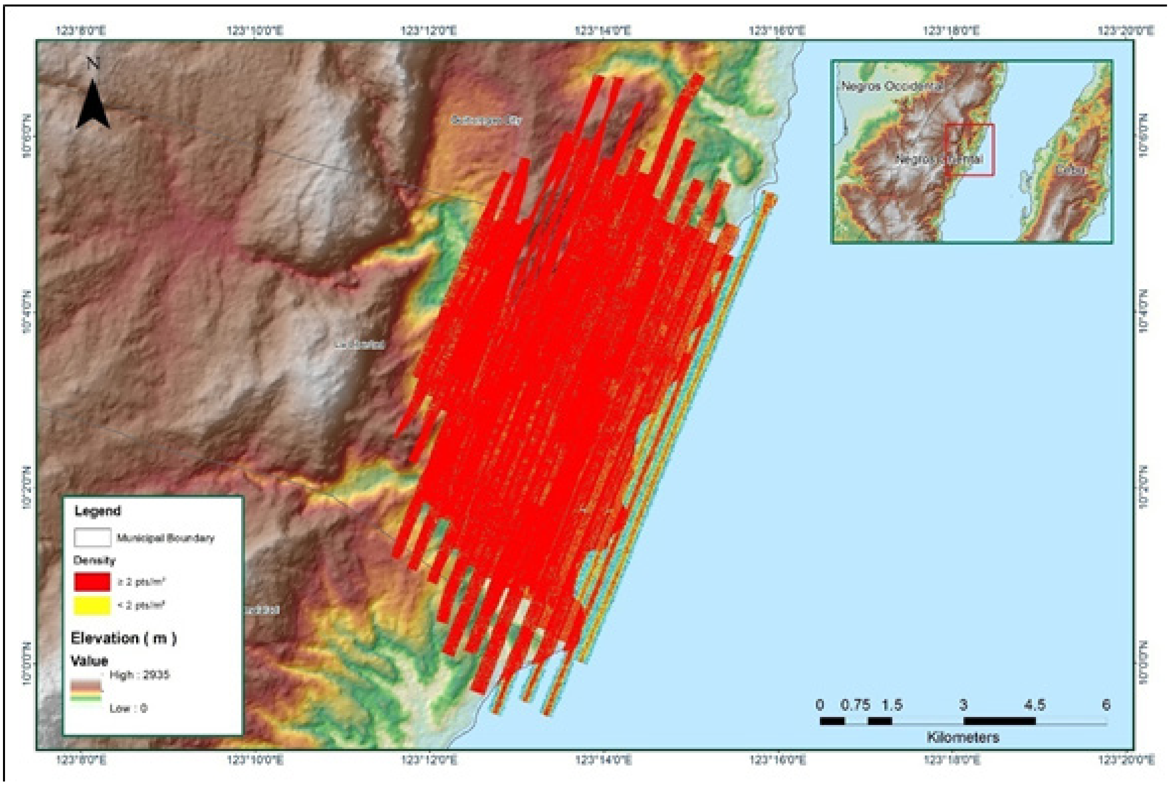


Figure A-8.13. Density map of merged LiDAR data

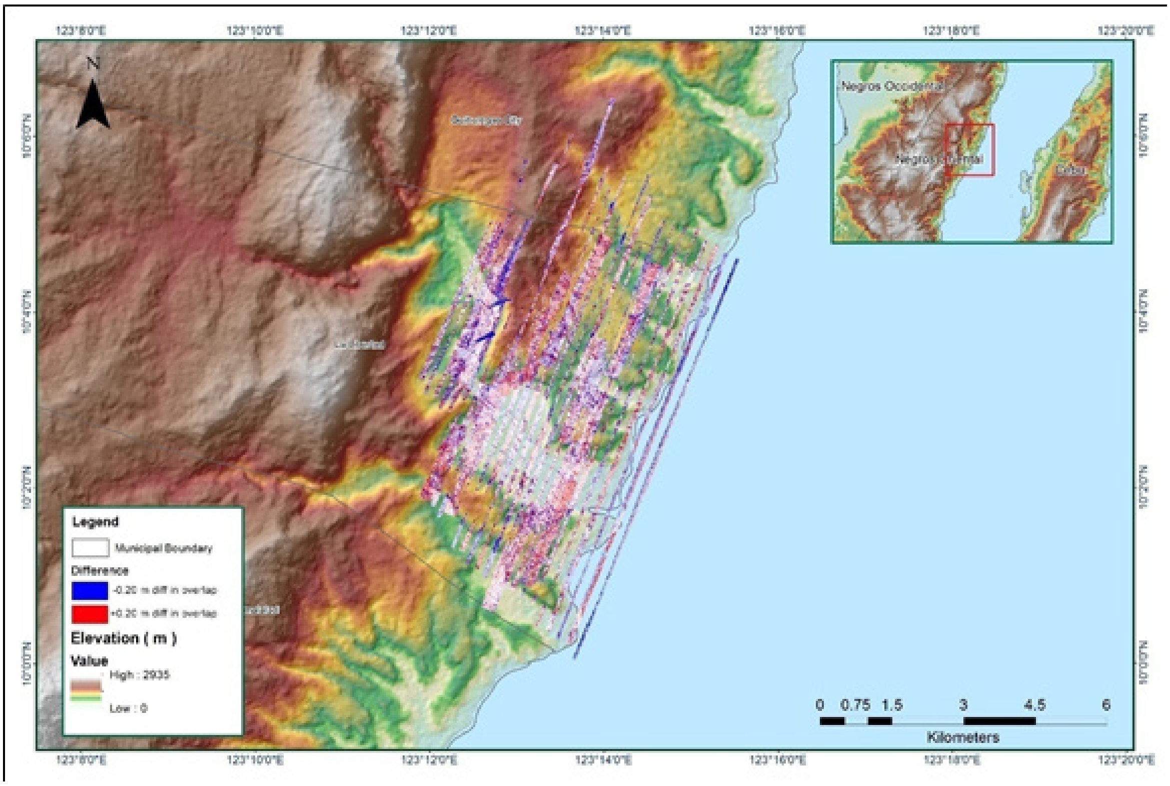


Figure A-8.14. Elevation difference between flight lines

Annex 9. Libertad Model Basin Parameters

Table A-9.1. Libertad Model Basin Parameters

Basin Number	SCS Curve Number Loss Model			Clark Transform Model		Recession Constant Baseflow Model				
	Initial Abstraction	Curve Number	Impervious	Time of Concentration	Storage Coefficient	Initial Type	Initial Discharge	Recession Constant	Threshold Type	Ratio to Peak
W400	11.24	59.502	0	14.012	3.2491	Discharge	0.3994	0.2	Ratio to Peak	0.001
W410	13.995	54.595	0	8.0705	0.29297	Discharge	0.25522	0.2	Ratio to Peak	0.001
W420	3.968	41.024	0	0.72185	0.6113	Discharge	0.49134	0.22604	Ratio to Peak	0.001
W430	10.103	61.786	0	7.9363	3.3235	Discharge	0.1701	0.15	Ratio to Peak	0.001
W440	11.085	95.368	0	42.889	2.5765	Discharge	0.0296559	0.15	Ratio to Peak	0.001
W450	9.3342	37.135	0	22.618	0.69034	Discharge	0.22493	0.15	Ratio to Peak	0.001
W460	8.9846	35.18	0	44.669	2.4347	Discharge	0.1054	0.15	Ratio to Peak	0.001
W470	9.3346	54.589	0	20.829	2.6761	Discharge	0.27572	0.2	Ratio to Peak	0.001
W480	9.3324	54.589	0	4.6449	0.13522	Discharge	0.68126	0.33208	Ratio to Peak	0.001
W490	8.6739	55.097	0	13.498	3.3755	Discharge	0.0116928	0.2	Ratio to Peak	0.0010165
W500	8.2749	89.289	0	49.476	4.208	Discharge	0.0190173	0.15	Ratio to Peak	0.0010151
W510	9.0522	55.292	0	37.163	5.6748	Discharge	0.28626	0.2	Ratio to Peak	0.001
W520	18.87	50.411	0	19.551	0.58623	Discharge	0.0031627	0.2	Ratio to Peak	0.001
W530	2.9667	71.321	0	4.8512	0.36282	Discharge	0.23374	0.2	Ratio to Peak	0.001
W540	8.2605	57.791	0	4.5794	0.2604	Discharge	0.33848	0.2	Ratio to Peak	0.001
W550	9.3346	56.196	0	24.885	1.6171	Discharge	0.0222474	0.2	Ratio to Peak	0.001
W560	8.8094	37.135	0	20.915	1.7189	Discharge	0.019109	0.2	Ratio to Peak	0.001
W570	10.424	76.109	0	33.962	2.1061	Discharge	0.42116	0.2205	Ratio to Peak	0.001
W580	3.9142	69.305	0	9.9283	0.0412646	Discharge	0.23123	0.2	Ratio to Peak	0.001
W590	3.9353	99	0	0.0639556	0.0321541	Discharge	0.0089144	0.2	Ratio to Peak	0.001
W600	13.348	74.716	0	3.1371	0.33366	Discharge	0.86416	0.2	Ratio to Peak	0.001
W610	2.8994	46.236	0	33.392	0.0303017	Discharge	1.284	0.15044	Ratio to Peak	0.001

W620	8.7819	97.02	0	0.37453	0.53649	Discharge	0.38005	0.2	Ratio to Peak	0.001
W630	3.0974	55.41	0	5.3003	0.13781	Discharge	0.34259	0.15	Ratio to Peak	0.001
W640	4.1823	77.018	0	6.124	0.0414817	Discharge	0.62555	0.2	Ratio to Peak	0.001
W650	5.8918	73.513	0	1.1487	0.39856	Discharge	0.72612	0.2	Ratio to Peak	0.001
W660	9.1949	64.595	0	40.075	3.3529	Discharge	1.3064	0.76233	Ratio to Peak	0.001
W670	3.592	43.852	0	43.859	0.38057	Discharge	0.1346	0.15	Ratio to Peak	0.001
W680	3.8184	45.087	0	4.8169	0.70356	Discharge	1.4699	0.2	Ratio to Peak	0.001
W690	7.0576	72.612	0	4.2847	4.1333	Discharge	0.66254	0.15	Ratio to Peak	0.001
W700	9.7823	99	0	52.456	1.7124	Discharge	0.31162	0.2	Ratio to Peak	0.001
W710	5.8158	61.203	0	22.382	0.7404	Discharge	0.33964	0.2	Ratio to Peak	0.001
W720	4.0979	74.881	0	4.1419	0.0384996	Discharge	0.25508	0.2	Ratio to Peak	0.001
W730	3.603	74.136	0	1.1152	0.0401893	Discharge	0.59535	0.2	Ratio to Peak	0.001
W740	10.534	78.946	0	0.10381	0.27936	Discharge	0.74524	0.2	Ratio to Peak	0.001
W750	9.7735	60.169	0	3.4387	0.54887	Discharge	0.25414	0.2	Ratio to Peak	0.001
W760	6.3499	59.938	0	16.274	2.6485	Discharge	0.18001	0.2	Ratio to Peak	0.001
W770	25.288	53.426	0	51.831	0.58137	Discharge	0.1959	0.15	Ratio to Peak	0.001

Annex 10. Libertad Model Reach Parameters

Reach Number	Muskingum Cunge Routing Model						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R110	Automatic Fixed Interval	492.6	0.0001	0.058474	Trapezoid	25	1
R150	Automatic Fixed Interval	5321	0.056111	0.30526	Trapezoid	25	1
R160	Automatic Fixed Interval	317.3	0.091224	0.061484	Trapezoid	25	1
R200	Automatic Fixed Interval	443.1	0.019018	0.136	Trapezoid	25	1
R210	Automatic Fixed Interval	5220	0.040481	0.061364	Trapezoid	25	1
R220	Automatic Fixed Interval	2543	0.002864	0.091308	Trapezoid	25	1
R240	Automatic Fixed Interval	42.43	0.0001	0.090317	Trapezoid	25	1
R250	Automatic Fixed Interval	84.85	0.0001	0.13633	Trapezoid	25	1
R270	Automatic Fixed Interval	208	0.0001	0.13664	Trapezoid	25	1
R280	Automatic Fixed Interval	1418	0.0001	0.090108	Trapezoid	25	1
R290	Automatic Fixed Interval	4125	0.056182	0.20442	Trapezoid	25	1
R30	Automatic Fixed Interval	1133	0.00189	0.090887	Trapezoid	25	1
R320	Automatic Fixed Interval	1417	0.009075	0.13684	Trapezoid	25	1
R330	Automatic Fixed Interval	523.1	0.0001	0.13676	Trapezoid	25	1
R340	Automatic Fixed Interval	5759	0.012458	0.13696	Trapezoid	25	1
R370	Automatic Fixed Interval	10915	0.022956	0.060536	Trapezoid	25	1
R50	Automatic Fixed Interval	2930	0.008573	0.086498	Trapezoid	25	1
R70	Automatic Fixed Interval	1624	0.018006	0.060554	Trapezoid	25	1
R90	Automatic Fixed Interval	3066	0.020662	0.13652	Trapezoid	25	1

Annex 11. Libertad Field Validation Points

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error (m)	Event / Date	Return Period of Event
	Longitude	Latitude					
1	123.21227	10.045751	0.78	1.2	0.1764	Pepang	100-Year
2	123.21227	10.045751	0.78	1.2	0.1764	Nitang	100-Year
3	123.2123	10.04577	0.94	0	0.8836	Seniang	100-Year
4	123.21313	10.046482	1.7	0.5	1.44	Quennie	100-Year
5	123.21313	10.046482	1.7	0.5	1.44	Ruping	100-Year
6	123.21327	10.046509	2.09	0	4.3681	Ondoy	100-Year
7	123.21291	10.046497	1.74	1.2	0.2916	Seniang	100-Year
8	123.21291	10.046497	1.74	1.2	0.2916	Quennie	100-Year
9	123.21292	10.04649	1.74	1.8	0.0036	Ruping	100-Year
10	123.2131	10.046407	1.7	0.5	1.44	Pablo	100-Year
11	123.21326	10.045727	2.2	1.8	0.16	Ruping	100-Year
12	123.21326	10.045727	2.2	1.8	0.16	Quennie	100-Year
13	123.21351	10.045213	2.1	1.2	0.81	Quennie	100-Year
14	123.21351	10.045213	2.1	1.2	0.81	Seniang	100-Year
15	123.21351	10.045213	2.1	1.2	0.81	Ruping	100-Year
16	123.21351	10.045213	2.1	1.2	0.81	Ondoy	100-Year
17	123.2128	10.04418	1.07	1.8	0.5329	Nitang	100-Year
18	123.21295	10.044135	1.17	0.5	0.4489	Quennie	100-Year
19	123.21301	10.044134	2.34	0	5.4756	Ondoy	100-Year
20	123.21276	10.041113	1.02	0.8	0.0484	Seniang	100-Year
21	123.21267	10.041177	1	0.5	0.25	Pepang	100-Year
22	123.21267	10.041177	1	0.5	0.25	Ondoy	100-Year
23	123.21287	10.041197	0.93	1.2	0.0729	Seniang	100-Year
24	123.21576	10.038912	0.56	0.5	0.0036	1949 Typhoon	100-Year
25	123.21587	10.038993	0.51	0.9	0.1521	Nitang	100-Year
26	123.23217	10.028292	7.05	0.1	48.3025	Seniang	100-Year
27	123.23256	10.028303	10.63	0	112.9969	Seniang	100-Year
28	123.23256	10.028367	10.63	0	112.9969	Nitang	100-Year
29	123.23256	10.028367	10.63	0	112.9969	Ruping	100-Year
30	123.23251	10.028374	10.58	0	111.9364	Ondoy	100-Year
31	123.23251	10.028374	10.58	0	111.9364	Yolanda	100-Year
32	123.21202	10.067391	4.66	1.9	7.6176	Ruping	100-Year
33	123.21207	10.067443	4.66	1	13.3956	Yolanda	100-Year
34	123.21208	10.067463	4.66	1.8	8.1796	Ruping	100-Year
35	123.20884	10.053492	3.76	0.6	9.9856	Ruping	100-Year
36	123.20898	10.053116	3.82	0.9	8.5264	Ruping	100-Year
37	123.20896	10.053098	3.82	0.5	11.0224	Seniang	100-Year
38	123.20887	10.05292	3.97	0.85	9.7344	Ruping	100-Year
39	123.20856	10.052886	5.21	0.55	21.7156	Yolanda	100-Year
40	123.20915	10.052668	3.4	0.1	10.89	Seniang	100-Year
41	123.20915	10.05263	3.44	0.8	6.9696	Ruping	100-Year

42	123.21052	10.050949	2.9	0.8	4.41	Seniang	100-Year
43	123.21043	10.050989	3.05	1.5	2.4025	Ruping	100-Year
44	123.21053	10.051427	2.88	2	0.7744	Ruping	100-Year
45	123.21058	10.051423	2.72	0.9	3.3124	Yolanda	100-Year
46	123.21052	10.051277	2.62	0.2	5.8564	Seniang	100-Year
47	123.21755	10.044382	1.36	0.4	0.9216	Amang	100-Year
48	123.21738	10.044177	1.6	0.95	0.4225	Nitang	100-Year
49	123.21697	10.044217	4.22	1.6	6.8644	Ruping	100-Year
50	123.21659	10.044977	1.54	0.5	1.0816	Amang	100-Year
51	123.21689	10.044369	3.86	0.5	11.2896	Amang	100-Year
52	123.21702	10.044214	1.93	0.4	2.3409	Karen	100-Year
53	123.22831	10.030704	6.25	0.6	31.9225	ITCZ	100-Year
54	123.22831	10.030736	6.25	1.9	18.9225	Nitang	100-Year
55	123.2276	10.031335	5.46	1.25	17.7241	Ruping	100-Year
56	123.2276	10.031355	5.46	0.4	25.6036	Yolanda	100-Year
57	123.22762	10.03126	5.5	1.25	18.0625	Nitang	100-Year
58	123.22777	10.031164	5.98	1.3	21.9024	Pepang	100-Year
59	123.22777	10.031164	5.98	1.3	21.9024	Ruping	100-Year
60	123.228	10.031049	5.99	0.5	30.1401	Yolanda	100-Year
61	123.23069	10.030536	6.97	0.38	43.4281	Seniang	100-Year
62	123.23069	10.030522	6.97	0.45	42.5104	Nitang	100-Year
63	123.23149	10.030513	6.84	0.95	34.6921	Yolanda	100-Year
64	123.23152	10.030533	6.9	0.95	35.4025	Nitang	100-Year
65	123.23152	10.030511	6.9	0.85	36.6025	Seniang	100-Year
66	123.23263	10.029301	7.55	0.3	52.5625	Yolanda	100-Year
67	123.2326	10.029304	7.62	1	43.8244	Ruping	100-Year
68	123.2326	10.0293	7.62	1	43.8244	Nitang	100-Year
69	123.23244	10.029326	7.78	2	33.4084	Ruping	100-Year
70	123.23241	10.029341	7.67	2	32.1489	Nitang	100-Year
71	123.23243	10.029329	7.78	0.2	57.4564	Seniang	100-Year
72	123.2321	10.029344	7.65	0.3	54.0225	Seniang	100-Year
73	123.23413	10.029214	7.69	0.6	50.2681	Nitang	100-Year
74	123.23411	10.029243	7.69	0.6	50.2681	Ruping	100-Year

Annex 12. Educational Institutions affected by flooding in Libertad Flood Plain

Table A-12.1. Educational Institutions in Libertad, Bohol affected by flooding in Libertad Flood Plain

BOHOL				
LIBERTAD				
Building Name	Barangay	Rainfall Scenario		
		5-year	25-year	100-year
Health Center	Cantupa	High	High	High
Lying In Paanakan	Cantupa	High	High	High